Application of the Spot Apparatus for Representation of Semantic Information and Consciousness with Mental Imagery and Cognitive Modeling

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Abstract

The paper considers the application of a mathematical model and apparatus of spots for representing semantic information and creating a cognitive model in the form of mental imagery. The adequacy of using the spot model is based on the elementary spatial properties inherent in both imagery and spots. In particular, based on the model of spots, we introduced the concept of "spiritual" imagery as a structure of conceptual-emotional imagery. Imaginative representation in the apparatus of spots also allows modeling reasoning and, in particular, non-monotonic reasoning, when conclusions are made on the basis of existing knowledge, and obtaining new knowledge can change the conclusions. Using the model of spots, consciousness can be modeled as a representation of external or cognitive imagery on the basis of imagery selected by the focus of attention. The concept of imagery-logical neural networks is proposed, in which each neuron performs an act of elementary reasoning. This allows creating intelligent systems capable of not only representing the imagery sphere of a person, but also modeling imaginative thinking.

Keywords: Mental Imagery, Cognitive Model, Causal Reasoning, Consciousness, Artificial Intelligence.

1. Introduction

One of the main reasons for the problem of unexpected, random errors in deep neural networks is the fact that the numerical values they operate with have no direct connection with the semantics (meaning) of the information being processed. Obviously, to solve this problem, it is necessary to use methods for representing and processing information in a form inherent to humans. Although neurophysiologists are currently conducting intensive research on the brain, this paper considers modeling of brain activity processes at the level of psychology. We will use the concept of mental imagery [1, 2] to represent semantic information in the imagery sphere of a person [1] and in the field of mathematical modeling of thinking, as well as for machine learning technology in the field of artificial intelligence (AI). Cognitive modeling is aimed at simulating human intelligence and is considered as an approach to creating strong AI [3]. For this purpose, it is necessary to develop a mathematical apparatus for representing mental imagery and create intelligent systems capable of processing semantic information in imaginative form. Mental (or secondary) imagery are an abstract term that allows us to describe the structure of semantic information stored in memory. The concept of imagery, which is close to the concept of "gestalt", is used in psychology and cognitive science, and plays a key role not only in perception, but also in memory, emotions, language, desires and actions-performances [2]. Imagery differs in modality (relation to different sense organs), by the degree of abstractness (imagery of sensations, perceptions, concepts, and verbal). In particular, there are emotional imagery, and these include, for example, musical ones. According to the author, all cognitive mental processes can be described in the language of mental imagery, the ordered structures of which form cognitive spaces in the imagery sphere [1, 4, 5].

One of the important properties of mental imagery is their elementary spatial properties, which are also reflected in natural language. For example, we can talk about the edges and different sides of a concept or phenomenon, about points of view, about the closeness or intersection of concepts. It is obvious that the spatial properties of mental imagery have a vague nature, and they cannot be represented using crisp geometric figures. The apparatus of a new mathematical object developed by the author - "spots" [6] - allows us to form a spatial-structural representation of imagery and the imagery sphere of a person in psychology, as well as an imagery representation of semantic information in AI [4, 5].

Consciousness and perception can be represented as a projection onto the imagery sphere (system) of a person [1], which plays the role of a basis for representation events of reality. Therefore, our perception is not absolutely objective, it always depends on our internal imagery system. Two people, observing the same event, can interpret it completely differently, because their imagery systems are different.

The imagery sphere of a person includes imagery of consciousness and imagery of the subconscious. It is formed on the basis of various information coming from the outside world. First of all, this is personal experience, cultural traditions assimilated by the individual, religious and philosophical views. Of course, the imagery system of a person is not completely static, it inevitably changes throughout his life under the influence of life events, education, receiving new impressions from works of art, studying scientific, religious and philosophical views. For example, propaganda and advertising have an obvious targeted influence on the imagery sphere of consciousness and the subconscious. An important part of the human imagery sphere is the imagery of his spiritual world, which are formed under the influence of art, literature, music and other cultural phenomena. Spiritual imagery is not limited to religious or philosophical ideas, but cover everything that contributes to the development of the personality, its emotional depth, moral values and creative potential.

