Review Article for *Progress in Biophysics and Molecular Biology*, Volume 131, December, 2017, Special Issue: Integral Biomathics: "The Necessary Conjunction of the Western and Eastern Thought Traditions for Exploring the Nature of Mind and Life" (Guest Editors: Plamen L. Simeonov, Arran Gare, Koichiro Matsuno and Abir U. Igamberdiev, pp.61-91. https://doi.org/10.1016/j.pbiomolbio.2017.08.010

Chreods, Homeorhesis and Biofields:

FINDING THE RIGHT PATH FOR SCIENCE THROUGH DAOISM[1]

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Abstract:

C.H. Waddington's concepts of 'chreods' (canalized paths of development) and 'homeorhesis' (the tendency to return to a path), each associated with 'morphogenetic fields', were conceived by him as a contribution to complexity theory. Subsequent developments in complexity theory have largely ignored Waddington's work and efforts to advance it. Waddington explained the development of the concept of chreod as the influence on his work of Alfred North Whitehead's process philosophy, notably, the concept of concrescence as a self-causing process. Processes were recognized as having their own dynamics, rather than being explicable through their components or external agents. Whitehead recognized the tendency to think only in terms of such 'substances' as a bias of European thought, claiming in his own philosophy 'to approximate more to some strains of Indian, or Chinese, thought, than to western Asiatic, or European, thought.' Significantly, the theoretical biologist who comes closest to advancing Waddington's research program, also marginalized, is Mae-Wan Ho. Noting this bias, and embracing Whitehead's and Waddington's efforts to free biology from assumptions dominating Western thought to advance an ontology of creative causal processes, I will show how later developments of complexity theory, most importantly, Goodwin's work on oscillations, temporality and morphogenesis, Vitiello's dissipative quantum brain dynamics, Salthe's work on hierarchy theory, biosemiotics inspired by Peirce and von Uexküll, Robert Rosen's work on anticipatory systems, together with category theory and biomathics, can augment while being augmented by Waddington's work, while further advancing Mae-Wan Ho's radical research program with its quest to understand the reality of consciousness.

Keywords: Epigenesis; Complexity; Biofields; Neurophilosophy; Consciousness; Daoism

> 'If you do not change direction, you are likely to end up where you are heading.'
>
> Lao Tzu (ascribed)

1. Introduction

Norbert Wiener introduced the term 'cybernetics' in 1948, characterizing it as the scientific study of control and communication in animals and machines. It subsumed the concept of 'homeostasis'. This term was coined by Walter Cannon in 1926, but the concept had been put forward by Claude

[1] 'Daoism' is the pinyin spelling, generally used by sinologists. The Wade-Giles spelling is 'Taoism'. 'Dao' becomes 'Tao'. I will use the pinyin spelling throughout since this is almost universally used among academics, particularly sinologists, except when quoting those (mainly Joseph Needham and Mae-Wan Ho) who used the Wade-Giles spelling, in which case I will insert the pinyin spelling in square brackets following this.

Bernard in 1865, and by Friedrich Schelling in 1799. Cybernetics and homeostasis, incorporated into systems theory and complexity theory, are now central not only to biology but have been taken up in a whole range of other disciplines, and these concepts are now transforming society. This is not the case with two concepts developed and named by the theoretical biologist C.H. Waddington, 'chreod' (or 'creode' or 'creod'), a path of development, and 'homeorhesis', the tendency to return to a trajectory or path of development when made to deviate from it. These concepts were developed through work in embryology and the study of biological development, and emerged under the influence of Alfred North Whitehead from the concept of 'morphogenetic field'. The notion of a morphogenetic field, influenced by the concept of field in physics, originated in the work of Hans Driesch, although the term was not used until 1912 when it was coined by the Lithuanian/Russian biologist, Alexander G. Gurwitsch (Lipkind, 1998, 39). The notion of mophogenetic field has always suffered from its association with Driesch's supposed vitalism and Idealist notion of entelechy as an immaterial organizing agent. However, I will argue that a deeper problem is antipathy to the concept of field, even in physics, despite the word being used and the supposed triumph of quantum field theory. Proponents of the notion morphogenetic field, for instance those influenced by Gurwitsch such as Marco Bischof and Fritz-Albert Popp, or Brian Goodwin (who undertook his Ph.D. with Waddington) and the biologists associated with him (such as Gerry Webster, Peter Saunders and Mae-Wan Ho), are treated as radicals on the margins of mainstream biology (as David Depew and Bruce Weber noted in their history of Darwinian evolutionary theory), even when, as with Brian Goodwin, they go out of their way to relate their work to more established research traditions (Depew and Weber, 1996, 418).

My contention, which I attempt to defend here, is that all these concepts should be fully embraced and should have been at the centre not only of biology but science generally, but their acceptance has been hindered by deep assumptions that developed with European civilization that are now blocking the advance of science. They are crippling our ability to make life and mind intelligible. Through an historical examination of the development of the concepts of chreod, homeorhesis and field by Waddington and other theoretical biologists, it is shown that there has been an unreasonable resistance to their acceptance. My claim is that, because these concepts were influenced by Chinese philosophy, they were alien to deep assumptions of mainstream Western thought, and this made it difficult for most biologists to incorporate them into their thinking. The consequence has been a fragmentation of the challenges to mainstream thought posed by alternative research traditions. Examining Chinese traditions of thought to reveal the coherence of these concepts when they are not interpreted and judged through the assumptions of mainstream Western science could free us from these blockages, it is argued. The work of Mae-Wan Ho, a theoretical biologist aligned with the tradition of theoretical biology but strongly influenced by Daoist philosophy, is shown to illustrate the potential of such freedom from old assumptions, in the process, advancing our understanding of life and consciousness. Her work is shown to pave the way for fully embracing and further developing the concepts of chreod, homeorhesis and biofields and also integrating other challenges to mainstream biology and science generally. This provides the basis for putting science on a different path, advancing not only biology, making the emergence of sentience and consciousness within nature intelligible, but advancing all the sciences and the humanities. Finally, it is suggested that this could have a major impact beyond science, facilitating a change in the direction of civilization.

2. Waddington's Research Program

In the early 1930s a group of outstanding biologists, inspired by the theoretical revolutions that had taken place in physics, D'Arcy Thompson's book *On Growth and Form* (published in 1917), and by the philosophy of Alfred North Whitehead, formed the Theoretical Biology Club at Cambridge

University from which they launched a major new research program, mathematico-physico-chemical morphology. They then attempted unsuccessfully to get the support of Cambridge University for this, and its participants dispersed (Abir-Am, 1987, 1-70). Unlike the research program of molecular biology which developed much later, this research program was never able to gain widespread support. Waddington, along with Joseph Needham who later became a leading sinologist, was a leading figure in this movement, and despite the failure to get support from Cambridge University and then losing his position at Cambridge, continued developing the research program until the end of his life, providing an alternative to the research program of the molecular biologists and proponents of the synthetic theory of evolution with their reductionist agenda. In the late 1960s and early 1970s he organized four major international conferences on theoretical biology, involving most of the leading opponents of reductionist biology (dominated by molecular biology and the synthetic theory of evolution) in Anglophone countries. The proceedings of these conferences were published in four volumes as *Towards a Theoretical Biology.* These have been a major reference point for strong anti-reductionist theoretical biology ever since, but Waddington's research program has seldom been embraced in its totality.

Central to Waddington's research program were the concepts of chreod, homeorhesis and morphogenetic field. Waddington himself wrote that he first used the terms of chreod (originally spelt creode) and homeorhesis in *Strategy of the Genes* published in 1957, although he had presented the idea of homeorhesis in *Introduction to Modern Genetics,* published in 1939, without naming it (Waddington, 1968, 178). Early in his career he had noted the various changes in the development of the embryo involved switching between different possibilities and was affected by a great many genes. The specificity resided within cells, and was characterized as a 'masked evocator'. While to begin with, he thought this evocator had to lie in the switch, through the influence of Alfred North Whitehead's characterization of 'concrescence' as a process of self-creation, Waddington recognized that this switching could be an internal property of such concrescence or self-causing self-formation related to but not determined by other acts of concrescence (Waddington, 1969, 81.). As Whitehead realized, his concept of concrescence broke with deep assumptions of Western thought, and was much closer to Indian or Chinese thought. As I will indicate later, through the influence of Chinese thought on Leibniz and the influence of Leibniz on Whitehead, it was actually influenced by Chinese thought, and ultimately, by Daoism. While used to characterize epigenesis – the differentiation of cells and generation of form in an organism's development from embryos into adults, Waddington defined 'chreod' very generally. In *The Nature of Life,* published in 1962 he wrote:

> There seems to be no generally recognized word to indicate a path of change which is determined by the initial conditions of a system and which once entered upon cannot be abandoned. I have suggested for this idea the word 'creode' from the two Greek words χρη necessity and άδος a path. We can say then that the hereditary materials with which an organism begins life define for it a branching set of creodes. Different parts of the egg will move along one or other of these creodes, so that they will, after a long process of progressive changes, finish up as one or other of a number of different end-results, as it might be heart muscle, nerve, kidney and so on. … A path of development, or creode, exhibit a balance between inflexibility (tendency to reach the normal end-result in spite of abnormal conditions) and flexibility (tendency to be modified in response to circumstances). I have used the word 'canalization' to refer to this limited responsiveness of a developing system (Waddington, 1962, 64).

Waddington characterized homeorhesis by contrasting it with homeostasis. In homeostasis a property such as temperature is kept constant through negative feedback. Homeorhesis is the capacity to maintain or buffer a chreod or path of development over time, so that if the system is made to deviate from this path of development or trajectory, it will return to the path further along. For instance, if a large chunk is taken out of an embryo early in its development it can still develop into a normal adult organism. This buffering was visualized through Waddington's concept and representation of epigenetic landscapes. Possible paths of development are represented by valleys, divided by ridges, which canalize streams. If a stream flowing down a valley is diverted, it will usually return to the centre of the valley further down. A very large diversion, however, might result in the stream flowing over a ridge into a different valley. The nature and degree of the buffering is represented by the steepness and height of the ridges and the difficulty the stream would have in flowing to a different valley.

While elaborated in the process of characterizing and comprehending developing organisms, Waddington argued these concepts could be applied more generally, suggesting they could be used to account for how the brain responds to stimuli (Waddington, 1969, 247), the development of cognition and language (Waddington, 2012, 288) and how cities (Waddington, 1972, 59-72), economies and societies develop (Waddington, 1977, chap.7). They were concepts designed not only to overcome reductionist materialism, but to overcome Cartesian dualism and the divisions between the natural and human sciences, the humanities and the arts by granting a place to experience in nature and making thought, consciousness and society intelligible.

All these notions emerged out of the concept of morphogenetic field that Waddington had embraced early in his career as a biologist. As noted, this concept had been introduced by Driesch in 1891, characterized as an harmonious, equipotential system, and was first explicitly characterized as field first by Gurwitsch in 1912. The concept was developed in the 1920s and 30s by Hans Spemann and Paul Weiss, Ross Harrison, and Ludwig von Bertalanffy (the founder of general systems theory). The field concept, borrowed from the physics of Faraday and Maxwell, functioned first of all as an analogy with magnetitic fields and as an heuristic device to study and model mathematically how cells differentiate and organize into forms according to their position in the developing organism. However, it was sometimes accompanied by physical explanations of its role. Gurwitsch argued that these fields are immaterial, generated by interpenetrating electric fields produced by the constituent cells to corollate actions and the development of organisms (Haraway, 2004, 57f.). He had identified biophotons, specific types of photons produced by living material that influence division rates in growing organisms, and took these to be products of such fields and central to their organization. Fields, he argued, unlike time, are not measurable and can only be described geometrically, not physically. Following Gurwitsch, theorists took morphogenetic fields to be electromagnetic fields, but in the 1920s they had little success in developing this idea (Bischof, 2000, 1-25). Other theorists postulated one or more potentially identifiable chemical substances distributed in space to define fields, with gradients functioning to orient cells, and by the late 1930s, this view came to dominate.

What then is a biological field? To characterize such work, Anton Markoš in a study of marginal schools of thought in biology, marginal by virtue of their commitment to do justice to the reality of life, offered a working definition of the concept that remains valid up to the present:

> A field is any entity whose components know of each other and therefore behave differently than when removed from the field. The verb 'know' stand for coherence and nonlocality. It follows that (1) changes in any part of the field are

> felt in all places within the field (coherence), and (2) such changes are inherent in the field, not a product of any external forcing (nonlocality) (Markoš, 2002, 94f.).

It could be added to this definition that such fields are at least to some degree immanent causes of themselves (or self-causing) and therefore at least partially autonomous from their environments and constituents. And they do not have what Whitehead characterized as a fallacious assumption of modern thought, that what exists must have a 'simple location' (Whitehead, 1978, 137). They only exist as such extensively and over durations. Although the notion of the field is now widely used in science, it is really alien to Western thought, looked upon with suspicion, and tends to be interpreted in a way that denies its full significance. For example, the greatest advances in physics over the last century culminated in the development of quantum field theory, but as I will point out in more detail later, it is usually interpreted as part of elementary particle physics. Like concrescence, the notion of field really derives from the influence of Chinese thought, ultimately, Daoism, on Western thought.

The notion of field was embraced by the members of the Theoretical Biology Club. It was first taken up among this group by Joseph Woodger while collaborating with von Bertalanffy. As with the other members of the Theoretical Biology Club, Woodger was strongly influenced by Whitehead who, under the influence of Michael Faraday, James Clark Maxwell and Hendrik Lorenz and the revolutions taking place in physics, had attempted to provide a philosophy that could make the reality of fields intelligible (Desmet, 2015, 190-223). As I will show later in this paper, the work of Faraday and Maxwell, focussing on and showing the relationship between magnetism, electricity and light, was really the triumph of the anti-Newtonian Romantic natural philosophers inspired by Friedrich Schelling and Roger Boscovich, who in turn were influenced by Leibniz. Both Schelling and Leibniz were directly influenced by Asian thought. Woodger was defending an anti-reductionist organicism in opposition to both mechanistic thinking and what he took to be Driesch's vitalism with his Platonic notion of entelechy. Needham and Waddington, who had worked in Spemann's laboratory in Germany in 1932-33, also embraced the term 'field'. Waddington introduced the notion of the individuation field to describe the formation of different organs with characteristic individual shapes. He emphasised that these fields could not be equated with a particular region, since if a field is cut in two, each half could constitute a complete field, while two fields brought together could constitute themselves as one field. Also, if part of a field is removed, the remainder could compensate for the defect and become complete again (Waddington, 1956, 27-28). These dynamic fields are influenced by both genes and the environment, but have their own, self-stabilizing trajectories.

Needham, who began as a biochemist concerned with the forms generated by chemicals, was also concerned to defend a hierarchical conception of nature with the focus on different levels of organization and the patterns associated with these. He also embraced the notion of field, which he characterized as wholes actively organizing themselves. Needham noted that while the notion of field was based on an analogy, it is possible that there is a formal identity between magnetic and morphogenetic fields. He acknowledged that the field concept has suffered greatly from inaccurate definition, but defended Waddington for having provided the best definition of 'field' as 'a system of order such that the position taken by unstable entities in one portion of the system bears a definite relation to the position taken up by unstable entities in other portions.' It is then 'a dynamic description of a spatio-temporal activity, not a mere geometrical picture of a momentary time-slice in the organism's history' (Needham, 1968, 108). He attempted to account for these field properties biochemically, with proteins seen as crystalline fibres oriented in patterns by active substances or hormones (Needham, 1968, 96ff., Webster and Goodwin, 1996, 97, Haraway, 2004, 124).

While Waddington did not refer to fields in his later work, he still assumed this concept. René Thom, who collaborated with Waddington to develop a mathematics able to conceptualize chreods and homeorhesis, suggested in a letter to Waddington that 'chreod' is a synonym for 'support of a morphogenetic field' (1968, 168). Waddington agreed with this suggestion. Thom, who played a prominent role at the famous Serbelloni conferences on theoretical biology in the late 1960s and early 70s, developed differential topology to model epigenetic landscapes, including paths of development and what is involved in the switch from one path of development to another (later called catastrophes), and coined the term 'attractor' to characterize the end point to which paths develop. Waddington also invited Lewis Wolpert to the first of these conferences in 1968. Wolpert's prime concern was to account for spatial pattern formation in organisms, relating this to Waddington's concepts of chreods, homeorhesis and epigenetic landscapes. Although he did not use the term 'field' in his contribution (he did use it in his later work), the problems he was addressing in his contribution, how the proper proportions between parts are developed and maintained, how within limits, a part can produce the whole or can become any other part, and how the polarity is maintained so that the parts maintain their correct positions, were essentially the problems of defining a field. His approach was to ask how positional information is conveyed to units to compute their position in the field and respond appropriately, and how this process could be modelled (Wolpert, 1968, 125-133). He proposed the existence of chemical morphogens, the gradients of which would serve to provide this information, triggering differentiated responses at particular thresholds. He was universally seen as contributing to the development of the concept of field.

At this time Waddington believed such positional information would be provided by patterns of oscillations. As he wrote in the proceedings of the second conference on theoretical biology:

> We could not have a 'neural plate substance, a fore-limb substance, a hind-limb substance' etc. but neural plate, fore-limb or hind-limb oscillatory patterns, which could be regarded as analogous to musical themes or chord sequences. The later phases of differentiation into the various cartilages, bones, muscles, etc., must certainly involve the 'activation' of different structural genes controlling the proteins in these different sorts of cells; but we could interpret these changes as similar to the development of the initial themes according to the conventions of some school of classical music composition (1969, 180f.).

When differentiation is conceived in this way, neighbouring cells can be taken to act as temporal templates which entrain the oscillations of the cells according to their position in the organism, a process that is now better understood than when Waddington was writing (Kauffman, 1993).

In an anthology co-edited by Waddington and published soon after the theoretical biology conferences, *Evolution and Consciousness,* included a chapter by Ilya Prigogine on the slime mould which supported this conjecture. The slime mould transforms itself from a community of protozoa into a single, multi-celled organism. The isolated cells (between 10 and 100,000) which develop from spores exude the chemical acrasin at increasing rates as the food supply is depleted, while at the same time becoming more sensitive to this chemical. The increased production destabilises the homogeneous solution producing a far from thermodynamically equilibrium state which generates dissipative structures in the form of oscillations. A certain critical wavelength exists which determines the spatial distribution of the cells. The cells oriented by this wavelength then aggregate, eventually forming a structure in which some cells become rich in cellulose and develop into a foot or base while others rise above it and become rich in polysaccharides. The mass on top eventually develops as a fruit, producing a large number of spores. Prigogine noted that predictions of the behaviour of individual cells based on the theory of dissipative structures have been verified by Keller and Segal (Prigogine, 1976, 107ff.). This anthology coincided with the redefinition of such anti-reductionist work around the concept of complexity theory, a reorientation embraced by Waddington in the book he was working on, *Tools of Thought,* published posthumously.

3. The Subordination of Waddington's Research Program

The conferences on theoretical biology were not meant to establish a dogmatic position but to define a direction for further research in biology, bringing together the most promising developments in theoretical biology and related disciplines, revealing the problems that had to be addressed and the challenges that lay ahead. If there was a target to all this it was to overcome and replace the reductionist thinking associated with molecular biology and the synthetic theory of evolution that had reduced biology to chemistry and statistics, with evolution explained entirely in terms of variation and selection of genes. Waddington gave a place to advanced developments in mathematics and theoretical physics, and included the burgeoning new field of complexity science, best represented at the conferences by Stuart Kauffman who later became a key figure in the development of complexity theory. Despite this, Waddington's research program failed to define the direction of biology, even among those who appreciated the deficiencies in molecular biology and the synthetic theory of evolution.

There were a number of reasons for this failure. One was that there were major differences between the theorists. Thom played a prominent role at the conferences as someone who had worked with Waddington to develop mathematical models adequate to his concepts. However, he was only one of the mathematicians, and his Platonist or Pythagorean understanding of mathematics differed not only from other mathematicians, but from the conception of mathematics defended by Alfred North Whitehead, the philosopher who had most influenced Waddington. David Bohm, the radical quantum physicist who was challenging not only mainstream interpretations of quantum mechanics but their very idea of science, played a prominent role at the conference. Howard Pattee, another theoretical physicist, upholding a more conventional view of science, also attended the conference. Pattee's conception of epistemological cuts, used to account for how molecules become symbols and to explain control, was based on John von Neumann's interpretation of quantum theory. If the insights of these two physicists are to be embraced, some work is required to reconcile their differences.

Kauffman's study of the emergence of order in Boolean networks simulating autocatalytic sets able to catalyse their own formation, fed into the later work of the Santa Fe Institute established in 1984, in which he came to play a leading role. His later work demonstrated the possibility of self-stabilizing canalizing of development purely on the basis of such Boolean networks (Kauffman, 1993, p.447f.). While vastly superior to the crude accounts of life of the molecular biologists, this was a bottom up explanation for the emergence of order and did not invoke support from the concept of morphogenetic fields, although there was no reason for not combining these two approaches, with fields providing the conditions under which Boolean networks can form, exist, self-catalyse, develop and be utilized. And in fact Kauffman's work on the origins of life, explaining it in terms of self-organization based on the emergence of autocatalytic sets in which chemicals catalyse or inhibit each other's reactions, is really a holistic explanation, showing how an environment is formed that constrains its components to reproduce it, to some extent transforming these components in doing so. However, many of those involved in the development of complexity theory saw complexity as it had initially been defined by Warren Weaver (1948), the originator of the project to understand complexity. For Weaver and his orthodox followers, complexity was the last frontier for reductionist science. Weaver did not take seriously the anti-reductionist traditions of thought that had made complex phenomena their focus to challenge Newtonian science and justify radically new alternatives. For complexity theorists following Weaver, the appearance of complex patterns at a macroscale is nothing but an appearance generated by interaction between very large numbers of elementary components acting on principles that require no reference to these broader patterns, and in no way are the effect of these broader patterns. There is no acknowledgement of downward causation. This has been clearly recognized by James Crutchfield, a prominent member of the Santa Fe Institute (1994). Norbert Wiener had already appreciated this in the 1950s when he argued that cybernetics, which underpins much of complexity theory, should be seen as a triumph of mechanistic materialism (1981, 44).

So, the marginalization of Waddington's work and the failure to take up his core concepts was not simply a matter of the continued dominance of molecular biology and the synthetic theory of evolution. These were being effectively criticised from a number of directions, although from less radical positions than had been defended by Waddington. Most importantly, it came from more mechanistic forms of system theory that had embraced cybernetics, information theory as developed by Shannon, Alan Turing's concept of a computation, von Neumann's idea of a computer, and the reductionist forms of complexity theory as initially promoted by Weaver (Scott, 2007), including neural nets, spin glass and cellular automata. Such approaches can give a place to emergence analogous to the emergence of mind within the brain. For example, through the individual entrainment of individual alternating-current generators in a national electrical power grid, a virtual governor emerges which controls the entire systems, even though it has no palpable or locatable physical existence. Such mutual entrainment of oscillations and their effects are really examples of cybernetic feedback, and have been used to develop much more complex control systems designed to achieve 'generalized optimal-superadaptive control' (Dewan, 1976, 179). This can be taken as a model of the mind's relation to the body. The success of general systems theory developing such ideas reduced the appeal of approaches requiring a more radical rethinking of the assumptions of science.

The more radical ways of thinking promoted by Waddington were dismissed as vague, lacking the rigour required to really advance science. Even some of Waddington's erstwhile defenders distanced themselves from his work. Thom in his introductory contribution to the conference on theoretical biology organized by Brian Goodwin and Peter Saunders in 1987, belittled Waddington's achievements. Listing the words that Waddington had coined, he wrote;

> 'Individuation' was the first term proposed by Waddington to describe the overall organising effect of an 'organizer' (such as the celebrated dorsal lip of the blastophor in amphibians). I do not think this attempted 'word launching' was a successful one. … 'Epigenetics' was the result of a marriage synthesis between 'Epigenesis' (the classical older theory opposed to 'preformation' in embryological theory) and 'genetics' …. Personally I am inclined to think that the distinction in embryology between 'genetic' and 'epigenetic' events is a moot question (perhaps as ill-defined as the classical problem of distinguishing inherited from acquired characters). … *Canalization* was the great discovery already presented in Waddington's (1940) book, *Organizers and Genes. …* Among biologists, however, it was considered as a useful concept but with no explicit application. The same observation applies also to the allied concept of *creod*. … I adopted the word, but in my mind for a fairly precise situation. The concept as Waddington proposed it was obviously too general, as nothing was said about the nature of the process and how it could be described. … Because of this too general, fuzzy setting, the creod concept had little relevance for verbally described processes. … I claim that the general theory of morphogenesis in biology has been plagued by vague conceptualizing and, accordingly, by a proliferation of ill-defined terminology. …

> Had people realised that the notion of a morphogenetic field is a purely descriptive notion, by itself devoid of any explanatory power, then a lot of trouble could have been avoided (Thom, 1989, 2,3 & 4).

