JOURNAL OF SCIENTIFIC EXPLORATION

A Publication of the Society for Scientific Exploration

(ISSN 0892-3310)

Editorial Office: *Journal of Scientific Exploration*, Society for Scientific Exploration,
Kathleen E. Erickson, *JSE* Managing Editor, 151 Petaluma Blvd. So., #228, Petaluma, CA 94952 USA
EricksonEditorial@att.net, 1-415-435-1604, (*fax* 1-707-559-5030)

Manuscript Submission: Submit manuscripts online at http://journalofscientificexploration.org/index.php/jse/login

Editor-in-Chief: Stephen E. Braude, University of Maryland Baltimore County, MD

Managing Editor: Kathleen E. Erickson, Petaluma, CA

Associate Editors
Carlos S. Alvarado, Atlantic University, Virginia Beach, VA
Daryl Bem, Ph.D., Cornell University, Ithaca, NY
Robert Bobrow, Stony Brook University, Stony Brook, NY
Courtney Brown, Emory University, Alanta, GA
Prof. Etzel Cardeña, University of Lund, Sweden
Jeremy Drake, Harvard–Smithsonian Center for Astrophysics, Cambridge, MA
Bernard Haisch, Digital Universe Foundation, USA
Michael Ibison, Institute for Advanced Studies, Austin, TX
John Ives, Samueli Institute, Alexandria, VA
Roger D. Nelson, Princeton University, Princeton, NJ
Dean I. Radin, Institute of Noetic Sciences, Petaluma, CA
Mark Rodeghier, Center for UFO Studies, Chicago, IL
Dr. Michael Sudduth, San Francisco State University, CA

Book Review Editor: P. D. Moncrief (pdmoncrief@yahoo.com)

Assistant Managing Editor: Elissa Hoeger, Princeton, NJ

Society for Scientific Exploration Website — http://www.scientificexploration.org

Chair, Publications Committee: Robert G. Jahn, Princeton University, Princeton, NJ

Editorial Board
Dr. Mikel Aickin, University of Arizona, Tucson, AZ
Prof. Olivier Costa de Beauregard, University of Paris, France
Dr. Steven J. Dick, U.S. Naval Observatory, Washington, DC
Dr. Peter Fenwick, Institute of Psychiatry, London, UK
Dr. Alan Gauld, University of Nottingham, UK
Prof. Richard C. Henry (Chairman), Johns Hopkins University, Baltimore, MD
Prof. Robert G. Jahn, Princeton University, NJ
Prof. W. H. Jefferys, University of Texas, Austin, TX
Dr. Wayne B. Jonas, Samueli Institute, Alexandria, VA
Dr. Michael Levin, Tufts University, Boston, MA
Dr. David C. Pieri, Jet Propulsion Laboratory, Pasadena, CA
Prof. Juan Roederer, University of Alaska–Fairbanks, AK
Prof. Kunitomo Sakurai, Kanagawa University, Japan
Prof. Yervant Terzian, Cornell University, Ithaca, NY
Prof. N. C. Wickramasinghe, Cardiff University, UK

SUBSCRIPTIONS & PREVIOUS JOURNAL ISSUES: Order forms on pages 207–209 or scientificexploration.org.

COPYRIGHT: Authors retain copyright to their writings. However, when an article has been submitted to the *Journal of Scientific Exploration*, the *Journal* holds first serial rights. Additionally, the Society has the right to post the published article on the Internet and make it available via electronic and print subscription. The material must not appear anywhere else (including on an Internet website) until it has been published by the *Journal* (or rejected). After publication, authors may use the material as they wish but should make appropriate reference to *JSE*: "Reprinted from "[title of article]", *Journal of Scientific Exploration*, vol. [x], no. [xx], pp. [xx], published by the Society for Scientific Exploration, http://www.scientificexploration.org."

Journal of Scientific Exploration (ISSN 0892-3310) is published quarterly in March, June, September, and December by the Society for Scientific Exploration, 151 Petaluma Blvd. So., #228, Petaluma, CA 94952 USA. Society Members receive online *Journal* subscriptions with their membership. Online Library subscriptions are $135.

JOURNAL OF SCIENTIFIC EXPLORATION
A Publication of the Society for Scientific Exploration

Volume 25, Number 2 **2011**

Editorial

Research Articles

Commentary

Essay

Letter to the Editor

Book Reviews

SSE News

Journal of Scientific Exploration, Vol. 25, No. 2, pp. 281–312, 2011 0892-3310/11

RESEARCH

Retroactive Event Determination and the Interpretation of Macroscopic Quantum Superposition States in Consistent Histories and Relational Quantum Mechanics

Sky Nelson

Submitted: 6/1/2010; Accepted: 1/5/2011

Abstract—The concept of "objective reality" is addressed, and an ontological model is suggested, in which correlations of events in the configuration space of the wave function are considered invariant with respect to changes of observer. It is suggested that these statements make the best sense when considered from within a fifth-dimensional framework, extrapolated from the four dimensions of spacetime in a direct way. A pair of postulates is then suggested which strengthens two current models of quantum theory into a broader picture, giving a physical interpretation of Macroscopic Quantum Superposition (MQS) states. Relational Quantum Mechanics (RQM) from Rovelli and Consistent Histories ("CH") from Griffiths are discussed and related to the postulates. By dropping the assumption that unobserved macroscopic events are "in a definite state" determined independently of an observer, a surprising but consistent theory of quantum macroscopic reality is arrived at (with fewer fundamental assumptions about everyday reality) that does not contradict experiment or everyday experience. As a result, a concept herein termed "retroactive event determination" is extended from a quantum principle (in CH) to a macroscopic principle. Macroscopic events that have not been observed by a particular observer are free to be retroactively determined. The feasibility of applying the physics of quantum operators to macro systems is analyzed using the concept of "macro projectors." Various concerns with this model are addressed, such as solipsism and decoherence of the wave function for macro objects. A discussion is also made of the philosophical context of the ideas suggested. Some experimental ideas are offered.

Keywords: Macroscopic quantum superposition—MQS—consistent histories—relational quantum mechanics—time—spacetime—retrocausation—framework—single-framework rule—macro pointers—synchronicity—meaningful coincidence—positivism—observer effect—measurement problem—delayed choice experiment—retroactive event determination—existential behavior—Many-Worlds model

> *The term 'happens' is restricted to the observation.*
>
> —Werner Heisenberg (1958)

Introduction

In this paper I tackle the much-debated concept of macroscopic quantum superposition states. While there is good reason to reject any ontological status for these (e.g., decoherence (Zurek, 2003) or the apparent definiteness of everyday experience), there is also the encouraging fact that MQS states have a fundamental place in the mathematics of Hilbert spaces, as can be seen in Griffiths (2002). In order to approach this, I begin in the next section, Objective Reality, with a discussion of "objective reality," and propose that the individual experiences of a given observer cannot be considered part of this objective reality, because the perception of a definite reality (according to Relational quantum mechanics) will change under a change of observer. I find, however, that *correlations* among events will be invariant under such a change of viewpoint, and this leads us to extend our conception of spacetime from the four Einsteinian dimensions into a fifth dimension (a dimension of correlation of possibilities).

Motivated by this and on largely epistemological grounds, I propose (in the section Postulates) two postulates related to the macroscopic perspectives of multiple observers. I show that these postulates are fully consistent with the mathematical formalism of Consistent Histories. I look at these postulates from the point of view of a traditional delayed choice experiment, and then from a (possibly controversial) macroscopic situation.

In the section Macroscopic Quantum Superposition States, I attempt to provide some justification for the use of quantum operators on macroscopic systems. Specifically, I focus on the inevitable unitary evolution of a system into MQS states in certain common circumstances, and I analyze the emergence of macro projectors from these unitary evolutions. I argue that instead of basing the existence of MQS states on Heisenberg's uncertainty principle and the phase states of individual micro systems, one can apply certain concepts of operators directly to these macro systems, and bypass some of the traditional difficulties with these concepts.

Of course, one should anticipate objections that the reader will have in applying quantum principles to macro events. In the section Concerns and Comparisons I discuss paradoxes of causality that might be of concern in this model. I also make note of the dimensionality problem associated with wave–function realism, comparisons with the Many-Worlds model, the concern of solipsism, and the well-known concerns regarding decoherence of quantum effects.

By its nature this paper strays outside of the pure physical sciences and touches on philosophical and metaphysical ideas. It is important to realize the philosophical context in which these ideas fall, so I make an attempt in the section Philosophical Grounds to provide the reader with some comparisons to standard philosophical stances on these issues. I also address in the section Evidence and Verification some possibilities for experimental verification.

Objective Reality

Does there exist a Mind-Independent reality? What structures should be considered “real”? What aspects of the world can be considered “objective” and which must be “subjective”? These questions have long been debated, and I will not answer them in depth here. However, I do wish to take a stand and propose a model for the sake of supporting my later arguments.

In the Relational model given by Rovelli (1996), the state of any observable cannot be said to be absolute, but rather is determined only from the point of view of a given observer (i.e. it is relationally defined). Hence, every measurement is seen as a relational exchange of information between two entities that now form a relationship. These relationships could be called “relational data” about the world, but they cannot be seen as “absolute facts” (Rovelli, 1996), since they are only determined from a single observer’s perspective. This implies that a single definite event from one observer’s point of view (POV) will not be definite from the point of view of another observer. In the Relational model, even if one is discussing a system S which has been observed by a number of observers (P_i), and “fixed” for those observers into a definite state, it is *always* possible to select a larger perspective of some observer K who is outside of this system. For this other observer K, the state of the system S and all the observers P_i will all be undetermined[1] (but correlated)[2]. The conclusion, then, is that single definite events from one POV can no longer be described as definite when one switches one’s POV or framework[3] to that of another observer. I will venture to say that this means single definite events cannot be considered objectively real.

