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EXPLORATION BY MEANS OF COMPUTER SIMULATION OF NONLINEAR HIERARCHICAL STRUCTURE OF NEURONAL MEMORY ON THE MODEL OF OLFACTORY BULB

Yuriy Belov, Sergiy Tkachuk, Roman Iamborak

Abstract: Results of numerical experiments are introduced. Experiments were carried out by means of computer simulation on olfactory bulb for the purpose of checking of thinking mechanisms conceptual model, introduced in [2]. 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 in base of conceptual model is confirmed on olfactory bulb at quantitative level.

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

ACM Classification Keywords: J.3 Life and medical sciences - biology and genetics; I.2.6. Artificial intelligence: learning - connectionism and neural nets; D.2.5 Software engineering: testing and debugging; E.2 Data storage representations - linked representations, object representation; H.1 Models and principles; I.5.1 Pattern recognition: models - neural nets; I.6.4 Simulation and modelling: model validation and analysis.

Introduction

More and more papers are dedicated to modelling of brain activity and thinking processes in particular lately. This paper concerns the sphere of mathematical and computer modelling and research of cognitive processes in brain. It is continuation of a paper [1]. 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 [2]. This one is used as a base in this paper.

Authors of [2] 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 [3]. Some essential constituents of thinking such as appearance of learning and identification, memory, imagination occur in the olfactory bulb [4-5]. 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 [2] by computer simulation as much as possible on experimental object chosen.

Correspondence between 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 [3]	Conceptual model [2]
olfactory bulb	neuronal model, which satisfies conditions of conceptual model
tufted cell	symbol neuron
mitral cell	quasisymbol neuron, quasireceptor neuron (more precisely

Experimentation on Olfactory Bulb Model

Every experiment consists of two parts:

1. Experimentation. There is description of actions made by 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 coincided because of absence of possible unexpected difficulties while experimenting.

Output Signals and Identification. Input signals sufficient for activation were being sent to inputs of receptor neuron, corresponding to one olfactory zone [3], during the time interval from 0 till 5 time units. Output was measured from quasireceptor neuron corresponding to olfactory zone above. 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 quasireceptor neuron after instant of time 5 as well.

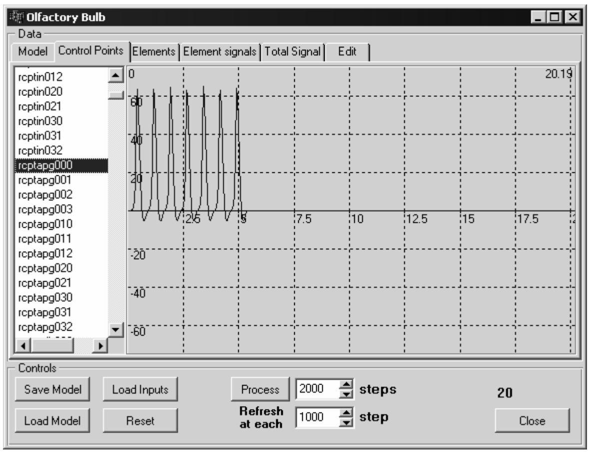


Figure 1. Generation of AP in receptor neuron.

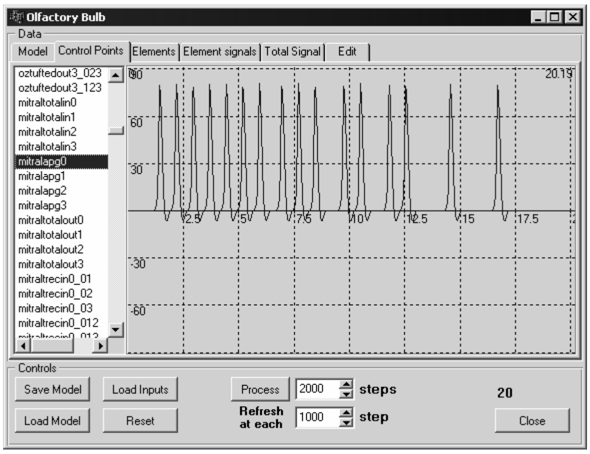


Figure 2. Generation of AP in quasireceptor neuron.

