Vindicating Personhood and Probability in Everettian Quantum Mechanics, and Doing It Thoroughly and Frugally

Jesse Holloway

Section I: Introduction

Everettian interpretations of quantum mechanics all solve the famous measurement problem—the problem of reconciling two apparently incompatible processes, the deterministic Schrödinger Equation, and the indeterministic collapse of the state vector, which govern the time-evolution of quantum state vectors—by saying that the appearance of the collapse of a state vector is merely an appearance, and that the Schrödinger Equation is the only law governing the time-evolution of the state vector. To use a familiar sort of example, suppose that a physicist, Mary, is measuring the x-spin of an electron which is in the eigenstate, $|S_z^+\rangle$, of the z-spin operator corresponding to positive spin in the z-direction. Orthodox quantum mechanics tells us that when such a measurement is made, the state vector of the electron has a probability of 0.5 of evolving into each of the x-spin eigenstates, $|S_x^+\rangle$ and $|S_x^-\rangle$. But if we assume that only the Schrödinger Equation is at work, something very different happens.

If Mary is to measure the x-spin of an electron, she must have a reliable detector. That is, she must have a detector that is such that the state $|\text{ready}\rangle_d|S_x^+\rangle_e$ would evolve into $|+\rangle_d|S_x^+\rangle_e$, and the state $|\text{ready}\rangle_d|S_x^-\rangle_e$ would evolve into $|-\rangle_d|S_x^-\rangle_e$, where $|\text{ready}\rangle$ is a state of the detector when it is ready to measure the x-spin of an electron, $|+\rangle_d$ and $|-\rangle_d$ respectively are states of the detector when it has reported a positive or negative x-spin, and $|S_x^+\rangle_e$ and $|S_x^-\rangle_e$ are the x-spin eigenstates of the x-spin operator corresponding to positive and negative x-spin, respectively. And if Mary knows how to read the detector, she must be such that the states $|\text{ready}\rangle_m|+\rangle_d$ and $|\text{ready}\rangle_m|-\rangle_d$ would evolve, respectively, into $|\text{“+”}\rangle_m |+\rangle_d$ and $|\text{“–”}\rangle_m |-\rangle_d$, where $|\text{ready}\rangle_m$ is a state of Mary when she is ready to read the detector, $|\text{“+”}\rangle_m$ is a state of Mary when she has seen that the detector indicates a positive x-spin, and $|\text{“–”}\rangle_m$ is a state of Mary when she has seen that the detector indicates a negative x-spin.

Now let's see how the measurement would go. The system consisting of the electron, the detector, and Mary, begins in the state

$$|\text{ready}\rangle_m |\text{ready}\rangle_d |S_z^+\rangle_e,$$

which is equal to the state

$$|\text{ready}\rangle_m |\text{ready}\rangle_d (1/\surd 2)(|S_x^+\rangle_e + |S_x^-\rangle_e),$$

since $|S_z^+\rangle_e$ is equal to $(1/\surd 2)(|S_x^+\rangle_e + |S_x^-\rangle_e)$.

Given the linearity of the Schrödinger Equation, each term will evolve independently of any others. So the state

$$|\text{ready}\rangle_m |\text{ready}\rangle_d (1/\surd 2)(|S_x^+\rangle_e + |S_x^-\rangle_e)$$

evolves into

$$|\text{ready}\rangle_m (1/\surd 2)(|+\rangle_d |S_z+\rangle_e + |-\rangle_d |S_x^-\rangle_e),$$

which evolves into

$$(1/\surd 2)(|\text{“+”}\rangle_m |+\rangle_d |S_x^+\rangle_e + |\text{“–”}\rangle_m |-\rangle_d |S_x^-\rangle_e),$$

or, equivalently,

$$(1/\surd 2) |\text{“+”}\rangle_m |+\rangle_d |S_x^+\rangle_e + (1/\surd 2) |\text{“–”}\rangle_m |-\rangle_d |S_x^-\rangle_e.$$

What began as a state vector with one term each, for Mary, the detector, and the electron, has evolved into a state vector with two terms for each. The first term, aside from its coefficient $(1/\surd 2)$, is just the state vector which would describe a physical system consisting of Mary, the detector, and the electron, where the electron has positive x-spin, the detector has indicated positive x-spin, and Mary has seen that the electron has positive x-spin. The second term, aside from its coefficient, is just the state vector which would describe of a physical system consisting of Mary, the detector, and the electron, where the electron has negative x-spin, the detector has indicated negative x-spin, and Mary has seen that the electron has negative x-spin. So it seems that there are, with equal being, two states of affairs resulting from the measurement—one in which the electron has positive x-spin, the detector indicates positive x-spin, and Mary has seen that the electron has positive x-spin; and another in which the electron has negative x-spin, the detector indicates negative x-spin, and Mary has seen that the electron has negative x-spin.

Now it may seem that this interpretation of quantum-mechanical measurements should be summarily dismissed, because it is not borne out by our experience. After all, no one has ever observed that, in the event of a quantum measurement such as Mary's, each of the quantum-mechanically possible results of the measurement occurs. Whenever we make such a measurement, we observe just one of the quantum-mechanically possible results. If all the other quantum-mechanically possible results also occur, why can't we observe any of them?

The Everettian answer to this question, the key to understanding how it could be that the Schrödinger Equation is the one dynamical law which governs the state vector, is that an observer can only observe things which are described by the same term of the universal state vector as she is. Hugh Everett (Everett 1957) explains this solution in terms of relative states. Let's consider again the state vector which describes the state of things at the end of Mary's measurement:

$(1/\sqrt{2})\,|\text{“}+\text{”}\rangle_m\,|+\rangle_d\,|S_x^{\,+}\rangle_e + (1/\sqrt{2})\,|\text{“}-\text{”}\rangle_m\,|-\rangle_d\,|S_x^{\,-}\rangle_e$.

