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Quantum processes and dynamic networks in physical and biological systems

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QUANTUM PROCESSES AND DYNAMIC NETWORKS IN PHYSICAL AND BIOLOGICAL SYSTEMS

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Dedicated to my three creative explorers and freedom-seekers,

Rachel, Erik, and Noah

ABSTRACT

Quantum theory since its earliest formulations in the Copenhagen Interpretation has been difficult to integrate with general relativity and with classical Newtonian physics. There has been traditionally a regard for quantum phenomena as being a limiting case for a natural order that is fundamentally classical except for microscopic extrema where quantum mechanics must be applied, more as a mathematical reconciliation rather than as a description and explanation. Macroscopic sciences including the study of biological neural networks, cellular energy transports and the broad field of non-linear and chaotic systems point to a quantum dimension extending across all scales of measurement and encompassing all of Nature as a fundamentally quantum universe. Theory and observation lead to a number of hypotheses all of which point to dynamic, evolving networks of fundamental or elementary processes as the underlying logico-physical structure (manifestation) in Nature and a strongly quantized dimension to macroscalar processes such as are found in biological, ecological and social systems.

The fundamental thesis advanced and presented herein is that quantum phenomena may be the direct consequence of a universe built not from objects and substance but from interacting, interdependent processes collectively operating as sets and networks, giving rise to systems that on microcosmic or macroscopic scales function wholistically and organically, exhibiting non-locality and other non-classical phenomena. The argument is made that such effects as non-locality are not aberrations or departures from the norm but ordinary consequences of the process-network dynamics of Nature. Quantum processes are taken to be the fundamental action-events within Nature; rather than being the exception quantum theory is the rule.

The argument is also presented that the study of quantum physics could benefit from the study of selective higher-scale complex systems, such as neural processes in the brain, by virtue of mathematical and computational models that may be transferred from the macroscopic domain to the microscopic. A consequence of this multi-faceted thesis is that there may be mature analytical tools and techniques that have heretofore not been adequately recognized for their value to quantum physics. These may include adaptations of neural networks, cellular automata, chaotic attractors, and parallel processing systems. Conceptual and practical architectures are presented for the development of software and hardware environments to employ massively parallel computing for the modeling of large populations of dynamic processes.

Once the monks of the Eastern Hall and the Western Hall were disputing about a cat. Nansen, holding up the cat, said, "Monks, if you can say a word of Zen, I will spare the cat. If you cannot, I will kill it!" No monk could answer. Nansen finally killed the cat. In the evening, when Joshu came back, Nansen told him of the incident. Joshu took off his sandal, put it on his head, and walked off. Nansen said, "If you had been there, I could have saved the cat!"

Mumonkan [1]

What does it mean to understand a picture, a drawing? Here too there is understanding and failure to understand. And here too these expressions may mean various kinds of thing. A picture is perhaps a still-life; but I don't understand one part of it: I cannot see solid objects there, but only patches of colour on the canvas. - Or I see everything as solid but there are objects that I am not acquainted with (they look like implements, but I don't know their use). - Perhaps, however, I am acquainted with the objects, but in another sense do not understand the way they are arranged.

Wittgenstein [2]

It is not so much our judgments as it is our prejudices that constitute our being... the historicity of our existence entails that prejudices, in the literal sense of the word, constitute the initial directedness of our whole ability to experience. Prejudices are biases of our openness to the world. They are simply conditions whereby we experience something - whereby what we encounter says something to us.

Gadamer [3]

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1 Zen Classic of Koans and Commentaries (trans. by Zenkei Shibayama Roshi)

2 Ludwig Wittgenstein, Philosophical Investigations, (trans. by G. E. M. Anscombe), Macmillan Company, New York, 1969

3 Hans-Georg Gadamer, Philosophical Hermeneutics (trans. by David E. Linge), Univ. of California Press, Berkeley, 1976

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PREFACE

For years certain fundamental questions have occupied my attention. These have almost always been interdisciplinary problems crossing over between physics, mathematics, biology and computer science (in the latter I will include most of artificial intelligence and pattern recognition). These questions have governed my choices and directions of academic and professional study research, those of both a formal and an informal nature. Most clearly these questions brought me into selecting and structuring this PhD program as I did, with the help of a wide and remarkably powerful committee of professors and advisors who are themselves involved in much interdisciplinary research in these same fields. It is clear that the work that is summarized within these pages and the structures that have been established for future research could not have been accomplished without this special scientific circle of mentors, colleagues and critics, including especially:

Dr. David Bohm (late), Birkbeck College, University of London
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It is difficult to make an appropriate expression of acknowledgment to these individuals and others who have in so many different ways contributed to the direction and substance of my work and to my overall learning in the interrelated fields of study that have comprised my doctoral program. I only hope that with future investigations and programs I will be able to contribute to the grand picture in a substantive and useful way.

The primary questions as I expressed them in my Doctoral Learning Agreement have continued to be at the forefront of my thinking but there has been a considerable amount of clarification and revision. Indeed, during the course of studies leading to the writing of this dissertation, new information and the discovery of new approaches has helped me immensely to clarify what I now understand to be some of the fundamental problems and the questions that must be asked, as well as the experimental directions that need to be examined. The process of reflection and revision has been strongly affected by the multidisciplinary activities in my professional activities and has contributed to a predominating philosophical overtone to this work, making it quite different from the usual physics paper or thesis. One of the fruits of these long investigations has been a renewed sense of the critical importance in approaching the 'quantum domain' as a philosophical investigation not to be separated from what is traditionally viewed as the practice of physics.

Goals and Intentions

If I am to succinctly and concisely state the whole purpose of this work and what is my intention (and in doing so, what is the fundamental thesis for which this is a dissertation), then it should be here at the very beginning, so that the reader can have some guidepost with which to walk through the sections that follow.

My thesis in its complete scope (and far beyond the limit of the doctoral research programme) comprises the following sixfold points:

- A quantum logic is fundamental in Nature and universally present throughout all natural phenomena, from the microphysical to the macroscopic, including complex biological and neurological systems.

- This quantum logic manifests itself in processes that have characteristics of superposition, non-locality and chaos when examined by classical measurement operations that are inherently localized and non-holonomic.

- This quantum logic is fundamentally connected with wholistic, indivisible processes (the holoflux) that are field-like and network-like in structure and behavior and that operate on all scales and dimensions of Nature.

- The holoflux provides a fundamental process in which individuation and differentiation occurs in a hierarchical set of complex spaces, topological structures that are characterized by non-linear dynamics which are the direct manifestation of stochastic events.

- The process by which coherent, organized, synchronistic behavior occurs across different scales and between different regions of measurable stochastic events is a consequence of the universality of the quantum logic itself and the network structures that constitute the holoflux.

- The quantum logic defines the holoflux through phase relationships among processes that are constituted by stochastic events which are themselves under the influence of other processes within the network of the holoflux, thereby creating a completely interconnected whole of Nature that manifests itself in quantum logical actions.

This is a very bold and far-reaching thesis and obviously far beyond the scope of any one dissertation or research programme. For that reason my focus within my dissertation research has been to establish a framework, both theoretical and experimental, by which investigations along the lines of the above broad and dramatic thesis can be conducted and by which different results from a wide variety of research activities can hopefully be compared and correlated.

If I am to sum up in a few key words the main activities of this research activity that is being reported herein, these words must be: integration, correlation, and synthesis. I have tried to bring together a diverse number of findings and arguments from throughout physics, mathematics, biology and other disciplines, determine ways in which they support and build upon each other, and then develop and synthesize a method for moving forward theoretically and experimentally to advance, confirm or disprove the major thesis. This has led into deep philosophical issues and concerns that bear upon the most basic views that we as humans hold about ourselves and our world, in particular our prejudices and pre-judgments about thinking, knowledge and the means by which we can measure and describe phenomena in our world. What changes in our world-views may be yet to come from investigation of quantum-like processes in Nature are yet to be fathomed, and this small effort is as its title claims, but a prolegomena to future studies.

INTRODUCTION

The goal of this work is one of re-examination and return in both a philosophical and scientific sense. There is a need for discovering fresh beginnings in the quest to understand quantum physics and how it fits into the picture of the greater whole of Nature. What began as a difficult adventure of exploration into possible relationships between quantum mechanics and neural processes within the brain has led to a plethora of possible connections between the quantum and classical, the microscopic and the macroscopic and an investigation into fundamental issues of measurement, scale and geometry. The common ground and connectivity between such superficially disparate phenomena as the mechanics of sub-atomic events and neural processes of perception and pattern recognition may be opening forth into a conceptual and formal foundation that has far wider relevance. This demands a clarification and distinction among concepts and questions as well as a prioritization - what are the important questions to be investigated - and a methodology - how can one test and verify certain very abstract hypotheses?

This work will not provide the far-reaching answers, but it aims to be an initial exploration, a prolegomena in the traditional sense, of the experimental and theoretical landscape that needs to be explored and of the possibilities that may be worth investigating. It is highly interdisciplinary, and that is both by intent and necessity. The questions that are being raised about non-locality, holonomy and interconnectedness on both the physical, neurological and cognitive levels can no longer be asked or answered without an interdisciplinary basis. In a way, the purpose of this work is to build such a basis from which scientific investigations, like vectors, can be directed outwards. Certain basic hypotheses are set forth and these are defended from a theoretical foundation, drawing upon some experiments that have been conducted and suggesting others that can demonstrate or disprove the suggestions. Several of the suggestions are for computer-based models and simulations that can be designed and implemented to serve a variety of theoretical investigations, by no means limited to the domain of quantum physics. However, the immediate need at hand and the focus of this work is to provide the foundation upon which a scientific structure of investigation can be erected.

In the conceptual forest that has grown forth, many similarities and analogies are of a dubious sort and could very well be superficial, likenesses in form but not substance. Others appear to be deeper and worthy of significant investigation, where experimentation may be possible in order to make a determination. Initial work seems to point to what may be a striking mathematical common ground that covers many apparent diverse domains such as the behavior of subatomic particles, dynamical systems of molecules, subcellular macromolecular structures, and neural processes of vision and cognition. This comprises what Finkelstein and Rossler have termed 'endophysics' or 'physics from the inside.' Less robust and seemingly loose connections are of significance, too, from the point of examining how scientific perspectives and connections develop and how useful models and analogies fit together with sensible theories.

In order to approach this highly speculative and theoretical field and to avoid the pitfalls of both imagination and reason, we are led to examine carefully some of the very most fundamental questions and issues underlying quantum physics. Early in this work it became apparent that in order to gain a deeper understanding of quantum Nature one must embark on a journey that is at once both highly theoretical and also deeply personal and psychological, cutting through long-established presuppositions, sweeping out clean forgotten assumptions. It requires one to attack the problem in a deeply phenomenological and ontological fashion that has not been customary within the physical or biological disciplines for a long time (certainly the last 150 years).

For reasons which should become clear within this paper this is not a popular approach by virtue of its demands upon the individual as scientist and person, but the claim being made is that such an approach is necessary. In the course of this work much more than the customary mathematical descriptions will certainly be considered and questioned. In fact one must go so far as to question matters that have generally been relegated in an ancillary fashion to philosophical analysis and psychological introspection. Not in the least we must question the "unreasonable effectiveness of mathematics." [[4]]

We are reminded by a cursory glance at the history of science that it is only recently that scientific validity became bound and limited to a rather finite domain of measurement, namely that which is by consensus considered to provide for reproducible empirical verification. It has not been so long ago that personal experience, of a sort that can be reported and shared but not reproduced in an external mechanism, was considered to be a valid form of evidence. I believe that it is legitimate scientifically to raise the question of whether or not science, and in particular physics and biology, have become too removed from the full range of possible measurement devices (including those for which we now do not have adequate interfaces other than language and discourse between humans) that may be required to properly measure some of the phenomena of interest, especially those involving quantum behavior. It may be, however (and to this I will allude in later sections), that with the advent of biomolecular and bioelectronic devices, and with the development of field-sensitive methods and tools of measurement, there may be possible the kind of experiments and measurements that will bring the gap between what has heretofore too often been labeled 'subjective psychological experience' and the ever-desirable world of reproducible empirical observations.

One aspect of the work that has emerged is the daring assertion that in quantum physics one must face some fundamental challenges to basic assumptions about being and identity, including the observer's own personal ontological and epistemological status. This is a hard challenge yet it is one that must be acknowledged as important in the formulation of any theory or worldview that incorporates quantum theory. It is an unusual claim within such a theoretical field so dominated by mathematical formalisms and it is certainly an unexpected development in the course of this work. One of the consequences of such a claim, however, is that such a psychological consideration is a prerequisite for developing the new kind of intellectual grasp and receptivity required for building a more comprehensive and complete formalism of quantum physics and larger-scale dynamical systems. What are at issue are matters of measurement, scale, order and dimension - ultimately matters of observation and perception. The notion, for instance, that

[4] Title of a well-known paper by E. Wigner; the claim here is that, contrary to Wigner, the unreasonable effectiveness lies in the fact that science, especially physics, has traditionally asked only those questions that lend themselves to formal, deterministic, mathematical expression and has tended to ignore those problems that are not reasonable formalizable.

everyday macroscopic measurement processes are in any way special or correct or more than an efficient and economical means of surviving in the universe is something that certainly must be questioned and perhaps discarded as a cognitive illusion, not that unlike familiar optical illusions where the observer has no strict control over the act of perception despite knowing the 'facts' that override the illusion.

This is admittedly a radical suggestion but it is not intended to reduce the signficance and necessity of having a solid mathematical basis for any theoretic development. Nor is it an attempt at oversimplification. What laws and forms emerge in any interdisciplinary field, especially one such as may relate quantum mechanics and neurobiology, may be more complex than relatively traditional formalisms already in place within the respective disciplines. Non-formal, nondeterministic computation may be an important model and tool for understanding the workings of fields at microscopic and macroscopic scales. However, such computation, while radically different than that of the traditional Turing machine, will not be without its mathematical basis. It is just that such a basis is not likely to be very metric or linear.

The perspectives and viewpoints that enable one to discover such new and radical mathematics are themselves more likely to be realized by persons who have broken through some conceptual barriers and conformisms. These thresholds could be part of some existential 'world-views' that would otherwise have prevented the synthetic-type thinking responsible for the new perspectives. This may seem like a radical and unscientific suggestion, but it is based upon the underlying tenet that some of the major barriers that block such 'integration' problems as the relations between quantum physics and biological and psychological phenomena are conceptual barriers in the minds of the persons thinking the questions and attempting some answers. Such barriers cannot (it is my claim) be crossed by a simple linear progression of thought (such as the advancement and proof of a theorem or the sound demonstration of a physical experiment). There is some kind of non-linear 'leap' involved on the part of the investigator/observer and it is, I believe, not far removed from the leap of 'kensho' or 'sudden-seeing' that the Zen Buddhists and others like them describe. In the course of the studies leading up to this work I have searched for the simple and 'uninvolved' way; i.e., something like a purely formal argument that, for all the mathematics, still amounts to a simple progression from point A to point B. It seems that while the mathematical expressiveness is at hand and can evolve, there is a first step that is not so simple, one that is akin to jumping from point A and finding oneself simultaneously at both A and B.

To reiterate, the point of this work is to advance our scientific understanding, including the development of a deeper mathematical foundation, into a new domain comprising quantum physics and related interdisciplinary fields. In this domain a way of integrating quantum theory with classical, macroscopic phenomena beyond 'basic physics' is sought. So-called 'quantum neurodynamics' is but one particularly interesting and provocative interdisciplinary branch that deals with biological neural communications and neural networks in general. To embark upon this advance into unknown or little-known territory is to engage in a raising of questions and doubts and reassessments - philosophical, psychological, metamathematical. In order to approach such a broad and potentially confusing theoretical spectrum and not get lost in a semantic maze we choose to focus in this work upon some of the principal ontological and epistemological issues that have emerged in quantum theory and in studies that attempt to bridge the gap to the macroscopic world. Attention will be given to several principle schools of research, notably three. These are: the work of David Bohm and B. J. Hiley on the ontological interpretation and implicate order in quantum theory, that of David Finkelstein on quantum networks and other quantum topologies, and the studies of Karl Pribram, Peter Kugler and other colleagues on quantum and holonomic models of neural function and on the fundamental principles of dynamical systems that apply cross-scalar to quantum physical events and biological or mechanical systems.

Early in the doctoral program of which this work is a culminating part, it was stated that one of the key objectives was to raise the right questions and not to expect grand answers. This remains a primary goal of the work that is embodied in this work. More than at the onset of this research, it is apparent that much of the confusion about quantum theory and its ramifications within physics and other sciences comes from a mixture and confusion of languages, mathematical or otherwise. If this work is able to help in sorting out what are some of the important and valid questions to be asked by theoreticians and experimentalists alike and to be tested computationally and in the lab, then it will have accomplished a great part of what it was set out to do.

SECTION 1 ONTOLOGICAL FOUNDATIONS

Physis and Aletheia - Prima Scientia

I begin with a short philosophical discussion of how the scientific spirit of investigation evolved among cultures more ancient than our own and how the very attitude toward what is Nature (and consequently, what it is that one can explore) was far different from what has developed within classical modern science. This approach is hardly meant as a historical diversion but as a means of getting to some of the roots of our problems in reconciling classical and quantum physics and in bringing together seemingly diverse scientific discoveries into a unified picture of the universe. Not a return but a renewal of the sense of Nature as an organic whole, fundamentally interconnected rather than an assembly of discontinuous parts, it is something that may be the missing conceptual ingredient for developing what is sought in a Unified Theory.

Such a conceptual shift is not something that can be accomplished or substituted by either mathematical formalism or experimentation. Indeed it is a psychologically prior ingredient for engaging in the creative theoretical investigations that will produce the kind of formalisms and experimental frameworks that are sought. By no means is it suggested that this philosophical aspect is THE missing key to developing a realistic unified theory. Rather it is a foundational ingredient without which physics is apt to spin its wheels in a torrent of theorizing directed at resolving apparent inconsistencies that may (I emphasize, may) disappear with a transformation of coordinate spaces or a change of frame of reference, much as has been demonstrated by the experience of relativity theory.

Science, and physics most certainly, must retain its analytical methods. There is no turning back to alchemy. However, something was transformed over the centuries and indeed millenia, I would claim, with regard to the way the natural world, the phenomenal universe, is experienced by the scientist as person, as one who approaches to measure and objectify his or her world. The alchemist of the sixteenth century may have had some ontic premises about the way the universe is, and while many particulars may be inaccurate by the standards of empirical physics and chemistry, the sense of interconnectedness and a richer causality is something that may be a lacking key ingredient for modern science to make headway in areas so seemingly diverse as quantum mechanics, neural networks and molecular biology. As no return to the 'golden past' is possible in any facet of life, what is being sought here is not a repeat but a synthesis that finds what was essential and brings it into a new form that can make more sense out of the theories and the data that have evolved over the centuries.

The ancient Greeks had some choice words that were used to describe what science, and particularly physics, claims to be. What originated with the Pre-Socratics has continued up through the present but more often in the background, particularly in the last few centuries, as a tradition of holism and organic thinking in contradistinction to a more dominant mechanist viewpoint about what exactly it is that science does. Philosophers such as M. Heidegger made the emphatic point that one ought to go back to exploring ancient metaphysical and scientific terms in order to better grasp an understanding of how things have developed over the centuries in our commonplace approach toward knowing the world. This point is, I claim, quite relevant in starting any (re)investigation of the roots of quantum phenomena and how wholeness or holonomy may be a fundamental quality of Nature. Such a primal wholeness is not something that is assembled, sum-of-parts fashion, out of what are fundamentally distinct and separate entities that happen to be aggregated by our perception. Rather it is something that is part of the nature of what it means to 'be' - part of the nature of 'Nature.'

Physis [ϕςις] is the origin of the word 'physics', but there is a wealth of meaning that has changed in the course of adding one letter! For the pre-Socratic Greeks and through Aristotle at least, it meant the power and force of emerging, arising, present-ing and enduring. Etymologically it is rooted in *phyein* which translated as the verb 'to grow', but growth itself is something that has come to be understood in a more limited way since the time of Heraklitos and Anaximander. *Physis* encompassed both 'being' and 'becoming' in the conventional senses of both as permanent and changing phenomena. To quote from some of Heidegger's eloquent descriptions of *physis* in his *Introduction to Metaphysics* [[5]],

> "It denotes self-blossoming emergence (e.g., the blossoming of a rose), opening up, unfolding, that which manifests itself in such unfolding and perseveres and endures in it: in short, the realm of things that emerge and linger on." (p. 11)

> "*Physis* as emergence can be observed everywhere, e.g., in celestial phenomena (the rising of the sun), in the rolling of the sea, in the growth of plants, in the coming forth of man and animal from the womb. But ... this opening up and inward-jutting-beyond-itself <in-sich-aus-sich-hinausstehen> must not be taken as a process among other processes that we observe in the realm of the essent." (p. 12)

> "*Physis* is the process of a-rising, of emerging form the hidden, whereby the hidden is first made to stand." (p. 12)

Nature was for the first scientists (my claim: not just the ancient Greeks, but those in many other cultures and times as well [[6]]) more than detach(able) 'physical' phenomena (in our modern sense as not-noumenal) that could be observed and measured, as if from a distance. Understanding did not develop by taking natural phenomena and creating a generalization of what it means to be physical. Rather, from an experience of the power of emerging and enduring, there itself emerged in the minds of the ancients a felt sense of what had to be called *physis* and what did not so qualify. There was a different sense of what were the boundaries of Nature. *Physis* encompassed those qualities and events that are today labeled as mental, psychic, vital; what was held in

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[5] M. Heidegger, An Introduction to Metaphysics, tr. by Ralph Mannheim, Anchor Books, NY, 1961

[6] Two cultural references should suffice for this adjunct claim - ancient China and India. Consider the I Ching or the Tao Teh Ching, dating from circa 2500 BP and even earlier in the case of the former. Descriptions of the natural world indicate a view of Nature as an organic, living whole where interconnectedness is a fundamental quality, not an oddity. The act of approaching Nature and learning about its ways was considered to be a spiritual discipline that involved all of a person's faculties, not merely the analytical dimensions of the intellect.
Similar texts from the Rg Veda and the Upanishads display a comparable set of attitudes and orientations among the 'first scientists' of India in the first millenium BC.

contrast to *physis* was *thesis* - law, rule, ordinance, the *nomos.* further, *physis* was restricted by *techne* [τεκνε] - creating, planning, building, formulating and producing.

Aletheia [αληθεια] was another quintessential concept for the ancient Greeks as they began to formulate an intellectual framework for examining the universe around them. Although the word is often translated as 'truth,' *aletheia* has a deeper and wider sense of birthing, emerging, unfolding, disclosing. *Eiletheia* was the name of the Minoan mother goddess in her aspect of giving birth, and so 'truth' had associated with it much more than the ideas of correspondence or coherence, but also a sense of a new life-form emerging, a new being, a passage and change of existence, a process of change and becoming. It is interesting to reflect on the different typical associations one makes with the birth process and to think of how that birth-dimension is missing in most discussions about truth in science. Truth becomes more of an inception, a start, a beginning-process that is not final, nor in any way ever complete, any more than the child is a complete version of the adult. Truth is also much more than something 'that works' - a pragmatic, useful theory or law that can be applied with little or varying degrees of risk at failure.

Everything about quantum and non-linear, dynamic systems (whether it is the neural processing of the brain or the behavior of highly complex inorganic systems that exhibit instabilities, bifurcations and moments of chaos) points to certain key factors involving measurement, scale and the delineation of the observation process. What matters for detecting stability versus instability is how one measures the system and at what scale. Consider even the simplest dynamic attractor functions such as the Lorentz system

$$\begin{aligned} \dot{x}_1 &= s(-x_1 + x_2) \\ \dot{x}_2 &= rx_1 - x_2 - x_1 x_3 \\ \dot{x}_3 &= -bx_3 + x_1 x_2 \end{aligned}$$

which with its absence of asymptotically stable equilibria or periodic orbits is deemed a 'strange attractor.' At one scale of spatial or temporal measurement there is nothing interesting; at another, a whole world of dynamic and unpredictable behavior; at still another, the chaos is seen to play a definite and predictable part in the whole system. What matters here is not the type of system - mechanical, molecular, atomic - but the qualitative characteristics of the dynamic processes. In the case of systems such as the Lorentz attractor, there is a sensitive dependence upon initial data which can result in radically divergent dynamical behavior. Measurement of quantum processes at the microcosmic scale is a statistical process and casts into question the role of initial conditions (which may be un-measureable) having an extraordinary role in affecting the final results of those measurements. This is not to be construed as an argument for hidden variables any more than that the behavior of the Lorentz attractor shows evidence of hidden variables. Lyapunov exponents, computed by

$$L_i = \lim \ (1/t)\log_2\left(\frac{p_i(t)}{p_i(0)}\right)$$

for the ith exponent of the ith dimension in a sphere within phase space can provide a measure of the convergence or divergence of such an attractor but the factors that govern orbits within a limit cycle (as in a simple harmonic oscillator) and therefore their convergence are to be found in comparatively simple relationships that are more highly dependent upon initial conditions than upon subsequent evolved states.

To speak of truth in such matters or a moving towards truth with an improved scientific theory is to speak of creating new modes of perception, new dimensional characteristics. It is a measurement process where the scale and the window of viewing are being changed and adjusted in order to find the best view that gives the most interesting information. This is a creative and synthetic process. It does not follow the old traditional rules of theoretical and experimental investigation that worked all right (but not necessarily all that well) for classical science. Those rules led to strongly reductionist and mechanistic models being applied to everything from biology to physics and with many bad fits and loose ends resulting. The new scientific process of investigation that is emerging in the study of non-linear and dynamic systems, it is claimed here, is one of a truth-seeking that is close to the original sense of *aletheia* - birthing, generating, giving forth (with both pain and gladness), and opening up of new worlds and new experiences.

Heidegger can again be a source of vision on this subject. In the same work cited above [2] he translates aletheia as unconcealment and declares that the essence of truth as unconcealment is inseparably bound up with the essence of being as physis. He writes:

> "[For the ancient Greek] The essent is true insofar as it is. The true as such is essent. This means: The power that manifests itself stands in unconcealment. In showing itself, the unconcealed as such comes to stand. Truth as un-concealment is not an appendage to being." (p. 87)

What can this mean for our search for integration and unity in fundamental physics and for implications that cross not only scales of size but orders of complexity? Why is it important to cultivate a renewed sense of physis and aletheia in the context of quantum mechanics, neurodynamics and the converging multiple disciplines that are the subject of this work and others like it?

Self-Organization

The reason, I claim, is that it is in the nature of quantum reality and the nature of complex, highly organized but generally dissipative systems, where stable states and chaos fit closely and delicately together, that verbs like 'to be' can only be described as emerging, unfolding, growing, and to use a very key contemporary phrase, self-organizing. Being as a steady-state affair and truth as an attribute are conceptually inadequate to handle the phenomena exhibited by highly complex systems. Something new is required in the way science can think about its subject. The shift from classical to quantum thinking cannot be expressed simply in a transition from Maxwell's equations to those of Schrodinger and Dirac.

What is self-organizing phenomena from an epistemological point of view? It is creative unconcealment, novel and unpredictable disclosing, opening-forth, like a birth process. It is truth/being in the way that Heraklitus and Parmenides both may have perceived things to be. It is how Heidegger describes aletheia, not how truth is usually conceived. One views a cellular automata machine generating a world like Conway's Life or something similar. Or one views Kugler's Insect World evolving as artificial insects deposit molecular by-products in a field. Or one examines the growth of microtubulin molecules into regular but imprecise structures under the influence of an acoustic vibration. What is special about such systems is that out of a large set of simple and predictable behaviors something unique emerges, something that could not be fully predicted in advance of actually letting the system run itself. The result is truth-as-disclosing/unconcealing. This does not mean, however, that what is true has no permanence or determinism. The point instead is that to mix up permanent, static processes with truth and for that matter with being is an error and that the primary quality of value is that of creative disclosing and revealing.

The thesis that is argued throughout this work and for which what follows is intended as a promotive scientific argument, is simple and straightforward. The universe on all its levels, from the microcosmic quantum states to mesoscopic or macroscopic phenomena (molecular, biological, and extending to large-scale events like populations of life forms, behavior of weather patterns, ecological activity), all the way to the cosmological level, is a self-organizing system. In a word, it's alive - and only when the fundamental orientation is made that one is dealing with organic, self-organizing phenomena can one proceed to build the formal theoretical structures that can encompass such a universe and make sense of how its parts interact, including events that are classed as non-local or coincidental.

Process Vs. Stasis

Process is not a set of interactions among static points in space and time but something from which the latter can be extrapolated in perception. Process is not one focal object moving from state to state and ending up in some final condition. Too much identity and permanence is assumed in this everyday but pervasive classical model. If the concept we have of a process is what worked for Newtonian mechanics but will not work for quantum mechanics, then we invite all sorts of confusion once we begin to speak of processes at the microphysical and macrophysical levels and how or why quantum events might be present.

What is a process? Or, for that matter, what is action? Is not action the fundamental entity in Nature, which is then bound into mass, length and time as ML2/T? Consider but one aspect of the quantum theoretic integration problem (another way of trying to concisely express the matter of quantum-like phenomena across multiple scales of phenomena) - that of non-locality. Specific actions are involved - namely, the generation of photons and the functioning of the measuring devices, including the reversal of spin on one photon. Can non-locality be understood without carefully examining the way we as observers describe the actions surrounding the perceived non-locality? What are some of those actions, and how does a set of actions constitute some kind of more unified behavior for which we might apply the word, 'process?'

Quantum mechanics and all of the dynamic systems that may be associated therewith seem to involve process as a fundamental but our understanding is often very classical. The common-sense notion of a process is one of interaction and change of state among definite objects, regardless of scale or physical status. A process in this sense is a motion from one state or set of states through some number of intermediate states to a final state. Moreover, all the rules of conventional mathematics are assumed; for instance, associativity and commutativity. This seems to work alright for events on the everyday macro-scale. For instance, there are metabolic processes in cellular organisms that involve discrete measureable interactions among nucleotides, amino acids, proteins and enzymes, etc. Molecules combine and recombine, reactions occur and states change. These are manufacturing processes, such as for fabricating plastics or steel. Particular sequences or even parallel operations take place according to a pre-defined algorithm and the result, within some window of error, is a specific state, namely that of the desired product. There are processes of discovery and fulfillment that describe individual or group psychological activity. Again, there are measureable types of action, steps and state-changes, that collectively in some orderly fashion meet a certain set of requirements for mental states to have been reached by the individuals concerned. No matter how abstract the language, one is still dealing with classical types of events.

A good illustration of abstract processes can be found in computer science and specifically in the development of certain parallel processing languages and algorithms. A process is typically some operation of a logic circuit (e.g., a microprocessor) that stands as a self-contained unit of action whereby some input data is transformed into another value. A variable changes value; i.e., state. It could be as simple as x := x +1. It could (and this is often forgotten!) be even simpler: x := x! The Communicating Sequential Process model (CSP) and the OCCAM language that developed out of the Computing Laboratory at Oxford under Tony Hoare in the 1970's (which eventually became implemented as the native language on transputer microprocessors) are examples of a formal language built upon elementary processes[7]. In the operation of the processor hardware, one logical process encompasses a single change of state involving the workspace (pointers to various local variables), vector space (pointers to arrays) and the instruction pointer. It is a coordinated transform operation that involves different portions of the silicon logic but at the completion of any process, no matter what variables were modified in local or external memory, one thing is certain and that is that the machine as a whole unit is at a closure point, ready to begin the next process. Furthermore, any process can be executed independently of any other - it is an elemental unit. Of course, process A may require communication (exchange of variable information) with another process B, and this may entail being put into a wait-state, but that is where parallel architectures come into the picture as the computational solution.

Nonetheless, in OCCAM and in other formal process models, the elements are still some kind of static atomic set, a group of irreducibles. In the final analysis the universe is composed of things that do not change, and if observation and measurement finds that they do in fact change, even over 10**15 years, then the threshold separating elements from composites is lowered a notch and there is a new population of elementals (e.g., the progression from atoms -> particles -> quarks -> colors -> ?). This has certainly characterized the conventional approach in many sciences, not only particle physics but biology and psychology. There is a global mind-set at work

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[7] Hoare, C. A. R. (1985)

here, one that permeates all of the sciences with a set of pre-judices and pre-dispositions, and that is the belief in deterministic, permanent *things*, objects outside of us the observers and somehow being the same unchanged object regardless of what day we observe it, no matter what has transpired between the last observation and this time here and now.

That is a bold assertion when we step back and look at it, so global and universal! We just take it for granted and let our entire lives be governed by it, leading to the fundamental classical viewpoint. The fascination and demand for some kind of static, Paramenidean permanent substance has been with science and in particular physics from the very beginnings, and a more Heraklitean view has always been on the fringe. The latter is a view that does not start with the parts but with the whole - in other words, with a field rather than with particles. However, if indeed our science is converging to where quantum physics is important for discussions of cellular behavior due to soliton wave transmission in the cytoskeleton, or where the latter may play a key role in dendritic network activity in the brain and thereby be significant for learning, memory and pattern recognition/invention, then there needs to be a way to deal with process as pure action, which manifests (when measured) in arrangements and configurations of objects (particles, molecules, cells) but which also can be examined from a holonomic and field-oriented perspective, one that starts from the whole and works inward to greater detail as becomes necessary or appropriate.

Re-Orienting and Re-Positioning

To reiterate some of the major claims in this work, one is that the fundamental concepts used in quantum physics still have dominant classical connotations which obscure discussion and investigation of macroscopic and complex systems that may have quantum-like behavior. Until a more proper break can be made out of the classical ontology into a true quantum world of discourse, it will be practically impossible to integrate quantum theory with other domains of physics and the biological sciences.

This claim perhaps needs to be restated, even at the cost of seeming to be a more radical assertion. Quantum phenomena have traditionally been considered to be some kind of special case that exists at the microphysical level and which may have some mesoscopic reality that could be determined experimentally. The ubiquitous SQUID (superconducting quantum interference device) has emerged to serve such an experimental need. However, the idea of a generalizable quantum structure extending across multiple scales and dimensions has been a foreign concept. The notion of a superposition of states is acknowledged as appropriate for discussions of photons but not for proteins, neurons and perceptual or cognitive states. The suggestion of such generally brings caveats and criticisms of overextended analogies and confusions of qualities and properties among disparate substances. However, research in theoretical biology and biophysics, notably by Rashevsky, Rosen, Kugler, Shaw [[8]] and others, coupled with brain studies by Pribram, Yasue, Jibu and others [[9]], is now pointing the way to a measurement process by which such claims can be substantiated and investigated. This entails the measurement of fields rather than points and

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8 Kugler & Turvey (1988), Kugler & Shaw (1990), Rosen (1991)

9 Pribram (1990), Pribram (1991)

particles, where now the action of the whole field as-a-whole, distinct from being merely the aggregate or integral of many points, is the most important factor and heretofore the most neglected. But how does one speak about a *field* that is more than a collection of points? Or shall one say, something that is ontologically different than a collection of things? Ordinary language and common sense thinking force physics into a framework that is difficult to escape - the universe is made of objects that can be identified, de-scribed [[10]], and which are assembled into larger units and disassembled into smaller pieces down to some fundamental iota. A field is always made of parts and elements that are distinct from one another. Process and communication among forms that are not objects, entities that maintain their identity by virtue of repeating a cycle of action, like the visual illusions that are generated by spinning propellers and vibrating strings - this is not the ordinary perception of the physical world. However, it may be the only reasonable way to look at the micro world where quantum effects manifest themselves and perhaps also for the macro world where quantum effects may be hidden and more present than at first meets the eye.

As will be developed in subsequent sections of this work, there has been a strong need for an integrated computational and analytical approach to be developed that can be applied and that can evolve for attacking the problem of field interactions. If there is some common ground between quantum fields and neurodynamic fields - if in fact there is a hierarchy of similar quantizable orders within Nature, ranging from the microphysical realm to the biological and cognitive domains, studying fields as continuous holonomic structures (instead of aggregates of discrete point-like entities and events) may be the missing link, and to do that a different order of mathematics and computation may be necessary. Thus a great part of my work in this project has come to focus upon the semi-theoretical, semi-practical aspects of developing a groundwork for field processing studies and the modeling of networks and sets of processes. This includes the architecture for a Parallel Field Computer and the Cybersoft artificial intelligence software that can be employed for both simulation and experimental studies in physics, biology and neuroscience. As with many research projects, there is often much more foundation work that needs to be done than first appears to be the case, and this project is no exception. The greater part of the doctoral project has been devoted to building a systemic foundation for discourse and formal modeling of quantum and holonomic phenomena - it has been a prelude and prolegomenon. If the Parallel Field Computer and Cybersoft architectures are the main concrete fruit that are seen to bear from my current work then that will itself be a satisfactory accomplishment. Hopefully there is more, hidden between the lines.

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10 de+scribere, to write down, to specify and identify

SECTION 2 QUANTUM PROCESS DYNAMICS

The best approach to presenting this admittedly speculative model of quantum holonomic process theory seems to be one of recounting its evolution over time, bringing in the different perspectives from quantum physics, neuroscience and non-linear dynamic systems theory. The greatest difficulty is in attempting to assimilate and correlate works and theoretical models that on the surface appear to be too divergent and even contradictory for comparison, let alone integration. The lines of reasoning I have followed have led to the belief that such integration is not only significant but necessary, as difficult and tenuous as it may seem at the beginning. It is my hope that this rationale will appear legitimate to the mind of the reader.

A Re-Statement of the Major Theme

The Problems

Quantum theory has not been able to give a satisfactory answer to certain basic problems without making assumptions that are overly complex (e.g., superluminal connections, wave function collapse, many-worlds) or in contradiction to experimental evidence (e.g., hidden variables). These problems include:

- Individual quantum events (not as statistical populations)
- The fundamental wave-particle duality
- Non-locality and the EPR-type processes
- The relation of a quantum system to a larger encompassing whole (the 'reality' issue [[11]])
- The duality of quantization and holomorphism or continua

Brain theory has not been able to give a satisfactory answer to its own class of basic problems. In some cases not even an unreasonably complex answer has yet to emerge although models of approximation abound. These basic problems include:

- The transformation of sensory events into neural impulses and back into field processes within dendritic fields (the 'dendritic field / axon hillock' problem)
- The transformation of sensation into perception
- Cortical learning and memory
- Non-local interactions among regions of the brain
- Imagination and innovation with relation to recognition
- A duality of quantized events and holonomic processes

[11] The essential question of whether or not the quantum system that is measured is more than a useful construct for predicting events that are themselves just useful constructs (the Copenhagen Interpretation). One of the issues must be whether or not the traditional concept of 'reality' as something that remains and can somehow be re-measured (re-verified) is valid - "Is Nature real?" might be the extreme form of the question. (Or is it a reasonably steady flow of manifestings and projectings?)

Biology has in general a similar set of unsatisfactorily answered problems that are closely related to those in quantum theory and neuroscience and which pertain in great part to complexity and self-organization. These quandaries include:

- Stability and control in chaotic or catastrophic systems
- Non-local connections among organisms
- Self-organization and morphogenic development
- The generic duality of quantum and holonomic behaviors

In the first place the similarities and common points among these problems lead to an intuition that perhaps there may be some unity among solutions to these problems, if such solutions do in fact exist. Secondly, the scope of these problems and the failures of conventional, somewhat classical approaches gives rise to an intuition that something may be in need of significant revision within basic quantum theory and throughout the physical and biological sciences. More than a few minor changes in the equations may be in order - what is tantamount to a paradigm shift seems to be required, yet the paradigm may already have been uncovered and presented long ago in the initial discoveries of both quantum theory and connectionist models of neural organization.

The Hypotheses

A holonomic reality is theorized to exist at the most fundamental pre-space-time scale of quantum physics and this holonomic nature, a holomovement or holoflux [[12]], is considered to be intimately related with the indeterminate and non-local behavior that quantum theory declares and experiment verifies. Major work in this area has been originated and contributed by Bohm, Hiley, co-workers and colleagues.

A holonomic structure is theorized to exist in the neurodynamic processing of the brain and this holoscape or neural holoflux is considered to have some fundamental similarities at the level of mathematical formalism with quantum physics. A quantum nature of information (Gabor) is presented as an example of uncertainty between frequency and space-time that is similar to the uncertainty of position and momentum (Heisenberg). This work has been primarily originated and extended by Pribram and co-workers, especially Carlton, Yasue and Jibu.

A dynamic network of fundamental processes prior to space-time and irreducible to elementary static objects is theorized to be the basis of a fundamental quantum universe, expressible as an algebra of processes that generate higher-level phenomena through the interactions in the quantum net. This work has principally been the fruit of Finkelstein and co-workers.

These three and apparently divergent developments in theoretical physics and neuroscience are indeed the pillars of a tripod that converge together to form the basis of a theory that pertains to micro- and macro- physics and to the biological and neural sciences. It may aptly be called a

[12] K. Pribram coined the term 'holoflux'. It is suggestive of both movement and structured dynamic process, whereas 'holomovement' may suggest a movement of some Thing within some Space, and likewise 'holoscape' may inadvertently suggest something like a landscape in a defined space-time geometry, neither of which is an intended connotation.

theory of quantum holonomic dynamics, and its basic claims have been outlined earlier. The universe is a dynamic process that is quantized and a holoflux. Within the flux, the processes that are generated by the whole, are many levels each with a complex interior structure that has a quantized and holonomic nature as well. Viewed locally some of these structures will appear as a stochastic process but from the perspective of the whole there will appear some types of coherence and order.

Without question there are significant differences between the ontological interpretation developed by Bohm and Hiley and Finkelstein's quantum dynamics. The reality of particles, for one thing, is itself radically different between the two models. These differences will be discussed in more detail later below. However both suggest that a holonomic interconnectedness at the quantum level and potentially at larger scales is fundamental in Nature and cannot be disallowed as an artifact or coincidence.

In attempting to understand the dynamics within the holoflux the work of Prigogine, Rosen, Kugler, Prueitt and several others is very significant again as a foundation and as a means to developing both a theoretical formalism and experimental verification. A wide variety of non-linear dynamic systems in the mesoscopic and macroscopic domains demonstrate both quantum and holonomic behavior. The stability mechanisms of dissipation and escapement that control these systems and regulate chaotic states are operations that are built from stochastic activity within elements of the system and such activity is theorized as being essentially a quantum-like, holonomic field process.

Briefly put the problem in determining both stronger mathematical expression and experimental verification of the quantum holonomic dynamics is one of measurement and scale and the solution consists principally in viewing the phenomena as a unified field (not a continuum of points and particles but a holoflux that is ontologically indivisible) rather than as a collection of points and point-like objects. It is a matter of a paradox that is directly consistent with the wave-particle dualism - a whole-parts duality whereby every phenomenon can be seen as a collection of separable entities or as an inseparable member of a whole.

If the basics of the quantum holonomic dynamics theory can be accepted for purpose of argument and study (which may be tantamount to the assumed premiss in a mathematical induction) then given the parallelism between quantum physics and neurobiology, the latter affords a promising opportunity to start serious investigation into the theory. Experimentation on the quantum microphysical level is obviously both difficult to the extent that it is possible and extremely limited in its possibilities. However, despite the obvious problems of experimental biology and neuroscience, it is a great deal easier to devise experiments that may give evidence for or against the holonomic process theory of the brain and therefrom lead to evidence for or against the larger theory being promoted here. Likewise the study of non-linear dynamic and chaotic systems in biology (including experimental psychology) can, if the basic tenets of the theory are accepted for the moment, provide a macro-scalar platform for study of the theory as it should apply to other less observable and more perturbable dimensions of Nature.

Given the prospect that studying field processes in the brain will lead into understanding the same types of processes in other level including the microscopic, it follows that efforts should be directed at devising methodologies and tools for doing such brain/biology-oriented research but in a way that can efficiently and with a minimum of error be translated into models for the microphysical and other hard-to-model/test dimensions of Nature. In other words, if there is more than some interesting analogies and superficial likenesses between what goes on inside atoms and particles and what goes on inside brains and neurons, then studying the larger and more accessible systems can provide useful knowledge about the smaller systems.

Such being one of the basic cornerstones of the theory, it follows that appropriate tools for modeling, simulation and analysis of the larger, neural-scale processes should be designed and implemented, but with a definite view toward the broader cross-scalar applications. This leads to the experimental or engineering side of the theory, which concerns the development of computational tools that are appropriate for studying field processes and thus are different from the customary tools that are oriented to the classical notion that a field is a set of points and not a complete indivisible whole.

The critical need for computational modeling tools that can assist the theoretical study of cross-scalar quantum behavior has emerged as one of the most important aspects of this work that has heretofore been poorly addressed. Once again this is a bold claim but the bibliographies and records of current research point this out. This doctoral project has itself evolved from an initial perspective that was primarily abstract - mathematical and philosophical - to one that emphasizes the identification and design of more optimal experimental (computational) tools. As will be described in later sections of this work, there is a need for a programming toolset that will allow researchers to develop a new quantum language and framework, one that is efficiently and easily testable through computational simulations, complete with the graphical and visual methods for comparing results and also empowered with the communication methods for translating results from one discipline to another.

Not so briefly, that is the main form of the theory restated and rephrased in preparation of what follows - a discussion of the principle theoretical models that have been described above, a discussion of their interaction, relationship and modifications as components of the larger quantum holonomic dynamics theory, and a presentation of plans and systems for conducting an open-ended series of research activities that should refine and decide the appropriateness of the theory.

Implicate Orders and Holomovement

Bohm and Hiley and their co-workers have worked for the past two decades and more on solving some of the critical problems in quantum theory, starting from a position that there needs to be an ontological foundation. Quantum theory as developed in the classical line from Bohr and Heisenberg has provided epistemological toolsets for managing large statistical populations of particles with obvious practical applications in physics and other sciences, but what of its connection to reality? Moreover, what are the free links as it were from conventional quantum theory that are available to build upon to that which goes beyond the established model? Links to gravity and relativity, potentially to string theory, and certainly to the cosmological dimension arguably are essential for a robust quantum theory. These are connections that, it may be pointed out, are essentially ontological issues - they concern 'what is', not merely how something may be practically used. Bear in mind that by saying 'what is' one is not committed to physical realism - that is one of the mistakes of the modern scientific era, confusing being with being-material! A quantum theoretic approach to integrating the microphysical world with that of large-scale observables and 'megascopic' (galactic and cosmological phenomena) is not a commitment to the view that particles, for instance, are substantial objects.

The philosophical dimension keeps cropping up and it is important. Is the 'what is' the important issue or should quantum physicists remain content to have a 'workable' theory? Perhaps too little attention to the philosophical issues has kept physicists and mathematicians from seeing some of the limits of their perspectives. This is worth a digression.

Consider an abstract space S which we know to be divided into a set of n regions $\{r_1, r_2, \dots r_n\}$. Our interest may include knowing in what manner these regions interact with one another. In other words, what are the parameters that govern exchange of information between r_1 and r_2, r_2 and r_n, and so forth. Another way of putting this is to say that there are processes with regions r_x and r_y as input and output respectively. Of course our focus tends to be upon the contents of these regions, for it is what is in r_n and r_{n-1} that we expect will interact with one another. There is a logical priority that it seems is often overlooked, perhaps because it should be so obvious, like the forest being there with the trees. The boundaries of the regions in S must be defined before one can begin to speculate about how any regions are related to others. This probably seems so obvious but is it always seen?

But how can the boundaries of regions that comprise the space S be defined without knowing the fundamental features that characterize one region from another? This appears to be a 'catch-22' - one doesn't know what makes up the set of features until one knows the boundaries of the region in question and vice versa. Somewhere in the scientific process there is a heuristic leap, a stab in the dark at what makes up a region in S and the most outstanding features within r. Something stands out and demands attention. Why this is so may have a great deal to do with the observer's previous history of experiences, but that does not matter at this moment. What matters is that there is an a-logical start to the whole process of discernment and discrimination, not unlike some of the reasoning processes involved in obtaining solutions to mathematical problems in combinatorics or even simple interpolations. Moreover, this first start is something that starts on a different 'logical' scale or level of discourse than the subject immediately at hand. It is a leap from 'above' the initial problem - metalogical and cross-scalar.

Rosen [13] and Kugler has pointed out in several papers [14] the variance between formal and artificial machines (e.g., conventional computers, Turing machines) and biological organisms. Discourse about computational mechanisms in biological or neural systems and attempts to mimic the performance of biological systems in, say, pattern recognition and classification, be it on the

13 Rosen, R. (1991)

14 Kugler, P. (1989), Kugler, P. et al (1990)

level of T-cell antigen identification or visual classification of spatial objects, can and does easily become mired because of a mistaken identification of computational processes in the formal domain, where the active set of features may be known but certainly not its complement set, and the biological domain where the complement set is a critical component of every 'computation.' This is one example and an important one at that of the manner in which regional boundaries, in this case conceptual ones, become ill-defined and remain so, leading to difficulties and paradoxes over how one conceptual space can be related to another.

Stapp's theory of a quantum theoretic mind-brain interface, and Young's theory of a hierarchical order of evolving consciousness, both discussed in Section Three, also deal with the issues of transfer of information and control from one scale to another. There are more than just levels of complexity at stake; the kinds of descriptions that can be used for the higher level are often structurally different from those that apply to the lower level. A vortex is conceptually different than just a spinning collection of particles or molecules. It has an influence downward upon the lower scale - molecular movements are influenced, controlled by the higher, relatively global structure, and there is a dependence of the form within the vortex upon the type of particles and the density, etc. But there are qualitative differences that cannot be explained just in terms of the lower scale processes. Perhaps, in a Wittgensteinian fashion of 'meaning as use' the structures that emerge in the higher level processes (for instance, emotive and cognitive functions, awareness, intention) and the qualitatively unique character of those structures are that way by virtue of how useful (or how commonly used) they are for the observer/participant accomplishing some goal (which may simply be survival and continuance).

Another good example is the confusion over 'self-organization' in natural phenomena. Fractals, Mandelbrot sets and others, are often termed 'self-organized.' This is quite misleading, because it gives the impression that there is something in the object (cloud, coastline, bacterial colony. etc.) that has a causal role in determining the dimensionality of that object. The fact that to the human observer there is regularity or smoothness is not grounds for suggesting self-organization on the part of the observed - it is in the observer's perception at a particular scale of observation that such regularity occurs. Of course, a very legitimate question exists as to why Nature seems to prefer fractal dimensionalities at some many scales, and why the 'what is' emerges and presents itself to the observer so often with regularity of form. Obvious suggestions include the role of the Second Law in driving toward equilibrium and a least action principle. There may be an innate quantized nature to natural processes, one that exists at many if not all levels of Nature, evident if only observers can work at the right 'scale.' The same concerns and constraints about self-organized or self-generated actions can be suggested with respect to such quantum-like manifestations and care must be taken to avoid looking for micro-quantum causal actions that are responsible for macroscalar quantum effects. The quantization may be the result of Nature's fundamental equilibrium economics of energy distribution - in other words, it may be the simplest and easiest way to achieve a stable existence.

When quantum mechanics was first derived in the first quarter of this century, logical positivism and reductionism were strong undercurrents that had a controlling influence over the mathematics and the sciences. The drive for clean-cut, deterministic, mechanical models was pervasive. The failures (Hilbert's Program, *Principia Mathematica*, Newtonian physics in general) can hardly be considered to have been final. One response arguably has been the non-realist 'utilitarian' thinking that has characterized the Copenhagen Interpretation and its derivatives - quantum mechanics (QM) works, it gives correct answers for the experiments that have been designed in terms of the concepts of measurement that are consistent with QM, so let it be and not be concerned about 'what is'.

Back to Greece, 500 B.C. and what was remarked earlier about *physis* and *aletheia*. Science, I will claim, must be concerned about the 'what is' in the sense of what manifests, shows itself, reveals itself, even if that is and perhaps must remain a mystery, to some degree indeterminate, not accessible to the convenient formalism of algorithmic mathematics. The claim is not that mathematical expression cannot be obtained but that even if there are barriers, that in itself does not remove the fundamental question of 'what is' from the legitimate forefront of science. A return of physics to *physis* is being argued for here, and in good part that is a return of quantum theory to consideration of how it relates to reality, including levels of reality more accessible to measurement than that of particles, namely chemistry, biology and neuroscience. When Stapp's theory of quantum mind-brain connectivity is examined in Section Three, the more radical issue of 'felt sense' will be examined. Consciousness is felt, experienced, lived. Can it be adequately described by any formal, symbolic system? Can the fundamental question of being, the 'what-is' of Nature, be addressed without also including this dimension of experiential feeling? The aim here is not to soften scientific rigour and precision where it is applicable and necessary, but perhaps it is necessary to expand the dimensionality of mathematics to include 'something' that encompasses the non-quantitatively measureable, the aspect of felt experience. Perhaps what is found in fuzzy logic may point to some beginnings in this respect. The qualitative is approximated through scalar ranges of values and this is different from purely assigning a numerical value to some state or condition in the first place. The 'fuzziness' of fuzzy logic is neither a deficiency of the observer nor of the object(s) being measured; it is there as part of the 'esse' of the phenomenon and cannot be got rid of by sleight of hand or computation.

Returning to the discussion of Bohm and Hiley's work, the main points of their theory can be summarized briefly as follows (these will be discussed in more detail gradually):

- Through the explanatory mechanism of the quantum potential and active information, an objective type of wholeness (not reducible to a sum of parts) can be introduced into quantum theory and this provides a mechanism for the strong connections of non-locality.

- Measurement is an objective and well-definable process such that a measured system has several 'channels' of probable course, only one of which has high probability. The supposed 'collapse' of a wave function does not occur, nor is a many-worlds interpretation required. Instead all but one of the channels of potentiality are reduced to extremely low probabilities. This will be discussed in more detail below. [[15]]

[15] The mechanism of this reduction is not clear but may, in the quantum holonomic dynamics theory, possibly be found in the notion that complex interior spaces regulate through some sort of dissipative and escapement transfers a control over the stability of such quantum channels and that in essence all the channels but one are left in an unstable, chaotic state - the probability that a given channel is in any definite state becomes infinitesimally small and it is the channel's indefiniteness that amounts to the low probability that the quantum system will enter into it.

- There is an "undivided wholeness of the measuring instrument and the observed object,"[16] and measurement must be understand as an interaction that alters not only local objects but a much wider domain. The measured and the measuring objects *"participate irreducibly"* in each other. An analogy that may work is to think of how a heated rod placed into a bowl of porridge affects not only the region of immediate contact but the surrounding medium (akin to a field) and is itself affected not only by the contact point but by the thermodynamic properties of the medium. In QHD it is suggested that the dynamic networks concepts of Finkelstein's work may be relevant for explaining the dynamics of 'irreducible participation.'

- Non-locality is seen to be more of the general case rather than the exception and the classical limit emerges as scale increases. However, there are allowances, argued for the symmetry and antisymmetry of the wave function, where EPR-type non-locality do not disappear in the macroscale. It is conjectured within QHD that within highly self-organized complex systems such as the neurodynamic fields of the brain, strict quantum non-locality may re-emerge as a real and experimentally verifiable phenomenon.

- Field variables rather than particle variables are the primary vehicles by which quantized energy can be imparted from one continuous system to another. A photon is not to be understood as a particle in the usual sense. Particle-like behavior is provided for by the rules of wave packet interaction that are defined over an entire field. Just as the effects of a wave function collapse are present even though, according to the ontological interpretation, no collapse actually occurred, so does discretized particle-like behavior occur without actual particles.

- An implicate or enfolded order that is based upon a holonomic enfoldment can be introduced as an overall framework for an integrated quantum relativistic physics. Based upon the notion of a particle as an organized structure of waves operating under the holonomic influence of a superwave structure, this holomovement is arguably the basis for the geometry of relativity and the dynamics of quantum theory. A pre-space process may be understood to underlie the development of space-time.

The basic principles underlying the Bohm-Hiley implicate order lie in the ontological interpretation. One of the prominent features is the quantum potential Q, often poorly understood as if it were some kind of hidden variable which it is not. Starting with the standard Schrodinger equation

$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\Psi + V\Psi$$

where the classical potential V is prominent and gives rise to

$$\frac{\partial S}{\partial t} + \frac{(\nabla S)^2}{2m} + V - \frac{\hbar^2}{2m}\frac{\nabla^2 R}{R} = 0$$

16Bohm and Hiley (1992), Chapter 1, p. 6

and

$$\frac{\partial R^2}{\partial t} + \nabla.(R^2 \frac{\nabla S}{m}) = 0$$

there is a distinguishing term $-h^2V^2R/2mR$ that is negligible in the classical case. Its absence yields a classical Hamiltonian-Jacobi equation

$$\frac{\partial S_c}{\partial t} + \frac{(\nabla S_c)^2}{2m} + V = 0$$

and that term's inclusion makes for a quantum version of the Hamiltonian-Jacobi equation of a particle. This same term is defined as the quantum potential Q. The latter is something present in the fundamental wave equation - rather than a hidden variable added for quantum theoretic purposes, it is what is ignored and left out in the classical limiting case. It is additional, not external, and the quantum Hamilton-Jacobi equation takes on the form

$$\frac{\partial S}{\partial t} + \frac{(\nabla S)^2}{2m} + V + Q = 0$$

What is unique about a particle in this ontological framework? What is interesting from our perspective is that the particle is never separate from a quantum field that is essential to its existence. This field can be represented by

$$\Psi = Re^{iS/\hbar}$$

Characteristic of this field is that it is (a) continuous and (b) causally determined. Now since the particle and the quantum field Ψ are inseparable, it is a fair question to raise as to why, as Bohm and Hiley emphasize, the particle is to be thought of as a distinct real entity. Rather, why not acknowledge that it is part and parcel of the field and that the semblance of a particle is a construct of the processes that take place within the field in some sub-space, sub-time pleroma? This point will need to be brought up again and again and not only with respect to elementary particles. It seems valid to ask it in terms of macroscalar phenomena as well.

Causal Determination

This concept of 'causal determination' bears some further remarks. The binding of particle and field is the basis for saying that the "combined system of particle plus field is causally determined.[17]" Bohm and Hiley later in *The Undivided Universe* extend the ontological model from ensembles to stochastic models. This, it is argued, does not bring physics back to classical models because the quantum potential differs significantly from classical field models. Something of the same structure is undeniably there - the deterministic influence of a field upon a particle - but the field is no longer the same as one would expect from a fundamentally Newtonian

[17] Bohm and Hiley (1991x) Ch. 3, p. 3

perspective. This is worth bearing in mind with respect to field models of neural function, namely that the field-matter reactions may not be what one would expect from a traditional electromagnetic potential model but rather from something akin to the quantum potential.

The quantum potential's effect is said to be independent of its strength. Instead it depends on its form. This is somewhat unclear and certainly difficult to conceptualize. By analogy, Bohm and Hiley compare the action of the quantum potential (wave) to the control of a ship's engines by a radio signal transmitted from off-ship. The form of the signal waves dictates how the ship's mechanical system and therefore its much greater energy (PE + KE) is controlled. The intensity of the control signal can vary without a consequent change in its effect on the ship's behavior.

There are some difficulties with this analogy, however. The energy systems being compared (radio control signal and mechanical drive system) are isolated systems, generated by different sources. It would be better to find some examples that have a closer binding between the low-energy control signal and the affected macro system, in fact a control-like signal that is embedded within the same large-scale system. There are many examples of this type of behavior in complex dynamic systems, especially those that have been labelled as 'chaotic.' One of the problems is to delineate the boundary between what one wants to term the control signal from the controlled system. Any such division seems arbitrary and dependent upon the observer's chosen scale of measurement.

In fact, calculations show the quantum potential Q to have an inverse relationship with the density of the wave packet, following the equation

$$Q = -\frac{\hbar^2}{2m}\frac{\nabla^2 R}{R} = \frac{\hbar^2}{m}\left[\frac{3\Delta x^2}{4\Delta x^4 + \frac{\hbar^2 t^2}{m^2}} \quad \frac{2\Delta x^4 t^2}{(4\Delta x^4 + \frac{\hbar^2 t^2}{m^2})^2}\right]$$

A particle will gain kinetic energy as the wave packet spreads, depending upon its initial position in the wave packet and not upon the uncertainty principle acting upon a pre-existing spread or distribution of velocities. One of the consequences of this perspective of Q is that energy is definite but constantly in flux. The particle energy is not indefinite; it is just in constant flux, like a 'jiggling', with an range of variation proportional to the average width ΔE of the packet. The time dependent part of $\frac{\partial S}{\partial t}$ is of that same order. This flux can be highly complex and, it may be conjectured for future research, it may follow a distinctive chaotic or fractal pattern. If so this could explain the apparent randomness as well as the fine-grained quality to the flux which may satisfy both the Bohm-Hiley argument for constancy and the question of why it has appeared to be irregular and indefinite according to previous models.

In a subsequent discussion the quantum logic and quantum process theories developed by Finkelstein will be discussed. It is worth pointing out that the complex 'juggling' motions of a particle, changes of the order of Heisenberg's principle that depart from a mean energy E_0, can be understood as a set of interacting processes, the net effect of which is a perturbation that follows the behavior of a chaotic attractor, something akin to a Lorentz Attractor on the Planck scale.

This may point toward a greater common denominator between the two theories than is evident or admitted at first glance. Hiley and Bohm suggest a basis in the vacuum fluctuations:

"Where does this fluctuating energy and momentum come from? Evidently it is to be attributed to the quantum potential which is now a function of time. But as we have seen earlier the quantum potential is implied by the guidance condition, $\mathbf{p} = \nabla S$, which, we recall, is to be interpreted as being brought about by the activity of the information in the quantum field. The energy and momentum then come from the self-movement of the particle and, as we have suggested earlier, may ultimately originate in the vacuum fluctuations. ...the electron viewed as a particle is never completely isolated because it is always affected by the quantum field and possibly by the vacuum fluctuations (so that *the degree of isolation of any given system is, in general, relative and limited* [italics added])." [[18]]

One begins to develop a picture of particles as entities that, to the extent one wishes to consider them as definite and localizable entities, are somehow inseparably connected and interwoven with other such particles. A network of interdependent processes emerges as a likelier candidate for a description of this situation, much more so than an array of point-like objects. The model does seem to be a paradox, pointing toward that which it would stand against; i.e., the notion that there is no distinct separability and that it is impossible to really speak of 'a' particle or 'the electron.'

Active Information

All the same the non-existence of the 'true particle' does not mean there is no place for the quantum potential, any more than the lack of solidity in a baseball makes it any less real for playing the game. It may help to understand the quantum potential by examining the macroscalar domain for analogous behavior. There definitely seems to be evidence for macroscalar effects that are similar in type to what has been suggested for the quantum potential. This is not to suggest that there is any common causal mechanism! What is common, however, is a concept of information. This is suggested explicitly by Bohm and Hiley in their concept of active information. It is presented as having a qualitative (form-based) dimension and not only a quantitative aspect (e.g., amplitude, frequency):

> "The basic idea of active information is that a form having very little energy enters into and directs a much greater energy. The activity of the latter is in this way given a form similar to that of the smaller energy." [[19]]

This is information in the sense of in-forming; i.e., establishing the form of some thing (a field, a flow of particles) that moves. Looking at the well-known double slit interference experiment, the model of the quantum potential as a carrier of active information can be used to explain the change in behavior introduced by the addition of a second slit. Why if both slits A and B are open is there not the same behavior for a stream of electrons moving through slit A as when only slit A is open? The quantum field, and therefore the potential, will be different for two open slits rather

[18] UU, Chapter 3, p. 23
[19] UU, Ch. 3, p. 8

than one. The confusion is in thinking that what matters for the flow of particles is only what is on one side of the barrier and that what exists on the other side is of no concern, supposedly because it is spatial and temporally 'removed' from any effects upon the particles as they approach the barrier. But if what matters is a continuous field structure that 'in-forms' the particles by providing channels or conduits, as it were, for them to move down, then the structure of this quantum field on both sides of the barrier will matter. And certainly the field will be different when two slits are open rather than only one.

It seems that the same logic can be applied to the case of light polarizers. It would be interesting and worthwhile, it seems, to conduct a series of experiments based upon light polarizers for the purpose of computing the quantum field structures as they should exist given the quantum potential model, and to study how this model correlates with actual polarization phenomena.

If the Bohm-Hiley concept of active information is confused with the usual notion of a measure of uncertainty and therefore knowledge of system states then things are apt to seem strange and out of the ordinary when this active information is associated with quantum fields. The quantum potential and its field does not carry or embody information in the classical sense (contrasted with the active, it is rather 'passive' - a measure of uncertainty about possible states but not a controlling factor in what states a system occupies) - it produces and engenders form for something. The quantum field is morphogenic (being careful here to not draw any connection with less-than-scientific theories that sometimes use the same terms [[20]]). It is a source and means of producing a shape, such as the probability distribution of electrons passing through a pair of slits.

Measurement has always been a fundamental concept and problematic issue in quantum theory and in fact it is the question of measurement that has led Wigner and others to conjecture an essential role to the 'consciousness' of the observer. Information, on the other hand, has been somewhat out of the spotlight until arising prominently in the Bohm-Hiley interpretation. A suggestion here is that information needs to be discussed in much greater detail within quantum theory than it has in the past. It needs to be examined as a generating-of-form-from-within: in-forming. A deeper look at in-formation generally in physical and biological systems could be a missing ingredient to understanding how morphogenetic processes take place without having to either invoke mysterious non-physical fields (akin to vitalism) or else brush off the matter as chance or coincidence (which is no explanation at all). The process of *in-forming* entails something more than mere transmission and exchange of energy; this is where the concept of morphogenesis gets bogged down, both the advocate and the critic alike looking purely at causal relationships and a mass-energy problem. When a person (A) informs someone else (B), the transmission is there, certainly. But there is a transformation of content and orientation within B that occurs not be*cause* of something that A does and transmits. The in-forming happens within B; it is a transformation the causal factors of which are to be found within B - other knowledge, other data, that interacts in the ordinary cognitive and emotive way within B. For an example, consider that A informs B that B's father has died. The actual exchange of data, viewed from the raw information theoretic point of view, is that same as if A had informed B that B's cat just had

[20] A number of popular-press articles and books make reference to 'morphogenic' behavior, some tracing their roots to Sheldrake (19xx and 198x), for which evidence is sorely lacking for many of the claims proferred.

kittens or that energy stocks were up this week. The in-forming process happens within B, *triggered* but not caused or manipulated by A. Depending upon - well, everything in B's life - the in-formational process results in anything from a dramatic mental and physical change in B as he deals with grief, loss, and all the typical feelings, to the extreme 'other case' of subdued mild sadness ("We weren't very close..."). The former is easier to understand and relate to but the full spectrum is there and must be acknowledged. What does this mean? The phenomenology points to something important - information is really in the receiving, the taking in and holding of a new content that interacts with potentially all other facets of a person's being.

And what does this mean for physics, after all? Particles are not persons, not even simple little ones. The point is that factors - physical energy transformations, within particle reactions and within the process of measurement - things that seem to be impossibly ineffectual or irrelevant on the basis of classical mechanics - may play a more significant role by triggering in-formational processes within the recipients of an interaction.

What are some other examples of active information? Bohm and Hiley suggest a few, including the molecular form of DNA as an in-forming content that through the RNA -> protein manufacture process provides the guides or channels for metabolic activity even though the actual energy driving those processes comes from other than the DNA itself. It hardly needs pointing out that the process of accessing the DNA code is driven by energy external to the DNA molecule and that the DNA functions much like a book that is read by the metabolic cellular systems. The radio control signal driving a ship or plane on automatic pilot or the code in ROM on a microprocessor function in similar in-forming ways that channel larger and external sources of energy.

Another example is in reading a map and it is a particularly good example because it brings out elements of both active and passive information. Looking at a map one acquires passive information - uncertainty about the environment is reduced. But this information also becomes active mentally and physically. The in-form-ing activity is low energy but it can trigger vast and varied mental activity and physical work, all of which is driven and fueled by other energy sources that are quantitatively much more powerful than those involved in the map-reading activity. How does one draw a distinction between active and passive information in this case? When is it one and not the other? Bohm and Hiley suggest a close link that may be extendible generally.

"The puzzle in this approach is that of how information that is merely passive within us is able to determine actual objective processes outside of us. We suggest that passive information is rather like a map reflecting something of these processes which can guide us to organize them conveniently for our use, e.g. by means of algorithms that enable us to calculate entropy and other such properties.

If the notion of active information applies both objectively and subjectively, it may well be that all information is at least potentially active and that complete passivity is never more than an abstraction valid in certain limited circumstances." [[21]]

[21] UU, Ch. 3, p. 10

A common criticism of this in-formational approach to quantum theory is that it makes the quantum potential into some kind of classical force that acts in Newtonian fashion upon particles. This is precisely what it is not, given that a very weak quantum field can effect a very large action. It is from form and not content (energy) that the quantum potential acts. Thus it cannot be a classical type of mechanism. This goes against the whole classical theme, that energy and information can only be measured in deterministic quantities. Moreover the classical view imposes a restriction of looking at Nature only as objects in states, for which form, ιδειν, is non-existent because it cannot be measured in quantities of mass and energy.
There should be no confusion on this point, that the energy required for the particle to do its work does NOT come from the quantum potential, but from other sources that are in accord with the rest of established quantum theory and particle physics. So no new force is being introduced - electrons, like ships, move by means of their energy systems. But control may be another matter altogether. In Section Four the notion of quantum chaos and a flux-like behavior that may exist in a network of 'pre-particle' quantum processes is discussed. Could the quantum potential be something more like the initial configuration of a chaotic attractor, a set of constraints that affects the evolution of the larger system but without the injection or transference of classically large amounts of energy? This configuration set could have a dynamic role across the time-history of a system; that is to say, its role is not limited to the *initial* conditions, but comparable moments where a minor perturbation can yield a powerful effect. Picture the equilibrium points of the classic Van der Pol equation:

$$\dot{x}_1 = x_2$$
$$\dot{x}_2 = -x_1 + \lambda(1 - x_1^2)x_2$$

As λ moves from < 0 to 0 to > 0, there is a qualitative change in the attraction rate (power) of the origin, moving from exponentially high to nominative (non-exponential but still positive) to a limit cycle. One can also find similar behavior in a saddle-node bifurcation, as defined by

$$\dot{x}_1 = a - x_1^2$$
$$\dot{x}_2 = -x_2$$

There are an infinite number of points in time when a fractional change in either the kinetic energy imparted into the oscillator system or the moment of a constant energy input will have magnified consequences for the trajectory in which the oscillating object will move.

This leads into what is a crucial part of the quantum holonomic theory, although as has been pointed out frequently, the aim in this work is to lay the groundwork of right questions and possible links and relations and not to come up with a full-blown theory or even a well-structured set of hypotheses. It is still too early for that [[22]]. Suppose there is such an in-formational

[22] In contemporary mainstream science it is unpopular to emphasize what one does not know or that, as in this instance, it is 'too early' to start jumping into highly structured theoretical models, experiments and so forth. But in other scientific circles, including Japan and China in the present era but certainly Europe and the West during pre-modern times, it was indeed respectable to emphasize what is not known, what is not clear, and what are the kinds of questions to ask in the future rather than the kinds of answers one has at the present. Part of the aim in this work is to re-instill a sense for that kind of thinking since it is seen as very lacking throughout physics and the biological sciences and very much needed in the growth of truly interdisciplinary, multi-faceted science.

field-like structure that influences the energetic activity of particles and larger systems. Not only must one have a workable model of how the particle does act but how something like the quantum potential/field interacts with it and also how the quantum field itself gets its energy source. There hâve been analogies made thus far of radio control signals, DNA coding and map reading, and in all those instances it is clear how matter-energy transports bring energy into the system in question. How so at the quantum level?

