The Quantum-Mechanical Frame of Reference

Part 1: Many-Worlds Reality

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Abstract: Psi-epistemic interpretations of quantum mechanics, such as Quantum Bayesianism and the many-minds theories, are criticised for their anthropocentric nature as well as the lack of ontology. If the well-established physics of Everett's formulation is taken at face value, the paradoxes are resolved just as these theories suggest, *and* an inherent physical ontology emerges: the superposition of all worlds containing the protagonist of the dynamics. The anthropocentric nature of the solution is a feature not a flaw. The missing explanatory principle is the nature of the protagonist, the operational subject of the dynamics.

The observer, the physical entity, is always just the measuring instrument, as specifically defined by Everett. As he demonstrates, it is the state of the memory, the *product* of the observer mechanism, that is the protagonist, the operational subject, in the collapse dynamics. The critical feature is that this entity is present simultaneously in a great number of quasi-classical worlds, all superposed. Thus the effective physical environment of this entity is the superposition of these worlds. This is the physical ontology of the epistemic interpretations: a world indeterminate except where observed. Schrödinger's cat is retrodicted.

The existing physics is perfectly correct. The objective physical world is a decoherent, quasi-classical world, exactly as understood in the current paradigm, but the world encountered by the protagonist is a superposition of worlds, literally a 'many-worlds reality'. It is this domain that is encountered as the physical world, and displays the apparently paradoxical phenomena in experiments. This is the operational quantum-mechanical frame of reference: Everett's relative state.

The measurement problem simply illustrates that the system is functionally bi-level: linear and collapse dynamics operate solely in their respective domains, at different levels of logical type. Both are psi-ontic.

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 protagonist in the collapse dynamics, meaning the relevant subject, is not the observer in the conventional sense, the physical entity, but its product, the state of the memory defined by the record of observations, as Everett (1957) states. This is the functional identity. The crucial significance is that this is multiply instantiated, and the effective physical environment is thus the superposition of all the worlds that instantiate it. This world superposition naturally operates both quantum-mechanical dynamics, and the famous paradoxes do not arise.

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 here to refer to the whole physical system, including the mind: the mind is here defined as the neuro-endocrinal information-processing system that produces and records 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. 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; emphasis in original)

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).

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. This, however, 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 physical observer, is in a superposition of all possible states. No explanatory principle is given, thus debate continues about the full meaning of his theory to this day. The resolution is that the physical reality of the inside view is a phenomenon of different logical type, and thus naturally operates different dynamics. The inside-view frame of reference follows the collapse dynamics, while the outside-view frame of reference follows only the linear dynamics.

The logic follows the quantum-mechanical structure laid out by Everett. As described in Section 2, the state of the memory is the central component of Everett's formulation. This is the inside view, a structure of information. It is with respect to this entity that the probabilistic predictions of quantum theory are shown to operate. This is the protagonist of the dynamics.

As described in Section 4, 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 5, 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'. This reveals the explanatory principle that makes sense of the great paradoxes. The world of the inside view is a completely different type of domain to the quasi-classical world of the current paradigm. As shown, it is by definition determinate only where observed.

The central principle is alien, but straightforward. As described in Section 8, in the physics of observation, the observer, the physical body-mind, is simply a complex and sophisticated measuring instrument, the observable being the contents of the sensorium: the representation of the state of the physical environment as reported by the sensory apparatus. The cumulative product of this process over time is the world hologram. On the outside view this is entirely subsidiary, a component of the body-mind, but on the inside view it is *this* entity that is the operational protagonist in the collapse dynamics of quantum mechanics. The world of this entity is the world superposition, and this operates the collapse dynamics as each observation is made. This is the physical reality encountered by each conscious individual.

