Abstract

For most neurons, the information the neuron passes on is contained within the times of sending out electrical pulses - so-called action potentials. It is still not fully understood how to read this “neural code”. The efficient coding hypothesis proposes that due to evolutionary pressures sensory systems evolved to transmit and process information in the most efficient way possible. However, the notion of efficiency seems to be different in different sensory systems. Cortical neurons keep their firing rates low to minimize metabolic expenses. So do insect olfactory receptor neurons (ORNs, the first layer of the olfactory system). Neurons in the insect antennal lobe (the second layer of the olfactory system), on the other hand fully use the space of possible firing rates to encode the maximum information about the odor. In my thesis, I studied how can single cortical neurons and their populations transmit and process information, while keeping metabolic expenses low, and also how the insect olfactory system encodes information about odors encountered in the air.

In the part of my thesis about metabolically efficient information transmission I focused mainly on the role of inhibitory neurons in efficient information transmission. Through mathematical analysis and Monte Carlo simulations of spiking neuronal models, I show how can the input from pre-synaptic inhibitory neurons decrease the trial-to-trial variability of the post-synaptic neuron, and by generalizing these results to a recurrent neural network I illustrated how the trial-to-trial variability can decrease with a stimulus-onset, phenomenon known as neural variability quenching. However, an information-theoretical analysis showed that the input from inhibitory neurons in the form of inhibitory feedback with a stimulus onset will only yield significant improvements in metabolically efficient information transmission if the information is being transmitted by a population of recurrently connected neurons, rather than a single neuron.

To understand the general principles governing neural coding, I next focused on the neural activity of the insect olfactory system. I analyzed the local field potentials (LFPs) and firing activity of insect ORNs stimulated with a novel odor-delivery device, capable of temporally precise stimulus delivery. These novel recordings showed that moth ORNs are much more capable of encoding the stimulus duration than previously thought. The properties of moth ORNs were revealed to be very similar to the properties of the majority of Drosophila ORNs, which allows the unification of the research on those species. Using the recordings of the LFPs I constructed a minimal model of the moth ORN, which reliably describes the firing activity while using only several interpretable parameters.

A simple and transferable model, that can describe the firing activity of the ORNs is essential for building an integrative model of the insect olfactory system. Such a model could be used to study the information-metabolic efficiency of the whole system and analyze if under certain conditions the high firing rates in the antennal lobe actually aid the information-metabolic efficiency. Therefore, the results of my thesis are a step forward to understanding the general principles governing the neural code.