Receptive field models fail to predict responses of V1 neurons to natural movies

Introduction

Much effort has gone into characterizing the receptive field properties of visual cortical neurons. However, the extent to which receptive field models are capable of accounting for the responses of visual neurons to natural scenes is largely unresolved. In this study, we compare the activity of neurons in area V1 of the anesthetized cat, recorded in response to a natural movie, to the predictions of a simple-receptive field model. We find that in most cases the receptive field model fails to adequately capture neural responses.

Model

A commonly accepted model of V1 simple cells is based on taking a linear weighted sum of image pixels over space and time, normalizing this value by the responses of other neurons, and passing the result through a point-wise non-linearity.

\[
I(x, t) = \sum_{i,j} R(x_i, y_j, t) \cdot f(x + x_i, y + y_j, t)
\]

Here we consider a somewhat simpler version without the response normalization step. The neuron’s response is modeled by computing the convolution of the image \(I(x, t)\) with a space-time kernel \(R(x, y, t)\) and passing the result through a point-wise non-linearity, plus an offset.

\[
\begin{align*}
\Delta t & = \alpha I(t) + \beta + \gamma \\
\Delta t & = \sum R(x_i, y_j, t)(x_i, y_j)
\end{align*}
\]

The receptive field kernel, \(R\), was obtained via reverse correlation with an M-sequence. The kernel was then convolved with the movie to generate the intermediate response \(I\). The parameters \(\alpha, \beta, \gamma\) and \(\rho\) where then adapted to arrive at an intermediate response \(r\) and the path of the neuron recorded in response to the same movie.

Results

Results are shown in the boxes at right. For all plots the following legend applies:

- **Predicted response**
- **Actual response (path)**

Discussion and Conclusions

For nearly all cells studied (for which we were able to obtain receptive field maps), the receptive field model failed to predict the actual response of the neuron. Correlation coefficient hover well below 0.5, meaning that the receptive field map place is of limited value in helping us to understand how a neuron behaves under realistic conditions.

Obviously we will have to take into account other factors in order to explain how V1 neurons respond to natural scenes. In addition to their feedforward input from the LGN, neurons in layer 6B receive massive input from other cortical neurons:

Lumping together the effects of feedforward input from the LGN and recurrent input from cortex and calling it the “receptive field” is not a good idea. In order to properly understand what cortical neurons are doing, it may well be necessary to model their response as a function of not only the input, but of other simultaneously recorded cortical neurons as well.