Introduction to fMRI Data Analysis

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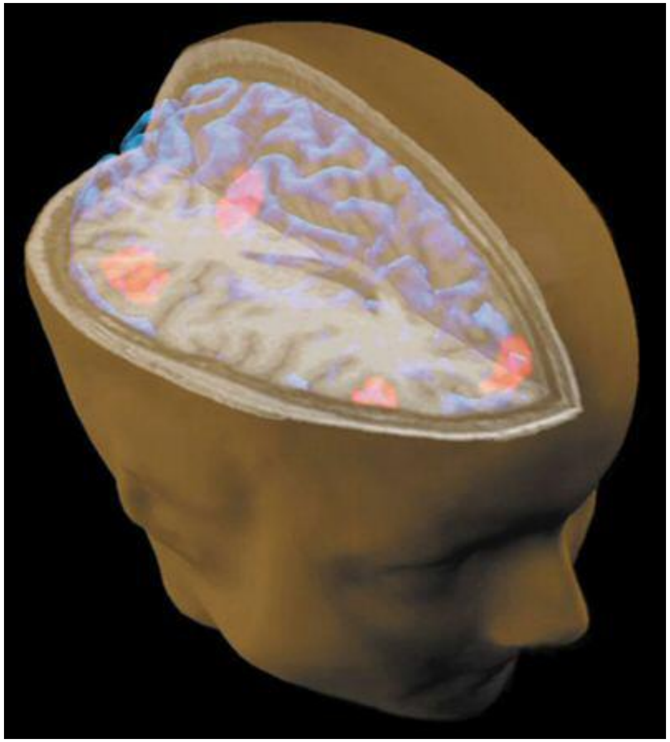

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Research Interests

- **Functional Neuroimaging (fMRI)**
- **MRI Physics & Pulse Sequence Developments**
- **Medical Signal & Image Processing**
- **Pattern Recognition & Neural Networks**


آزمایشگاه ملی نقشه‌برداری مغز
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اردیبهشت‌ماه ۱۳۹۹
۱
دوشنبه
ساعت: ۱۳ الی ۱۴
با موضوع
اصول فیزیک و مهندسی fMRI
سخنران
دکتر وحید ملکیان
لینک حضور در وبینار از طریق ایمیل ارسال خواهد شد.
در پایان وبینار از طرف سخنران ۲ سوال طرح می‌شود
به دونفر از کسانی که پاسخ درست ارائه کنند
۱ساعت استفاده رایگان از خدمات آزمایشگاه داده خواهد شد.
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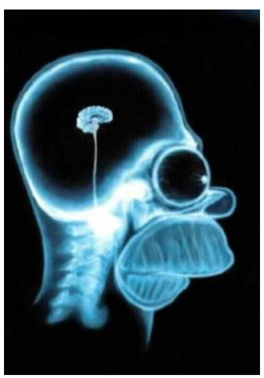
Outline

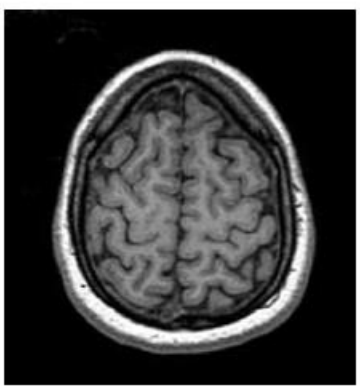
- Introduction
- Preprocessing
- Data Analysis
- Result Representation

sMRI & fMRI

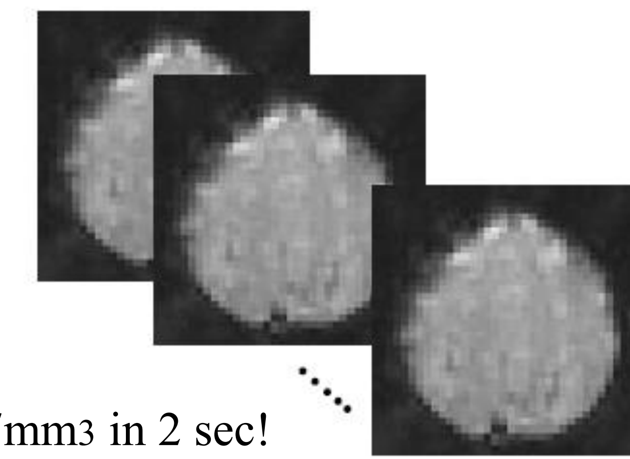
- sMRI studies brain anatomy.
  - High spatial resolution
  - Can distinguish different types of tissue

- fMRI studies brain function.
  - Functional images
  - Lower spatial resolution/ Higher temporal resolution





$1mm^3$ in 4 min!

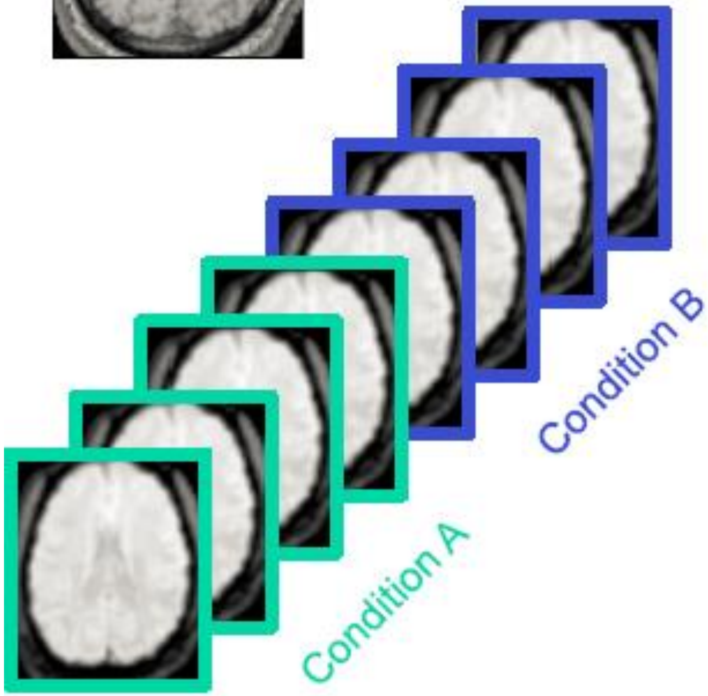


$27mm^3$ in 2 sec!

fMRI Data Acquisition

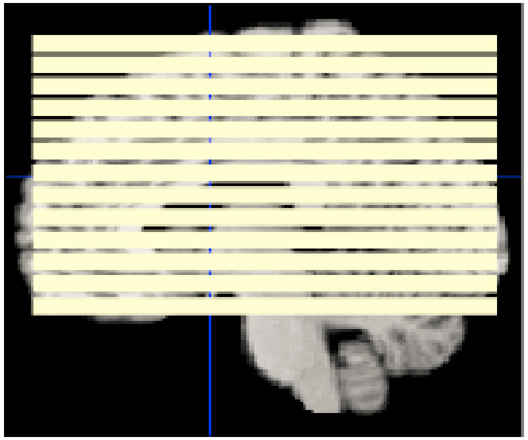
- Structural (T1) images:
  - High spatial resolution
  - Low temporal resolution
  - Can distinguish different types of tissue

- Functional (T2*) images:
  - Lower spatial resolution
  - Higher temporal resolution
  - Can relate changes in signal to an experimental manipulation



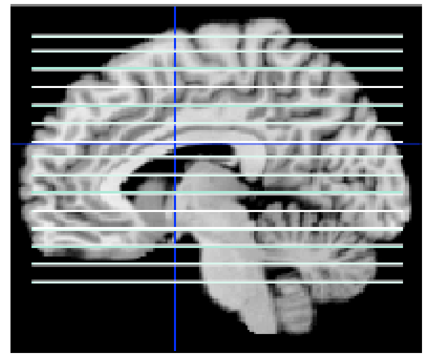
Terminology

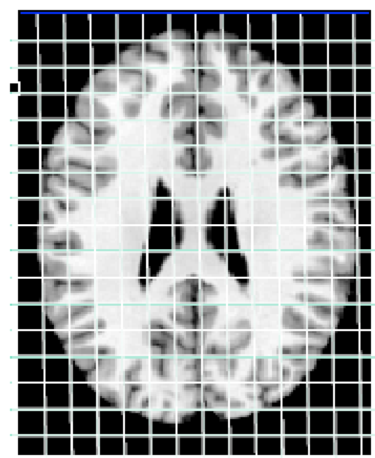
- MRI images are typically acquired in axial slices - one at a time.
- This can be performed in either a sequential or interleaved manner.
- Together the slices make up a 3 dimensional brain volume.



