CODING – DECODING as General Anticipatory Principle of Bio-Systems Functional Organization

Dobilas Kirvelis

Department of Biochemistry and Biophysics, Vilnius University
M.K.Čiurlionio 21/27, LT-2009 Vilnius, Lithuania
Fax: 370-5 2136660; E-mail: dobilas.kirvelis@gf.vu.lt
http://www.gf.vu.lt/usr/kirvelis/kirvelis.html

Abstract
Activities of living beings are presented as bioinformation procedures of closed-looped coding-decoding. In the process of coding, dynamic states of real dynamical structures of matter and energy are reflected in states of memory structures (DNA, hormones, neuronets). In the process of decoding the activated states of the structures of the memory are re-reflected in the dynamic states of the real structures of matter and energy. This is the essence of control. Biological evolution is interpreted as formation of hierarchically organized dynamic structures of closed-looped coding-decoding and reproduction of them. Increased complexity of these structures determines a higher level of control.
Keywords: coding-decoding, closed-loop, bio-information, control, integral transformations.

1 Introduction

Rapid development of informatics and biotechnologies raises the demand for new biosystemic concepts. Information-production coupling, adaptibility, biological computing are being widely discussed [1]. H.von.Foerster's concept of 'eigenbehavior' is being revised in the new, biosemiotic view [2]; autopoiesis (self-production) systems theory is under development [3]. The attempts are being made to integrate these bioconcepts in a cybernetic information aspect [4]. The increasing diversity of concepts and terms needs more general and unifying view. It could be the concept of closed-loop coding-decoding, if general cybernetic point of view was applied to coding-decoding procedures, which usually are used in a narrow sense of computer technology or communication theory.

Life can by considered as a self-reproducing, hierarchically developing system that relies on closed-looped bioinformational coding-decoding procedures. This process is dominated by informational control that is inseparable from cybernetics anticipation.

N. Wiener was the first who payed attention to the key importance of informational control processes for life. Fifty years ago he wrote that cybernetics is science about control and control systems, *i.e.* about information processes in living organisms, some

machines and society. Later, M. Conrad and H. von Foerster were pioneers in investigating biological information processing. "Life may be defined operationally as an information processing system – a structure hierarchy of functioning units – that has acquired through evolution the ability to store and process the information necessary for its own accurate reproductions" - L. Gatlin wrote [5]. "Life may be defined in many ways, but the most fundamental focus is on information" - stated D. Dusenbery[6]. According to R.Hauhs and H.Lange [7], the paradigm is shifting from the "matter and energy" picture to the informational one. R.Rosen describes complex systems relations as unspecified sort of coding problems [8].

The classic Shannon system - channel of memory or information transfer by communication line is an open coding-decoding. Therefore it ignores the sense of the transferred information and it discards semantics of information.

Developing the concept of life as an organized system, it was noticed that rather abstract terms of information and control induce some misunderstanding when applied to the functional organization of life. The terms of information and control are more acceptable after interpretation through closed-looped coding-decoding procedures and their processing mechanisms [9]. Symbols that are encoded-decoded get their functional sense when informational channel is closed through the controlled object. This is achieved by coupling of encoders and decoders to particular controlled object through the corresponding receptors and effectors. Decoding in purposeful system becomes the informational control and all this system becomes the anticipatory one.

It could be supposed that that the closed-loop system of coding-decoding, which is so essential for life, was formed 3-4 billion years ago, when the dynamic system of enzyme reactions (dynamic states) were reflected to the stable states of nucleic acids. It was a time when symbiosis of enzymes and nucleic acids emerged. The closed system of coding-decoding was a basis for formation of the organized systems, where informational processes determined the transformations of matter and energy, *i.e.* selective actions of the systems.

2 Closed-loop Coding-Decoding

CODING (ENCODING) should be understood as a reflection of a real system (nature or a technological process) in an abstract virtual form on MEMORY structures (DNA, hormones, neural networks) in such a way, that the re-reflection (DECODING) from the abstract to real would be possible (Fig.1).

