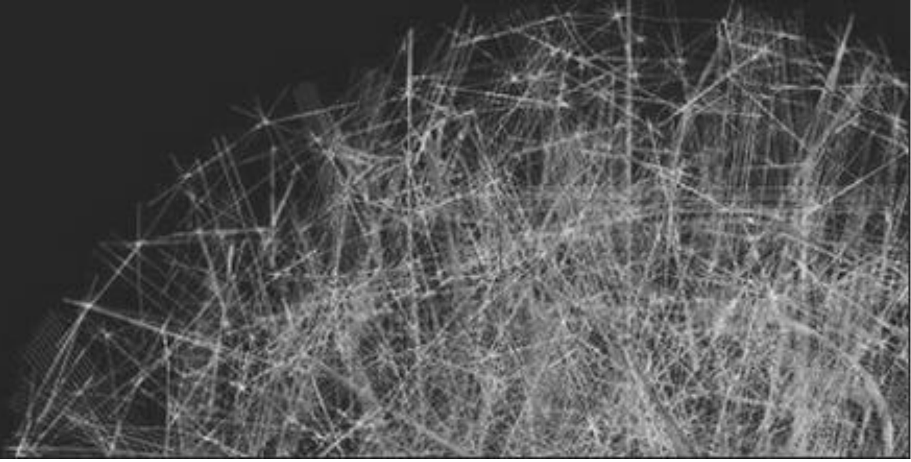
Planeta by León Ferrari

NeuroMat



Effect of synaptic plasticity on functional connectivity and global activity of a cortical network model

FAPESP

CAPES

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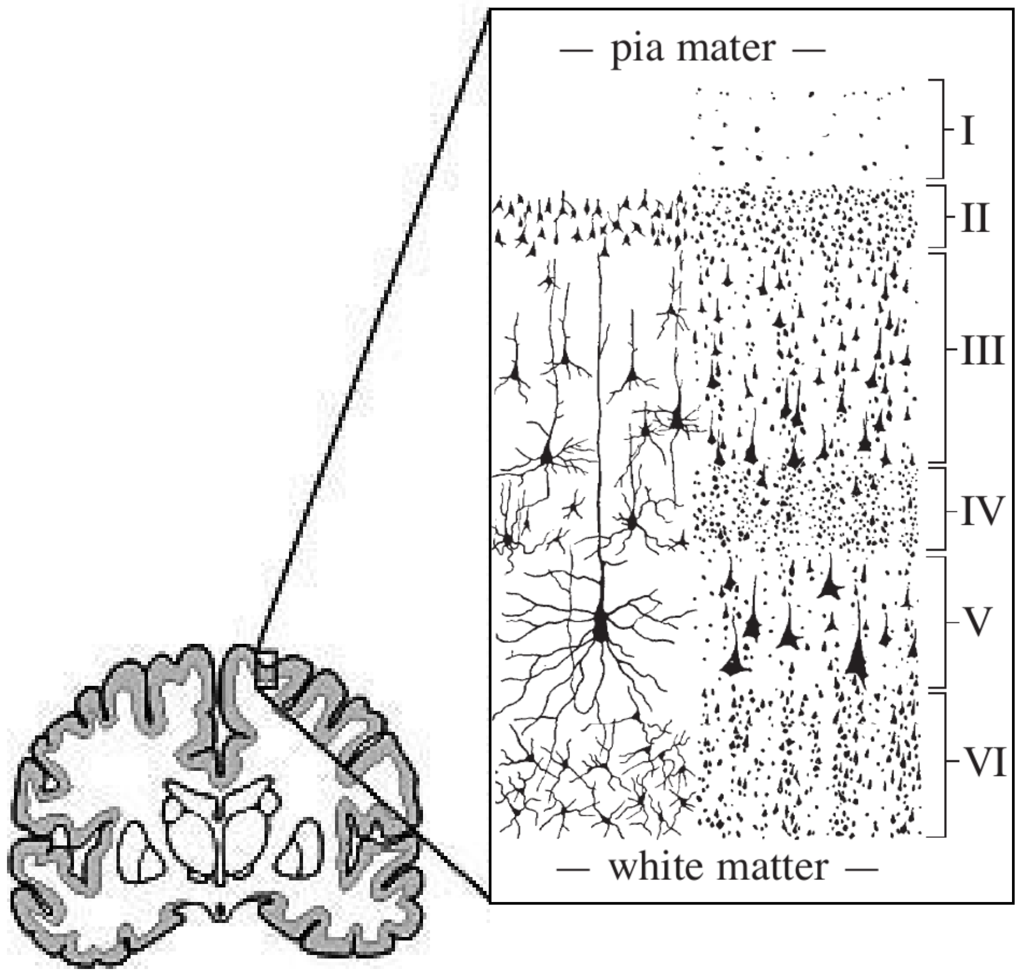
Introduction

Cerebral neocortex – Structural organization



General background

- Synaptic plasticity is believed to underlie learning and information storage in the brain, as well as neurorecovery after stroke and other brain damage or disease, which are among the main research foci of NeuroMat.

- Long-term plasticity can persist from a scale of seconds to hours or more.