Thom was more sympathetic to the notion of homeorhesis and the idea of epigenetic landscapes. He wrote of Waddington's picturing of the epigenetic landscape, 'There is no doubt that the model of the epigenetic landscape was for me the decisive clue to the discover of catastrophe models' (Thom, 1989, 5).

4. Reasons for Defending Waddington's Research Program

Why then support Waddington's research project? One reason is that reductionist theories in science, even mainstream complexity theory, not only cannot account for experience; they render experience, including feeling, awareness, emotion, consciousness and the sense of being a subject of experience, unintelligible. At most, experience can be granted a place as an epiphenomenon, and this is merely an *ad hoc* acknowledgement of the obvious reality of experience. While it is possible that some people have evolved into things approaching automatons who can only operate mechanically and have no sense of being conscious (which appears to be the case with behaviourists and psychologists promoting a computational model of the 'mind'), even these post-humans can be shown to experience pain and pleasure, and even these are incomprehensible from the perspective of mainstream science. Secondly, what one finds among most reductionists is that, as with experience, a whole range of phenomena, including final causes, are surreptitiously assumed despite their inconsistency with their reductionist program, and many of these assumptions derive from the traditions of anti-reductionist thought exemplified and further advanced by Waddington. Thirdly, Waddington's ideas and those he influenced have been taken up, developed and proven to be fruitful, but for the most part in a fragmentary way that has prevented the achievements of this tradition from being properly acknowledged and integrated. However, the most important reason, I will argue, is that Waddington's ideas were inspired by a radical tradition of thought, specifically, the work of Alfred North Whitehead, that had challenged the deep assumptions of modern science, assumptions that had given plausibility to Cartesian dualism and reductionist materialism. By virtue of having challenged and offered alternatives to these assumptions, this tradition could provide a far more coherent research tradition than mainstream science is capable of providing, even in its more radical forms as with complexity theory. This radical research tradition can incorporate what advances have been made by the molecular biologists and reductionist forms of complexity theory, while these approaches cannot account for the insights and achievements of the more radical anti-reductionists. And it is because of the failure to appreciate this with all its implications that advances in science challenging mainstream science, are dismissed or misrepresented, fragmented and then forgotten about. To begin with, however, I will examine claims that Waddington's ideas could not be developed with sufficient rigour to justify his aspirations for them to become the dominant tradition in biological thought.

The work of Thom and those he influenced illustrates much of this. Thom's criticism of vague definitions had already been made by Needham in 1936. There will always be vague definitions, and this is also true of mainstream science. As C.S. Peirce argued, it is important to have vague terms, or 'real vagues' as well as more precisely defined terms, if for no other reason than the future is open and it is necessary to give a place to future possibilities that cannot be anticipated. The theoretical 'objects' that science investigates, such as atoms, fields, systems or whatever, have to be defined vaguely to facilitate their investigation that will involve altering how these are understood, and to provide reference points for different theories of these objects. Science advances not by achieving absolutely precise, final definitions of concepts that are ascertained to be true but by continually refining definitions (for instance, what is an atom, or what is an electron, as well as what is a field) rethinking them in relation to other concepts, occasionally putting forward new and/or rival concepts, requiring both vague concepts and precisely defined concepts. This point was also made by David Bohm, following Alfred Korzybski, who pointed out that more precise concepts, such as those developed in mathematics, support longer chains of deductions, allowing the implications of theories to be explored, but at the expense of more limited applicability (Bohm & Peat, 2000, 1-14). The richness and complexity of what there is, is abstracted away from, and to fail to acknowledge this is to commit what Whitehead called the fallacy of misplaced concreteness, taking abstractions for concrete reality. In this regard, the relationship between Waddington and Thom echoed the relationship between Faraday and James Clark Maxwell. Faraday knew little mathematics, but in 1846 developed the concept of electrical and magnetic fields and their relationship, and applied it in his technological innovations. Maxwell formulated Faraday's ideas through mathematics in 1864, presenting his more refined concept of the electromagnetic field, revealing far more than Faraday could about the nature of this field, showing that light could be accounted for as electromagnetic radiation, and predicting the discovery of radio waves. However, all this was still dependent upon using the more informal concept of field developed by Faraday to characterize what was being investigated.

Thom was able to clarify and reveal the implications of Waddington's non-mathematical ideas. This meant going well beyond the intuitive understanding of the ideas Waddington was developing; but this is what should be expected. As P.T. Saunders and C. Kubal put it, 'While the properties of the epigenetic landscape can be understood in terms of those systems of non-linear differential equations, the converse is not true. It would be astonishing if it were; a pictorial representation, however ingenious, can hardly be expected to capture all the richness of a whole class of complex mathematical structures' (Saunders and Kubal, 1989, 17). However, it was a mistake by Thom to believe that his mathematics left behind Waddington's concepts. This was a consequence of Thom's commitment to a Pythagorean Platonism that identified reality with its mathematical representation, a commitment that led Thom to defend 'scientism', the view that science should at least aim to provide the one universal language capable of grasping the whole of reality, and in accordance with this, to defend determinism (Thom, 1983a, chap.16, Thom, 1983b, 11-21). This was challenged by Prigogine who (in accordance with Whitehead's philosophy and his critique of the 'fallacy of misplaced concreteness' - mistaking abstract models for concrete reality) argued that all mathematics involves idealizations and so cannot be identified with reality as such (Prigogine, 1983, 36-42). The relationship between the morphogenetic field identified through a relatively vague concept and the mathematical description of this was clarified by Gerry Webster and Brian Goodwin. Accepting Rom Harré and E.H. Madden's criticism of the conflation of logical necessity, through which predictive deductions are made, and natural necessity, by which causal powers bring about effects, they wrote 'the term "morphogenetic field" denotes *something* real, irrespective of the adequacy of our theories, because we can physically manipulate fields and because they cause things to happen. Knowledge of the existence of fields is, arguably, a permanent addition to our knowledge of what exists in the world' (Webster and Goodwin, 1996, 98).

Subsequently, it was shown by others observing what was being left out by Thom's mathematics, that Thom's mathematical ideas were limited. This led to the development of more general mathematics that integrated Thom's ideas with chaos theory and other developments in mathematics into a general mathematics of complexity. E.C. Zeeman, Thom's disciple, contributed to this at the conference organized by Goodwin, where he noted 'the failure of [Thom's] programme for structural stability', and sought to overcome this by introducing 'a little stochasticity' (Zeeman, 1989, 9).

5. Brian Goodwin's Development of Waddington's Research Program

It could be argued then that the failure of Waddington's research program compared to molecular biology was just an unfortunate confluence of circumstances. That this was not the case is evident from the career of someone with outstanding ability and perseverance who carried on Waddington's project. If there was one person among the participants of Waddington's theoretical biology conferences who best represented Waddington's own vision of the future for theoretical biology, it was his former student, Brian Goodwin. Goodwin maintained his commitment to the concept of morphogenetic fields, to explaining these through oscillatory patterns and to developing forms of mathematics adequate to such ideas. Like Prigogine, Goodwin was committed to comprehending all this through the concepts of thermodynamics. He went on to organize the conference referred to earlier on theoretical biology and to lead a group of radical theoretical biologists in Britain to challenge mainstream biology, relating this work to structuralism and participating in the burgeoning field of complexity studies. Goodwin contributed to advances in mathematics beyond catastrophe theory and became a major figure in the development of complexity theory, supporting Waddington's concept of chreods by showing that development in organisms is 'an intrinsically robust process' in which 'the dynamic organisation of the system resulting from the interactions for the constituent processes results in a morphogenetic sequence that does not require continuous fine tuning or parameters to guide the system to a particular state' (Webster and Goodwin, 1996, 233). This was illustrated with the single celled organism, *Acetabularia,* as well as with multi-celled organisms. However, while having some influence, the group associated with Goodwin remained marginal. As Depew and Weber (1996, 418) observed, he did not occupy positions in top universities, and ended up teaching at Schumacher College. And as noted, some of Waddington's core ideas were simply dropped. Goodwin's work shows that Waddington's concepts can be rigorously defended and can guide further developments, but also why the more ambitious research program of Waddington has disintegrated and faded into the background.

Goodwin's first major work, *Temporal Organization in Cells: A Dynamic Theory of Cellular Control Processes* (1963) used the mathematics of classical statistical thermodynamics to show how control of metabolism and epigenesis involving spatial differentiation and hierarchical ordering could be achieved by coupled biochemical oscillators. The role of coupled oscillators was taken much further than in reductionist forms of systems theory in that the organism itself was shown to identify and respond to resultant patterns, and deploy at specific times and places the conditions for such patterns to emerge, thereby advancing one of Waddington's key conjectures - that oscillations served to coordinate activity within the organism. Goodwin also showed through this approach how different oscillations characterized by radically different process rates could both be insulated from each other and influence each other, thereby explaining hierarchical ordering. While using statistics to avoid the problem of dealing with nonlinear oscillators, the work was commended, despite these limitations, in a review by Robert Rosen (1965).

Oscillations and rhythmic activity in achieving coordination was acknowledged, although not emphasised, in all Goodwin's later work, work in which he fully embraced and developed the concept of field. One of his contributions to an anthology was titled 'Developing Organisms as Self-Organizing Fields' (1987). It is by developing the concept of field that Goodwin explained Waddington's notion of chreods, that is, the capacity of a developing organism to respond to various perturbations so that at the end the result of development is perfectly normal. He pointed out that the kind of explanation for this offered by Wolpert, in which genes within cells interpret signals that specify their position in the field, their 'positional information', cannot account for pattern formations associated with the development of limbs. This requires holistic explanations in which constraints arise because elements are generated in groups which are constrained relative to each other. This process can be modelled by field equations. Thus a transformation from a five digit pattern to a four digit pattern of toes in frog's foot does not involve the loss of an individual digit, 'but a change in whole aspects of the pattern' (Goodwin, 1984, 113). Goodwin showed that 'domains of distributed potential, which are the morphological fields of developing organisms, give rise to actualized patterns of localized structure, which is overt organismic morphology. … Each organism carries within it the potential of creating a great variety of forms, for each morphogenetic field is described by equations with many solutions which define the set of morphological possibilities' (1984, 118).

In this scheme, what Waddington called a chreod becomes 'a trajectory through the space of solutions of the morphogenetic field equations'. The high degree of stability through variations in temperature etc. is what 'Waddington (1957) called genetic canalization' (Goodwin, 1984, 118). Goodwin characterized a fertilized egg as a 'developing organism insofar as it is a totality describable by a field,' which cleaves to produce 'complex parts such as neural plate, limb fields and eye fields' (1987, 176). In accordance with Waddington's broader understanding of chreods, he showed that 'once parameters were adjusted so that the intrinsic wavelengths of emergent patterns were smaller than the size of the initial regenerative domain that detailed structure could be generated, the system had a natural tendency to pass through a sequence of shape changes' (Webster and Goodwin, 1996, 233). He described this process as self-stabilizing cascades of 'symmetry-breaking bifurcations that have an intrinsically hierarchical property, finer spatial detail emerging within already established structures' (Goodwin, 1994, 100). On this basis Goodwin claimed that 'morphogenetic fields … have a definition as precise as any field used in physics' (1994, 88) and implicitly characterized chreods through them.

Goodwin developed another aspect of Waddington's research program. In the epilogue to the conclusion of the fourth and last symposium on theoretical biology, Waddington commented on Howard Pattee's contribution to the symposium in which Pattee had grappled with the question, How does a molecule become a message? Pattee concluded that a symbol can only function as a symbol when it is part of a system of symbols. Waddington suggested that the structures mediating global simplicity can profitably be compared with language and suggested that theorists of biology are just beginning to feel their way towards a language-metalanguage analogy so that the disjunction between genotype and phenotype will be seen as the analogue of symbol and symbolized. He argued that this requires a rethinking of what language is, arguing in opposition to most philosophers of language, including logical positivists and Chomsky, that the basic character of language is imperative, not indicative. It is meant to have an effect. As he concluded, 'To a biologist, therefore, a language is a set of symbols, organized by some sort of generative grammar, which makes possible the conveyance of (more or less) precise commands for action to produce effects on the surrounding of the emitting and the recipient entities' (Waddington, 2012, 288).

Waddington was severely critical of philosophers of language for their preoccupation with statements, referring favourably to Jean Piaget and Jerome Bruner who had argued that we are, first and foremost, practically engaged in the world, and should understand language in the context of such practical engagement. Utterances are first and foremost imperatives, and descriptions have a secondary status. Invoking Piaget and Bruner was not a random choice. Waddington had participated in an earlier conference on the life sciences in which both Piaget and Bruner participated (Koestler and Smithies, 1971). Piaget, who characterized his study of cognitive development as genetic epistemology, describing cognitive development as a process of assimilating inputs from the environment to cognitive structures and then accommodating these structures to better assimilate inputs from its environment, fully embraced Waddington’s work and characterized cognitive development as he himself had theorised it, as having its own chreods (Piaget, 1971, 18ff.). Waddington in turn praised Piaget and argued that his own work on genetic assimilation could be used to defend Piaget’s claims if it were ever shown that cognition and the ability to use language could develop in individuals in the absence of practical engagement in the world. This was later shown and used to dismiss Piaget’s work.

Following Waddington again, Goodwin characterized organisms as cognitive and cooperative systems, drawing upon developments in linguistics to develop this characterization (Goodwin 1976, chap.7). Goodwin and his colleague Gerry Webster aligned themselves with structuralism, a broad intellectual movement centred in France that was very fashionable at the time and later, and under the influence of Webster and Goodwin, was strongly promoted in biology by Atuhiro Sibutani (1989). While Sibutani aligned himself with the work of Saussure, Levi-Strauss and Chomsky, Goodwin, following Waddington, aligned himself with Piaget, starting his contribution to an anthology published in 1989 devoted to structuralist biology with the sentence, ‘Structuralism is based upon the proposition that actual phenomena are particular realisations from a defined set of possibilities’ (1984, 49). Piaget’s notion of cognitive structures as self-regulating systems of transformations did have much in common with Waddington’s notion of fields as this concept had been defended and developed by Goodwin.

The turn to structuralism, while promising, was problematic in several ways. Piaget was not a mainstream structuralist but a genetic structuralist, highly critical of many of the other structuralists (Piaget, 1971). Using Piaget to advance theoretical biology was a promising way of relating biology to cognitive development. With its assumption of the primacy of action and his interest in evolution as well as development of cognition, Piaget’s work, which gave a major place to the development of signs, including language, could also provide a bridge to the work of the biosemioticians influenced by C.S. Peirce. However, the French structuralists, and to a lesser extent, Piaget, were aligned with the structuralists in mathematics, a highly formalist approach that did not support Waddington’s understanding of mathematics, and which later ran into insuperable difficulties (Corry, 2004). Goodwin, and Peter Saunders, who also embraced structuralism at this time, were influenced by this philosophy of mathematics. As a consequence, they virtually identified structures with what could be represented through mathematics, rejecting concern with any substratum, or aspects of reality that could not be grasped in this way. This involved assuming that all creativity could be mathematically modelled, prestating all possibilities before their realization, the claim that Stuart Kauffman later rejected and provided very good arguments to reject (Kauffman and Gare, 2015, 219-244).

Also, reviving the rational morphology of the pre-Darwinian biologists associated with this structuralism meant abandoning some of Waddington’s core ideas. Goodwin not only argued that evolutionary theory should be subsumed under a theory of development, but denied any significance to variation and selection in explaining evolution, suggesting that to explain organisms by referring to their parents is equivalent to explaining the sun rising today by pointing out that it rose yesterday. This denied any significance to Waddington’s theory of genetic assimilation whereby the striving of organisms exploring new possibilities was granted a central place in evolution, with the survival of the most adaptable organisms concentrating genes over generations, facilitating the adoption of this particular chreod until the chreod developed without external stimuli.

The consequence of this was that what was a strengthening of Waddington’s research program, bringing it up-to-date and opening new directions for research, through efforts to fit in with current academic fashions helped disguise this program, the concepts associated with it, and its heuristic power, while weakening its appeal. As Anton Markoš wrote of this movement, ‘Biological structuralism was the red herring of the 1980s in biology, surviving tolerated, neglected, or ridiculed on the margins of mainstream biology' (2002, 81).

One of the last books written by Waddington, *Tools of Thought,* was largely focussed on the problem of understanding complexity, and the next phase of Goodwin's work was to embrace this quest, a quest that exploded with the establishment of the Santa Fe Institute in 1984. As a member of this institute and aligned with this project, Goodwin reformulated all his work around complexity theory, making major contributions to this research. A later book, written with Ricard Solé, *Signs of Life: How Complexity Pervades Biology* and published in 2000*,* provided an overview of all work in this research program along with accounts of their own research. This involved accepting one of the major advances in complexity theory, the study of networks and their common features, self-organized criticality, fractal patterns and the creativity associated with systems moving to the edge of chaos.

This did not involve a rejection of earlier work, but a new characterization of it. Through the study of networks it could be shown how living processes achieve functionality and robustness in their organization through their interconnectivity. Goodwin's engagement with this continued his quest to overcome all forms of reductionism. One facet of complexity theory embraced by Goodwin was the appreciation that mathematical models valid in one area, for instance in physics, could be valid in a totally different area. For instance, the Ising model and related models developed to model the magnetization of iron have been successfully applied to the distribution of galaxies, the adaptability of RNA viruses to their hosts, the interiors of rain forests, the development of cities, and voting behaviour. In each case it is shown how individuals responding only to their immediate neighbourhood generate patterns over a long range. With the mathematical model being applicable to a vast range of phenomena suggests there is no need to privilege one level of reality to explain phenomena. However, as noted above, the goal of complexity as defined by Warren Weaver had really been to explain complexity through mainstream reductionist science, and many complexity theorists, notably Per Bak, were overtly reductionist in how they defined their work (Gare, 2000). Goodwin's alignment with such thinkers led to a tendency to focus on patterns while ignoring the forces generating them. This was a tendency criticised by Howard Pattee who pointed out that computers can now simulate any pattern, and doing so cannot equate to explanation (1996, 381). This was not the case with the study of dissipative structures by Prigogine whose work played a major role in the development of complexity theory, since Prigogine's work was always tied to the development of thermodynamics. It meshed well with Waddington's research program, and it was embraced by Goodwin. However, despite Goodwin's early alignment with statistical mechanics, Prigogine did not define the direction of his work in complexity theory. So while chreods, homeorhesis and fields were absorbed into Goodwin's effort to understand complexity, they were relabelled again, further disguising Waddington's research program and blunting the challenge to the metaphysical assumptions of mainstream science.

In Goodwin's last work, *Nature's Due: Healing Our Fragmented Culture,* the full range of ideas associated with Waddington's work were revisited and supported, including the inspiration Waddington gained from Whitehead. It became evident that despite the rigorous defence of Goodwin's claims, the boldness of this last work diminished the status accorded his work by mainstream biologists. This was a possibility recognized by Goodwin. Referring to work influenced by Whitehead attempting to give a place to feelings in nature, Goodwin wrote, 'it remains a territory of extreme disagreement and dispute, and is generally rejected by the scientific and philosophical establishment, which continues to be split by the paralysing dilemma of living with and by feelings and qualities but being uncertain of their reality' (Goodwin, 2007, p.82). I will come back to this later.

6. The Fragmented Advance of the Post-Mechanist Tradition

The changes in direction of Goodwin's work were followed by most, but not all of the radical biologists with whom Goodwin was aligned, some of whom had participated in Waddington's symposia on theoretical biology. Despite these changes in direction and efforts to align their work with different research traditions rather than Waddington's research program, Waddington's ideas were advanced. Like Goodwin, Stuart Kauffman reaffirmed the bold quest for a reconception of life and its place in the cosmos present in Waddington's symposia in his 2016 book *Humanity in a Creative Universe.* Although this was not defined in relation to Waddington, it largely reaffirmed the radical ambitions of the movement for mathematico-physico-chemical morphology, including giving a place to experience and consciousness (Kauffman, 2016). And there have been other developments in biology, uninfluenced by the theoretical biology movement, but consistent with it and capable of further supporting it. The problem is that because Waddington's research program was marginalized, such ideas have not been properly integrated and fully developed. For anyone wishing to defend and revive Waddington's vision it is necessary to recognize all such achievements and relate these to each other.

The work of Thom itself is important in this regard. Despite having distanced himself from Waddington, the trajectory of this thought and those who were influenced by Waddington's ideas, and despite not acknowledging this, preferring to relate his ideas to Aristotle's philosophy, Thom continued to advance Waddington's concepts. This was also true of those influenced by Thom. For instance, a major work on morphogenesis taking Thom as a key reference point edited by Sarti, Montanari and Galofaro, *Morphogenesis and Individuation* (2015), is clearly dealing with a theme central to Waddington's research project, but does not mention Waddington. The term 'individuation' is taken from the French theorist Gilbert Simondon. Along with morphogenesis, Thom became interested in signs and language and how they function, writing two books largely devoted to this (1983 & 1990). This work was the main inspiration for the biosemiotics of Marcello Barbieri which, granting a place to mechanistic explanations, challenged mainstream biosemiotics inspired mainly by the work of C.S. Peirce and Jacob von Üexkull (Barbieri, 2003; Barbieri, 2008). It made no mention of Waddington's conjectures.

Biosemiotics inspired by Peirce and Jacob von Üexkull and led by Jesper Hoffmeyer and Kalevi Kull, emerged as another radical tradition alongside not only mainstream biology, but also the tradition of theoretical biology inspired by Waddington and his colleagues (Favareau, 2008). These biosemioticians have also embraced the work of Gregory Bateson, which itself was inspired by the work of Norbert Wiener on cybernetics, while partly under the influence of Whitehead, rejecting its mechanistic aspects (Hoffmeyer, 2008). Carrying on Wiener's project, Bateson deployed cybernetics to anthropology as well as biology, redefining information non-mechanistically in the process as 'a difference that makes a difference' (1972, 453). This non-reductionist form of cybernetics was entirely commensurable with Waddington's theoretical work. Links did develop between the biosemioticians and the theoretical biology movement, however. Howard Pattee's work on how a molecule becomes a symbol was accompanied by a major contribution to conceptualizing hierarchical order. He argued that such order develops through new, enabling constraints. This means that there is no need to postulate a life-force and then a Cartesian mind over and above physical processes to account for life and mind. Their emergence can be accounted for as self-reproducing constraints. This idea was taken up vigorously in ecology by Tim Allen and then in theoretical biology by Stan Salthe, who pointed out that semiotics as it was being developed by biosemioticians could be understood through such constraints (Salthe, 1993). Pattee's work was then embraced by the biosemioticians. And later, Hoffmeyer did examine and utilize Waddington's ideas. However, they have remained separate research programs.

While Barbieri has debated with these Peircian biosemioticians, the work of Piaget lauded by Waddington which could also be seen as a contribution to biosemiotics, has been ignored by both Barbieri and the Peircian biosemioticians, despite Peirce, von Üexkull and Piaget having emerged from a similar post-Kantian tradition of philosophy that emphasised the primacy of action over reflective thought in understanding cognition, signs and language. The concepts that Piaget offered, by filling out the Peircian notion of 'intepretant', could bridge the divide between these biosemioticians, as I will suggest below.

