

PROPOSITION OF A PHYSIOLOGICALLY PLAUSIBLE NEURONAL NETWORK FOR THE SIMULATION OF THE PRIMARY VISUAL CORTEX OF THE MACAQUE MONKEY

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ABSTRACT

New technology for cerebral data acquisition combined to the capacity of the nowadays computer process allows the construction of neural networks models, with similar characteristics to the biological neurons. These networks are capable of reproduce the operation of complex neuron structures. These models can generate data that can direct be related to those produced by real biological systems. In this work a computational structure is suggested for a neuronal network with natural characteristics, corresponding to the macaque monkey visual system, in way to situate the memory needs and processing inside the available computers performances.

INTRODUCTION

The purpose of this work is the application of the *NeuronalSYS* Software, developed in the Computational Neuroengineering Laboratory, NEUROLAB, of the Federal University of Santa Catarina, Brazil. The *NeuronalSYS* is a computational package with a biologically plausible neuronal network, able to simulate system with more than 10,000 neurons, each one with thousands of synapses (ANDREAZZA, 2007). In this work the package is used for the simulation of the macaque monkey visual system, turned to the object recognition circuit. The simulation describes the behavior of $1 \times 10^4 \mu\text{m}^2$ - $3 \times 10^5 \mu\text{m}^2$ section of the primary visual cortex, with their especial localizations and own characteristics. Network neuronal models proposed recently are focusing to the generation of properties like orientation, ocular dominance and to the development of maps and columnar systems to describe their macroscopic organization. The main goal of the *NeuronalSYS* is focusing network proprieties.

In one general way, the brain contains about 100 billion neurons that are part of a complex neural network with more than 200 trillion of connections. The understanding of its behavior is essential to cure several brain diseases. However, in function of its complexity, our knowledge is surprisingly limited (MORI and ZHANG, 2006). To overcome this difficulty, the studies of cerebral functions are concentrated on

very specific systems, such the visual system. A good example of that is the Dr.. Callaway group, at the Salk Institute for Biological Studies, La Jolla, California. Among other researches, the group studies the relationships between local circuits in primary visual cortex and early parallel visual pathways. The lab employs anatomical and physiological methods in vivo and in vitro to reveal neuronal circuitry and to identify functional properties of the neurons. Several papers published for this group, and for other researcher's group are about the macaque monkey visual cortex (CALLAWAY (1998), O'KUSKY and COLONIER (1982), BLASDEL and LUND (1983), YABUTA and CALLAWAY (1998)). In function of the available literature data, the macaque monkey primary visual system is analyzed in this work.

The primates' visual system includes the retina, the lateral geniculate nucleus (LGN) and the primary and secondary visual cortex, V1 and V2. The retina is the part of the eye responsible to collect information from visible light. The retina consists of a large number of photoreceptor cells, about 100 million, which releases neurotransmitter cells that send action potentials, through the optic nerve, ON, to the LGN. The maximum release is in the dark, when the cells are not stimulated and the sodium channels are open, and reduces in a logarithm form with the increase of the light intensity. The ON is formed by the convergence of the ganglion cell axons. There are about 1 million of ganglion cells and, approximately 100 of photoreceptor for each one.

The ON of the primates contains approximately 1.8 million of axons, about 90% of then goes to the LGN. Six layers of cells form the LGN, layers 1-2 with large cells are magnocellular (M) and layers 3-6, with small cells, are parvocellular (P). The neurons of LGN receive excitatory synapses mostly of the ON and of cortical afferents coming from the layer VI of the primary and secondary visual cortex. The LGN projects the majority of its axons to the spinal dendritic cells of the layer IVC of the V1 (LUND, 1984). The secondary visual cortex, V2, on the other hand, receives projections of the V1. The V2 processes this information and transmits it to several tertiary visual areas, like V3 and V4, and

to the middle (TM) or inferior (TI) temporal areas. The primary visual cortex measure approximate 1.5 mm of thickness and it is organized in six principal layers. The layer I is the layer that contacts the pia mater membrane. The layer IV is usually divided in IVA, IVB, IVC α and IVC β (CALLAWAY, 1998). The Figure 01 presents a hypothetical diagram of the parallels visual ways in the cortex.

