# The Quantum-Mechanical Frame of Reference

## Part 1: Many-Worlds Reality

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Abstract: Epistemological interpretations of quantum mechanics, such as QBism and the many-minds theories, are criticised for lack of ontology and their anthropocentric nature. However, if the well-established physics of Everett's formulation is taken at face value, an inherent physical ontology emerges: the superposition of all worlds containing the perceiving subject, the protagonist of the dynamics. The anthropocentric nature of the solution is a feature not a flaw: it is the nature of the operational subject of the dynamics that is the explanatory principle missing from the physics.

The observer, the physical entity, is always just the measuring instrument, as specifically defined by Everett. It is the state of the memory, the record of observations, the *product* of the observer mechanism, that is the protagonist in the observation dynamics. It is the effective physical environment of *this* entity, the superposition of all quasi-classical worlds in which it exists, that is encountered as the physical world, and of which the weird phenomena are revealed by experiment. This is Everett's relative state, thus problems of measurement and locality do not arise. Nonetheless, psi-ontology holds in both types of world.

The objective physical world is essentially classical, as understood in the current paradigm, while the world encountered by the conscious individual is the 'world superposition', literally a many-worlds reality. *This* is the quantum-mechanical frame of reference of the perceiving subject. This second-logical-type phenomenon forms a quasi-autonomous domain. The great quantum paradoxes exist because the system is functionally bi-level, and the two dynamics, linear and collapse, operate solely in their respective domains.

# 1 Overview

> ... the foundational work of John Bell and others has now revealed that any realist construal of quantum mechanics, if it is to reproduce the predictions of the conventional theory, must inevitably conflict with deeply rooted and intuitively appealing principles of classical physics or of common sense. (Lockwood, 1996, p. 159)

A realist construal is achieved quite simply by giving up a single, albeit highly significant, common-sense notion. The relevant subject in the observation dynamics is not the observer in the conventional sense, the physical entity, but its product, the perceptual reality defined by the record of observations.

Everett (1957, p. 457) defines the observer as the physical mechanism that formulates observations, and records them in memory: a classical measuring instrument. The term observer is here reserved for this physical entity, in humans the body-mind. The term body-mind is used to refer to the whole physical system, including the neuro-endocrinal information-processing system that gives rise to the observations made. The term individual is used to refer to the state of the memory in Everett's formulation, which he defines as the record of observations. This is the operational subject in the observation dynamics; as he states, it is: “Judged by the state of the memory” (1957, p. 462) that the collapse dynamics operates. As will be shown, it is the properties of the quantum state of the effective physical environment of *this* type of entity that are revealed in quantum physics experiments.

The key point is that two quite different types of frame of reference are defined in the new physics. As stated by Tegmark:

> … the development of relativity theory and quantum mechanics has taught us that we must carefully distinguish between two different views of a mathematical structure:
>
> - The bird perspective or outside view, which is the way a mathematician views it.
> - The frog perspective or inside view, which is the way it is perceived by a [self-aware substructure] in it. (1998, p. 23)

As he goes on to say, understanding how to predict the latter from the former is a major challenge. As described in detail by Barrett (1999) a century of exploration has not revealed the secret.

The key is at the heart of Everett's formulation. It is an entirely natural supposition that the inside view is defined by the outside view, objectively it could be no other way, but this is not the whole story. As Everett describes, *on* the inside view, the observations made are determinate while the rest of the world, including the body-mind of the observer, is not. No explanatory principle is given, thus debate continues

about the full meaning of his theory. As shown here, not only are the two types of frame of reference fundamentally different in kind, but both are ontologically fundamental. As a result, on each view the other is effectively subsidiary with respect to the process of observation.

As described in Section 2, the inside view, a structure of information, is the central component of Everett's formulation. It is with respect to the state of the memory that the probabilistic predictions of quantum theory are shown to operate. As described in Section 3, in the human neural system this takes the form of a three-dimensional field of information, akin to a hologram. This is the perceptual reality of the human observer: a virtual-reality representation of the world, formed by the integrated synthesis of all the observations made, mentally projected onto the surrounding space. This is here referred to as the world hologram.

