

The Ontic Probability Interpretation of Quantum Theory

Part II: Einstein's Incompleteness/Nonlocality Dilemma

Felix Alba-Juez
Felix Alba-Juez, Publisher
Saint George, Utah (USA)
<https://felixalbajuez.com>

ABSTRACT

After pinpointing a conceptual confusion (TCC), a Reality preconception (TRP1), and a fallacious dichotomy (TFD)¹, the famous EPR/EPRB^{2,3,4,5,6} argument for correlated 'particles' is studied in the light of the Ontic Probability Interpretation (TOPI) of Quantum Theory (QT). Another Reality preconception (TRP2) is identified, showing that EPR used and ignored QT predictions in a single paralogism. Employing TFD and TRP2, EPR unveiled a contradiction veiled in its premises. By removing nonlocality from QT's Ontology¹ by fiat, EPR preordained its incompleteness. The Petitio Principii fallacy was at work from the outset. Einstein surmised the solution to his incompleteness/nonlocality dilemma in 1949⁷, but never abandoned his philosophical stance⁸. It is concluded that there are no definitions of Reality: we have to accept that Reality may not conform to our prejudices and, if an otherwise successful theory predicts what we do not believe in, no gedankenexperiment will help because our biases may slither through. Only actual experiments could assist in solving Einstein's dilemma, as proven in the last 50 years. Notwithstanding, EPR is one of the most influential papers in history and has immensely sparked both conceptual and technological progress. Future articles will further explain TOPI, demonstrating its soundness and potential for nurturing theoretical advance.

List of Acronyms (Part I and Part II)

QT	Quantum Theory	EPR	The Einstein/Podolsky/Rosen Paper
TOPI	The Ontic Probability Interpretation	<i>PD</i>	Probability Distribution
<i>PI</i>	Physical Interaction	<i>GI</i>	Gauge Interaction
<i>TM</i>	True Measurement	TRC	The Reality Criterion
TCC	The Conceptual Confusion	<i>SD</i>	Standard Deviation of a <i>PD</i>
TRP1	The Reality Preconception 1	TFD	The Fallacious Dichotomy
EPRB	EPR-Bohm Gedankenexperiment	TRP2	The Reality Preconception 2

1. Introduction

In Part I we saw that, because -in most cases- a 'measurement' (*GI*) disturbs the state and TRC was mute regarding the property's 'reality', EPR needed to conceive how to predict the result of any 'measurement' "with certainty" and "without in any way disturbing the system". In TOPI lingo¹: how to make a *GI* work as a *TM*. Directly interacting with the local one of two *entangled* space-like-separated systems, EPR claimed QT predicts the property value for the remote one "with certainty" and, per the Principle of Locality, "without being disturbed". EPR further argued that the remote property must have existed all along, not somehow created by the 'measurement', as many QT pioneers had avowed would have been the case had the remote system been directly 'measured'. Ergo, it had to be an "element of reality".²

2. The Iconic EPR Gedankenexperiment

EPR describes its iconic thought experiment:

EPR8: *For this purpose let us suppose that we have two systems, I and II, which we permit to interact from the time $t=0$ to $t=T$, after which time we suppose that there is no longer any interaction between the two parts. We suppose further that the states of the two systems before $t=0$ were known. We can then calculate with the help of Schrödinger's equation the state of the combined system I+II at any subsequent time; in particular, for any $t>T$. Let us designate the corresponding wave function by ψ . We cannot, however, calculate the state in which either one of the two systems is left after the interaction. This, according to quantum mechanics, can be done only with the help of further measurements, by a process known as the **reduction of the wave packet**.*

We will refer to subsystems I and II as *SSI* and *SSII*. Knowing their states prior to interaction, Schrodinger's Equation predicts the future *composite* state ψ but **not** their *individual* states. This is because the equation governs the temporal evolution of the *composite* system in its state-space (a tensor product), not of the subsystems in their own state-spaces⁹. However, EPR believes the subsystems' states must have definite values that can be determined "only with the help of further measurements".

