The influence of forward model conductivities on EEG/MEG source reconstruction

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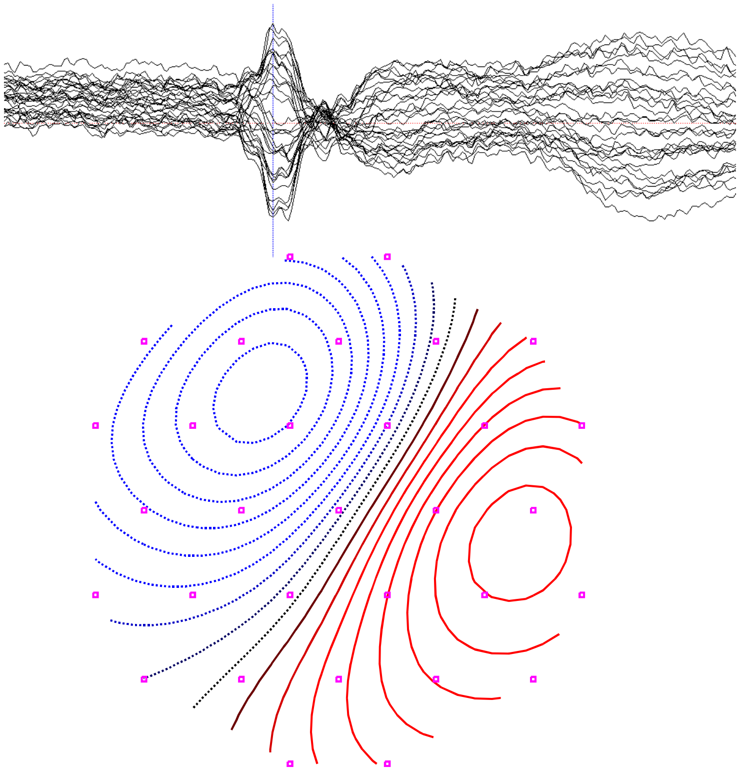
Introduction



- How does volume conduction influence source estimation?
- How does anisotropy influence source estimation?

Overview

BMTI
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1. Finite Element Modeling
   1. Software: SimBio and Galerwin
   2. Conductivity and anisotropy data

2. Sensitivity analysis
   1. Animal studies
   2. Human studies

SimBio and NeuroFEM

Image Registration (T1, T2, PD)

↓

Segmentation

↓

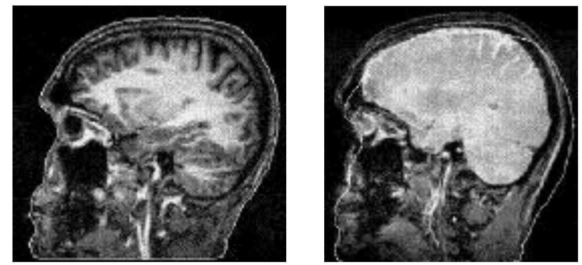
Mesh Generation BEM/FEM

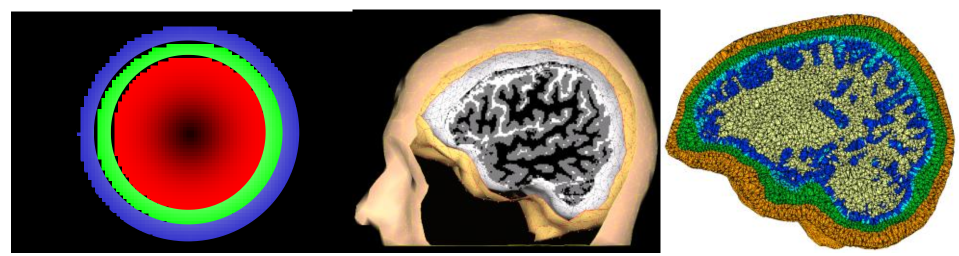
↓

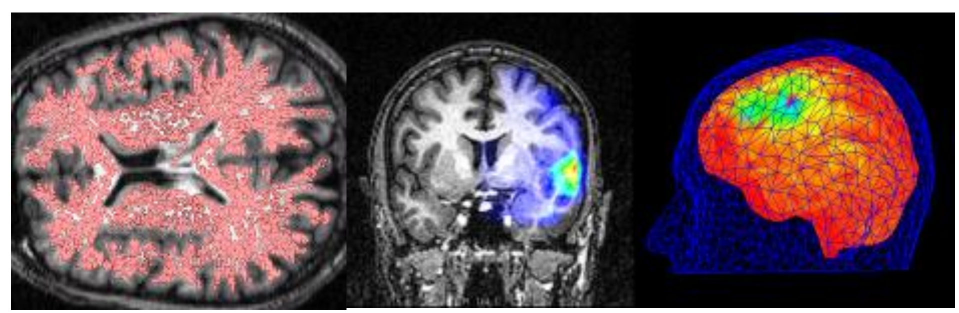
Forward toolbox
Inverse toolbox

↓

Visualisation







Galerwin

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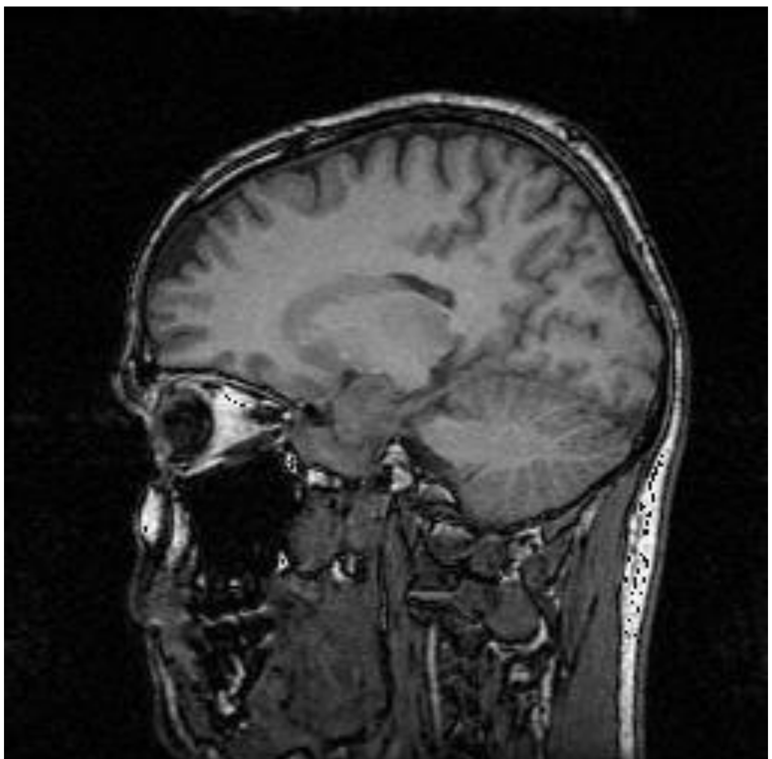
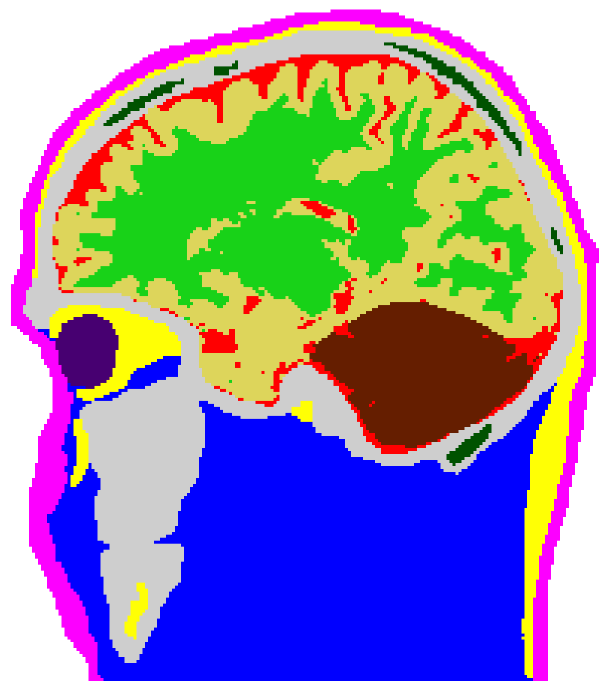
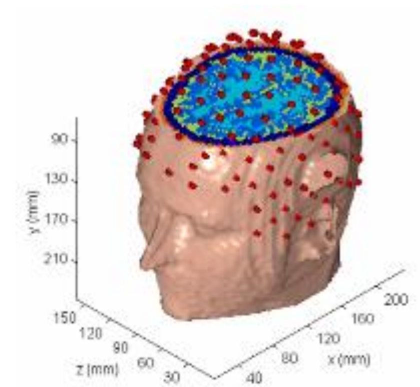
T1 weighted MR data:
- 1.6 mm slice thickness,
- 102 slices,
- 1 mm x 1 mm pixel size

