



Structural plasticity in NEST

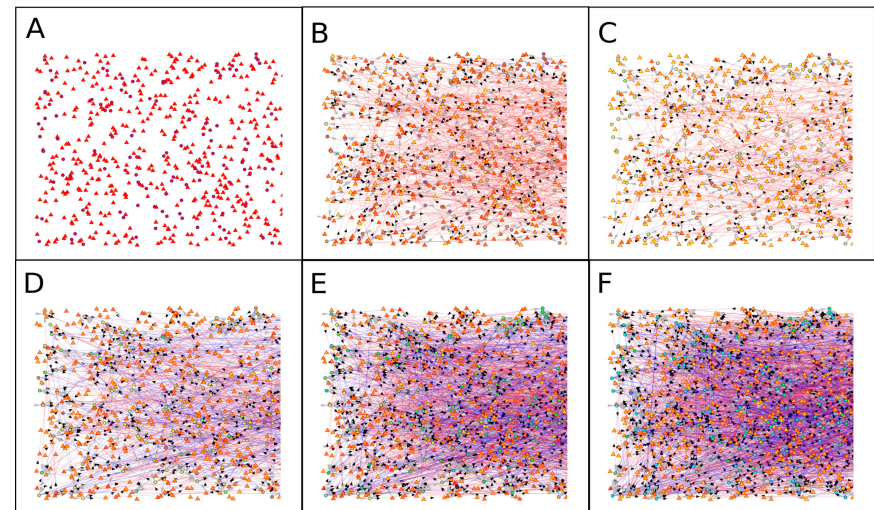
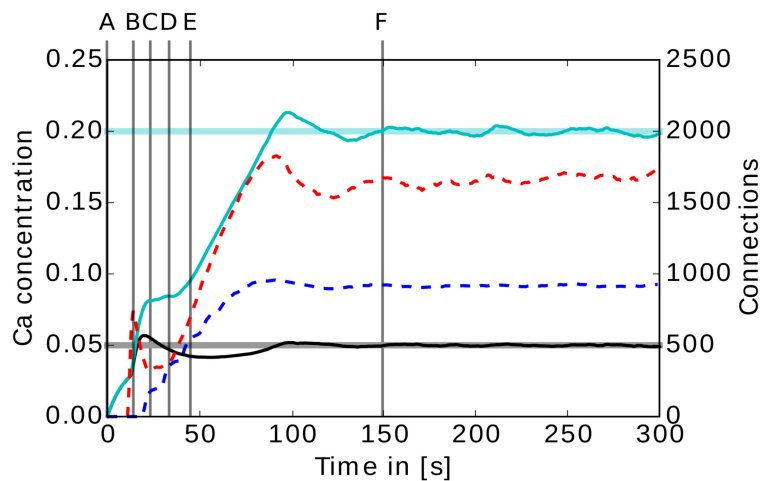
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Agenda

- Introduction and motivation
- Connectivity generation with structural plasticity
- Interactive visualization and steering tool
- Results
- Conclusions

What is structural plasticity?

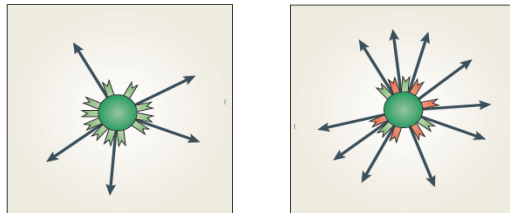
- Structural plasticity refers to the creation and deletion of synaptic connections in a neural network.
- Plays a role in the modeling of learning, memory [1], recovery after lesions [2] and brain development [3].



