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INFORMATION, SIGNS, KNOWLEDGE AND INTELLIGENCE

Understanding the special role of information in scientific knowledge formation is simultaneously accompanied by a high level of uncertainty regarding the nature of both information and knowledge. There are many approaches to information that can be constructively applied in some special areas of activity but remain completely useless in others. Against the background of such "informational diversity", many researchers more often had the idea of the need for a universal explanation of the information phenomenon. The need to solve this problem is intuitively substantiated by the fact that the formation of information and its application create the foundation for many processes of self-organization and control in systems of various nature: chemical, biological, social, technical, and others. From the same point of view, the concept of information is often referred to as the primary one when explaining other also little understood phenomena: signs, semantics, knowledge, psyche, intelligence, mind, consciousness, self-awareness, mathematics, probability, and others. The universal concept of information and concepts derived from it can become a set of tools for formalized analysis from common conceptual positions of information processes in various scientific fields. The article presents the results of research, within the framework of which a universal information concept was obtained using a set of basic statements (axiomatic approach) and means of terminological, graphic, mathematical formalization (means of overcoming uncertainties). The information phenomenon is presented as a special result of the interaction of physical objects: the property of an object acquired during interaction contains the characteristics of another object. This approach to explaining the nature of information (attributive-transfer nature of information, ATNI), made it possible to determine the components of the process of its formation: informational impact, information carrier, essence, and semantics of information. With their help, derived concepts are defined: information environment and its characteristics; cybernetic system, the formalized model of its controlled behavior and security criteria; signs and their relationship with information; knowledge and intelligence of the cybernetic system. The applicability of the proposed approach to the analysis of processes in information environments of various natures: protein, neural, computer, has been tested.

Keywords: nature of information, information environment, information impact, semantics of information, cybernetic system, controlled behavior, cybernetic system security, cybernetic system security, nature of signs, knowledge, intelligence of a cybernetic system.

Problem Statement. The increasing scale and depth of new knowledge in various scientific areas are reasonably associated with the development of information technologies. However, understanding the special role of information in obtaining scientific knowledge is accompanied by a high level of uncertainty regarding the nature of both information and knowledge. There are many different approaches to information that can be constructively applied in some special areas of activity, but remain completely useless in others. The scientific community is increasingly discussing the opinion about the need for a universal explanation of the phenomenon of information. The emergence of such a concept will create the foundation for explaining many other common concepts in various fields that are associated with information: "signs", "knowledge", "cognition", "mental representations", "semantics", "intelligence", "consciousness" and many others. From the standpoint of practical application, the universal concept can also become an effective tool for the formalized analysis of information processes in systems of various physical nature: biochemical, biological, social and technical.

Analysis of researches and publications. Numerous attempts to clarify information using various quantitative assessments of the complexity of a set of objects of different nature (sign messages, algorithms, semantic constructions, concepts, molecules) do not allow to reveal the essence of the information phenomenon. For example, the well-known combinatorial, probabilistic and algorithmic approaches to the “amount of information” [1] - [4] cannot explain the essence of a geographical map as information about any part of the area. Within the framework of another direction related to the “quality of information”, the semantic content of the term “information” is often explained using the terms “data”, “information”, “messages”, “signal-sign systems”, “knowledge”, “mental representations” , “Semantics”, “intellect”, “consciousness” and some others, which also have a high level of uncertainty [5] - [10]. As a rule, these terms themselves are explained through information. This approach significantly complicates the analysis of information processes, directing the course of reasoning in a closed-loop (“the principle of a vicious circle”) [11].

One can often come across opinions about the connection of information with a certain substance unknown for science yet. This explanation contributes to the widespread dissemination of myths about the universal information field (matrix), the ubiquitous energy-information exchange, quantum psychoanalysis and other parascientific phenomena.

Despite the large number of different approaches to understanding the nature of information, many researchers had the idea of the need to form a system of views that would allow obtaining a universal explanation of the phenomenon of information. If with the help of such a definition it will also be possible to obtain an explanation of the essence of related concepts that are intuitively associated with information (signs, semantics, knowledge, psychology, intelligence, thinking, consciousness, and others), then a set of tools will appear for the formalized analysis of information processes in various fields of science.

For the first time specifically and multifaceted about the problem of the universal concept of information was formulated in the work of Luciano Floridi “What is the philosophy of information?”, 2002 [12]. In this work, the concept of information refers to the fundamental concept by which other basic concepts of being, knowledge, life, intelligence, meaning, good and evil can be explained. Based on the results of the specification of tasks for the philosophy of information, 18 problems were identified, grouped into 5 sections: 1) analysis of the concept of information; 2) semantics; 3) the study of rationality; 4) the relationship between information and nature; 5) research of values [13]. The first and main problem on this list is – What is information?

The purpose of the article is to develop a universal concept of the phenomenon of information and a set of derived concepts for formalized analysis (terminological, graphic and mathematical) of processes in information environments of different physical nature.

The main material research. This paper presents the results of studies in which a universal concept of information is proposed using a set of basic statements (axiomatic approach) and means of terminological, graphic and mathematical formalization (means of overcoming uncertainties). With its help, related concepts are defined: essence and semantics of information; information environment and its characteristics; cybernetic system, its informational processes of behavior control and criteria of their safety; signs and relationship with information; knowledge and intelligence of the cybernetic system. The universality of applicability of the proposed approach to the analysis of processes in information environments of various physical natures: protein, neural, computer, has been tested.

1. Definition of the universal concept of information. At the beginning of the research, a set of initial statements was formed, limiting the scope of reasoning about the nature of information and the procedure for forming a concept for the term “information”:

1) the phenomenon of information existed before the appearance of life on Earth (example: a shadow from a rock, reflecting the shape of a rock). To describe the nature of information, it is necessary to exclude the terms associated with human consciousness (messages, information, knowledge, thinking, idea, intellect, semantics, understanding, falsehood, truth and many others);

2) the nature of information and information processes must be explained through the fundamental concepts of classical physics – matter, substance, physical object, object property, interaction, space-time and others;

3) it is fundamentally important to distinguish real objects with their properties (composition, structure, color, weight, possible states, location in the environment, their behavior, and many others) from information about these objects and their properties. The subject and information about this subject are two different physical objects at different points in space-time;

4) the properties of objects are determined by the nature of the ordering of their constituent parts and are manifested through interaction with other objects;

5) information is a special result of physical interaction of real objects;

6) information is always associated with a material object that is its carrier and located at a specific point in space-time.

There is always an opportunity to correct the essence of these basic statements or to expand their set.

Within the framework of a set of statements, imagine a frequently observed situation: two physical objects can interact. The interaction results can be as follows:

1) one or both objects cease to exist;
2) objects continue to exist without changing their properties;
3) objects continue to exist, but they lose old or acquire new properties;
4) the acquired property of at least one of the objects is determined by the ordering of the elements of the second object.

The last event is the most interesting. Let’s look at three examples. The rising sun has formed the shadow of the rock, repeating the shape of the rock. The second situation: on wet soil, a wild animal leaves a chain of tracks, the shape of each of which contains unique characteristics of both the species and the individual itself. The stream of light reflected from the tracks can change the direction of the hunter’s movement towards the escaped animal. Even without knowing the essence of information, we can talk about the informational impact on the hunter (behavior change after receiving valuable information). The third situation: a person – a witness of a dangerous event (strong earthquake in the ocean, sudden volcanic eruption) composes a text message. A message transmitted via communication channels can lead to dramatic changes in the life of society (introduction of a state of emergency, evacuation of the population). The common thing that unites all these different situations is the presence of such physical interactions between objects, the results of which are newly acquired properties of objects that reflect the property of the influencing object.

A similar example of the interaction of objects can be found in biochemical processes. In the processes of transcription (synthesis of RNA molecules on a DNA matrix) and translation (synthesis of proteins on an RNA matrix), an ordered set of DNA nucleotides determines an ordered set of amino acids in the synthesized protein. Also, DNA sections determine the sequence of actions within the framework of the regulatory and structure-forming functions of a developing living organism.

Within the framework of the basic set of limiting statements described earlier, and based on the analysis of not only the examples given, but also many others, it is possible to formulate the following concepts for the term “information” [14]:

1) information is a property of an object, acquired as a result of interaction with another object and is a mapping of the property of this another object;

2) information about object *A* in object *B*, i.e. *I(A:B)* is an ordered set of elements of object *B*, formed as a result of its interaction with object A and is a reflection of the ordering of the elements of this object *A*.

The first definition is simpler in terms of perception, and the second is more complex, but more strict in terms of semantic uncertainty. However, the remaining uncertainty in its components (“object”, “element of an object”, “display”, “ordering” and others) can be reduced by applying some basic concepts of mathematics (ie, using mathematical formalization). In what follows, the proposed paradigm will be called the attributive-transfer nature of information (ATNI).

