





Analysis pipelines, cortical models and spiking networks as tools for investigating the cognitive effects of slow wave activity in wakefulness and sleep

a.k.a. disentangling the brain complexity with a physicist's perspective

G. De Bonis on behalf of APELab-INFN Pomeriggio Tematico «Nuove Idee», INFN-Roma 19/06/2023



INFN-APELab & the Brain: a concept map



Data Analysis

Take-home message: the interplay between data and models





SCIENTIFIC MOTIVATION

«Dear Santa...» a.k.a. the Neuroscientist's wish list

- Move from qualitative to quantitative comparisons
- Minimize the impact of artifacts and provide easy-spot of biases
- Standardize and generalize methods and processes
 → structured pipelines & workflows
- Increase the visibility of innovative approaches and spread methods/results out of the lab
- Enable a common language for multi-disciplinary research



- Exploit cutting-edge technology and latest trends in software engineering
- Operate in a collaborative environment
- Adopt user-friendly software solutions

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Modified from https://www.theguardian.com/teacher-network/2015/dec/22/dear-santa-heres-christmas-wishlist-for-education-love-teachers





SCIENTIFIC MOTIVATION

The perfect gift

- Create and maintain an ideal setting for collaborative science
- Enable a collector of diverse experiences
- Act as a generator/incubator of research teams, connecting heterogenous communities
- Provide hints for novel scientific quests, prepare alternative research paths, support science-driven development of algorithms, models and software solutions
- Deliver real-life (i.e. not over-simplified) scientific use cases for technology



from Wikimedia Commons

Cobrawap – Evolutionary Road

1. Science-driven starting point

HBP-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.



Modified from https://blogs.iu.edu/sciu/2017/09/26/why-are-there-still-apes/





Cobrawap – Evolutionary Road

- 1. Science-driven starting point
- Compliance with «FAIRNESS»
- Integration as a service into the EBRAINS infrastructure 3.



From small scale (individual researcher)...

...to large scale (a user community supported by the EBRAINS infrastructure)

Steps to move forward:



- >> HPC resources
- >> Standardization of workflow build-up and management (Snakemake, CWL)
- >> User interface \rightarrow integration in the EBRAINS dashboard



 \rightarrow address a larger number of users \rightarrow increase user-friendliness











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Cobrawap under the magnifying glass Q

- focus on wave dynamics
- designed and developed in collaboration with Jülich Forschungszentrum
- > open source, public repository (GitHub)
- Python + expansion/integration of general common tools
- build up as a sequence of stages, each made up of blocks



slide by Robin Gutzen, INM6-Juelich

Comparing apples to apples ...









EBRAINS and the future

The Cobrawap network

Scientific Tasks (development/improvement of (new) blocks)

- Analyze spontaneous/stimulated/evoked data
- CBF (Cerebral Blood Flux) imaging data and correlation with coincident ECoG
- Natural sleep and generalized image processing
- TVB-Human and EEG \rightarrow towards human data and beyond surface recordings
- Intracranial electrodes (3d data and models)
- Studies across brain states \rightarrow motifs and waves in wakefulness

close connection and close connection scientific interplay between scientific and technical tasks



Technical Tasks (...towards an EBRAINS service)

- Cobrawap-doc
- Cobrawap-CI-TestSet
- JupyterLab-UNICORE (and execution on HPC platforms: JSC, CSCS, CINECA)
- Workflow management systems: Snakemake and CWL
- Spack & pip
- Docker
- Parallelization and speed up
- Input data: link with the EBRAINS-KG

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EBRAINS and the future

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Cobrawap as a service in EBRAINS (II)

but also demand for:

- scientific reproducibility
- structured analysis pipelines ٠
- flexibility to user customization
- user-friendly approach

workflow management systems

snakemake

- Cobrawap initially managed through Snakemake is extension to CWL
 - less python-oriented (more universal)
 - better I/O management between steps
 - native Docker support
 - more pronounced hierarchic organization into steps (same as Cobrawap!)