As I said before, there are, after the measurement, two equally real states of affairs, one in which Mary has seen that the electron she measured has positive x-spin, and one in which Mary has seen that the electron has negative x-spin. But this can't be quite right—it can't be that the same person has really seen that an electron has positive and negative x-spin at the same time! In order to be able to say that both states of affairs are equally real, we must say that there are two different observers, or persons. One person sees just the positive x-spin, and the other person sees just the negative x-spin. These observers—let's call them Mary$^+$ and Mary$^-$ are to be described (physically, that is) by the corresponding state vectors, $|\text{“}+\text{”}\rangle_m$ and $|\text{“}-\text{”}\rangle_m$. And what Mary$^+$ and Mary$^-$ can observe are not the entire states of physical objects, which may be entangled in different terms of the universal state vector, but the relative states of these objects—relative, that is, to Mary$^+$ and Mary$^-$. The state of all the physical objects, relative to Mary$^+$, is $|\text{“}+\text{”}\rangle_m\,|+\rangle_d\,|S_x^{\,+}\rangle_e$: if she were to look again at the detector, she would find it to be in the state $|+\rangle_d$; if she were to look again at the electron, she would find it to be in the state $|S_x^{\,+}\rangle_e$. The same goes for Mary$^-$, if you replace the pluses in the previous sentence with minuses. This is how it is that Mary$^+$ sees that the detector indicates positive x-spin, and the electron has positive x-spin, and that Mary$^-$ sees that the detector indicates negative x-spin, and the electron has negative x-spin. And thus it is possible to believe that the time-evolution of the universal state vector is governed only by the Schrödinger Equation, and so that all quantum-mechanically possible outcomes of a measurement are realized, without expecting to observe more than one of these outcomes, or being discouraged by our failure to do so.

Section II: Some strange consequences of many Everettian interpretations

In order to believe that quantum state vectors are governed entirely by the Schrödinger Equation, it is furthermore necessary to believe that, after a measurement on a quantum system, there are more pieces of state vectors[1] corresponding to entire persons than there were before the measurement. More specifically, each piece of a state vector that describes a person (again, physically) before the measurement is split into as many distinct pieces of state vectors describing a person as there are distinct quantum-mechanically possible outcomes of the measurement. On the plausible assumption that each term (such as $|``+"\rangle_m$) that completely describes a person's physical state describes the physical state of just one person, this means that a quantum measurement results in multiplication of persons. For each person who is around before the measurement is made, there are as many copies of that person after the measurement as there are distinct quantum-mechanically possible outcomes of that measurement. In the previous example, there is one Mary before the measurement, and there are two Marys, Mary^+ and Mary^-, after the measurement.

This conclusion, that people multiply upon making quantum measurements, is very strange. To accept it as true, to believe that people really multiply in this way, would be difficult, because it would be in great tension with other beliefs which we have and which are central to our understanding of things.

One modification we would have to make in our thinking, in order to believe that Everettian multiplication of persons occurs, is, naturally, a modification of our thinking about how people come to be. Our ordinary understanding is that people come to be

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[1] Not whole terms of the universal state vector, such as $(1/\sqrt{2})\,|``+"\rangle_m\,|+\rangle_d\,|S_x^+\rangle_e$, but pieces of those terms, such as $|``+"\rangle_m$.

through a certain process of growth. Zygotes become babies, babies become children, children become adults, and adults continue to mature throughout their lives. This is to say that things which are not persons, and have nothing personal to be said for them, become persons, by a long, continuous process. And the process, being continuous, is not one by which something instantly crosses a threshold of personality—instead, these non-personal things become more and more personal throughout their development into persons.

But Everettian multiplication presents us with another way in which people may come to be, for it presents people as coming to be by multiplying. When Mary makes her measurement of the spin of an electron, she splits into Mary$^+$ and Mary$^-$, and at least one of Mary$^+$ and Mary$^-$ is not Mary. Any resultant Marys who are not Mary are, evidently, new persons—that is, they were not around before the measurement was made. And the process by which these new persons came to be was nothing like the process of slow maturation just described. The new Marys came to be in the blink of an eye, almost instantly. Perhaps the process isn't, strictly speaking, instantaneous—after all, it will take time for the pieces of the universal state vector corresponding to the different states of the detector and the electron to interact fully with Mary's state vector, and split it into the terms which describe Mary$^+$ and Mary$^-$. However, even if the process is continuous over some (very short) interval of time, it is not a process of personal maturation—the new Marys do not, during this split, begin as non-persons and mature into persons. They only become different from each other—and come to differ merely on the small matter of whether they are perceiving that an electron has positive or negative x-spin.

So by accepting Everett multiplication, it seems that, though we thought that there was just one process by which people ordinarily come to be, we now must believe that there are two such processes, which could hardly be more different. There is a reason I speak of processes by which people *ordinarily* come to be. It might require no great revision of our systems of belief to accept that people may come to be in ways not involving the ordinary personal maturation. For example, if I collect an appropriate ensemble of atoms and put them together in just such a way as to behave just like the atoms making up a person's body do,[2] then it may well be that a person has been thereby created. This would be a case where a person came to be not through the ordinary process of personal maturation, for the ensemble of atoms may come to form the body of an adult human being without ever forming a child's body. But our system of beliefs about the formation of persons need not be seriously altered in the light of this possibility, for it is by no means *ordinary* that persons result from this sort of process.

On the other hand, if Everett multiplication of persons occurs, it is a process by which people ordinarily come to be. In fact, since some branching is occurring constantly (and uncontrollably), far more people would come to be by Everett multiplication than by the ordinary process of personal maturation. So in order to accept Everett multiplication we must accept an ordinary person-forming process which is quite different from the one we already accept, and indeed quite out of the ordinary!

The situation may be even worse. Some people (Ismael 2003, Albert 2010) think that we should not, in the context of Everettian interpretations, ask which of the persons resulting from Everett multiplication is identical to their originator—the conclusion being

[2] Of course, I mean that the atoms are being put together in some very exotic way, perhaps one by one, and "by hand". One way to put the atoms together is to fertilize an egg cell and place the zygote in a person's womb. The important thing is that there are other ways it could be done in principle.

that *none* of them is identical to her. If this is correct, then we may even have to revise our understanding of the process of personal maturation. After all, since branching is constant and uncontrollable, we are continuously and uncontrollably being replaced by other instantaneous observers. So we cannot say that, by the ordinary process of personal maturation, things which are not persons become persons. Instead, things which are not persons are being replaced by things which are successively more personal.

