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Commentary

Neural Quantum Superposition and the Change of Mind

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Utilizing the quantum mechanical formalism describing the "double slit" experiment, where quantum particles make a choice, a model is presented to describe the psychological equivalent in a human mind, Neural Quantum Superposition. The probabilities of choosing between two options are formally developed, and the evolution in time is analyzed. The importance of entangled (correlated) states of mind is highlighted, which also models the action leading to a change of mind.

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1. Introduction

In a recent article [1], the role of the logical and intuitive mind (elements of human consciousness) in the creation of *artificial intelligence* programs in chemistry (*chemoinformatics)* [2,3,4] was briefly discussed. Also, an *Arbeitshypothese* was briefly presented, showing that the patterns of human thought in the action of *decision making* and in the *change of mind* seem isomorphic with some basic formalisms of quantum mechanics (QM). In this article, a more extended presentation of such a hypothesis, *Neural Quantum Superposition* (*NQS*), is discussed. However, it is not a QM theory of neurophysiology or similar; it is only a *QM-like description* (in its mathematical appearance) of a possible model of the act of changing one's mind. Previously, some researchers have already pointed out the fact that human consciousness seems to manage problems whose structure cannot be described by simple logical (*Boolean*) statements [5] or by classical statistics [6]. These important theoretical approaches do not presume the existence of a real, biological QM fabric of consciousness, limiting their statements to the apparent similarity between QM formalisms and human behavior (*quantum cognition* [7]). Inside the dynamics of neurochemistry, the human mind is capable of allocating thoughts that are antinomic or do not obey the law of total probability, like, e.g., self-referential statements: a known liar expresses a sentence *S:* "*I am a liar*". If he speaks the truth, then *S* is false (as he contradicts it by saying the truth); if he lies, however, then *S* is false (as he is not a liar in this case). So, *S* cannot be proven true or false, although we **know** that it is true! It seems that *true* and *false* can coexist within a single statement *S* in human consciousness, which can be formally described by a *superposition* of the two antinomic states, as

State-of-mind(S) = Ψ(True) + Ψ(False).

This category of problems pertains to the Goedelian class of *incomplete systems*, where the non-provability of a true statement is formalized in the *incompleteness theorem* [8]. For example, think of a human eye perceiving all the objects contained in a room (chairs, paintings, etc.). The observer recognizes all the visible objects and compiles a list. This list, regardless of how hard the eye looks, will be incomplete. Why? Because the seeing eye cannot see itself! So, there is at least one object missing in the list, the eye, which cannot be *proven* to exist, but the observer *knows* that it exists (because he experiences the act of *seeing)* [9]. This approach can be extended to consciousness itself. Regardless of the amount of introspection, consciousness can hardly *completely* observe itself, thus leaving space for an ontological gray area of indetermination. In a social environment, the mind can manifest patterns of behavior not coherent with classical statistics (the so-called *sure thing).* Imagine an opinion poll with the question "*...is our local governor*

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doing a good job? ". Say, 34% of the interviewed people answer YES, 45% answer NO, and the remaining 21% say NOT SURE. They seem to float in a mental state of irresolution and uncertainty, where the two states YES and NO are mixed. Again, their state of mind could, inside of this QM-like *Ansatz,* be represented by a state of superposition Σ as

$\Sigma = \Psi(YES) + \Psi(NO)$

This *Ansatz* is legit as we have decided, in this article, to play by QM rules.

The interesting thing is that in neurochemistry, we have the same array of neurotransmitters (GABA, glutamate, dopamine, acetylcholine, etc., etc..) at the neuron's disposal, and yet their different deployment (call it a *constellation)* provides for the existence of a set of three states S of consciousness: S1 is linked to a constellation of neurotransmitters encoding the state of mind of answer YES. S2 is the constellation leading to answer NO. But what is the constellation S3 leading to NOT SURE? Which molecular species and in what concentration do they form a constellation that is responsible for the undefined answer? We are tempted to adopt the mysterious concept of superposition of states. The *sure thing* paradigm of classical statistics, where the sum of probabilities of all possible independent outcomes must equal 100%, breaks down when human consciousness is observed. In throwing dice, each face has a 1/6 probability of showing. There is no *seventh face* for a superposition of, say, numbers 3 and 5 at the same time! Dice do not conform to superposition of states. But, apparently, the human mind does. We want to highlight, however, to avoid misunderstandings, that the sum of probabilities of all the possible outcomes of measured eigenvalues of an observable in some quantum system is also 1! It is the mathematical treatment and the concepts of QM that are quite unique and specific to it, among them the concept of superposition. Therefore, we try to model the dynamics of the mind utilizing, as a tentative *Arbeitshypothese,* the QM superposition formalism used in describing hardware-based QM experiments. We shall focus on the superposition of neural quantum states and their time evolution. This approach will reveal isomorphisms between the QM formalism and the consciousness dynamics in *choice selection* and in the *change of mind.* To do this, we must introduce the paramount experiment of QM that represents the essence of quantum superposition: the *double slit experiment (DSE).*

2. The Double Slit Experiment

The *double slit experiment* displays the ontological probabilistic nature of quantum phenomena [10]. An electron shooting gun G sends single electrons downrange towards a screen S that contains two narrow slits close to each other. Behind S, there is a photosensitive film F. When slit B is closed, electrons pass one-by-one through slit A only and leave a blackened area on F in correspondence to the aperture A. When A is shut, then electrons travel through slit B only, and a black spot is detected on F corresponding to the location of slit B (Fig.1a, b). We describe the wave nature of the electron traveling along two paths A and B with complex quantum state functions Ψ_A and Ψ_B within a finite space *V.*

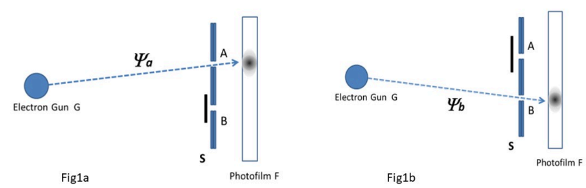

Fig.1(a,b). Single electrons travel from a source G to a photosensitive film F, passing through a barrier with two slits. When only slit A is open and B is closed, a blackened area of the many electron impacts is found on F (a). When slit A is shut and B is open, a similar effect is detected on F in correspondence with slit B.

