Delay analysis of fMRI time series

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Delay analysis

The high temporal resolution of fMRI allows to supplement the spatial analysis of the hemodynamic response to focal neuronal activation with a study of the temporal response in each region. Signal processing and time series analysis provide a number of tools for achieving this goal. This contribution suggests to apply a novel modelling technique to fMRI time series in order to estimate the temporal pattern of each voxel's response. With the assumption that the fMRI activation signal $y(t)$ can be modelled from the stimulus (paradigm) $x(t)$, the proposed technique efficiently extracts the past delays $\{t-d\}$ that are relevant in estimating the fMRI behaviour. This provides a unique insight into the temporal relationship between the stimulus and the actual activation. It is then possible to derive e.g. the effective delay of response in a given voxel, or identify regions with short-term or long-term delays.

Extraction of the relevant delays

The method relies on generalisation, i.e. expected error of a model on previously unseen data. Generalisation effectively measures the performance of a model and suggests a principled method for extracting the set of delays that optimises performance for time-varying processes [1]. This scheme is applied to fMRI time series as follows: 1) consider delays in chronological order; 2) estimate generalisation performance of the model including candidate delay; 3) accept delay iff it yields significant decrease in generalisation. Due to temporal structure in the data, we avoid the traditional caveat of stepwise feature selection that inputs corresponding to a combination of relevant features might be ignored.

Results

The following experiments are performed on a dataset acquired at Massachusets General Hospital, NMR center, consisting of 9 runs of a single subject, left-handed finger-to-thumb opposition task. 5 runs are used for modelling and extracting the delays, while 4 additional runs provide an independent generalisation estimate to validate our results. We use an FIR filter [2], i.e. a linear combination of past delays: $\widehat{y}(t) = \sum_{k=1}^{l} w_k\, x(t-d_k)$. The filter coefficients $\mathbf{w} = (w_1 \dots w_l)$ are estimated using least squares. The generalisation abilities of the linear model can not be calculated due to the unknown joint input-output distribution, but can be estimated using a number of methods [3], such as the *Final Prediction Error.* Finally, the significance of a decrease in generalisation error is assessed using a paired t-test [1]. The filter with extracted delays is compared to a reference filter using seven consecutive delays [2]. In most voxels, the extracted filter uses less parameters, but yields better modelling performance. In one case, the performance decreases of a non-significant amount, using only one filter coefficient, i.e. basically reproducing the activation signal. The figure compares both model's abilities for one voxel. The filter with extracted delays picks up a more complicated activation pattern, suggesting a long-term influence that is overlooked by the reference filter.

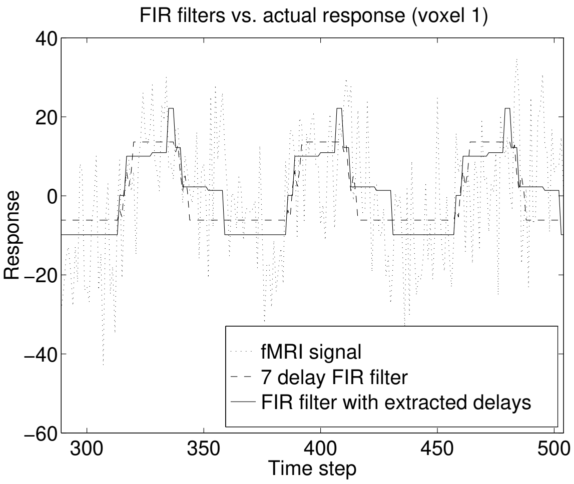

Figure 1: FIR modelling comparison

Conclusion

The proposed scheme refines the characterisation of the local fMRI response to a given stimulus in different activated regions. It provides insight into the temporal pattern of activation so as to e.g. differentiate between short term and long term response. Furthermore, it improves the FIR modelling of fMRI time series, and is straightforwardly applicable to non-linear models such as Neural Networks.

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References

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