Identity and uncertainty in Everett's multiverse

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17 February 2008

> How does it come about then, that great scientists such as Einstein, Schrödinger and De Broglie are nevertheless dissatisfied with the situation? Of course, all these objections are levelled not against the correctness of the formulae, but against their interpretation. …. The lesson to be learned from what I have told of the origin of quantum mechanics is that probable refinements of mathematical methods will not suffice to produce a satisfactory theory, but that somewhere in our doctrine is hidden a concept, unjustified by experience, which we must eliminate to open up the road.[2]

ABSTRACT

In the current debate on the concept of probability in the Everett interpretation of quantum mechanics Saunders and Wallace argue for a notion of pre-measurement uncertainty whilst Greaves and Myrvold attempt to do without uncertainty altogether. Both these approaches are controversial and I suggest a middle way. I develop in detail an argument which Wallace has hinted at and Greaves has seen as beside the point in order to show that Vaidman's concept of post-measurement uncertainty has more relevance to pre-measurement decision making than has hitherto been generally recognised. Further, Vaidman uncertainty leads naturally to another form of post-measurement uncertainty which clarifies the process of experimental confirmation of quantum mechanics in the Everett picture. I also stress the importance of Sider's theory of transtemporal identity in making Everett's multiverse intelligible.

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1 Dendritic unitary evolution

The world is more like a tree than a worm. So says the "relative state" interpretation of quantum mechanics introduced by Hugh Everett III (1957) and often called the many-worlds interpretation. Much work has been done on this idea but there is still an ongoing dispute about whether it is even intelligible. Two issues dominate the debate on intelligibility: how quantum probabilities are to be understood in a branching universe where all physical "possibilities" seem to actually occur and how the furniture of our everyday world can be constituted by the fundamental ontology of Everett's theory, that of the quantum-mechanical wave-function[3]. My aim here is to contribute to the work on probability.

We shall need a concrete example on the workbench so let Hydra be our subject. She is supposed to be well-informed about quantum mechanics and to be attempting to believe the Everett interpretation. She is about to use a Stern-Gerlach apparatus make a measurement of the spin of a particle relative to a spatial direction she has chosen. Simplifying somewhat, there are two "possible" outcomes for this measurement: the result UP (spin-up) and the result DOWN. According to the details of the experimental setup quantum mechanics assigns an "amplitude" to each of these outcomes which is a complex number. According to the Born rule of conventional quantum mechanics the square of the modulus of this number is to be interpreted as the probability of the outcome with that amplitude actually occurring. The squared moduli for the amplitudes of the outcomes UP and DOWN thus sum exactly to unity in our example which ignores bizarre outcomes of very low amplitude which will not be relevant in the following discussion.

Must Hydra abandon the Born rule as it is usually understood if she is to believe Everett? Simon Saunders and David Wallace have argued that she need not (Wallace 2005, Saunders & Wallace, 2008). They maintain that there can be pre-branching uncertainty about the outcome of such a quantum process. I have countered one of their arguments (2008) and their approach is currently controversial so I shall set it aside here. Simplifying for the sake of clarity, it is generally understood that what will actually happen according to Everett when Hydra makes her quantum measurement is that she, her apparatus and the surrounding environment will bifurcate into two branches, one where she sees the result UP and one where she sees the result DOWN, though Saunders and Wallace would dispute the way the idea is put. This is a simplification because our understanding of the process of Everett branching has been greatly advanced with the application of the concept of decoherence[4] and according to this understanding there will be an indeterminate number of branches for each outcome but,

[2] Born (1954 : 8 & 11).
[3] For a current challenge to the ontological coherence of Everett see Maudlin (2008).
[4] See Wallace (2007 Sec. 2) for an account and references.

again, that will not be relevant to what follows. For the purposes of what I have to say it will suffice to suppose that there are two branches each with an amplitude determined by the details of the experimental setup, the squared moduli of those amplitudes summing to unity.

On this view it looks as though Hydra prior to making her measurement, if she is to believe Everett, must somehow believe that she will see both outcomes severally, each outcome being seen within the context of a distinct personal experience. So an immediate challenge to the intelligibility of this view is how Hydra can expect, prior to measurement, that she herself will see anything at all. It looks as though there will be two distinct people after the measurement, HydraUP seeing the result UP and HydraDOWN seeing the result DOWN. How can both these people, or either one of them, be the same person as Hydra?

