Understanding Retrocausality -- Can a Message Be Sent to the Past?

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Abstract. We examine why exactly it is that a message cannot be sent into the past and received there using quantum physics, yet certain anomalous correlations can make it appear just that way. To accomplish this, we must first explore more deeply the usual concepts of superposition, entanglement, measurement, locality, and causality. From these reinterpreted concepts, and through analyses of the usual forward EPR experimental arrangement and a time-symmetrical backward version, we can better understand the fundamental inadequacy of the idea of "causality" (both forward and backward). We also discuss possible explanations for apparent retrocausal anomalies such as those of the recent experiments by psychologist Daryl Bem.

Keywords: causality, retrocausality, entanglement, quantum measurement, EPR, locality, realism, constraints, relations, time symmetry, parapsychology
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INTRODUCTION

"The only way to discover the limits of the possible is to go beyond them into the impossible."
-- Arthur C. Clarke, (Clarke's second law)

Can a message be sent into the past and received there using quantum physics?[1,2] If not, why not, exactly? If the dynamic equations of physics are time-symmetric, why can we send a message from past to future (evidently), but not from future to past? More generally, do experiments cause their results *and vice-versa*, as might be suggested by the examples reported below?

Are most phenomena ruled by the traditional forward cause-and-effect principle, while others somehow demonstrate *retrocausal* influence? If retrocausal effects have been demonstrated, does this necessarily demand a major revision of the extremely successful theory of Quantum Mechanics?

In this paper, we will suggest and attempt to show that all of these questions can have clear answers if only we will look deeply enough and reconsider some of our foundational assumptions about superposition, entanglement, and interactions at the quantum level. If quantum phenomena appear to us as "weird", and violate "common

[1] The title specifies sending "to" the past, rather than "into" the past, in order to indicate that the message is also received there, not merely extant.
[2] We do not consider here methods involving time "travel" via General Relativity, wormholes, etc.

sense", then we should take this as an indication that our underlying assumptions are faulty -- that our common sense could benefit from some reexamination and revision. In addition, we may be able to shed some light on some recently reported experimental anomalies that appear to involve backwards signaling.

Toward these ends, this paper presents the author's somewhat idiosyncratic view of quantum physics, but not ignoring orthodoxy, and with only slight departures from it. The discussion here will be mostly in an informal style in order to focus on the deeper underlying concepts that are at issue, rather than on the standard formal mathematics that often carries unrecognized and possibly unwise assumptions.

In the first section below we review two well-known quantum experiments in order to emphasize that the traditional concept of unidirectional cause-and-effect is inadequate, and in fact counter-productive, to a full understanding of quantum phenomena. In the next section, we explore the basic concepts of variables, values, superposition, and entanglement in an attempt to dispel some of the weirdness that is often associated with the quantum realm. In the final section, several controversial and important experiments are discussed and analyzed from the theory.

Reconsidering Two Classic Quantum Experiments

"We may say that there is at present no occasion and no reason to speak of causality in nature – because no [macroscopic] experiment indicates its presence and … quantum mechanics contradicts it."
-- John von Neumann, 1955

Let us first reconsider briefly two of the classic quantum thought experiments, with an admittedly skeptical viewpoint towards the concept of causality and its efficacy and appropriateness for representing quantum phenomena.

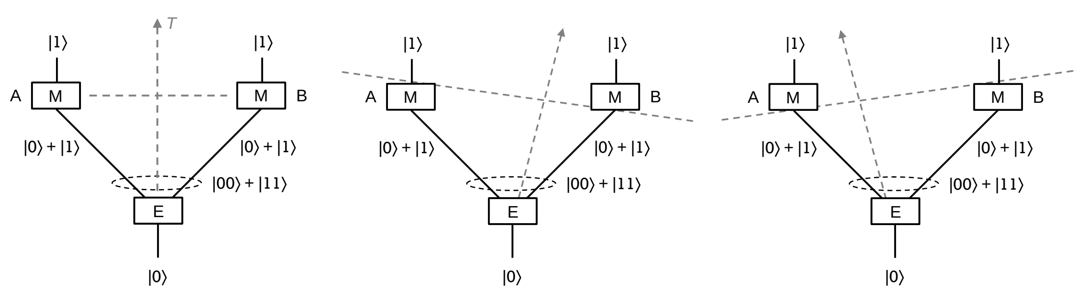


FIGURE 1. A simple EPR configuration (left), where two particles are entangled (E), move apart, and are later measured separately at A and at B. An observer moves in such a way (center) that he sees A measured before B. An observer moving oppositely (right) sees B measured before A.

EPR Redux

We may start with the simplest Einstein Podolsky Rosen configuration [1] shown in Fig. 1 (left), where two entangled particles are measured as binary variables (spin up or down, for example) independently at two distant locations. As has been well confirmed by experiments, the two measurements will give random but highly-correlated (identical) results, despite being unable to communicate with each other in the conventional sense.

Literally dozens of interpretations of the formalism of quantum mechanics (some are actually extrapolations or extensions) have been proposed to make "sense" of this phenomenon. (See [2] for a summary, and examples in [3] and [4].) The fact that none of these interpretations is fully and widely accepted after more than 80 years of discussion suggests again that something is lacking in our deeper conceptualizations of physical reality and interactions.

Somewhat disturbing, of course, is that the EPR phenomena seems to violate the deep principle of causality, that causes must precede their effects, and that what happens locally cannot affect something very far away (sooner than a light signal could transit). Even more disturbing is the realization that under appropriate relative motions (by Special Relativity) two observers could differ on their judgment of which measurement happened first (Fig. 1 center and right). Since neither measurement is in the (forward) light cone of the other, there is no canonical ordering (it is observer-dependent), and thus there can be no causal relationship between them in the usual sense. They remain independently random and yet perfectly correlated. (Tests of Bell's inequality show further how surprisingly strong this correlation is.) We will return to EPR in several ways below.

Delayed Choice Redux

John Archibald Wheeler's famous Delayed Choice thought experiment [42, 43] puts a very fine point on the issue of causality, see Fig. 2. In this interferometer Gedankenexperiment (and a careful experimental confirmation [44]), a future action can apparently determine the entire prior history of the transiting photon.

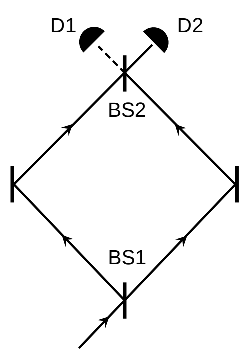


FIGURE 2. Wheeler's Delayed Choice experiment. With both beam splitters in place, all photons are detected at detector D2 due to interference at BS2. But if BS2 is absent, photons arrive equally and randomly at D1 and at D2. Wheeler observed that the decision about the presence or absence of BS2 could be made *after* a photon had already passed BS1.

