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Preprocessing of fMRI data

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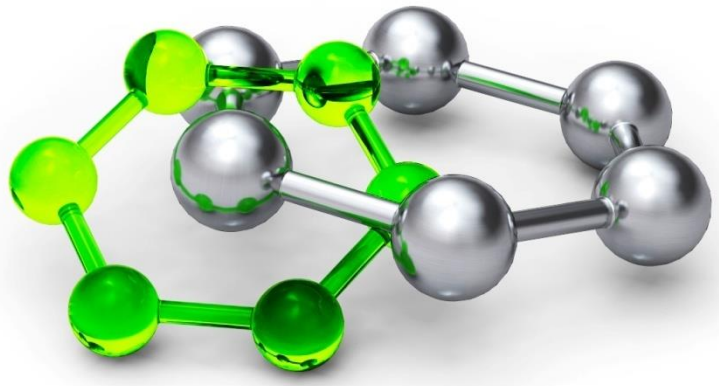
Brno, November 14th 2016



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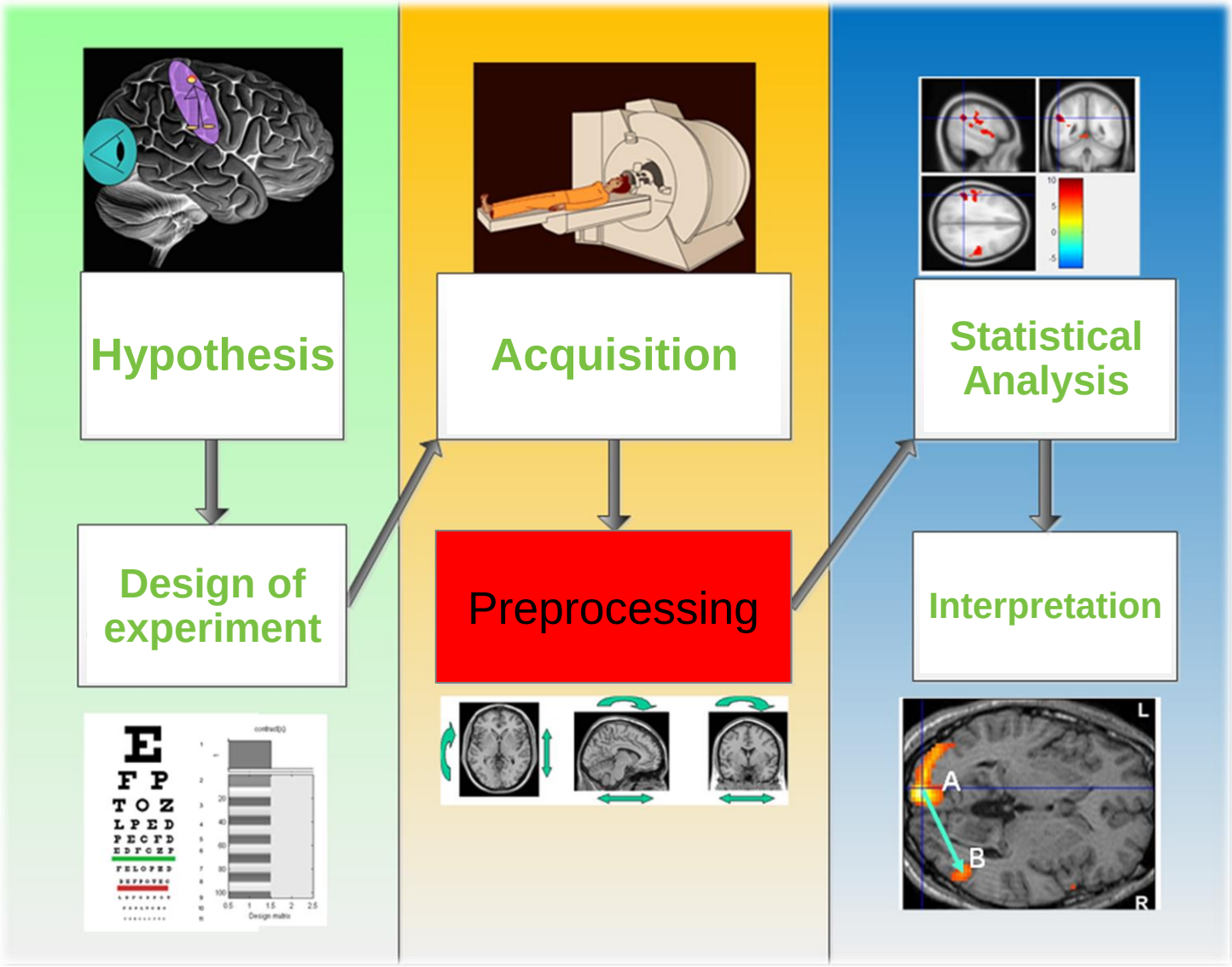
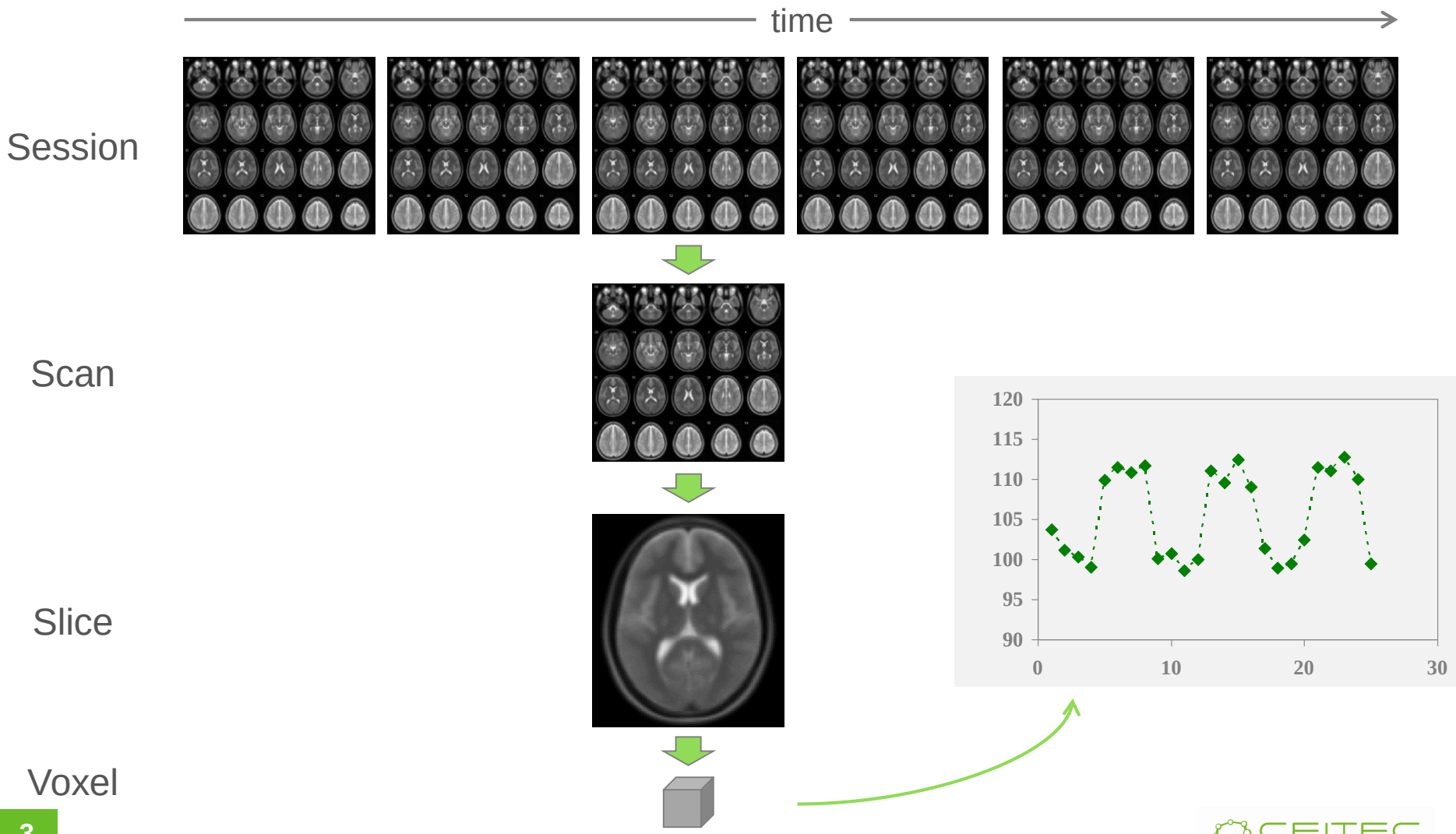
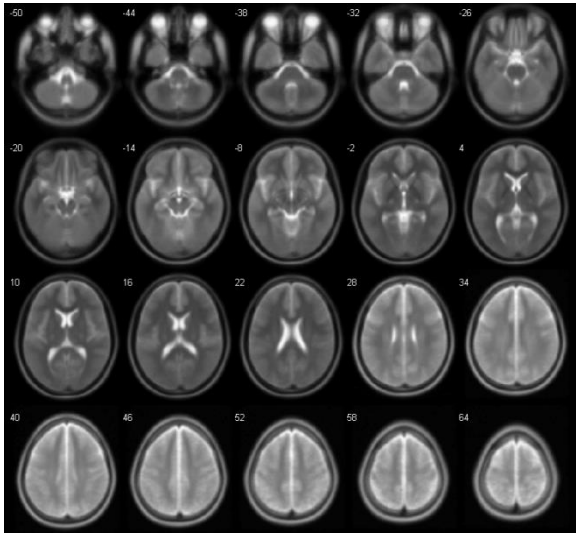

Hypothesis
Acquisition
Statistical Analysis
Design of experiment
Preprocessing
Interpretation
L
A
B
R

