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# Art, science and technology in an expanded field

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## Abstract

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ABSTRACT

The author suggests that new concepts in twentieth-century science not only provide commonalities between the arts, sciences and humanities, they also point to the emergence of a new philosophy of nature with some promising political, sociological and technological implications. These developments demand a thorough-going ethical practise and a fundamental reformulation of accepted notions of creativity, consciousness and natural and social organization. Outlining key concepts and discoveries in twentieth-century science and philosophy, the author draws attention to the existence of a strong organismic or process tradition in Western culture that is re-emerging in various fields of the physical, biological and social sciences. The author asserts that such a change in science and technology will have global ramifications for humans and that it is the amplification of these insights to which artists should turn their attention.

Artists working with new technologies occupy a territory that is overflowing with ethical and aesthetic dilemmas. Each new technological development engenders new problems. It is undoubtedly quite difficult for artists (as it is for most people) to orient themselves within such a rapidly transforming field. This is especially true when we consider the challenge that these new media present to traditional and contemporary assumptions about the transformative powers of art.

To be more specific, it does not take an artist's imagination to recognize that any new technology can be as easily deployed for the purposes of promoting ideological propaganda and mass manipulation as it can be used to further the interests of human liberation and mutual understanding. The dichotomies inherent in the cultural incorporation of new technologies were recognized as long ago as the 1930s by Adorno and Horkheimer in their *Dialectic of Enlightenment* [1].

A central concern of most of the theory undertaken in this area since then involves the generative role of scientific discourse in the constitution of new technologies. The logic of theory and design that underlies the technologies that surround us is intimately bound up with prevailing orthodoxies in the sciences. However, the classical assumptions that underlie many of these orthodoxies have not only been questioned by analyses in linguistics, anthropology, political economy and psychoanalysis, they have also come under serious criticism from within many of the scientific disciplines in which they have, until quite recently, prevailed. The bases for all of these criticisms share many things in common. Basic assumptions regarding what constitutes nature, culture, human perception and individual identity have all come under scrutiny.

The motivations for these analyses similarly rest on a profound dissatisfaction with accepted wisdom that is increasingly being perceived as collaborating in an oppressive network of alienated social relations with little, if any, ethical basis. An armoury of epistemological bombshells is in the process of formulation that promises to explode many of the myths under which the human and natural sciences appear to have laboured for centuries.

Over the past 30 years, a number of developments in the sciences have served to revive an ancient philosophical dispute with important implications for the ways in which science conceives itself and the world. These developments touch on the nature of self, on creativity and on the whole notion of form and organization in nature and human culture.

For more than four centuries, there has been an ongoing struggle for ideological supremacy within Western science between two very different approaches to nature and human culture. The first and oldest of these approaches can be described as organismic, holistic, cooperative, collectivist, relativistic and posited on the unity in diversity of all things. The other approach, which has become synonymous with science in most people's minds, can be identified as mechanistic, reductionist, anthropocentric, competitive, hierarchical, absolutist and posited on the efficacy of prediction and control. But the ultimate hegemony that the mechanistic view has achieved has more to do with political and economic expediency than any innate theoretical superiority. Just the same, mechanism has reached its own limits. It has failed both practically and conceptually to deal with the complexities of nature and human culture and is arguably responsible for many of the environmental and economic crises currently facing humanity.

A new scientific philosophy of nature is, however, beginning to emerge—a philosophy that has more in common with the organismic approach than it does with the mechanistic. A central focus of its attention is the empirically demonstrable interconnectedness of all things; an interconnectedness that demands a thorough-going ethical practise, encompassing not only human activities but natural processes as well. It is also a philosophy that demands humility; the old certainties of unrestricted prediction and control are grounded on false assumptions. Some scientists claim that this change heralds the beginning of the post-Einsteinian era in both science and human culture: the recognition that "God does play dice" and that uncertainty and chaos are not only ubiquitous throughout the universe, but also provide the dynamic matrix within which new forms of order are constantly being created. Such a conclusion should prove interesting to both artists and scientists. Having emerged from a number of different scientific disciplines, the new evolutionary paradigm of *self-organization* accepts as one of its fundamental premises the notion that creativity is immanent in all natural processes, including human culture. In such a view, humanity and technology are regarded as recent evolutionary manifestations of a creative principle that embraces the whole cosmos. The transformative powers of art and science are but two manifestations of this ongoing creative process.

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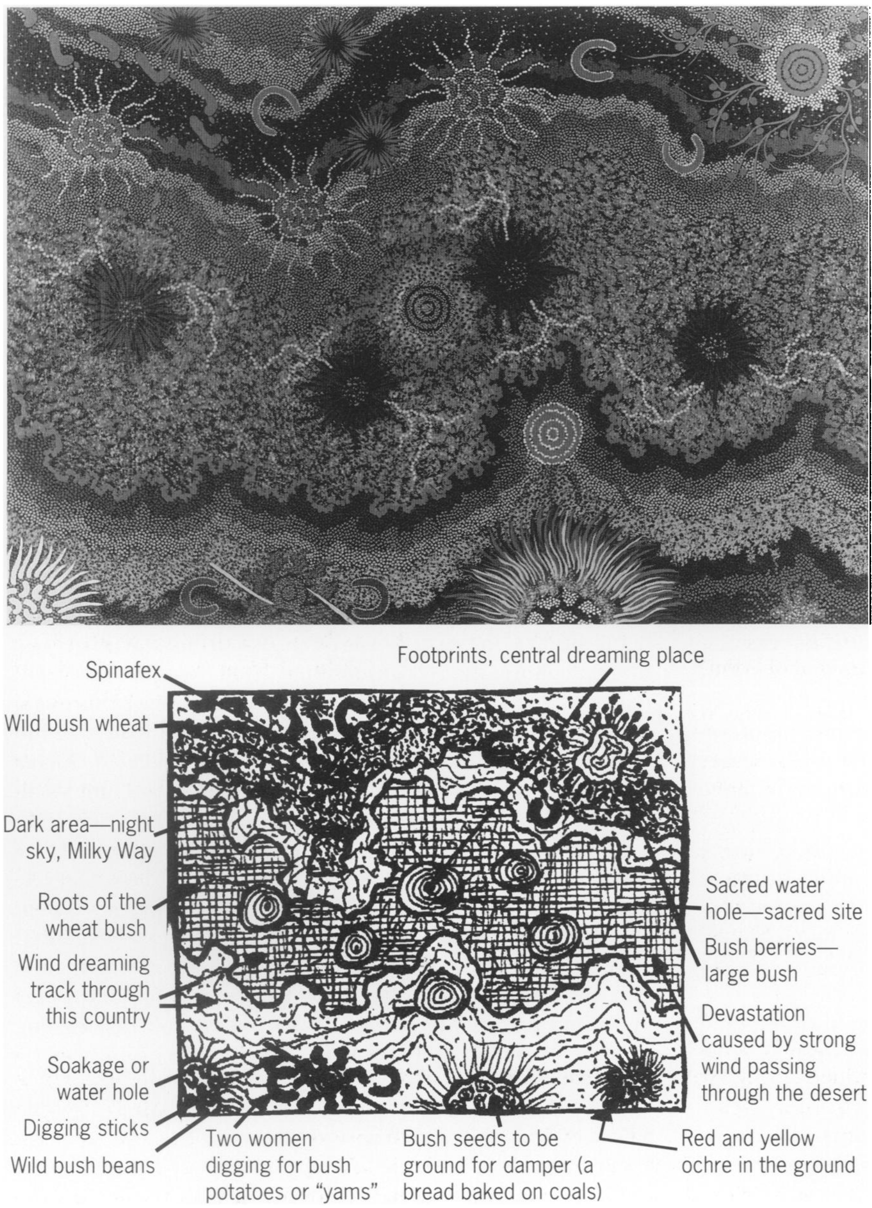
## An Old Worldview with a New Mythology

The idea that nature is inherently dynamic and creative, rather than passive and simply created, is both ancient and widespread. It exists in Taoism and other Eastern philosophies, as well as in the shamanic and matriarchal belief systems of tribal and early agrarian cultures. This idea can also be found in certain strains of Western mystical and religious thought. But perhaps most importantly for artists and scientists, various manifestations of this idea, which has come to be known as *organicism,* have survived into the present through the alchemical, vitalist and romantic traditions of Western art, science and philosophy [2].