This produces an interpretation akin to many-minds, but is more correctly a many-perceptions framework as proposed by Page (2011), or many-views, Squires (1996). Lockwood's (1989) many-minds theory operates on this basis, defining the mind as

the record of observations. Such approaches resolve the paradoxes but have no ontology. This is provided by the concept of world superposition. This is the physical reality encountered, and of which the properties are revealed by experiment. As described in Section 9, the apparent paradoxes of Schrödinger's cat (1935) and Wigner's friend (1961) are simply features of this type of frame of reference.

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 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 describes. It cannot be made to fit into the modern paradigm: the ordinary quasi-classical world. The solution is that the physical reality encountered by the protagonist is a class-of-worlds-as-a-world. In this domain the collapse dynamics operates as each observation is made.

The system is fundamentally bi-level in operation: necessarily since the two dynamics of quantum mechanics are incompatible. That is the meaning of the measurement problem, as described in Section 11. The incompatible dynamics operate naturally in the same unitary system, just at different levels of logical type. As Everett shows, the inside view gives the appearance of the standard von Neumann-Dirac formulation of quantum mechanics (1955).

It is only the definition of the operational protagonist 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, as is objective physical reality. There is a further dimension added to the ontology of the operational paradigm, that of logical type. The physical reality encountered is a second-logical-type phenomenon, the class-of-worlds-as-a-world. In the many-worlds universe the physical environment of the conscious individual is a many-worlds reality.

2 The Inside View

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. He defines the state of the memory as the sum total of the data recorded, the record of observations. As he makes clear, 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. This is the appearance of collapse he demonstrates. It is: “Judged by the state of the memory” (ibid) that the probabilistic predictions of quantum theory are shown to operate.

The central point is that 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 somewhat indirectly, in a footnote in his later paper:

> 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: each one here an individual.

As Everett demonstrates, 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 by 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 great difficulty is the lack of explanatory principle. The key point, developed in the following sections, is that the different types of entity, body and memory, physical and information, exist in different types of frame of reference, and thus encounter different types of world.

3 Phenomenal Perspectives

Everett's fundamental premise runs directly counter to the obvious view that information must be defined by its physical instantiation, but the operation of quantum computation demonstrates just such a 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, the state of the physical observer that Everett describes 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 *because* the world encountered on the inside view is the world superposition; and this is by definition indeterminate except where observed, as described in Section 6.

4 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 because this structure of information is the definition of the perceptual reality.

The perceptual reality is the representation of the physical environment. It takes the form of a virtual reality that represents the three-dimensional, physical world. As Dawkins states:

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

This is the virtual reality defined in the sensorium. This is the five-sensory observation of physical reality.

As is logically obvious but intuitively elusive, the only reality actually experienced *directly* is this virtual-reality rendering of what physical reality looks like, sounds like etc., rather than the physical reality itself. As Deutsch comments:

> What we experience directly is a virtual-reality rendering, conveniently generated for us by our unconscious minds from sensory data (1997, p. 120)

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

The virtual reality is purely the representation of the world, but this observation of physical reality is all the information accessible on the inside view.

The recording of the sequence of observations, each one a virtual-reality rendering of the physical world, forms the record of observations, in Everett's formulation. The state of the memory is the integrated synthesis of the record of observations. The perceptual reality is the inside view.

The neural activity of the virtual-reality representation, going on as it were '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 explains:

> 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. (2011, p. 10)

The net effect is a phenomenon like 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 field of information is utterly familiar to every conscious individual. This is the known world of the individual, the virtual-reality representation of the record of observations. Whenever the individual recalls an event, this is the accessing of a view of this field of information.

5 World Superposition

The world hologram is Tegmark's inside view: the integrated synthesis of the record of observations in Everett's formulation. Crucially, this is what defines the correlations established with the physical environment. The determinacy of the physical environment thus defined is Everett's relative state, named in the title of his thesis. This is the quantum-mechanical frame of reference. World superposition explains why this is the world of the individual in a physically ontological sense.

