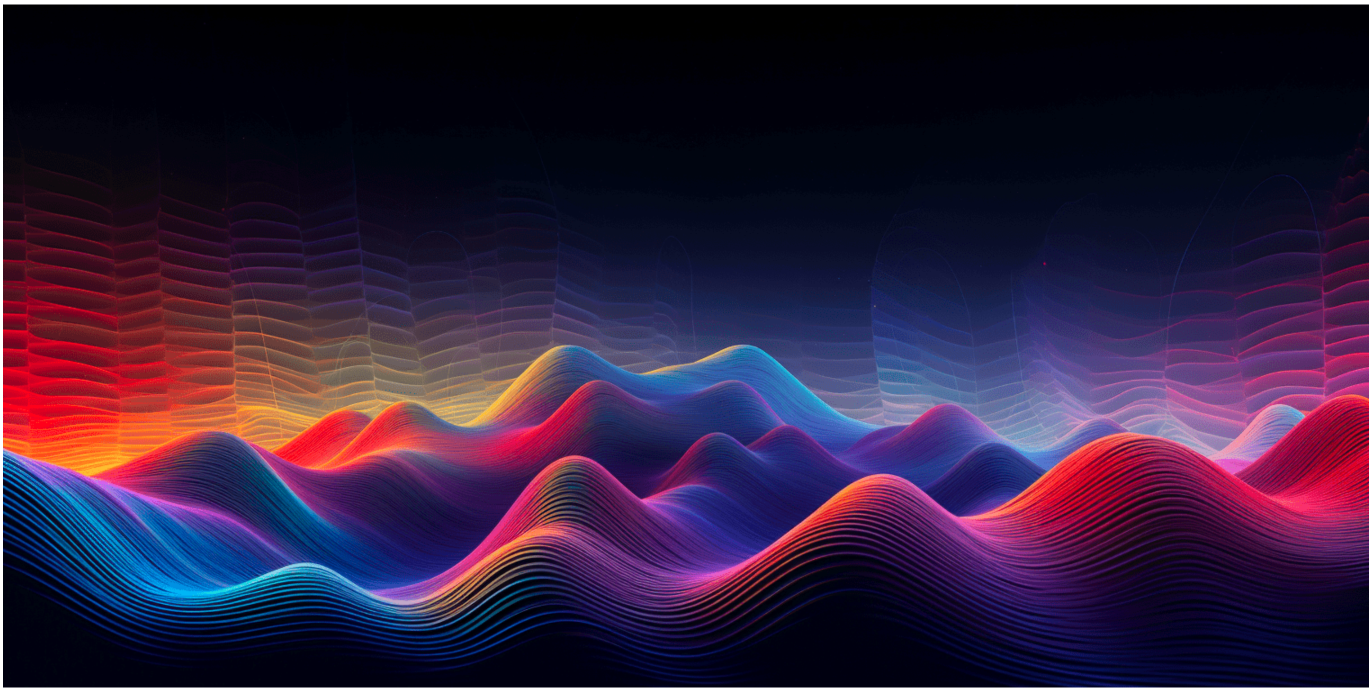
A single hidden variable interpretation of the quantum wave function

David Gentile



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Abstract

An interpretation of quantum mechanics is presented in which there is one hidden variable. While this number of hidden variables is insufficient to explain Bell nonlocality, it can help solve the measurement problem. It also provides a nonretrocausal explanation of the delayed choice quantum eraser experiment and a solution to the new Wigner's friend paradox. The key idea is that from the perspective of an outside observer, not entangled with an observed system, we treat all interactions within the system as unitary. However, from the perspective of an "observer" inside the system, entangled with the system, we treat all new entanglements as "micro-observations" and as a projection onto some basis of measurement. One particle can "observe" another. Thus, particles will have a defined value on one measurement basis from the inside perspective. This means that the wave function will at times describe an objective uncertainty, at other times a subjective uncertainty and at yet other times a combination of both. The wave function describes the total uncertainty, the minimal uncertainty that is present for any observer outside of the system, while for an observer inside the system, only the objective part of the uncertainty remains. The hidden variable is invisible to the outside observer.