If definite events from a single POV cannot be considered “objectively real,” what then can? In the Relational model, each interaction results in a correlation of the state of two entities. Rovelli says:

> P has information about the initial state (of S), and therefore has the information that the measurement (between Q and S) has been performed. The meaning of this is that she knows that the states of the S–Q systems are correlated, or, more precisely, she knows that if at a later time t3 she asks a question to S concerning property A, and a question to Q concerning his knowledge about A, . . . she will get consistent results. (Rovelli, 1996:15)

In other words, one can know in absolute terms that a correlation has occurred, even if one cannot know what the definite state of the system is.

For instance, say S is a spin-1/2 particle being measured in the z direction. If P^1 measures S, he can certainly state that the correlated wave function for this combined system after the interaction can be written as in Equation 1:

$$|\psi>=\frac{1}{\sqrt{2}}\{|S_+>|P^1_+>+|S_->|P^1_->\} \quad . \qquad (1)$$

If another quantum entity P^2 measures the system, then the correlated wave function would unitarily evolve into a further correlated state (Equation 2):

$$|\psi>=\frac{1}{\sqrt{2}}\{|S_+>|P^1_+>|P^2_+>+|S_->|P^1_->|P^2_->\} \quad . \qquad 2)$$

This correlation would be true from any of the perspectives P^2, P^3, K, etc. Furthermore, from the perspective of the entity P^1, he himself would be in a definite state $|P_+{}^1>$ (or $|P_-{}^1>$), meaning he had measured $|S_+>$ (or $|S_->$). So from that point of view, the system is in a definite state, and (more importantly) P and S are correlated.

The fact that two or more states are correlated, then, does not change when one switches from one to another POV. This is more than just "relational data." I shall therefore (for the purposes of this paper) consider the correlations among events in spacetime to be considered "objectively real."[4]

This declaration implies a sort of wave-function realism. I will delve more deeply into this in the section Philosophical Grounds. One of the main concerns with wave-function realism is that it supposedly introduces many extra dimensions into our ontology, since the dimension of the configuration space for a system of N particles contains 6N dimensions (Lewis, 2003) rather than the familiar three spatial dimensions. However, I think a different approach to this question of dimensionality could be helpful.

The argument goes like this. Let us begin by looking back at our definitions of the first four dimensions, and the physical properties these dimensions have. It is well-understood that a one-dimensional object (a line in Cartesian space) is a replication of a zero-dimensional object (a point)[5], ad infinitum, into a "new" direction that doesn't exist for the zero-dimensional point. Similarly, a two-dimensional plane can be thought of as a result of extending the one-dimensional line in a new direction that is not available to the line, and generating a set of "all possible versions" of the line. Moving further, a three-dimensional volume is a replication of all the possible two-dimensional planes, lined up in parallel. We can continue the description into the fourth (Einsteinian) dimension of time, by viewing time as the collection of all the possible versions of three-dimensional space, set side by side in an orderly fashion (which we experience one at a time, in order). The totality of time represents a collection of all the "versions" (i.e. days) of our three-dimensional world that exist over time.

Following this pattern, Bryanton (2006) concludes that there could be a structure which allows us to set all the possible four-dimensional worlds side by side in an orderly fashion. This would be a "dimension of possibilities," the five-dimensional structure that supports the objective reality as defined above. For instance, a spin-1/2 particle which passes through a Stern-Gerlach magnet aligned in the z+ direction will now take up two "points" in the five-dimensional configuration space, corresponding to the two possible states it could be found in. Clearly, in three-dimensional space, a definite event can only be assigned one value of time for a given observer. Similarly, an observer can only experience one four-dimensional timeline, based on a single coordinate in five-dimensional space. I will posit that the analog of "location" within this five-dimensional configuration space refers to "where one resides" among the various possible correlations of events (i.e. which events have been observed by a given POV and which ones have not). Note that this property of five-dimensional location is a quantity that is relative to the observer. On the other hand, we can consider the *correlations* of four-dimensional events (i.e. statements about which entities have interacted) as "objects" in the five-dimensional space. Note that this property, based on our discussion above and to follow, is invariant among various observers.

The reader may see some clear connections to the Many-Worlds theory here, or have other objections. These comparisons and considerations will be addressed in the section Concerns and Comparisons. This description has been short and intentionally hand-wavy, in order to move on to my central point.

Postulates

The postulates offered below are not original ideas; they are gleaned from various sources,[6] but their inclusion here in this particular order is intended to create a model that has a sort of completeness and can work together to provide greater insight into the nature of things. They are partly motivated on epistemological grounds, and so I am not claiming that just because the model presented is internally consistent that it is also a descriptive or "true" model of physical reality.

I suggest two basic principles:

Postulate 1:

- **Events are only "determined" or "undetermined" from a given observer's perspective. The only events that are "determined" for an observer are those that have been observed[7] by the observer. Those that are not yet observed are "undetermined."**

  "Undetermined" describes an event that still has multiple possible outcomes. It is more than the idea that I simply don't know what has happened yet. It is the fact that no definite statement can be made about the outcome of the event. I will use the phrase "it hasn't actually 'happened' yet" (with 'happened' in quotes) to convey the notion that the outcome of the event remains undetermined *even if the event already took place*. This postulate implies that the state of any observable is relative to the observer.

Postulate 2:

- **There is no definitive absolute perspective. The universe can only be meaningfully described from one perspective ("framework") at a time.**
  This postulate says that there is no global, bird's-eye perspective on our world that can see everything in a definite state. Definite states can only be experienced from a single perspective at a time, in which case Postulate 1 applies.

To understand the motivation for these principles, let's first consider (as a metaphor) the approach that particle physicists use to predict the existence of virtual particles. Any particle that exists for a timescale shorter than that on which the fabric of the universe would allow it to be measured (via the Heisenberg Uncertainty relations) cannot be said either to exist or to not exist. One cannot prove that these quantum fluctuations do or don't exist, so we have to assume that they do have some validity underneath the limits given by the uncertainty principle. Furthermore, we know that they have a tangible impact on the physics of the universe.[8]

In a similar way, we can consider MQS states more as logical conundrums rather than physical things, and yet arrive at a tangible physical result that has definite consequences. Just as one cannot peer within the Heisenberg limits to see virtual particles, via this metaphor one also cannot be *definite* about any event (macroscopic or otherwise) which one hasn't observed. The only way to be definitely sure of the state of an event is to observe it in some fashion. So I claim here that unobserved events have an indeterminate nature, and that this fact can be included in reliable theories regarding observed events.[9] This claim holds as long as the hypothetical MQS events cannot be shown *not* to exist. Until one observes a macroscopic object, one cannot actually say what state it is in, nor whether it is even in a definite state. One should not simply assume it is in some state if one is not oneself observing it. From a strict interpretation of Rovelli, it follows that even macroscopic objects have no observer-independent definite state.

For the following discussion, let's use the delayed choice experiment by Jacques et al. (2006). Consider two correlated events, such as the measurement of photon S by Q and by P in the diagram (Figure 1). These events are correlated

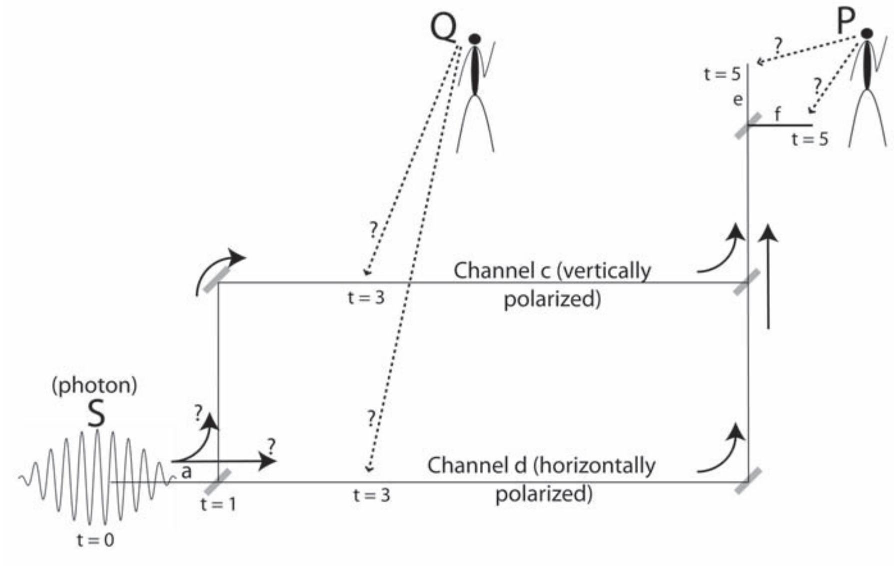

Figure 1. Schematic of the delayed choice experiment performed by Jacques et al.

in the sense that the measurement by Q will give a result that does not contradict the measurement by P. Our common sense tells us that the measurement by Q happens first, followed by P. Therefore, *if our measurement at P were to affect Q* (remember, Q happened first), we are stuck in a dilemma of acausality (Wheeler's delayed choice paradox).

Griffiths does a fine job of resolving this paradox, but I will attempt here to show how the proposed postulates interpret this situation. I have discussed Relational quantum mechanics at some length, and I now turn to Consistent Histories for some further clarification. Consistent Histories (Griffiths, 2002) theory postulates that we can look at the history of an unobserved particle S as a set (a "family") of possible histories, each of which must be internally consistent, according to certain mathematical requirements.[10] The particular knowledge one has of a system determines the framework of possible histories that are available, and only one framework can be used in a given analysis in order to maintain a consistent (non-paradoxical) description of the system. This is the inspiration for the second postulate, which states that one can only describe the world from a single perspective at a time.

