Guiding quantum histories with intermediate decomposition of the identity

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Abstract. The effect of a carefully chosen measurement action at an intermediate time is proposed to be able to influence the probability distribution of future outcomes. Using the consistent histories formalism, we may calculate the overlap between a current measurement action and an array of possible future states. We propose an interpretation of the mathematics in which a current measurement action reaches recursively into future states and returns a probability. Using intermediate decomposition of a quantum history, we decompose a state at an intermediate time into a complete set of states, using a grouping which distinguishes particular outcomes. The "meaning" of the grouping is defined rigorously, and it is shown that under certain minimal assumptions a 'meaningful grouping' will always increase the likelihood of a particular outcome. Grouping histories is not a physical process, but rather an information theoretic one that occurs spontaneously during the measurement process. The model is consistent with the standard Von Neumann measurement process under normal conditions, but leads to a proposed small deviation in the presence of a conscious observer that naturally accommodates the experimental evidence of certain psi phenomena. It is proposed that the effect of a conscious observer acting on a system is to group the histories in a distinguishable way, thereby minimizing the entropy increase of the system upon measurement. Compatibility with various models of quantum theory are discussed.

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INTRODUCTION

From quantum theory (and Bell's theorem in particular) we can surmise that properties of systems do not take definite values separately from measurement of those properties. Mermin [1] says the fundamental point of quantum mechanics is that

> Correlations have physical reality; that which they correlate does not.

Hence we know that the past state of a system should be described by a superposition of *possible histories* (rather than *actual facts*) over a sequence of time steps, obeying the constraints of consistency, completeness and orthogonality. This is the general undertaking of the consistent histories interpretation of quantum mechanics, [2] [3] which seeks to expand the notion of a quantum 'state' at a single instant of time to a quantum 'history' or chain of states evolving over time. Expanding on the foundations of quantum theory presented by Von Neumann and others, [4] one can treat a chain of quantum states over time using methods similar to those used for a single quantum state. A history can be broken down using the spectral theorem into any one of many different decompositions with respect to a set of basis states, a process known as "decomposition of the identity." [5] We require that the set of basis states are complete, so that they represent every possible outcome of a measurement, with no overlap (i.e. they are orthogonal). This allows us to expand the state of the system at an intermediate time into any number of complete, mutually consistent possible *histories*.

A set of possible histories are therefore "consistent" if they represent every possible option and are mutually exclusive. While this constraint provides a coherent framework for describing a physical system, it does not provide a *unique* framework. In general, a system may be described using many different possible frameworks, each of which gives rise to a set of mutually consistent histories. Consider the familiar example of a two slit interference experiment, where we choose how to measure the light emerging from the slits either at the distant screen, or alternatively right at the slit position. This is an example of two such consistent frameworks. It is a key constraint, however, that although any mutually consistent framework of histories is allowed, only *one* is allowed at a time. This "single-framework rule" allows us to avoid any quantum paradoxes by ensuring a well-defined perspective on the scenario in question. Hence we get the physical result that if one measures the light right at the slit position, one modifies the distribution of the light on the distant screen, and thereby disrupts the other framework. This is an example of two "incompatible" frameworks, descriptions which cannot both be simultaneously used to describe a system. This is a generalization of the familiar Heisenberg uncertainty relation.

Although there are potentially many valid ways to decompose the state of a system at a given time, an important question arises as to what is the most *useful* way to decompose a state in the history of a system. We will specifically consider cases where we decompose the system at a time that is not the beginning or ending of the evolution of the system, but an intermediate state. We will call such a decomposition of a history into its components an "intermediate decomposition of the identity." The question that we will discuss in this paper is whether there are more and less useful such intermediate decompositions, and whether nature makes use of these to allow for the influence of conscious Users on the probability distributions of measurement events.

An intermediate decomposition of the identity can be pictured quite accurately as a prism breaking up white light into its spectral components, and then a lens and a secondary prism combining those components back into white light, as in Fig. 1. If no measurement is made of the system in the region where the colors are separated, then the lens and the second prism recreate a perfect white beam. If instead a detector between the prisms captures and blocks one color of light but not the others, the secondary prism will not be able to recreate white light, because not all the colors will be present. It is well known that in quantum experiments analogous to this, a system can have an arbitrary intermediate decomposition made that will have no impact on the final outcome of the system *unless a measurement is made of the system during the intermediate decomposition.*

For instance, a beam of electrons can be filtered in device A so the surviving electrons have spin pointing in the positive $\hat{z}$ direction. This beam can then be separated into two beams along the $\hat{x}$ direction by a device B, a measurement which doesn't commute with the first. If the beams are recombined *without any filtering* of the electrons

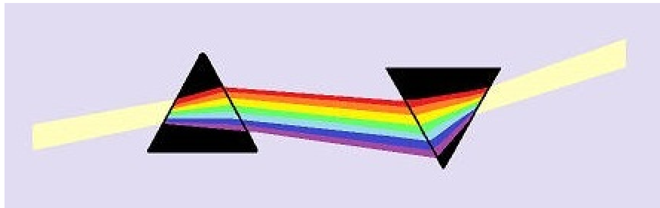

FIGURE 1: An intermediate decomposition of a quantum system is analogous to breaking up white light into a spectrum. If no measurement is made of the system in the intermediate decomposition basis states, the states can be considered unchanged, just as the spectrum of colors can be recombined into white light. Image credit: Helen Klus/CC-NC-SA. [6]

in the $\hat{x}$ device, and then sent through another device C to filter the $\hat{z}$ once again, this corresponds to no measurement being made during the intermediate decomposition. In such a case, it is as if no intermediate splitting occurred, giving each electron a probability of survival through the system of

$$\Big| \sum_{b'} \langle c'|b'\rangle \langle b'|a'\rangle \Big|^2 = \sum_{b'} \sum_{b''} \langle c'|b'\rangle \langle b'|a'\rangle \langle a'|b''\rangle \langle b''|c'\rangle \, .$$

If instead one actually interacts with the system at the intermediate state, then the total probability of the electron making it through the apparatus is given by adding the probability of all the possible measurement outcomes at the intermediate state. In this case one obtains only a single sum, indicating that the states before and after the intermediate measurement have become correlated with each other, constrained due to the actual measurement that fixed them in place. The resulting expression for the probability of survival through the device is

$$\sum_{b'} \Big| \langle c'|b'\rangle \Big|^2 \Big| \langle b'|a'\rangle \Big|^2 = \sum_{b'} \langle c'|b'\rangle \langle b'|a'\rangle \langle a'|b'\rangle \langle b'|c'\rangle \, ,$$

which is different from the previous case due to the single sum. [7] The double sum in the first case makes a significant difference in the physical behavior of the system, leading to the familiar interference effects of quantum mechanics.

In this regard it is important to remember that intermediate decomposition of the identity is not a *thing that is done* to the system, but rather a mathematical property of the states themselves. If an intermediate measurement *is* made, the final state of the system is affected, and the system collapses to one of the available histories with the probability given by the coefficient of the history. In this case one *does* measure a difference as a result of the intermediate decomposition. One has exploited the abstract mathematical properties of the system to express a physically measurable difference.

As a small aside, note that because in quantum histories we are dealing with projectors, and not kets, the coefficient of each history represents the probability without the need to square it. Hence each history has a weight that corresponds to its probability, rather than a probability amplitude which would be important if we were dealing with kets and bras directly.

The overall program we will pursue is to presume that when a measurement is made by a conscious entity (we will call it the "User"), the measurement action is postulated to group the available measurement outcomes into a "meaningful" distribution, and according to the theory presented here the User's choice of action may thereby affect the outcome of the experiment.

To achieve this we will need to make three new proposals. Firstly, we will precisely define the "meaning" of an action in the context of physics. Secondly, we will postulate that such an action projects onto the available histories (or trajectories, if you prefer) and tends to group them into a meaningful intermediate decomposition such that the measurement result has a minimal increase in entropy, or maximal information gained. Thirdly, we will propose that this grouping can be treated as an actual result with a probability rather than a probability amplitude, implying that the space of possible histories forms an objective and robust 'abstract information space' that has objective characteristics. By objective in this case we mean characteristics that can in principle be measured and agreed upon by different Users.

The first of these is simply a definition, and aside from the use of the label 'meaning,' should not generate controversy. Although the proposal is consistent with all aspects of current theory, the second and third proposals will not be as easy to impress upon those with a 'realist' predisposition. After all, if one decides a priori that matter, energy, space and time are the only fundamental things, then it is hard to imagine how one can group "histories" of physical things in a mathematically abstract space. Yet from the realist perspective it is also hard to imagine how one might measure instantaneous correlation at a distance, [8] or make a delayed choice that retroactively determines a prior state of a system, [9] [10] or erase the "fact" that a measurement has been made on a system, [11] or separate the properties of a particle from the property itself, [12] yet these experimental results have been confirmed without deviation from prediction. As Mermin alluded to earlier: the 'real' entities are the relationships *between* things, but the things themselves do not have independent existence.

An important aspect of the proposed model is that it does not imply or require that the User has any mental control over the system, as one might initially presume such a theory must. The effect of the User's action is to define the 'question' being explored by the experiment. The User action *divides up the various outcomes of the experiment into meaningful groupings.* It is proposed that the groups should be assigned actual probabilities, in which case the simple act of grouping the histories according to a certain measurement outcome automatically makes the measurement outcome more likely, as will be shown.

Furthermore, there is no value judgment placed on events, as one might be concerned about for a theory of meaning, and the process does not contain any new force or the need for unexplained transfers of energy. We will show that by simply modifying the distribution of possible histories, one allows the User the ability through purely causal means to affect the outcome of an experiment, so long as it has a highly unpredictable or probabilistic nature. No faster-than-light communication or other proposals commonly used to explain these phenomena that are at odds with known physics are suggested.

From many carefully controlled experiments that have aimed to understand the possible influence of conscious intention on physical systems, including but not limited to [13] [14] [15], the indication is that the effect size is fairly small. Yet the data seems to show (with high statistical power) that this effect is robust. We will focus our description on one particular type of effect, called psychokinesis, or PK, [16] [17] [18] although the application may be broader than this.

Our thesis is that it is lack of the correct model that continues to hamper acceptance of some of these weak but persistent phenomena. We need a model that predicts a small yet robust effect, depends on complexity of the system, and depends on the Users who are interacting with the system. It is with the hope of bridging the gap that the following model of "meaningful history selection" is proposed.

Compound History Groups vs. Elementary Histories

Before proceeding, it is important to present a little of the material examined in the consistent histories formalism. [2] A history of a quantum system does not have a fundamental level of detail or 'refinement' at which is the 'correct' description. Rather, one can generally *refine* a history by considering properties of the system that were not previously included in one's description, or alternately *coarsen* a history by ignoring details that were previously considered. Formally, coarsening amounts to summing up the histories which distinguish between the values of a property we wish to ignore, so that the coarsened history provides no information about that property. Refinement, conversely, provides new details about the system with respect to some property that had been previously ignored.

RG You can always coarsen a consistent family by combining histories and it remains consistent.

