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The XI-th International Conference “Knowledge-Dialogue-Solution” (KDS 2005) continues the series of annual international KDS events organized by Association of Developers and Users of Intelligent Systems (ADUIS).

The conference is traditionally devoted to discussion of current research and applications regarding three basic directions of intelligent systems development: knowledge processing, natural language interface, and decision making.

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PREFACE

The scientific Eleventh International Conference “Knowledge-Dialogue-Solution” took place in June, 20-30, 2005 in Varna, Bulgaria. These two volumes include the papers presented at this conference. Reports contained in the Proceedings correspond to the scientific trends, which are reflected in the Conference name.

The Conference continues the series of international scientific meetings, which were initiated more than fifteen years ago. It is organized owing to initiative of ADUIS - Association of Developers and Users of Intelligent Systems (Ukraine), Institute of Information Theories and Applications FOI ITHEA, (Bulgaria), and IJ ITA - International Journal on Information Theories and Applications, which have long-term experience of collaboration.

Now we can affirm that the international conferences “Knowledge-Dialogue-Solution” in a great degree contributed to preservation and development of the scientific potential in the East Europe.

The conference is traditionally devoted to discussion of current research and applications regarding three basic directions of intelligent systems development: knowledge processing, natural language interface, and decision making.

The basic approach, which characterizes presented investigations, consists in the preferential use of logical and linguistic models. This is one of the main approaches uniting investigations in Artificial Intelligence.

KDS 2005 topics of interest include, but are not limited to:

Cognitive Modelling
Data Mining and Knowledge Discovery
Decision Making
Informatization of Scientific Research
Intelligent NL Text Processing
Intelligent Robots
Intelligent Technologies in Control and Design
Knowledge-based Society
Knowledge Engineering
Logical Inference
Machine Learning
Multi-agent Structures and Systems
Neural and Growing Networks
Philosophy and Methodology of Informatics
Planning and Scheduling
Problems of Computer Intellectualization

The organization of the papers in KDS-2005 is based on specialized sessions. They are

1. Cognitive Modelling
2. Data Mining and Knowledge Discovery
3. Decision Making
4. Intelligent Technologies in Control, Design and Scientific Research
5. Mathematical Foundations of AI
6. Neural and Growing Networks
7. Philosophy and Methodology of Informatics

The official languages of the Conference are English and Russian. Sections are in alphabetical order. The sequence of the papers in the sections has been proposed by the corresponded chairs and is thematically based. The Program Committee recommends the accepted papers for free publishing in English in the International Journal on Information Theories and Applications (IJ ITA).

The Conference is sponsored by FOI Bulgaria (www.foibg.com).

We appreciate the contribution of the members of the KDS 2005 Program Committee.

On behalf of all the conference participants we would like to express our sincere thanks to everybody who helped to make conference success and especially to Kr.Ivanova, I.Mitov, N.Fesenko and V.Velichko.

V.P. Gladun, A.F. Voloshin, Kr.K. Markov

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MATHEMATICAL AND COMPUTER MODELLING AND RESEARCH OF COGNITIVE PROCESSES IN HUMAN BRAIN. PART I. SYSTEM COMPOSITIONAL APPROACH TO MODELLING AND RESEARCH OF NATURAL HIERARCHICAL NEURON NETWORKS. DEVELOPMENT OF COMPUTER TOOLS

Yuriy A. Byelov, Sergiy V. Tkachuk, Roman V. Iamborak

***Abstract**: System compositional approach to modelling and research of informational processes, which take place in biological hierarchical neuron networks, is being discussed. A number of computer tools have been successfully developed for solution of tasks from this domain. A raw of computational experiments, investigating the work of these tools for olfactory bulb model, has been conducted. The common-known psycho-physical phenomena have been reproduced in experiments.*

***Keywords**: system compositional approach, mathematical and computer modelling, elementary sensorium, hierarchical neuron networks, computer tools, olfactory bulb.*

Introduction

Physics, mathematics and modern computer sciences are universally recognized instruments for research of complex processes and phenomena of the real world. In addition to traditional research domains of these sciences more and more disciplines are being involved into their sphere of interest. In scientific literature dedicated to interdisciplinary research the expression “mathematical and/or computer model” occupies the most prominent place.

Recently a lot of scientific researches have been conducted, where those phenomena and processes are investigated, which have never been involved into the sphere of physico-mathematical and computer applications. The tendency to formalization appears especially in those knowledge domains, where a direct experiment giving the possibility to collect reasonably complete and objective information about the reality under research is practically impossible. It is commonly known that e.g. neuron sciences occupy one of the leading places in modern biology by the number of physicians, mathematicians and computer science specialists involved, competing with molecular biology, genetics and biotechnologies. While by complexity of appearing interdisciplinary problems neuron sciences even leave others behind.

Fast accumulation of enormous amount of experimental data, especially in the last decades of twentieth century and the beginning of a new century prepared a foundation for trying to develop (on a basis of modern imaginations and possibilities) a new concept concerning the natural mechanisms of recognition, memory and purposeful thinking. Also alternative approaches exist, which are dictated by queries of both fundamental and modern practical medicine and by search of new non-traditional ways of “intellectual” technics creation.

The idea, that theoretical constructions can appear only on a basis of wide experimental material reflecting the subject under investigation completely, is still popular in the scientific society. However, the history of natural science from one hand does not prove this concept, and from the other hand numerous examples urge as to think, that the motivating incentive for development and creation of a new concept is usually a limited set of fundamental facts. Though, the experiment without any doubts feeds theoretical constructions and serves as a foundation for a future theory. It is worth to underline, that similarly to the theory, which is supported with experimental facts, the experiment carries useful information only if it is being conducted according to a specific theoretical concept.

In the present paper we are interested with questions of mathematical modelling and research of cognitive processes inside the human brain. For this matter computer tools are introduced and discussed. While being created, they were oriented first of all to networks with complex architecture, namely non-linear hierarchical neuron networks of interacting neurons and neuron assemblies (which are created in turn from simpler neuron networks), generally speaking, with taking into account energy dissipation. The last circumstance, as it is known, lets us to respect and model very important aspects affiliated with self-organization. It is worth to underline that we will research and model multilevel hierarchical neuron networks with forward (ascending, aggregating), backward (descending, decomposition) and circular (parallel, positive and negative) connections. At that we will operate with so-called typical structures, from which, probably, the complex brain-like structures (e.g. memory), generally speaking, of large dimension are constructed. We hope that developed in cooperation with our colleagues [1,2] approach will help to achieve dipper understanding of human’s nature and brain activity. Need for research and modelling of such neuron networks with complex architecture appears when solving the tasks of multilevel information processing inside the brain and for computer modelling, complex behavior, decision making, etc.

