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Influence of anisotropic conductivities in EEG source estimation in patients with epilepsy

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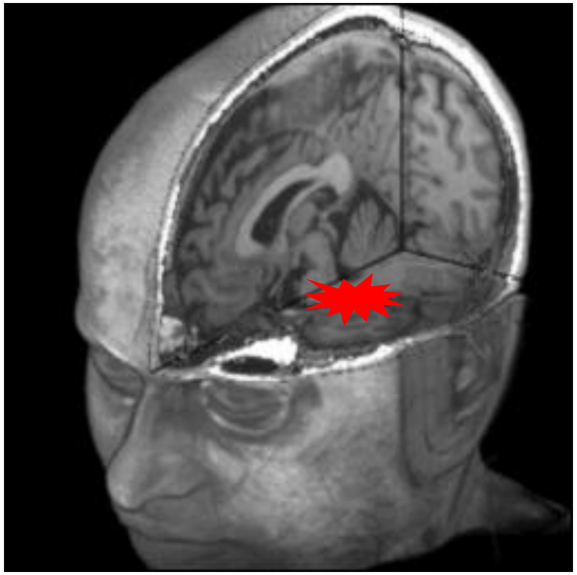
Introduction: Epilepsy

- Epilepsy
  - Neurological disorder
  - Seizure: abnormal synchronous brain activity
  - Prevalence: 0.5 – 1 %

- Epileptic onset zone in partial epilepsy
  - One or multiple region(s) in the brain responsible for the seizures



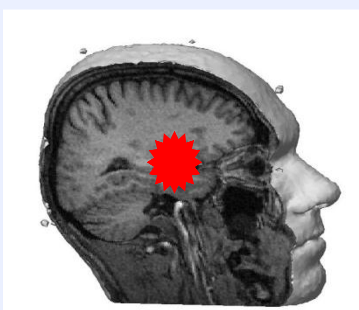
Introduction: Epilepsy treatment

Epilepsy

~ 75% → Medication

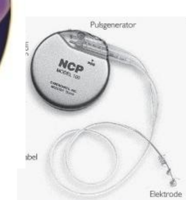
~ 25% → Refractory epilepsy

30-40% → Surgery



Goal of presurgical evaluation determining the epileptic onset zone

60-70% → nervus vagus stimulation



~ 1% → Deep brain stimulation

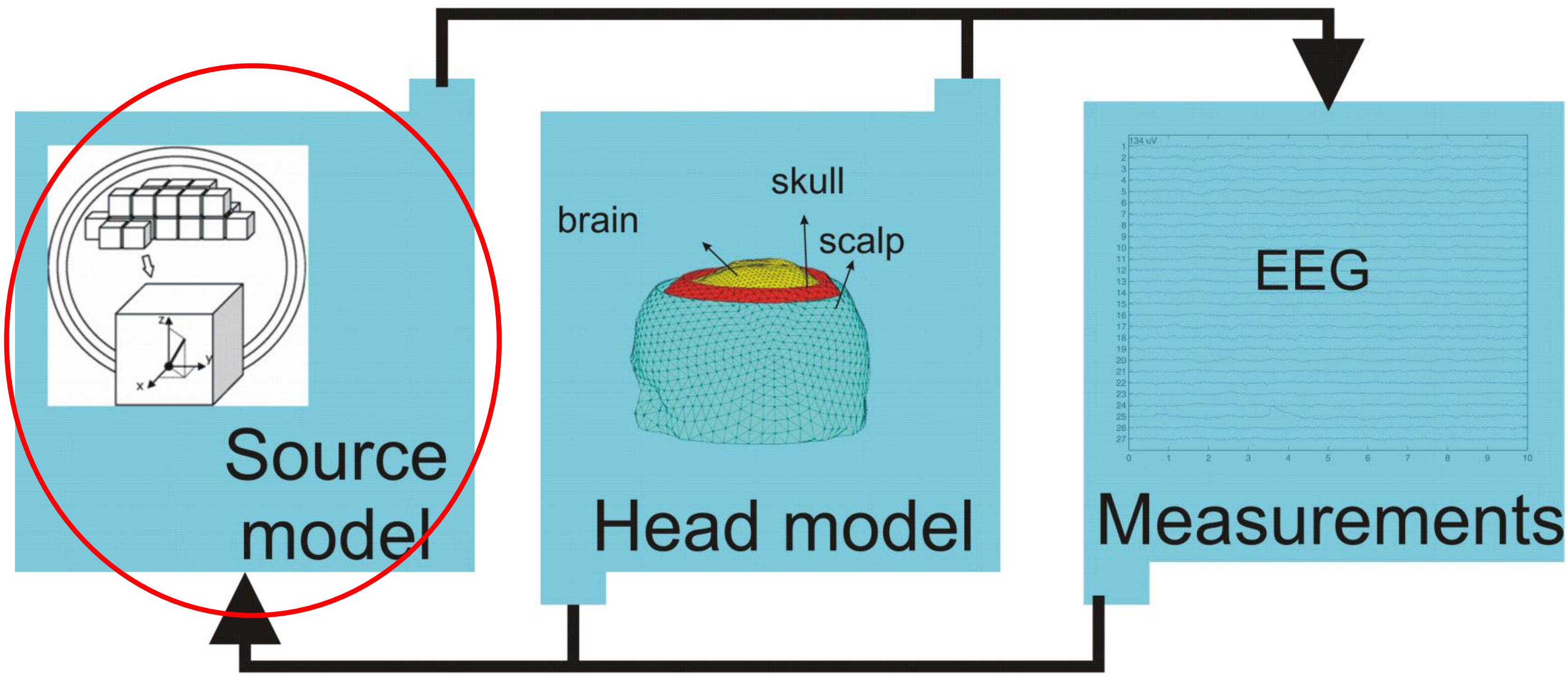
Content

- Introduction
- Source localization
  - Forward problem
  - Inverse problem
- Incorporating anisotropic conductivities
- Influence of anisotropic conductivities
- Future work

Source Localization

Forward problem

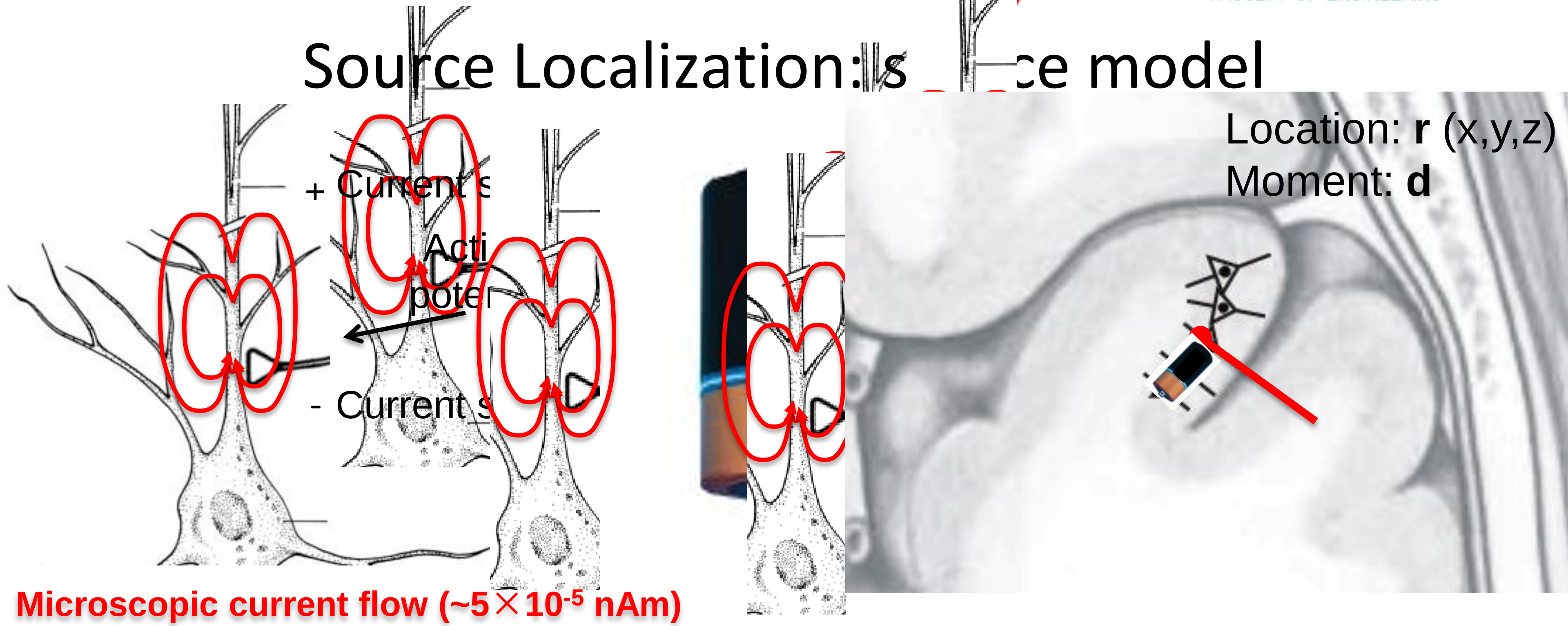
calculation of the **electrodepotentials** given **a source and head model**



Inverse problem

quantitative estimation of the **source parameters** in the **head model** given an **EEG fragment**

Source Localization: s ce model

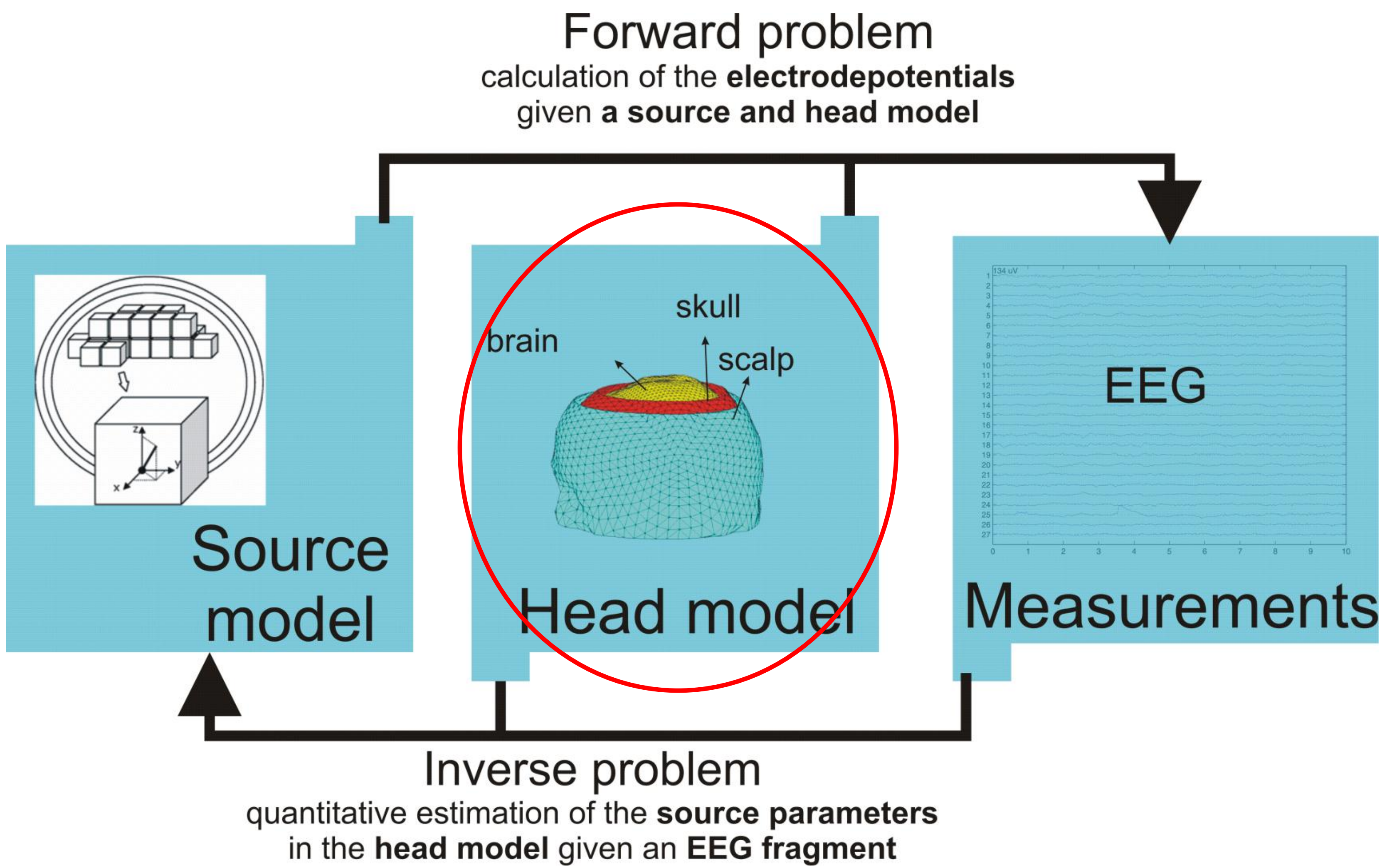


Microscopic current flow (~5×10^{-5} nAm)