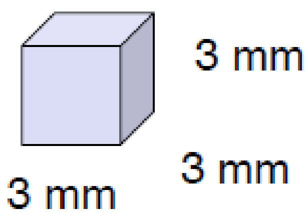
Terminology

- Field of View (FOV)
  - (e.g. 192 mm)
- Matrix Size
  - (e.g., 64 x 64)
- In-plane resolution
  - 192 mm / 64 = 3 mm
- Slice thickness
  - (e.g., 3 mm)
- Voxel Size
  - 3*3*3 mm



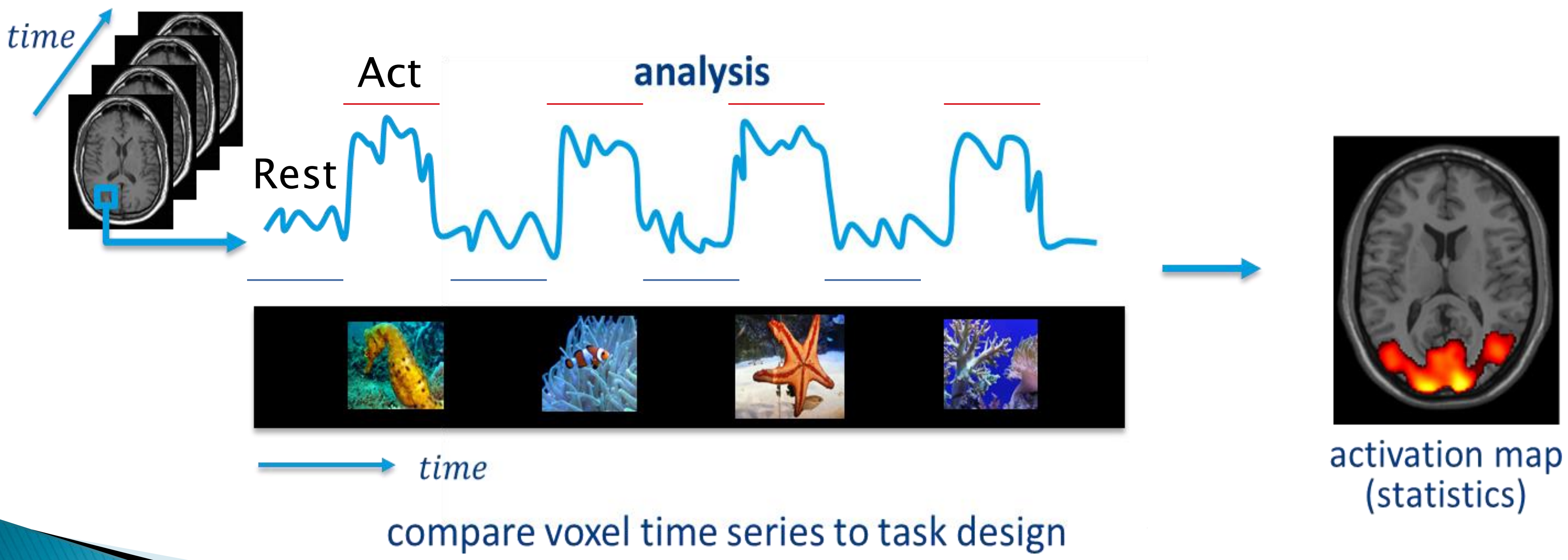


64*64*35 Voxels



fMRI Experiment

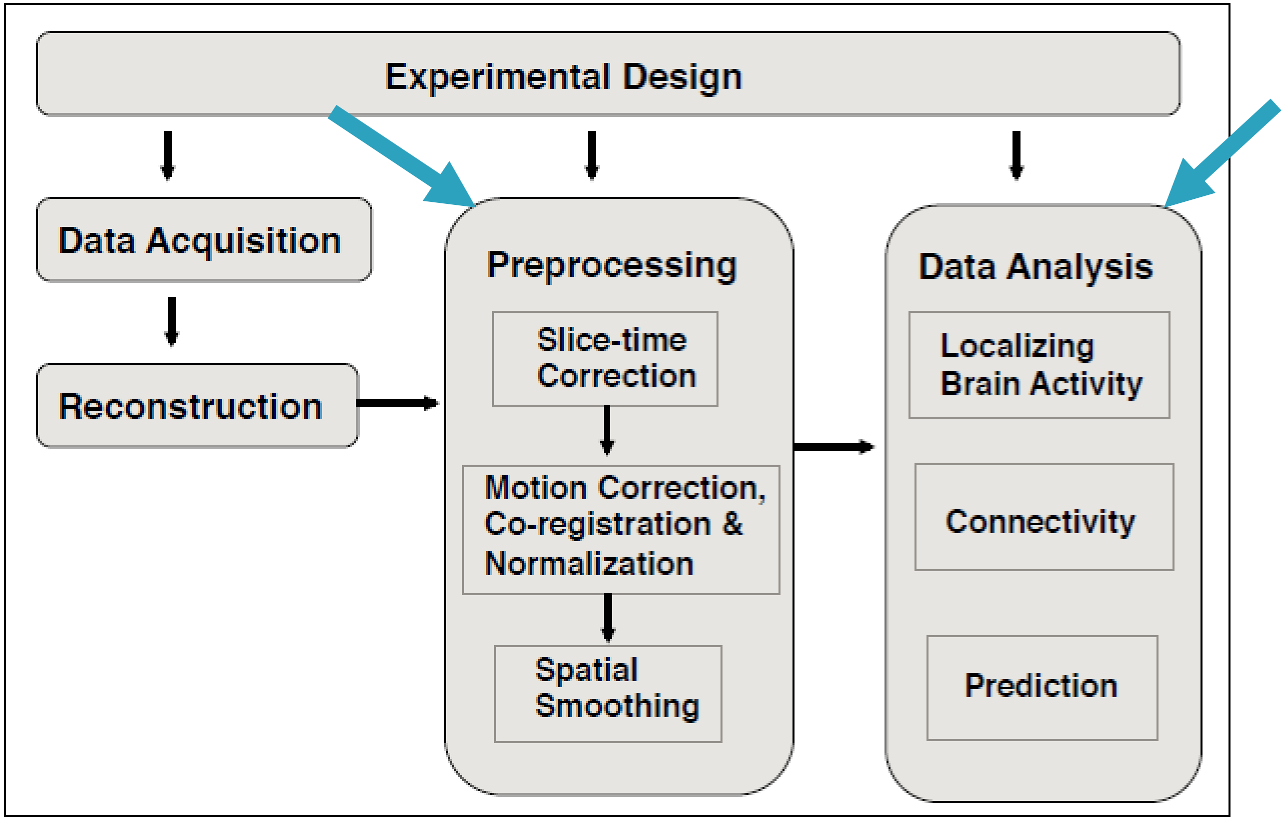
- An fMRI experiment consists of a sequence of individual MR images, where one can study oxygenation changes in the brain across time



