The Language Model of the World and Purposeful Human Behavior

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Abstract. Modern dialogue systems leave much to be desired since information about processing information in the human brain is not used in their development. The human effectively implements dialogue behavior as purposeful behavior because in their information processing system there is a model of the world with its language component. The paper presents a model of the world consisting of: (1) the posterior cortex, which provides the semantic processing of sensory information; (2) the hippocampus structuring this representation in fragments corresponding to individual situations; (3) and the anterior cortex, which forms on their basis a pragmatic level of information representation – a chain of such situations that make it possible to implement purposeful behavior; and also manipulate these hippocampal representations with the help of (4) the thalamus.

Keywords: dialogue, purposeful behavior, the human world model, language component of the human world model, processing information in the columns of the posterior cortex, processing information in the columns of the anterior cortex, inner speech.

1 Introduction

Modern dialogue systems are very simple. When replying to a question, even the most complex of them are limited to giving information about relevant facts [1], while primitive ones discredit the domain area by imitating a meaningless dialogue resembling communication only in its form [2]. At the moment, there has been a transition to dialogue systems that include a world model [3]. However, dialogue is not a series of passive answers to the questions posed [4]. This dialogue has its own motive, its purpose, its plan. That is, it is an example of purposeful behavior, and the system modeling it should include in its composition all the components necessary for the implementation of purposeful behavior. In order to understand what these components should be, it is natural to turn to the analysis of the human brain and its functionality in the process of implementing purposeful behavior.

The human brain is a natural neural network that provides a very non-uniform processing of information – that is, it is a highly heterogeneous neural network. And the processing of information in the process of purposeful behavior consists in the formation of a world model (and manipulation of it), which is subject to the influence of society through language.

The main organs of the brain used in the process of forming the world model use specific syntagmatic information (columns of the cortex of the cerebral hemispheres), specific paradigmatic information (the hippocampal lamellae), and control the processing energy – that is, they use nonspecific information (the thalamus).

The human language plays a crucial role in structuring the processing of information in the world model. Under its influence (under the influence of society), the language component of the world model (based on the extralinguistic information of the other two – multimodal – components of the world model of the dominant and subdominant hemispheres) is formed in the columns of the posterior cortex, which (the language component) is the basis for the formation of mechanisms for internal speech in the anterior cortex, and they, in the process of development of the individual, are transformed into mechanisms of purposeful behavior.

Functionally, all this variety of ways to process information manifests itself in the following: (1) the ability of the brain to process information sequences of various sensory modalities – syntagmas – with the identification of hierarchies of dictionaries of images for events of diverse complexity (in the columns of the posterior cortex) without any teacher and with a teacher; (2) the ability of the brain to form from the images of events stored in the columns of the cortex, images of whole spatial situations – paradigms (in the hippocampal lamellae), while matching these situations with language images-phrases describing these situations (ibid.); (3) the ability of the brain (using the thalamus) to form chains of such situations (in the columns of the anterior cortex) and manipulate them in the process of purposeful behavior.

2 Three-Component Model of the World

At the highest level, the heterogeneity of information processing in the human brain manifests itself in dividing the world model, which is formed in the human brain, into three parts: the language component of the world model and the two multimodal components of the dominant and subdominant hemispheres [6, 5]. The language component of the world model includes the model of language – models of all language levels from the acoustic-phonetic and graphematic (for spoken and written texts, respectively) to the semantic and pragmatic ones, and also includes a description of the world in terms of natural language words – signifiers which are signifiers for their multimodal equivalents in the multimodal components of the world model – their meanings. The multimodal component of the world model of the dominant hemisphere is a schematized multilevel model of the world formed under the influence of society (since it is under the direct influence of the language component located in the same place in the dominant hemisphere) and with the use of the knowledge of society. Finally, the multimodal component of the world model of the subdominant hemisphere, which is formed without the influence of the society (it is not directly influenced by the language component), is a two-level model that includes the knowledge gained by the individual in the process of their personal development.