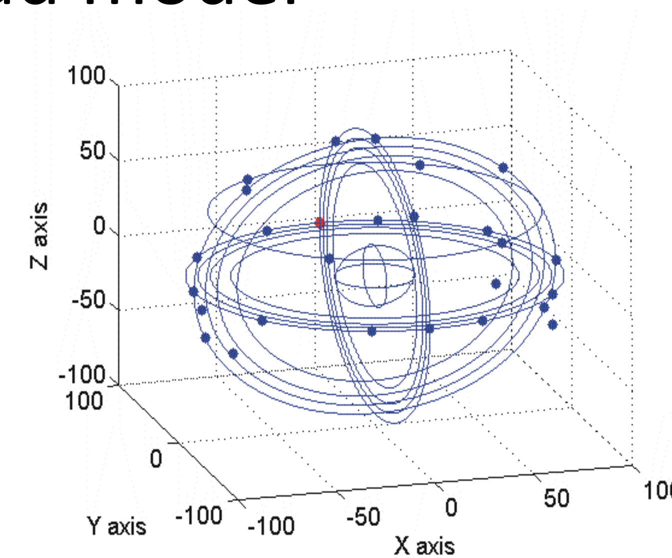
- Dipole model

- Cortical patch of 5 by 5 mm generates a measurable potential
- Currents have to be aligned orthogonally to the cortex: pyramidal neurons

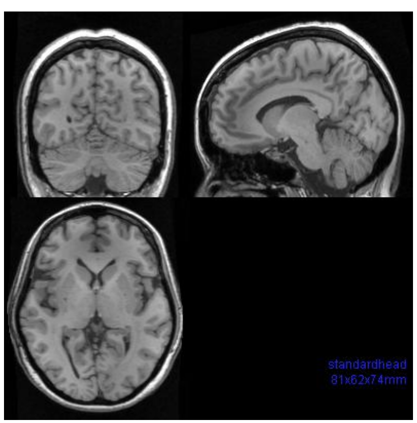
Source Localization

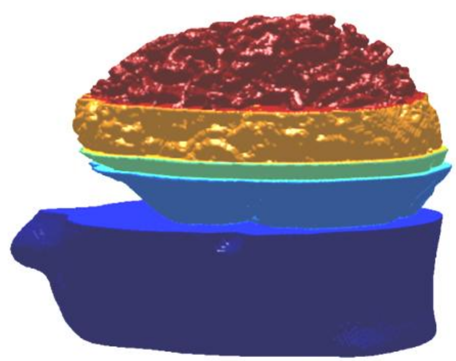


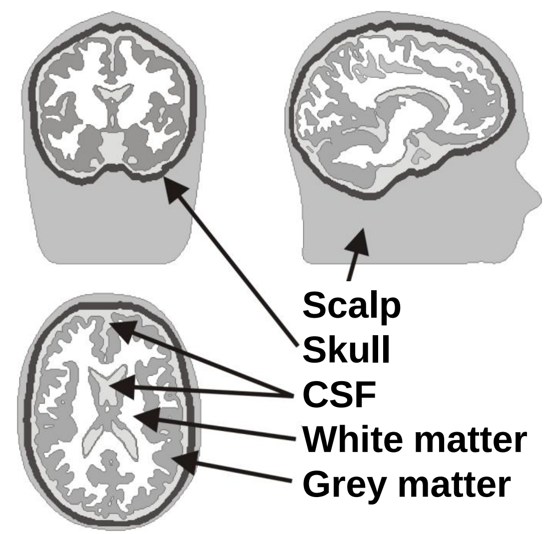
Source Localization: Head model



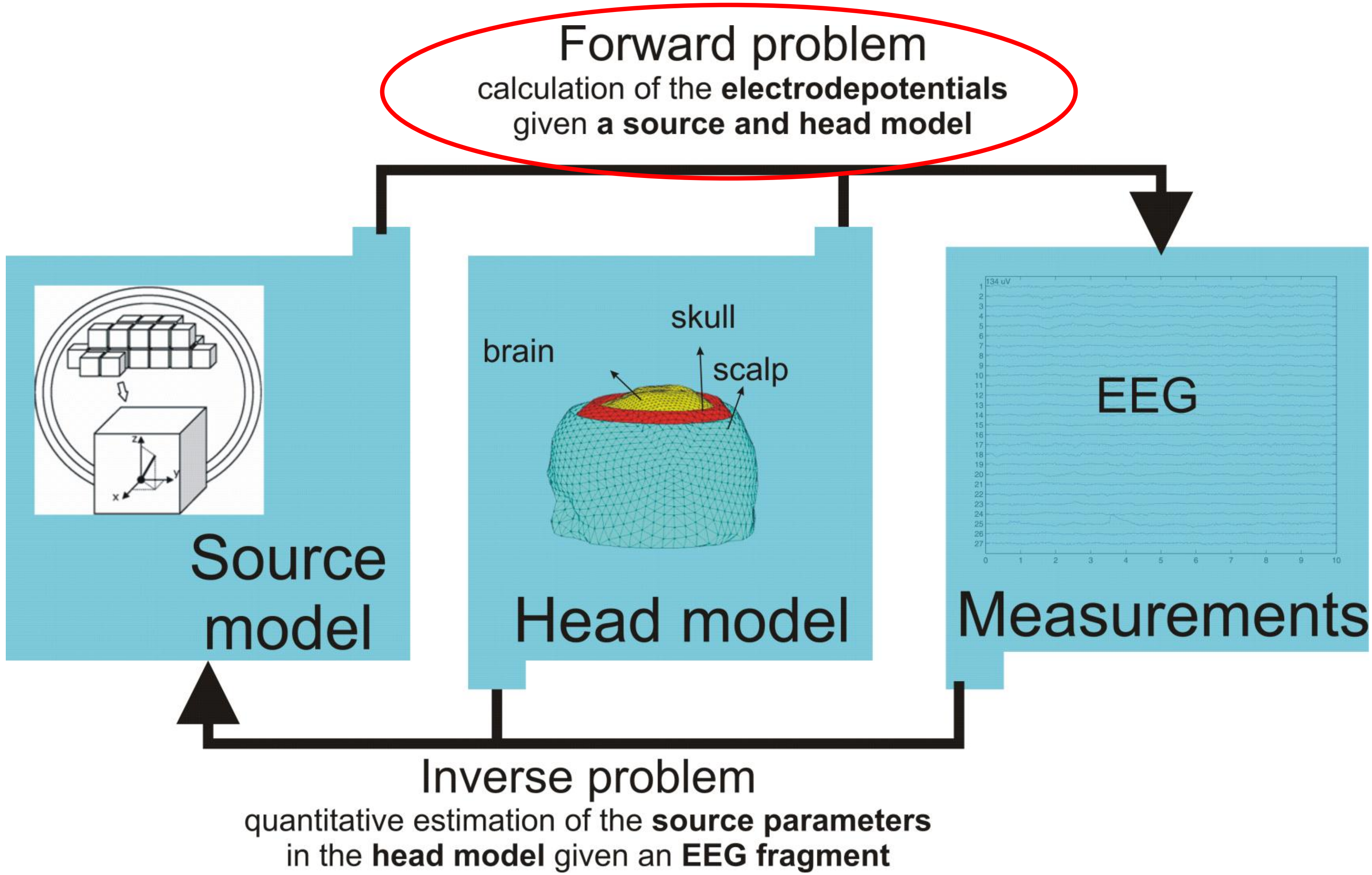
- Spherical head models
  - Simple, but unrealistic
- Realistic head models
  - Medical imaging
  - Requires segmentation







Source Localization

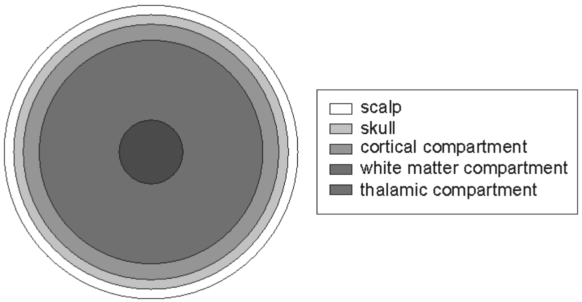


Source Localization: Forward problem

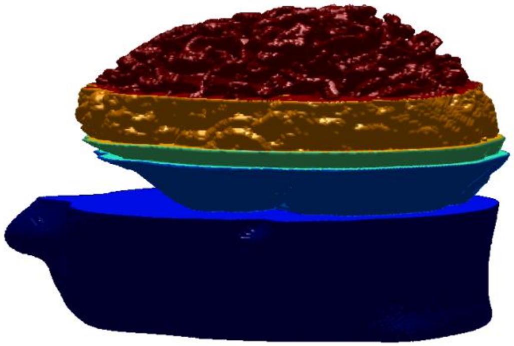
- Solving Poisson's equation in head model due to a dipole source

$$\nabla \cdot (\sigma(x,y,z) \cdot \nabla V(x,y,z)) = \nabla \cdot \mathbf{J}(x,y,z)$$

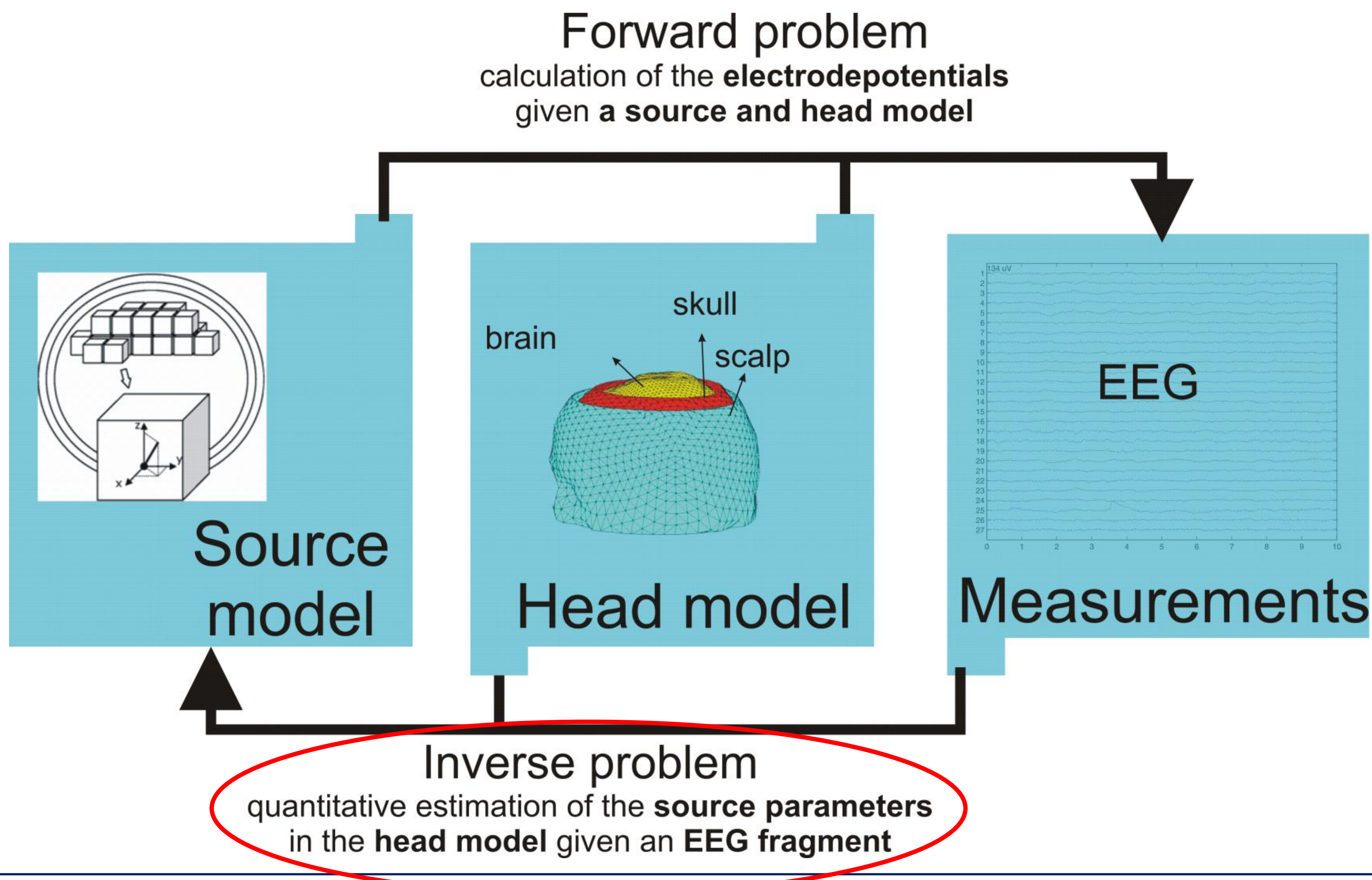
- Spherical head models
  - Analytical solution
    - De Munck, Zhang