The coded reflection in the memory is a model or a technological project of the real system. This model or a coded representation for control is the essence of information. Decoding is the realization of such a project or control of biotechnological procedures according information. In the process of decoding, the activated coded states of the memory structures or the projects for synthesis of reality are reflected in the dynamic states of the real world, real structures of body, *etc.*

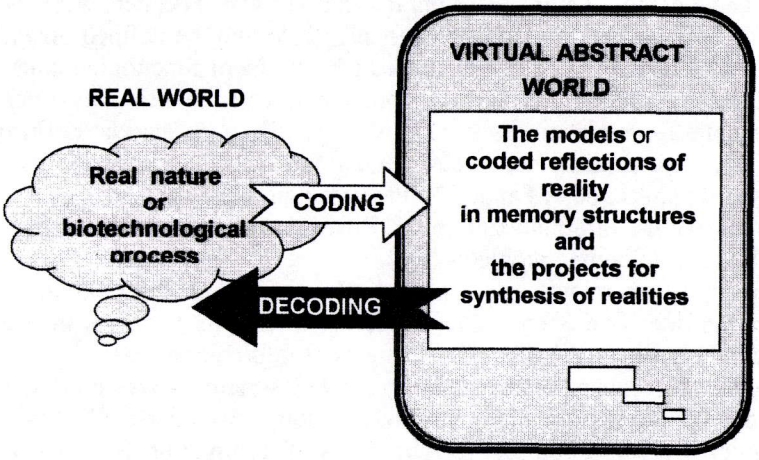

Figure 1: Coding – Decoding in life

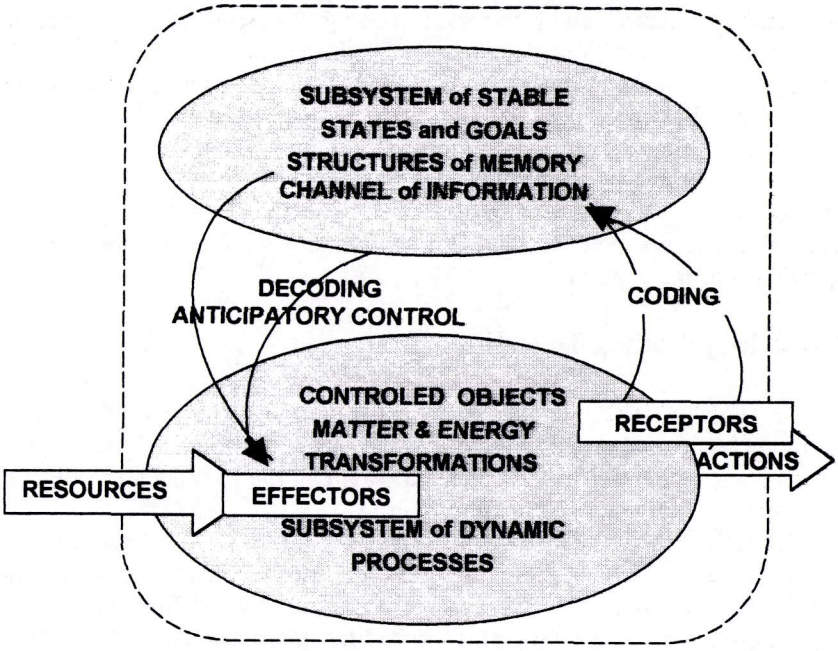

Figure 2: The closed-loop coding-decoding system. The classical Shannon's channel of information is open, without the objects of matter and energy transformations

3 Decoding as Anticipatory Control

All three functional technological components essential for J.von Neumann's theory of self-reproducing automata can be found in the living cells and beings: a) transformations and transport of matter and energy, carried out by enzymes; b) storage of technological programmes (memory), carried out by genes; and c) copying and multiplication of the technological programmes, carried out by replication of DNA. In essence, it is a structure of decoding system. Behind the structure of this system, anticipatory properties lie, *i. e.* the programme stored in memory is a model of future activities, which after decoding foresees and determines the future result. However, Neumann's system deals with neither the formation of action programmes, nor the emergence of coding procedure.