Generally, any system we consider has further details that we have ignored, but could potentially choose to consider. By considering these new details of the system, we are expanding into a more refined description which allows us to distinguish between different values of the new property. For instance, in an experiment with an electron we might be measuring the $\hat{z}$ component of the spin, by which we mean we have divided the available histories into those which have spin up and those which have spin down. This does not mean that spin is the only property of the electron, only that we are temporarily ignoring the other properties. Our measurement of spin cannot give us information about, say, the position of the electron (unless they are correlated in the experiment) because our particular refinement does not distinguish between the various possible values of the position.[1]

A refinement of this system could involve distinguishing between whether the electron ends up in one box or another. One description is not more fundamental than the other, as both levels of refinement obey all the expected behaviors of a quantum history. Hence, we can define the resolution of the available histories in whatever manner is useful. Any grouping of histories is an equally valid description of the system, for one can always coarsen a

[1]This example is complicated by the fact that when asked to measure the spin of an electron, most physicists will picture a Stern-Gerlach apparatus which separates electrons with different spins into spatially separated beams. In that particular experiment the position of the electron *is* correlated to the spin, but of course the position and the spin are separate properties that are not in general correlated.

consistent family by combining histories and it remains consistent. [19] In the process of meaningful history selection presented here, we will begin with elementary histories (the highest refinement) and group them according to various criteria in order to obtain compound histories. However, it is important to recognize that compound histories are not approximations. They are in all respects true quantum histories, obeying all laws of quantum systems. If we want to we can always refine them further, but in general we need only refine them to the point where we can track the properties we care about.

For our purposes, we will consider both elementary histories and compound histories. However, the distinction between them is not fundamental. A compound history is one which can be refined into subhistories, which provide more details about a property of the system. An elementary history is one which cannot be further refined with respect to a particular property. We will make use of their individual properties in the formalism that follows.

OBJECTIVE VS. SUBJECTIVE MEANING

We begin by introducing the notion of 'objective meaning' into physics. It is a common notion that the physical world can be fully described in terms of only matter, energy, space and time (or MEST). These are considered the fundamental qualities that, for instance, all psychological phenomena can be derived from.

One difficulty with this view is the apparent fact that it is not the *physical* occurrences that happen to us that matter to us, but rather the *meaning* they convey. In most cases we could care less about the vibrating air molecules on our ear drum except for the fact that they convey *information* to us. The physical properties of matter, energy, space and time are therefore tools we use to convey information (or what I will call here 'meaning').

One reason that meaning is considered a part of psychology and not physics is that we fail to distinguish between the psychological phenomena and the fundamental phenomena. Here I propose that we need to distinguish between "subjective" (or psychological) meaning and "objective" (or fundamental) meaning.

A common view is that all meaning is subjective. For instance, imagine I introduce myself to you by saying "Hi, how are you?" However, if the last time somebody said those words to you, they mugged you and stole your wallet, you may have a particular subjective or psychological meaning that is associated with those words. You may react to my harmless question in an unexpectedly defensive manner which is completely unrelated to what is really happening. This is an example of subjective meaning, and has led many to presume that *all* meaning is subjective. It arises from pre-existing psychological conditions, perceptual filters, or networks of assumptions that are true for an individual User, but are not universally true. Hence, meaning had no fundamental role in the development of objective physics, including quantum mechanics.

By contrast, we can now introduce a measure of "objective meaning" which is quantifiable and is unrelated to the psychology of the individual. It is labeled "objective" because it is, in principle, measurable with an instrument, rather than based on the relative state of individual observers.

Having discussed the grouping of elementary histories at intermediate times, we are in a position to define "objective meaning" in the following way:

> Objective meaning: A measure of how well the grouping of histories distinguishes between particular outcomes in the history space.

This definition is simply a statement about the information contained in the grouping of the elementary histories. It is inversely related to the entropy gained by the system as a result of the measurement. A "meaningful grouping" is therefore one which separates elementary histories into groups that are *not* evenly balanced with respect to a given property of the system, and thereby minimizes entropy of the distribution with respect to a particular property.

As we shall see, the natural tendency of a system is to divide itself into a statistically even spread of possible values of a property, leading to maximum entropy increase, and leading to no change in the likelihood of a given outcome. This corresponds to a non-meaningful grouping. However, we will examine whether there are cases when this is not so, and a meaningful (or uneven) grouping can lead to measurable consequences. A non-meaningful grouping cannot differentiate between the groups with respect to a given property, since it contains equal numbers of elementary histories with a particular value of that property. By contrast, a meaningful grouping separates the elementary histories into groups that *do* differentiate between the properties, and hence a meaningful grouping is one which allows the observer to distinguish between the outcomes of a particular experiment.

As an aside, while a general quantum measurement can describe interactions between inanimate objects, these do not lead to meaningful groupings. Meaningful groupings are proposed to be a result of some directed action taken, which implies a living creature. We will limit our discussion to measurements made by human Users without investigating the deeper question of carefully defining consciousness, which is a wide field pursued elsewhere. [20] [21] [22] [23] [24]

MEANINGFUL HISTORY SELECTION

We are now at the core of the investigation. The proposed elements involved in the process of meaningful history selection are defined as follows:

- History: A chain of quantum states connected in time. A history does *not* only represent past states, as the word typically implies in English. Rather, a history can represent states in past, present and future. In particular, we will be projecting the operator representing the User measurement action, defined below, onto the *future outcomes* of each 'history,' where each history is simply a particular trajectory an entity can follow from past into future.
- Definite state: a state which has been observed by the User.
- $[B]$ and $\langle b|$: User action, an operator determined by the measurement choice of the User. $[B] = |b\rangle\langle b|$ is a projector onto the state $|b\rangle$, and the action can be equivalently represented by either $\langle b|$ or $[B]$.
- Elementary history, $|e^k\rangle$: a chain of events at a level of refinement that cannot be further refined with respect to a particular property. The likelihood of an elementary history is purely probabilistic and cannot be traced to the properties of its subsystems. An elementary history has binary overlap with the action operator,

$$\langle b|e^k\rangle \approx 0, 1. \tag{1}$$

- Compound history: a chain of events which *can* be further refined into a more detailed description of its subsystems. The likelihood of a particular compound history can be traced to the properties of the elementary histories of which it is composed.
- Hits: Elementary histories $|e^k\rangle$ whose inner product with the User action $\langle b|$ are equal to unity, $\langle b|e^k\rangle \approx 1$.
- Misses: Elementary histories $|e^k\rangle$ whose inner product with the User action $\langle b|$ are equal to zero, $\langle b|e^k\rangle \approx 0$.
- Meaningful grouping: A grouping of histories which distinguishes well between outcomes in the history space with respect to a particular property, and therefore represents a distribution with less than maximal entropy.
- $[E_1]$, $[E_2]$: A intermediate decomposition or grouping of elementary histories. By convention, if the grouping is uneven with respect to the number of hits, I will take $[E_1]$ as the compound history which contains the higher density of hits, and $[E_2]$ the compound history with the lower number of hits.
- $[F_1]$, $[F_2]$: Unitary extension of $[E_i]$ backwards in time, correlated with history grouping $[E_i]$. These states are retroactively determined, hence they are states which lead via Schrödinger's equation to the measured outcome state, but remain in superposition up until a final measurement is made.

User Action

The User's action is commonly known as the "measurement." In other words, "User action" is what the User decides to measure. Here this statement "what the User decides to measure" is referring to an "action" taken by the User, represented by a Hermitian operator. Without a specific action, no experiment takes place. The action therefore defines the measurement basis, i.e. the set of possible outcomes that can result from the experiment. It should be kept in mind that there is not a single fundamental set of 'actual' possible outcomes from an experiment. Rather the choice of measurement basis determines the particular set of possible outcomes available for a particular run of the experiment.

In particular, we will consider the action to be a projective measurement of the system, so the operator $[B] = |b\rangle\langle b|$ projects the history space onto the bra $\langle b|$. Hence we will represent the User's action by $\langle b|$, where it is understood that the action itself is the projector $[B]$, a Hermitian operator. There is a one to one mapping between $[B]$ and $\langle b|$, so there will be no ambiguity.

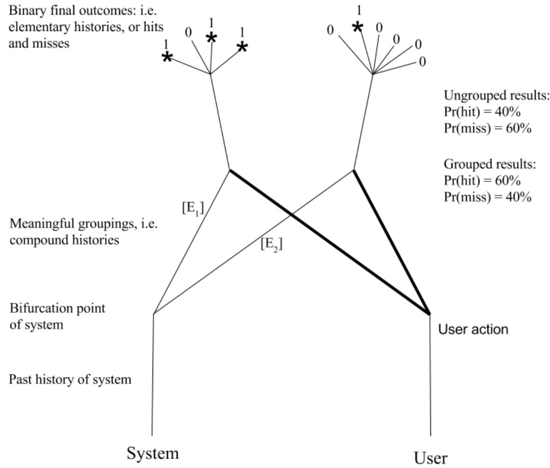

FIGURE 2: The process of meaningful history selection is diagrammed in this figure, with the reference of time (as an ordering principle) moving upward on the page.[a]

[a] All events are presumed to be space-like; no reference to faster than light signalling is implied in this model. The diagram is not a Minkowski diagram.

Projection Onto History Space

Once the action $\langle b|$ is defined, one can project $\langle b|$ onto the history space, $[\psi]$. The history space, for our purposes, can be visualized as a branching tree, where the moment of interaction is represented by the trunk of the tree. The process of projecting with $\langle b|$ onto $[\psi]$ happens recursively until a *binary* result is (approximately) reached. We can take the inner product $\langle b|\psi\rangle$ of $\langle b|$ with a given branch, and if the result is not close to zero or unity, we expand the branch into many subsystems (further, smaller branches) and take the inner product $\langle b|\psi_i\rangle$ of $\langle b|$ with each of these. The subsystems are found from applying the Schrödinger equation to the elements of the system. A branching occurs when two subsystems interact and correlate with each other into distinguishable possible outcomes. If $|\psi\rangle$ is originally composed of two subsystems $|\phi\rangle$ and $|\eta\rangle$ which have not interacted, then an interaction between the subsystems causes a branching in the tree structure, given by

$$|\psi\rangle = |\phi\rangle \otimes |\eta\rangle \rightarrow \sum_i |\phi\rangle_i \otimes |\eta\rangle_i = \sum_i |\psi\rangle_i \,.$$

The inner product $\langle b|\psi_i\rangle$ is a measure of how well the final outcome of a given history overlaps with the action taken. Any branch $|\psi\rangle_i$ for which $\langle b|\psi_i\rangle \approx 0, 1$ is relabeled $|e^k\rangle$ and recursion stops. The differences between subscript and superscript indices is a matter of clarity but is not significant.

In comparing histories with the action we are checking as to whether the history is consistent with the action. As we get into more detailed branches of the tree, we are looking in more detail at the evolution of the system and its subsystems, so we are more likely to get specific scenarios that are either fully consistent with the action or fully inconsistent with it. The idea is that if we let the recursiveness run long enough, we land on particular measurement outcomes which give us a "yes/no" answer as to whether that history is consistent with the action. Such an outcome, for which we get $\langle b|e^k\rangle \approx 0, 1$, is called an elementary history. Generally, it will be convenient to examine the history space recursively until we find these elementary histories, and then use the resulting binary probability amplitudes to perform our statistical calculations. Therefore, for a given elementary history, the intended goal is either met or not met.

