Multi-scale approach to explore the relationships between connectivity and function in whole brain simulations

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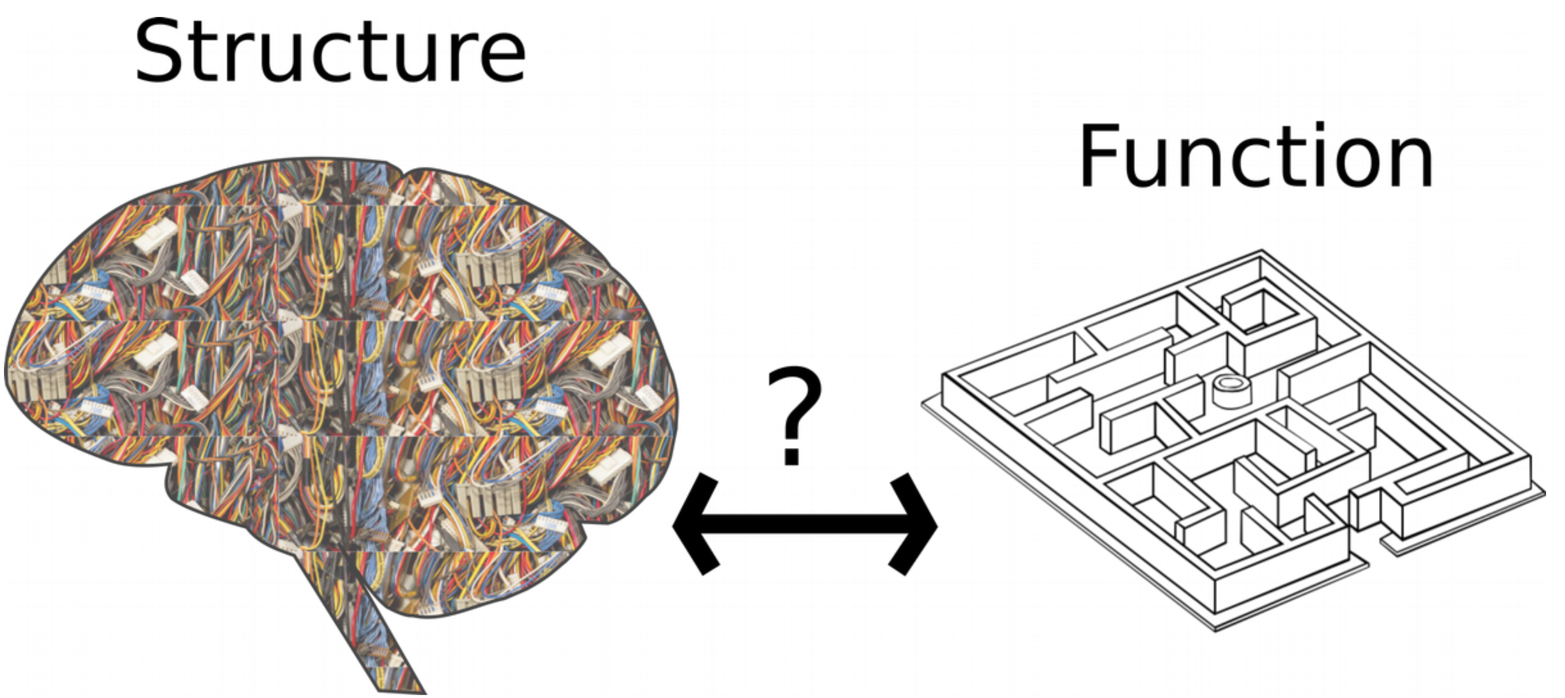
Agenda

- Motivation
- Introduction: structural and functional connectivity of the brain
- Our experimental setup: simulating a whole brain at multiple scales
- Visualizing and creating connectivity with structural plasticity
- Results
- Conclusions