Two beam splitters BS1 and BS2 each pass or reflect an incident photon on its path toward detectors D1 and D2. If both beam splitters are in place, and paths are of equal length, an incoming photon will take both paths (in superposition), and will interfere with itself at BS2, thus arriving at D2 exclusively. If BS2 is removed, however, photons will take one or the other path from BS1 (supposedly at random) and be detected at both D1 and D2 equally. Since beam splitter BS2 can be removed *after* the photon has already passed BS1 (the "delayed choice"), BS2's presence or absence can be said to determine what happened *previously* at BS1. Wheeler dramatically amplified the impact of this observation by proposing that such an interferometer could be composed using two paths of light bent around a distant star or galaxy by gravitational lensing, thus allowing the final beam splitter presence or absence to apparently determine what happened billions of years previously.

From these two experiments alone (and many others) we can infer that the traditional idea of *causality -- forward or backward -- has little meaning or explanatory power where the correlation of entangled quantum variables is concerned*. Something deeper is needed, to which we now turn.

BOUNDARY PHYSICS

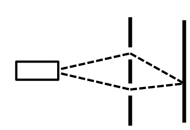
"Yet well over half a century after its inception, the debate about the relation of quantum mechanics to the familiar physical world continues. How can a theory that can account with precision for everything we can measure still be deemed lacking?" -- Wojciech Zurek, 1991.

The most significant problem in understanding quantum theory is not the mathematical formulation, it is in our conceptualization of what a "value" or "state" is, and in our classical macroscopically-trained assumptions about causality and the nature of time [5]. When we view quantum phenomena through these classical ideas, they often seem weird and nonsensical, even startling. In order to cope, questionable conclusions and inferences are often adopted, such as a fundamentally random "collapse" of state leading to a purely statistical "reality", things being "in two places at once", and even a reality that is created by observation and human "consciousness".

Values, Constraints, and Superposition

Quantum physics is often described as strange or nonsensical because it permits an object to be "in two places at the same time" or allows a particle to "go through both slits simultaneously". To ameliorate this difficulty, we prefer to think of *the value of a variable as the solution to a set of constraints or boundary conditions*. (As discussed later, some of these constraints may lie in the past, the present, or even the future.)

In this view, variables, and entire configurations or states, can have *multiple values*, that is, multiple solutions to the constraints that are placed on them, whether in abstract mathematics or in physical "reality". For example, in the Delayed Choice arrangement above, there are two possible paths after the first beam splitter. Similarly, if a traditional two-slit apparatus permits two alternative paths, the particle can be described as going both ways, in a sense taking both paths, in a combined state called *superposition*.



To mitigate the strangeness of this concept, consider the more familiar and yet entirely analogous example of a real polynomial equation with multiple roots, such as

$$x^2 - 1 = 0 \text{ , whose roots are } x = \{ +1, -1 \}, \qquad (1)$$

or, to take a slightly more complex example,

$$x^4 + 2x^3 - 2x - 1 = 0 \text{ , with roots } x = \{ +1, -1, -1, -1 \}. \qquad (2)$$

Each of these equations may be considered as a constraint on the value of x, distinguishing those several values that are valid or possible in the given situation from those that are not. Multiple solutions are of course nothing surprising in the case of real-world situations represented by polynomials. If we imagine, for example, a parabolic cannonball path height of x(t) at time t, we would see only one of the two values (the one above the ground, with positive x), even though both positive and negative paths are permissible solutions to the equation (constraint) of motion.

By direct analogy to polynomial equation (1) above, we could have a physical arrangement that included a quantum binary variable or *qubit* in superposition of two values (e.g. spins or polarizations or paths), written as a vector in Dirac notation as $|0\rangle + |1\rangle$.[3] This vector in Hilbert space represents a composite of two possible outcomes, equally weighted:

$$|0\rangle + |1\rangle \text{ , with measured outcomes } p(0) = p(1) = 0.5. \qquad (3)$$

In polynomial example (2) above, a *multiset* of four members (values) would be needed, as there are several occurrences of one solution, and the analogous superposition would be written $|0\rangle + \sqrt{3}|1\rangle$, having greater possibilities for one result state than the other, and 3 times the probability:

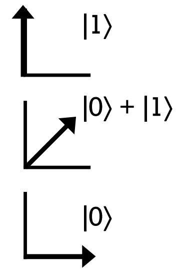
$$|0\rangle + \sqrt{3}|1\rangle \text{ , with measured outcomes } p(0) = 0.25 \text{ and } p(1) = 0.75. \qquad (4)$$

The point here is that a polynomial or other constraining equation with multiple solutions -- a situation frequently encountered in engineering and science -- is no different or stranger or less definite than a superposition (composite) of values in a quantum state variable or wavefunction. *In both cases, a constraint serves to restrict or reduce the domain of values that would otherwise be available*, whether mathematical and abstract, or physical and “real”. These composite values can be distinguished equivalently by a description of the constraint system itself, by a multiset of enumerated values, or by a vector formalism as is typical in quantum mechanics using a Hilbert space.

In orthodox quantum theory, one typically does not consider a state consisting of multiple or composite values (a superposition) as “real” or defined, but merely a probabilistic statement about outcomes of actual measurements (e.g. the Copenhagen

[3] For simplicity we will omit all normalizing constants in this and subsequent expressions.

Interpretation of quantum mechanics [48]). To the contrary, the present theory asserts that it is appropriate and advantageous to consider superposed values as equally as "real" and defined as are classical eigenvalues. The state $|0\rangle + |1\rangle$, for example, a vector at 45 degrees in a two-dimensional Hilbert space, is no less defined or definite than one at 0 or 90 degrees in the chosen basis coordinates. The state vector is a way of describing the *weighted possibilities* of various outcomes (and, upon squaring, their likelihood) if the system is measured in these coordinates. Prior to measurement "collapse" or projection, however, these composite values should be considered as singular and legitimate and defined as any other, just not aligned with the basis vectors of the coordinate space.



The concept of a multiple or composite value ties together our common sense notion of several distinct possible outcomes (the multiset) with a unique vector in Hilbert space. In everyday life, of course, we as macroscopic creatures will see only singular classical values. Everything we experience has a single position, takes only one path, and has only one outcome. Still, there are many paths from San Jose to San Francisco, even though we only drive along one of them on any given trip. It is a useful extension of "common sense" to consider multiple solutions to a constraint system as one value, though possibly composite. In the Delayed Choice configuration, for example, the particle does not itself move along both paths in the usual classical sense, but both paths are included in *one set of possibilities*, and these are captured in the corresponding Dirac vector or wavefunction.

