EPFL Image Reconstruction Hub:
Student Projects 2023

Pycsou-GSP: Accelerated and distributed inverse problem optimization on Graphs with an application on electrical Neuroimaging.

Type: Semester project (Bachelor or Master)
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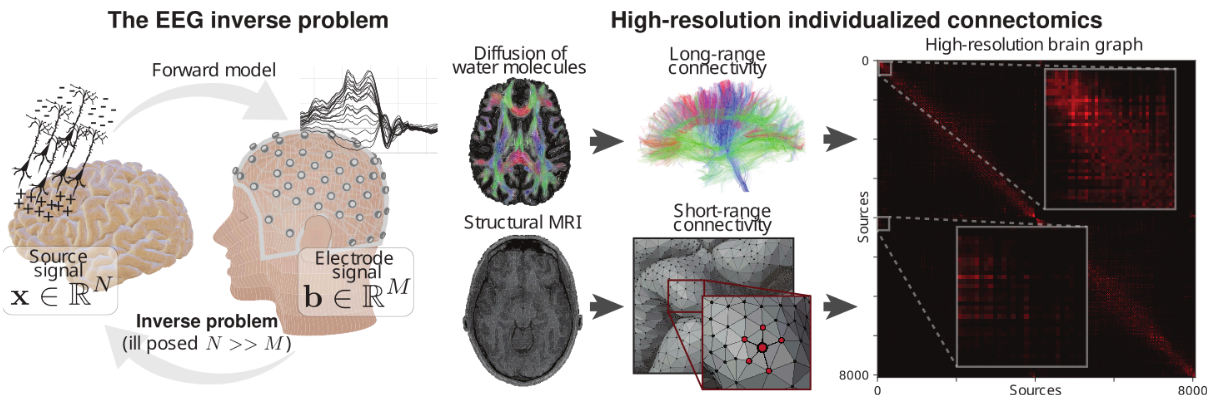

Description

Most approximation problems in real life are inverse problems. They include some of the most important mathematical problems in science and mathematics, since they allow us to estimate parameters (causes) that we cannot observe directly from certain observed data (effects). The list of applications that fall under this category is huge [1].

A massive proportion of the data collected today is based on irregular and complex structures that are best modeled by graphs. For example, social networks, traffic patterns, financial data, food ingredients, weather sensors, genetic networks or neural populations, among many more. Graphs allow us to model such data and their interactions (nodes and connections). Fortunately for us, the maturation of graph signal processing (GSP) [2] has formalized a set of tools that currently allows us to explore and model these complex signals. However, the irregularity of the domain of graph-signals poses a computational hurdle: the accessibility to matrix-free operators is very limited. This challenge forces scientists to resort to standard signal processing tools that are computationally cheaper but less suitable, often resulting in biased and noisy estimates.

At EPFL Hub for Advanced Image Reconstruction, we are developing Pycsou [3], an open-source computational imaging software framework for Python with native support for hardware acceleration and distributed computing.

The aim of this project is to develop an extension of Pycsou for inverse problems on graphs, (Pycsou-GSP). In particular, the main goals consist of the development of:

1. differential operators (such as gradient and divergence),
2. transforms (such as the Fourier transform and the wavelet transform),
3. non-code contributions in the form of documentation and tutorials.

The code contributions will be implemented to support hardware acceleration and distributed computation using Cupy [4] and Dask [5].

The resulting Pycsou-GSP extension will be tested in an application to electrical neuroimaging [6].

Electrical neuroimaging is a computational method for mapping the neuronal electrical activity from electroencephalography (EEG) recordings. Due to the small number of electrodes compared to the massive number of neurons, this is a very difficult problem to solve. Current methods produce images with very poor spatial resolution. This poses a real challenge for neurosurgeons that need to locate the origin of an epileptic seizure, for example.

Recent studies have shown the advantage of leveraging the fact that the brain has a graph structure: the neuronal populations form the nodes that are connected among them by axons [6]. Following this idea, the developed GSP tools will be used to introduce the graph-like structure of the brain to the reconstruction process of the neuronal activity image, with the objective of improving their spatial accuracy and precision.

Type of Work
90% programming and experiments, 10% theory.

Prerequisites
Good knowledge of Python 3 (and more specifically numerical computing packages such as Numpy). Good mathematical skills and a taste for abstraction and rigorous mathematics. Some previous knowledge of graph signal processing, functional analysis, approximation theory, inverse problems or sparse recovery is a plus.

References:

[1] Inverse problem, “Wikipedia”, https://en.wikipedia.org/wiki/Inverse_problem
[2] Shuman D. et al. (2013). The emerging field of signal processing on graphs: Extending high-dimensional data analysis to networks and other irregular domains. IEEE Signal Processing Magazine.
[3] Simeoni M., Kashani S., Rue Queralt J. & contributors (2022). matthieumeo/pycsou: Pycsou 1.0.6 (v.1.0.6). Zenodo. http://doi.org/10.5281/zenodo.4486431
[4] Nishino, R. O. Y. U. D., and Shohei Hido Crissman Loomis. (2017). Cupy: A numpy-compatible library for nvidia gpu calculations. 31st conference on neural information processing systems.

[5] Rocklin, M. (2015). Dask: Parallel computation with blocked algorithms and task scheduling. In Proceedings of the 14th python in science conference (Vol. 130, p. 136). Austin, TX: SciPy.
[6] Rue Queralt, J. et al. (2022). Connectome spectrum electromagnetic tomography: a method to reconstruct electrical brain sources at high-spatial resolution. bioRxiv.