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FOREWORD

Three years ago, when Radford University made a commitment to participate in the nation's "Decade of the Brain", economist Sam Leven and I discussed the importance of holding annual meetings to provide a focus for both the experimental and educational endeavors of the University. The conferences were to be modelled on the successful series of symposia on motivation conducted annually at the University of Nebraska. Our concern centered on how brain processes become organized during decision making--that is, on the variety of neural antecedents that determine which course of action is to be pursued.

Shortly thereafter, when it became clear that a sizeable laboratory would be made available for brain research, the administration of the University suggested that a dedication ceremony be planned when the laboratory became functional. An obvious possibility emerged: the dedication ceremonies could serve to inaugurate this series of conferences.

A decision needed to be reached as to the topic for the first conference. While we were engaged in this decision-making process, mathematician Paul Prueitt organized a series of meetings at Georgetown University. These conferences explored the ideas put forward in Pribram's Brain and Perception: Holonomy and Structure in Figural Processing. The data-based mathematical models proposed in this publication begged for implementation in parallel distributed processing neural network programming architectures. These two conferences were successful in bringing together a small group of like-minded scientists. Some of these were invited individually to present their work in more extended form at the Brain Research Center in Radford; others had already interacted with members of the Radford group in the past.

As these interactions gained momentum, Harold Szu and Paul Werbos felt that a more encompassing conference was in order. Szu suggested that it be held at what by now had become the "Center for Brain Research and Informational Sciences" (with the acronym B.R.A.I.N.S.) at Radford. This, then, would serve as the inaugural of a series which Szu baptized "Appalachian Conferences." The International Neural Networks Society (I.N.N.S.) voted to support such a conference and additional aid was provided by the National Institute of Mental Health.

Thus, the organization of the First Appalachian Conference on Neurodynamics came to pass. The focus was to be on processing in biological neural networks taking off from the Epilogue and Appendix A of Brain and Perception. Half of the program would deal with modelling synapto-dendritic and neural ultrastructural processes; the remainder of the program, with laboratory research results, often cast in terms of the models. The interchanges at the conference and the ensuing publication were to provide a foundation for further meetings. These would address how processes in different brain systems, coactive with the neural residues of experience and with sensory input, determine decisions.

The Dendritic Microprocess

The first order of business in a transdisciplinary conference is to describe how the scientists involved go about obtaining their results. The publications presented in Section I aim to accomplish this. In the first paper, I review what can be learned about the functional organization of the receptive fields of neurons from an analysis of the spike trains recorded in the neuron's axon. The mapped receptive fields reflect the effective functional processes occurring in the synapto-dendritic network. In this paper, I review a stepwise path taken in collaboration with Dale Berger, leading from data to a stochastic resonance model and then to congruence with the Gabor elementary function. The next paper, by Bankman, introduces some of the most recent techniques used to analyze the data gathering process, the axonal spike train per se, techniques that are fundamental to any further analysis and attempts at modelling. The paper by Adi Bulsara and his collaborators does the same for the modelling process: it brings up to date the random walk procedure used in the Berger and Pribram analysis by showing how stochastic resonance with added noise can enrich our understanding of the relationship between the essentially quantum field characteristics of the synapto-dendritic network and the essentially discrete axonal spike train.

Quantum Neurodynamics

The papers published in Section II take forward the finding that Hermetians such as Gabor functions are excellent descriptors of receptive field organization in the visual cortex. Kunio Yasue and Mari Jibu had developed a neural wave equation akin to Schroedinger's in their contribution as appendices to my MacEachron lectures published as <u>Brain and Perception</u>. Almost simultaneously, Dawes had also proposed a quantum neurodynamics based on the Schroedinger equation. His contribution here takes these proposals into the realm of practical applications. In the main text of <u>Brain and Perception</u>, I had reviewed the data from my own and other laboratories which showed that the best description of the functional dendritic field of a visual cortical neuron is a Gabor elementary function or related Hermitian. This function Gabor called a "quantum of information" because his mathematics was identical to that which Heisenberg had used in identifying the quantum in microphysics. Bruce MacLennon clarifies a considerable number of issues that involve modelling in neural network architectures, including the use of Gabor wavelets. Walter Schempp brings to bear his mathematical expertise to delineate the relationship between all of these quantum-type formulations and to show their relevance to current engineering and biological concerns. The concluding paper in this section, presented by Paul Werbos, outlines some of the pitfalls that must be avoided when the mathematical formulations found appropriate in one field of inquiry (quantum physics) are applied in another (biological neural networks).