Another consequence of the supposition that worlds, and the people in them, multiply upon quantum measurement, a conclusion which I find quite tickling, is that the past may be, in a sense, multiplied. Surely the new people who result from a quantum measurement all have a past. For they all have memories of doing things at times before the measurement was made—memories of speaking with people, or eating bananas, or what have you. If any of the new persons had not done those things—if her past does not extend beyond the time of the measurement—then almost all of her memories would be false. So, if we are to believe in the multiplication of persons with any confidence, we must say that each person on a descendant branch has a past extending beyond the time of the measurement.

In particular, Mary^+ and Mary^- must have a past—they must have done things before Mary's measurement was made. And, among the people who were around before the measurement, the only person who could reasonably share her past with Mary^+ and Mary^- is Mary. The things we may say that Mary^+ and Mary^- did before the measurement are just the things we may say that Mary did before the measurement.

Now suppose that, in 1957, ten years before she made her measurement, Mary discovered a new physical law—call it Mary's law—and that, at that time, no one else had ever discovered it. Since Mary^{+} and Mary^{-} did all of the things that Mary did, Mary^{+} and Mary^{-} each discovered Mary's law, at the same time. In other words, before the measurement was made (in 1967), just one person had discovered Mary's law in 1957, but after the measurement was made, two people had discovered Mary's law in 1957! Thus, if people multiply upon making a quantum measurement, and if each of the resulting people must have a past, we can change facts about the past—specifically, facts about how many people did something at a certain time in the past—simply by making a quantum measurement.

There is another problem, which is connected to the familiar problem of probabilities. The problem of probabilities, which arises uniquely for Everettian interpretations of quantum mechanics, is the problem of explaining what role is played by the familiar quantum-mechanical probabilities, calculated by the Born rule, in a universe in which all of the quantum-mechanically possible outcomes of a measurement are realized. There is an argument (Deutsch 1999, Wallace 2010a), from the non-probabilistic postulates of quantum mechanics, and some non-probabilistic assumptions of decision theory, with the conclusion that, when we place bets on the outcomes of quantum measurements, we ought to weight the reward to us on each branch by its Born-rule probability, or in other words by the quantum-mechanical weight of the branch, which is the modulus square of the branch's coefficient.

While this argument, if successful, shows that a rational agent should assign Born-rule probabilities as weights to rewards for measurement outcomes, there is much more work to be done. One matter, on which I won't concentrate, is that this argument, which supports what may be called the 'decision-theoretic strategy' for solving the problem of probabilities, only manages to recover one part of the role that probabilities have for us. Though the argument, if successful, tells us how seriously we should take each possibile future, it does not shed any light on why the relative frequencies of events we have observed in the pasts have come roughly in line with the probabilities assigned to them. Albert makes this objection in Albert 2010.

Another, perhaps more pressing matter, is that the decision-theoretic strategy sheds no light on why I ought to care selfishly about the people who will be around after I make a quantum measurement, if I cannot say that any of those future persons is identical to me. Putting the question another way, how is it that I ought to treat the fortunes and misfortunes of those future persons *as my own* future fortunes and misfortunes, if those people are not, strictly speaking, identical to me? I am not here disputing that the decision-theoretic argument is successful—I am insisting instead that, though it may be successful in showing that I ought to care selfishly about my Everett successors, it does nothing to explain how or why that is so. It seems to me that pointing out qualitative similarities between the experiences of those future persons and my own will not be enough. To make this point clear, imagine that there is another planet, far away, on which there are people having experiences that, up to now, are qualitatively no different from ours, but that in the future our experiences will be different than theirs. I may consider the person on that other planet whose experiences are most like my own, and express joy at his future fortunes, and sorrow at his future misfortunes. But it is clear that I do not in any way myself enjoy those fortunes, or myself suffer those misfortunes. So the defender of Everett multiplication of persons cannot rely on qualitative similarity of experience alone to explain why I should care selfishly about my successors—she must appeal to something else as well. Nor can she appeal to relations of identity between me and my successors, for she has already ruled those out.

Perhaps she could appeal to causal relationships between my experience and the experiences of my successors. An example of such causal relationships is the causal relation between my experience of intending to make a measurement and my successors' memories of having intended to make the measurement. But this won't do, either. It does manage to distinguish the case of Everett multiplication of persons from a "Twin-Earth" scenario, because in the former case there are causal relations between my experiences and the experiences of my successors, and in the latter there are no causal relations between my experiences and the experiences of my "twin". However, even if my having the experiences I do partially causes my successors to have the experiences they do, if these are understood as the experiences of people other than me, there is no reason I should regard them as my own experiences. That fact would only give me reason to take greater care to make sure that I do not cause my successors harm—but this is not the selfish sort of care which would ground personal continuity, or anything like it.

I have just pointed out three problems which face the defender of Everett multiplication of persons. I have given little reason to suppose that any of these problems is unsolvable, nor do I intend to espouse this view. However, it is striking that, though these problems arise from the same supposition (that of Everett multiplication of persons), they are very different in type. One is a challenge to our ordinary way of thinking about the development of persons, another is the conclusion that we can change the past, and the last is a demand for explanation of the normative relationships between a person and her successors. The differences between these problems suggest that a unified solution would be difficult to find. And in the absence of a unified solution, each of these problems, and any other problem that could be found, would have to be given a solution of its own, and the tenability of the belief in Everett multiplication of persons relies on every one of these solutions.

It would be preferable if we could find a unified solution to all these problems—that is, if we had an understanding of personal continuity which solved all these problems at once, without having too many rules or unseemly addenda. Of course, one way to solve all these problems at once is to deny that people multiply when quantum measurements are made. If there are as many people before a measurement as there are after the measurement, then none of the aforementioned problems arise. And there have been Everettian interpretations of quantum mechanics which make just this move.

The many-minds interpretation of quantum mechanics due to Albert and Loewer (Albert and Loewer 1988) takes a route like this. It says that each mind-supporting brain in each decoherent term[3] of the state vector of the universe supports continuously infinitely many minds, whose experiences (at that time) are qualitatively identical. And when such a term of the universal state vector splits (say, when a quantum measurement is made), each mind comes to follow one of the new terms of the state vector by a stochastic process. Each mind has a probability, given by the Born rule, of following each new term of the state vector.