At the present moment we ought to ascertain, that existing experimental data and imaginations concerning the neuron activity characteristics and interaction principles have not yet led to complete understanding of such information processing procedures as memorization, recognition, thinking, etc., inside the brain. The mechanisms concerning the functioning of attention, distinction of unconscious and conscious psychical processes, impact of emotions, etc. are still not explained.

Mathematical Model of Elementary Sensorium: Basic Notions

Under the *neuron model* of sensorium we will further understand a model, consisting of neurons and synapses, which incorporate a complex hierarchical network structure (generally speaking, of high dimension) of interacting neurons and neuron assemblies. *Synapse* will be regarded as a connection between two *neurons*. Neurons and synapses will be considered atomic.

Neurons are connected with each other by means of synapses. In turn, synapses and neurons are connected with pre- and postsynaptic *membranes*. If a pathway of a signal transmission is from a neuron to synapse, then the membrane is called *presynaptic*, if a signal is transmitted in opposite direction, then the membrane is called *postsynaptic.*

Regard the representation of sensory (non-verbal) information inside the brain. Let's consider, taking into account [3], that:

1. there is a model of outside world in the brain (neuron engram);
2. information about sensory environment is transmitted into the brain being encrypted by sensory systems;
3. the model of sensory environment is represented with sensory systems with their over-modal level (neuron model);
4. basic units of neuron system, neurons, correspond to the objects of outside environment;
5. objects of sensory environment effect the neuron model;
6. changes inside the model – "informational processes inside the sensory brain part"

The Main Basic Elements and Compositions of the Model of Elementary Sensorium

Let us pay more attention to the discussion of the main basic notions and elements as well as of the compositions of the model of elementary sensorium.

The model consists of *synaptic levels* (SL). There are *symbol* and *quasi-symbol neurons* (SN and QSN) on every synaptic level, which form respectively *symbol* and *quasi-symbol fields*. The main difference between symbol and quasi-symbol neurons is in what functions they perform and how their activity is being interpreted, though both have a similar structure. Symbol neurons correspond to a particular object as a whole. Those quasi-symbol neurons, which are connected by positive backward links with some symbol neuron, represent properties of separate object, to which the symbol neuron corresponds. On a higher hierarchical level they are located, a more complex object (and its more complex properties) they represent [2]. Symbol and quasi-symbol neurons in aggregate will be defined as *principal*.

Let us define symbol neurons SL-0 as *receptors*. It is possible, that on every level both symbol and quasi-symbol neurons exist. The only exception from this rule is SL-0 – the level of receptor neurons. This particular level does not contain quasi-symbol neurons. Receptor neurons correspond to indecomposable elementary objects, by which the system of generative properties of high-order symbol neurons SL is defined. Receptors are symbol neurons themselves.

Let us distinguish separately quasi-symbol neurons SL-1. They will be defined as quasi-receptor neurons, as long as they duplicate receptor neurons [2]. The set of quasi-receptor neurons will be denoted as *quasi-receptor field*.

Inside the model symbol and quasi-symbol neurons are organized into *basic structures* (BS), which form a hierarchical neuron network. The notion of basic structure is introduced based on neuron structures defined in [2-3]. Every basic structure is defined by some symbol neuron, which is located, for determinacy, on SL-*i*. This neuron will be defined as *determinative* for BS. BS consists of the determinative neuron *N* itself, the set of quasi-symbol neurons K_i on SL-*i*, which have positive forward and backward connections with SN *N*, the set of symbol neurons S_{i-1} from SL- *i*-1, whose axons converge into the determinative for BS symbol neuron. Also all synapses and inserted neurons, by which a connection between *N* and K_i, *N* and S_{i-1}, K_i and S_{i-1} is realized, belong to the basic structure. Aforementioned basic structure will be defined as BS corresponding to the neuron *N*.

It is worth to underline, that the neuron network, which is not provided with mechanisms for new BS creation, cannot be trained for recognition of new objects. It is capable to recognize only those objects, for which corresponding symbol neurons exist.

Further the principal parts of basic structures' components will be defined.

Let us consider the *i*-th synaptic level. A *symbol group* corresponds to each SN. Let us define the symbol group of the determinative neuron of the *i*-th synaptic level as a part of corresponding BS, which consists of quasi-symbol neurons, synapses, inserted neurons and synapses, which belong to the *i*-th synaptic level and mediate connections between the symbol neuron and corresponding to it quasi-symbol neurons. It is worth to stress, that the connections of the symbol neuron with other symbol neurons from the same SL are not included here.

Let us define a notion of *converging group* for the symbol neuron *N* from SL-*i*. This group is formed with symbol neurons from SL- *i*-1, which alter, most often indirectly via synapses and inserted neurons, the state of *N* (i.e. alter its membrane potential), and also with all intermediate neurons and synapses, i.e. neurons whose exit signals are entrance signals for *N*. Note, that even though this influence can be mediated with other neurons, it cannot be mediated with other principal neurons.

A notion of type of the neuron and single-type neurons is very important. Non-formally, the neurons are single-type neurons if they react to equal by quality entrance incentives. Let us introduce formal notions. Let us define a notion of *type of a neuron* for symbol neurons. On SL-0 the types of neurons are given as initial characteristics of the network and are taken from some set of elementary types. This set will be denoted as *RT*. For SL-*i* ($i \geq 1$) the notion is given inductively. Let us consider the symbol neuron *N* from SL-*i*. Let the symbol neurons from the converging group of neuron *N* have types $t_1, t_2,\ldots,t_n$. Then the type of neuron *N* by definition is $\{t_1 \cup t_2 \cup \ldots \cup t_n\}$. The type of quasi-symbol neuron is defined with the types of symbol neurons, whose exit signals are entrance signals for the considered quasi-symbol neuron. It is worth to underline, that inside the model the types of these neurons coincide. Two neurons are *single-type neurons*, if their types coincide. Obviously the *uniformity relation of neurons* is equivalence relation.

