Modulation of neuronal anticipatory activity in a topographical model of V1

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Introduction

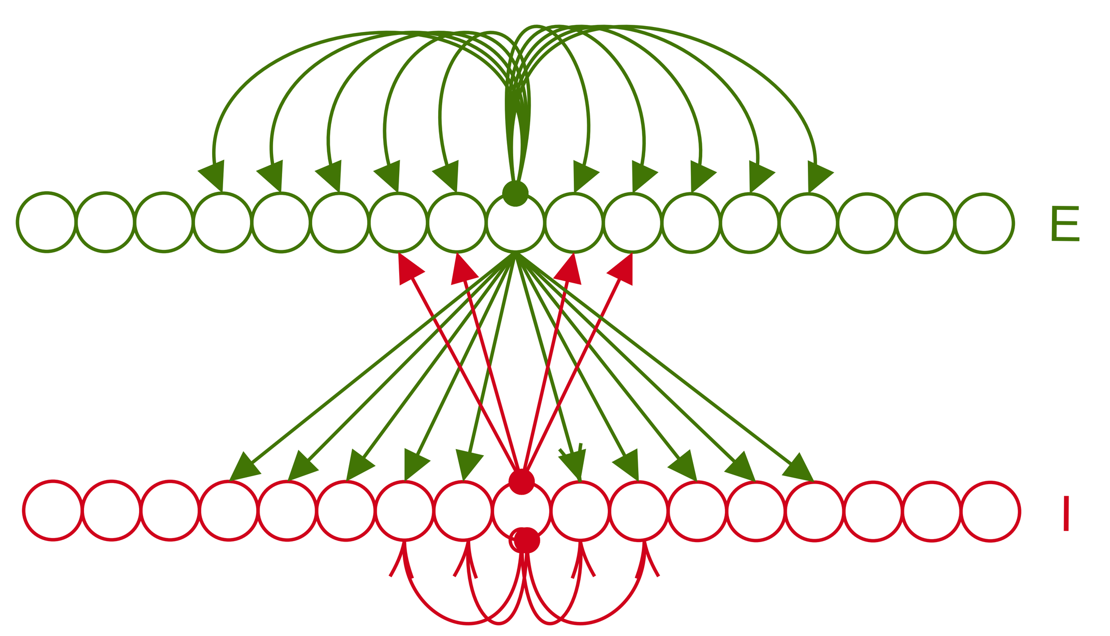
We present a model of primates' primary visual cortex (V1) which tries to mimic the interaction of neural activity which is spreading in different sub-populations. In particular, we focus on replicating recent results showing a differential treatment for the processing of a moving stimulus with respect to the length of its trajectory [1].

Network model

The model adopted consists of leaky integrate and fire point neurons with fixed threshold and exponentially-decaying post-synaptic conductances. The network has 20800 neurons divided in four layers, i.e., LGN-ON cells (6400 cells), LGN-OFF cells (6400 cells), Excitatory Cells (6400 cells), Inhibitory Cells (1600 cells). The cells are spatially mapped on a toroidal 2D grid with dimension $20\mathrm{mm} \times 20\mathrm{mm}$ (inspired by the 1D phenomenological model in [1]) and neuronal density equal to $20\ \mathrm{mm}^{-2}$.

Connectivity details

All layers are spatially organized on a regular 2D toroidal lattice structure. Cells are connected using a Gaussian spatial probability of connection $p_{ij} \propto \exp\{-\frac{1}{2\sigma^2} \cdot l_{ij}^2\}$ where l_{ij} is the Euclidean distance on the cortical surface and with different spatial spreads: $\sigma_{EE} = \sigma_{EI} = 1.05\ \mathrm{mm}$ and $\sigma_{II} = \sigma_{IE} = 0.525\ \mathrm{mm}$. Connected cells have a fixed weight and behave close to a balanced state ($0.39 \leq \frac{g_e}{g_{tot}} \leq 0.57$) regime. For each connection, the synaptic delay is proportional to distance $d_{ij} = d_0\ \frac{l_{ij}}{v_c}$, where $v_c = 0.02\ \mathrm{mm} \cdot \mathrm{ms}^{-1}$ is the conduction velocity of lateral connections [5].



Input and simulation info

The thalamic input is a spiking Poisson source driven by the filtered image of a moving dot stimulus with a regular motion on the plane. The stimulus is added with 10% Poisson noise and connects with the LGN ON and OFF cells. The dot is represented on the 5% of the grid dimension (i.e., $1\mathrm{mm} \times 1\mathrm{mm}$). All simulations have been performed using the NEST simulator [4] and the PyNN modelling language [3] with a $1\ \mathrm{ms}$ time-step.

