A Multi-layer Microcircuit Model of Somatosensory Cortex with Multiple Interneuron Classes

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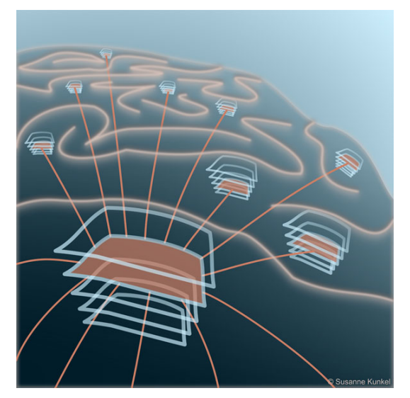

Introduction

We develop a model of mouse somatosensory (barrel) cortex incorporating three major classes of interneurons (PV, SOM and VIP cells) as a tool to study cortical network dynamics and sensory signal processing.

Model Overview

- The simulation software NEST 2.16.0 [1] is used to create a multi-layer cortical microcircuit model adapted from Potjans & Diesmann [2].
- The neuron model is the leaky integrate-and-fire neuron model.
- External input is provided by Poisson spike trains and two hundred thalamic cells.
- Synaptic short-term plasticities (STPs) are included in the recurrent connections.

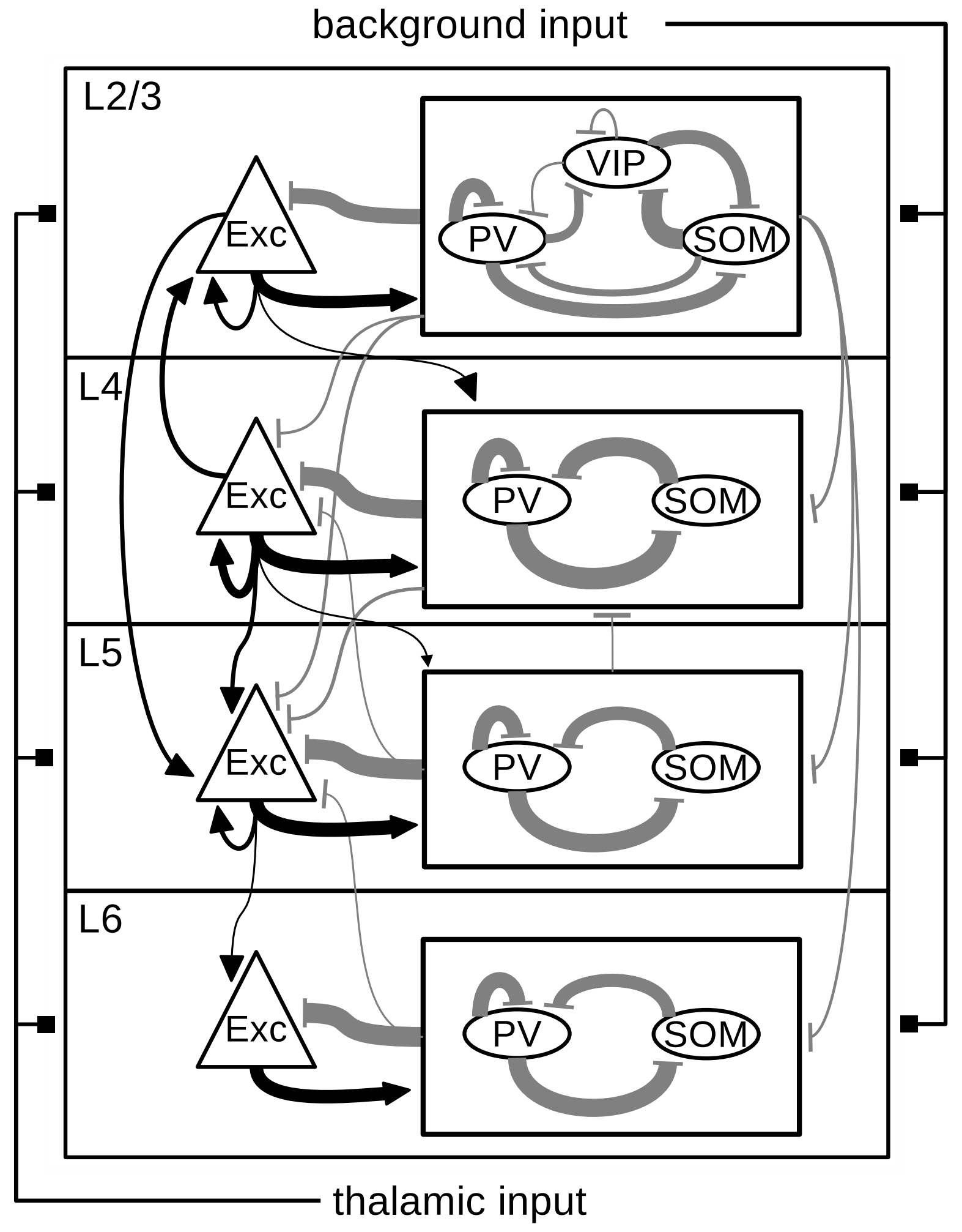

Figure 1: Model overview. Excitatory (black) and inhibitory (gray) recurrent connections with probabilities ≥ 3% are shown (widths indicate probabilities).

Network Ground State

- The ground-state firing rates of the populations in the optimized model are comparable to those of in vivo data from [3].

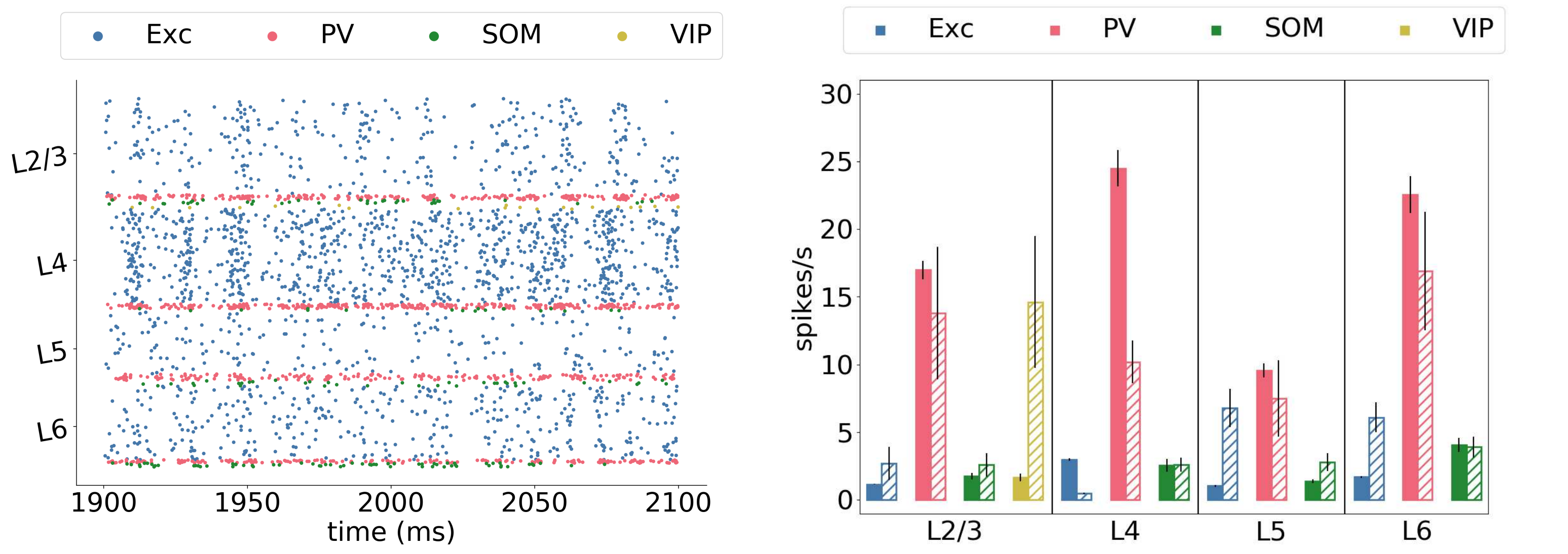

Figure 2: Raster plot (left) and firing rates (right) of the optimized model. Filled and hatched bars show simulation and in vivo data, respectively. Error bars show SEMs.

