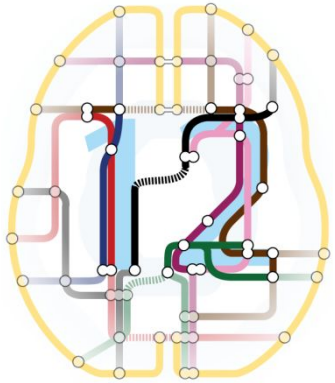
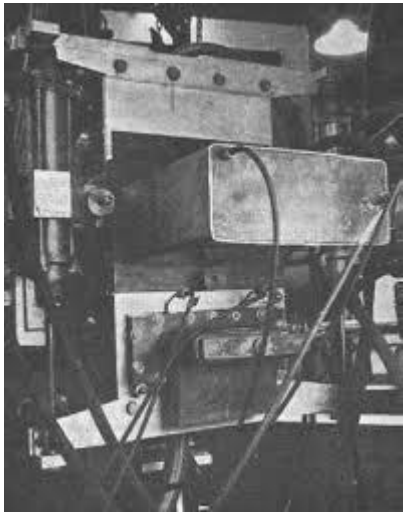


SPM in a nutshell

All the relevant information about SPM

in less than 15 slides

The Birth of SPM (1991)



Historical Context

- Developed by Karl Friston at MRC Cyclotron Unit, London
- Originally for PET; Addressed ROI limitations
- First whole-brain statistical analysis

Revolutionary Concepts

- Statistical parametric mapping
- Voxel-wise testing
- Subtraction images & t-maps
- "Glass brains"
- Foundation for modern analysis.

SPM Evolution Timeline

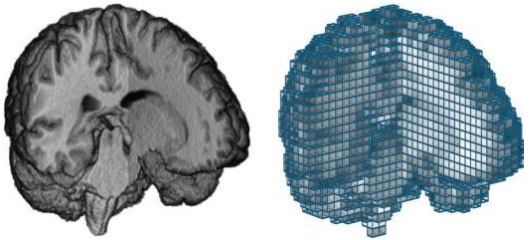
Open source software

- Developed on GitHub
  - https://github.com/spm

Past

- **SPM91** (SPMclassic): Original PET analysis, 33,500 lines of MATLAB code
- **SPM94:** Complete rewrite, 5,700 lines, unified GLM framework, GUI interface
- **SPM95/96:** fMRI support, motion correction, improved registration
- **SPM99:** Enhanced statistical inference, Random Field Theory integration
- **SPM2 (2003):** Improved normalization, VBM introduction
- **SPM5 (2005):** Unified segmentation, improved preprocessing
- **SPM8 (2009):** DARTEL registration, enhanced statistical methods
- **SPM12 (2014):** Modern interface, improved algorithms, 10-year stability
- **SPM25 (2025):** GitHub development, Python support, new toolboxes

Core SPM Principles & Theory



Statistical Framework:

- General Linear Model (GLM) at each voxel
- Parametric statistical testing
- Multiple comparisons correction

