APE Lab and the Brain

Presentazione delle attività di APE Lab per gli studenti del curriculum “Biosistemi”

(Physics – Lab II Project)

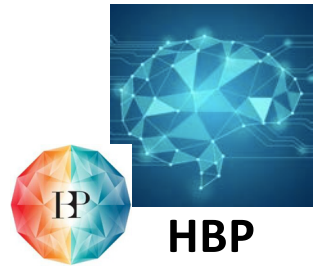
www.apegate.roma1.infn.it

https://twitter.com/APELab_INFN

APE Lab & the Brain

Our interests and efforts are focused on:

- hardware and software co-design for **distributed spiking neural network simulations** on **parallel computing architectures** (DPSNN)
- hardware and software co-design for **neuromorphic computing systems** (focus on network, latency, scalability, and on benchmark applications)
- **Thalamo-cortical spiking models** (beneficial effects of sleeps on classification tasks, sleep-memories interplay, synaptic plasticity, combination of contextual and perceptual information)
- data-constrained (**inference**-based) theoretical models for **connectivity** and **plasticity** (**mean-field** and **spiking** simulations)
- **data analysis** (from different and diverse sources, experimental and simulated datasets)
- **software tools** for the HBP infrastructure platforms



HBP

Human Brain Project

- Simulation of spiking neural networks
- Data analysis
- Theoretical models of cortical activity, connectivity and learning

Network architecture
Network Interface Card (APEnet)
Parallel Computing and GPUs

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Master Theses AVAILABLE Join us! ☺

HBP
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Our offer for the BioPhysicsLab

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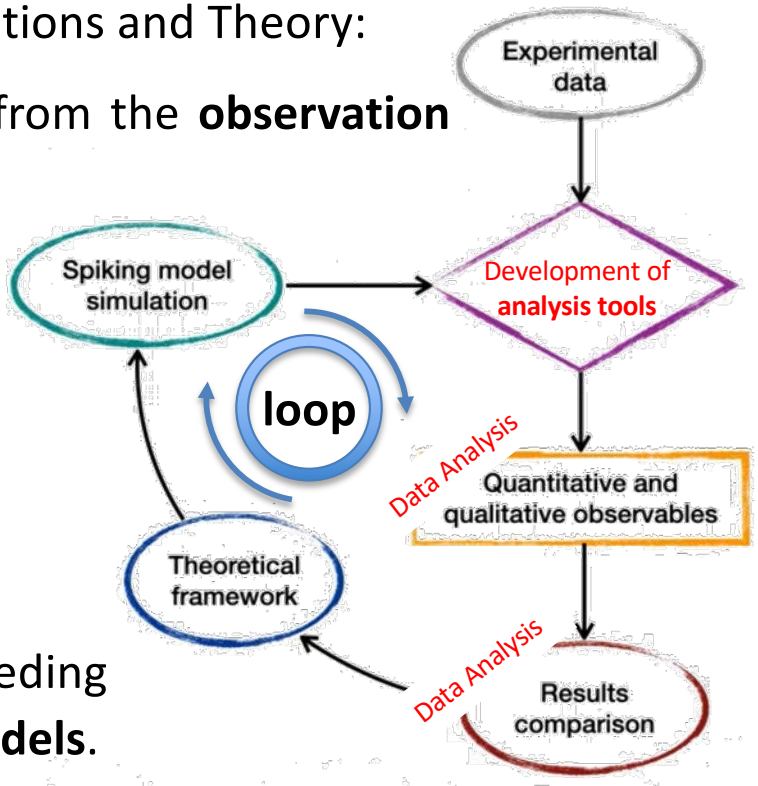
Data Analysis

The activity of Data Analysis is strongly related to Simulations and Theory:

- understand mechanisms and features of the SWA from the **observation** and the **interpretation** of experimental data;
  - define **benchmark observables** and design **flexible tools**, for **comparing and combining different data sets**, aiming at general claims and at statistically significant assessments;
  - define **methods and procedures** for the **validation of theoretical models and simulations**, the **comparison of models**, and the **comparison of experimental and simulated data**;
- extract results from experimental recordings for feeding **data-driven simulations** and **refining theoretical models**.



