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The Search for Biological Quantum Computer Elements

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Summary

The difficulties encountered in explaining the capacities of the human brain to generate conscious experiences with a neuron switching model has lead researchers to speculate that quantum phenomena may be involved in the human thinking process. This speculation goes beyond acknowledgement of the quantum mechanical basis for bio-molecular chemistry but suggests the architecture of brain functioning parallels the architecture of quantum computers. In this model classically observed neural components act like transmitting and receiving channels to quantum elements analogous to the state-preparation and measurement components in quantum computer architectures. Theories proposed by Penrose and Hameroff suggest such quantum element fields may be supplied by the microtubule structure encountered in neurons, while the DNA field has also been proposed as a candidate for quantum computation. Objections to the quantum brain model rests primarily on the de-coherence expected in the warm-soup environment which simply compounds the isolation difficulties encountered in conventional approaches to quantum computer element construction.

In this paper we will review the isolation requirement for quantum computation and suggest that the interpretation of the measurement state-preparation architecture described by vonNeuman and Henry Stapp leaves the door open for neural quantum operations that can be discovered by empirical investigations. We will review the evidence for biological quantum elements and present the experimental approach and evidence for quantum effects in neural networks carried out with neuron cultures on microelectrode arrays at the University of Milan. Further planned experiments designed to detect Rabi oscillations in neuron cultures will be presented. These experiments are designed to establish or set limiting bounds on the presents of quantum interactions in neuron structures.

keywords: Quantum Computers, Biological Quantum Effects, Micro Electrode Arrays, Bio-Quantum Elements, Process Ontology

Introduction

If the brain operates like a quantum computer then Nature has solved the difficult construction and de-coherence problems in a warm soggy environment and a search for biological quantum computing elements makes sense. Such elements could be used either to enhance our understanding and guide our construction of

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quantum computing elements or to be used directly as building blocks in such systems. The case for quantum computation in the brain has been made through several lines of argument. These include the foundations of physics argument, the inadequacy of the neural switching model argument, and what I will call the self discovery argument.

The foundations of physics argument is straight forward. Classic physics is an approximation to more accurate description of nature required to properly address phenomena at the atomic and molecular level. Since biology is based upon chemistry which in turn is based upon quantum physics it is obvious that quantum theory must ultimately govern the activities in the human brain. As we delve deeper into the structure of the brain components whose operation can only be explained by quantum mechanical rules must be present. Not surprisingly such components have been found and their investigation forms the main thrust of experimental research supporting the quantum mind theories proposed by Penrose (1991) and Hameroff (1998). The discovery of components operating according to the rules of quantum theory does not prove the brain operates like a quantum computer any more than the presents of a tunneling diode turns a conventional computer into a quantum computer. All that such discoveries show is that lower level structures of nature can be encapsulated and harnessed into aggregates, which for all practical purposes operate on new emergent principles (Baer 2006). Investigations be several investigators (Hameroff 1998) have shown that components such as nanotubules can perform quantum operations. However, attributing of macroscopic brain functions, such as binocular rivalry (Manousakis 2007), to quantum operations are still highly speculative.

The inadequacy of the neural switching model to explain brain operation has been addressed by many authors (Pinker 1997, Khrennikov 2006). Despite much metaphoric success in the neural network arena the neural pulse speeds and neuron counts are simply inadequate to account for the everyday brain operation. The performance of a basket ball player or the image recognition capacity of the human brain cannot be duplicated by computer operating near nano-second cycle times let alone the millisecond response times found in biological systems. For some a more compelling argument is the inability of any classic physics based explanation to address the explanatory gap or what has been identified as the “hard problem of consciousness”(Chalmers 1997). Quite simply the explanatory gap states that there is no explanation for the fact that you see these words in front of your nose. Photons entering your brain may produce a physical response in your neural structure but how such a response then generates sensations several feet away cannot be explained within conventional physics. Compelling as these arguments may be they only prove that brain operation is still a mystery. It is certainly attractive to connect the mystery of the brain with the mystery of quantum computation but that is only a possibility waiting to be proved not a fact that has been proved by the argument.

A third argument is based upon the knowledge interpretation of quantum theory and is in our opinion more compelling than the previously mentioned arguments but still not absolute because it is based upon metaphysical and epistemological principles that many workers simply reject outright. The principle is exemplified by the Eddington Fish Story (1944) which in demonstrates how the most fundamental laws of Nature must be the construction rules of the instrument, i.e. the brain, doing the investigation. In short the argument claims that *the first law of physics is that the physicist made the law*. If, for example, we always look at the world through rose colored glasses it should not surprise us that the most fundamental property we would ascribe to the world is that it is rosy. In classic physics the observer is excluded and all properties are attributed to the external world. Quantum physics acknowledges the role of the measuring instrument in creating the data from which the properties of the external world are deduced. Since the ultimate measuring instrument, through which we always look, is ourselves we should not be surprised if the fundamental properties of the world turn out to be the construction rules of our own brains. Furthermore we should not be surprised if the structure of the theory we use to understand the world turns out to describe the processing algorithms we execute during our investigations. In short we discovered quantum theory because our brains operates according to quantum principles.

Once we look at quantum theory as a blue print for our own data processing activity, hardware requirements that support such data processing will emerge. With this guidance we can then look for brain components that implement these processing requirements. The next section will discuss quantum theory as the theory of our knowledge processing system. First we discuss the metaphysical underpinnings of quantum theory and show how the wave function describes tangible oscillations in real systems. Then we will discuss the reason for expecting to find quantum computation in the brain. Lastly, we will discuss the search for biological component that could implement such processing and report on the progress in this endeavor.

