Quantum Like Measurements in Biological Systems

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Abstract. We identify a living system as one that, in order to survive, continual measurements on its surroundings (and on itself). We also define a conceptual observer that reads and interprets the output of the measurements. In a different discipline of science, quantum measurements are also associated with an observer who interprets reality through the collapse procedure. However, this time, the interpretation has nothing to do with survival skills. Nevertheless, since both disciplines belong to the science of Nature, we suspect they obey similar rules. Indeed, we demonstrate that both measurements follow one fundamental principle: they both correspond with re-coherent processes. Applying a quantum-like model, such as that of a spin glass neural network, we describe brain activity with the Hilbert space concept in what we refer to as quantum-like measurements.

1. Introduction
A lot has been written on the distinction between inanimate and animate systems [1, 2]. That said, the fact that a long lasting animate systems must possess a survival mechanism seems to be rock solid. In other words, an animal, in response to changes in its environment, will trigger a survival mechanism, even something that consumes a large amount of resources, such as running away. Tracking changes in the environment corresponds with constant measurements conducted on the surroundings and on the animate system itself, where each measurement is translated/interpreted by the animal so as to instruct the animal what to do. Quantum mechanics introduces a conceptual observer who carries out “subjective” measurements of the environment. Mathematically speaking, selecting a particular basis of states to span the Hilbert space, the observer defines his measuring device as the sum of projection operators of his “subjective” basis of states. This device, which projects all detected data into one state out of the spanning set, provides either a real or an interpreted data result [3]. Note that by using the term “subjective observer” we define an observer that initiates the measurement in response to a change in circumstances rather than allowing spontaneous measurements, as exist in the G.R.W. theory [4]. We can hardly believe that the “biological” phrase, “subjective interpretation of an observer,” which describes the procedure of quantum measurements, is only a manner of speaking. It looks as if both quantum and biological measurements are fed from the same fundamental concept. In the next section, it will be demonstrated that this fundamental concept refers to the coherence and decoherence of states.

2. Animate systems: Conceptual description by Hilbert space
In the literature, quantum collapse is occasionally associated with decoherence of states [5]. In fact, state re-coherence or decoherence is only a matter of perspective. For the observer who
conducts the measurement, a state, not included in his subjective spanning set, appears as a superposition of the device’s eigenstates. Such a state cannot be recognized by the observer, as it does not belong to his subjective set. At the end of the measurement, the vague superposition is clarified with a collapse into one of his subjective states by a process that is recognized with the violation of coherence. On the other hand, from the perspective of an observer (or simply Nature) who is familiar with the set before measuring, the new detected state appears as a superposition of his original states. In that sense, measurements enforce the old states to be coherent. The last description demonstrates that with a re-coherence process, an observer bends Nature to adjust into one of his subjective concepts. Biological measurements are mostly processed by the nervous system, where the brain is associated with most data interpretation.

All nervous systems are composed of a network of neurons, where a neuron cell processes and transmits information by electro-pulses and chemical neurotransmitters[8, 9]. A signal that is released by a particular neurotransmitter may encourage or prevent the receiving cell from firing. These activities have been modeled by a net of up/down spins in a spin glass quantum model [10, 11]. Simulations solving the Schrödinger equation for a correlated-spins Hamiltonian exhibit steady wave functions, entangled in a pattern of all fired or all unfired cells[13]. Each one of the entangled states is composed of a superposition of the simple product of the distinguishable “neuron states.” In this sense, brain activity is described as a quantum measuring process.

Following the spin glass model, we implement the following quantum terminology: Like a series of spin-$\frac{1}{2}$ particles, we consider the separated fired/unfired neurons as the original basis of states, the intermediate activities are interpreted as the measurement re-coherence process, terminating with the subjective coherent state. Although quantum and biological measuring processes probably feed on different mechanisms, they both share common characteristics: they feed on re-coherence processes and, like the quantum collapse phenomenon, biologic measurement, in spite its complexity, must end almost instantaneously, otherwise the animal will not survive.

