

# NeuroImaging Data Processing

aka. Statistical Parametric Mapping short course

## Course 1: Introduction

# Who am I ?

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- Electrical (or. electronics) engineer, then PhD on “Source reconstruction in EEG”.
- FRS-FNRS Research Director at the CRC & Professor at the School of Engineering, Montefiore (EEI)
- Linked to
  - “GIGA CRC human imaging” research unit
  - “GIGA in vivo imaging” tech platform
  - Montefiore Institute.
- Office at the Cyclotron Research Centre (B30).
- Interest in neuroimaging:

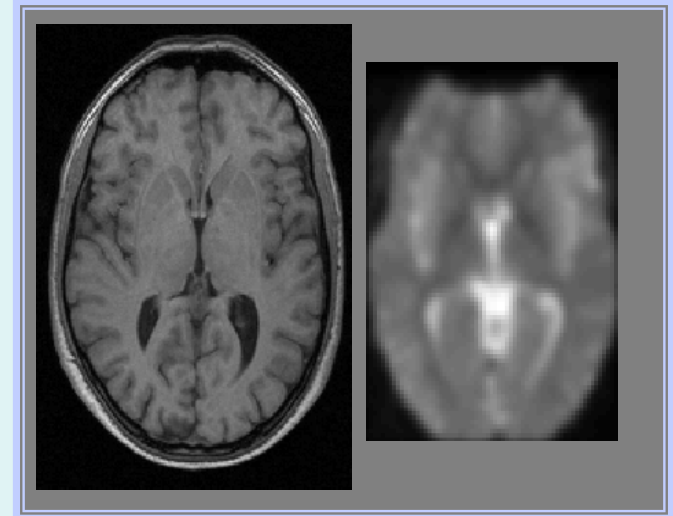
“How does the brain work and what is it made of?”

Contact: [c.phillips@uliege.be](mailto:c.phillips@uliege.be)

# Functional/structural neuroimaging

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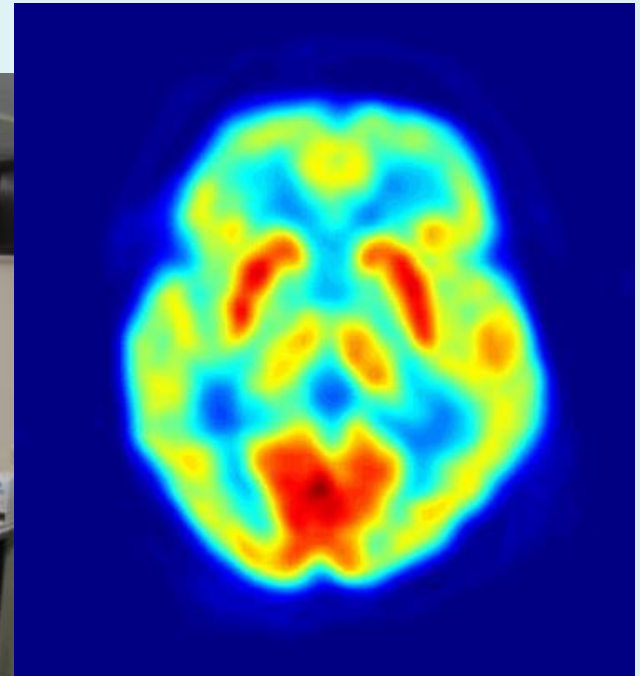
- functional anatomy –  
functional segregation



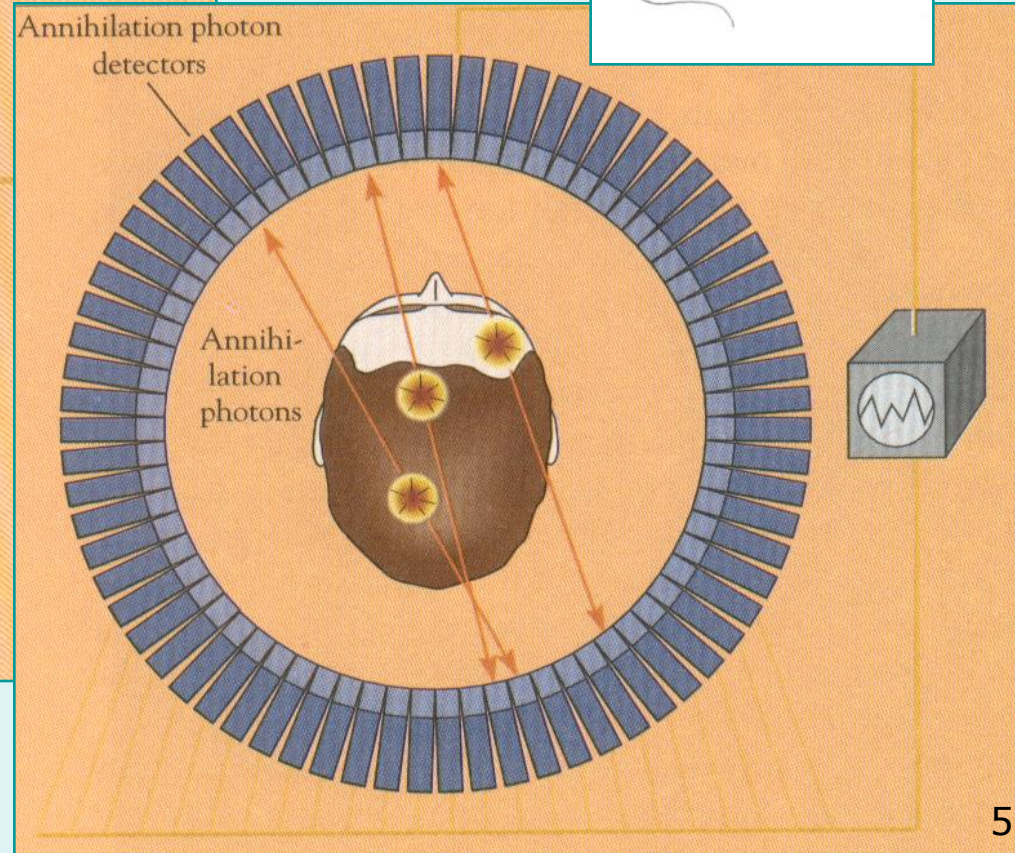
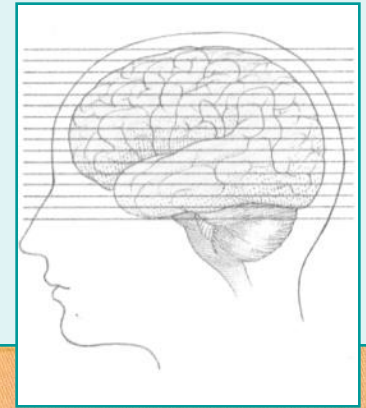
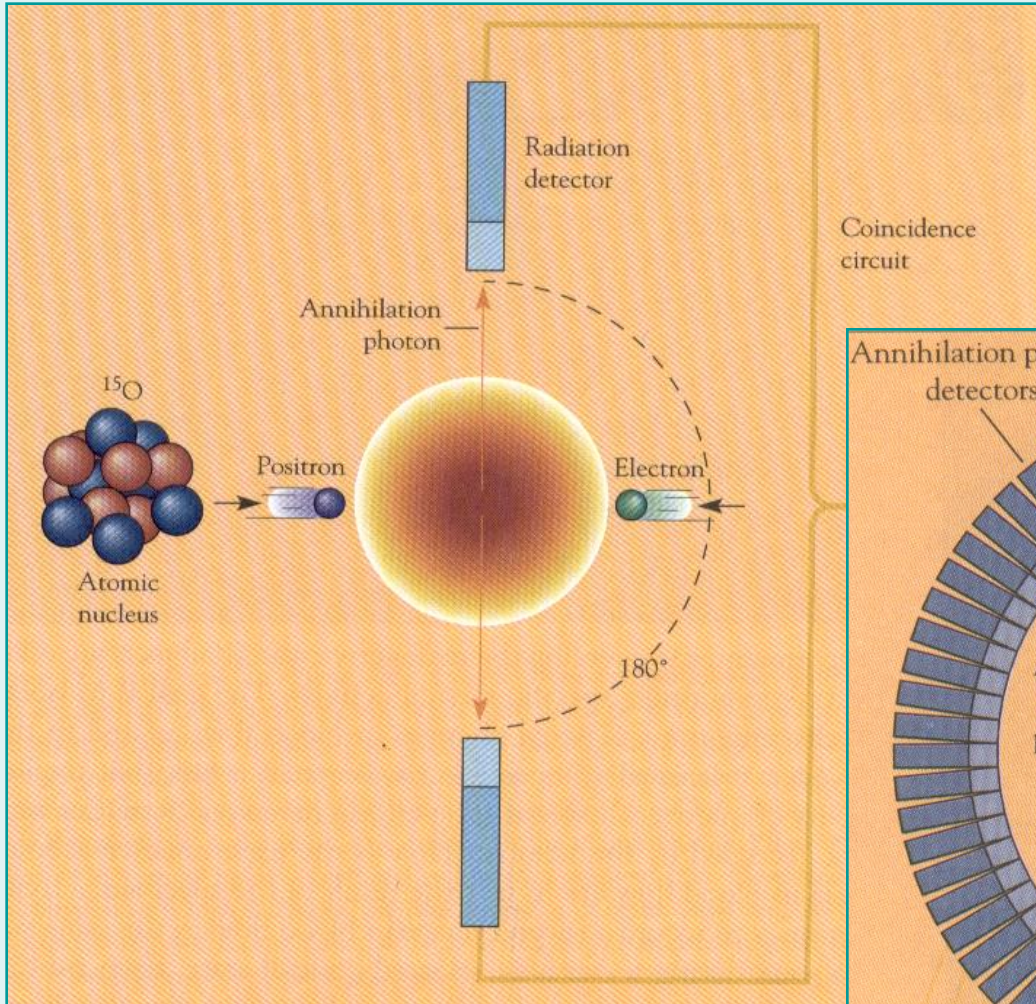
- Positron Emission Tomography (PET) & SPECT
  - regional Cerebral Glucose Uptake
  - other tracers...
- *functional* MRI (fMRI), Blood Oxygenation Level Dependent signal
- *structural* MRI (sMRI + DWI)
  - Grey/White density
  - White matter anisotropy
- *quantitative* MRI (qMRI + spectro + QSM)