Contents

1. Introduction.

We begin in section 2 by defining two types of uncertainty, objective and subjective. We then assert that the wave function represents the total uncertainty to an outside observer not entangled with the system, a combination of objective and subjective uncertainty. From this outside perspective, all interactions are treated as unitary interactions. From a perspective inside the system, all interactions are treated as projections on some basis. The particles "observe" each other and give each other definite values on some (unknown) measurement basis. From this inside perspective, only objective uncertainty remains. Thus, from the outside perspective, there is one hidden variable – a definite value on some measurement basis that is unknown. One hidden variable is insufficient to explain Bell nonlocality; however, it is helpful with other problems. We attempt to show, for example, that it offers a solution to the measurement problem. In section 3, after the most basic example, we first discuss a configuration in which, from the outside perspective, only subjective uncertainty remains. We then turn to a situation in which measurement by one observer, Alice, will resolve subjective uncertainty, but another, by Bob, will

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resolve objective uncertainty. In this configuration, we attempt to show that the results of the delayed choice quantum eraser experiment can be addressed. We also briefly discuss a case where only objective uncertainty is present. Then, in section 4, we attempt to tackle the measurement problem. In section 5, we consider various taxonomies provided by the new Wigner's friend thought experiment and show how this interpretation would resolve that paradox. Finally, in section 6, we provide a brief philosophical discussion.

2. Types of uncertainty

Let's define two different types of uncertainty. One we will call intrinsic or objective uncertainty, and the other is epistemic or subjective uncertainty. The first represents real uncertainty in the universe, and the other is about what information we have available. In statistics, historically, these conceptions of probability divided mathematicians into two camps, classicists and Bayesians, although today, both are mostly accepted as two valid but different approaches to probability. One simple example of a coin flip is enough to illustrate the difference. Suppose someone flips a coin and holds the result behind their back. To a classical statistician, the coin is represented as a random number generator. The odds are 50/50 heads/tails before the flip. However, when the coin is flipped but still hidden, the probability is now 1 or 0. We just don't know which. To the Bayesian, the odds are still 50/50 until we learn the result because Bayesian statistics is concerned with the information available to us.

While completely epistemic interpretations of quantum mechanics exist (Ali Barzegar, 2022), here, we assume that quantum mechanical systems can and do exhibit real objective, intrinsic uncertainty. This can be illustrated by many experiments, but the most well-known may be the classic 2-slit experiment (Ananthaswamy, 2018). The photons in this experiment clearly seem to pass through both slits in order to interfere with themselves. Both states exist in superposition with each other. This kind of uncertainty is more than us just not knowing which path the photon took. We might say the universe does not even "know". Our macroscopic world does not exhibit this sort of behavior, nor does classical physics. The coin flip in classical physics would not be described as intrinsically random, but rather, we just lack sufficient information to make predictions. Somehow in moving from the quantum world up to the macroscopic world, intrinsic uncertainty is lost.

Here, we assert that the wave function can represent objective uncertainty, subjective uncertainty, or a combination of both, depending on the circumstances, and that the transformation from one type of uncertainty to another is invisible in our standard Dirac notation. From the perspective of an "outside" observer, not entangled with an observed system, we treat all interactions within the system as unitary. The wave function then gives a perfect description of the system from this perspective, or at least gives us probabilities that accurately predict all experimental results, but what portion of it represents objective versus subjective uncertainty is unclear in the standard notation.

From the perspective of an observer "inside" the system[1], entangled with the system, we treat all new entanglements as "micro-observations". One particle can "observe" another. This transforms

[1] This outside/inside language is borrowed from (Nick Ormrod, 2023) where it is used to describe macroscopic observers with inside and outside perspectives in the new Wigner's friend thought experiment.

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some objective uncertainty into subjective uncertainty, at least temporarily[2], with every new entanglement. Assuming a new measurement is not completely compatible with the previous measurement, a "coin is flipped" when this happens. A nondeterministic event takes place. That is, from the perspective inside the system, projection onto some (unknown) basis has occurred, and a variable measured on that basis now has a definite value, while from an outside perspective, subjective uncertainty regarding that variable's value remains. Objective uncertainty also persists, however. Values for other variables which would have to be measured on an incompatible orthogonal basis remain objectively undetermined.

The wave function describes the total uncertainty, objective and subjective combined. One might ask "Exactly who's subjective uncertainty?" So, to be more precise, the wave function describes the minimal uncertainty that is present for ANY observer outside of the system. An individual observer could have greater uncertainty, for some idiosyncratic reason, unrelated to physical laws, but not less uncertainty. We label the subjective part of the wave function "subjective" because the uncertainty is due to a lack of information. The information exists but is unavailable. Similarly, the objective uncertainty represents the minimal uncertainty that any observer must have, even if entangled with the system. We label it "objective" because the information needed to resolve this sort of uncertainty does not exist.

