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Abstract

Actually, no one can clear up exactly how the neuron network of the human brain works. The anatomical maps abound but those functional, are poorly understood and little produced. It falls to computational Scientists to find the way to use Informatics in Neurology. The contribution of this article is to propose three principles of modeling. The first approach relies on the brain and nervous systems: making the analogy between the brain areas (their relationships) and Petri Nets (PN). The vision based on the cortex consisting in feigning the architecture in layer of this coat will allow deducting a model which will know how to reproduce the functioning of a cortical column and their connections. Finally, consider each neuron can be used as a way to produce a model that will represent their communications.

Key words: Petri Nets, brain, neurons, cortex, modeling.

1 Introduction

The research of a plausible brain modeling is topical. This evolution arouses the interest of the computer specialist which is sought to generate references helped by the neuroscientists. The connection of nerve centers by impulse sensitive and sensory constitutes the neural network, the key element being the neuron. It performs transmission and treatment of small information that pass along the nerve fibers (axons and dendritic tree). Their massive concentration gave to the cortex the name of gray matter. It is this film which integrates and synthesis the information to command the brain and the whole body. It is the most important part of this organ. To model a discrete event system, we can use Petri nets. It is a graphical environment which allows visualizing the evolution of a process. The ease of understanding which derives from him grants a very profitable simplicity. Parallelism, concurrency and real-time are system properties that are handled by this tool. Classes of network treat the temporal problem to widen its application. The analysis of the model is deduced from the graph and this will lead to a path of achieving full-scale of the network function. The representation is the fact of making more "readable": in sign, in symbol or in image, a model, that is to create a realization of a reference. The production of new representations is the purpose of the research made by neuroscientists. They are focused on the field of computational neuroscience.

2 State of art

2.1 Blue Brain Project

The Brain Mind Institute of the Ecole Polytechnique Fédérale de Lausanne (EPFL) has started since June 2005 the Blue Brain Project. The project aims to produce, within ten years, the first "real" electronic brain from biological data collected in neurology [9] [10]. With his team of 35 scientists, the initiator of this project, Professor Henry Markram, completed the first phase of its experience in December 2006 [9] [10] [12] [18]. The approach was first to simulate a cortical column of the neocortex of a rat. The tests of representation were used to polish model in silico: presentation of images and measuring the electrical activity of response [9].

Reverse engineering methodology allowed obtaining great accuracy at the cellular level of brain activity [10]. The cortical column in question consists of 10,000 neurons with 30 million synapses of 550 picometer in diameter and 1200 picometer in height, is taken in the somatosensory cortex of a rat about two weeks old in accordance with the dendritic trees of the fifth layer (layer of pyramidal cells) [10]. Modeling's role is to examine and evaluate the inconsistencies and relevance of the results. Ion channels of the cells were calibrated and discoveries from the experiments conducted were published in July 2008 in the European Forum of Neuroscience [10].

This first step is vitally important because the structure of the cortical column varies little in mammals, it is repeated millions of times but the cells constituting are about 300 types [12] [18]. "Each neuron has 500 building blocks, which had to determine the electrical characteristics, such as resistance, capacity, etc. Each block has in additional, 20 ion channels, each modeled by six equations", Felix Schürmann [12]. To collect biological data, a layer is detached from the column (kept alive) and responses to stimuli are recorded via 12 electrodes.

According to Henry Markram, "There are many models of the brain, but they often come from science of artificial intelligence. Our model is the first from biological data", more, "Neuroscience produce 35,000 publications per year, each specialist cannot read seriously over 100 of them. Only modeling can unify this knowledge very fragmented."[12]. The next step is to model the brain neither at the cellular level but at the molecular level with chemical protein reactions, and thousands of columns will be simulated together to increase the complexity of the network and finally to overcome this challenge [12].

To simulate the model, Brain Mind Institute has partnered with IBM, and a supercomputer of the generation "Blue Gene" is installed in the Lausanne campus [9], the Blue Gene/L [10]. With its 18.7 teraflops, is the third fastest supercomputer in the world [9] [12], and the most powerful existing in Switzerland, the world number one is a model of the same brand installed at Lawrence Livermore National Laboratory, California (478 teraflops). The Blue Gene/L consists of 8192 processors [10]. The calibration consists of tests to refine the accuracy of the biological model: gene expression, ion channels, dendritic integration properties, synapses, neuronal morphology, cellular composition, connector roads and properties of sub-circuits [10]. The next phase of this novel research will require a more powerful machine capable of processing calculations over than petaflops what is possible with the Blue Gene/P, forthcoming, of IBM [12].

