Universe Superposition, Relational Quantum Mechanics, and The Reality of the No-Collapse Universe

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Abstract: A perspective on Everett's relative state formulation is proposed leading to a relational quantum mechanics. There are inevitably a large number of different versions of the universe in which a specific observer could exist, and in the universe of the unitary wave function they are all existing and coincident. If these different versions of the universe are superposed the result is a universe in which the superposition of all of the identical copies sums to a single observer. The effective universe in the functional frame of reference of this observer would be highly indeterminate but determinate where observed by this observer. This would naturally relativise the universe of the conventional view since each observer would inhabit an effective universe in which different aspects were determinate. Although the identity of the observer as a physical body does not readily fit this concept, it appears to apply inevitably to the functional identity of an observer as depicted by Everett. In this relational quantum mechanics a collapse dynamics applies only to the functional frame of reference of the observer and raises no incompatibility with the linear dynamics.

1 Introduction

While quantum mechanics has passed every test of the accuracy of the formalism, the implications for physical reality appear to contradict fundamental common sense notions. This suggests a classic systems analysis problem where a paradox points to the mis-typing of some significant element of the system. Rovelli is specific about the element in question,

> I propose the idea that quantum mechanics indicates that the notion of a universal description of the state of the world, shared by all observers, is a concept which is physically untenable, on experimental ground. (1996,7)

In other words, the concept is a wrong general assumption, 'excess baggage' like many previous global assumptions as Hartle (2005) clearly illustrates. Rovelli's central message is that actuality is relative to the functional frame of reference of each individual observer, a conceptual extension of the principle underlying Einstein's special relativity. Since in Rovelli's relational quantum mechanics the functional frame of reference is determined solely by the correlations the observer forms with the environment, and thus the effective universe of each observer has a different definition, this equates to personal parallel realities for observers. Naturally this resolves the Wigner's friend paradox, which could be seen simply as an indication that quantum mechanics is relative to an observer's frame of reference as Rovelli proposes.

Taking Everett's relative state formulation at face value the universe is the coincident simultaneity of all possible versions of the determinacy of the universe. Depending on how the observer is defined, the same definition of the observer may well occur in more than one such version of the universe, thus a single observer exists simultaneously in more than one version of the universe. Since in the Everettian universe all versions are coincident in a single overall system one could argue that the observer so defined is a single entity present simultaneously in all of those versions of the universe. The determinacy of the effective universe of this observer would be the simultaneity of all of these versions of the universe, an effective superposition of all of them. This 'universe superposition' is a philosophical device, not a causal explanation; it is a metaphor for the unlocalised nature of the Everettian universe, with respect to which indexical version of the universe an observer is in, for an observer present in many such versions. This naturally produces a relativisation of the conventional view since the definition of the physical universe is different for each observer of this type, as in relational quantum mechanics; each observer has a different history of interactions with the environment. While there are difficulties with this idea with regard to the observer defined as a physical body in the ordinary manner, it appears to apply inevitably to any observer defined by a structure of information, including the functional identity of an observer illustrated by Everett as an automatically functioning machine.

2 Universe Superposition

There are, in the set of all possible universes, a very large number of versions of the universe one could be in at the present moment, each universe being in some way slightly different and the difference being something outside the scope of one's observations. If all of these universes exist there is inevitably an identical copy of oneself in each universe and, as Deutsch explains in the context of a multiverse of universes, one is all of them;

> If, aside from *variants* of me in other universes, there are also multiple identical *copies* of me, which one am I? I am, of course, all of them. Each of them has just asked that question, 'which one am I?', and any true way of answering that question must give each one of them the same answer. (1997, 279)

In the simplest conception of Everett's no-collapse formulation all of these variations on the universe exist superposed in a single universe, and thus all the identical copies are superposed. If the identical copies are truly identical such a condition equates to there being only one of this entity. Such an entity would exist in, and be correlated with, all of those versions of the universe, and the effective universe of this observer would be the superposition of all of them. While this universe superposition would naturally be determinate with respect to the definition of the observer, every possible variation of the rest of the universe consistent with the existence of this observer would be superposed in the universe superposition, which would thus be largely indeterminate. The universe superposition would be determinate where observed since all the superposed versions of the universe would necessarily have the same appearance to this observer.

