Human Brain Project

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High resolution wide-field spiking simulations of mouse cortical hemisphere

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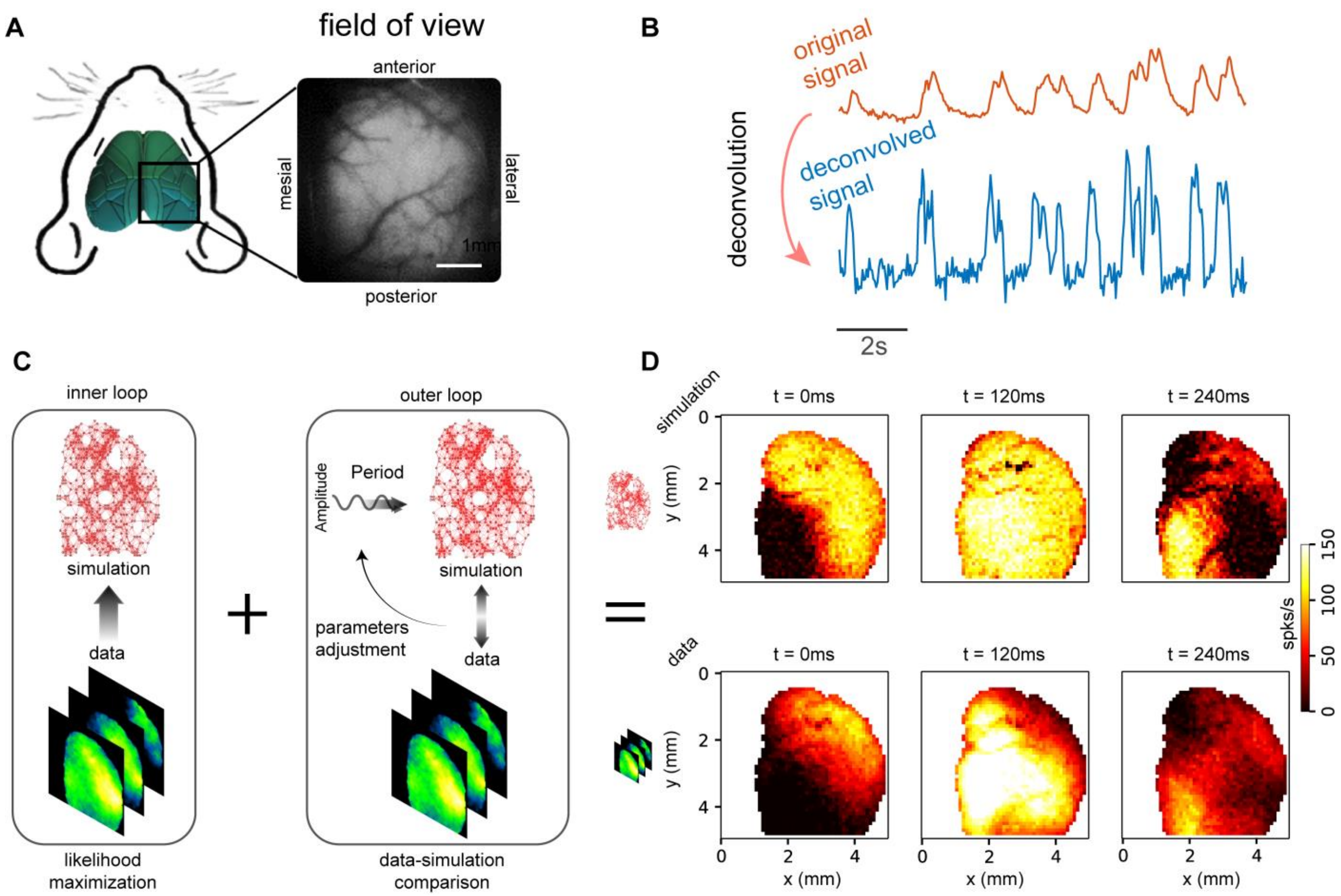
From recording to spiking simulation

- GOAL ➔
  - Reproduction of the spontaneous activity recorded from the mouse cortex during anaesthesia
- Starting point ➔
  - Parameters inferred from wide-field fluorescent imaging recording of the activity of excitatory neurons marked with GCaMP6f calcium indicator
- Methods ➔
  - Data constrained spiking simulation based on inferred parameters
  - Parameter refinement after the analysis with the CoBraWAP pipeline
- Expected results ➔
  - Spiking model expressing Slow Waves Activity comparable with the experimental recording and with the already calibrated mean-field model

Inferred mean-field model of mouse whole hemisphere



Capone et al., **Simulations Approaching Data: Cortical Slow Waves in Inferred Models of the Whole Hemisphere of Mouse**, 2022, doi: 10.48550/arxiv.2104.07445

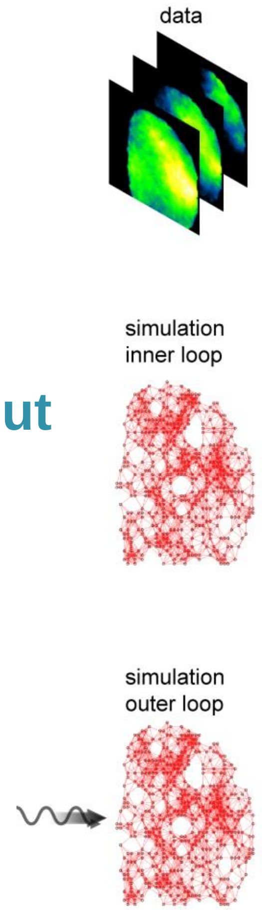
- Experimental dataset
  - Wide-field **calcium imaging** recording of cortical activity of the right hemisphere of a mouse (under ketamine anesthesia)
  - High **spatial resolution** (>2000 channels)
- Two-step inference method
  - Inner loop:
    - Parameters inferred from likelihood maximization for a generative mean-field model
  - Outer loop:
    - Grid search over parameters to detect optimal match, based on measures of spatio-temporal propagation of waves across the cortex (speed, directions and slow oscillation frequencies)