- Realistic head models
  - Numerical methods
    - BEM, FEM, FDM



Source Localization

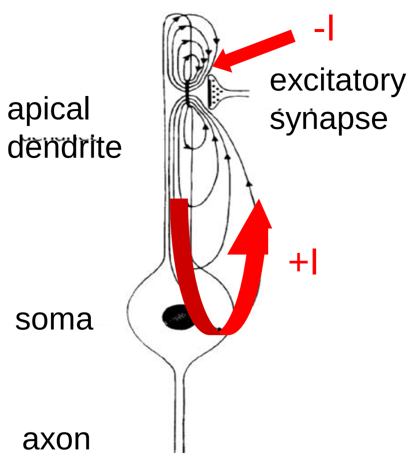


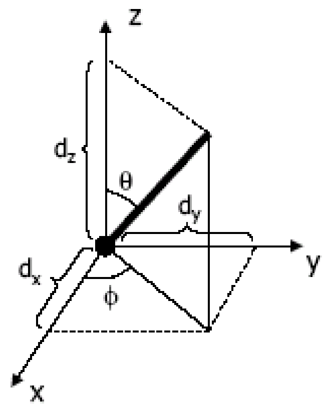
Source Localization: Inverse problem

- Fits the dipole parameters to a measured set of potentials

- Minimization of the Relative Residual energy:

$$RRE = \frac{\left\| \mathbf{V}_{electrodes} - \mathbf{V}_{model}(\mathbf{r},\mathbf{d}) \right\|}{\left\| \mathbf{V}_{electrodes} \right\|}$$





- Nelder-mead simplex method

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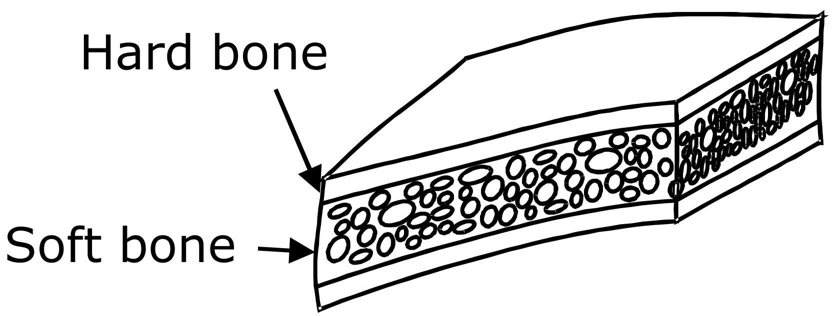
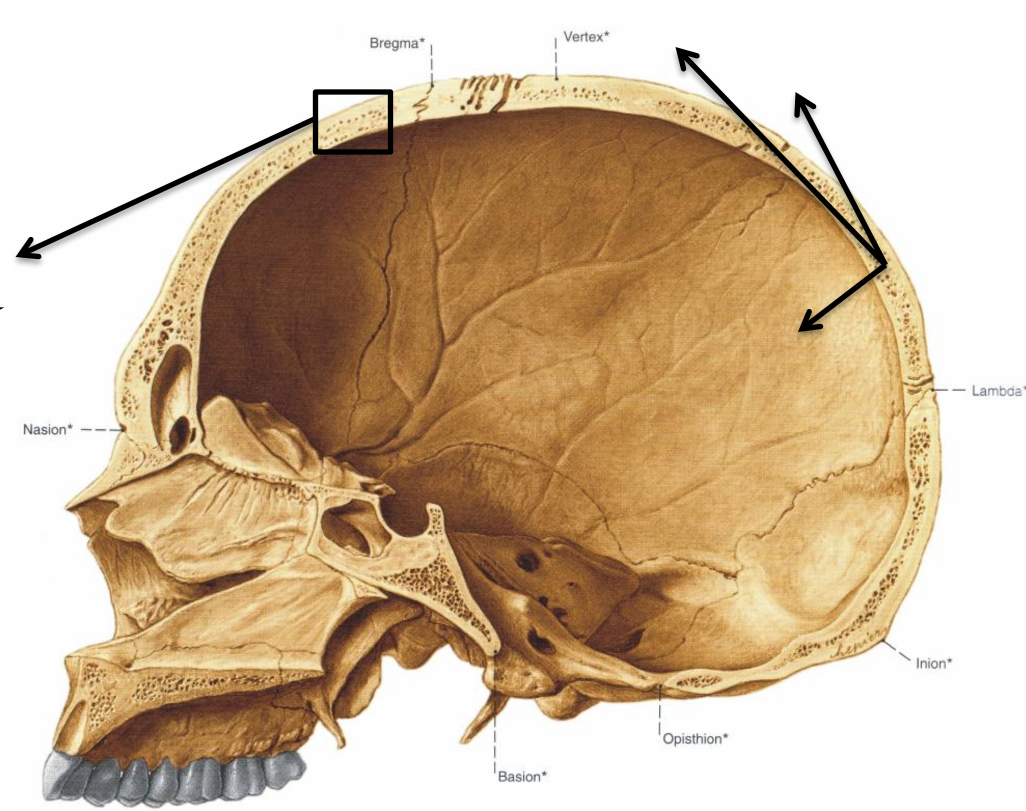
Anisotropic conductivities: skull

- Layered structure





$$\frac{\sigma_{\text{tangential}}}{\sigma_{\text{normal}}} = \frac{10}{1}$$

[Akhtari M. et al., Brain Topography, 2002; Marin G. et al, Human Brain Mapping 1998]

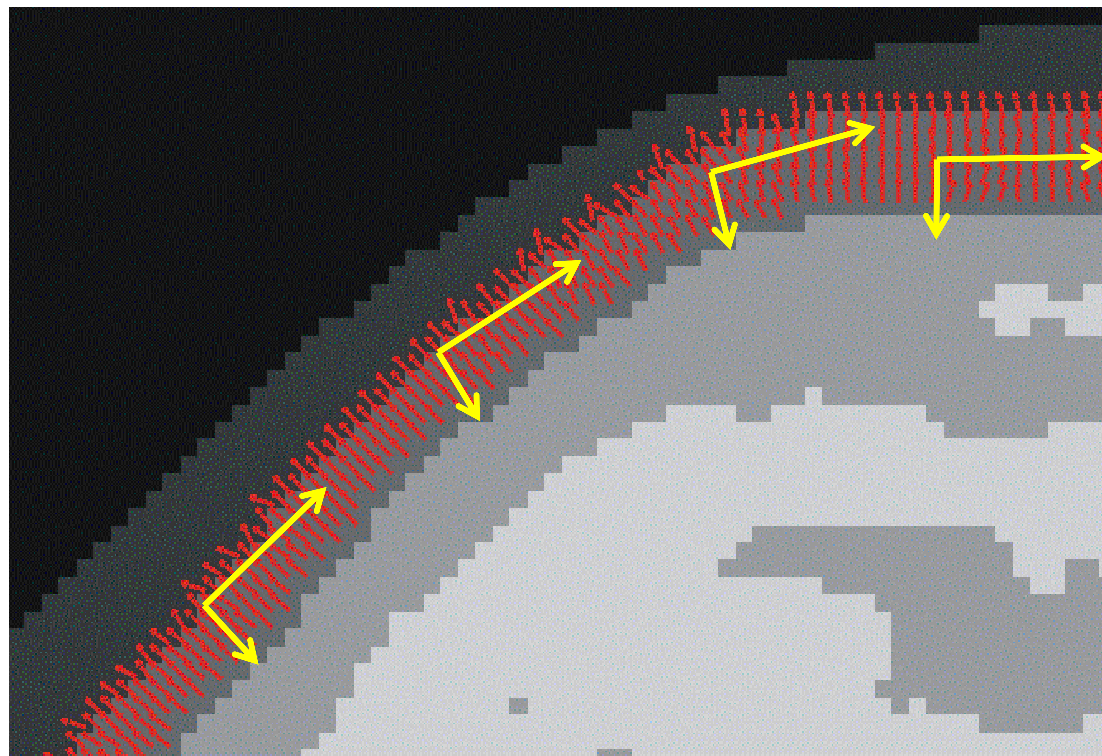
Anisotropic conductivities: skull

- Derive normal vector of a skull segment using medical imaging

$$\frac{\sigma_{\text{tangential}}}{\sigma_{\text{normal}}} = \frac{10}{1}$$

- Cartesian tensors and transformations

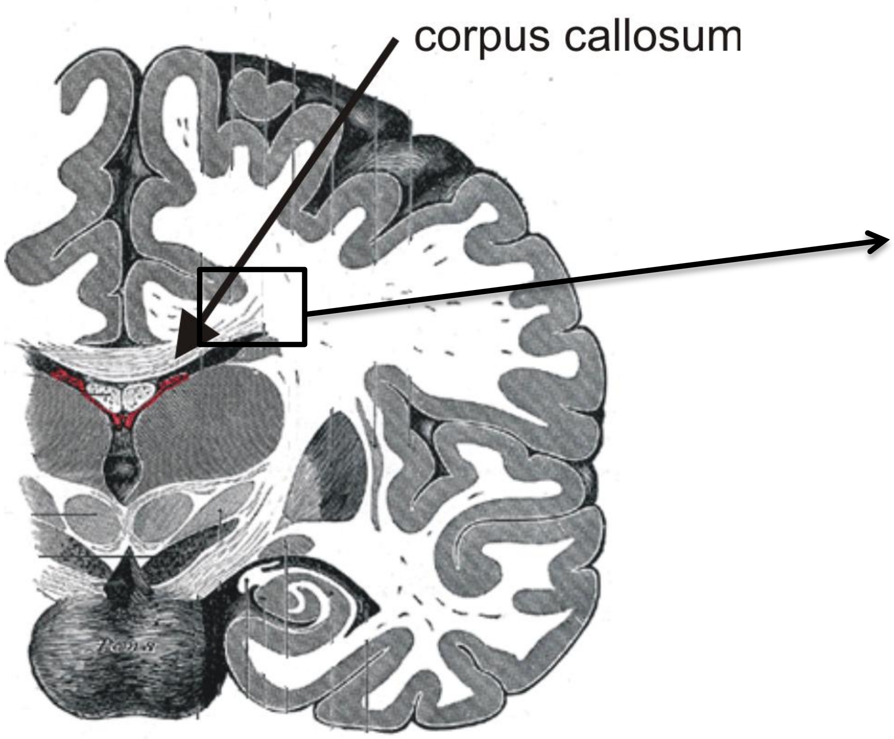
$$\mathbf{\Sigma} = R \begin{bmatrix} \sigma_n & 0 & 0 \\ 0 & \sigma_t & 0 \\ 0 & 0 & \sigma_t \end{bmatrix} R^T$$

