Survey Paper

Quantum holography: Is it relevant to brain function?

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In 1951, reviewing the state of our knowledge of auditory processes for Steven's Handbook of Experimental Psychology, Licklider ended with: "If we could find a convenient way of showing not merely the amplitudes of the envelopes but the actual oscillations of the array of resonators, we would have a notation [1] of even greater generality and flexibility, one that would reduce under certain idealizing assumptions to the spectrum and under others to the wave form... the analogy... [to] the position–momentum and energy–time problems that led Heisenberg in 1927 to state his uncertainty principle... has led Gabor to suggest that we may find the solution [to the problem of sensory processing] in quantum mechanics."

During the 1970's it became apparent that Gabor's notation also applied to the cerebral cortical aspect of visual and somatic sensory processing. The most ·elegant work was done with regard to the visual system. A recent review by Tai Singe Lee [2] in the IEEE casts these advances in terms of 2D Gabor wavelets and indicates the importance of frames and specifies them for different sampling schemes. For the monkey, the physiological evidence indicates that the sampling density of the visual cortical receptive fields for orientation and frequency provides a tight frame representation through oversampling.

The 2D Gabor function achieves the resolution limit only in its complex form. Pollen and Ronner did find quadriture phase (even-symmetric cosine and odd-symmetric sine) pairs of visual receptive fields. Currently, recordings made with multiple microelectrodes and data analysis with sufficiently powerful

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computers makes it possible to readily obtain additional data of this sort and to determine on the conditions under which phase encoding might occur.

The neurophysiological community has come to terms with the distributed nature of what can be conceptualized as the "deep structure" of cortical processing [3]. The accepted view is that distribution entails the necessity of binding together the disparate sites of processing. It is thus a property of a surface structure composed of widely separated modules made up of circuits of neurons. Binding is accomplished by temporal synchronization of spatially distinct oscillating neural processes. The emphasis has been that under the conditions which produce binding, no phase lead or lag is present. However, Saul and Humphrey [4,5] have found cells in the lateral geniculate nucleus that produce phase lead and phase lag within modules in the cortical processing initiated by them. In the somatosensory system, Simons and his group [6] have been analyzing the timing of the thalamocortical process to show how it enhances "preferred" features and dampens "non-preferred" ones; that is, it sharpens sensory discrimination. The process thus can act as a frame, that "captures" relevant features or combination of features. These results give promise to Gabor's prediction that we might find the solution to sensory (image) processing in the formalism, and perhaps even in the neural implementation of quantum information processing.

What makes the implementation so difficult is that, as noted, the deep structure of cortical processing goes on in the synaptodendritic processing web, the dendritic arborizations where brain cells connect with each other.

One of the most intractable problems facing brain neurophysiologists has been to trace the passage of signals through these dendritic trees of neurons. The received opinion is that such signals accumulate from their origins at synapses by simple summation of excitatory and inhibitory postsynaptic potentials to influence the cell body and its axon and thus the cell's output. This is not the case. Each synaptic site "is functionally bipolar – it both projects synapses onto and receives synapses from many other processes. Hence input and output are each distributed over the entire dendritic arborization where[ever] dendrodendritic interactions are important" ([7], p. 82). The anatomical complexity of the dendritic network has led to the opinion summarized by Szentagothai ([8], p. 40): "The simple laws of histodynamically polarized neurons indicating the direction of flow of excitation came to an end when unfamiliar types of synapses between dendrites, cell bodies and dendrites, serial synapses etc. were found in infinite variety."

The received opinion also focuses on the transmissive nature of synapses: thus the term neurotransmitters is, more often than not, ubiquitously applied to the variety of molecular processes stimulated by the arrival of an axonic depolarization at the presynaptic site. This focus appears to us to be misplaced. In any signal processing device, the last thing one wants to do if unimpeded transmission is required, is to physically interrupt the carrier

medium. Interruption is necessary, however, if the signal is to be processed in any fashion. Interruption allows switching, amplification, and storage to name a few purposes to which physical interruptions such as synapses could make possible.

What then might be the use to which synapses could be put when input and output are each distributed over an extent of dendritic arborization? In Ref. [9] I suggested that any model we make of perceptual processes must take into account both the importance of Imaging, a process that constitutes a portion of our subjective (conscious) experience, and the fact that there are influences on behavior of which we are not aware. Automatic behavior and awareness are often opposed, the more efficient a performance, the less aware we become. Sherrington noted this antagonism in a succinct statement: "Between reflex [automatic] action and mind there seems to be actual opposition. Reflex action and mind seem almost mutually exclusive – the more the reflex the less mind accompanies it."

Evidence was then presented that indicates that automatic behavior is programmed by neural circuitry mediated by nerve impulses, whereas awareness is due to the synaptodendritic microprocess, the excitatory and inhibitory postsynaptic potentials and their effect on dendritic processing. The longer the delay between the initiation in the dendritic network of postsynaptic arrival patterns and the ultimate production of axonic departure patterns, the longer the duration of awareness.