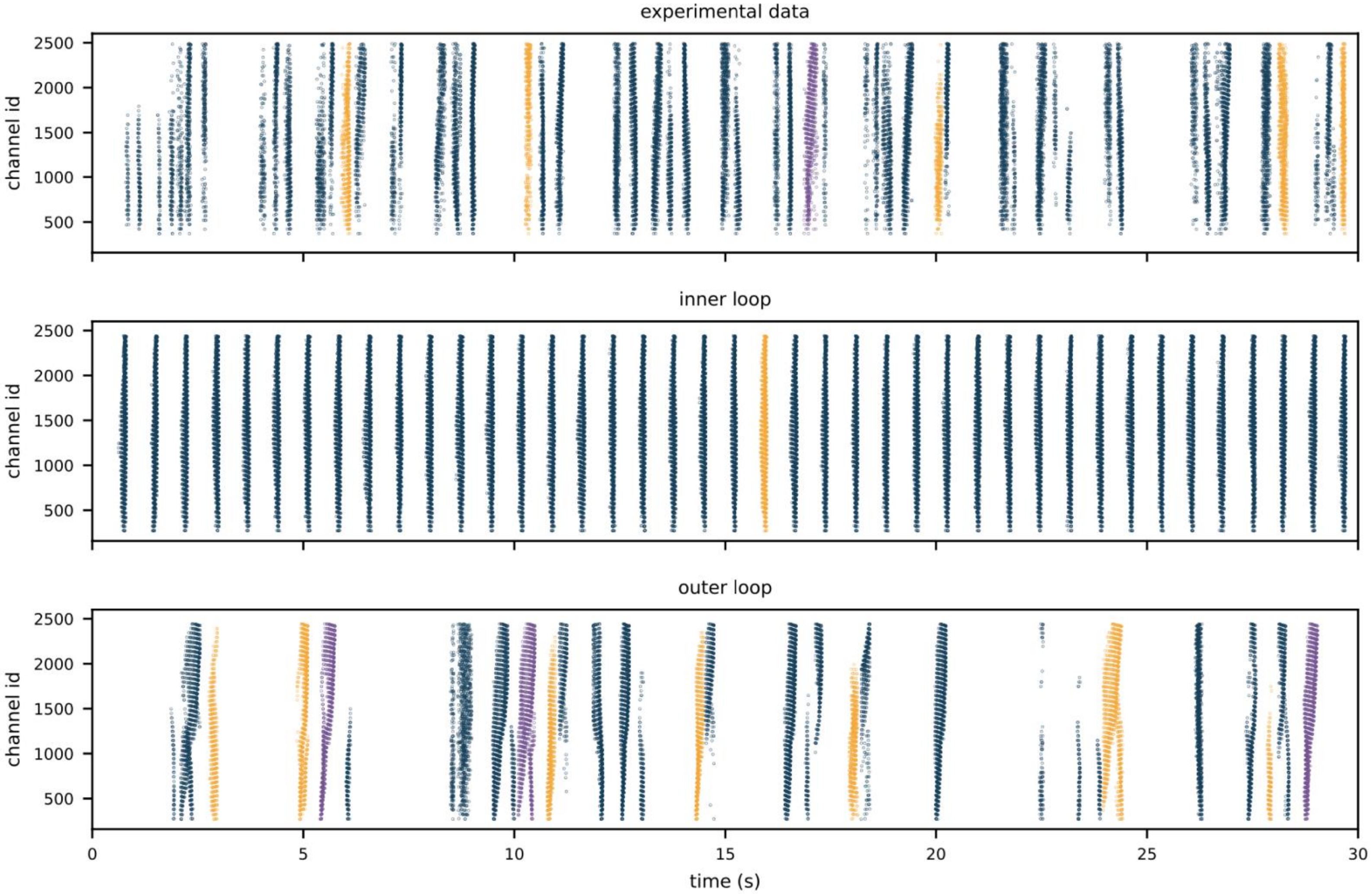
Inferred mean-field model of mouse whole hemisphere