# Imaging tools: PET

## Positron emission tomography



# Imaging tools: PET



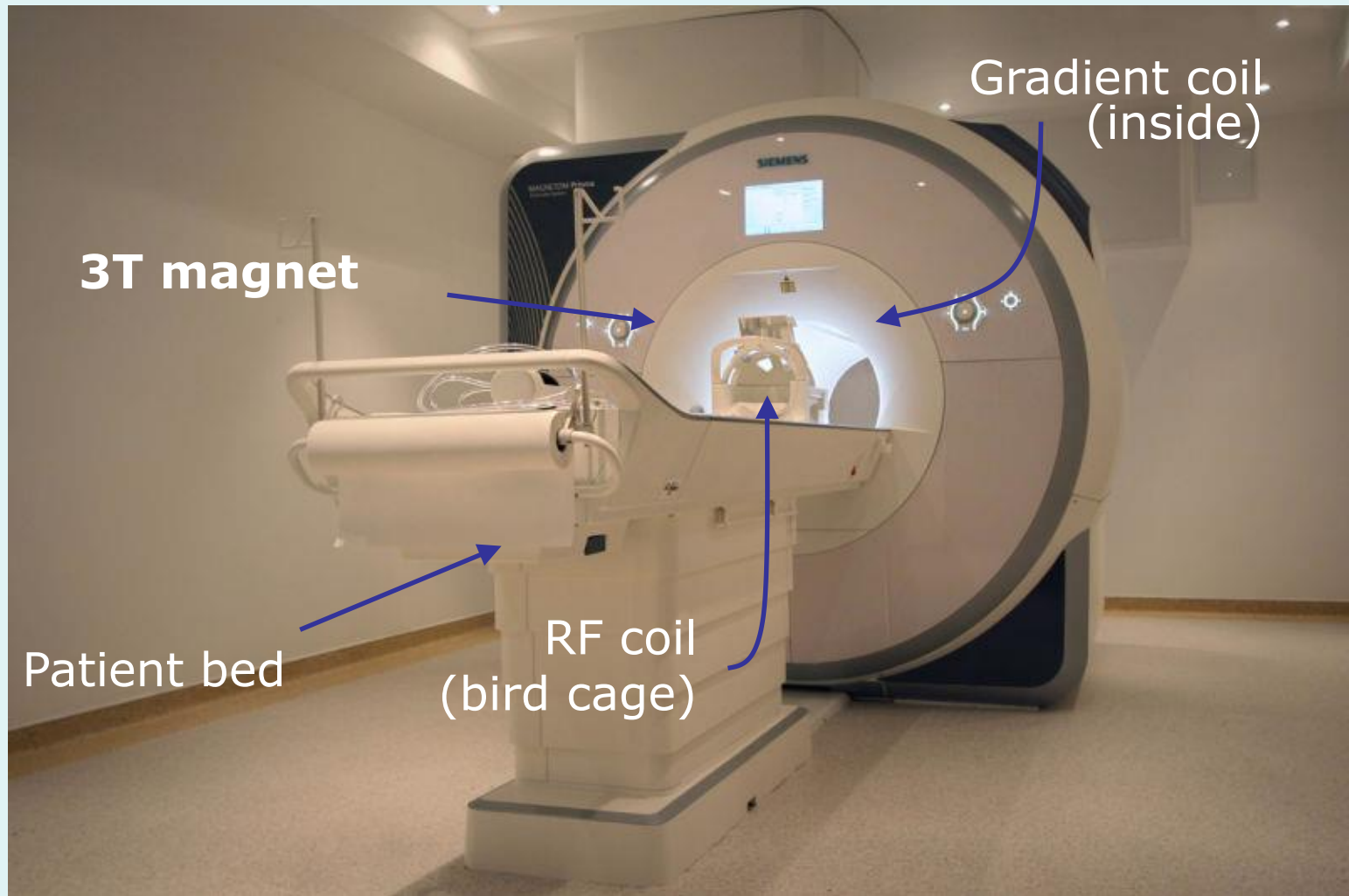
# Imaging tools: PET

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- $\text{H}_2\text{O}^{15}$  (a long time ago...)
  - measures blood flow directly
    - brain activation mapping
  - scan over 1-2 minutes
  - 12-15 scans per patient
- FDG & other/new radiotracers
  - Measures biological process (glucose, protein binding, synaptic density, etc.)
    - Disease (e.g. Alzheimer/Parkinson/MS) biomarkers
  - Scan over several minutes + modelling
  - 1 (quantitative) image per patient
- Spatial resolution limited by
  - molecule diffusion and scanning duration
  - scanner sensors
  - image reconstruction (artefacts + partial volume effect)