Based on the paper [4] as well as on papers [1,2] for more precise modelling it is worth to take into account, that before the impulses of single-type symbol neurons reach the target symbol neuron from the next level, the initial signals will undergo some modifications, while passing through the inserted neurons and the raw of synapses. At the same time, the signals from single-type neurons are capable to interact independently on the signals of neurons of other types. As a result a notion of *uniform converging group* will be introduced. Its definition is just the same as one of converging group with a single difference, that uniform converging group comprises those and only those neurons of converging group from SL-*i*-1, which are single-type neurons. Consequently, for the symbol neuron its converging group is decomposable into a set of uniform converging groups. It is worth to say, that there is a particular set of synapses and neurons, by which the uniform converging groups interact. At the same time these neurons and synapses are not themselves included into any uniform converging group.

A *projective group* of quasi-symbol neuron *N* from SL-*i* is a set of neurons and synapses, which consists of quasi-symbol neuron *N*, single-type symbol neutrons from SL-*i*-1, whose exits are entrances of *N*, and also synapses and inserted neurons, by which these connections are mediated.

A *descending group* of quasi-symbol neuron N_k from SL-*i* is formed with neuron N_k itself, all quasi-symbol neurons from SL-*i*-1 accepting the input (possible indirectly) from N_k without intermediate principal neurons, and also all intermediate neurons and synapses (if any). Note, that descending groups appear for neurons on SL-*i* for $i \geq 2$, as long as quasi-symbol neurons appear starting from SL-1.

Horizontal pair of symbol neuron N_s from SL-*i* is a neuron N_s' from SL-*i*, N_s itself, to which a signal is passed from N_s' without other intermediate principal neurons. All synapses and inserted neurons, through which the signal is passed from N_s' to N_s belong to horizontal pair as well. A notion of *horizontal co-pair* is analogical to one of horizontal pair with a single difference that *N* is not a receptor but a source of a signal.

A *horizontal group* of symbol neuron *N* is a union of all its horizontal pairs.

A *horizontal co-group* of symbol neuron *N* is a union of all its horizontal co-pairs.

Basic Properties of Notions Introduced for Elementary Sensorium

Taking into account neuro-physiological data [4] particular relations should hold between uniform converging groups, projective groups and symbol group. Let us define them formally. Consider a symbol neuron N_s from SL-*i*. Let N_k be a quasi-symbol neuron, which belongs to a symbol group of neuron N_s. By definition for aforementioned notations the following condition hold:

UCP1. Let $n_1, n_2, \ldots, n_p$ be a set S of all symbol neurons, which are included into projective group of quasi-symbol neuron N_k on SL-*i*. Then S coincides with a set of all neurons SL-*i*-1, which belong to a particular uniform converging group of the symbol neuron N_s. At the same time N_k is included into the symbol group of N_s. The opposite assertion holds as well. The set of symbol neurons S from SL-*i*-1 of some uniform converging group N_s coincides with a set of symbol neurons, for which such quasi-symbol neuron N'_k exists, that S is a set of symbol neurons of the projective group N'_k, while N'_k itself belongs to the symbol group of N_s. A projective group with a set of symbol neurons *S* and a uniform converging group with a set of symbol neurons *S* on SL-*i*-1 will be defined as *corresponding*.

UCP2. Vertebrates have the following property for some sensory systems, in particular for olfactory system [4]: often in the corresponding uniform converging and projective groups intermediate elements between the set *S* and target symbol and quasi-symbol neurons are equal. Only the neuron sprouts, diverging at the exit, are different. Some of them enter the symbol neuron, others – quasi-symbol. Further such corresponding groups will be referenced as *adjacent*. Note, that inside the olfactory bulb (OB) exactly the adjacent projective and uniform converging groups take place.

Let us specify a property, which connects uniform converging and descending groups (UCD1). Let two single-type symbol neurons N_s^1 and N_s^2 from SL-*i*-1 belong to the converging group of the symbol neuron N_s from SL-*i*. These neurons belong to the same projective group of some quasi-symbol neuron N_k (see UCP1). Let quasi-symbol neurons $N_{k,1}^1,\ldots,N_{k,m}^1$ and $N_{k,1}^2,\ldots,N_{k,n}^2$ (and only they) belong to symbol groups N_s^1 and N_s^2. Then these neurons belong to the descending group of the quasi-symbol neuron N_k. Let us define the part of descending group of neuron N_k, which consists of quasi-symbol neurons $N_{k,1}^1,\ldots,N_{k,m}^1$ and intermediate synapses and neurons, by which $N_{k,1}^1,\ldots,N_{k,m}^1$ are connected with N_k, as *descending symbol subgroup* of the descending group of quasi-symbol neuron N_k, corresponding to the symbol neuron N_s. Defined property is a generalization of some results from the paper [4].

Correspondence of the Sensorium's Conceptual Basis for the Olfactory Bulb

Let us give a description of the symbol group presenting in the neuron network described in [4]. Tufted cell (TC) represents a symbol neuron. Mitral cells (MC), which correspond to TC, represent the quasi-symbol neurons, while signal transmission is mediated with a granule cell.

Converging group cannot be described with a simplest case in the OB. Synaptic connections; so-called olfactory zones (OZ) are located between receptors (SL-0) and tufted and mitral cells (SL-1). They interact via inter-glomerular cells. Also inside OZ a pre-synaptic inhibition takes place. I.e. in general the converging groups on SL-1 inside OB are much more complex than the simplest case. This is a description of the converging group inside OB on SL-1 for the tufted cell [4].

Inside OB the uniform converging groups are strictly described – there are tufted cell N_s, some OZ and also all receptive neurons, whose axons are connected with this OZ. There are also some additional connections between different OZ, which belong to the converging group N_s - this interaction takes place via inter-glomerular cells. Thus, this fact reveals additional connections between uniform converging groups, which were mentioned above [4].

Regard the horizontal groups and co-groups presenting in OB [4]. High order tufted cells influence low order tufted cells via vertical short-axon cells. Hence, high order tufted cell together with some vertical short-axon cell and synapses between them forms a horizontal pair with tufted cell of low order, which has synapses with corresponding vertical short-axon cell. In turn tufted cells of low order form co-pairs with high order tufted cells. Analogically tufted cells of the same order influence each other via the horizontal short-axon cells [4]. Here also pairs and co-pairs exist, which in turn are parts of groups and co-groups.

The common part of adjacent projective and uniform converging groups is represented inside OB with olfactory zones – they represent the common part, which is specified in the definition of adjacent groups [4].

Description of Tools for Biological Neuron Networks Modelling

The tools are represented with software, which takes as input data a neuron network and its inputs declared in XML language [5]. The input neuron network is given with oriented graph.

