Image Transformations in a Cognitive System

Tunnel transition and combining ensembles

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***Abstract* — The nature of creativity and its hidden mechanisms are areas that researchers have only recently begun to approach. In this paper, within the symbol-image cognitive architecture paradigm, we consider some operations on graphs that can be compared to the process of image synthesis and transformation in a cognitive system. We address such phenomena as the combination of neural ensembles and tunnel (sub-barrier) transition in a cognitive system. We also consider degree of fusibility of a cognitive system that characterizes its creative ability.**

Keywords- graph; symbol; attribute; cognitive architecture; creativity.

I. INTRODUCTION

In the era of the rapidly developing ecosystem of living things (the Internet of Things) and human-friendly anthropomorphic robots [1][2][3], the issues related to developing artificial intelligence systems that are not only rational, but also creative, take on a special significance. The ability of cognitive systems to generate new thoughts and new images will turn machine into man's equal partner in addressing important issues of the 21st century, in solving its challenges, such as overcoming disease and resolving complicated economic problems.

In this paper, we discuss some of the mechanisms that could be employed in artificial cognitive systems to generate new information. Such ability is treated as a synonym for creativity.

The paper is organized as follows. A description of the model is provided in Section II. An example of the model's application is provided in Section III. The summary and conclusions are in Section IV.

II. DESCRIPTION OF THE MODEL

We consider the following organization of a cognitive system. Each image encoded in the system is represented by its attributes and the corresponding symbol. The attributes are linked together by the image's symbol [4][5]. The main role of symbolization is compressing information, but we believe it is equally important that it prevents images with the same attributes from being mixed together. This idea was briefly described in [6].

For the sake of brevity, we consider a two-layer system (graph), where the first layer encodes image attributes and the second layer encodes image symbols.

A. Basic Relationships

In our model, the following relationships are formed between a symbol and its attributes. When two or more attributes are activated, the symbol is also activated. Conversely, when a symbol is activated, the attributes of its image are also activated.

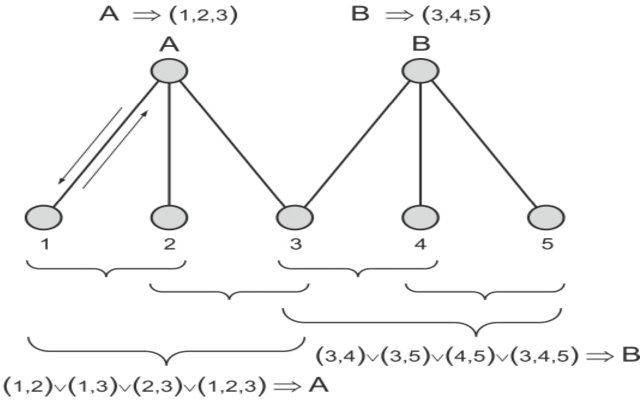

Figure 1**.** The basic model represented by a two-layer graph. The markers "A" and "B" correspond to symbols, 1, 2, 3, 4, 5 correspond to their attributes.

In Figure 1, the basic two-layer model is presented. The symbol "A" is activated when there are signals from particular attributes (nodes 1, 2, or 3) in different combinations, (provided that more than one node is involved). The symbol "B" is activated when there are signals from nodes 3, 4, or 5 in different combinations (also provided that more than one attribute is involved). When the symbol "A" is activated, this leads to the activation of an image consisting of a set of attributes (1, 2, 3). Activation of the symbol "B" leads to the activation of an image consisting of a different set of attributes (3, 4, 5).

Let us consider the following example. The relations between attributes and symbols in our model of a cognitive system work similarly to children's riddles. Something that is round, striped, and sweet (nodes: attributes) is a watermelon (node: symbol); something that is striped and orange, with sharp claws and teeth, is a tiger.

Concerning the problem of the possibility of images being mixed together, note that a cat and a dog have many attributes in common. According to our model, it is symbols that enable the cognitive system to tell them apart.

