LIÈGE université
GIGA
CRC In vivo Imaging

LIÈGE université
GIGA
In silico Medicine

Statistical Parametric Mapping

There and Back Again.

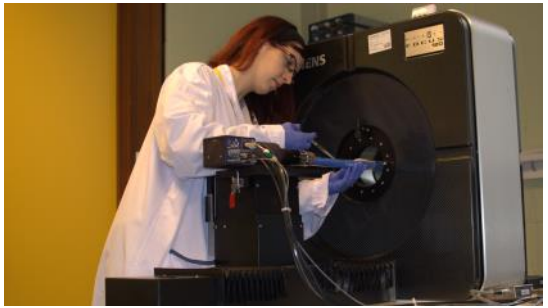
ORTHANC CON 2019

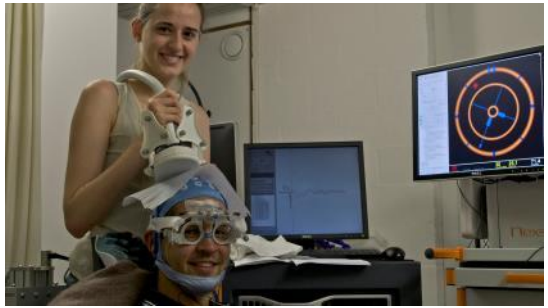
fnrs
LA LIBERTÉ DE CHERCHER

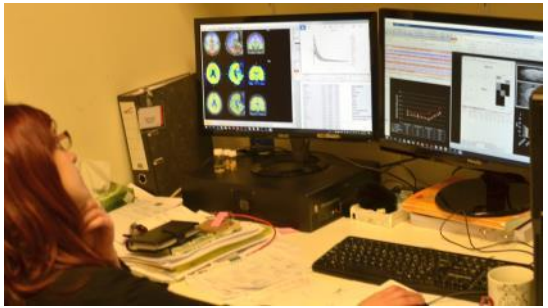
Christophe Phillips
c.phillips@uliege.be

GIGA Cyclotron Research Centre *in vivo* imaging

Human and animal imaging: MRI and PET + electrophysiology





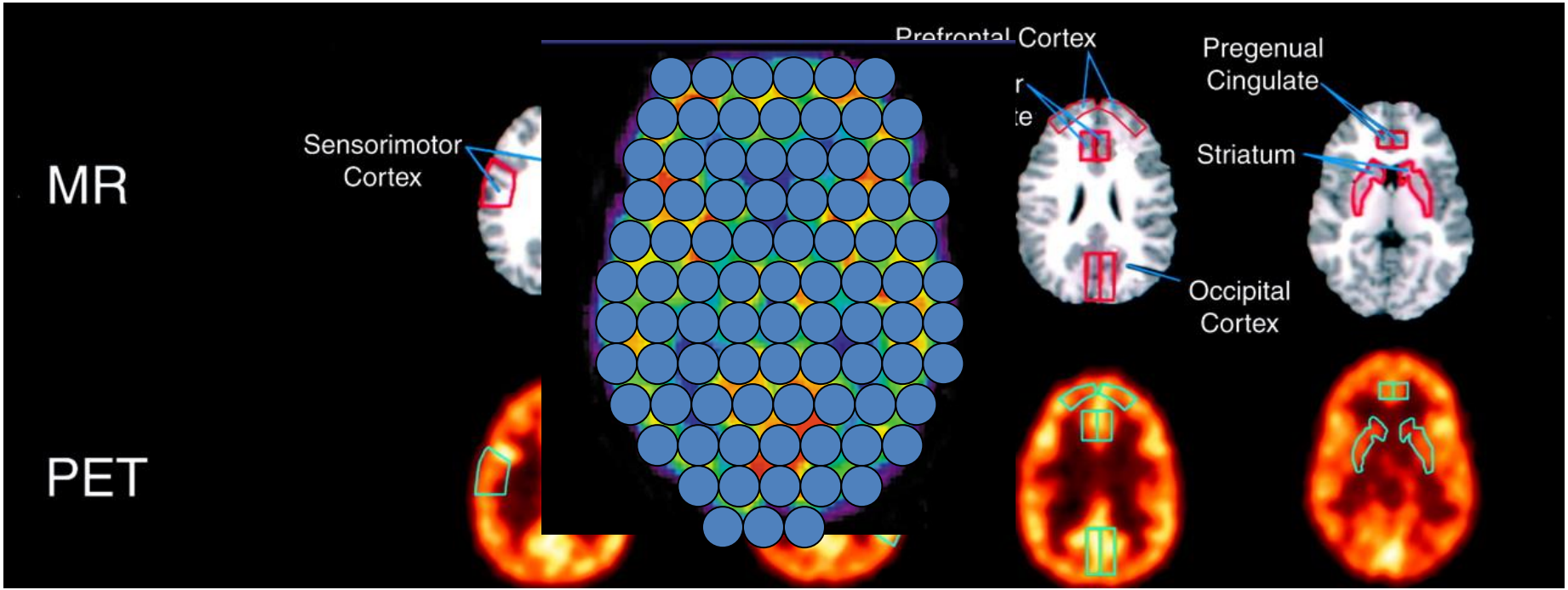


https://www.gigacrc.uliege.be/cms/c_4212477/en/portail-gigacrc
https://www.gigacyclotron.uliege.be/cms/c_4221332/en/portail-gigacyclotron

Statistical Parametric Mapping

- Historical background
- SPM concepts
- Further developments
- Software framework
- Now and then?