3. The basic idea and the delayed choice quantum erasure experiment.

Perhaps it is best to start with the simplest possible case as an example. Suppose we have one single random photon that we are not entangled with. From this outside perspective, we might write the wave function as:

$$|\psi\rangle = |\psi_{Initial}\rangle \quad (1)$$

Representing a superposition of all possible states. However, here, we assert that there is a hidden variable, only visible from an inside view, entangled with the system. The photon already has a determined value on some basis. This value was determined by its most recent interaction.

$$|\psi\rangle = |U_{+}\rangle \quad (2)$$

This indicates a positive value on some unknown basis of measurement. But then, of course, on some orthogonal basis of measurement, say V, we could also write the wave function as a superposition.

$$|\psi\rangle = \frac{|V_{+}\rangle + |V_{-}\rangle}{\sqrt{2}} \quad (3)$$

In equations (2) and (3), we see the minimum possible uncertainty that must exist for any observer, even if they are entangled with the system. There is no uncertainty on some basis and

[2] Micro-observations can be easily erased. Performing a new observation on an orthogonal basis to an existing measurement will destroy the information gathered by the previous measurement and create new objective uncertainty regarding the previously measured values.

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objective uncertainty on some orthogonal basis. If we then consider equation (1), we can see that while it correctly predicts the results we will see if we measure – namely, a random result on any basis on which we measure – it represents a mix of subjective and objective uncertainty. If we happen, by accident, to measure on the U basis, then our measurement will only resolve our subjective uncertainty as to the preexisting value. However, if we happen to measure on basis V, orthogonal to U, then our result is objectively undetermined until we measure, and a nondeterministic event takes place.

Let's now turn to a more complex example. In (Hobson, 2022), a pair of entangled photons or a biphoton is considered. Suppose two experimenters, Alice and Bob, each receive one of the pair. Each of the photon paths has been split into two paths they can follow with 50% probability. Because the states are correlated, if Alice receives a photon via path 1, then Bob will as well and the same for path 2. We can write the wave function from an outside perspective, which represents the minimum uncertainty we must have from that perspective as:

$$|\psi_{AB}\rangle = \frac{|A1\rangle|B1\rangle + |A2\rangle|B2\rangle}{\sqrt{2}} \quad (4)$$

Suppose Bob puts a phase shifter on one path and tries to get his photon to interfere with itself. He will not be successful. As (Hobson, 2022) points out, experiments have shown that this does not happen. (Hobson, 2022) following (M. A. Horne, 1990) and (M. A. Horne, 1989) also explains the theoretical reason interference does not appear; the nonlocal photon's contribution needs to be considered. When this is done, the phases always line up so that the photons decohere each other. Thus, all experimental evidence of superposition has been eliminated in this configuration. Hobson contends that this represents a measured state[3]. Other quantum phenomena such as entanglement persist, of course. The experimental setup discussed is diagramed below (fig. 1):

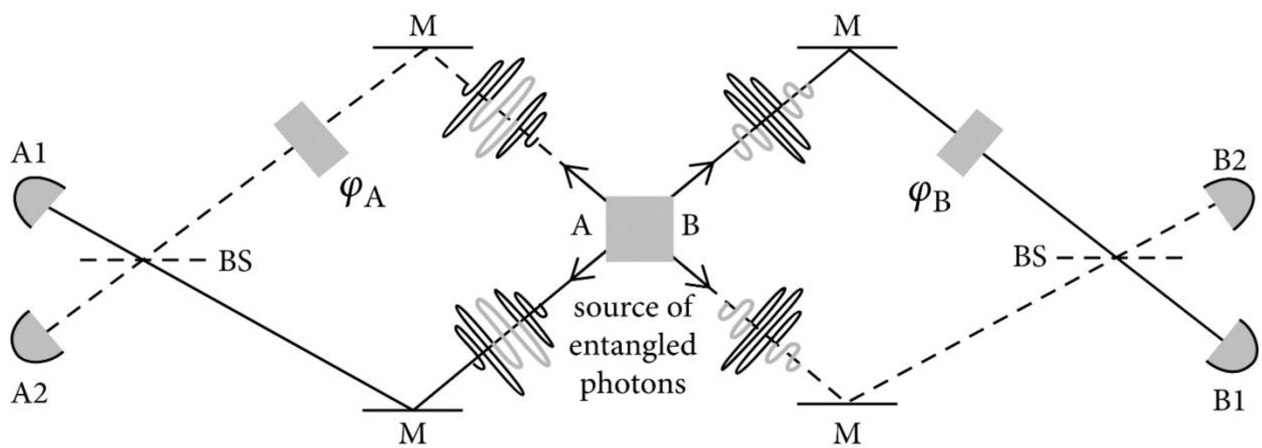

Figure 1 – A diagram of the experimental apparatus discussed.

We can write the two-point nonlocal quantum field amplitudes at the detectors as:

[3] This is not the first suggestion that decoherence can solve the measurement problem (Bacciagaluppi, 2020), but it a good jumping off point for our discussion here, since it was while trying to understand the claim in (Hobson, 2022) that we had the idea for this paper.

