Doctoral School of Information and Biomedical Technologies
Polish Academy of Sciences (TIB PAN)

SUBJECT: Transmission efficiency and reliability in neural networks inspired by brain architectures. Information Theory and Machine Learning Approach.

SUPERVISORS, CONTACT, PLACE OF RESEARCH

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Name of the institute in which the topic will be realized: **Institute of Fundamental Technological Research**

Scientific discipline: **Information and communication technology**

PROJECT DESCRIPTION

The brain, as a whole, can solve complex tasks within milliseconds – in some cases much more rapidly than any contemporary computer vision system (e.g. pattern recognition). The naturally important question arises: *what kind of mechanisms causes the brain to be so fast*? Understanding how neurons encode and decode information, process it, and control its transmission, is one of the greatest challenges of contemporary Science [1]. Researchers, for many years, conducted intensive studies on ways of neuron signaling [2,3]. One can accept that neurons and neuronal network architecture are adapted by Nature to make transmission the most effective, in particular, their parameters are close to optimal. Specifically, such optimization problems arise when one considers variables and structural brain parameters like synaptic weights, the firing rates of individual neurons, the synchronous discharge of neural populations, the number of synaptic contacts between neurons, and the size of dendritic boutons.

Shannon Information Theory [4] provides effective quantitative tools to evaluate the transmission of information between neurons, within the network of neurons, or at the opposite ends of the brain-machine and brain-brain interfaces. This theory is successfully used as an objective measure of behavioral changes in response to specific stimuli and changes occurring **during the learning process.** Defining the maximum information (or Mutual Information) that can be transmitted by individual neurons and networks can help us to understand how information is processed in the brain [5].

As part of the doctoral thesis, **an analysis of the information contained in the responses of the neural network to incoming signals and external stimuli** is provided. An important goal will be to explain **when neurons cooperate effectively during the information transmission process**. What are the natural **learning mechanisms** to adopt optimal parameters? A quantitative approach [6, 7] will be developed based on the methods of **Information Theory** and **Machine Learning**. Mathematical models of neurons reflecting their functional features will be considered, among others **IF neurons, Hodgkin-Huxley neurons, Levy-Baxter neurons,** or the **Izhikevich neuron model**. The neural networks will be treated as **communication channels** in the Shannon sense. Both the input and output signals will be represented as trajectories of some stochastic process treated as an Information Source. The encoded signals are represented as sequences of symbols from the input and output alphabets. As a starting point, the input signals will be considered, according to the literature, as trajectories of (homogenous or non-homogenous) Poisson stochastic processes or Markov processes.

The qualitative and quantitative results obtained will be used in **the process of designing the next generation of computers** that will be able to self-solve complex problems and learn from their own experiences. Obtained knowledge will be also used in the **construction of intelligent self-learning robots**.

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[5]**Pręgowska A, Kaplan E, Szczepanski J,** How Far can Neural Correlations Reduce Uncertainty? Comparison of Information Transmission Rates for Markov and Bernoulli Processes, Int. J. Neural. Syst. 29, 1950003–1–13, 2019.
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