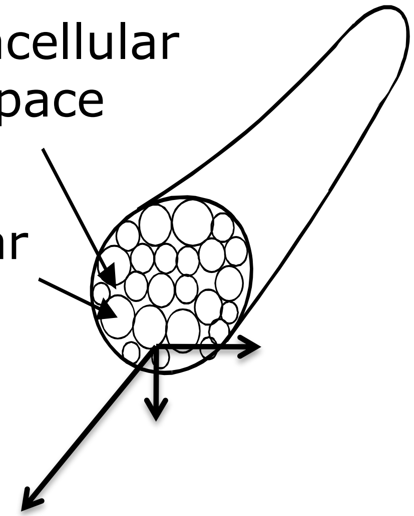


R = matrix indicating the rotation from local to global reference frame

Anisotropic conductivities: white matter

- Fiber structure



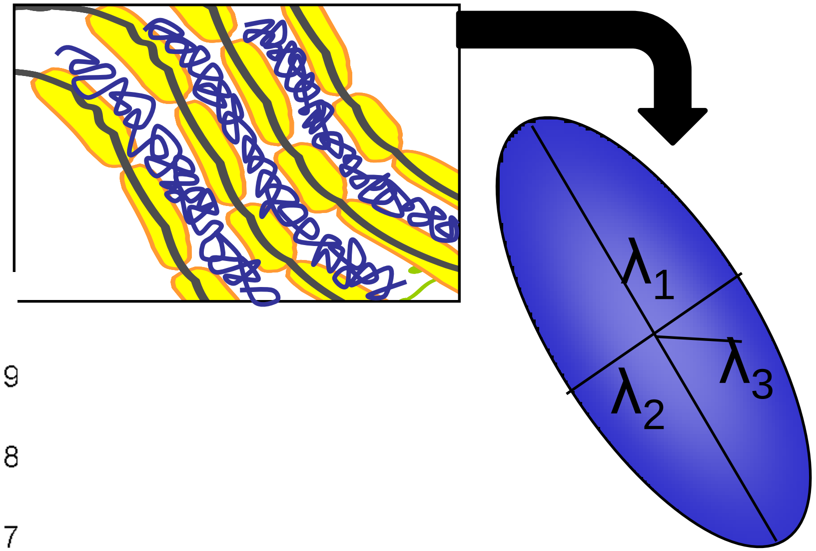


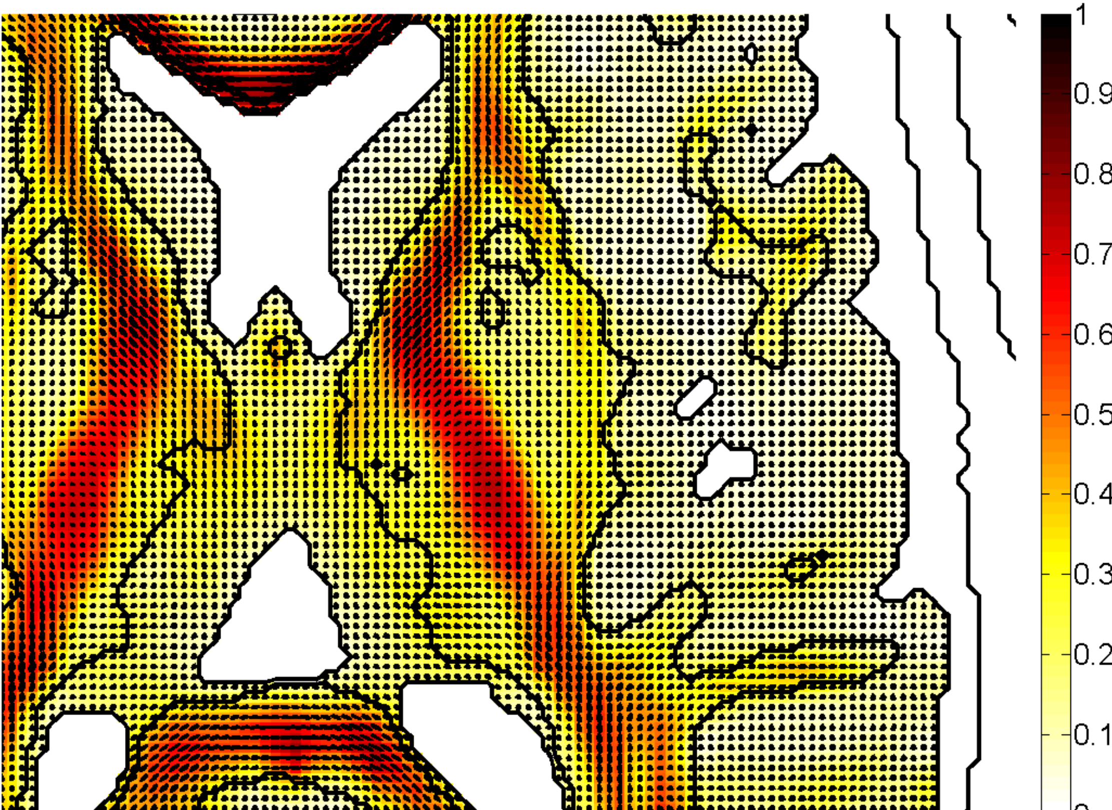
$$\frac{\sigma_{\text{longitudinal}}}{\sigma_{\text{transversal}}} = \frac{9}{1}$$

[Nicholson, P.W., Experimental Nuerology, 1965]

Anisotropic conductivities: white matter

- Diffusion Tensor Imaging
  - The fiber direction in white matter
  - Conductivities can be derived

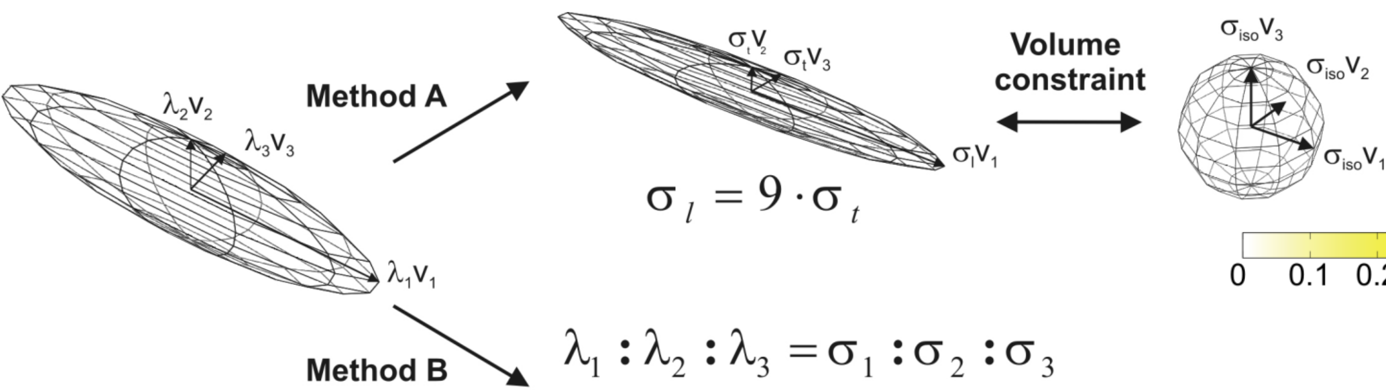


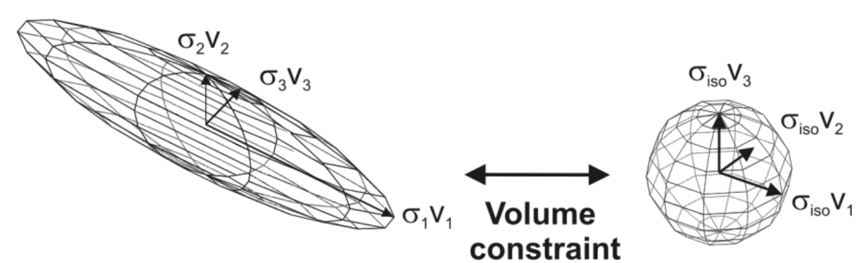


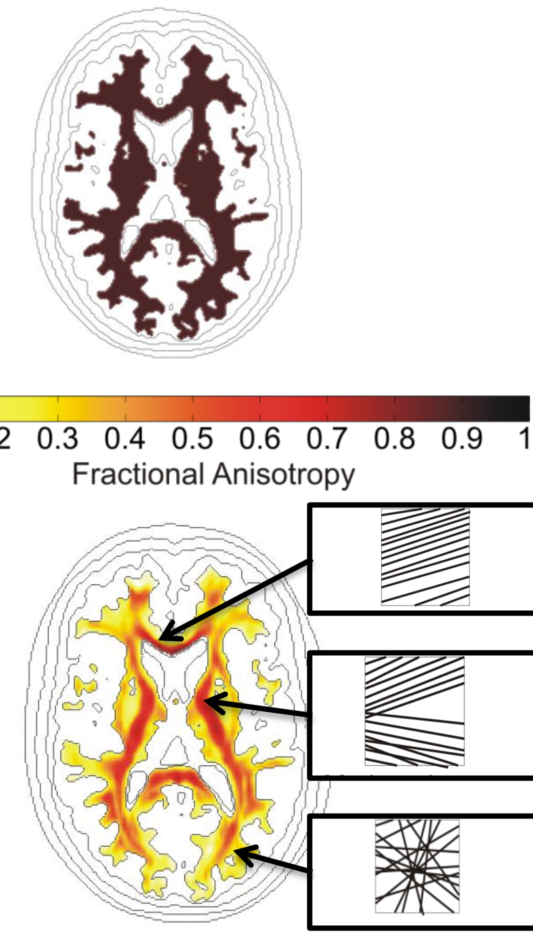
- Fractional Anisotropy
  - » mainly in white matter
  - » Also in grey matter

Anisotropic conducitivities

- From the diffusion to conductivity







Isotropic conductivities from literature

$$\sigma_{brain}^{isotropic} = 0.33 \, S/m$$

$$\sigma_{skull}^{isotropic} = \sigma_{brain}^{isotropic} / 16 = 0.021 \, S/m$$

Geddes L.A. and Baker, Med.Biol.Eng., 1967

Anisotropic conducitivities: forward problem

- Incorporating anisotropic conductivities in the forward problem
  - Finite Difference Method
  - For every center node:

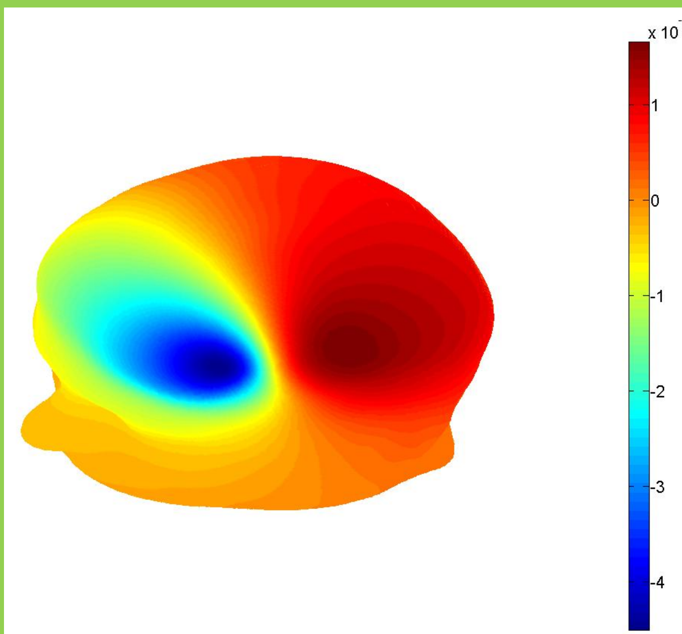
$$\sum_{i=1}^{18} A_i \varphi_i - \left(\sum_{i=1}^{18} A_i \right) \varphi_0 = I$$