EPR imaginarily 'measures' *momentum* P_I or *position* Q_I of *SSI*. To predict the 'measurement' of P_I , the wavefunction of the *composite* system is expanded in terms of the *momentum* eigenfunctions of *SSI*. But because *SSI* is entangled with *SSII* due to *momentum* conservation, the coefficients of the expansion are functions of the *momentum* eigenfunctions of *SSII*. Thus, after the 'measurement', *SSI* adopts one of its *momentum* eigenstates and *SSII* (despite being afar) adopts one of its own *momentum* eigenstates. Mutatis mutandis for 'measuring' Q_I . Obviously, the system imagined by EPR is not the dull aggregate of *SSI* and *SSII*: QT predicts that, even if they are space-like separated, a 'measurement' in *SSI* not only may affect its state but may also affect the state of *SSII*. The 'spooky action at a distance' between two 'particles', so despised by Einstein, was obviously at work. A decade before, and specifically at the Solvay 1927, he had denounced the 'one-particle nonlocality' as a sign of QT's *incompleteness*.¹⁰

2.1. EPRB Gedankenexperiment vis à vis TOPI

In 1951, David Bohm reconceived the EPR gedankenexperiment via two spin-1/2 qubits in the *singlet* state^{5,6}. There is a homology between EPR and Bohm (EPRB) setups. The philosophical problem is easier to clutch for the latter, so we will reinterpret EPR's assertions per EPRB. The homology is set with two bijections: a) $P \leftrightarrow \mathcal{S}/\hat{n}$ (Spin along \hat{n}); and b) $Q \leftrightarrow \mathcal{S}/\hat{n}'$ (Spin along \hat{n}'). For the spin operators to be noncommutative, \hat{n} and \hat{n}' are to be **not** anti-collinear. The homology is valid for both sites: *SSI* ↔ *Qubit-I* and *SSII* ↔ *Qubit-II*. **Figure 1** drafts EPRB setup.

Created in the joint *singlet* state, the two qubits travel in spacetime and, if the system remains isolated as a whole, its state is unaffected by their spatial separation. The *singlet* state is:

$$|singlet\rangle = \frac{\sqrt{2}}{2} \sin(\theta/2) \{|s_{I1}s_{II1}\rangle - |s_{I2}s_{II2}\rangle\} + \frac{\sqrt{2}}{2} \cos(\theta/2) \{|s_{I1}s_{II2}\rangle - |s_{I2}s_{II1}\rangle\} \quad (1)$$

$$\theta = 0 \Rightarrow |singlet\rangle = (\frac{\sqrt{2}}{2})|s_{I1}s_{II2}\rangle - (\frac{\sqrt{2}}{2})|s_{I2}s_{II1}\rangle$$

Where θ is the angle between the fields of two Stern-Gerlach magnets for potential *GIs* with the qubits. The other four ket-symbols stand for the four eigenvectors spanning the composite State-Space. Neither space nor time appears in the state, so any physical interaction between the

qubits is not of the dynamic type. Despite depending on θ , the *real* state is unique; it is the basis (eigenvectors) used to express the *singlet* state that changes for each potential value of θ . From Equation 1 (top), the probability for *Qubit-I* or *Qubit-II* to transition (upon a *GI*) to any one of their two eigenstates is 50% irrespective of θ , i.e. the *local* spins are perfectly *random* for any magnet orientation. Yet, their product shows rich probabilistic patterns, e.g. *deterministic* for $\theta=0$, and perfectly *random* for $\theta=90^\circ$.¹⁰ Thus, prior to any *GI* on a site, the qubit state is undefined. Per TOPI, it is false to say (as EPR8 does) that *SSI* and *SSII* states can only be determined with “the help of further measurements”. The fact that a single *GI* delivers a single value does not mean such a value was predetermined; and, even if it was, it may not have been the same because a *GI* may or may not be a *TM*.¹