Many theoretical biologists allude to the role played by oscillations in generating and maintaining order in organisms. As previously noted, this was an important dimension of Waddington's research program. However, even in the case of Goodwin, this was pushed into the background and was not a focus of his interest, although it was not forgotten. However, the importance of oscillations and their entrainment has been rediscovered in one specialist area of biology after another, revealing what Denis Nobel characterized as 'the music of life' (2006). Entrainment of oscillations was shown to be central to all forms of biological organization by Art Winfree, building on the work of Nobert Wiener who recognized such entrainment as the outcome of mutual feedback (Strogatz, 2003). It is now recognized that smell is not based on spatial properties of molecules fitting receptors, but on resonance of oscillations (McFadden and Al-Khalili, 2014, chap.5). This is only a special case of such a relationship involving receptors. Candace Pert in her work on the role of chemicals involved in communication in the functioning of the body, in memory and emotion, also argued that resonance is central to the functioning of organisms. Her work was on the highly specific relation between ligands and receptors. As with smell, these have usually been visualized as keys fitting into locks, but as Pert showed, their relationship is based on resonance of oscillations also. As she put it, 'a more dynamic description of the process might be two voices – ligand and receptor, striking the same note and producing a vibration that rings a bell to open a doorway to the cell' (2003, 24). This message can then change the cell dramatically. Ligands can be neurotransmitters, steroids or polypeptides, the most complex of the ligands. It is these that Pert showed were the molecules of memory, and interacted with the emotional state of the organism. As she summed up this relationship:

> The body is the unconscious mind! Repressed traumas caused by overwhelming emotion can be stored in a body part, thereafter affecting our ability to feel that part or even to move it. The new work suggests there are almost infinite pathways for the conscious mind to access – and modify – the unconscious mind and the body, and also provides an explanation for a number of phenomena that the emotional theorists have been considering (Pert, 141).

Another advance in science that supports Waddington's project, but which was developed quite independently of it, is 'endophysics' as developed by Otto Rössler, George Kampis and others, taking seriously that people, including scientists carrying out experiments and interpreting the results, are part of the world they are attempting to comprehend (Rössler, 1998; Kampis and Weibei, 1994). In Rössler's work, the world is characterized as an interface between the subject and the rest of nature generated by a process of enfolding, a view that is consistent with and could be used to advance the work of those inspired by Whitehead and Peirce.

There are other radical developments in theoretical biology associated with efforts to take seriously the implications of field theory. Alexander Gurwitsch continued to develop his ideas, and his research program was never completely abandoned. In a book published in English in 1970, A.S.

Presman demonstrated impressive results of research in the Soviet Union and elsewhere on the role of electromagnetic fields in biological processes (Bischof, 2000; Presman, 1970). Based in Russia with allies in Western Europe, particularly Germany, biologists inspired by Gurwitsch have continued to explore what role electromagnetic and other physical fields play in not only morphogenesis, but also the development of consciousness (Beloussov et.al., 2000; Popp and Beloussov, 2003; Tzambazakis, 2015). This has been associated with a revival of interest in biophotons. Catcha and Poznanski (2014) defending biophoton field theory, argued that this can actually account for consciousness. This research program has been taken up in USA by Beverly Rubik (2002; 2015), who has promoted the notion of the biofield as a bridge between the mind and the body. The proponents of photonic fields are not the only group arguing for the importance of physical fields in biology, however. Herms Romijn (2002) has tried to explain consciousness through virtual photons (a transient fluctuation that exhibits many of the characteristics of ordinary photons, but exist for a limited time in the interaction between charged particles). Romijn did not refer to the proponents of biophoton field theory, and they did not engage with his work. D. Lehmann (1992), a Swiss neurologist aligned with the research program of synergetics inspired by Hermann Haken, argued that electric fields are central to functioning of the brain and are responsible for its integration. It has been suggested more recently by the British biologist, Johnjo McFadden on the basis of experimental work that electromagnetic fields synchronize nerve firing, pulling together coherent ion channels in different parts of the brain, and this could play a role in the transition from being unconscious to being conscious (2006). If biophotons and weak electric or electromagnetic fields are central the organization of the body and to brain functioning, this indicates that, as Presman (1970) argued, integration associated with electromagnetic fields should be seen as communication rather than through an imposed force. If this argument is accepted, then such work could also be understood as a contribution to biosemiotics.

There have been other attempts to explain consciousness through quantum fields, notably those of Roger Penrose and Stuart Hameroff. According to their theory, 'consciousness arises from quantum vibrations in protein polymers called microtubules inside the brain's neurons, vibrations which interfere, "collapse" and resonate across scale, control neuronal firings, generate consciousness, and connect ultimately to "deeper order" ripples in spacetime geometry. Consciousness is more like music than computation' (Hameroff, n.d.). The theory is referred to as 'orchestrated objective reduction' (Orch-OR) (Hameroff, Craddock and Tuszynksi, 2014; Hameroff, 2006). Its proponents have defended their conjectures with experimental evidence showing that if crucial areas of the brain where such reductions could occur are prevented from functioning, people lose consciousness (Craddoc, Hameroff, and Tuszynski, 2015), suggesting that these reductions are what is experienced as consciousness. Despite this, there has been considerable scepticism about the possibility of coherence over such scales. This follows a severe critique of this claim by Max Tegmark (2002) arguing that it is impossible to maintain quantum coherence at body temperatures for the time required for such control of neuronal firings. Even by those promoting the importance of quantum coherence in explaining biological processes such as photosynthesis have accepted the validity of Tegmark's critique (McFadden and Al-Khalili, 2014, 255ff.; Goodwin, 2007, 117).

Alternative explanations of consciousness have been offered invoking different versions or interpretations of quantum theory. Much of this has been influenced by David Bohm, a major participant in Waddington's theoretical biology conferences. His speculative ontology originated in the quest to make sense of quantum theory and overcome the opposition between quantum theory and relativity theory, but was also concerned to enable life and conscious experience to be comprehended. Karl Pribram, and following him, Walter Freeman (1995 & 1999), working in neuroscience but influenced by Bohm, developed a holographic model of the brain and advanced the notion of the many-body field to explain its functioning. Paavo Pylkkänen (2007) has also defended

Bohm's theoretical work to explain consciousness, collaborating with him and his successor, Basil Hiley, in further develop this work. Henry Stapp (2009) has drawn on Whitehead to interpret what he claims is the Copenhagen version of quantum theory to explain consciousness. Beginning in the 1960s, the Japanese quantum field theorist Hiroomi Umezawa aligned with the Italian theorist Ricciardi developed a quantum model of the brain. This was associated with continued work on quantum field theory incorporating thermodynamics (1993). Their work was taken up and developed by Mari Jibu and Kunio Yasue (1995) to develop a general theory of quantum brain dynamics (QBD), work which has been further advanced by the Italian theoretical physicist Guiseppe Vitiello (2001) who developed a dissipative quantum model of the brain. Gordon Globus (2003; 2009) has developed equally radical ideas drawing upon and aligning his work with these Japanese and Italian theorists, but also integrating it with the work of Pribram (Globus, Pribram and Vitiello, 2004). Globus' work, which is also strongly influenced by Gestalt psychology, Martin Heidegger (who was strongly influenced by East Asian thought), process philosophy and post-phenomenology (including the work of Hubert Dreyfus), could be seen as aligned with efforts to naturalize phenomenology, work which could also support Waddington's research program (Kauffman and Gare, 2015), although the leading proponents of this appear to have their own distinct agenda. Although there is a general sympathy for process philosophy, these diverse efforts are divided by lack of agreement on what is quantum theory and how it should be interpreted, and on what is consciousness, and often, ignorance of each other's work.

Finally, major advances in mathematics and complexity theory not only have provided means for further advancing Waddington's research program, but for clarifying and supporting his understanding of mathematics while offering new forms of mathematics to better model evolution as Waddington understood it. After having abandoned the quest to reduce mathematics to logic and set theory, Whitehead had characterized mathematics as the study of patterns and their transformations, and it was this view of mathematics that Waddington had assumed. With the development of chaos theory and complexity theory, including neural nets, phase space portraits, cellular automata the study of fractals, this way of understanding mathematics most clearly illuminated what the advance of this research involved. However, it was with the development of category theory that what Whitehead was striving to achieve became fully intelligible, and his project advanced. As Michael Heather and Nick Rossiter showed, Whitehead in Part IV of *Process and Reality,* laying new foundations for geometry, was building on his earlier developments of Hermann Grassman's extension theory to represent connectivity in a physical world of process, in place of geometry formulated in terms of mathematical points. He had sketched a mereology (a theory of part-whole relations) but had not developed it (Heather and Rossiter, in press). His theory could enable mathematicians to bypass set theory, but this possibility was only fully realizable with the development of category theory. Developing category theory in this way, bypassing set theory with its limitations on reflexivity, also enables category theory to be formulated more simply and clearly and developed further.

Complexity theory was developed further by Robert Rosen by utilizing category theory to model anticipatory systems that have models of themselves, in the process developing a general theory of modelling. This work illustrated the implications and potential of category theory. Modelling, Rosen argued, involves finding congruence between entailments, either in modelling different branches of mathematics, or in modelling physical or biological processes. This involves recognizing that modelling requires simplification, with the models being more precise but less rich in detail than what is modelled. Category theory, with its focus on representing operations, is ideal for representing causal entailments and also lends itself to being interpreted through Peirce's characterization of mathematics as diagrammatical reasoning, along with Whiteheads characterization of mathematics as the study patterns and their transformations (Gare, 2015). The Newtonian tradition of science, committed to a totally objective view of reality, is extremely weak in modelling entailments and incapable of modelling the entailments characteristic of living beings where it is necessary to pose questions of ‘Why?’ Living beings as anticipatory systems having models of themselves, must include these models in any model of them. An implication of this characterization of modelling is that it shows the impossibility of grasping the complexity of reality through an ultimate mathematical model. It is necessary to recognize irreducible multiple models in genuinely complex systems with terms defined impredicatively (generalizing over a totality to which the entity being defined belongs). This enables entailments to be situated in contexts, including the context of their observation. In such modelling, mathematics cannot be reduced to syntactical relations between symbols, as Hilbert aspired to characterize mathematics, but must involve reference to what is being modelled, and can acknowledge the observer (Rosen, 2000c). Consequently, it is impossible to simulate the dynamics of such systems on a computer without using approximations. All this is consistent with and can be used to defend and further develop Whitehead’s understanding of mathematics, and justifies Waddington’s and Prigogine’s understanding of mathematics and its role in science as dealing with abstractions, as against Thom’s Pythagorean (or Cartesian) Platonism identifying existence with its mathematical models (Gare, 2016).

These advances open the possibility of developing more adequate mathematical models by fully exploiting the potential of category theory. Andrée Ehresmann and Jean-Paul Vanbremeersch in *Memory Evolutive Systems* (2007) have utilized category theory to develop an integrative dynamic model for self-organized multi-scale evolutionary systems, but unlike Rosen who attempted to represent living systems by a unique category, these authors have utilized a family of ‘configuration’ categories indexed to time. Quite apart from the promise this might have for representing chreods in the development of embryos and systems of similar complexity, they argue that this frees science from being dominated by the very limited notion of objects as physical objects located in space. ‘Objects’ should include ‘a musical tone, an odour or an internal feeling. The word *phenomenon* (used by Kant, 1790) or *event* (in the terminology of Whitehead, 1925) would perhaps be more appropriate’ they argued (2007, 21). An ‘object’ can be a body, property, event, process, conception, perception or sensation, and they attempted to take into account more or less temporary relations between such objects. In their models they ‘make use of fundamental constructions, to give an internal analysis of the structure of the dynamics of the system’ (2007, 33). Acknowledging the challenge this claim makes to traditional Western science, they wrote that ‘Long ago, the Daoists imagined the universe as dynamic web of relations, whose events constitute the nodes; each action of a living creature modifies its relations with its environment, and the consequences gradually propagate to the whole of the universe’ (2007, 21). Ehresmann and Plamen Simeonov (2012) have attempted to integrate Memory Evolutive Systems (MES) with Wandering Logic Intelligence (WLI), a ’practical framework for designing evolutionary communication architecture and their services and applications in terms of an ever growing model’ (2012, 105) as WLIMES to further advance theoretical biology.

7. Diagnosing the Problem and Overcoming It

Why then is there a mainstream reductionist or mechanist tradition of biology that is easy to identify, is strongly supported by funding bodies, dominates academic appointments in major universities and research institutions, and has insuperable problems in accounting for consciousness, often advancing by trying to explain in its own terms the achievements of the anti-reductionists, while the radical anti-reductionist tradition is fragmented, with advances often forgotten about and then having to be rediscovered or reinvented, with its members marginalized? Firstly, the anti-reductionist tradition, recognizing the autonomous dynamics of what is being studied, is not guaranteed to produce knowledge of how to control things and thereby the means to make new weapons, profitable technology and instruments of social control. Reductionism serves this purpose because it reveals how things can be controlled, to the extent they can be, by altering components, or in the case of the less common holistic forms of reductionism, by identifying controlling factors in the environment of what is being controlled. As Lewis Mumford pointed out:

> The fact is that organic models yielded to mechanical models in interpreting living phenomena mainly for two reasons: organisms could not be connected to the power complex until they were reduced, in thought even more than in practice, to purely mechanical units; and it was only through their attachment to the power system, which, as Comte noted, came in with the employment of the engineers as the key figures in advanced industries, that the physical sciences had, from the sixteenth century on, flourished (Mumford, 1974, 385).

However, there are deeper reasons that need to be identified, including reasons why modern civilization is driven by a passion for total control even though this quest and occasional successes continually generate new, more insoluble problems and is now associated with growing threats to the future of civilization. What should be evident from this schematic history of anti-reductionist biology after Waddington is the extent to which philosophical differences are implicated not only in biological research, but in the differences between those challenging mainstream thought, not only on the details of claims to being scientific knowledge, but on what is knowledge, what is science and what is mathematics and how they are related. This was clearly evident in Thom's criticisms of Waddington.

What has to be appreciated about Waddington's work and research program is how heavily it was influenced by the philosophy of Whitehead. It included a conception of mathematics and its role in science defended by Whitehead in his later work. Waddington affirmed this influence at the second theoretical biology symposium at Serbelloni (Waddington, 1969, 72-81), endorsing David Bohm's strong statement on the central role of metaphysics in science in which he proclaimed:

> I think the most important aspect of the interchange is the emergence of a common realization that metaphysics is fundamental to every branch of science. Metaphysics is ... something that pervades every field, that conditions each person's thinking in varied and subtle ways, of which we are not conscious. Metaphysics is a set of assumptions about the general order and structures of existence ... It seems clear that everybody has got some kind of metaphysics, even if he thinks he hasn't got any (Bohm, 1969, 41).

Bohm then went on to point out the implications of this:

> ... the practical 'hard-headed' individual has a very dangerous kind of metaphysics, i.e. the kind of which he is unaware... Such metaphysics is dangerous because, in it, assumptions and inferences are being mistaken for directly observed facts, with the result that they are effectively riveted in an almost unchangeable way into the structure of thought... [W]hat is needed is the conscious criticism of one's own metaphysics, leading to changes where appropriate and, ultimately, to the continual creation of new and different kinds. In this way, metaphysics ceases to be the master of a human being and becomes his servant, helping to give an ever changing and evolving order to his overall thinking (41f.).

It was in light of this observation that Waddington began his book, *Tools of Thought,* with a defence of philosophy, and a warning against the Conventional Wisdom of the Dominant Group, or

'COWDUNG'. The conventional wisdom of the dominant group in the twentieth century, according to Waddington, was that the world consisted of things. Following Whitehead, he aligned himself with Heraclitus who argued that the world consists of processes. According to COWDUNG, 'the world and everything in it is constituted from arrangements of essentially unchanging material particles, whose nature has already been largely, if not entirely, discovered by the researchers of physics and chemistry' (1977, 19). It is because COWDUNG is so deeply embedded in a culture that ideas contrary to it tend to be ignored or misinterpreted. Also, such contrary ideas are not consistent with each other, or at least do not appear to be. Given the marginal status and often insecure positions of those developing such alternative ideas, sorting our which ideas cohere with each other and which do not is time consuming and extremely difficult. It requires a great deal of knowledge across disciplinary boundaries and creative work to reconcile apparent inconsistencies. It is not difficult to see why opponents of COWDUNG do not carry out this work and so are often in disarray and prone to undermining each other, allowing the adherents to COWDUNG to neutralize opposing traditions by selectively appropriating and reinterpreting the advances made by such radicals that are impossible to ignore.

COWDUNG tends to be even more entrenched than Waddington acknowledged, presupposed in a range of notions that are difficult to challenge all at once. For instance, reductionism is deeply embedded in assumptions about what is involved in explaining anything. It is almost always assumed that an explanation involves showing that appearances are deceptive and what looks like an independent phenomenon is really an aspect or effect of something else. As G. Spencer Brown noted:

> To *explain,* literally to lay *out* in a *plane* where particulars can be readily seen. Thus to *place* or *plan* in *flat* land, sacrificing other dimensions for the sake of appearance. Thus to *expound* or *put out* at the cost of ignoring the *reality* or *richness* of what is so put out. Thus to take a view away from its *prime reality* or *royalty,* or to gain knowledge and lose the kingdom (1969, 126n.)

This is the case even when holistic theories are being proposed. So the development of the notion of field which initially was seen as revolutionary was assimilated to assumptions about explanations by claiming that all phenomena investigated by science will ultimately be seen as manifestations of one grand unified field. This would be a deterministic block universe. Any claim that what is being examined is partially self-organizing, or even self-creating, is left without any plausible means to defend its claim since it cannot involve such an explanation, and what explanations are offered are likely to be ignored unless surreptitiously a new form of reductionism is being introduced.

Whitehead explained such tendencies as a consequence of taking substances as the primary reality; that is, beings which are themselves unchanging but have changing attributes and relations, blaming this on Aristotelian logic. However, in the evolution of Western civilization something even more fundamental was involved. COWDUNG is characterized by a strong tendency to objectify the world and to take seriously only what can be objectified and measured, generating a sharp opposition between objects and subjects of knowledge, with a propensity to either Cartesian dualism, a materialist monism that eliminates mind, or an Idealist monism that eliminates matter. Processes are objectified, along with time, so that processes come to be thought of as changing spatial relationships between unchanging objects, or temporally extended objects. This tendency to objectify the world has engendered a range of other theoretical objects that have been upheld as the reference points for comprehending everything else, along with particles or space-time blocks. Propositions have been conceived of as Platonic entities, that is, as objects, along with facts, and the logical positivists understood mathematical truths as mental objects, consisting of nothing but a complex array of tautologies. Even when sensory experience is taken seriously as part of the physical world, there is a tendency to objectify it and take sensations as 'things' of some peculiar kind. In philosophy all this is associated with what Mark Johnson and George Lakoff characterized as 'objectivist semantics' according to which the actual world, along with any possible world, consists of entities and sets built out of those entities which have properties and stand in definite relation to one another at each instant, and that meaning consists in the relationship between abstract symbols and elements in models of the real world or possible worlds that consist of these entities. Correct reasoning is nothing more than manipulating symbols in accordance with the set-theoretical logic of the model (Johnson, 1987, ix-xxxi). This is what Cornelius Castoriadis characterized as the 'ensemblistic-identitary' ('set-theoretical,' 'logical') institution where 'the sovereign scheme is that of *determination* … The requirement here is that everything conceivable be brought under the rubric of determination and the implications or consequences that follow therefrom. From [this] point of view …, existence is determinacy' (1997, 11). In mathematics, it is associated with efforts to eliminate external referents and to reduce all mathematical reasoning to syntactic rules for the manipulation of symbols, a conception of mathematics that reached its most extreme form in Hilbert's formalist program (Rosen, 2000c).

This objectifying tendency is associated with blindness to context, both temporal and spatial. Propositions are really proposed answers to questions and can only be understood as such, and questions only make sense in the context of the reasons why they were asked. Such reasons involve a hierarchy of assumptions. The ultimate assumptions are metaphysical assumptions, such as the assumption that if something happens there must be a cause. 'Facts' are 'true propositions', and as Ludwig Fleck pointed out, are socially produced as such by validating propositions in the eyes of scientific or other intellectual communities (Fleck, 1979). Such social production requires enduring institutions, forms of communication and education over generations to maintain their status as facts. These institutions in turn require enduring biological processes, which in turn require enduring chemical and physical processes and structures. We can only develop science because we are part of and participants within nature. This is recognized tacitly within both special theory of relativity and quantum theory where the perspective of observers making measurements are built into these theories. Claims made for regularities in the physical sciences are always made in the context of boundary conditions that usually are set up by experimenters designed to reveal such regularities, blocking out actual or potential interferences which are then ignored along with the constructed boundaries. This was pointed out by Michael Polanyi, who argued that such boundary conditions could explain the possibility of hierarchical organization, as for instance the boundaries produced by chemical processes to produce the characteristics of metal make possible the creation of machines operating according to a higher level of organization incomprehensible through chemistry (Polanyi, 1969, chap.13). Howard Pattee developed Polanyi's account of hierarchical ordering by showing that these boundaries could be harnessed by enabling constraints. For instance, the order in DNA, in which by virtue of physical forces constituting the form of the nucleotide bases with near equipotential for any sequence of these bases to exist and then be reproduced, is constrained so that it can function as an enduring memory for much more complex chemical processes, just as the boundary constraints imposed by language on the sounds humans can make facilitates complex forms of communication. Appreciating this requires a background of tacit knowledge. All this tacit knowledge, including knowledge that scientists are conscious subjects are part of and physically engaged in the world they are striving to comprehend, is excluded from awareness by those dominated by this objectifying tendency.

Such objectifying tendencies have never completely dominated and there have always been people who rejected them. However, scientific communities impose COWDUNG routinely on people, blinding their members to alternatives. Claiming in 1975 that the conventional wisdom was that nature consists of material particles appears odd after the revolutions in physics from the mid-nineteenth century onwards. However, this does seem to have been the case in biology, particularly from the 1950s onwards. With the rise of biochemistry and molecular biology, biology was dominated by those claiming that all biology could be explained through chemistry, that is, through the atoms making up molecules from which organisms are supposedly composed, along with the Darwinian mechanism of evolution through variation and selection. Proponents of this view, such as James Watson, tended to think of the universe as composed of elementary particles. Even in physics there is a persistent tendency to privilege the ontological status accorded to particles over fields, and if fields are acknowledged, to treat them as nothing but mathematical constructs to facilitate predictions about particles, or as objects themselves. The persistence of this view is itself in need of explanation.

Recognizing the persistence of ways of thinking demonstrated to be defective has led radical thinkers to find ways of distancing themselves from their cultures to achieve some perspective on its limitations and to reveal alternative ways of thinking. In some cases, mathematics itself has facilitated this distancing. While Faraday developed the concept of field explicitly, Mary Hesse in her study of the history of the concept of field argues that before Faraday, the mathematician Euler had developed a mathematical concept of field in his work on hydrodynamics. He succeeded by ignoring current conceptions of the material world, unlike Bernoulli and other scientists who sought to develop their mathematical models to accord with the prevailing Newtonian cosmology (Hesse, 1965, 189ff.). It is for such reasons that some physicists make no effort to interpret their mathematics in physical terms, leaving behind defective conceptions of physical existence; but then this leads to the objectification of mathematical models while leaving current conceptions of physical existence unchallenged. Others have engaged in historical work to reveal a time before COWDUNG had come to dominate. They take an interest in the history of science. The deeper assumptions require longer histories. The most fundamental assumptions sometimes require a return to Ancient Greek thought to expose and bring them into question. This is what happened during the Renaissance, making possible the Seventeenth Century scientific revolution, and then again in Germany in the late Eighteenth and early Nineteenth Centuries, and it is happening around the world at present.

Often such work is undertaken by philosophers. Martin Heidegger, attempting to discover ways of thinking prior to the dominance of this objectifying tendency, illustrated this. However, scientists and mathematicians have also undertaken such investigations, returning to re-examine the scientists and mathematicians of the Seventeenth Century to question their assumptions, and to the Ancient Greeks to provide the necessary perspective on the current state of science. Invoking Heraclitus is common, but Heraclitus is not the only thinker investigated to achieve this distancing. Whitehead, who was a mathematician and scientist as well as a philosopher, studied Plato's *Timaeus.* Otto Rössler, in developing his radical ideas on endophysics in which the world is characterized as an interface between the subject and the rest of nature generated by a process of enfolding, challenging a whole range of current assumptions, invoked the work of Anaxagoras (1998, chap.1). The physicist Carlo Rovelli (2011) made a major study of Anaximander to demonstrate what is wrong with current physics. Thom made a study of Aristotle in order to recover a role for final causes, which in his mathematics he designated as attractors, thereby attempting to transcend the opposition that emerged in the Renaissance between Pythagoreans identifying reality with mathematics and denying final causes and Aristotelians who regarded mathematics as nothing but abstractions and gave a central place to final causes. And Robert Rosen (2000a) studied the Pythagoreans to identify and free himself from their assumption that mathematical intelligibility requires computability.