Experimental data

Stereotyped output from inner loop

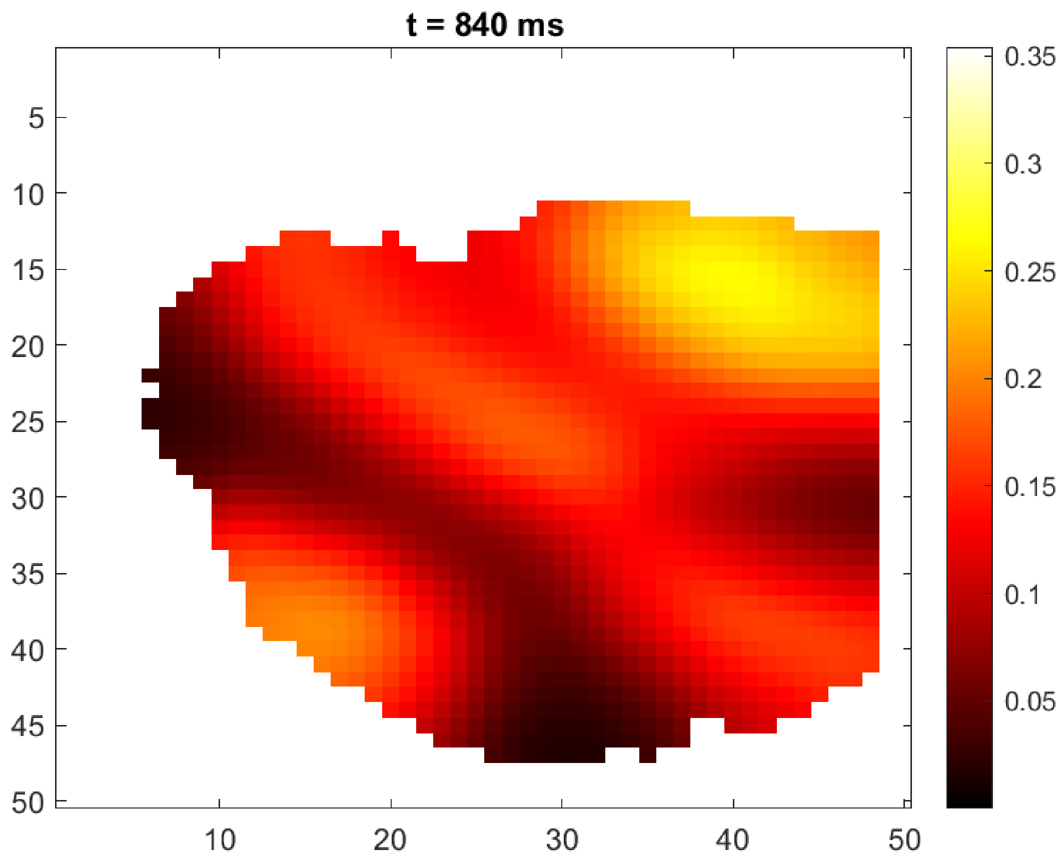
Parameter optimization





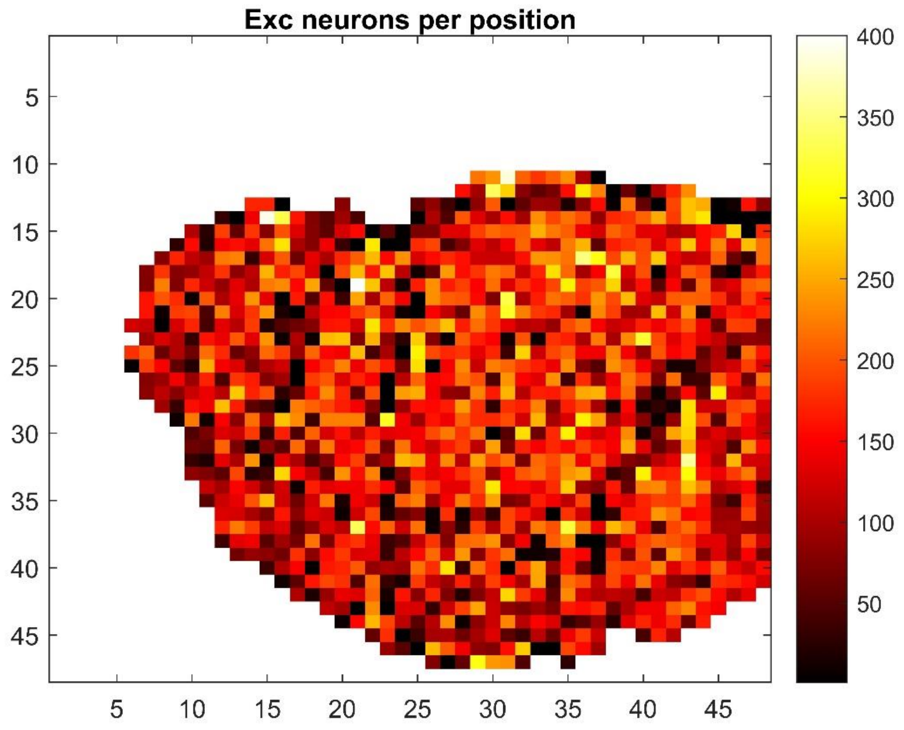
The spiking model

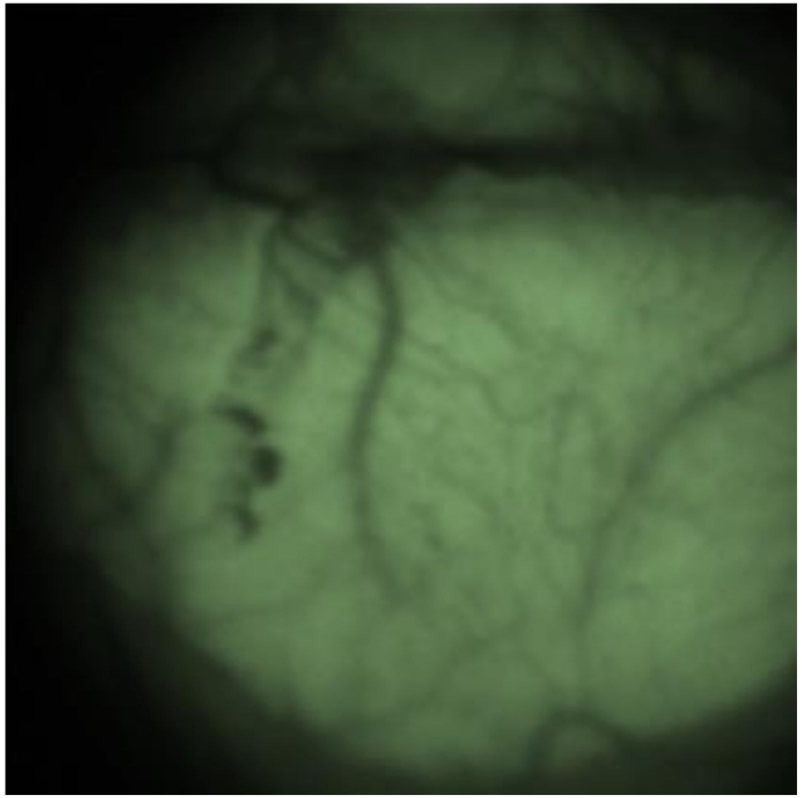
- Large-scale spiking simulation of whole cortical hemisphere of a mouse at biological neural density and high synaptic count per neuron
  - Neurons: 225 K
  - Synapses: 218 M
- Bidimensional grid of excitatory and inhibitory neural populations
  - Adex neuron
- Biological resolution
  - 1282 modules – 100 μm resolution
- Variable number of neurons per module and synapses per neuron
- Resulting waves @ ~2 Hz