The single probabilities $\Phi(A)$ and $\Phi(B)$ of finding the electron at a point of impact, POI, x_i or x_j on F behind slit A or slit B are given by $\Psi^2(A)$ and $\Psi^2(B)$, according to the Born density rule. Now, if both slits are kept open at the same time, one would expect that both dark areas behind A and B would appear at the respective POI. Then, the overall probability distribution Φ would follow the classical law $\Phi = \Psi^2(A) + \Psi^2(B)$. However, this is not what is observed experimentally. Instead of the expected sum of two *independent* density patterns, a remarkable *interference pattern* is recorded on F (see Fig.2).

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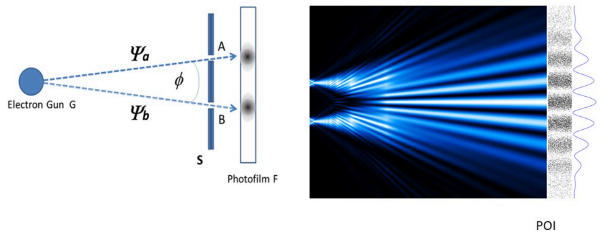

Fig. 2. If both slits are left open, electrons do not hit the film at the corresponding areas behind the slots, but an unexplained interference pattern appears all over the film. The dotted areas on the right show the multitude of points of impact on F, together with the cumulative probability density function on the far right (*computer graphics by Alexandre Gondran*)

This can only arise from two waves originating at A and B, which interfere along the way to F. But we have just *one* electron emitted, so how can one elementary particle travel through two separate slits at the same time and interfere with itself? It cannot go through A only, or through B only, because we would get no interference pattern in such a case. But it cannot go through both apertures at the same time, as it cannot split into two half-electrons, either. But, even more mindboggling, it cannot *not* go through both slits, because interference demands two points of origin of the overlapping waves! It is from the repetition of thousands of runs, each involving one electron at a time, that the dotted area POI in Fig.2 is generated. The cumulative aspect of brighter and darker stripes is *not* the shape of the electron wave function. It is the resulting image of the sum of all individual impacts at different positions x_i on F. When an electron hits the film at coordinate x_i, it is found there as one full electron with 100% probability. There is a sudden transition of the probability wave Φ, with an infinite number of position coordinates and the corresponding probability values, to one coordinate x_i only, a one-value Dirac distribution $(x_i, 0)$. This finding is called the *collapse of the wave function*. This fundamental experiment of QM is the source of a change of paradigm in confronting our logical mind with an ontologically inexplicable quantum world [11]. We must accept that "*something*" we call a single electron flies towards F along both paths A and B at the same time. *Something* that apparently *knows* about the existence of multiple paths to F! To model the interference pattern, the probability density function needs the *superposition of quantum states* Σ: formally, the electron perceives both slits at the same time

$\Sigma = a\Psi_A + b\Psi_B$ *eq.1*

and *a, b* being the weights of $\Psi_{A,B}$. With a symmetric arrangement of the experiment, where paths G-A and G-B are identical in length, $a = b = n$.

The probability density function is then

$\Phi = n^2(\Psi_A + \Psi_B)(\Psi_A + \Psi_B)^*$ *eq.2* (* meaning complex conjugate)

$\Phi = n^2(\Psi_A\Psi^*_A + \Psi_B\Psi^*_B + \Psi_B\Psi^*_A + \Psi_A\Psi^*_B)$ *eq.3*

and the QM normalization postulate, for having 100% probability inside the finite V in which Φ acts, requires

$\int \Phi\, dV = 1$ *eq.4*

Expressing the electron path functions simply with plane waves

$\Psi_A = e^{-i(kx(A)-\omega t)}$ and $\Psi_B = e^{-i(kx(B)-\omega t)}$

we obtain

$\Phi = n^2(e^{-i(kx(A)-\omega t)} + e^{-i(kx(B)-\omega t)})(e^{i(kx(A)-\omega t)} + e^{i(kx(B)-\omega t)})$

$\Phi = n^2(e^0 + e^0 + e^{-i(kx(A)-\omega t)}e^{i(kx(B)-\omega t)} + e^{-i(kx(B)-\omega t)}e^{i(kx(A)-\omega t)})$

and because paths A and B are isoenergetic (ω(A) = ω(B)) we have

$\Phi = n^2(1 + 1 + e^{-ikx(A)}e^{ikx(B)} + e^{-ikx(B)}e^{ikx(A)})$

$\Phi = n^2(1 + 1 + e^{-ikx(A)+ikx(B)} + e^{-ikx(B)+ikx(A)})$

$\Phi = n^2(1 + 1 + e^{ik\Delta x} + e^{-ik\Delta x})$

$e^{ik\Delta x} + e^{-ik\Delta x} = (\cos k\Delta x + i\sin k\Delta x) + (\cos k\Delta x - i\sin k\Delta x) = 2\cos k\Delta x$

with Δx being the difference in the two paths BF, AF between slit A and B and film F :

$\Delta x = x(BF) - x(AF)$. This difference is what determines a constructive or destructive interference and thus gives rise to the wavy intensity pattern on F (see Fig2).

