**Relations and operations in the behavior subject’s sign picture of the world**

According to modern theories of mental function emergence and the role of neurophysiological processes in it, the mental function formation is associated with the existence or communicative synthesis of specific information structures containing three information types of different origin: information coming from the external environment, information extracted from the memory and information coming from motivation centers. Binding of these components into a single entity is provided by naming them; it also ensures the emerging structures’ stability. We name such information structures as signs due to their resemblance to similar structures studied by semiotics. The set of signs formed by the subject during activities and communication creates his sign picture of the world reflecting his ideas about the environment, himself and other subjects.

The sign picture of the world allows to set and solve a number of tasks arising during behavior modeling for intelligent agents and their coalitions, such as goal-setting, purposeful behavior synthesis, role distribution and interaction of agents in the coalition. The paper considers a special object - causal matrix, which describes the structure of the sign components. On this basis, operations and relations in the sign picture of the world modeling the psychological characteristics of human behavior are determined.

**Introduction**

Apparently, the issue of sensation occurrence is one of the central issues of the cognitive psychology. Also, there is no clarity regarding the relation of this phenomenon to the subject’s picture of the world formation. In psychologists’ works, such as A. N. Leontiev’s ones [], the representation of each object or reality phenomenon in the mind consists of three components: image of the object, its cultural and historical meaning, and personal meaning. According to the image concept developed by the cognitive psychology, perception is considered as a categorization process, the meaning corresponds to the object’s mission, the sign’s semantic component, and the personal meaning is interpreted as a set of actions regarding the object preferred by the subject. It is easy to notice that this structure is close to the structure named as sign in semiotics [], so the approach developed in this paper can be pertinently called sign or semiotic one. The structure of the world picture described above is supported not only by the cultural and historical approach, but by other psychological theories as well, particularly by Stanovich’s three-process model []. According to it, unlike the well-known two-process model by Kahneman [], the mental processes are implemented by three subsystems: reflective, algorithmic and autonomous ones.

These considerations are supported by the results of many neurosurgery studies, first of all [], which associate the sensation occurrence, i.e. the transition from the neurophysiological level to the psychological one, with the circular motion of the brain cortex part excitation, which returns to the place of original signal projection after further processing by other brain structures ("sensation circle"). The mental function [] is based on the synthesis of three information types (i.e., forming ternary structures): information coming from the external environment (sensory one), information extracted from the memory and information coming from motivation centers. We should note that the works [] also indicate the possibility of the sign structure existence in the activity subjects’ pictures of the world. [] considers the formation mechanism of some cognitive functions and its relationship with the formation of the linguistic world model. The work [] deals with the emergence of communication mechanisms based on the semiotic approach. In [], Roy has suggested the sign model of the world as the basis of robots’ operating component.

In subsequent years, the application of the excitation return idea to explain the mechanisms of consciousness and the "sign" hypothesis was supported by the results of many studies including the data on the structure of the brain parts involved in the "sensation circle". The sign components are neutrally realized in various subsystems of the brain. The image component of the sign is realized through the distribution of neural activation from the primary sensory sections of the cortico-thalamic system to the associative ones. The researchers describe two ways of the activation: the lower (ventral) one determining spatially independent object characteristics of the incoming sensory information and the back (dorsal) one recognizing the spatial configuration and actions []. Existence of these two activation flows justifies the existence of object and procedural features in the image component of the sign (section []).

In the process of image recognition, the presence of feedback predicting the neurons’ preactivation (details in section []) creates the effect of re-entry into the primary cortex sections []. The personal meaning component is a product of interaction between the cortex motor sections and subcortical structures, such as thalamus, basal ganglia, amygdala and hypothalamus. These brain subsystems implement the integration of the previous action experience and the action choice in the current situation taking into account the current motive and purpose []. The hippocampus is also closely related to the personal meaning component, it plays an important role in the episodic memory formation, i.e. description of the current and recent activity situation []. Finally, the meaning component is the result of the generalizing and abstracting brain function realized by frontal and superior temporal sections of the brain cortex. These sections are also involved in the binding of all sign components with their subsequent naming [].

