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SIMULATION OF 2D NEURON MATRIX FUNCTIONING AND PRINCIPLES OF SYMBOLS CODING IN ECOMONITORING SYSTEM

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Abstract. *Basing on experimental results of electrical and optical properties of natural brain neurons investigations to simulate the functioning of 2D neuronal matrix model with properties of memory and symbols coding.*

Keywords: computer simulation; 2D matrix; brain; neuron; program model; memory; coding; symbol.

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Introduction

Experimental study of the structure and function of neurons in the brain and other cells is an important area of brain research during last decades [1; 2] including research with fluorescent markers. One interesting way of further carrying of such investigations is a construction of biotechnical systems where technical part and biological one (implants, cultured samples etc.) may be combined. Such combination have good prospects for the use for organism damage corrections, for disabled peoples cure, and etc. Also there are some supposing that the results of such research may be used for the construction of the screens on the base of obtained data about intracellular liquid crystal substances that can interact with fluorescent markers. LCD screen based on the use of liquid crystal mixtures of biological origin may have optical properties that are interesting in terms of creating new types of screens. Despite the fact that the experiments in this area of science is extremely labor-intensive, high-tech and expensive, a number of local researchers still keep them now in Ukraine in collaboration with foreign scientists [3; 4]. Among local researchers several research groups perform optical registration on the cells of various tissues and single cells [3]. All such studies have to be carried out under the control of luminescent, confocal microscopes using fluorescent markers, in our experiments – primulin and bis benzimid [4]. Tracking the processes during experiments perform digital picture sets that are written in the computer memory. Other sources of experimental data are taken into account for modelings are electrophysiological experiments (patch-clamp, voltage clamp, and others [1; 2; 5; 6]. Results of such experiments were combined with optical ones in attempts to analyze whether attempts of biotechnical system construction is possible. Samples of the brain neurons were inquired into the biotechnical system as rectangular 2D plate with cultured brain neurons constructed as 2D matrix. In details such construction we observed in our previous publications [4; 8]).

Task statement

Basing on the results of electrical and optical properties of natural brain neurons studying we suggest the way of development of computer models for 2D neuronal matrix with properties of memory and symbols coding.

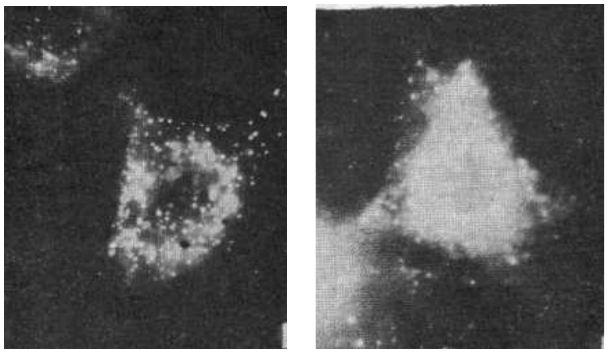
Main part. Physical and biochemical nature of novel 2D screen from bionic elements

In base of original model (version of 2-dimentional network from brain neurons) experimental results described in our previous articles are put [4 – 6]. The sense of registered phenomena [4] is in a fact that input electric signal changes optical properties of the neuron – luminescence of neuron become more intensive (fig. 1) [4]. Other results were taken into account during modeling – results of transmembrane electric currents studying in experiments with patch-clamp, voltage-clamp, and etc. [1; 2; 5; 6]. Basing on these facts the 2D model of hypothetic “quasi screen” was elaborated. Screen matrix is formed by brain neurons in culture condition on plastic chess-like plate armed with electrodes [8]. This biotechnical construction is incorporated into the electric circuit with measuring and information storage devices described in numerical manuals [1; 2].

At the next step we would like to elaborate a program model of this neuronal “quasi screen”. Abstract neurons were ordered on 2D matrix and corresponded to screen pixels.