As described in Section 4, the world hologram is multiply instantiated in the no-collapse universe of the unitary wave function: there are many versions of a quasi-classical world in the universe which contain it. These worlds are coincident and superposed, thus *on* the inside view of the world hologram the net result is their superimposed sum, here the 'world superposition'. The world of this inside view, meaning the effective physical environment, operates as described in QBism (Fuchs et al., 2013). As shown, it is by definition determinate only where observed.

This reveals the explanatory principle that makes sense of the great paradoxes. The world of the inside view is a completely different type of thing to the quasi-classical world of the current paradigm. It is a phenomenon of different logical type. Russell (1908) draws the essential distinction between a set, or a class, and its elements. The world of the inside view is a class-of-worlds-as-a-world. It is a second-logical-type phenomenon, and in consequence operates a dynamics not possible in the physical. This is Everett's (1957) relative state. It is for lack of such an explanatory principle that his theory has been incomprehensible no matter how it is approached, as Barrett (ibid) describes. Naturally, this world is ontologically fundamental.

The central principle is alien, but straightforward. As described in Section 6, in the physics of observation, the observer, the physical body-mind, is simply a complex and sophisticated measuring instrument, the observable being the sensorium: the representation of the state of the physical environment as reported by the sensory apparatus. The *product* of this process over time is the world hologram; and it is *this* entity that is the operational protagonist in the quantum-mechanical dynamics of observation, the collapse dynamics. At the centre of this field of information is the self concept, the three-dimensional virtual reality formed by the record of observations of the observer itself. This is the record of machine configuration in Everett's formulation.

It is only the definition of the operational protagonist in reality that needs to change in order to give a complete solution to the quantum paradoxes. All the existing physics is retained with its deeply rooted and intuitively appealing principles. This produces an interpretation akin to many-minds, but is more correctly a many-perceptions

framework as proposed by Page (2011). Lockwood's (1989) many-minds theory operates on this basis, defining the mind as the record of observations.

Like QBism, such approaches resolve the paradoxes but have no ontology. This is provided by the concept of world superposition: the physical reality encountered, and of which the properties are revealed by experiment, is a class-of-worlds-as-a-world. The current paradigm is maintained unchanged except for the addition of this second-logical-type phenomenon as ontologically fundamental. As described in Section 7, the apparent paradoxes of Schrödinger's cat (1935) and Wigner's friend (1961) are simply features of this type of frame of reference.

On both inside and outside views, the physical state of the system is precisely defined by the quantum state. Psi-ontology, meaning that the quantum state completely defines physical reality, holds in both contexts. General acceptance of the quantum state as the definition of physical reality is questioned because the seemingly weird phenomena in the mechanics are self-evidently impossible in objective physical reality. Given the two different types of frame of reference, however, the situation is clear: the physically impossible phenomena operate only on the inside view, in the many-worlds reality of the individual subject. Crucially, this is an emergent property not of a specific quasi-classical world, but of an entire class of worlds.

The determinacy of this class-of-worlds-as-a-world is defined by the record of observations, a structure of information. This is the domain in which the collapse dynamics operates. Thus there is no need to consider the quantum state defined by the wave function as anything other than fundamental. There is nothing 'deeper'. It is fundamental; and it does not incorporate the collapse dynamics. The existing physics of quantum mechanics is, however, complete. As demonstrated by Everett there is the appearance of collapse; the missing explanatory principle is that this operates at a different level of logical type. On the inside view, however, effectively, this is a real physical phenomenon. Thus the inside view is quasi-autonomous: collapse happens only here. Thus the measurement problem does not arise, as described in Section 9.