Although organicism has been made to appear esoteric, occult and distinctly "unscientific" in the latter half of the twentieth century by self-proclaimed "realists" and "rationalists" [3], it has nevertheless reemerged in the evolution of process-oriented approaches in a number of different scientific fields. The shift in orientation marks a profound transition in science's understanding of nature and culture. It is a shift that began with relativity, quantum theory and cybernetics and is now continuing through numerous applications of chaos theory and nonequilibrium systems theory.

**Fig. 1. Gabriella Possum Nungurraye, (a) *Bush Tucker Dreaming,* acrylic paint on stretched, primed linen, 104 × 144 cm. The painting is a symbolic representation of women's work in collecting food and other materials for ceremonial purposes around the Mt. Wedge region of the Central Western Desert. (b) Key to the elements represented in the painting.**




It is my contention that the shift to process-oriented science heralds the emergence of a new and highly sophisticated form of organicism. Although it does share something in common with older organismic philosophies, it incorporates a wealth of new empirical insights that are applicable to a vast range of hitherto poorly understood phenomena in the physical and social sciences.

Some of the unifying principles that have emerged from this shift to a process-oriented science are the complementarity of matter and energy and of field and form in any description of physical and behavioural processes; the essential openness and unpredictability, yet interdependence, of all phenomena; the self-similarity that natural processes show at different scales; the fundamental role that chaos plays in the spontaneous creation of more complex forms of natural order; and the recognition that individual perception does not passively mirror an objective reality "out there," but instead is a process by which organisms *actively create* the world of experience [4].

Although these unifying principles are empirically based, many artists have intuitively reached similar conclusions. To give an idea how common organismic views have been in twentieth-century art, the following list comprises artists who held such beliefs, as expressed through their theoretical and personal writings: Wassily Kandinsky, Paul Klee, Oskar Kokoschka, Jean Arp, Barbara Hepworth, Henry Moore, Antonin Artaud, Joan Miró, Leonora Carrington, Leonor Fini, Robert Motherwell, Theodore Roszak, Bryon Gysin, Joseph Beuys, and the recent "Land" artists of Britain, including Andy Goldsworthy, Richard Long, Chris Drury, etc.

The following quote from Artaud's *Heliogabale* expresses intuitively the central theme of organicism:

> I mean to say that in Syria the earth lives,
> and that there are stones that live . . .
> such stones are the vertebrae in the
> precious corners of the earth . . .
> stones that live as plants and animals live,
> and as it may be said, the sun lives [5].

## The Post-Einsteinian Philosophy of Organism

In both Georg Hegel's and Alfred North Whitehead's philosophies of "organism," living, biological organisms are only one special case of the generalized metaphys-

ical category of organism that they proposed [6]. Although the ancient Greeks, including the Stoics, Plato and Aristotle, as well as the alchemists, vitalists and earlier Romantic *naturphilosophers* of the Enlightenment, had held to similar beliefs, Hegel and Whitehead were two of the earliest philosophers to systematically explore the scientific and philosophical implications of such a notion.

For Hegel, the term "organism" not only applied to the realm of nature with its biological systems, but also to the realm of geist ("spirit" or "culture") with its political and cultural systems and institutions. Hegel was, however, unwilling to extend his concept of organism into the so-called "inorganic" world because he believed, as did many of his contemporaries and successors, that inanimate nature is governed by mechanistic laws [7]. Whitehead and more contemporary process philosophers such as Erich Jantsch and Rupert Sheldrake have all contested this position, however [8]. Whitehead and Sheldrake have drawn attention to quantum phenomena to justify their claims [9], Jantsch has pointed to far-from-equilibrium phenomena. The arguments in favour of these positions will be discussed later. All three have supported the notion that organismic behaviour is pervasive throughout nature and human culture.

Along with Hegel, all of these theorists have agreed that an organism can be defined as a cooperative, self-organizing entity characterized by the immanence of its pattern of organization. These immanent patterns of organization share some features in common with the theological notion of "spirit." They have been called *pneuma* by the Stoics; *entelechy* by Aristotle; *monads* by Anne Conway and Liebniz; *Begriff,* or absolute ideas, by Hegel; *individual subjective aims,* or *initial primordial aims,* by Whitehead; *emergent systems properties* by Jantsch; and *morphic fields* by Sheldrake.

Both Jantsch and Sheldrake have drawn attention to the fact that these immanent patterns of organization must contain some kind of organic memory. Both have proposed that this memory is contained within probabilistic fields of organization that give form to physical and mental phenomena.

On the one hand, these fields of organization transcend spatial separation. On the other, they have the ability to accumulate information over time. Consequently, each organism has a unique memory that constitutes its own individual history, but this unique history emerges from a more inclusive systemic memory corresponding to the historical background of the larger environment in relation to other organisms of its own kind.

Like a number of other philosophers, including Friedrich Nietschze, Samuel Butler and C.S. Peirce, Sheldrake has proposed that this organic systems memory is not just a feature of what we understand as life, but of the whole of the natural world. He proposes that each kind of organic system, whether it be a crystal, a bird or a particular form of behaviour, is shaped by *morphic fields,* from the Greek word *morphe* meaning "form." These morphic fields are specific to particular processes, shapes and patterns, and contain a collective and cumulative memory of all that system's past and present states. They are also probabilistic, rather than fixed (as are the *pneuma, entelechies* and *Begriff* of the Stoics, Aristotle and Hegel, respectively), in that they are constantly open to environmental and internal fluctuations.

Such formative fields may stabilize over time. For example, salt crystals have one distinctive crystalline form, *although there is no chemical reason why they should not take up any number of equally probable forms.* Depending on how strong the resonance of past examples of that form may be, cataclysmic or chaotic changes may cause certain forms and their corresponding fields to either disintegrate or evolve into other fields/forms with a new behaviour and/or appearance. Jantsch called the process by which information contained within these fields is transferred *synchrony;* Sheldrake has called it *morphic resonance* [10].

For those who are puzzled as to what connection such concepts have to artistic practise, the following is a quote from Kandinsky's 1912 paper, "On the Problem of Form":

> Behind matter the creative spirit is concealed within matter . . . the absolute is not to be sought in the form (materialism). The form is always bound to its time, is relative, since it is nothing more than the means necessary today in which today's revelation manifests itself, resounds. The resonance is then the soul of the form which can only become alive through the resonance and which works from within to without. The form is the outer expression of the inner content [11].

Kandinsky's insights were undoubtedly influenced by evolutionary speculations of his time—the essay from which this quote is taken specifically mentions the evolution of new values as the impetus for social and cultural transformation. It is interesting to note that Kandinsky's metaphysical speculations at the turn of the century are, in fact, much closer to contemporary scientific conceptions of the organization of matter than is the atomistic materialism that remains the "commonsense" view to this day.

With these points in mind, it now seems appropriate to discuss the remarkable foresight of some other artists earlier this century who tried to promote a synthesis of science and art within an organismic framework. Generally regarded by their contemporaries as either mad or hopeless idealists, these artists have been better treated by time than have their critics. Of all these artists, the one who appears today to have been most relevant in his concerns and aspirations is Joseph Beuys—a man who lived and breathed his personal philosophy to his deathbed.

## THE EXPANDED CONCEPT OF ART

Beuys was convinced of the pressing social need to forge a new and dynamic relationship between art and science. His statement that "everyone is an artist" came from his belief that the word "art" refers to universal creative faculties that manifest themselves not only in nature, but throughout human culture. Whether it be in medicine, agriculture, education, law, economics or administration, this universal creativity finds its constant expression in innumerable cultural forms. For Beuys, the principle of creativity was identical to the notion of constant renewal and resurrection. This basic principle, Beuys believed, should constitute the foundation for a "new science of freedom."

Beuys believed that, once an established cultural form becomes paralyzed and incapable of further evolution, it must be metamorphosed into a living, dynamic form that further cultivates development and creative expansion. This was the basis for Beuys's "expanded concept of art." In the words of Heiner Statchelhaus, the expanded concept of art "was no mere theory, but a basic principle of existence that transformed everything" [12].

