Knowledge Representation in the Sign-Based World of the Actor

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ABSTRACT

A number of recent studies on the modern theories on the emergence of mental functions and the respective role of neurophysiological processes, the formation of mental functions is associated with the existence or communicative synthesis of specific information structures that contain three types of information of different origins: information from the external environment, information extracted from memory, and information from motivation centers. These components are bound together via their naming; this also ensures the stability of the emerging structures. A set of signs formed by an actor during activities and communication produces their sign-based world model, which reflects their ideas about the environment, them-selves, and other actors. The sign-based world model allows setting and solving a number of tasks arising in behavior modeling for intelligent agents and their coalitions such as goal-setting, purposeful behavior synthesis, role distribution, and the interaction of agents in the coalition. This paper studies a special object, that is, the causal matrix, which describes the structure of the sign components within the matrix.

Keywords

Sign-based world view model, sign image, sign significance, sign personal meaning, knowledge representation, causal matrix

1. INTRODUCTION

The emergence of sensations is clearly one of the key problems in modern cognitive psychology. The relationship of this phenomenon to the formation of an actor's view of the world is also unclear. Psychologists, including A.N. Leont'ev [1], support the idea that the view on each object or event in reality in the consciousness includes three components: object image, cultural and historical significance, and personal meaning. According to the concept of an image that is being developed in cognitive psychology, perception is considered as a process of categorization. The significance corresponds to the purpose of the object and the semantic component of the sign, while the personal meaning is interpreted as a set of actions with the object preferred by the actor. It can be seen that such a structure is similar to the semiotic concept of a sign [2]; thus, it is appropriate to call the approach developed in this paper a sign-based or semiotic approach. In this model, unlike the known two-process model of Kahneman [3], psychic processes are implemented by three subsystems: reflexive, algorithmic, and autonomic.

These observations are also confirmed by the results of many studies in the area of neurophysiology, primarily [4], according to which the emergence of sensation, i.e., the transition from the neurophysiological level to the psychological one, is connected with the circular motion of excitation in the brain cortex regions, which, after additional processing in its other structures, returns to the areas of initial projections of the signal (sensation circle). The mental function [5] emerges on the basis of synthesis of three types of information (in essence, with the formation of three-component structures): information from the external environment (sensory), information extracted from the memory, and information from the motivation centers. It should be noted that [6] also mentioned the possible existence of sign-based structures in the world-view models of actors. In [7], a mechanism of forming certain cognitive functions was studied along with its relationship to the formation of the linguistic world view model. Paper [8] was dedicated to the occurrence of the mechanisms of communication based on the semiotic approach with fuzzy knowledge representation.

2. SYNTACTIC LEVEL OF THE MODEL

Clarity about learning outcomes serves many purposes. Let us define the syntactic level of the world image model following [9]. Let's assume that S is a set, which will be referred to as a set of primary signs,

$S \subset S^{+}$, where S^{+} is a set of signs. Each element $s \in S$ has the form $s = \langle n, p, m, a \rangle$, where $n \in N$, $p \subseteq P$, $a \subseteq A$, $m \subseteq M$. Here, N is a set of words of a finite length in some alphabet, which will be referred to as a set of names; P is a set of closed atomic formulae of the language for calculating the first-order predicates, which will be referred to as a set of properties.

M will be referred to as a set of significances and A as a set of meanings. According to the psychological considerations, each set is interpreted by a set of actions. Following the tradition accepted in the area of artificial intelligence (AI), the action can be represented using a rule [10]. The rule is an organized trinity of sets $r = \langle Con, Add, Del \rangle$, where Con is a rule condition, Add is a set of facts added by rule r, and Del is a set of facts eliminated by rule r. In a general case, each of these sets is a set of atomic formulas for calculating first-order predicates. The role of the rules in the sign model will be described in more detail in the next section.

Let us further introduce the binding operators.
$\Psi^{m}_{p} : 2^{P} \rightarrow 2^{M}$ is the binding operator for images p with significances m. The second operator,
$\Psi^{a}_{m} : 2^{M} \rightarrow 2^{A}$, binds the significances with meanings.
The third operator, $\Psi_{a}^{p} : 2^{A} \rightarrow 2^{P}$, binds the meanings with images. The introduced operators bind the sign components with each other. Their semantics will be defined in the next section. At a syntactic level of the model, the underlying algorithms of sign formation and self-organization procedures are defined [11].

3. THE SEMANTIC LEVEL OF THE MODEL

At the semantic level of the world-view model, the operational semantics of the binding operators introduced at the syntactic level is refined. As such, the meaning and personal meaning sign components are interpreted by the rules in the same way as in AI. The sign image is described by a set of atomic rules of calculation of predicates.