As we iterate out many levels through the branches of the tree, the smaller branches tend to carry less statistical weight due to the fact that there are so many other branches created at each step in the recursion. This brings the inner product closer to zero, so as a practical matter our iteration can stop after a finite number of iterations into the future, confident that all histories for which $\langle b|e^k\rangle$ has not converged to unity will eventually converge to zero, and can be treated as approximately zero weight elementary histories.

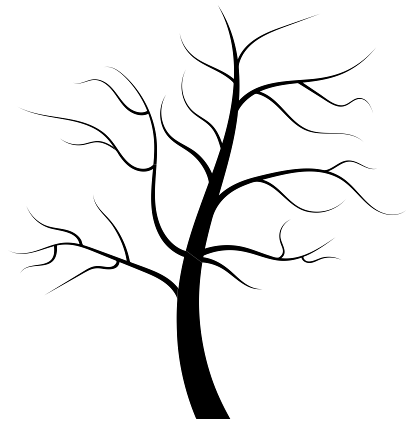

FIGURE 3: A schematic of the branching of histories that occurs as time moves up the page.

Meaningful Grouping

When $\langle b|$ occurs, it is hypothesized here that the elementary histories split into groups $[E_i]$, and the probability of each group is calculated. If the division of elementary histories is a meaningful grouping (uneven with respect to hits and misses), $[E_1]$ can be considered the group with the higher hit rate (i.e. it is composed of more elementary histories that match the action criteria), and we assign it a higher weight. The weight of the compound history group is derived from the usual Von Neumann method for projective measurement, [4] and is given by

$$w_1 = Pr(E_1) = \frac{\sum_k \langle b|e_1^k\rangle \langle e_1^k|b\rangle}{\sum_{k,i} \left|\langle b|e_i^k\rangle\right|^2} = \frac{N_{H1}}{N_{H1} + N_{H2}}, \tag{2}$$

where N_{Hi} is the number of hits in branch i. The weight of a branch is therefore the sum of all hits in a branch over the sum of all hits in both branches. This weight is normalized and can be interpreted as a probability.

One could object to our choice of normalization, arguing that we should divide by the total number of both hits and misses, instead of just the hits. Let's consider for a moment that we do this, writing $w_1 = \frac{N_{H1}}{N}$, where N is the total number of branches overall. Because the intermediate decomposition forms a complete basis, the branches represent all possible paths of evolution for the system. Clearly we *must* take at least one of the branches. Therefore the probability of the branches must sum to unity, and the weights w_1 and w_2 must be normalized. Normalizing the weights $\frac{N_{H1}}{N}$ and $\frac{N_{H2}}{N}$ we obtain

$$P(E_1) = \frac{\frac{N_{H1}}{N}}{\frac{N_{H1}}{N} + \frac{N_{H2}}{N}} = \frac{N_{H1}}{N_{H1} + N_{H2}},$$

which is the same as the expression given above.

To understand this weighting, consider an unlikely event which only has four elementary histories which are hits, and 96 that are misses. If the hits are evenly split between two equal sized history groups, there are two hits out of 50 elementary histories in each group. The likelihood of the event itself remains at $\frac{2}{50} = 4\%$, given by the ratio of hits to total histories. Also, the weight on each group is 50%, because the groups are indistinguishable, with respect to the property in question.

On the other hand, if we split the elementary histories into two equal sized groups, one which contains 3 hits and the other which contains 1 hit, then although the total likelihood of the outcome remains $\frac{4}{100} = 4\%$, the weight of the first history group is $\frac{3}{4}$ and the weight for the second history group is $\frac{1}{4}$. We postulate that this represents the likelihood of that particular group of histories becoming actualized. So even though the event itself is overall very unlikely, the first history group has a substantial bias, and has a greater (although still small) density of hits ($\frac{3}{50} > \frac{4}{100}$). Regardless of the overall likelihood of the particular outcome, our weighting formula allows us to consider how well each compound history group represents the particular outcome, *compared to the other groups*.

Finding weights of history groups through recursion

Equation 2 is valid in a simple scenario where all elementary histories occur at the same level. Specifically, this means that the time evolution of the system is very simple and uniform, so that an initial state evolves symmetrically into an array of final states whose inner products $\langle b|e^k\rangle = 0, 1$. In general, a system is composed of nested subsystems forming a heirarchy of interactions, leading to a tree structure that is quite complex. The elementary histories (where Eqn. 1 holds) then occur at different levels of branching in the tree structure.

In this more general case we must modify Eqn. 2 to account for the *depth of recursion* that we must travel into the tree structure in order to reach a subhistory where Eqn. 1 holds. The contributions of a *compound* history branch at level j are given as the *average* of the contributions of the subhistories of that branch. In other words, we "add up all the leaves on a branch and divide by the number of leaves." This gives us the weight of the branch. We must keep in mind that each 'leaf' is really another smaller branch that can be expanded into subhistories as well, leading to another layer of branches. The process can be truncated at the point when Eqn. 1 holds true for the subhistory. This

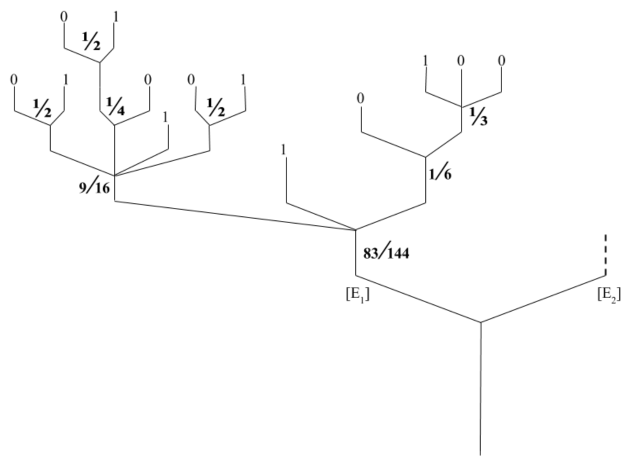

FIGURE 4: A more complex history tree structure, with associated hit counts of elementary histories.

is a recursion problem well suited to a software algorithm. The weight on the compound history group in the general case is then given by modifying Eqn. 2 with a recursion relation,

$$\begin{aligned} w_1 = Pr(E_1) &= \frac{N_{H1}}{N_{H1} + N_{H2}} \\ N_{Hi} &= \sum_j \langle b|e_{ij}\rangle \langle e_{ij}|b\rangle \qquad \text{if } \langle b|e_{ij}\rangle = 0, 1 \\ &= \frac{\sum_j \langle b|\mathcal{K}_{ij}|b\rangle}{\sum_j |\langle e_{ij}|e_{ij}\rangle|^2} \qquad \text{otherwise} \end{aligned} \tag{3}$$

where

$$\mathcal{K}_{ij} = \frac{\sum_k \mathcal{P}_{ijk}}{\sum_k |\langle e_{ijk}|e_{ijk}\rangle|^2} \tag{4}$$

and

$$\begin{aligned} \mathcal{P}_{ijk} &= |e_{ijk}\rangle\langle e_{ijk}| \quad \text{if } \langle b|e_{ij}\rangle = 0, 1 \\ &= \mathcal{K}_{ijk} \qquad \text{otherwise} \end{aligned} \tag{5}$$

where i is the compound history group whose weight we are calculating. Each level of recursion adds a new index to $\mathcal{K}$.

The procedure above allows some subbranches to be elementary histories and other subbranches to be broken up into further subhistories. An example of using this procedure to calculate weights on compound history groups of an arbitrary tree structure is below and shown in Fig. 4.

$$N_{H1} = \frac{\frac{\frac{1}{2}+\frac{\frac{1}{2}+0}{2}+1+\frac{1}{2}}{4}+1+\frac{0+\frac{1}{3}}{2}}{3} = \frac{83}{144} = 0.58. \tag{6}$$

N_{H2} would be found similarly, and the weight of $[E_1]$ is then given by the first line of Eqn. 3. Although an elementary history is defined such that the inner product with the action is either zero or one (Eqn. 1), the hit rate for a given branch can be a number ranging between zero and one, due to the various depths of recursion that must take place to find the elementary histories in the tree structure. In Fig. 5, a simpler example shows how to calculate the final weight on branch $[E_1]$ from the various elementary histories.

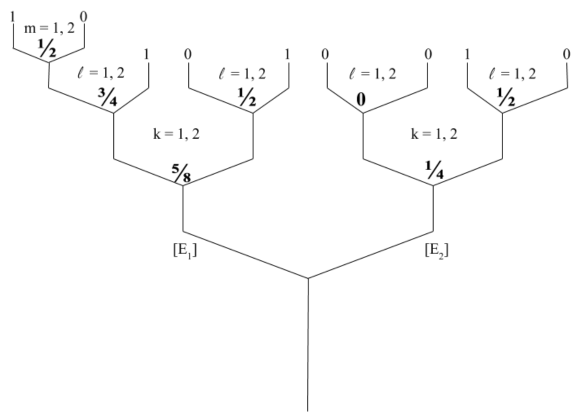

FIGURE 5: The weight of a history group $[E_1]$ can be calculated for elementary histories at arbitrary depths in the tree structure. Here the weight is $P(E_1) = \frac{\frac{5}{8}}{\frac{5}{8}+\frac{1}{4}} = \frac{5}{7}$

User influence on properties of meaningful groupings

The grouping of histories at intermediate times is a meaningless exercise if it does not have physically measurable consequences. In the current quantum framework, although the grouping is perfectly allowable from a theoretical perspective, there is no mechanism by which a User can influence this grouping. Another way to look at this situation is that, all things being equal, nature will tend to divide the histories into groups such that a selection of one state will result in the *maximum possible entropy increase*. This is simply a restatement of the laws of thermodynamics, where oxygen molecules in a room will never (statistically speaking) group themselves completely in one corner of the room. Similarly, if a system has a large number of possible outcomes (any realistic situation has a very, very large number of them), the vast majority of possible groupings of histories have an equal spread of hits and misses.

For example, consider a system that has $N = 1000$ possible outcomes (this is quite small), where half of the outcomes are hits, $N_H = 500$. If these hits were grouped equally into $[E_1]$ and $[E_2]$, there would be 250 hits in each group. The likelihood of a 10% deviation from this can be calculated from the binomial distribution,

$$2 \times \text{CDF}\left[(\text{BinomialDistribution}\left(500, \frac{1}{2}\right), 225\right] = 3\%, \tag{7}$$

where we are calculating the area under the curve of a binomial distribution that arises from finding the chance of getting, say, 225 heads out of 500 flips of a coin, each with 50% probability. The factor of two comes from including the area under both tails of the curve, because we are concerned with cases where we get either 225 or less heads, or cases where we get 275 or more heads.

This is a low estimate for the number of histories available to a realistic system composed of multiple quantum objects over extended time periods. If we increase N by only one order of magnitude, the probability of 10% deviation becomes $2 \times 10^{-10}\%$, which is exceedingly low. In the absence of any new theory, it is therefore overwhelmingly unlikely that one would ever obtain groupings that deviate significantly from the 'even distribution case' through intermediate grouping of events.