2. Mathematical formalization of the concept of information. Let there be an object A, which can be represented as a set (set) of its properties

$$A = \{at_i A\} \tag{1}$$

where an element of the set $at_i A$ is one of the properties of the object A (notation at from the "*attribute"*);

index $i = 1, \ldots, I$ – attribute number, I – number of attributes considered.

Let the attribute $at_i A$ (for example, a part of the shape of an object that looks like a hemisphere) can be represented as a relation on the Cartesian product of three sets of the coordinate system at the location *A*. Let's call this relation "hemisphere" and represent it as follows:

$$\text{“}hemispere\text{”} = at_i A \subset X_A \times Y_A \times Z_A, \tag{2}$$

where the subscript $_A$ indicates the location of the axes of the coordinate system in space near object A. In turn, each element of this relation (subsets on the Cartesian product) can be represented by an ordered triple (x, y, z), each of which belongs to the relation "hemisphere":

$$(x, y, z) \subset at_i A = \text{“}hemispere\text{”}. \tag{3}$$

Let us similarly describe the second object *B*: $B = \{at_j B\}, j = 1, \ldots, J$. Each property of this object can be represented as a relation on a Cartesian product:

$$at_j B \subset X_B \times Y_B \times Z_B, \tag{4}$$

moreover, object *B* does not have the shape of a hemisphere, i.e. all properties (attributes) of this object do not refer to the "hemisphere" property:

$$\forall at_j B \nexists \left(at_j B = \text{“}hemispere\text{”} \right). \tag{5}$$

With this designation, information on object B about the property of object A, which is a hemisphere, can be written as follows:

$$I(at_i A : B) = (B, at_{j+1} B) \mid f_{map}^{(t1)} : at_i A \longmapsto at_{j+1} B \tag{6}$$

that is, information about the property $at_i A$ of the object A in the object B is object B with the acquired (at time t_1) property $at_{j+1} B$, which was formed by the action $f_{map}^{(t1)}$, which mapped the feature of the property $at_i A$ ($at_i A =$ "*hemispere*") into new property $at_{j+1} B$ ($at_{j+1} B =$ "*hemispere*").

It is understood that expression (6) is not limited to application only to the property "hemisphere", which was used only for example. The proposed information paradigm makes it possible to formulate the following related concepts:

1) object A is a source of information $I(at_i A : B)$;

2) object B is an information carrier $I(at_i A : B)$, which determines the location of information in space-time;

3) the property $at_i A$ is the essence of information $I(at_i A : B)$, i.e. $at_i A = essence[I(at_i A : B)]$;

4) the acquired property of the information carrier $at_{j+1} B$ is the semantics (meaning) of information $I(at_i A : B)$, i.e. $at_{j+1} B = semantics[I(at_i A : B)]$. The property of object A is reflected in the semantics of information. When analyzing some information about the object A, the type of the information carrier is not critical, then the semantics of information can be simply denoted as $semantics(A)$;

5) f_{map} – mapping operator (index $_{map}$ – from word "mapping") determines the nature of the interaction of objects during the formation of information.

In turn, the essence of the mapping operator f_{map} can be viewed against the background of the relation F_{map} on the Cartesian product of the sets, with the help of which objects A and B were represented, i.e.:

$$f_{map}{}^{(t1)} \in F_{map} \subset \{X_A \times Y_A \times Z_A\} \times \{X_B \times Y_B \times Z_B\}. \quad (7)$$

In this case, a specific implementation of the mapping mechanism $f_{map}{}^{(t1)}$, which has formed, based on a specific property of object $A(essence[I(at_i A : B)] = at_i A)$, a new property of object $B(semantics[I(at_i A : B)] = at_{j+1} B)$, can be represented as an element of a subset of F_{map}:

$$f_{map}{}^{(t1)} : (at_i A \ I\!\!\rightarrow \ at_{j+1} B) \subset F_{map}. \quad (8)$$

Formula (7) can be interpreted as a description of a set of all information situations that can arise between objects A and B when they are interconnected through physical interaction F_{map}. Formula (8) describes a specific implementation of one of these situations. The elements of this subset (relations) are ordered pairs of properties from two objects, which can be designated by the following options (9), (10):

$$(at_i A, f_{map}(at_i A)), \quad (9)$$

$$(at_i A, at_{j+1} B) = (essent[I(at_i A : B)], semantics[I(at_i A : B)]) \subset F_{map}. \quad (10)$$

The proposed attributive-transfer approach to the nature of information (ATNI), formalized in expressions (1) - (10), opens up additional opportunities for the development of tools for analyzing various information processes. For example, for subjects of cognitive and/or constructive activity, the procedure for evaluating the information received is important. A person is constantly faced with the need to evaluate information according to different criteria ("good-bad", "truth-false", "authentically-unreliable", "actual-irrelevant", "useful-unnecessary" and others). Within the framework of the paradigm, with the help of the related concepts "essence-semantics", it becomes possible to highlight and clarify the meaning of the procedures for evaluating information about an object. For example, the following procedures can be distinguished:

1) comparison of the semantics of information about an object (i.e., a property of an information carrier) with the essence of information (i.e., a property of an information source);
2) comparison of the semantics of two or more different information about one object;
3) comparison of semantics of information about different objects and others.

Falling under the concept of "assessment", these procedures differ in the components being compared. The list of procedures itself can be expanded if we take into account that the essence of assessment is to compare the properties of physical objects of the same or different nature. The result of the comparison (i.e. – evaluation) of properties can be expressed in terms of one of the types of possible relationships between properties. An example of a commonly used relationship:

1) similarity relation – the ordering of elements in the essence of information ($at_i A = essence[I(at_i A : B)]$) is preserved in the ordering of other elements in the semantics of information ($at_{j+1} B = semantics[I(at_i A : B)]$), but in different proportions (example: a person's appearance and a photograph of a person);
2) the ordering relation – the ordering of the elements of the essence of information is replaced in the semantics of information by the ordering of elements of a different nature. An example from molecular biology – an ordered set of nucleotides in the structure of DNA determines an ordered set of amino acids in the structure of a synthesized protein (transcription and translation procedures).

In the example, only two types of possible relationships are considered. The size of the set of relations is limited by the number of forms of representation (description) of these compared properties. The choice of form depends on the subject of the assessment.

The proposed paradigm will further be used to represent from a unified standpoint the entities of more complex information processes that are associated with the use of signs, knowledge and intelligence. As an auxiliary tool for describing these entities, the concept of "information environment" will be previously considered and a model of the behavior of a controlled (cybernetic) system will be developed.

3. Information environment. The proposed paradigm was built on the assertion that information, as a special phenomenon of the physical world, could exist even before the appearance of life (biological systems). This approach made it possible to describe information through terms that can be associated with inanimate nature: object, property, impact, display. On the other hand, the experience of each person allows us to assert the important role of information in living nature. It is used in the interaction of living beings with each other and with the environment, directly affects their behavior and determines their ability to survive. Within the framework of determining the constructiveness of the proposed approach, it is interesting to check the possibility of its use for a formalized explanation from a unified standpoint of the essence of information processes of both inanimate and living nature. For example, how can information about the environment be used to shape the behavior of a biological or technical system? How is information related to the knowledge of the system and how is it applied in the process of cognition? How does the information and knowledge of the system relate to its behavior? What behavior of the system can be considered intelligent?

This formulation of the question allows us to turn to cybernetics, which explores the general laws controlled systems of various natures (chemical, biological, social, technical). Systems that shape their behavior under the influence of any external and/or internal factors will be further referred to as cybernetic systems (CS). The known models of such systems assume that they consist of a managed object and a subject of management. By exchanging signals between these components via forward and reverse communication channels, the behavior of the system is determined. A typical example of a graphical representation of a cybernetic system is a model of basic operations of industrial control systems [15], a fragment of which is shown in Fig. 1.