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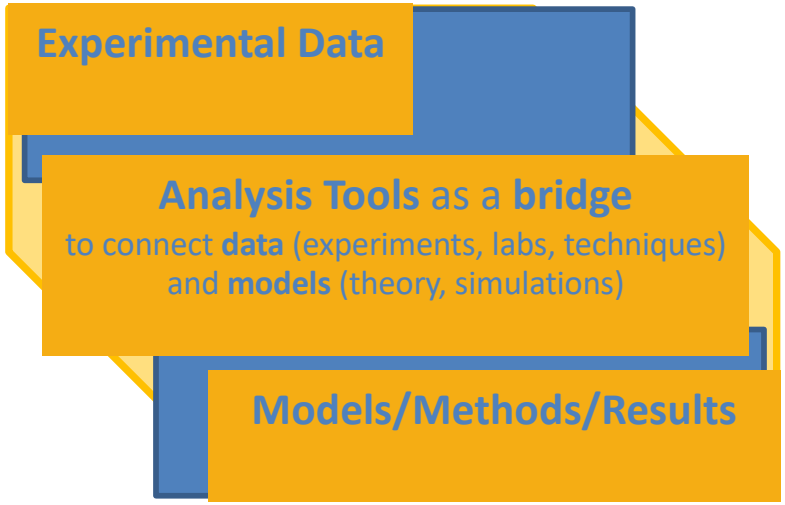
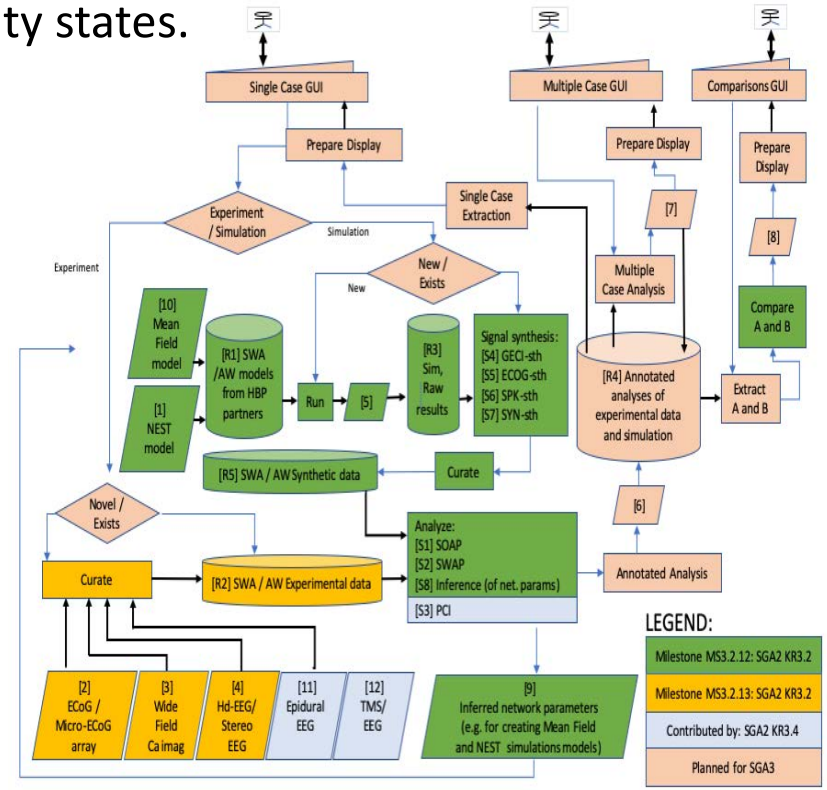
Workflows, Pipelines and Analysis Tools

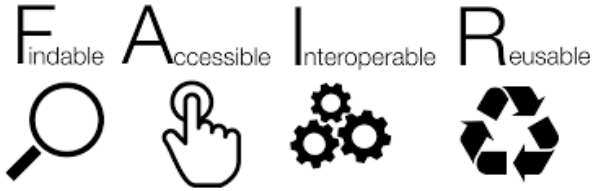
WaveScalES Scientific Mission: **multi-scale**, **multi-methodology**, **multi-species** investigation of **brain states**, their **transitions**, their **complexity** and their specific **cognitive functions**, starting from **deep sleep/anesthesia** to higher complexity states.

