Research Article

On the Tangled Hierarchy of Wave Functions and Observers

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This paper explores the intricate relationship between the observer, consciousness, and quantum mechanics, attempting to defend the interpretation of the wave function as a representation of consciousness. More precisely, in our framework, a quantum state, represented by a wave function, determines a state of consciousness related to the first-person experiences, w, of the events E, detected by senses. Building on Everett's many-worlds interpretation, we argue that the wave function is not an objective universal entity, but rather one that is inherently associated with the first-person experiences $w \in P$ of an observer $\mathcal{O}$. The set P also includes other observers, $\mathcal{O}'$, as subsets. We demonstrate that this proposal does not lead to solipsism, because there is no unique hierarchy of observers, as indicated above, but there are many possible hierarchies of observers, such that, e.g., the roles of the first-person observer, $\mathcal{O}$, and the third-person observer, $\mathcal{O}'$ are interchanged. The corresponding quantum states, $\psi_{\mathcal{O}}$ and $\psi_{\mathcal{O}'}$, are elements of the space of all possible quantum states, the Hilbert space, $\mathcal{H}$. It is this larger space that we identify as the objective reality. Thus, our approach overcomes the main obstacle faced by researchers who tried to make sense of quantum mechanics, namely, the wall of solipsism. In this framework, the Everett many-worlds interpretation and the wave function collapse interpretation are not mutually exclusive but instead represent complementary perspectives within the hierarchy of observers, each offering insight into the underlying physics from a different vantage point.

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1. Introduction

Quantum mechanics, despite its tremendous success as a scientific theory, remains deeply enigmatic, particularly regarding the role of the observer and the nature of consciousness. Since its inception, the founders of quantum mechanics have recognized the essential role of the observer, especially in relation to the ”measurement problem,” which persists to this day. The measurement problem refers to the difficulty of explaining how a quantum system—initially existing in a superposition of multiple possible states— collapses into one particular outcome when measured. This issue lies at the heart of various interpretations of quantum mechanics, including the Copenhagen interpretation and the many-worlds interpretation (MWI) developed by Hugh Everett[1][2][3]. In the Copenhagen interpretation, the wave function collapses upon measurement so that only one of the outcomes is observed. Everett's MWI, on the other hand, avoids wave function collapse by proposing that all possible outcomes of a quantum event occur in separate, branching universes, each experienced by a different version of the observer. However, critics of this view—such as Penrose[4][5][6] and Hameroff[7]—have suggested that consciousness itself could be linked to quantum processes. Their theory implies that the collapse of the wave function is a fundamental event tied to the emergence of conscious experience.

On the other hand, Zurek's work on decoherence[8][9][10] has significantly advanced our understanding of how classical reality emerges from quantum superpositions without invoking the collapse of the wave function. His research on environmental interactions explains how a ”preferred basis” is selected, leading to a classical world where we observe definite outcomes.

In this paper, we explore the idea that the wave function, a mathematical representation of quantum states, can be interpreted as describing states of consciousness. Whilst the wave function ψ, evolving according to the Schrödinger equation, contains a superposition of many possible worlds, an observer experiences—or ”measures” —only one. From the first-person perspective, an observer, by the very act of observation, enters one particular world. To the founders of quantum mechanics, it was clear that without the observer, quantum mechanics could not be properly understood. On the other hand, there have been numerous attempts[11][12][8][9][10][13][14][15][16] to put the observer out of any physical theory and thus interpret quantum mechanics without involving an observer. But it has turned out that the so-called “measurement problem” has not been actually resolved. It persists in the relative state theory[1][2], in its many-worlds interpretation[17], and even in the decoherence theory[8][9][10], which, despite being widely believed to provide an objective collapse mechanism, merely explains why we do not observe macroscopic superpositions[18][19].

Increasing evidence suggests that the role of the observer—and, in particular, consciousness—is essential for making sense of quantum mechanics[20][21][22][23][24][25][26][27][28][29][30][31][32][33][34][35]. The feeling is growing that we are on the verge of a paradigm shift in physics. Whereas Descartes placed consciousness outside the domain of natural sciences—an approach that, in fact, enabled their tremendous success—this development has led to the discovery of quantum mechanics, which cannot be understood without bringing consciousness back

According to Everett's theory of the universal wave function, quantum unitarity and Schrödinger evolution hold universally, even in measurement scenarios. The universal wave function ψ_U evolves unitarily according to the Schrödinger equation, encompassing many "branches", each associated with a different version of the observer's experiences, related to the respective experimental outcomes. However, this raises a fundamental question: Why is Ψ_U the way it is? What determines the initial conditions of the universal wave function?

Let us illustrate a wave function as a branching tree (Fig.1). The splitting points correspond to observations, e.g., measurements of an observable. Let the initial state be $|A\rangle$. Upon measurement, the state $|A\rangle$ evolves into a superposition of the states (branches) $|A_1\rangle$, $|A_2\rangle$, $|A_3\rangle$, ...,$|A_8\rangle$, ... In each branch $|A_i\rangle$ there is a copy of the observer who is aware of that particular outcome of measurement only. From the first-person perspective of the observer in the branch $|A_i\rangle$, she followed the path A_i. Namely, at the observation points λ_1, λ_2, λ_3, λ_4, λ_5, ..., consciousness selected [28][29][32] one of the available branches at that point, and thus followed the path from A to A_i (say $i = 3$, as shown in Fig.1). According to the terminology of Ref. [18][19], consciousness "hangs up" on a branch.

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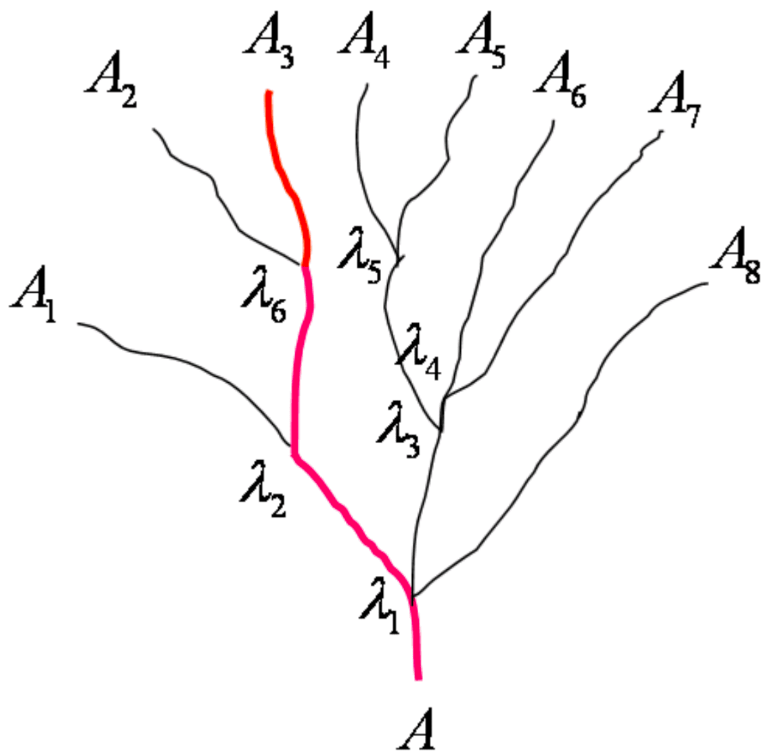

Figure 1. Graphical representation of a wave function as a branching tree.

That there are many branches, each with a different copy of the observer experiencing a different outcome, is a third person's view, the view of the observer who did not look at the result of the measurement. From the first-person viewpoint, consciousness follows only one particular path, associated with the world, subjectively experienced in that particular branch. My consciousness could have traveled along some other path, but it didn't. Consciousness is the first-person experience. The "universal" wave function contains the branches (paths) A_1, A_2,..., A_8,..., but only one is "vivid" to me.

Our approach unifies the Everett theory of many branches, each one bearing a copy of the observer, with Wheeler's view of the observer participator[36][37][38][39][40], including the concept of wave function collapse. Both approaches are valid. Everett's branches contain observers and their brain states with memory sequences. The observer participator experiences one branch only. This is so because the wave function is relative to an observer. Even the "universal wave function" must be given by certain initial (boundary) conditions. Who determined them? The universal wave function, if it exists at all, is relative to a meta observer (bird's perspective according to Zeh[35]). As shown in Refs.[32] and [18][19], one has to

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postulate consciousness as a primary, non-reducible entity that upon each observation "selects" one of the outcomes available in the wave function.

We advocate the view that the wave function is a mathematical representation of consciousness[32]. More precisely, the wave function is a mathematical representation of quantum states that we identify with the states of consciousness. At the current stage of scientific development, only those states associated with the degrees of freedom considered in physics—such as position, momentum, angular momentum, and spin—are included. The wave function considered in physics determines the state of knowledge about those degrees of freedom. This state of knowledge can be definite or uncertain, depending on whether the corresponding quantum state is a definite eigenstate or a superposition.

While the interpretation presented in this paper challenges conventional physicalist perspectives, it arises naturally from the unresolved foundational issues in quantum mechanics, particularly the nature of quantum states and the role of the observer. Rather than rejecting objective reality, this framework redefines it as the totality of all possible first-person experiences, formally described within the Hilbert space of quantum states. Importantly, this view does not collapse into solipsism, as it does not privilege any single observer's experiences but instead considers the entire structure of potential conscious states as fundamental.

The goal of this paper is not to provide a definitive proof of this framework but rather to explore its internal consistency and potential explanatory power. It offers a perspective that, if valid, could provide new insights into long-standing questions in both quantum mechanics and the philosophy of mind. Readers are invited to engage critically with the ideas presented, evaluating them based on their coherence and potential to clarify existing paradoxes rather than on adherence to preexisting ontological commitments.

2. Wave function of the universe and the observer

A quantum state of matter and gauge field configuration can be represented by a wave functional $\Phi[\phi(x), A(x)]$, where $\phi(x)$ is a set of scalar or spinor, and $A(x)$ of gauge fields. It can be expanded in terms of an infinite set of the quantities $\psi[T, \mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_n,]$, which are functions of the local time T and of coordinates $\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_n$ of matter and gauge field particles, e.g., electrons, quarks, photons, gluons, etc. A ψ represents the probability amplitudes for a multiparticle configuration. In principle, one could also include the gravitational field into such a description (for an attempt, see Refs.[41][42]).

Let us use a shorthand notation for a configuration of n particles:

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$$(\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_n) \equiv x^M, M \equiv in; i = 1, 2, 3; n = 0, 1, 2, \ldots, \infty. \tag{1}$$

Here x^M can be a complicated structure. In the case of a continuum configuration, e.g., a p-brane, the discrete index n becomes a continuous index, e.g., σ^a, $a = 1, 2, \ldots, p$ so that

$$x^M \equiv \mathbf{x}(\sigma^a), \sigma^a \in \mathbb{R}^p. \tag{2}$$

Then x^M represents an extended object, e.g., a string, brane, or whatever continuous extended object, or a system of such objects, as illustrated in Fig. 2. The space of all possible configurations $\{x^M\}$ is the configuration space, $\mathcal{C}$.

Figure 2. A configuration, described by coordinates $x^M \equiv \mathbf{x}(\sigma^a)$ can be whatever extended, e.g., a string-like or brane-like object, or any other structure.

The wave function[1] instead of $\psi(T, x^M)$. $\psi(x^M)$ assigns weights to the configurations x^M, so that $|\psi(x^M)|^2$ is the probability density for the occurrence of the configuration x^M. According to Barbour[43][44][45], $\psi(x^M)$ is a "mist" over configuration space. In Barbour's terminology, the space of all possible configurations is called "Platonia".