FEM model cross section:
- resolution of 1 mm x 1 mm x 3.2 mm,
- 1,456,069 hexahedral elements (voxels)
- adaptive JCG solver







Schimpf, Haueisen et al., Parallel Computing, 1998

Conductivity and anisotropy data

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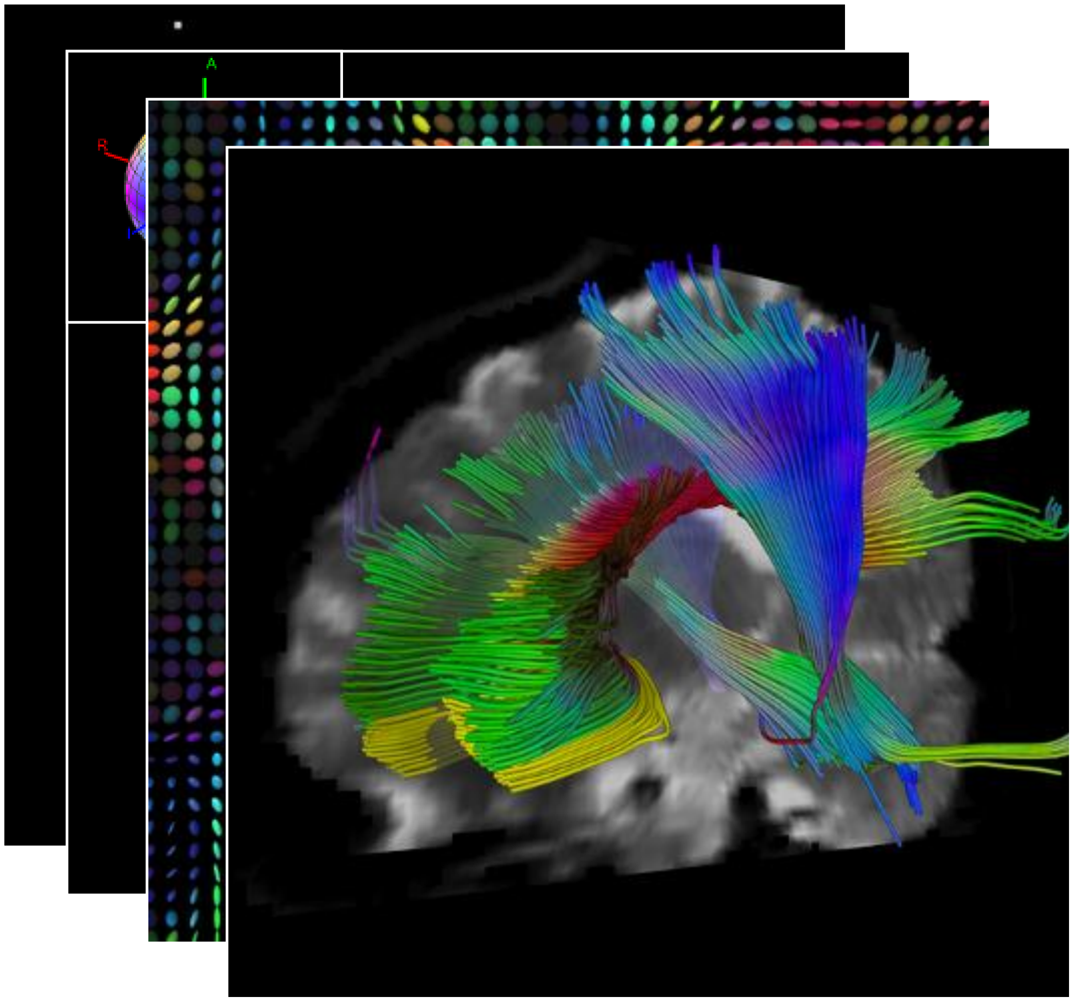
Human Diffusion Tensor Imaging



Anisotropy map (FA)

Anisotropy map color coded

Diffusion tensor as ellipsoid

Fiber tracking (main direction of strong anisotropic tensors)

