Gaussian process based independent analysis for temporal source separation in fMRI

Functional Magnetic Resonance Imaging (fMRI) gives us a unique insight into the processes of the brain, and opens up for analyzing the functional activation patterns of the underlying sources. Task-inferred supervised learning with restrictive assumptions in the regression set-up, restricts the exploratory nature of the analysis. Fully unsupervised independent component analysis (ICA) algorithms, on the other hand, can struggle to detect clear classifiable components on single-subject data. We attribute this shortcoming to inadequate modeling of the fMRI source signals by failing to incorporate its temporal nature. fMRI source signals, biological stimuli and non-stimuli-related artifacts are all smooth over a time-scale compatible with the sampling time (TR). We therefore propose Gaussian process ICA (GPICA), which facilitates temporal dependency by the use of Gaussian process source priors. On two fMRI data sets with different sampling frequency, we show that the GPICA-inferred temporal components and associated spatial maps allow for a more definite interpretation than standard temporal ICA methods. The temporal structures of the sources are controlled by the covariance of the Gaussian process, specified by a kernel function with an interpretable and controllable temporal length scale parameter. We propose a hierarchical model specification, considering both instantaneous and convolutive mixing, and we infer source spatial maps, temporal patterns and temporal length scale parameters by Markov Chain Monte Carlo. A companion implementation made as a plug-in for SPM can be downloaded from https://github.com/dittehald/GPICA.
Generative Temporal Modelling of Neuroimaging - Decomposition and Nonparametric Testing
The goal of this thesis is to explore two improvements for functional magnetic resonance imaging (fMRI) analysis; namely our proposed decomposition method and an extension to the non-parametric testing framework. Analysis of fMRI allows researchers to investigate the functional processes of the brain, and provides insight into neuronal coupling during mental processes or tasks.

The decomposition method is a Gaussian process-based independent components analysis (GPICA), which incorporates a temporal dependency in the sources. A hierarchical model specification is used, featuring both instantaneous and convolutive mixing, and the inferred temporal patterns. Spatial maps are seen to capture smooth and localized stimuli-related components, and often identifiable noise components. The implementation is freely available as a GUI/SPM plugin, and we recommend using GPICA as an additional tool when performing ICA on fMRI data to investigate the effect of the temporal source prior.

In fMRI, statistical tests are used to investigate the significance of activation in specific brain regions. By extending the non-parametric testing framework to incorporate functional prior knowledge, an increase in sensitivity can be achieved, entailing better evaluations and conclusions. The functional prior knowledge is incorporated by use of a proposed Graph-Based Cluster Permutation Test (GBCPT), entailing the possibility to expand the use of cluster permutations to multiple applications, wherever a graph-based setup can be used.

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