Pipeline

Task

Protocol



Processing

Pre-processing

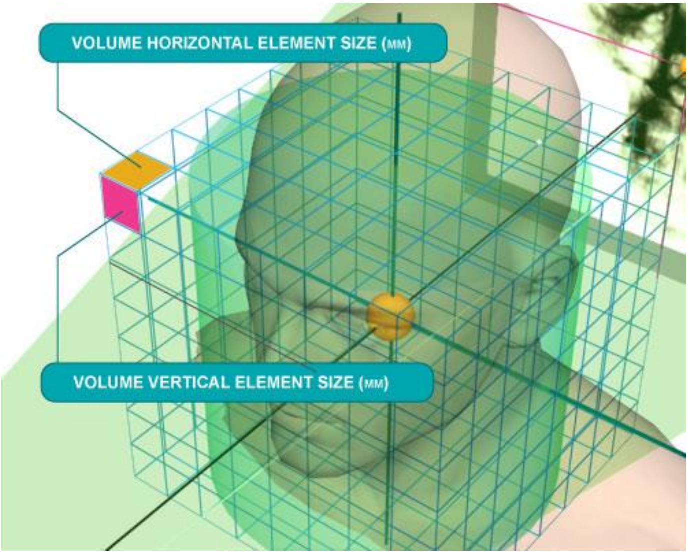
- Prior to analysis, fMRI data undergoes a series of preprocessing steps aimed at identifying and removing artifacts and validating model assumptions.

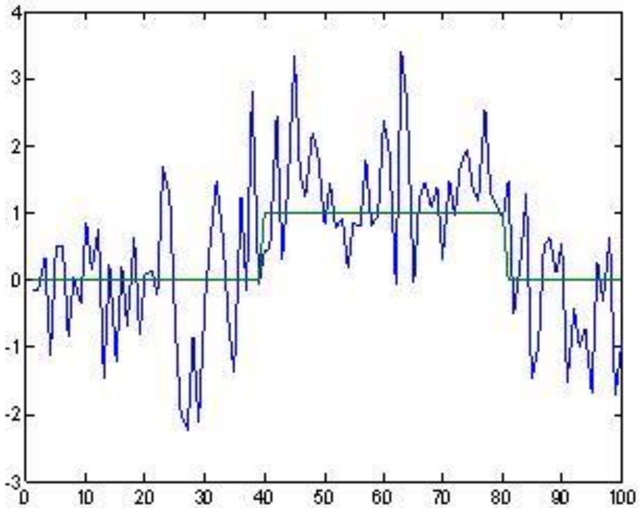
- The goals of preprocessing are

  - To minimize the influence of data acquisition and physiological artifacts;
  - To check statistical assumptions and transform the data to meet assumptions;
  - To standardize the locations of brain regions across subjects to achieve validity and sensitivity in group analysis.

fMRI Noise

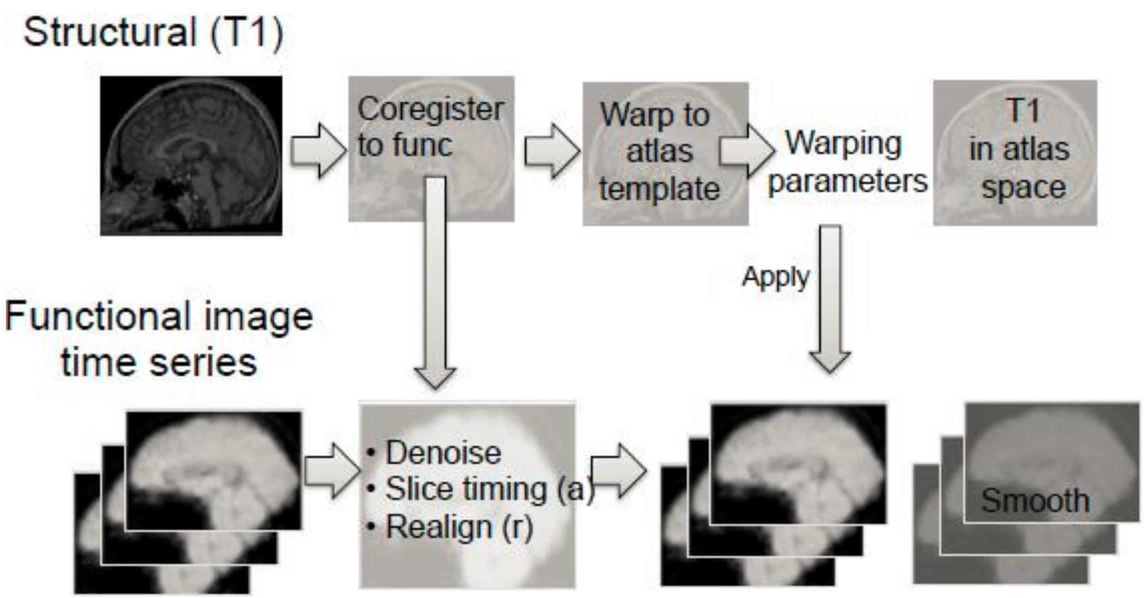
- Sources of noise
  - Thermal motion of free electrons in the system.
  - Low frequency signal drift.
  - Patient movement during the experiment.
  - Physiological effects: subject's heartbeat and respiration.





Pre-processing Pipeline

- Preprocessing is performed both on the fMRI data and structural scans collected prior to the experiment.

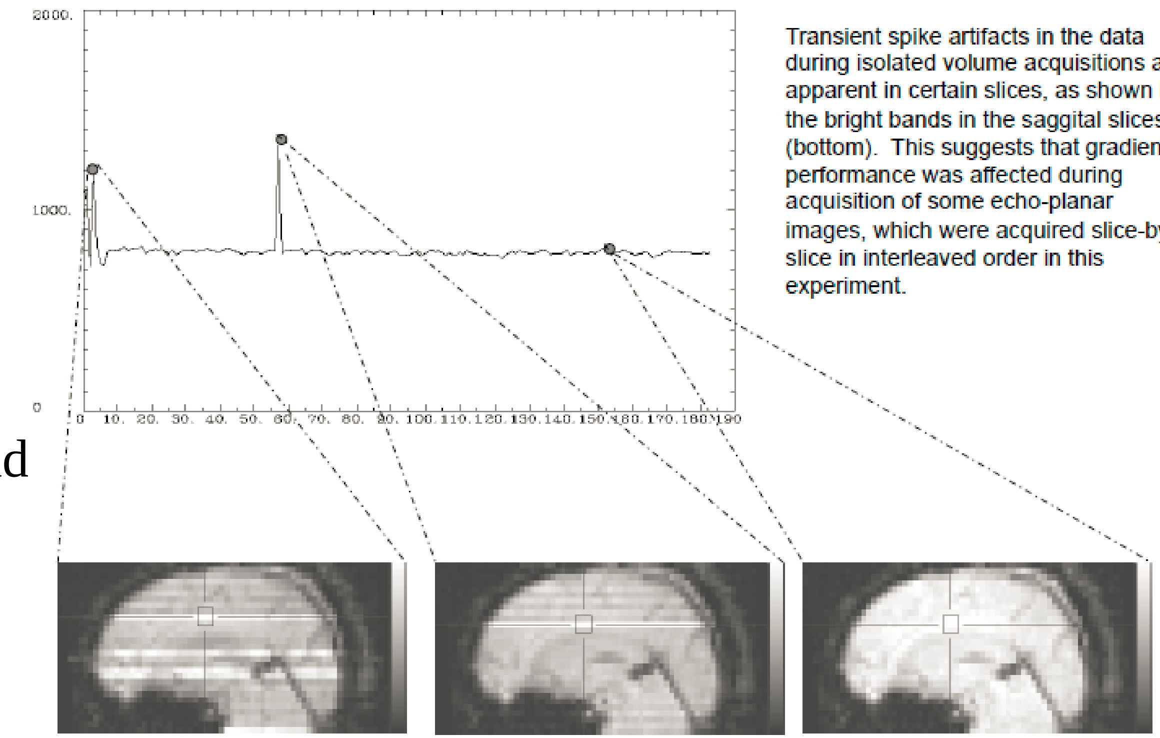


Pre-processing Steps

- Visualization and Artifact Removal
- Slice Time Correction
- Motion Correction
- Physiological Corrections
- Co-registration
- Normalization
- Spatial Filtering
- Temporal Filtering

Visualization & Artifact Removal

- Investigate the raw image data and detect possible problems and artifacts.
- fMRI data often contain transient spike artifacts and slow drift over time.



