WHY DID LIVING COMPLEXITY ARISE?
Beyond reductionism: Stuart Kauffman reinventing the sacred

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Stuart Kauffman has and continues to be one of the most eminent thinkers in the development of modern evolutionary biology. His theories on the self-organisation of matter have served to complement the ordinary explanation offered by Darwinism and complexity theories. In a recent contribution to the journal Zygon, dated 22 October 2006, Kauffman admits the possibility of accepting quantum factors in the emergence of life, at the same time as offering a self-creative and sacred image of nature, which is nevertheless different from traditional theism.

Stuart Alan Kauffman takes a stance against recent trends in the philosophy of biology. On the one hand, he offers an opinion regarding the recent controversy on theism-atheism arising out of the works of Dawkins and Dennett. Kauffman sticks to his previous position, refusing to believe in a transcendent God. However, he qualifies this position by defending his belief in a sacred world that should underpin our search for meaning. The world of complexity is not reductionism, but rather a major self-creative and emergent step towards superior levels of reality. This natural self-creativity prompts in us an attitude of reverence, respect and mystery. On the other hand, however, Kauffman has also taken an important step forward by accepting the role of quantum causality in the origin of life. In this sense, his authority reinforces heuristic speculations which attempt to explain life in terms of a quantum, emergentist and non-reductionist 'physical underpinning'.

Today, Kauffman's works are some of the most important in the field of biological self-organisation processes within the framework of complexity theories. His interdisciplinary training may perhaps explain the shear breath of his questions, and the ambitiousness of his answers. His analyses touch upon physics, biology, psychology, neurology and even philosophy, and his thinking directly affects the existing neo-Darwinist paradigm, not to deny it, but rather to complement it. The causes which produced life would depend on the ontology of the matter whose ontological properties prompted self-movement towards organised complexity. These properties are particularly evident in the genetic process and in the genetic networks already studied by other authors.

A coherent line of research

Stuart Kauffman was born in 1939. In 1960 he earned degrees in philosophy and physics from Dartmouth College, before moving to Oxford, where he continued to study philosophy, expanding his scope to include psychology and biology. Finally, he studied medicine at the University of California in 1968 and a short time later, decided to focus his professional activities exclusively on research. He carried out genetic research at the University of Chicago and, from 1975 to 1995, lectured in biochemistry in Pennsylvania. He has also remained in contact with other research institutes, such as the Complex Systems Institute in Santa Fe. Today, an emeritus professor at the University of Pennsylvania, he works at the University of Calgary, Alberta, where he directs a number of institutes on biological complexity. He has also been a NASA consultant since the year 2000.

His cornerstone work is *Origins of Order: Self-Organization and Selection in Evolution* (1993). Some time later, in 1995, he published *At Home in the Universe: The Search for the Laws of Self-Organization and Complexity*. Finally, in the year 2000, he brought out his last work: *Investigations*, in which he explored the same themes in more depth. In a paper published in 2006 under the title *Beyond Reductionism: Reinventing the Sacred*, he offers a series of new ideas which we shall comment on here.

How can one understand Kauffman's work? What causes does he propose to explain the emergence of complex biological systems? Is there really irreducibility between different emergent levels? In what sense can we talk about emergent novelties? How are they related to systemics and complexity? Kauffman's stance is anti-reductionist; he believes that reality cannot emerge from the mere evolution of linear systems. For Kauffman, the emergence of novelty stems from continuity and the systemic interaction of matter. New systems produce new forms of reality. In this sense, Kauffman's work fits into the traditional framework of emergence theory.

A good overview of Kauffman's contributions to the field can be found in a research paper on his work by Alfredo Pérez, published by the University of Madrid. This paper states that: 'The question is from where did the useful variation on which selection acts come from? [Margullis, 2000]. This is the problem that Kauffman aims to resolve. Furthermore, regarding the problem of the origin of life, one of the dominant trends sustains that life could not have existed until the appearance of a primitive genetic system, and said primitive genetic system was the result of chance. If the weight of the argument on the origin of life rests on the formation of a primitive genetic system created as the result of a random conjunction of different elements under certain conditions, then the emergence of life becomes an enormously improbable event. These problems are the ones that steer Kauffman's research, and can be expressed through the following questions: How can we convincingly explain the fact of the emergence and evolution of life? How can we explain the order found in complex adaptive systems? For Kauffman, the key lies in bearing in mind the self-organisational capacity of complex systems' (p. 8).