# 2 The Inside View

As stated by Greaves, Everett's formulation is the obvious choice since this is the only one that fits naturally with special relativity, and the formalism is retained in its pure and simple form:

> This is the ‘conservative’ solution, in the sense that it is the only solution that retains the existing physics (quantum state and unitary evolution) without amendment or addition. (2004, p. 1)

The difficulties with Everett's formulation are dissolved by understanding there are two different types of frame of reference in operation. This is the reason the theory has been incomprehensible. Logical type is the key: it is *because* two different types

of frame of reference are involved that the existing physics can be retained in full.

Everett defines observers in formal terms as physical mechanisms:

> ... automatically functioning machines, possessing sensory apparatus and coupled to recording devices capable of registering past sensory data and machine configurations. (1957, p. 457)

The machine makes observations, formulating each one as a representation of the physical environment observed, and records them in memory. (As described in the next section, the integrated synthesis of the past sensory data recorded forms the perceptual reality, the mental representation of the world of the observer. As described in Section 6, the integrated synthesis of the observations of machine configurations recorded forms the mental self-representation of the observer, the self-concept.)

He defines the state of the memory as the sum total of the data recorded, the record of observations; and it is only *this* structure of information that represents a specific outcome to observations made:

> When interaction occurs, the result of the evolution in time is a superposition of states, each element of which assigns a different state to the memory of the observer. (p. 462)

Each version of the state of the memory is specific and determinate, thus it is "Judged by the state of the memory" (ibid) that the probabilistic predictions of quantum theory are shown to operate. Thus the state of the memory of the observer is different to the state of the body of the observer. This is the crucial distinction he only approaches directly in his later paper, and in a footnote:

> At this point we encounter a language difficulty. Whereas before the observation we had a single observer state afterwards there were a number of different states for the observer, all occurring in a superposition. Each of these separate states is a state for an observer, so that we can speak of the different observers described by the different states. On the other hand, the same physical system is involved, and from this viewpoint it is the *same* observer, which is in different states for the different elements of the superposition (i.e., has had different experiences in the separate elements of the superposition). In this situation we shall use the singular when we wish to emphasize that a single physical system is involved, and the plural when we wish to emphasize the different experiences for the separate elements of the superposition. (1973, p. 68 n; emphasis in original)

The different experiences are the multiple different states of the memory, each one a different, specific version of the inside view.

The great difficulty here is that the behaviour of the system is different on inside and outside views. With respect to each of the different experiences, here the different versions of the individual defined on the different inside views, only one specific

version of events happens: each version perceives a different eigenvalue of the outcome. This is the point at which his formulation seems to break down, whichever approach may be taken, as described in depth by Barrett (ibid). The key point, developed in the following sections, is that the different types of entity, body and memory, physical and information, encounter different types of frame of reference, and thus different types of world, meaning the effective physical environment.

### 2.1 Quantum Computation

The great sticking point here is how this can possibly be the case. However, the evidence provided by the operation of quantum computation demonstrates this is a natural phenomenon. Despite operating in a physical superposition, each version of the computation has a separate operational existence, and proceeds with respect to each discrete structure of information in the superposition. In just the same way, each of the different inside views is functionally discrete, even though defined by a superposition of states in the physical brain. As Lockwood states, referring to the experiences in Everett's formulation as phenomenal perspectives:

> A superposition of phenomenal perspectives can exist; but it is not a phenomenal perspective in its own right. Rather, its existence is associated with the simultaneous presence of all of the phenomenal perspectives thus superposed. (1989, p. 234)

In other words, in this regard the observer mechanism operates the same principle utilised in quantum computation.

The great question then remains how all this relates to physical reality. It seems obvious that information is secondary, and that the experiences cannot be taken as relevant to the determinacy of physical reality unless some specific and discrete instantiation of each experience can be defined. As Barrett (ibid) demonstrates this is not possible no matter the approach taken. The resolution is that *in effect, on the inside view,* the information defines the determinacy of the physical reality.