It is this author's hypothesis that the answer lies in a much deeper complexity and order at the quantum level than has been generally imagined or theorized up to the present and that there are two main directions in which one can begin to look for answers. On the one hand there is the quantum dynamics and quantum networks as formulated by Finkelstein, which shall be discussed shortly, and then there is the forementioned work in complex non-linear systems including chaos, that can also provide macroscalar examples of behavior that may very well illustrate the dynamical structures and processes that manifest at the quantum level.

Bohm and Hiley directly suggest such micro-level complexity whereby an electron or any other particle may have a far richer 'inner structure' than is commonly imagined even when one takes into account the multiplicity of quark colors and charms and other attributes. They allude to the possible role of the vacuum plenum as a source for the energy that goes into such imaginable structures, keeping in mind that such interactions in the vacuum would not necessarily conflict with the strong established arguments that one cannot harness such energy or use it to generate classical information on a macro scale. This inner structure of a particle need not be something fixed! It could be highly dynamic, behaving like a neural network or a complex set of interacting surfaces (or strings that define topologies). Just as it is a mistake to think that there is but one uniform structure to large-scale space-time so it is a mistaken assumption that the internal structure of any given particle must be some constant configuration of whatever states or vectors that may be used to represent it. This inner structure may be such that it becomes better to conceive of the particle not as a thing but as a nexus or intersection of many lines, strings, surfaces. Indeed this is where this theory is headed. Particles may in one sense, as Bohm and Hiley describe them, exist as real objects, as real as atoms and molecules can be, but from another perspective and completely in line with notions of an in-formational quantum field, particles may not at all exist as real, permanent entities, not in the sense of Parmenides' *ousia* at least. The particle may be a dynamic intersection process, part of an immense network that encompasses the Whole, so that what goes on in one part of the larger expanse (network of processes?) is truly inseparable from what goes on in another. The parts are not simply connected as points that have lines running between - there are no points in the first place, only lines, to make an extremely (over)simplified analogy from geometry.

Let us recapitulate a few key points before going on and also take a look at how studies of the brain and other biological systems can have bearing on the topic. Given a many-particle system how is guidance and control effected? How does information get communicated? Notice that the question should not be phrased in terms of signal propagation - the issue is information and its communication, without presupposition of the means. Taking the quantum potential one has a very weak field to work with. It is not a de Broglie pilot wave [[23]] or anything that operates in a

[23] de Broglie, L., Journal Physique, 6e series, 8, 225 (1927)

strict mechanical fashion upon the particles. Once this point has been cleared up there should be less of the obvious and appropriate resistance to these concepts, since neither hidden variables nor mysterious forces are appropriate for developing a better theory of quantum physics. The significance of the quantum potential is not as a mechanical force but as a "contribution to the acceleration of the particle in its self-movement." [[24]]

Given a very weak field that must somehow exert a controlling effect over much larger energy processes, what could be the mechanism(s) by which such communication occurs? Allow for a complex interior structure to the entities that are so affected (particles) and look for the means by which these structures can be linked with the very weak quantum field. What better first start at such exploration than in observable systems that exhibit the same kinds of dynamics, even though the scales are vastly different? The brain is one such system that does show evidence of the modulating influence of very weak ion plasma fields, measurable as dendritic membrane potentials, upon the much higher energy level activity of neural firings. Examination of such phenomena with a perspective of seeking useful principles that will apply in the quantum domain can possibly lead into an unexpected discovery outside of the domain of neuroscience alone, just as the behavior of coupled harmonic oscillators viewed from a broader perspective has led to insights about the coupling of biological kinematic systems. [[25]]

The wholeness factor comes in as a consequence of the very weak quantum field having this directional effect through the internal structure of a particle, purely through its form and not by virtue of amplitude or other quantitative measures of the field. If something weak can have a strong effect, it can have a very wide and long-range influence, either by reason of beginning as a strong field but still maintaining strength over great distance while dissipating, or by remaining constantly a weak field but acting catalytically, undergoing little energy exchange or dissipation. This is one aspect of the quantum wholeness or indivisibility. It does not depend upon a specific temporal range. If non-locality is a general property of quantum fields then the quantum potential's effects are not limited to what can be transmitted at or below the speed of light. The potential is not bound by any spatio-temporal structure.

There is a likely problem here and again it seems to be fundamentally epistemological and linguistic. Given what has been said above, the quantum potential may be viewed as something that is weak, subtle, pilot-wave-like and yet exists (hidden! even) in the same dimensionality as the classical waves of Maxwell and Mach. This is not what is indicated or intended by the theory, and it only confounds the development of an approach to questions of the sort that Bohm and Hiley have been trying to raise concerning the relationship between the microcosmic and the whole. There are built-in assumptions about structures and things. Why is the quantum potential an object that must have the matrix of some type of space-time, different as it may be from the commonplace and classical? Can it not be viewed as process and relation, as a moving (i.e., changing, flux-ing) relational configuration that affects other processes but not as the classical viewpoint would have it, through exchanges of forces and quantities of energy? [[26]]

[24] UU, Ch. 3, p. 13

[25] Consider Kugler's ideas on arm movements and synchronies. Cf. Kugler (1991).

[26] Is it possible to speak of qualitative exchange of energy that is not measurable as an exchange of quantity but purely of form and relation, somewhat as one may speak of the quality of tone in a musical instrument changing over time? Granted there are measurable quantitative changes that occur which collectively and

The quantum potential need not be thought of as some kind of superluminal beast, nor must non-locality be imagined that way. There are alternatives, but they all require breaking through a conceptual barrier that, to reiterate a constant theme of this work, has less to do with the formal modern science of physics and more to do with the phenomenological, spiritual outlook of the human thinker upon his or her uni-verse. [[27]] The quantum potential can be viewed as a qualitative control force that operates outside of any space-time and influences the development of formative processes in a pre-space, pre-time holomovement or holoflux, and it is through the interaction of these processes that space-times emerge and manifest themselves - 'for a time.' In fact, a space-time construct may be purely a relational sort of thing - the interconnectivity and 'in-sync' dimension of many different processes.

The quantum potential should not be confused with the implicate order. But there is another angle of questioning that could be explored here. The general tendency is to think of anything like a quantum potential as being something that emerges point-like from a point in a space-time and operates upon other point-like entities in that space-time. Everything is dominated by the Cartesian perspective. Points make up lines, lines make up planes, and planes are what spaces are made from. Projective geometry gives a different view, something that artists seem to be generally more appreciative or aware of than scientists and engineers. Consider lines as being the consequence of intersecting planes, and points the mark of intersecting lines. A point emerges when lines intersect and it moves as the lines interact. The larger and more encompassing dimension forms (in-forms?) the lesser dimension. Is the quantum potential a way of viewing (measuring) the actions of a space folding in upon itself, creating localized regions that *appear* as particles? If one were to follow this thinking to its conclusion, it would seem that particles do not interact with each other after all - there are no collisions, no annihilations or creations, only folds and twists in a space that creates the mirage of such objects in the same fashion as folds in a garment may create the appearance of separable objects.

The quantum potential is subtle and diminutive in energy when compared to what it controls. This goes against the grain of that ever-present attachment in physics and the human condition to the value and reality of the positive and the full as opposed to the negative or empty. It is better to have more, not less - that is the foundation pre-judice that affects not only the highest scales of social process but interpretations of quantum mechanical reality as well. In the ontological model there are empty or unoccupied wave packets, and the information for which they are a representation diminishes to zero potential for activity in all but one, the 'occupied' packet. These are information sinks or holes. These are a problem for traditional quantum mechanics. What to do with all these zero-potential packets interspersed with the 'real' ones? However, it is only a

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syneretically *yield* the qualitative change, and yet none of those quantitative changes alone or in combination with any subset other than the set of all changes will yield the same qualitative state.

[27] The reader is strongly urged to consider why the word 'spiritual' will seem to many readers as out-of-place in this sentence - it longer has an acceptable place within mainstream scientific discourse. It is only in the last three hundred years that this distancing has transpired, to the point where connotations of wholeness and connectedness are disallowed and forgotten. IF as a culture we could only remember that *legein* and *logos* have to do with discourse and the everyday talk of the Agora, then it might not be so difficult to remember the connection between the heart, the intellect and the theories we construct in order to make the world and our lives more navigable and compatible.

problem if 'reality' is taken as being bound and defined by the 'real' wave packet alone, if the wave function is the only description of quantum reality, and if information is understood to be real, regardless of how much potential it has to produce action on a higher energetic scale.

The ontological model assumes definite particle trajectories and a guiding field structure that is powerful as a controlling factor but not in measurable energy. It is information that controls but with less energy. The quantum field's weakness in energy explains how it is manifest on the macro scale only in collective behaviors. The strength lies in the information, and it too can be dispersed, spread thin, reduced to zero-potential for activity. There can be elements comprising wave packets that are inactive, having no potential, but still real as information, and this information has a life of its own, apart from the larger energies that are controlled, much as the behavior of radio waves in space is independent of the kinetic energy of the planet or star from which they were emitted.

The arrow points to the fundamental concepts of be-ing and substance and the values that are attached to customary interpretations about being. It is so hard to get away from the static, classical language of time and place and substance! For that reason among others Finkelstein has labored long to advance the concept of a new language of process, Q, a quantum language oriented fundamentally toward process and event and away from dependence upon the Thing. Like the Bohm-Hiley ontological model, it is an approach toward a new kind of physics - and a metaphysics that sets the stage for what a physics can be and how it can fit in with other disciplines.

Quantum Dynamic Networks

Quantum events can be viewed as unique separate space-time occurrences that are causally linked and that form ensembles yet remain as individuated entities. This is the standard view toward particles and forces that has been dominant through classical physics and that is characteristic of most quantum mechanics. The work of Bohm and Hiley points toward a different view where particles are real entities with complex interior structures that form a holonomic connectivity with large ensembles and ultimately the whole of the universe if one intends the interpretation to its fullest. There is a deeper or more radical interpretation that breaks through the 'substance-barrier' of thinking of particles as defined permanent entities at all and looks at all quantum events as fundamental processes that cannot be reduced to the interaction of 'objects.' These processes interact as parts of a highly interconnected whole, a dynamic network, but not necessarily according to classical logic. The work of David Finkelstein is seminal in establishing this quintessentially 'quantum' model wherein we find a dominance of the process concept and, I believe, strong connections that support points of the Bohm-Hiley model, different as they are in many other respects, and ultimately a broader, more comprehensive quantum holonomic theory that is the point of this exploratory work.

Causal Nets and Quantum Processes

A major focus of Finkelstein's quantum logic, process and network theory has been on the application of quantum principles to fundamental mathematical categories. It is a locally finite theory, but not one based upon some indivisible substance-like entities but rather upon elementary processes that by virtue of their quantum nature cannot be isolated in a static space-time framework or any a priori dimensionality. Simon Saunders, in his introduction to the collection of essays, The Philosophy of Vacuum [[28]], in which papers by both Hiley and Finkelstein appear, argues that the common ground between the Bohm-Hiley work and that of Finkelstein begins and ends with algebraic set theory and that there is a gulf between the two theoretical developments on issues of non-locality.

> "Hiley is concerned with hidden variable theory, Finkelstein with the extension of quantum principles to the most elementary mathematical categories. ...it is Finkelstein who maintains the principle of locality at the fundamental level, for it is built into the concept of a 'causal network'." [[29]]

It is difficult to understand why the holonomic quantum theory in its present form, particularly as elucidated by Hiley, continually is labeled by many within the physics community as a theory of hidden variables. The quantum potential is not a classical type variable such as the type refuted by Bell's theorem. Nor is it a 'pilot wave' in the classical sense. Perhaps it is the paucity of analogy that forces Hiley, Bohm and others to draw images that are 'like' in the sense of 'as if' rather than 'like' in the sense of sharing fundamental traits and qualities. But this point may be returned to later. Consider Saunders' continuation:

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28 Saunders (1991)

29 ibid, p. 5

" ...What drives the Finkelstein programme is above all the demand for a locally *finite* theory. The algebra that underlies the quantum set theory, and thence the quantum topology (the basic subject of change), must be finite; therefore the algebraic operations cannot include negation. ...Hiley takes on a different view; it is non-locality that is fundamental to quantum theory, and which governs the determinate motion of individual systems subject to the quantum potential. What is characteristic of 'pre-space' is that physical space (and locality) are encoded in the implicate order. ...The algebraic description of pre-space is intrinsically non-local, or 'a-local'." [[30]]

The claim to be made here is that a misunderstanding exists (which is typical and rooted in the classical framework and the pre-judices that, like any framework, are engendered among those who are embedded within it) about non-locality, finite-ness and the difference between a process and a substance. Finkelstein's Quantum Network Dynamics (QND) proposes that elementary particles be viewed not as objects in a vacuum but rather as defects in a network, a topology of processes. The nodes of the network are not things! The network is composed by the action of many processes which can themselves only be adequately described in terms of a set of their neighbors. While Finkelstein does not make explicit references to cellular automata, there is a clear similarity between QND and the CAM models of Wolfram, Toffoli and others, wherein each cell has its next-state determined by the states of its neighbors. Now replace 'state' by dynamical process and one is closer to QND.

Particles as defects, as disturbances - somewhat like the ripples in a trampoline that occur wherever the athlete has made an impact with her foot or hand. Only in this case there is no outside mass bouncing in the net, only the activity of the net itself. There is clearly local finiteness, and yet there are global relations and effects, and here is where language bogs down and words run thin, leaving phrases like 'non-locality' which means to say that there is something that goes beyond the local frame but is not necessarily a direct causal link.

Consider further the trampoline as an analogy. Figures 2.1 through 2.4 below may be useful in visualizing what is intended. First of all, the behavior of the surface under the influence of a bouncing athlete can be replicated without an external stimulus (e.g., the athlete) by a number of actuators built into the trampoline surface. Force actuators on the boundary of the trampoline and embedded in the surface mesh could produce identical types of action. This could without question be simulated on a computer and in simplified form has been replicated over and over in various non-linear dynamics programs. The behavior of each actuator could be described by a set of rules that apply measurements of neighboring regions or the discrete states of neighboring actuators to determine the next state of a given actuator, as in cellular automata.

Let several portions of the trampoline surface be depressed gradually, in slow motion. Clearly there are local interactions that collectively affect neighboring regions in symmetrical manners and with apparent connection at a distance. However there is no need to project a mechanism for non-local communications or energy transfer. The transfer of energy in region A (Figure 2.1), measured by the elasticity of the fabric in that region, is affected by the shape and contour of the

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30 ibid, p. 5

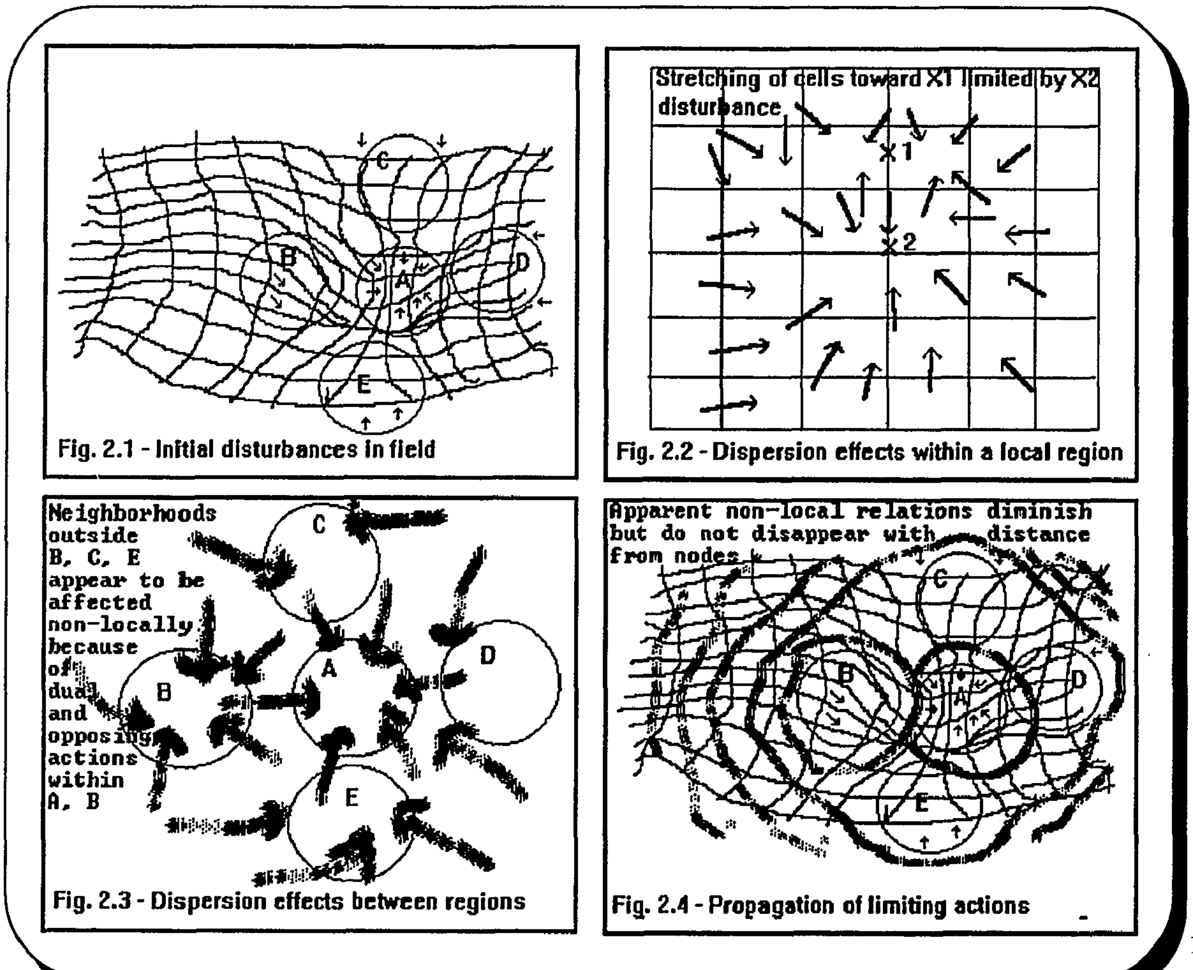

Fig. 2.1 - Initial disturbances in field
Fig. 2.2 - Dispersion effects within a local region
Fig. 2.3 - Dispersion effects between regions
Fig. 2.4 - Propagation of limiting actions

surface in regions B through E because in those regions and others the actions that result in surface deformations have created a much larger topological transformation that has a controlling effect on what can possibly occur within region A. There is a boundary set that defines how much deformation can occur within region A - how much the fabric can be bent and twisted. That boundary set is determined not only by the neighborhoods immediately surrounding region A but by the overall landscape or, to borrow from Pribram, the holoscape. Because the context is the 'whole' including those regions from which there could be no local action/communication, one has a sense of 'non-local' action. But in fact all the actions are happening locally, and it is the summation of these that makes up the holoscopic element, a collecting-together that takes place instantaneously at all points in the net that comprises this holoscape.

Again it must be kept in mind that this holoscape is more properly a holoflux, a holomovement (Hiley's term) - it is not some Thing but Process, always in motion, but not motion through a space-time like Heraklitus' River - instead, motion that is not 'in' something larger but just 'in' itself - a moving that does not depend upon an enveloping or imbedding structure but which defines what structures can be imagined and projected to contain things. The language forces one to think of 'moving' as always being a case of some substantial object changing position within some other substantial object (it may be the absence of mass that characterizes the latter but it is still identifiable in terms of substantial attributes - a classical space is something that can be filled up with objects; a hole is the inverse of whatever can fill it).

How important the language is for Finkelstein can be found in the first section of his book-in-progress, *Q: A quantum language*:

> "Any language entails a theory, and every theory starts with a language. When we use a language we assume that its words represent entities that may possibly exist and that its grammatical relations represent relations that may possibly hold among these entities. These assumptions constitute a theory. In particular, prequantum, prerelativistic assumptions about Nature and especially about time and number are deeply built into all natural languages. In the course of this work we develop a primitive artificial language called Q that modifies some of these presuppositions, based upon the operator algebras that have been found to be most suitable for quantum theory." [31]

In the Q model that underlies the language development Finkelstein proposes, relationships between individuals and collections, the one to the many, are at the root of the fundamental differences between quantum and prequantum theories. 'Classical' is understood as 'prequantum.' Common everyday experience, before (prior to) any physics or mathematics, pushes people into the pre-judicial framework of a certain kind of relations between parts and wholes, units and groups, members and classes. Then all of prequantum or non-quantum science continues to reaffirm those relations. One relation is that of commutability among members in a homogeneous set, assumed in a classical world to be interchangeable. Classical objects behave according to rules at the collective level; quantum objects follow individual rules. Classical theory predicts what the individual object will do because it will act just like any other individual object in the set; quantum theory cannot predict what an individual object will do, because the just-stated correspondence does not apply. Statistically quantum theory predicts a likely individual behavior, but this says nothing about the individual object set apart from the collection of all individuals.

The very notions that are fundamental in logic and all of philosophy are upturned in quantum theory, and it is not possible, claimed here and argued to be consistent with Finkelstein's model, to build a quantum theory using classical conceptual building blocks. Identity is not the same thing for the quantum and classical worlds - the same applies to concepts like continuity, membership, sameness, difference, etc. The problem in resolving classical and quantum physics becomes a question of resolving different logics, one based upon commutative distributive AND and OR operators, the other upon noncommutative nondistributive AND and OR.

At the heart of quantum behavior is spontaneity, which must be clearly distinguished from randomness or noise. At the quantum level, there are not merely random spreads of photons, meaning diffusion and noise, but also precision and control, as in the focusing of a polarized light beam. Quantum spontaneity does not mean indefiniteness but unpredictability at the individual level, only at the collective scale through statistical or probabilistic approaches. It is not the case that the Planck scale does not have a logic, only it is one that does not match with the customary logic that cannot accommodate a superposition.

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31 Finkelstein (1990), 1.1

The notion of a superposition is very poorly understood in quantum physics. Part of the reason may be that it is impossible to conceptualize using the everyday perceptual building blocks that are at one's disposal, and the mathematical expressions do not overcome that imaginative barrier. Some physicists would argue that it doesn't matter, since the mathematics will suffice for prediction of measureable events, but this does not answer the gap in the human under-standing. But it is natural to want to have more than a symbolic equivalence (the equation) - one wants a picture, or better yet, a framework with which to compare other levels of experience and see this quantum superposition in contrast with the non-quantum existence that is so familiar.

Superposition can be thought of in terms of collections and sets, as in photons that make up unpolarized light. Thinking in terms of sets may be more effective than thinking of states, which in turn lead to notions of substances, things in the same place and time. Instead there are equivalence sets. Consider, to borrow Finkelstein's base example, polarized light. There is an infinite number of possible combinations from any two homogenous collections A and B of photons, each collection of which is characterized by a particular polarization, that will be indistinguishable from a different combination drawn from collections X and Y, each of which is distinctly unique from the collections A and B. Moreover, if (A+B) is characterizable as type I (e.g., left and right circularly polarized light) and (A+B) is indistinguishable from (X+Y), then (X+Y) must be characterizable as type I. Likewise if half of (A+B) is type A, then half of (X+Y) is indistinguishable from type A. This may be taken to be a transition from photons of type X or Y to A. Notice that the term used is 'characterizable' and that the claim is not being made for identity. It becomes meaningless to argue about the identity of a collection of particles. However there can be an identity of processes which occur through the medium of different sets of particles. It is not required within quantum theory that the transition X--> A actually occurs to change photons from one type to another, only that the net effect is the same as if such a transition had occurred.

Mathematically, vector addition of the form $\Psi_1 + \Psi_2$ is the mechanism for representing quantum superposition, distinctive from matrix addition A+B, and is unique to quantum physics. The difference between these two methods of representing the mixing of two homogenous collections is a difference that must be reflected in any language oriented toward quantum theory - thus the motivation for the language Q. How this fundamental difference relates to the dichotomies between process and substance or between operations and things is not clear and can be the basis for further study. However, there is the potential for building an algebra of operations and operators that addresses what for Finkelstein are the fundamental operations of physics and that raises to primacy the question "What goes on here" over the traditional one of "What are things made of?" [32] This neo-operationalism does, it is claimed here, bring physics back to the original sense of *physis*. It also allows one to begin to think in terms of what Finkelstein calls a polytheory, that is to say a collection of partial views of different scales or levels of the universe, none of which can be effectively extended to serve as a comprehensive theory for the whole universe, but the union of which, along with appropriate transformations, provides the family of theoretical views that does yield a theory of the universe.

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[32] Finkelstein (1990), 1.9

> "A polytheory does not assume one total view but permits a plurality of partial views. ... Holotheories [on the other hand] have no such partition and are either c or q [classical or quantum]. Polytheories are classified c(c), c(q), or q(q) according to each of their views." [[33]]

The goal for Finkelstein is a "neo-operational q(q) polytheory." One of the objectives is to get clear of the classical holotheory; another is to clear the labyrinthine hedges of Hilbert spaces, of which some of the most pointed criticisms (made by Finkelstein) are its nonrelativistic treatment of space and time, its assumptions of globally instantaneous measurements, and an inability to express a basis for the set-theoretic aspects of quantum processes.

Does this mean that physicists should stop seeking for a grand unified theory of everything, as it is sometimes called in the popular scientific press and too often in physics journals as well? Insofar as such a theory would expand one representation, one holotheoretic framework based upon observer experiments and operations at a particular scale of interaction (e.g., quantum, atomic, biochemical, cosmological), to all scales of the universe, the answer would have to be yes. A unified theory that provides a transformation algebra to move from one 'local-scale' theory to another and that can describe the physical correspondence to those transformations is the kind of theory that will overcome (or avoid) the inconsistencies that have plagued the single-worldview theories. There is no reason why the mathematics and logics that apply within different segments or domains of such a unified theory need to be consistent with one another, only that there must be a method of transforming the one into the other. The picture of the universe at one scale (cosmological) may allow for several inconsistent explanations at the quantum scale, just as a simple quadratic equation can have multiple roots, only one of which makes sense for a particular application (context), which is something corresponding to the macro scale.

Quantum Principles and Languages

Processes may be understood as inputs or outputs in a succession of events. These inputs and outputs can be represented by vectors which in turn can be taken to be the sentences of a quantum language. In the context of an example drawn from elementary optics, the semantics of these vectors/processes are described:

> "An input vector <θ[may be paraphrased as, 'I emit a θ-polarized photon,' and an output vector [θ< as 'I count a 3-polarized photon'. The square bracket '[' divided the 'vacuum', as one usually calls the universe before the production of the endosystem and after its absorption, from the experimental emission-absorption process. the angle bracket < divided quantum operations, here input and output, from each other." [[34]]

In the case of forbidden transitions, such as is the case when two polarizers are at 90° to each other, the input operation precludes the output process - but this should not be thought of as a

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33 ibid, 1.10
34 Finkelstein (1991), 2.2

mechanical causal relationship. The output is not blocked; it never takes place, and the relation could be expressed as

$$[o<i[\, = 0, \text{ where 0 means, "stop" or "No-Op"}$$

Other transitions are compulsory, as in the case where two polarizers are parallel to one another and all photons passing through the first also pass through the second. Here the symbolic representation is

$$[o<=<i[^{*} \text{ and } <i[=[o<^{*}$$

Finally there are all other transitions which are simply allowed. They may or may not happen but theory will not predict one way or another. In the case of the polarizer, it means that a photon either passes through and is counted or it does not. The measurement process can tell the outcome, but there is no prediction for the particular transition. But the measurement process does not tell what is needed to explain the changes that occur when a diagonal polarizer is placed in between two that are perpendicular. Is this not the fundamental quantum non-commutativity problem?

Input and output processes (at least those that are homogeneous) can be represented by vectors. In the Q formalism, inputs are represented by column matrices and outputs by row matrices. So in the case of a single polarizer there are two possible vectors for inputs and outputs:

$$\begin{matrix}1\\0\end{matrix} =:<x[, \quad \begin{matrix}0\\1\end{matrix} =:<y[$$

These vectors do not cause the dynamics of the process; they are neither cause nor effect but representation. The vector provides a semantic content, a meaning, a name for the process, and in fact for any number of processes. Conversely, the process is what the vector symbolizes, and not a cause or effect of the latter. The vector may have what Finkelstein calls an ensemble of meanings, as a word or phrase in ordinary language can have multiple meanings for different contexts (uses). The span of meanings are potentials, possibilities, not needing to be actualized at any time or place in order to be real, again just like spoken language.

In the Q language being developed by Finkelstein, there is a need for describing the idealized processes named by vectors. To speak of 'states' is a throwback to classical prequantum physics, where every object has or exists within a state that can somehow be conceptually separated from the actions that define the object at every moment of its existence. The notion of a 'vection' is introduced as a homogenous input/output process, corresponding in syntax to tension, propagation and operation as entities that are represented by a symbolic quantitative construct (tensor, propagator, operator). Ultimately one is dealing with input and output processes that receive and send not 'things' but other processes - endosystems that in turn activate other input/output processes.

It is here that a leap is made from the usual model of communicating processes and computations (inputs and outputs). Typically one thinks of the input and output as involving some static element - the datum - which is transmitted and received. The datum is input and causes some other process to activate which in turn causes an output. Picture instead that what is being sent and received are themselves processes which can act upon and transform the receiver and all to which it is connected. Picture the OCCAM computing model again, with processes connected via discrete channels. Instead of data being sent from one process to another, there is code sent as well, code that may modify the nature of the receiver or sub-processes within it. The entire program space of such a computational environment takes on a highly dynamical and reconfigurable nature, unlike the typical Turing machine architecture, whether it be serial or parallel in implementation.

This kind of dynamics can be examined as a phenomenon of language, more specifically of a conversation, which is a process of language unfolding between speakers. The speakers are in a way part of the language process itself; the poles or points in a geometry of communication processes. The utterances of one speaker (A) are conveyed to a second (B); these sentences could even be represented as vectors, bringing the whole matter closer to match with the representations for quantum input/output processes. The sentence as received by the second speaker (B) alters that part of the conversation which involves B responding or making any kind of utterance to A or to a third (C); what is said changes what can be spoken. The process of B changes internally, affecting in turn A and C. As in the behavior of photons passing through polarizers, there are certain transitions that are forbidden, compulsory, and otherwise allowed. Whether something is in one category or the other really depends on what has been going on previously (corresponding to the orientation of the polarizers but also other constraints that may be the result of fabrication). But a great deal of what is allowed is simply that - it is potential, possible, and the theory does not say one way or another. Actual measurement gives the final tally of photons passing through to a detector and likewise the final record of what has been spoken or not spoken.

What is missing for both quantum physics and the study of interacting processes in general is not a more deterministic theory that will transform all the allowed transitions into compulsory or forbidden types. That is the classical approach. There is need for a method that describes the ranges through which a vector can be transformed, an algebra of transformational sets that can be applied to different entities (vectors) and the rules by which these transformational sets can modify one another. Perhaps it is a matter of having operators that change themselves in ways that cannot be deterministically predicted, something like the chaotic 'strange' (fractal) attractors that will be examined in Section 4.

Dynamical Theories and Laws

What does it mean to speak of a theory or a law of physics being dynamical? What is the scope that can change? How could there be meta-rules that govern the dynamical process and how would the observer know what has changed? The endosystem (the entity being observed or experimented upon) and exosystem (the experimenter, measuring devices and environment) are two components of a whole system and quantum theory asserts the inseparability of these two subsystems with an equally strong demand that a partitioning be recognized. As Finkelstein points out, nothing is given in quantum theory regarding how to make the partitioning. He introduces the concept of a 'third relativity':

> "The first relativity is that of classical theories, including special and general relativity, which fix both the endosystem and the exosystem and merely permute their variables among themselves; while the second relativity is that of quantum theories, which fix the endosystem but transform the exosystem, bringing in different variables. Third relativity transforms both endosystem and exosystem, and thus extends second relativity as second does first." [[35]]

The third relativity principle as thus formulated is that quantum theories are consistent from one partition or scale of the universe to another. How an exosystem affects the endosystem is not dependent upon the measuring apparatus being considered as part of the one or the other. It could be embedded in either subsystem. The distinction here is critical. At a given scale, such as that of Planck distances and particle interactions, quantum theory will be consistent no matter how the experimental arrangements are established. Change the scale, however, and quantum theory must be transformed in order to describe a new set of operations between observer, apparatus and observed.

How does this thinking relate to what was discussed earlier about Bohm and Hiley's holomovement? The terminology is dangerously and attractively similar in ways. One of the fundamental thesis points in this present work is that one cannot easily or summarily match the two theories together as similar or dissimilar. Both must be partitioned and there are clearly aspects that are alike and others that are different, and that is not an inconsistency on the part of either theory! It is the difference between a polytheory and a holotheory, the claim here being that to integrate the whole with the finite parts may not allow for a uniform framework that applies to both and to all parts simultaneously.

Process and Non-Locality, the Local and the Whole

How can a process model be integrated into a picture of the universe that is based upon a unitary holomovement but without those non-local effects (or the causal constructs for explaining those effects) that contradict the principles of locally finite actions? Some set of processes defines a localizable network but disturbances within that network have impact upon a remote network with which there are no communications at or below the speed of light. There are boundaries to that local net (a LAN, to borrow from computer terminology) but there is from one viewpoint no boundary - open gateways exist connecting LAN to LAN. The computer network metaphor gives way as one moves from the quite-defined connecting links between servers and nodes to the flux whereby any node could emerge as the connecting point to several other networks. One might think of the local network as a dynamic LAN whereby each node is capable, according to some rule or code that follows from the structure of the LAN, of acting as a gateway to one or

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35 Finkelstein (1990) (Quantum Net Dynamics), p. 464

more adjoining LANs. Still there is nothing to explain how non-local, holonomic effects arise. It should not be the role of a new quantum theory to explain away the phenomena but to encompass and compre-hend them. This burning question leads to the following suggested model, bearing in mind that it is a model and not a Fredkin-type claim for the universe, quantum or otherwise, being some type of giant computing machine.

A Quantum CAM (Cellular Automata Machine)

Several theoretical quantum computing machines have been suggested as devices that could incorporate quantum mechanical principles to the advantage of computing. Some of the most notable are those discussed by Feynman [[36]], Deutsche [[37]] and more recently by Kak [[38]]. The latter is discussed below in Section 3. These architectures, however, all focus on the potential for using the indeterminacy of quantum states for performing what are otherwise formal Turing machine tasks. This is not our interest at the moment. Rather we are brought back to the question of how a computational model - and not necessarily that of familiar Turing machines (which effectively means all computers built to date) - can be of use in understanding the process nature of quantum behavior and the ways in which local processes can fit together into a whole that can equally be understood to be undivided and yet be perceived as a combination of interdependent parts.

One approach that has emerged out of these present studies is to construct a model based upon a cellular automata network wherein each cell is a fundamental quantum process and wherein these processes are grouped into larger collections based upon the collective activities of the processes in the group. The composition of such a network into a computing device is sometimes referred to as a cellular automata machine (CAM). [[39]] CAM architectures have been implemented in software and dedicated hardware and the families of 1-dimensional and two-dimensional cellular automata (CA) are well understood. Earlier work by this author focused more heavily on applying neural network models to this problem, using the types of neural nets that have been developed in the computer science and cognitive science fields for pattern classification, adaptive machine learning, control and other applications. Cellular automata theory appears to offer some broader and more flexible conceptual structures, although from what follows it will appear that the distinction becomes more a matter of terminology than anything else. One could describe the following as a type of neural network, but the connotations might lead to confusion about applicability to traditional neural net problems.

A thought-experiment is presented here to consider how this sort of machine could be applied to quantum processes. The suggestion goes against the grain of traditional thinking about CAs and CAMs in one very important respect, namely that the rules governing the states of cells in the CA are not uniform! Typically one rule set applies for all cells in an n-dimensional array where $\{m_1, m_2, ..., m_i\}$ denotes the set of dimensional unit divisions. In principle the same rule set would

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[36] Feynman (1985), Feynman (19880

[37] Deutsche (1985a), Deutsche (1985b), Deutsche (1989)

[38] Kak (1992)

[39] Toffoli (1987), Eckart (1991)

apply to any scale e of division such that e is an integer > 1 and where e is applied to each dimension in the array (e.g., a cellular automata whose dimensions are defined by $\{em_1, em_2, ..., em_i\}$. This would at first seem to destroy one of the implicit values of a CA as a computational device, namely the simplicity engendered by that uniformity and the relative ease in performance compared to, say, differential equations. However, the concern here is not one of using a CA for computing a problem in fluid dynamics or many-particle simulation, but rather one of how CAs could interact in a way that results in perceived non-local behavior and holonomic connectivity while there are still only locally finite processes without either superluminal communications or hidden variables of any sort. [40] For instance. what patterns of behavior emerge when the rules governing a local region in a CA are affected by global conditions that arise only through the independent actions of other, perhaps distant CAs? It is not causal relationship that is being sought so much as what may appear to be self-ordering.

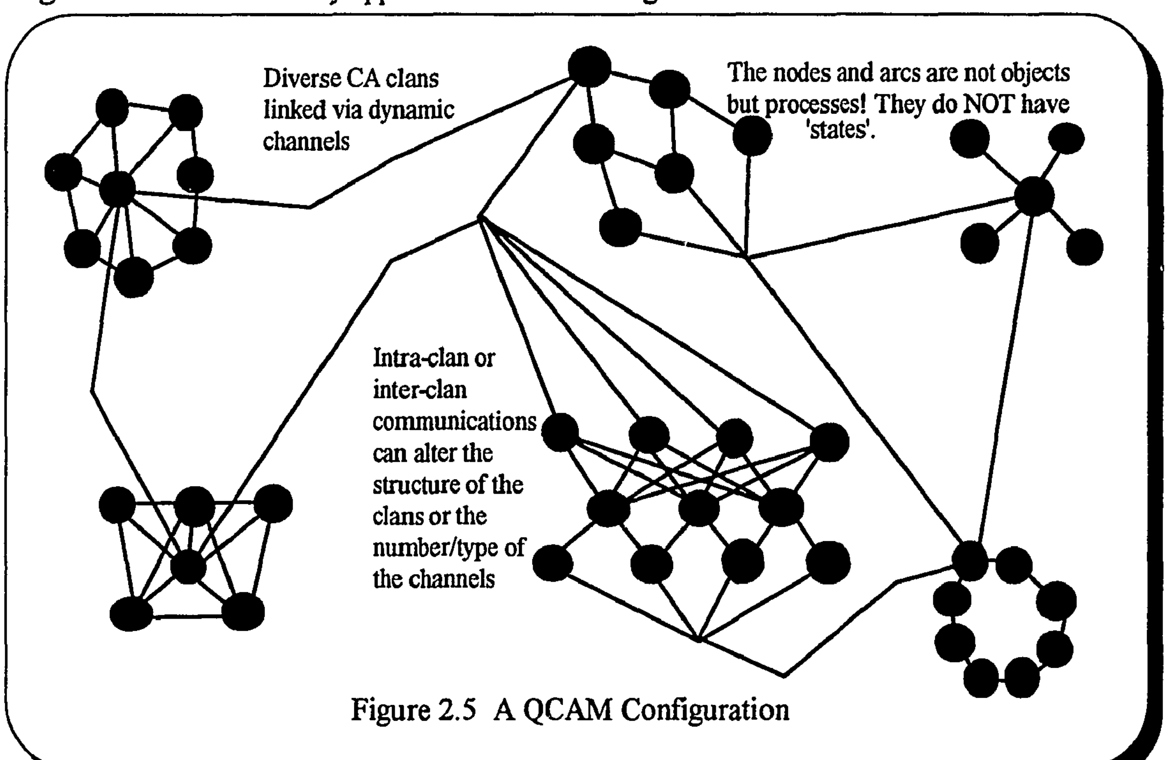

Figure 2.5 A QCAM Configuration

The QCAM consists of a set of CA regions or local networks (Cellular LocAl Networks or *clans*), each with a logic governing the internal cellular relationships and a set of operators that function as an algebra connecting two or more *clans*. Each such *clan* consists of a dynamical set of cells that have finite-distance connections with one another. It may be stipulated further that each cell has a potential point-to-point link with any other cell in the *clan* but that the probability of a given link l existing as part of the process encompassing all of the cells in a *clan* will vary over time. In other words the exchange of energy and information among pairs of cells within a

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40 A criticism has been raised concerning various 'chaotic' models of quantum mechanics on the grounds that the parameters implicit in chaos mathematics are equivalent to hidden variables that are, of course, disallowed by Bell's Theorem. However, the dynamical equations of chaos do not need any 'hidden' variables - it is the incremental effects of completely 'open' or 'non-hidden' variables that create apparently hidden behaviors.

clan is in constant flux. Figure 2.5 above gives a high-level view of a QCAM and an example of a *clan* is provided in Figure 2.6 below.

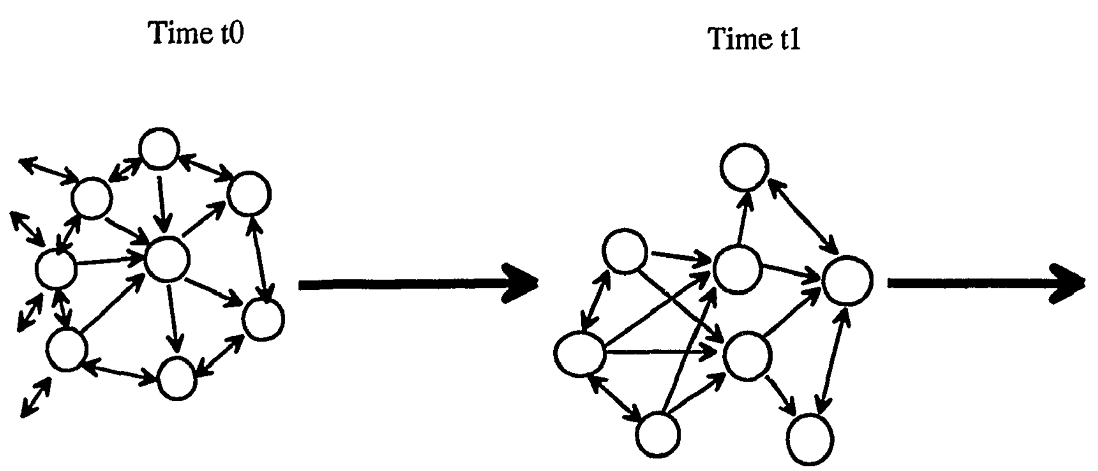


Figure 2.6 A QCAM clan in action

What makes the set of cells dynamic is that any given cell can be a member of more than one *clan* either in succession or consecutively. How a given cell behaves as a member of a given *clan* is determined not only by the logic of that *clan*. In the classical CA there is only one set and the relationships between cells are constant - there are no *clans*, only a homogenous tribe. This means that among *clans* in the QCAM there are logics that are inconsistent and contradictory when treated as a group but not necessarily when examined locally within the *clan*. Some, but not all. Furthermore the outcome of a logic l_1 that governs *clan* c_1 can affect the activity of a cell q within *clan* c_2 by reason of actions that affect cells ~q in c_2 with which cell q is linked. In algebraic terms, let domains A(x) and A(y) each have a set of operators O(x) and O(y). These two sets are not necessarily disjoint. Some operator [x] that is a member of O(x) is applied to an element p or a subset of A(x) consisting of elements {p0, p1, ...} in A(x). The result of this operation is an element or subset of elements {q0, q1, ...} also in A(x). But q_n may also be a member of A(y) such that the introduction of q_n into A(y) triggers an operator y[] in A(y) that acts upon qn to produce some r, unrelated by any logical connection directly with p. What is the relationship between p and r? How is it to be expressed, since the action of operator [y] may depend upon not one but an entire set of operations that create what can best be termed the configuration map of the network, the *clan*?

Here are the rudiments of the non-locality mechanism and hopefully the integration of quantum process theory with holoflux concepts. It may provide the underlying raison d'etre for hypothesizing such entities as the quantum potential construct. The QCAM has many overlapping *clans* and these share or overlap membership. Localized networks that constantly restructure their boundaries and internal activities based upon the relationships with neighboring networks. These must, it is emphasized, not be thought of as overlapping only in some space-time dimensionality. They overlap in an action-space or process-space (p-space) in which space and time are embedded. For any two processes p and q to be in the same part of p-space (in the same *clan*), there must be a link such that the execution of process p entails some aspect of the execution of process q (or vice versa). The entailment must include some spatial link but it is not the only link nor will it necessarily be the same in every instance. If the logic governing a given *clan* c1 results in process p it also affects q but not because of the logic for the *clan* c2 in which q is understood to be a natural member but because q is in c1 at the moment of the interaction.

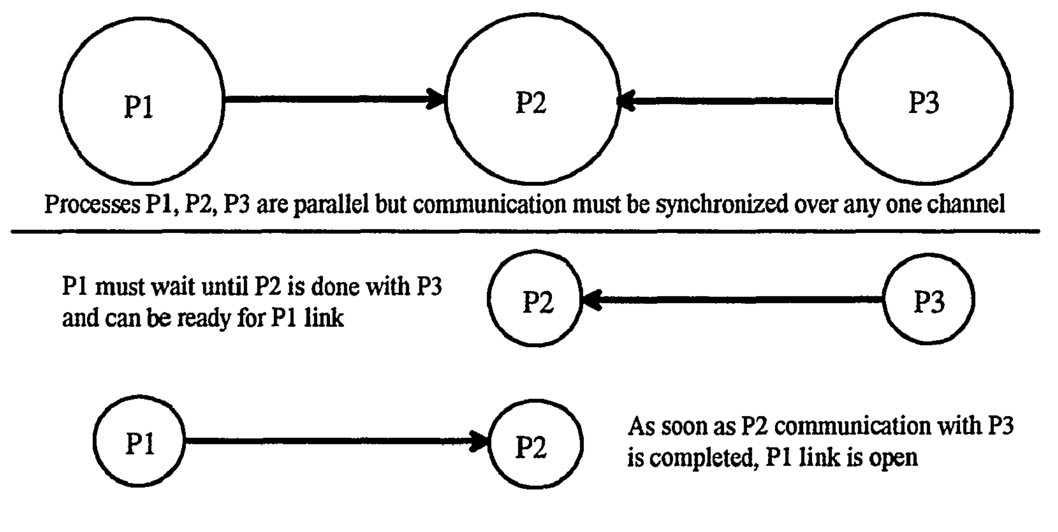
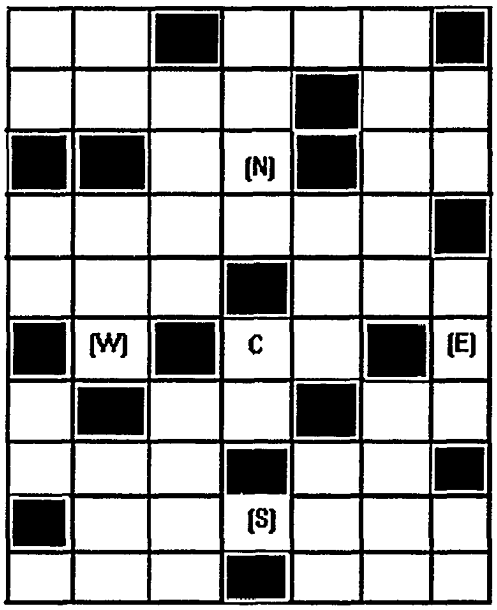


Figure 2.7 CSP Communications via Channels

The CSP/OCCAM model can again provide an illustration. Communications on channels between processes are dependent upon the states of both processes. P1 and P2 must both be ready and available for sending and receiving (respectively) a message on a channel. P2 may be busy because of internal computations or because of a communication on a different channel with process P3. P1's ability to communicate with P2 is thereby affected by events that transcend the interactions of P1 and P2. Corresponding to the QCAM discussion above, there is a logic for a *clan* c2 that applies to P1<-->P2 interactions and another logic governing P2<-->P3 interactions (c1). Figure 2.7 above provides a simple illustration of this communication sequencing, a concept that is often difficult to reconcile with the asynchronous nature of processing in the CSP model.

Actions on the borders or overlapped regions among clans will, according to this model, have far-reaching effects upon all of the cells within the affected regions, without the need for transmission of a signal and consequently without non-local exceptions. If process q is an embedded element of two different clans c1 and c2, any changes in c1.q and c2.q will be simultaneous. One change implies the other. But how does the action in one part of a clan affect the whole? It is the same old problem again. An event at the edge or border affects something distant without a direct link point to point. The problem is because physics is always thinking in terms of objects that are like balls linked with each other through forces that are like strings and wires. Instead there are actions, processes, doings which involve parallel interactions among field-like members of a larger process. It is not merely a problem of not being able to measure all the interactions without disturbing the remainder of a process; it is that there is no reduction of a fundamental process to particle-like points.



[A]

Cell Neighborhood Transformation Rules

Current State	(+)	(-)	
Next State:			
IF			
EWNS(-1)	-	+	
EW(-1) & NS(-3)	+	+	
* EW(-1) & EW(-3) & NS(-5)	-	+	*
EW(-2) & NS(-2)	-	-	
EW(-1) & NS(-3) & NS(-2)	-	+	
etc.			

[B]

Fig. 2.8 Cell Dynamics in a CLAN

The above illustrations are provided for giving a visual perspective on this notion of p-spaces, clans and process-entailment. In Figure 2.8a cell c is shown as an element within clan cl0. The state rules are given by the table in Figure 2.8b: if neighbors East(-1), East(-3), West(-1), West(-3), North(-5) and South(-5) are (+) then cell c becomes (-), else (+). The links between the cells are given to be such that all communications are subluminal. Processes in adjoining clans that share neighboring cells will affect the events in c10 by reason of these shared boundaries as if these processes were part of the overall process in c10. The key is that cells are linked within a clan in a fashion that cannot be mapped according to a strict space-time coordinate system. The implication is that there may be a different dimensionality that is required, something akin to wormholes, that establishes the linkage among cells. One has to carry the clan concept down to the ultra-microscopic scale and imagine the vacuum as a plenum filled with cellular processes that are interacting in such fashion, only with the rule sets themselves subject to change from the influence of higher-scaled processes. The last statement is critical. What is being said is that there are paths of influence from the macro to the micro, from the whole to the part. Conditions or processes covering a large number of cells and clans, affecting large numbers of channels between clans, will have a bearing on the interactions within the individual clans. What a cell is ultimately becomes a function (operation) of what all the other cells are doing, including hierarchical groupings of cells. Functionally this is even borne out by neural processes involved in perception, as Pribram and others have noted (cf. Section 3 and references). Depending upon the attention focus, which is a very high-level comprehensive 'system' function far beyond the sphere of individual neurons or neural networks, the activity of lower-level neuronal structures is oriented one way or another. For instance, certain neurons close to both the auditory and visual cortex regions of the mammalian brain are believed to have a dual function toward either type of signal input, and may be able to switch or shift toward the visual or auditory processing based upon the increased level of activity in one or the other cortex.

The order in which processes and communications occur matters. It seems that all of the clan processes will invariably involve non-commutativity at some level. But the operators are not distinct. If $\hat{Q}_1\hat{Q}_2 \neq \hat{Q}_2\hat{Q}_1$, one still has defined operators that hold the same meaning on either side of the equation. A given operator Q^* may be defined as a summing and thresholding within a clan (c10), bringing every subunit into the total effect based upon distance from some center. If, as a result of operations and communications from neighboring clans, certain processes from outside the local clan c10 are now treated as if they were indistinguishable from cells within clan c10, the operator Q^* will have different results, but this does not stem from the definition of Q^* itself. This seems to be pointing in the direction of some type of highly stochastic or chaotic operators for which it is not clear how to go about developing a formalism. However, set theoretic approaches may be useful if relationship factors between cells and clans can be described in terms of membership and exclusion.

In Section 4 further aspects of chaotic behavior and self-organization will be examined in greater detail. The proto-hypothesis that quantum processes are not isolated units but components of a network that cannot be divided into (or measured as) parts without loss of its essential qualities leads to some interesting questions about whether this could be a phenomenon that manifests on other scales than the microcosmic, and whether or not examination of such apparent phenomena will yield useful information - a new approach - to apply to the quantum questions. Thus in Section 3 the discussion turns to the biological realm and to the brain and neural networks in particular.

A Dynamical Process Algebra - Preliminary

The goal here as part of the overall intent underlying this project, namely to find a common ground of expression and language for understanding quantum processes and their connection with macroscopic phenomena, is to lay the groundwork - again, a prolegomena, an initial exploration - for an algebra that allows for dynamic changes within processes and their interconnectivity, in such a way that there is a communication between the whole space of processes and individual entities, and vice versa. The objective is not unlike Grassman's intent to develop a formalism that describes the processes of thought - actions that cannot be identified with quantitatively measureable observations but which underlie such events.

Admittedly this all-too-brief exploration is to just touch the surface of the matter. A work such as Finkelstein's _Quantum Relativity_ (unpublished; forthcoming) delves deeply into the foundations and construction of a quantum set algebra, ACTα, and its application to a quantum spacetime. Similar in depth and focusing upon the derivation of space-time from fermion and boson algebraic forms is Hiley's work on the holomovement. What sets this present approach apart is the attempt to work toward building a formalism from a more or less purely phenomenological basis of observing how communicating processes can interact and change one another in the course of performing their actions, looking in both directions - to the micro and the macro.

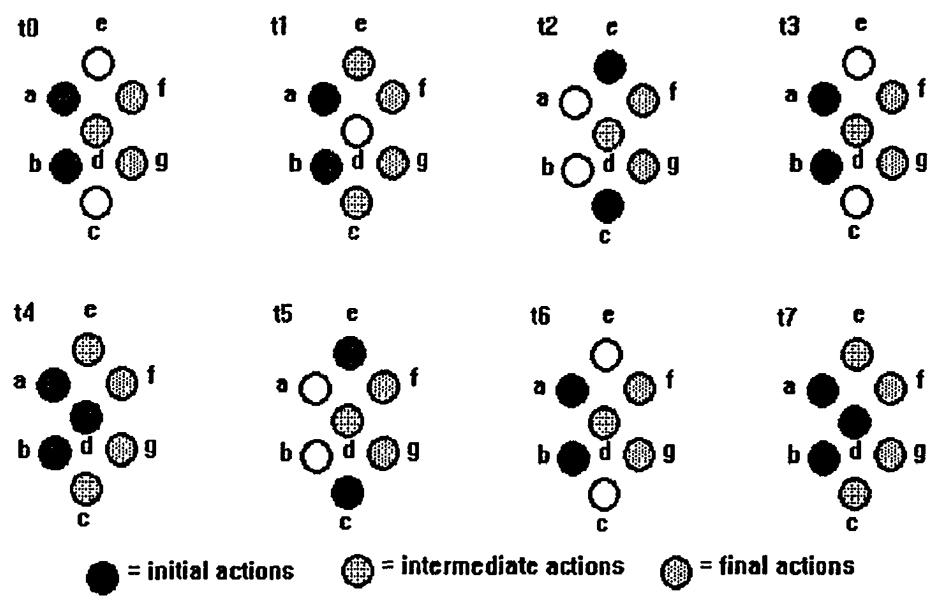
Consider now that there is a space ℵ consisting of fundamental processes |x|, any one of which may be simple (indivisible) or complex (divisible into simpler processes). Thus |x| may be described as a set $S_{|x|} \in \{aR\ , bR\ , aR\ , ct\ .\}$ where a, b, c, etc. are processes in ℵ and R are operators on those processes.

There is no initial consideration for how these processes correspond to anything in the physical world - it is for the moment a purely abstract space. A process is a happening, an action - something is different at the end, transformed, but the nature of that something is not a state or object, but another process. Any one movement begets another, and another, and so on. The nature of a process |x| is that it has at least one input and one output, connecting to at least one other distinct process (the input and output connection may be to the same process). It is important to remove the attachment to place |x| in any space-time. Radical as it may seem, action and movement do not presuppose a space-time coordinate system. *If the quantum world is fundamental and the classical is just the approximation or fringe zone, as is one of the key arguments herein, then it may be that space and time are evolutes of a primordial universe of processes that exist and interact beneath or before any coordinate system.*

It is not meaningful to denote 'simple' and 'complex' processes by different symbols, since there is no fixed type or class; a process |x| may subdivide into simpler forms as a result of some interaction with another process |x|'. One could say, however, that from some measurement point (i.e., some observer in a spacetime coordinate system) |x| appears to be simple or complex. In ℵ however, the 'composition' of some |x| is dynamic; i.e., there is more than one set of steps, parallel or sequential, that comprise what |x| is. Identity is no longer a stable entity. Some |x| could be described as xAy (A being some operator) and then due to a transformation of x or y it becomes (xBz)A(pCr), all the while |x| having a constant characteristic-set of behaviors.

Any process $|x|_i$ can be connected to any other process $|x|_j$. Let $|x|_i{:}C{:}|x|_j$ indicate the number of channels between such two processes, $0 \leq C \leq \infty$. The number of such channels need not remain fixed but there must be some operator that acts upon the process pair to make the change. In $\aleph$ there may be commutativity among operators that comprise some $|x|_i$ but this does not necessarily remain constant, because the composition of !

There is initially in $\aleph$ only one operator, ι, that of succession, akin to Peano's ι that generates the natural numbers N following the sequence $1, \iota 1, \iota\iota 1, \iota\iota\iota 1, \ldots$ Any other operators will have to be shown as derivable from ι. Succession appears to produce just a continuity of the same object but remember one is dealing not with objects but actions, and what appears to be an unchanging object is really a set of processes which may all be quite different (but in actuality things will appear similar). Why is this so? Because the successive processes are all managing to continue some type of similarity no matter how radically the environment is changing, and neighboring processes will themselves be changing. Figure 2.9 below illustrates abstractly the succession of actions that are different by virtue of external balancing forces but which maintain the same general process that gives the appearance of continuity.



Variations in the initial actions may be caused by external process interactions or a CA-type interaction within the subject process but the outcome is the same relative to the level of observation and measurement, in this case the activation of nodes

Fig. 2.9 Maintaining Succession Through Variation of Internal Processes

The nature of each $|x|$ is not fixed; in other words, what is simple from one level of analysis may prove to be complex from another. This is a matter of scale of observation or measurement. It is a form of relativity. Each $|x|$ evolves over time and undergoes changes, the transformation of which may lead to some sub-element $|x|_{i\,(n)}$ of $|x|_i$ having a transformation effect over some other $|x|_j$. This evolution must be derivable from operations applied to $|x|$ by other processes to which it is connected.

Any process $|x|$ can be further subdivided. As with particles, so with $|x|$; there is no ultimate elementary unit in $\aleph$. A given process $|x|$ is therefore a set of sub-processes, each of which can itself be a set of sub-processes. $|x|_i = \{|x|_{i(0)}, |x|_{i(1)}, \dots |x|_{i(n)}\}$. $|x|_{i(k)}$ may itself be a set of sub-processes. There are no limitations on the regression to this subdivisibility.

At the outset this appears to be a very uninteresting space - whatever is there simply subsists, in some sort of continuous succession ad infinitum. Perhaps this is the initial state of the universe - a set of processes all of which may be very different and qualitatively unique but because nothing changes, everything just goes on by the operation of ι, there is no perturbation, no discrimination from one moment to the next. No change, no variety. no variety, no distinction. No distinction, no identity. Nothing ex-ists or stands-out (*existere*).

Things can get interesting if there are other operators besides succession alone that can alter the configuration of the processes; i.e., creation and annihilation of processes, subdivision and aggregation of sub-processes, addition and subtraction of channels to other processes. This is where a world begins to take shape out of a matrix of uniform, indistinguishable repetitiveness. It is also a world where different times manifest themselves. Music is distinguishable only because of changes in frequency between the parts - it is, after all, the different frequencies that create parts and partitions in the first place.

What triggers change? What causes other operators to evolve and processes to transform themselves? It must be something that is implicit or potential within the notion of succession but which involves going beyond the domain of an individual $|x|$ to the interactions between processes. Creation and annihilation can be understood as consequences of some imbalance, a perturbation in the whole set of $|x|$, such that in order to maintain (or strive to maintain) the equilibrium of succession (continuity), new processes must be generated and others eliminated. A dynamics begins as a striving toward returning to balance, to center.

The problem, as Finkelstein pointed out [[41]], with introducing the notion of some underlying or primordial instability, is that a pre-existing stable system is implied; it is based on a space-time continuum description of the universe and a unitary one at that. There is no evidence that there should be a fundamental continuum and in Finkelstein's QND (quantum network dynamics), as has been discussed earlier, there is neither a separate space-time nor matter, only the quantum-space-time dynamical network. So how does one arrive at the differentiation which must come about to generate something other than constant succession ad infinitum, the separating that gives rise to the observance of imbalance or perturbation from a continuum point of view?

The key is in picturing the processes as a network of countless micro-nodes. One elementary nodal process $|x|$ can be a member of many different sets and each set comprises a network by which actions take place between processes, through 'channels' as discussed earlier. The nature of what 'is' $|x|$ changes as its composition-membership changes. The nature of succession means continuation but there may never be 'exactly' a continuation of $|x|'$ as identical to $|x|$, certainly not in the sense of the sequence $1, \iota 1, \iota\iota 1, \dots$ So there is always differentiation and no real thing like a

[41] Finkelstein, D. (1989), p. 1081

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This points to a general ontological case of the Uncertainty Principle. Instead of position and momentum or any two observables for one particle considered in isolation from others, there can be an indeterminate (not indefinite but uncountable) number of observable factors that define the process of a node a in the way that several fluid streams mixing together in a crucible determine the properties of the stream flowing from their junction. How stream a mixes into streams b, c, and d - the angles, the viscosity, the volume, etc. - all determine the quantities of measuring stream e that results.

Not all of these component factors can be measured to infinite precision simultaneously, and to what precision they can be measured is not simply determined, as with the Heisenberg principle; it will depend, it seems, on how those factors are themselves interconnected and dependent upon each other. This is not a theorem (yet) but a kind of intuition based upon real-world observation.

What emerges is something of the following, still a walking-towards a formalism for dealing with network-like processes:

Let **X** be a multiple-component operator that is represented by a vector with m components, each of which is representative of a relationship between n nodes $\{i_1, i_2, \ldots i_n\}$, where m >= n. (That is, among n nodes there are at least m connections but possibly more that matter for the **X** operator; these are <u>not</u> space-time physical connections, however. Instead of the usual operator as an instruction that extracts or produces some value from a function, **X** may produce a set of values from several functions, some of which may have arguments unrelated to each other. All of ℵ can be conceived as being pre-space-time actions - in a logical, not temporal sense.)

These relations could in a simple case describe probability or weight functions for an exchange of energy between nodes. They show how the action of one process (node) has an effect or contribution to another process. This operator extends conceptually from something like the momentum operator in three dimensions, $-i\hbar\nabla$, except that the number of dimensions has increased and the quantities are not necessarily the same type (e.g., all momenta p_x, p_y, p_z). The m components are not simple quantities but must describe complex relations; perhaps they are themselves operators built out of simpler components. However, the point is that nowhere does one reduce to a description of some quantity for a node that is given in isolation without consideration to the other nodes in the 'net'. Nothing has a property 'by itself.' It may be that a relationship r between nodes i and j is part of the complex operator **X** applied to node k, because r affects how i or j can be related to k.

Not only is noncommutativity an issue here but simultaneity in a computational sense. This is not a matter of time as clocked by some outside observer. A simple example is the following:

Initial Conditions:
x=10
y=2
Process:

Sequential	Parallel (Simultaneous)
x=y+5	x=y+5

z=x+8 z=x+8

Results:

Sequential Parallel

z=15 z=18

Is m a constant value for operator **X** or can it change? What would that mean? It is to say that under certain relations between nodes in the process network, other relations no longer matter. It does not mean the same thing as saying the values that describe those relations are zero. This is a kind of non-commutability that is different from the usual sense of an order to operators. It is not just a matter of the order in which some operators act upon a given function having a different outcome. Going back to the fluid dynamics analogy - turning off or simply ignoring stream d, there are still a, b, and c flowing together and mixing, forming stream e. The output may be the same, or virtually the same, as some combination of a, b, c, and d. The operator **X** still describes stream e but no longer with all the components. Some sets of values for the components describing a, b, and c will result in equivalences with or without d but others will not - this is what is meant by saying that there is a kind of non-commutativity of set membership as opposed to functional order.

Figure 2.10 below may help to explain the nature of an **X** operator. Regions S and T are linked by a set of weighted channels that control how outputs from S affect processes in T. This could be a mapping of a neural region within the visual cortex. The channels are dendritic fields that interconnect S and T neurons. Another region R has connections with both S and T and could in this analogy be a region of the auditory cortex. R operates upon both S and T in such a way that the mapping between S and T is affected by what transpires between R and S and between R and

T. The relationship between R and both S and T could be understood as an **X** type operator.

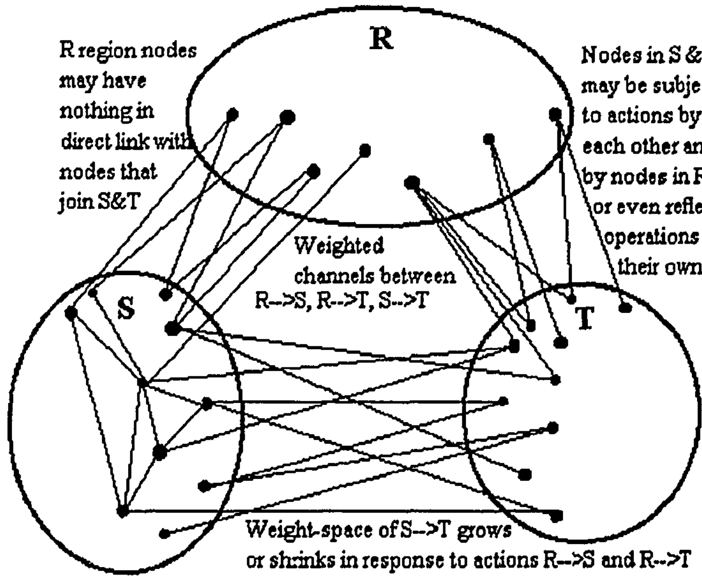

Fig. 2.10 X-operator and multiple regions of a process network

The operator **X** must be viewed as always providing a description of the whole process network but always from the perspective of one node or another. It is a kind of 'window' that declares, here is the value for a set of relations as viewed from this point in the net. But there are not just any arbitrary viewpoints; they must be from the nodes that exist. This is a kind of quantum relativity concept that could be explored for networks on any scale, not only that of the subatomic vacuum.

SECTION 3 QUANTUM-NEURAL MODELS

The Holonomic Brain

Why look at the brain or any biological system in order to try to understand something about quantum physics and quantum phenomena as a whole? It seems that there is a trend in the opposite direction, as further discussion of various theoretical research efforts will show, to apply formal similitudes from quantum physics to neural processes and biological transport mechanisms in general. The claim here, to reiterate an argument made earlier, is that if one grants the possibility that there is something in common, a quantum dimensionality to natural processes including biological ones, or at least the strong suggestion of such a link, then there may be reason to treat an experimentally observable macroscalar system (i.e., the brain and biological neural networks) as a simulation / testbed for studying quantum processes in general, the results of which could be extended at least as a working hypothesis to the realm of quantum events on the microphysical scale. It is an application of the dictum, 'As above, so below', to the scientific method as a means for generating testable hypotheses.[42] One of the goals of this work is to present in concise and direct form an integrated review of the theoretical investigations that associate quantum phenomena with neural processes. In the previous section critical work by the Bohm-Hiley school and by Finkelstein has been examined, focusing upon the physics. In this section the works of several researchers who address the quantum-brain issue are presented and critically albeit briefly evaluated.

It may be possible to discern more than one possible class of actions that link quantum mechanical events with macroscopic phenomena and to rule out the ways in which quantum effects are not responsible for large-scaled processes. For instance, it has been suggested [43] that quantum processes could be somehow responsible for the control of neurotransmitter exchanges among neurons and consequently for the basic mechanisms of memory and learning. There have been suggestions that herein lies an interface between brain neurochemistry and a non-physical mind or consciousness. Such a view, it is claimed, misconstrues the nature of both quantum mechanics and neural processing and an alternative can be shown.

The Pribram-Yasue Quantum Holonomic Model of Brain Function

Pribram's work on holonomy and neurodynamics grows out of studies on figural processing and the links between perceptual processing in the brain and the correspondence between those processes and sensory input. His goal was always to establish a demonstrable pathway for sensory data from first contact (e.g., photons impacting on the retina) through to perception in the visual cortex. To quote from the introductory 'Viewpoint' in Pribram's comprehensive work on the theory, "The holonomic brain theory espouses a *transformational* and *constructional* realism

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[42] Is there any reason to the contrary? Has science shown otherwise? It seems that there is a preponderance of evidence for common form and motif between the micro and the macrocosmic scales and that while a causal explanation for such commonality may be considered to be a metaphysical question, the connection is still apparent and worth considering in any speculative domain of science.

[43] Cf. references to E. Walker, J. Eccles, C. Muses

and thus goes beyond the direct realism proposed by Gibson in specifying the ecological details of the sensory and brain processes involved in perceiving." [44] Pribram's approach differs significantly from more traditional models in that a formalizable mapping is hypothesized to exist between real field phenomena - not collections of neural firing patterns but the bioelectric fields that exist because of such firings - among different regions of the neural system. Moreover, feedback signals between, for instance, the visual cortex and the retina are hypothesized as having a more significant role to play in the filtering of perceptual artifacts than has been allowed in the 'standard model' of neural processing. Figure 3.1 illustrates the holoscape contours that according to the theory exist within dendritic fields.

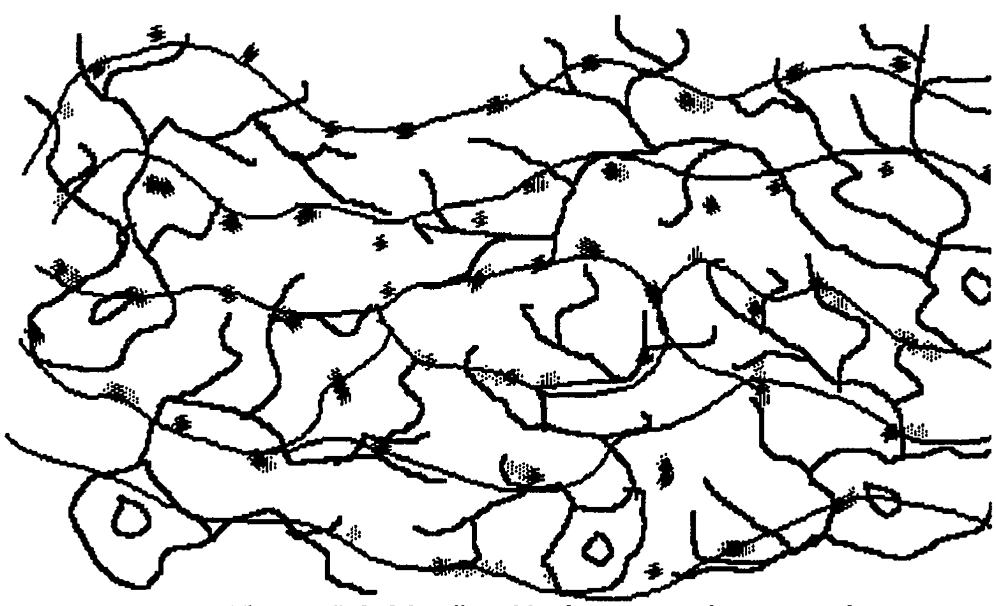

Figure 3.1 Idealized holoscape phase contours

The connection of the holonomic theory with quantum physics begins with and rests principally in the similarity of Pribram's model for neural processing and the mathematics underlying the optical hologram, an analogy that has its roots in several sources, not the least of which was Pribram's *Language of the Brain.* [45] This similarity and some of the popular misrepresentations of it, some of which have been circulated within the neuroscience community, has had some effect on the limited acceptance of Pribram's theoretical model. Earlier versions of the model rested heavily upon the Fourier transform relation which creates a duality between space-time and energy-momentum representations. It was difficult to see how global Fourier transforms could be performed by the transfer functions operating in the sensory system and this was definitely a problem with the early theory.

