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CHAOS, TIME AND TEMPORAL NUMBERS

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ABSTRACT

The concept of time differs significantly in philosophy and the humanities, on the one hand, and mathematics and physics, on the other. Mathematics and physics traditionally focus on reproducible periodic processes for the purpose of predicting their results. Philosophy and the humanities mostly consider time as a historical irreproducible flow of unique events that create history and the unique development scenario. An important scientific issue is to converge of both concepts, which is possible due to the modern views on the deterministic chaos theory. The concepts "dynamic set", "true", or "temporal" number should be used to adequately describe historical time. The characteristics of deterministic chaos processes with temporal numbers can be showed on an example of computational models of continuous cellular automata whose rules of transition between states include nonlinearity.

Keywords: Time, chaos, nonlinearity, foundations of mathematics, number, set theory, cellular automata, computational modelling.

INTRODUCTION

Time has always been remaining one of the most obvious givennesses and, at the same time, one of the most profound mysteries of nature. It has traditionally been one of the major research objects in philosophy and cosmology. Time is a complex category. Philosophy and physico-mathematical sciences interpret this concept differently. In philosophical ontology, time is eventful, unique, and historical. In mathematics and physics, time is a quasi-geometric coordinate of fundamentally reversible and reproducible processes. Some approaches to converging these positions emerged only in the twentieth century. The point of this convergence is the dynamic chaos theory resulted from computational iteration of simple deterministic equations containing nonlinearity. The characteristic unpredictability and emergence of this phenomenon came into collision with all previous mathematical physics aimed specifically at prediction and reproducibility. At the same time, synergetics and chaos revealed time to have another intrinsic property of being unique or truly historical in the system of physico-mathematical knowledge. This idea is more typical for the philosophical perception and understanding of time.

Chaos claims a very significant place in the new emerging post-non-classical scientific worldview (Stepin, 2013), which is largely conditioned by its ontological status of the beginning of all that exists and its intuitively perceived close interrelation with the nature of time.

Until now, mathematics has not developed any means of describing true historical time and related temporological emergence. At least, the basic concepts of the foundations of mathematics – number and set – are static. Therefore, the study of the ways to integrate true historical time into the foundations of mathematics as well as the development of mathematical means for describing temporological emergence are urgent scientific issues.

This task is of both theoretical and practical significance. The mathematical description of chaos and temporological emergence opens up the possibilities for describing psychic phenomena, origin of individuality, subjective properties, and ultimately consciousness itself. Having a mathematical language to describe historical time, we can build much more adequate mathematical and computational models of human-like social systems.

Chaos and related computational specifics

The transformation of the meaning of the time category in post-non-classical science is closely connected with the radical rethinking of the concept of chaos and utterly unexpected mathematical discoveries that led to emergence of post-non-classical science. The history of scientific knowledge has seen different views on chaos.

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The concept “chaos” was first used in ancient philosophy. Initially, the term was used in Hesiod’s texts and denoted some primal habitation of all that exists, pre-existing state of things. In the *Theogony,* Hesiod wrote, ‘First of all Chaos came into being; but next wide-breasted Gaia, always safe foundation of all… From Chaos were born Erebos and black Nyx...’ (pp. 33-34).

Back then, in the age of intuitive uncluttered perception of the surrounding world, the simplest observations resulted in surprisingly deep, prophetic ideas, many of which have not lost their relevance to this day. The idea of chaos, which is likely to have largely been adopted from cosmogonic myths, acquired new features in ancient philosophy. To Stoics chaos was not just a gaping ‘nothing’, but the protomatter, the primeval state of the world, out of which the universe eventually arouse... Losev noted, “Stoics took a significant step ahead by combining chaos as void and chaos as a principle of world life and life origin” (p. 429). Cosmogonic concepts of ancient philosophy are, to some extent, close to modern cosmological paradigm constructs.

Gradually, with extending knowledge of laws of nature and developing Christian dogmas, chaos was replaced by logos and marginalized in the worldview. It became the negative beginning of the universe similar to Tartarus, a companion of the abyss, decay and death (Voloshinov, 2017; Kulik, 2014).

