Extracting fMRI features

PRoNTo course

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Overview

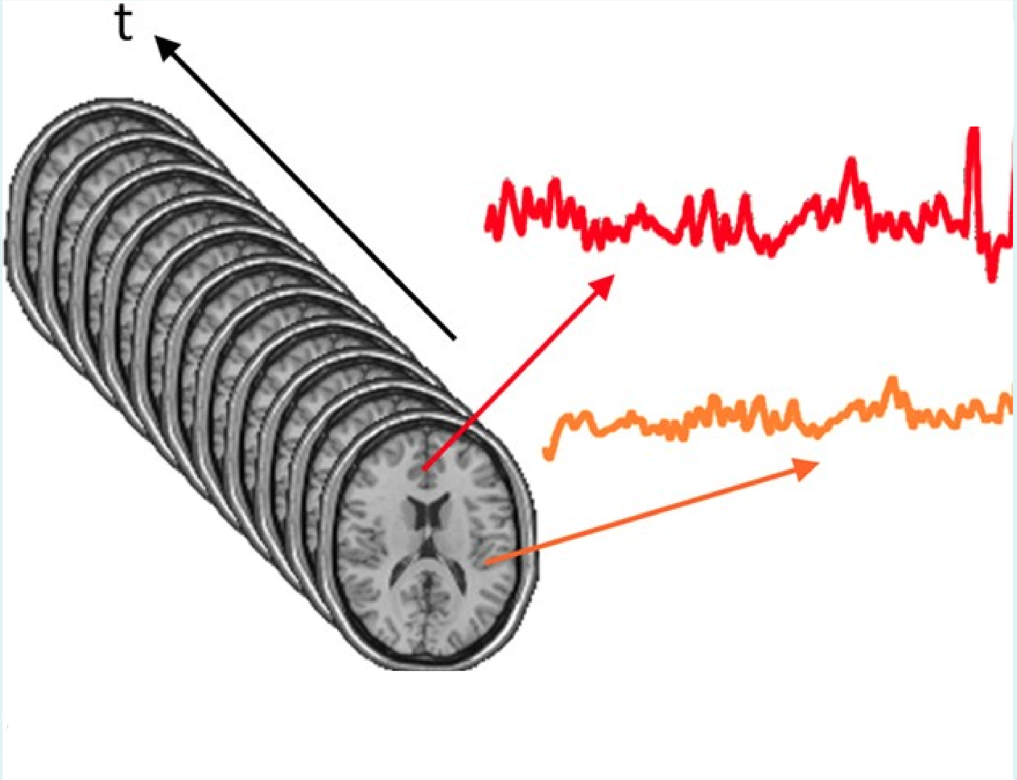
- Introduction
- “Brain decoding” problem
- “Subject prediction” problem
- Conclusion

Overview

- Introduction
  - fMRI data & processing
  - GLM & BOLD response
  - classical univariate approach
  - levels of inference
- “Brain decoding” problem
- “Subject prediction” problem
- Conclusion

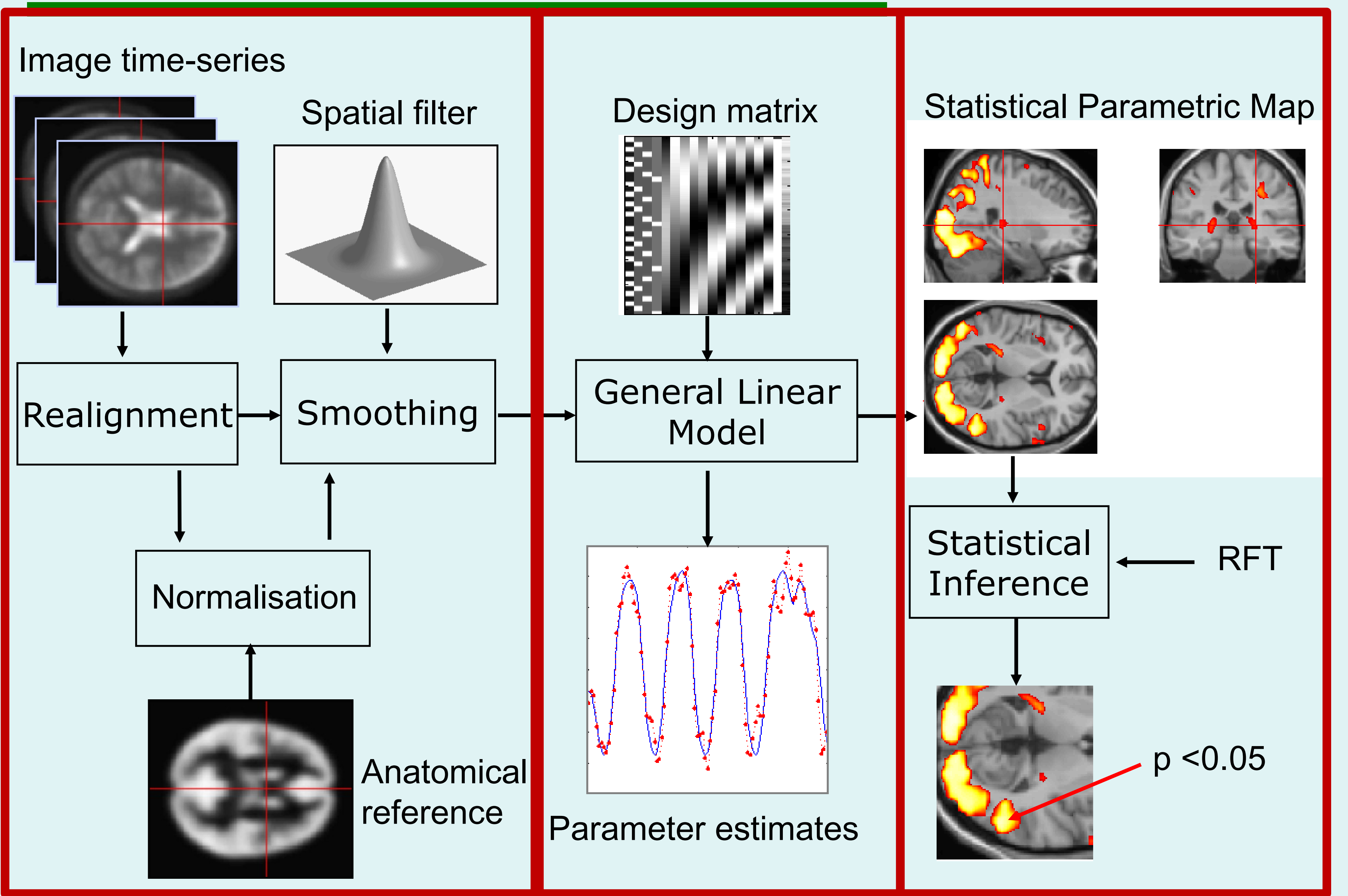
Data

fMRI time series = 4D image
= time series of 3D fMRI's
= 3D array of time series.

