COMPLEXITY, INTERDEPENDENCE & OBJECTIFICATION

by ***VASILEIOS BASIOS***
C.P. 231, University of Brussels, Brussels, B-1050, Belgium
*(*vbasios@ulb.ac.be*)*

> *There are powers and thoughts within us, that we know not till they rise*
> *Through the stream of conscious action from where the self in secret lies.*
> *But where will and sense are silent, by the thoughts that come and go,*
> *We may trace the rocks and eddies in the hidden depths below.*
> James Clerk Maxwell, [10]

1 Introduction

During the last twenty years or so, the investigation of fundamental aspects of complex systems in connection with the observer's participatory role in determining their understanding brings forth a novel perspective in science. The characteristic quality of complex systems to unfold their dynamics in a wide range of space and time scales and thus admit various different, irreducible but compatible, levels of description prompts us to search for the appropriate level of description in which unification and universality can be expected. It becomes more and more evident that the different levels of description possible of a complex whole point to a common origin on a deeper level. As a matter of fact, one might argue that certain filters, conceptual, epistemological, or methodological are inevitable if one engages in the description and/or explanation of complex entities which are given as a certain whole. The mere choice of the particular mode or framework of examination is what will permit the unfolding of any anticipated explanation or description for complex phenomena. The Protean nature of complexity though, forces us to let something escape. We are coming of age in acknowledging, more often implicitly than explicitly, this fact.

The main thesis of this presentation is that Complex Systems lend themselves to many distinct levels of descriptions. Some are dynamical, structural, geometrical or topological, metric or probabilistic. Others represent a hybridization of the above. Moreover, especially for living complex systems, any observation will necessarily be partial and always dependant on the observer's choices. This will be due to incompressible initial conditions and/or approximate parameter estimations. It becomes evident that no single set of known mathematical or other formalisms can yield a description of a complex whole that is both complete and consistent.

It means that a new double-edged approach is called for. On the one hand, we need a concerted approach which will synthesize and unify all relevant elements at different levels, by using different tools and descriptions. On the other hand, we need to discriminate between two things. The first is the several given aspects of the facts under scrutiny. The second is how these facts were acquired based on the specifics of sets of objects and relations which led to their conceptualisation in the first place.

We are fast approaching the point where we need to concern ourselves not only with the study of nature, but with the nature of that study.

Being aware of the limitations of our descriptions we can describe the limitations of our awareness. That, as a consequence, will outline the search for a *'Science towards the Limits'*, as William James called it. It will consist of a scientific endeavour capable of reflecting not only on its own abstractions (a discourse that *epistemology* already provides), but on its fundamental objectifications (a discourse that goes one step deeper into what can only be described as a *'pre-epistemology*').

Let us take a rude example to fix the main idea: Imagine the bees. Each one of them is an individual with certain function, genetic information, brain and organs, among which organs which facilitate their intercommunication. A colony of bees, though, is more than a bunch of them together. Each bee lives its own life but also lives the life of the colony. The emergent dynamics of the hive is totally compatible but never entirely reducible to the dynamics of each individual and vice versa. The story that the social-behavioural biologist narrates is based on facts filtered out of the total given facts for bees and hives to match his level of description. The geneticist will focus on how genetic material and gene expression is effecting the hive. A physicist will thy to model the collective behaviour based on the communication signals they exchange and how these trigger collective behaviour. The ecologist will seek out environmental factors responsible for the well being of bees and hive. The list of experts that could engage in the studies of bees could be endless. What we come to realize recently, due to the leading complex systems approach, is that all these levels of descriptions are interconnected, interdependent and sometimes what one emphasizes the other ignores. Some other times when one becomes aware of this "filtering of facts" at work, novel realizations emerge, new paths and bridges are forged and a fresh common ground is discovered to lay beneath our previous conceptual foundations. That is another "bonus" of complexity studies, the highlighting of the importance of being interdisciplinary.

2 What is Complexity that We Should Be Mindful of ?

"Mais quand une règle est fort composée,
ce qui luy est conforme, passe pour irrégulier"
(But when a rule is extremely complex,
that which conforms to it passes for random)
Leibniz, Discours de Métaphysique, VI, 1686

Looking into Webster's dictionary the word 'complexity' is defined as 'the quality or state of being complex'. Furthermore under 'complex' we read:

> *Main Entry: (1)* ***complex****, Function: noun, Etymology:*
> *Late Latin complexus totality, from Latin, embrace, from complecti,*
> *Date: 1643, (1) : a* <u>*whole*</u> *made up of complicated or interrelated parts.*

Self-referential as this definition may seem, it places the emphasis on 'whole' and 'interrelated parts'. We have come to realise that something complicated is not necessarily complex, although a complex system can be complicated. The terms 'whole' and 'interrelated parts' emerge as fundamental notions on which the *nonlinear* relations among constituent parts rely and are identified. This has been the case mainly in the physical sciences. But it is not necessarily restricted to these alone. Indeed, the connection between complexity studies and nonlinear science allows us to bridge the divide between subjective and objective narration in fields as diverse as physics, chemistry, biology, cognitive and consciousness studies – not to neglect sociology and economics.