44 Pribram[1991]

45 Pribram[1977]; cf. also Hinton & Anderson[1981]

Certainly, regardless of the viability of the current theory, misinterpretations of the earlier model based upon the analogy with optical holography illustrate the problems of undertaking interdisciplinary scientific thinking. Pribram points out that "the holographic model of brain function had to be described in terms of a complex spectral representation. Often description was erroneously made solely in terms of wave forms per se; sometimes, because of its counterintuitive nature, the spectral representation was discounted." [46] No claim was made that anything corresponding to coherent reference beams of energy were operating in the brain and yet that mindset was imparted to the theory by some of its critics.

In the holonomic model there are two major quantum aspects - that of function and that of implementation. On the functional side, Gabor transforms figure heavily, and herein lies a significant link with quantum theory. Gabor's elementary or Logon function is similar to Heisenberg's uncertainty measure and describes a minimal information uncertainty as a region within the graph of frequency and time. The limits are in the ability to simultaneously measure time (or space-time coordinates) and frequency. Gabor referred to this limit function as a quantum of information and it can be seen how this can be applied as a measure of efficiency for a communication channel, be it a telephone wire or a neural pathway. Whereas the Fourier analytical approach decomposes space-time patterns into a spectrum, the Gabor function sets both space-time and spectrum as orthogonal coordinates in a phase space. On the uncertainty relation Gabor wrote, "... although we can carry out the analysis with any degree of accuracy in the [space]time direction or the frequency direction, we cannot carry it out simultaneously in both beyond a certain limit. In fact, the mathematical apparatus adequate for treating this diagram in a quantitative way has become available only fairly recently to physicists, thanks to the development of quantum physics." [47]

The general form of a Gabor function or Gaussian wavelet for two dimensions, assuming radial symmetry and polar coordinates in the frequency domain, is given by

$$g_{x_0,y_0,f_0,\theta_0}(x,y) = W \bullet g_{0,0,f_0,\theta_0}(x,y) * \delta(x-x_0, y-y_0)$$

where

$$g_{0,0,f_0,\theta_0}(x,y) = \exp[i\ 2\pi f_0(x\cos\theta_0 + +y\sin\theta_0) + \phi]$$

and W = gain or amplitude, with the labels x_0, y_0, f_0, and θ_0 accounting for the double localization in both spatial and frequency domains. One of the important advantageous features of Gabor functions is their reciprocity in both domains. Interestingly, the human visual system has very fine sampling within the spatial domain but coarse resolution in the frequency domain. This has relevance for biology but it appears that a hypothetical neural system could have evolved with more equalized capabilities, as far as the underlying signal processing mechanisms are concerned. Gabor functions provide an optimal packing of information and reciprocity in both spatial and frequency domains, but the biological implementation, like any that can be made on the computer, can take a variety of forms. It is worth considering that representation of an image in space (e.g., pixels) or by Fourier analysis (spatial frequencies) are two special cases and are not necessarily the most accurate or efficient. Why have these latter methods risen to dominance so that the more

46 Pribram[1991], p. 27
47 Gabor (1946), p. 432

acceptable view is that the brain ought to work likewise? One could speculate that development and widespread use of computer-based analytics and graphics has had a significant part to contribute to this tendency.

A comparison of 2-D receptive field profiles as measured experimentally from cat neuronal tissue with 2-D Gabor wavelet functions shows a minimal amount of residual error, practically indistinguishable from Chi-square random error. [[48]] This however does not imply that neurons are somehow generating Gabor functions any more than Fourier transforms. Herein lies part of the confusion about the Pribram model. The Gabor functions are operating in the phase space that is defined by the bioelectric fields that exist among aggregate neurons and in particular among their dendritic regions. No specific cellular mechanism is performing a computational task as if it were a dedicated DSP chip! The Gabor wavelet function may be the best-fit approximation for the field that is constructed and maintained by the collective action of a population of dendritic intersections. This is an example of an emergent process that unfolds, like similar organized patterns occurring in cellular automata or natural fractal phenomena, from a large collection of elements each capable of a limited set of simple actions. There is no Gabor function engine in the neural system, but the Logon function may be the most energy-economical vehicle by which a neural dendritic field can operate.

Something that is not clearly expressed within Pribram's work but that is brought out by image processing researchers [[49]] is that for representation of a signal a set of Logons is required. The number and type depend upon the granularity of representation desired. It is possible to establish a quasicomplete set with minimal error that for the human visual system at least is perceptually irrelevant. Approximation is, for biology and for computer-based systems, sufficient if not exact. The inexactness is not the result of any quantum effects but simply the result of the fact that the Logon set is finite and does not continuously cover the image field.

Dendritic microprocesses are the critical mechanism by which the holoscape operates and is sustained. Microtubular processes, speculated to include soliton-wave transmission, may provide the base-level mechanism for the generation of dendritic fields. Hameroff and others have speculated on how microtubulin structures could act as the transmission and storage vehicles for neuronal signals. During an early phase of this doctoral project, attention was directed at building computer models that could emulate what the holoscape could be like in the neural domain. Such questions helped to give rise to the architecture of the Parallel Field Computer (cf. Section 5) as a simulation engine for modeling a holoscape.

In the Pribram model phase coherence within a neural landscape is the fundamental mechanism for information representation rather than point-to-point links between neurons. The coherent patterns are not associated with individual neurons but rather their stochastic firing activity in a given region contribute to the stability of the phase relationships among the fields.

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48 Daugman (1990) and Pribram (1991), p. 72

49 R. Navarro and A. Tabernero, *Gaussian Wavelet Transform: Two Alternative Fast Implenetations for Images*, Multidimensional Systems and Signal Processing, 2, 421-436 (1991)

"In the holonomic brain theory, computations proceed in collective cooperative ensembles constituting a holoscape. The holoscape is composed of vertically oriented spine-produced dipoles embedded in horizontal dendritic polarization fields. The computations in the holonomic brain theory are therefore formally equivalent to computations in quantum field theory and thus constitute quantum neurodynamics." [50]

One must be careful about leaps in reasoning of this sort. While the evidence and the mathematical similarities support the holonomic model, the description of just what is the holoscape remains confused. Is it a set of phase contours or the field of dipoles generated in the spines of dendrites? Moreover, mathematical similarities do not translate into formal equivalence. The fundamental neurodynamics equations

$$\frac{\partial \rho}{\partial t} = -v\,div(\rho \nabla S)$$

and

$$-\frac{\partial S}{\partial t} = \frac{1}{2}|v|^2 + U_{ex} - U_{op} - \frac{v}{4}\Delta \log \rho$$

can in fact be transformed into a single linear partial differential equation of the familiar Schrödinger form

$$iv\frac{\partial \psi}{\partial t} = (-\frac{v^2}{2}\Delta + U_{ex})\psi \quad (3.1)$$

This does not a priori mean that the same quantum processes that generate wave functions are at work in the neural space. They point toward something in common but that common ground may not necessarily be of a causal nature. This present thesis argues that such commonality points to underlying fundamental processes in Nature that may be implemented by diverse instruments, much as there are common features between the fractal patterns of continental coastlines and fractal patterns that emerge from annealing or from cloud formation. Science must begin to look at the process logic and ask whether or not there are underlying unities that do not share causal mechanisms. The metaphysical problem of a physics that has lost the spirit of physis and process returns hauntingly; existence has been stripped from that which does not have a physical mechanism as its foundation. The contemporary concept of Reality is at risk of being upturned if there are real processes that share a unity even though they may be implemented in totally different media.

The fractal-like dendritic network consisting of branches connected through chemical and electrochemical synapses and ephapses is mathematically a multiply-connected manifold. This Pribram and Yasue compare to a torus as the simplified representation. The density distributions within the ionic bioplasma that exists through the dipole elements in the dendritic network can be represented by a fluctuation in the isophase contours of the manifold, according to the neural wave equation (3.1) above. Supposing that the external static energy U_{ex} is minimal, approaching a limit of zero. This would make sense for a dendritic network as the amount of static energy affecting the structures from other parts of the brain system should be minimal. It is possible to derive the following neural wave function

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50 Pribram (1991), p. 35

$$\psi_n(x,t) = \left(\frac{1}{L}\right)\exp\left\{\frac{i}{v}\left(\frac{2\pi}{L}v \bullet x - \lambda_n t\right)\right\} \quad (3.2)$$

which describes relationships among isophase contours in the holoscape that have wave number vector n and a frequency λ_n/v. It is the phase difference among isophase contours and the changes in relations among those contours that yields a flow within a dendritic network, something akin it seems to magnetic flux. This flow has a particular velocity and other characteristics of a multi-particle/point collective flux in density distributions. It is described further as manifesting a "typical spatio-temporal interference pattern illustrated by the neural wave function 3.2 subject to the neural wave equation 3.1." [[51]]

Figure 3.2 provides a simplified view of neural information flow based upon the neural wave concept. The dendritic net or neuropil is a large set of coupled oscillators whose energy sources

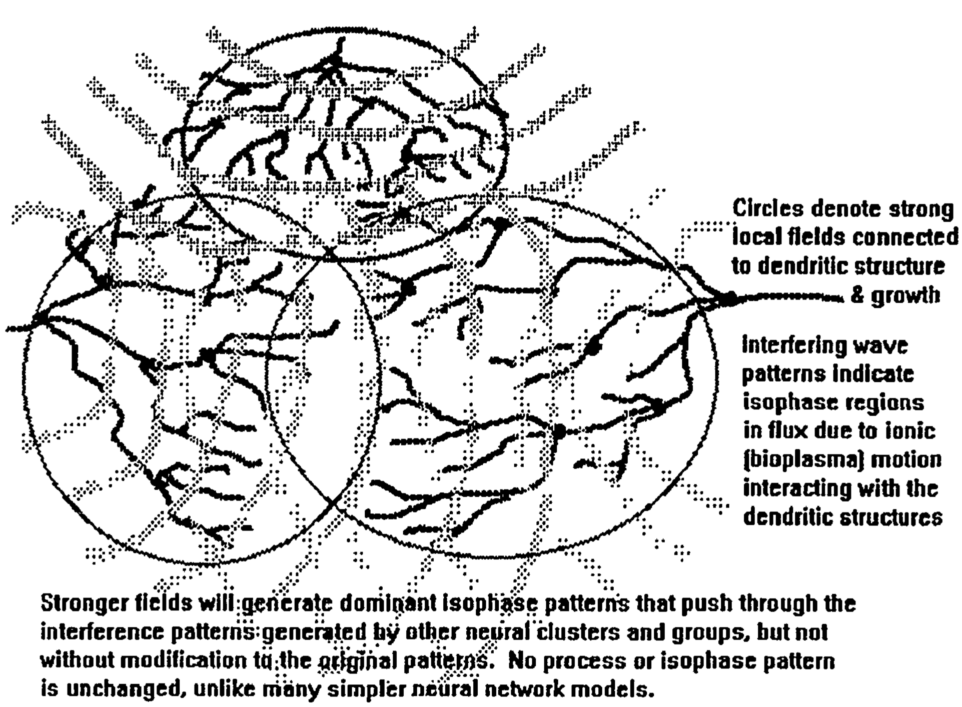

Figure 3.2 Neural Information Flow Through Isophase Interference Patterns

are the impulses traveling down input axons. A current-summing effect is generated from the various resonances that occur in the dendritic net, resulting in currents that travel to cell bodies and axon hillocks.

The Pribram model brings outs many likenesses between equations in quantum theory and those developed to describe neural waves and isophase contours. One of the problems is that while many formal similarities have been developed, no clear explanation is given as to the reasons why there should be such common forms. The neural wave equation is presented as a description of

51 Pribram (1991), p. 291

"the instantaneous state of isophase contours and the direction of [the equation's] change is given by the density distribution $\rho = |\psi|^2$ and the gradient of its phase." [52] Pribram goes on to draw the claim for global control of the "instantaneous state of the holoscape of isophase contours" through a distribution of phase differences. A reference is made to how amoeba-like cells act 'as if' engaged in activities that are like image processing in response to similar types of control stimuli. This leads to speculation, threading through the body of Pribram's work, about a type of "non-local cybernetics" operating in the brain and in other biological systems.

It is not the intent to douse cold water on what appears by all evidence to be a very strong and innovative model that points in the 'right direction' for neurobiology and that supports the thesis of quantum-like processes on the macroscopic scale. However, in striving to be as objective as possible, one cannot help but notice a strong element of enchantment with the language of quantum theory, particularly when it comes to concepts like non-locality. Pribram's concept is tied closely with the notion that field-effects, conducted through the ionic bioplasma generated by dendritic microprocesses, are responsible for certain actions that are far removed from one another in terms of neuronal (axonal) communications. In this sense there are 'non-local' effects - but this is certainly not non-locality from the perspective of quantum physics! Everything happening within the holonomic brain is happening at or below the speed of light by ordinary electrochemical processes. There are no EPR effects in the brain implied by the Pribram model. It is confusing to find references to non-locality where all actions are local physically if not local from the standpoint of traditional neurobiology.

Despite the confusion within the Pribram model on locality / non-locality, there is another analogy drawn from physics that stands out as significant. That is the concept of a least action principle. Changes in the density distribution of the ionic bioplasma develop in response to the isophase contours. There is a dynamical quantity L, the Lagrangian of the system, describing the difference between total kinetic and static energies, such that

$$L = \int_M \left(\frac{1}{2} |u|^2 - U_{ex} - U_{op} \right) \rho \, dx$$

This provides the time evolution of a system variable such that $J = \int_a^b L dt$ approaches a local minimum. The action integral J is less for the systematized time evolution than for all other virtual or potential time evolutions. That time evolution is governed or controlled by the collective isophase contours that comprise the holoscape.

> "Therefore, in neurodynamics, we interpret the least action principle with the action integral representing the global control of the distribution of the ionic bioplasma by the isophase contours. From the point of view of the holonomic brain theory, the least action principle is therefore nothing other than a control of the dendritic system by the patterns of isophase contours." [53]

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52 Pribram (1991), p. 292

53 Pribram (1991), p. 285

The least action principle can be extended into a fundamental dynamical law for any physical system, yielding such dynamical equations as the Euler-Lagrange equations. Within the neurodynamics formalism, the fundamental dynamical equation is given as

$$-\frac{\partial S}{\partial t} = \frac{1}{2}|v|^2 + U_{ex} - U_{op} - \frac{v}{4}\Delta \log \rho,$$

a familiar form where S is the phase of the oscillating portion of the membrane potential. This phase component is related to the current velocity within the ionic bioplasma. Pribram and Yasue argue that symmetry principles are provided by invariances within the external static energy U_{ex} and the neural wave generator $K = -\frac{v^2}{2}\Delta + U_{ex}$. Symmetry is said to be the principle attribute of "the fundamental dynamics of dendritic microprocesses which is represented mathematically by the fact that the neural generator commutes with the internal representation of the action of the symmetry group." [54]

The discussions by Pribram and Yasue and in earlier works by Pribram and Carlton (1986) lead in the direction of describing possible mechanisms for the development of object-form perception and cognitive prototypes. The notion of a complete normalized orthogonal system (CNOS) in a Hilbert space is introduced as a means of describing a cognitive context, something essential for transfer, learning and familiarization. This is not, of course, the only contender for describing such higher-level functions. Alternative models have been developed theoretically and implemented computationally by Grossberg, Carpenter, et al based upon adaptive resonance principles. Both theoretical developments have plausible elements from the results of neurobiological experiments but there is no decisive evidence yet to the correctness of either approach. An obvious area for fruitful research would be in the comparison of these with a view toward how they may be synthesized into a more comprehensive and even simpler description of neural processes.

Holographic Neural Models and Pattern Recognition

Independently from Pribram and others working directly in the neuroscience field, John Sutherland of Hamilton, Ontario (Canada) has developed a mathematical model for pattern storage and retrieval based upon holographic principles. This model merits being described at this point even though explicitly it is not a quantum model and does not make any claim for quantum physics. However it allows for quantum actions having effects, as will be seen when Schemp's work is discussed later. It is not based upon neurobiological investigations although the consistent strong behavior of the model through simulations and its usefulness as a practical, adaptive pattern recognition tool makes it a reasonable candidate for providing the mechanism by which learning and memory operate in biological systems. Sutherland has suggested several possible extensions of the model to multiple-cell networks corresponding to biological neural structures, but the strength of the model lies within algorithms that do not require such entities.

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54 Pribram (1991), p. 305

Known as the Holographic Network or HNET, Sutherland's model is based upon the use of a complex phase space to represent magnitude and certainty values for multi-feature patterns. Phase and magnitude within complex numbers are used to represent analog information and confidence level in that information (phase) value respectively. The magnitudes can be taken as probabilities ranging from 0.0 to 1.0. Pattern stimulus and response data fields are represented by arrays of complex values; each element in such an array corresponds to some measured feature of the pattern to be encoded (learned) or decoded (retrieved). All of the learning and recall operations that constitute the function of the network are conducted through encodings (enfoldings) and decodings of stimulus-response mappings within the complex space.

Given a set of scalars representing a stimulus field $S = \{s_1, s_2, ..., s_n\}$ (e.g., signal samplings, pixel values, time series values, etc.), the mapping is performed according to the function

$$s_k \rightarrow \lambda_k e^{i\theta_k} \text{ where } \theta_k = 2\pi\left(1 - e^{\frac{\mu - s_k}{\sigma}}\right)^{-1}$$

given μ = mean of distribution over s; k = 1 to n, σ = variance of distribution, and λ= vector magnitude (bounded by unit circle) providing a weight or dominance-factor of a given kth element within the stimulus field set. S has now been transformed to the set

$$[S] = \{\lambda_1 e^{i\theta_1}, \lambda_2 e^{i\theta_2}, \ldots, \lambda_n e^{i\theta_n}\}$$

Interestingly, both storage and accuracy in learning are improved to the extent that there is symmetry in the uniform distribution of phase (analog information) elements around the origin of the complex plane. The higher the symmetry, the higher the encoding density and the more distinct stimulus-response patterns may be stored. Generalized sigmoidal smoothing functions perform this mapping in the most efficient, i.e., symmetry-maximizing, manner. A distinction must be made between the encoding 'pre-process' that transforms stimulus and response pattern features into complex representation, and the learning or memory process that makes associations between stimuli and responses.

Learning is implemented computationally by complex inner products over the stimulus and response fields, mapping an association of stimulus element k to response element j, evaluating the complex product $x_{k,j} = s_k r_j$. For multiple patterns the encoding process may be represented by the matrix transformation $[X\ ] = [S]^T \bullet [R]$ where X is the correlation matrix. In the encoding process, patterns are presented one at a time and enfolded into the correlation matrix via a complex vector addition. The process minimizes disturbance or influence of previously encoded stimulus-response mappings by new learnings. However the encoding can be enhanced such that learning is a direct function of memory. The rate of learning is thereby controlled by the degree to which similar stimulus-response mappings have already been encoded. Encoding of a previously learned association will have less of an effect on the correlation mapping than a totally new association. This process is functionally similar in many ways to Grossberg's ART model. However, the Holographic model is far simpler than ART in even its simplest configurations (ART1, ART2), where the whole problem (and complexity) seems to arise from managing the competition and offsetting of one cluster by another. [55] Enhanced encoding generates a more sharp definition or "topological fold" in the correlation mapping region between nearby stimulus states, as is graphically illustrated in Figure 3.3 below.

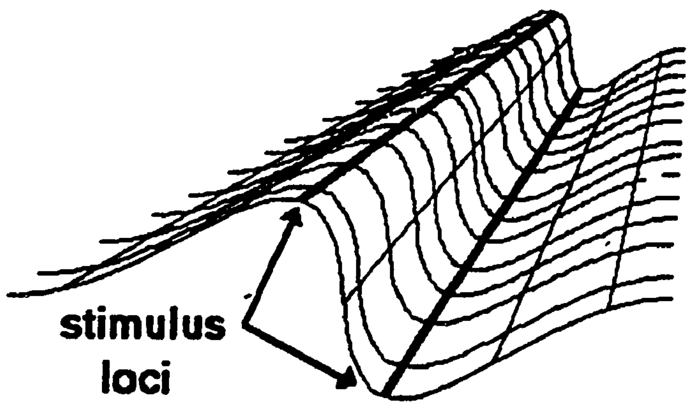

Fig. 3.3 Topological Fold Within The Correlation Space
Source: Sutherland (1992)

Decoding provides for the transformation of stimulus fields in a new pattern through all of the stimulus-response mappings previous learned or enfolded, in order to generate an associated response. The decoding transform is an inner product operation $[R] = \frac{1}{c}[X]^*[S]$ where $[S]$ is the new stimulus field $[\lambda_1^* e^{i\theta_1^*}, \lambda_2^* e^{i\theta_2^*}, \ldots]$ presented for matching of a learned response. A sequence of separate response components or potential associative responses for the new stimulus set are summed over time, each of which has a confidence or magnitude level that is statistically proportional to the level at which the new stimulus set approximates one that has been encoded earlier. One of these will be dominant and proportionately more than all others, provided that there have been a sufficient number of unique elements within the stimulus sets that comprised the encoding or training population of patterns. There will be a residual error within any generated response. The statistical variance for this error is proportional to the number of distinct and unique stimulus-response mappings in the correlation matrix. It is approximated by the equation

$$\phi_{error} = \frac{1}{\pi\sqrt{8}} \tan^{-1}\left(\sqrt{\frac{P}{N}}\right)$$

where N = size of stimulus field and P = number of random patterns encoded.

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[55] Neural learning models such as the Nestor RCE (Restricted Coulomb Energy) run into severe limitations because of having only one linear mechanism for controlling the division of an existing pattern class into two new classes. There is a poor distinction between elements that strongly and decidely belong in one class together and have repeatedly been associated with that class and those elements that have been borderline-classified into a particular class. The result is that when the distinctions between pattern types is strong, the model works reasonably well, but as the fuzziness between types increases, mismatches and false generation of new types grows.

The mapping onto the correlation matrix has some functional analogies with the Pribram-Yasue model of the holoscape as a flux of ever-changing isophase contours that are affected by new activities at the dendritic level as sensory inputs are transformed into perturbations in the ionic bioplasma. The holoscape could function in response to input signals in the manner in which the HNet correlation matrix encodes and decodes stimulus-response pairs. One can imagine a large volume of neural wave activity that is modulated by lower-energy, lower-frequency waves. The incoming stimulus-response mappings as it were are a bit like the pilot waves alluded to by Bohm and Hiley in their discussions on the quantum potential (cf. Section 2) - very low energy acting as a control over more powerful processes.

Sutherland's work suggests a biological basis for the HNET model but does not explore the hypothesis in depth since that issue is not the focal point of his research. One is left with the impression that here is an experimentally verifiable computer model for which it would be ideal if neurons and brains were an implementation. The HNET model is demonstrably more powerful in accuracy and performance than traditional back propagation neural networks and there has been a string of attempts to establish biological plausibility for the latter. Why not for the holographic network? If there were a biological plausible mechanism that could effect the encoding and decoding behavior of the correlation matrix then it would be a mechanism to explore in brain studies. The fact that such a mechanism has not been found and does not fit in with current pictures of neuron-to-neuron interactions may not be a problem if there turn out to be stronger grounds for the holonomic brain theory. The HNet correlation matrix may have its biological analogue not in a collection of cells or components of a cell but in the ionic bioplasma of dendritic fields. Why Sutherland's HNET model has not been more widely received in the research community is not easily explained; two reasons appear to be its elegant simplicity and its lack of visibility within the established circles of the neuroscience community. There may be a direct connection between those two factors, unfortunate as the case may be. It is unfortunate that experimental neurobiologists sometimes shy away from the application of a model that does not have any inception in biology but that stems from the computational domain, often with the argument that 'it isn't biology; it has no basis in the brain.' Perhaps the experimental evidence is waiting for an intuitive leap of faith to emerge. Often one must just envision the result and imagine it to be there, then go look for ways by which to test whether the vision is purely imaginary or grounded in something that is reproducible and shareable.

And what can the HNet model do for the question of quantum processes in the brain? As a simulation of one way that the holonomic brain could function, it supports the same analogues and connections that the Pribram-Yasue theory asserts. Also, it is consistent as a learning/decoding mechanism with the type of quantum mechanisms that other researchers have suggested to be operable in the brain, such as Walter Schempp of Germany. However, it does not necessitate that some type of quantum process be operable within biological neural networks. This is important to keep in mind for objectivity. None of the holonomic and holographic mechanisms require a quantum dimension, but it seems that they are both consistent and conducive to one.

A Suggested Experiment

It might be informative to take the HNET model and introduce a measure of uncertainty into two processes - the encoding and the stability of the correlation mapping over time. These uncertainties could be treated as the effects of quantum tunneling within the 'black box' of neuromolecular (perhaps microtubulin) structures that are the effectors of the stimulus-response mapping process. Whether or not certain features of the stimulus change before being 'fixed' into the correlation matrix can depend, in this thought experiment, upon the on/off states of some molecular gates. Likewise for whether or not the matrix 'holds' its state over some time interval. Given these effects which amount to introducing additional noise into the system, how does the HNET model perform when decoding is performed? How well can it overcome what amount to holes in the matrix that have been introduced during or after encoding?

An interesting variation on this experiment would be to examine the properties of synaptic boutons as was suggested by Eccles (see below) and to determine some plausible quantum effects on the transmission of ions across the synaptic boundaries, using that information to modify the logic of HNET. Will the system still be able to learn and to decode reasonably? These are questions that could be put to the test with a minimum of new neurobiological experimentation.

Walter Schempp's Work On Quantum Holography

The German mathematician Walter Schempp has studied quantum holography and the potential for single-photon holograms, based upon the treatment of coherent wave packets as symplectic spinors over a linear manifold akin to a hologram. The standard Heisenberg inequality becomes a special case, and there are implications for global/local connectivity such as is not explainable by standard neural network models but that can be effected through non-synaptic energy transfers between neurons, with significant implications for information storage and retrieval. Photonic associative memories could be constructed into highly and massively parallel computing machines with a high degree of fault-tolerance and adaptability.

Within quantum holography there is no distinction at the photonic level between split channels. The coherence length for an ultrashort (@ 100 fs) photonic pulse is the spatial length of that pulse, thus allowing for a recording only at points where object and reference beams are within that length. It is suggested by Schempp that the dendritic membrane of a neuron carries the structure of a manifold that corresponds to a quantum hologram plane and that adaptive resonance can occur between two given manifolds. Such adaptive resonance could provide a better source of electronic recording than traditional microelectrode methods which all require invasive techniques on neuronal membranes. Schempp explains the fundamental information processing thus:

> "[They are] the adaptive encoding and decoding steps, Because these processing steps are concerned with the flow and counterflow of photons, both the write-in and read-out steps are of a quantum theoretical character. the quantum parallelism according to which different alternatives at the quantum level are allowed to coexist in linear superposition, irrespective of how different from one another the quantum states might be, is equivalent to Niels Bohr's indeterminacy principle of spatio-temporal quantum

dynamics which says that in the phase shifted beam splitter interferometer experiment the collective stationary interference distribution appears if and only if we cannot determine the pathways of the optical photons." [[56]]

There is a suggestive link that emerges between the encoding and decoding processes that have been implemented and simulated with successful results by Sutherland's HNET model, the photonic holographic mechanism of Schempp and Pribram's larger-scale holonomic model of perceptual function. Could it be that molecular processes within microtubular structures that comprise the dendritic membranes, processes that could be describable by Fröhlich's soliton-type transmissions, provide the mechanism for photonic encoding and decoding that at the level of pattern processing is similar to Sutherland's correlation matrix operations of encoding and decoding and that at the level of object recognition and classification has the kind of experimental consequences one finds in Pribram's theory? In Schempp's model of a quantum holographic memory mechanism, biomolecules in cell membranes, formed of polymers and possessing high dipole moments, create what is known as a Debye layer of ionic bioplasma beneath the membrane. As a result of nonlinear resonant coupling, coherent Fröhlich wavelets occur when there has been sufficient thermodynamic noise generated by the field that exists between adjoining cells or dendritic fibers. These wavelets collectively form solitons that move throughout the membrane region. There is experimental evidence for these Fröhlich wavelets operating in the 10^{10} - $10^{11\,\mathrm{Hz}}$ band in cell cultures. [[57]]

One of the key implications of coherent wavelet activity at the micro-biological level is that the level of dendritic-field inter-neuron communication may be much higher and more significant than is acknowledged by the traditional model of well-defined synaptic interconnections. Schempp writes:

> "...the neuron doctrine fails which emphasizes that pathway conduction of neural wavelets is the sole basis for signal transfer and information transaction and completely neglects the activity of the glial cells in brain function. The information transfer which does not depend directly upon the synaptic organization form actually reflects the functional aspect of neural networks. This implies that neural holography based upon quantum holography provides a modelling closer to biological neural networks than the models that are based upon electronic circuitry diagrams like ADALINE (adaptive linear element) or MADALINE (multiple ADALINEs) which implement average and feedback." [[58]]

One might add back-propagation and other generalized feedforward networks to those mentioned by Schempp, as these are all based fundamentally upon sets of interconnections that are weighted for their signal strength and for which the cumulative signal is modulated by a conversion function (typically a sigmoid transform). This performs a form of smoothing or averaging operation over a discrete set of inputs. If pathway conduction of signals were the only means by which information were transferred, then not only are dendritic field effects practically ruled out but much variation

56 Schempp (1991), p. 8
57 Cf. Schempp (1991), p. 35, refs. 19-21, 31, 40, 48, 59, 63, 86
58 Schempp (1991), p. 35

and detail in the signal transfer process would be washed out by the averaging and thresholding, leaving much less than is present from the evidence of neurobiology.

Here is where quantum-level actions may have an influence over the inter-neuron connections. Perhaps the quantum effects have nothing in common with the scale of axonal and synaptic pathway signal transfers but operate on another but equally effective scale. Consider that the dendritic field effects may act as a type of control mechanism, a modulator for those synaptic junctions that are established. The fine-grain activity at the field level would act as a 'quantum potential' control wave for the courser-grained synaptic emissions. The dendritic field would serve as a kind of 'heat bath' in which synapses excite and inhibit themselves, allowing or disallowing strong signals to conduct. Currents within the field could serve to maintain energy wells and hills within the field such that, over time, the macro-scale growth or decay of synaptic features through the deposition or removal of transmitters and other molecules would occur. This brings to mind Kugler's termite-colony simulation illustrating the growth of large-scale structures (in this case termite hills and inter-colony bridges) through the cumulative action of field-like activities (the flights of a large population of insects making deposits in attractor-regions of the colony biosphere. [[59]]

The Self-Organization Issue

Schemp also introduces the concept of non-locality in the brain. Non-locality for him implies, (if not being equivalent to), phased correlations over spatial distances, where communications via neuronal interconnections are neither possible within a given time frame or are not biologically possible (i.e., no physical link of the type required).

> "Cell assemblies adaptively coding for coherent features in visual scenes may not be distinguished by the fact that the constituting neurons are particularly active. Rather it appears that such assemblies are characterized by global synchronization of oscillatory responses over considerable tangential distances across spatially separate functional columns and even between spatially separate regions of the cerebral cortex. In particular, these studies present experimental evidence that temporal coherence and adaptive resonant coupling form a basic principle of neural holography as a means for describing the dynamics of cortical coding and the cortical self-organization." [[60]]

The non-locality issue seems inseparable from the whole problem of self-organization. Perhaps it is appropriate to spend some time on this problem of self-organization. Everywhere in the sciences one is finding evidence of self-organizing, emergent phenomena. Fractals are the most ubiquitous lot since almost anything can be viewed at some scale or other to provide a fractal dimensionality. There is a tremendous confusion over fractal dimensions, chaos, randomness and how quantum phenomena relate to these. One cannot discount the phenomenological effect upon the observer - the unmistakable 'gestalt' of irregular, non-deterministic behavior, out of which at

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[59] Cf. Kugler (1989)

[60] Schempp (1991), p. 21. Also cf. Eckhorn et al (1988), Gray et al (1989), Singer (1990), Singer (1991), and von del Malsburg (1988)

some change of scale in observation regularity and structure emerge. But where is all this 'organizing' going on? Is it not in the mind of the beholder who imposes a measure of regularity and structure upon everything that is perceived and then declares that something is uniquely organizing itself according to some rule? Scale is the key, and as Kugler often points out, biological systems including humans are always shifting the scale of observation so as to find that which is optimal for the perceptual problems and the motor tasks at hand. Machines including formal computing devices are always locked into one particular scale of measurement. Biological entities have the power of adaptation - the ability to change scale as needed, a perceptual and cognitive telescope and microscope system built to optimize survival and control.

It might be more accurate to speak of 'emergent organization' rather than 'self-organizing." Does a cellular automaton organize itself in some global non-local manner? Do the gliders and guns of the Conway Life automaton have some non-local connectivity? Of course not. There are common rules affecting the space of cells, and so given a common starting point the cells evolve in similar paths and with similar consequences. Consider this analogy from the school of Everyday Affairs. Nimbus storm clouds brew over the horizon and soon fill the afternoon skies. The clouds are heavy with rain but for awhile, nothing, then suddenly the cloudburst. From horizon to horizon it is raining. On a macroscopic level, very similar to the processes in the brain, there is a phase transition that is distributed 'instantaneously.' How does one part of the cloud communicate to another that it is raining? Well, no one has ever thought of such a thing because it does not seem to make any sense. But obviously there is this nagging sense of collective synchronized action and state transitions. Why should there have to be any communicating? Why must there be an external causal agent? Consider how all the parts of the cloud or clouds have evolved over time according to virtually the same conditions and rules. One part of the cloud is essentially indistinguishable from any other except for location is space. So it makes sense that many regions of the cloud will arrive at the same state (transition into precipitation) at approximately the same time.

There need not be global synchronization or non-local communications between cortical columns and other regions of the brain in order to explain temporal coherence and adaptive resonance coupling. Separate cortical regions that do not have any neural links but which are synchronized in oscillatory behavior may be synchronized because of a common evolutionary cycle. Such a cycle may have nothing to do with long-term cycles of growth but only with recent processes and purely local nearest-neighbor type reactions. The whole point here is that apparent self-organization and non-local interactions may be the result of similarities in growth patterns and statistically similar population sets of neighboring entities.

Within the neural regions that do appear synchronized with others one can hope to find some common elementary processes that can provide the matrix for the emergent properties that evoke organization and communication of a whole greater than the sum of its parts. Whatever these elementary processes, it seems that within them, at the molecular level, is where one can find quantum effects upon the movement of particles in electrochemical reactions. There need not be anything more elaborate than that.

Of course this is very conjectural, and that is sufficient. What matters more for this discussion is that a quantum mechanical process clearly plays a central role in whatever system emerges. The role of quantum behavior is one that cannot be separated from the molecular holographic processes that are considered here. It is not analogy or circumstantial similarity but functionally a critical element. What is most important for the present study is that the role of quantum behavior does not seem to one of 'first impression' actions; i.e., that quantum effects directly transform particular cognitive or perceptual elements into one another.

A Quantum-Classical Interlude

Throughout the literature wherever quantum theory and the brain are brought together in the same discussion, there seems to be this common view that somehow, just by some indeterminate quirk of the microcosm, quantum effects are causing classical decisions to be executed. It is an increasing popular view, helping to shroud complicated problems in a permanent fog of uncertainty and interdeterminacy. More and more this begins to sound like the homunculus theory of the Middle Ages. Somewhere deep inside the mysterious machine that works by some God-only-knows necessarily complicated process, there must be a next-to-invisible agent.

However there is no homunculus and definitely not one that behaves according to a wave equation! A perennial confusion exists between the quantum and classical viewpoints of life, living, and consequently science. On whatever scale of size, quantum processes are not small versions of biochemical switches. It is inevitable that quantum processes are thought of in this classical way. That is conditioning and habit, of the same type that causes difficulty when switching from a stick-shift automobile to one with an automatic transmission or from a PC keyboard to one on a SUN computer. Science doesn't want to acknowledge the human-ness of the scientist enough, even at the dawn of the 21st century. Is there a fundamental fear or aversion to the chaos and indeterminacy, the non-commutability of human behavior? A century, even a generation ago, it seemed so clear, this gulf between the quantitative rigidity of *physics* and the qualitative numinosity of the psyche, but now *physis* re-emerges, more like Psyche...

MacLennan Field-Computational Model

MacLennan has advanced a systematic theory of field computation as a model for massively parallel analog computation wherein computation is understood as the 'continuous transformation of fields: continuous ensembles of continuous-valued data.' The scale of massive parallelism is not that of contemporary machines like the Connection Machine or transputer arrays; it is the scale of neurons and molecules, in the millions and billions and beyond. The key to what constitutes massive parallelism is that of continuity - when the data is so massive as to be considered not as discrete elements (as in an array) but as a single continuous quantity. One of MacLennan's claims is that it is possible to conceptualize and design a general-purpose 'universal' field computer, akin to what a Turning machine is for digital (discrete) computing, and that such a field computer would by definition have a set of basic primitive operations such that any field transformation could be performed. Both scalar fields (e.g., potential fields) and vector fields (e.g., gradient fields) would be accommodated by a true field computer. Such field operands could not be handled by a serial machine without sacrificing the continuity beyond comparison.

An assumption is made that any field must be realizable in a physical medium and therefore be limited to a finite region of space. Furthermore the range of values for a field will be limited but can vary continuously over that range. Physical constraints dictate the types of fields that make sense to consider for a field computer that could ever be physically implemented (for instance as an optical or molecular device). MacLennan argues for one possible universal set of field operations, that will serve to approximate any field transformation, namely one based upon the Taylor series

$$T(\phi+\alpha)=\sum_{k=0}^{n-1}\frac{T^{(k)}(\phi)(\alpha)^k}{k!}+R_n(\phi,\alpha$$

where

$$R_n(\phi,\alpha)=\int_0^1\frac{(1-\theta)^{n-1}T^{(n)}(\phi+\theta\alpha)(\alpha)^n}{(n-1)!}d\theta$$

Such a series constitutes a field polynomial that, with the simple set of operations constituting a local sum of general products, approximates nonlinear transformations. There are limitations in how the approximation offered by the Taylor series can be extended beyond local areas around a point into a general space not restricted to a point. The example is given of an nth degree polynomial of the form:

$$P_n(\phi)=K_0+K_1\phi+K_2\phi^{(2)}+\ldots+K_n\phi^{(n)}$$

The goal is to optimize selection of fields $K_0,\ldots,K_n$ in such a way as to minimize the logical distance between a given P_n and the goal transformation T. How does one find distance measures between field transformations? This, MacLennan points out, is an unresolved issue.

> "The usual development of an approximation theory presumes an inner product norm and a basis. Unfortunately, we have not found a suitable way to define an inner product on field transformations. One way to compare field transformations is to compare their values on a finite set of input fields..." [[61]]

Based on these foundations MacLennan has gone on to discuss field processing as it may occur in the brain cortex and specifically in dendritic processing. He also questions the assumption that knowledge processing can be equivalent to the interactions of discrete symbols. The notion of a *simulacrum* is introduced, being an idealized perfectly continuous computation, the inverse of a calculus. It is offered as an answer to the question of what, other than discrete symbols, can be a medium or structure for information processing?

> "The central idea in the theory of simulacra is the *image*, which is the vehicle of continuous information representation; images correspond to the symbols, formulas and

[61] MacLennan (1990), p. 47

other structures of calculi. The images in a simulacrum belong to one or more *image spaces*, which determine their topology. Examples of images include the set of all visual images (of bounded area and amplitude) and the set of all auditory images (likewise bounded). On the other hand, a single real number can be considered an image, and an interval of the real line is perhaps the simplest image space." [[62]]

In some respects the notion of a continuous computation is similar to Finkelstein's concept of fundamental processes whereby repetition breeds the image of substantiality and permanence. Eddies in the river give rise to the appearance of static structures, whereas after all there is only water flowing constantly albeit in very similar paths. A symbol has bounds, and symbolic, discrete computation has definite bounds to not only the 'program' but to each individual instruction. Instructions are WFF's - well-formed formulas - and cannot metamorphose into one another. Nor can new instructions emerge spontaneously within a formal language. This leads to a lack of adaptability, pointed out by Kugler, Shaw, Rosen and others, that sets apart the formal machine from its natural, biological, endomorphic counterparts that can generate new instructions as it were. Simulacra, to return to MacLennan's logic, could be considered as being entirely in movement or in flux, thus there is no fixed boundary ever between one computation and the next. One simulacrum could transpose into another and may in fact contain the 'seed' of many images. It is important to realize that in the conceptual shift from calculi to simulacra one is not throwing away the one form of representation and replacing it with another - there is a place for both.

Field interactions within the brain may be defined by excitatory and inhibitory synapses that actuate affine transformations. Input and output fields alike may occur as spike densities or graded polarizations. Second- and third-order interaction fields can emerge through the combination of multiple input fields feeding into a single synaptic region. This seems to fit in with the notion of non-linear functions being approximated by polynomials that are reducible to sums of first- and second-order interactions. Networks of neurons could be computing higher-order approximations to any one of a family of nonlinear functions.

There is an interesting question in all this regarding efficiency and least-action principles. What is the optimal configuration of processing elements for generating not one but many (an infinite number) of different nonlinear functions? What type of geometry is not locked into a particular computational model, or at least so predisposed to one that it becomes very inefficient for anything else? In digital computing, the ideal parallel processing architecture would be one that provides for unlimited interconnections between processing elements. Is that an ideal or an imposition because each connection must necessarily have a single value and one from a finite range? As a compromise there are virtual channels and routing devices (transputers) or massive arrays that can be used to simulated large-scale interconnection (Connection machine). The problem is that all communication channels are discrete and all signals are constant-valued; i.e., there is no in-line transformation based upon the field effects from neighboring channels. Anything else is considered undesirable noise and everything is done to prevent such transformations. Electronic computers hate water; biology loves it - fluids enhance fields and destroy discrete systems. A configuration that has indeterminate connections (dendritic nets) between processing elements and in which the state of a given connection is influenced

[62] MacLennan (1992), pp. 3-4

non-linearly by neighboring connections - this system allows for flexible computing where several functions can be implemented with equal efficiency. The brain's neural arrays seem to provide the most efficient design for rapidly switching from one function to another and with the least cost in energy. It would be interesting to explore the mathematical basis for demonstrating this notion of efficiency in transformation.

Other Quantum-Brain Models

Originally the scope of this research was directed at explicit quantum-brain relationships. The reasoning seemed to be that quantum phenomena might explain some of the uniquely non-linear, non-localizable phenomena involved in neural processes and higher cognitive functions, and that quantum theory might even shed light on questions of mind and consciousness. There were certainly several early seminal speculative works along these lines (Young (1971), Walker (1970), Eccles (1986), Penrose (1990)). The complexity of the brain and its obvious role as a measuring apparatus no doubt make it a focal point for considerations about quantum phenomena, more so than other biological systems. Early speculations by Wigner and others about the role of the human mind as an influencing causal factor in the process of measurement and so-called wave function collapse also contributed to the mystery, confusion and sense of inquisitiveness about this quantum-brain connection. However the development of a conceptual framework built around the notions of generalizable quantum processes operating on the mesoscopic and macroscopic scales and a duality of quantum and holonomic phenomena not limited to only certain unique categories in Nature has in one sense diminished the focus upon the brain over and beyond other biological systems. In other words, why only the brain? Certainly it does not seem to be unique and one would have to wonder strongly about why one biological system could have strong quantum factors and not another.

In any case there has been a significant number of research works that have suggested such connections between quantum theory and brain function that can provide the basis for future investigations into not only quantum-brain but generalizable quantum-holonomic associations. Not all of these pertain directly to the notions of universal quantum holonomic processes but they are pertinent in that they illustrate the breadth of thinking on the subject. Along with the research trends that have been discussed earlier, these various investigations are important and need to be presented together in a uniform context. This is an important element of this present work, namely presenting what has been suggested and done, hopefully to point towards some lines that ought to be explored more deeply and thoroughly in the future.

It is important to distinguish those lines of speculative thinking that would draw a connection between quantum physical events and mental phenomena from those that would link quantum events and neurobiological processes. Our primary interest here is in the latter and problems involving mind and consciousness are generally considered to be more philosophical issues, but things may not be that simple. It seems best to keep an open mind until there is more clarity about where lines should be drawn and boundaries established, including those of a conceptual sort. This is no different than when we are processing simple perceptual information and trying to distinguish objects from their backgrounds - until we have a fairly clear idea of what kind of thing we are observing, we cannot be certain as to where are the boundaries of the object and several alternatives have to be considered in parallel. The Necker Cube, Escher's *Ascending and Descending* and *Waterfall* lithographs and other graphic illusions are good examples of this sort.

The following section presents an overview of this variety of research, mostly speculative and theoretical, with criticism and comment upon how these approaches make sense in the light of the earlier discussions. The purpose underlying these and prior presentations is to give a broad picture of how quantum theory has been associated with bio/macroscalar processes and also to lay the groundwork for possible experimental approaches that may uncover evidence of such connections or others that have not been imagined.

John Eccles

One of the first scientists to raise the issue of quantum mechanical events having a causative role in neural processing, and therefore in macroscopic events, was Eccles [[63]]. In his seminal 1986 paper he presents a view of the synapse as the primary switching element in neural processing, for which the synaptic bouton is the principle component. The critical argument is that within the structure of each bouton there is a paracrystalline grid consisting of approximately fifty vesicles and that these act probabilistically in releasing the transmitter molecules. Eccles' argument is driven not so much by an attempt to demonstrate quantum effects but rather by a desire to show a possible basis for his dualist mind-body theory and how it might be reconciled with the conservation principles of physics. This dualist philosophical bias dominates the theme of the paper and does seem to detract from the overall argument.

Synaptic boutons are typically a terminal swelling of the axon and they contain synaptic vesicles and presynaptic dense projections. Figure 3.4 below illustrates a typical synaptic configuration - this is the type of dendritic interface that generates the bioplasmic field so central to Pribram, Schemp and others. Excitatory postsynaptic potentials (EPSP) are produced by the release by the vesicles of 5000 to 10000 transmitter molecules. This emptying is considered by Eccles to be a "quantal emission." Whether there are quantum mechanical actions involved is not evident from the behavior of the synaptic vesicles alone. What Eccles calls 'quantum' is basically the

[63] Eccles (1986)

probabilistic behavior of these vesicles.

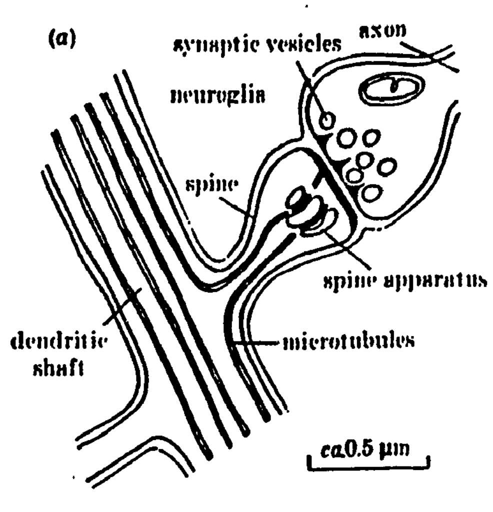

Fig. 3.4 Synaptic Structure
Source: Eccles (1986)

Eccles looks to the presynaptic vesicular grids as providing the targets for "non-material events such as the intention to carry out some movement." It is not as if those mental events cause an excitatory action on the synapse, but rather that those mental events somehow influence the "probability of a vesicular emission that is triggered by a presynaptic impulse." Emissions are viewed as probabilistic and the probabilities are deemed as modifiable by external factors. One of Eccles' worthy points is that an exploration of quantum mechanical properties of microcrystalline structures could shed light on how presynaptic vesicular grids operate. If the grids in the boutons behave in ways that are consistent with paracrystalline structures, then there is more evidence to suggest comparable bases for that behavior.

Eccles' hypothesis suggests that there is something akin to a probability field that acts upon a multitude of presynaptic vesicular grids. All things considered, there is much that sounds a familiar chord with the Pribram-Yasue model of phase-coherent bioplasmic fields. The Eccles' model complicates matters immensely with the emphasis on non-material mental intentions as the causal agent for the change in probabilities. This dualism surfaces also in the work by Henry Stapp on this subject, discussed below, and seems to typify many of the discussions that bring quantum theory and consciousness together, but not necessarily quantum theory and neural processing. Some of the experimental results presented by Eccles such as evidence that "a mental act of attention can activate appropriate regions of the cerebral cortex" seem to be explained more simply through the field-computational approach of Pribram, Yasue, MacLennan, and others. In no manner does Eccles suggest a role for massively parallel chaotic systems generating the type of phenomena for which a non-material agent (the 'mind') seems to always be brought up as a cause. Part of the reason for this is historical - much of the contemporary body of knowledge about chaotic and non-linear systems, scant as it may be compared to other subjects in mathematics or physical science, was simply not known or predicted during Eccles' time of writing.

Roger Penrose

Penrose has addressed the quantum-brain problem from the standpoint of his long-standing work in quantum gravity and twistor theory and an approach that looks for the effects of general relativity upon quantum mechanics more than the other way around. [64] The classical quantum notion of state-vector reduction is seen by Penrose as the time-asymmetric effect of some sort of quantum gravity and essentially stemming from a different structure of space-time than has been customarily used within relativity theory. Simply put, a threshold of curvature forces smooth time-symmetric evolution following Schrödinger's equation to yield into a time-asymmetric state-vector reduction. Bear in mind that one is still working here within the confines of an overall model where there are wave functions to collapse and where the notion of reduction still stands as a real change in the state of a system. According to one interpretation the presence of a single graviton mass in the proximity (unclear, though, how that is to be measured) of a quantum superposition acts as a trigger for the actual collapse of that wave function. Wave function collapse then would not require an act of measurement, and trees that fall in the forest but are not heard are actually falling. This is, as Finkelstein points out, the nexus of the whole problem about quantum theory, going back to the Wigner formulation that each quantum has a particular state vector which undergoes deterministic evolution $\Psi \rightarrow U\Psi$ and then unpredictably jumps to Ψ_λ. Penrose is looking for what amounts to a causal agent (a threshold level of space-time curvature on the scale of one graviton, and a corresponding scale of mass that he calculates to be approximately that of the Planck mass, $1*10^{-5}$gm) that makes an indeterminate physical object Ψ change (settle) into one particular state, and it is the formulation of such a question in terms of objects and causes that makes for the difficulty. If there is no singular object in the first place, what does it mean to look for a singular cause for a change of state? What if the whole notion of a fixed state is an illusion, or rather a repetitive process formed by the interactions of many nodes in a sub-quantal network, returning to Finkelstein's quantum dynamics and nets? To transcend this 'substantialism' does not necessarily discount Penrose's basic concept of a link between quantum events and cognitive processing, but it questions whether that connection is identifiable in one space-time location.

The connection between quantum physics and the brain for Penrose is in any case a quest for a new type of physical action that could play a role in the process of thought and perception, something that is different from the acceptable role of quantum-mechanical actions within neurotransmitter ions. Penrose develops a notion of how single-quantum sensitive neurons could exist in different parts of the brain, not all that different in principle from retinal cells that respond to a single photon of visible light. This move seems to be a further move down a mistaken path of looking for the wrong type of quantum action in neural processes; i.e., causal agents at the level of a particle-scale wave function collapse as opposed to quantum processes that operate at scale much larger than that of particles and atoms.

[64] Most of Penrose's ideas relating quantum theory, the brain and consciousness are to be found in Penrose (1989)

It is an interesting notion, however, that trigger actions, such as are found in retinal neurons, greatly amplify a signal by generating an electromagnetic field which is then transmitted, along with many other similar fields, along a neural pathway. Penrose is speculating that this amplified signal, while it does not meet the mass requirements for his one-graviton quantum threshold factor, could somehow trigger that scale of mass movement by a 'ripple effect' through adjoining neural tissue. Retinal neurons would then serve as quantum measurement devices that reduce superposed state-vectors into deterministic states. The brain becomes a type of passively parallel SQUID apparatus. But why should one be looking for causal agents to state-vector reduction in the first place, and even if that model made sense quantum mechanically, how would it have relevance to neural processes or the cognitive/affective descriptions attributed to mind and consciousness? One thing that does emerge as useful from Penrose's model is that if one thinks in terms of discontinuous state-vector reductions $\Psi \rightarrow \Psi_\lambda$ then action by some outside consciousness is not needed to explain that reduction - iff some mechanism akin to Penrose's quantum-gravitational threshold can be shown to exist.

The view of retinal neurons as somewhat simple single-neuron switching elements leaves a lot to be desired. While a single photon may trigger a neural response, it does so always as part of a large group of neurons in the visual system and a sequence of activity, some of which may be counter to the photon-activated event.

Could the brain act as a type of quantum computer along the lines discussed by Toffoli, Fredkin, Deutsche and others? There is an innate appeal to the idea - massive computational units (neurons and neural clusters) operating in parallel and producing the equivalent of a linear superposition, then with the equivalent of an observation measurement, the different computations are resolved into one deterministic result. This was a point of view initially explored within this doctoral project and in fact was one of the reasons for beginning the study. Multiple computational paths would evolve in a way that could be analogized to a quantum superposition of states, such that no one path could be measured during mid-process as being the one that would lead to a final outcome, and then by some action that would force the 'reduction', one and only one path would emerge as dominant. But where is there a place for quantum effects to be sustained through all the noise?

The problem, touched upon by Penrose in passing, is in the high-temperature of biology. How could any quantum effects be sustained long enough so that the results of process A in one portion of the brain could interact with the results of an independent process B? Reductions, as it were, will be occurring constantly and at every point in a neural pathway. It is as if every 'program' in this quantum computer could only be one instruction long. There would be no way to distinguish whether or not a particular biological state was the effect of some event e_1 or an event e_2, and with that indistinction goes the usefulness of the computer. All things considered, it seems to be a mistake to look for a biological mechanism by which the U -> R reduction model could be replicated within the brain as a computing device.

Now if Penrose were to look at Conrad's application of electronic superposition to nuclear conformation and self-assembly, discussed below and in Section 5, some of this problem of reduction and loss due to thermal noise would be resolved, because one would no longer be looking for long-distance, long-term quantum effects. Let the microscalar quantum processes be active where they are - among the components of atoms and in the boundaries and surfaces of macromolecules. This is an important and hopefully well-reiterated point - quantum actions may be responsible for such phenomena as solitons transmitted through cytoskeletal networks of tubulin or coherence and order within biological intra-cellular H_2O. Those phenomena may be manifest on a much larger scale than that of elementary particles, and their effects may be transmissible over macroscopic distances, perhaps even down the length of neuronal axons (1m+). This does *not* mean that the quantum actions at point A have themselves some interaction at point B which is macroscopically distant, only that the effects can be propagated through some type of network dynamics.

Arthur Young

His work appears to be relatively unknown in mainstream scientific circles, but Arthur M. Young has made some very interesting and provocative contributions in physics, cosmology and the philosophy of science. In fact it is difficult to characterize his two major works, *The Geometry of Meaning* [[65]] and *The Reflexive Universe,* [[66]] since both are highly interdisciplinary and, to coin a new term, *metadisciplinary*. What is particularly relevant to this work is his emphasis on the fundamental quantum of action, embodied in the photon, and the pre-eminent position of spontaneous act or impulse in all levels of Nature.

This is relevant to the quantum holonomic hypotheses being discussed in this work because it introduces some integrative principles that cross physics, chemistry, biology and psychology and introduces a philosophical perspective of meaning and purpose that addresses questions of 'why?' in addition to the more usual 'what?' and 'how?' A direct connection with the work already discussed may not be obvious. Once again our purpose is to draw together diverse approaches and to establish some of the right questions, the investigation of which may lead to some perceived connections and common ground.

Young's philosophy is very close to that of the ancient Greeks who practiced *physis* and who regarded truth as an ever-formative, ever-emergent *aletheia*. He writes of philosophy as being

> "'the science which investigates the facts and principles of reality.' In this sense, philosophy not only encompasses the natural sciences, but explores the implications of the findings of science, and also deals with the relationship between the knower and the known." [[67]]

Perhaps a philosophical stance such as this automatically puts Young's work into a category that many contemporary academic philosophers and scientists do not want to touch. It smacks of a return to principles that supposedly have gone out with the 19th century or even earlier. That there can be a disciplined study from the outside of the workings of science and scientists, one that can encompass a breadth of different investigatory methods and disciplines and contribute

[65] Young (1972) [Geo of M.]
[66] Young (1976) Refl. U.
[67] Young (1976a), p. xiii

something from the general to the particular - this is not popular. And if in this work one dares to bring in insights or evidence derived from ancient traditions, Greek or earlier as does Young in his drawing upon the wealth of the human mythic experience, then one is really treading dangerously on thin ice and quicksand.

Young has an extensive quote from Charles Sanders Pierce, the philosopher whose work in logic is at the roots of Finkelstein's quantum logic work [[68]] and it is worth repeating part of this quote since it sums up some of the main issues that are still blocking some potentially great leaps forward in physics and the biological sciences. The quantum holonomic hypotheses being discussed in this work may ultimately take shape in very different ways or find explanations by other theoretical frameworks, but one thing is clear - that there is a conceptual resistance to ideas such as pure spontaneity and acausal action, non-locality, wholeness, and the influence of the minute and indescribable upon larger systems. Pierce seemed quite aware of the problem in the 19th century even though some of the issues were different.

> "Instead of striving with might and main to find out what errors they [metaphysicians] might have fallen into, and exulting joyously at every such discovery, they are scared to look Truth in the face. They turn tail and flee her. Only a small number out of the great catalogue of problems which it is their business to solve have ever been taken up at all, and those few most feebly. ... Whether or not there be any real indefiniteness, or real possibility and impossibility? Whether or not there is any definite indeterminacy? Whether or not there be any strictly individual existence?"[[69]]

What is especially relevant to this paper is Young's perceived primacy of the principle of action and the importance of the 'spontaneous act' in Nature, but to explore this even lightly one must look at the broader foundation of his work. His 'geometrical' approach to meaning and knowledge is based upon a fourfold set of epistemic relationships that characterize the ways knower and known can be related:

- Objective General
  Relationships contained within the known object itself.
  Examples: equal sides and angles in an equilateral triangle,
  Pythagorean theorem, etc.

- Objective Particular
  Sensation-based data from a particular object.
  Examples: a given triangular piece being blue, flattened,
  dented.

- Projective General
  Qualities and values projected by the knower upon the object
  and all others in its class.
  Examples: solidity, fluidity, sturdiness, flimsiness.

[68] Personal communication with D. Finkelstein, June 1990
[69] Buchler, Justus (ed.), Philosophical Writings of Peirce, p. 314, Dover Publications, New York NY, 1955

- Projective Particular
  The function of a given object for the knower/user. This encompasses "relations of the knower to himself which he creates for the object, and would include his purpose in making it."
  Example: a triangular piece is used as a pendulum or as part of some instrument.

For Young, only the first is commonly accepted in science but all four really belong in the picture. He sees a strong similarity between this fourfold knowing and the four Aristotelian causes - formal, efficient, material and final, and establishes the following 'geometrical' relationship between the two sets:

```
                       final cause
                    (proj. particular)
                            |
                            |
material cause ---------+--------- efficient cause
 (proj. general)            |          (obj. particular)
                            |
                       formal cause
                      (obj. general)
```

Related to this categorization is a fourfold division of the cycle of action, consisting of position and the three derivatives - velocity, acceleration and control. The connecting link is in four types of action that comprise the learning cycle - position, reaction, spontaneous act (impulse), and control. This cycle can be thought of in the following way which is somewhat of the reverse order to how we usually conceive of position and its derivatives in relation to one another. There is a spontaneous act, followed by a reaction to the consequences, followed in turn by observation of the situation and then control (modulation) which may take the form of learned behavior. This spontaneity is something that most disciplines in science want to either avoid or explain away through some form of determinism and as an observation it seems that much of the reluctance to accept quantum theory stems from an unwillingness to allow for spontaneous, 'free' action.

A major objective of Young's work in *The Geometry of Meaning* is to establish a direct mapping of basic physical quantities and measure formulae with aspects of the epistemic/ learning cycles described above. Additionally it is his goal to 'make better sense' of mass (M), length (L) and time (T) so that they can be conceived as part of a more fundamental unit of measurement and not remain as undefined elementals that are just 'always there' in the sciences but inexplicable as to why they are basic quantities. This is not a simple reduction to one term but a reduction of M, L and T to being aspects of a primordially undivided whole. In the cycle of action, T becomes a common dividing factor:

control L/T^3

|

|

acceleration L/T^2 ---+---- position L

|

|

velocity L/T

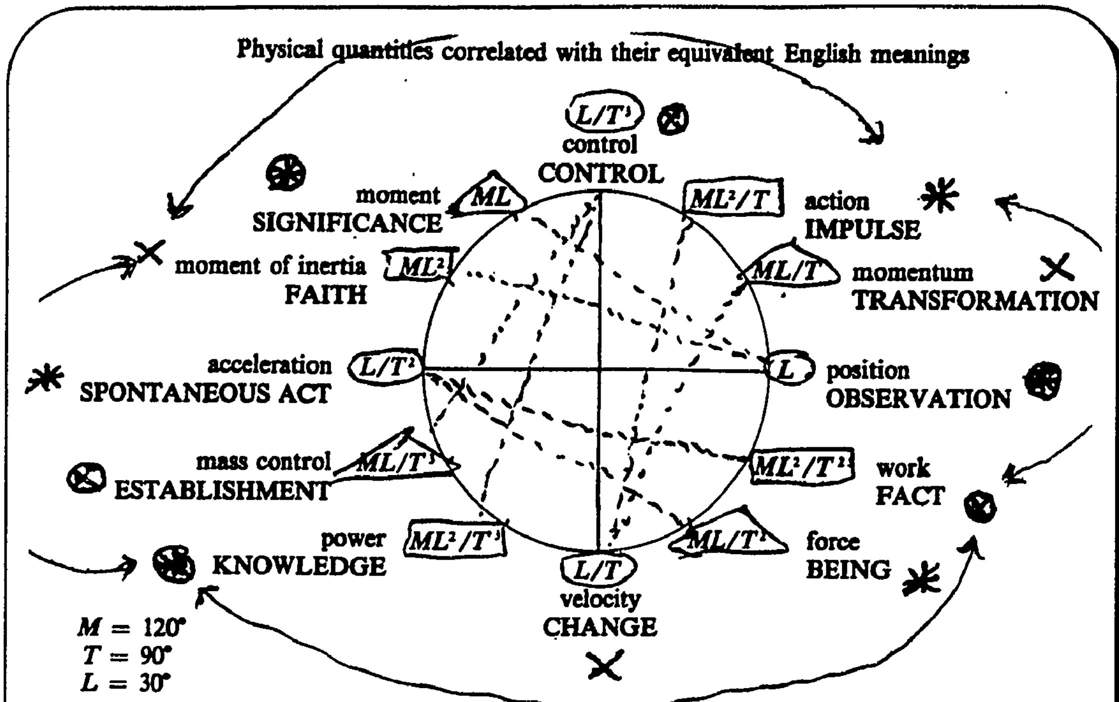

Fig. 3.5 The Rosetta Stone of Meaning (Measurement)
Source: Young (1976a)

Multiplying each of these formulae by M yields four more fundamentals (moment (ML), momentum (ML/T), force (ML/T^2) and mass control or power control (ML/T^3)), and likewise multiplying the latter by L yields another quartet (moment of inertia (ML^2), action (ML^2/T), work (ML^2/T^2) and power (ML^2/T^3). Each quantity occupies a position in a graphical representation Young terms the 'rosetta stone of meaning,' shown above in Figure 3.5. This might at first glance seem to be a trivial categorization, but there are some interesting relationships that present themselves based on the integration of Young's threefold and fourfold operators, the former being the triad of relationship (stimulus), act (response) and state (result). For instance M can be understood not merely as some undefinable vague quantity called 'mass' but as a generative factor of embodiment, incorporation, multiplication, growth, and integration. As such it corresponds to a 120° angular relationship within the measure formulae wheel with 'action' quantities (position, velocity, acceleration, control) to produce 'result' quantities (moment, momentum, force and mass control).

Young's approach is philosophically interesting but he appears at times to be driven too strongly by the desire to find a neat and complete system of significances, even to the point of sounding almost mystical, and certainly metaphysical about the sevenfold relationships and sets that can be found throughout physical and animate Nature. Not that metaphysics is bad! There may not be enough in science these days. One must be guarded, however, against mixing up logos and mythos. They both have their place but not indiscriminately mixed. The primary value in Young's theory appears to be the recognition of action (process) as the fundamental unit of being, rather than substance. Once the leap is made to the bandwagon of the magic number seven there emerge problems that one could expect from a mythos mixed upon with logos and the valuable, creative concept of action as *ontos* gets lost. An argument is made that sevenfold-ness is critical because of certain geometrical limits - a heptaverton model of the universe connects seven points each to each, the maximum number of triangles possible around each vertex, filling up 360° of space in a plane with equilateral triangles. The conclusion Young reaches, supporting it with Veblen and Young's seven postulates required for projective geometry, is that only seven dimensions are possible even within any imaginary space. There cannot be more than seven points connected to each other. But does this rule out the universe having fewer dimensions or having others that simply do not involve spatial-like characteristics? No, and Young's model is not built to handle anything outside of a universe that is made of extension-like dimensions, imaginary or not as they may be. What about non-extensional dimensions, and what would they be like anyhow?

There is an interesting duality between the process model and classical physics, which Young summarizes in the following table:

Classical physics	Theory of process
Universe based upon law	Universe based upon freedom
	Laws, constraints on freedom, are secondary
Deals with statistical aggregates	Deals with individuals
Objects are fundamental	Action is fundamental [70]

Quantum physics fits in with the process model, and photons are action quanta, not wave-objects or particle-objects 'out there.' Keep in mind that in a model such as Hiley's holomovement, or even in the older causal interpretation with the quantum potential (cf. Section 2), photons do not have trajectories - the notion of such is only a classical approximation to an inherently fuzzy path. Laws are important but without the inflexible and omnipotence generally attributed to them in the classical worldview. Process, for Young, entails uncertainty and something other than deterministic law. Somehow this seems to be within the very essence of *action* - flux, like Heraclitus' River.

All said and done, this is not to devalue Young's mytho-poetic model of the Universe! - one must just be careful about one system of meaning being elevated above any other. The other major plus in Young's work is to point out that one can not only look at Nature as having a structure,

[70] Young, A. (1976b)

something that the objective paradigm can handle, but it can have a purpose and use. The machine in the field is more than an assemblage of parts; it has a purpose to the designer and user. One must remember that the projective element is not fixed or out there - it is itself not objective, but created by each observer and user. What is often forgotten is that the projective dimension is as real as anything, despite not having a singular appearance to many observers. To omit the projective side which is always there no matter how different and how changeable is to lose the Phenomenon, the Happening, the Process.

The notion of form and in-forming that Bohm and Hiley have presented in their work has a kinshin with the projective elements of Young's model. Classical thinking and the 'physics without physis' relegates *form* to an ephemeral property of a physical substance/object. The quantum potential is one entity that presents the case for a projective, in-forming force, something different than the objective kinetic and potential energies and equally real. There is also a similarity between quantum potential and 'control phase', what Young calls the "3/4 [control] point that allows the 'turn' from uncertainty to control. Self-limitation is seen as *control* and that is also a *stabilization* of scale. Control is 3/4 of the turn of the arc from position through velcoity and the second derivative, acceleration. It would be also interesting to explore Young's polyverton extensions beyond three dimensions in the light of Grassman's algebras for representing the processes of thinking. Could one build from some elementary action units, like points and lines in a regular-solid topology, process models that correspond to the interesting heptaverton - with seven points connected each to each there are six equilateral triangles around each vertex, filling up the 360° of space. Are only seven dimensions possible? Can only seven points be fully connected even with imaginary space?

Henry Stapp

In three recent papers [71], Stapp addresses some of the fundamental questions that are at the heart of this research program, with special attention directed at the issue of how conscious and biological processes interact. The focus is clearly upon *consciousness* as an objective, *felt* phenomenon. Does quantum mechanics hold a place for consciousness? How does quantum mechanics relate to those other models in nature in which "unitary evolution is maintained and there is no selection of unique outcomes?" Stapp develops a quantum mechanical description of brain process and a mind-brain interface that evolves therefrom, with close connections to Popper's propensity interpretation and the Everett many-worlds interpretation of quantum mechanics.

The brain's hierarchical structure, Stapp points out, leads to a view of consciousness as a high-level process that is built upon lower-level classical processes which are controlled to some extent by the higher level. There are many such systems in Nature. A comparison is made to the control by a vortex of the molecules that move within its space. What is different about consciousness, for Stapp, is that it is a felt experience, or rather that it is clearly experienced always as such. What this implies is that because a description purely in terms of classical physics does not specify one way or another whether there is a felt experiential aspect, there is a fundamental difference from any description that includes the felt aspect.

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71 Stapp (1990a), Stapp (1990b), Stapp (1991)

What does this have to do with quantum mechanics? If a classical description does not suffice to explain a mind-brain interface, why not a quantum physical one? This approaches things from a different perspective - rather than trying to move from quantum-like phenomena to a comprehensive model, Stapp suggests the quantum method as an alternative-by-necessity - the classical doesn't work, so what else is there? Yet there are problems in applying quantum physics, and Stapp summarizes three:

> "The first problem, which has already been mentioned, is that quantum theory is primarily a theory of atomic processes, whereas consciousness appears to be connected with macroscopic brain activities, and macroscopic processes are well described by classical physics.
> The second problem is that, due to a failure of an essential condition of isolation, quantum theory, as developed for the study of atomic processes, does not apply to biological systems, such as brains.
> The third problem is that the orthodox Copenhagen interpretation of quantum theory instructs us to regard the quantum formalism as merely a set of rules for calculating expectations about our observations, not as a description, or picture, of physical reality itself." [[72]]

For Stapp the third problem is most fundamental; what is missing is a quantum ontology instead of a purely epistemological perspective, but not just a physicalist ontology. At least this much would be agreed upon unanimously by Bohm, Hiley, and Finkelstein among others. The ontological aspect has been sacrificed for a methodological explanation in order to avoid a fundamentally *different* view of Nature and be-ing, one where there is a universe of actual events, an ontological picture that goes back to Heisenberg. Events are the building blocks of the universe, each of which leads to a state that describes tendencies or dispositions for succeeding events, and so on ad infinitum. Back to *physis* and *ontos* as process. The universe as action first, apparent substance second. There is an integrative aspect to the things that happen (events); from the microcosmic there are actualized or realized complex high-level actions, the kind of thing that is registered on a measuring device (detector). Put another way, local processes have global effects, some of which have be seen as coherent interconnected events (macroscopic processes whether it be in a particle detector apparatus or a brain).

This integrative character should be examined more closely. Consider a Heisenberg state described by a function $\psi(x_1, x_2, \ldots, x_n)$. The integration is from the many pieces of collected information x_i combining to produce a new state ψ'. No one element makes the new state; it takes all the elements together. The new state can be represented as

$$\varphi(x_1)\int dx_1 \varphi^*(x_1)\psi(x_1, \ldots, x_n)$$

and there is a specific 'propensity' for this to occur, but that 'propensity' is driven by a collection of state information elements rather than any single element. That collection is not necessarily deterministic; its membership is dynamic and one might even say stochastic.