→ Offer **experimental data**, **simulation models**, **results** and **analysis tools** to the Scientific Community through **EBRAINS** (European Brain Research INfrastructureS) https://ebrains.eu/

→ Create a **reproducible** and **cooperative** scientific **framework** providing **FAIR** data principles and supporting data and model **comparison**.

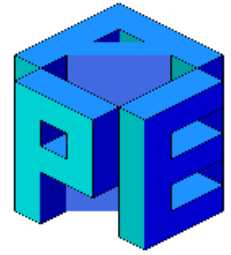






https://www.nature.com/articles/sdata201618

Build modular, adaptable and reusable pipelines



The issue of the **reproducibility of results** is a key-point in the scientific community, in particular in fields that involve life sciences. This aspect is a crucial element when **analyzing data** and when interpreting the outcome in the lights of theoretical models aimed at generating **plausible simulations** of the observed phenomena.

The case of neuroscience is not an exception: the **variety of the experimental techniques for data acquisition** and the **diversity of subjects and species** involved (due to **large biological variability**, but also to **brain states**, **physiological/pathological conditions**, **drug doses** and **data taking setups**) make challenging the building of reliable and generalizable data analysis tools aimed at identifying common observables when **comparing the outcome of different experiments** acquired with different experimental modalities, and at obtaining reproducible results.

In addition, for a fair comparison and an accurate **validation of the models**, biologically-plausible data-driven modelling of the phenomena should follow the same approach, subjecting the outcome of the simulations to the **same analysis tools used for the data**.

common framework for Experimental and Simulated data
→ release for the Neuroscience Community

[WaveScalES-APELab Software Pipelines]

SWAP and SOAP

https://github.com/INM-6/wavescalephant

APE-Fork: https://github.com/APE-group/wavescalephant

SWAP is **Slow Wave Analysis Pipeline**, a robust analysis procedure capable to extract, plot and statistically evaluate the **spatio-temporal features** of slow waves and **propagation** dynamics, offering a set of **software tools and methods** that allow going **from raw-data to statistical assessment of results**.

SWAP has been largely employed in the analysis of experimental data. Currently, efforts have been directed to the improvement of the pipeline towards **robustness and flexibility**, **expanding/integrating general tools,** aimed at extending the range of applicability (diverse experimental datasets and the outcome of simulations) and at integrating it into the **HBP platforms**.

Related Pipeline: **SOAP (Slow Oscillation Analysis Pipeline)**, to investigate the **local properties** of Slow Oscillations (SO) of the multi-unit activity signal between Up and Down states, complementing and enriching the information of the SWAP.

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[WaveScalES-APELab Software Pipelines]