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

Output signals of quasireceptor neuron, but not symbol one were analyzed in this experiment as a distinction with [3] it was performed. Former inconsistency between [2] and [3] is caused by fact, that authors of conceptual model described in [2] hold the opinion, which has some differences with one described in [3-5].

Since quasireceptor neuron excited after input signal to receptor neuron had stopped secondary spikes have been got [2]. It is evidence of identification of input stimulus because of quasireceptor neuron corresponding excited receptor neuron has excited. The fact of generation of AP after finishing sending of receptor input signals to model indicates the short-term memorizing of stimulus as well.

Validation of “Mental View” Existence. Input signal was sent to postsynaptic membranes of symbol neurons (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 symbol neuron was generating AP. Some time after instant of time 5 AP was being generated, it stopped later (fig. 4).

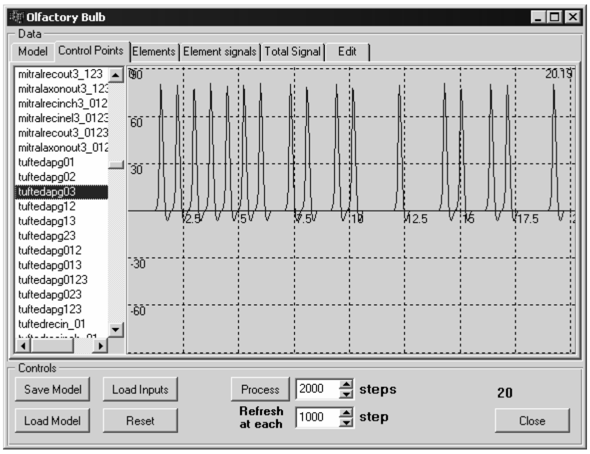


Figure 3. Generation of AP in symbol neuron.

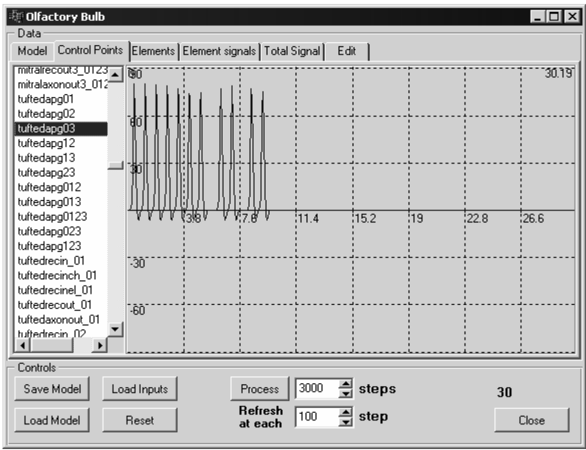


Figure 4. Generation of AP in symbol neuron.

When input signals was begun to send to input of symbol neuron, quasireceptor neurons began to generate APs too. After finishing sending signal to inputs of symbol neuron at instant of time 5 generation of APs in quasireceptor neurons was going on (fig. 5).

Exciting of mitral cells 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 [2] existence was confirmed in olfactory bulb.

Short-term Memory as Excitation Feedforward and Feedback Between Symbol and Quasisymbol Neurons. Connections from tufted cells to mitral ones going through granule cells [3] were broken before experimentation in this experiment. During experimenting on olfactory bulb more precise definition of breaking had to be done since connections between symbol neurons and quasisymbol ones in our case are not direct, but though the granule cells [3] 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 model of 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 after the instant of time 5. APs were stopped after of course. (fig. 6).

Activity of principal neurons (symbol and quasisymbol neurons) had some differences by different means of experiment realization.

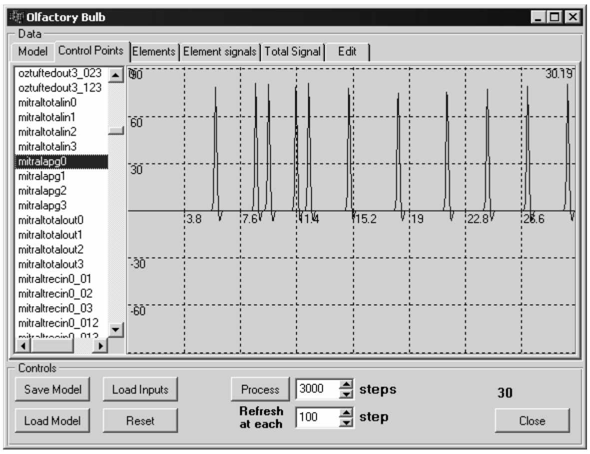


Figure 5. Generation of AP in quasisymbol neuron.