In the Renaissance, there was a revival of interest in ancient science and philosophy, which were rethought with a new spin of development of knowledge. The Kant-Laplace nebular hypothesis represented a self-organizing paradigm of the universe’s origin. In fact, it was a concept of self-organization of the Universe, and chaos was assigned a key role as the *universal Beginning*. Besides, in his work Kant (1755, 2009) argued the intuitive *conservation of complexity principle*, which is widely accepted to this day. According to this principle, the complexity cannot emerge spontaneously from the simple form, without the intervention of an external organizing cause.

Together with mechanics, science started developing probability ideas, which were precursors to the era of non-classical science. Due to discoveries in physics of microcosm, quantum uncertainty, the worldview lost its image of a well-tuned, once and forever started clock mechanism. ‘The universe endures,’ Bergson (1911, 1998) wrote (Fredkin, 2003): ‘The more we study the nature of time, the better we understand that duration means invention, creation of forms, continuous elaboration of the absolutely new.’ (pp.47).

The final rehabilitation of chaos and its return to the status of the fundamental principle of the universe took place in synergetics. Chaos was no longer a symbol of the triumph of indeterminism, decay, and heat entropy death, but rather a creative beginning of the universe, the fundamental principle of historical time and the source of creative evolutionary innovations. Prigogine (1980, 1985) distinguished the physics of the being and the physics of the becoming. He explained the concept of the arrow of time by connecting it with the second law of thermodynamics, and emphasized the role of small fluctuations in the dynamics of systems in the neighbourhood of bifurcation points. Prigogine (1980, 1985) paid a particular attention to the microstructure of space-time, emphasizing its temporality. One of Prigogine’s main ideas (Prigogine and Stengers, 2003) was the introduction of the time operator, as well as the fact that irreversibility becomes a fundamental property of matter yet at the level of the microcosm. Prigogine and Stengers (2003) saw probability as an objective deterministic phenomenon, as an integral property of our world, rather than as a measure of ignorance that had long been the standard in physico-mathematical sciences. The re-discovery of time in the 20th and 21st century science originated in his studies. True historical time began to appear in nonlinear dynamic mathematical models of physical systems. There came a new understanding of the principle of determinism and the organization of the universe as a whole...

Due to the development of computer sciences and advances in computer technology, ideas of digital physics and digital philosophy were developed in science (Mikulin, 2016; Fredkin, 2003). Digital physics and philosophy hold that the universe is computable and everything that happens there can be reduced to various computational algorithms (Wolfram, 2002). This paradigm is the basis of all modern physics and science as a whole. There is no doubt that the development of the universe can be presented as a colossal computational process. We can see the results of objective calculations of nature everywhere. The entire botany is essentially nothing but a collection of recursive algorithms generating various fractal structures. All plants are nothing but recursive fractals that emerge in the process of objective cellular computations (Goethe, 1790, 1957). However, even genetically identical cloned plants are not completely morphologically identical. This is due to the fact that no computational procedure takes place twice absolutely identically in the universe. Dermatoglyphics of identical twins is different. Patterns on fingers and virtually the entire fine structure of organisms, including the network of vessels and neural ensembles of the brain, are formed individually, even in case of the individuals’ genomic identity.

It is necessary to introduce the concept of *true or temporal numbers* to understand better and explain this fundamental property of all processes in reality. Nature makes all its calculations in *true numbers*. In this context true or temporal numbers can be defined as follows: All the parameters included in a particular computational algorithm or process have unique values every time in reality, at each unique moment in *historical time*. We propose calling these values true or temporal numbers.

A glass of water boils at 100 degrees Celsius under normal conditions, but in fact, this never happens. Every single glass of water boils at a different temperature at each given time. These differences are negligible at a certain level of consideration, but they always are. Moreover, at the microscopic level of consideration the boiling of water in each individual glass is a completely different historical process.