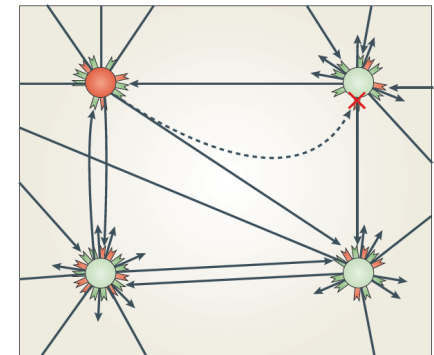
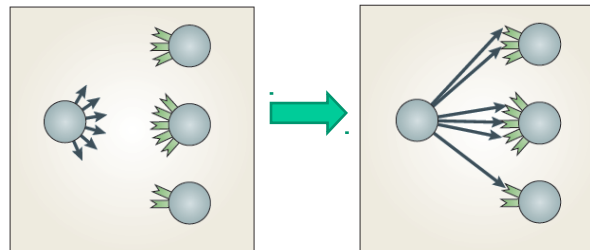
Which model are we using?

- The model we implemented in NEST is described in Butz & van Ooyen 2013 [4]:

Synaptic elements



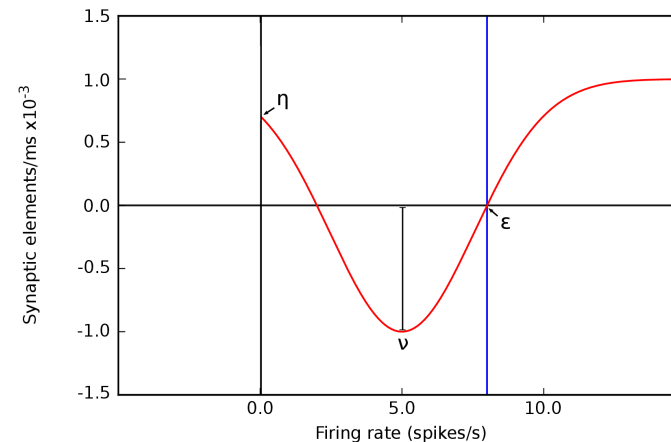
Synapse formation/deletion



- ↑ Axonal bouton: presynaptic element
- Dendritic spine: exc. postsynaptic element
- Dendritic spine: inh. postsynaptic element

Which model are we using?

- The algorithm consists of 3 repeating parts:
 - (1) Update average firing rate
 - (2) Update the number of synaptic elements

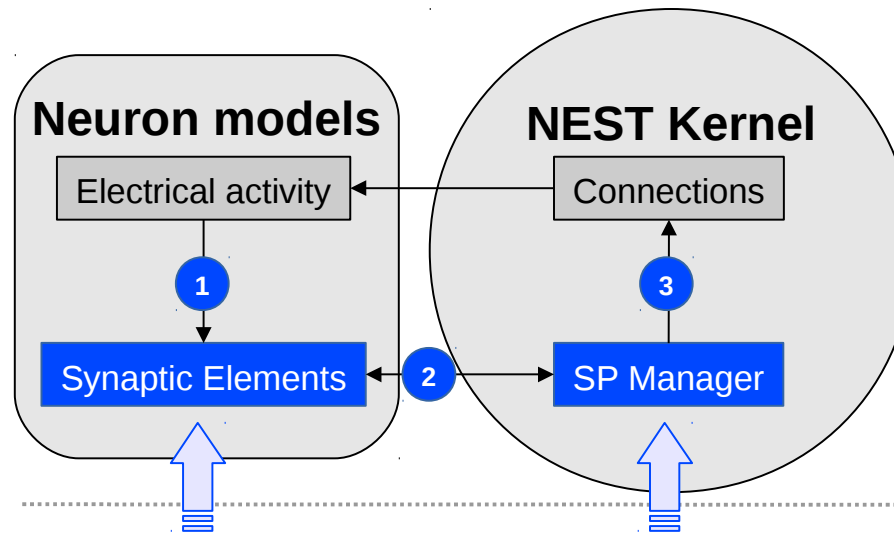


- (3) Update the network connectivity

Connectivity generation with structural plasticity

- The algorithm makes neurons create / delete synapses until they reach a target firing rate.
- The creation and deletion of synapses follows homeostatic rules.

