Physical Computation and Parallelism
(Constructive Postmodern Physics)

Keith Bowden (25th August 1994, DRAFT 4.2)
Computer Centre, University of East London,
Longbridge Rd, Dagenham, Essex RM8 2AS, UK.

There is increasing evidence that information may be the basic stuff of the Universe. We consider this proposition in the light of Bohm and Hiley's Quantum Potential, the work of the ANPA group on the Combinatorial Hierarchy, and the Natural Philosophies of Gabriel Kron and Maurice Jessel. We compare and contrast the philosophical backgrounds of both these and the more conventional Copenhagen interpretation. In conclusion we suggest that our approach should be termed Constructive Postmodern Physics.

Philosophy is the study of physical paradigms, ethical paradigms and belief systems. It can be classified into four historical periods, ancient, pre-modern, modern and postmodern (Fig 1). It is remarkable the extent to which the prevalent underlying philosophy of a period influences and predates both ethics and physics. For instance it is well known that the Great Machine Theory of Newtonian mechanics coincided with the philosophy of predeterminism in the Roman Catholic Church. It is less well known that Bergson predicted, and encouraged the search for, indeterminacy in physics *from purely philosophical arguments*.

Philosophy began with the ancient religions, the ethical arguments of the Greeks and the block world of Parmenides. The inadequacies of the latter led to the atomism of Democritus and the pre-modern period, followed by the great age of Western scientific discovery starting in the 17th Century with the mechanics and optics of Newton and culminating in the electromagnetic theory of Maxwell. The philosophical complacency and universality of the modern period was overturned by the discovery of quantum uncertainty and relativity and the Copenhagen Interpretation of Quantum Mechanics in the early part of the 20th century. Philosophy then bifurcated into two schools of thought.

Physics at the particle level shows peculiar nonNewtonian quantised behaviour. Quantum Mechanics is a set of procedures for predicting the evolution of these microscopic phenomena. It is not an ontology, or physical theory, explaining them. Various physical theories do exist. The conventional and generally accepted theory amongst the majority of laboratory physicists, educational establishments and the media, is the so called Copenhagen Interpretation of Quantum Mechanics. It essentially says that no (globally consistent) models of reality can be built. The world can only be described by locally consistent patches of theory which cannot be fitted together without global contradictions. Quantum Mechanics itself is not compatible with Relativity. Indeed Quantum Mechanics is not compatible with Newtonian Mechanics. These

Fig (1) Physics and Philosophy

PHILOSOPHY		←-PREMODERN-→←-------MODERN---------→			←DECONSTRUCTIVE→ POSTMODERN	←CONSTRUCTIVE→ POSTMODERN
		"CLASSICAL" extrapolation of the macrouniverse to the microuniverse			Wittgenstein et al no models of reality are possible	
		billiard ball models				informational models
		?BC	1600		1900	2000
Ancient Religions	Parmenides "Block World"	Democritus Lucretius "Atomism"	Newton... Predeterminism	Maxwell	Einstein, Schrodinger, Heisenberg, Bohr "Quantum Mechanics"	de Broglie, Jessel, Kron, Bohm, Bastin, Kilmister
PHYSICS						

problems are known as the measurement paradoxes of Quantum Mechanics.

This corresponds to the philosophical stance known as *Deconstructive Postmodernism*, initiated by Nietsche, Heidegger, Wittgenstein (Logical Positivism), Derrida and others, that all phenomena are just surface phenomena and that there is no deep underlying reality (or, for Wittgenstein, that we have no means of finding out what it may be). Deconstructive postmodernism is all pervasive. Its influence can be seen in contemporary literature, music, art, science, law and politics. It has been seen by some as beneficially revolutionary, by others as dangerous in that it provides an excuse for the dismantling of constitutional systems on the grounds that there are no absolute truths.

The alternative philosophical stance is known as *Constructive Postmodernism* [Griffin, 1993]. It is appalled by a philosophy that allows built in contradictions. In Physics it was spearheaded by David Bohm in that he provided (in 1952) an ontological model (that is one which includes a "physical" explanation), called the Quantum Potential, that reproduced, exactly *all* of the statistical predictions of quantum theory, thus refuting a so called proof of von Neumann that this was impossible. (Von Neumann made asumptions about contextuality that were too strong.) Bohm's fascinating theory, although almost unknown to the general public, has never been proved wrong. We will say no more about it here except that **it is based on a purely informational field that does not necessarily decay with distance**. Constructive postmodernism accepts the incorrectness of the standard Newtonian model but not the impossibility of an alternative deep reality. Note that a third reaction to the failure of modernism is known as *Antimodernism* and was typified by the Luddites.