The search for the self-organisational logic of life

Kauffman's contributions are historically based on the results obtained by Watson, Crick and Walkins. For these authors, the molecular structure of nucleic acids and the transfer of information between different organisms are essential factors. Thus, molecular structure transmits the hereditary genetic information required for the stability of the species.

Some time later, in 1965, the researchers François Jacob, Jacques Monod and André Lwoff were awarded the Nobel Prize in Medicine. Their research improved our understanding of the genetic control of enzymes, the synthesis of viruses, cellular differentiation and ontogenesis. It was then that the synthesis of a protein in the cytoplasm by the gene transcribed from DNA by RNA (ribonucleic acid) was understood. The so-called messenger RNA was found to control protein synthesis through its genetic code.

In 1977, the Russian-Belgian researcher Ilya Prigogine was awarded a Nobel Prize for his discovery of the characteristics that make order arise from far-from-equilibrium systems (when the particles of the system move randomly in total disorder). The order generated by fluctuations is a mechanism which produces self-organisation, an essential phenomenon for the formation of dissipative structures. Small variations in a system's fluctuations do not affect its stability; however, if they become larger, these fluctuations make the system unstable and push it to the edge of chaos. It is then that self-organisation arises, thus enabling the system to stabilise itself in a different ordered state.

Through situations of instability, fluctuations push systems towards totally new, stable, although also fluctuating, structures. The stability of biological systems is therefore dynamic and fluctuating, and forms the basis of the evolution of living systems in search of new ways of organising themselves in order to ensure adaptive stability. Prigogine's model has since been successfully applied to research aiming to understand the causes that prompted the evolution of living entities.

These ideas were soon developed by new research into the physics of chaos and its application to living systems. Basically, what these areas of research revealed is that life was not only produced by selection, but also by the primordial nature of matter and living matter (let us also remember the auto-poietic systems of Varela and Maturana). According to Darwinist principles, natural selection acts on the structures of ordered systems that have already been produced by evolution. Evolution selects only those ordered structures that have already been tried and tested by nature in accordance with ontological principles, prior to selection itself.

Kauffman's proposal: beyond reductionism

In order to explain Kauffman's point of view, we shall use the overview that the author himself provides in a recent paper entitled *Beyond Reductionism: Reinventing the Sacred* (2006). As mentioned earlier, Kauffman's position is in line with the emergence approach, at least in relation to its basic concepts regarding the origin of life.

Reductionism has been the general perspective of science over recent years. «Roughly, reductionism is the view that, as Nobel Laureate Stephen Weinberg eloquently puts it, the 'explanatory arrows always point downwards'». This downward-looking perspective leads us to explain everything on the basis of the elementary particles that make up the primordial substratum of the universe. A series of simple laws for this primordial matter would constitute the 'dream of the final theory', whose existence Weinberg has indeed postulated.

Kauffman underlines the 'increasing doubts among many scientists regarding the adequacy of reductionism' and mentions two Nobel Laureates, Philip Anderson and Robert Laughlin. Nevertheless, today, it is in string theory that reductionists seek that final theory, and seem to be going from strength to strength.

'But it is precisely in the province of string theory itself, that doubts are arising' says Kauffman. 'The early hope was that a single string theory would be found that would explain quantum gravity and all the known particles and forces. Such a single string theory would be the answer to Weinberg's dream of a final theory. But at present, it appears that there are as many as 10 to the 500^{th} power string theories. Hope for a single theory is fast fading and a number of high energy physicists are abandoning reductionism in the sense of finding such a single theory. Thus, Leonard Susskind, in the *Cosmic Landscape*, suggests a multiverse of «pocket universes», each with a randomly chosen string theory, and a landscape over these «pocket universes» with respect to those whose laws are life friendly. As a critical side note, part of Susskind's move is an attempt to explain the roughly 23 physical constants in physics like the speed of light, the ratio of electron to proton mass, and so on. No one knows where these constants come from or how to explain them. Weinberg himself uttered the «A» word – anthropic'.

'In short', concludes Kauffman, 'many, but not all physicists, are giving up on the adequacy of reductionism alone as a scientific principle to explain the properties of the world. In its stead a new scientific world view is just starting to come into view: Emergence'.

