Neuroinformatics and Semantic Representations

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Theory and Applications

Edited by

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For

Arkadiy N. Radchenko

in memoriam

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LIST OF ABBREVIATIONS

AI – Artificial Intelligence
ANN – Artificial Neural Network
API – Application Programming Interface
CPU – Central Processing Unit
CRF – Conditional Random Fields
DB – Database
DL – Deep Learning
DNC – Differentiable Neural Computer
EEG – Electroencephalogram
ELMo – Embeddings from Language Models
GAN – Generative Adversarial Network
GNG – Growing Neural Gas
GPU – Graphical Processing Unit
HMM – Hidden Markov Models
LDA – Latent Dirichlet Allocation
LSA – Latent Semantic Analysis
LSTM – Long-Short Term Memory
MDL – Minimum Description Length
MLP – Multilayer Perceptron
MVTU – Bauman Moscow Higher Technical School
NER – Named Entity Recognition
NLP – Natural Language Processing
NSN – Neurosemantic Network
QA – Question-Answering
RBNN – Radial-Basis Neural Network
RNN – Recurrent Neural Network
SNN – Spiking Neural Network
SOM – Self-Organizing Map
WTA – ‘Winner-takes-all’

PREFACE

Neuroinformatics can be broadly defined as a science "with an emphasis on data structure and software tools related to analysis, modelling, integration, and sharing in all areas of neuroscience research. Coverage extends to theory and methodology, including discussions on ontologies, modelling approaches, database design, and meta-analyses; descriptions of developed databases and software tools, and of the methods for their distribution; relevant experimental results, such as reports accompanied by the release of massive datasets; computational simulations of models integrating and organizing complex data; and neuroengineering approaches, including hardware, robotics, and information theory studies" (Definition, 2019).

In the late 1970s, at Bauman Moscow Higher Technical School (MVTU) there was a student research group "Neuroinformatics" headed by Alexander A. Kharlamov, an MVTU graduate student at the time. The group was awarded the bronze medal of the All-Union Exhibition of Achievements of National Economy (Moscow, Russia) for a digital model of a neuron with temporary summation of signals. This term became more widespread in Russia after the organization of the Russian Association of Neuroinformatics (this name was proposed by A. A. Kharlamov), which brought together scientists from various fields working in the framework of this scientific field.

If narrowly defined, neuroinformatics is a science studying the nervous system's functioning (primarily that of humans) at the information level, that is, the science of how the brain processes information. It is in this narrow sense that neuroinformatics is considered in this monograph. The processing of information in the brain is divided into two sections: signal processing and symbol processing. Signal processing is implemented on the periphery of analysers and effectors, while symbol processing occurs in their central (cortical) projections.

Symbol processing of information in the brain forms a model of the world as a hierarchy of representations of images of events of the external world with varying degrees of complexity and with different modalities. This model is divided into two parts: one of them deals with symbols of the language, and the other with images of multimodal representations. These two representations do not differ from each other in the way they process information. Both the linguistic and multimodal parts of the world model deal with information sequences representing the input texts (quasi-texts). The language model of the world deals with natural language texts. The multimodal model deals with quasi-texts of other modalities (apart from the linguistic). Thus, visual modality processes sequences of images of scenes projected onto the retina of the eye, which can be considered as quasi-texts – sequences of symbols of a quasi-language that has a multilevel hierarchical, as well as a natural language, structure.

If we consider the hierarchy of levels in a natural language, then the semantic levels (the level of presentation of the semantics of text sentences and the level of semantics of the whole text) and the pragmatic level of processing text information, which can also be placed into the category of meaning, are preceded by language levels related to formal processing of the text – processing of the text's representation form – at morphological, lexical and syntactic levels. In fact, one may not separate the formal (pre-semantic) and semantic processing of texts.

All that has been said about the analysis of natural language texts can also be said about the analysis of quasi-texts of multimodal representations. Therefore (broadly speaking), we assign all processing that is implemented in the symbol part of the information analysis by the brain to semantic representations.

Semantic representations in the brain are implemented as homogeneous semantic networks – graphs, where nodes are notions of the text, and arcs describe the relationships (links) of these notions in the text (quasi-text). Links between notions in a homogeneous network are not named, since only one type of link is used – that is, associativity – a relationship that takes into account the proximity of two notions in a text (quasi-text).