Transient spike artifacts in the data during isolated volume acquisitions are apparent in certain slices, as shown by the bright bands in the saggital slices (bottom). This suggests that gradient performance was affected during acquisition of some echo-planar images, which were acquired slice-by-slice in interleaved order in this experiment.

Easy but Important!

Slice Time Correction

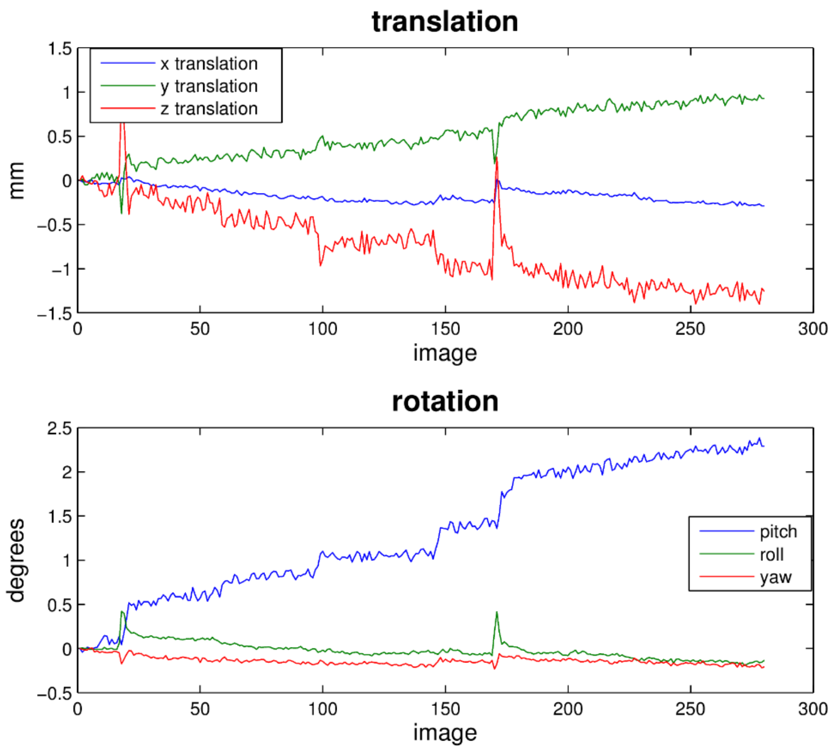
- Almost all FMRI scanning takes each slice separately
- Each slice is scanned at a slightly different time
- Slice order can be interleaved or sequential (up or down)

Slice Time Correction

- Temporal Interpolation
  - Use information from nearby time points to estimate the amplitude of the MR signal at the onset of the TR."
- Phase Shift
  - Slide the time course by applying a phase shift to the Fourier transform of the time course.

Head Motion

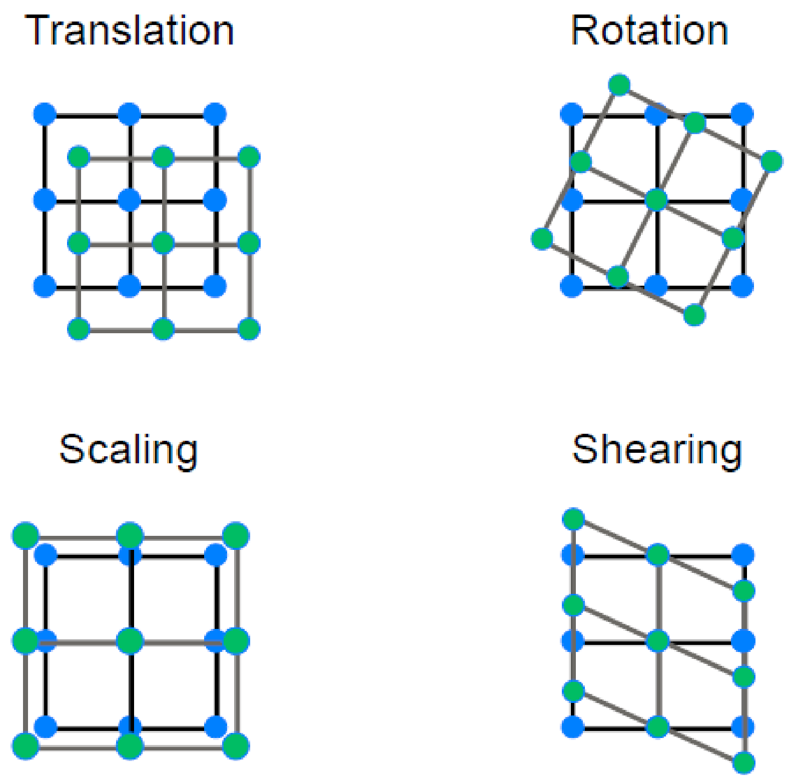
- Very small movements of the head during an experiment can be a major source of error if not treated correctly.
- When analyzing the time series associated with a voxel, we assume that it depicts the same region of the brain at every time point
  - Head motion may make this assumption incorrect.
- Can be corrected using a rigid body transformation.



Head Motion

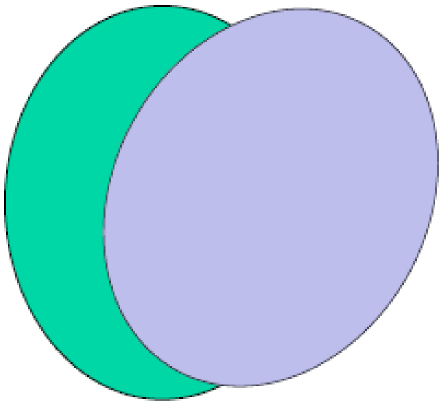
- The goal is to find the best possible alignment between an input image and some target images.
- To align the two images, one of them needs to be transformed.
- A rigid body transformation is used.
- It involves 6 variable parameters, 3 sets of translations and 3 sets of rotations (6 DOF).

- Linear transformations
  - Rigid body (6 DOF) – translation and rotation
  - Similarity (7 DOF) – translation, rotation and a single global scaling
  - Affine (12 DOF) – translation, rotation, scaling and shearing.
- Warping
  - Transformations where the equations relating the coordinates of the images are non-linear.



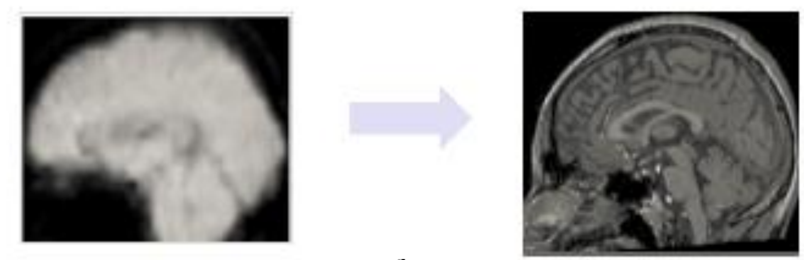
Head Motion

- The target image is usually defined to be the first (or mean) image in the fMRI time series.
- The goal is to find the set of parameters which minimizes some cost function that assesses similarity between the image and the target.
- Examples of cost functions include the sum of squared differences or mutual information.