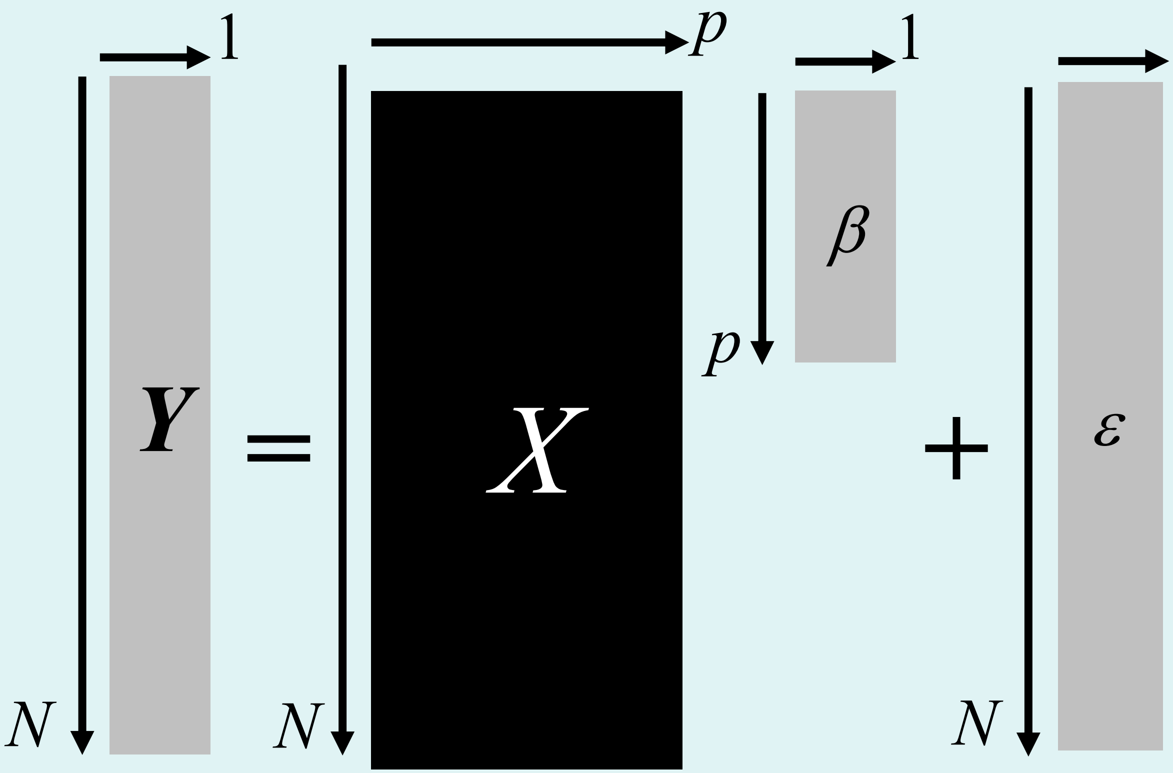


About the same for a series of structural MRI's…

Spatial pre-processing & SPM



GLM *univariate* approach



$$Y = X\beta + \varepsilon$$

$\boldsymbol{N}$: # images
$\boldsymbol{p}$: # regressors

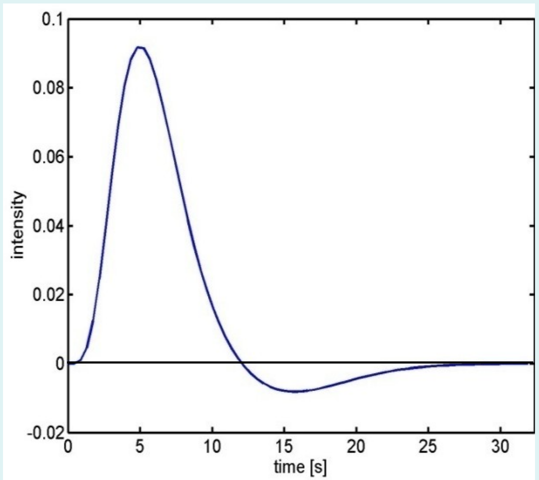
GLM defined by:

- design matrix X
- error term ε distribution, e.g.

$$\varepsilon \sim N(0, \sigma V)$$

BOLD response

Hemodynamic response function (HRF):



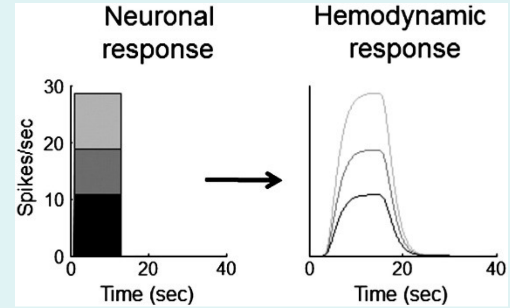
Linear time-invariant (LTI) system:

$u(t) \rightarrow$ $hrf(t)$ $\rightarrow x(t)$

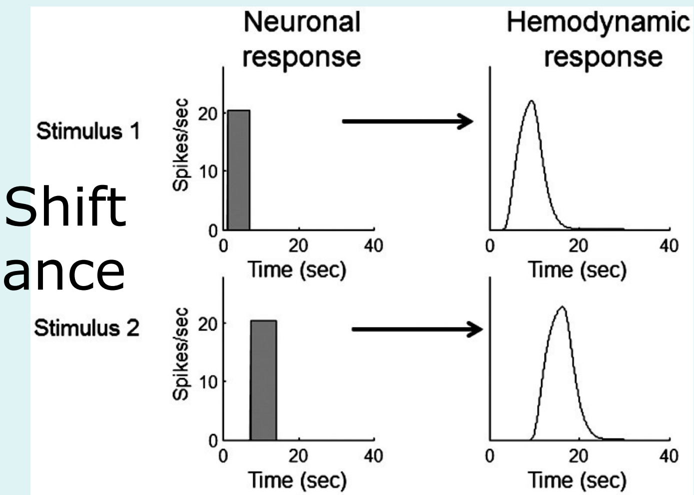
Convolution operator:

$$x(t) = u(t) * hrf(t) = \int_{o}^{t} u(\tau) hrf(t-\tau) d\tau$$

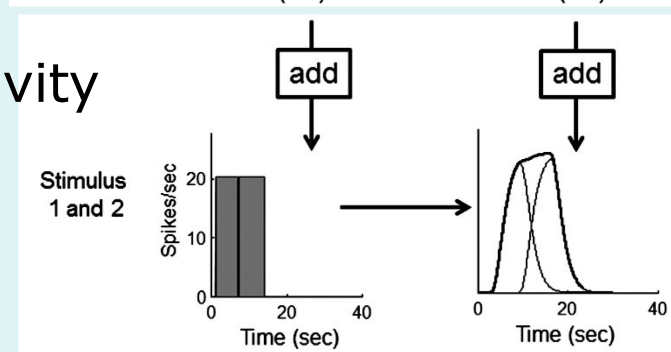
Scaling



Shift invariance



Additivity

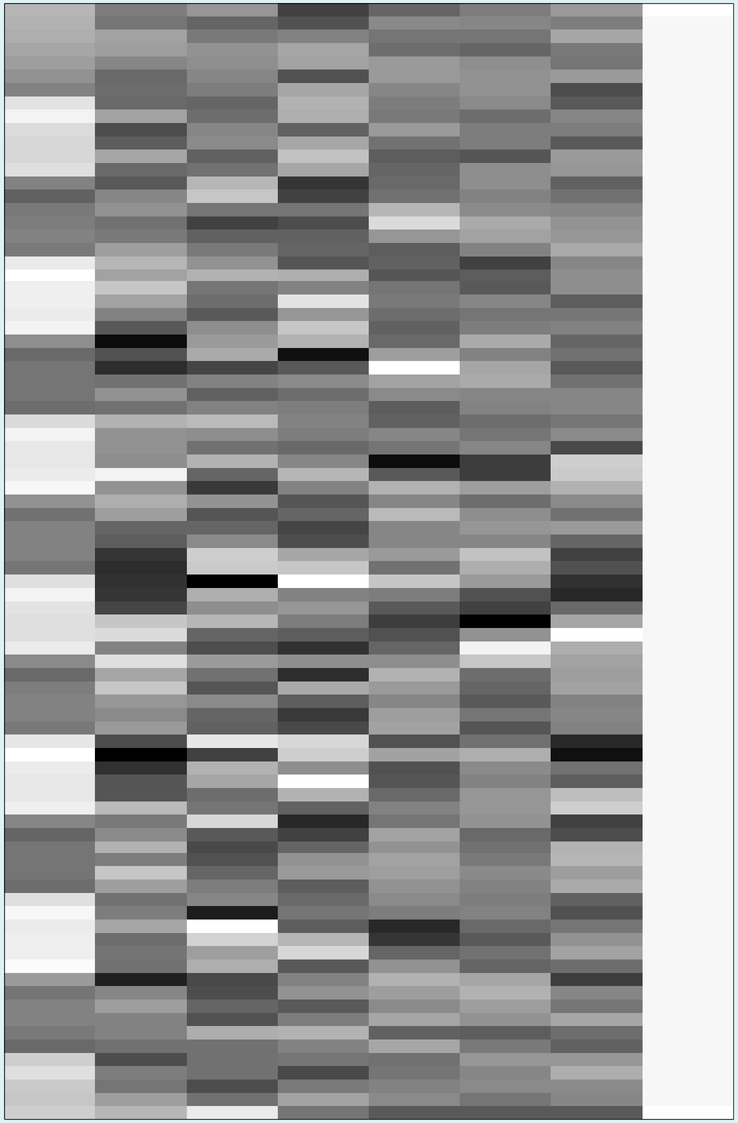


Boynton et al, NeuroImage, 2012.