In section [], we will describe a high-level conceptual part of the model; we will not delve into the sign structure details rather describing the general scheme of its formation and its syntax determination. Section [] provides interpretation of the sign components through the use of predicate logic and rule system (operational semantics). Further, the main attention will be paid to the neurophysiologically and psychologically plausible sign model and its structure (section []). At the structural level, basic mathematical objects will be suggested, sign components determined and algorithm of the image component described. Further, structural definition is given to the basic relationship groups of the sign components and the concept of semiotic network as the world picture model is introduced (section []). To demonstrate the constructed model’s applicability, section [] covers basic operations in the world picture modeling the known cognitive functions: generalization, script formation and the meaning agglutination.

**1 Syntactic level**

We determine the syntactic level of the world picture model according to the works []. Let there be given a set --- called the sign set. Each element --- has the form, where ---, ---, ---, ---. Here, --- is a set of finite length words in some alphabet, which we call the name set; --- is a set of closed atomic formulas of the first order predicate calculus, which we call the property set; --- will be called the value set; --- is the meaning set. Both the value set and the meaning set are interpreted by a variety of actions due to psychological considerations. As done regarding the artificial intelligence, we represent every action through the rule []. The rule is an ordered triple of sets ---, where --- is the rule condition; --- is a set of facts added by the rule; --- is a set of facts deleted by the rule. In a general case, each of these sets is a set of atomic formulas of the first order predicate calculus. In more detail, the role of these rules in the sign model will be described in the next section.

Now, let us introduce binding operators. --- is the operator coupling the images with the values. The second operator associates the values ​​with the meanings. The third operator associates the meanings with the images. The operators introduced associate the sign components with one another, and their semantics is determined in the next section. At the model’s syntactic level, the basic algorithms are determined: the sign formation and self-organizing procedures [].

**2 Semantic level of the model**

At the semantic level of the world picture model, operational semantics of the binding operators introduced at the syntactic level is specified, and the sign components are interpreted by the predicate calculus symbols and the rules determined in the artificial intelligence [].

Let us determine the binding operator (figure []) ---, so that ---, where --- is a set of different predicate symbols of the condition rule interpreting the value (hereinafter, we will associate one action, i.e. one rule, with each value for the explanation simplicity); --- is the set of image predicate symbols ---; --- and --- are --- and --- Booleans respectively.

The second operator ---, where ---, where --- is the set of rule condition predicate symbols interpreting the personal meaning (here, same as in the value case, each personal meaning is associated with one action, i.e. one rule, for the explanation simplicity); --- is Boolean ---. The third operator ---, where ---, where --- is the set of predicate symbols from multiple rule additions.

Of course, ---. It can be shown that under certain initial approximation, this iterative process converges to ---. Wherein, ---. It is easy to see that sufficient convergence condition is ---. If we introduce operator ---, it is easy to see that the operator couple forms Galois correspondence, and the sign is the fixed Galois closure point for operators --- and ---.

At the semantic level of the world picture model, it becomes possible to describe the relationship in the set of the sign components: the relationship of the set of images, values ​​and personal meanings. Each relationship of these domains can be translated to multiple names enabling to determine the relationship of the sign set. Further, we will provide semantic definitions for these relations and operations in the sign set. All relations and operations will be specified during the sign component structure consideration at the structural level.

**2.1 Operations and relationships in the sign set**

Let --- be a sign set, --- and --- - images of the signs --- and ---, --- - the --- sign value. The ordered sets --- and ---, where ---, will be named as image types for the signs --- and ---, respectively.

**Definition 1.** If for the signs --- and ---, then ---.

It is easy to see that the ratio --- is an equivalence ratio of the sign image set ---. The ratios --- determined lower are inclusion, similarity and contrast ratios accordingly.

**Definition 2.** If --- is valid for the signs --- and ---, then ---.

**Definition 3.** If --- is valid for the signs --- and ---, then ---.

**Definition 4.** If --- is valid for the signs --- and ---, then ---.

The given definitions are procedures for new relation elements generation in the sign set. Being started every time when the sign set is replenished with a new sign (or when the sign set starts being used), the procedures described either form a new relationship, or supplement one of the sign relationships with a new element.