Tangible Quantum Theory

The tangibility argument for quantum theory rests on the realization that the structure of quantum theory actually describes a computational algorithm that is executed by all systems in order to gain knowledge of their environment and react to it. An anthropomorphic visualization of such a system is shown in figure 1. Here sits a calculator with a set of instructions in front of himself. If the calculator carries out the instructions he is a system executing an operation that can be described in classic physical terms. Such a classic description can be written as a phase orbit and placed into the parallelogram at one end of the instruction cycle.

The instruction tell the calculator to calculate the action required to execute the activity described by the phase orbit and place the result in the thought bubble at the other end of the instruction cycle. At this stage he knows the action A0[s] required to carry out the calculation. The second part of the instruction tells him to take the action and calculate the form of activity in which it is stored. He now has the phase orbit Z0[s](ϕ) again. Each time the mathematician carries out the instruction cycle he also expends A0[s] amount of action in a form Z0[s](ϕ). This is the fundamental cycle.

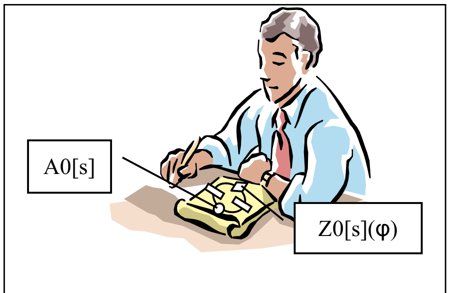
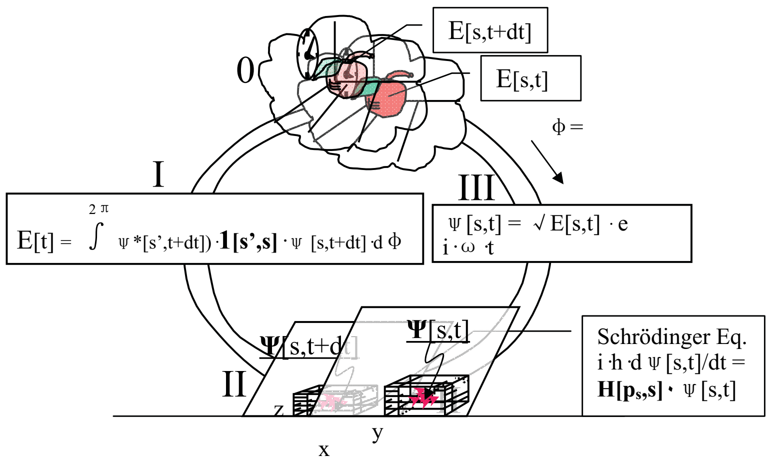


Fig 1 – Visualization of the Fundamental Activity

Now lets disturb the mathematician slightly. Not enough to prevent him from doing the calculation but just enough so that he executes a new motion Zt[s](ϕ)= Z0[s](ϕ) + Z[s](ϕ) which expends a small change in action At[s] = A0[s] +A[s]. The calculation is basically the same each time it is executed and can be ignored. The small changes however are characterized by the form Z[s](ϕ) and take A[s] amount of action per cycle to execute. If we now define the time "t=$\cdot\phi/2\pi$ " to act as a cycle counter the small disturbances in the basic calculation will be described by Zt[s](ϕ)= Z0[s](ϕ) + ψ[s](ϕ) and the action per unit cycle as the energy Et[s](t) = E0[s] +E[s](t). Hence the disturbance in the basic operation is characterized by the energy E[s,t] and its form ψ[s,t].

We now look for the explicit formula for the operations in the algorithm. The structure of quantum theory was initially analyzed by VonNeuman (1932) who defined a measuring process I and a quantum process II governed by the Schrödinger Equation acting upon deBroglie waves. The analysis was extended by Henry Stapp (1993) to include a process 0 corresponding to our classic world of action distributions governed by classic Hamilton's equations and a process III by which the action is converted into the waves. The fundamental structure of quantum theory connecting these four components looks like the processing cycle shown in figure 2. Here the Process 0 describes the action per unit time E[s](t) and is governed by classic relativistic equations of motion. Process III explains the action pattern in terms of a wave form ψ[s,t](ϕ). Wave forms are governed by Schrödinger's equation in the quantum world by what was called Process II by vonNeuman. While Process I measures the action in the wave form by integrating over one cycle.

It is of crucial importance to remember that in our presentation the symbols of quantum theory refer to the "small" disturbances in the underlying fundamental activity which supplies the "places"- Hilbert Space Cells- in which the disturbance actions described by the Fundamental Quantum Cycle can happen. The reader is urged to explore the theory of small oscillations (Goldstein 1965) and convince himself that small disturbances to fields of classic systems will always lead to oscillations described by the Schroedinger Equation in the non relativistic approximation. Hence our anthropomorphic visualization is actually as a statement about the structure of space itself.



