Cedalion: A Python-based framework for data-driven analysis of multimodal fNIRS & DOT in the everyday world

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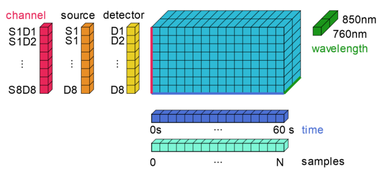
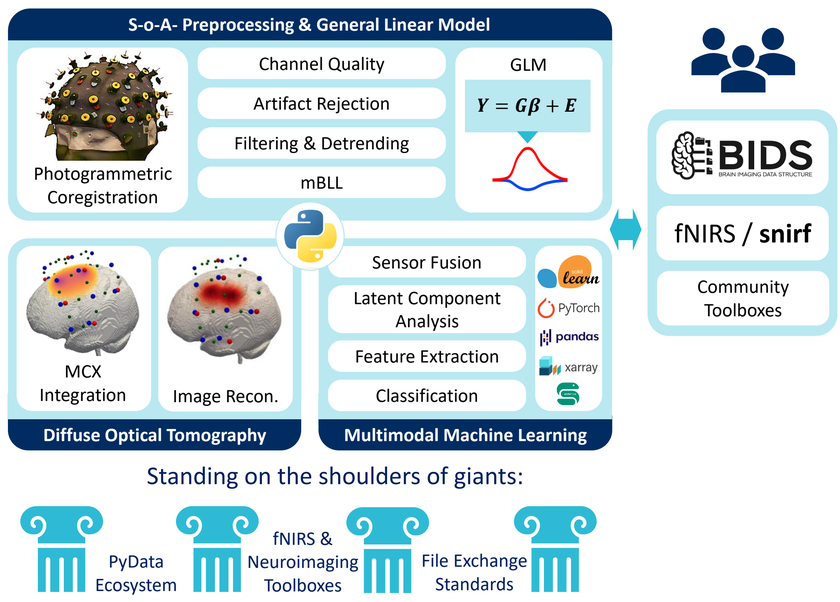
Motivation & Concept

fNIRS / DOT signals are inherently confounded by systemic physiological activity in the cerebral and extra-cerebral compartments. As a result, contrast, sensitivity, and specificity of the recovered hemodynamic responses are affected – a problem that is further amplified by natural behavior in experiments for neuroscience in the everyday world [1]. This motivates our research into new methods that make use of additional auxiliary measurements from physiological sensors and complementary neuroimaging modalities like EEG to explain variance in fNIRS signals and separate confounding components from those of interest. However, complex properties such as non-stationarities, non-instantaneous and non-linear coupling between the multimodal and multivariate time series make modelling the relationships between different signals a hard problem. A promising approach is learning these relationships from data with machine learning and AI. As we assume that these methods will play an increasing role in the upcoming years, we are developing Cedalion, a new Python-based framework, to aid the community in combining state of the art fNIRS/DOT methods with ML/AI. Towards improving contrast and statistical power in neuroimaging experiments, boosting performance in single trial analysis for BCI and Neuroergonomics and uncovering complex relationships between systemic physiology and the embodied brain [2].



Data Structures

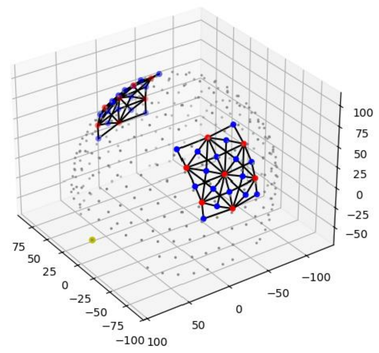
- xarray.DataArrays and pandas.DataFrames
- Multi-dimensional data arrays
- Numpy-compatible
- Labeled dimensions and coordinates to avoid many common errors
- Support for physical units
- Extendable functionality through accessors



Methods: New Toolbox

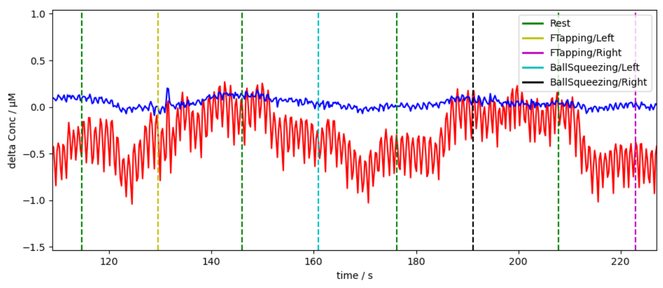
/io

- Read and write SNIRF and BIDS (wip)
- Read photogrammetry data, probe geometries, anatomies