In complex system studies one is confronted with nonlinear relations which usually give rise to a great number of states. In most cases this signifies many levels of ongoing processes of a different temporal and spatial scale. Complexity manifests through the presence of multi-stationarity and/or chaotic regimes of motion with emerging dynamics in a wide spectrum of characteristic times and lengths.

All these states unavoidably lead to the breaking of symmetries both in the spatial (pattern formation) and the temporal (irreversibility: what does it mean?) domains. It is now well understood that the above emergent patterns and rhythms are due to 'nonlocal' effects in a dual sense. The first is that the correlation lengths of the emerging patterns and rhythms are many orders of magnitude larger than the correlation lengths of their constituent parts. The second sense expresses itself through the concomitant limited horizon of predictability arising from s*ensitive dependence on initial conditions and parameters* -- which is the indispensable defining aspect of chaotic motion.

Of course complexity of form and structure is not a new or strange concept in the field of scientific investigations. Intricate patterns and forms -- structures with great beauty and delicate design -- have captured the attention and admiration of scientific thinking since the dawn of time. A classic reference remains D'Arcy's *'On Growth and Form'* [1]. Recently, the studies of structural complexity in relation to information processes, from physico-chemical and biological systems to man-made networks such as electricity's power-grid, the 'World Wide Web' and the internet, various social groups, etc., have made an impact on the scientific literature and created lively discussions (see, for example, [2, 3] for an introduction, specialized references can also be found therein).

Nevertheless, in addition to the structural aspects of complexity, its dynamical aspect has been the object of path-breaking research since the sixties. Owing to the early, seminal, contributions of Hermann Haken, Ilya Prigogine, Brian Goodwin, their co-workers, and many others, the role of nonlinear relations and fluctuations in self-organization, synergetics, pattern formation, irreversibility and, in general, to what now tends to be called `emergence' has been amply elucidated. For an overview of their work, one might consult [4, 5, 6].

These pioneering contributions go well beyond qualitative descriptions, analogies and metaphors. They address fundamental issues such as the interplay of structure, function and fluctuations; they invoke a non-classical -- sometimes circular -- causality (since the parts collectively determine the macroscopic order parameters and the macroscopic order parameters determine the behaviour of the parts' collectivity) and they offer a new apprehension of the fact that determinism does not necessarily imply predictability (a corollary due to sensitive dependence on initial conditions *and* parameters).

Through the analytical tools of theoretical physics and mathematics, unexpected relations between topological and geometrical aspects (*structure)*, dynamical laws (*functions*) and stochastic processes (*fluctuations*) were discovered in the heart of complex systems.

3 Fallen doctrine of classical determinism: (Classical) Objects Misbehaving

A curious thing about Complexity – often hailed as 'the third revolution of physics' -- is that it did not occur as a paradigm shift over unaccommodated data and unexplained facts. Definitely it is not the brainchild of a single investigator, like Relativity, and has not been followed by explosions threatening mankind, like Quantum Mechanics. Although its technological and conceptual advances are being harvested by the widest known array of disciplines in science, it constitutes a community of ideas and workers with a quite well-defined area of studies and a fertile laboratory of new concepts. Both of these are characterized by an explicit interdisciplinarity and an intrinsic multitude of approaches.

Probably it was the spectacular and rapid advance of Quantum Mechanics and Relativity that attracted attention away from the developments of nonlinear science in the turn of the previous century. Indeed, it is commonly believed that classical determinism had to be revised after the advent of the uncertainty principle[1] and the ever present, fundamental in nature, "quantum leaps". But this statement, although commonly accepted, tells only the story from the viewpoint of Quantum mechanics. As John C. Sommerer, one of the very early workers in chaos theory, put it:

To cast the situation as a mystery, classical determinism was widely believed to have been murdered (maybe even tortured to death) by quantum mechanics. However, determinism was actually dead already, having been diagnosed with a terminal disease 10 years earlier by Poincaré. Having participated in a very late autopsy, I would like to describe some of the findings.[7]

What the renowned mathematician Henri Poincare diagnosed was that classical systems with a given degree of complexity, due to the nonlinear interactions present among their parts, give rise to very complicated motion. Today we have arrived at calling this kind of motion -- which he first encountered -- `chaotic'. In the case of t Poincaré, the system at hand was the celebrated `three body problem' within the setting of classical Newtonian gravity. Poincaré's investigations inspired another famous mathematician of those days, Jacques Salomon Hadamard to study a more general setting for this phenomenon.