We developed a dynamic approach:

- \succ max flexibility
- max user-friendliness







Cobrawap as a service in EBRAINS (III)

The final goal

Cobrawap as a component in the EBRAINS dashboard

- ...step by step...
- CWL integration
- ion 🗸
- deployment on GitHub, GitLab and FENIX-HPC sites
- runnable from EBRAINS Collab
- continuous integration, testing and deployment
- available as a Docker image X

And, in the same spirit of «FAIRNESS»:

- > open-source code, fully documented (<u>https://cobrawap.readthedocs.io</u>)
- everyone can access, reuse and contribute (GNU General Public License v3.0)
- always welcoming to new scientific-driven features



GitLab GitHub







Progetto EBRAINS-Italy IR00011 - CUP B51E2200015006 • Missione 4 - Istruzione e Ricerca • Componente 2 • Azione 3.1.′



EBRAINS and the future

Cobrawap – Outlook

- 1. Science-driven project
 - \rightarrow scientific questions are the engine for any development
- 2. Compliance with "FAIRNESS"
 - \rightarrow focus on robustness and reproducibility through modularity, flexibility, generalizability
- 3. Integration as a service into the EBRAINS infrastructure
 - ightarrow increase the usability, for more users and more user-engagement





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THANK YOU!

JÜLICH Forschungszentrum

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Sofia Karvounari Eleni Mathioulaki





Alessandra Cardinale Giulia De Bonis Chiara De Luca Irene Bernava Cosimo Lupo Cristiano Capone Elena Pastorelli Leonardo Tonielli *Pier Stanislao Paolucci*



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Anna Letizia Allegra Mascaro Elena Montagni Francesco Resta *Francesco Saverio Pavone*



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Why do we study sleep?

• The occurrence of sleep passed through the evolutionary sieve and is widespread in animal species [despite it increases the animal's vulnerability and is in opposition with other vital functions (as feeding and reproduction)]

 \rightarrow must be essential for brain health and functions

- Sleep is known to be beneficial to cognitive and mnemonic tasks, while chronic sleep deprivation is detrimental.
- Sleep activity such as slow waves, and sharp waves and ripples have been shown to be beneficial for memory consolidation and task performances.
- Beneficial effects of sleep on **energetic consumption** have been proved.
- Experimental studies investigated the effects of sleep on firing rates and synaptic efficacies, hypothesizing about **homeostatic processes** occurring during sleep.
- Increasing experimental evidence is mounting for both the role played by the combination of bottom-up (perceptual) and top-down/lateral (contextual) signals.
- Despite the importance of the phenomenon, a complete understanding of its functions and underlying mechanisms is still lacking.







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MC-AdEx-BAC Outlook and collaboration opportunities

- "Plug-and-play" replacing AdEx in spiking networks, for easy exploration of the impact of apical -amplification, -isolation and -drive on cognitive simulations:
 - AdEx-like behaviour when synapses are linked only to somatic compartment
 - Preliminary successful application in ThaCo (incremental learning and sleep)
- To be released as NEST neuron model
 - Based on NEST multi-compartment model framework
- > Contribution to joint WP1-WP2-WP3 whole-brain **cognitive model** blueprinting effort
 - Could enable the inclusion of a plastic cognitive module at different scales (e.g. columnar, areal, ...), capable of incremental learning and awake-sleep cycles in the TVB (or TVB-like) framework
- Bio-inspired artificial intelligence applications using either the spiking model or an abstract version of it
 - Funded until 2026 by Italian FAIR (Future Artificial Intelligence Research) Project















Co-fu

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INFN-APELab & the Brain



SCIENTIFIC MOTIVATION

Interplay DataAnalysis – Models – Simulations

Cobrawap – Evolutionary Road

- 1. Science-driven project start
- 2. Compliance with «FAIRNESS»
- 3. Integration as a service into the **EBRAINS** infrastructure

From small scale (individual researcher)...

...to **large scale** (a user community supported by the EBRAINS infrastructure)

RARE

Scalability

Steps to move forward:

>> HPC resources

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>> User interface \rightarrow integration in the EBRAINS dashboard

slide by Robin Gutzen, INM6-Juelich

The role of the Cobrawap

- Cobrawap plays a central role in the outer loop and a posteriori validation processes.
- Need to analyze and process high spatial resolution data.
- Quantitative EMD distance over cumulated macroscopic local observables

Implemented methods as blocks in the pipeline

- Data preprocessing (spatial optimal sampling, region of interest selection, detrending, normalization...)
- Minima method to Down-Up transition time detection
- Wave detection method to crop the identified transitions into global waves
- Macroscopic local and global observables of the dynamics (speed, direction, inter wave interval, planarity)
- Gaussian Mixture Models to identify and detect principal traveling waves modes.

Inference Models: Conclusions

To sum up:

- We developed a method to infer parameters for large scale simulations reproducing experimental data.
- We developed an analysis tool to compare data and simulation and perform optimal-model selection.
- Good accordance between data and simulations for what concerns wave macroscopic features and spatial dynamics.
- Wave propagation modes not used to select the optimal model are well reproduced by the simulation.

What's next?

- Spiking whole cortex simulation
- Stimulated dataset inference and mean field simulation

