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ARTIFICIAL INTELLIGENCE

Behavior Control as a Function of Consciousness. I. World model and Goal Setting

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Abstract—Functions that are referred in psychology as functions of consciousness are considered. These functions include reflection, consciousness of activity motivation, goal setting, synthesis of goal oriented behavior, and some others. The description is based on the concept of sign, which is widely used in psychology and, in particular, in the cultural–historical theory by Vygotsky, in which sign is interpreted informally. In this paper, we elaborate upon the concept of sign, consider mechanisms of sign formation, and some self-organization on the set of signs. Due to the work of self-organization mechanisms, a new method for the representation of the world model of an actor appears. The concept of semiotic network is introduced that is used for the examination of the actor's world models. Models of some functions indicated above are constructed. The second part of the paper is devoted to functions of self-consciousness and to the application of the constructed models for designing plans and constructing new architectures of intelligent agents that are able, in particular, to distribute roles in coalitions.

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INTRODUCTION

The investigation of the phenomenon of goal oriented behavior and simulation of such a behavior is an important problem of artificial intelligence. A major problem in this field is the synthesis of goal oriented behavior under the conditions of static and dynamic environment. It is considered as a combinatorial search problem, and the main efforts in its solution are aimed at the struggle against computational complexity.

The first and most important phase in the synthesis of goal oriented behavior is goal setting, which, however, is not typically considered in artificial intelligence research—the goal or the set of goals are assumed to be given. It seems that this is due to the limitations of the symbolic approach used in artificial intelligence. Ways of overcoming this limitation are described in the present paper.

For this purpose, we introduce and study some constructs, namely, sign and its components name, image, significance, and personal meaning. These constructs are considered as external or syntactic level of the actor's world model. The internal or semantic level contains the basic procedures that interpret the syntactic constructs of the external level.

The description of the semantic level is beyond the scope of the present paper. We only note that on the semantic level images are interpreted by pattern recognition procedures and some algebraic constructs over them; significances and personal meanings are interpreted by sets of rules and strategies of their application (which are well known in artificial intelligence). For that reason, we will lean upon the reader's knowledge in the field of pattern recognition and knowledge representation for the time being.

First, we elaborate upon the concept of sign and show that an elementary step in the emergence or modification of an actor's world model can be represented as the process of forming (or actualization) of sign. Next, we describe the process of self-organization on the set of signs, which becomes possible due to the presence of four components in the structure of each sign. This enables us to consider various phenomena known in psychology, such as various types of world models of actors and the most important functions of consciousness—reflection, consciousness of activity motivation, and goal setting.

1. SIGN AS AN ELEMENT OF CONSCIOUSNESS

According to Leontiev [1], the representation of each object in consciousness includes three components—image of the object, its cultural significance (or purpose, and personal meanings. For brevity, we will below use the term *consciousness element* instead of the term *representation of each object in consciousness.*

The image of a potential element of consciousness, its significance, and meanings are not always connected in a whole; in this case, the sign is not formed (in the phylogenesis) or actualized (in the microgenesis), and the psychic reflection fixes for the actor the *biological significance* of the object rather than its personal meaning, not the *consciousness image* but rather the *perception image* and the *functional significance* of the object in a specific task instead of the *significance* developed in practical activities. Below we will use the term *percept* as a synonym of *perception image* and *image* as a synonym of *consciousness image*. Such a nonsign reflection of reality makes it possible to perform only "paired" transitions between two components of the knowledge about the object: from the percept to the functional significance (selection of a method of using a concrete object), from the functional significance to the biological significance (selection of a "goal" for a specific action), and from the biological significance to the percept (selection of a specific object satisfying the given requirements). Since the three aspects of knowledge about the object are at best connected by paired relationships, an "external observer" is required to see that these three components reflect the same real object [2].

Before describing mechanisms of sign formation, we consider relationships between the elements of consciousness and elements of the sign structure in semiotics [3, 4]. It is easy to see that

(a) the concept of *image* in psychology is identical to the concept of *representation* in semiotics [4]: according to the concept of image developed in cognitive psychology, perception is interpreted as the process of categorization [5], which exactly corresponds to the concept of *representation* in semiotics, where the representation is used to differentiate the objects corresponding to the sign under examination from other objects;

(b) *personal meanings* are interpreted by the sets of actions that are applied by the actor to an object [1]. In applied semiotics [6], this corresponds to the *pragmatic* component of the sign, that is, to the set of actions associated with this sign;

(c) the concept of *significance* in psychology corresponds to *meaning* in semiotics and semantics, that is, to the semantic component of the sign.

For the components of sign listed above, we retain the names adopted in psychology—image, significances, and significance. Up to the time when these components are linked into a sign, they are called perception, biological significance, and functional significance, respectively. Such linking becomes possible due to naming the emerging structure, which leads to the construct called *sign*.

The sign and its components become elements of the language structure; that is, the sign is incorporated into the world model of the actor (which does not happen without naming). Then, the object acquires a stable and conventional significance, personal experience in dealing with this object is reflected in the personal meaning as a sign component; and the event of object perception, which is a reflection in the simultaneous "picture" of the procedure of reproducing the object's properties in the motor functions of the perceiving organ is fixed as the image or representation of the object.

Let us elaborate upon these considerations.

2. SIGN FORMATION

According with the above reasoning, we assume that the formation (actualization) of a sign includes the following phases.

0. *Object localization*. This occurs in the space in which, in addition to the four dimensions of the physical space-time, there is the fifth quasi-dimension—the *dimension* of significances [7] (because each person as a carrier of consciousness lives in two realities—physical and language ones [8]). The actor estimates the position of an object relative to itself. This means that he must realize the self-consciousness function (reflection), know his "coordinates" in this space, that is, reside in the clear consciousness state as is said in psychiatry (know how to determine not only physical but also social parameters of himself in the situation where the person finds himself).

1. Percept *formation* is based on the procedure of reproducing the object's properties by the motor functions of the perception organ (for living organisms) or on processing the data obtained from sensors using pattern recognition methods (for artificial intelligence systems).

2. *Generation* of the set of pairs "percept–functional significance" of the functional significance of the object based on earlier experience or precedents.

3. *Evaluation* of the degree of closeness of the functional significance obtained in phase 2 to the functional significance obtained in phase 0 using a special procedure. If these significances are not close enough, then the percept formation is continued by returning to phase 1 (in psychology of sensor-perception processes, this mechanism is called sensory confidence).