We are left with a real term only that contains two local variables, *x(BF)* and *x(AF).*

We need, (eq.4), $<\Phi> = 1$ (normalization of the probability)

$\int \Phi\, dV = n^2 \int (1 + 1 + 2\cos k\Delta x)\, dV = 1$ and with $2\cos k\Delta x = \gamma$

$\int \Phi\, dV = n^2 \int (1 + 1 + \gamma)\, dV = 1$ *eq.5*

As plane waves are not square-integrable and thus not normalizable *in the beginning*, we can only say that $<\Phi>$

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~ $\int_V \Phi \, dV$. But this is irrelevant for our discussion; the point is the existence of a nonlinear term in eq.3, manifest as γ in eq.5. We see that the probability density is now depending on the third term where two separate variables act *simultaneously* to model the interaction intensity [12].

The parameter γ is a value determined also by the specific experiment geometry.

It is, as in eq.5, time-independent. We shall see later that in the description of the *NQS* consciousness dynamics, this parameter will be time-dependent.

The probability density is dependent on the angle between the two paths of travel. If, for example, the two trajectories were the same (when the distance between A and B becomes zero, there is only one path *k*), then $\Psi_A = \Psi_B = \Psi_\kappa$, and the interaction term would become $\Psi_\kappa{}^2$, and so $\Phi = \Psi_\kappa{}^2$. The mere existence of two slits (choices) automatically entails the existence of an entanglement between two apparently separate paths. We call them *entangled* because the existence of one path (when both slits are open) entails the existence of the other! Conversely, the manifestation of an interference pattern reveals the existence of two competing paths (choices). If the angle widens, the terms $\Psi_A \Psi^*_B$ decrease until total decorrelation is achieved (at 90^0). The two choices, A or B, have now become independent, and we no longer have a *DSE*, but two separate *single slit* experiments with vanishing interference. We shall transfer this knowledge about *DSE* into the more complex biological realm of human consciousness. The modeling of psychological experiments involving two options, A and B, will reveal an interesting isomorphism between the QM formalism of a *DSE* and the dynamics of conscious selection and the change of mind.

3. Neural Quantum States

DEFINITIONS

- We call the experiment of conscious perception, positive recognition, and awareness of two objects, A and B, an *Erlebnis Experiment*, *EE*.

- We call the human experiment of the selection of one option out of two (A, B) a *choice* within an *EE*. We model the system with Ψ_A , Ψ_B being norm-1 real functions, as found in modeling an “electron in a box.” We simply assume that Ψ_A , Ψ_B are steady waves inside a defined segment of the brain of length *L* and volume *V.* They are encoding the “awareness” of objects A and B. They are time-independent in this first approximation, depending on local variables, and describe the conscious state of mind, in which, simultaneously, an array of *stimuli*, visually or memory-generated, act on specific regions of the biological neural network we call the brain. If a test person M looks at two shirts of different colors in a fashion shop, we call his becoming conscious of the two shirts and of their colors an *Erlebnis.* We deal here with an *EE* where a choice between two options, the colored shirts, for example, must be performed.

Let N_A, N_B be two ensembles of biological neurons that are activated inside a specific brain region. Let f(N_A), f(N_B) encode different specific neurochemical constellations (consisting of chemical species, their concentrations, neural rest or action potentials, blood pressure, etc., inside the ensembles of neurons N_A, N_B). Thus, constellations f(N_A) and f(N_B) are real physicochemical systems and originate from the stimuli of the two objects, A and B, perceived visually at the same time during the *EE.* Let us now formally represent the constellations f(N_A) and f(N_B) as QM state functions Ψ_A and Ψ_B during an *EE.* Ψ_A and Ψ_B describe the effect of f(N_A) and of f(N_B) on consciousness.

A, B (*real objects*) $\rightarrow$ *transformation into* $\rightarrow$ f(N_A), f(N_B) (*neurochemistry*)$\rightarrow$*representation by* $\rightarrow$ Ψ_A,Ψ_B (QM *mathematics*)

We have introduced the concept of superposition of state functions as shown in eq.1.

$\Sigma = \alpha\Psi_A + \beta\Psi_B$ (α,β are now general parameters, no longer constants!)

If we assume in our *NQS Arbeitshypothese* that QM rules at the neural level, then we must accept that the density function is given by the squared superposition state of $\alpha\Psi_A$ and $\beta\Psi_B$, as in eq.2 of the *DSE.*

$$\Phi = \Sigma\Sigma = (\alpha\Psi_A + \beta\Psi_B)(\alpha\Psi_A + \beta\Psi_B)$$

$$= (\alpha^2\Psi_A\Psi_A + \Psi_B\Psi_B\beta^2 + \gamma\,\Psi_A\Psi_B) \quad [13]$$

In analogy, we have to assume that the two brain functions $\alpha\Psi_A$, $\beta\Psi_B$ generate an entanglement (or *interaction, correlation)* term $\gamma\Psi_A\Psi_B$, where the two choices A and B are *not separable*. Note that the entanglement term is mandatorily entailed in the application of QM superposition formalism to our neural *EE* description. Psychologically, this entails the following consideration: if two similar objects A and B are perceived by M and he must choose one of them, a mental state of entanglement, or interference*, is automatically present in his mind*!

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The normalization postulate again requires eq.5, with $<\Psi_A | \Psi_B>$ being the correlation coefficient, which is close to 1 when Ψ_A , Ψ_B are *similar, i.e.* highly colinear. We have assumed in this simple model that the mental perception of objects A and B is carried out by f(N_A) and f(N_B) by the neurons N_A and N_B along L inside the same V and encode *similar* (i.e., comparable) states of awareness. Note that we deal with the perception and choice between *sufficiently* similar objects (or thoughts) A and B. We confront an apple and a pear, or two colored shirts, etc. Choices between, say, "*I must call grandma*" and "*I must buy a new lightbulb for the kitchen*" obviously have decorrelated, independent Ψ_A and Ψ_B so that $<\Psi_A | \Psi_B> \rightarrow 0$. The action of *choice* might in such cases also be decided by circumstantial parameters, like "*...the hardware shop is closed now, so I choose to call grandma first...*".