One way to state what distinguishes quantum from classical mechanics -- and what our common sense must be extended to include -- is that in the quantum realm *possibilities are "real" and can interact to have real effects.* If what happens in the "real" physical world conflicts with our common sense, then it is common sense that must yield. Quantum mechanics is about those possibilities, not just actual interactions in the usual classical sense. (See for example the interaction-free bomb tester [6] and the quantum eraser experiments [7].)

Characterizing these composite values in several ways, e.g. as underconstrained or superposed, can be useful for thinking about quantum processes and states. For brevity, we will sometimes informally call such underconstrained or superposed values *open*, and single-valued fully-determined values as *fixed*. An open variable has some freedom in the preferred basis (several possible outcomes when measured), and thus a further constraint may be applied. The typical open balanced superposition (all values equally weighted) can also be referred to as *neutral*, or the "neutral past" to its dependents.

In general, nature may be said to take advantage of all opportunities open to it (as in the familiar path integral or sum-of-histories approach [8]), and these are defined by the constraints imposed by a physical configuration. Informally, we might say: *Everything that can be, is, and everything that can happen, does.*

Relations, Functions, and Boundary Conditions

"The law of causality, I believe, […] is a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm." -- Bertrand Russell, 1913

While single variables can be represented as having multiple values, as discussed above, configurations including several variables are best thought of as embodying one or more *relations* among the variables. A relation is *a restriction on joint values* of two or more variables. For example, if integer variables x, y, and z are constrained by the equation

$$x + y = z \, , \tag{3}$$

then x, y, and z are singly and pairwise completely unconstrained, but their 3-joint values are restricted to triples satisfying the given equation. In quantum physics, entanglement, discussed more below, is a state that typically involves a constraint on joint values of two or more variables, but not on the variables individually.

Several existing interpretations of quantum mechanics, including Cramer's quite successful Transactional Interpretation [9, 10], utilize both forward and backward "waves" or other imagined communication to establish the total relationship between entities in a quantum interaction. It is suggested here that these two aspects be combined into a single relation, a non-directional constraint on joint values, *neither causal nor retrocausal*. Causality (in either direction) should be eschewed for more-symmetrical bidirectional concepts such as *influence, dependence,* and *correlation*.

To expand on and generalize this point, Fig. 3 shows a simple algebraic relation (not function) between Fahrenheit and Centigrade temperatures. This F-C relationship is usually thought of in terms of a strictly-forward *conversion function* or process, with two algorithms (sets of computational steps) to be executed depending on the desired direction. Although the computation may in practice be implemented directionally, the F-C relation can be expressed symmetrically, and is here illustrated as a composite of three subrelations (not functions) each constraining two variables. When these variables are linked together appropriately, no directionality is implied until one of F and C is chosen as open, and the other given a particular fixed value. Then only might it be said that the fixed value "causes" the open value to become fixed.

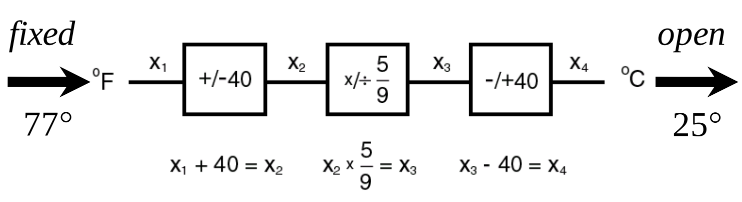


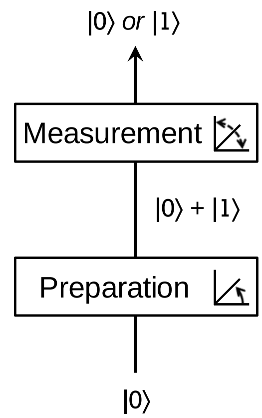
FIGURE 3. Fahrenheit-Centigrade temperature relation as a composite of three two-variable subrelations. The direction of computation depends on which variable is fixed and which is free.

In orthodox quantum mechanics, and in quantum computing, one usually speaks of states, and of operators that are essentially *functional*, that is, directional. However, if every transformation is unitary and thus symmetrical, a *relational* representation can be more useful and appropriate.[4] Further, constraints need not be “hard” boundary conditions such as initial or final positions, or the presence or absence of a beam splitter. They can be partial influences, weighted just like wavefunction coefficients.

Preparation and Measurement

"Even the great initial success of the Quantum Theory does not make me believe in the fundamental dice-game, although I am well aware that our younger colleagues interpret this as a consequence of senility. No doubt the day will come when we will see whose instinctive attitude was the correct one."
-- Albert Einstein, letter to Max Born, 1944

The most controversial aspect of quantum mechanics from the beginning has been *measurement* of a quantum variable. Typically, the initial state of a qubit is *prepared* (e.g. unitarily rotated) into a balanced superposition of states $|0\rangle$ and $|1\rangle$. This qubit may then undergo some processing or interaction with other qubits, and eventually it is *measured* -- a process that is considered in orthodox quantum mechanics to be a projection operator or “collapse” of the wavefunction, and thus non-unitary, irreversible, and non-deterministic (i.e. random, causeless, and unpredictable in principle) [48].



Without detailed justification here, we subscribe to the view that *quantum measurement is a unitary transformation like any other evolution of the wavefunction*. (This is similar to several well-known interpretations of quantum mechanics such as Decoherence [12], as well as to Wheeler-Feynman Absorber Theory [13].) In this view, in the simplest case, *measurement is just the time-reverse of preparation*, and consists of the *unitary* rotation of a superposed state to again align with one of the basis vectors of the Hilbert space, the eigenstates. There is no collapse, no information loss, and no randomness inherent in this process. By this model and understanding of measurement, a better name for it might be “postparation”.

Briefly, it should be pointed out that if measurement were really a fundamentally random “collapse” -- in principle causeless and unpredictable -- then *something* would still be needed to determine the outcome, e.g. 0 or 1 in a binary system. To extend Einstein’s famous complaint slightly, does God himself not only roll his dice, but also reach down and set the result of every measurement? In a more mundane but real sense, one bit of information would have to be supplied from *somewhere* to make this binary determination. Ultimately, it must be concluded that *the idea of a truly causeless event has no meaning*, and furthermore would violate conservation of information and energy were it possible.

[4] Note that the meaning of relation here is not quite the same as in Rovelli’s Relational Theory of Quantum Mechanics [11].

In the absence of continual divine intervention, *the necessary determining information can come from only one place -- the measurer, and the (future) dependencies to which it is connected.* A constraint or boundary condition in the future can determine an otherwise underconstrained value, just as can an initial boundary condition in the past, or both can have effects. Both past and future constraints can be influential. The symmetry of preparation and measurement follows directly from giving up the orthodox *assumption* of non-unitary measurement that has traditionally been derived from Bohr's statistical interpretation of the wavefunction and von Neumann's "collapse" hypothesis ("Process 1") [49].