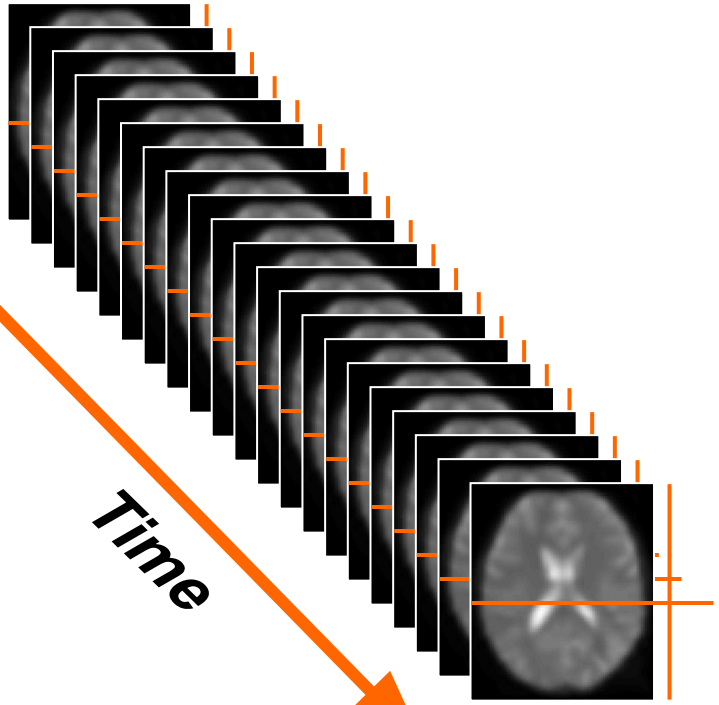
Spatial Processing

- Image registration and normalization
- Spatial smoothing for signal enhancement
- Template-based standardization
- Motion correction and artifact removal

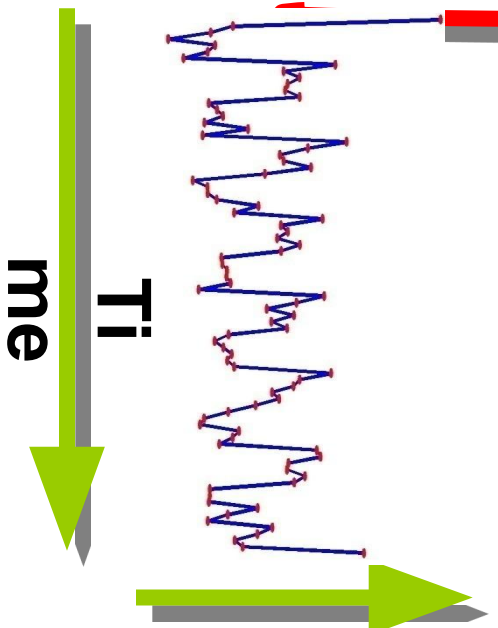
Generative Modeling

- Model-based statistical inference
- Haemodynamic response function modeling
- Convolution with experimental design
- Bayesian statistical approaches