## 3 The World Hologram

The state of the memory, defined as the record of observations, is the crucial component of Everett's formulation. This is an entirely familiar feature of the human system: this structure of information defines the perceptual reality. This is the representation of the physical environment in the form of a virtual reality that represents the three-dimensional, physical world:

> What we experience directly is a virtual-reality rendering, conveniently generated for us by our unconscious minds from sensory data (Deutsch,

1997, p. 120)

> Our brain constructs a three-dimensional model. It is a virtual reality in the head. (Dawkins, 1998, p. 276)

> Every last scrap of our external experience is of virtual reality. (Deutsch, 2011, p. 10).

In other words, as is logically obvious but intuitively elusive, the reality actually experienced directly is the virtual-reality rendering of what physical reality looks like, sounds like etc., rather than the physical reality itself. This is the virtual reality defined by the integrated synthesis of the record of observations. This is the inside view.

This neural activity 'in here' is not experienced as such, but forms a field of information mentally projected out into space, seeming to be 'out there'. As Deutsch goes on:

> Consider the nerve signals reaching our brains from our sense organs. Far from providing direct or untainted access to reality, even they themselves are never experienced for what they really are – namely crackles of electrical activity. Nor, for the most part, do we experience them as being where they really are – inside our brains. Instead, we place them in the reality beyond. We do not just see blue: we see a blue sky up there, far away. We do not just feel pain: we experience a headache, or a stomach ache. The brain attaches those interpretations – 'head', 'stomach' and 'up there' – to events that are in fact within the brain itself. (p. 10)

The net effect is exactly like that of a hologram. The virtual-reality rendering of the world is experienced as a three-dimensional field of information that is mentally projected onto the three-dimensional physical world to coincide precisely. This is here termed the world hologram.

This is simply the display of the human navigation system. However, this is also Tegmark's inside view of the world. Crucially, this is the integrated synthesis of the record of observations in Everett's formulation that defines the correlations established with the physical environment. The world thus defined, meaning the effective physical environment of the individual, is Everett's relative state named in the title of his thesis. The concept of world superposition explains why this is the world of the individual in an ontological sense.

# 4 World Superposition

Ascribing physical actuality to the wave function, the universe seems best described as a multiverse of many physical worlds, as described by DeWitt (1970). A modern update is given by Wallace: “According to our best current physics, branches are real.” (2011, p. 2). On this view the unitary wave function of the no-collapse

universe defines decoherent quasi-classical worlds, each akin to the conventional classical concept of a world, a space-time array of macroscopically determinate physical entities.

In this context, a specific inside view, a specific world hologram, is multiply instantiated: there is a great number of slightly different versions of a quasi-classical world in the universe which contain an observer with this record of observations. Moreover, the identical observation records place all the multiple instantiations at the same location in space-time, thus all instantiations are coincident.[1] As stated by Cox, the language of many worlds is very misleading:

> There is only one 'world', and it is a world in which everything that can happen does happen and everything is in a superposition with everything else. (2017, p. 54)

With respect to the world hologram, a structure of information, the result of the superposition is a single structure of information. In other words, there is only one instance of a specific inside view in the unitary system. *Physically*, these worlds are effectively separate because they cannot interact with each other. As Wallace states, the worlds are: "... mutually dynamically isolated structures instantiated within the quantum state" (2010, p. 70). Nonetheless, in a superposition, identical and coincident 'copies' of a structure of information can only make sense as a single instance. Different phenomenal perspectives are simultaneously present, but there can hardly be different identical phenomenal perspectives in a superposition. *On* the inside view, therefore, from within the perceptual reality of the world hologram, the world is the effective superposition of all the quasi-classical worlds in which it is instantiated: the many-worlds reality.

Following Everett in taking the effective physical environment to be defined by correlations gives the same result. The inside view is correlated with all the quasi-classical worlds in which it is defined, thus the effective physical environment is their superposed sum. Thus the effective physical environment with which the inside view is correlated is the many-worlds reality of the world superposition. This is here defined as the quantum-mechanical frame of reference: the quantum sum of all of the worlds in which this inside view exists and with which it is correlated.