Configuration space can contain the degrees of freedom of numerous possible observers $\mathcal{O}$ and the belonging universes $\mathcal{U}$. The wave function is then

$$\psi(x^M) = \psi(x_{\mathcal{O}}, x_{\overline{U}}) \equiv \psi(\mathcal{O}, \overline{\mathcal{U}}), \tag{3}$$

where $x_{\mathcal{O}} \equiv \mathcal{O}$ is the configuration of an observer, and $x_{\overline{\mathcal{U}}} \equiv \overline{\mathcal{U}}$ is the configuration of the rest of the universe. In principle, every conceivable configuration is possible, but once $\psi(x^M)$ is given, it determines which configuration is more probable. According to Barbour, the wave function is concentrated over such configurations that contain observers. This is in agreement with the view expressed in Refs.[32][28][29][31][30], according to which the wave function is a mathematical representation of consciousness, or shortly, the wave function is consciousness. The aim of this work is to further elaborate on this idea, point out its consequences, and show that it does not imply solipsism if we consider a space of all possible wave functions, each one representing particular first-person experiences.

The vast configuration space may contain as a subspace a 1-parameter family of very involved configurations $x_0^M(\tau) = (\mathcal{O}(\tau), \overline{U}(\tau))$ that at every value of the parameter τ represent degrees of freedom of an observer $\mathcal{O}$ together with her brain, coupled by sense organs to the external world, i.e., to the rest of the universe $\overline{U}$. The rest of the universe $\overline{U}(\tau)$ can contain the degrees of freedom of other observers as well:

$$\overline{U}(\tau) = \Big(\mathcal{O}'(\tau), \mathcal{O}''(\tau), \ldots, \overline{\overline{U}}(\tau)\Big), \tag{4}$$

so that

$$x_{\mathcal{O}}^M(\tau) = \Big(\mathcal{O}(\tau), \mathcal{O}'(\tau), \mathcal{O}''(\tau), \ldots, \overline{\overline{U}}(\tau)\Big), \tau \in (-\infty, \infty). \tag{5}$$

The brain configurations can also contain the memory of the past brain configurations, as discussed in Refs.[43][29][31][32][46]. If in the sequence of configurations $(\ldots, \mathcal{O}(\tau_1), \mathcal{O}(\tau_2), \mathcal{O}(\tau_3), \ldots)$ each configuration $\mathcal{O}(\tau_n)$ contains the record (memory) of the previous configurations $\mathcal{O}(\tau_{n-1}), \mathcal{O}(\tau_{n-2}), \ldots$, then such a self-referential sequence of configurations $(\ldots, \mathcal{O}(\tau_1), \mathcal{O}(\tau_2), \mathcal{O}(\tau_3), \ldots)$, can be the neural correlate [47][34][35][23][24] of a sequence of consciousness states of an observer[2] (see also Section 3.). But such a sequence is not identical to the observer's stream of conscious experiences, analogously as a gramophone plate is not identical to the piece of music recorded on it[3]. There must be a "device" that plays the record. Such a device is a wave function over the configuration space, a "mist", exhibiting the evolution described by the Schödinger equation.

A wave function $\psi(x^M)$ over configuration space $\mathcal{C}$ can be considered as a vector in an infinite-dimensional space, more precisely, as infinite components of a vector $|\psi\rangle$, the basis vectors being $|x^M\rangle$:

$$|\psi\rangle = \int |x^M\rangle \mathcal{D}x^M \langle x^M | \psi\rangle, \tag{6}$$

where $\mathcal{D}x^M \equiv \prod_M \mathrm{d}x^M$ is a volume element[4] in $\mathcal{C}$, and

$$\langle x^M | \psi\rangle \equiv \psi(x^M). \tag{7}$$

The vector $|\psi\rangle$ is called the state vector or quantum state, and the wave function is thus a representation of a quantum state.

It can be localized in a certain region of $\mathcal{C}$, for instance, like a wave packet of certain width σ_0 (Fig. 3), which at an initial time T_0 can be arbitrary, say Gaussian,

$$\psi(T_0, x^M) = \prod_M \frac{1}{\sqrt{\pi}\sigma_0} \exp\left[-\frac{\left(x^M - x_{\mathcal{O}}^M(T_0)\right)^2}{2\sigma_0^2}\right]. \tag{8}$$

It then evolves according to the dynamics given by the Schrödinger equation so that at later times $T > T_0$ it deviates from the Gaussian form (see Fig. 3 for a schematic illustration).

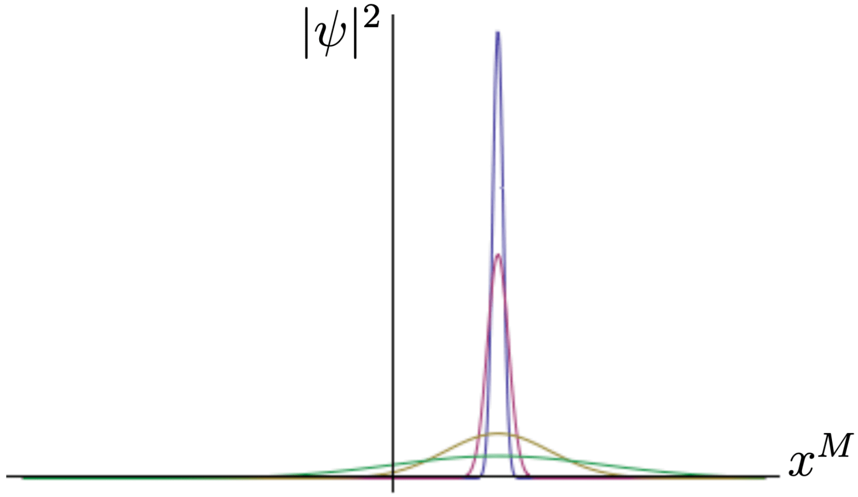

Figure 3. Localization of the probability density $|\psi|^2$ of different initial widths σ_0 in the space of all possible configurations at a fixed initial time T_0.

Now let us ask ourselves what such a wave packet represents. Recall that the points x^M of $\mathcal{C}$ represent all possible configurations, including very complicated ones, and also very simple ones. A wave function, e.g., a wave packet of the sort illustrated in Fig. 3, is concentrated on a subset of points in $\mathcal{C}$, i.e., a subset of configurations. If configurations within such a subset are simple, the corresponding wave function can only represent very simple, if any, conscious experiences.

Things become interesting if $\psi(T, x^M) = \psi_{\mathcal{O}}(T, x^M)$ is concentrated on a complicated self-referential configuration $x^M_{\mathcal{O}}(T, x^M)$, with memories of "past" configurations[43][29][31][46], and coupled to "external" configurations, also contained in the same wave packet $\psi_{\mathcal{O}}(T, x^M)$. This is then the wave function of the universe associated with an observer $\mathcal{O}$; it represents the universe $U_{\mathcal{O}}$, experienced by this observer. The squared amplitude $|\psi|^2$ is peaked on a point $U_{\mathcal{O}}$ in $\mathcal{C}$ (Fig. 4). The universe $U_{\mathcal{O}}$ contains, besides $\mathcal{O}$, other observers, $\mathcal{O}'$, $\mathcal{O}''$,..., as well, but on those observers, the wave function $\psi_{\mathcal{O}}(T, x^M)$ is much less sharply peaked than on $\mathcal{O}$, or not peaked at all. Such a wave function $\psi_{\mathcal{O}}$, sharply peaked on an observer $\mathcal{O}$, represents $\mathcal{O}$'s conscious experiences[5]. It is the wave function of the universe experienced by the observer $\mathcal{O}$. Because $\psi_{\mathcal{O}}$ is less sharply peaked on other observers $\mathcal{O}'$, $\mathcal{O}''$,..., within the same Everett world, it represents their conscious experiences in much less detail than those of the observer $\mathcal{O}$. However, there exist alternative wave functions, $\psi_{\mathcal{O}'}$, $\psi_{\mathcal{O}''}$,..., peaked on the observers $\mathcal{O}'$, $\mathcal{O}''$,... . Thus, $\psi_{\mathcal{O}'}$ represents the universe $U_{\mathcal{O}'}$, experienced[6] by the observer $\mathcal{O}'$, which in most of the features is identical with the universe $U_{\mathcal{O}}$, experienced by $\mathcal{O}$. Only their "private", inner, experiences are different, whilst the external world they are aware of is the same.

In the presence of interactions, the wave function $\psi_{\mathcal{O}}(T, x^M)$ evolves like a branching tree. It then contains many Everett's versions of the observer $\mathcal{O}$, namely, $\mathcal{O}_1$, $\mathcal{O}_2$,..., and belonging Everett's versions of the world[1][2][3][17][34][35][27][28][29][31][32]. Relative to $\mathcal{O}$, at every measurement or observation, the wave function collapses so that $\mathcal{O}$ is aware only of one particular eigenvalue of the measured or observed quantity, and thus only of one of the available Everett's worlds. This implies that the $\mathcal{O}$'s neural correlates become entangled with just one of the Everett's worlds.

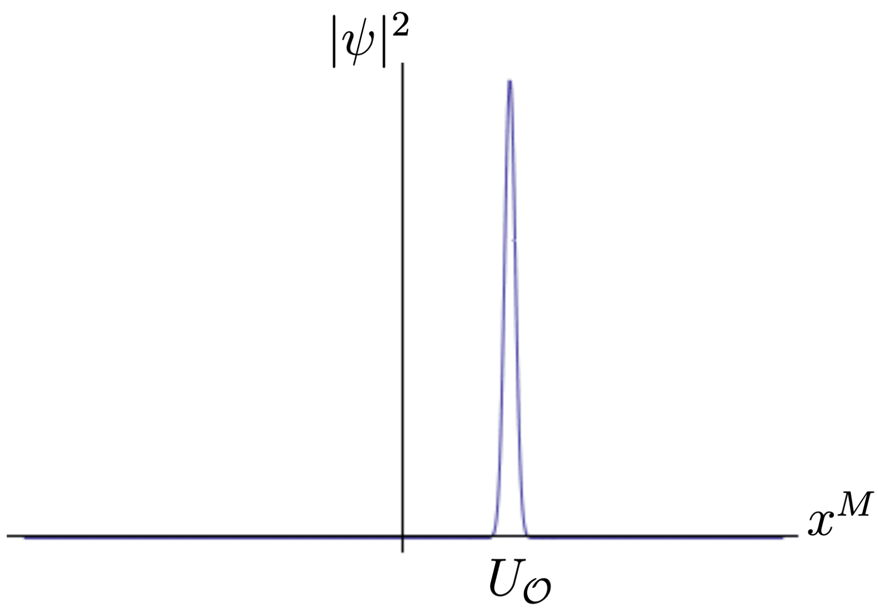

Figure 4. Localization of the probability density $|\psi|^2$ around a point $U_{\mathcal{O}}$ in $\mathcal{C}$ that represents the degrees of freedom of a universe containing an observer $\mathcal{O}$.

If you now contemplate this situation from your first-person perspective, then at every measurement situation or observation, the wave function (representing your consciousness) collapses into a "narrower" wave function, an eigenfunction[7] of the measured or observed quantity (observable). In other words, you become associated with just one of the available possibilities (worlds/branches) comprised in the wave function before the collapse.