The spiking model - Neural density

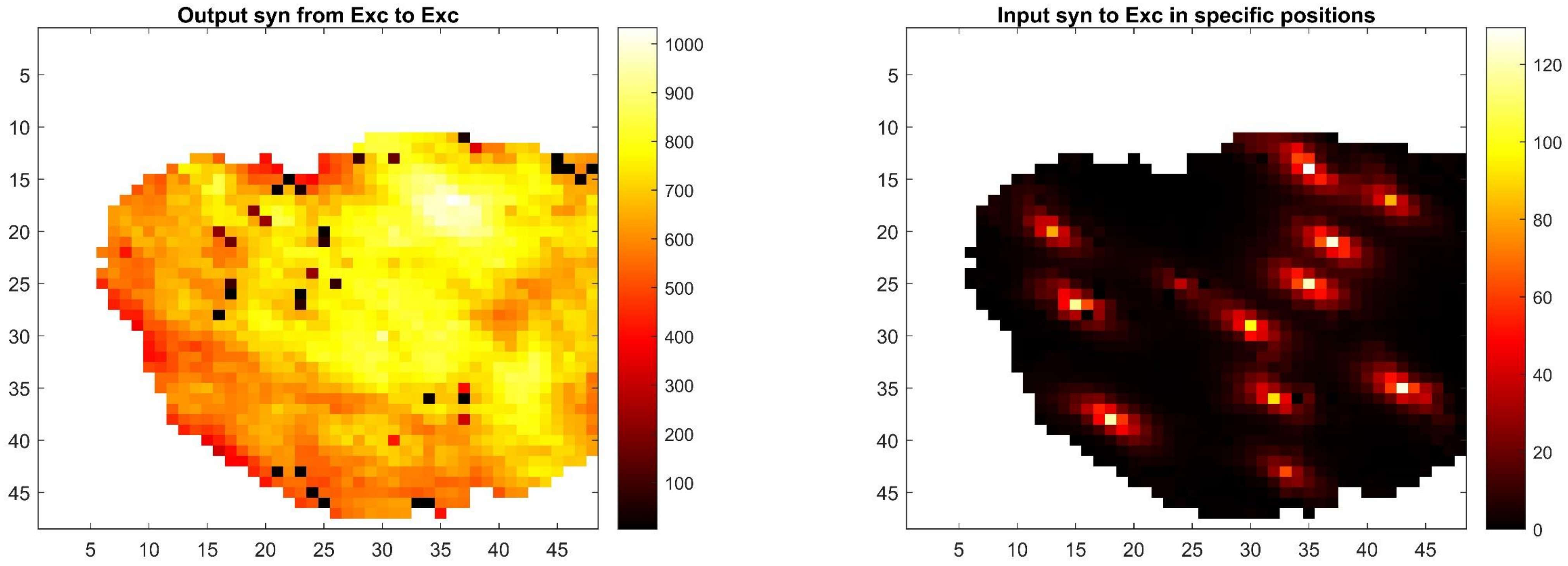
- Neuron per population has been adjusted to reflect experimental neural density





The spiking model - Connectivity

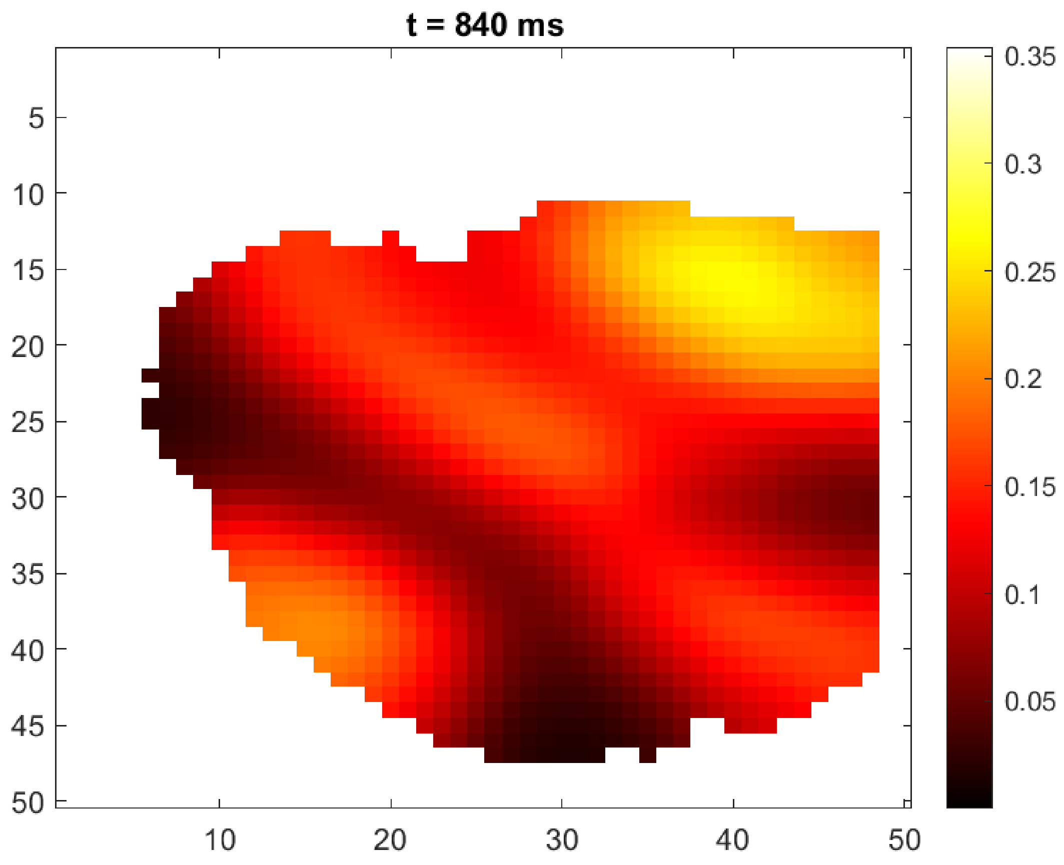
- Connection probabilities among populations based on exponentially decaying elliptical kernels with inferred parameters