Let us define the binding operator (Fig. 1),

- $^{m}{}_{p}(p^{(i)}) = m^{(i)}$, so that $m^{(i)} = \{r\ 3_c(r) \subseteq 3(p^{(i)})\}$,

where 3c (r) is a set of various predicate symbols of condition Con of rule r, which interprets the significance m for certain sign s (for simplicity, each significance will be hereinafter bound with only one action,3 (i) or one rule,); (p) is a set of predicate symbols of image p(i); p(i) $\in 2^P$, $m^{(i)} \in 2^M$, 2^P and 2^M are Booleans P and M, respectively. The fact that the condition of rule r that interprets the significance m of the sign s is a subset of the set of sign image attributes means that the action described by rule r can be applied to the object, to which the sign *s* corresponds if the condition of rule r is met for the image of this object.

The second operator $\Psi^{a}{}_{m}(m^{(i)}) = a^{(i)}$, where $a^{(i)} = \{r * 3_c(r) \cap 3_c(r^*) \neq \emptyset\}$ 3c (r) is a set of predicate symbols of condition Con of rule r* interpreting personal meaning $a^{(i)}$ (as in the case of significance, for simplicity each personal meaning hereinafter will be bound with only one action, or one rule);

m(i) ∈ 2M , a(i) ∈ 2A ,2A is Boolean for A. The third operator Ψ ap (a(i)) = p(i+1), where p(i+1) ⊆ 3a (r_j*), a(i) ∈ 2A, p(i+1) ∈ 2 P , 3a (r_j*) is a set of predicate symbols from the set of rule r_j* additions.

Of course, p(i) ≠ p(i □1). It can be shown that for a certain initial approximation this iterative process converges to a certain value of p. As such, $|3_c(r) \cap 3_c(r^*)| \geq 2$. It can be seen that $3_c(r) \subseteq 3_c(r^*)$ is a substantial condition of convergence. If operator $\Psi_m{}^p = \Psi_a{}^p \Psi^a{}_m$ is introduced it can be seen that a pair of operators $\Psi^{m}{}_{p}$ and $\Psi_{m}{}^{p}$ form a Galois correspondence, and the sign is a Galois fixed-point value of operators $\Psi^{m}{}_{p}$ and $\Psi_{m}{}^{p}$.

At the semantic level of the world-view model, it is possible to describe the relationships on the set of sign components: the relationships on the set of images, significances, and personal meanings. Each relationship from these families can be translated upon the set of names, which allows one to determine the relationships on the set of signs.

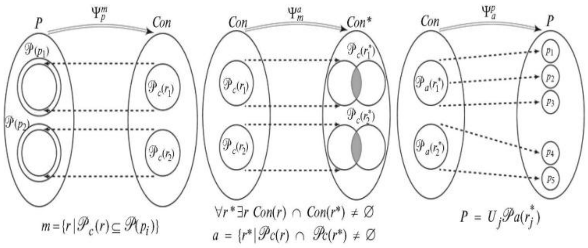

Fig. 1. Binding operators of the sign components.

4. THE STRUCTURAL LEVEL OF THE MODEL

The structural model of the sign components considers the modern neurophysiological data on the structure of the corticothalamic subsystem of the brain and the mechanisms of activation transfer between the cortex regions. A set of predicate symbols 3(·) will be replaced by a set of attributes organized in special structures (causal matrices), which, in turn, form a causal network. The combination of attributes (predicate symbols) to such structures allows the use of a single formal description to describe both the image component of the sign (a set of predicate symbols) and the significance and personal meanings (rules with effects and conditions).

To study the structure of the sign components, let us consider an example of an image component, which participates in recognizing the represented object or process based on the sensory information from the external environment and motor information captured by internal sensors (as a result of recognizing the sign image, the sign is actualized). Prior to naming the sign, let us call it a protosign, or an attribute.

Let us assume that in the input data f low sequence (x1, x2,..., xh) is highlighted with the length h of vectors xi of actual numbers from 0 to 1, which will be referred to as events. Each event xt of length q represents a record of outputs from q sensors and each element of the event means the degree of confidence (the subjective probability in the Bayesian sense) in triggering the corresponding sensor. As an example, event (0.1,0.9,0.9) comes from three sensors, that is, red, blue, and green transducers, and means that the degree of confidence in triggering the red transducers is 0.1, and for the blue and green ones it is 0.9.

The image component of the sign is primarily responsible for recognizing the represented object based on the incoming information. In the process of functioning of the sign image, a special recognizing function is used and built, which accepts an input sequence of vectors that contain information about the object attributes at certain moments of time. The recognizing function determines whether the object represented by the sign exists (is encoded) in this sequence. Below, we will consider this function as already built as a result of a special learning process.

The recognizing function (i.e., encode the characteristic attributes of the object or process) will be presented by a special structure, that is, a causal matrix Z = (e1, e2,..., eh) having dimension q by h, where q is the dimension of events (quantity of sensors), and h is the length of the sequence of events. As such, each column et of the causal matrix is a binary vector of length q and encodes the attributes (to which row 1 corresponds), which must be present in the input event at the moment of time t in order for the represented object or process to be recognized in the input data f low, i.e., it defines the set of simultaneous characteristic attributes. As an example, the image of sign s representing the “face” object can correspond to the causal matrix:

$$z = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix},$$

where the first row is the characteristic vector of information from the left eye transducer in the image, the second one is the characteristic vector of information from the right eye transducer, the third one is from the nose, and the fourth one is from the mouth. The arrows represent time transitions (sac-cades) from triggering one sensor to triggering the next one.

