Neural population activity in the visual cortex: Statistical methods and application

Abstract:
The traditional approach to understand the visual cortex is to relate the responses of a visual cortical neuron to the visual stimulus. However, the response of a neuron is not only related to the stimulus but also on the responses of other neurons. One approach to identify the interactions across neurons is dimensionality reduction, which identifies latent variables that are shared among neurons. The focus of this thesis is to apply dimensionality reduction to activity recorded from visual cortical neurons to gain insight into the underlying neural mechanisms that govern the interactions among neurons. In the first part of this thesis, we use dimensionality reduction to ask if the complexity of the visual stimulus varies with the complexity of neural activity in monkey primary visual cortex (V1). We systematically vary the number of neurons, trials, and stimuli, and find that dimensionality reduction returns sensible and interpretable outputs. This motivates us to use dimensionality reduction for visual brain areas beyond primary visual cortex that are farther from the sensory periphery.

In the second part of this thesis, we focus on understanding the activity of neurons in monkey V4, a visual brain area known for mid-level visual processing. Because V4 neurons selectively respond to complex features of visual stimuli and interact with higher-cortical brain areas, new statistical methods are needed. For example, we develop an adaptive stimulus selection algorithm that efficiently chooses natural images that elicit diverse responses from V4 neurons. Next, to relate the recorded V4 activity to activity recorded from other brain areas, we develop a novel dimensionality reduction method that identifies linear and nonlinear interactions among brain areas. We use these methods to characterize a latent variable that slowly drifts in V4 activity on a long time scale (30~minutes). We find that the slow drift is present in both V4 and PFC, and is related to slow changes in behavior, suggesting that the slow drift is an arousal signal. Overall, this thesis advances a new way to analyze population activity recorded from the visual cortex that can better elucidate how visual cortical neurons transform visual input into behavior.

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