Böhr, Güllmar, Knab, Reichenbach, Witte, Haueisen: Brain Res, 2007

Conductivity and anisotropy data

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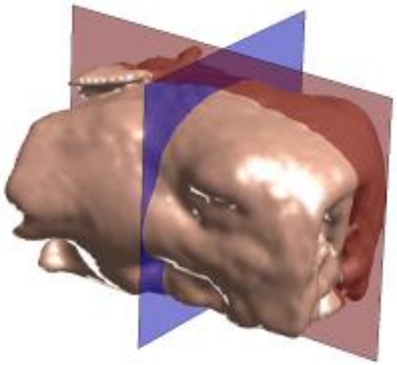
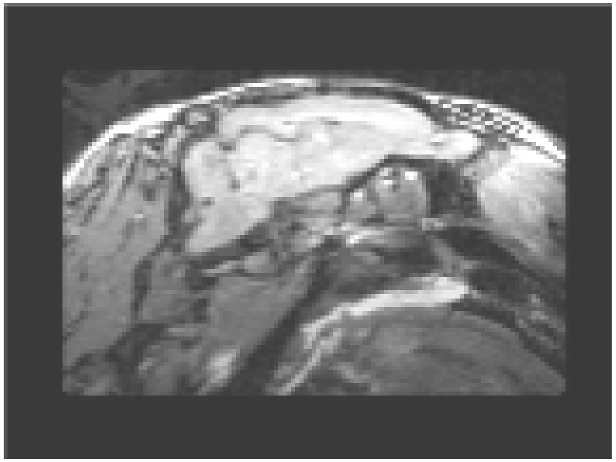
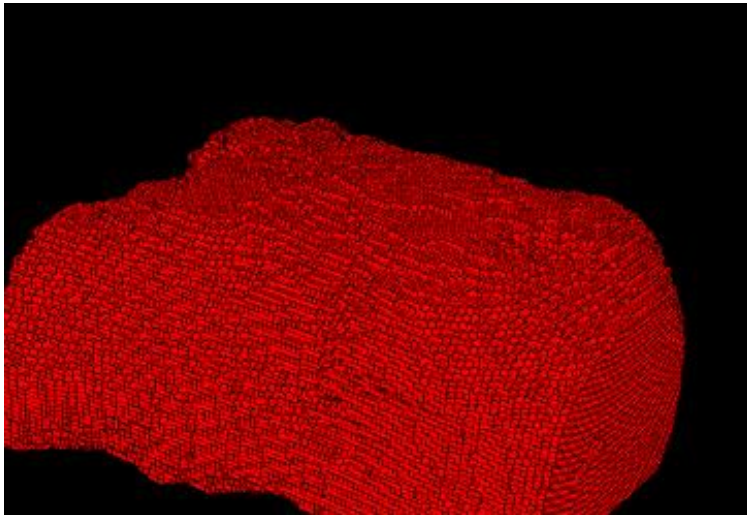
Rabbit imaging



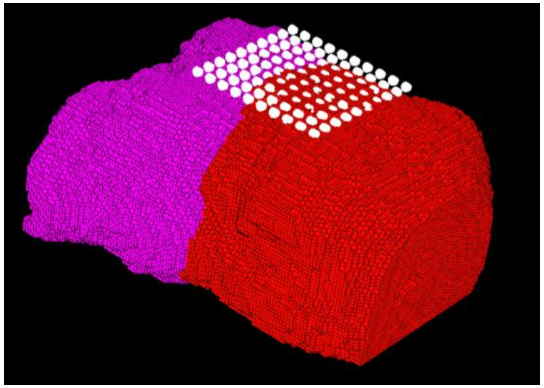


Flash3D T1
(isotropic resolution 0.625 mm)

TSteam - DTI



633172 cubic elements (0.6mm)



Overview

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Animal sensitivity analysis

Simulations with a block of white matter

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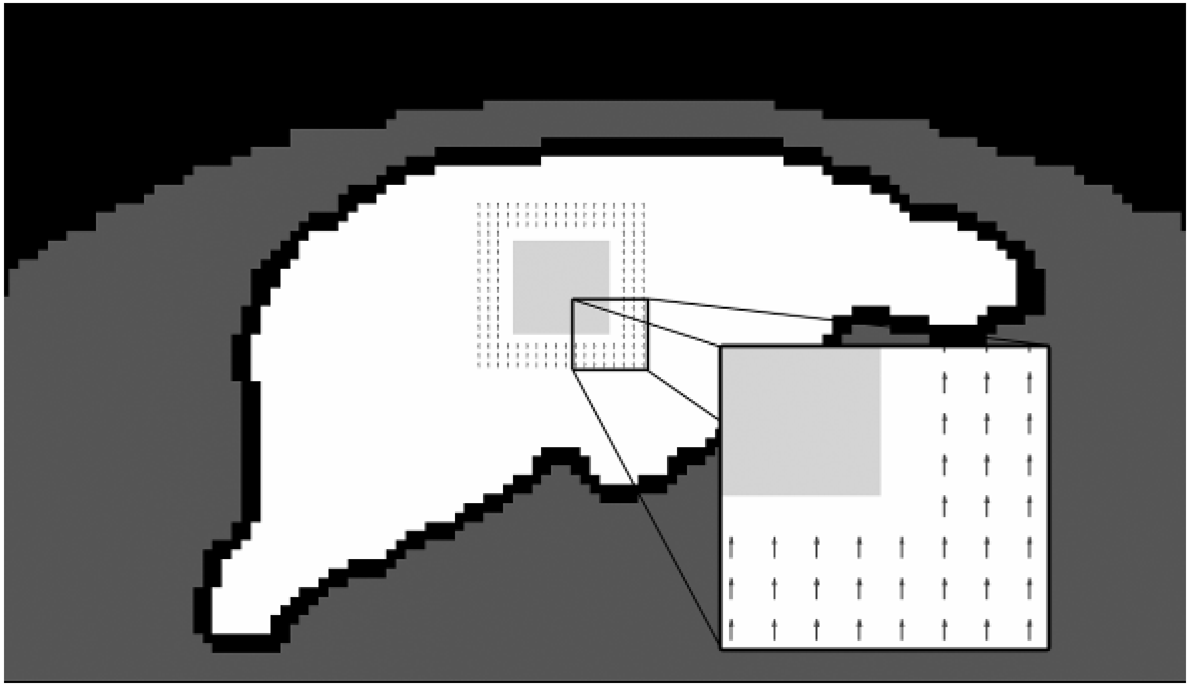