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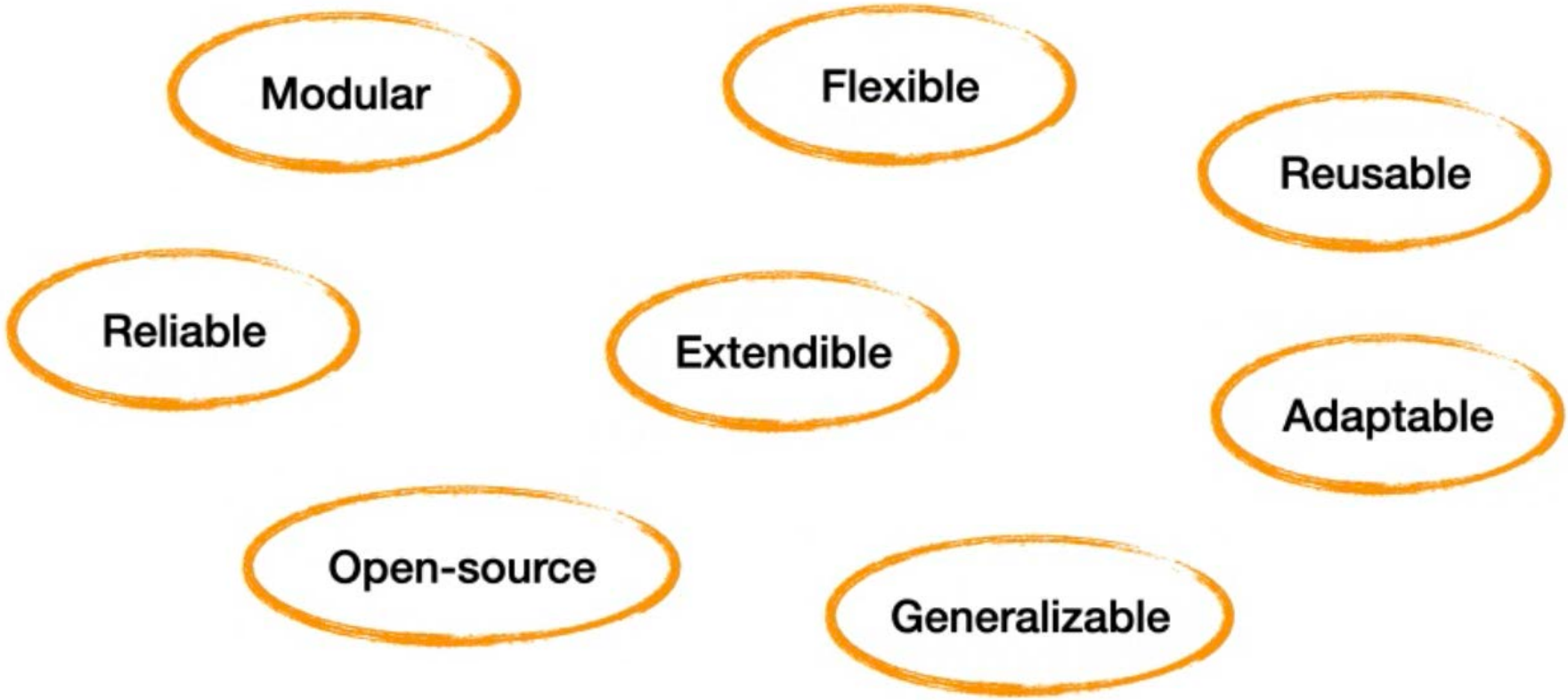