8. Invoking Chinese Thought: From Lao-Tzu to Joseph Needham

However, examining the origins of European or Western thought among the Ancient Greeks still involves being limited by one civilization. The sense that there are such limits has provoked major philosophers and scientists to look beyond Western civilization for new ways to thinking that could bring to light, facilitate questioning and possibly provide alternatives to current ways of thinking. Most famously, Leibniz studied Chinese thought for this reason, and Whitehead, who was influenced by Leibniz and a tradition within German philosophy, science and mathematics influenced by him, which in turn influenced the field theory of Faraday and Maxwell, argued that his own philosophy of organism 'seems to approximate more to some strains of Indian, or Chinese, thought, than to western Asiatic, or European, thought. One side makes process ultimate; the other side makes fact ultimate' (Whitehead, 1978, 7). If this is the case, Waddington's thought manifests the influence of Chinese thought, and it seems that it is for this reason that it has been more difficult to assimilate to Western traditions of thought, even by radicals concerned to question mainstream thought.

This was the conclusion drawn by Joseph Needham after Cambridge University blocked research in mathematico-physico-chemical morphology by refusing to accept a grant from the Rockefeller Foundation (Abir-Am, 1987). Needham's turn to the history of science can be seen as an effort to show the coherence of the tradition that led to his research program and the limitations of mainstream thought, and in the process of developing this history, Needham came to appreciate the enormous influence of Leibniz on this tradition, and beyond Leibniz, Chinese thought. On this view, Whitehead's organicist philosophy was seen by him as the culmination of a tradition going back through Lloyd Morgan, S. Alexander, Jan Smuts, Engels, Marx, Hegel, Schelling and Herder to Leibniz. The spectacular originality of Leibniz, the ultimate source of the opposition to the tradition of Cartesian dualism and Galilean-Newtonian science, Needham argued, derived from the influence on him of twelfth century Chinese philosopher who synthesized Daoism and Buddhism with Confucianism, Zhu Xi (1130-1200). Needham wrote of Zhu Xi (Chu Hsi): 'Behind him he had the full background of Chinese correlative thinking, and ahead of him he had - Gottfried Wilhelm Leibniz' (Needham, 1956, 291). Needham's massive study of science and civilization in China, told from the perspective opened up by Whitehead's Chinese influenced philosophy, was designed in part as a way of clearing the path for the advance of the radical reconceptualization not only of biological theory but of science as such, exemplified by his own work and that of Waddington (Gare, 1995, 309-328). More broadly, he claimed that the perspective created by Whitehead paved the way for a synthesis of all that was most valuable in Chinese and Western civilization.

It appears from the study of Chinese thought that language has played a part in encoding deep assumptions. European languages, with their 'subject, verb, object' structure, privilege nouns that identify things, essences or substances. These are then are seen as doing something or having something done to them or attributed to them, leading to efforts to identify the nature of these things underlying appearances. Ancient Chinese languages, by contrast, having no definite or indefinite articles, focused on events and relations, fostered concern to orient people to live in the context of the becoming of the world. It is for this reason, A.C. Graham argued (1989, Appendix 2), that Western philosophy was dominated by metaphysics and epistemology while Chinese philosophy focused on how to live and how to cultivate people, including oneself. While until recently, 'way' had no place in Western philosophy, it is central to Chinese thought. *Dao* means 'path' or 'way' – and since it did not have either a definite or indefinite article (neither 'a' nor 'the') and could be singular or plural, it is best treated as the part-whole sum of ways. While it is tempting to treat *Dao* as equivalent to the Western notion of Being for this reason, *Dao* is essentially a concept of guidance. It is immanent in, but not identical to Being. *Dao* can also be a verb, understood as 'guide'. *Dao* does not necessarily determine actions, and as a consequence Chinese philosophers allowed that it is possible to participate in developing *Dao* by augmenting the way or even to open new ways. As Confucius (551-479 BCE) put it, 'It is Man that can enlarge the *Dao* which he follows, and not the *Dao* that can enlarge men' (Chan, 1963, 44). And as Chuang Tzu wrote 'A road [path or *dao*] becomes so when people walk on it' (Chan, 1963, 183f.).

Needham discussed the concept of *Dao* in relation to early Confucian philosophy and to Daoism, and then in relation to Zhu Xi, noting that initially Confucians meant by *Dao* the ideal way or order of human society, while for Daoists it meant the way the universe works, or, as Needham put it, 'the Order of Nature'. Zhu Xi, in constructing a cosmology for Confucianism in the twelfth century CE, used this term to cover both meanings (Needham, 1956, 37). In characterizing the meaning of '*Dao*' for Zhu Xi, Needham wrote:

> [T]he original meaning of *tao* [*Dao*] was 'way', while that of *li* was the graining or pattern of markings (Gestalt) in any natural object. 'The term *tao [dao]*', [Zhu Xi] says, 'refers to the vast and great, the term *li* includes the innumerable vein-like patterns included in the Tao [Dao]' (Needham, 1956, 484).

For the earlier Daoist natural philosophers, however, *Dao* encompassed '*li*' rather than *li* being defined in distinction from *Dao*, and it was only with Wang Bi (the leading neo-Daoist of the third century CE) that *li* understood as principle or pattern, reason or rationale, was introduced to characterize *Dao* (Mu, 2009, 48). In Lao Zi's (Lao Tsu's) *Dao-De-Jing*, *Dao* included all these meanings, characterizing both the source of and what guides natural processes. As Bo Mu pointed out in his exposition of the *Dao-De-Jing*:

> [T]he metaphysical *dao* is … not like Platonic Form, beyond and above, but consists of and in particular things in the universe, i.e. *wan-wu*… [W]hen the *dao* is possessed or manifested in particular things, it becomes its manifested character …. In sum, the *dao* is the ultimate source, unifying power, and fundamental principle of nature and the universe; it manifests itself through particular individual things. (Mu, 2009, 45)

Explicating the *Dao-de-Jing*, David Hall and Roger Ames (1998) wrote:

> The natural cosmology of classical China does not require a single-ordered cosmos, but invokes an understanding of a 'world' constituted by 'the ten thousand things'. There is no Being behind the beings - only beings are. And *in toto*, these beings are *dao*. Continuity makes *dao* one; difference makes *dao* myriad; change makes *dao* processional and provisional. *Dao* is thus both the One and the many, or better, the field and foci through which it is entertained. The Chinese 'world as such' is constituted by 'worlding' (*ziran*), a process of spontaneous arising, or literally, uncaused 'self-so-ing', which references no external principle or agency to account for it. The one and the many stand in a holographic relationship: there is the indiscriminate field (*dao*) and its particular focus (*de*). *Dao* as field is always entertained and focused from some perspective or another, from some particular. Just as in a holographic display where each detail contains the whole in an adumbrated form, so each item of the totality focuses the totality as its particular field (1965f.).

Showing how Zhu Zi developed this conception of *Dao,* Needham ascribed to him the insight that 'first, the existence of a universal pattern or field determining all states and transformations of matter-energy, and secondly, the omnipresence of this pattern. The motive power could not be localized at any particular point in space and time. The organization centre was identical with the organism itself' (Needham, 1956, 466). Zhu Xi also saw this matter-energy as consisting of two opposing forces, that nature works in a wave-like manner, and that new things are produced by reactions which we now call chemical (Needham, 1956, 467). On this basis he was able to set forth a comprehensive philosophy of cosmic and human creativity, formulating a viable account of the formation of the world in stages to provide a foundation for the Confucian concepts of human nature and self-cultivation.

These ideas were developed and embraced by only some philosophers in China, and the Chinese did not develop science as an organized systematic inquiry as it emerged in Europe in the Seventeenth Century. However, developed to oppose the philosophy of Legalism, the domineering orientation of the Qin dynasty very similar to the domineering orientation came to dominate European civilization and the West (Rubin, 1976, chap.3), these ideas had a major influence on Chinese and other East Asian cultures, making it easier for at least some East Asians, and Westerners exposed to Chinese traditions of thought, to think in this non-domineering way. It is against this background, with the influence of Chinese thought on Western thought along with creative responses by East Asian scientists in their efforts to critically appropriate and advance the achievements of Western thought without completely abandoning their own cultural traditions, that it also becomes easier to understand and then further develop the core concepts of Waddington: chreods and homeorhesis (and individuation), understood in relation to fields, and also to see why such ideas are not easily assimilated by those thoroughly immersed in mainstream traditions of European thought. Chreods are paths. They individuate to become paths within broader paths. The paths are within and guided by fields, but fields are generated and transformed by what they guide. They are aspects of processes. As Needham wrote, the notion of field is 'not a mere geometrical picture of a momentary time-slice in the organism's history but is dynamical' (Needham, 1968, 108).

When considering the development of organisms and their cognition, or cities, or the development of ecosystems or the entire cosmos, when freed of the assumptions of mainstream Western science it should also be clear why the concept of 'chreod' is potentially such an important concept and why it should be given a prominent place in science, with the very idea of what science is and the role of mathematics in science adjusted accordingly. And in doing so, it should be evident why Waddington was justified in believing that science reconceived this way, displacing old assumptions, would overcome its current fragmentation. All these domains can be seen to involve inter-related paths of development characterized by fields within fields, which also develop, with new fields emerging from other fields along self-stabilizing paths. Cybernetics and homeostasis are aspects of an order that has come into existence, but it is through chreods and homeorhesis that diverse kinds of new order come into and are maintained in existence.

9. Mae-Wan Ho's Theoretical Biology

That orienting scientific research by this general conception of the world makes a difference can be seen in the work of Mae-Wan Ho. Ho was born and first educated in Hong Kong and was a colleague of Brian Goodwin and aligned with the research tradition inspired by Needham and Waddington. She was strongly influenced by Chinese thought while developing her ideas in Britain. The most radical of the biologists aligned with Goodwin, her radicalism, and her achievements as a consequence of this radicalism, manifest in the greater constancy of her perspective, were summed up in a paper she wrote with Peter Saunders, 'Beyond neo-Darwinism – An Epigenetic Approach to Evolution' (1979), in another by herself ‘Toward an Indigenous Western Science: Causality in the Universe of Coherent Space-Time Structures’ (1994a), and later, and more fully, in *The Rainbow and the Worm* (2008). The arguments in this were further developed in its sequel, *Living Rainbow H_2O* (2012).

In ‘Beyond neo-Darwinism’, Ho and Saunders referred to and aligned their work with Waddington’s notions of ‘epigenetic landscape’, developmental pathways, ‘homeorhesis’ and ‘heterorhesis’ (to describe an adaptive change of state resulting in a large variation in morphology). Accepting Goodwin’s suggestion that organisms are ‘cognitive’ systems that take in information about survival and reproduction from the environment, they argued that the organism in some sense internalizes the environment during evolution: ‘there is a successive canalization of novel developmental responses to environmental challenges and possibly a fixation of these responses through genetic assimilation’ (1979, 585). However, they argued that Waddington had been unclear on the mechanism involved in canalization and novel developmental responses. This was the challenge. Noting that it is not the genotype but the epigenetic system that interacts with the environment to generate the phenotypes on which natural selection can act, and that the response to the environment is at the morphological biochemical level, they suggested that these changes could leave a chemical imprint in the cells that could persist over generations, resulting in changes being assimilated to later generations. Pointing out that physicochemical systems possess many properties of biological systems, including persistence of environmentally produced changes, they argued that it should be possible to provide physical explanations for such changes. Rejecting explanations in terms of chance variations and selection does not require recourse to vitalism, they proclaimed.

In her later work, Ho, did not deploy the terms ‘chreod’ and ‘homeorhesis’; however, she did describe aspects of what should be regarded as chreods, and more importantly, developed a conception of physical existence to defend this concept and to integrate it with a range of ideas that in the past challenged mainstream science, along with ideas now emerging in post-reductionist science. Although at one stage Ho, like Goodwin, embraced Piagetian genetic structuralism, for the most part she characterized her own work as ‘a Whiteheadian “process” view in which organisms are seen not as the consequence of natural selection of past random mutations but as dynamic structures which are immanent and simultaneous with process.’ On this view, ‘The organism, as well as the human observer as organism, are firmly located within nature where they are empowered to shape their own evolution and destiny’ (Ho and Fox, 1988, 14). She tentatively defined life as ‘a process of being an organizing whole’ (Ho, 2008, 6). Being alive:

> … is to be extremely sensitive to specific cues in the environment, to transduce and amply minute signals into definite actions. Being alive is to achieve the long-range coordination of astronomical numbers of submicroscopic, molecular reactions over macroscopic distances; it is to be able to summon energy at will and to engage in extremely rapid and efficient energy transformation (Ho, 2008, 11).

She embraced Henri Bergson’s ‘intuition of inner organic time of “pure duration” as a dynamic heterogeneous multiplicity of succession without separateness’ which, she argued, ‘the advances in neuroscience over the last two decades have borne out’ (Ho, 2008, 320). She also embraced Erwin Schrödingers’ observation that ‘Consciousness is never experienced in the plural, only in the singular’, claiming ‘[t]hat description is just what the state of coherence entails: a multiplicity that is singular’ (Ho, 2008, 331).

This was seen by her to accord with Whitehead’s philosophy of organism, according to which, as Ho interpreted it (very much in accordance with Chinese traditions of thought as described by Needham and others):

> An organism, according to Whitehead, is 'a locus of prehensive unification'. This corresponds to a field of coherent activities that is sensitive to the environment, drawing on its experience of the environment to make itself whole. Whitehead asserts that the fundamental particles of physics such as protons and electrons are organisms, as much as, at the other extreme, planets such as Earth and even galaxies. Nevertheless, he does recognize gradations of organisms and hence of consciousness. Each organism, in the act of prehensive unification, enfolds the environment consisting of others into a unity residing in a 'self', while aspects of the self are communicated to others. The realisation of 'self' and 'other' are thus completely intertwined. The individual is a distinctive enfoldment of its environment, so each individual is not only constituted of others in its environment, but also simultaneously delocalised over all individuals. The society is thus a community of individuals mutually delocalised and mutually implicated. (Ho, 2008, 321f.).

To advance this conception of physical existence and explain life through science, Ho first focused on developments in thermodynamics or energetics, and then electromagnetic fields and finally quantum coherence, particularly in relation to liquid crystals. Both the notions of energy and of fields can be seen as developments of *Naturphilosophie* that, inspired by Herder, Goethe and Schelling, all influenced by Leibniz, had challenged Newtonian science at the end of the Eighteenth Century. One of the most important aspects of Ho's work is that it privileges the concept of field, and tacitly assumes the validity of quantum field theory rather than mainstream quantum mechanics. Field theory, as first put forward by Faraday who argued that what exists are extended, enduring forces rather than objects with properties, was inspired by *Naturphilosophie* along with the work of Roger Boscovich, who was directly inspired by Leibniz. His work was part of the tradition of thought that Needham claimed had been inspired by Chinese thought (Williams, 1980). This notion of field was a major influence on Whitehead, whose first significant work (since lost) was a study of Maxwell's equations. Field theory was and remains a challenge to mainstream Western thought, and is resisted accordingly. As Globus, Pribram and Vitiello (2004, xi) noted in relation to the resistance to fully appreciating the advances in science based on the notion of field, 'it is the concept of field which is found frightening. The ontological prejudice by which "things" are made of little beings, individuals, atoms, able to survive even in the absence of any interaction with similar beings, strongly contrasts the idea, implicit in the concept of fields, of abandoning the individual as "the actors" able to establish or not establish some sort of relation with other individuals. In the concept of field the "action" is more fundamental than the actors, and there cannot exist one isolated, single actor, but only a multitude of them.'

As Rodney Brooks in *Fields of Color* (2016, 46f.) has shown, mainstream physics, despite speaking of fields, almost always reverts to privileging particles. Brooks defended the work of Julian Schwinger and Hideki Yukawa against Feynman, Schrödinger and de Broglie against Born, Heisenberg and Dirac, and Lorenz against Einstein, noting that in each case those defending the primacy of particles prevailed over those defending fields. This defence of fields over particles is not dependent upon the acceptance of Schwinger's theories, however. There are a number of theorists explicitly defending the primary reality of fields, although they are still in a minority. Schrödinger continued to defend and develop the concepts of fields to the end of his life (Bitbol, 1996, 221f.), and even Feynman eventually concluded he had to embrace the primary reality of fields (Wilczek, 2008, 83f.). The major problem is that those utilizing quantum theory ignore its ontological implications and tacitly assume the primary reality of particles (Kuhlmann, Lyre and Wayne, 2002). Significantly, a number of Japanese theoretical physicists are among those who have fully embraced the notion of field. It was Yukawa who in 1935, isolated from other physicists but free from the tendency to think in terms of particles, recognized that radiation from the strong field could exist as quanta (mesons) the propagation of which could be described by a field equation, with a mass 200 times greater than an electron. Continuing this tradition, Umezawa in his exposition of quantum field theory showed why it is necessary to leave behind quantum mechanics, embrace quantum field theory, and privilege fields (1993, 8ff.). Pointing out that quantum field theory, unlike quantum mechanics, applies to the macro-level, Umezawa applied quantum field theory to neuroscience, specifically to account for memory. Subsequently he influenced other theorists concerned with the implications of quantum field theory for understanding macro-patterns, life and consciousness (Jibu and Yasue, 1995, Part III; Vitiello, 2001; Yasue, Jibu and Della Senta, 2002; Globus, Pribram and Vitiello, 2004; Blasone, Jizba and Vitiello, 2011).

When Schwinger was writing six physical fields were acknowledged. Now, with the acceptance of the Higgs boson, at least seven fields have to be recognized. Einstein and those who supported his conception of science, have striven to develop a grand unified field theory implying a determinist block universe in which temporal becoming is only an appearance, while Schwinger argued for the irreducibility of time to a dimension of space. This is consistent with allowing the possibility of new fields emerging. In quantum field theory, fields exist in three different forms: as quanta – which are chunks of fields that have a life and death of their own, self-fields which are created by a source and are always attached to that source, and the vacuum field which is the background field to the quantum fields. The seven basic types of field are the two matter fields or fermions: leptons and quarks, and the force fields: the gravity, electromagnetic, strong, weak and Higgs fields and their associated force carriers or bosons There are also component fields, for instance, the electromagnetic field contains the electric and magnetic fields, and the strong field contains three fields with charges +1, -1 and 0. Lepton fields have four component fields accommodating the two possible 'spins' and charges, while baryon fields are constituted from quark and gluon fields. Since within field theory there are no particles to spin, this notion is replaced by 'helicity', a mathematical concept related to the number of field components and how they change when viewed from different angles. Fermions include leptons and quarks, baryons which are made up of an odd number of quarks, and composites of these, including protons. The bosons are force carriers and include gravitons, photons, gluons, mesons, weakons and Higgs bosons. Mesons are composite bosons composed of quarks and anti-quarks. The 'self-fields' are attached to quanta of fields, whether these be fermions or bosons. Self-fields are also attached to large entities formed from these fields. For instance, the gravitational field and magnetic field of the Earth are self-fields of the Earth. Energy is found in the oscillations within these fields, directly proportional to frequency of these oscillations. Ho focused on and has shown a role in biological organization for electromagnetic and associated fields (electric, magnetic and photon fields) and has also suggested a possible role for the vacuum field, and examined the potential of all these fields as resonators capable of entrainment and of precise communication to form emergent biological fields and to engender consciousness.

Viewing organisms through thermodynamics and field theory, Ho argued, requires a synthetic approach to complement analysis. Organisms need to be viewed as first of all, dissipative structures transforming energy, then maintaining themselves in existence while grappling with new situations, and developing through this. Such developments preceded RNA and DNA because physico-chemical systems are able to preserve changes, effectively, remembering the past. So while analysis leads to giving a privileged place to DNA, followed by RNA and then proteins, understanding organisms developing through their evolution requires that we work out how the most primitive forms of life as dissipative structures, consisting of water and proteins largely held together by hydrogen bonds, constructing RNA molecules, utilizing these to stabilize their reproduction, which in turn were used to construct DNA molecules characterized by far greater stability. As part of living processes, their role cannot be understood in abstraction from epigenesis, which can also involve remoulding DNA. As Ho argued in 'On not holding nature still' (1998, 132), the genome is fluid.

Ho's contribution to the thermodynamics of life, building on the work of a range of theorists, including Ilya Prigogine and Herbert Fröhlich (1968), involved shifting from describing living systems in terms of a succession of equilibrium states to describing them in terms of forces and flows, working towards a science of organized heterogeneity. While Prigogine had provided the mathematics required to model the process by which structures, including living beings, are able to maintain themselves by feeding on negative entropy, Fröhlich, focusing on energy transfer dynamics, had argued that energy could be stored in an organism in a variety of vibrations (or oscillations), that these vibrations could account for the coherence of organisms, and electric dipole oscillations could be propagated as coherent waves along filaments within cells with minimal dissipation of energy. Ho pointed out that organized heterogeneity can involve the creation of a hierarchy of near-equilibrium regimes despite the whole being far from equilibrium, thus maximizing the efficiency of energy transformations. She was particularly concerned to show in such transformations energetic cycles are coupled so that the output of one cycle is prepared to be an input of the next cycle. This added a new dimension to the place accorded by Waddington and Goodwin to resonance and entrained oscillations. 'Coupled cycles are the ultimate wisdom of nature', she argued. 'They go on at all levels, from the ecological to the molecular through the range of characteristic timescales from millennia to split seconds' (Ho, 2008, 54). These have a fractal pattern, being self-similar at all temporal scales. They provide the capacity to store useable energy in hypercycles at multiple levels, and to be able to transform energy quickly with minimum entropy production since energy yielding activities supply energy directly to the energy requiring activities. As Ho put it, '*There is always energy available within the system, for it is stored coherently, and ready for use, over all space-time domains*' (2008, 93). Organisms are excitable media poised to respond to specific signals disproportionately because large amounts of energy are available to amplify small, weak signals, often into macroscopic action.

Building on her work on thermodynamics, Ho argued that development of pre-patterns and patterns in the 'embryonic field' could be due to electromagnetic fields. As she and her colleagues noted:

> Electrodynamical forces include polarization fields (which may phase order macromolecular arrays ….), electronic or proton currents, dipole interactions, electromechanical forces and deformations (such as are involved in the interaction of proteins and calcium), electrodiffusion of ions and larger molecules by electrophoresis and dielectrophoresis … as well as polarization waves, dipole oscillations, phonon and photon exchanges of a resonant nature or otherwise. (Ho et.al., 1994b, 196).

Since 'all molecular and intermolecular forces are electromagnetic', it is probable that 'electrodynamical forces are sufficient by themselves to mobilize and organize the molecules within the embryonic field into macroscopic pattern' (Ho et.al., 1994, 196). To test this hypothesis, they demonstrated that weak magnetic fields affect pattern formation in *Drosophila* embryos.

Electromagnetic fields are also central to the formation of intermolecular complexes that organize the cell, Ho argued. Such organization involves communication between components of this field, with molecules resonating at the same frequency being capable of great specificity and selectivity in attracting each other over long distances (Ho, 2008, 135). In this way, molecules and molecular structures can communicate, exchange energy and organize themselves in relation to each other. Only weak signals are required for such communication, and these can come from diverse components or aspects of electromagnetic fields.

To play the required role, Ho believed that these electromagnetic fields must be quantum coherent. She concluded that the fields of biophotons identified by Gurwitsch and his followers, including Fritz-Albert Popp with whom Ho collaborated as part of her exploration of the role quantum coherence, could play a significant role in such biological organization. As Ho noted, Popp's work is consistent with the theory of coherence in quantum optics, and that 'observations are consistent with the idea that the living system is one coherent "photon field" bound to living matter.' Popp claimed that this field is 'coherent simultaneously over a whole range of frequencies that are nevertheless coupled together' (Ho, 2008, 195). Biophotons are in a 'squeezed state' in which the indeterminacy of position and momentum are equal. They are emitted from quantum patches, that is, the coherence volumes and times in which the probability amplitudes are maintained, rather than from a precise location. They can be trapped or stored for a long time, and they can be focused to a spot of atomic dimensions, or extended over the whole volume of an organism (Bischof, 2003, 38f.). Organic matter is largely transparent to these biophotons, it is claimed, enabling the components of an organism to be instantly informed about each other. The conclusion that Ho and Popp came to through their collaboration was that biophotons are central to communication required for biological organization, including morphogenesis and consciousness, and that:

> Biocommunication is the key to biological organization. An organic whole, in contrast to a mechanical whole, does not consist of a hierarchy of parts which exert control over other parts. Instead, it is a maximally responsive and transparent system in which changes and adjustments propagate simultaneously 'upwards', 'downwards' and 'sideways' in the maintenance of the whole. So, instead of 'control', it is much more appropriate to think in terms of 'communication'. (Ho and Popp, 1994, 432).