Goals

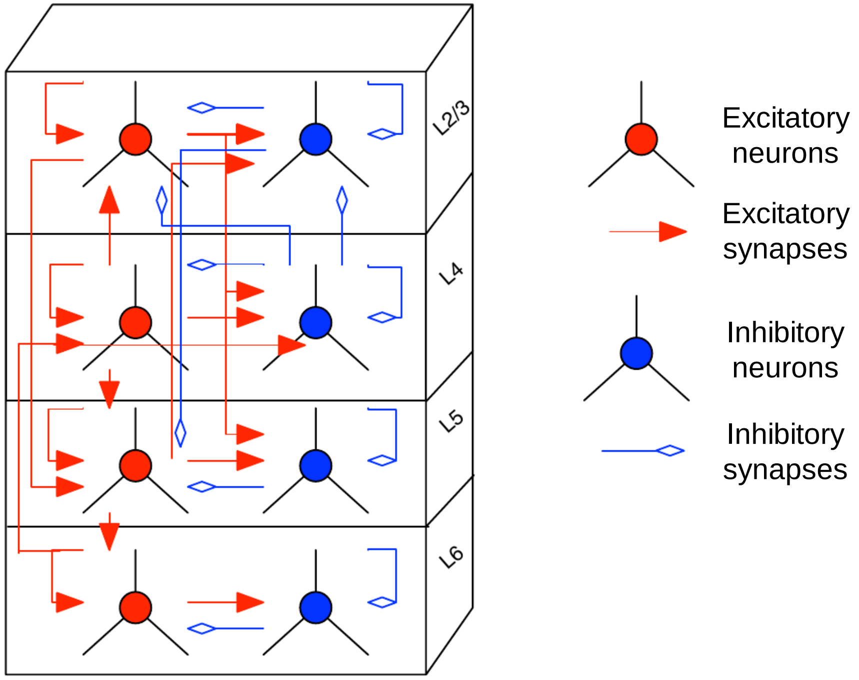
Goals

- To study the effect of synaptic plasticity rules on the behavior of neural spiking activity patterns in a cortical network model.

- To study the changes in the functional connectivity of the network as disclosed by graph-theoretic measures.

Methods

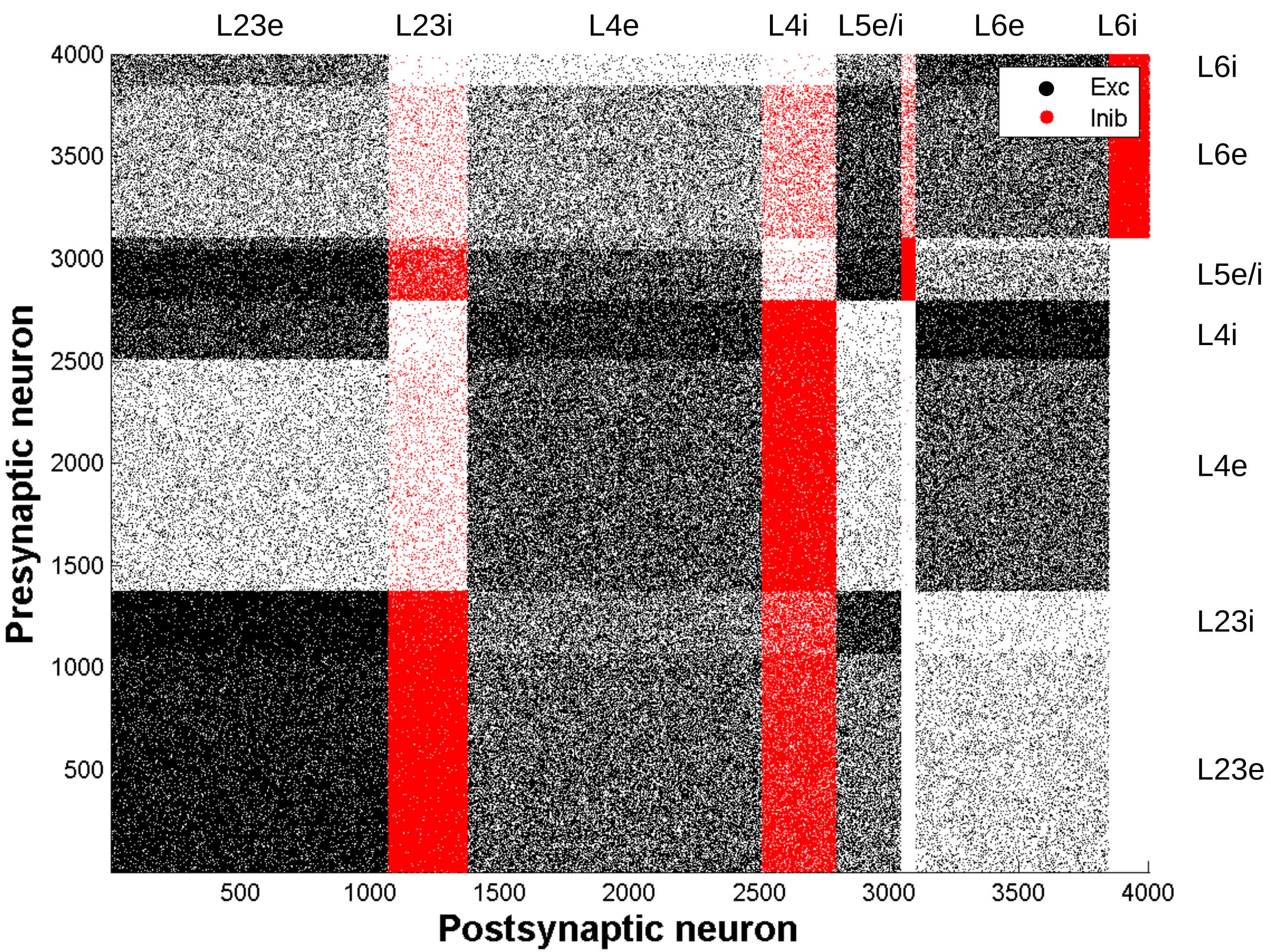
The network



- 4000 neurons;
- Excitatory/inhibitory rate = 4:1;
- ~780.000 synapses.