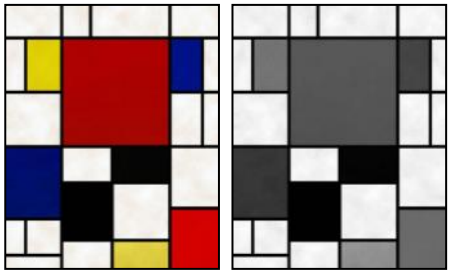
From PET analysis using ROIs…



…to the very first SPM{t}

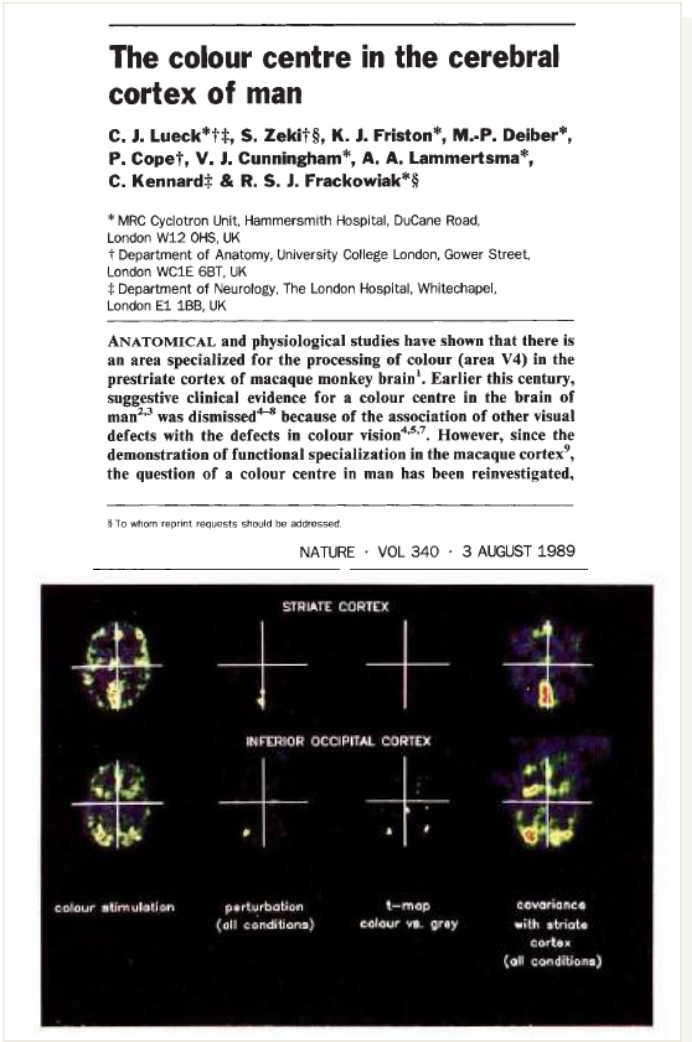
- An area specialised for the processing of colour, the “colour centre” (V4) highlighted by cognitive substraction using PET.
- Three subjects:

Colour trials (2 scans)



Grey trials (2 scans)

- Compatible with earlier findings on monkeys using electrophysiology.



The colour centre in the cerebral cortex of man

C. J. Lueck*†‡, S. Zeki†§, K. J. Friston*, M.-P. Deiber*, P. Cope†, V. J. Cunningham*, A. A. Lammertsma*, C. Kennard‡ & R. S. J. Frackowiak*§

* MRC Cyclotron Unit, Hammersmith Hospital, DuCane Road, London W12 0HS, UK
† Department of Anatomy, University College London, Gower Street, London WC1E 6BT, UK
‡ Department of Neurology, The London Hospital, Whitechapel, London E1 1BB, UK

ANATOMICAL and physiological studies have shown that there is an area specialized for the processing of colour (area V4) in the prestriate cortex of macaque monkey brain[1]. Earlier this century, suggestive clinical evidence for a colour centre in the brain of man[2,3] was dismissed[4–8] because of the association of other visual defects with the defects in colour vision[4,5,7]. However, since the demonstration of functional specialization in the macaque cortex[9], the question of a colour centre in man has been reinvestigated,

§ To whom reprint requests should be addressed.

NATURE · VOL 340 · 3 AUGUST 1989

SPM inception by Karl Friston

Back in 1991, emerging functional imaging community

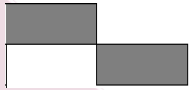
→ *SPMclassic*

- providing valid inferences about signals across the entire brain
- open source and freely available to
  - promote collaboration and a common analysis scheme across laboratories,
  - allow the methods to be closely scrutinised by others