To repeat, I am setting aside Saunders' and Wallace's proposed perspective on this, derived from an idea of David Lewis's. According to that idea, both HydraUP and HydraDOWN exist prior to the measurement and "overlap" on single corporeal states. It is also worth mentioning why Derek Parfit's well-known reflections on personal fission are not relevant here since some commentators on Everett have suggested that they are. Parfit discusses imaginary cases involving Star Trek teleporters and brain hemisphere transplants but there are significant resemblances between those scenarios and what appears to be involved in the Everett interpretation (1984: 199ff). Put into the context of the example of Hydra, Parfit says that "what matters" for Hydra is the relation of physical and psychological continuity she bears to HydraUP and HydraDOWN, not which person she will be (ibid.: 261ff). David Papineau has suggested that this Parfittian notion of what matters can be applied to understanding Everett (1996:237) but caution is called for. Parfit gives no reason to suppose that there are any grounds for believing that Hydra can expect to have experiences after fission.

This point seems to have been overlooked by Hilary Greaves and that has had a crucial impact on her view of the role of the concept of uncertainty in Everett theory. She writes:

> Parfit (1984) argued that what matters in survival - and therefore, presumably, what matters in *quality* of personal future also - is the existence of future person-stages bearing appropriate relations of structural similarity and causal connectedness to one's present person-stage. This dictates that in a case of fission, I-now must care about each appropriately related successor as one of my future selves - the rationale being that, whether we've realized it or not, this is in any case all there has ever been to caring about our futures. This being so, we should be able to develop prescriptions for rational action that altogether bypass the issue of uncertainty. (2004: sec. 4.3, Greaves' emphasis).

The last sentence here underwrites Greaves' current project with Wayne Myrvold (2008) where they attempt to give an account of confirmation theory within an Everettian framework without any reliance on a subject's uncertainty, either pre- or post-branching. But Parfit's concept of what matters is wholly impersonal. According to Parfit multiple "successors" of I-now are in no sense my future selves. However, if for instance Hydra has a project which matters to her, such as writing a book she has in mind, she can, according to Parfit, be confident that HydraUP and HydraDOWN will share that concern. So if what matters to Hydra is the book then she can be at least as confident that it will be written after fission as she would be that it would be written were there no fission.

But what seems to matter in the Everett case is something different. For the Everett interpretation to make sense it seems compelling that Hydra must be able to expect to have observational experiences on making the measurement. In that case it is apparently incumbent on Everett theory to be able to give an account of how personal identity can survive fission, *pace* Parfit, and the transtemporal identity of objects in general since HydraUP will need to be able to believe that the apparatus showing the result UP is the same apparatus as the one she prepared to make the measurement. Greaves apparently recognises this since she makes an appeal to so-called temporal counterpart theory and would say that Hydra has to expect to see each outcome (2004: sec. 4.1.3). But Greaves seems not to have noticed that temporal counterpart theory undermines the "rationale" for her sense of caring about future person-stages. Why should Hydra care about the outcomes UP and DOWN if there are important consequences for her in those branches? Because those are consequences which she expects to experience, not because she should distribute her caring over her successors in the Parfittian sense. But now the problem is that Hydra seems to have to expect to experience each outcome with certainty. Without the Parfittian rationale to which Greaves appeals, the motivation for Hydra's pre-fission caring about her future outcomes has to be found somewhere else.

A potential such somewhere else is discussed but set aside by Greaves herself (2004: Sec. 4.2) when she considers an argument hinted-at by Wallace (2002: Sec. 8.1). Wallace himself seems not to set much store by that argument whilst not wholly dismissing it, as I shall explain later. It is an argument which relates to Bas van Fraassen's Reflection Principle (1984, 1996). In Section 3 I shall present a novel form of this argument and in Section 4 I shall discuss the significance of its relation to the Reflection Principle. In the meantime, I want to return to the issue of how the concept of transtemporal identity can survive in branching contexts.