The generalization operation is determined with the set of sign pairs belonging to the ratio ---; the work result --- is a new image including all common features of the original images. Namely, if --- is the image set, ---, then ---, so that for any ---, where ---, so ---. The image formed as the generalization result can be a basis for the new sign formation.

Proceeding to the sign values, it is necessary to recall that the value is a set of generic actions performed by the subject with the object represented by the sign. However, every action is matched by a set of certain roles substituted by the considered action participants as described by Fillmore []. Thus, the value of each sign will be associated with an ordered set called the role set. It is clear that each role can also be substituted by the sign. These considerations underlie the formation of relations in the sign set generated by their values, which may logically be called the script one.

So, if --- is a set of all possible roles, the value of each sign is a subset of this set. For simplicity, we assume that each value includes one action. Now, let --- be signs, --- - the sign values, where ---.

**Definition 5.** If --- is valid for the signs --- (the sign --- substitutes the role ---), then ---.

This ratio can be logically called the script one as it allows generating complex structures - scripts, which are sign networks linked by their values and names. At the semantic level, it is possible to introduce another number of relationships generated by the values ​​and personal meanings [].

Let us define the ​​closing operation according to values ---. If --- is a sign with the value --- and --- is one of this value’s roles, the operation constructs a new sign ---, in which the role is substituted by the sign ---. While this, the meanings and values ​​of the original signs merge.

On the basis of personal meanings, the sign sets naturally generate the relations of absorption and opposition []. Let us recall that every meaning corresponds to a set of specified (particular) actions.

Let us introduce the operation of agglutination ---. Here, same as above, we assume that each meaning corresponds to one action described by the rule --- for the explanation simplicity. If --- are signs and --- are their meanings, the agglutination operation generates a new sign --- with the meaning ---, where --- or ---. It is clear that in both cases ---, where --- are sets of rule conditions and --- are sets of facts added and deleted by the respective rules.

**3 Structural level of the model**

Next, we will focus on the structural model of the sign components taking into account modern neurophysiological data on the structure of cortico-thalamic brain subsystem and mechanisms of activation transmission between the cortex sections. The set of predicate symbols --- will be replaced by the set of signs organized as special structures (causal matrices), which construct a causal chain in turn. The combination of attributes (predicate symbols) into these structures allows describing the image component of the sign (set of predicate symbols), values and personal meanings (rules with effects and conditions) with a single formalism.

Let us consider the structure of the sign components using the example of the image component involved in the recognition of the presented object or process on the basis of sensory information coming from the external environment and registered by the internal motor data sensors (the sign is actualized due to the sign image recognition). Before naming, the sign will be called a protosign or attribute.

Let us suppose that the input data stream includes a sequence --- of vector --- length --- for real numbers from 0 to 1, which will be called events. Each event --- of the length --- is a record of --- sensor outputs, and each event element provides a certainty degree (subjective probability in the Bayesian sense) of the corresponding sensor triggering. For example, the event --- is received from three sensors – red, blue and green ones; it means that the certainty degree of the red sensor triggering is ---, and for the blue and green ones it is ---.

The image component of the sign is primarily responsible for the recognition of the object presented on the input information basis. During the sign image functioning, a special recognizing function is used or constructed receiving an input of vector sequence, which contains information about the object’s attributes in particular moments of time. The recognizing function determines whether the object represented by the sign is present (coded) in this sequence. Further, we will consider this function to be built as a result of special education process (for details, []).

Let us present the recognizing function (i.e., encode the characteristic attributes of the object or process) with a special structure - the causal matrix --- of the dimensionality ---, where --- is the event dimension (number of sensors) and --- is the event sequence length. Each column --- of the causal matrix is a binary vector of --- length encoding the attributes (which correspond to 1), which must be present in the input event at the moment --- to let the presented object or process be identified in the input data stream, i.e. set a plurality of simultaneous characteristic attributes. For example, the sign image --- representing the object "face" may correspond to the causal matrix ---, where the first line is the characteristic vector of information from the left eye image sensor, the second one comes from the right eye sensor, the third one – from the nose, the fourth one – from the mouth (figure []).