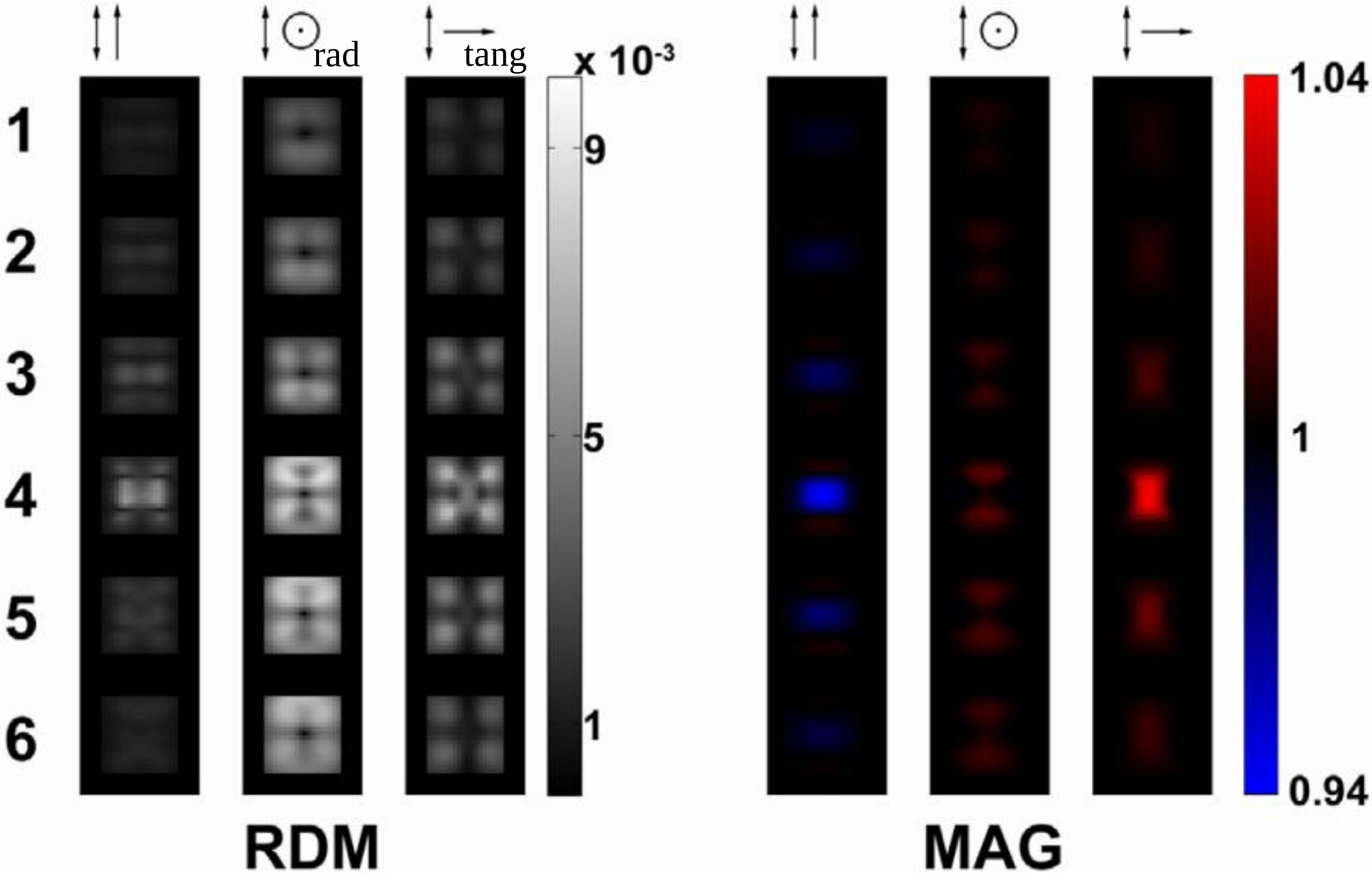
Sagittal slice with
4 tissue types:

- skin
- skull
- gray matter
- artificial white matter block

- source space with 3 layers of dipoles around the anisotropic block
- dipole orientation left/right, rostral/caudal, and inferior/superior
- anisotropic conductivity of 1:10 in caudal-rostral orientation

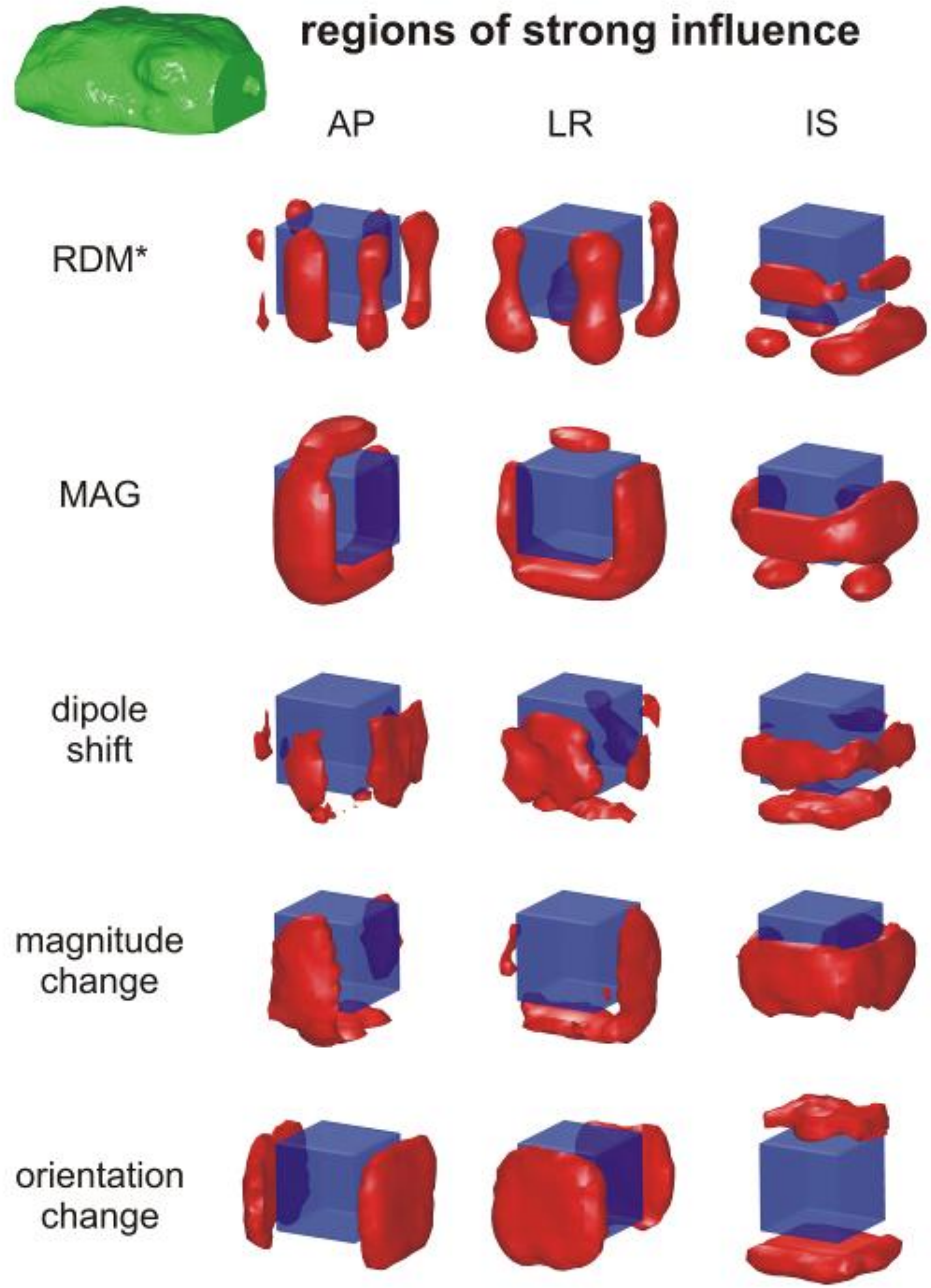
Animal sensitivity analysis

Differences in the forward computations



Simulations with a block of white matter

Values above the 0.8 percentile for RDM*, MAG, dipole shift, magnitude change and orientation change are visualized by red surfaces.