The spiking simulation

- NEST simulator (v3.3)
  - ~98 s of elapsed time / 1 s of simulated activity on Intel Xeon CPU-E5-2620 @2.10 GHz (network initialization time: ~450 s)

- NEST GPU simulator
  - ~8 s of elapsed time / 1 s of simulated activity on Intel Xeon Gold 6130 CPU @2.10 GHz plus TESLA V100 GPU (network initialization time: ~4930 s on current version, working on improvements)



CoBraWAP - Collaborative Brain Wave Analysis Pipeline

- Reusable and adaptable tool, able to analyze diverse datasets of slow rhythms in the cerebral cortex
- Based on reproducibility and modularity, to be adaptable to different input data types and different analysis methods to address various scientific questions
- Extracts key spatio-temporal characteristics from experimental or simulated brain wave dynamics

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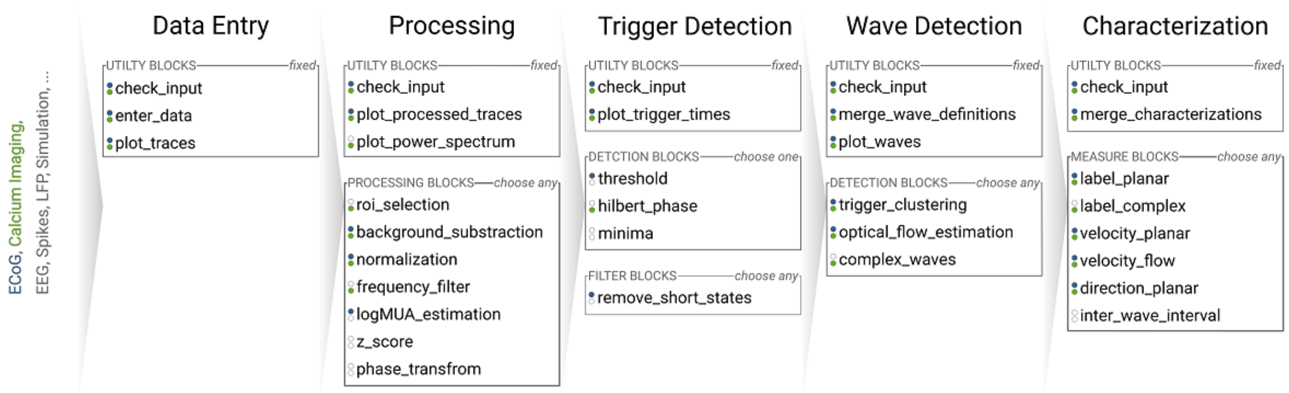
Designed and developed in collaboration with Julich Forschungszentrum

neo elephant NetworkUnit fairgraph snakemake

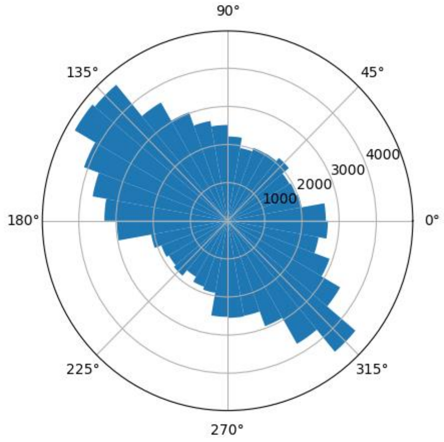
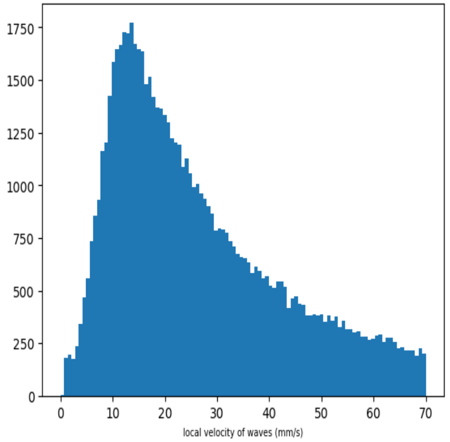
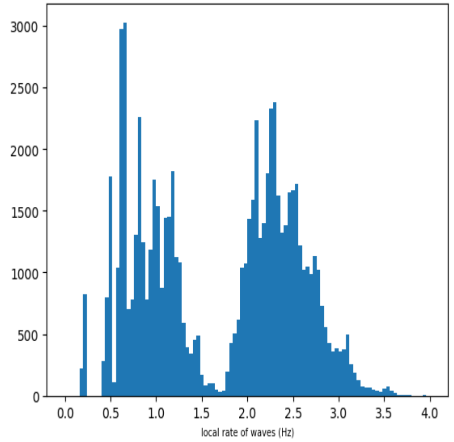
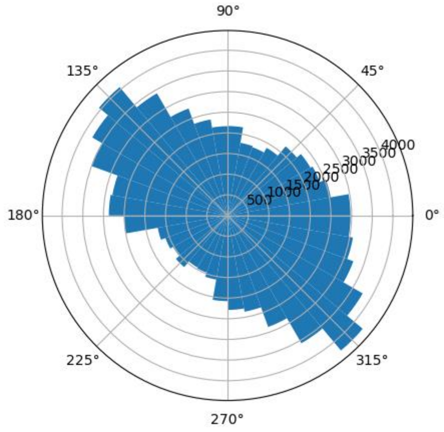
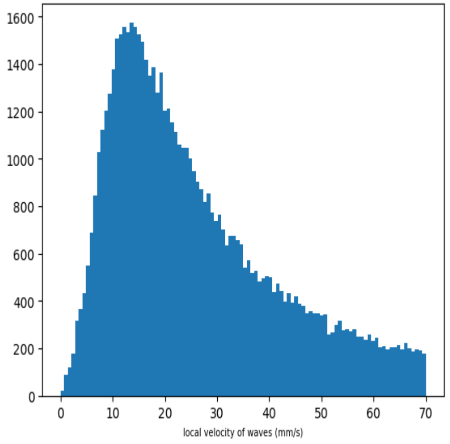
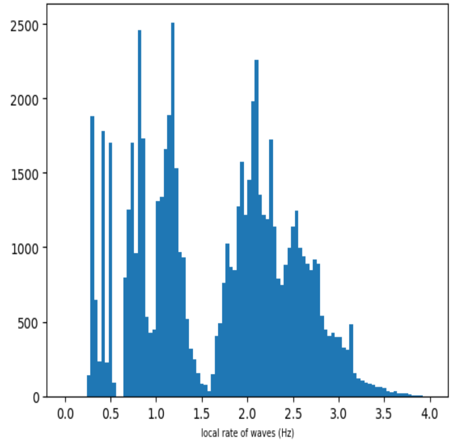