neo elephant NetworkUnit fairgraph snakemake

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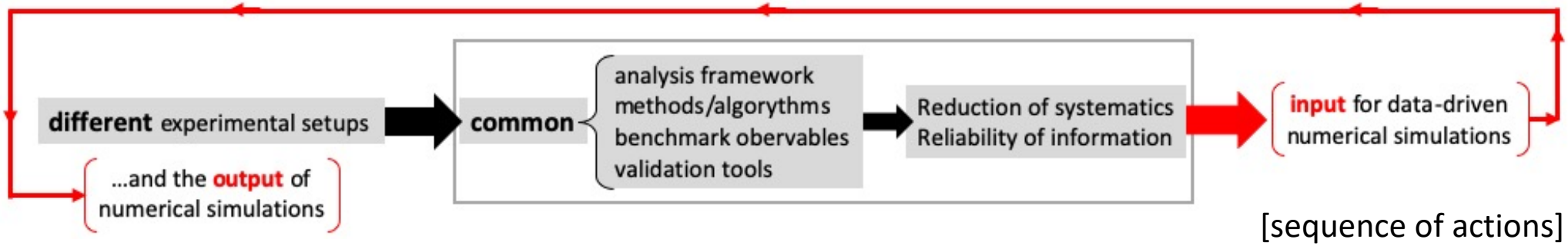
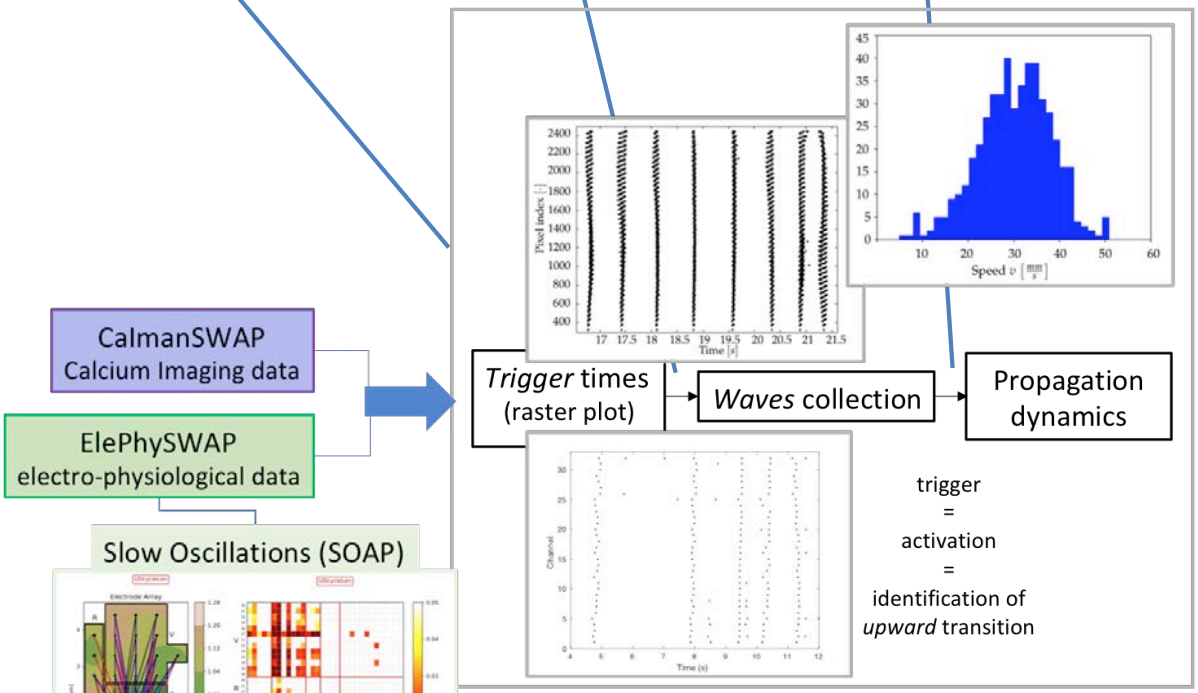
Common Analysis Framework and Pipeline Stages



[sequence of actions]

Data Entry | Processing | Trigger Detection | Wave Detection | Wave Characterization



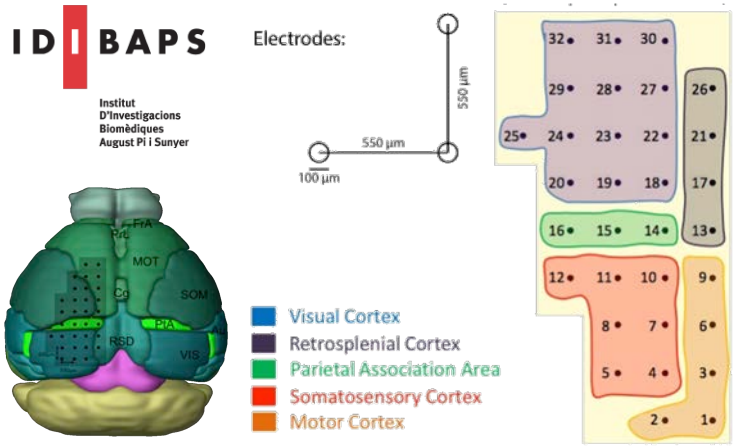
[each *stage* is made up of *blocks*]