There are a number of different schools of constructive postmodernism, but like the Quantum Potential people, **they generally consider *information* to be fundamental.** Many of the founders of constructive postmodern philosophy, C S Pierce, William James, Bergson, Whitehead and Hartshorne, are panexperientialists, that is, like the strong AI people, they believe in the existence of the material world, but in order to do so require that all material objects have a degree of sentience or intelligence. (Contrast a "conventional" approach due to Roger Penrose at Oxford University (who is very strongly anti strong AI) who proposes a model called quantum gravity to resolve the measurement paradoxes of quantum mechanics.) An alternative view, taken by this author, by Pierre Noyes at SLAC, Mike Manthey at the University of Aalborg and others, is that all we actually know about is information (that is sense data, memory and imagination) and the communication of information. In this view of the world **there is no distinction between ontology and epistomology**, that is, what exists is what we know. On the surface this view does not seem too far from Wittgenstein's, however the difference is that he saw all questions of ontology as meaningless.

An extreme version of this view is solipsism, that until proven otherwise all one knows about is one's self and (maybe) our interaction with the outside world. This view is actually all that is necessary in order to undertake the analyses of Manthey, and Bastin and Kilmister, described below. Manthey's analysis results in the same group structure as particle physics. Bastin and Kilmister's work, a four level hierarchical structure related by four constants with very similar values to the dimensionless coupling constants of (Grand) Unified Field Theory. This is an important difference between Constructive Postmodern Physics and modern physics. Constructive Postmodern

Physics calculates fundamental numbers such as the coupling constants, the charge and mass ratios of the elementary particles etc. directly. Conventional physics only ever calculates numbers in terms of other (measured or calculated) numbers. It is really not a quantitative theory at all in this sense but only a qualitative theory. (At least it is relative rather than absolute.) Bastin and Kilmister's Process of Discovery is not only solipsist but also stoical in the sense that there is no element of causality, that is it is simply an analysis of the process of observation.

Many postmodernist physicists are members of a research group called ANPA based at Cambridge and Stanford Universities. The main program undertaken by these workers is to try to build a bridge between Information Theory and Physics. This work was initiated, in the 1940's, by Ted Bastin and Clive Kilmister who decided that to get information from dimensional physical structures there must be a hierarchy of levels in which the elements of each new level is formed from the operators of the previous level. Together with Gordon Pask and John Amson they experimented with computer models. Later, the late Frederick Parker-Rhodes discovered the mathematics for these notions using binary algebra and a matrix mapping between levels. He came up with a simple, unique, four level, Boolean construction, now known as the Combinatorial Hierarchy, which has a number series, associated with the basis vectors, under exclusive-or, at each of the four levels of this Hierarchy, which takes the form 3, 10, 137, 1.7×10^{38}. This series gives ***the number of different ways*** that information can interact at each of the four different levels of the hierarchy. It takes very similar values to the four coupling constants of the Standard Model of Physics, which are

Fig (2) Two four-level information structures

(GRAND) UNIFIED FIELD THEORY	**COMBINATORIAL HIERARCHY**
A four level informational structure.	A four level informational structure. It is unique and minimal.
Associated with the four levels are four dimensionless "empirical" numbers, called the ***coupling constants***, taking the values O(1), O(1), 137 and 1.7×10^{38}.	Associated with the four levels are four numbers taking the values 3, 10, 137 and 1.7×10^{38}.
The first two are related to the strengths of the weak and strong nuclear forces and the last two give the strengths of the electromagnetic and gravitational forces.	The hierarchy is based on the "exclusive-or" operator, $\oplus$ on bit strings. Exclusive-or can be shown to be the unique comparison operator on bit strings.
The strengths of these forces are believed to be given by ***the number of different ways*** their associated "messenger particles" can interact. Following Eddington, Pierre Noyes has defined a particle as a "conceptual carrier of information (conserved quantum numbers) between events (collisions)".	These numbers give the ***number of different ways*** that entities at each level of the hierarchy can interact. The entities concerned are bit strings which have been associated with the process of observation by Bastin and Kilmister.

believed to give ***the number of different ways*** that particles can interact at each of the four levels of the theory (weak nuclear, strong nuclear, electromagnetic and gravitational). The number of different modes of interaction is considered to be responsible for the strengths of the corresponding fields (Fig 2). In his two books Parker-Rhodes developed an ontological theory of the universe based on information theory. Unfortunately much of this is very obscure.