Sequential **stages** made of block **modules** customizable according to the need of the specific analysis

Analysis of simulation results - a proof of concept

- CoBraWAP applied to the simulation output
- Input of Stage 1 adapted to correctly import the simulation results
  - Firing rate of excitatory population are used as a proxy for the neural activity
- The pipeline allow a fast and quantitative accurate measure of some main observables:
  - Waves directions, velocities, IWI, rastergram, etc.
- Enables the comparisons among different simulations and/or among different data acquisitions

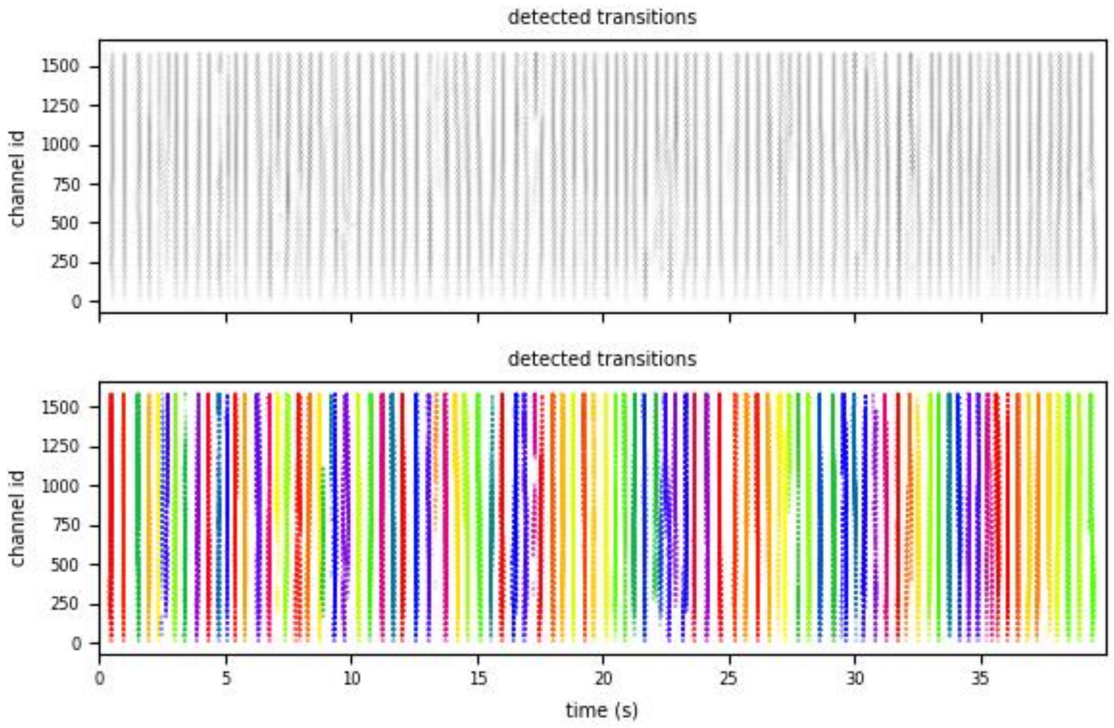
Results comparison: NEST vs NEST GPU

	Direction	Velocity	IWI
NEST			
NEST GPU			

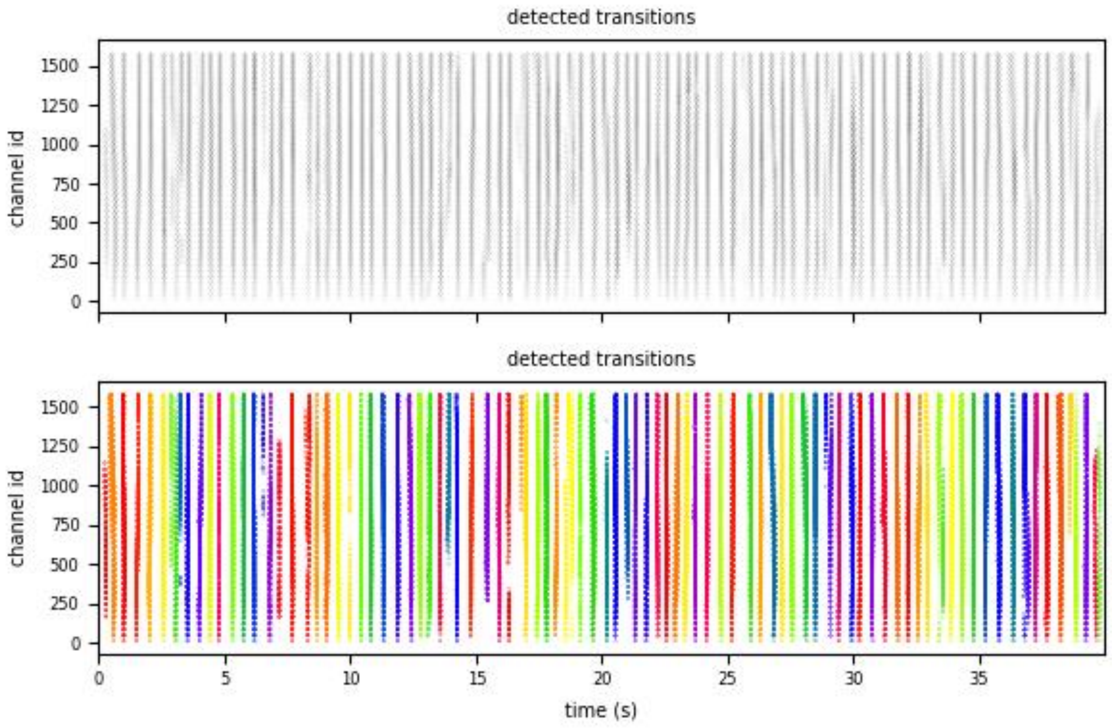
Results comparison: NEST vs NEST GPU

Rastergram of detected waves

NEST



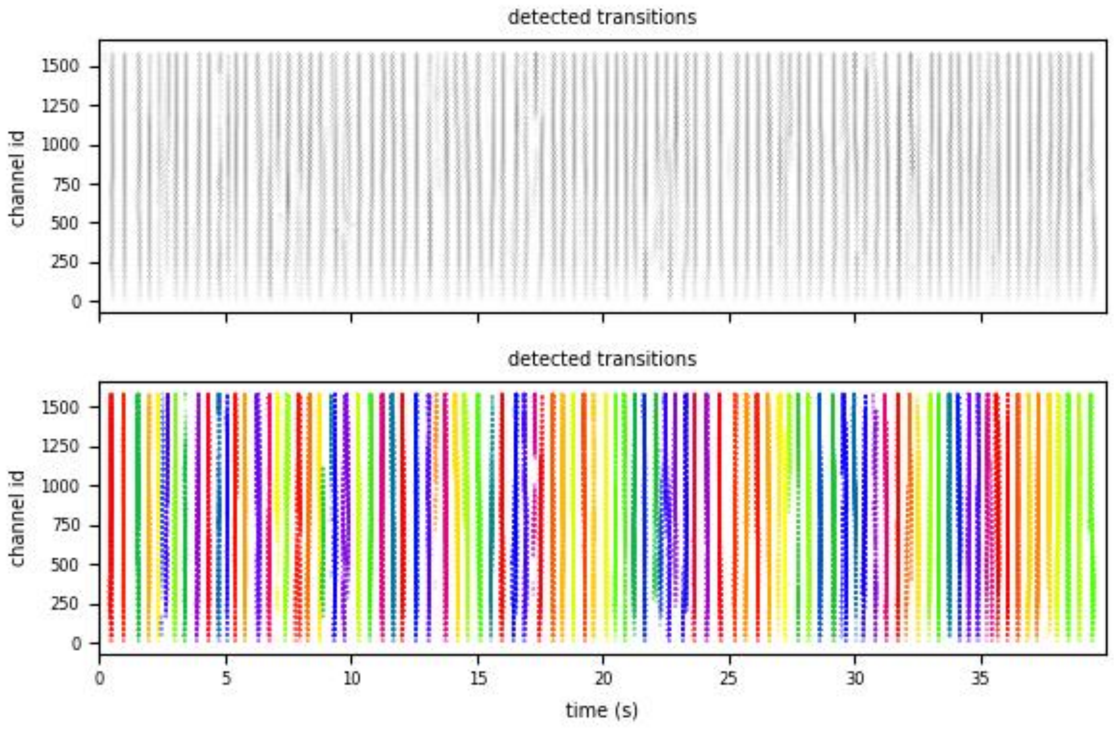
NEST GPU



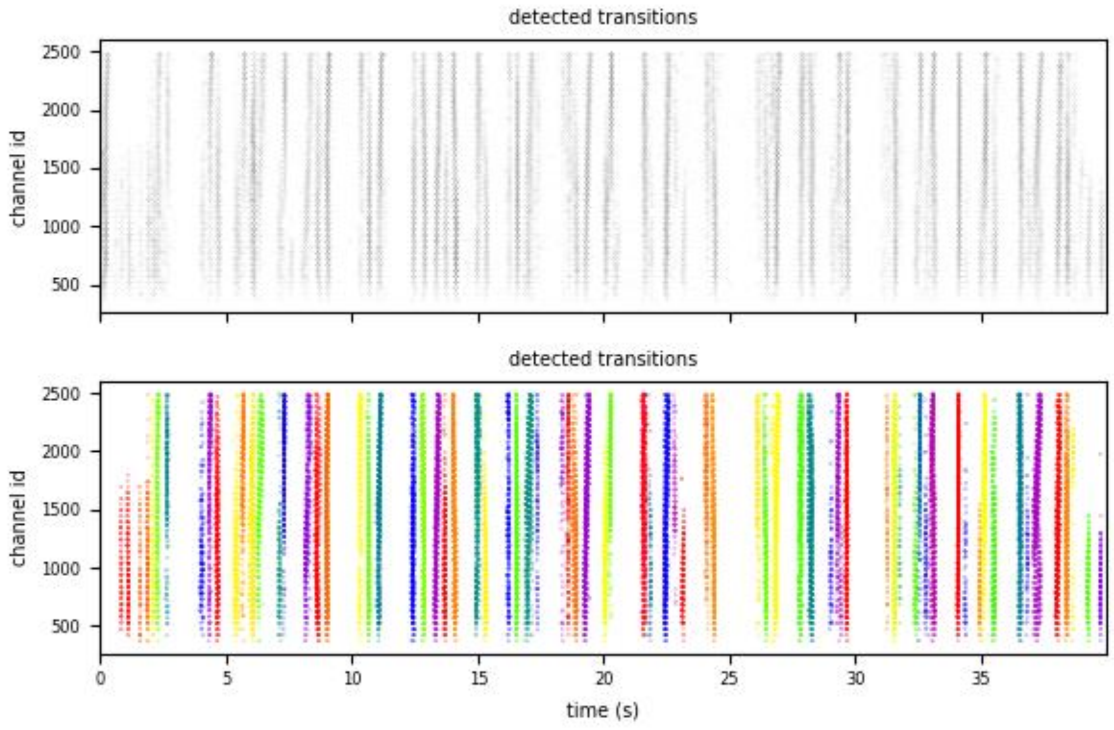
Results comparison: simulation vs experiment