Because there are, on this interpretation, continuously many minds before and after a quantum measurement, it is possible to identify each mind present before the measurement with just one mind present after the measurement. Given this, the many-

[3] Decoherent terms of the universal state vector are terms which do not interfere with one another—no observer sees effects from more than one decoherent term, though if decoherence has not occurred yet, one may see effects from multiple terms of a state vector.

minds interpretation can say that quantum measurements do not cause people to multiply or split, and avoid all the problems that arise from supposing that people do thus multiply. However, many people, though they may find this property of Albert's and Loewer's many-minds interpretation attractive, nonetheless reject it for other reasons. One reason is that it separates the mental from the physical in a way that might make many people uncomfortable—though all *physical* systems evolve deterministically, *mental* systems evolve stochastically. This makes the specification of the laws of a many-minds universe less simple than that of the universe of a more traditional Everettian interpretation of quantum mechanics. Whereas in traditional Everettian interpretations there is just one fundamental law (which governs the deterministic evolution of the state vector of the universe), the many-minds universe is governed by two laws (which govern the deterministic evolution of the state vector and the stochastic evolution of the minds).

My hope at this point is to find an Everettian interpretation of quantum mechanics which denies that people multiply when branching of the state vector occurs, but which suffers none of the damaging disadvantages of the currently existing views which deny Everett multiplication of persons. To find such a view, I'll examine a way of thinking about Everett multiverses first mentioned, as far as I know, by Jenann Ismael, and a recent view due to Alastair Wilson, which adopts this way of thinking. Finally, after giving reasons against Wilson's view, I'll present my own view.

Section III: Ismael's metaphorical branching and Wilson's Indexicalism

Ismael (Ismael 2003) distinguishes two ways of thinking about branching Everettian universes. On one, when a term of the universal state vector splits into two decoherent terms, one world, which was associated with the original term, literally splits into two worlds, which are said to have common histories at times before the measurement is made. On the other, different worlds only have similar histories, but do not have any history in common. Most traditional Everett interpretations have understood Everett universes in the first way. Wilson, however, presents a rather novel way (Wilson 2013) of looking at Everettian interpretations of quantum mechanics, which involves thinking of Everettian universes in the second way. In this section I will present this view as Wilson does, and I will discuss what he takes to be its advantages. In the next section, I will point out problems with this view, and present my modifications.

Wilson seems to believe that the fundamental difference between his view and others is a difference between one position, which is prevalent in the literature, and which he calls 'Collectivism', and another position, which is his position, and which he calls 'Individualism'. I will not be using those terms to refer to these positions. Instead, I will call 'Tree-Actualism' what he calls 'Collectivism', and I will call 'Branch-Actualism' what he calls 'Individualism'. Here are the positions, formulated exactly as Wilson formulates them, except for the change in names:

Branch-Actualism: If X is an Everett world, then X is a metaphysically possible world.

Tree-Actualism: If X is an Everettian multiverse, then X is a metaphysically possible world.

He suspects that Tree-Actualism is prevalent in the literature due to the influence of a certain metaphysical principle, which he calls (and which I will call) OMOW (One Model, One World), and which I formulate below exactly as he does:

OMOW: Each model of a physical theory represents exactly one metaphysically possible world.

Wilson takes Tree-Actualism to follow from OMOW, because he thinks that the models of Everettian quantum mechanics are Everettian multiverses (the "trees"). So if OMOW is true, then each Everettian multiverse is a single metaphysically possible world.

The second ingredient of Wilson's view is something called 'Divergence'. When using this term Wilson has in mind a distinction, much like Ismael's, proposed in a paper by Simon Saunders (Saunders 2010). Saunders distinguishes two ways in which Everett worlds which are similar may become dissimilar. Two worlds are said to overlap when a spatiotemporal segment of one is numerically identical to a spatiotemporal segment of the other, and they are said to diverge when these segments, though not numerically identical, are nonetheless qualitatively identical. Wilson, then, believes that we must understand Everett worlds as diverging rather than overlapping. He gives:

Divergence: Everett worlds do not overlap; each macroscopic object and event exists in one Everett world only.

Though the distinction between divergence and overlapping was couched in terms of numerical or merely qualitative identity between segments, it is no large leap from divergence thus explained to Wilson's Divergence—so long as we accept that neither a macroscopic object nor an event may be contained in two numerically distinct spatiotemporal wholes.

The third ingredient of Wilson's view is that ordinary contingent propositions (which he wants us to understand as the sort of propositions that have non-trivial objective chances) should be identified with sets of Everett worlds. I'll call this position 'PASEW' (abbreviating 'Propositions-as-sets-of-Everett-worlds'). His final ingredient is a prescription on how we ought to understand 'actuality', according to which each Everett world is actual according to all its own inhabitants, and not to anyone else. (This is not, however, a denial of the reality of inhabitants of other Everett worlds.) Following him, I'll call this 'Indexicality-of-actuality'. Here, then, is the whole package, and everything but the names of the ingredients comes directly from Wilson:

Divergence:	Everett worlds do not overlap; each macroscopic object and event exists in one Everett world only.
Branch-Actualism:	Distinct Everett worlds comprise alternative metaphysical possibilities.
PASEW:	Ordinary contingent propositions are sets of Everett worlds—a proposition P is true at an Everett world w if and only if w is a member of P.
Indexicality-of-actuality:	Each Everett world is actual according to its own inhabitants, and only according to its own inhabitants.

Wilson takes his view to have two important advantages, because it gives a solution to two obstacles to our understanding the Born rule as giving objective probabilities in Everettian quantum mechanics. The first problem is the appearance that there is just no room for non-trivial (i.e. not equal to zero or one) objective probabilities in the theory. After all, the theory is globally deterministic—the entire state vector at one time determines the entire state vector at a future time, and, at least on some Everettian interpretations, the state vector determines all other facts about the Everettian multiverse. And if the application of non-trivial objective probability to future outcomes is possible only in cases where there is objective uncertainty about the future, then it seems that there is no hope, since there can be no objective uncertainty in a globally deterministic theory.

Ismael 2003 proposes an explanation of how genuine chances may arise in a globally deterministic theory with a structure like that of Everettian theories. On Ismael's view, it is true that there can be no objective uncertainty about the future in an Everettian theory—if a physicist is about to perform a quantum experiment, then she knows exactly what lies ahead. If, say, she measures the observable $\hat{O}$ of a particle in the state $|\Psi\rangle =$

$a\,|O{=}1\rangle + b\,|O{=}2\rangle$, then she knows that after the measurement is complete there will be one observer, in a branch with weight $|a|^2$, who sees the outcome O=1, and another observer, in a branch with weight $|b|^2$, who sees the outcome O=2. There is nothing else to know about the future, and nothing to be uncertain about. In particular, Ismael believes, we may not ask which of those future observers is identical to the observer existing now, before the measurement has been made.