---

[1] From the Wikipedia entry: "In quantum physics, the Heisenberg uncertainty principle states that the position and momentum of a particle cannot both be known simultaneously. The more precisely known the value of one, the less precise is the other."

Hadamard probably was the first to articulate what we now call `sensitive dependence on initial conditions' or `the butterfly effect' -- that hallmark of chaos. Indeed, it was in the year 1898, almost twenty years before the dawn of quantum mechanics, that Jacques Hadamard published his work on the motion of particles in surfaces with negative curvature, demonstrating that this motion is everywhere unstable [8].

In order to deal with the discoveries of Poincaré, Hadamard had to transcend the limitations of the mathematics of his era and to invent a novel method. He utilized a simple description of all the possible sequences, induced by the motion on the geodesics of surfaces with negative curvature. His idea was to project this motion onto partitions upon the surfaces in the regions and examine all possible trajectories of the visiting particle. By constructing a finite set of forbidden pairs of 'symbols' associated with each region of the partitioned surface, he subsequently showed that the possible sequences are exactly the ones which do not contain the forbidden pairs. Actually he was the first to introduce the new and powerful tool we now call 'symbolic dynamics' into the fundamental notions of discrete probability. That was to serve as a spring board for what later became *information theory.*

Although quite mathematical for the physicists of his time, this work proved to be rather fertile. It was later taken up by George David Birkhoff and John von Neumann in their work, during the early 1910's, on the so called “ergodic hypothesis”. The ergodic hypothesis is a key working hypothesis in statistics where it is -explicitly or implicitly- assumed that the average of a process parameter over time and the average over the statistical ensemble are the same. Which means that to observe a process for sufficiently long times is equivalent as observing a sample of many independent realisations of the same process. Further decisive progress came again through Henri Poincaré. He was concerned with the instability and integrability problems of dynamical systems and provided a celebrated result which further increased his fame even more by winning an important prize put forth by King Oscar II of Sweden and Norway. This contest consisted of several questions, one of them formulated by Karl Weierstrass and concerning “our understanding of the solar system”, in other words the “three body problem”: the Sun, Moon and Earth, attract each other thanks to Newton's gravitation law. Could a solution be found in a closed form, or just a form, manifesting in a converging series? Poincaré won, although his celebrated result is a negative one, because he managed to show that this particular motion does not have any conserved quantity and thus is non-integrable(a). In his own creative way he made explicit the limits of classical determinism. Nevertheless, highlighting these limits, Poincaré's work opened up an area of research that enabled us to deepen our understanding of the solar system – exactly as that competition demanded. It also enabled us to deal with a wide class of systems with unstable motions. Poincaré based his approach on geometry and provided us with a wealth of techniques and concepts which are widely used today in chaotic dynamics. He is thus considered as the founding father of the theory of Nonlinear Dynamical Systems.

(a) *Actually what Poincaré showed is that what is called the Bernoulli* technique *of finding a conserved quantity cannot yield any conserved quantity reducible to the momenta and positions of the bodies. Curiously enough, a Finnish mathematician named Sundman was later able to find a series of the type Weierstrass had asked for. But Sundman's technique, though constructive, is useless for any calculation. So it remains undeservingly forgotten.*

The work of Birkoff, Poincaré, and others was almost equalled by Aleksandr Mikhailovich Lyapunov and his celebrated 'Russian School' in dynamical systems. Later on, Aleksandr Aleksandrovich Adronov, in his work on nonlinear oscillators, formalized and deepened the understanding of the particular class of planar dynamical systems and prepared the ground for the interpretation of the experimental results of Lord Rayleigh III, laid out in his famous treatise “Theory of Sound”, as well as those the Dutch physicist Balthasar van der Pol and the German engineer Georg Duffing on forced oscillators with friction. These latter works were later taken up by Lady Mary Lucy Cartwright and John Edensor Littlewood. While Adronov was “leading his group” in Russia, in the other parts of Europe this area of study was almost halted. The theory of Relativity and Quantum Mechanics were attracting almost all the attention.

Yet, although the1910-1950 period was generally stagnant in the area of nonlinear dynamics, even so some work paved the way to a renaissance in the field during the mid sixties. In a series of papers starting from 1921, Marston Morse presented a scheme for the enumeration of orbits in the class of systems considered by Hadamard. This body of work motivated the studies of Emil Artin, Gustav Arnold Hedlund and Heinz Hopf, which finally proved that motion of a ball on a surface of constant negative curvature was ergodic. One of the first physicists to realize the importance of these results was Nikolai Sergeevitch Krylov. He argued that a physical billiard ball is a system with negative curvature along the lines of collision. Later, Yakov Grigorevich Sinai showed that a physical billiard ball can be ergodic (the well studied `Sinai billiards').