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Now let us suppose that a wave function is initially spread all over the vast configuration space $\mathcal{C}$, then you can hardly be aware of anything. But because of the collapse of the wave function[8], you then become associated with a particular possible universe, represented here as a narrow region in the configuration space, more precisely, a narrow region in the Hilbert space spanned by basis vectors $|x^M\rangle$:

$$|\psi\rangle = \int \mathcal{D}x^M |x^M\rangle \psi_w(x^M) \longrightarrow \int \mathcal{D}x^M |x^M\rangle \psi_{U_\mathcal{O}}(x^M). \tag{9}$$

Here $\psi_w(x^M)$ is a wide wave packet, spread over $\mathcal{C}$, whereas $\psi_{U_\mathcal{O}}(x^M)$ is a collapsed wave packet (Fig. 4), spread over a region of $\mathcal{C}$ that contains an observer $\mathcal{O}$, say you. After such a collapse, $\psi_w(x^M) \to \psi_{U_\mathcal{O}}(x^M)$, you became aware of a universe $U_\mathcal{O}$.

In contrast to the Everett interpretation, the above reasoning leads us to the conclusion, as previously argued in Refs. [32][28][29][31][18][19] and Introduction, that there is no objective "universal" wave function, and that every wave function is associated with an observer; the wave function collapses relative to an observer, who becomes aware of one of the possibilities incorporated in the wave function. Within the context of Everett's theory, it is usually stated that wave function collapse is a subjective event. However, according to our reasoning, previously advocated in Refs. [32][28][29][31][30][18][19], subjective (relative) is a wave function itself and the particular world it comprises. In the configuration space of all possibilities, everything can exist, but in actuality, nothing happens until a wave function —relative to an observer— brings life to a particular universe. In the Hilbert space, there are many alternative wave functions that "bring life" to many distinct observers and the associated universes.

To sum up, in our interpretation, a quantum state, represented by a wave function, determines a state of consciousness. The basis states $|x^M\rangle$ for sufficiently involved configurations determine definite states of consciousness. A generic state vector $|\psi\rangle$ determines an indefinite state of consciousness, a superposition of possible definite perceptions.

3. Formalization of quantum mechanical wave function as first-person experiences

We have been talking about wave functions using various phrases, such as 'being relative to an observer', 'representing states of consciousness', 'experiences', etc. We will now provide more formal definitions of those terms and concepts. We will start by defining the set of all possible first-person experiences and then segment it into different types of subsets. After that, we will explore a subset that aligns with the quantum mechanical wave function used in physics to describe the external phenomena.

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Let C be the universal set[9] of all possible first-person experiences. Formally:

$$C = \{w \mid w\text{~is a possible first-person experience}\}$$

We can partition C into subsets based on different types or qualities of experiences. For example, let us define a few subsets:

- Perceptual Experiences (P):

$$P = \{w \in C \mid w\text{~is a perceptual experience}\}$$

- Memories (M):

$$M = \{w \in C \mid w\text{~is a memory of a past event}\}$$

- Thoughts (T):

$$T = \{w \in C \mid w\text{~is a thought or idea}\}$$

- Emotions (E):

$$E = \{w \in C \mid w\text{~is an emotional experience}\}$$

We can then express C as the union of these subsets:

$$C = P \cup M \cup T \cup E$$

This notation assumes that each first-person experience falls into one of these categories, but we could also allow overlaps if needed, by relaxing the strict partition and considering intersections between subsets (e.g., an emotional memory).

The quantum mechanical wave function used in physics includes the perceived external phenomena, the elements of the subset P of C. It does not include the elements of other subsets of C. In principle, the wave function could be defined to include all first-person experiences, i.e., all elements $w \in C$, but only those of P are relevant for current physics.

A $w \in P$ stands for experiences such as:

- seeing 3D objects of the perceived world,
- seeing the black spot on a screen, indicating the position of a photon's impact,
- hearing a click of a Geiger counter, indicating the moment of an excited state decay,
- finding the electron in the left box, after initially the wave function was spread over two boxes,

- any other experience connected to the outcome of a quantum experiment,
- reading a book or an article describing the discoveries provided by science about the macrocosmos and microcosmos,
- watching TV or reading articles, and thus learning about distant countries and events therein,
- on the basis of all received information, having an experience of knowing how the world and the universe look like.

A generic state related to those experiences can be expressed as a superposition

$$|\Psi\rangle = \sum_{x \in P} \psi(x)|x\rangle,$$

where $|\Psi\rangle$ is a quantum state of first-person experiences within P, and $|x\rangle$ is a basis state of an experience x, which in general is not w. Namely, the states $|x\rangle$ are assumed to form a complete set of basis states, while the states $|w\rangle$, in general, are not complete. The distinction between x and $|x\rangle$ (or w and $|w\rangle$) is analogous to the distinction between position and position state. A generic state of experience is thus a superposition of basis states of experience. For example, in the case of the electron in the boxes, before "looking" into the boxes, the state of experience was a superposition of two possible states of experience, namely, the electron being in both boxes. After "looking", the state of experience is knowing that the electron is in, say, Box 1. If not looking at all, the state of experience concerning that setup remains a superposition state.

The word 'consciousness' in this paper means first-person experiences, and 'consciousness state' means a state of first-person experiences. First-person experiences include not only awareness of the directly perceived surroundings but can also include knowledge about the situation in a distant location, country, planet, galaxy, structure of a crystal, atom, quark, depending on the source of information. A definite experience of seeing an object at a certain location, or obtaining the information about something, is a result of wave function collapse, which happens:

a. after looking at the screen, which reveals the electron's position,
b. after first entering a new place, which reveals its detailed configuration,
c. after first learning about the structure of matter, say, a crystal, atom, etc.

In all three cases, the wave function, involving those first-person experiences, was initially spread, bearing uncertainty about the questions, such as "Where is the electron?", "What precisely does the new place look like?", "What is the structure of matter?" The state of consciousness regarding that particular

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configuration was first indefinite (the wave function was spread over the configurations in question). After obtaining the information through a suitable channel, the state of consciousness became definite, i.e., the wave function representing such a state has collapsed.

4. A model of the observer entangled with a universe.

We will now provide a model of the observer. Let a brain state of an observer be parametrized by a set of parameters

$$\mathcal{O} = \{w_1, w_2, \ldots w_i, \ldots\}, \tag{10}$$

denoting a configuration of the brain events, corresponding to the observer's perceptions/experiences of the external world. The parameters $w_1, w_2, ..$ correspond to the observer's experience of seeing, e.g., the room (or a laboratory), an apparatus, etc. In other words, the external world is represented by the brain configuration (10).

But since in the outside world there are other observers[10] $\mathcal{O}' \equiv \mathcal{O}_{1'}$, $\mathcal{O}'' \equiv \mathcal{O}_{2'}, \ldots$, the set $\mathcal{O}$ has to be extended according to

$$\mathcal{O} = \{w_1, w_2, \ldots, w_i, \ldots, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots, \mathcal{O}_{r'}, \ldots\}. \tag{11}$$

Suppose that, possessing advanced technology, the observer $\mathcal{O}$ monitors the brain state of an observer, say $\mathcal{O}_{1'}$. She then finds that $\mathcal{O}_{1'}$ consists of the set

$$\mathcal{O}_{1'} = \{w'_1, w'_2, \ldots, w'_i, \ldots, \mathcal{O}'_{2'}, \ldots, \mathcal{O}'_{r'}, \ldots\}, \tag{12}$$

where $\{w'_1, w'_2, \ldots, w'_i, \ldots, \}$ is a representation of the set $\{w_1, w_2, \ldots w_i, \ldots\}$, and $\{\mathcal{O}'_{2'}, \ldots, \mathcal{O}'_{r'}, \ldots\}$, is a representation of $\{\mathcal{O}_{2'}, \ldots, \mathcal{O}_{r'}, \ldots\}$.

Thus, by monitoring the observer $\mathcal{O}_{1'}$, the observer $\mathcal{O}$ finds in $\mathcal{O}_{1'}$ a representation[11] of the same state that the observer $\mathcal{O}$ herself is directly aware of. The content of the $\mathcal{O}$'s brain state is thus

$$\mathcal{O} = \{w_1, w_2, \ldots, w_i, \ldots, \{w'_1, w'_2, \ldots, w'_i, \ldots, \mathcal{O}'_{2'}, \ldots, \mathcal{O}'_{r'}, \ldots\}, \mathcal{O}_{2'}, \ldots, \mathcal{O}_{r'}, \ldots\}. \tag{13}$$

In other words, Eq. (13) means that the observer $\mathcal{O}$'s brain configuration comprises the brain events $w_1, w_2, \ldots, w_i, \ldots$, representing the external world, the brain events $\mathcal{O}_{2'}, \ldots, \mathcal{O}_{r'}, \ldots$, representing other observers, and the detailed configuration of the monitored observer $\mathcal{O}_{1'}$.

Concerning the external world state, reflected in the brain state, parametrized by the set $\{w_1, w_2, \ldots, w_i, \ldots\}$ and denoted as $|w_1, w_2, \ldots, w_i, \ldots\rangle$, there exists a theory that describes its dynamics.

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This is quantum mechanics, according to which the state $|w_1, w_2, \ldots, w_i, \ldots\rangle$ can be represented in terms of a wave function

$$\psi_{\mathcal{O}}(x^M) = \psi_{\{w_1,w_2,\ldots,\}}(x^M) \equiv \langle x^M \big| \mathcal{O}\rangle = \langle x^M \big| w_1, w_2, \ldots\rangle. \tag{14}$$

Here $|x^M\rangle$ is a position (coordinate) basis state of experience. Including also the other observers, the wave function becomes $\psi_{\mathcal{O}} = \psi_{\{w_1,w_2,\ldots,\mathcal{O}_{1'},\mathcal{O}_{2'},\ldots\}}$.

If the observer $\mathcal{O}$ precisely monitors the brain configuration of the observer $\mathcal{O}_{1'}$, the wave function relative to O is

$$\psi_{\mathcal{O}} = \psi_{\{w_1,w_2,\ldots,\{w'_1,w'_2,\ldots,w'_i,\ldots,\mathcal{O}'_{2'},\ldots\},\mathcal{O}_{2'},\ldots\}}. \tag{15}$$

Even if the observer $\mathcal{O}$ does not precisely monitor $\mathcal{O}_{1'}$'s brain states, the fact remains that the observer $\mathcal{O}_{1'}$ (or any other system that qualifies as an observer) possesses a brain state that is in correspondence with the external events. Therefore, the wave function can still be written in the above form, with the understanding that the set $\{w'_1, w'_2, \ldots\}$, is not exactly isomorphic to the set $\{w_1, w_2, \ldots\}$, but only approximately[12]. The wave function $\psi_{\mathcal{O}}$ is thus "sharply peaked" (see Sec. 2) on the observer $\mathcal{O}$, and less sharply peaked on the observer $\mathcal{O}_{1'}$; it represents the universe, experienced by the observer $\mathcal{O}$.