One can consider the entropy increase obtained in a measurement which groups the histories in the most statistically likely grouping, where there are an equal number of elementary histories having "hits" in each group (and equal size groups). In order to illustrate, we will consider a system which has 32 elementary histories, eight of which are hits,

$$[E] = 1111\,1111\,0000\,0000\,0000\,0000\,0000\,0000$$

so $P(hit) = \frac{1}{4} = \frac{8}{32}$. Then an even distribution of hits into each compound history would be

$$[E_1] = 1111\,0000\,0000\,0000$$

$$[E_2] = 1111\,0000\,0000\,0000.$$

The normalized weights associated with each history are found from Eqn. 2, which tells us to take a ratio of the number of hits in each history group $[E_i]$ compared to the total number of hits in the sample space of 32 histories. The total number of hits in both groups is $N_{H1} + N_{H2} = 8$, and in the even grouping case the number in each history group $[E_i]$ is $N_{H1} = N_{H2} = 4$. Using the Von Neumann entropy, $S = -\sum_i P_i \ln P_i$, the entropy of this distribution is

$$S = -P(E_1)\ln P(E_1) - P(E_2)\ln P(E_2) = -\frac{1}{2}\ln\left(\frac{1}{2}\right) - \frac{1}{2}\ln\left(\frac{1}{2}\right) = 0.69. \tag{8}$$

The entropy is maximized when $P(E_1) = P(E_2)$, i.e. when the distribution is uniform. Given the discussion in the previous section, it seems that any grouping that is made spontaneously by nature will maximize the entropy of the outcome measurement (or minimize the information contained in the grouping).

The relation of entropy to meaningful measurements

Now let's consider the hypothesis that the user can have some influence on *the way the elementary histories are grouped*. We can examine the Von Neumann entropy increase caused by a "meaningful" grouping of elementary histories, analogous to Eqn. 8. One possible such grouping is

$$\begin{aligned} [E_1] &= 1111\,1000\,0000\,0000 \\ [E_2] &= 1110\,0000\,0000\,0000. \end{aligned} \tag{9}$$

Using Eqn. 2 the weights of these compound history groups are $P(E_1) = \frac{5}{8}$ and $P(E_2) = \frac{3}{8}$. The entropy is

$$S = -P(E_1)\log P(E_1) - P(E_2)\log P(E_2) = -\frac{5}{8}\log(\frac{5}{8}) - \frac{3}{8}\log(\frac{3}{8}) = 0.66,$$

which is less than that obtained in the evenly grouped case. In general any deviation from the random 'natural' distribution will result in a smaller increase in entropy when the measurement occurs. Hence our proposition is that the effect of measurement by a conscious User may be to *minimize the entropy increase* of the system as a result of the measurement. While the second law of thermodynamics ensures that the entropy will always increase in any physical interaction, the increase postulated to be *minimized* by a conscious observer posing a meaningful question.

It is not altogether surprising that the effect of a conscious User taking action in an experiment may be to minimize the increase in disorder of the resulting system. This is indeed the effect of life in general and consciousness in particular on systems: to increase the organization of the components of the system.

Calculating the hit probability in a meaningful grouping

It is well known that an even distribution over a discrete sample space gives rise to the maximum value of the entropy. We will assume that all subhistories at a given level in the tree structure are equally likely. Let us now show that *any* grouping of the elementary histories will result in a 'hit' probability greater than or equal to the evenly grouped case.

First we propose that the overall probability of a hit is found from Bayesian conditional probability,

$$P(hit) = P(hit|E_1)P(E_1) + P(hit|E_2)P(E_2) = \frac{N_{H1}}{N_1}\frac{N_{H1}}{N_H} + \frac{N_{H2}}{N_2} + \frac{N_{H2}}{N_H}, \tag{10}$$

which uses Eqn. 2 with $N_H = N_{H1} + N_{H2}$. This says that the overall probability of a hit is the probability of a hit in $[E_1]$ times the likelihood that we are actually in $[E_1]$ plus the probability of a hit in $[E_2]$ times the likelihood that we are actually in $[E_2]$.

The "evenly grouped" case, where $N_{H1} = N_{H2}$, is only well-defined when $N_1 = N_2$. In this case, $P(hit)_{grouped} = \frac{N_{H1}}{N_1} = \frac{N_H}{N}$. This is equivalent to the probability of getting a hit in the case where no grouping occurs at all, because it is simply the number of hits over the total number of histories. We will therefore use the terms "evenly grouped" and "ungrouped" to mean the same thing. In the case where $N_1 \neq N_2$, the term "evenly grouped" is not well defined, and the term "ungrouped" will strictly be used.

The probability of receiving a hit in the ungrouped case is simply the number of hit outcomes divided by the number of total histories, or

$$P(hit)_{ungrouped} = \frac{P(hit)}{P(hit) + P(miss)} = \frac{\sum_k |\langle b|e^k\rangle|^2}{\sum_k |\langle e^k|e^k\rangle|^2}, \tag{11}$$

where k runs over the total number of elementary histories.

In contrast, the probability of receiving a hit in the grouped case is given by Eqn. 10, where the probability of getting a hit conditional upon being in history $[E_1]$ is

$$P(hit|E_1) = \frac{\sum_k |\langle b|e_1^k\rangle|^2}{\sum_k |\langle e_1^k|e_1^k\rangle|^2}, \tag{12}$$

and the probability of being in history group $[E_1]$ given that we took the action $\langle b|$ is

$$P(E_1) = \frac{\sum_k |\langle b|e_1^k\rangle|^2}{\sum_{k,j} |\langle e_j^k|e_j^k\rangle|^2}, \tag{13}$$

where j runs over the number of groups, and k runs over the number of elementary histories in each group. This results in

$$P(hit)_{grouped} = \frac{\sum_k |\langle b|e_1^k\rangle|^2}{\sum_k |\langle e_1^k|e_1^k\rangle|^2}\frac{\sum_k |\langle b|e_1^k\rangle|^2}{\sum_{k,j} |\langle b|e_j^k\rangle|^2} + \frac{\sum_k |\langle b|e_2^k\rangle|^2}{\sum_k |\langle e_2^k|e_2^k\rangle|^2}\frac{\sum_k |\langle b|e_2^k\rangle|^2}{\sum_{k,j} |\langle b|e_j^k\rangle|^2} = \frac{N_{H1}}{N_1}\frac{N_{H1}}{N_H} + \frac{N_{H2}}{N_2}\frac{N_{H2}}{N_H}, \tag{14}$$

where

$$N_1 = \sum_k |\langle e_1^k|e_1^k\rangle|^2$$

$$N_2 = \sum_k |\langle e_2^k|e_2^k\rangle|^2$$

are the number of total elementary histories in each group (so $N = N_1 + N_2$), and

$$N_{H1} = \sum_k |\langle b|e_1^k\rangle|^2$$

$$N_{H2} = \sum_k |\langle b|e_2^k\rangle|^2$$

are the number of hits in each group, so

$$N_H = N_{H1} + N_{H2} = \sum_{k,j} |\langle b|e_j^k\rangle|^2.$$

In the last definition we are summing over all elementary histories in all groups.

Eqn. 14 appears to be the statement that either one or the other of the history groups $[E_1]$ and $[E_2]$ becomes actualized, even though the elementary histories that they contain have outcomes that are still undetermined because they haven't occurred yet. Although the elementary histories are still in superposition, we are actually trimming some branches of the tree of histories, making them inconsistent with known facts and therefore inaccessible to the system. Therefore the weights given by Eqn. 2 are probabilities rather than probability-*amplitudes*. This is the key step that results in a modified probability distribution after the intermediate decomposition.

The grouped case reduces to the ungrouped case in the limit that $N_{H1} = N_{H2}$ and $N_1 = N_2$, which is the case of equal grouping where the number of hits in each group and the number of total elementary histories in each group are equal.

We can now compare the grouped case to the ungrouped case. We want to show that $P(hit)_{grouped} \geq P(hit)_{ungrouped}$ for any choice of N_{H1}, N_{H2}, N_1, N_2. Comparing Eqn. 11 to Eqn. 14,

$$\frac{\sum_k |\langle b|e_1^k\rangle|^2}{\sum_k |\langle e_1^k|e_1^k\rangle|^2}\frac{\sum_k |\langle b|e_1^k\rangle|^2}{\sum_{k,j} |\langle b|e_j^k\rangle|^2} + \frac{\sum_k |\langle b|e_2^k\rangle|^2}{\sum_k |\langle e_2^k|e_2^k\rangle|^2}\frac{\sum_k |\langle b|e_2^k\rangle|^2}{\sum_{k,j} |\langle b|e_j^k\rangle|^2} \geq \frac{\sum_{k,j} |\langle b|e_j^k\rangle|^2}{\sum_k |\langle e_j^k|e_j^k\rangle|^2} \tag{15}$$

or more simply

$$\frac{N_{H1}}{N_1}\frac{N_{H1}}{N_H} + \frac{N_{H2}}{N_2}\frac{N_{H2}}{N_H} \geq \frac{N_{H1}+N_{H2}}{N}. \tag{16}$$

We therefore need to show that

$$\frac{N_{H1}^2}{N_1} + \frac{N_{H2}^2}{N_2} \geq \frac{N_H^2}{N}, \tag{17}$$

where we know that

$$\begin{aligned} N_{H1} + N_{H2} &= N_H \\ N_1 + N_2 &= N \\ N_{H1} &< N_H \\ N_{H2} &< N_H \\ N_1 &< N \\ N_2 &< N \\ N_H &\leq N. \end{aligned} \tag{18}$$

Rearranging and expanding the right hand side of Eqn. 17 gives

$$\left(\frac{N}{N_1} - 1\right)N_{H1}^2 + \left(\frac{N}{N_2} - 1\right)N_{H2}^2 \geq 2N_{H1}N_{H2}.$$

We can simplify $\left(\frac{N}{N_1} - 1\right) = \frac{N_2}{N_1}$ and $\left(\frac{N}{N_2} - 1\right) = \frac{N_1}{N_2}$, so

$$\frac{N_2}{N_1}\frac{N_{H1}}{N_{H2}} + \frac{N_1}{N_2}\frac{N_{H2}}{N_{H1}} \geq 2.$$

Defining $X \equiv \frac{N_2}{N_1}\frac{N_{H1}}{N_{H2}}$, this reads

$$X + \frac{1}{X} \geq 2. \tag{19}$$

We can check where this is minimum by setting the derivative equal to zero,

$$Y' = \frac{d}{dX}\left(X + \frac{1}{X}\right) = 1 - \frac{1}{X^2} = 0,$$

so the extrema are at $X = \pm 1$. Equation 19 is valid only for the positive root, $X = 1$. Since all the input parameters in Eqn. 17 are positive numbers representing counts of histories, we are guaranteed $X > 0$, and this requirement is satisfied. At $X = 1$ the left hand side and right hand side of Eqn. 19 are equal. This is the minimum. The minimum can also be seen in Fig. 6. Given the constraints in Eqns. 18, $X = 1$ occurs when $N_2 = N_1$ and $N_{H1} = N_{H2}$. This is the criteria for even grouping, so we have shown that the meaningful grouping always has a greater probability of hits (Eqn. 14) than a non-meaningful grouping.