Again, we have

$$\int \Phi\, dV = \int (\alpha^2 \Psi_A \Psi_A + \Psi_B \Psi_B \beta^2 + \gamma\, \Psi_A \Psi_B)\, dV = 1 \quad \text{eq.6a}$$

so that we need (with the constant $<\Psi_A | \Psi_B>$ absorbed in γ)

$$\alpha^2 + \beta^2 + \gamma = 1 \quad \text{eq.6b}$$

meaning that the total probability of finding any kind of mix of two correlated mental states is 1 and is carried by three probability parameters.

4. Time Evolution Operator

Because neurons are time-dependent chemical systems, the three probability parameters in eq.6 must now be considered as time-dependent. To model the time-dependence of an *EE* dealing with decision making, we utilize a reversible time evolution operator T, where ω is a frequency linked to the energy of the system by $\omega = E / \hbar$

$$\boldsymbol{T} = e^{-i\omega t}$$

that acts on a wavefunction and models the forward action of time on Ψ

$$\Psi_t = \boldsymbol{T}\Psi$$

For the probability density to be conserved, $\boldsymbol{T}$ must be unitary

$\boldsymbol{T}^{-1}\boldsymbol{T} = 1$ and therefore $< \Psi_t \mid \Psi_t^* > = < \Psi | \boldsymbol{T}^{-1}\boldsymbol{T} | \Psi>$

The operator $\boldsymbol{T}$ represents a reversible rotation in an Euler plane (see Fig.3). Euler's formula is a mathematical formula that expresses the fundamental relationship between the trigonometric functions and the complex exponential function, stating for any real x:

$$e^{ix} = \cos x + i \sin x$$

The radius r of the Euler circle is taken as 1, and it rotates counterclockwise by an angle θ. The initial moment sees $r = \gamma_{max} = 1$, and the projection of r onto the real axis after some rotation gives rise to a γ_τ. The difference between 1 and γ_τ is contained in the two coefficients α^2 and β^2. The speed of rotation is determined by ω. Where does an energy term $\omega = E / h$ come from? From a chemist's perspective, a first interpretation could be: when the brain recognizes and stores information of a visually perceived object, chemical work is performed inside a devoted set of neurons N_j. Glucose is processed, and inside all involved neurons, a specific membrane polarity is established, leading to an overall electronic potential, which is stored energy. The QM neural function Ψ_j, here postulated to describe the state of consciousness linked to the perceived object j, belongs to a corresponding energy state ω_j. If the brain perceives and encodes two objects, say, the red and the blue shirt, we have two distinct energy states ω_A and ω_B, with state functions Ψ_A and Ψ_B.

The amount of energy used is contextual and circumstantial, as we deal with the human mind and not with an inanimate machine like a diffractometer! The action of mood, memories, pre-existing likes and dislikes, external influencing factors, and more, can result in emotionally different perceptions of the objects by the test person M and may lead to a diversified mental (= neural) energy accounting.

We apply the time evolution operator to equation 2, obtaining equation eq.7

$$\Phi = (e^{-i\omega(A)t}\alpha\Psi_A + e^{-i\omega(B)t}\beta\Psi_B)\,(e^{i\omega(A)t}\alpha\Psi_A + e^{i\omega(B)t}\beta\Psi_B)$$

$$= \alpha^2\Psi_A\Psi_A + \beta^2\Psi_B\Psi_B + \gamma e^{-i\omega(A)t}e^{i\omega(B)t}\Psi_A\Psi_B + \gamma e^{-i\omega(B)t}e^{i\omega(A)t}\Psi_A\Psi_B$$

$$= \alpha^2\Psi_A\Psi_A + \beta^2\Psi_B\Psi_B + \gamma e^{-i\Delta\omega t}\Psi_A\Psi_B + \gamma e^{i\Delta\omega t}\Psi_A\Psi_B$$

with

$$\gamma e^{-i\Delta\omega t}\Psi_A\Psi_B + \gamma e^{i\Delta\omega t}\Psi_A\Psi_B = 2\gamma\Psi_A\Psi_B\cos\Delta\omega t$$

and in analogy to eqs.6, we want $\int \Phi\, dV = 1$

$\int(\alpha^2\Psi_A\Psi_A + \beta^2\Psi_B\Psi_B + \gamma\, \Psi_A\Psi_B \cos\Delta\omega t\,)\, dV = 1$ (with the 2 absorbed in γ)

$$= \alpha^2 + \beta^2 + \gamma \cos\Delta\omega t \int \Psi_A\Psi_B\, dV = 1$$

$$= \alpha^2 + \beta^2 + \gamma \cos\Delta\omega t = 1 \quad \text{eq.7}$$

The constant $<\Psi_A | \Psi_B>$ can be absorbed in γ, keeping in mind that Ψ_A and Ψ_B are not time-dependent. At any time *t*, eq.7 *must* hold, and as γ is now time-dependent, also α^2 and β^2 *must implicitly* be.

We now have $\Delta\omega = (E_B - E_A)/h$ expressing the energy difference of the two neurological state functions in the *EE,* and three implicitly time-dependent probability parameters $\alpha, \beta, \gamma \Rightarrow \alpha(t), \beta(t), \gamma(t)$, because the weights of the mental states expressed by Ψ_A and Ψ_B can and will change in time, as shown here below.