In formulating this concept, Beuys came to the conclusion that human culture (including science) had evolved from "fundamental ideas on art." These ideas were expressed culturally through collective or individual rituals aimed at maintaining or reestablishing an intimate relationship with nature on the

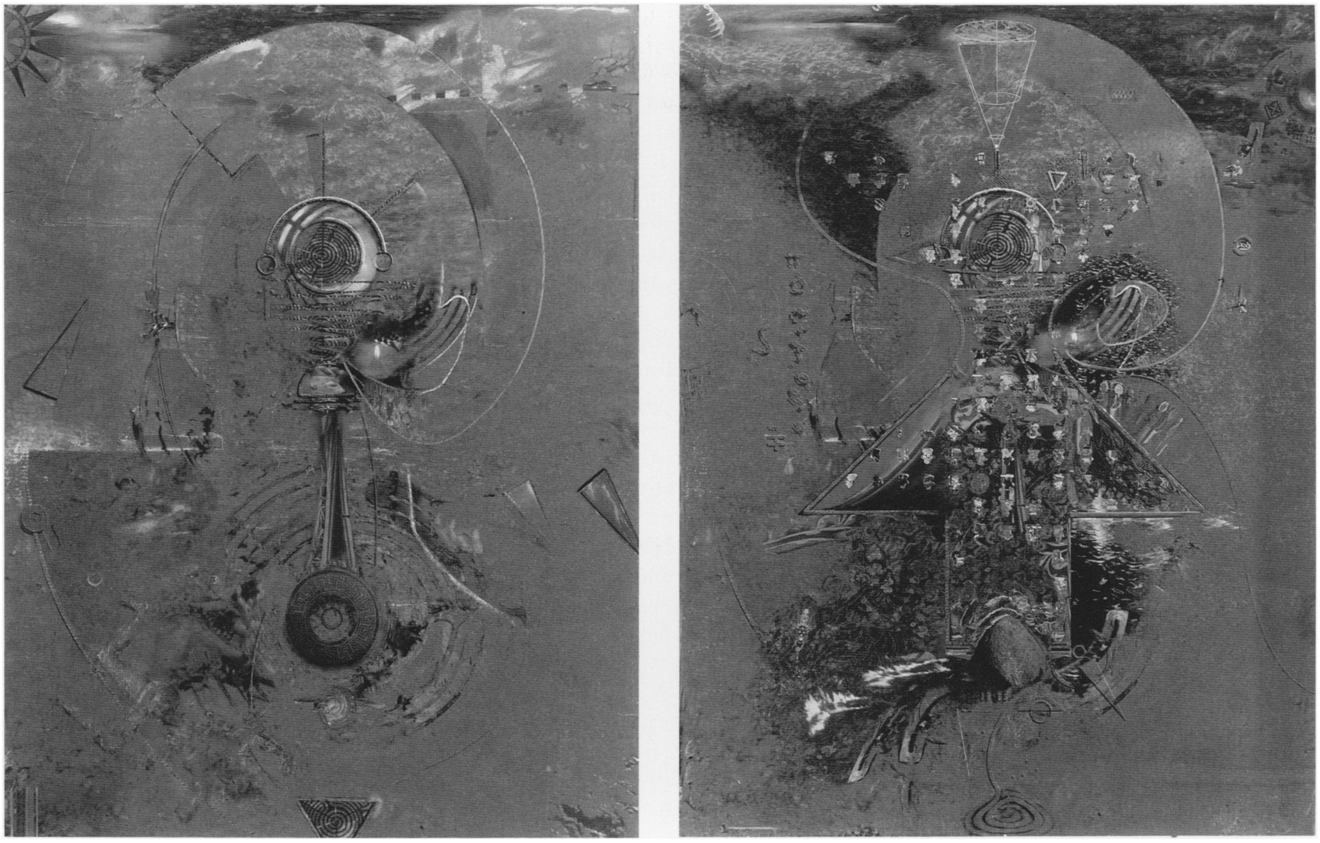


**Fig 2. Phillip George, *Mnemonic Notations*, (a) No. 7 (1991); (b) No. 12 (1992); each 2.3 m (h) × 1.6 m (w); Tips software, gouache on colour laser copy paper on canvas with gold leaf. The series of works comprising *Mnemonic Notations* refers to notions of place and memory, as well as the symbolic correspondences between the human body and the land. Reproduced with permission of the artist.**

basis of personal experiences. It was through such rituals that song, dance, theatre, sculpture and painting evolved. As Merchant points out in her groundbreaking work *The Death of Nature*, such rituals, and the spiritual beliefs they embody, act as normative constraints on human activity [13]. In other words, if one believes that the earth is one's mother and that to dig a mine shaft is to tear her flesh and open her womb, certain ethical and spiritual observances must be made.

The emergence of industrial society in the West with its correspondingly mechanistic approach to nature and culture rapidly put a stop to such "superstitious" and "irrational" behaviour. Beuys's familiarity with scientific literature had made him very much aware of how the institutionalization of scientific mechanism had undermined the cultural significance of these earlier organismic beliefs. He recognized this as a process that had led not only to increasing fragmentation in modern society, but to personal alienation, both from nature and from the deeper levels of our own experience.

Rather than turning his back on science, however, Beuys sought instead to draw attention to this social process and to the fact that the modern state had evolved symbiotically with the mechanistic view. Yet, he believed that despite their ideological collaboration, it was

> necessary for this reductive process to have taken place. For it was in this way that we came to accept a mental discipline which stimulated our activities to such an extent as for them to become a process of liberation; in other words, we rediscover ourselves in this process as being independent from God and all former ties, but that *we must rediscover these ties on a higher plane*, after we have, as it were, freed ourselves [14] [italics mine].

"The expanded concept of art," "a new science of freedom": to Beuys these two concepts were synonymous. Of course, Beuys is not the only person to have expressed such ideas. As long ago as 1915, a year before his untimely death, Franz Marc made this comment:

> The art to come will be giving form to our scientific convictions. . . . It will be profound enough and substantial enough to generate the greatest transformation the world has ever seen [15].

Wassily Kandinsky expressed similar views around the same time [16].

## System Evolution: Time as an Irreversible Process

> *Time is a river which sweeps me along, but I am the river; it is a tiger which destroys me, but I am the tiger; it is a fire which consumes me, but I am the fire*
>
> —Jorge Luis Borges [17]

Fundamental to any understanding of the organismic behaviour evident throughout nature is the recognition that time is an irreversible process. All of the natural structures that we perceive in the universe, from galaxies to snowflakes to human beings, have been brought into being through processes that occur in the forward flow of time. Such an observation may at first seem banal, but the irreversibility of natural processes has important implications for all manifestations of life and evolution.

Although it may seem somewhat strange, both classical and quantum physics treat time as though it were reversible. The belief that time is a mere illusion has been a persistent one among scientists until this century. Consequently, past, present and future have

invariably played the same role in the scientists' equations. But such a description does not correspond with our everyday experience. Nor does it correspond with the real evolution through time of most natural phenomena. Science-fiction stories and modern recording devices may have made us familiar with the concept of reversible time, but as far as the vast majority of natural systems is concerned, time is never reversible. It may flow at an almost infinite multiplicity of different rates through different processes, but it does, nevertheless, always flow in one direction—from past to future.

The concept of *evolution* obviously incorporates the notion that time is irreversible. Yet, in the three scientific fields in which the concept first emerged, i.e. biology, physics and sociology, the word "evolution" has had quite different meanings.

In physics, the concept of the evolution of a (mechanical) physical system was introduced by Sadi Carnot in 1824 but was later formalized in the 1850s by Rudolf Clausius as the Second Law of Thermodynamics. The Second Law states that all physical systems tend towards *thermodynamic equilibrium* with their environment. In other words, everything in the universe inevitably loses energy to the environment over time, until energetic equilibrium with the environment is reached. At equilibrium, all processes, e.g. motion and heat exchange, come to a standstill. According to Ludwig Boltzmann's later conception of the Second Law [18], the available energy in the universe is inevitably running down; increasing *entropy,* or molecular disorder, is characteristic of all systems (entropy being a measure of the energy in a system that is no longer available for work). Jantsch reports that the filmmaker and novelist Alain Robbe-Grillet once described his work as following this same, disintegrative process [19], a fact that underscores the wider influence of Boltzmann's pessimistic misconception.