Thus, in the monograph two representations are correlated: the biological one as natural neural networks and cognitive neural networks that are formed on their basis; and the informational one interpreting the processing of information of different levels of different modalities by these cognitive networks. This interpretation is presented from different angles in separate papers of the monograph. The first chapter presents theoretical issues regarding the transition from biological representations, from the cellular level of information processing to the level of interpretation of information processes that occur in two main organs of the brain – the cortex and the hippocampus (involving the thalamus) when the world model is formed and used in the process of purposeful behaviour. The transition from the information model to semantic text processing algorithms is shown in more detail. A bridge is created to the analysis of social processes to improve mutual understanding in communication by synchronizing the models of the world of communicants. The second chapter presents applications that enable the use of semantic-text-analysis technology for the purpose of expert evaluation, identification of implicit knowledge, and even for analysis of non-textual information. The third chapter presents a different approach to the use of artificial neural networks based on neurons with temporal summation of signals, as well as an attempt to combine different modalities for a more effective analysis of the situation being evaluated.

A very heterogeneous structure of the model of the world formed in the human brain also suggests a very heterogeneous structure of the system for the formation of purposeful behaviour. It includes parts of the world model of various sensory and effector modalities complementing each other in the formation of semantic representations of individual situations. It includes both the sensory (describing) and the effector (algorithmic) parts, and includes an energy component for controlling the attention switch when moving from one situation to another. At the same time, a collection of representations of individual images of events of different modalities is formed within the framework of entire situations. This paper does not consider the periphery of sensory and effector organs, which is also very difficult. It is only about uniform mechanisms for processing information of different sensory and effector modalities both in the cortex and in the hippocampus that is reduced to a uniform representation.

This representation can be modelled on the basis of artificial neural networks from neurons with temporary summation of signals that simulate pyramidal neurons of the third layer of the cortex. Neural networks of such neurons model the functions of cortical columns regarding sensory information processing.

The effect of neuron electronic non-compactness on the processes of interaction of postsynaptic potentials leads to the formation of an approach to the processing of information by such neurons that is fundamentally different to that seen in most existing artificial neural networks (Radchenko, 1969; 2007). The dependence of the neuron response to the temporal structure of the sequence of input signals resulting from the electronic non-compactness makes it possible to selectively address one specific neuron from many similar ones with a fragment of the input information sequence. Such selective addressing leads to a fundamentally different understanding of the structure of information processing in a neuron. Delays arising from the propagation of the postsynaptic potential along the dendritic membrane lead to the introduction of a shift register into the structure of an artificial neuron as a dendrite model. The various distributions of excitatory and inhibitory synapses on this dendrite model as addresses of specific neurons, in turn, are modelled by the nodes of an n-dimensional unit hypercube in the multidimensional space R^n. Then any input sequence can be represented as a sequence of triggered neurons – a trajectory in a multidimensional signal space provided that there will be a complete set of these addresses (neurons with corresponding distributions of exciting and inhibitory synapses). In the binary case, it is 2^n, where n is the length of the shift register.

A column of the cerebral cortex, as a combination of electronically non-compact pyramidal neurons of the third layer, performs structural processing of specific information, modelling a fragment of a multidimensional signal space. The model is implemented by an artificial neural network based on neural-like elements with temporary summation of signals. Input sensory information is a matrix of information streams, where each information stream can be considered as a quasi-text consisting of repeating elements of different complexity and different frequency of occurrence.

The brain is a parallel computer that performs layer-by-layer parallel processing of information from sensory organs through the subcortical nuclei between different sections of the cortex, and again through the subcortical nuclei between different sections of the cortex to effectors. The cortex column, which simulates a fragment of the multidimensional space, converts the incoming input information stream into a trajectory in the multidimensional space. In the multidimensional space, during the structural processing of input quasi-texts of various modalities, dictionaries of event images (interoceptive and external worlds) of varying complexity are formed that make up a multilevel hierarchical structure.

Parallel processing is interrupted during the transition from the posterior to the anterior cortex. Now, the process involves the hippocampal lamellae, in which situations are modelled (including both sensory and motor information), which are further manipulated by the anterior cortex, just as the posterior cortex manipulates sensory images of events of different complexities and of different modalities.

Information relations between the levels of information representation in the cortex enable filtration of words of previously formed dictionaries of the current level from input texts and quasi-texts, passing new information characterizing the relationships of these words in the input information to higher levels, which at the next level can also be used to form dictionaries of the next level. As a result of this processing, dictionaries of event images of different levels are formed – from the simplest to the most complex elements of this modality.