Let us now consider the case in which w_1 denotes a system S and w_2 an apparatus A that measures the state of S,

$$w_1 = S, w_2 = A, \tag{16}$$

the environment being $E = w_3, w_4, \ldots, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots$. Then (15) can be written as ψ_{SAE}. Suppose that initially the system S is in a superposition state $\sum_n c_n(0)\psi_{S_n}$, and the total state is

$$\psi_{\mathcal{O}} = \psi_{SAE}(0) = \psi_S\psi_{AE} = \left(\sum_n c_n(0)\psi_{S_n}\right)\psi_{AE}. \tag{17}$$

After an interaction with the apparatus A, coupled to the environment E, the total state, coupled to the environment, evolves into a superposition of the entangled states

$$\begin{aligned} \psi_{\mathcal{O}}(t) = \psi_{SAE}(t) = \sum_n c_n(t)\psi_{\{S,A,E\}_n} \\ = \sum_n c_n(t)\psi_{\{S,A,w_3,w_4,\ldots\{S',A',w'_3,w'_4,\ldots,\mathcal{O}'_{2'},\mathcal{O}'_{3'},\ldots\},\mathcal{O}_{2'},\mathcal{O}_{3'},\ldots\}_n} \end{aligned} \tag{18}$$

In the above superposition, there are as many branches as there are different eigenstates of the system S. A branch contains a representation $\{S'_n, A'_n, (w'_3, w'_4, \ldots, \mathcal{O}'_{2'}, \mathcal{O}'_{3'}, \ldots)_n\}$ of the system S, apparatus A and the environment E, reflected in the $\mathcal{O}_{1'}$'s brain.

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However, an observer's brain state also includes records/memories m_1, m_2,..., of the past observations/experiences/perceptions. Therefore, we assume that such record states are also added to the set (11), so that $\mathcal{O} = \{w_1, w_2, \ldots, m_1, m_2, \ldots, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots\}$. In order to simplify the notation, we will mostly keep on writing $\{w_1, w_2, \ldots, \}$ and assume that the record states are also present within the set $\mathcal{O}$.

An observer does not only perceive the representation $\{w_1, w_2, \ldots, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots\}$ of the external worlds; she also perceives (is aware of) what she has perceived. The set of her brain events, $\mathcal{O}$, therefore includes $\mathcal{O}$ itself, so that Eq. (11) extends to the following self-referential set:

$$\begin{aligned} \mathcal{O} &= \{\mathcal{O}, w_1, w_2, \ldots, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots\} \\ &= \{\{\mathcal{O}, w_1, w_2, \ldots, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots\}, w_1, w_2, \ldots, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots\} \\ &= \{\{\{\mathcal{O}, w_1, w_2, \ldots, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots\}, w_1, w_2, \ldots, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots\}, w_1, w_2, \ldots, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots\} \end{aligned} \tag{19}$$

Above, we have an idealistic situation of exact self-reference. In practice, self-reference is approximate, and the set $\mathcal{O}$ includes only an approximate representation of itself, denoted $\overline{\mathcal{O}}$. Therefore, instead of (19), we actually have

$$\begin{aligned} \mathcal{O} &= \{\overline{\mathcal{O}}, w_1, w_2, \ldots, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots\} \\ &= \{\{\overline{\overline{\mathcal{O}}}, \overline{w}_1, \overline{w}_2, \ldots, \overline{\mathcal{O}}_{1'}, \overline{\mathcal{O}}_{2'}, \ldots\}, w_1, w_2, \ldots, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots\} \\ &= \{\{\{\overline{\overline{\overline{\mathcal{O}}}}, \overline{\overline{w}}_1, \overline{\overline{w}}_2, \ldots, \overline{\overline{\mathcal{O}}}_{1'}, \overline{\overline{\mathcal{O}}}_{2'}, \ldots\}, \overline{w}_1, \overline{w}_2, \ldots, \overline{\mathcal{O}}_{1'}, \overline{\mathcal{O}}_{2'}, \ldots\}, w_1, w_2, \ldots, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots\}, \end{aligned} \tag{20}$$

where $\overline{w}_1, \overline{w}_2, \ldots$, denotes a representation of $w_1, w_2, \ldots$,, and $\overline{\overline{w}}_1, \overline{\overline{w}}_2, \ldots$, a representation of $\overline{w}_1, \overline{w}_2, \ldots$,, etc. Such a self-reference can be considered (amongst others) as a defining property of consciousness, and the self-referential set (20) a definition of the observer. For the reason of simplicity and clarity of notation, we will keep on using expression (19), with the understanding that it actually means (20).

Returning now to the superposition state (18) involving many branches, we assume that each observer is defined analogously to Eq. (19) (or, more precisely, to (20)), so that we have

$$\begin{aligned} \psi_{\mathcal{O}}(t) &= \psi_{\mathcal{O}SAE}(t) \\ &= \sum_n c_n(t) \psi_{\{\mathcal{O}, S, A, w_3, w_4, \ldots, \{\mathcal{O}'_{1'}, S', A', w'_3, w'_4, \ldots, \mathcal{O}'_{2'}, \mathcal{O}'_{3'}\}, \mathcal{O}_{2'}, \mathcal{O}_{3'}, \ldots\}_n}, \end{aligned} \tag{21}$$

where

$$\mathcal{O}'_{1'} = \{\mathcal{O}'_{1'}, S', A', w'_3, w'_4, \ldots, \mathcal{O}'_{2'}, \mathcal{O}'_{3'}\} \tag{22}$$

is a self-referential representation of $\mathcal{O}_{1'}$ as reflected within the $\mathcal{O}$'s brain state. A superposition similar to (21), without explicitly mentioning self-reference, was considered by Everett.

Let us now split the environment $E = \{w_3, w_4, \ldots, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots\}$ into two parts, $E = E_I \cup E_{II}$, and consider the case in which the part $E_I = \{w_i\}$, $i = 3, 4, 5, .., N_I$, is isolated from the rest of the

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environment, $E_{II} = \{w_j, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots\}$, $j =, N_I + 1, N_I + 2, \ldots, N_I + N_{II}$. The wave function, associated with (or relative to) the observer $\mathcal{O}$ is then not the superposition (21), but

$$\psi_{\mathcal{O}}(t > t_1) = \psi_{E_I} \sum_n c_n(t) \psi_{(SAE_{II})_n}$$

$$= \psi_{\{w_i\}} \sum_n c_n(t) \psi_{\{S,A,w_j,\mathcal{O}_{1'},\mathcal{O}_{2'}\}_n},$$

$$i = 1, 2, \ldots, N_I; j = N_I + 1, N_I + 2, \ldots, N_I + N_{II}. \tag{23}$$

Recall that $E_I = \{w_i\}$, $i = 3, 4, 5, \ldots, N_I$, i.e., $E_I = \{w_3, w_4, \ldots, w_{N_I}\}$ is a shorthand notation for the set $E_I = \{w_3, w_4, \ldots, w_{N_I}, m_1, m_2, m_3, \ldots, m_k\}$, where $w_3, w_4, \ldots$ are the $\mathcal{O}$'s brain events that correspond to the external world, whilst $m_1, m_2, m_3, \ldots, m_k$ correspond to the records/memories of previous observations.

At time $t > t_1$, the observer $\mathcal{O}$ thus sees a superposition of the entangled states $\psi_{\{SAE_{II}\}_n}$ of the system S, apparatus A, and the environment E_{II}, containing the observer $\mathcal{O}_{1'}$, as well as the other observers $\mathcal{O}_{2'}$, $\mathcal{O}_{3'}$,..., within the n-th branch. Each branch $\psi_{\{SAE_{II}\}_n}$ contains a version $(\mathcal{O}_{1'})_n$ of the observer $\mathcal{O}_{1'}$, with a distinct record of the measurement result, S_n. All Everett's versions of the observer $\mathcal{O}_{1'}$ are thus in a superposition; there is no collapse of the wave function. However, subjectively, each version $(\mathcal{O}_{1'})_n$ is aware of a definite value S_n; subjectively, relative to $(\mathcal{O}_{1'})_n$ the wave function collapsed, but the total wave function, encompassing all those observers $(\mathcal{O}_{1'})_n$ remained in the superposition.

Suppose now that at time $t = t_2$, there is an interaction between E_I and the remaining states. Then the wave function (23) evolves so that at $t > t_2$ it becomes the superposition (21) with different versions of $\mathcal{O}$'s experiences/perceptions, $\{S, A, w_1, w_2, w_3, w_4, \ldots, m_1, m_2, \ldots, m_k, m_{k+1}, \mathcal{O}_{1'}, \mathcal{O}_{2'}, \ldots\}_n$, the sequence of records having acquired an additional record, m_{k+1}, of the observed/measured value S_n, entangled with A_n and the environment E_n. However, the observer "measures" herself through the self-referential loop (19), which is a defining property of self-awareness or consciousness. She can therefore be aware only of a definite branch in the superposition (21).

But relative to an outside observer, who is not in interaction with $\psi_{\mathcal{O}}$, the wave function remains in superposition. Between the outside observer, say $\mathcal{O}_{-1}$, and the observer $\mathcal{O}$, there is the analogous relation as between $\mathcal{O}$ and $\mathcal{O}_{1'}$:

$$\psi_{\mathcal{O}_{-1}} = \sum_n c_n(t) \psi_{\{\mathcal{O},w_1,w_2,\ldots,m_1,m_2,\ldots,\mathcal{O}_{1'},\mathcal{O}_{2'},\ldots,\}_n}, \tag{24}$$

We thus have a hierarchy of representations in which the observer's $\mathcal{O}_{-1}$ brain state contains a representation of the brain state of $\mathcal{O}$, whose brain state in turn contains a representation of the observer

$\mathcal{O}_{1'}$, etc.. The hierarchy can be tangled in such a way that within $\mathcal{O}_{1'}$ there is a representation of $\mathcal{O}$. The situation is analogous to the hierarchy of a picture within a picture, or a story within a story, a movie within a movie, etc., as lucidly discussed by Hofstadter [48]. The concept of hierarchy of representations is illustrated in Fig. 5. In the left figure, the boy's first-person experience is represented as the scene in the bubble, which contains a landscape and a nearby girl. The girl's experience is represented as the scene in the inner bubble, which contains the same landscape. These two representations are not at the same hierarchical level. In the right figure, the situation is reversed. In the bubble is represented the girl's first-person experience that contains the landscape and the boy.

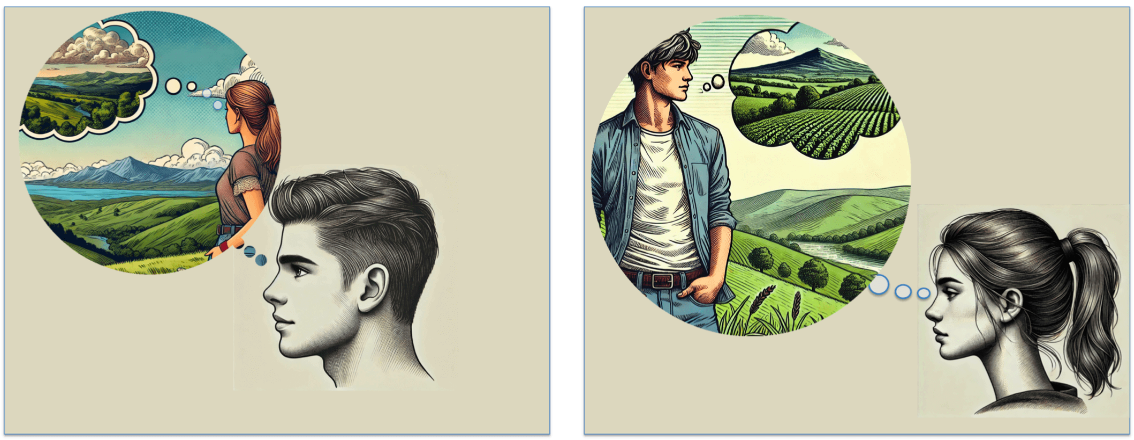

Figure 5. An illustration of the concept of hierarchy of representations. Left: The boy's first-person experience. Right: The girl's first-person experience.