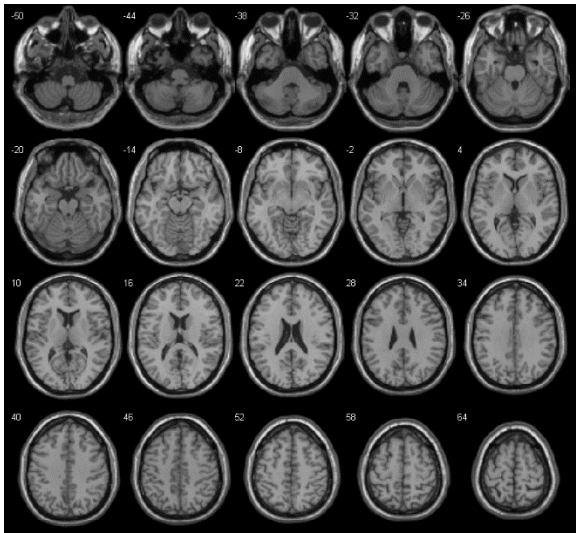
fMRI data


time
Session
Scan
Slice
Voxel
120
115
110
105
100
95
90
0
10
20
30

fMRI data

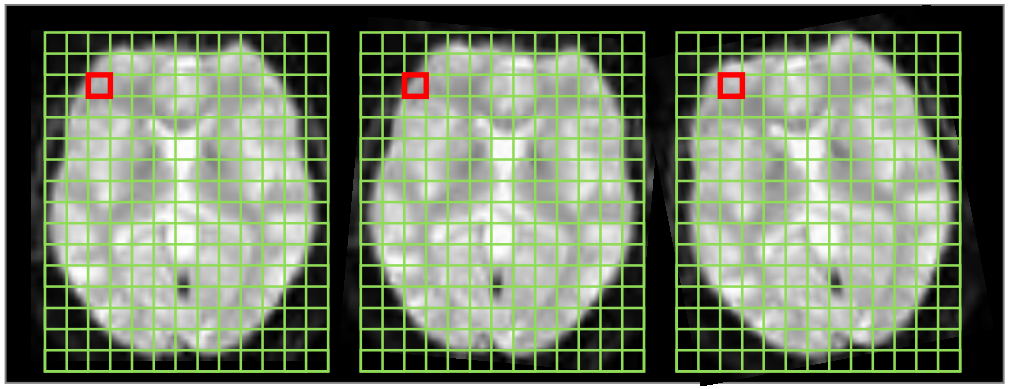
- Functional scans
  - BOLD EPI sequence
  - TR ≈ 0.5 s (multiband) – 3 s (standard EPI)
  - Voxel size ≈ 3×3×3 mm
- Structural scan
  - T1 sequence
  - Voxel size ≈ 1×1×1 mm
- Data describing subject's behavior during task execution.





Movement correction

- All scans are mutually translated and rotated due to subject movement
- Data analysis is usually processed individually for every single voxel
- **Particular voxel has to correspond to the same place in the brain in each scan**



- Finding of optimal parameters of translations and rotations in relation to the reference scan (typically first scan of the series)

Movement correction

- Rigid transformation
  - 6 parameters: 3 translation, 3 rotation
- Iterative process
  - Minimization of criterial function
    - **Sum of square differences between reference and registered scan**
    - **Mutual information**

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ 1 \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ 1 \end{bmatrix}$$

original coordinate

new coordinate

rotation around x, y, z axis

translation in x, y, z axis

Movement correction

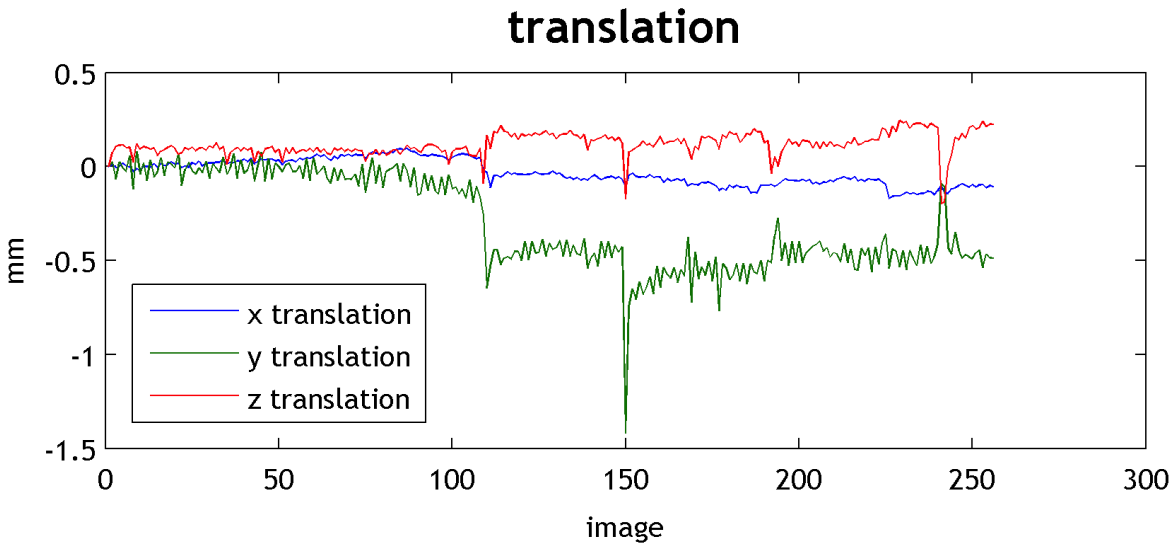
$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ 1 \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ 1 \end{bmatrix}$$

