

Emergence of precise firing sequences driven by temporally structured stimuli in large scale neuron networks

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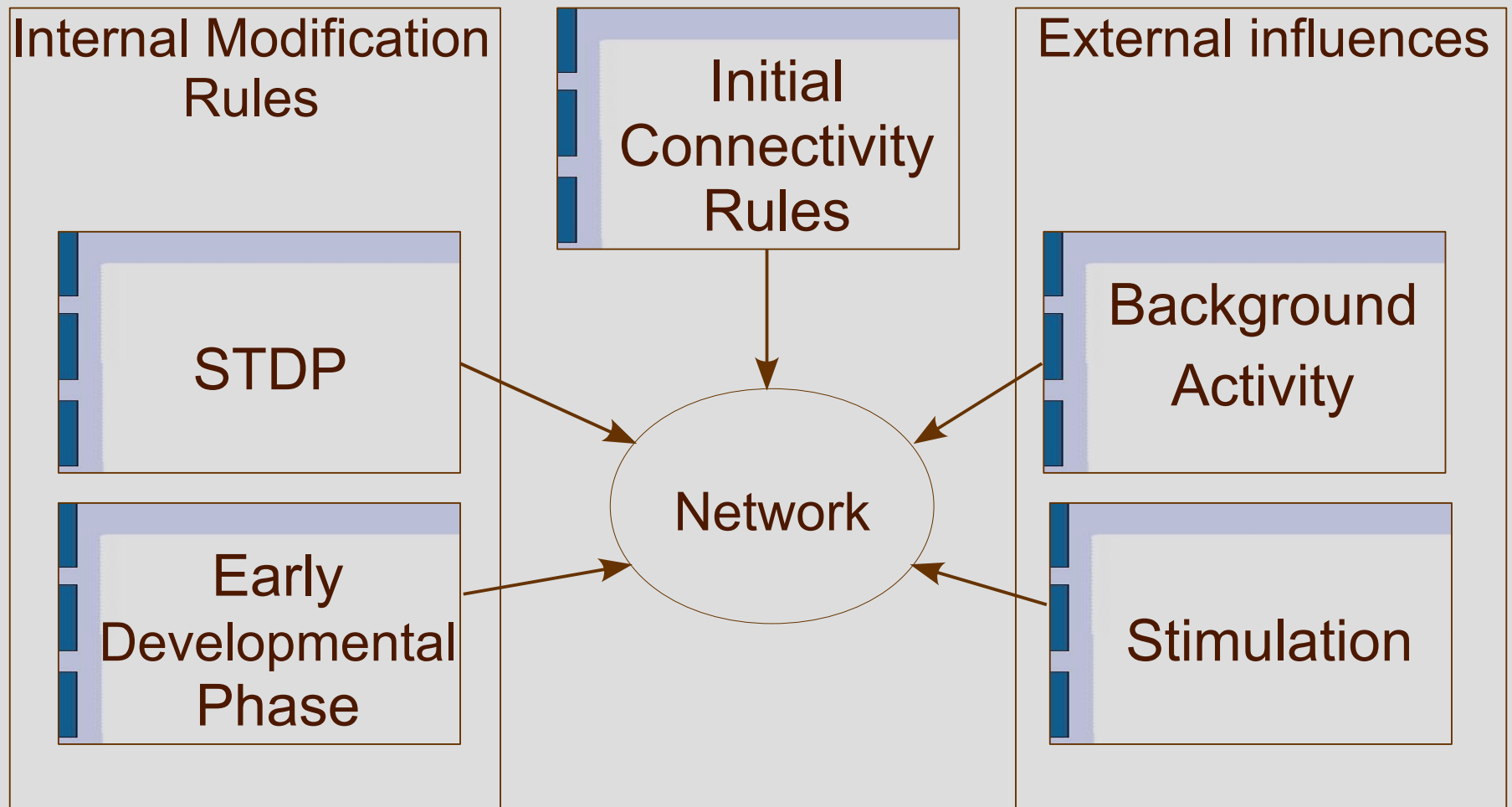
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Neural Network Model

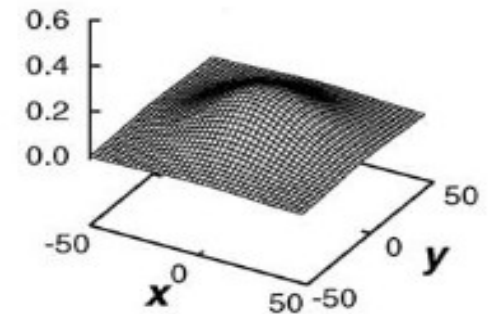
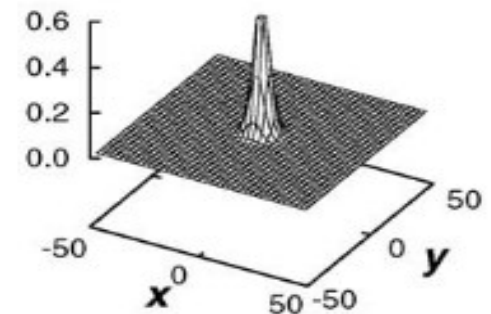