The Everett interpretation does not take into account the above hierarchy of representations. Such a hierarchy indicates that the wave function is an observer-dependent concept (relative to an observer) and that there is no objective, universal wave function. What is objective is the totality of (i.e., the set of all) possible wave functions, associated with different observers. Thus, instead of the wave function $\psi_{\mathcal{O}}$, given in Eq. (15), which includes a representation of the observer $\mathcal{O}_{1'}$ à la Eq. (12), there exists as well a wave function $\psi_{\mathcal{O}_{1'}}$, associated with the observer $\mathcal{O}_{1'}$, in which the role of $\mathcal{O}$ and $\mathcal{O}_{1'}$ is interchanged:

$$\psi_{\mathcal{O}_{1'}} = \psi_{\{w'_1,w'_2,\ldots,\mathcal{O},\mathcal{O}_{2'},\mathcal{O}_{3'}\}} \tag{25}$$

As $\psi_{\mathcal{O}}$ includes a representation of the world seen by the observer $\mathcal{O}_{1'}$, so $\psi_{\mathcal{O}_{1'}}$ includes a representation of the world seen by the observer $\mathcal{O}$.

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From the totality of possible wave functions, associated with the observers that can communicate with each other, every one of those observers infers that there exists an objective world as a cross section of their private, relative, wave functions. These wave functions with a common cross section belong to a subspace of the Hilbert space of all possible quantum states. The latter space is spanned over the basis states of all possible configurations.

5. Quantization of wave function

We proposed an interpretation of quantum mechanics according to which the first-person experience of the universe is given by a wave function. Different first-person experiences of the universe are possible[13], given by the wave functions $\psi_{\mathcal{O}}$, $\psi_{\mathcal{O}'}$,$\psi_{\mathcal{O}''}$,... A wave function evolves according to the Schödinger equation, whose general solution contains the set of all possible wave functions. To obtain a particular solution, one must choose an initial condition, i.e., the value of the wave function at an initial time. This is similar to the law of motion in classical physics, $\ddot{x} + \partial V/\partial x = 0$, that contains a set of all possible trajectories $x(t)$, determined by the set of all possible initial conditions. But the classical theory is an approximation to the corresponding quantum theory in which position is not definite and the law of motion for position x is replaced by the law of motion for a wave function $\psi(x)$—the probability amplitude for observing a definite position x. But the wave function also does not always evolve deterministically—it may collapse. This indicates that the wave function itself must be quantized [49] so that the law of motion for the wave function is replaced by a law of motion for a wave functional $\Phi[\psi(x)]$—the probability amplitude of observing a definite wave function $\psi(x)$. We will now describe a procedure that leads to the quantization of the wave function [49] and explore its implications.

In quantum field theory, a state can be expressed in terms of multi-particle configurations according to[14]

$$|\Phi\rangle = \sum_r \int \mathrm{d}^3\mathbf{x}_1 \mathrm{d}^3\mathbf{x}_2 \dots \mathrm{d}^3\mathbf{x}_r \psi(\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_r) a^\dagger(\mathbf{x}_1) a^\dagger(\mathbf{x}_2) \dots a^\dagger(\mathbf{x}_r)|0\rangle, \tag{26}$$

where $a^\dagger(\mathbf{x})$ creates a particle with coordinates $\mathbf{x} = (x^1, x^2, x^3)$, and $\psi(\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_r)$ is a multi-particle wave function. The probability density of observing a configuration of particles at positions $\mathbf{x}_1$, $\mathbf{x}_2$, ..., $\mathbf{x}_r$ is given by $|\psi(\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_r|^2$.

From the Schrödinger equation for the state (26), one finds that a wave function $\psi(\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_r)$, $r = 0, 1, 2, \dots, r$ satisfies the Schrödinger equation

$$i\frac{\partial \psi(\mathbf{X}_r)}{\partial t} = \sum_s \mathcal{H}(\mathbf{X}_r, \mathbf{X}_s)\psi(\mathbf{X}_s), \tag{27}$$

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that can be derived from the action

$$I = \int \mathrm{d}t \left(\sum_r \int \mathrm{d}\mathbf{X}_r \psi^*(\mathbf{X}_r)\dot{\psi}(\mathbf{X}_r) - \sum_{rs} \int \mathrm{d}\mathbf{X}_r \mathrm{d}\mathbf{X}_s \psi^*(\mathbf{X}_r)\mathcal{H}(\mathbf{X}_r, \mathbf{X}_s)\psi(\mathbf{x}'_s) \right) \tag{28}$$

where we used the compact notation $\mathbf{X}_r \equiv (\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_r)$, $\mathrm{d}\mathbf{X}_r \equiv \mathrm{d}^3\mathbf{x}_1\mathrm{d}^3\mathbf{x}_2 \ldots \mathrm{d}^3\mathbf{x}_r$, and where $\mathcal{H}(\mathbf{X}_r, \mathbf{X}_s)$ denotes the matrix representation of a Hamilton operator including an interaction term.

A wave function $\psi(\mathbf{X}_r)$ evolves deterministically until, upon observation, it collapses into a narrower wave function, localized around a state $|\mathbf{X}_r\rangle \equiv |\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_r\rangle$. This means that the wave function, in general, does not evolve deterministically, but satisfies a more fundamental equation.

We can consider Eq.(28) as a classical action and quantize it by replacing ψ and its conjugated momentum ψ^* by operators

$$\psi(\mathbf{X}_r) \to \hat{\psi}(\mathbf{X}_r) \equiv A(\mathbf{X}_r), \quad \psi^*(\mathbf{X}_r) \to \hat{\psi}^*(\mathbf{X}_r) \equiv A^\dagger(\mathbf{X}_r), \tag{29}$$

satisfying the commutation or anticommutation relations

$$[A(\mathbf{X}_r), A^\dagger(\mathbf{X}'_s)]_\pm = \delta_{rs}\delta(\mathbf{X}_r - \mathbf{X}'_s), \tag{30}$$

$$[A(\mathbf{X}_r), A(\mathbf{X}'_s)]_\pm = 0, \quad [A^\dagger(\mathbf{X}_r), A^\dagger(\mathbf{X}'_s)]_\pm = 0. \tag{31}$$

Defining the vacuum state according to $A(\mathbf{X}_r)|0\rangle = 0$, the Fock space basis is given by the action of the creation operators $A^\dagger(\mathbf{X}_r)$ on $|0\rangle$.

A generic state is a superposition

$$|\widetilde{\Phi}\rangle = \sum_{kr} \int \mathrm{d}\mathbf{X}_{r1}\mathrm{d}\mathbf{X}_{r2} \ldots \mathrm{d}\mathbf{X}_{rk})\widetilde{\psi}(\mathbf{X}_{r1}, \mathbf{X}_{r2}, \ldots, \mathbf{X}_{rk})A^\dagger(\mathbf{X}_{r1})A^\dagger(\mathbf{X}_{r2}) \ldots A^\dagger(\mathbf{X}_{rk})|0\rangle. \tag{32}$$

The coordinates $\mathbf{X}_r$ embrace all sorts of configurations, including very complicated structures. If the meaning of $\mathbf{X}_r \equiv (\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_r) \equiv x^M$ is extended as in Sec. 2 to denote not only a system of r point particles, but also more complicated systems, they can describe the degrees of freedom of an observer. In our interpretation, this means that $\mathbf{X}_r$ parametrizes (conscious) perceptions—experiences—-associated with what the observer perceives as the degrees of freedom of the universe in which she lives. We can extend the meaning of $\mathbf{X}_r$ to include all degrees of freedom of consciousness, namely, the first-person experiences, including memories, thoughts, qualia in general, etc., as discussed in Sec. 3. Thus, a particular $\mathbf{X}_r = \mathbf{X}_r^{\mathcal{O}}$ represents here the parameters $\mathcal{O}$ given in Eqs. (19,20), and is analogous to the time capsules introduced by Barbour [43].

Eq.(32) describes a multi-configuration state $|\widetilde{\Phi}\rangle$, analogous to a multiparticle state $|\Phi\rangle$, given in Eq.(26). Writing $\mathbf{X}_{r1} \equiv \mathbf{X}_r$, the term with $k = 1$ in Eq. (32) reads

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$$|\widetilde{\Phi}\rangle|_{k=1} = \sum_r \int \mathrm{d}\mathbf{X}_r \widetilde{\psi}(\mathbf{X}_r) A^\dagger(\mathbf{X}_r)|0\rangle$$
$$= \sum_r \int \mathrm{d}^3\mathbf{x}_1 \mathrm{d}^3\mathbf{x}_2 \ldots \mathrm{d}^3\mathbf{x}_r \widetilde{\psi}(\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_r) A^\dagger(\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_r)|0\rangle. \tag{33}$$

It corresponds to Eq.(26) if $A^\dagger(\mathbf{X}_r) \equiv A^\dagger(\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_r) = a^\dagger(\mathbf{x}_1) a^\dagger(\mathbf{x}_2) \ldots a^\dagger(\mathbf{x}_r)$.

The operator $A^\dagger(\mathbf{X}_r)$ creates a state in the configuration $\mathbf{X}_r$,

$$|\mathbf{X}_r\rangle = A^\dagger(\mathbf{X}_{r1})|0\rangle. \tag{34}$$

Similarly to $|\mathbf{x}\rangle$ being called a single-particle position state, we will call $|\mathbf{X}_r\rangle$ a single-configuration state, hence

$$\mathbf{x} \text{ single particle position} \longrightarrow \mathbf{X}_r \text{ single configuration}$$

$$|\mathbf{x}\rangle \text{ single particle position state} \longrightarrow |\mathbf{X}_r\rangle \text{ single configuration state}$$

In particular, a configuration can be a self-referential configuration of Eqs. (19,20) —a time capsule[15] — parametrizing a momentary consciousness state of an observer, i.e., a state of the first-person experience.

For a special choice of the wave function in Eq. (33), $\widetilde{\psi}(\mathbf{X}_r) = \delta(\mathbf{X}_r - \mathbf{X}_r^{\mathcal{O}})$, we have for a fixed r that

$$|\Phi\rangle|_{rk=1} = A^\dagger(\mathbf{X}_r^{\mathcal{O}})|0\rangle \equiv |\mathbf{X}_r^{\mathcal{O}}\rangle. \tag{35}$$

In general, a realistic state is not so sharp; it is smeared by a wave packet $\widetilde{\psi}_{\mathcal{O}}(\mathbf{X}_r)$, centered around $\mathbf{X}_r^{\mathcal{O}} \equiv \mathcal{O}$:

$$|\Phi\rangle|_{rk=1} = \int \mathrm{d}\mathbf{X}_r \widetilde{\psi}_{\mathcal{O}}(\mathbf{X}_r) A^\dagger(\mathbf{X}_r)|0\rangle. \tag{36}$$

Omitting the tilde and writing $\mathbf{X}_r \equiv x^M$, the wave function $\widetilde{\psi}_{\mathcal{O}}(\mathbf{X}_r) \equiv \psi_{\mathcal{O}}(x^M) \equiv \psi_{\mathcal{O}}$ is the same as the wave function considered in Secs. 2 and 3. The discussion in the previous sections thus holds for a single configuration state of the general, multi-configuration state $|\widetilde{\Phi}\rangle$ in Eq. (32). How then to interpret those multi-configuration states?

