Nonlinear dynamics emerging in large scale neural networks with ontogenetic and epigenetic processes

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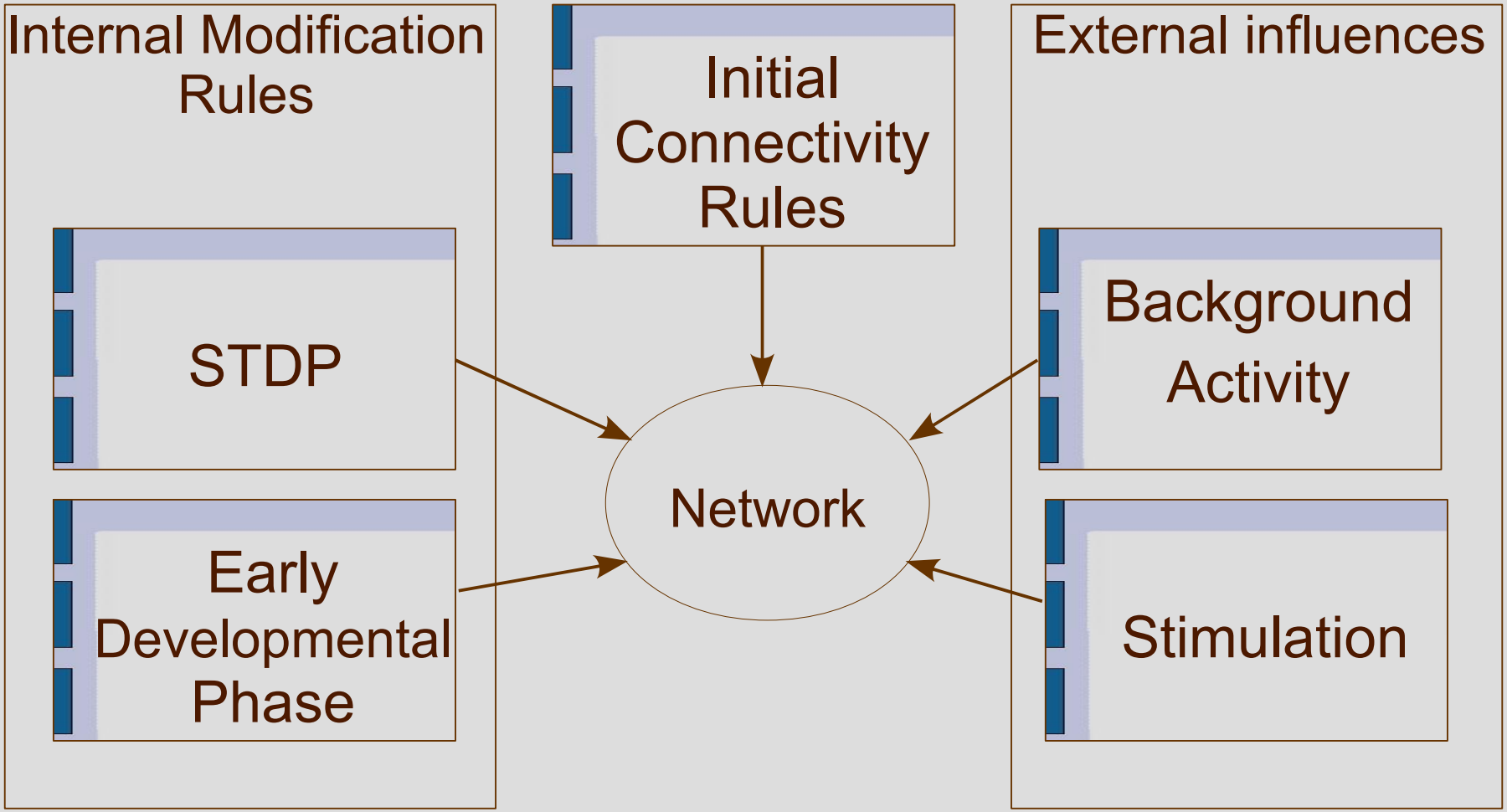
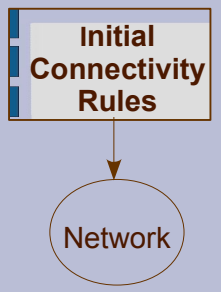
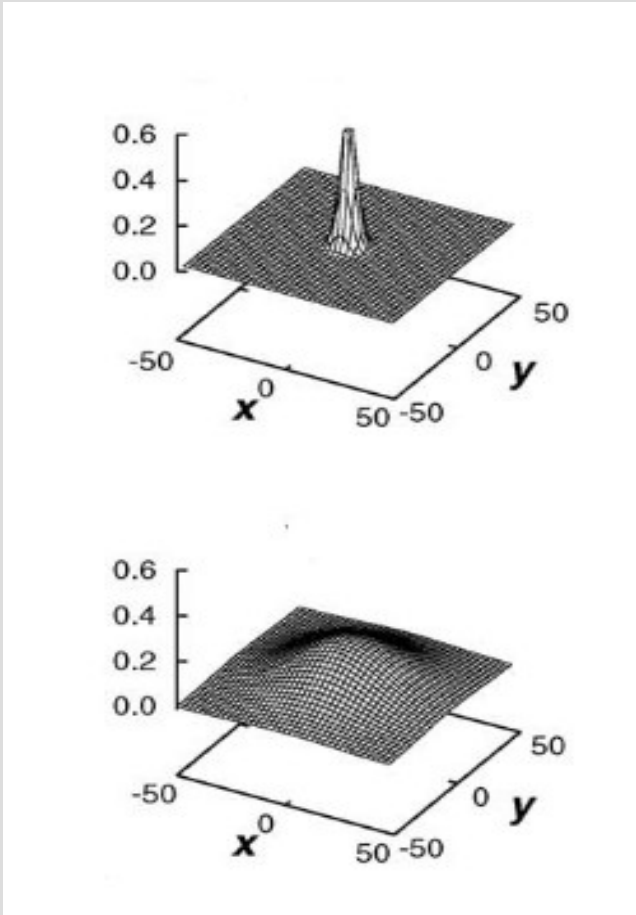
Neural Network Model