In their forthcoming book, Ted Bastin and Clive Kilmister are attempting to bridge this same gap by looking at Physics as a process of discovery or innovation. From this they construct the Hierarchy and relate it to Physics with a much greater degree of clarity than Parker-Rhodes achieved. Pierre Noyes (Stanford) is trying to directly relate particle physics to bit string algebra. Following the work of Sir Arthur Eddington who, even before Parker-Rhodes, was addressing the same issues, Noyes defines a particle as "**a conceptual carrier of information** (conserved quantum numbers) between events (or collisions)". This, he claims, is all we can ever know about a particle. Anything else is metaphor or speculation or religion. Thus we see the beginnings of a Physics based upon a theory of local parallel processing with the speed of light as the maximum velocity of information propagation.

My colleague Peter Marcer was very much influenced by the work of the late Maurice Jessel, a doctoral student of the physicist Louis de Broglie in the sixties in Paris. (de Broglie is famous for wave-particle duality and the pilot wave theory which led directly to David Bohm's Quantum Potential.) Jessel was interested in holography but was persuaded by de Broglie to go back to first principles and derive a more general theory. Jessel went all the way back to the pioneering work on light propagation of Christian Huygens in the seventeenth century, the beginning of the modern period as defined earlier. Translating some of Huygens' material from the original old Dutch, Jessel found that modern interpretations of Huygens' work were not at the time all that accurate. Jessel restated Huygens Principle thus "The perturbation that goes out through a closed surface *S* that contains a wave (or field) source is identical to the perturbation that can be obtained by cutting off the source and replacing it by appropriate sources distributed on the surface *S*" (Fig 3). He further developed this as a mathematical formula from which he found that he could not only rederive Gabor's work on holography but also some exciting new results indicating amongst other things that it should be possible to produce a wave field to cancel any given field in real time. Thus active acoustic attenuation or even "black light" should be possible.

Marcer was struck by the fact that Huygens' Principle, although considered to be part of Physics, described **the evolution only of *information*.** He strongly believed that there should be a connection between this local parallel computational process and the Boolean exclusive-or operation defined by the Combinatorial Hierarchy. He coined the phrase "Huygens' Machine" to describe such a system. He was, about this time, (1985) introduced to my work on Kron's Method of Tearing by the journalist Tony Durham, and noticed the strong resemblance to a theory of General Systems he was developing with a King's College based research group that included Maurice Jessel. Peter also introduced me to ANPA where I presented a paper I had written which was inspired by Peter's observation.

Gabriel Kron's Method of Tearing or Diakoptics, as he called it, is both a computational technique and a Natural Philosophy. It has been rediscovered recently by the