A multi-configuration wave function $\psi(\mathbf{X}_{r1}, \mathbf{X}_{r2}, \ldots, \mathbf{X}_{rk})$ is the probability amplitude of observing a set of configurations $\mathbf{X}_{r1}, \mathbf{X}_{r2}, \ldots, \mathbf{X}_{rk}$, $k = 0, 1, 2, \ldots, \infty$. In particular, for the configurations which are time capsules, a multi-configuration wave function determines the probability amplitude of observing those time capsules. In other words, how likely consciousness finds itself experiencing those time capsules. According to Sec. 3, this means how likely a given state of first-person experiences will collapse into those basis (definite) states of experience. A single-configuration wave function determines how likely consciousness would experience upon observation one particular time capsule, $\mathbf{X}_r = \mathbf{X}_r^{\mathcal{O}} \equiv \mathcal{O}$.

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A two-configuration wave function, $\psi(\mathbf{X}_{r1}, \mathbf{X}_{r2})$, determines how likely consciousness experiences two configurations at once. In the case of two time capsules, it means that consciousness experiences being in two observers, $\mathcal{O}$ and $\mathcal{O}'$, at once. Normally, this would be a rare event. Consciousness typically experiences being in a single observer only.

A two-configuration state is given as a superposition of the basis states $A^\dagger(\mathbf{X}_{r1})A^\dagger(\mathbf{X}_{r2})|0\rangle$. The superposition coefficients, namely the wave packet profiles $\psi(\mathbf{X}_{r1}, \mathbf{X}_{r2})$, are either symmetric or antisymmetric with respect to the interchange of $\mathbf{X}_{r1}$ and $\mathbf{X}_{r2}$, depending on whether the creation operators are commuting or anticommuting. Examples of antisymmetrized probability densities $|\psi(\mathbf{X}_{r1}, \mathbf{X}_{r2})|^2$ are illustrated in Fig. 6.

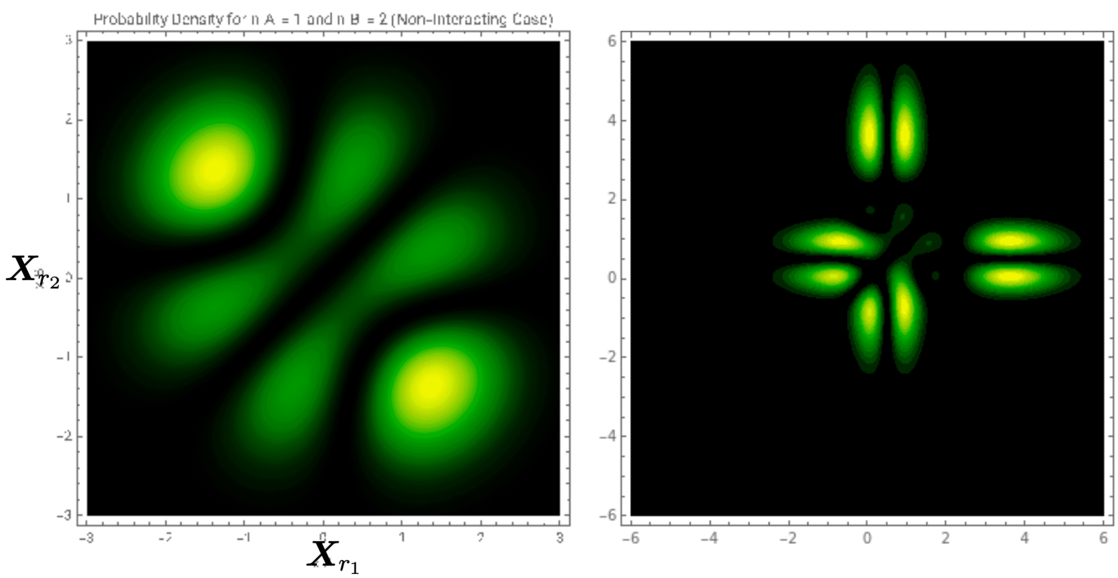

Figure 6. Examples of the two-configuration probability density $|\psi(\mathbf{X}_{r_1}, \mathbf{X}_{r_2})|^2$ for an antisymmetric wave function. As a model for the plot, we took excited states of the harmonic oscillator.

Explicitly, a quantum state (32) for a fixed r is[16]

$$|\Phi\rangle = \int \mathrm{d}\mathbf{X}_{r1}\,\psi(\mathbf{X}_{r1})A^\dagger(\mathbf{X}_{r1})|0\rangle + \int \mathrm{d}\mathbf{X}_{r1}\,\mathrm{d}\mathbf{X}_{r2}\,\psi(\mathbf{X}_{r1}, \mathbf{X}_{r2})A^\dagger(\mathbf{X}_{r1})A^\dagger(\mathbf{X}_{r2})|0\rangle + \ldots$$
$$= |\Phi_1\rangle + |\Phi_2\rangle + \ldots \tag{37}$$

Its norm,

$$\langle\Phi|\Phi\rangle = \langle\Phi_1|\Phi_1\rangle + \langle\Phi_2|\Phi_2\rangle + \ldots = 1, \tag{38}$$

is conserved in time[17].

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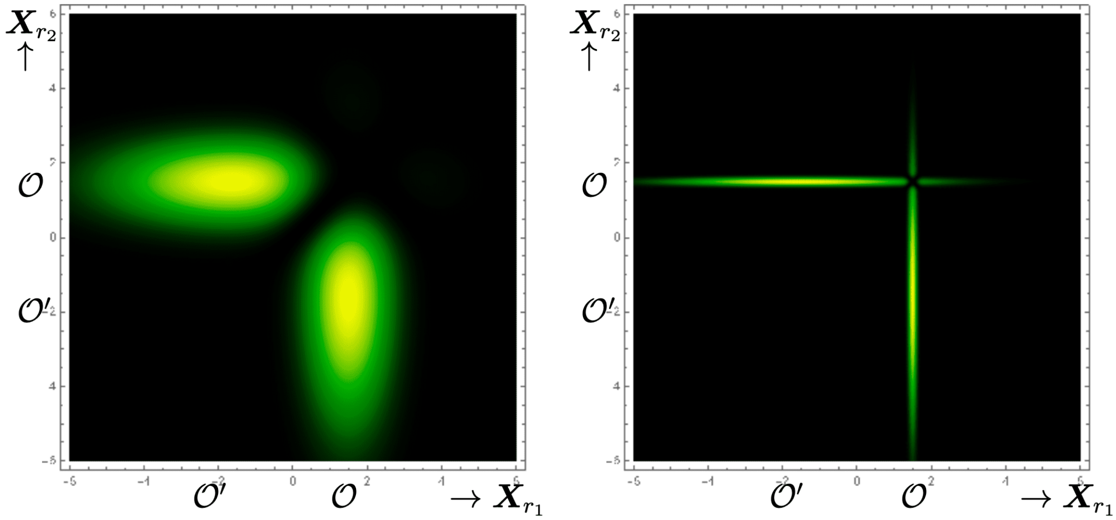

Figure 7. An example of the two-configuration probability density $|\psi(\mathbf{X}_{r_1}, \mathbf{X}_{r_2})|^2$, before and after the collapse into a narrow wave packet around the configuration associated with the observer $\mathcal{O}$, while remaining a wide wave packet around the configuration $\mathcal{O}'$, associated with the other observer.

For an observer, say, $\mathcal{O}$, the probability is normally concentrated on a single-configuration state, $|\Phi_1\rangle$, while the probabilities of multiple-configuration states are negligible. But in general, under suitable interactions, they could be excited. This means that in such cases, not only the consciousness states of the observer $\mathcal{O}$, but also of other observers, $\mathcal{O}_{1'} \equiv \mathcal{O}'$, $\mathcal{O}_{2'} \equiv \mathcal{O}''$,..., could be experienced at once to a certain extent. The multi-configuration state (37), which in our interpretation is the multi-observer consciousness state, provides a possible theoretical explanation of some states of consciousness (states of first-person experiences) that occur during sleep. Moreover, not only dreams, but also meditation and other atypical states of consciousness, could be explained as particular cases of the generic state (37).

In particular, this theory predicts the existence of such entangled states in which the first-person experience of an observer $\mathcal{O}$ would also include—to a certain degree of accuracy—the experience of another observer, $\mathcal{O}'$, and in the case of a multi-configuration state, several observers at once. If this framework is correct, an observer in such a state would have a direct experience correlated with another observer's state, without requiring classical information transfer. In principle, this could imply a mechanism by which an individual becomes aware of another person's experience, consistent with reported but unverified phenomena often categorized as 'anomalous cognition.' [18] However, this should not be interpreted as an endorsement of such claims but rather as a natural mathematical consequence of the proposed structure.

An example of an entangled two-configuration state is given in Fig.7. Before collapse, the state is spread over a wider range of possible first-person experiences in both configurations. After the collapse onto one of the two configurations, say the one associated with the observer $\mathcal{O}$, the first-person experience is concentrated at that configuration, while it remains blurred as a wider wave-packet around the configuration $\mathcal{O}'$. Because of the antisymmetricity of the wave function, a change of first-person experience in one configuration is reflected in the corresponding change of first-person experience in the other configuration. This is illustrated in Fig. 8.

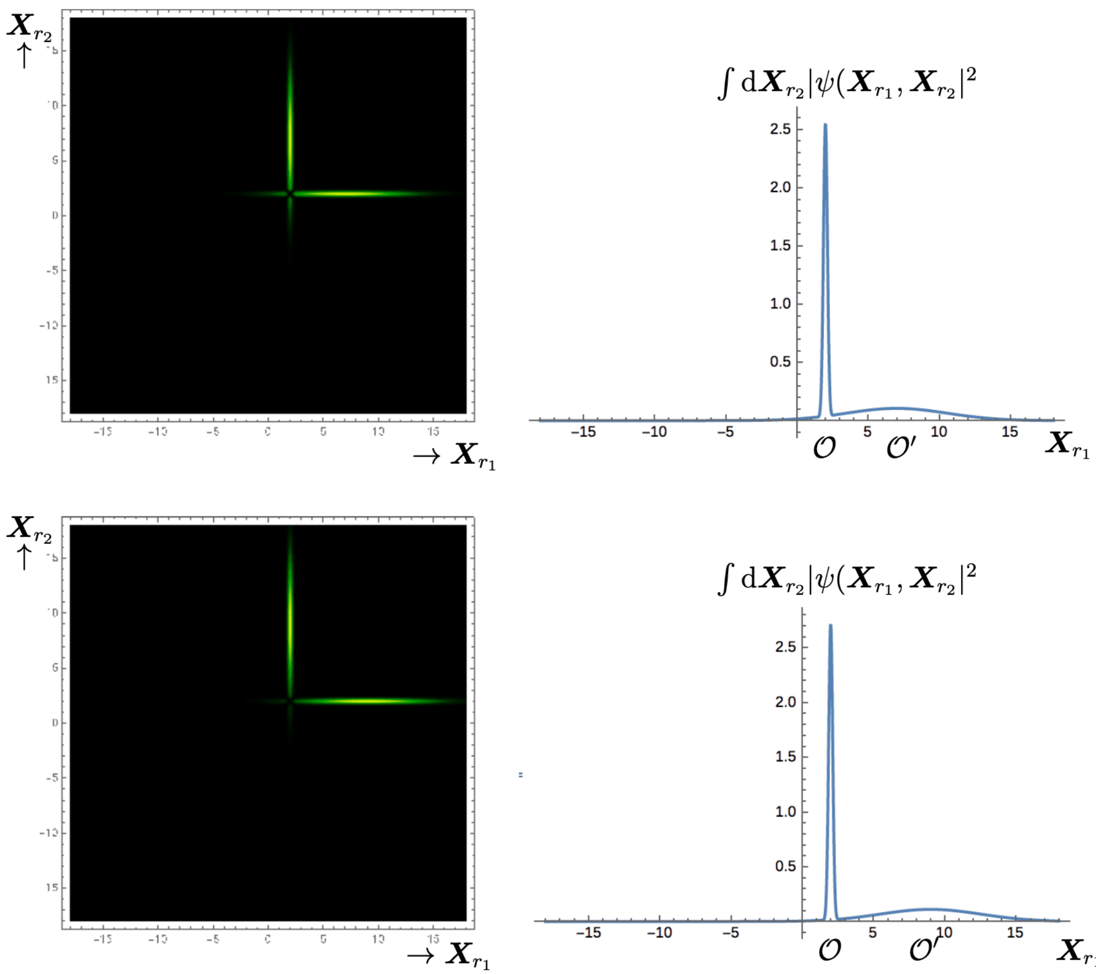

Figure 8. An example of the change of a two-configuration state, illustrating the entanglement of the observers $\mathcal{O}$ and $\mathcal{O}'$. The first-person experience is spread over both observers, sharply around $\mathcal{O}$, and blurred around $\mathcal{O}'$. In the lower plot, the position of the configuration $\mathcal{O}'$ of the local maximum is slightly shifted to the right in comparison to the position in the upper plot. The observer $\mathcal{O}$, entangled with the observer $\mathcal{O}'$, is thus aware that something has happened to $\mathcal{O}'$. Because the wave packet around $\mathcal{O}'$ is wide, the (conscious) experience associated with such an entangled state cannot know what precisely has happened.

