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611

Delay analysis of fMRI time series

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Abstract

- Estimate the temporal pattern of each voxel's response.
- Assumption: fMRI signal can be modelled from stimulus.
- Extract the past delay that are *relevant* for modelling.
- Identify regions with short-term or long term delays.

fMRI time series

The stimulus (or paradigm) is $p(t)$. (usually a square wave)

The fMRI response is $y(t)$. (time series recorded in each voxel)

We want to finde the "best" way of modelling $y(t)$ from $p(t)$.

fMRI modelling

The fMRI time series is modelled from past values of the stimulus:

$$\widehat{y}(t) = f\left(p(t-1), \ldots, p(t-T)\right)$$

$t-1, \ldots t-T$ are the delays, not necessarily consecutive.

Importance of the right input choice:

Not enough input
 $\Rightarrow$ can't capture the underlying mapping.

Too many inputs
 $\Rightarrow$ over-parameterised model
  $\Rightarrow$ bad performance.

We want to select $t-d_1, \ldots t-d_l$ so that $\widehat{y}(t)$ is as accurate as possible.

Extraction of relevant delay
 $\subset$ variable selection
  $\subset$ analysing the structure of the data.

Input selection

Optimal strategy: exhaustive search.
$\Rightarrow$ not computationally feasible.
Especially when long-term delays are involved!

Stepwise methods: suboptimal techniques–incrementally add or delete inputs.

- *Forward selection* starts from an empty input space, adds one at a time.
- *Backward elimination* starts with a full input space, deletes one at a time.

Stepwise regression: combination of forward selection and backward elimination.
We need a choice criterion, a **selection criterion** and a stop condition.
Eg: r^2, F-test, mutual information, ...

Generalisation error

Error on previously unseen data:

$$G(f) = \int \left(f(\mathbf{p}(t)) - y(t)\right)^2 p(y, \mathbf{p})\, \mathrm{d}y \mathrm{d}\mathbf{p}$$

$\mathbf{p}$ is a vector of past values of $p(t)$.

Average error on "new" data, not used for estimating f.

Extraction of Relevant Delays

Extract delays on the basis of generalisation. (Goutte 97)

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1. Initialise: $d = 0$; $G_{min} = \sigma_x^2$; no input selected.
2. Model: $d = d + 1$; add delay $t - d$ to selected inputs; estimate generalisation error $\widehat{G}$ for resulting model.
3. Test: if $\widehat{G}$ is significantly smaller than G_{min}, keep delay $t-d$; $G_{min} = \widehat{G}$. Discard otherwise.
4. Iterate: Go to step 2 until stop condition is reached.

Generalisation estimation:

$\triangleright$ Split-sample
$\blacktriangleright$ Cross-validation
$\triangleleft$ Algebraic estimators

Significance: paired t-test on

- residuals ($\triangleright$, $\blacktriangleright$)
- ∘ corrected residuals ($\triangleleft$)

Experiments

subjects : single subject,

task : left-handed finger-to-thumb opposition,

modality : whole brain echo-planar fMRI images,

paradigm : 9 runs of 48 images,

run : 12 rest, 24 activation, 12 rest,

sampling time : 2.5 seconds,

volume : 64 × 64 × 2,

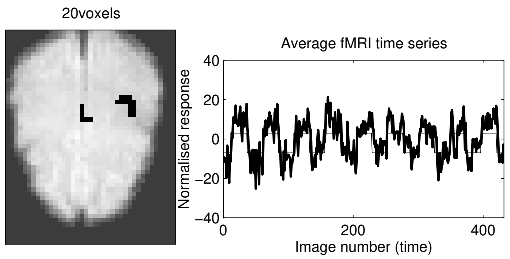
ROI : 39 × 49 voxels in one slice,

location : axial slice through primary motor cortex and SMA,

voxel size : 3.1 × 3.1 × 8 mm

Preprocessing

20 voxels are selected by thresholding the cross-correlation function.



Brain map and average activity of the selected voxels.