4. Phases 1–3 are executed until a degree of closeness is reached that is sufficient from the viewpoint of special procedure mentioned in the description of phase 3.

5. Using a special procedure, the actor obtains from the cultural environment accumulated in a natural language system the pair *sign name–significance* and evaluates the degree of closeness of the functional significance obtained in phase 4 to the significance obtained from the cultural environment. If these significances are not close enough, then the percept formation is continued by returning to phase 1.

6. Linking the name from the pair *sign name–significance* to the percept constructed after the completion of phases 1–5. At this time, the percept turns into an image.

7. Formation of personal meanings of the sign based on precedents of actions with the object.

8. Linking the name from the pair *sign name–significance* to each personal meaning. From this time on, the functional significance turns into the significance and the biological significance turns into the personal meaning.

9. Continuing the mapping *biological significance–percept* by including the personal meaning (formed in the preceding phase) in the domain and by including the image formed in phase 6 in the set of values.

As a result a sign corresponding to the object is formed.

R e m a r k. It is implied by phase 2 that the sign cannot be formed outside of the cultural environment.

It is clear that phases 0–9 are described only schematically. This scheme will be elaborated in the further presentation.

2.1. Linking Procedures

Let

(1) A be the set of significances (both biological and personal).

(2) M be the set of meanings.

(3) P be the set of object features.

Then,

(1) $a \subseteq A$ is a subset of the set of personal meanings (it may be empty);

(2) $m \subseteq M$ is a subset of the set of significances (functional or cultural-historical);

(3) $p \subseteq P$ is a subset of the set of features (percept of image).

Transitions from the set of properties P to its subsets are performed using the actor's pattern recognition procedures.

The sign formation begins with executing these procedures. As a result, the universal set of properties P is replaced with its subset that represents the object under examination and differentiates it from other objects. In the first phase of the sign formation, this process results in forming the perception image of percept. On the internal or semantic level, the construction of the percept is associated with the sequential application of a set of pattern recognition procedures [9, 10].

Regarding m, in the first phase of the sign formation the subsets m of M are functional intents of the object, i.e., ways in which it can be used; later, they are transformed into significances.

The subset a of the set of personal meanings A emerges due to the experience of handling this object. Any subset of personal meanings a is interpreted as the set of such actions with the object corresponding to the sign that were evaluated as successful by a certain procedure. This special procedure is one of the functions of self-consciousness; it will be considered later.

In essence, we mean that m and a are formed based on precedents.

Let us introduce linking mappings. These mappings are partial functions of the elements of the sets of subsets of P, M, and A with values in M, A, and P, respectively. Our purpose is to demonstrate how these mappings are constructed by the actor. We assume that the actor already has some minimal experience; that is, we assume that he has already performed certain actions.

The first such mapping $\Psi_p^m : 2^P \to 2^M$ is the procedure of linking the image (or percept) p to the (functional) significance m in such a way that $\Psi_p^m(p^{(i)}) = m^{(i)}$, where $p^{(i)} \in 2^P$, $m^{(i)} \in 2^M$ and 2^P and 2^M are the sets of all subsets of P and M, respectively.

The second mapping $\Psi_m^a : 2^M \to 2^A$ links the significances (or functional significances) to personal meanings (or biological significances) in such a way that $\Psi_m^a(m^{(i)}) = a^{(i)}$, where $m^{(i)} \in 2^M$, $a^{(i)} \in 2^A$, and 2^A is the set of all subsets of A.

The second mapping $\Psi_a^p : 2^A \to 2^P$ links the personal meanings (or biological significances) to the image (percept) in such a way that $\Psi_a^p(a^{(i)}) = p^{(i+1)}$, where $a^{(i)} \in 2^A$ and $p^{(i+1)} \in 2^P$.

It is seen that the procedures described above are iterative (the superscripts in parentheses indicate the iteration index).

Adhering to the procedure described by phases 0–9, we will consider how the sign of an object is formed in the microgenesis or at the stage of sign actualization.

2.2. Forming Functional Significance and Perception Image

We assumed above that the actor has certain activity experience, which is fixed, in particular, in precedents (examples) of applying the mapping $\Psi_p^m : 2^P \to 2^M$. We assume that the set of precedents is a set of ordered pairs $\langle p, m \rangle$ such that $\Psi_p^m(p^{(i)}) = m^{(i)}$, where $p^{(i)} \in 2^P$ and $m^{(i)} \in 2^M$.

To describe the process of forming the percept and functional significance, we use elementary topological considerations. Note that (P, T_P) and (M, T_M) are discrete topological spaces with the topologies $T_P = 2^P$ and $T_M = 2^M$, respectively. Then, $\Psi_p^m : 2^P \to 2^M$ is a mapping of the topological space (P, T_P) into the topological space (M, T_M). Let $N = \langle i_1, i_2, \ldots, i_n \rangle$ be a sequence of mappings Ψ_p^m of (P, T_P) into (M, T_M). Then, the binary relation $\geq$ is a direction on N and $(\Psi_p^m|N, \geq)$ is a sequence with respect to the directed set N. Since $\Psi_p^m(p^{(i)}) = m^{(i)}$, where $m^{(i)} \in (M, T_M)$, Ψ_p^m is a direction in M.

Let m be a point in the space (M, T_M) and σ be the system of neighborhoods of m. As a result of applying the mapping Ψ_m^p (which is the inverse of Ψ_p^m), an initial percept $p^{(0)}$ emerges.

As a result of pattern recognition (which is beyond the scope of this paper), a percept $p^{(1)}$ is formed in (P, T_P). The mapping Ψ_p^m assigns to it the functional significance $m^{(1)}$ in (M, T_M).

Three cases are possible:

(1) $m^{(1)} = m$,

(2) $m^{(1)} \notin \sigma$,

(3) $m^{(1)} \in \sigma$.

First, consider case 2. For definiteness, assume that $p^{(1)}$ is a singleton. Then, since $m^{(1)} \notin \sigma$, another singleton $p^{(2)}$ should be generally selected and then the mapping $\Psi_p^m(p^{(2)}) = m^{(2)}$ should be applied again. (Informally, this means that the feature $p^{(1)}$ was selected poorly and was insignificant. From the viewpoint of pattern recognition, fine tuning of the recognition procedures is required.)

This process continues until case (3) is obtained.