Potjans TC, Diesmann M, 2014. The cell-type specific cortical microcircuit: relating structure and activity in a full-scale spiking network model.

Adjacency matrix of topological connections



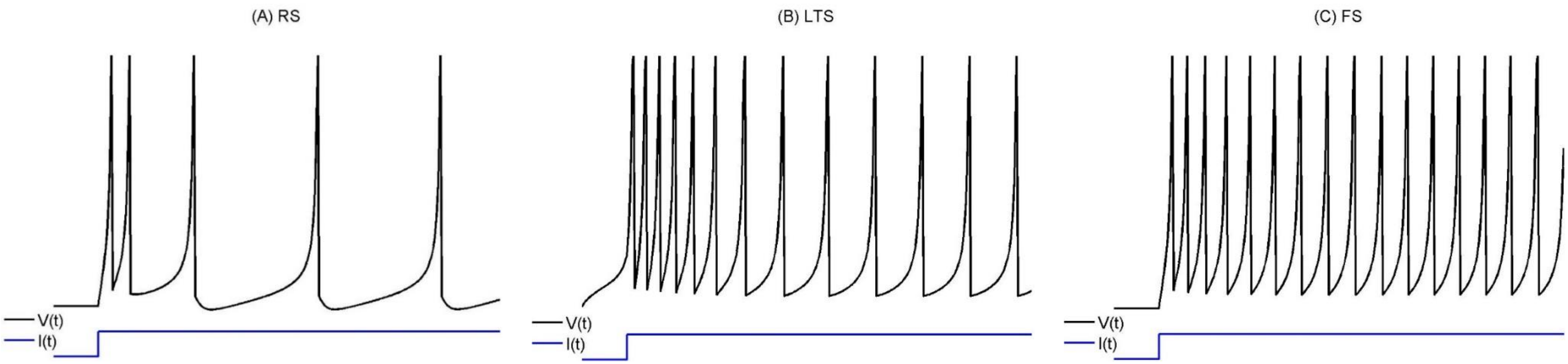
Neurons: Izhikevich model

$$C\frac{dV}{dt} = k(V - V_{rest})(V - V_{threshold}) - u + I$$

$$\frac{du}{dt} = a\{b(V - V_{rest}) - u\}$$

If V ≥ 30mV, then:

$$\begin{cases} V \leftarrow c \\ u \leftarrow u + d \end{cases}$$

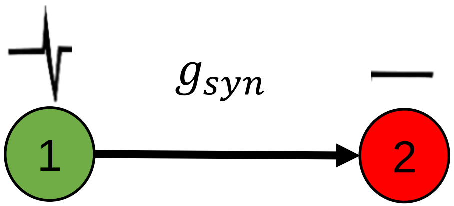


A) regular spiking (*RS*); B) low threshold spiking (*LTS*); C) fast spiking (*FS*).

*Izhikevich EM (2007). Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting.

Synapse model

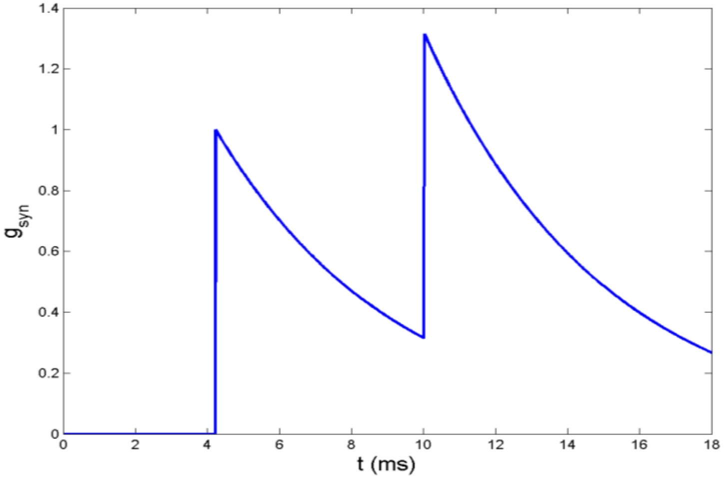
- Event-based model:



If pre- fires a spike, $g_{syn} \rightarrow g_{syn} + g_{max}$

$$\frac{dg_{syn}}{dt} = -\frac{g_{syn}}{\tau}$$

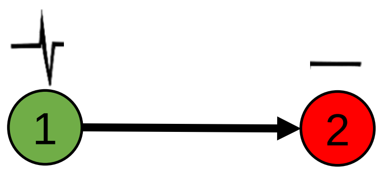
$$I_{syn} = \sum g_{syn}(t)(V(t) - E_{syn})\,;$$