Güllmar, Haueisen et al.
IEEE TBME 2006

Experimental validation

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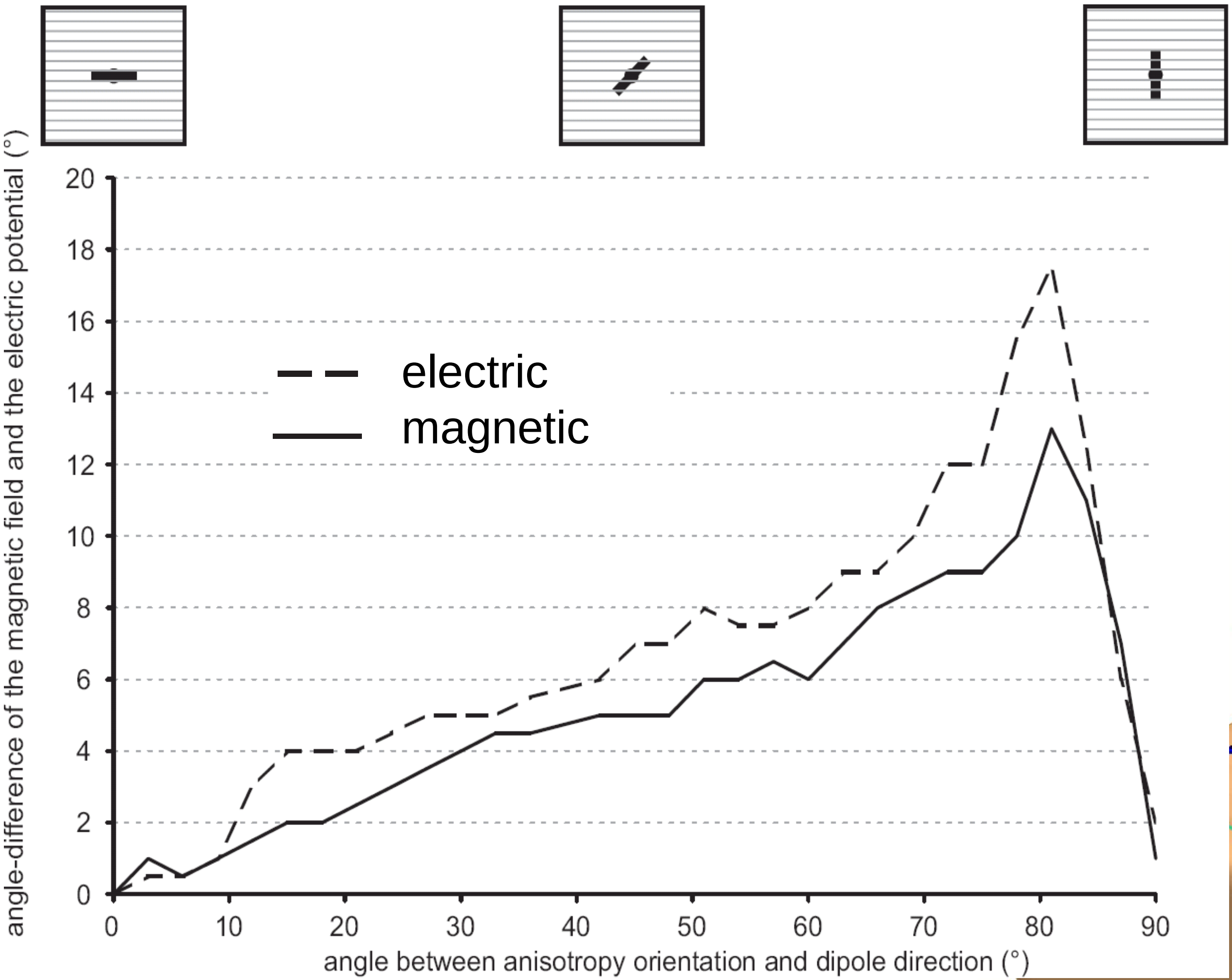
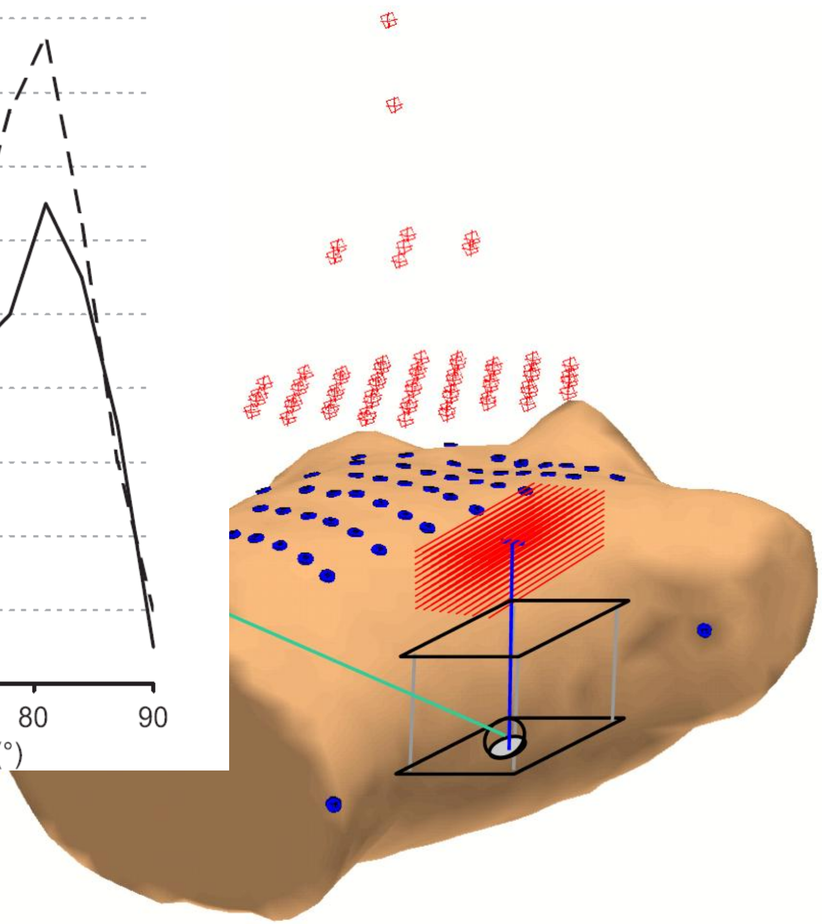