Such differences can be ignored when solving certain problems within classical science. However, these factors become significant and even fundamental when considering the self-organizing evolutionary processes of development. The fact that nature performs calculations not with fixed accuracy, but in true or temporal numbers, makes the entire dynamics of the universe's evolution historical, creative, and unique.

In some cases, in order to get a good result and prediction, it is enough to substitute numbers with high, but fixed, accuracy into the computational procedure guessed from nature in the process of scientific cognition. However, often, the proximity of the values of the parameters substituted into the procedure is unimportant, their mismatch is what is important… Nonlinearity is a universal amplifier of the smallest differences in nature. The apotheosis of their significance is deterministic chaos, when even the highest proximity of initial conditions plays no role. The trajectories diverge very quickly and are completely dissimilar from one another.

True numbers carry an inherent time component, some kind of a unique marker that makes it impossible to accurately determine and reproduce the true number in principle. This is caused by the fact that the true number is instantaneous. Its exact value exists only at the moment of calculation and depends on the entire state of the universe at a given moment in time.

True historical time can be represented as parallel calculations with true numbers forming the history of the universe. The universe determines or calculates its new future state every time during these parallel calculations. The instantaneous indefinable accuracy of true numbers is not significant for some processes. This applies to the phenomena studied within classical science operating mainly with "smooth" mathematics. However, *nonlinearity* is a universal amplifier of the time information component of *true numbers*. True numbers carry the information about their unique spatial and temporal localization in the scenario of the universe's evolution.

Nature always makes its calculations differently. Some part of the true or temporal number always remains unknown to us. There are processes for which the bit significance decreases rapidly as they move deeper into the bitmap structure of the universe's computer. However, there are processes for which the bit significance does not decrease. And even the furthest bits can radically change their scenario. These are processes with deterministic chaos at their core. Thus, nature stores a huge information resource for its evolution, drawing information from chaos, hidden bits of true numbers and calculations of true time…

Periodic and chaotic processes associated with time

The stereotypical ideas of time as something measurable, as a property of reality firmly connected with regular periodic processes, are inherited from classical science. These ideas have prevailed in the exact sciences up till present. The ideal of time is considered an ultra-precise atomic clock, whose operation is based on ideally ordered, ideally periodic oscillations produced by objects of atomic scale. In general, these ideas are characteristic of non-classical science, too. All extremely precise experiments to verify the theory of relativity have been carried out with this very type of a clock. We will call it a *ticking clock*. Let us consider the phenomenon of radioactive decay. The decay of each atom is an unpredictable spontaneous event. Something happens in the nuclear substance, which ultimately leads to its "spraying". At the same time, there is observed a clear statistical pattern in the aggregate of decaying radioactive atoms, which can be used to measure time. In this case, we deal with *a cumulative clock* instead of *a ticking one*.

In this regard, it would be highly interesting to test the general theory of relativity using experiments with a cumulative clock rather than a ticking one. The main idea of such an experiment could be as follows. A certain amount of radioactive substance should be divided into two equal parts containing the same number of atoms. Then one part will be left on Earth, while the other being placed on some cosmic body, for example, an asteroid, in a low gravity environment. In a certain extended Earth time period, the numbers of remaining and decaying atoms in both portions should be measured. If the general theory of relativity is correct, these numbers should be statistically significantly different. We need to mention that the radioactive material selected for the experiment should have long enough half-life to eliminate the errors caused by flights and transportation. Obviously, we speak of a thought experiment that is both very expensive and problematic to conduct. However, similar bodies are likely to be found in the universe. Relativistic concentration gradients of decaying elements must be observed in dust clouds containing atoms of heavy elements and located in the areas affected by strong gravitational fields.

Mathematical foundations of temporological emergence

The understanding of time as a process of formation, every act of which is absolutely unique, has begun to penetrate and be perceived as such in the field of physico-mathematical knowledge recently. The concept of time in classical mechanics was reduced to the parameter and the t-axis relative to which graphs of reversible smooth and reproducible processes were constructed. For the first time, the understanding of time in the context of temporological emergence appeared and started to be recognized as a unique historical phenomenon in mechanics and physics only in the last third of the twentieth century. We mean chaos theory and nonlinear dynamics (Gleick, 2008).

