Efficient Encoding of Sequence Identity through Balancing Excitation and Inhibition

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1 Introduction

In this report we propose to study an experimental phenomenon of temporal sequence representation in layer 2/3 of the neocortex through the lense of excitation/inhibition balance in the network (Deneve, Machens, 2016).

2 Verbal Model

Before specifying a model computationally, it helps to think through the scenario that the model is meant to capture. The experiments show that the layer 2/3 network activity transitions between two distinct states: a sparse mode, where just a few cells encode the cell identity, corresponding to the case where the network is able to predict its input and a high entropy mode, where the majority of the cells fire, corresponding to an unpredicted violation in the sequence.

We first notice that in order to capture these effects in layer 2/3, we need to make assumptions of what inputs arrive to this layer from layer 4. I make the following assumption: neurons in layer 4 don't encode the sequence identity, but rather are receptive to the individual frames. We assume that cells in the layer 2/3 receive input from layer 4 cells, where different cells receive activation from different cells. One cell may be activated by a layer 4 cell receptive to frame A and B and another by frame A, B, C and D. To reach firing threshold, there must be enough signal to make the cell fire. We endow the feedforward connections from layer 4 to layer 2/3 with depressing and facilitating dynamics. Previous simulations have shown that transient responses can be accounted for by depressing synapses, see figure 1.

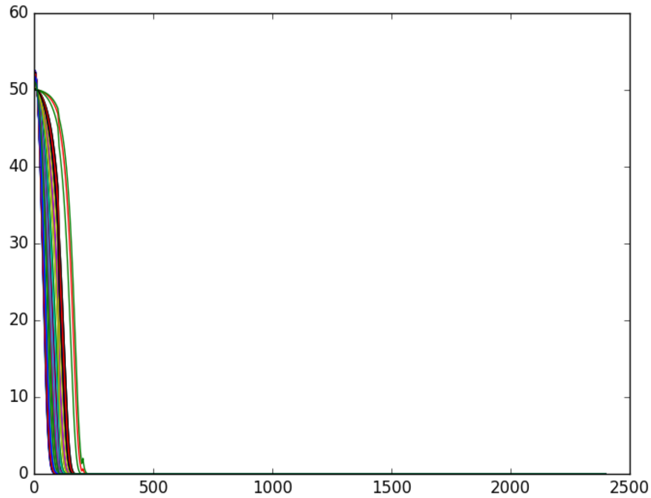

Figure 1. Transient responses due to synaptic depression in feedforward synapses
We propose that the sustained firing of a minority of cells is due to a winner-take-all dynamic, stemming from the shared pool of inhibition acting in a feedback loop with the excitatory cells. Figure 2 displays a winner-take-all dynamic in a very simple rate-based modeling set up. In the model we have 9 excitatory neurons and 3 inhibitory neurons. The neurons obey the following differential equation:

$$dr_i/dt = -r_i(t) + F(I + \sum_j W_{i,j} r_j(t))$$

$W_{i,j}$ is made so that the inhibitory to excitatory weights are -1 and excitatory to excitatory and excitatory to inhibitory weights are 1.

We inject a high current I into the first cell and a low current into the rest of the cells. The winner-take-all dynamic selects the cell with the highest input rate and maintans it in a steady firing rate, as illustrated by the blue line in figure 2. The rest of the excitatory neurons in the figure (green) decay to a 0 rate. The purple line in the figure corresponds to inhibitory neurons.

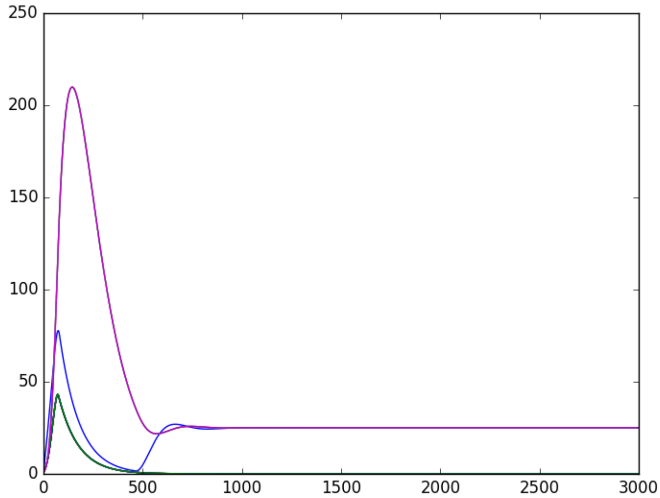

Figure 2. Winner-take-all dynamic in a rate-based network, lines represent rates We hypothesize that the winner-take-all dynamic will also act to select a cell firing with high-rates in the winner-take-all dynamic. We next hypothesize, how the violation in sequence identity further impacts network firing.

3 Hypothesis

We hypothesize that a violation in the sequence acts as a switch to turn off the minority of cells firing in response to the sequence identity. This in turn momentarily alters the excitation-inhibition balance in the group of cells, e.g. sends an error signal, and the network acts to restore the excitation-inhibition balance and thus a large number of cells fire. We implement a homeostatic balancing rule to maintain excitation-inhibition ratio(Xue et al, 2014).
Experimental work has shown that change in activity in even one cell in a recurrent layer 2/3 network in the somatosensory cortex is enough to recruit a number of inhibitory neurons and therefore alter circuit activity (Kapfer et al,2014). Shutting this cell down, as in a violation frame, can thus possibly disinhibit a whole number of excitatory cells and lead to widespread firing.

4 Summary

We propose to study the problem of encoding sequence identity in layer 2/3 of the neocortex through the prism of an excitation-inhibion balance, ensured through homeostatic plasticity acting concurrently with a winner-take-all dynamic. In this model, unexpected inputs alter the excitation-inhibition balance in the network, by turning off the minority of cells firing in a sustained way in response to a concrete sequence identity. The model seeks to elucidate the mechanisms behind the non-linearity in the responses of cortical cells– e.g. encoding of a sequence by a small number of cells, the turning off of which is concurrent with a wide-spread and disproportionate firing of the entire network.

5 Citations

Denève,S. Machens, C. M. Efficient codes and balanced networks. Nature Neuroscience, (2016).
Kapfer, C., Glickfeld, L.L., Atallah, Bassam, V., Scanziani, M. Supralinear increase of recurrent inhibition during sparse activity in the somatosensory cortex, Nature Neuroscience, (2014).
Xue, M., Atallah, B.V. Scanziani, M. Equalizing excitation-inhibition ratios across visual cortical neurons. Nature 511, 596–600 (2014).