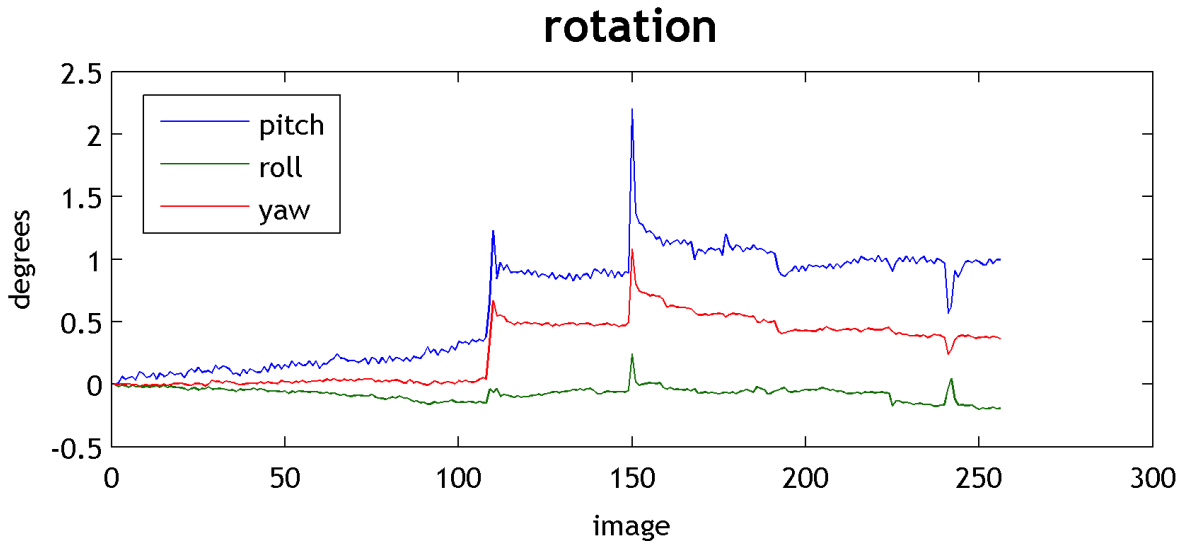
rotation around x, y, z axis

translation in x, y, z axis

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(q_1) & \sin(q_1) & 0 \\ 0 & -\sin(q_1) & \cos(q_1) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(q_2) & 0 & \sin(q_2) & 0 \\ 0 & 1 & 0 & 0 \\ -\sin(q_2) & 0 & \cos(q_2) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(q_3) & \sin(q_3) & 0 & 0 \\ -\sin(q_3) & \cos(q_3) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ 1 \end{bmatrix}$$

