Nature Remains Behind the Veil: Superluminal Signaling Fails to Credibly Explain Strong Correlations

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Abstract:
The full meaning of experimental violations of Bell inequalities is not clear, although they do confirm quantum mechanical theory and that local realism is not plausible. Some thinkers wanting to preserve some kind of realism postulate messaging between entangled particles. Such messaging must be superluminal to achieve known results of the strong correlations. Here it is shown that no "natural" (uncontrived) process can mediate all the correlations of entangled particles in certain complex circumstances. Hence, our universe is not like a machine and not computable without contrived interventions.

Is Our Universe Like A Machine?

Is our universe like a machine? More specifically, can it (in functionalism that is equivalent to how it functions) be represented with a broadly-defined "computer program"? This question is closely connected to whether or not the world is "realistic" in the sense of definite configurations of "what is there and what it is doing" as a classic catchphrase puts it. We grapple with that question here by showing how "realistic" theories of representation - even with exotic special help in the form of superluminal signalling - would fail to explain the strong correlations of quantum mechanics. This concise discussion is based on a longer, more involved treatment by the author [1]. There is more to unpack here first than the simple question suggests, and things have gotten bumpy in recent decades due to an atavistic resurgence of determinism. The question addresses not only "how does it all work" but also "can we even form a 'picture' of what it is and does? The classical universe was imagined as both determined and representable. The most familiar facet of this is determinism: given a specific state X at time t_0, the further evolution of the universe is inevitable. Note that the whole idea of specifying a definite state X implies the following: reality is in fact well-structured enough to *have* such clarity of specification in principle.

That leads into our next machine-like characteristic: representability or realism. "Realism" is sometimes colloquially put as there being a definite "what is there, and what is it doing." We can think of realism as the world being explicitly describable in principle. Such a world is like a drawing, with definite points and lines (or perhaps field amplitudes) at definite places at all times. We also imagine some comprehensible chain of causal interaction (such as in classical electromagnetism, at least not counting the singularity of point charges.) Deterministic, realistic systems lend themselves to being modeled by computers (real or idealized ones as may be), altho even then there are certain problematic issues. Still, a mechanistic world can essentially be approximated and modeled ("represented," not just manipulating a collection of working heuristics) according to protocols of artificial intelligence theory. Randomness can be added easily, even if ironically the randomizer is technically deterministic.

The development of quantum mechanics and the mystery of how the "wave function" behaved, as well as it's ontological realness in light of the measurement ("collapse") problem, eroded confidence in a deterministic and realist universe. The pioneers imagined that the world was *intrinsically* unpredictable in some ways and to some degree. Furthermore, one could not fully "picture" what went on in the micro-world. The long-dominant Copenhagen interpretation accepted this ambiguity as a given of nature, at least in practice which is what really mattered. The Leggett–Garg inequality [2] showed broadly that quantum reality was not classically realistic. More familiar and specific challenge to realism arrived as the Bell Inequality [3,4], showing that we could not even imagine definite local properties attached to entangled particles.

Some interpretations (actually theories, despite the name and insistence of many proponents) of quantum mechanics rebelled against the muddle world as imagined and accepted by Copenhagen. Many-worlds chose to imagine that the wave-function was real and continued to evolve deterministically, with unobserved outcomes only being hidden from us by decoherence *etc*. Despite the contortions of its defenders it cannot seriously explain the variation of probabilities of outcomes as a function of wave amplitude squared (the "how many" of outcomes to compare *is* the number of representative states and their continuing branchings, no matter how the problem is papered over.) De Broglie-Bohm mechanics took a different tack, imagining particles guided by a quantum potential to actually end up at a specific destination. This vision imagined real particles at real places, "beables" representing agents and doings—even if unusual and not quite "classically classical." These theories still involve non-locality to explain all known results, meaning some kind of superluminal interaction is required. This stresses the idea of ordinary causality limited by light speed, and requires a special preferred reference frame (or "foliation.")