Initial
Connectivity
Rules

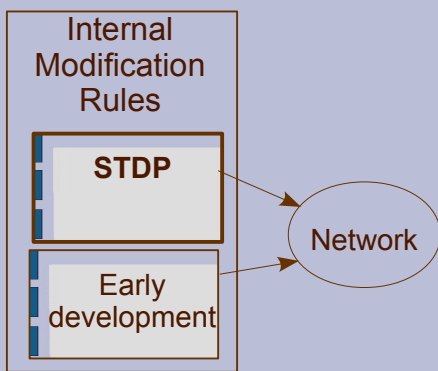
Network

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

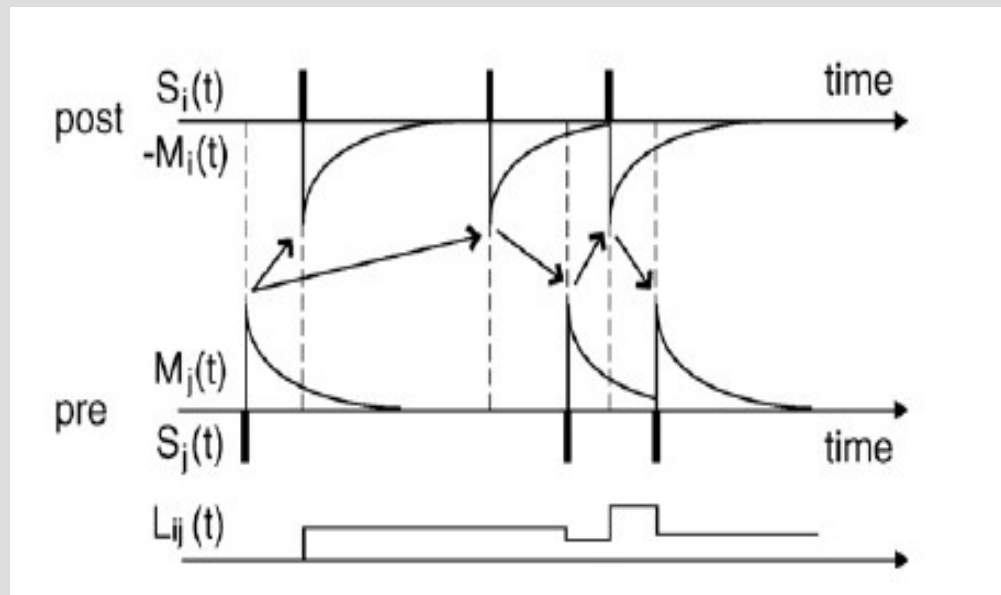


STDP Modification

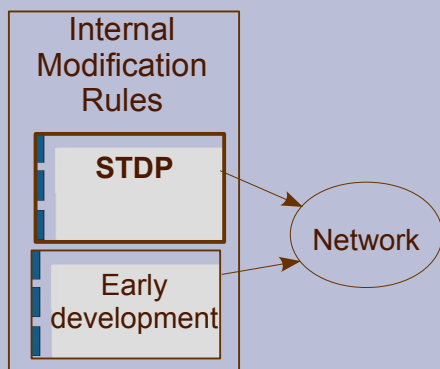
- To implement the STDP rule the following real valued function is used:

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

j – presynaptic , i – postsynaptic unit

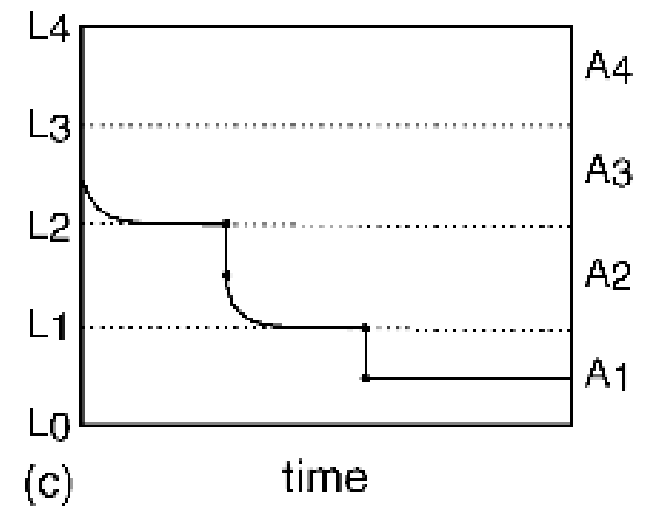
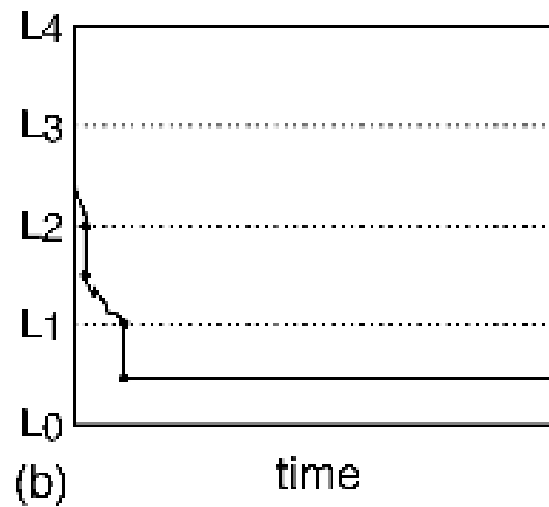
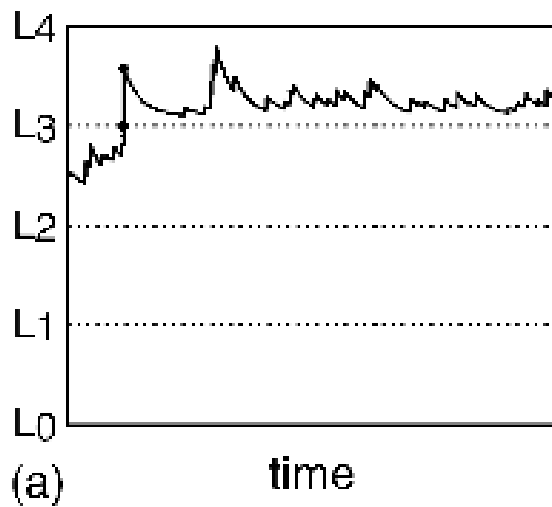


STDP Modification

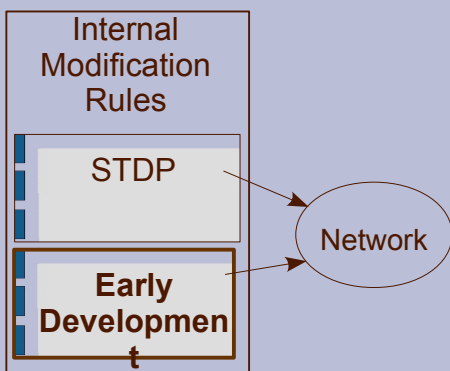


- Synapses are characterized by an activation level which is an integer valued function:

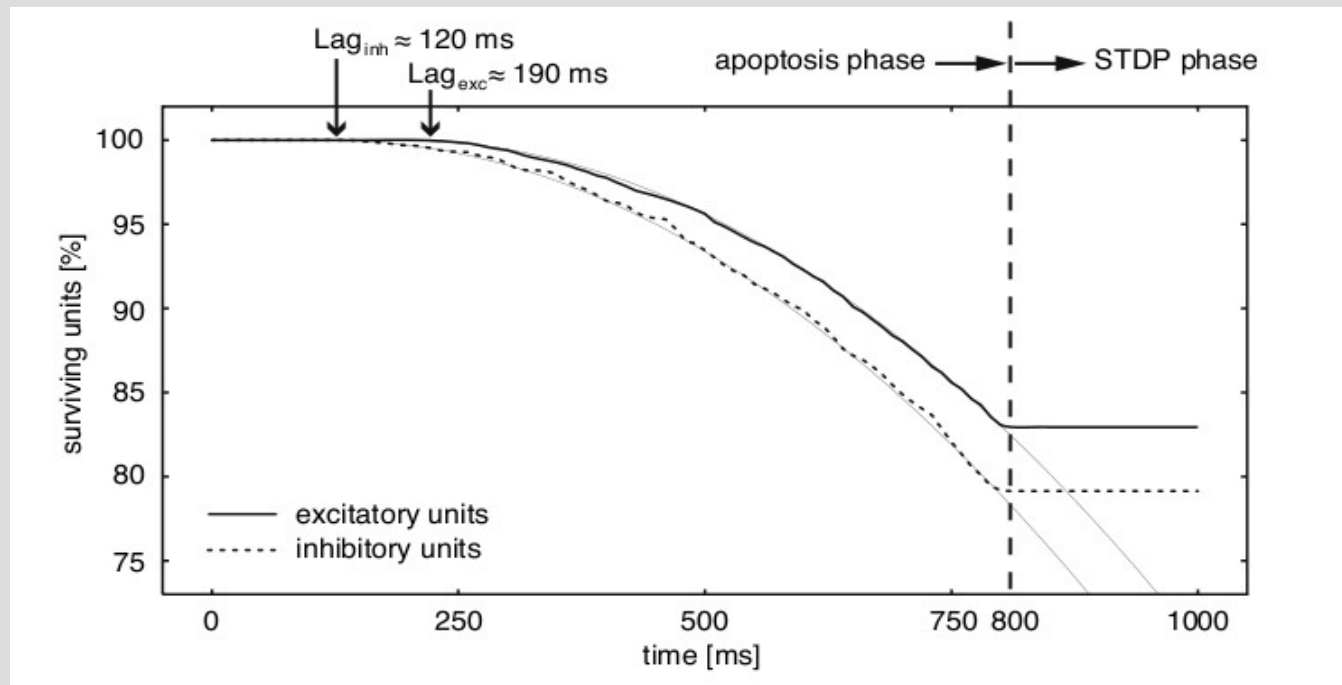
$$A_{ji}(t) \in [A_1 < A_2 < A_3 < A_4];$$