Mathematics in its foundations remains completely static. Temporological emergence in the field of mathematical knowledge is absent. Moreover, the very paradigm of the foundations of mathematics sees temporological emergence as opposing to the essence of mathematical knowledge focused on identification, description, and study of reproducible order and strict causality. At the same time, the development of scientific knowledge is demonstrating more and more clearly that temporological emergence is also a manifestation of some highest and extreme form of order, which dialectically turns into its own opposite and necessarily supplements the very essence of the deterministic description of reality.

Let us illustrate this with an example. Imagine a perfectly regular cone and a perfectly regular ball falling on its apex (Fig. 1). The perfect cone is placed on the perfect plane, and the projection of the ball centre of gravity coincides with the projection of the apex of the cone up to some highest available precision. Where will the ball fall? The naive answer is that in the ideal case it will remain on the apex of the perfect cone and will not fall at all. However, this event has zero probability.

The Laplace's demon, determinism by Laplace (1814, 2011) has remained the basic causality paradigm for a significant part of the philosophical and physico-mathematical community. A true rethinking of Laplace's paradigm began only with the advent of chaos theory and synergetics. It is there that a new understanding of the essence of causality, regularity, and temporological emergence arises.

In the example considered, the ball will fall. But what will be the cause and source of unpredictability of its fall? Following the logic of the classical theory of probability, the ball cannot stay on the apex of the cone as the probability of the full coincidence of the real coordinates of the projections of the ball centre of gravity and the cone apex equals zero. One can speak only of probability density. However, some scenario will happen in reality (Fig. 2).

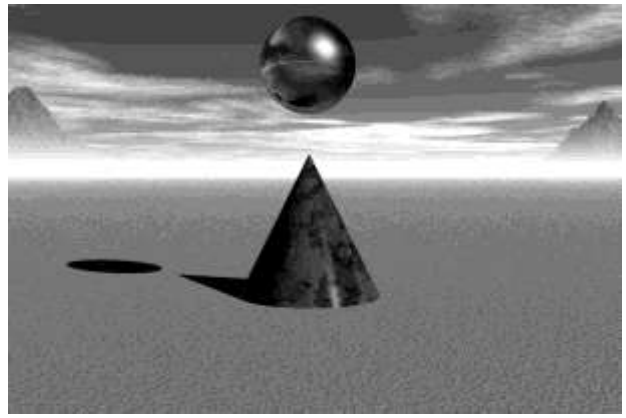

Fig. 1. The fall of *the perfect ball* on *the perfect cone.*

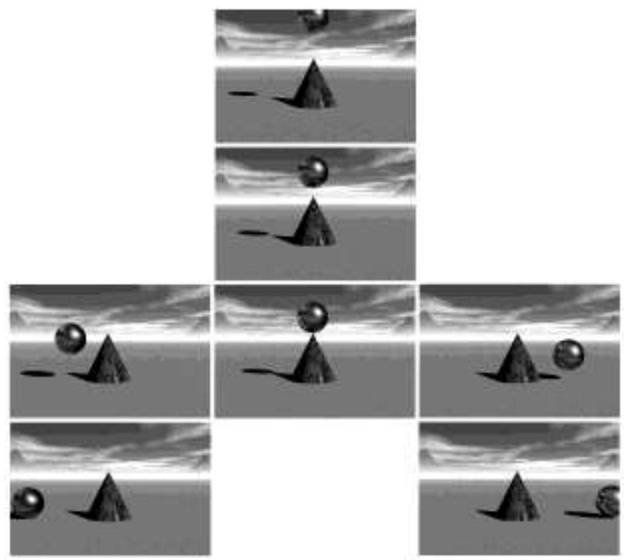

Fig. 2. Various scenarios of the ball falling.