But if no dice are involved, why do quantum measurements typically give random-appearing results, in keeping with the usual assumption and governed by the coefficients of the wavefunction? Perhaps the outcomes of measurements typically made in our macroscopic, room-temperature world *appear* highly random because the measurement device and the future to which it is connected are highly complex and disordered. Perhaps such *a measurement event -- and thus the theory itself -- is not fundamentally random or statistical in nature at all, but usually seems so when a large number of particles are involved.* The complex stochastic nature of the measurer in effect selects from among the weighted possibilities inherent in the wave function, and thus both the preparer and the measurer jointly determine a classical outcome. A human observer, being a macroscopic entity, must see (and in many cases partially determine) classical but random-appearing results as well.

By the same argument, if the future dependencies of the measurer include more possibilities for one outcome than another, a *bias* will exist towards that result. Rather than the uniform (assumed random) distribution typically found with macroscopic measurement devices in the laboratory, an unbalanced distribution will be seen, even if the source is a "quantum-random" process such as nuclear decay.[5]

Ultimately, by this theory, all such outcomes must be determined by combined influences from the future and the past, including (by backward influence) the observers and their dependencies. Acceptance of this symmetrical view of measurement within the physics community is sparse today, but the consequences of unitary measurement are quite significant when fully unfolded and appreciated. As examples, below we will consider some situations where seemingly-random measurement outcomes appear to have been deliberately manipulated via future conditions to produce interesting phenomena.

Sending and Receiving a Message

It is generally assumed that we can communicate from past to future but not from future to past. In conventional terms, the sending and receiving of a message accomplishes a transfer of information, and is thus strictly a causal process. The receiver's state is changed upon receipt of the message, and thus he must lie in the forward light cone of the sender. But if quantum processes can be influenced by

[5] Significantly and recently, a number of experimental data sets have shown variability in decay processes that had been considered fundamentally constant according to orthodox quantum theory [50].

future interactions, as argued above, then the situation becomes somewhat more interesting.

For example, if it were possible for the *measurer* to manipulate a quantum measurement to obtain a non-random *biased* outcome, that bias would also have been present in the superposed state when and where it was originally created (cf. the EPR or Delayed Choice experiments). It might seem that this effect could be used to send a message *backwards in time* from the point of measurement to a point near the source, or from one arm of an EPR configuration to the other. Examples given below will show why this is not possible, and why so much has been written about this matter more formally in the literature along with its equivalence to other phenomena such as cloning and superluminality [45, 46, 47].

Basically, since quantum mechanics does not permit fully reading (measuring, observing macroscopically) a quantum variable without reducing (collapsing) it, sending and receiving a message are actually somewhat synonymous. If the message (a biased quantum measurement) had been in fact received in the past, it would not have remained open, and so there would be no freedom in the future to send it. Such a quantum message *can* be sent into the past, but *only if it hasn't been read there*, since this would destroy the message.

Similarly, in an EPR entanglement, no information can be transmitted from one party to the other. One way to confirm this is to note that neither of the correlated entities is necessarily within the light cone of the other, and so neither of them can be identified as the receiver or the sender. The order of the two measurements can be observer-dependent, and so no unique causal direction is defined for such a message. However, each participant might also move in such a way that they think that they were measured first (or last), and each will be correct from their perspective even though no information has been transferred [14, 15]. Thus the two participants will always agree on their correlated measured state, but not necessarily on who determined it. Again, this scheme cannot transfer information backwards in time, as will be elaborated below, even with the added possibility of biased quantum measurement

Entanglement, EPR, and Time-Reversed EPR

Two qubits that interact can become *entangled*. This state, often considered weird and mysterious, is just the effect of *a constraint on joint values* of two (or more) variables. In the simplest case of the EPR arrangement, two qubits are each placed in a superposition $|0\rangle + |1\rangle$ but their joint value is constrained to be, say, $|00\rangle + |11\rangle$. That is, while each is equally likely to produce 0 or 1 upon measurement, the two resulting classical values are constrained be the same no matter which is measured first.[6]

Figure 4 (left) shows an entanglement generator that takes one input qubit and produces two qubits in the entangled $|00\rangle + |11\rangle$ state if the input is $|0\rangle$, and in the

[6] There is no need here for measuring at two different angles, as required for tests of Bell's inequality.

|01⟩ + |10⟩ state if the input is |1⟩.[7] One may consider the two qubits as having separate (but not independent) states, or as having one joint state. In the latter view, the joint state may be thought of a single superposition of two values, typically |00⟩ and |11⟩. Entanglement and superposition are in this sense strongly related, not separate, phenomena [16].

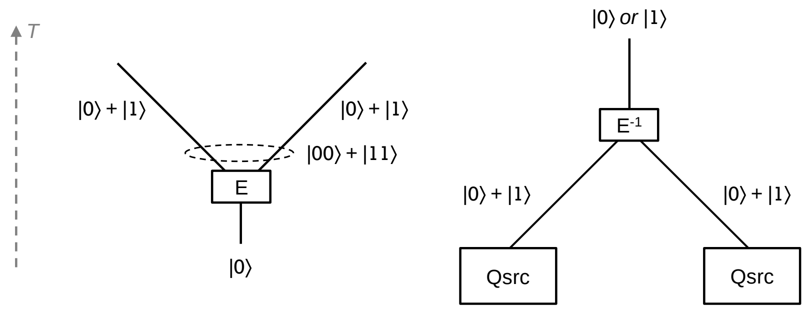


FIGURE 4. EPR and time-reversed EPR relations. In the usual EPR arrangement, a single qubit conditions an entangled pair. In the reversed configuration, two qubits, each a superposition, are generated, arrive at the disentangler, and, depending on relative phase, produce a single basis state.

By symmetry, it is not difficult to imagine a time-reversed version of EPR [17], see Fig. 4 (right), somewhat similar to a Hanbury-Brown and Twiss arrangement [18, 19]. In this configuration, two independent qubits, each in superposition |0⟩ + |1⟩ are generated by quantum processes and then passed to a "disentangler" E^{-1}, which is just the inverse of the entanglement operator E. Depending on the phase relationship between the two arriving qubits, the result is basis state |0⟩ or |1⟩, just the mirror image of the normal forward EPR.

The two generated qubits in the reversed system are in principle independent and not entangled, so any joint values of their superpositions are possible. But their interaction in the future may result (backwards) in some entanglement if the output of operator E^{-1} is somehow biased by its future dependencies. Just as the forward entangling operator E can bring about entanglement of two qubits moving forward, so also can the reverse operator E^{-1} bring about entanglement of two arriving qubits by backwards influence on the supposedly-random source processes (cf. the similarity of Delayed Choice again).