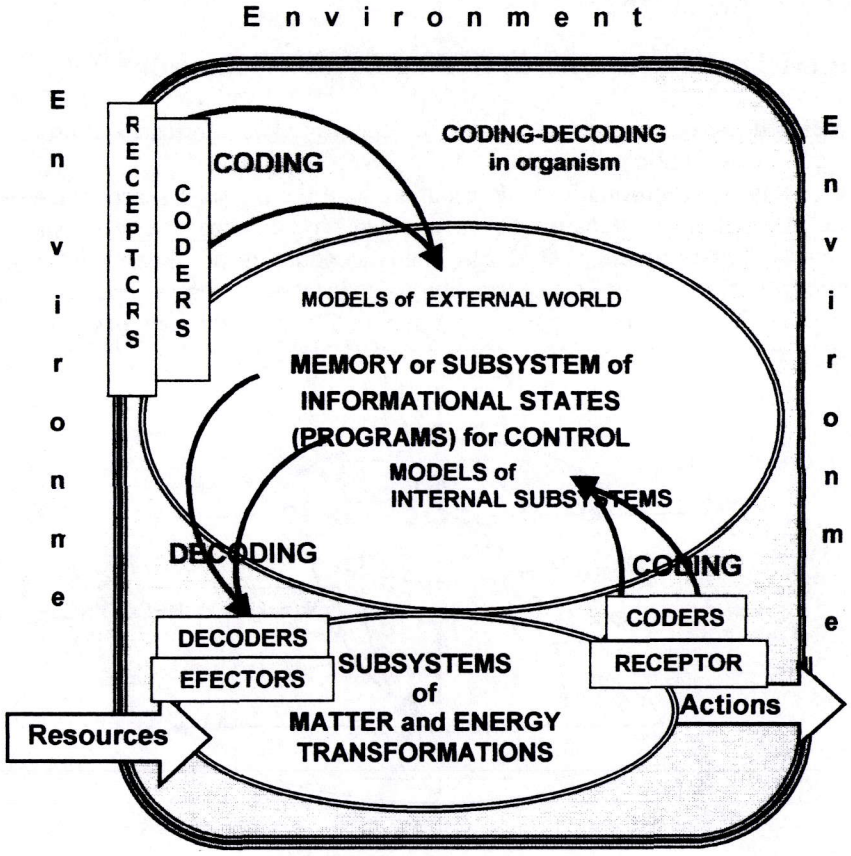

Figure 3: Coding–Decoding as combined control in the organised systems

The concept of an organized coding-decoding system explains the biological phenomena from a point of view of functional organization, cybernetics, control and information theory. Physical and chemical transformations of energy and matter in the bio-informational flows are considered as only a means (signal) for realization of some informational programs of goal-oriented control.

Control systems of three types are known: feedforward, feedback, and combined feedforward-feedback. A complete organized system in general is a combined system (Fig.3). The important difference among these types of systems is information processing for carrying out regulatory function. In addition, there are few types of qualitatively different adaptive mechanisms, depending upon whether the adaptive loop is feedback or feedforward, and whether the adaptive loop possesses memory or not.

It is generally supposed that feedforward control is anticipatory. However, feedback control could also be regarded as anticipatory: if the effect extent of the simple feedback regulator exceeds the goal extent, decoding structure sets the regulator in order to decrease the effect, and *vice versa*.

4 Integral Transformations as Coding-Decoding Procedures

The closed-loop coding-decoding may be represented as informational procedure of the integral transformations.

The coding is an informational procedure, where the physical space (subsystem **X**) with the states **u(x)** is transformed to another physical space ξ with states **U(ξ)** according to kernel function **$\Phi(x, \xi)$**. Then decoding is an inverse informational procedure (re-reflection or re-transformation) of the states of memory space **U(ξ)** on the physical space **X** according inverse kernel function **$\Psi(x, \xi)$** as the state **u(x')** (Fig.4.).