All these stages of our investigations were done, and results were already published in different scientific and technical journals [4; 7 – 9]. Further stages we

planned were: 1 – simulation of 2D "quasi-screen" functioning (model 1), and 2 – elaboration of program for the simplest symbols coding at such screen (model 2). Obtained results are given below.



a *b*

Fig. 1. Effect on neurons labeled by primulin and activated by agonist-neuromediator GABA. Fluorescent granules containing primulin complexes with proteins are seen: *a* – control. Fluorescence in the absence of agonists influence; *b* – enhanced fluorescence of neurons in case of gamma-aminobutyric acid (GABA) influence on the neuron

Description of "quasi screen" with bionic elements for biotechnical system

Probable "quasi screen" with bionic elements for biotechnical system may be imagine as 2D neuron matrix on plastic plate with cultural brain neurons in dissociated culture incorporated into electric circle with standard measuring and data stored devices. 2D neuron matrix may be imagined as a model like chessboard with alternating rows and columns that separate the cells which contain optically active elements. Designing a screen in a modern biophysical laboratories are absolutely real. This screen is specially designed plastic lining with specific «chess-like" geometric profile, armed with electrodes. The structure of such a screen we described previously in details [8]. For our model-1 we assume that in some cells of this screen there are bionic photosensitive elements [8].

Assumptions of the model

When designing a model, we made the following assumptions.

1. Each screen pixel can be in 3 states, the model color coded by "red", "yellow", "achromatic".

2. Actions of a pixel can be described by a model of the 4 phases. Nature of these phases corresponds to 4 defined states of protein molecules of channel-receptor complex (CRC) that contains channel of electrical current (phase description see further).

3. The demonstrational velocity of the model has been increased 60 times: one minute of real processes in nature (as recorded in the experiment), corresponds to 1 second model.

4. Image coding occurs by the establishing of a different color points set in a given time interval.

Description of bionic elements

As mentioned above, the light-sensitive elements of the screen are bionic elements with variable optical properties. According to our experiments these bionic elements may be following.

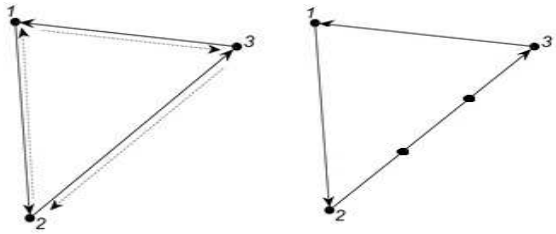
1. Complex protein molecule and molecule optically active substance (fluorochrome).

2. "Luminescent" neurons described in our article [4].

Our model is designed for the second version of the screen where optically active elements are the neurons with fluorochrome molecules inside. We have developed a model based on dynamic changes in the optical characteristics of the neurons that we described previously in [4].

Dynamics of optical neuron characteristics changes in screen matrices

According to the results of the experimental neuron reaction studying, the receipt of the excitation signal can be represented as three consecutive phases that have their physical, biochemical and physiological sense (fig. 2). Besides of them we suggest to include to our model other points too, for more adequate reflexion of studied phenomena.



a *b*

Fig. 2. Each pixel of the screen works by three-member cycle (difference between *a* and *b* is described in text)

Vectors mean transition of the system from one state to another. Vertices of the triangle are three states in which the system can be (fig. 2). These three states on the model are colored with white, red and yellow colors. Respectively:

– top 1 corresponds to described phases 1 and 4 (achromatic);

– top 2 corresponds to phase 2 (red);

– points at vector 2 – 3 means transition (yellow, orange);

– top 3 corresponds to phase 3 (achromatic).

Model 1

Model 1 demonstrates the activity of quasi screen with neurons for the case when activated signal is inputted to active element at the left top of neuronal matrix and then is moved to the right bottom angle. We suppose that each active element of the screen may be activated with further relaxation. Below we describe these phases of activation and deactivation of each element.

1. The first phase of bionic element activation in time moment t_0, before activated signal is inputted (see fig. 2). Moment t_0 is characterized by signal amplitude $A = 0$, fluorescence intensity is going to zero (E_0). Such pixels are achromatic at our model (figs 3 – 5).

2. The second phase of bionic element excitation is at time moment (t_1). The phase is depicted at fig. 2 as point 2. Interval $t_1 - t_0 = 20$ s. During system transition from the phase 1 to phase 2 the amplitude of activated signal – electrical current grows to the maximum $A = A_{max}$. Pixel luminescence is maximal (E_{max}). At model the neurons of this phase are marked by red color (figs 4 and 5).