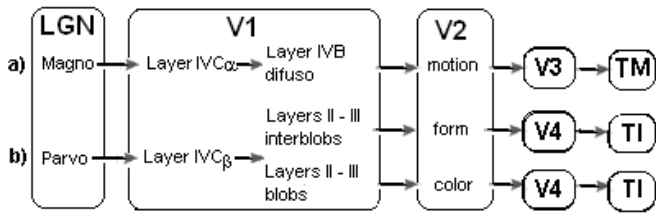


Figure 01: Pathways of the visual system: Each kind of visual processing has a particular via of perception. a) Motion: via M, with projections mainly in the IVC α layer. This layer project to IVB layer that, for its turn, sends projections to dorsal visual areas associated with motion interpretation. b) Shape and color: via P, with projections mainly in the IVC β layer, from where they are sent to blobs and interblobs areas of the II-III layer. Both of then projects to ventral areas, specialized in color and shape identification and, in sequence, to V4 and to inferior temporal areas (YABUTA and CALLAWAY, 1998).

The visual information is processed in parallels pathways that keep segregated, when the sings are project to the visual areas. There are two major pathways for visual processing, that can be summarized in three questions: 1) spatial localization, it means, the “where is it?”, processed by magnocellular cells (M); 2) object recognition, it means, “what is it?”, processed by parvocellular - interblob cells (P-IB); 3) color recognition, or “what color is it?”, processed by parvocellular - blob cells (P-B). Several papers have been published in recent years with the goal of modeling part of the visual system. An example is the model developed by Oliveira (OLIVEIRA, 2001). The idea is to simulate a V1 mammal area based in topographic maps. Other example is the group of Prof. Risto Miikkulainen, which works at the Department of Computer Science of the Texas University at Austin. They proposed the first self organizing neural network of the primary visual cortex (MIIKKULAINEM *et al.*, 1998 e 2005).

The goal of this work is to build a neuronal network, for the object recognition pathway, since the retina until the exit of the V1. To reach this objective is necessary a good description of the macaque monkey primary visual cortex.

PRIMARY VISUAL CORTEX STRUCTURE

The primary visual cortex has regions of high activity and low activity of cytochrome oxidase (CO), respectively blob and interblob regions. Both regions have different characteristics for the processing of visual information. In the blob region are present neurons with high sensitivity of color and light, whereas the interblob region is responsible for the shape recognition. In the retino-geniculo-cortical system, the parallel pathways M and P converge to the IVC α and IVC β layers of the V1 (BLASDEL and LUND, 1983). They are associated, respectively, with motion and shape-color perception. In the V1

the terminations of exit come from II-III, IVB and VI layers. They send projections, respectively, to striped cortical areas, thin and thick, of the secondary visual cortex, V2, and to the LGN.

The patter of connections, which leave the retina, remains segregated (LUND, 1984). That is important to determine the functional differences between the striped cortical areas (LIVINGSTONE and HUBEL, 1988). Yabuta and Callaway (YABUTA and CALLAWAY, 1998), through the reconstruction of the axonal and dendritic arbors of the spinal dendritic neurons presents in the layers IVC α and IVC β showed how the afferents coming from LGN innerve V1. Their work shows still the buttons distribution in IVC layer. In this work is considered just the excitatory buttons, or in other words, the description of the connections established by the parvocellular neurons (P) of the LGN. The afferents coming from layers P aim only the IVC β layer of V1. There are 17.3×10^3 neurons and 37×10^6 synapses, and 30×10^3 neurons and 44×10^6 synapses in 1 mm^2 of cortical surface in the laminas IVC α e IVC β , respectively (O’KUSKY and COLONIER, 1982). In usual network models, 2×10^4 connections can consume approximately 2×10^5 kB of computational memory (MODEI *et al.*, 2004).

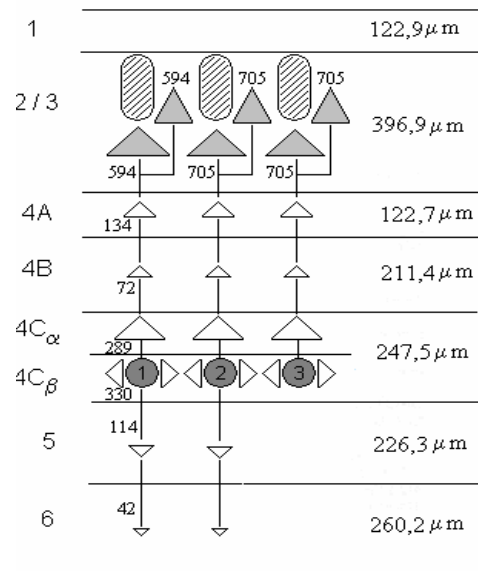


Figure 02 – Via of shape recognition in macaque monkey primary visual cortex. The IVC β layer has two kinds of neurons: neurons 1 and 2 send axonal terminations mainly to layers VI, V, IVC α , IVB, IVA and II-III; neurons 3 send axonal terminations to layers IVB, IVA and II-III data from or must of the data from (YABUTA and CALLAWAY, 1998). The right column shows the thickness of each layer. The triangles are proportional with the number of connections in each layer.