# Imaging tools: MRI

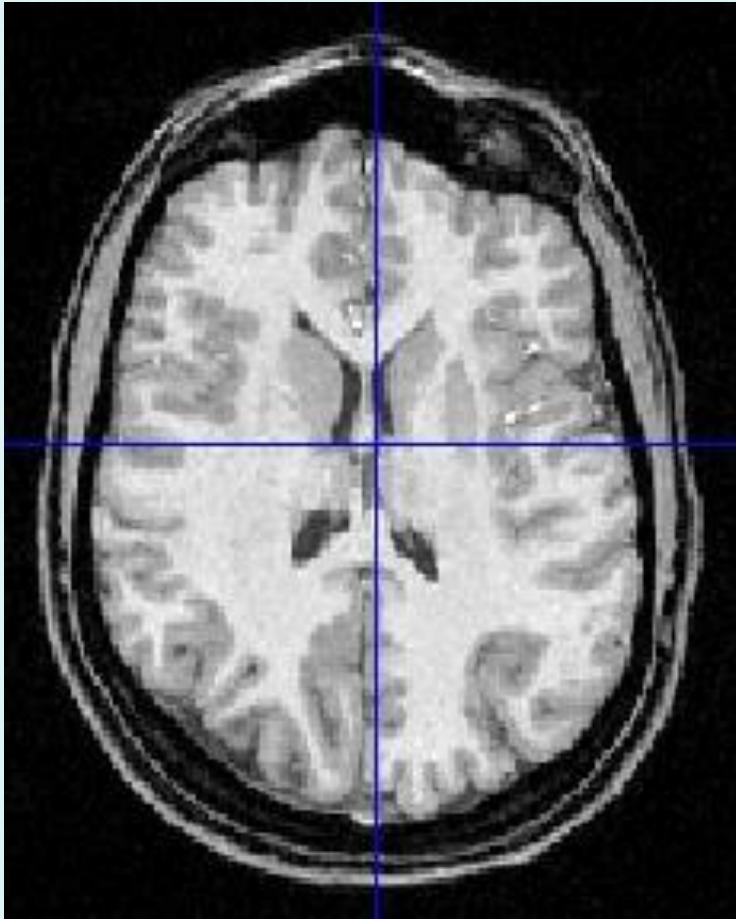
## Magnetic Resonance Imaging



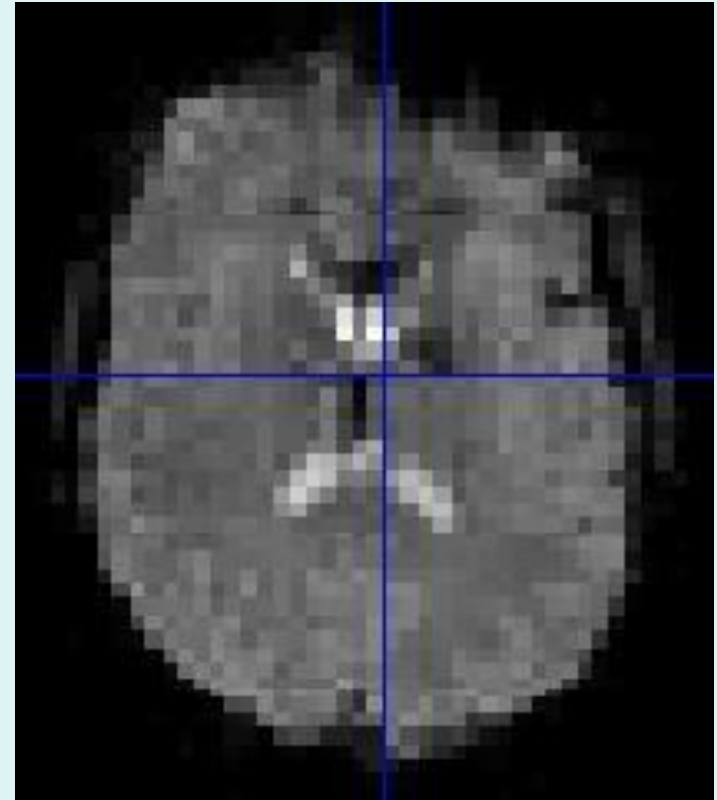
# Imaging tools: MRI

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## T1 contrast



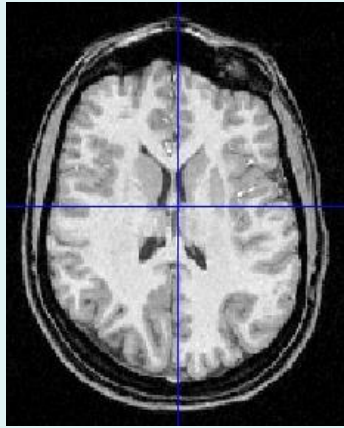
## T2\* contrast



**Acquisition time:** a few *minutes* vs. a few *seconds*  
**Spatial resolution:**  $\sim 1 \times 1 \times 1$  mm<sup>3</sup> vs.  $\sim 3 \times 3 \times 3$  mm<sup>3</sup>

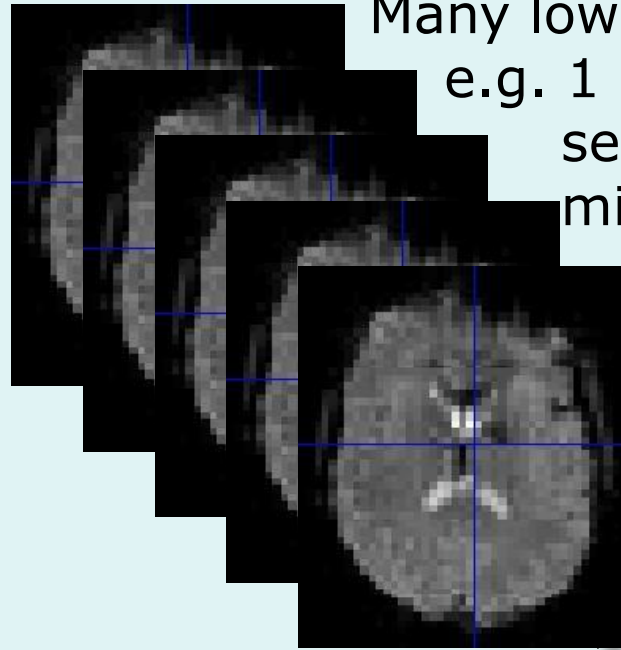


# Imaging tools: MRI



one high resolution image

**Vs.**



Many low resolution image,  
e.g. 1 image every 2  
seconds during 20  
minutes

## fMRI signal:

Blood Oxygenation Level Dependent (BOLD) signal,  
an indirect measure of neural activity.

↑ neural activity ⇒ ↑ blood oxygen ⇒ ↑ fMRI signal

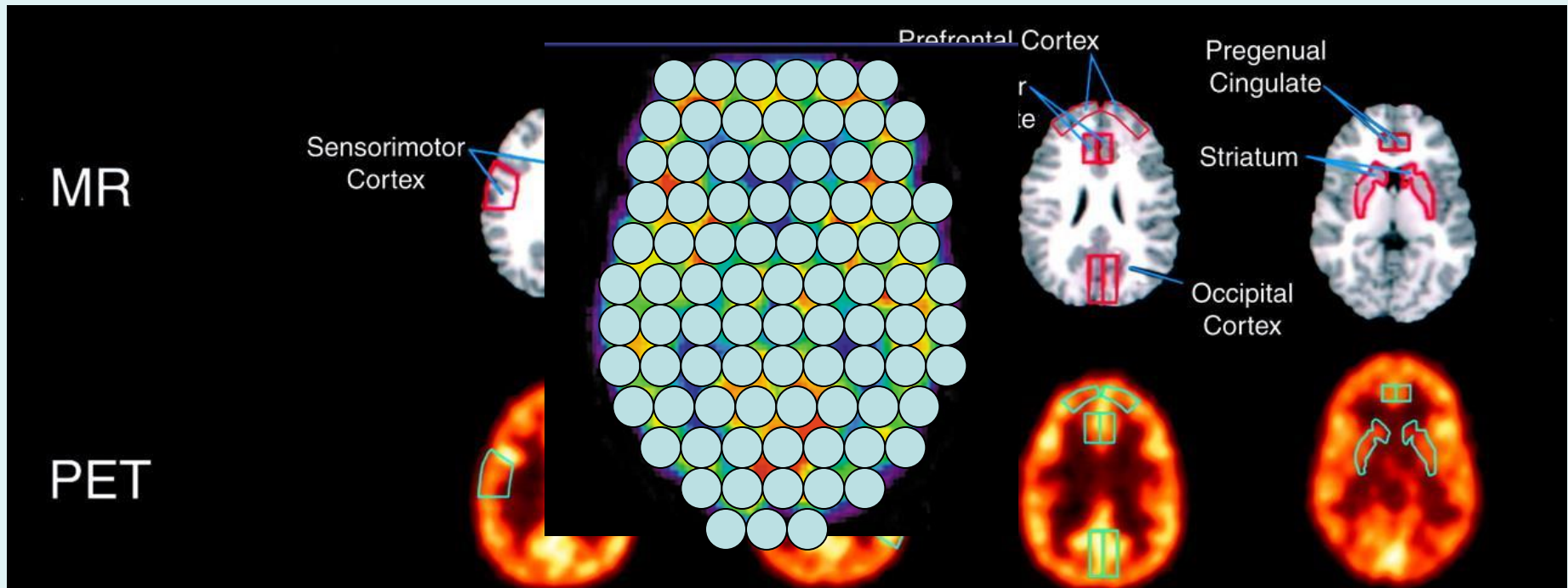
# Statistical Parametric Mapping

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- Concepts
- Software
- Resources

# Statistical Parametric Mapping

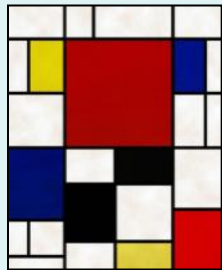
## From PET analyses using ROIs...



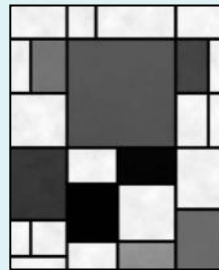
# Statistical Parametric Mapping

## ...to the very first SPM{t}

- An area specialised for the processing of colour, the “colour centre” (V4) highlighted by cognitive subtraction 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

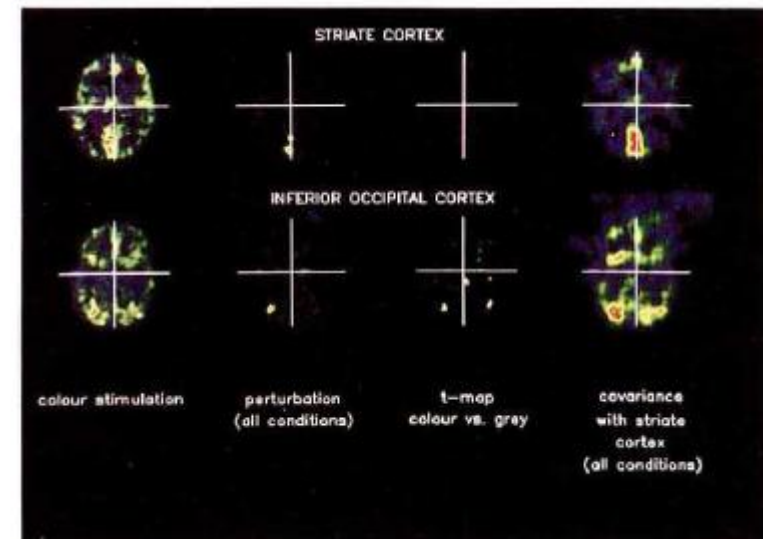
† Department of Anatomy, University College London, Gower Street, London WC1E 6BT, UK