After more than a century of development, today we come to appreciate a 'billiard' -- or a pinball, in modern terms -- as a typical example of a chaotic system [9]. Figure 1 illustrates the complexity of such a seemingly simple system. In describing the sequence of the trajectory of a test-particle visiting each disk here, complexity enters through the nonlinear relationship (the curved surfaces of disks) that develops among its parts (the disks). It is this aspect that renders the dynamics of such a system chaotic. If the reflecting surfaces were flat (i.e. rectangular boxes instead of disks) the system would be complicated but not complex -- the parts would uniquely define the whole as their linear superposition. Not so in complex systems. There the whole is more than its parts because of the intricate, non-linear, interrelations between parts and whole. Thus emerging properties are attributed to such systems.

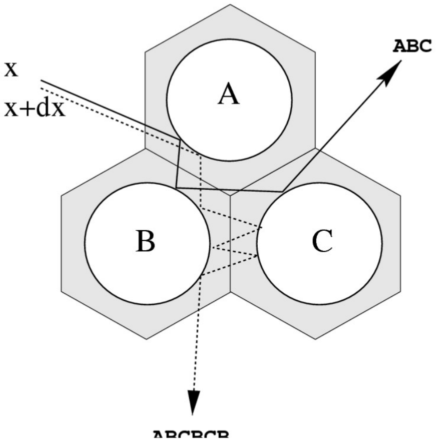

Figure 1. *Motion of a test particle in `pinball' serves as a simple, representative and very descriptive model for chaotic/complex systems. Complexity gives rise to chaos on account of the strong nonlinear relations among its parts. Here two initial points differing only by the slightest follow very different courses of evolution. One hitting the disks ABC the other bouncing around ABCBCB and going totally in the other way. This is the "sensitive dependence on initial conditions" or "butterfly effect" [7, 9,11] .*

4 Coming of the age of complexity.

The connection between deterministic causality and the stability so typical of classical systems did not escape, even in earlier days, the penetrating genius of James Clark Maxwell. Reflecting on the roots of causality, he wrote:

It is a metaphysical doctrine that from the same antecedents follow the same consequents. No one can gainsay this. ...It is not of much use in a world like this, in which the same antecedents never again concur, and nothing ever happens twice. . .The physical axiom which has a somewhat similar aspect [with this doctrine] is `that from like antecedents follow like consequents.[10]

Chaos and complexity studies have shown that the classical belief in determinism as a reliable source of prediction, represents no more than a fantasy. This fantasy stems from the Newtonian/Laplacian paradigm. As a matter of fact, it embodies something more than even a fantasy. It embodies a persistent fallacy in scientific and philosophical thought, which has lasted for over three hundred years. Pierre Simon Laplace's all-knowing daemon, the god of naïve reductionism, is symbolized in one of his most famous proclamations which appeared in his classic treatise *"Essai philosophique sur les probabilités"* (published in Paris in 1825):

. . . if we can imagine a consciousness great enough to know the exact locations and velocities of all the objects in the universe at the present instant, as well as all forces, then there could be no secrets for this consciousness. It could calculate anything about past or future from the laws of cause and effect.

A relevant discussion about the Newtonian/Laplacian doctrine and modern developments of chaos theory can be found in [11], (pp. 9-14). This Laplace's daemon prevailed as a paradigmatic bias which was overthrown only by Werner Heisenberg's uncertainty principle. What is of interest here regarding this principle is that on a different level, it speaks of complex systems as well. So let us follow Heisenberg's line of thinking. He states that:

In the strict formulation of causality -- `When we know the present precisely, we can calculate the future' -- it is not the final clause, but rather the premise, that is false. We cannot know the present in all its deterministic details. Therefore, all perception is a selection from an abundance of possibilities and a limitation of future possibilities.[11]

This is true for quantum mechanics on account of its ontologically probabilistic nature. But is it not also true of complex dynamics? Even if we think of them as ontologically deterministic, could we ever hope to know in perfect detail their precise initial conditions? If we ascribe to the fact that initial conditions are represented by the continuum of real numbers, can we pin down with infinite precision real numbers? How one can pinpoint an infinitely small point without using an infinite amount of information?

For the mind of the Laplacian god of naïve reductionistic mechanics, that would be definitely true. However, in any act of projection, such as measuring or specifying the initial conditions that we poor humans need to work with, we necessarily lose all absolute certainty, ending up with probabilities. We must stress, once again, that the above is unavoidable even if the laws are deterministic and our theories stipulating these laws turn out impeccable.