Quite apart from the issue of decoherence eliminating superposition, the concept of a universe superposition with respect to the physical body appears inherently flawed, because each of the apparently identical bodies is quantum entangled with a different version of the universe, and thus at the quantum level they are not identical. However, they are all experientially identical, all of these bodies have the same identical mind; one could equally well say that there is one mind which is in all these bodies in all these versions of the universe. Subjectively, from the perspective of such a mind, the effective universe is a superposition of all of them.

3 The Singular Observer

Identifying the observer as mind in order to explain the determinacy of subjective experience is well established (Albert & Loewer 1988; Albert 1992; Lockwood 1996; Donald 1997). In the absence of collapse, the post-measurement state of the

body of an observer making a measurement of an observable that begins in a superposition of two eigenstates is an entangled superposition of two versions of the observer. Each records a specific eigenvalue, as Everett states “each element of the resulting superposition describes an observer who perceived a definite and generally different result, and to whom it appears that the object-system state has been transformed into the corresponding eigenstate.” (1973,10). However, since the different versions of the observer are superposed, the result, objectively, is a single observer whose sensory apparatus and neural system are in a superposition of two different states.

As Lockwood concludes, the observer “is *literally* in two minds” after such a measurement (1996,166). The term 'mind' here will be used to refer to the structure of information instantiated in the neural network of the body, and, as an initial position, considered to be the observer. In a literal manner this solves the problem; the experience of each mind is the experience of a determinate neural state, and thus each observer observes a determinate result. By defining the mind as a mathematical structure of information, the concept of two separate singular minds in a situation where their physical instantiation is superposed becomes straightforward. The mind is non-physical and instantiated as information, and as such it obeys different rules to the physical with respect to superposition. Just as superposed instantiations of numbers in a quantum computer exist as dinge an sich, and each takes part in one version of the computation as a singular entity, each variant of the observer is a singular entity in the context of its version of reality; subjectively each specific and singular version of the observer makes a specific observation. Although the physical register of a quantum computer is in a superposed state, each superposed version of the computation is carried out with respect to a specific value, and thus there is a single determinate value effective in the context of that version of the computation. Similarly each superposed version of the observer is effectively a singular entity relative to the outcome of the observation in its version of reality. Chalmers draws the same analogy between superposed mental states and quantum computation and states that his theory “predicts that a superposed brain state should be associated with a number of discrete subjects of experience.” (1997, 349)[1].

4 Logical Levels

The mind-matter dualism on which an interpretation based on mind relies can be explained by the different nature of mathematical and physical structures. Naturally the mathematical structure of information defining the mind is instantiated in the physical, however, since the mind as a structure of information

1 Citing organisational invariance Chalmers holds that the computational process instantiated as one of the superposed brain states must necessarily be functionally identical to the same process in a brain not in a condition of superposition with orthogonal physical states. Barrett (1999,211n) rejects this, but his objection applies to the physically objective view of the situation, while here it is the subjective view which is proposed as effective.

is inherently singular, meaning that superposition of mathematical structures of information is not a meaningful concept, when a superposition is observed the mind fissions. The result is multiple parallel information processes instantiated in a single physical instantiation, as with computation in a quantum computer. The time evolution of the mind is thus logically different to the time evolution of the matter and energy instantiating it.

Similarly, a mathematical structure of information has no intrinsic location, the concept only has meaning with regard to a physical instantiation; objects have location, numbers and ideas do not. Nonetheless the mind has extrinsic location defined by the observations made; the record of observations provides an approximate definition of location in space and time. Every ostensibly[2] identical copy of the body makes the same observations, and thus the extrinsic location of the mind is identically the same with respect to location in space and time in every indexical version of the universe in which it is instantiated. Indexical location with respect to which version of the universe the body is in is unknown and unknowable, thus the extrinsic location is defined solely with regard to location in space and time, and the same mind with the same identical extrinsic location is present in all indexical versions of the universe where it is instantiated.

Clearly structures of information exist at a different logical level to the physical, at least with regard to superposition and location. Although dependent on the physical for instantiation, the mind as a mathematical structure of information is present ubiquitously in all instantiations. Subjectively, from the perspective of this mind as the observer, it is a single entity present in a large number of versions of the universe, all of which are coincident in space-time in the same overall universe defined by the unitary wave function, and the effective universe is the subjective superposition of all of them. Thus a naturally occurring difference in quantum definition between the subjective and objective frames of reference arises. The functional frame of reference of the observer is the universe superposition, the effective universe of this observer, defined by the superposition of the wave functions of all of the possible variations of the universe instantiating this observer. The objective frame of reference by contrast is usually taken to be a specific determinate version of the universe, while the overall frame of reference is the underlying universal reality defined by the unitary wave function.

