CONCEPTION OF PARADIGMS 
EVOLUTION IN SCIENCE — 
TOWARDS THE COMPLEX 
SYSTEMS APPROACH

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ABSTRACT:
The article shows a wide depiction of conception of paradigms evolution in science and surrounding reality. The presented approach is based on a new formula of system paradigm approach, which assumes wide depiction in analysis, description and synthesis of real systems as complex systems governed by long-range dependencies in space and time domain. A process of deepening science knowledge within a given time is strictly connected with ruling paradigm of perceiving reality; each paradigm change is based on a scientific revolution and leads to the change of reality perceiving and science problems too. It seems that the lack of awareness of this process itself and its consequences don't allow to have a wide depiction of many scientific problems.

Keywords: paradigms evolution, complex systems science.

RESUMO:
O artigo demonstra o grande descrição da evolução dos conceitos dos paradigmas da ciência e a realidade circundante. A visão apresentada é baseada numa nova fórmula do sistema de encarar o paradigma, que assume uma grande descrição em análise, expõe e sintetiza o sistemas reais como sistemas complexos governados por dependências a longo prazo em espaço e tempo. Um processo de aprofundar conhecimento, num determinado período de tempo, na ciência está intimamente ligado com o paradigma governante de realidade percutiva; cada mudança de paradigma é baseada numa revolução científica e leva à mudança, da
realidade percebida e também dos problemas da ciência. Parece que a falta de consciência deste processo e as suas consequências não permitem ter uma descrição larga de muitos problemas científicos. Palavras Chave: evolução de paradigma, ciência como sistema complexo.

RESUMEN:

El artículo demuestra la gran evolución concepción de los conceptos de los paradigmas de la ciencia y la realidad circundante. El enfoque presentado está basado en una nueva fórmula de enfoque del paradigma, que asume una gran descripción en análisis, expone y sintetiza sistemas reales como sistemas complejos gobernados por dependencias a largo plazo en espacio y tiempo. Un proceso de profundizar el conocimiento, en un determinado periodo de tiempo, está íntimamente relacionado con el paradigma gobernante de realidad perceptiva; cada cambio de paradigma está basado en una revolución científica y lleva al cambio, de la realidad percibida y también de los problemas de la ciencia. Parece que la falta de consciencia de este proceso y sus consecuencias no permiten tener una amplia descripción de muchos problemas científicos. Palabras-Clave: evolución de paradigma, ciencia como sistema complejo.

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1. INTRODUCTION

The eternal human eager was, is and will be the problem of understanding himself and the surrounding reality. This matter can be viewed in different time and space scales. From the beginning each human generation has created special "intellectual space". In such a case, because a lot of generations were before ours, one can say that a phenomenon is in a macro scale, and from the time point of view this process is a long-term one. But this major intellectual oeuvre of previous generations can be quickly understood by one a man from the next generation i.e. in a micro scale. Paradoxically in a time scale it will be a short-term process. People's intellectual achievements are nested, i.e. previous generations' achievements are understood and modified by actual generations, which pass their own achievements to their descendants, etc. The whole process has got a self-similarity property (Peitgen et al. 1992).

It is well known that self-similarity is a property that is directly connected with fractals. Benoit Mandelbrot gave such a definition of fractal (Mandelbrot 1982): "a ( ) shape that can be subdivided in parts, each of which is (at least approximately) a reduced-size copy of the whole", so fractal geometrical objects are spatial self-similar while fractal time series have got statistical self-similarity property. Sometimes the notion "spiral path of evolution" is, in a sense, the self-similar structure not only by its geometrical self-similarity but also by special character of the history expansion in time.

In the expansion of different parts of science or engineering there also can be noticed the self-similar stages, which starting from the static and the linear models, through non-linear ones, now concerns modeling of dynamical, physical phenomena nested in the previous educating layers.