5. Psychological Preferences

Eq.7 shows the time dependence of the interaction term. We identify three phases in the *EE* concerning the decision-making process. In the very first phase of our *EE* (approx. 0.1- 0.2 sec), two objects, A and B, are visually exposed to test person M. M will perceive, recognize, and categorize A and B (this is a blue shirt, this is a red shirt) before starting the mental choice procedure. Immediately after, in a second phase, the actual mental work of *decision-making about which shirt to select,* starts at *t=0*. At this point in time, the interaction term is dominant and contains ***all*** probability density because no judgment step has been accomplished yet. Thus, uncertainty and hesitation are maximal (at $t=0$ we have $\Phi = 1 = \gamma_{max}$ *and* $\alpha,\beta = 0$). A moment later, at t_{later}, M's mind starts to untie the entanglement because his natural, pre-existing preferences start to act. For example, M's personal color preferences may be "*first preferred color is blue, then red with approximate preference weights 3:1*". This means that upon forming his judgment about which shirt to buy, M will start favoring the blue shirt over the red one in a 3:1 psychological preference pattern. These weights start now to be manifested in the inflation of coefficients α^2 and β^2 while γ_{max} deflates to γ_{later} (see Fig.3).

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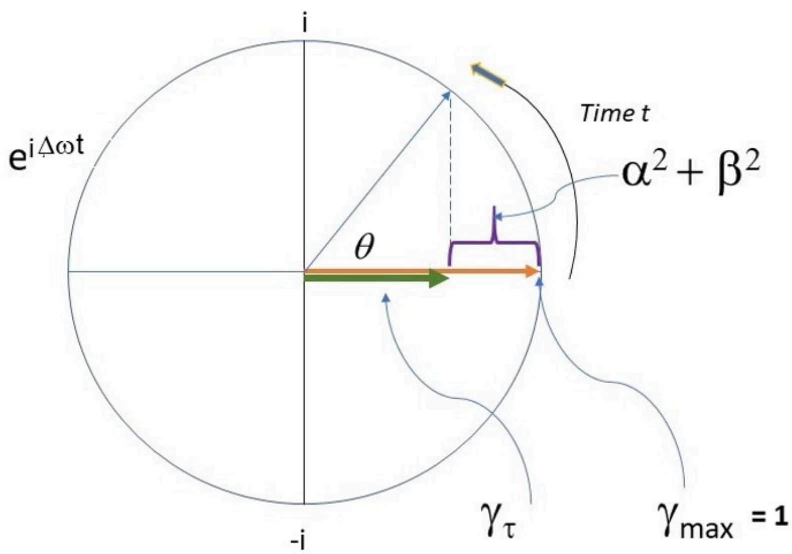

Fig. 3. Rotation in an Euler plane. The real part of $e^{-i\Delta\omega t}$, that is $cos\Delta\omega t$, causes the modulating of γ_{max} over time. The shrinking of γ_{max} to a smaller $\gamma\tau$ allows the increase of the two individual probability terms α^2 and β^2 . The sum of γ_τ, α^2 and β^2 must be always 1 (100% probability)

Formally, this is represented by the time evolution operator acting on γ . When operator ***T*** starts to act with the flow of time, the rotation diminishes the γ part, and the importance of α^2, β^2 increases accordingly in sync. This keeps the requirement of ($\alpha^2 + \beta^2 + \gamma\ cos\Delta\omega t = 1$) valid at all times. The decrease of γ will reach a point where the probabilities α^2 and β^2 may become equal to γ itself, and then grow even larger. Now the probability of either A or B being chosen is larger than the probability of being in an undecided state of mind. We can understand α^2 and β^2 as *weighted stimuli* or *signal amplitudes* sent to the neural network where the choice process is underway. If a specific signal is strong enough and the voltage reaches a *threshold,* it triggers the neuron's action potential. At this decisive point ($t = t_{choice}$), the ensemble of neurons avalanches, they all fire, and a choice is made.

However, there is no way by which this, and *any* other known theory, can indicate which signal, α^2 or β^2, grows first to become dominant and determine the result!

6. The Speed of Decision Making

The larger the difference in the two potentials ω_A and ω_B is, the faster the rotation and the deflation of the interaction term (γ deflation speed ~ $cos\Delta\omega t$). Example 1: If two objects are equal, then $E_A = E_B$ and $\Delta\omega$ is zero. The interaction term does not change with time; the rotation speed is zero within a homeostatic situation. Psychologically, this means that the test person, who must decide between equal objects A and A, cannot decide within a finite time, as there is *no discriminant* information to drive a selection. This is equivalent in the *DSE* to having both slits identically placed, that is, they are one and the same slit. The experiment itself has collapsed into redundant information, and speaking of choice is now meaningless! Here we have a nice isomorphism between the *DSE* and the *EE* test.

Example 2: Suppose a vegan, who dislikes meat, is confronted with a grilled T-bone steak and a mixed vegetables dish. The neural states $\alpha\Psi_{SALAD}$ and $\beta\Psi_{STEAK}$ correspond to two very different energy levels, and a large $\Delta\omega$ will cause a fast rotation, where γ deflates rapidly and the highest probability density flows into α^2 ($\alpha^2 >> \beta^2 > \gamma$).

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Example 3: A meat lover looks at chicken wings and pork ribs. These two dishes are both from the grill and have more flavor and texture similarities than the options in example 2. Thus, $\Delta\omega$ will be smaller due to closer energy levels, and the dish selection may evolve at a slower pace, with the customer showing some hesitating behavior.