Oriented Graph of Neuron Network. Vertices and Edges. The first stage of the neuron network construction is specification of vertices. Vertices are intended to define specific points inside the model. Under "specific points" we understand locations of the neuron network, where some signal transformation, as a rule nonlinear, takes place. During the modelling these locations with sufficient precision can be substituted with a single point, i.e. vertex. The examples of specific points are pre-synaptic and post-synaptic membranes, axon hills, etc. The edges of the graph define the direction of signal transmission. They have such attributes as type, length, and coefficient of signal amplification/decrease.

Neurons and Synapses

To specify the network in a more informative way the basic types of biological neuron network elements are distinguished. Also with their help the way, how to pass signals through the edges, is defined. In a graph, this represents a neuron network, neurons and synapses represent its sub-graphs, every edge belonging to a single network element, neuron or synapse (Fig. 1). Some vertices can belong simultaneously to both neuron and synapse. In this case vertices model either pre- or postsynaptic membranes. Some vertices inside the neuron network are entrance vertices. They correspond to the endings of dendrites of receptor neurons in Natural Neural Network (NNN). For each entrance vertex the input signal is given as a set of pairs (moment of time, level of signal).

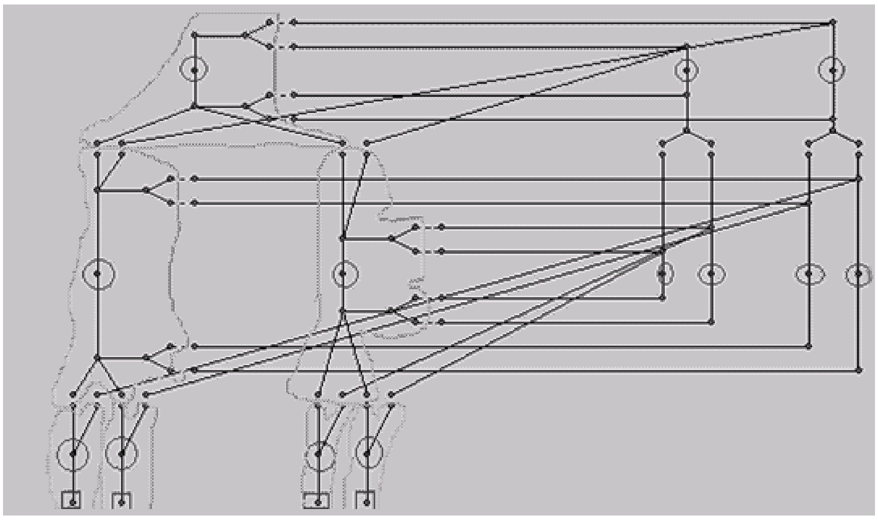

Fig. 1 Example of neuron network model in computer tools.

For clearness some neurons are rounded with curves. Entrance vertices are marked with squares. Vertices, where generation of action potential takes place, are marked with circles.

If the level of signal is needed for a particular moment of time, which is not specified in input, the signal is calculated as a result of linear interpolation. At the same time, the enquired moment of time should be located between the minimal and maximal moments given in input. All vertices are also exit vertices, i.e. it is possible to obtain the exit signal from them in any particular moment of time.

The design of data structure for neuron network vertex description provides a possibility to store the history of signal behavior inside the vertex, which enables to analyze the signal changes inside the vertex during experiment. Upon completion of simulation of the network behavior the tools enable to monitor the history of every vertex.

Time Inside the Model. Time inside the model is discrete, tools enabling to define the discretization interval. In workflow the signal level is recalculated in each point for every discrete moment of time.

Input Data Inside the Model. During simulation of aforementioned processes, which take place inside the neuron network, there is a possibility of real-time visual representation of signal level in any vertex in every discrete moment of time. The more intensive signal level is in the vertex in particular moment of time, the bigger is a circle diameter with a center in this vertex. Also it is possible to view a chart of signal level dynamics in any point upon the modelling completion. It is possible to visualize a summary signal level of a particular neuron.

Input Data Representation. The input data is being read from XML-document, where the neuron network structure is defined. Let us refer to three main elements of this document.

1. *ports* – vertex description. Each vertex is defined with a title, unique identifier, 2D coordinates, type (regular vertex or, so-called, generator of action potential (AP), see below). For AP generators the number of vertex (which stores AP sample), a threshold signal level, coefficients of length and amplitude increment relatively to the sample is defined. Also a non-obligatory parameter for every vertex is a list, which defines a signal level, as a rule, of entrance activity by means of pairs <moment of time, the signal level in a vertex in this moment of time>.

2. *synapses* – signals description. The main characteristics for synapse are its class (chemical or electrical), type and the list of edges. Every edge is defined with an ordered pair of vertex numbers, length and weight. Note, that the notions of length and transmission time are similar in tools. In the simplest case synapse consists of two vertices, which correspond to pre- and postsynaptic membranes, and one edge, which corresponds to synaptic chink connecting two vertices. Thanks to facilities presented in tools there is a possibility to use several edges for more adequate synapse description.

3. *neurons* – neuron description. Each neuron has a particular type. At the moment there is only one neuron type implemented in tools – simple neuron. Similar to synapse, neuron has a list of edges, the order of which is just the same as the order of edges in synapses.

Entrance receptor signals of the neuron network are also defined in XML-document, which consists of a list of elements. Each element defines a signal for one of the entrance vertices as a list of pairs, which specify the level of entrance signal in a particular moment of time.

Signal Values Calculation. Each vertex of the network is characterized with definite condition in any moment of discrete time $\Delta t \cdot i$, where $i \in [0..n]$, Δt – discretization interval. Condition is defined with a current signal level of the vertex, in which stage the action potential is and with other parameters depending on the type of the vertex. The network condition in the current moment of time $\Delta t \cdot (i+1)$ is defined with conditions of vertices in the network graph.

Let us define a signal processing, which takes place in the vertices. Two types of vertices are used in tools: *simple vertices* and *AP generators*. Signal values are defined on entrances of simple vertices in discrete moments of time. Linear spline is constructed based on these points. It can be used for exit signal value calculation in any moment of time. AP generators have more complex behavior. Dependency of the exit signal from the entrance signal is just the same as in previous item. The exception, however, is in the following. If signal power reaches the critical level of depolarization and in this moment the vertex is not in condition of refractor period, then the action potential with predefined parameters is generated. The type of action potential of the vertex is determined based on the sample taken from [6, p.27-54], given with a list of pairs of coordinates – dependency of membrane potential from time. In every moment of discrete time for every vertex the values of all adjacent vertices are being corrected, taking into account to which object this vertex belongs.