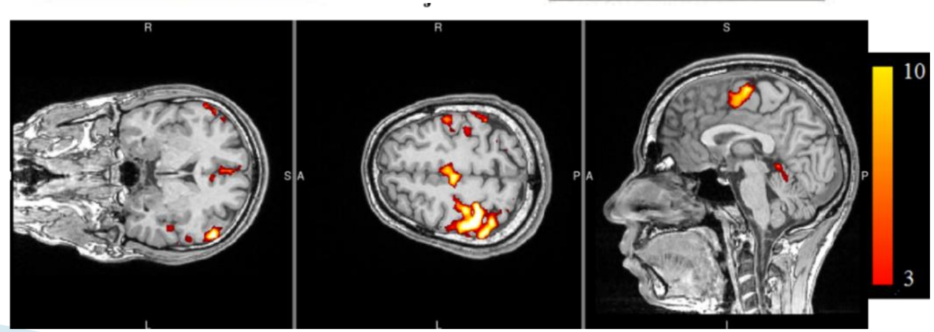


Co-registration

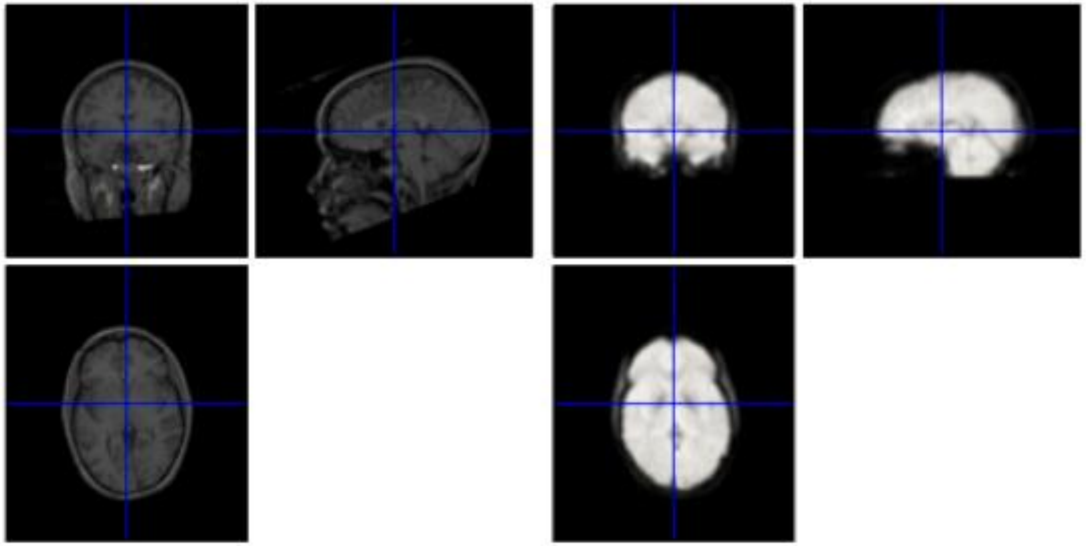
- A structural MRI collected in the beginning of the session is registered to the fMRI images in a process referred to as co-registration.
  – Allows one to visualize single-subject task activations overlaid on the individual's anatomical information.
  – Simplifies later transformation of the fMRI images to a standard coordinate system.



Activation Map

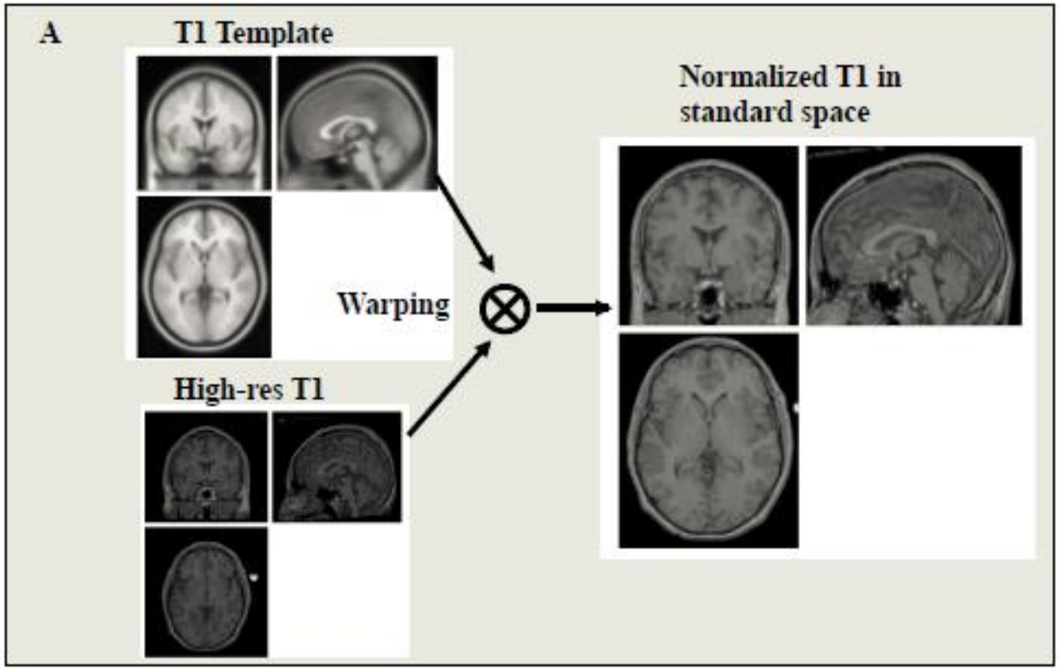


- There are certain key differences between co-registration and motion correction.
  - Functional and structural images do not have the same signal intensity in the same areas.
    - They cannot be subtracted.
  - Their shapes may differ!
- Use at least an affine transformation (12 DOF).



Normalization

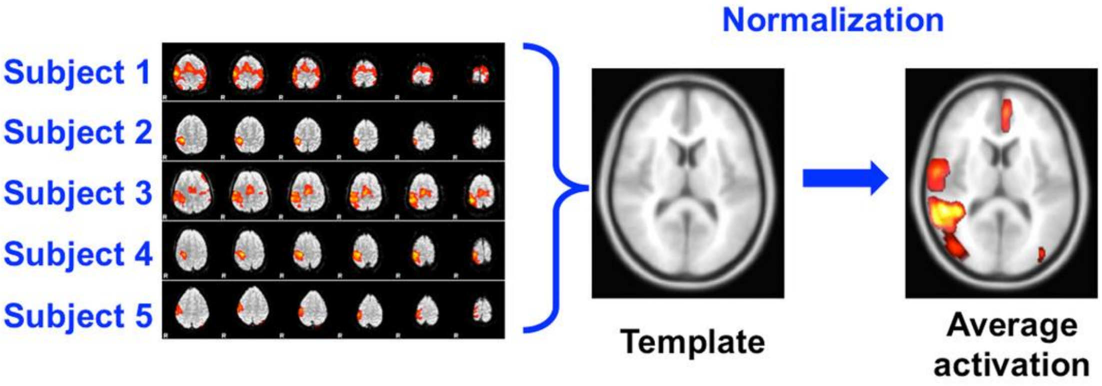
- Normalization allows one to stretch, squeeze and warp each brain so that it is the same as some standard brain.
- The structural MR image used in the co-registration procedure is warped onto a template image.