FIG (3) Huygens Principle

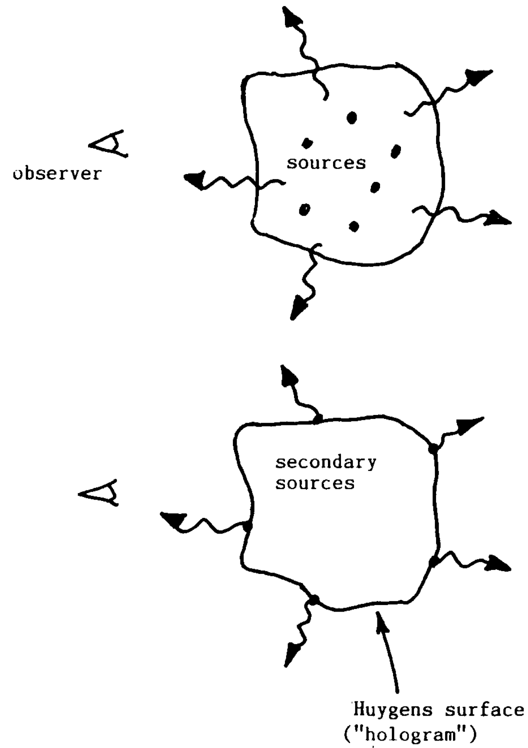


FIG (4) Kron's method

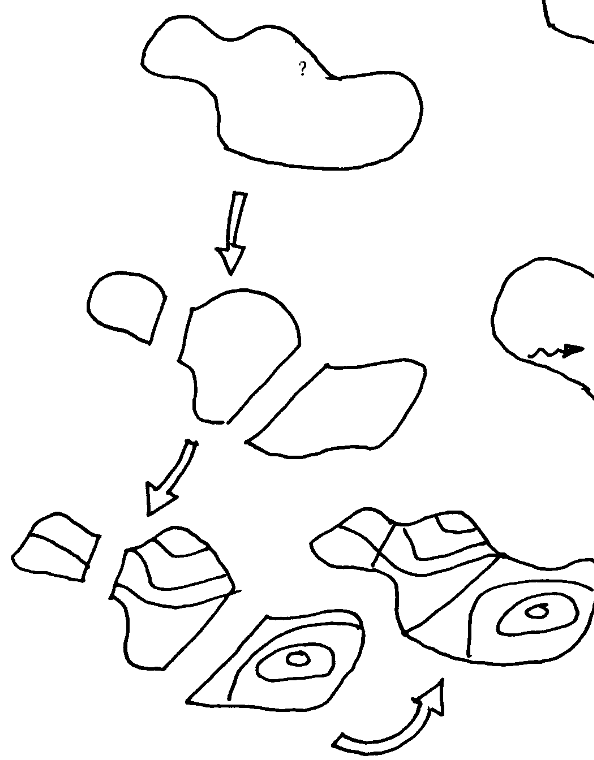
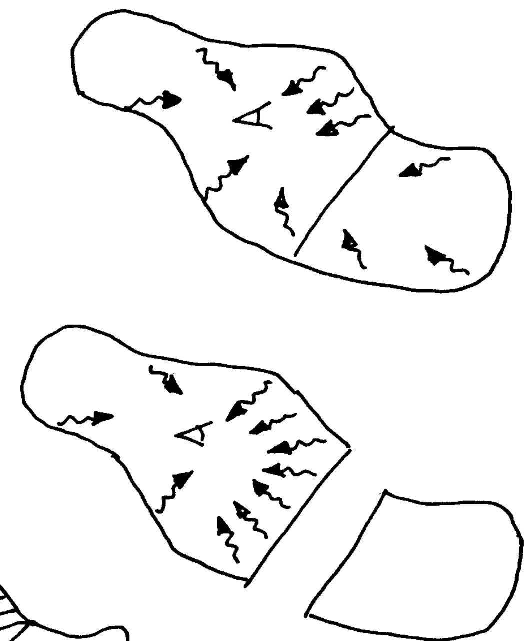


FIG (5) Kron's Method from Huygens' Principle



parallel processing community where it goes under the name of "domain decomposition". It is a technique of taking a physical problem, splitting it up topologically into subproblems, solving each subproblem, and then recombining the subsolutions into an exact overall solution. Even on a single sequential processor this method of solution is very much faster than classical approaches (such as matrix inversion). It is ideal for parallel processing in that each subproblem can be solved in parallel on a different processor. It is unique among decomposition techniques in that the extra information - the correction - needed to make the combined solution an exact one, is obtained from the "intersection layer" or boundary between the subproblems (Fig 4). As in Bohm's holomovement, information about every part of the system is stored everywhere. Kron was undoubtedly searching for an ontology of Engineering.

In the fifties, when Kron's ideas were first introduced, controversy raged over their validity. Clive Kilmister remembers arguments in the meetings of the British Society for the Philosophy of Science. Eventually the issue was resolved in the mid sixties when Sun Ichi Amari, then a student at Tokyo University produced a proof of the correctness of Kron's Method based on some ideas of the mathematician J Paul Roth in Homology Theory or Algebraic Topology. The basic tool of homology theory is the ***exact sequence***, a sequence of mappings called boundary operators, between successively higher dimensional spaces. The idea is that the boundary of a boundary is zero. Roth took the unusual approach of defining a ***twisted isomorphism*** between two dual exact sequences. Homology theory is ***difficult***; later, in the seventies, my doctoral supervisor, Harry Nicholson at Sheffield, produced a simpler analysis based on *scattering theory*. Scattering is defined as a collision of two informational processes.

My first contribution to all this was to produce a third derivation of Kron's Method based on Jessel's formulation of Huygens' Principle. Imagine Jessel's scenario inside out (Fig 5). The area of interest is surrounded by a set of sources representing the boundary conditions of a problem. Then that set of sources can be replaced by a set of sources on a smaller boundary within the original one and we have torn the problem into two subproblems separated by an internal boundary or intersection layer. The information distribution on this internal boundary is then a hologram of the original source distribution. The technique can be applied again in order to reduce the problem still further.

