Simulating structural plasticity of large-scale networks in NEST

Mikael Naveau[1], Markus Butz[1]

[1]Simulation Lab Neuroscience - Bernstein Facility for Simulation and Database Technology, Institute for Advanced Simulation, Jülich Aachen Research Alliance, Forschungszentrum Jülich, 52425 Jülich, Germany

E-mail: m.naveau@fz-juelich.de

Model of Structural Plasticity (MSP) [1]

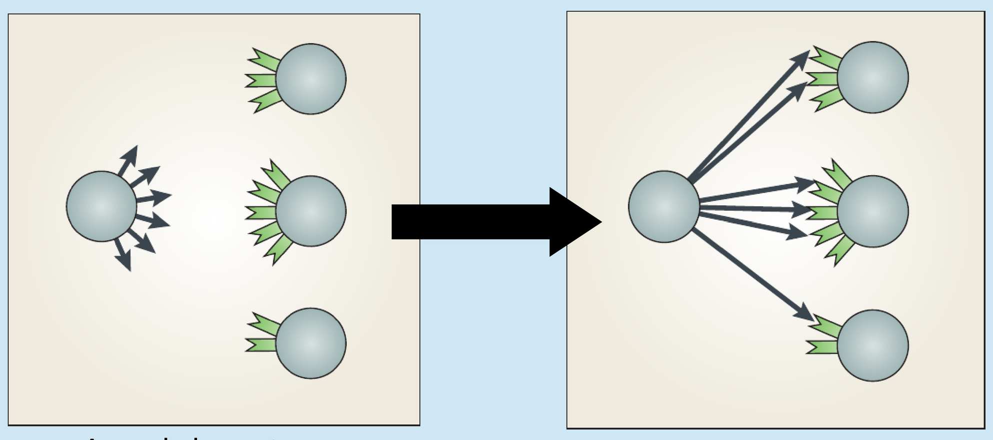
Activity-dependent rewiring of the connectivity between neurons

Synaptic elements (axonal boutons and dendritic spines) are formed or deleted according to the average electrical activity of the neurons.

The intracellular calcium concentration is used to approximate the average electrical activity:

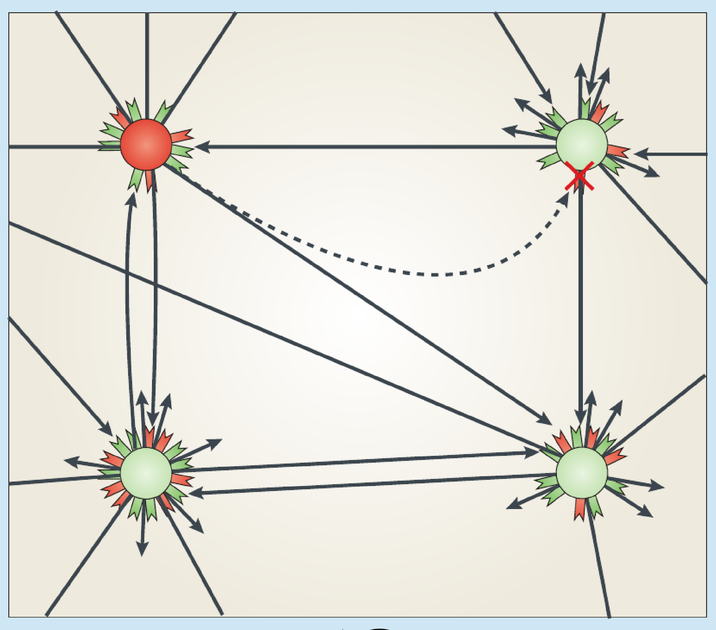
$$\frac{d[Ca^{2+}]_i}{dt} = \begin{cases} \frac{-[Ca^{2+}]_i}{\tau_{Ca}} + \beta, & \text{if neuron } i \text{ spikes} \\ \frac{-[Ca^{2+}]_i}{\tau_{Ca}} & \text{otherwise} \end{cases}$$

Synapse formation



Network rewiring

The deletion of synaptic elements break the associated synapses.



