Intersubjective Gravity and Entanglement

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Abstract

Although quantum theory and relativity are two of the monumental achievements in modern physics, their exact relationship remains somewhat uncertain. Indeed, while the nature of quantum theory is subjective at the fundamental level, relativity involves a rule that is invariant under observers' different reference frames. This paper argues that quantum theory and relativity are connected in such a way that Alice's and Bob's choices of coordinate bases, which correspond to the apparatus outcome in quantum measurement, are related to Einstein's field equation. That is, the phenomenon of gravity corresponds to a commonality among observers, thereby involving an intersubjective aspect, rather than being objective. This shared feature of intersubjectivity is also discussed in terms of entanglement and locality.

Key Words: Gravity, Quantum, Entanglement, Subjectivity.
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Introduction

For around a century, in the realm of physics, general knowledge about our nature has been dominated by quantum theory and relativity (Peres, 1997). These two theories have been confirmed with unprecedented accuracy and precision and survived countless experiments. On the other hand, there have been many inconclusive attempts to understand how these two monumental achievements are, in fact, connected.

One of the reasons why it is difficult to connect quantum theory and gravity is because the basic premise of each theory differs at the fundamental level. For instance, quantum theory, particularly the Copenhagen interpretation, provides a separation between the object and the observing party and describes an interplay between the two. Indeed, quantum theory seems to be subjective (i.e., observer dependent) at the fundamental level. On the other hand, relativity appears to strongly emphasize objectivity (i.e., physical reality being observer-independent). This paper outlines the relationship between quantum theory and relativity, which seem to exhibit opposing characteristics. In particular, the phenomenon of gravity as a common feature among observers is discussed. In section 2, the link between quantum theory and relativity is outlined, followed by the philosophical background of reality and subjectivity in section 3. In section 4, quantum entanglement from the Heisenberg perspective is discussed, which is similar to gravity as it has shared aspects among observers. Our concluding remarks can be found in section 5.

Quantum Theory and Relativity

Let us consider a set of finite discrete dots, as seen in Figure 1 (A). When the number of points is small, it may not be very apparent. However, as the number of dots grows, one is able to identify or understand them as a circle (B). That is, the background space where the points are embedded serves to provide a continuous and perfect meaning such that the points are understood in context.

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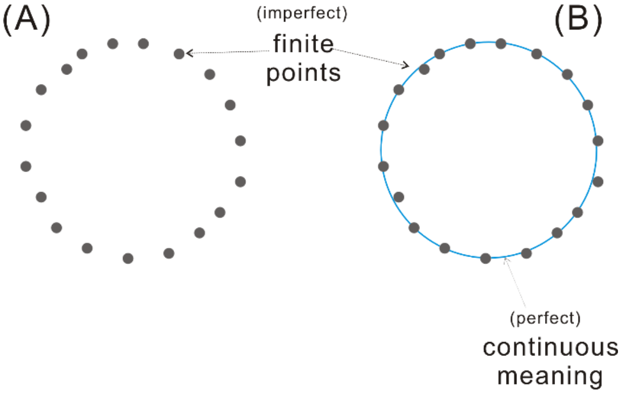

Figure 1. When an observer observes a set of finite dots as in (A), the object is perceived and understood to be a circle as in (B).

In quantum theory, a measurement apparatus is an interesting and rather strange concept. Ironically, it is both classical (i.e., directly observable in the physical world) and quantum mechanical (in that it may be entangled with a quantum system to be measured). In fact, an apparatus in quantum theory is similar to the classical framework discussed with Figure 1. That is, the framework in Figure 1 (B) serves both as a physical paper but also as an idealized continuous meaning that may only be imagined in one's thoughts. Similarly, a vacuum serves as both a classical framework for observing a physical object and a continuous and idealized setting in the mind. This is similar to what the measurement apparatus achieves (Figure 2).