The central problem with the above description is that it only holds true for systems already at, or very close to, equilibrium with the environment. Examples of this range from crystals, machines and experimental apparatuses (essentially *equilibrium structures*) to our own solar system and the trajectory of a bullet or missile on the surface of the earth. Both of the latter are *near-equilibrium systems* that are passively shaped or acted upon by gravitational fields. Systems at, or close to, thermodynamic equilibrium cannot draw energy from the environment to increase the complexity of their own structures. In other words, the kinds of systems described by classical dynamics are *passive* to the forces that are intrinsic to their own nature or that are imposed on them from the environment.

However, in biology and sociology, evolution describes transformations or changes that lead to higher orders of complexity. Biological and sociological systems are not passive to the forces intrinsic to or imposed upon them. Such systems are inherently dynamic and self-modifying in response to changes in their environment [20]. They are not just acted upon, they are themselves *actors.*

These two scientific descriptions of evolution appear contradictory. On the one hand, we have increasing disorder in thermodynamics and, on the other, increasing order in biology and sociology.

## General Systems Theory and Hierarchical Organization

One of the first steps towards an integration of these apparently contradictory ideas occurred in 1952, when Ludwig von Bertalanffy published his first book, *Problems of Life* [21]. It described a new approach to understanding complex natural and technological systems, which he called General Systems Theory. The book was an attempt to formulate the beginnings of an integrated theory of order and organization in both "animate" and "inanimate" nature.

Von Bertalanffy felt that the mechanistic subject/object framework was inadequate, simplistic and misleading. What he proposed instead was an approach that sought to understand the way in which *holistic,* related systems function and evolve.

As early as the 1930s, the quantum physicists Bernal, Schroedinger and Wigner had already come to the conclusion "that life is a member of the class of phenomena which are open or continuous systems able to decrease their internal entropy at the expense of substances or free energy taken in from the environment and subsequently rejected in a degraded form" [22].

Von Bertalanffy, like Bernal, Schroedinger and Wigner, insisted that what we generally think of as "living" systems are *not* closed, self-contained, mechanical systems. They are essentially open to the environment and operate in a fundamentally different manner from any kind of machine. In such open systems, entropy does not have to accumulate in the system and increase until thermodynamic equilibrium is reached. Open systems have the ability to "export" their internal entropy back into the environment. Thus, entropy can remain at the same level, or even decrease in a living system.

Von Bertalanffy identified two fundamental principles of living nature: "hierarchical organization on the one hand, and the characteristics of open systems on the other" [23]. According to von Bertalanffy, whether they be social or economic systems of human society or

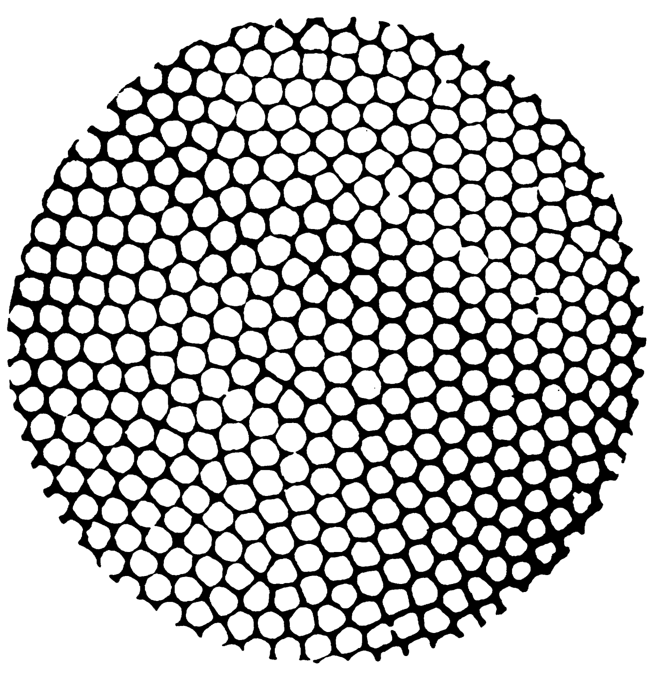


**Fig. 3. The Bénard instability is one example of a hydrodynamic dissipative structure. If a layer of liquid is heated from below, cooperative behaviour occurs beyond a critical temperature gradient. Macroscopic convection streams become dominant. Viewed from above, a pattern of regular hexagonal cells develops. Reprinted with permission from Erich Jantsch [8] Copyright 1980, Pergamon Press PLC.**

the nervous and immune systems of insects, all systems display similar forms of hierarchical organization and a dynamic openness to the external environment that provides these systems with the energy, matter and information to maintain that organization.

The word "hierarchical" as a description of the stratified organization apparent in nature has received some criticism, however, because it is rather misleading. When von Bertalanffy used the term "hierarchical," he did not mean a control hierarchy with orders issuing from the top down, as in a modern corporation or feudal pyramid. Rather, he was referring to the successive evolution through time of forms and processes of increasing *complexity,* from the relatively simple at the subatomic level to the extremely complex interplay of processes apparent in human societies and the earth's biosphere.

In von Bertalanffy's original systemic view, natural order was thought to be stratified in discrete, but interrelated, levels within levels within levels [24], a concept that bears similarities to Conway and Liebniz's monadology and the concept of dialectics elaborated by Hegel. Such natural forms of organization have been called *holarchical* by Arthur Koestler [25] and *hetrarchical* by Fritjof Capra [26]; they are wholes made up of parts and are themselves parts of higher-level wholes and vice versa. In Hua Yen Buddhism, this radical vision of interdependence is imaged as the Jeweled Net of Indra, "a cosmic canopy where each of us—each jewel at each node of the net—reflects all the others and reflects the others reflecting back" [27].

Rather than using the analogy of an ancestral tree or a "Great Chain of Being" as a "metamodel" for evolution as so many evolutionists have done in the past, Gilles Deleuze and Felix Guattari have insisted on the importance of using an alternative organic "map" when describing the holistic interconnectedness of human and natural processes. They feel that a more appropriate descriptive model of the multiplicitous connections that exist between different orders of nature is the *rhizome:* "A rhizome is an underground sprout such as a bulb, not a root, but a stem. Its oldest parts die off in the same measure as it rejuvenates itself at the tip. . . . The rhizome continuously generates new relations . . . not copies, as the ancestral tree, but a map" [28].

Many cultures throughout the world seem to have recognized this and integrated such organic maps into their mythology and art. Australian aboriginal paintings from the Balgo and Pintupi regions, for example, often utilize such rhizomatic maps as descriptions of the physical/psychic landscape. Gabriella Possum Nungurraye's painting *Bush Tucker Dreaming* (Fig. 1a and Color Plate A No. 2), a symbolic representation of women's work, is a beautiful example of the Pintupi painters' genius. It is women's work to bring in food—wild bush fruits, berries, yams, beans, long beans, sweet flowers, emu eggs, bush banana, quandongs, seeds and water. They also collect feathers, fur and spinafex resin (a sticky black substance that sets hard—for making dance decorations and mending cuts), ochres for body paint, substances for sand paintings (flowers, feathers, crushed spinafex grass), soft tussocks or lily roots and firewood. They must grind seed and make and cook damper and witchety grubs. Fig. 1b provides a key to the painting.

The work of other contemporary artists such as Australian painter/photographer Phillip George are similarly attempting to express an intuition of natural order (Figs 2a, b) [29].

In contrast to classical scientific conceptions of organization, in a rhizome there is no determining frame of reference, no control issuing from a central power source. In the words of Deleuze and Guattari, "Any point on a rhizome can be connected with any other, and must be. This is very different to a tree or root, which fixes a point and thus an order" [30]. In reference to Deleuze and Guattari's work, Jantsch comments that the rhizome is "a self-organizing process system—like a dissipative structure, the gene pool of bacteria, an ecosystem or the Gaia system" [31]. He also suggests that the three organic images of ancestral tree, root and connecting rhizome, taken together and applied according to their appropriate contexts, offer extremely useful descriptive analogies for what he calls time- and space-binding in evolution [32].

Deleuze and Guattari's insights also find parallels in the following quote from the physicist Ilya Prigogine. His idea of a scientific description of nature "does not presuppose any fundamental mode of description: each level of description is implied by another and implies the other. We need a multiplicity of levels that are all connected, none of which may have a claim to pre-eminence" [33].