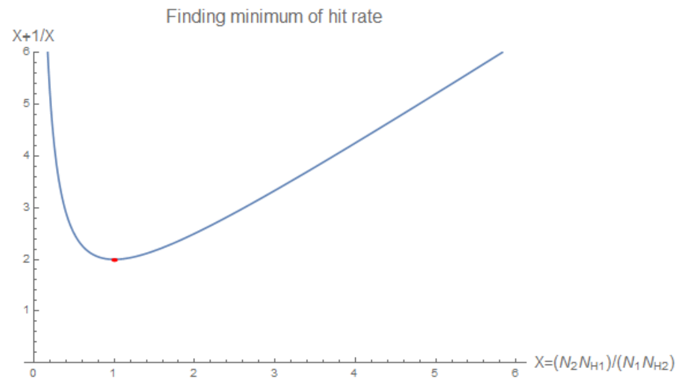

FIGURE 6: Any grouping other than $N_1 = N_2$ and $N_{H1} = N_{H2}$ results in an increased likelihood of hits.

Retroactive Event Determination

We will now discuss a topic from the formalism of consistent histories whose significance I believe has not been adequately discussed. We will label it "retroactive event determination." In the consistent histories formalism, a history of the system is defined at exactly two times if it describes the state of the system at an initial time and at a final time. Such an evolution is very simplistic, but we are guaranteed that any family of such histories is consistent, so long as the state at the second time represents a complete decomposition of the identity (i.e. every possible outcome for the system is represented).

From this starting point we can always find out details of the system at some intermediate time by performing unitary evolution of the system, either starting from the first event and working forward in time, or starting from the last event and working backward in time. In the consistent histories formalism, time is not so much a 'measure' as an 'ordering principle.' One can unitarily extend the system either forward or backward from a particular state at any resolution one chooses.

A simple two-time history can be written

$$[N_1] \odot [\psi_0]$$

$$[N_2] \odot [\psi_0],$$

where $[\psi_0]$ represents the prior history of the system S at time t^1 and $[N_i]$ represent the two possible outcomes at time t^3. Note that in our notation the initial state is on the right and the increase in time proceeds from right to left. This is in accordance with the tradition that measurement operators act from the left, and if they are done in succession then the list of them reads from right to left.

Next we unitarily extend the system backwards *from* the final state *to* an intermediate time t^2, between t^1 and t^3. Using the projectors $[E_i]$ to represent the states at that time,

$$[N_1] \odot [E_1] \odot [\psi_0]$$

$$[N_2] \odot [E_2] \odot [\psi_0].$$

It should be emphasized that t^2 can be any time between t^1 and t^3, and does not represent a *particular* time. Hence, the span between t^1 and t^3 can in principle be arbitrarily long. There is no fundamental limit on this time span.

We can make a measurement of the system at time t^3. What happens then? The collapse postulate of quantum mechanics says that the User either measures $[N_1]$ or $[N_2]$, but not both. Consequently, the system *is* in one state, and not the other. In consistent histories we say the histories decohere and the unmeasured history becomes inconsistent with the measured result, being assigned zero weight. In either viewpoint, experimental data from experiments testing Bell's theorem confirms that the properties measured at t^3 *do not have definite values before* t^3. It should be clear from this discussion that this is true not only of the state $[N_i]$ at t^3, but also of the backwards unitarily extended state $[E_i]$ at t^2. The properties of the system at t^2 only take actual values at t^3.

This phenomenon was made explicit in Wheeler's delayed choice gedanken experiment, [25] where he showed that making the 'delayed' choice of measurement basis for a particle just before the particle hits the final screen appears to determine the behavior that the particle had when it passed through the slits, moments before. This phenomenon has been experimentally demonstrated. [8] [9] It is important to note that this is not a quirk of a particular experiment, but a fundamental principle in quantum systems that is true in general situations. Whenever we perform a projective measurement on a system in a quantum superposition, we get a definite outcome, and the entire history since the system became superposed falls into place when the measurement outcome is obtained.

The name "retroactive event determination" emphasizes that it is not retro*causation*, and thereby does not pose any threat to causality. The reason it is not retrocausation is that the properties being measured did not have a definite value prior to the measurement, even in the past. Therefore a prior state cannot be said to be *caused* to take a definite state based on the measurement outcome in the present, but rather its prior state becomes *determined* in the present. I am arguing here that, although one cannot change a fact that has already been observed, if instead a quantum 'fact' has *not* been observed, then it is not a fact, and hence we are not technically 'changing it.' The name retroactive event determination is intended to capture this subtlety, and fend off objections of paradox.

One might argue that another User could observe the system in question at the prior time, hence causing the possibility of receiving conflicting stories from the two Users. However, because in relational quantum mechanics any interaction between User 1 and the system correlates User 1 to the system from the perspective of the User 2, then whatever measurement result User 2 obtains will also retroactively determine the state of User 1. Through the joint principles of relationality and consistency, paradox is made neatly impossible. These issues have been discussed in greater depth in my previous articles. [26] [27]

It should be clear that we can also fill in the time between the event $[E]$ and the current moment $[N]$ to whatever degree we want by unitarily extending the history again between these two events. Here we will insert an event F,

$$[N_1] \odot [F_1] \odot [E_1] \odot [\psi_0]$$

$$[N_2] \odot [F_2] \odot [E_2] \odot [\psi_0].$$

This can be done as needed to fill in details about the system that were previously not accounted for. For instance, if another system S' interacted with system S and we decide to include a description of it in our model, we can do the intermediate unitary extension above. A state E_1 for particle E is correlated to state F_1 for particle F, etc, and this correlation happens at time t^{2+}, between t^2 and t^3.

Summary of Meaningful History Selection

With the definitions now in place, the process of meaningful history selection is summarized below.

The User takes an action $\langle b|$ by interacting with the system. The action projects onto the history space, calculating the inner product with each branch of future possible outcomes. In general, a branch will not have a clear result, in that there are some configurations of the system represented by the branch that will result in the User measurement obtaining "Yes" and others such that the User measurement obtains "No." The action then recursively checks each subhistory on that branch, until finding outcomes that answer the question definitively, so that Eqn. 1 is satisfied. The weights on each branch can be calculated through the recursive procedure outlined in Eqns. 3 and 4.

We next introduced the notion of a meaningful grouping of histories. Histories are grouped in a meaningful manner if the grouping maximizes the information gained by a measurement, or equivalently minimizes the entropy of the distribution. We postulate that as a result of an action taken by a conscious User, the groups will each tend to have a different number of hits, resulting in a different weight, so that one group can be distinguished from another based on the property in question.

By convention we choose $[E_1]$ to represent the grouping of histories with the higher number of hits, thus leading to a greater weight w_1 (given by Eqn. 2, or more generally Eqns. 3 and 4) on that compound history. Since the User's action comes at an intermediate time between initial and final states of the system, we propose that the compound history groups are assigned probabilities rather than probability-amplitudes, reflecting the idea that the set of consistent histories becomes truncated. The weight calculated above is interpreted as a probability of occurrence for that compound history group. We can picture this as the tree of available histories having its branches trimmed.

Importantly, we showed that if one accepts this model, one finds that the simple act of grouping the elementary histories in a meaningful way with respect to property A, then one increases the likelihood of the specified outcome of property A.

An Example With A Deck Of Cards

To examine how this works, let us consider a computer program that shuffles a representation of a standard deck of 52 virtual cards and allows the user to select the card on top of the virtual deck. The computer can be linked to a quantum-sourced random number generator to ensure that we are testing the quantum collapse of a physical system, rather than a pseudo-random algorithm. The shuffling occurs by choosing a number from 1 to 52 randomly, and comparing this to a look up table containing all of the available "virtual cards" (e.g. ace of clubs, king of diamonds, etc.). The card that is matched in the lookup table is selected without replacing and stored in the array representing the shuffled deck.

The software now presents the User with a choice of "suit." The User clicks a button to select clubs, hearts, spades or diamonds. The User's ultimate goal will be to draw a virtual card of the chosen suit from the top of the deck. We will assume the User selected clubs. Next the User is presented with a button to click which selects the first card in the array. Upon clicking, the action taken by the User can be loosely phrased as the question "is there a club on top of the deck?" In the procedure outlined here, the shuffling happened prior to this moment, so *no new randomization occurs* once the User clicks the button to select a card.

The first step above, "shuffling," leaves the deck in a superposition of quantum histories that we'll label $[e^k]$. This model requires that the state of the system is defined relationally, in the sense of relational quantum mechanics [1] [27] [28]. As a result, the macroscopic array of registers in the computer that store the numbers for the cards remain in a superposition of histories, along with any systems in the environment that have interacted with the registers through the process of decoherence. In the absence of any modifications to existing theory, since there are 13 clubs in the deck, the likelihood that the top card is a club is $P_{club} = \frac{13}{52} = 25\%$. Let's see how this number changes in the model at hand.

When the User clicks a button to select a suit, this defines the action $\langle b|$ as the property that the top card on the deck is a club. The projection operator $[B] = |b\rangle\langle b|$ represents the measurement "What is the suit of the top card of the deck?"

There are 52! ways in which the deck could be shuffled, and $\frac{52!}{4}$ ways in which a club could be the first card. A selection of nine of these are listed in Table 1. Without loss of generality we can consider that selecting each card during shuffling was a single-step process with only one way to achieve that outcome. In other words, we consider the shuffling step to consist of *elementary histories*, where the outcome of each random number selection does not depend on any subsystem details and represents the only possible way to achieve that outcome. If the RNG selects the 2c (two of clubs), we consider this the only possible way to get a 2c. Collapse of the RNG to the state representing 2c is a fundamentally stochastic quantum event and cannot be traced to a cause in one of its subsystems. There are 52! such unique elementary histories for the virtual deck of cards.

Due to the limited complexity of this example, all of the elementary histories occur at the same level of branching. Each output result where the top card has a specific value is traced back to a common shuffling step. Hence every one of the 52! possible outcomes is the result of the same number of intermediate steps. By contrast, in a more realistic situation, two specific outcomes might have very different paths of circumstance that lead to them, and hence the number of bifurcations in the history tree before we get to an elementary history that is either "yes" or "no" would be different for each. In the present case, this is not necessary and Eqn. 2 is adequate.

The initial state ψ_0 at time t^0 and the 52! possible outcomes $[e^k]$ of the shuffling event at time t^1 together define a consistent family of "two-time" histories,

$$[e^k] \odot [\psi_0].$$

The histories represented by $[e^k]$ originally became distinct when the deck was shuffled, for this led to the 52! possible elementary histories. However, the histories extend through time until they are either selected as an actual event or truncated as an inconsistent event. The key point is that our measurement action $\langle b|$ will act at an intermediate time between the two projectors written above.

Even though the User has not selected a card yet, we can project the User's choice of suit, $\langle b|$, onto the array of future possible outcomes, $[e^k]$ (i.e. the elementary histories). Each of these elementary histories will be either a "hit", leading to a club on top, or a "miss", leading to a different suit on top. In other words, the User has access to a set of 52! histories that have not been observed yet, some of which are hits and some of which are misses.

We might be concerned about *when* exactly the measurement of the top card actually takes place, as we consider whether the deck of cards still remains in a superposition when we actually measure it. It is a mathematical property of the histories that they can be unitarily extended over the intermediate time between the initial projector, ψ_0, and the elementary histories, $[e^k]$, while remaining orthogonal and consistent. The relational view of quantum mechanics ensures that the histories remain in a superposition with respect to the User, even though they become correlated to various subsystems of the environment. The User can therefore interact with the system at *any* convenient time between the initial and final states.