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72 Stapp (1990a), pp. 4-5

But what of feeling and thought? How is there a way to avoid what Stapp calls a "run-away ontology: the supposedly actual things to which the tendencies refer consist only of shifts in tendencies for future actual things, and so on..." [[73]], which has the consequence of leaving out consciousness from a description of Nature? Stapp wants to extend the concept of the Heisenberg actual event to include an experiential aspect, "the *feel* of this event," "the aspect of the actual event that gives it its status as an intrinsic actuality." The obvious question that raises itself is what the feel of an actual event is like, what is its structure or form? One place to begin looking is in the brain, assuming a correspondence between brain processes and thought. Is there a direct correspondence? Could one talk, as Stapp argues in his answer to the latter question, about an isomorphism between the structure of each human experience (feel) and the physical structure of brain events? There are problems and philosophical caveats that arise as soon as one begins talking about sameness of form between things that are so fundamentally different - the language of brain processes is a language of synapses and neurotransmitters, the language of consciousness is one of feelings and thoughts. There is a danger to finding too close a mapping between some proverbial 'elemental thought' and a particular brain state or even configuration.

A few things are clear. The brain has macroscopic states that are highly sensitive to perturbations at lower levels and not only to initial conditions (although it is hard to conceptualize where to draw the line on an 'initial' condition). Also these lower level states are easily shown to be susceptible to quantum processes. Here one is back to some of Eccles' main points. Classical trajectories for body-temperature calcium ions diffusing at the synaptic junction are, Stapp reiterates, inappropriate. If the probability for vesicle release at a particular synapse is approx. 0.5, there are some 2^N possible configurations of synaptic vesicle releases among N synapses, the changes wherein would have some effect on the macroscopic states that evolve. But this is really not saying anything new. What would be new is to find that some particular 'actual event' at the quantum level percolates into a specific macroscopic state that can be measured classically, and that these kinds of relationships fit into some kind of taxonomy of actualization patterns.

This appears to be what most people want out of a quantum-brain connection, but it may not be the right question to ask! It is almost ... too deterministic. Suppose instead that the changes in macroscopic brain states that result from microscopic variations are from a high-level perspective random fluxes within a region of potential states. It would be as if the feelings and thoughts one has are randomly generated and then some type of filtering takes over, eliminating those that are not consistent with some set of criteria active at the moment - the mood, or the 'train of thought.' Why should there be a coherence imposed on the effects from the micro to the macro, when the notion of coherence in consciousness is something that can only exist at the highest levels? There is a question of awareness and attention that needs to be raised. What is the mechanism by which attention is directed at a particular thought, image, feeling that may be a spurious variation or mutation of the previous two seconds of brain activity?

There are, in Stapp's analysis, some very fundamental qualitative issues about felt experience. "Why, when we look at a triangle, do we experience three lines joined at three points, and not some pattern of neuron firings?" Why is the triangle, an external pattern of disjoint, unrelated events and tendencies (marks of ink on paper, reflections of light from a cut surface, etc.),

73 Stapp (1990a), p. 7

transformed into a singular entity that contains structural information about the triangle that is not contained in any parts of the triangle but only the whole unit? "The brain," Stapp writes, "does not convert an actual whole triangle into some jumbled set of particle motions; rather it converts a concatenation of separate external events into the actualization of some single integrated pattern of neural activity that is congruent to the perceived whole triangle." [[74]] The "why" may be best answered by looking at the "how" of the organism's existence. Stapp does not go into this, but pattern classification and recognition into a set of types is fundamental to all aspects of survival, to any kind of goal-directed 'doing.' For information about triangles, trees, or pterodactyls to be useful there must be a 'handle' at some level that can allow for comparison and evaluation along the lines of is/is-not or belongs/not-belongs. The neural architecture of the brain fits that kind of classification processing. It could be said that the neural system that evolved into present neural biology is the type that best serves the requirements of classification and identification, which in turn best serves survival. Grossberg's adaptive resonance model gives one theoretical framework by which new classifications and taxonomies can evolve and self-modify; the Kohonen map is a simpler model, and the Sutherland holographic network is yet another with biological plausibility. For any of these theories, however, there is the same overriding issue about whether or not a classical physics can suffice or if quantum mechanics brings something critical into the picture.

Euan Squires

The point of departure for Squires is the incomplete nature of quantum theory as evidenced by the failure of purely local, Lorentz-invariant models in the face of measurements such as the classical Stern-Gerlach spin measurement. The problem can be stated as one of how to reconcile the singular result of which the observer can be aware with the superposition of both possible results in

$$|\Psi\rangle = \alpha|+,Me^{+}\rangle + \beta|-,Me^{-}\rangle$$

when the electron spin starts out in a direction other than that of the z-axis. This is after all the 'classical measurement problem' with quantum physics. For Squires, this has raised questions about the role of consciousness as a resolving factor in a dualistic but non-Cartesian model of the universe. In two recent papers he presents the argument that because measurement yields only one result while theory contains two, there is an incompleteness that must be resolved.

Squires tenders two fundamental assumptions - realism and free choice. The realism lies in the demand that calculations must fit with experience, unlike the view whereby the states $|\chi\rangle$ and $|\phi\rangle$ might be orthogonal but still translatable to the observable - as if "We decree that, regardless of the calculation, the answer really means the answer we observe." [[75]] Observers (at least those one can know about from self-similarity - humans) experience things with one result, one outcome. How can the wave function be a complete description if it does not have the same type of phenomenological experience?

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[74] Stapp (1990a), p. 13

[75] Squires, E. (1990a), p. 4

This orientation does not, however, satisfactorily address the possibility that there are "superpositions in real life"; i.e., phenomena experienced not only at the macroscopic level but, as Young would have it, projectively, without being clearly A XOR B. This is indeed part of the argument within this thesis for looking at the brain and neural processing in particular for the phenomenological equivalents of wave functions that are *like* the processes going on at the Planck scale and which may differ in a more fundamental way than just scale - there may be macro-superpositions that do *not* collapse when measured but which just go on and on indefinitely. This would be at the level of perception, object recognition, and decision or choice of action. "What is that object in the sky? A bird or a man, or something that is both and yet neither? " "What is my value judgment about X? Is it beneficial or harmful?" "What am I feeling now - happy, sad, peaceful, pensive?" The point here is that it is not correct to assume that in 'real life' everything is experienced through a classical logic. Quantum physics is not the only place where the notion of a superposition state has meaning and it should be a surprise that mathematically the descriptions of reality are not what classical logic dictates, if that classical logic does not work for everyday experience either!

The aspect of choice for Squires lies in the unrelatedness and lack of causal connection that must exist between parts of an experiment (e.g., polarizer settings or routing of a beam to one polarizer or another) such that it becomes at all meaningful to talk of locality and connectivity between some aspects of the whole. One must be able to assume that the experimenter can choose the polarizer settings in the Aspect experiment and that whatever factors cause him to choose A over ~A, those factors are not deterministically linked with the decay of the atom that emits the photons. Otherwise the entire Universe is a rigid Turing machine and in effect all local causality loses meaning.

To go beyond physics one must know the bounds of physics, and that is a not well-attended subject, Squires argues. What is physics if not that which is relativistically invariant - a common-sense approach that is supported by any attempt to work within an established inertial frame. And on such a basis, EPR-type experiments *seem* to create a problem because one is now viewing the world as a set of light-cones with objects inside or outside of them. The problem should not be there if one dismisses the fundamental requirement of objects existing in definite states - there are no 'things' at particular coordinates either within or outside of the light cone, only noncommutative groupings of actions that, because of the ordering and relationship among themselves, have specific outcomes. Perhaps the famous Rubik's Cube is a better analog for the processes of the Aspect experiment than models of waves and photons and light cones.

However, Squires' objective seems to be more along the lines of a role for something 'outside' of physics, the "extra ingredient that relates the wave function [understood as a $|\Psi>_x$ existing at all points of space and time] to our experience," and this something is the conscious mind. The crux of the argument is that "consciousness certainly exists and that there is no natural place for it within physics." [76] Although he acknowledges this as sounding very much like Descartes, Squires wants to contrast his view with that of the Father of all Dualisms by saying that physics is fundamentally something representable by a wave function is an abstract (configuration) space, something not really *physical*, and that it is the interaction of this with consciousness that

[76] Squires (1990a), p. 12

produces material things (particles, atoms, worlds). Matter, in short, is itself the "consequence of the interplay between two non-materialistic concepts, a physical wave function and a conscious mind." Elsewhere Squires reiterates the distinction between physics and reality - "'Physics' ... is not matter,; rather it is a wave function" and matter emerges through the interplay of consciousness with this wave function. This is not at all dissimilar to some of the Vedic and Buddhist metaphysics against which quantum physics is often compared, but the response has to be similar - how does this explanation do anything to simplify and explain how things work and how they can be predicted? Does it do anything other than move the problem further back, essentially de-materializing the physical world and making it an interference pattern of sorts generated from two intangible universes?

This matter of consciousness is continually coming up whenever one starts looking deeper into cellular, molecular, subatomic interactions. Why should it be there in the microtubules of the cytoskeleton, or in the fitting of enzymes and proteins? Sometimes it seems that the homunculus of the Middle Ages has not left science, only changed out of an alchemist's robe into the white lab coat of a microbiologist. Consciousness, it is argued here, can best be understood as a set of actions, processes that involve and group together many other actions, and it is not some sort of thing that exerts 'fifth forces' upon particles and atoms. There may be coherent phenomena in molecular transport and conformation, but the fact that that occurs does not imply a singular agent that is responsible and somehow organizing it from the outside. There is a big danger with trying to make consciousness into an object, and it appears that Squires is grappling with this problem that as been handed down from our cultural and linguistic heritage.

One objective of Squires seems to be a solution to the 'many-worlds' interpretation that will not replicate an infinite of physical worlds. There is no clean way out of it. Instead of many worlds there are now "many views of one world":

This brings one back into pure philosophy and discussions like Wittgenstein's on the nature of pain come to mind, or those interesting sutras of the Vijnanavada and Yogacara schools of Mahayana Buddhist thought. Changing the language, one might ask, is the conscious mind one huge multi-perceptron neural net that is constantly selecting from a rapidly branching set of views? How is this not a splitting of consciousness? And surely there is a problem in knowledge of universality or commonality of consciousness. How could one know that in doing the same experiment the same weights would be given to the different possible views that result, yielding the same type of conscious view as the outcome of the experiment? It appears that one is exchanging an overly complex theory for one that solves the complexities by becoming fuzzier and more vague about its fundamental elements; i.e. consciousness and its many views, and being forced into a description of a universal consciousness that defies description or measurement by definition.

> "Here we have *one* mind which observes *one* world: the conscious mind simply selects one of the results, randomly, with the only available quantities $|\alpha|^2$ and $|\beta|^2$ [probabilities] giving the weights. To me this is conceptually easier to accept than the idea of splitting of consciousness. However, it does have a big problem. After *I* have observed a particular result of an experiment, how can *you* be sure that if you observe the same

experiment then you will obtain the same result (as you must if I can assume that all the people I meet are conscious). The only answer lies in some sort of universality of consciousness. ... only consciousness can carry the non-locality which we know from the Bell's theorem to be implicit in quantum theory, provided, as is true in this theory, that experiments yield unique results." [77]

The wave function that starts out with spin in the form

$$|\Psi>= \alpha|+, up, U^{ON}, D> + \beta|-, down, U, D^{ON}>$$

gets transformed into one that includes brain states for both observers,

$$|\Psi>= \alpha|+, Me^{+}, You^{+}> + \beta|-, Me^{-}, You^{-}>$$

and to avoid observers suddenly having split identities or not being the same person as one was being conscious about, there is postulated that "*there is only one conscious mind*" - one wave function and one universal consciousness. That the experience of being conscious and the feelings that go with saying "I am aware of this or that" is in some way universal is almost something that cannot be disputed nor demonstrated, and it is not clear how it simplifies the understanding about the behavior of spinning photons or spinning dreams and imaginings.

Michael Conrad

Conrad's work has focused upon molecular computing and mechanisms by which such devices could be implemented naturally in biology or artificially within a machine. A model of coherent hydrogen bond dynamics forms one foundation of Conrad's molecular computing theory. In this model, mobile protons bound at the membrane interface in water are treated as analogous to electrons in a thin metal layer. The basic concept is one of mobile protons inducing charge oscillations in polar side-groups of the membrane. The claim is that Bose condensations can occur at high (biological-norm) temperatures if protein interactions occur as a result of interactions between the mobile protons and hydrogen bond chains linked with proteins and nucleic acids. This would generate a sort of 'proton superconductivity' but at high (room-level) temperatures.

This model goes contrary to the prevailing view which holds that protons are too massive for pairs to undergo a Bose-Einstein condensation at room temperatures. What could cause delocalization (degeneration)? Particle densities that equal or exceed the de Broglie wavelength for the particle are a requirement. Average distances between protons in the order of 1 A would work but this seems far too low for the watery biological medium. Admixture of proteins into hydrogen-bonded chains could, it is suggested, lower the activation barrier for proton mobility. Any factors contributing to weakening of hydrogen bonds or the 'seeding' of negative proteins and ions will enhance closer packing.

Proton superflow could play a role in the formation and extension of 'shape-based fitting' in biological systems, such as exists among kinases and related enzymes. Object molecules are

[77] ibid, p. 14

recognized by lock-key fitting, in a fashion similar to fitting jig-saw puzzle pieces together. This mechanism plays a role in the control of electrical properties (and thereby diffusion) within cellular membranes, and also in the control of firing behavior of some neurons.

Tactilization offers a translational scheme for converting macroscalar signals into a mechanism accessible by macromolecules. "The basic idea," according to Conrad, is that "nontactile signal patterns impinging on the external membrane of a cell are transduced to physiochemical patterns and dynamics inside, and that it is these that can exploit the tactile pattern processing and self-assembly properties of proteins and other macromolecules." [[78]]

How might quantum mechanics relate to molecular tactilization? Consider photonic input to the retina, transformed into neural impulses. The second messenger molecule cAMP activates a variety of kinase enzymes which in turn regulate ion channel proteins and the transmission of neural impulses. This increasing microscoping down in scale (cAMP to kinases to effector macromolecules) is later reverse into a macroscoping outward into (relatively) macroscopic actions such as neural impulses, antibody releases, muscle cell contractions, etc.

It is not necessary to look only in the direction of proton supermobility. in more recent work Conrad has been developing a model of molecular self-assembly that can be applied to protein assembly and folding, nucleic acid replication, and a host of enzymatic reactions including many that could be involved in immune response mechanisms. The critical concept is the relationship between quantum electronic superpositions and non-Born-Oppenheimer nuclear conformations that can be influenced by the former in such a way as to allow for the rapid 'exploration' of many possible configurations and fits with adjoint molecules.

Conrad's self-assembly model is discussed further in response to the model developed by Donald and also in Section 4 with respect to quantum chaos and how it may play a role in molecular processes including dendritic field interactions.

M. Donald

Donald's approach to relating quantum mechanics to the brain shares something in common with Conrad in that both are looking to the interactions among proteins and other macromolecules in the capacity of switching or gating (a way in which lock-key fitting could be interpreted). What is a quantum switch and how might it be implemented in protein arrays - that is the focus of Donald's work (and clearly he is not alone but in growing company). However, very unlike Eccles and Walker (discussed below), he is not looking for quantum mechanical effects having repercussions or influence over synaptic responses, nor is he exploring for mesoscopic quantum effects on the molecular level as does Conrad. In a personal communication he writes,

> "I fully accept that the biologists' classical 'ball and stick' models of molecules in the brain are quite sufficiently accurate to give entirely correct mechanisms for learning. My objects were to try to explain how such 'ball and stick' models could possible be appropriate within a totally quantum mechanical theory of the universe; to explore

78 M. Conrad (1988), 288

> whether it was possible to find simple abstract descriptions of 'observers' within such a theory which were compatible with the biologists' picture; and, ultimately, to use those descriptions as the basis for an interpretation of quantum mechanics."

Donald views the brain as a complex switching mechanism, as opposed to a system that provides through its neural-dendritic structure a basis for generating fields that interact and mix, as in the Pribram-Yasue model. It is a much more object-state driven model of physics and the brain, instead of one that makes first principles to be action and process. This switch/state viewpoint inherently discounts process as something that objects do or have done to them, and understandably leads into the whole dilemma of collapsing wave functions that Donald attempts to unravel through a variant of the many-worlds theory.

> "it [Donald's work] is concerned with discussing the change in time of one of the switch states, a collection of which will form the information-bearing portion of the brain. ... The key ingredients here are a formal definition of a switch and a formal definition of the a priori probability of that switch existing through a given sequence of quantum collapses." [[79]]

This view still holds to the 'hardware/software' view of the brain as a machine that processes information, an entity apart and separate from the neural processes that occur, which here are viewed as switches effecting information transmission by changes of states. What is particularly interesting in Donald's approach, despite these criticisms, is that he raises an important question about the relationship between a quantum mechanical universe and the possible kinds of physical structures (substratum) that *can* exist as a brain-like instrument. Given quantum physics, what kind of brains can be built, naturally or presumably artificially, that efficiently process information? And given brains and neurons with sodium-channel gates, is there something that can be learned about quantum mechanics and how it applies to the macroscopic? In this aspect Donald is in concurrence with the fundamental view underlying this present work:

> "I claim instead that the first step towards an interpretation of quantum mechanics is to analyze the appearance of observed matter, and that a good place to start may be to try to analyze how a brain might appear to its owner."[[80]]

Donald raises two propositions as being essential for any switch that can be involved in a physical manifestation of consciousness: (a) neuronal sodium channels qualifying as switches, and (b) the inability to find, in evidently non-conscious physical manifestations, similar complexities of switches such as those in the brain. What is a switch and do sodium channels as observed in the brain qualify as switches? Are there other natural phenomena that act as switches in the complex manner of neural sodium channels? Donald recognizes the complex nature of these channels as being more than simply on/off gates, but it would be fruitful to look more closely at the molecular processes involved in these channels and how the wave of depolarization due to sodium influx is spread across the cell and how that triggers more distant sodium gates to activate. The problem is not just switching and gating; it involves field-like communication in molecular structures.

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[79] Donald, M. J. (1990), p. 49

[80] Donald, M. (1990), p. 52

Perhaps through cytoskeletal microtubulin structures (nets) there are myriads of signals being sent in the form of perturbations within the microtubulin that act like structures in a vast cellular automata net. The connectionist aspect of neural transmission activity seems to be overlooked in Donald's approach or at least not sufficiently emphasized. Molecules and brains do not operate like balls and sticks.

In fact Donald does give some closer examination to the activity of membrane proteins when he considers the general notion of a neuron as a surface whose fundamental process is in the opening and closing of switches/channels. He examines the definiteness of location for vesicles and channels, the overall unpredictability of neural processes and how there is a 'collapse' to definite positions and states when any form of neural measurement is taken, such as making a micrograph. "It would not be incompatible with the laws of quantum mechanics to imagine that a brain is set up at some initial time in a quantum state appropriate to what has been referred to above as the biochemical model. In this model, all the atoms in the brain are localized to positions which are well-defined on the Angstrom scale. The question then would be how rapidly the atom positions become unpredictable, assuming perfect knowledge of the dynamics." [81] This is the wrong question to be asking. Once again the problem of definiteness versus ability to measure definiteness comes up, as if there would be more information if one had all the definite positions. The issue is not whether or not transmitter molecules or entire vesicles exist in some location - of course they do - but whether any kind of measurement can be made that does not radically disturb the local environment, and how does the measurement process affect the fields that result from atomic and molecular interactions, regardless of the exact locations of any components.

Throughout the same paper Donald expresses awareness and concern for the same criticisms and for the question of interdependencies. He recognizes the field aspect to the problem and the fundamental difference between the 'warm and wet' biology and the dry mechanical 'ball and stick' systems. But the idea that information processing is a matter of phase relationships between fields that are generated and sustained within dendritic regions (Pribram and Yasue) more than complex switching (something that really matters only when neurons are sending spike trains to other regions of the brain [82]) is noticeably absent in Donald's approach. For him the brain has a quantum state dictated by the states of its channels and there is a 'collapse' into a new state where the switch gains a definite status. He takes for granted that "the state reached at each collapse is a brain state with sodium channels having well-defined statuses." This emphasis on the classical switching model is, like the lock-key picture of DNA and protein assembly and enzymatic reactions, forced into a quandary of trying to explain how certain chemical processes can occur (a) at the sustained speeds they do without more rejections or failures, (b) with the massive parallelism that is evident in neurological functions, and (c) with the regional non-locality or synchronicity that is found especially in perception mechanisms. [83] The information processing of the brain *cannot* be modelled by a three-dimensional family of switches even if these switches operate as sodium channels and are in fact affected by the quantum states of those channels.

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81 ibid, p. 66

82 Attributed to V. Mountcastle, "Neurons do not have spike trains; axons do". Most of the Artificial Neural Network (ANN) models extent today are founded upon the partial and inaccurate view that neurons must do their communicating with one another by 'firing', thus omitting entirely the realm of dendritic field interactions.

83 Cf. Pribram (1992), esp. Part I, Lectures 4 and 5

However, can the opening and closing of sodium channels and other switch-like play a dominant role in effecting the ionic fields that are generated by dendrites and to which they respond? How can one make the bridge from the discrete to the continuous and then back again? Ion flow makes the fields, and the fields control the channel states. It may be worth examining the several possible states in which channels may exist other than simply open or closed. Bear in mind that in the open state there has been a resting potential across the cell membrane, now depolarizing with ion influx, and the closed state brings back the resting potential. Donald gives examples of several types of states in which these channels may exist:

♦*average* (thermal equilibrium quantum state, held at U or V and 'immobilized');
♦*inactivation gate* (average quantum state of an inactivation gate assumed to be a simpler structure within a channel);
♦*sliding helix* (average quantum state of a small volume containing part of a helix formation moving against the membrane background structure);
♦*tight-shut/wide-open* (average quantum state in definite and complete U or V (open/closed) state);
♦*average-at-fixed cycle* (thermal equilibrium quantum state of immobilized channel that has been depolarized for some time); and
♦*average membrane* (thermal equilibrium quantum state for a channel at rest for some time).

A Molecular Faucet

The opening and closing of a channel through the mechanism of a set of twisting molecular helixes that act as a type of van der Waals 'faucet' is most interesting [84] and ties in with what has been discussed earlier (and later in Section V) of Conrad's quantum-computing self-assembly theory. This does not seem to bode well for the idea of channels switching or collapsing in and out of definite states but it may make sense as a way of explaining how quantum electronic and nuclear interactions, modulated by local neighborhoods around cell membranes, *including the cytoskeletons of neighboring but not physically connected dendrites,* can control the opening and closing of sodium channels and the behavior of any number of cellular actuators/receptors. Sometimes the initially exotic hypothesis must give way to one that at first seems mundane because of its consistency with the known body of theory and experiment, but eventually it then turns out that the seemingly mundane can be very astonishing!

Suppose the following (not necessarily astonishing, however!) toy channel model. Obviously this is another thought experiment that needs to be more tuned to neuromolecular biology. It is not clear how definite the geometry of channel structures is understood and this appears to be another candidate for the type of real-time, in vivo molecular scanning tunneling microscopy that is discussed in Section V. There is in this model a winding of four helixes which twist clockwise or counterclockwise to open or close the space between them. Two issues present themselves. First there is the movement of a molecule through the channel passage and the question of how this is modulated, and second there is the matter of twisting and untwisting by the helixes - how this movement is effected and how it affects molecules that may move in and out of the channel. Perhaps it is more appropriate to call the channel a valve because that is how it *acts.*

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84 Cf. Catterall (1986) and Guy (1986)

As they twist these molecules impinge on their neighboring helices' ability to move and also upon any molecules attempting to pass in or out of the channel. The space constricts or expands, and the movement of the helixes conceivably will affect surrounding parts of the cytoskeleton due to interconnectedness with the tubulin and molecules that make up the membrane.. There are many loose configurations in the helixes themselves, though; they are not rigid balls and sticks but are subject to conformational changes that can be mediated by the quantum states of electrons and nucleons in their composition. It might be possible to model the entire channel/valve structure as an assemblage of springs with varying degrees of tension and rigidity, but even that still leaves one with a very classical picture, because while a steel spring can wobble and jiggle in many paths, there is still a singular structure to the steel wire or tubing that makes up the spring. Here one is dealing with a molecule that fluctuates in its structure. The spring analog is a device that changes its diameter and radius as it expands, contracts, and gyrates near or away from other springs.

Such a model of dynamic springs could be implemented in a computer simulation but it would be non-trivial. The models and hardware architectures discussed throughout Sections IV and V and even the 'quantum cellular automata machine' (QCAM) presented in section II could be employed with some modification to suite this purpose. The difficulty is in ascertaining the equations for the electronic-nuclear interactions in such an environment where everything is in motion and with a degree of Brownian motion at that. As Conrad points out, interactions with radiation or thermal and inharmonic nuclear motions can trigger transitions into superposed electronic states of the form

$$\Psi_e(x_e, t) = \sum_{el} a_1(t) e_1(x_e) \exp\left(\frac{-iE_{e(1)}\, t}{\bar{h}}\right)$$

where $t = t_u + \tau_{el(e)}$.

The critical assumption (one among probably many) is that the Born-Oppenheimer assumption does not apply here, but this as been well demonstrated for macromolecular assembly and for individual proteins. Conrad finds three possible courses of development for the possible eigenstates into which the electronic system of such a non-Born-Oppenheimer molecule can evolve: fast divergence due to mutual inconsistency between electronic and nuclear wave functions, slow divergence due to the same reasons, and fluctuation between minima but no divergence to any particular state. In any case there are electronic-nuclear interactions that will affect molecules in close proximity to the helical structures and this means that sometimes the channel is fluctuating at different points from being more to less open. Perhaps because of this fragile state, external processes such as the rise and fall of classical ionic fields among dendrites can have effects, in the same way as radiation and thermal noise. The action is clearly quantum mechanical, but some of the causes could be very classical (although some might say, just barely so). Releases of Na and Ca ions and the behavior of cAMP in relatively remote dendritic fields will result in a flux in field strength at those regions of activity. By themselves these fields are very slight and apt to be disregarded as they have been by many neuroscientists. However, when there is a positive phase relationship among many polarizations, when there are isovalent contours linking equivalent polarizations in a dendritic network and these contours come in contact, electromagnetically, with the quantum-sensitive channels, there may be a stronger interaction because of the fact that the helical channel proteins are in a superposition state and can be easily shifted one way or another toward a definite state.

As indicated before, this hypothetical model needs to be cast in the light of more precise experimental data. However in the most general form it points toward the kind of manner in which quantum theory should be viewed as having a role in neural processing, not as an effector of collapsing states that turn switches to a definite on or off condition but as the method by which molecules control their fitting and movement, at the level of short and long-range weak nuclear interaction forces. This may not be as exciting, perhaps, to those seeking to find a Turing-type machine that operates with uncertainty to produce intelligent decisions (the author admits to having started quite naively from a perspective like this years ago) but it should be exciting for the prospects of showing how things work and how they might be predicted, even if next to impossible to replicate without building an entire biological brain.

Koichiro Matsuno

Some interesting observations and speculations have been made by the bioengineering researcher Matsuno regarding the relationship between the internal measurement within biological systems required for detecting and implementing material (molecular) flow continuity and equilibrium, wherein there is an uncertainty relationship (defined as $\Delta i \Delta t \approx 1$) where Δi is the normalized fluctuation rate in a material flow, $\delta^{*}f/\delta t$ and the Heisenberg uncertainty principle. This measurement may take place in many forms that do not involve a separate apparatus; i.e., the flow itself across a cell membrane must in some way be part of the measurement mechanism. Fluctuations that emerge are part of the internal measurements induce other fluctuations and perturbations, which in turn disturbs the continuity of material flow. A stop-start jerkiness results in the material flow, much like congested crosstown traffic. There is a connection here with the Heisenberg principle where the measurement process, including the actual apparatus, is one source of the energy that gives rise to the uncertainty level.

For Matsuno it is no longer valid to take for granted that "measurement would cause a superficial violation of the physical principle of the conservation of energy that was permissible in the framework of external measurement." [[85]] The internal measurement must play a significant role. How can this be implemented among molecules? This is right at the very crux of the difference issue between Turing machines and living organisms, in line with Rosen's observations about the ineffable failure of formal deterministic systems to account for not only the variability but the responsiveness - the radical fast response, compared to the actual number of computational steps, usually NP-complete (order N^2 or beyond), that would be required by a Turing machine to do the same task.

A thought experiment is always a useful place to start. Consider a radiation field that interacts with particles in a box of volume V and N degrees of freedom of motion. The quantity e_i measures the energy associated with each degree of freedom and the uncertainty principle applies to the measurement of this e_i at any time t by the relation

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[85] Matsuno, K. (1992), p. 69

$$\Delta e_i \Delta t \sim \bar{h}, \ (i=1,2,...,N)$$

This uncertainty Δe_l has the quality that both the object measured and the measuring apparatus are the field itself, the molecules present in the volume V being used as the vehicle for that measurement. It is as if one wanted to measure the density of an atmosphere on an alien world of known mass by dropping and throwing about a ball of a known mass and studying the ballistics. There are two elements to the uncertainty Δe_l: fluctuation within that measured energy $\Delta_m e_l$ and deviation of the reference point $\Delta_r e_l$. What is this point? There is no human observer or machine. Yet there has to be some point of reference in the field, some set of coordinates, from which the initial measurement commences. It is unclear how the radiation field of Matsuno's example still acts as an apparatus. It can be measured itself since it has a total energy E with its own uncertainty paralleling that of the individual degrees of freedom,

$$\Delta E \Delta t \sim \bar{h}, \ E = \Sigma_{i=1}^{N} e_i.$$

The standard deviation of measurable fluctuation from the average fluctuation will approach zero, since in such a uniform volume each degree of freedom will have approximately an equal amount of energy, no preference to one direction or another. This results in a relationship between the average fluctuations of both types (measured and reference point deviation) along any particular degree of freedom as being proportional to the total degrees of freedom:

$$\Delta_m e \Delta t \sim \frac{\bar{h}}{N}$$

$$\Delta_r e \Delta t \sim \frac{N-1}{N}\bar{h}$$

As N increases, the measured fluctuation approaches zero and the fluctuation of the reference point, not surprisingly, becomes more constant. What does this entail? For Matsuno, the uncertainty principle itself should be reinterpreted to take into account that each degree of freedom in the system generates information, at a rate (for the above example) of

$$i_r \sim \frac{2kT}{N\bar{h}} \text{ bits/s/degree-of-freedom}$$

Are quantum mechanical measurement processes generating information that is useful to the ordering and flow of biological material? This is the essence of Matsuno's argument, and it has dramatic implications if one is able to envision a way to harness or replicate the process so that instead of material flow regulation relevant to metabolic processes there is something similar that can be translated into electronic signals and ultimately into the type of analog and digital signals useful to general-purpose computing. This seems to be where Matsuno is heading, although not perhaps so dramatically as to suggest that the same mechanisms based around Na^+ and Ca^+ flow by which cell volume is regulated can play a role in performing the equivalent of NP-complete computations. He looks instead at point mutations in genes and cell motility as areas where microscopic information generation is occurring and derives an equivalence in the bits/ degree-of-freedom between the radiation field of biological significance for the earth and DNA, finding them to both be approx. 10^{-17}. [[86]] It is still not clear how any of this generated information really fits into the picture of genetic or cytoplasmic regulation, and as with so much in these fledgling interdisciplinary fields, much more analysis and refining of concepts needs to be done. A link needs to be drawn between the information generation and its use or effect in macroscopic structures.

There is an evident connection between the concept of internal measurement as implemented in molecular interactions and the type of neural information flow as presented in Pribram's brain holonomics. All along the problem faced in explaining how information is stored and transmitted is one of interfaces - between neurons, between dendritic fields, and between those fields and neural soma. What is best understood is how axon-hillock firings occur, but what is least understood is how the inputs ever occur in the first place. The language of Matsuno gives rise to some speculation here about cell surfaces, regulation, measurement, and information flow, particularly among neurons. Cells regulate their volumes, and recent studies on heart muscle cells indicate a wide variety of sensitivities (Cl^- especially) that control the rates at which cells under hyposmotic conditions will decrease in volume and return to a level equal or (usually) lower than the initial volume, once the hyposmotic condition is removed. This volume regulation is believed to have a direct connection with the cytoplasm working to maintain adequate and regular levels of metabolic components. Volume changes in order to compensate and control concentrations. All along a neuronal somatic surface and in the dendrites, also for that matter in the hillock, there are ionic variations induced by chemical compounds and by electromagnetic fields.

One could say, following Matsuno, that at all of these points - actually, the entire surface (which, because of the fractal nature of the neuron, is immense compared to the basic soma volume) - the cell is engaged in making measurements. Here is MacLennan's field computer hard at work! The massively parallel measurement is in some way integrated or summed - not in the arithmetic sense but in some fashion where every point counts. This produces a change in the entire structure - a new gradient, a new topology, like a balloon inflating or bread dough being kneaded slowly by one hand. All of the inputs make the whole cell change as a unit and that change gets propagated back into every part. No matter that electromagnetic fields in the dendritic regions are miniscule and not capable of large-scale effects, such as magnetizing cell elements. They are more like a biological version of Bohm and Hiley's quantum potential, something that controls by form and not raw content. This could be very interesting now. Suppose that Pribram's isophase potential landscape concept is extended to the surface and interior of the neuron. Dendrites and the cell membrane act then like a massive phased array of receptors to measure, by the molecular jitter and wobble of components that make up pores (recall the twisting helical valves mentioned earlier) with the molecules that flow in and out of those pores, the energy and the phase of those external fields. In analogous terms, the cell surfaces *read* the fields and obtain the information. A reminder: in-form-ation - it is always a process, not some object!
To continue the speculation: as the external bioplasma field changes, the cell-antenna reacts with changes in the material flow in and out of the receiving surface. That surface, particularly at the synapses, rich in receptors and effectors, is really a filter for the flow of components (ions, amino acids, etc.) that are the ingredients of on-going processes, some of which do contribute to an occasional axon-hillock firing. The cell as a whole is 'simply' a filter of processes - allowing some, disallowing others - on the basis of information that is presented to it from the outside. So it is

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[86] Matsuno, K. (1993), pp. 39-40

also a translator, changing the inform-ing from one type into another. Certain intracellular processes will not be activated unless the complete filter, the whole cell, is in a particular condition (state-space region), and this condition would be a response to the fields in which the cell is immersed.

This line of thinking is tantamount to removing some of the object-ness of the neuron and of cells in general. Instead of this body of cytoplasm and immersed smaller objects that acts like a pump or a circuit board, a new picture emerges. The cell is a network of processes that are controlled by measurements being continuously made of the conditions in other processes outside the local network. Perhaps the cell is best thought of as a clan from the quantum cellular automata model (cf. Section 2). It is a local net that talks with other local nets and also with the wide-area net that is just there, ubiquitous, qualified by all the local nets but having its own existence apart from whatever is going on within any of the local nets. Suffice it to say that this kind of speculation is, like all the rest, dangerous and contagious, but also it does seem reasonable to say that Matsuno has provided an especially good springboard for questioning how quantum processes matter on the large scale, and how measurement and flow fit into that picture.

Evan Walker

An early speculative thinker in the problem of relationships between quantum theory, the brain and cognitive processes was Evan Walker. Similar to Eccles, Walker argues for a fundamental duality and goes so far as to promote "new quantities, the c_i variables, [that] must be introduced into the representation of the state vector as true *hidden* variables." [[87]] Such variables are claimed to have a "general character as non-local variables" but it is never clear just what this means. Walker strongly states the case for a hidden-variable quantum physics where the variables are "true *hidden* variables, that is completely inaccessible to measurement." It fails to be clear at all why one would consider such to be a viable theory if there must always remain a completely indefinable portion removed from observation.

The specifics of Walker's model revolve around c_i hidden variables that are infinite in number and non-local, implying that conditions on the c_i "cannot arise from a specification of the initial conditions on the measured object or the measuring apparatus." The great leap is then made that these conditions are non-physical constraints and irreducible from any finite measurement set. Following this line of reasoning one is led to a further claim that the system is "dispersion free and therefore causal (though not physically causal...), yet the system remains physically indeterminable." there is a further concept of associativity that Walker introduces to distinguish physical immeasurableness from complete indiscernability - hidden variables could somehow be associated with physical quantities although never measured through the latter.

All this is unclear and unsettling to say the least. That consciousness becomes identified with a subset of the c_i hidden variables should come as no surprise but it is hardly something that can be clarified further. Walker goes on to hypothesize quantum mechanical tunneling between macromolecules in the synapse as the mechanism for information transmission. This in itself is not disturbing; it is simple and consistent with a variety of views about dendritic communication,

[87] Walker (1972), p. 47

some of which have been already discussed briefly in this paper. When Walker suggests a special code for neural impulses arriving at the postsynapse, things begin to go askew not only of physics but of neuroscience. Synapse firing becomes dependent upon macromolecules being properly encoded to send and receive transmissions. The brain has once again turned into a giant digital computer, this time one with the equivalent of local area network packet-switching protocols! There is much too much mixture of computing concepts, physics and biology. This is the bane of such interdisciplinary endeavors in science such as the present work and many of those discussed herein. It is all too easy to get concepts confused, to gloss things over and suddenly find oneself in a morass of indeterminate thinking.

Nonetheless some of Walker's observations about quantum tunneling and synaptic clefts do support the consensus notion that field effects rather than purely axonal point-to-point neural communications are of critical importance. Given a synaptic potential barrier of approx. 70 mV, an electron would require approx. 1.4 x 10^{-20}g-cm/sec to cross that barrier. Walker derives a spatial uncertainty of 7 x 10^{-8}cm and approx. 1.0 x 10^{-14}sec in temporal uncertainty. Given synaptic impulse delays of approx. 1 ms, there is a reasonable (@ 0.5) probability of crossing a 180 A barrier. The typical synaptic cleft is about 200 A wide, suitable for tunneling of electrons on the basis of the previous numbers.

As with Eccles, the discussion of quantum tunneling as an affective process in neural transmission gets confused with issues of synaptic events leading to consciousness. There appears to be some kind of pervading notion that consciousness being somewhat of a numinous entity that cannot be given an exact 'position' ontologically or physically, is somehow like in substance with quantum processes. Heisenberg's uncertainty principle is constantly being thrown up as an example of fuzziness and then the leap to talk of consciousness occurs. Be that as it may there are some useful aspects to Walker's hypothesis about synaptic quantum tunneling if one can get free of the consciousness issue and the binary transmission concept that Walker imposes upon axonal signals, as if they were digital packets passed back and forth. It is worth excerpting at some length from Walker:

> "...as a volley of pulses arrive at a synapse, they bring about the polarization or electron excitation of consecutive sections of the molecules which are located on the presynaptic membrane and lie perpendicular to the cleft. ... the molecule acquires a positive charge; that is, sufficient energy will have been absorbed to cause ionization. ... If the sequence of polarizations in one of the postsynaptic molecules matches the sequence in the presynaptic molecules, we assume the potential barrier to be small enough that the process of tunneling of an electron from one molecule to the other molecule can take place and, from there, propagate as an impulse through the second cell. If the pattern does not match up, then no tunneling is possible and no impulse is propagated across the synapse." [[88]]

There is an obvious problem with Walker's coded-message model of neural information processing but a similar mechanism could operate at the synaptic exchange, driven by Frohlich

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88 Walker (1970), 160-61

soliton wavelets, for instance. The probability function for synaptic transmission in Walker's model is given as

$$P = \frac{E(V-E)}{V^2} 16 \exp(-2L\sqrt{2m(V-E)/h})$$

which yields either an extremely small probability or an equally improbable distance L that separates the molecules or difference between potential V and energy E. Walker's suggestion is that there are molecules "distributed throughout the brain that the electron can use as 'stepping stones' in making the transition from one synapse to another" and that RNA may be such an intermediary molecule. Figure 3.6 below provides an illustration of Walker's potential well concept.

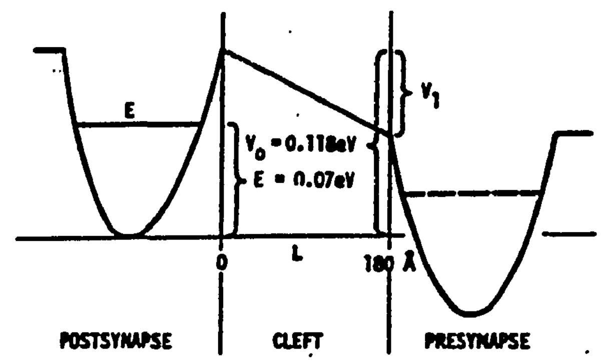

Figure 1. Energy diagram for electron at a synaptic (or ephaptic) junction. Electron is shown as occupying energy level in a postsynaptic molecule with an energy of 0.07 eV in mammalian synapses (0.09 eV in the frog synapse as discussed in the text). This value is dictated by the requirement that de-excitation of the macrogate molecules be reversible by membrane polarization. Height of the potential barrier V_0 is 0.118 eV as determined by experimental data (see Figure 4). Presynapse is depolarized by a potential energy V_1.

Fig. 3.6 The Quantum Potential Well Source: Walker (1977)

There is a spread or flow of the wave packet through the chain of intermediary molecules connecting two synaptic molecule, dependent upon the probability that the charge has reached a given molecule. Transition to the synaptic molecule at the receiving end is dependent upon a 'match' in energy levels between the propagating electron and that molecule. In Walker's model, transitions at one synapse will propagate to others and continue propagating if (and only if) the synaptic molecules satisfy the resonance requirements. Where does the energy get transferred if the pre/post-synaptic connection does not occur? Walker suggests the intermediary molecules receive the energy and that it in essence 'bounces around' until finding an appropriate synaptic molecule. Somehow this explanation gives no satisfactory account of energy dissipation into non-synaptic regions. Energy does not remain localized within the brain; it is not a closed system. Walker does not take into proper account the field-like qualities of dendritic nets such as are addressed by Pribram, MacLennan and others.

How does the Walker model fit in with experimental data on synaptic transition times? Some n molecules activated in the presynapse can transfer energy to some $knN^{1/3}$ presynaptic molecules, k >= 1. $N^{1/3}$ is given as the number of molecules lying along any one transference path. Any k<1 would not allow for distribution of the energy propagation throughout the volume of the brain in such a way as to met the requirements in Walker's model for maintaining a constant flow of energy. Taking M as the number of 'intermediary' molecules in the brain (e.g., RNA as one suggested type) and N as the total number of synapses in the brain, the number of synapses reachable in a time interval θ is approximately $tnN^{2/3} = k\tau M$. The average transition time τ for an exchange between two adjacent synaptic molecules is given as

$$\tau = \nu^{-1} \int_{a}^{\infty} QP^{-1} dr$$

where Q is the probable number of molecules between r and r+dr of a given molecule's center of mass, a is the average radius, ν is ground state frequency and P is probability of transmission. The values obtained for τ by Walker are in the order of 7.2×10^{-13}sec. This yields a value for k of approximately 6.73, which Walker finds close enough (by orders of magnitude) to 1.0 .

There are many questions that evidently can be raised with respect to the above approach to quantum connections and neural synaptic activities. Walker has made many somewhat naive assumptions about neurobiology and there is the omnipresent mixing of neural modeling with speculations on the nature of consciousness as a spatial and temporal distribution and resonant-like activity of synaptic transmissions. The 'coded message' picture of synaptic activity is outmoded and counter-productive to the goals of establishing a quantum mechanical effector within synaptic transmissions. This seems to be indicative of the typical confusion in quantum theory that has persisted since the time of Bohr and Wigner, namely thinking that is fundamentally classical; i.e., object and substance-oriented.

Despite some of the forementioned problems in Walker's model, it may provide a useful starting point for investigating the consequences of such tunneling phenomena on a large population of highly interconnected dendritic fields through computer simulation. There are some advantages to starting with something that is simple to construct and test. This point shall be returned to later in this section, where an experimental model is discussed.

Subhash Kak

The flaws in the artificial neural network (ANN) model, emphasizing threshold functions at the expense and mostly ignoring of field-modulated effects, prevents one from building a computer that emulates the type of brain that Pribram, Penrose, Walker, and many others have been studying and discovering. In a personal conversation D. Mikulecky (Medical College of Virginia, Dept. of Physiology) pointed out that while traditional artificial intelligence (AI) rather quickly ran aground and afoul of being able to emulate cognitive and perceptual function through formal symbolic systems, ANNs have been just enough more successful at things like picture matching and object classification to avoid running aground as fast or as dramatically, but it is nonetheless clear that ANNs have not yet been able to reproduce the dynamics and spontaneity of the nervous system, and that means much more than just neural nets in the brain, but the central nervous system integrated with the endocrine and hormonal mechanisms that have such a major control on neurotransmitter and receptor activity within the brain. Kak, a researcher coming out of the ANN school, begins a recent exploratory paper [[89]] by asking how autonomous recognition processes in the brain fit together with intentionality to create logical, cognitive thought (a realistic AI) and sees *indivisibility* or the fuzziness between borders in any measurement process as having a critical role. It is worth repeating his quotation from Bohr:

> "The crucial point [is] the *impossibility of any sharp separation between the behavior of atomic objects and the interaction with the measuring instruments which serve to define the conditions under which the phenomena appear.* In fact, the individuality of the typical quantum effects finds its proper expression in the circumstance that any attempt of subdividing the phenomena will demand a change in the experimental arrangement introducing new possibilities of interaction between objects and measuring instruments which in principle cannot be controlled. ... [evidence] must be regarded as *complementary* in the sense that only the totality of the phenomena exhausts the possible information about the objects." [[90]]

Complementarity somehow implies wholeness and integrity. As Finkelstein points out in other language, one can have maximal information about something without knowing everything about it in quantum theory, although not in the classical view, where knowing is separated as an act apart from all other forms of acting and doing. Knowing is part of the whole set of actions in quantum theory, not an external window into *some* action(s) at a (logical) distance. Kak raises the point that just as classical physics is a generalizing limit upon quantum process, logical thought is a limit upon more generic thought processes where the 'components' continuously flow together and are indivisible. This sounds a bit vague but perhaps not if one reflects upon Pribram's model of isophase patterns of potential in dendritic fields. The signals are flowing and indivisible as part of a vast borderless field. Why has it been so difficult to localize and identify this pattern as this thought, this percept, this intention? Because there are no such objects when viewed from the outside - the divisions are there, they do get made, in the context of attention and the gravity or pull of perception toward one pole or another. But the same isophase potentials could give rise to any number of different percepts, if the organizational context were different. Indivisible fields are being constantly marked out and cut up in different ways depending on how the rest of the brain needs to use the information. To put it in concrete terms, a dark shape that is reasonably uniform in color, opaque, distinguished from a surrounding space by a function approximating πr^2, can be equally and nearly simultaneously (certainly sequentially) interpreted as a dish, a frisbee, a disk, a blade, an abstract geometrical form, a hat...

What Kak wants to do is go beyond the limits of ANNS in such a way as to bring in the stochastic and 'complimentary' aspects of biological brain processing. The solution he argues for is a characterization of the brain in a quantum mechanical fashion. Neural nets, in a most general way, produce a final measurement that is one of several stored eigenvectors V_i such that for an interconnection weight matrix M and a nonlinear sigmoid function sgm,

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89 Kak, Subhash (1992)

90 Bohr,, N. (1961) *Atomic Physics and Human Knowledge*, Science Editions, New York

$$sgmMV_i = V_i$$

ANN approaches that compute for a global energy minimum (Hopfield type nets) often reach only local minima and this can be viewed as an incomplete computation. The quantum mechanical approach on the other hand works from the concept of a wave function Ψ comprising and including within it several eigenfunctions that correspond to different measurements. There is in the evolution of the wave function, as it were, a set of parallel computations (but *not* Turing computations!) for all the eigenfunctions Ψ_i that match with possible measurements f_i such that

$$\hat{f}\Psi_i = f_i\Psi_i$$

and based upon a selection of different measurement criteria one f_i will be made over others, but all possibilities will be available, governed only by their probabilities $|c_i|^2$.

An interesting question is raised about the relationships between thinking and language. How can non-human organisms so rapidly identify invariances and classify instances into classes without language structures for differentiating those classes and their features? Kak suggests that consciousness can be viewed as a "sum of potentialities of thought behavior" where the potentialities are different cognitive functions and levels of awareness, attention, concentration. This view of consciousness seems more in sync with some of the previously discussed work such as that of Pribram, Stapp, and Penrose. Consciousness is always 'spread out' in many directions even though the self-observer may not be conscious of that. Is it localizeable? No, but it is associable with the brain and the rest of the body, and for Kak this implies that a hypothetical machine embodying quantum computing principles would be as alive as an animal or human. But this may not be as astonishing a claim as it first seems. What he is saying is that if a machine, no matter how it were constructed, truly functioned and behaved (not just externally as in responding to a Searlian inquisitor but in every internal mode) like a human being or a cat, down to the spontaneous and creative responses that might be expected or required from queries about self-observation, then it would qualify as being alive and conscious.

Charles Muses

One last and relatively early thinker to be mentioned is Charles Muses, a collaborator with Arthur Young on several exploratory ventures in the 'mathematics of consciousness' and the qualitative aspects of hypercomplex numbers and algebras. In several papers he argues for the association of higher orders of complex numbers i^n, $n > 2$, with deeper dimensionality other than extension in several axes. Asking the fundamental question, "How many *possible* kinds of number, how many forms of unity, are there?", he presents a "mirroring in mathematics not only of the nature of the sensibly observable world, but of the nature of mind itself, the nature of consciousness." The initial evidence for this is the progression, as one moves from ordinary complex algebra to quaternions and octonions, deeper within the structure of matter into quantum mechanics and infinitesimal non-commutative processes.

"Finally, *number as extension*, or metadimension, can be shown to evolve inevitably into *number as transformation*, which is a much higher category, since extension itself is but one form of transformation. The first three forms of number-as-transformation form a closely related grouping, and the first of these, which we term A_1, forms the *trans numbers*, which are independent of the entire metacomplex 'plane' formed by the eight kinds of partible or extensible numbers, u_1 through u_8, already discussed, with zero or u_0 at the origin." [[91]]

The impartibility and indivisibility by zero of these trans numbers leads to this notion of numbers composed not of points in extension along some dimension but of transformation - as Muses says, "distinction without severing, without cutting." A comparison is made to the behavior of nonlinear waves, where superposition and consequent analysis by such techniques as Fourier transforms are not possible because of the interactions between different frequencies.

"Thus we begin to conceive a form of unity (A_1), characterized by an integrity so intense that to try to affect or isolate one point is impossible because at the slightest approach of perturbing energy, the entire unity is at once affected and responds as a whole which is never indifferent to or independent of any smallest tendency to change of condition resulting from interaction with it in any way." [[92]]

However there is a clear and evident problem in depicting the hypernumbers as a mathematics of consciousness as opposed to the real and ordinary complex numbers of classical and quantum physics. Elsewhere Muses seems to be following a logic of 'higher dimensionalities map to smaller objects and less certainty.' One cannot treat mind and consciousness as if it were some ultra-microscopic quantum event 'deeper yet' than quarks and gluons. This is the problem from Descartes' time of always associating mind and the mental with the small and invisible. It isn't what can be seen and touched, so it must be hidden *inside*. Is this not rooted in the equally mistaken notion of physical matter being equatable with extension and that in turn with substance? Take away the substance and replace it with action, and one has the same qualities that are attributed to the mental. One does not have to look inside but at the actions and process.

Muses is looking for a link that will also integrate psychokinetic and telepathic types of experience, but he cannot escape the dualism that is characteristic of modern science because it is so built into the fabric of culture and everyday language and thought. Language like "the neuron protozoa are merely transducers, not originators, and must be arranged and planned for by another category of entity obviously not in the brain per se," or later in the same article, talk of "more sophisticated, noetic types of energy-fields which can, by trigger effects, guide the molecular bio-electromagnetic fields", [[93]] all bespeaks a dualism that, not dissimilar from Eccles, seeks a non-material but substantive source of action that affects a material substance.

There also seems to be a confusion in Muses' writings about the basic nature of quantum physics, reflected in a characterization of quantum events as random, unexpected, uncertain. This is hardly

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91 Muses, C. (1968), p. 37

92 Muses, C. (1968), p. 38

93 Muses, C. (1968), p. 80

a unique misinterpretation but unfortunate nonetheless since it confuses the whole issue of where the dialogue can proceed, since one is already off track with a notion of particles not having a real position or momentum, only some uncertain fuzziness, which could not be farther from the truth, or at least the fundamentals of what Bohr and Heisenberg set out to do with quantum theory! Muses would not be the first to misunderstand $\bar{h}$.

Despite these criticisms, Muses does introduce some creative suggestions about how number and dimensionality relate to types of experience (experiment, measurement) over and beyond the usual quantitative and extensional meaning. The connection linking quaternionic and higher numbers with stability of complex systems, memory as a non-commutative, non-associative process, entropy, morphogenesis - all this is quite provocative. What remains unclear to the present author is how this mapping occurs. Suggestive statements are made, but the explanation is wanting. Muses is unfortunately far too unclear about details, and there seems to be have been very little done in the last two decades to continue these explorations. The initial work is highly intuitional and leaves too much unsaid, but what is said is provocative enough to deserve a closer look in the future.

Coda and Reassessment

What has been the result of examining these different approaches to the questions of quantum theory and the brain and likewise for consciousness? There is variety and confusion, to say the least, and not only in the physics. One thing emerges clearly. The dichotomy between thinking about (picturing) quantum phenomena as something having to do with substantial objects that have real positions in a classical-like space and thinking about quanta as processes that are not objects anywhere, anytime - this dichotomy runs through the schools and views about neural processes and how every mental event, from sensation to cognition, is processed in the brain. There is additionally the confusion between (theoretically) measureable neural processes that take place in or around cells and ultimately macromolecules and the ineffable mental processes that cannot be localized. But simply because the mental cannot be localized does not make it an automatic candidate for association with microphysical quanta! This unfortunate linguistic rope binding the two classes of phenomena must be loosened and only then might some similarities and common ground emerge more clearly.

There is a valid criticism for much of the discussion that has been generated and covered in this present section. Much philosophical talk and little action in the way of building an original, testable model, something that can be measured and dissected. A review of other people's models and theories but not a stand-alone new one. There is a need, however, to assimilate what has been presented already, before going on to build a theory and to design experiments or even build simulations. It is all a matter of really knowing what one is looking to find in the first place. And if the object of the search is not a thing but an action, putting the matter quite simply, the entire strategy for the search must be different. Something that is only action and change will not act as if it were an inert object which does not operate but has things happen to it, the proverbial billiard ball. But if the billiard ball can move around freely on its own and do some hitting and swerving and jumping, it cannot be measured by the techniques used on passive wooden billiard balls!

Perhaps it is time to realize that classical experimentation and observation is will not work for quantum physics nor will it work for what neuroscientists and biologists want to discover.

An Experimental Model for Quantum-Effect Connectionist (Neural-like) Networks
Rationale

Why another model, and a thought-experiment at that? There is one clear reason. Out of all that has been said about quantum physics and biology, there is no good way to measure whether any of this talk amounts to anything verifiable. A theory can only be as good as its ability to be supported by evidence and its ability to simplify the phenomena at hand. Possibly simpler answers that cannot be verified are not worthwhile, and all this talk about quantum processes on the larger scale of Nature must be subject to the most rigorous criticism, beginning with the question of how to show something measurable for all the speculation. Otherwise one runs the risk of having only an interesting model instead of a predictive theory.

One of the avowed key objectives and rather difficult goals of this research project has been to point out directions for exploratory, inventive, 'self-discovery' models. For the most part the computer has been very well used to analyze but not sufficiently, it seems, to synthesize new knowledge. A basic tenet of the author is that one does not and should not go about trying to build so-called 'strong AI (artificial intelligence)' systems as an approach to meeting this goal of uncovering new knowledge and new relationships. There is simply not enough known about the possible relations and the boundary conditions of interacting physical systems to attempt codifying into a formal symbol language the rules and constraints that would be necessary for such a system. There is no expert system architecture for exploring interdisciplinary theoretical physics. However, there are other approaches, and everything in this project is inherently geared and attuned toward building a framework, first at the conceptual and ideational level, and later at the practical, programmable level, for triggering 'synthesistic', synergistic thoughts - intuitive flashes of discovery. Section 5 includes a description of the 'Cybersoft' architecture as it can be applied in very general ways to fields outside of science; here the focus is on building lower-level components specific to domains where it makes sense to look for quantum-like behavior or significant correlations between quantum mechanical and macroscalar processes.

Questions

Modeling and experimenting must begin somewhere, even if the choices are a bit arbitrary, like picking a starting value for an iterative function. Measurement of actual brain processes, despite technological advances, is still far from the levels of reproducibility and precision that seems necessary if one is to demonstrate conclusively the presence or absence of quantum effects. There appears to be no clear and present means for ruling out the stochastic elements that arise simply from attempting to measure neural activity, be it chemical or electromagnetic. In short, working with actual brains and neural tissue does not, after all, seem like a viable near-term solution to the problem of how to look for real evidence for macroscopic quanta. That conclusion may seem obvious but as a cursory review of the literature suggests, some of which has been mentioned above, there is a lot of confusion about what can be measured.

Is there a way out? Is there a useful direction for investigation or is the whole problem constrained to being an at-best interesting thought experiment? The claim is that there can be a positive response if one is willing to look aside from biological experimentation and consider the wealth of opportunities provided by purely computational neural networks. Granted these are not proven, exacting simulations of any known biological networks, although many computational nets have been designed to mimic the simpler neurobiology of planaria and insect life forms or the behavior of small groups of mammalian neurons. It suffices for the moment that these nets are generalized representations of neural behavior and they are practical experimental testbeds. Results are reproducible and controls are manageable. With deference to Dr. Pribram and the many others who argue for more neurobiological experimentation and less simulation, it is simply the case that for the moment the effects of 'friction' can be ignored. There are adequate models of neural biochemical processes that could provide the base for a perturbable system.

There is a philosophical point here that cannot be overstated. Experimentation is critical for validation and bringing theory into line with observation. It is also a key path to discovery - new relationships, new hypotheses. But a great deal of scientific discovery has come about through powerful intuitive leaps and global, wholistic comprehension - what Penrose calls the "non-algorithmic nature of mathematical thought" [94] What are the ingredients, the trigger conditions and events, for inspirational leaps of creativity in science and what contributes to the 'readiness-at-hand' (to borrow from Heidegger) for such processes? Simulations, analogical model-building, scientific 'fictions' built for the sake of creating an image, a potential 'what-if' scenario - all these can, if they are properly directed, have a very fruitful place within science and particularly within theoretical physics. To date most of the experience in conducting research from the starting point of prototyping, fabrication and simulation has been within the broad domain of computer science and especially artificial intelligence - now the claim is made that it belongs within physics and other disciplines. Besides the swimming pool filled with the wealth of experimental potential, there is a need for some diving boards at different elevations, so that the pool can be entered from many more angles and velocities than from the deck alone.

Suppose for a moment that quantum effects could be built into a computational neural net, through a simple engine that models electromagnetic current strength effected through microtubular quantum tunneling, for instance, rather than the decay of a radioactive substance. Electronic states and their effects upon nuclear conformations influence molecular processes that are responsible for the release of neurotransmitters and the firing of synapses. This idea is in line with work previously discussed by Conrad, Matsuno, and Yasue. This can be modeled although the computational load will be dramatically high (and for this a parallel computer is virtually a necessity for anything other than a toy model). A simulation of many quantum tunneling events could result in a 'map' of particle paths that are in turn influenced by the molecular equivalent of many variable-width Gaussian slits. An overriding question is how much effect electronic and photonic emissions can have upon neurotransmitter exchanges; in the computational model these effects would have to be measured by results occurring at some barrier point (corresponding to the detector surface in the two-slit experiment) at which any emitted particles would arrive. In the macromolecular world these surfaces - the 'detectors' - are in motion and affected by their neighbors. All this leads to an inexorably complex simulation! If one is starting from the standpoint of simulation first, experimental verification second, one has a freer hand. A robust model should be able to show some overall difference in the behavior of the network that is

94 Penrose (1989)

attributable to the quantum effects 'generator'. How does the network act, given identical inputs and initializations, in a purely 'classical' mode without these 'special effects', and what differences occur if the quantum effects are introduced?

The effects of this quantum modulation can be imagined as a modulation of input weights on the synaptic contacts that are activated by dendritic fields from neighboring neurons, over and beyond the classical weighting that may occur due to neighboring activity, duration, and amplitude. It could be an in-form-ational potential analogous to the Bohm-Hiley quantum potential; i.e., not a push-pull force but one originating in the form of the environment, in this case the dendritic bioelectronic field. One could take the resulting 'difference set', namely a set of measureable and definable quantities that distinguish the two networks, and look for comparable phenomena in actual biological networks. But what is it that can be easily measured within both biological and computational nets? One quantity is pattern recognition - the ability of the network to classify different input patterns into a set of categories. Such classification abilities and conclusions should vary according to the modulations imposed upon the network structure in response to the purported quantum events - some patterns may be classed differently, or the probability distribution among possible classifications for a given pattern may be broader or narrower. Whether these changes would be to the improvement or detriment of the classification process is not clear.

Methods

A simple simulation/experiment has been designed after repeated investigations with a variety of neural network designs in order to determine which designs are most promising for this task. The latter work has included designing and testing a variety of classical neural networks including backpropagation, counterpropagation, Hopfield, Kohonen self-organizing map, outstar avalanche, cascade correlation, adaptive resonance, and the forementioned HNET holographic network. Much of this work was performed on a PC with INMOS transputers as the parallel processing engine. Code was developed in both C and OCCAM for running on T8xx series transputers. The preliminary objectives were to study the behavior of different network architectures in a parallel computing environment for purposes of selecting optimal hardware and software architectures and to evaluate the relative pros and cons of these networks from the standpoint of simple pattern classification. Results are described in Dudziak(1990) and Dudziak(1991). Appendix 2 contains further material including selected program listings that are the result of these studies. Almost all of these efforts were conducted within the scope of the Internship but were constrained by various factors relating to the corporate work environment, some of which impacted the ability to rigorously follow through beyond simple prototypes.

The HNET software package was used extensively in a PC environment, with pattern data acquired from simulations of the CMD-2 drift chamber detector track segments (cf. Appendix 1). The work was limited by lack of access to source-level code for modifying the network in ways like suggested above, however there was a vast amount of data to use and the HNET system allows for significant customizing on input preprocessing and encoding methods. Initial results

have shown that some track segment patterns missed by a standard statistical method can be detected by the neural net, but the results are still too preliminary to be definitive.
Recently access has been provided to a number of robust biologically-based neural simulators (Aspirin/Migraines from Mitre Corporation, Genesis from Caltech, and the Rochester Connectionist Simulator from the Univ. of Rochester). A powerful set of tools is also available now through the MATLAB system of mathematical software; the latter includes a neural network toolbox (which is in the process of being evaluated). Other simple but extensible object-oriented C/C++ set of neural net functions is also being considered. [95] The public domain code provided through Masters (1993) is particularly useful for prototyping purposes since it is completely written in C/C++. Coupled with the vast recent improvements in workstation technology such as the multi-processor Sun SPARCstation series of computers, these programs and function libraries promise to deliver the kind of software that is necessary for building a quantum-sensitive neural network. Much of the work performed earlier on transputer-based systems can now be implemented much more easily on a workstation with no serious cause for concern over computational performance requirements. On the whole, the software that is available through the public domain and from products such as MATLAB greatly surpasses in versatility the software that was developed ad hoc during earlier phases of this project, including the Internship phase.

Instead of settling upon only one neural network architecture, it may prove fruitful to test several types and look for common responses to the quantum models that are introduced into the inter-layer connections or the threshold processes. This is one advantage of working with a standard set of development tools such as the MATLAB Toolbox and the other referenced tools, since variations between individual programs can be mitigated. Furthermore, recent reports indicate that at least for straightforward back-propagation networks, the MATLAB environment offers faster performance than several C-based implementations. [96]

Object-oriented programming techniques have emerged as an invaluable means for designing software that is easily modifiable and evolvable. The C++ language has emerged as one of the strongest and most widely used such object-oriented tools and C++ will be the language for whatever custom programming will be needed in these models. In this way the quantum behavior that is built into the neural networks can evolve in complexity and be easily replaced without large amounts of recoding or risk of introducing errors. Previous experience has shown that having an easily reconfigurable software environment is critical and the lack of such can restrain development of alternative solution-paths that seem to be not cost-effective because of the level of effort required in reprogramming. C++ systems should alleviate this sort of problem and the growth of program development interfaces on both PC and workstation platforms makes C++ an increasingly versatile environment, an improvement over standard C. [97]

Two Network Models

[95] Masters (1993) and also Freeman & Skapura (1991)

[96] Nazari & Ersoy (1992)

[97] Several grants are in various stages of development at present for obtaining funding to conduct future spin-offs from this doctoral project and success in obtaining an award will help significantly toward solving the hardware/software resource problem.

Two specific implementations are proposed and are in progress. For the purposes of this doctoral program what matters is that there are some practical models that can be built and put to the test, not that any specific one of these be fully implemented at present. It can be expected that each of these models will take several months of serious programming and testing in order to attain useful results that will be useful on their own or useful for incorporation into more robust models. In both cases a fairly standard neural network example is used as a control, and modifications are made to introduce quantum-like behavior at the inter-neuron level, not implying that the brain has such mechanisms but that similar mechanisms might have comparable effects on the performance of a network. A simple dataset is employed, one that can be analyzed by non-neural methods. The purpose of so doing is to look for characteristic and tell-tale signs that might be noticed in biological networks and serve as triggers for future analysis of quantum behavior. In a word, the aim is to see "What if..." and to build a mechanism that can easily be changed to accommodate more sophisticated 'what ifs' as time goes on. The software is that originating in Masters(1991). While MATLAB offers many advantages, the uncertainty of its availability has made it necessary to operate within the constraints of what is known to be available and ready-at-hand.

A Quantum Mechanical Harmonic Oscillator Neural Net

A standard Kohonen Map network is the basis for this model. This net is based upon competitive learning among initially equivalent neurons. It is an unsupervised learning network; i.e., mappings of input to output patterns are not presented in any training phase to the net as in back-propagation. The objective is to discover patterns and relationships between the inputs that are presented. The elementary Kohonen network is illustrated in Figure 3.7 below. Unlike back-propagation and most feed-forward nets, in the Kohonen net the neurons adjust weights in response to presentation of input data but the number of such neurons that can adjust weights is extremely small (often only one neuron). In this model there are no hidden layers and one output neuron. Weights are initialized randomly - a traditional approach common to many neural net models. Learning rate and learning reduction factors can be controlled by user selection.

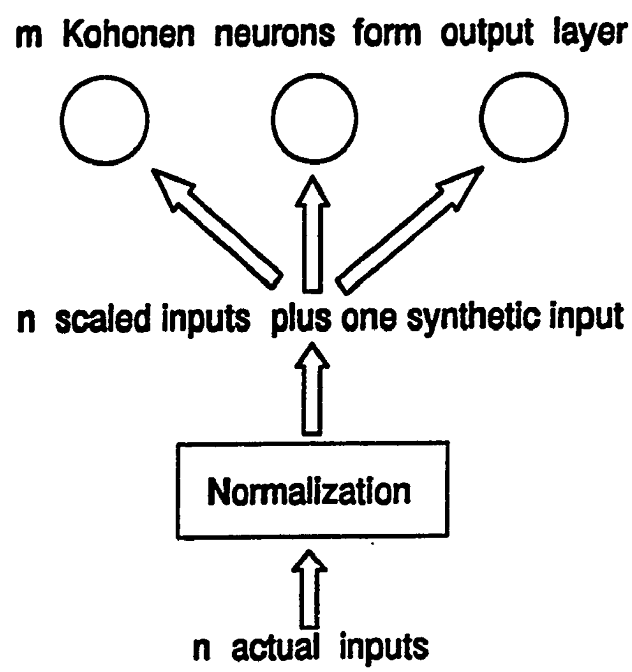

Fig. 3.7 Fundamental Kohonen Map Architecture
Source: Masters (1992)

The Kohonen algorithm works to minimize the error, and upon minimization, a new set of random weights is generated and learning restarts, the cycle continuing until a minimal error level is attained or a cycle limit is reached. The n inputs are normalized by one of several methods and the (s=n+1) neuron generally reflects a scaling value. Each of the m output neurons N_{out} produces output equal to the weighted sum of its inputs, with *no* activation function. Ordinarily there is no weighting or special characterization given to the order or source of these inputs arriving at N_{out}. What matters is the value of $\sum_{i=1}^{n}(x_i w_i) + s w_n$. Classification is simple and straightforward; after training on a set of samples, the weights are fixed and unknown cases are used as input to the net.

The output neuron N_{out} with the maximum activation level is dominant and the class for each unknown case is thus determined.

Because of the lack of multiple layers, the Kohonen network is a purely linear system and depends upon having an appropriately large variety of output neurons for handling specific cases and types of input data. While it offers similarities to biological learning behavior, there are many other networks that are much more elegant and compact. However, the Kohonen net is simple, trains relatively quickly and does *not* have a self-created 'black box' - it is easier to understand how a classification is established.

Normalization of inputs is required in order that each input vector will lie within symmetric bounds (e.g., [-1, 1]. The Z-axis normalization method is an effective means of preserving absolute-magnitude information that could otherwise be lost by simple length adjustment (compression) on the raw input vector. A vector length l is computed from the individual input variables, along with a scaling factor f and a synthetic variable s which are respectively independent and dependent upon the input data:

$$l=\sqrt{\sum_{i=0}^{n-1} x_i^2} \qquad f=\frac{1}{\sqrt{n}} \qquad s=f\sqrt{n-l^2}$$

One aspect of the Kohonen network that makes it similar to the perceived behavior of biological learning systems is its use of competitive principles, something found in more complex form within such networks as the Grossberg-Carpenter ART series. Each output neuron is linked to the inputs and the output from that layer is weighted. For a given input vector presentation there is only one 'winner', namely the output neuron with the highest activation level; i.e., the maximum weighted input vector. The weights are adjusted such that the winning neuron for one presentation will respond more strongly the next time a similar input vector is received. There are several methods for adjusting these weights, the most common being the Kohonen additive method and the Widrow-Huff subtractive method. The former adds a fractional portion of the input vector to the weight vector of the winning neuron:

$$w^{t+1}=\frac{w^t+\alpha x}{\|w^t+\alpha x\|}$$

This could result, however, in rapid fluctuations on the basis of particular input vectors and the orders in which they are presented to the network. The subtractive method adjusts weights by using an error difference measured by subtracting the current weight vector from the input vector and applying an adjusted portion of that difference to the original weight vector:

$$e=x-w^t \qquad w^{t+1}=w^t+\alpha e$$

Masters in [98] suggests that weight adjustment should be done after cumulative processing of one pass with the entire training set, using a mean correction, rather than after each input vector. The intent is to avoid fluctuation or 'fibrillation' and to enhance convergence. Along with this

98 Masters (1993)

suggestion is the argument that weight vectors should *not* be rescaled or renormalized after each adjustment, lest convergence become less attainable or impossible. The weight vector should progressively get shorter and shorter as the error factor is corrected. If it is renormalized after each training epoch, it will always be reset to its original size and convergence will not occur.