Here, we find that even superluminal signalling, operating under reasonable "uncontrived" rules of interaction, runs into logical contradictions. A specified program of signalling cannot properly coordinate the relationships found for entangled particles showing the "strong correlations" that are so astonishing to our intuitions. Our universe is not realistic. Maybe the old-guard Copenhagen interpretation wisely appreciated that it's better to just say we can't represent how such things happen.

Realism Tries to Reconcile with the Mystery of the Strong Correlations

One of the most impressive and perplexing features of our universe is there being strong correlations that violate the Bell inequality. One expression of these correlations is through entangled pairs of photons, typically emitted simultaneously in opposite directions and later tested for polarization state. If one of a pair of entangled photons is measured to have, say, a 20 degree linear orientation, then the other one will always be found to have the same state by another 20°detector, regardless of how widely separated. Very important: this *not* like just sending out two such photons to start with: if the detectors had been set to 35° instead *etc*., then the correlation still applies, as required by the experimentally verified rules of entanglement. (And here we see the relevance of "free choice" in setting our detectors.) Hence, we can't even imagine the photons as having specific initial polarizations being maintained all the way to and through the detection process.

The Bell theorem (and later, the CHSH inequality [5] and other work) generalizes on these basic facts, and to include unequal polarization tests of the particles in the entangled pair *etc*. The BT says that not even *any* kind of associated property intrinsic to each particle could produce the observed correlations that are predicted by quantum theory. The BT thereby also eliminates the efficacy of local *hidden* variables. Such inherent properties would constitute local realism, widely considered disproved by Bell's theorem combined with *experiments* showing correlations over a variety of measurement relationships. (HVs had no true justification anyway and no place in the quantum state—other than as a contrivance for attempting to get a local realist, causal explanation of correlations.)

Hence, we are thus granted the surreal condition of nonlocality, meaning there must be some actual connection between the entangled particles, however far away. This is so unlike normal interactions it was called "passion at a distance" by Abner Shimony. There is some controversy over how definitive these experiments are and their implications, even so we presume here that the implications are as commonly accepted. Does this make for a non-representable and non-computable universe?

Not necessarily, although the insights revealed here make any alternative a difficult proposition. First, we must accept that we don't *know* how to explain or conceptualize what happens when entangled photons show correlations that cannot be explained by local properties. Some just accept this situation as one of Nature's enigmas, something we can't represent realistically at all. Others want to find a way to conceptualize how these correlations happen—an *explanation* to some extent, in classic (even if not quite "classical") terms. These realist theories should seek to mechanize—abstractly speaking if need be—what happens as a specific model, otherwise are they really "pictures" of Nature as opposed to the misty inscrutability of Copenhagen? So the issue here is logical clarity and consistency of postulated conditions and changes, not to be confused with whether the influence has to literally be like a "force" or field interaction even as currently conceived. We find here that even that bar fails to be met.

Someone wanting a "real" picture of what happens can imagine that the photons somehow communicate with each other later, possibly long after their creation and over great distances. We can't understand that causally, because known causality is limited by light speed—and anything faster requires a special reference frame anyway. The paradigmatic realist solution is nevertheless *superluminal signaling* (SLS) between the entangled particles. SLS is popular among fans of deBroglie-Bohm mechanics, but is not tied to that perspective. To avoid violation of Lorentz invariance manifested as contradictory standards of simultaneity, proponents typically first assume initial local realism (definite initial states for both particles) and simultaneity standards of a preferred frame of reference (also constructible as a "foliation.")

The simplest next assumption for SLS (and preserving conservation of angular momentum) is that both particles start in the same state. Then they postulate influences, not clearly imagined in kind but simultaneous by the standards of the PF, to be immediately exerted by a measured particle upon its entangled partner (or partners as can be.) The result could be *e.g.* a sudden change in the polarization state of the partner, to match that of the just-measured "sender." The aim is to demonstrate how the correlations are enforced. An excellent description, including how a preferred frame works, is found [6] through the website "The Information Philosopher."

