View on Organized System

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Abstract

The concept of an organized system and the historical review of the problem are presented. The concept explains biological phenomena and cybernetics systems in a point of view of functional organization. Cybernetics and information theory consider physical and chemical transformations of energy and matter in organized systems only as signals and a means for realization of some purposive informational control programs. Life (or Artificial Life) is considered to be an adaptive system that stores information. The more such a biological (or artificial) system (species) is effective in storing and using information, the fitter the programs are. Evolution of systems from non-organized and dissipative transformations through elementary organized-regulators, programmed controllers, servo-controllers up to anticipatory systems is discussed. The elementary functional components of a biological cell, a multicellular organism, and an animal are analysed as organized systems.

Keywords: organized system, signals, information, encoding-decoding, control.

1 Introduction

Whereas modern biology is becoming a dominating science, whereas humankind is evolving into the information and robotic society, it's actual to determinate systems in terms of functional organization. It is useful to divide systems into non-organized and organized groups.

Physics and chemistry deal with non-organized systems in which only matter and energy transformations take place. The traditional concept of a system represents the matter and/or energy transformations as a cause-effect or influence-reaction relations/laws. This is the concept of a non - organized system. The relations/laws are originated from thermodynamics.

The theory of Artificial Life (Alife) postulates, that life is a physical process, and the essence of a living system is metabolism, adaptive organism-environment responses, reproduction, and ability to evolve (Bedau, 1992; Cariani, 1992; Langton, 1989,1992; Rasmussen, 1982,1992). Cybernetic informational control processes are supposed to be of a secondary importance, not essential. According to the new science classification system offered by the European Community, cybernetics, which is the science about control, control systems, i.e., about information processes in living organisms, some machines and society, is put among biological sciences, as a general life science (Official Journal of the EC, 1991). There lies an important prediction for the future, because, in terms of the evolution of matter, life is the first and the most advanced ORGANIZED system, whose evolution is caused by information-control processes. A dictionary says: "**life...1** active force in animals and plants that makes different from all others form of matter, such as stones or machines or dead bodies...**2** matter in which this force is presented and which can grow, produce new form, etc....".This "active force"- entelechies, archeaus, vis vitalis, organic (organizing) forces, is that non-material factor of living organisms, which, according to many outstanding thinkers from Aristotle to H. Driesch, determines the essence of life. And this force is information control processes. The transformations of matter and energy in biological systems can be regarded as signals and a means to realize informational control programs. Life can be considered to be an adaptive system that stores information. The more such a biological system (species) is effective in storing and using information, the fitter it is. The storage of information is performed by two structural matter/energy transformation mechanisms: a genetic one according to Darwin and a neural one according to Lamarck, as we understand now.

According to the EC science classification system, BIOMECHANICS & CYBERNETICS (B115) is a branch of the **type** GENERAL BIOMEDICAL SCIENCES (B001), that still includes theoretical biology, history & philosophy of biomedical sciences, general aspects of evolution and bioinformatics, biomathematics, biometrics (Official Journal of the EC, 1991). The **type** BIOPHYSICS (B002) is the rest of modern BIOMEDICAL SCIENCES (B000) that use modern physicochemical methods. In this classification biophysics is presented as more experimental science, only physiological (or system) biophysics (B130) may be represented as theoretical one. Alife science needs association of cybernetics with physiological biophysics. In this context, it is useful to review the origin of biology-biophysics, the most important points of its development, and the structure of modern biophysics as a science of organized systems, as Alife science, in the point of view that the information, but not matter/energy is the essence of the understanding of life.

Aristotle's "physics" was the science of living and non-living nature, and was not divided into separate parts. He demanded that all three questions be answered, e.g.: What elements does the leaf is composed of? How does the leaf grow? What functional purpose does the leaf serve? Today's physics and classical biophysics ignore the last question and consider it inappropriate. This methodology - based on the principles of causal logic and extremely successful ever since in physics, the fundamental science of non-living nature, - is nevertheless unsatisfactory when it comes to explaining the phenomena in living nature. In living nature, information-regulation and control processes take a special place, and for them the third Aristotle's question about functional meaning is perfectly legitimate. It is the concepts of organized systems that are more appropriate for life phenomena, but these concepts are outside the scope of classical physical sciences. The interpretation of functional significance is left for biologists as a secondary, not the most important question.

The purpose of the present paper is to explain the differences between physical and cybernetic approaches to the living organisms, on the basis of the concept of an organized system.

2 Classification and Evolution of Open Systems

In trying to understand living systems in terms of systems theory, one can classify them as "non-organized" and "organized". This classification becomes clear if one takes a physicochemical thermodynamics approach.

From the thermodynamic point of view, life (living system) is defined as an open thermodynamic system that is able to utilize free energy from its environment and whose entropy **S** is either stable or decreases. To put simply, life is able to uptake necessary resources in its environment and use them to maintain its own system organized (or even to increase that order). In other words, the living system uses these resources for "repair" and "construction".