From our point of view, the peculiarity of spiritual imagery is that they are multidimensional polymodal, that is, they include not only the intellectual component (thoughts, ideas, philosophical concepts), but also the emotional component (feelings, experiences, empathy). At the same time, the emotional component of the spiritual imagery has a fundamental influence on its semantic content, so that if the emotional component is ignored, the meaning of the spiritual imagery is lost. Visual examples of this are the imagery of perception of a loved one, the imagery of perception of the object of hobbies (fishing, hunting, hobbies), the imagery of perception of fans of players of their football teams or favorite stars. Based on the model and apparatus of spots, an imagery-logical computational cognitive model [4, 5] is proposed, which allows one to represent causal reasoning [7]. In particular, the proposed model allows one to adequately display such properties of imagery as multidimensionality, multi-levelness, and polymodality. A concept of a new type of neural networks is also proposed – imagery-logical ones, which process information in a way similar to causal reasoning. In this model, each neuron carries out an elementary act of reasoning – analysis or synthesis of input information.

2. The Spot Model and Mental Imagery Modeling

"A spot" is a vague (blurred) figure or region in an abstract semantic information space. Clear geometric figures are considered here as a special and limiting case of spots. We will call the representation of imagery based on spots a spatial representation of mental imagery. In general, the structure of spots and the properties of their environment (space) can only be determined by qualitative information about their elementary spatial relations (ESRs), such as separateness, intersection, inclusion, indistinguishability, etc., with other spots. In this paper, we will limit ourselves to a brief description of the apparatus of spots, which is described in detail in previous publications [6]. We will only note that since a spot is not a set of elements, the concept of a spot should be described independently of the axiomatics of a class or set. Briefly, a "spot" can be defined as a mathematical object for which the concept of a logical connection between spots is introduced. For example, for spots a and b, the logical connection ab is a logical value and obeys two axioms [6]:

$$\forall a(aa) \tag{1}$$

$$\forall a \forall b(ab = ba) \tag{2}$$

For spots, the concept of their environments is introduced, which are also spots. The environment $\tilde{a}$ of a spot a obeys three axioms:

$$\forall a\ (a\tilde{a} = 0) \tag{3}$$

$$\forall a\ (\tilde{\tilde{a}} = a) \tag{4}$$

$$\forall a \forall x(ax + \tilde{a}x = 1) \tag{5}$$

The set of spots, relative to which the information about other spots is determined using the ESR, is called the spot basis, and the set of such ESRs is called the spot image on this basis. Note that the concept of the basis is analogous to the concept of a coordinate system, and the image of a spot on the basis is a certain generalization of the concept of "measurement". In the general case, the spots of the basis can intersect. If they are separate, then such a basis is called orthogonal. When the spots of the orthogonal basis do not intersect any others, then such a basis is called atomic. Note that the spots of the latter are similar to points, pixels or voxels (volume pixels). As an example of an orthogonal basis of spots (non-intersecting), we can cite a set of fragments (parts) of spots formed when they intersect. Approximately, it can be considered as an atomic basis of spots. Note that the size of the spots of such a lattice determines the clarity of their mapping, which will be better than the clarity of the mapping on the original basis of "large" spots.

The proposed mathematical apparatus is based on the use of L4-numbers, i.e. logical 2×2 matrices [6], instead of real numbers, for encoding the ESR between spots. For spots a and b, the L4-number α is defined as

$$\alpha = \langle a|b\rangle \equiv \begin{bmatrix} ab & a\tilde{b} \\ \tilde{a}b & \tilde{a}\tilde{b} \end{bmatrix} = \begin{bmatrix} C & A \\ B & D \end{bmatrix}$$

where A, B and C are the parts of the partition at the intersection of spots a and b, which are represented as logical quantities (Figure 1).

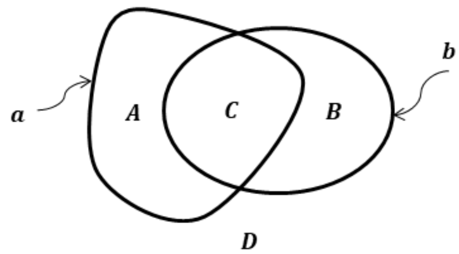


Figure 1. Euler-Venn diagram for the elementary relations between spots.