Rastergram of detected waves

Simulation



Experiment



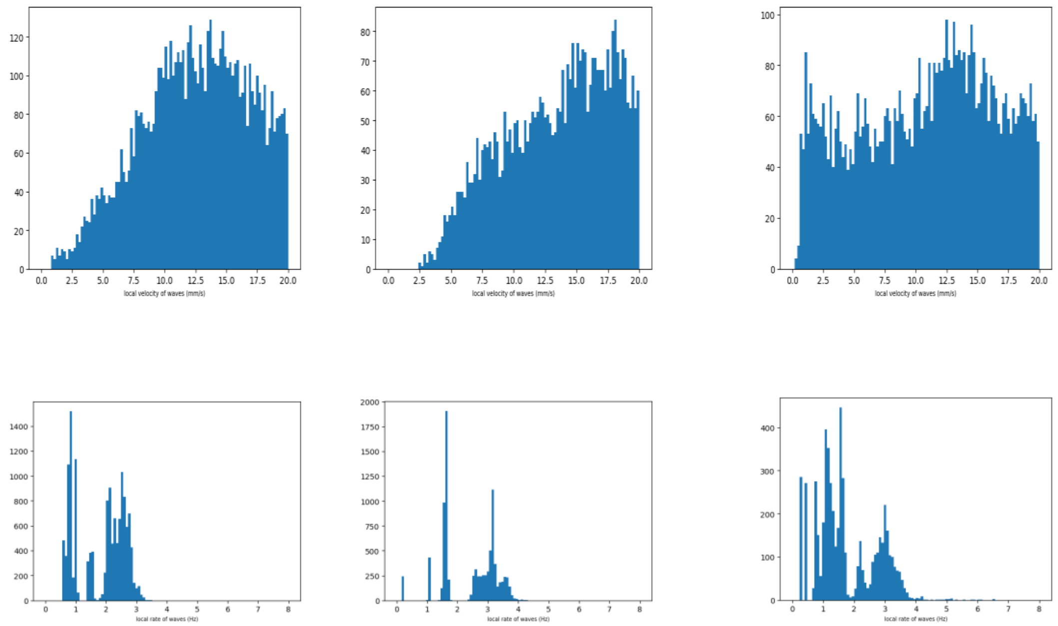
Parameter modulation for a biological match

- Example: modulation of adaptation parameters produce changes in waves frequency as well as on velocity an IWI

b = 1 **b = 3** **b sinusoidal modulation**

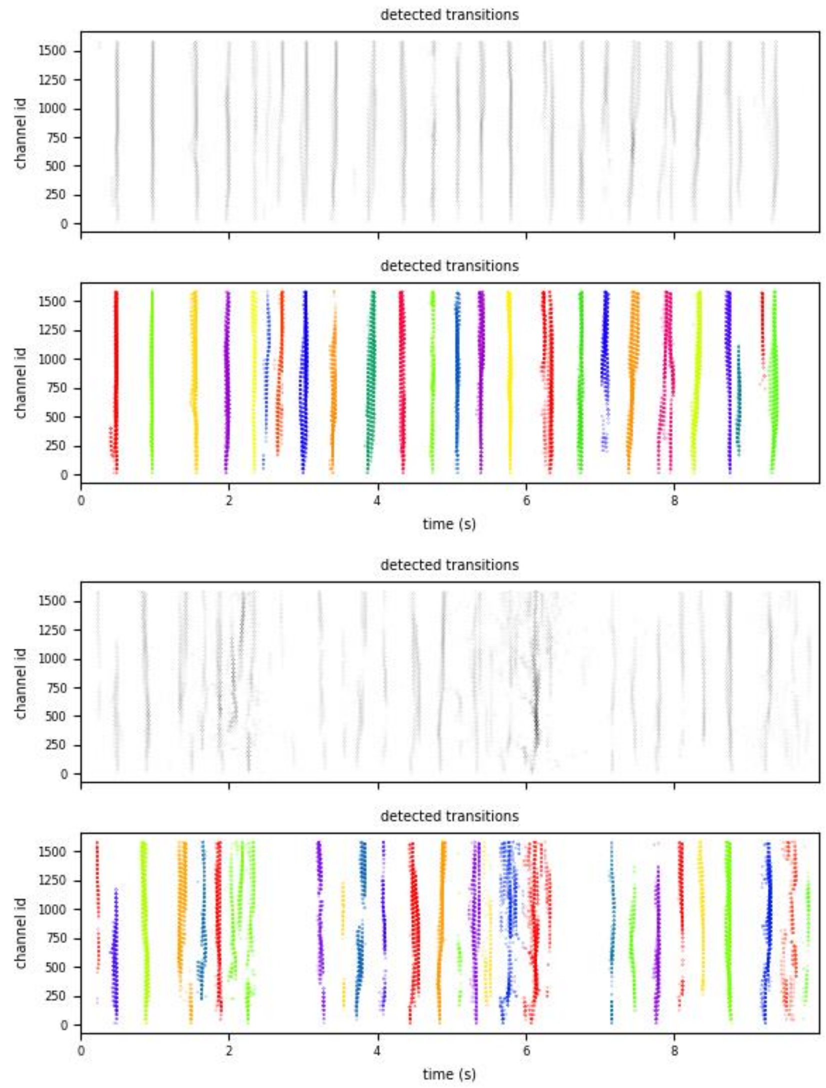
velocity

IWI



b = 1

b sinusoidal modulation



Future activity

- Parameter calibration is required, to increase biological plausibility
  - Modulation of adaptation parameters could adjust wave frequency
  - Change in the connectivity kernel could adjust directions
- Simulation output qualitatively aligned between NEST and NEST GPU
  - Match in terms of directions, velocity, IWI and rastergram
  - Quantitative comparing needed
- Porting of NEST GPU simulation on multi-GPU
  - Further acceleration expected
  - Great advantages for large grid search

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Thank you

www.humanbrainproject.eu

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