On this view the effective universe of the mind as observer is highly indeterminate, and a case could be made for saying that the only determinacy of the effective universe is the definition of the observer itself. Donald, in discussing his formulation of quantum mechanics based on the mind as observer, proposes that even the most fundamental properties of the universe such as the arbitrary physical constants may be determined only by observation, concluding that “Only the finite amount of information which determines one's structure as observer would determine the “world” in which one lives” (1997). On this view the functional frame of reference of each observer is defined solely by that observer.

2 Meaning identical apart from the version of the universe with which it is quantum entangled.

5 The Body of Information

In the subjective functional frame of reference the effective universe is highly indeterminate, and this applies also to the body of the observer. The mind exists not only in all the all of the structurally identical copies of the body of the observer, it exists in the bodies of observers where the structure of the body is slightly different but that difference does not impact the definition of the mind. The layout of the specific pathways of minor blood vessels interior to the body of a given observer, for instance, could be in any number of different configurations. In the universe of the unitary wave function every different variation of this observer exists, thus variations with the same mind but different configurations of the blood vessels exist. The same is true for every physical variation of the body possible with the same mind, variations embodying physical distinctions of aspects of the body which have not impacted the mind. By the same reasoning as before there is one mind which is in all of these bodies and in the Everettian universe they are all coincident. Subjectively, from the perspective of this mind, reality is a universe superposition in which not only the majority of the universe is indeterminate, but the majority of the fine detail of the structure of the body is indeterminate also. Calling the mind the observer may seem like a step away from physical realism, but this mind does not exist in vacuo; while objectively it is a pattern of information in a very large number of bodies, subjectively it exists in and is part of a real and specific physical body, the superposed sum of all of the bodies in which this mind exists.

6 The World Hologram

The mind has been defined as the pattern of information represented by the neural state, a specific datum, but while it might be possible to characterise a mind solely in terms of static data it is hardly a full description since it lacks any functional or operational definition[3]. A complete solution would require a definition of the missing mental dynamics[4], but there is a yet more economic definition of the observer entirely isomorphic to experiential identity for which the dynamics is simple and self evident. Each observation is the registration of the information representing that observation in the neural network. This information is integrated into the sum total of information about the world acquired from previous observations[5]. This structure of information is intensely familiar to each one of us,

3 Chalmers, for instance, characterises observers as combinatorial-state automata, with “a formal structure determined by their states and state-transition relations” (1996,317).

4 At the least one would need to define both how the mind evolves over time with respect to beliefs and determinate records of observations, and how these interrelate with and correspond to the version of the world this observer has observed.

5 This is not to say that it becomes a permanent record at this stage, solely that by being data in the neural network it is automatically part of the definition of the sensory experience of the reality of this observer; in due course integrated into the long term memory to a greater or lesser degree.

for while we each form a concept of reality embodying all this information, and this is a process we are not aware of or familiar with, the result is both an internal model of the world and the availability of a formulated image of any aspect of this information; the world known through observation. It is this information formulated as spatially distributed imagery that one observes when recalling the appearance of a significant place one has visited, or where one might have put the house keys down. Since this body of information is viewed in terms of a spatially distributed image while in fact being a structure of information in the neural network it is akin to a hologram of the known world[6].

This division of a part of the mind is not arbitrary; this is the operational level of subjective experience, the experience itself and the record of experiences, as distinct from all the processes which go to make up subjective experience. It corresponds to a cut further along the von Neumann chain than the level of sensory input from the body's sensors. From the point of view of observation these are the input to the neural system while the sensory image is the output. The world hologram could be considered to be the identity of the observer at this level of operations, the experiential identity. Logically this structure of information corresponds exactly to the minimal definition of an observer at the experiential level; as each observation is formulated it is added to the definition of the world hologram.

The observation is defined here as the structure of sensory information observed, and the world hologram is the cumulative integrated record of that information. The dynamics is logically elementary, being the sequential addition of new observations to the cumulative record. This world hologram *is* the subjective reality, as with the observation of the present moment the whole world hologram is subjectively portrayed as 'out there' mapped onto the real world; it is the known world of this observer. Since this structure of information is formed by the accumulation of observations to the neural network it amounts to a cumulative observation of the reality of this observer to date[7].