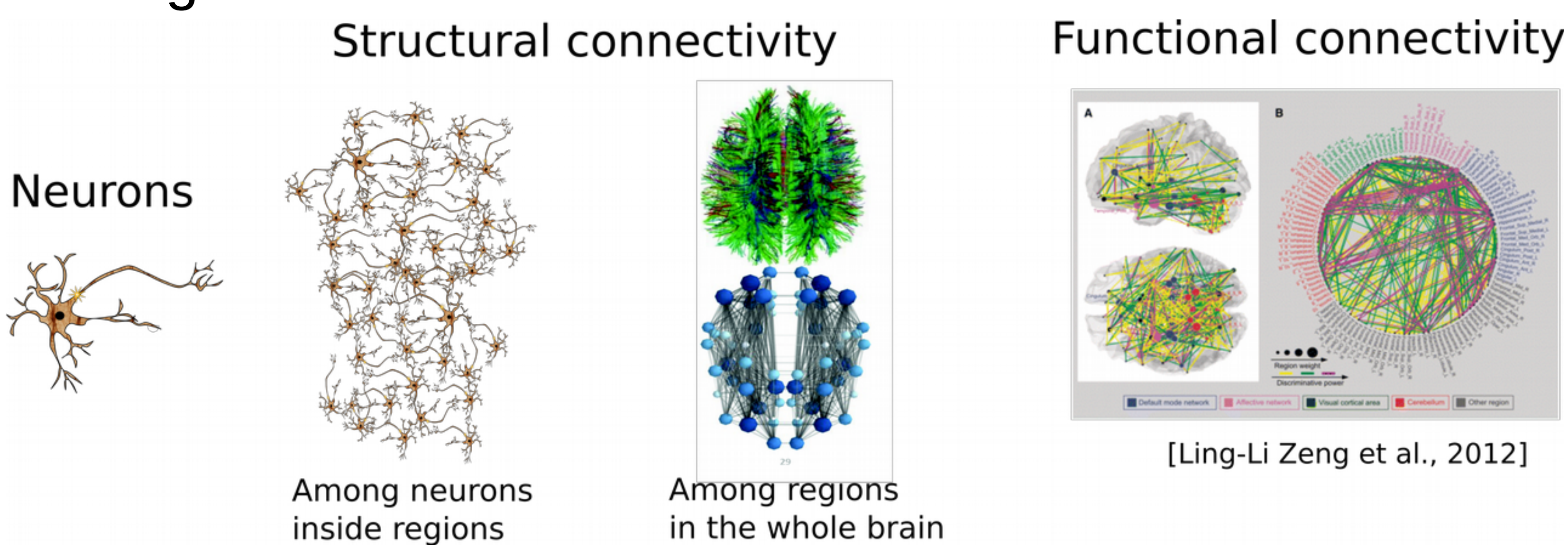
Motivation

We want to better understand the relationship between connectivity and function in the brain at different scales.



Structural and functional connectivity of the brain

- The connectome plays a fundamental role in explaining the high-level activities of the brain.
- Simulations can help unravel correlations among them.
- Current experimental data is incomplete / not detailed enough.



[Deco et al., 2014]

