Mission project based on the participation on the neuroimaging open source software PyHRF
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Contributions to the PyHRF open source software
"Development of state-of-the-art neuroimaging simulations"

Aims of the project

The main goal of the project is to develop a realistic functional magnetic resonance imaging (fMRI) data simulator. It will help researchers explore the power of experimental design, assess the limit of analysis methods (for example assuming the canonical HRF model) and explore the influence of different sources of noise on fMRI results. To achieve this I will take advantage of the tools already developed in PyHRF. This package, formerly developed by Philippe Ciuciu and Thomas Vincent in the PARIETAL/INRIA team extensively explored the problem of joint activation detection and HRF estimation as an alternative to the standard assumptions in fMRI data analysis. It already embeds a 2D simulator platform of hemodynamic activity. Moreover, starting this year, a research engineer was hired by the research team to refactor the software code and a bigger community is getting involved to boost the structure, capabilities and accessibility of the packages under an open source philosophy.

Work plan (32 days plan)

The development steps of the project would be:

1. Build the 3D spatial support of the system (5 days)
    a. Select and document real datasets to use as template and to extract parameters afterwards.
    b. Create the interface to inject the 3D datasets into the framework

2. Develop tools to generate binary clusters in 3D (activation maps) constrained by the cortical mask. Should include parameters related to scale and shape (5 days)

3. Work on the Implementation of methods to inform, from the real datasets, the parameters of the simulation steps algorithms: (11 days)
    a. The developed binary activation maps (3 days)
    b. The artificially generated hemodynamic response, considering the JDE proposed HRF models (3 days)

    c. The physiological (hemodynamic) noise, considering physiological models implemented already in PyHRF (3 days)
    d. The acquisition related noise, like movement, considering the information available from well established preprocessing techniques (2 days)

4. Validate the generation of the 3D artificial datasets (5 days)

5. Work on the development of tools to assist the comparison of experimental designs in the case of the GLM and JDE pipelines (6 days).
    a. Related to design efficiency
    b. Related to adjusting parameters according to stimuli specific hypothesis for which previous experimental data is available.

Impact of the project

This project will provide an interesting open source tool to the broad neuroimaging research community and particularly strengthen the collaboration between the language neuroimaging team UNICOG and the signal processing, image analysis and machine learning team PARIETAL at NeuroSpin.

Moreover it is expected that this project will:

- Extend the study of the methods already implemented in the platform to the more realistic 3D case.
- Open the possibility to test different sources of noise and physiological models, also informed by real datasets.
- Open the possibility to study experimental design hypothesis to compare and aggregate them in a systematic way but still adaptable to specific experimental cases.
- Open the possibility to compare fMRI data analysis pipelines in a systematic way.

Context of the project

Currently, the analyses of fMRI data mostly rely on linear regressions based on a “canonical” HRF (Hemodynamic Response Function). This model of the HRF originates from measurements made in visual areas and it is known that it can fit less well the responses in other brain areas. Various algorithms have been developed to tackle the problem of estimating the HRF in order to improve the interpretation of activations in brain areas that are different from visual areas and, also to characterize it across subjects.

Pyhrf is a set of tools for within-subject fMRI data analysis, focused on the characterisation of the hemodynamics[1]. This set of open source tools helps close the gap between the latest signal processing techniques and FMRI research[2]. The software is mainly written in Python, with some C-extension that handle computation intensive parts of the algorithms. Also the package relies on classical scientific libraries: numpy, scipy, matplotlib as well as Nibabel to handle input/outputs and NiPy which provides tools for functional data analysis[1].

Adding simulation tools to this software is an important step to assist the study of the rest of the fMRI processing pipelines and to assist experimental design by considering measures of efficiency, although this still have not been completely explored with the package. Currently it is possible to simulate different types of stimulus induced signals and noise in two dimensional maps. However to be able to exploit all the potential of the mentioned tools some development is still necessary. In particular the extension of the models to more realistic three-dimensional simulations with similar properties to those of real data.

[1] Pyhrf is a set of tools for within-subject fMRI data analysis, focused on the caracterisation of the hemodynamics.

[2] Vincent, Thomas, et al. "Flexible multivariate hemodynamics fMRI data analyses and simulations with PyHRF." *Frontiers in neuroscience* 8 (2014).