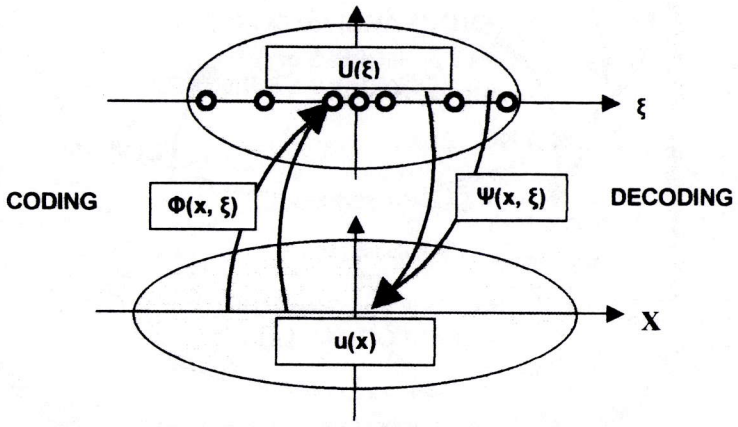

Figure 4: Integral transformations as CODING-DECODING

Ideal coding-decoding must satisfy orthogonal set of the kernel functions

$$\int_{-\infty}^{+\infty} \Phi(\xi,x)\cdot\Psi(\xi,x')d\xi \approx \delta(x-x')$$

Then coding-decoding as integral transformations may be expressed mathematically:

$$U(\xi) = \int_{-\infty}^{+\infty} u(x)\cdot\Phi(\xi,x)dx,$$
$$u(x) = \int_{-\infty}^{+\infty} U(\xi)\cdot\Psi(x',\xi)d\xi$$

A

$$U(\xi) = \int_{-\infty}^{+\infty} u(x)\cdot\Phi(\xi-x)dx,$$
$$u(x) = \int_{-\infty}^{+\infty} U(\xi)\cdot\Psi(x'-\xi)d\xi$$

B

A - for non-homogeneous procedures, and B - as convolution integrals for homogeneous ones. Such integral coding-decoding may be realized in discrete form too, when kernel functions are expressed as matrix-operators $[\Phi],[\Psi]$ that satisfies orthogonality condition

$$[\Phi]\cdot[\Psi]\approx \mathrm{I}.$$

For the particular situations (for example, in neural nets) it is rational to use complex kernel functions:

$$\Phi(\xi,x)\approx\exp\{-i\cdot\Omega(\xi,x)\},$$
$$\Psi(\xi,x)\approx\exp\{+i\cdot\Omega(x',\xi)\}.$$

A

$$\Phi(\xi-x)\approx\exp\{-i\cdot\Omega(\xi-x)\},$$
$$\Psi(x-\xi)\approx\exp\{+i\cdot\Omega(x-\xi)\}.$$

B

The simplest coding-decoding kernel functions are, as follows:

$$\Phi(\xi,x)\approx\exp\{-i\cdot\xi\cdot x\},$$
$$\Psi(\xi,x)\approx\exp\{+i\cdot x'\cdot\xi\}.$$

A

$$\Phi(\xi-x)\approx\exp\{-i\cdot(\xi-x)^2\},$$
$$\Psi(x-\xi)\approx\exp\{+i\cdot(x-\xi)^2\}.$$

B

Fourier functions (A) for non-homogeneous transformations and Frehnel functions (B) for homogeneous ones. These functions represent technology of coding-decoding. Fourier and Frehnel coding-decoding transformations have characterics of quasi-holographics features.

5 Life as Hierarchically Organized Coding-Decoding System

The living being as an organized system includes two functionally different subsystems: the controlling one (a controller) that operates by information (information flow), and the controlled one that carries out transformations of matter and energy for goal-oriented actions. The cell's controller consists of genes, and the controller of

multicellular organism is augmented by hormone regulation (animal's controller has nervous system, in addition) (Fig. 5). In animal, this three-level structure of control linked by feedbacks to the environment forms a hierarchically organized coding-decoding system. Coding-decoding processes are essential for reproduction of organisms, since the stability of functional structures can be ensured by multiplication of discretely coded genetic projects of the organism. Biotechnology of reproduction becomes a rather steady bio-information technology.