The N elementary histories represent the highest level of granularity, and the inner products are $\langle b|e^k\rangle = 0, 1$ as required by Eqn. 1. We can next imagine collecting these into two subgroups by decomposing the identity into two arbitrary divisions, so $[E] = |E_1\rangle\langle E_1| + |E_2\rangle\langle E_2|$. This coarsens the resolution of our basis.

TABLE 1: Possible configurations of cards in the deck. Each configuration is shown vertically, with the ket labelling it shown first, then the first card, second card, etc, going down the list.

$\lvert c^1\rangle$	$\lvert h^1\rangle$	$\lvert c^2\rangle$	$\lvert h^2\rangle$	$\lvert c^3\rangle$	$\lvert d^1\rangle$	$\lvert d^2\rangle$	$\lvert c^4\rangle$	$\lvert c^5\rangle$
Ac	4h	5c	2h	5c	7d	Kd	6c	Qc
2s	5s	9s	2c	6h	8d	3h	7d	Jd
7c	Kd	7s	6d	Ad	9s	9c	Ah	3h
Kh	Kc	3d	5h	3c	5c	Ah	4c	Ks
Qd	3c	Ad	Js	2c	4s	Qc	8h	4d
8c	Ac	2c	Ah	Jh	Jd	3d	2d	Qc
...	...	...	...	...	...	...	...	...

The grouped states could be given by, for example,

$$[E_1] = \Big(|c^1\rangle\langle c^1| + |h^1\rangle\langle h^1| + |c^2\rangle\langle c^2| + |d^2\rangle\langle d^2| + |c^4\rangle\langle c^4| + |c^5\rangle\langle c^5| + \cdots \Big)\frac{1}{N_1}$$

$$[E_2] = \Big(|h^2\rangle\langle h^2| + |c^3\rangle\langle c^3| + |c^6\rangle\langle c^6| + |s^1\rangle\langle s^1| + |c^7\rangle\langle c^7| + |c^8\rangle\langle c^8| + \cdots \Big)\frac{1}{N_2}$$

where the symbols d, c, h, and s stand for diamond, club, heart and spade respectively. The state $|h^2\rangle$ represents NOT a two of hearts, but *the second configuration which has a heart on top*. See Table 1 for clarity on this notation. It is easy to see that none of the projectors in $[E_1]$ project onto the group $[E_2]$, so each of the groups $[E_i]$ are mutually exclusive. This means a given deck configuration (i.e. each elementary history) either lies in one group or the other, but not both. It is not required that the groups be equal in size, so the normalization factor N_i provides the proper weighting for each composite history.

Non-meaningful grouping

To begin, let's assume the basis groupings $[E_1]$ and $[E_2]$ are arbitrary. Since there are $\frac{52}{4} = 13$ clubs and $\frac{3*52}{4} = 39$ non-clubs in a standard deck, there are $\frac{N}{4}$ "hits" (i.e. clubs on top) and $\frac{3N}{4}$ "misses" (i.e. some other suit on top) among the available histories in $[E]$. Remembering our discussion earlier about the unlikelihood of spontaneously unbalanced groupings in large datasets, and given the enormous number of elementary histories in this scenario, an arbitrary division of elementary histories between $[E_1]$ and $[E_2]$ will be approximately even in their allotment of hits and misses. We can represent this division as

$$[E_1] = 1111\,0000\,0000\,0000$$

$$[E_2] = 1111\,0000\,0000\,0000$$

where the symbol 1 stands for a collection of elementary subhistories in which a club is on top, and 0 otherwise. Rather than considering 52! possible (elementary) histories, we are now considering only two (compound) histories. There are an enormous number of elementary histories (on the order of $\frac{52!}{2}$) in each compound history. For the sake of convenience we have represented all of these histories by only 16 elementary histories which show the *relative numbers* of hits and misses. The above grouping of histories can be written explicitly as

$$\begin{aligned} [E_1] &= \frac{1}{16}\Big(|c^1\rangle\langle c^1| + |c^2\rangle\langle c^2| + |c^3\rangle\langle c^3| + |c^4\rangle\langle c^4| + O \Big) \\ [E_2] &= \frac{1}{16}\Big(|c^5\rangle\langle c^5| + |c^6\rangle\langle c^6| + |c^7\rangle\langle c^7| + |c^8\rangle\langle c^8| + O \Big) \end{aligned} \tag{20}$$

where $[c^k] = |c^k\rangle\langle c^k|$ represents a the kth elementary history with a club on top, and we have omitted twelve terms that represent misses (not a club on top).

TABLE 2: The inner product of each elementary history with the basis state defined by the User action is either one or zero.

$\langle b\vert c^i\rangle = 1$	$\langle b\vert h^i\rangle = 0$
$\langle b\vert d^i\rangle = 0$	$\langle b\vert s^i\rangle = 0$

Of crucial importance is the overlap between the bra $\langle b|$ representing the measurement taken and the elementary subhistories, $[e^k]$. Using the notation in Eqn. 20 and the inner products in Table 2, each elementary history has either complete overlap or no overlap with our measurement.

The binary overlaps of the action with the elementary histories allow us to easily calculate the probability or weight of each *group*, $[E_i]$. Using Eqn. 2,

$$Pr(E_1) = \frac{\left|\langle b|c^1\rangle\right|^2 + \left|\langle b|c^2\rangle\right|^2 + \left|\langle b|c^3\rangle\right|^2 + \left|\langle b|c^4\rangle\right|^2}{\left|\langle b|c^1\rangle\right|^2 + \left|\langle b|c^2\rangle\right|^2 + \left|\langle b|c^3\rangle\right|^2 + \left|\langle b|c^4\rangle\right|^2 + \left|\langle b|c^5\rangle\right|^2 + \left|\langle b|c^6\rangle\right|^2 + \left|\langle b|c^7\rangle\right|^2 + \left|\langle b|c^8\rangle\right|^2} = \frac{4}{8} = 50\% \tag{21}$$

This represents a non-meaningful question, i.e. one which does not distinguish well between the possible outcomes. Each compound history E_i is equally likely to occur (with probability 50%), and once that group of histories is selected, there are four hits out of sixteen possible elementary histories remaining. The "hit" outcome has not increased in likelihood from the original 25%.

To clarify the interpretation of this result, we must remember that no measurement observation has yet been made on the cards, and hence the grouping $[E_i]$ is not something the User *experiences* or directly measures. The User does not *know* that the history space has been trimmed to remove a subset of histories, yet the proposition of this paper is that the User does in fact reduce the number of available histories in the history space through this result, typically as a result of interactions with some subsystem that is only consistent with $[E_1]$ and not $[E_2]$. Hence, they find themselves *actually in* the history group $[E_1]$. Once the history group $[E_2]$ has been removed (set to zero weight), we can calculate the likelihood of finding a club on top from within the remaining group $[E_1]$. To do this we look at the density of states representing a "hit" within this group, which is $\frac{4}{16} = 25\%$ in our example, unchanged from the random case, as we should expect for a non-meaningful grouping.

Meaningful Grouping

Now we consider the proposed "meaningful" grouping. In this case, the measurement $\langle b|$ by the User refines the system into history groups which are not evenly divided among hits and misses. An example of such a meaningful collection of histories is

$$\begin{aligned} [E_1] &= 1111\,1000\,0000\,0000 \\ [E_2] &= 1110\,0000\,0000\,0000 \end{aligned} \tag{22}$$

This division of elementary histories has the same total number of hits and misses, because it is drawn from the same sample space of elementary histories. However, the elementary histories are distributed in an uneven way. The first compound history $[E_1]$ in the intermediate decomposition contains more elementary histories that result in a hit, and the other has more misses. Therefore, *if one were definitely in the first history group*, they would have a likelihood of $\frac{5}{16} = 31\%$ to obtain a measurement result that is a hit (club on top). This is more likely than the hit rate prior to the grouping, but still not fully determined.

In explicit notation, the groups are written as

$$\begin{aligned} [E_1] &= \frac{1}{16}\left(|c^1\rangle\langle c^1| + |c^2\rangle\langle c^2| + |c^3\rangle\langle c^3| + |c^4\rangle\langle c^4| + |c^5\rangle\langle c^5| + O\right) \\ [E_2] &= \frac{1}{16}\left(|c^6\rangle\langle c^6| + |c^7\rangle\langle c^7| + |c^8\rangle\langle c^8| + O\right) \end{aligned} \tag{23}$$

where we have omitted terms that represent misses (not a club on top). Now we can find the weight of history group

TABLE 3: The probability of a hit or miss given various simple groupings of a deck of virtual cards.

Histories	Weight	$P(hit\|E_i)$	E_1		E_2		$P(hit)$	$P(miss)$
			Hit	Miss	Hit	Miss		
1111 0000 0000 0000 1111 0000 0000 0000	$P(E_1) = \frac{1}{2}$ $P(E_2) = \frac{1}{2}$	$\frac{1}{2}$ $\frac{1}{2}$	$\frac{1}{4}\frac{1}{2} = \frac{1}{8}$	$\frac{3}{4}\frac{1}{2} = \frac{3}{8}$	$\frac{1}{4}\frac{1}{2} = \frac{1}{8}$	$\frac{3}{4}\frac{1}{2} = \frac{3}{8}$	$\frac{1}{4} = 25\%$	$\frac{3}{4} = 75\%$
1111 1000 0000 0000 1110 0000 0000 0000	$P(E_1) = \frac{5}{8}$ $P(E_2) = \frac{3}{8}$	$\frac{5}{16}$ $\frac{3}{16}$	$\frac{5}{16}\frac{5}{8} = \frac{25}{128}$	$\frac{11}{16}\frac{5}{8} = \frac{55}{128}$	$\frac{3}{16}\frac{3}{8} = \frac{9}{128}$	$\frac{13}{16}\frac{3}{8} = \frac{39}{128}$	$\frac{34}{128} = 27\%$	$\frac{94}{128} = 73\%$
1111 1100 0000 0000 1100 0000 0000 0000	$P(E_1) = \frac{3}{4}$ $P(E_2) = \frac{1}{4}$	$\frac{6}{16}$ $\frac{2}{16}$	$\frac{6}{16}\frac{3}{4} = \frac{18}{64}$	$\frac{10}{16}\frac{3}{4} = \frac{30}{64}$	$\frac{2}{16}\frac{1}{4} = \frac{2}{64}$	$\frac{14}{16}\frac{1}{4} = \frac{14}{64}$	$\frac{20}{64} = 31\%$	$\frac{44}{64} = 69\%$
1111 1110 0000 0000 1000 0000 0000 0000	$P(E_1) = \frac{7}{8}$ $P(E_2) = \frac{1}{8}$	$\frac{7}{16}$ $\frac{1}{16}$	$\frac{7}{16}\frac{7}{8} = \frac{49}{128}$	$\frac{9}{16}\frac{7}{8} = \frac{63}{128}$	$\frac{1}{16}\frac{1}{8} = \frac{1}{128}$	$\frac{15}{16}\frac{1}{8} = \frac{15}{128}$	$\frac{50}{128} = 39\%$	$\frac{78}{128} = 61\%$
1111 1111 0000 0000 0000 0000 0000 0000	$P(E_1) = 1$ $P(E_2) = 0$	$\frac{1}{2}$ 0	$\frac{1}{2}$	$\frac{1}{2}$	0	0	$\frac{1}{2} = 50\%$	$\frac{1}{2} = 50\%$

$[E_1]$, using Eqn. 2 and Table 2,

$$Pr(E_1) = \frac{\left|\langle b|c^1\rangle\right|^2 + \left|\langle b|c^2\rangle\right|^2 + \left|\langle b|c^3\rangle\right|^2 + \left|\langle b|c^4\rangle\right|^2 + \left|\langle b|c^5\rangle\right|^2}{\left|\langle b|c^1\rangle\right|^2 + \left|\langle b|c^2\rangle\right|^2 + \left|\langle b|c^3\rangle\right|^2 + \left|\langle b|c^4\rangle\right|^2 + \left|\langle b|c^5\rangle\right|^2 + \left|\langle b|c^6\rangle\right|^2 + \left|\langle b|c^7\rangle\right|^2 + \left|\langle b|c^8\rangle\right|^2} = \frac{5}{8} = 62.5\% \qquad (24)$$

This value can be interpreted as the probability of the compound history grouping $[E_1]$.