Implementation in NEST



User interface (PyNEST/SLI)

- 1 The number of **synaptic elements** is updated depending on the electrical activity of the neurons

The **SP manager**:

- 2 Gathers the number of synaptic elements per neuron
- 3 **Creates/deletes** synapses to update the connections between the neurons

Connectivity generation with structural plasticity

- The structural plasticity algorithm can:
 - model the phenomenon of creation/deletion of synapses
 - generate connectivity /
fill in missing connectivity data
- It works as a controller, taking the system from state A to state B following a trajectory formed by a series of instructions which change the connectivity through time.

Connectivity generation with structural plasticity

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Interesting features

- Exploration of different connectivity configurations and their relationship to the dynamics of a neural network.
- Characterization of the parameter and solution spaces.

Navigating the parameter space

- Degenerate solution space
- A setup which matches the desired target activity might be difficult to find
- Sensitive to measure speed and delays in the structural changes

Navigating the parameter space

- Simple, well defined setups, usually reach stability.
- A big challenge arises when structural plasticity is enabled simultaneously on several interconnected populations with possibly differing levels of activity.
- The speed at which the synaptic elements are created has a large impact on reaching an stable configuration.
- The delay in updating the connectivity of the network strongly influences the performance and stability of the system as well.

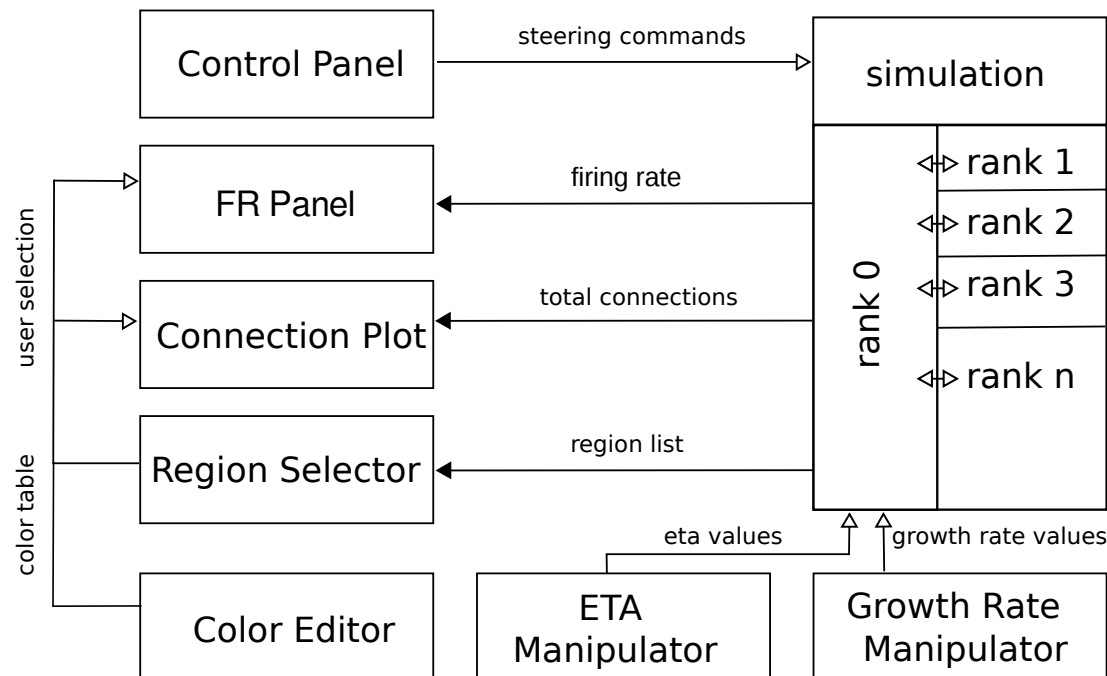
Navigating the parameter space

Working with structural plasticity online requires:

- simultaneous analysis of several changing variables
- ability to compare the level of activity of several regions simultaneously
- ability to change simulation parameters at any moment in each population of the network