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$$\psi_{A1,B1} = \psi_{A2,B2} = \frac{1 + exp(i\,\phi_B)}{2\sqrt{2}} \text{ (5)}$$

$$\psi_{A1,B2} = \psi_{A2,B1} = \frac{1 + exp(i\,\phi_B + \pi)}{2\sqrt{2}} \text{ (6)}$$

where ϕ_B is the phase change imposed by Bob and we have assumed Alice is not altering her photon and the various phase changes imposed by the experimental set up have been subsumed into a zero phase shift in eq. (5) and a shift of π in eq. (6)[4].

The joint probabilities are then given by:

$$P(A1, B1) = P(A2, B2) = |\psi_{A2,B2}|^2 = \frac{1 + cos(\phi_B)}{4} \text{ (7)}$$

and

$$P(A1, B2) = P(A2, B1) = |\psi_{A2,B1}|^2 = \frac{1 + cos(\phi_B + \pi)}{4} \text{ (8)}$$

Then, we have P(B1) = P(A1,B1) + P(A2,B1) = 0.5 regardless of the phase. And in general, P(A1) = P(A2) = P(B1) = P(B2) = 0.5 regardless of any phase change added by Bob.

If we suppose that intrinsic uncertainty still exists, we will obtain the right answers using our mathematical expressions. However, we can also suppose that intrinsic uncertainty has been eliminated and that all that now remains is epistemic uncertainty about which path the photon has taken. Either interpretation gives us the same results – 50% probability, consistently, at every detector.

Here, we assume the latter. In this specific configuration, and only in this configuration, where Alice and Bob measure their photons on the basis the photons measured each other, the "coin" has already been flipped. Thus, one crucial component of what we need a measurement to accomplish has already occurred. One single entanglement counts as an "observation". We can legitimately speak of Alice's photon as the observed system and Bob's photon as our measuring device, which we have not yet queried. A nondeterministic event occurred as the photons separated. We are not suddenly dealing with a classical system of course. We can still do things like erase the measurement and reintroduce objective uncertainty, but for the moment Bob's photon has measured Alice's and vice versa and the pair can now be viewed as having one or another determined value on the measured basis but not both values, we simply do not know which.

Let's suppose path 1 represents reality. Then, to an outside observer unentangled with the system, who has subjective uncertainty, equation (4) still appears to be the correct description of the system and still describes their minimum possible uncertainty, and over many observations of many photons with preestablished values on random bases, it will give correct statistical predictions. However, for an observer entangled with the system, in this specific case, equation (9) is correct.

$$|\psi_{AB}\rangle = |A1\rangle|B1\rangle \text{ (9)}$$

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[4] In effect what we have done is to assume that Alice and Bob are initially measuring on a pure state basis, before any phase shift is introduced by Bob. This will not be the case in general, but it makes the example pedagogically simpler and changes nothing important in the analysis.

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One might object that having this information preexisting when the photons are still together constitutes hidden variables. However, Bell's inequality (BELL, 1964), (Maccone, 2013) only tells us that it is not possible for values on multiple incompatible orthogonal measurement bases to be preexisting (Napolitano, 2021). It is not possible in this example that a value on some unknown measurement basis, U, is preexisting and then also have preexisting values on an incompatible orthogonal basis such as V or W. Hidden variables sufficient to explain Bell nonlocality have been ruled out experimentally; however, that does not mean there cannot be an ANY hidden variable[5].

Let us now have Bob change the phase by π/2.

$$P(B1) = P(A1, B1) + P(A2, B1) = \frac{1 + cos(\pi/2)}{4} + \frac{1 + cos(\pi/2 + \pi)}{4} = 0.25 + 0.25 = 0.5 \quad (10)$$

$$P(B2) = P(A2, B2) + P(A1, B2) = \frac{1 + cos(\pi/2)}{4} + \frac{1 + cos(\pi/2 + \pi)}{4} = 0.25 + 0.25 = 0.5 \quad (11)$$

We now have introduced new objective uncertainty because Bob's basis of measurement has changed. Bob's measurement is now completely uncorrelated with Alice's, and the result is intrinsically uncertain before measurement. We still have a 50% subjective chance of A1 or A2. And now, in each case, there is a 50% objective chance of B1 or B2. That objective uncertainty will be resolved when Bob's photon first becomes entangled with his measuring device. This distinction between types of uncertainty is invisible, however, in our notation. We might instead wish to write something like the following where P_T, P_O, and P_S represent the total probability, the objective probability, and the subjective probability, respectively.

$$P_T(B1) = P_S(A1) * P_O(B1|A1) + P_S(A2) * P_O(B1|A2) \quad (12)$$

$$P_T(B1) = 0.5 * \frac{1 + \cos(\phi_B)}{2} + 0.5 * \frac{1 + cos(\phi_B + \pi)}{2} \quad (13)$$

$$P_T(B1) = 0.5 * 0.5 + 0.5 * 0.5 = 0.5 \quad (14)$$

A well-known result in quantum mechanics is that if we perform a measurement and then measure again on an incompatible orthogonal basis, the information gained from the first measurement is destroyed (Napolitano, 2021). Alice's photon measured Bob's photon, and Bob's photon was in a definite state where only subjective uncertainty existed until Bob erased this information and reintroduced objective uncertainty.