# 5 Many-Worlds Reality

In this frame of reference, everything not observed is indeterminate because every possible different variation of objects and events is included in the superposed sum. Conversely, everything observed is determinate because it is, by definition, identically the same in all versions of the world in the resulting superposition. Thus the physical

1 This addresses a level 3 (or 4) multiverse in Tegmark's (2003) classification, not 1 or 2.

world of the inside view is exactly as defined in QBism: determinate only where experienced and observed.

One of the direct implications of QBism is that macroscopic objects exist in a state of indeterminacy. This is of course a radical departure from the established worldview, standing directly in contradiction to the concept of decoherence that operates in all ordinary macroscopic situations. However, the concept of world superposition explains why both are true, in the different contexts of inside and outside views. The many-worlds reality of the inside view is a domain of different logical type: a class-of-worlds-as-a-world.

Intuition formed in the objective physical world suggests powerfully that the state of the information instantiated in the physical must depend on, and follow, the state of the objective physical instantiation. This is precisely true on the outside view, as is obvious, but on the inside view this is reversed. The effective state of the physical world of the inside view is defined by the record of correlations, i.e. the record of observations, the information defining the world hologram, the inside view. This provides the ontology for the QBism world.

The difference in logical type is crucial. On the outside view, in the standard frame of reference, the state of information depends on and follows the state of the objective physical instantiation. On the inside view, in the quantum-mechanical frame of reference, the world hologram defines the determinacy of the world, meaning the effective physical environment. By definition this is determinate only where defined by the record of observations, the inside view. In consequence, the collapse dynamics operates as each observation is made, as Everett describes. This dynamics operates solely in the quantum-mechanical frame of reference because it is an attribute of this second-logical-type phenomenon, the world superposition. As the definition of the world superposition changes, the physical frame of reference changes, and the physical environment defines a world in which that specific observation has been determinately made. No such phenomenon can occur in physical reality, hence the measurement problem. The world is physical, but the change of the world is a different kind of thing altogether. This is addressed in Part 2.

# 6 The Functional Identity

The one major change required to produce a realist construal is the nature of the individual on the inside view. The standard identity for human observers is of course the physical body, including the mind: the mind is here defined as the computational capability that gives rise to the cognitive functions of the physical body system. This identity is simply correct on the outside view. On the inside view, however, the body-mind, like the rest of the world, is determinate only where observed and recorded in memory, in other words, as defined by the world hologram.

Naturally, the world hologram resides in a body-mind, one that gives rise to it and instantiates it. On the inside view, however, in the physical reality of the world superposition, every possible version of the physical body-mind that instantiates this inside view is superposed. Therefore, every possible variation of the attributes of the body-mind that are not observed are included in the superposition. As a result, these attributes are indeterminate. Thus only what is observed is determinate, even with respect to the body-mind of the observer.

The integrated synthesis of all the self-observations of the physical observer is the self-concept. This self-concept is necessarily a component of the world hologram, indeed the central feature. This is the three-dimensional, virtual-reality representation of the body-mind at the centre of the world hologram, an avatar figure. Just as the world hologram is the known world, this is the known self. Remarkably, since only that which is defined by the self-concept avatar figure is determinate, the physical identity of the individual on the inside view is *completely* defined by this avatar figure, the known self. This is the identity at the heart of Everett's formulation. The self-observations of the observer, external and internal, correspond to the machine configurations recorded along with sensory data on external events.

Such a definition may seem unrealistically minimal to account for the full nature and the complete identity of a conscious individual. However, this is the full definition of the active protagonist in the real world, directing thought and action. As Everett states, referring to the physical observer as the machine:

> … the actions of the machine at a given instant can be regarded as a function of the memory contents only, and all relevant experience of the machine is contained in the memory (1957, p. 457)

In other words, every aspect of the decision-making capability of the observer is contained in the memory, defined as the record of observations. With regard to human observers, all the attributes of character are included: values, beliefs, expectations, criteria and algorithms for decisions are all defined in memory.