Anisotropic block in a torso phantom



Liehr, Haueisen: Phys Med Biol, 2008

Animal sensitivity analysis

Simulations with measured conductivity tensors

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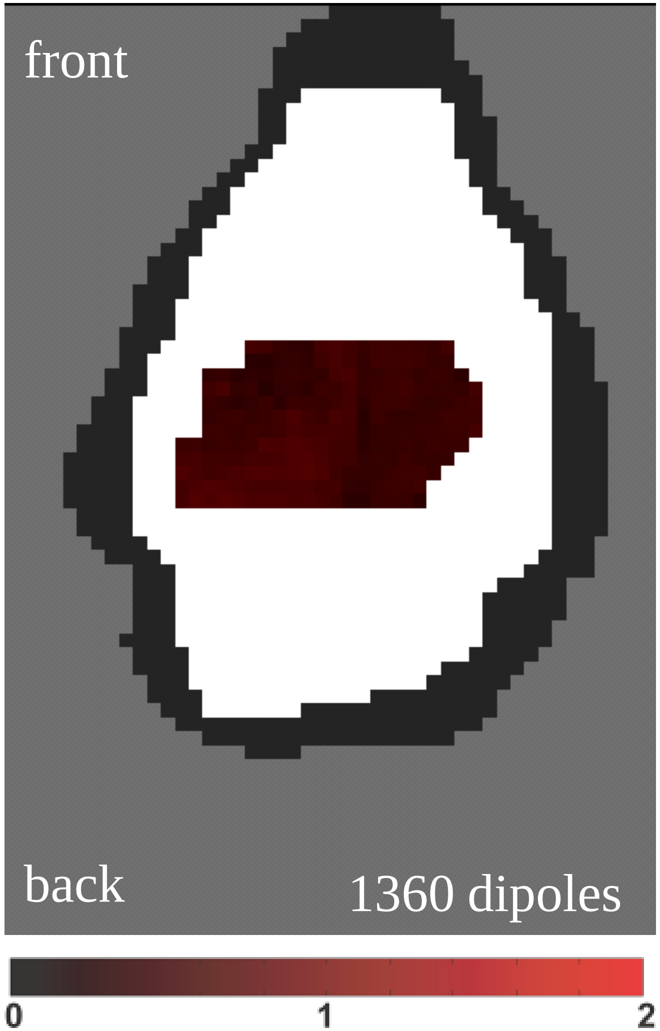
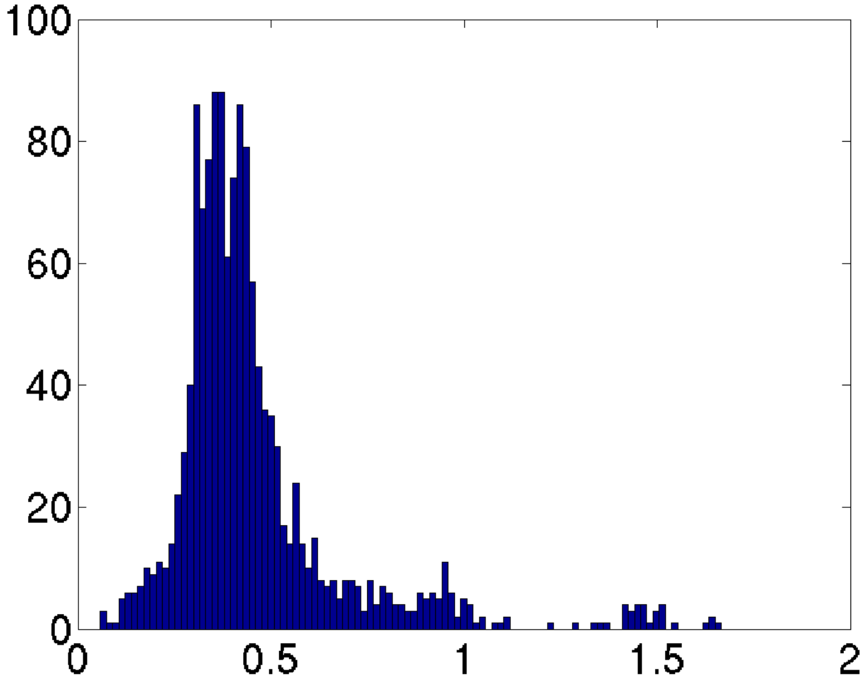


Dipole shift in mm

Source localization error

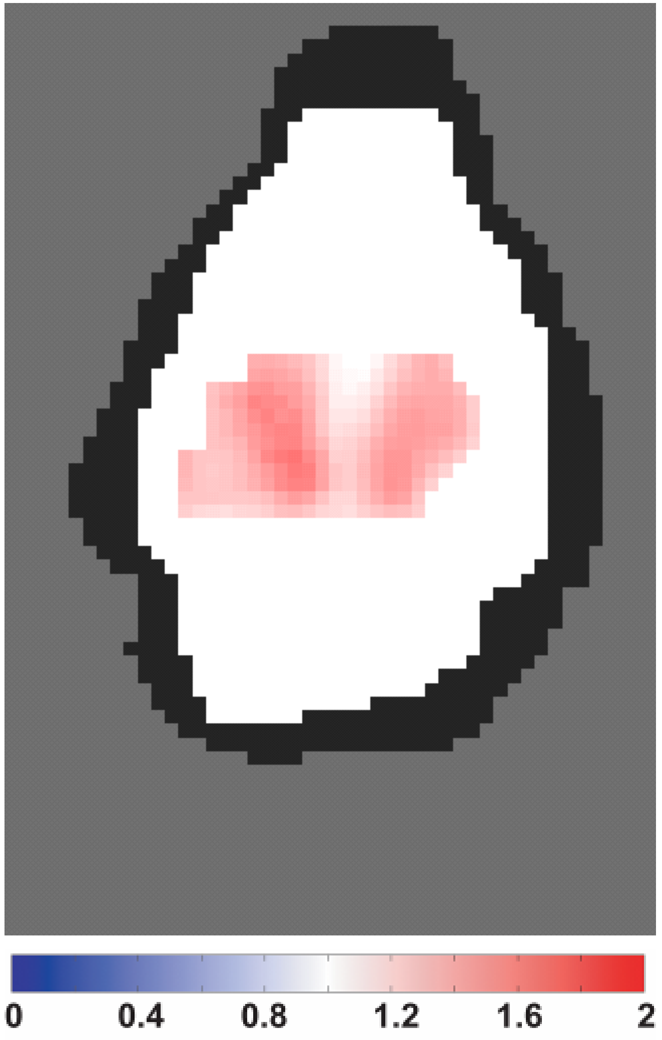
Forward computation:
anisotropic model
Inverse: isotropic model



Histogram of the dipole shift

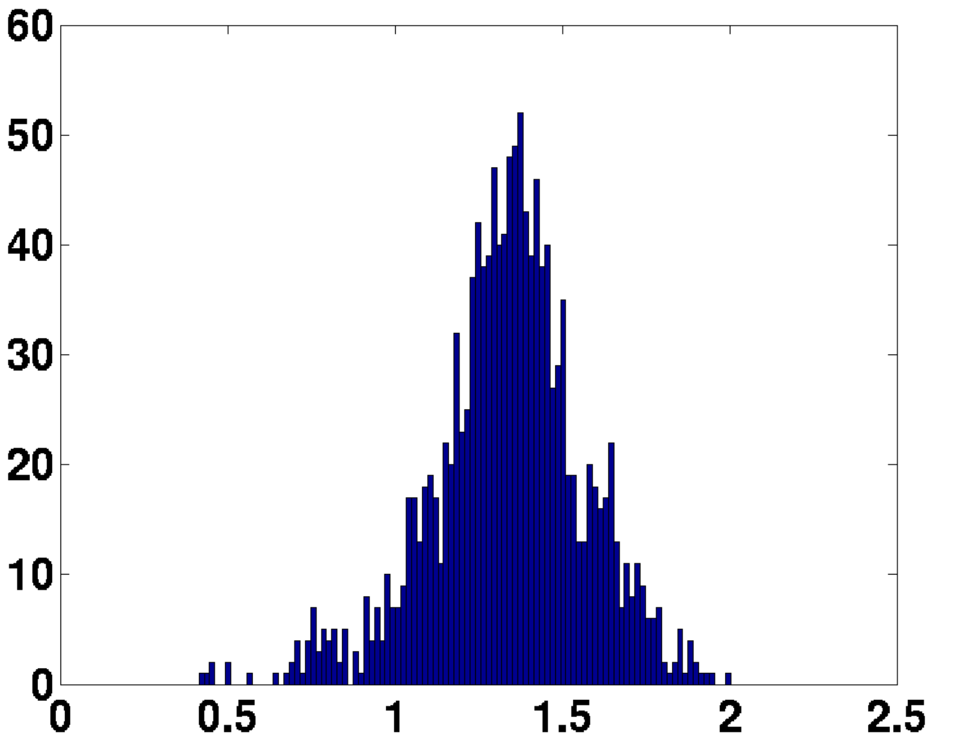
Animal sensitivity analysis

Simulations with measured conductivity tensors



Magnitude change (relative to 1)