How then does chance come in? Well, after the measurement has been made (but *before* either observer checks to see the outcome), there is one observer in a branch with weight $|a|^2$, and another in a branch with weight $|b|^2$ (and neither is identical to me, the observer who was around before the measurement was made, but instead bears to me relations like those Hume thought to exist between instantaneous observers). Each observer may ask which branch of the Everett multiverse she inhabits or, what amounts to the same thing, which outcome has occurred for her. And, given what she knows—the state of things immediately before the measurement, and the terms of the state vector associated with each branch after the measurement—she must use the Born rule (assuming we have a successful quantitative argument for the Born rule) to calculate the probability that each outcome occurred. Those probabilities, calculable by the descendant observers, ground each outcome's probability of occurring, attributable at a time before the measurement occurs. These indexical questions cannot be asked before the measurement is made, because the first observer is not related to either of the events on descendant branches in such a way that she can speak indexically about them. However, because there will be observers who can ask these indexical questions, the notion of non-trivial, objective chance remains coherent, even in a globally deterministic theory of the Everettian sort.

This is a very good proposal, and perhaps the best which can come from a theory of overlapping Everettian worlds. But Wilson's theory might be able to do better. Wilson claims that every ingredient of his view is necessary in order for us to understand non-trivial objective probabilities within an Everettian interpretation. One must be a Branch-Actualist in order to be able to apply these probabilities to a single Everett world, since for a Tree-Actualist objective probabilities are probabilities of outcomes of the Everett multiverse (which, given the global determinism of the theory, must be either zero or one). He claims that PASEW is necessary because, since objective probabilities are attributed to propositions, propositions must be such that the squared-amplitude measure is defined over them (and, I add, may be plausibly applied to them). He believes that Indexicality-of-actuality is needed so that objective probabilities may be assigned to *all* propositions about the future, including propositions such as 'the actual outcome will be spin-up'—if we regarded all of our multiverse as actual, such propositions wouldn't be coherent, since there would not be just one outcome we could regard as actual.

Finally, Divergence is necessary, Wilson claims, or we will be unable to make sense of contingent propositions about the future. As he puts it, in his characterization of the overlapping worlds picture, 'agents facing impending quantum interactions are located in every world which emerges from the interaction'. After all, since the worlds' segments before the measurement are numerically identical, they must contain the same agents. But this would mean that each outcome would occur to that agent. Now, this characterization of the overlapping worlds picture is unfair to some possible versions of it—here I have Ismael's version in mind. By refusing to speak of a 'transcendent I' which is present at each moment, before and after the interaction, Ismael avoids the consequence that, before I make a measurement, I am in many worlds, one in which each outcome occurs. I am just one observer, she would say, and I will not experience either outcome, because I will not be identical to any of the observers who will be around after the measurement—they will bear the appropriate Humean relations to me, but they will not be me. But I think anyway that Divergence will leave us better off. Adhering to Divergence, we never place agents or objects in more than one Everett world, and they do not replicate themselves within their Everett world. So, for any person *S* at any time, there is exactly one person *S*' at any later time who *S* may expect to become—the question, then, is just what happens to *S*'.

So much for what Wilson refers to as the Incoherence Problem. Wilson also thinks that his view is helpful in completing the familiar decision-theoretic argument, proposed by David Deutsch and David Wallace, for the conclusion that the objective probabilities of Everettian quantum mechanics are given by the Born rule (rather than being given by some other rule). He believes that Wallace has successfully defended each of his assumptions needed to establish the desired conclusion, except for that which is called Branching Indifference. Branching Indifference says that a rational agent doesn't care about the number of branches that will result from her decisions—if a certain measurement splits the term of the state vector she inhabits into *N* terms (thus creating, on traditional Everett interpretations, *N* copies of herself and everyone else inhabiting that term of the state vector), without changing the rewards of any person on any of those branches, she is indifferent as to whether or not the measurement is performed.

Wilson rejects two of Wallace's defenses of this principle. The first defense which he rejects he calls the 'Pragmatic Defense' of Branching Indifference, claims that no physically possible act could result in more or less branching than any other act (Wilson calls this claim 'branching homogeneity'), and thus that no physically possible agent could be assigned a preference order, over acts available to her, which is sensitive to number of branches. He rejects this defense because it commits its proponents both to branching homogeneity and to what he calls a functional conception of desire, according to which, if no physically possible act of an agent can change a certain parameter, then that parameter does not feature in the agent's preference ordering. The second defense of Branching Indifference, which Wilson presents on behalf of Wallace, is that there is no such thing as branch count, and so agents cannot care about increasing or decreasing that count. Wilson rejects this defense as well, in part because he thinks that even if branch number is not well defined, there may be cases in which there will be determinately more branches if a measurement is performed than there will be if it isn't performed.

Wilson thinks that his Indexicalism can provide a better defense of Branching Indifference. I'll help myself to his words:

> Take any contingent proposition P that an agent might care about; according to Indexicalism, P corresponds to a set of Everett worlds. Introducing additional branching amounts to taking some Everett world w, which either is or is not a member of the set P, and generating multiple Everett worlds which are qualitatively identical to w up to some time t and different after t. But recall that the statement of branching indifference concerns a case in which all the things the agent cares about (i.e the 'rewards') are the same at all of the post-branching Everett worlds. Thus, all the post-branching Everett worlds are in the set

> corresponding to P if and only if w is in that set. Therefore introducing additional branching will not change the truth-value of P at any world; and since P was an arbitrary proposition that an agent might care about, introducing additional branching never changes anything that an agent might care about.

If you agree that any contingent proposition an agent might care about corresponds to a set of Everett worlds, and is true in just the Everett worlds which are in the set, then to me it seems that the rest of the argument will go through. No such proposition (except, perhaps, the value of a certain quantum measurement, which we may suppose nobody cares about) will have its truth-value changed if you introduce additional branching, so insomuch as we care only about those propositions, we will be indifferent to branching.