Asymmetric spike-time-dependent plasticity (STDP) rule

$$\tau_- \frac{dM}{dt} = -M \qquad e \qquad \tau_+ \frac{dP_a}{dt} = -P_a$$

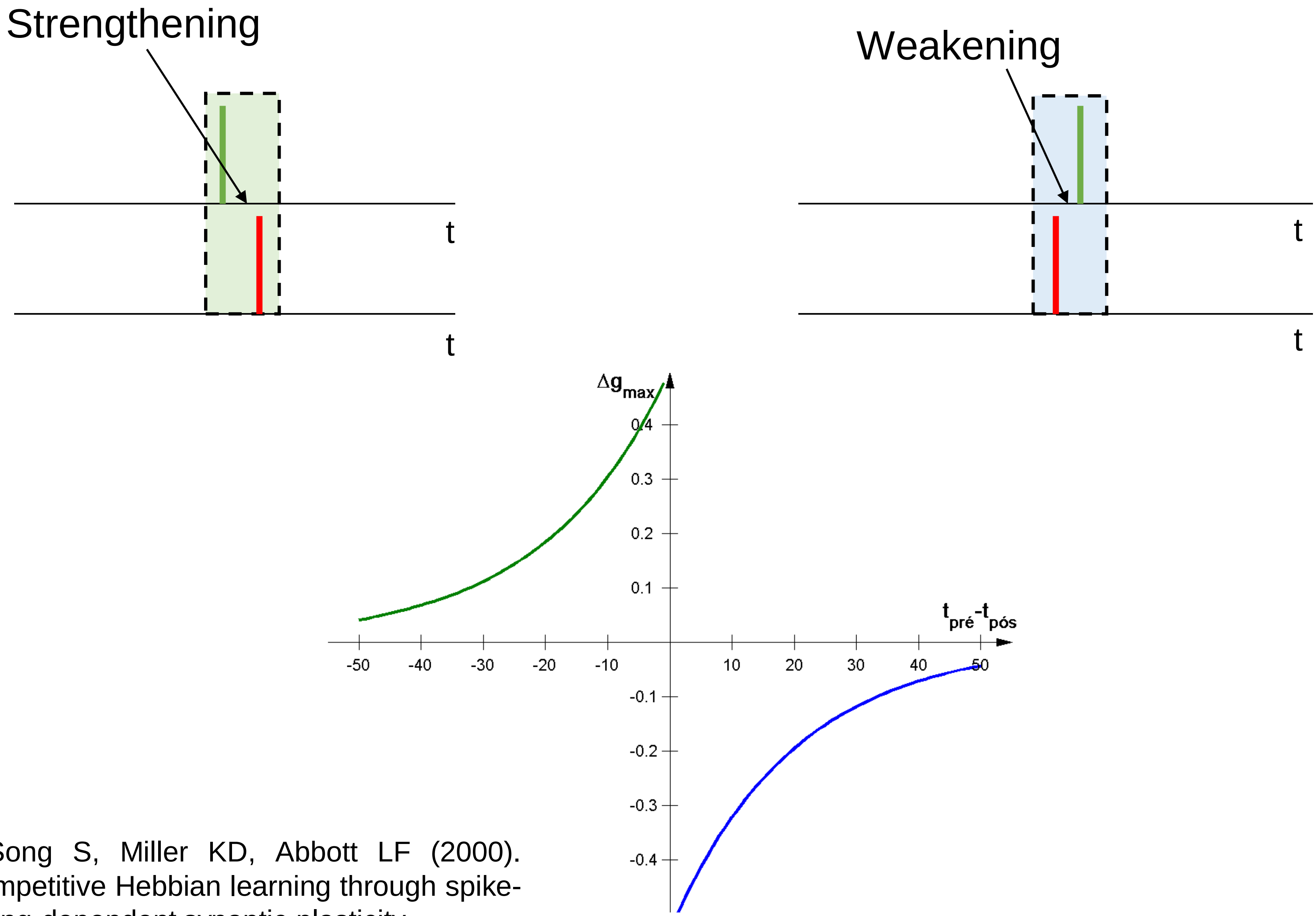
If:



$$P_a \to P_a + A_+$$
$$g_{max} \to g_{max} + M g_{lim}$$

$$M \to M - A_-$$
$$g_{max} \to g_{max} + P_a g_{lim}$$

* Song S, Miller KD, Abbott LF (2000). Competitive Hebbian learning through spike-timing-dependent synaptic plasticity.



* Song S, Miller KD, Abbott LF (2000). Competitive Hebbian learning through spike-timing-dependent synaptic plasticity.

Simulations

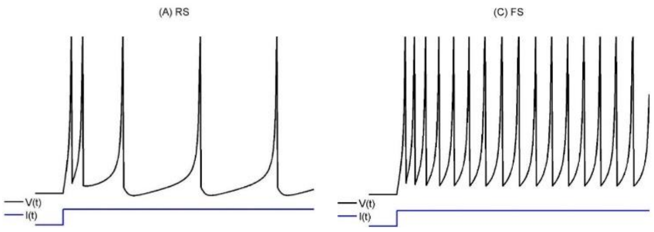
- Duration of simulation: 10000 ms;

- Input: poissonian spike train generated and connected to neurons of layers 4 (L4) and 6 (L6), which is the main input layers of the cortex;

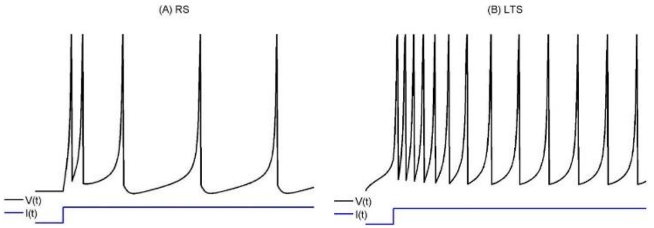
- Electrophysiological classes used:
  - Excitatory: regular spiking (RS);
  - Inhibitory: low-threshold spiking (LTS) or fast spiking (FS).

Simulations

- Two versions of the model were constructed:
  - RS_FS
    - Without synaptic plasticity,
    - STDP in excitatory synapses.