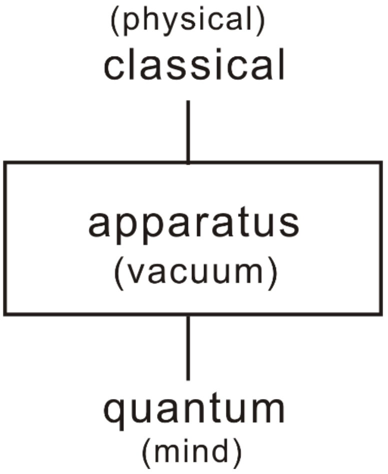

Figure 2. An apparatus in quantum theory plays an unusual role in that it has both classical and quantum aspects. It may be said that a vacuum corresponds to an apparatus, whereby classical space is filled with a continuous quantum negative sea of consciousness.

In order to grasp the idea of a shared pattern among observers, let us review a few simple examples. As seen in Figure 3, while the locations of two points (x_1 and x_2) may change for two different observers, Alice and Bob, the distance between the two remains the same. One way of interpreting this is that each point may appear differently to Alice and Bob, yet the meaning of x_1 in the context of x_2 (or vice versa) appears to be the same. In fact, what we often call a physical law corresponds to a pattern that is guessed or recognized by the observers, such as Alice and Bob.

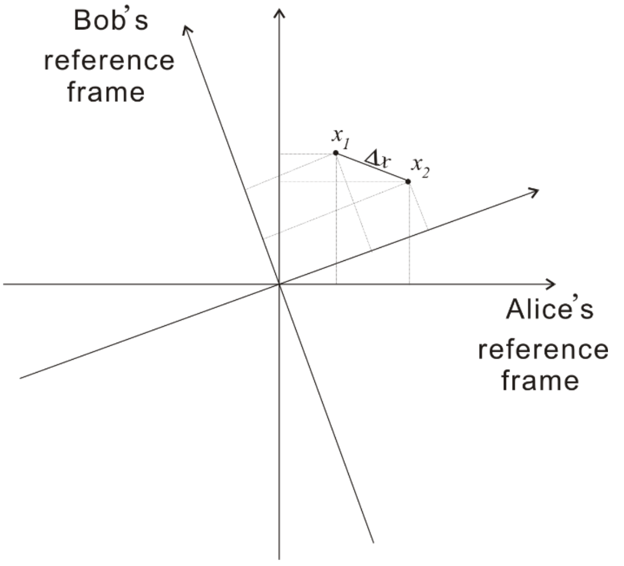

Figure 3. While x_1 and x_2 may appear different to Alice and Bob, the distance remains the same for observers in different reference frames.

Another example may be considered, as shown in Figure 4. An observer may observe two points in different contexts depending on the structure of the background: namely, in a straight framework (A), or in a curved context, as seen in (B). That is, a vacuum apparatus may provide a different way to perceive the two points, depending on the structure of the apparatus.

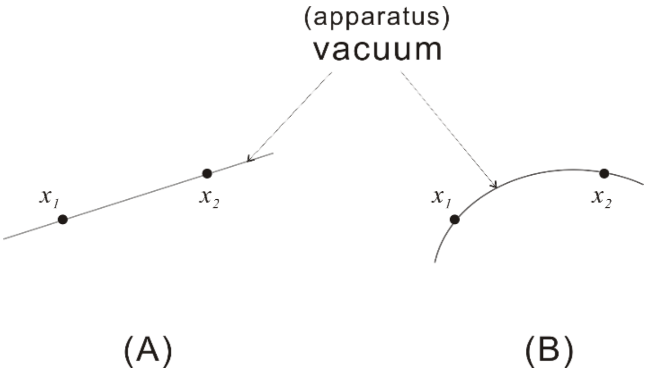

Figure 4. The relation between two points is understood in the context of being either in a straight background (A) or a curved framework (B).

Let us now consider the following entanglement between a system and an apparatus in quantum measurement, where the system corresponds to the observable universe, with N degrees of freedom bounded by the holographic principle (Susskind, 1995):

$$|\psi\rangle = \frac{1}{\sqrt{N}}\sum_{i=0}^{N-1} |i\rangle_{sys}|i\rangle_{app} \qquad (1)$$

As discussed earlier (Figure 2), an apparatus in quantum theory plays a dualistic role connecting quantum and classical realms. With equally probable outcomes, the result of the correlation, as in (1), yields one of the following states of apparatus, which are directly observable in classical space.