But of course there are other propositions agents might care about, which we cannot evaluate merely by looking at a single Everett world. Propositions about the number of copies of me there are throughout the Everett multiverse, ones which we would most expect to violate Branching Indifference, are of just such a sort. By introducing further branching, we can make a difference, as far as these propositions are concerned—we can create more copies of ourselves, or we can abstain from doing so (though some uncontrollable branching might happen in either case). And if we ought to care about these propositions, then we will not be indifferent to branching. So Wilson must deny that these propositions matter to us, and he goes on to do so. He thinks that we should only care about actual things, and given that Indexicalism entails that by introducing further branching we only bring into existence non-actual things, he thinks that we shouldn't care about the extra things and people we bring into existence by branching. He thinks that the best motivation that we might have for denying that we should only care about actual things (and not about things which are real, though non-actual) is that it is undermined by Everettian quantum mechanics, though he does not spell out how that is.

Section IV: My view

Wilson's view has inspiring elements which I think are necessary for an acceptable Everettian understanding of quantum mechanics. What I think is best and most important about Wilson's view is Divergence. By accepting it, we find a simple way to make sense of ordinary contingent propositions about the future, without saying that each of the quantum-mechanically possible results happens to an agent who performs a quantum measurement. And we can understand the probabilities calculated by the Born rule as probabilities that a certain outcome of a quantum measurement will be the one we see. Nonetheless, I do not think we need to accept Wilson's full view—indeed some of its tenets seem clearly wrong.

The first matter on which I think we must diverge from Wilson is that of Branch-Actualism. As I have said above, Wilson seems to believe that the most important difference between his and other Everettian interpretations of quantum mechanics is that between Branch-Actualism and Tree-Actualism. But these positions don't even disagree, if we understand them in the way Wilson first defines them! Branch-Actualism says that if X is an Everett world, then X is a metaphysically possible world, and Tree-Actualism says that if X is an Everettian multiverse, then X is a metaphysically possible world. And these could both be true—there might be some possible worlds which are full multiverses, but there might also be some which consist of just a single Everett world. I believe that we should understand the debate between Branch-Actualism and Tree-

Actualism as a debate over what we should regard as the metaphysically possible world we inhabit, if we believe in the Everettian multiverse.

Wilson takes our Everett world to be the metaphysically possible world which we inhabit, and takes our Everett multiverse to be something like David Lewis' plurality of possible worlds. But it seems clear to me that, if an Everettian interpretation of quantum mechanics is correct, we should take everything in our Everett multiverse to be in the same metaphysically possible world. After all, there might have been another Everett multiverse instead of this one. The universe might have begun in a different state than the one which indeed began the universe. There might have been an Everett multiverse whose state vector obeyed an equation other than the Schrödinger Equation (it could have been the Schrödinger Equation with different numerical constants, or it could have been an equation of a wholly different sort). Alternatively, we might have existed in an Everett multiverse in which some terms of the state vector just didn't give rise to any concrete objects. (That is, while some terms of the state vector corresponding to an Everett world consisting of real, concrete objects such as persons and cats and trees, gave rise to those objects, other terms in the same expansion of the state vector, while having the right form for corresponding to an Everett world containing persons and cats and trees, just didn't give rise to those things. Perhaps it might have been that a term simply stops giving rise to concrete objects when it has a part corresponding to ninety-two protons forming a uranium nucleus.)

Let's consider this last possibility, though any of the others will do just as well. You might call such an Everett multiverse, in which some of the terms which should have given rises to objects simply (perhaps inexplicably) failed to do so, a 'multiverse with holes'. Our Everett multiverse could have had holes in it, and if it had, things would have turned out differently than they did. Our Everett multiverse, which we should suppose is whole, and this other Everett multiverse, which has holes, are two different possibilities. Therefore, we should take our Everett multiverse to be the metaphysically possible world which we inhabit.

A similar objection, by the way, may be leveled against Lewis' view of possible worlds (something like this seems to be done in Forrest and Armstrong 1984). Lewis thinks that each possible world is just as real as ours, but couldn't it have been that only some of those possible worlds were realized? That would be a different way for things to turn out—a different possibility. The result of this line of thinking would be that what Lewis took to be possible worlds were not whole possible worlds, but merely parts of the same possible world.

On PASEW: I suppose ordinary contingent propositions, such as 'The ball will roll down the hill' and 'The result of a spin-measurement on this electron will be up', may be understood by thinking of sets of Everett worlds. And such a proposition will be true at a world just in case that world is in the set which corresponds to that proposition. This all seems fine, to me, as a way of evaluating whether or not a proposition of this sort is true in a certain Everett world. But I don't think that this should be taken as an account of what those propositions are, nor do I think Wilson should be accused of intending it to be taken this way. Someone who would take this seriously as an account of ordinary contingent propositions—someone who would say that an ordinary contingent proposition just is a set of Everett worlds in which the proposition is true—would be setting up an understanding of propositions which has very little unity. Propositions of a different sort, such as descriptive propositions about things like art and philosophy, or normative propositions in general, would have to be identified with wholly different objects—I imagine that it would be hard to find any feature of all these objects, of so many different kinds, which could unify them as propositions. And though the work of deciding how to evaluate the truth of propositions and assign probabilities to them is important for Wilson's purposes of understanding quantum mechanics, the project of saying exactly what is a proposition, of identifying propositions with other objects which we already recognize, is not.

Finally, my use of the term 'actual' differs from Wilson's. Given that I deny his Branch-Actualism in favor of Tree-Actualism, this should not be surprising. While Wilson says that each Everett world is actual according to all and only its own inhabitants, I say that each Everett world is actual according to all (and only) the inhabitants of its Everett multiverse. In a way, our use of the term is the same—for something to be actual to me is just for it to inhabit the same metaphysically possible world that I do. Our disagreement, then, stems only from our disagreement on what we should take to be the possible world we inhabit.

Though I do not accept Wilson's Indexicality-of-actuality, I can imagine that there might be some use for a term which follows a similar principle. We might say that two things are 'local' to one another just in case they inhabit the same Everett world. Indeed, from now on I will break from Wilson's convention of speaking of terms of the state vector and Everett worlds, understood as concrete worlds which correspond to those terms. Instead I will say that the concrete worlds which correspond to terms of the state vector are *localities*, so that they may not be confused with possible worlds.

