

The purpose of the project is to study the stability and efficiency of information that can be written in neuronal connections called synapses, which is related to processes of learning and memory in neural networks.

Information about the content of learning in humans and animals is written in the brain in synapses. Empirical data show that synapses are dynamic and often unstable objects: they can modify their structure, neurophysiological properties, molecular components, or even they can spontaneously appear and disappear in a matter of minutes and hours. These dynamical processes are generally called “synaptic plasticity”, and due to them organisms can learn, i.e. acquire and encode new information.

However, the fact that synapses are so dynamic causes a certain fundamental problem: how is it possible then that synapses can maintain the information in their structure (or biophysical properties) for much longer time scales: months and years? This problem is a kind of mystery, and it seems to be basic and important not only for neuroscience, but also for the so-called “artificial intelligence”, where the purpose is to build intelligent systems that are capable of learning, remembering long what they have learned, and using effectively the learned information.

It is known from theoretical physics that information is always in some way related to energy. In particular, the problem of energetic costs of encoding and storing information seems interesting, also because synapses are very small and are subject to stochastic noise (e.g. thermal). The question which will be studied here is: what is the energetic efficiency of synapses in the processes of learning and memory, both on a microscopic level (single synapse) and on a mesoscopic (network of neurons). This topic seems to be interesting for statistical mechanics, and will be investigated with the methods of stochastic nonequilibrium thermodynamics, since synapses and generally neural circuits operate out of thermodynamic equilibrium.

Memory traces exist in the brain in the form of collective synaptic activity, which is extended in time. Such memory traces can be represented as stochastic trajectories of activity, i.e., they can be described in the framework of stochastic dynamical systems, which is the subject of applied mathematics.

Therefore, the problem of synaptic information stability in “unstable” or stochastic synapses has an interdisciplinary character, because it concerns with neurobiological topics, which can be described by methodology taken from statistical physics (thermodynamics) and applied mathematics. In particular, within the currently existing models of synaptic plasticity, we will try to find the relationships between the amount of encoded information, its accuracy, its duration, and associated metabolic cost. These topics are relatively new and not well understood in neuroscience, and it seems that they require an interdisciplinary approach.

The expected end result is to gain an understanding about the mutual relationships between information and energy in synapses. The hope is to find mathematical formulas linking information and energy, which could provide a deeper understanding of learning and memory on levels of interacting synapses and their molecular components, in the framework known from physics and applied mathematics.