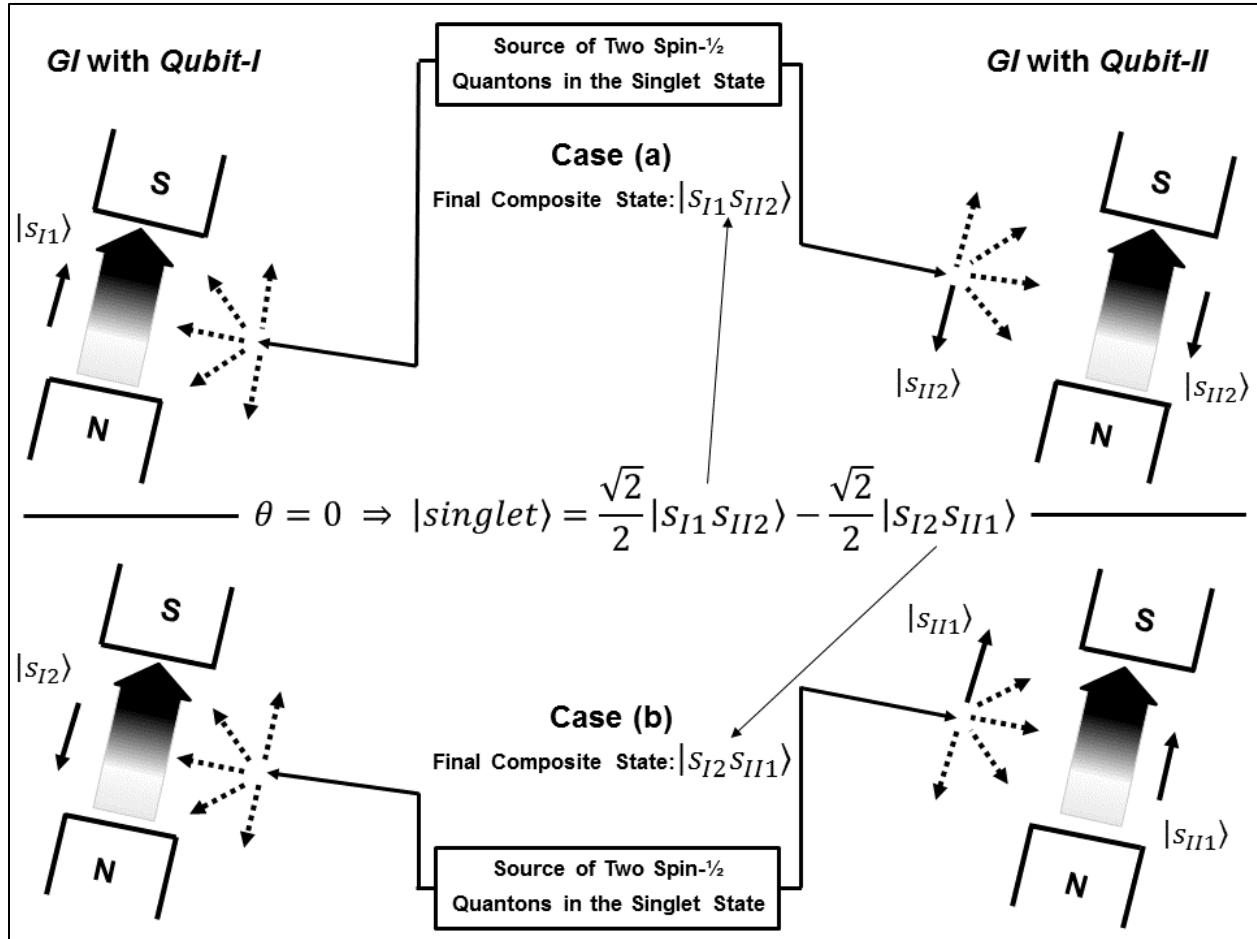


Figure 1: Two Spin-1/2 Qubits in the Singlet State – A GI with Qubit-I occurs First