In this way, the biophoton field, along with other components of electromagnetic fields, could regulate biochemical and morphogenetic processes, and Ho suggested, play a role in memory.

Her last work was inspired by Needham's suggestion that, as he put it, 'Liquid crystals … are not important to biology and embryology because they manifest certain properties which can be regarded as analogous to those which living systems manifest (models), but because living systems actually are liquid crystals' (Needham, 1968, 157). Her argument is that it is because of the peculiarities of water molecules, which are strong dipoles, that they can take the form of liquid crystals with properties characteristic of living organisms. Making up 70% of organisms, water provides the conditions for coherent electromagnetic organization, including quantum coherence at ambient temperatures, while allowing diverse vibrational transitions. The connective tissue that ties all the cells in the body to one another contains bound water and is also a liquid crystal, capable of intercommunication. The crucial chemical is collagen made up largely of polypeptides that bind water and also influence its vibrational transitions. It is collagen, Ho argued, that contains the cellular memory that determines body pattern during development, the cells remembering the structure into which they are committed to develop. With electrodynamic activities patterning the liquid crystal domain of the morphogenetic field, liquid crystals could be involved in the long-term memory that enables the developing organism to make specific structures and organs later in its development.

By virtue of this, claimed Ho, '[i]n a literal sense, the embryo is conscious of its body, and remembers what grows and develops where and when' (Ho, 2008, 228). This is a broader conception of consciousness than that associated with conscious awareness focused on by the emerging science of consciousness, but Ho rejects this narrow focus as a bias of Western thought. For the Chinese, the seat of consciousness is the heart as much as the head. She suggested that '[t]he self-image or memory of our body could exist in some quantum hologram-like interference pattern' so that 'we may literally have an image of ourselves in both the brain and the heart; or in our ear, our foot, or our hand. Each part is a literal microcosm of the whole, as envisaged in traditional Chinese acupuncture theory' (Ho, 2008, 240). She argued that the form of consciousness associated with the central nervous system and the brain is based upon and presupposes this more general form of consciousness. As she put it:

> Body consciousness possessing all the hallmarks of consciousness – sentience, intercommunication and memory – is distributed throughout the entire liquid crystalline matrix that connects each single cell to every other. Brain consciousness associated with the nervous system is embedded in body consciousness and is coupled to it. (Ho, 2008, 237).

This accords with Maurice Merleau-Ponty's conception of incarnate consciousness, particularly as it was developed in his later works (Kauffman and Gare, 2015, 223f.), and in defending and developing this view, Ho could find some support from the work of Candace Pert on the role of polypeptides in body memory.

Ho also conjectured that liquid crystals could enable electromagnetic fields to maintain quantum coherence at body temperatures. This would explain how we are able to 'gate and bind our experiences in a series of local simultaneities that appear abruptly as large scale phase-synchronized activities in separate parts of the brain that has no obvious source in the brain itself.' She suggested that 'they are generated (almost) instantaneously in the liquid crystalline matrix in which all cells, including neurons in the brain, are embedded' (Ho, 2008, 240f.). Anesthetics work, she suggested, by breaking up this coherence, explaining this as the consequence of removing bound water from proteins and membrane interfaces (Ho, 2008, 237).

These ideas are fully developed in *Living Rainbow H_2O* published in 2012. The picture she finally presents is summed up in the introduction to this book:

> [Q]uantum coherence is a sublime state of wholeness; a quantum superposition of coherent activities over all space-times, constituting a pure dynamic state towards which the system tends to return. The organism is a macroscopic quantum being, and has a wave function that never ceases to evolve by entangling other quantum organisms in its environment. The organism is thick with coherent activities on every scale, from the macroscopic down to the molecular and below. I call the totality of these activities "quantum jazz" to highlight the immense diversity and multiplicity of players, the complexity and coherence of the performance, and above all the freedom and spontaneity. … The quantum coherent organism plays quantum jazz to create and recreate herself from moment to moment. Quantum jazz is the music of the organism dancing life into being. It is played out by the whole organism, in every nerve and sinew, every muscle, every single cell, molecule, atom, and elementary particle, a light and sound show that spans 70 octaves in all the colours of the rainbow. (Ho, 2012, 3f.)

In embracing the concept of field and characterizing fields dynamically, Ho was rejecting extreme forms of objectification that take primary reality to be measurable, precisely defined objects, reducing the status accorded to process to nothing but change of position, or eliminating it entirely, while situating the subject outside this objective world or denying the existence of subjects entirely. In this objectivist scheme, the organism is treated as an arrangement of matter, the outcome of past struggles for survival among its progenitors. Spelling out the implications of the opposing view, Ho argued that 'the organism itself – its functions, volitions and actions – will then be rightly perceived, not as the sole *consequence* of natural selection, but as a focus of being *immanent to process* and emerging *simultaneously* with it. Thus relocated within nature, the organism becomes both actor and producer of the evolutionary drama' (Ho, 1988, 118). That is, Ho was defending a first or second person perspective on living beings, rather than assuming a third person objectivism. To investigate organisms without objectifying them requires minimum intervention to achieve sympathetic understanding of organisms as co-participants in nature. As she put it:

> The dilemma of the absolutely ignorant external observer betrays the alienation from nature that the mechanistic scientific framework of the west entails, for it is premised on the separation of the observer as disembodied mind from an objective nature observed. That is also the origin of the subjective-objective dichotomy, which, when pushed to its logical conclusion, comes up against the seemingly insurmountable difficulty that in order to have sufficient information about the system, one has in effect to destroy it. … Ideally, we should be one with the system so that the observer and the observed become mutually transparent. … Perhaps such a state of enlightenment is just as what … the Taoists [Daoists] of ancient China would say, being one with the Tao [Tao], the creative principle that is responsible for all the multiplicity of things. (Ho, 2008, 314)

10. Defending Ho's Research Program

Impressive as Ho's achievements are, her work can be criticized, and it can be further advanced to integrate other theoretical developments in biology. Much of Ho's work has elicited skepticism, particularly her engagement with quantum theory and support for biophotonics and integral biophysics and associated with this, her claims for the role of quantum coherence in liquid crystals. In fact, there is a tendency by neurobiologists to dismiss all work in their discipline that invokes the notion of field. As Walter Freeman (1995, 34) put it, 'With continuing advances in the analysis of anatomical pathways in the cerebellum, it became increasingly obvious the concept of fields of energy flow made no sense. What are those axons for, if activity can flow diffusely?' However, Ho's understanding of fields did not reduce these to fields of energy flow or ignore the importance of neurons and their axons, or hormones. She was simply arguing that traditional explanations of the brain's functioning through neurons, axons and synapses is not enough.

Ho's claims can find support from other theorists. The claim that consciousness is an aspect of an electromagnetic field, without claiming quantum coherence for this field, has been defended by Johnjoe McFadden in an anthology in which most of the other contributors were explicating and defending Orch-OR theory. Reviving speculations of the early Gestalt psychologists on the relationship between physical brain fields on perceptual fields, McFadden proposed that 'Digital information within neurons is pooled and integrated to form an electromagnetic information field. Consciousness is that component of the brain's electromagnetic field that is downloaded to major neurons and is thereby capable of communicating its state to the outside world' (2006, 396f.). He argued that Orch-OR theory cannot account for most of the essential features of consciousness, while the influence of the endogenous electromagnetic field on neuronal firing can account for all these features. He did not exclude direct quantum effects in the brain, but argued that these were likely to be in the interactions between the brain's electromagnetic field and voltage gated ion channels in the neuronal membrane.

Ho was not content to simply defend the role of electromagnetic fields, however, and her work hinged to some extent on her claims for quantum coherence in these fields. Such coherence is required for the generation of holographic memories (Jibu and Yassue, Section 41) that Ho believed to be important. If, influenced by Tegmark, biologists are skeptical about the role of quantum coherence in Hameroff and Penrose's 'Orch-OR' theory of microtubules it can be expected that, given the distances and times involved, they would be far more skeptical of Ho's claims that entire organisms are quantum coherent liquid crystals at ambient temperatures. And her arguments for this have been questioned. Her claim that organisms are capable of astonishing efficiency in the conversion of energy which can only be accounted for by postulating such quantum coherence has been dismissed by Alex Hankey (personal communication) who has shown in his own work (2015, 301) that this efficiency can be explained through complexity theory as an effect of self-organized criticality rather than through quantum theory.

However, Hameroff and others have vigorously defended their claim that quantum coherence is possible at body temperatures in microtubules where they are insulated from thermal noise (Hagan, Hameroff and Tuczinski, 2002; Hameroff and Penrose, 2014) and that such coherence is necessary to account for consciousness. An even stronger defence is available to those invoking quantum field theory. Herbert Fröhlich (Fröhlich , 1968, 1977, Tzambazakis, 2015, 8f.), the theoretical physicist responsible for introducing quantum field theoretical techniques to condensed matter physics, examined long range coherence in biological systems. He showed that such coherence, equivalent to achieving superconductivity and superfluidity at room temperatures, could be achieved through longitudinal electric modes associated with oscillating electric dipoles containing more energy than thermal equilibrium. This is 'motional' order rather than spatial order. Focusing on macroscopic wave functions, he could see no problem in putting forward this claim. Umezawa rejected Tegmark's argument because, as he pointed out, neither neurons nor other brain cells are treated as quantum objects as assumed by Tegmark, and the quantum variables are basic field variables (Vitiello (2001, 86). Vitliello argued that what Tegmark had really shown were the limits of quantum mechanics, and thereby why it is necessary to use quantum field theory in modelling the brain. Ho herself and her collaborators provided further evidence that the fields she was referring to are quantum coherent and that they are required to account for consciousness. They claimed to have shown that biophotons could only have been produced by quantum coherent fields (Popp, 1988). And she showed coherence in the whole of living organisms through her research using a polarizing light microscope and other observational techniques that is simply not acknowledged by most biologists and cannot be explained by them. She and others have demonstrated coherent patterns in the behavior of molecules, completely aligned with their electrical polarities, in radiation from these, and in neural activity achieved almost instantaneously, and such work is continuing, with important implications for medicine (Tzambazakis, 2015). These phenomena cannot be explained by the electro-chemical pulses associated with the transmission of signals through neurons, dendrites, axons and synapses. Ho has also shown that the time taken for vision to take place after receiving stimuli is far less than would be required if only the chemical processes of signal amplification through neurons were involved (Ho, 2008, 8).

Support for Ho's claims comes from Walter Freeman who teamed up with Vitiello to challenge mainstream neuroscience and to defend the role of quantum coherence in brain dynamics, proclaiming:

> The common belief is that, if physics has to be involved in the description of brain dynamics, classical tools such as non-linear dynamics and statistical mechanics should suffice. However, many-body field theory appears to us as the only existing

> theoretical tool capable to explain the dynamic origin of long-range correlations, their rapid and efficient formation and dissolution, their interim stability in ground states, the multiplicity of coexisting and possibly non-interfering ground states, their degree of ordering, and their rich textures. It is historical fact that many-body quantum field theory has been devised and constructed in past decades exactly to understand features like ordered pattern formation and phase transitions in condensed matter physics, similar to those in the brains, that could not be understood in classical physics.
>
> The notion of coherent collective modes, which are macroscopic features of quantum origin, has been used in many practical applications (in solid state physics and laser physics, for example). In a familiar crystal, a magnet, the ordered patterns observed at room temperature, without recourse to low-temperature superconductivity or superfluidity, are well known examples of macroscopic quantum systems. (Freeman and Vitiello, 2006, 96)

This proclamation was made on the basis of Umezawa's claims for quantum field theory. However, in developing her ideas, Ho aligned herself with the work of David Bohm whose theories, particularly his later work, also tend to be dismissed by mainstream scientists. However, this dismissal is usually based on confusion between Bohm's general claims and his specific theories. Bohm was primarily opposed to physicists, under the influence of neo-Kantianism or logical positivism, abandoning the quest to comprehend experimental findings where both particle-like characteristics and wave-like characteristics have been found. For genuine science, Bohm claimed, this requires a radical rethinking of what exists to account for these observations. Bohm never claimed that his own theories were final solutions. They were designed first of all to illustrate what is genuine science. The hostility to Bohm really reflects the hostility to questioning deep assumptions about the nature of being, and this is preventing the advance of science. Bohm's arguments and conjectures have inspired a number of radical thinkers, including Paavo Pylkkänen who has also attempted to use his ideas to comprehend consciousness in a way that could support Ho's work, although she does not refer to him, nor does he refer to her. Bohm originally formulated his version of quantum theory as a particle theory with an additional pilot wave which does not carry energy or momentum, before developing the more radical holistic theories associated with the notion of the holographic implicate order being make explicate that influenced Ho. However, he saw these theories as only provisional and aspired eventually to develop his theory as a quantum field theory (Bohm, Hiley and Kaloyerou). When he died he had not been entirely successful in this project, as Pylkkänen, who collaborated with Bohm and Hiley, pointed out (Pylkkänen, 2007, 174-180). As far as Ho's work is concerned, it is what Bohm was aiming at that is important. She was aligned with Bohm in his quest to advance quantum field theory according a place to holograms and making the reality of consciousness intelligible.

The claim that consciousness is a quantum process is also supported by an increasing number of more orthodox theorists. Although Stapp defended the orthodox Copenhagen interpretation of quantum theory as formulated by von Neumann who argued that consciousness is involved in measurement and the collapse of the wave packet, Stapp also aligned himself with the process philosophy of Whitehead, and argued that an essential aspect of quantum events is non-locality. As he put it, 'the structure of *predictions* of quantum theory itself demands that the basic process of nature be intrinsically global: it *cannot* respect spatial separations in the way that familiar causal processes do. Thus the extent to which we confine our thinking to processes of the familiar local kind the quantum choice *must* appear to come from nowhere' (Stapp, 2009, 144). Stapp argued that quantum theory so interpreted can account for the experience of making choices as described by the psychologist William James. On this view, which to some extent accords with Ho's, 'the mental universe of each human being consists exclusively of the felt quality of actual events constructed out of the symbols that are the building blocks of the (generalized) body-world schema: consciousness is the felt quality of the manipulating actions of these symbols upon each other' (Stapp, 2009, 138). On this basis, Stapp (2017) defended the reality of free will. However, Stapp's way of construing consciousness itself manifests a Western bias towards what is focused upon. What is left out of Stapp's account of experience that has a central place in Ho's, is the background pre-symbolic, pre-predicative experience, awareness or feeling of situated embodiment along with unreflective spontaneous action (as described by Merleau-Ponty, for instance, but also acknowledged by William James), taken for granted in the more focused experience, attention and decision-making that Stapp was concerned to account for.

It could be demanded of quantum theory that it be developed to account for Ho's (and Merleau-Ponty's) characterization of experience, and neuroscientists associated with Umezawa have developed ideas on and explanations of consciousness closer to Ho's. While advancing quantum field theory, Umezawa and Luigi Maria Riccardi developed a quantum model of the brain which could account for memory. These ideas were further developed in Japan by Mari Jibu and Kunio Yasue. Jibu and Yasue, along with Stuart Hameroff and Karl Pribram, developed a theoretical framework for quantum optical coherence in cytoskeletal microtubules that, although focusing more on the brain, accorded with Ho's conjectures on quantum coherence of electromagnetic fields in liquid crystals. They argued that ordered water within cylindrical microtubules, behaving as waveguides, could facilitate superradiance and self-induced transparency, with superposition of states among microtubules. These in turn could be in superposition with other microtubules, accounting for a coupling of microtubule dynamics over wide areas. Like Ho, they claimed that this could account for the unity of thought, holographic memory, information processing, and consciousness (Jibu, Hagan, Hameroff, Pribram and Yasue, 1994).

This work was elaborated into a general theory of quantum brain dynamics (QBD) by Jibu and Yasue in *Quantum Brain Dynamics and Consciousness* (1995), a work that largely supports and complements Ho's explanation of consciousness. In this they asked "What is mind?" and "What is Life?" and proclaimed, having reached the same conclusion as Ho: 'We will address these two issue from the new point of view that *water is the fundamental constituent of both life and consciousness'* (p.158). They then characterized quantum brain dynamics as the quantum electrodynamics of the electric dipole field of dipolar solitons and water molecules. The main difference with this work is that, unlike Ho, these authors conceived consciousness only in relation to the brain, postulating a 'cortical field' and 'corticons' as cortical field bosons. However, it is not difficult to grant a place to the body from the perspective of these theorists since their arguments for quantum coherence in the brain can be used to defend quantum coherence in the whole body, and in fact, this had already been recognized by Umezawa and accepted by Jibu, Yasue and Vitiello (Vitiello, 2001, 92), although this was not the focus of their research. The importance of understanding consciousness in relation to the whole body of the organism has been recently argued by Hinterberger et.al. (2015) while examining the relationship between synchronicity and consciousness. In doing so, they pointed out the significance of the body in emotion.

The ideas of these Japanese theorists were then further advanced by Vitiello (2001) and others (Globus, Pribram and Vitiello, 2004) whose work not only concurs with Ho's, but offers more detailed explanations of the relationship between quantum fields, water, thermodynamics and the growth of the organism that could integrate Ho's conjectures with the work of Candace Pert on the role of polypeptides throughout the body in memory and emotions. In *My Double Unveiled: The dissipative quantum model of brain* Vitiello conjectured that:

> [T]he filamentary propagation of the em field in structured water may be the origin of the formation of the cytoskeleton, namely of that complex structure made of microtubules which pervades the cell and which is so crucially relevant to any metabolic activity. … [R]esonance occurs when the molecule oscillatory characteristic frequency matches the field frequency. The gradient force thus acts selectively on the surrounding molecules according to a well defined resonance pattern. … The attracted molecules may in turn contribute to a change of the field frequency in the filament, with consequent, say, attraction of molecules of different characteristic oscillatory frequency. The filament thus gets coated by a molecular pattern, which may stabilize into a polymeric structure if the coating molecules may form stable chemical bonds. … Such a scheme thus provides a dynamical description of cytoskeleton formation and of its structure. (Vitiello, 2001, 57f.),

All these conjectures, along with experimental work supporting Ho's contentions, can still be doubted. However, it is possible to look at the issue of invoking quantum field theory to explain various facets of life, mind and consciousness from a different angle and ask whether the diversity of coherent extensive patterns in living organisms, the almost instantaneous coherence achieved in these patterns, along with consciousness itself, could be accounted for in any other way except through quantum coherence acting non-locally. Conversely, it is also necessary to account for the breakdown of coherent extensive patterns, as occurs for instance with cancer or in mental breakdowns that are as yet not properly explained by giving some account of the breakdown of cohesive forces. The more rational approach, as suggested above, would be to recognize the observed phenomena that need to be explained and then to use work in biology to guide the further development of quantum theory to explain consciousness; and this, effectively, is what Umezawa and those he inspired have been doing.

Ho acknowledged the provisional nature of her work, pointing out that science itself is in flux with no claim to truth settled for very long. Much of her work is speculative, including work on the role of quantum coherence in biological organization and the identification of quantum coherent electromagnetic fields in liquid crystals with consciousness. She embraced this aspect of science and acknowledged the boldness of her conjectures, writing in her last book,

> When I first proposed the organism is quantum coherent in the early 1990s, only a handful of exceptional scientists thought that quantum theory had anything to do with biology. The situation has changed greatly since then. … But [scientists who spoke about quantum coherence in 2010] have yet to catch up with the quantum coherent organism, brain and body together, or mind and body undivided. (Ho, 2012, 80)

Work commensurable with Ho's research program continues, its successes and the challenges it faces reported in the anthology, *Fields of the Cell* (Fels, Cifra and Scholkmann) published in 2015. While the conclusions reached were that there is no definitive proof that biophotons are quantum coherent, the contributors to this work have conclusively demonstrated that biophotons are involved in synchronizing cells, and that there must be some way in which cells are able to recognize the small number of weak biophotons among the billions of biophotons impacting on them, and they reviewed further work showing the importance of synchronicity in biological organization, including the development of consciousness. What is most important is that Ho's conceptual framework is such that she could at least begin to make intelligible the most important features of life and consciousness in a way that mainstream concepts prevent. And it is by virtue of this that she was able to integrate the findings and developments of a great many researchers who have been marginalized and their arguments, research findings and observations ignored by mainstream biology. To a considerable extent, Ho was able to ask crucially important questions and put forward promising proposals because she was not encumbered by deep assumptions, or COWDUNG, that have crippled or clogged up most Western thought in the quest to understand life.

11. Overcoming the Limitations of Ho's Research Program

There does seem to be other problems with Ho's work, however. To begin with, her focus on quantum coherent electromagnetic fields not only involved downplaying the importance of electro-chemical and mechanical processes (for instance, the role of vibrations of membranes) in biological organization, but a consequent failure to study the interactions between these different processes (as examined by Vitiello (2004)). This is particularly important for understanding the role of the brain and its specialized regions, their different contributions to cognition and how these different contributions are integrated. However, these problems were addressed by Umezawa and by neuroscientists influenced by him, including Vitiello. Ricciardi and Umezawa (2004) in their ground-breaking paper on memory (originally published in 1967) not only acknowledged different functions of the brain, the regionalization of the brain necessary to deal with these and the need to coordinate these regions, but argued that quantum field theory is required to account for such differentiation and subsequent integration of the different functions. Vitiello argued for a crucial role in humans of the frontal lobes in making possible the separation of thought and action.

Related to this, in her concern to show that the physical world has many of the properties of life to account for the emergence of life, Ho did not adequately acknowledge the uniqueness of life. Ho's speculations on consciousness is defended with reference in *The Rainbow and the Worm* to Walter Freeman who demonstrated that the brain functions holistically and is creative (Ho, 1997) and to the work of J.J. Gibson. She also emphasized the importance of memory. This is superior to most work on the science of consciousness, which tends to ignore long traditions of philosophy, Gestalt psychology and radical work in neurobiology that have investigated the nature of consciousness in the past. However, Ho's work still underestimates the complexity of conscious experience.

Firstly, she did not acknowledge that, as Friedrich Schelling argued, living beings in actively maintaining and developing their forms through exchanging material with their environments, are asserting their ordering principles in opposition to the homogenizing forces of their environments. In the process, they define their environments in relation to themselves as their worlds (Gare, 2013, 8). This argument was based on another principle, that nature is made up of opposing forces, either balanced or unbalanced, which is actually central to modern science, although seldom discussed in this way. Secondly, Ho did not acknowledge that organisms in some sense model themselves, being simultaneously involved in the flux of becoming and able to maintain their identity through this flux. This was postulated by John von Neumann who argued that living beings must have models of themselves, an idea developed by Robert Rosen in his theory of anticipatory systems. The importance of this is most evident in the case of consciousness, as Kant and everyone influenced by him realized; however, in the case of more primitive organisms, such an identity is of a more basic and immediate kind, without the reflexivity associated with consciousness. Furthermore, as the proponents of the microgenetic theory of consciousness argue, building on the work of the Leipzig school of Gestalt psychology, the higher forms of self-reflexive consciousness are built on and presuppose the more primitive and immediate forms of cognition as inchoate, pre-conscious felt dispositions (Bachmann, 2000, chap.1; Brown, 2015). Each act of cognition up to and including language and reflective self-consciousness, unfolds through moulding the more basic and more global forms of cognition to achieve greater specificity to achieve these more advanced and more detached forms of cognition.