Visual interpretation of the causal matrix. 1 - detection area for the sensor responsible for the left eye, 2 - for the right eye, 3 – for the nose and 4 - for the mouth. The arrows indicate the time transitions (saccades) from one sensor’s triggering to the next one.

In the above example, each attribute of the "face" sign image can also be represented by a sign in the subject’s picture of the world. Thus, the case where the characteristic attributes of the sign image are sensor data is special. More generally, the sign image forming attributes are other signs corresponding to these characteristic attributes. Therefore, we can compare the image --- of the sign --- to the set --- with the power ---, each element of which corresponds a causal matrix line number --- sized ---, i.e. each attribute --- corresponds to the characteristic binary vector specifying discrete time moments of ones, during which this attribute must be present in the input data to successfully recognize the sign image (actualize the sign).

Each sign’s image can correspond to multiple causal matrices setting various precedents of the presented object or process observation in the environment. All sequence of the sign image --- causal matrices will be denoted as ---.

To clarify the definition of the set ---, we introduce a domain of embedded binary relations --- defined by the sign set ---. We consider the sign --- as an element of the sign image --- or --- if ---. If known that the sign --- is corresponded by one in the --- column of the sign --- causal matrix ---, we will use the ratio --- so that ---.

**3.1 Sign image recognition**

Let us briefly describe the algorithm of the sign image recognition (sign actualization) in figure []. We will consider the sign images to be grouped according to the set similarity into nodes organized as hierarchical structures (for details, []). Lower-level nodes include causal matrices of the signs being attributes for the signs, the causal matrices of which are included in higher-level nodes. These nodes and sign image causal matrices are formed as a result of education []; in this algorithm version, we consider all matrices and nodes to be formed and not updated. Further, we will restrict ourselves to the case where all matrices within one node have the same number of columns, which is a natural condition due to the matrix similarity. The period of time, during which all node causal matrix columns are processed, is called the computing cycle of the node.

Scheme of the sign image recognition algorithm

The algorithm input data is certain initial time ---, recognizable attribute prediction vector at this hierarchy level --- and the input function --- setting the sequence of the event input vectors ---. As a result of the algorithm, an output function --- is formed, which is a sequence of recognizable attribute vectors, and an expectation function, which is the vector sequence of prediction event for the recognizable attributes of the hierarchy lower level.

The recognition computing cycle in the level node starts with defining the initial node’s state through a real vector of the hierarchy upper level - the expectation vector --- formed on the basis of the upper level node status (steps [] - [] at the time moment ---). The initial state is defined as a sign subset where the images are predicted on the basis of the expectation vector. We introduce a constant --- determining the threshold of the recognizable image predicted weight, above which the relevant causal matrices fall into the active matrix set --- (step []). Next, causal matrices are selected from the set of active ones; for them, the usual distance according to the first column --- rate --- from the event --- at the initial moment of time does not exceed the constant --- (step []). The updated set of active causal matrices obtained this way is the current state of the node (step []). On the basis of the active causal matrices, the output node vector is calculated by the voting method at the initial moment of time --- (steps []-[]).

The expectation vector --- is determined as a normalized vector, --- component of which is equal to the sum of all --- elements of the causal active matrix second columns with weights corresponding to the elements of the expectation vector --- (step []). Since the idea of the future input signal is used (the second column of the causal matrices), --- is the expectation vector for the hierarchy lower level.

After determining the initial state, the main cycle starts working, which repeats the output vector and state calculation in the following moment until the time exceeds the characteristic node time (the number of causal matrix columns, steps [] - []). At the start of this stage, the state, i.e. the set of active causal matrices ---, is updated due to the removal of the matrices, the corresponding columns of which are much different from the current event --- (step []). Next, the output vector --- is calculated by the voting method according to the matrix number in the set of active causal matrices corresponding to the image (steps [] - []).

At the end of the main cycle, the expectation output vector is calculated for the next moment of time ---. The expectation vector is equal to the normalized vector, the elements of which are equal to the column element sum of the active causal matrices corresponding to the current moment of time regarding the weights of the initial expectation vector --- (step []).