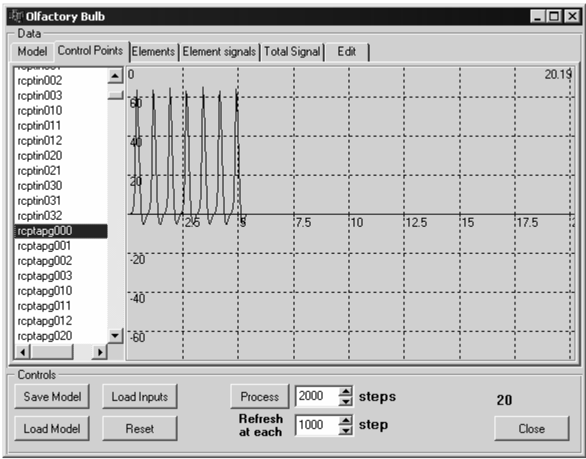


Figure 6. Generation of AP in receptor neuron.

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

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

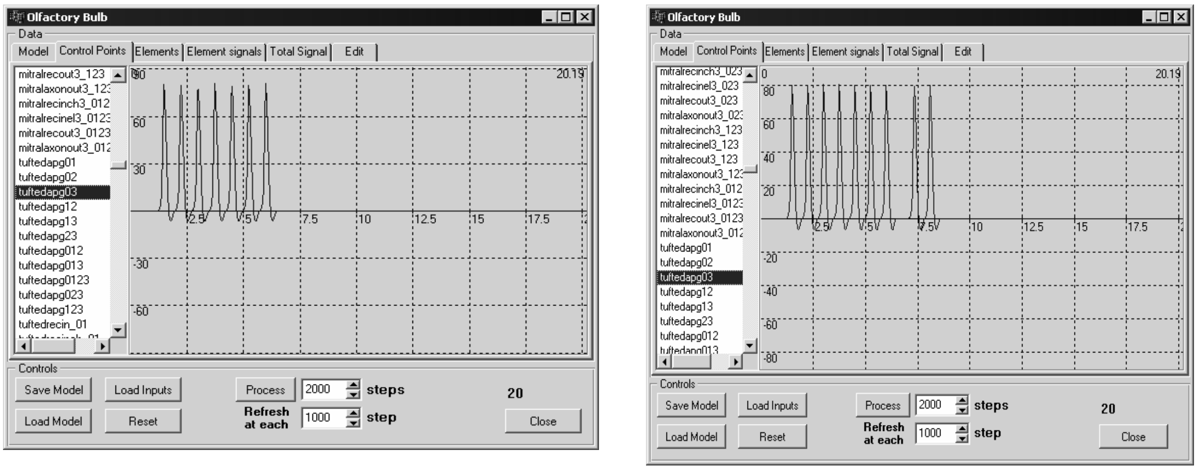
This experiment confirms well known hypotheses adhered by authors as well. It says closed neuronal cycles realize a function of short-term memory

Thus repeated spikes in quasisymbol neurons didn't occurred when cyclic connections mentioned 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 have 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 quasisymbol and symbol neurons occurred after input signals sending to receptors had finished (fig. 9-11) along with when input signals were sent.

When sending suitable input stimuli separated by short time (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)



a) b)

Figure 7. Generation of AP in symbol neuron a) by means of removing connection in cases 1 and 2; b) by means of removing connection in case 3.