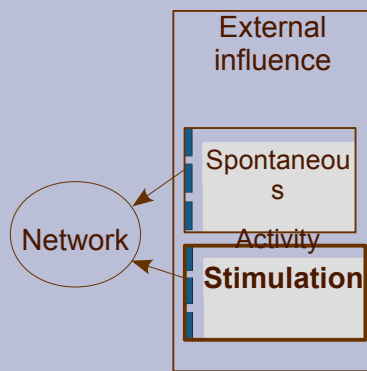
Early Developmental Phase



- 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



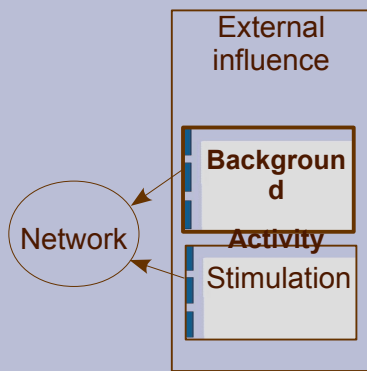
- The duration of each stimulus is $100ms$, its rate is $0.5Hz$
- Two sets of units labeled A and B are composed of 400 randomly chosen excitatory units
- Each set is divided into 10 groups of 40 units

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

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

$$AB : \left[\underbrace{A_1, A_2, \dots, A_{10}}_{5 \text{ times}}, \underbrace{B_1, B_2, \dots, B_{10}}_{5 \text{ times}} \right]; \quad BA : \left[\underbrace{B_1, B_2, \dots, B_{10}}_{5 \text{ times}}, \underbrace{A_1, A_2, \dots, A_{10}}_{5 \text{ times}} \right],$$

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:

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

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

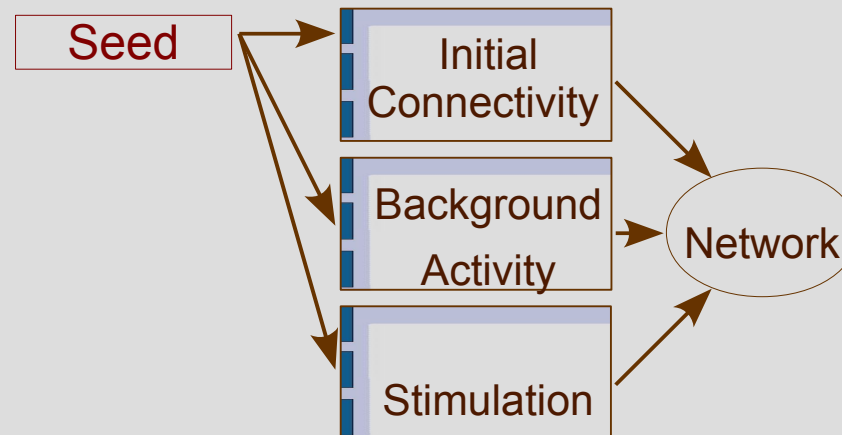
$$V_i(t+1) = V_{rest} + B(t) + (1 - S_i(t))(V_i(t) - V_{rest})k_{mem} + \sum_j \omega_{ji}(t)$$