Images of the events of the external world represented in these three parts of the world model are combined on a level-by-level basis (by association).

All components of the world model are formed on the basis of information processing in the columns of the posterior cortex in interaction with the hippocampal lamellae, which form the representation of situations by combining into paradigms the images of the events of hierarchies of posterior column dictionaries.

These same brain organs are involved in the formation of purposeful behavior (also with the participation of the hippocampus), but in this case the accent is shifted from the posterior cortex to its anterior parts, and it is those images of situations stored in the hippocampal lamellae that are the objects of manipulation in this case. The situation image sequences are processed by the anterior cortex in the same way as the posterior cortex processes sensory flows. At the same time, a hierarchy of dictionaries is also formed, but in this case the fragments of the situation chains become words (as they are represented in the hippocampal lamellae).

3 Mechanisms of the Brain: Cortex, Hippocampus, Thalamus

The three main organs of the brain are responsible for shaping the human model of the world. The cerebral cortex and the hippocampus are responsible for the processing of specific information (syntagmatic and paradigmatic, respectively), the thalamus organizes this processing through manipulation using non-specific information (information on the localization of individual elements of manipulation in the cortex and the hippocampus – its topology). Specific information is understood as information sequences (syntagmas) obtained from sensory organs and encoded in them (sensory organs) in some way, the results of their processing in the columns of the cortex in the form of a hierarchy of dictionaries of the event images, as well as their integration into situations (paradigms) in the hippocampal lamellae.

3.1 Processing of Sensory Sequences in the Cortex

The sensory flow comes (after some switchings in the subcortical nuclei, the processing in which also involves coding including denoising and increasing the dynamic range of signals) to the columns of the cortex of the primary projection zones of their modalities (visual, auditory, etc.). The columns form a hierarchy of dictionaries, each level of which represents information of its own degree of complexity. The cortex columns transform information sequences into trajectories in a multidimensional signal space, where the abovementioned associativity manifests itself: repetitive fragments of the sequences are mapped into the same fragments of trajectories. Local fragments of the multidimensional signal space modeled by the columns are virtually combined (physically they are combined by the attention mechanism formed by the thalamus) into a global multidimensional signal space, in which the world model is represented as a set of trajectories. The signal information sequence is transformed into a multidimensional space with the help of an associative transformation F_n [5]:

$$A \to \hat{A},\, F_n(A) = \hat{A}, \tag{1}$$

where A is an information sequence, and $\hat{A}$ is a trajectory in the n-dimensional signal space.

The information sequences are structurally processed in the cortex columns. At each level of the column hierarchy, dictionaries of the event images are formed (which are subsequently manipulated by the hippocampal lamellae through the thalamus):

$$\{\hat{B}_l\}_{k_i} = H_h RMF_n(\{A\}_{k_i}), \tag{2}$$

where $\{\hat{B}_l\}_{k_i}$ is a dictionary – a set of fragments of trajectories in the multidimensional signal space corresponding to repeating fragments of the sequences from set $\{A\}_{k_i}$ obtained by F_n transformation, H_h is threshold transformation, R is the memory read function, and M is the memory write function.

The input information for the next level of processing is the information obtained after processing at the previous level of the column hierarchy after the formation of the dictionary of this level. In this case, the fragments represented in the dictionary of this level are filtered in the input sequence:

$$F_{n,C}^{-1}\left(\tilde{A}, \{\hat{B}_j\}\right) = C, \tag{3}$$

where $F_{n,C}^{-1}$ is inverse transformation that has the ability to filter the dictionary words in the input stream, $\tilde{A}$ is an arbitrary input sequence from set$\{A\}_{k_i}$.