7 Experiential Identity and Reality

As with the mind there are a large number of versions of the universe containing a specific world hologram, and the effective universe in the functional frame of reference of this structure of information is a superposition of all of them. Moreover, this world hologram is to the mind as the mind is to the body. Not only do all of the identical minds have the same identical world hologram, there are

6 Naturally the observations and the consequent world hologram are structured not solely in terms of visual information but in all five senses.

7 This definition of the world hologram is purely functional and unrelated to any specific areas of the brain or class of memory. While the world hologram obviously comes under the banner of memory there are properties of the mind associated with memory, such as learned stimulus-response associations, which would not be observed unless the observer noticed their effect, and thus would not necessarily be part of the world hologram.

minds which are not identical, having different characteristics and predispositions, as yet unobserved in operation, which nonetheless have the same identical world hologram. Thus, as before, from the perspective of this structure of information as an identity, it exists in a reality which is largely indeterminate, and this indeterminacy includes not only the world and the body but even the rest of the mind.

Objectively this world hologram appears to be no more than a structure of information in a physical biological system, a physical body to which one would ordinarily attribute the status of observer. Subjectively, however, this structure of information is not only one's world but also oneself. One knows one is the body, but one knows only that much of the body which one has observed. One observes the body not only externally in mirrors but internally through proprioception, and these observations are added to the world hologram. The rest us unknown, and, in a universe superposition, indeterminate. One knows one is the mind, but again one does not know the whole of one's mind. What one knows are all the mental properties one experiences, such as thoughts, feelings, memories and expectations, all of which are observations and are added to the world hologram, all else being indeterminate.

Considering the world hologram as the identity of the individual may seem unrealistically minimal, but, naturally, it defines everything one has direct evidence of being. Moreover, as before, this individual exists in, and is correlated with, a real and specific physical body, the superposed sum of all of the bodies in which it exists. At the core of this world hologram is a representation of the individual, the self image, the avatar in the idiom of virtual reality technology. This avatar is the body-mind one knows oneself to be, it is a representation of all of the information about oneself one has observed. In the superposition of universes containing this world hologram everything about the body-mind not defined by this set of observations is in a state of superposition of all of the physical arrangements which could give rise to this set of observations. Subjectively it is the humanoid form of the complete self image, which is mapped onto one's physical presence. At the same time it is the definition of the determinacy of the body-mind in the effective universe of this observer.

On this view, each specific world hologram is the determinant of a physical functional frame of reference which is at all times subjectively determinate. Each world hologram defines a subjective reality, the known world, with the 'avatar' self image at its core. The world hologram is instantiated in physical reality as the universe superposition, and in this reality the avatar is instantiated as the superposition of all of the bodies with this world hologram. Thus this structure of information, essentially a memory record, is closely akin to the real world, the determinacy of the universe superposition, the effective universe of this individual. On this view it seems that as physical observers we are indeterminate, and yet each observer system gives rise to cumulative observation records which are specific and determinate, which appears to be exactly the conclusion Everett came to.

8 Memory Configurations

It is the memory configurations of versions of the observer which Everett claims provide the appearance of collapse and the resolution of the measurement problem by requiring only the linear dynamics, 'pure Process 2 wave mechanics'.

> In conclusion, the continuous evolution of the state function of a composite system with time gives a complete mathematical model for processes that involve an idealized observer. 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. Judged by the state of the memory in almost all of the observer states, the probabilistic conclusion of the usual "external observation" formulation of quantum theory are valid. In other words, pure Process 2 wave mechanics, without any initial probability assertions, leads to all the probability concepts of the familiar formalism. (1957,462)

Assigning independent existence to the memory of an observer seems intrinsically absurd, thus interpreting Everett apparently involves making sense of an observer that has this memory configuration. However, if there is no determinate observer, and as Everett states, “there is no single unique *state* of the observer” (1957,459), then the only functional identity of the observer as a determinate entity is the state of the memory. Everett, moreover, proposes an automatically functioning machine as a model of an observer, and concludes his description by making the 'function of the memory contents' the sole causal functional process of the observer.

> If we consider that current sensory data, as well as machine configuration, is immediately recorded in the memory, then 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. (1957,457)

Since it is solely the contents of the memory that are to define the functionality of the machine, and additionally all relevant experience is contained in the memory, it is therefore this mathematical structure of information which is deemed to constitute the functional identity of the observer, the cumulative record of sensory information and machine configuration. It is 'the state of the memory', here the state of the world hologram, according to which the probabilistic formulations are upheld in a no-collapse situation. Thus only the functional identity, the state of the memory, is determinate and operates as a discrete entity while the observer itself as a physical entity is indeterminate. As the integrated structure of information recording the observations of the observer the world hologram seems to fit Everett's concept of the functional identity of the observer precisely.