In case of a natural language text, these dictionaries form images of events of the morphological, lexical, syntactic and, finally, semantic levels (a separate sentence). The semantic level is understood as the level of representation of the semantics of a separate sentence, where the lexical component of the sentence semantics is represented by pairwise co-occurrence of notions (words or phrases). Pairwise co-occurrence of notions enables formation of a (virtually) homogeneous semantic network of the whole text from such representations of individual sentences.

Thus, the so-called cognitive semantic networks are formed in the brain, that is, networks that are built on a physical substrate (a natural neural network, brain neurons). These networks are based on the principle of taking into account the co-occurrence of individual images of events in situations, that is, the semantic links between notions in these networks are of only one type – the associative one. Therefore, only homogeneous cognitive semantic networks are formed (that is, associative ones). At the same time, at the first stage of formation, the semantic network is characterized exclusively by frequency weights.

Information constantly added during further learning requires its correlation with information previously processed and already stored in the network, which requires constant adjustment of weights for both notions – network nodes – and their relationships (links).

The role of the novelty filter is played by the hippocampus. Its lamellae form and store information about the relationships of the images of events stored in the cortex columns and the way they are connected in various situations. The notions of an associative network formed in the columns of the sensory (posterior) cortex are re-ranked by the hippocampus in the process of an iterative procedure resembling the algorithm of the Hopfield network. The structure of the representations of situations in the lamellae of the hippocampus resembles the structure of the semantic graph of a separate sentence of the text, the extended predicate structure.

At present, the semantic analysis of texts usually comes down to the identification of relatively simple facts, sometimes the links between them. This is the so-called sentiment analysis, the identification of named entities and similar algorithms. This simple type of analysis begins to gradually become more complicated by combining various algorithms. One of the development trends is the formation of simple models of the analysed world in the form of networks (for example, a subway network) which necessitates involvement of more complex architectures than simple artificial neural networks, which also include short-term and long-term memory. This has not manifested itself explicitly so far, but the structure of the brain becomes visible in these architectures. This trend is manifested foremost in attempts to create systems that implement intelligent dialogue as opposed to so-called chat-bots.

Analysis of the trends in application of artificial neural networks to create systems that implement intelligent dialogue, including those for text analysis, shows that researchers began to move from simple homogeneous artificial neural networks to solve simple problems of text analysis (classification, clustering) to heterogeneous systems from neural networks, that is, to move from a vector representation (distributional semantics) of text units of different linguistic levels to a network representation of the contents of the whole text (corpus of texts), increasingly attempting to follow the architecture of natural neural networks of the human brain. Researchers offer more and more complex generalized pre-trained models, and have moved from simple models that can be trained on an inexpensive home computer to large networks that not every video card can hold; and the successful training of such networks on video cards from scratch requires many months of net time and costs a great deal of money when renting equipment.

The scope of application of neural network models for automatic language recognition tasks is now booming. Researchers offer something new almost every week, but are still far from strong dialogue agents, since existing machine-learning approaches cannot go beyond the data from the training sample. In addition, pragmatics of texts is still not taken into account in most tasks. And if it is taken into account, there is a limitation in predicting a small number of pragmatic classes (intents). This approach makes it possible to solve a number of problems for business; however, despite the assertions of many researchers and popularisers in the field of automatic language processing, an ImageNet for NLP has not yet been created (unlike computer vision), and the existing complex models are rather an analogue of a pre-trained probabilistic auto-encoder, GAN, or a Boltzmann network for images. This is undoubtedly an important step in the formation of the field, but there are still many more unsolved problems in the NLP than solved ones. The transition from distributional semantics to network representations of the subject domain model that has taken shape in this direction will help resolve existing problems in the field of automatic language processing, including those in the field of intelligent dialogue.

Thus, the topic analysis of the text formed within the network representation of texts (and quasi-texts) using a network n-gram model of the text makes it possible to identify not only the main topics of the text, but also the hierarchical structure of the topic tree (topic trees): the main topic, subtopics dependent on it, sub-subtopics, etc.

Such an analysis reveals the topic structure of the text using only information on proximity in the context of the length of n words of the text dictionary (associative type of communication) in the semantic network. The same mechanism makes it possible to extract the topic structure for any notion represented in the semantic network of the text. This graph describes the semantic structure of the notion.

Interpretation of such a representation as applied to the behaviour of communicants in the process of dialogue makes it possible to understand what happens to the communicants' models of the world when they form a single representation (idea) of the world.