My second contribution was to derive a hierarchical version of Kron's method and to show that the information flow within this system is (in a sense) optimal and that it is the computational equivalent of a physical paradigm called the ***holomovement*** due to David Bohm. The holomovement is a very general idea that has the quantum potential as a special case. Information about every event in the universe is holographically enfolded within the fields at every other point in the universe. Hierarchical tearing gives a vivid visual picture of this. The problem with Kron's method is that, for very big problems, tearing the system up into too many pieces increases the size of the total subsystem boundaries, or intersection layer, to a size where its solution becomes more computationally intense than that of the subsystems. My solution to this problem was to tear the original system up into a small number of subsystems and then to tear the subsystems up into subsubsystems and so on, recursively. The size of the intersection layer at any level of tearing is then relatively small. It turns out that for real problems there is an optimal depth of tearing.

The major problem with classical matrix inversion of large problems on modern fast processors is not computation time but storage of the matrix inverse. The original matrix may be sparse but the inverse in general is not. In the hierarchical tearing algorithm normal matrix multiplication is replaced by a function. Matrix inversion is then replaced by an inverse function which is recursively defined in terms of a set of similar "smaller" functions. The leaves of this tree involve real matrix multiplication by a set of small (typically five by five) matrices. The total storage required is of a similar order to that for the original matrix.

My current work, like that of most of the others involved, involves trying to cross the bridge between Information Theory and Physics. In particular to try to make more clear what it is that Peter Marcer refers to as a Huygens' Machine. Note that I am not talking about the Information Theory of Shannon and Weaver here. Their's was a theory of communication. As a number of people have observed recently there isn't yet a coherent theory of information. Similarly, Brian May of Inmos recently pointed out that there is no paradigm for parallel processing equivalent to that of the Turing Machine. If I can cross the particular bridge that I'm aiming for I will be able to identify Jessel's formulation of Huygens' Principle, or maybe a further generalisation of it, as a paradigm for Parallel Processing. Huygens' Principle is adept at elevating interesting concepts in Physics. It is possible that there could be some exciting implications for parallel processing but we shall see. Further, I will have to start with a suitable definition of information.

I am attempting to analyse a system in which all that is assumed is that one is communicating with a set of other entities. This analysis will immediately apply to a set of interconnected parallel processors. Huygens' Principle must apply to the information crossing the boundary around any connected subset of the processors. The "sources" to which it will apply consist of the set of data within the memory of the processors in the subset, at the start of the analysis, plus any subsequent data input interactively in the duration. Clive Kilmister has suggested looking at the homology of the system. Scattering theory may equally be relevant. Any analysis of solipsism will also be applicable to each of the individual entities. Thus each entity is undertaking Bastin and Kilmister's process of discovery and I can immediately import the Combinatorial Hierarchy. In Manthey's approach each entity is accepting "co-occurring" input from (and sending output to) a number of asynchronous information streams. It is this, combined with a mutual exclusion on certain events, that leads to the quantum mechanical group structure (Clifford algebra) mentioned above. This analysis must also be relevant.

The crucial building block needed to proceed with this work is a definition of information. These seem to fall into two camps. The first consists of "Computer Sciencey" definitions typified by Parker-Rhodes definition of the information content of a statement as "the number of yes/no questions" needed to arrive there. This is a context dependent or relative definition, of what I would prefer to refer to as *knowledge*. Thus it also describes ***new*** information, and is what must be described by Bastin and Kilmister's Process of Discovery. The second camp, due to Stonier and Scarrot, defines (absolute) information as that which is contained within the structure of an organised system. An organised system is defined recursively and hierarchically in terms of a set of other organised systems. This clearly defines that which is described in David Bohm's holomovement (he referred to "active information") or the hierarchical version of Gabriel

Kron's natural philosophy. All data, whether information or knowledge or garbage, is measured in *bits*. Thus we have transformed the job of building a bridge between the classical or general systems approach to Physics and the Information Theory approach, to a bridge between two kinds of information. In this model time and space are requirements of communication and information respectively.

