

Is There a Quantum Origin in the Biological Memory?

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Abstract. Under the premise that all behaviors in nature have a quantum explanation, we would like to wonder if the biological memory also possesses a quantum explanation. In this work we investigate the possibility to obtain some quantum signatures that we can recognize in processes involved in the codification of data in neurons. For this purpose, we propose to use the optical criteria in order to distinguish classical and quantum time series of photon signals. Taken into account that a neuroscientist locates the memory in the synapse configuration, we conjecture that neuronal network could be more efficient if the neuronal network functioning was considered a quantum system.

1. Introduction

Think that you are in a dark room, and that you can smell the scent of your favorite dish. A lot of molecules can lead you to your objective. What is the mechanism that allows neurons to acquire memories from classical and quantum information? Molecules from the scent, photons from images and so on. This problem is very complex. There are many people in the world investigating how neurons store one single memory. Now with the rise of technological developments, the biological processes involved in several human functions can be observed at micro and nanoscale. In such way we may rephrase the question: What does a memory mean in the classical and quantum worlds? How can we transit between them? From the theory of “Relative State” of the quantum Mechanics [1], we obtain the most elemental definition of memory. This article is devoted to memory processes that could have a quantum origin. In order to accomplish this objective, in section 1 we discuss some rules that quantum memory must follow. In section 2, we introduce a short outline of the biological memory, then in section 3 we establish the difference between a classical memory and a quantum memory. In the 4th section we present a brief description of the status of storage of information in neurons. In section 5 we propose a methodology to research the possible quantum character in the memory before we conclude.

2. Memory in the quantum world

The main characteristics of a system with quantum coherence is its reversibility. One atom can absorb energy from a photon. The electronic state changes from one quantum state with a lower energy to another with a greater one. In this case, we can say that the atom has a memory



from something that comes from its environment. But this memory has a half-life close to the decay time, which represents only a few pico or nanoseconds. The description of a joint system consisting of a quantum system S and its environment is depending of its interaction. That means, on one hand that the system is capable of absorbing the interaction carriers from the environment, for example atoms in a photon reservoir where the environment consists of a bath of photons. On another hand, the interaction is dependent also on the possibility of the system S to interact with the photon bath. Then, it is necessary that the quantum system has eigenvalues corresponding to the energies of the photons in the bath. The complexity of the interaction will be dictated by the Hilbert space dimension, because the quantity of states that can be excited in the system is proportional to this dimension, the number of photons of the system and the environment interchanges increase with this space. Each photon missing in the bath field was absorbed by the system. When the average number of photons \bar{n} missing in the bath is constant over time, we can say that the system and its environment are in equilibrium. In such condition, we can say that the system is a witness of the environment. Each photon absorbed with a given energy changes the state of the system. The system can go from one eigenstate to another, passing for all possible combinations in its space. It is then easy to think that the number of states in the environment is greater than the number of states in the system. If we consider the system as a witness of the behavior of the environment, its description is only a partial description of the reality of the environment. Now what happens if the environment disappears suddenly, is that there is a very short time interval before all system states emit all photons spontaneously. The interval between the disappearance of the environment and the event in which the last photon is out of the system is the time that lasts the memory of environment in the system.

3. Memory in the classical world

If you build a very big ensemble of atoms and/or molecules, the average potential is also an ensemble of atomic quantized potentials. The average of this potentials allows energy states which separation between neighbors are virtually unpredictable. If we increase the number of components the energy levels tends to continuous: Our classical world. In a system in which we have a very big ensemble of atoms and complex molecules, the Hilbert space dimension exploits. Now the basis state of this ensemble is not longer the basis state of a single atom or molecule, then a very complicated distribution of potential energy, allows new configurations in the distribution of all its components in such a way the memory of the interactions of this system with its environment can remain longer, for a very long time and thermodynamic equilibrium where the state that we can measure with our instruments is the most probable state, over all another possibilities. One simple example comes from the quantum optics: When we send a quantum state of n inside of a Mach-Zehnder interferometer, we have $n + 1$ different interference patterns. If we are not able to separate each of them, then we will only see the average. But the average have the same pattern that the interference from one single photon [2]. This is, the more stable pattern.

3.1. The memory in a neuron

Neurons are the basic unit of the nervous system. A neuron is a specialized cell with an architectural conformation that is capable of rapid voltage changes in its membrane, which gives rise to an action potential that allows it to communicate with other cells. An action potential is generated by a sudden flow of Na ions across the respective channels in the cell membrane. When a stimulus is the most depolarizing of the membrane, the change in potential opens up the Na channels, allowing it to decrease the concentration outside of it and increase in the interior. The neuron as an object of the universe has memory, but it is a dynamic interacting

memory. One photon, one single molecule can change the average potential surrounding it, then its connectivity with neighboring neurons can change, resulting in a new memory. There are studies where the individuality of both photons and cells are fundamental in some processes like the navigation sense of birds, or photosynthesis [3], but it is not clear if one memory can be registered in only one neuron [4], or this memory requires a minimal set of neurons [5]. Because a neuron is not a computer, people are looking for the mechanism that allows one neuron to store information. In [6] it is proposed that phosphorus is the only biological element with a nuclear spin able to be used in processes of quantum information. However, other neuroscientists think that memory can be related to one or more neurons but also to the neuronal network. Instead of storing memories in a single neuron, or a minimal set of neurons, the memories can be stored in the network. This means, one memory may be associated with the connectivity of one or more neurons.