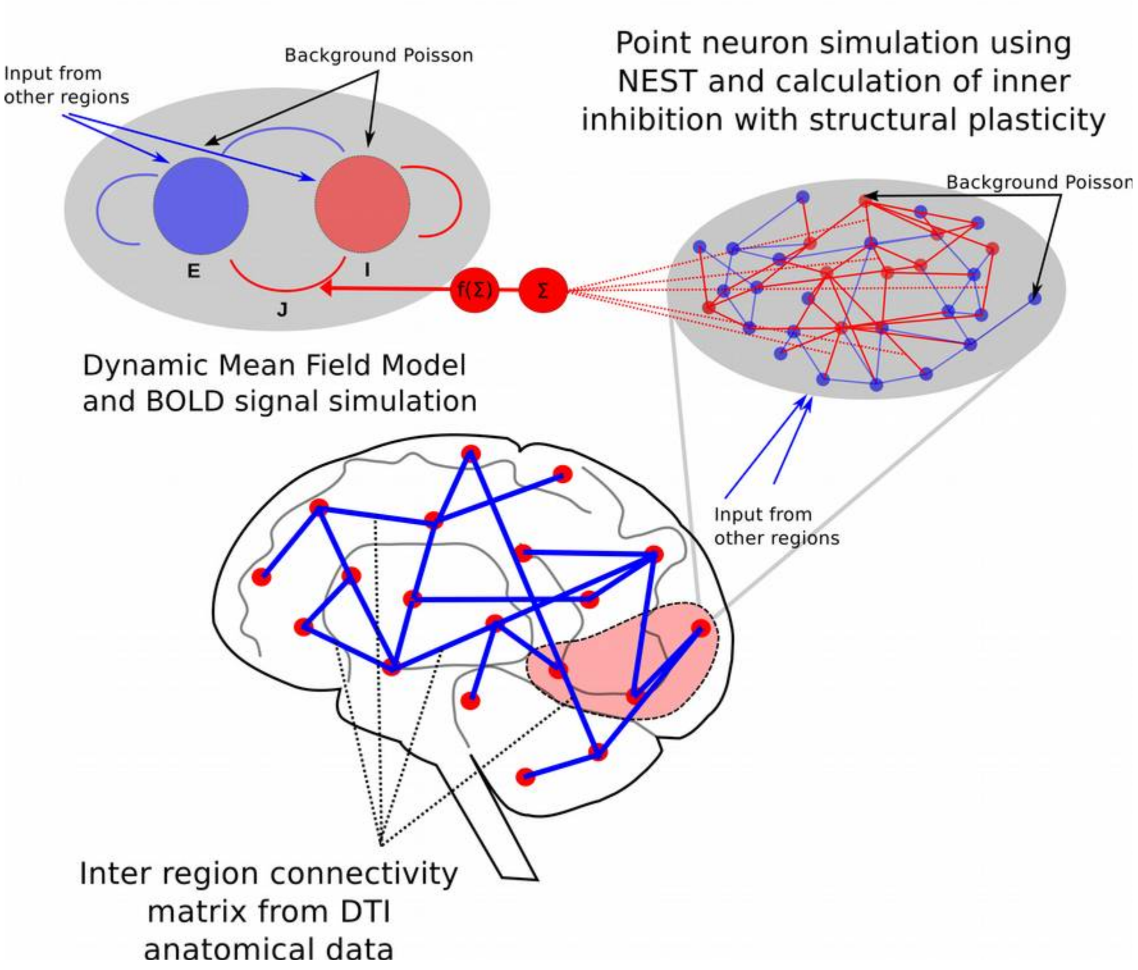
Our approach

- Use a multi-scale simulation which:
  - self generates missing connectivity information using local measurements of electrical activity.
  - efficiently generates a coarse signal comparable to experimental data.
  - provides an interactive visualization tool of the impact of structural changes in activity at different scales.

Our experimental setup

- Our multi-scale simulation consist of a whole brain parcellated into 68 regions as described in Deco et al. 2014 [4].
- Regions are connected between each other using experimental DTI data.
- Each region is modeled as:
  - a dynamic neural mass (DMF).
  - a small point-neuron populations in NEST [6].