In case (3) we have the following situation: the sequence $(\Psi_p^m, \geq)$ with respect to the directed set $(\Psi_p^m|N, \geq)$ converges to the point m if and only if it remains in the neighborhood σ beginning with a certain k. However, the topology (M, T_M) is discrete; hence, every set in it is open. Therefore, if m is the limit of the sequence $(\Psi_p^m, \geq)$ then $m^{(i)} = m$ beginning with a certain k. This also exhausts case (1). Therefore, $p^{(i)} = (\Psi_p^m)^{-1}(m) = \Psi_m^p(m)$.

Furthermore, according to the procedure above, the actor obtains from the external cultural-historical environment a pair *name–significance* $\langle n, m^0 \rangle$. Let σ^0 be the system of neighborhoods of the point m^0 in (M, T_M). Then, we again have three cases:

(1) $m = m^0$,

(2) $m \notin \sigma^0$,

(3) $m \in \sigma^0$.

If $m \notin \sigma^0$, then we again must apply recognition procedures and the mapping Ψ_p^m until case (3) is obtained. It remains to use the same reasoning as in the preceding paragraph replacing σ with σ^0 and m with m^0.

This phase is completed by a monotone extension of the function Ψ_p^m to the set $\{\langle p^{(i)}, m^0 \rangle\}$.

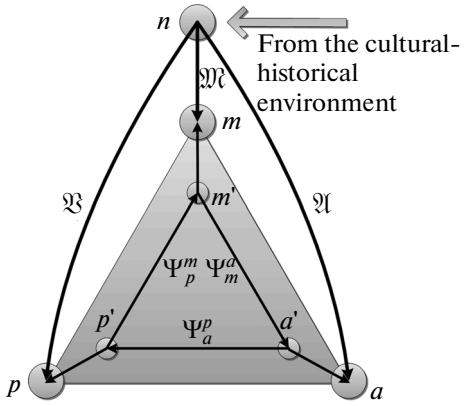

Fig. 1. The process of sign formation and its naming: p', m', and a' are the percept, functional significance, and biological significance; n is the name of the sign; m is its significance; p is its image; a is its personal meaning; $\mathfrak{P}$, $\mathfrak{A}$, and $\mathfrak{M}$ are the function of percept naming, the function of biological significance naming, and the function of obtaining the pair $\langle n, m\rangle$ from the external environment, respectively.

2.3. Naming

We consider the procedure of obtaining the pair $\langle n, m\rangle$ from the external environment as a function $\mathfrak{M}(n)$ that produces the name n given the argument m. Then, $(\Psi^m_p)^{-1}(\mathfrak{M}(n))$ is a function that assigns the name n to the percept p'. We denote it by $\mathfrak{P}(n)$. In other words, $\mathfrak{P}(n)$ is the percept naming function. After the percept p' has obtained a name, it turns into the image p.

At the next step, the biological significances are named and thus they are transformed into personal meanings.

As was mentioned above, the set of personal meanings is formed based on the actor experience in handling the object corresponding to the sign under consideration and based on the evaluation of the success of this handling using self-consciousness mechanisms. For definiteness, we assume that this experience is fixed in the mapping $a = \Psi^a_m(m)$; i.e., it is fixed in the form of the pair $\langle m, a\rangle$. Then, the function $\mathfrak{A}(n)$ of naming the biological significance a' has the form $\mathfrak{A}(n) = \Psi^a_m(\mathfrak{M}(n))$. The biological significance a' becomes the personal meaning a (Fig. 1). This process completes by a monotone extension of the function Ψ^p_a to the set $\{a\}$.

It is easy to see that the following holds:

(1) The triple $\langle p, m, a\rangle$ is a fixed point of the operator $\Psi^m_p\Psi^a_m\Psi^p_a$.

(2) If s is a sign, then $\Psi^p_a\Psi^m_p\Psi^a_m$, $\Psi^m_p\Psi^a_m\Psi^p_a$, and $\Psi^a_m\Psi^p_a\Psi^m_p$ are identical operators.

(3) $\Psi^m_p(\mathfrak{P}(n)) = \mathfrak{M}(n)$ and $\Psi^a_m\Psi^m_p(\mathfrak{P}(n)) = \mathfrak{A}(n)$.

Six more such fact can be written.

3. SELF-CONSCIOUSNESS PROCEDURES ON THE SET OF SIGNS

Consider the structures that can emerge on the set of signs as a result of self-organization. Simulation of self-organization in the world model makes it possible to operationalize the idea of "knowledge activity" [6], which was formed in artificial intelligence under the influence of the concept of the stimulating role of knowledge in human behavior proposed by Festinger in 1956. According to Festinger, knowledge is not only accumulated and used by a actor; the knowledge live their own life, enter into relations, form harmonized consistent systems of notions or are involved into conflicts and are opposed to each other. In the latter case, the knowledge dissonance shows itself as a behavior stimulating force. As was stated in [16], views and attitudes have the property of combining into a system in which the elements are consistent; the existence of contradictory relations between certain elements in the system of knowledge is a motivating factor.

First, we consider the self-organization mechanisms induced by sign images.

3.1. Relations on the Set of Images

Let $S = \{s_1, s_2, ..., s_k\}$ be the set of signs, $p = (x_1, x_2, ..., x_g)$ and $q = (y_1, y_2, ..., y_h)$ be the images of the signs s_p and s_q, respectively ($p, q \in \{\overline{1,k}\}$).

Let π be the set of images of the signs from S. The images p and q in π are sets of feature values; the indexes of features indicate their membership in certain sets of features (domains); for example, the equality $i = j$ indicates that the values of the features x_i and y_j belong to the same set, e.g., X_i.

The ordered sets $\tau_p = \langle i_1, i_2, \ldots, i_p \rangle$ and $\tau_q = \langle j_1, j_2, \ldots, j_q \rangle$, where $i_1, i_2, ..., i_p \in \{\overline{1,g}\}$ and $j_1, j_2, ..., j_q \in \{\overline{1,h}\}$, are called the types of images of the signs s_p and s_q, respectively.

Let us introduce the operator *Pat* that, for every sign s_p, looks through all the other signs and performs the operations listed below (completes binary relations).

1. If, for the sign s_p and a sign s_q ($p \neq q$), it holds that $\tau_p = \tau_q$ and $x_i = y_i$, then $R_1 := R_1 \cup \{(p, q)\}$, $R_1 \subseteq \pi \times \pi$.

It is easy to verify that R_1 is an equivalence on the set of images π. The relations R_2, R_3, and R_4 defined below are the inclusion, similarity, and opposition relations, respectively.