In the simplest Kohonen feature map network, there is only one winner among competing neurons for a given pattern classification. Only one neuron gets its weights updated in a positive direction. However, variations allow for competition and inhibition among neighbors, output neurons that may be in a one-dimensional, two-dimensional, or higher configuration. Weights are adjusted in supportive neighbors according to a graduated schema - the closer the neighbor, for instance, the stronger the weighting, creating a 'gravitational' type of effect. This can result in rather interesting self-organization behavior similar to that found in cellular automata.

It is for the self-organizational features that the Kohonen network seems particularly well-suited for studying possible effects by gradually introducing quantum mechanical models into the weighting and activation logic. The initial question to be examined is whether or not quantum mechanical processes can have any significant effect on the self-organization and learning rate behavior in a simple network like the Kohonen feature map. The outcome of such investigations could justify examining the same type of variability in other more complex neural networks and studying the usefulness of the 'quantum principle' for neurocomputing.

Are there cyclical patterns that exist in the behavior of some neurons in a given network and can these patterns be modified or controlled, or in some fashion can the information be used to improve the network performance? Perhaps most relevant to the topics of this project, aside from computational accuracy and performance considerations, can cyclical activity in artificial neural networks into which quantum mechanical processes have been introduced indicate anything that is similar to observable behavior in biological neural networks in the brain? This really is the whole point for moving forward with the construction of any models like the ones proposed here and being currently implemented.

The oscillator function is applied to the weighting function within each neuron as a modulator of the weight factor strength that can be applied to any given input. By itself applying such a function to one neuron is trivial and uninteresting, but results might be very interesting, especially in view of the self-organizing properties of the network, if the same function were operating asynchronously among all neurons. Would any coherence arise? Would all the effects neutralize each other over the long run in the network?

The real interest is in the differences between a classical solution of probability density and the quantum mechanical solution. A comparison of the two on the usual context of particles following an orbit is shown in Figure 3.8 below. At high quantum numbers the quantum and classical densities converge. At lower numbers the differences could very significantly alter the response of a neuron and collectively the ranges occurring in the transmission of an input signal through the net.

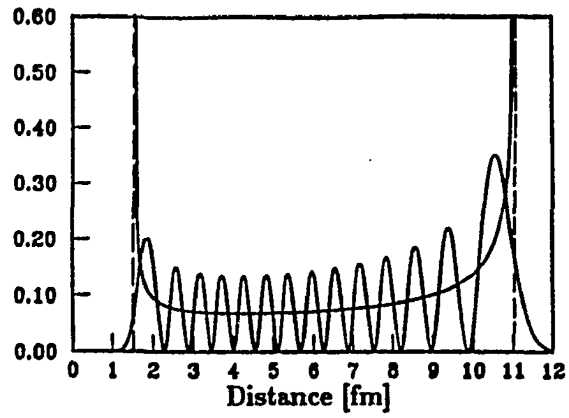

Fig. 14.7. Comparison of the classical probability density $w(r)$ with the quantum mechanical probability density $w_{nl}(r)$ for $n = 14$, $l = 10$ and $a = 0.3\,\mathrm{fm}^{-2}$

Fig. 3.8 Comparison of Quantum and Classical Probability Densities
Source: Schmid, E. W. et al (1987)

Given a spherically symmetric oscillator potential

$$V(r) = cr^2 = \frac{1}{2}m\omega^2 r^2$$

the radial Schrodinger equation is expressible as

$$-\frac{\hbar^2}{2m}\frac{d^2}{dr^2}v_l(r) + \frac{\hbar^2}{2m}\frac{l(l+1)}{r^2}v_l(r) + \frac{1}{2}m\omega^2 r^2 v_l(r) = Ev_l(r)$$

When l=0, the oscillator potential exerts on mass m a force proportional to the displacement - a linear oscillation. If l<>0 there is a centrifugal potential and a potential well in the range of r exists, wherein the mass m moves. The body moves usually back and forth between a minimum distance r_1 and a maximum distance r_2, $r_1 <> r_2$ but as Fig. 3.8 shows there is a fluctuation across the full span of the probability density. Transposing back to the Kohonen network, there will be an oscillation in the strength of the weight factor that is applied to each set of inputs from other nodes in the net. The oscillations will be occurring at each node without any prior or established communication or coordinations among the nodes. These will act as weight modulators to the inputs received from other neurons at the dendritic interface but without any foreseeable linear association with the strengths of those inputs or the activity of adjoining neurons. Will coherence emerge, or any type of apparent self-organization? How this will manifest over time is an open question, one that perhaps the above suggested simulation, once it is built, can answer one way or another.

A Spin-Flip Probabilistic Neural Net

Again the standard Kohonen networks is the basis. The reason for the Kohonen network is not because of any outstanding performance as a network but because of the 'control' that are desirable - a simple network that is well-known and introduces fewer vagaries into the simulation. What is introduced into the behavior of each node is a 'spin' that is either +z or -z, which can be interpreted as the node gives a positive or negative bias to the weighted input that is received from the other nodes. The bias can be used as an ε factor that increases or reduces the inputs to a node or as a modulator of outputs to other nodes.

The spin concept is borrowed straight from elementary physics. Corresponding to an additional magnetic field $B_1 = \frac{1}{2}B_1[\cos(\omega t)x^\wedge + \sin(\omega t)y^\wedge]$ that would be applied to a spin 1/2 electron in a uniform magnetic field $B_0 = B_0\hat{z}$, there is a field B' that can be measured by the state values of neighboring nodes in the network. In other words, the environment around node n produces a condition that influences the 'spin' of node n, which is turn influences the field B'.

How is this probability density of spin at node n determined as +z or -z? This leads back to the Pauli-Schrödinger equation for the two-component wave function Ψ of an electron at rest in a uniform magnetic field, namely

$$\frac{g_s\mu_B}{\hbar}SB\Psi = i\hbar\frac{\partial\Psi}{\partial t}$$

The spin $S = \hbar\sigma/2$ where σ is the vector of Pauli spin matrices,

$$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix},\ \sigma_y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix},\ \sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

Initially the electron has spin +x. The spin executes a precession around the magnetic field with a frequency of 2Ω. The resulting angular momentum expectation value that the electron is in a particular spin state S in the x direction at time t is

$$\frac{\hbar}{2}\langle\sigma_x\rangle = \frac{\hbar}{4}\begin{pmatrix} e^{i\Omega t} & e^{-i\,\Omega t} \end{pmatrix}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\begin{pmatrix} e^{-i\,\Omega t} \\ e^{i\Omega t} \end{pmatrix}\ or$$

$$\hbar/2 \bullet \cos 2\Omega t$$

and similarly for the y and z directions.

There is a precession frequency of 2Ω which may be used in this model and varied according to some outside influence to the network that can be viewed as corresponding to a magnetic field of influence. This could be the persistence of certain features and characteristics in the input data set, or the 'pull' or 'drift' of the network toward a given class of patterns and output decisions. In other words, a disposition of the network toward a particular state or class of states could be treated as analogous to a magnetic field. This is certainly different from many of the artificial neural network models that work from principles of entropy maximization or the action of a dissipative process toward some equilibrium state, but it seems worth exploring. Recent conversations with experimental neurophysiologists and neurochemists indicate that behaviorally some aspects of the brain's neurotransmitter metabolism and the mechanisms that may be responsible for attention can be viewed as competing attractor forces vying for control of perceptual and cognitive functions. [99]

An extension of this concept of having a time-dependent (or stimulus-modulated) magnetic field (or its appropriate counterpart in a neural net pattern recognition context) instead of a uniform field would use a field defined by

$$B_1 = \tfrac{1}{2}B_1\left[\cos(\omega t)\hat{x} + \sin(\omega t)\hat{y}\right]$$

The probability of an electron being in a particular spin state is derived as a function of $\Psi(t)$,

$$\frac{\beta^2}{\Delta^2}\sin^2\Delta t \ \textit{where} \ \Delta = \sqrt{\beta^2 + \left(\frac{\omega}{2} - \Omega\right)^2}$$

It may be objected that approaches such as the above are purely abstract forays into mixing quantum mechanics with neural nets for no known reason or benefit. It is certainly not an attempt to argue for spin properties, for instance, within biological neural behavior. However, it is a method for introducing some type of indeterminacy that is not purely stochastic, random-walk behavior, and it may point to a different technique for dealing with some of the fuzziness inherent in pattern recognition, adaptive learning, and attention.

An Analytical Tool - Fractal Dimensions and the Hurst Exponent

In order to measure some of the variations between network outputs given the introduction of quantum-like behaviors at the reception and activation levels, there are a variety of analytical tools that can be applied. Naturally the differences in pattern learning rates and classifications is significant, but this is showing final results and not much about the processes involved. Visualization of error surfaces should also be useful. MATLAB, should it be available for work in progress and for subsequent stages of research, has a number of powerful visualization tools in its function libraries, including 3-D surface generation and rendering (*surf*, *surface*, *mesh*, *contour*, and *surfl*).

One special method being designed involves the use of fractal dimensions, range analysis (R/S analysis) and the Hurst exponent (H) which measures the cyclical and random qualities of a series of data. This approach appears to offer different advantages over Fourier analysis which has also been used to identify cyclical behavior in a variety of time series. H can distinguish random from non-random series, even if the series is non-Gaussian. The fractal dimension, given by

$$D = \log N / \log(0.5 * r)$$

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99 Personal conversations with M. Bieber and D. Mikulecky, Medical College of Virginia, Richmond, VA

where N = number of circles (r = radius) required to cover the 'coastline' pattern of a 1-D series, is the inverse of H. The Hurst exponent measure has wide applications in geophysical, economic and biological domains, being derived from studies by W. Hurst on fluctuations in Nile River flooding.

In the present case the data would be the cumulative weights of the network output neurons over some time interval, or the cumulative errors in those weights. Perhaps the discrete Fourier transform of the error set could be the quantity actually measured. What is the best set of features for measuring the transformations in the network is not known or even a strong suggestion at this time, but in any case a pattern of feature values over time will be modeled as a 1-D series. The Hurst exponent is derived by first determining a range for values in a series S of length t with u observations:

$$X_{t,N} = \sum_{u=1}^{t}(e_u - M_N)$$

where $X_{t,N}$ = cumulative deviation in S over N periods (t periods compared to one M_N)
e_u = deviation in period u,
M_N = average of e_u over N periods.

The period 'width' N starts at some reasonably small value considering the number of total observations, and increases up to perhaps t/2. For a sampling of 1000 observations, N might vary from 5, 6, 7, ... , 500. It is to be expected that as the sampling for computing M_N decreases, stability in the estimate will fall off. For each set or step of N periods, a new range R_N and standard deviation S_N are calculated by obtaining the maximum and minimum values attained by $X_{t,N}$ in the summation step. With N=5 and t=1000, there are 200 separate R_5/S_5 values that are then averaged to yield an R/S[5].

This process is continued for all of the range of N. Hurst devised a relationship $R/S=(a*N)^H$ which, taking the logarithm, yields

$$\log(R/S) = H * \log(N) - \log(a)$$

where N = number of samples in a given period,
R/S = rescaled range of the observable deviations,
a = a constant.

Figure 3.9 below shows a variety of R/S analyses with Hurst exponents indicated.
What does it all mean? A Hurst exponent may range $0 < H < 1.0$ with the following properties:

$0 < H < 0.5$ ----- Mean-reverting or antipersistent (ergodic). What goes up will most likely go down in the next period, and vice versa. The closer H moves to 0, the more the correlation tends toward the negative. A series may appear random but it will be even more volatile, choppier, than random.

H = 0.5 --------- Random-walk. Correlation, measured by $C = 2^{(2H-1)}-1$, is zero. Randomness does not imply the normal distribution, although probability could be so distributed. H however tends to be greater than 0.5 in many natural phenomena, therefore not normally distributed and not random.

0.5 < H < 1.0 --- Persistent or trend-reinforcing. If the observed value moves up, it will tend to stay up or move further in the next period. There are trends and they tend to be reinforced. H=1.0 would indicate 100% correlation. The closer H moves toward 0.5, the greater the noise. The evidence suggests that this persistent type of time series is more common in natural phenomena than not, and consequently the speculation arises that this may also be true of many events at the quantum mechanical level, as well as quantum-like processes in structures such as the brain.

The program that has been designed, HURST.C, will accept a series of real numbers in an ascii text file and produce output in the form of logarithmic values for R/S and the corresponding periods of observation (e.g., N=5, 6, ... N_{max}). This output, also in the form of an ascii text file, can easily be put into a spreadsheet or graphics package for charting.

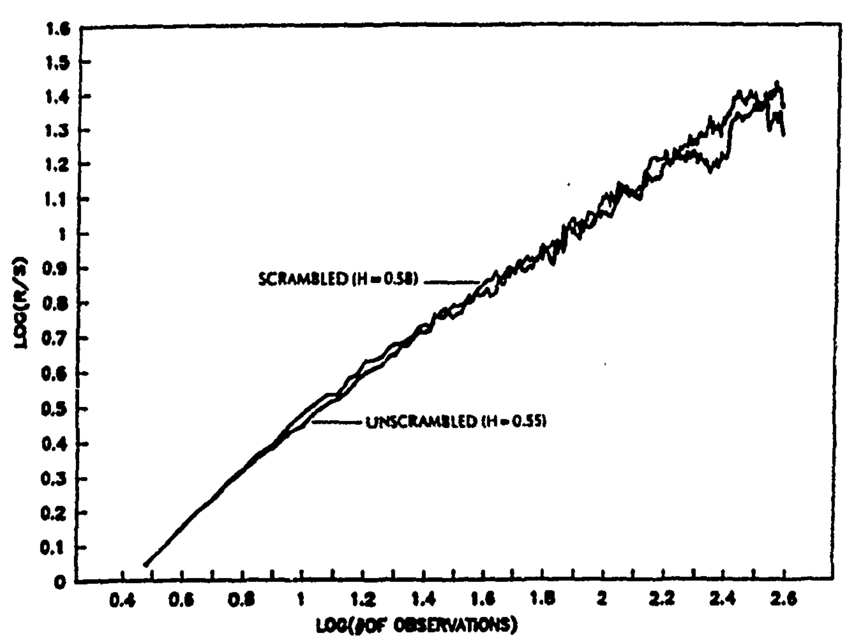

FIGURE 7.6 Scrambling test for R/S analysis: random Gaussian numbers. Unscrambled H = 0.55; scrambled H = 0.58.

Fig. 3.9 Examples of Hurst Exponents and R/S Analysis of Time Series
Source: Peters (1992)

Over and beyond projected utility in measuring chaotic vs. random behavior in the fluctuations of output within neural networks, the R/S analysis may have value in exploring periodicity and randomness in much more straightforward series such as measure the frequency of K_S and K_L decays as measured against other events. Are there characteristic qualities to the patterns of randomness, ergodicity or persistence among different observables? Is there any kind of temporal lagging or correlation between, say, decay activity of different types? Most of the methods for analysis in particle physics experiments appear to be view events statistically as groups but without any distinction as to patterns of order or disorder among the different groups. All this is seen as fruitful directions for the next phase of exploration, applying the speculative and front-edge thinking of this research project to concrete theoretical and experimental physics, in collaboration with groups such as the Pittsburgh and Novosibirsk teams, the project of which is described below and in Appendix 1.

Future Directions and Applications

As part of the Internship of this doctoral program and continuing into the near future, there has been ongoing collaboration since early 1991 with experimental research teams at the University of Pittsburgh (under Dr. J. Thompson) and at the Budker Institute of Nuclear Physics in Novosibirsk (under Drs. S. Eidelman and E. Solodov). This work, as explained in greater detail within the Program Summary and in Appendix 1, *Computing Development for Phi Factory Work at Novosibirsk*, has focused principally upon the design of improved computing architectures for the CMD-2 and CMD-3 collectors and upon the development of refinements to both the standard histogramming algorithms for track reconstruction and the conventional approaches to particle identification.

Initially this experimental work did not appear to be directly related to the topics covered within this research program, particularly the highly speculative hypotheses about quantum processes and biological neural networks. The theoretical topics and issues in neutral kaon decay and related experiments, for which the Phi Factory is principally being designed, had seemed to be somewhat removed from issues of non-locality, quantum gravity, macroscopic quantum logical phenomena and the like. Indeed, the role of neural network and connectionist-like programming techniques for the Phi Factory project, as it is called by the primary teams, was quite different from any of the discussions herein regarding neural nets. Their value for Phi Factory applications has exclusively been in classification and autoassociation, traditional uses at that.

The connection with the doctoral program seemed to be principally as new learning in areas of particle and experimental physics as well as neurocomputing. However, recent thinking within this program has opened up a new possibility that could be explored, namely the use of neural nets as simulators for the behavior of particle interactions, such as the decay of neutral kaons (K^0), which exist in two varieties: K_L. and K_S . According to the Standard Model, while several kaon decays are allowed, $K_L \rightarrow \pi\pi$ is a CP violation as is the asymmetry

$$A = \frac{\Gamma(K^+ \rightarrow \pi^+\pi^-\pi^+) - \Gamma(K^- \rightarrow \pi^+\pi^-\pi^-)}{\Gamma_{total}}$$

This would be quite a different application for neural networks, quite apart from the usual classification and filtering of external input patterns, and as such the initial notion for how to employ connectionist architectures within the CMD-2/CMD-3 detectors for the Phi Factory. Instead of operating as an adaptive filter for the processing of track registrations in the drift chamber and other detector components, a neural net could be used to model the logical space of particles creating and annihilating. The main value would be in discovering consequences that are not predicted by traditional models nor by experimental evidence, based upon a model that would incorporate the known relationships and rules. Given that levels of luminosity required for detecting CP-violating K_S and K_L decays with sustainable accuracy have not been attained in the past, there is much that remains unanticipated. This kind of application of a neural net to modeling particle dynamics has not been seen in the literature; however it is not unlike Mikulecky's application of neural nets to classical modeling network thermodynamics. [[100]] Some of the forementioned modifications of a neural net to reflect quantum modulations of weights and vector spaces could be applied and put to a 'reasonableness test.'

One of the raisons d'etre for the Novosibirsk Phi Factory is to generate the 1-3 x 10^{33}/cm^2/sec luminosity required to yield experimental evidence for the forementioned CP-violations. The ϕ resonance is a source for K_S and K_L. At 510 MeV, the ϕcross-section is 4 x 10^{-30}cm^2. This yields a probability of decay into a pair of K_S and K_L at 0.344, a rate of 2.75 x 10^3 / sec. [[101]] Experiments with sufficient production rates for neutral kaons should verify and refine many of the theoretical predictions for CP-violations. For any given decay sequence there will be both a frequency of occurrence and a set of constraints governing its antecedents and consequents. The latter are collectively what would be important to test in order to verify their consistency with one another and in order to search for possible dependencies and relationships among decay sequences that have not been detected through experiments or by other theoretical means. For instance, there are other rare decays such as $K_S \rightarrow \gamma\gamma, K_S \rightarrow e^+e^-, \mu^+\mu^-, K_S \rightarrow \pi^0\gamma\gamma$. It could be that some of the branching activity among these decays can be understood as being controlled or influenced by other observables.

Current estimates for trigger and counting rates indicate a 12 KHz rate of decay and Bhabha (e^+e^- scattering) of about 60 KHz. Additional showering from Bhabha events hitting solenoids and producing secondary gammas is estimated at approx. 120 KHz. In the end there will be about 200 KHz of particles reaching the detector apparatus. But it is the 12 KHz Φdecay rate that is most significant and it is estimated that digital processing of 10-20% of these events will be adequate, meaning a processing rate of 1-2 KHz. As described within Appendix 1, the CMD-2 and future CMD-3 detector consists of a 3690-channel drift chamber, a vertex detector, fast trigger counter, and two calorimeters ((LXe and CsI). The drift chamber is divided into layers, each of which has an increasing number of sectors, and the data collected provides the critical information for track reconstruction. [[102]]

100 Mikulecky, D. (1993)

101 Eidelman, S., Solodov, E., & Thompson, J. (1990)

102 For detail of algorithm, refer to p. 21 in Appendix 1 document.

Given a set of decay predictions, it should be feasible to assign decay paths (e.g., $K_L \to \pi\pi$) to particular nodes in a network. If a node is sufficiently activated, a decay occurs. This network is not a traditional feed-forward net with a prescribed input and output layer; it is more like a sparsely-interconnected Boltzmann net that is NOT expected to iterate down to a global equilibrium state. It runs forever, more or less, because the net is receiving energy inputs continuously, and decay processes create non-linear jumps in energy for individual nodes. The net is being used as a filter, not a classifier.

These various decay types [103] can be assigned symbolic identifiers $\{A_0, B_0, C_0, ..., Z_n\}$. One or more nodes in the network would be assigned a given decay A_i or B_i,... and so on and these nodes can be distinguished by association with members of a set $S = \{A_0, B_0, C_0, ... Z_n\}$. An individual node n is denoted by <X|y> where $\mathcal{X} \in S$ and y is an integer (there will be different numbers of nodes for particular decay sequences). The firing of a given assigned node <X|y> would indicate the occurrence of a specific decay. That node firing is triggered by the accumulation of inputs received from other nodes in the net to which n is connected.

Here is where the similarity with a traditional neural net runs thin. In a standard neural net the inputs are generally all of a similar range of values and are weighted, the result being that the neural input is an inner product operation of the form $\sum_{j=1}^{n} \omega_{ij} v_{ij}$. This result is in turn operated upon by a threshold function (typically sigmoidal) that determines if, when and to what degree the neuron sends output to those nodes that are in turn connected to its output side. Only when the modified input summation value matches the threshold criterion (be it a fixed numeric value or a more complex set of symbolic values) does the node *activate* and send output to other nodes. The 'HEPNet', as such a construction might be called if it is applied to high energy physics experiments, has nodes <X|y> driven instead by inputs $\rho_{ij} v_{ij}(Q)$ where ρ_{ij} is a probabilistic weight derived not from activity on the i-->j link nor from a back-propagation of errors in output signal strength but rather from outside the i-->j path; it is a measure that an event v_{ij} did occur, taking into account all of the factors represented within the net that have a bearing upon that event. It is a measure of the probability that v_{ij} occurred.

The event v_{ij} is an indicator of the type of decay that occurred, and $\mathcal{Q}$ is a logical expression conveying the constraints that go along with the particular decay interaction and which affect the value or 'weight' of other inputs to the <X|y> node. Some event may have occurred but its effect upon a node n denoted by <X|y> could have been neutralized by other processes along the way. $K^0 \to \pi^+\pi^-$ but pion decay (including those that result in production of kaons) is also occurring. The result is that instead of an inner product operation the input to <X|y> is more like a predicate calculus deduction process. This begins to make the structure of the network appear more and more like the structure of a logic program (as in PROLOG implementations, with facts and rules). From another perspective it begins to appear a little like the quantum-net cellular automaton discussed in Section 2.

Once again the notion of a self-organizing cellular automata machine with heterogeneous and dynamic 'rules' governing the interactions and relationships among cells and their neighbors

[103] Refer to Tables 3, 11, and 12 within Appendix 1.

emerges in this forum of ideas. Whether or not the forementioned network simulator has any serious utility for experimental physics applications such as those of the Phi Factory remains to be seen. It is hoped that aspects of this work can be continued directly out of this doctoral project through existing and new academic collaborations, and every indication is that this will take place, despite the vagaries of international logistics, funding, practical 'other' commitments, and so forth.

What could emerge from the construction and operation of this type of neural network? Unexpected consequences and vagaries that conflict with the traditional analysis of kaon decay (or other particle behaviors) are the type of phenomena sought and expected. The aim would be not to supplant but rather to enhance the existing framework of understanding by creating a computational machine that could conceivably exercise the known or accepted logic enough and in a 'clean' computational environment so that the 'unforeseen' comes up frequently and clearly enough to be noticed. It is certainly hoped that the construction underway and continuing on the prototype networks described above will produce useful components for something more immediately useful to physics research. Of course, the point should not be lost that one of the primary reasons for this model-building and exploration is to examine if quantum-like behavior within a network will create noticeable, reproducible perturbations in behavior that are like some processes and events in the (micro)physical world. Perhaps there will be a way to affect a network through large-scale connectionist interactions such that behavior similar to some of what is observed through particle physics experiments (such as kaon decay and CP-violation) emerges as a self-organization phenomenon in the network. All things and more are possible.

In the next section further explorations will be made into the concepts of cellular, connectionist networks that may illustrate the underlying process-nature, and the chaotic flux within it, that underlies quantum phenomena. That discussion will lead into more suggested computational models including one that is again underway but hardly near any stage of completion at present. The mixing and hybridization of connectionist algorithms with dynamical systems theory is increasingly the subject of research in the mainstream neural network community. It remains to be seen whether or not these strategies and methods have any real value for doing quantum physics. Intuition says yes, but verification remains a long way off. Somewhere in between, hopefully, comes the insight and invention that yields a well-formed theory. What is going on here is scouting the woods and testing the waters, looking for better ways to move forward, knowing that the conventional ways have not been as fruitful as anyone would have hoped, and certainly not as simple or concise as expected. With patience and imagination, all things and more are possible.

Section 4 CHAOTIC NETWORKS AND QUANTUM FLUX

Introduction and Connection

To understand how a quantum dynamics applies to both the microscopic and the macroscopic may require, due to the fundamental issues of scalability and irreversibility, answering the big question about how quantum physics and general relativity fit together. There may be no escaping that problem. Certainly that is a solid example of where the micro and macro worlds interface. This may require, along the lines pioneered by Bohm, Hiley, Finkelstein, and a few others, a thorough examination of how and why space-time dimensions and metrics arise. How is there stability in a metric system? How do irreversible processes emerge (and is this also a question about the emergence and stability of the time metric)? As the metric scale diminishes, approaching the Planck distance level, the very dimensionality fluctuates, increasingly in an unpredictable and seemingly chaotic manner. The vacuum flux is beneath space-time and generally ignored because it is unpredictable and uncontrollable. Nonetheless, as the scale increases, there is not only the apparent continuity out of discreteness that mystified Zeno but there is stability and linearity where one should only expect a continuation of disorder and unpredictability. Is there a place for some type of non-classical chaos at the quantum scale? Is 'chaos' even the right concept to use? The intuitive notion that comes to mind is that just as the edge of a cut piece of metal or fabric appears incredible jagged and highly fractal when viewed under a microscope, from human-scale viewing distances or farther the edge becomes a well-defined straight line or smooth curve. Is space-time fractal and how does it keep its shape? Perhaps the theory that integrates quantum physics and relativity will show a counterpart to the relativistic role of gravity in producing a curvature to space, only here it will be something more to do with the fractal nature of space-time and the role of some type of attractors that stabilize the universe so that the vacuum flux is not random but ordered.

These are the kinds of questions that have led to consideration about chaos theory and how it can apply to all of the previous discussions in Sections 2 and 3 about quantum processes, networks, cellular automata, and quantum-like modulations of connectionist (neural) nets. This is a bit like walking on ice, because even the basic idea of chaos is not well-defined classically and there is much confusion between chaos and randomness, although tools like the Hurst exponent and Lyapunov functions can help in making the discriminations. A goal here in this section is to scope out a simulation model that could incorporate a variety of chaotic behaviors and be used to study what happens when very large, massive sets of chaotic entities are interacting as part of a network or CAM-type system. In this sense the aim is to begin bringing together the computational modeling discussions that have been presented in the latter pages of Section 2 and also in Section 3.

New Sets of Tools

Much of the earlier discussion in this paper has been a philosophical exploration of the notions underlying quantum physics as process and the possible connectivity of a quantum logic with macroscalar processes. What has been lacking is a strong formalism for expressing a quantum process universe that spans from the domain of 10^{-30} to 10^{-3}m and transcends the limitations of thinking purely of cause and effect in three spatial dimensions, something that acts as a bridge between the Hermitian operators of the standard quantum model and classical Newtonian mechanics. There is as of yet a felt sense that new mathematical tools and models are required to describe processes that are wholistic and yet local, events that are interconnected without being causally linked, whether it be on the micro domain of particle interactions or on the much larger scale of neural networks in the brain. A few promising mathematical explorations have been begun, particularly toward the development of higher-order algebras that might serve as topological algebras or process algebras with a capability of giving form to otherwise nebulous concepts and thereby a pathway to deriving some form of empirical verification. Foremost there is the work discussed earlier by both Finkelstein and Hiley based upon Grassmann and Clifford algebras. There are problems in bridging the gap between the algebraic models and empirical investigation or even computer simulation. How does the connection get made with the rest of physics, so that some of the maths can be put to the test with known phenomena - or is it a more a problem of how to start picturing the 'rest of physics' in a way that is compatible with the Grassmannian algebra of forms and in-form-ing? Perhaps the problem lies in thinking of the objects in the world, whatever the scale at which they manifest themselves, as isolated things that interact rather than as operations and interactions that give rise to the appearance of substance. This criticism is akin to what Finkelstein expresses recurrently concerning the differences between the commutative lattice-based quantum theory (CQ) and the noncommutative theory (Q) that is the object of study.

> "This commutative quantum (CQ) logics has a strong classical component. The predicates it represents by vectors of a Hilbert space are of order 1 (predicates about quanta, not about predicates) and degree 1 (pure cases, not mixtures). These are subject to quantum superposition. Its higher-order and higher-degree predicates are not. This is physically reasonable for macroscopic operations, but it is also limiting, in that it excludes microscopic quantum operations. In this paper we propose as a further step toward a universal algebraic quantum physical language a noncommutative one called Q which is richer than CQ in much the way that CQ is richer than C, having a still stronger superposition principle; namely, one which applies to higher-degree and higher-order predicates as well as to first-degree, first-order predicates. This goes beyond the Copenhagen quantum theory, which insists that the observer is classical." [[104]]

In this work the claim is made that the CQ approach may not be all that reasonable after all for macroscopic operations. The superficial evidence points to something of the order of a noncommutative quantum logics with application even to the macroscopic world that is more than mere analogy or appearance. The very brief examination of relationships that may exist between quantum physics and neurobiological processes leads more toward rather than away from a sense of the there being a fundamental quantum nature to reality that transcends scale. Things are quantized not merely or only because of size (scale), but because of a fundamental aspect to the way the world works. That is the key word - 'works.' Not 'is' - that always brings one back to the static realm of substance and ontos. Work is energy and energy (energeia) is physis. And physis is process, happening, the flux of Heraklitos' river. Somehow there must be a way of expressing

[104] Finkelstein (1991)

the types and relations of processes that can occur interdependently and across multiple scales, a process algebra that is consistent with a quantum logic.

In the course of this work a suggestive new approach has emerged, again something of a synthesis from seemingly unrelated domains such as the relevance of chaos theory for neural networks. It is speculative and even as yet not well-defined, but it is an approach that can be studied now with mathematical and computational tools such as those that have been learned, acquired or are in the process of being engineered through the body of this doctoral project. One of the many goals in this project was to define a reasonable new investigative path for future research that would bring together quantum theory and certain macroscalar processes wherein the quantum foundation seems to be strong and this is that path, or at least the opening through the woods that shows promise of being a negotiable path.

Quantum Chaos
Random Attractions

> "A very small cause which escapes our notice determines a considerable effect that we cannot fail to see, and then we say that the effect is due to chance. ... it may happen that small differences in the initial conditions produce very great ones in the final phenomena. A small error in the former will produce an enormous error in the latter. Prediction becomes impossible. ..." (Poincare)

Consider an individual particle p as a finite collection S_i of n processes p_k Each p_k is an operation or interaction, definable in the simplest possible terms as a functional mapping involving one or more variables. (These are not to be confused with the traditional operators of quantum mechanics, although there may be some direct link possible for expressing a process pk in terms of the basic Hermitian operators.) Each variable may itself be expressible as a set of operations. Each p_k is itself defined as an enumerable set of operations across j sets of other processes. The value of n or any j is dynamic over time, depending upon operations that determine the weight or effect of the interaction between some p_k and the other processes that comprise S_i and which by some operator determines the membership in p_k or in the larger set S_i.

The set S_i may be viewed as a collection of points in a phase space where each dimension corresponds to one of the processes p_k. Instead of thinking about one of these dimensions as being extensional (e.g., 0 to ∞ as distance), this dimension should be conceptualized as a measure of activity steps, much as the processing of computations in a program. The scale of measurement in one of these process dimensions is a measure of the interaction or communication with a given process - what is the level of activity in pk that affects other pk within Si. As one moves from one step to the next, whether it is in a procedural or functional (e.g., lambda-calculus) program, one goes 'further along' some path of process towards completion. Actually there may be no final completion point, but still one is further along the more of the process is performed, even if it is in a 'Do While "Forever"' loop that never ends. Over time the dimensionality of this phase space may change, depending upon the previous states of S_i and, as suggested above, the flux in memberships within the operational sets p_k.

This notion of a dimensionalized representation of process and activity is difficult to express and it is a goal offered for the theoretical research community to explore. How does one measure the state of a process that may itself be a composite of many more elementary sub-processes and many parallel processes at that? Suppose processes p_1 and p_2 are interdependent and both include a sub-process q. How does one quantify the effects within p_1 that are to be attributed to changes within $q[p_1]$ as opposed to those attributable to $q[p_2]$? It does seem similar to issues of representing system states in computer programs, especially those that are parallel systems. The CSP and OCCAM formalism developed by C. A. Hoare [[105]] and extended by others into the transputer implementation is one possibly useful tool for this task.

A particle from this perspective is a dynamical system, but it is fundamental that it not be viewed as a collection of parts but rather of processes. This is where the first of many breaks from traditional dynamical systems theory occurs. Most such systems are collections of parts - particles, molecules, cells, fan blades or even economic time series. The suggestion here is that the collections are not of objects that move through a space but of processes that happen in that space. The nature of the process p may be translatable into a change of position of a given mass - that is to say, a process could be described or expressed in those terms - but this does not mean that it is ontologically that change of position. More to the point, the particle may be a chaotic attractor, which when viewed from the much-reduced dimensionality of classical physics appears to have such qualities as position, mass, kinetic energy, etc.

Parallel computing may give a useful perspective. Imagine a vast array of distinct processes that fall into a finite set of types or classes based on the instructions executed. It does not matter for the moment what computations are performed, only that these processes are connected with one another according to a dynamical topology that varies according to the data that is being passed between processes. Processes communicate by messages of different length and encoding. In other words, the connections are variable and driven by data flow. A dynamical, self-organizing program is something that emerges not as a prestructured, predetermined composition but as a cluster of process activity and communications which may or may not sustain itself over time. It is like a whirlpool or eddy in a river. This leads back to the cellular automata (CA) and quantum CA machine concept discussed in Section 2 earlier. How is the state of such a system composed of parallel processes to be described, both instantaneously and evolving over time? What is the equivalent of a wave function for the network?

The n-dimensional set Si is suggested as such a representation. Each dimension reflects the activity component of a particle process-element within the network. The observable, as it were, is not a measurable physical thing but a process. In the simplest analysis this component could be represented by a single number that measures the weight associated with the process/node, much as nodes in a neural network typically have weighted interconnections. But there could be more complex representations that are themselves functions. It appears that no such function can describe an eigenstate of an observable associated with a given process pk because of the non-stationary nature of these pk. There does not seem to be any reason why an ensemble measurement would lead to the same values in all instances. At any rate the unit of measurement

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105 Hoare (1976)

for one of these process dimensions might be not a scalar nor a vector but a set whose membership is not restricted to one type and whose membership is dynamic; i.e., the number of elements can change as processes being described by such a set change or are replaced over time by different processes with different features.

Instead of thinking in terms of a probability density within space-time it may be more appropriate to think in terms of an attractor region within an n-dimensional phase space. Possibly the attractor region of possible solutions is such that all but a few dimensions are negligible and the connections between two such attractor regions is thin or sparse over time, leaving two regions to appear virtually disconnected. Possibly there are bifurcation points in the evolution of such an attractor where the number of dimensions actually changes. Is it possible, for instance, that the fractal dimension of even a simple attractor could change over time? Certainly this is true of any number of macroscopic time series, such as economic indicators (interest rates, bond prices), where there are linear and non-linear phases and both cyclical and random-walk periods.

Consider simple point and limit cycle attractors. A gravity-damped pendulum is a point attractor - a time series of velocity or position drops in amplitude until it is a horizontal line (disappearing into a point) and a phase space map has a line (in this case a contracting spiral) that ends in a point, the 'attractor point' that is the phase space origin. Limit cycles, on the other hand, have an example in an undamped pendulum, one that is periodically given a boost of new energy from outside the system. The time series for velocity or position might form a sine wave, for instance, and the corresponding phase map would be a closed circle. More interesting are the 'strange' attractors (also called fractal attractors) where the period remains constant but the magnitude of energy input varies according to some parameter (for instance, the magnitude of the previous input) that is typically unrelated. A phase portrait will appear random and chaotic, and equilibrium is now neither a point (origin) nor a line (radius of the phase circle) but a region of space.

The *Lorentz attractor*, given by the equations

$$dx/dt = 10(y-x)$$
$$dy/dt = xz+28x-y$$
$$dz/dt = xy-(8/3)z$$

was originally developed as a simplified weather model but also served to describe the flow of a fluid within a layer of fluid having a uniform depth and a uniform difference in temperature between the upper and lower surfaces. A three-dimensional phase space suffices given the above equations. Whereas in the point and limit cycle attractors there is convergence to a singular entity (point or periodic path, respectively), here there is convergence to a non-recurrent path. This is the essence of the *strange* or *fractal attractor* in general. Whatever the initial conditions, there is rapid convergence to a point on the recurrent curve and thenceforth following of the curve ad infinitum. but the curve does not recur, nor is the sequence the same for even very similar initial conditions. Nonetheless many different initial conditions will result in paths that are similar in behavior, indistinguishable at some level of measurement. Also, if the attractor is thought of more as a complete whole consisting of paths through a particular space rather than as the movement of a singular point, then it becomes easier to conceive of the attractor as a process instead of a set of functional outputs.

It is worth pointing out that the accepted integration technique used for the differential equations found in the Lorentz attractor and related phenomena is the Runge Kutta method. Using first-order derivatives one can attain the level of accuracy found in Taylor expansions with higher-order derivatives. Given an initial equation of the form

$$dy/dt = f(t,y)$$

one can next derive

$$y_{n+1} = y_n + k_0/6 + k_1/3 + k_2/3 + k_3/6$$

where the constants k_n are all expressible as functions of t and y and a set time step.

Now consider a more complex attractor, such as the Pickover system, described by the equations

$$x_{n+1} = \sin(ay_n) - z_n\cos(bx_n)$$
$$y_{n+1} = z_n\sin(cx_n) - \cos(dy_n)$$
$$z_{n+1} = e(\sin(x_n))$$

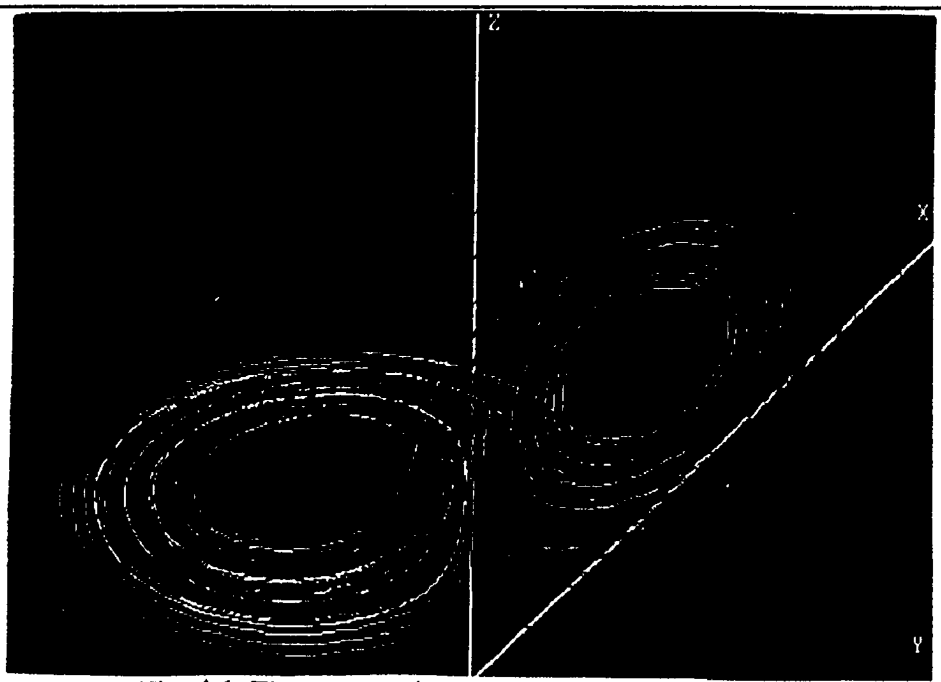

Fig. 4.1 The Lorentz Attractor   Source: Stevens, R. (1989)

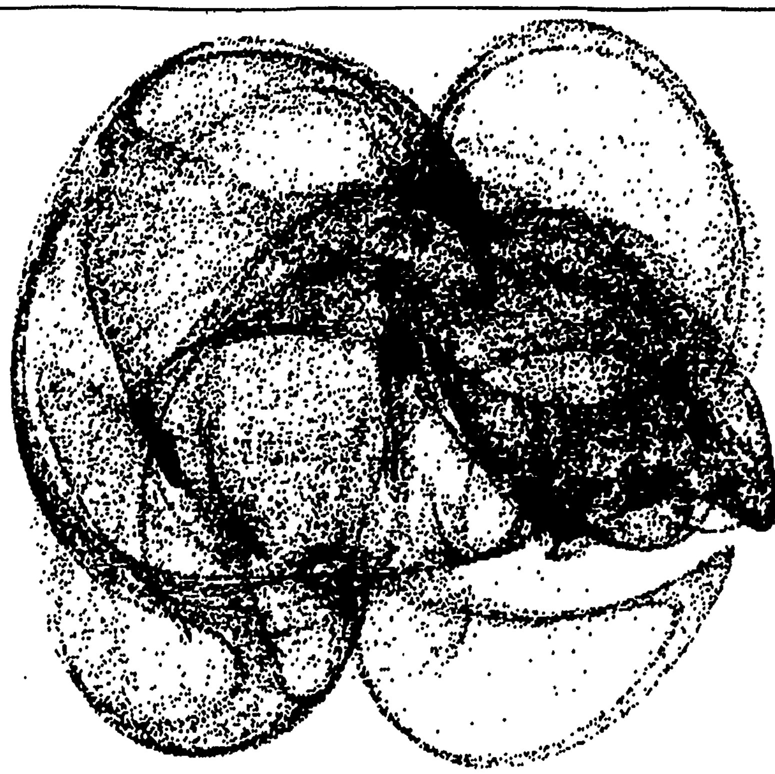

Fig. 4.2 The Pickover Strange Attractor   Source: Stevens, R. (1989)

Irrespective of initial conditions, the point (x,y,z) moves toward the attractor in what seems to be a random fashion, unlike the Lorentz attractor. Figures 4.1 and 4.2 above illustrate the Lorentz and Pickover attractors respectively. Note the seemingly random distribution of paths and the apparently distinct paths. These 'paths' are deceptive; movements of points as they are being generated are NOT sequentially along the apparent paths! If one watches the generation of the Pickover attractor on a typical computer screen, particularly one driven by a slower processor than an 80486, it is obvious that the successive points are being generated at widely separated positions. One is tempted to say that point p1 is unrelated to point p0, but this is only in terms of contiguity or proximity; after all, there is an obvious mathematical relationship between p1 and p0 in that p1 is generated from the (x,y,z) values of p0, as shown by the equations above.

Chaotic Solitons

Paul Werbos raises some interesting notions with respect to quantum field theory and chaotic attractors. Although this is not the place for a review or criticism of his 'neoclassical' approach to quantum physics, it is worth mentioning how chaotic methods apply. Particles and "stable 'multibody systems'" are identified as solitons. A soliton can be defined most generally, by

$$\phi(\underline{x}, t) = e^{ivt}\underline{\phi}(\underline{x} - \underline{v}t, 0)$$

Most of the study on solitons has focused upon one-dimensional (spatial) solitons, and little is known about the behavior or formalism necessary to identify higher-dimensional solitons. It seems plausible that particles could be modeled as solitons and particle interactions as the dynamics of a field or network of solitons. Werbos' argument is that techniques from chaos theory that have proved useful in locating strange attractors for ordinary differential equations can be applied to the problem of finding solitons of nonlinear partial differential equations. He argues also for a need to "adopt a different definition of 'stability,' a definition more suitable to the analysis of time-symmetric systems." [106] Another way of putting the question is to ask, how might attractors be characterized in terms of statistical ensembles, so that chaotic solitons might be identified?

Consider a vector field $\phi(\underline{x}, t)$ with complex components and an evolution of ϕ governed by nonlinear partial differential equations over three-dimensional space. To work with a chaotic attractor in the field it may be simpler to examine a statistical field description, but this in turn depends upon the probability distribution that describes the movement of the system along the path of the attractor. Werbos suggests working with statistical moments rather than explicitly calculation probability distributions for given time intervals. A collection of functions u_n that are each within 3n-dimensional space can be treated as a single function within a combination space made from the 3n-dimensional spaces, referred to as a Fock space. Chaotic solitons can be viewed as localized equilibria within such a space. But what are they equilibria of? The dynamical equations that govern the ways statistical ensembles will evolve over time need to be determined before it makes sense to talk about equilibria.

Werbos suggests a tool, the "reification operator," as a means of transforming dynamical equations that otherwise will suffer from an infinite regression of information from higher-order to lower-order terms. This operator is compared to the Fourier transform as when applied to electrical circuits. It can be applied to a vector of statistical moments in order to derive a wave equation which can in turn be used to search for chaotic solitons. One of Werbos' claims is that "familiar methods from quantum field theory can be used to 'detect' chaotic solitons." [107]

The Work of Chirikov

Some mention must be made of the research of B. V. Chirikov at the Budker Institute of Physics (Novosibirsk, Russia). Quantum chaos is distinguished from the classical dynamical chaos that arises in a system without any noise and which in fact is the source of noise. The fundamental randomness of quantum mechanical events, Chirikov points out, is related directly to the quantum measurement, an outside element or introduction into the quantum system itself. Qualitatively this results in two 'parts' to the problem of quantum dynamics and quantum chaos: the dynamics as described by the wave function $\Psi(t)$ and the measurement including the registration of the result, the so-called collapse of the wave function.

The basic model that Chirikov works with is the standard map: $\left(n, \theta\right) \rightarrow \left(\bar{n}, \bar{\theta}\right)$ where

$$\bar{n} = n + k * \sin\theta \ and \ \bar{\theta} = \theta + T * \bar{n}$$

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106 Werbos (1992)

107 Werbos, P. (1992)

n, θ = action-angle dynamical variables
k, T = strength and period of perturbation, respectively

This map is periodic in θ but also in n with a period of $2\pi/T$.

There are two general approaches to defining and discriminating dynamical chaos, one which emphasizes statistical characteristics such as ergodicity and Bernoulli properties, the other emphasizing physical trajectories and local instabilities of motion. A positive Lyapunov exponent or the Kolmogorov-Sinai (KS) dynamical entropy h are general characteristics, however not sufficient in themselves because of the need to establish boundaries for motion types to be excluded. For Chirikov there are two levels of chaos:

> "(i) the 'first-rate chaos' (h>0) with truly random trajectories, and
> (ii) the 'second-rate' chaos which is just sufficient to admit a simple statistical description by a sort of kinetic equation. ... What is important for quantum chaos is that even on the second level of classical chaos the motion phase space has to be continuous to provide traditional statistical description." [[108]]

The size of a phase-space cell on the quantum mechanical level and the finite nature to the number of cells for any quantum motion preclude classical mixing. It seems to be inadequate, as Chirikov would have it, that classically chaotic systems by themselves provide an adequate model or definition for quantum chaos. This leads to Chirikov's definition of quantum chaos as "statistical relaxation in a discrete spectrum," which proceeds in both time directions and also leads to a kind of steady state that is not the same but similar to a classical statistical equilibrium. This steady state is related to Mott's states that are the effect of resonant backscattering in disordered solids. In fact, one of Chirikov's points is the similarity between quantum dynamical chaos and Anderson localization effects in disordered solids. [[109]]

In answer to the question of whether infinite-time-scale chaos like in the classical limit can be possible within quantum mechanics, Chirikov's answer is a very qualified yes. Yes, but only in 'exotic' ways; the quantum motion must be unbounded and this means a continuous spectrum but the momenta must increase exponentially over time. An example is given of a flow over an N-dimensional torus specified by $\dot{\theta}_i = v_i(\theta_k)$ where the momenta of the Hamiltonian system defined by

$$H(n, \theta) = \Sigma_k n_k v_k(\theta_i)$$

grow exponentially as soon as the toroidal flow system is chaotic.

It is difficult to follow some of Chirikov's lines of reasoning and to determine how his approach can be tested experimentally. The main point for this discussion seems to be the importance of distinguishing between quantum and classical chaos and not mistaking the latter for the former. This is worth keeping in mind as one investigates possible abstract models that could be

108 Chirikov, Boris V. (1991a), p. 13
109 Fishman, S., et al (1984) and Shepelyansky, D. L. (1987)

developed for simulating quantum behavior out of chaotic attractors and fractal structures. What is clearly chaotic in a classical frame of reference may not after all be translatable into the quantum domain. But it is simply not clear where to draw the lines because there are so many similarities between classical statistical behavior and 'quantum chaos.' One of Chirikov's main points remains the need for a new ergodic theory that can address the finite-time rather than infinite-time statistical properties of any dynamical system. As long as one is applying chaotic models based upon infinite-time to the quantum realm there will be problems because of omitting the finite-time aspects. It may be that the similarities and analogies exist all the same, but the substantial link cannot be established while there are such variances in the conception of time-scale.

A Chaotic Quantum Network

What follows is one suggested type of abstract thought-experiment, a simulation that should be feasible to implement with current computing technology. The value of such a simulation is for experimenting with different mathematical representations in order to see if some are more efficient than others and if they could be applied to the actual physics.

We begin with a very simple model of a single particle p. Forgetting about ordinary space-time, in which p has coordinates x, y, z and t, this particle also exists in S_3, a three-dimensional process space. (It is three-dimensional only for the initial purposes of this model and the computer simulations used for it; the intent is to expand the dimensionality and in no way to confuse it with spatial dimensions.) Call these three process dimensions d1, d2, and d3. Each dimension is a measure of the activity level for a certain type of elementary operation, following the suggestions made earlier. Each process can be analogized to a computational sequence, a program that has multiple functions and segments. The dimensional measure points to where that process is with respect to its computation, not a simple location in real space or phase space. An analogy may be made with the behavior of the simple Lorentz attractor where the point p moves in concentric orbits of either increasing or decreasing radius about one of two foci, the attractor points, shifting from one orbit to the other aperiodically. The process of the Lorentz system may be described by something of the following:

- increasing radius, attractor A
- decreasing radius, attractor B
- shifting from A to B
- shifting from B to A
- increasing radius, attractor B
- decreasing radius, attractor B

and one could envision the movement of a point in one dimension that represented a history of these process states.

Imagine now that a virtual particle, or a collection of such entities that forms a highly interconnected network, is representable by a set of processes similar to the above. A picture emerges where abstract points in a matrix (network) that are not ever inherently or absolutely associated with particles of a given type become potential points of creation, annihilation and states in between these 'endpoints' of an ontological spectrum. what moves a point into one process or another is driven by the whole, the network of connections around it, and the shift from one process or state into another can be as non-linear as the shifts in movement and direction within a chaotic attractor. This is the direction in which a new *process physics* may be headed, and in so moving it may hold keys for explaining relationships for which concepts like the quantum potential and the implicate order are intended to express. Bear in mind the 'pilot wave' nature of the quantum potential. It is a problem if one posits an independent signal that must get its energy from somewhere and if it is a foreign source then how does one avoid a deterministic hidden-variable or superluminal model of quantum physics? But what if the quantum potential is treated like an 'x-factor' in a chaotic attractor (Lorentz or Pickover, for example)? It is fair to represent such a factor as a measure of the element of transition from one process to the next. There is such a transition; it occurs over a given interval of time, it involves a specifiable exchange of energy, etc. However there is no entity that can be removed from the context of the system, and the variables of time and position are not predictable from outside the system.

For purposes of this model let there be only three types of process which are identified only as: unfolding or expansion (Λ), folding or contraction (Υ), and stasis or remaining in a constant state (Ξ). These are not separate states that evolve from different algorithms but are different aspects of the same evolving chaotic system. That is to say, an object that is performing process Λ can transform into performing process Ξ by the action of rules or algorithms that depend upon the The simple Pickover strange attractor discussed earlier provides the starting point for this system, and it is possible to produce radically different geometries from the same set of equations just by varying the basic parameters. For a given particle p there can be only one of these processes dominant at a time, and the determination is made on the basis of how p is behaving with respect to the influences (inputs) from neighboring processes.

The location of p within the phase space S_3 defined by d1, d2, and d3 controls the activity of p and these in this 'toy physics' model consist of Λ, Υ, Ξ. The location and movement of p within S_3 in turn affects any other particles or systems that are within the same phase space and within the scope or range of connectivity with p. This type of relationship approaches that found in cellular automata and in neural networks, but with greater (tighter) interdependencies among the nodes (and p is essentially one node among many in an n-dimensional network).

In order to model p and the networks that evolve around it and to do so in a way that is practical and potentially useful for real physics (whatever that may be!), some form of graphical representation can be given to the behavior of p and its process-universe. One can model changes in the S_3 process phase space as if they were changes in the movement of some point, edge or volume within a conventional xyz coordinate system, namely that of the computer graphic space. Three sets of results can be expected to be interesting (if not insight-ful) - the shapes that p takes over the course of system evolution, the sets of shapes among the different instance over time of particle/node p, p', p'', etc. (the dynamics of p), and the sets of such observables for many particle/nodes p_i operating and interacting together.

Is it possible to create an artificial ensemble of particle-like entities whose fundamental nature is to be a dynamical process influenced by and dependent upon other like entities? Can this kind of system evolve into something that offers any semblance of self-organized behavior? And perhaps most important, could such a system be used as the basis for a more robust and complex process model that employs the time-dependent Schrodinger equation, for instance, and behaves with a similar dynamical but self-organized behavior? Within this program of study the goal has been to define foundational first steps and a direction for subsequent research. Given that, the S-Net system has been designed as a computational exercise and a platform for future modeling.

The S-Net Dynamical System and Program
Design Methodology

A sample C program that generates the xyz coordinates of a strange attractor, hereafter referred to as P1 ('P' for C. Pickover, to whom the discovery of the specific dynamical system for this attractor is attributed), was obtained from a standard text on fractal programming techniques. [110] This program was modified for use on a standard 386 or 486 PC with VGA graphics resolution (640x480 pixels). The program modifications included making provision for the entry of parameters from standard user input (keyboard) or from a standard ascii text file. The original sample program without any changes to the basic algorithm was maintained as a reference point against which to check the accuracy of changes made in specific functions for the S-Net program.

The initial system of equations used within the sample program and from which the S-Net system evolved are:

$$x_{n+1} = \sin(ay_n) - z_n\cos(bx_n)$$
$$y_{n+1} = z_n\sin(cx_n) - \cos(dy_n)$$
$$z_{n+1} = e(\sin(x_n))$$

There are five principle parameters {a, b, c, d, e} which can vary independently and generate significant effects in the path of the point moving in phase space. The equations can be extended to allow for significant more dynamicism as in the following set:

$$x_{n+1} = \alpha z_n\sin(ay_n) - \beta z_n\cos(bx_n)$$
$$y_{n+1} = \gamma z_n\sin(cx_n) - \delta z_n\cos(dy_n)$$
$$z_{n+1} = \varepsilon z_n(\sin(ex_n))$$

The parameters in {a, b, c, d, e} are referred to as the scalar parameters (since they affect scalar values of x and y. The parameters in $\{\alpha, \beta, \gamma, \delta, \varepsilon\}$ are referred to as the transcendental parameters since they operate upon transcendental functions.

Phase one of the design consisted of making a thorough quantitative and qualitative analysis of the variations within the topology of the P1 attractor that occur by virtue of changes to first the scalar parameter set and then the transcendental parameter set and then both. The single attractor program SNET1 was implemented to run a test set of scalar and transcendental parameters and to allow for evaluation of the P1 attractor as it was generated by each parameter configuration. The

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110 R. Stevens (1989)

program displays the attractor after $5*10^5$ iterations as a projection into the XY-plane, then the YZ-plane, and ten the XZ-plane.

Test data is entered into an EXCEL spreadsheet from which an ascii delimited text file, SNET1.DAT, is produced. The latter is input to SNET1.EXE. Initially the choice of test set parameters is arbitrary, in order to create a diverse enough range of types. As there is no known and reliable method for predicting the density distributions of points generated by the attractor, this process proceeds by trial and error - does the resulting pattern appear distinctive enough to become one of the prototype patterns or not?

Phase two of the project consists of classifying structural types to the different patterns that emerge through running the test sets. Having done this, a taxonomy of P1 attractor shapes is defined. These form the attractor set A s.t. x E {x1, x2, ... xn}. The patterns produced by the SNET2 program consist of an 8x8x8 cellular array imposed upon the attractor space, large enough so that generated points in the attractor will be located within the array of cells. The density of points located in each cell is recorded and the resulting pattern of densities makes up the representation for the particular attractor phenomenon. Admittedly this method neglects a great deal of available produced information about the sequence of points in the attractor, but for now the main point is to design and fabricate a simulation toolset and later to refine it. In a future version it may make sense to employ an unsupervised neural net, something like a Kohonen feature map, to make classifications out of a very large set of attractor parameters. This approach could address the question of how many basic patterns are there. However this is not very relevant to the problem immediately at hand. All that is needed is a reasonable set of distinguishable patterns, in order to determine if collective and interactive behavior among a large population of attractors can generate transformations from one pattern type into another. what matters first is how transformations can occur, whether it is in the context of ten possible types or a hundred types.

In order to arrive at a concise and reasonable set of parameter sets for use in further modelling with S-Net, a back-propagation neural network was employed to classify parameter sets. The network was trained using the sample test set parameters and the class of attractor shapes. The back-prop net being used is a simple three-layer network with sixty-four input nodes, one for each of the cells in the pattern array. There are eight nodes in a single hidden layer and eight output nodes. This allows for up to 255 different patterns.

Phase three of the design consists in building a network of these P1 attractors. The similarities to both cellular automata and the OCCAM communicating sequential process model should become apparent. Processes are dynamically instantiated, meaning that over the course of the network's evolution in time the number of attractors can vary. A set of rules R governs the interconnectivity of these attractors; i.e., whether or not an effective channel exists between them. Among the factors are distance between any two given attractors and the type and proximity of neighbors. The basic algorithm for determining if attractor p1 'connects' with p2 is to cycle through R and cull out the disallowed channels, allowing all others. How a given attractor operates depends upon the parameters (discussed above) and these are set by the interactions among attractors, effected through the open channels. All that the set R really does is to establish a network configuration, reducing a fully-connected network to a subset. What happens within an attractor depends upon the inputs received over its allowed channels and the nature of the processing within the attractor.

For simplicity the first version of SNET3 will consist of a randomly configured population of P1-type attractors in an xyz-space, each attractor set to initial conditions for a predefined pattern type. As each computational period commences, the attractors begin stepping through their sequences, as in SNET1 and SNET2, generating new xyz positions. With each time interval, the scalar and transcendental parameters are modified according to the connectivity rules for neighboring attractors. Over time this will modify the attractors in a way that should be distinguishable from the 'control case' where connectivity does not enter into the picture and attractors simply evolve into the types that are predetermined by their initial conditions.

Of interest in this simulation is what types of changes are most prevalent and whether or not anything resembling self-organized, self-regulating behavior begins to emerge from the processes of the attractors. What are the effects of adding more and more attractor nodes or modifying the different rules? How robust are the individual attractors, and are the changes that occur in any way homogenous throughout the attractor space? These and many other questions can only be answered by large-scale running of an efficient and easily modifiable simulation such as the SNET3 system is intended to provide. While the questions may seem abstract and unrelated to any specific topic in physics, it is the intent that having built the engine and tested it, and having derived some behavioral patterns that one might watch for in any kind of test, it will be possible to apply the model to real-world physics, using perhaps data on K_S and K_L decays, as discussed earlier in Section 3.

Computational Tools and Environments

Limited and sporadic access to proper simulation and mathematical modeling tools has been one of the problems that have beset this project. However, various ad hoc solutions have been implemented to take maximum advantage of what has been available. These have included the use of some commercial software packages that include some analytical and statistical functions even though they are of lesser quality and capacity and definitely slower in performance, as well as an informal library of 'home-grown' utilities. These include the analysis functions provided by Microsoft Excel and the S-Plus statistical toolset. A principal barrier has been the lack of a robust database management system for handling data that may be generated from simulations. This problem has been met adequately for the foreseeable near-term future with the use of PC-based database tools such as Microsoft Access. This provides both query and archiving functions which are important.

While transputers have long been a preferred computing environment for parallel processing and lend themselves very well to this S-NET simulation architecture, there have been extensive delays in the development and release of new transputer chips (the T-9000 series). With the advances over the past few years in not only RISC computers (e.g., Sun SPARCstations) but also Intel 80486 and Pentium technology, there are few advantages seen in implementing the S-NET programs on the older, slower T800-series transputers. Thus the shift in the course of this project to portable C programs that run on PCs and offer little problem for migration to Sun and other RISC-based platforms.

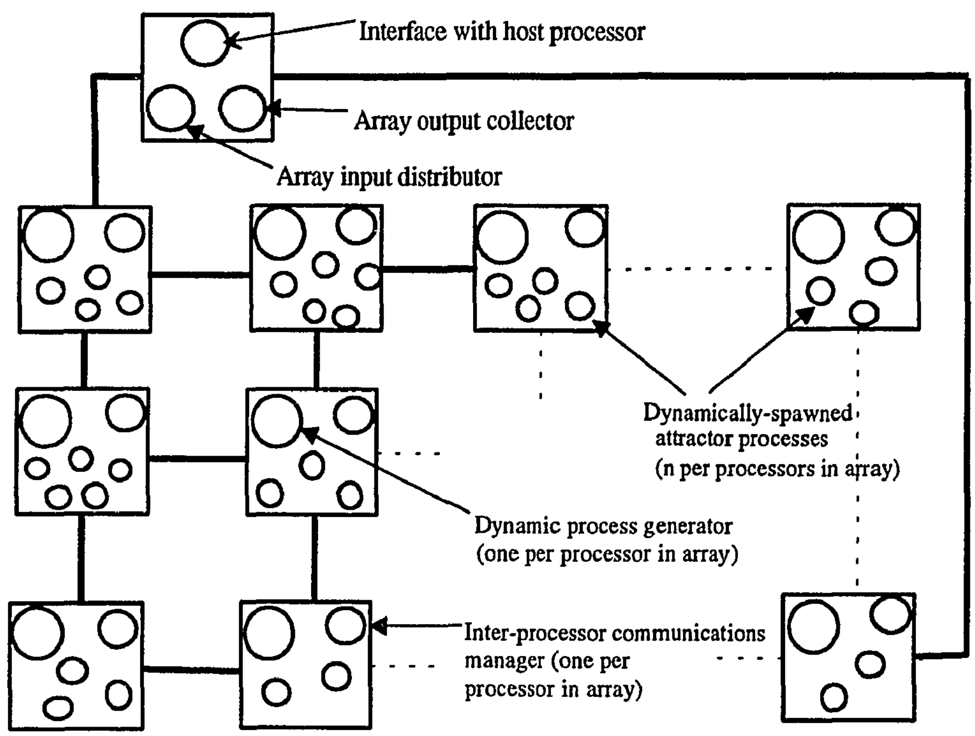

Figure 4.3 Possible SNET3 Configuration Across Transputer Array

The present work on the S-NET simulator programs is being done on a 486-based PC with 10 Mb RAM and VGA graphics. All coding is done using Microsoft C/C++ 7.0 and Visual C++, with a close adherence to ANSI C standards. The development is proceeding at a pace where publishable results may be available by the end of 1993 if not sooner. However, for performance improvement if for no other reason, the target architecture is a scaled down version of the Parallel Field Computer discussed in Section 5, consisting of the following:

80486 PC with minimum 8 Mb RAM and 300 Mb disk
14"+ SuperVGA color monitor
INMOS B008 or equivalent transputer motherboard
INMOS B490 T9000 development module
INMOS B426 development modules (5)

Alternatives include using the Transtech TTM100 Vector Processor module and four or more TTM31 transputer modules. Figure 4.3 above gives an illustration of how SNET3 processes interact and how the processes are mapped onto multiple processors. The specific architecture is unfortunately more dependent upon access and availability to hardware than upon technical merit. Clearly the T9000 transputer offers the most powerful integer computations and communications handling between processes, while the i860 offers outstanding floating point capability. The DEC Alpha processor is perhaps a more highly rated chip in terms of MIPS and MFLOPS but its availability is very scant.

Consequently the software modules are being intentionally designed for easy porting to a parallel environment. It is the author's hope that before software development on this and other proposed simulations described in this paper are too much farther along, there will be a more definite opportunity to focus on having the adequate computational power.

SECTION 5 QUANTUM DYNAMICS RESEARCH FRAMEWORK

New Sets Of Methods And Tools

Early in the course of beginning these investigations it became clear that certain new scientific structures and tools were needed for this type of interdisciplinary research to flourish. The fundamental problem is seen as a problem in measurement. What are the scales and how to use them? What are the geometries - this is another way of phrasing the question about a unique appropriate quantum logic. The toolkit is apparently not the same one that physicists, biologists, and neuroscientists have been accustomed to using all along.

Certainly this new toolkit must include the right theoretical tools already available from within physics, mathematics and other disciplines. But what of experimentation? How is one to define what will be the right experiment, or even an adequate simulation? It is the claim within this work that traditional models for doing experimental science are not adequate for studying purported holonomic behavior any more than differential equations are suitable for establishing a formalism of wholistic dynamical systems. Traditional experimentation is object (point) driven. Consider brain research. As has been argued throughout this paper, collecting data points that consist of individual neural firings does not yield a picture of a neural holoscape any more than analysis of individual electrical signals in a telephone wire will provide a clue to understanding the language of the speakers. Looking only at the axon hillock does not let one see the action of the dendritic fields. However, the former 'discretized' method of study is the known and accepted way of gathering data about the behavior of a living neural structure. There has until recently been little potential for doing much else, in part due to engineering and computation limitations.

Clearly one factor of the avoidance within certain scientific communities of the questions raised within this paper can be attributed to the difficulty in getting beyond speculation and metaphorical thinking into formalism and experiment. It is difficult enough trying to do straightforward neuron-level studies or develop purely physical tests for hypotheses in particle physics, much less trying to develop a measure for correlations that may exist across different dimensions of phenomena. The notion goes against the grain of established thinking that abhors non-locality or the dissolution of *substance*. Form and something like a quantum in-form-ational potential is supposed to be ephemeral, not as real as the classical object-world.

How does one approach the question of coherence and/or self-organization among quantum events in a complex and inherently untouchable space as the brain? How does one do experiments relating to measurement on the brain when virtually any disturbance caused by an invasive experiment is guaranteed to alter the results of the experiment in a way that throws into question the validity of the results? An interesting form of this questioning is to ask how could the formalism of quantum mechanics be used to describe these kinds of measurement disturbances - even if the interactions are purely at the classical level.

What is being suggested as a first step toward empirical and experimental investigations into wholistic (and perhaps) holonomic system behavior is not an abandonment of current experimental methods. To the contrary, for brain studies techniques such EEG, ERP and direct multi-point microelectrode collection of neural spike activity will be essential, especially as engineering developments allow for the collection of multi-electrode data. For instance, real-time EEG based upon 128 electrode sources can be expected to provide more accurate discrimination between field regions than what has been presently available. In a seemingly unrelated field such as economics, there are obvious and clear sources for the experimental data (stock market prices, averages, indices, futures, options, derivatives - to name but a few!). How does one begin to talk about fields and holonomy in that domain? There are no immediate answers but the argument is made here that by building a computational toolset that allows scientists to share and view mathematical models from a variety of disciplines one can hope for intuitive leaps and discoveries to emerge with greater likelihood than through the present circumstances.

Sometimes it makes sense to jump out of the particular domain in which one is working and studying and examine what is common or similar across several domains in order to define a tool or a method that can turn out to be stronger for the particular object of study but *not* for that alone. This appears to be the case when it comes to computational methods, and it has certainly been the case from direct experience, alas something that is not easily quantified or formalized. That is why the strong bent in this work on reviewing and assimilating seeming diverse or orthogonal concepts, with even a somewhat reduced content of mathematical formalism. Words are indeed often a poor means of communication some concepts whereas mathematics is better, but it seems that in the formative process of *synthesizing* - before any appropriate analysis can be done - words with some math may be the best way to go about exploring.

MacLennan, considered earlier in Section 3 [[111]], speaks of the need for a theory of continuous or field-like computation and proposes the idea of a *simulacrum* as a model for continuous or connectionist knowledge representation, analogous to the idea of a *calculus* in discrete epistemology. Such a model as MacLennan's could have value as a computational framework for quantum field phenomena and particularly as a method for representing and simulating quantum logical networks. It is an interesting hypothesis to consider that in the operation of a computing machine composed from billions of simple processors (e.g., nano-scale processors consisting of finite-state molecular automata [[112]]) there may be emergent properties that are macroscopic quantum effects. One of the major hurdles from the outset is again how to compare observables in diverse domains - what does one use as the underlying feature set for judging similarity and commonality? What are the criteria for evaluating the common ground and equivalence between what may be very different mathematical formalisms that emerge from different disciplines? It is a problem of fundamental scientific discovery and inquiry and the argument is made that the complexity of the investigation requires the employment of new methods and tools that have heretofore been considered as belonging to 'artificial intelligence' or 'computer science' and not part of the theoretical physics toolset.

The problem is not one of needing better and better hardware or of changing the base methods of collecting data. Back to the context of the brain, methods of correlating and interpolating the neuronal electrical activity to that of a holonomic field need to be worked out through integrated simulations and experiments. If we can build a model of how we think a holonomic field behaves

111 MacLennan, B. 1990

112 Conrad (1985), Hameroff (1987), Lawrence (1990)

then we can view graphically the activity of such a field. The isophase contours can be mapped and represented in 2-D and 3-D graphics. That gives a base from which to examine the experimental results and investigate how the experiments can be conducted to demonstrate similar types of behavior. We do not know that the experiment will bear out the same results as the simulation - that is the point of the experiment in the first place. However, at the present time we do not know in what manner to conduct the experiment such that a compatible order of results may be obtained; i.e., sets of actual and interpolated membrane potentials such that isophase contours can be examined for behavior that supports or contradicts the theoretical predictions.

The problem is analogous to trying to develop a test for general relativity without any reliable way of accurately measuring the deflection of light traveling from astronomical bodies. Our hypothesis would be that a massive body such as the sun should deflect light rays in accordance with the theory. Suppose that the planet Mercury did not exist and our means of testing this hypothesis consisted in placing a set of satellites and photoreceptors in space in order to produce an apparatus that could make the necessary comparisons between light in the presence of the massive object and light that had passed through a space without such an object. We would first need to establish the geometry for such an array of collectors and this would require some simulation in its own right. At this point in time our work in studying the holoscape/holoflux within the neurobiological domain is at a similar position - where do we place the electrodes and what transforms do we apply to the actual received data in order to build a field model that is NOT overridden with noise and artifacts that are the result of the experiment and not the actual brain activity? It is not clear even what disturbances are introduced by the contiguity of different measuring devices - analogous to not knowing how events in interstellar space would affect the accuracy of the photoreceptor array for the deflection experiment.