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A two-configuration entangled state of first-person experience could form if two persons are in a close relationship, e.g., a mother and child, a married couple, identical twins, etc. The entanglement persists even when the persons are separated.

A multi-configuration entangled state among many persons might form in a crowd and manifest itself as collective consciousness. It could also form in a flock of birds, a swarm of bees, a school of fish, etc., which move synchronously as a single organism. In such a case, the $|\psi|^2$ of the entangled multi-configuration state is not more sharply peaked around one particular individuum, but is more or less equally distributed over all individua, as schematically illustrated in Fig. 9.

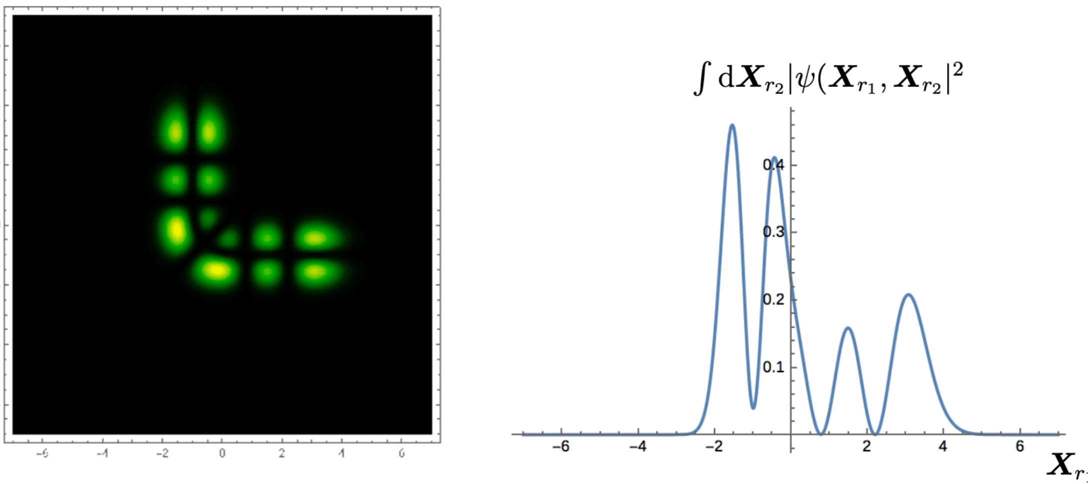

Figure 9. An example of the two-configuration probability density $|\psi(\mathbf{X}_{r_1}, \mathbf{X}_{r_2})|^2$ that is not predominantly peaked around any particular configuration, but exhibits several local peaks of comparable sizes.

A single-configuration within a multi-configuration state can parametrize:

a. the first-person experience of a human, a bird, a bee, a fish, etc.,

b. the first-person experience of a single cell, for instance, a neuron.

Let us assume that a neuron has a rudimentary first-person experience. Then, along the analogous lines as discussed above, a generic state is a superposition of multi-neuron first-person experiences. This means that besides a single neuron first-person experience state, there can exist a state in which first-person experience is spread over several or many neurons. This is precisely what happens in the brain: neurons together form an entangled state of first-person experience. Similarly, a flock of birds may form an entangled state of first-person experience associated with the flock as a whole. Such a state must be distinguished from the state associated with me, observing the flock of birds. In the latter case, the flock of birds is a subset of the configurations parametrizing my first-person experience, as explained in the previous sections. One wave function is ψ_{flock}, the other one is ψ_{me}[19]. They represent two different first-person experiences, analogous to those illustrated in Fig. 5.

It is important to acknowledge that discussions of nonlocal correlations in conscious experience intersect with domains often regarded with skepticism in mainstream science. However, history has shown that certain once-dismissed concepts—such as quantum entanglement itself—eventually became core aspects of physical theory once experimental evidence emerged. The predictions outlined here should be viewed as hypotheses emerging from the mathematical structure of the framework, rather than as claims requiring immediate acceptance.

Future work should focus on whether such correlations can be rigorously tested using controlled experimental conditions. If such correlations were ever empirically observed, they would require an explanation, whether within this framework or an alternative one. Regardless of the outcome, the fact that quantum mechanics naturally allows for such possibilities suggests that the relationship between consciousness and fundamental physics deserves further careful exploration.

6. Discussion and Conclusion

In this work, we have explored the deep interconnection between the observer, consciousness, and the quantum wave function. Extending the framework of Everett's many-worlds interpretation, we proposed that the wave function is not an objective, universal entity, but one that is relative to each observer. More precisely, we argued that the wave function is a mathematical representation of the states of consciousness—defined as the states of first-person experience. Within this framework, every observer exists in a unique quantum reality, shaped by the evolution of their conscious experience.

This perspective suggests a fundamental rethinking of how reality itself is constructed, emphasizing the active, participatory role of consciousness in the unfolding of the universe. In fact, we identified the unfolding of consciousness with the unfolding of an experienced universe, this process being described by the evolution of a wave function. Thus, quantum mechanics—long regarded as one of the most enigmatic theories in science—may find a deeper resolution through the inclusion of the conscious observer as an integral part of its formalism. By embedding the observer within the quantum framework in the way proposed in this paper, we offer a potential solution to long-standing conceptual issues, such as the measurement problem. Specifically, we argued that wave function collapse occurs when its degrees of freedom contain a self-referential loop concerning the outcome of a measurement.

Our model emphasizes the need for a paradigm shift in quantum mechanics, one that fully acknowledges consciousness as a fundamental, irreducible entity. This challenges the traditional notion of an objective, observer-independent universe and instead highlights the subjective nature of the universe. Since there is not only one such subjective universe, associated with a wave function concentrated on a "time capsule," but there are many of them, our model escapes solipsism. Namely, the totality of all possible subjective universes can be regarded as objective reality. Mathematically, it is described as the Hilbert space of all possible quantum states associated with subjectively experienced universes. Furthermore, this perspective offers a novel way of interpreting atypical conscious experiences—such as dreams, meditation, and altered states of awareness—as manifestations of wave function spreading in the absence of measurement, and also of a multi-configuration state.

"The hard problem of consciousness, in the way it is usually thought of, is harder than hard, it's impossible" [50]. In our framework, consciousness is fundamental; it is not something to be explained in terms of brain activity, because the brain itself—like all perceived physical structures—exists within consciousness. Attempts to explain (my) consciousness as an activity of my brain are akin to a serpent eating its own tail: a self-referential paradox. Similarly, explaining another person's consciousness through their brain activity (as I observe it) conflates different representational levels, since any observed neural processes are themselves mere representations within my conscious experience. It is like a picture within a picture, a story within a story... .

Let me emphasize once more: our interpretation does not imply solipsism. The wave function is a representation of a quantum state, which we interpret as a state of consciousness. Many such states exist. One is such that you experience yourself being a person A, perceiving a world that includes person B as a representation in consciousness. Another wave function (quantum state) is such that you experience yourself being person B, perceiving a world that includes person A. There is a common cross-section world shared by both persons (and all others), which they interpret as an objective reality. In both cases, there is the "I"—the first-person experience, the "me feeling". Consciousness is fundamental; the "external" world is a part of consciousness, and yet, in this framework, there is no solipsism. Objective reality is the Hilbert space of all possible quantum states, associated with different possible states of consciousness perceiving the world. Thus, in a simplified and compact form, one could say that quantum mechanics is a mechanics of consciousness.

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The perspective developed in this paper suggests a radical yet structured reformulation of physical reality. It provides a coherent way to interpret quantum states without resorting to an external reality, while still maintaining an objective structure. By doing so, it offers a new perspective on the measurement problem, the role of the observer, and the ontology of quantum mechanics.

While this proposal may initially seem to blur the boundary between physics and philosophy, it is deeply rooted in the well-established mathematical framework of quantum mechanics. It does not claim to dismiss or invalidate existing interpretations but instead provides an alternative conceptual foundation that may lead to new insights. Naturally, questions remain—particularly regarding the precise mechanism by which the perceived classical reality emerges from this space of conscious experiences. The elements of the latter space—especially perceptual experiences that are relevant for physics—need to be properly identified, classified, mathematically described in detail, and connected to the observables of quantum mechanics. These open issues present promising avenues for future theoretical and empirical exploration.

Ultimately, this paper aims to stimulate further discussion and inquiry rather than to present a final answer. After all, even a century after the discovery of quantum mechanics, its foundations remain enigmatic and controversial. Therefore, the time has come to explore out-of-the-box ideas that extend beyond current domains. If consciousness and quantum mechanics are indeed intertwined at a fundamental level, then reconsidering the nature of reality in these terms may be a crucial step toward a deeper understanding of both.

Footnotes

1 For simplicity, we occasionally omit T and write $\psi(x^M)$.

2 A more precise definition of the observer as a machine or an automaton with a memory sequence was provided by Everett [1][2][3]. His definition applies as well to the human or whatever brain, and the phrases such as “the machine is aware of A”, or, “the machine perceived A”, are justified and have a precise meaning. According to Everett “... all the customary language of subjective experience is quite applicable to such machines, and forms the most natural and useful mode of expression when dealing with their behavior, as is well known to individuals who work withe complex automata”.

3 This metaphor is taken from Barbour’s book “The End of Time” [43].

4 With a proper normalization of $\langle x^M|\psi\rangle$, such that it is a density of a suitable weight, no determinant of the configuration space metric need to occur in $\mathcal{D}X^M$ (see [51][32]).

[5] Here physics touches biology, and especially neuroscience, where much effort is devoted to understanding the relationship between conscious experiences and neural correlates in brains [47][34][35][23][24]. A detailed model is beyond the scope of this section, aiming at providing a conceptual background for further development of this important topics (see also [52]). A further elaboration is in Sec. 3.

[6] For a more formal discussion of these ideas see Sec. 3.

[7] In the case of a continuous observable, the wave function with a broader wave packet collapses into a wave function with a narrower wave packet.

