Quantum Robotics: From Theory to Experiments

Sergey Grigor'ev
Independent Researcher, Ekaterinburg, Russia
sir.grig2011@yandex.ru

Abstract

Revolutionary Hameroff-Penrose model of quantum consciousness has been recognized now. Orhestrated obgective reduction of wave function has applied quantum principles in high organized biology systems. Herbert Frochlich’s theory of biological coherence explains the ordering in such systems. Trigger mechanism of living neuron discharge also investigated as quantum effect. This opens ways for research works in applied physics and engineering in biology inspired quantum robotics.

Introduction

Hameroff-Penrose model of quantum consciousness [1, 2] widely recognized now [3, 4, 5]. The TSC2016 conference in the University of Arizona proved this [6]. Stuart Hameroff had elaborated the theory of memory storage in cell protein microtubules. Roger Penrose had suggested orhestrated objective reduction of quantum states in living cells. This is right, revolutionary idea. Herbert Frochlich's theory of biological coherence explains the ordering in living systems and the creation coherent bio-oscillations [7]. Trigger mechanism of neuron discharge investigated as quantum effect, which is similar to impulse laser generation [8]. Here we consider this problem more in detail and corresponded achievements in brain inspired neuromorphic nano-electronics.

Neural networks and nanowire neuromorphic structures

The interest to use principles of nervous system and brain for the creation devices for information processing exists since the creation of first electronic computers. The first mathematical model of living neural network was developed W. McCalloch and W. Pitts in 1943 and the design of neural network was offered. In 1949 the neurophysiologist D. Hebb studied the mechanism of function of cellular ensembles consisting of neurons. Soon F. Rosenblatt created the first neural network electronic device for recognition of images - Perseptron. Von Neumann considered neural network structure of the computer as preferable, but practically the development of computers went by realization structurally and technologically simpler binary logic on triggers.

The situation began to change at the beginning of 21st century with the development of electronic chips with permission of 10-20 nanometers that is the first approaches to the nanotechnology. The structure from crossed wires (conductors) in which each crossing forms active or passive contact [9] was offered in 2003 (figure 1). Such structure is very convenient for various applications in the nano-electronics.

The second modern direction is connected with the development of new materials for electronics. Gordon Moore in 1970 offered the technology of creation of multilevel elements of memory on materials with changing phase structure. The Hewlett Packard corporation was engaged many years in the creation of the nonlinear multilevel element of memory on the material with changing phase structure - the memristor which work is similar to work of alive synapse.

In 2009 such memory was created on the basis of semi-conductor elements from titanium dioxide and with crossed nanowires structure [10].

The group of scientists in University of California at Los Angeles and Caltech in 2006-2007 have created nano-technological memory of extremely high capacity on bistable rotaxane molecules in which the structure with crossed nanowires is also used [11]. This memory consists of many mesoscopic ensenbled bits (e-bits). Molecules in a e-bit are entangled, but e-bit in general is readable. Nevertheless, all bits represents correlated structure.

The similar decision is found in Stanford University on the basis of chalcogenide glasses [12]. It is shown that neuromorphic elements with crossed nanowires can be integrated into the processors made by MOS technology. Comparative analysis of overall performance of a brain of animal and modern computers is also provided in this article. It is shown that the best supercomputers essentially lag behind animals in the decision even the simplest problems of orientation in space.

Memristor for neuromorphic structure of the processor is created at Michigan University with the use of silver on silicon [13].

Complex Ge/Si nanowire processor with field-effect transistors was created in Harvard University. This architecture could be cascaded to realize integrated nano-processors [14].

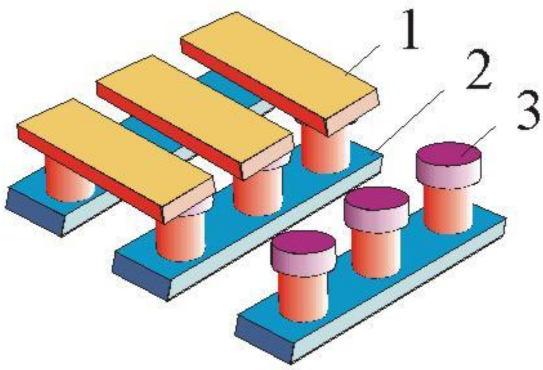

Figure 1. The example of nanowire crossbar structure of processor in classical mode: upper layer of nanowires (1); bottom layer of nanowires (2); nonlinear electroconductive elements (3).

