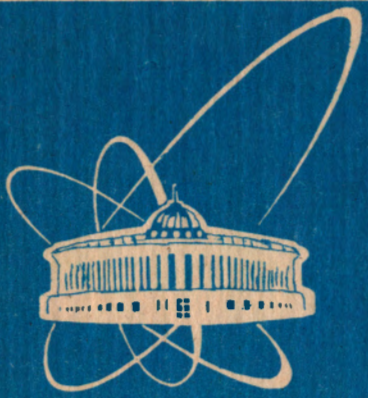

СООБЩЕНИЯ
ОБЪЕДИНЕННОГО
ИНСТИТУТА
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

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INFORMATION AS THE BASIS OF LIFE

1996

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Информация как основа жизни

Излагаются представления, согласно которым жизнь есть форма существования информационных систем, материальные компоненты которых обеспечивают воспроизведение и развитие кодирующей их информации. Рассматриваются три вида информации: генетическая, поведенческая и логическая. Показано, что носителями первых двух видов информации служат компоненты живых организмов (ДНК и нервная система), носителями логической информации — человеческая речь и разные формы ее записи. Описываются основные закономерности динамики информации, лежащие в основе эволюции.

Работа выполнена в Отделении радиационных и радиобиологических исследований ОИЯИ.

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Information as the Basis of Life

The concept treating life as a form of existence of information systems whose material components ensure reproduction and development of their coding information is described. Three types of information — genetic, behaviour and logic — are considered. It is shown that carriers of the first two types of information are components of living organisms (DNA and nervous system) while carriers of the logic information are human speech and its various recorded forms. The basic regularities of information dynamics underlying evolution are described.

The investigation has been performed at the Division of Radiation and Radiobiological Research, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 1995

1. Introduction

One can successfully deal with the problems of life origin, evolution of living organisms, development of intelligence and technogenesis only if one knows the answers to two fundamental questions: what is the difference between the living and the lifeless and what is the difference between human beings and other living organisms?

It becomes clearer and clearer that the phenomenon of life is based on information; that life is essentially a system which ensures continuity and evolution of various forms of information on our planet; that the basic difference of man from other living creatures is the presence of that type of information which was formed in a human society, i.e., logic information (Blumenfeld, 1977; Korogodin, 1983). Indeed, it is logic information that has become independent of individual people, existing in the form of oral and written speech, and capable of being implemented into different technologies.

This formulation of the life essence needs substantiation and explanation, which is the topic of this paper.

2. Genetics and the Essence of the Living

We entitled the article «Information as the basis of life», paraphrasing the title of article «Gene as the basis of life» by Muller (1929). The reason is as follows. As is known, Muller was the first to connect life with information though he did not use the term «information». Let us explain ourselves.

By 1929, when the above-mentioned article was published, the foundation of genetics was already laid. Works by Mendel, de Vries, Johannsen, Morgan and his followers made it quite clear that all hereditary properties of living beings are related to genes. Geneticists were taken up with three questions: how are genes structured? how do they affect life processes? how do they change, or mutate? Looking for answers to these questions, Muller (1929) became the first to describe the ideas which stated that the gene reproduces in an autocatalytic way, i.e., it itself catalyses synthesis of its copies; that the gene affects development of other properties and traits of an organism owing to its inherent property of heterocatalysis, i.e., the ability to catalyse synthesis of other compounds; that evolution results from changes, or mutations, in those sections of the gene which are responsible for heterocatalysis;

that the origin of life is related to appearance of genes, and evolution is related to changes in properties of genes to provide heterocatalysis; that the gene is thus the basis of life.

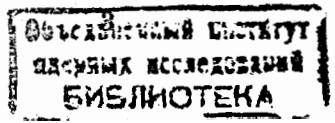
Shrödinger (1944) introduced the term «genetic information», relating this information with genes, and proposed that the evolution process should be considered as the result of changes in the genetic information caused by mutation of individual genes.

3. Information as the Basis of Life

There arises a question of the relation between the gene and the information. If one calculates the amount of information in the gene by Shannon's formula (1948), it will turn out to be approximately the same in all three cases (initial gene, working mutant, dormant mutant), though in two cases the information is different and in the third one there is no information. Obviously, Shannon's formula does not determine the «amount of information» but the «capacity of the information tare» which may either contain information or be empty (Korogodin and Fajczi, 1985). Thus, information is not a mere set of bases making up a gene but their certain sequence containing this information. This concept of genetic information is in good agreement with the algorithmic definition of information proposed by Kolmogorov (1965): a sequence of bases making up a gene is an algorithm for building the given protein by the given cell.

