Comparison of experimental monkey resting state data with large scale neural network simulations

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Aim and Motivation

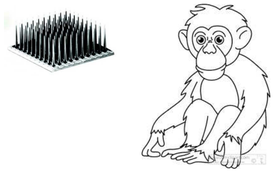
To better understand the network activity of macaque motor cortex, we aim to develop a spiking neural network model that enables us to understand network mechanisms of observed experimental findings and relates structural and functional connectivity.

To validate the ground state model (without function/behavior) we compare experimentally recorded resting state data with the model activity. We here present the first iteration of the corresponding comparative data analysis.

Experimental Resting State Data

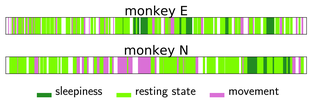
Massively parallel spiking data were recorded from pre-/motor cortex of an awake macaque monkey at rest, i.e. while the animal was not involved in any task nor received controlled stimuli. The monkey's behavior was video recorded and revealed periods with and without spontaneous body movements. We qualified periods without motor activity as "resting state" periods.

- two macaque monkeys
- 4x4 mm^2 10x10 electrodes Utah Array
- layer 4-5 of monkey motor cortex
- 15-20 min registration accompanied by video recording
- approx. 140 single units per monkey after spike sorting



Preprocessing

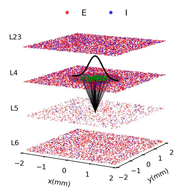
- Based on their spike widths, single units were classified as putative excitatory (**exc**) or inhibitory (**inh**).
- Only resting state (**RS**) periods were extracted from the data and cut into 5 s slices for the comparison.



Video-based behavioral segmentation.

Cortical Network Model

The simulated network is based on the generic layered cortical microcircuit [1], simulated using NEST [2]. To enable comparison with the experimental data, the model was extended [3] to cover 4x4 mm^2—the same cortical surface area as the Utah array.



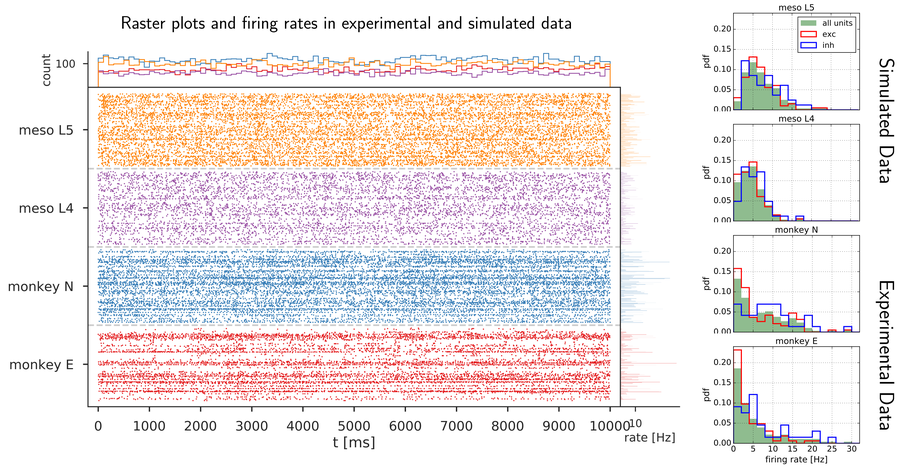
- ∼1.2 million leaky integrate-and-fire neurons in 4 layers with excitatory (E) and inhibitory (I) populations
- ∼5.5 billion static current-based synapses
- external input with Poisson statistics
- uniform neuron distribution with periodic boundary conditions
- connection probabilities derived from experimental data [1]
- distance-dependent connectivity with Gaussian profile