3.2 Formation of Dictionaries Using the Example of a Text Representation

These levels of dictionaries for each sensory modality can be interpreted meaningfully in terms of hierarchies of representations of the corresponding modalities. Thus, for auditory verbal modality, for example, these are: (1) acoustic-phonetic level; (2) morphemic level; (3) lexical level; (4) syntactic level; (5) level of the semantic compatibility of words (the level of semantics of a particular sentence). These are the levels of language that are represented in the language component of the world model.

They are formed by gradual filling of dictionaries of the appropriate levels. The lower – acoustic-phonetic – level of representation is omitted for simplicity (spoken and written texts at this level are represented differently). At the morphemic level, from the set of input sequences $\{A\}$, a dictionary of inflectional morphemes (word endings) $\{B_1\}$ is formed as the most frequently encountered in the texts of the events. After the formation of the inflexion dictionary, the processing of input sequences (texts encoded by a binary code in some way) results in the filtration of inflections. The processing of the rest of the sequences (texts without inflections) leads to the formation of dictionaries of the root bases $\{B_2\}$. By processing input sequences with the dictionaries of root bases, inflectional structures of syntactic groups $\{B_3\}$ will be obtained (let us call them syntaxemes) – a formal representation of the syntax [7]. After processing the input texts with the syntaxeme dictionaries, dictionaries of pairwise compatibility of root bases $\{B_4\}$ will be obtained – a representation of lexical semantics [8, 5].

3.3 Semantic Network as a Model of the World (Domain Area)

And now the most interesting thing begins: a pairwise combination of words makes it possible to form a directed graph (a pair of root bases after another pair), which is not a chain. It branches and cycles, that is, we obtain some semantic network N, but a homogeneous (associative) one:

$$N \cong \{< c_i c_j >\}, \quad (4)$$

where c_i и c_j are vertices of the network – the words of natural language texts, or quasi-words of quasi-texts of various modalities and even multimodal quasi-texts, too.

It is this network that is the model of the world. Its various parts formed from texts (spoken or written), quasi-texts (information sequences of some modalities other than the textual modality are meaningful multi-level structured quasi-texts). But one must remember: this is a virtual network: images of events exist in the corresponding dictionaries, but they are collected together either under the influence of an external situation or internal representations (for example, in the hippocampal lamellae through the thalamus).

The world model, therefore, is the entirety of the event images of all the components of the world model of all modalities (all elements of the aggregate of the semantic networks):

$$M = \cup_m M_m, \quad (5)$$

where the unimodal model of the world M_m is a collection of all event images of only one modality:

$$M_m = \cup_{ijkm} B_{ijkm}, \quad (6)$$

where B_{ijkm} are images of i-th events of j-th dictionaries at k-th levels of the m-th modality stored in columns of the posterior cortex.

The dynamics of changes in dictionaries formed in the modal and multimodal hierarchies is very slow and reflects the dynamics of the external (and internal – interoceptive – not to be confused with the spiritual) world of human [9].

3.4 Formation of Representations About Situations in the Hippocampus

In contrast to the syntagmatic representations formed in the cortex columns, paradigmatic representations are formed in the lamellae of the hippocampus, the second organ of the brain manipulating specific information: images of the links of the words in the dictionaries are formed in the hippocampal lamellae (as Hopfield associative memory [10]) – that is, images of events of the external world represented in the cortex columns, within whole situations. It should be borne in mind that we have three components of the world model, and therefore, in the lamellae of the hippocampus of the subdominant hemisphere, representations of images of specific events (from the multimodal image – particular – component of the world model) are combined. And in the lamellae of the hippocampus of the dominant hemisphere, representations of images of abstract events (from the multimodal schematic – abstract – component of the world model) are combined with images of language events (from the language component of the world model).

This makes it possible, on the one hand, to segment the world in terms of such situations, both abstract and particular, that is, not only to perceive and evaluate the degree of novelty, but also to analyze these situations regarding their abstract composition – for example, the extended predicate structure of the sentence P (which is included in the paradigmatic representation in the lamella) describing this situation:

$$P = (S, O, < O_i >, < A_j >), \quad (7)$$

where P is an extended predicate structure in the composition of S – the subject, O – the main object, $< O_i >$ – other – secondary – objects, and $< A_j >$ – attributes.