  - System of equations

$$\mathbf{A}\varphi = \mathbf{I}$$

  - Head model (1mm resolution): approx. 4500000 elements => approx system

3D potential distribution with with anisotropic conductivities



[Saleheen et al., 1998 & Hallez et al., 2005]

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- Incorporating anisotropic conductivities
- Influence of anisotropic conductivities
  - Estimation errors due to different anisotropic conductivity models of white matter (method B vs method A)
  - Estimation errors due to neglecting anisotropic conductivities
  - Estimation errors due to neglecting anisotropic conductivities in the presence of noise
- Future work

Influence of anisotropic conducitivities

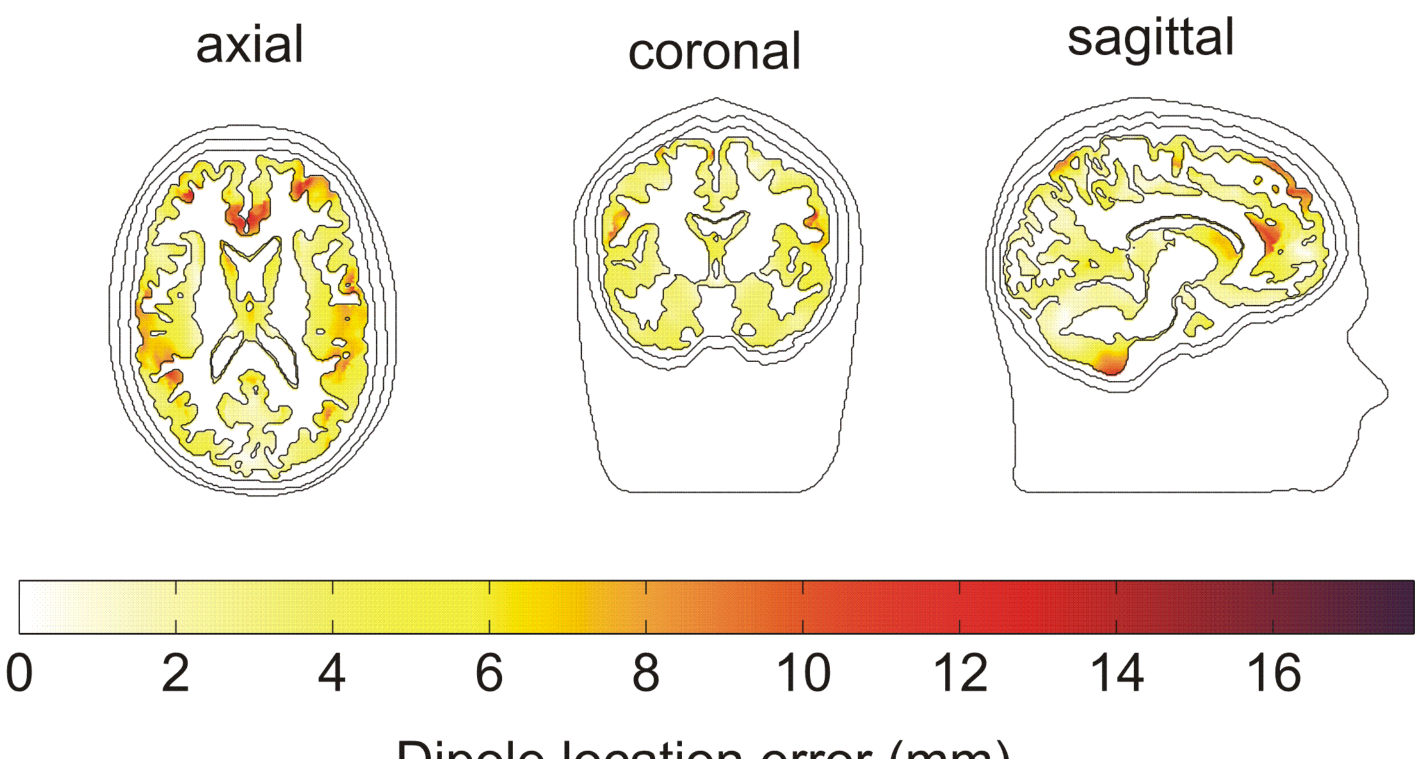
- Estimation errors due to different anisotropic conductivity models of white matter (method B vs method A)

Error on dipole location $\left\|\hat{\mathbf{r}} - \mathbf{r}\right\|$

Error on dipole orientation $\angle\left(\hat{\mathbf{d}}, \mathbf{d}\right)$

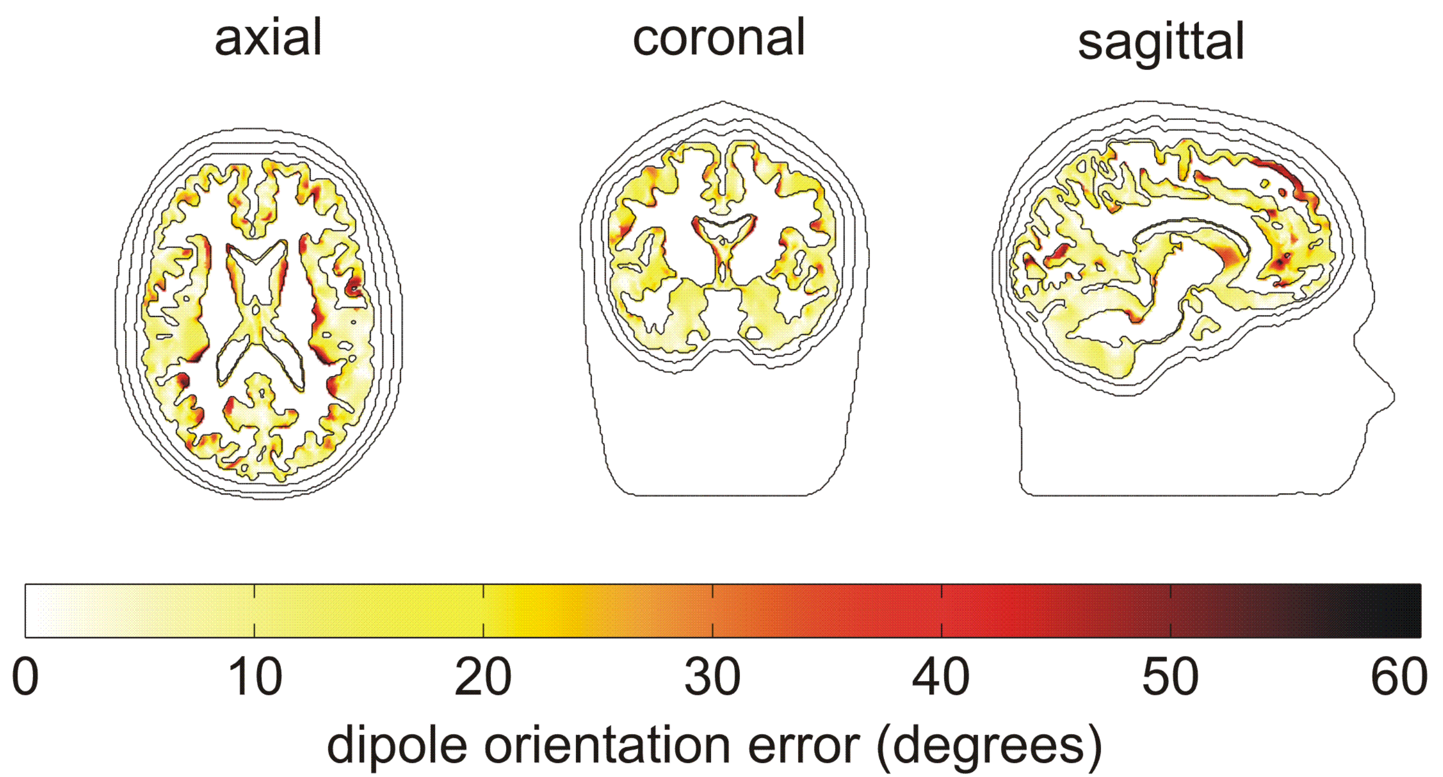
Influence of anisotropic conducitivities

- Estimation errors due to different anisotropic conductivity models (method B vs method A)
  - Dipole location error



Influence of anisotropic conducitivities

- Estimation errors due to different anisotropic conductivity models (method B vs method A)
  - Dipole orientation error



Influence of anisotropic conducitivities

- Estimation errors due to neglecting anisotropic conductivities

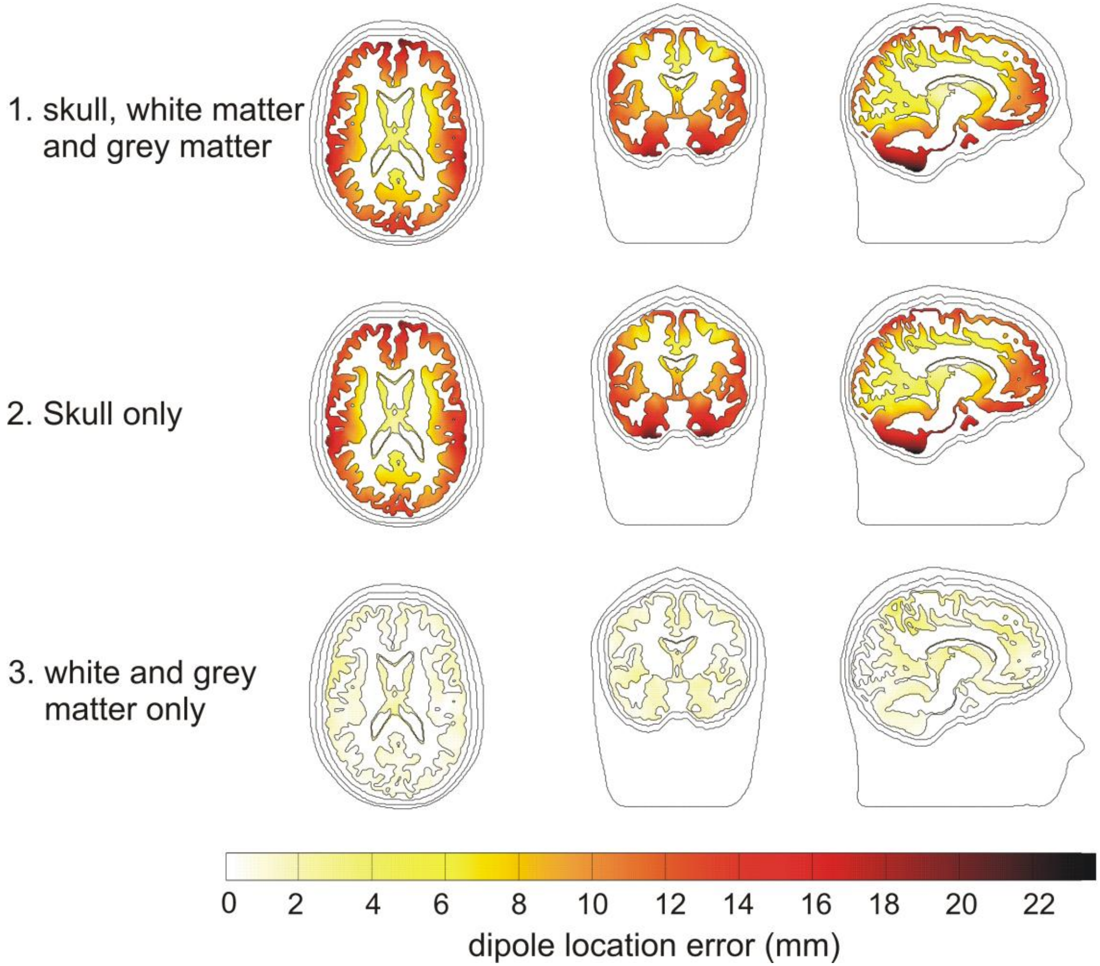
- Skull, white matter and grey matter
- Skull only
- White and grey matter