The visualization of the field of cells, known as Hilbert Space, is shown in Process II portion of figure 2. The space variables chosen look like the a block of cubes labeled by Cartesian coordinates x,y,z. We will however continue to use the general space label "s" to emphasize that Cartesian space is not the only way to organize our display of knowledge. The amount of energy in each cycle can be zero. In this case each fundamental activity described in figure 1 is undisturbed and corresponds to the classic description of empty space while the disturbance amplitude in each quantum cell is zero. This empty space is shown as a thought bubble sum of all the individual spaces and serves as the background in which things can happen. We have placed an apple into this empty classic space to act as a classic system described by a classic energy distribution. The apple therefore has two complimentary descriptions. First as a classic object shown in the thought bubble whose motion is described by Hamilton's equations, and second as a wave pattern in Hilbert space whose motion is governed by Schrödinger's Equation.

The integration formula in Process I contains a unit matrix used to sum the energy contribution from each individual cycle. We therefore use the energy to specify the amount of the system i.e. apple, is in each cell. Dividing both sides of this formula by the total energy normalizes the wave function which can then be treated as probability amplitude.

$$P[s] = \psi * [s,t]) \cdot \psi[s,t]/E[t] \tag{1}$$

If the Hilbert space cells are set up to record any quantity “q” then this matrix is replaced by a diagonal matrix Q[s’,s] in which each element specifies the “q” value assigned to the occurrence of the energy in that cell.

$$< q >= P[s] \cdot q[s] = \psi * [s,t]) \cdot Q[s,s] \cdot \psi[s,t]/E[t] \tag{2}$$

Thus rather than talking about abstract probabilities our tangible interpretation states that the system of interest is physically distributed in among the cells “s”. The amount of the apple in the cell “s” is given by the fraction of its total energy in “s” and if that apple is described in quantum terms as oscillating motions in space then the amplitude of the oscillation in each cell is the square root of the energy in each cell. This is due to the fact that in our interpretation the observable content of space is a small perturbation of the system defining space and thus approximated by an oscillatory motion whose amplitude is related to the square root of the energy in the oscillation.

If the underlying Hilbert space cells are dismantled and reconstructed in a different configuration then the same disturbances defining the apple would be redistributed among the new configuration of cells. If the reconstruction of the new space cells can be described by a similarity transform S[x,s] this can lead to lead to new state vectors and Q matrices with off diagonal terms.

$$\begin{aligned} P[s] \cdot q[s] &= \psi * [s',t] \cdot S[s',x']S * [x',s']Q[s',s] \cdot S * [s,x]S[x,s]\psi[s,t]/E[t] \\ &= \psi * [x',t]) \cdot Q[x',x] \cdot \psi[x,t]/E[t] \end{aligned} \tag{3}$$

The last three formulas presented are intended to convince the reader that the formalism of quantum theory can be implemented as tangible physical systems if Hilbert space cells are tangible physical systems that execute the fundamental activity and generate the perception of space. The world view accompanying such an assertion is provided in the next section.

The Quantum Universe

So far we have considered only an isolated system. The motions occurring in this system are due to interactions between internal parts. If these parts were divided into several subsystems in such a way that the interaction between subsystems is small compared with the internal interactions then we could treat each sub-system as an isolated part with its own identity and treat the external interactions as perturbations. This leads to the concept of a quantum universe shown in figure 3(Baer 2007). The figure consists of three discernible cycles each consisting of a Hilbert space array connected to its own classic display in which moving particles and fields appear. These are connected to each other through a set of interaction lines.

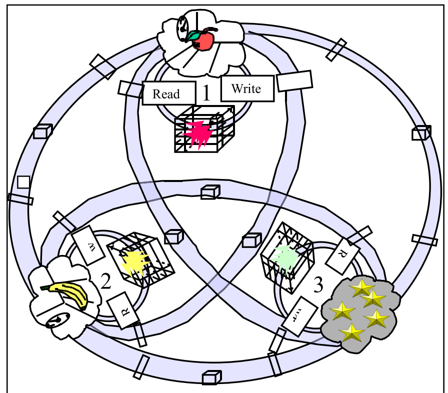


Figure 3 One Instant of a Three Part Quantum Universe

The rectangles along both the internal and external interaction lines are the same measurement and state preparation functions shown in the previous figure. We have labeled the measurement process II as the Read function(R) and the state preparation function as the Write function (W). The rectangles are also shown on the interaction branches although no label is attached to keep the drawing less messy. This drawing represents one time instant and each branch is 2π long. Most of the action in each cycle is transformed into its internal Hilbert space through the Write functions but a small amount is also transformed into the interaction paths. These produce displacements in the Hilbert space cells shown as boxes on the interaction paths and from there as input action to one of the other parts.

The formalism of quantum theory can again be applied to the three part universe if we define three comprehensive normalized state functions (see eq.1) for each of the parts and a Hamiltonian matrix as follows:

$$\begin{matrix} E[1] \\ E[2] \\ E[3] \end{matrix} = \begin{pmatrix} \Psi^*[1] & \Psi^*[2] & \Psi^*[3] \end{pmatrix} \begin{pmatrix} H[1,1] & H[1,2] & H[1,3] \\ H[2,1] & H[2,2] & H[2,3] \\ H[3,1] & H[3,2] & H[3,3] \end{pmatrix} \begin{pmatrix} \Psi[1] \\ \Psi[2] \\ \Psi[3] \end{pmatrix}$$

If the Hamiltonian is diagonal there would be no interaction, the cycles would execute independently, and the energy would stay constant in each sub-system. The off diagonal elements allow energy transfer and observable motion in each individual classic display. Each of these parts could be further broken into sub-sub-parts by expanding the matrixes. So for example $\Psi[1]$ could become $\Psi[1][s1]$ where s1 explicitly names the Hilbert space cells in the first system and H[1,1] would then become H[1,1][s1',s1].

