Remarks on Nondeterministic Computation, Choices, and Formal Language

Daegene Song

ABSTRACT

Based on the equivalence of the two different types of measurement protocols and the asymmetry between the Schrödinger and Heisenberg pictures, it has been previously proposed that negative sea fills the universe as a nondeterministic computation - a time-reversal process of the irreversible computations presented since the big bang. The goal of this paper is to extend the proposed subjective universe model, i.e., the universe as a quantum measurement: Motivated by the relationship between quantum theory and classical probability theory with continuity, it is argued that the frame of reference of the observer may be identified with classical probability theory where its choice, along with big bang singularity, should correspond to the quantum observable. That is, the physical version of singularity resolution corresponds to the case, where big bang singularity is equivalent to the continuity of the negative sea, or aether, filling the universe as a frame of reference of the observer. Moreover, based on the holographic principle, we identify the choice of the observer with the degrees of freedom proportional to the Planck area on the horizon. We also discuss that the continuity or infinity present in every formal language of choice acceptable in nondeterministic computation may be associated with the universal grammar proposed by Chomsky in linguistics.

Key Words: nondeterministic computation, free will, language

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1. Introduction

A central issue in physics has been the apparent discrepancy between the classical and quantum worlds. Indeed, subatomic particles, such as photons or electrons, exhibit peculiar behavior, such as a single photon moving through two different paths at the same time, which is unseen in the classical world. Therefore, why do such odd phenomena generally occur on small scales, i.e., at the microscopic level rather than the macroscopic level such as in buildings, stars, etc.? There have been a number of suggestions associated with this dilemma between the quantum and classical worlds including the example of decoherence (Zurek, 1981; 1982). However, no conclusive consensus has been reached among researchers to date.

In (Hardy, 2001), it was shown that one can derive quantum theory from a set of simple axioms. In particular, the removal of one axiom - continuity - is equivalent to the classical probability theory. In this paper, we will argue

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that, when we take classical probability as the choice of the observer, with continuity imposed on the classical choice, it should correspond to the quantum observable. In particular, we will discuss how classical probability theory, as the observer's choice, can be identified with the degrees of freedom lying on the horizon, and that the continuity area corresponds to the negative sea or, as suggested in (Song, 2016), the aether, which fills the universe. This is rather surprising because, for many years, people have often considered the classical as an approximation of quantum theory. However, quantum theory does not exclude the classical world. In fact, classical spacetime is an integral part of standard quantum theory because it contains not only unitary transformation but also measurement, where the latter is completed in classical spacetime.

In sect. 2, we review the previously proposed equivalence between the two-system and single-system protocols with negative sea. In sect. 3, we will argue that the choice of the observer in measuring the observable universe may be described by the classical probability theory with continuity, which is equivalent to the quantum observable. We will then conclude with brief remarks.

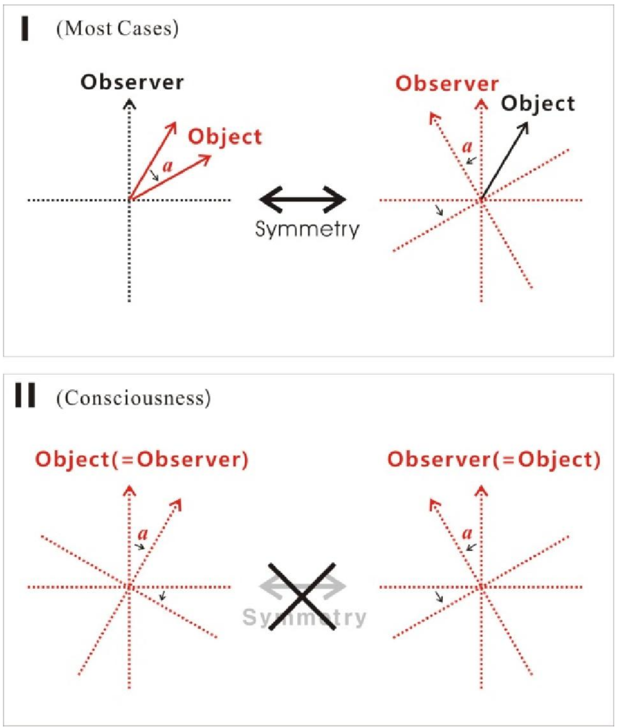

Figure 1. [i] Most physical phenomena obey the symmetry between the Schrödinger and the Heisenberg pictures. [ii] In the case of consciousness, this symmetry breaks down.