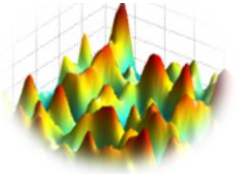
Main concept

$$y = \beta + \varepsilon$$

Contrast *c*



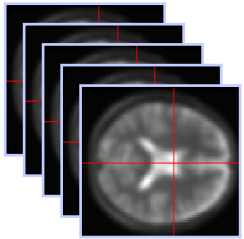
Random Field Theory

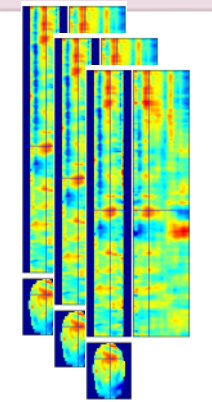


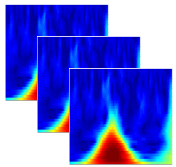
Pre-processings

General Linear Model

Statistical Inference

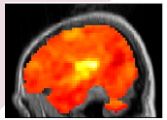


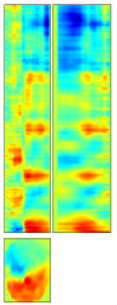


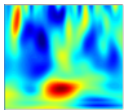


$$\hat{\beta} = (X^T X)^{-1} X^T y$$

$$\hat{\sigma}^2 = \frac{\hat{\varepsilon}^T \hat{\varepsilon}}{rank(X)}$$







$$SPM\{T, F\}$$

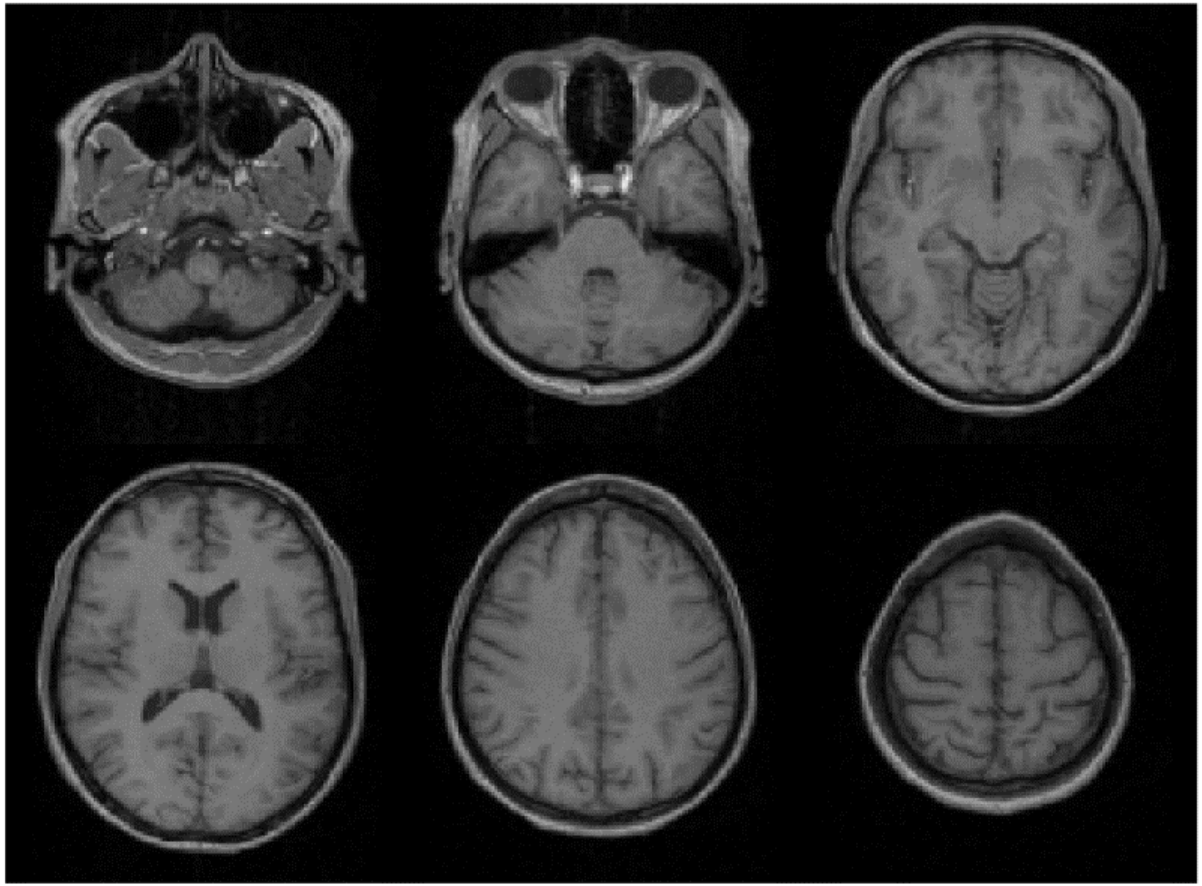
Spatial (pre-)processing

- Imaging modalities:
  PET, then functional and structural MRI
  → realignment, coregistration, segmentation, normalization, smoothing