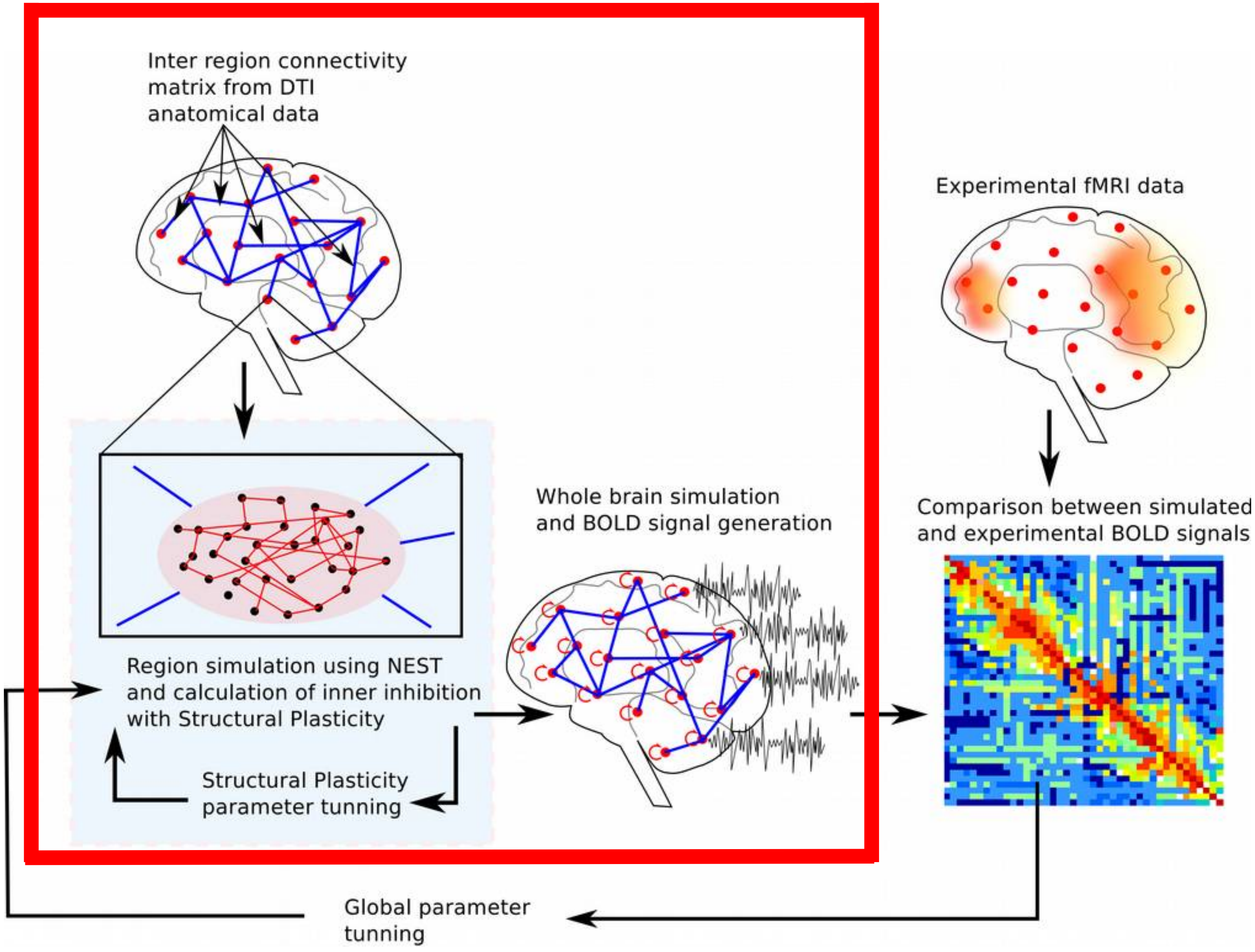
Multi-scale simulation



Our experimental setup

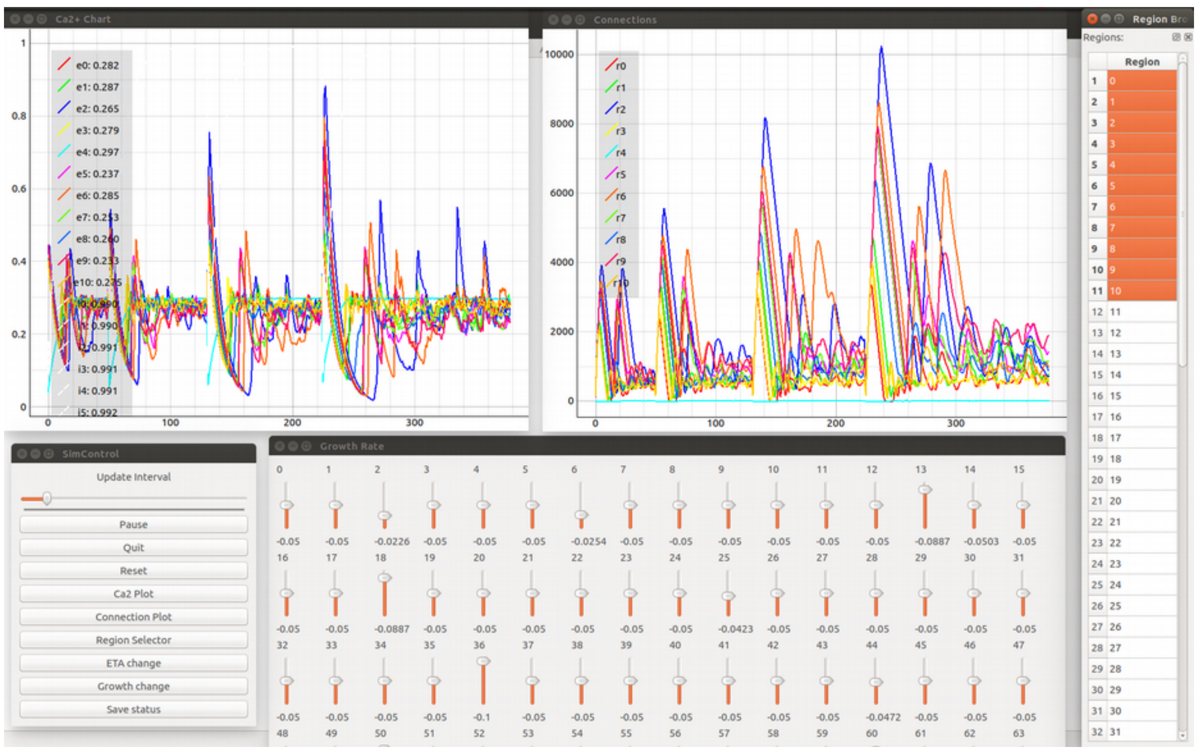
- Structural plasticity [1,2] in NEST is used to calculate the missing inner inhibitory connectivity required to match experimentally observed firing rates.
- We allow the point-neuron network to self-generate the missing connectivity following simple homeostatic rules [3].
- We export the connectivity as input for the DMF simulation. The DMF produces an activity pattern used to generate a blood-oxygen-level dependent (BOLD) signal.
- The comparison between long time simulation output and experimental fMRI data is work in progress.
- Our approach makes use of supercomputers.