Delay extraction

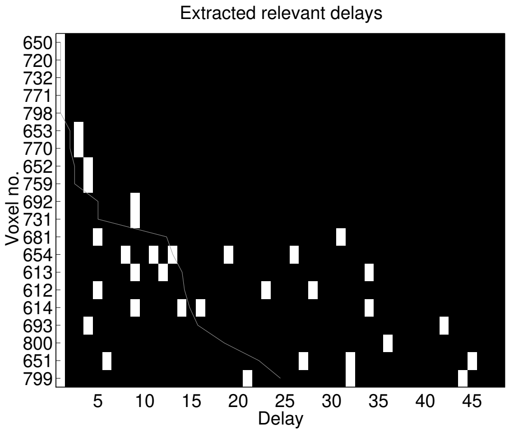
Relevant delays are extracted on the 20 selected voxels.

Voxel-based extraction.

Maximum delay: 48 time steps (one run).

Paired t-test threshold: 0.2.
(cf. Bendel&Afifi 77)

5 runs are used to extract the delays,
4 runs to evaluate generalisation.



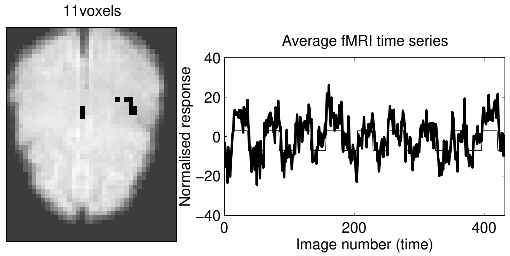
Average delay in gray.

ERD: 1 to 6 relevant delays for FIR filtering (depending on the voxel).

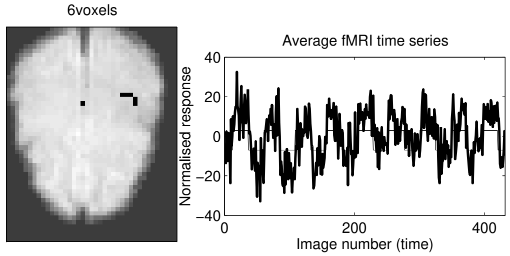
Delay analysis

Delays are between 1 and 45

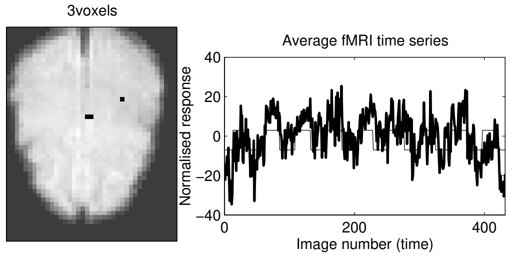
Voxels with a short average delay
(≤ 5 images)



Voxels with medium average delay
(between 12 and 16 images)

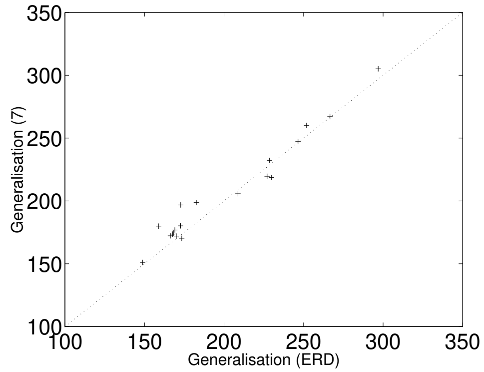


Voxels with a long average delay
(≥ 18 images)



Generalisation

Generalisation is compared to the 7 consecutive delay FIR filter (Nielsen 97).



Extracted delays: fewer but generalise better

Conclusion

Refines fMRI modelling,

Insight into temporal patterns,

Differentiate short-term and long-term,

Straightforward application to non-linear models.

References

Bendel & Afifi, JASA 72:357, 1977, 46-53.

Goutte, Neural Networks for Signal Processing VII, 1997, 92-101.

Nielsen et al., *NeuroImage*, 5:4, 1997, S473.