Recent support for this proposal comes from the work of David Alkon and his colleagues who showed that as the result of Pavlovian conditioning there is an unequivocal reduction in the boundary volume of the dendritic arborizations of neurons. These neurons had previously been shown to increase their synthesis of mRNA and specific proteins under the same Pavlovian conditions. Although these experiments were carried out in molluscs, such conditioning induced structural changes akin to the synapse elimination that accompanies development as the organism gains in experience, and therefore, automaticity in the appropriate sites in the cortex of rats exposed to enriched environments.

The hypothesis put forward thus states that as behavioral skills are attained, there is a progressive shortening of the duration of dendritic processing that occurs between the initiation of post-synaptic arrival patterns and the production of axonic departure patterns. This shortening is presumed due to structural changes in the dendritic network which facilitate transmission.

But, as we have seen, signal transmission in the dendritic network is far from straightforward. As Alkon points out in a Scientific American article [10]: "Many of the molecular [and structural] transformation take place in dendritic trees, which receive incoming signals. The trees are amazing for their complexity as well as for their enormous surface area. A single neuron can receive from 100,000 to 200,000 signals from separate input fibers ending on its dendritic tree. Any given sensory pattern probably stimulates a relatively small

percentage of sites on a tree, and so an almost endless number of patterns can be stored without saturating the system's capacity."

The picture becomes even more complicated when we consider the spines that extend perpendicularly from the dendritic fiber, hairlike structures (cilia) onto which axon branches terminate. Each spine consists of a bulbous synaptic head and a narrow stalk which connects the head to the dendritic fiber. Thus, synaptic depolarizations and hyperpolarizations become relatively isolated from the dendritic fiber because of the high resistance to the spread of polarization posed by the narrowness of the spine stalk. It appears, therefore, "that there is an isolation of the activity at a given site from the ongoing activity in the rest of the cell... Part of the strategy of the functional organization of a neuron is to restrict synaptic sites and action potential sites to different parts of the neuron and link them together with passive electronic spread" ([7], p. 137). Further more, "it has been shown that synaptic polarization in a spine head can spread passively with only modest decrement into a neighboring spine head" ([11], p. 2192). Thus, spine head polarizations passively spread to interact with each other via extra- as well as via the intracellular cable properties of dendrites. The interactions (dromic and antidromic) among spine originated dendritic potentials (that need to become effective at the cell"s axon) thus depend on a process which is "discontinuous and resembles in this respect the saltatory conduction that takes place from node to node in myelinated nerve" ([11], p. 2193).

The intracellular spread of dendritic polarizations can be accounted for by microtubular structures that act as wave guides and provide additional surface upon which the polarizations can act [12–14]. The extracellular spread may be aided by a similar process taking place in the glia which show a tremendous increase in the metabolism of RNA when excited by the neurons which they envelope [15]. But these mechanisms, by themselves, do not account for the initial relative isolation of the spine head polarizations, nor the related saltatory aspects of the process.

To account for these properties we turn to the dendritic membrane and its immediate surround. Dendritic membranes are composed of two oppositely oriented phospholipid molecules. The interior of the membrane is hydrophobic as it formed by "lipids which form a fluid matrix within which protein molecules are embedded – the lipids can move laterally at rates of 2 μ/sec; protein molecules move about 40 times more slowly (50 nm/sec or 3 μm/min)" ([7], p. 44). Some of the intrinsic membrane proteins provide channels for ion movement across the membrane.

The outer layer of the membrane "fairly bristles with carbohydrate molecule attached to the membrane protein molecules: glycoproteins. The carbohydrate may constitute 95% of these molecules [which form a] long-branching structure [that resembles] a long test tube brush, or a centipede wiggling its way through the extracellular space. It attracts water, imparting a spongy turpor to the extracellular space" ([7], pp. 45–46).

On the basis of these considerations, we proposed that a perimembranous process occurs within dendritic compartments during which boson condensation produces a dynamically ordered state in water. This proposal originates in the work of Umezawa and his collaborators Ricciardi, Takahashi and Stuart. First, Ricciardi and Umezawa pointed out the possibility of a domain structure that provides a long range order within each [dendritic field of a] neuron. Then, Stuart, Tkahashi and Umezawa generalized this idea to a more extended region of brain tissue, assuming the existence of two quantum fields interacting with each other.

We have gone on to speculate that as each pattern of signals exciting the dendritic arborization produces a macroscopic, ionically produced change of the charge distribution in the dendritic network, it triggers a spontaneous symmetry breaking of a radiation field (a boson condensation) altering the water molecular field in the immediately adjacent perimembranous region. A macroscopic domain of the dynamically ordered structure of water is created in which the electric dipole density is aligned in one and the same direction. It is this domain of dynamically ordered water that is postulated to provide the physical substrate of the interactions among polarizations occurring in dendritic spines.

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