It may be useful to remind ourselves at this point that two uniformly-distributed streams of data (quantum or classical) can be (or can become) correlated without affecting their distributions or apparent randomness in any discernible way. And by the relational symmetry arguments given above, this *correlation can come about either forward or backward, that is, via either past or future interactions* between the two streams [17]. In both classical and quantum domains, dynamics are properly characterized by *time-symmetrical* equations (relations), and unidirectional cause-and-effect would be an *additional* assumption that is not made here. Classical variables are

[7] Many different implementations are possible including polarizations of photons, spins of particles, etc, or using the abstract quantum computational primitives H (Hadamard rotation) and CNOT (Controlled NOT).

usually thought to be fixed by their pasts, but supposedly quantum-random variables are thus susceptible to influence from their futures -- as experiments have repeatedly confirmed.

EXPERIMENTS, IMAGINED AND ACTUAL

"The real factual situation of the system S2 is independent of what is done with the system S1, which is spatially separated from S2." -- A. Einstein, 1951

This fundamental statement by Einstein of the locality principle must be evaluated based on the meanings of the key phrases "real factual situation" and "independent of what is done". It has been well-verified that measurements of two entangled quantum variables can give seemingly random and independent results, and yet be constrained to be highly correlated even if separated by a large distance.

Entanglement is often thought of as a separate phenomenon from superposition, and a significant mystery in itself, but actually it is just the result of an interaction with a superposed variable. Both superposition and entanglement are serious challenges to our "common sense" -- and another motivation to revise and extend this framework -- as explored further below in both thought and actual experiments.

Sending a Message to the Past via Superposition?

"When, however, the lay public rallies round an idea that is denounced by distinguished but elderly scientists and supports that idea with great fervor and emotion -- the distinguished but elderly scientists are then, after all, probably right." -- Isaac Asimov, corollary to Arthur C. Clarke's First Law.

Two slightly different schemes may be proposed for backwards signaling involving quantum superposition. One uses a qubit measured by the intended sender of the message (in the future). The other uses a classical bit already measured at the source (in the present), see Fig. 5. Neither accomplishes backwards transfer of information.

In Scheme 1, a qubit in a binary superposition is generated and propagates into the future, perhaps over a great distance. There the sender measures (collapses) the qubit in a way that determines, or at least biases, the measurement depending on bits of the intended message. Back near the source of the qubit, the receiver hopes to detect this bias or deviation from uniform randomness, and thus receive the message.

Of course this scheme does not work, since the receiver disturbs or collapses the superposition while trying to obtain information from it, and thus effectively "sends" his own message. In fact, by attempting to extract perfect information, the measurement interaction must be strong enough to perfectly destroy any message that was present due to the future biased constraint. However, this may not be entirely so for partial, or "weak", measurements [40, 41], not analyzed here.

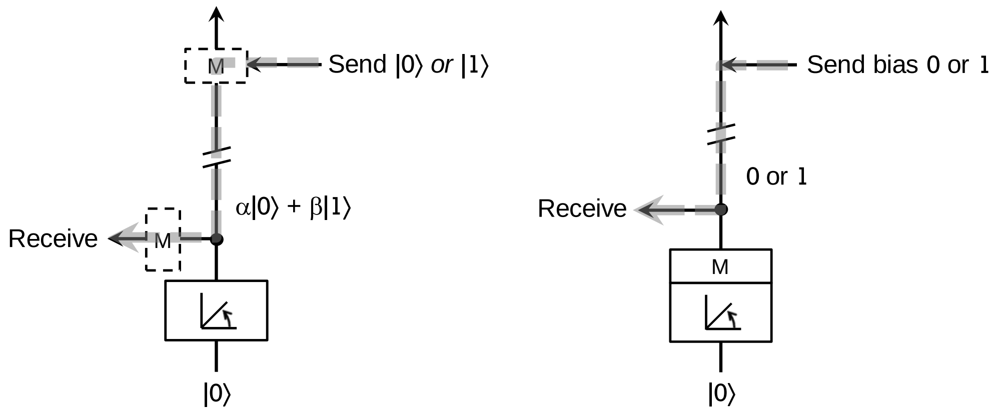


FIGURE 5. Attempting to send a message back in time using superposition. In Scheme 1 (left), the sender measures (collapses) a *superposed* value in a biased way, hoping that this bias can be detected earlier. In Scheme 2 (right), the sender biases a *classical* value created by earlier measurement similarly. These schemes do not work because the intended receiver disturbs the superposition while trying to obtain information from it.

Note however, that in Scheme 1 the message *has*, in a meaningful sense, propagated backwards from the sender to the source, just as in the quantum Delayed Choice configuration. However, the message cannot be read or received there without destroying it by the act of measurement (actually, fixing some *other* message), unless cloning of an unknown quantum state were possible, which it is not [45].

In Scheme 2, a qubit is similarly generated at the source, but then immediately measured to produce a classical bit, which then propagates into the future. The sender tries to influence or bias the measurement that determined the classical result by conditioning its future -- that is, by attaching it to dependencies that are more receptive to one value over the other, in a sequence determined by bits of the intended message. By placing these "weights" on the bit, it is hoped that the measurement process back at the source will be affected, and thus the applied bias can be seen there and interpreted to receive the message. This scheme might work *if* the theory suggested above is valid (future dependencies of a measurement determine its classical outcome) *and* the sender's bias "weight" is significantly greater than that presented by the receiver's measuring apparatus at the source, see a similar scheme suggested in [29]. It might be said that to be successful, the receiver cannot "care" very much at all what the message is. Again, weak measurement may be relevant here, and might act to deny even a partial or statistical transfer of information.

Perhaps surprisingly to some, there is indeed an abundance of good evidence that this kind of intentional biasing of the classical result of a quantum measurement can occur [20-22] and that apparent backwards influence can be the result, see for example [23-28]. The biases observed in these carefully-controlled parapsychology experiments are typically small (on the order of 1 in 10^4) and difficult to replicate, but nevertheless fairly consistent over time, and (importantly) subject-dependent. Below we suggest another possible explanation for these phenomena that does not require actual information transfer backwards in time.

Sending a Message to the Past via Entanglement?

If superposition cannot be employed to allow signaling backwards in time, perhaps an entangled pair can make this possible by sending the message in one arm of an EPR arrangement, and receiving it in the other, see Fig. 6. Generally, this scheme fails for a similar reason as Scheme 1 above, in that any attempt to read or receive the message is a measurement, and thus collapses the superposition in both arms. Again, a message *is* sent into the past, but cannot be received there.