An extended predicate structure corresponds to the multimodal image of the extended predicate structure, which is represented in the same place in the hippocampal lamella:

$$\mathfrak{P} = (\mathfrak{S}, \mathfrak{O}, < \mathfrak{O}_i >, < \mathfrak{A}_j >), \quad (8)$$

where $\mathfrak{P}$ is an image interpreted by an extended predicate structure, in the composition of $\mathfrak{S}$ – image of the subject, $\mathfrak{O}$ – image of the main object, $< \mathfrak{O}_i >$ – images of other – secondary – objects, and $< \mathfrak{A}_j >$ – images of the attributes.

On the other hand, it makes it possible to name these situations according to their main concept (name, or predicate), and if necessary to expand this naming into a description including other concepts (moving from a paradigmatic description to a syntagmatic one).

3.5 Energy Support for the Processing of Specific Information by the Thalamus

The thalamus is a structure that mediates all information flows in the brain that participate in interaction with the cortex [11]. However, only 6% of the information from the main volume of the sensory flow goes into the thalamus, but all interactions between the separate cortical areas, as well as between the cortex and the subcortical formations are accompanied by the control actions of the thalamus. The function of the thalamus is the formation of a focus of attention, which enhances some information processes to the detriment of others. Due to the thalamus, the brain becomes a parallel machine, since the thalamus can not only focus on one process, but also distribute it evenly among many processes while supporting efficient parallel associative information processing.

3.6 Anterior and Posterior Attention

It should be noted that the focus of attention, which is formed by the thalamus, has two different goals [12]. On the one hand, under the influence of the sensory flow, the attention is focused on current processes related to the perception of the external world, on the other hand, under the influence of the anterior cortex, the attention is focused on processes related to tasks solved in the process of purposeful behavior. Thus, the posterior and anterior types of attention are always in the reciprocal relationship.

3.7 Interaction of the Anterior and Posterior Cortex Areas with the Hippocampus

The anterior cortex is essentially the control (motor) cortex. In this sense, the motor cortex is its lower level of direct physical impact on the world. The anterior cortex, on the one hand, is a continuation of the posterior cortex, and in this sense, the hierarchy of processing operations that works with sensory information, has its continuation in the anterior cortex. But this continuation is mediated by the hippocampus. The hippocampus, as a storehouse of information about situations, structures the external world, and therefore simplifies the interaction of the anterior cortex with it. Rough structuring into fragments allows rough construction of plans for interaction with this external world, the details of which are determined in the process of implementing these plans using detailed representations of the posterior cortex. And these plans in the anterior cortex are a chain of names of situations represented in the hippocampal lamellae.

4 Interpretations

4.1 Extended Predicate Structure in the Hippocampal Lamella as a Situation Model

It is in the lamellae of the hippocampus where information on the relationships of images of events stored in the columns of the posterior cortex is formed, stored and dynamically changed, as they are presented in particular situations [5]. That is, the model of the world is not only a collection of images of events stored in the cortex columns (virtually represented as a homogeneous semantic network), but also a set of images of situations stored in the hippocampal lamellae. Moreover, this hippocampus representation structures the initial model of the world – a semantic network: in a separate lamella of the hippocampus a graph is stored that is a sub-network of a global network describing a particular situation. The structure of this situation (8) is described by the structure of the extended predicate structure of the sentence (7) describing this situation.

4.2 Linear Representation of the Situation Model as a Natural Language Sentence

The image of the situation in the elements of the situation initialized by the input situation in the columns of the cortex in the subdominant hemisphere is stored in the CA_3 field of the hippocampal lamella as a Hopfield network [10].

