Neural Quantum Superposition
and the Change of Mind

KEYWORDS: Quantum superposition, quantum consciousness, decision making, change of mind, time evolution operator, double slit experiment, mathematical psychology

ABSTRACT: 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.

1. Introduction
In a recent article [1] the role of the logical and intuitive mind (elements of the 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 to 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 than S is false (as he contradicts it by saying the truth), if he lies however then S if 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 the human consciousness, which can be formally described by a superposition of the two antinomic states, as

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State-of-mind(S) = \psi(True) + \psi(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 manifests patterns of behavior not coherent with classical statistics (the so-called sure thing). Imagine an opinion poll with the question “...is our local governor doing a good job?”. Say, 34% of the interviewed people answer YES, 45% answer NO, and the remaining 21% says NOT SURE. They seem to float in a mental state of irresolution and uncertainty, where the two states YES, NO are mixed. Again, their state of mind could, inside of this QM-like Ansatz, be represented by a state of superposition \( \Sigma \) 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 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 to try to model the dynamics of the mind utilizing, as a tentative Arbeitshyphothese, 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 \( \Psi_A \) and \( \Psi_B \) within a finite space \( V \).

![Fig.1a](image1.png) ![Fig.1b](image2.png)

**Fig.1a,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 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 probability \( \phi(A) \) and \( \phi(B) \) of finding the electron on a point of impact, POI, \( x_i \) or \( x_j \) on F behind slit A or slit B is 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 \( \Phi \) 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).
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 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 $\Phi$, 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 for 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 $\Sigma$: formally the electron perceives both slits at the same time

$$\Sigma = a\Psi_A + b\Psi_B \quad \text{eq.1}$$

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
\[ F = n^2 (\Psi_A + \Psi_B)(\Psi_A + \Psi_B)^* \quad \text{eq.}2 \quad (\ast \text{meaning complex conjugate}) \]

\[ F = n^2 (\Psi_A^* \Psi_B + \Psi_B^* \Psi_B + \Psi_B \Psi_A + \Psi_A \Psi_B^* ) \quad \text{eq.}3 \]

and the QM normalization postulate, for having 100% probability inside the finite \( V \) in which \( \Phi \) acts, requires
\[ \int \Phi \, dV = 1 \quad \text{eq.}4 \]

Expressing the electron path functions simply with plane waves
\[ \Psi_A = e^{-i(kx(A) - \omega t)} \quad \text{and} \quad \Psi_B = e^{-i(kx(B) - \omega t)} \]

we obtain
\[
\Phi = n^2 \left( e^{-i(kx(A) - \omega t)} + e^{-i(kx(B) - \omega t)} \right) \left( e^{i(kx(A) - \omega t)} + e^{i(kx(B) - \omega t)} \right)
\]
\[
\Phi = n^2 \left( e^0 + e^0 + e^{-i(kx(A) - \omega t)} e^{i(kx(B) - \omega t)} + e^{i(kx(B) - \omega t)} e^{i(kx(A) - \omega t)} \right)
\]

and because paths A and B are isoenergetic (\( \omega(A) = \omega(B) \)) we have
\[
\Phi = n^2 \left( 1 + 1 + e^{-ikx(A)} e^{ikx(B)} + e^{-ikx(B)} e^{ikx(A)} \right)
\]
\[
\Phi = n^2 \left( 1 + 1 + e^{-ikx(A)+ikx(B)} + e^{ikx(B)+ikx(A)} \right)
\]
\[
\Phi = n^2 \left( 1 + 1 + e^{ik\Delta x} + e^{-ik\Delta x} \right)
\]
\[
e^{ik\Delta x} + e^{-ik\Delta x} = (\cos k\Delta x + is\sin k\Delta x) + (\cos k\Delta x - is\sin k\Delta x) = 2\cos k\Delta x
\]

with \( \Delta x \) 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)
\[
\int \Phi \, dV = \int n^2 \left( 1 + 1 + 2\cos k\Delta x \right) \, dV = 1 \quad \text{and with} \quad 2\cos k\Delta x = \gamma
\]
\[
\int \Phi \, dV = n^2 \int \left( 1 + 1 + \gamma \right) \, dV = 1 \quad \text{eq.5}
\]

As plane waves are not square-integrable and thus not normalizable in the beginning we can only say that \( <\Phi> \sim \int_V \Phi \, dV \). But this is irrelevant for our discussion, the point is the existence of a nonlinear term in eq.3, manifest as \( \gamma \) 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 $\gamma$ is a value determined also by the specific experiment geometry. It is, as 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 would be the same, (when the distance between A and B becomes zero there is only one path $k$) then $\psi_A = \psi_B = \psi_k$ and the interaction term would become $\psi_k^2$ and so $\phi = \psi_k^2$. 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°). 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 the 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 recognizing 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 $\psi_A, \psi_B$ being norm-1 real functions, as found in modeling an “electron in a box”. We simply assume that $\psi_A, \psi_B$ 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 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 now formally represent the constellations \( f(N_A) \) and \( f(N_B) \) as QM state functions \( \Psi_A \) and \( \Psi_B \) during an EE. \( \Psi_A \) and \( \Psi_B \) describe the effect of \( f(N_A) \) and of \( f(N_B) \) on consciousness.