One advantage of nonlocality is that the "instructions" need not reference hidden variables—direct reference to polarization state will suffice. These "signals" enforce the strong correlations between the particles, regardless of their separations. Note however these signals are strongly considered unable to transmit genuine, usable information of any kind, such as would enable FTL communication between conversants *etc*. Nevertheless, I also present below an argument challenging the prohibition against FTL transfer of authentic information, given certain assumptions.

Proponents expect that a well-constructed theory of this kind, which is non-local realism, could give results fully equivalent to what we find. Hence, there seems to be no way to experimentally refute the theory, although proving it true wouldn't be available either. However, those for whom it matters could consider this "explanation in principle" to be consistent with a realist universe that could be modeled explicitly, instead of being inherently vague and inscrutible at its microscopic core. I use "superluminal realism" to label the idea that adding SLS to explain the strong correlations preserves "realism," in the sense that at least might still apply to quantum mechanics (setting aside the separable issue of whether indeterminism is genuine.)

The concept of superdeterminism [7,8] tries to get around the signaling problem by, in standard versions, taking away the "free choice" (technically: statistical independence) of the experimenters to pick truly independent settings for detectors. A claimed justification is causal unity of the universe going all the way back to the big bang. However, suppose Alice uses photons from a distant galaxy to set her polarizers, and Bob at his end uses digits of the cube root of 17, or notes from Beatles songs. Is it credible that the galaxy can encode such contrived sequences? And the emitters might be very simple entities like a few atoms, hardly able to store the information of very contrived sequences inside themselves. There is even the point that detectors could be LP, but for reasons of atomic physics we would expect the initially emitted state to be CP. We won't dwell further on superdeterminism or other attempts to finesse or evade standard implications and limitations. We will assume statistical independence, and presume there are no credible ways to avoid non-locality, such that *some* kind of "message"—even if sent *retro*causally into the past instead of instantaneously—needs to be sent in any realistic depiction. The logical consistency problems discussed here are very general and should not depend on message type.

Superluminal Signaling Fails Complex Consistency Tests

Here I outline several conceptual arguments showing that a reasonable implementation of SLS would not be fully consistent if certain complicated detection schemes are used. First I explain how SLS would work in order to be consistent in familiar simple tests. Then I show that various complicated detection packages, under the same logic, would be inconsistent with the known outcomes predicted by standard quantum mechanics. The basic action of SLS is to imagine (or as equivalent to) the following process, for a case with positive correlation of polarizations. The basic, unmodified "measuring devices" AKA "detectors" normally used are calcite prisms that perform orthogonal separations of polarization state (such as 20° and 110° linear polarization, RH versus LH circular *etc,*) followed by photon counters. Here we'll simplify as if just "detecting" such-and-such unique state.

For the sake of very important conceptual background, let's first think carefully about what is truly a detector calibrated for a given quantum state. A paradigmatic simple example is a linear polarization filter set to fully transmit light having some particular angle of vibration, such as 55 degrees. Despite the pervasive meme, measurement is not *all* about statistics. We can prepare photons in the 55° state. All these photons (ideally) will pass this filter. Other linear states may or may not pass, probabilistically depending on the relative angle (in generalized polarization, on similarity to the characteristic state.) If they do pass, they are "detected as" being in that angle, even if they did not start that way. But is that act of measurement intrinsic to only the LP filter all by itself? No, it depends on other context and prior interactions too. We can place an optical rotator in front of this filter. It rotates the linear angle of polarized light by say, 20 degrees—but importantly, does not absorb or detect (*collapse*) any light.

So: if a 35° photon transits the OR, it gets rotated to be at 55 degrees and is then in the correct eigenstate for certain detection. *As far as we know*, this compound system is legitimate and fully equivalent to a simpler "35 degree detector." Indeed, standard "circular polarization filters" actually pair a quarter-wave plate (which converts circular into a certain linear orientation) with a linear polarization filter. Note that it shouldn't logically or physically matter how widely separated the components are.