Dipole magnitude estimation error



Histogram of the dipole magnitude errors

Animal sensitivity analysis

Simulations with measured conductivity tensors

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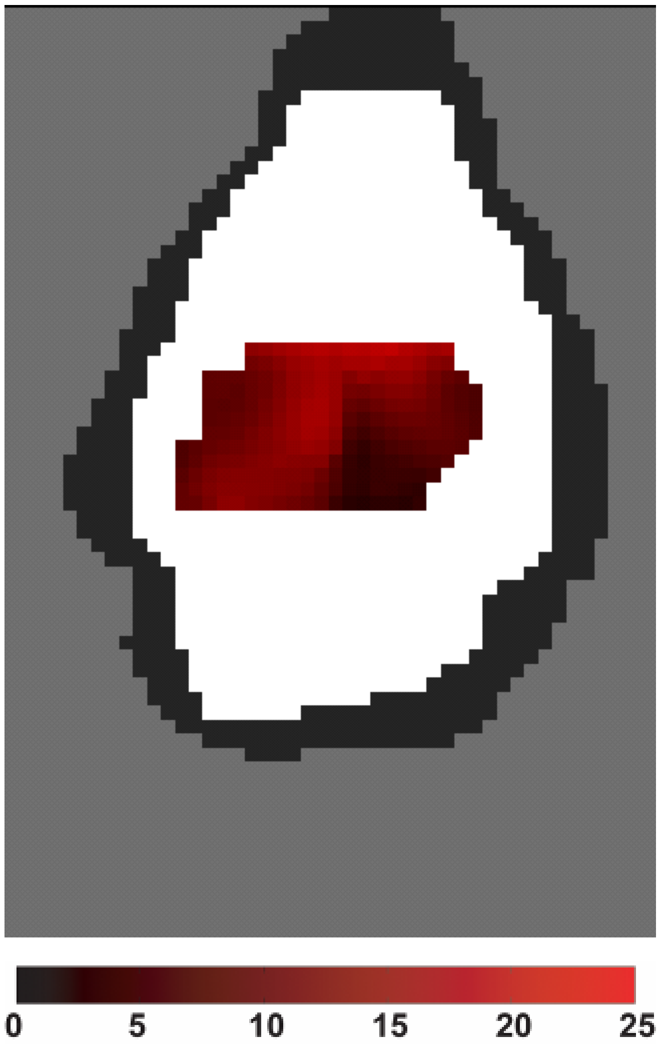
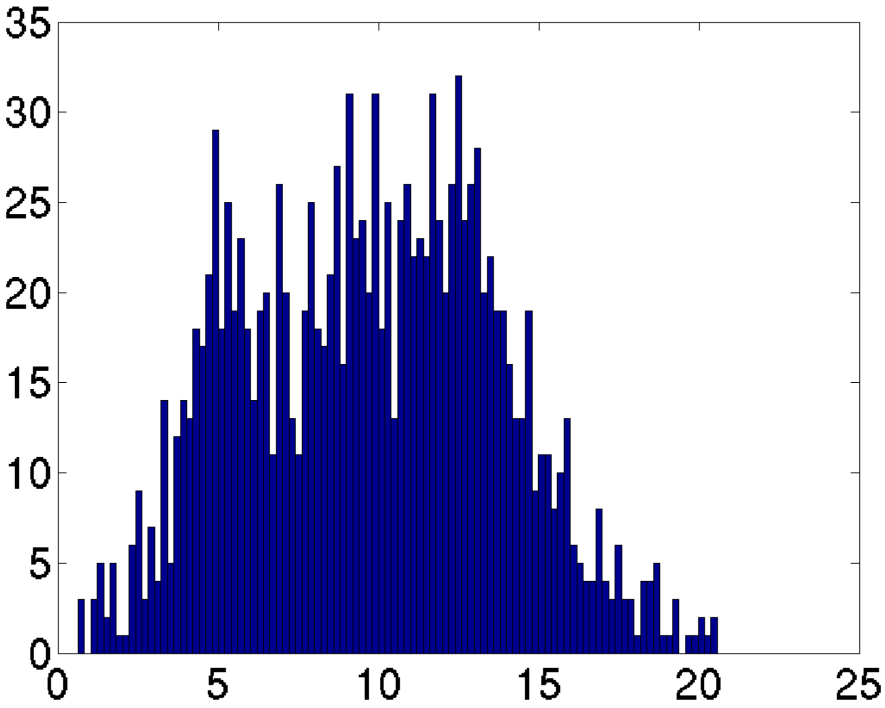


Orientation change in deg

Dipole orientation estimation error



Histogram of the dipole orientation errors

Sensitivity analysis

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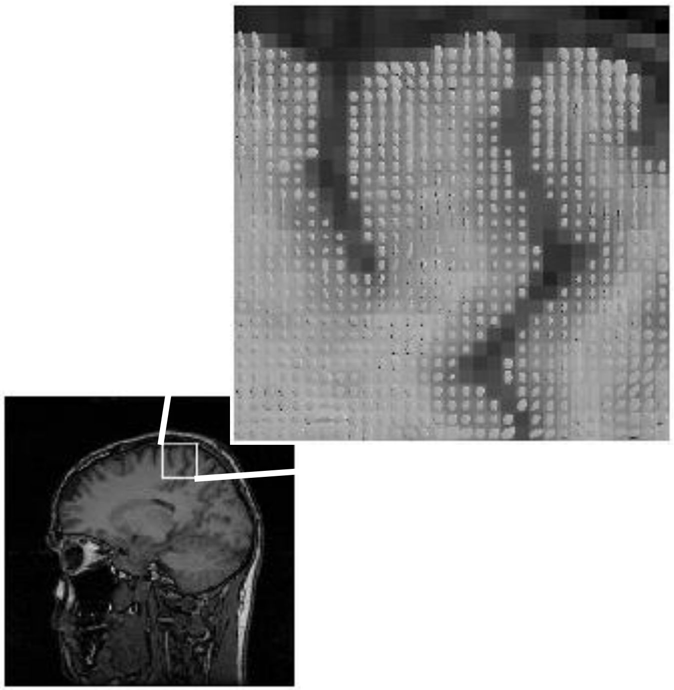
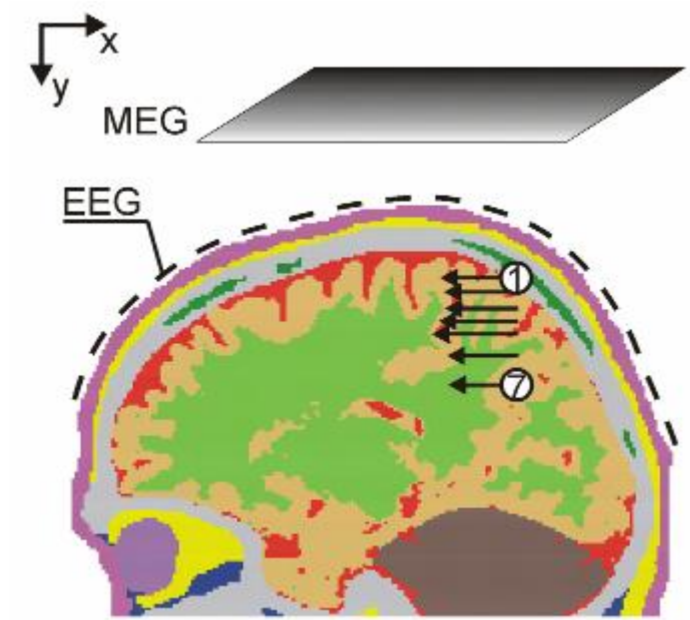
Forward simulations with isotropic and anisotropic human head models