If Lewis's idea mentioned above is rejected what alternatives are there? In a previous article I suggested a scheme whereby the bodies of HydraUP and HydraDOWN could be considered as proper parts of the single post-measurement body of Hydra (2000: 104-106). Whatever the merits of that, I have since discovered that there is a theory of transtemporal identity which seems to do what is required more effectively. That is Ted Sider's "stage theory" (1996, 2001). As I mentioned, Greaves has briefly explained the idea (2004 : sec. 4.1.3) but it could well do with some reëmphasis and elaboration.

2 Expecting each[5]

Inspired by Lewis's idea of modal counterparts (1986) Sider introduces the concept of temporal counterparts. According to Lewis, if I could have been blond then I have modal counterparts in some possible worlds who are blond. I am not any of my modal counterparts but I bear the modal relation *could have been* to those counterparts. In a similar vein Sider suggests that I have past temporal counterparts. I have a past temporal counterpart who is a boy scrumping apples. I am not that boy but I bear the temporal relation *was* to that boy. According to Sider, people who have a future will have future temporal counterparts and in a case of personal fission the person prior to fission will have more than one future counterpart simultaneously post-fission (2001:201). Thus at the time the outcomes of Hydra's experiment are seen there are two future counterparts of Hydra and, prior to measurement, she bears the temporal relation *will be* to each of them. HydraUP and HydraDOWN are distinct persons having distinct experiences but they both bear the temporal relation *was* to Hydra. Sider's stage theory makes it intelligible for Hydra, in attempting to believe Everett, to say that she will see the result UP and she will see the result DOWN. She will not be one person seeing both, she will be each person seeing each outcome.

This is certainly unfamiliar territory but coming to believe Everett was never going to be easy. Sider's idea is intelligible and has not as yet been shown to be inconsistent and it appears to be perfectly adapted to making sense of Everett, though it was not conceived for that purpose. Note that the application of Sider's idea to branching applies generally to transtemporal identities, not just that of persons. ApparatusUP which shows the result UP and ApparatusDOWN which shows the result DOWN are distinct apparatuses but both of them were the very apparatus which Hydra prepared to make the quantum measurement. HydraUP can speak truly when she says "Look, the apparatus which is now showing the result UP was the one I prepared for the measurement".

But the coherence of the idea of expecting each is only a first step towards reforming our understanding of the Born rule, which must be done to embrace Everett unless a concept of pre-measurement uncertainty such as Saunders' and Wallace's is available. Hydra also has to somehow qualify her attitude towards seeing each outcome in the light of the amplitudes which her application of quantum mechanics assigns to each of the outcome branches. And this qualification needs to be crucial in guiding what would conventionally be understood as her chance-centred behaviours such as betting. All commentators on Everett would agree that something would be seriously wrong if Hydra were not inclined to place bets on outcomes, given particular payoffs, in the same way as a person following the Born rule understood as referring to a stochastic process. Lev Vaidman (2002: Sec. 6.4) and Greaves (2004: Sec. 2.3) have argued that the squared modulus of branch amplitude should be regarded as determining the degree to which a subject should "care" about the predicaments associated with each outcome branch and that a subject such as Hydra should weight the values of payoffs according to this measure.

Greaves (2004, 2007b) and Myrvold and Greaves (2008) make no use of any concept of uncertainty in attempting to give a comprehensive account of how the apparent role of probability in quantum mechanics can make sense in the Everett interpretation although they do not give any reason to deny that a concept of post-measurement uncertainty is available. What I shall do now is attempt to show that a concept of post-measurement uncertainty which is generally recognised within Everett theory can be used to motivate Hydra's pre-measurement betting behaviour.

3 The Born-Vaidman rule

Vaidman has noticed that there is a straightforward sense in which a concept of uncertainty about outcomes can apply in Everettian contexts (1998: 253). Suppose that Hydra decides to blindfold herself and not to remove the blindfold until some time after the measurement has been made, assuming she obtains her evidence for any outcome visually. After the measurement both HydraUP and HydraDOWN remain blindfolded for a short period. During that period both are uncertain as to which outcome she will see when she removes her blindfold. Whilst uncertain, what probability should HydraUP assign to seeing the result UP or the result DOWN on removing her blindfold? Vaidman suggests, very naturally, that she should assign probabilities equal to the squared moduli of the amplitudes of the respective branches. HydraDOWN should do likewise of course. I shall call this postulate the Born-Vaidman rule.