Also: In these cases we set detector D_2 much farther than partner D_1 from EPE. We presume it unlikely that PF is discrepant enough from our lab frame, to allow interaction at D_2 to happen first by PF standards. Even so, we can rotate the entire apparatus 180° and compare results as needed.

So: entangled photon P_1 is detected first by PF standards (maybe not in the lab frame, but the final results are the same in these *simple* cases) at D_1 as being in a given state Ψ_1. Of course, the entering photon may have been in some other polarization state (if there was indeed such a definite thing, such as from a specified preparation); but being "found" as a certain polarization makes for "a measurement" and is the basis for the correlations of entanglement. Immediately, the partner photon P_2 changes from its previous state Ψ_2 into the other state Ψ_1. We'll set the other detector D_2 to the same specification as D_1. So when P_2 arrives at D_2 it makes a "click" which shows the correlation, that it too is found to be in state Ψ_1. Statistics from more trials at other settings can demonstrate the fullness of the strong correlations.

However: P_2 can't always simply change into "whatever state P_1 was finally detected in."

We can foil that simple protocol by making detection a more complicated, cascaded process. For example: we can modify a photon before it hits a simple "direct detector," in a way that does not "collapse" it into a specific knowable state. We will place a +20° optical rotator OR in front of D_1. D_1 is set for 55° (and will remain such, throughout the following other adjustments), making this compound system a "35° linear detector." So: suppose both photons start as 10° linear. If photon P_1 enters the complex, it is rotated by OR to 30°. It then has around an 82% chance of passing D_1. Suppose it does. D_1 clicks and *as far as we know*, we can rightly say we "detected P_1 at 35 degrees."

Then, apply the following reasoning to SLS under entanglement. The correlation means that we need for D_2 to always click if also set for *35*°, not 55°. Hence, P_1 can't act like sending a message to P_2 which says: "Whatever happened to me before, I was actually found at 55°. So, you must now *become* a 55° photon." That would not work correctly at D_2, and we would already prove that SLS was inconsistent. Instead, we note that P_1 started at 10° but was rotated to 30° even before actual detection. When it hit D_1, the measurement constituted another rotation, this time by 25°. So if at the moment of detection, P_1 instead sends a message to "*rotate* 25 degrees," then P_2 becomes the correct state for correlation.

This process works equivalently in either direction and order of interaction, for any linear photon state and detection angle, as it must. (The distinction between alteration by OR and the genuine measuring (and fixing) of final photon orientation is interesting in itself, in relation to the special status of "measurement.") Note in particular that if entangled photons start in an ambiguous "undefined state," there is no clear way to message the proper change-command to the partner under these more complex circumstances.

However, not all is well. Polarization has two degrees of freedom and we need to account for correlations involving any type of presumed initial photon state that is tested for any other polarization eigenstate. It is reasonable to presume that the actual starting states of photons emitted in most ways would be circular polarized, such as two RH states. In order to enforce the strong correlations, the superluminal message must describe a change from a polarization state to *any other* polarization state. Mathematically that is simple enough (the equivalent of sending the photon through a few specified optical elements), but will it work?

We return to our previous arrangement, but now imagine two RH photons speeding from the source. The problem is that the effect and implications of an optical element are relative to what transits it, and what comes next. So ... a rotator is named from changing the angle of linear polarization a set amount. It does this by changing the *relative phases* of superposed RH and LH states. Hence, there is no actionable effect on a pure RH or LH state by itself! If the RH photon is detected "as" 55° at D_1, the detection event doesn't "know" what happened at OR. It will presumably send a message to P_2 of how to convert from RH to 55° linear. Consider then what happens now at D_2. Since P_2 has been converted to 55° linear, it is NOT set to correlate with the 35° D_2. So we have a failure. The directly-constructible change-command is not universally effectual.