$$0_{app}, 1_{app}, 2_{app}, \ldots \qquad (2)$$

Furthermore, it is assumed thak_{app} $(0 \leq k \leq N-1)$ actually corresponds to the observer's kth reference frame or kth coordinate of classical spacetime. Now, Alice's coordinate (such as (x, y, z, t)) may be noted as $(0 \leq m_{app} \leq N-1)$ while $(0 \leq n_{app} \leq N-1)$ is denoted as Bob's choice of reference frame (such as (x', y', z', t')). Then, the relation between quantum theory and gravity may be outlined as follows: Alice's and Bob's choice of classical coordinate (or reference frames) n_{app} and m_{app} are related such that Einstein's field equation is satisfied.

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu} \qquad (3)$$

where G is a gravitational constant, c is the speed of light. That is, relativity provides a common pattern shared by Alice and Bob.

Subjectivity and Physical Reality

As many philosophers have noted for centuries, there are a number of subjective limitations when observers observe or attempt to understand nature. For instance, it may not be possible for an observer to know the true reality of an object but only a representation of the object.

In contrast, science has enjoyed tremendous predictive success for centuries due to precisely the opposite reason to the subjective limitation of knowledge. For instance, the scientific properties of a particular object should remain the same when measured in different locations or times. Indeed, if the outcome varies depending on who is observing, the credibility of the theory can be challenged. That is, scientific knowledge appears to be an objective truth.

However, this assumed objectivity in science was challenged at the beginning of the 20th century with the advancement of quantum theory. Naturally, much confusion arose regarding the exact nature of quantum theory, and there have been different ways of looking at the phenomenon. It transpired that the widely accepted approach was also the most economical and efficient one: namely, the Copenhagen interpretation, which describes an interaction between the observing party and the object, embraces subjectivity fully.

In a series of papers (Song, 2007; Song, 2016), it has been suggested that the subjectivity appearing in quantum theory may not be just some minor defect or mole that is present in the objectivity dominating scientific laws. Rather, physical reality may, in fact, be subjective (i.e., associated with or dependent on the observer's consciousness—an area of study that is also often considered to be unexplored territory (Koch, 2004).

In fact, there have been different attempts to connect consciousness with quantum theory, particularly the latter's measurement problem. For instance, Penrose argued (Penrose, 1989) that there might be a non-computable element in consciousness based on Gödel's incompleteness theorem. In (Song, 2007), it is evident that, as Penrose predicted, there exists an element of non-computability in conscious activities because certain self-observations in consciousness inevitably lead to a failure of the two-picture formalism in quantum theory (i.e., Schrödinger and Heisenberg pictures).

In particular, in (Song, 2020), detouring the collapse of the wavefunction, the continuity in the evolution of quantum states was associated with consciousness, and a Dirac-type negative sea corresponds to the observer's consciousness filling up a vacuum. That is, the inseparable relation between the observer's mind and nature, particularly using the Heisenberg picture in quantum theory, was outlined such that the physical reality of universe is subjective.

Entanglement

If the universe is indeed dependent on and inseparable from the observer's mind, a question arises as to how science has enjoyed such immense success while appearing to exhibit seemingly observer-independent, objective truth. One possible resolution to this contradiction between subjectivity versus objectivity comes from a well-known quantum phenomenon called entanglement. In a landmark paper (Einstein *et al.,* 1935), Einstein, Podolsky, and Rosen (EPR) came up with an idea that may provide a possible insufficiency in the subjective quantum theory.

In (Bell, 1964), Bell proposed a remarkable idea to verify the claim in EPR's paper. Subsequently, various researchers have experimentally shown (Aspect *et al*., 1982; Tittel *et al*., 1998) that non-locality is indeed the central part of quantum theory that distinguishes itself from the classical counterpart. This appeared to contradict relativity, where superluminality is strictly prohibited. However, there is a flip side to entanglement that does not allow superluminal signaling among observers (Ghirardi *et al*., 1980).