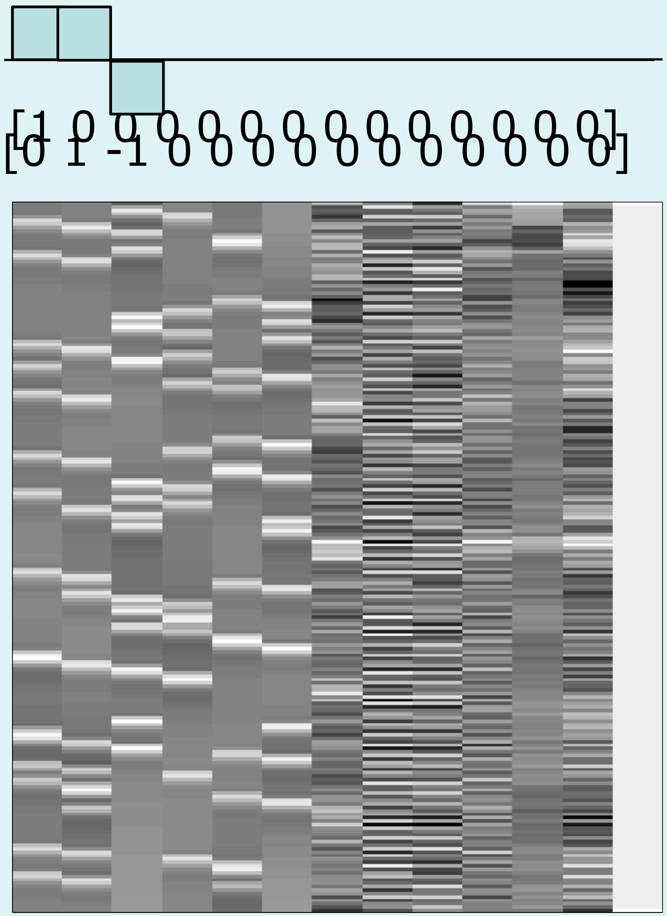
Confounds modelling

Model

- condition(s) of interest, i.e. “activation”
- “confounds”:
  - BOLD response
  - estimated movement parameters



Contrast & inference



A contrast selects a **specific effect of interest**.

- ⇨ A contrast c is a vector of length p.
- ⇨ $c^T\beta$ is a linear combination of regression coefficients β.

$$c = [1\ 0\ 0\ 0\ \ldots]^T$$

$$c^T\beta = \mathbf{1} \times \beta_1 + \mathbf{0} \times \beta_2 + \mathbf{0} \times \beta_3 + \mathbf{0} \times \beta_4 + \cdots$$

$$= \boldsymbol{\beta_1}$$

$$c = [0\ 1\ -1\ 0\ \ldots]^T$$

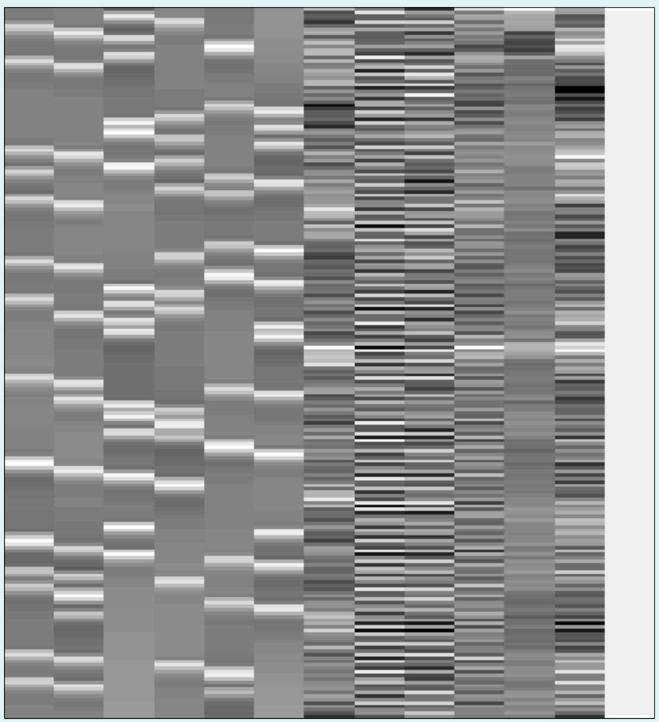
$$c^T\beta = \mathbf{0} \times \beta_1 + \mathbf{1} \times \beta_2 + \mathbf{-1} \times \beta_3 + \mathbf{0} \times \beta_4 + \cdots$$

$$= \boldsymbol{\beta_2 - \beta_3}$$

$$c^T\hat{\beta} \sim N(c^T\beta, \sigma^2 c^T (X^T X)^{-1} c)$$

Contrast & inference

[0 1 -1 0 0 0 0 0 0 0 0 0 0 0]



Question: β_2 larger than β_3 ?

=

$\beta_2 - \beta_3 = c^T\beta > 0$?

Null hypothesis: H_0: $c^T\beta=0$

Test statistic: $T = \dfrac{\textbf{\textit{contrast} of estimated parameters}}{\sqrt{\textbf{variance estimate}}}$

$$T = \frac{c^T\hat{\beta}}{\sqrt{\mathrm{var}(c^T\hat{\beta})}} = \frac{c^T\hat{\beta}}{\sqrt{\hat{\sigma}^2 c^T\left(X^T X\right)^{-1} c}} \sim t_{N-p}$$

Classical inference

The Null Hypothesis H_0

= what we want to disprove (no effect).

⇨ The Alternative Hypothesis H_A

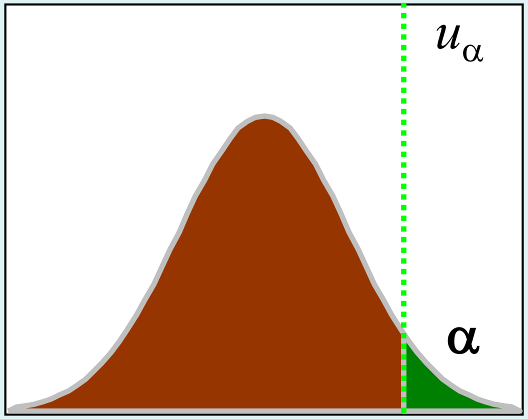
= outcome of interest.

Significance level α:

Acceptable *false positive rate α*.