Acknowledgments

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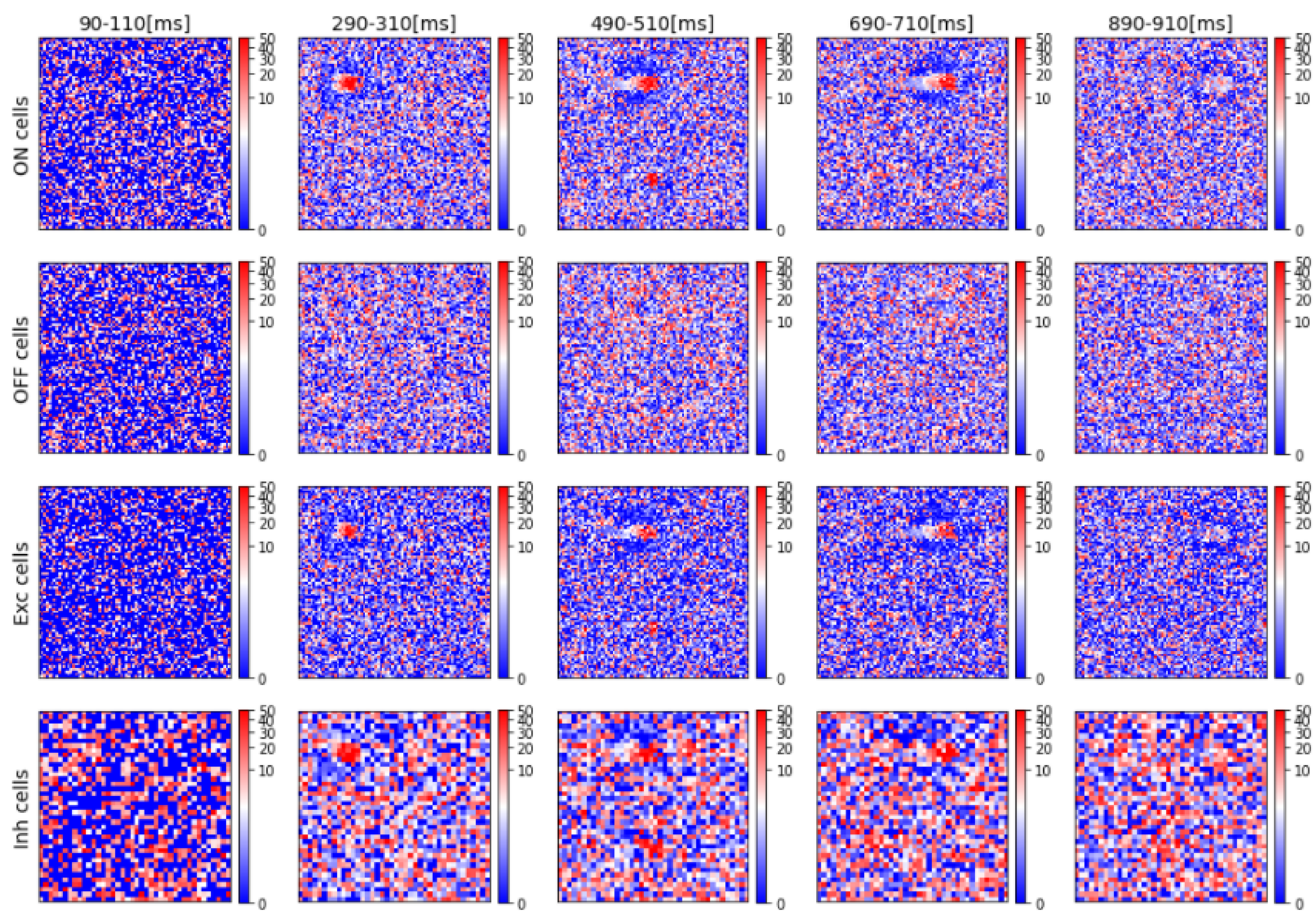
Main results

We found in our model that, by using large excitatory and small inhibitory connections [2], inhibitory cells show a observable pre-activation with the long trajectories, while they fire without anticipation along the flash control conditions. The pre-activation of inhibitory cells is likely due by the interplay between both inhibitory and excitatory lateral connectivity [1], but the mechanism underlying it still need be to be clarified. Future works will investigate the role of inhibitory cells on the excitatory cells and also exploring the role of traveling waves in processing the stimulus information on the network [2, 5].