Ascribing physical actuality to the wave function, the universe equates to Everett's many physical worlds, as described by DeWitt (1970). A modern update is given by

Wallace: “According to our best current physics, branches are real.” (2009, 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 that 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, these worlds are: “... mutually dynamically isolated structures instantiated within the quantum state” (2010, p. 70). Thus each world is an ordinary quasi-classical world:

> … *the totality of macroscopic objects: stars, cities, people, grains of sand, etc. in a definite classically described state*. (Vaidman, 2008; emphasis in original)

Nonetheless, in a superposition, identical and coincident 'copies' of a structure of information can only make sense as a single instance. As Lockwood states, different phenomenal perspectives can be simultaneously present, as Everett describes, 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 physical reality of the inside view is the reality of the world superposition: literally a many-worlds reality.

Following Everett in taking the effective physical environment to be defined by correlations gives the same result in the physical reality of many worlds. World superposition is a different way of saying the same thing. 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. 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-mechanical sum of all of the worlds in which this inside view exists.

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

6 The Indeterminate World

In this frame of reference, everything observed is determinate because it is, by definition, identically the same in all versions of the world in the resulting superposition. Equally, everything not observed is indeterminate because every possible variation of objects and events is included in the superposed sum. The resulting world is what Vaidman calls a centred world, meaning a relative or perspectival world, defined for every different physical system:

> In this world, all objects which the sentient being perceives have definite states, but objects that are not under her observation might be in a superposition of different (classical) states. (2002)

The physical reality of the world superposition is of this nature. On the inside view, macroscopic objects exist in a state of indeterminacy except where observed. This is the nature of the physical reality encountered by each conscious individual.

As stated in QBism this indeterminacy makes perfect sense of quantum theory:

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

This is of course a radical departure from the established worldview, and the whole idea seems to stand 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 outside-view world is a specific decoherent quasi-classical world, in this context a first-logical-type phenomenon. The many-worlds reality of the inside view is the class-of-worlds-as-a-world, a second-logical-type phenomenon. The reason is alien to the current paradigm of physics, but just this addition to the ontology resolves all the difficulties. It produces a system that operates both dynamics simultaneously. Here this is held to be the meaning of the measurement problem.

7 Collapse

The second-logical-type phenomenon of the world superposition explains Everett's premise: the appearance of collapse in physical reality. When an observation is made, and the record of observations changes, this changes the definition of the world superposition. Thus in appearance, meaning on the inside view, there is collapse. The great puzzle has been how this could possibly affect objective physical reality in any way. Naturally, it does not. As Everett states there is only the appearance of collapse. On the inside view, however, collapse is a real phenomenon.

The difference in logical type is crucial to understanding the collapse dynamics. 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. As is obvious, making an observation can hardly be causal on physical reality. On the inside view, however, the making of an observation alters the world hologram, and thus the definition of the many-worlds reality: this is now the superposition of all quasi-classical worlds in which the updated version of the world hologram exists. This version of the world hologram exists only in worlds in which a specific version of the observation was determinately made, and the physical reality is as defined by that specific observation. In consequence, the collapse dynamics operates, effectively, as each observation is made.

This dynamics operates solely in the quantum-mechanical frame of reference of the individual because it is an attribute of the world superposition: collapse of the state vector is a second-logical-type phenomenon. As the definition of the world superposition changes, the physical frame of reference of the inside view changes, and as a result the physical environment defines a world in which that specific observation has been determinately made.

The world is physical, meaning defined by the quantum state. The change of the quantum state of the world is a different kind of thing altogether. On the inside view, each correlation added to the state of the memory defines this frame of reference as existing in a slightly different version of the world, with a different quantum state, one in which a specific version of the observation is determinately defined. On the outside view this quantum jump is a virtual phenomenon. On the inside view it is the updating of the determinacy of physical reality. This is described more fully in Section 9.

8 The Functional Identity

The single change required to produce a realist construal of the world defined by quantum mechanics is the nature of the protagonist, i.e. the individual on the inside view. Remarkably, on this view, this is the only valid and effective identity.