Let us illustrate the “more than one attribute” rule. Given the attributes “striped” and “round”, we can guess “watermelon” and given the attributes “striped” and “with sharp teeth”, we can guess “tiger”. However, given only one attribute (e.g., “striped”), we cannot guess what the object is. And conversely, specifying a symbol (e.g., watermelon), brings its attributes to mind (“striped”, “round”, “sweet”, “with seeds”, etc.).

In a real-world system, the number of layers is obviously much greater. For example, there is the integrative symbol “carnivores” (Lat. Carnivora) above the symbols “cat” and “dog”, etc.

B. Attribute and Attention

We assume that a cognitive process starts when one of the cognitive system’s elements appears in the field of attention. The development of a thought involves revealing connections between that element and its neighbors, as well as forming its new relationships and connections with other elements of the cognitive system.

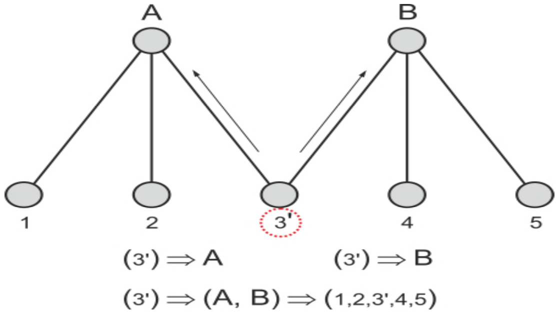

Figure 2. Activation of two symbols by one attribute.

According to our concept, prolonged activation of one attribute (for a time interval $t > t_{att}$) increases its influence. As a result, that attribute, even if it is alone, can activate the associated symbols. In Figure 2, the attribute “3” is activated by attention and, in turn, activates the symbols “A” and “B”.

For example, thinking about speed, we can recall a car, a cheetah, and an airplane.

Below we look at the ways in which a system based on these rules can generate new information by transforming images – that is, creating new images out of existing ones.

C. Combining ensembles

The symbols associated with a certain attribute can be activated by activating the attribute for a time interval $t > t_{att}$. These symbols, in turn, activate the rest of their attributes. As a result, a new ensemble combining the elements of two images (symbols and attributes) is formed.

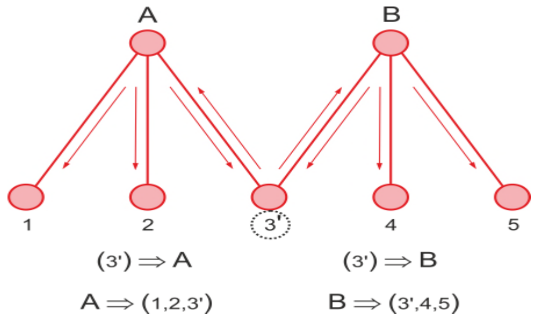

Figure 3. The activation of symbols A and B leads to the activation of all their attributes. This gives rise to an ensemble ("A + B").

In Figure 3, the attribute “3” is enhanced by attention or emotion, i.e., it receives additional activation from “neurons” (represented by nodes in our model) that are external relative to the ensembles A and B. Due to enduring activation, it activates both neuron-symbols “A” and “B” simultaneously. These two images, i.e., symbols "A" and "B" plus all their attributes, are temporarily united into an ensemble. Starting from that moment, the attributes of image “B” also belong to the symbol “A”, and vice versa (for a certain time interval). This mechanism could serve as the basis for metaphorical thinking (feature transfer). We briefly described this problem in [7]. Issues related to the integration of information in the cognitive system are also discussed in [8].

Let us consider the following example of metaphorical thinking. In [9], the general metaphor “argument is war” is presented. G. Lakoff and M. Johnsen write, “We see the person we are arguing with as an opponent. We attack his positions and we defend our own. We gain and lose ground. We plan and use strategies. If we find a position indefensible, we can abandon it and take a new line of attack.” What they describe in this passage is attribute transfer between the concepts “war” and “argument”.