It is accepted, that the concept of a “system” was introduced by the ancient Greeks, however, it was best defined in thermodynamics. A classification of thermodynamic systems can be easily derived from the Prigogine's equation:

$$dS/dt = d_iS/dt + d_eS/dt, \quad (1)$$

where dS/dt is entropy rate in an open thermodynamic system,
d_iS/dt is entropy rate if the system was isolated,
d_eS/dt is entropy rate due to the exchange with the environment.

The second law of classical thermodynamics states that the entropy of isolated systems always increases, i.e.,

$$d_iS/dt > 0, \quad (2)$$

which means that, as time passes by, systems break, decompose, and gradients even out (Nicolis, 1989). That is characteristic of non-organized systems.

Open thermodynamic systems, on the other hand, are able to reduce their entropy S, i.e. to increase organization. Based on the entropy exchange rate, d_eS/dt, as opposed to d_iS/dt, one can make up four groups of systems, which encompass simple non-organized, dissipative, organized homeostatic, and organized evolving systems. The latter two include both living and other cybernetic systems.

2.1 Non-organized open thermodynamic system

This is a classic physicochemical systems whose entropy S, even if the system is open, increases, i.e.,

$$dS/dt > 0, \text{ because } d_eS/dt < d_iS/dt. \quad (3)$$

All basic laws of physical and chemical transformations root in this law. The general laws of physical multi-component systems can be expressed in general form as the phenomenological Onzager’s linear equations. They state, that in the case of a system with gradients of various potentials, the spontaneous equalizing flows take place, and the system develops to equilibrium; of course, the law of conservation being valid.

The traditional concept of a system represents the matter and/or energy transformations, as cause-effect or influence-reaction relations/laws (Fig.1). This is the concept of a non-organized system.

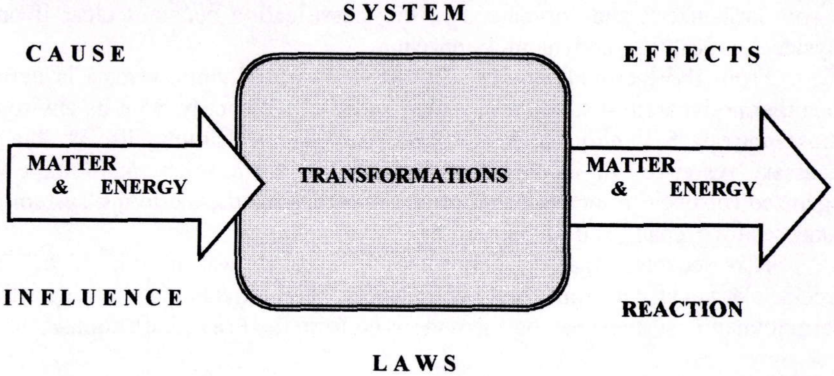


Figure 1: Diagrammatic representation of a non-organized system.

The relations/laws are, as was remarked, originated from thermodynamics. They are applied to the matter/energy transformations and to the evaluation of signal properties, *i.e.* the properties of material carriers of information. It is important in characterization of activity of informational control structures. If the classical physics approach was taken, the first thing we should do is to find the most fundamental features of living organisms that set them apart from non-living structures. For this, the methodology of physicochemical thermodynamics and its phenomenological observations can be used.

2.2. Dissipative system

This is an open thermodynamic system that, during its periodic relaxation, obtains a portion of free energy from its environment to compensate for the amount of degraded energy due to an increase in entropy:

$dS/dt=0$, because $d_eS/dt=d_iS/dt$. (4)

Dissipative system has a property to retain the stationary state of organization, where S=const, *i.e.* the system can take resources from the environment in order to self-repair after degradation. Physics understands this property as a self-organization and pays special attention to it, explaining it only by the matter/energy transformations.

This property is characteristic of systems with a certain non-linear feedback. The phase-trajectories of these systems are closed loops that amount to periodic auto-oscillating relaxations. Linear dynamic systems have the closed loops as well, but only in the case of theoretic solutions, because in reality they are not stable. Stabilization needs some non-linearity.

Some classic examples are Lotka-Volterra's predator-prey model. (Fig.2) It is not only a good theoretic example, but it also has its real equivalent in nature.

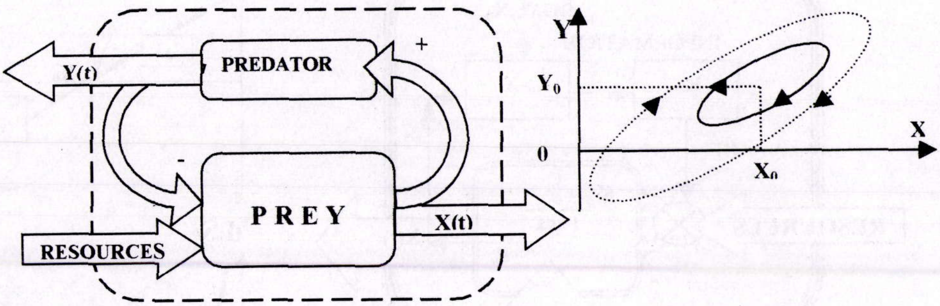


Figure 2: Predator-Prey-Like system.