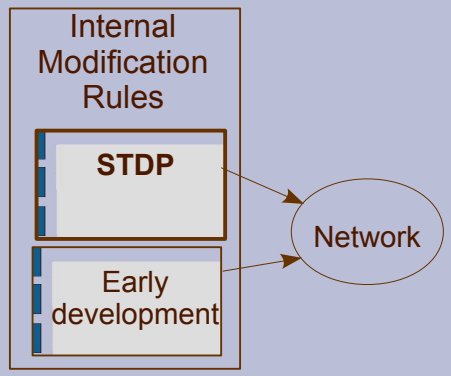


Network Connectivity

- *8,000 of* excitatory and 2,000 inhibitory units are distributed (Sobol quasi random distribution) on a *100x100* lattice
- Connections between cells are established following a 2D Gaussian probability density



Connectivity probability for excitatory (top) and inhibitory (bottom) units

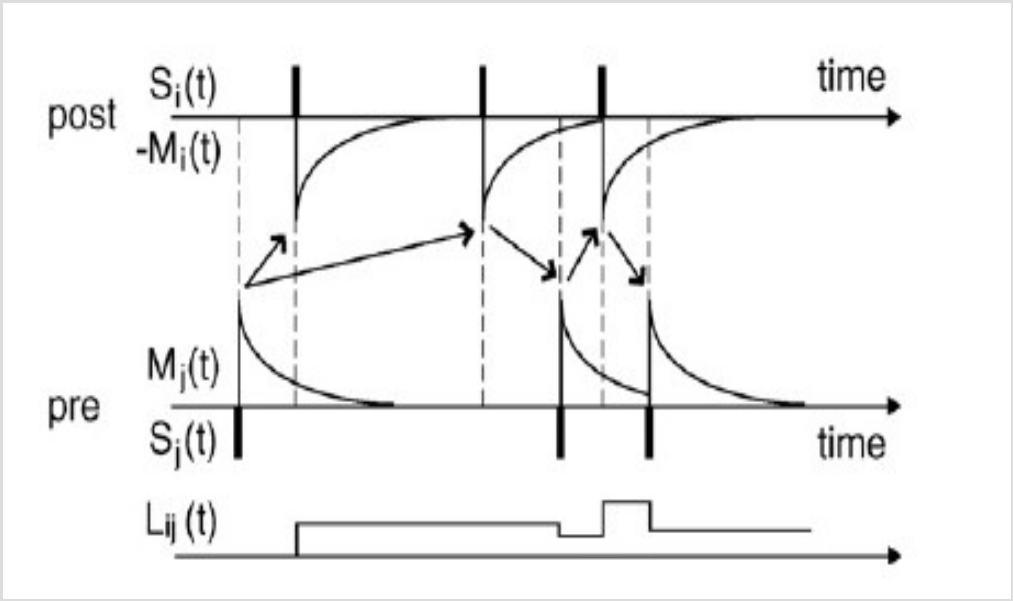


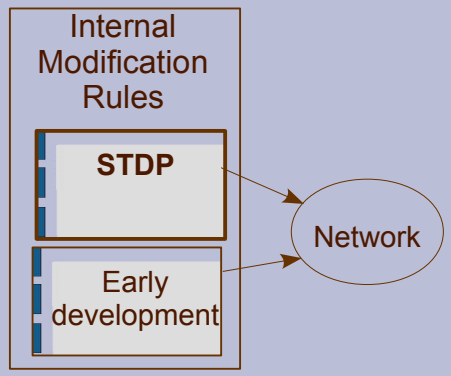
STDP Modification

- To implement the STDP rule the following real valued function is used:

$$L_{ji}(t+1) = L_{ji}(t)\,k_{act} + \left(S_i(t)\,M_j(t)\right) - \left(S_j(t)\,M_i(t)\right)$$

$$j - presynaptic\,,\; i - postsynaptic\,unit$$

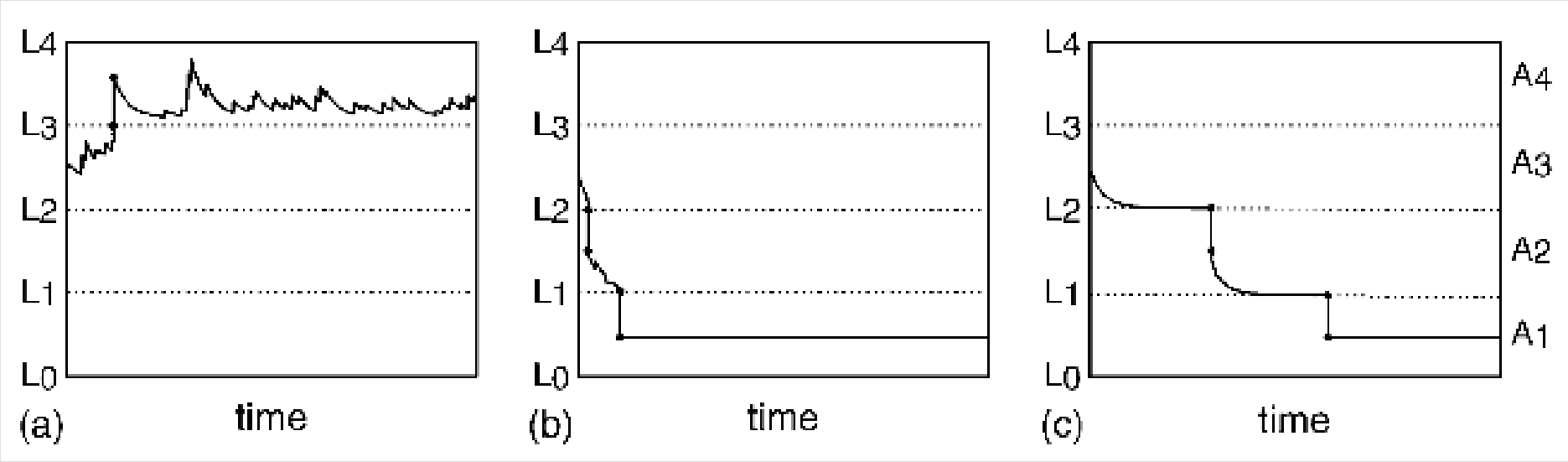


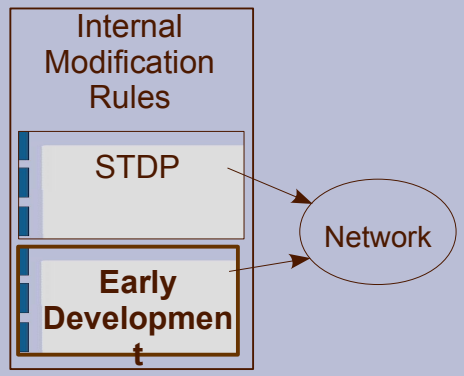


STDP Modification

- Synapses are characterized by an activation level which is an integer valued function:

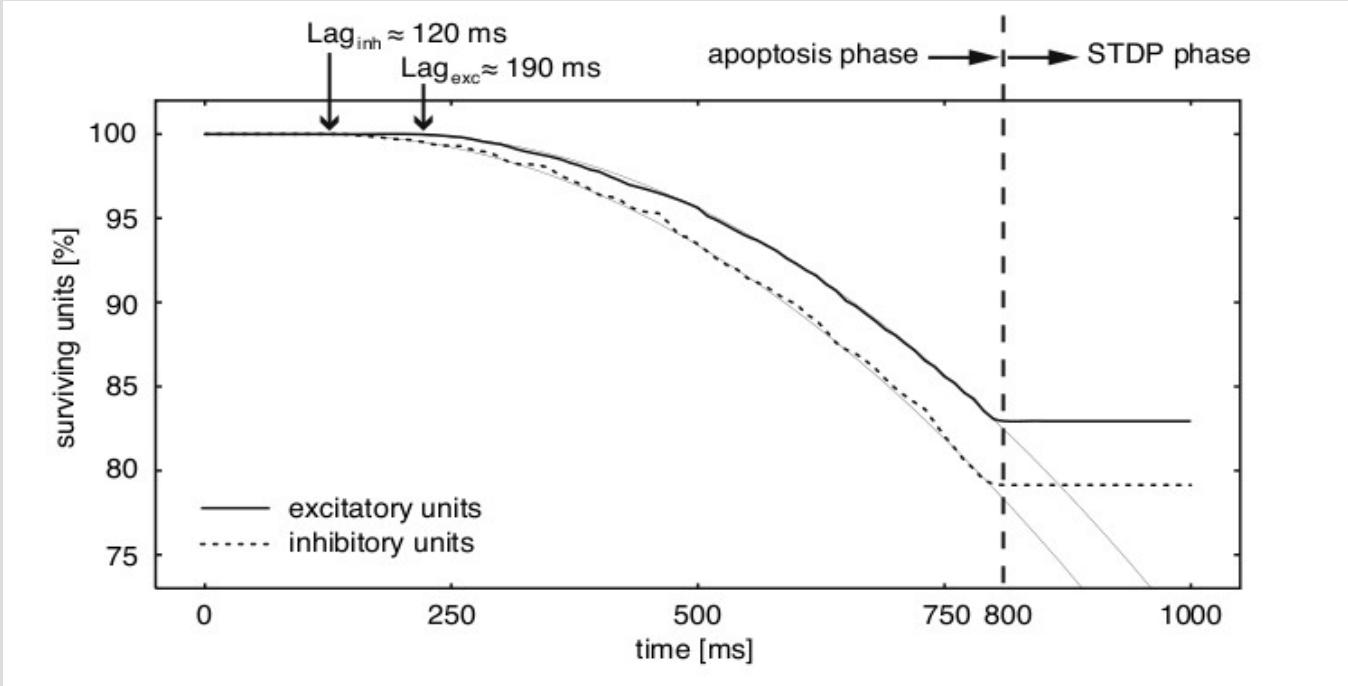
$$A_{ji}(t) \in [A_1 < A_2 < A_3 < A_4];$$

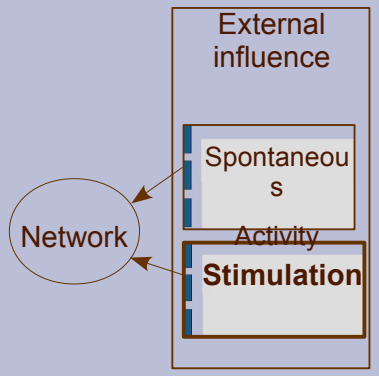




Early Developmental Phase

- If the firing rate exceeds a threshold value, the unit definitively stops its activity with some probability.
- The early developmental phase takes place during the first 800 milliseconds of the simulation. After that time the STDP phase starts.





Stimulation

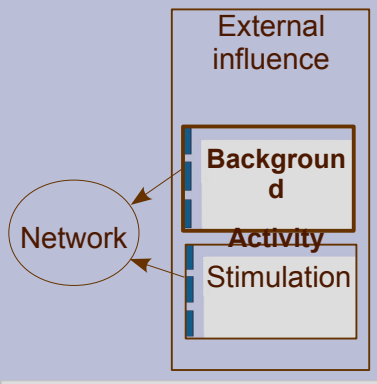
- The duration of each stimulus is *100ms*, its rate is *0.5Hz*
- Two sets of units labeled *A* and *B* are composed of *400* randomly chosen excitatory units
- Each set is divided into *10* groups of 40 units

$$A=\{A_1, A_2, \ldots A_{10}\}; \quad B=\{B_1, B_2, \ldots B_{10}\}$$

and receives a strong depolarization each ms of stimulation either in order *AB* or in order *BA*:

$$AB:[\underbrace{A_1, A_2, \ldots A_{10}}_{5\,times}, \underbrace{B_1, B_2, \ldots B_{10}}_{5\,times}]; \qquad BA:[\underbrace{B_1, B_2, \ldots B_{10}}_{5\,times}, \underbrace{A_1, A_2, \ldots A_{10}}_{5\,times}],$$

the sequences of *AB* and *BA* stimulations are random and equiprobable



Background Activity

- The background activity simulates the input of afferents to the network
- Throughout the simulation, each unit receives an *input* equivalent to a fixed number of afferents generating a postsynaptic potential of *0.84mV* following an independent Poisson process with mean rate of *5 inputs/s*

Unit State

- A unit fires if its state function *S(t)*=1. It depends on the membrane potential and the refractory period:

$$S(t+1)=H(V(t)-\theta_q)\,H(t_{ref}-\Delta_{prev\,spk}\,t);\qquad H(x)=0:x<0;1:overwise$$

- External activity, potential leakage and postsynaptic activity of projecting units contribute to the membrane potential:

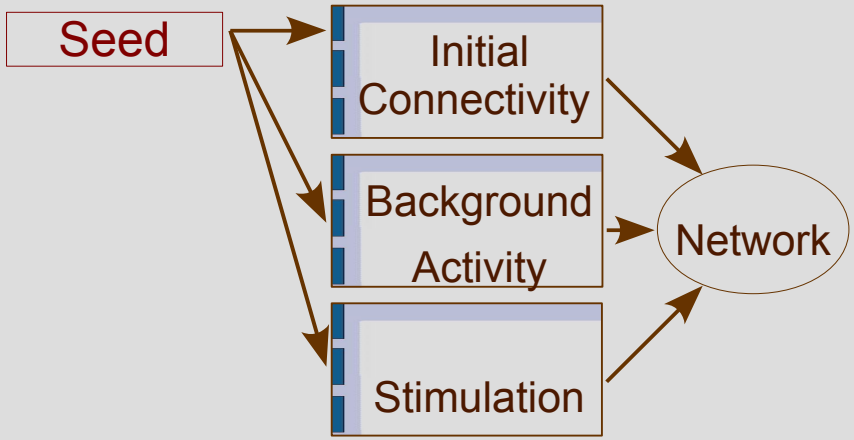
$$V_i(t+1)=V_{rest}+B(t)+(1-S_i(t))(V_i(t)-V_{rest})k_{mem}+\sum_j \omega_{ji}(t)$$

- The postsynaptic potential depends on the synapse activation level:

$$\omega_{ji}(t+1)=S_j(t)\,A_{ji}(t)\,P_{[q_i,q_j]};\quad q_i,q_j\in[excitatory,inhibitory]$$

Simulations

- Keeping the same rules and the same parameters the simulations were repeated *30* times with different random generator seeds
- Each seed generates a different network connectivity, as well as different stimulation and background activity patterns

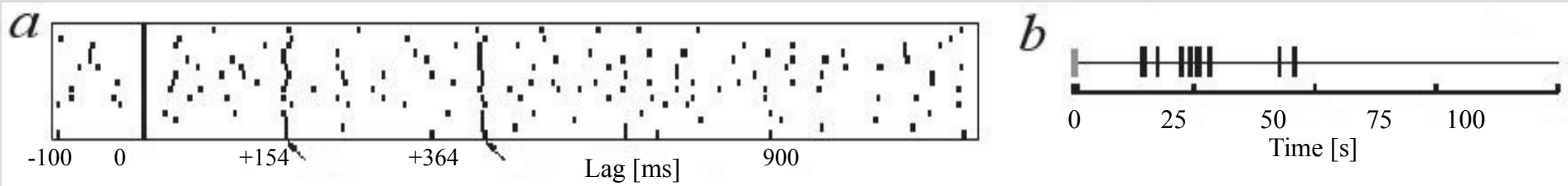


- These seeds were reused to reproduce the *30* simulations in absence of stimulation

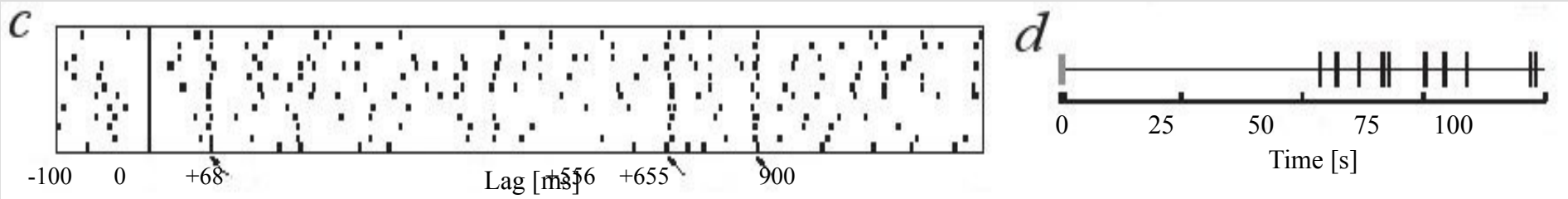
Spatiotemporal Firing Patterns

- Spike trains of all units active by time $t=T_{end}=100{,}000ms$ except units receiving stimulation were scanned for occurrences of firing patterns
- Pattern Grouping Algorithm (PGA) was used for pattern detection [Tetko,Villa 2001]
- Rasters and occurrence times of two detected patterns:

a triplet $\langle 23E5, 23E5, 23E5 ; 154 \pm 3.5, 364 \pm 3.0 \rangle$



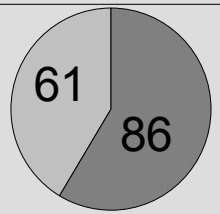
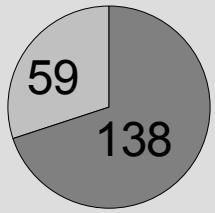
and a quadruplet $\langle B9B, B9B, B9B, B9B ; 68 \pm 2.0, 556 \pm 1.0, 655 \pm 4.0 \rangle$