Voxel-wise time series analysis



single voxel time series

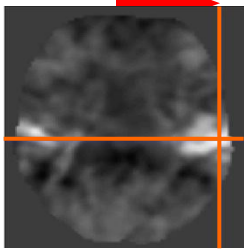


Model specification

Parameter estimation

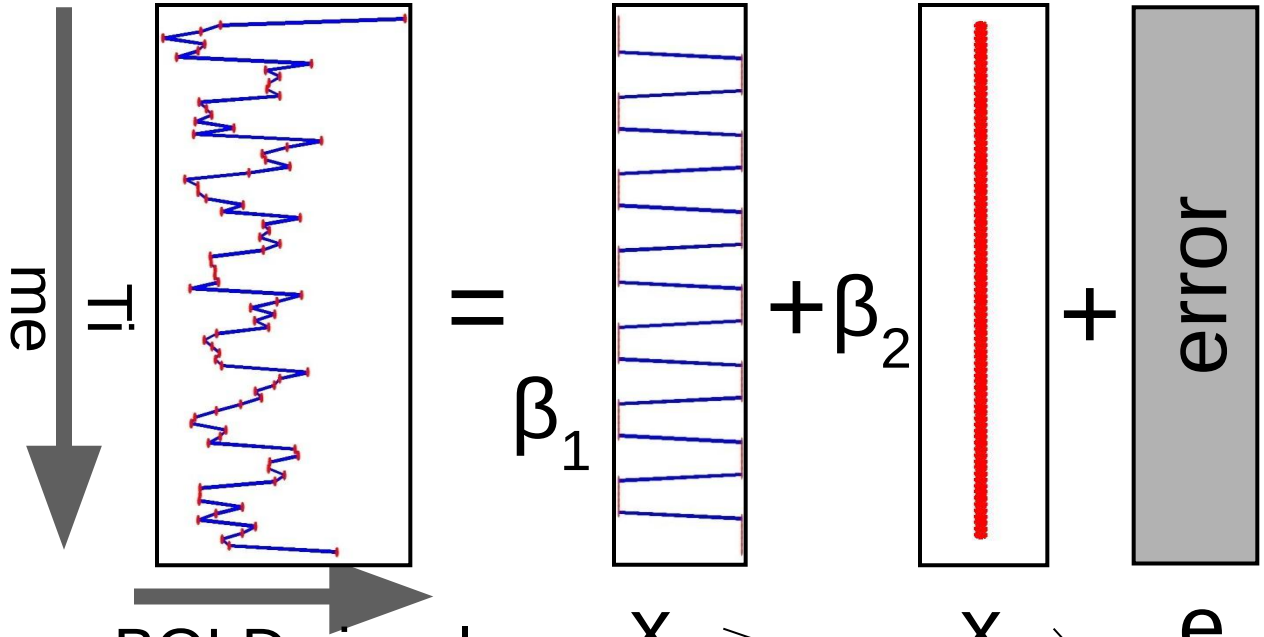
Hypothesis

Statistic



SPM

Single voxel regression model



What Makes SPM Unique?

SPM Philosophy

- Mass-univariate approach (test at every voxel)
- Parametric statistical methods
- Model-based inference
- Topological inference using Random Field Theory
- Open science and collaborative development

Key Advantages

- Comprehensive statistical framework
- Rigorous multiple comparisons correction
- Flexible experimental design support
- Extensive validation and theoretical foundation
- Large user community and extensive documentation

SPM Software Architecture

Core Components

- Spatial Processing: Realignment, normalization, smoothing
- Statistical Modeling: GLM specification and estimation
- Results & Inference: Statistical maps and visualization
- Specialized Toolboxes: VBM, DCM, connectivity analysis

User Interface

- Graphical User Interface (GUI) for interactive analysis
- Batch processing for automated workflows
- Command-line scripting for advanced users
- Integration with MATLAB ecosystem

The Preprocessing Pipeline

Data Import & Quality Check - DICOM conversion, visual inspection

Realignment - Motion correction using rigid-body registration

Slice Timing Correction - Account for acquisition timing differences

Coregistration - Align functional and structural images

Segmentation - Tissue classification (GM, WM, CSF)

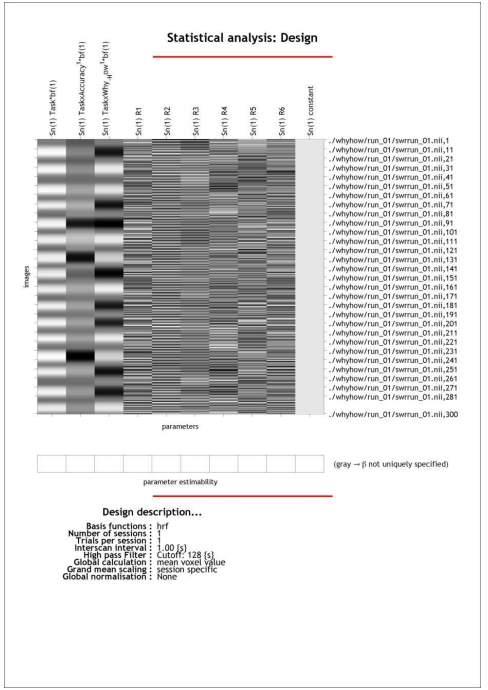
Normalization - Transform to standard MNI space

Smoothing - Spatial filtering (typically 6-8mm FWHM)

First-Level Analysis (Subject Level Analysis)

Design Matrix Specification

- Experimental conditions and timing
- Haemodynamic response function convolution
- Motion parameters as nuisance regressors
- Temporal derivatives and basis functions



Model Estimation

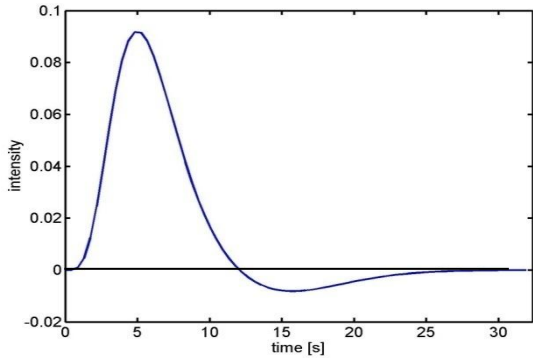
- GLM parameter estimation at each voxel
- Maximum likelihood or ReML estimation
- Temporal autocorrelation modeling
- Residual analysis for model validation