Similar systems are Turing's brusselator, Zhabotynsky-Belousov's oregonator, and the like ones.

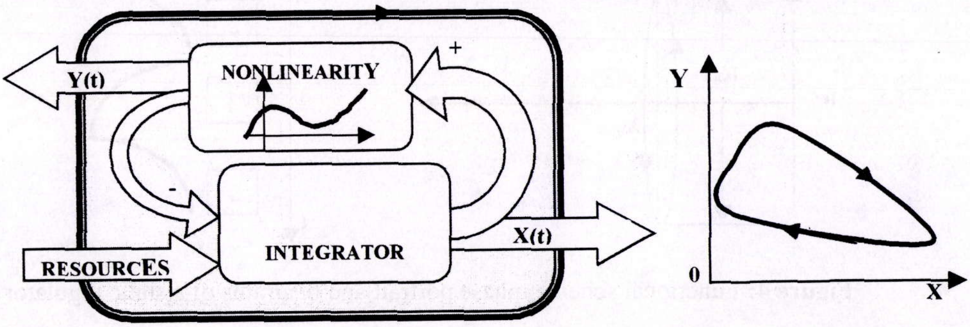


Figure 3: Dissipative system as relax-oscillator.

Such dynamic systems have some properties of self-regulation; however, they can hardly be called "organized". Most works of physical chemistry classify similar phenomena as "self-organized", especially when dealing with dissipative structures. However, it would be hard to find in these simple dissipative systems anything like feedback as information or control, be able to quantify these factors by information units, or, for that matter, call these systems "organized".

2.3 Organized Self-Regulating - Homeostatic System

The simplest system that can be called "organized" is the regulator (Fig.4) [Kirvelis, 1998, 1999].