These parts and the environment D can be expressed through the intersection operation ∩ of spots:

$$A = a \cap \tilde{b} \qquad B = \tilde{a} \cap b \qquad C = a \cap b \qquad D = \tilde{a} \cap \tilde{b} \tag{6}$$

Table 1 represents coding some ESR with L4 numbers.

Table 1. Some ESR of spots.

Elementary spatial relations	**L4 number**
intersection, $a >< b$	$\begin{bmatrix}1 & 1\\1 & 1\end{bmatrix}$
separation, $a <> b$	$\begin{bmatrix}0 & 1\\1 & 1\end{bmatrix}$
inclusion (more), $a > b$	$\begin{bmatrix}1 & 1\\0 & 1\end{bmatrix}$
inclusion (less), $a < b$	$\begin{bmatrix}1 & 0\\1 & 1\end{bmatrix}$
indiscernibility, $a \approx b$	$\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$

Based on L4-numbers, we define an L4-vector $\boldsymbol{a}_X$ for a spot a on the basis of spots $X = \{x_i\}$, which encodes the mappings of this spot a. In such a vector, L4-numbers are used as elements instead of real ones:

$$\boldsymbol{a}_X = [\langle a|x_1\rangle; \langle a|x_2\rangle; \dots; \langle a|x_n\rangle]$$

Similarly, we define an L4 matrix **A**, which encodes ratio of two bases, for example, $X = \{x_i\}$ and $Y = \{y_j\}$:

$$\mathbf{A} = \langle Y|X\rangle \equiv \begin{bmatrix}\langle y_1|x_1\rangle & \cdots & \langle y_1|x_n\rangle\\ \vdots & \ddots & \vdots\\ \langle y_m|x_1\rangle & \cdots & \langle y_m|x_n\rangle\end{bmatrix}$$

For L4-vectors and L4-matrices, multiplication rules are introduced that differ from those for numeric vectors and matrices. By definition, the result of multiplying an L4-matrix $\boldsymbol{A} = \langle Y|X\rangle$ and an L4-vector $\boldsymbol{a}_X$ will be a new L4-vector $\boldsymbol{a}_Y$

$$\boldsymbol{a}_Y = \boldsymbol{A} \cdot \boldsymbol{a}_X = \langle Y|X\rangle\ \boldsymbol{a}_X \tag{7}$$

Therefore, the meaning of multiplying an L4 matrix and a vector is to recalculate the mapping of spots from one basis to another basis. The rule for the product of an L4 matrix $\langle X|U\rangle$ and an L4 vector $\boldsymbol{a}_U$ for an atomic $U = \{u_k\}$ and an arbitrary basis $X = \{x_i\}$, whose spots a can intersect, is presented in the formulas of [6]. The result of this product will be the vector $\boldsymbol{a}_X$ – the mapping of a spot a on the basis X:

$$\boldsymbol{a}_X = \langle X|U\rangle \cdot \boldsymbol{a}_U \tag{8}$$

Note that the algorithm corresponding to equality (8) defines the synthesis procedure in information processing. The opposite case corresponds to equality

$$\boldsymbol{a}_U = \langle U|X\rangle \cdot \boldsymbol{a}_X \tag{9},$$

where $U = \{u_k\}$is the orthogonal intersection basis of spots $\{x_i\}$ of an arbitrary basis X (the multiplication rule for this equality see [6]). Note that this algorithm corresponds to the procedure of analysis in information processing. In the general case, the multiplication rule of the L4 matrix and the L4 vector are considered in [6], and it is a combination of formulas (8) and (9). There, using examples of the problem of restoring the shape of figures using the data of its ESR with basic figures, the verification of the obtained matrix multiplication rules (8) and (9) is carried out.