Our experimental setup



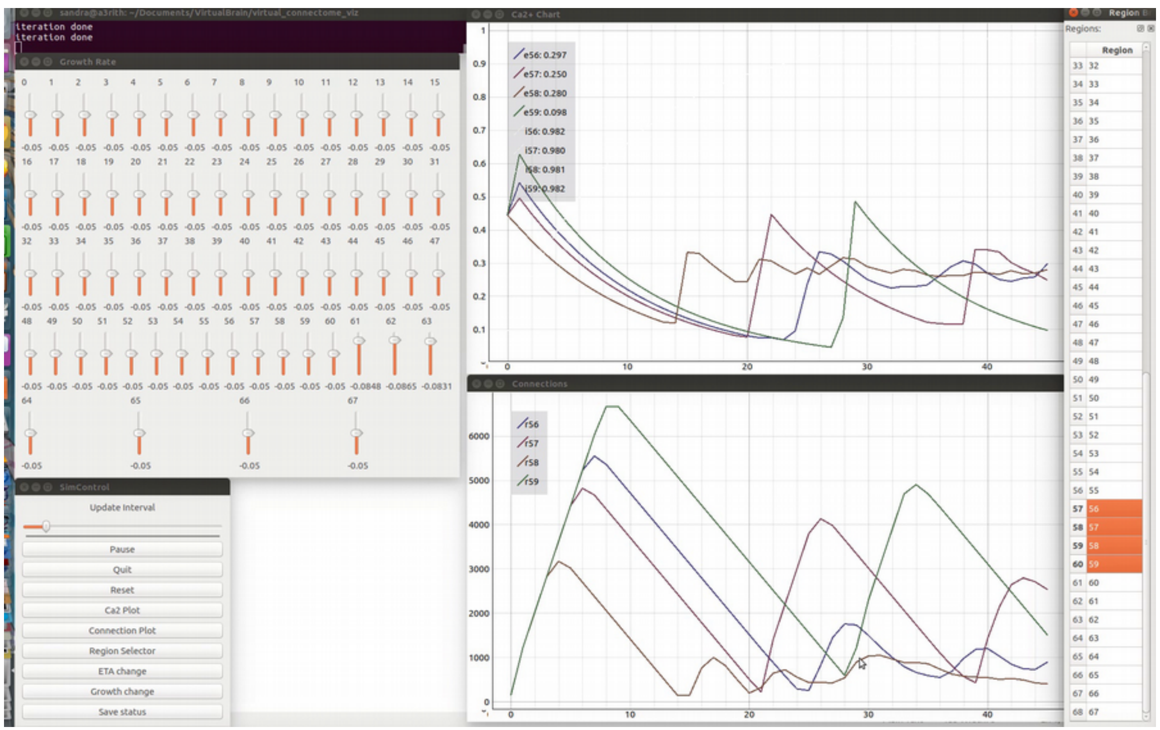
Visualizing connectivity generation

- We use an interactive tool designed to visualize and steer the changes in connectivity for this complex multi-population network.