‡ 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<sup>1</sup>. Earlier this century, suggestive clinical evidence for a colour centre in the brain of man<sup>2,3</sup> was dismissed<sup>4-8</sup> because of the association of other visual defects with the defects in colour vision<sup>4,5,7</sup>. However, since the demonstration of functional specialization in the macaque cortex<sup>9</sup>, the question of a colour centre in man has been reinvestigated,

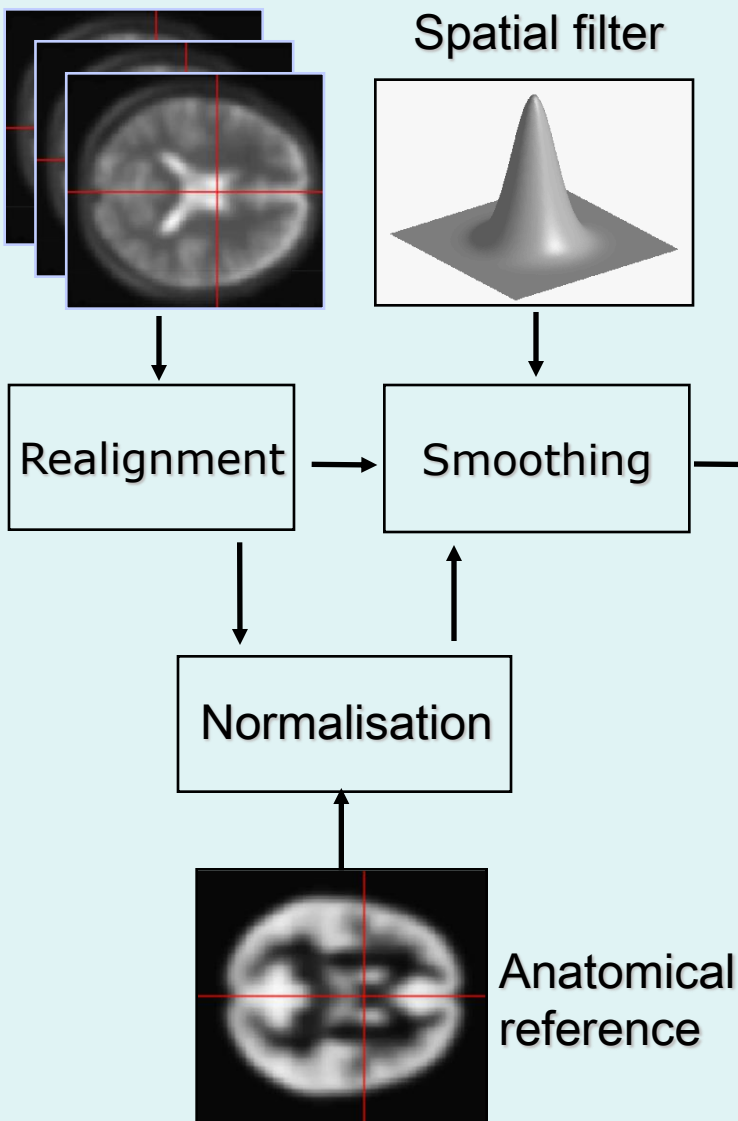
§ To whom reprint requests should be addressed.

NATURE · VOL 340 · 3 AUGUST 1989

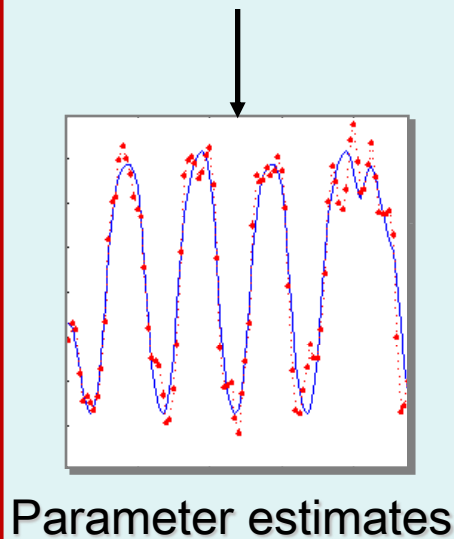
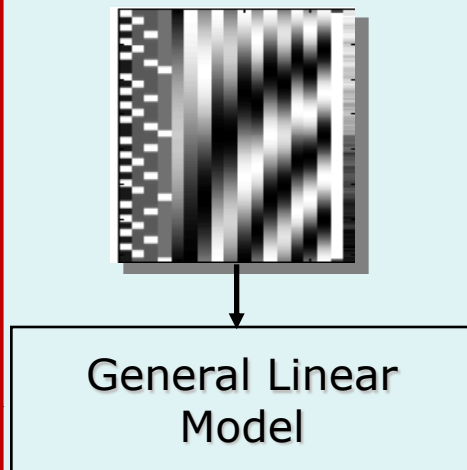


# Statistical Parametric Mapping

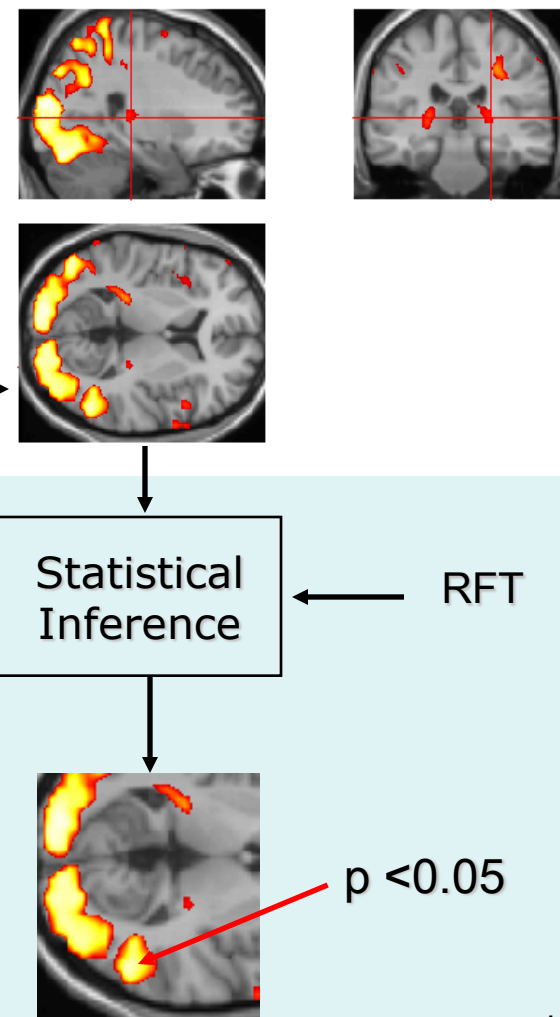
Image time-series



Design matrix

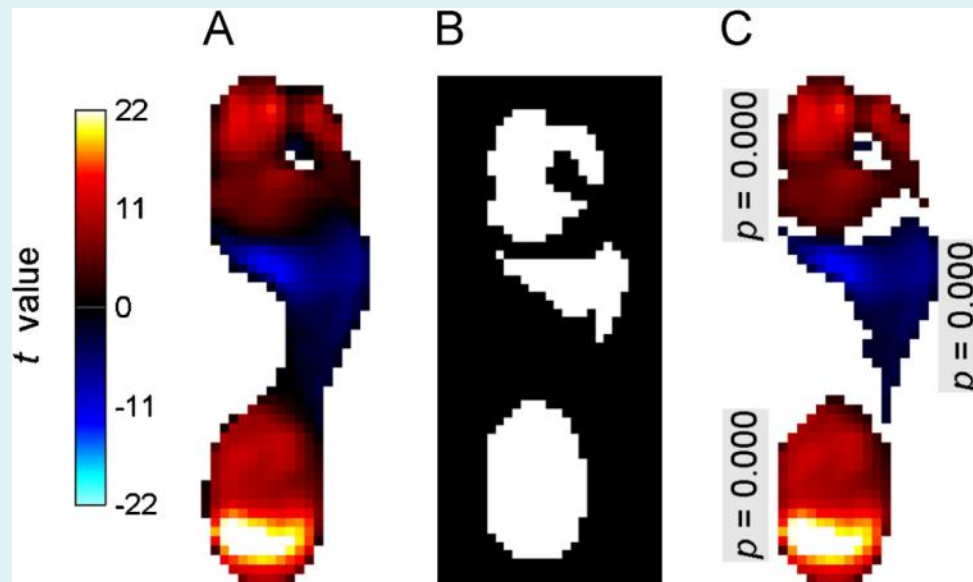


Statistical Parametric Map



# Statistical Parametric Mapping

- **Statistical Parametric Mapping** refers to the construction and assessment of *spatially extended statistical processes* used to test hypotheses about functional imaging data.