4. Quantum neuronal network

If a particular memory is located in a neuron or a set of neurons, we need to investigate how neurons have to be organized to store a memory? This question allows us to think about the configuration space available in order to store memories. If one memory may be stored in a single neuron, then the possibility of memories in the brain is dependent of the number of neurons available. But if one memory is established in a particular connection of the network, then the possibilities of storage grows exponentially. For the moment, there is no clear evidences over the storage mechanism, we can only say that spin is a very interesting candidate to explain the storage of information, while random walks (quantum random walks [7]) may be the mechanism for the neuronal network, if we are looking for quantum evidences. Spins conjecture has been cited in [6]. Here we conjecture about the advantages of memory stored in the neural network. It is well known that a quantum signal that travels a given network does not need to travel all possible paths in order to take the shorter-time path in concordance with a classical signal, but quantum signals can interfere in some pathways that are not useful. If the ions of different channels of communication have an atomic mass lower than 40 amu (Na^+ , K^+ , mainly) the question raised above means the possibility than an individual current of ions or the potential generated by themselves can be considered as the superposition of the several options built in the network. For this mass scale there are evidences of quantum paths superpositions. Arndt and coworkers [8] have shown that the interference of ^{60}C is possible. A ball of carbon atoms can obey the rules of quantum superposition when launched at an optical grid with a period near to a micrometer. Because this molecule is more or less 50 times heavier than our ions (the speed can be considered similar), and considering that the neuronal network can be modeled as a biological grating, if the network has spatial gaps of 50-100 micrometers, then, it is possible that a single ion can travel over different paths before activating a single synapse. The consequences of this possibility are very interesting. In quantum mechanics phenomena, we know that the quantum effects are hidden in superposition instead of detection. A set of ions can activate only one synapse, but determining which synapses in particular has a dependence of the superposition. Then, there is a difference between both process, this difference comes from the quantum interference, the possibility that each ion has to go along each path producing self-interference. In the theory of optical random walks, one photon that travels through a $n \times n$ beamsplitters network has only two preferential paths [9], while the probability to find it in any output port is depending on the two imposed initial conditions: the input port selection and the pathway n -phase differences among all paths.

Then, in this conception of the memory, each ion belonging to a given ion-current has the possibility to travel for several pathways, and its probability to activate a synapse depends on their initial conditions and phases in the several pathway-options. This mechanism may be very efficient, because the interference can destroy such pathways that are not appropriate for the

establishment of a new memory, or to remember it. In such case the initial conditions are related with the correlation to a particular memory, because, these conditions define the more probable paths that information must travel.

5. Quantum memory detection

In 1926, Adrian and Zotterman [10] studied the action potentials that come from neurons. They found a succession of action currents with the same form and time relationships. Most of action currents conformed to a standard size. There is a uniformity on the type of signals that keep the communication between neurons. What is very interesting is that these signals can be simulated in time and form by algorithms that take into account the electrical processes involved [11]. Apparently the quantity of ions and electrical potential associated are very well defined. This kind of uniformity in the signals represents the possibility to have quantum effects by interference in the neuronal network. If someone says that one process in particular has quantum effects, it will be considered a conjecture until the effect can be tested. Because we are conjecturing that neuronal networks may work like a quantum neuronal network, the first step to test it requires to have a criterion to measure the quantum behavior of the signals. In quantum optics, statistics of light signals is determined by the criteria of fluctuations around the average [12]. Paraphrasing Schrödinger [13], if the signals emerging from the cells have a standard deviation equal to the square root of the average in some observable, then the process involved has random behavior. Now, if the ratio between this quantity is lower than one ($f = \sigma_s/\sqrt{s}$) the signal can be considered a quantum signal, and it is possible to observe quantum effects like quantum interference. Particularly if $f \approx 1/2$ [14] the signals can be considered to have a quantum chaotic behavior.

6. Conclusions

We have made a brief description about classical and quantum memories. Regarding the possibility of the existence of quantum effects that could explain the functioning of the memory, we have theorized about the memory alike a set of memories located in the different neuronal configurations established by the interaction with the environment. We have conjectured that if the potentials that control gates and synapses are generated by currents of ions that follow a quantum criterion of number of charges, then it is possible to have quantum effects in the neuronal network, hence, in the memory. Moreover, we propose a criteria to distinguish signals with quantum signatures using the factor f in order to know if it is possible to have quantum coherence in the communication between the environment and neurons; and communication between neurons.

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