INFORMATION PROCESSING IN BRAIN-INSPIRED NETWORKS: SIZE AND DENSITY EFFECTS

***B. Paprocki*[1]*, A. Pregowska*[2] *and J. Szczepanski*[2]**

[1]*Institute of Mechanics and Applied Computer Science, Kazimierz Wielki University, Bydgoszcz, PL*

[2]*Institute of Fundamental Technological Research, Warsaw, PL*

1. Introduction

Understanding how neurons encode and decode information is one of the greatest challenges of the contemporary science [1]. One of the fundamental questions regarding brain networks analysis is how the efficiency of signal processing is affected by network architecture and mechanisms formed in the process of evolution, particularly long-range and inhibitory connections. Special interest lays in disclosure the influence of, first, size of the network (understood as number of neurons) and second, density of it (distance between cells). The efficiency essentially depends on how neurons cooperate processing the information. Number of papers address questions on how neuronal mechanisms adapt to make the transmission more efficient. Most of them provide qualitative results, while the information theoretical approach delivers the quantitative perspective.

We propose methods of Shannon Information Theory [2] as a tool to quantify neural processes in a rigorous mathematical way: neural networks are treated as communication channels, therefore the information is understood as Mutual Information (MI) between input (stimuli) and output signals (response) [2, 4]. We apply the Levy-Baxter probabilistic model of neuron [3] that best suits the information-theoretical approach. This model contains all essential qualitative mechanisms participating in the transmission and it provides results consistent with physiologically observed values.

Presented results show that mechanisms in organisms evolve in a way that entails improvement of the neural information-energetic transmission efficiency. Our simulations suggest distinct roles for the network's size and density. We conjecture that the size assures high reliability of transmission, whereas density boosts its efficiency.

2. Brain inspired networks

In general, the brain can be regarded as an ensemble of individual neurons, interconnected in such a way that output of one neuron becomes input to some of the others. Full description of brain networks requires detailed characterization of their topologies. Not only placement of neurons is important, but also their types and connections between them (including long-range connections and linkage with information source). The proposed brain inspired network consists of number of nodes (i.e. *size*), each of them being a pair of excitatory (*E*) and corresponding inhibitory (*I*) neuron, distributed uniformly over the circle of radius r (defining *density*), see Fig. 1.

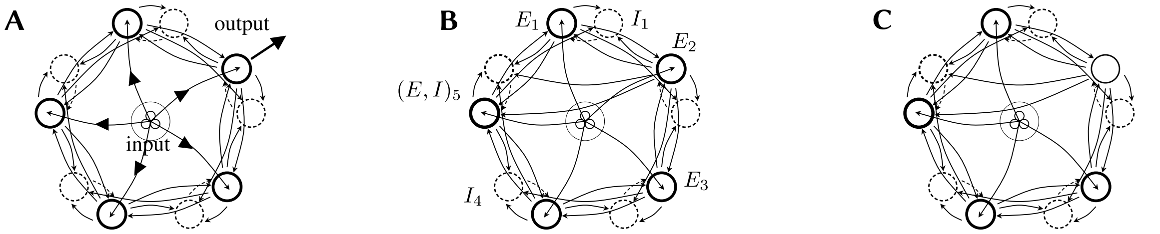

Figure 1. Five-node *brain inspired* neural network. **A**, a symmetric case. This basic case is then modified by: **B**, *long-range* connection $E_2 \to (E, I)_5$, and **C**, removing access to the information source from neuron E_2.

3. Results and Conclusions

Our previous results for brain inspired networks consisting of five nodes [5] show that inhibitory neurons (i.e. if inhibition strength $b > 0$) can improve information-energetic transmission efficiency by 50 percent in comparison to architectures lacking inhibitory connections (if $b = 0$). Transmission is most information-energetic effective if inhibitory-excitatory strength ratio is below 0.5. Moreover, it was found that long-range connection can lead to improve target neuron's information-energetic efficiency significantly, even by 70 percent, if neuron starting this connection has no access to the source of stimuli. If the connection originates from neuron that has such access, it can bring a 40 percent loss to the target neuron's efficiency, however this connection increases the efficiencies of starting neuron and neurons neighboring target neuron by up to 24 percent.

We also observe that the most effective network is the most dense one (i.e. with the smallest r). Two times increase of r can cause even three times decrease of the information-energetic efficiency.

In this paper we put important question about the role of network size. We study this problem for symmetrical networks consisting of 5, 20 and 40 nodes. Fig. 2 show Mutual Information dependencies on firing-rate of information source and on synaptic success. Three inhibitory-to-excitatory balance parameter values are considered: $b = 0, 1, 2$. Surprisingly, it turns out that transmission efficiency is independent of number of nodes. We conjecture that the role of network size (node-wise) is closely related to network reliability rather than transmission efficiency.

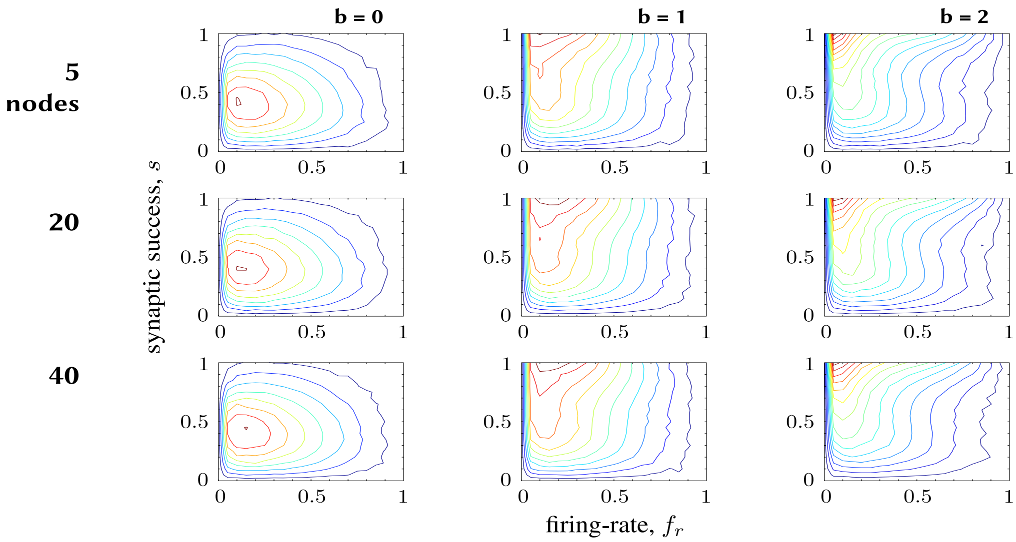

Figure 2. Mutual Information dependencies on synaptic success s, in neural network architectures consisting of 5, 20 and 40 nodes with activation threshold set to 0.2 and inhibition strength $b = 0, 1, 2$.

4. References

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