The cells of IVC β have axons that rise through layer IVB and arbor mainly in layer II-III. They have just sparse axonal arbors in layer IVA, IVC and occasionally in deeper layers. The neurons of layer IVC β contribute with 41.3×10^3 synaptic buttons to layer II–III, without any preference for blob or

interblob regions, which means, half of them does connections in each region. They contribute, on average, with 1,378 buttons for cell in the II–III layer. In Figure 02, there is a hypothetical scheme of the principal afferents from IVCβ layer. The density of neurons in the VI is approximately 200,000 neurons in one mm² of cortical surface. For the shape recognition pathway, in 10⁴ μm² of cortical surface there are 400,000 synaptic buttons.

There are different densities of neurons in each layer. The IVCβ layer is denser than IVCα. The II-III layer has proximally 56,000 (28%) neurons. The layer IV has 90,000 (45%) neurons, half of which are in the layer IVC. To determinate the number of synaptic buttons in each layer, it is necessary to consider the relative contribution of each afferent layer. The Figure 03 brings the distribution of the main synaptic contributions in V1 and the neuronal density of each layer. The information will be used to build the neuronal network (ANDREAZZA, 2007). For example, IVCβ layer contributes with 60x10³ synaptic buttons in layer VI and receives from this layer 110x10³ buttons (CALLAWAY, 1998; O’KUSKY and COLONIER, 1982; YABUTA and CALLAWAY, 1998).

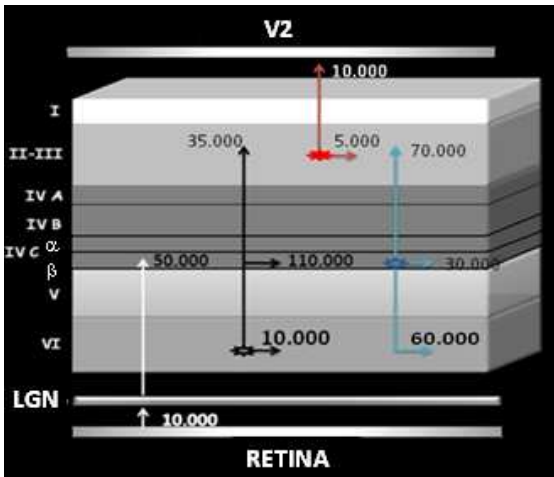


Figure 03 - Localization and number of buttons associated with the shape recognition pathway, for 10⁴ μm² of cortex. For this pathway, the IVCβ layer is the enter of the signal from LGN.

THE NATURAL NEURAL NETWORK

The goal of the proposed network is to describe the dynamic of the visual acquisition data system, turned to the object recognition circuit. The developed program has a central looping that carries on the signals from the afferent plate, the retina, through the network, until the last layer of the visual cortex, the efferent plate. The exit of the primary visual cortex, where the signal comes in pulses, is considered here the effective end of the visual acquisition data circuit. The dendritic arbors are simplified as showed in the right bottom of the Figure 04. As an example of the network conception, the figure shows the model structure of the dendritic arbors of each neuron. The distance between the nodes represents the distance traveled by the signal in each unitary time interval used by the computational program. Each one of the nodes represents one level of the tree and joins the set of signals that goes through the tree at that particular level, at some specific time. For the

dendritic arbor, the numerical value of each node, or dendritic potential (DP), is the summation of all excitatory postsynaptic potential (EPSP), that reach the synaptic buttons at that level and the DP coming of the immediately anterior level. The distribution function of synaptic buttons in the dendrite trees is represented by the equation 1. In the network, the dendrite tree has 100 levels.