An Integrative Solution

The solution that is herein developed and which is in the process of gradual implementation is both organizational and methodological in nature. Once again, to the chagrin of the traditional graduate education philosophy but as a fact of reality, this solution, as is the case with programs and models outlined in previous sections, is not a fait accompli. There is no finished product and large body of test results. There are designs for structures both physical and organizational. A proper long-range environment is required in order to carry out theoretical studies in concert with experiments that can then reflect back upon the theory and vice versa. So much is not clear about what is the form of what is being sought that there must be a structure for investigating things in many diverse directions and yet being able to have some common ground on which to correlate and compare results. This structure *is* an organization and of necessity it involves more than a configuration of equipment and resources. It demands the integrated and diffused research of several groups of scientists and different experimental and theoretical frameworks. It is a big picture and a big demand, but that does not stop it from being part of the solution and a goal to be worked towards.

The present situation is exactly this - spread across the table are many different papers, the likes of which are described and referenced within this work, all of which seem to touch upon the notion that quantum processes are taking place at more scales and in more domains than that of elementary particle physics. Each paper is written in a different language and often with a very different mathematical vocabulary. It is next to impossible to transfer abstract or experimental information between these diverse thought-spaces. It is difficult to determine what is shared in common and what is similar, particularly in the mathematics. A common platform such as a highly visualized object-oriented modelling system could be a great asset toward bringing the gap, much as such devices and systems have proven useful in other fields, neural networks, symbolic artificial intelligence, and dynamic systems being three cases in point.

There are two major components to this solution. The first consists in establishing a laboratory environment that can be devoted and directed explicitly to these kinds of research issues. This environment is, as shall be described, not massive in the physical sense since one is working in the computational domain, and yet it is complex in that it goes beyond the scope of any single program or fixed architecture. In fact the distinguishing characteristic of this workbench or toolset is that it be flexible enough from the point of future evolution by the direction of the user and from the point of internal or self-generated modifications under the control of programs that have been explicitly designed to generate novel associations and conceptual relations.

The second is the need for a broader plan to integrate that toolset and several others into an on-going, open-ended interdisciplinary program of research, one that is analogous in principle (though not in scope or funding) to the establishment in high-energy experimental physics of various collider experiments, typically involving the collaborative research of many diverse scientists from an international community. This is of course the long-term view, far beyond the scope of this doctoral project. However, it is important to have a focus on the horizon as well as immediately in front of oneself - both are necessary to avoid becoming lost or wandering too far afield.

Organizational Components

Initial Efforts: The EPR Lab and BCN Project

With this view in mind, a major effort within this research project has been directed toward designing the practical basis for such a research framework. Consistent with the academic philosophy of the Union Institute, a significant amount of effort has been directed toward aspects of establishing a research environment that are not only abstract and theoretical but interpersonal, social, and organizational. It never was an original goal of this project to put so much effort into these dimensions of research, but the task emerged gradually in the second and subsequent years of the formal program and could not be avoided. There was no intent to make either the organizational or computational environment(s) an object of activity that had to be completed during this program, since these are tasks that can really only happen through the fortunate conflux of a group of individuals and a considerable source of funding. These have both yet to coincide but the opportunities do look better now than ever before.

Thus the concept of the Endophysics and Pattern Recognition Laboratory was formed, in order to provide a stable and long-term organizational framework for conducting theoretical and experimental studies relating to holonomic field phenomena in physics, biology and the neural sciences. The problem is too big for one research team or project. As has been emphasized throughout this paper, the work thus far and comprising this Project Demonstrating Excellence consists of laying some foundations and planning how the whole building will be conducted. The concept of an Endophysics and Pattern Recognition Laboratory (EPR Lab) is one of the fruits of this labor and its formulation over the past two years has been a major undertaking and a vast learning experience, albeit a bit unusual as part of a doctoral program in physics or any science.

The EPR Lab developed through several iterations of planning stages, insofar as it was a proposed research group within SGS-THOMSON Microelectronics, a major European-based semiconductor manufacturer. The Lab was intended to be devoted to basic and applied research relating to quantum and dynamic processes in biology and physics. The applied nature of its charter is to study how these processes can be used to understand pattern recognition and cognitive behavior and to develop synthetic devices, using silicon-based and/or biomolecular technologies, that will perform similar functions in recognition and cognition. Naturally these were very broad, ambitious and long-term goals, in no small way influenced and dictated by the requirement that the proposed lab fit functionally within the plans and intentions of the company. Without such goals it is likely that we will never have a big enough picture by which to encompass everything that is necessarily or potentially related and which can help to achieve the fundamental aim of understanding quantum dynamic systems.

Details of the efforts and organizational planning toward establishment of this EPR Lab were outlined in several working corporate documents, summarized in Dudziak (1991). The planned structure of the EPR Lab was simple. A small team of research scientists, engineers and/or technical staff were expected to be added to assist an initial 'pioneer' one-person effort, facilitated through direct sponsorship by SGS-THOMSON and by external funding (NSF, DARPA, corporate sponsorship). They would work on a number of projects in close collaboration with research teams from the Center for Brain Research and Informational Sciences (under the direction of Dr. Karl Pribram) and the Ecological Physics and Natural Computing Laboratory (under the direction of Dr. Peter Kugler), both of which are located at Radford University and with members of the faculty from Virginia Polytechnic Institute in nearby Blacksburg. In addition, close collaboration was already underway with the Neural Network Research Facility in the Dept. of Physics at Georgetown University in Washington, D.C.

Several particular projects have been targeted and initiated, and these are described below in the section entitled, 'Computational Environment'. Since most of the initial work to develop this Quantum Research Framework requires building up a strong set of analytical and experimental tools, a major focus of the EPR Lab had been on providing the computational framework within which to begin modeling dynamical processes at micro and macro scales. The EPR Lab grew within the context of SGS-THOMSON's efforts in advanced technology for which, within the U.S.A. and especially in the area of neural network-related developments, the present author had been the primary catalytic figure.

Due to organizational changes and realignments as are typical of large corporations in the 1990's, the EPR Lab project and all related efforts within SGS-THOMSON were cancelled in early 1992 while in mid-stream. Although there are some possibilities that this project could re-emerge through a combination of corporate and government funding, it does not seem likely at this time. Present activities aimed at resuming key portions of the same fundamental programme are described in the next subsection below.

The interdisciplinary and long-term scope of this projected work does indeed require a coalescence of interests and perspectives and a sharing of results among a community of scientists. If one thing is clear from the research undertaken in this doctoral project it is that there is a wealth of creative and intelligent speculative thinking on the subject of quantum processes and wholeness from many sources worldwide which needs to be refined and integrated. This is fundamentally an issue of communication - how does one get the right minds together and in such a way that there is not only the kind of dialogue one finds at workshops and conferences (hopefully) but a flowing, ad hoc exchange of ideas and concepts, including elements of mathematics that can be built into the larger formalism that is necessary but still missing.

A prototype for a structure that could work to meet those ends had already been laid in the domain of neural and cognitive science, primarily through the efforts of Drs. Paul Prueitt and Edward Finn on the Neural Network Research Facility at Georgetown University. This structure was termed the Behavioral and Computational Neuroscience Project (BCN Project). During the course of this doctoral research the present author become involved in several proposal efforts and workshops with the BCN Project group because of the importance seen in creating networks of communication and dissemination among several research teams that collectively have the potential for making some breakthroughs in the work on field-like, wholistic problems in physics and (neuro)biology. Many of the scientists associated with the BCN effort were specifically interested in the quantum-brain connection and the efforts to establish the BCN as a functioning entity were deemed an important ingredient to fostering research in the quantum-brain question by more than just this author.

An important aspect of the BCN Project consisted of a plan to create an inter-university network the purpose of which will be to bring closer together ten teams that are working on similar issues relating to holonomic phenomena in physics, neuroscience and computer science mainly. A major emphasis was upon creation of a computational environment that can be shared between the collaborating groups for modeling simulations. My contributory role within the establishment of the BCN Project had been to work closely with Drs. Edward Finn and Paul Prueitt of Georgetown University, participating in the development of several proposal efforts that are currently under consideration by different agencies, NSF and the University Research Initiative in particular. There had been several presentations to mixed audiences of scientists, engineers and technical managers for the purposes of communicating what is the fundamental holonomic model, how quantum theory may apply, and how research may be conducted, including the development of biomolecular and bioelectronic tests. This has produced a considerable amount of useful and constructive feedback which has had direct bearing on the whole picture of this doctoral program and this PDE, plus also the direction and planning of the EPR Lab and subsequent present activities that have succeeded the latter.

While the BCN Project has officially dissolved and gone the way of many academic proposals, its contribution has been lasting in that other smaller projects and collaborations have emerged. Again its role in this doctoral project has been in the short term a contribution to the design of interactive research and communication tools such as is now underway and forms a major part of the new work done in this project, and in the long run it has helped to refine and focus designs for the way research programs and projects should be conducted. In brief the work with the BCN group as on the EPR Lab has been a remarkably fruitful learning experience, positive for all the pitfalls, backtracking and unattained objectives.

Recent Activities - Netrologic and Arcova

Within the operational context of Netrologic, a small advanced research and development company with whom the author was associated in 1992, and more recently with Arcova, a similar but much more physics-oriented firm, a new and more promising approach has been made toward establishing the organizational foundations and the technical designs for doing quantum theoretic studies. The focus was not upon creating a formal structure as in the EPR Lab effort but rather on establishing a stable basis for quantum phenomena research within some practical application areas and for cooperative links to researchers in both industry and academia. The expressed need is for more appropriate computational modeling tools. The plan underway is to find the best means for building and using those tools, a process that clearly will take time measurable in years. Once again, it cannot be emphasized that the present project is a prolegomena - a prelude and ground-laying to a new direction in physics. An interdisciplinary physics is emerging, and with it the requirements for a mathematics that must perhaps speak in a different set of symbols, some of which may be highly intuitive, visual and not precisely algorithmic. Clearly the dramatic role of visualization in analysis and discovery has been demonstrated extensively in fields like computational fluid dynamics and aerospace engineering. For all this the notion of a powerful workbench that provides computational power with visualization and strong features of automated reasoning and pattern recognition is very appealing. To lay the groundwork for such a structure, a research framework that many independent researchers can work with and build upon - that emerges as the primary task at hand and the current focus of this scientist.

There are several ways to develop these tools, the most customary being to solicit government research funds. However, this is particularly problematic especially under current economic conditions. The solution being undertaken by this author is twofold and in parallel. First, efforts are being made to obtain Phase I level research and development funding from appropriate agencies such as NSF, NASA and DOD. Second, efforts are in progress to seek commercial funding for the development of a software toolset that has application to financial, medical and other markets while serving the needs of most abstract studies in other fields including physics. The core of this software is precisely what is needed for studying quantum phenomena, as shall be demonstrated in the section below ('An Evolvable Computational Environment'). In fact, there are some prospects indicating that quantum logic algorithms may explicitly have value for fields as seemingly distant and removed from physics as economics and social sciences, so portions of a system that can be built to serve commercial needs in the latter domains can be useful in the more arcane topics. Whether the development takes place under the auspices of sponsored corporate R&D or through an academic lab or center is perhaps not as important as that a flexible and transportable software environment be built, not something that is locked into one model or hypothesis.

Termed CyberSoft, the software toolset that is being designed has several characteristics, the primary ones being high levels of user interactivity, three-dimensional graphic visualization, and artificial intelligence with a focus on automated reasoning and the generation of hypotheses and associations to be evaluated by the user. Unlike most analytical software, CyberSoft aims to provide a synthetic, generative functionality that creates novel information. The following subsections provide additional information on the architecture as it has been designed to date.

Clearly there must be no mistaking that the software development efforts underway will not result in a universal tool. However the components that must be built for the CyberSoft commercial product will be relatively easy to adapt to any number of scientific applications, and this plan to bootstrap scientific research activity and tool development through commercial products does promise a practical way of solving a mundane but burdensome problem, that of funding the basic research.

Relevance To Doctoral Program

One may ask how this organizational activity, namely defining and setting up the EPR Lab and participating in the BCN activities, and subsequently planning software products within Netrologic and Arcova, fits in as a direct component of this PhD program. That is a legitimate question since it is a bit unusual. The answer is twofold. First of all, in order to qualify for a doctoral degree, it is arguable that one should demonstrate more than just academic expertise. One should in fact demonstrate an ability to organize research programs and projects, since presumably that is a major activity in which someone with a doctorate may be expected to engage. It is not very useful if one has the technical background but cannot effect the practical events required to carry out creative work in his or her field. It is this researcher's firm belief that such activities as have just been described fulfill that demonstration, notwithstanding the 'pending' status of the organizations within both the corporate and academic environments. Regardless of top-level approval and funding to support these activities, the projects have been prepared and presented in a manner that is appropriate for a someone holding a PhD in a scientific field. Arguably, completion of a research grant application should be part of every science graduate student's curriculum.

Secondly, within the context of the Union Institute doctoral program, there is explicitly a requirement for practical and interdisciplinary development, proficiency that is what should be expected of a doctoral holder. The Internship dimension of this program evolved from more than a learning of technology relating to VLSI hardware design and neural hardware and software in particular. Involvement in the design and development of a silicon-based processor for handwritten character recognition led directly into the planning of business relationships between the parent company, technical partners and customer companies. This project, despite being ultimately abandoned as a product undertaking by the company, has led to an experientially-based learning of business and marketing that would probably not have received otherwise and which is an important part of establishing any serious new long-term research programme in our current society. Purely theoretical research in physics or any other field may appear to be removed from the business domain, but this is no longer the case in the present historical period. Obtaining research funding is an increasingly rigorous requirement, and often the burden upon the scientist is to show the connection between theory and at least potential application, onerous and unappealing as that may be. Furthermore, it is argued herein that powerful and relatively expensive computational tools and the need for extensive software development form essential future and permanent elements for quantum theoretic research. This would be the case in pure physics or interdisciplinary domains such as those of this project. Such resources demand more substantial economic and interpersonal resources than ever before, and the ability of a doctoral candidate to perform in the organizational domain is significantly important along with proficiency in subject material and original research methods.

The work in laying the foundations for the EPR Lab, working on the RP100 Recognition Processor project (for handwritten character recognition) and collaborating on the BCN Project is a critical part of fulfilling that practical, interdisciplinary aspect of the Union program. Even more so are the subsequent activities undertaken and continuing in the context of associations with Netrologic and Arcova. They have provided preparation for the rest of a 'lifework', a continuation of work in both industry and academia focusing upon fundamental research and development. That is why it is now a belief that such a component of organizational/social mastery is a necessary component for any type of doctoral program. This stems in part to the belief that a degree of 'Doctor of Philosophy' should be more than a higher level of proficiency within one discipline - more than increased knowledge and skill in demonstrating original research, it should involve some demonstration of practical wisdom, something that cannot be gained other than through experience working with different people and organizations.

CYBERSOFT And Field Computation -
An Evolvable Computational Environment

Holonomic Field Processing and the Parallel Field Computer -

Having the right organizational structure in place to do long-term research and collaboration with other groups of scientists is critical. But what of the tools to conduct the work and to communicate the results in a way that will maximize intellectual dissemination without degradation and foster creative building onto the results, be they theoretical or experimental or both? There are two important and related issues here. Having sufficient computer resources is not the right question. A bigger and better supercomputer is not the answer to the problem of how to model and test hypotheses such as have dominated the presentation in this paper. The issues concern having the basis for a computational 'control set' so that results from different experiments and simulations can be more efficiently compared and correlated. Furthermore, there is a need for convenient and concise means by which results can be communicated between different researchers who want to communicate but who are hampered by what amounts to speaking different languages - in this case technical languages.

It is not always easy for physicists, biologists, neuroscientists, mathematicians and computer scientists to communicate clearly with one another, even when the natural human barriers and defenses are reduced. But without improved collective and cooperative endeavors it will be difficult for people to assimilate the huge mass and variety of knowledge that may be required to make the breakthroughs and answer whether or not there is substance to these hypotheses. Furthermore, if creative insights are to emerge from the mixture and confluence of divergent streams of thought, as has frequently been the case through the history of science (the 'specialist' is a creature of the twentieth century and the so-called 'Renaissance Man' was more the norm for a person who studied natural science rather than the exception), there must be more of a common and evolvable 'meta-language.' At the first level there is the natural spoken language (e.g., English, German) and at a second level there is the formal language of mathematics. With the complexity and interdisciplinary requirements of modern science there is a third level that is dominated by the medium of computational expression. To paraphrase the communications scholar McLuhan, the Medium becomes the Language.

For those endeavors to succeed attention must be given increasingly to how research can be conducted to produce more easily assimilatable and communicable results. This has been a major attention item with the work of those involved in promoting the Behavioral and Computational Neuroscience Project and it has become a focal point in the present work toward establishing a computational framework specifically for working with quantum phenomena and holonomic fields.

Computer modeling, simulation and analysis is an integral part of any scientific research activity, and increasingly so in domains such as theoretical physics that have been historically somewhat removed from the need to perform massive computations. Furthermore, complex graphical displays are often accepted as being the most intelligible form of expression, a virtual requirement for extracting possible mathematical formalism from an otherwise unmanageable mass of numeric results that cannot be adequately processed by the human brain other than visually.

One of the underlying principles being argued in this work is that non-formal, intuitive reasoning has an important, even essential place in science and that this is something to be yet recovered and re-established in contemporary science and philosophy of science. Visualization is an important method by which such reasoning and concept generation can operate. One of the most important contributions of the modern high-performance workstation in the scientific lab is the ability to rapidly generate, present and organize visualization of what otherwise would remain at best arrays of numbers. It is essential that these types of resources be brought to bear upon the mathematical research in quantum theory and theoretical physics as a whole.

Initially it would seem to be most beneficial were one to begin with computer-based models, simulations that could be refined and later put to the test by some yet-to-be-determined real-world experiment. But in what way should the simulation proceed and how will one know that it is anything more than yet another interesting computer model? Furthermore, how can one approach the non-deterministic and non-algorithmic nature of this problem using machines that are themselves bound entirely by formalism and determinism? Computing devices have been strictly Turing machines, bound by the rules of what they can do, not allowing for any freedom outside of the confines of the instruction set. The instruction set is not only finite but fixed. The architecture is completely fixed, and this is true of even the so-called reconfigurable ('programmable') gate array devices or those analog-logic neural processors. Transistors are transistors and there is nothing that corresponds to biology. One can twist the protein or DNA strand and get different information, but still processable within the larger structured mechanism. Twist the electronic circuit and the entire machine fails. Clearly some other kind of computing seems to be required, a type that is in principle not bound by the Church-Turing thesis, something that is not a computer in the traditional sense but which may very well have to be approximated by simulations on a Turing-type computer until such time as the engineering technology is able to build the right non-Turing machine. The ideal hardware would be capable of scaling up to millions of processors that can be extensively interconnected. The internal architecture, including interconnectivity among processors, should be modifiable by virtue of the behavior of the system over time. This begins to sound more and more like a biological system - a cell or a network of cells - an organism that exists as a singular whole, above and beyond an assemblage of parts.

Such a machine would satisfy or at least provide a testable platform for the kind of analog field computation argued for by MacLennan and others, where spatially continuous fields of information are emphasized rather than discrete information processes. A key point of MacLennan's argument, of course, is that with sufficiently dense and numerous processors (10^7 - 10^9) the overall effect is one of virtual continuity, despite the actual discreteness of the elementary processors. What matters is the preservation of a topology. He writes, [[113]]

> "It is a central tenet of field computation ... that it does not matter whether the spatial distribution of a quantity is *really* continuous or *really* discrete; to be considered a field it is sufficient that it approximate a continuum well enough to apply continuous mathematics. We believe that for the practical purposes of biological modeling and computer technology, all that matters is whether a phenomenon *looks* continuous or discrete, a methodological tenet called the *Complementarity Principle* ... We may put it: *Continuous models should be practically indistinguishable from approximately-continuous discrete models, and vice versa.*"

Molecular computing devices of the sort described by Lawrence, Conrad and others may provide the medium for implementing such a computer but this technology does not exist at the present time. While Scanning Tunnel Microscopy (STM) has reached a point that allows for nanometer engineering, there has been no success yet at producing a reliable circuit, even at the order of a transistor, much less a logic gate that maintains its structure sufficiently over time. Advances are being made in the development of suitable substrates [[114]] that will provide a conductive surface for metal deposition by the STM device and that will remain stable in its structure over long

[113] MacLennan, B. (1990)

[114] Graphite, gold or platinum on an insulator, and silicon are potential substrates. Typically the STM tip is used to deposit and manipulate individual atoms on the substrate surface. Atomic Force Miscroscopy (AFM) is a related alternative being explored since the strong electrical fields of the STM are not present.

periods of time. Large-scale system design appears to be considerably difficult at least with present technology; perhaps an autonomous 'robot' STM machine could be employed to create massive arrays of computing and storage surfaces. Thus it seems any design efforts toward building a computer that emulates connectionist field computation, be it neural, biological or atomic, must begin with the digital and analog technology that exists presently.

How does one start with the computational hardware and software that is available - formal languages on formal machines, and work consciously toward the evolution of a machine that has not been invented - but for which we have countless paradigmatic examples in biological organisms ranging from the simplest virus to the human being? How does one develop the most efficient and promising platform that will lead not to a dead end nor to a massive problem of translation but to smooth transitions into radically different technologies? There is a sense that the ultimate computer for processing holonomic phenomena may be in the form of biomolecular devices that not only mimic but synthesize the behavior of natural organic processes. The ultimate measurement device for quantum behavior and for verifying some of the consequences of a holonomic model in quantum physics may be a biomolecular instrument that does not operate like a Turing machine and does not introduce some of the macroscopic observer disturbances into the quantum measurement as most physical experiments do. If that is the case, then how does one best go about working so that what is done today using conventional computing can most easily migrate to future technologies and so that the results can be shared with others in the same or related fields? There are systems integration issues that need to be addressed, and if the final resolution is that something can be engineered today, using silicon digital microprocessors running C++ code, versus waiting n years to (hopefully) perfect a molecular computer, it seems that the interests of research are best served by the digital simulation.

These kinds of issues are too often set aside for the more interesting theoretical questions. They are 'implementation issues' often considered to be something apart from the true science. The point here is that such a division is artificial and misleading. How one implements the experiment and how one expresses the results influences the human thinking and interpretation of those results in irrevocable ways both for the primary investigator(s) and those to whom the results are communicated. There must be attention to optimality within the implementation of any research programme, especially one where there is no agreed 'standard model' for conducting simulation or experiments. No one has set the rules and to adhere to tradition for tradition's sake is hardly adequate science, although human nature, particularly with age, often gets locked into a traditionalist mentality.

Such have been the dominant thoughts leading up to this work. The developing theoretic structure has helped to create an answer to the above questions and in a way that seems to bring out the inherent synergy of working on these problems from an interdisciplinary perspective such as has been done in my work. The hypothesis is that perhaps the best measuring devices for holonomic field effects and quantum events on micro- or macroscopic scales are biological (organic) in nature, and neurobiological specifically, and has led to the following systematic design of an experimentation environment for modeling and analyzing quantum holonomic field phenomena.

HPFE/PFC Architecture - Hardware and Software

The design is called the Holonomic Field Processing Environment (abbrev. HFPE) and consists of computational tools designed to integrate biological, electronic, mechanical and molecular experimental devices and architectures. It is not yet built and will take several person-years of coordinated efforts. Within this doctoral project the aim was set to establish a basic set of architectural requirements and a preliminary design. The central hardware component is called the Parallel Field Computer (PFC), a supercomputer-type resource providing for highly reconfigurable and expandable multiprocessing with extensive analog and digital input capabilities and powerful graphics output features. The central software element is the CyberSoft analysis and synthesis toolset that has been referenced earlier and which is described further below. The CyberSoft component is what in this plan sets the PFC and the HFPE apart from other massively parallel computer environments, in that it is tailored toward artificial-intelligence-based assistance in the generation of hypotheses and algorithms that can fit experimental data for which commonplace linear and non-linear methods do not apply well.

Integral to the PFC is an object-oriented design that applies to both the hardware and software configurations that will be internal to it. The object-oriented paradigm of programming, typified by such languages as C++ and Common LISP (CLOS - Common LISP Object System), is ideal for rapid prototyping and top-down design of simulations. The PFC is intended to bridge the gap between fast multiprocessors that are essentially number-crunchers and a true bioelectronic workstation with multiple sensors (inputs) and effectors (outputs). Naturally its starting point is with conventional silicon processors, in this case 32-bit transputers that have been designed specifically for large-scale parallel processing. Software for the PFC consists of standard development toolsets that are being customized and extended for the type of parallel real-time processing required in studying field phenomena and to accommodate the object-oriented logic needed for the PFC to be an effective and truly evolvable machine, and the CyberSoft system. Both the PFC and CyberSoft are described in more detail below. Other major components of the HFPE include modeling and graphics systems operating on Silicon Graphics IRIS Workstation (or Sun SPARCstation) and PC computers, all of which can be networked and directly interfaced into the PFC machine.

This architecture is based extensively on work that had been initiated or contemplated at both the Center for Brain Research and Informational Sciences and the Ecological Physics and Natural Computing Laboratory at Radford University and at several other research centers that have been discussed earlier in this dissertation. [[115]] Figure 5.1 below summarizes some of the principal models that have been already developed using conventional systems and which have algorithmic components that are precursors of what will be run on the PFC. Where the latter goes beyond any system or experimental framework yet designed is in the following features:

- The integration of different components, particularly those that can be biomolecular or cellular in nature and function and the emphasis on multiple streams of real-time processing that provide the investigator with more than one view (literally, through multiple graphics displays) into the behavior of holonomic systems. The PFC architecture

[115] These include: (Hameroff, Conrad, Koruga, G. Gross, etc.). Cf. Bibliography.

allows for the deployment and selection of multiple graphics windows on one or more monitors.

- The object-oriented programming framework that will facilitate development and reusability of modular code for applications that will run on the PFC. An object-oriented approach is a natural choice for optimizing distribution of processing tasks among the resources of the PFC and will assist in building hardware-independent modules that can be transferred to future-generation processing elements of the PFC.

- The development of 'parallel-viewpoint applications'. By the latter is meant the following. Parallelism in the PFC does not consist of only the employment of multiple processors to get the job done quicker. That is the usual value of a parallel machine no matter what its underlying technology. The PFC will, for example, allow a user to simultaneously view a simulated neurodynamic field from several analytical perspectives where each may consist of a variation of some fundamental wave equation that affects the time evolution of the overall holoflux.

Figure 5.2 below illustrates the basic PFC architecture as a series of evolving technological progressions that make use of object-oriented parallelism. The architecture is intended to be fully open-systems compatible, meaning that different host machines can be connected and that the parallel processing array can take advantage of the wealth of new 32-bit and 64-bit processors (i860, 320C40, T9000, Alpha). Figure 5.3 below illustrates the high-level modular division of the PFC architecture as a more mature system that can be directed to serve several distinct tasks 'in parallel' and add to not only a performance gain in raw computing but a convenience gain for researchers who would otherwise be forced to carry out more tasks sequentially and with much replication of code and hardware.

The purpose of the Parallel Field Computer (PFC) is summarized by the following three aims:

Firstly, to generate simulations of field processes as are evidenced to exist in both inorganic and organic structures (such as the brain) and to measure the dynamic activity that is hypothesized to take place therein, taking as a starting point the mathematical models developed by MacLennan et al. [[116]] One should be able to describe the parameters of an energy field and to experiment with different models (algorithms) for simulating the field processes. These experiments will produce outputs that the user should be able to compare and evaluate. Visual displays offer one medium for such comparative study. From such analysis the user should have at his or her disposal means to modify a model such that it comes more into line with a desired effect.

Secondly, to provide real-time or near-real-time analysis for experiments involving phenomena believed to exhibit quantum effects (including neurodynamic activity as can be measured by EEG, evoked potential and other forms of neural measurement), and to compare the actual measured field activity in response to different stimuli with the hypothesized fields predicted by the mathematical models. This is the necessary

[116] Cf. footnote 4 (MacLennan, 1991), especially Appendices A and B

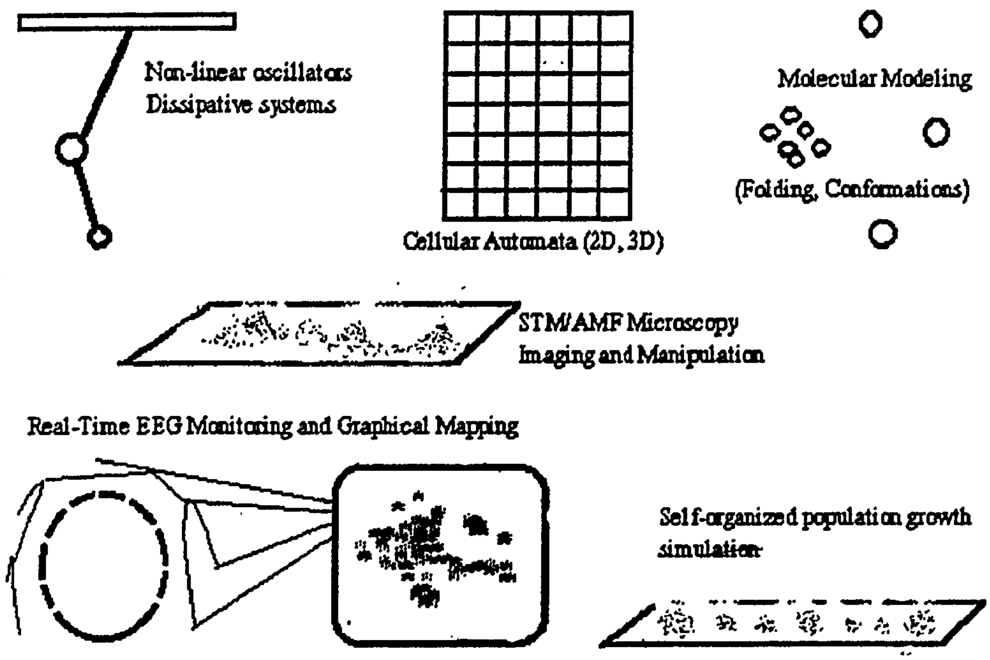

Fig. 5.1 Principal computing models (types) for a Parallel Field Computer

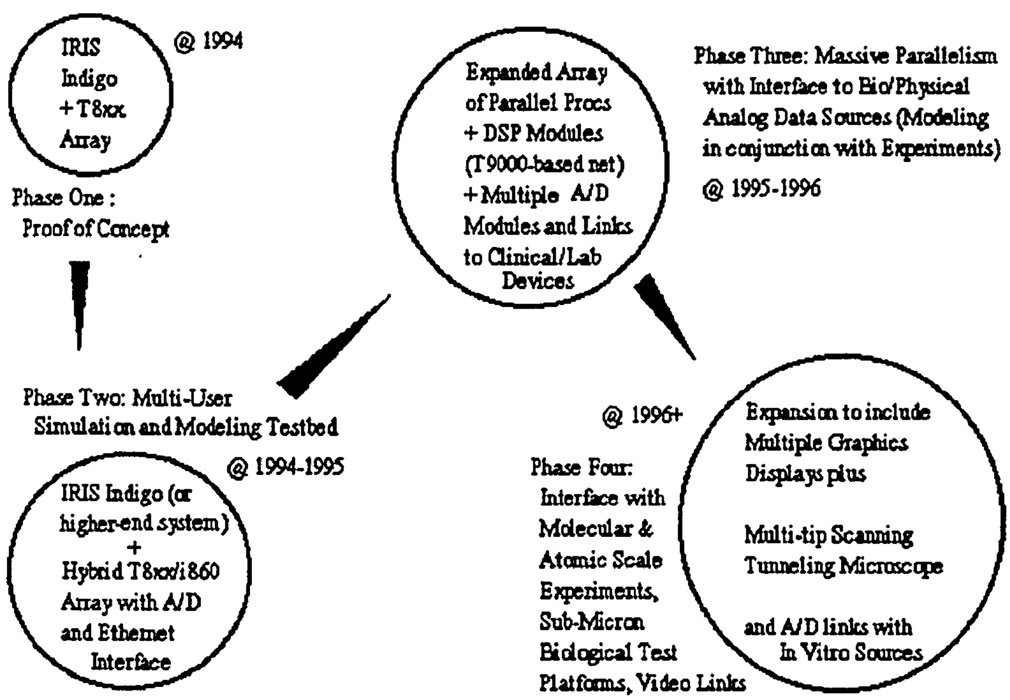

Fig. 5.2 Basic Evolution of Parallel Field Computer Architecture

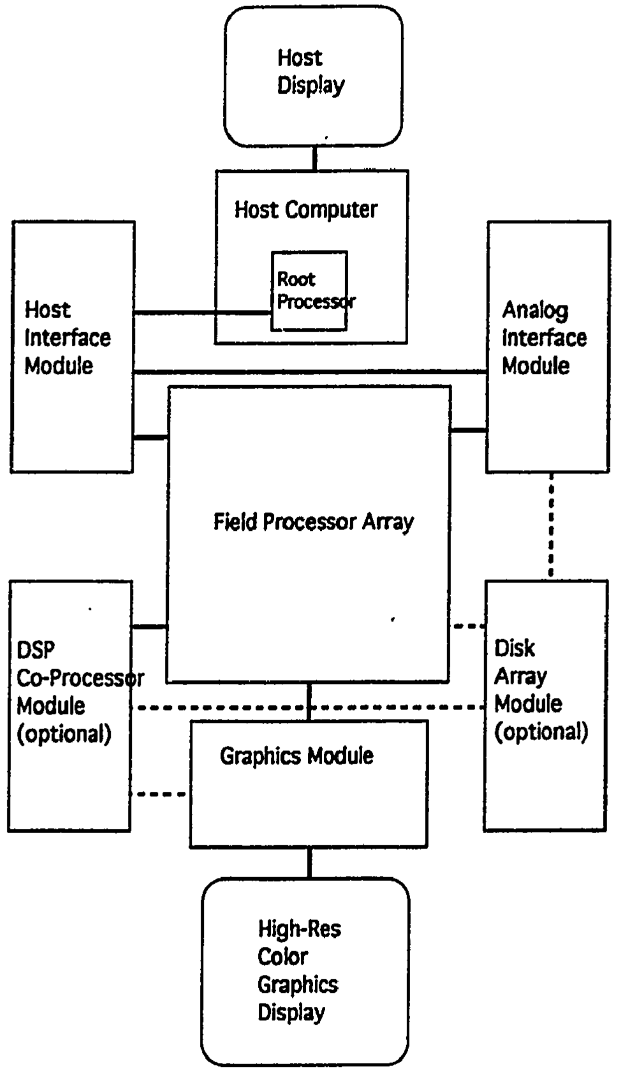

Fig. 5.3 Mature Parallel Field Computer Modular Design

counterpart to the more abstract mathematical model-building and testing. By examining the simulation and the experiment with a set of tools that allow for quick comparisons, visual and otherwise, with an ability to rapidly change 'view' of the problem (provided by the computation tools associated with the PFC), the user can hope to develop a 'point-counterpoint' programme for developing a theoretical model that is closely aligned with the experimental evidence. Figure 5.4 below illustrates how this can be implemented.

Thirdly, and in the long term, to provide simulation, testing and analysis of real-time field activity generated in a substance such as a molecular surface (e.g., a Langmuir-Blodgett (LB) film of oligomeric heptocyanoacrilate deposited upon a carbon-based substrate). This would provide the so-called 'acid test' for any theoretical model. Can it be synthesized and replicated? If the model is generalizable beyond the contexts of the experiments, then it should be possible to build a true field computing machine. Such a device would clearly need to be interfaced with the digital-analog world of computers and the PFC is proposed to be the type of architecture that can accommodate such interfaces.

Figure 5.5 below illustrates in more detail the operation of the PFC for this third global function class.

Choice of a Digital Parallel Processor

The INMOS transputer architecture that has been selected for the main digital processing elements of the PFC affords easy reconfiguration and modification of both the hardware and software that will be used throughout this work. Unlike other parallel machines, the transputer provides a high degree of versatility for incorporating different inputs and outputs into the system (VME bus, SCSI, GPIB, Fiber Optic, A/D, D/A, etc.) and increasing the size of the processor array responsible for the major computational load can be handled simply and efficiently. One very obvious benefit to this is that the implementation task for many projected experiments and simulations can be made easier and simpler. Moreover, the basic transputer processing model, based upon the Communicating Sequential Processing (CSP) theory developed by C. A. R. Hoare and others at Oxford in the 1970's, [117] lends itself admirably to tasks where many divergent computations, each requiring variable and indeterminate amounts of time and resources, can

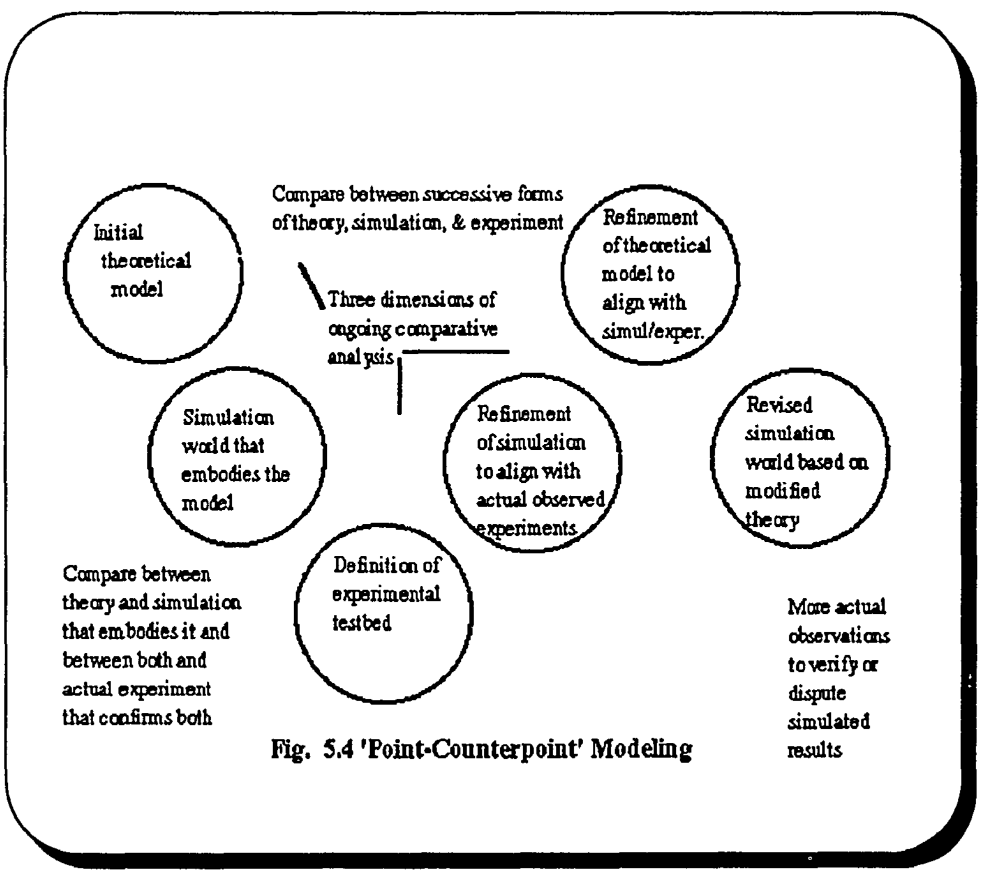

Fig. 5.4 'Point-Counterpoint' Modeling

communicate with one another over prescribed data channels. The result is a clean, efficient architecture that is not difficult to modify or to understand.

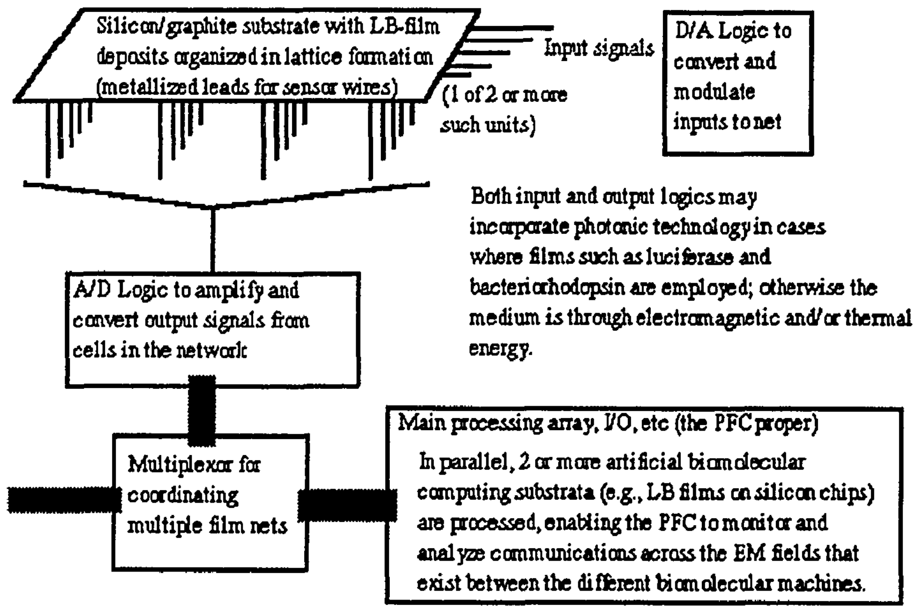

Fig. 5.5 PFC integrated with molecular/biological testbeds

If it appears that the argument is made for a 'mix-and-match' type of computer that can be modified in hardware almost as readily as one can alter a typical 'C' program in software, then the observation is totally correct. That is the exact intention. Only with such a versatile architecture can one expect to make the rapid changes necessary in order to keep pace with changes in theoretical models and experiments. And only with an easy-to-use object-oriented linguistic interface can one expect to build bridges between theoreticians and experimentalists speaking what amount to virtually different languages.

The general principles of the transputer and the CSP model of parallel processing are described in the general literature, in the INMOS Technical Manuals (cf. Bibliography, Section III), and in Hoare (1986). Technical data on i860s and 320C40s are published by Intel and Texas Instruments respectively.

The most significant reason for selecting the transputer, however, is that the CSP model is so close to the heart of the basic quantum process theory that is being formulated in this research project. In particular it is close to the quantum dynamics and networks advanced by D. Finkelstein. [118] Since so much focus seems directed to the CSP model, it seems especially sensible to concentrate on a computer system that actually implements that model.

117 Hoare, C. A. R. (1976)

118 Private communications re: similarities between Q Language, CSP and Kron's Tensor Networks.

The Silicon Graphics family of workstations has been selected as the host and main processing unit because of a number of excellent features, not the least of which is its outstanding high-resolution, high-speed graphics output. However, comparable Sun SPARC-based workstations offer, with graphic co-processor hardware, very much the same power as the Silicon Graphics devices. The UNIX operating environment and other standard Sun and Silicon Graphics software components are also considered to be highly favorable, if not essential, features for this type of computing.

PFC System Architecture

The PFC consists of a host computer, a large processing array and five functional modules. Figure 5.3 above shows these main components of the PFC machine:

- host machine
- host interface module
- field processing array (FPA)
- analog interface module
- mass storage module
- graphics output module
- signal processing module

The role of the host computer is twofold. First and principally during any operation that involves the FPA, the host provides a human user interface. That interface is intentionally minimal in order that the PFC can in theory at least use a variety of computers as a host - IRIS, SUN, IBM PC, or NeXT. The field processing array (FPA), illustrated in Figure 5.6 below, is designed as an *m* by *n* array of T9000 transputers, with an initial prototype version existing as T800 transputers. The size of this array may be decreased or increased arbitrarily without degradation of system functions but only affecting computing performance, since each of the processors in this array serves as an arbitrary worker that may be assigned a variable set of tasks. The processors in the FPA, having four links each, are connected to form a grid, leaving those processors on the perimeter of the grid with links that are available for connection to transputers within the other system components.

With the virtual channel architecture built into the T9000 and its associated link switch co-processor chip, the C104, the T9000 array has an extremely powerful capacity for interconnection over and beyond the four physical links that are provided on each transputer. The upper limit currently set by T9000 link addressing limits is 64,000 virtual channels per processor, meaning that a process on a given T9000 could have channels to over 64,000 other processes on any number of separate processors. Obviously this interconnection capability extends the dimensionality of any model far beyond a three or four dimensional hypercube.

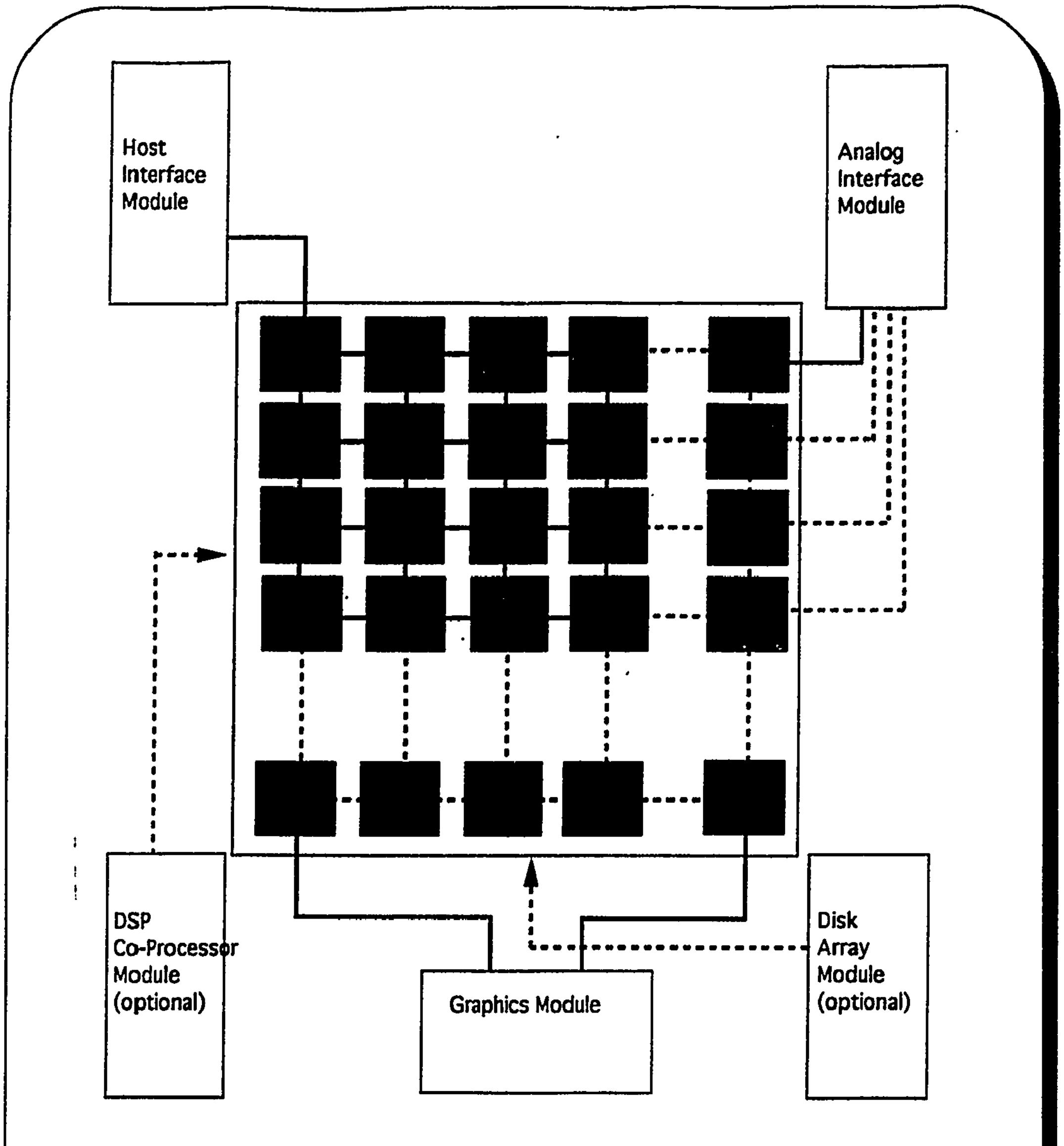

Fig. 5.6 PFC Field Processor Array Module

CYBERSOFT And Its Components

The hardware component of the PFC is actually fairly straightforward and is hardly the most innovative component in the Quantum Dynamics Research Framework. The manner in which the processor array is designed has innovations because of the mix of processor types and this mixture is not generally found in parallel systems. However it is mostly an engineering innovation rather than something of theoretical import in physics or computer science.

It is in the software toolset that this program of study claims to have made an innovative contribution to physics and computer science. This toolset is based on a computational architecture that is named *cybotics*; the software that is its implementation has been named CYBERSOFT. The terms derive from 'cybernetics,' itself a term coined by the mathematician Norbert Wiener in the early twentieth century to denote the science of control systems and intelligent behavior. Cybernetics predates 'artificial intelligence,' 'cognitive science,' and a host of more recent labels that have been introduced to give some definition to the studies of how humans think and how certain functions can be implemented in machines. It is a term used widely in the former Soviet Union and Eastern Europe during the 1950's through 1980's, while in the U. S. in particular subject names changed more rapidly, perhaps dictated more by business and marketing opportunities than by science. In a way this is making a return to first principles, but with the benefit of the outstanding accomplishments that have been made over the past decades in artificial intelligence, neural networks, object-oriented programming and parallel processing especially.

The driving force behind this software effort and the thinking-out of the cybotics/CYBERSOFT concepts does not come exclusively from any one application area. It has been influenced by demands and deficiencies in expert systems and the use of neural networks for many diverse applications of pattern classification and database exploration or 'mining.' On the physics side there has been the perceived need to move fluidly and flexibly between different models, some of which may be running concurrently, and to compare results in ways that do not disturb the processes that are running. There is a need for a kind of interactive workbench that lets the user navigate between simulation models and multiple variations on a given algorithm - for instance, variations on a set of chaotic attractor equations. Even more there is a need to have some 'on-board' intelligence that can bring certain parts or views into a running model to the attention of the user, aspects of a simulation 'world' that might otherwise be missed. The suggested chaotic attractor network that was presented in Section 4 and which is being implemented at this time is such a case where the model world needs to have capabilities of 'guided discovery' built into the system rather than reliant completely upon the observational and analytic skills of the user.

The key element in cybotics is the central role of multiple, cooperative, synthetically agents with intelligence-like attributes. These entities, known as *cybots*, populate a dynamic world of information objects and have adaptive learning capabilities. They can be thought of as robots that move about and navigate in a multidimensional space where the objects and fields are informational entities rather than physical objects. This space comprises the user's computerized data world - the files and records and streams of data that are accessible to the user through the computer. The term I-SPACE ('information-space') is used to describe this intangible and ever-changing space. The cybots work with each other and with the human user as if they were a team of assistants to that user, capable of being trained and of automated adaptation or learning, based upon the informational context created and influenced by the user in the I-SPACE.

The I-SPACE

Without an interactive context and some form of linguistic dialogue, be it through natural language or rigid formal languages (e.g., programming languages such as FORTRAN, PASCAL, C), all data is meaningless, whether it is something in the physical world or in a computer. Data can be anything, but it is not information except for some purpose or application. Data needs a context to become information. As humans there is no such thing as being context-free. Nor do one's orientations and attitudes, one's generic prejudices toward the world, remain constant. Rather, they are changing from moment to moment, and so do the structures and forms created about our world. People are always changing data into information for one purpose and then another, and often what was information today is useless data tomorrow.

In the computer space there will be many different kinds of objects - letters, papers, notes, graphs, pictures, charts, sketches, project timetables, budgets, etc. There may be one dominant physical organization of this data which is the one that we usually think about - directories and sub-directories of files, folders, and so forth. However, that is only one of many possible logical structurings to the data in the computer and the data streams that may be coming into the computer from a multitude of sources, including automated online sources like email, fax, subscription telecommunication services, etc. That physical organization may always be invisible and irrelevant to the user. At any given time there is some type of significant structure to all this data that matters to the user, and in this structure many data objects simply do not count and others are highly important. The user, much less the builder of an application cannot comprehensively or universally cover all possible contexts that may arise by means of a single system structure. The user must have flexibility to 'grow' a system according to his or her needs and proclivities. For the physicist modeling quantum phenomena in varying scales, perhaps using something like the Quantum Cellular Automata Machine as a simulator, this object structuring could consist of a classification according to the size and shape of clan membership or the type of relationships held with other clans. Networks of processes modeled by chaotic attractors (cf. Section 4) could be structured into objects that correspond (denote, *mean*) different types of attractor geometry. It is possible that over time the ways that the computer data space is organized could be modified by the self-organizing, emergent phenomena that occur in that space to reflect categories that 'make sense' to the observer.

We term the structure of a computer's data sets over some period of space and time to be an I-SPACE or Information Space. There are many parallel I-SPACES for a given human- computer pairing. The ideal I-SPACE is one that is configured by a user according to his preferences and which adapts over time to the user's activities. But how can this process of configuration and reconfiguration take place in ways that are not cumbersome and tedious for the user? The solution in our system is to employ a variety of virtual assistants, robot-like software entities that carry out pre-assigned but trainable tasks on behalf of the user. These assistants are the CYBOTS.

What is a CYBOT?

A cybot is a software robot. It is a an object that can best be described as an agent that performs different processes and tasks under the control of the user or another cybot. It is not something that we claim has intelligence, only properties and processes that are functionally like what one would expect from a dedicated intelligent worker. Ultimately all of the control decisions belong to the human user and, we claim, intelligence is something that belongs to biological entities but cannot be manifested by formal machines. (This is not to say that there cannot be silicon-based living organisms that even incorporate formal machines into their organic structures, but that computers as we know them, built of non-self-modifiable electronic components, are not organic living systems.)

Cybots are, for purposes of this discussion, akin to 'demons' in UNIX environments or in LISP-based AI systems. They hold something in common with Gelertner's 'software agents'[[119]] and Stallman's 'anthrobots.' [[120]] A cybot is assigned a task or set of tasks, which amount to different programs and functions to be performed in the interests of the user's applications. These may include keeping a watch for particular price changes or fluctuations in a given commodities market, patterns of buying and selling that may emerge from the user's own behavior, different kinds of news topics that may be coming in over the Reuters service, and so forth. There may be high or low levels of interaction between a given cybot and the user or other cybots in the I-Space in which they 'live' and operate.

A key feature of a cybot is the employment of adaptive learning algorithms that can be assigned or tuned for observing patterns of behavior on the part of the user or any other facet of the system and bringing these patterns to the attention of the user. For instance, a cybot may be programmed to record the objects within an I-Space that a user most frequently uses and the order in which certain steps or operations are performed, for the purposes of presenting the user with alternative organizations, views or reports.

Communications between the user and a given cybot may take place on multiple levels. There is always the base level of formal commands such as may be given through command lines, menus, dialog boxes and actual programmed code. However it is the intention to capitalize on its developments in the field of natural language processing and to provide a *well-structured natural language interface* - a simplified grammar and vocabulary that is oriented to a specific type of application area and which does not allow for the kinds of ambiguities that result from true natural language exchanges.

While the language used to describe a cybot is highly anthropomorphic, this should be understood not as an attempt or claim that software constructs will have their own cognitive abilities and personalities. To the user a cybot will quite possibly seem human-like as much as any computer system with a robust natural language interface might seem to most persons. However a cybot is an element of software, a subsystem with a certain degree of autonomy relative to other parts of the program, and its personality is a function of the attributes and properties that the programmer gives it, notwithstanding the novel behaviors that may emerge unexpected and unanticipated by the programmer.

A Walk Thru I-SPACE

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[119] Gelertner (1991)

[120] Marty Stallman, an entrepeneur scientist-businessman and the founder of Anthrobotics, Inc. (Phoenix, AZ), has developed an architecture of software agents based on emotional characteristics and relationships. [private communication]

For a given user and a given class of application interests there may be multiple I-Spaces with which the user will want to interact over time. One may think of these I-Spaces as perspective views or even as tailored worlds, into which data flows and becomes information, from which the user obtains and inserts new information, and from which data is discarded as it becomes irrelevant. It is maintained as a fundamental premiss that the user must have a strong degree of dynamic control over building and managing the I-Space and that one effective way to realize this end is through powerful graphics and the concept of a network of objects that the user can navigate through freely. This network is termed a cybernet and it is the domain in which the user can both browse through his or her information structures and also view the kinds of activity that is occurring over time. The underlying notion of a cybernet is found in much of the work on hypermedia systems, object-oriented knowledge-based tools, cyberspace and virtual reality. Gelertner's concept of a trellis-world [121] is very close to the concept of a cybernet, with some differences being in the ways we plan to allow for the user and the cybot agents to restructure and reform both the graphic appearance and the semantic contents of the cybernets in which they work.

Why are these things important for research in quantum physics and dynamics? What will be the special value for putting so much emphasis on computer modeling systems and graphical user interfaces, operating systems, databases, and so forth? Plain and simple the main value is in the enhancement and focusing of observations, assimilation and correlation of data, and the enhancement of the discovery process that characterizes the basic scientific process. there is simply too much data and too many possible connections to rely exclusively on the human observer to drive the analysis and the synthesis. The purpose of CYBERSPACE and all its features is not limited to applications in scientific research but it squarely will serve the latter by automating and refining many actions that are typically 'human.' Data processing limits can be extended relatively easily through adding faster and more numerous microprocessors; information processing and assimilating limits require a new approach to how the observer, the experimenter interacts with the data or a real experiment or a simulation.

A Design for a Quantum Computing Testbed and Experiment

Based on the above field computing and parallel processing concepts and technology, a machine has been designed for experimenting (through observation and fabrication) at the nanometer scale and testing some of the thus-far purely theoretical notions about quantum processes and networks. The machine and proposed experiments will not be working at subatomic scales but at the level of macromolecular structures with the capability of manipulation and imaging at the atomic level in the best case and at least at the molecular level.

The key is in employing scanning probe microscopy and scanning tunneling (STM) in particular, combined with the power and versatility of the PFC architecture. The scanning tunneling (or more generally, scanning probe) technology is relatively new [122] but over the past several years it

121 Cf. note 3 above

122 The STM was first developed in 1981 by G. Binnig and H. Rohrer of the IBM Zurich Research Laboratory for studying the local conductivity of surfaces.

has advanced rapidly to where many of the speculative operations projected by scientists like Feynmann and Wheeler regarding molecular and atomic manipulation are now implemented or at least within the scope of present engineering. Many machines have been built employing alternatively contact and non-contact atomic force microscopy and scanning tunneling principles, and what is new in this design is not the probing technology but the ability to perform multi-tip operations and analyze the data in real-time, plus the approach of using comparative analysis of actual atomic-level images to discriminate changes in quantum electronic and nuclear states.

The basic principle of STM operation is quite simple and consists of a fine probe tip that is brought to within a few $\overset{o}{A}$ of a surface. The sample and probe are protected form vibrations by placement on a stage suspended within another stage that is in turn suspended from springs within a steel frame. Magnets and copper plates can be used to induce eddy currents to counteract motion of the stages. Placement and movement of the probe is controlled by a tripod made from piezoelectric materials and a piezoelectric plate with a metal tripod base. Application of voltage to a leg of this tripod causes the other legs to move slightly and in this manner ultrafine adjustments can be controlled.

A small voltage is maintained between the probe tip which comes to an ultimate tip of one or two atoms and the specimen surface. This voltage allows for electron tunneling between the sample and the tip; for a fixed bias voltage the current is proportional to

$$I \propto \exp(-A\sqrt{\Phi Z})$$

where Φ = average work function of sample and tip and

$$\mathrm{A} = 2\sqrt{2m/\bar{h}} = 1.025 eV^{-1/2}\overset{o}{A}^{-1}$$

Because of the extreme sensitivity of such tunneling to distance, the resulting current produces a good measure of the distance between the probe tip and the sample surface. This data is used to regulate and maintain the constant distance of the tip from the sample, and is digitized and fed into an image processing unit. The result is a computerized image of the actual surface.

The obtainable resolution can be of the order of individual atoms, as have been demonstrated in imagery of gold, platinum, cooper, sulfur, and other materials. There are four primary difficulties: vibrations from natural or artificial sources, approaching the surface with the probe tip, scanning across the surface, and sharpening the tip. Multi-stage suspension of the sample and the scanning probe assembly, described previously, combined with motion-dampening magnets alleviates the effects of vibration. Piezoelectrics are used to control steady placement and movement of the probe, which is attached to a flexible cantilever apparatus. The probe is sharpened by applying a strong electric field that dislodges surface atoms from the probe.

With the probe maneuvered to a distance from the sample that is equivalent to the inter-atomic spacing between atoms in the sample, tunneling electrons can make the jump to either adjacent atoms in the sample structure or to the tip of the probe. The density of electrons at the surface is measured by the number that tunnel to the probe tip, creating a current; transformation into analog and then digital signals produces the image. One of the advantages of the STM over even atomic force microscopy (AFM, based upon the van der Waals force exerted between surface and probe) is its simplicity. Capable of operation from 4 K to 973 K, it can operate in a wide variety of environments - vacuum, air, water, ionic organic solutions. The main use of vacuum technology is to keep the sample stable and clean.

On the other hand, AFM systems have been in widespread use because of the broad range of samples that can be handled. AFMs may operate in contact mode, where the probe is brought into actual contact with the surface and moved laterally, maintaining contact, or non-contact mode (similar to the STM concept), or thirdly in tapping mode, whereby the tip is repeatedly raised and lowered during lateral movement, thereby eliminating the lateral forces while not sacrificing the values of actual contact.

In the proposed design, shown in Figure 5.7 below, either a commercially available scanning probe microscope [[123]] or one to be assembled from components, as a team from Florida Institute of Technology has done, will provide the core instrumentation. This part of the machine is no different from any standard STM that is in use today. Digitization hardware and software provides for the production of high-resolution 3-D imagery. The unique features of this design lie in four areas:

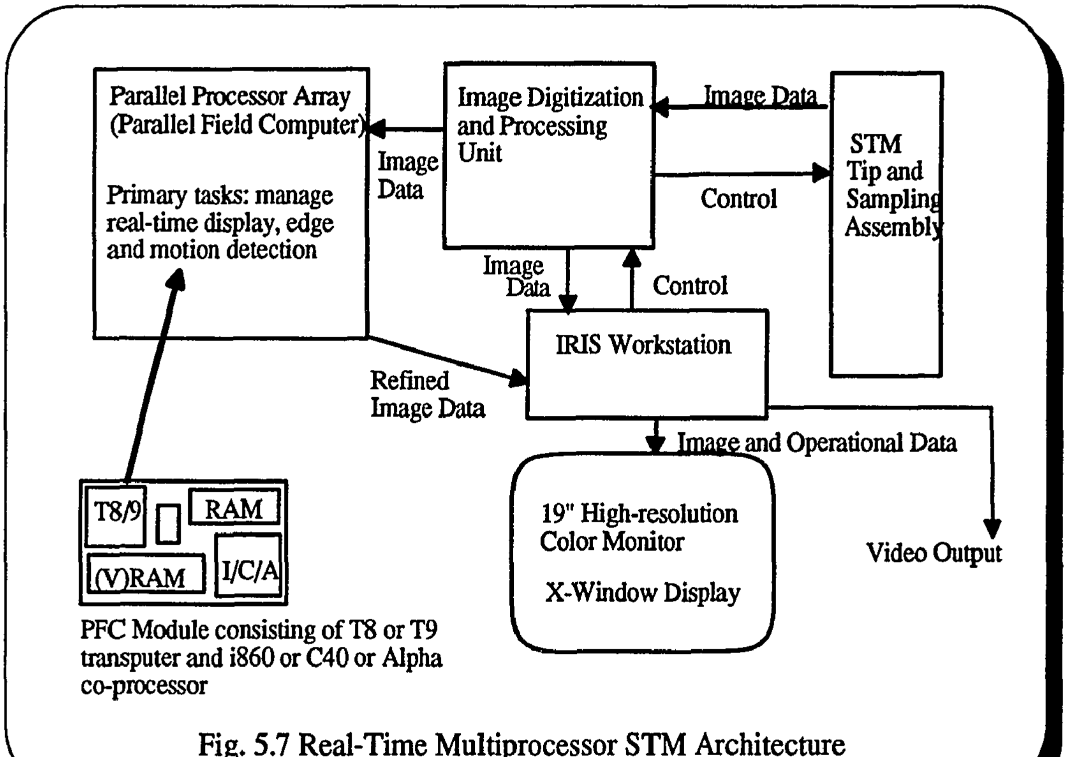

Fig. 5.7 Real-Time Multiprocessor STM Architecture

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[123] Two sources are Digital Instruments, Inc. (Santa Barbara, CA) and Park Scientific Instruments (Sunnyvale, CA).

- use of multiple and interchangeable tip assemblies for both measurement and manipulation, including simultaneous multiple manipulations
- fabrication of custom multi-point tips using the basic single or double-tip STM device as a 'cutting tool' to make a variety of nano-'garden-variety' tools
- use of parallel DSP and conventional processing for real-time image refinement and analysis including edge and motion detection
- provision for real-time video display of nanoscale processes and fabrications

Most STM and SPM machines currently employ a personal computer (generally 486-based) for control and communication, with the graphic display being driven by a separate image processor board. This new design will be built around the Silicon Graphics IRIS workstation with its powerful graphics processors and UNIX environment. A Personal IRIS Indigo machine with 64 Mb RAM and a 400 Mb+ hard disk will be adequate. The forementioned PFC machine will be linked via one SCSI interface with the IRIS and via a second SCSI interface with the image processing unit. The architecture is really a quite simple extension of the basic STM machine. Each frame of image data is routed to both the graphics display unit and the parallel processor array of the PFC. From the workstation panel the user can control the type of analysis being performed in the PFC on the image and can work with the results through various windows on his display.

What are some of the advantages? First there is the power of real-time imaging for the purpose of detecting changes in the structure of the observed sample, such as minute topological shifts in microtubules as an ionic plasma moves through the tubule, or the jostling and bumping of molecules back and forth in a catalytic reaction prior to a binding fit. The manipulations of protein folding are another example of motions on the molecular and atomic level that have not been observed even though the capability appears to be feasible given the basic SPM mechanism. There is theoretical support for propagation of solitons through the H_2O that fills the tubules, and this is being investigated by Yasue, Hameroff, Dayhoff and others. [124] Conrad has theorized on the effects of electron motions upon nuclear coordinates and consequent conformational interactions. The electronic system can perform a computational-like task of searching for a lower energy minimum, then dragging the nuclear system to a corresponding conformational minimum, and is itself then moved into a minimum that is more consistent with the nuclear conformational energy state.

Integral to this design is the use of multiple tips for both recording surface features and for manipulations. The use of multiple tips for recording will serve three main purposes:

- the ability to simultaneously measure a surface from two points in the 0.5 to 1.0 micron scale and to detect and associate changes in a material's properties, particularly its geometry, texture, and conformation.
- the ability to view the same region from more than one perspective, thereby allowing a refined three-dimensional image; one could think of this as stereoscopic microscopy at the nanoscale - the value is the same as offered by stereoscopy in optical devices.
- the ability to manipulate with one tip and observe effects in molecular conformation at other points of a macromolecular structure by means of the second tip.

124 Cf. Yasue (1993)

The use of multiple tips for manipulation will offer the opportunity to engage in more skillful and powerful manipulations than are possible with only one tip. The principle is really elementary; it is like moving rice and peas with two chopsticks instead of one, or like having a knife and fork to cut one's meat instead of only a fork. Figure 5.8 below provides some illustrations of the type of tip assemblies that are envisaged with this architecture.

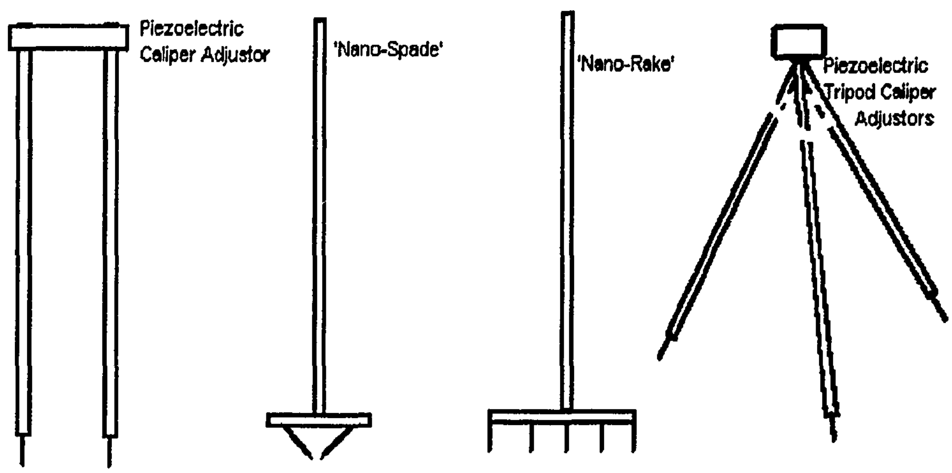

Fig. 5.8 Novel STM Tips and Tip Assemblies

How can these tips be engineered and how can they be accommodated within the STM assembly? The latter question is answered rather simply that it is a matter of fabricating the piezoelectric mechanisms and the stages in which they sit in such a way as to handle multiple and removable tips. The tip assemblies should be interchangeable much as drill bits. Appropriate control circuitry will need to be designed to manage both the control and data traffic and a simple embedded control processor solution will suffice. Many microcontrollers would be adequate but the T425 transputer is chosen due to the on-chip memory and simple external memory interface, the four serial links, and basic familiarity of design. Figure 5.9 below illustrates the high-level logic for the tip control module for an individual tip assembly. One T425 is the master controller and is connected via the SCSI interface module with the IRIS host workstation. Its three remaining links are available for connecting to additional T425-based Tip Control Modules.

The sharpening of simple single-tip units is accomplished by means of a strong electric field that dislodges surface atoms until only one remains. However, it may be feasible for manipulations to have a tip that acts more like a rake or shovel. No clean tunneling would occur and this would not do for creating surface images but it could suffice for moving large numbers of atoms and small molecules around at one time. These kinds of odd-shaped tips could be fabricated by themselves being the sample subject of an STM operation with a single tip. Figure 5.10 below shows how this might be done to dislodge atoms from the edge of a 'nano-rake'.