The self-similar path of science evolution results directly from changes in perception of the reality by a human. From taxonomical point of view there can be pointed a few crucial periods, ruled by different scientific conceptions: chaos, teleology, determinism, stochastic and general systems theory. In 1962 Thomas Kuhn published his famous work "Structure of scientific revolutions" where for the first time he used the term paradigm (Kuhn 1962). One should understand this notion as an intellectual model that presents
a level of human reality understanding at a specified stage of his evolution, but even Kuhn explained the meaning of this word in twenty different ways. According to Kuhn's conception in science there are periods of "normal science" and some specific moments when scientific revolution appeared. Periods of normal science are connected with the specific view and approach to scientific problems solving based on actual achievements. However, a special moment sometimes appears in time when actual scientific conceptions, such as each model, exhaust their possibilities, goes in a critical phase and scientific revolution comes — dynamical transition to the next stage. Classical example of such transition was the beginning of XX century. In 1900 William Thomson (Lord Kelvin) said that: "There is nothing new to be discovered in physics now; all that remains is more and more precise measurement." Five years later, in 1905 Albert Einstein published his three famous works and among them special relativity theory, which soon became ovule of the scientific revolution.

At which stage of reality understanding is human being now and what model should he use to be able to fully understand actual science and the surrounding reality? It seems that now we are bystanders of the complex systems paradigm stage, but it is worth present the previous paradigms of the world understanding, because they still shape our actual vision of science.

II. PARADIGMS EVOLUTION

The first, earliest approach concerns a prior phase of human development when the nature was perceived as rampant creation and omnipotent chaos was ascribed by caprices of powerful and inconceivable demons that govern it. Relating to the Greek mythology Chaos (gr. Χάος) was treated as the beginning and the source of everything in the whole world. From Chaos eternal darkness first arise and gods that govern darkness (Erebus, gr. Ἐρεβος), night (Nyx, gr. Νύξ), light (Aether, gr. Αἰθήρ), day (Hemera, gr. Ἁμερα) and Earth was also born (Gaia, gr. Γαῖα), abyss of netherworlds (Tartarus, gr. Τάρταρος) and love (Eros, gr. Ἑρως). It was considered that it was only possible to influence on them by magical practices or by counting on their favor. At that stage of development
no one realized laws that governed nature. They were like something inconceivable, enigmatic and formidable.

The second stage can be associated with the birth of philosophy and science derived from it. This process can be identified with the perceived by Greek world order (*cosmos* – gr. κόσμος – order, world structure), which can be straightened out by the reason and one can influence it by any rational action. The philosophy of Aristotle, who wrote in his *Metaphysics* wrote that (Apostle 1966): “the whole is more that sum of its parts”, it’s being a part of this formula and in excellent form expresses context of spatial perceiving of systems. Aristotle introduced also notions: holism and teleology. The term holism (gr. ὅλος) stands for a view that according to it phenomena should be expressed holistically and organically. The whole thing can’t be expressed by the sum of its parts and the world is subjected to evolution, during which new wholes emerge. The term teleology (gr. τελεος = achieving goal + λογος = exploration, examination, study) signifies that developing processes in nature and society head towards the realization of some final goal. Aristotle also pointed out the time conditions of the system. As a matter of fact during European scientific revolution Aristotle teleology was rejected but all the ideas included there don’t lose on their actuality and now even gain more. The best proof is the appearance of interdisciplinary area of science – the general systems theory (von Bertalanffy 1968, Klir 1969).

What is more, next, the third stage can be associated to the determinism and the differential equations paradigm. Determinism (lat. determinare – to separate, to restrict, to describe) is a view that assumes the dependence in the universe between actual and previous states (theretofore describes following); basis of physical, biological, psychological and sociological theories that postulate unambiguous phenomena predictions; in methodological sense: principle that explains regularities in physical, biological psychological phenomena in contradiction to randomness (Maryniarczyk 2000). The basis of determinism is a belief of possibility of existence strict and common laws that determines reality. The conception of determinism appeared in ancient times: Thales from Miletus thought that swing water was the reason of earthquakes; Parmenides justified how mind determines being and Democritus suggested that determinism should be a being of the mechanistic conception of the world. Gradual evolution of conception towards the mechanistic...
determinism achieved its apogee when Thomas Hobbes assumed that in the world exists only the mechanistic body action and Baruch (Benedictus) Spinoza announced his theory of common order: reality consists of reasons and results connected by necessity. However, Blaise Pascal showed the necessary connection between object states where starting state unambiguous sets its future state. Pierre Simon de Laplace, who thought that the actual state of the universe is a result of previous ones, developed this form according to the rule, which states that if a human knew at some moment all forces in nature and placement of all beings and calculate them, he would have formula for the movement of the nearest scope; everything will be certain, future and present will be obvious (Maryniarczyk 2000). Mechanistic determinism describes a history of phenomena and processes by functional depiction, which in a mathematical language is presented for example by different types of equations.