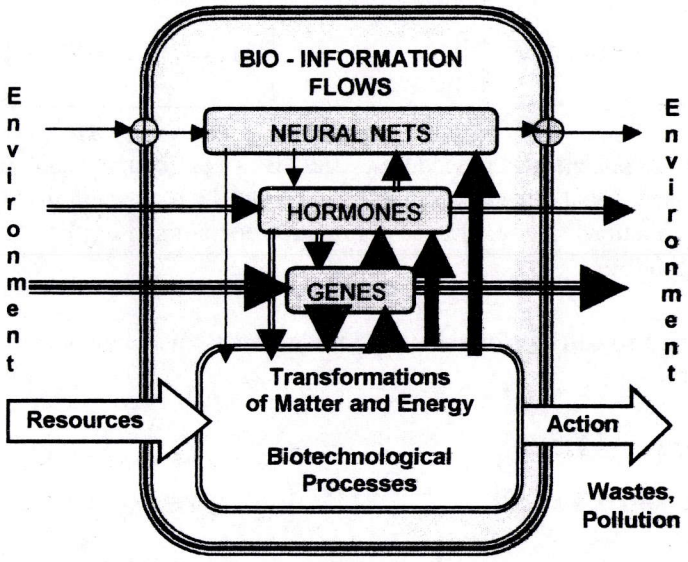

Figure 5: Animal as hierarchically organized coding-decoding system

Many phenomena of living nature could be explained in the best way by using the terms of information technologies. Some obvious phenomena of informational technologies in life are connected with coding-decoding procedures:

1. Spores and seeds are carriers of biotechnological programmes or projects of future organisms. The essence of the existence of plants, fungi and animals are replication, improvement and spreading of these projects.
2. Sexual reproduction is the diversification of these programmes or projects.
3. Genetic mutations are the alterations of the programmes. Adaptive modifications are alternatives of programme realization .
4. Gene engineering is a purposeful insert of new individual components to the genetic programme.
5. Apoptosis is programmed cell disintegration that is necessary for most effective destruction of some parts of organism.

6. The processes of morphogenesis are carried out under the informational control by hormones.

7. The influence of pheromones on behaviour of insects is an example of the action of informational programs by special signal molecules.

8. Activities of the nerve system that determine the behaviour of animals are the obvious products of informational technologies.

9. Biogenetic laws (F. Muller, E. Haeckel) that describe the reflection of phylogenesis on ontogenesis are the examples of the evolution of coding-decoding procedures.

Coordination of activities of multicellular organism by hormones can be explained in terms of agents theory as selective receiving of molecular signals, their informational processing and decision-making for action. This is the activity of the coding-decoding systems. The more dynamic control of multicellular animal is additionally carried out by the special structures of nerve cells, neural nets, which receive, process and send information. Undoubtedly, the neural control of multicellular organism is a network of coding-decoding procedures.

The nerve system is a typical coding-decoding system, which reflects and codes not only the environment of the animal, but its inner state as well. Animals control their activities according to this information. In addition, the structures of virtual decoding are found in neocortex of warm-blooded animals. They are the sensory screens, which give the animal opportunity of virtual vision (mental vision), hearing, *etc.* There the principle of closed-looped coding-decoding as analysis by synthesis (A-by-S) [10] is implemented.

The idea of A-by-S suggests that there may be two parallel screens in the sensory projection cortex:

1. The sensory screen SS, which receives the reflection of the environment from peripheral receptors and translates it into the subjectively experienced scene.

2. The adjacent reconstruction/synthesis screen RS, which reproduces the image, that is retrieved from memory and represents the hypothesis about the object identity.

