Philological Sciences

Филологические науки

UDC 81.23+004.82

Interdisciplinary Approach to the Mental Lexicon: Neural Network and Text Extraction From Long-term Memory

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Abstract. The paper touches upon the principles of mental lexicon organization in the light of recent research in psycho- and neurolinguistics. As a focal point of discussion two main approaches to mental lexicon functioning are considered: modular or dual-system approach, developed within generativism and opposite single-system approach, representatives of which are the connectionists and supporters of network models. The paper is an endeavor towards advocating the viewpoint that mental lexicon is complex psychological organization based upon specific composition of neural network. In this regard, the paper further elaborates on the matter of storing text in human mental space and introduces a model of text extraction from long-term memory. Based upon data available, the author develops a methodology of modeling structures of knowledge representation in the systems of artificial intelligence.

Keywords: mental lexicon; text extraction from memory; associative-semantic networks; regular and irregular morphology; connectionism; human brain; artificial intelligence.

Introduction.

The problem of mental lexicon organization became one of the discussed topics in psycho- and neurolinguistics from late 20th to early 21st cc. Representatives of various fields (linguists, specialists in computer modeling, neurophysiologists and cognitive psychologists) have scrutinized the topic. Specialized research editions are published, devoted this scientific field ("The Mental Lexicon Journal", "Brain and Language", "Cognitive neuropsychology", "Journal of Neurolinguistics" etc.), and in Canada annual conference is convened entitled (International Conference on the Mental Lexicon).

The interest to this problem emerges from the rapid development of cognitive science, which became leading research paradigm in 21st century. Sciences got fuzzy borders within it, which allowed casting a complex interdisciplinary glance at the problem concerned. It is obvious today data by any single science absolutely not enough for the solution of such fundamental questions as the structure of the bran, language and mind: "Synthesis of the humanities and natural-scientific knowledge is not optional decoration and fashion tribute but necessary condition of scientific progress: major linguistics questions cannot be solved without consideration of the facts of biology and psychology..." [25, p. 329–330].

Verbalized knowledge stored in human brain has been referred to as mental lexicon in present-day academic world; in fact it is interior language system. Mental lexicon includes the special skills, "a certain amount of resources and funds, aimed at assisting the speech activity" [21, p. 378]; "Mental lexicon is the sum of human knowledge about words, their meaning and the relationship between those words. It is arranged by the rules that represent the orthographic, phonological and semantic characteristics of words" [24, p. 236]; "Mental lexicon is considered as storage of declarative knowledge and as an analog of semantic memory" [22, p. 27].

In this paper the author surveys the main problems connected with the principles of mental lexicon organization. Question about the type and nature of mental representation as well as problems of storing them in human long-term memory are discussed.

The goals of this paper are:

1. To present a novel model of process text extraction from long-term memory.

2. To describe a method of modeling structures of knowledge representation in the systems of artificial intelligence.

Studies devoted to the problems of mental lexicon do not place special emphasis upon the issue of text storage in long-term memory and the process of its extraction during recollection. Moreover in the field of cognitive modeling and artificial intelligence insignificant attention has been paid to the modeling of language as psychical construction, which diminishes the efficiency of the works mentioned, because the creation of strong artificial intelligence is impossible should its algorithms not encompass principles of human language organization. Therefore the goal of this paper is to produce our vision of these problems and to represent our findings.

Regular / Irregular Morphology within the Mental Lexicon

One of the most urgent and studied question is the specificity of processing regular and irregular morphology in mental lexicon. Researches of the processing English past-tense regular and irregular verbs show that there are two main opposite view on the problem of the functioning the mental grammatical rules in the brain. First approach, modular or dual-system, suggests that regular and irregular forms are processed by two distinct brain mechanisms: regular verbs are computed by rule-processing system, while irregular verbs are processed in associative memory [13; 16]. Second approach, the connectionist and the network or single-system, postulates that both regular and irregular grammatical forms are processed by single mechanism in associative memory [12].

M. Ullman and his colleagues researched peoples with several brain disorders. Their studies show that Parkinson's patients with defective Broca's area do more mistakes in regular than irregular verbs. In contrast, Alzheimer's patients with defective Wernicke's area do more errors in irregular versus regular verbs. On the basis of these data human language competence was divided into mental lexicon and mental grammar by supporters of modular or dual-system approach.