Opto-electronics also investigates and elaborates holography devices for image recognition, and optic processors including non-linear optic circuits. Scientists hope to create all optic computers with the achievements in nano-photonics and nano-plasmonics [15].

Achievements in physics have revealed unusual properties of nano-materials, for example, quantum tunneling of Klein type in graphene [16].

Quantum informatics

There are some approaches for elaborations of quantum processors noted in LANL Roadmap for quantum informatics LA-UR-04-1778 (2004): Nuclear Magnetic Resonance; Ion Traps; Neutral Atoms in Cavity QED; Optical Circuits; Solid State Superconducting Circuits; "Unique" Qubits. Authors of this document do not exclude the possibility that further progress on various of the other proposals, including electrons on liquid helium, quantum Hall edge states, carbon tubes and balls, semiconductor nanowires, or others might make them worthy of detailed assessment at a later date.

The principle of spin processor was suggested by B.E. Kane [17]. Processors on single entangled spin quantum bits have proved in last decade to be not operational because of great number incontrollable correlations [18]. Therefore, mesoscopic quantum bits are considering now as candidates for elements of quantum processors. First of all, there are mesoscopic superconductive quantum interferometer devices (SQUID-cells) working at cryogen temperature.

Above mentioned construction with mesoscopic ensembled bits, elaborated in California University and Caltech, may be considered as the prototype of room temperature mesoscopic quantum computer.

Frohlich's concept of biological coherence.

Herbert Frohlich is famous English scientist, one of the authors of the theory of superconductors. He had considered long-range phase correlations between charged particles [7]. Those correlations could provide the order present in biological systems, superconductors, superfluid liquids, lasers.

The problem relates to non-linear dynamics. Simplest example is presented by two coupled pendulums well known in classical mechanics. The system of many coupled oscillators saturate one general frequency. Super-radiation in a cyclotron or plasma generator is similar process in engineering [19]. This process well investigated now.

Albert Einstein in 1916 had investigated spontaneous and stimulated emission and the role of collective effects in the formation of spectral lines. Many years later, R. Dicke had shown, that quantum oscillators separated in space interact via general field of radiation and the formation of super-radiation is possible. Described dipole-dipole interaction leads for phase correlation for a part of dipoles and energy of separated dipoles locally arise. An energy of dipole interaction may be expressed as:

$$P=\Sigma[(d_i)^2 / \Delta r_i \quad (1)$$

where d_i - dipole momentum (vector); Δr- a distance between dipoles.

Herbert Frohlich was a first who have considered how lattice vibrations take influence on electrons in solids. Ultrafast lattice dynamics is well investigated now. The generation of resonant hyper-acoustic and optic-acoustic oscillations (up to 10-15 THz) is possible now via intensive ($>10^{12}$ W/cm^2) femtosecond laser pulses [20].

Quantum model of trigger effect in living neuron

Herbert Frohlich's theory of biological coherence [7] predicts the possibility of coherent impulse discharge. Quantum electronics and optics give the theory of quantum generators.

Considering quantum model of neuron improves classical model of electric ionic conductivity in nerve system. Ionic conductivity is very old destination of nature, experimentally tested on warm and mollusc. Higher animals and human use more efficient mechanisms in myelined nerve fibers. High frequency waves in proteins was investigated by famous physicist A. Davidov in 1970ths [21].

Del Giudice et al [22] had applied Quantum Field Theory (QFT) for living cells system. He had shown that electric dipoles of cells generate multy-component field. This field defined by general QFT equation:

$$\Box A_\mu + M^2 A_\mu = J_\mu \quad (2)$$

where $\Box = 1/c^2\, \partial^2/\partial t^2 + \Delta$;

Δ is Laplace's operator;

A_μ is vector potential;

M is a mass of particle, which creates a field; M~0.3 kT in energy units;

J_μ is a current of particles;

μ is a dimension (μ=0,1,2,3…).

Estimated mass corresponds to optic phonons according to modern achievements in quantum electronics [23]. Thus, Del Giudice et al had developed Frohlich's theory and had revealed that generated oscillations also propagate in cells. This opens way for electro-dynamic modelling of nerve system.

High frequency wave conductivity in nerve fibers is considered in author's works [24, 25]. Wave quantum polarises membrane, consisting polar molecules, similar to photo-effect. Quantum mechanical equations for neuron function are given in the article [8] and are summarized down.