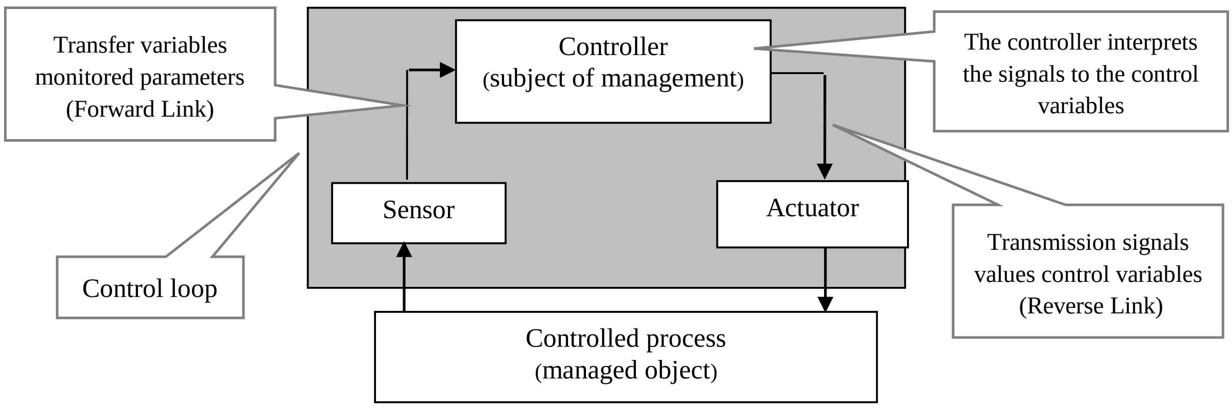

Figure 1 – Model of basic operations of industrial control systems

Within the framework of the model, the values of the state parameters of the managed object, formed by the sensors, are sent to the controller (the subject of management) using signals from the direct communication channel. The controller interprets these signals and generates variable values of the control parameters. The latter, using the signals of the reverse communication channel, are transmitted to the actuators, which on their basis transfer the control object to the desired state. The disadvantage of this and other similar models of operations of cybernetic systems is the lack of explicit representation of information and its properties. This significantly complicates many studies related to the use of information in management processes. For example, within the framework of determining the criteria for the safe behavior of technical cybernetic systems of critical infrastructure in conditions of unauthorized information influences, some uncertainties arise:

1. Is it possible to apply classical approaches to information security (observance of confidentiality, integrity and availability of information) while ensuring the security of a cybernetic system without specifying the place of information and its semantics in the system?
2. What is the safe behavior of the system and is it possible to formalize its criteria?
3. Is it enough to observe only information security criteria to ensure the safe behavior of the cybernetic system?

To overcome such uncertainties, the next section will consider a model that, based on the proposed paradigm, will explicitly represent information, its semantics and essence in the processes of forming the behavior of a cybernetic system. Preliminarily, in this section, we will introduce the concept of an information environment, which will help clarify some aspects of information processing in management processes.

In what follows, under the information environment of a cybernetic system (hereinafter – IE) we mean a set of interrelated elements of the same physical nature (hereinafter – operational elements, OE), which allow:

– to fix the results of information influences in the form of changes in the values of the properties of these elements (following the proposed paradigm, the acquired values of properties are the semantics of information, hereinafter – semantics);
– store the semantics of information;
– to form semantic constructions based on information semantics;
– perform various operations on semantics (comparison, union, analysis, synthesis, and many others);
– create and provide processes for using semantics in the interests of other systems;
– based on semantics, form informational influences for the exchange of information with other CS.

In humans and higher animals, which are classified as biological cybernetic systems, the following two types of the most famous information environments can be distinguished:

– protein information environment (PIE);
– neural information environment (NIE).

Apparently, there are more such environments. The most famous are listed. Let's try from the standpoint of the ATNI paradigm to highlight the general characteristics of some information environments and clarify their meaning.

3.1. Protein information environment (PIE). Characteristics:

1) the source of information is a piece of DNA (gene), consisting of a sequence of nucleotides;
2) the carrier of information in the environment is a synthesized protein;
3) the information in the environment, $I(gene: protein)$ a synthesized protein, the sequence of amino acids in the structure of which reflects the sequence of nucleotides in a piece of DNA (gene);
4) the essence of the information in PIE is the structure of a gene (a sequence of nucleotides on a piece of DNA). That is, within the framework of the accepted designations:

$$essence[I\left(gene: protein\right)] = \text{“}gene\,structure\text{”}; \tag{11}$$

5) the semantics of information in PIE – the sequence of amino acids in the structure of the synthesized protein. That is, within the framework of the accepted designations:

$$semantics[I\left(gene: protein\right)] = \text{“}protein\,structure\text{”}; \tag{12}$$

6) the operator of the information environment mapping is a set of rules (gene code) that implements in living cells the mapping of the sequence of nucleotides in a gene (DNA segment) into a sequence of amino acids in a synthesized protein. That is, within the framework of the accepted designations:

$$f_{map}{}^{(PIE)} = \{rule_m\} : \text{“}gene\,structure\text{”} \longmapsto \text{“}protein\,structure\text{”}, m = 1,...,M \,, \tag{13}$$

where $\{rule_m\}$ is a set of M rules that implement information mapping;

7) operational elements of the environment – cells of a biological organism, which are interconnected by the extracellular matrix and transport;

8) operations with semantics in the protein information environment:

– combining proteins (semantics of the environment) with each other and with other organic substances, to form cell components (organelles), intracellular structure (cytoskeleton) and extracellular matrix;

– application for the implementation of motor, transport, signaling and other functions of cells and the whole organism;

– use as a catalyst for biochemical processes in the cell during metabolism;

– many other.

9) features of protein information environments (PIE):

– PIE is a set of operational elements (i.e. cells of the body), each of which contains within itself the same sets of information entities in the form of DNA;

– each operational element, using a standard set of rules, reads individual entities of information (DNA sections – genes) and forms the semantics of these sections (proteins with a given structure);

– within the framework of both cells and the whole organism, the formed semantics (i.e. proteins) perform various functions: structural, protective, signaling, regulatory, transport, receptor, motor and others;

– a complex of semantics serves as a building material for an organism (biological cybernetic system), controls its development, determines its properties in the environment and the order of its use (i.e. determines the phenotype of an organism);

– the mechanism of development of the organism is based on the division of the *OE(cells)*, during which sets of entities are copied. The set of the organism's capabilities for survival in the environment (the phenotype of the organism) is determined by the same sets of information entities (genotype), which are found in all cells of the organism and almost do not change during the lifetime;

– the essence of information can change during the formation of a new separate organism by:

– combining information entities (genes) of parental organisms;

– the effects of some random factors of the external and internal environment (radiation, chemical effects, errors of biochemical mechanisms , and others).

3.2. Neural information environment (NIE). Specifications:

1) source of information – objects of the external environment (OEE);

2) information carrier – neurons and their associations (neural network, NN);

3) information in the environment, $I(OEE:NN)$ – a part of the neural network (network pattern), the properties of which have changed when displaying the properties of objects in the external environment.

Note, under the structure of NN we mean a set of neurons (operational elements of the environment) and synaptic connections between them;

4) the essence of information for the NIE is the properties of objects in the external environment. That is, within the framework of the accepted designations:

$$essence[I\left(OEE:NN\right)] = \text{“}\textit{environmental object attribute (EOA)}\text{”}. \qquad (14)$$

Note. Fundamental differences between NIE and PIE:

– essences of information are located in the external environment of the cybernetic system;

– the set of entities may change;

– an essence can be any object of the external environment, which allows for informational impact on the neural network;

5) the semantics of information in NIE is the properties of the pattern of a neural network, which are formed by exchanging packets of electrical impulses between neurons through their synaptic contacts. At the synapse itself, excitation is transmitted by mediator molecules. The

interaction between neurons refers to electrochemical processes. Initially, packets of impulses are generated by sensory neurons of the sense organs. The intensity of the pulses (the number of pulses in one packet) depends on the magnitude of the external influence on the sensor.

Using the example of a person, we will present in more detail the formation of NIE semantics. The human sense organs are differentiated according to channels of external information influences of various nature: optical (vision), acoustic (hearing), mechanical (touch), chemical (taste, smell, touch,). External influences with the help of sensory neurons of the sense organs form a spatio-temporal image of the external environment. This image in the form of a set of several parallel sequences of packets of pulses is transmitted along neural highways. Such a set can be called neuroelectric semantics (*NESem*). Such semantics are supported in the information environment by the neurophysiological mechanism of short-term memory and are destroyed by the next external influence on the sensors. In NIE, one can also distinguish a kind of semantics of a different nature, which is formed using the mechanism of long-term memory. These semantics are formed under the influence of neural impulses on the pattern of the neural network of the coronal part of the brain. The mechanism of long-term memorization (coding) of images in neuron patterns has not yet been fully understood. Most likely, it is associated with the formation of new synaptic connections and changes in the effectiveness of existing connections. In turn, the properties of synaptic connections are regulated by the biosynthesis of proteins in neurons that conduct packets of electrical impulses through themselves. These proteins determine the level of sensitivity of the synaptic membrane to the mediator [16]. Such semantics can be called neuroprotein semantics (*NPSem*). These two kinds of information semantics can be described as follows:

$$NESem[I(OEE:NN)] = \text{"spatio-temporal set of packets of electrical impulses of neurons of a neural network pattern";} \quad (15)$$

$$NPSem[I(OEE:NN)] = \text{"a set of synaptic connections between neurons of a neural network pattern and values of their efficiencies ";} \quad (16)$$