In passing I should mention that some work initiated by David Deutsch may be relevant to providing a derivation of the Born-Vaidman rule[6]. The overall idea is that considerations of symmetry can be used to underpin probability in the Everettian context even though they are known to fail in classical contexts. The

[5] Greaves has emphasised this locution (2004: Sec. 4.1.3).
[6] See Greaves (2007a Secs. 2 & 3) for an account of this work and references.

reason would be that in classical contexts the symmetry is always broken, the die falls one way only, whereas in Everettian contexts, where the wave-function of the relevant quantum system is not understood to "collapse", symmetry is preserved through to the outcomes. The suggestion is that within an Everettian framework physical probability can be made more transparent than hitherto. But this work remains controversial and so I shall for now take the Born-Vaidman rule as a postulate. As such it would not appear to be on any less firm ground than the Born rule in wave-collapse interpretations of quantum mechanics.

Some commentators have doubted the relevance of the Born-Vaidman rule to understanding Everett[7]. For a start, the conditions are contrived, experimenters do not generally wear blindfolds and it is questionable whether there is a relevant state of uncertainty in a non-blindfolded observer between the moment a result occurs and the moment s/he notices that is has occurred. Secondly, the uncertainty occurs after measurement and it has long seemed that the great problem about uncertainty in Everett theory is the apparent lack of it pre-measurement. In short, Vaidman uncertainty is, at best, too brief and in the wrong place. I shall now attempt to show that these objections to Vaidman's idea fail. The Born-Vaidman rule can be relevant to guiding pre-measurement betting behaviour even if Vaidman uncertainty does not actually occur. *Counterfactual* Vaidman uncertainty is all that is required.

To see this, suppose that Hydra's spin measurement is such that the amplitudes for the UP and DOWN branches as given by quantum mechanics are equal, that is, that the squared moduli of those amplitudes are both one half. Now suppose that after the measurement HydraUP and HydraDOWN are both in a state of Vaidman ignorance. They will both assign a probability of one half that they are on the UP branch. Suppose further that HydraUP and HydraDOWN are betting women and are both told that the person on the UP branch will receive a three-to-one payoff for any stake paid prior to finding out which branch they are on and that the person on the DOWN branch will lose her stake. HydraUP and HydraDOWN should both regard this as a bet worth taking and will pay whatever stake they feel they can risk.

Go on to imagine that Hydra is told in advance what the payoff regime will be and that HydraUP will only receive payment if the stake is paid in advance of the measurement. Hydra knows that, if in a state of Vaidman ignorance, both HydraUP and HydraDOWN would consider the bet good and would thus regret not having paid the stake in advance. That seems to be a good reason for Hydra to pay the stake in advance. That is, it would seem that Hydra should bet as if she were facing a genuinely chancy setup.

Now, it might be said that if Hydra believes she inhabits the Everett multiverse there can be no chancy setups but that is not so. Even in the multiverse a quasi-classical betting machine could be constructed so that once it is set in motion there is a single outcome which can be predicted with certainty for all practical purposes if the relevant initial conditions at the time the device is set going are known with sufficient accuracy. The machine is constructed so that no *relevant* branching takes place after it is set going despite its being a multiversal object. Without knowing those initial conditions a punter will be in a classical state of ignorance about the machine and will assign probabilities to what s/he considers to be the possible outcomes in the classical manner. What we have seen is that there seems to be good reason for Hydra to place bets in advance of the quantum measurement in exactly the same way as she would if she were dealing with a quasi-classical betting machine for which the classical ignorance probabilities of the outcomes match the squared moduli of branch amplitudes for the Everettian quantum measurement.

Finally, take the further step of imagining that Hydra is told in advance what the payoff regime will be, is told there will be no payoff without prior payment but is also told that HydraUP and HydraDOWN will not be held in a state of Vaidman ignorance after the measurement. Hydra knows that HydraUP will be happy to have won and HydraDOWN will be sad to have lost. But Hydra also knows that if HydraUP and HydraDOWN were in a state of Vaidman ignorance they would both regret not having paid the stake before the measurement. HydraDOWN may be sad to have lost but she cannot reasonably regret having taken a bet which she would have considered to be a good one. A rational gambler can regret having lost a good bet but s/he cannot thereby rationally regret having accepted it.