Living neuron (figure 2) works as laser with parallel pumping: many entering nerve fibers excite the membrane of neurons body containing bistable molecules; the membrane generates output impulse witch propagates in long fiber of neuron. This fiber is the elongation of neuron's body membrane. Signals propagate in fiber membranes via selective diffraction on molecular groups of lipids and polypeptides.

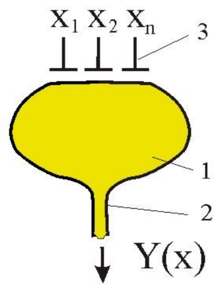

Figure 2. The scheme of living neuron: the membrane of neuron body (1), output fiber (acsone) and output signal (2), entering nerve fibers and signals (3).

Stimulated radiation is characterized by large radius of coherence due to Einstein's effect, therefore a nano-wire network is able in large number of the crossings used for coherent processing of images (up to 10^7 crossings per mm^2).

Suggested quantum mechanical model of neuron and artificial neuristor takes in account energies of inversed states E_1 and E_2 , general electric potential of aggregate U and considers the superposition of two inverted quantum states [8]:

$$\psi=\psi_1(r) \exp((-i/h)E_t\, t + \psi_2 (r) \exp((-i/h)E_2\, t \qquad (2)$$

where ψ_1, ψ_2 -are wave functions for inversed states of the system, and $E_1=E_{10}$ -U, $E_2=E_{20}$ +U because of a system is polar dielectrics, t is time. The solution of this equation is the function, which has the extremum on U:

$$S\sim[\cos(U+(E_2 -E_1) - \cos(U-(E_2 -E_1)] \qquad (3)$$

Therefore, U is action potential of living neuron known in the physiology and the threshold of excitation for artificial quantum neuristor.

A neuron makes quantum summarizing of two fuzzy sets of signals:

- entering from receptors or other neurons,
- stored in synapses before the summarizing.

If two sets sufficiently coincide, electric charge of membrane increases. Other case electric charge relaxes.

Bio-chemical reactions in living cells (ATP→ADP) provide energy for logic processes in proteins. Living nature is careful, therefore energy of living neuron is a little higher thermal one at room temperature ($kT= h\omega \sim 0.025$ eV) and external electromagnetic activity in visible band in living organisms is absent (with the exception of vision receptors, where a conformation of rodopsine molecules convert visible light to solitons). Bio-oscillations create stimulated coherence, which exists when cell is alive. Similar coherence takes place in permanent working lasers.

Molecular dynamics of organic materials including polypeptides at room temperature was investigated with X-ray and neutron diffraction methods [26]. Those investigations have shown that intensive vibrational modes exists at 150-300 cm^{-1} (4-9 THz) and rotational modes exists at 50-100 cm^{-1} (1.5-3 THz). The amplitude of atomic oscillations (displacements) in molecules is very high and reaches 0.15 nm. High anharmonicity of oscillations takes place. This type of oscillations plays fundamental role in living organisms

The structure for recognition of signals by brain is well studied, in particular, by D. Hubell and T. Wiesel, Nobel Laureates, and can be applied to creation of technical systems.

Preliminary processing will be exposed for the analysis of the image (a scaling, division into elements and classifications by types). Quantum neuristor is the best set logic device for brain inspired architecture.

The model of neuron is compatible with Hameroff-Penrose model of quantum computation in brain.

Conclusions

1. The idea of quantum consciousness, created by founders of quantum informatics, is recognized now by scientific society.
2. All proteins encode memory and take place in information processing. There are some types of biological memory similar to computers (hard memory, operational memory, local memory).
3. Living neuron is mesoscopic system, which combine quantum and classical properties. Some theories of different correlated mesoscopic systems elaborated now.
4. Achievements in the nanotechnology gave some examples for the elaboration new quantum devices, inspired by living nature and brain. Nanowire crossbar structure is suitable for a prototyping artificial quantum neuron - neuristor. Room temperature coherence may be stimulated by Frohlich's phonon oscillations. Quantum neuristor will be principal new logic element for neuromorphic net architecture for consciousness robotics.
5. Achievements in Ouantum Field Theory (QFT) and applied physics have revealed unusual quantum properties of nano-materials. This open new ways for understanding of brain and consciouness and for realization artificial intellect as predicted by Ray Kurzweil, technical director of Google.

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