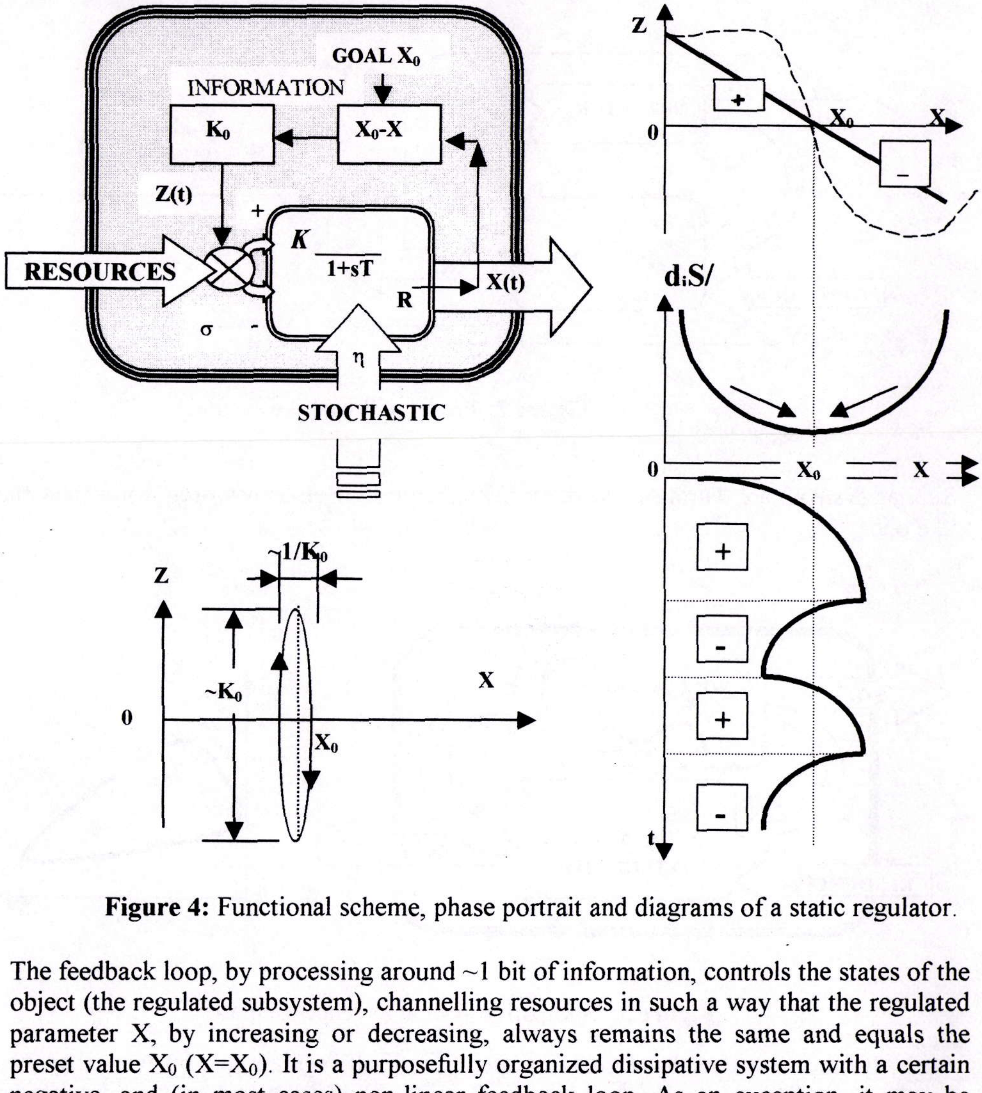


Figure 4: Functional scheme, phase portrait and diagrams of a static regulator.

The feedback loop, by processing around ~1 bit of information, controls the states of the object (the regulated subsystem), channelling resources in such a way that the regulated parameter X, by increasing or decreasing, always remains the same and equals the preset value X_0 ($X=X_0$). It is a purposefully organized dissipative system with a certain negative, and (in most cases) non-linear feedback loop. As an exception, it may be linear as well. Such a regulator acts as Prigogine's dissipative systems, but, in addition, one can estimate the amount of processed information according to C. Shannon's formula. The sign of the feedback signal Z determines the state of the controlled subsystem, [+] increases X, [-] reduces X. If the existence time t[+] and t[-] is evaluated statistically, recalculation to probabilities enables one to find the amount of information controlling the regulator, transferred by Z.

As seen in the Figure 4, the system attains the minimal dissipation when the regulated parameter X equals the preset value, the goal X_0. In this situation, the error is the smallest and the negative loop transmits the largest amount of information. It is in this organization that the feedback structure becomes a controlling subsystem, or an information channel with a coder-processor-decoder.

When not one, but many parameters are regulated in the system, such a system is called homeostatic. The goal of regulation or preset goals can be not only constant parameters but also processes that are pre-programmed in the system but seem stochastic in the environment. In the former case we are dealing with a tracking or servo-system, known in cybernetics, and in the latter with programmed control. Information processes play an even more important role in these systems.

The criterion or criteria for regulation/control may be not only various parameters, but the requirements for some optimum (minimum or maximum) as well. In the latter cases we are dealing with optimisers, cybernetic systems with optimal control. These are still higher-level homeostatic systems, performing still more complex procedures of information processing. In their control subsystems should emerge informational structures employing certain algorithms to search for an optimum.

All aforementioned regulatory systems are simple cybernetic systems that realize constant functional goals without changing their internal structure. They, as well as all dissipative systems, can utilize resources in the environment and maintain

$$dS/dt=0. \qquad (5)$$

A feature that distinguishes them from simple dissipative systems is that they have much smaller energetic relaxations. The more advanced procedures of informational processes and subsystems underlie more continuous and stable functioning.

2.4. Organized Evolving Systems

It can be the best understood by looking at the diagram in Fig.5. An organized system is composed of two subsystems: matter and energy transformations or the controlled subsystem; and the controlling or control subsystem, which processes information to steer the matter and energy transformations in a meaningful, goal-oriented direction.

It immediately becomes obvious that life, living system is an open non-equilibrium thermodynamic system, which can take free energy and materials from its environment, and can maintain or even reduce its internal entropy. With regard to the concept of dissipative systems, it is worth noting the "ability to take from the environment". It is there that the necessity to receive, encode, and process information, the necessity to make decisions and decode-interpret information arises. That requires the appropriate structures capable of performing these functions. (Fig.6.) Considering the essence of life, thermodynamic and energy-matter transformations overshadow the importance of information processes. Therefore, it becomes important to understand the executing mechanisms.

Wherever information or programmed behaviour manifests itself, one finds a functional goal-orientation. That means that we are dealing with an organized system. The biology term "organism" was derived from the concept "organized". Up to the beginning of the last century, when the name "biology" was not yet invented, theoretical works on living nature had been called the theory of organic entities. The term "organic", which today is most likely to be encountered as "organic chemistry" or "organic material", roots in the concept "alive-organized".