Nanoneurology

An alternative set of methods for exploring the functional organization of the synapto-dendritic processes directly addresses the microarchitecture and microprocesses surrounding the synapse. Sir John Eccles introduced this topic in his keynote address -- more on this presently. In Section III, Stuart Hammeroff and Glen Rein discuss the cellular infrastructures, the operations of the microtubules and the neurochemistry that regulate processing at the synapse. Next, Judy Dayhoff and Harold Szu address the adaptive changes that occur in this microarchitecture as a function of learning. These papers lead us from the essentially linear invertible and reciprocal stochastic resonance processes that guide sensory-motor behavior to an irreversible, largely chaotic or otherwise deterministic modification of the synapto-dendritic microstructure.

Perceptual Processing

The last section returns us to the perceptual process per se. The papers of Walter Freeman, Bruce Bridgeman and Barry Richmond report the research from their laboratories which demonstrates above all that the perceptual act is based not only on current sensory input but also a variety of encoded residues of prior experiences. Furthermore, there is no single neuron that acts as a solitary detector of current input; rather, ensemble processing is what occurs. Richmond explores the nature of the ensemble process in information theoretic terms; Bridgeman in terms of the content of a perception; and Freeman in terms of Chaos theory. Freeman's contribution shows that, at least in the early stages of olfactory processing, no invariant neural pattern can be made out that identifies a particular operant. He suggests that whatever remains constant in recurring experiences must be encoded in some invariant response to an invariant environmental configuration. His data do not preclude the possibility that such invariances become encoded elsewhere in the brain. As detailed in Brain and Perception, in the visual system the shifting patterns coordinate with imaging are processed into objects that demonstrate invariance across images. Reciprocal interactions between striate and the peri and prestriate systems of the brain are involved. As a concluding paper, Harold Szu and his colleagues present a novel technique of growing live neurons on electrons to determine how the resulting connectivity patterns interact to produce efficient processing.

Achievement

The keynote address given by Sir John Eccles brought our various endeavors into focus. In his discussion of the details of the synaptic process, he stated that he is averse to modelling: that if you want to make a brain you don't model it, you make a baby! Despite this bias, at the end of the conference, he told several of us that this was the best conference he had attended in decades. And it turned out that, in fact, Eccles himself had begun his collaboration with Friedrich Beck of the Institut fur Kernphysik of the Technische Hochschule in Darmstadt from which I have his permission to quote as detailed in the Afterword.

Excitement was generated; a thirst for knowledge and for evidence permeated the conference. Charles Peirce, the pragmaticist philosopher, stated that knowing can be achieved in three ways: 1) Through induction, i.e. through the gathering of observations and placing them in some sort of order; 2) Through deduction, i.e. through rigorously formulating and formally manipulating the orderings achieved through induction. However, Peirce noted that neither of these procedures really added to our knowledge base. He suggested that: 3) Only through abduction, the proper use of analogy, could knowledge grow.

Our use of models in this conference was abductive rather than inductive or deductive. As such, we need to examine the text of the proceedings of the conference carefully to see whether we used or abused the use of analogy. Was our use of the processes of quantum microphysics merely a cute exercise in metaphor? Was our use of Schroedinger's equations and Heisenberg's matrices sufficiently based in laboratory observation and experiment? Are the non-linear dynamics of the currently popular chaos theory simply fads we must bear or do these formulations really pose more clearly (and perhaps even answer) questions we only dimly perceived as recently as a decade ago?

There is no question as to our intent. Even Sir John, who has worked the vineyard of synapses all his long and illustrious career, became convinced of the validity of our mathematical procedures as a means for organizing the wealth of accumulated fact about neural processing. Only among behavioral neuroscientists would serious doubts arise. In physics, molecular biology, astronomy and paleontology, theorists, using mathematical formulations, and the gatherers of observations have worked out the "proper" collaborative use of analogy. In large part this has come about by distinguishing what in biology is called homology, a set of proven (tested) relationships among structures, from mere analogy, a correspondence among functions. With regard to neural networks, this distinction comes out to be the difference between pursuing biologically relevant applications (homology) versus implementing more generally useful applications (analogy). This conference showed that, not only it possible to pursue homology, but that the endeavor can be a warm, human and exciting adventure. We very much look forward to Appalachian II.