Some readers may notice that in this configuration, we are very close to the configuration of the delayed choice quantum erasure experiment (Yoon-Ho Kim, 2000). We only need to have Alice direct her two beams each into one hole of a two slit experiment and place Bob significantly farther from the photon source than Alice, and Bob then plays the role of the eraser. The Copenhagen interpretation, with no hidden variables, struggles to explain the results of this experiment without resorting to hypothesizing retroactive erasure of "which way" information. And interpretations with multiple hidden variables are ruled out by Bell's inequality. Our "one hidden variable interpretation", however, has no difficulty explaining the results of the experiment without either of these problems.

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[5] This idea takes the middle ground in the historical Einstein, Bohr debate where Einstein thought there must be sufficient hidden variables to avoid any nonlocality (A. Einstein, 1935), and Bohr believed the wave function was a complete description of the system.

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The experiment will of course involve many pairs of entangled photons, and each photon will measure the other half of its pair on some random basis. There will then be populations of biphotons with preexisting values on some measurement basis. Those that happen to be predetermined to be on path A1 we can call "population A1", and they will be objectively undetermined between the B paths – these will only go through Alice's slit number one. Additionally, those biphotons that happen to be predetermined to be on path B1 will be objectively undetermined on the A paths. Those photons will go through both of Alice's slits and interfere with each other. This means that if we only look at the results on Alice's detection screen that correspond to photons that were measured on path B1, we will see an interference pattern. Suppose for simplicity, rather than every possible population, we have only 4 populations - those biphotons that are 100% determined to be on paths A1, A2, B1, or B2. From the inside perspective, we can write:

$$|\psi_A\rangle = |A1\rangle , |\psi_B\rangle = \frac{|B_1\rangle + |B_2\rangle}{\sqrt{2}} \quad (15)$$

$$|\psi_A\rangle = |A2\rangle , |\psi_B\rangle = \frac{|B_1\rangle - |B_2\rangle}{\sqrt{2}} \quad (16)$$

$$|\psi_B\rangle = |B2\rangle , |\psi_A\rangle = \frac{|A_1\rangle - |A_2\rangle}{\sqrt{2}} \quad (17)$$

$$|\psi_B\rangle = |B1\rangle , |\psi_A\rangle = \frac{|A_1\rangle + |A_2\rangle}{\sqrt{2}} \quad (18)$$

From an outside perspective, assuming all possible populations exist, equation 4 still describes the system, and gives the minimum uncertainty that must be present from an outside perspective, and still makes correct statistical predictions from that perspective. However, from the inside perspective, these different preexisting populations exist.

Detector B1 will pick up all the population B1 biphotons, of course, and then also half of each of the A1 and A2 populations. The A1 and A2 populations in the mix will smear the pattern out slightly on Alice's detection screen, but an interference pattern will remain. This is a heuristic argument, but it shows that one hidden variable is all we need in order to explain the results of this experiment without resorting to retro-erasure. One "coin flip" already happened as the photons were created, so it does not matter how delayed Bob's measurement choice is. The population B1 biphotons were always going to be objectively undetermined on the A paths and interfere with themselves at Alice's detector. Population B2 biphotons interfere with themselves as well; however, the pattern is 180 degrees out of phase with the pattern produced by the B1 population. If viewed together, the patterns wash each other out. All Bob does, after Alice's results have been recorded, is choose to look at some of the existing populations and not others. He does not retroactively erase "which path" information.

To conclude, this section, let us suppose that both Alice and Bob alter their basis of measurement by π/2.

$$P(B1) = P(A1, B1) + P(A2, B1) = \frac{1 + cos(\phi_B - \phi_A)}{4} + \frac{1 + cos(\phi_B - \phi_A + \pi)}{4} = 0.5 \quad (18)$$

$$P(B2) = P(A2, B2) + P(A1, B2) = \frac{1 + cos(\phi_B - \phi_A)}{4} + \frac{1 + cos(\phi_B - \phi_A + \pi)}{4} = 0.5 \quad (19)$$

Both have now measured on a basis orthogonal to the basis on which the photons measured each other, and both results, taken individually, are objectively undetermined, but they perfectly