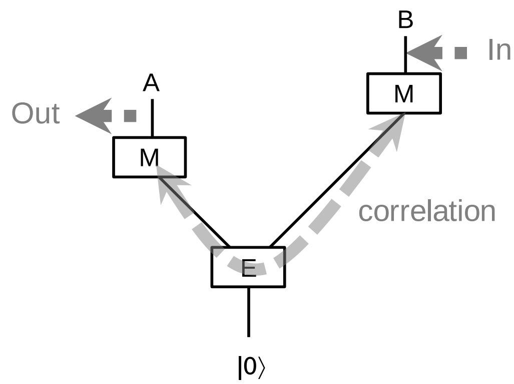


FIGURE 6. Attempting to send a message back in time using an entangled pair. The sender changes or biases one of the measured values (B), hoping that this bias can be detected earlier in the other arm (A) via the correlation present in the entanglement. Even if biasing at B were possible, this scheme does not work because the intended receiver disturbs or "collapses" the value at A when trying to obtain information from it, and thus effectively "sends" his own message.

Since which measurement is made first is observer-dependent by relativity, it could not even be said in which direction the message was "sent". The two outcomes will be correlated due to the entanglement, but neither measurement "came first" and determined those outcomes.

If the entanglement is instead created by a future interaction [17], a similar attempt could be made to signal backwards, but it fails for the same reason. It does not matter whether the entanglement is due to a past or a future interaction. However, a fully time-reversed version of EPR has other interesting properties, as described below.

Correlation via Future Interaction

Consider a basic EPR arrangement again, but reversed in time (Fig. 7). In place of the two entangled qubits propagating into the future *away* from the entangler, we instead supply two similar qubits, each in a superposition of the same basis values, each from an *independent* quantum source and traveling *towards* a *dis*entangler (the inverse of the entangler). Since the two arriving qubits are independent and not entangled, if their relative phase is adjusted appropriately, the resulting state will be either $|0\rangle$ or $|1\rangle$.

However, again note that the possibility exists for the interaction between the two independent qubit streams to *bring about some entanglement* between them by constraining their joint values. Recalling the symmetry of the *relation* represented by the disentangler, it is possible for a bias placed on the later "output" to influence its "inputs" such that they agree (or disagree) more than chance. In this case, a bias towards $|0\rangle$ will bring about more of the joint state $|00\rangle + |11\rangle$, while a bias towards $|1\rangle$ will result in more of the joint state $|01\rangle + |10\rangle$.

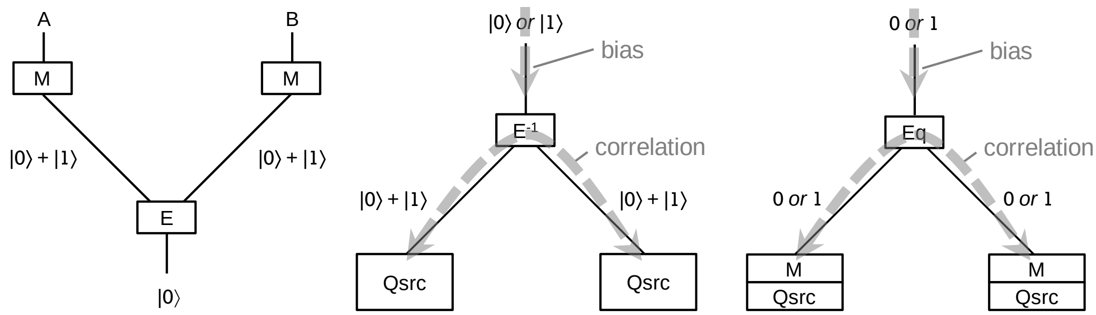


FIGURE 7. Correlation via a time-reversed EPR arrangement. A simple EPR configuration (left) is time-reversed (center), utilizing independent random sources (qubits) in the two arms, and a disentangler (inverse of E) producing a single eigenstate. A further modification (right) introduces a measurement (M) in each arm, thus producing classical values 0 and 1, and replaces E^{-1} with its classical counterpart (a simple Equality test Eq), so that the result is a classical value (0 if unequal, 1 if equal). Correlation between the two sources may again be induced by a bias on the output, see text.

Now suppose the system is further modified to instead produce two classical randomly-determined values, 0 or 1, by inserting a measurement operator M in each arm, thus implementing two random number generators (RNGs). Further, replace the quantum disentangler with its classical counterpart, a simple equality comparison of the two bits. The result is just a single bit indicating equality (1) or inequality (0)[8].

Of course, the resulting configuration (Fig. 7, right) is no longer a general quantum system, but it still retains important characteristics of the reversed EPR arrangement. Given our postulate of unitary measurement and backwards influence, the equality relation will still constrain the connected variables, as described previously. Thus *if the output of the equality test is biased towards 1, the inputs in the two arms must be correlated to some degree, despite their random origins.*

The equivalent and usual forwards interpretation of this situation is that if the two streams are correlated, the output of the equality test will produce more 1s. While this latter statement represents more conventional and "sensible" cause and effect, the former backwards interpretation may be more relevant and suggestive of the direction of influence in this case. If a bias exists on the output, the two incoming variables are jointly constrained by the relation E^{-1}, and thus must be somewhat correlated. Neither the inputs nor the output exclusively "cause" the other due to their interaction and mutual constraint.

Note also that this hypothesized backwards influence does not imply information transfer, only correlation. The two input streams do *not* actually communicate with

[8] We have ignored the issue of synchronization between the streams, as this is not difficult.

each other. But *correlation can give the appearance of information transfer, and even precognition*, in cases where two supposedly random sources are being compared and the result is biased by constraints placed by the future on that outcome.

Whenever a quantum-random source is involved, as it is in most parapsychology experiments (e.g. an RNG target generator that uses a quantum process to produce classical bits), the present theory posits that future conditions determine in part the generator's classical "output", and the target for that experimental trial. Thus *there is an opportunity -- in fact, a requirement -- for backwards influence from the trial results and all that is connected to them.* In practice, this evidently includes the experimenter (via his interactions with the data) as well as other dependencies. This configuration and these influences will play an important role in the real-world experiments to be described next.

More-Challenging Completed Experiments

"However strange may be the phenomenon of precognition, we must not let ourselves be diverted from the truth by the strangeness of appearances. A fact is a fact, even though it may upset our conception of the universe; for our conception of the universe is terribly infantile."

-- Charles Richet, Nobel Prize in Physiology/Medicine 1913

From the above arguments, it would seem that with an entangled pair of random sources, and some bias on the results, we can indeed see extra-chance correlations that *appear* to be anomalous forward or backward transfer of information [30]. This is ironic, of course, since the targets in experiments such as those described below are carefully randomized specifically to *prevent* any information leakage or pattern recognition by the subject. However, *it is precisely this randomization that enables the correlation that we can (mis)interpret as signaling*.