I've indicated now where my view stands on each of the tenets of Wilson's Indexicalism. But it is necessary to say more about how Wilson applies his view, and specifically how he applies Divergence, in his defense of Branching Indifference. In particular, I find it very curious that, even though he accepts Divergence, he continues to speak of worlds as being brought into existence as he argues for Branching Indifference. As I quoted above, he says 'Introducing additional branching amounts to taking some Everett world w ... and generating multiple Everett worlds which are qualitatively identical to w up to some time t and different after t.' This quote alone might not be good evidence that he thinks that worlds are brought into existence by branching. After all, he may have just been using a figure of speech to discuss whether branching should affect our evaluation of certain propositions. But later on he clearly speaks of people as being brought into existence by branching—that is, he believes that when a branch I'm on splits in two, a new person (just like me) has been brought into existence. Of course, his Everettian interpretation is not the first to say that new people are created when branches (with people on them) split. Many Everettian interpretations do that. But I find this stance curious in his case, because I think that accepting Divergence should lead one away from this stance. (Or, perhaps better, accepting Divergence gives us a way out of this stance!)

Consider a case in which I make a quantum measurement which has two possible results, up and down. The state vector, or the branch of it which I inhabit, will evolve so as to split into two branches, one where the result of the measurement is up, and one where the result is down. There are then two localities, and their histories are each represented by a line traveling down a diagram representing the evolution of the state vector, from the beginning of time to the time of the measurement, and then down one of the new branches. These lines would be drawn on the same part of the diagram until they split at the point where the measurement is made. Now, according to Divergence, each person exists in just one locality. So I (the person who was about to make the measurement) exist in just one locality, and only one of the people who exist after the measurement can be me, or have me as an antecedent person-stage. But where did the other person come from? Surely we don't want to say that one of the resulting people has a past which extends before the measurement, while the other simply materialized when the measurement was made! The other person must have been around before the measurement was made (or must have a person-stage who was around before the measurement was made). So there were, before the measurement was made, two people who had the qualities I had immediately before the time of measurement—I in my own locality, and the copy of me in the other locality.

This must be so for any branching event: the people who result must each have a past, and according to Divergence they do not have numerically identical pasts, so there must be as many people before the branch splits as there are new branches after the branch splits. The same reasoning goes for any other sort of object, and for localities. Wilson says that, by causing a branch to split, we bring new localities into existence. But these localities have pasts extending before the branch split, so they must have been around before the branch split. Wilson might say that we create the localities, and their pasts with them, but that is incomprehensible.

If we understand that what Divergence really means is that localities are not copied upon branching, but instead the copies are always present and merely become different upon branching, then there is a very easy defense of Branching Indifference in sight. Branching may change the number of terms in an expansion of the state vector, but it does not change the amount of localities there are—there are just as many localities at any moment in time as at any other. Localities, and the people and objects in them, are not created or destroyed by branching, but only change. Since branching does not change the number of localities there are, there is no reason for an agent to care whether branching occurs or not, unless some of the resulting branches would have different rewards for the people in them than the unsplit branch.

This defense of Branching Indifference, besides being very simple, also seems more plausible than Wilson's, which tells us that we can create additional people by causing additional branching, but that we shouldn't care about their fates because they won't be actual. He seems to be suggesting that, since those people are not actual for us, we can't do anything for or against them. It is true that, once they exist, we can't do anything that will affect them in any way. But, on Wilson's view, we can choose to bring them into existence or not, by causing additional branching to occur. So their fates should certainly matter to us as we deliberate on whether we should cause additional branching. If their fates would be good, it is a choice between creating people with good lives or not creating them; if their fates would be bad, it is a choice between creating people with bad lives or not creating them. Wilson will deny that these choices should matter to us, by denying what he calls a 'truly universal ethics', but I find this move unconvincing.

And indeed I think that if Branching Indifference is to be at all defensible, then it must be that this branching does not result in any multiplication of worlds, or localities.

After all, if all our lives are good, and we can create more people who have lives just as good as ours with very little effort or cost to ourselves (say, by simply running a quantum randomizer), then we should certainly do it.

From accepting Divergence I arrived at the conclusion that branching events do not change the number of localities there are. Now we should ask how many localities are associated with a given term of the state vector. I see two ways of answering the question. One is to say that there are just as many localities associated with a given term $|\Phi\rangle$ of the state vector as there are terms into which $|\Phi\rangle$ eventually splits. But this approach quickly runs into problems. For instance, suppose that a branch splits into two branches that will undergo no further splitting. On this approach, just two localities will be associated with that term of the state vector—one will associate with one descendant branch, the other with the other. Of course, you can't say of each locality that it undergoes a stochastic process, having equal probabilities of associating with each resulting branch. Then there would be a chance that both localities would associate with the same branch, and one branch would be left with no localities—and thus our multiverse would be left with a hole. The same would go if any finite number of localities were associated with the antecedent branch. It must be determined that one locality will go with one branch, and the other with the other.

There are two ways this could be so. Consider two localities, A and B, associated with one branch which will split into α and β. One way it could be determined, that one locality will go with one branch, and the other with the other, is that A is determined to go with α, and B to go with β. But what could determine A to have one fate, and B another, if A and B are, up to a certain moment in time, exactly the same? The other way is that either *A* will go with α and *B* with β, or *A* with β and *B* with α, with each outcome having some probability. In such a case, the localities *A* and *B* must have the same probabilities of going with each branch (that is, P(*A* follows α)=P(*B* follows α) and P(*A* follows β)=P(*B* follows β)). Otherwise, at least one of the localities will have a probability of following a branch, which is not the probability given by the Born rule![4] Such a locality would not be quantum-mechanical, and so we should reject an interpretation of quantum mechanics which posits such localities. But if the branches have unequal quantum-mechanical weights, then we are again met with the conclusion that the probabilities that each locality has of following each branch will not obey the Born rule!

Given these arguments, the only way that a finite number of localities could obey the Born rule, without leaving holes in the multiverse, is for qualitatively identical localities to be determined to follow different branches. Though perhaps there is a way to hold that qualitatively identical localities could be determined to follow different branches, I will not examine whether or not this is so. For, even if one could hold such a belief, it must not be believed that we can posit merely a finite number of localities in an interpretation of quantum mechanics. Branching, after all, must be continuous, since at any moment there is some probability of a quantum tunneling event. Given any single branch corresponding to a locality as complicated as ours, in any interval of time that branch will have split into a continuous infinity of branches. And therefore, assuming that Divergence holds, a continuous infinity of localities must be assigned to each decoherent term in a universal state vector.