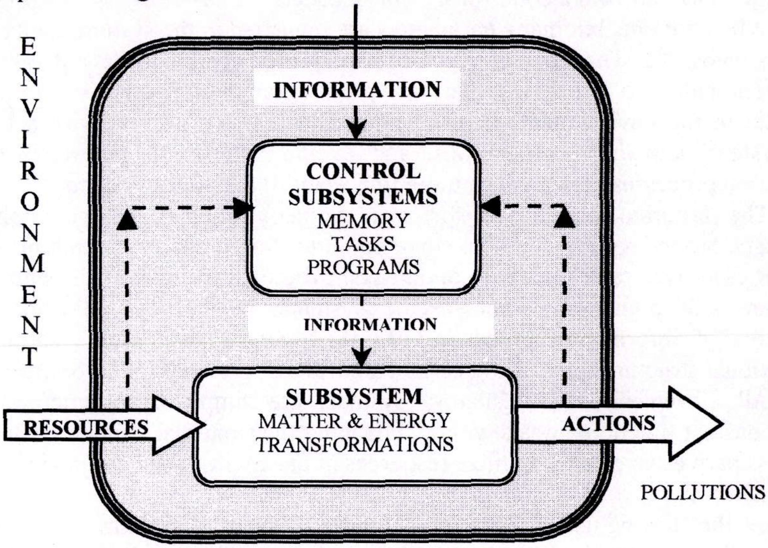


Figure 5: The functional structure of an organized system.

The control subsystem is a special ingredient of an organized system, which ultimately determines the behaviour of a system. It should be able to receive, store, process and pass on information. Obviously, it can also control information flow. The controlling subsystem has to have memory, and its successful functioning depends on various processes of encoding, decoding, noise suppression, and reliability enhancement. The program and goals are stored in the memory structures. This subsystem is less concerned with minimizing energy and matter expenditure or efficiency, and aims at achieving the fastest and the most reliable decision-making instead. It processes a non-material entity, information, whose material carriers are called signals. The conservation law applies to signals as well as to all energy and matter transformations, whereas information defies it. Information processes are governed by special laws which are defined in mathematical information theory.

The reaction of the organized system may be expressed by the conditional equation

$$REACTIONS = \begin{cases} ACTIONS,..if.INFORMATION = .YES., \\ 0,...............if.INFORMATION = .NOT. \end{cases} \quad (5)$$

The reaction of a non-organized system obeys only *ACTIONS*, the laws of thermodynamics.

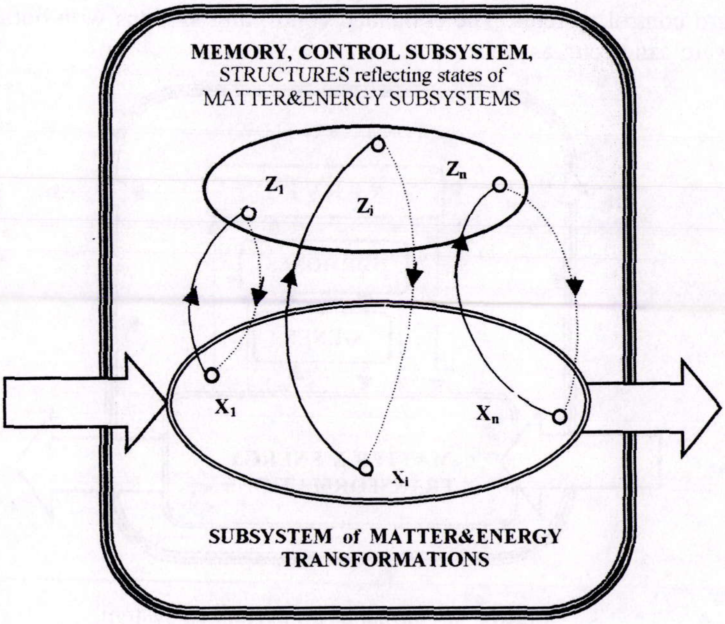


Figure 6: Schematic interpretation of coding (—►—) decoding (--►--) in the organized systems.

The controlled subsystem, acted upon by the information provided by the controlling system, times and directs matter and energy transformations in a goal-oriented, and not the most probable, direction. This process may be thought of as decoding, and the switching device (structure) may be called a decoder. Here, the functional-semantic importance of information can already be seen. Without a controlled subsystem, a controlling subsystem (which now processes information without decoding) hangs in a hazy information space. For instance, in the simplest organized system, a regulator (thermostat), the feedback link processes ~1 bit of information, which turns up or down the utilization of resources, thus maintaining certain parameters constant in the face of changes in the environment. [Kirvelis, 1999].

Encoding-decoding is inseparable from the information control processes. In the simplest organized system, coding is a reflection of a real, natural system in an abstract structure, e.g. memory (Casty, 1989). Decoding is a reflection of an abstract structure in a real system, and this is a base of control. In the complex organized systems, decoding is often directly connected with prediction. A reflection of a natural system in a formal one is a model of the natural system.

Information channels in organized systems need not necessarily be connected by feedback. They may have *a priori* information about the system itself and/or the environment, and by receiving partial, incomplete information about changes in the environment may channel resources according to the program. These systems are direct or feedforward control systems. The combined controlling systems with both feedback and feedforward can occur, as well.