To model imagery, it is necessary to associate them with a certain set of spots, and the relationships between the imagery with the corresponding ESR between the spots. Let us take as an example the imagery of some concepts and consider how their meaning is determined. By analogy with natural language, the meaning of a concept represented by a spot can be described using its relationships with other known concepts. Consequently, the semantics of an imagery is represented by a mapping of the corresponding spot a on this basis in the form of an L4-vector a. Figure 2 shows the Euler-Venn diagram illustrating the modeling of the semantic content of a mental imagery using spots. Here, the basic spots inside the imagery under study model the detailing of the imagery, and its environment models the context.

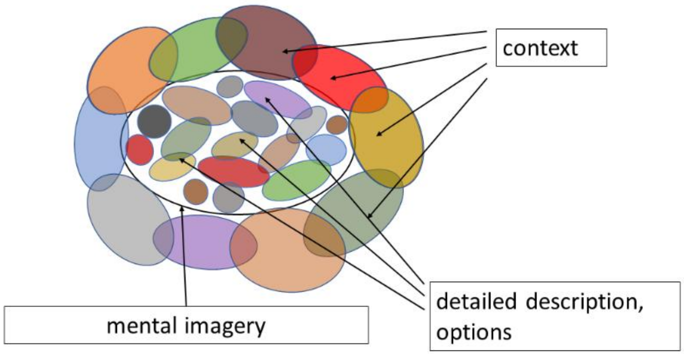
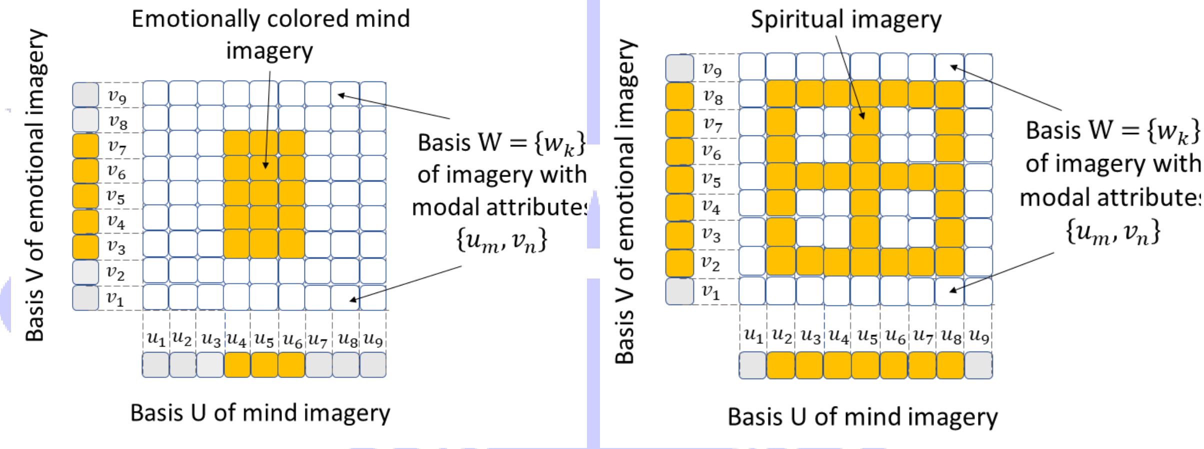


Figure 2. Euler-Venn diagram for representing mental imagery using the spots model

The polymodality of spiritual imagery containing mental and emotional components can be modeled using the concept of multidimensionality of spots. We can form their Euler-Venn image, which has projections onto two imagery spaces (two bases of spots): the basis of mind imagery and the basis of emotional imagery. In such a representation, we can clearly explain the nature of the qualitative difference between spiritual imagery and simply emotionally colored mind imagery. For the latter, the emotional component is an analogue of the "cylindrical extension" of a flat base in geometry. In this case, the emotional component does not fundamentally affect the meaning of the imagery (Figure 3a). In the case of a spiritual imagery, the semantic and emotional components form complicated structure, so that ignoring the emotional component (that is, the projection of such an imagery onto the mind space) leads to the loss of the meaning of the spiritual imagery (Figure 3b).



(a) (b)

Figure 3. Euler-Venn diagram for representing mental-emotional imagery using "two-dimensional spots".
(a) Emotionally colored imagery. (b) Spiritual imagery.