3. Concept generation in a 2-D Hilbert space

Suppose that we have two correlated neurons, labeled by a and b, with a set of states of distinguishable particles

\[ |0,0\rangle = |0\rangle_a |0\rangle_b, \quad |0,1\rangle = |0\rangle_a |1\rangle_b \]
\[ |1,0\rangle = |1\rangle_a |0\rangle_b, \quad |1,1\rangle = |1\rangle_a |1\rangle_b \]  (1)

where the states $|0\rangle$ and $|1\rangle$ refer to an unfired and a fired state, respectively. These two correlated spaces can be transformed into two new spaces, representing the concepts equal with the states,

\[ |=\rangle_a = \frac{1}{2} (|0\rangle_a |0\rangle_b + |1\rangle_a |1\rangle_b) \]  (2)

and the opposite with the following spanning set

\[ |\ne\rangle_a = \frac{1}{2} (|0\rangle_a |1\rangle_b + |1\rangle_a |0\rangle_b) \]  (3)

Fired or not, $|=\rangle_a$ means that both neurons are in the same state, whereas $|\ne\rangle_a$ means that they are activated in opposite manners. Note that now, in the new representation, the distinguished basis of Eq. 1 becomes undefined.

Conventional quantum measurements correspond with projection operators multiplied by the corresponding eigenvalues that stand for the measurement output. Implementing conventional algebra, the measurement output is presented by numeric eigenvalues. In Feynman’s famous Young experiment for electrons, the number of electrons that come through both slits and hit a screen location is counted. However, in order to demonstrate the electron’s particle nature, Feynman chose to present this measurement output by a click sound rather than expressing it.
by a number. Mathematically speaking, we can express Feynman’s click device as a series of projection operators, something like

$$\sum \omega_{\hat{r}_i} |\hat{r}_i\rangle \langle \hat{r}_i|,$$  \hspace{1cm} (4)

where $\hat{r}_i$ are the $2-d$ screen coordinates and $\omega_{\hat{r}_i}$ describes the click through an “eigensound.” Indeed, presenting a measuring device by means of projection operators allows us to symbolize the eigenvalues as strings, clicks, and so on. It is only the fact that all scientific works and studies must be expressed by means of written symbols that prevents us expressing the “eigenoutput” in an unwritable manner. Going back to our toy model, suppose that our system is insensitive to the $\pm$-phases. The simplest way of representing a measuring device is with the eigenstrings $\prime\prime =''$ and $\prime\prime \neq''$, so that

$$M_{x,y} = '' ='' \{\pm\} \langle\pm| + |\pm\rangle \langle\pm| \} +$$

$$+'' \neq'' \{\pm\} \langle\pm| + |\pm\rangle \langle\pm| \}.$$ \hspace{1cm} (5)

4. Concept Generation in the brain

Biological measurements are mostly processed by the nervous system, where the brain is associated with most data interpretation. All nervous systems are composed of a network of neurons, where a neuron cell processes and transmits information by electro-pulses and chemical neurotransmitters [8],[9]. A signal that is released by a particular neurotransmitter may encourage or prevent the receiving cell from firing. Searching for re-coherent processes we observe that the post synaptic dendrites are assemble to form a single pulse in the body cell[12] as shown in fig. 1. The whole net activity have been modeled by a net of up/down spins in a spin

![Figure 1](image-url)

Figure 1. Diagram of a neuron showing possible re-coherent process at the dendrites body cell junction. The image is taken from ref.[12]

glass quantum model [10],[11]. Back in 1974, the existence of persistent states in the brain was introduced in ref. [13]. A rigorous formulation relating a direct product of 2-D space $\mathcal{H}^2 \otimes \cdots \otimes \mathcal{H}^2$ where $\mathcal{H}^2$ represents a single neuron was reviewed in ref. 1. For the $\mathcal{H}^2 \otimes \cdots \otimes \mathcal{H}^2$ space we can define spanning sets [12]

$$|i\rangle = \sum_{j=1}^{2N} A_{i,j} |\sigma_1,\sigma_2,...,\sigma_N\rangle_j$$ \hspace{1cm} (6)

where $|\sigma_1,\sigma_2,...\sigma_N\rangle_j$ represents the $j$-state of the spin-states product $|\sigma_{1,j}\rangle|\sigma_{2,j}\rangle\cdots|\sigma_{N,j}\rangle$. the $i$ set of $A_{i,j}$ characterizes the spanning set and consequently the measuring device. Selecting a set
as expressed in eq. 6 enable us to define a projective operator that can be serve to detect the spanning set associate concepts.