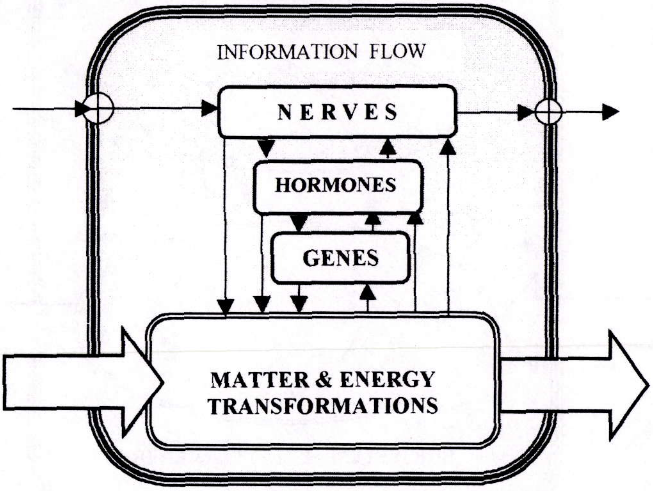


Figure 7: Animal as an organized system.

There is no doubt that control (regulation) and information play a crucial role in biological, technical and social systems. Some typical biological examples are the Jacob-Monod operon in the cell, neural and hormonal systems and the whole organism in multicellular animals.

It immediately becomes obvious that life is an open non-equilibrium thermodynamic system that can take free energy and materials from its environment, and can maintain or even reduce its internal entropy. With regard to the concept of dissipative systems, it is worth noting the "ability to take from the environment". It is there that the necessity to receive, encode, and process information, the necessity to make decisions and decode-interpret information arises. That requires the appropriate structures capable of performing these functions. Considering the essence of life, thermodynamic and energy-matter transformations overshadow the importance of information processes. Therefore, it becomes important to understand the executing mechanisms.

These systems can decrease their entropy $dS/dt < 0$.

An open thermodynamic system, the entropy change of which is larger than dissipation due to exchange, can evolve and become more and more adapted. In some cases, this feature is present in systems capable of storing resources.

However, the anticipatory systems, which increase their internal organization, thereby obtaining new functional abilities in achieving unchanging, constant goals, are much more interesting (Fig.9). These features hinge upon novel structures and functioning algorithms. The most conspicuous practical example of such systems is biological evolution, and the theoretical explanation is John von Neumann's machine capable of reproducing itself and evolving(Yčas, 1994). As Neumann's theory shows,

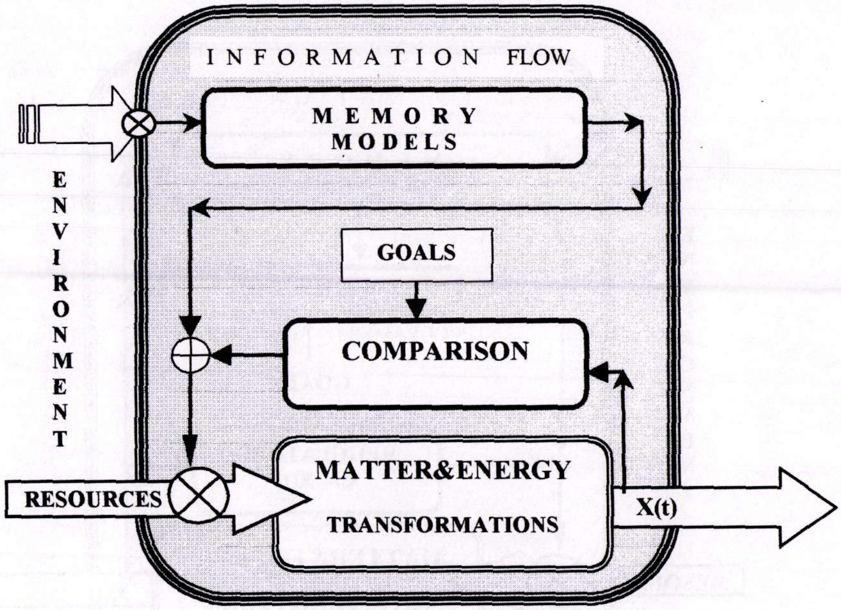


Figure 8: Combined feedforward-feedback control system.

such a system should be composed of three crucially important components: besides material structures E, it should have a structure I, keeping the blueprint of the machine itself and its manufacturing process, as well as a structure C, the structure of project copying. However, in order to enable the machine to evolve, its structure I should contain two parts: one stable and unchanging (Ic) and the other one constantly evolving (Iv), so that I=Ic+Iv. The evolving information component Iv is the one that underlies Darwinian evolution.

Neumann's example shows that the most important cornerstone of evolving systems is the information component of the system, whereas the material component plays a secondary role. One can see all that very clearly in biological systems where it manifests itself in genetic research as mutations and modifications: changes of informational structures are called mutations, whereas changes of material components are called modifications.