2.2 Parallel simulations

Djurfeldt published October 18, 2006 an article on the parallel simulation of neural network within the FACETS project started in 2005 by Meier at the University of Stockholm. The medium of the simulation is, as the Blue Brain Project, a Blue Gene/L supercomputer. The simulator used is SPLIT, written in C + +. Layers II and III of the neocortex have been the subject of the study: 22 million neurons and 11 billion connections, the equivalent of 16 cm^2 cortex (that of a small mammal like the rat or mouse). The overall organization of the structure corresponds to a several minicolumns, grouped into hypercolumns. In reality, 100 to 200 minicolumns form a hypercolumn; in SPLIT this number is configurable and in their experiments, it is set to 100 by hypercolumn. The idea is to simulate the transfer of ions in interneuronal exchanges following the equations governing the formalism of Hodgkin-Huxley. This approach allows tracing the process of memorization knowing that pyramidal neurons are responsible for this phenomenon. During the days Blue Gene Watson, the 8192 processors of Blue Gene/L were mobilized with a memory usage of 336 MB each making a total of about 2.8 TB. To cover the 22 million neurons, SPLIT uses 8 supercomputers Blue Gene/L [4].

Another simulation tool based on the study of individual neurons has been proposed by Hines in an article published March 7, 2008. It is composed of several databases stipulating the functioning of ion channels, the properties of cell membranes, and the model of structure adopted, the type of constituent neurons, the region to simulate and the neurotransmitter in question. It is part of the program NEURON v6.1. For a single neuron, the simulation was done on two different types of machines: x86_64 Intel dual-processor dual-core 3.2 GHz Dell Precision 490 and an SGI Prism Extreme with 32 1.5 GHz Itanium2 processors and 300 GB shared. For a simulation of the entire network of neurons, the supercomputer EPFL IBM Blue Gene/L with 8192 processors (770 MHz PowerPC 440) was used. Purkinje cells of the cerebellum are the focus of these experiments [6].

2.3 Other models

Mathematical models of the functioning of neurons and neural networks have been established since 2002 and consolidated in tutorials used for computer modeling. One example is the Hodgkin-Huxley model that governs the passage of ions in ion channels taking into account the properties of the cell membrane. The Mathematical Biosciences Institute (MBI) at the University of the State of Ohio publishes such documentations as a basis for mathematical researchers in computational neuroscience [2]. Similarly, SIAM News, volume 31, number 5 highlights two mathematical models of the functioning of the brain that is the Markov Random Field (MRF) and Gibbs Random Field (GRF) for vision, learning and memory processes [8].

Testing models amateurs have also emerged:

- the "GENESIS Neural Database and Modeler's Workspace" project of the GENESIS group: a database prototype done in MySQL with graphical interfaces in Java. It simulates the ionic conductance [19];
- Neurofit is a program made in Matlab in order to visualize changes in tension in cell membranes [1].

Other institutions have also proven themselves by using the Blue Gene/L: one of them is University of Nevada. Simulation of the cortex of mice: 16 million neurons with 8000 connections per neuron. The experiments were conducted with respect for temporal constraints, with a constant multiplicative factor [3].

3 Modeling

3.1 Brain

Mental functions are lateralized in the brain. It would appear that information takes several trips most does not succeed. The first attempt to answer is: a delayed reaction from one of the two hemispheres forces the other to react and take a unilateral decision hence the existence of certain disorders of perception. In General, the left hemicorpus is controlled by the right hemisphere of the brain and vice versa. Only the smell escapes this rule [15].