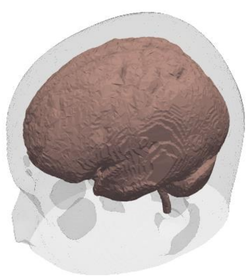


/nirs

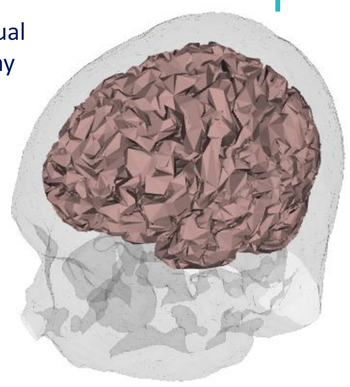
- Standard fNIRS conversions:
- Int to OD and concentration



Colin27 & ICBM152 Atlases



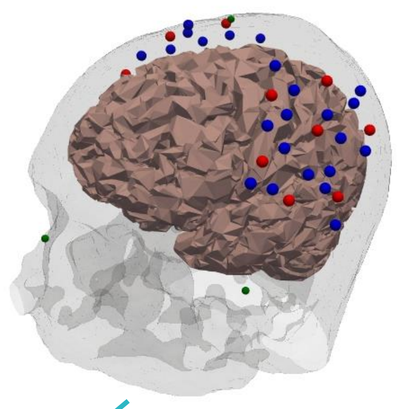
Individual anatomy



/geometry

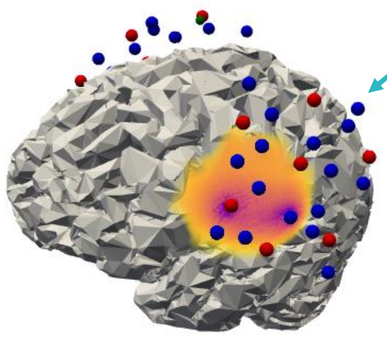
- Segmentation processing
- Photogrammetric analysis
- Optode (co)-registration

Automatic and manual optode detection and projection onto scalp surface



MCX / nirfaster

- Plug-in-support of toolboxes (e.g., photon/fluence simulation with MCX & nirfaster)



Accurate forward model generation

/sigproc

- Filtering, masking, pruning
- Quality metrics (e.g., PSP, SCI, SNR)
- Motion artifact detection & Correction (e.g. SplineSG, PCA, …)
- Signal decomposition & latent component analysis

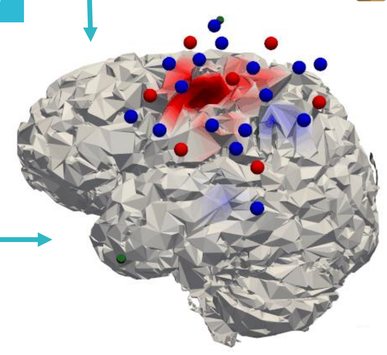
/sigdecomp

/imagereco

- DOT image reconstruction:
  - forward model
  - solver

/models

- General Linear Model
  - HRF and SC regression



scikit learn

PyTorch

- Advanced data driven analysis with machine learning
- Single trial analysis

Conclusion and Outlook

Cedalion is a modular and open-source Python package that combines much of the key functionality of HOMER2/3 and AtlasViewer with the rich Python ecosystem of machine learning and data science tools for data-driven analysis using packages such as sklearn, PyTorch and Pandas. Our goal is 1) to facilitate the development of new data-driven methods, by simplifying the integration of machine learning workflows and conventional fNIRS data processing streams. 2) to provide user-extensible data structures and functionality that allow for easy data exchange with popular frameworks, and with established toolboxes through standardized file formats like SNIRF and BIDS. 3) to support the construction of workflows that chain existing functionality of versatile and well-tested analysis toolboxes that provide specific preprocessing methods for each neuroimaging modality. 4) to establish a community-centered development philosophy that focuses on easy contribution and distribution of new methods and clearly credits contributors and incorporated published work on its documentation page. Cedalion is an ongoing development project, and its first release will be at the fNIRS Conference in September 2024.

Availability

Framework code and example jupyter notebooks at

https://github.com/ibs-lab/cedalion

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References

[1] von Lühmann *et al.*, "Toward Neuroscience of the Everyday World (NEW) using functional near-infrared spectroscopy," *Current Opinion in Biomedical Engineering*, vol. 18, p. 100272, Jun. 2021, doi: 10.1016/j.cobme.2021.100272.
[2] Scholkmann, *et al.*, "Systemic physiology augmented functional near-infrared spectroscopy: a powerful approach to study the embodied human brain," *Neurophotonics.*, vol. 9, no. 03, Jul. 2022, doi: 10.1117/1.NPh.9.3.030801.

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