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"Rethinking Neural Networks:
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AFTERWORD

By: Karl H. Pribram

A Convergence :

In concluding this publication I will take up once again a discussion in which Sir John and I have been engaged for well over thirty years. As a confirmed mind/matter dualist, Eccles has, with Karl Popper, (Popper and Eccles, 1977) pioneered an interactionist stance which holds that psychological processes can and do influence what is going on in the brain. I have accepted this view but claim that it is only a part of the total story. My expressed challenge (Pribram 1986) is that epistemologically a dualist position is tenable only at the verbal level of natural languages; that at other levels of interaction -- e.g. at the neural-behavioral systems level -- a multiplicity of cognitive, affective and conative processes can be discerned (a pluralist stance); and, furthermore, that ontologically an identity relation characterizes the elementary neural and elementary psychological (communicative) relationship at the synapto-dendritic level. This identity position leads to a tension between idealism and realism while resolving (in terms of a neutral monism) that between mind and brain: Reciprocally interacting processes are identified which are neither material nor mental and are subject to measurement as quantities of information (in Shannon's and Gabor's terms).

A major step forward in resolving some remaining issues is possible on the basis of Sir John's presentation during this conference. Eccles once again presented his dualist interactionist views. He placed the causal action of mental phenomena at the synapse. The process alters chemical transmission by influencing the probability of opening a channel in the presynaptic vesicular grid. In a paper written with Friedrich Beck (1993), a mathematical physicist, the process is viewed as follows:

> "The interaction of mental events with the quantum probability amplitudes for exocytosis introduces a coherent coupling of a large number of individual amplitudes of the hundreds of thousands of boutons in a dendron. This then leads to an overwhelming variety of actualities, or modes, in brain activity. Physicists will realize the close analogy to laser-action, or more generally to the phenomenon of self-organization."

> "Exocytosis is the opening of a channel in the presynaptic vesicular grid and discharge of the vesicle's transmitter molecules into the synaptic cleft. It is as a whole, certainly a classical membrane-mechanical process. In order to investigate the possible role of quantum mechanics in the probabalistic discharge, one has to set up a model for the trigger mechanism by which Ca2+ prepares the vesicle of the presynaptic vesicular grid for exocytosis."

And again:

> "Since the resulting excitatory post-synaptic depolarization is the independent statistical sum of several thousands of local excitatory presynaptic potentials at spine synapses on each dendrite, we can concentrate on the process of exocytosis at each individual bouton".

Compare these passages with some by Yasue, Jibu and Pribram taken from Appendix A of Pribram's *Brain and Perception* (1991):

> Once the distribution of charge carriers in the ionic bioplasma evolves due to the distribution of dendritic isophase contours, the pattern of oscillations of

the membrane potentials in each location changes. This is because the amount of charge carriers in each location affects the $Ca2+$ controlled ATP cyclic process and so the resulting oscillations of biomolecules of high dipole moments. Thus, the fundamental activity of the dendritic network is represented by a reciprocal feedback and feedforward control of the distribution of the dendritic ionic bioplasma due to the oscillating component of membrane polarizations. To summarize, let us recall the idealized case of synchronized oscillations (1):

$$\theta\ (t\ ) = e^{\cdot i\,(\omega t+\alpha)} \qquad (1)$$

There, $S(x\ ,\ t) = (\omega\, t + \alpha)$ and we have a vanishing spatial frequency $k = 0$ and constant angular frequency ⍰ . This highly cooperative oscillating network of membrane polarizations prohibits the flow of ions (i.e., charge carriers).

By contrast, under less idealized conditions, the charge carriers in the dendritic network evolve and distribute as a function of the local phase differences of the oscillating components of the membrane polarization. This less idealized general case describes a holoscape (2). The spatial frequency of the phase relations among

$$\theta\ (x\ ,t\ ) = e^{\ i\ S(x\ ,\ t)} \qquad (2)$$

the contours of the holoscape (3), guides the charge carriers in each location to change with an energy proportional to that frequency. In other words, the dendritic holoscape of contours (2) at any moment controls the further time evolution of charge carriers in the entire dendritic network. According to the theory presented here, this pattern of charge carriers (i.e., ionic bioplasma) in the dendritic network of primary sensory cortex processes sensory input. Thus, the dendritic holoscape (2) of this cortex can be regarded as coordinate with image processing.