⇨ threshold u_α

$$\alpha = p(T > u_\alpha \mid H_0)$$



Null Distribution of T

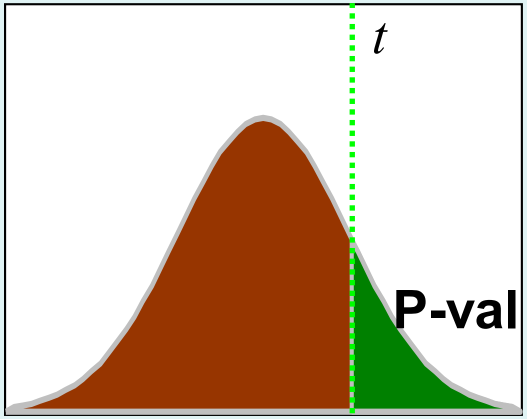
Observation of test statistic t

= a realisation of T

⇨ Reject H_0 in favour of H_A if $t > u_\alpha$

p-value = evidence against H_0

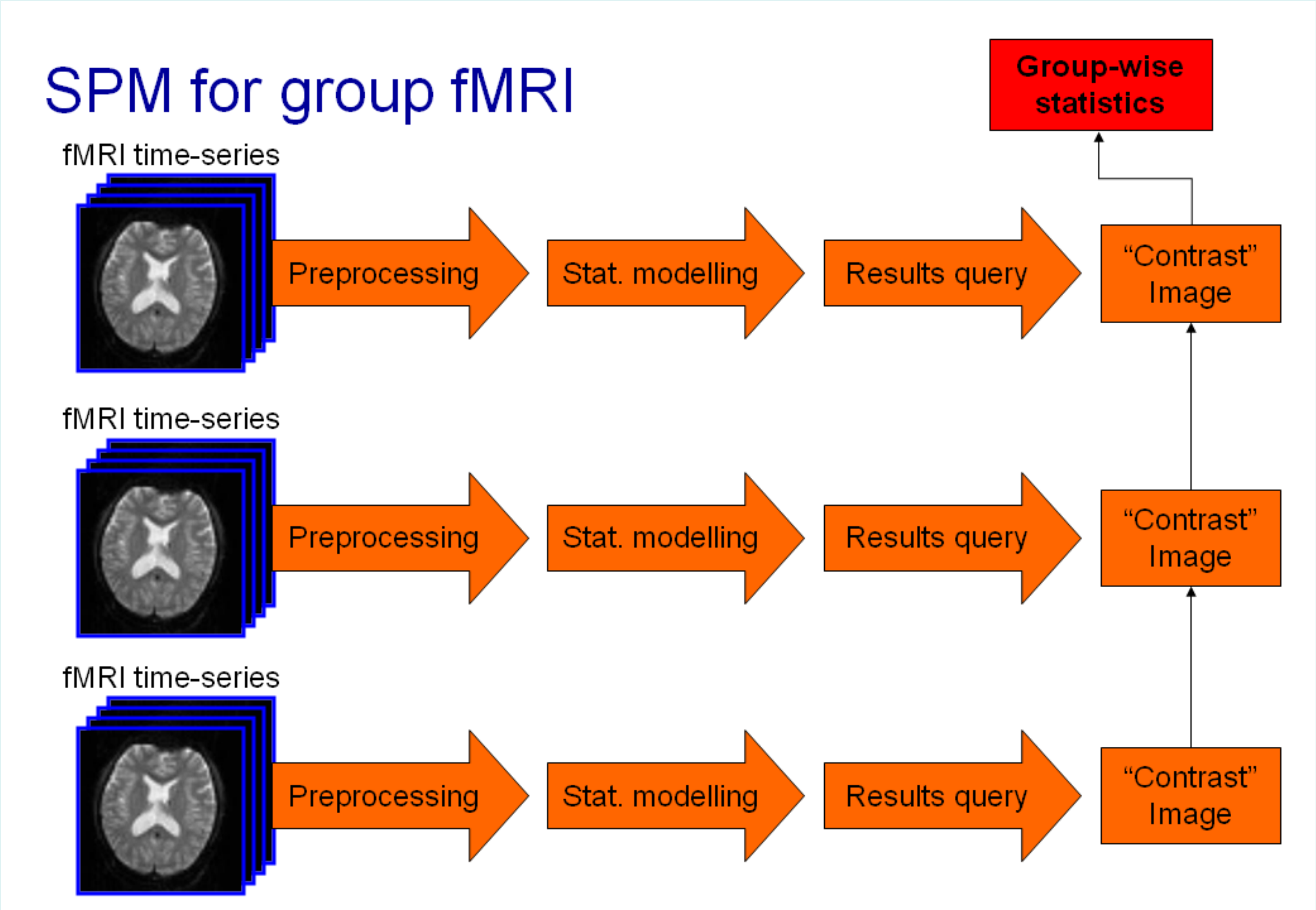
$$p(T > t \mid H_0)$$

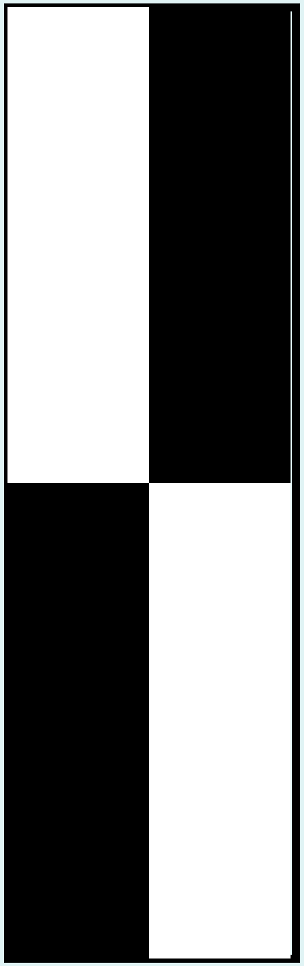


Null Distribution of T

Group-level analysis

Group A vs. Group B design



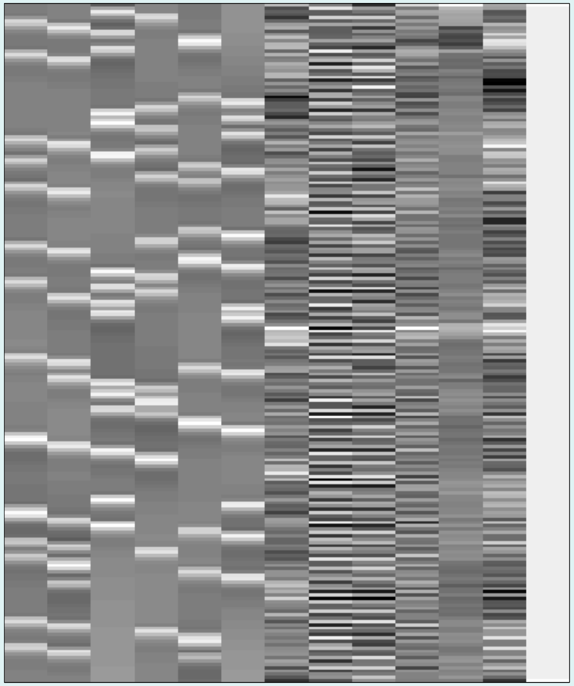


"Summary statistics" approach.

Overview

- Introduction
- “Brain decoding” problem
  - BOLD signal & HRF
  - Raw signal
  - Beta images
- “Subject prediction” problem
- Conclusion

Brain decoding



Data:

fMRI time series from 1 (or a few) subject(s)

Goal:

Find temporary mental state, from fixed set, of a subject based on pattern of brain activity.

➔ decode BOLD signal over 1 or few images

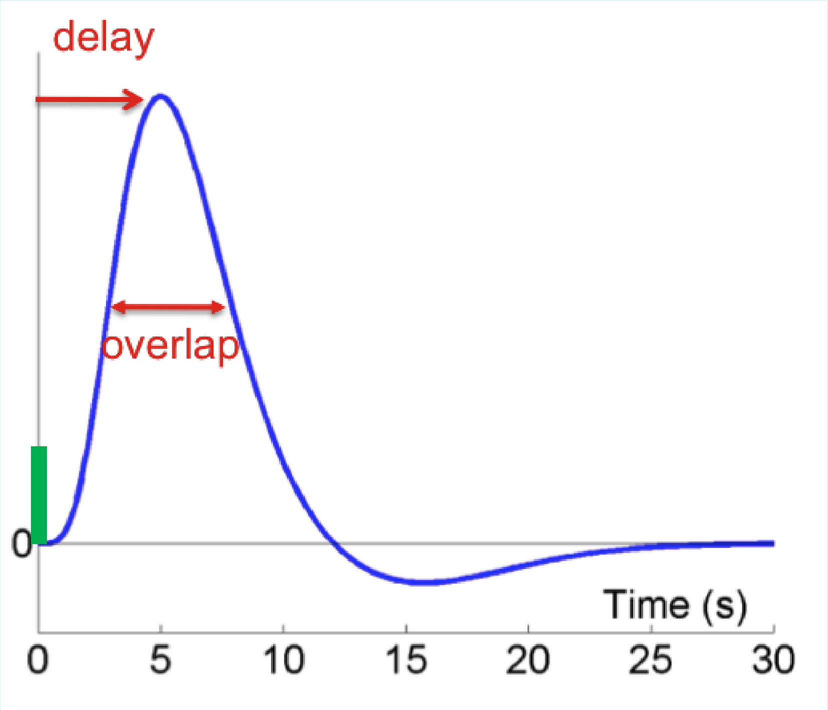
Similar to FFX analysis

Brain decoding: signal

Use the raw BOLD signal but

- Block or event-related design?
- How to account for haemodynamic function?