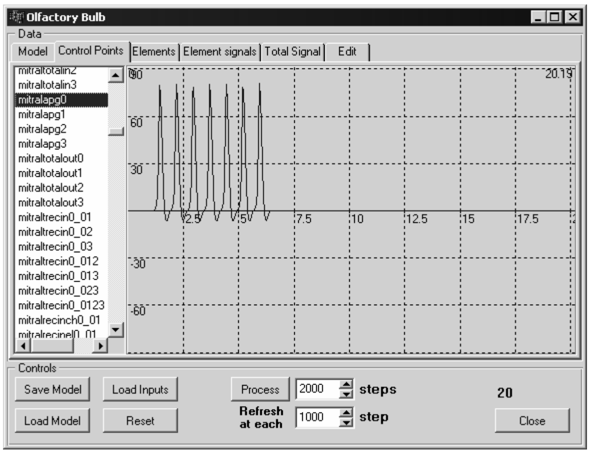


Figure 8. Generation of AP in quasisymbol neuron by means of removing connections in all three cases.

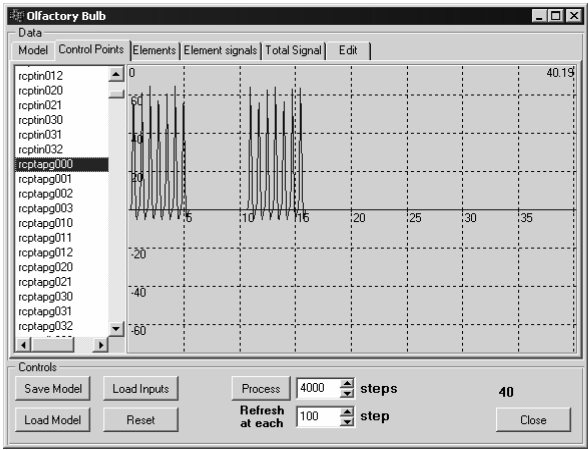


Figure 9. Generation of AP in receptor neurons during the time intervals from 0 till 5 and from 10 till 15.

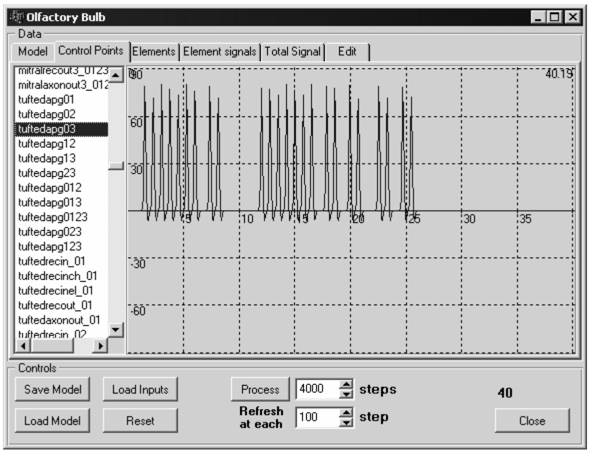


Figure 10. Generation of AP in symbol neurons during the time interval from 0 till 15.

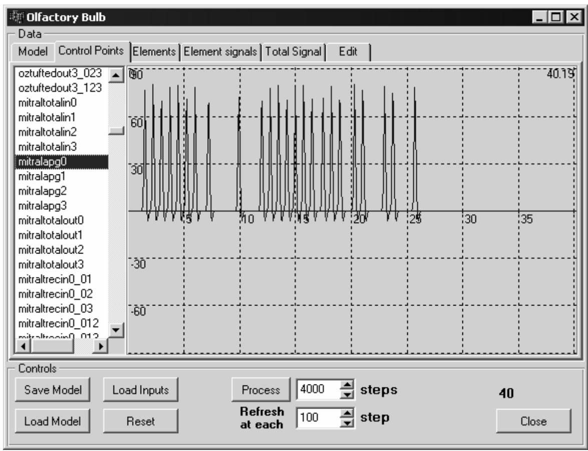


Figure 11. Generation of AP in quasisymbol neurons during the time interval from 0 till 15.

Synaptic plasticity corresponds to increment 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.

been realized. It is long-term and short-term synaptic plasticity respectively.

During the time intervals from 0 till 5 and from 10 till 15 units input signals were being sent to receptor neurons. Output signals of symbol and quasisymbol neurons were measured.

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 during the identification of the pattern represented in environment, existence of mental view [2], functions of excitation 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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