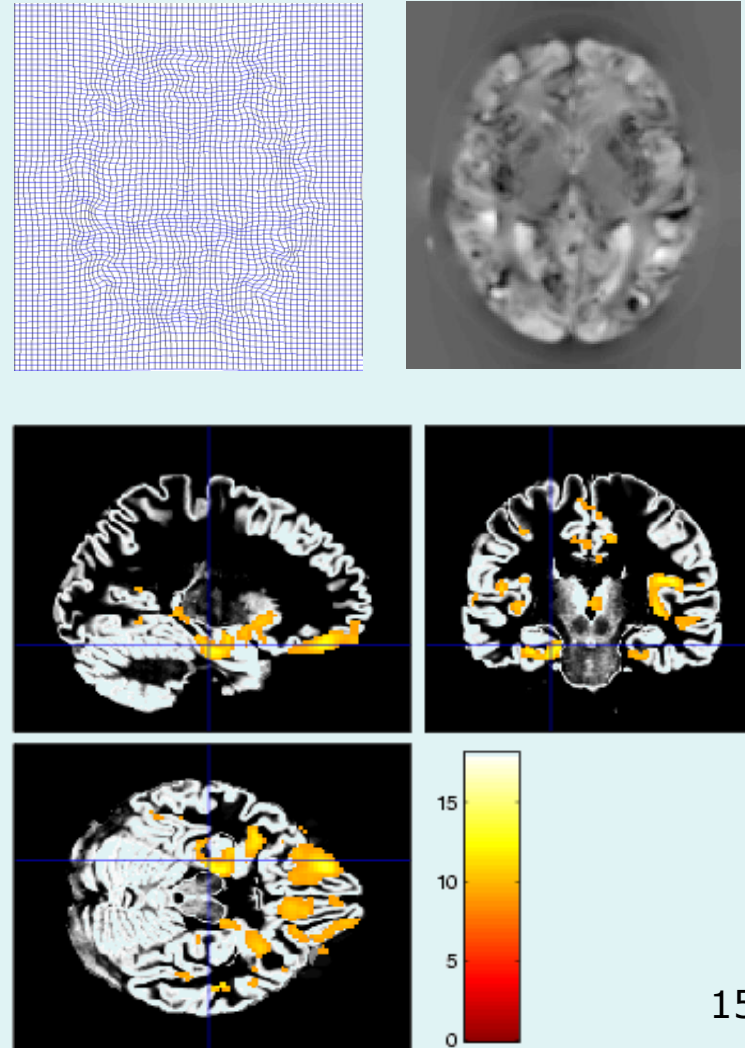


*Pedobarographic statistical parametric mapping (pSPM)*, T. Pataky, Journal of Foot and Ankle Research, 2008.

# Statistical Parametric Mapping

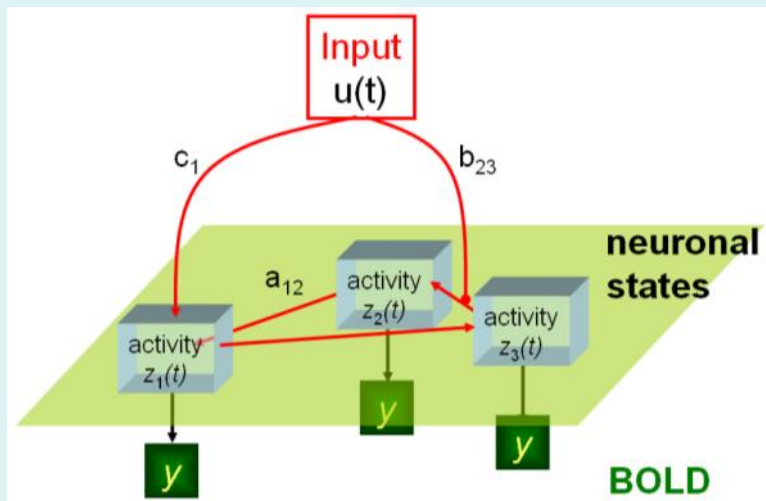
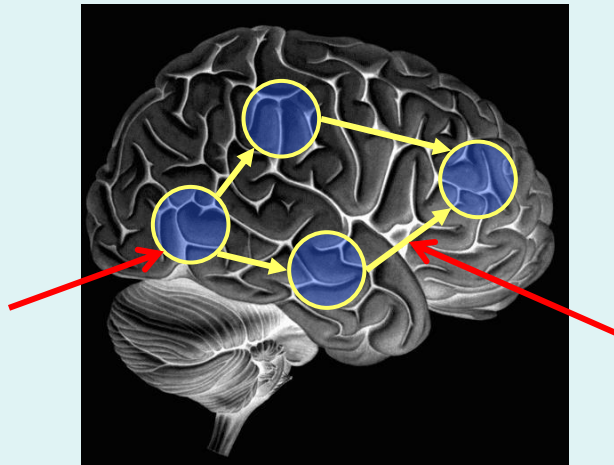
## Voxel-Based Morphometry (VBM)

- VBM is the most widely used method for computational neuroanatomy.
- It is essentially Statistical Parametric Mapping of regional segmented tissue density or volume.
- The same general linear modelling & RFT machinery in SPM can then be used to study differences in structure.



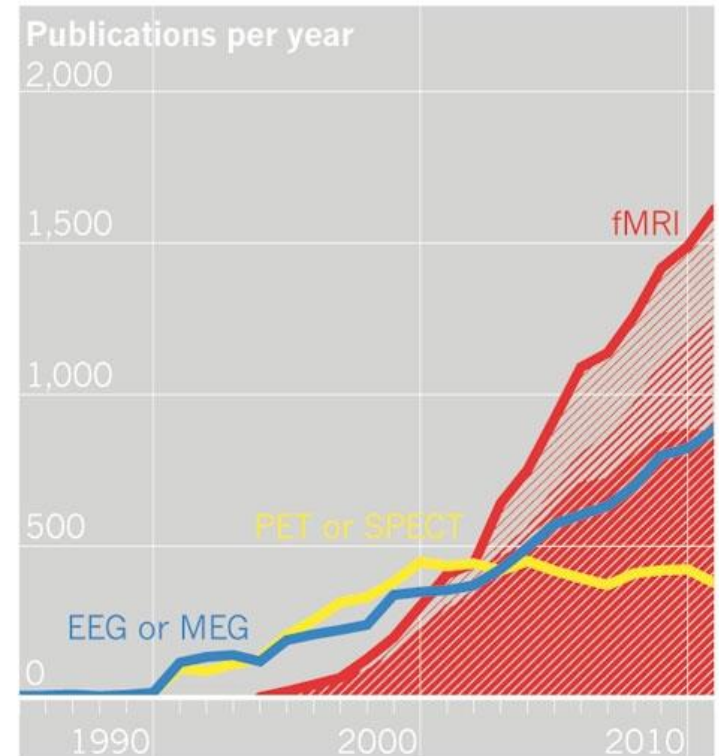
# Statistical Parametric Mapping

## Dynamic Causal Models



### THE RISE OF fMRI

Use of fMRI has rocketed, and now more studies are looking at connectivity between regions.



### fMRI publications by subject:

Activation Connectivity Other

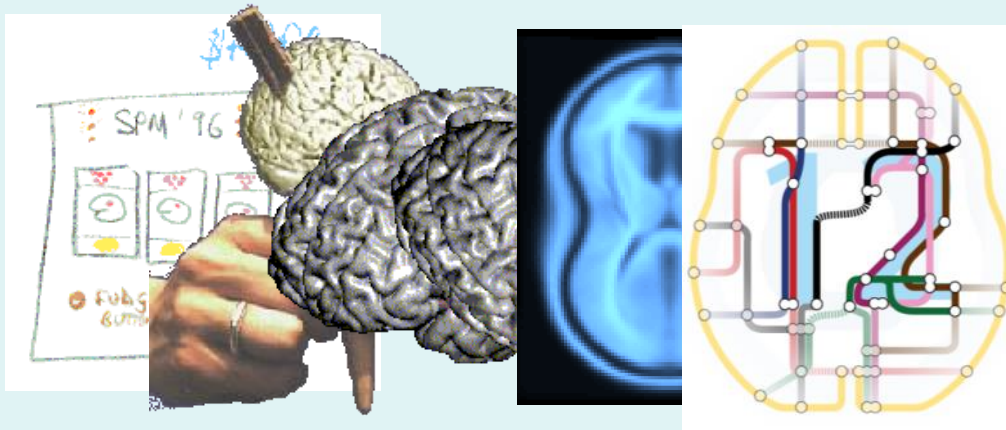
fMRI, functional magnetic resonance imaging; PET, positron emission tomography; SPECT, single-photon emission computed tomography; EEG, electroencephalography; MEG; magnetoencephalography  
Data from ISI Web of Knowledge. Nature, April 2012