Definitely the vivid discussions over causality, determinism and quantum mechanics -- and relativity, to some extent – dealt with what chaos and complexity studies were whispering until the sixties and seventies. With the appearance of fractals, self-organization, emergent pattern-forming systems, and the realization that seemingly simple, deterministic yet non-linear, dynamical systems (which are, by the way, fully transparent to rigorous mathematical investigations) give rise to chaos, we now have entered a new frontier in science.

Actually, it is not uncommon scientific ideas to follow meandering pathways in the course of time. Sometimes re-surfacing and sometimes immersing back in the collective consciousness and behaviour. There is a multitude of reasons. Social, societal, competition for available resources between scientific communities, the appearance of influential scientific leaders, pressing technological demands and the like all contribute to what emphasis will be given at a given scientific quest at a given time. This is not an issue touching on the post-modern simplistic discussions about truth being a construction and the short-minded denial of the existence or not of objective truth. It is more an issue of “the truth about what in the service of what” as the philosopher Isabelle Stengers so radically puts it. The history of science provides a plethora of such instances[2].

Moreover these are not the only filters that are in play in the quest of truth, scientific or otherwise. Naturally personal bias, preconceived mental frameworks, emotional preferences, metaphysical conditioning, all paint decisively our picture of reality. Scientific endeavour is no foreigner to this fact, Francis Bacon's called attention to what he called the various “idola”

---

[2] Here is a curious anecdotal instance from antiquity: *Hero of Alexandria* and *Ctesibius* have had actually invented the prototype of the steam engine, but their contemporary administrators worried about the impact on labour. If engines were used to irrigate fields and for production, what the slaves will do? We do not need another Spartacus, was the counter argument of the politian to the scientist of the era. *“The Forgotten Revolution: How Science Was Born in 300 B.C. and Why It Had to Be Reborn”*, by Lucio Russo, Springer (2004)

(“idola” or “idols”, are illusions grouped in four categories: common to the tribe, particular to individual, due to language constraints or misuse and due to abuse of authority). In this encounter with our “idols” it is science that, according to Bacon's conception, will liberate us from their grip. Four hundred years after Bacon's we come today to realize that this is due to a fundamental faculty of our consciousness. We filter out our findings, we group and process them in order to carve out a place for us to be. As it is far more easy to see the biases of others, than our own (we see the speck of the eye to our brother but fail to see the plank in our own, as the parable puts it) it is far difficult to practice a science that reflects upon its own foundations. Today Emilios Bouratinos' treatment of *“self-locking versus self-releasing objectification”* ([12, 13], also his entry in this book) serves exactly this purpose. By proposing a method of developing science rather that yet another actual science it awakens us to our own biases. This cannot but broaden and deepen our understanding of our place within the greater reality that hosts us.

The lessons we are learning from this new era of emerging complexity studies are numerous and still continuing. One that we shall focus on is that we must be fully aware of what kind of objects we are dealing with. We looked through the microscope of quantum mechanics and we discovered an ever changing reality of dancing entities; we looked through the telescope of relativity and we shaw a plenum universe of energy field. Now that we are looking at the complex cosmos around us we might need neither microscope nor telescope. Nevertheless, we need to be aware of the color of the glaces on our eyes, especially if these glaces filter out and obscure the fact that this complex cosmos around us is ablaze with life.

The Complex and the Living

> Τό πᾶν ἀλλ' έστι τι τό ὅλον παρά τά μόρια
> (The whole is different from its parts)
> Aristotle, Metaphysica 1045a

Along with the Newtonian/Laplacian determinism, another bias which has prevailed was that animals, and for that matter the dogma that all living beings, are machines. The echo of the notorious Cartesian treatment of the animals as automata still remains with us alienating the human race from the surrounding life. Indeed a mere mechanical conception of nature leaves no place for life. And the inadequacy to deal with the fundamental question “what is life” has been haunting physical sciences ever since.

It is well known that many early workers exploring the foundations of quantum mechanics, like Wolfgang Pauli and Ervin Schrödinger, were preoccupied with the question 'what is life?'. Niels Bohr was the first to point out that a generalized complementarity principle, which he proposed in the framework of quantum mechanics, could be at work in the case of living systems. Indeed living systems are the most profound of complex dynamical entities. Ever changing in time, yet keeping a distinct sense of wholeness and identity, dynamically adjusting themselves, equipped with vast yet undermined information processes, they stand out on the highest levels of the hierarchies for both structural and dynamic complexity. Non-living complex systems could provide a stepping stone towards a renewed, richer and deeper understanding of the phenomenon of life. The one condition for this to happen is for us to avoid at all costs the straight-jackets imposed by pre-ordained paradigmatic thinking.