3. Additional points are characteristic (middle points) for the excitation of bionic elements at time moment ((t_2, t_3) (depicted at fig. 2 as points at vector between 2 and 3). Interval $t_2 - t_0 = 30$ s and time points near it. At these time points the amplitudes of activated signal (electrical currents) are going to decrease (bionic element luminescence is decreased) $A = A_{min}$. Pixel luminescence falls to minimal values (E_{min}). At model elements of this phase are marked by yellow and orange depending on current amplitudes and intensity of luminescense (figs 4 and 5).

4. The fourth phase of bionic element activation is at time moment t_4. Interval $t_4 - t_0 = 180$ s. The phase is characterized by signal amplitude (electric current) $A = 0$, luminescence intensity is going to zero (E_0). These elements are achromatic at model too (fig. 3).

At the screen at figs 3 – 5 the bionic elements are depicted by the circles at defined positions on screen matrix. This arrangement of bionic screen elements is determined by conditions in which the existence of bionic elements is possible under the experimental conditions. The initial view of the model and the initial step of the program is shown at fig. 3.

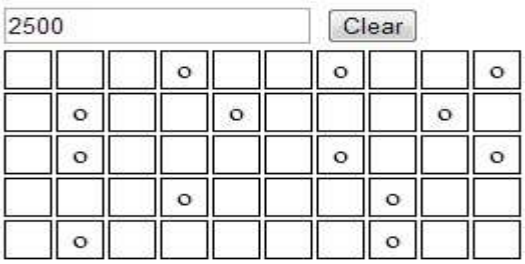


Fig. 3. Initial phase

The next figure shows the model at 101-th second from process start. It is possible to see that one element is at the second phase, some other elements are at phase number three.

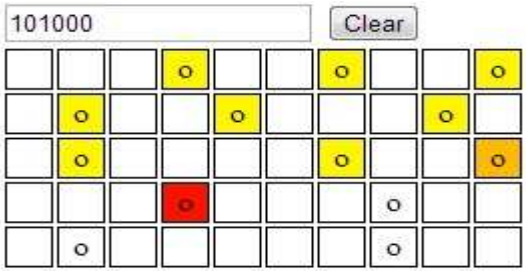


Fig. 4. Working model at 101th second from process start

At the last picture one can see the work program at 120-th second from process start. We can also see here that all elements gradually, after a specified period of time move from one phase to another. It means that activated signal is moving from the upper left angle to the bottom right angle.

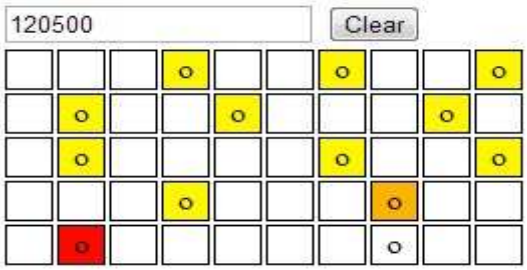


Fig. 5. The final phase

Mathematic simulation of 3 stages of screen pixel functioning

Mathematic simulation of 3 stages of screen pixel functioning may be done for each pixel using mathematic approaches and models developed for simulation of single molecular channel functioning [2]. The conditional probability of finding a channel (and, respectively a pixel in our model) in state j at time t, if it was in the state i at zero time is denoted as pij (t). The conditional probability can also be written in the form of a matrix **P**(t) = (pij(t)). Since the behavior of the channel corresponds to a Markov process, the matrix **P**(t) satisfies the direct differential equation of Kolmogorov

$$\frac{\partial P(t)}{\partial t} = P(t)A(t).$$

Methods of fluctuation analysis may be used for our model as for single molecular channel one. One important application of the fluctuation analysis is to measure the conductivity of a single channel. The same problem can be solved, and with reference to systems that exist in multiple states. The relation for conduction of channels with two states includes

dispersion and average conductivity. These two parameters corresponds exactly to $C(0)$ and $g(\infty)$; for the calculation of $C(0)$ note that $P(t)$ approaches to 0. Then the formula can be written as

$$\tilde{\gamma} = \frac{\sum_i \gamma_i^2 p_i(\infty) - (\sum_i \gamma_i p_i(\infty))^2}{\sum_i \gamma_i p_i(\infty)\left(1 - \frac{\sum_i \gamma_i p_i(\infty)}{M}\right)},$$

where $\tilde{\gamma}$ – average conductivity of open channel, defined by way described above; M – maximal possible conductivity. The same approaches we used also in terms of our model

The equations used in the fluctuation analysis of elementary currents.