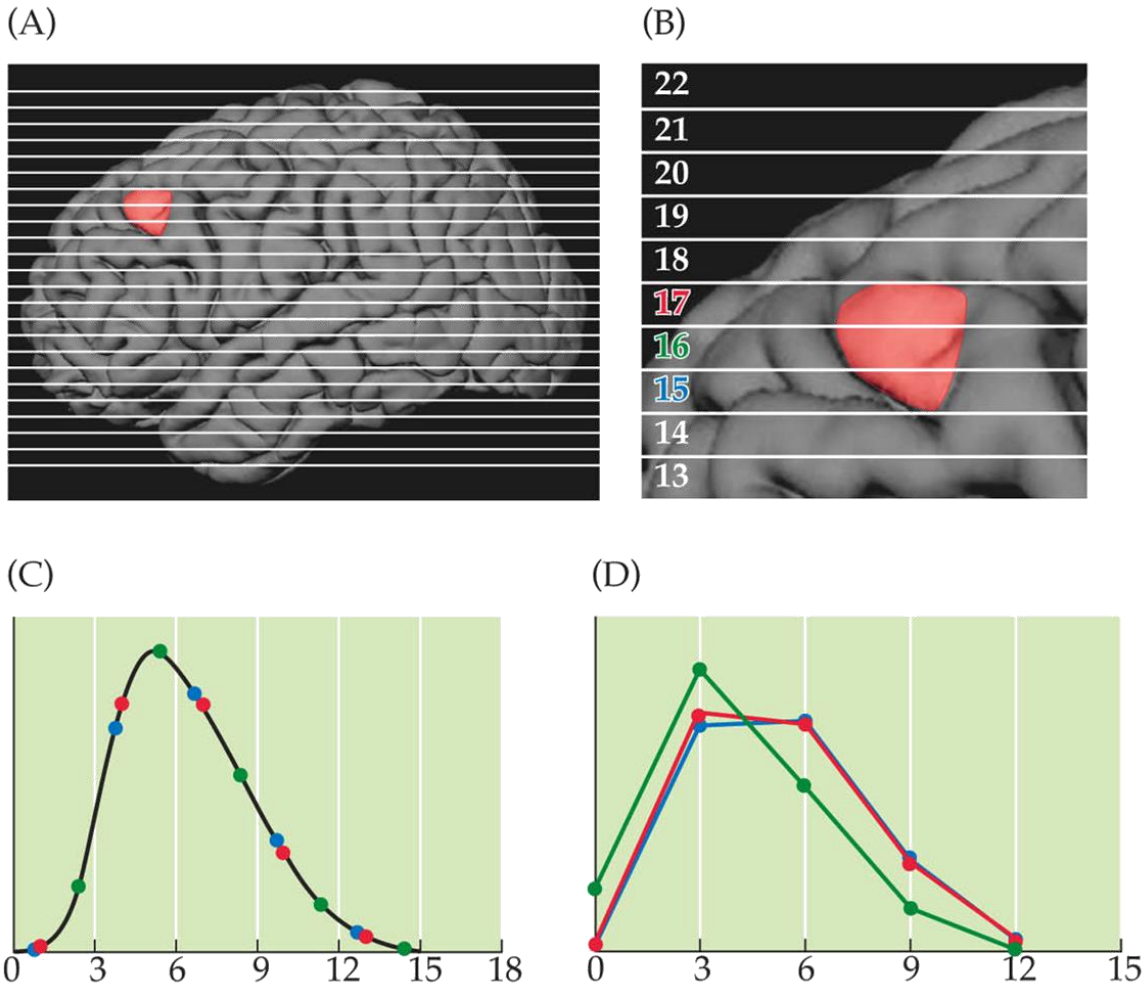
Movement correction





Slice time correction

- Difference between acquisition time of the first and the last slice (~TR)
- Different phases of hemodynamic response in various slices for particular time point
- Statistical models assume the same acquisition time in all voxels
- Temporal interpolation of the signal to the reference time points.



Spatial registration and normalization

Registration

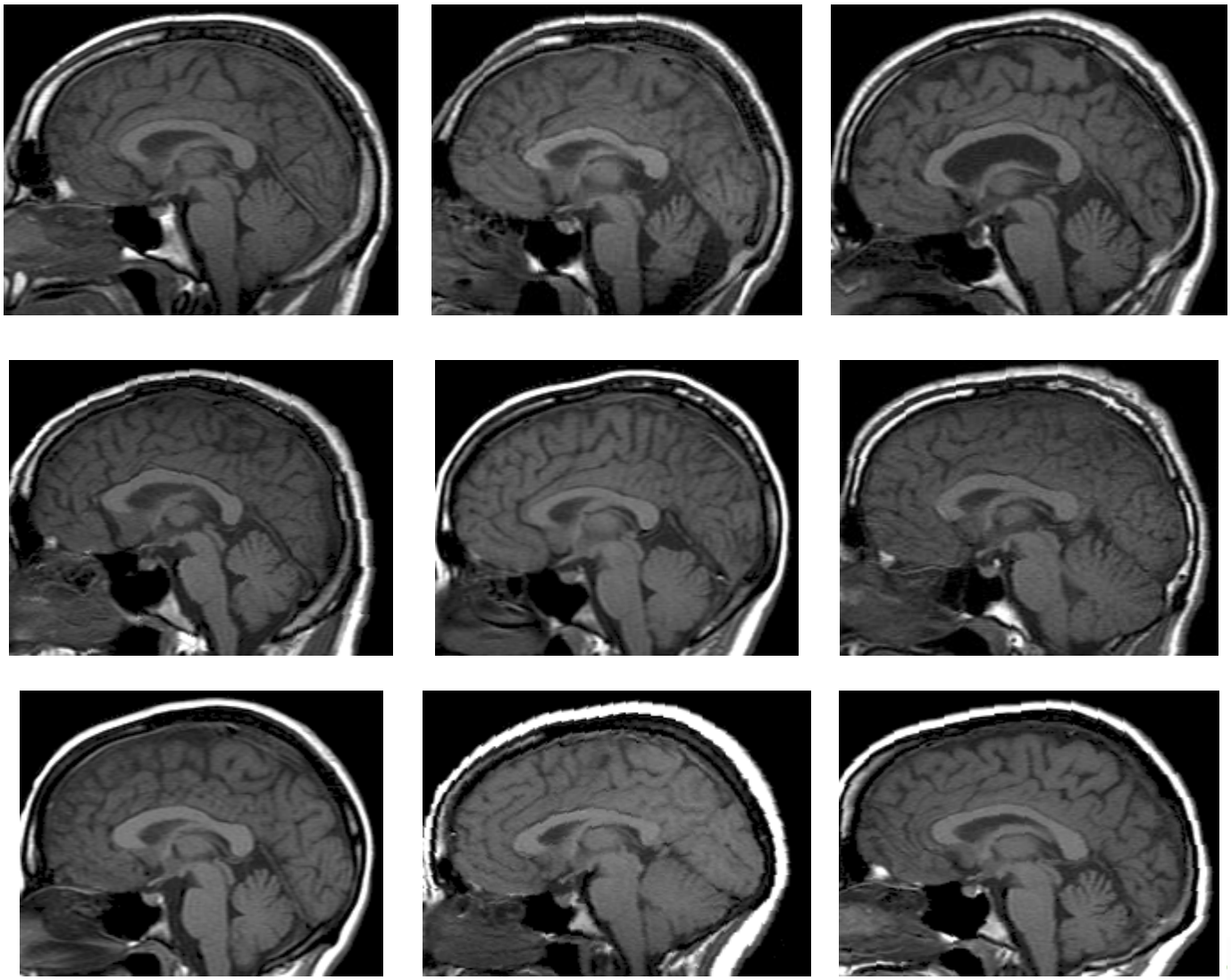
Single subject registration of two brain scans obtained by different acquisition sequences