Revisiting Aristotle, though daring, may prove helpful in this respect. Aristotle maintained that plants are animals compared with rocks, but are rocks compared with animals. Something similar applies to complex systems and their emerging properties. As Leibniz, essentially, suggested the complexity[3] of a living being is infinite, while that of any man made machine cannot be but finite. The parts of an organism are made of other parts and these of other parts ad infinitum, whereas the parts of a part of a machine reach a point where there are no more parts in them. Machines are just made up by concrete objects, organisms are not, Leibniz reasoned. Indeed complex systems can be seen as more 'alive' compared to machines, but still complex systems viewed partially and in a reductionistic fashion remain sophisticated machines compared to living systems. Actually, nowadays we come to understand that the complexity of living process goes as far down as the macromolecular level and that quantum processes play essential role in life's molecules interactions. We know today that the basic biochemical processes of life, such as ligand binding, enzyme recognition, photosynthesis and metabolism are partially but essentially determined by quantum mechanical processes. Thus, we understand that the complexity of the living organisms has to be, for sure, infinite. Moving from the naive mechanistic logic of hard objects towards the sophisticated logic of living organisms, one should not be surprised if one finds himself going through a further logic – that of complementarity, self-reference and paradox. The case of quantum mechanics suggests as much.

The idea that complementarity can be useful not only in physics but in other areas as well -- particularly in biology (see [14], p. 87) -- was familiar not only to Bohr, but to other early thinkers in the field as well. As Walter Elsasser remarked as early as 1968:

> *"L. Brillouin has gathered a great many illustrative examples to show how in problems of classical physics any initial uncertainty increases with time. His work is clearly related to the fact that since the advent of quantum mechanics there have been the two schools of thought: those who tried to return to classical determinism and those who found in quantum theory a challenge for investigating all possible ramifications or generalizations of indeterminacy which may be part of physical description and prediction."*[15]

Brillouin's work belongs to the second category, so does Elsasser's, who had already investigated the implications of the generalized complementarity principle in the fields of statistical mechanics and biology [15, 16].

Since the discovery of the double helix of DNA and the genes carried within, biology's main dogma, the so called "Central Dogma", was that everything emanates from the genetic code.

---

[3] actually the term in his "Monadology", §64, of the year 1714, where this thought appears for the first time was closer to the word "intricacy". The word complexity was not widely used during this time.

The fact that there are other mechanisms at work which control gene expression and influence even the genetic material by catalytic actions, the so called “epigenetic networks” of biochemical reactions has only recently resurfaced. Their complexity and fundamental role in biology led modern biology to revise the domain of validity of its central dogma. And, when it comes to modern thinking in biology, no one has expressed the urgent need for a radical change more eloquently (and convincingly) than Richard Strohman [17]. Already from the mid-90s he had anticipated the 'surprising results' of the genome project, which became public knowledge around 2001. Building on the ideas of Goodwin [6] and others on the role of self-organization, nonlinearity and dynamic complexity in systems biology, Strohman developed a sound argument about the profound implications of complex systems studies for epigenetic networks. His main point was to challenge the underlying naive reductionist view of modern biology that 'everything is in the genes’. Indeed, he explained why no further understanding of molecular biological systems could rely 'on genes alone'.

Strohman realised that the nonlinear interrelations involved in gene expression necessitate a change in perspective that will influence the entire area of investigations. This radical change will help scientist move from an object-mediated view of biological systems to a system-wide understanding of dynamical processes. After the `surprises' generated by the conclusion of the genome project (when 'mainstream' biology was stunned to learn that humans have far fewer genes than expected in comparison to other simpler life forms) we now realize that a gene represents a functional unit acting in relation to a whole, and not an agent operating on its own in the DNA.

As Strohman put it when he introduced a collection of state-of-the-art publications dedicated to the topic:

> *“Human disease phenotypes are controlled not only by genes, but by lawful self-organizing networks that display system-wide dynamics. These networks range from metabolic pathways to signalling pathways that regulate hormone action. When perturbed, networks alter their output of matter and energy which, depending on the environmental context, can produce either a pathological or a normal phenotype. Study of the dynamics of these networks by approaches such as metabolic control analysis may provide new insights into the pathogenesis and treatment of complex diseases.”*[18]

In the above quotation we would like to underline particularly the concepts of self-organization, system-wide dynamics and network structure. These concepts rely heavily on the presence of non-linear interrelations within a complex whole. They reveal the fundamental relevance of the recent advances in complexity and statistical mechanics, which result from the seminal work of Albert-László Barabási and co-workers [19]. Although a deeper dynamical system's perspective is absent from these investigations of `life's complexity pyramid', as they call it, the authors themselves (as well as many others) maintain that such a step has to be taken -- eventually.

How this will be accomplished and where it will take our understanding of complexity, entropy, information and life remains, of course, to be seen. Nevertheless, it is certain that we can expect not just interesting theoretical breakthroughs in biology. We can also expect some fundamental questions to be raised about the logic and mode of thinking that permeates such investigations – like those raised by Walter Elsasser.