5. Quantum-like measuring device

Associating the coherent activities with quantum-mechanics-like states, we can define a measuring device composed of entangled states. The primary basis is the distinguishable states basis for \( N \) neurons

\[
|I\rangle = \prod_i^{N} |\nu_i\rangle,
\]

where \( \forall i, \nu = 0, 1 \) describes a neuron’s activity and \( i = 1, 2, ..., N \) indexes the \( N \) neurons. There are \( 2^N \) \( |I\rangle \)-states. When brain activity ends, all participating neurons become coherent to form a concept. Mathematically speaking, we obtain a new basis composed of \( 2^N \)-entangled states,

\[
|\epsilon\rangle = \sum_I A_I |I\rangle
\]

We can now sum projection operators to represent the measurement

\[
M = \sum_\epsilon [M_\epsilon] |\epsilon\rangle \langle \epsilon|,
\]

where \([M_\epsilon]\) represents the output of the measurement. It can describe numerical values (eigenvalues), strings (eigenstrings), images (eigenimages), it can also trigger some senses (eigensenses). In all cases, we need an observer to read/feel/respond to the outputs.

6. Summary

We described a living system as one that conducts measurements on itself and on its surroundings in order to survive. Presenting similarities between the known quantum measurement theory and animal/phenomenological survival skills, we derived a quantum-like mathematical formalism describing processes in living systems. The fundamental concept that is common to both biological and quantum measurements is the coherence between the primary states to generate a concept. In its philosophical aspect, maybe instead of considering a world that is subject to external measurements we can consider measurements as part of Nature. In both biological and quantum measurements, we need an observer, which can also be considered as part of Nature.

In this definition, we distinguish between two types of measurements: measurements that lead to other activities, such as survival activity, and measurements with no purpose.

References

[1] F. Mosconi, T. Julou, N. Desprat, D. K. Sinha, J.-F. Allemand, V. Croquette and D. Bensimon, Nonlinearity 21 (2008) T131–T147.
[2] A. Annila and E. Kolehmainen, Journal of Systems Chemistry 6(2) (2015) DOI 10.1186/s13322-015-0008-8.
[3] Y. G. Roth, Int. J. Theor. Phys., 51 (2012).
[4] G. C. Ghirardi, A. Rimini, and T. Weber, Physical Review D, 34 (1986).
[5] S. Maximilian, Reviews of Modern Physics, 76 (4) (2005).
[6] Y. Roth, Results in Physics 7, (2017). Pages 4101-4103
[7] Mathworld.wolfram, http://mathworld.wolfram.com/YoungGirl-OldWomanIllusion.html
[8] W. Gerstner, W. M. Kistler, R. Naud and L. Paninski, Neuronal Dynamics: From single neurons to networks and models of cognition, Cambridge University Press (2014).
[9] E. R. Kandel, J. H. Schwartz, Principles of Neural Science, Fifth Edition, McGraw-Hill (2013).
[10] J. R. L. de Almeida and D. J. Thouless, Journal of Physics A: Mathematical and General 11 (5) (1978).
[11] D. J. Amit, H. Gutfreund, H. Sompolinsky, Storing Infinite Numbers of Patterns in a Spin-Glass Model of Neural Networks World Scientific, Singapore (1985)
[12] M. Schuld, I. Sinayskiy, F. Petruccione, *The quest for a Quantum Neural Network*, Quantum Information Processing, 13 (2014).
[13] W. A. Little, *Mathematical Biosciences* 19, (1974).
[14] R. P. Feynman, R. B. Leighton, and M. Sands, *The Feynman Lectures on Physics* Vol. III, Addison-Wesley, Reading, MA (1965)
[15] Jenkins, F.; White, H. (1976). *Fundamentals of Optics (4th ed.).* McGraw-Hill. ISBN 0-07-032330-5.
[16] S. Wolfram, *Reviews of Modern Physics*, 55(3), (1983).
[17] E. N. Zalta, *Stanford Encyclopedia of Philosophy*, First published(2012); substantive revision (2017)