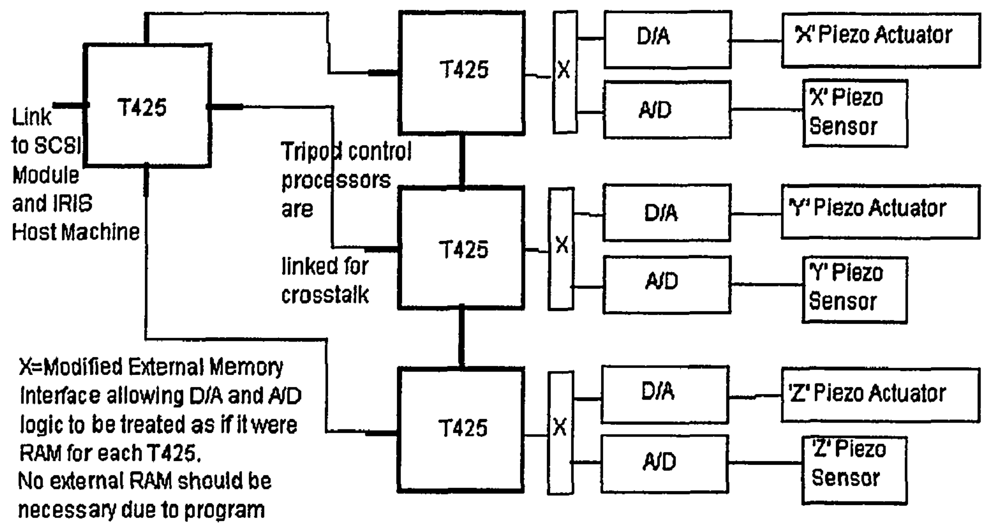

Fig. 5.9 Scanning Probe Tip Control Module

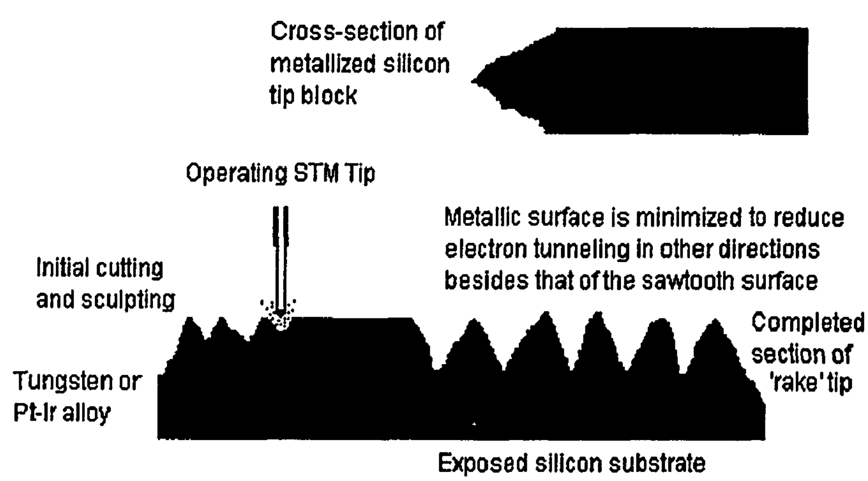

Fig. 5.10 Applying STM For Customized Tip Fabrication

<u>The Experiment</u>

The type of quantum computing experiment proposed is closely based upon work of Conrad, Hameroff, and Yasue. It consists of an investigation of how quantum interactions and dependencies existing between electronics and nuclei in macromolecules can speed up processes of minimum energy nuclear configuration. The quantum electronics is suspected as a basis for jostling and jiggling between components of a macromolecule that is self-assembling or two macromolecules coming into a catalytic reaction, so as to provide many more possibilities by which molecules approaching one another could fit. Enzymatic reactions can be pictured as pattern recognition operations but the classical lock-key picture does not suffice to explain the speed at which enzyme action occurs (typically 0.1 ms - 1 ms). If the lock and key both undergo communicative conformational changes during the fitting process, then the observed speeds can be understood. Recall Conrad's basic argument:

> "The minimum-energy state is determined primarily by the complementary shape properties of interacting molecules; hence, by the nuclear conformations. Our assumption is that the docking of the molecules is influenced by the electronic wave function and, therefore, is sped up by the superposition of electronic states. The non-Born-Oppenheimer character of the complex is thus essential to the model." [125]

Further in the same paper he states the objective in terms of a physical description:

"The physical picture that will emerge ... is that the nuclei of the self-assembling molecules exhibit a bobbing motion in response to the changing phase relations among the different components of the electronic wave function, over and above the motions connected with thermal agitation. Interference effects among different components of the wave function then serve to trigger the transition from one nuclear conformation to another." [126]

The problem is not dissimilar to that of trying to fit moving shapes into odd-shaped slots, similar to the popular game Tetrys, except that the slot destinations are themselves moving and altering shape over time, principally due to the short-range van der Waal interactions. The comprehensive wave function of the electronic-nuclear complex can be expressed as a solution of the Schrodinger equation

$$i\hbar\frac{\partial\Psi\left(x_e, x_n, t\right)}{\partial t}$$

where x_e and x_n represent the electronic and nuclear coordinates respectively. Before any molecules interact, this wave function splits into a product of individual molecular wave functions that are subsequently, post-contact, modified by an interaction term which can be understood as a measure of perturbation. If one is able to remove the information associated with dissipative processes, then one could construct a time-dependent wave function, the changes in which could be associated with changes in potentials and in turn with self-assembly.

There is a gulf of experimental evidence and methodology for dealing with this implication. It is difficult to conceive of a suitable experiment that could verify the self-assembly model. One area for possible results may be in the study of microtubulin and MT-associated proteins (MAPs), mentioned earlier in Section 3. Yasue, Jibu, and Hagan [127], for instance, report the theoretical

125 Conrad (1992), p. 125

126 ibid, p. 130

possibility of quantum coherence in the water content of microtubules (MTs), leading to superradiance effects and magnetic-like ordering of the H_2O. The conditions in the model are, however, nearly ideal; one can only speculate on the chances that such coherence would really manifest itself in the noisy and distractive environment of ionized water and interference from pumping action by other MTs, not to mention simple thermal noise and biomagnetic fields. The Hamiltonians of such coherent systems are remarkably free from considerations of thermal noise or any variations imposed by even inert molecules or the conformations of a surrounding vesicle. There must be some reasonable way to verify if some of this theoretical speculation is on the right track or not or if they are too 'pure' to be real.

How to observe ordered states of water or other internal dynamics within an MT is an open question. However, the observations could be indirect, providing evidence for the above and for the self-assembly model. Contractile changes in MAPs such as dynein and kinesin which play a role in both stabilizing MTs and in cytoskeletal movement, should be observable if one had a high-speed scanning probe device capable of registering definable changes in MTs. The 8 nm dimers (composed of $\alpha$and βtubulin monomers) that make up the longitudinal subunits of each MT are known to be arranged in a twisted hexagonal lattice that can take on a number of different shapes resulting in different neighborhood relations among subunits. Conformational changes in tubulin can be induced by hydrolysis of bound high-energy phosphates, binding of MAPs, and folding in neighboring proteins. The MAP known as MAP2, specific to dendritic cytoskeleta, cross-links MTs and is active in phosphorylation processes. It appears to be essential for long-term potentiation (synaptic plasticity believed integral for learning and memory). MAP2 is linked to membrane receptors by cyclic AMP, calcium ions, and protein kinases. It is degraded by the proteolytic enzyme calpain. [[128]]

What is hypothesized here is that conformational changes in MTs and MAPs could be observed if one had the correct instrumentation, and these results could then be compared against the results of simulations based upon the quantum-effects self-assembly model. If there is a strong consistence between the two, then at least there is stronger evidence that the model makes sense.

Using the STM system described above, it should be possible to experimentally measure such conformational effects in the following manner. Images of a given base substance such as an individual microtubule within a larger network will be produced by examining and recording the sample from many views, each obtained by nanometer-scale adjustments of the probe tip(s) from the sample. This is where the multiple tips and the prospects of triangulated perspectives on a sample come into play. The sample can be treated as if it were a landscape viewed through a synthetic aperture radar by moving the tip and obtaining several images. From these multiple images it should be possible to characterize topological features that can be distinguished within any of the original images. These features may be highly qualitative - high ridges, flat fields, tight spirals - that have characteristic measures. The next step is to introduce the enzymatic reactions that create known strong conformational changes. The MT is still being observed as the sample within the STM. Hopefully the act of administering an ionic bath or solution containing calpain

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127 Yasue et al (1993)

128 cf. Hameroff et al (1992)

will not add extraneous disturbances to the sample or the probe mechanism. If this is true, then one can repeat the multiple-perspective measurement process and obtain a new set of image data.

The essence of the experiment lies in comparing and correlating the before and after image data in order to measure what changes have occurred. This is analogous to comparing two satellite weather photographs or topographic readings and determining how things have changed. Instead of elevation changes due to seismic activity or cloud formation changes due to storm patterns, one has changes in the topology of a network of MTs. The resulting measured changes in conformation can be taken and compared against the corresponding changes that emerge from a pure computer simulation.

This proposed experiment is a first-generation attempt at something that has never been tried before. There is an enormous amount of groundwork ahead that can only be accomplished by having a formal research team devoting the time to the effort and working closely with groups such as Hameroff's team at the Univ. of Arizona to identify what is practical and what is not. The above outline is not presented as a finished product, nor is the design of the next-generation STM machine anywhere near defensible as a proven design. However it is a broad step in the right direction.

Current Status

The groundwork for the above modeling tools and programming environment has been laid and the first stages of implementation are beginning. It was not the intention to complete such a system as part of the doctoral PDE but only to lay out the foundations and begin the work. Given the fact that two R&D environments (SGS-Thomson EPR Lab and Netrologic) have been disrupted due to corporate economics, it is fortunate that things have progressed as far as they have and that there is some continuity. Future work on the PFC and Cyberspace models will depend upon the availability of appropriate funding and/or opportunities to engage in a research program beyond the completion of the Union PhD program. Such opportunities are being explored by this author through local universities and colleges in the Richmond and Radford, Virginia areas and with firms such as Sachs Freeman Associates (SFA). A proposal is being written and circulated for the establishment and funding of a Center for Parallel Dynamical Physics and Biomolecular Computing, which would be affiliated with one or more colleges and universities and provide a facility much along the lines of the PFC. The recent new developments and availability of T9000, TI320C40 and Alpha processors open up more potentials for the type of reconfigurable and extensible parallel processing that is necessary for those models and simulations proposed within previous sections of this work.

Perhaps the brightest and most solid prospects are also the most recent developments for a research/teaching faculty position within the Medical College of Virginia at Virginia Commonwealth University. With support from principally the Biomedical Engineering Dept. and others (Physics, Medicinal Chemistry, Physiology) it appears that, as this doctoral program draws to a close, the above projects have (especially compared to past efforts) a very viable future and at this date plans are being made for proposals to both government and private funding sources.

SECTION 6 - RETURN TO ONTOS AND PHYSIS

A Reorientation of Purpose and Direction

It was the original intention behind this work to produce something that would stand as an innovative and organic whole, a work that represents a process of thinking and discovering and revisiting of concepts and viewpoints relating to the topic of quantum phenomena, wholeness, and relations among processes. The problems that have beset physicists and other scientists in fitting quantum phenomena into the matrix of conventional experience are seen as stemming from the hardship of building a truly interdisciplinary, holistic scientific framework, one which also provides the mathematical basis for a reliable formalism. This 'ur-intention' governing this work has been frought with difficulties in establishing a solid platform from which to begin any kind of investigations, theoretical or otherwise. It would be so much easier if one could identify a singular problem task that can be modeled on a computer, test results with various analytical and statistical tools, and produce a particular final result that essentially says 'yes' or 'no' to a pointed hypothesis. Most research projects are more singular, focused and analytical rather than synthetic. Instead the task has been to circumspect what is being thought about by physicists, cognitive scientists, biologists and philosophers and look for the right questions and the right ways to evaluate questions and hypotheses. It is precisely the nature of the beast that synthetic reasoning becomes more important, more critical, and the tools for synthetic thinking have been lacking in the scientific and philosophical repertoires.

The work has taken many turns and side-paths, particularly in the study of what are adequate modeling and simulation tools that can be used for rapid prototyping and configuration of tests that otherwise are exorbitantly demanding in time and energy and financial costs. There has truly been a significant evolution over the course of this work, one that has been as much a response to dramatic circumstantial changes that have affected the direction of research and even the opportunities to engage in particular research activities as also a progenitive activity, an inventive process that has almost on its own brought attention and focus to certain philosophical domains of discussion, as well as to contemporary social and political factors that are influencing the course of science. The Union Institute process emphasizes the importance of examining the broader social implications of any doctoral project and looking for the interdisciplinary connections wherever practical. Initially in this research it appeared difficult to see how one could get beyond the purely theoretical domains of theoretical and mathematical physics and maintain the interdisciplinary center. However, the very process itself of conducting this work in the context of independent study and working in a commercial environment (as opposed to the typical purely academic one where the student is relatively free and unencumbered to focus on pure research and upon highly specialized topics) appeared to force attention across several disciplines. It has been as if the process itself makes demands for multiple viewpoints.

Many of these domains and influences have been underrated, if not deliberately eschewed, within the traditional scientific community. There is a growing political conservatism, a different type of 'political correctness', within the academic community, one that is in great part dictated by the growth of mega-universities and de facto academic corporations, competing against one another for (primarily) government R&D funds. Fields like physics and electronics appear to be far less overcome by strict sectarianism than others, including, strange as it may seem at first, certain segments of the computing science field. Particularly this has been the case in artificial intelligence and the neurocomputing community. For such a new area of research there has been some remarkable growth of dogma and a reluctance to open dialogue with different channels of thought. By no means is this a majority condition nor is it meant as a criticism of any collective body of researchers; it is simply a condition that appears more marked than in other disciplines and certainly more pronounced in the latter decades of the twentieth century than in recent times.

This type of phenomena has occurred many times before and it is by no means limited to science and technology but rather appears to be endemic in societies that have reached a certain level of structure and complexity. Perhaps it is not the complexity but the transformation of value systems that once emphasized the excitement and adventure of making and sharing discovery and now emphasizes the placement of the individual in a hierarchical ranking system. It seems to be a natural course of events within established societies and one can find evidence for it in ancient Rome and Greece, in Mayan Mesoamerica and in China. In a word there is a 'calcification' of intellectual thinking that is plaguing academic scientific fields and philosophy, to the point where the reasons and purposes of philosophy are themselves unclear and forgotten. The separation of philosophy from science, a division that grew over centuries but most intensely since the eighteenth century, has led to a forgetting about Being and the fundamental issues of what it is to be. This breaking-away and forgetting may be one of the significant factors in the proliferation of so many apparently unresolvable differences between branches of the sciences and in particular within physics. It is as if the major trunk and root structure of the Tree has been forgotten and one is trying desperately to establish a connection and communication between the branches and limbs.

An expected and predicted criticism of this work is that it covers too much ground, it describes and reviews rather than focuses upon a particular aspect, it lacks a strong original research result of a mathematical and physical nature. About this some points are made in the section following the immediate next one. But first it merits to consider additional epistemological points.

The Philosophical Dimension Reconsidered

The philosophical dimensions have emerged as critical foundations to future theoretical or experimental work, given the need to define and distinguish concepts that have acquired diverse meanings in different disciplines. More than anything it appears that the basic notions of substance, identity and causation are at issue and they control the dialogues concerning how quantum processes exist on scales other than the microcosmic, and indeed what a particle can be if it is not one thing for all observers. Shifting from 'things' to 'actions' is a philosophical problem that has consequences for every 'logos'. As in a gravitational field the dialogue here is drawn back to fundamental ideas and principles that have been at the center of philosophical thought since the days of the pre-Socratics. One cannot help but think of the fragments of Heraklitus that speak to today with a fervor and passion, a spiritedness that has been long lacking in the practice of philosophy and science.

"Thunderbolt steers all things. [5.8]
This world-order, the same for all, no god made or any man, but it always was and is and will be an ever-living fire, kindling by measure and going out by measure. [5.12]
In opposition there is agreement; between unlikes, the fairest harmony. [5.45]" [[129]]

The previous sections have dwelt at length upon the modern scientific dimension, the process of physics as it is understood to be today, especially, a complex mathematical and empirical investigation. Increasingly it is dominated by the use of computers to process the models, and all this spells out the dominance of formal systems and a mindset that is geared toward putting the phenomenon into a formal system before it can be declared 'understood' and in some way, 'acceptable.' But not all phenomena can be assumed to behave in ways that are deterministic and formalizable. Perhaps more clearly, all phenomena are not computable by Turing machines as all familiar computers (von Neumann and parallel types) have been.

Since the time of the Renaissance and Enlightenment periods, there has been a definite and obvious move to dissociate science and in particular the physical sciences, from philosophy and the metaphysical. Questions of consciousness and perception have been almost forcibly distanced by physical scientists and are only lately coming back into the foreground, most notably in highly interdisciplinary areas of study that bring together biophysics, molecular biology, and complexity theory. In some cases the merging may be for the wrong reasons (e.g., a confusing simplistic misunderstanding of the Uncertainty Principle to imply that everything is fuzzy, indefinite, and forever undefinable, coupled with an equally wrong view that consciousness must be that way since for thousands of years no one has been able to point to it in space-time). Why is this so?

Partly there is the notion that if something is not physical, tangible, 'objective-particular' to use Young's terminology, it is not real, so if reality must in some way be attributed to the non-physical, it must be less defined, fuzzy, the kind of gray-zone entity that cannot be easily described. What you can't touch is less defined, otherwise you could touch it - it's something of that sort of view. There is also the Gnostic-Cartesian view of the split world that can never be truly integrated, only lived through carefully. And there is the mythos and confusion about randomness, chaos, disorder, and complexity. All that is constantly and historically seen as something less than perfect, something that could be better if it were only more regular, neater, cleaner. It's the Platonic Impulse toward a universe of regular polygons and polyhedra that seems to surface in everyone at one time or another. But it does not need to be that way and Nature certain is not. The messy and disorderly from one scale and set of values is often just the thing that holds stuff together and provides order and structure - witness the microtubulin of the cytoskeleton. glial cells in the brain, bone cells, and the way most plants grow. Apparent fuzzy structures can provide the lightest, least-energy means of overcoming gravity and maintaining a structure - any structure, including one that changes a lot but still remains being some structure capable of supporting whatever is the rest of the organism (for example- roots of trees being the most efficient way to build a support structure that will hold up a massive tree and allow for the support beams and struts (the roots) to do double duty by being conduits for water and nutrients, even though this means having much lighter weight roots.

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129 Introduction to the Pre-Soctratics, p. xx

On the other hand there is a problem in following a pendulum swing in science to get bug-eyed about 'consciousness' and find it everywhere, until the word and the concept start to become stretched into oblivion. It just doesn't make much sense to talk about molecular recognition as consciousness - the molecules do not have self-reflexion. Neither do cells, which do not perceive things even though they perform object recognition and can adapt to changes in the environment. A science of consciousness really does need to be nurtured, but it must be a science that knows how to discriminate and set aside, even though it is itself in the middle of many disciplines.

This work began with discussion of physis and aletheia. There is a strong need for a physics that looks for the physis in Nature and is filled with aletheia, that drive toward disclosing, opening, and revealing. The barriers of ordinary everyday language fight against these two primal elements and it is difficult to express in words, but the opportunity is there and quantum theory may very well be the common foundation for beginning to deal with the physis in all scales and domains of science, particularly that in the biological sphere. It is hard to get rid of built-in ontic assumptions (even quantum theory has been quite 'classicized') but not impossible. The language of quanta may be in need of re-examining and redefining but it is there to be the language for building a new science of physis from out of a science of physical objects.

A Recapitulation of the Research Accomplishments

The primary accomplishments of this project do not yield either a formal proof nor a set of empirically reproducible results at this time. They consist of designs for experiments and simulations and the groundwork for development of formal models that can be tested in the future. Much of the research has been conducted into examining and evaluating many computational models and architectures for their appropriateness in studying quantum physics, chemistry, and biology. The results include the architecture described in Section 5 for a digital parallel field computer and for a real-time scanning tunneling microscope.

Throughout the program and this document many different models or analytical tools have been outlined and suggested. These include:

Quantum cellular automata machines
Dynamical processes and how they can be formalized
Quantum mechanisms in macromolecular self-assembly and ion channel activity that can explain the connection between neurodendritic field processes and neural firing activity
Dynamical, 'quantized' neural networks that incorporate some quantum mechanical behavior in order to modulate and test the performance of the network
Networks and large populations of chaotic strange attractors
Design of a 'Parallel Field Computer' employing a MIMD architecture
Design of a real-time, multi-tip, multi-feature scanning tunneling microscope that can be integrated with high-performance parallel computing

Perhaps the most exciting accomplishment has been the very intangible and preliminary work toward building more complete and simpler mathematical tools, such as a dynamical process algebra and a quantum cellular network language that can provide a pathway to understanding how complex macroscopic and irreversible processes emerge from the quantized micro-flux world - in essence, how space and time emerge and give form to a structured and ordered universe. Ultimately that is the big question and it is where the photon, the brain, and the cosmos all come together. Unfortunately this area of mathematical development appears to have been the most illusive and difficult, and not only for this author in this incipient work.

There is a lot of unfinished and incomplete work. The hardware and software tasks for the PFC and the STM architecture presented above have not left the conceptual stage. Grants and other funding for such work need to be secured. There is personal dissatisfaction with the level of completeness for any of the simulation models that have been presented, and much more could have been accomplished even within the time frame of this program, if there had not been so many personal and economic roadblocks. The expenses of appropriate computer equipment have been a major barrier to accomplishing more in the way of programming and having some hard, tangible simulation results for this PDE rather than outlines of proposed experiments. More could have also been realized in the development and explication of the mathematical side; much of this PDE has dealt with philosophical foundations and issues and not enough has been established towards a solid formalism. Much more could have been done at the level of Grassmann and Clifford algebras and group theoretic models, and this is only beginning to get underway now that there is both an improved grounding in personal understanding of the subjects but a clarity of directions and proper questions.

Lest this sound like too much self-criticism, it must be said that overall the work has been accomplished to the level that was or should have been reasonably expected and it meets the satisfaction of both requirements, prior agreements, and the critique of the doctoral committee. The groundwork has been laid and this project has really provided a base and foundation for many projects and studies, almost too many than can be accomplished in one lifetime, even with much help and adequate computing power. Now is the time for practical beginnings. The future work is taking off without interruption and will include a refinement of the cellular automata and neural network models and eventual implementation on either Silicon Graphics or 486 PC computers. It may be possible to integrate and extend to multiple-particle simulations some of the computational modeling of the quantum potential done at Birkbeck College under Dr. Basil Hiley. The design of the Parallel Field Computer is being revised to fit requirements and needs at the Medical College of Virginia and something of the sort will, with adequate funding, be taking shape over the next year. There will be clear and relatively stable opportunities now to organize and develop both the theoretical and computational aspects of what has been alluded to in this PDE. Perhaps most exciting is what has emerged most recently on the theoretical front - a coinciding of a much clearer understanding of the algebraic approaches by both Hiley and Finkelstein to quantum theory, the scope of the problem of integrating quantum physics with relativity theory, and some new ideas about how to apply fractals, chaos, and network dynamics to the problem of pre-space and the emergence of the dimensional universe from that pre-dimensional holoflux.

Closure

The focus of this research and certainly some of the underlying philosophical viewpoints of this learner have changed significantly during its course. Many angles of applying quantum physical theory to mesoscopic and macroscopic phenomena have been examined and the main ones discussed in earlier sections. Clearly there is a proliferation of 'quantum' thinking that now pervades every scientific area including those applied sciences of economics and sociology. There is a bigger and deeper set of questions that arises, one that affects our very notions of logic, truth, substance, being. Quantum theory goes, as Finkelstein has pointed out in different ways, far beyond physics. I would like to claim that it brings physics back closer to the original physis of Heraklitus and the pre-Socratics. it brings mythos and logos back together.

What is the impact and meaning of the quantum viewpoint? Why is it so dominant in twentieth century (and particularly late twentieth century) thinking? Why does it seem to grow out of the world-view that has made itself dominant in the later centuries of this millennium?

These are, it is my claim, the real questions and the real substance of dialogue toward which this research work is truly just a Prolegomenon. Let it stand and be measured as a beginning, as a sketch on the ground of where a new building will be erected (and hopefully it provides something more like an architectural plan). In the realm of logos and mythos a work like this should be the gateway by which someone can be inspired to think of new ways of thinking, new experiments, new challenges to the old traditions. For at least the author it has served this purpose and helped to define an entire broad course of research and investigation for the foreseeable future. There is an incredible amount of work yet to be done but being on the beginning of the path is always at least one step in the right direction.

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"As below, so above"
- Hermes Trismegistus Reversi

SECTION 7 BIBLIOGRAPHY

INTRODUCTION

The following bibliography consists of the major and minor source materials and references that are being used during the course of the doctoral project or which have been important in earlier related work. It is divided into three sections:

I. Primary References
Technical works that are considered to be of principal importance in the development of the doctoral research programme and which are significant for further studies in topics that are substantively related to the doctoral project area.

II. Secondary References
Technical works that have been used in the course of mastering different subjects relevant to the overall doctoral proficiency requirements or which have useful supportive connections to the subjects covered in the research programme.

III. References Pertaining Primarily to the Internship
Technical works principally on topics of parallel processing and neural networks.

I. PRIMARY REFERENCES

Albert, D. Z. (1983) On Quantum-Mechanical Automata, *Physics Letters* 98A, 249-52

Baracca, A., Bohm, D., Hiley, B. J., & Stuart, A. E. G. (1975) On Some New Notions Concerning Locality and Non-Locality in the Quantum Theory, *Nuovo Cimento* 28B, No. 2, 453-65

Barrow, John D. & Tipler, Frank J. (1986) *The Anthropic Cosmological Principle*, Oxford Univ. Press, Oxford

Bell, J. S. (1982) *Speakable and Unspeakable in Quantum Mechanics*, Cambridge Univ. Press, Cambridge, UK

Bohm, David (1951) *Quantum Theory*, Prentice-Hall, New York

Bohm, D. (1952) A Suggested Interpretation of the Quantum Theory in Terms of "Hidden" Variables (Parts I & II), *Physical Review* 85, No. 2, 166-93

Bohm, D. (1957) *Causality and Chance in Modern Physics*, Van Nostrand, New York

Bohm, D. (1971) Quantum Theory as an Indication of a New Order in Physics. Part A. The Development of New Orders as Shown Through the History of Physics, *Foundations of Physics* 1, No. 4, 359-81

Bohm, D. (1973) Quantum Theory as an Indication of a New Order in Physics. Part B. Implicate and Explicate Order in Physical Law, *Foundations of Physics* 3, No. 2, 139-68

Bohm, D. (1976) *Fragmentation and Wholeness*, The Van Leer Jerusalem Foundation, Jerusalem

Bohm, D. (1980) *Wholeness and the Implicate Order*, Routledge & Kegan Paul, London

Bohm, D. (1986), A New Theory of the Relationship of Mind and Matter, *The Journal of the American Society for Psychical Research*, Vol. 80, No. 2, April 1986

Bohm, D. & Hiley, B. J. (1975) On the Intuitive Understanding of Nonlocality as Implied by Quantum Theory, *Foundations of Physics* 5, No. 1, 93-109

Bohm, D. & Hiley, B. J. (1981a) On a Quantum Algebraic Approach to a Generalized Phase Space, *Foundations of Physics* 11, Nos. 3/4, 179-203

Bohm, D. & Hiley, B. J. (1981b) Nonlocality in Quantum Theory Understood in Terms of Einstein's Nonlinear Field Approach, *Foundations of Physics* 11, No.s 7/8, 529-46

Bohm, D. & Hiley, B. J. (1984) Measurement Understood Through the Quantum Potential Approach, *Foundations of Physics* 14, No. 3, 255-74

Bohm, D. & Hiley, B. J. (1985a) Active interpretation of the Lorentz "boosts" as a physical explanation of different time rates, *Amer. Journal of Physics* 53 (8), August 1985

Bohm, D. & Hiley, B. J. (1985b) Unbroken Quantum Realism, from Microscopic to Macroscopic Levels, *Physical Review Letters* 55, No. 23, 2511-14

Bohm, D. & Hiley, B. J. (1987) An Ontological Basis for the Quantum Theory", *Physics Reports* 144, No. 6, 323-75 (2 parts)

Bohm, D. & Hiley, B. J. (1989) Non-locality and Locality in the Stochastic Interpretation of Quantum Mechanics, *Physics Reports* 172, No. 3, 93-122

Bohm, David, Hiley, B. J., & Stuart, A. E. G. (1970) On a New Mode of Description in Physics, *Int'l J. of Theor. Physics* 3, 171-83

Bohm, D. & Hiley, B. J., (1990) The Undivided Universe, *pre-publication manuscript*

Casti, John L. (1989) *Alternate Realities: Mathematical Models of Nature and Man*, John Wiley & Sons, New York

Chirikov, Boris V. (1991a) *Chaotic Quantum Systems* (pre-print)

Chirikov, Boris V. (1991b) Patterns in Chaos, in *Chaos, Solitons & Fractals*, Vol. 1, No. 1, 79-103

Conrad, M. (1992a) Quantum Molecular Computing: The Self-Assembly Model, *Int'l Journal of Quantum Chemistry: Quantum Biology Symposium*, Vol. 19, 125-143

Conrad, M. (1992b) Molecular Computing: The Lock-Key Paradigm, *IEEE Computer*, Vol. 25, No. 11, 22-29

Conrad, M. (1988a) Quantum Mechanics and Molecular Computing: Mutual Implications, *Int'l Journal of Quantum Chemistry: Quantum Chemistry Symposium*, Vol. 15, 287-301

Conrad, M. & Liberman, E. A., (1982) Molecular computing as a link between biological and physical theory, *J. Theor. Biology*, Vol. 98, 239-252

Deutsch, David (1985a) Quantum theory, the Church-Turing principle and the universal quantum computer, *Proc. Royal Soc. London*, A 400, 97-117

Deutsch, D. (1985b) Quantum Theory as a Universal Physical Theory, *Int'l J. of Theor. Physics*, Vol. 24, No. 1

Deutsche, D. (1989) Quantum Computational Networks, *Proc. Royal Soc. London*, A 425, 91-111

Donald, M. (1990) Quantum theory and the brain, *Proc. Royal Soc. London A*, Vol. 427, 43-93

Eccles, J. C. (1986) Do mental events cause neural events analogously to the probability fields of quantum mechanics?, *Proc. Royal Soc. London*, B 227, 411-28

Einstein, Albert, Podolsky, Boris, & Rosen, Nathan (1935), Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?, *Physical Review* 47, 777-80

Finkelstein, David (1963) The logic of quantum physics, *Transactions of the NY Academy of Science* 25, 621-63

Finkelstein, D. (1966) Matter, Space and Logic, *Boston Colloq. on the Philosophy of Science*, Vol. 5, 1966, 199-215

Finkelstein, D. (1969) Space-Time Code, *Physical Review* 184, No. 5, 1261-71

Finkelstein, D. (1972a) Space-Time Code II, *Physical Review* D, Vol. 5, No. 2, 320-28

Finkelstein, D. (1972b) Space-Time Code III, *Physical Review* D, Vol. 5, No. 12, 2922-31

Finkelstein, D. (1974a) Space-Time Code IV, *Physical Review* D, Vol. 9, 2219+

Finkelstein, D. (with Frye, G. & Susskind, W.) (1974b) Space-Time Code V, *Physical Review* D, Vol. 9, 2231+

Finkelstein, D. (1976) *Beneath Time*, (unpublished, based upon lecture to the) Int'l Society for the Study of Time III, Alpach, Austria, July, 1976

Finkelstein, D. (1977) The Leibnitz Project, *Journal of Philosophical Logic* 6, 425-439

Finkelstein, D. (1978) Process Philosophy and Quantum Dynamics, in Hooker (ed.), Physical Theory as Logico-Operational Structure

Finkelstein, D. (1979) Logos/Mythos, The Kenyon Review, New Series Vol. 1, No. 1, 136-150

Finkelstein, D. (1982) Quantum Sets and Clifford Algebras, *Int'l J. of Theor. Physics* 21, Nos. 6/7, 489-503

Finkelstein, D. (1985) "Superconducting" Causal Nets, *Int'l J. of Theor. Physics* 27, No. 4, 473-519

Finkelstein, D. (1986) The Universal Quantum, *The World View of Contemporary Physics*, Colo. St. Univ., Ft. Collins CO, Sept. 25 - 28, 1986

Finkelstein, D. (1987a) Coherent quantum logic, *Int'l J. of Theor. Physics* 26, 109-29

Finkelstein, D. (1987b) Finite Physics, in Herken (ed), *The Universal Turing Machine - A Half-Century Survey*, Kammerer & Unverzagt, Hamburg

Finkelstein, D. (1989a) Quantum Net Dynamics, *Int'l J. of Theor. Physics* 28, No. 4, 441-67

Finkelstein, D. (1989b) First Flash and Second Vacuum, *Int'l J. of Theor. Physics* 28, No. 9, 1081-1098

Finkelstein, D. (1992) Q: A Quantum Language (pre-publication)

Finkelstein, D. (in progress, 1993) Quantum Relativity (pre-publication)

Finkelstein, David & Halliday, W. H. (1991) Q: An Algebraic Language for Quantum-Spacetime Topology, *Int'l J. of Theor. Physics* 30, No. 4, 463-486

Finkelstein, David & Halliday, William H. (in progress) Schroedinger Equation in Quantum Time (pre-publication)

Finkelstein, David & McCollum, Gin (1974) Unified Quantum Theory, in *Proc. of the Conference on Quantum Theory and Structures of Time and Space*, Feldafing, July 1974, 15-53

Finkelstein, David & Shlomit Ritz (1983) Computational Complementarity, *Int'l J. of Theor. Physics* 22, No. 8, 753-78

Finkelstein, D. & Rodriguez, Ernesto (1984) Relativity of Topology and Dynamics, *Int'l J. of Theor. Physics* 23, No. 11, 1065-97

Frescura, F. A. M. & Hiley, B. J. (1980) The Implicate Order, Algebras, and the Spinor, *Foundations of Physics*, Vol. 10, Nos. 1/2, 2/80

Frescura, F. A. M. & Hiley, B. J. (1980) The Algebraization of Quantum Mechanics and the Implicate Order, *Foundations of Physics*, Vol. 10, Nos. 9/10, 10/80

Frescura, F. A. M. & Hiley, B. J. (1984) Algebras, Quantum Theory and Pre-Space, *Revista Brasileira de Fisica, Volume Especial*, July 1984

Hanlon, B. E. & Joshi, G. C. (@1990) Spontaneous CP Violation form a Quaternionic Kaluza-Klein Theory

Healey, Richard (1990) *The Philosophy of Quantum Mechanics: An Interactive Interpretation*, Cambridge Univ. Press, Cambridge

Hiley, B. J. (1989) Vacuum or Holomovement (in progress; private communication)

Hiley, B. J. & Peat, F. David (eds.) (1987) *Quantum Implications: Essays in honour of David Bohm*, Routledge & Kegan Paul, London

Hoare, C. A. R. (1985) *Communicating Sequential Processes*, Princeton Univ. Press, Princeton

Hoare, C. A. R. (1986) *The Laws of OCCAM*, Oxford University Programming Research Group, Oxford

Kak, Subhash (1992) Can We Build A Quantum Neural Computer?, *Technical Report* ECE/LSU 92-13, Lousiana State Univ. Dept. of Electrical and Computer Engineering

Kugler, Peter N. & Shaw, Robert E. (1990) Symmetry and Symmetry-Breaking in Thermodynamics and Epistemic Engines: A Coupling of First and Second Laws, in Haken and Stadler (eds.), *Synergetics of Cognition*, Springer-Verlag, Berlin

Kugler, P. N. & Turvey, M. T. (1988) Self-Organization, Flow Fields, and Information, *Human Movement Science* 7, 97-129

Kron, Gabriel (1939) *Tensor Analysis of Networks*, John Wiley & Sons, New York

MacLennan, Bruce (1990) Field Computation, (Pre-Publication)

MacLennan, Bruce (1992) Neural Computation Without Sigmoids (Pre-Publication)

Matsuno, Koichiro (1993) Biology in the Eyes of Molecules, *Nanobiology*, Vol. 2, 37-41

Matsuno, Koichiro (1992) The Uncertainty Principle as an evolutionary engine, *BioSystems*, Vol. 27, 63-76

Morrison, Michael A. (1990) *Understanding Quantum Physics*, Prentice-Hall International, Englewood Cliffs

Nash, C. G. & Joshi, G. C. (1987) Composite systems in quaternionic quantum mechanics, *Jour. Math. Phys.* 28 (12) 2883-2890

Pao, Yoh-Han (1989) *Adaptive Pattern Recognition and Neural Networks*, Addison-Wesley, Reading

Penrose, Roger (1987) Computability in the Laws of Physics and Thought, *Proc. of the 11th Int'l Wittgenstein Symposium*, 4th-13th Aug., 1986, Kirchberg/Wechsel (Austria)

Penrose, R. (1988) On the Physics and Mathematics of Thought, in Herken (ed.), *The Universal Turing Machine: A Half-Century Survey*, Oxford Univ. Press, Oxford

Penrose, R. (1989) *The Emperor's New Mind*, Oxford Univ. Press, Oxford

Pribram, Karl H. (1991) *Brain and Perception: Holonomy and Structure in Figural Processing*, Lawrence Erlbaum Associates, Hillsdale NJ

Prigogine, Ilya (1980) *From Being to Becoming: time and complexity in the physical sciences*, W. H. Freeman, San Francisco

Prigogine, Ilya (1984) *Order out of Chaos: Man's new Dialogue with Nature*, Bantam, New York

Rosen, Robert (1991) *Life Itself*, Columbia University Press, New York

Saunders, Simon and Brown, Harvey R. (eds.) (1991) *The Philosophy of Vacuum*, Oxford Univ. Press, Oxford

Schempp, Walter (1991) Bohr's indeterminacy principle in quantum holography, adaptive neural networks, cortical self-organization, molecular computers, magnetic resonance imaging, and solitonic nanotechnology, (pre-publication)

Squires, E. (1990a) How to Test for Cartesian Dualism by Quantum Experiments, *Proc. of the 1990 Symposium on Modern Physics*, Joensuu

Squires, E. (1990b) Quantum Theory and the Relation between Conscious Mind and the Physical World, (pre-publication)

Sutherland, John (1990) A Holographic Model of Neurological Function, AND Corporation, Hamilton, Ontario, (private communication)

Sutherland, John (1990) A Holographic Model of Memory, Learning and Expression, *Int'l Journal of Neural Systems*, Vol. 1, No. 3, 259-267

Thom, Rene (1990) *Semiophysics: A Sketch*, Addison-Wesley, New York

Walker, E. H. (1977) Quantum Mechanical Tunneling in Synaptic and Ephaptic Transmission

Werbos, Paul (1992) *Chaotic Solitons and the Foundations of Physics: A Potential Revolution*, unpublished preprint (available from author at National Science Foundation, Room 1151, Washington, D.C. 20550); to appear in *Applied Mathematics and Computation*

Werbos, Paul (1992a) Quantum Theory, Computing and Chaotic Solitons, in Yamakawa, T. (ed.), *Iizuka-92 Proceedings*, Fuzzy Logic Systems Institute, Fukuoka, Japan and in *IEICE Trans. Fundamentals*, Vol. E76-A, No. 5, May 1993

Werbos, Paul (1993) Chaotic Solitons in Conservative Systems: Can They Exist?, *Chaos, Solitons & Fractals*, Vol. 3, No. 3, 321-326

Yasue, K. (1981a) Quantum mechanics and stochastic control theory, *Journal of Math. Physics*, 22, 1010

Yasue, K. (1981b) Stochastic calculus of variations, *Journal of Functional Analysis*, 41, 327

Yasue, K., Jibu M., Hagan, S. (1993) Consciousness and Anesthesia: A Hypothesis Involving Biophoton Emission in the Microtubular Cytoskeleton of the Brain, *2nd Appalachian Conf. on Behavioral Neurodynamics*, Radford University, Radford, VA, Oct. 3-6, 1993

Young, Arthur M. (1976a) *The Geometry of Meaning*, Delacorte Press, San Francisco

Young, Arthur M. (1976b) *The Reflexive Universe*, Delacorte Press, San Francisco

Zurek, W. H., van der Merwe, A., & Miller, W. A. (1988) *Quantum and Cosmos: Essays in Honor of John Archibald Wheeler*, Princeton Univ. Press, Princeton

II. SECONDARY REFERENCES

Abraham, R. and Shaw, C. D. (1988) *Dynamics: The Geometry of Behavior (Four Parts)*, Aerial Press, Santa Cruz, CA

Amari, S. (1962) Topological Foundations of Kron's Tearing of Electric Networks, *RAAG Memoirs*, Vol. 3, London

Aspect, Alain, Dalibard, Jean, & Roger, Gerard (1982) Experimental Test of Bell's Inequalities Using Time-Varying Analyzers, *Physical Review Letters* 49, 1804

Bak, P. (1991) Self-Organized Criticality and the Perception of Large Events, in *Spontaneous Formation of Space-Time Structures and Criticality* (T. Riste & D. Sherrington, eds.), Kluwer Academic Publishers, Amsterdam, 25-31

Bak, P. & Chen, K, (1988) Self-Organized Criticality, *Physical Review A* 38, No. 1, 364-374

Bak, P. & Chen, K. (1991) Self-Organized Criticality, *Scientific American*, Jan. 1991, 46-53

Barrow, John D. (1988) *The World Within the World*, Oxford Univ. Press, Oxford

Barton, G. (1989) *Elements of Green's Functions and Propagation*, Oxford Univ. Press, Oxford

Behnke, H., Bachmann, F., Fladt, K., & Suss, W. (eds), (trans. by S. H. Gould) (1983) *Fundamentals of Mathematics, Vols. 1, 2, & 3*, MIT Press, Cambridge, MA

Benedikt, Michael (ed.) (1992) *Cyberspace: First Steps*, MIT Press, Cambridge, MA

Blakemore, Colin & Greenfield, Susan (eds) (1987) *Mindwaves: Thoughts on Intelligence, Identity and Consciousness*, Blackwell, London

Bohm, David & Peat, F. David (1987) *Science, Order and Creativity*, Bantam, New York

Burks, Arthur W. (ed) (1970), *Essays on Cellular Automata*, Univ. of Illinois Press, Urbana

Campbell, Jeremy (1985) *Grammatical Man*

Casti, John L. (1987) *Linear Dynamical Systems*, Academic Press, Orlando

Casti, J. & Karlqvist, A. (eds) (1987) *Real Brains, Artificial Minds*, Elsevier, New York

Chew, G. F. (1985) Gentle Quantum Events as Source of Explicate Order, *Zygon* 20 (2), 159-164

Christensen, Steven M. (ed) (1984) *Quantum Theory of Gravity: Essays in honor of the 60th birthday of Bryce S. Dewitt*, Adam Hilger Ltd., 1984

Clauser, John F. & Freedman, Stuart J. (1972) Experimental Test of Local Hidden-Variable Theories, *Physical Review Letters* 28, 938-41

Conrad, M. (1989a) Physics and Biology: Towards a Unified Model, *Applied Mathematics and Computation*, Vol. 32, 75-102

Conrad, M. (1989b) Force, Measurement. and Life, in *Newton to Aristotle: Toward a Theory of Models for Living Systems*, (eds. Casti, J. & Karlqvist, A.), Birkhauser, Boston, MA

Conrad, M. (1988b) Proton Supermobility: a Mechanism for Coherent Dynamic Computing, *Journal of Molecular Electronics*, Vol. 4, 57-65

Conrad, M. (1985) On Design Principles for a Molecular Computer, *Communic. of the ACM*, May 1985, Vol. 28, No. 5, 464-480

Cutland, N. J. (1984) *Computability*, Cambridge Univ. Press, Cambridge UK

Dewitt, Bryce & Graham, R. Neill (1973) *The Many-Worlds Interpretation of Quantum Mechanics*, Princeton Univ. Press, Princeton

Davies, P. C. W. & Brown, J. (eds) (1988) *Superstrings: A Theory of Everything?*, Cambridge Univ. Press, Cambridge UK

Demys, K. (1972) CM (Consciousness-Matter interactions) Quantum Theory: The Beginning of a Quantum Psychology, *Journal for the Study of Consciousness*, Vol. 5, No. 1, 239-242

Dodd, J. E. (1985) *The ideas of particle physics*, Cambridge Univ. Press, Cambridge UK

Dretske, Fred I. (1982) *Knowledge and the Flow of Information*, MIT Press, Cambridge MA

Dretske, F. (1985) Machines and the Mental, *Proc. of the Amer. Philosophical Association* 59, No. 1, 23-33

Eckart, J. Dana (1991) A *Cellular* Automata Simulation System, *SIGPLAN Notices* 26:8, 80-85

Eckart, J. Dana (1992) CELLANG : A Cellular Automata Language, (pre-publication)

Eriksson, Karl-Erik, Lindgren, Kristian, & Mansson, Bengt A. (1987), *Structure, Context, Complexity, Organization*, World-Scientific, Singapore

Feynman, Richard P., Leighton, Robert B., & Sands, Matthew (1965) *The Feynman Lectures on Physics, Vol. III*, Addison-Wesley, Reading

Feynman, Richard P. (1985) A Quantum Mechanical Computer, *Optic News* 11, 11-20

Feynman, Richard P. (1998) Quantum Mechanical Computers, in Zurek (1988)

Fishman, S. et al (1984) *Physical Review* A29, 1639ff

Freeman, James A. & Skapura, David M. (1991) *Neural Networks: Algorithms, Applications, and Programming Techniques*, Addison-Wesley, NY

Gal-Or, Benjamin (1983) *Cosmology, Physics and Philosophy*, Springer-Verlag, New York

Gates, S. J. Jr, Grisaru, M. T., Rocek, M, & Siegel, W. (1983) *Superspace or One Thousand and One Lessons in Supersymmetry*, Benjamin Cummings, Reading

Gelernter, David (1991) *Mirror Worlds*, Oxford Univ. Press, Oxford

Geroch, Robert (1985) *Mathematical Physics*, Univ. of Chicago Press, Chicago

Green, Michael B. & Schwarz, John H. (1987) *Superstring Theory (Vols. I & II)*, Cambridge Univ. Press, Cambridge UK

Greiner, W.(1989) Quantum Mechanics - An Introduction, Springer-Verlag, Berlin

Griffin, David R. (1986) *Physics and the Ultimate Significance of Time*, State Univ. of New York Press, Albany

Grossberg, Stephen (1982) *Studies of Mind and Brain*, Reidel, Dordrecht

Hameroff, Stuart R. (1987) *Ultimate Computing: Biomolecular Consciousness and Nanotechnology*, Elsevier-North Holland, Amsterdam

Hameroff, Stuart R., Dayhoff, Judith E., Lahoz-Beltra, Rafael, Samsonovich, Alexei V., and Rasmussen, Steen (1992) Models for Molecular Computation: Conformational Automata in the Cytoskeleton, *IEEE Computer*, Vol. 25, No. 11, 30-39

Happ, H. H. (1971) *Diakoptics and Networks*, Academic Press, New York

Harr, D. Ter (1982) *Elements of Hamiltonian Mechanics*, 2nd. ed., Pergamon Press, New York

Haugeland, John (ed.) (1985) *Mind Design*, MIT Press, Cambridge MA

Hennessy, Matthew (1988) *Algebraic Theory of Processes*, MIT Press, Cambridge MA

Herbert, Nick (1985) *Quantum Reality*, Anchor Press Doubleday, New York

Hinton, Geoffrey & Anderson, James (eds.) (1981) *Parallel Models of Associative Memory*, Lawrence Erlbaum Assoc., Hillsdale NJ

Jacobson, Nathan (1985) *Basic Algebra Vols. I & II*, W. H. Freeman, New York

Jauch, Josef M. (1968) *Foundations of Quantum Mechanics*, Addison-Wesley, Reading

Jordan, Thomas F. (1986) *Quantum Mechanics in Simple Matrix Form*, Wiley-Interscience, New York

Josephson, Brian D. & Pallikari-Viras, Fotini (1991) Biological Utilization of Quantum Nonlocality, *Foundations of Physics* 21, No. 2, 197-207

Joshi, A. W. (1984) *Matrices and Tensors in Physics*, 2nd ed, John Wiley, New York

Kaku, Michio & Trainer, Jennifer (1987) *Beyond Einstein*, Bantam, New York

Katchalsky, A. & Curran, P. F. (1965) *Nonequilibrium thermodynamics in biophysics*, Harvard Univ. Press, Cambridge, MA

Koch, Christof & Segev, Idan (eds) (1988) *Methods in Neuronal Modeling*, MIT Press, Cambridge MA

Langton, C. G. (ed) (1989) *Artificial Life, Sante Fe Institute Studies in the Sciences of Complexity*, Addison-Wesley, Reading

Landauer, Rolf (1967) Wanted: a physically possible theory of physics, *IEEE Spectrum*, Sept. 1967, 105-09

Lawrence, A. F. & Birge, R. R. (1990) Mathematical Problems Arising in Molecular Electronics: Global Geometry and Dynamics of the Double Well, *Proc. of the Santa Clara Symposium on Molecular Electronics*, (F. Hong, ed.), Plenum Press, New York

Lawvere, F. W. & Schanuel, S. H. (eds.) (1984) *Categories in Continuum Physics*, Springer-Verlag, Berlin

Liboff, Richard L. (1980) *Introductory Quantum Mechanics*, Addison-Wesley, Reading

Margenau, H. (1977) *The nature of physical reality*, Ox Bow Press, New York

Margenau, H. (1984) *The miracle of existence*, Ox Bow Press, New York

Margolis, Norman (1984) Physics-Like Models of Computation, *Physica* 10D, 81-95

Masters, Timothy (1992) *Practical Neural Network Recipes in C++*, Academic Press, NY

Mays, Wolfe (1977) *Whitehead's Philosophy of Science and Metaphysics*, Martinus Nijhoff, The Hague

McClelland, James & Rumelhart, David (eds) (1986) *Parallel Distributed Processing, Vols. I & II*, MIT Press, Cambridge MA

McClelland, James & Rumelhart, David (1988) *Explorations in Parallel Distributed Processing*, MIT Press, Cambridge MA

Mickens, Ronald E. (ed.) (1990) *Mathematics and Science*, World Science Publ., Singapore

Mikulecky, Donald C. (1993) *Applications of Network Thermodynamics to Problems in Biomedical Engineering*, New York University Press, New York

Misner, C. W., Thorne, K. S., & Wheeler, J. A. (1973) *Gravitation*, W. H. Freeman, San Francisco

Muses, Charles (1967) Time, Experience, and Dimensionality: An Introduction to Higher Kinds of Number, *Annals of the NY Academy of Sciences*, Vol. 138, Feb. 1967, 646-660

Muses, Charles (1968a) Hypernumber and Metadimension Theory, *Journal for the Study of Consciousness*, Vol. 1, No. 2, 29-48

Muses, Charles (1968b) Hypernumber and Their Spaces: A Summary of New Findings, *Journal for the Study of Consciousness*, Vol. 1, No. 2, 251-256

Muses, Charles (1970) On the Modification of Random Fluctuations by a Target-Seeking Process Utilising Random Energies, *Journal of Bio-Medical Computing*, Vol. 1, 75-80

Muses, Charles & Young, Arthur M. (eds) (1974) *Consciousness and Reality*, Avon Books, New York

Mycielski, Jan (1986) Can Mathematics Explain Natural Intelligence, *Physica* 22D, 366-75

Nazari, J. & Ersoy, O. (1992) *Implementation of Back-Propagation Neural Networks With MATLAB*, Report TR-EE 92-39, School of Electrical Engineering, Purdue University, West Lafayette IN

Newbury, N., Newman, M., Ruhl, J., Staggs, S. & Thorsett, S. (1991) *Princeton Problems in Physics with Solutions*, Princeton Univ. Press, Princeton NJ

Nishio, Tomoyuki (1990) An Investigation of Correlation Possibility in Neurocomputing and Quantum Mechanics, *Proc. of the Int'l Conf. on Fuzzy Logic & Neural Networks*, Iizuka, Japan, July 20-24, 1990, 503-506

Nomizu, Katsumi (1966) *Fundamentals of Linear Algebra*, McGraw-Hill, New York

Ohanian, Hans C. (1976) *Gravitation and Spacetime*, W. W. Norton, New York

Oster, G. F., Perelson, A., & Katchalsky, A. (1971) Network Thermodynamics, *Nature* 234: 393-399

Pagels, Heinz R. (1985) *Perfect Symmetry*, Simon & Schuster, NY

Peat, F. David (1985) *Synchronicity*, Bantam, New York

Peat, F. David (1988) *Superstrings and a New Theory of Everything*, Bantam, New York

Peirce, Charles Sanders (1991) *Peirce On Signs* (ed., James Hoopes) , Univ. of North Carolina Press, Chapel Hill

Peters, Edgar (1992) *Chaos and Order in the Capital Markets*, Harper-Row, New York

Philippidis, C., Dewdney, C., & Hiley, B. J. (1979) "Quantum Interference and the Quantum Potential", *Nuovo Cimento* 52B, 1, 15-28

Pierce, John R. & Posner, Edward C. (1985) *Introduction to Communication Science and Systems*, Plenum Press, New York

Pietsch, Paul (1981) *Shufflebrain*, Houghton-Mifflin, Boston

Pribram, Karl H. (1977) *Languages of the Brain*, Brooks/Cole, Monterey

Pribram, Karl H. (1990) Introduction: Brain and Consciousness, in E. Roy John (ed.), *Machinery of the Mind*, xxi-xxxvi, Birkhauser Boston Inc., Cambridge MA

Rasmussen, S. et al (1990) Computational Connectionism Within Neurons: A Model of Cytoskeletal Automata Subserving Neural Networks, *Physica D*, Vol. 42, Nos. 1-3, 428-449

Rosen, R. (1985) Organisms as causal systems which are not mechanisms: An essay into the nature of complexity, *Theoretical Biology and Complexity*, Academic Press, New York

Roth, J. P. (1955) The Validity of Kron's Method of Tearing, *Proc. Nat. Acad. Sci.*, Vol. 41

Resnikoff, Howard L. (1989) *The Illusion of Reality*, Springer-Verlag, New York

Sachs, Robert G. (1987) *The Physics of Time Reversal*, University of Chicago Press, Chicago

Schlegel, Richard (1980) *Superposition and Interaction: Coherence in Physics*, Univ. of Chicago Press, Chicago

Schwinger, Julian (1970) *Quantum Kinematics and Dynamics*, W. A. Benjamin, New York

Shankar, Ramamurti (1988) *Principles of Quantum Mechanics*, Plenum Press, New York

Shannon, C. E. and Weaver, W. (1949) *The Mathematical Theory of Communication*, Univ. of Illinois Press, Urbana

Sheldrake, Rupert (1981) *A New Science of Life*, J. P. Tarcher, Los Angeles

Sheldrake, Rupert (1988) *The Presence of the Past*, Times Books, New York

Shepelyansky, D. L. (1987), *Physica* D28, 103ff

Schindler, David (ed) (1984) *Beyond Mechanism: The Universe in Recent Physics and Catholic Thought*, University Press of America, Washington

Schmid, E. W., Spitz, G., Losch, W. (1987) *Theoretical Physics on the Personal Computer*, Springer-Verlag, Berlin

Schneiker, C., Hameroff, S., Voelker, M., He, J., Dereniak, E., & McCuskey, R., (1988) Scanning tunnelling engineering, *Journal of Microscopy*, Vol. 152, Pt. 2, 585-596

Sklar, Lawrence (1977), *Space, Time, and Spacetime*, Univ. of Calif. Press, Berkeley

Squires, E. (1991a) The Dynamical Role of Time in Quantm Cosmology, (pre-publication)

Squires, E. (1991b) Time in a Quantum Universe, (pre-publication)

Squires, E. (1990c) One mind or many - a note on the Everett interpretation of quantum theory, (pre-publication)

Stevens, Roger T. (1989), *Fractal Programming in C*, M&T Publishing, Redwood City

Sutherland, John (1991) A Transputer Based Implementation of Holographic Neural Technology, *Transputing '91*, P. Welch et al (eds.), IOS Press, Amsterdam

Sutherland, John (1992) *HNET User Reference Manual*, AND Corporation, Hamilton, Ontario

Szentagothai, J. (1978) The neuron network of the cerebral cortex. A functional representation, *Proc. R. Soc. Lond.* B 201, 219-48

Szentagothai, J. (1983) The modular architectonic principle of neural centers, *Rev. Physiol. biochem. Parmacol.* 98, 11-61

Tarozzi, Gino & van der Merwe, Alwyn (eds) (1985) *Open Questions in Quantum Physics*, D. Reidel, Dordrecht

Tarozzi, Gino & van der Merwe, Alwyn (eds) (1988) *The Nature of Quantum Paradoxes*, D. Reidel, Dordrecht

Toffoli, Tommaso (1982) Physics and Computation, *Int'l Journal of Theoretical Physics* 23, 165-76

Usher, M. J. (1984) *Information Theory for Information Technologists*, Macmillan, New York

von Neumann, J. (1955) *Mathematical Foundations of Quantum Mechanics*, Princeton Univ. Press, Princeton

Walker, Evan Harris (1970) The Nature of Consciousness, *Mathematical Biosciences* 7, 131-78

Walker, E. H. (1972) Consciousness in the Quantum Theory of Measurement Part 1, *Journal of the Study of Consciousness* 5, 46-63

Walker, E. H. (1972) Consciousness in the Quantum Theory of Measurement Part 2, *Journal of the Study of Consciousness* 6, 257-77

Warner, Seth (1965) *Modern Algebra, Vols. I & II*, Prentice-Hall, New York

Watanabe, Satosi (1969) *Knowing and Guessing: A Quantitative Study of Inference and Information*, John Wiley, New York

Wesley, J. P. (1984) A Resolution of the Classical Wave-Particle Problem, *Foundations of Physics* 14, No. 2, 155-70

Wheeler, John Archibald (1) (1982) The computer and the universe, *Int'l J. of Theor. Physics* 21, 557-572

Wheeler, John A. & Zurek, W. H. (eds) (1983) *Quantum Theory and Measurement*, Princeton University Press, Princeton

Wiener, Norbert (1961) *Cybernetics: or Control and Communication in the Animal and the Machine*, 2nd ed., MIT Press, Cambridge MA

Wolf, Alan, Swift, Jack B., Swinney, Harry L., & Vastano, John A. (1985) Determining Lyapunov Exponents from a Time Series, *Physica 16D*, 285-317

Wolfram, Stephen (1984) Cellular automata as models of complexity, *Nature,* Vol. 311, No. 4, 419-24

Wolfram, Stephen (1985) Undecidability and Intractability in Theoretical Physics, *Physical Review Letters* 54, No. 8, 294-97

Wolfram, Stephen (ed) (1986) *Theory and Applications of Cellular Automata,* World Scientific, Singapore

Young, Arthur M. (1980) *Which Way Out? and Other Essays,* Robert Briggs Associates, San Francisco

Zambrini, J. C. (1986) Variational processes and stochastic versions of mechanism, *Journal of Math. Physics,* 27, 2307

Zeh, H. D. (1970) On the Interpretation of Measurement in Quantum Theory, *Foundations of Physics* 1, No. 1, 69-76

III. References Pertaining Primarily to the Internship

Abbreviations:
IEE_89 = Proc. of the First Int'l IEE Conference on Neural Networks, IEE Press, London, 1989

NATUG1_89 = Proc. of the First Conference of the North American Transputer Users' Groups, Salt Lake City UT, April 5-6, 1989
NATUG2_89 = Proc. of the Second Conference of the North American Transputer Users' Groups, Durham NC, Oct. 18-19, 1989
NATUG_90 = Proc. of the Third Conference of the North American Transputer Users' Groups, Santa Clara, CA, April 26-27, 1990

Abbruzzese, Francesco (1988) A Transputer Implementation of a McCulloch & Pitts Network, in Chiricozzi, E. & D'Amico (eds), *Parallel Processing and Applications*, Elsevier Science Publishers, North-Holland

Aleksander, Igor (ed) (1989) *Neural Computing Architectures*, North Oxford Academic Publishers, Oxford

Allinson, N. M., Brown, M. T. & Johnson, M. J. (1989) {0,1}n Space Self- Organising Feature Maps - Extensions and Hardware Implementation, *IEE_89*

Anderson, James A. & Rosenfeld, Edward (eds) (1988) *Neurocomputing: A Reader*, MIT Press, Cambridge MA

Bennett, C. H. (1973) Logical reversibility of computation, *IBM Journal of Res. Devel.* 6, 525-32

Bennett, C. H. (1983) On various measures of complexity, especially 'logical depth', Lecture at Aspen (IBM Report)

Bennett, C. H., Brassard, G., Breidbart, S. & Weisner, S. (1983) Advances in crptography, *Proc. of Crypto 82*, Plenum Press, NY

Board, John A. Jr. & Shue-Jen Lu, Jeffrey (1989) Performance of Parallel Neural Network Simulations, *NATUG2_89*

Catterall, W. A. (1986) Molecular properties of voltage-sensitive sodium channels, *Annual Review of Biochemistry*, Vol. 55, 953-985

Churchland, Paul (1989) Cognitive Neurobiology: A Computational Hypothesis for Laminar Cortex, *Biology and Philosophy* 1, 25-51

Churchland, Patricia (1986) *Neurophilosophy*, MIT Press, Cambridge MA

Daugman, J. G. (1990), An Information-Theoretic View of Analog Representation in Striate Cortex, in Schwartz, E. (ed.), *Computational Neuroscience*, MIT Press, Boston

Defense Advanced Research Projects Agency (DARPA) (1988) *DARPA Neural Network Study*, AFCEA International Press, Fairfax

Dudziak, M. J. (1990) Partitioned, replicative neural networks for cooperative robot systems, *NATUG_90*

Dudziak, M. J. (1991) Proposal for Endophysics and Pattern Recognition Laboratory, *SGS-THOMSON Microelectronics internal document*

Duranton, M & Mauduit, N. (1989) A General Purpose Digital Architecture for Neural Network Simulations, *IEE_89*

Edelman, Gerald M. (1987) *Neural Darwinism*, Basic Books, New York

Feild, William B. Jr. & Navlakha, Jainendra K. (1989) Transputer Implementation of Hopfield Neural Network (in press 1989)

Forrest, B. M., Roweth, D., Stroud, N., Wallace, D. J. & Wilson, G. V. (1987) Implementing Neural Network Models on Parallel Computers, *The Computer Journal*, Vol 30, No. 5 (1987), 414-19

Fredkin, Edward & Toffoli, Tommaso (1982) Conservative Logic, *Int'l J. of Theor. Physics* 21, Nos. 3/4, 219-53

Gaudiot, J. L., von der Malsburg, C. & Shams, S. (1988) A Data-Flow Implementation of a Neurocomputer For Pattern Recognition Applications, *Proc. of the 1988 Applications of Artificial Intelligence Conference*, Dayton, Ohio, October, 1988

Grabec, Igor (1989) The Second Maximum-Entropy Principle and Self-Organization (to be published in Biol. Cybernetics)

Grossberg, Stephen (1987) *The Adaptive Brain*, North-Holland, Amsterdam

Grossberg, Stephen (ed) (1988) *Neural Networks and Natural Intelligence*, MIT Press, Cambridge MA

Guy, H. R. & Seetharamulu, P. (1986) Molecular model of the action potential sodium channel, *Proc. National Academy of Sciences U. S. A.*, Vol. 83, 508-512

Guyot, Frederic, Alexandre, Frederic, Haton, Jean-Paul & Burnod, Yves (1989?) The Cortical Column, A New Processing Unit for Cortex-Like Networks, CRIN/INRIA & Institut Pasteur (unpublished paper)

Hillis, W. Daniel (1986) *The Connection Machine*, MIT Press, Cambridge MA

Hoffman, Geoffrey W., Benson, Maurice W., Bree, Geoffrey M. and Kinahan, Paul E. (1986) A Teachable Neural Network Based on an Unorthodox Neuron, *Physica* 22D, 233-46

INMOS, Ltd. (1993) *The T9000 Hardware Reference Manual* (1st ed.), INMOS, Ltd., Bristol, England

INMOS, Ltd. (1991) *The Transputer Development and iQ Systems Databook* (2nd ed.), INMOS, Ltd., Bristol, England

INMOS, Ltd. (1989) *The Transputer Databook* (2nd ed.), INMOS, Ltd., Bristol, England

INMOS, Ltd. (1989) *The Transputer Applications Notebook: Systems and Performance* (1st ed.), INMOS, Ltd., Bristol, England

INMOS, Ltd. (1989) *The Transputer Applications Notebook: Architecture and Software* (1st ed.), INMOS, Ltd., Bristol, England

INMOS, Ltd. (1988) *OCCAM 2 Reference Manual*, Prentice Hall, New York

Kamangar et al (1989) Implementing the back-propagation algorithm on the Meiko parallel computing surface, *Proc. of the First Int'l Conference on Applications of Transputers*, Liverpool, UK, August 23-25, 1989

Kanerva, Pentti (1988) *Sparse Distributed Memory*, MIT Press, Cambridge MA

Lee, F. H. & Stiles, G. S. (1989) Parallel Simulated Annealing: Several Approaches, *NATUG2_89*

Margolis, Norman & Toffoli, Tommaso (1989) Cellular Automata Machines, in Doolen, Gary, et al (eds), *Lattice Gas Methods for Partial Differential Equations*, Addison-Wesley, Reading

Muhlenbein, H. (1989) The dynamics of evolution and learning-towards genetic neural networks, *Int'l Conf. on Connectionism in Perspective*, Zurich, (in press 1989)

Obermayer, K., Heller, H., Ritter, H. & Schulten, K. (1990) Simulation of self-organizing neural nets: a comparison between a transputer ring and a connection machine CM-2, *NATUG_90*

Oglesby, J. & Mason, J. S. (1989) Dynamic Scheduling For Feed-Forward Neural Nets Using Transputers, *IEE_89*

Priese, Lutz (1976) On a Simple Combinatorial Structure Sufficient for Syblying Nontrivial Self-Reproduction, *Journal of Cybernetics* 6, 101-37

Reilly, Douglas L., Cooper, Leon N., & Elbaum, Charles (1982) A Neural Model for Category Learning, *Biological Cybernetics* 45, 35-41

Reilly, Douglas L., Scofield, Christopher, Elbaum, Charles, & Cooper, Leon N. (1987) Learning System Architectures Composed of Multiple Learning Modules, *Proc. of the IEEE First Annual Int'l Conf. on Neural Networks, June 1987*, IEEE Press, NY

Rosenfield, Israel (1988) *The Invention of Memory*, Basic Books, New York

Soucek, Branko (1989) *Neural and Concurrent Real-Time Systems: The Sixth Generation*, John Wiley & Sons, New York

Soucek, Branko & the IRIS Group (1992) *Fuzzy, Holographic, and Parallel Intelligence*, John Wiley & Sons, New York

Takada, Hiroshi (1989) Implementation of Neural Networks on Parallel Systems," *Second Int'l Transputer Conference, Belgian Institute for Automatic Control*, Antwerp, Oct. 23-24, 1989

Toffoli, Tommaso (1977), Computation and Construction Universality of Reversible Cellular Automata, *Journal of Computer and System Sciences* 15, 213-31

Toffoli, Tommaso (1980) Reversible Computing, MIT Laboratory for Computing Science, Cambridge MA

Toffoli, Tommaso (1984) CAM: A High-Performance Cellular-Automaton Machine, *Physica* 10D, 195-204

Toffoli, Tommaso & Margolus, Norman (1988) *Cellular Automata Machines: A New Environment for Modeling*, MIT Press, Cambridge MA

Vanhala, J. & Kaski, K. (1989) Simulating neural networks in distributed environments, Proc. of the 11th technical meeting of the Occam User Group, Edinburgh, Scotland, 25-26 September, 1989

Villareal, James & McIntire, Gary (1987) Simulation of Neural Networks Using a Transputer Array, *Proc. of the 1987 Space Operations Automation and Robotics Conference*, Houston, Texas, 1987

von Neumann, John (ed. & compl. by Arthur W. Burks) (1966) *Theory of Self-Reproducing Automata*, Univ. of Illinois Press, Urbana

Wasserman, Philip D. (1989) *Neural Computing: Theory and Practice*, Van Nostrand Reinhold, New York

LIST OF FIGURES

APPENDIX 1

Computing Development for Phi Factory Work at Novosibirsk

M. Dudziak, S. Levitan, E. Solodov, J.A. Thompson, C.M. Valine

March 23, 1993

1 Summary

The University of Pittsburgh is presently collaborating with the Budker-INP physics institute at Novosibirsk with the CMD2 at the present VEPP-2M, with an eye toward the successful utilization of the Φ-factory planned to be built there. Members of this collaboration and others have discussed the physics and other aspects of this work in the literature and at various planning conferences. [1,2,3,4,5,6,7], [8,9,10], [11,12,13], [14], [15,16,17], [18,15,16,17,19].

The primary physics goals are study of K_S physics, with a hope for a measurement of ϵ'/ϵ, the parameter which measures direct CP-violation in neutral kaon decays, at the level of 10^{-4}. This parameter is a test of the consistency of the standard model. It can be zero in a model proposed by Wolfenstein [8,9], but the two current measurements are still consistent with zero, and are inconsistent at the two standard deviation level with each other. [20,21]. Subsidiary physics goals include the measurement of e^+e^- annihilation into both the leptonic and hadronic channels, important for interpretation of the muon g-2 measurement, quark structure studies of the Φ and f_0, rare Φ and η decays, and CPT and quantum mechanics tests which can only be done in a coherent state like the Φ factory.

Our plan for successful phi factory work includes progress on several fronts:

1. development of accelerator concepts and their practical realization to achieve the required high luminosities of order $10^{33} cm^{-2} sec^{-1}$
2. upgrade of the detector, using a liquid Xenon calorimeter for good spatial and energy resolution for π^0's;
3. simulation and planning of how to use the data to control the sytematic errors at the level required to measure ϵ'/ϵ
4. development of fast and accurate computer support, both online and offline. The computer development is critical to the success of the project. The expected heavy data acquisition load of about 10 Mbytes per second, for example, is similar to the load presently envisioned for the GEM detector at the SSC. Even this heavy load assumes that only 20% of the Φ decays need to be recorded, and

the remaining 80% of the Φ decays can be classified and sufficient information calculated online and stored for for later calibration use to control the systematic uncertainties in the high statistics analysis.

This proposal asks for money to support the computer development aspects of the project. Pittsburgh's involvement in the physics studies and some visits relating to accelerator development are covered by Thompson's existing DOE grant.

Data acquisition, track reconstruction, and particle identification are important problems generally in high energy physics experiments. In our case, the high data load, the necessity to reconstruct nearly all events, and the importance of reliable particle identification using ionization patterns, give an opportunity to explore new techniques in communications, data throughput, and pattern recognition, which may be of use in other contexts.

The data acquisition system proposed for CMD3 is based on transputers embedded in a VME framework. Such a system promises low cost to speed ratios and allows development at present lower data rates and later straightforward extension to high data rates.

In addition, speed and parallelization of the code will be studied. Alternate algorithms and techniques will be studied, including applications of neural net techniques, either to improve reliability, to improve speed, or as a debugging tool to understand the present standard reconstruction codes. A common concern about the use of neural net techniques is their dependence on the details of the training set and possible resulting biases. For this reason the neural net techniques would not be used except in a subsidiary or complementary fashion until (or unless) they are shown to have adequate bias control. Since the primary codes will not be based on neural nets, there will be a natural opportunity to evaluate both relative speed and relative reliability of the neural net code relative to straightforward extensions of present code. Whether or not the neural net code replaces the more standard code (particular delicate at the trigger stage), study of neural net results will be a useful debugging tool and has already begun to point to areas of useful refinement of the standard code.

The input of participants interested in these questions from a computer science perspective will allow independent development and bias studies beyond that which would occur if only high energy physics personnel were involved. The participation of high energy physics personnel will encourage practical applications to be developed.

1.1 History of the Project

The Pittsburgh involvement in the Novosibirsk project arose from Thompson's 6-month NAS exchange visit at Novosibirsk in the fall of 1989. A cooperative research agreement has been signed between the University of Pittsburgh and INP to further this research.

Both the Frascati laboratory in Italy and the Institute of Nuclear Physics at Novosibirsk are planning to build such a Φ factory, each hoping to begin operation in 1995/96. In the short term, a lower luminosity machine, the upgraded VEPP-2M, of expected luminosity $\approx 10^{31}$ is now operational at Novosibirsk and is allowing preliminary studies of much of the interesting physics as well as a test of the suggested analysis strategies for the full luminosity machine. The DOE support of the University of Pittsburgh collaboration with the Budker Institute of Nuclear Physics in Novosibirsk focusses on the near-term physics with VEPP-2M which is relevant to understanding the problems to be faced at the planned Φ-factories. Physics conclusions from these studies will be interesting in themselves and the technical conclusions will be useful in understanding the functioning and systematic problems in detectors planned for use at future Φ-factories in Italy and Russia.