As Deutsch states, it is not only all the memory that is encoded in the virtual-reality mechanism of the world hologram, but also all the operational knowledge of the individual:

> … every last scrap of our knowledge — including our knowledge of the non-physical worlds of logic, mathematics and philosophy, and of imagination, fiction, art and fantasy — is encoded in the form of programs for the rendering of those worlds on our brain's own virtual-reality generator. … All reasoning, all thinking and all external experience are forms of virtual reality. (1997, p. 121)

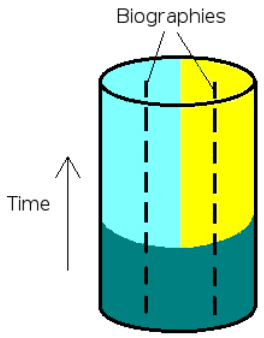
While all the information generated by observations is part of the world hologram, the programs that *produce* the world hologram are of course defined in the neural network of the brain; and attributes of these algorithms may well be defined by the DNA. How-

ever, on the inside view the DNA is indeterminate, as are all the information and algorithms in the neural system, except where observed in operation: every possible variation of all these factors is instantiated in the quasi-classical worlds that are superposed. Thus the only algorithms that are determinately defined on the inside view are those observed in action, and thus defined in the world hologram, along with the rest of the determinate character and psychology. Just as the world hologram is the sole definition of the determinacy of the physical world on the inside view, the self-concept avatar is the sole definition of the determinacy of the body-mind. This is the complete definition of the functional identity.

# 7 Solution

The physical reality encountered by the individual subject is the world superposition, and this is what gives rise to the apparent paradoxes. In this kind of world, Schrödinger's cat and Wigner's friend are simply retrodictions, straightforward examples of how the dynamics operate in the quantum-mechanical frame of reference.

In the world of the scientist in Schrödinger's thought experiment, as an individual on the inside view, there really is a superposition of dead and alive cat in the box. Before the scientist makes the crucial observation, he is defined as existing in all the worlds containing the box, half of which have in them a live cat, and half a dead one. On making the observation of the state of the cat, he is thereby defined as existing in just one half of those worlds, corresponding to a specific state of the health of the cat. As shown below, this logical dynamics is graphically illustrated in Lockwood (1989, p. 231; adapted).[2]




Parallel worlds in the Schrödinger©cat experiment.

There are two sets of physical biographies, live-cat and dead-cat. Here the digram de-

2 In Lockwood's concept a specific mind follows each biography in each world, whereas here one individual follows its biography in many parallel worlds simultaneously.

scribes the difference between the physical, and the world hologram of the of the scientist. In the lower section, before the observation is made, the world hologram is the same in the different versions of the world, containing no information about the current state of the cat. This therefore constitutes a single inside view. Thus the effective physical environment includes both sets of biographies of the cat, superposed. Once the observation is made, there are two different versions of the the scientist's world hologram, in the different biographies corresponding to the different states of the cat. The effective physical environment of the scientist now corresponds to either one state of the cat or the other. This is the enactment of the collapse dynamics as described in detail in Part 2.

Similarly, if the scientist is Wigner's friend, Wigner's biography remains unchanged because he is exists in all the worlds where his friend did the experiment, with either outcome. His diagram remains all one colour past the point where the one for the scientist's divides into two.

In this context, problems of the interpretation of probability are also naturally resolved. Taking the many versions of a determinate quasi-classical world as real phenomena, probability can be seen as an objective fact on the inside view. When a fair coin is tossed, given the very large number of worlds in the superposition, the percentage of worlds with each outcome must necessarily be represented precisely by the standard numerical probability of each outcome: one half. When an observation of the result is made, the individual will thereby be defined as existing in only those worlds, one half of the total number, in which that specific result was the case. This is essentially the counting worlds approach of Deutsch (1999) and Żurek (2005).