3. Cognitive Modeling on the Spot Apparatus

Spatial representation of imagery using spots allows modeling such important properties of the psyche and cognitive processes as differentiation and integration of perceptual imagery, attention, discriminative ability and the property of brain concentration, formation of abstract-generalized imagery and thinking. It seems surprising, but such a wide range of mental properties, as shown in the work [5], can be described using a concept based on a relatively small number of ESRs between spot-imagery and operations with them, which are also applicable to describing the relationships between imagery. In particular, imagery representation provides a visual interpretation of the process of understanding the meaning of concepts, thoughts, objects, events or phenomena. Indeed, the phenomenon of understanding can be represented as a representation (comparison) of the corresponding conceptual imagery on the basis of known mental ones. The learning process, i.e. obtaining knowledge, in AI can be represented as the problem of finding an unknown L4 matrix $\boldsymbol{A}$ (knowledge matrix) using a set of training examples $\{\boldsymbol{x}_i, \boldsymbol{y}_i\}$ that satisfy the equality:

$$\boldsymbol{y}_i = \boldsymbol{A} \cdot \boldsymbol{x}_i$$

For the task of pattern recognition (classification), $\boldsymbol{x}_i$ are L4 vectors representing them on pixels, and $\boldsymbol{y}_i$ is the corresponding L4 vector represented on the basis of the considered image classes. Let us consider the bases of the spots $X = \{x_i\}$ and $Y = \{y_i\}$ of the training data. From these vectors, we can form L4 matrices $\boldsymbol{X} = [\boldsymbol{x}_i], \boldsymbol{Y} = [\boldsymbol{y}_i]$ and write the solution for the matrix A in the following general form:

$$\boldsymbol{A} = \boldsymbol{Y} \cdot \boldsymbol{X}^{-1} = \langle B_Y | Y \rangle \cdot \langle Y | X \rangle \cdot \langle X | B_X \rangle \tag{10}$$

Here B_X and B_Y are the atomic bases on which the L4 vectors $\boldsymbol{x}_i$ and $\boldsymbol{y}_i$ are represented, respectively. Equation (10) provides a schematic interpretation of the process of cognition or learning in the field of AI. In the sport model, the multiplication of an L4 matrix by an L4 vector models reasoning, where the vectors $\boldsymbol{a}$ and $\boldsymbol{b}$ represent the semantics of concepts or imagery, and the L4 matrix $\boldsymbol{A}$ encodes knowledge (information) about the relationship between the two bases. Thus, the product of L4 matrix $\boldsymbol{A}$ and the L4 vector $\boldsymbol{a}$ models the following reasoning [4].

$$\boldsymbol{b} = \boldsymbol{A} \cdot \boldsymbol{a} \Leftrightarrow \boldsymbol{a} \vdash_{\boldsymbol{A}} \boldsymbol{b} \tag{11}$$

where a is the premise, $\boldsymbol{A}$ is the inference rule based on knowledge, and b is the conclusion. Equality (11) can correspond to reasoning with non-monotonic logic, when conclusions are made on the basis of existing knowledge, and the receipt of new information can invalidate some of the previously made conclusions. Non-monotonic reasoning solves the problem of obtaining conclusions when the description of a situation or problem is incomplete. More specifically, relation (11) should be attributed to the direction of causal reasoning, which is a branch of non-monotonic reasoning [7]. However, relation (11) can also represent classical categories of reasoning, such as deductive, inductive, and abductive, using the equality

$$\boldsymbol{a}_Y = \langle Y|X\rangle\, \boldsymbol{a}_X \tag{12}$$

Inductive and abductive reasoning in the apparatus of spots correspond to the following problems.

1) Induction: given a set of data $\{x_i, y_i\}$, find a matrix $\langle Y|X\rangle$ that satisfies the conclusion using equality (12).
2) Abduction: find a matrix $\langle X|Y\rangle$=$\langle Y|X\rangle^{-1}$, so that given the data of the consequence $\boldsymbol{a}_Y = \{\langle a|y_i\rangle\}$, determine their cause $\boldsymbol{a}_X = \{\langle a|x_i\rangle\}$. This corresponds to the formation of the hypothesis $\boldsymbol{a}_X$ by solving the problem inverse to equality (12):

$$\boldsymbol{a}_X = \langle X|Y\rangle\, \boldsymbol{a}_Y$$

4. The Concept of Imagery-Logical Neural Networks

Based on the apparatus of spots, a new concept of imagery-logical neural networks is proposed, where the role of weight coefficients of each layer is played by L4 matrices, and input and output signals are L4 vectors [8]. An important feature of such a network is that it uses a new model of neurons. Indeed, each neuron in the new network performs such processing of semantic information, presented in imaginative form, which is equivalent to elementary reasoning according to the rules of inference defined in the apparatus of spots.