Dialogue, being the most important means of culture, education and all social communication in society in general, now acquires the status of a necessary part of any social, political or business process. A similar situation has been observed before with common written literacy (reading and writing skills). Nowadays, in the context of the digital information society, communication literacy is especially in demand. First, the knowledge industry has emerged in the information society, and a new type of product has emerged – an intellectual product. Secondly, in conditions of an information explosion and rapid changes in society, not only social stratification occurs, but also a stratification of the general semantic space. Increasing complexity and diversity of social forms conditioned strong erosion of meanings, objectives and interests. Thirdly, dealing with meanings becomes the most important socio-economic and political component in the activities of the individual and society. Thus, communication literacy is becoming a passport to the future.

What is communication literacy? This is the coordination of mutual understanding at the level of the individual; the synchronization of subject domain models of various social groups in the process of working on a single project; the mutual coordination of political and economic activities of various countries around the world; and the conduct of fundamental scientific research through the efforts of entire states. Everywhere, at all levels, the coordination of objectives, understanding and meaning of joint activities in various business processes, communication between specialists and, finally, dialogue are required. A key trend in modern society, an individual state and even wider civilization is the formation of technologies for providing a collective mind (intelligence).

Given the isomorphism of the human's multimodal model of the world to its linguistic component (Kharlamov & Ermolenko, 2015a; 2015b), the proposed ideas and technological approaches presented in this monograph could offer a very valuable and practical solution to the problems of protecting society from existing threats, including future threats. For example, one can see what ugly forms communication contacts take sometimes in social networks (lies, flooding, fakes, unchecked aggression, terrorist propaganda, etc.). The adoption of interaction technologies and communication literacy can effectively help the formation of modern social networks in all their manifestations, from social and expert networks of the "collective intelligence" to instant messaging networks, especially for self-organization and network-centric management processes in society in the context of rapid changes and a variety of social forms.

The problem of synchronization of world models (subject domain models) of persons presented in this paper is crucial in resolving many modern conflicts at various levels, from mutual misunderstanding of individual persons in the subway or shops to mutual misunderstanding between entire nations and states. The formation of close models of the world is possible only if there is a common objective in the dialogue process.

To complete the model of the world in the process of synchronization, it is necessary to involve the necessary information from sources of expertise, which can become equally undisputed for all participants in the dialogue. In the simplest case, when one of the participants is recognized by everyone as an opinion leader, it is they that are the source of information for completing the models of the world of many other participants, especially young people. This is already partially happening at an intuitive level in distance education systems, in the blogosphere and in social networks. In this case, there is an urgent need for the opinion leader to take into account the features of the intentional plan (determination) for all participants in the dialogue. Using the correct methods and technology for synchronizing models makes it possible to do this efficiently and painlessly, providing timely solutions to current problems in the process of achieving objectives in view.

The TextAnalyst technology of automatic semantic analysis of texts presented in the monograph and implemented on the basis of the neural network approach, being cognitive, is statistical in nature and enables automatic identification of key text notions in their relationships with their semantic weights (formation of an associative text network). Such a network representation, in turn, makes it possible to implement automatic abstracting of text and automatic comparison (classification) of texts. The personal TextAnalyst product on the basis of this technology is a convenient analytic tool implementing the function of preprocessing large volumes of text information. Moreover, texts are processed according to the principles specific to the processing of textual information in the human brain. The hypertext representation of the text obtained as a result of this processing, with an associative network of key notions as a tool for navigating the text, is a unique non-linear representation of the text typical of humans, effectively visualizing this information. The fact is that, in the human mind, it is homogeneous semantic networks that are formed, in which the links between the notions are not marked up by relationships other than co-occurrence (in space or in time).

Using the mechanism of hypertext representation of information actually transforms the database of texts into a class of knowledge bases. Such a knowledge base enables, due to associative navigation with the help of a homogeneous semantic network, strict selection of the information that is needed at the moment, with the degree of detail that is needed at the moment, which makes it possible to avoid compressing this information when analysing large volumes of text information, as modern analysis systems do, and, on the contrary, to increase its volume as much as is necessary for an adequate analysis.

The same database can become an intellectual repository of a person's knowledge based on the texts of this person, if one supplements it with a question-answer system. It can identify the user's objective and expand the text database by searching in external text repositories.