Error on dipole location $\left\| \hat{\mathbf{r}} - \mathbf{r} \right\|$

Error on dipole orientation $\angle\left(\hat{\mathbf{d}}, \mathbf{d}\right)$

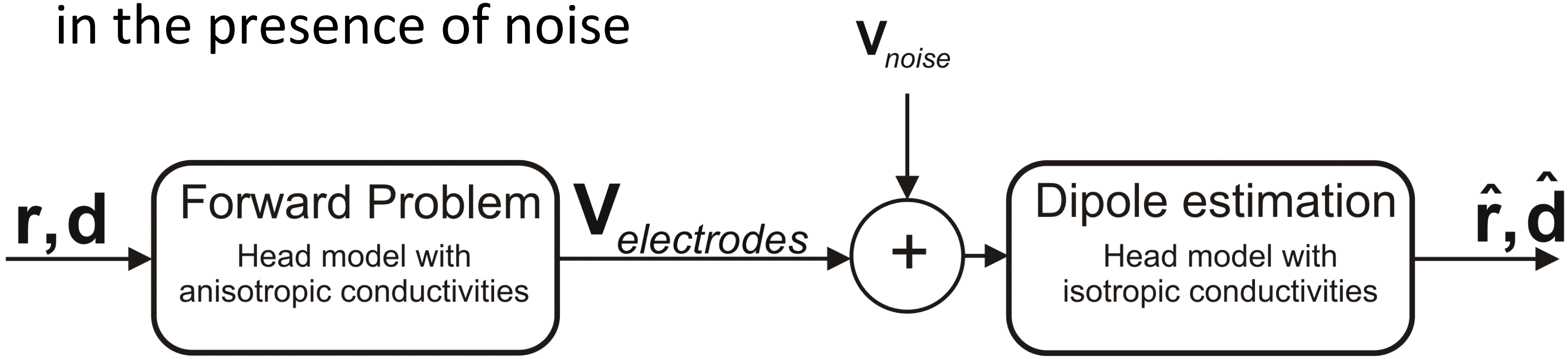
Influence of anisotropic conductivities

- Dipole location errors due to not incorporating anisotropic conductivities
  - Error is largest when skull anisotropy is neglected
  - Error is largest at the edges than in center
  - Error due to neglecting white matter anisotropy is very small

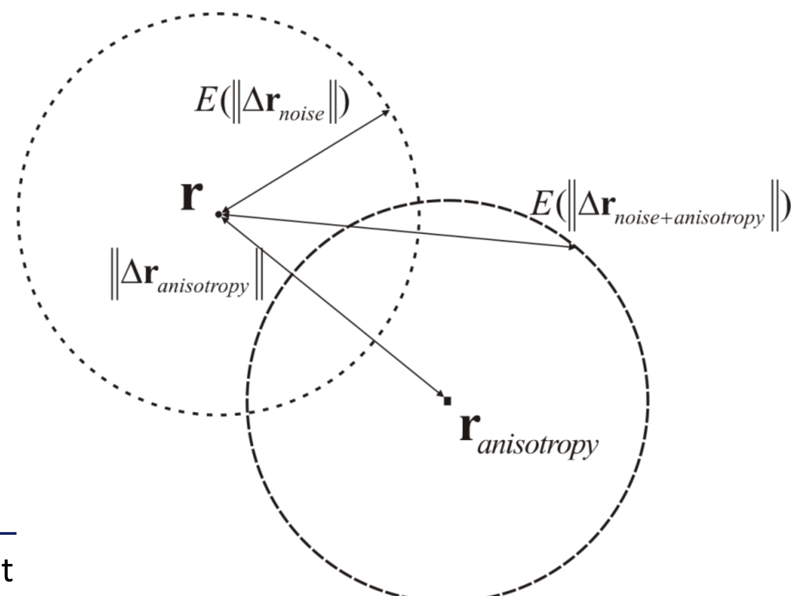


Influence of anisotropic conductivities

- Estimation errors due to neglecting anisotropic conductivities in the presence of noise



- Skull, white matter and grey matter
- Skull only
- White and grey matter



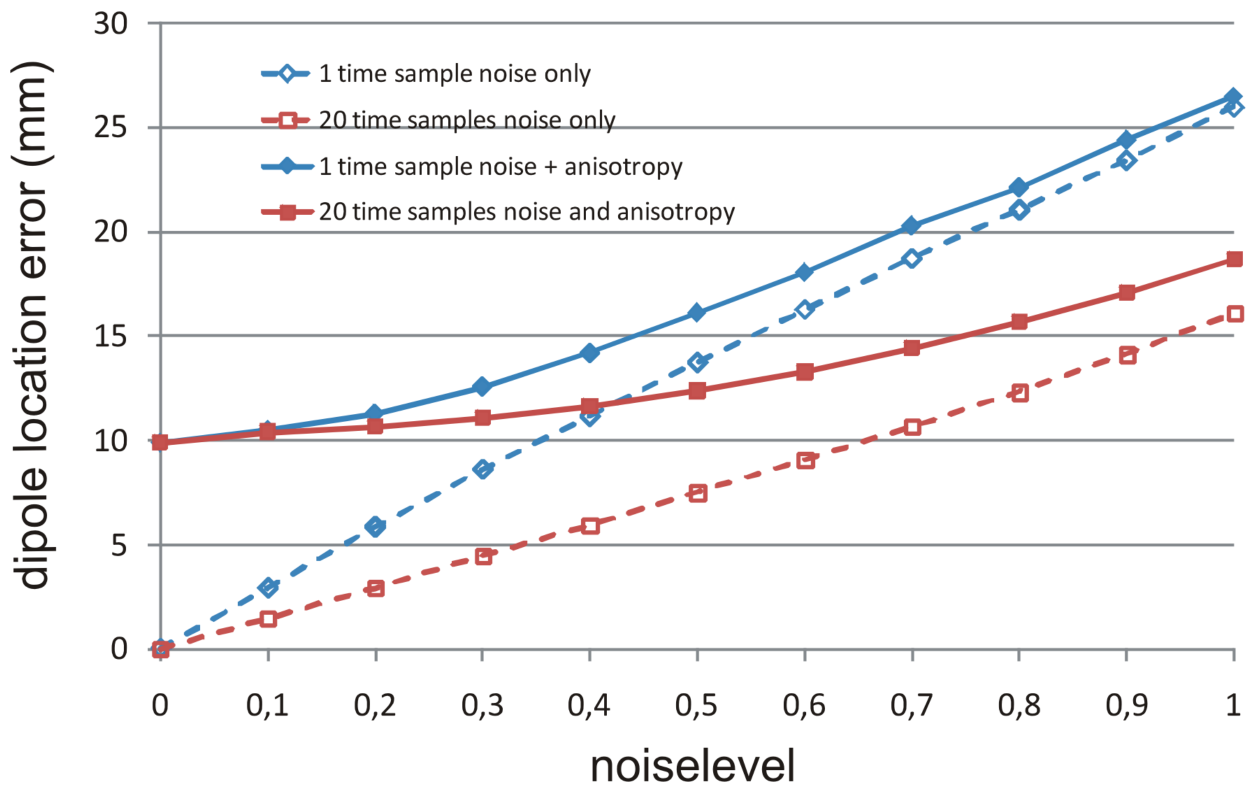
Error on dipole location $\|\hat{\mathbf{r}}-\mathbf{r}\|$

Error on dipole orientation $\angle\left(\hat{\mathbf{d}},\mathbf{d}\right)$

Influence of anisotropic conductivities

- Estimation errors due to neglecting anisotropic conductivities in the presence of noise

$$noiselevel = \frac{V_{noise}^{RMS}}{V_{dipole}^{RMS}}$$

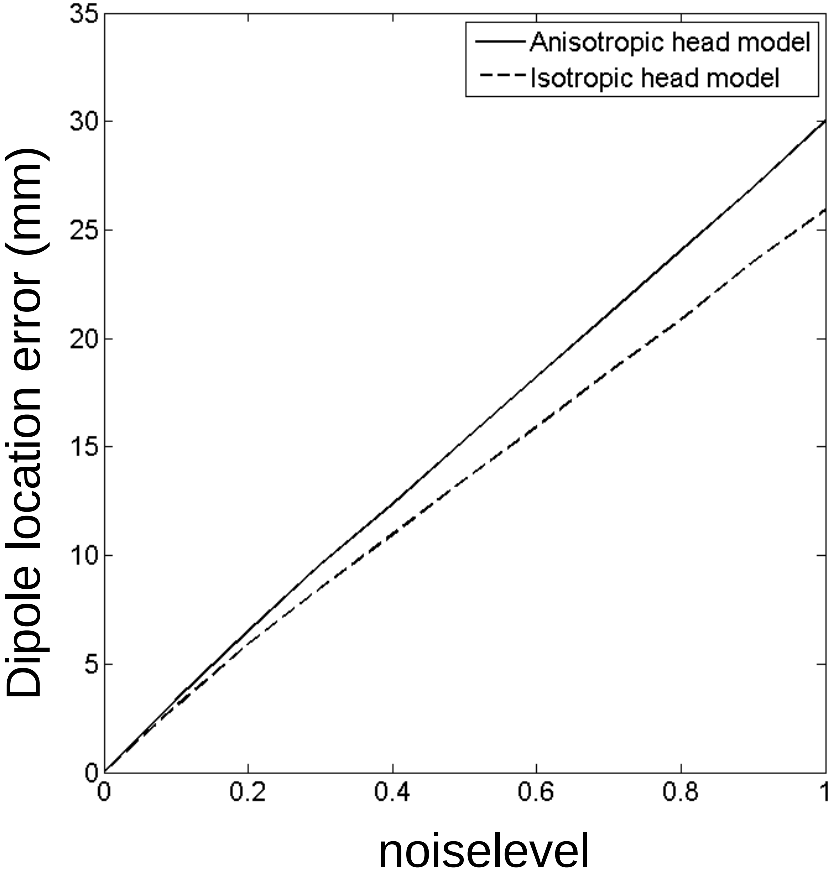


Dipole estimation over

- 1 time sample
- 20 time samples by first component of SVD

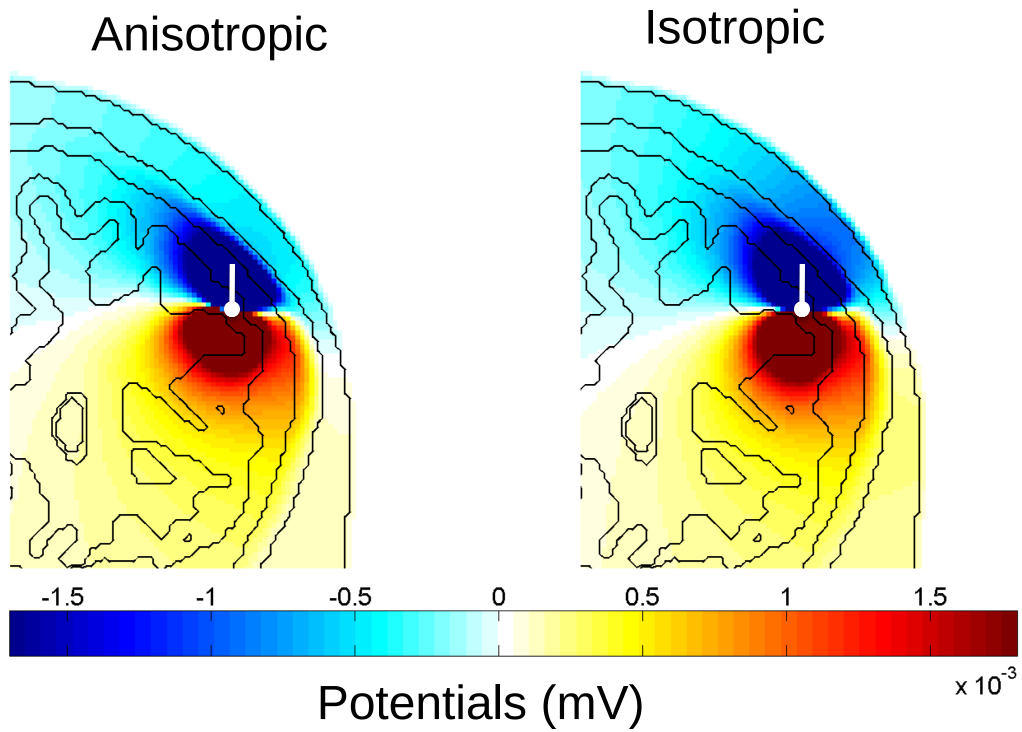
Influence of anisotropic conductivities

- Average dipole location error due to noise in anisotropic and isotropic head model
  - Error due to noise only is larger in anisotropic head-model than in isotropic one