In my interpretation of the Consistent Histories formalism, one finds that there can be constructed certain frameworks in which events are not required to be determined at the moment they happen. Rather, the possible histories of the system can be constructed in various ways, only some of which allow us to make concrete statements about certain properties of the particle S at certain times. Some of these will give us information, for instance Equation 3,[11] about the path a photon takes inside an interferometer, but will lead to superposition states in the output at time = 5, where the superposition states are defined as in Equation 4. This particular framework will give us definite information about the particle inside the detector, but it precludes information about the state of the particle in the output.[12] Another consistent history (Equation 5 and Equation 6) will give us definite information about the output of the interferometer, but not allow us to make specific claims about which path the photon took inside the device (for instance at time = 3).[13] The critical assertion of Consistent Histories is that one cannot combine these two descriptions. There is no overview of the situation which would tell us how the photon behaved overall, both inside the device and at the output.

$$\begin{aligned} Y^c &= [0a] \odot [1c] \odot [2c] \odot [3c] \odot [4c] \odot [5\bar{c}] \odot [6\bar{c}] \\ Y^d &= [0a] \odot [1d] \odot [2d] \odot [3d] \odot [4d] \odot [5\bar{d}] \odot [6\bar{d}] \end{aligned} \tag{3}$$

$$\begin{aligned} |\bar{c} &>= (|e > +|f >)/\sqrt{2} \\ |\bar{d} &>= (-|e > +|f >)/\sqrt{2} \end{aligned} \tag{4}$$

$$\begin{aligned} Y^e &= [0a] \odot [1\bar{a}] \odot [2\bar{a}] \odot [3\bar{q}] \odot [4\bar{q}] \odot [5e] \odot [6e] \\ Y^f &= [0a] \odot [1\bar{a}] \odot [2\bar{a}] \odot [3\bar{q}] \odot [4\bar{q}] \odot [5f] \odot [6f] \end{aligned} \tag{5}$$

$$\begin{aligned} |\bar{a} &>= (|c > +|d >)/\sqrt{2} \\ |\bar{q} &>= (e^{i\phi_c}|c > +e^{i\phi_d}|d >)/\sqrt{2} \end{aligned} \tag{6}$$

Let's consider the perspectives of person P and person Q in examining the previous equations. Each of them should be assumed to get a definite result from their measurement.[14] We see then that Q's measurement at time 3 utilizes the information in the framework (Equation 3), because this is the only framework that can give him definite information at that time. Person Q will not be able to make a definite statement about the state of the system at time 5 because of the superposition state at that time, according to this framework. On the other hand, P's measurement at time 5 requires a different framework to get a definite result (Equation 5), which will allow him no definite description of the state of the system at time 3. We see that each observer has a different perspective, from which certain events are determined and others are undetermined. Griffiths goes to great efforts to show that no paradox is generated so long as one restricts oneself to one framework at a time.

Finally, let's consider this situation from the POV of an outside observer, K. Observer K will walk into the lab room with no knowledge of the states of S, P, or Q. The framework which K would employ to describe the situation could be something like Equation 7.

$$\begin{aligned} Z^a &= [0S_0, Q_0, P_0] \odot [1S_1, Q_0, P_0] \odot [3S_1, Q_1, P_0] \odot [5S_1, Q_1, P_1] \\ Z^b &= [0S_0, Q_0, P_0] \odot [1S_2, Q_0, P_0] \odot [3S_2, Q_2, P_0] \odot [5S_2, Q_2, P_2] \end{aligned} \quad (7)$$

This description shows that K has no knowledge of the *results* of the measurements by P and Q, but he can be certain that the measurements of P and Q were made, because their states remain correlated to those of S throughout both histories. Furthermore, it is only at time = 5 that K makes an observation[16] of the whole system and gets a definite result for the state of the system. Only at this point would he be able to confirm that S, P, and Q are all in definite states. Notice that all the events at time = {0, 1, 2, 3, 4, 5} now become retroactively determined, from the POV of observer K. This is a central conclusion of this paper, clearly visible in CH, that I refer to as Retroactive Event Determination (RED).

Notice that I have opted for the word "determined" and very carefully avoided the use of the word "affected," because it would be erroneous (and against the intent of the CH formalism) to say that our choice of framework retroactively *affected* the system in question. Rather I am pointing out that the different families of histories that can be constructed for a given situation will result in different information that can be gleaned about the system. Returning back to our earlier discussion, one can say that **from K's POV the measurements by P and Q don't actually 'happen' when they happen**.[17]

This line of thought may bring up the objection that K could hypothetically observe Q's measurement secretly, so that when P makes his measurement, event Q has already been determined in some "absolute" sense, even though P may not know it. This, however, is exactly the point of Rovelli's Relational quantum interpretation, in which any exchange of relevant information between K and Q, whether secretive or not, results in a correlation of the states of K and Q. As a result, when P measures the photon S, they are actually measuring a wave function that represents the correlated states of S, Q, and K. Any measurement by P will therefore always produce results that are consistent with

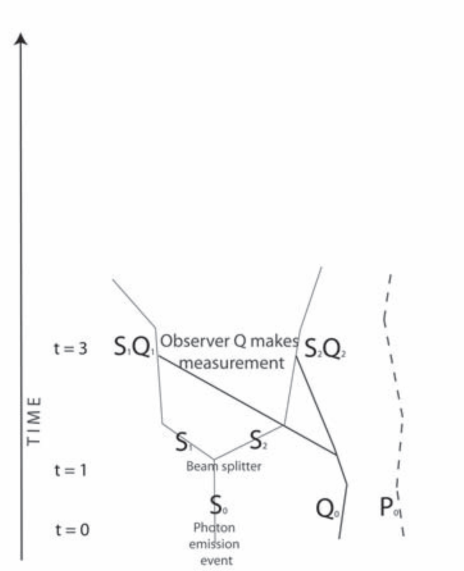

Figure 2. **(Left) A "5-D wave function tree" representation of the light in the Jacques et al. experiment, from the perspective of P. (Right) The worldline of P is shown as a dashed line to the right.**

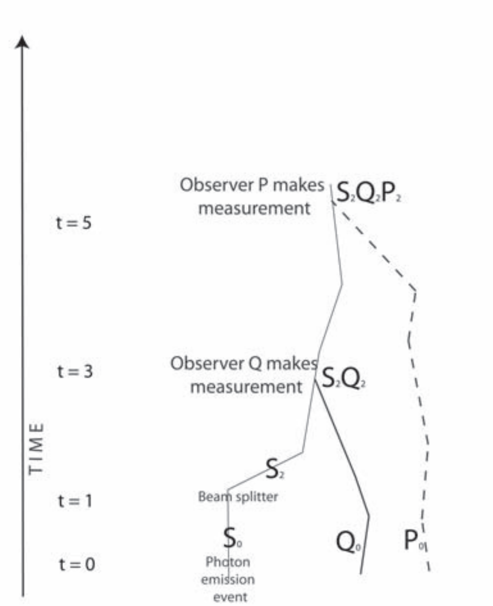

Figure 3. **At the moment of measurement by P, the photon is observed in a particular state. All other possible states for the wave function disappear from P's point of view. The events at t = 1,3 are retroactively determined at the moment of measurement.**

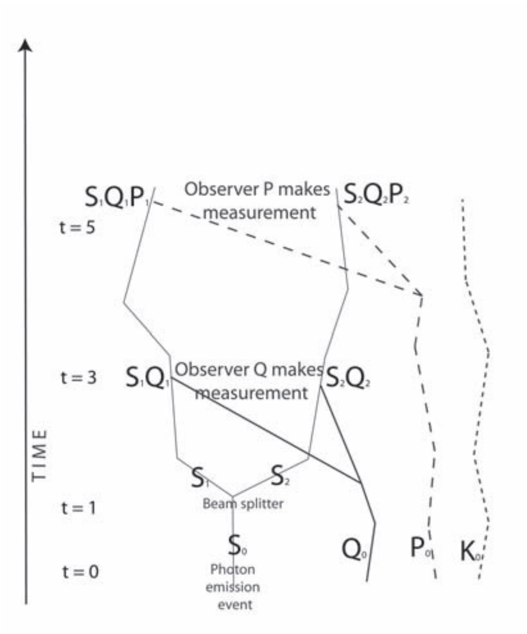

Figure 4. This is an overview of the system's wave function, from the perspective of an outside observer, K. The states of S, P, and Q all are undetermined before K interacts with the system.

any future measurement by K. A graphical representation (Figure 2, Figure 3, and Figure 4) is shown of the overall scenario from the perspectives of the various observers.

Issues like these show the complementary nature of the Relational and the Consistent Histories approach. CH requires frameworks to be defined which are perspective-dependent. Rovelli proposes the same idea in his Relational model:

> A quantum mechanical description of a certain system cannot be taken as an "absolute" (observer-independent) description of reality, but rather as a formalization, or codification, of properties of a system *relative* to a given Observer. (Rovelli, 1996:6)

Macroscopic Quantum Superposition States

So far, our discussion has been limited to uncontroversial microscopic situations. I now turn my attention to the question of MQS states. I will carefully avoid the standard approach to the subject, usually based on building a macroscopic model from the pieces of the microscopic model, because this approach is doomed to failure from decoherence. Instead, I will remind the reader that macro projectors are a perfectly legitimate aspect of the Hilbert space formulation of quantum mechanics. I will try to uncover the nature of these, and propose that they have emergent properties that do not exist for the individual micro wave functions they are composed of. In the end, I will claim that the macro projectors inherit (via linearity) the "undeterminedness" that I have been describing from the micro states that make them up.