**3.2 Causal network**

We introduce a special procedure ---, which associates two disjoint column index subsets --- with each sequence --- of the sign image --- causal matrices, so that ---. The set --- will be called condition column indices, and the set --- - effect column indices. For example, if the procedure --- provides two sets --- and --- for the matrix sequence --- consisting of only one matrix ---, it means that the appearance of an attribute corresponding to the first matrix row causes the appearance of an attribute corresponding to the second matrix row in the sequence. Thus, the procedure --- establishes causal relation regarding the set of input events and can be implemented in various ways including FCO, Norris algorithms, etc. []. In this paper, we will consider only the cases where the causal matrix columns belong to two subsets (conditions and effects). There may be situations when the causal matrix columns form a chain of causes and effects; in this case, the function --- will issue more than two column subsets.

If the effect column set for the sign image --- matrices --- is not empty ---, we assume that the sign is an action or process, the result of which is encoded in the effect columns and its condition - in the condition columns (the corresponding sign is procedural). Otherwise, if the effect column set of the sign image --- matrices --- is empty ---, i.e. if it cannot be determined which events precede others by the causal matrix sequence, we will consider the causal relationship not to be established, and the sign to represent an object or situation (the corresponding sign is object).

The following statements are true concerning the properties of the procedure ---:

--- - the causal matrix column cannot be both the condition and the effect at the same time,

--- - other column types, except the condition and effect ones, are absent,

--- - among the causal matrix columns, there must be at least one condition column, whereas the effect one may be absent (in the case of object attributes),

--- - all conditions precede the effects in time.

Causal matrix example

Proceeding to the notation used at the semantic level of the model (section []), we can consider the causal matrix --- to be a rule ---, in which:

--- is a set of the attributes-conditions for the rule: ---;

--- is a set of the attributes added by the rule: ---;

--- is a set of the attributes deleted by the rule: ---.

The causal matrix example based on the above is shown in figure [].

Now, we introduce the notion of causal network, which will determine the heterarchy of the causal matrix set. The causal network --- is a labeled directed graph, in which

* each node --- corresponds to the sign image --- causal matrix sequence --- referred to as ---;
* the edge --- belongs to the graph edge set --- if --- and ---, i.e. if the sign --- is an element of the image ---;
* each graph edge --- is associated with a label --- - a sequence of three integers:

- --- - the index of the original matrix in the sequence --- can accept a special 0 value, if the sources are matrices of the sequence;

- --- - the index of the target matrix in the sequence ---, the row of which is associated with the attribute ---;

- --- - the column index in the target matrix, in which there is 1 in the row corresponding to the attribute ---, can accept positive ​​(condition columns) and negative values (effect columns).

The causal network is a special type of non-uniform semantic network []. An example of such network is given in figure [].

Causal network example of the sign image set. Here, the causal matrices are shown as squares; the condition columns are left white parts of the squares, the effect columns are right black parts of the squares. The --- label is displayed at the start of each arrow, the --- label is the square number, at which the arrow points, and the --- label is displayed at the end of each arrow.

Similarly, the causal networks are determined for the other sign components - value and personal meaning. For each sign ---, the sets --- and --- are determined, i.e. the domains of embedded relationships --- are a value element and --- are a meaning element. The --- set is interpreted as the role composition of the --- sign, for example, subdomain elements or the action role in accordance with the semantic level of the model. The set is interpreted as an instant component constitution of the situation observed and experienced by the world picture subject or action committed by the subject at the moment. The sets ---, --- and procedures ---, --- are determined similarly.

Three types of causal networks differ from each other due to relationships generated on the basis of these networks for the corresponding set of the sign components, operations performed in these networks and the role played by them during the implementation of cognitive functions, such as behavior planning []. Now, we can clarify the definition of the sign [] using the introduced formalism of the causal matrices and causal networks.

**Definition** **6.** As the sign, we consider ---, where --- is the sign name, --- is the sign image, i.e. the causal matrix sequence corresponding to a certain causal network node with images regarding all input and output links, --- is the sign value, i.e. the causal matrix sequence corresponding to a certain causal network node with values regarding all input and output links, --- is the sign image, i.e. the causal matrix sequence corresponding to a certain causal network node with personal meanings regarding all input and output links.