Registration of anatomical and functional brain scans

Normalization

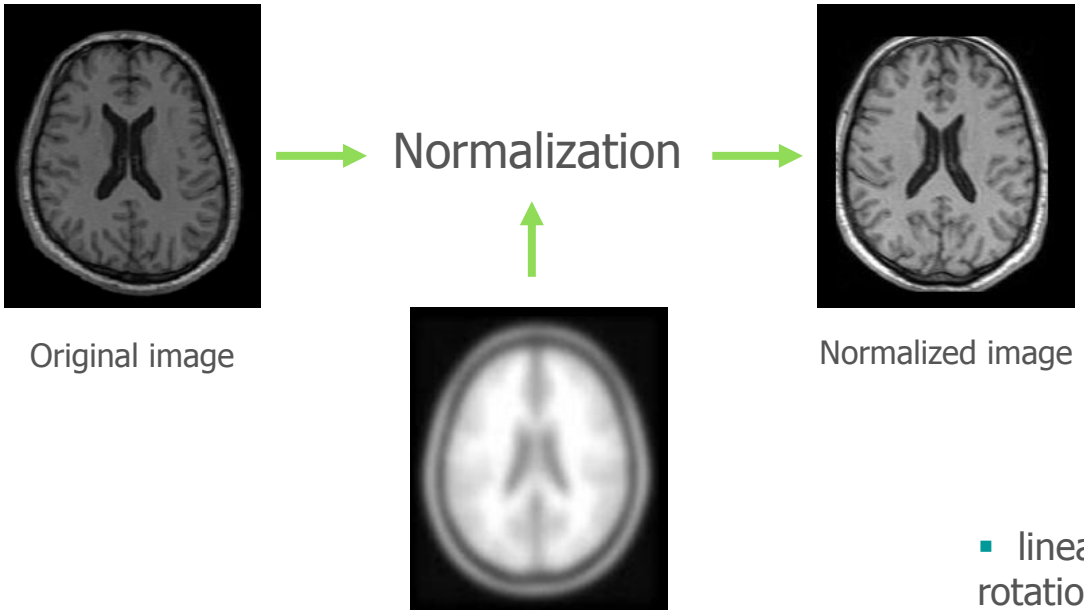
Registration of single subject scans to standardized spatial template

Spatial registration and normalization



Spatial normalization

- Comparison of results between subjects (localization)
- Transformation of the coordinate system to the standardized space



- linear transformation – translation, rotation, scale, slope
- nonlinear transformation – deformation based on cosine function set

Spatial normalization
standardized spaces

- Talairach space
  - Based on atlas Talairach a Tournoux (1988)
  - Single subject (woman, 60 years, cadaver)
  - One hemisphere
  - First widespread

- MNI (Montreal Neurological Institute) space
  - Combination of many MR scans of right-handed healthy controls
  - Scaled to Talairach space
  - Used in SPM, FSL and many others

Spatial normalization

- Iterative process
- Minimization of the difference between reference and registered image
- Affine and nonlinear transformation

1. step
Finding of 12 parameters for affine transformation of coordinates **y** = **M**.**x**

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ 1 \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ 1 \end{bmatrix}$$

2. step
Finding parameters **q** of coordinates nonlinear transformation based on basis functions **d** (cosine functions)

$$y_1 = x_1 + \sum_j q_{j1} d_j(\mathbf{x})$$

$$y_2 = x_2 + \sum_j q_{j2} d_j(\mathbf{x})$$

$$y_3 = x_3 + \sum_3 q_{j3} d_j(\mathbf{x})$$

Spatial filtration
smoothing

- **SNR** (signal to noise ratio) improvement
- Data fits better to **normal** distribution requirement

- **Lower accuracy** of spatial localization

- Convolution with Gaussian kernel

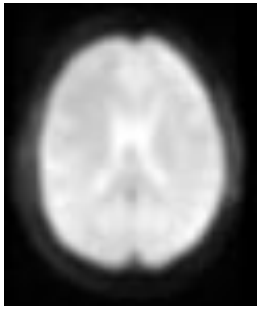
$$f(x,y,z) = g(x,y,z) * h(x,y,z) = \sum_{i=-m}^{m} \sum_{j=-m}^{m} \sum_{k=-m}^{m} f(x-i, y-j, z-k) \cdot h(i,j,k)$$

- Parameters of Gaussian kernel – FWHM (Full Width – Half Maximum)
  - FWHM is usually twice the size of voxel [mm]