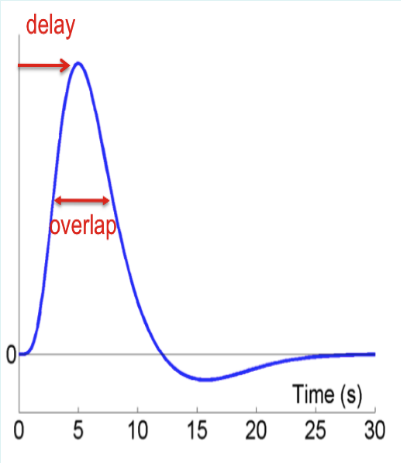
Standard impulse response function ➔

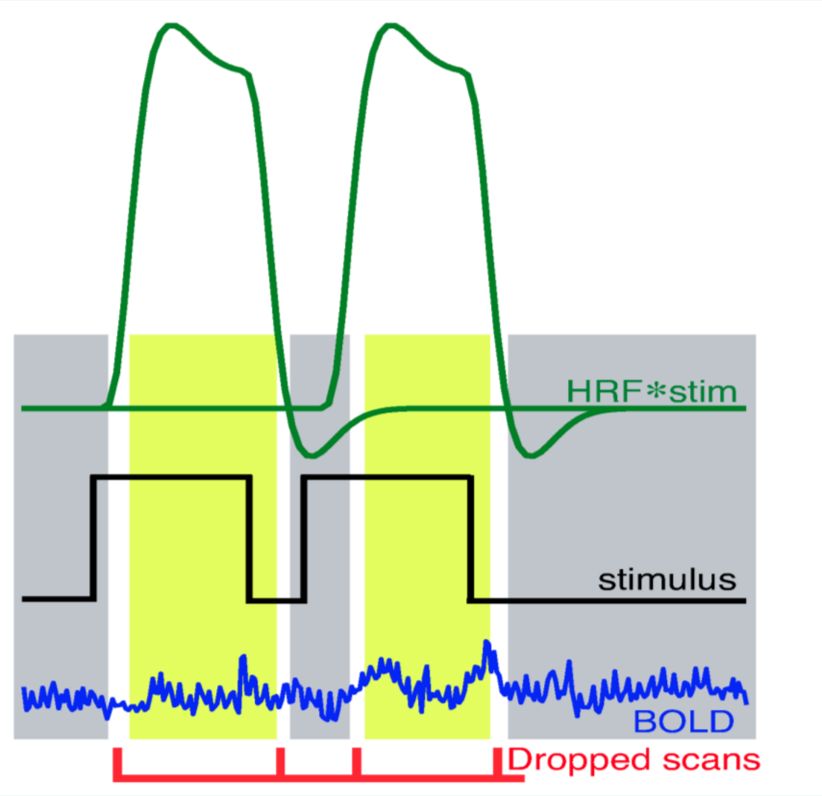


Brain decoding: raw BOLD

Design:

- Block or event-related design
- Accounting for haemodynamic function, with HRF ‘delay’ & ‘overlap’

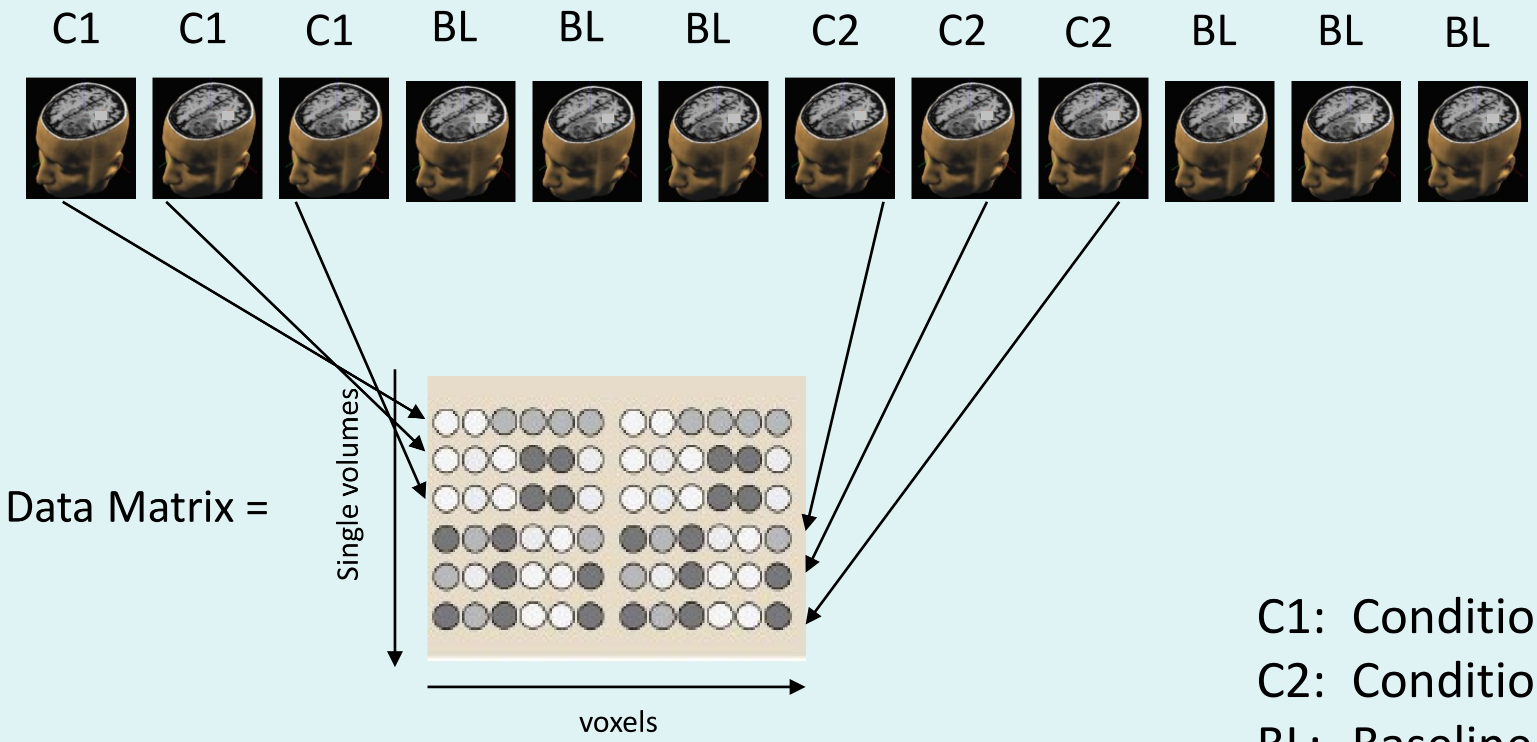




Brain decoding: raw BOLD

Design:

- Block design
- Use single scans

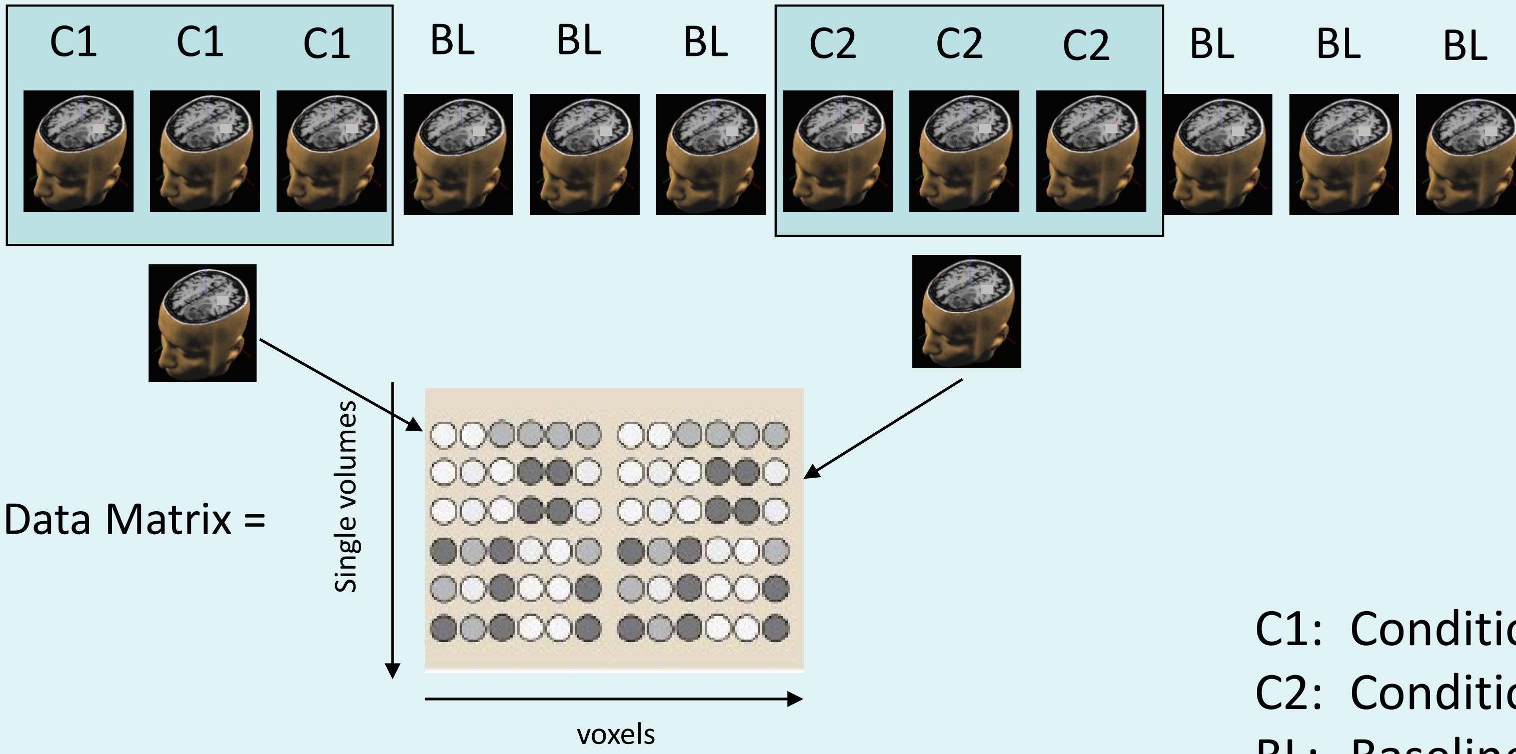


C1: Condition 1
C2: Condition 2
BL: Baseline

Brain decoding: raw BOLD

Design:

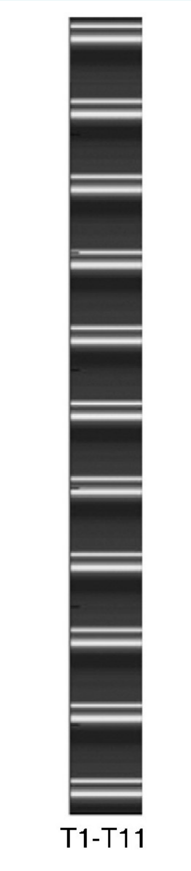
- Block design → **Average scans** over blocks/events
- Use single scans



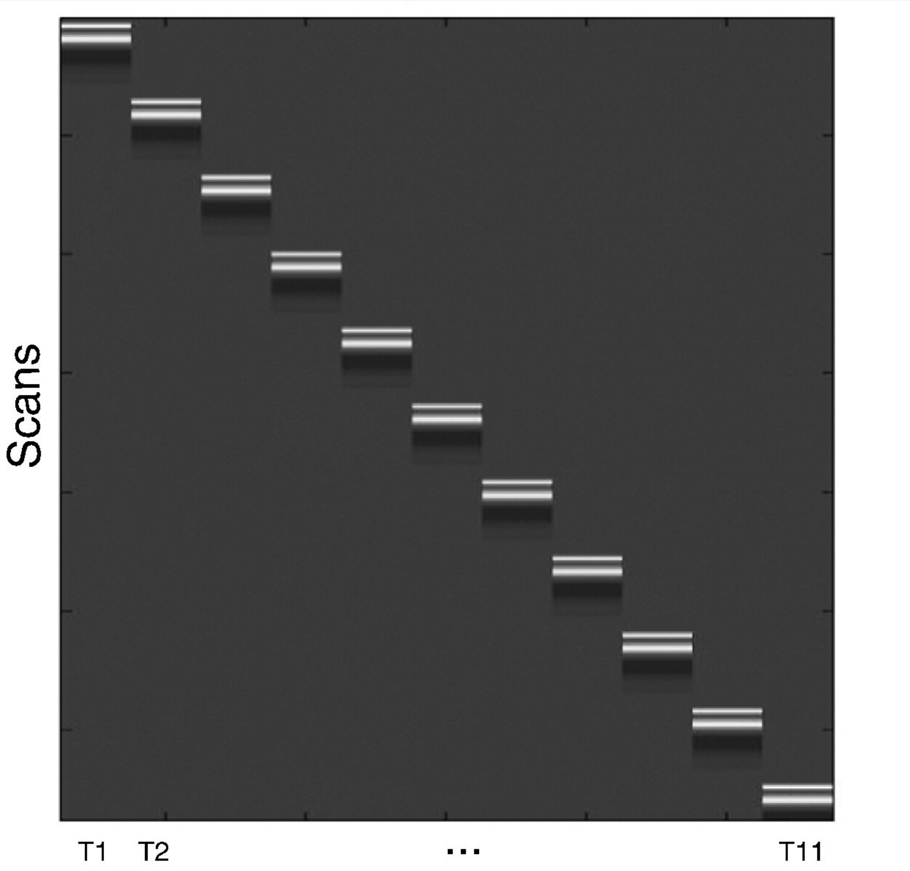
C1: Condition 1
C2: Condition 2
BL: Baseline

Brain decoding: beta image

1 GLM and 1 beta per event/block



LSA



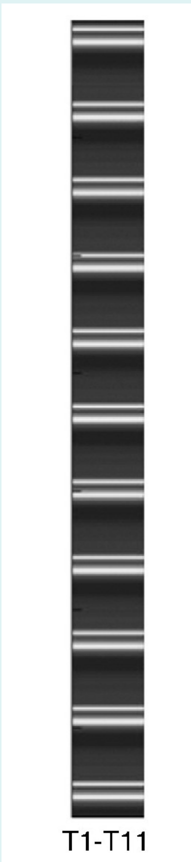
LSU

“Least Squares All” (LSA) and
“Least Squares Unitary” (LSU)