To return to Niels Bohr and his epistemological reflections: *"no experience is definable without a logical frame. Any apparent disharmony [among observed phenomena or levels of phenomena] can be removed only by appropriately widening the conceptual framework "*. It means that we must take on board the notion of Emilios Bouratinos' that there is a need to investigate the pre-epistemological level of conceptualisation. As he writes, *". . . modern science is constantly broadening, deepening and differentiating the world image. But if the world image is being constantly enriched, so must our ways of knowing it. . . "*[12, 13], (see also his entry in this book)

6 Pre-Epistemology: The Complex and the Subjective

The sciences of complexity and the entire field of complex systems' studies reject the notion of a monolithic paradigmatic description. They call instead for a creative interplay beyond and above paradigms. The challenge is to find appropriate levels of description to express any underlying hidden universalities.
This redefinition of the objectification scheme required for understanding any complex system, is not a question of just choosing the best model available. The situation calls for something radically different. We must find a way for articulating the fact that both the deterministic description and the probabilistic description of a given reality reveal aspects of its truth. Moreover, such nonlinear thinking makes us aware of the extent to which these partial objectifications can be considered as reflecting the system's realities.

Whatever the benefits of a paradigmatic conceptualization, it also brings limitations. Complexity forces us to reflect on our objectification scheme. Regardless of the kind of thinking this scheme arises out of (reductionistic, holistic, mechanistic, probabilistic, dualistic or metaphysical) any description filters and thus reflects only partial aspects of the unified picture of a complex system – and it does so only on one level of the abstracting structure required for portraying it.

One of the great twentieth century's mathematicians working on probability, Bernard Osgood Koopman, maintained that '*knowledge is possible, while certainty is not*'! As he wrote in 1940, *"both in its meaning and in the laws it obeys, probability derives directly from. . . intuition and is prior to objective experience"* [20]. As a result of Koopman's work, intuition and subjectivity can now be rehabilitated theoretically. But there is a condition: they must be practiced openly, knowingly and honestly (see also [12, 13]).

Furthermore we shall be able to cope with the lighting of intuition, not to shun away from it but bravely to embrace it. Since intuition strikes at this rare moments where our conceptual veils and mental filters suddenly cease to obscure the deepest nature of reality, its communication to others through language or paradigmatic thinking makes it seem a very subjective experience. Only a disciplined inquiry conscious of the rationalization process itself can produce convincing verification. Intuition, insight, instinct all might refer to the same faculty of our consciousness of occasionally lifting barriers obscuring comprehension. The ability to pass -on the basis of clues, pointers and bits and parts of given facts- from the unknown to the known in Sufi parlance is “firâsa”. Interestingly enough “firâsa” also means the instrument of conjectural knowledge. A conjectural knowledge, nevertheless, fully aware of its own conjectures.

Daniel Robinson, a distinguished professor of philosophy, is hosting and moderates a heated, ongoing, dialogue among neuroscientists about brain/mind studies, and he has chosen these words to stress the need of self-reflection in scientific practice when dealing with the complex realities of neuroscience:

“The cosmos is ablaze with facts, the great plurality of them beyond our senses and even our ken. Out of that fierce and brilliant fire, we pull a few bits -the visible or nearly visible ones- and begin to weave a story. On rare occasions, the story is so systematic, so true to the bits in hand, that other stories flow from the first, and then others, and soon we are possessed of utterly prophetic powers as to which ones will come out next. It is the philosopher, however, who must put the brakes on the enthusiasms of the story tellers, for left to their own devices, they might conjure a future that vindicates only our current confusions” [21]

It follows that the crucial question confronting us is: To what extent can we experience reality without being blinded by our preconceived ideas about it? How can we be free from our own projections if we deny their very existence?

Outlook

The sciences dealing with complexity find themselves at a crossroads. According to some sceptics, the very notion of complexity is ambiguous. Furthermore, the sceptics believe that it has given rise to a very ambitious project. They insist that its basic concept is far too all-embracing, holistic and blurred to ever become the subject of a proper scientific investigation. Needless to add that similar sceptical reservations had been raised in the past against the study of Time and Space, Entropy and Information, Cognition and Consciousness. Sceptics in science frequently want to fit reality into their static vision of science. But the real challenge for investigators would be to fit their vision of science into the dynamics of reality. We shouldn't allow our concepts to fashion the picture of the world. Rather we should allow the essence of the world to fashion the nature of our concepts.

Scientific thinking today has reached a stage which doesn't compare with that of any other in its history. The feeling is that Complexity and Emergence, Time and Space, Entropy and Information, Cognition and Consciousness are now at the forefront of fundamental research in the physical sciences. Despite that, these realities cannot be defined in exclusively objective and quantitative terms.