Anticipatory systems have specific features such as structures capable of creating models of itself and their environment, which can control their behaviour by making predictions (Rosen, 1985). Such a system is the nervous system in animals. The evolution of the structures of the nervous system brings about the advancement of information acquisition, storage and processing which underlie learning and teaching, i.e., information storage and passing it down to the offspring. This feature underlies Lamarkian (exosomatic) evolution.

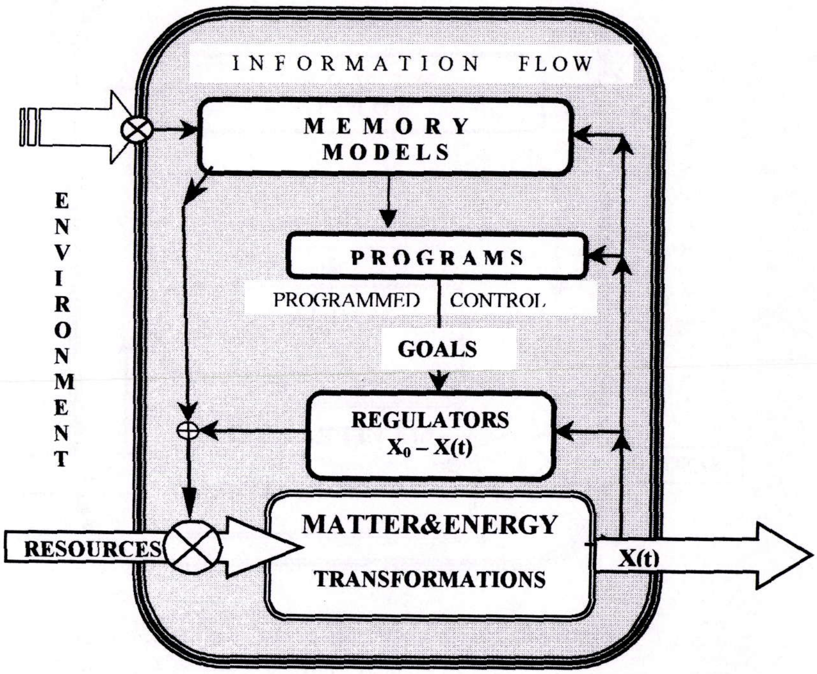


Figure 9: An organized anticipatory

It is both Darwinian evolution through some informational changes of genetic structures due to stochastic processes and Lamarkian evolution due to passing down information stored in the nervous system that ultimately enable the adaptation of organized biological systems. The primary change ought to be informational-programmed, *i.e.* a mutation, which disseminates and establishes itself in the environment. Phenotypic variation is most expressed in nature, but it is genotypic–informational variation, which determines the further evolution. The most conspicuous organized system, no doubt, is life itself whose essence resides in its informational control subsystems and their algorithms designed to realize tactical and strategic goals. In contrast, transformations of matter and energy are but a means of the realization of this informational evolution.

It should be noted, however, that all biological systems may have common strategic goals, which determine the behaviour of individuals and populations and which probably can expressed in the following imperative, "I shall flourish, and so shall my species". Here arises a question, "Can such systems alter their strategic goals? And if so, which class of systems would they belong to?"

Or, perhaps, the name 'self-organizing' systems should be applied not to simple dissipative systems but the organized systems that can change their strategic goals.

However, that would be a totally new class of organized systems.

3 Historical Review

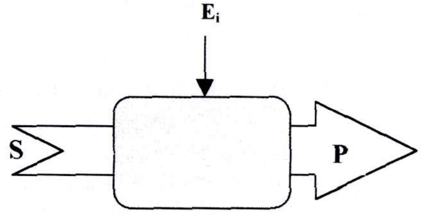
Biologists today cannot reject goal-orientation in living nature, and at the same time avoid confrontation with the "hegemony" of the physicist's way of thinking. The goal and non-material factors, determining the essence of living organisms, have been emphasized in life sciences since Aristotle. This is Aristotle (384-322B.C.) and H. Driesch's(1876-1941) entelechies, Paracelsus (1493-1541) archeaus, G.E. Stahl (1659-1734) managing souls, A. Sniadecki's (1768-1838) organizing or organic forces, H.P.Treviranus' (1776-1837) vital forces. R. Descartes (1596-1650) saw both material and non-material-spiritual forces manifesting in the living organism (Biziulevičius, 1992; Folta, 1981; Sniadeckij, 1804). Information theory today regards all these "forces" as informational control processes, which are realized by material carriers (signals) of non-material information. In biological systems they are: DNA, RNA, enzymes (for genetic information), hormone molecules (for hormonal information), neuronal networks and neural impulses (neuronal information). As M.Yčas puts it, this is where the soul of the living resides. 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 less probable (as a rule), but functionally meaningful states, being steered by certain information processes and signals. That unavoidably leads to the expenditure of free energy and quality materials. As one of the cybernetics pioneers, W. Ross Eshbi, put it as early as in 1953, a goal-oriented system, choosing its actions that are more effective than what pure probabilities may offer, can do so due to the information it obtains. No wonder the famous Russian biologists theoretician I.I.Shmalghausen (1968), having familiarized himself with the essence of cybernetics and information, not long before his death wrote a book "Cybernetics, as a fundamental teaching about the self-development of life".