Normalization

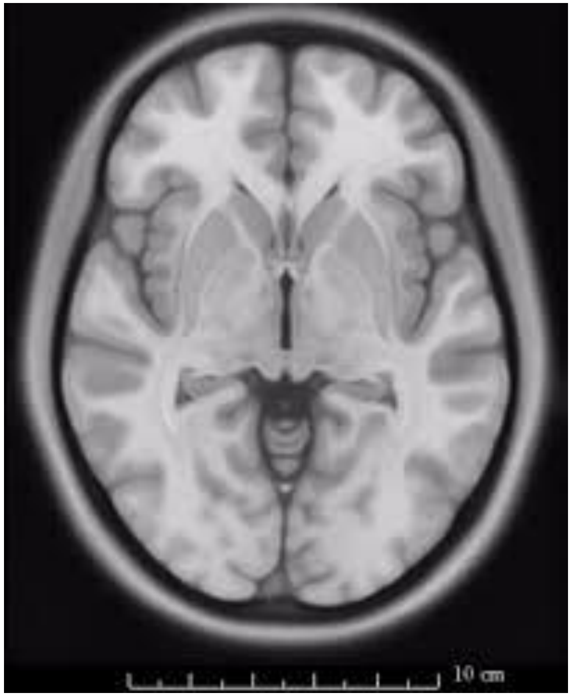
- Pros
  - Spatial locations can be reported and interpreted in a consistent manner.
  - Results can be generalized to larger population
  - Results can be compared across studies
  - Results can be averaged across subjects

- Cons
  - Reduces spatial resolution.
  - Introduces potential errors.



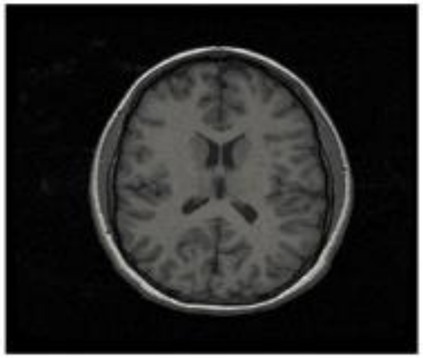
Brain Atlases

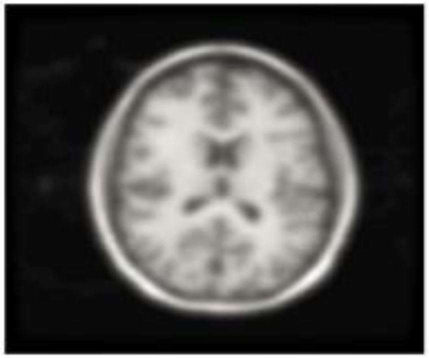
- Montreal Neurological Institute (MNI)
  - Combination of many MRI scans on normal controls (152 in current standard).
  - All right-handed subjects.
  - More representative of population.



Spatial and Temporal Filtering

- In fMRI it is common to spatially smooth the acquired data prior to statistical analysis.
- Can increase signal-to-noise, validate distributional assumptions and remove artifacts.





- Pros
  - May overcome limitations in the normalization by blurring any residual anatomical differences.
  - Could increase the signal-to-noise ratio (SNR).
  - May increase the validity of the statistical analysis.
- Cons
  - The image resolution is reduced.

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Efficient de-noising of high-resolution fMRI using local and sub-band information

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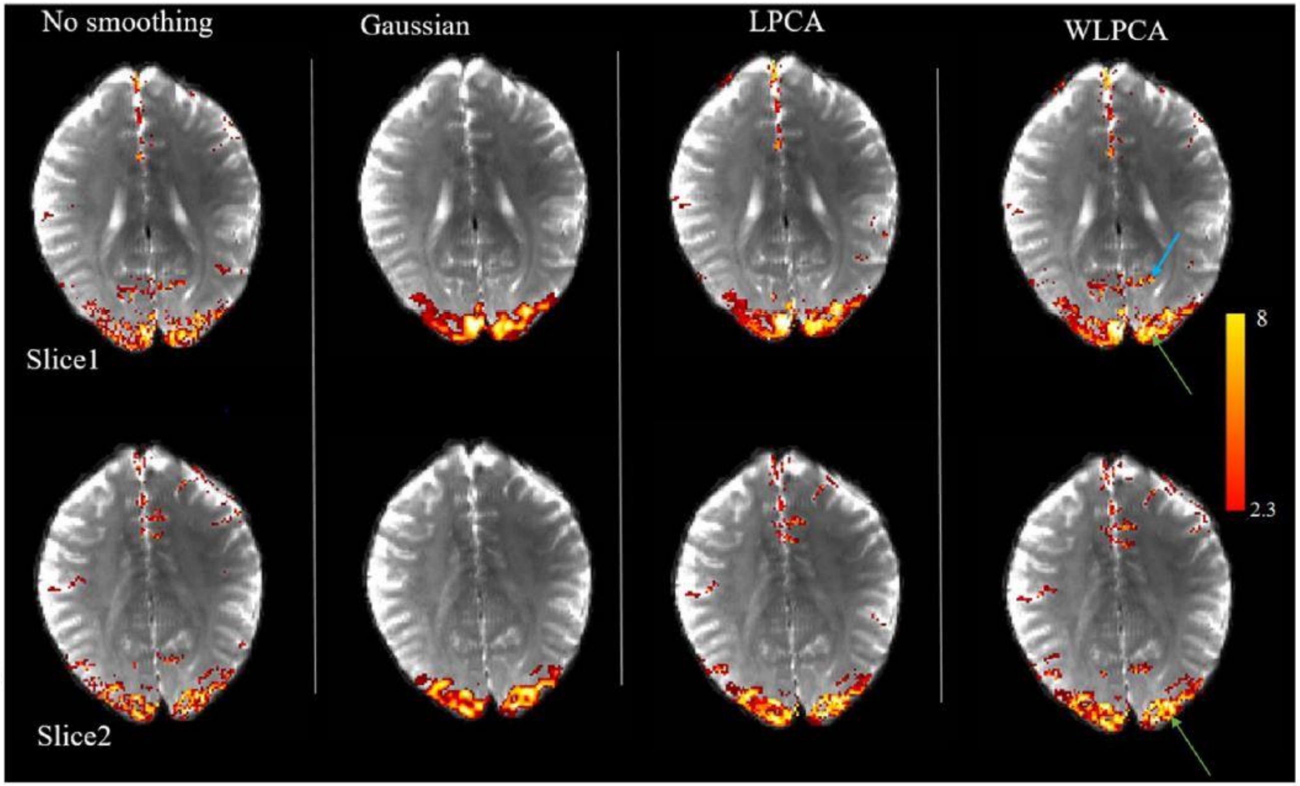
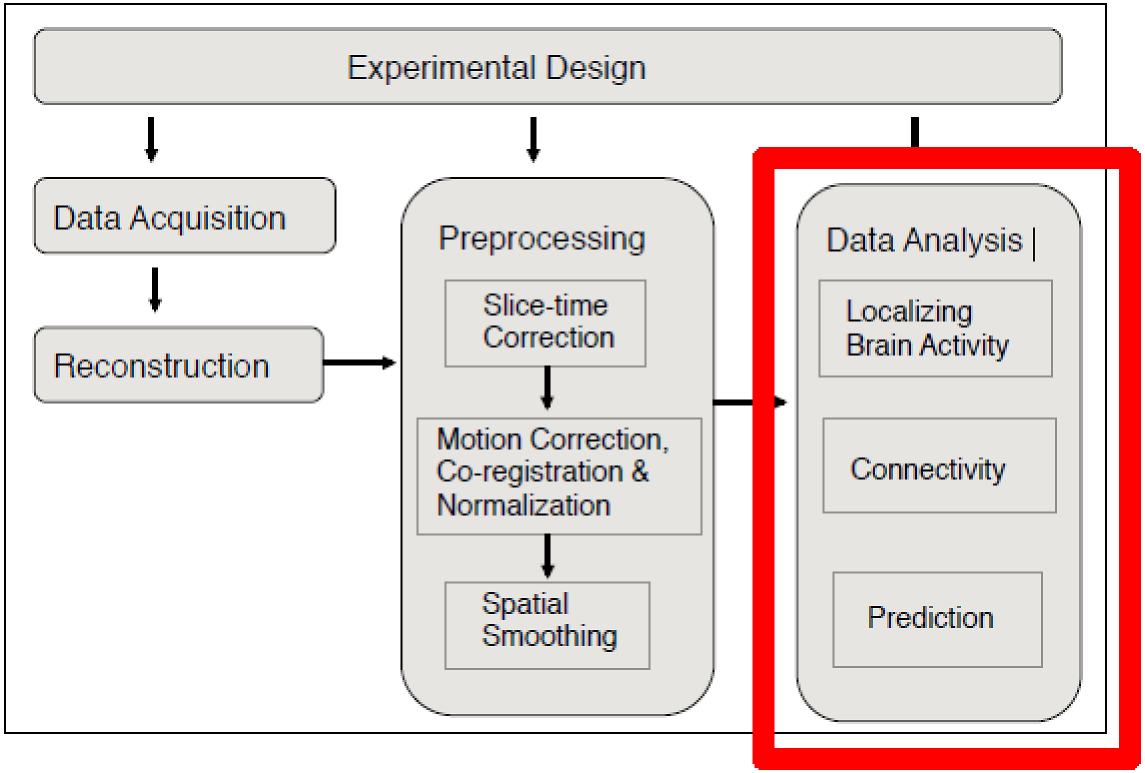