7. Perturbations

The initial natural preferences of M may undergo modifications along the selection process due to contextual and circumstantial perturbations of varying magnitude. A "pure" preference parameter, like "*blue is my color of choice*," can be altered by a sudden circumstantial event and lose its original ranking (e.g., $\alpha^2 = 3$). Suppose that M is ready to pick the blue shirt and suddenly a red exotic sports car dashes by the fashion shop. M gets a sudden psychological input that tells "*red is sexy and fast*! ". At this point, the pure natural preference "blue" gets blindsided by a perturbation δ_{red}, that may change the natural predominance of *blue* because

$$\alpha_{perturb}\Psi_A^{perturb} \neq \alpha_{nat.pref}\Psi_A^{nat.pref}$$

We have now $\alpha_{perturb} = \alpha_{nat.pref.} + \delta_{red}$, or explicitly in this example $\alpha_{perturb} = \alpha_{blue} + \delta_{red}$,

which may modify the selection result. The role of such perturbations is now analyzed formally. How can the state of initial total uncertainty ($t=0,\ \gamma = \gamma_{max}$) break down and the generated probability density flow into the individual density factors α^2, β^2? At first, random perturbations $\delta\Psi$ are introduced into eq.7 to modify the initial total entanglement

$$\gamma_{max}\Psi_A\Psi_B = 1 \quad ; \quad (\alpha^2, \beta^2 = 0)$$

and we define a perturbed function Ψ_ι^P as

$$\Psi_\iota^P = \Psi_\iota + \delta\Psi_\kappa$$

$$\Phi = \gamma_{max}\Psi_A\Psi_B \text{ ———}\delta\text{---> } \gamma_p\Psi_A^P\Psi_B^P = (\alpha\Psi_A + \delta_B\Psi_B)(\beta\Psi_B + \delta_A\Psi_A)$$

$$= \gamma\Psi_A\Psi_B + \delta_A\alpha\Psi_A\Psi_A + \delta_B\beta\Psi_B\Psi_B + \delta_A\delta_B\Psi_A\Psi_B \quad \text{eq.8}$$

The new terms $\delta\alpha\Psi_A\Psi_A$ and $\delta\beta\Psi_B\Psi_B$ are *seeds* generating *individual*, *decoupled* probability densities for A and B. As δ_A and δ_B are free parameters, we can write $\delta_A = \alpha,\ \delta_B = \beta$ leading to

$$\langle\Phi\rangle = \alpha^2 + \beta^2 + \gamma_p\langle\Psi_A\Psi_B\rangle \quad \text{eq.8a}$$

(with the last very small term $\delta_A\delta_B\Psi_A\Psi_B$ adding to the first), which is isomorph to eq.5.

Conservation of total probability in eq.8 has $\gamma_p < \gamma_{max}$, as some probability is now carried by the perturbation terms $\delta_A\alpha,\ \delta_B\beta$. We recognize now that an initial complete mental entanglement state, $\gamma_{max}\Psi_A\Psi_B$, expressing total uncertainty, partially decays spontaneously into the two decoupled, individual mental states Ψ_A and Ψ_B, by the random action of mentally endogenous (e.g., flashes of memories) or exogenous (e.g., the visual stimulus of the red sports car) perturbations δ. Comparison of eq. 8a with eq.7 shows

$$\gamma_p\Psi_A\Psi_B = \gamma\Psi_A\Psi_B \cos\Delta\omega t \text{ --> } \gamma_p = \gamma\ re(e^{i\Delta\omega t}) = \gamma\cos\Delta\omega t$$
eq.9

meaning that the random action of perturbations (conscious or unconscious, both are carried out by chemical agents) during the choice *EE* is equivalent to the *flow of time* eroding the initial state of total uncertainty.

We have the time-dependent eq.10

$$\Phi = \gamma\Psi_A\Psi_B\cos\Delta\omega t + \delta_A\alpha\Psi_A\Psi_A + \delta_B\beta\Psi_B\Psi_B$$

$$\Phi = \gamma_p\Psi_A\Psi_B + \alpha^2\Psi_A\Psi_A + \beta^2\Psi_B\Psi_B \quad \text{eq.10}$$

with $\delta_A = \alpha,\ \delta_B = \beta$ *and* $\gamma_p = \gamma_{max}$ *at* $t = 0$ (eq.7 *!*)

showing the growth of α^2, β^2 probabilities depending on the change of γ with time: *perturbations are psychologically necessary to start the rotation*! This makes sense, as the effect of any perturbation to manifest itself takes some finite amount of time.

At $t_0 = 0,\ \delta\alpha\Psi_A\Psi_A + \delta\beta\Psi_B\Psi_B$ is, per definition, equal to zero, as the perturbations have not acted yet. For a subsequent time t_{later}, the γ_{max} term has decreased at a certain rate (~$\Delta\omega$), and the two pure state terms inflate because δ manifests itself in $\alpha^2,\ \beta^2$ in a way that the normalization postulate $\alpha^2 + \beta^2 + \gamma\cos\Delta\omega t = 1$ holds at all times. Explicitly, if we consider a starting time $t = t_0 = 0$ for the choice *EE*, and a later time t_{later}, we write

$$\gamma_{max}(\cos\Delta\omega t_0 - \cos\Delta\omega t_{later})\Psi_A\Psi_B = (\gamma_{max} - \gamma_{later})\Psi_A\Psi_B$$

$$= \delta_A\alpha\Psi_A\Psi_A + \delta_B\beta\Psi_B\Psi_B$$

$$= \alpha^2\Psi_A\Psi_A + \beta^2\Psi_B\Psi_B \quad \text{eq.11a}$$

or equivalently

$$\Delta\gamma_t \rightarrow 1 - \gamma_{max}\cos\Delta\omega t_{later} \rightarrow \alpha^2 + \beta^2 \quad \text{eq.11b}$$

meaning simply that the difference in time between an initial state of uncertainty and a later smaller state of uncertainty is reflected in the individual weights α^2, β^2 of the two states of mind.