Further, we will assume that each sign has a value, i.e. ---. If the sign has no image, i.e. ---, it will be called the category sign (we will distinguish between metaconcepts and categories as specified in []). Finally, if the sign has no assigned personal meaning, i.e. ---, it will be called impersonal.

**4 Semiotic network**

Next, we determine three domains of sign set binary relations generated on the basis of fragment structure of the three causal network types including the respective sign components. These relations correspond to the relations introduced at the semantic level.

**4.1 Image set relations**

Let us start with the determination of the sign set relationship generated with the causal network images. This will require determination of equality, similarity, inclusion and opposition for two causal matrices:

**Definition** **7.** Two causal matrices --- and --- are equal (---) if and only if the matrix dimensions are equal, sets of effect and condition column coincide ---, and each binary vector ---, matrix column --- are equal to corresponding binary vector ---, matrix column ---.

**Definition 8.** Two causal matrices --- and --- are similar (---) if and only if there are two binary vectors --- and ---, matrix columns --- and ---, and their by-component multiplication (i.e. multiplication of the components corresponding to the same attribute; if the corresponding attribute is absent in the vector, it is believed that there is zero in its place) is not equal to the zero vector ---, and both of them are either condition columns --- or effect columns ---.

**Definition 9.** The causal matrix --- is included in the causal matrix --- (---) if and only if any binary vector ---, matrix column --- have a binary vector ---, matrix column ---, so that --- (--- is bit-by-bit "or"), and both of them are either condition columns --- or effect columns ---.

**Definition 10.** Two causal matrices --- and --- are opposed to each other (---) if and only if the dimensions of the matrices are equal ---, the sets of effect and condition column indices coincide --- and each binary vector ---, matrix column --- have no intersection with the respective binary vector ---, matrix column ---, i.e. ---, where --- is bit-by-bit "and".

In addition to the previously introduced relationship domain "be an image element" ---, based on the relation definitions for the set of causal matrices, we determine four relationships based on the sign set ---.

**Definition 11.** The pair of signs --- and --- belongs to the image equivalence relation ---, if the sequence --- is element-by-element equal to the sequence ---, i.e. their power is equal and every causal matrix of the first sequence is equal to the corresponding matrix of the second sequence, i.e. ---.

**Definition 12.** The pair of signs --- and --- belongs to the image resemblance relation ---, if each causal matrix --- in the sequence --- has a resemblance matrix --- in the sequence ---, i.e. ---.

**Definition 13.** The pair of signs --- and --- belongs to the image inclusion relation ---, if each causal matrix --- in the sequence --- has an inclusive matrix --- in the sequence ---, i.e. ---.

**Definition 14.** The pair of signs --- and --- belongs to the image opposition relation ---, if the power of the sequence --- is equal to the power of the sequence --- , and each causal matrix of the first sequence is opposed to the corresponding matrix of the second sequence, i.e. ---.

Regarding the definitions introduced, the image relation domain --- is formed by the relations of "be an image element", image equivalence, similarity, inclusion and opposition.

**4.2 Value set relations**

The domain of value relations --- includes the relations "be a value element" ​​--- and, similarly to the image case, relations of value equivalence ---, similarity ---, inclusion --- and opposition ---.

In addition, an important role in the value network during the cognitive function modeling is played by the following two relations: the classification relation ---, causal relation --- and scenario relation ---.

Example of relation elements in the value causal network. Here, the set --- is interpreted as "square, triangle, circle and trapezoid are geometric shapes being objects for drawing action". The set --- is interpreted as "the drawing action is determined by the roles of subject (the person who draws), tool (by what the drawing is made) and object (what is drawn)". The symbols are the same as in figure [].

**Definition 15.** The pair of signs --- and --- belongs to the relation of classification --- if --- is the category object sign and there is only one --- sign value causal matrix ​​with a single column, in which the only one corresponds to the sign ---, i.e. ---.

**Definition 16.** The pair of signs --- and --- belongs to the scenario relation ---, if --- is the procedural sign, --- is the object sign, possibly, the category sign, and the --- sign is the sign value element, i.e. ---.

Examples of relation elements --- and --- are shown in figure [].