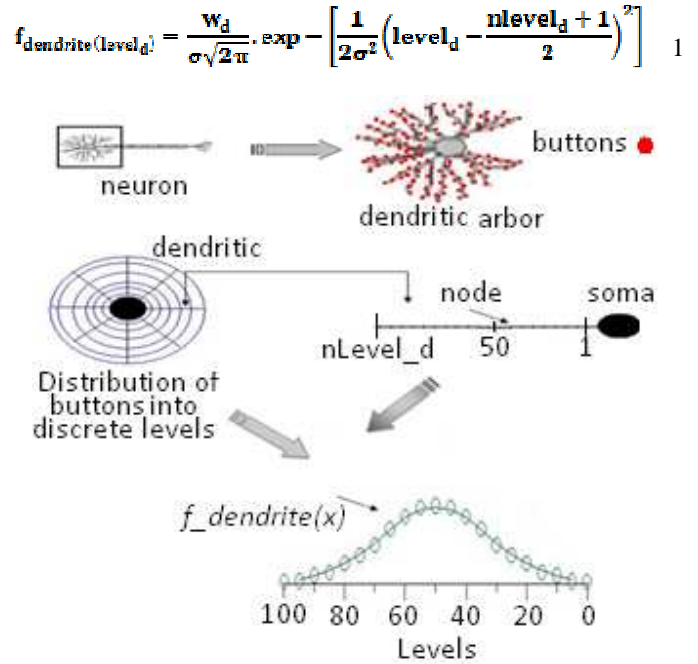


Figure 04: Density of buttons for the dendritic of the neuron and scheme of the arbor simplifications. The left side shows a regular neuron, in which the dendrite innerves a circular region with 200 μm of diameter, and the axon is 1,000 μm long.

Table 1: Main structural parameters

nLayer, layer	number of layers of the structure, and number of one specific layer
nNeuron_x, neuron_x	Number of neurons in the x-direction and x-coordinate of one specific neuron in each layer
nNeuron_y, neuron_y	Number of neurons in the y-direction and y-coordinate of one specific neuron in each layer
nLevel_a, level_a	number of levels of the axonal arbors, and one specific level
nLevel_d, level_d	number of levels of the dendritic arbors, and one specific level
nButton, button	maximum number of buttons in each axon level and one specific button.
attenuation	Attenuation fraction of the signal between two levels

Constructive and Dynamic Parameters

The most complex neural network does not even come close to the complexity of the primates’ brain. That is also truth for any of its systems of neurons, including the visual system, or just the primary visual cortex. Anyway, the only possibility to reproduce, at least partially, the complexity of this system is

through the knowledge of the spatial position and properties of all synaptic buttons involved in the signal processes. As the exact arrival time of the signal in each synapse is fundamental for the dynamic description of the network, it is necessary to know the spatial position of the synapse in both, dendritic and axonal arbors. This information is saved in the synapse matrix, described below. Otherwise, the dynamics of the dendritic and axonal arbors are saved, respectively, in the signal_out and signal_in matrix.

synapse(layer, neuron_x, neuron_y, level_a, button) = N
 Synapse is a structural parameter that includes the spatial position of all synapses in the network. For each synapse (layer, neuron and level_a) the argument indicates the exact button of the axonal arbor where the signal is coming from. The numerical value, N, is an integer that indicates the level of the dendritic arbor, layer and neuron, which is connected with the axon.

signal_out(layer, neuron_x, neuron_y, level_a) = interger
 This dynamic parameter describes the temporal situation of the levels of all axonal arbors of the structure. As the signal in the axonal arbor remains constant, with an action potential value, the parameter just localizes the position of all afferent signals in the network. Therefore, signal_out is an integer with values 1 (one) or 0 (zero), if there is, or there is not, an AP in one particular level of the axonal arbor. The temporal distance between two simultaneous AP in one axonal arbor is the refractory period in the neuron somata.

signal_in(layer, neuron_x, neuron_y, level_d) = \sum PSP
 This dynamic parameter describes the temporal situation of the levels of all dendritic arbors of the structure. Its numerical value corresponds to the summation of all EPSP that reach the node, coming of the nodes one level above, after the attenuation that corresponds to a distance between two nodes, or unitary distance, add to the summation of all EPSP that reach the node through the synapses of that level. PSP is a real number.