9 Correlations

The world hologram defines a physical universe, by virtue of being the referent for the universe superposition, although the definition has only the level of resolution of sensory experience[8]. Since this entity is correlated with the effective universe solely by the observations made it also forms a correlations record. A very similar definition of a functional frame of reference is produced by considering correlations at the physical level. As the physical body interacts with the environment correlations are established, and the body acts as a repository for this information. The resulting structure of information is a cumulative record of the correlations. As with the world hologram, the cumulative correlations record as a ding an sich is a structure of information which exists ubiquitously in all of the universes in which it is instantiated, and all are coincident. Thus the functional frame of reference in which it exists is the effective superposition of all of the universes instantiating it. This equates to relational quantum mechanics.

In Rovelli's relational quantum mechanics the environment system is defined solely by the physical correlations established with the environment. As he emphasises, “Correlation is “information”...” (1996,9), and it is solely the cumulative sum of this information that defines the determinacy of the effective environment system; “a complete description of the world is exhausted by the relevant information that systems have about each other.” (16). Exactly this is the case in a universe superposition of all of the universes containing this correlations record, which would be indeterminate except where defined by this structure of information, since all possible variations of those aspects of the universe not defined by these correlations would be effectively superposed[9]. In the frame of reference of this structure of information it would be the sole definition of the determinacy of the effective universe. As before the definition of the effective universe is the known world of the observer, now 'known' at the physical level rather than solely the experiential level.

The universe of which the determinacy is defined by the correlations record is the familiar domain of the world hologram. The universe of the correlations record must naturally be determinate about everything defined in the world hologram, since the world hologram is the sensory record of a subset of the correlations made with the environment. The difference is that while in general the physical correlations record defines no greater extent of the universe than the world hologram, the definition is to a very much higher level of resolution.

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8 The effective universe is the superposition of all of the universes instantiating the world hologram of integrated observations, and since every possible variation of physical definition is included, the net result is determinate only to the level of definition of the observations. Thus it is a domain defined at the quantum level determinate only to the level of resolution of the sensory perceptions of the observer.

9 One might well suppose that there could be properties of the universe not defined by the correlations record which are nonetheless the same in all of these universes, and are thus determinate in the universe superposition although not defined by the correlations record. However, if one follows Donald on this point, as cited above, this would not be the case.

Everett states that it is with regard to the state of the memory that the probabilistic assertions of Process 2 are upheld, and there is the appearance of collapse. If the 'memory' is a record of observations in the widest possible sense, meaning correlations formed with the environment by any physical entity, as on Rovelli's view[10], the correlations record is the state of the memory. A specific correlations record is instantiated in a large number of universes, and as a ding an sich it exists ubiquitously in all of them. This is simply a metaphor for the natural state of the Everettian no-collapse universe. All of the versions of the universe in which this structure of information exists are coincident aspects of a single unitary system. Thus this structure of information is present in a large number of different coincident arrangements of the universe, each defined throughout space-time by a different wave function, and the functional frame of reference of this structure of information is the simultaneity of all of them, defined by the superposition of all of the wave functions. This 'state of the memory' will be considered to define the functional identity of the observer at the level of resolution of the physical.

10 The Dynamics

The time evolution of the identity of the cumulative correlations record as the observer is logically elementary, being the sequential addition of new correlations to the identity. As a mathematical structure of information the correlations record is intrinsically singular and discrete, so if there is a change in the definition of the universe instantiating this structure of information such that more than one possible outcome exists for its time evolution, it fissions, thus there is a branching tree of correlations records[11]. With each addition of a new correlation the functional frame of reference changes because the universe superposition is the superposition of all of the universes containing this new referent. In a universe superposition the 'universe' the observer defines by being the referent is the *determinacy* of the universe superposition, while the universe the observer observes is the universe superposition as a whole. By virtue of this difference the system gives rise to an inherently iterative collapse dynamics.