6) the operator of mapping the information environment. Unlike *PIE*, the neural information environment uses several channels for generating information about the external environment, which are associated with various sensory organs. In turn, each such channel consists of a sequence of external and internal components of informational influences. External components are physical processes of various nature (optical, acoustic, chemical, mechanical) that transmit influences from objects in the external environment. All internal components of the channels are implemented by the mechanisms of the neural information environment. The external and internal components of the channel are interconnected by the sensory neurons of the sense organs. These neurons convert external influences of a different nature into effects of a single electrochemical nature. Taking into account the semantics of *NIE* highlighted above, each channel can be formalized as follows:

$$f_{map}^{(NIE)} = \{rule_m\} : \text{"}OEE\text{"} \longmapsto NESem(OEE) \longmapsto NPSem(OEE),\ m = 1,...,M, \quad (17)$$

where $\{rule_m\}$ is a set of rules connecting sequentially between the essence of information (property of an external object) and two types of information semantics $NESem(OEE)$ and $NPSem(OEE)$. Each $\{rule_m\}$ is implemented by its external environment mechanism and *NIE* mechanisms common to all channels;

7) operational elements of the *NIE* are neural cells of a biological organism that interact with each other through synaptic connections;

8) operations in the neural information environment. It is possible to distinguish the following operations:

– formation and storage of semantics;
– analysis of semantics (i.e. dividing semantics into parts);
– synthesis of semantics (i.e. combining semantics into semantic constructions);
– comparison of stored semantics with current ones, comparison of various stored semantics with each other;

– application of the results of comparison of semantics for the formation of the behavior of biological cybernetic systems;

– many other;

9) features of *NIE* of Biological Cyber Systems:

– *NIE* is a set of operational elements (neurons) interconnected by synaptic connections. Such connections allow neurons to exchange electrochemical processes that reflect the properties of objects in the external environment;

– *NIE* neurons may differ in their structure (morphologically, functionally), which allows the formation of various patterns that specialize in typical operations on semantics;

– the entire neural network, which forms the basis of the *NIE* biological cybernetic system, is a set of neuron patterns that implement various functions of processing semantics and interact with each other;

– different properties of a neural network can serve as the basis for the formation of different types of semantics $NESem(OEE)$ and $NPSem(OEE)$ with different lifetimes. Each pattern may have its kind of semantics. In this case, a set of interacting semantics of different types retains the essence of the features of information (i.e. properties of an object of the external environment);

– patterns interact with each other through the exchange of $NESem(OEE)$;

– the existence of *NPSem* semantics (in fact, an imprint of the essence of the information in long-term memory) makes it possible to hypothesize the possibility of recovery (regeneration) of the corresponding *NESem* by applying a pattern of a set of generating impulses to the synaptic contacts. In this case, the set of pulse packets from the pattern output will contain the features of *NESem*, which at one time formed the stored *NPSem* (i.e., the previously recorded features of the information essence are read);

– rebuilt *NESem** can be used to compare against streamed *NESem*, i.e. to compare the current information about the object with the previously received and stored in memory;

– each operational element of the environment (neuron) is involved in the processing not of all specific semantics, but only of its parts;

– the processes of formation and processing of NIE semantics are implemented by molecular mechanisms, which include those that use proteins. This allows us to assert the presence of a relationship between the PIE and NIE information environments of one biological cybernetic system: semantics (proteins) from the internal entities of information (i.e., from genes) of one environment (PIE) participate in the formation of information semantics of another environment (NIE).

3.3. Computer information environment *(CIE)*. Specifications:

1) the source of information – objects of the external environment;

2) the information carrier – electronic memory registers, which are connected by transmission lines of electrical signals. Each register consists of a set of triggers. One trigger – one memory location. Triggers are semiconductor devices that, under the influence of an electrical signal, can switch to one of two possible states. The conditional names of state values are “1” or “0”;

3) the information in the environment, $I(OEE:CIE)$ – these are the states of the computer memory registers and the electrical signals of the communication lines between the registers. The values of the parameters of registers and signals display the properties of objects in the external environment;

4) the essences of information for the CIE are properties of objects of the external environment. That is, within the accepted designations:

$$essence[I(OEE:CIE)] = \text{“environmental object attribute (EOA)”}; \quad (18)$$

5) the semantics of information in the *CIE* are:

– the values of the parameters of electrical signals that reflect the properties of external objects (hereinafter referred to as signal semantics, *SignSem*). Such semantics are formed by touch input devices of a computer (keyboard, TouchPad, video camera, microphone, and others). Sensors convert influences from environmental objects into *CIE* electrical signals;

– the values of the states of the registers, which are formed by the action of *SignSem* electrical signals through the connecting lines (contacts). In what follows we will call them register semantics, *RegSem*.

Explanation: In the *CIE*, an electrical signal is an electrical process whose parameters are predefined. For example, the generated electrical process consists of signal elements of the same duration (this is the first parameter, the value of which is always constant). The signal amplitude (this is the second signal parameter) in the electrical process can change only at the border of the signal elements and can take only one of two values (for example, 0.05 mV and 0.5 mV, which corresponds to the logical “0” and “1”). The amplitude in such a signal is usually called an information parameter.

By changing the values of this parameter, you can transfer the displayed environmental object attributes (*EOA*) over the connecting lines. The second parameter, the duration of the signal element, is usually called the accompanying parameter. Knowing its constant value at the point of signal registration at a known time of the beginning of transmission of the first element makes it possible to recover the transmitted amplitude values. A signal with only two values of the information parameter is usually called a binary (2-ary) signal. In communication systems, there are electrical and radio signals that use more values of the information parameter (4-ary, 8-ary, 16-ary, etc.). Some signals contain several information parameters. Signals with a finite number of information parameter values are called digital (discrete) signals. They are best suited for transferring logic “0” and “1” (i.e. bit sequences).

The two kinds of *CIE* semantics can be described as follows:

$$SignSem[I(OEE:CIE)] = \text{“}\textit{electrical signal information parameter values}\text{”}, \quad (19)$$

$$RegSem[I(OEE:CIE)] = \text{“set of values for register memory elements”}. \quad (20)$$

SignSem semantics only exist on trunks between registers during electrical signal transmission (short-term memory). The semantics of the *RegSem* type are stored in registers for a long time (long-term memory).

6) operator of displaying information environment. The *CIE* uses several channels for generating information about the external environment, which are associated with various technical sensors (optical, acoustic, radio wave, gravitational and others). These sensors convert external influences into *SignSem* signal semantics. The latter are converted to the stored semantics of *RegSem*. Stored bit sets can be converted by processors under program control (bit sets representing the conversion algorithm). Taking into account the *CIE* semantics highlighted above, each channel can be formalized as follows”:

$$f_{map}^{(CIE)} = \{rule_m\} : \text{“}OEE\text{”} \longmapsto SignSem(OEE) \longmapsto RegSem(OEE),\ m = 1,...,M, \quad (21)$$

where $\{rule_m\}$ is a set of rules connecting, sequentially among themselves, the essence of information (property of an external object) and the semantics of this entity. Each $\{rule_m\}$ is implemented by its external environment mechanism and the *CIE* mechanisms common to all channels;

7) the operational elements of the *CIE* are semiconductor memory registers interconnected by electrical connection lines.

8) operations in the information environment. Computer processors allow performing any actions with semantics like *RegSem* that can be described by an algorithm (a set of specific instructions). A processor is a collection of several registers connected by semiconductor devices that allows you to perform Boolean algebra operations. The execution of a set of instructions (programs) is implemented by the processor’s cyclic access to memory registers with *RegSem* semantics and instructions (commands). Operation results are sent to memory registers;

9) features of computer cyber systems:

– *CIE* is a set of operational elements (semiconductor memory registers) interconnected by electrical communication lines. Such connections allow registers to exchange electrical signals that reflect the properties of objects in the external environment;

– in the *CIE*, two types of semantics can be distinguished:

– signal semantics *SignSem* are the values of information parameters of electrical signals, which reflect the features of the properties of external objects;

– semantics of registers *RegSem* are the values of states of memory registers, which are formed by the action of electrical signals through connecting lines (contacts). *RegSem* also displays the properties of objects in the external environment through *SignSem*;

– using processors with *RegSem* semantics, it is possible to perform any operations that are described in computer programs;

– through technical input-output devices of the *CIE*, it is possible to exchange semantics with information media of a different physical nature.

In this section, to further clarify the essence of information processes in cybernetic systems, the concept of information environment was introduced. Within the framework of the analysis of environments of different physical nature (protein, neural, computer) using uniform methodological positions, it was possible to describe the general characteristics and highlight the features of their implementation. This confirms that the *ATNI* paradigm is universally applicable.

4. The role of information in the cybernetic system. The concepts of information and information environment formulated above made it possible to obtain a new model of the cybernetic system with the help of graphic and mathematical formalization. The model clarifies the role of information in control processes and the formation of system behavior.