Construction of the Natural Neural Network

For each neuron, the buttons in the dendritic and axonal arbors can be thousands. In this way, the functions of buttons density, respectively $f_{dendrite}(level_d)$ and $f_{axon}(level_a)$, can be considered continua. These functions, for the regular case, are showed in the Figure 04. Both functions are discretized in subintervals called levels. The dendrites and axons are discretized, respectively, in nLevel_b =100 and nLevel_a =10 levels. Each node represents the set of buttons localized in the respective level. The temporal distance between two nodes, or levels, is the distance covered by the signal in the computational time unity. As the branches of the dendritic arbor are unmyelinated fibers, the signals are rapidly attenuated. This is called attenuation of the signal. The signal has a slow speed, up to 1.5 m/s. For the axon arbor, myelinated fibers, the numerical value just indicates the position of an action potential, AP, or excitatory presynaptic potential. That is because the branches are interrupted by the Nodes of Ranvier, at which the AP is regenerated. The speed of the signal is up to 100 m/s (DEUTSCH and DEUTSCH, 1993). Based on the thickness and length of the macaque monkey V1 nervous

fibers, we consider here the speed of the signal 1 m/s and 100 m/s, respectively, in the dendritic and axonal arbors. The length of the axons and dendrites are, respectively, approximately 1000 μ m and 100 μ m. Considering the speed of the signal in the dendrites and axons, each arbor is divided in subintervals that are covered by the signal in the same time interval, 1 μ s. In conclusion, each level is covered in 1 μ s, which is the computational time interval.

The typical neuron geometry allows the information in the SNC to be both convergent and divergent. In other words, the dendrites in each neuron receive thousands of synaptic contacts coming from hundreds of different neurons. Inputs from several different neurons converge on one single neuron. On the other hand, the ramifications of its axons can innerve hundreds of other neurons (Figure 05). This way, the several branches in the axons “terminal tree” allow one single neuron to influence, through its axon, thousands of other neurons. This applies to retina-LGN connections, since each of LGN cells receives signals that come from an excitatory field that covers approximately 1.000 retina neuroreceptors.

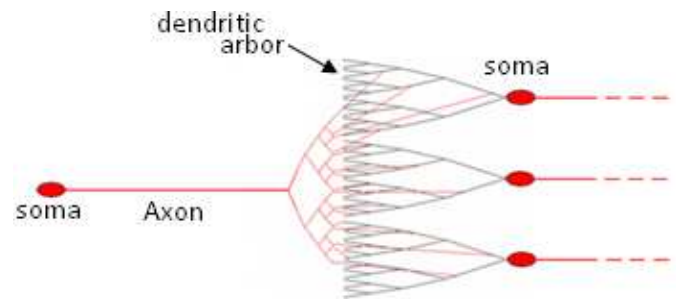


Figura 05: Each neuron of one cortex layer as a receptive field in other layers, that can includes 30-80 neurons. In the innerved neuron, the synapses can be localized in any of the dendrite branches and any distance of the soma. (DEUTSCH and DEUTSCH, 1993).

Considering the independence of the buttons localizations, one from the others, all excitatory field in the intermediate layers can be described by a bidimensional gaussian function (equation 2) (SCHROEDER, 1991). As a consequence, the receptive field of each neuron, in all layers, is described by the function represented on Figure 06.

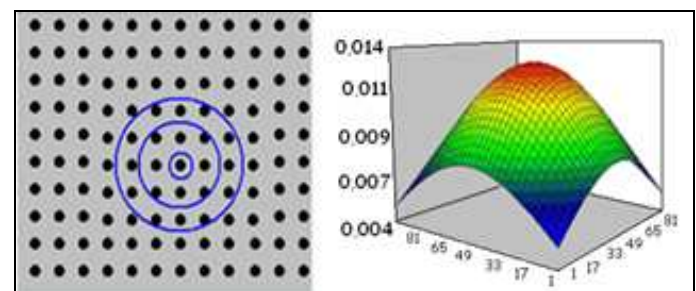
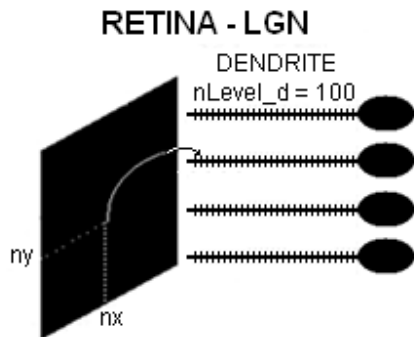


Figure 06: Connections drawn in a 2D gaussian. The center of the circles is the space position, in the other layer, of the excitatory neuron. The circles are lines with the same probability of synapses. In the software geometry each neuron of layers IVC β and VI innerves two other layers, with a receptive field with 16-49 neurons by layer.