Edges in simple neuron have such characteristics as length and coefficient of signal change, i.e. the signal while passing through the edge is being processed with linear transformation. We stress on simple neuron (not on just neuron) to underline the flexibility and extensibility of tools. With a time-flow signals change in vertices depending on their edge connections with other vertices: $v_j(t) = \sum_{e \in I} v_{s(e)}(t - l_e) \cdot c_e$, where generally $v_k(t)$ - the signal value in the vertex *k* in the moment of time *t*, I - set of edges entering the vertex *j*, l_e - the time of signal transmission through the edge *e*, $s(e)$ - the beginning of the edge *e*, c_e - weight coefficient of the edge *e*. Note, that this transformation is inherent for all vertices and is the first transformation, which can be followed with specific transformations related for every particular type of vertex.

In most simple implementations of synapse models the signals are transmitted in a similar for edges way with exceptions in regions, where mechanisms of plasticity are represented. Plasticity is fulfilled with change of the coefficient of signal transmission in synapse according to the following rule:

$$c_{ij}^1 = \begin{cases} c_{ij}^0 \cdot \lambda_{inc}, & v_j(t + l_{ij}) \geq v_n \\ c_{ij}^0 \cdot \lambda_{dec}, & v_j(t + l_{ij}) < v_n \end{cases}$$

where c_{ij}^0 - current coefficient of signal transmission, weight coefficient of a synapse, c_{ij}^1 - new coefficient of signal transmission while passing through the edge (i, j), $v_j(t + l_{ij})$- signal level in the vertex *j* in the moment of time $t + l_{ij}$, λ_{inc}- coefficient of increase, λ_{dec} - coefficient of synapse weight decrease, v_n - constant, which specifies a border between the increase and decrease of weight coefficient of a synapse. For more precise modelling a more complex synapse type is implemented, where the signal is described with integral transformation:

$v_j\left(t+l_{ij}\right)=c_{ij}\int_{t-\Delta t}^{t} v_i\left(\tau\right)\cdot e^{-\lambda(t-\tau)}d\tau$, where $v_i\left(\tau\right)$- signal level in the vertex i in the moment of time τ , $v_j\left(t+l_{ij}\right)$- signal level of the vertex *j* at the moment of time $t+l_{ij}$, l_{ij} - time of signal transmission through the edge (i, j), c_{ij} - weight coefficient of an edge, Δt - time interval, which is taken into account during the exit signal calculation, $\lambda > 0$ - parameter defining signal extinction. In such synapses signal level on post-synaptic membrane at the moment of time $t+l_{ij}$ depends on the level of signal on pre-synaptic membrane during the time period $[t-\Delta t, t]$. Thus, during the calculation of the current state for a particular network vertex not only one previous state is taken into account, but all network states, which appeared during a whole period of time. Consequently, more precise modelling results are obtained. For each neuron the summary level of signal at the moment of time t is calculated as a sum of signals of all edges of the neuron, where signal of the edge s_{ij} is calculated as $s_{ij}(t)=\int_0^{l_{ij}} v(\lambda)d\lambda \approx \sum_{k=0}^{[l_{ij}/\Delta l]} v(\Delta l\cdot k)\Delta l$, where Δl - step of discretization of numerical integration, $v(\Delta l\cdot k)$- the level of signal at the distance $\Delta l\cdot k$ from the beginning of the edge, l_{ij} - length of the edge (i, j).

Verification of Correspondence of Tools for Olfactory Bulb Model

In this section the testing of tools' functionality for olfactory bulb model [4] is described. Testing has been performed on the precisely described in [4] neuron network. Experiments for OB phenomena [7-8] proof have been tried.

The neuron network of olfactory bulb constructed with use of experimental data based on [4], in major follows the basic concept. Aforementioned programming environment has been used for olfactory bulb modelling. Parameters of OB model are given in XML language.

Entrances are represented with four vertices, i.e. four types of receptors were examined in model, which react differently on complex scents in adequate scent environment [4]. Let us introduce the results of conducted experiments. Signals to the entrances 1-3 of groups during experiments 2-3 have been passed with conditional time intervals 0–5 and 10–15. To the last exit corresponding to mechano-receptors during experiments 1-3 the signal has been passed continuously. Let us describe conducted experiment and obtained results with more details.

Testing of Mechano-receptors. Pure air has been passed to entrance. Consequently only one mitral cell has been excited. Other principal neurons have not generated action potentials.

Recognition of Complex Signal. Incentives a, b, c, d have been passed in concentration, which is enough for excitation [4]. MC1 and TC14 have reached excitation. Cells MC1 and TC14 have generated AP. The rest of tufted cells have not been activated with exception of TC124, which has given a faint response during scent recognition.

Recognition of Full Odorant Spectrum. A full spectrum of incentives has been passed to entrances. All receptors have been in excitation. Consequently, all mitral cells and almost all tufted cells have also been excited. However with a time-flow all of them have been trigged with TC1234.

Excitation of Principal Neurons not Connected with Mechano-receptors. In condition of low air speed complex scents TC12, TC13, TC123, and TC23 are able to distribute themselves. A component affiliated with airflow is absent in them. This happens only given that air speed is low – faint level of signal at the entrance of mechano-receptors in compare to other types of receptors.

Synaptic Plasticity. We have implemented plasticity of synapses, which are connected with principal neurons. Taking into account computer simulation it is possible to conclude, that aforementioned modification of synapses based on the modelling of plasticity mechanisms leads to the following fact. During repeated passing of inputs to receptors the reaction of corresponding mitral and tufted cells increases in sequence of generated action potentials and in duration of rhythmic activity. This evidences, that synaptic plasticity is an important component of short-term memory.

We succeeded to reproduce all phenomena, which were planed during experimentation. This proves the correspondence of tools to commonly known morphological, electro-physiological and psychological data.

Conclusions

A system compositional approach to mathematical and computer modelling of the particular type of natural hierarchical neuron networks is discussed. Primary basic components and compositions of the model of elementary sensorium are described. Also basic properties of introduced definitions and notions are specified.

Computer tools for modelling of informational processes in biological hierarchical neuron networks are developed.

A series of computing experiments concerning the functioning of tools with a model of olfactory bulb was conducted, where common-known psycho-physical phenomena are reproduced.