In parallel, in one of the lamellae of the hippocampus of the dominant hemisphere, an image of the semantic structure of the sentence is formed that describes this situation – an extended predicate structure for a particular predicate, but in an image representation as a generalized form (8) containing abstract images instead of the subject, the main object, secondary object and attributes.

In the same lamella, the concepts of the language model are also stored that name the corresponding abstract images of the extended predicate structure, but these are presented syntagmatically – in the form of a sentence containing this extended predicate structure.

There are two representations (and they are synchronous) of that kind: one is a syntagm in terms of sensory representations, the other one is a syntagm in terms of the motorics of articulatory organs – the lower level of the language component of the world model of the anterior cortex. This representation is formed at the junction of the frontal and temporal cortex.

4.3 Formation of Networks of the Dominant (Abstract Network) and Subdominant (Particular Network) Hemispheres

Similar to the formation of a (virtual) semantic network of a natural language text (spoken or written) as a language component of the world model (see Section 2.3), semantic networks of quasi-texts of other (besides natural language) modalities are formed – multimodal components of the world model and the dominant and subdominant hemispheres. The difference lies only in the fact that the initial information sequences are formed by their specific sensory systems according to the laws of processing information of their modality.

4.4 Interpretation of the Anterior Cortex (as a Pragmatic Level of Representation) by the Example of Inner Speech: Purposeful Behavior

The columns of the anterior cortex are functionally the same as the columns of the posterior cortex. The essential difference lies in the information they process. It general terms, if the entirety of the content of the posterior cortex – a semantic network – is a semantic representation, then the entirety of the content of the anterior cortex is a pragmatics: it is a hierarchy of dictionaries of chains of situations, the elements of which are the situations represented in the hippocampal lamellae. The difference between the representations can be shown by the example of the internal and then expanded human speech [4]. Another difference (see Section 3.2) is that the information in terms of the sensory flow is processed in the columns of the posterior cortex, and the columns of the anterior cortex process information in terms of motor control.

Inner speech is formed on the example of the material of the expanded external speech of a teacher, which is analyzed in the hierarchy of the posterior cortex of the dominant hemisphere, the sensory syntagms of which are stored in the lamellae of the hippocampus of the dominant hemisphere. In the process of teaching the individual, at the lower level of the anterior cortex (the motor part – the Broca area), by repeating the syntagms pronounced by the teacher, dictionaries of motor syntagms of the lower level are formed, and further – of higher levels as it occurs in the hierarchy of the posterior cortex columns. These motor syntagms, as well as sensory syntagmas, are recorded also in the hippocampal lamellae synchronously with sensory syntagmas (see Section 3.2).

Thus, at the input of the anterior cortex a sequence of images (in terms of motor) of natural language sentences are received from various hippocampal lamellae, which is fragmented (clustered) into separate fragments – image chains of sentences – and stored in the hierarchy of the anterior cortex columns.

These chains, as well as the semantic networks of the posterior cortex, describe the external world, but, unlike the static representation in semantic networks (where all elements of the network co-exist simultaneously), they describe the world dynamically – in the form of sequences of syntagms, sentences. This is the next level of information presentation – a pragmatic level that follows the upper (semantic level of pairwise semantic co-occurrence) level of the hierarchy of representations of the posterior cortex.

At this level, events are represented in the form of chains of situations of various modalities f_m, described by separate sentences A_i (or quasi-sentences) – modal components of the subframe:

$$\hat{f}_m = *_i \quad \hat{A}_i, \tag{9}$$

where (*) designates concatenation. Such modal components of the subframe are combined at the next level over all modalities in the subframe:

$$\hat{S} = \cup_m \hat{f}_m = \hat{f}_1 \cup (\cup_{m \neq 1} \hat{f}_m), \tag{10}$$

where $\hat{f}_1$ is a component of the subframe of the natural language modality, which names a subframe (event) in the hippocampal lamella. Further, the subframe chain is combined into a frame – a sequence of situations as they are represented in the hippocampal lamellae:

$$\hat{F} = *_p \hat{S}_p = \hat{I} * (*_p \hat{S}_p), \tag{11}$$

where $\hat{I}$ is the name of the frame that is a word or syntagm in the natural language modality.