First, I will make the point that a major mark against the existence of MQS states is that they are never observed in the lab. For instance, Zurek (2003:4) says "Given almost any initial condition, the Universe described by |Ψ> evolves into a state containing many alternatives that are never seen to coexist in our world." Or alternately, Griffiths (2002:367) asks "Is it a defect of quantum mechanics . . . that it allows the physicist [to use a framework which employs MQS states] given that MQS states of this sort are never observed in the laboratory?"[18] But why should one ever expect to "see" or "observe" a macroscopic quantum superposition, even if one is willing to accept that they are real? As in *micro*scopic physics, one can only develop equations that point to the existence of these states, and one should be able to measure effects that are the *result of* these states, but one should never expect to see coexisting states (as such), whether in micro or macro physics.[19] So we must do away with the argument that if MQS states existed we would somehow *see* them, simply because it is in the very nature of quantum entities in general to choose a particular state when measured.

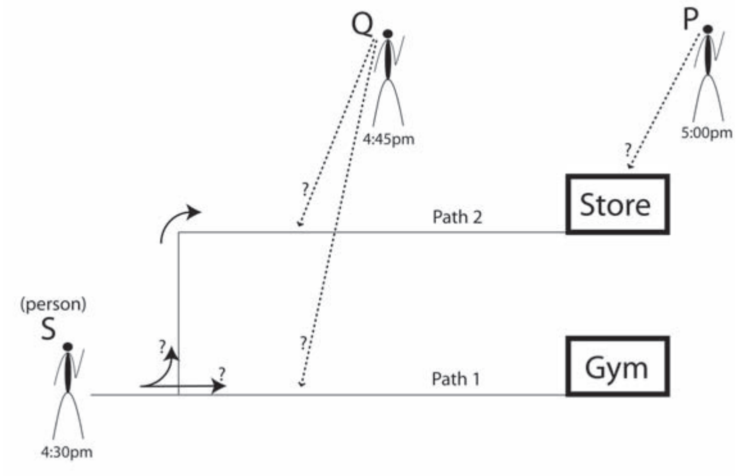

Figure 5. Macroscopic quantum superposition scenario, from P's perspective.

Let's set the stage with a Gedanken experiment. Imagine going to the grocery store (Figure 5, Figure 6, Figure 7). You arrive at 5:00 p.m., and accidentally run into a good friend (person S). Is it possible that, from your perspective, person S's history was undetermined until you actually observed her at 5:00 p.m.? In other words, from your perspective, her whereabouts were unknown at 4:45 p.m., and so you cannot rightfully say that you know her existence was in a determined state at that time, i.e. that she was on her way to the grocery store. Instead, this theory says that her state was undetermined, and multiple outcomes were possible. The only way to *know* that she was actually on her way to the grocery store would be through a measurement of some kind. One might ask, could you try to prove that this was the case by asking your other friend (person Q) to call person S at 4:45 p.m. and ask what S's plans were, without telling you the result? In this case, person Q would be performing a measurement, and the wave functions of Q and S would become correlated. However, you still would not know what S's plans were, because from your perspective the states of both Q and S are still undetermined. Therefore Q and S are still free to be determined. So if you then saw person S at the store at 5:00 p.m., you would still be surprised because the history of S would be falling into place at that moment. Yet, if you checked in with person Q, you would find that, without fail, Q's information about S would be consistent with your observation of S at the store: Namely, Q would report that S had been on her way to the store at 4:45 p.m.

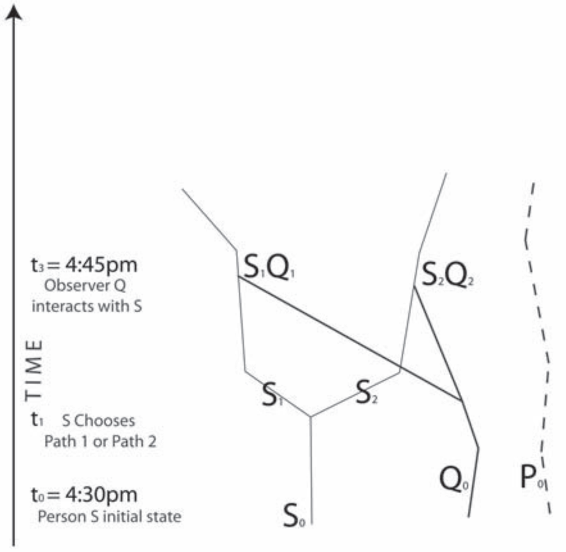

Figure 6. Wave function tree for a macroscopic situation, from P's perspective. Persons Q and S are in undetermined states.

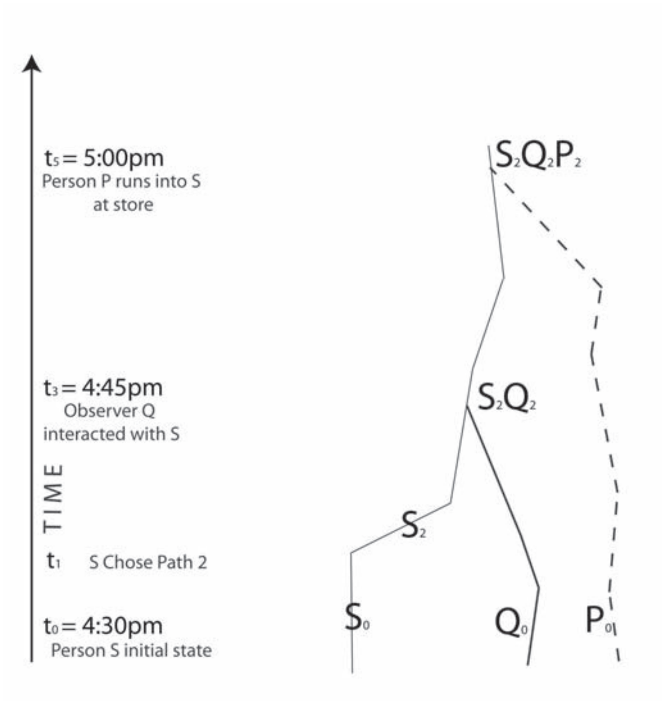

Figure 7. Macroscopic situation from P's perspective after observing person S at the store. The states of P, Q, and S all are retroactively determined from P's perspective.

From your perspective (P), this allows for the possibility that, had you gone to the gym instead of the store, the potential for an event "P accidentally runs into S at the gym" exists as well, because S and Q are not determined until 5:00 p.m. from P's perspective. Depending on the choices of P, the same outcome ("running into S," whether at the gym or at the store) is possible with different circumstances, through the action of retroactive event determination. In this way, Newtonian causality always remains true when measurements are made, but people are able to make "free will choices" in the moment that could theoretically lead to seemingly "fatalistic" experiences.[20]

In other words, one is making an unallowable assumption if one assumes that the state of a *macroscopic object* is determined if one has not oneself observed it, for there is no way to prove that it is determined except through observing it. In this case, it is possible and reasonable to wonder if the event called "person S heads to the grocery store" did not really 'happen' when it happened (the event at 4:45 p.m. was not determined until 5:00 p.m.).

So how, exactly, does the Hilbert space formulation of quantum mechanics lead to the existence (at least on paper) of MQS states? This is laid out carefully by Griffiths (2002, see for example Chapter 17) with the conclusion (for one particular example) that ". . . whatever the initial apparatus state, unitary time evolution will inevitably lead to an MQS state in which the (macroscopic) pointer positions have no meaning." In other words, using a family which has a definite state early in the history often leads to superposition states later in the history, and if those superposition states of *micro*scopic systems are correlated to *macro*scopic systems, they will represent an MQS state. Granted, one is free to choose another framework which does not lead to this conclusion, but it will of necessity (due to the consistency conditions) call for undetermined states earlier in the history.

Griffiths points out that

> If one supposes that the usual Hilbert space structure of quantum mechanics is the appropriate sort of mathematics for describing the world, then MQS states will be present in the theory, because the Hilbert space is a linear vector space, so that if it contains (two possible states), it must also contain their linear combinations. (Griffiths, 2002:277)

Said another way, if the world can be described by a Hilbert space formulation as quantum mechanics suggests, the linearity of the space will lead to superposition states, at least in a physicist's notebook. There is no fundamental limit to the linearity of the space.[21] One might say that MQS states should actually be considered a prediction of quantum theory, rather than an unfortunate byproduct. In CH, it is shown that paradoxes arise through "a process of implicitly . . . choosing families which contain no MQS states, and then inferring from this that the future influences the past, or that there are mysterious non-local influences . . . " (Griffiths, 2002:283). The physicist's *avoidance of MQS states* in fact causes paradoxes which lead to the violation of such stalwart theories as special relativity!

So let's define our terms. Following Griffiths's (2002:236) lead, "it is . . . possible to consider projectors which correspond to macroscopic properties of a piece of apparatus, such as 'the pointer points upwards'." A macro projector, then, projects onto an enormous subspace of the system being described, and it ". . . singles out regions of the Hilbert space corresponding to macroscopic properties." Let's consider a simple binary macroscopic system, a coin toss. For every possible particle configuration of the atoms in the coin we define a basis vector Ω_j, and the number of basis vectors necessary to span the Hilbert space Z is enormous. The property "Heads" in a coin toss projects onto a subspace of Z, call it Z^+, and "Tails" similarly projects onto Z^-. "Such a macro projector is not uniquely defined" says Griffiths, as is clear from the vast number of possible particle configurations that can lead to the same outcome (e.g., Heads).