The conclusion would seem to be that there are good reasons for Hydra prior to branching to bet as if she were facing an equivalent chancy setup even if she knows that she will not be subject to Vaidman ignorance. Counterfactual Vaidman ignorance suffices to motivate Hydra's pre-branching betting behaviour.

4 On Reflection

Wallace has hinted at the possibility of an argument along these lines (2002: Sec. 8.1). He states that the argument, as he sees it, depends on a principle of rationality derived from Bas van Fraassen's Reflection Principle (1984, 1995) and he notes that the universality of such a principle is challenged by Adam Elga (2000). However, the argument I have given above does not rely an any such principle as an assumption. My aim has been to give a specific argument to show how counterfactual post-measurement uncertainty can underwrite pre-measurement decision making in the context of Everett theory without appeal to any general principles calling for further support.

[7] For example, Albert (2008) and Wallace (2006 Sec. 4.2).

Although not according any importance to the argument as he himself gives it, Wallace has remained nonetheless open to the possibility that some effective argument may be given for the relevance of Vaidman uncertainty. Having dubbed the "expecting each" approach to Everett branching the 'fission program' he writes, with reference to the strategy of appealing to Vaidman's idea:

> This strategy provides, so far as I can see, the only promising means to salvage the fission program; however, I do not find it wholly satisfactory, for two (admittedly very inconclusive) reasons. (2006: Sec. 4.2)

My claim is that the argument have have given in the previous section is indeed wholly satisfactory. As I have said, Greaves and Myrvold do not see this route as necessary to the fission program. Having reviewed the argument from Reflection and referred to Wallace, Greaves considers a thought experiment:

> Suppose (somewhat artificially) that I am confronted with the choice of whether or not to sign a particular form. After I make my choice, a Stern-Gerlach experiment will be carried out. If I signed, my spin-up successor will be force-fed olives, and my spin-down successor will be given chocolate. If I didn't sign, no-one is fed. But I hate olives. How do I decide whether having one successor worse off and another better off is preferable to having all my successors stuck with the status quo? Do I sign or not? (2004: Sec. 4.3)

A little later Greaves then goes on to write:

> I can now say why, in my view, the Reflection approach obscures the logic of Everettian decisions. Suppose, for the sake of argument, that, in the above scenario, the relevant outcomes (chocolate, hunger, olives) are equally spaced in terms of utility. Then if I strictly prefer signing the form to not signing it (perhaps in a fission setup in which the spin-down successor has higher quantum-mechanical weight), that is so *because* I care more about my spin-down successor than I do about my spin-up successor. It is not *because* my post-fission selves will suffer weighted disorientation, although (as emphasized by the Reflection argument) that is also true. (*ibid*. Greaves' emphasis)

In my view Greaves' thought here needs to be turned on its head. I believe that the argument I have presented shows exactly how Greaves' notion of caring needs to be seen as arising out of the concept of Vaidman uncertainty. Hydra can appear to care about her futures in a way which guides her betting just *because* it is *possible* for her to experience Vaidman uncertainty in those futures.

Having acknowledged the relevance of the Born-Vaidman rule to Everettian quantum mechanics without pre-measurement ignorance it is worth dwelling on the state of Vaidman ignorance further. I shall now argue that this can lead to a new insight into the nature of the Everettian multiverse and thereby clarify how the process of theory confirmation should be understood.

5 Branch cross-section and evidence

Return to Hydra's spin measurement and imagine that she is blindfolded. The blindfold screens her visually from the apparatus readout but it does not screen her causally from the relevant process of decoherence which originates in the apparatus so Hydra branches into HydraUP and HydraDOWN, both of whom are in a state of Vaidman ignorance. Consider HydraUP in this state. What is she ignorant about? She is ignorant as to whether the result in that branch is UP or DOWN and she assigns probabilities to these possibilities according to the Born-Vaidman rule which tells her to assign probabilities equal to the squared moduli of amplitude. But note how different the Born-Vaidman rule is from the Born rule. The Born rule tells us to assign probabilities to possible future events whereas the Born-Vaidman rule is telling HydraUP to assign a probability to what the state of her actual, present environment is and it is telling her to do this on the basis of some extant property of her environment. HydraUP, in using the Born-Vaidman rule, says to herself, "Quantum mechanics tells me that the squared modulus of amplitude for the UP branch is U so I shall assign a probability of U to my seeing UP when the blindfold is removed. If the result on this branch is UP, and if quantum mechanics is correct, then the squared modulus of amplitude for the branch I'm now on is U". The quantity U is some real property of a branch. So is the quantity D, the squared modulus of amplitude calculated for the result DOWN. And U+D=1, for all practical purposes.