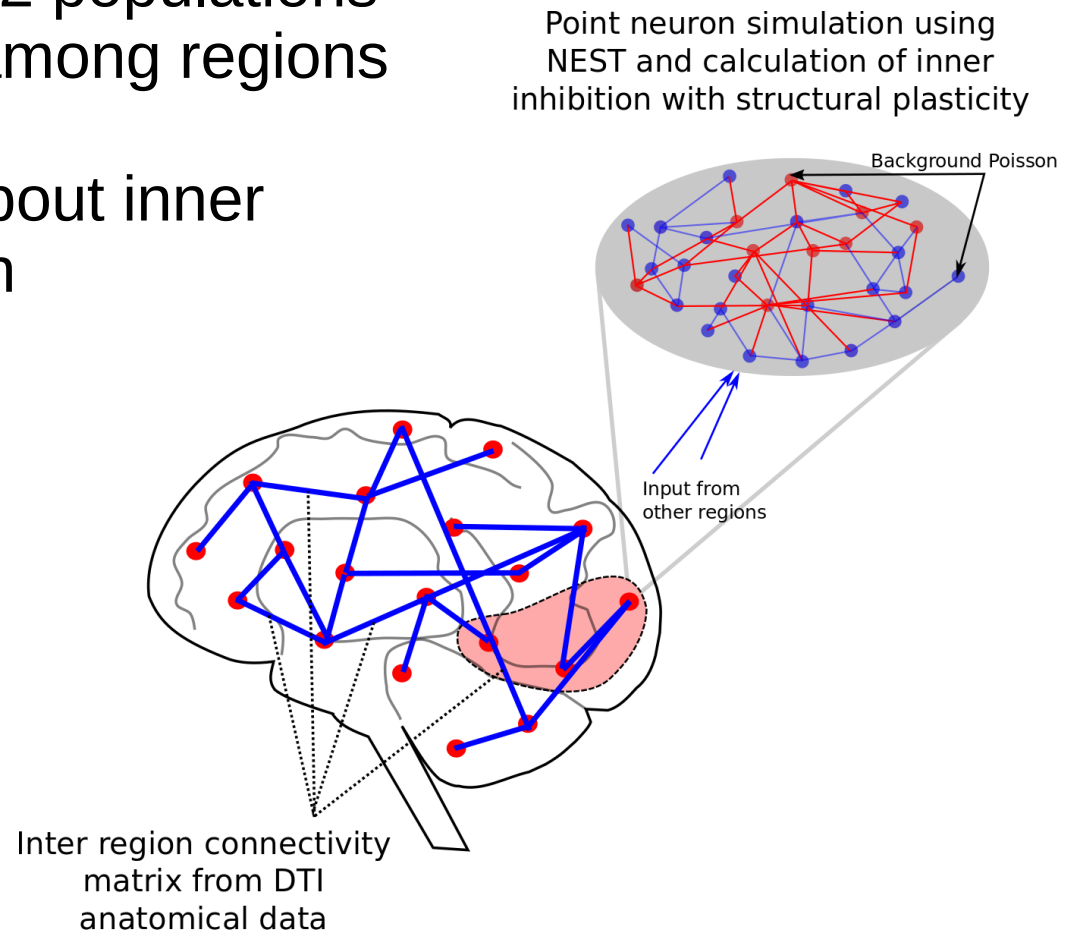
Modular solution

We developed a modular, interactive steering and visualization tool.