These are, however, much more recent developments. Prigogine, Jantsch, Deleuze and Guattari have information at their disposal that von Bertalanffy certainly did not. It was to take more than 20 years for von Bertalanffy's initial insights to gel into a more complex and

**Fig. 4. The Belousov-Zhabotinsky reaction is a chemical dissipative structure. In this reaction, malonic acid is oxidized by bromate in the presence of iron ions. (Photo: Phillip George, from video by Adam Lucas, *Alchemy in the Laboratory* [1992].)**

empirically testable theory of the dynamics of evolving systems. However, Deleuze and Guattari's insights into dynamic structuration are highly compatible with it.

## Non-Equilibrium Systems Theory

*There is a region, midway between the disintegration of chaos and the sterility of infallible order, in which life exists.*

—Roland Penrose [34]

A decisive breakthrough in these new theories occurred in the late 1960s with Prigogine's pioneering work on *dissipative structures* in chemical reaction systems. These dissipative chemical reactions are not "normal" in the sense in which most of us are familiar. Until the 1950s, they were poorly understood, if they were recognized at all.

Some of these chemical reaction systems, such as the Bénard instability, show the emergence of hexagonal cells as the solution reaches a critical temperature (Fig. 3). Others, such as the Belousov-Zhabotinsky reaction, display the emergence of coloured spiral formations or concentric circles that become increasingly complex over time (Fig. 4) [35].

What is most interesting about dissipative chemical reactions is that they display characteristics that normally we would associate only with living things. Like living organisms, these reactions "import" energy from the external environment in order to maintain or increase their own internal organization, while "exporting" unusable energy in the form of waste. Because chemical dissipative structures like the Belousov-Zhabotinsky reaction display life-like behaviour, it is possible that through studying them, we can find unifying principles that not only underlie the evolution of life, but that also show how "life" emerges from the so-called "inanimate" world.

Dissipative structures can only exist in conditions that are described by scientists as *nonlinear* or *far-from-equilibrium.* In these kinds of turbulent, unstable, chaotic conditions, matter displays radically different properties from those with which we are familiar from classical physics. In such conditions, matter and energy are able to *self-organize.*

As Prigogine points out, there are two kinds of chaotic or disorderly behaviour in nature, but only one of them generates self-organization. The first kind of chaos is that of thermodynamic equilibrium—the random mush of molecules characterized by maximum entropy and the Second Law of Thermodynamics. The other kind of chaos is "active, hot and energetic—a far-from-equilibrium turbulent chaos" [36]. In the far-from-equilibrium conditions typified by turbulent chaos, new forms of order emerge and are maintained by a complex of nonlinear processes.

Traditionally, Western scientists have dealt almost exclusively with natural processes that display *linear* behaviour. Linear behaviour evolves gradually and predictably along a single path. This path can be plotted using the differential calculus of Newton and Liebniz. Such a path could be the orbit of one of the planets around the sun or the trajectory of a cannonball through the air. In a linear equation, there is always only one "correct" solution.

Because of the enormous predictive powers of such mathematics, classical science has focussed its attention on phenomena that demonstrate this kind of linear behaviour. Even in those cases where simple, predictable behaviour cannot be demonstrated, many scientists still feel confident that linear equations provide a useful approximation. But linear equations describe only the simplest and most regular phenomena that we find in nature.

Over the last few decades, however, the study of chaotic and dissipative systems has revealed that most natural phenomena actually exist in far-from-equilibrium conditions and exhibit nonlinear behaviour. Even some simple systems that normally show linear, predictable behaviour, such as pendulums and planetary orbitals, can be pushed into the nonlinear domain. In this nonlinear domain, a system has the ability to evolve along more than one possible path of behaviour. Equations with *more than one stable solution* are required to model them. The number of possible paths the system can take determines the complexity of the probabilistic equation used to describe it. Far-from-equilibrium processes are thus essentially unpredictable.

Dissipative structures are a complex of far-from-equilibrium processes. Whether it be a hurricane, a chemical reaction or an ecosystem, it is far-from-equilibrium processes that enable these dissipative systems to organize their own behaviour and structure. Through such a complex of irreversible processes, dissipative structures are able to continuously "import" matter, energy and information from other organisms and the external environment, while at the same time "exporting" matter and energy that is no longer available for work. In this way, dissipative structures are capable of exhibiting three special characteristics: *self-regulation, self-renewal* and *self-transcendence* (i.e. the ability to creatively overcome structural and behavioural limitations). The Second Law of Thermodynamics is not contradicted by a system that behaves in this way.

Some very special conditions are required in order for dissipative structures to emerge. Certain *boundary conditions* must be met, i.e. the space in which the reaction unfolds has to be over a certain critical size or volume. Usually, a *catalytic agent* must be present, i.e. a substance that aids or accelerates the reaction without itself undergoing a change. And the system has to be provided with a continuous influx of physical or chemical energy above some critical value or threshold that will allow the reaction to begin and maintain itself.

Let us take the human body as an example of a dissipative structure. The body takes in sensory information, food, oxygen and different types of energy, such as heat and other forms of electromagnetic radiation from the environment. It excretes unusable matter, energy and information back into the environment in the form of various waste products. These waste products are, in turn, recycled by other organisms. Through these interactive processes, dissipative structures can maintain an incredible structural and behavioural stability, despite the constant replacement and reproduction of internal components and fluctuating environmental conditions.

Such an observation leads us to the fact that *dynamic stability* is a ubiquitous feature of dissipative structures. On the one hand, this is the ability of an organism to resist environmental and internal fluctuations through *negative feedback* when such fluctuations threaten to overwhelm it. On the other hand, dynamic stability allows an organism to amplify some fluctuations through *positive feedback* when some kind of change in structure or behaviour is required. In those areas of behaviour in which a high degree of flexibility and creativity is required (e.g. social behaviour or food gathering), the organism remains highly sensitive to influx, close to a state of chaos.

In a dissipative organism, myriads of feedback loops are hooked together in such a way that its internal organization can continuously adjust to the demands

of its environment. Removal or damage of some part of the organism can be partially or totally repaired by feedback processes that replace or compensate for the lost or missing part. This is not something we see happening in a machine.

## Order through Fluctuation

Through his studies of dissipative chemical reactions, Prigogine discovered that the ordering principle underlying the dynamic stability of natural systems could be understood as *order through fluctuation.*

A key to understanding this new ordering principle is the phenomenon of *iteration.* Practically every process in nature involves some kind of iteration. Iteration occurs whenever a process feeds some of its own outputs back into itself as it evolves over time. It is a form of dynamic self-reference that involves "the constant reabsorption or enfolding of what has come before" [37]. It happens in scrolling weather systems, in predator-prey relationships, in the cycling replacement of cells in our own bodies and in the constant process of creation and destruction of elementary particles from the vacuum state. Even at the cosmic scale, this kind of iterative, attracting, self-organizing behaviour is apparent in galaxial formations that are millions of light-years in size and duration.

In the nonlinear realm of most dynamical systems' behaviour, iteration can amplify small disturbances, making both predictability and determinism totally impossible. Such systems are "infinitely sensitive to the changing movement of everything else" [38]. This is what is known in chaos theory as "sensitive dependence on initial conditions"—the recognition that, in the right circumstances, a butterfly flapping its wings in Hong Kong can generate a week of storm activity 3 weeks later in New York. Such a recognition in the sphere of human activity has empowering ramifications for human agency.

In the words of Jantsch, "the role of fluctuations renders the laws of large numbers invalid, giving a chance to the individual and its creative imagination" [39]. This explains why, in the realm of human culture, one person or a small group of people acting or applying pressure in the right place at a sensitive time can have a profound effect on the outcome of a particular situation or, more importantly, on the evolution of wider social relations. Prigogine comments that "since even small fluctuations may grow and change the overall structure . . . individual activity is not doomed to failure" [40].

The key to understanding how chaotic and dissipative systems actually evolve lies in the phenomenon of *bifurcation.* When any dynamical system is disrupted to the extent that it is unable to maintain its original stable state, it reaches the first of a series of *instability thresholds,* or *bifurcation points,* and is forced to evolve in a new direction [41]. The evolution of a system from its stable state through these bifurcation points can be mapped using a bifurcation diagram (Fig. 5). The possible paths of evolution that it represents resemble a "decision tree" with branchings at each instability threshold. Each branching represents two or more evolutionary options or choices for the system: "most of these choices lead to chaos, some to order. The ones that lead to order are stabilized by coupling iterations, creating an interlocked net of feedback" [42]. This stabilization process is known as *autocatalysis* or *crosscatalysis* [43].