# Statistical Parametric Mapping

## SPM software

*“The SPM software was originally developed by Karl Friston for the routine statistical analysis of functional neuroimaging data from PET while at the Hammersmith Hospital in the UK, and made available to the emerging functional imaging community in 1991 to promote collaboration and a common analysis scheme across laboratories.”*

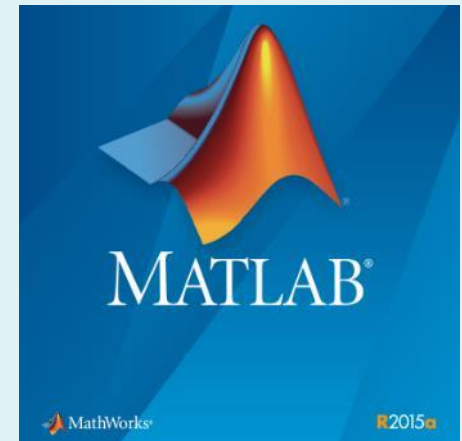
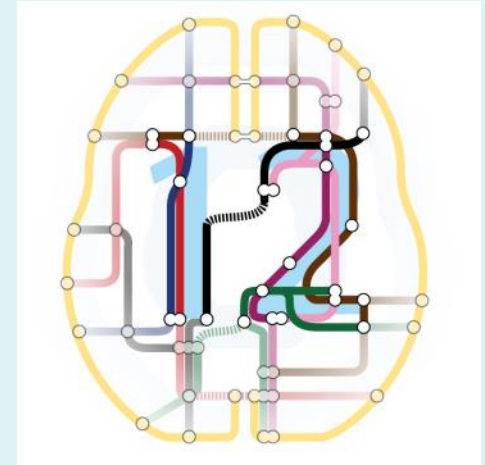


SPMclassic, SPM'94, SPM'96, SPM'99, SPM2, SPM5, SPM8 and SPM12 represent the ongoing theoretical advances and technical improvements of the original version.

# Statistical Parametric Mapping

## Software: **SPM12**

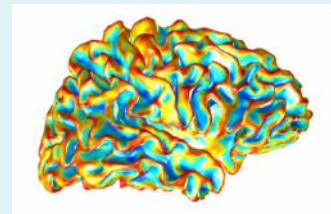
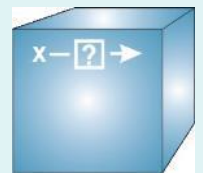
- Free and Open Source Software (GPL)
- Requirements:
  - MATLAB: **7.4** (R2007a) to **9.15** (R2023b)  
no MathWorks toolboxes required
  - Supported platforms:  
Linux, Windows and Mac
- *Standalone & containerized versions available.*
- Available on
  - on <https://github.com/spm>
  - through <https://www.fil.ion.ucl.ac.uk/spm/>



# Statistical Parametric Mapping

## Data File Formats

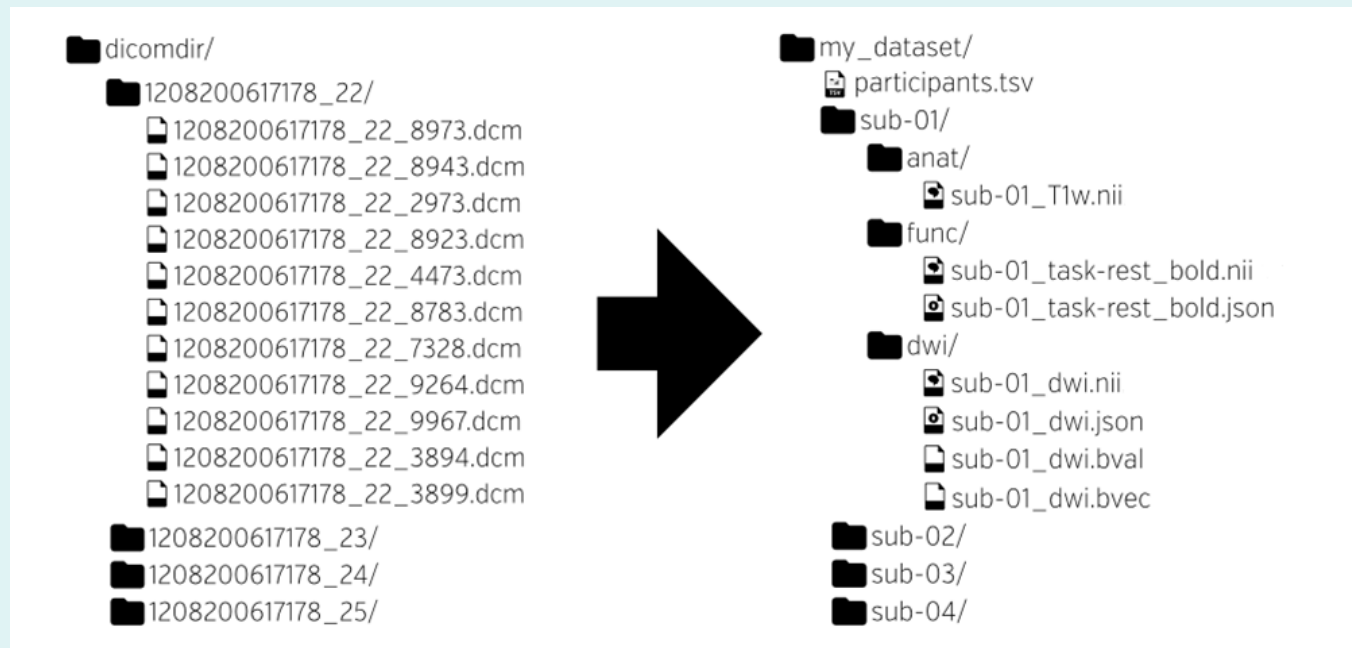
- **DICOM**: Digital Imaging and Communications in Medicine
- **NIfTI**: Neuroimaging Informatics Technology Initiative
  - NifTI: volumetric data format (\*.nii, \*.hdr/\*.img)
  - GIfTI: geometry data format (\*.gii)
- **Analyze™**: Mayo Clinic Analyze 7.5 file format (\*.hdr/\*.img)
- **Interoperability**:
  - Compatible with many tools: AFNI, fmriPrep, ANTs, Freesurfer, FSL, ...



# Statistical Parametric Mapping

## Brain Imaging Data Structure (BIDS)

*“A simple and intuitive way to organise and describe your neuroimaging and behavioural data.”*