It is important to realize that the transfer process starts after the common attribute of two concepts is found. In the case of the metaphor “argument is war”, the term “confrontation” represents the common attribute, while the transfer process follows the mechanism described above.

G. Lakoff and M. Johnsen write, “The most important claim we have made so far is that metaphor is not just a matter of language, that is, of mere words. We shall argue that, on the contrary, human thought processes are largely metaphorical.”

D. Tunnel transition

Under certain conditions, the activation of attributes can lead to transitions on the same (attribute) level (activation of attributes through attributes) rather than the activation of symbols. Suppose that there is a neurotransmitter acting at the network’s attribute level, dynamically strengthening the connections and thus facilitating the transition from one attribute to another. Under such conditions, attributes (neuron attributes) can activate each other without the activation of symbols (see Figure 4). We called this effect “tunnel (sub-barrier) transition”. In this case, the activation wave can “dive” under an adjacent symbol and activate one of the more remote symbols rather than the nearest one.

This process could be controlled by presence or absence of a neurotransmitter. Favorable conditions for such a process could also be created by the "constitutional" characteristics of the cognitive system, e.g., relatively weak connections between the attribute and symbolic levels (attribute-symbol), or, on the contrary, by the relatively strong connections at the attribute level (attribute-attribute).

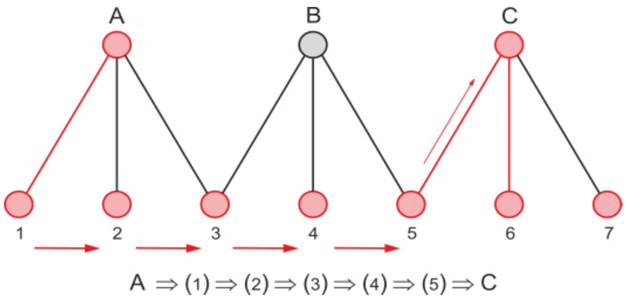

Figure 4. Flow within the cognitive system.

We would like to emphasize that Hebb's rule [10] describes the strengthening of connections between closely spaced (directly contacting) neurons. In contrast, the tunnel transition corresponds to the formation of connections between non-neighboring neurons that are not directly connected.

E. Fusibility of thinking

Within our model, the presence of a “neurotransmitter” in a subnet containing attributes and/or the cognitive system’s constitutional features make this system more "fusible", i.e., more fluid (akin to molten metal). It would be interesting to study the "coefficient of fusibility" (K_{fus}) of a cognitive system defined as the ratio of the connection strength at the attribute level to the strength of attribute-symbol connections:

$$K_{fus} = W_{atr} / W_{symb} \qquad (1)$$

Note that mental disorders can be associated with different types of associative thinking impairment. For example, the so-called acceleration of thinking (racing thoughts) is characterized by an excessive emergence of associations. As a result, thinking becomes superficial, with attention being switched too easily.

Let us examine how the character of thinking depends on K_{fus}. The creative process involves working with associations as the mechanism of new image production. We believe that the "coefficient of fusibility" may control the ease with which associations emerge in the cognitive system. At low values of K_{fus}, the "flow" (activation of connections) between images on the same attribute level and the subsequent merging of different images into new ones is hampered, and the system becomes rigid. Such a system can only work with the images (symbols together with their attributes) it already contains. The system can analyze them, i.e., it knows the properties of each symbol and can attribute it. However, such a cognitive system is virtually incapable of synthesizing new images. As K_{fus} increases, it becomes possible for new images to appear within the cognitive system. With $K_{fus} > K_{critical}$, flow across the attribute level becomes too easy, numerous associations arise, but they are not fixed in new images. This process represents a thinking disorder.

In psychology, our concept corresponds (to some extent) to Raymond Cattell’s concept [11] of fluid and crystallized intelligence, where *crystallized* intelligence is the ability to operate with already acquired knowledge, skills and experience, while *fluid* intelligence (or *fluid* reasoning) corresponds to the ability to reason and solve novel problems in new ways.