A, B (real objects) \( \rightarrow \) transformation into \( f(N_A), f(N_B) \) (neurochemistry) \( \rightarrow \) representation by \( \Psi_A, \Psi_B \) (QM mathematics)

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

\[
\Sigma = \alpha \Psi_A + \beta \Psi_B \quad (\alpha, \beta \text{ are now general parameters, no longer constants!})
\]

If we assume in our NQS Arbeitshypothese that QM rules at 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!

The normalization postulate again requires eq.5, with \( <\Psi_A|\Psi_B> \) being the correlation coefficient, which is close to 1 when \( \Psi_A, \Psi_B \) 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 \( \Psi_A \) and \( \Psi_B \) 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 \( \gamma \))

\[
\alpha^2 + \beta^2 + \gamma = 1 \quad \text{eq.6b}
\]
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 \( \omega \) is a frequency linked to the energy of the system by \( \omega = E / \hbar \)

\[
T = e^{-i\omega t}
\]

that acts on a wavefunction and models the forward action of time on \( \Psi \)

\[
\Psi_t = T\Psi
\]

For the probability density to be conserved, \( T \) must be unitary

\[
T^{-1}T = 1 \quad \text{and therefore} \quad <\Psi_t|\Psi_t^*> = <\Psi|T^{-1}T|\Psi>
\]

The operator \( T \) 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 \( x \) :

\[
e^{ix} = \cos x + isinx
\]

The radius \( r \) of the Euler circle is taken as 1, and rotates counterclockwise by an angle \( \theta \). The initial moment sees \( r = r_{\text{max}} = 1 \), and the projection of \( r \) onto the real axis after some rotation gives rise to a \( \gamma_t \). The difference between 1 and \( \gamma_t \) is contained in the two coefficients \( \alpha^2 \) and \( \beta^2 \). The speed of rotation is determined by \( \omega \). Where does an energy term \( \omega = E / \hbar \) 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 \( \Psi_j \), here postulated to describe the state of consciousness linked to the perceived object \( j \), belongs to a corresponding energy state \( \omega_j \). If the brain perceives and encodes two objects, say, the red and the blue shirt, we have two distinct energy states \( \omega_A \) and \( \omega_B \), with state functions \( \Psi_A \) and \( \Psi_B \).

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

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

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

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 \( \int_V \Phi \, dV = 1 \)

\[ \int (\alpha^2 \Psi_A \Psi_A + \beta^2 \Psi_B \Psi_B + \gamma \Psi_A \Psi_B \cos \Delta \omega t) \, dV = 1 \]

(with the 2 absorbed in \( \gamma \))

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

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

The constant \( <\Psi_A|\Psi_B> \) can be absorbed in \( \gamma \), keeping in mind that \( \Psi_A \) and \( \Psi_B \) are not time-dependent. At any time \( t \) eq. 7 must hold and as \( \gamma \) is now time-dependent also \( \alpha^2 \) and \( \beta^2 \) must implicitly be.

We now have \( \Delta \omega = (E_B - E_A)/\hbar \) 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 \( \Psi_A \) and \( \Psi_B \) 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 judgement step has been accomplished yet. Thus, uncertainty and hesitation are maximal (at \( t=0 \) we have \( \Phi = 1= \gamma_{\text{max}} \) and \( \alpha, \beta =0 \) ). A moment later, at \( t_{\text{later}} \), 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 judgement 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 \( \alpha^2 \) and \( \beta^2 \) while \( \gamma_{\text{max}} \) deflates to \( \gamma_{\text{later}} \) (see Fig.3).
Fig. 3 Rotation in an Euler plane. The real part of $e^{i\Delta\omega t}$, that is $\cos\Delta\omega t$, causes the moduling of $\gamma_{\text{max}}$ over time. The shrinking of $\gamma_{\text{max}}$ to a smaller $\gamma_t$ allows the increase of the two individual probability terms $\alpha^2$ and $\beta^2$. The sum of $\gamma_t$, $\alpha^2$ and $\beta^2$ must be always 1 (100% probability).