We have already introduced the concept of *true or temporal numbers*. The source of probability in the example with the ball and the cone is temporological emergence that is difficult to describe by means of traditional mathematics. Temporal numbers allow us to describe this phenomenon. The essence of temporal numbers is that some part of them being beyond the accuracy of the specific calculations is unique and at the same time specific.

The founder of the Institute for Time Nature Explorations of Lomonosov Moscow State University (Levich, AP. On "dynamic sets". Retrieved April 11, 2019 from:

http://www.mce.su/archive/doc61551/doc.pdf) noted that mathematics at the set theory level was poorly adapted to describe changing systems, or, as it should be specified, temporologically emergent systems. Such systems include all the objects that are most interesting to modern science – brain, society, universe... Levich, in particular, posited the idea of developing a dynamic set theory in which membership would be a temporal, time characteristic.

There were attempts to expand and modernize a traditional mathematical set theory in the twentieth-century science. Zadeh (1965) introduced the concept of fuzzy or uncertain sets into mathematics. Fuzzy sets were intended to reflect real objects whose membership in a certain set could be expressed quantitatively in fractions as a special membership function associated with a fuzzy set. In this case, we talk about the sets conjugate to true time. The microstructure of these sets of true or temporal numbers is changeable and each of its time section is fundamentally unique. Processes resembling "boiling" constantly occur in the depth of these dynamic numerical sets.

The idea of a dynamic set theory correlates well with true or temporal numbers. The set of temporal numbers, therefore, could be considered as a dynamic set, the members of which would be unique whenever referred to. In a static sense, a dynamic set of temporal real numbers could be considered as a dynamically changing collection of subsets of the set of real numbers, which are like frames of an endless movie, or rather continuously changing and non-repeating ripple on an analog TV screen not connected to the antenna.

Thus, returning to the analogy with the ball and the cone, we can demonstrate that the concepts of temporal numbers and dynamic sets allow us to identify the causes and source of the unpredictable, but inevitable, fall of the ball. In this case, the temporal part of the number of real coordinates of the projection of the ball centre of gravity and the projection of the apex of the cone onto the plane will be of crucial importance.

The introduction of *true or temporal numbers* and dynamic sets enables an effective study and adequate description of the phenomenon of deterministic chaos, which plays a key role in the structure of reality, acting as the primary source of information for all evolutionary processes in the universe. The synthesis of information "from nothing" is actually a synthesis of information from the temporological emergence reflected by the mathematically temporal part of the true numbers.

At first glance, true or temporal numbers and dynamical sets contradict the very essence of the mathematical approach focused on reproducibility and repeatability of calculation results. At the same time, they bring true time in its historical understanding in the foundations of mathematics. The introduction of the description language of a time temporological aspect of reality into the foundations of mathematics opens the way to a mathematical description of the phenomenon of individuality, subjective sensations, phenomena of psyche and consciousness, which would be problematic or even impossible within the traditional set-theoretic paradigm.

Computational modelling of temporal emergence

The word size of a digital computer, which is a sequence of discrete binary bits, is fixed and limited. Due to this feature, digital computers are poorly adapted to represent real numbers. At the same time, real numbers are an important tool for the mathematical description of reality. There have been developed some techniques to represent real numbers in a digital computer memory. The most common technique is floating-point representation in the form of a sign bit, mantissa (or the significand) and a number order. At present, the technique of digital operations with floating point numbers is perfected and the calculations are made with the highest accuracy. The efforts of scientists and experts have always been aimed at minimizing computational errors. Meanwhile, they are fundamentally inherent. Nature goes the opposite way. Performing its calculations, the universe does not fight an inherent error, but, on the contrary, uses it for creating unique objects, acting out their fates, subjective sensations, time itself, and all of us. Due to the inherent computational error, floating-point numbers can, to a certain extent, serve as some approximation of temporal numbers. Let us explain this using an example of the three-dimensional continuous cellular automaton model with nonlinear transition rules. The main idea of the model is as follows. The cube is divided into equal cubic segments (Fig. 3).