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Simulating structural plasticity with NEST [2]

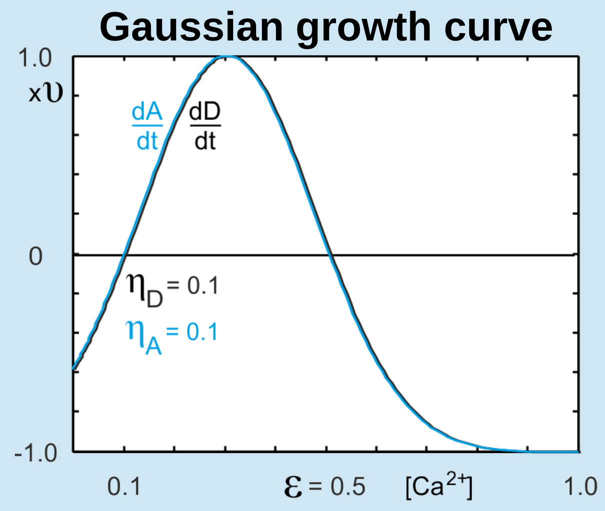
```
# Neuron model
n_exc = 800
n_inh - 200
izhikevich_d = { 'a': 0.1, 'b': 0.2, 'c': -65.0,
   'd': 2.0, 'beta_Ca': 0.001, 'tau_Ca': 10000.0}
exc = nest.Create('izhikevich', n_exc, izhikevich_d)
inh = nest.Create('izhikevich', n_inh, izhikevich_d)

# Synaptic element: growth curve
gc = {
    'growth_curve': "gaussian",
    'growth_rate': 0.001,
    'eta': 0.1,
    'eps': 0.5,
}

# Synaptic elements: associated neurons
nest.SetStatus(exc, 'synaptic_elements',
    {'Axon_exc': gc, 'Den_exc': gc, 'Den_inh': gc})
nest.SetStatus(inh, 'synaptic_elements',
    {'Axon_inh': gc, 'Den_exc': gc, 'Den_inh': gc})

# Synapses parameters
exc_syn_params = {'weight': 0.5, 'delay': 1.0}
inh_syn_params = {'weight': -0.5, 'delay': 1.0}

nest.CopyModel('static_synapse', 'synapse_exc')
nest.SetDefaults('synapse_exc', exc_syn_params)
nest.CopyModel('static_synapse', 'synapse_inh')
nest.SetDefaults('synapse_inh', inh_syn_params)

nest.SetKernelStatus({
    'MSP_synapses': {
        'synapse_exc': {
            'post_synaptic_element': 'Den_exc',
            'pre_synaptic_element': 'Axon_exc',
        },
        'synapse_inh': {
            'post_synaptic_element': 'Den_inh',
            'pre_synaptic_element': 'Axon_inh',
        },
    }
})
```

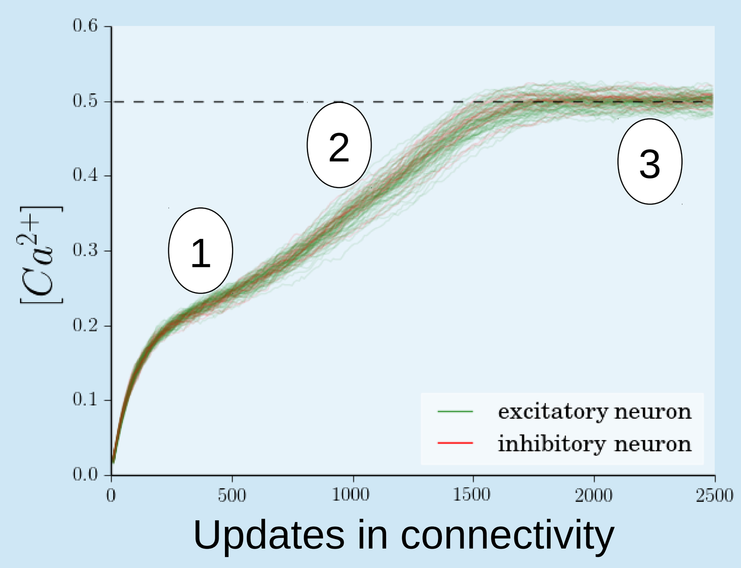
Implementation of structural plasticity in NEST