That the formalism of quantum theory can be represented in graphic forms has been discussed elsewhere (Chung 1996) we are concerned with the implications that the insights such a representation provides for the question of biological quantum computers and the problem of decoherence. If the architecture of quantum theory describes the Universe then we are no longer concerned with particles and fields in a box driven by a Newtonian time, and neither are we concerned with probability waves propagating in a box. Instead, we have the architecture of an interacting set of quantum cycles. Each cycle generates a classic sensation that is transformed into physical motions. The observer is included in our interpretation of quantum theory not because he slightly disturbs the thing he is observing but because he *is* the execution of a quantum cycle. The quantum universe is no longer a classic space but rather an interactive set of computational entities. The classic space is a display mechanism within each of those beings. If the third person in figure 3 describes the rest of the universe then its display space would be identified with inertial space. However, space is generated by measurements made on its Hilbert Space and deviations in the motion defining those cells would appear to be the massive stars shell surrounding us.

Adopting the world view implied by the quantum universe allows us to recognize the possibility that biological systems incorporated as quantum cycles are to first order of approximation isolated systems. As such they operate like quantum computers because their Hilbert space content is controlled by Schrödinger's equation. The rectangular function boxes drawn on the interaction branches of figure 3 are the input and output gateways from the internal activities that are hidden and only accessible to the other cycles through interactions. The first person sees the second person system as an apple, not because the second person is an apple but because that is how the first person interprets and remembers the interactions.

To summarize we have shown that the structure and equations of quantum theory are consistent with a tangible interpretation of the wave function as small oscillations in real systems and that the architecture of quantum theory suggests a world view in which isolated systems occur naturally. Our next task is to show that these real systems are memory cells

Hilbert Space as Memory Cells

The Copenhagen School of Quantum Theory interpretation of the wave function as a probability amplitude. Probabilities are informational in character and may be useful to predict the statistical result of experiments but certainly do not satisfy the desire for tangible reality. This desire lead Einstein (Einstein 1935) to conclude that quantum theory was incomplete. Though the specific EPR paradox proposed by Einstein was resolved in favor of the Copenhagen Interpretation the acceptance of reality as a statistical possibility is difficult to reconcile with the tangibility of our experience.

A knowledge interpretation does not contradict the existence of probabilities but merely states that if these probabilities are in fact all we can know of the real world then this knowledge must itself be stored in physically real terms. In other words the symbols of quantum theory must point to some knowledge storage system and its data content. That this knowledge storage system can be identified with the memory cells in our own brains can be demonstrated with the following exercise

The apple in figure 2 appears as an external object in front of the readers nose. This appearance is a combination of external stimulation and an internally generated sensory expectation. The extent to which visual images are the result of internal processing has been well documented (Lehar 2003, Hoffman 1998). The simplest way to become aware of the internal processing is to close ones eyes and note the sensation associated with the expectation of seeing the apple. Descriptions of this sensation varies from individual to individual but is typically described as a white ghost image placed at the location in which we expect to see the apple when we open our eyes. The appearance of this expectation is the result of a measurement made upon the memory cell holding our knowledge of the apple. Our contention is that the memory is described by the wave function of the apple while the memory itself is the Hilbert Space of cells in which the information required to produce an expectation of the sensory display associated with the appearance of the apple.

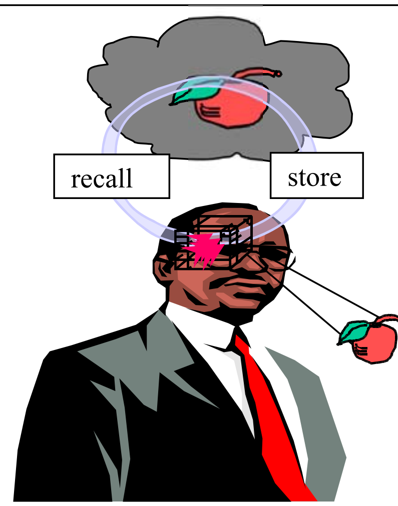


Figure 4 – Hilbert Space cells in a 2'd person

If the sensations experienced by the reader acting as the first person are generated from data stored by actual Hilbert space cells in ourselves then we would expect the same quantum measurement cycle to be present in a second person. A second person looking at the same apple has been placed into the readers first person view point in figure 4. What the second person actually experiences is clearly hidden from objective view and must be imagined in the thought bubble above his head. This though bubble is connected with his memory by a similar quantum measurement cycle we postulate for the first person. Hence we would expect to find a field of Hilbert space cells in which the memories are stored as tangible physical entities and the fundamental activity defined in figure 1 being executed by these cells.