Figure 1 assumes a *GI* occurs first to *Qubit-I* depicting the two cases: (a) *GI-I* delivers a spin aligned to the magnetic field ($|s_{I1}\rangle$); or (b) *GI-I* delivers a spin anti-collinear to the field ($|s_{I2}\rangle$). All arrows at the field’s entrance are dotted conveying that the pre-*GI* *Qubit-I* state is undefined. However, as soon as *GI-I* occurs, *Qubit-II* detangles from *Qubit-I* and (from Equation 1) its probability to transition (upon any *GI-II*) to one of its eigenstates ($|s_{II1}\rangle$ or $|s_{II2}\rangle$) is not 50% anymore but given by:

$$Pr(|s_{II1}\rangle/|s_{I1}\rangle) = Pr(|s_{II2}\rangle/|s_{I2}\rangle) = \sin^2(\theta/2) \quad (2)$$

$$Pr(|s_{II2}\rangle/|s_{I1}\rangle) = Pr(|s_{II1}\rangle/|s_{I2}\rangle) = \cos^2(\theta/2)$$

But a glimpse at **Equations 2** shows they correspond to the behavior of an *isolated* qubit when the angle between its direction and the magnetic field is $\theta + \pi$. This proves that *Qubit-II*, while detangling, adopted a spin anti-collinear to that of *Qubit-I*, namely $|s_{II2}\rangle$ for (a) and $|s_{II1}\rangle$ for (b). And this state adoption by *Qubit-II* occurred whether it will ever undergo a *GI* or not, as indicated by the only solid arrow before reaching site *II*. It also follows that the angle between the two spin states adopted by *Qubit-II* upon two *GIs* on *Qubit-I* is the same as the angle formed by the respective magnetic fields on site *I*. Hence, if -remaining isolated after detangling- *Qubit-II* ever interacted with a field collinear to the one on site *I* ($\theta = 0$), its pre-*GI* state for cases (a) and (b) would be an eigenstate, and its post-*GI* state would be the same: *GI-II* would be a *TM*.¹ It is crucial to realize that *Qubit-II* is undisturbed by *GI-II* not because both qubits are space-like separated but because its pre-*GI* state is an eigenstate whenever *Magnet-II* is aligned to the direction *Magnet-I had* when *GI-I* occurred. The ‘spooky’ effect occurs (per QT/TOPI) as a result of *GI-I* happening; *GI-II* may or may not ever occur.

Going back to the homologous EPR setup, $\theta = 0$ means that the same property (*P* or *Q*) is ‘measured’ on sites *I* and *II*, with their homologous spins on each site being not anti-collinear and forming the same angle in both sites. With TCC proviso¹, this is what EPR needed: pre-*GI-II* and post-*GI-II* results for *P* or *Q* agree and are predicted “with certainty” from the respective results of *GI-I*. The *GIs* on site *I* are not *TMs*, so TRC does not apply; the *GIs* on site *II* are *TMs*, so TRC applies¹. It is also vital to understand that the state adopted by *SSII* when ‘measuring’ *P* on site *I* is different from that adopted when ‘measuring’ *Q* on site *I*.

3. The Reality Preconception 2

Firmly believing in the Principle of Locality, EPR affirms:

EPR9: *We see therefore that, as a consequence of two different measurements performed upon the first system, the second system may be left in states with two different wave functions. On the other hand, since at the time of measurement the two systems no longer interact, no real change can take place in the second system in consequence of anything that may be done to the first system. This is, of course, merely a statement of what is meant by the absence of an interaction between the two systems. Thus, it is possible to assign two different wave functions to the same reality (the second system after the interaction with the first).*

Intriguingly, instead of relying on Relativity Theory (RT), EPR enforces *locality* by the very assumption of ‘no interaction’. Per RT, the only way for two space-like events to be correlated is through a common cause in their past¹¹. This is valid, of course, if RT itself is *complete*, i.e. if every possible “Element of Reality” has been included in its *Ontology* and represented in its *Foundation*¹, a topic to be argued in future articles.