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: the operating system of the hardware. This physical 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. The logic is the same as for the rest of reality. On the inside view, 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.

Such a definition may seem unrealistically minimal to account for the complete identity of a conscious individual. However, 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. However, on the inside view the DNA is indeterminate, as are all the data and algorithms in the neural system, except where observed in operation. All this is indeterminate because 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.

Therefore, as Everett states, referring to the physical observer as the machine, this is the full definition of the active protagonist in the real world, directing thought and action:

> … 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. This is the identity at the heart of Everett's formulation. 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 i.e. the world hologram.

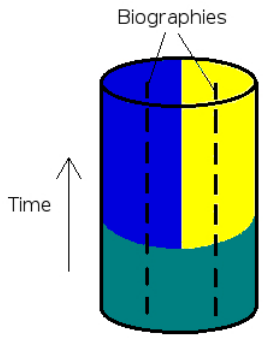
This is the definition of the real person 'in here'. This is the complete definition of the functional identity. As Von Baeyer states:

> If I am the agent, the objective world is everything outside my mind—including other agents and even my own body. All of that I may, if I chose, treat quantum mechanically and describe by wavefunctions. (2016, p. 154)

9 Schrödinger's Cat

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 experimenter 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).



Parallel worlds in the Schrödinger's cat experiment.

There are two sets of physical biographies, live-cat and dead-cat: each biography is a worldline in a specific quasi-classical world.[2] In the lower section, before the observation is made, the world hologram of the experimenter is the same in the two sets of versions of the world: it contains 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 experimenter's world hologram, in the different sets of quasi-classical worlds corresponding to the different states of the cat. Thus the effective physical environment of the experimenter now corresponds to either one state of the cat or the other. This is the enactment of the collapse dynamics, as encountered on the inside view. This is described in detail in Part 2.

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.

Similarly, if the experimenter 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 digram for the experimenter divides into two: in his class-of-worlds-as-a-world the cat is still both alive and dead. The determinacy of the effective physical environment, the many-worlds reality, is defined solely by the world hologram. This is what accords different definitions of physical reality to different individuals, even in the same place at the same time, like Schrödinger and his cat.

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. On this view there is literally no reality of any kind except what is defined by experience. However, it is not necessary to abandon the objectivity of the quantum state as physically 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 obvious, the world superposition. Both views are valid. QBism is simply inside-view physics.

10 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 observations made is determinate. The central tenet of Quantum Bayesianism follows automatically. Only that much of the physical environment experienced through the senses is determinate.

This means that probabilistic expectations at all levels of scale are defined by

Bayesian probability. 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 the answer to the question posed by Saunders: “Why should subjective probability track chance?” (2004, p. 2). Lewis's (1980) '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.

11 Dualism

The dualism inherent in quantum theory is clearly illustrated by the concept of logical type, and the way in which this dissolves the measurement problem. As Russell (1908) demonstrates, failing to take logical type into account inevitably produces nonsense results and paradox. The collapse dynamics has been incomprehensible because there can be no such thing in the physical world defined by the linear dynamics.

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 resolution is that the system operates at two different levels of logical type, in the different contexts of the inside and outside views.

The linear dynamics operates only on the outside view: as the time parameter of the wave function advances, no change occurs on the inside view between the making of observations. Collapse occurs only on the inside view. As has been described, this is Everett's appearance of collapse. There is no such process on the outside view: it is an emergent, second-logical-type phenomenon. On the inside view this is a real phenomenon: it is the effective enactment of the quantum concept of time as described

in detail in Part 2.

The net result is the appearance of the cycle of the dynamics as described in the standard formulation of quantum mechanics, as Everett states. The resolution is that operational physical reality is a bi-level system, with two quasi-ontological bases. There are two different levels of operation, at two different levels of logical type. Both are psi-ontic, defined by the quantum state. This is the reason both types of frame of reference are not only real but ontologically fundamental, an apparent oxymoron.