Note that the values U and D attach to some extant physical quantity hitherto unknown to science. That is the implication of Everettian theory incorporating the Born-Vaidman rule. Vaidman himself has called this quantity a "measure of existence" (1998: 254-5, 2002: Sec. 3.5). That label is perhaps unfortunate as it gives the impression that existence comes in degrees, although Vaidman has not understood it in that sense. Given that this quantity is the squared modulus of amplitude I suggest that it can conveniently and naturally be thought of as the relative cross-sectional area of a branch. The quantities U and D are the cross-sectional areas calculated for the UP and DOWN branches relative to the branch from which they bifurcated. The suggestion is that this is some sort of novel physical extension. The idea is not new. Michael Lockwood (1989:232) has called this quantity a superpositional “dimension”, not meaning that to be taken too literally, and attributes the origin of the idea to Deutsch.

Having acknowledged that the Born-Vaidman rule leads naturally to the idea of branch cross-section as a new physical quantity it is possible to gain a further insight into the nature of the confirmation theory which is appropriate to believing Everett. What is at issue here is not the empirical confirmation of Everett theory as against some other interpretation of quantum mechanics. It is generally recognised that the reasons for accepting Everett, if there are good reasons, are in the domain of grounding realism in physics. The issue of confirmation in Everett theory turns rather on how it can make room for the possibility of quantum mechanics itself being disconfirmed.

The problem for the Everett interpretation can be put very starkly. Quantum electrodynamics is a theory which has already been confirmed to a high degree of accuracy. That is, measured frequencies of outcomes correspond very closely to what are expected according to the probabilities predicted by the Born rule. Suppose that experimental techniques advance so that it is possible to confirm the theory to a further decimal place of accuracy. From an Everettian point of view, why bother? We know what the result will be according to Everett and why bother doing an expensive experiment when you know what the result is going to be? According to Everett every “possible” measurement of frequencies will actually occur in some branch. All “possible” results of the experiment will exist so what can the experiment possibly tell us if we believe in Everettian quantum mechanics?

Consider an experiment conducted with the newly improved equipment. According to conventional quantum mechanics using the Born rule there will be a certain range of observed frequencies of particle interaction which are to be taken as confirming the theory to a further decimal point of accuracy. If the observed frequency lies outside that range then that must be taken as disconfirming evidence. Quantum theory will predict that the errant frequencies are possible, they are consistent with the correctness of the theory, but they are so improbable that, if observed, they cannot reasonably be understood to have occurred because of phenomena conforming to the theory for that would be too unlikely. Rather, the observation of errant frequencies must be taken as evidence against the theory. What defines certain observed frequencies as errant is a matter of convention. The scientific community must decide what degree of improbability in the observed frequencies is tolerable. Everyone will agree that if the probability assigned by quantum mechanics to a certain range of frequencies is one-in-a-billion and what is observed lies within that range then that must be taken as evidence against the theory because it would be unreasonable to assume that a one-in-a-billion series of events had been observed. Where exactly the cut-off point of improbability is to be placed will be a matter for the scientific community to judge.

Of course, Hydra will predict that all possible frequencies will actually occur. Simplifying somewhat, she predicts, using Everettian quantum mechanics, that if she conducts the experiment there will be, for instance, a branch of relative cross-section one billionth where the observed frequency is that which the conventional interpretation assigns a probability of one-in-a-billion. The issue will be complicated by the matter of branch number indeterminacy but we can set that aside for the sake of argument. So, call the branch where the one-in-a-billion statistics occur the branch MAVERICK. Now consider HydraMAVERICK on the branch MAVERICK. Suppose first of all that she's blindfolded and so subject to Vaidman ignorance. Applying the Born-Vaidman rule she'll assign a probability of one billionth to finding herself on branch MAVERICK when the blindfold is removed. When the blindfold is removed and she does see MAVERICK she'll be very surprised. But it would be false reasoning for her to believe that the relative cross-section of her branch is one billionth. It was overwhelmingly unlikely when the blindfold was on and remains so once it is off. What HydraMAVERICK must believe is that she is seeing results which disconfirm quantum theory. In fact she's mistaken, but it would be irrational for her to think otherwise.