The no information transfer in entanglement is more vividly apparent in the quantum cloning phenomenon. Although perfect cloning is not allowed in quantum theory (Wootters *et al.*, 1982), partial (Bužek *et al.*, 1996) or probabilistic (Duan *et al.*, 1998) copying has been shown to exist. Interestingly, the no signaling rule provides an upper limit to the optimality of partial (Gisin, 1998) and probabilistic (Hardy *et al.*, 1999) cloning. Therefore, superluminality seems to be possible among objects but is not allowed among observers. This is another feature of quantum theory that treats observers, who are thought to be made of particles, different from the observed objects.

In order to discuss this rather awkward situation, one may consider the following postulates involving the two main variables in quantum theory:

- state vector ≡ representation of objects
- observable ≡ observer's reference frame

These variables, in fact, present quantum theory as an interaction between an observer and the object, as advocated in the Copenhagen interpretation. Indeed, this interpretation treats observables as reference frames for the observer's yield entanglement, not to be the correlation of objects but rather the correlation of the observer's choice of reference frames (Song, 2017). Let us consider how this works. If we assume the qubits correspond to the objects to be observed, the correlation yields the following state:

Objects at Alice and Bob:

$$\frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)_{AB} \tag{4}$$

This well-known state exhibits a correlation between objects A and B, an approach known as the Schrödinger picture. The observable, which may be identified as the choice of the measurement made by Alice or Bob, can be represented through Pauli matrices.

$$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \sigma_y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \tag{5}$$

and correspond to the following:

Alice's reference frame=

$$(\sigma_x \otimes I, \sigma_y \otimes I, \sigma_z \otimes I)_{AB} \tag{6}$$

Bob's reference frame =

$$(I \otimes \sigma_x, I \otimes \sigma_y, I \otimes \sigma_z)_{AB} \tag{7}$$

It can be seen that Alice's and Bob's choices of reference frames at each end are not correlated. On the other hand, in the Heisenberg picture, the situation discussed above becomes exactly the opposite. That is, the states, or the objects to be observed, remain uncorrelated, as follows:

Objects at Alice and Bob:

$$|0\rangle_A |1\rangle_B \tag{8}$$

However the correlation as in (4), and applied to observables, yields the following (Deutsch *et al.*, 2000; Hewitt-Horsman *et al.*, 2007):

Alice's reference frame =

$$(\sigma_z \otimes \sigma_x, -\sigma_y \otimes \sigma_x, \sigma_x \otimes I)_{AB} \tag{9}$$

Bob's reference frame =

$$(I \otimes \sigma_x, \sigma_x \otimes \sigma_y, \sigma_x \otimes \sigma_z)_{AB} \tag{10}$$

It can be readily seen that unlike (6,7), Alice's and Bob's choices of measurement bases at each end are correlated. Therefore, in the Heisenberg picture, the correlation appears with the subjects rather than with the objects.

To see an example of this correlation, let us consider a case when Alice and Bob apply the following rotation at each end of the maximally entangled state:

$$R \equiv \begin{pmatrix} \cos\frac{\theta}{2} & -\sin\frac{\theta}{2} \\ \sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{pmatrix} \tag{11}$$

In the Heisenberg picture, the rotated Alice's observable when the z-axis is chosen, corresponds to the following:

$$\begin{pmatrix} 0 & -\sin\theta & \cos\theta & 0 \\ -\sin\theta & 0 & 0 & \cos\theta \\ \cos\theta & 0 & 0 & \sin\theta \\ 0 & \cos\theta & \sin\theta & 0 \end{pmatrix} \tag{12}$$

and the rotated Bob's observable when the z-axis is chosen, is the following:

$$\begin{pmatrix} 0 & -\sin\theta & \cos\theta & 0 \\ -\sin\theta & 0 & 0 & -\cos\theta \\ \cos\theta & 0 & 0 & -\sin\theta \\ 0 & -\cos\theta & -\sin\theta & 0 \end{pmatrix} \tag{13}$$

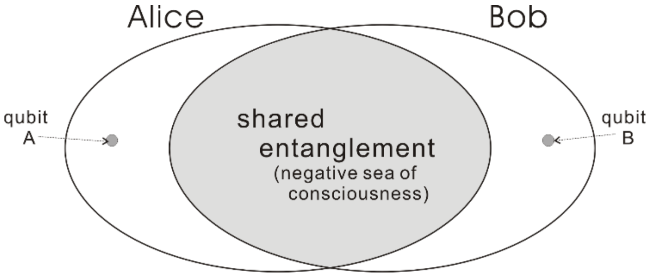

Figure 5. Entanglement in the Heisenberg picture may be understood as correlated choices of Alice's and Bob's reference frames, while objects *A* and *B* remain uncorrelated.