In this case, the dictionary of one of the levels of the hierarchy of the frontal cortex (the dominant hemisphere) consists of the images of predicates (stored in the hippocampal lamellae of the dominant hemisphere), which are repeated more often than abstract images of names (according to A.R. Luria, the inner speech is predicate speech [4]).

Any such chain of predicates corresponding to a particular sequence of actions can be reproduced with the help of the thalamus. This is the action plan.

4.5 Purposeful Behavior as a Chain of the Situation Images

Purposeful behavior is not an innate function of human [4]. It is formed under the influence of the teacher. First the teacher makes an individual do this or that: “Do this!” And this “this” can be done in one act and in one situation: from beginning to end. The hippocampus records the operations performed in the act. If you remember, the events of the multimodal and language components are brought together in one hippocampal lamella: I perceive, I say, I do. By the way, one can just speak: speaking is also purposeful behavior. The initial situation is the target one. Then tasks become more complicated. There is a transition from one situation to one or more intermediate situations. In this case, the thalamus is also involved: under the influence of the teacher’s instruction (“Do this!”, “Do that!”), the thalamus focuses attention on one or the other of the hippocampal lamella. A sequence of operations is performed that are represented in the situations from the current to the target one.

This sequence of situations is registered in the columns of the anterior cortex. Unlike sensory information sequences that contain only specific information (even if it is multi-modal), the anterior cortex receives a sequence that is partially specific – the anterior cortex is connected with all sensory cortical areas – and partially non-specific (partially informational, partly energetic – about the location of a particular hippocampal lamella containing information about the required situation. Moreover, this is specific information of two types: multimodal and language types. As the columns of the posterior cortex, the columns of the anterior cortex form hierarchies of representations of events of diverse complexity. The language motor component in these representations has the least variability: there aren’t as many words of the language as multimodal events of the external world. Therefore, all multimodal information is filtered out, and only the language information remains. Due to the great complexity of the internal structure of these information sequences, many levels of processing do not work: only the most frequently repeated elements of these sequences remain in their language form. And these are predicates. That is, the dictionary of fragments of predicate chains is gradually formed that describe the external world (or its subset – domain area) as a set of elements of the task flow algorithm.

Thus, inner speech is a chain of predicates expressed by the corresponding words of the language, which always accompanies any purposeful behavior [4]. According to John Lilly [14] these are (sometimes parasitic) internal (subconscious) subprograms in the verbal form that accompany all human actions including purposeful ones.

5 Conclusion

Consideration of the essentially heterogeneous processing of information in the brain allows for the conclusion that the architecture of the purposeful dialogue systems cannot be homogeneous, that it must necessarily include a world model with a search subsystem for this world model, a natural-language sequence of questions and answers necessary to understand the questions and to formulate answers to these questions taking into account the reaction of the world model, as well as the attention mechanism that makes it possible to form the processing operations from accurate focusing on one process to full defocusing with the involvement of all possible processing operations. The dialogue must be implemented as a purposeful process, in which the motive, purpose and plan of the dialogue are clearly seen. And the functioning of the system for implementing a purposeful dialogue must include the following steps: (1) formation of a world model (including a language model), which includes both hierarchies of syntagmatic sensory (in the posterior cortex columns) and effector (in the anterior cortex columns) processing and presentation of information, and the paradigmatic representation (in the hippocampal lamellae); (2) identification of the purpose of the dialogue; (3) formation of a dialogue plan as the choice of a chain of images of a pragmatic level of information representation; and (4) monitoring the implementation of the plan by correlating the incoming current information with that presented in the plan, with the possibility of adjusting the plan in order to approximate the real conditions.

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