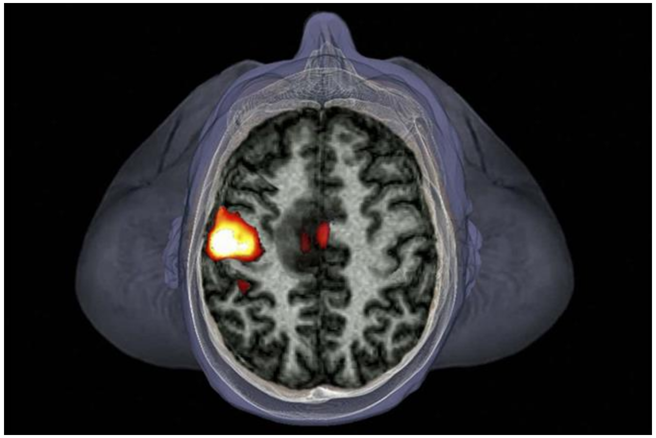
Data Analysis



Statistical Analysis

- There are multiple goals in the statistical analysis of fMRI data.

- They include:
  - localizing brain areas activated by the task;
  - determining networks corresponding to brain function;



Introducing The GLM

DATA = MODEL + ERROR

DATA = KNOWN * UNKNOWN + ERROR

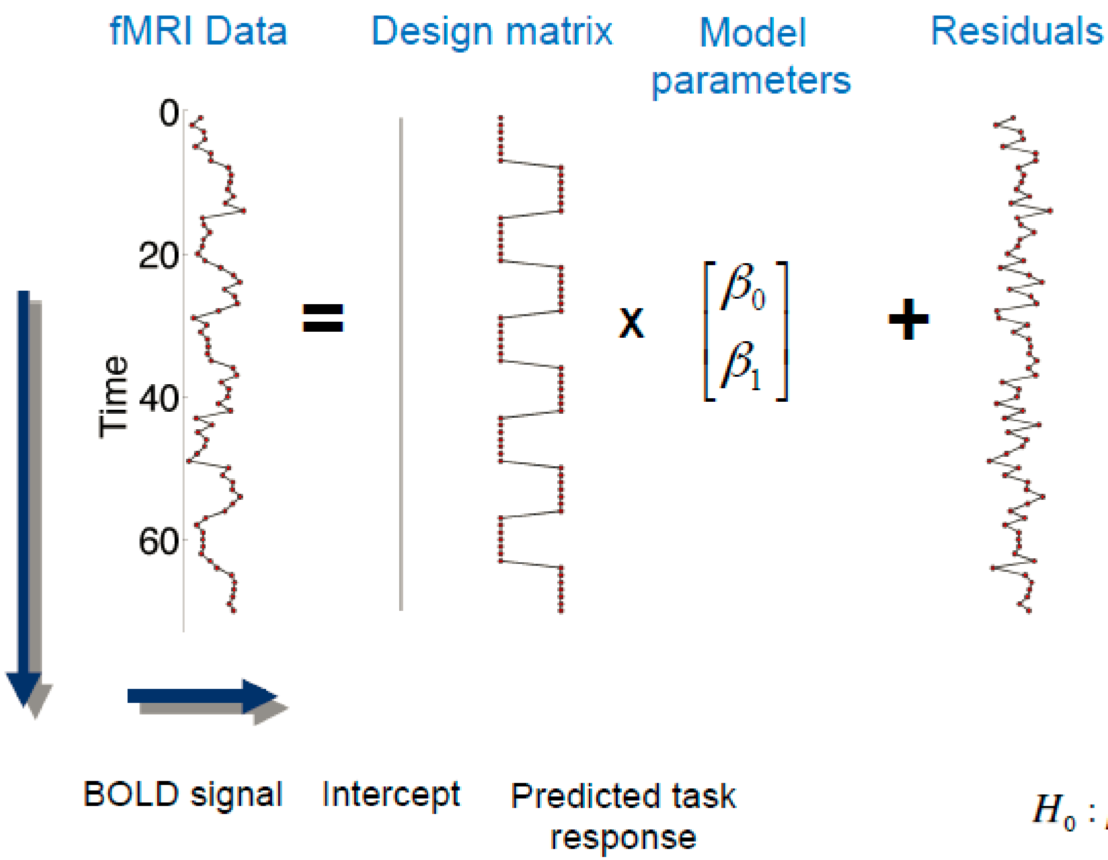
- Where Y is a matrix with a series of observed measurements
- Where X is a matrix that might be a design matrix
- Where b is a matrix containing parameters to be estimated
- And ε is a matrix containing error or noise

The model functions are assumed to have known shapes, but their amplitudes are unknown and need to be estimated.