QBism avoids the conceptual difficulties of quantum mechanics by associating the quantum state with a cognitive state; so there is literally no reality except what is defined by experience. However, it is not necessary to abandon the objectivity of the quantum state as fundamental in order to reap the benefits of this type of perspective, and thus resolve the paradoxes. QBism is literally correct, *on the inside view*, in the quantum-mechanical frame of reference. Provided the cognitive state is defined as the world hologram, the quantum state is defined solely by the cognitive state, and the ontology is the world superposition. On the outside view, of course, objective physical reality is the quasi-classical world of the current paradigm. QBism is inside-view physics.

# 8 Quantum Bayesianism

World superposition explains the reality of Qbism's most radical implication: what is real for the individual is determined solely by what the individual experiences. Furthermore, the observations made are defined only to the resolution of the sensory apparatus of the observer. Thus for the observation of any given macroscopic object,

the set of all possible worlds in which this observation is made by this observer includes every possible microscopic definition of this object. The net result on the inside view is that only that much of the object defined by the sensory observation made is determinate. The central tenet of Quantum Bayesianism follows automatically. Only that much of the physical environment experienced through the senses is determinate. Therefore, probabilistic expectations at all levels of scale are defined by Bayesian probability, including, somewhat bizarrely, observations of submicroscopic quantum phenomena via the correct apparatus.

In most real-world situations, the subjective assessment of probability is just a best guess because the information available about complex situations is not complete. In an ordinary classical world the actual likelihoods would be defined by the physical reality in all its determinate detail. In the world superposition, however, the quantum-mechanical definition of probabilities of future events is defined solely by the record of observations. Thus the data used in the subjective, Bayesian assessment of probabilities is the same information as defines the quantum-mechanical world itself on the inside view – the only view available. This provides a straightforward answer to the question posed by Saunders: “Why should subjective probability track chance?” (2004, p. 2). His 'principal principle', that it should do so, is inherent. Subjective probability tracks chance because these are the subjective and objective attributes of the same thing. Subjective probability is Bayesian probability, which is defined by the record of observations; chance is the probabilistic future of the world defined by the quantum state, which on the inside view is defined by the record of observations.

In QBism, as with the Copenhagen interpretation, the quantum formalism is taken to mean the physical world is only determinate where observed. This obviously contradicts the laws of the objective, decoherent, physical world of the current paradigm. As has been shown, both are true. These are the different types of world of the inside and outside views. They exist at different levels of logical type.

# 9 The Second-Logical-Type Dynamics

The radical difference between inside and outside views is clearly illustrated by the concept of logical type, and the way in which this dissolves the measurement problem. Russell (1908) draws the essential distinction between a set, or class, and its elements. As he demonstrates, failing to take logical type into account inevitably produces nonsense results and paradox.

The collapse dynamics is incomprehensible because there can be no such thing in the physical world defined by the linear dynamics. This phenomenon, however, operates solely in the world of the inside view, the class-of-worlds-as-a-world. In this frame of reference, collapse occurs on observation because the addition of an observation to the world hologram alters the definition of the class of worlds, and thus

the quantum mechanical frame of reference. The addition of a new correlation alters the relative state. This is how the world encountered actually works. This explains the core concept of Everett's formulation. This is the effective enactment of the quantum concept of time as described in Part 2.

The measurement problem arises because the linear and collapse dynamics are incompatible. As Barrett states:

> … if one supposes that measuring devices are ordinary physical systems just like any other, constructed of fundamental particles interacting in their usual determinate way (and why wouldn't they be?), then the standard theory is logically inconsistent since no system can obey both the deterministic and stochastic dynamics simultaneously. This is the measurement problem. (1999, p. 15)

The operational system, however, is bi-level, and the two dynamics operate in the different contexts of the two levels, the inside and outside views. The linear dynamics of the wave function operates only on the outside view: as the time parameter of the wave function advances, no change occurs on the inside view in-between the making of observations. Collapse occurs only on the inside view. There is no such process on the outside view: it is an emergent, second-logical-type phenomenon. This is explained in detail with illustrations in the Appendix of Part 2.