Data Analysis – MEA data

Features of the SOs and differential excitability

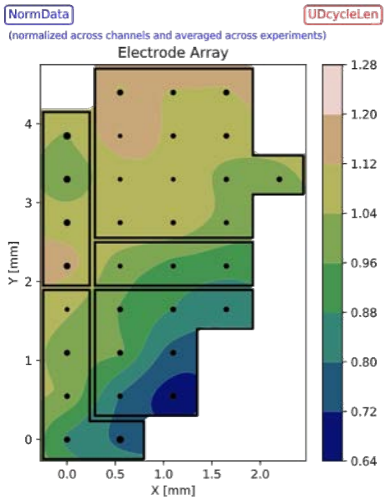
RESULTS

- **differentiation of cortical areas**
- **gradients of excitability**, in particular along a direction from fronto-lateral towards occipito-medial regions.



OUTCOME and PERSPECTIVE

- classification of **brain states** (levels of anaesthesia)
- **input for theoretical models and data-driven simulations**.



G. De Bonis et al., **Front Syst Neurosci. (2019)** **arXiv:1902.08599 [q-bio.NC]**

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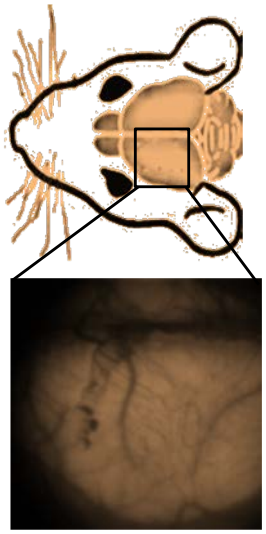
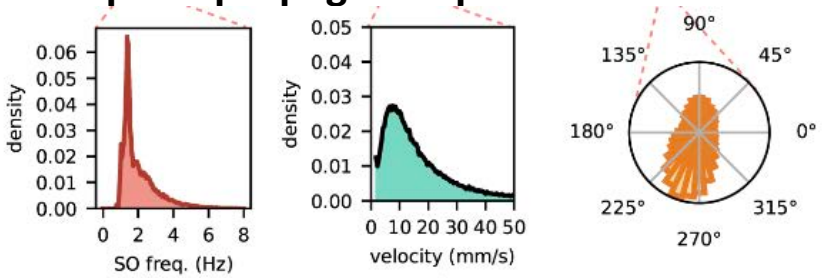
Data Analysis – Optical Imaging data

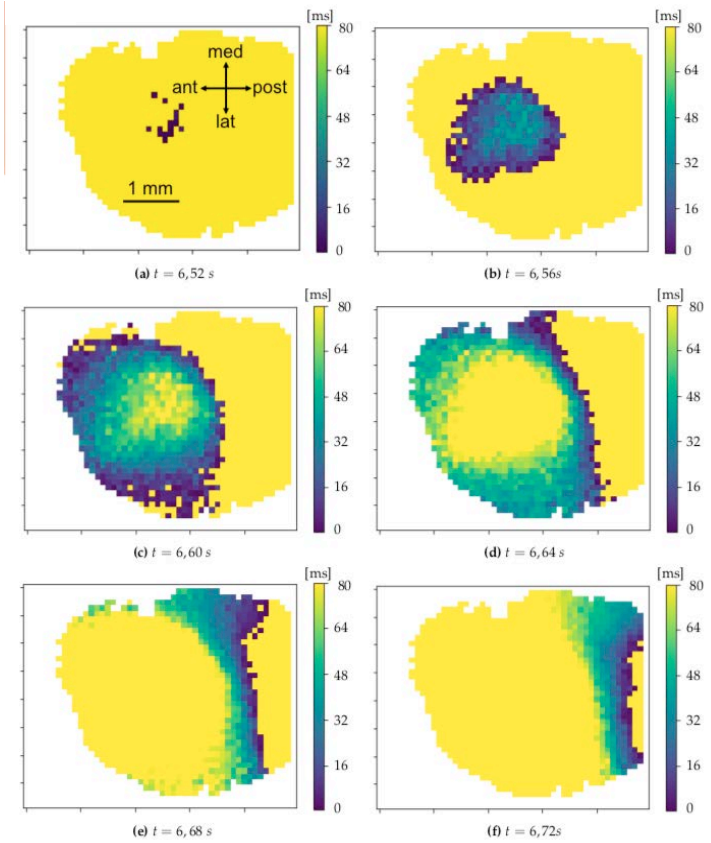
Detection of wavefronts, SW propagation, features of the SWs