Such equations are following.

1. Johnson noise (voltage) in resistance for conditions of current fixation

$$S(f) = 4kT \operatorname{Re} Z(f);$$

$$\sigma_V^2 = \int_0^\infty S(f)df = 2\pi kTf_c R = 2{,}55 \cdot 10^{-20} f_c R^2;$$

$$\sigma_V = 1{,}6 \cdot 10^{-10} f_c R^1.$$

2. Johnson

$$W(f) = S(f)/|Z(f)|^2 = 4kT \operatorname{Re}[1/Z(f)];$$

$$\sigma_I^2 = \int_0^\infty W(f)df = 2\pi kTf_c / R - 2{,}55 \cdot 10^{-20} f_c / R^2;$$

$$\sigma_I = 1{,}6 \cdot 10^{-10} f_c / R^1.$$

3. Time constant, frequency of reaction rate cutoff

$$\tau = (2\pi f_c)^{-1};$$
$$\alpha = 1/\tau = 2\pi f_c.$$

4. Dispersion, the autocorrelation function and the spectrum

$$\sigma^2 = C(O) = S(O) f_c \pi / 2.$$

5. Conductivity of the single channel

$$\gamma = \frac{\sigma_G^2}{\mu_G} = \frac{\sigma_I^2}{\mu_I V} = \frac{C_I(O)}{\mu_I V} = \frac{\pi f_c W(O)}{2\mu_I V} = \frac{W(O)\alpha}{4\mu_I V}.$$

Model 2

Next step of model development is to state that activated neurons in some positions mean some symbols. Phenomena like this are characteristic for human brain activity and we desided to spread our model possibility for cases of symbols coding by neuronal 2D matrix. Figures 6 – 9 demonstrate how symbols CIRCLE and TRIANGLE may be coded in framework of our assumptions.

At fig. 6 the initial phase of model functioning is demonstrated. All neurons in all positions are not active: electrical currents are absent and luminescence is absent also.

On fig. 7 the second phase of model functioning is demonstrated. Neurons only on first 13 positions are active (the first and partially the second line). It means that electric currents in them are present and luminescence is present also. Values of electric currents amplitudes and intensity of neuron luminescence are described in [5; 6]. Only one neuron at 13 positions demonstrates maximal values of electric current amplitudes and intensity of neuron luminescence. This order of maximally luminescent neurons is coded by the **CIRCLE**.

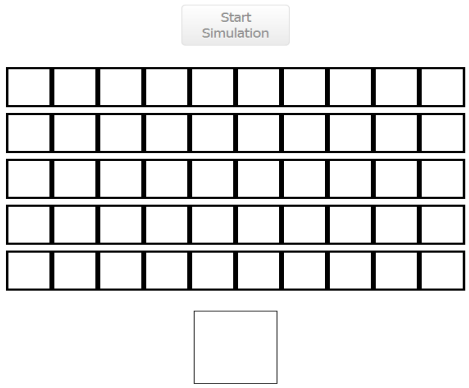


Fig. 6. Initial phase (explanation see in text)

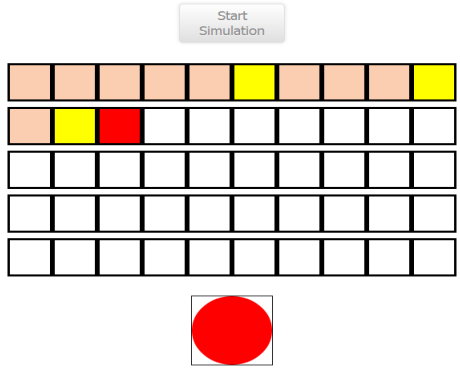


Fig. 7. Phase of the circle coding (explanation see in text)

On fig. 8 the third phase of model functioning is demonstrated (phase of triangle coding 1). Neurons at first 14 positions are active (the first and partially the second line). It means that electrical currents in them are present and luminescence is present also. The values of electric currents amplitudes and intensity of neuron luminescence are described in [5; 6]. Two neurons in positions 10 and 14 demonstrate maximal values of electric current amplitudes and intensity of neuron luminescence. This phase is coded by the **TRIANGLE**.