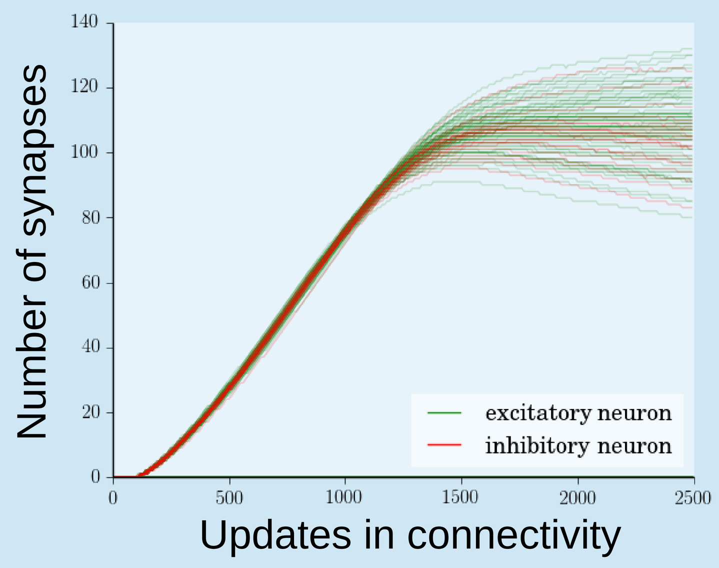
The synaptic elements can be defined for every neuron model implemented in NEST. The synapse models are registered to the NEST kernel to update the connectivity during the simulation.

nest:: simulated()

