10th International Workshop
Neural Coding 2012

Book of Abstracts

Prague, Czech Republic,
September 2–7, 2012
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Transmission efficiency in the brain-like neuronal networks.
Information and energetic aspects

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Biological systems evolve as compromises and many of them can be expressed in terms of energy efficiency [1, 2]. Inspired by brain network architecture we analyze the communication channels composed of the main brain ingredients. We study the information-energetic transmission efficiency of such neuronal networks. The Shannon Information Theory is applied and the fundamental concept of this theory, Mutual Information between input and output signals is estimated with high accuracy. The entropy estimator is that of high quality proposed in [3] and the encoded information were of 10^6 bits long to reach high accuracy. The model of neuron considered is that in the spirit of probabilistic approach proposed by [1] and further explored in [4].

The network constitutes from nodes each of them being a pair excitatory neuron and corresponding inhibitory one. The nodes are distributed uniformly over the circle (Fig. 1). Each node is connected with neighboring nodes and additionally the nodes can be connected through long-range connections. Source signals are modeled by Bernoulli process (spike or no-spike) and they can support excitatory neurons only. We study a variety of complementary architectures (Fig. 1). The following parameters affect the effectiveness of this communication system: Source parameter – firing rate \( f_r \), entropy \( h \); Neuron parameters – synaptic failure \( s \), threshold activation \( g \), inhibitory level of dumping \( b \), number of synapses \( l \); Network parameters – size \( r \), number of nodes \( n \). We assume that most energy is consumed by spikes. Thus, with Mutual Information for a given neuron denoted by \( M1 \), we analyze the information-energetic formula:

\[
\Lambda(b) = \max_g \left( \frac{\max_{(s,f_r)} M1(s,f_r,b,g)}{\vartheta(s^0,f_{r}^0)} \right),
\]

where \( \vartheta(s,f_r) \) is equal to \( s \cdot (n f_r + b f_I + \sum_w f_w) \), \( s \cdot (b f_I + \sum_w f_w) \), \( s \cdot \sum_w f_w \) for with- and without access to the source and for inhibitor, respectively. \( \vartheta(s^0,f_{r}^0) \) are the values maximizing \( M1 \). The denominator is proportional to the number of spikes actually used to transfer information. The role of inhibitors, long-range connections and size-delay effects are studied and information-energetic optimal parameters are determined.

Figure 1: Brain-like neural architectures we studied. Each one has five nodes and source of size \( l = 3 \). A, a symmetric case. B, \( E_2 \) has no access to the source of information. C, symmetric case with added long-range connection from \( E_2 \) to \( E_5 \). D, a combination of B and C.
Inhibitors influence: Parameter $b$, being a ratio of inhibitory neurons’ strength in relation to excitatory neurons’ strength, affects every signal that $I$ neuron sends forward. If $b = 0$, then amplitude of every inhibition signal is reset to zero as if $I$ neurons had completely no effect on the structure’s behavior. The bigger the $b$ is, the more potent inhibition signals are in relation to excitatory ones. If $b = 1$ then both types of neurons react with the same strength. It turned out that inhibitors can strength the effectiveness of transmission even by 50 percent (Fig. 2A).

Size effects: The most important effect of the size increase is a delay in transferring the information. Therefore it was expected that the transmission is most efficient for smaller size, i.e. for $r = 1$ ($r$ is radius of the circle) but surprisingly further increase of the size ($r = 2, 3, 4$) does not change effectiveness significantly (Fig. 2B). We also observe that a two times increase of the size can cause even three times decrease of the information-energetic efficiency.

Long-range connections role: We observe that long-range connection can lead to improve target neuron’s information-energetic efficiency significantly (even by 70 percent) if the neuron starting it has no access to the source of the stimuli. If the connection originates from neuron that has such access, it can bring a 40 percent loss to the target neuron’s efficiency (Fig. 2C) – however this connection increases the efficiencies of starting neuron and neurons neighboring target neuron by up to 24 percent.

Conclusions: Our research shows, both through qualitative and quantitative results, that the brain-like networks significantly improve the information-energetic transmission efficiency.

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