Influence of anisotropic conductivities

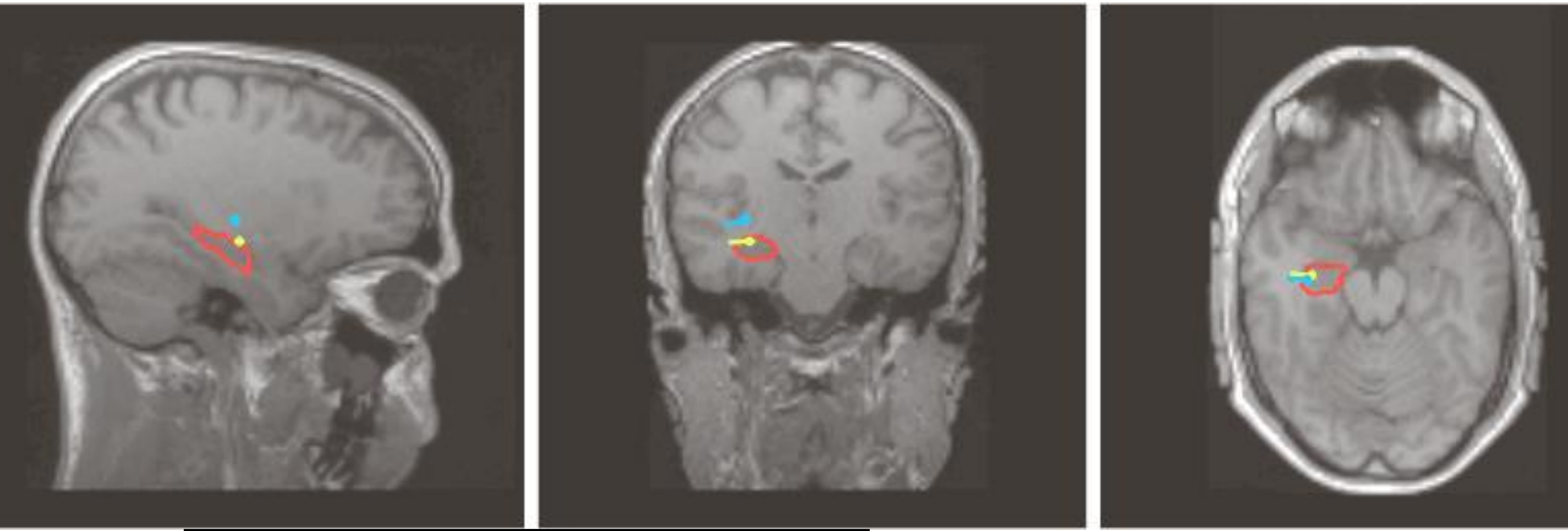
- Anisotropic conductivity makes the problem more illposed
- Potentials are more attenuated and smeared out over the surface



- Incorporating anisotropic conductivities will provide a more accurate estimation, but the illposedness will make it more difficult

Influence of anisotropic conductivities

- Application of an averaged epileptic spike
  - left hippocampus (manually segmented)
  - Surgery outcome: seizure free



Anisotropic conducting head model
Isotropic conducting head model

Localization difference: 9.8 mm

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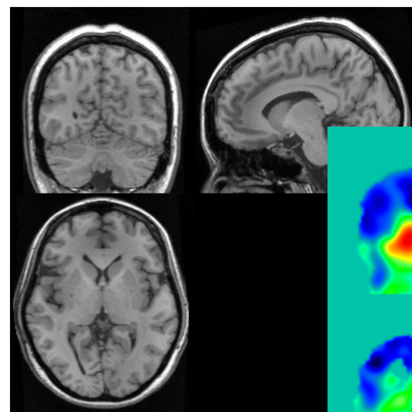
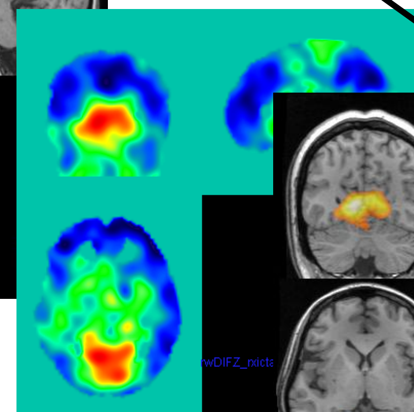
- Source localization
- Incorporating anisotropic conductivities
- Influence of anisotropic conductivities
- Future work
  - Incorporation of functional imaging as a priori knowledge
  - Multi-level approaches on solving the inverse problem
  - Brain Connectivity

Future work

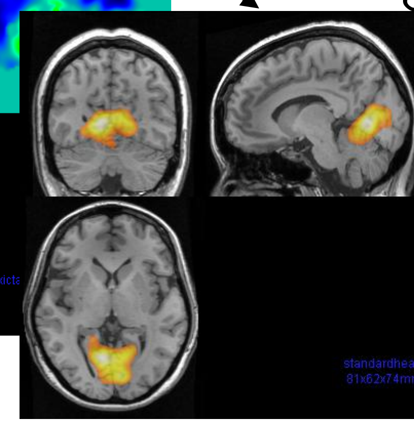
- Incorporate functional activation (SPECT or fMRI) boundaries as a priori knowledge



MR image



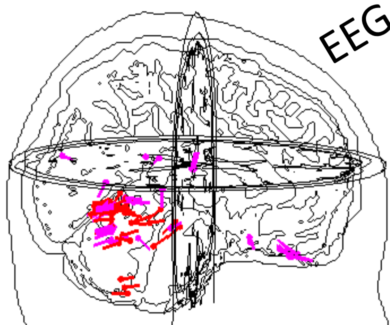
SPECT



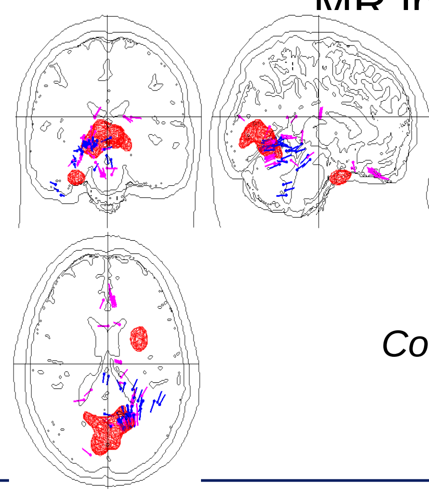
SPECT-MR

SPECT-MR coregistration

EEG-MR coregistration



EEG source localization

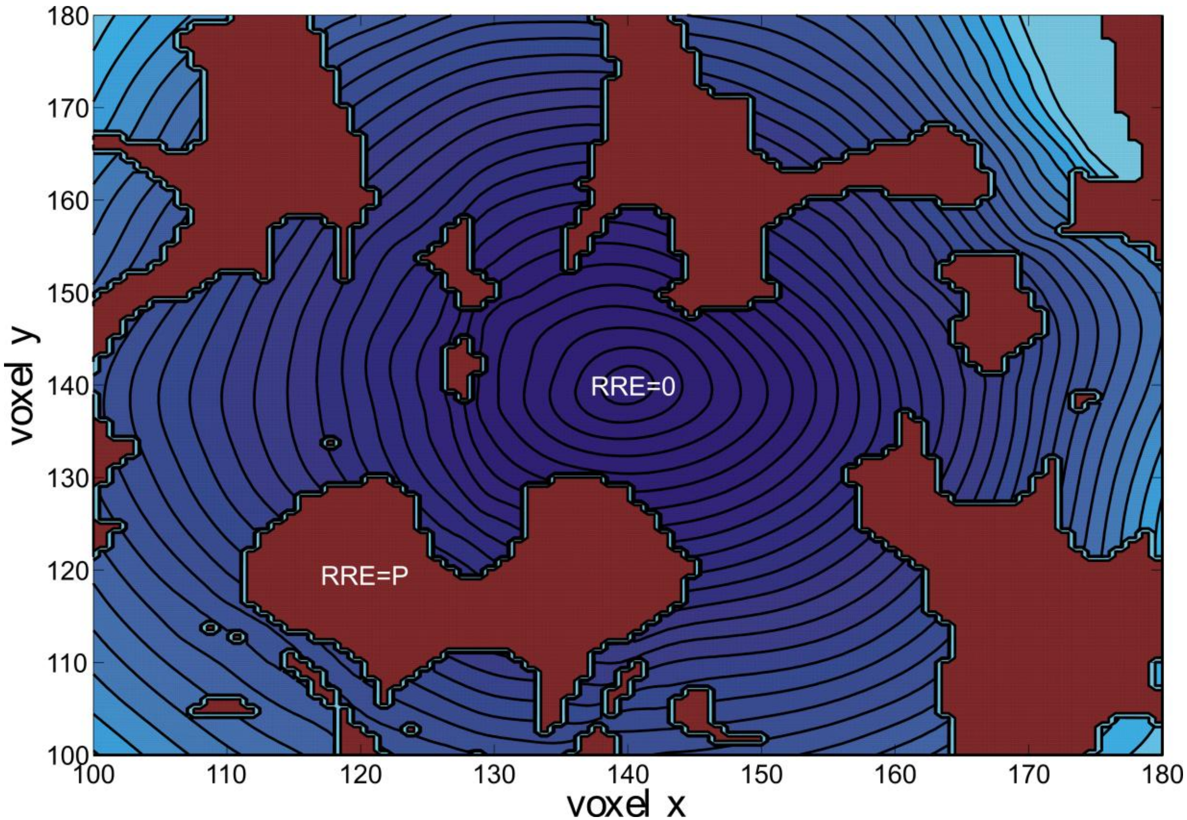


Colloboration with Maarten De Vos, prof. Van Huffel (ESAT), prof. Van Paesschen (Neurology, Gasthuisberg)

Hallez et al., 2009

Future work

- Multilevel techniques to efficiently solve the inverse problem in a discrete non-convex search space



Collaboration with prof. Luc Dupré and Guillaume Crevecoeur (EELAB)