Although many futures could manifest themselves at each instability threshold, only one actually does, and it is impossible to predict which path the system will choose. In a situation in which the choice of paths has not been successful, the steps in the process that led to that state are not stabilized by autocatalysis or crosscatalysis. In such a situation, a dissipative organism still has the choice of retreating along the same path on which it has already come. This is because it seems to "remember" the initial conditions that made a particular development possible [44].

Sometimes the organism will enter a chaotic regime and fluctuate erratically until either it begins to break up and dissolve into chaos or it is given another "push" into orderly behaviour. But if the organism is pushed far enough away from its normal stable state and has enough environmental energy/matter/information at its disposal, it can evolve into a higher state of complexity that is better able to survive in the new conditions. This process is known as *self-transcendence* and is manifest at all levels of dissipative self-organization. It involves a break or flight from "business as usual" and is characterized by the spontaneous emergence of totally novel features in the organism, i.e. features that had not previously existed [45]. During this phase, an organism's energy and resource utilization undergoes a marked change.

When the organism is close to its stable state, entropy production tends toward a minimum. But, near the instability phase, during the transition at which new structures form, the organism's entropy production increases significantly.

> In other words, the system doesn't spare any expense for the creative building up of a new structure . . . as long as an inexhaustible reservoir of free energy is available in the environment. Only an established system, going for security, has to economize [46].

This principle holds for all dissipative systems, from spiral galaxial formations through to the Belousov-Zhabotinsky reaction and all of the more conventional manifestations of life and human culture.

Erich Jantsch, Humberto Maturana, Ilya Prigogine and Francisco Varela have all pointed out in their work that this kind of behaviour, which represents relative autonomy from the environment and the organism's capacity to "know" what has to be imported and exported to maintain and renew itself, can be understood as a primitive form of consciousness. This is true even at the level of a dissipative chemical reaction. It seems that each of the constituents is in some sense "informed" about the position and activity of other parts of the system and that the whole can "remember" the past stages of its own evolution and make "intuitive," creative choices about which evolutionary path it should take.

## The Creative Role of Chaos

In stark contrast to the classical mechanistic view, both chaos and nonequilibrium systems theory maintain that evolution proceeds *because* of the increasing chaos and disorder in the universe, not in spite of them. In contrast to the modern orthodoxy of neo-Darwinism, chaos does not take freedom away from organisms by subjecting them to forces totally beyond their control. Instead, it can increase their freedom, provide them with information for potential behavioural modifications, and spontaneously generate new and more complex forms of order.

As environmental or internal chaos increases, the necessity of an organism's survival leads it to increasing complexity or, if it cannot cope, retrogressive behaviour or death. Although the processes that force evolutionary change may be chaotic, the changes themselves are not. They occur in coherent, evolutionary sequences that are probabilistic and, therefore, unpredictable. But they are *not*

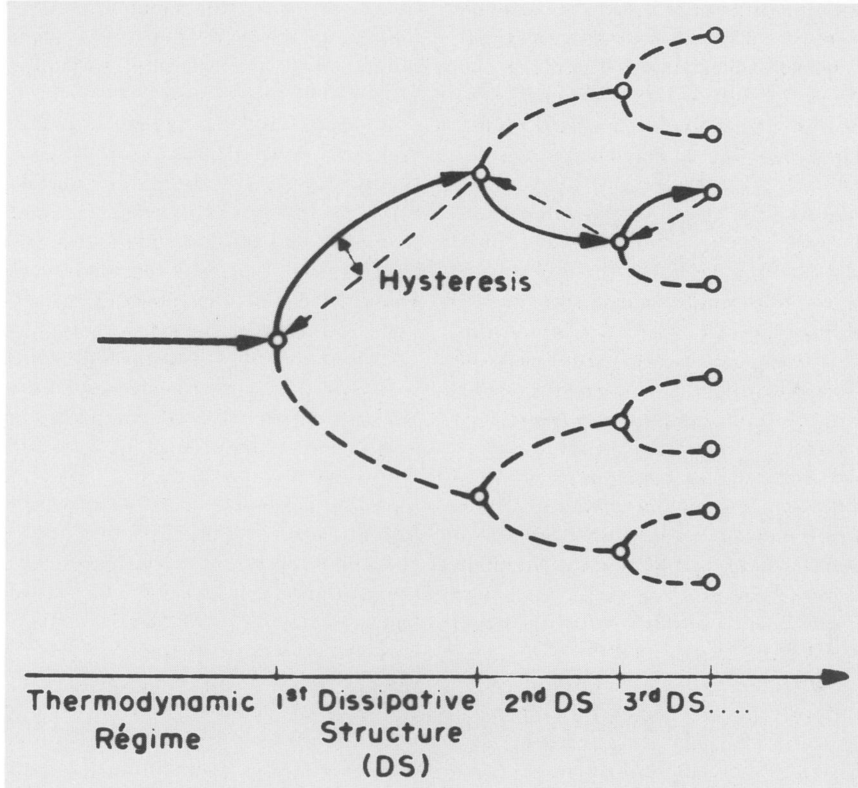



**Fig. 5. Macroscopic indeterminacy in the evolution of a dissipative structure. At each instability threshold, there is choice among two or more possibilities. If nonequilibrium, however, is diminished again, the structure retreats along the same path upon which it has come, except for the so-called hysteresis effect that is due to the work invested in restructuration. The structure "remembers" the initial conditions. Reprinted with permission from Erich Jantsch [8] Copyright 1980, Pergamon Press PLC.**

random as neo-Darwinists frequently claim.

The indeterminate or probabilistic nature of an organism's relationship to the environment implies that it has relative freedom in the behavioural options that are available to it at critical junctures. In the words of Briggs and Peat:

> The greater an organism's autonomy, the more feedback loops required both within the system and in its relationship to the environment. In other words, greater freedom implies greater connectedness to the environment [47].

This conception of organismic freedom as relative to the complexity of the processes that constitute it is again in stark contrast to the evolutionary views of neo-Darwinian nihilists, such as Jacques Monod and Richard Dawkins, who see "random" mutation and natural selection as "objective constraints" that narrow, if not totally abolish, the concept of individual freedom [48].

Perhaps one of the most inspiring things for artists about chaos and nonequilibrium systems theory is their recognition of a fundamental creativity in nature, and that it is chaos that generates this creativity. Perhaps more accurately, it could be stated that the response of dissipative organisms to far-from-equilibrium chaos is to be creative in order to survive.

An organism's creativity, its novel response to disorder, is drawn from the very source that threatens to overwhelm it. Survival, creativity, freedom and chaos are thus intimately related at the instability threshold of evolving systems. As long as the organism's limitations do not force it to retreat along its own evolutionary path, the greater the disorder imposed on it, the greater its freedom of behavioural choice. Evolutionary order thus emerges from an infinite sea of disorder (or "order of an infinite degree," in Bohm's words), a chaotic matrix that holds within itself infinite potentiality. Such an insight recalls the Babylonian myth of Tiamat, the primordial feminine Chaos, from which all creation proceeds.

The scientific recognition that chaos or disorder is responsible for spontaneously generating new order has long been recognized intuitively by artists, a point that is illustrated quite succinctly in this quote from Miró:

> I begin my pictures under the effect of a shock . . . which makes me escape from reality. The cause of this shock may be a tiny thread sticking out of the canvas, a drop of water falling, this print made by my finger on the shining surface of this table. In any case, I need a point of departure, even if it's only a speck of dust or a flash of light. This form begets a series of things, one thing giving birth to another thing [49].

Although the Dada and surrealist movements were possibly paradigmatic of such chaotic explorations, numerous artists have drawn inspiration from chaotic phenomena. Leonardo himself is often quoted as deriving inspiration from the various stains on his studio's walls or from clouds in the sky. Composers John Cage, Steve Reich and Karlheinz Stockhausen all explored elements of chance, spontaneity and natural order in their music. In the 1950s and 1960s, loose-knit political art movements such as COBRA, the Lettrist and Situationist International and FLUXUS explored notions of spontaneity and free play as means of liberating the individual's latent creative potentialities. This was seen as the first stage of a process that would ultimately lead to the liberation of collective possibilities in a new form of society. In the 1970s and 1980s, most of this kind of activity seemed to have gone "underground," or at least to have been reduced to explorations at the margins of the art world and popular culture. Some of its more obvious manifestations during that time can be seen in music and performance with such groups as the Sex Pistols, Survival Research Laboratories, Cabaret Voltaire, COUM Transmissions and the Temple of Psychic Youth [50]. The performance work of Survival Research Laboratories in particular is a radical critique of industrial culture and the everyday violence to which we regularly subject ourselves (Color Plate B No. 3).