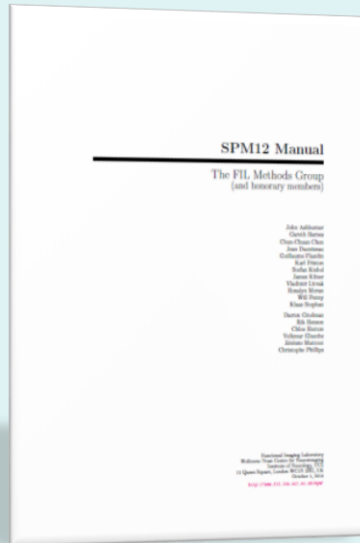
<http://bids.neuroimaging.io/>

# Statistical Parametric Mapping

## SPM Documentation

## Peer reviewed literature

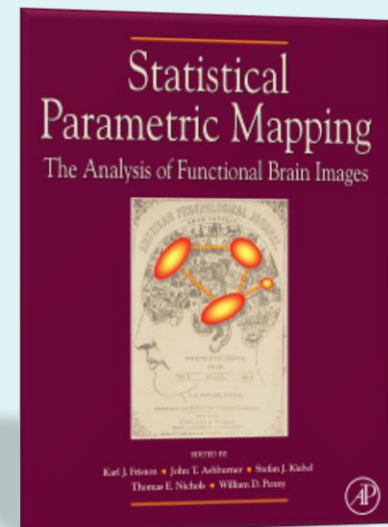
PDF  
Manual



MATLAB  
code and  
comments

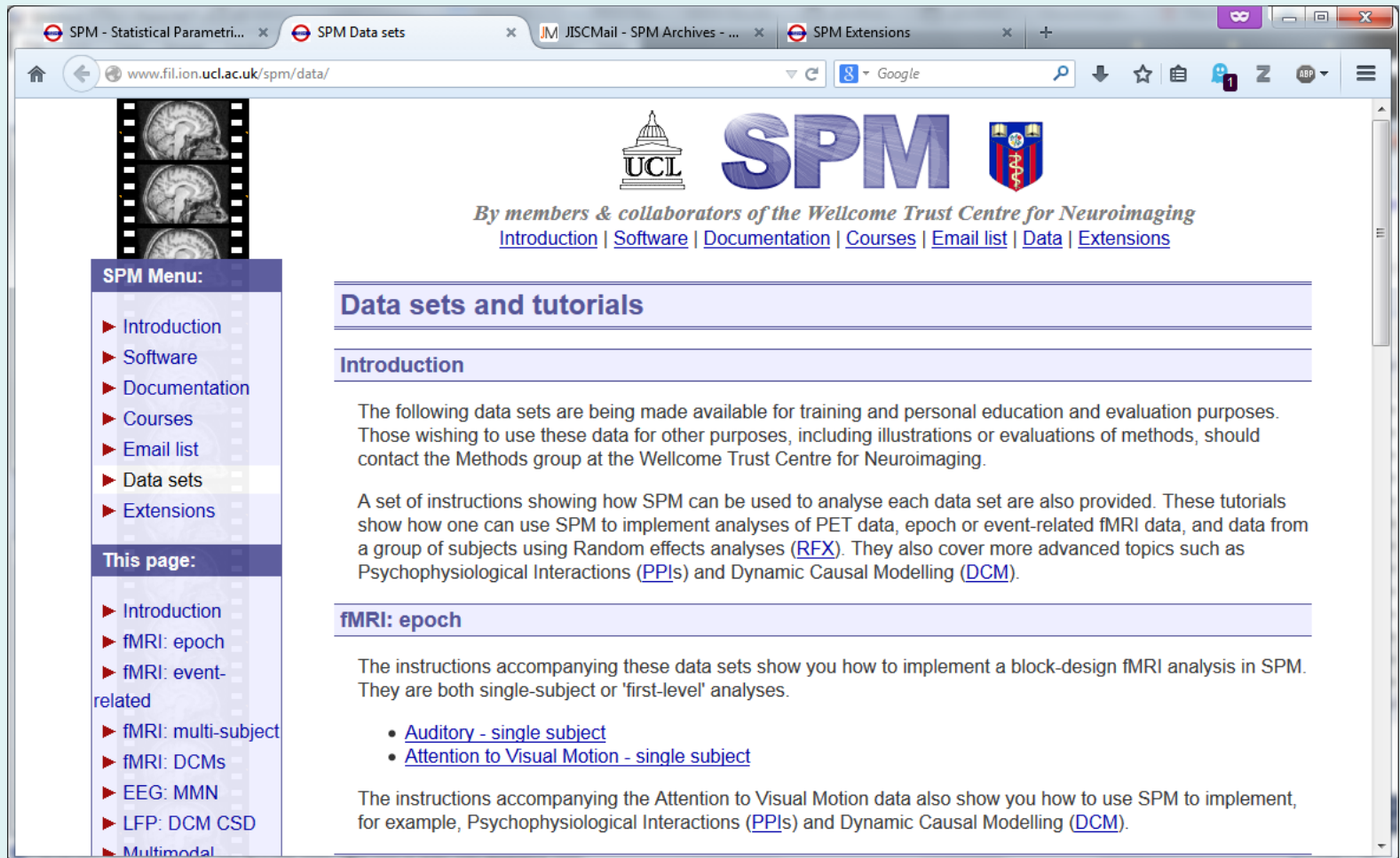
```
% Step 1: MLE estimate of hyperparameters
% Gradient dF/dh (first derivatives)
P = IC - IC*X*Cq*ICX';
U = speye(n) - P*Y*Y/N;
for i = 1:m
    % dF/dh = -trace(dF/dIC*IC*Q(i)*IC)
    PQ(i) = P*Q(i);
    dFdh(i,1) = -spm_trace(PQ(i),U)*M/3;
end
% Expected curvature E(dF/dhh) (second derivatives)
for i = 1:m
    for j = i:m
        % dF/dhh = -trace(P*Q(i)*P*Q(j))
        dFdh(i,j) = -spm_trace(PQ(i),PQ(j))*M/3;
        dFdh(j,i) = dFdh(i,j);
    end
end
```

SPM  
Book



# Statistical Parametric Mapping

## SPM datasets



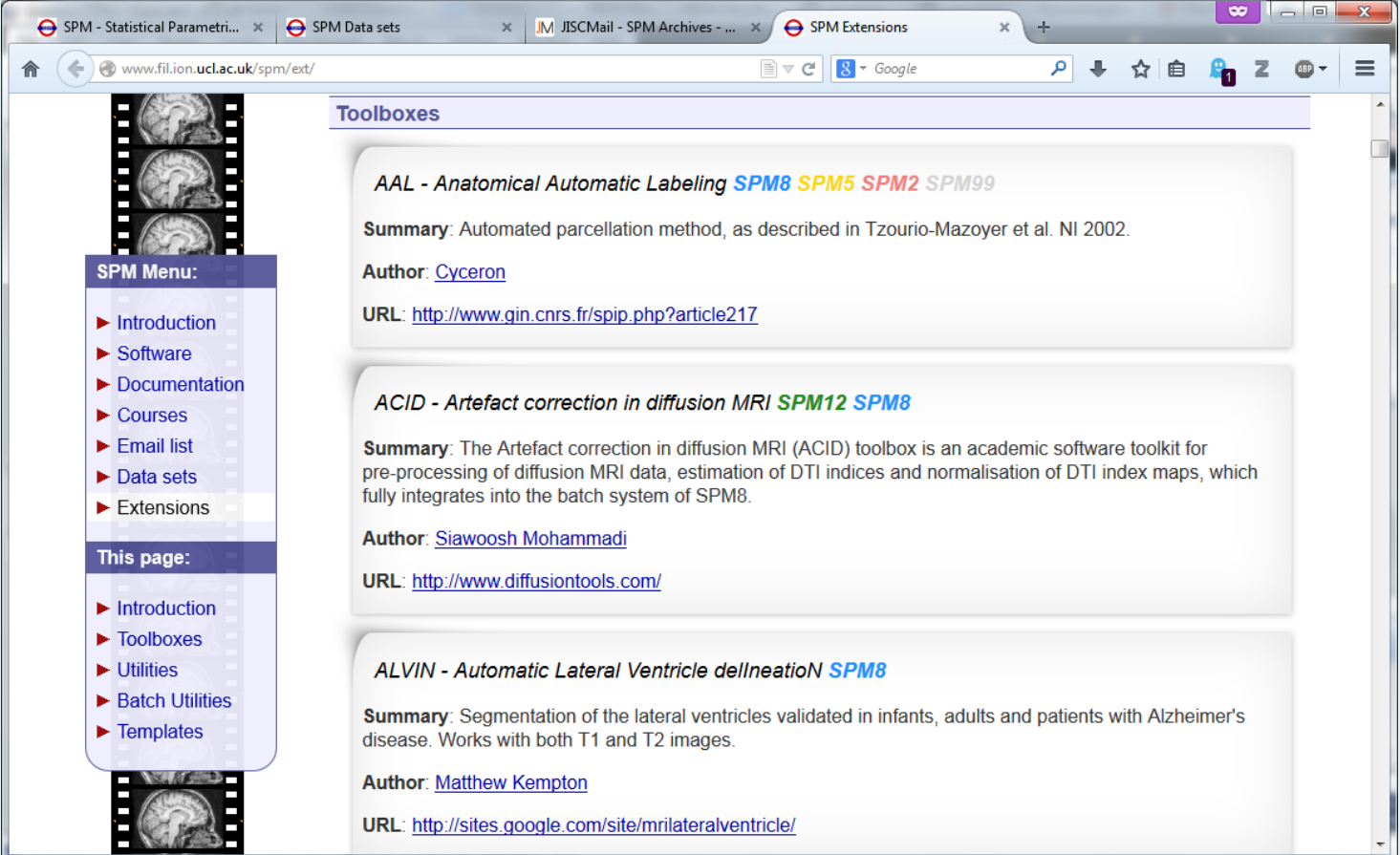
The screenshot shows a web browser window with the URL [www.fil.ion.ucl.ac.uk/spm/data/](http://www.fil.ion.ucl.ac.uk/spm/data/). The page features the SPM logo, the UCL logo, and the Wellcome Trust Centre for Neuroimaging logo. Below the logos, there is a navigation menu with links to Introduction, Software, Documentation, Courses, Email list, Data, and Extensions. The main content area is titled "Data sets and tutorials" and includes an "Introduction" section. The introduction text states: "The following data sets are being made available for training and personal education and evaluation purposes. Those wishing to use these data for other purposes, including illustrations or evaluations of methods, should contact the Methods group at the Wellcome Trust Centre for Neuroimaging." It also mentions that a set of instructions showing how SPM can be used to analyse each data set are also provided. These tutorials show how one can use SPM to implement analyses of PET data, epoch or event-related fMRI data, and data from a group of subjects using Random effects analyses (RFX). They also cover more advanced topics such as Psychophysiological Interactions (PPIs) and Dynamic Causal Modelling (DCM). The "fMRI: epoch" section is highlighted, and it contains the text: "The instructions accompanying these data sets show you how to implement a block-design fMRI analysis in SPM. They are both single-subject or 'first-level' analyses." It lists two data sets: "Auditory - single subject" and "Attention to Visual Motion - single subject". The text also mentions that the instructions accompanying the Attention to Visual Motion data also show you how to use SPM to implement, for example, Psychophysiological Interactions (PPIs) and Dynamic Causal Modelling (DCM).

