Statistical models of information processing in neuronal systems

Abstract
Understanding the mechanisms by which the brain processes and transmits information is a major goal of computational neuroscience. Neurons transform stimuli into sequences of action potentials, but the efficiency of this "neuronal code" is not fully understood. While spike count or temporal patterns alone may partially explain stimuli encoding, combining both features provides a more comprehensive representation.

In my thesis, I investigated information transmission in neuronal systems from the rate coding perspective by focusing on the instantaneous firing rate, which integrates rate coding and temporal coding features. Using classical statistical models of neural activity, I found that dispersion measures of the interspike intervals can differ significantly from the instantaneous rate dispersion measures in a model-dependent manner. Applying our findings to experimental data revealed that this approach offers deeper insights into the information-encoding mechanisms of neurons. Building on this foundation, I investigated the influence of biophysical properties on rate coding. Basic integrate-and-fire models lack firing rate and membrane voltage saturation, which is inconsistent with observed neural activity. Incorporating reversal potentials increased the slope of the "firing rate vs. input" curve, but did not achieve saturation. Extending the model to include two nodes (dendritic and somatic) effectively limited both voltage and firing rate, aligning the model more closely with biological observations.

In order to understand the rate coding principles that govern information transmission in neuronal systems, I studied how male moth *Agrotis ipsilon* olfactory receptor neurons (ORNs) optimize information transmission under challenging sensory conditions. Analyzing responses to pheromones amid varying concentrations of volatile plant compounds (VPCs) showed that these backgrounds can suppress neural responses in pheromone-responsive ORNs but also increase the information transmitted per spike. This study highlights ORNs' optimization mechanisms for navigating complex olfactory landscapes, enabling insects to detect crucial pheromonal cues despite environmental interference.

Extending my research from neuron populations to neural networks, I investigated the effect of spike frequency adaptation (SFA) on neural variability quenching in cortical networks. Using a model with excitatory and inhibitory subpopulations, I demonstrated that SFA mechanisms significantly influence trial-to-trial variability, crucial for efficient information transmission.

Overall, my work provides a comprehensive analysis of information transmission from the perspective of rate coding, progressing from single neuron to complex neural networks. These findings enhance our understanding of the underlying mechanisms of neural coding, offering refined models that better reflect biological realities.

Keywords: Neural coding, variability, randomness, olfaction, rate coding