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correlate, even nonlocally, when considered together. Assuming we do not allow superdeterminism, this nonlocal correlation has been conclusively experimentally demonstrated (Hensen, 2015), (Storz, 2023). The description of the system in this case is no different than in standard interpretations. From both the inside and outside perspectives, equation (4) describes the state of the system. There is only objective uncertainty in this case, as knowledge of the hidden variable adds no useful information.

$$|\psi_{AB}\rangle = \frac{|A1\rangle|B1\rangle+|A2\rangle|B2\rangle}{\sqrt{2}} \quad (4)$$

4. The measurement problem

Let us now complete a classical observation. After the photons measure each other, we have a couple more steps. First, one of the photons, let's say Bob's, must become entangled with Bob's measuring device and then with Bob. We then have, from the point of view of an outside observer, not entangled with the system:

$$|\psi_B\rangle \otimes |Device\rangle \otimes |Bob\rangle \quad (19)$$

Obviously, however, Bob does not experience himself in a superposition, so what is happening from the inside perspective? From the inside perspective, something important happens in each of these steps. Once entanglement with the macroscopic device takes place, the measurement can become thermodynamically irreversible. Whereas we could have erased the "memory" of a single photon, the result has now left an indelible mark on the universe. More on this is discussed below in this section.

Finally, Bob looks at the measurement. Let's say he finds the photon took path 1. Now, we can finally write:

$$|\psi_B\rangle = |B1\rangle \quad (20)$$

With no uncertainty. No wave function collapse postulate is needed here. Since Bob is now part of the entanglement, he now knows which path has been taken. The wave function still persists and describes the outside perspective; all that has happened is that Bob is now allowed to take the inside perspective, which has existed all along. Bob can now see the formerly hidden variable.

One thing to note here is that the Dirac notation we use is perfectly suited for the Copenhagen interpretation of QM, which dominated physics for decades. The unmanifested part of the wave function only seems to disappear when a human observation takes place and only then does epistemological uncertainty disappear. The notation makes no distinction between objective and subjective uncertainty. This is understandable since it does not need to make such a distinction in order to make correct probabilistic predictions.

The removal of objective uncertainty is only a partial solution to the measurement problem. We have not left the world of quantum weirdness behind; at best, we are starting to straddle the line between the quantum and macroscopic worlds. Measurements can be erased, and objective uncertainty reintroduced. To complete the journey to the macroscopic world, we need many entanglements, where each micro-observation changes a bit of objective uncertainty into subjective uncertainty, and then thermodynamic irreversibility ensures that the result cannot be erased.

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In a chaotic macroscopic object, most new entanglements will neither perfectly preserve previous measurements nor perfectly erase them. To simulate a new random entanglement, let Bob set the angle to $\pi/4$.

$$P(B1) = P(A1, B1) + P(A2, B1) = \frac{1 + cos(\pi/4)}{4} + \frac{1 + cos(\pi/4 + \pi)}{4} = 0.43 + 0.07 = 0.5 \quad (21)$$

$$P(B2) = P(A2, B2) + P(A1, B2) = \frac{1 + cos(\pi/4)}{4} + \frac{1 + cos(\pi/4 + \pi)}{4} = 0.43 + 0.07 = 0.5 \quad (22)$$

$$P_T(B1) = P_S(A1) * P_?(B1|A1) + P_S(A2) * P_?(B1|A2) \quad (23)$$

$$P_T(B1) = 0.5 * 0.85 + 0.5 * 0.15 = 0.5 \quad (24)$$

Here, we have used $P_?$ for a probability that is neither purely objective nor subjective. Knowing the measurement from Alice's photon here would give us 85% certainty about the path of Bob's photon. We might say 70% of the uncertainty is now subjective and 30% of the uncertainty is objective, depending on how exactly we wish to quantify it. We don't know Alice's result, so overall, including our subjective uncertainty, the results are still 50/50, but the objective uncertainty is not as great as when Bob completely erases the previous measurement.

For a macroscopic measuring device, however, the basis of measurement will not be random. Bob has separated the photon's paths by a macroscopic distance. When multiple entanglements take place at his detector, they will all be measuring on a very similar positional basis. Thus, while each measurement might erase a small portion of the information gained by the previous measurement, most of the information from each measurement will be preserved, and there will be a myriad of separate, perhaps slightly imperfect, records of the event, each with very little, if any, objective uncertainty. Thus, objective uncertainty is essentially eliminated by the time we reach the macroscopic observer.

Additionally, and importantly, macroscopic observations cannot be erased. It will not be possible to introduce a single new observation on a basis that is completely orthogonal to the bases of all the existing micro-observations. We have "too many witnesses" now, each with a slightly different perspective. In addition, thermodynamic chaos will ensure that we cannot address each particle individually. With a macroscopic number of "witnesses" even if each of them only has a partial "memory" of the event, when taken together, they represent a permanent record that the event took place. Nonerasability is the defining feature of a macroscopic measurement.