Let the cybernetic system *CyberSyst* be influenced by a set of external factors (EF_i, i is the number of the flow set). In turn, such a system can perform actions act_m relative to the environment from a finite set of different actions (alphabet of actions)

$$ACT = \{act_m\},\ m = 1, ..., M, \tag{22}$$

where m is the number of the action;

M is the volume of the set of possible actions. Let the reaction of the system to the impact EF_i lead to a change in its position in the external environment, and, consequently, to a new state of its impact EF_{i+1}. The system's reaction can be described by the set of its actions A_{i+1}:

$$A_{i+1} = (act_1,\ ...,\ act_k,\ ...,\ act_K), \tag{23}$$

where k is the number of the action in the set;

K is the volume of the set of actions; each action is selected from the alphabet *ACT*. Let us denote the current i-th state of *CyberSyst* through an ordered pair consisting of a set of current environmental influences EF_i and a set of response actions of the system A_{i+1}:

$$CyberSyst_i = (EF_i, A_{k+1}). \tag{24}$$

The system maintains its state for a time interval of duration T_i. The change of these states occurs at the moments of a change in the position of the system in the surrounding (i.e., EF_i changes to EF_{i+1}) after performing the selected set of actions A_{i+1}. Example: the system stood, then turned 180^0, then walked for 2 minutes, then switched to running – these are four adjacent states $CyberSyst_1$, $CyberSyst_2$, $CyberSyst_3$, $CyberSyst_4$, which correspond to four periods of states of different durations T_1, T_2, T_3, T_4). It should be clarified that the performed set of actions that changed the position of the system in the environment may not change the nature of the effects of the environment on the system (the wolf, which ran for two hours and did not meet the prey, remained hungry). The sequence of states will be called the trajectory of the system's behavior. Different trajectories lead to different results (either the feeling of hunger remains, or a successful hunt eliminates it). Fig. 2 shows a model of the trajectory of the system's behavior from three adjacent states $CyberSyst_{i-1}$, $CyberSyst_i$, $CyberSyst_{i+1}$. The structure of the cyber system contains the following components: 1) the Subsystem of Objects of Internal Environment (SOIE); 2) Control

SubSystem, CSS; 3) Internal Sensors (IS) and External Sensors (ES); 4) Internal Actuators (IA) and External Actuators (EA). The CSS control subsystem is implemented in the information environment of the cybernetic system. The main component of this subsystem is the Decision-Making Center (*DMC*).

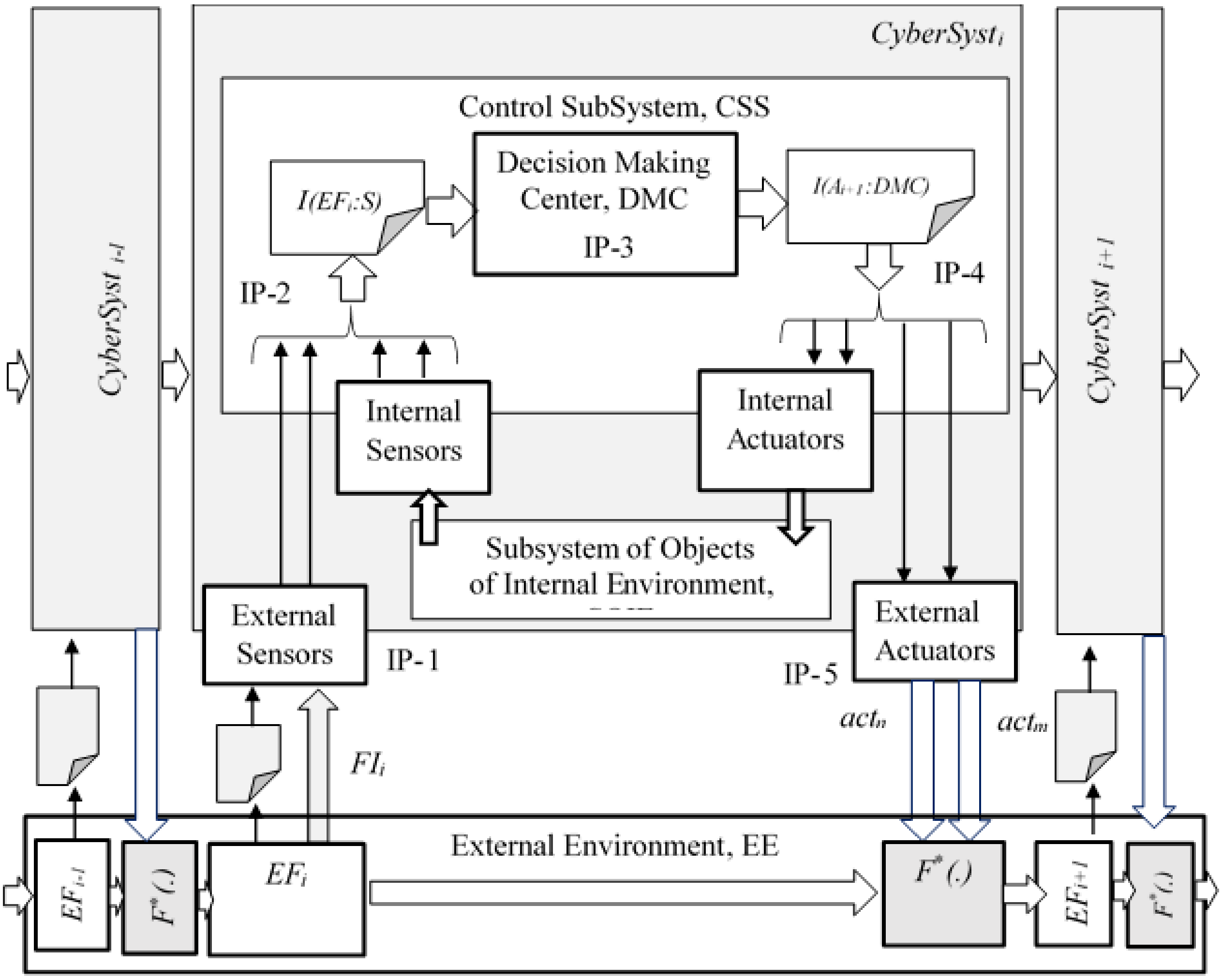

Figure 2 – A model of the trajectory of cybersystem behavior

The behavior of the cyber system is formed as follows. The current position of the system in the environment EF_i influences the cyber system through a set of Physical Impacts (FI_i), among which there is natural information (optical and acoustic images). External sensors *ES* transform these impacts and form their own information of the cyber system about the state of the environment $I(EF_i:S)$ at their outputs. Further, this information is sent to the center of decision-making *DMC* through the Forward Link (*FL*) of the control subsystem. This center, following the given rules (represented by the decision making operator $F_{DMC}[.]$), generates commands to the actuators about the actions of the system, which will transfer it to the next state EF_{i+1}. The commands represent information $I(A_{i+1}:DMC)$. Through the *Reverse Link (RL)*, this information is fed to *external actuators EA*, which convert it into environmental impacts A_{i+1}. The system's actions transform the conditions of its presence in the external environment (in the model, the transformation is represented by the transition operator $F^*[.]$). The proposed model makes it possible to distinguish a control loop, consisting of a sequence of five adjacent information processes (*Information Process, IP*):

– formation of information about the state of the external environment by sensors (IP-1);
– transfer of information from sensors to the decision-making center (IP-2);

- making a decision on the response of the cyber system to the external environment (IP-3);
- transfer of information (commands) from the decision-making center to the actuators (IP-4);
- implementation of actions on the external environment to actuators (IP-5).

It is clear that the state of objects in the internal environment also affects the formation of the behavior of a cyber system. Information about this, formed by internal sensors, can play the role of a motivator when making a decision (feelings of hunger and/or thirst for biological systems; messages about a low battery level, antenna rotation angle and/or the current value of the internal clock for technical systems). Within the framework of the developed model, control processes from internal sensors are formalized, but the analysis of the nature of their influence on decision-making has not yet been studied in detail. Further, only processes from external sensors are considered.

With an unambiguous correspondence between the commands from the decision-making center $I(A_{i+1}{:}DMC)$ and the actions of the actuators, the change in the states of the system can be mathematically represented by the system of equations:

$$\begin{cases} EF_{i+1} = F^{*}[EF_i,\ I(A_{i+1}{:}DMC)]; \\ I(A_{i+1}{:}DMC) = F_{DMC}[I(EF_i{:}S)]. \end{cases} \quad (25)$$

Such a formalized representation of information processes (IP-1) – (IP-5) makes it possible to simplify the analysis of several situations. Consider an example of analyzing topical issues of countering unauthorized influences on the management processes of technical and/or social systems (i.e. manipulating someone else’s behavior in their interests). By the model, the main threats, in this case, will be:

- substitution of information $I(EF_i : S)$, $I(A_{i+1} : DMC)$ in the forward link and/or reverse link;
- violation of the given rules of decision-making $F_{DMC}[I(EF_i : S)]$.