$$k\,(\,x,\,t\,) = \nabla\ S\ (\,x\ ,\,t\,) = \left(\ \frac{\partial S(\,x\ ,\,t\,)}{\partial x^1}\ ,\ \frac{\partial S(\,x\ ,\,t\,)}{\partial x^2}\ \right) \qquad (3)$$

To return to Beck and Eccles:

> "So as to make the model quantitative we attribute to the triggering process of exocytosis a continuous collective variable q for the quasiparticle. The motion is characterized by a potential energy V(q) which may take on a positive value at stage I, according to the metastable situation before exocytosis, then rises towards a maximum at stage II, and finally drops to zero (the arbitrary normalization) at stage IV."

> "The time dependent process of exocytosis is described by the one-dimensional Schroedinger equation for the wave function Ψ (q ; t)

$$i\,h\,\frac{\partial \Psi\,(q;t\,)}{\partial t} = -\,\frac{h^{\,2}}{2M}\,\frac{\partial^2\ \Psi\,(q;t\,)}{\partial q^{\,2}} + V\,(q)\,.\,\Psi\,(q;t\,)$$

The initial condition for t=0 (stage I, beginning of exocytosis) is a wave packet left of the potential barrier."

And again, Yasue, Jibu and Pribram:

Because the neural wave equation (4) is linear, analysis of neurodynamics can be performed within the realm of conventional mathematical analysis. For example, the existence of solutions to the neural wave equation (4)

$$i \nu \frac{\partial \Psi}{\partial t} = \left(- \frac{\nu^2}{2} \Delta + U_{ex} \right) \Psi \qquad (4)$$

for a wider class of external static potentials Uex is known (Kato, 1964). The use of the neural wave equation in neurodynamics opens the possibility to represent the dendritic microprocess within a new mathematical framework.

It seems worthwhile to notice here that the formal similarity between neural and quantum processes has been pointed out both in physics and in neurology. In physics, Margenau (1984) has suggested that a process similar to electron tunnelling occurs in the neural microprocess. Hameroff (1987) has developed the theme that soliton waves occurring in microtubules could account for dendritic processing. And in the context of the current appendix, the formulations of Frölich (1975), Umezawa (Stuart et al., 1978; 1979), and Singer (Singer, 1989; Gray & Singer, 1989, Gray et. al., 1989) become especially relevant. Further, as noted in Lectures 2 and 4 of this volume, Gabor developed a communication theory based on psychophysics that used the same formalisms as those used by Heisenberg in his descriptions of quantum microphysics. From the neurological standpoint, the holonomic brain theory is based on these proposals. Neurodynamics as developed in this appendix incorporates this formalism in a mathematical model in which the fundamental equation is of the same form as in the quantum theory.

Finally, from Lecture 4 of Brain and Perception:

"Activity in axons and in other dendrites such as those stemming from reciprocal synapses produce depolarizations and hyperpolarizations in the dendritic spines. The postsynaptic effects are ordinarily invoked by chemical transmitters whose action is modified by other chemicals that act as regulators and modulators."

These postsynaptic effects must overcome an obstacle before they can influence spike generation at the axon hillock.

"The stalks of the spines are narrow and therefore impose a high resistance to conduction (active or passive) toward the dendritic branch. Spine head depolarizations (as well as hyperpolarizations) must therefore interact with one another if they are to influence the action potentials generated at the axon hillock of the parent cell of the dendrite."

Thus the activation of interacting polarizations "occurs in parallel, is distributed, discontinuous and resembles in this respect the saltatory mode of conduction that takes place from node to node in myelinated nerve' (Shepherd et al., 1985, p2193). In the holonomic brain theory such parallel processing is described as nonlocal and cooperative and is represented by a Hilbert space. The mathematical similarity between the quantum and neural mechanics can [thus] have a basis in neurophysiological reality: For instance, as described in the epilogue to these lectures, the microtubular structure of dendrites can serve to provide cooperativity by way of boson condensation to produce soliton or phonon patterns of excitation practically instantaneously (Frohlich 1968, 1983, 1986; Hameroff 1987)."