Sp

Im

→

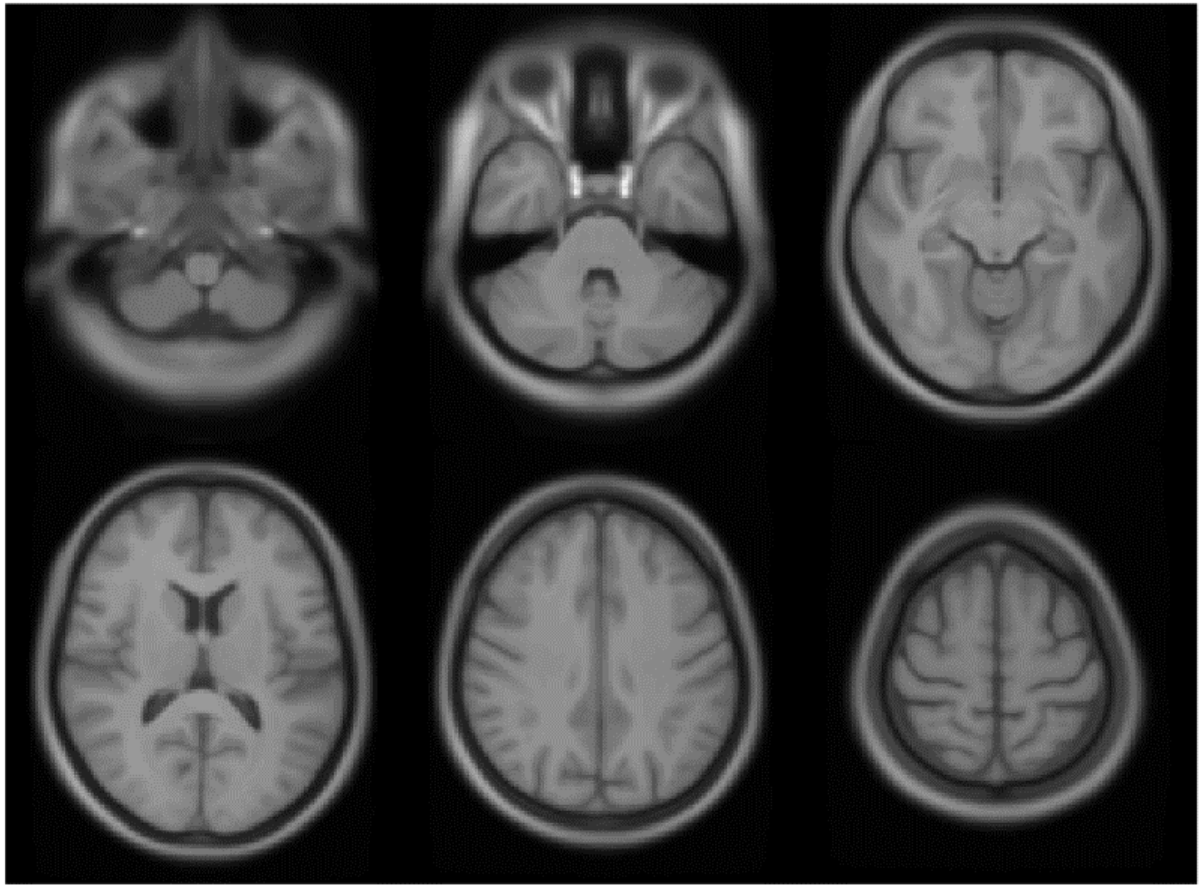


Single Subject

Sp

Im

→

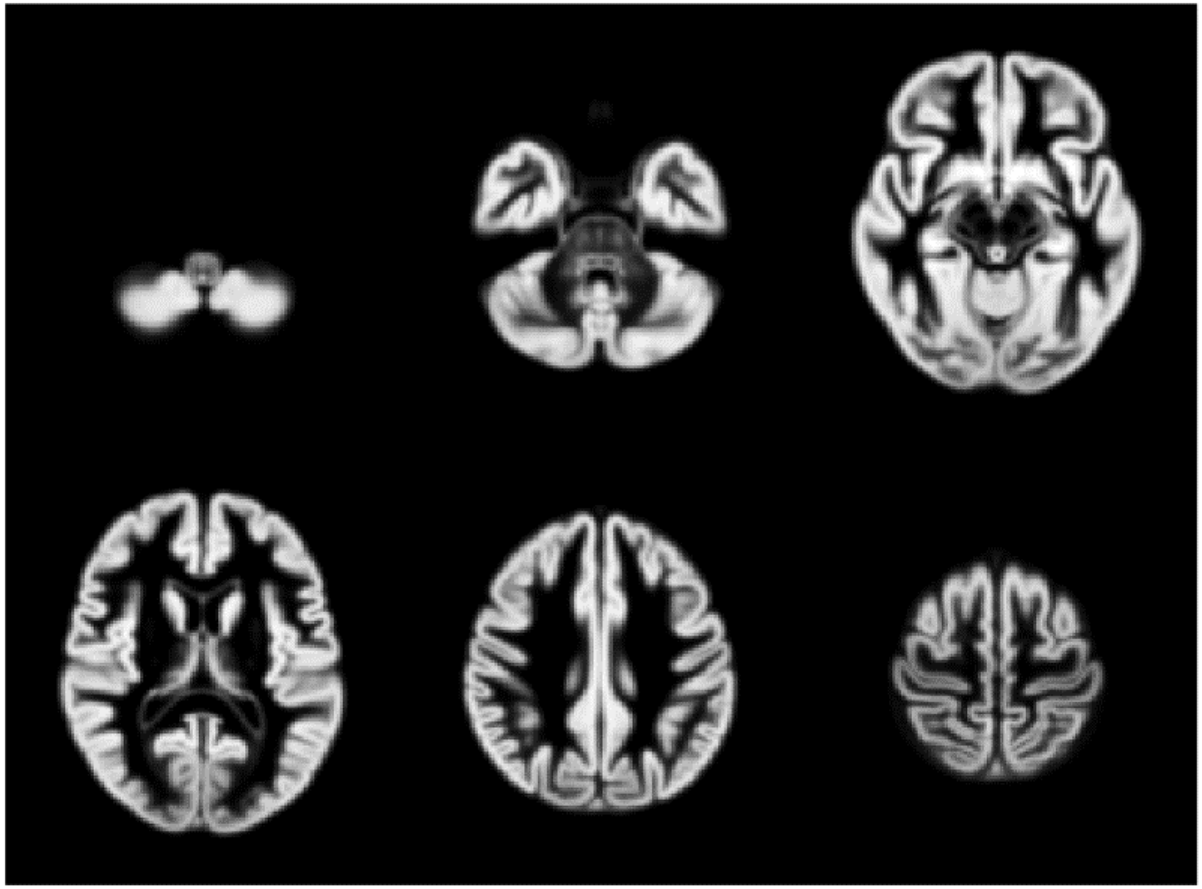


471 Subject Average

Sp

Im

→



471 Subject Average

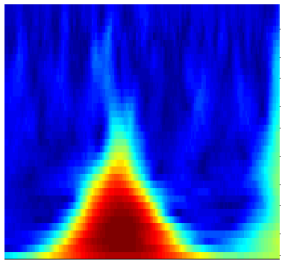
Spatial (pre-)processing

- Imaging modalities:
  PET, then functional and structural MRI
  → realignment, coregistration, segmentation, normalization, smoothing

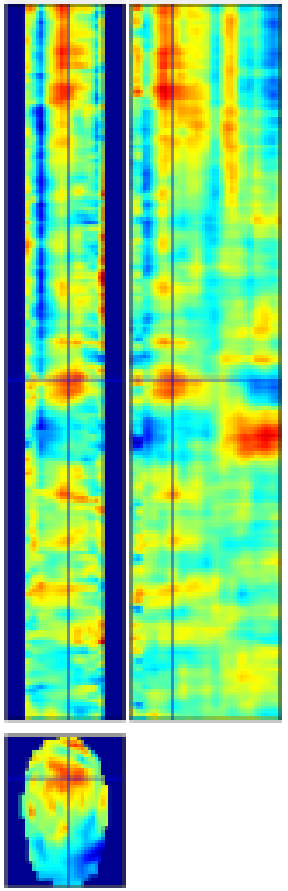
- Electrophysiological data:
  EEG, MEG, Local field potential,…
  → filter, epoch, time-frequency decomposition, etc.
  → turn data into **images**

Spatial (pre-)processing

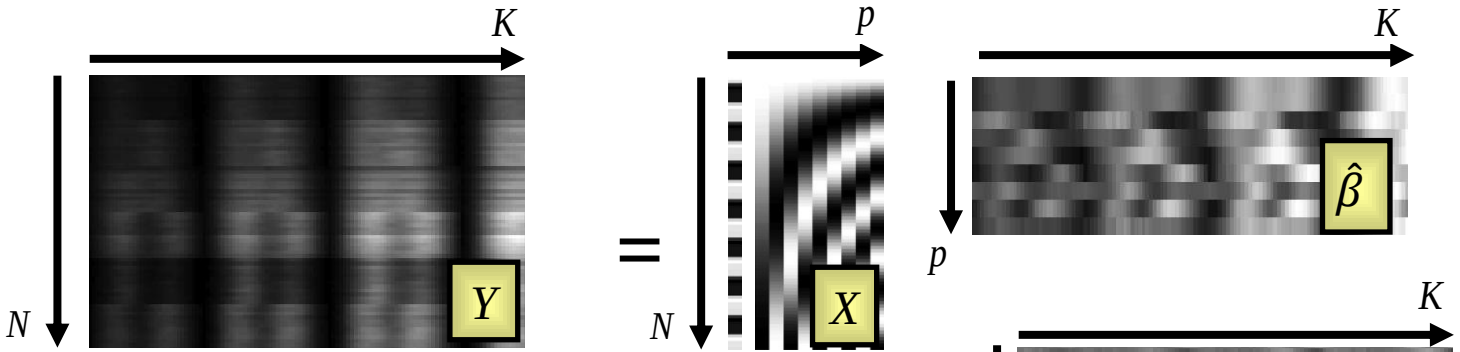
- Imaging modalities:
  PET, then functional and structural MRI
  → realignment, coregistration, segmentation, normalization, smoothing



- Electrophysiological data:
  EEG, MEG, Local field potential,…
  → filter, epoch, time-frequency decomposition, etc.
  → turn data into **images**