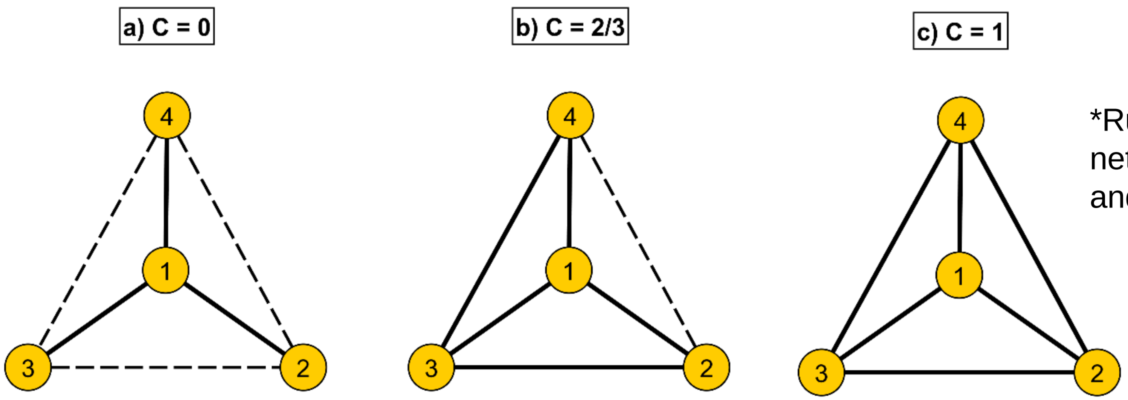


  - RS_LTS
    - Without synaptic plasticity,
    - STDP in excitatory synapses.



Measures

Clustering Coefficient (*C*)



*Rubinov M, Sporns O (2010). Complex network measures of brain connectivity: Uses and interpretations.

Example of a graph to ilustrate how to calculate C for the node 1.

Synchrony index (*C*)

$$X^2(N) = \frac{\sigma_S^2}{\frac{1}{N}\sum_{i=1}^{N}\sigma_{S_i}^2};$$

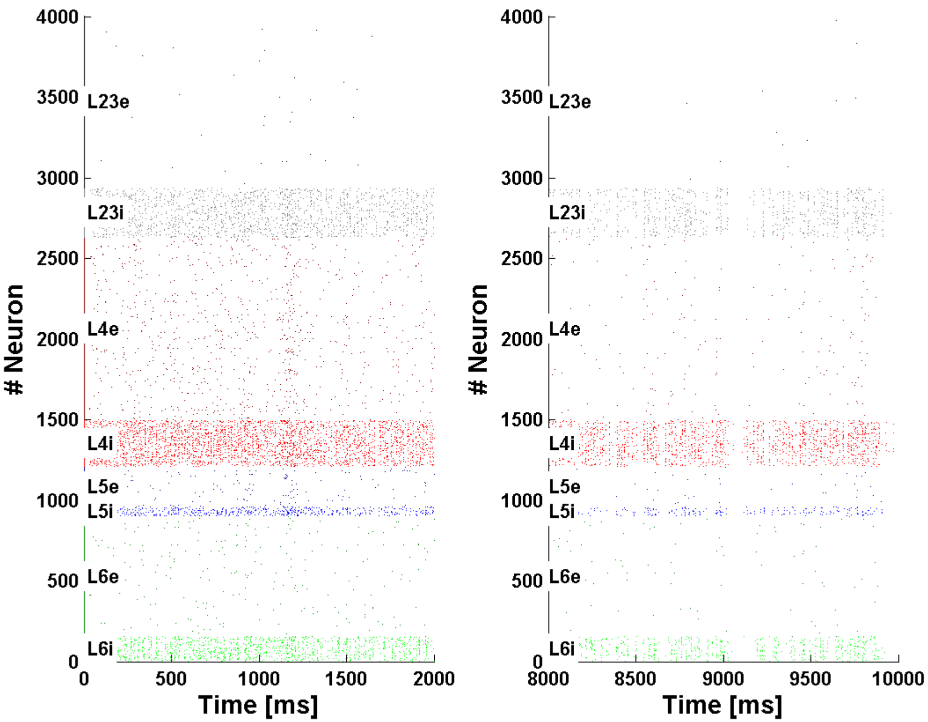
$$0 \leq X \leq 1$$

*Golomb D (2007). Neuronal synchrony measures.

Preliminary results

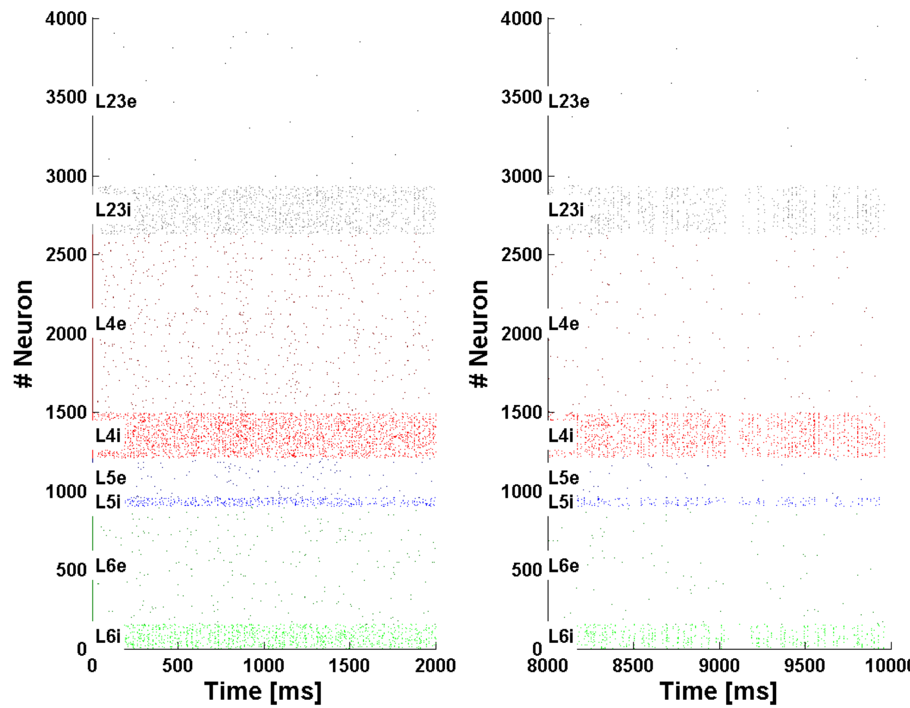
RS – FS:

No synaptic plasticity



f_{mean} = 0,636 Hz; X = 0,026

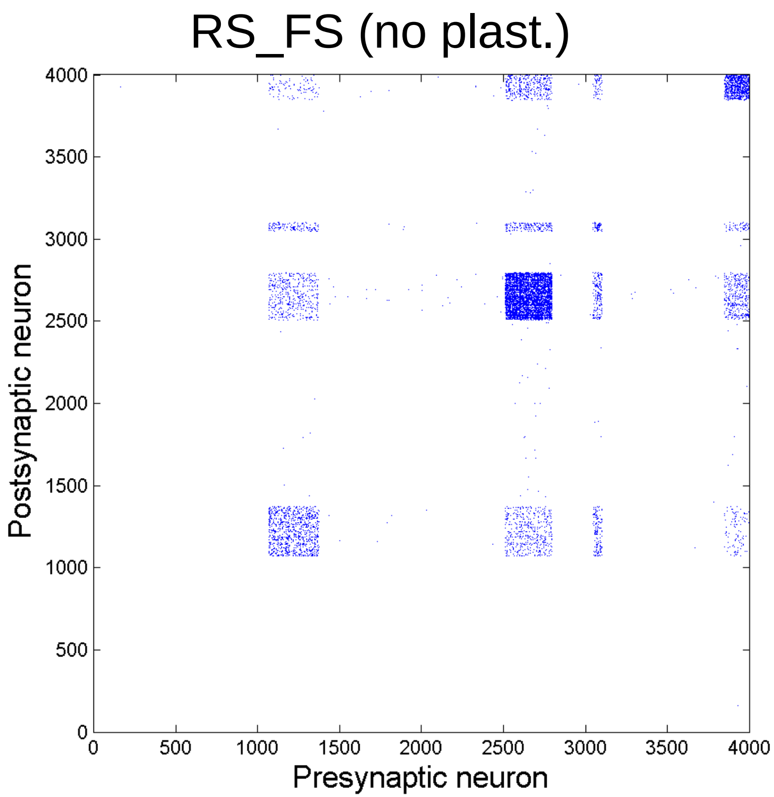
STDP – Excitatory synapses



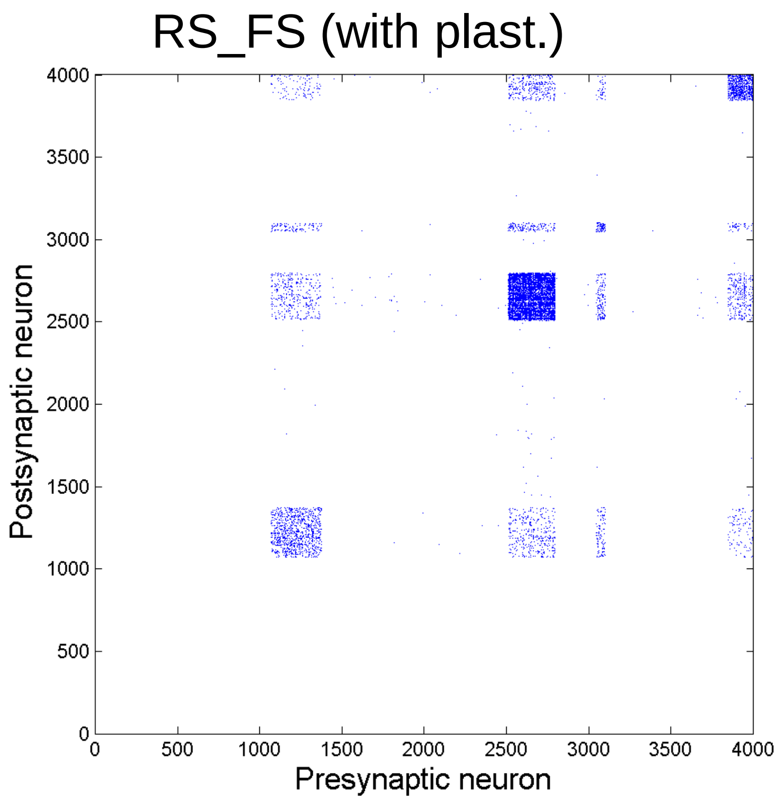
f_{mean} = 0,608 Hz; X = 0,027

The version with synaptic plasticity has a little higher frequency and synchrony, but not considerable.