The universe superposition defines the linear dynamics, and thus the range or spectrum of possible next moments, the time evolution of the effective physical universe defined by a specific wave function. All of the possible new correlations that could be added to the referent are instantiated in the linear dynamics of this physical system, the effective universe. As an extrapolation of this linear dynamics all of the possible new states of the individual exist superposed and mixed at the

10 “By using the word “observer” I do not make any reference to conscious, animate, or computing, or in any other manner special, system. ... the observer can be a table lamp.” (1996,3)

11 As with any entity of which the identity is a structure of information, the evolution of the identity is always a specific and singular sequence of states of the definition of that entity, and where the logic of that evolution forks there are multiple descendants. A form letter for use in a business, for instance, may go through a number of iterations before being put into use, and is then adapted for individual cases.

physical level. At the level of information process each discrete and singular addition of a new correlation to the referent results in a different discrete and singular referent. Each referent defines the determinacy of a different effective universe, the universe superposition of this version of the individual at this moment, and the cycle begins again. Each such universe superposition defines the range or spectrum of possible next moments for this version of the individual at this moment, and so on. This iterative loop is the exercise of the collapse dynamics, a transtemporal sequence in the unchanging overall linear dynamics of the no-collapse universe, giving rise to a branching tree of subjectively singular and discrete referents, each with a corresponding effective universe. Objectively all possible versions and moments are subsumed in the overall linear dynamics, subjectively the reality is a sequence of determinate observations.

The linear dynamics is here assumed to be a static layout of the universe throughout space-time, corresponding to a specific wave function, and the overall linear dynamics to be the static layout of universe of the unitary wave function[12]. On this view there is no collapse, as Everett holds, only the appearance of collapse, the subjective appearance of collapse to observers being induced by the change in the effective universe in the functional frame of reference of the observer as new correlations are made with the environment system. As Everett states the "state function ... gives information only concerning the probabilities of the results of various observations which can be made on the system." (1973,3). Thus the wave function can be seen as the probabilities of observations, of the addition of correlations to the definition of the observer, and the consequent change in the effective universe for which this definition of the observer is the referent.

11 Operational Levels

With each new observation the definition of the correlations record changes, thus the definition of the universe superposition changes as does the effective linear dynamics in the functional frame of reference. Objectively, in the overall objective frame of reference, this change is brought about by the quantum mechanical processes in the physical world, and every possible variation of this process exists superposed and mixed; objectively one could account for this change as the result of progression along the linear time dimension of space-time in the unchanging four dimensional layout of the universe of the unitary wave function. Subjectively, in the functional frame of reference of the correlations record, only one version of this process happens, because when there is more than one possible next observation the correlations record fissions and for each version of the correlations

12 Decoherence reduces or eliminates superposition in specific versions of the universe, giving rise to larger numbers of more specific versions of the universe, however, decoherence is inevitably a linear effect, thus the overall effect is still a static four dimensional layout. For simplicity the term linear dynamics will refer to the linear development of the quantum definition of the universe including the effect of decoherence.

record there is only ever one version of events. Thus, while objectively all possible versions of the process occur superposed and mixed, subjectively there is a collapse of the possibilities to a specific outcome. Thus the collapse dynamics applies only to the subjective functional frame of reference, and in objective terms there is only the appearance of collapse subjectively.

The level of operations of the subjective realty is here an information process at a different logical level to the physical, and following different rules of logical operation, at least in regard to superposition and location. Thus while the collapse dynamics inherent to the reality of the correlations record is incompatible with the linear dynamics, it operates at a different logical level to the physical, the logical level of the linear dynamics. The collapse dynamics is of course instantiated in the linear dynamics, just as the computation of a quantum computer is instantiated in the hardware, but the time evolution of the functional frame of reference of the observer is a branching tree, instantiated[13] in a single linear dynamics, and each functional frame of reference constitutes a series of discrete singular subjective definitions of the reality, the effective universe. This presumably applies to any functional frame of reference defined by a mathematical structure of information.

On this view the linear dynamics is the dynamics of the physical, and the collapse dynamics is the dynamics of the information structure of the correlations record, and they are the time evolution of the system at different operational levels. Returning to the problematic measurement situation, Barrett's classic example (1998) is examined from both perspectives. When an observer *O* goes to measure the x-spin of a physical system *S* that begins in a superposition of x-spin eigenstates, the initial condition of the physical system to be measured is indeterminate.

$$|\text{“ready”}\rangle O\ (\alpha\,|\text{x-spin up}\rangle S + \beta\,|\text{x-spin down}\rangle S)$$