Some of these issues were taken up by Vitiello (Vitiello, 2001, 140) who in developing his dissipative quantum model of the brain, described 'a self-interaction or back-reaction process'. As we have seen, Vitiello's work accords with Ho's basic assumptions and so can be used to augment Ho's work. Vitiello's model is based on two facts, that the brain is a dissipative open system permanently coupled with its environment, and that quantum fields have an infinite number of states of minimal energy, that is, the vacuum states, each of which can be characterized by a particular ordering identified by its code, which, Vitiello argued, could serve as memory code. Being in the lowest energy state both makes it robust, guarantees that it is easy to create and is readily excited in the recall process. Thus, the brain is a mixed system involving two separate but interacting levels, memory based on quantum dynamics, and the electrochemical processes of neuro-synaptic dynamics, creating a Double in the relationship between memory and ongoing activity. As Vitiello described his theory and its implications, 'the overall mathematical structures of the model and in particular the specific dissipative character of the dynamics strongly point to consciousness as a "time mirror", as a "reflection in time" which manifests as nonlinear coupling or dialogue … with the separable own Double. … In some sense, the unavoidable coupling with the external world is "interiorized" in the dialectic, permanent relation with the Double' (Vitiello, 2001, 141). Developing this idea later with Walter Freeman, they wrote, 'the Double is conceived as a massively coherent, highly textured brain activity pattern that by replaying the past can predict the future. Therefore the Double is Mind, not Matter, yet it is completely entangled with brain matter that is shaped in the original AM [amplitude modulation] pattern' (Freeman and Vitiello, 2016, 16). They concluded, 'the relation between matter and mind can now be expressed in terms of the evolution of dynamic trajectories along parallel time lines, one corresponding to reconstructing the past in remembering, the other to forecasting environmental trends by extrapolation into the future in predicting' (Freeman and Vitiello, 2016, 17).

Thirdly, organisms are actively searching for new inputs and accommodating themselves to their environments, and in doing so are capable of creativity. Ho's conception of consciousness understates its orientation to the future, particularly in the case of more highly developed forms of consciousness associated with humans. For instance, her identification of proprioception with quantum coherence of the electromagnetic field of the organism functioning as a liquid crystal, explaining this through the generation in the organism of a hologram-like interference pattern, could not easily explain the experience of phantom limbs after amputations where people continue with passive anticipations (or protensions) of what they can do with these limbs, nor could she recognize the significance of and then account for the capacity to knock on an imaginary door, something that some brain damaged people are unable to do. These reveal the importance of an embodied anticipatory imagination to experience. More generally, she did not acknowledge the qualitative differences between cognition in different organisms – amoeba, plants, fish, various mammals and humans, and attempt to comprehend the uniqueness of each. That is, she barely touched on the characteristics of what Gerald Edelman characterized as higher-order consciousness.

Not acknowledging the uniqueness of humans, Ho did not attempt to explain the evolution of various levels of cognition. While her holistic approach, conceiving the whole organism and not only the brain as a quantum coherent liquid crystal, was a better basis for accounting for the diffuse felt directedness which, according to the Leipzig school of Gestalt psychologists and the microgenetic theorists of consciousness, she could not explain the actual genesis of the various forms of differentiation of separate sensations, perceptions, distinct acts of remembering, distinct thoughts, and so on. She not only did not offer explanations for the capacity of humans to use metaphors and construct stories to augment awareness of broader contexts, including awareness of the significance of the distant past, including the whole history of the cosmos made possible by such stories, but did not provide the framework to develop such an explanation. This requires a much more complex notion of memory as a condition for all other higher-order aspects of consciousness, such as language, than Ho considered. In fact, this seems a problem for all those who have invoked quantum theory to account for consciousness, most of whom have ignored the work of the microgeneticist theorists of consciousness. As Gerald Edelman argued:

> *Memory is a system property:* it differs depending on the structure of the system in which it is expressed. In biological systems, memory must not be confused with the mechanisms that are necessary for its establishment, such as synaptic change. Above all, biological memory is not a replica or a trace that is coded to represent its object. In whatever form, human memory involves an apparently open-ended set of connections between subjects and a rich texture of previous knowledge that cannot be adequately represented by the impoverished language of computer science – "storage," "retrieval," "input," "output." To have memory, one must be able to repeat a performance, to assert, to relate matters and categories to one's own position in time and space. (Edelman, 1992, 238)

Correspondingly, Ho did not attempt to explain the capacity to form long-term goals on the basis of such narrative memory. That is, she did not attempt to explain imagination and the capacity to envisage new scenarios, hypothetical situations and fictitious worlds, humanity's creative capacities on which societies and civilizations are based. Nor could she account for tensions and conflicts between different levels of awareness and consciousness engendering various forms of self-deception associated with sub- or semi-conscious motives. A more complex relationship between quantum coherence and experience is called for.

But again, such work has been advanced within the school of thought inspired by Umezawa. Freeman and Vitiello, alluding to Merleau-Ponty, have argued for a central place for imagination, although they are inferior to Ho in not acknowledging the central place proprioception plays in all forms of awareness and consciousness in animals. Alluding to the capacity of the brain to generate a time-reversed copy of the organism as an open system and thereby hypothesize what will come next, they wrote 'where do the hypotheses come from? The answer is from imagination. … [T]he mirror copy exists as a dynamical system of nerve energy, by which the Double produces its hypotheses and predictions, which we experience as perception, and which we test by taking action. It is the Double that imagines the world outside us, free from the shackles of thermodynamic reality. It is the Double that soars' (Freeman and Vitiello, 2016, 15). They suggested that the frontal lobes enable the organism to think without acting, and block action without thought. Gordon Globus, integrating Gestalt psychology and post-phenomenology with process philosophy while engaging with work in quantum field theory as developed by Umezawa and Vitiello, has attempted to characterize the full complexity of human existence (Globus, 2003; Globus, 2009). In doing so, he has attempted to free quantum brain dynamics, including Vitiello's work, from a residual dualism between the mind, located in the brain, and the external world (2009, p.116f). Since Globus aligned his own work with process philosophy and embraced quantum field theory, his work is commensurable with Ho's, supplements it, and could be used to augment it in a way that the proponents of the microgeneticist theories of consciousness have called for, although I will suggest below, even Globus' work is not enough by itself in this regard.

Ho was concerned with humanity and human consciousness, and to complete this paper it is necessary to defend and extend her efforts (and those of Waddington, Needham and Goodwin) to overcome the Cartesian dualism that continues to afflict not only modern science but the broader culture. To this end, it is important to appreciate that the notion of fields was associated with process thinking, and to acknowledge the centrality of becoming in the original idea of fields. Processes are extensive and durational and do not have a simple location in space and time. Time, as it was understood by the *Naturphilosophen* and by the main proponents of field theory, including Whitehead, Waddington, Needham and Ho herself, cannot be treated as equivalent to an extra dimension of space and is not infinitely divisible. Time involves durational becoming with an open future in which possibilities have not yet been actualized, a past in which possibilities have been actualized, and a present where possibilities are in the process of being actualized. Space on the other hand should be understood as characterizing the potential and actual causal relations between processes, with different forms of space emerging with the evolution of the universe, life and humanity. Accordingly, we should speak of time-space rather than space-time, as Milič Čapek (1971, 229-37) argued, and allow for a multiplicity of these supporting and interacting with each other. To understand reality in this way requires what Michael Polanyi (1969, chap.13) termed 'indwelling' in that which is being comprehended, captured to some extent by what Ho referred to as synthetic thinking. Ho allowed for fields within fields, both within morphogenesis and more broadly to conceive the universe as 'a nested hierarchy of individualities and communities' (Ho, 2008, 334). Fields focused upon have to be seen in the context of broader fields and/or more specific fields, which again requires indwelling to contextualize that which is being investigated (Bitbol, 1996, 227ff.). We have to acknowledge that scientists and their experimental apparatuses are part of the world they are trying to understand. By thinking in this not completely objectifying way, Ho was able to present biological fields as emerging from and being developments of physical fields, although with some degree of autonomy from the fields from and within which they emerged, capable of then utilizing these physical fields for autonomous ends. However, the physical fields were referred to in a fairly unsystematic way, based on research findings about particular fields in organisms, such as the morphogenetic field, the electric field, the electromagnetic field, the biophoton field and the vacuum field, with minimal effort to characterize the emergence of new fields or to acknowledge the importance of disposition feelings in living organisms driving their quest to maintain themselves in existence against environmental forces.

The possibility of the emergence of new fields, and the hierarchical ordering that such emergence engenders, can be made intelligible by Pattee's notion of enabling constraints, although Pattee did not conceive such ordering in terms of fields. This also makes intelligible the ordering of the sequence of emergent fields, as when in an embryo fields for specific parts of the body such as a leg emerge within the total embryo field, and then the field of the extremity of the leg where digits develop emerges from this field. Allowing fields emerging within fields, there are multiple temporalities with various processes existing over different minimum durations, with some durations containing and integrating others. This complex view of temporality was developed by Bergson (Čapek, 1971, 159), whose work Ho embraced. It was consistent with Goodwin's early work, and was central to the traditions of Chinese thought that influenced the development of the concept of field. In discussing the mind, Ho emphasized that it is non-local, containing diversity in a unity, but it should also be seen as multi-temporal, containing multiple durations within a hierarchy of durations. It is by virtue of this complexity that we recognize enduring forms within change, and presence of the past in the present. This was well conveyed in the lines of the Sung Dynasty poet, Li Po (1963, 193):

> Petals are on the gone waters and on the going,
> And on the back-swirling eddies,

> But today's men are not the men of the old days,
> Though they hang in the same way over the bridge-rail.

Appreciating the reality of becoming involves acknowledging the reality of possibilities, along with propensities or powers and liabilities to make possibilities actual. Acknowledging possibilities might be regarded as of no significance, merely acknowledging logical possibility, as a determinist committed to a block universe might still acknowledge possibilities as logical abstractions or mere terms used to define what there is. However, it is also possible to take a realist rather than a nominalist approach and grant possibilities a definite ontological status as potentialities. Whitehead did this in characterizing them as eternal objects that are selected by actual occasions as part of their concrescence or self-formation, while in his cosmology C.S. Peirce took possibilities as Firstness (equated with impersonalized feeling), actual existences (which are a limitation on possibilities) as Secondness, and laws as Thirdness. Following Peirce, Stuart Kauffman argued for an interpretation of quantum theory in which the paradoxes of theory were dissolved by distinguishing possibilities (or 'Possibles') from what is actual, and pointing out that a different logic pertains to possibilities than pertains to actuals (Kauffman, 2016, 124). For instance, it is not necessary to accept the excluded middle where possibilities are concerned; a proposition about possibilities can be both true and false. Such possibilities can be outside space, or non-local, but inside time. Following Kauffman and embracing this strong sense of the reality of possibilities to interpret quantum field theory (where electrons, for instance, are treated as excitations of an underlying electron field rather than particles, and a field is conceived of as 'a set of infinitely many degrees of freedom extended across spatial regions or the whole of space' (Jibu and Yasue, 1995, 221)), possibilities can be conceived of as propensities of existing fields in their extensive and durational becoming, including possibilities for, or propensities to interact with other fields and to participate in the emergence of new fields, as has been shown to occur in condensed matter physics with the formation of crystals (Vitiello, 2001, 12ff.). This accords with those quantum theorists who argue that quantum theory should be seen as reintroducing real potentialities and propensities or dispositional states into physics (Bschir, 2016, 36ff.). While possibilities are infinitely divisible, what exists is not. The primary beings of the universe only exist as processes of extensive, durational becoming which sustain possibilities or dispositions, including dispositions which if realized, are incompatible with the realization of other dispositions. It is in relation to such extensive, durational becoming that paths need to be understood, including necessary paths or chreods, and the epigenetic landscapes that represent these. Epigenetic landscapes and their mathematical models are mappings of the possibilities of fields in their process of becoming, revealing those real possibilities that an epigenetic process will most probably follow, or have a propensity to follow and realize, as a valley, while at the same time, mapping other possibilities and propensities, including adjacent possible paths that could be followed. It is by taking adjacent possible paths that an organism can respond creatively to new contingencies, as with pre-adaptation where a trait evolved to serve one function is co-opted to solve a new problem (Gabora, Scott & Kauffman, 2013).

In the case of elementary quantum processes these paths and their mappings are relatively simple, but become increasingly complex with emergent enabling constraints involving fields within fields, or co-extensive, mutually dependent fields which are nevertheless irreducible to each other. This is the condition for the development of organisms which, by incorporating models of themselves and their environments, are able to anticipate and then respond to what is anticipated. These are the anticipatory systems as characterized by Robert Rosen, systems which require multiple models to represent them, with each being components of the others but without there being a largest model from which the other models can be derived (Rosen, 2012). The mathematics involved in such modelling requires the use of impredicative concepts characterized by circular definitions, or technically, where ‘a set M and a particular object m are so defined that on the one hand m is a member of M, and on the other hand, the definition of m depends of M’ (Kleene, 1952, 42). Effectively, this is modelling processes that are, in philosophical language, internally related to each other. As Rosen argued, it is only with such models that final causes characteristic of anticipatory systems can really be said to have a place, and accordingly, in which it is necessary to recognize components as functional components and not simply fractionated components of the whole. While Thom’s use of the term ‘attractor’ was meant to equate to a final cause, such attractors were nothing but where the dynamics of a system lead to. This is how the notion of attractor was conceived when it was embraced by complexity theorists and incorporated into dynamical systems theory. Systems were then classified according to whether they led to a point, periodic motion, quasiperiodic motion where there is more than one possible frequency, or to chaos. Later, the ‘edge of chaos’ and ‘criticality’ were recognized as attractors of self-organizing systems. There was no recognition by these complexity theorists of paths of development to more complex systems, although this was focussed on by complexity theorists who had embraced hierarchy theory, such as Howard Pattee and Stan Salthe.

By contrast, in anticipatory systems there are multiple fields irreducible to each other but inseparable from each other operating over diverse durations, there is a form of downward causation constraining components to functionally serve the end that the process is realizing. This is an essential aspect of final causation. As Salthe argued, ‘constraints from the higher level not only help to select the lower level-trajectory but also pull it into its future at the same time. Top-down causality is a form of final causality’ (Salthe, 1993, 270). For instance, when the field of the leg emerges from the field of the whole embryo it clearly has some autonomy, as is evident from experiments transposing of material from the leg to another part of the embryo, such as the wing. It will still develop as leg tissue, but according to its position in the wing field, constrained by the whole to serve a function. As a function, however, it cannot be identified simply as a fractionated component of the organism but has to be recognized through its function, as a leg facilitating locomotion, although as such it utilizes the potential of physical structures and can be used for other and completely new ends. Organism as such are emergent ‘objects’ with final causes which cannot be modelled as dynamical systems (Ehresmann and Vanbremeersch (2007, 139ff.).

Modelling mathematically all the complexity that Ho identified in organisms, including chreods and consciousness, will require not only the insights of Rosen but the further advances in mathematics made possible by the further development of category theory by Ehresmann and Vanbremeersch (2007, esp. chap.10), by Ehresmann and Gomez-Ramirez (2015) and by Ehresmann and Simeonov (2012; 2017) with the development of biomathics. Progress in deploying category theory to model consciousness has been made also by Goro Kato and Daniele C. Struppa (2002).

12. Biosemiotics and Genetic Structuralism

Once final causes and functions are acknowledged, it become possible to appreciate semiosis and the centrality of semiosis to all living beings. Epigenesis was always understood by Ho, along with all members of the theoretical biology movement, as a process involving interactions of the epigenetic process with the genome and the environment, and it was assumed that an organism’s metabolism involves a constant exchange with its environment. For the most part, the fields that Ho wrote about were whole organisms or parts of them. She situated these in broader contexts, including ultimately the entire cosmos, and on occasion wrote about ecosystems and society. When discussing the brain she always situated this as part of and integrally related to the rest of the body. However, despite reference to cognition, the organism within its environment was not treated as a field. That it should be was argued by Jacob von Uexküll, who claimed that it is only possible to understand an organism when seen in relation to its surrounding world, or *Umwelt,* the environment to which it is sensitive and has a meaning for it. This was accepted by the ethologists such as Konrad Lorenz, by von Bertalanffy, by the biosemioticians and by Piaget. Vitiello's dissipative quantum field theory supports this claim. As he put it, '*Consciousness seems thus to emerge as a manifestation of the dissipative dynamics of the brain. …* [C]onsciousness appears to be not solely characterized by subjective dynamics; its roots, on the contrary, seem to be grounded in the permanent "trade" of the brain (the subject) with the external world. Consciousness is only possible if dissipation, openness onto the outside world is allowed' (2001, 141). It is only through recognizing, as Jacob von Uexküll argued, the organism in its environment as an irreducible field, that biosemiosis, the production and interpretation of signs by the organism as whole and within it can be fully understood, and therefore, it is only by seeing the organism in its surrounding environment that epigenesis can be properly characterized. As the biosemiotician, Jesper Hoffmeyer, argued, embracing Waddington's emphasis on the autonomy of the zone between the genotype and the phenotype, 'this is a zone where not only embryological but also semiotics influences are of the essence. And in fact, perhaps the most crucial single aspect of the embryological process (after the attainment of brute viability) is the development of the Umwelt of an organism' (Hoffmeyer, 2008, 200). Elaborating on this, Hoffmeyer suggested it is necessary to provide an extra layer, the *Umwelt landscape* to map this 'canalysation process', arguing 'that it is *the semiotic competence of animals* that seriously puts (or should put) the intermediate embryological zone (the combined epigenetic-Umwelt landscape) at the forefront of the agenda in evolutionary thinking.' Selection should be seen as flowing down 'semiotically constructed pathways' (2008, 200).

As noted above, biosemioticians embraced and developed Peirce's theory of signs, explaining a vast variety of forms of semiosis from the vegetative semiosis where growth is the interpretant, to semiosis in animals where action is the interpretant, to the complex forms of symbolic semiosis associated with human culture, with the later forms building on and being dependent on the more basic forms of semiosis, including the dispositional feelings studied by the proponents of microgenetic theories of consciousness. They also investigated the semiosis that operates inside organisms, that is, endosemiosis, although differentiating what is internal and external is problematic. As Hoffmeyer noted, in terms that resonate with those of Rössler's endophysics, 'the processes of life are … played out across multiple surfaces, one enveloping another' (2008, 213). It is this differentiation through engendering and enfolding surfaces that we have the co-emergence of subjects defined in opposition to objects, although these are really aspects of the same emergent processes. And as Merleau-Ponty pointed out, subject and object are reversible, as when I touch one of my hands with the other. (It appears that with meditation some people are able to dissolve this opposition, achieving a form of experience of being prior to this division.) Such work challenges and provides an alternative to work on feedback utilizing the standard concept of information, unless information is redefined as it was by Gregory Bateson, as 'a difference that makes a difference'. This broader definition can allow for a variety of forms of information ranging, as John Collier argued, from a lowest level of physical information determined by distinctions to explicit representation in linguistic social communication, with the higher levels involving extra restrictions on the lower levels (Collier, 2011). Bateson's work was taken up and developed by the biosemioticians, and, aligned with them, Søren Brier, who developed the concept of 'cybersemiotics' (Brier, 2010). It is through this work on semiosis interpreted to accord with Waddington's notion of canalysing along semiotically constructed pathways that it should be possible to revive, develop and then redeploy Waddington's notion of homeorhesis.

Such work can be further augmented by the work of Piaget. Peirce was strongly influenced by Kant. His highly general theory of semiosis postulated three components – representamen or sign, object and interpretant (which can in turn become a sign), is applicable to everything from cell functioning and plant growth to the development of art and science. The notion of 'interpretant' enfolded the place accorded to synthesis by Kant in perception and judgement, that is, the constructive aspect of experience involving schemata and imagination. As Sandra Rosenthal observed,

> Peirce in appropriating Kantian schemata, takes from Kant the fundamental insight that concepts are empirically meaningful only if they contain schematic possibilities for their application to sensible experience. … However, Peirce's pragmatic appropriation of these insights radically alters Kant's understanding of the schema. Such a schema is no longer a product of the productive imagination as distinct from the understanding of the faculty of judgment. Rather, both understanding and imagination are unified and transformed into a creative functioning of habit as providing a lived or vital intentionality between knower and the known. (Rosenthal, 1994, 26)

Peirce developed his philosophy before the rise of Gestalt psychology which, utilizing the concept of field, focussed on its synthetic aspect in the context of the organism rather than in relation to a transcendent ego. As Piaget characterized the core idea, formulated in 1912, of the founders of Gestalt psychology, Wolfgang Köhler and Max Wertheimer, 'perceptible structures were interpreted by means of field models applicable alike to perception, to the nervous system, to the organism, and even to an agglomeration of physical phenomena made up by Köhler – a physicist by training – and given the name *physische Gestalten*' (Piaget, 1971, 245). The Gestalt psychologists set about determining the laws of form. The consequence of this was that higher totalities were reduced to perceptual or motor Gestalts.

Piaget, who originally studied philosophy aligned with neo-Kantianism, also was strongly influenced by Kant and embraced his notion of schemata, redefined as 'structure' which the organism can transfer or generalize from one object, situation or circumstance to another, as when a baby having played with a ball generalizes the cognitive structures generated by this to another ball. Piaget argued that the main problem with the work of these Gestalt psychologists was that they irrevocably subordinated these forms to equilibrium laws, constrained from without as well as from within, giving no place for constructive activity or development. Piaget's own work was an attempt to overcome this deficiency, and it was through acknowledging order in this development that Piaget recognized that his work required Waddington's concept of chreods, with the development of cognition being seen as founded on and a further development of the morphogenesis of the organism. That is, Piaget did not reject Gestalt psychology but advanced beyond it. Piaget also grappled with the nature and role of signs and symbols, up to and including language, seeing language as built on and presupposing the structures developed through practical engagement in the world whereby organisms develop the capacity to recognize invariant patterns in their environments (Furth, 1981, Part III). Seen against the common background of Kant and post-Kantian thought, the ideas of the biosemioticians and Piaget's theory of cognitive development are commensurable. There is no reason for not acknowledging a place for structures, as conceived by Piaget as hierarchically organized self-regulating systems of transformations, as aspects of semiosis as characterized by the Peircian biosemioticians, as I have already suggested.

Considering all this, we can revisit Ho's engagement with Piagetian genetic structuralism and her effort to conceive consciousness. As Waddington and then Goodwin and Ho argued, it is possible to understand morphogenetic fields as developing structures as Piaget had conceived them. In Ho's contribution to the structuralist phase of the theoretical biologists she not only completely aligned her own work with Piagetian genetic structuralism as did Goodwin, but emphasised process. As she put it:

> Piaget (1968) defined a *structure* as a system of transformation. From an evolutionary perspective, however, it is *structuring* rather than structure that should concern us. This takes us right to the heart of Whitehead's (1920) nature as *process.* … in the time-honoured tradition of the resolution of opposites, a 'structuralism of process' offers us a synthesis of the eternal and existential. And it does so via the participation of the organism in the *con-structuring* of reality. Time and creativity are of the essence. … Piaget (1968) identified three main properties of structures: *wholeness, transformation and self-regulation*. I introduce a fourth, which is characteristic of organismic structures: heredity, or memory. (Ho, 1989, 31).

She continued:

> A life-history is thus presented as a sequence of forms connected by transformations from a particular structure in the context of the co-existing contingencies. … In the organism, the novel environments or habits adopted may result in physiological changes which predispose the development of the next generation to occur in certain ways. This is the essence of the internalisation of contingencies, which Waddington (1957) expressed as the canalisation and eventual genetic assimilation of a novel developmental response. (Ho, 1989, 34f.)

However, the chapter in which she wrote this was entirely devoted to morphology, not cognitive development or consciousness. As such, it could be seen as a contribution to what the biosemioticians, and Kalevi Kull in particular, characterized as vegetative semiosis where the generation of form itself is seen as an interpretant in a semiotic process, and thereby a sign for other life-forms (Kull, 2009). Once this is accepted, it is not difficult to characterize cognition associated with action, and then with thought dissociated from immediate action, as developing from such vegetative semiosis.

12. Rethinking Waddington and Ho through Robert Rosen

I have suggested elsewhere that Peircian semiotics requires a more complex understanding of causation than Peirce provided, and that this can be provided by hierarchy theory based on the idea notion of enabling constraints as it was developed by Pattee, Rosen and Salthe, along with Rosen's characterization of causal entailment in anticipatory systems (Gare, 2007). Conceived along these lines it is not difficult to see how semiosis associated with action and symbols can be understood in the same way as vegetative semiosis as developing structures, effecting a synthesis of Waddington's theoretical biology, biosemiotics and Piagetian developmental psychology right up to the most abstract forms of symbolic semiosis. This is associated with a constructivist theory of knowledge and of consciousness, which can be defended through Robert Rosen's work on anticipatory systems in which he argued that functional components of living beings cannot be identified with the fractionated components they can be analysed into (Rosen, 2000b). Considering Rosen's arguments, Ho's explanation of consciousness, most importantly proprioceptive consciousness through quantum coherence, while illuminating looks too simplistic. Can it be defended? With modifications based on the ideas I have already argued for, I believe it can.