2. If, for the sign s_p and a sign s_q, it holds that $\tau_p \subset \tau_q$ and $x_i = y_i \; \forall i \in \tau_p$, then $R_2 := R_2 \cup \{(p, q)\}$, $R_2 \subseteq \pi \times \pi$ (inclusion relation).

3. If, for the sign s_p and a sign s_q, it holds that $\tau_p \cap \tau_q \neq \varnothing$ and $\forall i \in (\tau_p \cap \tau_q)$ and $x_i = y_i$, then $R_3 := R_3 \cup \{(p, q)\}$, $R_3 \subseteq \pi \times \pi$ (similarity relation).

4. If, for the sign s_p and a sign s_q, it holds that $\tau_p \cap \tau_q \neq \varnothing$ and $x_i \neq y_i$ ($\forall i \in (\tau_p \cap \tau_q)$), then $R_4 := R_4 \cup \{(p, q)\}$, $R_4 \subseteq \pi \times \pi$ (opposition relation).

In essence, these definitions are procedures that generate new elements of relations on the set of signs. These procedures are executed each time when the set of signs is completed with a new sign (or when the set of signs is first used); they either form a new relation or complete some of the relations on the set of signs with a new element. Therefore, the interaction of images of various signs results in the formation of a heterogeneous semantic network [11] on the set of images. This network includes four types of relations—equivalence of images, inclusion of images, similarity of images, and opposition of images.

3.2. Operations on the Set of Images

By way of example, consider the *generalization* operation.

The partial generalization operation Θ is defined on the set of image pairs belonging to the relation R_3. The operation Θ produces a new image that includes all *common* features of the initial images. Let π be the set of images, $p_1, p_2 \in \pi$, $p_1 = (x_1, x_2, ..., x_g)$, and $p_2 = (y_1, y_2, ..., y_h)$. Then, Θ: $\pi \times \pi \to \pi$ so that, for all $p_1, p_2 \in \pi$ such that $(p_1, p_2) \in R_3$, $\Theta(p_1, p_2) = p_3$, where $p_3 = (z_1, z_2, ..., z_l)$, so that $\forall i \exists j, k$ such that $z_i = x_j = y_k$.

The image constructed by the generalization operation provides a basis for forming a new sign. The new sign is formed similarly to the sign formation procedure described in Section 2 with some modifications.

1. Generation of the set of pairs *image–significance* (sign significances) based on the preceding experience and precedents.

2. The actor obtains from the cultural environment accumulated in a natural language system the pair *sign name–significance*.

3. Linking the name from the pair *sign name–significance* to the image.

4. Formation of personal meanings of the sign based on precedents of actions with the object described by the generalized image.

5. Linking the name from the pair *sign name–significance* to the personal meaning.

6. Continuing the mapping *personal meaning–image* by including the personal meaning formed at the preceding step in the domain of and by including the image formed at step 1 in the set of values.

As a result, the sign corresponding to the generalized image is formed.

The pairs of images (p_3, p_1) and (p_3, p_2) extend the inclusion relation R_2. The new sign s_3 is a generalization of the signs s_1 and s_2 formed based on their images (Fig. 2).

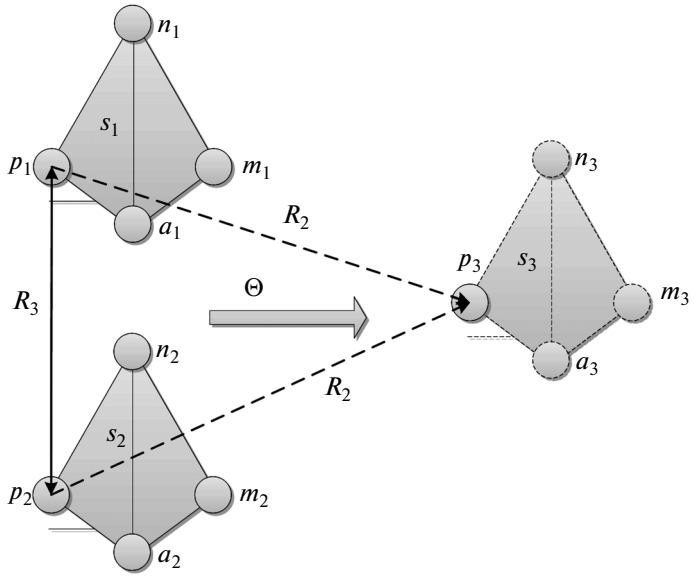

Fig. 2. Example of generalization by features. The generalization operation Θ of the pair of signs s_1 and s_2 belonging to the similarity relation R_3 produces the image p_3 of a new sign s_3 so that the pairs (p_3, p_1) and (p_3, p_2) complete the inclusion relation R_2.

3.3. Relations and Operations on the Set of Personal Meanings

We have seen that each sin is associated with a personal meaning.

On the set of personal meanings, the operator *Mean* naturally induces the subsuming, opposition, and agglutination (i.e., gluing or joining) significances. Let us define these relations. As before, let $S = \{s_1, s_2, ..., s_k\}$ be the set of signs.

We introduce the set of actions ACT and the function I that maps the set of personal meanings into the set of all subsets of the set of actions 2^{ACT} [15]; this function assigns a subset $act \subseteq ACT$ to each personal meaning a in 2^A: I: $2^A \to 2^{ACT}$ so that, for each $a \in 2^A$, $I(a) = act$, where $act \in 2^{ACT}$.

For each sign s, the mapping I assigns to each personal meaning a of this sign the set of actions act that are applicable to the object represented by the sign s. This function is called *interpretation*.

Now, let $I(a_1) = (\alpha_1, \alpha_2, ..., \alpha_g)$ and $I(a_2) = (\beta_1, \beta_2, ..., \beta_h)$ be the interpretations of the personal meanings of the signs s_1 and s_2. If the action α_i adds a fact (see [15]) and the action β_j deletes the same fact [15], then α_i and β_j are said to be opposed to each other and belong to the opposition relation $R_5 := R_5 \cup \{(\alpha_i, \beta_j)\}$, $R_5 \subseteq ACT \times ACT$; this relation is the set of pairs of actions that form contraposition scales in the sense of [12].

On the set of personal meanings, we define the following relations.

(1) $\sqsubseteq (a_1, a_2)$ or $a_1 \sqsubseteq a_2$ (reads as *significance* a_2 absorbs the significance a_1) if $I(a_1) \subseteq I(a_2)$.