2. Asymmetry and Measurement

In (Song, 2007; 2012), the subjective nature of existence was motivated by the contradiction that appeared in the self-observation of consciousness. The precision of advancements in physics, which previously attempted to create an objective rule for physical systems, finally led to the description between the observing party and the object shown in quantum theory at the beginning of the 20th century. This advancement, which exhibited subjectivity, was not easily accepted by many researchers at the time (Einstein *et al.*, 1935).

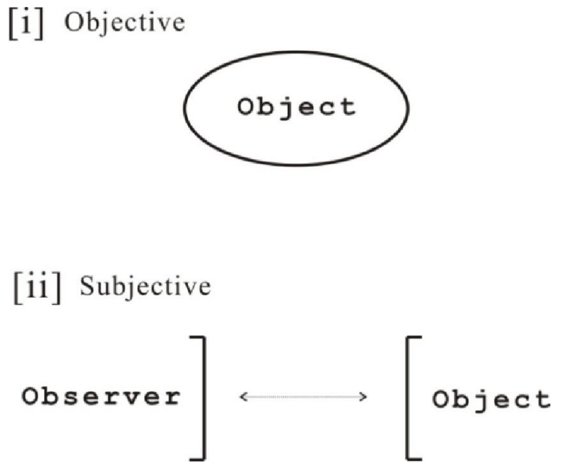

Figure 2. Paradigm shift: Previously, finding the objective pattern of a given object was pursued [i]. However, with quantum theory, the relation between the observer and the object is studied instead [ii].

In particular, it was argued (Song, 2008) that one may consider the observable as the frame of reference of the observer, when observing the given quantum system. This postulate leads to an asymmetry between the Schrödinger and Heisenberg pictures, i.e., active and passive transformations, respectively, when the very object being observed is the frame of reference itself - a phenomenon that only occurs in consciousness (Figure 1). It was then argued that, to successfully keep this inconsistency from occurring in the case of consciousness, the basic assumption of treating the observer and the object separately, when considering the measurement to be the relative difference between the two, should stop. Instead, the two entities are not separable, and their existence should be subjective.

Conversely, another highly debated subject is in regard to free will. This is due to the deterministic worldview, which was held until the development of quantum theory and often regarded as having no place for the nondeterministic aspect of free will. However, with randomness as an essential ingredient of the theory, many suspected quantum theory may open the possibility of the existence of free will (Conway *et al.*, 2008; Mandayam Nayakar *et al.*, 2011; Brassard *et al.*, 2012; Lloyd 2012). Nevertheless, free will has not only randomness, but two seemingly contradictory aspects instead, i.e.,

1. from a subjective perspective, the observer is able to freely choose;
2. to the outside, the choice ought to be unpredictable and random.

That is, with all the initial conditions known about the observer, the choice should be random to the outside; however, from the subjective aspect, the observer is free to choose. The next section will review the theory that the subtlety involving free will may be physically realized using a nondeterministic computation.

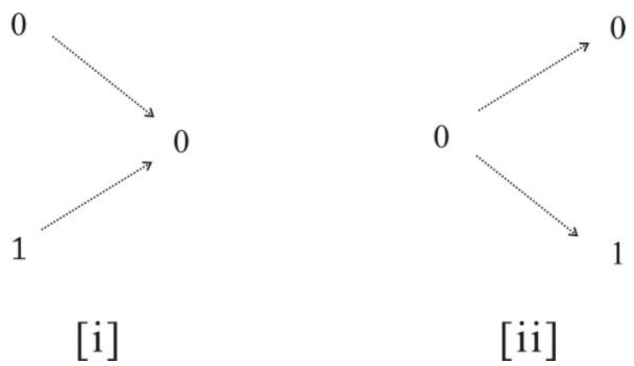

Figure 3. [i] Irreversible computation: Given the output, it is impossible to determine the trail back to the input. Landauer has shown (Landauer, 1961) that this process necessarily dissipates energy. [ii] Nondeterministic computation (or free will): The time-reversal process of the irreversible computation in [i].

Motivated by the black hole information problem (Hawking, 1976) and two different measurement protocols in quantum theory, it was argued (Song, 2014a) that the process of black hole radiation should be considered as a quantum measurement. In particular, it was shown that the observer's free will outside the black hole results from the choices made inside the horizon, with the memory state, as follows:

$$O_{\theta}^{out} = Q_{\theta}^{in} \quad (1)$$

That is, the observer's choice is hidden behind the horizon yet fills the vacuum outside the horizon with negative information, which may be considered the consciousness of the observer. It is interesting to note that free will, when used with black hole entropy, indeed has the dual aspects discussed above.