There is one catch. If the reader looks at the second person what he is seeing is the result of his own measurement Process II displayed on his own perceptive space. The quantum cycle superimposed on the second person in figure 4 is a symbolic projection and cannot actually be seen by the first person. It must be inferred from the result of interactions. By eliminating the appearances due to our own processing we can draw the second person's processing cycle as a stand alone vision shown in figure 5. The portion shown inside the dashed rectangle is identical to the 2^{nd} person node shown in the quantum universe with the exception that the interaction branches have here been outfitted with extensions that join the data paths we can see directly. Thus the apple to his lower left is the apple we see in the first person view. Photon paths lead to the 2^{nd} persons eyeball can be followed. From there we can still trace neural pulses along the nerves until they reach a state preparation Process III rectangle. As described above Process III transforms the classic description of things we can see directly into the quantum description of displacement beyond our senses. This is the gateway to the 2^{nd} persons conscious awareness and marks the exit point from our domain of experience. What happens inside the 2^{nd} person has been given the name Neural Correlates of Consciousness (NCC) and is now clearly identified with the quantum processing cycles. Except for the small perturbations introduced through the interactions the vast bulk of these cycles are isolated from ourselves and evolve according to Schrödinger in their own time. Hence, they act like a quantum computer driven by an internal clock. Such an internal clock is usually denoted as the Feynman curser. It may be presumptuous to assume that the physical evolution of the cycles defining the 2^{nd} person is a calculation but, at least metaphorically, we describe the thought process of other individuals in this way.

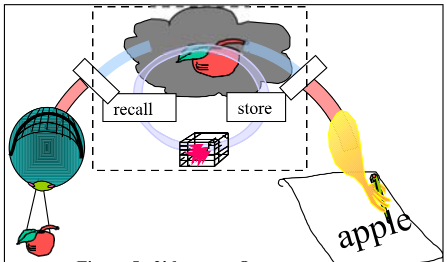


Figure 5 –2'd person Quantum Computer Architecture

The inner quantum cycles are attached through the external Write function represented by rectangles on the output interaction branches. This is the gateway through which signals from the quantum domain reappear in our classic view and correspond to the measurement output from a quantum computer. In figure 5 we have attached the neural pathways that lead to motor control at this point. These signals can be traced as classic objective entities that lead to observable motions that can be recorded. In this case the record "apple" might be the answer to a pattern recognition task the second person was set up to perform.

The lesson we can take away from the above discussion is that the architecture of a quantum computer and that of a conscious being is similar. In both cases the interaction pathways lead to isolated quantum processing elements that occur beyond the reach of our sensors. Beyond the reach does not imply a level of difficulty that can be overcome by some arduous journey but is a fundamental limit imposed by our finite extension and the recognition that we can only experience what is within that extension.

The above stated arguments provide a rational for believing the brain acts like a quantum computer and therefore nature has solved the isolation problem. Architectural similarity does not prove the conjecture is true. But if it were true we could learn from, copy, and utilize already existing structures to build devices which now seem out of reach. Given the potential pay off it seems reasonable to search for tangible experimental evidence. The general topic and extensive experimental investigations conducted by one of us will be discussed in the next section.

Experimental Approach to Quantum Brain Phenomena

Experimental proof that the brain is a quantum computer requires the discovery of brain phenomena that can only be explained by evoking quantum models. We classify approaches as internal or external.

Internal approaches are psychological in nature and are characterized by the utilization of the input and output circuitry naturally available in human beings. Experiments typically provide setup instructions, stimulus, and response measurements to a cooperating subject. The idea is to develop models of processes that must be going on in the brain that explain the response from a subject given a controlled set of input. The vast majority of investigations along these lines have sought to fit neural circuitry models to response data thus assuming the brain acts like a classic computer. The inadequacy of this assumption was discussed in the introduction. It is doubtful that our ability to perform pattern recognition can be implemented with pulses traveling at 100m/sec and even more doubtful that our ability to generate representations of objects at far distances from our brains can be explained in classic terms.

The use of quantum models to explain brain response is being addressed by a growing number of investigators. Investigation of the brain as a quantum-like computer (Khrennikov 2007) avoids the need for exact quantum mechanical representations of large bulk phenomena by treating the brain as quantum-like and appealing to metaphoric similarity. This is essentially the argument we developed in the last section. A recent paper (Manausakis 2007) has gone a step farther by calculating the probability distribution of dominance duration of rival states in binocular rivalry from known values of neuronal oscillation frequencies and firing rates using orthodox quantum theory. In binocular rivalry the brain is stimulated with simultaneous but different left and right eye scene input. The three dimensional scene generated by the brain will switch between rationalizing the left and right input with a characteristic frequency. The frequency was calculated by assuming the left and right interpretation corresponds to orthogonal quantum brain states that transform into each other according to quantum mechanical rules.

The internal psychological approach sends signals into the system of investigation and draws its conclusions from what comes out. This leaves the complex layer of classic neural pathways between the external stimulus and the presumed gateway to the quantum domain. Since the exact operation of this preprocessing layer is not fully understood, it is very difficult to draw conclusions about quantum operations. Some, perhaps undiscovered, algorithm executed by classic switching circuit could explain most evidence. This difficulty can be overcome by directly measuring neuron signals at the source. Since 2002, a group headed by one of us (Pizzi 2004-2007) has been concerned with the direct acquisition of signals from cultured neurons in Micro-Electrode Arrays (MEAs). MEAs allow neurons to grow directly on electrodes imbedded in petri dishes. The signals of living cells can then be monitored. During the first experiments, we noticed anomalies in the electrical signals coming from separate and isolated neural cultures that suggested that either neurons were extremely sensitive to classical electromagnetic stimulation or some form of entangled state communication between isolated systems was occurring.

The case for entangled state communication is highly speculative but can be understood as follows. Figure 6 shows a diagram of two neural cultures starting on the left with an initial single stem cell. As the culture grows identical systems are manufactured which presumably interact producing complex entangled states. The neurons, or sub-elements such as the DNA or microtubules form the Hilbert space of a quantum system. At some time during the growth process the cultures are separated however entangled state communication between them could remain.