Filling missing connectivity information

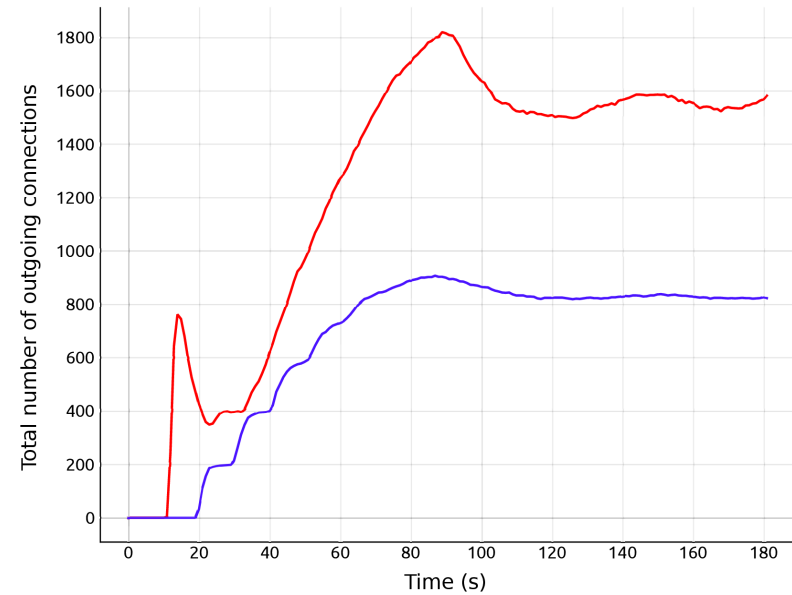
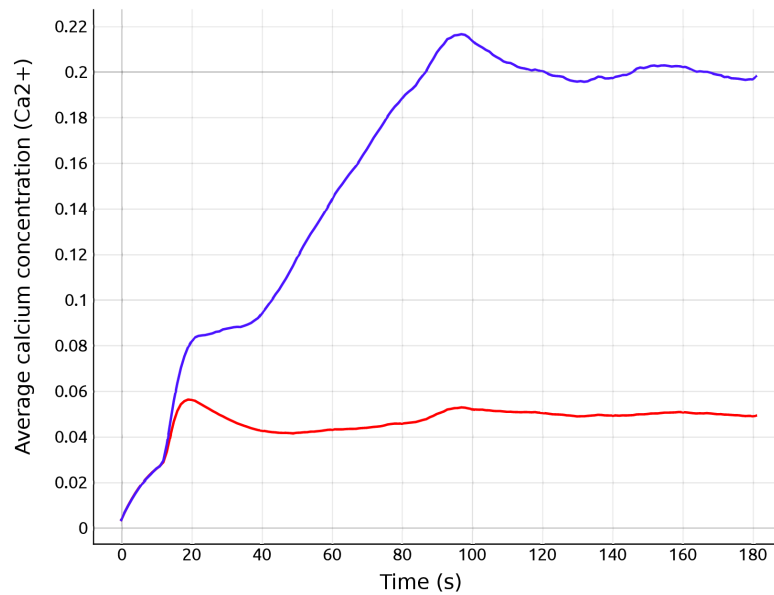
- 68 regions, each with 2 populations
- Defined connectivity among regions using DTI
- Missing information about inner connectivity per region
- Target activity 3Hz