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 (Kirvelis, 1998,1999). A special new quality that determined the evolution of all biological systems, evolved from predator-prey-like interaction and circular functional causality is *information*, which underlies the emergence of all these organized, or ordered, systems(Waterman, 1966; Dusenbery, 1992; Scwarz, 1998).

4 The Functional Elements of Alife

The functional components of the biological organized system are, as follows: 1) the elementary enzyme-catalysed reaction in cell, 2) the neuron in animal, and 3) the hormone-gland in multicellular organism.

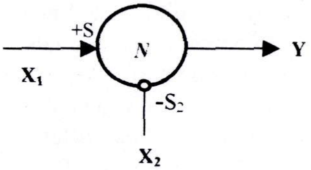


$$Y=\frac{dP}{dt}=\begin{cases}\frac{k\cdot E_i\cdot S}{K_M+S},..if.E_i\geq 0,\\ 0,............if.E_i\leq 0.\end{cases}$$

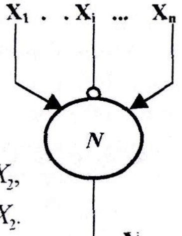
Figure 10: Diagrammatic representation of the elementary enzyme reaction and conditional Michaelis-Menten equation

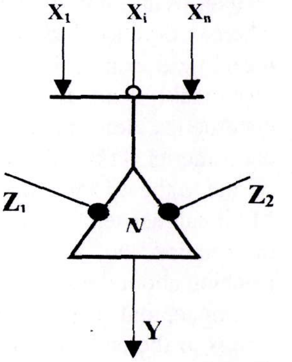
The elementary enzyme reaction presented in Fig. 10 is the main typical component of the dynamic organized system, which controls matter/energy processes. From the point of view of organized systems, the enzyme reaction is a decoder or a component of a decoder. The inhibitors are regulators of dynamic characteristics that modify the function of the *ACTION*. More specific molecular information translators or matrix synthesis are being controlled by enzymes, too.

There are special neural cells that are specialized only for processing of information in



$$Y=N\{S_1\cdot X_1-S_2\cdot X_2\}=\begin{cases}S_1\cdot X_1-S_2X_2,..if.S_1\cdot X_1\geq S_2\cdot X_2,\\ 0,..............if.S_1\cdot X_1\leq S_2\cdot X_2.\end{cases}$$





$$Y=N\left\{\sum_{i=1}^{n}S_i\cdot X_i\right\}=\begin{cases}\sum_{i=1}^{n}S_i\cdot X_i,.if.\sum_{i=1}^{n}S_i\cdot X_i\geq 0,\\ 0,............if.\sum_{i=1}^{n}S_i\cdot X_i\leq 0.\end{cases}$$

$$Y=\begin{cases}N\left\{\sum_{i=1}^{n}S_i\cdot X_i\right\},..if..Z_1.OR Z_2=0,\\ 0,..................if..Z_1.OR Z_2\neq 0.\end{cases}$$

Figure 11: Diagrammatic representation of the analogue neurons without and with information conditions **Z,** and their equations of reactions

animals. This neurons or neural nets control muscles, glands, and nerve structures, all *ACTIONS*, not only matter/energy transformations, but the information flow, as well. The simplest analogue neurone as a component of an organized system is presented in Fig.11.

It has been suggested that the neuron reaction is firing frequencies of neural impulses. The neuron is considered to be a summator of continuous (analogous) inputs (spike frequencies) with positive (+) and negative (-) signs.

It is able to weigh every synaptic input by a synaptic weight *S*, which may take on any value. Since synapses may be excitatory and inhibitory, the weights of excitatory synapses are often considered positive (+*S*), whereas the weights of inhibitory synapses are negative *(-S)*. Therefore, the quasineuron's static functional characteristic maybe described by a non-linear equation, with is a "diode-like" non-linearity with saturation at X_M (in the case when the sum of inputs exceeds the maximal frequency that the neuron may reach). More general neural functional characteristics are presented in Fig.11. It is especially necessary to pay attention to prohibiting inputs Z, that have the very high negative inhibitory weights. These inputs permit to realize the complex logical functions, and they actually are the information control. In a similar manner hormone-gland physiological systems of multicellular organisms functions are carrying control.

4 Conclusions

- Alife investigations need a new conception, different from the present explanations by physical and chemical transformations;
- The concept of an organized system presented in this paper can be useful in joining together energy and material transformations in a purposively functioning scheme (in a point of view of information and control);
- The concepti of an organized systems for explanation of the biological phenomena in a point of view of cybernetics and information theory considers physical and chemical transformations of energy and matter only as a means for realization of some purposive informational control programmes.

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