In order to obtain a measurable modification to the probability distribution of the outcomes, we would need to have some of the histories (e.g. $[E_2]$) be made inconsistent with measured results, i.e. become trimmed from the tree, thus leaving behind only the history group $[E_1]$. In more complex scenarios, this might be accomplished interacting with some correlated subsystem and thereby rendering *some* of the histories inconsistent. Even without such an event, however, we can see that the probabilities are still modified by the grouping.

The key physics appears in the assertion that the intermediate decomposition can be assigned an actual probability, rather than a probability amplitude. In other words, one of the two histories becomes trimmed. As it turns out, as long as we have made a meaningful grouping, *it does not matter which history group becomes trimmed* from the consistent tree of available histories. In either case, so long as *some* branch is trimmed and actually becomes inaccessible to us, the overall likelihood of a 'hit' increases.

To see why this is so, note that in the meaningful grouping provided above, the weight of the state $[E_1]$ is $P(E_1) = \frac{5}{8} = 62.5\%$, which we can treat as the probability of actually ending up in that history group. Once we actually get into that history group, the likelihood of a 'hit' is found by counting the elementary histories within $[E_1]$ that correspond to hits. There are five of these, out of 16 total possible histories still available to us in $[E_1]$, giving a weight of $P(hit|E_1) = \frac{5}{16}$. Hence the likelihood of a hit is $P(hit|E_1)P(E_1) = 19\%$, which is less than the original likelihood of getting the desired card on top through random chance (25%). However, there is also a likelihood that we *actually* ended up in $[E_2]$ with probability (given by Eqn. 2) $P(E_2) = \frac{3}{8} = 38\%$. in which case the likelihood of a hit would be $P(hit|E_2) = \frac{3}{16} = 19\%$. Thus there is an additional likelihood of a hit given by $P(hit|E_2)P(E_2) = 7\%$. Hence, even though we do not know which history group we are in, as a result of the measurement action $\langle b|$ the total likelihood of a hit is 19% + 7% = 26%, which is slightly increased from 25%.

By treating the space of possible histories as actual mathematical objects in a real mathematical (but not physical) history space, we find that the meaningful grouping of such histories allows us to evolve into a particular subgroup of the history space. The statement that we are *actually in* one of those subgroups gives rise to a modified probability distribution for the outcomes, regardless of which history group we are actually in. In this example a small redistribution of the histories into the intermediate decomposition groups gives rise to a small increase in the likelihood of the desired outcome. One can check (see Table 3 for sample distributions) that anything other than the even grouping (with maximum entropy) will increase the chances of getting a hit. The effect in this case will tend to be fairly small but robust, consistent with experimental evidence described in the next sections. We changed the grouping of hits by a substantial amount ($\frac{1}{4} \rightarrow \frac{5}{8}$ is a difference of 12.5%) and obtained a resulting increase in probability of the desired outcome of only 1%. As discussed later, this example would be more realistic if the number of elementary histories was vastly increased from 32, in which case the grouping of histories could be far more refined, and would result in even smaller modifications to the probability, or at least a more refined continuum of possible values.

The effects predicted here result from the intermediate grouping of histories, with the key point that such grouping is a result of our choice of which properties of the system to distinguish. This is what we do when we take the 52! elementary histories and group them according to a coarse property "club on top." We are no longer distinguishing among many of the other properties of the configurations, such as whether it is an ace or a three. By choosing to distinguish the configuration according to the suit of the card on top, we group the elementary histories into the compound history groups which reflect this property.

The Model Applied to Existing Experiments

PEAR Lab Experiments

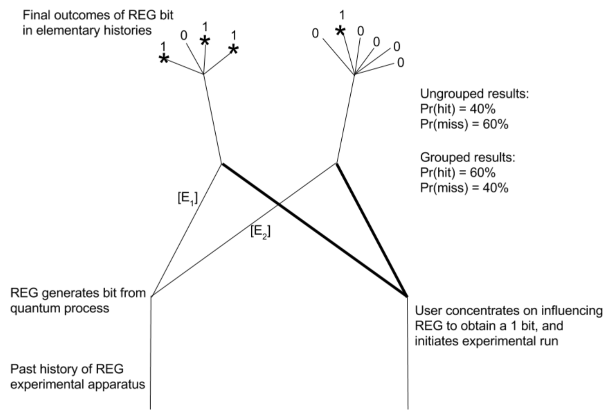

FIGURE 7: In a typical REG experiment, a User aims to control whether a randomly generated bit is a 0 or a 1. If the User is able to group the potential histories into a meaningful group, the chances of obtaining the target bit increase.

In experiments performed by the Princeton Engineering Anomalies Research (PEAR) lab, a User focused on influencing the outcome of a genuine (quantum-sourced) random number generator, called an REG. A diagram is included in Fig. 7 to show how the proposed model applies to such an experiment.

In the diagram the *overall* density of hits among total future outcomes is six out of ten, or 40%. If the histories are grouped as drawn, the likelihood of a hit increases to $P(hit)_{grouped} = \frac{N_{H1}}{N_1}\frac{N_{H1}}{N_H} + \frac{N_{H2}}{N_2}\frac{N_{H2}}{N_H} = \frac{3}{4}\frac{3}{4} + \frac{1}{6}\frac{1}{4} \approx 60\%$, where we used Eqns. 2 and 14. This is an exaggerated result because we have modeled a system that should have a large number of available histories with only ten sample histories.

Comparison to other formulations

The approach taken here is consistent with the conceptual and mathematical formulation of quantum mechanics provided by Feynman. [29] The double-slit experiment, for instance, can be seen as a system with many possible physical paths, each path going through one slit or the other. In the language used here, we treat the elementary histories as those paths which take a particular path through the slits. The sum-over-histories approach reflects this same concept when it considers the contribution to the action from every possible path that the particle can take through the slits. The additional proposition in this paper is that a conscious User has the effect of grouping the particular paths in a manner which minimizes the entropy of the grouping. This connection needs to be more fully explored.

In the weak measurement model, [30] one typically relies on the two-state vector formalism, in which both a past cause and a future effect act together to bring an intermediate measurement result. Inherent to this process is a slicing approach, where one divides up the individual outcomes based upon their alignment with a final measurement outcome. Information about the system can be inferred or confirmed via the appropriate slicing of the data, without having actually collapsed the system into an eigenstate during the experiment. There appears to be crossover with the method presented here, and the connection should be explored further.

The relational model of quantum mechanics, as first presented by Rovelli, [28] is a necessary piece of the picture presented here. It is the relational nature of things that allows them to escape objective collapse by decoherence. In the relational model, decoherence is a process occurring between subsystems, rather than a process occurring with an "objective environment." Hence, although the registers in our computer example are macroscopic entities which have clearly decohered with the environment, this decoherence is really just correlation with the other entities in the immediate environment. So long as no relevant information transfer has taken place between the User and the register or its correlated environment, the register remains in a superposition state with respect to the User (as a result, say, of the original radioactive decay in the quantum generated RNG device).

The Ithaca Interpretation of Quantum Mechanics [1] is perhaps less well-known, formulated by N. David Mermin, from which the starting quote was taken. This view emphasizes the experimental findings in Bell-type experiments that make it clear that there is no fundamental ground of *things*, but only *relationships among things*. The relational model and IIQM have much overlap. The model of meaningful history selection presented here takes very seriously the propositions from the IIQM, which makes possible the process of retroactive event determination outlined above.

The transactional interpretation shares a similarity to the approach taken here. In the TIQM the forward in time 'retarded' traveling wave function interacts with a backward in time 'advanced' traveling wave, forming a handshake in the intermediate time (the present). The intermediate decomposition of the identity discussed here may be identical to this process. Although the TIQM formulation has an explicit reference to time as a variable in the description of advanced and retarded waves, these details are not included in the consistent histories perspective. Whether a linear metric of time is necessary as a matter of ontological understanding of reality is uncertain. In the approach taken here, we side with consistent histories and rely on time as an ordering principle (e.g. "which event came first?"), without concerning ourselves to its actual value as a metric ("at exactly what time did this event happen?").

The consistent histories or decoherent histories approach [2] serves as a mathematical model for the formalism presented here. This model shows us how to handle a chain of quantum events over an extended period of time. Although we typically *associate* a time index with a ket vector, there is no fundamental place for time to be tracked within a ket. This is not an accident; it reminds us that time is not an absolute measure in quantum mechanics. Consistent histories embodies this by providing a mathematical structure through which we can project a measurement at some present moment onto a system which has been evolving for some arbitrary amount of time. Through the existing formalism it is clear that we can essentially project onto the *past states* of the system. Consistent histories obtains all the standard results of quantum theory and is able to unravel many of the typical paradoxes by insisting that, while many histories may be available for a system, one must choose a particular framework for the measurements we are making. Within that framework, all measurements are consistent and paradoxes are avoided. If one insists on incorporating a second framework simultaneously with the first (corresponding to performing a different measurement) one will tend to invite back in paradoxes stemming from this "illegal" action.

In the model presented here, we extend the interpretation of the consistent histories formalism to examine the projection of a current action forward in time as well. This emphasizes the symmetric nature of the mathematics in consistent histories. Although we tend to impart on the world the anthropomorphic view that the only thing accessible to us is the present moment, the mathematical formalism of consistent histories shows us that this imposition of a single time is not appropriate.

Modeling Types of Psi Phenomena

The motivation for the proposal here is in various forms of unexplained data. This author has tracked examples of meaningful coincidence both personally and in stories from other individuals. These happy accidents appear to be very common experiences, even in the realm of science, including the discovery of the cosmic background radiation/big bang (Penzias and Wilson), penicillin (Sir Alexander Fleming), LSD (Dr. Albert Hoffman), X-Rays (Wilhelm Rontgen) and vulcanization of rubber (Charles Goodyear). There is also the coincidental location of Albert Einstein's patent office within a short distance of the train station where there were clocks representing time in many different cities. The problem of synchronizing clocks across large distances was central to that time period, and Einstein's proximity to the train station and employment examining patent applications for ingenious devices which could accomplish this feat gave him ample opportunity to think about the synchronization of time from a theoretical perspective. Einstein's breakthrough paper on special relativity in 1905 had time synchronization at its root. This is circumstantial evidence for which surprisingly little rigorous effort has been made to track and understand. A proposed experiment to test this phenomena follows in a later section.