The third stage of the paradigm change became when the analytical research methods were applied: classical science was separated from philosophy. Teleological cosmos was superseded by phenomena description that can be described by a mathematical form. There was accepted the reductionism rule (von Bertalanffy 1968, Cempel 2005) introduced by René Descartes and Galileo Galilei, which states that: "each problem should be divided into so many small parts, that is possible". However, this approach is proper when analyzed processes don’t evince long-range dependencies and feedback i.e. can be separated into independent casual-effect relations. Thanks to this approach in the XVIII century it was assumed that science achieved such a high level that little would be discovered and nineteenth century physics, as it was mentioned before, were convinced that their only actions would be more and more precise calculations of some physical constants. Mankind started to think that discovered unvarying laws of nature precisely, once and for all, could determine a movement of each part of the universe, whose future can be exactly calculated. Karl Deutsch, who said that (Deutsch 1951): "( ) mechanism springs to mind notion of the whole exactly equal to the sum of its parts; mechanism can be moved in opposite direction; it always behaves exactly the same no matter how frequently it is decomposed and again composed, no matter of order in which it was decomposed. In mechanistic setup parts don’t undergo important changes neither interaction, nor their own past and each part is in the right place with proper momentum"
and will be in this place and instantiate its specific function in unambiguous and full manner?, aptly decrypted essence of this idealistic, mechanistic model of world (see Fig. 1).

Figure 1: Mechanistic model – a synchronized cogwheels. This combination of the cogwheels can be moved into both directions.

It is easy to see that the analysis of such imaginary model required many simplified assumptions, such characteristic case is the problem of Newtonian mechanistic model of movement of celestial bodies, which models The Solar System that consists of many bodies, but most of them are missed assuming that their influence on the whole system is very small. If one wants to estimate the scale of difficulty of full analysis that takes into account all system elements, it should be for example assumed that system consists of \( n \) elements. Then \( 2^n \) equations are given i.e. even when \( n = 10 \) exist \( 2^{10} = 1024 \) equations. Newton’s theory is based on linear variables relations and assumes that each cause corresponds with an immediate result, and each system searches for its equilibrium and also that nature is ordered. However, Henri Poincaré (Poincaré 1952) said that even for the problem of three bodies interaction one solution can’t be found, thus nowadays taking differential paradigm isn’t possible to give the exact description of cooperation of three ore more companies, servers, crossroads, don’t even mention human society, because in the surrounding reality appear mostly
phenomena that are nonlinear and dynamic. They are characterized by high sensitivity of changes of the initial conditions and critical levels (Lorentz 1963).

The fourth stage is connected with stochastic paradigm. Its basis is the central limit theorem and a theory of random walk connected with the Brownian motion (Mantegna and Stanley 2000). This denotes that the assumption of independence of events in the system, i.e. processes that became in previous time moments don't have any influence on the processes that will become in the future moments. Hence, one can expect the normal distribution with a stable mean and finite variance. If the probability distribution of the process (system) events is in a basin attraction of Brownian motion (Mantegna and Stanley 2000), modeling can always be based on one or multidimensional random walk. In such a case the differential equations are reduced to the analysis of a simple structure with a few degrees of freedom. However, they are useless in the analysis of more complicated structures with many degrees of freedom. The scale of complicity of microscopic approach can be presented when analysis of gas movement is taken into account — 1mg of gas has got $10^{20}$ particles. In this simple, as one can think, example writing of such equations and its solution is practically impossible. Because no one was able to do this with microscopic analysis of the system the macroscopic analysis was developed. It was based on the average values that represent the "coarse grain" properties of the parts movement and stayed in the thermodynamical equilibrium state. In this context the mechanical statistics and the stochastic paradigm should be mentioned. However it turned out that the normal distribution is the particular case, one of the possible power-law distributions, sometimes called self-similar (Mantegna and Stanley 2000). The first one, who showed such distribution, was Vilifredo Pareto (Pareto 1897). This topic was continued by Paul Lévy (Mantegna and Stanley 2000, Lévy 1937), who introduced the general central limit theorem and the whole class of the $\alpha$-stable distributions that has slowly (power-law) decaying tails. In such a way he commented the fact that the probability of finding a person, who is ten times higher than the other one is limited (matches to the normal distribution), but the chances of finding someone who is a hundred times richer than others is much bigger than from a normal distribution. He also embarrassed many statistical mechanics because the power-law tails means infinity of their moments (mean,
variance) and in closed systems infinite variance means infinite value of temperature (Mantegna and Stanley 2000). In this place it should be underlined, that the basis of these deliberations is the classical statistical mechanics connected with conception of the entropy in a form that was proposed by Boltzmann. Now it is known that Boltzmann entropy is only a particular case and can be in an easy way expanded to the non-extensive form (Tsallis 1988), which perfectly does with the problem of the infinite value of the second moment by the use of q index.