(2) $\perp (a_1, a_2)$ or $a_1 \perp a_2$ (reads as *significance* a_1 is opposed to the significance a_2) if $\exists\alpha_i \exists\beta_j (\alpha_i \in a_1, \beta_j \in a_2)$ such that $(\alpha_i, \beta_j) \in R_5$.

(3) $\sqcup (a_1, a_2, a_3)$ is the ternary relation of significance agglutination if $I(a_1) \cup I(a_2) = I(a_3)$.

3.4. Relations and Operations on the Set of Significances

As was mentioned above, the significance of any sign reflects the ways of using the object represented by this sign that are conventional in the society; therefore, this significance can be interpreted by a certain action. Then, the interpretation of significance is directly connected with the interpretations of elements of the sign's personal meaning.

Note that the personal meaning, in distinction from the significance, reflects the individual preferences of the actor, while the significance reflects the ways of using the object represented by this sign that are conventional in the society. Thus, a significance can be reflected in the language vocabulary by a group

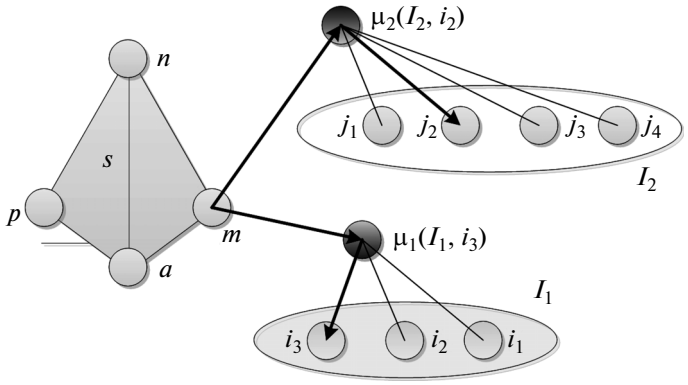

Fig. 3. Example of the structure of significance m of the sign s that includes two instances $\mu_1(I_1, i_3)$ and $\mu_2(I_2, j_2)$, where $I_1 = \{i_1, i_2, i_3\}$ and $I_2 = \{j_1, j_2, j_3, j_4\}$ are sets of semantic valences.

of synonymic predicate words, such as verb, verbal noun, participle, or adverbial participle, which are uniquely characterized by their set of semantic valences [17].

Let $I = \{i_1, i_2, ..., i_q\}$ be the set of all possible semantic valences. Then, each group of synonymic predicate words can be characterized by a subset of this set $I_m = \{j_1, j_2, ..., j_k\}$ ($I_m \subseteq I$). For example, the group of predicate words (ride, run, go) can be characterized by a set of semantic valences *actor*, *means*, *direction of motion*, *goal*, and *quantitative characteristic*.

Let s be a sign with the significance m. An instance μ of the significance m of the sign s is expressed by a predicate word and semantic valence. We denote this fact as $\mu(I_m, i)$, where $\mu \in m$ is an instance of the sign significance and $i \in I_m$ is the semantic valence of the predicate word characterized by the set I_m. Figure 3 shows an example of a sign s whose significance m includes two instances $\mu_1(I_1, i_3)$ and $\mu_2(I_2, j_2)$.

Consider the signs s_1 and s_2, and let $\mu_1(I_1, i)$ and $\mu_2(I_2, j)$ be instances of the significances of s_1 and s_2, respectively. Define the operator *Des* that, for each sign s_1 looks through all the other signs and completes the relations described below using the following rules.

1. If $I_1 = I_2$ and $i = j$, then $R_1' := R_1' \cup \{(\mu_1, \mu_2)\}$, $R_1' \subseteq M \times M$.

2. If for the instance of the significance μ_1 of the sign s_1 there exists an instance of the significance μ_2 of the sign s_2 such that $I_1 \cap I_2 \neq \varnothing$, $I_1 \neq I_2$, and $i = j$, then $R_2' := R_2' \cup \{(\mu_1, \mu_2)\}$, $R_2' \subseteq M \times M$.

3. If for the instance of the significance μ_1 of the sign s_1 there exists an instance of the significance μ_2 of the sign s_2 such that $I_1 = I_2$ and $i \neq j$, then $R_6 := R_6 \cup \{(\mu_1, \mu_2)\}$, $R_6 \subseteq M \times M$ is called a situational relation.

Similarly to the relations R_1 and R_3, the relations R_1' and R_3' are, respectively, an equivalence and similarity relation on the set of significances.

With each instance of the significance μ, we associate a label τ and we write $\mu_1(\tau_1, I_1, i)$ and $\mu_2(\tau_2, I_2, j)$. On the set of labels, we define a linear order: $\forall\tau_1\forall\tau_2$, it holds that either $\tau_1 \leq \tau_2$ or $\tau_1 \geq \tau_2$.

Consider a relation on $M \times M$. Its restriction on $M_{\text{scen}} \times M_{\text{scen}}$, where $M_{\text{scen}} \subseteq M$, is called a scenario relation R_7 if it is constructed in the following way.

4. If $\mu_1 \in M_{\text{scen}}$, $\mu_2 \in M_{\text{scen}}$, $I_1 \neq I_2$, $i \neq j$, and $\tau_1 < \tau_2$, then $R_7 := R_7 \cup \{(\mu_1, \mu_2)\}$.

An elementary scenario induced by the sign s is defined as the set of instances of significances $M_{\text{est}}(s)$ such that, $\forall\mu_1 \in M_{\text{est}}(s)$ and $\mu_2 \in M_{\text{est}}(s)$, it holds that

(a) if $\mu_1 \in m$, $\mu_2 \in m$, and $\tau_1 \geq \tau_2$, then $(\mu_1, \mu_2) \in R_7$ (in this case, the scenario relation R_7 is defined on the set of instances of significances of the sign s, i.e., $M_{\text{scen}} = m$);

(b) if $\mu_1 \in m$, $\mu_2 \notin m$, and $\tau_1 \geq \tau_2$, then $(\mu_1, \mu_2) \in R_6$.

Figure 4 shows an example of an elementary scenario $M_{\text{est}}(s_1)$ induced by the sign s_1; more precisely, an elementary scenario formed by two instances μ_2 and μ_3 of the significance of the sign s_1 such that (μ_2 such that μ_3) $\in R_7$. In the example in Fig. 4, $M_{\text{est}}(s_1)$ also includes the instances of the significances μ_1 and μ_4 such that $\{(\mu_1, \mu_2), (\mu_3, \mu_4)\} \subseteq R_6$, where μ_1 and μ_4 are instances of the significances of the signs s_2 and s_3, respectively.