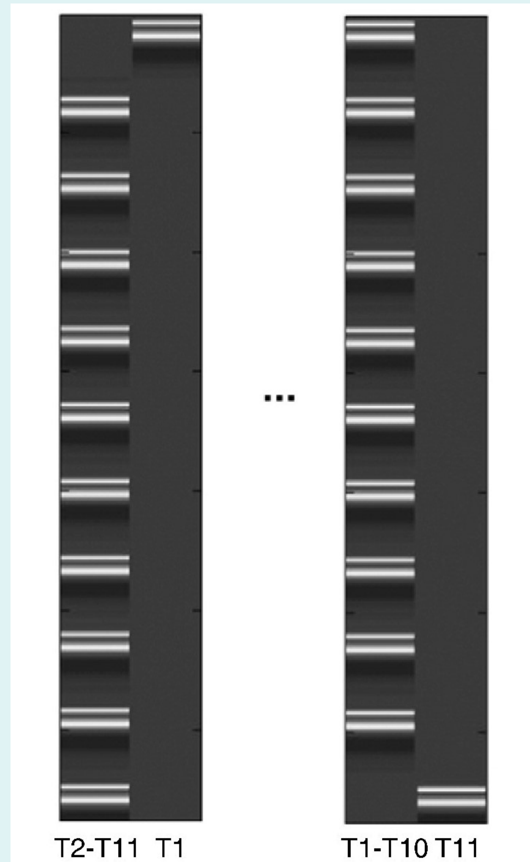
Abdulrahman & Henson, Neuroimage, 2016

Brain decoding: beta image

N GLM's and 1 beta per event/block



LSA



LSS

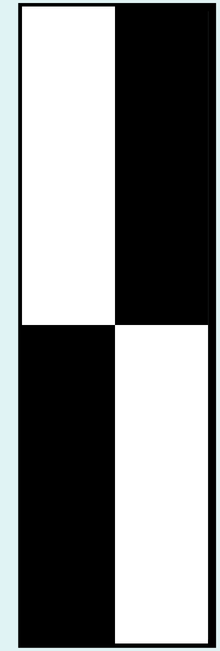
"Least Squares All" (LSA) and
"Least Squares Separate" (LSS)

Abdulrahman & Henson, Neuroimage, 2016

Overview

- Introduction
- "Brain decoding" problem
- "Subject prediction" problem
  - Definition & summary approach
  - Event/block design
  - Resting state design
- Conclusion

Subject prediction



Data:

N subjects 1 (or a few) images
per subject(s)

Goal:

Find target value (class or score) of a subject based on pattern from many subjects.

➔ decode “summary” image(s) per subjesct

Similar to RFX analysis

Subject prediction: summary image

fMRI time series

➔ summary image

Event/block design

➔ build contract image(s)

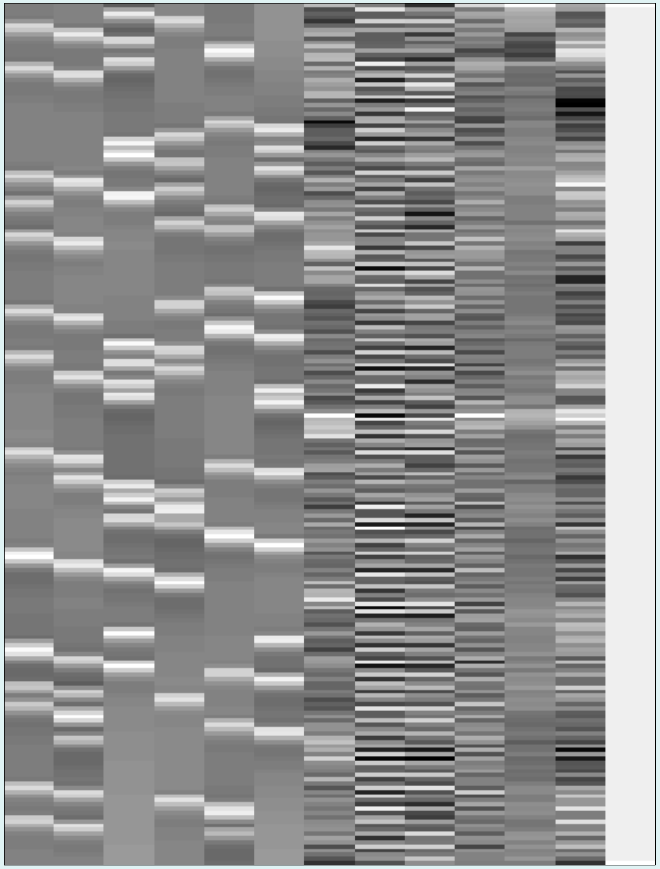
e.g.

- main/average effect,
  [1 0 0…] or [0 1 1 0…]/2
- difference between 2 conditions
  [1 0 -1 0…]
- …

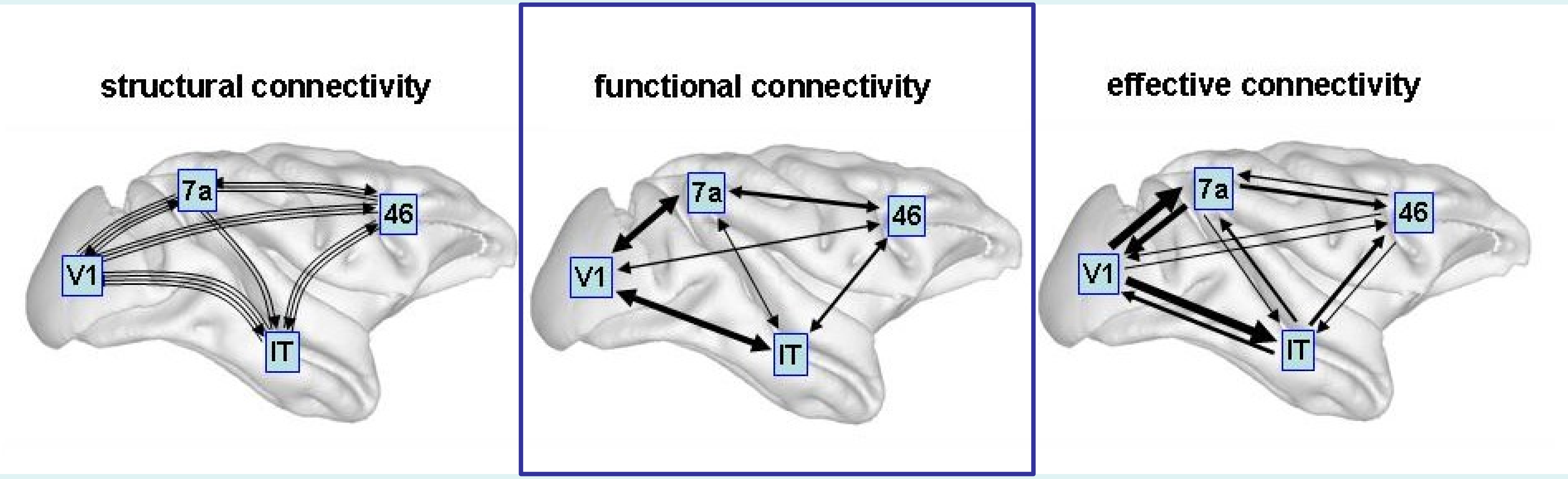
[1 0 -1 0…]

[1 0 0…]

[0 1 1 0…]/2



Brain connectivity



Functional connectivity = statistical concept

Statistical dependence estimated by measuring *correlation* or *covariance*

http://www.scholarpedia.org/article/Brain_connectivity

Resting state fMRI

Resting state functional MRI [...] is a [...] method for evaluating regional interactions that occur when a subject is not performing an explicit task.