Despite the distinct states predicted by QT, **EPR9** decrees that *SSII* is in the same *real* state. I call this ‘The Reality Preconception 2’ (TRP2), which violates the EPR4 dictum¹. Kemble¹² quickly argued that the EPR argument was not sound, but his counterargument was not sound either. Furry¹³ pointed out the incompatibility of EPR premises with QT. Bohm^{5,6} suggested TRP2. Jammer⁸ recounts in detail all early criticisms to the EPR argument.

This is the logical trap behind TRP2: if it is true that *SSI* and *SSII* do *not* interact: (a) the composite state must be a *product-state*^{10,1}; (b) the expansion coefficients for *SSI cannot* depend on *SSII* eigenfunctions; and c) **EPR9**’s first sentence is *not* true, rendering its last sentence invalid. **EPR9** relies on a cross-influence among wavefunctions that *contradicts* its own ‘no

interaction' assumption. It might not be the type of interaction EPR would philosophically approve, but the mere existence of cross-relations implies an interaction. EPR used and ignored QT's controversial prediction in the same paralogsism.

Furthermore, TRP2 uncovers an *incompleteness* nuance: first, 'incomplete' meant that the same abstract state represented more than one *real* state ('real' by virtue of TRP1) so that a "counterpart in the physical theory" for many a 'real' state was missing¹. Now EPR asserts: the same *real* state ('real' by virtue of TRP2) corresponds to more than one *abstract* state. **EPR9** dogmatically removes *nonlocality* from the *Ontology* and, inevitably, preordains not only QT's *incompleteness* but also its *incorrectness*.

4. Misusing 'The Fallacious Dichotomy'

Before resorting to TFD¹ as the coup de grâce, EPR states:

EPR10: *Thus, by measuring either A [P_I] or B [Q_I] we are in a position to predict with certainty, and without in any way disturbing the second system, either the value of the quantity P [P_{II}] or the value of the quantity Q [Q_{II}]. In accordance with our criterion of reality, in the first case we must consider the quantity P as being an element of reality, in the second case the quantity Q is an element of reality. But, as we have seen, both wavefunctions belong to the same reality.*

Based on TCC¹, TRP1¹, and TRC¹, EPR concludes: in one case, it is P_{II} the one which is real (single value); in the other, it is Q_{II} the real one. But in both cases, because what happened to *SSI* did not (by virtue of **TRP2**) affect *SSII* at all, P_{II} and Q_{II} must have existed all along, i.e. they had, in EPR's language, a "simultaneous reality". Finally, using TFD¹, via a reductio ad absurdum argument, EPR reaches a contradiction that, alas, already existed in its premises:

EPR11: *Previously we proved that either (1) the quantum-mechanical description of reality given by the wave function is not complete or (2) when the operators corresponding to two physical quantities do not commute the two quantities cannot have simultaneous reality. Starting then with the assumption that the wave function does give a complete description of the physical reality, we arrived at the conclusion that two physical quantities, with non-commuting operators, can have simultaneous reality. Thus the negation of (1) leads to the negation of the only other alternative (2). We are thus forced to conclude that the quantum-mechanical description of physical reality given by wave functions is not complete.*

Despite QT predicting the opposite, EPR insists the 'real' state of *SSII* has not changed and applies the 'Uncertainty Principle' incorrectly¹. The purpose is to assert that P_{II} and Q_{II} do not have "simultaneous reality" (one of them has a *PD*), while they must have it because QT predicts them "with certainty" and "without disturbance". EPR contends that such a logical contradiction (both alternatives false) can only imply that QT is *incomplete*. Instead of contrasting QT predictions with **TRP2**, EPR could have humbly admitted that perhaps QT was revealing something new about Nature's modus operandi and, ergo, a shift from thought experiments to *real* ones was mandatory to confirm/refute those predictions. Such refutation would prove that QT was *incorrect* (untrue), not merely *incomplete*. Technology was not ready for such a feat -- not even in 1964, when John Bell¹⁴ started his seminal work (future article).

The truth is that EPR did not start "with the assumption that the wave function does give a complete description of the physical reality". Otherwise, EPR would have accepted that the *predicted* physical reality did change in *SSII* when the 'measurement' in *SSI* took place. Had EPR fully accepted QT predictions, no "simultaneous reality" of P_{II} and Q_{II} could have been

claimed and no contradiction had occurred. The contradiction EPR claimed to have unveiled was already veiled in their premises. The Petitio Principii fallacy was at work from the very outset.