Spatial filtration
smoothing

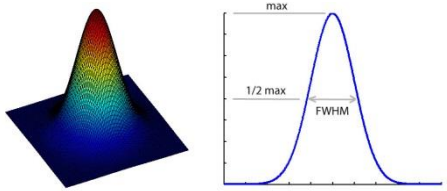
Original image

Filtration



Filtered image

Gaussian filter



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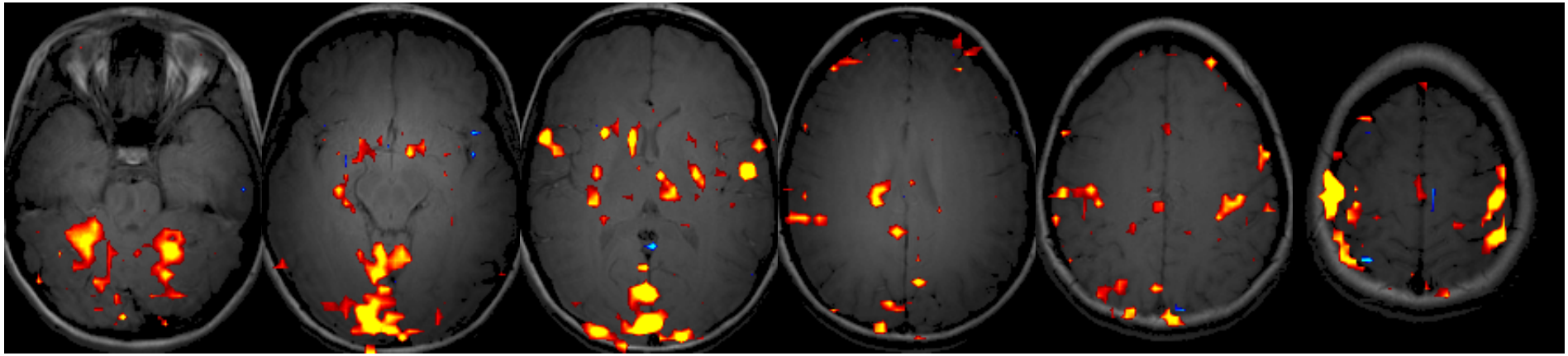
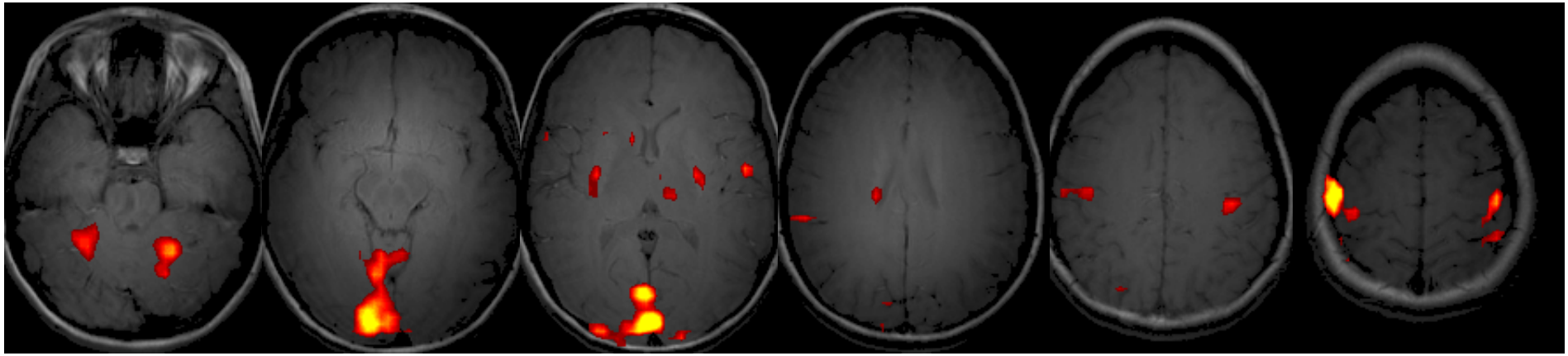
Spatial filtration

Effect of smoothing on activation map

Unsmoothed data

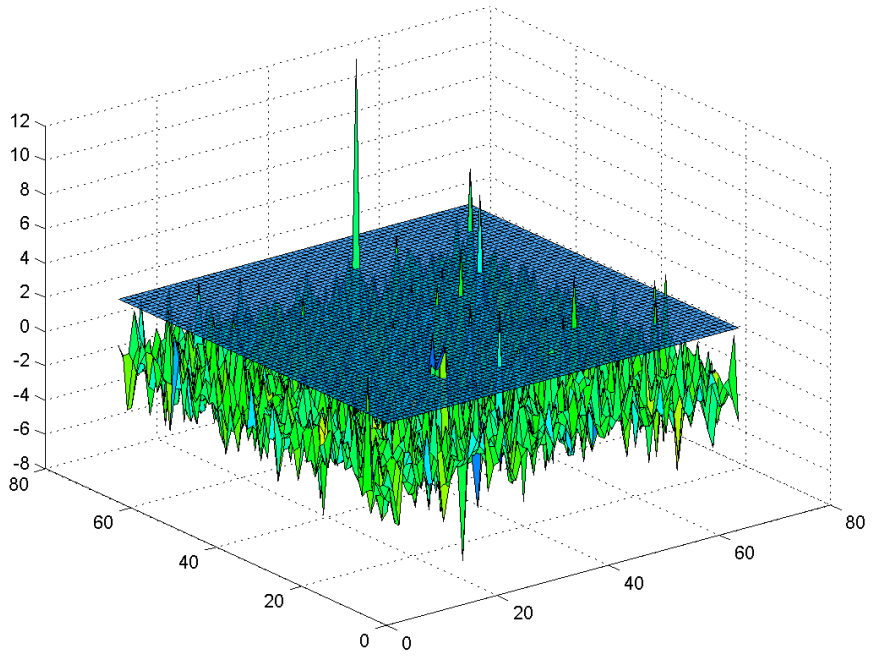


Smoothed data (FWHM ~ 12mm)