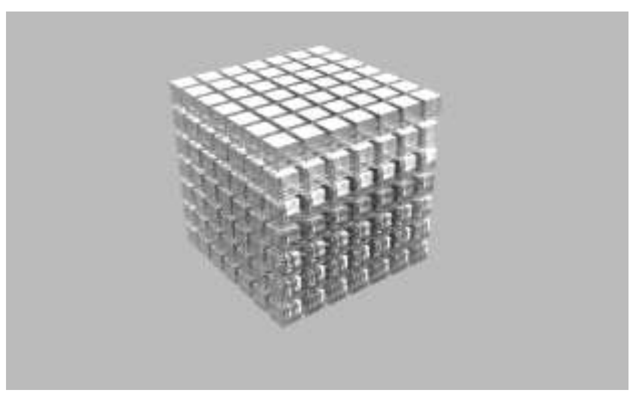

Fig. 3. The segmented computational space of the three-dimensional cellular automaton.

Each cubic cell has 26 neighbors, the entire faces of six of which touch the given one. Our model considers this very neighborhood (Fig. 4).

Not all cubic cells have the same number of neighbors. This rule does not hold for the cells on the edges of the cube. Assume that the opposite cube faces touch each other so that all cells have an equal number of neighbors. A two-dimensional cellular field can be formed into a torus. In this case, each cell of the cellular field has eight neighbors. A four-dimensional cube can also be closed. In this case, it will be formed into a four-dimensional torus. Then the opposite faces will touch each other and the number of neighbors will be the same.

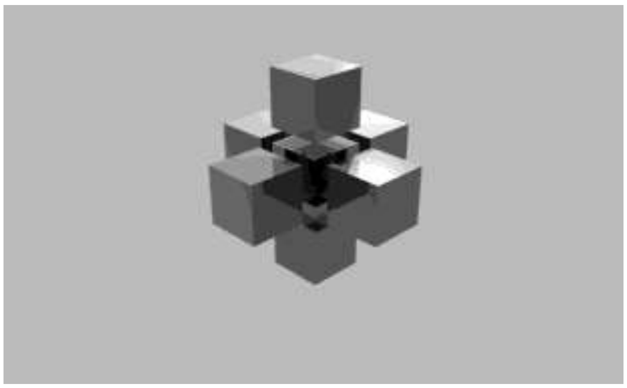

Fig. 4. The six-element cell neighborhood of the three-dimensional cellular automaton.

So, initially, a random real number in the range from 0 to 1 is placed in the central cell of the cube of size $n \times n \times n$ cells, while n is odd. Then the following transition rules operate. The state of each cell at the next sample time is calculated by using a nonlinear recursive equation capable of demonstrating a transition to chaos according to the Feigenbaum scenario through a series of period-doubling bifurcations (Malinetsky, 2017). The average of the states of six cells from the neighborhood of the given one is substituted into the equation as the initial value for each iteration. These six cells include those that are directly in contact with the current full faces.

Thus, the algorithm includes the following steps. In the first step, a random number in the range from 0 to 1 is placed in the central cell of the cube. Next, for each cell, the average of the states of its six-element neighborhood is calculated. Then these averages are substituted into a nonlinear recursive equation. The code fragment for calculating the state of the cell of the cellular automaton at the next moment of time in Python is the following:

```
for i in range (1, n):
    for j in range (1, n):
        for k in range (1, n):
            S = x[i+1,j,k] + x[i,j+1,k] + x[i,j,k+1] + x[i-1,j,k] + x[i,j-1,k] + x[i,j,k-1] + x[i,j,k]
            S = S / 7
            y[i,j,k] = R*math.sin(math.pi*S)
```

For the first generation, the states of almost all the cells will be zero, except for six cells with the faces that are directly adjacent to the original one. The next generation will have more nonzero cells. At the same time, the growing spatial configuration of the cubes will have strict central spatial symmetry (Fig. 5). After a certain number of generations, the growing configuration will fill the entire internal space of the cube and meet with itself, since the cube is closed.