Adjacency matrices of functional connections



C = 0,021

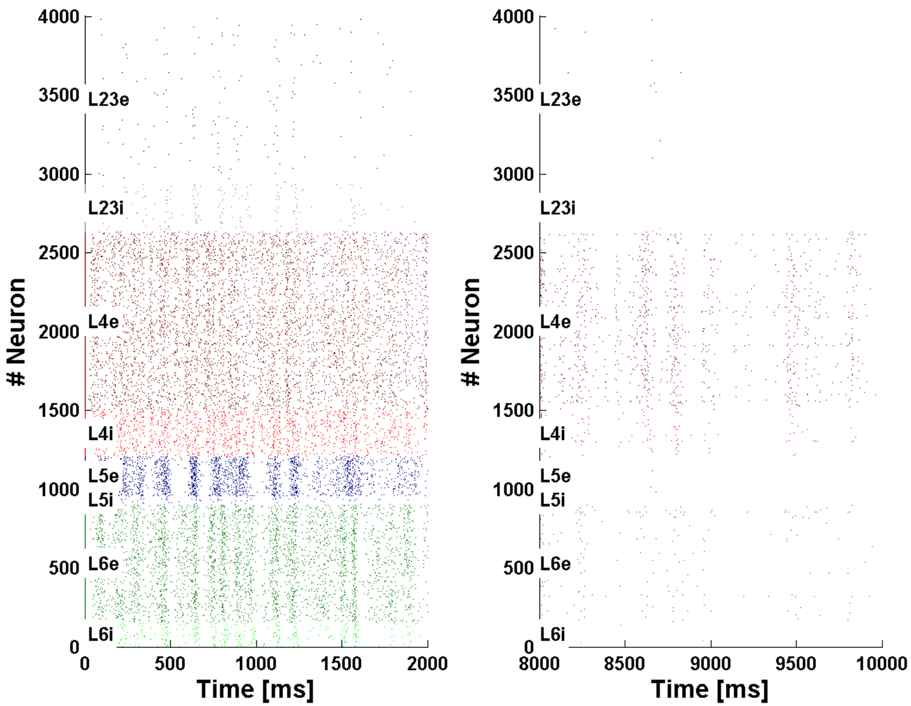


C = 0,024

The functional matrices didn't show considerable changes.

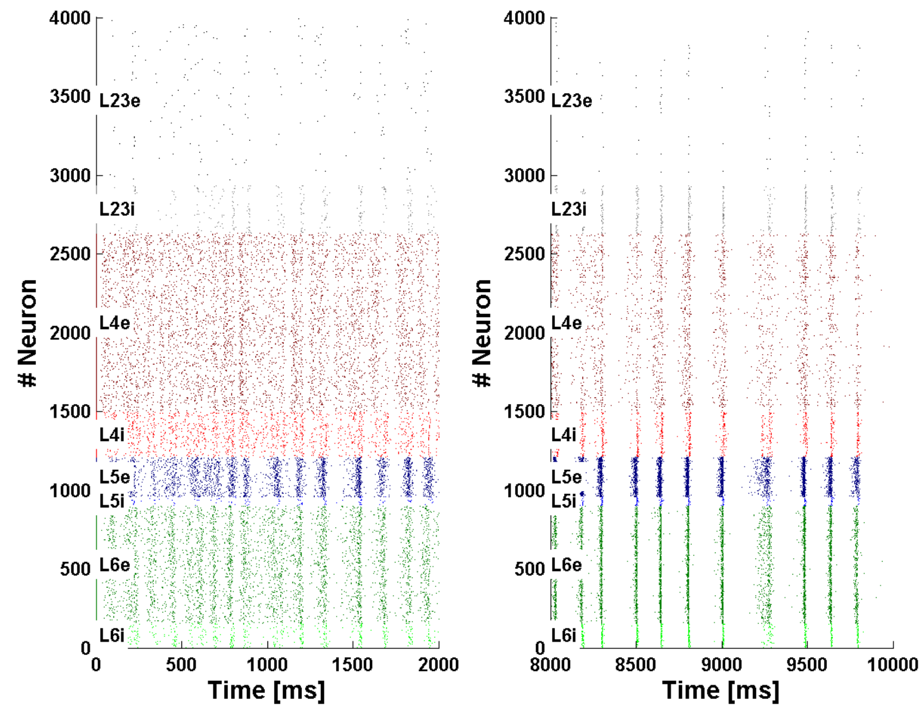
RS – LTS:

No synaptic plasticity



f_{mean} = 0,744 Hz; X = 0,032

STDP – Excitatory synapses

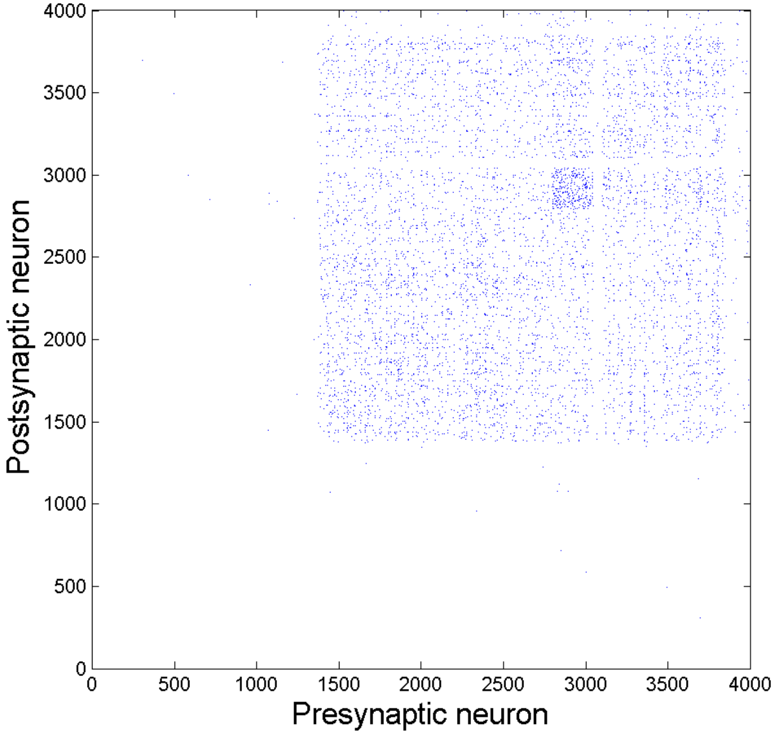


f_{mean} = 1,668 Hz; X = 0,067

The version with synaptic plasticity has a higher mean frequency. And is possible to see a more synchronous activity of the network.