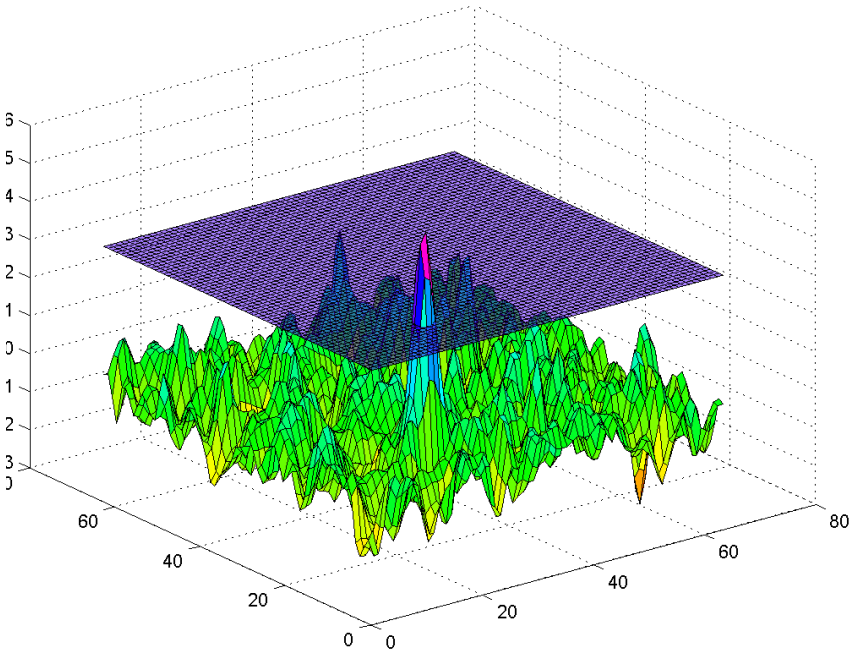


Spatial filtration
Effect of smoothing

Before smoothing



After smoothing



*simulated data

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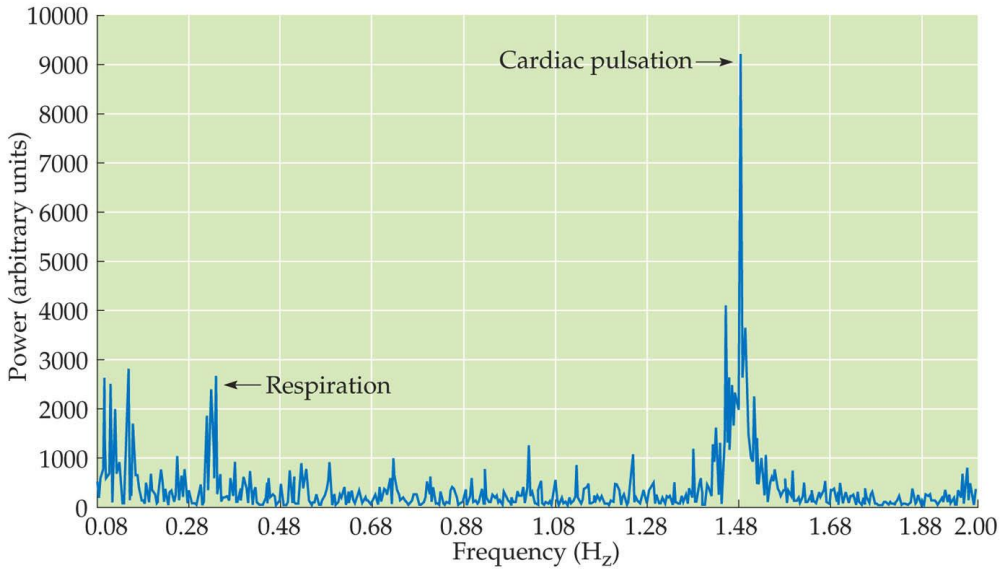
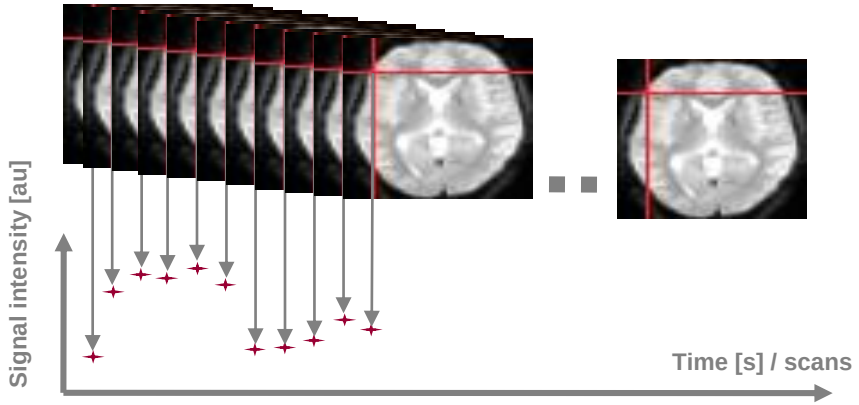
Filtration in time domain

- Identification of unwanted frequencies
  - Drift (low frequencies)
  - Physiological noise (high frequencies)
  - Spectral leakage (high frequencies)
- Suppression of these frequency components by low pass and high pass filters
- **Danger** – suppression of useful components, which are overlapped with noise



Other steps

- Suppression of geometrical distortion – Unwarp method
- Normalization of average scan intensity to reference level (grand mean scaling)



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Thank you for your attention

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