In the above example, each attribute that comprises the image of the “face” sign can also be represented by a certain sign in the actor’s world image. Thus, sensor data as a characteristic attribute of the sign image is an isolated case. In a more general setting, attributes that form the sign image are other attributes that correspond to these characteristic attributes. Therefore, we can compare the image p of sign with set S p(s) of power q, each element of which corresponds to the row of causal matrix z of dimension q by h, i.e., each attribute $s_i \in S$ p(s) corresponds to a characteristic binary vector that defines in the places of units the discrete moments of time, at which the given attribute must be present in the input data in order to successfully recognize the image (actualize) sign s.

Each sign image can correspond to several causal matrices, which define various cases of observing the represented object or process in the external environment. The entire array of the causal matrices of the image of sign s will be denoted by Z p(s).

To refine the definition of set Sp(s), let us introduce a family of embedded binary relationships {p , ^{1}p , ^{2}p,...} defined for set of signs S. We assume that sign s_i is an element of the image of sign s,

(s_i , s) $\in$ p, or $s_{i\ p}$ s if $s_i \in$ Sp(s). If it is known that sign s_i corresponds to a unit in the t column of a certain causal matrix $z \in Z\ ^p(s)$ of sign s, we will use relationship ^{t}p , which provides ^{t}p $\subset$ p.

4.1. A Causal Network

Let us introduce the special procedure $p : 2^Z \rightarrow 2^N \times 2^N$, , in which each array of causal matrices $Z\ ^p(s) \subset Z$ of the image of sign s finds two corresponding non-overlapping subsets of indices of columns $I^c \subset N$, $\forall\ i \in I\ ^c i \leq h$ and I e $\subset N$, $\forall\ i \in I\ ^e i \leq h$: $p(\ Z\ ^p\ (\ s)) = (I\ ^c , I\ ^e)$ to provide $I\ ^c \cap I\ ^e = \emptyset$. Set I^c will be referred to as indices of the condition columns, and I^e, as indices of the effects. As an example, in the case where for the array of matrices Z comprising only one matrix ((1, 0), (0, 1)) the procedure Λp returns two subsets {1} and {2}, the emergence of the attribute that corresponds to the first row of the matrix causes the emergence of the attribute that corresponds to the second row. Thus, the procedure Λp establishes the cause-and-effect relationship for the set of input events and can be realized in different ways, including on the basis of Norris algorithms, FCO, etc. [6, 7]. In this paper, we will only study the cases, where the columns in a causal matrix refer to two subsets (conditions and effects). It is possible that the columns of the causal matrix form a chain of causes and effects, in which the situation function Λp will return more than two column subsets as the result.

In the case, where the set of effects columns is not blank I e $\neq \emptyset$, for matrices $Z\ ^p(s)$ of the image of sign s, one can presume that the sign represents some action or process, the result of which is encoded in the columns of effects, and the condition is encoded in the columns of conditions (the corresponding sign is procedural). Otherwise, when for matrices $Z\ ^p(s)$ of the image of sign s the set of columns of effects is blank $I\ ^e \neq \emptyset$, i.e., when for the given array of causal matrices it is impossible to determine explicitly which events precede others, we assume that the cause-and-effect relationship is not established and the sign represents a certain object or situation (the corresponding sign is objective).

The following statements regarding the properties of procedure Λp are valid:

- $I\ ^c \cap I\ ^e = \emptyset$ – a column of a causal matrix cannot represent a condition and an effect at the same time;
- $I\ ^c \cup I\ ^e = h$ – there are no types of columns other than the columns of conditions and effects;
- $I\ ^c \neq \emptyset$ – there must be at least one column of conditions among the columns of a causal matrix, while there can be no effects (in case of objective attributes);
- $\forall\ i \in I\ ^e$, $j \in I\ ^c i > j$ – all conditions precede an effect in time.

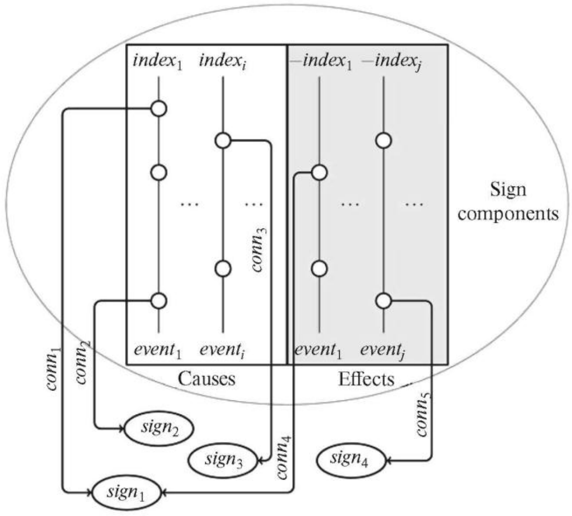

Fig. 2. An example of a causal matrix

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