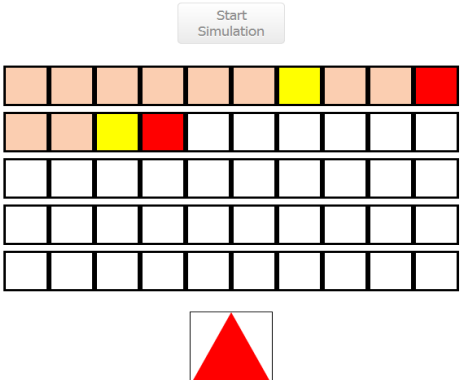


Fig. 8. Phase of triangle coding 1 (explanation see in text)

On fig. 9 the fourth phase of model functioning is demonstrated (phase of triangle coding 2). Neurons at all 50 positions are active (all lines and columns). It means that electrical currents in them all are present and luminescence is present also. As in cases of figs 7 and 8, the values of electric currents amplitudes and intensity of neuron luminescence are described in [1; 2; 5; 6]. Two neurons in positions 13 and 17 demonstrate maximal values of electric current amplitudes and intensity of neuron luminescence. This phase is also coded by the **TRIANGLE**.

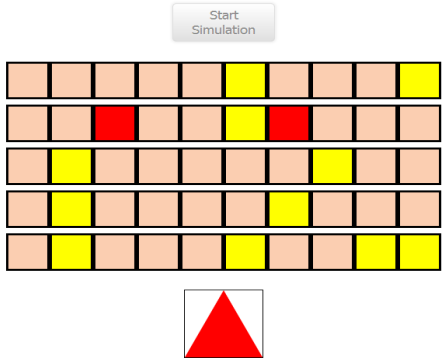


Fig. 9. Phase of triangle coding 2 (explanation see in text)

Difference between TRIANGLE 1 and TRIANGLE 2 is in fact that two active neurons are coding triangles, independently on activity of all other neurons in all other 48 positions.

Conclusions

Following conclusions may be done at the end of present work.

1. Computer model of 2-dimential neuron matrix functioning is developed (model 1).

2. Computer model symbols coding by 2-dimential neuron matrix is developed (model 2). In developed original model of biotechnical system two figures: triangle and circle may be coded (model 2). In our model activity of one neuron on matrix of 49 other neurons is coding the CIRCLE. Activities of TWO NEURONS on matrix of 48 other neurons are coding the TRIANGLE. Difference between TRIANGLE 1 and TRIANGLE 2 is in fact that two active neurons are coding triangles, independently on activity of all other neurons in all other 48 positions. In terms of designed model triangle may mean any searched flying object, and the circle means the absence of such object.

3. Results of mathematical description of few phases molecular element simulation for matrix are represented. Systems which may be described in such a way potentially are systems with “memory” if system can stay in some of the states longer than in other states. Thus, the proposed model can be extended for modeling the screen with elements that have properties of memory.

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В. М. Шутко, О. М. Ключко, Ю. Л. Манагадзе. Моделювання функцій 2D матриць нейронів та принципи кодування символів у системі екомоніторингу

Базуючись на результатах експериментальних досліджень електричних та оптичних властивостей природних нейронів мозку розроблено програмні моделі функціонування 2D матриць нейронів з властивостями пам'яті та кодування символів.

Ключові слова: комп'ютерне моделювання; 2D матриця; мозок; нейрон; модель програми; пам'ять; кодування; символ.

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В. Н. Шутко, Е. М. Ключко, Ю. Л. Манагадзе. Моделирование функций 2D матриц нейронов и принципы кодирования символов в системе экомониторинга

Основываясь на результатах экспериментальных исследований электрических и оптических свойств природных нейронов мозга были разработаны программные модели функционирования 2D матриц нейронов со свойствами памяти и кодирования символов.

Ключевые слова: компьютерное моделирование; 2D матрица; мозг; нейрон; модель программы; память; кодирование; символ.

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