EPR admitted that had a stricter ‘criterion of reality’ been adopted, concluding “simultaneous reality” would have been a non sequitur. But, after proposing a new “definition” of reality, EPR immediately labeled it as “unreasonable”. There are simply *no* definitions of Reality: the only reasonable attitude is to accept that Reality may not conform to our prejudices and, if an otherwise very successful theory predicts something we do not believe in (*nonlocality*), no thought experiment will help because our prejudices may creep in. Only actual experiments could do the trick (as proven in the last 50 years). EPR finishes, stating:

EPR12: *While we have thus shown that the wave function does not provide a complete description of the physical reality, we left open the question of whether or not such a description exists. We believe, however, that such a theory is possible.*

I hope I have convincingly argued against EPR having shown that QT “does not provide a complete description of reality”.

5. Einstein’s Incompleteness/Nonlocality Dilemma

Despite EPR’s logical flaws, I am determined to be fair to Einstein, so let me reproduce what he said 13 years later¹⁵:

... when I consider the physical phenomena known to me, and especially those which are being so successfully encompassed by quantum mechanics, I still cannot find any fact anywhere which would make it appear likely that requirement [locality] will have to be abandoned. I am therefore inclined to believe that the description of quantum mechanics ... has to be regarded as an incomplete and indirect description of reality, to be replaced at some later date by a more complete and direct one.

Evidently, in 1948, Einstein was open to change his mind upon learning of “any fact anywhere which would make it appear likely that...” it made sense for him to accept *nonlocality*. A year later, in ‘Reply to Criticisms’⁷, he reformulated TFD¹, now endowing it with synthetic value:

By this way of looking at the matter, it becomes evident that the paradox [EPR] forces us to relinquish one of the following two assertions: (1) the description by means of the ψ -function is complete; (2) the real states of spatially separated objects are independent of each other.

His relinquishing option (2) shows that, in 1949, he surmised the solution to his dilemma: if QT was *complete* then the Principle of Locality (or at least its universal supremacy) had to go. Nonetheless, Jammer⁸ interviewed Einstein in 1953 confirming he never abandoned his view that QT was an *incomplete* description of physical reality. As it is well known, in 1964, John Bell¹⁴ proved that behind the apparent Lorentz-invariance of quantum phenomena, there was a deeper level that was not Lorentz-invariant, namely that *nonlocality* was a *real* feature of Nature. He also proved that no hidden-variable theory could avoid *nonlocality*. Copious experimental data followed suit (next articles); I am sure that Einstein (dismayingly) would have changed his mind had he seen the evidence we have today. Even so... 20 years into the 21st century, the struggle about Reality continues.

Conclusions

QT/TOPI clearly shows that *SSI* and *SSII* detangle upon the first GI occurring to one of them, leaving both (now independent) systems in correlated states -- irrespective of whether a GI ever happens to the other system. This will help to understand the infamous ‘measurement problem’

in a future article. A second ‘Reality Preconception’ (TRP2) was identified, showing that EPR used and ignored QT’s prediction of *nonlocality* in a single paralogism. Employing TFD¹ and TRP2, EPR unveiled a contradiction already veiled in its premises. The Petitio Principii fallacy had been at work from the very outset. By 1949, Einstein lucidly surmised the solution to his incompleteness/nonlocality dilemma but never changed his mind. The lesson is that there are no *definitions* of Reality: we have to accept that Reality may not conform to our prejudices and, if an otherwise successful theory predicts what we do not believe in, no gedankenexperiment will help because our biases may slither through. Only actual experiments could help solving Einstein’s dilemma, as proven in the last 50 years. Notwithstanding, EPR is one of the most influential papers in history and has greatly sparked both conceptual and technological progress. Future articles will further explain TOPI, demonstrating its soundness and potential for nurturing theoretical advance.

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