Below a map representing the global functional compartments of the brain [14]:

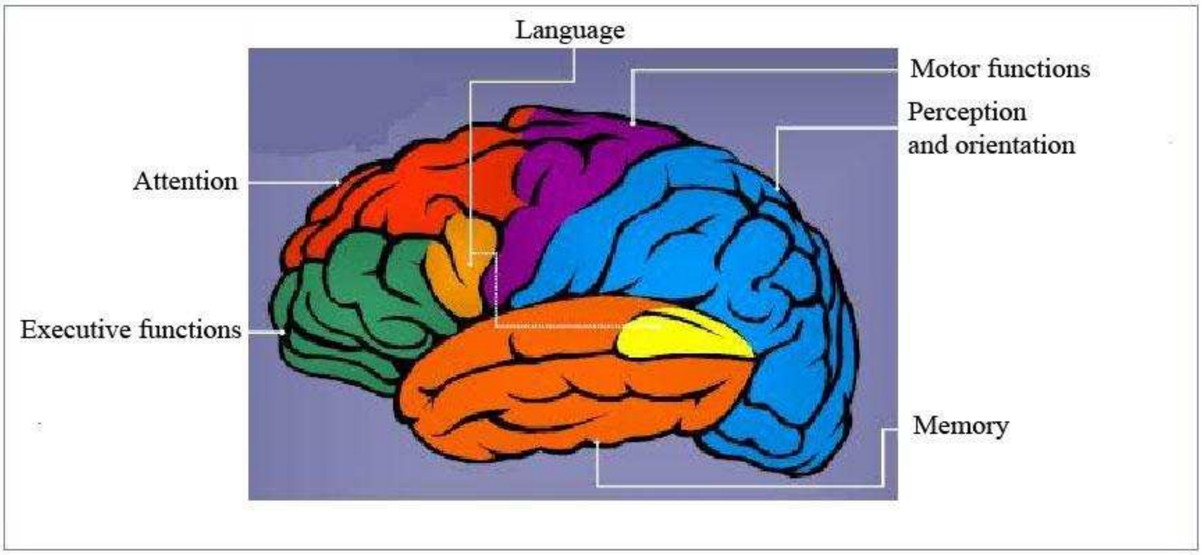

Figure 1: **Neuropsychological map of the brain**

The above data lead to a design of parallel type of the operation of the brain. The idea is to design a model to represent the functions of learning, memory and execution of movement. For this, we will first admit that the brain has a distinct functional structure, which allows considering that a place in PN will be illustrative of an area of the brain. The transitions mark the interzones passages that are supposed instantaneous. The arcs connect these areas and their valuations depend on the relevance of the information debited by the upstream place to achieve the desired activity: that is to say that the more the weight of the arc is important, the greater the information required by the transition, to make the crossing are numerous. This means that the information will be represented by the marks. The timer is then assigned to places. The PN of model Van der Aalst and flow time network appear to be adequate to this model. For p-PN, the notion of dead marks simulates the futility of certain information for crossing a step.