In this way, the space Z is naturally divided into two macro projectors, [H] and [T]. All possible configurations of particles lie in one of these two subspaces (and only one). Due to the linearity of the space, various properties of projectors that apply to each of the constituent micro projectors would also apply to these two macro projectors. For instance, we know that [H] and [T] are orthogonal because every micro state that makes up [H] is orthogonal to every micro state in [T].[22] The kets |H> and |T> represent collections of basis vectors for Z, and yet they behave as if they are basis vectors spanning a two-dimensional Hilbert space. The projectors [H] and [T] form a decomposition of the identity in the usual sense that [H] + [T] = I. (See Appendix 1 for a complete derivation of this result.)

Here I would like to venture into more controversial territory. This grouping of an enormous Hilbert space of particle configurations into two distinct regions represents the emergence of a new phenomenon in the system: "Headsness" or "Tailsness." Any flip of the coin will land in one of an enormous number of basis states Ω_i corresponding to a particular configuration of the atoms in the coin, but each possible state will lie (for our purposes) in one of the two groups, H or T. The complete Boolean algebra for this system will include countless states which are superpositions of the form $\Psi = \Omega_i + \Omega_j + \dots$, and similarly countless numbers of these superpositions will include one micro state which falls in [H] superposed with a micro state which falls in [T]. So it seems like one must conclude, if one agrees with the conjectures thus far, that there would exist states that are macroscopic superpositions of [H] + [T]. Under normal conditions, in macroscopic situations that could be constructed analogous to the interferometer experiment above, these macro projectors would evolve unitarily.[23] Before the experimenter looks at the state of the coin, the state of the *micro*scopic configurations of the atoms in the coin will be undetermined (or have no interpretation at all). Does this not apply to the state of the *macro*scopic projectors as defined above as well? I would suggest so.

If the state of a coin after it is tossed can be described by such a macroscopic superposition, I suggest that the same principle should be extendable via the same methods to macroscopic objects of arbitrary size and nature. There has been nothing in the discussion so far of a principle that would expire after some pre-specified duration. Instead, quite the opposite, I have stated that the undetermined nature of system S from the perspective of person P remains so, for as long as P does not make an observation of S. There has likewise been nothing so far to imply that these principles would not hold true once a certain size collection of particles was reached. Rather, the linearity of quantum mechanics implies that systems of arbitrary size will display the properties of macroscopic projectors described above.

So where are we left regarding the existence of macro projectors? Griffiths says

> . . . these examples illustrate the fact that the concept of a quantum history is really quite general, and is by no means limited to processes and events at an atomic scale, even though that is where quantum histories are most useful, precisely because the corresponding classical descriptions are not adequate. (Griffiths, 2002:112)

Macroscopic Quantum States are here to stay, and this leaves for future work understanding their interpretation.

Concerns and Comparisons

Let's begin with a comparison to Everett's theory. One can draw similarities to Many-Worlds interpretations, yet there is a distinction in that the theory proposed here supposes only one present reality for the individual, and there is no philosophical need to propose a plethora of other physical worlds that will never be observed. Not all states are given credence. Rather, correlations between states limit the available states, and furthermore one cannot speak meaningfully in definite physical terms about states which one has not observed. I would suggest that it is generally the subtle assumption of "objective definite reality" that requires the concept of many other real physical worlds, and that is specifically thrown out here.

So in RED I conclude that there is only one version of "me" and of my observed world. But does this not create a paradoxical conflict? From another observer's POV, isn't my state undefined? Indeed it is. In our earlier example (Equations 3–7), I formulated historical descriptions of systems making explicit use of the single-framework rule. From one framework, one can know the outcome of a situation, and yet it may remain meaningless to talk (with certainty) about the path leading up to that outcome. Of course, one can always gain more information about the system and become certain about more aspects of its history, but the assertion remains that until one gains information about the history of the event, it is not meaningful to talk in definite terms about its history. So it is not meaningful to sit in my point of view and ponder what my state looks like from your point of view.[24]

Ultimately this brings the concern that these postulates seem to be solipsistic. If the world is fully relational in nature, and what is determined or not is totally defined per observer, then it seems that reality is defined by the observer. How is it possible to have any sort of common or objective reality in such a view? We must consider the second postulate carefully: A comparison between viewpoints is forbidden. What is "*in a definite measurable state"* is indeed relative to the observer. It is perfectly possible for multiple undetermined realities to match up without contradiction, as long as one follows the rules stated in this paper. This does not mean that one individual's view is all that matters; quite the opposite! All views are on equal footing in their ability to describe the real world, but they describe different parts of that world.

Approaching solipsism from another tack, our declaration that correlations are objective means that our individual perspectives on the correlations between events are indeed considered relative. Yet the actual events we experience do not comprise all of objective reality, so we are not being solipsistic because we are not claiming to describe all of objective reality with a simple description of our own experiences. We CAN speak definitively about the *correlations of events*, but this is not solipsistic because everyone will agree on these correlations.

Another concern regards the dimensionality of the wave function. Since I am claiming a form of "realism" to the wave-function, I should address Lewis' point that according to wave-function realism ". . . the world we live in does not have the three dimensions we take it to have, but in fact has at least 10^{80} dimensions, and perhaps an infinite number of dimensions" (Lewis, 2003:3). The problem is that an N-particle system requires (3N) independent coordinates to parameterize the properties of the system.[25] Yet for dynamical laws to be invariant, the 3N degrees of freedom of the wave function configuration space must somehow be reduced to a three-dimensional symmetry. He resolves this in the following way:

> Even though the *values* taken by the 3N parameters are independent of each other, the *directions* referred to by the parameters are not all independent; every 3rd parameter refers to the same direction . . . (so) the coordinates of quantum mechanical configuration space range not over 3N-dimensional points, but over three-dimensional *particle configurations*. (Lewis, 2003:10)

It seems that if one selects a given particle configuration, one effectively reduces the space from 3N-dimensional to third-dimensional. This is exactly what happens when one observes an event; one obtains (relative to oneself) a single definite particle configuration space, which has the usual three spatial dimensions.[26]

Concerning the comparison of the RED model to "collapse theories" such as the Copenhagen Interpretation, there are two main points. First, the theory proposed here is based in part on Relational quantum mechanics, in which the idea of collapse still has meaning but is defined relationally. Therefore, there is no such thing as "objective collapse," because a wave function that person P is observing is collapsed for person P, but the same object may be in a superposition state for person S. A wave function is a strange beast, taking a definite value when it is measured by one observer and yet remaining in superposition for other observers. Second, in this model, MQS states are purported to exist and there is clearly no fundamental distinction between micro and macro systems, so there is no need to find a boundary between the two, which is usually considered a major limitation of the Copenhagen model. In

RED, the foundation and the house that rests on it are built of the same material.

Next, as suggested earlier, I would like to tackle decoherence. There are several problems with the theory: the motivation for it, the assumption of objective definite states (states that are well-defined for all observers), and the use of the partial trace. As noted earlier, a major motivation for decoherence theory is to explain the complete lack of first-hand experience we have with superposition states in everyday life. Anytime I observe a macro system, I find it in a definite state. Furthermore, if I retroactively observe any system (e.g., either by talking to someone who witnessed the system earlier, or watching a video of the system), I will always find that *it had been* in a definite state. However, I have made the argument above that I cannot assume that the system *is* in a definite state *in this moment* unless I am observing it. The tense of the italicized verbs above is critical in understanding this point. There is no way, other than observation in the present moment, to make a definite statement about the state of a system, and such definiteness is only defined relative to the perspective of that observer. This undermines our assurance that MQS states can be ruled out simply by common sense, since not being able to directly witness MQS states is not evidence that they don't exist.

So decoherence theory makes the assumption of objective definite states (the "environment"), which I regard as unacceptable. According to decoherence theory, ". . . the environment is monitoring the system. Therefore, its state must contain a record of the system" (Zurek, 2000:859). I would correct this to say that the environment is composed of individual macro quantum objects, which will themselves evolve unitarily into superposition states through interaction with the system. Although they do contain a record of the system (i.e. of its superposition state), they do not help us get any clearer on the objective definite state of the system. For instance, if we videotape the results of a quantum experiment, not only is the result of the experiment undetermined for a person who has not read the measurements, but also the details of the recording on the videotape are in a superposition of the possible outcomes from the perspective of a given observer, until the videotape is watched by that observer. The pieces of the environment become part of the system, and objective definite states do not exist.

All of this leads to the central process of decoherence: the step of "ignoring . . . the information in the uncontrolled . . . degrees of freedom" (Zurek, 2003:10), i.e. performing a partial trace over the environment. But if all states are relative to an observer, then this step is not justified. An object in the environment will interact with the quantum system in question and itself evolve unitarily into an MQS state, and the off-diagonal terms cannot be ignored. Taking the partial trace over the environment is only valid if the objects in the environment can be said to be in a definite state, i.e. if "the states of the environment . . . are (mutually) orthogonal" (Zurek, 2003:10). According to relational quantum mechanics, this would only be true for an observer who had observed that aspect of the environment. Generally, though, the objects in the environment do not have a definite objective state relative to all observers (the possible states of the environment are not orthogonal), so the method of tracing over the environment is invalid in such a view.

I disagree, then, with the following statement: "In the real world, even when we do not know the outcome of a measurement, we do know the possible alternatives, and we can safely act as if only one of those alternatives has occurred" (Zurek, 2003:7). Rather, all we can do is know that if we check retroactively, it will be clear that only one of those alternatives *had* occurred. Furthermore, the interference effects of the superimposed histories of the MQS states should not be considered meaningless; they might become important to consider in the case of synchronicity, a process of meaningful history selection identified by Jung (1972). While synchronicity has not been scientifically proven (or disproven), there is ample circumstantial evidence for it, and in light of the current theory it merits further research.