GLM and mass univariate approach

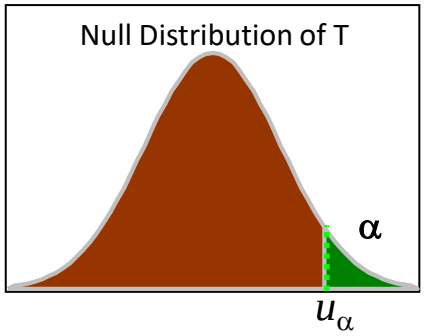


$$Y = X\beta + E$$
$$E \approx N(0, \sigma^2 C_\varepsilon)$$

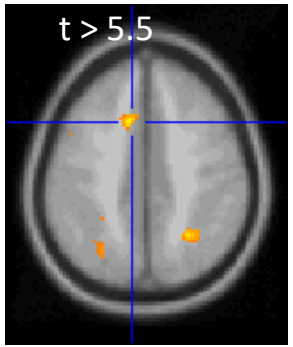
Express your question as a linear combination of β parameters: $c^T\beta$

Image-wise statistical inference

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

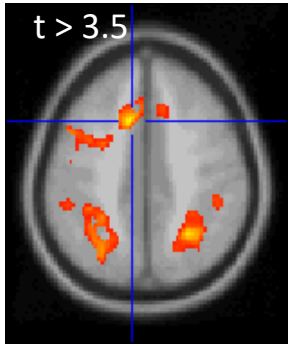


High Threshold

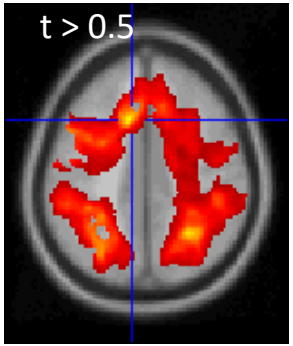


Good Specificity / Poor Power

Med. Threshold



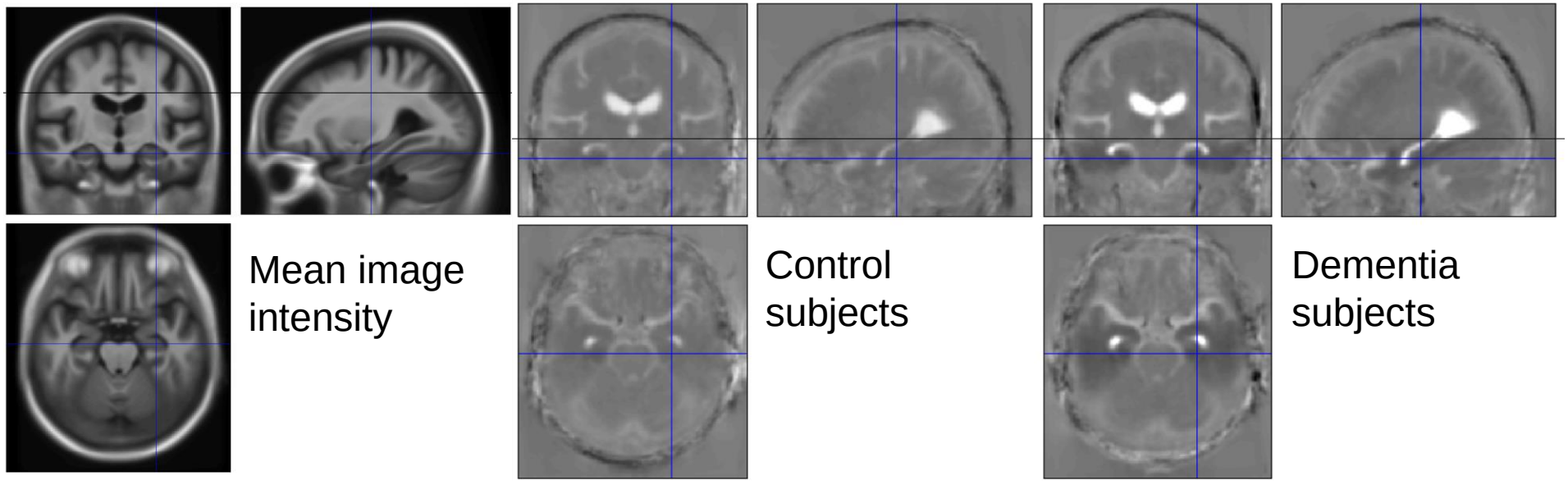
Low Threshold



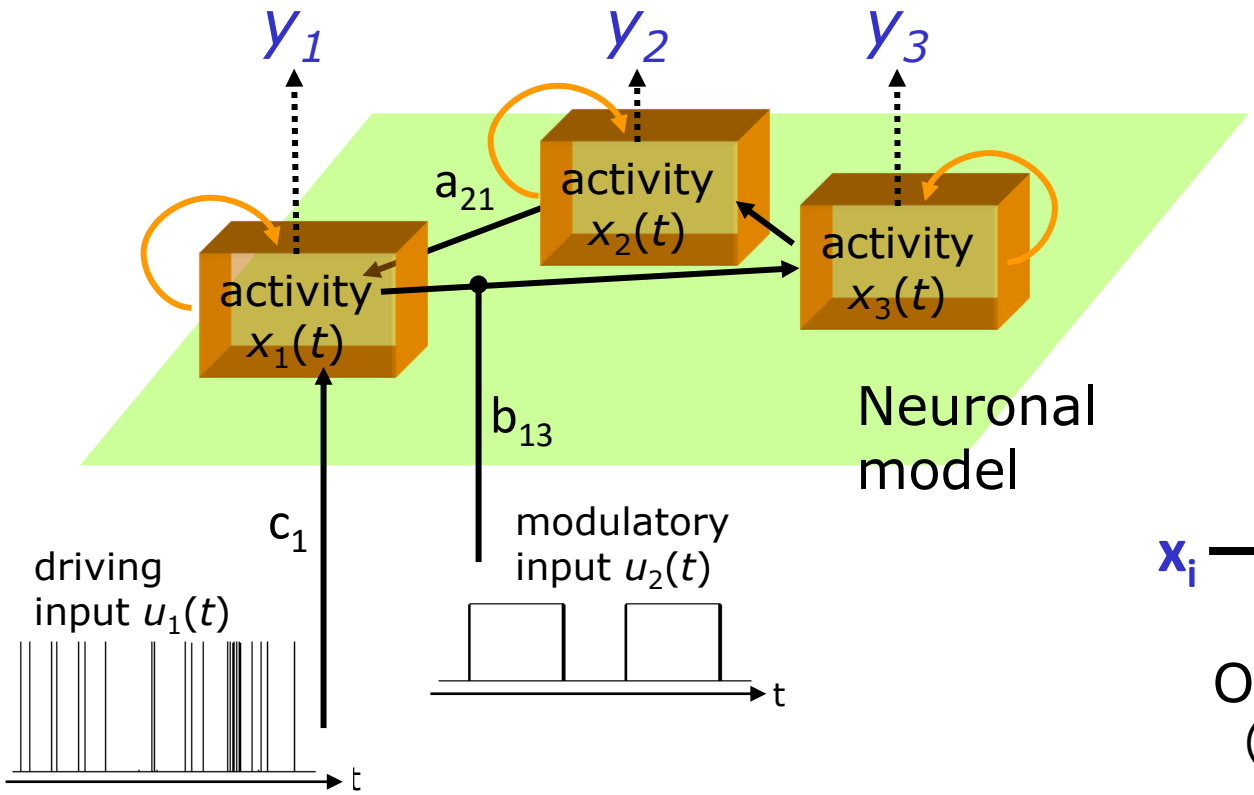
Poor Specificity / Good Power

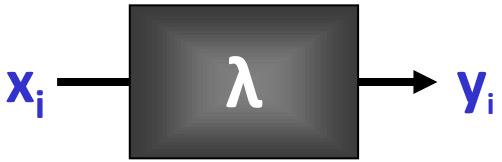
Need to control for “family-wise error rate”!

Voxel-based morphometry (VBM)



Dynamic causal modeling (DCM)



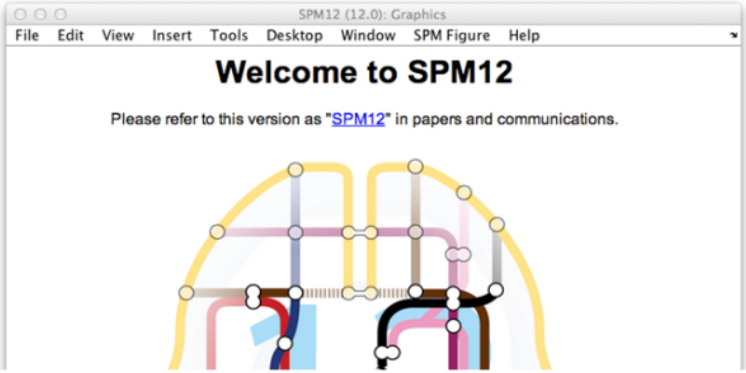