**4.3 Personal meaning set relations**

The domain of personal meaning relations --- includes the relations "be a meaning element" --- and, similarly to the image case, relations of meaning equivalence ---, similarity ---, inclusion --- and opposition ---.

Also, we introduce situational relation of the personal meaning set ---.

**Definition 17.** The pair of signs --- and --- belongs to the situational relation ---, if --- is the procedural sign, --- is the object sign not included in the category, and the sign --- is the --- sign meaning element, i.e. ---.

On the basis of the situational relation definition, it is possible to introduce the concept of situation determined on the basis of the procedural sign with all the object signs not included in the categories, together with which it belongs to the situational relation.

**Definition 18.** The sign set --- will be called the situation if --- is the only procedural sign in the --- set and for all ---.

Example of the relation elements --- and situation is provided in figure [].

Example of the relation elements in the meaning causal network. Here, the set --- is equivalent to the situation "Ivan draws a trapezoid with a pencil". The symbols are the same as in figure [].

**4.4 Semiotic network**

The semiotic network consists of five elements ---, where

--- are causal networks of the image, value and personal meaning sets respectively,

--- is the domain of sign set relations formed on the basis of three causal networks, i.e. ---.

--- is the domain of sign set operations (which are defined below).

**5 The structure of operations in the semiotic network**

At the structural level of the world picture model, we clarify the definitions of operations functioning in the world picture and generating new signs or scenarios on the basis of two input sign components. In other words, the generation of, for example, a new image on the basis of two other sign images results in the formation of other new sign’s components according to the rules of the operation. In this paper, for each causal network, the definitions will be given as examples using the ones given at the semantic level in the section []. For the explanation simplicity, we will consider each sign component to be characterized by one causal matrix (one action, one rule). Further, the procedure of the new sign formation described in [] will be used and denoted here as ---.

**5.1 Operation of generalization**

Generalization is a key cognitive process allowing to organize the knowledge in a hierarchical form, create compact representations of the reality objects and processes. In psychology, there are three kinds of generalization: syncrete, complex and concept []. During the syncretic generalization, the leading role is played by personal sign meaning, i.e. subjective attitude of the world picture subject to the represented objects. During the formation of complex generalization, the sign images and objectively existing attributes are used. The concept generalization is based on the sign values, it is formed in the process of reviewing generic-specific relationships, the knowledge of which is coordinated with other participants of the common activity.

Let us define the operation of image generalization (complex generalization formation) as ---. Let --- be signs, so that ---, i.e. belong to the similarity relation. The newly formed sign will be denoted as ---.

According to the definition ---, it means that ---, i.e. the causal matrices are similar. We define the new causal matrix --- as follows: ---, where each column --- has a pair of matrix --- columns --- respectively, so that --- and ---. In other words, the matrix --- is a generalization of the matrices --- and --- containing only the events, which are a event generalization for both matrices.

Let --- and --- be sets of procedural causal matrices, for which the signs --- and ---, accordingly, are attributes. In these two sets, we find a pair of similar causal matrices: ---. Next, we define the procedural causal matrix --- - a new matrix in the value causal network, which will be the generalization of matrices --- and ---: ---, where each column --- has a pair of matrices --- columns ---, so that

* in each of them, the reference to the corresponding sign values --- and --- is replaced by a reference to the only empty matrix --- of the newly formed sign ---
* --- and
* either simultaneously ---
* or simultaneously ---.

According to the generated pair of matrices --- and ---, we get a new sign --- with the help of new sign --- generation procedure --- as the operation result; its image is a generalization of sign images --- and ---, and its value is a certain role in the generalized action with the signs --- and ---. The newly formed procedural matrix --- can be included in a node of the existing value network or serve as a separate node for a new sign representing a new generalized action.

