Relational Decision-Making Processes

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ABSTRACT

The nonlocal aspect of entanglement is often considered to show the solid distinguishability of quantum weirdness from classical theory. In this paper, this peculiar facet of entanglement is discussed in light of the observer-dependent subjective model, in which vacuum is filled with the quantum negative sea of the observer's reference frame. The correlation of observers' choices with respect to the observed, as opposed to the ordinary correlation of state vectors with respect to the choice of observables in the observer-independent objective scheme, will be considered. In particular, we will argue that, unlike in the objective model, it is the observers' conscious negative sea that interact and share with each other. The presented discussion is consistent with the previous proposal of continuous or infinite negative sea as an innate aspect of universal grammar shared among observers.

Key Words: Information, Decision-Making, Entanglement, Language

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Introduction

Since quantum mechanics first developed in the early twentieth century, its subjective and probabilistic nature has resulted in much debate (Peres, 1997). Causality, which had always been useful in science, no longer seemed to apply. In 1935, Einstein, Podolsky, and Rosen discussed the possibility of a nonlocal aspect in the correlation of quantum vectors in order to argue the incompleteness of the theory (Einstein *et al.*, 1935). Indeed, in the case of entanglement, when the measurement is made from one side, the result of the other, distant side appears to be influenced instantaneously. Bell suggested a clever method in which this *spooky action at a distance* could be experimentally verified (Bell, 1964). A large number of experiments over have yielded the outcomes predicted by quantum theory with remarkable precision (for example, see (Aspect *et al.*, 1982; Tittel *et al.*, 1998)).

Therefore, it appears that quantum mechanics with its nonlocal nature refutes the locality suggested in relativity. However, another twist has arisen: it is not possible to send information nonlocally using entanglement. Indeed, regardless of Alice's choices, the vector at Bob's end remains random (Ghirardi *et al.*, 1980). In the case of quantum cloning, although perfect cloning is not possible (Wootters *et al.*, 1982), partial (Bužek *et al.*, 1996) or probabilistic (Duan *et al.*, 1998) instances have been reported to exist. However, various studies have confirmed that even the imperfect copies cannot be used for signaling either partially (Gisin, 1998) or probabilistically (Hardy *et al.*, 1999). Therefore, one may summarize the situation with regard to entanglement as follows:

- Superluminal effects occur between distant entangled quantum pairs.
- However, information cannot be sent nonlocally using entanglement.

These assertions appear contradictory; if faster-than-light influencing is possible, why should superluminal signaling be impossible? This strange situation leads us to examine that there may be a misunderstanding in the way space and time are viewed at the basic level.

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In (Song, 2007; Song, 2012), a different way of viewing the universe is proposed. Unlike the previous objective scheme, which assumes an objective (i.e., observer-independent) existence and seeks to find objective rules that govern them, a subjective model is suggested. It is a goal of this paper to examine entanglement from the new perspective of this observer-dependent subjective model and see if any new insights may be gained. Indeed, it will be discussed that, while the objective model yielded a nonlocal aspect from a correlation of the objects being observed, a subjective approach provides a correlation of observers' reference frame or interaction between observers' consciousness in the Dirac-type negative sea (Figure 1).

	Objective Model	Subjective Model
Correlated	Object	Observer
Random	Observer	Object

Figure 1. Previously, entanglement was considered as a correlation of the objects being observed (or eigenvalue outcomes) with respect to the observer's choice of reference frame. In the subjective approach, it is the reference frame that is correlated with respect to the observed or the state vectors.

Table 1. Entanglement in the Objective Model: Correlation of qubits q_1 and q_2 with respect to Alice's and Bob's choices q_3 and q_4, respectively.

	q_3	q_4	$q_1(q_3)$	$q_2(q_4)$
(1)	+	+	−	−
(2)	+	−	−	+
(3)	−	+	+	−
(4)	−	−	?	?

Objective Perspective

For centuries, science has sought to find objective rules and facts. However, in opposition to this traditional approach, where objective existence is assumed, a radical change emerged with the development of quantum theory, which began to describe a relationship between an observer and the object being observed. In a sense, as science became more and more precise in terms of measurements and predictability, the objective model began to show its fundamental limits; quantum theory has begun to reveal the subjective limitations of scientific knowledge. Nevertheless, it should be noted that, while quantum theory indeed provides only a subjective relationship between the observed and the observer, this does not mean the existence must be subjective.