Let us suppose, for example, that after many entanglements, an attempt at a hypothetical measurement of a macroscopic system on basis orthogonal to a previous measurement basis is made, such as is done in the new Wigner's friend thought experiment. For example, see (Nick Ormrod, 2023). It cannot be on a basis orthogonal to all the bases used for all the existing micromeasurements, however. So, although perhaps it can mostly erase them, it cannot do so completely. Let us suppose an original value of "1" is recorded in a quantum experiment rather than an alternative "0". Initially, a myriad of micromeasurements on nearly parallel bases all record it as "1". After an attempt at erasure, suppose the typical particle or "micromeasurement device" only retains a small degree of correlation with the initially measured particle. As in (21) and (22), we have a combination of uncertainty types. In this case, objective uncertainty predominates, but subjective uncertainty is not completely eliminated. Even if knowing the result of a given micromeasurement would now only give us only 51% certainty that the initial result was "1", we can repeatedly use Bayes's formula[6] for probability updates across a macroscopic number of micro-observations. The result will be (almost) 100% certainty that the initial result was "1". If we treat the universe as a hypothetical "observer" entangled with the system, with access to all the micromeasurements, there is still zero uncertainty as to the initial result. Erasure failed. To an observer outside the system, of course, subjective uncertainty persists until they "open the box and take a look at the cat" (Schrodinger, 1937). Until then, the wave function still describes their epistemological state but no longer describes a potential uninstantiated alternate reality. That path is now permanently closed. (So hopefully the cat is still alive).

5. A brief taxonomy of this interpretation.

In recent years, a new, more complex version of the Wigner's friend experiment has garnered interest. (Frauchiger, 2018) A key feature of these thought experiments is that they treat an observer as a quantum system in a larger experiment and arrive at a contradiction. The contradiction can be resolved but only at a cost. Different authors have published proofs that enumerate all the logical possibilities. For example: (Bong, 2020) and (Nick Ormrod, 2023). This provides a couple of different taxonomical systems with which to classify interpretations. Working through the possibilities on these lists, let us start by saying what this interpretation is not.

1. Events are absolute. Two macroscopic observers don't disagree on the result of a measurement.[7]
2. There is only one world; no multiworld hypothesis is needed.
3. Bell nonlocality is a fact.
4. There is no superdeterminism. Choices are possible.
5. There is no superluminal signaling or superluminal dynamics.

Using the taxonomy provided in Bong, 2020, the implication of these assumptions is that you cannot treat a macroscopic observer as a quantum system as is done in the new Wigner's friend thought experiment. Macroscopic systems constantly transform objective quantum uncertainty into ordinary subjective uncertainty with every particle entanglement. In addition, macroscopic observers differ from subatomic ones in that they are nonerasable. It will not be possible to make a single measurement on a basis that is perfectly orthogonal to all the existing micro-observations. And thermodynamic irreversibility ensures that the particles cannot all be addressed individually. The myriad imperfect microrecords of the event now add up to a permanent macroscopic record of the event.

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[6] $P(H_i|E) = P(H_i)\, P(E|H_i) / P(E)$

where:

$$P(E) = \sum_{i=1}^{n} P(H_i)\, P(E|H_i)$$

H_i here represents the hypothesis "1" and E is the slight evidence from each individual micromeasurement.

[7] This is only true for macroscopic observers. "Micro-observations" can be erased and are therefore not absolute.

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Our solution to the paradox does not pick just one of the possible resolutions to the puzzle but a bit of two options:

1) Micro-observations are not absolute because they can be erased.
2) Macroscopic observers cannot be treated as quantum objects because their observations are thermodynamically irreversible and nonerasable.

In short, in the thought experiment (Nick Ormrod, 2023), Alice and Charlie have a spacelike separation from Daniella and Bob. All perform measurements. Daniella has an inside perspective and precedes Bob who has an outside perspective. The latter then supersedes the former, and Bob's measurement on an orthogonal basis to Daniella's measurement effectively erases hers, assuming Daniella's measurement is a simple quantum micromeasurement and not an observation by a macroscopic observer, in which case Bob will not be able to perform a completely orthogonal measurement.

Let us now discuss classifying our interpretation with the taxonomy provided by (Nick Ormrod, 2023). There, the assumptions we have made of "Bell nonlocality" and "no superluminal dynamics" would imply that our only remaining choices are "nonabsolute events" and "information loss". We do not argue that micro-observations are absolute, so we have no problem there. However, we do argue that macroscopic observations are absolute. The argument from (Nick Ormrod, 2023) would then be that if from the perspective outside of the system, all interactions inside the system are viewed as unitary, as we have stipulated, then it must be possible for Bob to perform a measurement orthogonal to Daniella's. And, if we stipulate that such a measurement is impossible, then this implies information loss.