[8] Recall that wave function represents a quantum state which, according to the paradigm adopted here, is the state of your consciousness.

[9] Notice the difference between the symbol C, used here, and the symbol $\mathcal{C}$, used in the previous section.

[10] Here we change the notation so that for other observers, instead of $\mathcal{O}'$, $\mathcal{O}''$, $\mathcal{O}'''$, ..., we use the symbols $\mathcal{O}_{1'}$, $\mathcal{O}_{2'}$, $\mathcal{O}_{3'}$,...

[11] We leave aside here the fact that such a representation, because of the limits of the monitoring, is only approximate. Instead of monitoring by an instrument, the observer $\mathcal{O}$ can just communicate with $\mathcal{O}_{1'}$ in a usual way, from which $\mathcal{O}$ infers that $\mathcal{O}_{1'}$ has an internal representation of the outside world that more or less corresponds to $\{w_1, w_2, \ldots w_i, \ldots\}$. Concerning other observers, $\mathcal{O}_{2'}, \ldots, \mathcal{O}_{r'}$, she infers that they also have an internal representation of the external world.

[12] Analogously, a Xerox copy is not an exact reproduction of the original document.

[13] This means that I can be a person A, or I can be another person, say, B, or any other person.

[14] We referred to such expansion in Sec. 2.

[15] We will occasionally use this suggestive name, though the parametrization of configuration space here differs from Barbour's parametrization. Moreover, in our setup, we admit in the configuration space the existence of trajectories $\mathbf{X}_r(\tau)$ —worldlines—parametrized by a parameter τ. In particular, there can be worldlines in $\mathcal{C}$ traced by time capsules.

[16] For simplicity, now we omit tilde.

[17] This follows from the Schrödonger equation $i\partial|\Phi\rangle/\partial\tau = H|\Phi\rangle$ and hermicity of the Hamilton operator, $H^\dagger = H$. For the purpose of this paper it is not necessary to write the explicit H. This is elaborated in Ref. [53].

[18] In the past, scientists had rejected outright and considered as nonsense several unusual phenomena such as i) the connection between the moon and tides, reported by fishermen and sailors, ii) falling stones from the sky, reported by farmers, iii) the connection between doctors' handwashing and reduced maternal mortality, observed by Ignaz Semmelweis[54]. All those observation had been considered as nonsense, a fiction, because they had no explanation within the science of the epoch.

[19] Nagel[55] asked "What is it like to be a bat?". In our setup, the relevant questions are "'What is it like to be a single bird?" or "What is it like to be a flock of birds?", contrasted to your or my everyday experience of "being me".

References

1. a, b, c, d *H. Everett, "Relative State" formulation of quantum mechanics, Rev. Mod. Pys., 29, 454–462 (1957).*
2. a, b, c, d *H. Everett, On the Foundations of Quantum Mechanics, Thesis, Princeton University (1956), pp 1–140.*
3. a, b, c *H. Everett, Theory of the Universal Wavefunction, in "The Many-Worlds Interpretation of Quantum Mec hanics" (Eds. B. S. DeWitt and N. Graham, Princeton Univ. Press, 1973), pp. 3–140.*
4. ^ *R. Penrose, S. Hameroff, Consciousness in the universe: A review of the 'Orch OR' theory, Physics of Life Revi ews, 8 (2), 48-93 (2011).*
5. ^ *R. Penrose, Shadows of the Mind: A Search for the Missing Science of Consciousness (Oxford University Pres s, Oxford, 1994).*
6. ^ *S. Hameroff, R. Penrose, Orchestrated objective reduction of quantum coherence in brain microtubules: A m odel for consciousness, Neuroquantology, 4(1), 49-62 (1996).*
7. ^ *S. Hameroff, The 'consciousness' of quantum processes in the brain: A review of the Orch OR model, Journal of Consciousness Studies, 14 (1), 23-36 (2007).*
8. a, b, c *W. H. Zurek, Pointer basis of quantum apparatus: Into what mixture does the wave packet collapse?, Phy s. Rev. D 24, 1516–1525 (1981).*
9. a, b, c *W. H. Zurek, Decoherence and the transition from quantum to classical, Physics Today 44,36–44 (1991).*
10. a, b, c *W. H. Zurek, Decoherence, einselection, and the quantum origins of the classical, Reviews of Modern Phy sics, 75 (3), 715?-775. (2003).*
11. ^ *D. Bohm, A Suggested interpretation of the quantum theory in terms of hidden Variables, I and II, Physical Review, 85 (2), 166-193 (1952).*

12. ^J. S. Bell, Speakable and Unspeakable in Quantum Mechanics (Cambridge University Press, Cambridge, UK,1987).

13. ^B. D'Espagnat, In Search of Reality (Springer-Verlag, New York,1983).

14. ^S. Goldstein, Quantum theory without observers, Phys. Today 51, 42–47 (1998).

15. ^G. C. Ghirardi, P. Pearle, A. Rimini, Markov processes in Hilbert space and continuous spontaneous localization of the wave function, Physical Review A, 4bf 2 (1), 78-89 (1990).

16. ^A. Bassi, K. Lochan, S. Satin, T. P. Singh, H. Ulbricht, Models of wave-function collapse, underlying theories, and experimental tests, Reviews of Modern Physics, 85 (2), 471-527 (2013).

17. a, bB. S. DeWitt, Graham, N. The Many-Worlds Interpretation of Quantum Mechanics (Princeton University Press. Princeton, NJ, 1973).

18. a, b, c, d, eHervé Zwirn, The Measurement problem: Decoherence and convivial solipsism, Found. Phys. 46, 635 (2016).

19. a, b, c, d, eHervé Zwirn, Everett's interpretation and convivial solipsism, Quantum Rep. 5, 267? 281, (2023), https://doi.org/10.3390/ quantum5010018.

20. ^F. London, E. Bauer, La Th orie de L'observation en M canique Quantique (Hermann, Paris, 1939).

21. ^J. Von Neumann, Mathematical Foundations of Quantum Mechanics (Princeton University Press, Princeton, NJ, 1955).

22. ^E. P. Wigner, Remarks on the mind-body question, in "Symmetries and Reflections: Scientific Essays" (MIT Press, Cambridge, MA, 1961).

23. a, b, cH. P. Stapp, Quantum theory and the role of mind in nature, Foundations of Physics, 31 (10), 1465-1499 (2001).

24. a, b, cH. P. Stapp, Quantum Theory and Consciousness: An Overview of the von Neumann/Wigner Interpretation (Springer, Cham, Switzerland, 2017).

25. ^D. J. Chalmers, "The Conscious Mind": In Search of a Fundamental Theory (Oxford University Press, Oxford, UK, 1996).

26. ^M. Kafatos, R. Nadeau, The Conscious Universe: Parts and Wholes in Physical Reality (Springer, New York, 2000).

27. a, bM. Pavšič, Towards understanding quantum mechanics, general relativity and the tachyonic causality paradoxes, Lett. Nuovo Cim. 30 (1981) 111

28. a, b, c, d, e, fM. Pavšič, On the quantization of gravity by embedding space-time in a higher dimensional space, Class. Quant. Grav. 2, 869 (1985), Arxive:1403.6316 [gr-qc].

29. a, b, c, d, e, f, g, h*M. Pavšič, Classical theory of a space-time sheet, Phys. Lett. A 107, 66-70, (1985).*

30. a, b, c*M. Pavšič, On the interpretation of the relativistic quantum mechanics with invariant evolution parameter, Found. Phys. 21, 1005-1009, (1991)*

31. a, b, c, d, e, f, g*M. Pavšič, The Embedding model of induced gravity with bosonic sources, Found. Phys. 24, 1495-1518, (1994).*

32. a, b, c, d, e, f, g, h, i, j*M. Pavšič, The Landscape of Theoretical Physics: A Global View; From Point Particles to the Braneworlds and Beyond, in Search of a Unifying Principle (Kluwer Academic, 2001).*

33. ^*B. Rosenblum, F. Kuttner, The observer in the quantum experiment, Found. Phys. 32, 1273–1293, (2002).*

34. a, b, c, d*H. Zeh, On the interpretation of measurement in quantum theory, Found. Phys. 1 69–76, (1970).*

35. a, b, c, d, e*H. D. Zeh, The strange (hi) story of particles and waves, Z. Naturforsch. A 71, 195–212, (2016) [arXiv:1304.1003 [physics.hist-ph]].*

36. ^*J. A. Wheeler, Quantum mechanics, a half century later include the observer in the wave function, Episteme 5, 1– 18 (1977).*

37. ^*J. A. Wheeler, The computer and the universe, International Journal of Theoretical Physics 21, 557–572, (1982).*

38. ^*J. A. Wheeler, On reccognizing "law without law", Am. J. Phys. 51 (5), 398–404, (1983).*

39. ^*J. A. Wheeler, Information, physics, quantum: The search for links, in "Complexity, Entropy, and the Physics of Information" (Zurek W. Ed., Wesley, Redwood, California, 1990).*

40. ^*J. A. Wheeler and K. Ford, It from bit, In "Geons, Black Holes & Quantum Foam: A life in Physics" (Norton, New York, 1998)*

41. ^*M. Pavšič, Klein-Gordon-Wheeler-DeWitt-Schrödinger Equation, Phys. Lett. B 703, 614 (2011) [arXiv:1106.2017 [gr-qc]].*

42. ^*M. Pavšič, A Novel approach to quantum gravity in the presence of matter without the problem of time, Int. J. Mod.Phys. A 35 04, 2050015, (2020), [arXiv: 1906.03987 [physics.gen-ph]].*

43. a, b, c, d, e*J. Barbour, The End of Time (Oxford Univ. Press, 1999).*

44. ^*J. Barbour, B. Z. Foster, N. Ó Murchadha, Relativity without relativity, Class. Quant. Grav. 19, 3217–3248 (2002).*

45. ^*J. Barbour, Scale-invariant gravity: particle dynamics, Class. Quant. Grav. 20, 3217–3248 (2002).*

46. a, b*D. Podolskiy, R. Lanza, On decoherence in quantum gravity, Ann. Phys. (Berlin) 528, 663–676 (2016).*

47. a, b*See e.g. http://www.neuroscientificallychallenged.com/glossary/neural-correlate/ and https://en.wikipedia.org/wiki/Neural_correlates_of_consciousness*

48. ^*D. R. Hofstadter, Gödel, Escher, Bach: The Eternal Golden Braid (Penguin Books, London, 1979).*

49. a, b*M. Pavšič, A novel view on successive quantizations, leading to increasingly more "miraculous" states, Mod. Phys. Lett. A 34 23, (2019) [arXiv: 1901.01762 [hep-th]].*

50. ^*https://www.theintrinsicperspective.com/p/consciousness-as-a-godel-sentence/comments*

51. ^*M. Pavšič, Relativistic quantum mechanics and quantum field theory with invariant evolution parameter, Nuovo Cim. A 104, 1337-1354,. (1991).*

52. ^*R. Lanza, A new theory of the Universe, Am. Scholar 76, 18 (2007).*

53. ^*M. Pavšič, A new perspective on quantum field theory revealing possible existence of another kind of fermions forming dark matter, Int. J. Geom.Meth. Mod. Phys. 19 12, 2250184, (2022), [arXiv: 2205.02787 [physics.gen-ph]].*

54. ^*https://en.wikipedia.org/wiki/Ignaz_Semmelweis*

55. ^*T. Nagel, What Is It Like to Be a Bat?, The Philosophical Review,83 (4), 435-450, doi:10.2307/2183914. JSTOR 2183914, (1974).*

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