The cumulative correlations record defines the functional identity of the observer, to which will be added either the observation of x-spin up or x-spin down. At the physical level after the observation the two possible results are superposed and the two physical variants of the observer exist superposed also, no collapse has occurred. This is the time evolution of the linear dynamics.

$$\alpha\,|\text{“spin up”}\rangle O\,|\text{x-spin up}\rangle S + \beta\,|\text{“spin down”}\rangle O\,|\text{x-spin down}\rangle S$$

This is the objective perspective; if the observer is Wigner's friend then this is her definition as far as Wigner is concerned before he enters the room. Subjectively, however, each of these superposed situations instantiates a different

13 The term 'instantiation' is used here as Chalmers uses the term 'implementation', meaning that “the causal structure of the system mirrors the formal structure of the computation. That is, the system implements the computation if there is a way of mapping states of the system onto states of the computation so that physical states that are causally related map onto formal states that are correspondingly formally related.” (1996, 318). Thus the causally related sequential states of the single physical system defined by the linear dynamics map onto a branching tree of correspondingly formally related sequential states of the functional frame of reference of the observer, implementing, or instantiating, a collapse dynamics.

identity of the observer, and while they are physically superposed, subjectively they are singular. The correlations record of the first situation has fissioned to become two different correlations records, giving rise to the definitions of two different variations of the observer, one the initial identity of the observer plus the observation x-spin up, and other the initial identity of the observer plus the observation x-spin down. These two different correlations records exist in two different functional frames of reference. The two are physically superposed, but subjectively, meaning in the functional frame of reference of the individual entity defined by each structure of information, each is subjectively a singular experience, an observation by a singular identity defined by a specific correlations record. This provides exactly the outcome predicted by the standard von Neumann-Dirac collapse formulation, which is that the quantum-mechanical state of the system will collapse either to

$$\left|\text{“spin up”}\right\rangle O \left|\text{x-spin up}\right\rangle S$$

or to

$$\left|\text{“spin down”}\right\rangle O \left|\text{x-spin down}\right\rangle S$$

which, subjectively, is exactly what it does. Subjectively, one or the other happens, as the observer defined by the correlations record fissions, and in the functional frame of reference of each of the resulting versions of the observer there is a specific determinate result. Two different versions of Wigner's friend each experience a specific, different, determinate result to the measurement. At the operational level of information structures there are two different results of the observation, two parallel situations exist. In each of the two parallel situations the observer has made a determinate observation, and the resulting cumulative correlations record is the referent for a new universe superposition which defines a new linear dynamics as a result.

12 The Reality of Subjective Reality

Like the universe proposed on early interpretations of quantum theory the universe defined solely by correlations is indeterminate except where observed. In a universe with multiple observers of equal status this is a severe problem since it requires an explanation of how mere observation affects the global, and presumably physical, definition of the world. While universe superposition produces a relational quantum mechanics in which observation changes the physical functional frame of reference, this poses no paradox. Naturally, observation does not make any difference to the physical situation, it does not induce determinacy at the physical level in the overall frame of reference. It results in determinacy of the effective universe in the functional frame of reference of the observer, because it changes the referent. In the new definition of the functional frame of reference a new correlation is defined, and thus

determinacy exists where before there was indeterminacy. But this is not so much a physical change as a change in perspective, a change in the position of the viewpoint taken, and thus a consequential change in the effective environment. This is now the environment of the observer having made that observation and added that correlation to the definition of the referent. This is the perspective of the observer from a different point in the overall reality of the unitary wave function. Naturally the observer does not actually change position, this is the slightly different perspective of a slightly different version of the observer, nothing changes position except the functional frame of reference.

At the level of the physical the overall linear dynamics of the unitary system is unchanging. Decoherence modifies the linear time evolution of the unitary wave function, but this too is a linear effect, there is no discontinuity. The time evolution of the correlations record is discontinuous with the collapse giving rise to a branching tree of singular identities. Hence the subjective appearance of collapse at the physical level in a no-collapse universe, since the functional frame of reference of the correlations record is, at each point in the time evolution, an effective physical universe, the universe superposition. Thus Everett's statement that “the formal theory is objectively continuous and causal, while subjectively discontinuous and probabilistic” (1973,9) is borne out at the physical level, although the collapse dynamics is not a physical process. The functional frame of reference of the correlations record is a physical universe, but the time evolution of this effective universe operates on the logical principles of information. The range or spectrum of physical possibilities is determined at each point by the linear dynamics of the physical, but the time evolution of the identity of the observer is always a specific determinate change, the addition of a specific correlation, resulting in a new version of the effective universe defined by this new referent. The time evolution of the effective universe of the observer is the subjective effect of the change in the definition of the correlations record, a collapse dynamics.