GLM

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

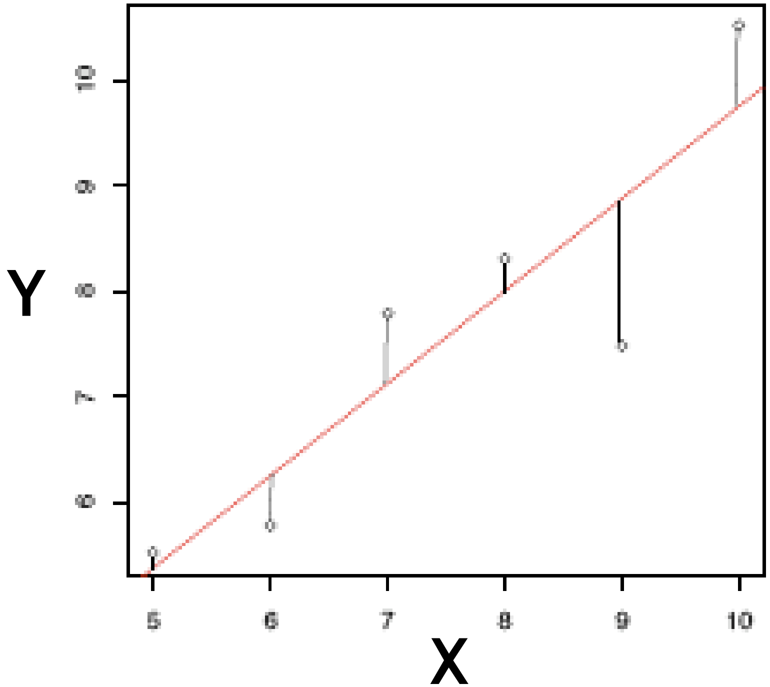
One Voxel



$$H_0 : \beta_1 = 0$$

GLM: Simple Linear Regression

$$Y = \beta_0 + X_1\beta_1 + \varepsilon$$



β_{0}: is the Y axis intercept

β_{1}: is the gradient of slope

Y: the black circles

ε: diff between Y and observed Y

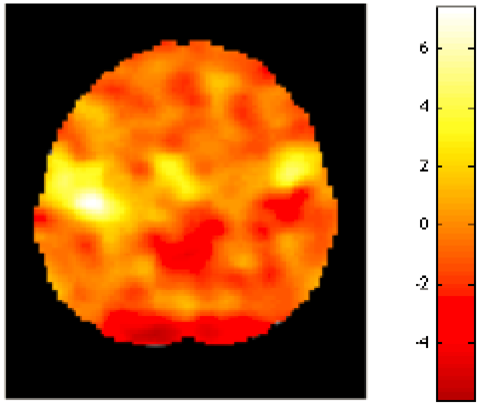
- This is done by choosing β_0 and β_1 so that the sum of the squares of the estimated errors $\Sigma\, \varepsilon_i^2$ is as small as possible.

Method of Least Squares

Statistical Images

- Calculate **β** for each voxel time-series.
- Perform a statistical test to determine whether task related activation is present in the voxel.

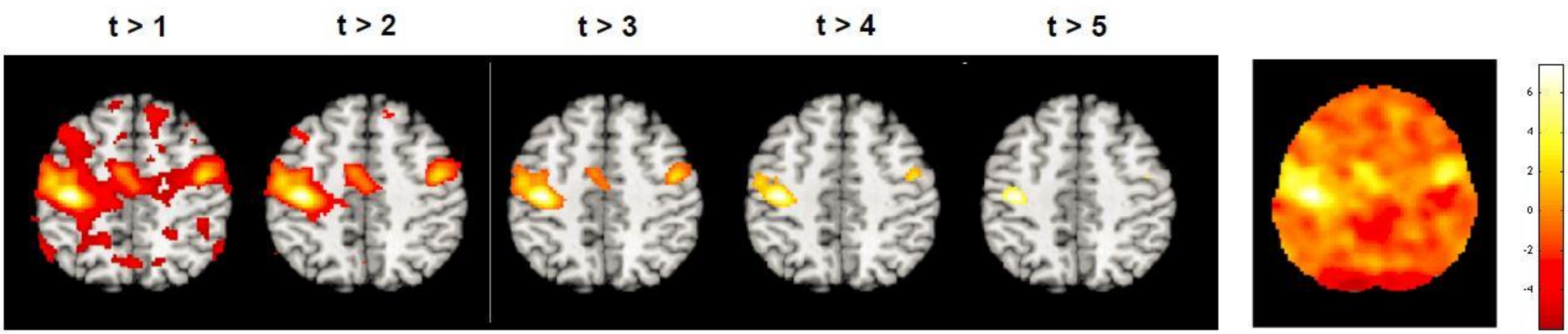
$$H_0 : \mathbf{c}^T \boldsymbol{\beta} = 0$$



Statistical image:
Map of t-tests
across all voxels
(a.k.a t-map).

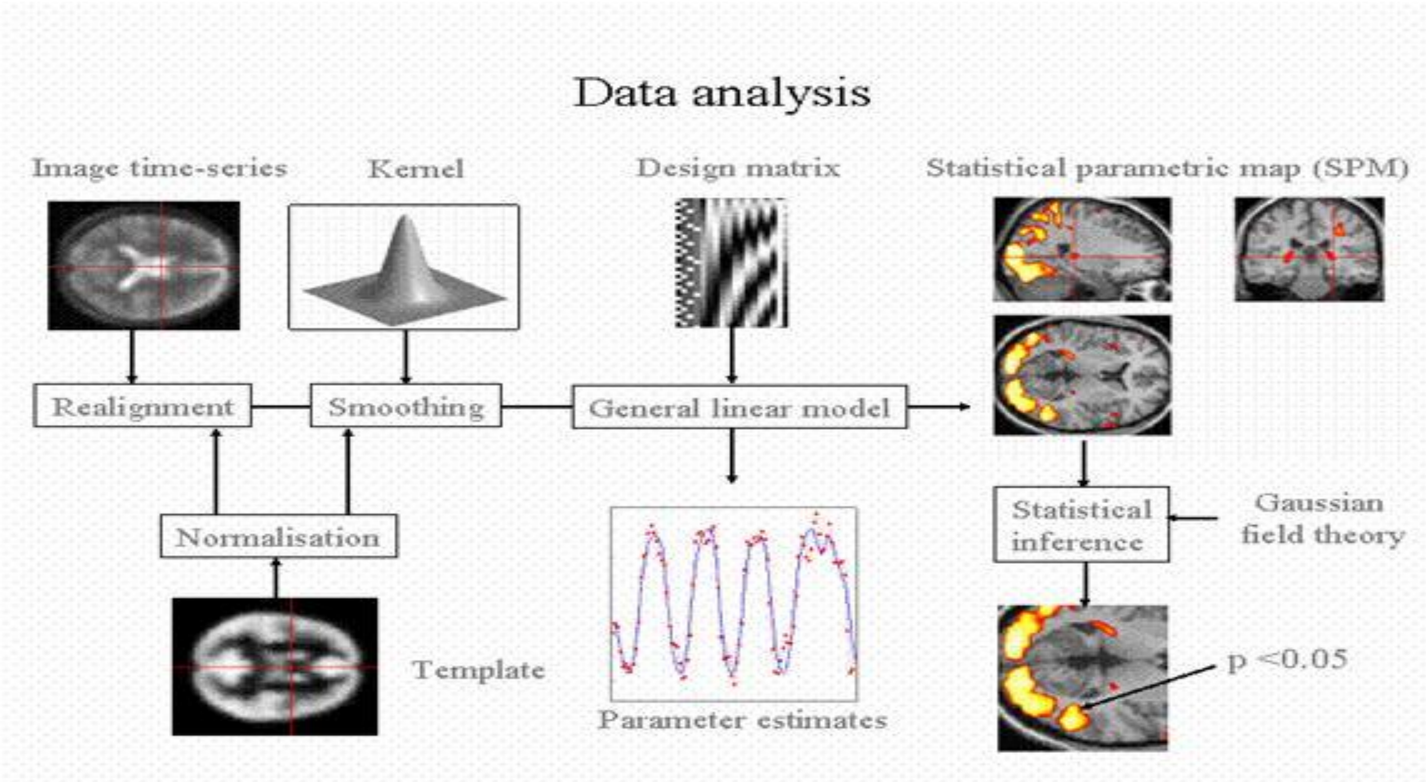
Thresholding

- Choose an appropriate threshold for determining statistical significance.
- Choosing a threshold is a balance between sensitivity (true positive rate) and specificity (true negative rate).



So Far …

Pre-stats Stats Post-stats



Software…

- FSL (Oxford)
- SPM (UCL)
- Free-surfer (MGH)
- AFNI (NIH)
- CONN
- Brain Voyager, Brain Suite and …

Take home message

- Be aware of your data acquisition protocol. Learning MRI could help!
- Look at your data before start!
- Motion is WORST: When in doubt, throw it out!
- Choosing a threshold is a balance. Take care of it!
- Pre and Post processing are not always the “one size fits all” practice in fMRI studies!

A journey of a thousand miles must begin with a single step.

Lao Zi

Thank you …