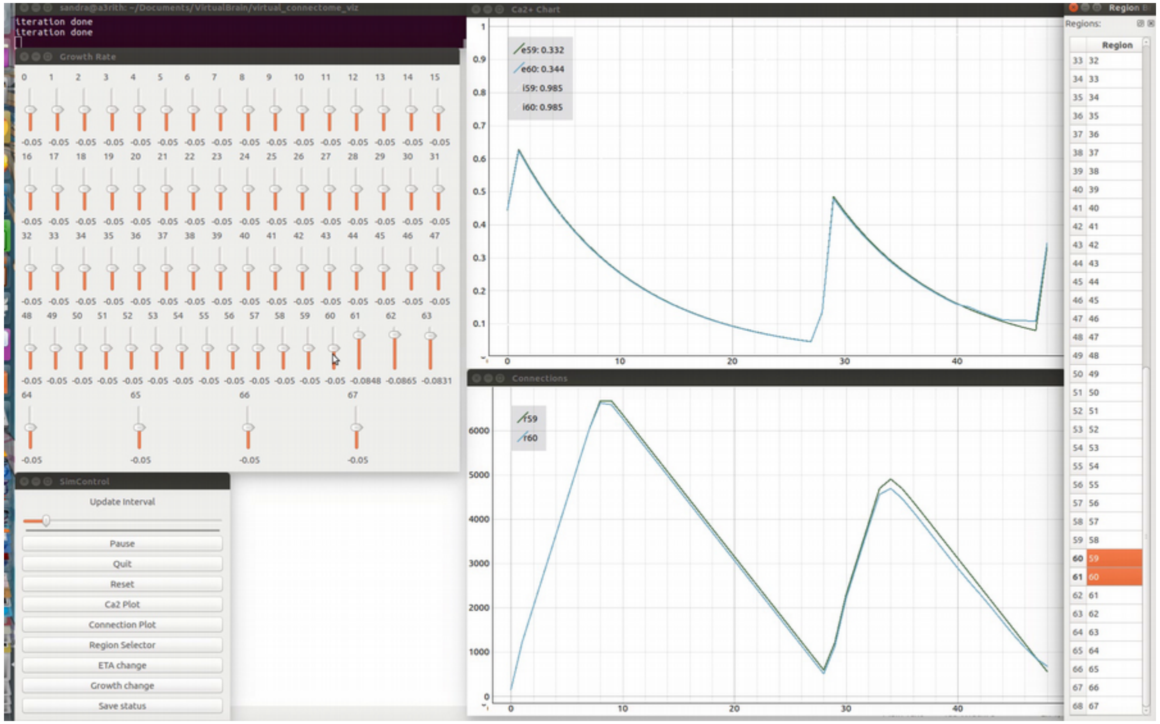
Results

- Visualize multiple regions and control connectivity growth parameters.



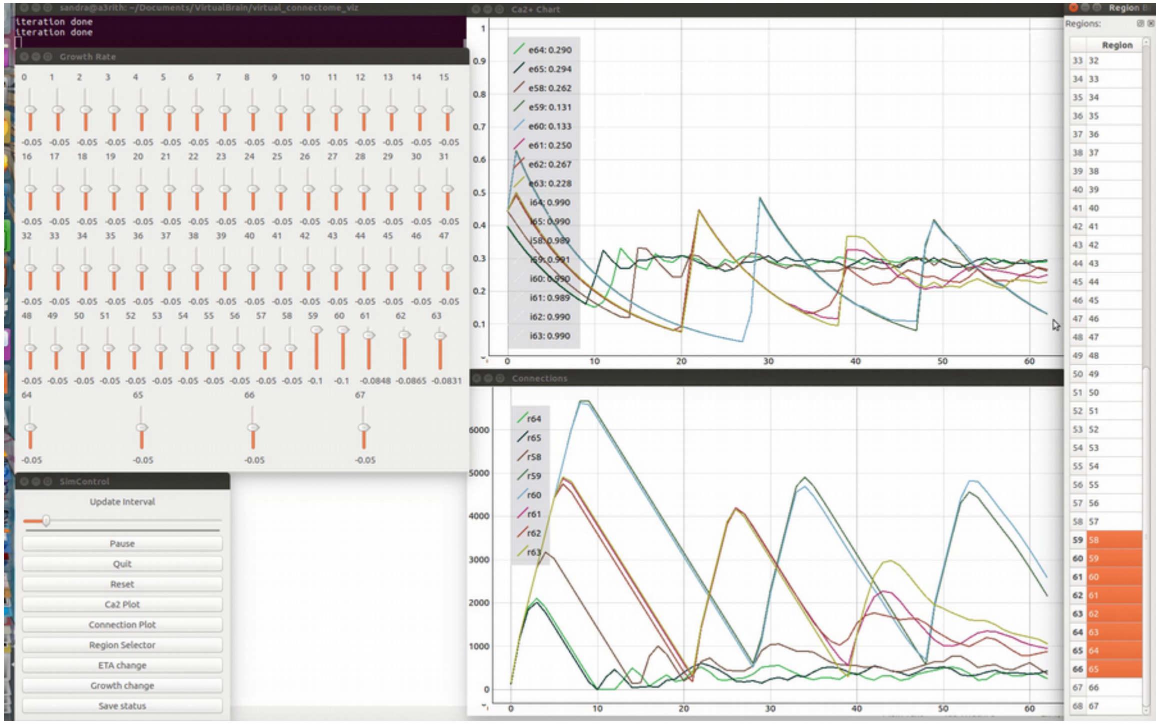
Results

- Detect highly coupled regions which require particular tunning.