Living beings are very special kinds of physical beings. They are dissipative structures self-differentiating along paths of development engendering hierarchical organizations based on enabling constraints, but they are more than all this. They are anticipatory systems, and it is by virtue of this that they are alive. As Rosen argued, living beings cannot be identified with the sum of their fractionated components, and their specific characteristics can be defined independently of the physical processes that are required and are utilized by them, such as the energetic processes and forms of integration that Ho described. However, they still must be recognized as physical processes and it is necessary to understand how these physical processes make life and consciousness possible. The best way to understand physical processes in relation to living beings, and the structures they generate, is in terms of how living beings utilize them. It is here that mechanistic forms of explanation can be apposite, providing it is acknowledged that mechanistic explanations always presuppose teleology, and life cannot be understood as a collection of mechanisms. For instance, the compounds such as calcium carbonate that form bones of legs provide strong structures than facilitate locomotion, among other things, including on occasion entirely new uses. It is here that most of the work undertaken by neuroscientists can be recognized as important. Work on different types of neurons, dendrites, axons and their interconnections, synapses, specialized regions of the brain, neural nets, brain waves and other electrical and magnetic patterns can be seen as having an important place in cognitive processing, providing they are understood as making possible and being involved in and largely determining the nature of conscious living rather than being identified with it. Long term memory is possible because physical processes, including certain chemicals, for instance as Candace Pert argued, polypeptides, are able by themselves or through their modifications of electromagnetic fields, to maintain records of past events. RNA and then DNA complement polypeptides in this regard. However, biomolecules are assembled and disassembled over a short time span of a couple of weeks, and the long term stability characteristic of memory can only be explained through quantum field theory, that is, through the electromagnetic vacuum field.

As such, these biochemicals, vacuum states and modulations of electro-magnetic fields are not memories, but by virtue of their relation to biofields, they can serve as sign vehicles that have the properties that enable them to be organized by codes with all the differentiation that coding entails. Similarly the claim by Ho that consciousness is the quantum coherent liquid crystal, Jibu and Yasue's that 'creation and annihilation dynamics of corticons and photons in the QBD system in the sub-microscopic world of the brain' is 'the entity we call consciousness or mind' (Jibu and Yasue, 1995, 179), along with Hermes Romijn's claim that the 'fleeting, highly ordered 4-dimenional (space and time) patterns of virtual photons (electric and/or magnetic fields), generated by assemblies of dendritic trees of a specialized (e.g., cortical) neuronal network … encode for subjective (conscious) experiences (Romijn, 2002, 74), are misleading. These physical processes should be seen as crucial to making consciousness and such subjective experiences possible, and as crucial components of living beings as conscious subjects, rather than being identified with or as encoding subjective, conscious experience. Explaining the possibility of these is not insignificant, however. If the world were ultimately composed of nothing but interacting particles along with forces of attraction and repulsion, machines or even digital computers, even allowing for the diverse patterns identified by complexity theorists, consciousness would be inconceivable. Furthermore, as Pylkkänen (2004) argued, following David Bohm, the nature of consciousness is largely determined by the quantum dynamics that make it possible and these dynamics are utilized by thought, and have many of the same characteristics.

Adopting this perspective, rather than identifying quantum coherent fields associated with liquid crystals with consciousness, which amounts to identifying a fractionated component of an organism with its function, such quantum coherent fields should be seen as explaining the possibility of consciousness and as crucial to the consciousness of living beings and determining to a considerable extent the nature of conscious experience. It can be argued that living organisms have evolved to be able to utilize coherent quantum fields, those associated with quantum coherent electromagnetic processes and vacuum states facilitated by liquid crystals, as a means of constraining, coordinating and stabilizing neural activities, including patterns of virtual biophotons and vibrations in microtubules, thereby augmenting semiosis, including the memory required for this. This has greatly increased the sensitivity of organisms, for their capacity to identify diverse ends and possible actions, their capacity for quick responses, to reassess goals, interpretations and possible actions, and also, particularly with humans, for the creative development of semiosis; that is, for enhancing cognitive structures. Quantum coherent electromagnetic fields would then be inseparable from consciousness as a highly-developed form of cognition, including proprioception and a sense of where the organism is in its world. Consciousness as such should be seen as built on and presupposing simpler forms of semiosis and cognition associated with interactions between the organism and its environment and within the body, forms of semiosis that are associated with feeling and awareness rather than consciousness. Consciousness in humans has engendered the imaginative development of complex ideas in literature, philosophy, science and mathematics. In making such complex semiosis possible, such quantum coherence is different from the quantum coherence that might occur outside living organisms. As Ho argued, organisms are organized into vast fractal hierarchies of energetic processes, including neural activity, self-organizing to criticality such that negligible energetic activity, for instance, the energetic activity associated with interpreting signs defining the situation of the organism in its environment, can trigger a massive cascade of transformations, resulting in the rapid deployment of large amounts of useable energy for quick action by the entire organism.

From this perspective, coherent electromagnetic fields made possible by liquid crystals in organisms situated within environments are at the apex of and supervene by suffusing and coordinating through constraining hierarchies of fields and their structures over multiple scales. These fields include, maintain, develop and create new repertoires of possibilities (or cognitive structures or concepts) for interpretation and action (that is, habitual, skilled forms of interpretation and action) at multiple levels of organization, including repertoires for modifying or creating new possibilities (accommodating cognitive structures or developing new habits). This coordinating function would not be simply local. It would operate simultaneously over different durations, such that these possibilities could be actualized according to particular circumstances. These 'possibilities' could then be conceived of as possible chreods, and include cognitive structures as characterized by Piaget, including chreods of development of these cognitive structures.

This accords with what Waddington argued at the second theoretical biology conference commenting on a presentation by Richard Gregory on how information controls behaviour. Waddington responded:

> Richard Gregory asks the question – a very good one – how so little information controls so much behaviour, and answers it by arguing that the information triggers pre-existing models of objects in the perceivable world which have already been formed within the brain. This is an attractive thesis, but I find the word 'model', with its suggestion of miniature clockwork railway locomotives and other object-like hardware, rather inhibiting to an imaginative grasp of what is involved. I should prefer to think of these 'models' as chreods. …. [W]e have to suppose that the space of brain states is divided into a number of domains, each characterized by a vector field which, at any given time, is dominated by a particular attractor. … In such a picture it is easy to realize the provisional character of the 'internal information', i.e. the boundaries of the various domains, the characteristics of the vector field and attractors, and to appreciate that this must be subject to continual change and adaptation through processes of learning. (Waddington, 1969, 247)

Waddington's claims in this regard can be supported by the experimental work of Walter Freeman who showed that when an rabbit learns to identify a new odour, it does not store memories that are compared with present inputs, but effect ‘global modulations constituting generic commands’ (1995, 165).

In this scheme, there can be chreods within chreods as organisms define their worlds and their place within them as the context for identifying both broader contexts and more particular situations, along with specific events, objects, organisms, persons, signs, actions, or utterances. The repertoire of possibilities could be actions which are simultaneously interpretations (in Peircian biosemiotics terminology, where the interpretants are actions as part of what Jacob von Uexküll referred to as function-circles, or with what Piaget referred to as sensori-motor intelligence) or a separate interpretation of signs followed by a choice of actions (associated with the development of ‘inner-worlds’ as conceived by von Uexküll, or with Piaget’s ‘operational intelligence’).

Such cognition involves the constitution of and orientation in the world by the organism in its environment as the field of all its fields of activity, with anticipations or protensions and also retentions (to use Husserl’s terminology), with protensions being fulfilled or challenged and then registered as such as retentions. That is, to use Gerald Edelman’s terminology (which can be seen to fill out Vitiello’s notion of the Double), there is a re-entrant mapping so that what comes to be experienced as present has been anticipated and is actually a construction, a ‘remembered present’ based on memory of the past, and this, argued Edelman, is the basis of primary consciousness (Edelman and Tononi, 2000, chap.9) on which higher-order consciousness associated with symbols and language is build (Edelman, 1992, chap.12). This temporality of being-in-the-world is more fundamental than what is normally thought of as memory, the conscious reflective re-presentation of the past, contextualized through stories to situate the present in history. This basic temporality of anticipatory systems is associated with the capacity of living organisms, including plants, to anticipate and change on the basis of what has been anticipated, and also to respond creatively to failures of anticipation, involving a form of abduction. That is, organisms, on the basis of memory, are oriented to the future.

What is involved in all this becomes clear when such temporal integration breaks down, as it does to some degree when people suffer damage to the right frontal lobe of their brains. Frequently, they can no longer acknowledge the failure of protensions, for instance, they cannot acknowledge that one of their limbs is paralysed, a condition known as anasognosia (McGilchrist 2009, 41). Such people lose the capacity to appreciate anything new or to see things in context, and they lose the capacity to develop new cognitive structures. This is a defective condition, highlighting what is normal. Chreods normally develop through the restless, exploring activities of organisms that open up new paths of evolutionary development; of swimmers, runners, climbers, fliers, herbivores, carnivores, scavengers etc., along with new forms of symbiosis with new synergies. They are selected for success in the paths they pursue, and this has concentrates genes required for the successful pursuit of these paths. In the case of humans, such restless exploration associated with the imagination and the capacity for institutionalize practices has led to the development of new cultural, social, political and economic forms.

As noted, more developed forms of consciousness are associated with developments of inner worlds of organisms mediating between interpretation and action, and then with humans, the incorporation into these inner worlds the perspectives of others. To begin with, this is associated with the development of mirror neurons that, functioning as signs, respond to the actions of others in the same way as they respond to the organism’s own actions, but such incorporation of the other can be augmented with the development of the more complex forms of semiosis associated with culture (Favareau, 2002; Thellefsen, 2001). These complex forms of semiosis are associated with a capacity to see oneself from the perspective of others, to interpret interpretants, to reflect upon their adequacy based on memory of failed anticipations and modify these accordingly, associated with a greatly extended capacity for abduction. It is this incorporation of the others and symbolic semiosis that paves the way for reflective self-consciousness as a participant in a socially defined world maintained through cultural, social and economic fields, sustained by the embodied dispositions of their members, or habituses (to use Pierre Bourdieu's terminology) who effectively incorporate these fields in orienting themselves in their own creative becoming (Gare, 2002). These fields are assumed as the context of memory and focussed perception, action and thought; in the language of a phenomenologist strongly influenced by Gestalt psychology, Aron Gurwitsch, they are the fields of consciousness (Gurwitsch, 1964, Part Five and Six). As Samuel Todes (2001, 83) argued, building on Gurwitsch's work, 'memory, our sense, and our ideas presuppose in our experience a probability of order founded on the condition that all our experience occurs in a holistic spatiotemporal life-field generated by our holistically active body in its attempt (which must be at least minimally successful) to meet its needs unified as all its "own", all belonging to its singular bodily self.'

It is within these broader contexts that coherent electromagnetic fields can be essential components of the 'mind field' postulated by the neurophysiologist John Eccles, without definite position in space and 'carrying little or no energy, which nevertheless can trigger neural processes, for example in the motor cortex' (Hiley and Pylkkänen, 2005, 20). The capacity for creativity could be accounted for by organisms' capacity to self-organize at different levels, including the central nervous system or cortical field, to the edge of chaos in which there are generated multiple equipotential attractors, any one of which could prevail as a consequence of minimal inputs. Walter Freeman has also shown that chaotic attractors are essential to the functioning of the brain where it is important that resonance patterns and entrainment do not develop (Freeman, 1999, 89f.). It is in this way that imagination, including the radical imagination postulated by the social philosopher Cornelius Castoriadis, could be accounted for.

That is, it is being able to influence which of a range of pre-existing possibilities maintained by the complex hierarchically organized fields composing the organism and its communities, each organized to follow different possible paths, including paths to the edge of chaos, that makes this quantum coherence serve the function of enabling the organism to cognize quickly different possibilities and to choose between them, and to explore and even create new possibilities. Such influence is mediated by complex forms of semiosis through which organisms orient themselves within their environments, including above all a proprioceptive sense of embodiment within their world, including their social worlds with their histories. And it is only as functional aspects of semiosis of the whole organism, actively and emotionally engaged in its world, that it is possible to understand qualia such as the experience of different colours. 'Qualia' are experienced in the process of discriminating between aspects of the world, and are essentially relational, something revealed most clearly by the Gestalt psychologists. As such, this semiosis can suffer defects, including false protensions, as with the experience of phantom limbs. False protensions are just one way in which organisms manifest deficiency of comprehension of themselves in their environments.

It is in the context of the whole organism in its environment, constructed as a surrounding world embedded in a social world, that quantum coherence as described by Ho and neuroscientists can explain the experience of being a subject not completely local with the freedom to act spontaneously. Conceived in this way, choice is not necessarily a matter of self-assertion, but of finding the best way. As Ho (2008, 332f.) wrote, 'the overt act, or choice, does follow from the antecedent, but it cannot be predicted in advance. One can at best retrace the abstract "steps" and represent the evolution of the conscious being as having followed a "trajectory". In truth, the so-called trajectory has been traced out by one's own spontaneous actions, both overt and covert up to that point. … In a sense, the quantum coherent organism is most spontaneous and free, which is the Taoist [Daoist] ideal in poetry and art, and indeed in life itself.'

It has been through humanity's complex forms of semiosis and the social and cultural fields generated by these that through philosophy, history and science people have been able to understand the physical world and their place within it as embodied, situated, free agents. Acknowledging the constructive nature of knowledge is usually associated with a rejection of realism, suggesting that what we take to be reality is only a virtual reality, and we are cut off from the possibility of knowing reality as it is in itself. However, drawing this conclusion manifests the failure to have overcome Cartesian dualism. From the perspective defended by Ho and further developed here, freed from the deep assumptions that have dominated Western civilization that identifies what is knowable with what can be objectified, it is through us that nature is achieving consciousness and understanding of itself. There is no need to measure this consciousness and understanding against some supposed grasp of the world that is independent of any subject, because we can appreciate that subjectivity is an aspect of living participants in a creative world in its process of becoming. We as knowing subjects are part of the creative becoming of nature. The very idea of virtual reality implies something that is not virtual reality against which it can be seen to be in some sense inferior, and we have been freed from having to acknowledge any significance to the duality assumed by this idea. Such is the achievement of the synthesis of Eastern and Western thought.

13. Conclusion

Identifying the roots of Waddington's theoretical biology in a tradition of thought influenced by Chinese thought, making this tradition and its assumptions explicit and showing how they facilitated this relatively coherent vision for theoretical biology, advanced by the successful integrative work of Ho, indicates the potential of utilizing non-Western traditions of thought to advance current science. Extending this integrative work to encompass a range of work in theoretical biology, including hierarchy theory, quantum brain dynamics, Robert Rosen's ideas on the mathematics of anticipatory systems, and then using this to defend developments in biosemiotics and Piagetian theories of cognitive development, offers further grounds for optimism in this regard. On this basis we are much closer to understanding the nature of life, sentience and consciousness and the place of consciousness in nature. However, it is not simply a matter of advancing science. All this work should be seen as an effort to free science, and culture more broadly, of deep assumptions that have dominated European and then Western culture. While these assumptions associated with an extreme form of objectivism are partly responsible for the success of European and Western science, they have engendered a dualism between the objective and the subjective which is not only hindering the further advance of science, but is having a damaging effect on civilization and its relationship to the rest of nature.

The focus of this paper has been on three concepts: chreods, homeorhesis and fields, although for the most part these concepts have only been alluded to rather than being the focus of discussions of the work of various theorists. In returning to these concepts, I am suggesting it is these that need to be at the core of the challenge to mainstream reductionist science to unify it and maintain a constancy of vision. 'Chreod' as 'necessary path', influenced by Whitehead's notion of concrescence as the creative process of self-formation of an actual occasion, the primary beings of the cosmos, resonating with the Chinese notion of Dao, should function to orient research in all branches of science and the humanities. Refined through the notion of homeorhesis interpreted and defended through Peircian semiotics, it has the potential to replace the excessive focus on prediction and control fostered by mainstream science with a focus on what is required to foster healthy people, societies, civilizations and ecosystems. These concepts provide the means to identify and understand the path that current civilization is on, which appears to be a path to global ecological destruction, to reveal what alternative paths there are, and what is required to switch from this path to some viable alternative. In the concluding chapter to his last book, *The Man-Made Future* (1978, 337), Waddington quoted with approval the report of a group set up by the Club of Rome on the state of the international order, chaired by the eminent economist Jan Tinbergen of Holland: 'In recent years we have come to realize that despite considerable achievements in many fields the path along which we have chosen to travel seems destined to disaster and despair … and as we struggle to make sense of our present predicament, the future, like some gigantic tidal wave, threatens to consume us.' The recovery of Waddington's concept of chreod, bringing into focus the significance of paths, should enable us to recognize that we are still on this same path, but also that we can change direction. As Waddington (1978, 337) put it: 'The problem amounts to nothing less than discovering a new way in which the whole world can arrange its affairs – economic, industrial, agricultural and social.' This is the project that those inspired by his work are engaged in (Gare, 2017).

Presupposed by the concepts chreod and homeorhesis is the concept of field. Although it has been obscured by logical positivist interpretations of science or by representations of time as equivalent to a dimension of space, this was and remains a major challenge to atomism and its associated reductionism, a superior challenge to that provided by the concept of system. While initially aligned with process thinking, the concept of system, incorporating cybernetics, lent itself to being domesticated by mechanistic thinkers with the help of metaphors from information technology. For the anti-reductionist potential of the concept of field to be realized, it was necessary to develop a concept of fields emerging from and within fields, with multiple levels of fields, and fields inter-penetrating with and being mutually constitutive of other fields, with paths of development and emergence of new fields. While this was implicit in the Daoic thought of the ancient Chinese by virtue of the vagueness of its language without articles, the challenge was to preserve this understanding while being analytically rigorous. Embryology provided the ideal site for developing this concept of field, but it needed to be related to the concept of fields being developed in physics to be fully successful, and then extended to the organism as a whole in its environment, the brain, cognition, consciousness and communication, and then to ecosystems, communities, societies, cities, cultures and civilizations. While the term 'field' was not a central focus of Ho's work, it persisted in the background and gave coherence to all her work, and extending the concept was one of the most important aspects of and achievement of her synthetic efforts. Although Ho did not engage with work in sociology and human ecology, she did point out some of the implications of her work for these fields of study, and her work provides support for further efforts in this direction.

Bibliography:

Abir-Am, Pnina G. 1987. The Biotheoretical Gathering, Transdisciplinary Authority and Incipient Legitimation of Molecular Biology in the 1930s: New Perspectives on the Historical Sociology of Science. History of Science xxv, 1-70.

Bachmann, Talis. 2000. Microgenetic Approach to the Conscious Mind. John Betjamins, Amsterdam.

Barbieri, Marcello. 2003. The Organic Codes: An Introduction to Semantic Biology. Cambridge University Press, Cambridge.

Barbieri, Marcello. 2008. Life is Semiosis. Cosmos and History 4 (1), 29-52.

Bateson, Gregory. 1972. Steps to an Ecology of Mind. Ballantyne Books, New York.

Beloussov L.V. et.al. (Eds). 2000. Biophotonics and Coherent Systems. Moscow University Press, Moscow.

Bischof, Marco. 2000. Field Concepts and the Emergence of a Holistic Biophysics. In: L.V. Beloussov, L.V. et.al. (Eds), Biophotonics and Coherent Systems. Moscow University Press, Moscow, pp.1-25.

Bischof, Marco. 2003. Introduction to Integrative Biophysics. In: Popp, Fritz-Albert and Beloussov, Lev. (Eds.). Integrative Biophysics: Biophotonics. Kluwer, Dordrecht, chap.1

Bitbol, Michel. 1996. Schrödinger's Philosophy of Quantum Mechanics. Kluwer, Dordrecht.

Blasone, M., Jizba, P. and Vitiello, G. 2011. Quantum Field Theory and its Macroscopic Manifestations. Imperial College Press, London.

Bohm, David. 1969. Further Remarks on Order. In: C.H. (Ed.) Towards a Theoretical Biology 2 Sketches. Edinburgh University Press, Edinburgh, pp.41-60.

Bohm, D., Hiley, B.J. and Kaloyerou, P.N. 1987. An Ontological Basis for the Quantum Theory. Physics Reports, 144, (6), 321-375.

Bohm, David and Peat, F. David. 2000. Introduction. In: Science, Order, and Creativity, 2nd ed. Routledge, London.

Brier, Søren. 2010. Cybersemiotics: Why Information Is Not Enough. University of Toronto Press, Toronto.

Brooks, Rodney A. 2016. Fields of Color: The theory that escaped Einstein, 3rd ed. Universal Printing, Silver Spring.

Brown, G. Spencer. 1969. Laws of Form. George Allen & Unwin.

Brown, Jason W. 2015. Microgenetic Theory and Process Thought. Imprint Academic, Exeter.

Bschir, Karim. 2016. Potentiality in Natural Philosophy. In: Eastman, Timothy E., Eppeson, Michael and Griffin David Ray (Eds). Physics and Speculative Philosophy: Potentiality in Modern Science. De Gruyter, Berlin, 17-46.

Čapek, Milič. 1971. Bergson and Modern Physics. Reidel, Dordrecht.

Castoriadis, Cornelius. 1997. World in Fragments. Curtis, David Ames. (Ed. and Trans.). Stanford University Press, Stanford.

Catcha, Lleuvelyn A. and Poznanski, Roman R. 2014. Genomic instantiation of consciousness in neurons through a biophoton field theory. Journal of Integrative Neuroscience 13 (2), 253–292.

Chan, Wing-Tsit (Ed. and Trans.). 1963. A Source Book in Chinese Philosophy. Princeton University Press, Princeton.

Collier, John. 2011. Kinds of Information in Scientific Use. tripleC 9(2), 295-304.

Confucius. 1963 Analects, 15:28 In: Chan, Wing-Tsit (Ed. and Trans.). 1963. A Source Book in Chinese Philosophy. Princeton University Press, Princeton, 15:28.

Corry, Leo. 2004. Modern Algebra and the Rise of Mathematical Structures, 2nd rev. ed. Birkhäuser Verlag, Basel.

Craddoc, T.J.A., Hameroff, S.R. and Tuszynski, J.A. 2015. Anaesthetics Act in Quantum Channels in Brain Microtubules to Prevent Consciousness. Current Topics in Medicinal Chemistry 15 (6), 523-533.

Crutchfield, James P. 1994. Is Anything Ever New? Considering Emergence. In: Complexity: Metaphors, Models, and Reality. Cowan, George A., Pines, David and Meltzer, David (Eds.). Addison-Wesley, Reading, 515-530.

Depew, David and Weber, Bruce H. 1996. Darwinism Evolving: System Dynamics and the Genealogy of Natural Selection. MIT Press, Cambridge, Mass.

Desmet, Ronny. Fall/Winter 2015. The Gestalt Whitehead. Process Studies 44(2), 190-223.

Dewan, E.M. 1976. Consciousness as an Emergent Causal Agent in the Context of Control System Theory. In: Globus, Gordon G., Maxwell, Grover and Savodnik, Irwin (Eds.). Consciousness and the Brain: A Scientific and Philosophical Enquiry. Plenum Press, New York, chap.7

Edelman, Gerald. 1992. Bright Air, Brilliant Fire: On the Matter of the Mind. Allen Lane, London.

Edelman, Gerald M. and Tononi, Giulio. 2000. Consciousness: How Matter Becomes Imagination. Penguin, Harmondsworth.

Ehresmann, Andrée C. and Gomez-Ramirez, Jaime. 2015. Conciliating neuroscience and phenomenology via category theory. Progress in Biophysics and Molecular Biology 119, 347-359.

Ehresmann, Andrée C. and Simeonov, Plamen L. 2012. WLIMES, the Wandering LIMES: Towards a Theoretical Framework for Wandering Logic Intelligence Memory Evolutive Systems. 2012. In: Simeonov, Plamen L., Smith, Leslie S. and Ehresmann, Andrée C. (Eds.). Integral Biomathics: Tracing the Road to Reality. Springer, Heidelberg, 105-122.