Future work

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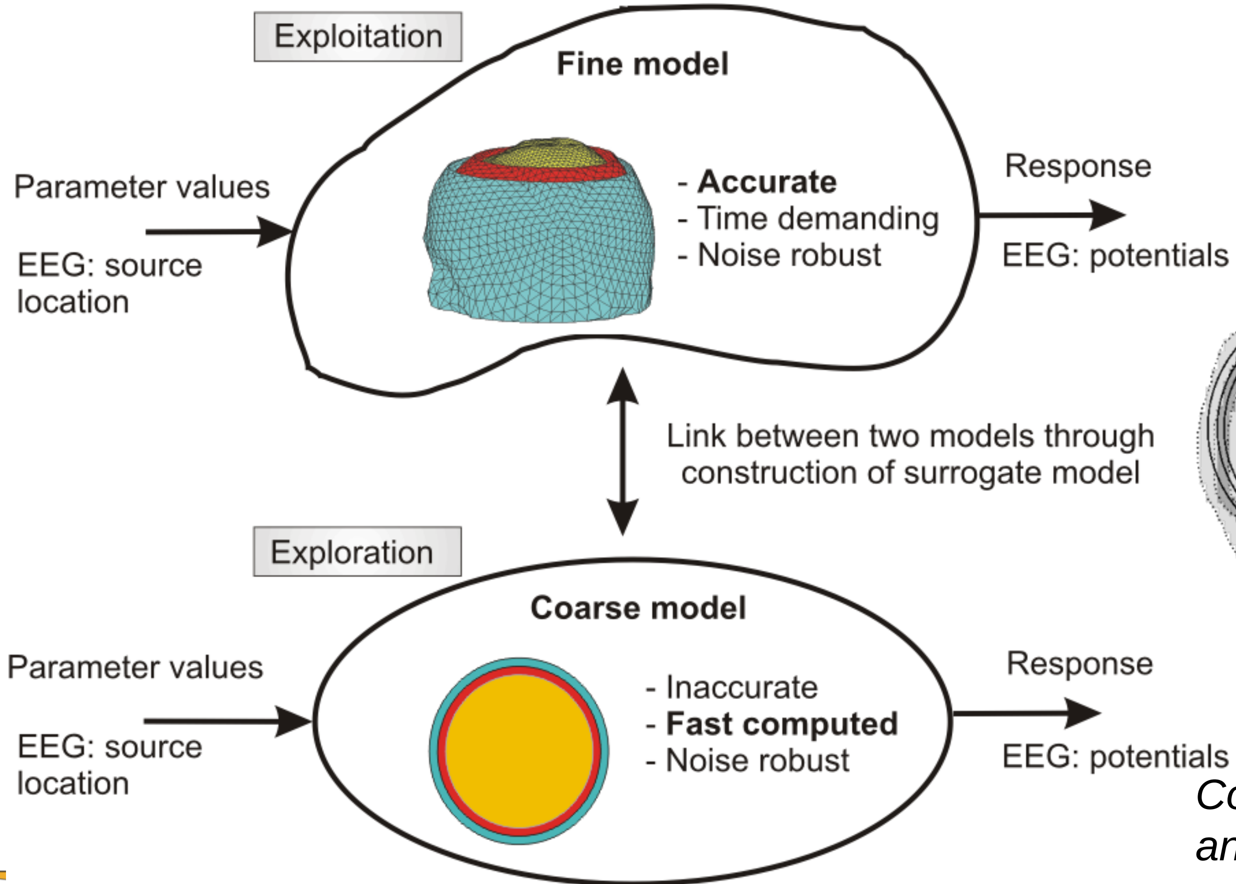
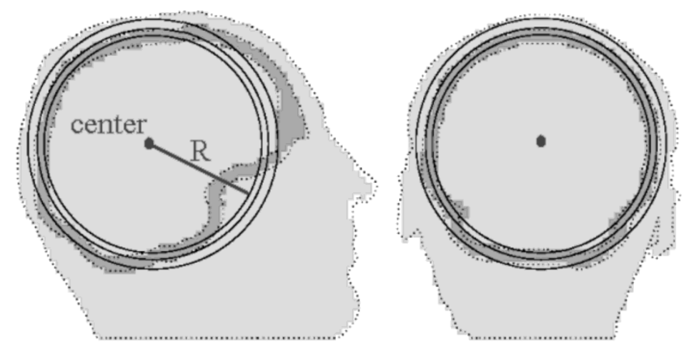


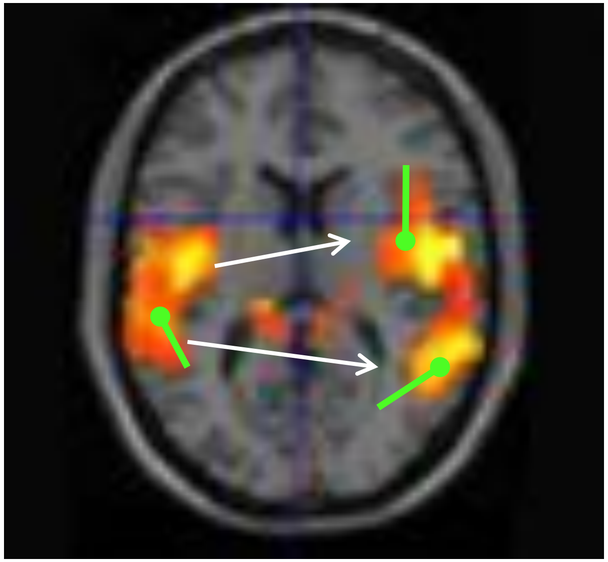
Crevecoeur et al, 2008



Collaboration with prof. Luc Dupré and Guillaume Crevecoeur (EELAB)

Brain Connectivity

- Use EEG source localization to estimate location and time series of dipoles
- Use connectivity to estimate causal relationship

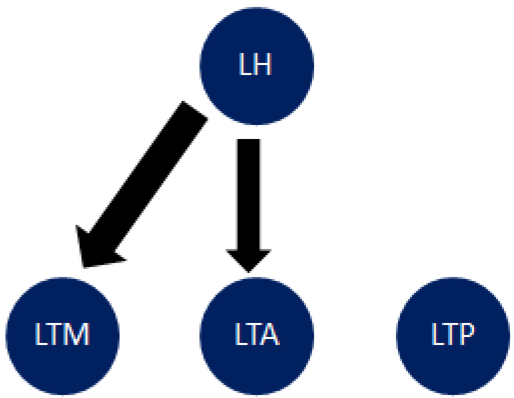


Brain Connectivity

van Mierlo et al. 2009

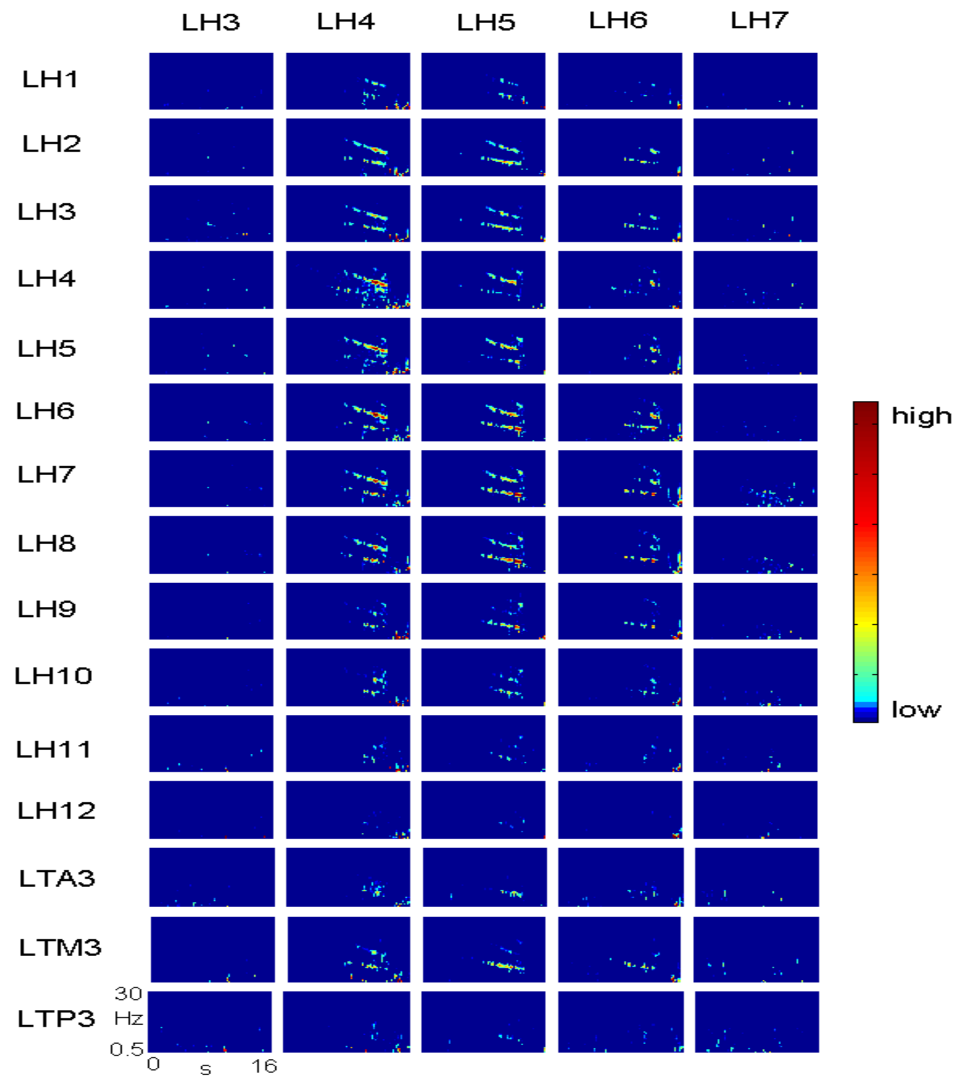
- Intracranial recordings during

The functional connectivity pattern between the brain regions through energy weighted Adaptive Directed Transfer Function:



Between LH contact points:

The information flow spreads from LH4 and LH5 symmetrically to the other contact points



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  Wouter Deburchgraeve

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  Prof. dr. Koen Van Laere
  Prof. dr. Patrick Dupont

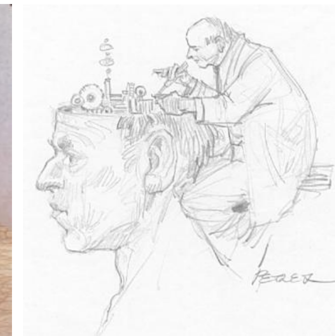
Klinische en Experimentele Neurologie

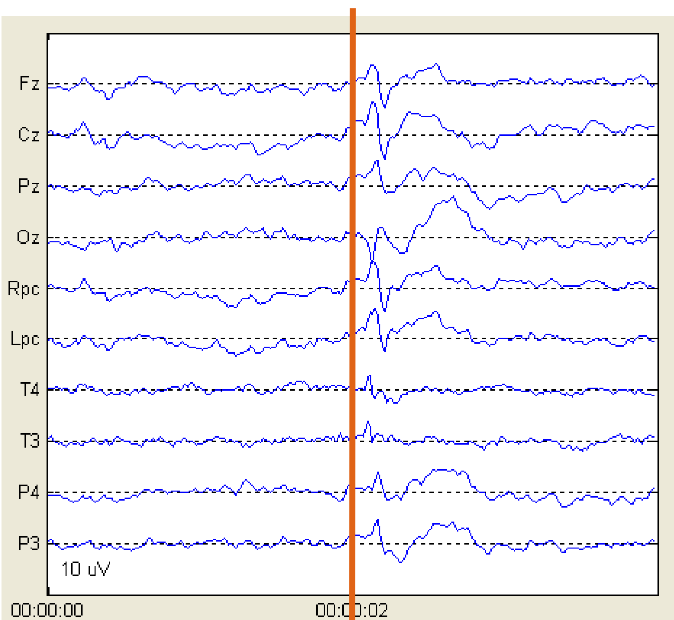
Division of Nuclear Medicine



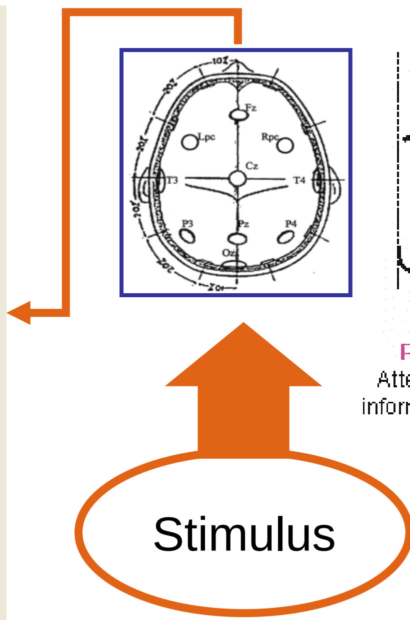

Future Work: Event related potentials

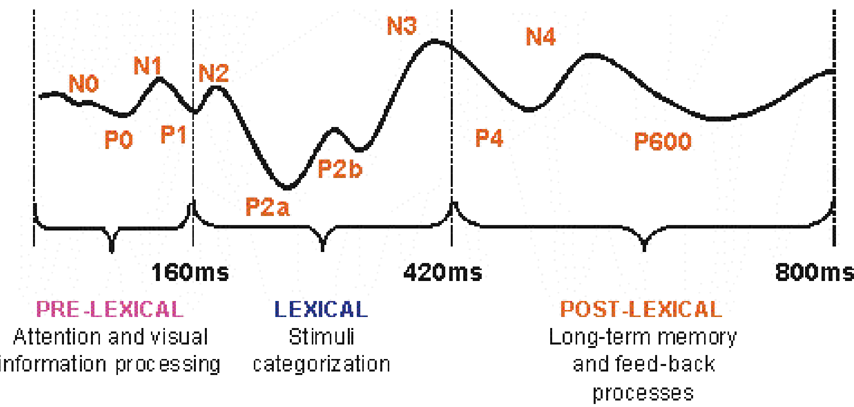
- Functionality of the brain
  - How does the brain work when doing certain tasks?





Stimulus





- Diagnosis of Dyslexia
- Which brain regions are involved?