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Eqs.11a, b nicely show the formal link between the deflation of a state of uncertainty by a rotation of Φ in an Euler plane (radius = 1), the resulting inflation of two additional components α^2, β^2 , its speed of decay depending on $\Delta\omega$ and the interesting connection and equivalence to psychological perturbations δ (eq.11a).

8. Decision Making

The action of a unitary time evolution operator $\boldsymbol{T}$ on Φ generates a rotated probability density distribution Φ' preserving the norm (the unit length of $r = \gamma_{max} = 1$!): $\boldsymbol{T}\Phi \dashrightarrow \Phi'$. Repeated smooth incremental rotations lead to a point $t_{choice} = \tau$ where a decision is made (α^2_τ or $\beta^2_\tau > \gamma_\tau$). The probability density matrices $\boldsymbol{P}_i$ may evolve along the rotation processes from to $t = 0$, to $t_1, t_{2....}$to $\tau = t_{choice}$,

as (scheme 1)

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$$P_o = \begin{pmatrix} 0 & \gamma_{max} \\ \gamma_{max} & 0 \end{pmatrix} \xrightarrow{T_1} \begin{pmatrix} \alpha^2_1 & \gamma_1 \\ \gamma_1 & \beta^2_1 \end{pmatrix} \xrightarrow{T_2, T_3, \ldots\ldots T_{choice}} P_\tau = \begin{pmatrix} \alpha_\tau^2 & \gamma_\tau \\ \gamma_\tau & \beta_\tau^2 \end{pmatrix}$$

Scheme 1 An initial probability matrix, P_o, of a choice experiment has all probability in the entanglement term γ_{max}.The action of the time evolution operator ***T*** at later times $t_1, t_2, \ldots t_{choice}$ is the mechanism to inflate the probability terms for A and B, until a neurochemical threshold is reached where a decision is made at t_{choice}

As for $\boldsymbol{P_o}$ at $t = 0$ (initial total uncertainty of the mental state), the $\boldsymbol{P_j}$ matrices following the reiterated action of $\boldsymbol{T_j}$ during small time intervals are never diagonal, as the interaction term would be zero in such a case, meaning that A and B would pertain now to independent eigenvalues (with $0 \leq \alpha^2, \beta^2 \leq 1$ and $\gamma = 0$)! Independent eigenvalues in a diagonal ***P*** matrix would mean, at the neurological level, that the perception of one object is *independent* from the perception of the other. But this entails *canceling out* the simultaneous cognition, or awareness, of the other! This is equivalent to a DSE turned into two independent *single slit experiments* (!), where, if the electron passes through, say, slit A only (choice eigenvalue = A), then slit B *must* be closed, that is, non-existent for the electron. Because, if both were open and available (a choice is now feasible), interference would arise at once, as we well know! This is a fact *that contrasts with life experience in an EE*, where A and B are *always simul- taneously present* in the cognitive process of the mind. If, for example, M selects the blue shirt, this does not mean that the red shirt is instantly cancelled out of his conscious perception! On the contrary, a residual temptation for the red shirt may very well be nudging his mind (the lasting influence of the red sports car!). This same reasoning, therefore, entails that the mere existence of state functions Ψ_A and Ψ_B in the mind *must generate* an entanglement term $\Psi_A\Psi_B$! In other words, selecting Ψ_A does not cause a deletion of Ψ_B at the neurological level (and vice-versa).

It is important to outline that the dimensionality of the cognitive selection process is preserved by the unitary (isonorm) time evolution operator ***T***. Quantum consciousness seems to differ from the QM of hardware measurements in preserving the dimensionality of S. This is absolutely necessary to continuously guarantee the existence of an interaction term, which is fundamental to make a choice possible. In other words, *only a nonzero interaction term* (= simultaneous awareness of both objects A and B) makes any choice procedure possible. This is in stark contrast with the DSE, where, after the electron has hit the photographic plate at one position eigenvalue x_i , the probabilities of *all other position eigenvalues vanish* (see Fig.4).

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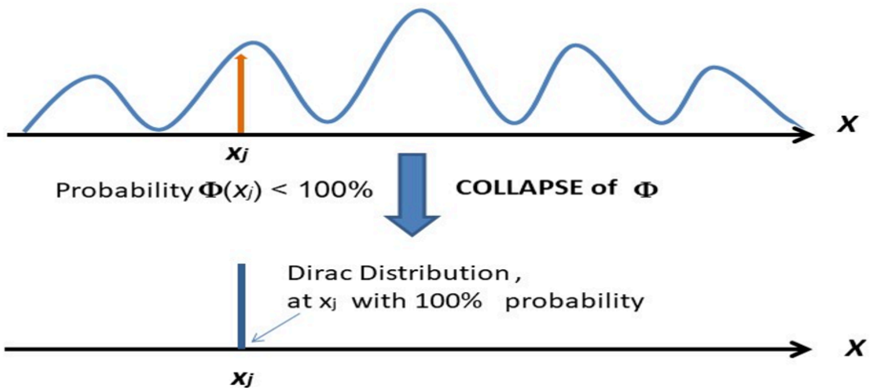

Fig. 4. Collapse of the cumulative probability density function. When a single electron, traveling as an interference wave, hits the film F at a coordinate x_i that has an initial probability $p(x_i)$<100%, it is found there after impact as a whole particle with probability 100%.