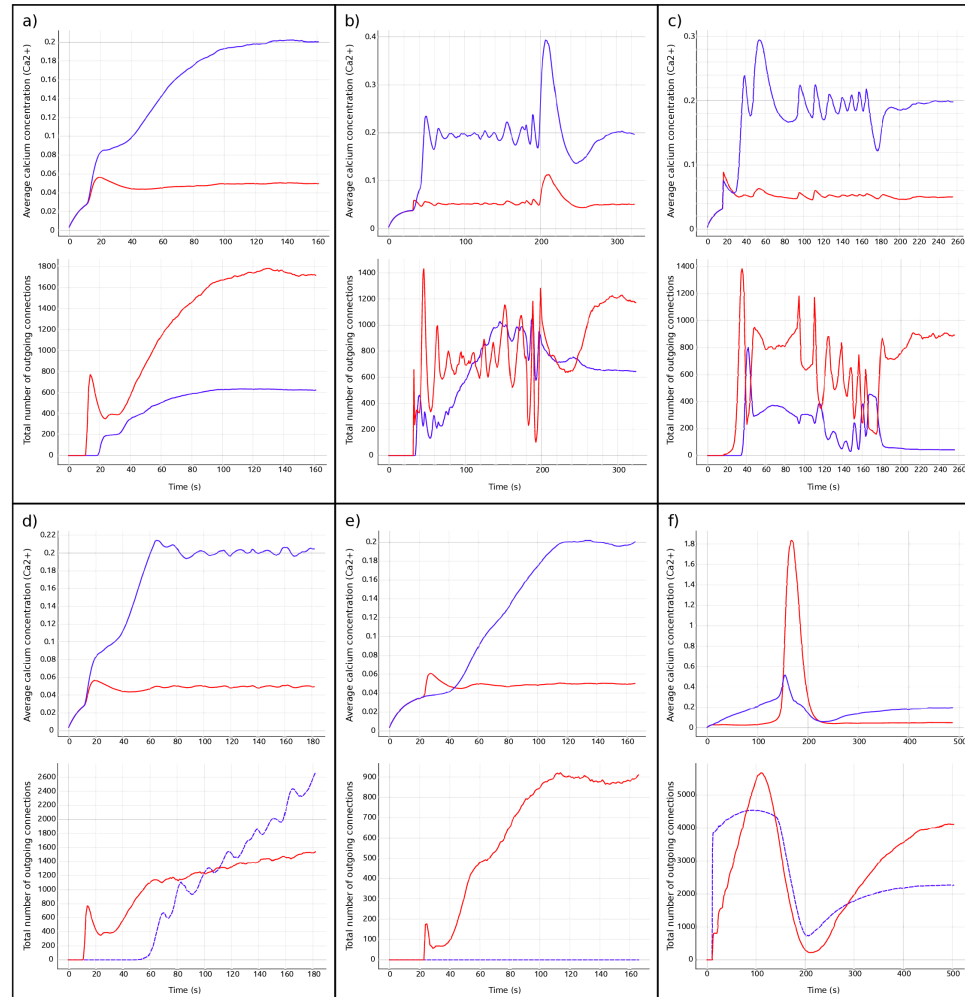
Exploration and steering



Exploring a simple setup



Multiple trajectories



Conclusions

- Structural plasticity works as a controller which takes the system from state A to state B by changing the connectivity progressively and following homeostatic rules.
- As any controller, delays and sensitivity to changes are essential to reach stability.
- Exploration of the parameter space is fundamental to understand the dynamics that the system can show.

Conclusions

- Our interactive tool provides the means to visualize and steer connectivity generation of a running NEST simulation of complex non-linear systems.
- Our solution promotes rigorous analysis of complex network models and supports well-informed selection of parameters for simulation.
- It can be easily configured to different setups and to explore other variables in the network.
- First step into automated online parameter space exploration.

- (1) Lamprecht, Raphael, and Joseph LeDoux. "Structural plasticity and memory." *Nature Reviews Neuroscience* 5.1 (2004): 45-54.
- (2) De Paola, V., Holtmaat, A., Knott, G., Song, S., Wilbrecht, L., Caroni, P., & Svoboda, K. (2006). Cell type-specific structural plasticity of axonal branches and boutons in the adult neocortex. *Neuron* 49 (6), 861-875.
- (3) Hensch, T. K. (2005). Critical period plasticity in local cortical circuits. *Nat. Rev. Neurosci.* 6 (11), 877-888.
- (4) Butz, M., & 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.
- (5) K.-F. Wong and X.-J. Wang. A recurrent network mechanism of time integration in perceptual decisions. *The Journal of neuroscience*, 26(4):1314–1328, 2006.
- (6) G. Deco, A. Ponce-Alvarez, P. Hagmann, G. L. Romani, D. Mantini, and M. Corbetta. How local excitation–inhibition ratio impacts the whole brain dynamics. *The Journal of Neuroscience*, 34(23):7886–7898, 2014.

Thanks for your attention

Questions?