Finally, I would like to ask how RED impacts our notions of the flow of energy. The Liouville equation (Equation 8) concerns the time evolution of the states of a system.[27] One property of this equation is that trajectories of the states never cross or merge. This is also a fundamental result in the consistency conditions of histories in CH, and the reader is referred to Griffiths (2002:137–147, 164). Such crossing of trajectories leads to histories that are not orthogonal, and thereby cannot be considered as part of the same framework. So in this particular way CH automatically ensures the integrity of the Liouville equation:

$$\imath \frac{\partial \rho}{\partial t} = [H, \rho] \; . \tag{8}$$

One could also note that the postulates above imply that there is not a definite energy to a system from a given POV unless it is being observed by that POV. Yet one would expect the Liouville equation (and the conservation of energy) to govern the system just as it would in any quantum system. When MQS states naturally evolve in the dynamics of the system, the corresponding density matrices representing those superpositions evolve according to the Liouville equation as expected. The postulates have no affect on the Liouville equation. One could also make note of the fact that Newton's laws of motion or conservation of energy would hold whenever a measurement or calculation is made. Whenever one interacts with a system, one will find it in a state *as if* it had evolved there continuously. Yet one cannot make claims about the state of the system when one does not interact with it. This should not be considered a violation of these fundamental laws.

Philosophical Grounds

. . . there must be 'something' . . . that does not depend on us.
(d'Espagnat, 1998:11)

Here we will briefly analyze the philosophical implications of this paper.[28] The basic premises of RED lead to a sort of "middle ground" in the ancient debate over the nature of reality. RED might be considered a form of "wave-function realism," in that it acknowledges the necessity of an objectively real "something" in the form of the invariant correlations of states of the universal wave function. Yet it is decidedly of the moderately idealistic bent, considering that its fundamental notion is of the relative nature of definite states. In d'Espagnat, this thirst for a middle ground is well-stated:

> But their [the laws of quantum mechanics] very existence requires an explanation of some sort, the minimal element of which seems to be the existence of something external to us acting as a support of them. It is this something that should, by definition, be called Mind-Independent reality.[29]

There is indeed a structure in the theory presented here, namely correlations of events, which "does not just simply boil down to 'us'" (d'Espagnat, 1998:11).

Let us then look at the theory from the perspective of the moderate or transcendental idealist. Would it not be a Kantian approach to accept that it is impossible to prove that unobserved events are definite, and neither can one prove that they are not, yet one should be able to build his philosophy of the natural world based on the "objects-for-us" (d'Espagnat, 1998:3) that we experience, without concern for the (inherently unattainable) proof? In the RED model, the noumenal descriptions are the correlations between events, while the "world as experienced" is pre-conditioned by the mind (POV) of the observer. Furthermore, the RED model is attractive to the Kantian in that one is not required to question the reality of what one experiences. One is only required to question the *definiteness* of what one *doesn't experience.*

Looking at the terms employed by Whiteheadian philosophers, ". . . an actual entity is a determinate entity that can have many capacities insofar as it exists for (or is objectively given to) *other* actual entities, but *which* capacity will be fulfilled is indeterminate" (Moore, 2010:44). According to this approach, the overall potentiality of an object is complete eternally ("eternal objects"), but *which* quality or *which* event will become manifest ("actual entities") in a given moment is indeterminate.

This could possibly describe the model put forward here, in which correlations (or relationships between entities) define the eternal objects, and a given determinate state is considered an actual entity. Whitehead's eternal objects are completely static and permanent, at least in a sense, so in the model proposed here one would need to consider the correlations among objects to be static and permanent. But maybe it is good enough to have the eternal objects represented by an infinite (and therefore unchanging) collection of *possible correlations,* whose *relative weights* nevertheless evolve over time. This leaves us with only a *finite set* of accessible (significant weight) states. According to Moore (2010:48) ". . . the actual entity chooses to spontaneously manifest an anticipated feeling *and in so doing* it ultimately contributes to the form of an eternal object." Similarly, the events that occur (actual entities) can affect the states available to a system (correlations/eternal objects) by adjusting their relative weights.

The ideas presented herein point to a model that would provide relevant material for further philosophical analysis. I think it is safe to say that this model has a number of similarities to a number of well-known philosophical stances, including the classic positivist stance "Whereof we cannot speak, thereof we must keep silent" (Wittgenstein, 1961), or phrased well by d'Espagnat (1998:6): "Philosophers anxious to keep aloof from unwarranted metaphysics commonly stress . . . the wise observation that we should only speak of what we can possibly know." In that spirit, I say "We can speak of that which we haven't observed, but not in definite terms."

Evidence and Verification

RED makes claims about the retroactive determination of events in the macroscopic domain. In theory, certain types of experiments should be able to be performed retroactively and to get a positive correlation between events in the experimental "timeframe" (i.e. "in the past") and choices made when the experiment is actually performed, after the fact. Specifically, non-local experiments such as those in Radin (2008) should be amenable to such retroactive event determination. Because the causal relationship in these experiments does not rely on physical cause and effect, any experiment that can get positive results in such a situation should be theoretically possible to perform after the fact. The reader is referred to a number of experiments that have been done (Leibovici, 2001, Dunne & Jahn, 1992, Schmidt, 1976) or could feasibly be done (Nelson, 1998, Smith, Laham, & Moddel, 2010, Radin, 2008). Experiments that rely on physical cause and effect would not show any RED effect, because one can trace physical effects and their causes through linear, forward-in-time processes. RED is not actually *causing* any changes in the past; rather, it is retroactively determining them. Therefore the non-local nature of experimental testing is, I believe, essential.

An interesting parallel of this model with virtual reality programming has been brought to my attention, which may be helpful in understanding the implications of the two postulates. In massive multiplayer online games (MMOGs), there is a common difficulty with synchronizing the actions of a large number of physically distributed players in a real-time virtual world. One technique for dealing with this is called "optimistic synchronization" (Reiher, n.d., Hsu, Ling, Li, & Kuo, n.d.). Some of the parallels between RED and optimistic synchronization include: The virtual world is only rendered in a definite state from the perspective of each user (relational, Postulate 1); there is no objective definite world, but rather only the collection of worlds as rendered by all of the various users (Postulate 2); events that are observed in common between two players must agree on the specific details (consistency).

Optimistic synchronization is not proof that the world *does* work this way, nor could it be a completely correct analog. Yet it may be a useful model which demonstrates the way in which relationality and consistency of histories work together in actual application to create a virtual world.

Conclusion

I have attempted to present a coherent model for understanding macroscopic quantum superposition states. Beginning with a clear definition of "objective reality," the fifth dimension was introduced as a means for understanding the invariant nature of the correlations between quantum objects. Two postulates were presented that attempt to provide a solid argument showing that nature is undetermined except when observed. Postulate 1 says that any event (macroscopic or otherwise) unobserved by a specific observer remains in a superposition of possible histories for that observer. Its outcome is undetermined until its state is observed, and then is only determined for that particular observer. Postulate 2 says that there is no definitive global perspective that can see all events in a definite state. One is always limited to speaking about definite events only as described from a particular local perspective. From each local perspective, some events have been observed (and are definite) and other events have not been observed (and are in a superposition of self-consistent histories).

Specifically, I have pointed out that events don't actually 'happen' when they happen—what I have called retroactive event determination. This means a distinction is made between "when an event becomes determined" and "the time coordinate at which that event actually occurred." A distinction is also made between events that have been "witnessed" and are therefore "facts" from a given observer's perspective, and events that have not been "witnessed" from that perspective, which still have multiple outcomes available (from that perspective). When a given event is observed by a given observer, the history (or histories) to which that event belongs falls into place for that observer. This must happen in such a way that all of the events in the history can be consistent with each other <u>and</u> with other correlated events observed by other observers.

Through retroactive event determination, the various histories can fall into place in such a way that events are always consistent when compared.

I attempted to justify the application of quantum effects to macroscopic systems by the use of macro projectors. The grouping that defined these projectors was considered an emergent quality that does not exist for the microscopic projectors that compose them.

In attempting to address a number of anticipated difficulties, solipsism in particular is a difficult concept to conquer, because overcoming it requires a reliance on the stated postulates and the overriding of common sense. Yet I tried to convince the reader that this is not a concern because the definite events that make up an individual's relative experience are not fundamentally objective. Rather, the correlations that events have *are* objective, and everyone will agree on these.

In conclusion, the philosophical nature of the argument presented here is somewhere between realism and moderate idealism. I concede that there is an objective reality, but that its nature is indefinite and not to be regarded as physical.

A weakness of this paper is that it questions the nature of how events occur in time and space, thereby challenging our general concepts of energy and information transfer, without providing a comprehensive new model. For instance, if energy is flowing through a system, but the manner in which the energy was flowing at time T is not determined for a certain observer until after time T, what does it say about the absolute existence of energy at time T? All I have stated here is that whenever a measurement is made, the energy will have evolved *as if* it had been smoothly evolving all along.

Another important omission that is outside the scope of this paper but will need to be addressed involves asking what impact the emergent grouping of "heads" or "tails" has on the outcome of a given set of events. I have focused on justifying the existence of MQS states and provided a means for understanding how they could permeate our world without being detected (as yet), but I have not made clear what factors play in to the manner in which a particular macroscopic history falls into place. I have described the "how," but not the "why." Further research should be done into the implications of the macroscopic quantum states (MQS) suggested by the postulates here, specifically with regard to "synchronicity"[30] and the role of "meaning" in affecting the outcome of retroactive event determination.

An appealing aspect of this model is that it adds no new assumptions to our understanding of the situation. Instead, it subtracts the assumption that something exists whether or not it is being observed. This idea aligns with the spirit of scientific tradition as perceived by David Hume (Isaacson, 2007), by challenging us to believe only what one can actually observe, and no more, and making no assumptions about the continuity of reality between observations. This is used here to challenge an implicit assumption of "objectively determined reality" that we all live with on a day-to-day basis.