However, we do not have just one macromeasurement. Rather, we have a myriad of micromeasurements. In theory, yes, each of them could be measured on a basis orthogonal to their unique original measurement basis, and the original information that had been recorded would then be erased. However, in practice, thermodynamic chaos will render such measurements impossible. We would have to, in effect, reassemble Schrödinger's dead cat one subatomic particle at a time. Thus, we would argue that even though Bob cannot perform an orthogonal measurement, information is not lost in the absolute sense since orthogonal measurements are still possible, at least in theory.

Information is *effectively* lost, however, in the sense that it becomes irretrievable. As with other thermodynamically irreversible events, we cannot "put the genie back into the bottle", so to speak. When nondeterministic events occur, they pick one path, and eventually, after multiple entanglements, there is essentially no record that the other path ever existed. This is the flip side of having a future that is not predestined. An arow of time exists, and paths not taken are forgotten.

6. Philosophical discussion.

Some readers may be uncomfortable with the idea of intrinsic uncertainty. The idea that every effect has a physical cause is deeply ingrained in physics. We have two ways to address this issue. First, we can make philosophical arguments in favor of nondeterminism. Second, we can provide a way around nondeterminism.

First, while we cannot disprove determinism, we can argue that it is a poor fit for the universe we experience. Most obviously, of course, we as humans experience choice. However, also consider, for

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example, evolution, which needs random mutations in order for creatures to adapt. Additionally, consider AI, which needs (pseudo)-random numbers in order to learn. Additionally, consider that if we only ever use deductive logic, we ourselves can never learn. All the information in Euclidian geometry, for example, is already contained in its axioms. All deductive logic does is shuffle that information around. A fully deductive or deterministic universe never loses information, but it never gains information either. It just moves information around and "restates it" in a different form. It cannot "learn". It's sterile and unchanging from the point of view of the information needed to describe it.

Finally, nondeterminism fits much more easily with the existence of an arrow of time than determinism does. Rather than fully deterministic laws that operate equally well running backward in time as they do running forward in time, in a nondeterministic universe, paths diverge moving forward in time, whereas they would merge in the reverse direction. A direct connection from this proposed quantum arrow of time to the thermodynamic arrow of time might be possible as well, by noting that well-ordered systems are easier to erase than disorderly ones. Disorderly systems, then, are more likely to achieve permanent status. None of these considerations prove that determinism is impossible. However, they do argue that it is a poorer fit for the universe we experience than nondeterminism.

We can present a potential way around intrinsic uncertainty, however. Rather than supposing that the "objective uncertainty" as we have presented it here is truly random, we can suppose that it is merely pseudorandom. The definition of objective uncertainty we have used here is that it is the uncertainty that must be present for any observer, even if they are entangled with the system. We can suppose that there is a completely unobservable field that can be sampled to generate a random number when needed. The "universal computer" simply calls the "Rand()" function. On the downside, this is a whole new theoretical object that adds nothing observable to the theory. However, on the plus side, it does eliminate nondeterminism for those who insist on it.

7. Summary

We treat all new entanglements as micro-observations from an "inside" perspective. These observations transform objective uncertainty into subjective uncertainty on the basis measured but leave values on other potential bases of measurement objectively undetermined. This transformation of uncertainty is invisible in standard Dirac notation. If we look again at equation (4):

$$|\psi_{AB}\rangle = \frac{|A1\rangle|B1\rangle+|A2\rangle|B2\rangle}{\sqrt{2}} \quad (4)$$

Depending on the basis on which Alice and Bob choose to measure it may represent completely subjective uncertainty, in the case where they both measure on the same basis on which the photons measured each other. Alternatively, it may represent completely objective uncertainty in the case where they measure on a basis orthogonal to the original. Or it may represent a combination of both if they measure on some other random basis.

The wave function represents the total probability, objective plus subjective, the minimal uncertainty that any outside observer must have. The objective probability is what is uncertain to an observer that is part of the system, the minimal uncertainty that any observer must have.

On a quantum level, measurements are erasable. However, in general, random new entanglements will each reduce the ratio of objective to subjective uncertainty, and as these accumulate

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and become thermodynamically irreversible, we are left with only subjective uncertainty and results that cannot be erased.

This gives us an interpretation of quantum mechanics that avoids difficult ideas such as nonabsolute macroscopic events, many-world hypotheses, superdeterminism and superluminal dynamics. It also avoids the idea of wave function collapse. It refines and extends a proposed solution to the measurement problem; it explains the results of the quantum eraser experiment without difficulty, and it provides an arrow of time.

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