Paradigm shift:

- Activation ➔ functional segregation
- Spontaneous ➔ functional integration

Goal:

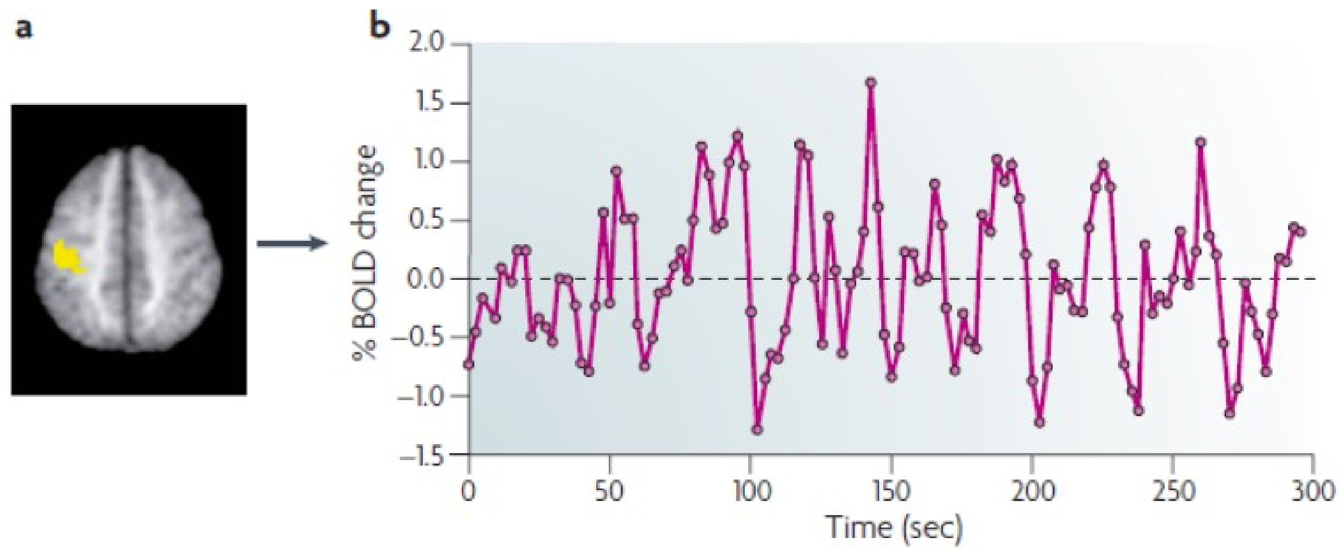
Summarize rs-fMRI time series into 1 (few) map(s).

https://www.humanconnectome.org/study/hcp-young-adult/project-protocol/resting-state-fmri

Rs-fMRI: model based approach

Pick one (few) region(s) of interest:

- Extract BOLD signal time-series



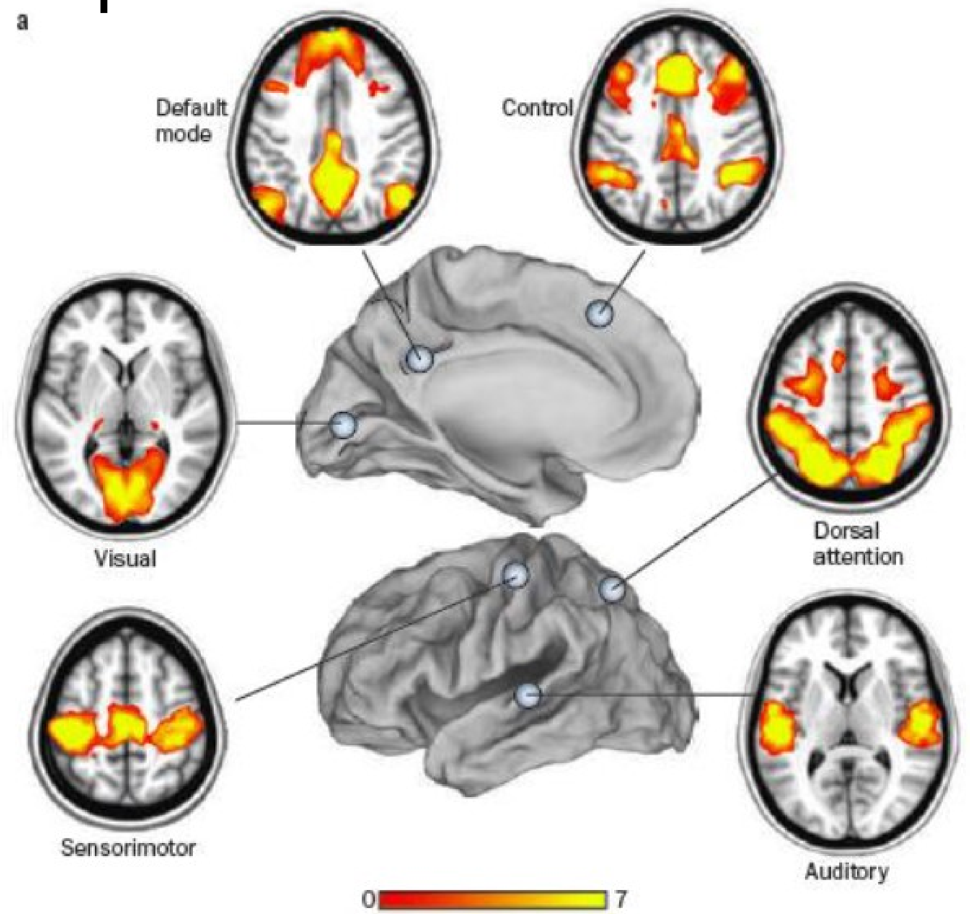
Fox & Raichle, 2007, *Nature Reviews, Neuroscience*

- Enter time series as regressor in a GLM & find correlation map

Rs-fMRI: model based approach

Multiple/different region of interest

➔ multiple/different maps



Zhang & Raichle, 2010, *Nature Reviews, Neurology*

Rs-fMRI: model free approach

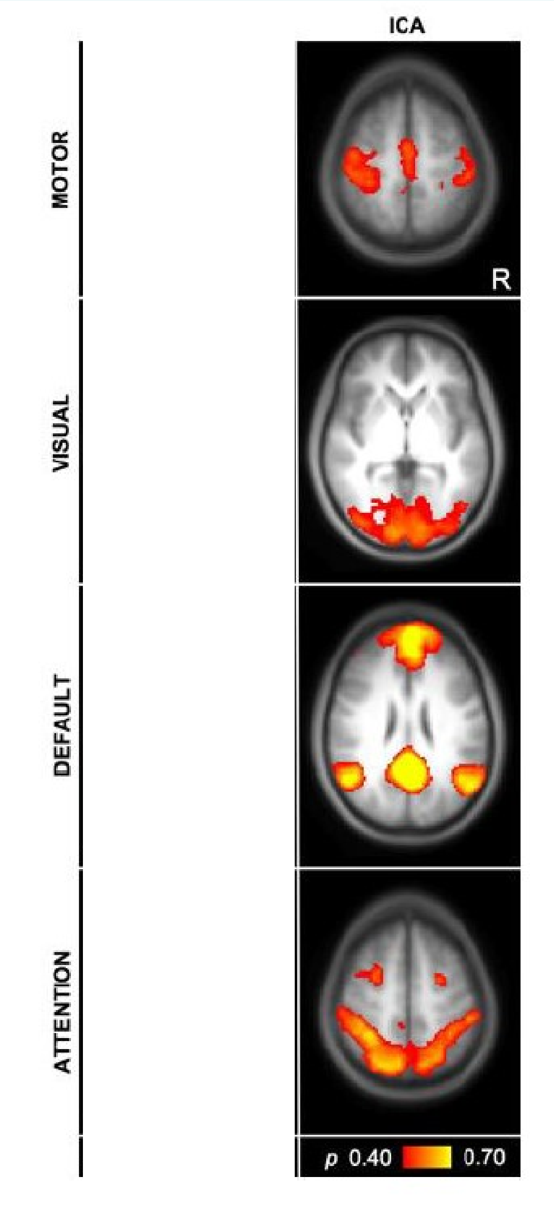
Decompose original fMRI time series into linear combination of

- basis vectors, PCA
- independent components, ICA

i.e. data driven approach.

➔ A few basis/component maps per subject

Rs-fMRI: model free approach



Van Dijk, 2010, *J Neurophysiol*

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Conclusion

1 sample = 1 image

- What is your question of interest?
- At what level of inference ?
- What is the experimental design?
- How much data is/will be available?

Thank you for your attention!

Any question?

“Univariate vs. multivariate” concepts

Univariate	Multivariate
•1 voxel	•1 volume
•target → data	•data → target
•look for difference or correlation	•look for similarity or score
•General Linear Model	•Specific machine (SVM, GP,...)
•GLM inversion	•training & testing cross-validation
•calculate contrast of interest	•estimate accuracy of prediction

Brain connectivity concepts