The described technology is the basis for the automation of expert activities conducted on the basis of publications by authors and teams of authors, the methodology of which is presented in the monograph. The tools for conducting such an expert evaluation are presented, using the TextAnalyst technology for automatic semantic analysis of texts, which implements separate stages of automatic processing of large text corpora with the formation of numerical characteristics of the individual components of these corpora. Correlation of such averaged numerical evaluations with evaluations from experts makes it possible to automate (and thus objectify) the process of conducting an examination, which facilitates an examination and makes it more available, thus making it possible to compare expert evaluations obtained from individual experts.

The results of such expert evaluation are presented on the example of the analysis of the subject domain of human capital assets. The results obtained, as usual, have two sides. On the one hand, they confirm the possibility of automatically identifying and ranking the parameters of human capital assets. On the other hand, it is obvious that the tool is rather rough, and the inclusion of linguistic information is required in order to use not associative, but heterogeneous semantic networks for the same analysis.

On the material of the works “Other Shores” by V. Nabokov and “Embankment of the Incurables” by J. Brodsky, the capabilities of the TextAnalyst neural network approach were tested for analysing text perception and interpretation, as well as for identifying and studying implicit textual information.

The hypothesis put forward in the study was confirmed: the neural network approach used in the TextAnalyst technology reveals the potential of associative links at several levels. Explicit information is revealed at the level of the semantic network, and implicit information is revealed using the associative search function.

Automatic text analysis performed using this technology enables research at several levels. It allows identification of objective information expressed explicitly (the topic structure of the text as the external outline of the narration, the semantic structure as the semantic basis of the text containing objective information worded by the author). Meanwhile, associative search reveals word associations that indicate the author’s evaluation paradigm and intentions and make it possible to draw conclusions about implicit information and connotative meanings.

Thus, the neural network approach used in the TextAnalyst technology makes it possible to determine the factual basis of the plot, which forms the topic structure, semantic portrait of the text, semantic accents, information significant for the author that is presented in the semantic network. Subtext implicit information, evaluativity and connotative details are revealed with associative search operations.

The use of the mechanism for comparing semantic networks of natural language texts enables comparison of other similar network structures also (not only those obtained from natural language texts), including signal networks (genetic quasi-texts) of various genetic diseases, which can be used to classify such networks, and, therefore, for the diagnosis of diseases.

Using this approach to compare and classify genetic “texts” makes it possible to automate the processing of the results of genetic experiments, the volume of which in well-known repositories (for example, GeneNet) is very large. This facilitates and improves the interpretation of the results of genetic experiments.

In fact, the representation of genetic quasi-texts in the form of lists of word pairs is not entirely correct, as in the analysis of natural language texts. Some pairs of words differ in the type of relationship (link). In the future, it will be possible to use triples instead of word pairs in quasi-texts, including, in addition to the word pair, the type of relationship between them.

Along with the points of view regarding neuroinformatics and semantic representations discussed above, it is necessary to mention other points of view and consider expanding the approach in order to involve multimodal semantics.

In most sections of the monograph, information analysis is considered where neurons with temporary summation of signals having a generalized dendrite of a relatively small dimension are used. As a result of the analysis of information sequences using neural networks based on such neurons, a representation appears in the form of trajectories in a multidimensional space, which allows for the automatic structural analysis of information with the formation of event dictionaries of varying complexity, the formation of syntactic sequences and, as a result, the formation of semantic networks, as well as subsequent analysis of texts based on these networks (for example, the formation of a text abstract), their (texts) comparison and classification.

Using networks based on neurons with temporary summation of signals having dendrites of large size (the so-called neurosemantic networks) for analysis of information makes it possible to form more compact dictionaries of events that take into account not only the nucleus (representation core), but also particular details (fringe).

In a neurosemantic network, information is always stored in some context – any image belongs to some episode, and its environment is always visible, which can be accessed through the associative link of neurons. The homomorphism property proposed V.I. Bodyakin (Bodyakin, 1990; Bodyakin & Gruzman, 2012) is achieved due to the work of the neurosemantic network formation mechanism, in which its structure is constantly optimized and the structure's bit-resource is minimized. At the same time, the relationships of images that are formed in the neurosemantic network turn out to be isomorphic to the relationships of processes in the subject domain, the symbolic stream of which is fed to the network input, which allows unknown links to be detected in information streams. This capability to detect links is implemented by adding another (recursive) neurosemantic network, for which the energy of the original network serves as input signals.

Finally, the multimodal representation of semantics, in contrast to the use of the semantic representations of individual modalities, turns out to be more efficient and more ergonomic in the process of solving practical problems, for example, traffic management, or monitoring industrial enterprise safety.