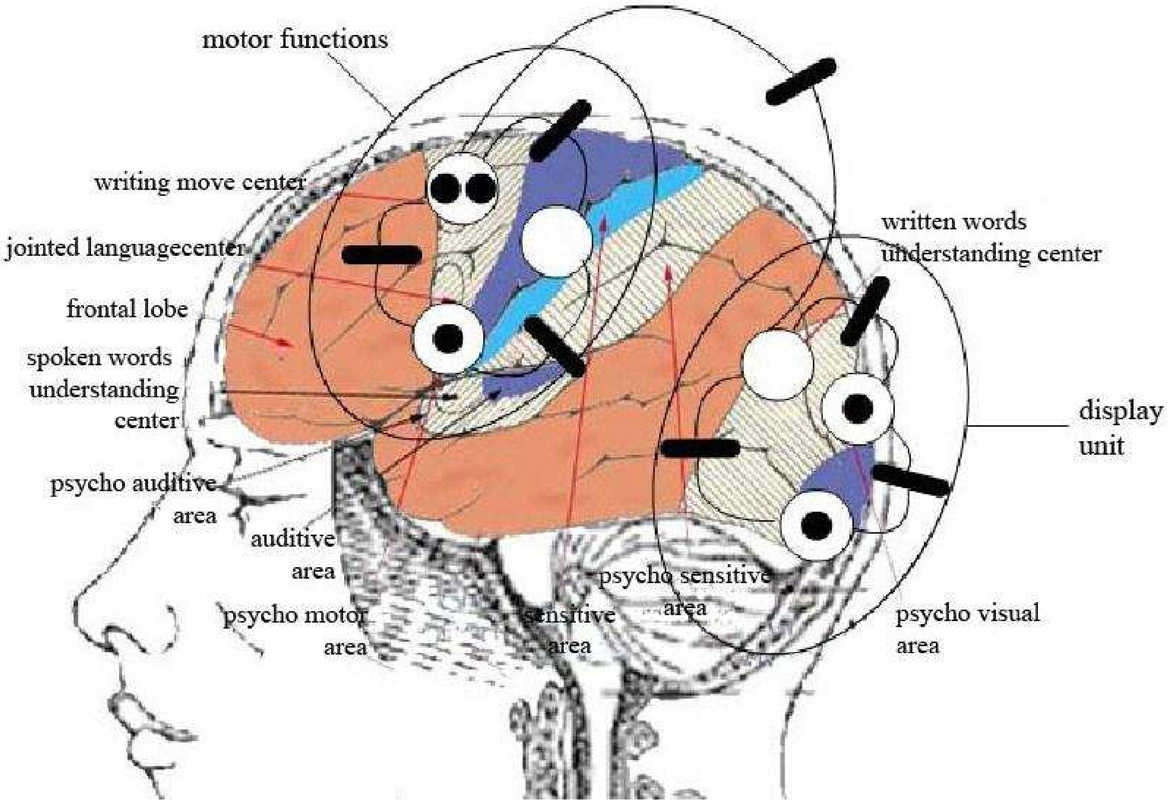

Figure 2: **Writing movement modeled by a PN**

The problem encountered in the modeling test relates mainly on the lateralization of brain function. Furthermore, compartmentalizing the brain is a simplifying assumption that tends to become a truth, but of microstructures distort this theory. The side of PN, the lack of precise meaning of the control flow between the parts of the brain does not lead yet to a directed graph. Nevertheless a non-oriented PN which would retain the properties of an oriented PN could solve the problem.

3.2 Cortex

An interpretation of the procedure of the prefrontal cortex and the basal ganglia is that they function as a computer in the opinion of O'Reilly, formulated in an article published October 6, 2006 in Science, "The neurons in the prefrontal cortex are binary they have two states, active or inactive and the basal ganglia is essentially a big switch that allows to switch dynamically different parts of the cortex". The prefrontal cortex is the executive center of the brain and supports cognition, problem solving and decision making. This part of the cortex is a social network expanded by the features, binary type mentioned above. This gives the brain its flexibility in handling new symbolic information [11].

For the motor cortex, the organization layer is still valid but there is some functional fragmentation. The first concepts of motor cortical organization were made by John Hughlings Jackson in the 19th century. The results of electrical stimulation made by Penfield and Boldrey during neurosurgical operations in humans evoke functional maps grouped in the homunculus of Penfield presented with Ramsussen in 1950 [5].

The main motor regions of the cortex are distinguished by their granular layer (IV) who is very thin or absent. In these areas, layer V is particularly important. The dendrites of pyramidal cells of each layer of the cortex provide strong vertical connections in cortical columns. Inside of these columns, the cells share common input and output connections. In addition to these vertical connections, there are also strong horizontal connections between the columns. In layers II and III (and IV in other cortical areas), the pyramidal cells form dendritic plexus. The axons of pyramidal cells in layer V also send recurrent collaterals before entering the white matter [5].

Because the neocortex is composed of six layers that are connected together vertically and horizontally and that the communication of command from top to bottom and from bottom to top is done in a parallel manner, the use of PN to translate this parallelism can therefore be an approach to modeling the cortex. The proposal is: a layer of a column will be taken as a place, the interface between layer will be represented by a transition, and the number of neurons which are able to unload their neurotransmitter is equal to the number marks in place. Arcs will determine the nerve cells that will be able to carry out the shooting. This cortical column will be related to other via a nesting of the supra network.