- 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

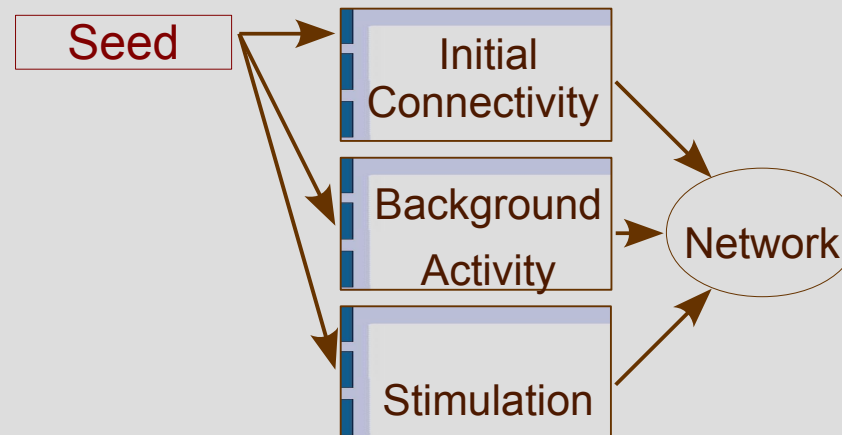
- Keeping the same rules and the same parameters the simulations were repeated 30 times with different random generator seeds
- Each seed generates a different network connectivity, as well as different stimulation and background activity patterns



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

Coupled Networks

- 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

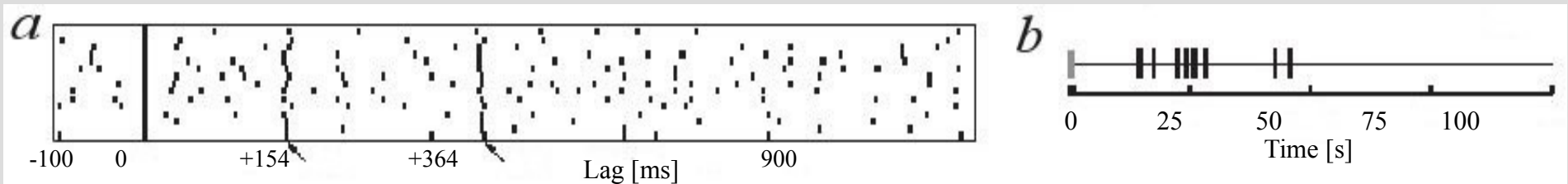


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Spatiotemporal Firing Patterns

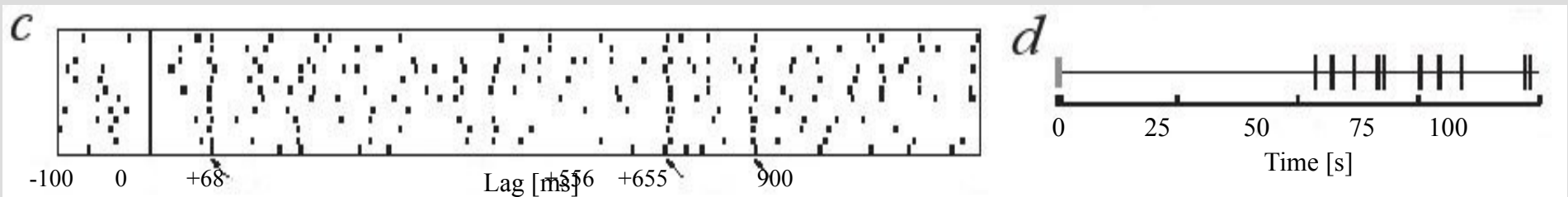
- Spike trains of all units active by time $t=T_{end}=100,000ms$ except units receiving stimulation were scanned for occurrences of firing patterns
- Pattern Grouping Algorithm (PGA) was used for pattern detection [Tetko, Villa 2001]
- Rasters and occurrence times of two detected patterns:
a triplet