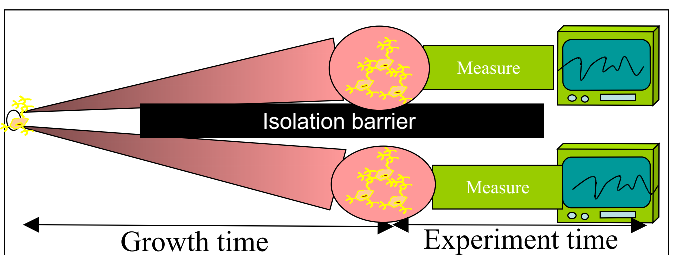


Figure 6 Corrolated signals from entangled states

Entangled state communication can be understood as signals travelling backward (Josa 1998) in time through the common origin of interaction. For such communication paths to remain intact some portion of the systems would have to remain isolated for extended periods of time. The classic world view would eliminate this possibility because of thermal interaction between the neurons and the rest of the universe. However if our Quantum Universe conjecture is correct all forms but specifically living potentially conscious entities are, to first approximation, isolated systems and only their interaction pathway extensions are accessible and subject to thermal interaction and de-coherence. Hence if the two neuron cultures could be completely isolated from each other and signals measured that show a high degree of correlation the possibility of long term isolation and quantum based communication would be indicated. This is the hypothesis that such an experiment is designed to investigate.

The basic experimental setup for the non-local experiment is shown in Figure 7. Two Microelectrode Array Basins containing living neurons grown from a single stem cell are separated by a distance D(8 cm). An electromagnetic shield is placed around one basin and data acquisition cables so no detectable leakage, crosstalk or induction between the basins occur. Voltages of independent neural activity are measured and recorded for each basin. Stimulation of basin-S using an 80 milli-second laser pulse is monitored by Pulse detector. Voltages from the pulse detector, basin-S, and basin-R are sampled (1 khz) and recorded in computer files. The files are then analyzed for signal patterns indicating communication has occurred between the two basins. The result of this analysis claims communication not attributable to electromagnetic origins does occur. We are not talking difficult statistical analysis or subtle occasional coincidences. This claim is based upon easily observed and obvious signal responses in the receiver basin-R.

Figure 7 Experimental Setup

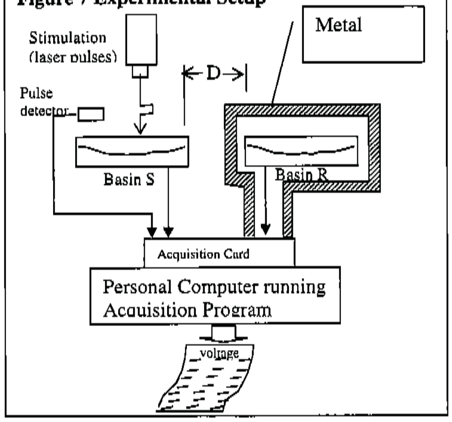


Figure 8 shows a plot of the first 30 seconds of voltages taken at 1khz intervals. The pulse, Stimulated basin-S, and receiver basin-R plots are shown. Random laser pulses occur near 1809, 13561, 14465, 23505, 25313, and 26217 milliseconds from 30000 ms start time shown on the dark upper line. The response notch from the stimulated basin shown on the magenta second line and the receiver basin shown on the yellow third line can be made out. We can expand the graphs around the pulse location in order to see the wave forms more clearly. This was done in figure 9.