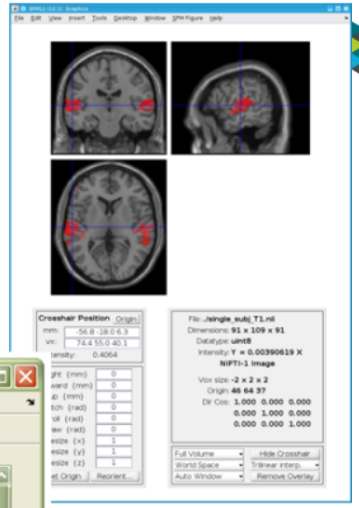
Output model
(fMRI, EEG,…)

Software

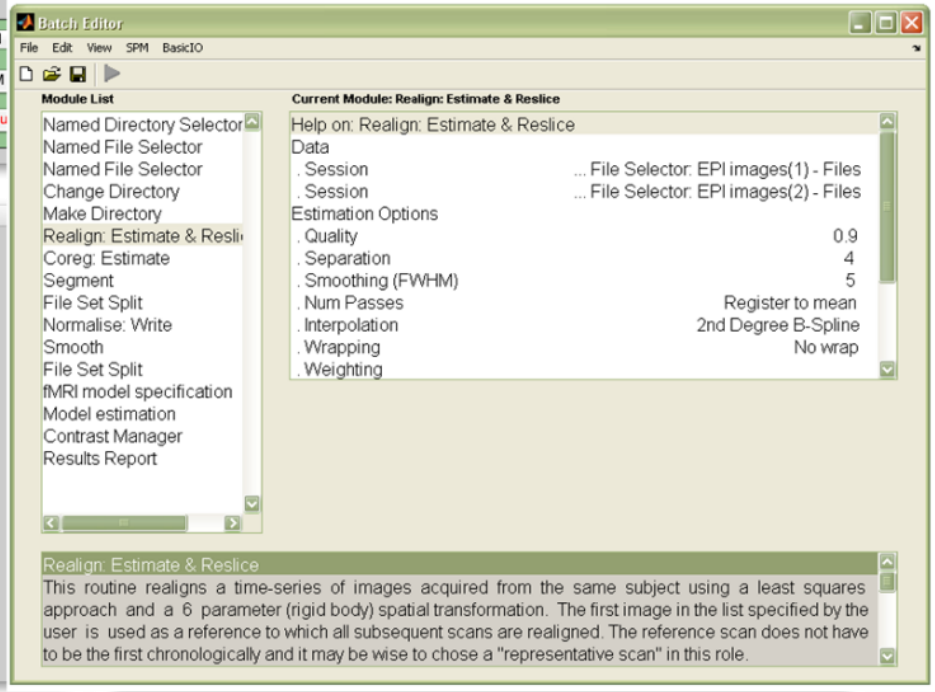
- Matlab based (Octave compatible + stand-alone compiled version)
- Open source, GNU GPL v.2
- 9 major releases and about 38 core contributors over 28 years
- includes external packages, e.g. `FieldTrip` and `MatlabBatch`

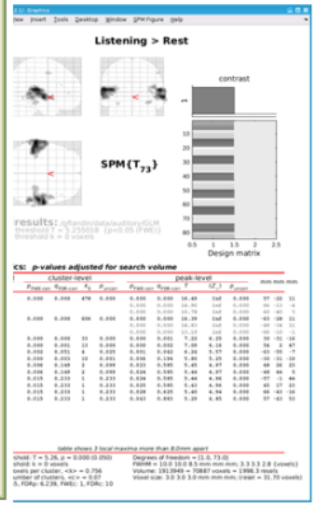

SPM12 (12.0): Menu
Realign ...
Slice timing
Smooth
Coregist...
Normali...
Segment
Specify 1st-level
Review
Specify 2nd-level
Estimate
Results
Dynamic Causal Modelling
SPM for functional MRI
Display
Check Reg
Rend...
FMRI
Toolb...
PPIs
ImCalc
DICOM
Help
Utils...
Batch
Copyright (c) 1991,1994-2014


SPM12 (12.0): Graphics
File Edit View Insert Tools Desktop Window SPM Figure Help
Welcome to SPM12
Please refer to this version as "SPM12" in papers and communications.