Another example brings further troubles. For Arrangement II suppose we replace OR with a half-wave plate HWP. A HWP is defined by having one lateral axis, the "slow" axis, retard the matching angle of polarization by a half-wavelength in phase relative to that passed by the orthogonal "fast" axis. In this case, the HWP's fast axis is set to 20°. This optical axis acts differently in principle from an OR. It "reflects" the angle of incoming linear polarization around itself. Hence, incoming 10° light again becomes 30° light, *but* incoming 44° light exits at –4° instead of 64°, *etc*. We keep D_1 at 55°. Again, consider an entering 10° photon P_1. It exits HWP at 30°. If pinged by D_1, the second change angle is again 25°. The entering photon and both rotations are the same as before, so can we expect equivalent results at the distant D_2?

Amazingly, the answer is no. The problem is that this combination of HWP and linear detector have a different detection setting than the previous case. This combination is actually a "detector for photons at –15 degrees" because that state is flipped by the HWP to match a subsequent 55° LD. For consistent positive correlation under normal circumstances, D_2 needs to be set for that angle. But P_2 will set set for 35° according to the protocol that worked the first time. Hence, if P_2 gets the same "rotate 25 degrees" message as from the OR + linear detector combination, coincidences are no longer guaranteed. (Yet if P_2 is instead detected first in the preferred frame, it does send the correct message for the combo-detector! If a linear photon is turned a given amount before it hits a HWP, the result is different than if the same "instruction" is received *after* it passes.)

We also have trouble with circular photons here. If a CP photon transits HWP, it is flipped to opposite chirality. That much is fine, because with a LH detector further along for P_1 we would have a compound "RH detector" to have consistency with P_2. However, the conversion from LH to 55° if D_1 pings, constitutes an instruction that would convert a *LH* photon into a 55° linear. Since P_2 is RH we get conversion to 145° = –35° instead, which is *not* what we need to get final correlation for a *net* –15° detector. And even if P_2 could somehow get the simple conversion instruction for a RH photon, the result 55° is still wrong. Hence in this arrangement, *neither* initially linear nor circular photons give correct results. We have "fooled" the photon into being unable to correctly adjust its partner.

For the next refinement (Arrangement III), let's think literally one step deeper about the meaning of "measurement." Once a photon passes *e.g.* a 20° linear filter, it *is* a 20° linear photon, to the extent things are real at all. It has been measured as such, "collapsed." So, if we place another filter, say 50° setting; on further along: there is no refinement of the measurement, but just a constant mismatch between the two filters. That extra LF might as well be just a 75% transmission gray filter ... except that it isn't. Suppose we use such a compound filter in our tests of entangled photons. We first have a 55° LF_a, followed by a 85° LF_b and then a photon counter. Imagine again a 10° photon passes LF_a and sends a rotate 45° message to P_2. So far, so good. However: unless photons can remember they were already affected by a LF, the photon passing the second filter (it will happen 3/4 of the time) will send another message, this time saying "turn thirty degrees." If still in flight, P_2 will turn again, ending up at 85°—and therefore will no longer pass correlation tests. Yet as far as we know, the compound filter is an authentic albeit inefficient quantum detector for "55° photons." It should work and instigate signalling like any other same-calibration detector.

Critics will understandably feel that the second encounter is just not the same as the first one. Maybe so, but an entangled photon then needs to somehow track it's identity moving forward, like with a little sticky note saying "Hey—I have already been measured once, so I don't signal after that." Normally we don't consider such "memory" to be credible unless it can somehow be modeled or explained causally. Not that *any* of the signaling is modeled or explained causally, for that matter! It is usually just "taken for granted" as a convenient feature of reality. However, even then we should expect logical consistency with basic principles of of what it is to be "the same" or "a different" circumstance as consistent with the imagined properties of the entity in question. For photons, that would mean no extra little tweak that is not part of their quantum characterization *per se*. Furthermore, in cases of partial-polarizing filters in sequence, we might *need* multiple messages sent to pin down narrowing to a more specific final state. Then what?