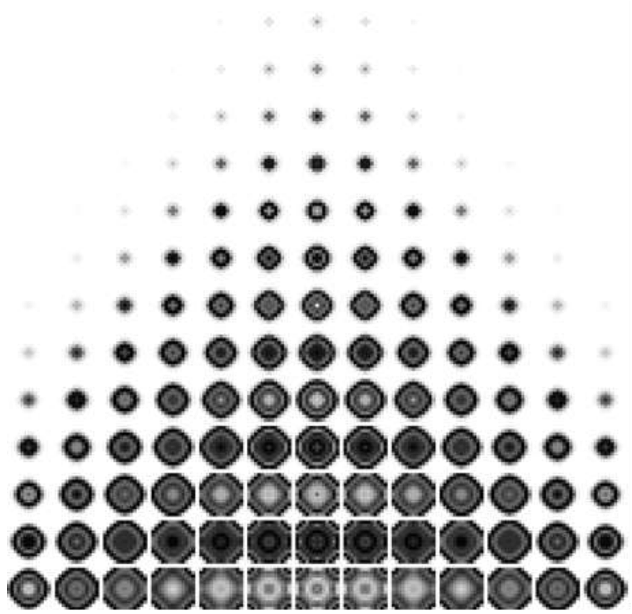

Fig. 5. The slices of the three-dimensional cube 13 × 13 of the first 13 generations.

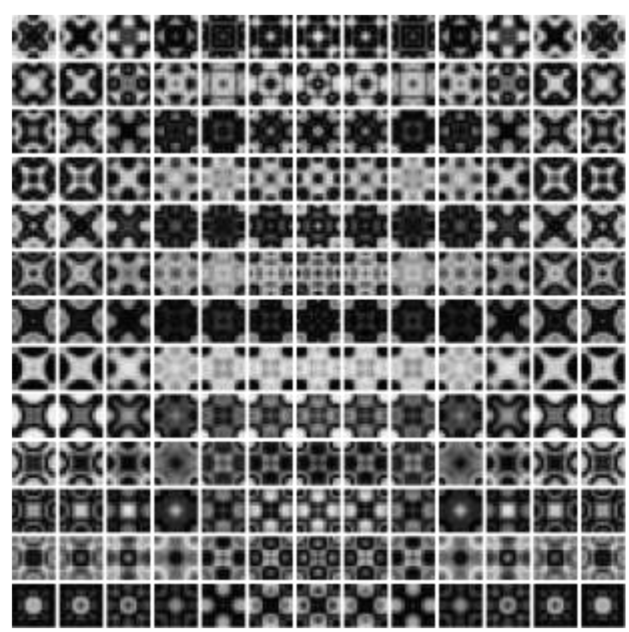

Fig. 6. The symmetric evolution stage of the cellular automaton (generations 50-63).

Further, the configuration will continue to evolve in the entire space provided. From an arithmetic point of view, the contents of the cube must constantly change and, at the same time, retain the symmetry property related to the central cell for an unlimited time, since the equations are the same in all the cells. Therefore, centrosymmetric cells should always contain identical numbers. A typical picture of the intermediate evolution stage of a cellular automaton starting from the 50th generation is shown in Figure 6.

However, when the value of the parameter of the equation (we mean the nonlinear equation that can generate chaos) is in the chaos zone, the symmetry is broken after a certain number of generations of the cellular automaton (Fig.7) and the spatial structure continues evolving in a complex asymmetric quasi-chaotic form.