SPM12 (12.0)

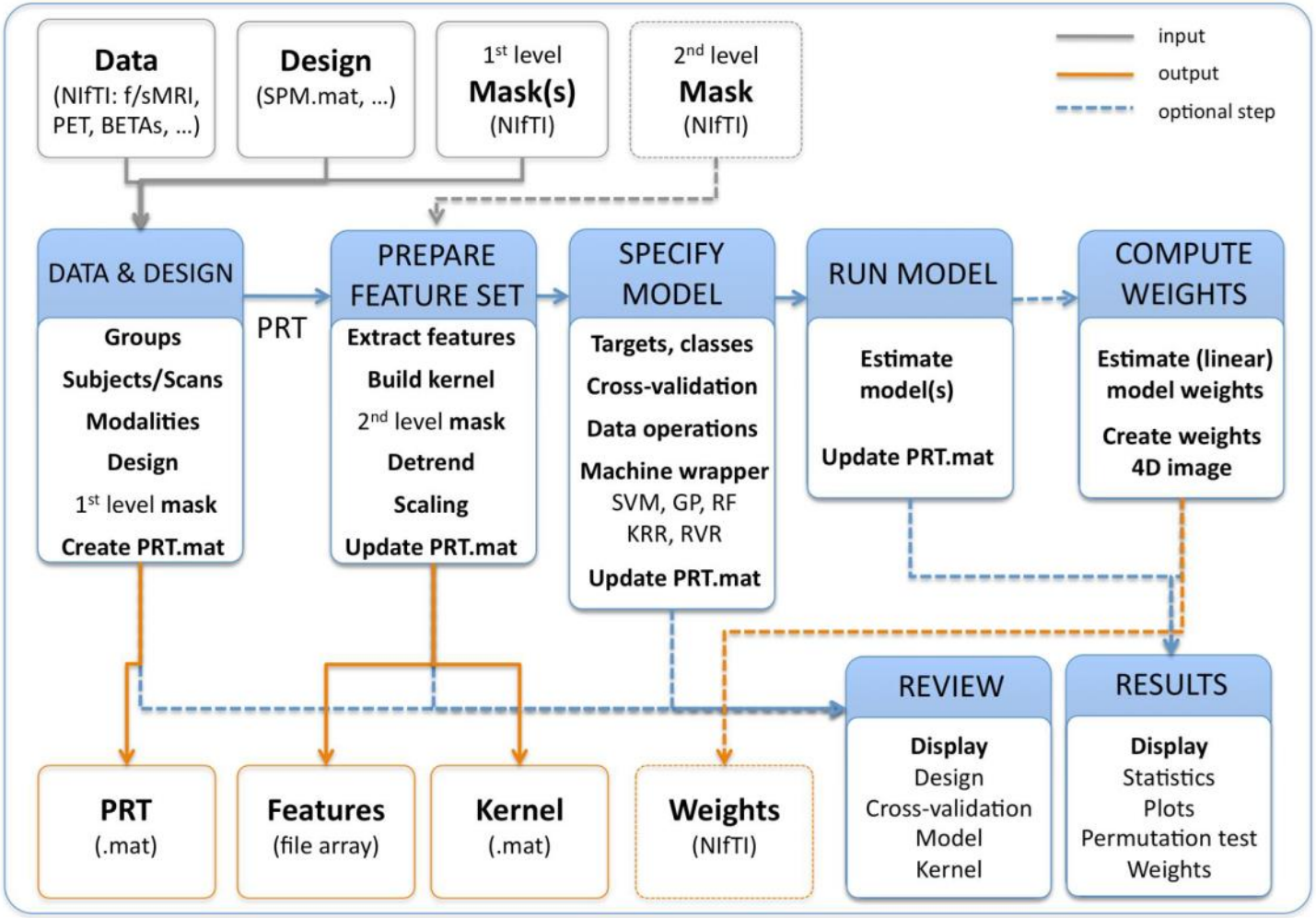

Batch Editor
File Edit View SPM BasicIO
Module List
Named Directory Selector
Named File Selector
Named File Selector
Change Directory
Make Directory
Realign: Estimate & Resli
Coreg: Estimate
Segment
File Set Split
Normalise: Write
Smooth
File Set Split
fMRI model specification
Model estimation
Contrast Manager
Results Report
Current Module: Realign: Estimate & Reslice
Help on: Realign: Estimate & Reslice
Data
. Session ... File Selector: EPI images(1) - Files
. Session ... File Selector: EPI images(2) - Files
Estimation Options
. Quality 0.9
. Separation 4
. Smoothing (FWHM) 5
. Num Passes Register to mean
. Interpolation 2nd Degree B-Spline
. Wrapping No wrap
. Weighting
Realign: Estimate & Reslice
This routine realigns a time-series of images acquired from the same subject using a least squares approach and a 6 parameter (rigid body) spatial transformation. The first image in the list specified by the user is used as a reference to which all subsequent scans are realigned. The reference scan does not have to be the first chronologically and it may be wise to chose a "representative scan" in this role.