The main criticism of the idea of sensory screen is that this kind of screen implies the existence of a homunculus watching the screen. The A-by-S functional structure addresses this critique by eliminating the homunculus in place of which there is a feedback system such that SS "watches" RS. This interpretation is analogous to the classical Shannon's channel with memory, in which encoder and decoder are connected by feedback. It is thought that such a channel ought to function according to the quasi-holographic principle, whereby $\mathbf{Q}^{-1}$ is the quasi-holographic dispersion of the image by means of a certain orthogonal (encoding) basis over the structure which records memories. $\mathbf{Q}^{+1}$ then is the inverse quasi-holographic transformation which accomplishes the synthesis, reconstruction and decoding of the desired or mental object. These quasi-holographic transformations are consistent with and may mediate the associative principles. The associative information processing and memory organization may be instrumental for predicted search and retrieval in large information areas. Since the proposed visual analyzer uses image prediction, and verifies or falsifies predicted

images with those of the actual scenes, it could also be called the anticipatory image analyzer organized by closed-loop coding-decoding principle.

6 Life as Adaptive Closed-Looped Coding-Decoding System

Life in ontogentic scale can be considered as an adaptive system that continually accumulates the experience by increasing the amount of information and uses it. This information is a neural one in multicellular animals and a humoral one (carried by concentrations distributions of growth factors, histohormones, hormones, *etc.*) in multicellular organisms. The amount of genetic information (in a classic sense) is constant.

In a species level, adaptation usually is related to small changes of genetic information. The significant changes of coding-decoding system (control system) are possible only in macroevolutionary scale only.

Microevolutionary changes of coding-decoding system are related to change of information in genetic memory structures only. It is supposed that the coding-decoding system of genetic memory (but not of particular genetic information) practically has been stable for the last billion year (the macroevolutionary scale). The coding-decoding system of neural memory is more labile.

Biological evolution can be discussed as change of formation and reproduction of hierarchically organized dynamic structures of closed-looped coding-decoding. Increasing complexity of these structures gives a higher level of informational control. A regulator is a simple system, which could be a primary prototype of coding-decoding systems. Such a dynamic structure with a feedback is rather frequent in bio-systems. In feedback link such structure-regulator codes two states of the system and processes approximately 1 bit of information in the control procedure. The regulator may by represented as the simplest closed-loop coding-decoding system. The analogue of a regulator could be seen in the "predator-prey" system [9, 11].

The storage of information in the biological systems is performed by two different structural matter/energy transformation mechanisms: a genetic one according to the stochastic Darwinian way, and a neural one according to the Lamarckian way. The traits that are acquired as modifications cannot be transferred to offspring genetically (in contrast to Lamarck hypothesis), but some acquired neural information can be transferred to offspring learning and imitation, as we see it now [12].

6 Historical Review

Biologists today cannot reject functionality (orientation to goal) in living nature, but at the same time avoid confrontation with the "hegemony" of the physicists way of thinking. Nevertheless, the goal and non-material factors, determining the essence of living organisms, have been emphasized in life sciences since Aristotle. These factors were named entelechies by Aristotle (384-322 B.C.) and H. Driesch, archeaus by Paracels, managing souls by G. E. Stahl, organizing forces by A. Sniadecki, and vital forces by H. Treviranus. R. Descartes saw both material and non-material-spiritual forces

manifesting in the living organism. All these factors are understood as control processes in cybernetics, where non-material information is carried by material carriers. In biological systems these material carriers are DNA, RNA, some proteins (all for genetic information), hormone molecules (for humoral information), neuronal networks and neural impulses (neural information). As M.Yčas puts it, this is where the soul of the living resides [12]. Information processes drive material-energy transformations not in a random, but in a goal-oriented and pre-programmed direction.

Non-living, non-organized systems develop towards the state with highest probability, whereas organized systems develop towards thermodynamically less probable (as a rule), but functionally meaningful states by steering of certain information processes and signals. That unavoidably leads to the consumption of free energy and quality materials. One of the cybernetics pioneers W. Ross Ashby put it that a goal-oriented system can choose more effective actions than pure probabilities may offer due to the information it obtains.

Conceptual analysis of interacting processes in biology and their future evolution brings to the conclusion that evolution of predator-prey-like systems leads to the origin of information, regulation, control and anticipation, and they are qualities of the organized systems. A special new quality that determined the evolution of all biological systems and evolved from predator-prey-like interactions and circular functional causality is *information*, which underlied the emergence of all these organized/ordered, systems.