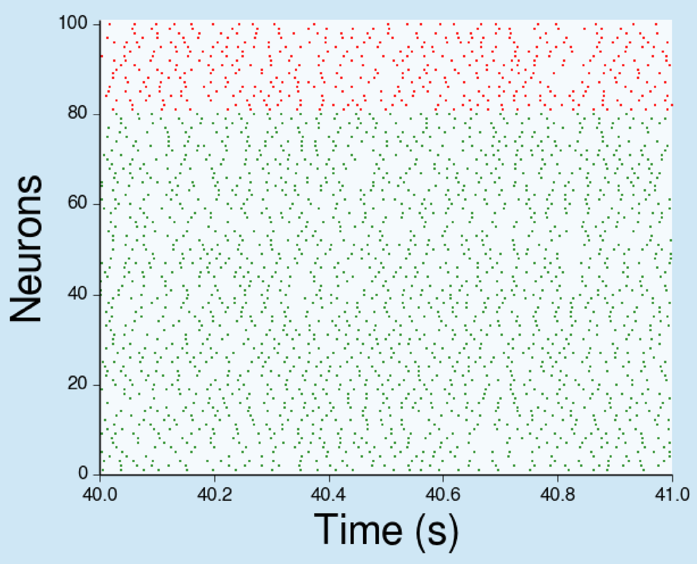
Gaussian growth curve



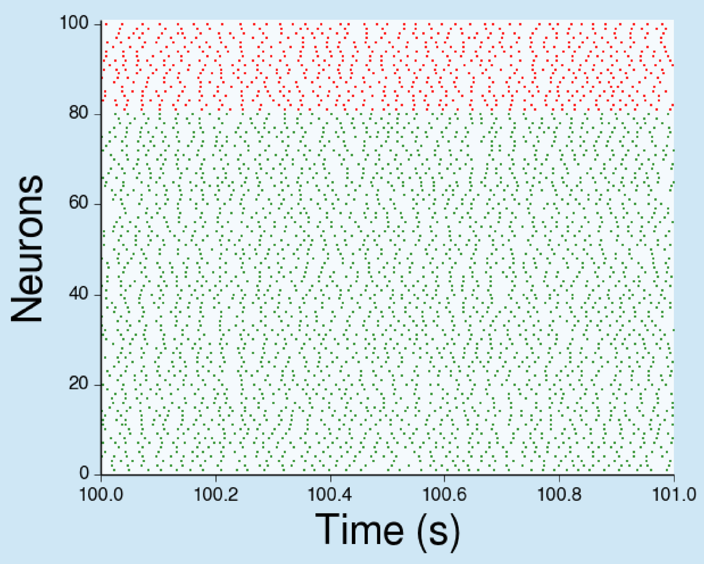




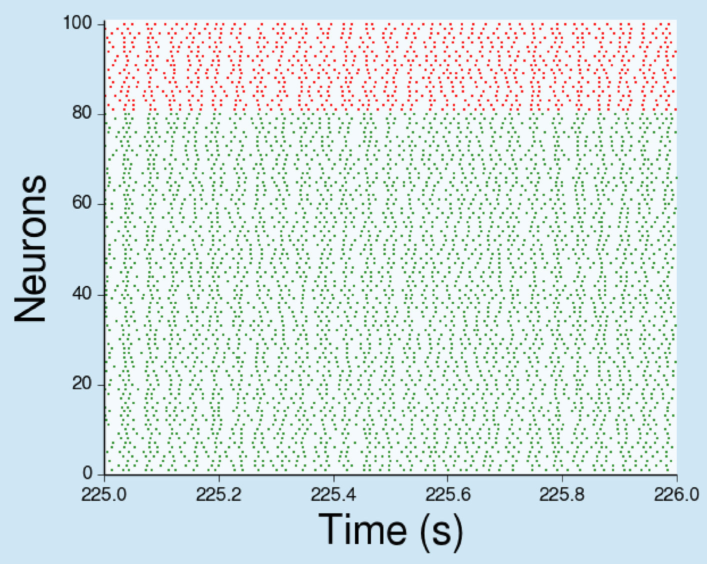
1 Noise level



2 Growing phase



3 Equilibrium



Simulating large-scale networks using High Performance Computing (HPC)

NEST simulator is fast and memory efficient [3]

NEST runs on a wide range of UNIX-like systems, from personal computer to BlueGene supercomputers.

Simulation on JUQUEEN - Jülich Blue Gene/Q

IBM PowerPC® A2, 1.6 GHz, 16 cores per node

16 GB SDRAM-DDR3 per node

Neuronal Network

Simple model of spiking neurons [4]

80% of excitatory neurons / 20% of inhibitory neurons

2000 updates in connectivity (200 s)

The equilibrium in electrical activity (ε) is reach for each simulation

# Neurons	# Synapses*	Connection density	# cores**	Simulation time
10^3	5×10^4	5.00%	128	00:08:05
2×10^3	10^5	2.50%	128	00:09:04
5×10^3	2.5×10^5	1.00%	128	00:14:28
10^4	5×10^5	0.50%	128	00:18:19
5×10^4	2.5×10^6	0.10%	512	00:27:42
10^5	5×10^6	0.05%	512	00:40:33
10^5	10^7	0.10%	512	00:42:18

* at the equilibrium phase. Estimate the number of synapses formed during the simulation

** 4 threads are attached to each process using OpenMP

[1] Butz M and van Ooyen A (2013) "A Simple Rule for Dendritic Spine and Axonal Bouton Formation Can Account for Cortical Reorganization after Focal Retinal Lesions." PLoS Comput Biol 9(10):e1003259
[2] Gewaltig M-O & Diesmann M (2007) "NEST (Neural Simulation Tool)." Scholarpedia 2(4):1430.
[3] Helias, Moritz, Susanne Kunkel, Gen Masumoto, Jun Igarashi, Jochen Martin Eppler, Shin Ishii, Tomoki Fukai, Abigail Morrison, and Markus Diesmann (2012) "Supercomputers Ready for Use as Discovery Machines for Neuroscience." Frontiers in Neuroinformatics 6: 26
[4] Izhikevich (2013) "Simple Model of Spiking Neurons." IEEE Transactions on Neural Networks 14:1569-1572
[5] Van Ooyen, Arjen (2011) "Using Theoretical Models to Analyse Neural Development." Nature Reviews Neuroscience 12(6):311–26