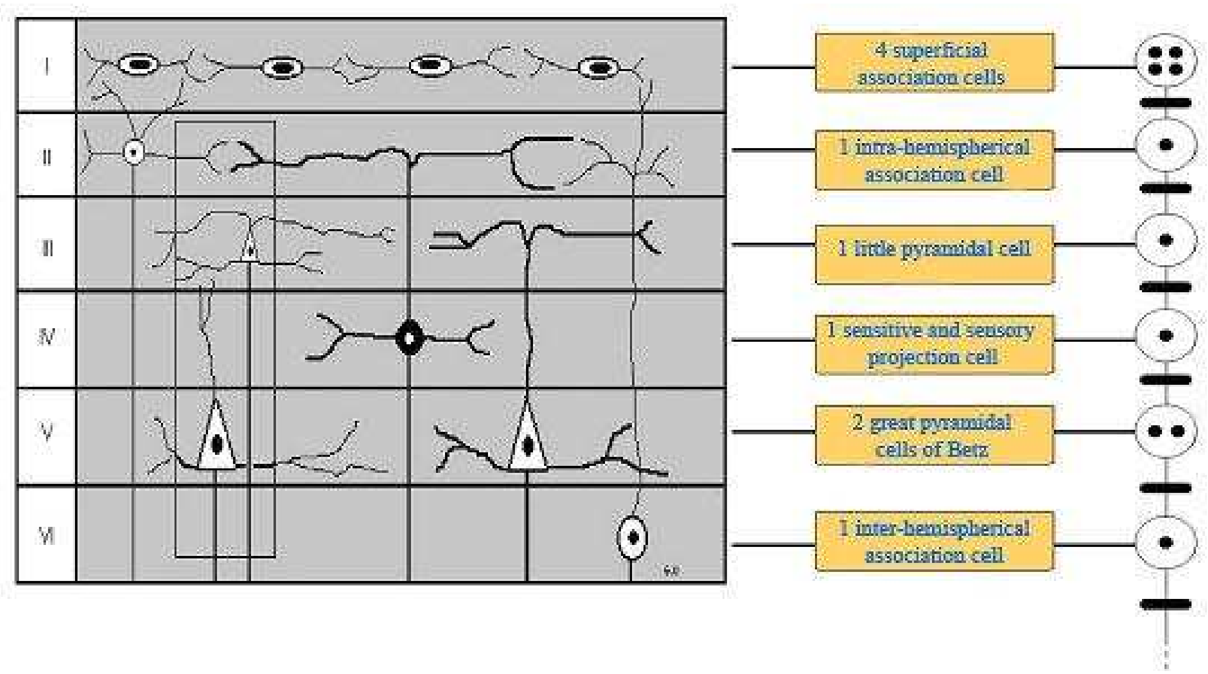

Figure 3: **Analogy between layers of the cortex and PN**

The matters relating to the functions of the different layers of the cortex have not been well elucidated, specifically those of cells constituting each. This limits the possibility of taking into account all the neurons of a layer to form a unit, but also creates an ambiguity by considering one by one these cells and their relationships within the same layer.

3.3 Neuron

Neurons communicate with each via combinations of electrical signals [16], the signal issued is a function of the sum of received signals [7]. At rest, permanent potential with a value of -75 mV to -65 mV exists between the two sides of the membrane of a neuron (inside being electronegative) [13] [16]. The number of potential action (brutal membrane polarization inversion) per unit of time characterizes the intensity of a stimulus [16] [20].

Really, at a synapse, the transmitter neuron loose of neurotransmitters that bind to the synaptic button of receptor neuron. A threshold on the number of attached molecules trigger an electrical signal from which the transmission [7] [13]. The action of a synapse may however be inhibitory or excitatory [7] [20]. The average number of excitatory synapses must exceed 40 to cause the outbreak [20]. The opening of Na^+ channels is the cause of the reverse bias, and the opening of a K^+ channel allows bringing back the resting potential: it□s the refractory period [13]. Note that the receiver is opened if the molecule of neurotransmitter is good [17].

The model that will result from this representation is equivalent to neural networks. The soma is likened to a place that stores electric charges from neurons related to the one considered. These electric-chemical charges are the tokens and a sufficient number of charges allow the crossing of a synapse, hence the notion of weight of the arc. Similarly, the incidence after is used to define the number of action potential that will boost the neuron below the synaptic space.