Clearly, the physical reality of the world superposition is no less physically real than the quasi-classical world assumed in physics: it is the totality of a great many of them. Thus the new paradigm subsumes the old, as is natural. This means the current paradigm is maintained unchanged except for the addition of this second-logical-type phenomenon as ontologically fundamental.

Both domains are ontologically quasi-fundamental: on each view the other is effectively subsidiary with respect to the process of observation. There is a fundamental dualism.

QBism is a modern version of 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, however, both are true. These are the different types of world of the inside and outside views. They are different types of frame of reference, existing at different levels of logical type.

Classical physics experiments betray no sign of the nature of the class-of-worlds-as-a-world on which they are performed. 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, a second-logical-type phenomenon.

12 Conclusion

The great paradox of quantum theory is the incompatibility of the two dynamics, linear and collapse. The resolution is that they operate in different frames of reference, at different levels of logical type. This is the meaning of the measurement problem.

As Tegmark describes, there are two fundamentally different types of frame of reference essential to physics. The outside view is the familiar objective physical reality of modern science, the 'view from nowhere'. 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 demonstrates, there is no need to postulate collapse in objective physical reality, on the outside view, because there is the *appearance* of collapse, on the inside view.

The missing piece of the puzzle is the functional identity of the protagonist of the collapse dynamics. This is not the observer, the physical entity that makes observations, but the product of its operation, the state of the memory, defined as the record of observations. As Everett states it is: "Judged by the state of the memory" (ibid) that the standard von Neumann-Dirac formulation of quantum mechanics *appears* to be enacted. In humans the integrated synthesis of the record of observations takes the form of a three-dimensional virtual reality, mentally projected onto the three-dimensional physical world to coincide precisely, here the world hologram. This is the functional identity of the protagonist. As a structure of information in the many-worlds universe, the protagonist exists in a great many different versions of the quasi-classical world, all superposed. Thus the effective physical environment of this entity is a class-of-worlds-as-a-world: the many-worlds reality. This operates the collapse dynamics, in effect, as each observation is made because this alters the definition of the class-of-worlds-as-a-world.

Thus there are two different operational domains within the context of the unitary system. The physical reality of the outside view defined by the wave function follows the untrammelled linear dynamics, hence the many worlds. The physical reality of the inside view, defined by the world superposition, follows the collapse dynamics, hence the appearance of specific outcomes to observations in the physical reality of the protagonist. This is the operation of the unitary system at first and second levels of logical type.

In the many-worlds reality, the apparent paradox of Schrödinger's cat is retrodicted. The cat really *is* alive and dead at the same time, in parallel versions of the world. That is just standard many-worlds theory. Given the individual as the world hologram the situation is straightforward. Until he makes the crucial observation, the experimenter is in *both* versions. Before he does, however, in his many-worlds reality, the cat is indeed, quite literally, alive and dead at the same time.

The explanation is anthropocentric, but this is a feature not a flaw because the physics itself is anthropocentric. Collapse is an inside-view-only phenomenon, as Everett demonstrates so clearly. The ontology is the world superposition. This is inside-view physics, the physics of the class-of-worlds-as-a-world. This means there are two quasi-autonomous frames of reference. In addition to the classical ontology of physical reality there is also the class-of-worlds-as-a-world, the physical reality of the inside view. The evidence is the dualism of the two incompatible dynamics. The

missing explanatory principle is the nature of the protagonist.

Logical type is the key. It is *because* two different types of frame of reference are involved that the existing physics is retained in full. The duality of quasi-autonomous domains, of different logical type, validates the quantum theory; *and* all the physics is retained in its current, deeply rooted and intuitively appealing form. The modern scientific paradigm of the objective, physical, quasi-classical world is unmodified, but the real world encountered by the conscious individual is the many-worlds reality. Both are psi-ontic, defined by the quantum state. The new paradigm subsumes the old.

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