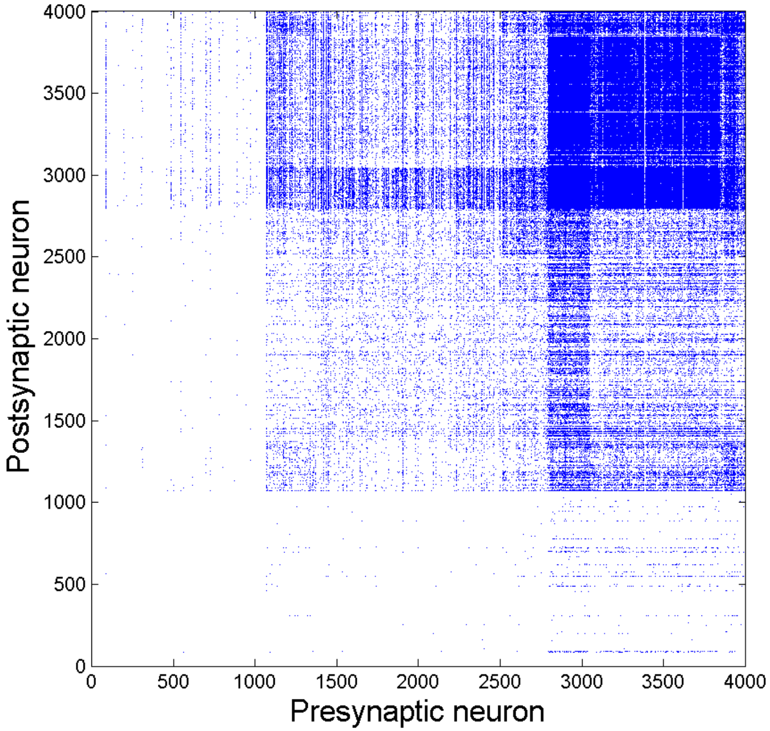
Adjacency matrices of functional connections

RS_LTS (no plast.)



C = 0,014

RS_LTS (with plast.)



C = 0,246

The formation of clusters of synchronous neural activity was facilitated for the case with synaptic plasticity.

Partial conclusions

- Even without specific input patterns, STDP may induce changes in the functional connectivity of the cortical network with impact on its global activity;

- The network composition in terms of electrophysiological classes of the neurons has influence on the global activity;

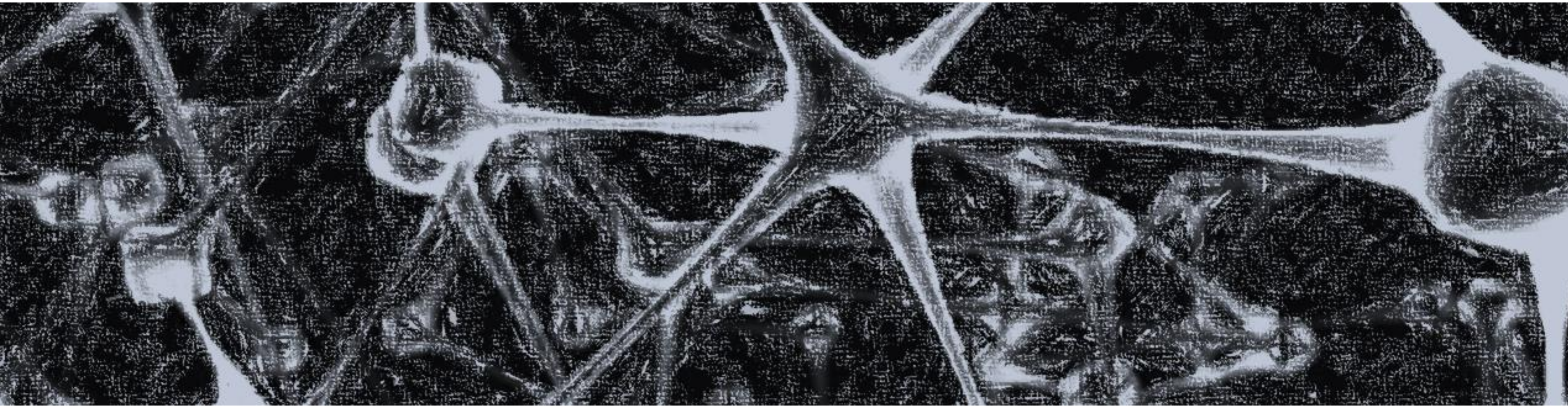
Next steps

Next steps and future studies

- To characterize the topological and functional matrices of the network with graph-theoretic measures;

- To add STDP on inhibitory synapses and study the effect in this neocortical architecture;

- To induce lesions in the network and study the effects of synaptic plasticity in the reorganization of activity.



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