RESULTS

- Development of new **tools and methods**, integrated with established ones, for supporting **quantitative studies** of neuronal dynamics for imaging data, aimed at **overcoming the limited spatial resolution of electrode arrays** (from electrodes to pixels).
- Statistical analysis of observed **spatio-temporal propagation patterns**.





Propagation of the wavefront along the cortex surface

M. Celotto et al., **Methods Protoc. (2020)**
arXiv:1811.11687 [q-bio.NC];
C. Capone et al., in preparation

...started from the work of students from Physics Lab. II (Biosystems), 2018 + inputs from 2019

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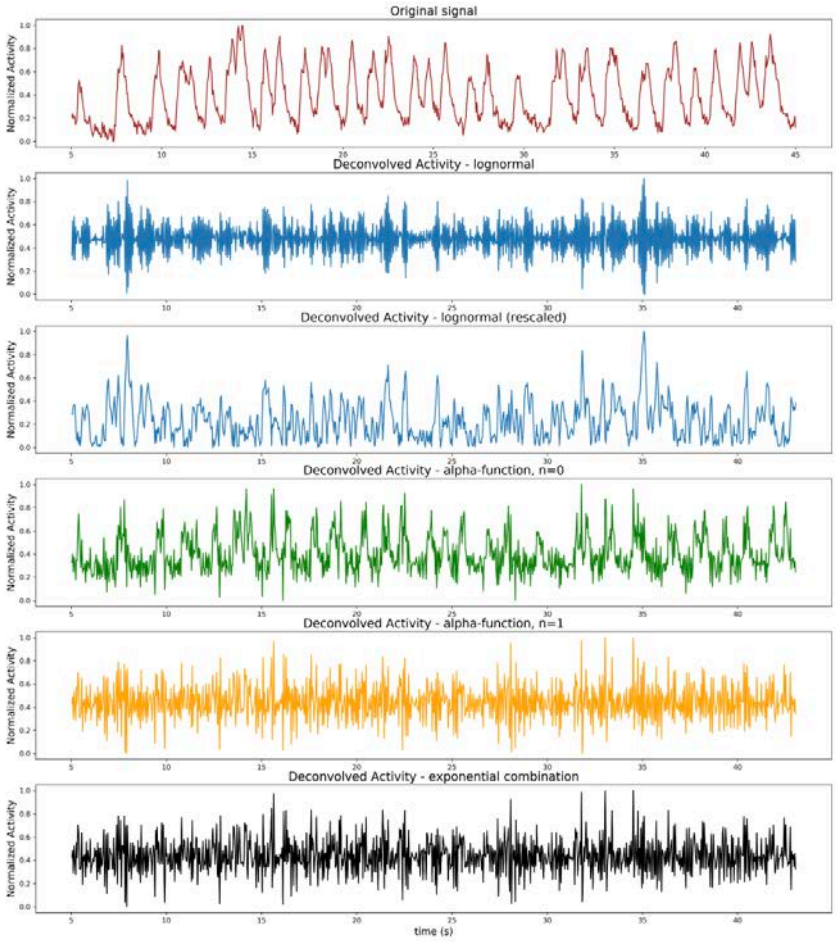
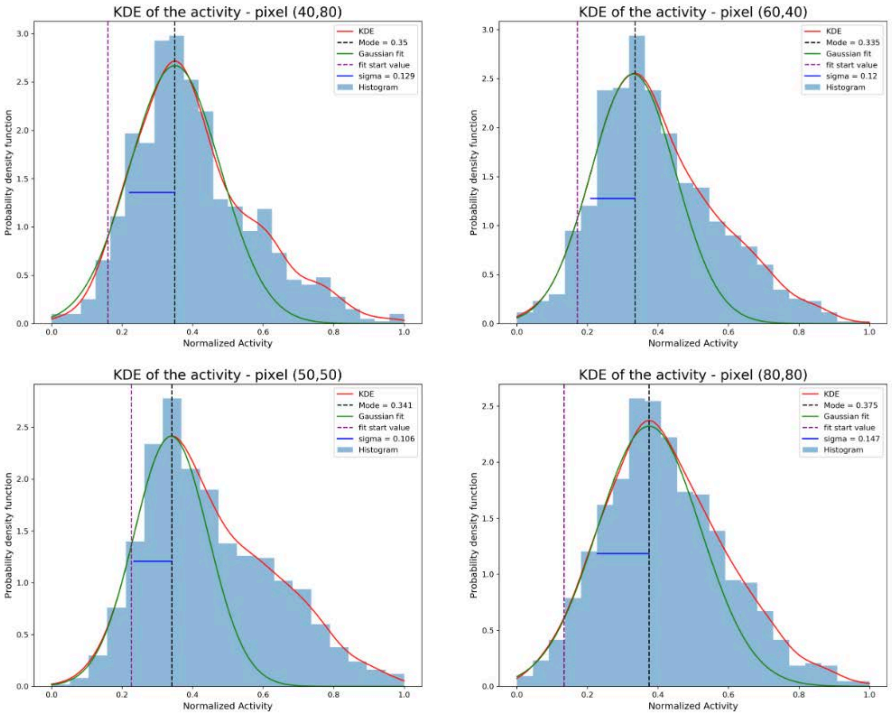
Data Analysis – Analysis Tools