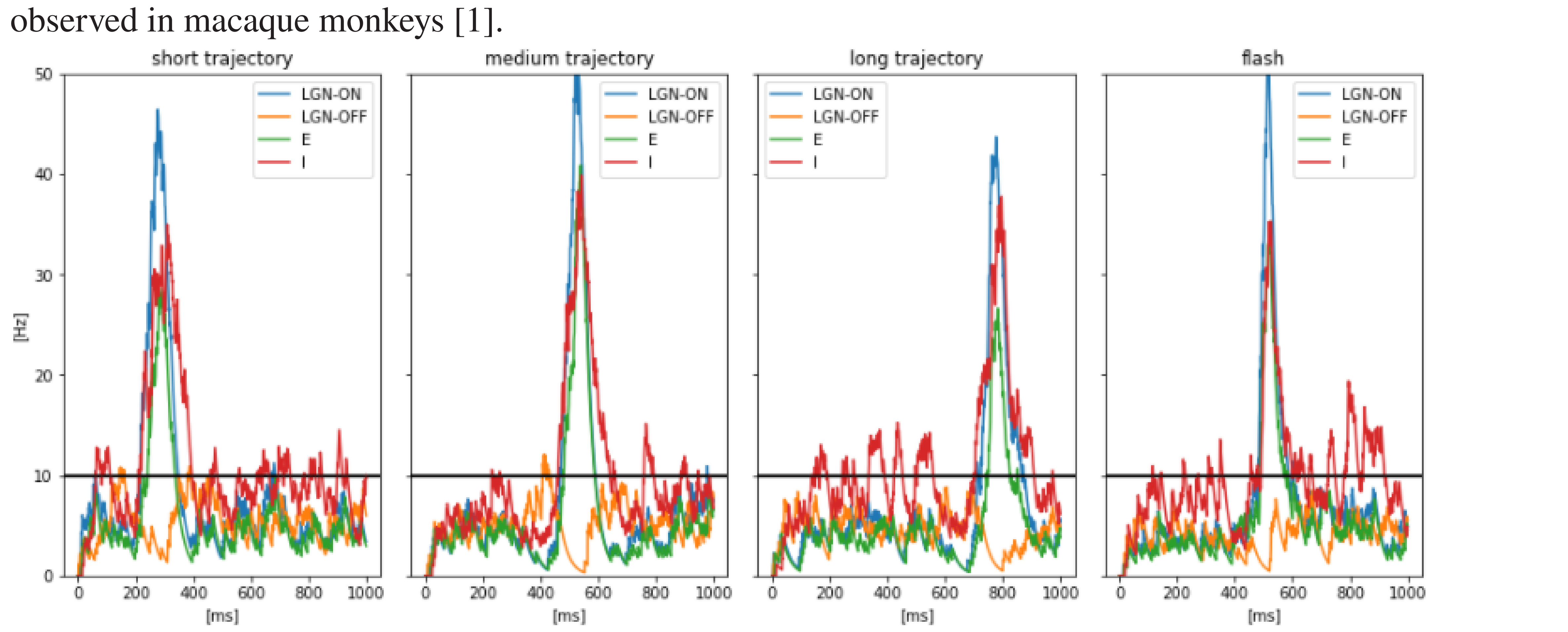
Stimulus-related network behavior

We represent here the average firing rate for the different sub-populations of the model, respectively from the row on the top to that on the bottom: LGN ON cells, LGN OFF cells, Excitatory and Inhibitory cells. Each column represents a snapshot in time which shows the temporal dynamics of activation in the network. The stimulus duration is of $1000\ \mathrm{ms}$ and the snapshots are representing the windows with different time scales. The stimulus is a focalized dot appearing at $t = 200\ \mathrm{ms}$ and disappearing at $t = 800\ \mathrm{ms}$ and flashing from $t = 480\ \mathrm{ms}$ to $t = 520\ \mathrm{ms}$.



Incremental cell pre-activation depends by the input trajectories

Four positions in the 2D map have been chosen so that they refer to peak activities of the input at $t \in \{250\ \mathrm{ms}, 500\ \mathrm{ms}, 750\ \mathrm{ms}\}$ and for the flash period at $t = 500\ \mathrm{ms}$. They correspond respectively (from left to right) to a short, medium, long trajectories and a flashed stimulus. We plot the firing rate at these positions (averaged over an area of radius 3 neurons) as a function of the simulation time. The incremental pre-activation of the inhibitory neurons along the medium and long trajectory is reminiscent of the anticipatory response observed in macaque monkeys [1].



References

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