However, many other studies convincingly demonstrated that all language processes are computed by single system in associative memory and disturbance in system may lead to selective disorders in speech production [12, p. 208; 3]. Moreover research of the processing Russian verbs with richly inflected morphology suggests that factors such as frequency, analogy and probability play a major role in mental lexicon. Besides in complicated inflected language such as Russian it is difficult to identify regular / irregular verb because there are many verb classes [5; 6].

Therefore the division into the mental lexicon and mental grammar is irrelevant for languages with richly inflected morphology. Experimental data suggest that "morphological and syntactic (i.e. grammatical) information about word is represented in mental lexicon" [22, p. 27]. There isn't a boundary between lexicon and grammar in human brain. Thus all knowledge about language including several grammatical rules is stored in mental lexicon.

Representation of Knowledge in Human Long-term memory

One more problem connected with mental lexicon besides morphological processing is the topic of basic component within mental lexicon. In traditional linguistics the lexicon is register of the word. However, mental lexicon is not only words' list. It includes a lot of lexemes, phrases, idioms, texts and several mental grammatical rules.

Many various studies suggests that basic component of mental lexicon is the word [4; 17; 19; 23]. In this context it is necessary to understand how words are stored in long-term memory. What are lexemes in human brain? How are they interrelated? How are multimorphemes and polysemantic words represented in mental lexicon? How is lexical access realized? And finally, what is information stored with the words in human mental lexicon?

First of all it is necessary to mention that several specialists write about the word as a unit in mental lexicon. We disagree with this proposition because we firmly convinced that there aren't stand-alone units in the brain. Every word or concept is connected with countless other words / concepts. *Therefore we suppose that more correctly to consider word as the basic component but not as a unit.*

As we know, mental lexicon is the verbal part of long-term memory; long-term memory in turn is the product of the brain. Consequently mental lexicon, long-term memory and the brain have the same structure. It is known that a lot of neurons in the brain are connected in a complex network for any cognitive processes by means of neurotransmitters [1; 9]. Therefore we convince that *cortical representation of language as well as cortical representation of knowledge is the*

network representation. Besides the fundamental type of connects in mental lexicon is associations that we have shown previously [18]. Such associative-semantic network models consistent with the recent data of neuroscience.

Thus mental lexicon in the brain is constructed on the principle of network. Moreover it has a hierarchical structure but that we will discuss in the next section of this paper. So how are knowledge represented within network? How are mental representations organized? And how do we find the necessary word in our mind without trouble (the problem of lexical access)?

Neurolinguistic studies suggest that lexical access is a complexity psychical process which includes several levels of processing [4; 8]. A. Caramazza, for example, points: "The dominant view is that lexical access involves at least two distinct stages of processing. The first stage involves the selection of a semantically and syntactically specified lexical representation or lemma; the second stage involves the selection of its corresponding lexical-phonological representation or lexeme" [4, p. 177]. Furthermore often one word has several meanings and lexical access becomes more complicated in this case [2].

In reality lexical access is the process of search the mental information in the neural network because every word is a "label" for the concept. We have already discussed that word / concept is the basic component in mental lexicon. However, what does it mean? How are word / concept represented in the associative-semantic network of the mental lexicon?

As we know now, early versions of the semantic networks are more simplified than in point of fact. For example, G. Scragg mentioned that semantic network is the sum of graphs. Each of graphs is the concept or mental representation; all graphs are connected with one another [14]. However, today, from the viewpoint of the *connectionism*, this proposition is not entirely true.

Connectionism as one of the approaches within cognitive science was founded in 1980, when J. McClelland and D. Rumelhart developed the interactive model of processing information [11]. It is important to accent that this model is based on the idea of *parallel distributed processing* of information. We know speed transmission of nerve signal between neurons is slowly; at the same time the cognitive processes go very fast. How is it realized? And connectionists give the convincing answer: it is realized by the parallel distributed processing of information.