We will assume that information about the state of the external environment $I(EF_i : S)$ and a set of commands for actuators $I(A_{i+1} : DMC)$ take the values $x_m^{(EF)} \in \{x_m^{(EF)}\} = \Omega_{EF}$ and $x_n^{(A)} \in \{x_n^{(A)}\} = \Omega_A$, where the sets of values Ω_{EF} and Ω_A are the alphabets of controlled states and admissible sets of performing actions. Indices *m* and *n* are the numbers of the elements of these alphabets. Then the control rule $F_{DMC}[.]$, which is implemented by the decision center *DMC*, can be described by the binary relation

$$F_{DMC} = \{(x_m^{(EF)},\ x_n^{(A)})\} \subset \Omega_{EF} \times \Omega_A. \quad (26)$$

Representation (26) allows one to formalize the criteria of information security of such cyber systems through the security function $SEC_{CyberSyst}[.]$:

$$SEC_{CyberSyst}[I(EF_i : S), I(A_{i+1} : DMC)] = \exists I(EF_i : S)\{[I(EF_i : S),\ I(A_{i+1} : DMC)] \in F_{DMC}[.]\}, \quad (27)$$

that is, for the current value of the information at the output of the sensor $I(EF_i : S)$, the condition is satisfied that the ordered pair of information values $[I(EF_i : S),\ I(A_{i+1} : DMC)]$ belongs to the decision rule $F_{DMC}[.]$. If this condition is met, $SEC_{CyberSyst}[.] = 1$ (security is ensured), if not, $SEC_{CyberSyst}[.] = 0$ (security is not provided). Further in the article, the proposed graphical and mathematical models for controlling the behavior of a cybernetic system will be used to determine the essence of the sign, knowledge, and intelligence.

5. Signs and information exchange between cybernetic systems. Cybernetic system control functions are implemented in the information environments of these systems by various operations on semantics: formation, storage and transmission of semantics, their comparison, splitting semantics into parts, combining semantics and many others. In the course of interaction with the environment, semantics are formed using External Information Channels (EIC), the characteristics of which are limited by their physical nature. With their help, the cyber system can receive information only about those objects of the external environment that can manifest themselves through physical influences in the range of sensors (“sense organs”). For example, a person perceives with his eyes only electromagnetic influences in the optical range of oscillations. Radio waves and other electromagnetic vibrations are not perceived. Each cybernetic system can be characterized by the "event horizon of system", i.e. a limited set of environment objects, information about which can enter the system. Such sets are limited by the nature of the physical interaction perceived by the EIC sensor and the level of sensitivity of that sensor. However, there are several possibilities for humans to overcome these limitations. One of them is the use of signs to exchange information with other people. Initially, in the course of evolution, it became possible for people to communicate with each other using acoustic signs (speech). Much later, it became possible to exchange information using graphic signs (writing). The use of signs allows us to speak about the emergence of a "event horizon of the society", which is much wider than the event horizon of an individual.

The question of the use of signs and sign systems is closely related to the question of the relationship between information and a sign. Semiotics (the science of signs, sign systems and methods of using sign systems) represents a sign as an intermediary object, through which the mind has transmitted the idea of another object [17]. In this case, as a rule, the following related concepts are distinguished [18]:

sign carrier (sign vehicle) – an item that is used as a sign;

the meaning of a sign (designatum, referent) – an object represented by this sign;

the meaning of a sign in the mind (interpretant, sense, the meaning of a sign in the mind) – that which represents (connects) the sign and the meaning of the sign in the mind in the process of communication or cognition. The relationship between these concepts is often illustrated by the semantic triangle diagram (Fig. 3).

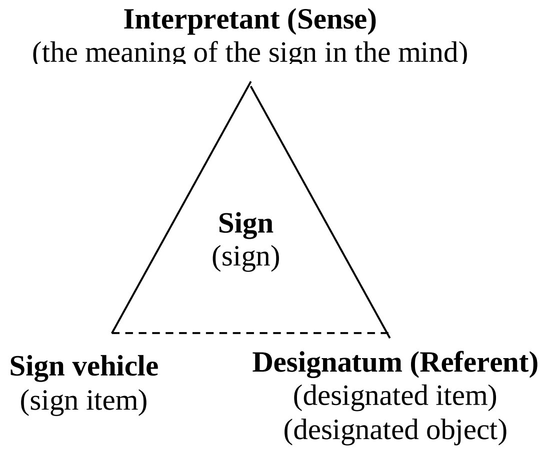

Figure 3 – Sign and related concepts (semantic triangle)

According to Charles Peirce's ideas, the sign receives its meaning not as a result of direct connections with the referent (the dotted line at the base of the triangle), but only through thought processes [17]. This view of the nature of the sign and related concepts contains some ambiguities, for example:

1. What is the nature of the relationship of the sign with the designated object and the process of thinking?
2. How are the sign and its components related to information?
3. How is a sign, which is a physical object, used to exchange ideas related to mental objects?

Let's try to explain the essence of the sign using only those concepts that fall within the framework of the following statement:

signs are physical objects that can be used to exchange information about other objects only between physical systems that have the following properties:

1) receive, store information, carry out operations with its semantics;

2) form their behavior based on the information received about the environment.

The given restrictions make it possible to abandon the use of concepts that are often used to explain the nature of signs and sign systems, but, at the moment, they contain significant uncertainties. These concepts include the following: idea, consciousness, mind, thinking, communication, cognition, representation, understanding, and some others. On the other hand, these restrictions do not apply to the application of the concepts of information, information environment, and cybernetic system, the essence of which was clarified above using the *ATNI* approach. As a result, the following definitions were obtained:

1) a sign is an object (object, phenomenon or process), the semantics of which in cybernetic systems is associated with the semantics of another object;

2) the referent of the sign (extensional, referent) is an object, the semantics (image) of which is compared to the semantics (image) of the sign in the information environments of interacting systems;

3) sign exchange of information is the exchange of information between cybernetic systems by transferring the signs themselves or their semantics.

The proposed approach makes it possible to replace the semantic triangle (Fig. 3) with a diagram (Fig. 4) that explains the nature of the sign through the information of cybernetic systems. Refinement of the figure: since the common carrier for all information in a cybernetic system is its information environment, operations on information can be considered as operations on semantics.

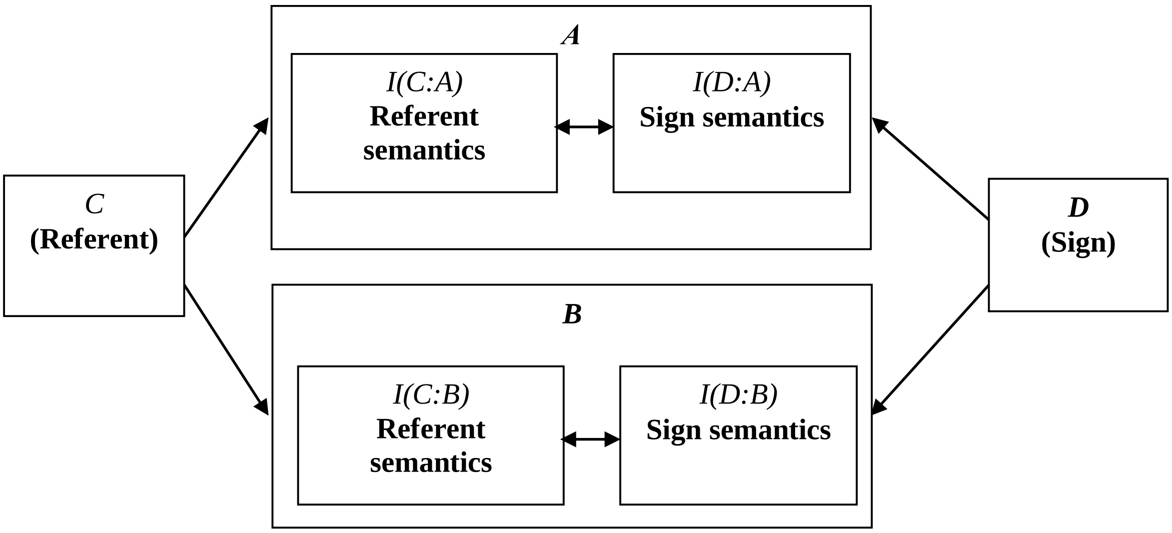

Figure 4 – The structure of the relationship between information. and sign

The diagram shows four objects *A*, *B*, *C* and *D*, two of which (*A* and *B*) are cybernetic systems. Object *D* can become a sign for objects *A* and *B* if, in information environments *A* and *B*, the semantics of object *D* will be interconnected with the semantics of object *C*. Unidirectional arrows on the diagram denote infogenous operators f^*_{map}. Double-headed arrows indicate operators of the semantic matching. More strictly, the relationship between objects in the diagram can be described as follows:

$$D = sign[C:(A,B)] \mid ([I(C:A) \leftrightarrow I(D:A)]), [I(C:B) \leftrightarrow I(D:B)]), \qquad (28)$$

where *D* is an object that is the signal “$sign[C:(A,B)]$” for between cyber systems *A*, *B* and denotes object *C* if the systems have matched information (semantics) about objects *D* and *C*.