9. Change of Mind

Imagine M having chosen the blue shirt ($\alpha^2 > \beta^{\,2} > \gamma$). He is ready to pay but suddenly hesitates and says " *I changed my mind*", replaces the blue shirt, and takes the red one ($\gamma < \alpha^2 < \beta^{\,2}$). This reversible mental mechanism is only feasible, contrary to the *DSE*, because a residue of the interaction term must still be present at the neurological level. Through $\gamma e^{i\Delta\omega t}\Psi_A\Psi_B$, the probabilities α^2 , $\beta^{\,2}$ can be redefined. The *reversible thermodynamics* of isothermal neural processes (at or close to equilibrium) go hand-in-hand with the reversible operator T and allow, by infinitesimal displacements of temperature and molecular concentrations, a transitory re-inflation of γ ($\gamma > \alpha^2, \beta^{\,2}$) with now diminishing α^2. Hereafter, a subsequent inflation of $\beta^{\,2}$ can follow ($\gamma < \alpha^2 < \beta^{\,2}$), which may manifest itself in the purchase of the red shirt. The phases of Ψ_A and Ψ_B may not change with respect to each other, but their local amplitude, or intensity, does, which is the magnitude of α^2, β^2. The actual occurrence of this change of mind and its probability are obviously an individual psychological matter and cannot be quantitatively calculated!

10. Discussion

The entanglement term provides a sort of "tank" for a probability potential. It connects two separate states, A and B, and contains parts of both. It can move probability density between A and B. To the organic chemist, the concept of a "bonding orbital" is familiar. In a σ-bond between atoms A and B, the distribution of the two electrons can be described as a superposition of three states, where electrons are shifted from one atom to the other via resonance:

$\Psi_\sigma = \alpha\psi(A^-B^+) + \beta\psi(A^+B^-) + \gamma\psi(AB)$. The quantitative expression for $\gamma\psi(AB)$ is called the "overlap integral", $<\psi_A|\psi_B>$. It is identical to the interaction term in our *NQS* treatment. Without an overlap term, there would be no molecules, only disconnected atoms in the Universe. We would not exist. The psychological equivalent would be a state Ω where two states of mind overlap. But it is this overlap that connects the otherwise separate states. Ω has the vital role of allowing judgement and evaluation in the mind. Without it, human decisions could be taken in a detrimental and irreversible manner. Ω allows danger management, compromise, strategic moves, and survival. Neurochemistry has a central role. Take an initially tranquil person having a lot of drinks in a bar. Alcohol itself does not necessarily cause aggression. It increases the amount of aggression a person feels when provoked. Therefore, when a person feels challenged, rather than ignore that behavior, he responds in an aggressive manner. He can end up limited in the ability to have restraint: the response may be a 100%, one-way violent choice! The interaction term is zero in such a case. Interestingly, in various cultural areas (German, Anglo-Saxon, Latin), one speaks of *blind rage, blinde Wut, furia ciega, furia cieca.* The accent is on *blind.* This underlines what was

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said before: only *one* choice is perceived in a state of mental blindness. The other choice, relaxing and renouncing violence, is utterly non-existent at the conscious level, that is $\alpha^2_{VIOLENCE} = 100\%$, $\beta_{RELAX} = 0\%$ and of course $\gamma = 0\%$! It is the non-vanishing interference, or entanglement, or overlap, call $\gamma\Psi_A\Psi_B$ in any way you want, that seems to be in control and separates a human mind from a machine. Here is also where a hypothetical QM mind differs from a hardware QM measurement, where the act of making a decision (*the measurement*) results in an irreversible outcome with 100% probability (the clash of an electron on a film, for example). In the mind of a sentient (conscious) being, the probabilities of alternative outcomes are not vanishing. It is well known that quantum superpositions are very unstable. In quantum computers, the existence of such states requires temperatures near zero Kelvin. Obviously, our brain works at physiological temperatures, and therefore the criticism that such neural superpositions will be extremely short-lived is understandable. This effect of degradation of the superposition state is called *decoherence* (to the organic chemist, remember spin-lattice relaxation in ^{1}H-NMR? Same thing!). Now, as we don't know *everything* about our brain, there might be some yet unknown mechanism that allows QM superpositions to last longer than expected. Or, as Descartes said, *cogito, ergo sum!,* we have to acknowledge that we do have an individual conscience. For the more spiritually oriented reader, maybe a *soul.* Science cannot define what the fabric, or matrix, of the conscience is. However, inside this model of NQS, it would have to be capable of stabilizing the hypothetical neural quantum superpositions and stabilizing them for a time long enough for us to make decisions.

The basic question of *what* it is that a quantum-mechanical-like model is describing is left unanswered. If consciousness is a single manifestation of a *monistic* structure *per se*, then, when an ethanol molecule binds to GABA receptors in the brain, the established dipole-dipole interaction field (obeying QM laws!) should already be the altered state of consciousness itself! That is *holism*, the electromagnetic field *is* consciousness. If *dualism* is invoked, neurochemical agents and their fields must interact with something separate, an embossed *consciousness field*. The consciousness field should have the property of being impervious and robust against decoherence phenomena, which make macroscopic superpositions of quantum states very unstable due to environmental electromagnetic noise. But this field would need exchange quanta to interact with the neurochemically established electromagnetic fields (photons or something entirely new?).

11. Conclusions

The *Neural Quantum Superposition* approach tentatively shows a formal isomorphism between quantum mechanics and human psychological behaviour in the dynamics of making a choice and in the change of mind. Starting from the principle of superposition of quantum states, a time evolution operator is introduced to model the probabilities of possible choices. *NQS* describes the effect of perturbations influencing the outcome of selection processes. The unitary time evolution operator models the mental modifications of preferences and the subsequent change of mind. *The here presented approach does not prove anything.* The isomorphism discussed may very well be a pure coincidence with no deeper meaning. Or maybe not.

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11. in ref (1) it was proven that a Boolean treatment of the *DSE* is inadequate.
12. Technically, to determine n^2 as the normalization constant, a finite space *V* to limit the integration boundaries could be defined.
13. γ is not the simple product of α and β, as these quantities are, contrary to a hard-wired real experiment, like the DSE, subject to variations depending on time and mental state. Thus, γ introduces a necessary degree of freedom.

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