Moreover connectionism postulates that concepts / mental representations *aren't contained* in network: graph of the semantic network is not concept. It is feature / characteristic of the mental representation. These features or characteristics are activated and graphs connected with it are activated too. As a result an all large area of activated network is the structure of knowledge. Some scientists write that "concepts are not defined in a knowledge net, but their meaning can be constructed from their position in the net" [10, p. 165]. Furthermore that extensive network site, which constructs a concept, has connects with countless of other graphs and mental representations; and in the speech activity it attracts the giant cluster of various information.

If the concept is constructed in the brain so complicated and includes countless of components, then how is the whole text represented in the mental lexicon? And how is process of text extraction from long-term memory during recollection realized? Below we produce our model of this psychical process.

Text Extraction from Long-term Memory

Previously we have already considered the basic ideas connected with the mental lexicon. Now we are going to discuss the problem of text representation in the long-term memory and its extraction during recollection. Prior to present our model of this psychical process we should touch upon the topic of mental lexicon's nucleus. Experimental data suggest that the nucleus of mental lexicon is the most active part in it: "Elements of crossing the most of connects are the most active part of the mental lexicon's nucleus" [20]. The nucleus of mental lexicon includes the most general words or concepts, which have maximum connects with other. Moreover the process of lexical access begins from the activation of nucleus. Thus mental lexicon has a hierarchical structure, in which the nucleus is an apex (Fig. 1).

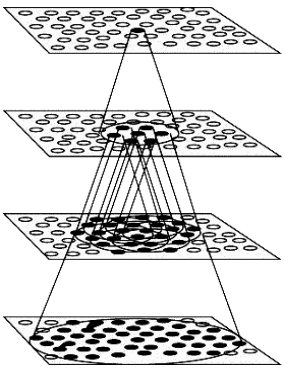

Fig. 1. Hierarchical structure of Mental Lexicon with the nucleus on the apex

Based on the connectionist approach we think that text as well as concept or mental representation has a distributed organization. There isn't a special place in the brain where text is stored; it scattered all over the neural network. And text extraction from long-term memory is complicated psychical process including a lot of operations and realizing in several stages.

The first step of recollection connects with an activation of *semantic kernel* of the text, i.e. those parts of the network, which construct the key words or concepts. As a rule it is the most general knowledge in the mental lexicon. However, it is important to mention that initially *the concepts are activated not from this text.* At first the general mental representations, which are in the nucleus of mental lexicon, are activated and then they activate those graphs or part of network, which construct the basic concepts of the text.

For example, have a look at the sentence *"Forty-ears-old Mary moves the chair"*. Although in the text tells about Mary, initially that part of the network, which constructs the concept *'human'* (generally), will be activated. Then concept *'human'* in turn will activate the part of the network connected with it, which will construct concept *'woman'*, and at the same time will inhibit concepts *'man', 'boy', 'girl'* etc. Moreover, the parallel activation of other mental representations will be realized. Other parts of the nets will be activated and will construct the concepts *'to do'* (generally) and *'things'* (generally) etc. It should be mentioned that all activated parts of network will be connected with one another by associative-semantic links (Fig. 2).