- Over a range of external input and relative inhibitory strengths, the model is able to fulfill the criteria on firing rates, spiking irregularity, and pairwise correlations of spike counts derived in [4].

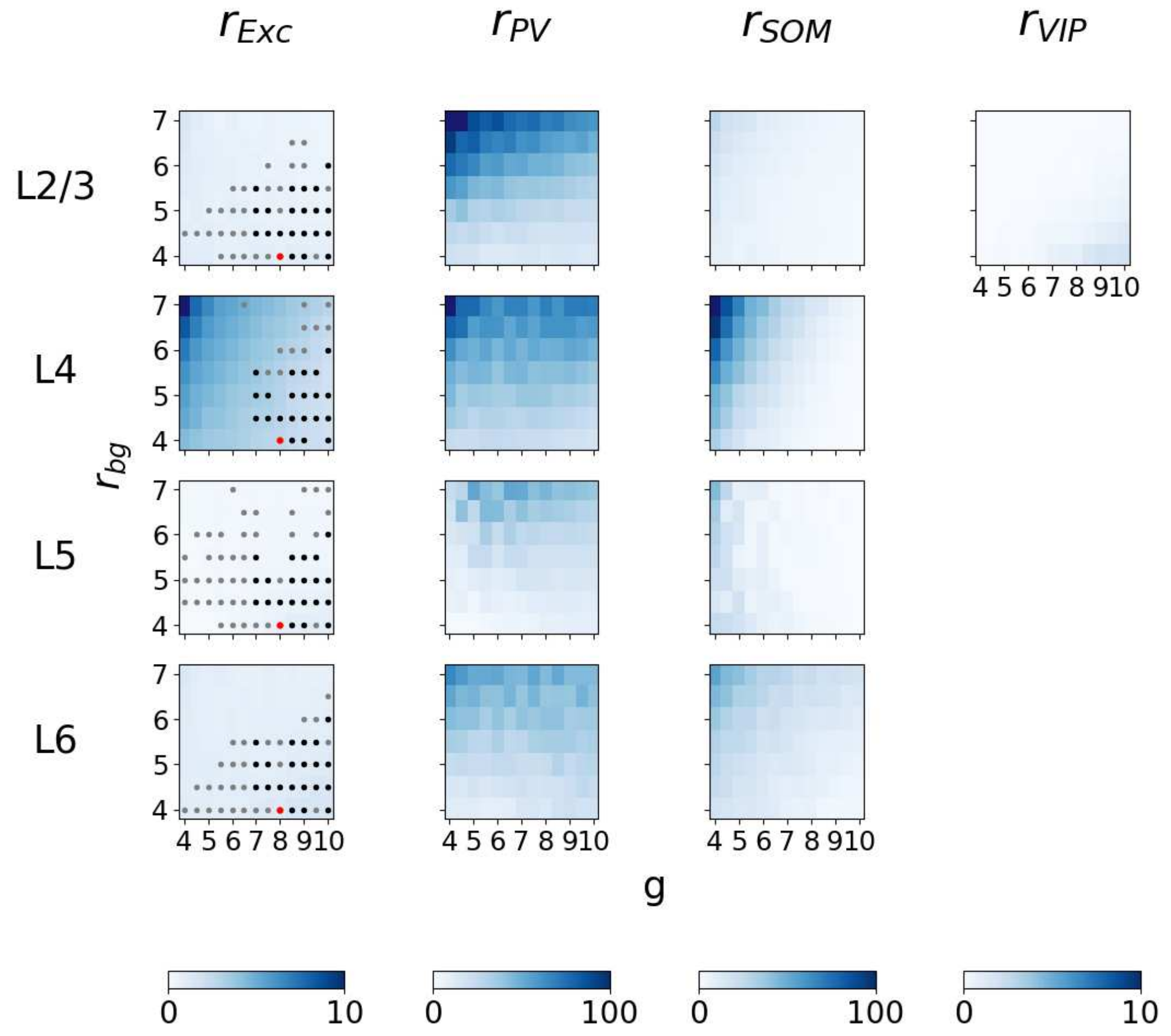

Figure 3: Ground states over different parameters. Firing rates of each population (r_{Exc}, r_{PV}, r_{SOM}, r_{VIP}, spikes/s) over different levels of relative inhibitory strength (g) and external input (r_{bg}, spikes/s) are shown by blue color. Dots in the first column show where the simulations fulfill the criteria in [4] (gray: fit in single layer, black: fit in all layers). The red dots indicate the parameters used in Figure 2.

Network Dynamics

- The changes of firing rates in L2/3 in response to activation of PV, SOM, and VIP cells show their respective roles of inhibition and disinhibition.