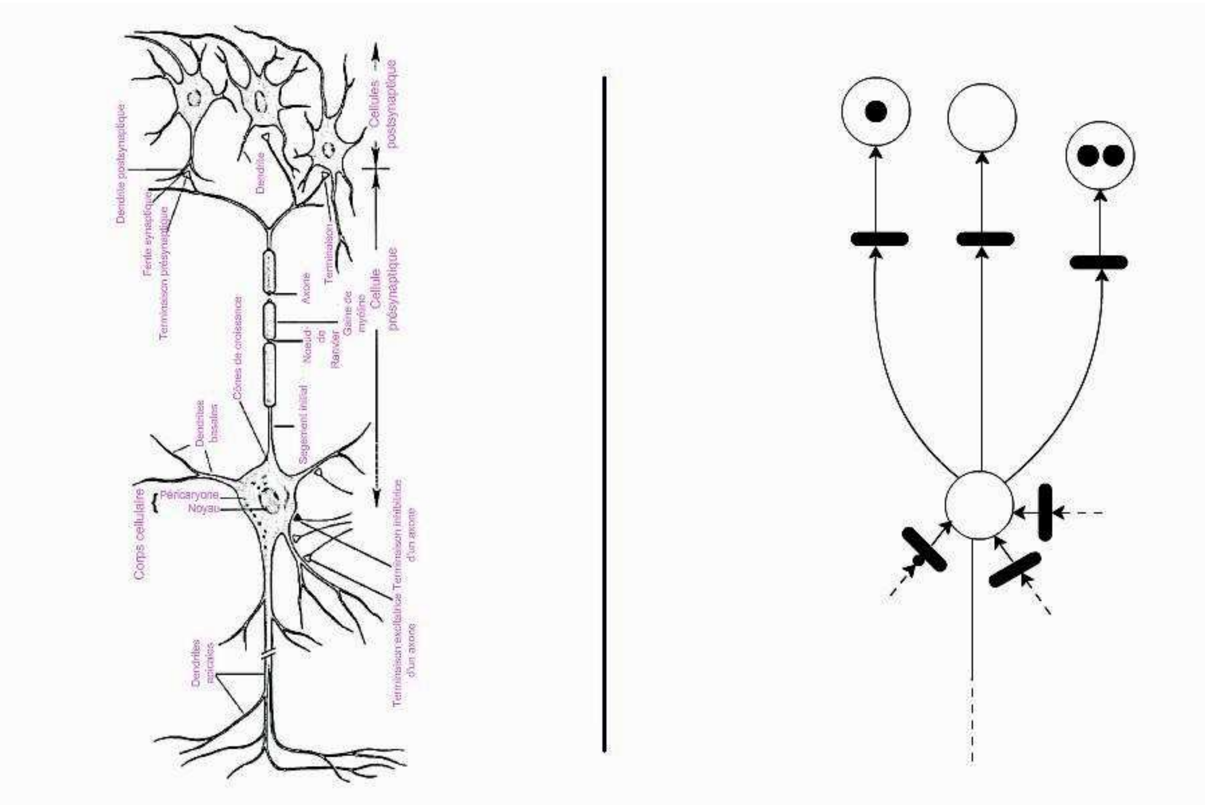

Figure 4: **Interneuron relationship modeled by a PN**

The difficulty is to know the threshold at which a synapse makes the transfer of nerve impulses. Selectivity complicates modeling because the reaction of neurons to a particular neurotransmitter will be diversified so a generalization is not feasible: it should be taken case by case basis. A contradiction also occurs on the notion of inhibitor arc: in PN it's the absence of upstream marks that characterizes it, for neural networks the inhibition effect is felt at the downstream neuron but neurotransmitters are always released.

4 Conclusion

The more unknown organ of our body is the brain. Every developed living system has a brain, but the man's brain differs by the presence of the cortex which gives the faculties of language, cognition, perception, imagination, basically, of consciousness. Nerve endings are in the sensorial and sensitive organs and are the sources and exit points of the commands generated by the cortex. Extensions of neurons provide this function of transmission. Systems having variables that evolve discretely use Petri networks to perform their modeling. They have the opportunity to consider the synchronization and the notion of duration. Block, liveliness and boundedness are the main features governing PN. The cortical map is variable depending on the individual and their personal experiences, the representation that everyone has of the outside world is also differentiated. To understand the functioning of the neural networks (biological), the brain and the layers of the cortex, computational neuroscientists are trying to create models of references. The generated model will be the first step toward building hardware or software functional links governing the human brain. The functional modeling of the brain is based on maps existing since the 1937. The dawn of computer development forced the medical community to generate models able to follow this evolution. Several laboratories are working on this.

