Should we talk about Neural Tissue instead of Neural Network ?

Damien Depannemaecker, UNIFESP São Paulo, ddepann@gmail.com
Antônio Márcio Rodrigues, UFSJ São joão del-Rei, amr@ufsj.edu.br
Antônio-Carlos G. de Almeida, UFSJ São joão del-Rei, acga@ufsj.edu.br

Computational neuroscience has been developed in parallel with growing knowledge of biological aspects. First studies by Cajal and Golgi on neural tissues had shown the morphology of neurons and the gap between them. Then Sherrington came up with the idea of the chemical synapses and the corresponding neurotransmission mechanism that were later confirmed by Loewi's work. Historically, discoveries in neuroscience have highlighted the importance of neurons and networks of neurons. McCullogh and Pitts have established that simplified neuronal models are able to resemble complex properties of the brain function. The proposition of the Hebbian theory by Donald Hebb, in 1949, added more enthusiasm to the view of the synaptic circuitry (or neural network) as the solely core of the brain function. Later, based on previous contributions on neurodynamics performed by Rosenblatt, Rumelhart and al.(1986) proposed the backpropagation method to estimate the error contribution of each neuron of the network, based on which optimal synaptic weight readjustments are carried out, this method guided the development of different neural network algorithms used for years in machine learning. Most of the studies and applications in computational neurosciences consider only networks of neurons with synaptic communications. However, the brain is not only formed by neurons and synaptic circuitry. The networks of the brain are immersed in a substrate and the connection between neurons may also be non-synaptic. The substrate is the ionic fluid and the extracellular matrix. Directly affecting the excitability of the neurons is the ionic balance between the intra and extracellular spaces, also known as the ionic homeostasis. Several mechanisms take place in the ionic homeostasis and the interplay between them constitutes a system of high complexity. The Na/K pump, co-transporters, exchangers and ionic channels form this system. Based on the model that has been developed in the Laboratory of Experimental and Computational Neuroscience (LANEC, UFSJ) by Almeida et al [1] and Rodrigues et al [2], we proposed a realistic model of a neural tissue, named Neural Tissue Model (NTM). The NTM consists of twenty one excitatory neurons and one inhibitory interneurons, inserted in an extracellular matrix represented by ionic electro-diffusional process (ED). Parameters of the NTM has been based on observations of dentate gyrus of rat hippocampus. Communication between neurons, randomly initialized, is based on a synaptic communication model proposed by Teixeira et al. [3]. Stimulation by current injection is applied to four of the neurons, and is followed by adaptation of synaptic communication, in function of the expected state of one output neurons. A comparison between the NTM and two conventional artificial neural networks, based on backpropagation (ANN-BP), and direct feedback alignment (ANN-DFA), was conducted. Simple pattern recognition tasks were used in the comparison, divided in two classes, and XOR-like problem. Results show that with the NTM the number of presentations of the full dataset (NPD) to get a correct separation of the two classes is much lower than with ANN-BP and ANN-DFA. For a XOR-like task, on 1000 trials, the median NPD is 41.0 for ANN-BP, 27.0 for ANN-DFA, and only 3.0 for NTM. The study also evaluated the effect of the parameters representing the neuronal tissue structure on the performance of the NTM (extracellular volume, ED, cell size and density, synaptic network initialization, synaptic weight initialization). Convergence rate of the NTM to solve the tasks were very sensitive to these parameters. The irregularity in the extracellular matrix, represented by a non-uniform ED improved the NTM performance (median NPD with uniform ED = 10.0, with non-uniform ED = 3.0). The NTM is able to converge to different levels of connectivity, and therefore to stabilize in a normal operating state (meaning bellow the threshold that could lead to seizure). This work shows the importance of non-synaptic interaction between neurons. The irregularity and variability in a neural tissue for fast adaptation to respond to a specific task is essential. The complexity in nature seems to be an explanation of the efficiency of biological system.

References

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