The reason is simple: they also constitute the ultimate prerequisites for the observations carried out in their name. You need to have emerged into complexity to become aware of its operation;

you need to be in time and space to observe their function, or even their occasional absence; you need to be experiencing entropy to sense it; you need to be properly informed to be in a position to assess information; you need to be cognizant to cognise; and finally you need to be conscious to know the significance – and operations -- of consciousness.

In our times the very foundations of what we perceive as a properly established epistemological ethos have been cast in doubt. This calls for a radically new kind of science -- one that can reflect on its own foundations. It also calls for a new kind of scientists. They need to be aware not only of their limitations, but of their objectifications. In addition, they need to be familiar with the relative merits of different, complementary, or even seemingly contradictory approaches to their subject-matter.

Never before has the need for qualitative change in science been so apparent and pressing. The importance of complexity studies lies in that it has made such a radical change not just possible, but imperative. It can only directly inform and inspire the struggle for introducing self-reflection into the practice -- and the understanding -- of science.

Acknowledgements

I would like to express my gratitude Robert G. Jahn, Brenda Dunne and Emilios Bouratinos, for inspiring discussions, sharing ideas and very fruitful comments. This chapter is widely based on author's [22].

REFERENCES

1. Thompson, D'Arcy Wentworth (1942) *On Growth and Form*, Cambridge University Press, Cambridge.

2. Barabasi, A.-L. (2002) *Linked: The New Science of Networks*, Perseus Books Group, Cambridge (MA).

3. Strogatz, S. (2003) *Sync: The Emerging Science of Spontaneous Order*, Hyperion, New York.

4. Haken, H. (2004) *Synergetics: Introduction and Advanced Topics* (Reprinted Edition), Springer-Verlag, Berlin.

5. Nicolis, G., and Prigogine, I. (1989) *Exploring Complexity*, W. H. Freeman, New York; see also Nicolis, G., and Prigogine, I. (1977) *Self-Organization in Nonequilibrium Systems: From Dissipative Structures to Order Through Fluctuations*, John Wiley & Sons, New York.

6. Goodwin, B. (2001) *How the Leopard Changed Its Spots: The Evolution of Complexity*, Princeton University Press, Princeton (NJ).

7. Sommerer, J.C. (1995) *The end of classical determinism*, Johns Hopkins APL Technical Digest **16**(4), 333-347.

8. Hadamard, J. (1898) *Les surfaces a courbures opposées et leurs lignes geodesiques, Journal de Mathematiques Pures et Appliquée* 4, 27-73.

9. Cvitanovic, P., Artuso, R., Mainieri, R., Tanner, G., and Vattay, G. (2005) *Chaos: Classical and Quantum*, Niels Bohr Institute, Copenhagen, available on http://www.ChaosBook.org. (Open Access)

10. Mahon, B. (2003) *The Man Who Changed Everything: The Life of James Clerk Maxwell*, John Wiley & Sons, New York.

11. Peitgen, H.-O., Jurgens, H., and Saupe, D. (1992) *Chaos and Fractals: New Frontiers of Science*, Springer-Verlag, New York-Berlin.

12. Bouratinos, E. (2005) *A new conceptual framework for physics*,in R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective, World Scientific.

13. Basios, V. and Bouratinos, E., (2006) *Gödel's Imperative for a Selfreflective Science,* Collegium Logicum Vol. **9**, publication series of the *Kurt Gödel Society*, Vienna.

14. Jammer, M. (1974) *Philosophy of Quantum Mechanics*, John Wiley & Sons, New York.

15. Elsasser, W.M. (1968) *Theory of quantum-mechanical description*, Proceedings of the National Academy of Sciences (USA) **59**(1), 738-744.

16. Elsasser, W.M. (1937) *On quantum measurements and the role of the uncertainty relations in statistical mechanics*, Physical Review **52**(1), 987-999.

17. Strohman, R. (1997) *The coming Kuhnian revolution in biology*, Nature Biotechnology 3, 194-200.

18. Strohman, R. (2002) *Maneuvering in the complex path from genotype to phenotype*, Science **296**(5568), 701-703.

19. Oltvai, Z.N., and Barabasi, A.-L. (2002) *Life's complexity pyramid*, Science, **298**, 763-764; and also, among many, Albert, R., and Barabasi, A.-L. (2002) *Statistical mechanics of complex networks*, Reviews of Modern Physics **74**, 47 – 97.

20. Koopman, B.O. (1940) *The axioms and algebra of intuitive probability*, Annals of Mathematics **41**, 269-292.

21. Daniel Robinson (2007) in his conclusion of *"Neuroscience and Philosophy: Brain, Mind, and Language"* Columbia University Press, NY, 2007.

22. V. Basios, *Encountering complexity:in need for a self-reflecting (pre)epistemology,* in R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 499-518, (2005)