5 References

[1] Allan W., *« neurofit », http://www.uoguelph.ca/~awillms/neurofit/*, mai 2004.

[2] Borisyuk et al., *« Tutorial in Mathematical Biosciences I », http://lib.org.by/info/B_Biology/Borisyuk A., B.G.Ermentrout, A.Friedman, D.Terman. Tutorials in Mathematical Biosciences.. Mathematical Neuroscience.. v. 1 LNM1860, Springer,2005/ISBN 354023858.178s/_B_.pdf*, Lecture notes in Mathematics, août 2004.

[3] Christophe J., *« simulation d'un cortex de souris sur un super-calculateur ? », http://www.automatesintelligents.com/labo/2007/mai/simulationcortexsouris.html*, Automates intelligents, mai 2007.

[4] Djufeldt et al, *« Massively parallel simulation of brain-scale neuronal network models », http://www.bgconsortium.org/news/Past_Results/kth bgwreport06.pdf*, Blue Gene Watson Consortium Days, octobre 2006.

[5] Ethier C., *« Propriétés fonctionnelles et organisation du cortex moteur chez le chat »*, Faculté de Médecine Université Laval Québec, 2007.

[6] Hines et al., *« Fully implicit parallel simulation of single neurons »*, *http://www.neuron.yale.edu/neuron/static/papers/split/multisplit.pdf*, Yale University et EPFL, mars 2008.

[7] Mansour S., *« Réseaux de Neurones, une introduction »*, *http://www.lirmm.fr/~terrat/ENS/EDI/TER2007/26 - Les reseaux de neurones SALJOQI Mansour.pdf*, Université des sciences de Montpellier, mars 2009

[8] Martin et al., *« Cooperativity and parallelism in mathematical models of brain function »*, *http://www.siam.org/pdf/news/99.pdf*, SIAM news, volume 31, numéro 5, 1998.

[9] Michel D., *« Le cerveau humain copié »*, *http://apeis-du-cher.over-blog.fr/36-index.html*, Apies, août 2007.

[10] Michel G., *« Le projet Blue Brain de lEPFL: vers une reproduction du cerveau humain »*, *http://www.invention.ch/revue-de-presse/2008/epfl-blue-brain.htm*, La Revue Polytechnique, janvier 2008.

[11] Michel, *« Une partie de notre cerveau fonctionnerait comme un ordinateur.htm »*, *http://www.techno-science.net/?onglet=news&news=3255*, Vie et Terre, octobre 2006

[12] Nassim, *« La modélisation du cerveau est possible selon les Suisses »*, *http://www.algerie-dz.com/forums/showthread.php?t=65135*, Forum Algérie, décembre 2007.

[13] Saïghi S., *« Circuits et systèmes de modélisations analogiques de réseau de neurones biologiques : application au dveloppement doutils pour les neurosciences computationnelles »*, *http://tel.archives-ouvertes.fr/docs/00/32/60/05/PDF/2004_These_Saighi.pdf*, Université Bordeaux I, soutenu le 29 novembre 2004.

[14] *« carte neuropsychologique du cerveau »*, *http://www.institutsmq.qc.ca/publications/materiel-didactique/*, GENeP, 2004

[15] *« deux hémisphères »*, *http://www.journaldunet.com/science/biologie/dossiers/06/0602-cerveau/6.shtml*, linternaute science, 2009.

[16] *« La communication nerveuse »*, *http://www.crdp-montpellier.fr/ressources/RD/SVT/.._CSVT_CCCAR_CCCar07_CCCar07.pdf*, juillet

2009.

[17] *« Le fonctionnement d'une synapse »*, *http://www.journaldunet.com/science/biologie/dossiers/06/0602-cerveau/5bis.shtml*, l'internaute science, 2009.

[18] *« Les mystères du cerveau prêts à être percés »*, *http://www.amge.ch/2007/11/27/les-mysteres-du-cerveau-prets-a-etre-perces/*, Association des Médecins du canton de Genève, novembre 2007.

[19] *« Modelers Workspace Channel Database »*, *http://www.genesis-sim.org/hbp/channeldb/*, GENESIS, 2007.

[20] *« neurones et synapses »*, *http://www.journaldunet.com/science/biologie/dossiers/06/0602-cerveau/5.shtml*, l'internaute science, 2009.