The emergence of life: how it cannot be reduced to physics

Kauffman's scientific work focuses on the most solid, mechanical and physical-chemical foundations causally involved in the origin of life. However, he has been against reductionism right from the start. His stance is more in line with emergence, a theoretical framework which is today becoming increasingly popular, and which is being espoused by more and more physicists and biologists who are abandoning reductionism as a doctrine of the past.

Kauffman's emergence is not 'dualism', but rather systemic monism that justifies the emergence of novelty when the continuity of the evolutionary process (based on the physical world) combines with the evolutionary genesis of new systemic structures that produce ontological novelties.

His emergence is systemic and ontological. Kauffman himself says that 'the ontological view (in emergence) is that new entities with their own properties and causal powers arise and are part of the furniture of the universe'.

How did life arise? We do not really know, although in Kauffman's opinion, certain theories do exist, even if none have yet been definitively established. The first is based on the properties of DNA and RNA, their helical structure and reduplicative capacity. The second is based on the recently-discovered properties of RNA, not only for carrying information, but also for acting as enzymes, speeding up chemical reactions in the cytoplasm. The third theory is based on the chemical structure of lipids, which experimental research has shown to be capable of growing and dividing. These processes may form part of the origin of life.

The fourth theory is that proposed by Kauffman himself, and defended by Freeman Dyson, and may also describe the events occurring in the origin of life. It rests on the observation that cellular life is based on collective processes of autocatalysis, where catalysis is the acceleration of the speed of reaction. No molecule can catalyse its own formation. However, a system of molecules may maintain interactive systemic relations that, together, control the regularity, stability and replication of a system that would thus be autocatalytic. These systems, along with lipid chemistry, may have created the basic replicative stability of the living systems in which the subsequent function of DNA and RNA would have been possible.

Does the appearance of these systems, i.e. life, represent an emergence in relation to the physical world? Kauffman's answer is yes. Darwin's natural selection acts on already emerged biological entities, capable of self reproduction and heritable variation. 'This', says Kauffman, 'seems clearly to be ontological emergence, not reducible to physics'. 'In short, Darwin's natural selection is a new law operating on the level of self reproducing entities with heritable variation, regardless of the physical underpinning. In contrast to Weinberg's claim, here the explanatory arrows point upward'.

The emergence of living agents

Life is not only a level of emergence not reducible to physics due to the novelty of its self reproducing structures with heritable variability thanks to Darwinist selection, but also due to the supposition of 'agency' (the capacity to select directed actions).

In many of his works, Kauffman asks about the minimum properties a physical system must have in order to be considered an 'agent'. 'A minimal molecular agent is a system which can reproduce itself and carry out at least one work cycle in the thermodynamic sense'. 'A bacterium, swimming up a glucose gradient, and performing work cycles, is an agent, and glucose has value and meaning for the bacterium, without assuming consciousness. Of course, it is natural selection that has achieved this coupling. But teleological language has to start somewhere, and I am willing to place it at the start of life. Either here, or later in the evolutionary pathways, meaning and value arise in the biosphere. They too are ontologically emergent'. As we will see, the evolutionary appearance of sensation-consciousness also plays a key role in this emergence.

The emergence of consciousness and its quantum origins

However, the fact is that consciousness has also arisen in living organisms. 'We are, in fact, conscious', states Kauffman. 'That is, we have experiences of the world. The philosophers call these «qualia». For years, philosophers of mind have tried to argue that such experiences are «ghosts in the machine». This is just false. We are, in fact, conscious. Whatever explains consciousness, it is clearly ontologically emergent'.

However, how can we explain the fact of this emergence? At the end of the day, the aim is to explain the causes of emergence, i.e. the causes (or real facts) that explain why in the animal world and in ourselves, the emergence of consciousness arose evolutionarily (and before sensibility).

Kauffman refers to three different answers to this question; however, we do not know with any certainty which (if any) is correct. The first response is the dualist one. The author refers to Saint Augustine, Schroedinger and Tibetan Buddhism. The second answer, which is the predominant view among cognitive scientists today, reduces the question to complex computer programmes. At heart, this is nothing more than the modern continuation of reductionism. The third answer, which is the one Kauffman himself espouses, refers to consciousness in a quantum medium produced by evolution in biological structures.

