Computational Neuroscience - Coursera Notes

TvB

Contents

Introduction

Three types of computational models covered.

1. Descriptive models

- How do neurons respond to external stimuli nd how do we describe this quantitatively with a neural encoding model
- How can we extract information from neurons

2. Mechanistic Models

- How can we simulate the behaviour of a single neuron on a computer?
- How do we simulate a network of neurons? i.e. The Human Brain Project

3. Interpretive or Normative Models of the Brain

- Why do brains operate the way they do?
- What are the computational principles underlying their operation?

Recommended Texts

- Theoretical Neuroscience: Computational and Mathematical Modeling of Neural Systems by P.Dayan and L.Abbot
- Tutorial on Neural Systems Modelling by T. Anastasio

Software Required

Use MATLAB or the open source Octave http://www.gnu.org/software/octave

Some Goals

1. Quantitatively describe what a biological neuron or network of neurons is doing given experimental data
2. Simulate on a computer the behaviour of neurons and networks.
3. Formulate computational principles underlying the operation of neurons and networks in the brain.

What is Computational Neuroscience?

To explain how brains generate behaviours? Characterizing what nervous systems do, determining how they function and understanding why they function

Receptive Fields

In the 60's, researchers planted electrodes into an area of the cats brains. They were able to record electrical signals of specific brain cells. In order to get the cells to respond, various stimuli were presented to the cat. Visual cortical brain cells. The neurons would fire only when there was a thin bar of light oriented 45 deg horizontally. More importantly the frequency of the response was dependent on the orientation, 45 degree in one direction produced a higher frequency response than 45 deg in the other direction and no change in frequency for perfectly horizontal bars.

A receptive field is a set of cells that respond to a specific input stimuli.

Descriptive model of receptive field

The retina behind the eye captures an image. The retinal ganglion cells transmit this image as signals to cells in the Lateral Geniculate Nucleus (LGN) and then onwards to the primary visual cortex (V1). It has been found that certain cells repond when a point of light is directed onto the center of the retina and off when the light is in the surrounding region. Alternatively, there are cells which respond when light is on the surrounding area of the retina, and off when light is on the center. These are dubbed respectively, *On-Center/Off-Surround*, and *Off-Center/On-Surround*.

Recording cells from *V1* shows various receptive fields. The experiment with the cat demonstrated oriented receptive fields. If many cells are measured in the *V1*, one finds many different oriented receptive fields, which can be characterized using reverse correlation.

Mechanistic Model of Receptive Fields

Q: How are the receptive fields constructed from the neural circuitry of the visual cortex?

A: Need to look at the neural circuitry of the optical system.

The LGN primarily has center surround receptive fields, and the primary visual cortex contains the oriented receptive fields. Moreover, it has been found that one V1 cell is connected to many LGN cells. So how do many center surround receptive field cells converge to one oriented receptive field? Model suggested by Hubel & Wiesel claims that the LGN cells are oriented such as to properly stimulate the oriented receptive field. There is contreversy with this simple model. V1 cells are often connected to each other, providing inputs to other V1 cells. This is an example of a mechanistic model.

Interpretive Model of Receptive Fields

Q: Why are V1 cells shaped this way? Why is there a preference for orientation and center/surround? Are there computational advantages?

Efficient Coding Hypothesis: Suppose the goal is to represent images as faithfully and efficiently as possible using neurons with receptive fields, RF1, RF2, etc.

$$I = \sum_i RF_i r_i$$

The linear combination of RF_i the various receptive fields reconstruct the image I using natural neural responses. Also, we want there to be a minimum number of neurons that must be fired to reconstruct the image. To model this system, one can start with a random set of RF's and run an efficient coding algorithm on natural image patches. Natural images are chosen because it is assumed that brains have been optimized to recognize natural images.

Some methods of efficient coding are *Sparse Coding*, *ICA*, *Predictive Coding*. When random receptive fields are optimized to natural images, the resulting set of fields are oriented and have both the + and - regions.
They are localized. The conclusion is that the brain may be trying to find faithful representation of natural images by using oriented receptive fields.