Obviously, the primary half billion years only chemical evolution took place on the Earth (Oparin, 1938; Calvin, 1969). At the end of the chemical evolution the translation hypercycles occurred, as Eigen has shown (Eigen, 1971; Eigen and Schuster, 1979). Due to natural selection, this way resulted in the occurrence of living cells. These were original procaryotes, their traces having three-three and a half billion years age are found in various places of the Earth (such traces are claimed to be found also in cosmic subjects).

As more and more new organisms came into being (owing to genetic variability and natural selection) and trophic relationships were established between them, biocenoses and ecosystems were formed, and finally the biosphere appeared spreading all over the globe. There was enough time for it, about a billion years. As the oxygen-carrying atmosphere evolved and plants left the sea, the kingdom of terrestrial multicellular animals started forming. Origination of animals capable of moving and adapting to the environment (aquatic and terrestrial) was marked with the nervous system coming into existence. It was a special genetically programmable apparatus that co-ordinated all types of activity of these organisms. The life conditions becoming more complicated, the role of behaviour grew more and more important to animals (Yčas, 1991).



Complementing hereditable behaviour reactions, learning and teaching evolved on the basis of the nervous system. There appeared the behaviour information, which was stored in the nervous system of the highest animals and controlled their actions. The behaviour information evolved independently from the «life experience» of animals and could be passed on not only «vertically», from generation to generation, but also «horizontally», from parents to children, from a neighbour to a neighbour and even from organisms of one species to organisms of another.

One can only assume what is the carrier of behaviour information (Dubrovsky, 1980). The only indubitable fact is that it is stored in neurons and «recorded» in some chemical compounds, most probably in RNA molecules. But there is no doubt about the decisive role of the behaviour information in the life of populations of the multicellular animals (both invertebrates and vertebrates) and about its importance in their evolution (Severtsev, 1922; Shmalgausen, 1968; Krushinskiy, 1977).

One can easily see that the behaviour information has much in common with the genetic one. It is reproduced by means of imitation, i.e., actually by means of autocatalysis, and affects various aspects of life, which is similar to heterocatalysis. However, just as in the case of the genetic information «unsuccessful» mutations result in death of the cell or organism thus ceasing to exist, so «harmful» experience or habits will usually produce damaging effect on the life of animals and population and are also eliminated through natural selection.

For animals to lose the behaviour information can be as fatal as for any cells and organisms to lose the genetic information.

Evolution of behaviour reactions and behaviour information related to the communication between animals prepared the coming of speech, which is the form of communication typical, as some authors believe, of man alone (Porshnev, 1976; Panov, 1980; Macphail, 1982). Initially only a supporting addition to behaviour reaction, the speech communication gradually raised to a dominant position and give rise to speech, first oral and then written.

This was the end of transition to the third type of information — the logical one. The carrier, or the tare of the logical information was the language. With formation of the speech man finally acquired his present state (Porshnev, 1979). The logical information can be transmitted from man to man not only «horizontally» but also in any other direction in time and space uniting the manking into a common information system. And yet, the information keeps its two basic properties: autocatalysis, which ensures its reproduction, and heterocatalysis, which ensures its «ability».

The speech, the word have created not only the man but also technologies, his inevitable companions. Arising from socialized human knowledge concentrated in the logical information, technologies are as much a criterion of its viability as are specific features of animal behaviour for the behaviour information and morphology and physiology of living organisms for the genetic information. Useful or harmful technologies gradually die out and reproduction of the relevant logical information

stops as well. Only that part of it which proves to be «useful» contributing, to improvement of human life, will be viable (Korogodin, 1991).

4. Information Systems and von Neumann's Automation

We have singled out three types of information: genetic, behaviour and logical. The same properties are typical of all three types, making them different from the properties of other objects of the material world. As to the difference between these types of information, it is not only in the turn of their coming into existence but also in the typical carriers and those information systems beyond which they can neither reproduce nor function (Korogodin, 1991).