The multimodal semantics in the monograph are presented with the example of its use in the control system of a mobile integral service robot, which includes modules of navigation, control, world model representation and dialogue implementation in its architecture. The use of all available sensory information presented in an integral form as a multimodal model of the world, makes it possible to implement an effective intelligent speech dialogue of a human companion with the robot during the performance of work tasks both in the process of task assignment and in the process of performing them, mainly in contingency (abnormal) situations, significantly simplifying the human companion's interaction with the robot. If there is an intelligent speech dialogue subsystem, even an unqualified employee can work with the robot, which is very important in terms of the feasibility of using service robots.

It also presents a system for supporting various tasks of industrial enterprise safety, following regulations, identifying violations (and violators) in order to reduce costs for compensating damage by employees who neglect safety regulations, tracking unauthorized persons on the territory of the facility, etc. The introduction of the textual (natural-language) modality into the system representations to complement the visual modality, makes it possible to form a compact and well-interpreted (by human) formal descriptions of behaviour scenarios. The territory plan correlates all the representations and is a convenient tool for visualizing the scene for the operator.

Thus, the monograph presents, to a greater or lesser extent, all aspects of the description of semantic representations arising from computer science (and, ultimately) from brain biology. It is shown how the processing of information at the cellular level makes it possible to interpret the processes and results of processing and representing the interaction of two main organs (cortex and hippocampus) at the system level that are involved in the processing of specific information, columns of the cortex and lamellae of the hippocampus, with the participation of the control structure, the thalamus. And, as a result, to provide an even higher level of interpretation – to describe the interaction of these structures (in this case, the cortex is divided into two non-similar parts – the anterior and posterior cortex) in the process of purposeful behaviour.

The monograph also shows how the use of these representations made it possible to implement a technology for automatic semantic analysis of texts, providing processes for the formation of a semantic portrait of a text in the form of an associative (homogeneous semantic) network, automatic abstracting of texts, comparison of texts by meaning and classification of texts. A number of examples show the effectiveness of the developed technology. Finally, attempts are shown to go beyond the analysis of only one sensory modality (textual) by using the approach to work with multimodal information, including visual and textual modalities.

Modern intelligent technology simulates the intellectual functions of humans. This is manifested to the greatest extent in the use of artificial neural networks (ANNs), as presented in the paper "Distributional vs network semantics. Approaches to the analysis of texts" by A. A. Kharlamov and D.I. Gordeev. The main element of an ANN is a neural-like element (artificial neuron). The functions that it simulates – image recognition – work better than empirically generated artificial intelligence algorithms. However, the range of tasks that they (ANNs) solve is very limited. So far, this includes only image recognition. The thing is that an increase in computational performance on its own does not make the solver more intelligent.

However, if one follows the prototype, one can solve all the intelligent problems as effectively as a human. But to do this, one needs to understand well how the human brain works. Over the long history of its development, neurobiology has accumulated a huge number of facts that can underlie such an understanding. Neuroinformatics, being one of the scientific areas of neurobiology, provides insight into this. The paper "Semantic network as a model of the world, and purposeful behaviour" by A.A. Kharlamov attempts to summarize a wide variety of such ideas.

This book presents the basics of neuroinformatics of brain structures using one type of neurons – neurons with temporary summation of signals, electronically non-compact neurons (as opposed to other brain structures based on a different type of neuron with spatial summation of signals, electrically compact neurons). Such representations were first made by A.N. Radchenko (Radchenko, 1969; 2007). These electronically compact neurons are described in the paper, "On a type of artificial neural network based on neurons with temporal summation of signals" by A.A. Kharlamov. Structures based on the first type of neurons underlie the brain organs that realize semantic representations, their formation and their manipulation. These structures are the cerebral cortex and the hippocampus.

Semantic representations are the basis of the human world model, which is subject to purposeful behaviour. It is semantic notions that make a human what they are. They underlie language proficiency, the basis of the second signalling system. Understanding how the neuroinformatics of the cerebral cortex and the hippocampus work makes it possible to effectively simulate the most complex intellectual functions of the human brain: semantic analysis of texts, intellectual dialogue, and the behaviour of an integral robot.

Semantic representations do not just involve language information. The same semantic concepts underlie the extralinguistic part of the model of the world. Moreover, these two parts – linguistic and extralinguistic – work together to solve the intelligent problems of purposeful behaviour. Multimodal semantics is a way to efficiently simulate the higher intellectual functions of humans. On the other hand, multimodal semantics is the best way to integrate analysing and synthesizing functions into a single representation, that is, it is multimodal semantics that underlie the integral robot.