Development of analysis tools (*blocks*) for SWAP: deconvolution, KDE (Kernel Density Estimation)





Deconvolution of optical imaging data

→ inference of model parameters

(the loop: from data to model)

work of students from Physics Lab. II (Biosystems), 2020 → pre-print in preparation

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Data Analysis
Proposed items of activity (1)

(1) Optical Imaging

Topic: Analysis of electrophysiological data collected from anesthetized mice with optical imaging techniques (wide-field microscopy). **New dataset**: isoflurane, stimulated data.

Target: Study of waves propagation patterns, propagation speed, excitability, multi-areal connectivity; **comparison ketamine vs isoflurane**; **comparison spontaneous vs perturbated** data; comparison with electrodes data.

The candidates should:

- be interested in cortical activity during sleep;
- be interested in statistics and statistical analysis of experimental data;
- know/be willing to learn MATLAB and Python, and Python-based tools (Elephant, Snakemake, Neo)

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Data Analysis
Proposed items of activity (2)

(2) SWAP

Topic: Development and improvement of the analysis pipeline, test on experimental and simulated data.

Target: Focus on reliability, robustness, reconfigurability, portability, parallelization, open source.

The candidates should:

- be interested in programming, code optimization, parallelization;
- be interested in computer science and algorithms;
- know/be willing to learn MATLAB, Python, Python-based tools (Elephant, Snakemake, Neo) + any other programming languages/tools useful for improving performance.

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Data Analysis
Proposed items of activity (3)

(3) Epidural EEG and Measures of Complexity

Topic: Analysis of electrophysiological data collected from mice under anesthesia and in natural sleep, using epidural EEG recordings.

Target: Test of the SWAP software tools to different datasets, and evaluation of possible extensions; determination and classification of waves propagation patterns; comparison of different anesthetics and natural sleep; measures of complexity and level of consciousness.

The candidates should:

- be interested in cortical activity during sleep, and in quantitative assessment of the level of consciousness;
- be interested in statistics and statistical analysis of experimental data;
- know/be willing to learn MATLAB and Python, and Python-based tools (Elephant, Snakemake, Neo)

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