Evolution of Ideas on Non-Matterial "Forces" in Nature

CLOSED-LOOP CODING-DECODING

2002 P.C. Marijuan.....INFORMATION-PRODUCTION COUPLING
1989 H.Maturana, F.Varela.....AUTOPOIESIS
1985 R .Rosen.....ANTICIPATION
1982 H. Pattee .....SEMANTIC CLOSURE
1977 H.von Fuerster .....EIGENBEHAVIOR
1962 F.S. Rothschild, T.A.Sebeok.....BIO-SEMIOTICS
1948 N.Wiener, C.E.Shannon.....INFORMATONAL CONTROL
1938-1955 P.Teilhard de Chardin .....IDEA of NOOSPHERA
1940 H.Driesh..... VITAL FORCES, ENTELECHIES

1804 A.Sniadecki... .....ORGANIZING (ORGANIC) FORCES

VIS VITALIS.....G.Treviranus (1779-1837)

CONTROLLING SOUL .....A. Shtall (1660-1734)

REFLECTION of SOULS.....R.Descartes(1596-1650)

ENTELECHIES.....Aristotle (384-322 BC)
PSICHE.....Plato (427-347 BC)

8 Conclusions

1. CLOSED-LOOPED CODING-DECODING might be a general principle of the life functional organization. It is the essence of the ORGANIZED SYSTEM.
2. CODING is a reflection of a real dynamical system by means of the receptors on the steady structures of MEMORY (DNA, hormones, neural nets) in such a way, that the re-reflection back to real dynamical system would be possible. This is the essence of INFORMATION.
3. DECODING is implementation of the coded projects or programs (INFORMATION) noted on MEMORY by means of the effectors. It is a real dynamical matter and energy transformation process and CONTROL by information.
4. DECODING in the organized systems is inseparable from informational ANTICIPATION, because it is a CONTROL by purposive informational project stored in memory structures.
5. ONTOGENESIS is a manifestation of the biological decoding procedures.
6. PHYLOGENESIS is a manifestation of the biological closed-looped coding-decoding procedures, realized by natural methods of the genetic engineering.
7. BIOSPERE is a complex system consisted of organized components, activities of what are defined by closed-loop coding-decoding procedures. The determinant structures are genes, hormones and nerves that's realize closed-loop coding-decoding.
8. NOOSPHERE is a knowledge-based part of biosphere, the functioning of which is based on closed-looped coding-decoding taking place in the brain. The functioning of the biosphere is based on closed-loop coding-decoding of genetic and hormonal information.

Acknowledgement

I express my thanks to Kastytis Beitas for his most valuable assistance in preparing this paper.

References

1. *BioSystems*, 2001, V 60, N 1-3; *BioSystems*, 2002, V 64, N 1-3.
2. Rocha LM. Eigenbehaviour and symbols. *Systems Res*, 1996, V 12, N 3, 371-384.
3. Maturana HR, Varela FJ. The tree of knowledge. Shambhala Publ, Boston, 1987.
4. Gitt W. Information, science and biology. *Technical Journal*, 1996, V 10, N 2, 181-187.
5. Gatlin LL. Information theory and the living system. Columbia University Press, New York, 1972.
6. Dusenbery DB. Sensory ecology. How organisms acquire and respond to information. W.H. Freeman and Co, New York, 1992.
7. Rosen R. Anticipatory systems. Pergamon Press,Oxford, 1985.

8. Lange H. Are ecosystems dynamical systems? *Int. J. Computing Anticipatory Systems*, 1999, V 3, 169-186.
9. Kirvelis D. The origin of new qualities in the evolution of interacting dynamic systems. *AIP Conference Proceedings*, 1999, V 465, 313-326.
10. Kirvelis D. Visual analyzer as anticipatory system (Functional organization). *AIP Conference Proceedings*, 2000, V 517, 277-286.
11. Kirvelis D. The origin of information and regulation (control) in the evolution of predator-prey-like systems. In: Proceedings of XIV EMCSR'98, Cybernetics & Systems'98, University Vienna, 1998, V 1, 363-367.
12. Yčas M. Apie biologiją. Candela, Kaunas, 1994.