Preprocessing

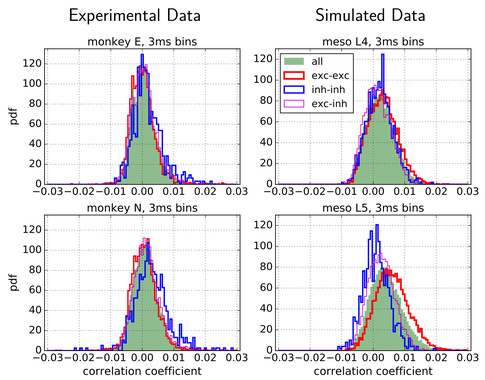
- Spiking activity of layer 4 (L4) and layer 5 (L5) was extracted.
- The recorded model neurons were subsampled to match the numbers of excitatory and inhibitory single units in the experiment.

Spiking activity

The raster plots of an example 10 s observation (middle figure) of simulated and experimental activity reveal that although population spike counts are similar (top histogram), the average firing rates (**FR**) tend to be more homogeneous in the simulated results (meso L5 and meso L4, bar plot on the right side of raster plot). This is shown in detail in the FR distributions on the right (mean FR per unit, 5 s slices), which are narrower for mesocircuit results.



Pairwise Fine Correlations

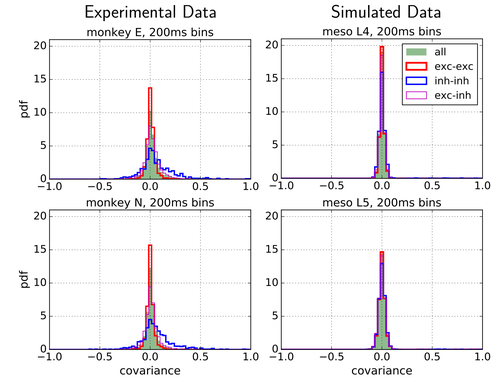


Pairwise fine temporal correlation (**CC**) between single units can be used to estimate synchrony in the data. Spike trains are binned into 3 ms bins, a scale characteristic for single action potentials. Therefore only coincidential spikes contribute to the resulting statistics.

- Within each dataset distributions for exc and inh pairs differ between each other.
- Mean CC of experimental data is higher for inh compared to exc units and vice versa for model L5.
- Mesocircuit results seem to be less skewed than experimental distribution, which has a larger positive tail.

Pairwise Covariances

Pairwise cross-covariances (**COV**) calculated with 200 ms bins reveal co-modulation of firing rates between examined spike trains. Non-stationarities, e.g. abrupt changes of FR, can lead to asymmetric COV distributions with large positive tails.



- Putative excitatory and inhibitory distributions differ significantly in experimental data, but not in the model, both in average value and shape.
- Statistics of exc units are remarkably similar in all datasets.
- Only experimentally obtained COV distributions for putative inhibitory pairs show a pronounced positive tail (asymmetry).

Summary

- Spiking activity statistics show similar population counts but different average FR per unit distributions for simulated and experimental results.
- Pairwise measures reveal asymmetries pronounced in experimental inh pairs and virtually absent in simulated data.
- Connectivity parameters used in the model are derived from various species and cortices, probably contributing to mismatches observed between model and macaque motor cortex activities.
- Resting state, often described as a superposition of multiple brain states, may be notably less homogenous than current simulation.
- Outlook: succesive adaptation of the model connectivity to values specific to monkey motor cortex, until experimental and simulation statistics agree.

References

[1] Potjans & Diesmann (2014) The cell-type specific cortical microcircuit: relating structure and activity in a full-scale spiking network model. Cereb Cortex 24

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[4] Dehghani, Peyrache, Telenczuk, Le Van Quyen, Halgren, Cash, Hatsopoulos, Destexhe (2016) Dynamic Balance of Excitation and Inhibition in Human and Monkey Neocortex. Sci Rep 6

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Acknowledgments: Supported by DFG GR 1753/4-2 Priority Program (SPP 1665), Helmholtz Portfolio Theme Supercomputing and Modeling for the Human Brain (SMHB). This project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 720270 & 785907.