The results in the Heisenberg picture seen in (9,10) provided a correlation of the observer's reference frame or shared consciousness among observers (Figure 5). The reason for the appearance of consciousness is because the unitary evolution of the observer's reference frame occurs in the complex Hilbert space, rather than in the 3-dimensional classical space.

This shared aspect between observers may, in fact, be associated with the commonality experienced in science: namely, gravity. That is, similar to the shared consciousness among subjects, such as Alice and Bob, gravity may be considered a shared phenomenon among observers (i.e., intersubjective). In fact, intersubjectivity differs from objectivity in the sense that physical reality is subjective, yet a common feature exists that is shared among different subjects. As pointed out earlier, this shared feature corresponds to gravity, as outlined by Einstein’s field equation.

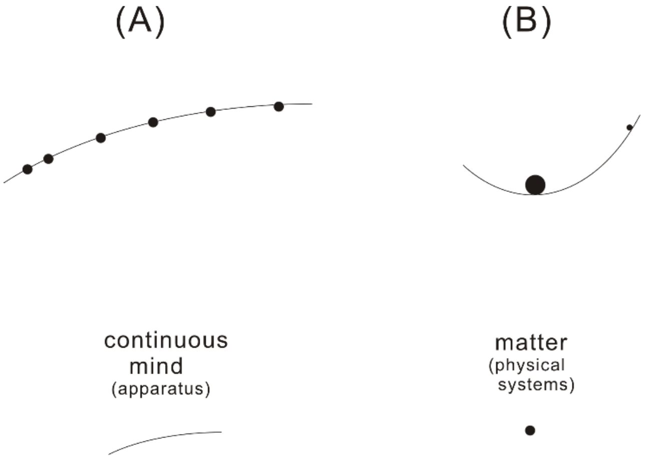

Figure 6. The relation between mind and matter may be understood as a physical system in the framework of apparatus.

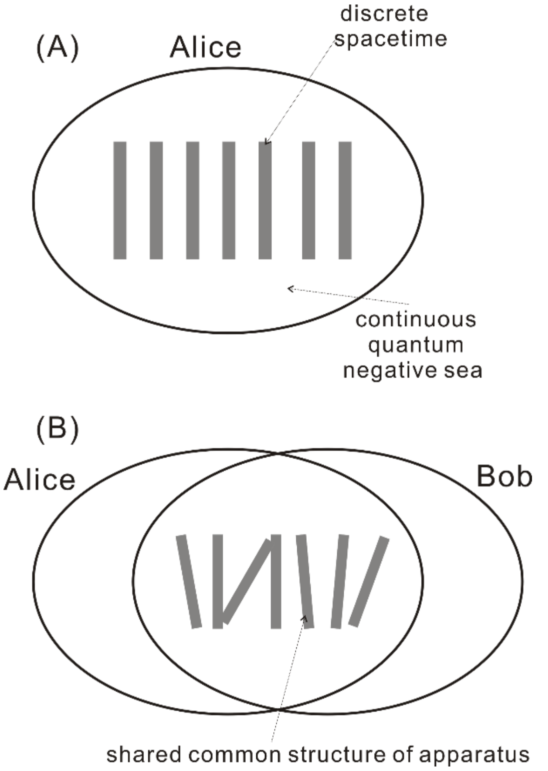

Figure 7. A vacuum may be considered as classical discreteness being embedded in a continuous quantum negative sea of consciousness (A). On the other hand, Alice and Bob share a common structure of apparatus (vacuum), as suggested in relativity (B).

Based on the connection between quantum theory and relativity outlined above, the relation between matter and mind may be visualized as in Figure 6. That is, the continuous mind serves as an apparatus in the background of the physical system. Another example may be that the Dirac-type negative sea is continuous and results from quantum unitary evolution going backwards in time in the Heisenberg picture, and discrete spacetime is embedded (i.e., the vacuum (Figure 7 (A)). This was the crux of the subjective reality for a single observer. For multiple subjects, such as Alice and Bob, they share a common structure: a vacuum, or an apparatus that corresponds to both classical and quantum realms, as drawn with an example in (B).