Formally, this is represented by the time evolution operator acting on $\gamma$. When operator $T$ starts to act with the flow of time, the rotation diminishes the $\gamma$ part, and the importance of $\alpha^2$, $\beta^2$ increases accordingly in sync. This keeps the requirement of $(\alpha^2 + \beta^2 + \gamma \cos \Delta\omega t = 1)$ valid all time. The decrease of $\gamma$ will reach a point where the probabilities $\alpha^2$ and $\beta^2$ may become equal to $\gamma$ itself, and then grow even larger. Now the probability of either A or B to be chosen is larger than the probability of being in an undecided state of mind. We can understand $\alpha^2$ and $\beta^2$ 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 ($t = t_{\text{choice}}$), 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, $\alpha^2$ or $\beta^2$, grows first to become dominant and determine the result!

6. The Speed of Decision Making

The larger the difference in the two potentials $\omega_A$ and $\omega_B$ is, the faster is the rotation and the deflation of the interaction term ($\gamma$ deflation speed $\sim \cos \Delta\omega t$). 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, rotation speed is zero within a homeostatic situation. Psychologically this means that the test person,
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 sport 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 \( \delta_{\text{red}} \), that may change the natural predominance of blue because

\[
\alpha_{\text{perturb}} \Psi_A^{\text{perturb}} \neq \alpha_{\text{nat.pref}} \Psi_A^{\text{nat.pref}}
\]

We have now \( \alpha_{\text{perturb}} = \alpha_{\text{nat.pref}} + \delta_{\text{red}} \), or explicitly in this example \( \alpha_{\text{perturb}} = \alpha_{\text{blue}} + \delta_{\text{red}} \), which may modify the selection result. The role of such perturbations is now analyzed formally. How can the state of initial total uncertainty (\( t=0, \gamma = \gamma_{\text{max}} \)) break down and the generated probability density flow into the individual density factors \( \alpha^2, \beta^2 \)? At first, random perturbations \( \delta \Psi \) are introduced into eq.7 to modify the initial total entanglement

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

and we define a perturbed function \( \Psi^P \) as

\[
\Psi^P = \Psi + \delta \Psi
\]

\[
\Phi = \gamma_{\text{max}} \Psi_A \Psi_B \Rightarrow \gamma_{\text{P}} \Psi_A^P \Psi_B^P = (\alpha \Psi_A + \delta_A \Psi_A)(\beta \Psi_B + \delta_B \Psi_B)
\]

\[
= \gamma \Psi_A \Psi_B + \alpha \delta_A \Psi_A \Psi_B + \beta \delta_B \Psi_B \Psi_A + \delta_A \delta_B \Psi_A \Psi_B
\]

eq.8

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

\[
<\Phi> = \alpha^2 + \beta^2 + \gamma_{\text{P}} <\Psi_A \Psi_B> \quad \text{eq.8a}
\]

(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 $\gamma_p < \gamma_{\text{max}}$, 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, $\gamma_{\text{max}} \Psi_A \Psi_B$, expressing total uncertainty, partially decays spontaneously into the two decoupled, individual mental states $\Psi_A$ and $\Psi_B$, 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 $\delta$. Comparison of eq. 8a with eq.7 shows

$$\gamma_p \Psi_A \Psi_B = \gamma \Psi_A \Psi_B \cos \Delta \omega t \quad \rightarrow \quad \gamma_p = \gamma \Re(e^{i\Delta \omega t}) = \gamma \cos \Delta \omega t$$

meaning that the random action of perturbations (conscious or unconscious, both are carried out by chemical agents) during the choice $EE$ are 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 $\gamma_p = \gamma_{\text{max}}$ at $t = 0$ (eq.7 !)

showing the growth of $\alpha^2$, $\beta^2$ probabilities depending on the change of $\gamma$ 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 zero, as the perturbations have not acted yet. For a subsequent time $t_{\text{later}}$ the $\gamma_{\text{max}}$ term has decreased at a certain rate ($\sim \Delta \omega$) and the two pure state terms inflate because $\delta$ 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 all time. Explicitly, if we consider a starting time $t = t_0 = 0$ for the choice $EE$, and a later time $t_{\text{later}}$, we write

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

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

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

or equivalently

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

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 $\alpha^2, \beta^2$ of the two states of mind.