Western patriarchal society is, however, not overly tolerant of such anarchistic tendencies and often attempts to marginalize or denigrate artists (and other individuals) who display such sympathies. Chaos has been socially constructed as a destructive threat, rather than a creative force, and has, therefore, had a dead weight of negative moral baggage attached to it.

This observation leads us to the fact that, complementary to the radical creativity permeating nature and human culture are conservative "rules of the game" that limit and structure the behaviour of dissipative organisms.

Social conservatism is just one example of how such rules can operate. Although these rules may themselves evolve, for those organisms that make inappropriate choices or that are pushed too far from their stable state to reorganize themselves, stagnation or disintegration will inevitably result. On the other hand, successful and well-timed choices can be quickly amplified and integrated into an organism's behaviour as a new "habit." This is especially true with regard to the evolution of human values, and, if Sheldrake's theory of formative causation is correct, current social movements and the values that they embody will quicken the pace of social change through morphic resonance. This means that the potential to make similar value changes will increase exponentially as the human population rapidly becomes more attuned to such shifts in thinking.

## CONCLUSION

The social and political implications of the new paradigm of self-organization are extremely radical. If all of nature is constantly transforming, renewing and recreating itself and equilibrium is the equivalent of stagnation and death, we have an open-ended conceptual understanding for the continual transformation of human society. But rather than providing all the answers, or even attempting to do so, this new organismic philosophy problematizes many areas of human life, especially those areas that touch upon work and creativity. My sincere hope is that the new science will help to provide a unifying and authoritative framework within which a diverse range of current social movements (aimed at the amelioration of social and racial inequalities) can implement the initiatives for new solutions that are currently required.

The emergence of easily accessible video, computer and other communications technologies means that the ability of marginalized groups and individuals to have their voices heard becomes increasingly possible. The widespread creation and distribution of alternative forms of information is already undermining the current hegemony of an oppressive and intensely patriarchal mode of thinking. We are in a situation that is comparable to the sixteenth and seventeenth centuries, when the printing press made it possible for the disenfranchised to assert their role in political and economic processes—a situation that led to a radical transformation of human society.

In the complex interplay of social processes, artists play an important role either in perpetuating conservative modes of artistic practise that support the status quo or in exploring hybrids of new and traditional modes and thus expanding our perception of the individual and society. John Stewart suggests that "one of the functions of art may be to render us truly conscious that reality is wonderfully and mysteriously more rich and complex than we are led to believe on the basis of any finite set of perceptual modes" [51].

Individuals working through internal pressure groups or unions within institutions who surreptitiously make suggestions for subtle changes can be effective. But, given the exponential growth of global conservatism over the last 5 decades, guerilla tactics—e.g. developing alternative communication networks and organizing with like-minded individuals, organizations and community groups to appropriate or create media and public events, conferences and information outlets for applying political pressure in sensitive areas—seem more appropriate. Similar strategies have proven most effective for the Establishment Right and the Extreme Right, so why not use their own tactics against them?

Emerging concepts in art and science have much more than historical precursors in common. They also share certain ways of seeing. For this reason, art and science have the potential to cross-pollinate and form a hybrid that can act as a powerful catalyst for social, political and economic change. The more artists cooperate and organize with other creative individuals and organizations to explore these new perspectives and values in a publicly accessible and participatory way, the more consumer capitalism will respect and recognize the need to appropriate these new values for its own economic survival.

A recent example of large corporations' willingness to embrace environmental concerns involved a sculptor friend, David Cranswick, who recently completed an outdoor installation titled *Constructing Nature* for the 1991 Australian Perspecta, involving lasers, reflective materials, solar-powered lights, a sensor and 600 river red gum trees (Color Plate A No. 1). This piece draws attention to the way in which Western culture attempts to impose a particular order upon our natural environment. If the 600 river red gum trees in the installation had been allowed to grow to maturity, the geometric configuration of the tree planting would have broken down to be replaced by an organic order [52]. Cranswick already has sponsorship for materials from 3M Corporation and was donated the trees for his installation by the Australian corporation BHP. In addition, at the time of this writing, plans are in place for the mass-production of hand-drawn and computer-generated images of Cranswick's piece for placemats in McDonald's restaurants throughout Western Sydney as an advertisement for Perspecta! Where do we draw the line between collaboration, appropriation and subversion?

There are rich underground tributaries of history and culture for artists to draw upon in the search for an organismic, interdisciplinary artistic language. Never mind how strange or contradictory it may at first seem. It is a voyage of discovery. Anyone can participate.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### References and Notes


**1.** Theodore Adorno and Max Horkheimer, *Dialectic of Enlightenment*, John Cumming, trans. (London: Verso, 1986).

**2.** See Evelyn Fox Keller, *Reflections on Gender and Science* (New Haven, CT, and London: Yale Univ. Press, 1985); George R. Lucas, *The Rehabilitation of Whitehead* (Albany, NY: State Univ. of New York Press, 1989); Carolyn Merchant, *The Death of Nature: Women, Ecology and the Scientific Revolution* (San Francisco: Harper & Row, 1980); Betty Jo Teeter Dobbs, *The Foundations of Newton's Alchemy or "The Hunting of the Greene Lyon"* (Cambridge: Cambridge Univ. Press, 1975).

**3.** The increasing association of alchemical, vitalistic and romantic ideas with "irrational" and "unscientific" forms of thinking in the twentieth century (witness the derogatory common usage of the word "romantic") could be attributed to three major historical processes: (1) the successes of the mechanistic approach to biology and to evolutionary theory, (2) the emergence of modernist theories, such as existentialism and phenomenology, as humanistic alternatives to scientific materialism, and (3) an organized assault on vitalist and religious concepts in science on the part of groups such as Helmholtz's School of Medicine in the late nineteenth century (in which Freud was a participant) and the Logical Positivists in the 1930s and 1940s.

**4.** This is not the same thing as saying that perception constructs a totally "fictive" internal world that is an arbitrary representation of the external world, as some deconstructionists claim. See Humberto R.

Maturana and Francisco J. Varela, *The Tree of Knowledge: The Biological Roots of Human Understanding* (Boston: Shambhala, 19 John Stewart, "Can Science Be an Art? Epistemology as the Vehicle for a Trip from Science to Art and Back," *Leonardo* **22**, No. 2, 255–261 (19 Heinz Von Foerster, "The Need of Perception for the Perception of Needs," *Leonardo* **22**, No. 2, 223–226 (1989).

**5.** Antonin Artaud, *Oeuvres completes* (Paris: Gallimard, 1967) pp. vii, 24.

**6.** See G.W. Hegel, *Hegel's Science of Logic*, A.V. Miller (London: George Allen and Unwin, 1969).

**7.** Although Hegel rejected the central tenet of evolution, i.e. a temporal flux and gradual transformation of form in nature, his philosophical focus on the rise and variation of forms of self-consciousness in the historical process not only was deeply indebted to the early evolutionists and Romantics, but furthered, in some respects at least, the radical political agenda of the alchemists and early evolutionists, especially with regards to Hegel's influence on the young Karl Marx and the Situationist Guy Debord.

**8.** See Erich Jantsch, *The Self-Organizing Universe: Scientific and Human Implications of the Emerging Paradigm of Evolution* (Oxford: Pergamon Press, 1980); and Rupert Sheldrake, *The Presence of the Past* (New York: Random House, 1988).

**9.** The most convincing evidence for organismic behaviour at the quantum level surrounds the inconsistency of most interpretations of quantum theory, particularly in relation to the Einstein-Podolsky-Rosen thought-experiment, empirically tested in a systematic way for the first time by Alain Aspect and his research team in France in 1981. The experiment shows that either classical science's commonsense notion of objective reality or the fundamental notion of locality must be abandoned. "Locality" means that events and objects that have a distinct spatio-temporal existence (in three dimensions) cannot "signal," or communicate, with one another faster than the speed of light. Aspect's experiment showed that information was being transferred between such "distinct" quantum phenomena at faster-than-light speed, implying that reality is "seamless" at some level that is beyond normal perception and the scope of orthodox physical theories and that cooperative systemic behavior is in evidence even at the quantum level. David Bohm's theory of the "implicate order" is a convincing attempt to come to grips with this phenomenon.