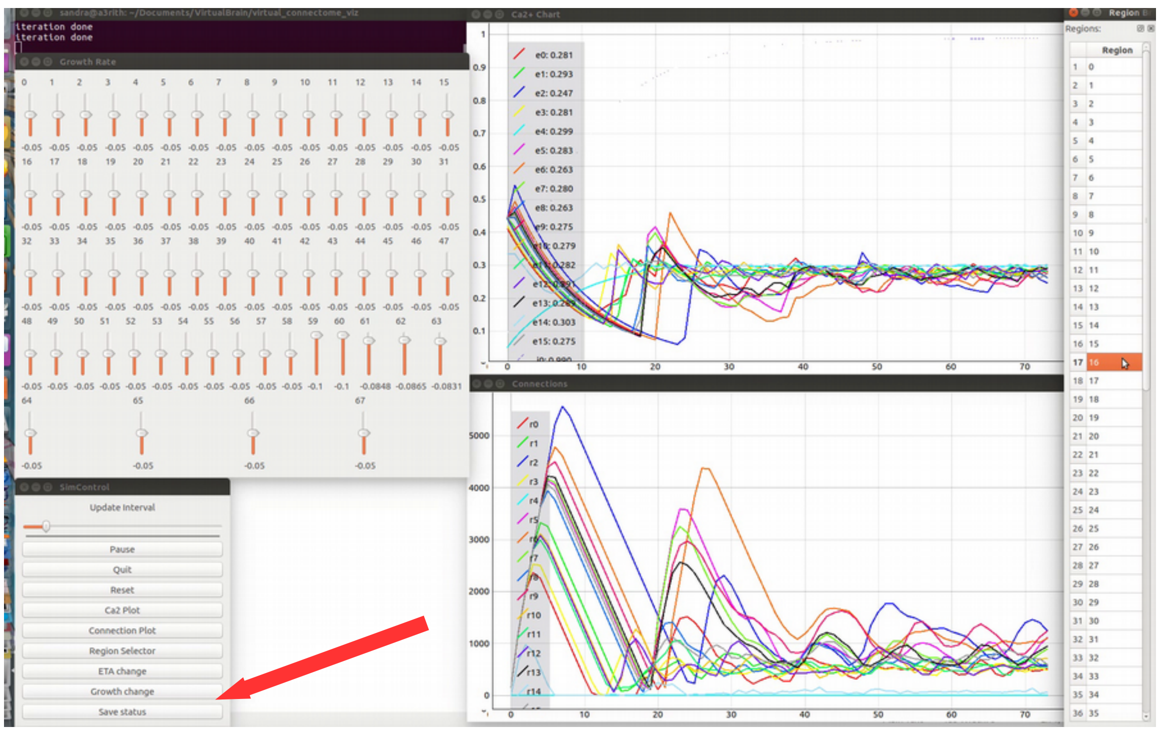
Results

- Observe how the activity in each region moves towards the target.



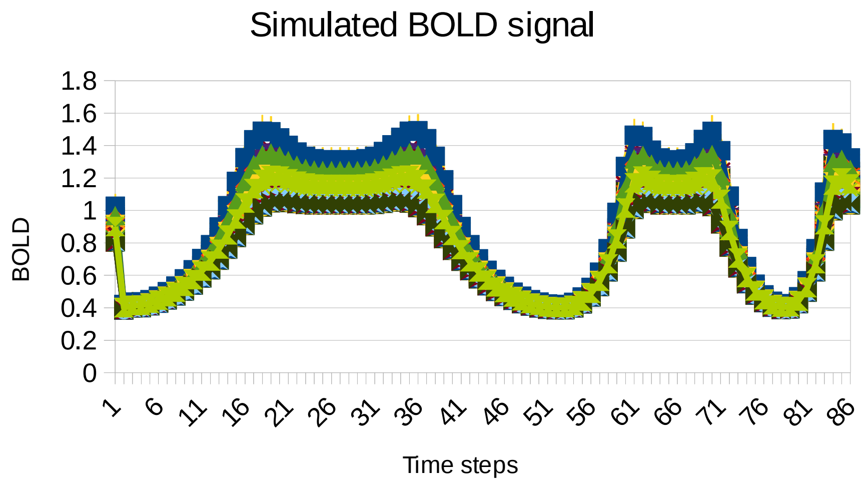
Results

- Save connectivity and export to the DMF simulation.

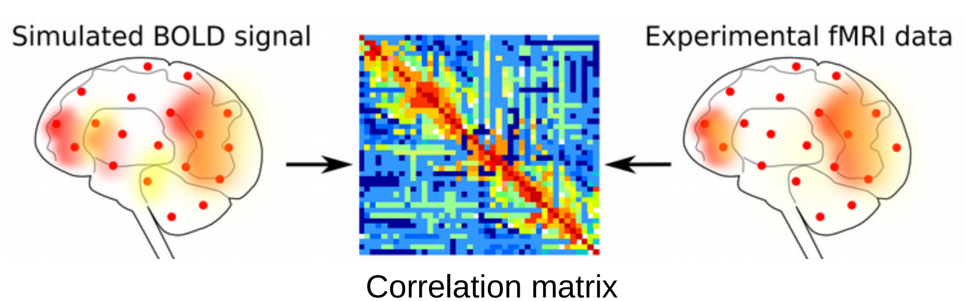


Results

- Generation of BOLD signal using the DMF simulation.