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MATHEMATICAL AND COMPUTER MODELLING AND RESEARCH OF COGNITIVE PROCESSES IN HUMAN BRAIN. PART II. APPLYING OF COMPUTER TOOLBOX TO MODELLING OF PERCEPTION AND RECOGNITION OF MENTAL PATTERN BY THE EXAMPLE OF ODOR INFORMATION PROCESSING

Yuriy A. Byelov, Sergiy V. Tkachuk, Roman V. Iamborak

***Abstract**: Results of numerical experiments are introduced. Experiments were carried out by computer simulation on olfactory bulb for the purpose of checking of thinking mechanisms conceptual model, introduced in [1]. Key role of quasisymbol neurons in processes of pattern identification, existence of mental view, functions of cyclic connections between symbol and quasisymbol neurons as short-term memory, important role of synaptic plasticity in learning processes are confirmed numerically. Correctness of fundamental ideas put to base of conceptual model is confirmed on olfactory bulb at quantitative level.*

***Keywords**: thinking phenomena, olfactory bulb, numerical experimentation, model, neuronal network.*

Introduction

More and more papers are dedicated to modelling of brain activity and thinking processes in particular lately. Because of the great complexity of research object, construction of conception, which doesn't conflict with wide variety of experimental data and conforms to known psychological and psychophysical phenomena, is hard enough. One of few such conceptions is conceptual model described in [1]. This one is used as a base in this paper.

Authors of [1] have carried out qualitative analyses of described conceptual model and haven't found contradictions with experimental materials. That is why authors of this paper have carried out certain qualitative analysis of conceptual model. A computer toolbox for simulation of informational processes in natural neural networks was developed for this purpose.

Olfactory bulb was chosen to carry out numerical experiments because of existence of deep research results in it; detailed data of structure are known [2]. Some essential constituents of thinking such as appearance of learning and identification, memory, imagination occur in the olfactory bulb [3-4]. Authors' attention is concentrated just on them.

This paper introduces experiment statements and their interpretations as well. When carrying out latest ones authors make their aim to confirm correctness of conceptual model [1] by computer simulation as much as possible on experimental object chosen.

Correspondence Among Cells of Olfactory Bulb and Conceptual Model

There are unambiguous correspondence among many cells of olfactory bulb and conceptual model proposed by the reason of conceptual model and olfactory bulb is in relation of abstract – specific respectively. Basic correspondences between cells of olfactory bulb and ones of conceptual models are listed in Table 1.

Table 1. Basic correspondences between cells of olfactory bulb and ones of conceptual model

Olfactory bulb [2]	**Conceptual model [1]**
olfactory bulb	neuronal model, which satisfies conditions of conceptual model
tufted cell	symbol neuron
mitral cell	quasireceptor neuron

Experimentation on Olfactory Bulb Model

Description of every experiment consists of two items:

1. Experimentation. There is description of actions made my experimenters. Construction of neural network for toolbox, essential input data to former and measurement of network output data were carried out in this part as well.

2. Interpretation of the experimentation results. What way obtained results fit the conceptual model were emphasized in this part in.

Every experiment description follows in detail. Note, planning of experiments and carrying out them have concurred because of absence of possible difficulties while experimenting.

Output Signals and Identification. Input signals enough for activation were being sent to inputs of receptor neuron, corresponding to one olfactory zone [2], during the time interval from 0 till 5 time units. Output was measured from mitral cell corresponding to olfactory zone above of. As a result action potentials (APs) were being generated by receptor neurons for period of time during which input signals were sent. After that formers finished (fig. 1). But generation of APs was going on in mitral cell after timestamp 5 as well.

As well as in mitral cell after stopping sending of input signal to receptor neuron, input generation of AP of tufted cell was going on too (fig. 3). That may be caused by large weight of connection between mitral and tufted cells.

Output signals of mitral cell but not tufted one were analyzed in this experiment as distinct from [2] it was performed. Former inconsistency between [1] and [2] is caused by fact, that authors of conceptual model described in [1] hold the opinion, which has some differences with one described in [2-4].

Since mitral cell excited after input signal to receptor neuron had stopped secondary spikes have been got [1]. It is evidence of identification of input stimulus because of mitral cell corresponding excited receptor neuron has excited. The fact of generation of AP after finishing sending of input signals to model indicates the short-term memorizing of stimulus as well.

Checking of "Mental View" Existence. Input signal was sent to postsynaptic membranes of tufted cells (but not receptor neurons) during the time interval from 0 till 5. Sending input signals was stopped after. During the time interval from 0 to 5 tufted cell was generating AP. Some time after timestamp 5 AP was being generated, after that it stopped (fig. 4).

When input signals was begun to send to input of tufted cell, tufted cell began to generate APs too. After finishing sending signal to inputs of tufted cell at timestamp 5 generation of APs in mitral cells was going on (fig. 5).

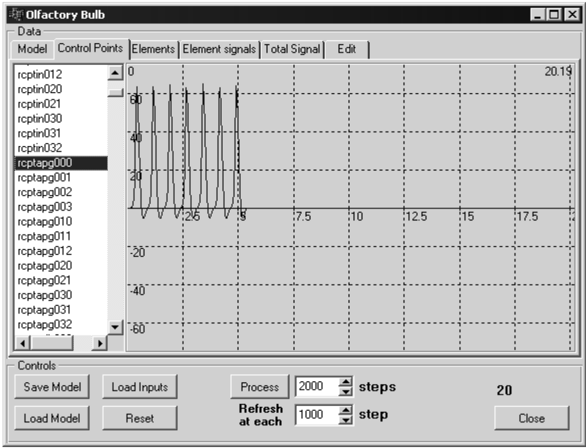

Figure 1. Generation of AP in receptor neuron.

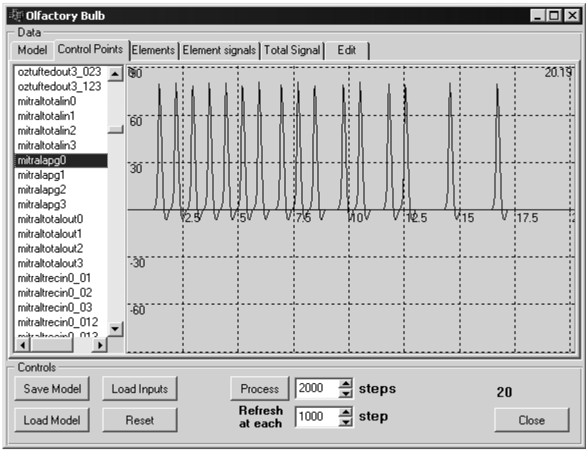

Figure 2. Generation of AP in mitral cell.