In the field of psi research there is significant evidence that consciousness can have a small but robust influence on the outcome of physical experiments, as discussed already. A related phenomenon is the "series position effect," [14] otherwise known as the "boredom" phenomenon or the "beginner's luck" effect, in which the ability to influence the outcome of a probabilistic event declines through repetition of the experiment by a single User. There is also a body of evidence supporting the "experimenter effect" and other situations where the expectation of the User appears to influence the outcome of certain experiments. [13] (Also see [16] for an example of this apparent effect on an unrelated experiment's outcome.) It has been suggested [31] that one of the reasons that even well designed experiments to test psi phenomena have difficulty consistently replicating results is that those experiments have not properly controlled for the expectation of the experimenter themselves. This is natural, since it is taken as a fundamental tenet of current scientific method that the experimenter can be completely separated from the system. Experiments such as these indicating that experimenter bias may have a causal influence on outcome should motivate us to search for minor additions that may be made to current theory that can bring such currently anomalous data under the umbrella of current theory without violating any known physics. It is in this spirit, based on a careful consideration of the commonalities between the varied phenomena, that the current explicit model is offered.

Three well-studied areas of psi that this model may be applicable to are psychokinesis (PK), precognition, and the experimenter effect. In each field evidence exists indicating a small but robust effect, which is consistent with the model presented here.

Psychokinesis

In regards to psychokinesis, I am specifically referring to the ability to score above chance in an activity that is designed to have random outcomes. This is referring to a setup that utilizes a true random number generator and bits in a computer as the physical system being affected by the User's intended measurement outcome, such as in [32] [18] [17] [33]. It does not escape notice that, due to the premises of the relational interpretation of quantum mechanics, this model should just as easily apply to larger and more robust physical objects, such as the cascading marbles forming a normal distribution on a pinball board. [34]

Such systems consist of many repetitive trials of a single statistical event. According to this model, each event has a tree of histories associated with it. The effect of the User action is to project a specific outcome, such as obtaining a 1 bit from the random number generator, onto the future possible outcomes of the system, and group them in a meaningful way according to this property. As a result, the likelihood of the particular outcome increases as described in this paper, and over a large number of repeated trials the User scores above chance in their ability to 'influence' the outcomes of the device.

Psychokinesis is therefore *not* the act of moving physical objects with one's intention, but rather grouping the histories of that object in a meaningful way, such that they are *retroactively determined* in accordance with the intention that was defined in the User action.

Precognition

In some precognitive experiments, a User's biological systems are monitored to determine whether the User can subconsciously predict the emotional impact of a photograph that will appear in front of them momentarily. [35] [36] [37] One can imagine the User flowing down a river of events, and a rock is protruding from the water in front of them. Before hitting the rock, the User will be aware of the ripples in the water that indicate the approaching rock.

This metaphor is an apt description of the model presented here. As a User continuously acts on a system, they increase the likelihood of a given outcome by a small amount. This effect is theoretically cumulative, and after some repetition of similar measurement actions the User is in a compound history group which has a very high density of hits. This means the User is much more likely than before to experience the target outcome. It is not entirely unreasonable to suppose such a high hit density proximity might be perceivable by the User. This would rely on the stated proposition that the space of possibilities represents a real mathematical space, which contains real data about possible histories of a system and their likelihood. This mathematical space is clearly not located at a specific coordinate within spacetime. Presumably an event that is very likely could make a larger impression on an individual than an event which is not particularly likely, giving rise to the data observed in the experiments above.[2]

[2]Thanks to Julia Mossbridge for this metaphor.

The experimenter effect

The possible effect of the experimenter's internal bias during an experiment which involves a highly probabilistic, complex or sensitive situation under study is consistent with the model presented here. We have postulated that a User can influence the grouping of histories according to a specific property, as defined by the User's action. If a User believes an experiment will not work, it does not escape our notice that the bias could affect the action $\langle b|$. The User's preference for a given outcome would be projected onto all the elementary histories, and those that confirm the bias would be considered hits. Therefore, according to the proposed model, these outcomes would become slightly more likely, thus confirming the preference of the experimenter.

Proposed Meaningful Coincidence Experiment

An experiment could be designed to test for these principles by trying to mirror a commonly reported experience of meaningful coincidence. Such an experiment would need to be based not on the physical configuration of an outcome (as is done with all current physics experiments), but rather on the meaningful arrangement of the outcome parameters. There are many circumstances that could be used to test for synchronicity, and the following is one suggestion. This procedure tests for the usefulness of meaningful coincidences in the process of seeking relevant information. The idea tries to model the experience of opening to a random page in a book or magazine, or turning on a random TV station, and accidentally finding information that is personally relevant to one's current experiences.

The experiment could be conducted online, and the Users could be constrained to only run the experiment once every half hour, in order to maintain interest in the task and avoid boredom. The nature of the task is inherently fulfilling and will tend to draw Users to return more than once.

The website is set up to offer guidance to the User. The guidance is in the form of passages from a philosophical text, such as ecstatic poems by Rumi or excerpts from the Tao te Ching. This ensures a genuine interest for the User. Each passage has been prerated and assigned various tags, corresponding to the general topics covered by the passage. The passages are then correlated with a set of topics in a lookup table. The table records the correlation between each passage and each topic, based on the keywords associated with the passage.

The User logs into the system and is asked to select a topic of interest from a 'Table of Contents.' Once the User selects a topic, they trigger a random number generator that selects a specific passage. The measure of meaningful coincidence is represented by how well the randomly selected passages correlate to the topic of interest that the User chose.

The null hypothesis would result in the average correlation score between topic and passage, meaning that sometimes there was a good match and sometimes a bad match, averaging out over all. If the model here is correct one would instead expect to see a greater than chance likelihood of correlations between topics of interest chosen and the passages presented.

The experiment is highly repeatable across a vast pool of potential Users, and can address the issue of User burnout by allowing only a single interaction over a predesignated time period. The pre-analysis of the passages and their correspondence involves some human decisions, but could be performed in advance by an experienced psychologist to avoid biases and artifacts. The resulting scales would allow for directly calculable statistics and a potentially large sample size.

DISCUSSION

The model presented here is based on analysis of existing experimental evidence for 'anomalous' effects of consciousness on matter, as well as careful analysis of circumstantial evidence for meaningful coincidence. Simultaneously, the model holds closely to existing quantum theory, does not negate any of its premises nor needlessly call into question quantum theory's existing formalism. Rather to the contrary, it takes seriously all of the implications of the mathematics and ontology of quantum theory, further perhaps than some physicists would care to go due to the uncomfortable landscape the standard theory lives on. The theory presented here adds as few new ideas as possible to quantum theory. It does not rely on any of the standard tricks to modify quantum theory, such as faster than light communication, etc., which conflict with known data. The result is a fluid proposal that arises naturally and fits neatly into the collection of existing experimental evidence, spanning traditional physics experiments, psi experiments and the circumstantial but vast body of evidence supporting meaningful coincidences. As a result we have attempted to provide a new framework within which these diverse phenomena fit while incorporating nothing that conflicts with any known experimental evidence.

This model proposes that a User's action causes a division of the available histories (or future trajectories) into a meaningful grouping, and that the User actually *ends up in* one of these groupings, while the other groups of histories become inaccessible. The history generally includes information about many correlated systems, so as a result of the trimming of the inaccessible histories, some potential configurations of the system will never occur, and others become more probable. This (typically small) change in likelihood has experimentally measurable results, explaining for instance some experiments in parapsychology.

"Objective meaning" is given a precise definition. Meaning is closely related to information, in that an increase in meaning corresponds to a decrease in specific possibilities, which results from interacting (and therefore correlated) systems. A meaningful action is one that leads to a meaningful grouping, which is a grouping that can provide more information about a particular property of the system. It is proposed that histories group themselves according to meaningful groupings that maximize information gained (minimize the entropy gained) from the measurement. This is the new physics proposed.

Within this framework, one can reasonably claim that directed action will pull a User towards an intended final future outcome, with certain caveats. It should be cautioned that this does not imply that we simply wish for something and then the outcome tends to occur. Rather, the meaningful grouping relies on a measurement *action* taken by the User, so the cause is not mental but physical. Additionally, it should be noted that the groupings tend to have a small effect.

The experimental data on "anomalous effects of consciousness," gathered from a breadth of experiments done by a variety of experimenters over a long expanse of time, seem to indicate such phenomena have a very small but robust effect. It is reasonable therefore to expect our model should in general predict a small effect size. The process of meaningful history selection, adapted with minimal modification from the standard quantum formalism, is consistent with this. For illustrative purposes in our examples we provided a relatively coarse division of elementary histories into the two compound history groups. Because of the coarse division, the groups had significantly different numbers of hits and misses, as a percentage of the total. This results in a rather dramatic (and maybe unrealistic) weighting of the histories.

For instance, in the card game, we considered only 32 histories (instead of the factorial of 52), eight of which were hits. Therefore when we divided them into groups, the non-meaningful division of groups had four hits in each group, leading to 50% weight on either group. The next grouping that could be made with this resolution was five versus three hits in each group, leading to a 62.5% versus 37.5% weight on each group, which is quite different! By contrast, if we considered the actual 52! histories available for the card deck, $\frac{52!}{4}$ would be hits, and we could shift them from the even grouping by as little as one 'hit' configuration at a time (i.e. move one configuration that has a club on top from group $[E_2]$ to $[E_1]$). In doing so the weight of the group $[E_1]$ would become

$$Pr(E_1) = \frac{\frac{52!}{4*2} + 1}{\frac{52!}{4}},$$

because initially half of the $\frac{52!}{4}$ hits would be in group $[E_1]$. This would change the chance weighting of 50% on each history by less than one part in 10^{30}. Hence, in systems with normal levels of complexity, the spectrum of 'ability' to shift the grouping of histories into meaningful groups can be very refined and have a broad range, at least from a theoretical perspective. From a practical point of view, it is clear from experiment and experience that such results are not typically large, and are generally well-disguised. Again, the model presented here is consistent with this.

One should keep in mind the image of a branching dendritic tree structure. The Schrödinger equation gives rise to a vast branching structure of possible histories as the various elements in the measured environment evolve, interact and form correlations. These are the branches of the metaphorical tree, each branch representing a unique configuration of the physical space. When the User takes an action that is consistent with only one of the compound history groups (e.g. $[E_1]$), they are *trimming the tree* to remove any elementary histories associated with the other group (e.g. $[E_2]$). By removing a branch and all of its subbranches from the tree, the density of 'hits' on the remaining tree branches will be higher (or lower) than before. The likelihood of ending up in a branch that is a hit has then been modified from prior values.

Of particular interest is the suggested possibility that if we begin with a very unlikely event, we can act repeatedly with the method prescribed here in order to gradually shift the probability distribution in a certain direction. Over time, through recursive action, what was once a very unlikely outcome is postulated to become very likely.

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