13 The Observer

As with Everett's observer system and the memory configuration, the functional frame of reference of the correlations record is not the frame of reference of the physical body; in the problematic measurement situation the physical body is in a superposed state with more than one observation realised, and more than one correlations record superposed. As before, there is no single unique state of the physical body of the observer, only the 'memory', the correlations record, is determinate. Given that we encounter only determinacy, the explanation adopted here is that we are entities defined by this record, rather than determinate physical bodies on the conventional view; as Everett suggests, the memory configurations define the functional identity of the individual. If we are entities defined by mathematical structures of information, then the time evolution of each observer's effective physical reality is a collapse dynamics. Nonetheless, as with the world

hologram, each individual is a physical entity in a physical world, although both body and world are highly indeterminate.

While it seems obvious we are ordinary bodies, an even more fundamental sense of identity and existence is the subjective life of each person, the stream of consciousness, the flow of observations and the experience of the process of reality. On this view each individual is primarily an information process in the overall system of the Everettian universe, one defining at each point in time the determinacy of both the body and the effective universe of that observer. The reason each individual is in a personal physical parallel reality, with each person in a different personal version of the effective universe, is because each individual is the sole referent for a specific version of of the determinacy of the physical reality. We encounter each other in physical reality, and it seems entirely obvious that we are all in the same physical reality as we do. However, in each individual reality other observers are, like any other property of the reality, highly indeterminate. At the same time this is not a solipsistic view, all observers are acknowledged as equally real, each in a personal parallel reality. It's multisolipsism! This is a many worlds situation where each world is a universe superposition. Functionally the presence of other observers in the personal reality can best be understood as the presence of icons, each one representing another subjective universe superposition, a personal parallel reality.

14 Conclusion

Rovelli's interpretation explains the paradoxical nature of quantum mechanics and demonstrates why the observer is necessarily treated as having extraordinary status. It certainly fits the facts, and it equally certainly entails a departure from the assumptions of generations of scientific inquiry; relational quantum mechanics equates to personal physical parallel realities. Rovelli's relational quantum mechanics is presented as applying solely between one system and another, however, a functionally identical system is naturally instantiated in an Everettian universe if the observer is in a 'universe superposition'; in other words, if the indexical location of the observer of an effective universe defined solely by correlations is indeterminate.

On this view the measurement problem is resolved by taking subjective reality to be an information process. The subjective identity defined by a structure of information not only gives rise to measurement records which are inevitably determinate, it produces a collapse dynamics at a different logical level to the physical. Thus, while the two quantum mechanical dynamics are incompatible, they are simply different operational levels of the same system. The physical universe is defined by the unchanging layout of the overall linear dynamics, and the shifting viewpoint of the observer is defined solely by the cumulative correlations record, giving rise to the appearance of collapse with the addition of each new correlation. Thus on this view there is no such thing as collapse at the

physical level, only the appearance of collapse, as on Everett's thesis. The linear dynamics is the dynamics of objective reality, the overall physical definition of the universe, and the collapse dynamics is the dynamics of subjective reality, the dynamics of the effective universe of an individual observer.

The observer defined as the cumulative correlations record defines the determinacy of the reality, thus the observer seems to be defining the world it observes, but it is simply defining the world it *has* observed, there is no self-observation. Not only is this all the definition this effective universe has, it is only the surface of the world facing the observer that becomes part of the definition. This is at least strange to our conventional way of thinking, but entirely in accord with the holographic principle, according to which there is no more definition to reality in the volume behind the interface with the environment system, than that which is defined by the interface, the observed surface of the environment system. There is no more definition to the region beyond the interface in that it is indeterminate, but it is nonetheless a physical universe, it is just the actuality of a no-collapse universe. This is simply the Everettian universe.

The effective universe of each individual observer can be conceptualised in physical terms as the 'universe superposition', the simultaneity of all of the possible versions of determinacy of the universe concomitant with the existence of the individual entity defined by a specific record of correlations with the environment. Each reality is thus determinate with regard to the definition of the correlations record and otherwise indeterminate. Alternatively it can be conceptualised in information terms, as the interface to the Everettian universe of the unitary wave function, the information defined by the interface being the correlations, and the functional identity of the individual observer the correlations record.

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