[4] Proof: Say *A* has a probability of following α given by the Born rule—given, that is, by α's quantum-mechanical weight. If *B* has a different probability of following α, then its probability of following α will *not* be given by α's quantum-mechanical weight, and so will not obey the Born rule.

At this point, it may seem that I have, by admitting Divergence, committed myself to an insane position. I have reached the conclusion that each decoherent term in a universal state vector is associated with a continuous infinity of localities. That means that, since the beginning of the universe, or rather since the universal state vector first became divisible into decoherent histories, there has been a continuous infinity of localities such as the one we inhabit. But, in reality, this is no more crazy than any Everettian interpretation which does not accept Divergence. If branching occurs continuously, then, even if there was not initially a continuous infinity of localities, there is one such infinity now, and there have been such infinities at moments which are arbitrarily close to the beginning of the universe. Why would it be any more outrageous that such an infinity should have existed at just one more moment? Indeed, I think that it is more reasonable to believe that we had a continuous infinity of localities all along, rather than to believe that the world began with one locality, which multiplied into a continuous infinity of localities. One good reason is that it is this feature of my view which allows me not to accept that two or more people may have numerically identical pasts as a result of Everett branching.

At this point, I should like to make a short comment on imagery. Everettian universes have traditionally been understood, metaphorically, as trees with branches. This is very suitable imagery for a view which represents localities as overlapping, but it is misleading for a view which represents localities as diverging. Rather than imagining a tree with branches, my view is better metaphorically understood by imagining the many localities as the many columns of a pantheon, which begin, alike in color, at the ground, and come to differ in color as one looks upward.

Given that my view posits that a continuous infinity of localities is associated with each decoherent term of the universal state vector, it seems that I can now help myself to a very simple way of understanding of probability in quantum mechanics. Now that, for each term of the state vector, there is a continuous infinity of localities to work with, I can say that each locality undergoes a stochastic process when a measurement is made on a quantum system, the relevant probabilities being given by the Born rule. That way, objective probabilities are made intelligible without the help of the decision-theoretic strategy. Furthermore, it is clear not only how it is that agents should care about potential outcomes in accordance with the Born rule, but also how we could have rationally come to believe in the Born rule (that is, our observed frequencies have an explanation, something that doesn't seem to be given by the decision-theoretic strategy).

Of course, there is another Everettian interpretation of quantum mechanics which has all of these advantages concerning probability: Albert and Loewer's many-minds interpretation. By now it is evident that my view quite resembles this one. But, of course, there are differences. On Albert's and Loewer's many-minds interpretation, there is one physical world, constituted by the state vector of the universe, but each working brain supports a continuous infinity of minds, each of which can only attend to one term of the universal state vector. On my view, there is a continuous infinity of localities associated with each term of the state vector, and each working brain supports just one mind. Thus no separation of brains and minds is essential to my view.

One thing which might be said against the many-minds interpretation is that this separation of brain and mind constitutes an addition of more fundamental ontology, and thus that the many-minds interpretation is less ontologically simple. The *fundamental* *ontology* of a universe includes just the most basic things of that universe, and the *emergent ontology* includes all the things which are not basic, but are present simply in virtue of the presence of basic things, and the relations between them. Since, on the many-minds interpretation, minds are postulated independently of physical objects, and follow entirely different laws, minds, as well as physical objects or their state vectors, must be taken to be fundamental. Such a complaint might come from adherents to the school of New Oxford Everettians (Wallace 2010b). The New Oxford Everettian view (which I will not fully spell out) takes itself to have the advantage that the fundamental ontology includes just the state vector of the universe, and that branches, and concrete things within, are emergent. That is to say, it is a monist fundamental ontology.

Could the same charge be made against my view? Does my view commit to a dualism in fundamental ontology, while other views can get by with a monism? It might seem so. After all, I have committed myself to the reality of the universal state vector, which evolves deterministically, and of the continuously infinitely many concrete localities, which evolve stochastically. But I do not think I am thereby committing myself to two distinct types of fundamental things.

When a physical theory includes a mathematically describable entity, such as a state vector, or an electric field vector, in its fundamental ontology, it does not merely attribute reality to a mathematical object. After all, if state vectors are taken as purely mathematical objects, the state vector corresponding to this universe is no more real than the state vector corresponding to any other possible Everett universe. Similarly, if electric fields are understood as purely mathematical objects, then any vector function giving values for electric fields in space and time is just as real as any other. But when we attribute reality to electric fields, we attribute reality to something physical, which is merely described by a vector function. Likewise, if a state vector is said to be part of the fundamental (or emergent) ontology of a physical theory, then we must understand something physical to be included, which is described by the mathematical object.

Now physical theories are responsible not merely for devising a mathematical framework with which to describe the world, but also for interpreting that mathematical description—for saying what it means for a mathematical framework to correctly describe a world. Any Everettian interpretation will use state vectors—understood now as mathematical objects—to describe the physical world. But different Everettian interpretations might interpret the state vector differently. In particular, I propose that we should interpret the physical reality of a state vector as consisting in and constituting the reality of the continuous infinities of localities which correspond to decoherent terms of the mathematical state vector. Furthermore, I propose that we should interpret the deterministic evolution of the state vector as consisting in and constituting the stochastic evolution of localities. This being done, the fundamental ontology of my view includes both the physical state vector and the continuous infinities of localities, but it is nonetheless a monist fundamental ontology. To posit the physical state vector, as I am choosing to understand it, is just to posit the continuous infinities of localities.

Here, then, is my view: there is, fundamentally, nothing but the physical state vector of the universe, or—what amounts to the same thing—a continuous infinity of physical localities corresponding to each term of the mathematical state vector. These localities evolve deterministically when no branching occurs, and stochastically when branching does occur, each locality having a probability of following a branch of the state vector given by that branch's quantum-mechanical weight. In each case the whole state vector evolves according to the Schrödinger Equation. The metaphysically possible world we inhabit includes not just our locality, but all of the localities associated with our universal state vector—that is, our possible world includes the whole state vector.

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