Again it should be noted that, contrary to widespread scientific opinion, there *is* a substantial amount of evidence for the ability of some people to consciously influence the distribution of the outputs from a high-quality random number generator, both with individual subjects [33, 20-22] and in a global network [23, 28]. As a matter of scientific integrity, these carefully-acquired results cannot be legitimately ignored.

The Bem Experiments

In 2011, highly-regarded Cornell psychologist Daryl J. Bem published a summary of nine experiments conducted at Cornell involving time-reversed versions of standard psychology experiments. Of the nine, all but one are reported to have yielded statistically significant results. (See [31] including Bem's web site for a preprint of the paper and several interesting responses and discussion.)

Here we only consider one of the experiments (Bem's #1, Fig. 8 below), while others may be analyzed in a similar way. This test is a simple forced-choice task typical of many experiments in parapsychology. The Subject is presented with a display of two curtains side-by-side and asked to guess which one, left or right, has a picture behind it. The Subject makes his guess, and the curtains are opened, revealing the Target picture on one side and a blank wall on the other.

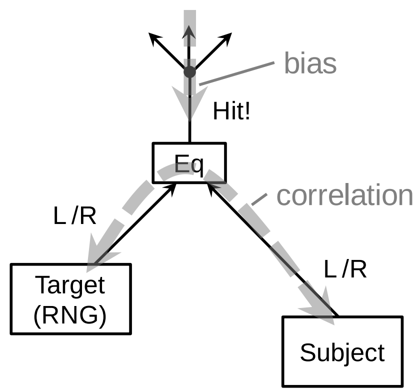


FIGURE 8. Bem experiment #1. It is suggested that the observed correlation could be induced by interaction (the Equality test/relation), plus bias on the outcome, via backwards influence from future conditions (possibly including the experimenter).

While the experiment appears to test for simple clairvoyance (the ability to detect on which side the picture is hidden), in fact the choice of which side and of which Target picture to display are randomly made (by the computer, using an attached RNG) only *after* the Subject's guess has been registered. Thus the test could be considered precognitive, asking for information to be acquired from the future somehow. The results of this experiment showed guessing near chance (50%) overall, but significantly above chance for a subset of the images considered to be erotic in nature (53.1%, p = .01). Those Subjects scoring above the midpoint on "stimulus-seeking" via a preparatory questionnaire scored even more highly on the erotic picture subset (57.6%, p = .00002).

Do these results imply genuine precognition, transfer of information from future to past? Considering again our example of time-reversed EPR, it seems possible that a future interaction (comparison) of the Subject's guess with the later-generated Target could bring about a correlation that gives the *appearance* of information transfer. People who are particularly successful at such tasks ("psychics") often say they just clear their minds and allow the answer to present itself. This sounds very much as if *they are themselves acting as RNGs*, utilizing the general neural activity, noise, or even quantum effects in the brain to produce a guess that is not consciously chosen but essentially random, *and thus susceptible to correlation brought about by backwards influence from future conditions*.

If the outcome of the future interaction (equality comparison) is slightly biased, as discussed previously, by the experimenter or other future dependencies of the interaction, this would bring about exactly the effect that we see -- an extra-chance correlation of somewhat-random guesses and the random targets without disturbing the distribution of either. No information need pass from future to present, but it would appear so -- regardless of which came first, guess or target. The order of guess and target generation would not matter -- exactly as has been seen repeatedly in parapsychology experiments of this type [32, 33, and references therein].

It should also be noted that in this experiment feedback was given to the Subject after each trial by showing the Target picture on the correct side of the screen. This interaction provides yet another path for correlation to be affected between Subject and Target.

The Radin Interferometer Experiments

Next, we consider that the correlation mechanism described above has much more general effects, and could provide a plausible explanation for phenomena that are traditionally thought to be quite different in nature, and perhaps even more controversial than precognition.

Parapsychologist Dean Radin recently published a summary of his experiments involving a table-top Michelson interferometer device that also shows evidence of possible correlation and/or backwards influence on a quantum process [34], Fig. 9 below. The basic task requires the participant to "intuitively sense the presence of the photons in a specific area of the interferometer" (and thus perhaps impede those photons, or acquire "which-way" information) or not, depending on a pre-planned counterbalanced sequence. Analyses of CCD images of the resulting interference patterns are then used to determine the degree to which one of the photon paths was "blocked" or somewhat impeded. Results were reported to be strongly different from the control condition where no participant was present ($z = -2.82$, $p = 0.002$), and especially so for the subset of the participants who were experienced meditators ($z = -4.28$, $p = 9.4 \times 10^{-6}$), see the full paper [34].[9]

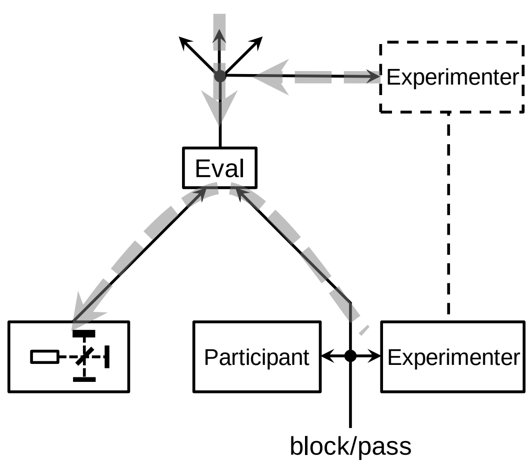


FIGURE 9. Radin interferometer experiment, suggesting that the observed correlation is possibly due to bias on the results via backwards influence from future conditions including the experimenter.

[9] Note that Radin reports differences in the intended direction as negative z scores, that is, reduced interference.

In this experiment, the Participant is attempting to have an effect on the apparatus by "observing" it remotely. The direction of his intention on each trial is determined by a preset balanced sequence of block/noblock directives, not his own choice or that of the experimenter. Presumably, the interferometer apparatus functions normally according to the laws of quantum physics, and thus it is difficult to imagine any way in which the Participant's mental actions or intention could *directly* influence the device.

So we must look for another path for that influence, and again we are led to consider the possibility of correlation mediated by entanglement through past or future interactions. Since the direction of intention, to block or pass light within the device, is dictated to the Participant, not chosen by him, he actually has no ordinary connection to the device at all, unlike the Subject in the previous experiment by Bem.

It is interesting that this experiment contains aspects of both clairvoyance ("observing") and psychokinesis ("affecting"). The Participant is instructed to *observe* the photons in a specific area of the interferometer, thus playing the role of a detector, "collapsing" the wavefunction and preventing the expected interference pattern. But this observation might also be interpreted as *affecting* the apparatus remotely, and altering its normal behavior. The author remarks that "This experiment indicated that a non-locally 'observed' quantum system behaved differently than an unobserved system." As discussed above, *a single causal direction does not fully or appropriately describe the situation*, so this ambiguity should be expected.