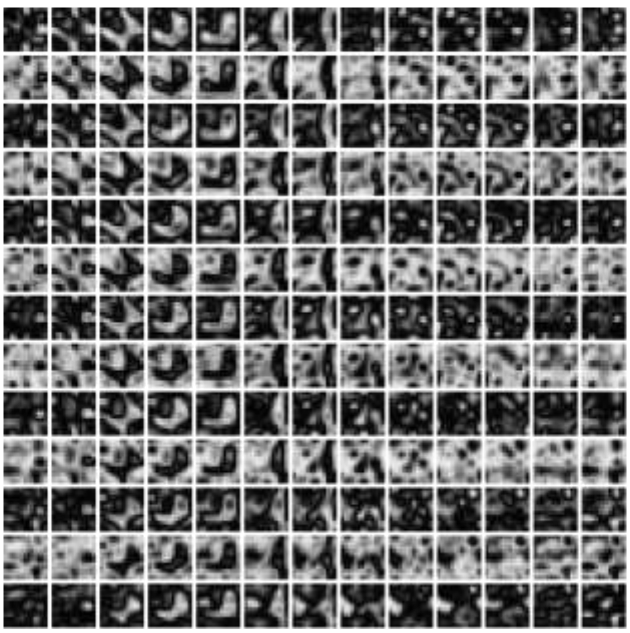

Fig. 7. The stage of symmetry violation and chaos (generations 150-163).

From the point of view of arithmetic, this result is impossible and wrong. It is caused by the accumulated inherent hardware error in the operation of the digital computer system. The whole mathematics and technology are mobilized to eliminate or minimize such errors. However, in the recursive processes similar to the described one, nonlinearity will still win and increase any minor deviations to a macroscopic scale. A similar algorithm can be programmed using fixed-point numbers to do calculations with some fixed accuracy, just as if we did arithmetic in column up to a certain decimal place. In this case, symmetry would never be broken.

The question arises – which of the options is closer to reality – the first or the second? If the given cube were technically made of electronic analog elements using the same local calculation procedures, which scenario would be implemented in practice – ideal with calculations to a given accuracy, or "erroneous" with a gradually accumulated error and nonlinear amplification of small fluctuations? The second naturally would, since nonlinearity would gradually amplify any low-level noises in the elements, up to quantum fluctuations or the influence of cosmic rays.

CONCLUSION

Growing nervous tissue consisting of special cells called neurons is a distributed communication environment formed by the chaotic plexus of mobile thin thread-like processes connecting nerve cells in a network. To some extent, the properties of this communication environment resemble the above considered three-dimensional cellular automaton. The only difference is that local connections between cells in the given model are more regular. In fact, the natural environment for the distribution of electrochemical signals of neural tissues of the nervous system and brain in its systemic properties is largely similar to the network communication environment of a continuous cellular automaton. Everything that is generated by the brain, all products of consciousness, mental processes are ultimately changeable dynamic structures formed by a mosaic of electrochemical activities of nervous tissue changing as a result of local interactions.

Rhythmic patterns, sound associations, dynamic and static images, verbal constructions in a natural language, music fragments, algorithmic procedures are somehow all generated and encoded by the cascades of electrochemical signals in a distributed cellular network environment of neural tissue. All this forms what we perceive as psyche, consciousness, and thinking. The understanding of the meaning of these processes is the subject of philosophical research. This study demonstrates the possibility of going beyond the traditional verbal philosophizing and expanding the capabilities of the philosophical language with images and computer algorithmic procedures. In this case, we have a somewhat wider understanding of the thesis on the verbal character of thought and philosophical language. A natural language is not only a word in its isolated form. A natural language is rhythm, music, and image association fields... Otherwise, literature, poetry, as well as philosophy, would be unthinkable.

The entire array of diverse cognitive protoconstructs makes up a scientific worldview. A new type of cognitive protoconstructs described in this paper is computer algorithmic procedures reproducing the games of continuous cellular automata in a three-dimensional cellular computational space. Using images, mathematical models, and computer procedures, an attempt was made to create a new in-depth understanding of chaos and the nature of true historical time, for description of which the foundations of mathematics should be supplemented with new true or temporal numbers and dynamic sets. All this is necessary to approach the possibility of understanding the occurrence of the phenomenon of subjective sensations, and ultimately, the "I". By getting these opportunities, ways will be opened for adequate modeling and description of the behavior of social systems. A new chaos paradigm and related methodological approaches will indicate the possibility of an adequate mathematical description and modeling the psyche and consciousness elements, which, in turn, may be crucial to create promising machines, robotic systems with rudimentary subjective sensations as the basis for creating true powerful artificial intelligence.

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