This book consists of two parts dealing with theory and application. The theoretical part presents the basics of neuroinformatics of the anterior and posterior cortex of the cerebrum together with the hippocampus. These theoretical concepts are based on the works of A.N. Radchenko (Radchenko, 1969). This theoretical part describes the processing and presentation of sensory information of various modalities, which is unified at the preprocessing stage in the periphery of the analysers, and appears in the columns of the cortex and lamellae of the hippocampus for uniform processing and presentation. An attempt to present the informatics of the columns of the human cerebral cortex and the hippocampal lamellae is given in the paper "Structural processing of information in the human brain. Model of the world" by A.A. Kharlamov.

Information processing in the sensory cortex leads to the formation of a hierarchy of dictionaries of event images of varying complexity with various modalities, and also multimodal representations at the upper levels of the hierarchy.

The role of the anterior cortex, which is essentially the motor cortex, is to manipulate the images of situations that are stored in the lamellae of the hippocampus. Images of events stored in the cortex columns are combined in the lamellae of the hippocampus into images of spatial-temporal situations (networks or fragments of a network) of the human model of the world. The hippocampal lamellae that store representations of situations, are filters that make it possible for a person to adequately respond to situations of the external world. The paper "Semantic network as a model of the world, and purposeful behaviour" by A.A. Kharlamov attempts to summarize the most diverse ideas about information processing in the cortex and hippocampus.

Another function of the hippocampus is the reordering of information stored in the cortex and hippocampus under the influence of information received at the input of sensory organs. This reordering allows dynamical changes in the model of the world in accordance with the dynamics of changes in the external world of humans.

Images of events of varying complexity and different modalities stored in the columns of the cortex are combined into representations of situations in the lamellae of the hippocampus, forming semantic networks that adapt to the input information in the process of reordering. The unification of such semantic networks forms a model of the world for humans. The reordering process actually ranks the nodes of the semantic network, which makes it possible to identify the Alpha and Omega in the formed representation. This process is described in the paper "Network n-gram model of the text. Topic tree as a minimal tree-like subgraph of the semantic network of text" by A.A. Kharlamov.

The mechanisms of information processing in the human brain that are presented make it possible to predict the mechanisms of information interaction of persons in the process of social communication (dialogue). These mechanisms are presented in the paper "Synchronization of subject domain models of communicants in the process of dialogue" by A.A. Kharlamov, V.A. Ryzhov and M.A. Pilgun. Using this representation makes it possible to effectively implement the dialogue procedure, the understanding of which will provide a solution for the problem of organizing an intelligent dialogue, the instrumental mechanisms of which (the mechanisms for creating the world model that is used in the dialogue process) are described above.

The second part of the book describes applications that were implemented on the basis of theoretical representations of the aforementioned neuroinformatics. These theoretical constructions are interpreted in a most understandable way by the example of the analysis of the natural language of humans, which is presented in the texts. The tool for automatic semantic analysis of texts – a software system called TextAnalyst – described in the paper "TextAnalyst, the technology of automatic semantic analysis of texts" by A.A. Kharlamov is implemented on the basis of these representations. Most applications are devoted to automatic semantic analysis of texts.

Despite the fact that the history of automatic text analysis dates back around twenty years, the success in this area is by no means impressive. Therefore, involving knowledge of brain informatics can effectively solve the problems of text analysis. One can judge the effectiveness of text analysis algorithms by the quality of one single function performance – text summarization, since this function completes a series of processes in text analysis.

Out of the whole set of representations about information processing in the brain, two representations were used for text analysis. Of all the representations about information processing in the columns of the cortex, the process of forming a semantic network was used, for which the information reordering algorithm in the lamellae of the hippocampus is used to calculate ranks of the vertices. As a result of this analysis, a convenient representation of the meaning of the text was obtained in the form of a uniformly semantic (associative) network of the text, the nodes of which are ranked by their semantic weights. This presentation of the text turned out to be convenient for subsequent analysis: semantic networks of different texts can be compared; therefore, texts can be classified. The minimal tree-like subgraph extracted from the network – the topic tree – is a "table of contents" representing the main topics of the text, their subtopics, sub-subtopics, and so on to a given level. A topic tree can be formed for any notion and group of network notions, which allows extracting only information relating to this notion from the text. The ranks of the network notions make it possible to calculate the ranks of the sentences containing them and, therefore, to produce abstracts of texts. Finally, the hypertext representation of the text based on its semantic network enables associative navigation through the text, which makes this representation a convenient quotation book, in which the efficiency of information retrieval is combined with a given accuracy and at the same time with the required completeness of presentation.