$$f_field(neuron_x, neuron_y) = \frac{2w_f}{4\pi\sigma^2} \cdot \exp - \left\{ \frac{2}{\sigma^2} \cdot \left[\left(\frac{neuron_x - x_0}{2} \right)^2 + \left(\frac{neuron_y - y_0}{2} \right)^2 \right] \right\} \quad (2)$$

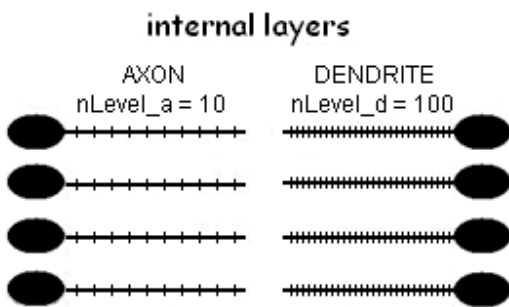
Where w_f is the weight that defines the integral value of the function, σ the standard deviation, $neuron_x$ and $neuron_y$ the coordinates of the neuron and x_0 and y_0 the coordinates of the receptive field's central neuron (According to Table 1).

The internal part of the structure has four layers, representing the LGN and the VI, IVC β and II-III layers of V1. Each one of the layers has $nNeuron_x \times nNeuron_y$ neurons. Both the receptive and excitatory fields, cover 16-49 neuron, depending on the position of the neuron (BLASDEL e FITZPATRICK, 1984; HOPFIELD e BRODY, 2000).



$$afferent(nx, ny) = 10^5 \cdot neuron_x + 10^3 \cdot neuron_y + level_d$$

Figure 07: Afferent fibers, from retina to LGN (Layer 1). The positions in the afferent plate are connected with the first layer that represents the LGN, following a normal distribution. Each neuron of the first layer has approximately 100 connections from an excitatory field with 1,000 of points. The positions of the buttons in the dendritic arbors follow the density distribution shown in the Figure 04.



$$synapse(layer, neuron_x, neuron_y, button) = N$$

Figure 08: Internal connections, from LGN to layers II-III (Layers 1 to nLayer). The connections between the internal layers of the network follow the same distributions for the excitatory and receptive fields (normal distribution) and for the density of buttons distribution in the dendritic and axonal arbors (Figure 04).

The structure is built in three parts, which are showed in the Figure 07, afferent fibers, Figure 08, internal connections, and efferent fibers. The afferent fibers connect the retina and the LGN. There are in the retina approximately 100 photoreceptors for each LGN cell. Following this proportion, in the proposed structure are 100 connections for each neuron of the first layer. The excitatory field of each cell involves a region with approximately 1,000 positions in the afferent plate. The hundred of photoreceptors connected with each LGN neuron are chosen following an uniform random distribution. The efferent plate is innervated in the same way. Each neuron of the II-III layer, the last layer of the structure, connects with 100 points of the efferent plate, uniformly distributed in one region with 1,000 points. The internal connections, for all layers, follow the proportions showed in the Figure 04, where the density of buttons in the dendritic arbor is showed.

Dynamic of the Program

The computational structure is shown in the Figure 09. Initially the software builds the neural network based on biological parameters that include the density of neurons in each layer, the function of density of buttons in the dendritic and axonal arbors, and the schemes of signal distribution in the primary visual cortex of the macaque monkey. In the sequence it reads a file with the image that will be process by the neural network. At the present time of the research, the image is just black or white.

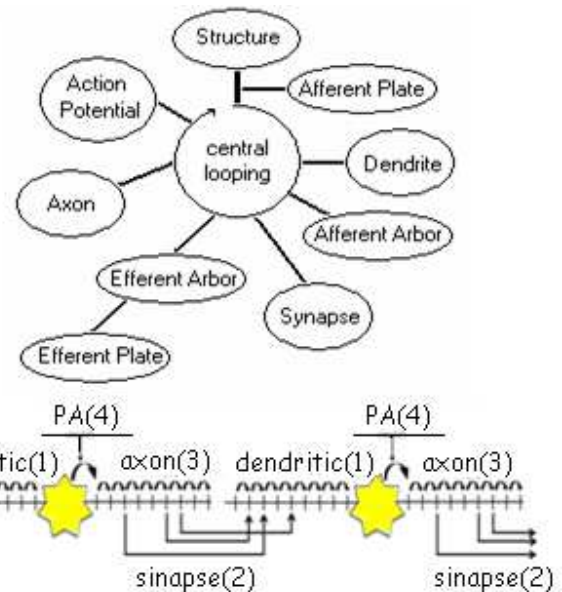


Figure 09: Computational structure of the *neuronalSYS* program. In the bottom, it is a sequence of events for the actualization of the whole matrix of the program.