Notably, this picture is also consistent with the subjective approach in quantum theory, particularly the Copenhagen interpretation. While the traditional approach in physics has been to find an objective pattern of a given physical system, the subjective approach attempts to provide a relationship between the observing party and the object, i.e, with the observable and the state vector, respectively (Figure 2). The above equivalence of quantum measurement protocols and black hole evaporation indeed provides an explanation of how the special status of the observable in the subjective approach arises, i.e., by considering the objective observing party, or the apparatus, as traveling backward in time or negative sea filling the vacuum.

3.Classical and Quantum

The equivalence of two different measurement protocols in (1) has been extended to the cosmological model (Song, 2015). In (Lloyd, 2000), the universe was modeled as a computation process, and the maximum number of possible irreversible computations since the big bang has been estimated based on the Margolus-Levitin theorem (Margolus *et al.*, 1998), which suggests the minimum time required to perform elementary gates equals $\pi\hbar/2E$. Based on this computational model of the observable universe, it was elaborated (Song, 2015) how the observer's choice, or free will, may play an essential role in building the specific model of the universe by using a nondeterministic computation (Figure 3). That is, by viewing the universe as a computational process, it was argued that the entropy of the observable universe corresponds to the number of computations of nondeterministic computation, which is a reverse process of irreversible computation, such that it fills the vacuum as a Dirac-type negative sea, as shown in Figure 4.

The observer's choice is a nondeterministic computation that travels backward in time all the way to big bang singularity.

The nondeterministic computation chooses the acceptable path of computational processing, which is different from probabilistic computation. This should correspond to the observer's subjective experience of making choices freely, i.e., rather than randomly, as in a probabilistic computation, which fits the first criteria among the dual aspects of free will discussed earlier (also see, Song, 2014b).

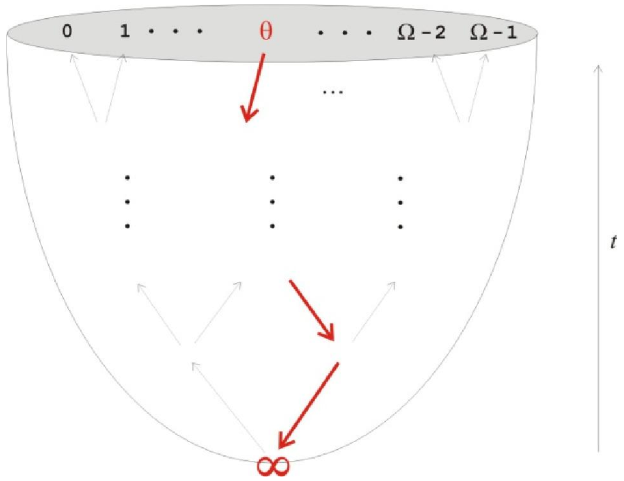

Figure 4. The universe as quantum measurement: By considering the universe as a computational process, the subjective model suggests that the negative sea, which corresponds to the time-reversal process of irreversible computation, fills the universe, where Ω is the number of equally accessible microstates of the observable universe and θ, $0 \le \theta \le \Omega - 1$, is the measurement choice made by the observer.

As a result, the entropy of the observable universe corresponds to a logarithm of possible choices that the observer is able to choose. Indeed, it was argued, that for any Ω equally accessible microstates of the universe:

The observer's choice corresponds to the reality of the universe.

Therefore, the subjective universe model, i.e., the universe as a quantum measurement, which is proposed in (Song, 2015), suggests that the observer's freely chosen will is the actual existence with the dual aspect of free will as well.

In (Hardy, 2001), it was shown that quantum theory can be derived from a set of axioms. In particular, it was argued that, with the same set of axioms - except continuity - they yield classical probability theory. Therefore, if we use the notation $+\infty$ to represent the continuity axiom (for example, see the discussion in (Galvão *et al.*, 2001) for the connection between continuity of a qubit and the infinite number of classical bits), we may write:

$$\text{Class. Prob.} + \infty \Leftrightarrow \text{Quantum} \qquad (2)$$

When one performs a measurement of a quantum state, an observable is used, where both the state and the observable are associated with complex vector space. However, the observer does not have direct access to this vector space but rather only to a classical frame of reference, which is defined by classical spacetime. Therefore, when we refer to the classical frame of reference, we wish to identify it as the frame of reference in spacetime that has a corresponding quantum observable.

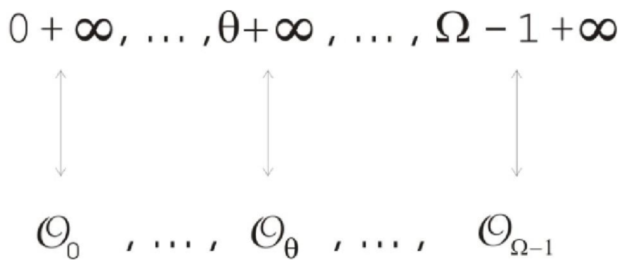

Figure 5. The choice of the observer in classical spacetime among the equally probable Ω can be made equivalent to the choice of the quantum observable. In particular, the continuity, or $+\infty$ present in every choice of the formal language $0 \le \theta \le \Omega - 1$, should correspond to the universal grammar proposed by Chomsky.