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

The action of a unitary time evolution operator $T$ on $\phi$ generates a rotated probability density distribution $\phi'$ preserving the norm (the unit length of $r = \gamma_{\text{max}} = 1!$): $T \phi \rightarrow \phi'$. Repeated smooth incremental rotations lead to a point $t_{\text{choice}} = \tau$ where a decision is made ($\alpha_\tau', \text{or} \beta_\tau' > \gamma_\tau$). The probability density matrices $P_i$ may evolve along the rotation processes from $t = 0$, to $t_1, t_2$... to $\tau = t_{\text{choice}}$, as (scheme 1)

$$P_o = \begin{pmatrix} 0 & \gamma_{\text{max}} \\ \gamma_{\text{max}} & 0 \end{pmatrix} \xrightarrow{T_1} \begin{pmatrix} \alpha_1 & \gamma_1 \\ \gamma_1 & \beta_1 \end{pmatrix} \xrightarrow{T_{\text{choice}}} P_\tau = \begin{pmatrix} \alpha_\tau & \gamma_\tau \\ \gamma_\tau & \beta_\tau \end{pmatrix}$$

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

As for $P_o$ at $t=0$, (initial total uncertainty of the mental state) the $P_i$ matrices following the reiterated action of $T_i$ 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 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 simultaneously 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 $\mathcal{Y}_A$ and $\mathcal{Y}_B$ in the mind must generate an entanglement term $\mathcal{Y}_A \mathcal{Y}_B$! In other words, selecting $\mathcal{Y}_A$ does not cause a deletion of $\mathcal{Y}_B$ at 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 for the existence of an interaction term, which is fundamental to make a choice possible. In other words, only an 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).

![Diagram of wave function collapse](image)

**Fig.4** Collapse of the cumulative probability density function. When a single electron, traveling as 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 he 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 be still present at neurological level. Through $\gamma e^{i\lambda t} \Psi_A \Psi_B$ the probabilities $\alpha^2, \beta^2$ can be redefined. The reversible thermodynamics of isotherm 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 $\gamma (\gamma > \alpha^2, \beta^2)$ with now diminishing $\alpha^2$. Hereafter a subsequent inflation of $\beta^2$ can follow ($\gamma < \alpha^2 < \beta^2$) which may manifests itself in the purchase of the red shirt. The phases of $\Psi_A$ and $\Psi_B$ may not change in respect to eachother, but their local amplitude, or intensity, does, which is the magnitude of $\alpha^2, \beta^2$. 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 “bonding orbital” is familiar. In a $\sigma$-bond
between atoms A and B, the distribution of the two electrons can be described as superposition of three states, where electrons are shifted from one atom to the other via resonance: 

\[ \Psi_e = \alpha \psi(A\rightarrow B) + \beta \psi(AB) + \gamma \psi(BA) \]. The quantitative expression for \( \gamma \Psi_e(AB) \) is called the “overlap integral”, \( \langle \psi | \psi_0 \rangle \). 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 \( \Omega \) where two states of mind overlap. But it is this overlap that connects the otherwise separate states. \( \Omega \) 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. \( \Omega \) allows danger management, compromise, strategic moves and survival. Neurochemistry has a central role. Take an initially tranquil person having lots 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 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 conscious level, that is \( \alpha^2 \text{VIOLENCE} = 100\%, \beta \text{RELAX} = 0\% \) and of course \( \gamma = 0\% \) ! It is the non-vanishing interference, or entanglement, or overlap, call \( \gamma \Psi_e \Psi_0 \) 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 critic 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 \( ^1\text{H}-\text{NMR} \) ? 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 spiritual 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 to stabilize the hypothetical neural quantum superpositions and stabilize 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.

REFERENCES and NOTES

(3) a) J.Gasteiger and T.Engel (Eds.) , Chemoinformatics, WILEY-VCH Verlag, Weinheim,( 2003)

   c) in 2009 the Journal of Chemoinformatics was established
(7) for a wide overview see https://en.wikipedia.org/wiki/Quantum_cognition and

(8) see for an overview https://plato.stanford.edu/entries/goedel-incompleteness/
(9) no, the trick of using a mirror does not work, guess why!
(10) a) R.Feynman et al., Feynman Lectures on Physics, Vol.3, Addison-Wesley
    pp. 1.1-1.8,(1965)
    b) for heavy particles see S.Eibeneberger et al., Physical Chemistry Chemical Physics, 15(35)14696-14700,(2013)
in ref (1) it was proven that a Boolean treatment of the DSE is inadequate.

Technically, to determine $n^2$ as the normalization constant a finite space $V$ to limit the integration boundaries could be defined.

$\gamma$ is not the simple product of $\alpha$ and $\beta$, as these quantities are, contrary to a hard-wired real experiment, like the DSE, subject to variations depending on time and mental state. Thus, $\gamma$ introduces a necessary degree of freedom.