It is also worth noting that this particular experimenter (Radin) is known to be highly successful -- one of the most successful ever in parapsychology. His innovative and carefully-designed experiments nearly always show the phenomena he is investigating, and there has never been any hint of file-drawer problems, improper data selection or analysis, or any other improprieties. It is well known among parapsychologists that some experimenters are significantly more successful in finding the effects they seek in their experiments than others -- the notorious "experimenter effect" -- sometimes even independently of their belief or expectation about the phenomena [32, 33, 35, 36]. In [34], Radin discusses this issue, and the possible effect his own intention and mental state may have had on the results in this experiment. The present theory supports the experimenter effect, and can serve as a starting point toward explaining it.

Given the abundant evidence on this point, and the enabling theory expressed above, we are convinced that *highly-successful experimenters in this field are often important participants in their experiments, amplifying or even producing themselves the extra-chance results that are observed.*

Future Experiments with Physical Apparatus

In the case of the interferometer or other physical apparatus, the above considerations suggest several interesting variations that might be tried in future experiments of this type: 1) the participant receives no feedback about the results of some of his trials (thus eliminating his backwards connection and perhaps enabling isolation of this variable), and 2) the experimenter is blind to who is a meditator and who is not (thus eliminating his ability to affect that distinction in the data, even unconsciously), and 3) the participant attempts (in some cases perhaps blindly) to influence the apparatus *after* the data has already been recorded, see also [37].

Three Paths to Anomalous Results

If an experiment of this type has been conducted, and the results show anomalous extra-chance results, there are several ways in which this could have come about, several ways for correlation to have been established, see Fig. 10. Given the careful separation of Subject and Target typically employed in parapsychological experiments, it seems quite *un*likely that information can actually be transferred between them by normal means. But as we have seen, where RNGs are involved, correlation can mimic information transfer.

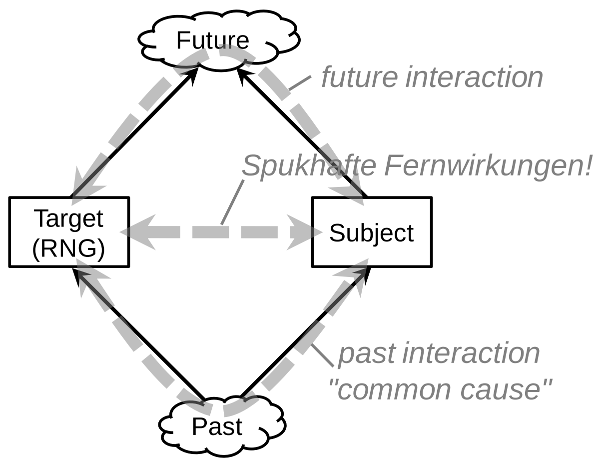


FIGURE 10. Three paths to correlation. If an extra-chance correlation is found between the Subject and the Target streams, it could have been brought about by 1) an interaction or common cause *in the past*, 2) what Einstein famously called "spooky action at a distance" *in the present*, or 3) backwards influence via interaction *in the future* -- or a combination of these three.

Given a random generator based ultimately on a quantum process [38, 39], some freedom exists for a past or future constraint to determine its classical output. Although the whole point of an RNG is to be disconnected from prior influence (or any external source, for that matter), i.e. to be history-neutral (as well as unpatterned), a real physical generator does in fact have an origin and a history. Although it seems highly unlikely, we cannot entirely rule out the possibility that physical components of the RNG and the Subject retain some slight entanglement from their interactions in the distant past, perhaps even in cosmological time.

Also, it cannot be totally ruled out that electromagnetic, gravitational, or some other conventional but unrecognized interaction in the present could bring about a slight entanglement or correlation between Target and Subject due to proximity.

Perhaps more interesting, and less often considered, a correlation between Subject and Target may be brought about through an interaction in the future -- in particular through a bias affected backwards through the comparison between them, as suggested above. This is a possible mechanism for some psi phenomena that should be seriously investigated.

SUMMARY

People like us, who believe in physics, know that the distinction between past, present, and future is only a stubbornly persistent illusion. -- Albert Einstein, 1955

We have argued that:

1. All states and values are "real" and definite, including superpositions that are linear combinations of laboratory basis vectors. A superposition can also be thought of as an underdetermined value, and thus open to reduction by a future constraint.
2. All transformations are unitary, including quantum measurement. There is no "collapse", no fundamental randomness, and God does not play dice. Events considered quantum random such as measurement and radioactive decay are not actually causeless, but are partially determined by future boundary conditions and dependencies.
3. All evolution is thus time-symmetric, and so the appropriate conceptualization is via relations rather than functions. A relation in general is a constraint on joint values of several variables, a special case of which is quantum entanglement.
4. In general, one *can* send a message into the past via superposition or entanglement, and arguably have an effect on possibilities there. But the message *cannot* be received there because doing so would affect the superposition, removing possibilities, and in effect "send" a message instead.
5. Correlation due to past *or future* entanglement can appear to be information transfer if underdetermined events are involved. Future constraints can have an effect if the past does not determine the future completely, i.e. when a superposition exists.
6. Some well-known and confirmed psychic or "psi" phenomena can plausibly be explained in this way, including clairvoyance, precognition, and the apparent influence of the experimenter and future dependencies upon results.
7. By extension, unrecognized entanglements such as those discussed here may have significant implications across all of science, and for society as a whole as well.

Implications for the General Psychology and for Society

"...a performance that may someday be considered understandable, but that, in these primitive times, so transcends what is said to be the known that it is what I mean by magic."
-- Charles Fort in "Wild Talents", 1932

One of our goals in this research should be to build a better bridge between science and the entire human experience, to expand the reach and the intellectual power of science, and thereby to bring about a better partnership with the whole of nature including currently unexplained phenomena. It should be apparent that the generalized entanglement phenomena as discussed above, even if uncommon and only small in amplitude, can have significant philosophical meaning and impact beyond that it has on science. It potentially provides a sociological bridge to many varieties of traditional Eastern thought and wisdom, including a deep principle of connectedness that is mostly absent in orthodox Western science. It also enables a scientific worldview more inclusive of everyday human psychology and experience, and thus can allow non-scientists to better relate to the activities and meaning of science.

In particular, there is a very large difference between the usual *functional models* of the world that encourage us to see everything unidirectionally in terms of use, manipulation, control, and competition, and the more symmetrical omnidirectional *relational models* we advocate that represent -- and encourage -- symbiosis, mutuality, co-existence, and cooperation.

We ask: *Which of these is a better model for Science in the 21st Century?*

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