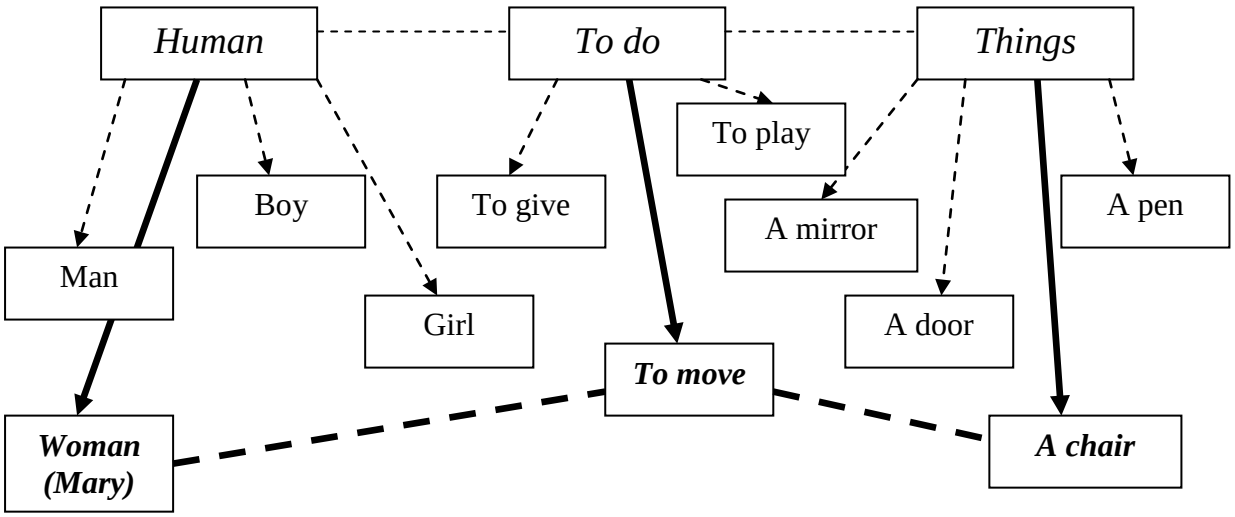

Fig 2. Model of the text extraction from long-term memory (the case of the one sentence)

Thus on the first step of text extraction the process of activation the several associative-semantic network's parts, which construct a semantic kernel of the text is realized.

The second step includes an expansion of nets: more graphs and parts of the network activates, and special concepts of the text connects with one another. Here may be a *process of*

substitution the text component. Concepts, which locates in semantic kernel of the text, almost aren't incurred these process, but special concepts are incurred. We think that it is associated with the spreading-activation theory of human semantic processing [7]. According to this theory the intensity and distance between concepts are different; and mental representations, which are closely connected ('*fire*' and '*red*') have more strong connection than other ('*fire*' and '*water*').

Thus probability of change as more as the special concepts are closely. For example text tells "*There is a heavy rain in summer*". Then '*summer*' may changed in '*autumn*' during recollection, because '*heavy rain*' is connected more strong associative-semantic links with '*autumn*', than with the '*summer*'.

So the text extraction from long-term memory is the most complexity psychical process, which includes a lot of operations and is realized in several stages that we have demonstrated above.

Cognitive Modeling and Problems of Creation the Artificial Intelligence

The cognitive modeling of psychical processes in the systems of artificial intelligence is the question of the hour. Problems of creation the artificial intelligence is also the part of cognitive science. Computer models, which can perform certain algorithms, are developed at present. Some results have already achieved in these field of research.

However, there are a lot of shortcomings in existing systems. We suppose it is connected with the fact that principles of human language organization (i.e. mental lexicon) aren't considered. Meanwhile, we are convinced that *creation of strong artificial intelligence is impossible should its algorithms not encompass principles of human language organization.*

Currently we conduct an investigation at Laboratory for Robotics and Artificial Intelligence at Immanuel Kant Baltic Federal University by the modeling of cognitive processes by means of artificial growing neural networks. The Laboratory has high-class android robot AR-600, which was developed by Russian scientific company "The Android Technology".

In order to modeling the structure of knowledge representation (mental lexicon) we use the described above hierarchical model of the mental lexicon, in which associations are the fundamental types of connects. Moreover, we use our model of process the text extraction from long-term memory. These algorithms, which should underlie of our model will help to modern and improve existent systems because they aren't imitation of cognitive processes. These algorithms is similar to processes in the human brain.

Our work is based on the modified version of the associative SOINN (Self-organizing incremental neural network) [15]. Input information from every sensory systems of robot goes into the specific SOINN, where the multistage structure of patterns and classes is formed. The information clustered in this layer participates in constructing of associative layer, which includes one neuron-prototype from each class from each system. Relations between two neurons-prototypes means that there are associations between them (Fig. 3).