Ehresmann, Andrée C. and Vanbremeersch,. Jean-Paul. 2007. Memory Evolutive Systems: Hierarchy, Emergence, Cognition. Elsevier, Amsterdam.

Favareau, Donald. 2002. Beyond self and other: On the neurosemiotic emergence of intersubjectivity. Sign Systems Studies 30(1), 57-100.

Favareau, Donald. 2008. The Evolutionary History of Biosemiotics. In: Barbieri, Marcello (Ed.) Introduction to Biosemiotics: A New Biological Synthesis. Springer, Dordrecht, pp.1-67.

Fels, Daniel. Cifra, Michal and Scholkmann, Felix (Eds.). 2015. Fields of the Cell. Research Signpost, Kerala.

Fleck, Ludwig. 1979. Genesis and Development of a Scientific Fact, [1935], Bradleym Fed and Trenn, Thaddeus J. (Trans.). University of Chicago Press, Chicago.

Freeman, Walter J. 1995. Societies of Brains, Lawrence Erlbaum, Hillsdale NJ.

Freeman, Walter J. 1999. How Brains Make Up Their Minds. Weidenfeld and Nicholson, London.

Freeman, Walter J. and Vitiello, Giuseppe. 2006. Nonlinear brain dynamics as macroscopic manifestation of underlying many-body field dynamics. Physics of Life Review, 3, 93-118.

Freeman, Walter J. and Vitiello, Giuseppe. 2016. Matter and Mind are Entangled in Two Streams of Images Guiding Behavior and Informing the Subject Through Awareness. Mind and Matter 14(1), 7-24.

Fröhlich, H. 1968. Long-Range Coherence and Energy Storage in Biological Systems. International Journal of Quantum Chemistry 2, 641-649.

Fröhlich, H. 1977. Long-Range Coherence in Biological Systems. Rivista Del Nuova Cimento 7(2), 399-418.

Furth, Hans G. 1981. Piaget & Knowledge: Theoretical Foundations, 2nd ed. University of Chicago Press, Chicago.

Gabora, L. Scott, E.O. and Kauffman, S. 2013. A quantum model of exaptation: Incorporating potentiality into evolutionary theory. Progress in Biophysics and Molecular Biology 113, 108-116.

Gare, Arran. 1995. Understanding Oriental Cultures. Philosophy East and West 45(3), 309-328.

Gare, Arran. 2000. Systems Theory and Complexity. Democracy and Nature 6(3), 327-339.

Gare, Arran. 2002. Process Philosophy and the Emergent Theory of Mind: Whitehead, Lloyd Morgan and Schelling. Concrescence: The Australasian Journal for Process Thought: An Online Journal 3, 1-12. http://www.concrescence.org/index.php/ajpt/article/view/118

Gare, Arran. Spring, 2007. The Semiotics of Global Warming: Combating Semiotic Corruption. Theory & Science 9(2), http://theoryandscience.icaap.org/content/vol9.2/Gare.html

Gare, Arran. 2013. Overcoming the Newtonian paradigm: The unfinished project of theoretical biology from a Schellingian Perspective. Progress in Biophysics and Molecular Biology 113, 5-24.

Gare, Arran. 2014. Daoic Philosophy and Process Metaphysics: Overcoming the Nihilism of Western Civilization. In: Yi, Guo, Josifovic, Sasa, and Lätzer-Lasar**,** Asuman (Eds.). Metaphysical Foundations of Knowledge and Ethics in Chinese and European Philosophy. Wilhelm Fink, Paderborn, 111-136.

Gare, Arran. 2015. Creating a New Mathematics. In: Intuition in Mathematics and Physics. Desmet, Ronny (Ed.) Process Century Press, Anoka, pp.167-186.

Gare, Arran. 2017. The Philosophical Foundations of Ecological Civilization: A Manifesto for the Future. Routledge, London.

Globus, Gordon G. 2003. Quantum Closures and Disclosures, John Benjamins, Amsterdam.

Globus, Gordon G. 2009. The Transparent Becoming of World: A crossing between process philosophy and neurophilosophy. John Benjamins, Amsterdam.

Globus, Gordon G., Pribram, Karl H. and Vitiello, Giuseppe (Eds). 2004. Brain and Being: At the Boundary Between Science, Philosophy, Language and the Arts. John Benjamins, Amsterdam.

Goodwin, Brian. 1963. Temporal Organization in Cells: A Dynamic Theory of Cellular Control Processes. Academic Press, London.

Goodwin, B.C. 1976. Analytic Physiology of Cells and Developing Organisms. Academic Press, London.

Goodwin, Brian C. 1987. Developing Organisms as Self-Organizing Fields. In: Yates, F. Eugene et.al. (Ed.). Self-Organizing Systems: The Emergence of Order. Plenum, New York, pp.167-180.

Goodwin, B.C. 1989. A Structuralist Research Programme in Developmental Biology. In: Goodwin, Brian, Sibatani, Atuhiro and Webster, Gerry (Eds.). Dynamic Structures in Biology. Edinburgh University Press, Edinburgh, chap.4

Goodwin, Brian. 1994. How the Leopard Changed its Spots. Weidenfield & Nicolson, London.

Goodwin, Brian. 2007. Nature's Due: Healing Our Fragmented Culture. Floris Books, Edinburgh.

Graham, A.C. 'The Relation of Chinese Thought to Chinese Language', Disputers of the Tao: Philosophical Arguments in Ancient China, Chicago: Open Court, 1989

Gurwitsch, Aron. 1964. The Field of Consciousness. Duquesne University Press.

Hagen, S., Hameroff, S., & Tuczyinksi, J. 2002. Quantum computation in brain micro-tubules: Decoherence and biologisla feasibility. Physics Review E 65, 061901, 1-11.

Hall, David L. and Ames, Roger. 1998. Dao. In: Craig, E. (Ed.). Routledge Encyclopedia of Philosophy, Routledge, London and New York, CD version, Version 1.0, p.1965f.

Hameroff, Stuart. 2006. Consciousness, Neurobiology and Quantum Mechanics: The Case for a Connection. In: Tuszynksi, Jack A. (Ed.). The Emerging Physics of Consciousness. Springer, Berlin, chap.6.

Hameroff, Stuart R., Craddock, Travis J.A. and Tuszynksi, Jack A. 2014. Quantum effects in the understanding of consciousness. Journal of Integrative Neuroscience 13 (2), 229-252.

Hameroff, Stuart and Penrose, Roger. 2014. Consciousness in the Universe: A Review of the 'Orch OR' Theory. Physics of Life Reviews 11, 39-78

Hameroff, Stuart. (n.d.). Overview of SH. http://www.quantumconsciousness.org/content/overview-sh [viewed 21-02-2017].

Hankey, Alex. December 2015. A complexity basis for phenomenology: How information states at criticality offer a new approach to understanding experience of self, being and time. Progress in Biophysics & Molecular Biology: Focussed Issue: Integral Biomathics: Life Sciences, Mathematics, and Phenomenological Philosophy, 119(3), 288-302.

Haraway, Donna Jeanne. 2004. Crystals, Fabrics, and Fields: Metaphors That Shape Embryos. New Atlantic Books, Berkeley.

Heather, Michael & Rossiter, Nick, Formal Representation of Space, in: Dziadkowiec, Jakub, Core Issues in Contemporary Process Thought. Vol. 1: History and Metaphysics, Lexington, KY USA (in press).

Hesse, Mary B. 1968. Forces and Fields, TLittlefield, otowa.

Hiley, Basil and Pylkkänen, Paavo. 2005. Can Mind Affect Matter Via Active Information? Mind & Matter 3(2), 7-27.

Hinterberger, Thilo, Önal-Hartmann, Cigdem, and Salari, Vahid. 2015. In: Fels, Daniel. Cifra, Michal and Scholkmann, Felix (Eds.). Fields of the Cell. Research Signpost, Kerala.

Ho, M.W. and Saunders, P.T. 1979. Beyond neo-Darwinism – An Epigenetic Approach to Evolution. J. Theor. Biol. 78, 573-591

Ho, Mae-Wan and Fox, Sidney W. 1988. Processes and metaphors in evolution. In: Ho, Mae-Wan and Fox, Sidney W. (Eds.). Evolutionary Processes and Metaphors. John Wiley & Sons, London.

Ho, Mae Wan, 1988. On not holding nature still: Evolution by process, not by consequences. In: Ho, Mae-Wan (Ed.). Evolutionary Processes and Metaphors. Wiley, New York.

Ho, Mae-Wan, 1989. A Structuralism of Process: Towards a Post-Darwinian Rational Morphology. In: Goodwin, Brian, Sibatani, Atuhiro and Webster, Gerry (Eds.). Dynamic Structures in Biology. Edinburgh University Press, Edinburgh, chap.3,

Ho, Mae-Wan, 1994a. Toward an Indigenous Western Science: Causality in the Universe of Coherent Space-Time Structures. In: Harman, W. and Clark, J. (Eds.). New Metaphysical Foundations of Modern Science. Institute of Noetic Sciences, Sausaluto, 179-213

Ho, Mae-Wan et.al. 1994b. Can Weak Magnetic Fields (or Potentials) Affect Pattern Formation?' In: Ho, Mae-Wan, Popp, Fritz-Albert and Warnke, Ulrich. Bioelectrodynamics and Biocommunication, World Scientific, Singapore, chap.7

Ho, Mae-Wan and Popp, Fritz-Albert. 1994. Bioelectrodynamics and Biocommunication – An Epilogue. In: Ho, Mae-Wan, Popp, Fritz-Albert and Warnke, Ulrich. Bioelectrodynamics and Biocommunication, World Scientific, Singapore, chap.18.

Ho, Mae-Wan, 1997. Quantum Coherence and Conscious Experience. Kybernetics, 26, 265-276.

Ho, Mae-Wan. 2008. The Rainbow and the Worm: The Physics of Organisms, 3rd ed. World Scientific, New Jersey.

Ho, Mae-Wan. 2012. Living Rainbow H_2O. New Jersey: World Scientific.

Hoffmeyer, Jesper (Ed.). 2008a. A Legacy for Living Systems: Gregory Bateson as Precursor to Biosemiotics. Springer, Dordrecht.

Hoffmeyer, Jesper. 2008b. Biosemiotics: An Examination into the Signs of Life and the Life of Signs. Favereau, Donald (Ed.). University of Scranton Press, Scranton.

Jibu, Mari, Hagan, Scott, Hameroff, Stuart R., Pribram, Karl H. Yasue, Kunio. 1994. Quantum optical coherence in cytoskeletal microtubules: implications for brain function. Biosystems, 32, 195-209.

Jibu, Mari and Yasue, Kunio. 1995. Quantum Brain Dynamics and Consciousness: An introduction. John Benjamins, Amsterdam.

Johnson, Mark. 1987. The Body in the Mind. University of Chicago Press, Chicago.

Kampis, George and Weibei, Peter. 1994. Endophysics: The World From Within. Aerial, Santa Cruz.

Kato, Goro and Struppa, Daniele C. 2002. Category theory and consciousness. In: Yasue, Kuni, Jibu, Mari and Della Senta, Tarcisio (Eds.). No Matter, Never Mind. John Benjamins, Amsterdam.

Kauffman, Stuart A. 1993. The Origins of Order: Self-Organization and Selection in Evolution. Oxford University Press, New York.

Kauffman, Stuart A. and Gare, Arran. 2015. Beyond Descartes and Newton: Recovering life and humanity, Progress in Biophysics and Molecular Biology 119, 219-244.

Kauffman, Stuart A. 2016. Humanity in a Creative Universe. Oxford University Press, Oxford.

Kleene, S.C. 1952. Introduction to Metamathematics. D. van Nostrand, New York.

Koestler, Arthur and Smithies, J.R. 1971. Beyond Reductionism: New Perspectives in the Life Sciences: The Alpbach Symposium 1968. Beacon Press, New York.

Kuhlmann, Meinard, Lyre, Holger and Wayne, Andrew. 2002. Ontological Aspects of Quantum Theory. World Scientific Publishing, Singapore.

Kull, Kalevi. 2009. Vegetative, Animal, and Cultural Semiosis: The semiotic threshold zones. Cognitive Semiotics 4, 8-27.

Lehmann, D. 1992. Brain Electric Fields and Brain Functional States. In: Friedrich, R. and Wunderlin, A. (Eds). Evolution of Dynamical Structures in Complex Systems. Springer-Verlag, Berlin.

Lipkind, Michael. 1998. Alexander Gurwitsch And the Concept of the Biological Field, Part I. Summer. 21st Century, 36-51.

Markoš, Anton. 2002. Readers of the Book of Life: Contextualizing Developmental Evolutionary Biology. Oxford University Press, Oxford.

McFadden, Johnjoe. 2006. The CEMI Field Theory: Seven Clues to the Nature of Consciousness. In: Tuzynski, Jack A. (Ed.) The Emerging Physics of Consciousness. Springer, Berlin, chap.12,

McFadden, Johnjoe and Al-Khalili, Jim. 2014. Life on the Edge: The Coming Age of Quantum Biology. Crown, New York.

McGilchrist, Iain. 2009. The Master and his Emissary: The Divided Brain and the Making of the Western World. Yale University Press, New Haven.

Mu, Bo. 2009. Chinese Philosophy A-Z. Edinburgh University Press, Edinburgh.

Mumford, Lewis. 1974. The Myth of the Machine: The Pentagon of Power. Harcourt, Brace, Jovanovich, N.Y.

Needham, Joseph. 1968. Order and Life, [1936], MIT Press, Cambridge, Mass.

Needham, Joseph. 1956. Science and Civilisation in China, Vol. II. Cambridge University Press, Cambridge.

Noble, Denis. 2006. The Music of Life: Biology Beyond the Genome. Oxford University Press, Oxford.

Pattee, H.H. 1996. Simulations, Realizations, and Theories of Life. In: Boden, Margaret (Ed.) The Philosophy of Artificial Life. Oxford University Press, Oxford. 379-393.

Pert, Candace B. 2003. Molecules of Emotion: The Science Behind Mind-Body Medicine. Scribner, New York.

Piaget, Jean. 1971a. Biology and Knowledge: An Essay on Relations between Organic Regulations and Cognitive Processes. University of Chicago Press, Chicago.

Piaget, Jean. 1971b. Structuralism. Routledge and Kegan Paul, London.

Po, Li . 1963. Poem by the Bridge at Ten-Shen. Ezra Pound Translations, [1926]. New Directions, N.Y., p.193.

Polanyi, Michael. 1969. The Structure of Consciousness. In: Marjorie Grene (Ed.) Knowing and Being: Essays by Michael Polanyi. University of Chicago Press, Chicago, chap.13.

Popp, F.-A. et. al., 1988. Physical Aspects of Biophotons. Experienta 44, 576-585.

Popp, Fritz-Albert and Beloussov, Lev. (Eds). 2003. Integrative Biophysics: Biophotonics. Kluwer, Dordrecht.

Presman, A.S. 1970. Electromagnetic Fields and Life. Sinclair, F.L. and Brown Jr. Frank A. (Trans.). Springer Science, New York.

Prigogine, Ilya. 1976. Order Through Fluctuation' in Evolution and Consciousness. Jantsch, Erich and Waddington, C.H. Addison-Wesley, London.

Prigogine, Ilya. 1983. Law, History … and Desertion. SubStance, 12 (3), 36-42.

Pylkkänen, Paavo. 2004. Can quantum analogies help us understand the process of thought. In: Globus, Gordon G., Pribrum, Karl H. and Vitiello, Giuseppe (Eds). Brain and Being: At the Boundary Between Science, Philosophy, Language and the Arts. John Benjamins, Amsterdam, chap.10.

Pylkkänen, Paavo. 2007. Mind, Matter and the Implicate Order. Springer, Berlin.

Ricciardi, Luigi Maria and Umezawa, Hiroomi. 2004. Globus, Gordon G., Pribrum, Karl H. and Vitiello, Giuseppe (Eds). Brain and Being: At the Boundary Between Science, Philosophy, Language and the Arts. John Benjamins, Amsterdam, chap.14.

Romijn, Herms. 2002. Are Virtual Photons the Elementary Carriers of Consciousness? Journal of Consciousness Studies, 9(1), 61-81.

Rosen, Robert. 1965. Book Review. Bulletin of Mathematical Biophysics, 27, 497-500.

Rosen, Robert. 2000a. The Church-Pythagoras Thesis. In: Rosen, Robert. Essays on Life Itself, Columbia University Press, New York, chap.4.

Rosen, Robert. 2000b. The Mind-Brain Problem and the Physics of Reductionism. In: Rosen, Robert. Essays on Life Itself. Columbia University Press, New York, chap.8.

Rosen, Robert. 2000c. Syntactics and Semantics in Language. In: Rosen, Robert. Essays on Life Itself. Columbia University Press. New York, chap.10

Rosen, Robert. 2012. Anticipatory Systems: Philosophical, Mathematical, and Methodological Foundations.,2nd ed. Springer, New York.

Rosenthal, Sandra B. 1994. Charles Peirce's Pragmatic Pluralism. SUNY Press, N.Y.

Rössler, Otto E. 1998. Endophysics: The World as an Interface. World Scientific, Singapore.

Rovelli, Carlo. 2011. The First Scientist: Anaximander and His Legacy. Westholme, Yardly.

Rubik, Beverly. 2002. The Biofield Hypothesis: Its Biophysical Basis and Role in Medicine. The Journal of Alternative and Complementary Medicine, 8(6), 703-717.

Rubik, Beverly. 2015. The Biofield: Bridge Between Mind and Body. Cosmos and History, 11(2), 83-96.

Rubin, Vitaly A. 1976. The Theory and Practice of the Totalitarian State: Shang Yang and Legalism. In: Individual and State in Ancient China: Essays on Four Chinese Philosophers. Levine, Steven I (Trans.). Columbia University Press, N.Y., chap.3.

Salthe, Stan. 1993. Development and Evolution: Complexity and Change in Biology. MIT Press, Cambridge, Mass.

Sarti, Alessandro, Montanari, Federico and Galofaro, Franceso (Eds.). 2015. Morphogenesis and Individuation. Springer, Heidelberg.

Saunders, Peter T. and Kubal, Carmela A. 1989. Bifurcations and Epigenetic Landscape. In: Goodwin, Brian and Saunders, Peter (Eds.). Theoretical Biology: Epigenetic and Evolutionary Order from Complex Systems. John Hopkins University Press, Baltimore, chap.3.

Scott, Alwyn C. 2007. The Nonlinear Universe: Chaos, Emergence and Life. Springer, Berlin.

Sibutani, Atuhiro. 1989. How to Structuralize Biology? In: Goodwin, Brian, Sibatani, Atuhiro and Webster, Gerry (Eds.). Dynamic Structures in Biology. Edinburgh University Press, Edinburgh, chap.2.

Simeonov, Plamen L. and Eheresmann, Andrée C. 2017. Some Resonances between Eastern thought and Integral Biomathics on the example of WLIMES. Progress in Biophysics and Molecular Biology.

Stapp, Henry P. 2009. Mind, Matter and Quantum Mechanics, 3rd ed., Springer, Berlin.

Stapp, Henry P. 2017. Quantum Theory and Free Will: How Mental Intentions Translate into Bodily Actions. Springer, Cham, Switzerland.

Strogatz, Steven. 2003. Sync: How Order Emerges from Chaos in the Universe, Nature, and Daily Life. Hyperion, New York.

Tegmark, Max. 2000. The importance of quantum decoherence in brain processes. Physical Review E. 61: 4194–4206. Bibcode:2000PhRvE..61.4194T. arXiv:quant-ph/9907009. doi:10.1103/physreve.61.4194.

Thellefsen, Torkild Leo. 2001. C.S. Peirce's Evolutionary Sign: An Analysis of Depth and Complexity within Peircian Sign Types. Semiotics, Evolution, Energy, and Development. 1(2): December.

Thom, René. 1983a. Logos Phoenix. In: Mathematical Models of Morphogenesis. Brookes, W.M. and Rand, D. (Trans. and Eds). Chichester: Ellis Horwood, 1983, chap.16.

Thom, René . 1983b. 'Stop Chance! Silence Noise! SubStance, 12 (3), 11-21.

Thom, René, 1990. Semio Physics: A Sketch: Aristotelian Physics and Catastrophe Theory [1988]. Addison Wesley, Redwood City.

Thom, R. 1992. An Inventory of Waddingtonian Concepts. In: Goodwin, Brian and Saunders, Peter (Eds.). Theoretical Biology: Epigenetic and Evolutionary Order from Complex Systems. John Hopkins University Press, Baltimore, chap.1.

Thompson, D'Arcy Wentworth. 1917. On Growth and Form. Cambridge University Press, Cambridge.

Tode, Samuel. 2001. Body and World. Cambridge, Mass., MIT Press.

Tzambazakis, Antonios. 2015. The evolution of the biological field concept. In: Fels, Daniel. Cifra, Michal and Scholkmann, Felix (Eds.). Fields of the Cell. Research Signpost, Kerala.

Umezawa, Hiroomi. 1993. Advanced Field Theory: Micro, Macro and Thermal Physics. American Institute of Physics, New York.

Vitiello, Giuseppe. 2001. My Double Unveiled: The dissipative quantum model of brain. John Benjamins, Amsterdam.

Vitiello, Giuseppe. 2004. The dissipative brain. In: Globus, Gordon G., Pribrum, Karl H. and Vitiello, Giuseppe (Eds). Brain and Being: At the Boundary Between Science, Philosophy, Language and the Arts. John Benjamins, Amsterdam, chap.17.

Waddington, C.H. 1956. Principles of Embryology. Macmillan, New York.

Waddington, C.H. 1962. The Nature of Life. Atheneum, New York.

Waddington, C.H. 1968. Letter to Thom. In: C.H. Waddington (Ed.). Towards a Theoretical Biology 1 Prolegomena. Adline, Chicago. p.178.

Waddington, C.H. 1969a. Cellular Oscillations and Development. In: Waddington, C.H. (Ed.). Towards a Theoretical Biology 2 Sketches. Edinburgh University Press, Edinburgh, pp.179-83

Waddington, C.H. 1969b. In: Waddington, C.H. (Ed.). Towards a Theoretical Biology 2 Sketches. Edinburgh University Press, Edinburgh, pp.72-81.

Waddington, C.H. 1972. Biology and Human Environment. In: Human Identity in the Urban Environment. Bell, Gwen and Tyrwhitt, Jaqueline (Eds.). Penguin: Harmondsworth, Penguin, pp.59-72.

Waddington, C.H. 2012. Epilogue. In: Waddington, C.H. (Ed.). Biological Processes in Living Systems: Toward a Theoretical Biology, Volume 4, [1972]. Adline, New Brunswick, pp.283-289.

Waddington, C.H. 1977. Tools for Thought. Paladin, Frogmore.

Waddington, C.H. 1978. The Man-Made Future. St. Martin's Press, New York.

Weaver, Warren 1948. Science and Complexity. American Scientist 36, 536-544.

Webster, Gerry and Goodwin, Brian. 1996. Form and Transformation. Cambridge University Press, Cambridge.

Whitehead, Alfred North, 1978. Process and Reality, (Corrected Edition), [1929]. The Free Press, New York.

Wiener, Norbert. 1981. Cybernetics: or Control and Communication in Animals and Machines, 2nd ed. M.I.T. Press, Cambridge, Mass.

Wilczek, Frank. 2008. The Lightness of Being: Mass, Ether, and the Unification of Forces. New York: Perseus.

Williams, L. Pearce. 1980. The Origins of Field Theory. University Press of America, Lanham.

Wolpert, Lewis. 1968. The French Flag Problem: A Contribution to the Discussion on Pattern Development and Regulation. In: C.H. Waddington (Ed.). Towards a Theoretical Biology 1 Prolegomena. Adline, Chicago, pp.125-133.

Yasue, Kuni, Jibu, Mari and Della Senta, Tarcisio (Eds.). 2002. No Matter, Never Mind. John Benjamins, Amsterdam.

Zeeman, E.C. 1992. A New Concept of Stability. In: Goodwin, Brian and Saunders, Peter (Eds.). Theoretical Biology: Epigenetic and Evolutionary Order from Complex Systems. John Hopkins University Press, Baltimore, chap.2.