I believe we are reaching the end of the deconstructive postmodern period and are about to enter an age of constructive postmodern philosophy. Natural laws of all sorts, scientific, political and artistic, will be rebuilt based on rules about information, observation and knowledge. We will no longer think of a billiard ball world but an information age in a very fundamental sense. Not only will Information Theory tell us much about our knowledge of the world but Physics will teach us new things about how to build computers. For instance it is known that there are only two means of sending information through space without distortion. One relies on waves generated by Huygens' operators in a linear medium. It can be shown that this is only possible in even dimensional space-times with dimension greater than three. The other relies on stable particle-like pulses called solitons travelling in a nonlinear medium. Light soliton transmission through optical fibres the equivalent of 12,000 miles long, without a repeater, has recently been demonstrated. (Light) solitons also have the property that they can pass through each other with no effect other than a phase change. This provides the means for a simple computational element. Gabriel Kron in the sixties did some work on what he called a Crystal Computer. Light solitons in crystals may provide the basis for his dream to come true.

Acknowledgements

I am grateful to countless people for ideas upon which this talk is built. Particular mention should go to Jamie Andrews of the Department of Mathematics, University of Exeter, who introduced me to Constructive Postmodernism and to Alex Bowden of Generic Technology, Cambridge. I am also indebted to Clive Kilmister, Basil Hiley, David Finkelstein, Ted Bastin, Peter Marcer, Pierre Noyes, Mike Manthey, Germano Resconi and to the late Maurice Jessel.

References

1. Amari, S. [1962], "Topological Foundations of Kron's Tearing of Electric Networks." *Research Association for Applied Geometry Memoirs.* **3**, pp. 88-116. Tokyo.

2. Bastin, T. and C. W. Kilmister [1994], *Combinatorial Physics.* Unpublished.

3. Bohm, D. [1980], *Wholeness and the Implicate Order.* Ark, London.

4. Bohm, D. and B. J. Hiley [1993], The Undivided Universe. Routledge, London.

5. Bowden, K. [1990], "On General Physical Systems Theories." *International Journal of General Systems,* **18**(1), pp. 61-79.

6. Bowden, K. [1993], "The Spatial Transmission of Information." *Proceedings of the 15th International ANPA Conference.* University of Cambridge, Cambridge.

7. Bowden, K. [1994], "Hierarchical Tearing: An Efficient Holographic Algorithm for System Decomposition." *International Journal of General Systems,* **22**(?).

8. Gaudefroy, A. [1990], "Le Principe de Huyghens en Acoustique." Communication to the French Academy of Sciences.

9. Griffin, D. R. [1993], *Founders of Constructive Postmodern Philosophy.* SUNY, New York.

10. Gunther, P. [1989], *Huygens' Principle and Hyperbolic Equations.* Academic Press, Boston.

11. Jeans, J. [1930], *The Mysterious Universe.* Cambridge University Press, Cambridge.

12. Jessel, M. [1962], *Contribution aux Theories du Principe de Huygens at de la Refraction.* Theses pour DSc, Faculte des Sciences de L'Universite de Paris.

13. Kron, G. [1963], *Diakoptics: The Piecewise Solution of Large-Scale Systems.* McDonald, London.

14. Lynn, J., Balasubramanian and Sen Gupta [1970], *Differential Forms on Electromagnetic Networks.* Butterworth, London.

15. Manthey, M. J. [1992], "A Vector Semantics for Actions." *Proceedings of the 14th International ANPA Conference, University of Cambridge, Cambridge.*

16. Nicholson, H. [1978], *Structure of Interconnected Systems.* IEE Control Engineering Monograph 5, Peter Peregrinus, London.

17. Noyes, H. P. and David O. McGoveran [1989], "An Essay on Discrete Foundations for Physics." *Physics Essays,* **2**(1), pp. 76-100.

18. Parker-Rhodes, F. [1981], *The Theory of Indistinguishables.* Reidel, Dordrecht.

19. Parker-Rhodes, F. [198?], *The Inevitable Universe.* Unpublished.

20. Penrose, R. [1989], *The Emperor's New Mind.* Oxford University Press, Oxford.

21. Resconi, G. and M. Jessel [1986], "A General System Logical Theory." *International Journal of General Systems,* **12,** pp. 159-182.

22. Roth, J. P. [1955], "The Validity of Kron's Method of Tearing." *Proceedings of the National Academy of Sciences,* **41**.

23. Scarrot, G. G. [1989], "The Nature of Information." *The Computer Journal,* **32**(3).

23. Shellard, E. P. S. [1992], "The Numerical Study of Topological Defects." DAMAP, University of Cambridge. Unpublished.

24. Stonier T. [1990], *Information and the Internal Structure of the Universe,* Springer Verlag.

25. Zukav, G. [1979], *The Dancing Wu Li Masters.* Hutchinson, USA.