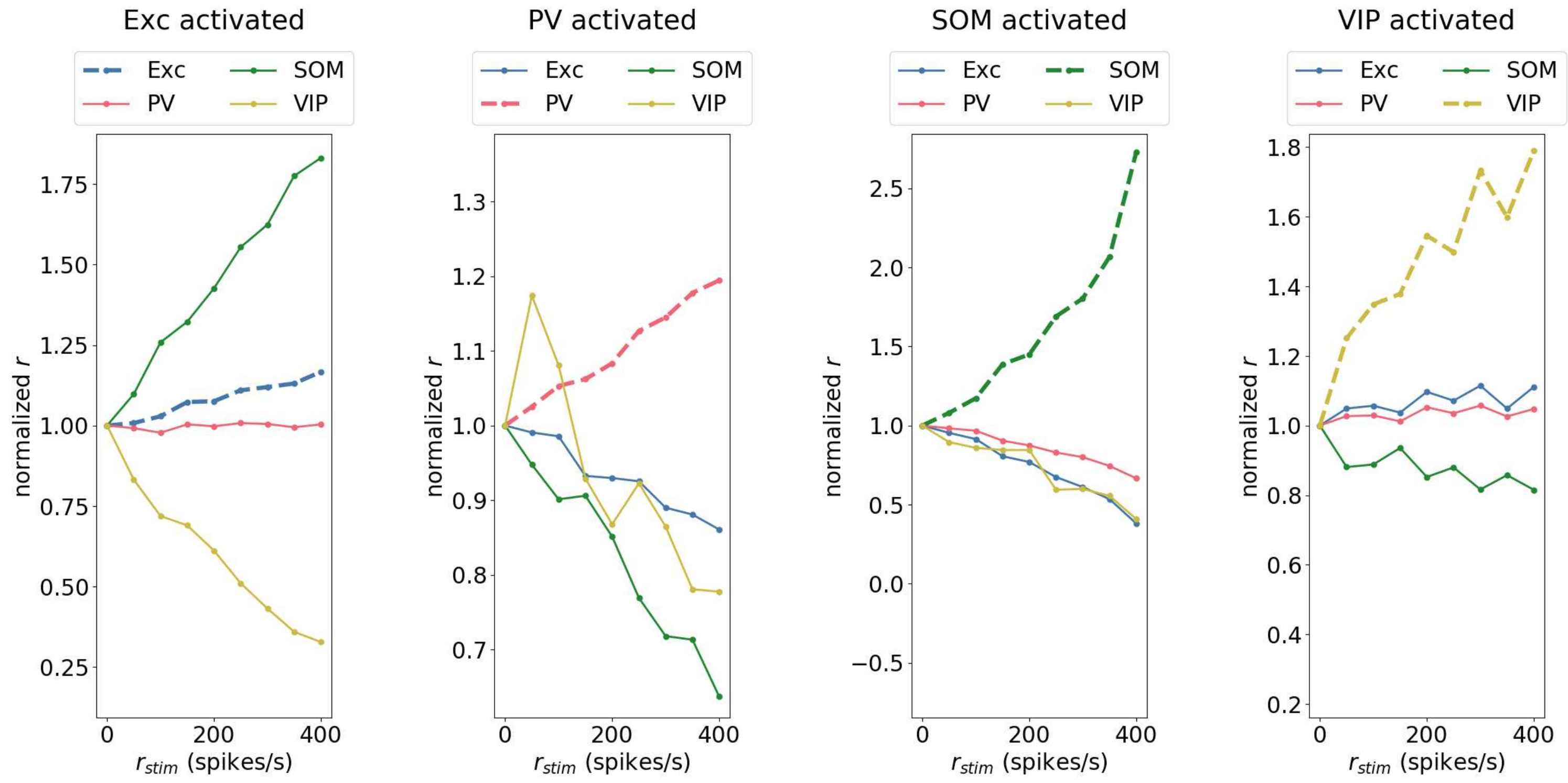

Figure 4: L2/3 network responses (normalized firing rates) to activation of different cell classes. Dashed lines represent stimulated populations. r_{stim}: firing rate of stimulus.

- The model with STPs shows clearer multi-layer spiking responses to simulated transient thalamic input (100 spike/s, 10 ms) as compared to a version without STPs.

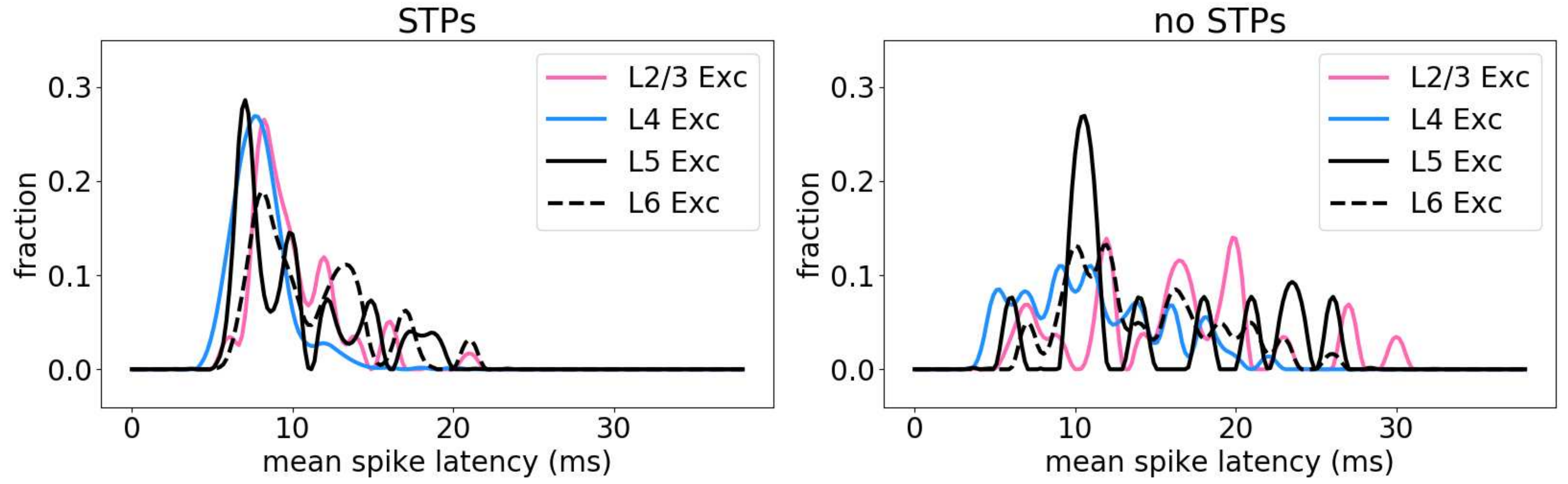

Figure 5: Multi-layer responses of Exc cells to the thalamic input, showing the distribution of cells in terms of mean spike latency (n of repetitions=10, bin=1 ms).

Outlook

- Further analysis of the model aided by mean-field theory [5] may reveal the mechanisms behind these results and explore the specific roles of different interneuron types in state-dependent modulation of sensory signal processing.
- As a model of barrel cortex, it is particularly suited to studying whisker sensation, but it may also provide insights into the contributions of the distinct interneuron types to other sensory processes, such as visual discrimination learning [6].

References

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