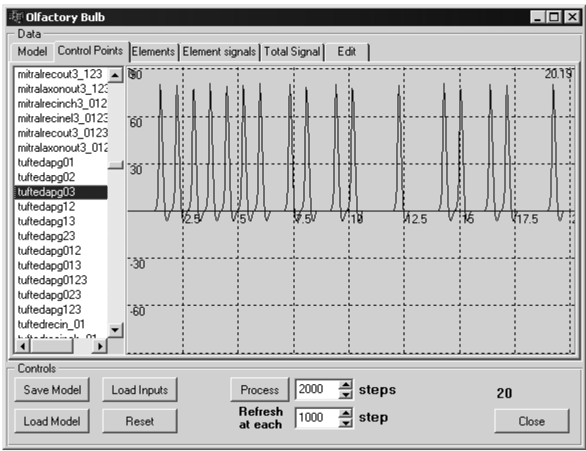

Figure 3. Generation of AP in tufted cell.

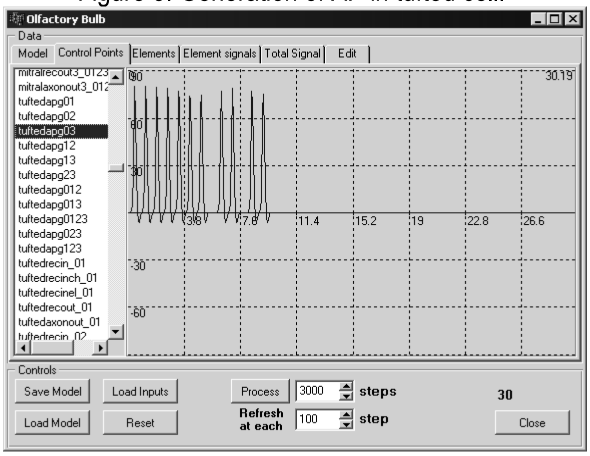

Figure 4. Generation of AP in tufted cell.

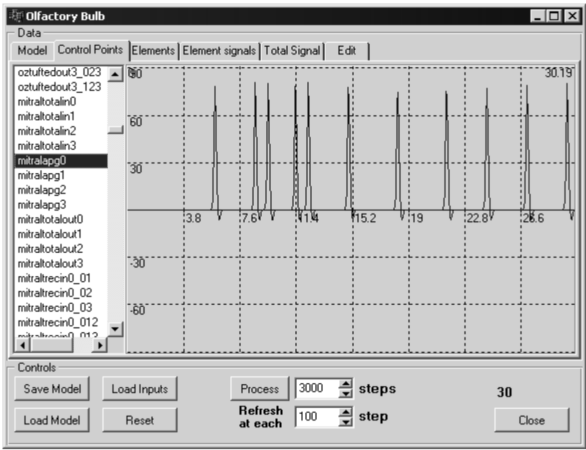

Figure 5. Generation of AP in mitral cell.

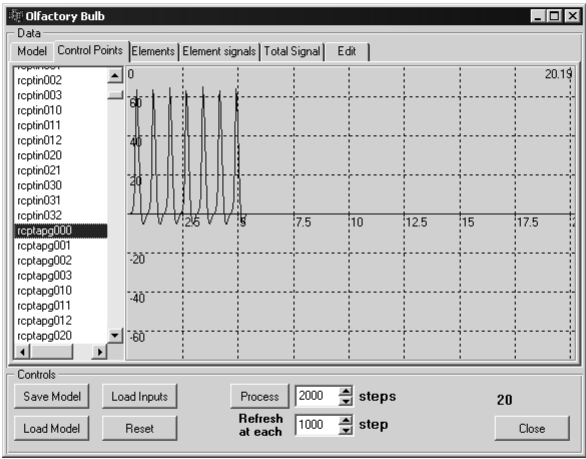

Figure 6. Generation of AP in receptor neuron.

Exciting of mitral cell took place in this experiment, quasireceptor neurons were excited in other words. In conceptual model former corresponds to “imagination” of object in the moment this one is not represented in environment. In other worlds mental view [1] existence was confirmed in olfactory bulb.

Short-term Memory as Feedforward and Feedback Between Mitral and Tufted Cells. Connections from tufted cells to mitral ones going through granule cells [2] were broken before this experiment. During experimenting on olfactory bulb more precise definition for breaking had to be done since connections between tufted cells and mitral ones in our case are not direct, but though the granule cells [2] and are much complicated than simplest case of conceptual model. As the result there are possible several implementations. Thus three cases of breaking connections from tufted cells to mitral ones were distinguished in neural network modelling olfactory bulb:

1. by means of removing granule cell and all input and output connections with former;

2. by means of removing all connections from tufted cells to granule ones and from granule cells to mitral ones;

3. by means of removing all connections from granule cells to mitral ones.

In all three cases input signals were been sent to input of receptor neuron during the time interval from 0 till 5 time units. In the issue APs were generated by receptor neurons by the timestamp 5. APs were stopped after of course. (fig. 6).

Activity of principal neurons (mitral and tufted cells) had some differences by different means of experiment realization.

Let consider realization by means of first and second cases. When sending signals to receptor neuron inputs AP were being generated by tufted and mitral cells. After input signal sending stopped generation of AP stopped there immediately (fig. 7a, 7b, 8).

Breaking connections by means of 3 case when signal sending to receptor neuron inputs stop tufted cells generated additional AP as a response to inputs from themselves which came to from granule cells.

This experiment confirms well known hypotheses adhered by authors as well. It says closed neuronal cycles realize a function of short-term memory.

Thus repeated spikes in mitral cells didn’t occurred cyclic connections above broken. It can be make up a conclusion that cyclic connection is one of the realization mechanisms of short-term memory.

Learning by the Synaptic Plasticity. Taking into account of modelling of synaptic connection weight growing when sending input signal to receptor neurons one of the short-term and long-term memory mechanisms are realized. It is long-term and short-term synaptic plasticity respectively.

