Post-doc proposal: Extracting brain PET-MRI joint structures for statistical analysis

Context:

This post-doc is part of the Physics and Engineering for Medicine initiative (PIM, in French) of the new Paris Saclay campus (PSC, http://www.campus-paris-saclay.fr/en), that builds on the outstanding research resources in physics and engineering of the Campus to make significant advances in the field of Medicine. The medium-term goal is to create a PIM Institute that would gather PSC actors highly involved in advanced medical imaging and therapy techniques. A first step towards this goal is to establish a unique cooperative research and educational environment in PSC to meet the challenges brought by the advent of integrated Positron Emission Tomography/Magnetic Resonance Imaging (PET-MRI) imaging.

Project:

Many applications of joint PET-MRI images will require statistical analysis of these images, across subjects for group studies in clinical research, and longitudinally on a single subject in clinical practice. This statistical analysis might be challenging due to the number of parameters to investigate and associated issues: the small number of available samples compared to the large size of the multi-modal images (when it is not possible to define regions of interest a priori) and the possibly low Signal-to-Noise Ratio (SNR) of the functional images (be they MR or PET images). To optimize the sensitivity under an accurate control of the specificity when performing inference, it is thus essential to account for the structure of multi-modal images: not only do the two modalities share information, but also this information is best captured by considering image patterns that match the underlying physiopathology rather than voxels. Taking into account the image structure in the statistical analysis is typically performed by means of a **dictionary learning procedure**: several components are identified based on a linear mixing model together with a prior on their statistical structure. Standard priors include sparsity, smoothness or being piecewise constant in the spatial domain. With respect to standard modeling approaches (clustering, independent component analysis), sparse dictionary learning has some key advantages: 1) it makes it possible to obtain overlapping components; 2) it performs all estimation procedures by minimizing a single criterion instead of multiple inconsistent steps; each step of the alternate optimization is a convex problem, which benefits to the stability of the solution; 3) it can be implemented using online versions, hence with reduced memory and computational costs (Mairal et al 2010); 4) it is straightforwardly extended to multiple datasets (including multiple subjects or multiple modalities) with adaptive constraints on the kind of similarity imposed on spatial and functional components. This setting has been used successfully on resting-state and activation functional MRI (Varoquaux et al 2011, Varoquaux et al. 2013).

Dictionary learning for brain images

The Parietal group has developed with many partners a public library that implements this approach (http://scikit-learn.org/, see http://nilearn.github.io for the corresponding neuroimaging toolbox), and has the ability to enhance it with fine-tuned priors and penalties to accommodate the constraints of the imaging data. The aim of the project is to adapt these approaches to extract structures jointly from PET and MRI data without imposing exact correspondence: a structure may be present in one modality and not the other. The project will draw from the expertise of the Parietal group in resting-state data analysis (Varoquaux et al 2011), as in this unguided experimental paradigm matching of functional structures across time points and subjects is no guaranteed. We have extended it recently to the joint modeling of multiple functional protocols (Varoquaux et al. 2013)

Recently, evidence has increased that a single discriminative or statistical model based on fixed segmentation of the image would not be optimal in terms of performance, and that detection sensitivity and accuracy can be improved by using a judicious combination of spatial modeling, data randomization and sparse model fitting or statistical test (Varoquaux et al 2012, Bühlmann et al 2012). The Parietal group has set up such a framework for functional MRI data analysis (Varoquaux et al 2012) , which is now used in many other settings, such as the detection of hyper/hypo-signals, the classification of images, or the detection of outliers (da Mota et al. 2013).

The candidate will develop some novel statistical and classification analysis for clinical studies that better take into account the data structure than traditional techniques. He/she will rely on state-of-the-art implementations of dictionary learning using efficient estimation (online learning) and tunable criteria (the penalties of the analysis models). In collaboration with the "Imaging & Psychiatry" research unit (U1000, CEA/SHFJ, Orsay) and in order to understand the functional impact of psychiatric disorders, the developments will be applied to a dataset that includes PET (study of the dopaminergic system with a highly selective dopamine transporter ligand) and task-based functional MRI data across different groups of subjects (depressive, schizophrenic, controls). For this purpose, joint analysis will bring strong benefits as PET gives access to quantitative brain neurotransmission parameters, while functional MRI has a good spatial resolution that will make it possible to relate the functional differences to specific brain structures. It is expected that this approach will boost the statistical sensitivity of the tests performed on PET-fMRI data.

Required skills

- [Mandatory] Expertise on medical imaging (MRI or PET)
- [Mandatory] Good knowledge of statistics
- [Mandatory] Basic knowledge of machine learning
- The candidate should be willing to work in a multi-disciplinary environment (statistics, medical imaging, research in psychiatry)

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