The fifth stage is connected with the general systems theory and results of contestation that some systems futures don’t depend on the character of particular subsystems, but have rather a general character and concerns different domains: economy, biology, meteorology, etc. However, the power and success of the classical science caused that change of basic paradigm that turns to “single track” dealing with causality and whole decomposition seemed to be expendable. Meanwhile, according to the increasing concentration of research, appeared a partitioning of science and more and more similar disciplines. The efforts of perceiving different systems in isomorphism and homomorphism categories were the reaction to this increasing division. The creator of the general systems theory, biologist Ludwig von Bertalanffy, wrote (von Bertalanffy 1968): "Because basic future of living being is its organization, traditional methods of research of the particular elements and processes can’t give comprehensive explanation of the life phenomenon. Such research doesn’t give any information on the coordination of particular parts and processes. Thus, the main task of biology should be discovering laws, which govern biological systems (at all levels of organization). We think that the endeavors of finding basis for theoretical biology leads to a fundamental change of the world’s view. The properties and ways of action at higher levels of organization can’t be explained by summing properties and ways of action of its component parts. However, when we know a set of component parts and relations existing between them, the higher levels of organization can be described by their elements.”

Independently of the emergence, after the Second World War, of the general systems theory the cybernetics also appeared (Ashby 1956). Its creators also contested the mechanistic paradigm, which assumes that the universe works according to “the rule of random action of anonymous elements”. They pointed out a need for
“searching for new basis, new conceptions and methods that allows to consider congeners and organisms like the whole” (Frank et al. 1948).

The last, sixth stage is connected with the complex systems paradigm, in which, in contradiction to the others, long-term time factor should be taken into account. Harold Edwin Hurst (Hurst 1951), who was hydrologist and in the first half of XXth century worked in Assuan at dam of the Nile River, did the breakthrough (Fig. 2). The starting point of his analysis was an effort to model an ideal reservoir that never dries up and also never overflows according to known model of the random Brownian motion that was published by Albert Einstein in 1905 (Einstein 1905) (similar model was earlier, in 1900, used by Louis Bacheliér (Bacheliér 1900), who created a model of the stock valuation). This model assumes that process analyzed in time is influenced by so many independent events with the same probability of distribution, that it is a structure without memory with features typical of a process with the short-range dependencies and, when analyzed in the statistical categories, is similar to the white noise. Such process has got so many degrees of freedom that can be described only by a model of the random walk, which is being a part of the aforementioned before stochastic paradigm. Of course such assumptions were results of so far ruling conception of the classical statistical mechanics and also were necessary to justify the use of the central limit theorem that next allows the use of the Brownian motion model.