III. EXAMPLE

As an example, let us consider the poem *“The Soft Moscow Rain”* by Osip Mandelstam, translated by Richard McKane [12]:

It shares so stingily
its sparrow cold –
a little for us, a little for the clumps of trees,
a little for the cherries for the hawker’s stall.
And a bubbling grows in the darkness,
the light fussing of tea-leaves,
as though an ant-hill in the air
were feasting in the dark green grass;
fresh drops stirred
like grapes in the grass,
as though the hot-bed of the cold
was revealed in web-footed Moscow.

Let us consider the main symbols and their important attributes that are mentioned in this poem.

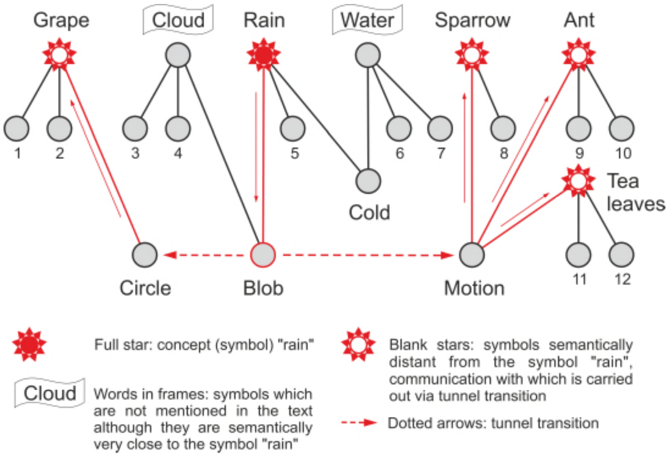

Figure 5. Semantic connections in Mandelstam’s poem *The Soft Moscow rain*. "Tunnel transitions" result in unexpected combinations of symbols.

In Figure 5, we can see that symbols that are semantically close to the term “rain” (such as “cloud” and “water”) do not appear in the poem. At the same time, connections are established via attribute-attribute transitions between semantically distant symbols, such as “rain”, “ant-hill”, “tea leaves”, and “grapes”. The artistic value of the poem and the fact that it is a masterpiece seems to be due to the “tunnel effect” which reveals distant connections, thus helping to communicate an impression of the rain.

IV. CONCLUSION

Problems associated with understanding the mechanisms of creativity and reproducing them form a barrier to creating general Artificial Intelligence (AI), which has not been overcome so far. It seems that entirely anthropomorphic AI could only be developed if artificial intelligence systems were able to think independently and perform creative tasks. To achieve this, we will have to solve the problem of generating new information in the cognitive system, which was discussed within the framework of Dynamic Theory of Information [13]. In this paper, we made an attempt to show the possible basic mechanisms of information synthesis in the cognitive system, illustrating them with some operations on graphs. The main concepts discussed in this paper are:

- formation of ensembles that combine different images;
- the "tunnel effect", i.e., the attribute-attribute transition that leads to unexpected combinations of symbols;
- the "degree of fusibility" of a cognitive system.

The formation of ensembles and the “tunnel effect” are associated with the mechanism that can transform images in the cognitive system. In the former case (the formation of ensembles), image transformation is caused by the transfer of attributes from one image to another. In the latter case (the “tunnel effect”), the attributes of semantically distant symbols are combined together. This can result not only in the enrichment of an existing image, but also in the generation of a new image (e.g., as in Mandelstam’s poem, where *rain* is associated with an *ant-hill* and *grapes*). Both mechanisms are characteristic of cognitive processes, not the simple image classification provided by existing artificial neural networks. It should be emphasized that in both of the above cases, new information is generated. These mechanisms could be closely connected with the intuitive and creative thinking process.

The concept of the degree of fusibility, as well as the coefficient of fusibility introduced in this paper, when applied to an artificial cognitive system, could provide a way of controlling the rigidity of artificial cognitive systems, making them more adept at reflecting the reality or, on the contrary, more intuitive and creative.

Implementing these mechanisms could help to achieve an AI that can think creatively and has intuition. The next step would be to develop these ideas further as a mathematical model.

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