The physics program for the CMD2 detector at VEPP-2M started in late 1991 with initial debugging, then a scan of hadron production over center of mass energies in the range of the machine from 360 MeV to 1400 MeV. These results are important in interpretation of the muon g-2 measurements. The measurements near the phi will allow a new measurement of the phi width, new precision measurements of the 4 major decay modes of the phi, limits on rare decay modes of the phi and eta, and a new limit on the CP-violating decay $K_s \rightarrow \pi^+\pi^-\pi^0$ and other K_s physics.

The CMD2 detector at the VEPP-2M accelerator is a barrel/end cap geometry calorimeter with a high precision central drift chamber. CMD2 uses a CsI barrel calorimeter and a BGO end cap calorimeter and has only rough radial segmentation. The CMD2 detector is similar to detectors planned at future Φ-factories, and ideas about planned Φ- factory detectors and analyses can be tested in the CMD2 running. In particular, from this early data taking, there is a chance to compare the calorimeter response to that expected from simulations, to give confidence in the simulation techniques. The data in the range of the Φ-will be used for studies of the important Φ-factory processes.

The University of Pittsburgh group is closely involved in the thinking and planning of two projects: a) study of the $\Phi \rightarrow S^\star\gamma$, [11,12,13] and b) studies of the channel: $\Phi \rightarrow K^0K^0 \rightarrow \pi^+\pi^-\pi^+\pi^-$ [14] of particular interest for quantum mechanics tests similar to EPR paradox questions [15,17,16] and preparations for CPT violation measurements [19], as well as efficient rejection of the normal K_{long} three body decays. Pittsburgh contributes to these physics topics mainly through simulation studies and limited analysis, (students supervised by Thompson, and with the help of visitors from BINP using the computer facilities here.

1.2 Pittsburgh Interests in Data Acquisition

Because of its central role in the success of the Φ factory, Pittsburgh is also interested in the data acquisition upgrades and computer algorithm performance studies. For these aspects of the work, we would be joined by Steve Levitan, (Pitt electrical engineering professor interested in fast computer codes, (Craig Valine, (Pitt electrical engineering graduate student), and Martin Dudziak (consulting scientist previously with Thomson INMOS, a major supplier and developer of transputers). Levitan and Valine are interested in joining in the algorithm investigations, including their implementation in the transputer network. Dudziak is interested in both the implementation of the transputers in a fast data acquisition system which exploits their parallelism and studies of the performance codes, especially comparison of neural net techniques with techniques more standard in high energy physics. Valine has begun some preliminary investigations including learning about the present code and collaboration with Dudziak on simple neural net studies of the drift chamber pattern recognition. These preliminary studies have already yielded some ideas about necessary checks of the standard algorithms.

Close collaboration with the BINP personnel is necesary to ensure that the work carried out by U.S. personnel here is timely and appropriate to the detector conditions. Thompson's present physics collaboration keeps her in close communication with the BINP work, particularly with senior CMD2/3 personnel S. Eidelman, E. Solodov, and B. Khazin. Solodov has been a moving force behind the development of the CMD3 detector proposal, particularly the triggering and data preprocessing work described here. In order for the work to be effective, we anticipate a long term stay for Valine in Novosibirsk working on the transputer hardware, and short term visits, about 4 a year (two of our personnel to BINP and two of BINP personnel here). From our side we must be sure of Valine's effective integration into the BINP work and be present to understand more fully local developments. From their side, wider contacts with general developments in the U.S. is desirable, as well as visits which allow intensive computing on the Pittsburgh facilities, either at the University of Pittsburgh or at the Pittsburgh Supercomputing Center.

The preparation of this proposal by Dudziak, Levitan, Solodov, Thompson, and Valine during a visit of Solodov to the University of Pittsburgh is an example of the close collaboration which is essential for good progress and results.

2 Summary of Relevant CMD3 Technical Plans

2.1 Counting and Trigger Rates

The trigger and counting rates have been developed in detail by Solodov and are discussed in more detail elsewhere [2,?]. Here we summarize the ideas essential for the present discussion.

1. At the maximum designed luminosity of 3x$10^{33} cm^{-2} sec^{-1}$ the rate of decays from the Φ will be about 12KHz, and the rate of Bhabha (e+e- scatters) will be about 60kHz. In addition to events recognized as Bhabha's in the detector, an important background comes from Bhabha events hitting focussing solenoids and producing showers and secondary gammas, which could give additional photons in the calorimeter. The rate of such events is about 120 kHz. The machine design incorporates special scrapers and plans for localization of the places where losses occur. These efforts are expected to reduce particle losses in the vicinity of the CMD3 detector to about 30 kHz.

   In all, about 200 kHz of particles will hit the detector.

2. Interesting events must be classified for further study. For events not kept, sufficiently detailed calculations must be stored to allow normalization and control of systematic errors in the delicate CP-violation and other studies.

   The most important aspect of the systematic studies for the ϵ'/ϵ measurement is the determination of the vertex resolution. The normal decays of the charged and neutral kaons are important for this work. For this reason, there is a special burden on the front end trigger and event preprocessing electronics. Initially we would expect to run at lower luminosity, in the early stages of the machine operation, fine-tuning the trigger and preprocessing, studying all events carefully, and moving to storage of only a sample of the normal decays in running at full luminosity. In this way we expect to keep the total data acquisition load to 10 Mbytes/sec.

As described in Appendix I, the CMD3 group believes that it will be possible to limit full reconstruction to only 10% of the Φ decays, or about 1kHz of events. For the rest, pattern recognition and some shorter calculations will be required. For this assumption, which implies about 5 Mbytes of data transfer to the storage devices, a data acquisition system close to the necessary parameters has been designed in INP, Novosibirsk (Proceedings of the V international Conference Instrumentation for colliding beam physics, 1990, Novosibirsk. S. Baru et al, p. 432). The block diagrams from this work are presented in fig.1 and fig.2. A special processor for vertex finding in the drift chamber is proposed.

2.2 Transputers for CMD3 Online Computing and Data Acquisition

The main idea of this system is to create enough computing power to provide full reconstruction of all events in real time. At a 1 kHz event rate the reconstruction time should be around 1 millisecond. The CMD-2 reconstruction program for these events requires 200 milliseconds per events on the micoVAX 3600. These results indicate ascale of required power as 200 microVAXes 3600. At the moment, for a reasonable price this computing power could be built only using a microprocessor architecture. For the starting phases of this project, as a cell processor, one expects to use transputers of the T800 series (INMOS). Relative to other microprocessors transputers have some important features:

1. Transputers have 4 serial built-in high speed (1.5-2.2 MB/s) I/O channels-links, working in parallel and independent of the central processor. It will provide transportation of data between different parts of the reconstruction line. These connections may be built using optical fibers to protect from the accelerator electrical noise.

2. Transputers have a built-in program manager which allows the running of any number of parallel tasks in a time sharing mode with a very fast switching from task to task of 0.6 microseconds.

3. For parallel programming the transputer architecture is supported by high level programming languages (OCCAM, F-77, C), allowing connections and syncronization of tasks without operation system.

4. The computing power is very high with very low price.

Table I: Transputer Costs and Performance

Processor	Power (MWH/s)	Price/unit
microVAX 3600	2.9	15-20 k$
IMS T800-20	4.0	315 $
IMS T800-30	6.0	400 $
IMS T805	??	??
IMS T9000	25-30	500-1000 $

All these features allow the creation of one, two or three dimensional computing structures of the systolic type. For on-line computing at the Φ factory, about 200 of the T800 transputers would be required, fewer of the higher numbered versions. There are different ways of integrating transputers into a data acquisition system:

1. To use only serial I/O channels for data input.

2. To use a transputer bus system (parallel I/O) for data input and serial links for transputer connections.

3. To use standard VME, MULTI-bus or other system for data input and serial links for transputer connection.

The first method would be too slow for the *Phi* factory. The third one is the most common way of integrating transputers into a system which has sufficient data input speed.

The block diagram of the proposed system is shown in fig.1.

The first level of the system consists of a line of transputer modules (TM), installed into a standard bus (VME, FASTBUS ...). The bus interface must provide data to the transputer memory in DMA mode with a speed of 10-15 MB/seconds. At that level transputers receive detector data and perform some part of the reconstruction program. Then the results of this work are transported to a second level of the system.

The minimum number of the TM in the first level depends on the ratio (Bus speed)/(output serial links speed). If only one serial link is used this ratio is around 10, and at a total event rate of 1 kHz, each TM requires about 10 milliseconds for the reconstruction program. The second level consists of a line of TM, connected to a first level TM by serial links. The exact topology depends on how the reconstruction program will be " disassembled" to elementary processes, either with a parallel processing or "pipeline" technique.

An example of a possible topology is presented in fig. 2. The second level may be divided into sublevels. At the last sublevel the recording of events onto hard magnetic media is provided.

The second level can be removed from the first one to a long distance, which helps to transport data from the high noise level of frontend electronics to the control room of the detector.

```
 --------------------------------------
!                                      !
!          Second level                !
!                                      !
 - -------------------------------------
     !                             !
     ! LINK  1.5 MB/s              ! LINK
     !                             !
   ------                        ------
   ! TM !      First level       ! TM !
   ------                        ------
     /\                            /\
     ||    .   .   .   .   .   .   ||    DMA
     \/        10-15 MB/s          \/
<=======================================> VME, FASTBus, ...
```

Figure 1: CMD3 Proposed Trigger and Data Acquisition System

3 Computer science Background

This section describes the use of connectionist algorithms in track reconstruction and classification. A brief description of the overall context of such algorithms is given, both from the computer science and from the high energy physics perspective, and anticipated applications in this case are described.

3.1 Introduction

Applications of connectionist (neural network) algorithms to problems in HEP have included track finding [22,23], calorimeter clustering [24], jet type [22] , jet-jet mass reconstruction, jet flavor tagging, hodoscope correlations [23], photon pairings in the presence of backgrounds [25], and particle identification [23,26]. These studies have demonstrated the usefulness of the neural net approach for feature-based discrimination tasks, with special success in the area of particle identification through the combination of redundant pieces of information, no one of which is determining in itself.

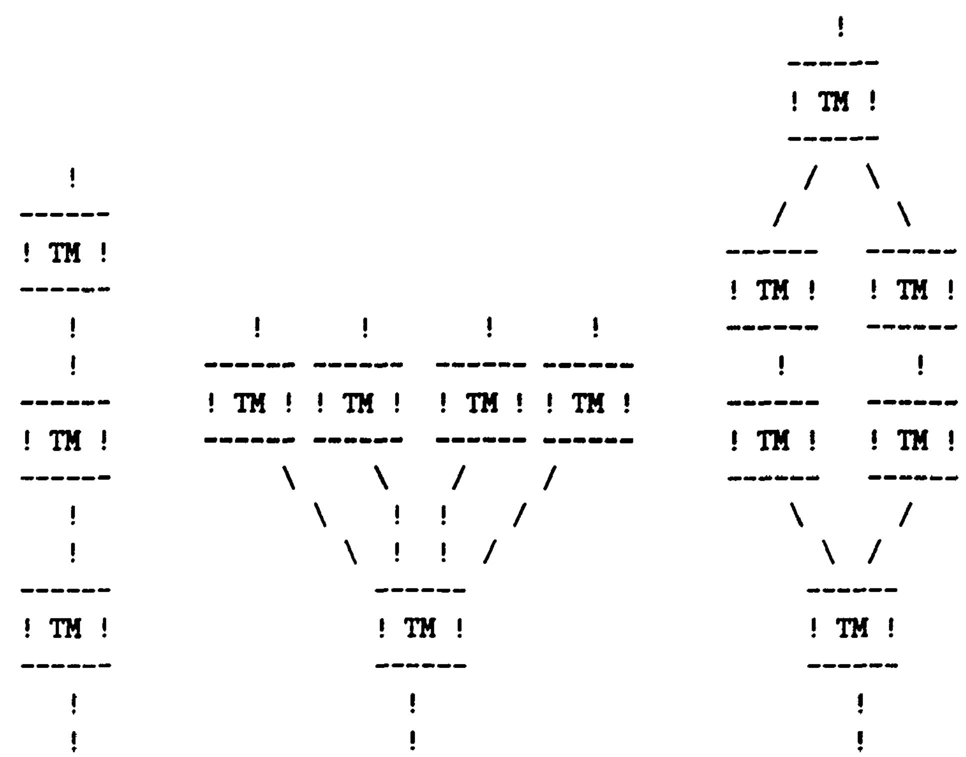

Figure 2: Possible Transputer Topologies in the CMD3 Trigger and Data Acquisition System

3.2 Proposed connectionist investigations in CMD3

We are considering two possible ways to use neural nets within the Phi Factory work. One would be for particle identification, using previously reconstructed tracks and ionization patterns. The particle identification problem can be approached in conventional codes via a maximum likelihood approach and, as previous successful work shows, seems to lend itself well to neural net techniques. The new aspect we would bring to this use of neural nets would be our high need for reliability and the importance of particularly thorough bias testing. The neural net techniques would not be used as a primary method, but would be studied as a parallel activity, because of the interest of M. Dudziak and some members (Y. Merzlyakov and A. Chertovskik) of the computer science support group at BINP.

The problems we propose to examine within the CMD3 and future Phi Factory experiments using neural computational methods are of general interest in high energy physics. Enough work has been done to indicate that advantages may arise from the use of neural net techniques, but also that one must be very careful in avoiding biases. Our application is sensitive to biases and we hope to learn something about techniques for controlling biases from our work.

In our case, since we are looking for small effects of order 1 in a million, we would use neural nets as a substitute for the standard code only if a) they represented a substantial speed improvement over conventional techniques and b) they could be shown to be highly reliable and efficient. Efficiencies must be high and the study of systematics and efficiencies must be well under control to reach the desired accuracy of 10^{-4} in ϵ'/ϵ. Because of the stringent redundancy check requirements, all events must be treated and classified and some quantities such as effective masses or vertex positions calculcated.

The track reconstruction algorithm is described in Appendix I. Briefly, it consists of:

1. finding track segments in individual cells in the drift chamber
2. looking for overlaps or cell-crossings between cells in the same layer of the drift chamber (inner, middle, or outer).
3. looking for long tracks which connect layers
4. combining recognized tracks and possibly extra hits to give an overall classification of the event and calculation of required parameters.

Existing algorithms apply histogramming and statistical pattern recognition techniques and have been developed and refined by several groups in the HEP community. [?] Algorithms based on these standard approaches will continue to form the core analytical approach used within the CMD3 project and it is for the performance improvement of these algorithms that the transputer-based parallel processing architecture is being designed. However, preliminary investigations by Dudziak, in collaboration with Solodov, Thompson, and Valine, indicate the potential feasibility and advantages of using neural networks to complement the established histogramming algorithms.

3.3 Brief Description of Work to Date

In order to begin to study the application of neural net algorithms to drift chamber data, it was decided to start with a simple task: compare the efficiency of the neural net algorithm to the standard reconstruction techniques. The time information for each of the six wires in a cell was binned crudely into bins of 100ns each (about .4 cm) . A holographic (neural) net algorithm examined a grid of wire number versus time bins as input, with a statement of whether or not the track was recognized by the standard algorithms as output. After a few hours of training on a sample of about 350 events, (where an "event" is a track fragment in a cell), a (different) sample of 350 independent events was found to be recognized correctly in 90 % of cases, with the neural nets more permissive than the standard algorithms. (The neural nets find about 10% extra segments compared to the standard algorithms and miss about 2 % of segments found by the standard algorithms. Causes for the disagreements are being studied. This preliminary investigation has thus already led to an interesting idea: examining the standard algorithm failures for possible recovery, since decays of particles in flight can spoil the recognition of straight line segments in a given cell. In this sense, even this preliminary limited exploration has indicated a promising line of development for improvement of the standard algorithms. Thus, we see that the neural net approach offers useful insights at least as a complement to the usual methods.

It is too early to tell whether the speed advantages and security against bias of the neural net routines will be sufficiently compelling for the neural net routines to supplant the standard algoritm approaches.

Analysis On the basis of our preliminary investigations we believe it is possible that connectionist algorithms can, in combination with the histogramming algorithm, provide a higher degree of accuracy in track segment detection, track reconstruction, and interaction-type classification, than the standard method alone.

Efficiency of current methods is being studied, and the neural nets will help in that study. A connectionist model may be able to attain greater accuracy through its adaptive capabilities and in particular through better handling of incomplete or noisy drift chamber hit data. If this improved accuracy would indeed be the case, neural networks will be useful for HEP experiments at this lower level of data acquisition and can play an important role in experiments other than that of CMD3 and the Φ Factory.

Performance – Speed, Parallelism, Networking If the connectionist approach provides equivalent but not necessarily superior analytical benefits to the traditional approach, then one must weigh the advantanges of using one method instead of the other. Neural nets adapt well to parallel computing architectures and there are a number of specialized neural hardware implementations available, in addition to general-purpose parallel processors. Potentially the neural network algorithm can provide improvements in performance speed that would then reduce the complexity and expense of hardware required for the data acquisition system. This would be an implementation advantage that could also be extended to a variety of HEP experiments.

The [Preliminary] Neural Net Tracking Hypothesis We formulate the following statement as an element of this proposal:

A connectionist algorithm can be effectively employed to identify track segments within drift chamber cells and to correlate these segments into whole tracks which can then be classified according to the type of particle interactions that are allowable.

This line of research has developed as an ancillary topic within the CMD3 project. However, its outcome could play a significant role in the future design of detection equipment and software within HEP and related domains outside of HEP where high-speed data acquisition and classification tasks are critical. Consequently, an important goal within this project has emerged to determine the validity of the Neural Net Tracking Hypothesis.

Methodology Work currently underway by the proposal technical team has led to the selection of several candidate neural network architectures for consideration in this project. These include the Holographic Network architecture developed by J. Sutherland [27], a model that diverges significantly from the traditional feed-forward and

Hopfield/Boltzmann classes of neural nets. Currently this model is the primary algorithm under investigation for application to the track detection/reconstruction problem. A standard back-propagation model will be applied to the problem for purposes of a 'control' by which to measure the performance and accuracy of the holographic network. The reasoning here is that back-prop networks have been used so widely in a variety of applications within HEP that they offer a methodological 'benchmark' against which other models can be tested. It is our preliminary judgment that the holographic network offers many strengths not found in back-prop and other feed-forward models but there have been very few other studies using the holographic net against which our research can be compard. One other neural network, however, that will be studied under the auspices of this project include the Adaptive Resonance (ART) model (Grossberget al [28]), because of its utility for developing new categories and classes within an observation set. Performance considerations may rule out the use of the ART network for anything other than off-line processing, but in our judgment it merits consideration.

Holographic Neural Network Model Conventional connectionist models, while they vary widely in design, most typically perform their adaptive learning tasks through the adjustment of weighted connections between nodes or cells. These cells correspond very loosely to threshold-driven functions modeled after biological neurons and are typically arranged in a number of layers so that the data flow from input pattern to output classification is a kind of percolation through the various interconnected cell layers. This picture is most clearly the case in feed-forward models, of which back-propagation is one common variety.

The holographic model developed by Sutherland [27] maps patterns consisting of features (stimuli) to response vectors, using a multidimensional complex domain for storage of the learned (trained) associations. It is in some respects a 'non-connectionist' neural model in which, due to the encoding process (mathematically similar to principles of digital holography), a very large number of stimulus-response mappings can be enfolded onto a single set of complex array elements, and learning can occur within a very small number of encoding operations. There is no feedback of an error term and no hidden layers or arbitrary parameter settings. The principal mathmatical basis lies in the representation of both stimulus and response as a sequence of patterns over time and in the translation of a scalar value into a complex form wherein phase represents analog information and magnitude corresponds to confidence or certainty in that phase value. A stimulus pattern defined by:

$$s = \{s_1,\ s_2,\ s_3, \ldots,\ s_N\} \tag{1}$$

is mapped into the complex domain according to:

$$s(k) -> lambda(k) ei0(k) \tag{2}$$

Encoding occurs within the complex correlation matrix, associating stimulus element k to response j by the product:

$$xk, j = sk.rj \tag{3}$$

where

$$sk = lkei0kandrj = gjei0j \tag{4}$$

In canonical form, encoding consists of the matrix transformation:

$$[X] = [S]T.[R] \tag{5}$$

and decoding in turn consists of:

$$[R] = 1/c[S] * [X] \tag{6}$$

The normalization cefficient c is a function determined by the stimulus field and is used to normalize the response magnitudes to a probabilistic range (0.0 to 1.0).

The holographic model incorporates an enhanced encoding system that optimizes against the danger, inherent in many neural nets, from a large number of similar trained associations distorting the entire population of mappings and ignoring new distinctive features in future patterns that are encoded. This enhancement process bases future learning rates (attentiveness to new patterns) on the extent to which similar assiciations have previously been learned. Conceptually there are some links here with the principles underlying Adaptive Resonance Theory.

The holographic model is described in detail within Sutherland [1], [2], included within Appendix XXX.

Plans and Methods for Neural Network Experiments The methodology to be employed for analyzing detector output using neural networks will be initially conducted in both Pittsburgh and Richmond using data prepared by Valine under the direction of Thompson and Solodov. Valine will continue this work at Pittsburgh and Dudziak will continue it at Richmond. The HNET software package will be employed along with a standard back-propagation model as a 'control' with which to compare the performance of HNET against a common neural net, in addition to its comparison against the Standard Track Detection Algorithm.

Test data will be of two types:

- simulated hits and computed results {{XXXX Describe more}} produced by the XXX programs

- actual experimental data collected by CMD2 from VEPP-2M in NSK and processed by the standard CMD3 reconstruction programs.

The test data will be supplied to the neural networks via ASCII text files.

All neural network processing will be conducted on PC 386 and/or 486 workstations running DOS and WINDOWS operating environments. The HNET program currently runs only under WINDOWS.

Test data will be prepared from the ASCII source files into a variety of experimental tables using standard editing and utility programs. Records for the inputs and results of each class of experiments will be maintained in an SQL-compatible database.

The results from each run will be saved to disk and processed using both graphics and statistical analysis tools including S-PLUS, a powerful statistics and mathematical modeling package. Tests conducted by the team at Pittsburgh and at Novosibirsk may include analysis using standard HEP programs from the CERN library set, including, but not limited to, the Physics Analysis Workstation (PAW) software available from CERN.

The Experimental Environment for the Algorithm Comparisons Completely simulated event data is produced by the CMD3 Monte Carlo programs (based on the CERN GEANT simulation program) running on the VAX clusters at the University of Pittsburgh computing center (typically a VAX 6000). Thompson was involved in the early setup of the GEANT framework for CMD during her 1989 NAS exchange stay at Novosibirsk. The GEANT framework has now been highly developed by the team of young physicists in the CMD2/3 group (V. Savinov, T. Purlatz, for overall GEANT structure; R. Demina and A. Maksimov for the drift chamber, A. Kuzmin for the CsI calorimeter, A. Numerotsky and M. Shubin for the muon system). The events simulated are for the CMD2 detector presently running at VEPP-2M. This detector is similar to the detector planned for CMD3, and evaluation of its performance is used to develop benchmarks and improvements for CMD3. These simulation results are presently being compared with data from the CMD2 detector, and areas of disagreement with data are being resolved.

To test the standard histogramming algorithms, these simulated events are input to the CMD2 reconstruction programs.

This same simulated event data is then prepared for input to the neural network testbed. The latter consists of a set of database and graphics tools plus the HNET and other neural network programs, all running on a 486-based PC Workstation operating under the Microsoft Windows environment.

4 Plan of Work

4.1 Transputers, and speeding up of Reconstruction Code

After studying the reconstruction code, and ways to improve it or speed it up, Valine will travel to Novosibirsk where he will assist in the installation of the code into the VME/transputer system for the CMD2 experiment. It is expected that he will spend approximately 6 months at the Budker-INP institute in Novosibirsk, then return to Pittsburgh, continuing his studies of algorithms and discussing his results with Levitan and Thompson, before returning to Novosibirsk for approximately another 6 months to complete his work. Part of his master's degree work would include comparing the performance of the code in the transputer system, in the Novosibirsk VAX's and the University of Pittsburgh VAX 6000 cluster, and perhaps in one or more of the machines available through the Pittsburgh Supercomputing Center (to which Thompson's and

Levitan's groups have access through other grants so that a small additional burden for these studies could be included with present work.) Valine has worked with a CRAY-YMP at the PSC in previous work as a data assistant for P. Pomianowski, University of Pittsburgh graduate student.

4.2 Neural nets

Some preliminary ideas for study of the neural net techniques hae been discussed in previous sections. Our plan is to begin with the recognition of single segments in the drift chamber, in order to get experience with the chamber construction and data. Later, it is hoped that the techniques can be expanded to the problem of tracks crossing cells, which presently may be lost, and to overall event recognition, including either overall patterns from the tracking reconstruction, or perhaps extending to also to particle identification.

For the neural net comparisons, as well as for consultations on implementation of the transputer networks, it is expected that Dudziak would make an initial trip to Russia to discuss neural net strategies and comparisons, and then would work primarily in the U.S., with communication by electronic mail and occasional trips to Pittsburgh to discuss progress, particularly during visits of Russian colleagues here. Thompson and Levitan would each make a trip to Novosibirsk over the course of the project, to help in supervision of Valine and consult with Novosibirsk colleagues. And 1-2 trips per year (each of about 6 weeks) of Russsian colleagues here would be required, to compare results between Novosibirsk and here, and to plan continuing strategies for the use of the neural nets and the comparison of their results to those of the standard algorithms. The total travel money requested would be about 4 trips per year (Valine and either Thompson,Dudziak, or Levitan from the U.S. side, and E. Solodov, A. Maksimov, Y. Merzlyakov, or A. Chertovskik from the Russian side.

4.3 Personnel

1. Julia Thompson, Principal Investigator. Thompson's previous experience with high energy physics analysis and present active physics collaboration with the CMD2 collaboration at BINP provides the connection on the U.S. side between the computer science aspects and the high energy physics aspects.

2. Steven Levitan, Co-principal Investigator. Levitan's work with fast computer codes gives experience with a variety of machines, codes, and strategies for pattern recognition.

3. Martin Dudziak, Consulting Scientist. Dudziak's experience with transputers and neural net code is of help in settling technical questions about transputers and setting procedures and strategies for comparison of neural net techniques with the more ordinary reconstruction code. Dudziak is formerly of Thomson-Inmos, and Netrologic Corporations. Dudziak accompanied Thompson on a trip to BINP in May, 1992, in order to evaluate progress with transputers at that time and advise on future development.

4. Craig Valine, Master's degree electrical engineering student. Valine became interested in this field while working as a data analysis assistant for P. Pomianowski. In his work with Ms. Pomianowski he has had substantial programming experience as well as an opportunity to work with the CRAY YMP at the Pittsburgh Supercomputing Center.

5. B. Khazin, Budker-INP, senior scientist and group manager for the CMD2 project. As one of his activities, Khazin also works with the drift chamber reconstruction.

6. Evgeny Solodov, Budker-INP, senior scientist from the Russian side. Solodov is one of the group leaders for the CMD2 project and is responsible for most of the design of the trigger strategies for the CMD3 project, as well as the present CMD2 trigger and reconstruction algorithm.

7. Y. Merzlyakov, senior BINP scientist responsible for the DAQ software for CMD2 and CMD3.

8. A. Chertovskik, junior BINP scientist contributing to the transputer development at BINP.

9. A. Maksimov, junior BINP scientist, manager of the global reconstruction and developing a likelihood function which incorporates all information from the detector.

10. V. Zavarzin, junior BINP scientist working on drift chamber reconstruction and developing DAQ for CMD2.

4.4 Budget Summary

This proposal is for support of the computer development aspects of the project. The salaries for students doing physics analysis for the present VEPP-2M data are covered through the DOE grant. In this grant we ask for:

1. the consultant's fee for M. Dudziak who has the responsibility for the neural net evaluation studies,

2. support and tuition remission for Craig Valine, the EE master's degree student who will be implementing the reconstruction code in the transputers, testing ideas for performance improvement of the code, and working with Dudziak on the neural net tests,

3. support for an undergraduate working on this project

4. 1/2 month salary each for Levitan and Thompson. (?)

5. Related travel and a small amount for miscellaneous computer expenses, are also included. We request support for 4 trips per year, two from our side to BINP and two from BINP here. Expenses of our personnel in Russia are paid

by BINP, and we pay all expenses of BINP personnel in the US. Past practice has been for each side to pay transatlantic plane fare for its own personnel. In this case, however, we request money for the transatlantic plane fare for the BINP visitors to Pittsburgh, since the present econonomic situation is such that the plane fare, even on Aeroflot, can only be paid in hard currency, and the minimum round trip cost is approximately a year's salary. Senior scientists are often required to buy such tickets from their own money, and money for travel for junior colleagues is difficult to arrange. Allowance of this cost would greatly facilitate our collaborative efforts.

6. A small VME test system is also required, adequate for the present tests to assess feasibility of the transputer plan. A more powerful system as the transputer host would be required for the actual construction of the phi factory system. If the present efforts are able to demonstrate feasibility, the cost for the final system would be requested from other sources.

5 Appendix: Details of CMD3 Data Rates and Detector Information

The following signals with corresponding time resolution will be available for use with the trigger system.

- Drift chamber	3690 channels 2 x 2 cm cell	100-200 ns
- Vertex detector	500 channels 5 mm cell VDC	1000 ns
- Fast trigger counter	1300 channels of 10x10 cell	1-3 ns
- LXe calorimeter	1300 towers 10x10 cell 20000 strips	10 ns 3 microseconds
- BGO (CsI) cal.	72 lines 1440 crystals	1 ns 3 microseconds

The first level trigger should use the fastest information from fast counters, LXe towers, BGO(CsI) timing and possibly YES-NO information from DC. If the fast counter is used as a pretrigger and the simpliest coincidences are used, the rate of such a pretrigger will be around 100 kHz. Almost all particles (mostly Bhabha events) give this pretrigger. If one expects not more then 5% of event losses, the first level decision time should not exceed 500 ns. This time should be used to recognize:

- enough points in DC to be a track
- minimum two towers in LXe
- delayed signal from BGO (or CsI)
- minimum two charged crossing fast counter

If there are fired two opposite towers with 500 Mev energy deposition, it is a Bhabha event and should be rejected.

The output rate for the ideal first level trigger should be only connected with Phi resonance production. As shown above it would be about 12 kHz. But it is more realistic with respect to the speed of the detectors and available electronics to aim for event rate suppression by a factor of 10 and assume the rate will be 10 kHz. However, it should be noted that the full 12kHz of Φ decays need to be studied at least enough to classify them, and in many cases certain quantities such as vertex position and effective masses must be stored on tape for normalization and systematic error estimation purposes.

The first level trigger gives a start signal for digitizing fired channels.

The second level trigger has 5 microseconds for a descision if 5% deadtime is assumed. The following tasks should be solved by the second level special processor(s):

1. - to find a vertex in the DC and the invariant mass of the pair
2. - to calculate the number of clasters in the LXe calorimeter and calculate the total energy and invariant mass for each pair to determine pi0s.
3. - are there many charged tracks in DC and no gammas?

If the processor(s) can do it and appropriate cuts are used, the output rate should be around 300 Hz mainly from charged kaon decays. But again it is reasonable to assume, that a factor of 10 is a good number for the second level trigger. It means that about 1000 event/sec should be digitized. If 5% losses are acceptable, the time for digitizing and recording raw data to the memory should be about 50 microseconds.

The third level trigger should make a complete reconstruction of all events in real time.

6 Appendix:Drift Chamber Track Reconstruction Code

The way in which experimental information passes during data processing could be divided into several stages.

```
                    Stage 1.
1) Reading events from the digitizing electronics (KLUKVA).
   (after the first and second level triggers).
2) Third-level trigger.
3) On-line processing.
4) Writing to primary tape ("raw" tape)

                    Stage 2.
 Reading of primary tape.
6) Off-line processing ("pumping") - obtaining the physical
   parameters of registered particles.
7) Writing to secondary tape.

                    Stage 3.
8) Reading of secondary tape, event selection.
9) Plotting histograms, fitting, obtaining physical results.
```

In the case of the phi-factory the background to interesting rare events, such as the CP-violating process $e+e- \rightarrow KsKl \rightarrow pi+pi-pi0pi0$ is produced by ordinary processes with high branching ratio ($e+e- \rightarrow e+e-, mu+mu-, K+K-, pi+pi-pi0$, $KSKL \rightarrow pi+pi-3pi0, 2pi0pimunu$ etc.) Rejection of these events with high reliability is possible only after complete event processing (finding of tracks and obtaining their parameters. This fact leads to unification of 2) and 3) and to transmission of some functions from 6) to 3). In this case the results of on-line processing will be written on a primary tape together with "raw information".

Let us make some estimations of event size. The main part of the information is produced by the drift chamber and LXe calorimeter. The drift chamber has about 30 layers. Taking into account the probability for one particle to hit 2 neiboring wires on the same layer, one can obtain up to 50 hits per track. Each hit produces 6 bytes of information (address, time, amplitude * 2 bytes each). So, the total amount of information per track in the drift chamber is 300 bytes. LXe calorimeter has the estimated transverse shower size of about 10 cm. So, one can get 20 channels * 14 bytes * 4 bytes (address+amplitude) =
= 1.2 Kbyte/shower.

```
The length of typical events:
K+K-                 0.6 Kb

Ks Kl                 4.8 Kb
```

```
3 pions            3.0 Kb
```

For the event size 5 Kb and event rate 1-2 kHz one can get the total flux of information of about 5-10 Mb/s. This could be provided by any backplane bus standard: VME, FASTBUS etc.

We plan to write on tapes about 10-1000 events per second with average length 2 Kbyte, for a total equivalent time of about 10^7 seconds (about one-third of a year, or running time of a year with assumed 30 % combined machine and detector live time).

So the total amount of information to be written is 2*10 Gb. Use of the EXABYTE cassette tape drives seems to the cheapest solution. The capacity of one cassette is 4.5 Gb. So, we should have 10000 cassettes. The tape drives with reading or writing spead of 500 Kb/s are widely used now, and also in our experiment. A few drives should be used in parallel, as can easily be accommodated by a distributed transputer system.

The main problems are connected with processing data from the drift chamber. In spite of its cylindrical symmetry there are several features making the event reconstruction more difficult:

1. High inhomogenity of the magnetic field (up to 30%) due to the influence of the superconducting solenoids installed inside the detector near the interaction point for beam compression.

2. The value and the direction of the drift velocity in the cells of the DC strongly depends on the position and direction of the track.

3. The tracks of the charged particles produced by kaon dacay, could be oriented in any possible direction and could start in any point inside the drift chamber.

For performing the primary search of track segments it is reasonable to divide the DC into regions of such size, that the magnetic field inhomogenity could be neglected at least for the first approximation. For this purpose the inhomogenity inside such regions should be less than 10%. From the other side, each track segment should contain at least 6-8 points. To satisfy these requirements, the drift chamber could be divided into 3 superlayers, being subdivided into 8,16 and 24 sectors correspondingly (counting from the center of the drift chamber to the outside). To perform the segment search, one should select sectors containing the number of hits above a certain threshold. Then the so called "histogramming algorithm" should be applied to each of these sectors. This algorithm is based on projecting all hit points in a sector onto some straight line and plotting a histogram of their distribution for different directions of that line. When the line is approximately perpendicular to a track segment, one could see a sharp peak on the corresponding histogram. Such histogramming is equivalent to dividing a sector into straight parallel strips of a certain direction and width and subsequently plotting the number of hits in each strip. To take into account track curvature, one should replace the straight strips with curved ones, using their curvature as an additional search parameter. At the final stage, the drift time should be also taken into accout by representing each hit as two points shifted by the drift distance from the wire position in the direction transverse to "strips". The algorithm described above represents only one, the most difficult stage of event processing. The general structure of the whole algorithm is shown below.

```
1. Segment search.
   1.1. Selection of sectors containing a sufficiently large
        number of hits.
   1.2. Search for segments in each sector using the
        "histogramming algorithm".
   1.3. Fitting of each found segment with an arc of a circle in
        the R-phi plane.
   1.4. Defining z-coordinates using stereo wires and fitting
        segments by a straight line in z-direction.
2. Linking of segments into tracks.
   2.1. Linking of segments taking into account the inhomogenity of
        the magnetic field.
   2.2. Fitting of the obtained track using equations connecting
        parameters of neighboring segments.
   2.3. Incorporation of points which have not been included yet
        into any segment.
3. Final fitting of the particle trajectory.

4. Secondary vertex search. Fitting of vertex coordinates.
```

Some additional comments are necessary for steps 2.1 and 2.2 of the above algorithm. In a homogeneous magnetic field the following conventional criterion is applied to determine that two segments belong to the same track: the angles of both segments of the line, connecting the centers of segments, should be equal.

In the case of an inhomogeneous magnetic field these angles should be propotional to the integrals of magnetic field along the particle trajectory from the center each segment to the point in the middle between centers of 2 segments . These integrals should be calculated numerically for each pair of segments during track finding.

In the case of a strongly inhomogeneous magnetic field it is very difficult to describe a particle trajectory using one global equation. It is much easier to represent a trajectory as a set of arcs of circles, but with parameters of neighboring arcs connected with certain equations. These equations could easily be obtained from the magnetic field shape. Such a method is known as a "local track fitting".

To realize the event processing at the rate of 1000 events per second we plan to use about 200 T800 transputers working in parallel. There are several ways to organize the parallel processing.

1. Parallel processing of different events. The disadvantage of this method is that each processor should keep the whole program in its memory.

2. Parallel processing of one separate event.

   (a) Performing subsequent stages of algorithm as a pipeline.

(b) Parallel processing of independent parts of information: finding and fitting segments in different sectors, fitting of different tracks etc.

(c) Independent processing of different detector subsystems: drift chamber, vertex detector, calorimeter etc.

It is possible to realize all these methods using a transputer network, connected by fast serial links. In this case the structure of the network should correspond to the structure of the algorithm.

Contents

References

[1] I. Dunietz, J. Hauser, and J.L. Rosner, Phys. Rev. **D35**,(1987) 2166.

[2] S. Eidelman, E. Solodov, and J. Thompson, Nuclear Physics B (Proceedings Supplement) **24A** (1991) 174. (Plans for the Novosibirsk Phi Factory, contribution to the Phi Factory Workshop at UCLA, April, 1990, and PITT-90-08.).

[3] C. Buchanan, R. Cousins, C. Dib, R.D. Peccei, and J. Quackenbush, "Testing CP and CPT Violation in the Neutral Kaon System at a Φ Factory", UCLA/91/TEP/44,November, 1991.

[4] B. Khazin, XXVI International Conference on High Energy Physics, Dallas, August 6-12, 1992.

[5] G. Vignola, XXVI International Conference on High Energy Physics, Dallas, August 6-12, 1992.

[6] P. Franzini,, XXVI International Conference on High Energy Physics, Dallas, August 6-12, 1992.

[7] J. Lee-Franzini,, XXVI International Conference on High Energy Physics, Dallas, August 6-12, 1992.

[8] L. Wolfenstein, "CP Violation and $\overline{p}$ p Experiments", CMU-HEP86-5, 1986.

[9] L. Wolfenstein, Nuclear Physics B, (Proceedings Supplement) **24a** 32 (1991). (Status of CP Violation , UCLA Workshop on Testing CPT and Studying CP Violation at a Phi Factory.).

[10] Summary talks of L. Maiani (p. 719) and R. Baldini Ferroli (p. 665), Proceedings of the Workshop on Physics and Detectors for DAΦNE, Frascati, April, 1991.

[11] See, for example, reviews of L. Maiani, R. Baldini, and F. Close, p. 309, Proceedings of the Workshop for Physics and Detectors at DAΦNE, April, (1991)., Frascati, Italy.

[12] N.N. Achasov and V.N. Ivanchenko., Nucl. Phys. **B315**(1989)., 465.

[13] S. Eidelman, J.A. Thompson, and C.H. Yang, p. 437, Proceedings of the Workshop on Physics and Detectors for DAΦNE, Frascati, Italy, April, 1991.

[14] R. Demina, V. Savinov, and J.A. Thompson, p. 515, Proceedings of the Workshop on Physics and Detectors for DAΦNE, Frascati, Italy, April, 1991.

[15] P. Eberhard, Contribution to the Phi Factory Workshop at UCLA, April, 1990.

[16] Ghirardi, Plenary talk, p. 261, Proceedings of the Workshop on Physics and Detectors for DAΦNE, Frascati, April, 1991.

[17] Talks at dedicated EPR Workshop, UCLA, November 8, 1991.

[18] N.W. Tanner and R. Dalitz, Ann. Phys. (N.Y.),**171**,463 (1096).

[19] Julia A. Thompson, "CPT-Violation: Present Status and Planned Measurements at Phi Factories", , UCLA Mini Workshop on Low Energy Signals from the Planck Scale, October 29-30, 1992.

[20] K. Peach, Blois Conference on CP Violation, 1989, Phys. Lett. B. **206**,169 (1988).

[21] Y.Y. Wah, XXVI International Conference on High Energy Physics, Dallas, August 6-12, 1992.

[22] C. Peterson, "Neural Networks in High Energy Physics", p. 465, Proceeding of the first International Workshop on Software Engineering, Artificial Intelligence and Expert Systems in High Energy and Nuclear Physics, **New Computing Techniques in Physics Research**, ed. D. Perret-Gallix, W. Wojcik, CNRS, Paris, 1990.

[23] B. Denby, "Neural Network Tutorial for High Energy Physicists", p. 481, Proceeding of the first International Workshop on Software Engineering, Artificial Intelligence and Expert Systems in High Energy and Nuclear Physics, **New Computing Techniques in Physics Research**, ed. D. Perret-Gallix, W. Wojcik, CNRS, Paris, 1990.

[24] T. Altherr andJ.C. Seixas, " Neural Networks and Calorimeter Cluster Recognition", p. 511, Proceeding of the first International Workshop on Software Engineering, Artificial Intelligence and Expert Systems in High Energy and Nuclear Physics, **New Computing Techniques in Physics Research**, ed. D. Perret-Gallix, W. Wojcik, CNRS, Paris, 1990.

[25] Terry C. Awes, "A Neural-Network Approach to the Problem of Photon-Pair Combinatorics", p. 525, Proceeding of the first International Workshop on Software Engineering, Artificial Intelligence and Expert Systems in High Energy and Nuclear Physics, **New Computing Techniques in Physics Research**, ed. D. Perret-Gallix, W. Wojcik, CNRS, Paris, 1990.

[26] J. Conway, et al., Nucl. Instr. and Methods bf A310, 618 (1991).

[27] J. Sutherland, Holographic Network Architectures.

[28] Grossberget, Adaptive Resonance Model.

APPENDIX 2

<u>Neural and Chaotic Attractor Code Samples</u>

SNET3.C	Chaotic attractor module with point-density storage
CORRDIM.CPP	Correlation Dimension model
HURST.C	Hurst exponent calculator
UCL25AB.OCC	Transputer code (OCCAM) for unsupervised learning model based on Euclidean distance measures

<u>Component Code Files</u>

CLUSTMOD.OCC

EDCLLINK.OCC

PATTERNB.OCC

```
/* SNET3.C
   M. Dudziak 6/93
   Modification of snet1.c. Still produces only one attractor but now
   saves point density information in an array which is written to disk.
   This array consists of 512 equal-sized cells (8x8x8) in the region of
   that the attractor can be expected to occupy. These cells will then
   serve as feature-elements in an input vector that can be fed into a
   neural network for classification of the attractor according to the
   type of pattern that is generated. The classifications will be used
   to build a taxonomy of attractor variations, into which the future
   evolved patterns that emerge from multiple attractor interactions and
   dependencies can be classified.

Structure of SNETx.PAR ---
   A B C D E
   A = number of iterations to perform in each cycle for each plane
   B = whether or not to pause after each pattern cycle and wait for
      user to press a key to continue to the next pattern
   C = whether or not to prompt for saving images of the XY plane
   D = whether or not to display YZ plane
   E = ditto for XZ plane

Structure of SNETx.DAT ---
   Set A B C D E
   Set = identifier of the pattern for record-keeping purposes

*/

#include <stdio.h>
#include <math.h>
#include <dos.h>
#include <graph.h>
#include "tools.h"

struct outrec
{
  float cr;
  int r;
};

#define TRUE 1
#define FALSE 0
#define TABCELLS 8

union LIMIT XMax,YMax,XMin,YMin,Pval,Qval;
struct outrec s;
unsigned char PALETTE[16]={0,1,2,3,4,5,20,7,56,57,58,59,60,61,62,63};


/* put in args for user loop control and for image saving */
main(argc, argv)
int argc;
char *argv[];
{
  float Xmax = 2.8,Xmin = -2.8,Ymax = 2,Ymin = -2, X = 0, Y = 0, Z = 0;
  /* These are set for screen display purposes */
```

```
float deltaX,deltaY,Xtemp,Ytemp,Ztemp,Xspan,Yspan,Zspan;
float celldX, celldY, celldZ;
float a, b, c, d, e;
/* original: float a = 2.24, b = .43, c = -.65, d = -2.43, e = 1; */
int col,row,color,count,fcnt,newset,set,user_ctrl,save_img;
int max_row = 479, max_col = 639, OPERATOR = 0;   /* set up for VGA */
int ch, dispXZ, dispYZ;
int table[TABCELLS][TABCELLS][TABCELLS];
int ix,iy,iz;                       /* indices for table */
int recmark = -1;
long int i,j,k,max_iterations;
FILE *fparam, *fdata, *fout;
char in_file_name[13], out_file_name[13], param_file_name[13];
char img_f_name[13];

Xspan=Xmax-Xmin;
Yspan=Ymax-Ymin;
Zspan=Ymax-Ymin; /* just use Y, so similar */
deltaX = max_col/Xspan;
celldX = TABCELLS/Xspan;
deltaY = max_row/Yspan;
celldY = TABCELLS/Yspan;
celldZ = celldY;
strcpy(in_file_name, "snet2.dat");
strcpy(out_file_name, "snet2.out");
strcpy(param_file_name, "snet2.par");
strcpy(img_f_name, "P2_AA_00.PCX");
count=0;
printf("SNET2 - Single P1 Attractor running with scalar parameter values from SNET2.DAT\n");

/* Open the input data and parameter files */
if ((fdata = fopen(in_file_name, "r")) == NULL)
{
  printf("\nCan't open data file %s.\n", in_file_name);
  return(FALSE);
}
if ((fparam = fopen(param_file_name, "r")) == NULL)
{
  printf("\nCan't open parameter file %s.\n", param_file_name);
  return(FALSE);
}
else
{
  fcnt = fscanf(fparam,"%ld %d %d %d %d",
                &max_iterations,
                  &user_ctrl,
                    &save_img, &dispYZ, &dispXZ);
  fclose(fparam);
  /* error checking on parameters */
  if (fcnt != 5)
  {
    printf("Errors in parameter file\n");
    return(FALSE);
    /* more later! */
  }
}
```

```
/* Open the output file */
if ((fout = fopen(out_file_name, "wb")) == NULL)
{
 printf("\nCan't open output file %s.\n", out_file_name);
 return(FALSE);
}

do        /* i/o ok, proceed */
{
 if ((fcnt = fscanf(fdata,"%d %f %f %f %f %f",
                    &set, &a, &b, &c, &d, &e)) == 6)
 {
  newset=TRUE;
  count++;
 }
 else
  if (fcnt != EOF)
  {
   printf("Error in reading input data.\n");  /* abend */
   newset=FALSE;
  }
  else
   newset=FALSE;      /* reached normal EOF */


 if  (newset==TRUE)
 {
  _setvideomode(_VRES16COLOR);
  for (i=0; i<TABCELLS; i++)      /* initialize density table */
   for (j=0; j<TABCELLS; j++)
    for (k=0; k<TABCELLS; k++)
     table[i][j][k]=0;
  for (j=0; j<2; j++)
  {
   _clearscreen(_GCLEARSCREEN);
   for (i=0; i<max_iterations; i++)
   {
    /* Compute next XYZ point */
    Xtemp = sin(a*Y) - Z*cos(b*X);
    Ytemp = Z*sin(c*X) - cos(d*Y);
    Z = e*sin(X);
    X = Xtemp;
    Y = Ytemp;
    /* find cell/bucket in which this XYZ occured  - do this
       only once in cycle of different planes */
    /* use table lookup */
    if (j==0)
    {
     ix = (X-Xmin)*celldX;
     iy = (Y-Ymin)*celldY;
     iz = (Z-Ymin)*celldY;

   /*  for (k=0; k<TABCELLS; k++)
      {
       if ((X>k*Xspan) && (X<=(k+1)*Xspan))
       {
```

```
        ix=k;
        break;
      }
    }
    for (k=0; k<TABCELLS; k++)
    {
     if ((Y>k*Yspan) && (Y<=(k+1)*Yspan))
     {
       iy=k;
       break;
     }
    }
    for (k=0; k<TABCELLS; k++)
    {
     if ((Z>k*Yspan) && (Z<=(k+1)*Yspan))
     {
       iz=k;
       break;
     }
    }    */
    table[ix][iy][iz]++;
   }

  /* Find best-fit pixel location for this XYZ point */
  if (j==0)
  {
   col = (X - Xmin)*deltaX;
   row = (Y - Ymin)*deltaY;
  }
  else
   if ((j==1) && (dispYZ==TRUE))
   {
    col = (Y - Xmin)*deltaX;
    row = (Z - Ymin)*deltaY;
   }
   else
    if ((j==2) && (dispXZ==TRUE))
    {
     col = (X - Xmin)*deltaX;
     row = (Z - Ymin)*deltaY;
    }
  /* Do the actual display */
  if ((col>0) && (col<=max_col) &&
     (row>0) && (row<=max_row))
  {
   color = readPixel(col,row);
   color = (++color)%15 + 1;
   plot(col,row,color);
  }
 } /* end of main iteration cycle */
 /* save the XY plane-image into a file */
 if (j==0)
 {
  if (save_img==TRUE)
  {
   printf("Save this image? (Y/N) : ");
```

```
        ch=getch();
        if ((ch=='y') || (ch=='Y'))
          save_screen(0,0,max_col,max_row,img_f_name);
        }
      }
      if (user_ctrl==TRUE)
        getch();
    }   /* end of alternate-plane cycle -- note: does not yet do XZ */
    /* Write out the table for the XYZ values */
    k = fwrite(&set, sizeof(int), 1, fout);
    k = fwrite(table,sizeof(int), sizeof(table),fout);
    k = fwrite(&recmark, sizeof(int), 1, fout);
    /* temporary for easier testing */
/*     fprintf(fout,"%s\n",set);
    for(i=0;i<TABCELLS;i++)
      for(j=0;j<TABCELLS;j++)
        fprintf(fout,"%d %d:: %d  %d  %d  %d  %d  %d  %d  %d\n",
          i, j, table[i][j][0], table[i][j][1], table[i][j][2],
          table[i][j][3], table[i][j][4], table[i][j][5],
          table[i][j][6], table[i][j][7]); */
  } /* end of processing for a new set */
 } /* end of main do-loop */
 while ((fcnt != EOF) && (newset==TRUE));
 fclose(fdata);
 fclose(fout);
 set=99;   recmark=0;
 /* debug/test output file -- write out first set only */
 fout=fopen(out_file_name, "rb");
 i=fread(&set, sizeof(int), 1, fout);
 i=fread(table, sizeof(int), sizeof(table), fout);
 i=fread(&recmark,sizeof(int),1,fout);
 printf("Output from file...Set: %d\n",set);
    for(i=0;i<TABCELLS;i++)
    {
      for(j=0;j<TABCELLS;j++)
      {
        printf("%ld %ld:: %d  %d  %d",
          i, j, table[i][j][0], table[i][j][1], table[i][j][2]);
        printf(" %d  %d  %d  %d  %d\n",
          table[i][j][3], table[i][j][4], table[i][j][5],
          table[i][j][6], table[i][j][7]);
      }
      getch(); getch();
    }
 printf("Record end mark:%d\n",recmark);
 fclose(fout);
};


        /*+-----------------------------------------------------+
          |                                                     |
          |   readPixel = Read a Pixel from the Screen          |
          |                                                     |
          |                                                     |
          +-----------------------------------------------------+*/
```

CORRDIM. CPP

```
#include <stdio.h>
#include <string.h>
/* #include <iostream.h> */
#include <math.h>

/* Cf pp. 216-217 of E. Peters book on Chaos Theory in Markets */

void main(int argc, char *argv[])
{
        struct outrec
        {
                float cr;
                int r;
        };

        static float x[2000];
        static float z[1000][10];
        float d, theta, theta2, cr, nptsq;
        FILE *fdata, *fout;
   struct outrec s;
        char in_file_name[12], out_file_name[12];
        int npt, dimen, tau, dt, r;
        int i,j,k,l, lag;

        /* Set up init values for constants - later get these
       from menu selections or a file */
        theta = 0.0; theta2 = 0.0; cr = 0.0; lag = 0;
        strcpy(in_file_name, "cordim.dat");
        strcpy(out_file_name, "cordim.out");

        /* Get values of parameters from user - later use menu/file */
        printf("Input npt, dimen, tau, dt, r: ");
        scanf("%d, %d, %d, %d, %d", &npt,&dimen,&tau,&dt,&r);

        /* open the input data file */
        if ((fdata = fopen(in_file_name, "r")) == NULL)
        {
                printf("\nCan't locate input file %s.\n", in_file_name);
                return;
        }
        else
        {
        printf("Opened input file ok");
                for (i=0; i<npt; i++)
                {
                        if (fscanf(fdata,"%f4", &x[i]))
                                {
          printf("Read in data: %f6",x[i]);
                                }
                        else
                                printf("Error in reading input data.\n");
                                return;
                }

                fout = fopen(out_file_name, "w");
```

```
            for (i=0; i<npt; i++)
                    for (j=0; j<dimen; j++)
                            z[i][j] = x[i+(j-1)*tau];

            npt=npt - dimen*tau;
nptsq=npt*npt;
            for (l=0; l<12; l++)
{
                    for (k=0; k<npt; k++)
            {
                            for (i=0; i<npt; i++)
                            {
                                    d=0.0;
                                    for (j=0; j<dimen; j++)
        {
                                            d=d+pow((z[lag][j] - z[i][j]),2);
                                    }
                                    d=sqrt(d);
                                    if (d>r)
                    theta2=0.0;
                                    else
                                            theta2=1.0;
                    theta = theta + theta2;
                            }
                            lag = lag+1;
                    }

                    cr = (1.0/nptsq)*theta;
                    /* write out to file and to screen */
                    printf("%d,    %d", cr, r);
                    s.cr = cr;
  s.r = r;
  fwrite(&s,sizeof(s),1,fout);
                    l = l+1;
                    r = r+dt;
                    cr = 0.0;
                    theta = 0.0;
                    theta2 = 0.0;
                    lag = 0;
            }
            fclose(fdata);
            fclose(fout);
  }

}
```

```
/* HURST.C
   M. Dudziak 6/93
   Calculate Hurst Exponent values for a given time series
*/

#include <stdio.h>
#include <math.h>
#include <dos.h>
/* #include <graph.h> */


#define TRUE 1
#define FALSE 0


/* unsigned char PALETTE[16]={0,1,2,3,4,5,20,7,56,57,58,59,60,61,62,63}; */


/* put in args for user loop control and for image saving */
main(argc, argv)
int argc;
char *argv[];
{
 FILE *fdata, *fresults;
 char in_file_name[13], out_file_name[13];
 int start_per, end_per, num_samp;
 int arrlim, i, j, k, p, ix;
 int ok, count, fcnt;
 float ts[500], lndiff[500], avg_lndiff[250];
 float lnRS[100], period_log[100], summ_diffs[100];
 float mean, logRS, stdev;

 strcpy(in_file_name, "ts.dat");
 strcpy(out_file_name, "hurst.out");
 printf("HURST Exponent Calculator for Generic Time Series\n");

 /* Open the input data file */
 if ((fdata = fopen(in_file_name, "r")) == NULL)
 {
   printf("\nCan't open data file %s.\n", in_file_name);
   return(FALSE);
 }

 /* Open the output file for ascii output */
 if ((fresults = fopen(out_file_name, "w")) == NULL)
 {
   printf("\nCan't open output file %s.\n", out_file_name);
   return(FALSE);
 }

 /* first line of input file has parameter data */
 if ((fcnt = fscanf(fdata,"%d %d %d",
                     &start_per, &end_per, &num_samp)) == 3)
   ok=TRUE;
 else
 {
```

```
    printf("Error in reading parameter input data.\n");  /* abend */
    return(FALSE);
  }

  if  (ok==TRUE)
  {
    /* Read in all the input values for the time series */
    count=0;
    fcnt=BOF;
    do
    {
      fcnt=fscanf(fdata,"%d", &num);
      if (fcnt != EOF)
        ts[count++]=num;
    }
    while (fcnt != EOF);
    arrlim=count-1;
    if (arrlim != num_samp)
    {
      printf("Mismatch on number of samples: Num_samp= %d,  Read in = %d\n", num_samp,
arrlim);
      return(FALSE);
    }

    /* Compute logn of differences from one series value to the next */
    summ=0;
    for (i=0; i++; i<arrlim)
    {
      lndiff[i]=log(ts[i+1]-ts[i]);
    }


    /* Process each period from start-period to end-period inclusive */
    for (i=start_per; i++; i<end_per+1)     // loop thru periods
    {
      p=i-start_per;                              // index for lnRS and period_log arrays
      ix = 0;                    // always start with first element of ts
      summ=0;
      for (j=ix; j=j+i; j<arrlim)      // do groupings by period size
      {
        avg_lndiff[ix]=0;
            for (k=j; k++; k<j+i)                // process one group
            {
              avg_lndiff[ix]=avg_lndiff[ix]+lndiff[k];
            }
        avg_lndiff[ix]=avg_lndiff[ix]/i;
        ix++;
      }
      /* Get differences between each lndiff and the avg lndiff for each period */
      ix=0;
      for (j=0; j+i; j<arrlim)
      {
            for (m=0; m++; m<i)
              summ_diffs[ix][m]=0;
            for (k=j; k++; k<j+i)
            {
```

```
          summ_diffs[ix][k-j]=summ_diffs[ix][k-j]+(lndiff[k]-avg_lndiff[ix]);
        }

        /* Find max and min of sums of differences in each period */
      max_summ_diff=
      min_summ_diff=

      /* Find range between max and min */
      rs=max_summ_diff - min_summ_diff;

      /* Compute Standard Deviation of series (original values)*/
      mean=avg_lndiff[ix]/i;
      stdev=0;
      for (m=0; m++; m<i)
      {
        stdev=stdev+(lndiff[i+])-mean;
      }
      stdev=sqrt(stdev);


      ix++;
    }


   /* Compute logn of R/S and period for the given period */
   lnRS[p]=AVG of log(rs/stdev) for each period instance;
   period_log[p]=log(i);
  }

  /* Output all the logRS and logPeriod data to file */
  ok=fprintf(fresults,"**** HURST Exponent Output ****\n");
  ok=fprintf(fresults,"Period range: %d to %d\n", start_per, end_per);
  for (i=0; i++; i<(end_per-start_per))
  {
   ok=fprintf(fout,"%d :: %f    %f", i, lnRS[i], period_log[i]);
  }



   /* For later --- do some graphics
        _setvideomode(_VRES16COLOR);

        color = readPixel(col,row);
        color = (++color)%15 + 1;
            plot(col,row,color);
        k = fwrite(&set, sizeof(int), 1, fout);
        k = fwrite(table,sizeof(int), sizeof(table),fout);
        k = fwrite(&recmark, sizeof(int), 1, fout);  */

  fclose(fdata);
  fclose(fresults);
 }
};
```

```
-- UCL25AB.OCC
-- Main bootable program for an OCCAM version of the UCL Unsupervised
--     Learning Model based upon Clustering by Euclidean Distance Measure
-- Model 2.5: Use a pipeline architecture to distribute the sequential
--     tasks for processing each pattern across several processes but
--     maintain the fundamental algorithm in a single sequential process.
--     This model (UCL25AB) is set up for a single transputer.
-- Version AB
--
-- Basic Design:
--
--      Processor 0 : user.intf
--              Get user cmds and comm with filein proc; also receive results
--      Processor 1 : filein
--              Read in patterns from n files on disk on 2nd host and send on
--      Processor 2 : pattern.handler
--              Pre-process patterns and ship down approp. pipe
--      Processor 3 : results.handler
--              Handle all intermed. or final output to user
--      Processors 4 & 5, etc. : pipe + cluster.learning
--              Compute euclidean distance betw pattern and cluster ctrs

#INCLUDE "hostio.inc"
PROC ucl (CHAN OF SP fs, ts, []INT mem)
  #INCLUDE "uclnprot.inc"
  #USE "userintb.t8h"
  #USE "filein.t8h"
  #USE "patternb.t8h"
  #USE "uclpipe.t8h"
  #USE "cluststr.t8h"
  #USE "resultb.t8h"
  #USE "dbgutil.t8h"                -- debug!!!
  VAL numworkers IS 2:          -- NOTE! Must be a power of 2 !!!
  CHAN OF PATTERN.PACKET to.pattern.handler:
  CHAN OF SYSTEM.PACKET user.to.filein, filein.to.user, from.results.handler:
  CHAN OF INT userintf.status:
  CHAN OF INT stopper:   -- debug!!!
  [numworkers+3]CHAN OF PATTERN.PACKET data.in, data.out:
  [numworkers+3]CHAN OF SYSTEM.PACKET results.in, results.out:
  [numworkers]CHAN OF WORK.PACKET to.learning, from.learning:

  VAL model.id IS "Model 2.5 (Multi-DataSet) ":
  VAL version.id IS "Version AB (Test version on 1 T8) ":
  VAL config.id IS "Config: 6+ T8s on a B008 + B003(s)":
  PAR                           -- debug !!!
    dbg.timer (stopper)       -- debug!!!
    SEQ                         -- debug!!!
      PAR
        user.interf (fs, ts, to.pattern.handler,
                     from.results.handler, userintf.status,
                     model.id, version.id, config.id)

        filein (fs, ts, user.to.filein, filein.to.user, to.patthdlr)

        pattern.handler (to.pattern.handler, data.in[0], data.in[1])

        PAR i = 0 FOR numworkers
          PAR
            pipe.proc (data.in[i], data.out[i+2], data.out[i+3],
                             [i]               ing[i]
```

```
                    results.in[i+2], results.in[i+3], results.out[i])
          cluster.learning (to.learning[i], from.learning[i])

      results.handler (results.out[0], results.out[1],
                       from.results.handler, userintf.status)

    stopper ! 0    -- debug!!!
:
```

```
#INCLUDE "edclprot.inc"
--{{{F edclprot.inc    ---- Protocols for the EDCL programs
--:::F EDCLPROT.INC
--}}}
PROC cluster.learning (CHAN OF PATTERN.PACKET pat.to.cluster,
                       CHAN OF SYSTEM.PACKET cluster.to.res.hdlr)
  #INCLUDE "edclcnst.inc"
  --{{{F edclcnst.inc    ---- Special constants for the EDCL programs
  --:::F EDCLCNST.INC
  --}}}

  --{{{  Common Vars
  [max.patterns][max.attribs]REAL32 patt.table:
  [max.patterns][max.attribs]REAL32 wts:
  [max.patterns][max.clust.members]INT cluster.table:
  [max.patterns]REAL32 distance:
  BOOL going, get.input:
  REAL32 min, threshold, x:
  INT ip, j, n, ninput, ninattr:
  INT active.nodes, cl.num.result, cluster.num:
  INT total.time:
  [max.patterns+1]INT time.check:
  TIMER tclock:
  --}}}
  SEQ
    --{{{  Init vars
    going := TRUE
    get.input := TRUE
    ip := 0
    SEQ i = 0 FOR max.patterns
      cluster.table[i][0] := 0
    --}}}
    WHILE going
      SEQ
        ALT
          --{{{  Input on pat.to.cluster (all except terminate only at beginning
          get.input & pat.to.cluster ? CASE
            --{{{  Get special parameters
            params; threshold; ninput; ninattr
              SKIP
            --}}}
            --{{{  Read an input pattern into array (must be done before continu
            realpat; n::patt.table[ip]
              IF
                (ip = 0)
                  --{{{  Set up the first node
                  SEQ
                    SEQ i = 0 FOR ninattr
                      wts[0][i] := patt.table[0][i]
                    active.nodes := 1
                    cluster.table[0][0] := 1
                    cluster.table[0][1] := 0
                    ip := 1
                  --}}}
                (ip < (ninput-1))
                  ip := ip+1
                (ip = (ninput-1))
                  -- All patterns from input set read in (future action here)
                  SEQ
```

```
              tclock ? time.check[0]     -- Start timing here
          TRUE
            SKIP
      --}}}
      terminate
        SEQ
          cluster.to.res.hdlr ! quit
          going := FALSE
    --}}}


  IF
    (NOT get.input)
      SEQ
        tclock ? time.check[1]       -- Get start time for pattern 1
        --{{{  Cycle thru all patterns in set just read in
        SEQ i = 1 FOR (ninput-1)
          SEQ
            -- Cycle thru all active nodes (clusters)
            j := 0
            WHILE (j < active.nodes)
              SEQ
                --{{{  Compute euclidean dist. measure betw a pattern & ac
                distance[j] := 0.0 (REAL32)
                SEQ k = 0 FOR ninattr
                  SEQ
                    x := (wts[j][k] - patt.table[i][k])
                    distance[j] := distance[j] + (x * x)
                j := j + 1
                --}}}

            --{{{  Analyse the distances, seeking a mininum < threshold
            min := minbase
            SEQ k = 0 FOR active.nodes
              IF
                (distance[k] < min)
                  SEQ
                    min := distance[k]
                    cluster.num := k
                TRUE
                  SKIP
            x := SQRT(distance[cluster.num])
            IF
              (x <= threshold)
                cl.num.result := cluster.num
              TRUE
                cl.num.result := out.of.bounds
            --}}}

            --{{{  Process a pattern record
            IF
              (cl.num.result = out.of.bounds)
                --{{{  No fit w any existing cluster; form a new node
                SEQ
                  SEQ j = 0 FOR ninattr
                    wts[active.nodes][j] := patt.table[i][j]
                  cluster.table[active.nodes][0] := 1
                  cluster.table[active.nodes][1] := i
                  active.nodes := active.nodes + 1
                                     !             0; 1
```

```
            --}}}
          (cl.num.result >= 0) AND (cl.num.result < max.patterns)
            --{{{  Update weights and cluster table
            REAL32 x, y, a, b:
            INT cx, num.member:
            VAL REAL32 one IS 1.0 (REAL32):
            SEQ
              x := REAL32 ROUND cluster.table[cl.num.result][0]
              y := x + one
              SEQ k = 0 FOR ninattr
                SEQ
                  a := (x/y) * wts[cl.num.result][k]
                  b := (one/y) * patt.table[i][k]
                  wts[cl.num.result][k] :=  a + b
              cx := cluster.table[cl.num.result][0]
              cluster.table[cl.num.result][0] := cx + 1
              num.member := cx + 1
              IF
                (num.member < max.clust.members)
                  cluster.table[cl.num.result][num.member] := i
                TRUE
                  cluster.table[cl.num.result][max.clust.members-1] :=
              cluster.to.res.hdlr ! debugout; 0; 2
            --}}}
          TRUE
            SKIP
        --}}}

        tclock ? time.check[i+1]
      --}}}

      --{{{  Final time processing and output of cluster table
      -- Note: time.check[0] has initial start, tc[1] at end of
      -- processing 1st pattern, etc. and tc[max.patterns] has final tim
      -- calculate total time spent (in ticks)
      total.time := 0
      PAR
        SEQ x = 0 FOR ninput
          cluster.to.res.hdlr ! results; cldata; x;
                                 max.clust.members::cluster.table[x]
        SEQ x = 1 FOR ninput
          total.time := total.time +
                          (time.check[x] MINUS time.check[x-1])
      cluster.to.res.hdlr ! time; total.time
      --}}}
      --{{{  Reset vars for next cycle
      get.input := TRUE
      ip := 0
      --}}}


    TRUE
      SKIP

:

-- eof CLUSTMOD.OCC
```

```
#INCLUDE "confprot.inc"
-- Note that this simple proc serves only to set up connections between
-- links on fixed processors.  The process running on the T2
-- (e.g., set.c004...) must be terminated by sending it a cmd to stop.
-- (cf. conflink.occ, confprot.inc)


PROC wire.c004 (CHAN OF CONFIG.PACKET cp.cmd, CHAN OF BYTE cp.ack,
                VAL INT num.connects, VAL []BYTE wiring.table)
  -- cp.cmd sends byte-stream cmds to set.c004 on the T2
  -- set.c004 acknowledges each connection between link-link or input-output
  -- (no ack returned on other operations)
  -- num.connects is the number of connections to make
  -- wiring table consists of pairs of connections, used in accord w the
  -- num.connects param
  -- VAL root.out IS 10 (BYTE):
  -- VAL p1.link0 IS 1 (BYTE):
  INT j:
  BYTE x:
  SEQ
    cp.cmd ! reset
    -- Make the n connections
    j := 0
    SEQ i = 0 FOR num.connects
      SEQ
        cp.cmd ! biconn; wiring.table[j]; wiring.table[j+1]
        PAR
          cp.ack ? x
          j := j+2
    cp.cmd ! terminate
:

-- older stuff
PROC init.c004.0.1.2 (CHAN OF CONFIG.PACKET cp.cmd)
  VAL root.out IS 10 (BYTE):
  VAL p1.link0 IS 1 (BYTE):
  VAL one.out IS 11 (BYTE):
  VAL p2.link0 IS 2 (BYTE):
  SEQ
    cp.cmd ! reset
    cp.cmd ! biconn; root.out; p1.link0
    cp.cmd ! biconn; one.out; p2.link0
    cp.cmd ! terminate
:

-- eof edcllink.occ
```

```
#INCLUDE "edclprot.inc"
--{{{F edclprot.inc    ---- Protocols for the EDCL programs
--:::F EDCLPROT.INC
--}}}
PROC pattern.handler (CHAN OF PATTERN.PACKET to.pat.hdlr,
                      [2] CHAN OF PATTERN.PACKET pat.to.pipe)
  #INCLUDE "uclconst.inc"

  --{{{  Common Vars
  REAL32 threshold:
  INT ninput, ninattr:
  INT group.id, pipe.out.id:
  BOOL going:
  [max.attribs]INT ipat:
  [max.attribs]REAL32 rpat:
  --}}}
  SEQ
    going := TRUE
    WHILE going
      SEQ
        to.pat.hdlr ? CASE
          --{{{  Get special parameters (incl. group id) and pass on
          params; group.id; threshold; ninput; ninattr
            SEQ
              IF
                ((group.id REM 2) = 0)    -- even-numbered group ids
                  pipe.out.id := 1
                TRUE
                  pipe.out.id := 0
              pat.to.pipe[pipe.out.id] ! params; group.id;
                                         threshold; ninput; ninattr
          --}}}
          --{{{  Process pattern record and pass on
          pat; group.id; ninattr::ipat
            SEQ
              SEQ i = 0 FOR ninattr
                rpat[i] := REAL32 TRUNC ipat[i]   -- convert ints to reals
                pat.to.[pipe.out.id] ! realpat; group.id; ninattr::rpat
          --}}}
          terminate
            going := FALSE

    pat.to.ced ! terminate
:

-- eof PATTERNB.OCC
```

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