The Mind/Brain Relationship :

Despite these agreements as to the details of the relevant synaptodendritic process, there remains an important point of disagreement between Eccles and myself which surfaces only tangentially in these quotations. Eccles views mental processes as unidirectional causal influences on the operation of the synaptic mechanism. By contrast I see the interaction between the physiological and the psychological process as reciprocal. The evidence for such reciprocal interaction at every level (subsynaptic, synaptic, neuronal and neural systems) makes up the substance of the various lectures composing *Brain and Perception* (1991). Reciprocity leads to bootstrapping, that is, self organization, within the brain/mind matrix.

What is missing in Eccles account, is the emergence of mentality (including consciousness) from the operation of the neural process. This is an inconsistency: In the paper presented at this conference, Eccles makes an excellent case for the emergence of feeling and self-consciousness as rooted in the evolutionary development of the very same synapto-dendric cortical architecture which he claims is receptive to psychological influence. In his view, however, this development only "allows" mind to influence brain. Still, Eccles felt sufficiently comfortable with the view that mentality emerges from an interaction between biology and culture to write a book *The Self and its Brain* (1977) with Karl Popper a strong advocate of the emergentist view.

My own stance begins by taking computer programming as its metaphor. At some point in programming, there is a direct correspondence between the programming language and the operations of the hardware being addressed. In ordinary von Neuman configurations, machine language embodies this correspondence. Higher order languages encode the information necessary to make the hardware run in ever more abstract and generally useful languages. When the word processing program allows this Afterword to be written in English, there is no longer any similarity between the user's language and the binary of the computer hardware. This, therefore, expresses a dualism between mental language and material hardware operations.

Transposed from metaphor to the actual mind-brain connection, the descriptions of the operations of the neural wetware made up of dendrites and synapses and the electrochemical operations occurring therein, seem far removed from those used by behavioral scientists to describe psychological processes. But the distance which separates these languages is no greater than that which distinguishes word processing from binary.

What is different in the mind-brain connection from that which characterizes the program-computer relationship is its intimate reciprocal self-organization at every level. High level psychological processes such as those involved in cognition are therefore the result of cascades of biopsychological bootstrapping operations rather than the result of solely top-down programming procedures.

Eccles proposes that the elementary neurophysiological operations of dendrons have a counterpart in elementary psychological operations he calls psychons. He has been severely criticized for failing to delineate what he conceives to be a psychon, that all of his beautifully detailed descriptions are limited to dendrons. If we take seriously the possibility that at the dendron level something is occurring which is akin to a computer being programmed in machine language, it behooves us to delineate the psychon. A reciprocal rather than a unidirectional causal relationship would be more productive, allowing bootstrapping of mind-brain organizations. Beck and Eccles appear to recognize this when they state that "physicists will realize the close analogy to laser action, or more generally, to the phenomenon of self organization." This statement comes pretty close to my own formulation which used the optical laser produced hologram as its initial metaphor for processing at the synapto-dendritic level (Pribram 1966).

Computers process information in terms of Boolian BITS, the amount of processing achieved being measured by Shannon's unit, the reduction of the amount of uncertainty. The holonomic brain theory is based on the evidence that the unit of processing in the cortical receptive dendritic fields, is a quantum of information, a Gabor wavelet or similar Hermetian. But Gabor, as did Shannon, defined his elementary unit to deal with the efficiency with which human telecommunication could proceed. As an hypothesis, therefore, Pribram's *Brain and Perception* takes the idea that a quantum of information describes not only an elementary neural but also an elementary psychological communicative process. In short, the biopsychological language that corresponds to computer machine language is a language based on the quantum of information. In Eccles' terms, the quantum of information, measured in Gabor-like terms, which has been found to describe processing in a dendritic receptive field, is also a measure of the psychon. The contributions to this publication specify various examples of psychons in the biopsychological language of mind-brain interactions at the level of sensory systems.

This conference and its proceedings, therefore, provide an opportunity to examine the convergence of proposals for the how of the mind-brain relation: proposals in detail, not just in philosophic stances. The fact of the influence of psychological process on brain function has been demonstrated in a variety of studies using both micro and macrorecordings of brain electrical potentials. Some of these studies are presented here by Barry Richmond, Bruce Bolster and Walter Freeman. Others were reviewed in Brain and Perception. Still others are in progress in B.R.A.I.N.S. and were shown in preliminary form during the conference. The emergence of the capability of higher order psychological processing as a function of higher order synapto-dendritic organization is the burden of Eccles' presentation, a view most scientists are comfortable with. This is indeed progress. The resolution of remaining differences may not be far away.

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