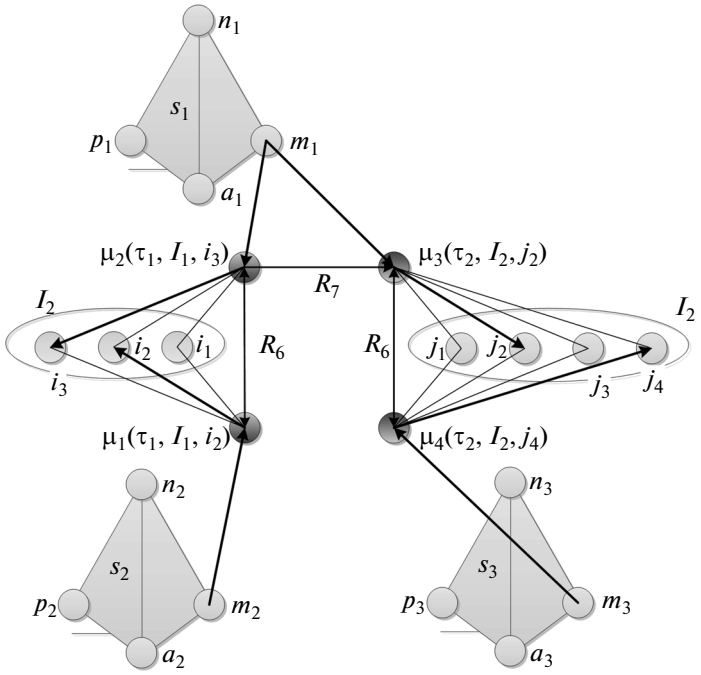

Fig. 4. Example of an elementary scenario $M_{\text{est}}(s_1) = \{\mu_1, \mu_2, \mu_3, \mu_4\}$ generated by the significances of the sign s_1. Since the pairs of instances of the significances (μ_1, μ_2) and (μ_3, μ_4) belong to the relation R_6 and the pair (μ_1, μ_3) belongs to the relation R_7 in this example, these instances belong to the elementary scenario $M_{\text{est}}(s_1)$ by definition.

4. SELF-ORGANIZATION ON THE SET OF SIGNS AND WORLD MODELS OF A ACTOR

According to the preceding section, self-organization mechanisms form three basic types of structures on the set of signs. Each such structure (see [11]) is called heterogeneous semantic network or, if there is no source for confusion, semantic network. We consider three such networks.

1. The semantic network $H_P = \langle 2^P, \Re_P \rangle$ on the set of images, where $\Re_P = \{R_1, R_2, R_3, R_4\}$ is the family of relations on the images.

2. The semantic network $H_A = \langle 2^A, \Re_A \rangle$ on the set of personal meanings, where $\Re_A = \{R_5\}$ is the family of relations on the personal meanings.

3. The semantic network $H_M = \langle 2^M, \Re_M \rangle$ on the set of sign significances, where $\Re_M = \{R_1', R_3', R_6, R_7\}$ is the family of relations on the significances.

The triple $H = \langle H_P, H_A, H_M \rangle$ is called a *semiotic* network.

It is seen from the above reasoning that transitions between the networks H_P, H_A, and H_M are implemented using the procedures Ψ_m^a, Ψ_a^p, and Ψ_p^m.

The level of sign names can inherit each of the semantic networks described above. Due to this inheritance, one can speak about forming a semantic network on the level of signs (and not only on the level of their components).

On the other hand, there is the concept of *world model* of the actor. According to Artem'eva [13], the traces of interaction with objects in this psychic structure are fixed in the system of actor's experience on the semantic level: "we could see how biased is the actor's attitude to the object world that contacts him, how actively he (the actor) structures this world thus creating its projection for himself. Things are always attributed properties that characterize their relationships with the actor. In particular, geometric shapes prove to be equipped with strongly coupled complexes of properties among which emotional and evaluation properties are the basic ones. The actor forms a world model or view of things' properties in relation to himself and to each other." We propose to differentiate between three types of world models—rational, common sense, and mythological [2].

We have seen that one can define feature generalization (and classification) operations on the network H_P (Section 3.2). These are the operations that are characteristic of a rational world model. Based on these considerations and some psychological experiments (which are beyond the scope of this paper), we believe that this is the network on the set of images (and its inheritance to the level of sign names) that underlies the rational world model. We emphasize the importance of the word *underlies*. All types of the world model use networks on images, significances, and scenarios; however, there is a "control" network that serves for formulating the goal, search for appropriate actions, call of scenarios, and modification of personal meanings. For example, in the rational world model, a goal is set in the image network; then, appropriate roles in the scenario as conditions for actions aimed at achieving the goal are found in the significance network; and then objects' significances, which can be motives, obstacles, or means for achieving the goal, are taken into account [14]. Note that degenerate world models can be described that use only two networks (e.g., H_A and H_M in the nihilistic world model [2]) rather than three.

The common sense world model is characterized by following certain behavior stereotypes or scenarios. Thus, inheritance to the level of sign names results in forming the *common sense* world model. We also note that the network on significances is only a leading one; for example, simulation of the official's world model is realized on two networks—network of scenarios and network of personal meanings. For that reason, when demand for new object emerges (e.g. fund allocation for science and culture), a scenario appears in which the significance of goal turns from ambivalent into the significance of obstacle. Since there are no images in this process, we deal with a degenerate world model here. In the general case, the chosen scenario (on the network of significances) in the common sense world model is completed by images of the objects (including partners) that can best (according to estimates on the network of significances) perform the roles written in the scenario (e.g. a chief chooses employees for a new team that are appropriate for new jobs or a bride and bridegroom make a list of guests for the wedding according to their ideas of how a "good" wedding should look like).

In the mythological world model, each role has an invariable significance; in this case, the leading network is a network on significances. In other words, inheritance of the network H_A to the level of sign names results in forming the *mythological* world model.

5. GOAL SETTING

The problem of controlling the behavior of an actor includes the phases of planning and plan execution. The first task in planning is to set a goal. We apply the apparatus developed above to solving this problem. The planning itself and its execution will be considered in the second part of this paper.