5. Conclusion

The paper considers the application of the apparatus of spots for imagery modeling of cognitive mental processes and representation of causal reasoning based on mental imagery. Their spatial representation using spots allows creating a simple and visual model for understanding and interpreting complex properties of the psyche and mental processes. Imagery representation in the apparatus of spots also allows modeling both classical reasoning (deduction, induction and abduction) and reasoning using non-monotonic logic inherent in humans, when conclusions are made on the basis of existing knowledge, and obtaining new knowledge can change the conclusions. The possibility of using the apparatus of spots for representing semantic information in imaginative form and its application in the field of AI is shown. This allows formulating a paradigm of intelligent neuromorphic systems of a new type, capable of not only representing information in imaginative form, but also modeling imaginative thinking.

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7. About the Author

Nikolai Anatolievich Simonov received his PhD degree in radio-electronics in 1986. His current research interests include the development of a new mathematical model and mathematical apparatus of "spots" for the representation and processing of qualitative and quantitative information, mental imagery, and its application to semantic modeling in the field of AI.

THEORY AND APPLICATIONS OF SYMBOLIC COMPUTING WITH ARTIFICIAL INTELLIGENCE PERSPECTIVE
(A Unique Concept Developed in the Framework of A.A.Markov's Constructive Mathematical Logic and Presented in Russian Academy of Sciences)

Human Brain	Computer
Brain is constituted with neurons and synapses.	Computer can be constructed using IC, transistors, diodes, capacitors, and transistors.
The memory growth of a brain increases every time synaptic links are connected.	The memory growth of the computer can be increased by adding memory chips to it
The brain has a built-in backup system.	The backup systems are manually constructed.
Brain has a memory power of about 100 teraflops (approx. 100 trillion calculations/seconds)	Computer has a memory power of about 100 million megabytes.
The memory density of the brain is 10^7 circuits/cm^3.	Computer has a memory density of 10^{14} bits/cm^3 .
The energy consumption is 12 watts of power.	The energy consumption is in terms of gigawatts of power.
The information is stored as electrochemical and electric impulses.	The information is stored in numeric and symbolic form (as in binary bits).
The weight of the brain is around 3.3 pounds.	Its size and weight varies depending on type system- from a few grams to tons.
The information is transmitted using chemicals that fire the action potential in the neurons.	The communication happens using electrical coded signals.
The information processing ability of the brain is low.	Computer has the ability to process large amounts of information.
The input or output equipment is the sensory organs.	The input and/or output equipment includes keyboards, mouse, web cameras.
Brain is self-organized.	Computer has a pre-programmed structure.
Brain implements massive amounts of parallelism.	Computer has limited parallelism.
Brain is reliable, and self-maintaining.	Since computer performs a monotonous job, it can't rectify its mistakes on its own.

- Brain is a self organizing, self learning and self reproducing structure, whereas a computer is a fixed structure.
- Brain does not store any information in any particular cell or a group of cells, but it stores as a pattern of interconnected neuronal cells, whereas a computer stores an information permanently in a fixed cell array, which of course could be replaced with another information as and when required by means of an instruction. Unlike computer storage, a neuronal pattern could be a part of or a sub pattern of other patterns.
- Brain creates around 100 trillion contacts on an average and this differs from individual to individual in the brain, that is about 109 connections per cubic mm of cortical grey matter, whereas a computer does create interconnection of cells on its own.
- Brain of a new born baby is capable of creating very few number of neuronal contacts, and this capability increases as the baby grows both physically and intellectually based on the level of exposure to the environment, whereas a computer does not grow either physically or intellectually; it just executes instructions.

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