The Codes of Curvature: Reconstructing Macaque V4 Receptive Fields with Gabor Wavelet Noise

CPSC 490 Project Description
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De Facto Adviser: Professor James Mazer, Neurobiology

Summary

In order to understand the visual processing performed by the brain, it is necessary to understand the underlying representations of visual information used by neurons along each step of the process. Computational neuroscientists have made great strides in understanding the linear filtering that the brain performs in the early visual system, such as in V1. However things get more difficult as the neural processes begin performing nonlinear computations. The motivation of this project is to explore the application of two different spike-triggered statistical analyses, spike-triggered averaging and spike-triggered covariance, to tease apart the underling filter kernels that are combined in nonlinear fashions in later visual processing. To do this, the project consists of two major components: 1) building neuron models and 2) analyzing real data. The research will be conducted under the supervision of Professor James Mazer.

Goals

The primary goals of this project are 1) to understand techniques that can used to to recover filter information from visual processes which include non-linear elements and 2) to explore the underlying structure of V4 neurons’ receptive fields.

Research Plans & Methodology

I. V1 & Curvature Detection Models
The first part of the research is to build working models of V1 Simple Cell and Complex Cell neurons. I will then use the spike-triggered analytic techniques on them in order to build up an intuition for the analysis I will be doing on real macaque data.

II. The Macaque V4 Experiment
The second component of the project is to analyze V4 cell data collected from macaque monkeys using the spike-triggered covariance technique to better understand the
stimulus features that drive cell activity. The data to be analyzed was collected from a monkey shown a stimulus especially designed to drive the subunits that are hypothesized to serve as inputs to V4 neurons. The stimulus is wavelet noise, generated by superimposing a variety of Gabor wavelets of different orientations and positions. This stimulus should effectively cover the entire stimulus space that the neurons respond to. Using spike-triggered covariance, we will locate the combinations of Gabor wavelets which are usually active at the time that the neuron fires. This will tell us how much about the mathematical processing that leads to curvature and shape detection. Once the filters have been recovered using spike-triggered analyses, a curvature detector model will be constructed, tuned to respond to the same filters as the natural cell, and its output compared to a given stimulus compared with the actual cell's.

III. Mathematical Techniques Used

Background

I. Non-Linear Processing in the Visual System
Non-linear processing has traditionally been difficult to understand yet critically important to understanding the mechanisms underlying all but the simplest components of V1. Currently the majority of research focuses on the first component of the Wiener kernel, corresponding to spike-triggered averaging. Techniques like spike-triggered covariance make it possible to extract the linear filters (which are normally hidden after their outputs are combined via a nonlinear process).

II. The Mazer Lab
The research for this project will be supervised by Prof. Jamie Mazer. The Mazer lab is part of the systems neuroscience group at the medical school. Their research agenda is to understand the nature of visual attention and its relationship to behavior, focusing especially on cortical area V4. The lab combines biological techniques such as single-cell recording from mice and macques with computational modeling and data-analysis.

Personal Experience & Qualifications

I am prepared to tackle this research project thanks to training in computational neuroscience obtained a combination of computer science and cognitive science courses: CPSC 475 Computational Vision & Biological Perception (Fall 2012), NBIO 582 Computational Neuroscience (Spring 2012), CGSC 110 Introduction to Cognitive Science (Fall 2011) and CGSC 201 Brain & Thought (Fall 2011). In these courses I
have developed skills in understanding the concepts of cognitive neuroscience, the analysis of neural networks and programming in Matlab and Numpy.

**Deliverables**

1. **Final Written Report.** Scientific paper which describes:
   a. the construction of V1 simple cell and V1 complex cell models
   b. analysis of V1 models using spike-triggered average and spike-triggered covariance techniques
   c. the construction of the curvature detector as a way to model the V4 macaque data
   d. analysis of macaque V4 data and curvature detector model using spike-triggered average and spike-triggered covariance techniques
   e. discussion of similarities and differences of spike-triggered averaging and spike-triggered covariance analysis between V1 and V4 cell models
2. **Models.** Delivered as Matlab files.
   a. V1 Simple Cell Model. This model will be analyzed using spike-triggered average analysis.
   b. V1 Complex Cell Model. This model will be analyzed using both spike-triggered average analysis and spike-triggered covariance analysis.
   c. Curvature Detector Model. This model will be used to model macaque V4 cells. It will be analyzed using both spike-triggered average analysis and spike-triggered covariance analysis.
3. **Lab Notebook.** Detailed log of research activities.

**Potential References**