Fig. 8

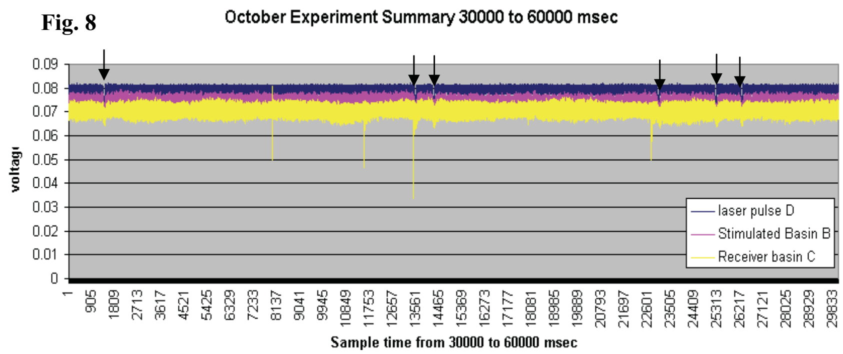


Fig. 9

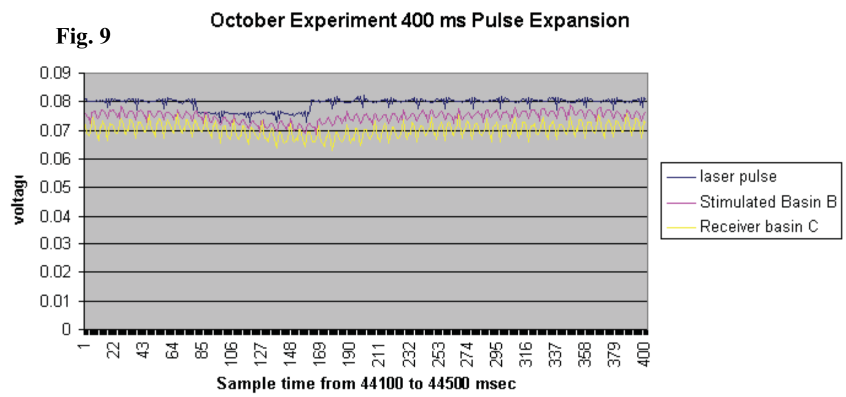


Fig. 10

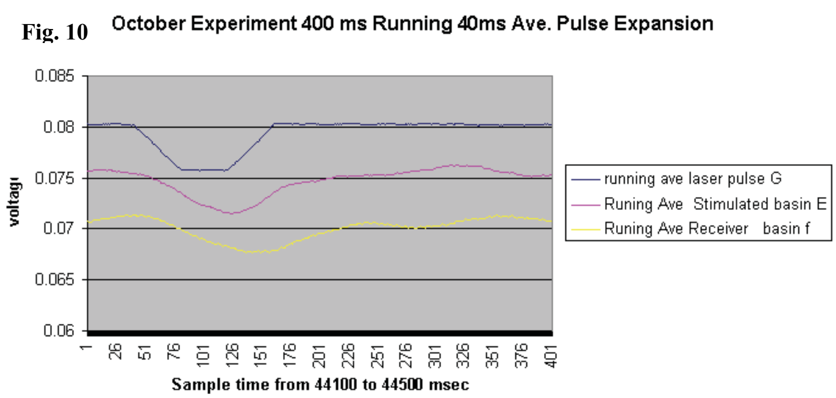


Table 1: Voltage and Delay for 10 pulses

	AVE	STDEV
Delay between Pulse center and Stimulated basin center	24.7msec	2.2ms
Delay between Stimulated and Received basin center	16.7msec	9.6ms
100ms average Laser Pulse Voltage drop	3.1mv	.5mv
100ms average Stimulated Voltage drop	2.8mv	1.0mv
100ms average Receiver Voltage drop	1.5mv	1.0mv

To see the amplitude response more clearly we run the data through a low pass filter averaging 40 samples at a time. The plot of the running average is shown in figure 10. The 80 ms laser pulse is converted to a diagonal drop, flat bottom, and diagonal rise. The magenta middle line shows the stimulated Basin-S responding with a delay. The bottom yellow line shows the receiver Basin-R responding with a corresponding delay.

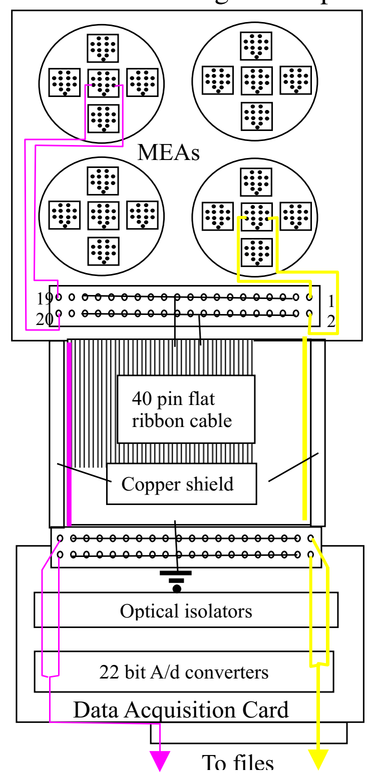


Fig. 11 MEA's and Cabeling

The graphs shown above provide visual examples of individual laser stimulation pulses along with the response in the stimulated and isolated receiver basin. Although visual inspection clearly shows wave form correlations a simple statistics performed on ten pulses in the first minute of data show a consistent voltage drop and delay as the stimulation works its way through first Basin-S and subsequently to Basin-R.

Though many additional checks and tests could be done we believe the data showing 1ms samples from laser, stimulated and received locations show clear evidence of correlation between the signals. The next question to be asked is whether the experiment was conducted with sufficient care to justify the conclusion that non-electromagnetic communication has been observed.

The Microelectrode Array (MEA) and cabling used to conduct the experiment are shown in figure 11. At the top is an MEA with four neuron growth basins consisting of a glass disk with tungsten $100 \times 100\mu$ microelectrodes. Since it takes

one month to grow neurons from a parent stem cell source four basins are available in order to conduct grow and conduct multiple experiments. For the non-locality experiment only two electrode pairs from two separate basins are wired to the two outside leads of a 40 pin flat ribbon cable. The remaining pins are grounded to act as shields. The entire cable is encased in a copper shield. The acquisition card is the NI6052E 181 DAQ produced by National Instruments, 333 kHz, optically shielded, 16 analog inputs, two 182 analog outputs, and eight digital I/O lines.The digitized data streams coming from the Basin-R(magenta) and Basin S (yellow) are then recorded in files.

Two questions arise. First, do the measured signals come from the neurons, and second, are the signals isolated.

To answer the first question signals were measured coming from basins filled with culture liquid, without cells, and compared with signals coming from basins containing cells. In the first case the pure culture liquid showed the response of a conductor while in the second case the cell response is detected.

The second question was answered by injection of a 10volt test signals on one of the basins while measuring the voltage coming from the second basin. Cross-talk was measured to 100db below the input stimulation voltage and well below the 1 to 10 milli-volt range involved in the experiment. Similar measurement taken with empty basins showed no significant background noise due to electromagnetic interference.