This way of presenting textual information makes it possible to solve many various problems, some of which are presented in this book. These are tasks of finding relevant information, as described in the paper "Ranking the Parameters of Human Capital Assets Using a Homogenous Semantic Network of a Text Corpus" by A.A. Kharlamov, P.P. Kuznetsov and V.G. Novikov, tasks of identifying specific features of a text (corpus of texts describing a subject domain) – connotations of a text in a broad sense, tasks of expert evaluation of a person (team)'s creative activity, as described in the paper "Toolkit for informational and analytical expert evaluation of authors based on their texts" by A.A. Kharlamov, B.I. Vasin and M.A. Pilgun. Most clearly represented is the solution to the problem of extracting implicit information from the text (see the paper "Implicit knowledge in the perception of the text [on works of V. Nabokov and J. Brodsky]: Neural Network Approach" by M.A. Pilgun and A.A. Kharlamov).

One of the papers presents an analysis of the genetic (so-called signalling) network as a network formed on the basis of a genetic quasi-text. A genetic quasi-text is similar to a common natural language text, and therefore the text analysis algorithm presented is applicable to it. It allows identification of the most significant vertices (vertices of the highest rank) in the signalling network, that is, it provides the basis for choosing the place to affect this network with the aim of the most effective amendment, as described in the paper "Using a homogeneous semantic network to classify the results of genetic analysis" by A.M. Kulikov and A.A. Kharlamov.

The final part of the book presents views on the subject, expanding the mechanisms described in the first two parts. A different view of a neuron with temporal summation (as in A.B. Lavrentyev's paper "Neurosemantic Approach") and the dimension of the space represented by a set of such neurons that significantly exceeds the length of the temporal convolution implemented by this neuron, provides a different view of the representation of sensory information in the cortex columns. Such a neuron reveals repeating fragments of input information in the same way as a whole sequence of neurons of smaller dimension does.

Another view goes beyond the representation of only one modality (as in the paper "Multimodal semantics in management and monitoring" by A.A. Kharlamov, R.M. Zharkoy, K.V. Ermishin and V.V. Arzumanov. Such a multimodal representation makes it possible to state the effective integration of modalities in systems such as an integral robot.

Unfortunately, the monograph does not include works describing the application of the general approach presented to the processing of information of modalities other than textual, for example, of visual modality. Let this be a pretext for writing future publications.

In the introduction to the monograph, I would like to thank all my colleagues with whom we repeatedly and for a long time discussed and tried to solve the problems presented, and my family who have supported my work for a long time.

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PART I

NEUROINFORMATICS AND SEMANTIC REPRESENTATIONS: THEORY

CHAPTER ONE

THE SEMANTIC NETWORK AS A MODEL OF THE WORLD, AND PURPOSEFUL BEHAVIOUR

ALEXANDER KHARLAMOV

Introduction

The task of implementing purposeful behaviour in artificial systems is far from complete. To see why, it suffices to look at the behaviour of a robot that performs a specific task, or the behaviour of a team of robots (Osipov, Chudova, Panov & Kuznetsova, 2018) for which the simplest purposeful actions are mediated by the most complex logic. Since the human brain is a very effective universal solver, to solve the aforementioned problem, it suffices to look at how humans implement the purposeful behaviour.

In the process of purposeful behaviour, humans use a model of the world (Kharlamov, 2018; Osipov, Chudova, Panov & Kuznetsova, 2018). This model of the world is very heterogeneous. The human model of the world consists of three components (Kharlamov, 2017): the language model of the world, which includes the model of language, and two extralinguistic (multimodal) components; the socialized schematic multilevel representation of the dominant hemisphere; and the individual two-level imaginary representation of the subdominant hemisphere (Bianki, 1989).

The schematic representation of the dominant hemisphere is formed under the influence of society through the linguistic part of the model of the world. Therefore, it is well developed both in scope and depth. But, being formed on a large diverse material of society, it contains only the most essential features of the material presented, and therefore is schematic. However, it is multilevel (Glezer, 1985).

By contrast, the individual imaginary representation is formed without the participation of society, using solely the personal information of the individual. Therefore, it is very variable in the representation of the same objects, and contains only two levels of representation along the vertical: part-whole (Glezer, 1985).