Returning to the universe model in Figure 4, let us define the observer's equally probable choice θ to be the choice of the classical frame of reference, where $0 \le \theta \le \Omega - 1$, and Ω is the number of equally accessible microstates of the universe. With this identification and following (2), the classical choice of θ with continuity may be considered as equivalent to the degenerate quantum observable O_θ. Therefore, as shown in Figure 5, we will use the notation $\theta + \infty$ as the equivalent of the observable O_θ, i.e.,

$$\theta + \infty \Leftrightarrow O_\theta \qquad (3)$$

In particular, the classical choice of θ with equal probability $1/\Omega$ corresponds to the horizon degeneracy conjectured from the holographic principle (Susskind, 1995). The Bekenstein-Hawking entropy (Bekenstein 1973; Hawking, 1975) corresponds to:

$$S_{BH} = \frac{kA}{4l_P^2} \qquad (4)$$

where k is the Boltzmann constant, A the area of the horizon, and l_P is the Planck length. Conversely, Boltzmann's entropy law yields a logarithm of the number of possible configurations,

$$S_B = k \ln \Omega \tag{5}$$

The holographic principle states that the degrees of freedom inside are encoded on the horizon surface. That is, the number of possible internal degeneracies corresponds to

$$\Omega = e^{\frac{A}{4l_P^2}} \tag{6}$$

or ~1 bit per Planck area is encoded on the horizon. By following the argument of the holographic principle and our suggestion of classical probability with continuity, we suggest that:

The choice θ of the observer with continuity, or $+\infty$, has the classical degrees of freedom residing on the horizon.

It should be noted that the above claims that the degrees of freedom on the horizon, as in the holographic principle, correspond to the classical domain. Ever since the discovery of black hole radiation (Hawking, 1975), the statistical nature of entropy has been debated by scholars; however, the above suggestion of horizon entropy, which corresponds to the classical configuration, is consistent with the statistical calculation of the entropy, as shown in (Gibbons *et al.*, 1977).

A primary area of research, in an attempt to understand the mental process, has been the study of human language. In particular, linguist Chomsky has claimed (Chomsky, 1965; 1980) that there is a universal structure in all languages, which is neither learned nor acquired by experience. This concept came to be known as universal grammar, and its innateness remains controversial and debated (Nowak *et al.*, 2002; Cook *et al.*, 2007). If we consider the choice of the observer, which may be represented in binary bits, a formal language (3) implies that every language, i.e., $0 \le \theta \le \Omega - 1$, contains the continuous part, or $+\infty$. This property is in every language θ, and it is consistent with the proposal of universal grammar. That is, while formal language is written as a finite combination of classical bits, it always contains the continuous or infinite (Figure 5) conscious aspect dominated by the quantum theory of negative sea.

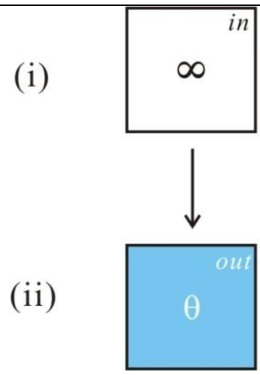

Figure 6. The physical version of singularity resolution: Big bang singularity, with the choice of the observer, can be considered as equivalent to the observer's classical choice θ with continuity, or O_θ, and as negative sea filling the observable universe.

4. Remarks

In this paper, we have provided a more specific model of the subjective universe model proposed in (Song, 2008; 2012), i.e., the observer and the object are not separable. It was discussed that the choice of the observer in classical spacetime with continuity fills up the universe as negative sea. Moreover, the classical choice of the observer has degrees of freedom on the horizon, which are proportional to the Planck area and the continuous negative sea, or the aether, serve as a conscious frame of reference of the observer; this may be considered as a resolution of big bang singularity, as shown in Figure 6. It was also discussed that the continuity part, or $+\infty$, which is present in every formal language, as shown in Figure 5, should correspond to the universal grammar proposed in linguistics.

Moreover, the above argument suggests that discrete spacetime at the Planck level follows classical probability rules, i.e., as the frame of reference of the observer, yet each classical degree of freedom is associated with continuity, which leads to quantum theory. This picture is in fact consistent with quantum theory, which has two components: the unitary transformation, which occurs in complex Hilbert space, and the measurement sector, which occurs in classical spacetime.

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