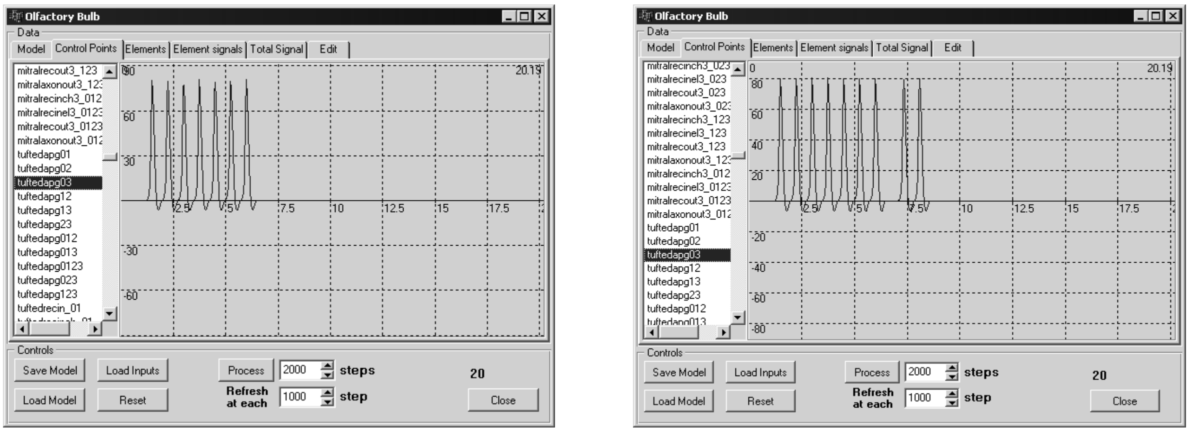

Figure 7. Generation of AP in tufted cell

a) by means of removing connection in 1 and 2 cases; b) by means of removing connection in 3 cases.

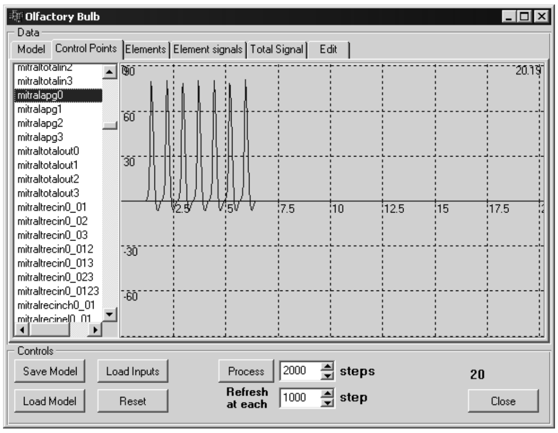

Figure 8. Generation of AP in mitral cell by means of removing connections in all three cases.

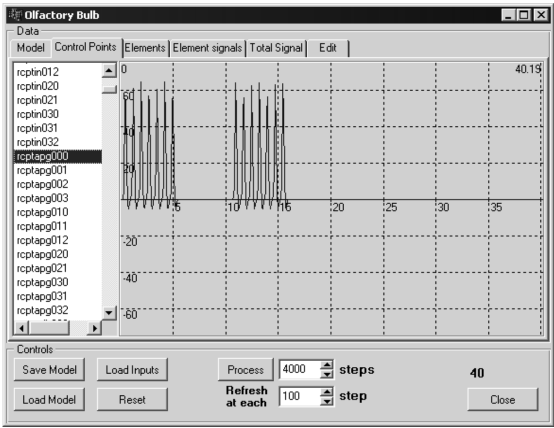

Figure 9. Generation of AP in receptor neurons during the time intervals from 0 till 5 and from 10 till 15.

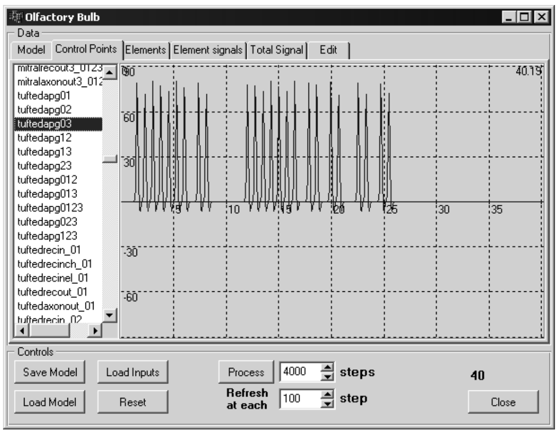

Figure 10. Generation of AP in tufted cells during the time interval from 0 till 15.

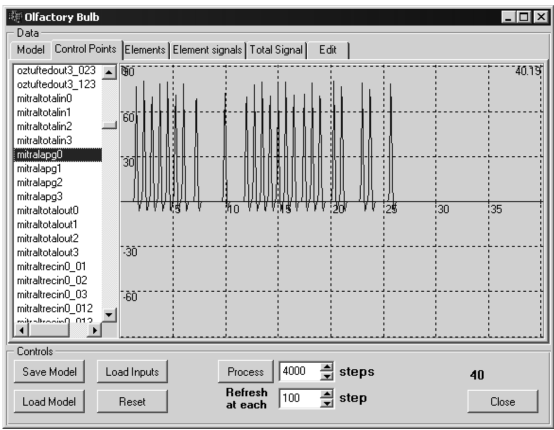

Figure 11. Generation of AP in mitral cells during the time interval from 0 till 15.

During the time intervals from 0 till 5 and from 10 till 15 units input signal was being sent to receptor neurons. Output signals of tufted and mitral cells were measured.

Receptor neurons were generating APs during former time intervals (fig. 9).

When sending input stimuli during time interval from 0 till 5 generation of APs by mitral cells and tufted ones held after input signals sending to receptors had finished (fig. 9-11).

When sending suitable input stimuli separated by short time interval (5 time units) while using toolbox it is obvious that output signal spread much longer during the second time interval of input stimuli sending (from 10 till 15) than during the first one (from 0 till 5) (fig. 9-11)

Synaptic plasticity corresponds to growing of weight of feedforwards and feedbacks in conceptual model. Hence one of the mechanisms of learning is realized in terms of conceptual model. Since outputs of mitral cells and tufted ones were spreading longer in presence of growing of synaptic weights in complex neuronal interactions of tufted, mitral and granule cells, it can be concluded that phenomena of synaptic plasticity conform to its function expected in conceptual model entirely.

Conclusion

Following hypotheses concerning conceptual model have been confirmed in the issue of carrying out of experiments by computer simulation: key function of quasisymbol neurons at the time of the identification of the pattern represented in environment, existence of mental view [1], functions of cyclic connections (feedforward and feedback) between symbol and quasisymbol neurons as short term memory. Important functions of synaptic plasticity in learning processes are confirmed also.

Described above experiments confirm principal positions of conceptual model on quantitative level. Former positions were discussed as credible hypotheses of its authors before. But it must be emphasized that results of experiments do not ensure the full correctness of conceptual model, they can be treated as partial confirmation of this one.

Principal positions of conceptual model which could be verified on olfactory bulb model were confirmed in this paper. They confirm validity of fundamental backgrounds of conceptual model not only on qualitative level, but on quantitative one too.

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