Remarks

In this paper, the relation between subjective quantum theory and intersubjective relativity is outlined. One of the benefits of the current approach is that i provides an alternative way of looking at the connection between the two theories, where the traditional quantization of gravity has been unsuccessful. Moreover, comparing entanglement and gravity in terms of commonality yields resemblance to some of the recent suggestions of connecting entanglement with wormholes (Maldacena et al., 2013). It is also noted that more of this paper’s proposal details are expected in the future to see how it relates to the conjecture, ER=EPR, in (Maldacena et al., 2013).

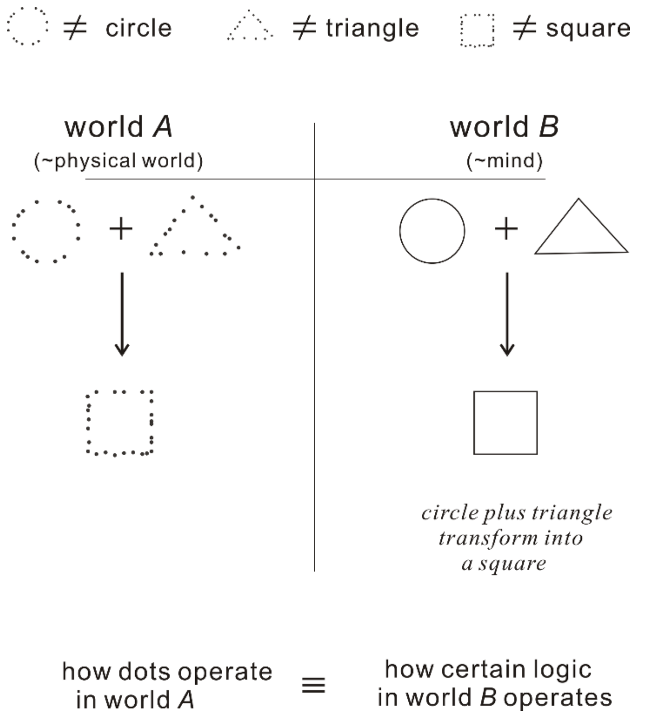

Figure 8. Although not necessary, two different worlds (i.e., A and B) exhibit a similarity. This example illustrates a common logical structure between the imperfect physical world and the perfect mind.

In ancient Greece, Plato discussed ideal objects that cannot be found in the physical world. Indeed, a perfect circle, triangle, square, and so on do not exist in the observed world and are imagined objects that exist only in thought. Let us consider an example, as seen in Figure 8, where there are two different realms. In world A, there are a finite number of dots following a certain pattern of interaction. In world B, there exist a perfect circle and triangle; when combined, these shapes transform into a perfect square. Comparing these two realms, it may be said that the way those dots operate in world A is equivalent to a certain logical process in world B. While this comparison may sound trivial and obvious, there is no reason for these two different worlds (where one comprises dots and the other consists of perfect geometrical figures) to have a similar structure.

Certainly, world A resembles the physical world, while world B is similar to the mind of an observer, such as Alice or Bob. Indeed, while a physical law often says something like a circle plus a triangle transform into a square, it does not need to hold in world A because it is a logical process in world B. Noting this peculiar coincidence, the following may be said:

The way physical systems behave and interact with each other is equivalent to a certain way in which observers perceive or understand that pattern.

The 18th-century philosopher Immanuel Kant discussed a philosophical version of the Copernican revolution, where the emphasis in human knowledge about the universe shifts from the object (i.e., the observed nature) to the observer. One of the motivations for this remarkable claim was that it is certainly possible for the orientation of the observing party to influence the way the object is perceived. That is, knowledge of the physical reality of the object may depend more on the observer than on the object itself. Similar to our discussion above, Kant also discussed that space and time are like an apparatus for observing objects. For instance, the observer needs a spatial distance to perceive an object and, similarly, needs a temporal difference to make an observation.

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