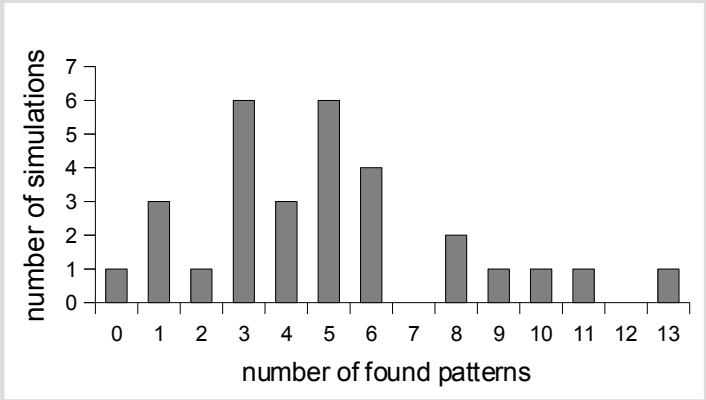
Distribution of Detected Patterns

PGA was set to detect patterns of 3 and 4 spikes

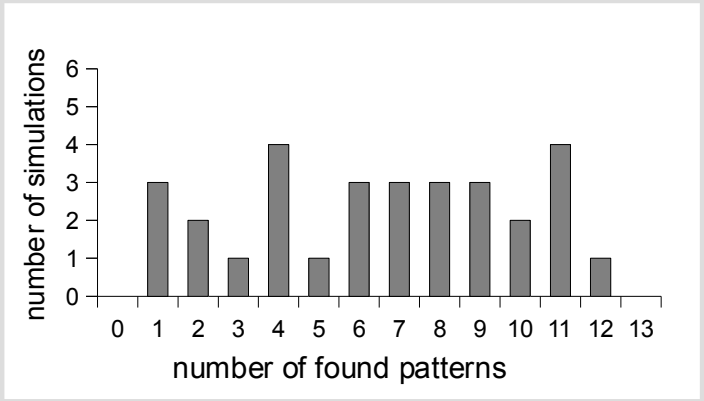
The majority of detected patterns are composed by events of one single unit

stimulation	ON	OFF
total patterns	147	197
triplets/ quadruplets		
multi-unit patterns	5	6

stimulation **ON**:



stimulation **OFF**:



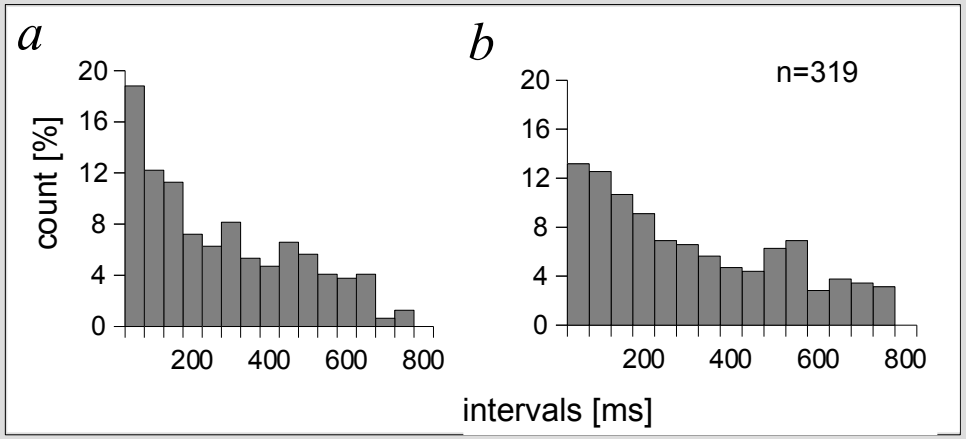
Intra Pattern Intervals

Distribution of the first (a,c) and the second (b,d) intervals of triplets:

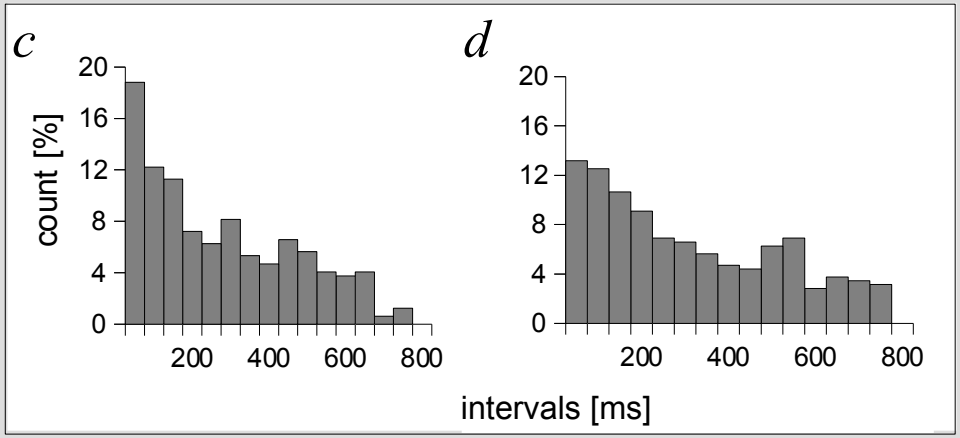
In case of quadruplets all sub-triplets are taken into account:

1.|| | ¦ 2.|| ¦ | 3.| ¦ || 4.| | ||

stimulation **ON**:

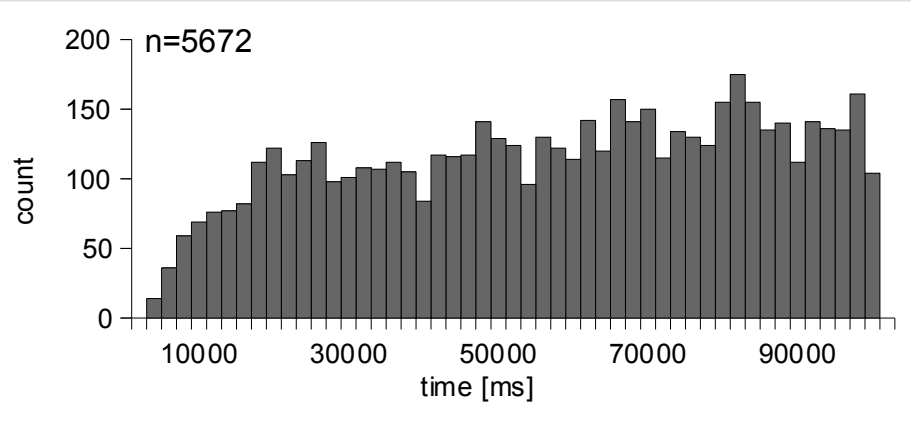


stimulation **OFF**:

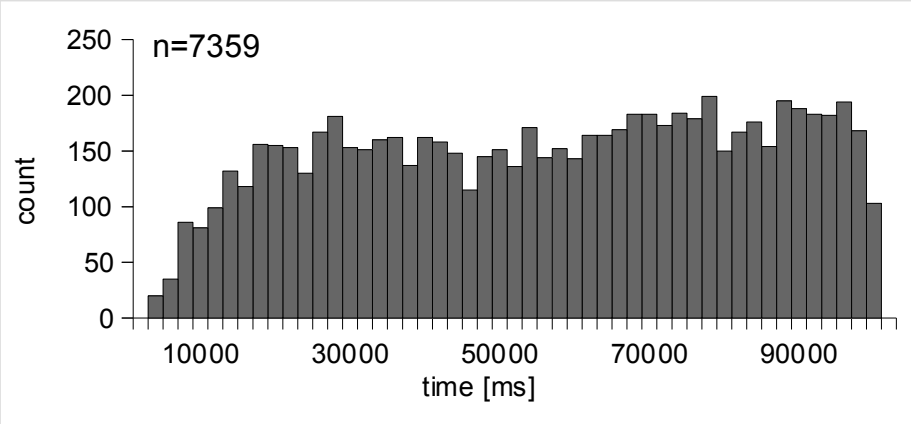


Dynamics of Patterns

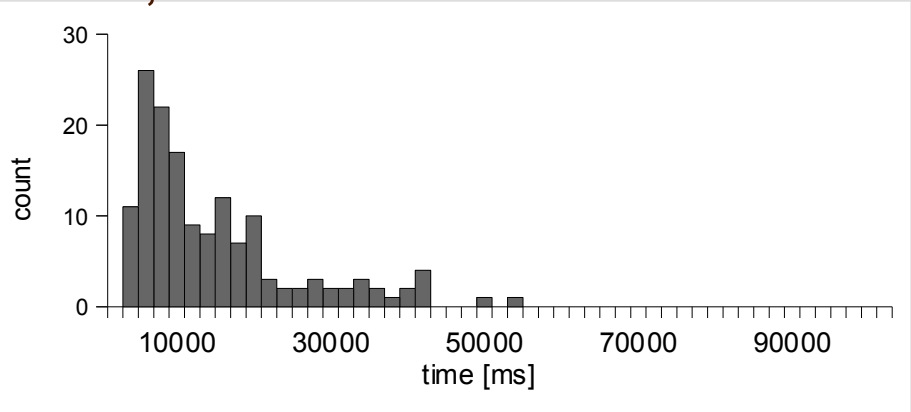
stimulation **ON**:

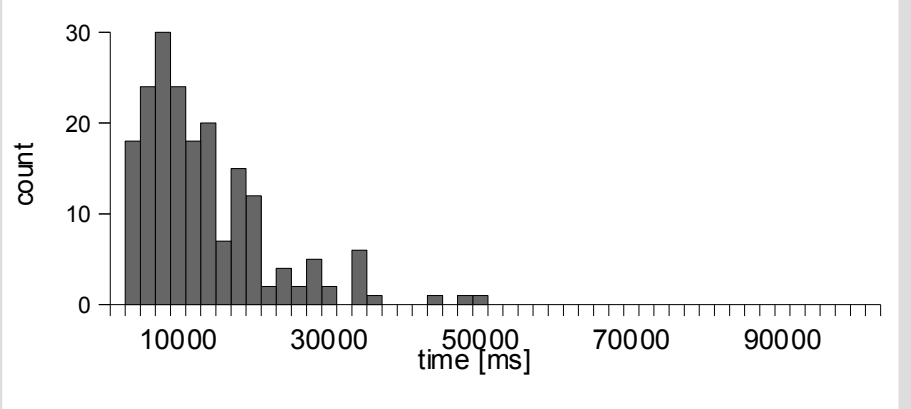


stimulation **OFF**:



Cumulative histogram of the detected patterns occurrences, bin=2,000ms

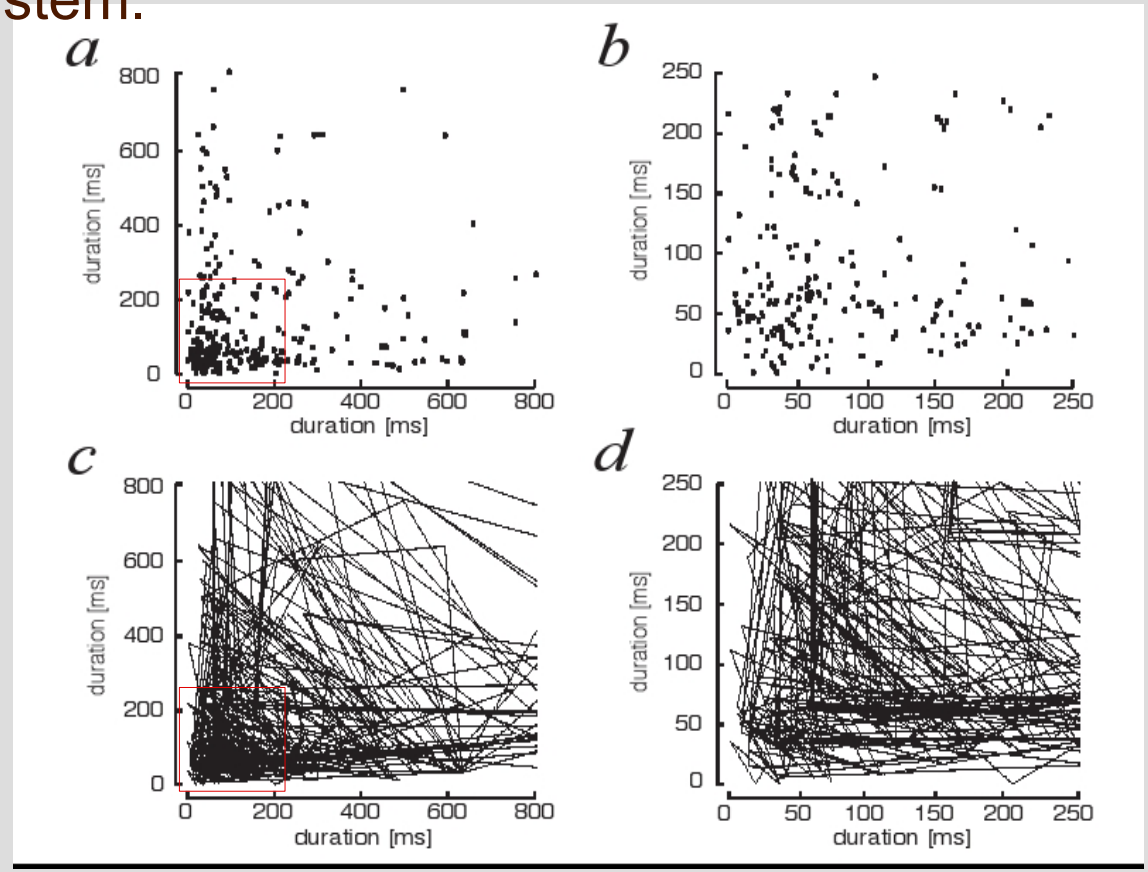




Histogram of the detected patterns' onsets, bin=2,000ms

Nonlinear Dynamics

On the return map of all the events of a simulation that were part of a pattern plotted together a possible attractor trajectories are distinguishable. This gives a hint about a possible underlying non linear dynamical system.



Thank You for Your Attention

Acknowledgments

PERPLEXUS FP6 EU Project #034632

GABA FP6 EU Project #043309

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