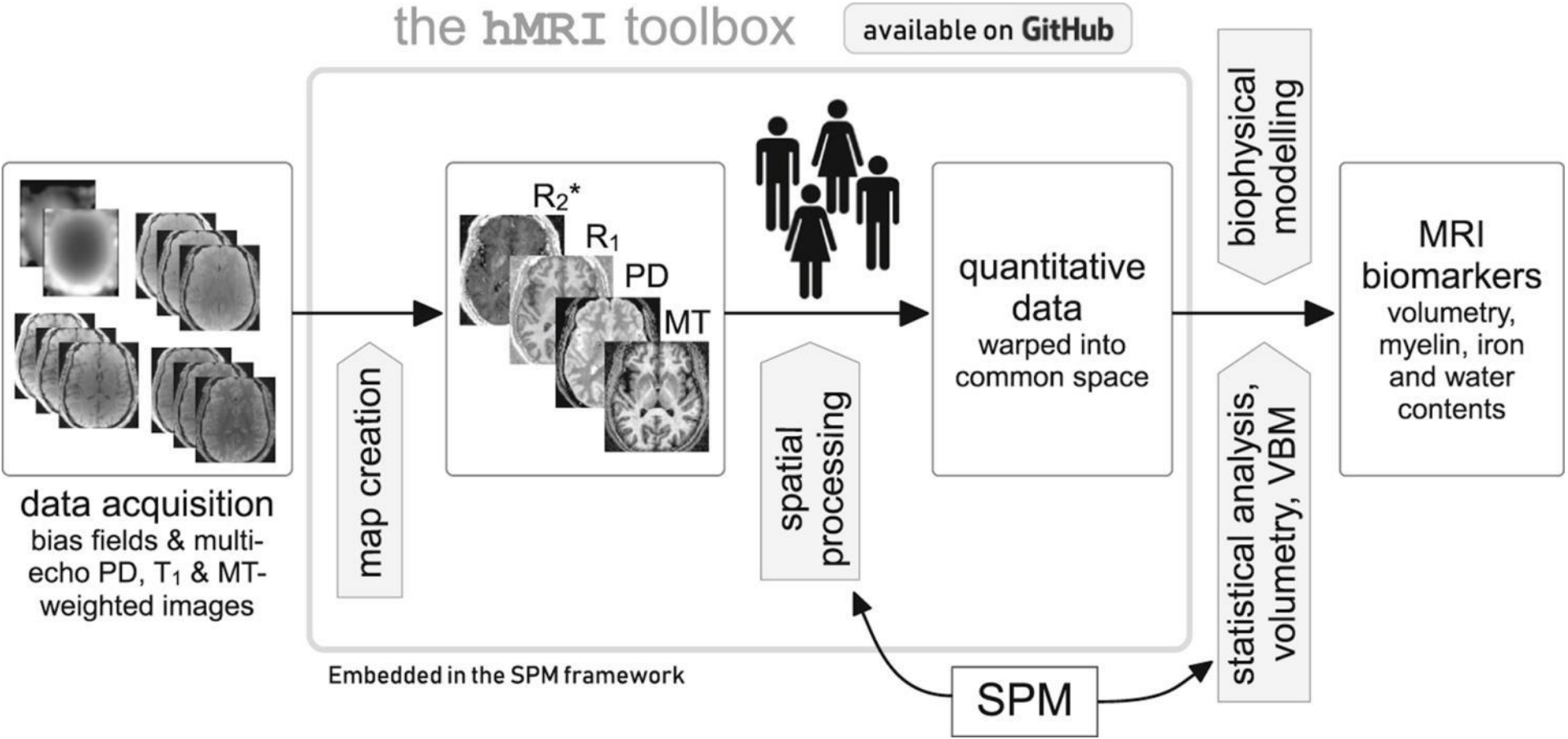

Listening > Rest
contrast
SPM{T23}
Design matrix

Software

- Matlab based (Octave compatible + stand-alone compiled version)
- Open source, GNU GPL v.2
- 9 major releases over 28 years, about 38 core contributors
- includes external packages, e.g. `FieldTrip` and `MatlabBatch`
- extensions, relying on I/O, batching, display, etc. functions:
  - extra methods (>65): resting fMRI, repeated measures, multi-statistics,…
  - extra modalities: NIRS, diffusion and quantitative MRI,…
  - extra fields: mice, rats, monkeys,…

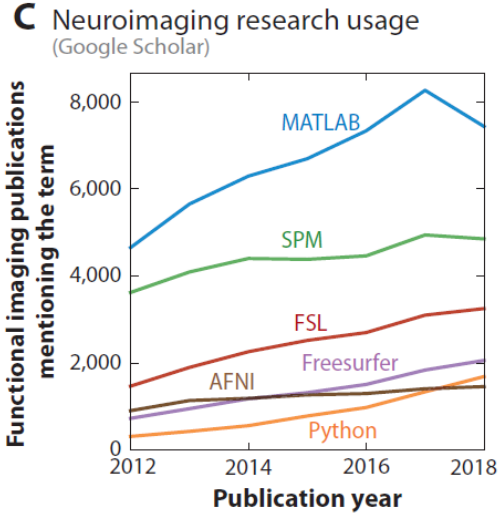
PRoNTo FRAMEWORK




the hMRI toolbox
available on GitHub
data acquisition
bias fields & multi-echo PD, T1 & MT-weighted images
map creation
R2*
R1
PD
MT
spatial processing
quantitative data
warped into common space
biophysical modelling
MRI biomarkers
volumetry, myelin, iron and water contents
statistical analysis, volumetry, VBM
SPM
Embedded in the SPM framework

Now…

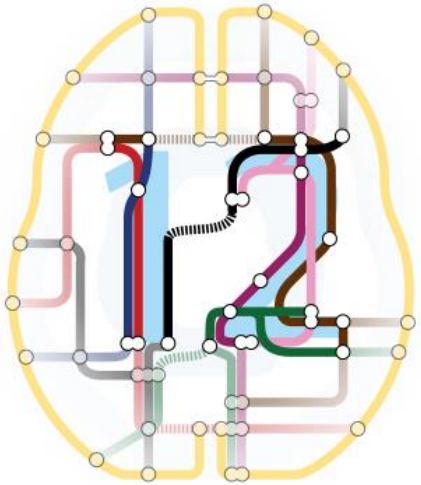
- Many other software solutions since 1991…
- Still the most used software for neuroimaging data analysis!
- Open resources available
  - multiple courses organized every year (for users)
  - teaching material
  - papers (open access in PDF's since 1994)
  - mailing list and community



R. A. Poldrack, et al. (2019)

…and then?

- Keep on educating users and developers!
- Taken for granted by many…
- …but still need support and developments!
- Stick to Matlab? Or switch to…
  - Python/Julia?
  - Cloud/web-based version of the tool?



LIÈGE université
GIGA
CRC In vivo Imaging

Thank you for your attention!

Special thanks to
Karl Friston, Father of SPM,
Guillaume Flandin, Head of SPM development,
and all the SPM developers

References

- SPM code, references, example data, extensions,…
  https://www.fil.ion.ucl.ac.uk/spm/
- SPM on GitHub
  https://github.com/spm
- R. A. Poldrack, et al., Computational and Informatic Advances for Reproducible Data Analysis in Neuroimaging, Annu. Rev. Biomed. Data Sci. 2019. 2:119–38.
  https://doi.org/10.1146/annurev-biodatasci-072018-021237
- P. Bandettini, Twenty years of functional MRI: The science and the stories, NeuroImage, 2012.
  http://dx.doi.org/10.1016/j.neuroimage.2012.04.026