Goal setting is a complex process; it includes not only the selection of goal but also the determination of conditions and a specific method to achieve it. It was mentioned above that the nature of the goal setting process is determined by the type of the actor's world model (WM). In the case of the common sense WM, the leading component is *significance*; that is, the actor leans upon the plot-role structure and uses existing signs to select an appropriate situation that will be assigned to be the goal.

To denote the operation of transitions on the network of significances, images, and personal meanings, we define the nondeterministic transition operator Tr that acts on the sets of subsets 2^P, 2^A, and 2^M: $Tr(x) = x'$ where $x, x' \in 2^A$ or $x, x' \in 2^P$ or $x, x' \in 2^M$. The left composition of the operator Ψ_x^y, where $x \in \{m, a, p\}$ and $y \in \{m, a, p\}$ (i.e., any of the operators Ψ_p^m, Ψ_m^a, or Ψ_a^p) with the transition operator in the network y is denoted as $\underline{\Psi}_x^y$: $\underline{\Psi}_x^y = \Psi_x^y \circ Tr(x)$, where $Tr(x) = x'$, $x \in 2^A$, or $x \in 2^P$, or $x \in 2^M$ and $x' \in 2^A$, or $x' \in 2^P$, or $x' \in 2^M$. By the composition of operators, we mean the application of the left operator to the result of application of the right operator. The right composition of the operator Ψ_x^y, where $x \in \{m, a, p\}$ and $y \in \{m, a, p\}$ with the transition operator in the network y is denoted as $\overline{\Psi}_x^y$: $\overline{\Psi}_x^y = Tr(y) \circ \Psi_x^y$, where $Tr(y) = y'$, $y \in 2^A$, or $y \in 2^P$, or $y \in 2^M$ and $y' \in 2^A$, or $y' \in 2^P$, or $y' \in 2^M$. For example, the left composition of Ψ_p^m with the transition operator in the network of images is written as $\underline{\Psi}_p^m = \Psi_p^m \circ Tr(p)$.

The goal is set in the framework of an activity. We consider the case when the actor is aware of the motive of his activity, that is, the sign of the demanded item is included in the world model of the actor. Then, the motive of his activity (in the common sense world model) is the significance (m) of this sign. The motive is satisfied if there exists a sign such that the result of application of the right composition of the operator Ψ_a^p with the transition operator ($Tr(p) \circ \Psi_a^p$) to the personal meaning of this sign is the image of the demanded item sign. (On the semantic level, there exists a sign such that the result of an action that interprets its personal meaning is the image of the demanded item sign.)

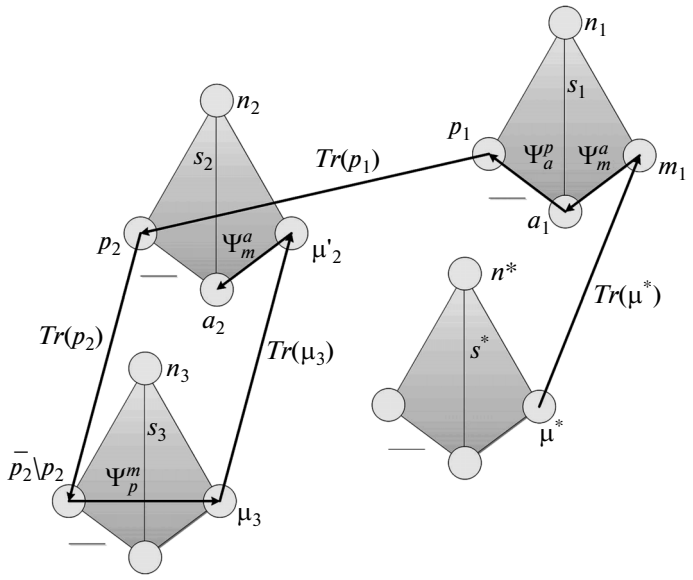

Fig. 5. Illustration to the goal setting algorithm. s^* is the sign of the demanded item, and μ^* is an instance of its significance or, in other words, motive of activity. The arrows denote the operators Ψ_p^m, Ψ_m^a, Ψ_a^p, and *Tr*.

Then, the sign that gives the image of the demanded item sign when the right composition of the operator Ψ_a^p with the transition operator is applied to it will be called the goal sign. On the semantic level, the goal sign is the sign whose personal meaning structure includes an action whose application results in the formation of features of the demanded item image (satisfaction of the demand). Thus, the goal setting process is to construct a sequence of signs that ends with a sign from which the motive can be reached, that is, the demand is satisfied.

According to Section 3.4, we represent the sign significance by a set of pairs *action–role of object in this action*; the image (*p*) of such a sign is represented by a set of features (i.e., pairs *feature–feature value*), the personal meaning (*a*) is represented by a rule corresponding to the action of the actor with the object; the condition and effect of the action of such a rule are specified by a set of properties.

In what follows, s^* denotes the sign whose the instance of significance μ^* is the motive of activity. In the goal setting algorithm described below, we use both syntactic and semantic considerations without emphasizing their difference.

Algorithm GS

Input: demanded item sign s^* and the motive μ^*.

S t e p 1. Transition $\mu^* \to a_1$ (the operator $\underline{\Psi}_m^a$ is used). On the subnetwork of significances (in the scenario with the generating sign s^*), apply the transition operator *Tr* to μ^* until a significance m_1 is obtained whose sign s_1 has the personal meaning a_1 such that the corresponding interpreting action on the set of added features p_{add} contains the set p^* of features of the sign s^*; $\underline{\Psi}_m^a: \mu^* \to a_1$, where a_1 is such that $p^* \subseteq p_{add}(a_1)$ (application of the operators $Tr(\mu^*)$ and Ψ_m^a in Fig. 5). If s_1 is different from s^*, then the goal sign thus found with its personal meaning is the goal and the algorithm stops. Otherwise, go to Step 2.

S t e p 2. Transition $a_1 \to \bar{p}_2$ (the operator $\bar{\Psi}_a^p$ is used). On the subnetwork of images, apply the transition operator *Tr* to the image containing one or several features of the condition p_{cond} of the rule that interprets the personal meaning a_1 of the sign s_1 until the maximum (in cardinality) set of features p_2 of the sign s_2 that is a subset of p_{cond} is obtained. The union of the features of the image p_2 of the sign s_2 with a feature (or several features) from the set $p_{cond} \backslash p_2$ is called the extended image $\bar{p}_2$ so that $\bar{\Psi}_a^p: a_1 \to \bar{p}_2$, where $\bar{p}_2$ satisfies the conditions $p_2 \subseteq \bar{p}_2$ and $\bar{p}_2 \subseteq p_{cond}$ (application of operators Ψ_a^p and $Tr(p_1)$ in Fig. 5).