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



and a quadruplet

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



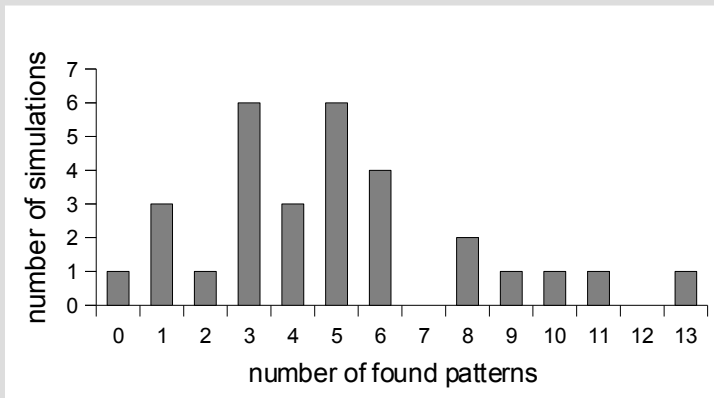
Distribution of Detected Patterns

PGA was set to detect patterns of 3 and 4 spikes

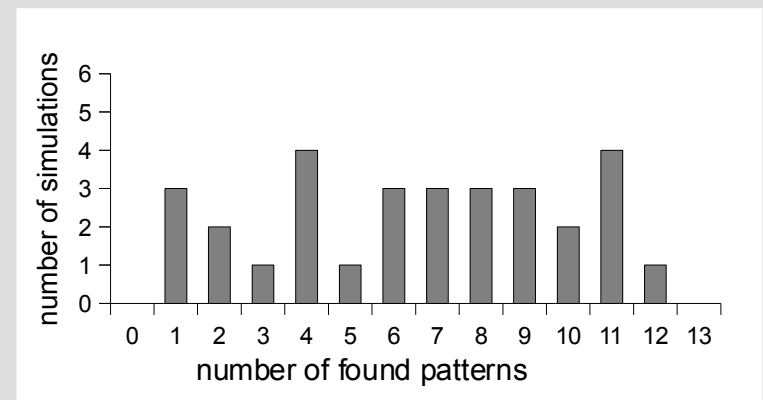
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Distribution of Detected Patterns

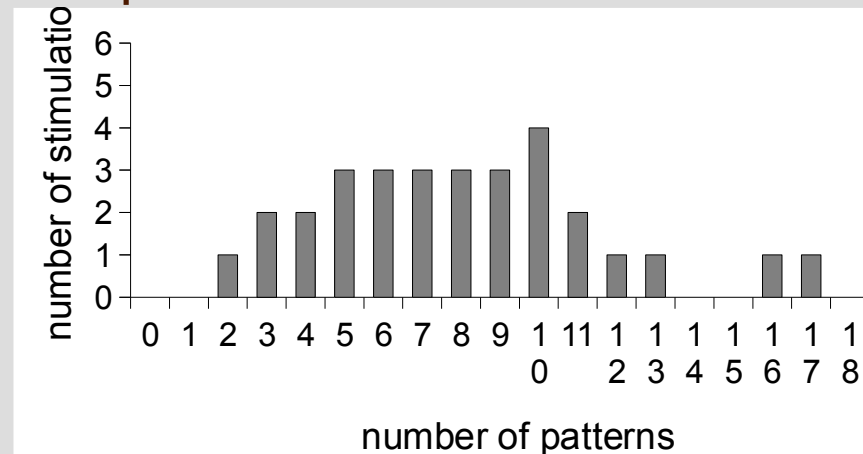
stimulation **ON**:



stimulation **OFF**:

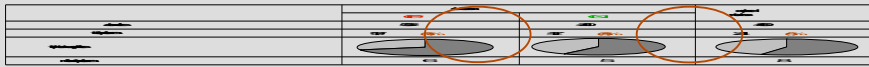


coupled networks:

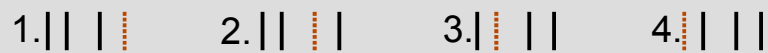


Intra Pattern Intervals

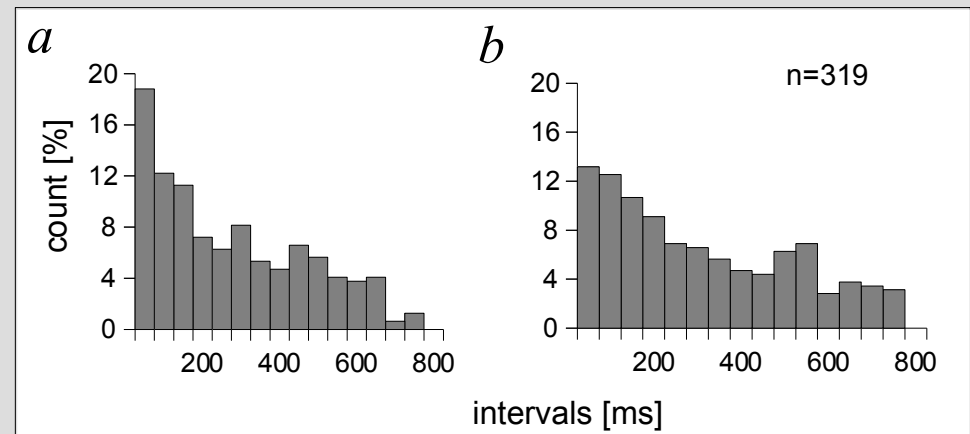
Distribution of the first (a,c) and the second (b,d) intervals of triplets:



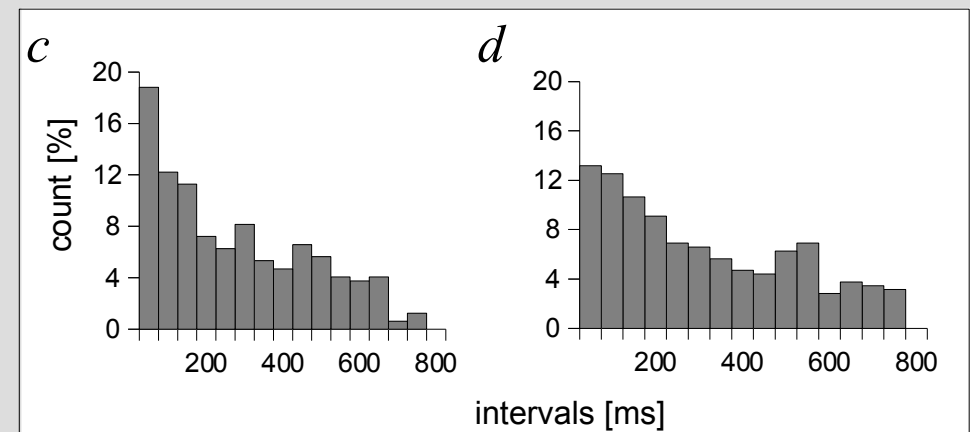
In case of quadruplets all sub-triplets are taken into account:



stimulation **ON**:

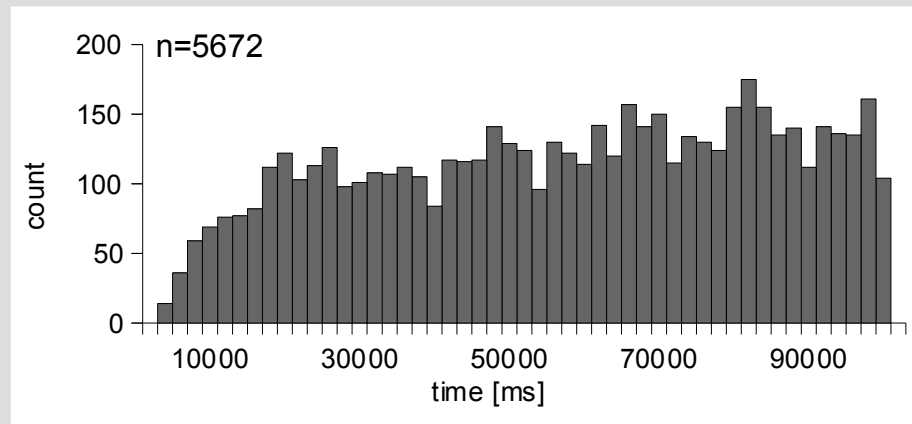


stimulation **OFF**:

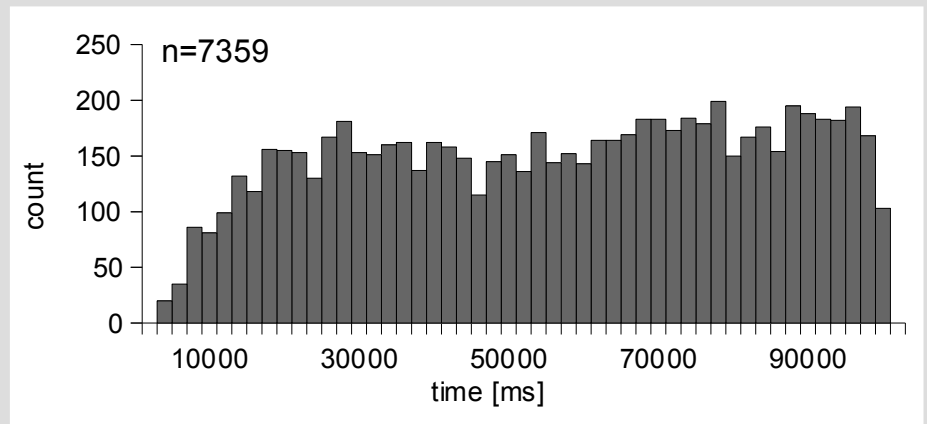


Dynamics of Patterns

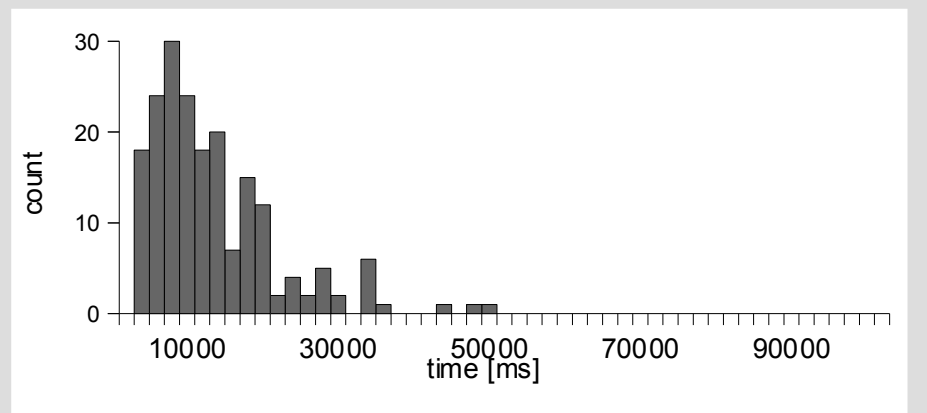
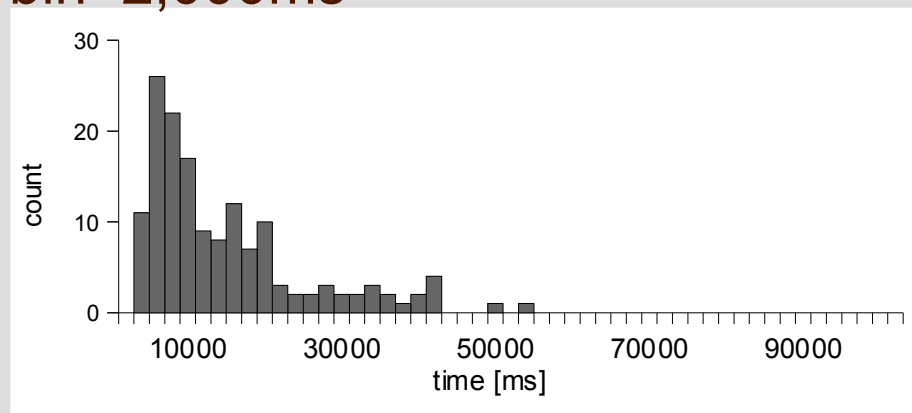
stimulation **ON**:



stimulation **OFF**:



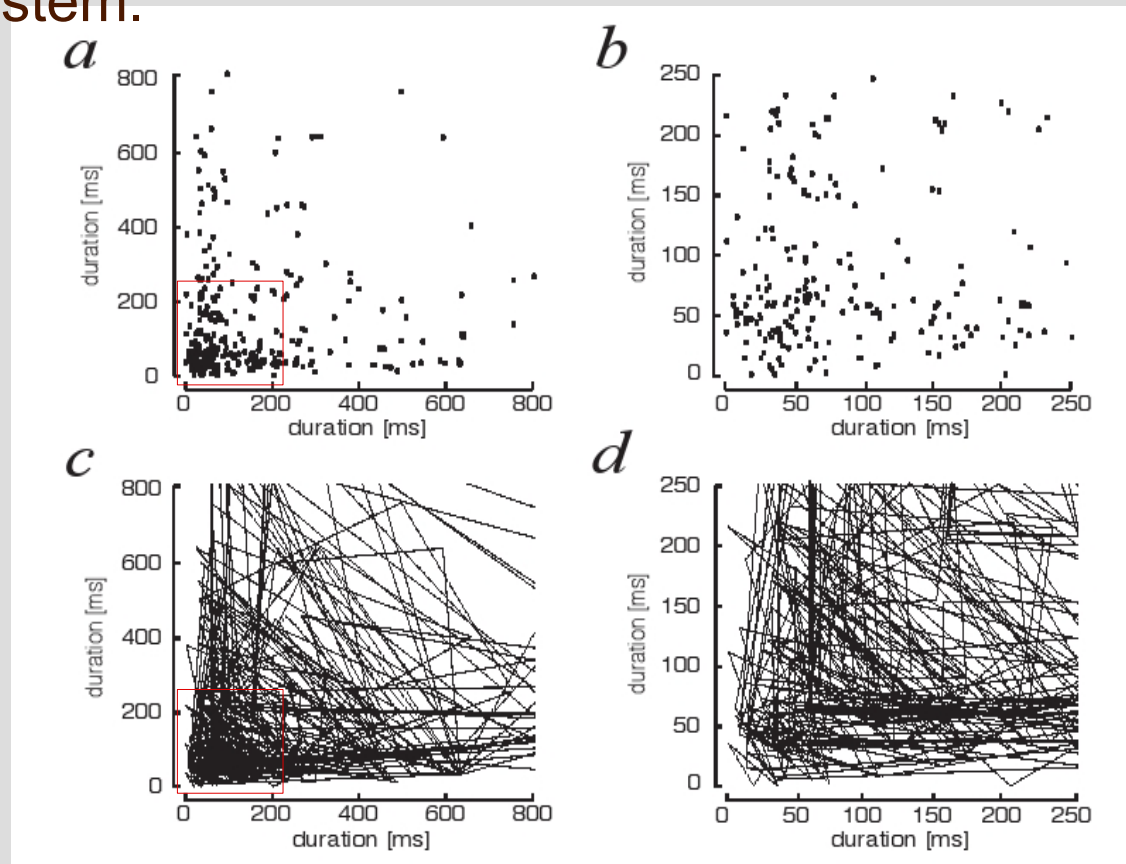
Cumulative histogram of the detected patterns occurrences, bin=2,000ms



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

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<http://www.neuroheuristic.org/>