The figure shows the central looping of the program. In the bottom is the sequence of events: dendrites, synapses, axons and action potential. Following the looping:

1. The signals in all dendritic arbors of the structure go to the next level, level_d + 1, with the correspondent attenuation.
2. All synapses with AP transfer the signal to the dendrites. The same thing happens with the afferent fibers that innervate the parvocellular layer of the LGN. These fibers

provide excitatory inputs that come from ganglion cells.

$$signal_in_{k,t+1} = attenuation \cdot signal_in_{k+1,t} + PSP \cdot \sum_k signal_out_{k,t}$$

- The APs in all axonal arbors go to the next level, level_a + 1, always with the same value. The efferent fibers transmit the signal to the efferent plate, which is the visual part of the program.

$$signal_out_{k,t+1} = signal_out_{k-1,t}$$

- If the signal that arrives in the somata its equal or greater than the critical threshold level of fire, and the cell is not in his refractory period, one action potential is generated.

The efferent plate represents the signal patter that leaves the network each time interval. The values for each position of the plate, zero or one, is saved in the efferent(x,y) matrix. The behavior of this matrix is studied here.

RESULTS:

The construction and operation of the proposed neuronal network reproduces the main characteristics of the primary visual system of the macaque monkey, according to the available data in the literature. The considered region covers retina, LGN and the V1 layers, VI, IVCβ and II-III. The implemented structure is represented in a schematic form in the Figure 10. The signals that come from V1 are considered the final representation of the data acquisition circuit. The density functions of buttons are based on experimental data (CALLAWAY, 1998; O'KUSKY e COLONIER, 1982; LUND, 1984). They are discretized in levels that represent intervals travelled by the signal in 1μs, that is the computer's time unit. This organization reduces the amount of computational memory required. Despite that, considering the large amount of connections in each V1 unit of volume, the proposed network is adjusted for cortical surfaces around 10⁴ μm² to 3.10⁵ μm².

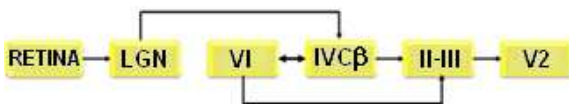


Figure 10 –Schematic representation of the *NeuronalSYS* structure.

The Figure 11 shows the distribution of buttons in the dendritic and axonal arbors generated by the program. Both curves agree with the distribution showed in Figure 04.

The synapses are distributed amongst the dendritic and axonal arbors using, respectively, one-dimensional and exponential Gaussian probability distributions, which are valid for all the neurons existent in the network. In both cases a RANDOM routine is used, that generates a pseudo-random sequence that is equally distributed. The objective is to make the button distributions in each arbor meet the distributions used, and that the positioning of each button be chosen randomly. Figure 11A shows the results for the dendrites. The arbor is divided in 100 levels and the distribution is centered on the intermediate spot. The curve's opening depends on the

standard deviation. Each neuron, individually, follows the theoretical curve, presenting little dispersion, as shown in the figure. In this case two IVCβ neurons were randomly chosen, the (30,25) and (6,30) neurons. The curves reproduce the way in which the buttons, that they form, distribute themselves in the dendrites of the neurons in II-III. The standard deviation controls the probability of connections occurring in the extremes. In this paper the standard deviation used is σ = 10. This choice concentrates the majority of the buttons in the region situated between the levels 20 and 80. Figure 11B, shows the button distribution in the axons. The theoretical exponential function used reduces the probability of connections occurring close to the soma. Even though, both figures are showing just the connections between the IVCβ and II-III layers, they exemplify what occurs in all layers. This is also true for each of the neurons used in the computer's structure. All of them have distributions of buttons in the dendritic and axonal arbors similar to those shown in the figures.