The proposed approach to the nature of the mark makes it possible to formulate the following statements:

1) the order of matching of information (semantics) in cybernetic systems and the process of its implementation can be called an “agreement about signs”. For artificial cybernetic systems, such an agreement is formed by the developer. For natural systems, this agreement can be realized by learning within the framework of behavior according to the model “do like me” and others;

2) the possibility of transferring a set of signs (sign message) in space-time between cybernetic systems using information influences allows not only to activate the already existing semantics of the receiving system, but also to link them into semantic constructions new for the system;

3) in general, the new semantic construction is information about the semantic construction of the transmitter system;

4) in the case of the formation of a sign message based on its own semantics about a new object within the event horizon of the transmitter system, then the new semantic construction of the receiver system will be information about the new object that is outside its event horizon. This new information is generated by an intermediary system;

5) the transmission of a sign message is associated with the problem of ambiguity of the semantic structure formed based on this message – is there a real object that is the essence of information for the formed semantic structure? (hereinafter – the sign-semantic problem);

6) the solution of the sign-semantic problem allows to expand the horizon of events of the cybernetic system due to the formation of information about new objects using symbolic messages from intermediary systems.

Within the framework of the proposed paradigm of the sign, the list of the listed statements regarding sign systems and the order of their application by cybernetic systems can be significantly expanded. In turn, each of the statements opens up opportunities for additional research that are beyond the scope of this work.

6. Knowledge of the cybernetic system. The above concepts of cybernetic systems, their information environments and information exchange with the help of sign messages make it possible to distinguish the following categories of semantics that can be used by a cybernetic system in the formation of its behavior:

– semantics formed by natural information influences using the system sensors (hereinafter – Own Semantics, OS);

– semantic constructions formed using various operations of combining their own semantics (hereinafter – own semantic constructions, OSC);

– semantic constructions formed by combining their own semantics based on the received sign message (hereinafter referred to as external semantic constructions, ESC).

It seems interesting to analyze these categories in terms of their relationship with objects of the external environment. Own semantics are the result of informational influence from objects of the external environment, which are located within their own event horizon. Such objects belong to the category of the essence of information regarding their own semantics already formed. The use of such semantics in the decision-making process in the formation of behavior allows the system to achieve the result necessary to maintain its existence. For example, consider the “fox” cyber system, which previously, within the framework of its own experience:

– formed its own semantics “hare”;

– semantics “hare” is connected in the information environment with semantics from internal sensors “to overcome hunger” and a set of commands to actuators “to run to the object”.

Under such preconditions, the appearance of an object “hare” within the event horizon of the “fox” system, it becomes possible to achieve the state of “overcome hunger” through the implementation of the behavior “run to the object”. At the same time, the key operation at the center of the decision-making of the system will be the comparison of two own semantics: the stored “hare-memory” and “hare-actual”.

Now let’s consider another example, in which the system “hunter” with the help of the received (heard or read) symbolic message “Pegasus is a horse with the wings of an eagle” with the help of its own semantics “horse” and “wings of an eagle” forms an external semantic construction

$$\text{“}Pegasus\text{”} - (\text{“}Horse\text{”},\ \text{“}eagle\text{'}s\ wings\text{”}).$$

Since the “hunter” system has no chance of encountering a real “Pegasus” object and forming its own actual semantics “Pegasus”, the external semantic construct “Pegasus” cannot be used to form behavior that allows one to achieve the state of "overcoming hunger". The same fate awaits the own semantic construction "Pegasus", which was formed in one way or another in the information environment of the system (for example, during sleep).

These two examples show how important semantics, which can be formed with the help of information influence from objects of the external environment, are important for the choice of effective behavior of a cybernetic system. In the ATNI approach, such objects are called information entities. Thus, all semantics of the cybernetic system can be divided into two more categories:

– semantics for which there are essences of information (I);
– semantics for which there are no essences of information (II).

It is obvious that the systems' own semantics $semantics(.)$, upon the fact of their formation, belong to category I. External semantic constructions belong to category II, but can go to category I after the solution of the sign-semantic problem (i.e. after establishing the fact of the presence of the corresponding essence of information). The situation is similar concerning their semantic constructions.

After the performed analysis, we will introduce the concept of "knowledge of the cybernetic system" and formulate the corresponding definition. Let's preliminarily clarify the situation. Let a set of semantics $\{semantics(.)\}$, be formed in the information environment of the cyber system, each of which is hypothetically associated with some object of the external environment *y*. In turn, the external environment is designated as a set of *REALITY*, consisting of real objects *x* (that is $x \in \{x\} = REALITY$).

In this case, knowledge of the cybernetic system $KNLG^{(CyberSyst)}$ can be represented by a set of existing semantics $\{semantics(y)\}$, for each of which (sign |) there exists (sign $\exists$) a real object $x \in \{x\} = REALITY$, semantics of information from which in cybernetic system semantic $\{semantics[I(x : CyberSyst)]$ will be equal to or similar (sign $\cong$) to the existing $\{semantics(y)\}$. In short, this definition of knowledge can be presented as follows:

$$KNLG^{(CyberSystem)} = \{semantics(y)\} \mid \exists x(semantics[I(x : CyberSyst)] \cong semantics(y) . \quad (29)$$

In other words:

knowledge of a cybernetic system (knowledge*) is those semantics of its information environment, for which the same or similar semantics can be formed by informational impact from a real object.*

In the context of this definition of knowledge and the categories of semantics obtained above, knowledge includes all semantics for which there are essences of information. By the fact of its formation, all own semantics belong to knowledge. Also, knowledge includes all semantic constructions for which the fact of the existence of real objects with the same (similar) semantics of information is established. The process of establishing such a fact about real objects can be called the process of cognition. The final stage of this process will be the procedure for comparing the existing semantic construction and the semantics of information from a real object (this procedure has already been discussed above in section 2 of the article). The cognitive process by the society of cybernetic systems will be more complex Its features are expected to be determined in subsequent studies. Of particular interest is the process of cognition of those real objects whose spatio-temporal scales are beyond the event horizons of cyber systems and their societies. The specifics of information processes in scientific cognition that overcome such limitations are also planned to be determined in the framework of subsequent research.

The definition of knowledge, expressed by the description (29), was obtained using the *ATNI* approach in the context of a formalized model of information processes of a cybernetic system and its behavior. Without first understanding this context, such a definition becomes obscure. If we accept the statement that knowledge is formed and applied only by cybernetic systems, then it becomes possible to interpret the description (29) in the form of less strict, but more accessible definitions:

knowledge *(I) is information, the meaning (semantics) of which is confirmed by reality;*

***knowledge** (II) is information about an object that exists in reality.*

In the next section, based on the obtained definition of the nature of knowledge, an attempt is made to determine the essence of intelligence.

7. Intelligence of the cybernetic system. The large-scale introduction of computer technologies in various social spheres is accompanied by an increase in interest in the concepts of “artificial intelligence” and “intelligence”. Increasingly, there are computer programs and systems that are credited with intellectual abilities. However, the criteria for distinguishing smart devices from conventional ones remain a mystery. First of all, this is due to the presence of ambiguities in the existing interpretations of these terms.

Very often, intelligence is associated with consciousness and its ability to understand, learn, gain knowledge, reason, plan, think logically, creatively and critically, and solve emerging problems. In this understanding of the intellect, now only a person is its bearer, since only he has consciousness. In turn, the uncertainties associated with consciousness and its listed abilities do not allow such an approach to intelligence to be made constructive for the practical sphere.

It is possible to single out another approach associated with the statement that intelligence is observed in animals [19] - [22] and plants [23], [24]. Moreover, these carriers of intelligence are proposed to be considered as goal seeking agents that acquire, store, retrieve, and internally process information at many levels of cognitive complexity [19]. This understanding of intelligence is more constructive, since it explains it only by information processing and purposeful behavior. Let’s call this explanation of intelligence Information-Behavioral Approach to Intelligence (*IBAI*). A similar approach linking intelligence with information-dependent behavior can be found in the field of Artificial Intelligence (AI). AI carriers are technical systems (intelligent agents, rational agents) that perceive the environment and take actions that maximize the system's chances of success [25], [26]. Kaplan and Haenlein define artificial intelligence as “a system’s ability to correctly interpret external data, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation [27]. Such an explanation of intelligence also does not use consciousness and its abilities that are poorly understood now (rational and creative thinking, will, logic, creativity, cognition, planning and many others). An attempt is made to explain intelligence through a limited set of concepts: “data”, “learning”, “knowledge” and “adaptive behavior”.