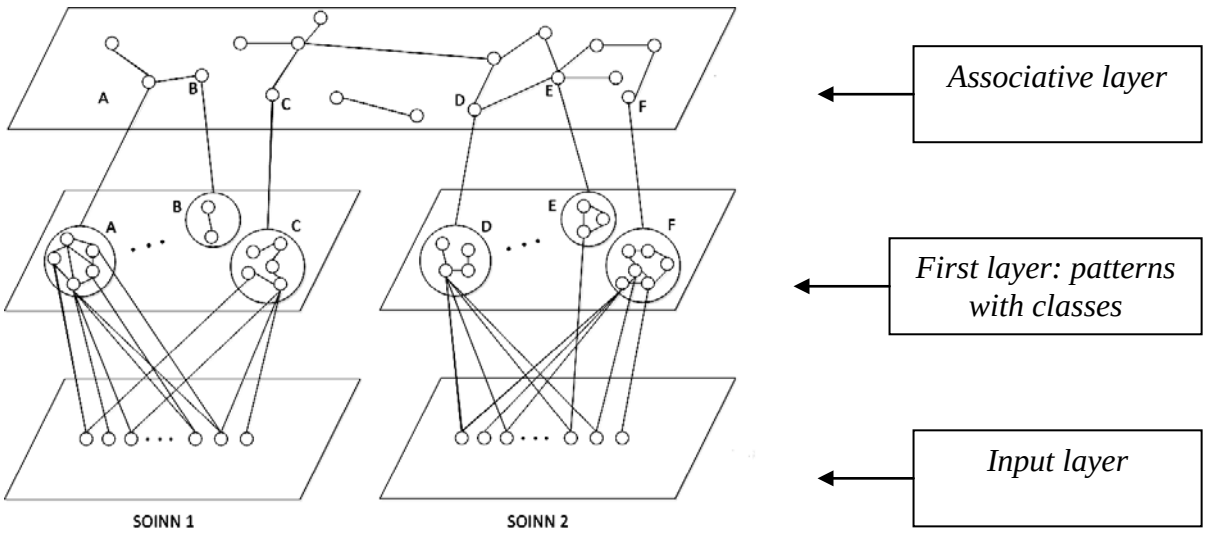

Fig. 3. The modified version of SOINN with associative memory

It is known that children's nucleus of mental lexicon is formed in the first years of life; and then augmentation nets and expansion of mental lexicon are realized. Therefore, we decided to repeat human ontogenesis (i.e. initially we constructed within system those words / concepts, which are "members" of nucleus); so we realized the model that is similar to development of human brain.

We showed to robot several things and at the same time named it (from the nucleus of mental lexicon), in order to establish the associative relations between visual and sound images. Moreover, we gave in arms of robot those things in order to tactile sensations are recorded in memory.

This study had just begun. We construct the nucleus of mental lexicon but then associative-semantic network in the robot will grow *independently*. The microphones and cameras at the Laboratory will are turned for constant input of information. And new knowledge and relationship well are formed by oneself. Then received the some results we can compare it with natural development of the human brain.

Conclusion.

In this paper we have discussed the problem of mental lexicon organization, which is the one of the most complicated topic in cognitive science. Goals of the paper were: 1) present our model of text extraction from long-term memory; 2) describe a method of modeling the structure of knowledge representation in the systems of artificial intelligence.

We suggest that text extraction from memory is a complexity psychic process, including a lot of mental operations and stages. We also show that creation of strong artificial intelligence is impossible should its algorithms not encompass principles of human language organization because *word* is only way to name the mental representation.

Thus we hope that our investigations and developed models will complementary clarify the problems of mental lexicon organization and knowledge representation.

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УДК 81.23+004.82

Междисциплинарный подход к ментальному лексикону: нейронная сеть и извлечение текста из долговременной памяти

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Аннотация. Рассматриваются принципы организации ментального лексикона в свете современных исследований в психо- и нейролингвистике. Комментируются два основных подхода к проблеме его функционирования – модулярный или двусистемный, разрабатываемый в рамках генеративизма, и противоположный, односистемный, представителями которого являются коннекционисты и сторонники сетевых моделей. Отстаивается точка зрения, согласно которой ментальный лексикон – это сложное психическое образование, опирающееся на специфическое построение нейронной сети. В этой связи обсуждается вопрос хранения текста в ментальном пространстве человека и представляется модель извлечения текста из долговременной памяти. На основе имеющихся данных разрабатывается методика моделирования структур представления знаний в системах искусственного интеллекта.

Ключевые слова: ментальный лексикон; извлечение текста из памяти; ассоциативно-семантические сети; регулярная и нерегулярная морфология; коннекционизм; человеческий мозг; искусственный интеллект.