Here is an example of the image generalization operation. Let us have two signs --- and --- with the names "apple" and "orange" respectively. The causal matrices for the sign image components --- and --- are as follows (attributes are shown instead of ones):

---

The sign value components --- and --- are connected by the causal network to the procedural signs --- "peel an apple" and --- "peel an orange" (here, the vertical bar separates the condition and effect columns):

---

As a result of the image generalization operation ---, two signs are formed: generalized on the image attribute basis sign --- named "fruit" and generalized on the basis of value attribute sign --- "peel", which is a generalized action that can be done to the fruit:

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**5.2 Operation of closing by the value**

Another important cognitive function is the ability to generate possible scenarios based on the sign values. This process plays a special role in the everyday world picture, where most cognitive processes forming the human behavior, such as planning and communication, are based on the finding, application and formation of new scenarios []. In the simplest case, the scenario means an action, in which the particular role performers are fixed, i.e. the scenario is a specified action. Formally, the scenario is the sign set ---, where the only procedural sign is ---, and all other signs form two subgroups: --- - the set of role signs and --- - the set of scenario participant signs. The role signs of the set --- are category signs associated with the scenario --- relationship ---. The participant signs of the set --- are either not the signs not being the category signs associated with the --- scenario relation --- or signs, which belong to the classification relation --- being paired with other signs of the set ---.

We define the value closing operation ---, which forms the scenario --- according to some procedural sign ---. In fact, the scenario formation means the iterative inclusion of the signs in the --- set when considering the relation elements --- and ---:

[Step 1] Include the procedural sign --- in the scenario ---.

[Step 2] Add the scenario with the signs associated with the --- scenario relation: ---.

[Step 3] Add the scenario with the signs, which are not the category signs and associated with the scenario object signs by the classification relation: ---.

[Step 4] Repeat the step 3 until the scenario is no longer added with new signs or all the signs of the set determined by the task are tried. For example, during the goal-setting, only a certain subset of the signs is used, which are candidates to the scenario formed [].

An example of the generated scenario is shown in figure [].

Scenario example. The central procedural sign is ---. The role signs are ---, the participant signs are ---. The scenario relation elements are marked by solid arrows, the classification relations – by the broken ones. The rest of the symbols are the same as in figure [].

**5.3 Operation of meaning agglutination**

In conclusion, we present a typical example of the personal meaning network operation - agglutination. Agglutination, or fusion, of two sign meanings allows to create a new meaning of the third sign, usually already present in the picture of the world. In psychology, the new meaning is a combination of experience data elements being one of the main mechanisms of imagination and creative activities []. Examples of the meaning fusion are allegorical figures by Leonardo da Vinci in the art and words like "Moidodyr" or "Aibolit" in linguistics.

Using the introduced formalism, we define the operation of agglutination: ---. Let ---. The sign of the world picture, being formed or already existing, is denoted by ---. As a result of the operation, the sign --- receives a new meaning--- represented by causal matrix --- built as follows. Let --- and ---, the causal matrix is ---, where ---.

Proceeding to the rule notation, we can say that the new meaning presented by the rule --- is the condition and effect unity of the rules --- and ---: --- and either ---, or --- [].

As an example, let us take the formation of the new personal meaning in the "Saint Petersburg" sign as a result of agglutination operation for the "newspaper" and "coffee" signs meanings represented as the following matrices (actions "read newspaper", "drink coffee"):

---

---

The new causal matrix --- will be as follows. The condition columns are consistent unity of the matrix condition columns --- and --- (excess zero lines are omitted)

---

The effect columns are consistent unity of the matrix effect columns --- and --- (excess zero lines are omitted)

---

In this case, we do not consider the matter of choosing the sign ---, the new meaning of which is formed.

**Conclusion**

This paper presents a new approach to the integration of the activity subject’s knowledge of the environment, own features and operation consideration based on this knowledge - the sign picture of the world. The world picture model is described at the syntactic, semantic and structural levels. The four-component sign concept, which has been introduced in the previous authors’ papers on the basis of neurophysiological and psychological considerations, is used. A special mathematical structure is introduced - the causal matrix integrating the static information representation in the form of the attribute set and the procedural information as a rule with effects and conditions. Three types of semantic networks are introduced on the basis of the causal matrix set – image, value and personal meaning causal networks. Using the presented formalism, it is possible to construct algorithms of the relation replenishment with the sign set modeling basic object links and processes of the external world. The paper describes important operations in the world picture modeling key cognitive functions - generalization, scenario formation and meaning agglutination.