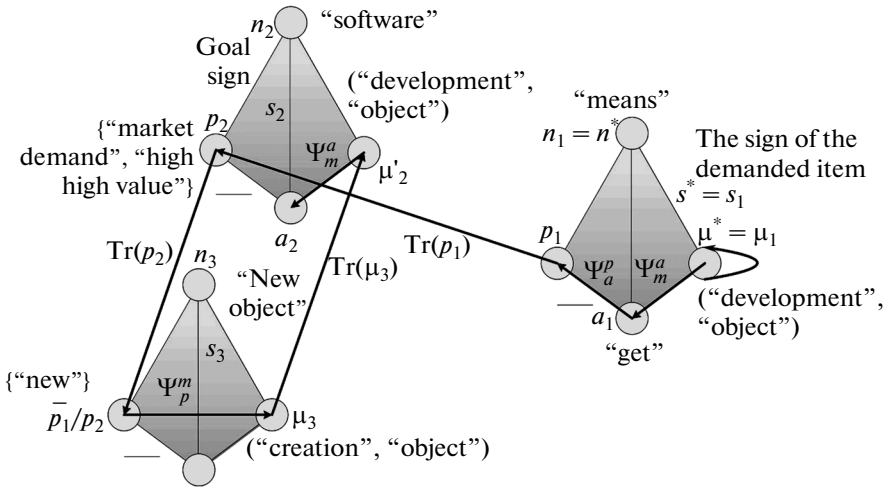

Fig. 6. Example of goal setting of a development team leader with the common sense world model. For the leader, the sign with the name *means* is the sign of the demanded item. The arrows denote the operators Ψ^m_p, Ψ^a_m, Ψ^p_a, and *Tr*.

S t e p 3. Transition $\bar{p}_2 \to \mu_3$ (the operator $\bar{\Psi}^m_p$ is used). On the subnetwork of significances, apply the operator *Tr* to a significance of the sign s_3 whose image coincides with the set of features $\bar{p}_2 \backslash p_2$ until an instance μ_3 is obtained such that

(1) the elementary scenario $M_{\text{est}}(s_3)$ generated by the sigh s_3 (with the first instance of the significance μ_3 according to the ordering $\geq$) coincides with an elementary scenario (with the first instance of the significance μ'_2 in M_{scen} according to the ordering $\geq$) generated by the sign s_2 found at Step 2 accurate to the signs s_2 and s_3 (i.e., without regard to these signs);

(2) the personal meaning a_3 corresponding to the instance of the significance μ_3 is interpreted by an action such that the set of features of its result includes the set of features of the image p_3 of the sign s_3 itself so that $\bar{\Psi}^m_p$: $\bar{p}_2 \to \mu_3$, where μ_3 is the first instance in the set M_{scen} of the scenario $M_{\text{est}}(s_3)$ and $\exists M_{\text{est}}(s_2)$ such that $M_{\text{est}}(s_2) = M_{\text{est}}(s_3)$ without regard to the signs s_2 and s_3 (application of the operators $Tr(p_2)$, Ψ^m_p, and $Tr(\mu_3)$ in Fig. 5).

S t e p 4. Transition $\mu'_2 \to a_2$ (the operator Ψ^a_m is used). Finding the personal meaning a_2 corresponding to the significance μ'_2 of the sign s_2. Stop.

Output: either the sign s_1 and its personal meaning a_1 or the sign s_2 and its personal meaning a_2.

As a result of the algorithm operation, the sign s_2 is found that is distinct from the sign of the demanded item s^* whose personal meaning a_2 is interpreted by an action that leads to the demand satisfaction. Thus, the sign s_2 with the personal meaning a_2 becomes the goal (see Fig. 5).

E x a m p l e. As a simple example, consider the goal setting procedure of a software development team leader (Fig. 6).

In this case, the team leader uses the common sense world model, the motive of his activity is the significance of the sign *means* (*of living*); one of the instances of its significance is *getting*, which has the semantic valence *object*. In other words, an instance of the sign significance is the pair (*getting*, *object*). Assume that the image of this sign contains the features *high value*, *market demand*, and *new*.

Algorithm GS

Input: the sign *means* and the motive (*getting*, *object*).

S t e p 1. The transition *significance–personal meaning*. The scenario is formed by the semantic valences of the predicate word (in this case, *getting*). The actor seeks the sign, and his personal meaning is interpreted by the actions he is going to undertake to satisfy the motive. In other words, the set of additions of the rule that interprets the personal meaning must include the required features of the object that can be sold to get means of living, for example, *high value*, *market demand*, *new*, etc. Assume that the *personal meaning get* of the sign *means* will be found.

S t e p 2. The transition *personal meaning–image*. The execution of the action corresponding to the personal meaning thus found requires that the features from the action condition be found. A sign whose image contains the required features is sought. Since the team leader deals with software, he sooner or later finds the sign *software* because its image contains the features *high value* and *market demand*. The missing features from the rule condition together with the found features form the extended image, for example, *new software*.

S t e p 3. The transition *image–significance*. A sign is sought that contains in its image the feature *new*, for example, *new object*. Select an instance of the significance of this sign. The instance of significance must be the first one in a scenario coinciding with a scenario of the sign *software*. Such an instance may be *development* because the world model of the team leader contains the corresponding scenario. For the scenario induce by the sign *software*, the first instance is *to develop*.

S t e p 4. The transition *significance–personal meaning*. The personal meaning of the sign *software* corresponding to the significance instance *to develop* is chosen. The action that interprets this personal meaning contains in the set of added features such features as *high value*, *market demand*, and *new*, which are contained in the image of the sign *means* and satisfy the motive. Thus, the current sign is the goal one, and the goal is the pair *to develop–software*.

Output: the sign *software* and its personal meaning *to develop*.

CONCLUSIONS

In this paper, we considered the concept of sign, self-organization mechanisms on the set of signs, and formation of a sign-based world model. This provides a basis for the description of a model of one of the functions of consciousness—goal setting. An implementation of this function is described, and a simple example illustrating the operation of the algorithm is discussed.

The semantic or procedural level of the sign-based world model and model of other functions of consciousness (reflection and synthesis of goal oriented behavior) remained beyond the scope of this paper. These issues will be considered in the second part of the paper.

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