According to this model, the wave–particle duality is now translated into an "undetermined versus determined" duality. Events that are determined from one reference frame may be undetermined (and still selectable) from another.

Notes

[1] The use of the concept "undetermined state" simply refers to a state that can be written as a linear superposition of eigenfunctions of the system. If one has not made a measurement of such a system, the most that can be said about the system is the probability of obtaining each eigenstate, if a measurement were to be performed. I refer to this as an "undetermined state."

[2] To avoid controversy in this initial step, we could require that the system S is a spin-1/2 particle and the "observers" P_i are also microscopic (and therefore quantum) systems that become correlated with S. These could all be observed by a macroscopic observer K, for whom all the states S and P_i are undetermined until a measurement is made.

[3] We will discuss the definition of framework from the Consistent Histories formalism at a later point. For our purposes here it is roughly equivalent to "point of view."

[4] This will certainly bring up philosophical questions, which will be acknowledged later, and our justification of our use of the words *objective* and *real* may not be rigorous, at least from a philosopher's perspective. I will address these concerns later, to the best of my ability, while acknowledging that it may be the case in the future that these terms need to be modified in order to conform to standard uses.

[5] This is intended as a conceptual sketch rather than a formal proof. I hope, though, that any sketchy use of terms will be forgiven and will not detract from the image I am trying to paint.

[6] See, for instance, Rovelli, Griffiths, and any basic treatment of positivism.

[7] The act of "observation," as used in this paper, refers to the most general definition of observation, the exchange of information in the information theoretic sense. Therefore, it makes no special reference to sentient beings. For instance, an electron interacting with an electric field is an example of the electric field observing the electron (or vice-versa).

[8] For instance, in the vacuum of space, the existence of virtual particle pairs predicts Hawking radiation (Baez, 1994). Because of Hawking radiation, black holes will eventually dissipate themselves into space. Virtual particles are also a key aspect of the Standard Model for forces, in which virtual particle pairs are responsible for inhibiting the range of force-carrying particles (Virtual Particle, n.d.). Zero point fluctuations are another consequence of this principle.

[9] Admittedly, we make use of some very hotly debated philosophical material from over the centuries, regarding the views of positivism, realism, etc. We will attempt to address some of these in the section Philosophical Grounds, given that they are a foundation for the claims in this paper.

[10] The nature of the consistency requirements is beyond the scope of this paper, but is based generally on the overall orthogonality of the histories.

[11] In the notation used by Griffiths, the state is represented by the letter, and its coefficient represents the time step of the history. States c and d represent definite/distinct states in the internal arms of the interferometer, and e and f represent distinct states at the output of the interferometer.

[12] The superposition state at time 5 does not commute with the projector onto the state $|e>$ or the projector onto state $|f>$. Therefore it is impossible to make a definite statement as to whether the particle emerges in the e or f channel of the interferometer.

[13] The phase factors in Equation 5 account for differences in the path length of the two paths of the interferometer, and are irrelevant to our current discussion. What is important is that from this framework one can make definite claims about the state $|e>$ or $|f>$ at the end of the experiment.

[14] It is taken as common sense that every measurement should obtain a definite result.

[15] Here I must change notation slightly to accommodate the various entities. The observers S, P, and Q are clearly shown, the subscripts represent the states, and the time is in front of each term as usual. Some of the time steps are skipped for brevity, but this has no relevance on the problem.

[16] It doesn't matter whether K measures S, P, or Q, since S, P, and Q are all correlated.

[17] Remember that the use of single quotes around the word 'happen' convey the notion that the outcome of the event remains undetermined *even after the event has taken place*.

[18] To be clear, Griffiths' answer to his own question is basically "No."

[19] True, quantum physicists measure results in statistical experiments that imply the existence of superpositions of wave functions, but each individual observation is of a particle in a definite state.

[20] I hope the reader will forgive the undefined use of colloquial terms, simply used to provide a sense of an everyday description of this type of experience.

[21] Decoherence provides a limit to the size at which one can observe entanglement, and this is an issue I take up in the section Concerns and Comparisons.

[22] Indeed, because the Ω_i form an orthonormal basis, all the micro states are orthogonal with each other, $<\Omega_i|\Omega_j> = \delta_{ij}$.

[23] For instance, the coin flip results might be arranged to serve as the macro pointer for the results of a light interference experiment, and thereby be correlated to the microscopic results.

[24] This statement is *not* intended as making an assertion about the role of empathy in the world, or the relevance of "being able to see through another's eyes."

[25] If one wants to totally describe the state of the system, one needs 6N dimensions in order to describe the positions and momenta.

[26] I want to remind the reader that the earlier assertion in this paper, that the fifth dimension represents the possible states of the wave-function, seems to be a different use of the concept of dimension than that which applies to the dimensionality of a configuration space. In the example above, I began with a fifth-dimensional view, and then by choosing a particular POV we lost the context of the five-dimensional view and saw only the four-dimensional (three space plus time) events of our experience.

[27] ρ represents a density matrix for the system, and $[\ ,\ ]$ is the commutator relationship for operators.

[28] Admittedly, philosophy is beyond my area of expertise. But the subject matter of this paper requires a certain analysis of the philosophical stances taken. I will try to do this with as little offense to the serious philosopher as possible.

[29] I will stop short of calling the concepts in this paper a "Mind-Independent reality," because I am of the suspicion that Mind may be precisely what is responsible for the objective reality I have described. I opt instead for "observer-independent reality," or "objective reality."

[30] As mentioned earlier, synchronicity can be loosely defined as the occurrence of "meaningful coincidences," i.e. events that are causally unrelated, but which carry a meaning to the observer that make it seem extremely unlikely for the events to be purely a matter of chance. The term synchronicity was originally coined and analyzed by Jung (1972).

Acknowledgments

I am grateful for the feedback of the following people, either in discussions about these ideas which contributed to the theory, or in editing of the manuscript: Dana Nelson-Isaacs, Joseph Dowd (for his extensive editing and contributions), Jeremy Qualls, Gaylen Moore, Thomas Bischof, Jude Rowe, Brant Hindman, Rob Bryanton, all drop-ins to the Expecting Synchronicity discussion group, the reviewers from the *Journal for Scientific Exploration*, and the facilitators of http://www.PhysicsForums.com for their guidance.

References

Baez, J. (1994). *Hawking Radiation*. http://math.ucr.edu/home/baez/physics/Relativity/BlackHoles/hawking.html (modified by Ilja Schmelzer in 1997)

Bryanton, R. (2006). *Imagining the Tenth Dimension.* Talking Dog Studios, Inc.

d'Espagnat, B. (1998). *Quantum Theory: A Pointer to an Independent Reality.* http://arxiv.org/abs/quant-ph/9802046

Dunne, B. J., & Jahn, R. G. (1992). Experiments in remote human/machine interaction. *Journal of Scientific Exploration, 6,* 311–332.

Griffiths, R. B. (2002). *Consistent Quantum Theory.* New York: Cambridge University Press.

Heisenberg, W. (1958). *Physics and Philosophy.* New York: Harper & Row.

Hsu, C., Ling, J., Li, Q., & Kuo, C.-C. (n.d.). *On the Design of Multiplayer Online Video Game Systems.* http://viola.usc.edu/Research/alex_SPIEitcom03.pdf

Isaacson, W. (2007). *Einstein: His Life and Universe.* New York: Simon and Schuster.

Jacques, V., Wu, E., Grosshans, F., Treussart, F., Grangier, P., Aspect, A., et al. (2006). *Experimental Realization of Wheeler's Delayed-Choice GedankenExperiment.* http://arxiv.org/abs/quant-ph/0610241v1

Jung, C. (1972). *Synchronicity—An Acausal Connecting Principle.* London: Routledge and Kegan Paul.

Leibovici, L. (2001). Effects of remote, retroactive intercessory prayer on outcomes of patients with bloodstream infection: Randomised controlled trial. *British Medical Journal, 323,* 1450–1451.

Lewis, P. J. (2003). *Life in Configuration Space.* http://philsci-archive.pitt.edu/archive/00001272/

Moore, G. (2010). *From Chaos to Qualia: An Analysis of Phenomenal Character in Light of Process Philosophy and Self-Organizing Systems.* [Unpublished Master's thesis, Advisor David Odell-Scott, Kent State University.]

Nelson, R. (1998). *Global Consciousness Project*. http://noosphere.princeton.edu/

Radin, D. (2008). Testing non-local observation as a source of intuitive knowledge. *EXPLORE: The Journal of Science and Healing, 4*(1), 25–35.

Reiher, P. L. (n.d.). *Experiences with Optimistic Synchronization for Distributed Operating Systems.* http://lasr.cs.ucla.edu/reiher/papers/tw_experiences.pdf

Rovelli, C. (1996). *Relational Quantum Mechanics.* http://arxiv.org/abs/quant-ph/9609002v2

Schmidt, H. (1976). PK effect on pre-recorded targets. *The Journal of the American Society for Psychical Research, 70,* 267–291.

Smith, C. C., Laham, D., & Moddel, G. (2010). Stock market prediction using associative remote viewing with untrained viewers. *Proceedings of the 29th Annual Meeting of the Society for Scientific Exploration;* June 10–12, 2010; Boulder, Colorado.

Virtual Particle (n.d.). http://en.wikipedia.org/wiki/Virtual_particle

Wittgenstein, L. (1961). *Tractatus Logico–Philosophicus.* London: Routledge & Kegan Paul.