In (Song, 2012), it is argued that the subjective relation described in quantum theory corresponds to not only a limitation of scientific knowledge but of reality itself. The discussion of subjective reality was proposed in (Song, 2007) through the argument of the self-reference phenomenon in consciousness. In the case of consciousness, the very object being observed is the observer himself or herself. The symmetry present in quantum theory in fact breaks down, leading to the conclusion that the observer and the object being observed are not separable and that existence should be subjective.

In order to discuss entanglement in the subjective model, let us first review nonlocality in the objective scheme. The attachment of the term "physical reality" to quantum mechanics was discussed in (Einstein *et al*., 1935) as follows:

"If, without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity."

In particular, the attempt was made to find the physical reality of the objects being observed with respect to the choice of an observable. In (Song, 2008), an assumption in regard to the observer's conscious reference frame and objects being observed was made as follows:

Postulate: *Given a qubit, an observer's reference frame is identified with the corresponding observable.*

If we accept this postulate, the argument of entanglement and nonlocality may now be considered as studying the physical reality of the observed, or state vectors, with respect to the observer's choice of reference frame.

In order to view the nonlocal aspect of eigenvalue outcomes with respect to the basis choices, let us consider the following entangled state of two qubits (Hardy, 1992):

$$|\psi\rangle_{12} = \frac{\sqrt{3}}{2}|00\rangle_{12} - \frac{1}{2\sqrt{3}}\left(|01\rangle + |10\rangle + |11\rangle\right)_{12} \quad (1)$$

Now, consider a case where qubits q_1 and q_2 are sent to two distant parties, Alice and Bob, respectively. With equal probability, Alice (Bob) chooses to measure the qubit in either Z or X where the following is true:

$$Z \equiv \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}, \quad X \equiv \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \quad (2)$$

In particular, when Z is chosen, the identity operator is applied to q_1 (q_2 for Bob), and an additional qubit $|0\rangle_3$ ($|0\rangle_4$) is prepared at Alice's (Bob's) end. When X is chosen, the Hadamard gate

$$H \equiv \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \quad (3)$$

is applied to q_1 (q_2), and $|1\rangle_3$ ($|1\rangle_4$) is prepared by Alice (Bob). In such a case, the following density state may be obtained:

$$\rho = \left(\frac{3}{4}|0\rangle\langle 0| \otimes |0\rangle\langle 0| + \frac{1}{12}|0\rangle\langle 0| \otimes |1\rangle\langle 1| + \frac{1}{12}|1\rangle\langle 1| \otimes |0\rangle\langle 0| + \frac{1}{12}|1\rangle\langle 1| \otimes |1\rangle\langle 1|\right)_{12} \otimes \left(\frac{1}{4}|0\rangle\langle 0| \otimes |0\rangle\langle 0|\right)_{34}$$
$$+\left(\frac{1}{6}|0\rangle\langle 0| \otimes |0\rangle\langle 0| + \frac{2}{3}|0\rangle\langle 0| \otimes |1\rangle\langle 1| + \frac{1}{6}|1\rangle\langle 1| \otimes |0\rangle\langle 0|\right)_{12} \otimes \left(\frac{1}{4}|0\rangle\langle 0| \otimes |1\rangle\langle 1|\right)_{34}$$
$$+\left(\frac{1}{6}|0\rangle\langle 0| \otimes |0\rangle\langle 0| + \frac{2}{3}|1\rangle\langle 1| \otimes |0\rangle\langle 0| + \frac{1}{6}|0\rangle\langle 0| \otimes |1\rangle\langle 1|\right)_{12} \otimes \left(\frac{1}{4}|1\rangle\langle 1| \otimes |0\rangle\langle 0|\right)_{34}$$
$$+\left(\frac{1}{3}|0\rangle\langle 0| \otimes |1\rangle\langle 1| + \frac{1}{3}|1\rangle\langle 1| \otimes |0\rangle\langle 0| + \frac{1}{3}|1\rangle\langle 1| \otimes |1\rangle\langle 1|\right)_{12} \otimes \left(\frac{1}{4}|1\rangle\langle 1| \otimes |1\rangle\langle 1|\right)_{34}$$
$$+ \text{off-diagonal terms} \quad (4)$$