For HydraMAVERICK without the blindfold to believe that the relative cross-section of her branch is one billionth would be a mild version of someone who saw a stone on the road in front of them suddenly jump into the air and concluded that it had done so because a huge number of atoms in the stone and the ground just happened to have their motions appropriately aligned. That would be unimaginably unlikely and so is not to be believed without further evidence. Notice now that HydraMAVERICK is making a probabilistic judgement even when the blindfold is off. She estimates that according to quantum theory the branch she is on should have a tiny relative cross-section and she judges that to be highly improbable. HydraMAVERICK without the blindfold is in a state of ignorance about her environment which is not Vaidman ignorance. She is ignorant about what the actual cross-section of her branch is relative to the branch she was in before doing the experiment even though she's observing the result MAVERICK.

Hydra's prediction was that the cross-section of the branch where she would see MAVERICK would be tiny but HydraMAVERICK cannot reasonably believe that that prediction has been confirmed because she has to judge it highly unlikely that she is on a branch with such a small relative cross-section. Of course, Hydra predicts this in advance. She predicts that the cross-section of the branch where MAVERICK is seen is a billionth and that HydraMAVERICK cannot reasonably believe that it is a billionth. So Hydra predicts that HydraMAVERICK will falsely believe that quantum theory has been disconfirmed but HydraMAVERICK herself cannot believe that she is falsely believing in the disconfirmation of quantum theory because there is another possibility which she must count more likely: that what Hydra predicted has not in fact happened. Perhaps there's no such thing as branching after all, or perhaps there is branching but the result MAVERICK has occurred on a branch of much higher amplitude than was predicted. The upshot is, bearing in mind Siderian stage theory, that before doing the experiment Hydra must believe that there are future branches where her only rational option will be to believe that quantum theory has been disconfirmed.

So why is it worth Hydra doing her experiment in the first place if she believes Everett? Well, for one thing her belief in Everett cannot amount to certainty. She may see results which she believes disconfirm quantum mechanics and Everett along with it. Certainly Hydra knows that even if Everett is right she'll see results which disconfirm quantum mechanics but she also knows that it would be unreasonable for her to believe that she is subject to illusion like that. At the same time, Hydra knows that if quantum mechanics is indeed correct at the enhanced degree of accuracy then she will have confirmed that on a branches of high combined amplitude. And Hydra knows that if Everett is right then future branch amplitude matters in the sense that it is as good a guide to her actions as probabilistic reasoning is thought to be in situations of classical ignorance. Furthermore, Hydra knows that if she doesn't do the experiment then she will remain ignorant about whether quantum theory applies at the enhanced level of accuracy which has become accessible.

Something which this reasoning underlines is that the Everett picture is saturated with a type of uncertainty which has not been recognised. Apart from the special case of Vaidman uncertainty, any observer at any time must be uncertain as to what the cross-section of their branch is relative to some earlier event. This is not something which is directly measurable; an observer can only make a probabilistic judgement about what that value is. The predicament of HydraMAVERICK makes that point clearly but it is quite general. Recall Hydra's spin measurement where she predicts the result UP on a branch of cross-section U and the result DOWN on a branch of cross-section D. HydraUP, on seeing the result UP, cannot conclude that the relative cross-section of her branch is U. It might be that the prediction was awry. The best HydraUP can rationally do is assign a *high probability* to the relative cross-section of her branch being U. There's no known way that she can measure U directly.

Recall Max Born's words in the opening quote: "somewhere in our doctrine is hidden a concept, unjustified by experience, which we must eliminate to open up the road. ". Ironically, hidden in the Born rule is the concept that the world evolves stochastically rather than dendritically. That is not justified by experience.[8]

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[8] My thanks to Peter J. Lewis, Simon Saunders, Lev Vaidman and particularly Victor Durà Vilà for valuable comments on an earlier draft.

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