Zurek, W. (2000). Einselection and decoherence from an information theory perspective*. Annelen der Physik. (Leipzig) 9*(5), 853–862.

Zurek, W. (2003). *Decoherence and the Transition from Quantum to Classical—REVISITED.* http://arxiv.org/abs/quant-ph/0306072v1

APPENDIX 1
Derivation of Justification for MQS States in a Coin-Toss Thought Experiment

Assuming a coin made of three atoms in fixed relative position, I will show that these atoms exist in a (macroscopic) superposition of heads and tails after the coin is tossed, before it is observed. This example can be easily extended (using the linearity of the vector space) to consider the vast number of atoms actually in the coin.

I consider the coin as a collection of (quantum) atoms in a fixed spatial relationship. The coin toss is made to happen inside a vertical cylinder with just the right diameter so as to restrict the lateral motion of the coin (see Figure 8). The coin has the ability to rotate around an axis perpendicular to its face, or to flip end over end (heads to tails or vice versa). Ignoring for the moment the end-over-end motion, one can describe the final state of the coin as a point on a one-dimensional line, which is wrapped into a circle such that it represents the degree of rotation of the coin around the axis normal to its face. One can divide up the rotational freedom around this axis into '*n*' possible rotational states (such that the '*n*' possible states span the 360 degrees of full rotation, and each state is different from the next by 360/*n* degrees).

The positions of the atoms will be measured via some interaction that can be represented by a quantum operator which we will not specify (it could be any number of possible physical interactions, such as an interaction with a photon bouncing off the coin). I therefore consider each atom to have *n* possible eigenstates (of the position operator) available to it. (The system does not have to be considered discrete. Considering the system as a continuous spectrum of states would give an infinite superposition of possible eigenstates of the position operator for the coin, but would not affect our argument here.) I have arranged the system in this manner simply to limit the number of degrees of freedom that must be considered.

I start by considering a consistent family of histories describing one atom in the coin alone, labeled '*m'* (Equation 9). The first 'time step' represents the state before the flip, and the second time step is afterward. There are '*n*' possible histories Y_i,

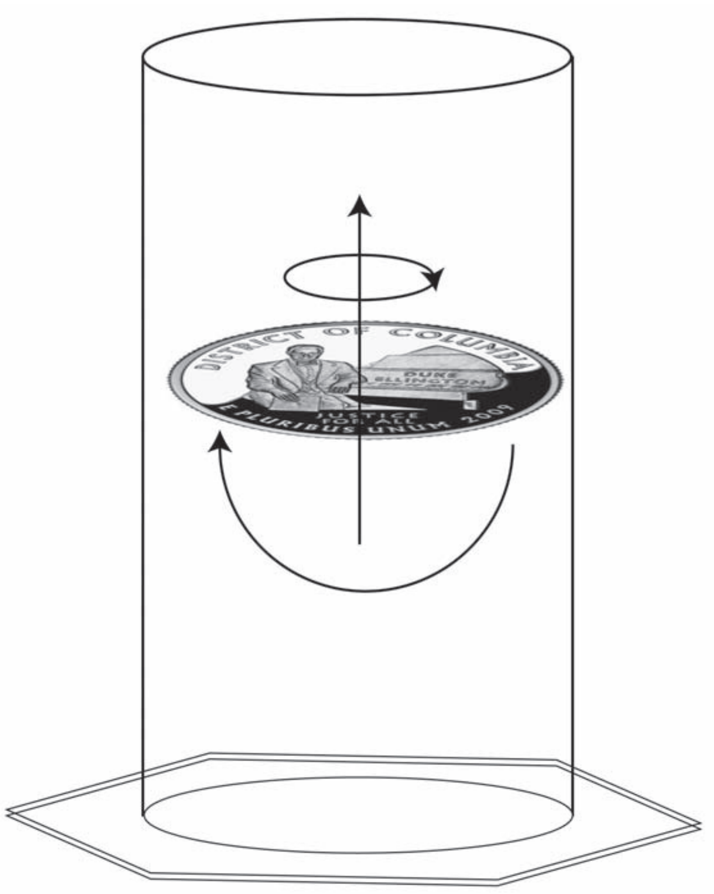

Figure 8. The coin cannot move laterally.

corresponding to the '*n*' possible position eigenstates ("final outcomes") defined above. I have selected $n = 4$ for this example (see Figure 9), though in macroscopic situations it will be enormous or even infinite.

Equation 9: The coin starts in an initial state and ends in one of four final outcomes.

$$\begin{aligned} Y^1 &= [\phi_0^m] \odot [\phi_1^m] \\ Y^2 &= [\phi_0^m] \odot [\phi_2^m] \\ Y^3 &= [\phi_0^m] \odot [\phi_3^m] \\ Y^4 &= [\phi_0^m] \odot [\phi_4^m] \end{aligned} \tag{9}$$

Figure 9. The possible rotational eigenstates for n = 4.

This set of histories means that before the toss the atom is described by a projector onto a single state, and after the coin toss it can be described by a superposition of projectors onto the four available states. This is not an unusual description of things. I shall now extend this system to include a second atom in the coin.

Equation 10: Histories for two atoms in the coin considered together.

$$\begin{aligned}
Y^1 &= [\phi_0^1, \phi_0^2] \odot [\phi_1^1, \phi_1^2] \\
Y^2 &= [\phi_0^1, \phi_0^2] \odot [\phi_2^1, \phi_2^2] \\
Y^3 &= [\phi_0^1, \phi_0^2] \odot [\phi_3^1, \phi_3^2] \\
Y^4 &= [\phi_0^1, \phi_0^2] \odot [\phi_4^1, \phi_4^2] \\
Y^5 &= [\phi_0^1, \phi_0^2] \odot [\phi_5^1, \phi_5^2] \\
Y^6 &= [\phi_0^1, \phi_0^2] \odot [\phi_6^1, \phi_6^2] \\
Y^7 &= [\phi_0^1, \phi_0^2] \odot [\phi_7^1, \phi_7^2] \\
Y^8 &= [\phi_0^1, \phi_0^2] \odot [\phi_8^1, \phi_8^2]
\end{aligned} \tag{10}$$

The set of histories in Equation 10 starts by describing the two atoms as projectors onto their respective initial states. After the toss (before the measurement) they can be described in $2n$ possible histories. The number of distinct potential outcomes has doubled, simply because two or more atoms are being considered in fixed relationship to each other, so the end-over-end motion of the coin must now be considered. Each possible rotational outcome of the system also corresponds to another distinct outcome with the coin flipped over. In this case atom 1 and atom 2 are in correlated states after the toss due to their fixed relative positions in the coin, and they represent a composite superposition state, i.e. if I observe one atom in a definite state, the other atom also will be found in a correlated definite state relative to me (or at least its possible states will be severely restricted by its relationship to the atom that was observed by me).

We can consider a third atom in the coin in the same way, as follows in Equation 11.

Equation 11:

$$\begin{array}{l}
Y^1 = [\phi_0^1, \phi_0^2, \phi_0^3] \odot [\phi_1^1, \phi_1^2, \phi_1^3] \\
Y^2 = [\phi_0^1, \phi_0^2, \phi_0^3] \odot [\phi_2^1, \phi_2^2, \phi_2^3] \\
Y^3 = [\phi_0^1, \phi_0^2, \phi_0^3] \odot [\phi_3^1, \phi_3^2, \phi_3^3] \\
Y^4 = [\phi_0^1, \phi_0^2, \phi_0^3] \odot [\phi_4^1, \phi_4^2, \phi_4^3] \\
Y^5 = [\phi_0^1, \phi_0^2, \phi_0^3] \odot [\phi_5^1, \phi_5^2, \phi_5^3] \\
Y^6 = [\phi_0^1, \phi_0^2, \phi_0^3] \odot [\phi_6^1, \phi_6^2, \phi_6^3] \\
Y^7 = [\phi_0^1, \phi_0^2, \phi_0^3] \odot [\phi_7^1, \phi_7^2, \phi_7^3] \\
Y^8 = [\phi_0^1, \phi_0^2, \phi_0^3] \odot [\phi_8^1, \phi_8^2, \phi_8^3]
\end{array} \tag{11}$$

In this situation, all three atoms are in a superposition of the 2*n* possible outcomes. I define a “configuration” as in Equation 12, which represents the *i*th possible configuration of the three atoms. The sum of all the possible configurations is represented by the identity projector Equation 13.

Equation 12:

$$[\Omega_i] = [\phi_i^1, \phi_i^2, \phi_i^3] \tag{12}$$

Equation 13:

$$[I] = \Sigma_{i=1}^{2n} [\Omega_i] \tag{13}$$

In any real macroscopic situation, both *m* and *n* will be enormous. By symmetry, approximately half of the histories will project onto a final state in which the coin is in heads position, and half with the coin in tails position. These two possible types of configurations are not distinguishable from an atomic perspective; together they simply represent the full sample space of the experiment. However, there is no reason they can't be arranged together in groups in the sum of configuration states (Equation 14). The first sum (from $i = 1$ to n) represents all states that correspond to a physical configuration of atoms such that the coin is "heads up," and the second sum (from $i = n + 1$ to $2n$) is similarly grouped for "tails up." [H] is a projector onto the subspace including all the "heads up" configuration states, and [T] is similarly defined.

Equation 14:

$$[I] = \Sigma_{i=1}^{n}[\Omega_i] + \Sigma_{i=n+1}^{2n}[\Omega_i] = [H] + [T] \tag{14}$$

The final result is a superposition of macroscopic properties of the coin, inherited directly from the indeterminacy of the atomic states via the linearity of Hilbert spaces. My proposition is that this type of treatment can be done for an arbitrary system, and can therefore apply to any type of macroscopic object, according to the rules laid out in this paper.