Statistical Inference

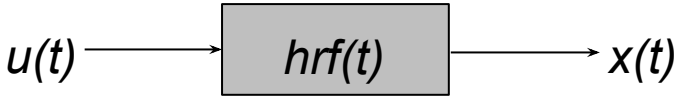
- Contrast specification for hypothesis testing
- T-statistics and F-statistics computation
- Parameter estimate maps (beta images)
- Statistical parametric maps
    - (SPM{T}, SPM{F})

Problem 1: BOLD response

Hemodynamic response function (HRF):



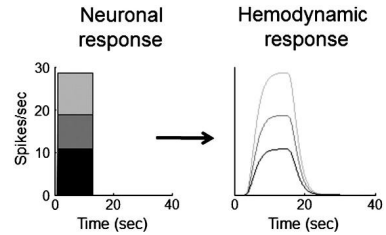
Linear time-invariant (LTI) system:



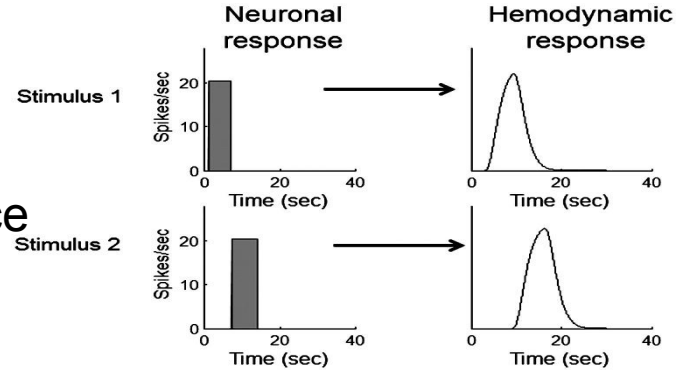
Convolution operator:

$$x(t) = u(t) * hrf(t)$$
$$= \int_o^t u(\tau) hrf(t-\tau) d\tau$$

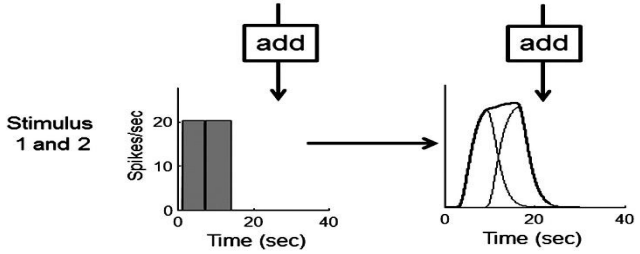
Scaling



Shift invariance



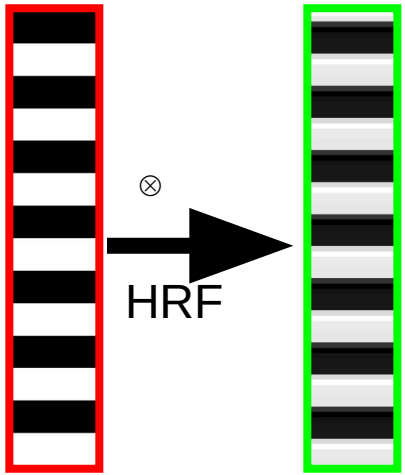
Additivity

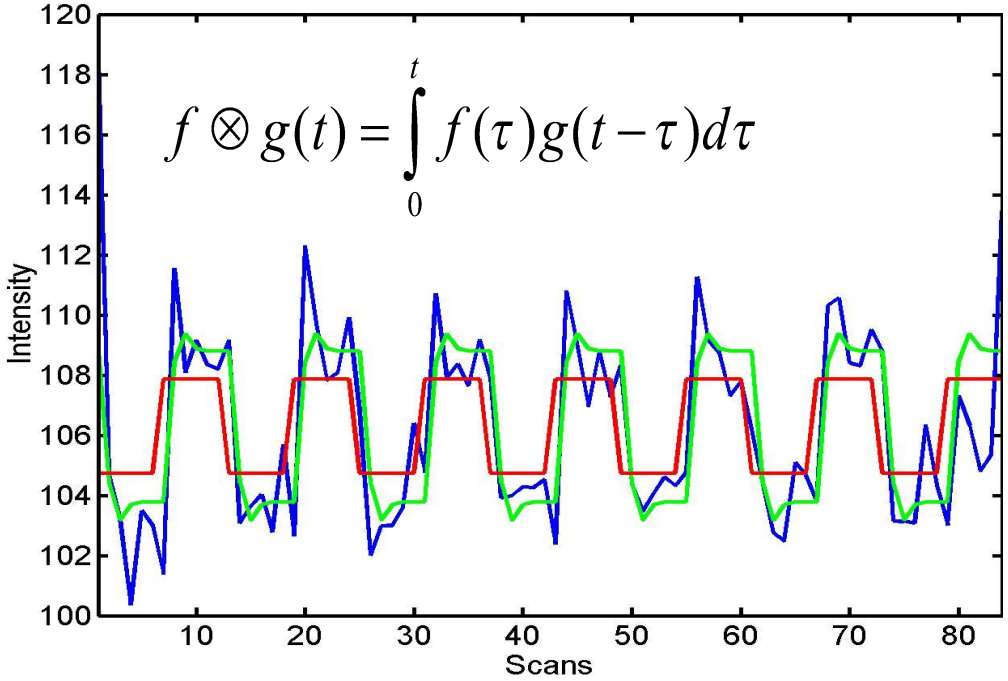


Boynton et al, NeuroImage, 2012.

Convolution model of the BOLD response

Convolve stimulus function with a canonical hemodynamic response function (HRF):

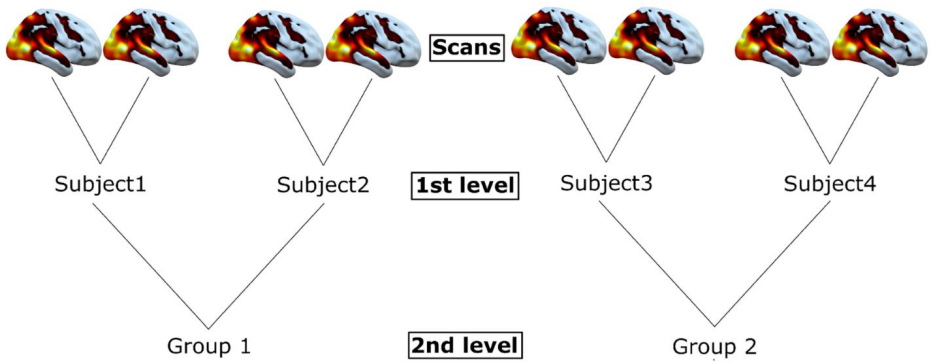




Second-Level Analysis (Group Level Analysis)

Fixed vs. Random Effects:

- **Fixed Effects:** Within-subject consistency
- **Random Effects:** Population-level inference
- **Mixed Effects:** Hierarchical modeling



Analysis Types:

- **One-sample t-tests:** Activation vs. baseline
- **Two-sample t-tests:** Between-group comparisons
- **Paired t-tests:** Within-subject contrasts
- **ANOVA:** Multiple factors and interactions
- **Regression:** Continuous covariates and correlations

Image source: https://emotion.utu.fi/wp-content/uploads/2023/09/TUE_6_SS_2ND.pdf

Best Practices & Common Pitfalls

Best Practices:

- Always inspect data quality before preprocessing
- Use appropriate smoothing kernels for your data
- Validate coregistration and normalization accuracy
- Check design matrix for proper specification
- Apply appropriate multiple comparisons correction
- Document analysis parameters for reproducibility

Common Pitfalls to Avoid:

- Ignoring motion artifacts in data
- Over-smoothing high-resolution data
- Inappropriate statistical thresholds
- Circular analysis (double-dipping)
- Inadequate sample sizes for group studies
- Misinterpreting correlation vs. causation

Useful Links

- Official SPM courses
  - SPM team is regularly offering on-site and online courses
  - Also releasing the documents almost always!
  - Link: https://www.fil.ion.ucl.ac.uk/spm/course/
- Andrew Jahn - Andy's Brain Book
  - Andy has been constructing neuroimaging tutorials; in SPM, FSL, well you name it!
  - Webpage: https://andysbrainbook.readthedocs.io/en/latest/SPM/SPM_Overview.html
  - Youtube: https://www.youtube.com/channel/UCh9KmApDY_z_Zom3x9xrEQw