Within the framework of the *IBAI* and with the help of the formalized concepts presented in this work above, it becomes possible to formulate the following definition of intelligence:

***Intelligence** is a behavior of a cybernetic system that is capable of forming new knowledge and applying it to improve state of the system in the external environment.*

Consider a single plant that thrives on a semi-desert where other plant species cannot exist. The response to adverse environmental influences in such a plant is, for example, a very deep root and a special leaf shape. Thanks to these features, the existence of a plant is possible. The knowledge of such a system will be the plant’s genome, based on which the features of its structure are formed. Can such a plant be called a carrier of intelligence? No, since his knowledge (genome) is not shaped by plant behavior. They are obtained within the framework of the behavior of a population of such plants, which, over the lives of a large number of generations, with the help of natural selection, has formed new knowledge (altered genome). New knowledge has allowed the population to adapt to the changed environmental conditions. This plant population can be classified as a cybernetic system with intelligence. Does such a system have consciousness and logic? Apparently “not” (from the standpoint of a person’s lifespan). However, if a formalized definition for the term “consciousness” appears in the future and if events are considered over a longer period, then the answer may change to “yes”. In this aspect, it is interesting to analyze the results of the Neolithic revolution (approximately 9-10 thousand years ago), during which mankind began to grow cereal plants and switched to a sedentary lifestyle. During this period, mankind, using artificial selection, changed the morphology of wheat, improving its properties for itself. Archaeologists and historians speak about this figuratively – “man tamed wheat”. However, there are also facts that the peculiarities of wheat cultivation affect not only a person's lifestyle but also his physiological characteristics: changes in the shape of the spine, bones of the limbs, joints. They say about these facts – "wheat has tamed man". From the standpoint of the proposed definition of intelligence, this situation can be considered as the interaction of two intelligent cybernetic systems (two populations). The study of the features and patterns of such interaction is possible using the approaches proposed in this work.

If we consider animals from the proposed positions, then we can also highlight interesting features. For example, a population of wolves can be viewed as an intelligent system with knowledge in the form of a genome. An individual wolf can also be viewed as an intelligent system, but in terms of the formation and use of knowledge in the neural environment during the life of one wolf. The situation is different for dogs. The emergence of the dog population itself and its changes became possible through the use of neural knowledge of another cybernetic system – humans. That is, the intelligence of a dog population is not independent. It exists in symbiosis with human intelligence. The issues of interaction of intelligences with knowledge in various information environments is also a promising area of research.

Now about artificial intelligence. Within the framework of the proposed representation of intelligence, a rational agent can only be a computer program that can form new knowledge and apply it for the adaptive behavior of the control object. The vast majority of programs are not capable of generating new knowledge. They contain only the knowledge of the programmer. Within the ATNI paradigm for AI, the following problems can be identified:

1. What is the best way to present existing knowledge in the information environment of an intelligent agent in a formalized way?
2. How can new knowledge be formed in a specific situation (i.e. how, on the basis of actual own semantics and existing reliable semantic constructions, to form new constructions and check their truth)?
3. How to improve the behavior of the system, having received new knowledge?
4. How can several intelligent agents unite their event horizons? Best Unification Criteria?

The ATNI paradigm allows not only further expanding the list of these questions and formalizing them from general methodological positions, but also provides a set of tools for relevant research.

Conclusion. The article proposes a solution to the problem of a universal explanation of the phenomenon of information. The concept obtained is based on a set of basic statements about information, which made it possible to refuse to explain its essence using terms that are themselves accompanied by a high level of uncertainty. The phenomenon of information is presented as a special result of the interaction of physical objects: the property of an object acquired during interaction contains the characteristics of another object. This approach to explaining the nature of information (Attributive-Transfer Nature of Information, ATNI) made it possible to single out the components of the information generation process: information impact, information carrier, essence and semantics of information. To clarify the proposed approach, a mathematical representation of information and the process of its formation was obtained.

With the help of ATNI, derived concepts were defined: information environment and its characteristics; cybernetic system, formalized model of its controlled behavior and security criteria; signs and their relationship with information; knowledge and intelligence of the cybernetic system. The universality of the ATNI applicability was tested in the framework of the analysis of the processes of information environments of various natures: protein, neural, computer.

The obtained graphic and mathematical models of the cybernetic system and its behavior based on processing information about the state of the environment can be used to analyze the processes of self-organization and control of dissipative systems of different physical nature (biological, social, technical). With the help of the models, formalized criteria for the safe behavior of the system in conditions of unauthorized information influence for manipulation have been developed.

With the help of ATNI and cybernetic system models, a new sign paradigm has been developed. In it, the sign is explained as an object (object, phenomenon, or process), the semantics of which is associated in cybernetic systems with the semantics of another object. Graphic and mathematical models of the sign are proposed. Through the transfer of signs or their semantics, cybernetic systems can exchange information about objects that are outside their event horizons.

On the basis of ATNI, the analysis of the semantics of cybernetic systems exchanging symbolic messages is carried out. The classification of these semantics is proposed, the conditions for the use of sign messages for the formation of the effective behavior of the system are determined. These results made it possible to formulate a new concept for knowledge and clarify the essence of the cognition process. Knowledge is understood as such information, the semantics of which is confirmed by the existence of the corresponding object in reality. A mathematical representation of knowledge was also obtained.

Within the framework of the existing information-behavioral approach to intelligence, the proposed ATNI approach and the concept of knowledge, a new explanation of the essence of intelligence was obtained, which is universal in relation to its different carriers: humans, animals, plants, technical systems. Intelligence is understood as such behavior of a cybernetic system, which is capable of forming new knowledge and applying it to improve the state of the system in the external environment. Some questions of interaction of carriers of intelligence with knowledge in information environments of various nature are considered. Criteria for evaluating the presence of intelligence in computer programs are proposed.

To test the possibility of the practical application of the proposed ATNI approach and models of behavior of the cybernetic system for the sphere of cyber defense, the following have been developed: 1) the paradigm of cyberspace and cybersecurity [28]; 2) a model of information processes of cyber security of a corporate IT system [29]; 3) the cybernetic model of APT and the method of forming templates of indicators of compromise to determine this attack [30]; 4) a model of processes for assessing the state of cybersecurity of Power Grid [31]. The paper identifies some relevant areas of further research in the fields of information application, knowledge formation and intellectual behavior, artificial intelligence application.

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ІГОР ЯКОВІВ

ІНФОРМАЦІЯ, ЗНАКИ, ЗНАННЯ ТА ІНТЕЛЕКТ

Розуміння особливої ролі інформації у формуванні наукових знань одночасно супроводжується і високим рівнем невизначеності щодо природи як інформації, так і знань. Існує велика кількість різноманітних підходів до інформації, які можуть конструктивно застосовуватися в одних спеціальних сферах діяльності, але залишаються абсолютно марними в інших. На тлі такої "інформаційної різноманітності" у багатьох дослідників все частіше виникала ідея про необхідність універсального пояснення феномена інформації. Необхідність вирішення цієї проблеми інтуїтивно обґрунтовують тим, що формування інформації і її застосування створюють фундамент для багатьох процесів самоорганізації та управління в системах різної природи: хімічних, біологічних, соціальних, технічних та інших. З цих же позицій концепт інформації часто відносять до первинного при поясненні інших також мало зрозумілих феноменів: знаки, семантика, знання, психіка, інтелект, розум, свідомість, самосвідомість, математика, ймовірність і багато інших. Універсальний концепт інформації та похідні від нього концепти можуть стати набором засобів для формалізованого аналізу з єдиних понятійних позицій інформаційних процесів у різних наукових сферах. У статті представлені результати досліджень, в рамках яких за допомогою набору базових тверджень (аксіоматичний підхід) і засобів термінологічної, графічної, математичної формалізації (засоби подолання невизначеностей) отримано універсальне поняття інформації. Феномен інформації представлений як особливий результат взаємодії фізичних об'єктів: набута при взаємодії властивість об'єкта містить особливості іншого об'єкта. Такий атрибутивно-трансфертний підхід до пояснення природи інформації (Attributive-Transfer Nature of Information, ATNI), дозволив визначити компоненти процесу її формування: інформаційний вплив; носій інформації; сутність і семантика інформації. З їх допомогою визначено похідні поняття: інформаційне середовище і його характеристики; кібернетична система, формалізовано модель її керованої поведінки і критерії безпеки; знаки і їх взаємозв'язок з інформацією; знання та інтелект кібернетичної системи. Перевірено застосовність запропонованого підходу до аналізу процесів в інформаційних середовищах різної природи: білкової, нейронної, комп'ютерної.

Ключові слова: природа інформації, інформаційне середовище, інформаційний вплив, семантика інформації, кібернетична система, керована поведінка, безпека кібернетичної системи, природа знаків, знання, інтелект кібернетичної системи.

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