Following this way of thinking, in a period that proceeded H. E. Hurst’s studies, the assumption was taken that water, which comes from many sources and rivers in the whole Nile River basin (and not only), undergoes the random walk model was taken. At first sight this assumption seemed right, but required the acceptance of the mentioned above conditions. However, the geographical location and the historical background of the conducted studies were quite specific and had a main influence on Hurst’s results. If the analyzed time series were random, range of the water inlet changes should be proportional to the square root of time i.e. \( r^{0.5} \), but effects of confrontation of the theoretical model and the empirical data inspired Hurst to give a proposal of his own model, where parameter (index) \( H \) was crucial. It was, by offspring, called to honor Hurst, the Hurst exponent. The general model of random walking was introduced, called also the fractional random walking, in which basic change is
transition from $\frac{1}{2}$ to $H$. Benoit Mandelbrot lately called this model the fractional Brownian motion (Mandelbron and van Ness 1968, Mandelbrot and Wallis 1969). It is a model that is based on the long-term (or long-range) dependencies. Hurst also discovered that the great amount of the natural systems don't undergo the Gaussian random walking. Most of the natural phenomena, such as river flooding, temperature and rainfalls undergo fractional random walking, which, after Fourier transform implementation, in the frequency domain is described by the excess 1/f noise.

1/f noise should be understood like a non-classical clock mechanism (Grabowski 1990). The mechanistic approach assumes that the clock frequency $f$, imposed by the clock constructor, is constant. This means, for example, that frequencies of rotation of each rigidly connected cogwheels is determined strictly and once for all. In the case when between cogwheels small stone falls the device stops or gets damaged. In the stochastic approach small deviations of the clock working frequency are admitted; it can be understood as some kind of “skid” of the cogwheels, which is strictly limited by the variance or the standard deviation (Fig. 3).
Figure 3: Not all elements of the real complex system are rigidly connected. Thus "skid" and dispersion of rotation of the wheels appears.

In the case of the universal universe $1/f$ type clock frequency $f$ of each particular elements of the whole system flexible adapts to the conditions according to the self-organization rule and the dispersion of frequency i.e. cogwheels "skid" (wheels aren't connected rigidly) is high; its distribution is governed by power laws (Grabowski 1990). The intrinsic feature of the $1/f$ processes is that they represent the inward properties of the system dynamics and often can be measured in noninvasive ways. The existence of such spectrum means that processes aren't short-range dependent and the last studies showed that the noise model behaves excellent with the assumption of the superposition (Grabowski and Strza lka 2005).

It is also worth mentioning the discovery of the deterministic chaos in the seventies the XXth (Peitgen et al. 1992, Lorentz 1963). The chaos it is a notion that was for the first time introduced in Tien-Yien Li and James A. Yorke work (Li and Yorke 1975). Chaos is one of the most frequently existing forms of reality, which can be often sustained and, as it turns, it is only an ostensible disorder. Chaos appears everywhere where in equations, which describe real systems exist nonlinear terms or the possibility to have results of the measurements with sufficiently large precision (i.e. infinite precision) doesn't exist. In reality it is some kind of system where case and necessity, complexity and simplicity coexist and act together to create a new quality.
3. CONCLUSIONS

Taking into account both deterministic and stochastic approaches in terms of the classical Brownian motion or the white noise there were still considered only the special cases, limited in time and space, according to the simple system paradigm. Universe, human organism, economy, weather, earthquakes, ecosystems, epidemics, computer systems, etc. can't be fully understood when one takes into account only their separate parts. Mankind, taking into account a view based only on the classical clock mechanism, gets wrong assuming that the deterministic equations lead to the regular behavior. There is a question: do people really understand the universe taking into account the progress in technology? The elements of technology, such as for example computers, are important achievements. But they are rather the approach to build their own micro world, which is so simple that we are able to force it to do, which was intended, than to provide the understanding of the universe. The main goal of the technique is to work quasi-deterministic. In technology, similarly to the nature, it was understood or still wants to be understood, the functioning of particular elements, but rather no one understands the functioning of the whole system and the phenomena existing inside, their dynamics and functioning in the thermodynamical non-equilibrium states. Thus we still can't optimize and take full control interactions between servers and clients, mobile phone systems, information flow in hierarchical structure of the computer, the Internet network or computer programs. Similarly, we can't still give the solution of equations for the whole Solar System.

The spiral development path leads mankind to the general systems theory and its higher-level paradigm of the complex systems, starting from the chaos paradigm through the teleology and the determinism paradigm. However, especially concerning the spatial and the temporal conditions, studies in this topic show that recognized processes have also the self-similar (fractal) character and thus the self-similar path (philosophy) of the paradigms evolution in science was presented.
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