Recall that «information is information, and not matter, not energy» (Wiener, 1948). Information can only exist when fixed in a carrier. For example, genetic information carriers are molecules of nucleic acids, behaviour information carriers are nervous tissue and brain structures, logical information carriers are the speech (oral or written, natural or artificial). But even in this form the information is not efficient. To affect developments in the material world, the carriers together with their information must be included in devices that might be called «information systems». Von Neumann was the first to propose a block diagram of these devices in 1948 (Neumann, 1952). This block diagram is schematically shown in the figure.

Von Neumann proposed that the block diagram should be used as a logical circuit of a universal self-reproducing automaton (see the figure). Information is an algorithm for reproduction of material components of information system. However, this diagram can be regarded as a structural diagram of material devices designed for reproduction of physical carriers together with their information used for coding these devices. In this case individual units can be either united with one another or spatially separated but in close functional connection. In the former case we have a diagram of devices necessary for reproduction of the genetic and behaviour information, and in the latter for reproduction of the logical one. In other words, the block diagram of von Neumann's automaton is actually a functioning scheme of living systems.

Applicability of the self-reproducing automaton diagram to description of living organisms was obvious for von Neumann himself. We may only extend its application range from simple unicellular to any other living systems up to the human community. In the latter case the self-reproducing information system is all mankind united into a whole by technical means of communication (i.e., transmission, reception and storage of information) and technologies developed on this basis.

It should be stressed that the principles of operation of living information systems represented by the block diagram of von Neumann's automaton apply to the already formed organisms and their communities. The diagram does not refer to

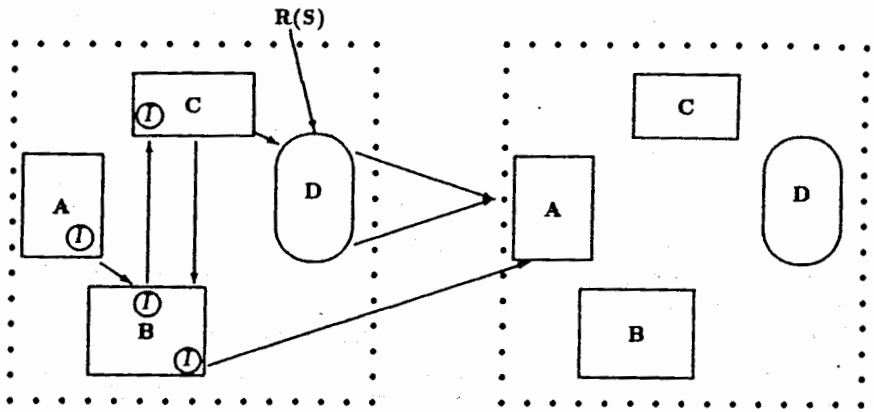


Figure. The block diagram of a self-reproducing von Neumann's automaton (1952), which can be regarded as the structural scheme of any living information system, from a cell to a hyman society. Individual units can be united into a whole entity or can be spatially separated but maintain close interaction. «*A*» is a unit containing or accepting information «*I*» (description of an automaton and methods of its construction); «*B*» is a unit copying this information and transmitting a copy to block «*C*» and another copy to block «*A*» of the automaton of the next generation; «*C*» is a unit reading information «*I*» and, in accordance with it, transmitting instructions to units «*B*» and «*D*»; «*D*» is a block using resources «*R*» for the environment «*S*» and, in accordance with the instructions from unit «*C*», constructing from them all four blocks of the automaton of the next generation. When the construction is finished, unit «*B*» of the automaton of the first generation, instructed by unit «*C*» transmits a copy of information «*I*» to unit «*A*» of the automaton of the next generation.

arising of living organisms. The earlier stages of life evolution on the Earth, which took about half a billion years and were discussed by Oparin (1938), Calvin (1969), Eigen (19?1) and others, are still mental speculations. The considerations described in this paper allow, for example, an assumption that the living organisms could arise as whole entity comprising the simplest versions of all four blocks of von Neumann's automaton and their coding information (see the figure) and not result from integration of finished blocks, which developed independently and later united both with each other and with the appropriate information (Korogodin, 1991). We think it somewhat changes the approach to the problem of life arising and developing.