- Comparison between experimental and simulated BOLD signals (work in progress)



Results

- With this approach the fitting and parameter space exploration:

  - is around 10 times faster than brute force fitting algorithms

  - is more robust since it progressively achieves global stability

  - aids a better understanding of the parameter space

Conclusions

- Using this approach it is possible to fill gaps in connectivity data of highly coupled multi-population networks and explore the impact of structure in function at different scales.
- Navigate through the dynamic parameter space of structural plasticity in NEST and reach stable connectivity patterns which can be then used in a larger scale model (DMF).
- At the population scale, computationally efficient simulations, producing an output that can be compared to coarse experimental data.
- At the neuron scale, provide more insight and control over the local connections in the brain.

Conclusions

- Using models at different scales: study and verify the interactions, links and equivalences among them.
- Supercomputer setup allows us to simulate large scale networks and iteratively explore large parameter spaces.

References

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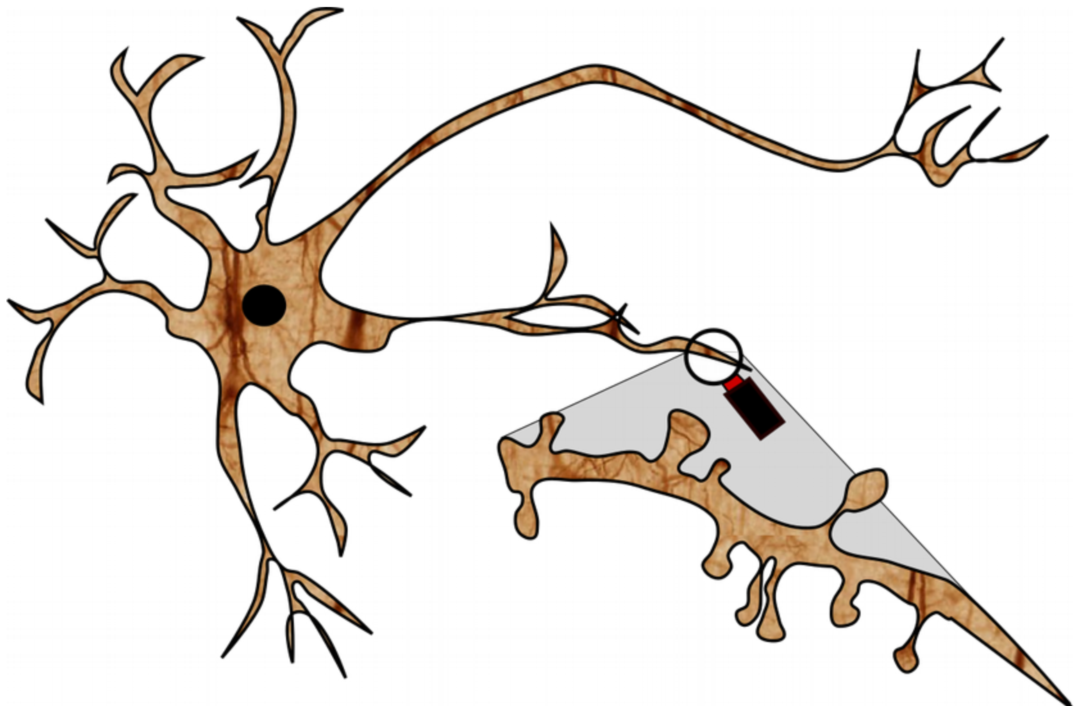
(5) Zeng, Ling-Li, et al. "Identifying major depression using whole-brain functional connectivity: a multivariate pattern analysis." Brain 135.5 (2012): 1498-1507.

(6) H. Bos, A. Morrison, A. Peyser, J. Hahne, M. Helias, S. Kunkel, T. Ippen, J. M. Eppler, M. Schmidt, A. Seeholzer, M. Djurfeldt, S. Diaz, J. Morén, R. Deepu, T. Stocco, M. Deger, F. Michler, and H. E. Plesser. NEST 2.10.0, Dec. 2015.

Thanks for your attention

Questions?



Use case

- In the configuration used here, only inhibitory connections can be created.
- The desired electrical activity has a frequency of 3 Hz and an inverted Gaussian curve describes the growth rate of connection points for neurons.
- It is important to note that in this work, we are only focusing on the calculation of connectivity for the large scale simulation.
- The comparison of the results obtained by the simulation of the whole brain using the DMFM model and is subject of future work.