With this, Kauffman aligns himself with the general framework of quantum neurology, coming close (although he does not mention them in the text we are analysing here) to both the hypothesis posed by Hameroff-Penrose and the possibility of the existence of other quantum phenomena in living cellular tissue.

'The third view of mind and consciousness', says Kaufmann, 'which I tentatively favour, is that it is related to quantum behaviour. The standard physicists' answer is that quantum effects cannot occur at body temperature'.

'However, recent theorems in quantum computing, and facts about cells cast doubt on this conclusion. The theorems show that, if measurements are made and work is done on a quantum computer, its qubits can remain «quantum coherent» when they should «decohere» towards classical behaviour. Thus, if work is done on a system, parts of it may remain quantum coherent at body temperature in principle. But cells do thermodynamic work and might be able to carry out such measurements and work to maintain some variables quantum coherent. Second, cells are crowded by proteins and other molecules, and the water between these molecules is largely ordered, not like an ordinary liquid. This may permit quantum coherence physically in cells. No one knows. It seems worth investigation in its own right. Meanwhile, my approximate theory is that mind is acausal, quantum mechanics is acausal on the familiar Born interpretation of the Schroedinger equation (to the grief of Einstein), that consciousness is due to a special state where a system is persistently poised between quantum and classical behaviour, that the emergence of classical behaviour in the mind-brain system, perhaps by decoherence, is the «mind making something actual» happen in the physical world, and —big jump— that consciousness itself consists in this quantum coherent state as lived by the organism. This is a long jump, but not impossible. I don't even think it is stupider than other theories of consciousness, and may be true. Whatever the case, consciousness is ontologically emergent in this universe'.

Kauffman and the trends of the philosophy of biology

These interesting considerations by a person of the stature of Stuart Kauffman reveal certain trends that are well worth highlighting:

1) His qualified positive assessment of the hypotheses of quantum neurology is indicative of a growing tendency to admit that this heuristic line is the best constructed (within its obscurity) and the one most able to explain the physical medium in which the sensibility-consciousness which emerged during the evolutionary process exists. Earlier we mentioned Margullis, who asked 'where did the useful variation on which selection acts come from?' Here, the answer would be: from the emergence of quantum states which supported sensation (probably in the unicellular world, perhaps with the appearance of the cytoskeleton and microtubules); subsequently, selection made more efficient sensitive systems possible in pursuit of optimum survival.

2) Kauffman understands perfectly that any assessment of quantum neurology is a mere question of science, and as such, is philosophically neutral. This is compatible with his atheist stance, in the sense of not leaning towards the acceptance of a personal God. Valuing the contributions of quantum neurology is merely the consequence of scientific honesty, which prompts us to try and explain the real phenomenological experience of our consciousness, or in other words, of that which constitutes society and human history. Kauffman is not concerned that accepting the relevance of quantum neurology hypotheses constitutes *eo ipso* an acceptance of theism.

3) Even from his decidedly atheist viewpoint, Kauffman steers his anti-reductionist and emergence stance towards a way of understanding our feelings of reverence towards a creative universe that he describes as sacred. His approach to the mysterious sacredness of nature is reminiscent of Einstein's hotly debated religiousness.

'God is the most powerful symbol we have created. The Spaniards in the New World built their churches on the holy sites of those they vanquished. Notre Dame sits on a Druid holy site. Shall we use the God word? It is our choice. Mine is a tentative «yes». I want God to mean the vast ceaseless creativity of the only universe we know of, ours. What do we gain by using the God word? I suspect a great deal, for the word carries with it awe and reverence. If we can transfer that awe and reverence, not to the transcendental Abrahamic God of my Israelite tribe long ago, but to the stunning reality that confronts us, we will grant permission for a renewed spirituality, and awe, reverence and responsibility for all that lives, for the planet'.

4) This 'sacred' emergence in the face of a nature that, surprisingly, points upward and which demands superior explanatory criteria that arise from the evolutionary creativity of the universe itself, demonstrates the increasing trend towards taking very seriously attempts aimed at overcoming

reductionism. Although Kauffman does not make the jump from this sacred nature to the hypothesis sustained by religious traditions of a transcendent God, modern theism is much more comfortable with the 'atheist' sacredness of Kaufman than with the reductionist robotism of the *ancien régime* of science. Theism is but the opening up of the last superior level that explains the ontological origin of life, sensibility and consciousness in the physical universe.

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