Assuming the cabling and leads are properly constructed so that we can conclude that measured voltages actually come from cell cultures in their respective basins the next question to be addressed is whether the stimulation of Basin-S might leak into Basin-R and hence the correlation in the measured signals might simply be due to the fact that both basins are responding to the same stimulus.

Information we have is that the receiver Basin-R was shielded with a metal jacket surrounding the culture so that no light or other forms of EM radiation could penetrate. Figure 12 shows a photograph of the actual apparatus for the December 04 experiment. The golden box shown in the blowup in figure 13 is the Faraday cage. The cables coming outside are also shielded, and the small hole around the cables is also shielded inside. On the left there is a small metallic box, the hardware controller. Visual inspection indicates concern that light may leak through the glass substrate forming the support structure of the basins. Similarly Electrodes in the MEA's could be shorting or provide current paths through spilled culture media. These concerns are addressed by performing end to end tests. Such tests would maintain the identical setup as that shown in figure 1-1 with the exception that the neuron cell colony is replaced by a culture liquid containing fibroblasts or possibly cells of a different DNA. If the stimulation, shielding, and cabling were identical and the only difference were the material content of the MEA basins then repeatable differences in measurement results must be attributed to the only variable in the experiment. This variable is the neuron cell culture DNA. Such end to

Figure 12 Apparatus showing EM schielding

end tests have been done. So for example the pairings of basin content listed in table 2 showed no measured signal correlation. Unfortunately these experiments were also done under similar but not identical conditions. Hence it is not possible to take them as absolute proof that the basins are adequately isolated.

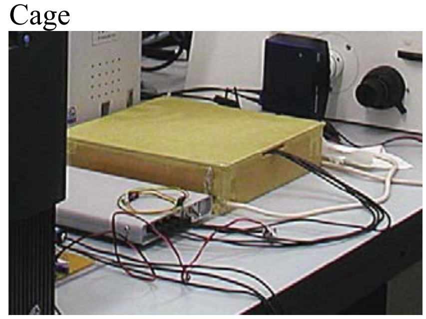
Table 2: End To End test with different Basin Content

Basin-S	**Basin-R**	**Result**
Culture liquid	Human Neurons	No Correlation
Fibroblasts	Human Neurons	No Correlation
Rat Neurons	Human Neurons	No Correlation

In fact, since the neurons must grow in a culture and adhere to the electrodes over a month gestation period, it is not straight forward to simply replace a basin content leaving all other connections the same. At minimum a basin including neurons must be connected and disconnected. This leaves the possibility that some new and possibly unknown variable has been introduced.

We next considered the possibility that the phenomenon could be due to an electromagnetic field coming from the laser supply circuit that was too weak to be detectible with our measure instruments. To test this hypothesis we constructed a suitable circuit consisting of a selective sensor able to collect extremely weak induced electromagnetic fields that might reach the MEAs. We used a large squared ceramic capacitor (100 nF) and connected it to a sensitive amplifier. The amplified signal was sent to the acquisition card and analyzed. The test showed a peak in the MEA receiver channel simultaneous to the laser activation. Because the same peak was present after substituting the laser with a dummy load in order to simulate the current absorption equivalent to the one generated by the laser we concluded that stimulation from the laser supply circuit was the cause of the neuron response.

Figure 13 Blowup of Faraday Cage



We believe that neurons receive and amplify an electromagnetic spike through the air whose value, before reaching the Faraday shielding, is under the sensitivity of our instrumentation (2 mV). The exact value under a double Faraday cage could not be measured but is estimated to be several orders of magnitude less. We believe the neurons are the active receiving element because the MEA basins are connected to the ground, and their shape is not suitable to act as antenna and because the spikes observed in the neural basin are never present in the other control basins.

A large body of literature exists to explain, by means of super-radiance, stochastic resonance, and other theories how the neural activity can be amplified and processed inside the cellular and extracellular system. The neural reactivity may be due to the presence of microtubules in their cellular structure. In fact microtubules are structurally and dimensionally similar to carbon nanotubes, whose quantum properties are well known. Moreover, the tubular structure of carbon nanotubes makes them natural cavity antennas; their peculiar configuration can act as an array of antennas and amplify the signal.

Hence we must conclude this section with the statement that the evidence we have been able to see suggests electronic isolation has been achieved and correlated signals observed were from isolated neuron basins but does not constitute compelling proof that quantum communication has been observed. The possibility also exists that neurons are extremely sensitive to low levels of radiation below the levels of our current instrument to detect. In the future we hope to extend the shielding by employing high Mu-metal shielding and extend our experiments to search for evidence of other quantum effects in neurons. Regardless of the final outcome of these experiments we believe the MEA approach is an excellent method for investigating the possibility of quantum effects in biological systems and encourage other laboratories to duplicate our experiments.

Conclusion

We have presented a tangible interpretation of quantum theory that includes the observer not simply as a small disturbance but as an equal member of a universe in which each part executes self-measurement activities. In order to maintain the individual identity we actually observe such parts would need to be isolated so that measurement interactions are small perturbations. This suggests the possibility that the cognitive components of biological systems are sufficiently isolated to perform quantum computations. If true, such components can serve both as guides and resources for the construction of quantum computers. Lastly, we reviewed experimental procedures that might be applied in order to experimentally verify these conjectures. The current results indicate that neurons either exhibit effects attributable to quantum phenomena or are extremely sensitive to electromagnetic radiation below levels we were able to measure. In either case the response of neurons is significant and we urge other laboratories to investigate these effects.

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