Yet another challenge is raised by the use of Renninger-style [9] "null-result" measurements. Rather than either immediately absorbing a photon versus transmitting a unique state, a polarizing beam splitter will separate a photon's components into two streams. Hence, even if we imagine that measurements really occur at true *filters*, in *this* case it has not happened yet. (In dBB the photon really turns one way or the other, but something else must still continue on the other track to enable further interference.) Now for Arrangement IV we can introduce a null "measurement" at one detection system by having one sub-path quite longer than the other one, or even to go on and on. If I fail to get a click at the horizontal-component branch when photon P_1 should have arrived, I know by elimination that its vertical-component branch must click later. So I already have sort of "collapsed" this photon into what must happen later, without even detecting it!

This is already weird enough *per se*, but null measurements make entanglement even harder to visualize because P_2 has to be found as the same eventual state. Yet relativity of simultaneity means that either P_2 was detected first and "caused" photon P_1 to not be even be *found in* the H detector, OR I can imagine that the null result happened "first" and somehow affected photon P_2 without there even having been a proper interactive measurement! We can add yet further complications to this (and to the other cases here) with an initial ordinary beam splitter and then variously-arranged filtered paths, recominbations, partial separations, unreliable detectors *etc*. Since the inconsistencies are clear in the examples described, we will pass over such further challenges other than this mention.

These are all experiments we can and should do, although I expect the results to be as normally predicted. Hence, there is a problem for simple mechanistic signaling theories or picturings. The implications of all this are stunning: a reasonable realist theory about how SLS would work, cannot guarantee the proper and known results of EPR correlation experiments. Using a HWP + polarizer combination "fools" the SLS into sometimes given wrong results under any reasonable and uncontrived concept of "signaling." We don't even need to consider all possible detector relationships, because any predicted violations of perfect correlation implies a flaw in the theory.

Note that it does no good to say things like: "the entangled particles aren't really 'sending' anything to each other. They are just no longer bound by space-time separations. It's more like being next to each other, or even almost like they are the same particle." The logical problems are *the same* regardless of how we imagine the relationship or mediating process between the particles. As long as one insists on an actual state for each particle to be in (realism in the broadest sense), then the effects of certain interactions simply cannot be logically relatable in a way that will yield the correct results. Or, at least these interactions cannot be handled by any realist conception that wants to avoid massive contrivance in *lieu* of natural credibility.

Is True FTL Communication Possible?

There is still a possible issue regarding genuine FTL communication of actual information. The implications of that accomplishment make this entire discussion more difficult, I refer the reader to the extensive work and controversy on this subject. The method here is effectively an elaboration of the FLASH concept proposed by Herbert [10] for application to a single interaction. Single interactions were shown to be ineffectual for this purpose, leading to the "no-cloning theorem" [11]. However, in this case we employ multiple interactions combined with careful selection of a *subset* of interactions.

We use a compound detector D for this purpose. Its first element is a quarter-wave plate with horizontal fast axis, that is rotationally free within a *small* angle. The QWP is paired with a subsequent fixed linear filter set at 135°. Hence the full apparatus is a "R state detector," because an entering RH state is converted to 135° and then passes the linear filter. If a random orthogonal (what we expect from a source) mixture of RH and LH are directed at D, in the long term half will pass (although converted into linear!) and half will not. Sometimes there will be a "run" like a run of heads in coin toss, of say, many "RH" hits in a row (or mostly RH.) If we examine the change in angular momentum of the QWP, we could find it increased by $n\hbar$ or nearly, because of the conversion of n RH states to linear *etc*.

On the other hand, suppose a mix of diagonal linear (45° and 135°) is sent to D. The 45° will be made into RH, and the 135° be made into LH. Either of these has a 50:50 random chance of passing LF. If there is a run of many passes, that run has no clear connection anymore to which circular state happened to pass or to which linear state entered the QWP. Hence this time, the run will not show the significant change in angular momentum of the QWP. Hence, we could distinguish between the two types of supposedly equivalent mixtures.