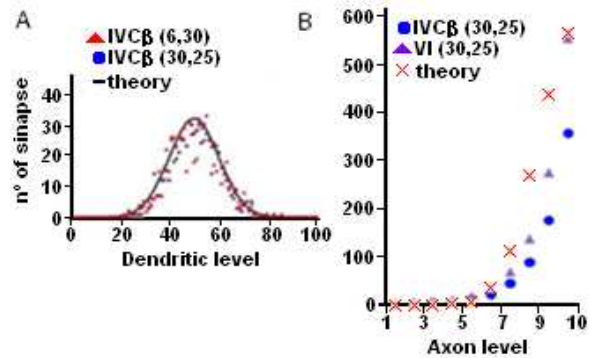


Figure 11 – (A) Distribution of buttons in the dendritic arbors following Gaussian functions. Each interval in the abscises represents a distance of 1,0 μm, that is traveled in a computer time unit of 1,0 μs. Both the button distributions curve produced by two neurons of the IVCβ layer, the (30,25) and (6,30) neurons, and the theoretical curve are represented. (B) Distribution of buttons in the axonal arbors following exponential functions. Each interval in the abscises represents a distance of 20 μm, that is traveled in a computer time unit of 1,0 μs.

For the construction of the network was used a pseudo-random generating routine with uniforme distribution existent in the FORTRAN 90 compiler, from COMPAQ (Compaq Visual Fortran Professional Edition 6.6 a), the RANDOM routine. This routine utilizes a SEED that defines the random sequence produced. That is, to produce a different pseudo-random sequence a different SEED is necessary. The algorithm used a modified version of the random number generator proposed by PARK and MILLER (Random Number Generators: Good ones are hard to find, CACM, October 1988, Vol. 31, No. 10). Routines of this type may contain tendencies in the beginning. In order to avoid this in the program the first 5,000 numbers are slighted. The question that emerges is whether the properties of the generated network are dependent of the value used for the seed. To verify this, the results produced by four different seeds in the construction of the network and in it's dynamic are compared. The seeds used

were: SEED = 1, SEED = 12345, SEED = 79891 and SEED = 999999. The dynamic of the network is easily observed in the exit of the V1. Figure 12 shows the distribution of the action potentials in the computer time of 135 μ s for all cases. All results show the same pattern. Despite the small difference in the position of the synapses, the overall behavior repeats itself, showing that the seed used in the random routine does not influence the results. The number of action potentials is practically constant and they are situated in such positions that reproduce the same image. Therefore, it has concluded that the results obtained with the network are independent from the seed chosen at the beginning of the random routine used in the program.

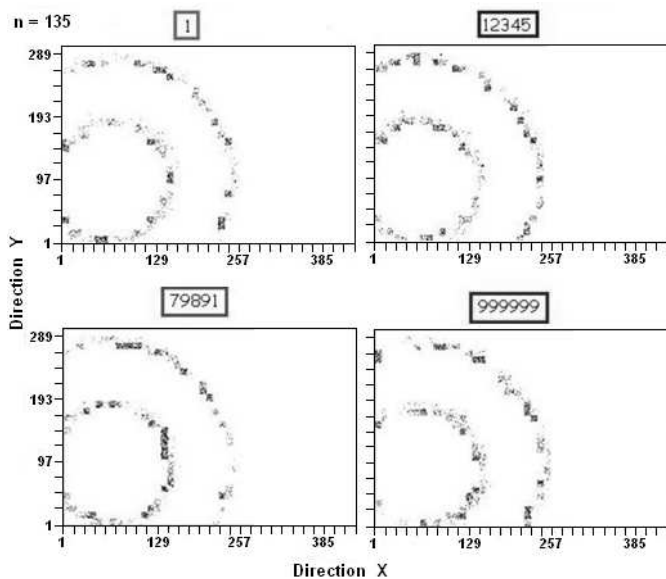


Figure 12 - Exit patterns of the network. The figure shows the behavior of the network for several seeds for the random routine used for the construction of the network. The seeds utilized are, clockwise, 1, 12345, 999999 and 79891. The points in the figure represent the positions of action potentials within the computer time frame analyzed.

CONCLUSIONS

The proposed neural network reproduces the main characteristics of the macaque monkey visual system, from the retina (afferent plate) to the exit of the primary visual cortex (efferent plate). It is built based on biological parameters that describe the density of neurons and buttons in four layers of the visual cortex and in the parvocellular layer of the lateral geniculate nucleus. The function of density of buttons is based on experimental data (CALLAWAY (1998), O'KUSKY and COLONIER (1982), LUND (1984)). One of their properties is the division of the dendritic and axonal arbors in, respectively 100 and 10 levels, in way to reduce the number of buttons in two orders of greatness. Because of it, the simulation of the primate primary visual cortex is possible, in the part corresponding to the recognition of static objects

ACKNOWLEDGMENTS

CNPq for providing a scholarship to the first author.

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