For simplicity, let us denote $\pm$ as representing the eigenvalue outcomes ± 1. When $q_3 = +$ and $q_4 = +$, there is a probability of 1/12 that the outcome of q_1 and q_2 will be $-$ and $-$. That is, when Alice and Bob choose to measure in Z, there is a 1/12 probability that the physical reality of q_1 and q_2 will both be -1. In such a run, we may consider a case in which $q_4 = -$ while q_3 remains +, meaning that the physical reality of q_2 would be $+$. On the other hand, when $q_3 = -$ and $q_4 = +$, then the physical reality of q_1 and q_2 are $+$ and $-$, respectively. However, this runs into a contradiction when q_3 and q_4 are both $-$ (i.e., when both Alice and Bob choose to measure in X-basis) since there is no $+$ outcome for both q_1 and q_2 (Hardy, 1992) (also see Table 1). Therefore, this argument shows that the qubits could not have agreed with its physical reality with respect to the basis choices before they separated.

Subjective Perspective

Motivated by the black hole information problem (Hawking, 1976), the concept of the subjective model, which suggested that the observer and the observed are not separable, was more specifically provided. That is, the inside of the horizon fills up the outside as the negative sea of the observer's conscious reference frame (Song, 2014a). Moreover, the argument was extended to the cosmological model, and it was discussed that the observer's choice of reference frame corresponds to a time-reversal process of irreversible computations since the big bang such that it fills up the vacuum as the Dirac-type negative sea (Song, 2016) (Figure 2).

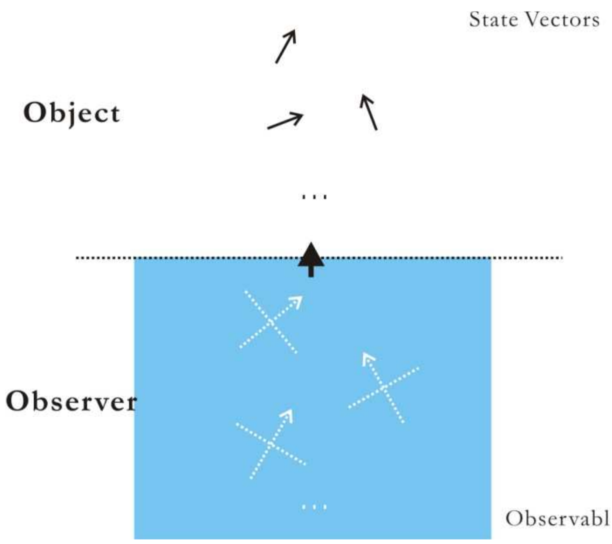

Figure 2. The measurement or observation may be considered in light of the object being observed (state vectors) and the observer's reference frame (observables). In particular, in the subjective model, the observer's reference frame is considered to be the Dirac-type negative sea (or the aether) that fills up the vacuum.

In particular, the proposed subjective cosmological model suggests the dynamical part to be the observer's reference frame rather than the observed, or the state vectors as in the Heisenberg dynamics (Song, 2008). It is noted that the correlation of observables in the Heisenberg picture was discussed in (Deutsch *et al.*, 2000)

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with an analysis of local information flow in various entangled cases. In this paper, while the correlation of observables is considered similar to (Deutsch *et al.*, 2000), an extra condition of identifying the observable as the observer's reference frame (as discussed in the previous section) is added, such that the correlation of observers' choices is analyzed.

In order to examine the properties of entanglement in a new model, it is appropriate to study the physical reality of the observer's choice of reference frame with respect to the observed (i.e., as opposed to the previous consideration of observed [state vectors] with respect to observers [observables]). In (Song, 2009), the correlation of the observer's choices was considered with the following entangled state:

$$|\phi\rangle_{12} = \frac{1}{\sqrt{2}}\left(|00\rangle - |11\rangle\right)_{12} \quad (5)$$

Similarly, to the previous example in (1), it is assumed that Alice and Bob choose to measure the qubits q_1 and q_2 in *Z*- or *X*-basis with equal probability. Again, when *Z*(*X*) is chosen, the state $|0\rangle$ ($|1\rangle$) is prepared at each end. The density state may then be written as follows:

$$\begin{aligned}\rho = &\left(\frac{1}{4}|0\rangle\langle 0|\otimes|0\rangle\langle 0|\right)_{12} \otimes \left(\frac{1}{2}|0\rangle\langle 0|\otimes|0\rangle\langle 0| + \frac{1}{4}|0\rangle\langle 0|\otimes|1\rangle\langle 1| + \frac{1}{4}|1\rangle\langle 1|\otimes|0\rangle\langle 0|\right)_{34} \\ &+\left(\frac{1}{4}|0\rangle\langle 0|\otimes|1\rangle\langle 1|\right)_{12} \otimes \left(\frac{1}{2}|1\rangle\langle 1|\otimes|1\rangle\langle 1| + \frac{1}{4}|0\rangle\langle 0|\otimes|1\rangle\langle 1| + \frac{1}{4}|1\rangle\langle 1|\otimes|0\rangle\langle 0|\right)_{34} \\ &+\left(\frac{1}{4}|1\rangle\langle 1|\otimes|0\rangle\langle 0|\right)_{12} \otimes \left(\frac{1}{2}|1\rangle\langle 1|\otimes|1\rangle\langle 1| + \frac{1}{4}|0\rangle\langle 0|\otimes|1\rangle\langle 1| + \frac{1}{4}|1\rangle\langle 1|\otimes|0\rangle\langle 0|\right)_{34} \\ &+\left(\frac{1}{4}|1\rangle\langle 1|\otimes|1\rangle\langle 1|\right)_{12} \otimes \left(\frac{1}{2}|0\rangle\langle 0|\otimes|0\rangle\langle 0| + \frac{1}{4}|0\rangle\langle 0|\otimes|1\rangle\langle 1| + \frac{1}{4}|1\rangle\langle 1|\otimes|0\rangle\langle 0|\right)_{34} \\ &+ \text{off-diagonal terms} \quad (6)\end{aligned}$$

An argument similar to the nonlocality may be considered; however, the reality of q_3 and q_4 with respect to q_1 and q_2 (rather than q_1 and q_2 with respect to q_3 and q_4, respectively) should be addressed. First, when q_1 and q_2 are both $+$, then there is a 1/2 probability that q_3 and q_4 are both $+$. In such a case, when q_2 is $-$ while q_1 remains +, the reality of q_4 with respect to q_2 is $-$ at Bob's end. On the other hand, when q_1 is $-$, $q_3(q_1) = -$ as well. However, when both q_1 and q_2 are $-$, both q_3 and q_4 should be $-$, but such a term does not exist in (6) (also see Table 2). In the subjective approach, the correlation exists between the observer's choices of reference frame while the object being observed (state vectors) turns out to be uncorrelated and random.

Table 2. Entanglement in the Subjective Model: Correlation of Alice's and Bob's choices q_3 and q_4 with respect to the state vectors q_1 and q_2.

	q_1	q_2	$q_3(q_1)$	$q_4(q_2)$
(1)	+	+	+	+
(2)	+	–	+	–
(3)	–	+	–	+
(4)	–	–	?	?

Remarks

In this paper, we have outlined that in the subjective model, entanglement implies correlation between the observer's choices of reference frame rather than the state vectors (or the observed). In particular, in the proposed model where vacuum is considered to be filled with the Dirac-type negative sea of consciousness (Song, 2016) (or the aether (Song, 2017a)), entanglement implies the interaction between Alice's and Bob's reference frames in the conscious negative sea (Figure 3). This is rather different from the previous understanding that individuals share and interact in the same physical world while possessing their own consciousness. Indeed, the presented discussion indicates how the subjective existence of each observer interacts with that of other observers in the negative sea of consciousness.

In (Song, 2016), the potentially important role of free will in building the definitive model of the universe using nondeterministic computation was explored. Nondeterministic computation chooses the acceptable path of the computational process (i.e., the observer's choice), which is different from probabilistic computation (Song, 2014b). In computational complexity, it is known as the language accepted by the algorithm.

Figure 3. In the subjective model, entanglement implies that the correlation between Alice and Bob occurs in the negative sea in terms of correlated choices of reference frames.

In particular, it was discussed that, based on the axiomatic analysis of quantum theory, the continuity or infinite aspect of quantum theory should be associated with universal grammar (Chomsky, 1965; 1980), an innate structure common to individuals, in linguistics. In particular, universal grammar was asserted to share a similarity with the secret keys shared by two parties in cryptography, which helps people to communicate securely with encrypted messages (Song, 2017b). Indeed, the continuous or infinite aspect of quantum theory was considered as a semantic aspect of language such that one is able to convey an encrypted meaning of infinity with only a finite list of **0**'s and **1**'s. This implies that Alice and Bob must share a common continuous or infinite quantum negative sea. The argument regarding entanglement in the negative sea presented above strengthens the argument for identifying the infinite negative sea of consciousness with universal grammar.

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