This ability to distinguish between orthogonal mixtures (if quickly enough, as we'll see) supposedly leads to FTL communication. First, a detection regime based on a given base like, RH/LH or 45°/135°, ought (per the attempt to make "realism") to force the distant entangled partners to conform to each particular mixture involved—so they will present proper correlations. Hence, a change in the choice of base should "immediately" (*per* the PF we presume) force the distant partners to change accordingly. (This is of course just an ensemble implication of the individual change-signals.) So if Bob can detect this change, he thereby gets a loosely-defined FTL message from Alice.

However, note that in *our* case this is a long-term statistical process, and subject to much ambiguity about where to draw the line in being confident of an actual corresponding change at the other location. The implications of being able to distinguish such mixtures thereby seem muddy. Still, the situation is quite interesting as a way to break away from simple full-ensemble thinking, and start considering the implications of exceptional "runs" etc. In this case we tricked the prohibition against distinguishing between 50:50 orthogonal mixtures, by selecting out rare *subsets* that are very much NOT 50:50 mixes. The idea of subset selection in experiments of this kind, and to measure both spin transfer and other aspects of polarization, surely deserves more attention and study, regardless of just how the implications pan out.

Conclusion

We have seen that simple rules cannot be effectual in consistently mediating (however the mediating process is imagined to be or consist of) the required transformations of entangled particles as imagined in realism. That doesn't mean there is *no* way at all for the correlations to be managed. What it tells us is that any such process cannot be "natural" in a way I will now define. If we assume realism, then "naturalness" means that the behavior of constituents must correspond to what we know about them. As far as we know, photons are characterized by their polarization state, the expectation value for energy, and (contrary to simplistic descriptions) their coherence length (range of superposed possible energies, hence use of "expectation value" instead of just "energy.") I leave aside exotic quirks like orbital angular momentum. Entanglement complicates this picture of course, but not by adding new parameters *per se* to any single photon. Whatever program the universe could be run on, is only "natural" if it is logically isomorphic to the imagined consistency of properties of the particular things it is representing. That is, not contrived like by including a "demon" that can watch things happen and intervene.

So, consider again *e.g.* the above case of an entangled photon that needs to "send a signal" at its first interaction with a polarizing filter, but not at its subsequent interaction with a second such filter. As noted, the photon would have to carry with it a sort of "note" telling it to not send a signal at the second interaction. That "note" would constitute an additional parameter attached to the photon. Now consider that yes, a real computer program simulating our universe could be sophisticated enough to track these encounters and manage their relationships accordingly. But such a program violates "naturalness," because it involves a contrived overseer in effect that extends beyond the actual character of the particles and fields etc. as we know them. Yes, the whole signalling enterprise could be considered "going beyond" the direct properties of the particles—but it would not violate naturalness as here defined, if it could be pegged to the basic properties of things and their interactions.

So the final conclusion is that entanglement relationships require something more than straightforward realism can provide. Either there is controlling "program" that is very contrived

and is not simply a model of the constituents of the world as we know it, or the world is just not representable in realist terms. I think the latter is the likely and justifiable viewpoint, although of course it's something we may not be able to be sure of. Bohr was right to say we can't picture what happens in the world. It is surely relational and contextual. This view roughly corresponds to the quantum homily that "some properties aren't real until you look" (not to be confused with the straw man "things don't even exist until someone looks.") A recent essay [12] by science popularizer Ethan Siegel makes the appeal so cogently and well, I quote from it here:
"Understanding the Universe isn’t about revealing a true reality, divorced from observers, measurements, and interactions. The Universe could exist in such a fashion where that’s a valid approach, but it could equally be the case that reality is inextricably interwoven with the act of measurement, observation, and interaction at a fundamental level."

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