5. Dynamics of Information

The block diagram of von Neumann's automaton (see the figure) also allows one to understand better the basic property of living systems which makes them

different from lifeless objects of the surrounding nature. It is their ability to perform purposeful actions (Blumenfeld, 1977; Korogodin, 1083; Yčas, 1991). This fundamental difference between living and lifeless objects is already stressed by Lorentz (1967). In our opinion this difference appeared at the origin of living cell. Living cell was the primary auto- and heterocatalytic system protected by homeostasis. Such system not only «aspired to survive», but was capable of «purposeful action» due to the direct and opposit connections with environment, this ability promoted to reproduce the information coding it — the final goal in activity of any living system. It is obvious in the case of uncellular organisms and cells while in the case of human communities it is obscured by many intermediate stages. Yet, in all cases achievement of the final goal, which is autocatalysis of information coding the given living system, is always related to more or less extended programme for realization of heterocatalysis, which provides the possibility of carrying out autocatalysis.

Any purposeful action, no matter how simple or complicated it is, can be described by a transformation

$$[S, R]\,\frac{Q(I)}{p, P} \rightarrow [Z, W],$$

where S is the situation or environment in which the action is performed; R are the resources necessary for it; Q is the combination of von Neumann's automaton, or the operator directly performing the action; I is the information coding the operator; Z is the goal even; W are «by-products» accompanying performance of Z; p and P are the probabilities of performance of Z spontaneously and with the given operator used (Korogodin, 1991).

Now let us pay attention to the following fact. Performance of any purposeful action Z is always and inevitably accompanied by accumulation of by-products W. It changes the initial situation S in which the action takes place. It could be depletion of resources R in the environment, supply of life products to it from living systems W: various biogenetic and technogenetic «wastes». Transforming their environment by all this, living systems have to look for other resources instead of depleted ones. On the other hand, the environment is enriched with new components which may provide resources for living organisms that do not yet exist. Variability of information coding the given living system may give rise to new living systems capable of using the «by-products» of initial systems as their resources and thus becoming at the same time conditioners for the environment S. There can also arise the variants of initial systems which will replace depleted resources by by-products of the conditioners. One can easily show that this is a schematic line for origination of not only new living systems but also their communities tied together by trophic relationships. But this is also a line for construction of a biological hierarchy that implies arising of more and more highly organized living objects including human communities.

This development of life based on the simplest living objects and gradually becoming more diverse and more complicated in organization can be called «autogenesis of information». If the number of factors n necessary and sufficient for reproduction of a living system in its life zone is considered to be a dimension of this zone (for the given biological system), then one can show that autogenesis of information tends to increase the number n. Thus, the dimension of the life zone n can indicate the level of organization of living organisms (Korogodin, 1991). Regularities of autogenesis of information, which occurs with acceleration and constantly produces its new forms, are the same for all types of information and naturally follow from our definition of «the living». These concepts are good to explain both the hierarchical structure of the biosphere and the similarity in specific features of biological evolution, social development, science and culture pointed out by Eigen (1971), Lotman (1992), Gumilev (1993), and others.

6. Conclusions

We are not going to consider development of man and processes of technogenesis related to the dynamic of logical information — all this is described in the book (Korogodin, 1991). It should only be recalled that the state of the manking is fully determined by technogenesis. Technogenesis is independent of the will of individual people. In any case, one can state that at least in the past ten thousand years the man has not undergone any changes as a biological being, unlike technological progress, which is responsible for the increase in the number of people «beyond the biological norm» and for the possibility of their living in diverse parts of the globe.

We would like to stress another fact, namely that it is information that underlies life in all its manifestations. Only information possesses true continuity, including continuity in time, while non-information components of living systems are always and inevitably doomed to die. Also, there is constant connection between the genetic, behaviour and logical information both from the viewpoint of the development history and from the viewpoint of the activity of information systems. It is especially clear with man whose physical status is determined by the genetic information, preparation for independent activity by the behaviour information, and the activity itself by the logical information drawn out of the common global information pool enriched in its turn by this activity.

All three types of information are always capable of performing two functions: autocatalytic reproduction of themselves and heterocatalytic activity producing, in the long run, conditions for autocatalysis.

We would like to end the paper with the following statement. Life is the form of existence of information systems whose material components provide conditions for autocatalysis of the coding information. The problems of life origin, biological

evolution, noogenesis and technogenesis are thus reduced to problems of arising and development of various forms of information and its carriers.

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