**10.** According to Sheldrake, "This memory doesn't just get stored in the chemical genes, as conventional biology assumes, but rather depends on a direct connection by . . . morphic resonance, through space and time. So it's as if organisms 'tune in' to all previous organisms of the species (the more similar something is to something that's happened before, the greater the resonance) and in turn contribute to the collective memory. This memory is cumulative . . . and happens independently of conventional forms of connection or communication. . . . David Bohm thinks that morphic resonance would work by things that have happened going into the implicate order, which is beyond space and time, and then getting folded back into the world, into the explicate order. . . . Some people like the idea of extra dimensions. Others think of a kind of morphic ether. All these are different models. No doubt many more can be suggested. But as far as this theory is concerned, it doesn't matter which model you have of the process. The key thing is the investigation of the idea that this process does happen." (From an interview with Rupert Sheldrake by Adam Lucas and Andrew Nethery for radio station 2SER-FM, in Sydney, Australia.)

**11.** Herschel B. Chipp, ed., *Theories of Modern Art* (London: Univ. of California Press, 1968) pp. 155–157.

**12.** Rainer Statchelhaus, *Joseph Beuys* (New York: Abbeville Press, 1991) p. 64.

**13.** See Merchant [2].

**14.** Gotz Adriani and Thomas M. Messer, *Joseph Beuys: Drawings Objects and Prints* (Stuttgart: Institute for Foreign Cultural Relations, 1989) p. 12.

**15.** Franz Marc, "Aphorisms, 1914–1915," in Chipp [11] p. 436.

**16.** Chipp [11] pp. 152–170. See Jürgen Claus, "The Cosmic and the Digital Code," *Leonardo* **24**, No. 2, 119–121 (1991).

**17.** Jorge Luis Borges, quoted in Jantsch [8] p. 19.

**18.** Ludwig Boltzmann, *Theoretical Physics and Philosophical Problems: Selected Writings* (Dordrecht/Boston: Reidel Pub. Co., 1974).

**19.** See Jantsch [8] p. 286f. Jantsch goes on to explain: "[Robbe-Grillet's] intuitively correct attempt went astray in many details since . . . self-organization dynamics cannot be explained in terms of the older notions of equilibrium thermodynamics . . . the idea of self-organization is central for the roman nouveau."

**20.** For a detailed discussion of these issues, see Ilya Prigogine and Isabelle Stengers, *Order out of Chaos: Man's New Dialogue with Nature* (New York: Bantam, 1984). See also James Gleick, *Chaos: Making a New Science* (London: Penguin, 1988); David Bohm and F. David Peat, *Science, Order and Creativity* (New York: Bantam, 1987); and Evelyn Fox Keller, *Reflections on Gender and Science* (New Haven, CT, and London: Yale Univ. Press, 1985).

**21.** Ludwig von Bertalanffy, *Problems of Life: An Evaluation of Modern Biological Thought* (London: Watts, 1952).

**22.** James Lovelock, *Gaia: A New Look at Life on Earth* (Oxford: Oxford Univ. Press, 1979) p. 4.

**23.** Ludwig von Bertalanffy, *General Systems Theory* (London: Penguin, 1969) p. 12.

**24.** It should be emphasised that any "level" of description should be recognized as the level of the observer's attention, rather than any hard and fast demarcation between different structures and processes.

**25.** Arthur Koestler, *Janus: A Summing Up* (London: Fontana, 1984).

**26.** Fritjof Capra, *The Turning Point* (New York: Simon & Schuster, 1982).

**27.** Joanna Macy, "The Ecological Self: Postmodern Ground for Right Action," in *Sacred Interconnections: Postmodern Spirituality, Political Economy and Art* (Albany, NY: State Univ. of New York Press, 1990) p. 43.

**28.** Jantsch [8] p. 234.

**29.** For another example of Phillip George's work, with his discussion of it, see Lynn Roberts-Goodwin and Phillip George, "Computer Users' Report," *Leonardo* **26**, No. 1 (1993).

**30.** Gilles Deleuze and Felix Guattari, *On the Line* (New York: Semiotext(e), 1983) pp. 10–11. "There are no points or positions in a rhizome, as one finds in a structure, tree or root. There are only lines" (p. 10). Lines of segmentation, lines of flow, lines of rupture and of flight, "these three lines are immanent and caught up in each other. . . . A rhizome can be cracked and broken at any point: it starts off again following one or another of its lines, or even other lines. We can never get rid of ants, because they form an animal rhizome that never ceases to reconstitute itself, even when almost completely destroyed" (p. 71).

**31.** Jantsch [8] p. 234.

**32.** Jantsch [8] pp. 231–238.

**33.** Quoted in Briggs and Peat, *Turbulent Mirror: An Illustrated Guide to Chaos Theory and the Science of Wholeness* (New York: Harper & Row, 1989) p. 149.

**34.** Roland Penrose, *Miró* (London: Thames and Hudson, 1985) p. 198.

**35.** For a discussion of the order shown in the Belousov-Zhabotinsky reaction, Mae-Wan Ho, "Reanimating Nature: The Integration of Science with Human Experience," *Leonardo* **25**, No. 5, pp. 607–615 (1991).

**36.** Briggs and Peat [33] p. 139.

**37.** Briggs and Peat [33] p. 136.

**38.** Briggs and Peat [33] p. 74.

**39.** Jantsch [8] p. 8.

**40.** Briggs and Peat [33] p. 151.

**41.** The realization that life and instability are intimately connected was, interestingly enough, noted by the artist and critic Jean Metzinger in an article on Picasso's Cubist perspective in the Parisian magazine *Pan* in 1910: "Form, used for too many centuries as the inanimate support of color finally recovers its right to life and to instability" (from Chipp [11] p. 196). An artistic insight is, however, scientifically useless unless it can be backed up by empirical evidence. It was more than 50 years after Metzinger's observation that scientific evidence for this connection was discovered.

**42.** Briggs and Peat [33] p. 143.

**43.** Autocatalysis means that "certain molecules participate in reactions in which they are necessary for the formation of molecules of their own kind." Cross-catalysis means that certain molecules participate in reactions in which they are necessary for "the formation of molecules of an intermediate kind and subsequently of their own kind." From Jantsch [8] p. 31.

**44.** As has already been discussed, self-organizing systems possess a memory of their past states. Although these systems are not conscious in the sense that we understand it, they have the ability to store certain types of information. For example, they can recognize food, danger and other systems like themselves without needing to be directly "taught" by other individuals. They can also learn from their own experience. The orthodox view is that this information is "programmed" in deoxyribonucleic acid (DNA) or stored in the brain. But even dissipative chemical reactions display a primitive form of systems memory, and they have neither brains nor DNA. For a detailed discussion of these issues, see Sheldrake [8].

**45.** "Close to the instability threshold marking the transition from one structure to another, the model breaks down. In this phase, it is not the general which is of decisive importance, but the particular—in short, the creative." See Jantsch [8] p. 56. Although the older model may break down at the transition stage, and prediction of what kind of change and the relationships it entails is not possible, once these factors are known at their new values, it is possible to construct a new model and, consequently, to predict whether these changes will dominate the overall system in the new circumstances.

**46.** Jantsch [8] p. 50.

**47.** Briggs and Peat [33] p. 144.

**48.** See Jacques Monod, *Chance and Necessity* (New York: Knopf, 1972); and Richard Dawkins, *The Selfish Gene* (Oxford: Oxford Univ. Press, 1976).

**49.** From *Je travaille comme un jardinier*, quoted in Penrose [34] p. 171.

**50.** See V. Vale and A. Juno, eds., *Industrial Culture Handbook* (San Francisco: Re/Search, 1984).

John Stewart, "Can Science Be an Art? Epistemology as the Vehicle for a Trip from Science to Art and Back," *Leonardo* **22**, No. 2 (1989) p. 255.

**52.** For a detailed discussion of Cranswick's piece, with his discussion of it, see David Cranswick, "Red Gum/Red Light," *Artlink* **11**, No. 4 (Summer 1991–1992) p. 80.