# 10 Conclusion

QBism presents a simple but radical resolution to the paradoxes of quantum theory: the world is determinate only where personally observed. As the authors state this:

> ... removes the paradoxes, conundra, and pseudo-problems that have plagued quantum foundations for the past nine decades. (Fuchs et al., 2013, 1)

As with many-minds theories, such a deep and dramatic break from the prevailing worldview is given little credence in the absence of an ontology. This is provided by taking Everett's formulation at face value.

As Tegmark describes, there are two different types of frame of reference essential to physics. The outside view defines the objective physical reality. The inside view is that of a self-aware substructure *in* the world. As he states, it was Everett who demonstrated their interrelationship in quantum theory:

> Here the difficulty of relating the two viewpoints reached a new record high, manifested in the fact that physicists still argue about how to interpret the theory today, 70 years after its inception. … It took over 30

> years from the birth of quantum mechanics until Everett [1957] showed how the inside view could be related with this outside view. (1998, p. 10)

As Everett's formulation shows, these different types of frame of reference are inherent in quantum theory, indeed axiomatic. What has not been clear is *why* they are related in this manner. This is nonetheless of paramount importance because the outside view is the 'view from nowhere', meaning it does not define any kind of frame of reference except 'all of reality', which immediately runs into problems of interpretation in the relativistic world. The inside view, of course, is the exact opposite. This is the frame of reference of the individual subject, and this naturally has specifics of location, velocity and so on.

As Everett describes, taking the correlations established by observations to define the determinacy of the effective physical environment provides the appearance of collapse, within the domain of the unmodified linear dynamics. Thus there is no need to postulate actual collapse. This, however, leaves the physics incomplete: what *is* this process of collapse? The missing explanatory principle is that the protagonist of the dynamics is not the observer, the measuring instrument, but its product, the record of observations, here the world hologram. In other words, the entity engaged with the physical environment in which the results of quantum physics experiments are produced is the world hologram. It is this entity that comprises the self-aware substructure Tegmark (1998) addresses, and this is the true identity of the perceiving subject, as described in detail in Part 2. The crucial point is that an entity of this nature encounters a different type of frame of reference as the real physical world.

In the frame of reference of this individual, the effective physical environment is a class-of-worlds-as-a-world. It is a completely different type of thing to the objective physical reality of the outside view, but *this* is the type of world encountered, and on which experiments are carried out. This is the underlying meaning of quantum theory. It is the properties of *this* type of world that are revealed by quantum physics experiments such as the double slit. This is the missing piece in the great puzzles about quantum theory.

Classical physics experiments betray no sign of the nature of the many-worlds reality. They give results corresponding to a single quasi-classical world because all the worlds in the world superposition give identically the same result. Quantum physics experiments, however, reveal the state of the system unobserved: superposition.

Given this distinction, the missing explanatory principle becomes accessible. The physical frames of reference of the observer and the individual are of different logical type: quasi-classical world and class-of-worlds-as-a-world. Naturally, for the great majority of phenomena their frames of reference are identical; the definitions of Newtonian and relativistic frames of reference are necessarily the same. With respect to observation and its role in the dynamics, however, they differ. There is no measurement problem because the unitary system does in fact operate the two

incompatible dynamics simultaneously, but at different levels of logical type. Phenomena impossible in the objective physical reality of the standard view occur naturally in the world superposition.

The many-worlds reality operates as QBism describes. The ontology, however, is clear. Because the protagonist of the dynamics is the individual, defined as the holographic field of information formed by the integrated synthesis of the record of observations in Everett's formulation, the effective physical environment is the superposition of all quasi-classical worlds in which it is instantiated, a class-of-worlds-as-a-world.

Certainly, understanding the world hologram as the real person, and the protagonist of the dynamics, constitutes a scientific revolution, but nothing like as major as seemed to threaten. This interpretation is not just anthropocentric, it is anthropoholistic, but all the physics is retained in its current form, as is the modern scientific paradigm of the objective, physical, quasi-classical world. The real world encountered by the conscious individual, however, is the many-worlds reality of the quantum-mechanical frame of reference. The new paradigm simply subsumes the old.

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