PET, fMRI (1<sup>st</sup> and 2<sup>nd</sup> level), PPI, DCM, EEG, MEG, LFP.

# Statistical Parametric Mapping

## SPM Toolboxes

User-contributed SPM extensions: <http://www.fil.ion.ucl.ac.uk/spm/ext/>  
+ GitHub now!

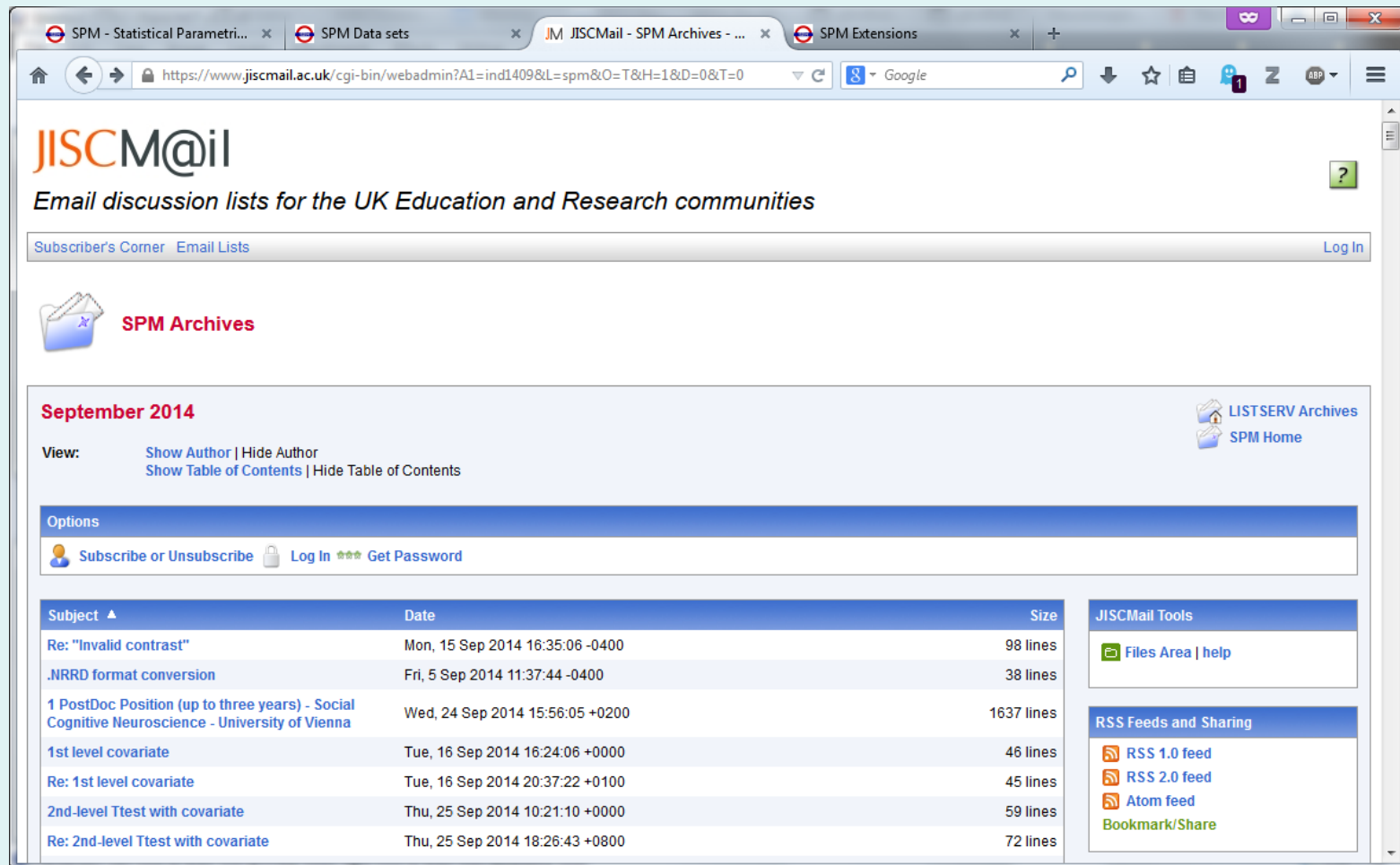


The screenshot shows a web browser window displaying the SPM Extensions website. The browser tabs include 'SPM - Statistical Parametri...', 'SPM Data sets', 'JISCMAIL - SPM Archives - ...', and 'SPM Extensions'. The address bar shows 'www.fil.ion.ucl.ac.uk/spm/ext/'. The website has a navigation menu on the left with 'SPM Menu:' and 'This page:' sections. The main content area is titled 'Toolboxes' and lists three toolboxes:

- AAL - Anatomical Automatic Labeling** [SPM8](#) [SPM5](#) [SPM2](#) [SPM99](#)  
**Summary:** Automated parcellation method, as described in Tzourio-Mazoyer et al. NI 2002.  
**Author:** [Cyceron](#)  
**URL:** <http://www.gin.cnrs.fr/spip.php?article217>
- ACID - Artefact correction in diffusion MRI** [SPM12](#) [SPM8](#)  
**Summary:** The Artefact correction in diffusion MRI (ACID) toolbox is an academic software toolkit for pre-processing of diffusion MRI data, estimation of DTI indices and normalisation of DTI index maps, which fully integrates into the batch system of SPM8.  
**Author:** [Siawoosh Mohammadi](#)  
**URL:** <http://www.diffusiontools.com/>
- ALVIN - Automatic Lateral Ventricle delineation** [SPM8](#)  
**Summary:** Segmentation of the lateral ventricles validated in infants, adults and patients with Alzheimer's disease. Works with both T1 and T2 images.  
**Author:** [Matthew Kempton](#)  
**URL:** <http://sites.google.com/site/mrilateralventricle/>

# Statistical Parametric Mapping

## SPM Mailing List



The screenshot shows a web browser window with the URL <https://www.jiscmail.ac.uk/cgi-bin/webadmin?A1=ind1409&L=spm&O=T&H=1&D=0&T=0>. The page header includes the JISCMAIL logo and the tagline "Email discussion lists for the UK Education and Research communities". Below the header, there are navigation links for "Subscriber's Corner" and "Email Lists", and a "Log In" link. A section titled "SPM Archives" is visible, followed by a "September 2014" header. The main content area displays a list of email messages with columns for "Subject", "Date", and "Size". To the right of the message list, there are sections for "JISCMAIL Tools" (including "Files Area | help") and "RSS Feeds and Sharing" (including "RSS 1.0 feed", "RSS 2.0 feed", "Atom feed", and "Bookmark/Share").

**September 2014**

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[Show Table of Contents](#) | [Hide Table of Contents](#)

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Subject	Date	Size
Re: "Invalid contrast"	Mon, 15 Sep 2014 16:35:06 -0400	98 lines
.NRRD format conversion	Fri, 5 Sep 2014 11:37:44 -0400	38 lines
1 PostDoc Position (up to three years) - Social Cognitive Neuroscience - University of Vienna	Wed, 24 Sep 2014 15:56:05 +0200	1637 lines
1st level covariate	Tue, 16 Sep 2014 16:24:06 +0000	46 lines
Re: 1st level covariate	Tue, 16 Sep 2014 20:37:22 +0100	45 lines
2nd-level Ttest with covariate	Thu, 25 Sep 2014 10:21:10 +0000	59 lines
Re: 2nd-level Ttest with covariate	Thu, 25 Sep 2014 18:26:43 +0800	72 lines

JISCMAIL Tools  
[Files Area | help](#)

RSS Feeds and Sharing  
[RSS 1.0 feed](#)  
[RSS 2.0 feed](#)  
[Atom feed](#)  
[Bookmark/Share](#)



# SPM co-authors

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- Guillaume Flandin
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- Darren Gitelman
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- Rik Henson
- Andrew Holmes
- Chloe Hutton
- Maria Joao
- Stefan Kiebel
- James Kilner
- Oliwia Kowalczyk
- Vladimir Litvak
- Andre Marreiros
- J r mie Mattout
- Rosalyn Moran
- Tom Nichols
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- Will Penny
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- Jean-Baptiste Poline
- Ged Ridgway
- Holly Rossiter
- Mohamed Seghier
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- Sungho Tak
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# Open Science

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- Open Methodology
- Open Source
- Open Data
- Open Access
- Open Peer Review
- Open Educational Resources