Results:

Correlation:
above 0.98

Magnitude:
more than 50% change

Tissue anisotropy seems to have a minor influence on source localization but a major influence on dipole strength estimation.

Haueisen et al., The influence of brain tissue anisotropy on human EEG and MEG. Neuroimage 15:159-166, 2002

Sensitivity analysis

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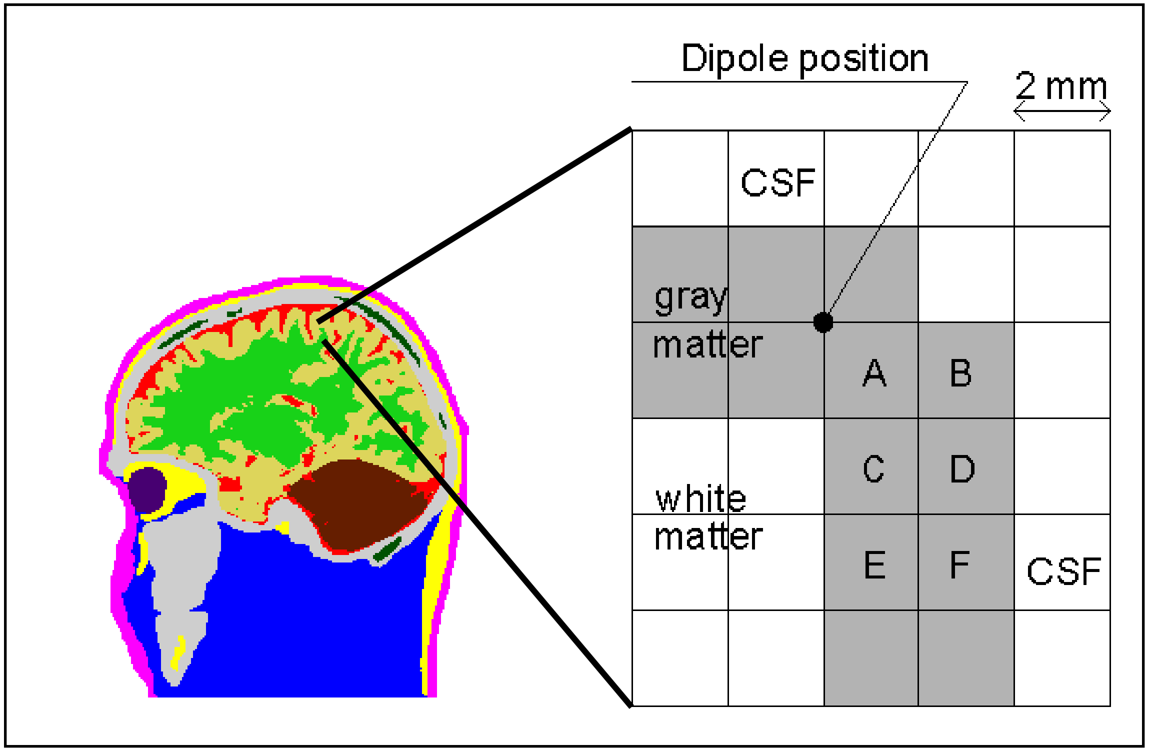
Simulations with conductivity changes of single voxels



Results:

Correlation:

Change in A: 0.98

Change B-F: >0.999

Magnitude:

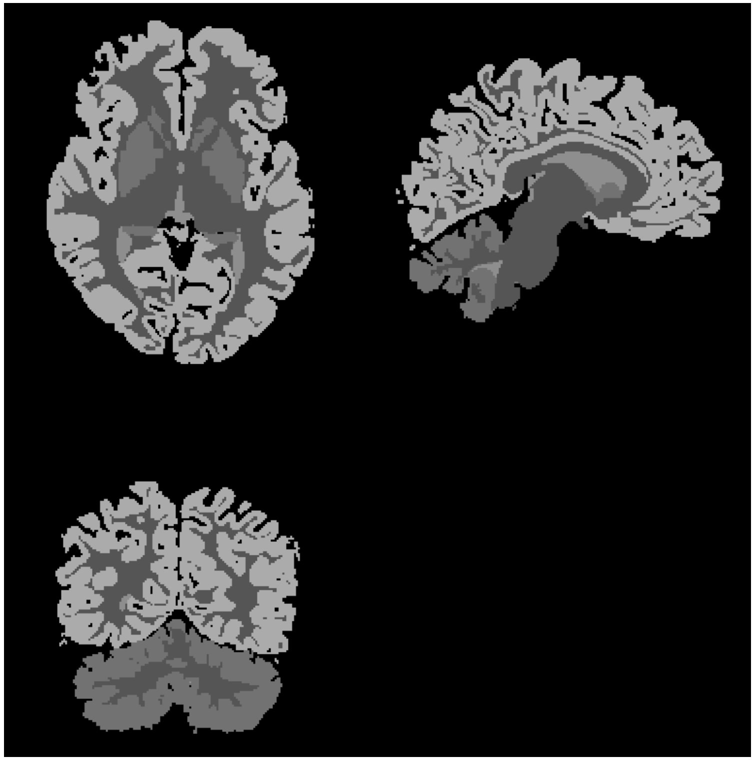
Change in A: 2 - 60%

Change B-F: < 1%

Conductivity changes in the vicinity of the dipole influence source estimation.

Haueisen et al., The influence of local conductivity changes on MEG and EEG. Biomed. Tech. 45 (7-8), 211 – 214, 2000

Human sensitivity analysis



- 5 tissue types
- 3.2 million cubic elements (1mm)
- 130 electrodes
- 25,000 dipoles perpendicular to cortical surface
- anisotropies of 1:2, 1:5, 1:10 and 1:100

Comparison of isotropic and anisotropic model output by RDM and MAG mapped to each dipole position

Human sensitivity analysis

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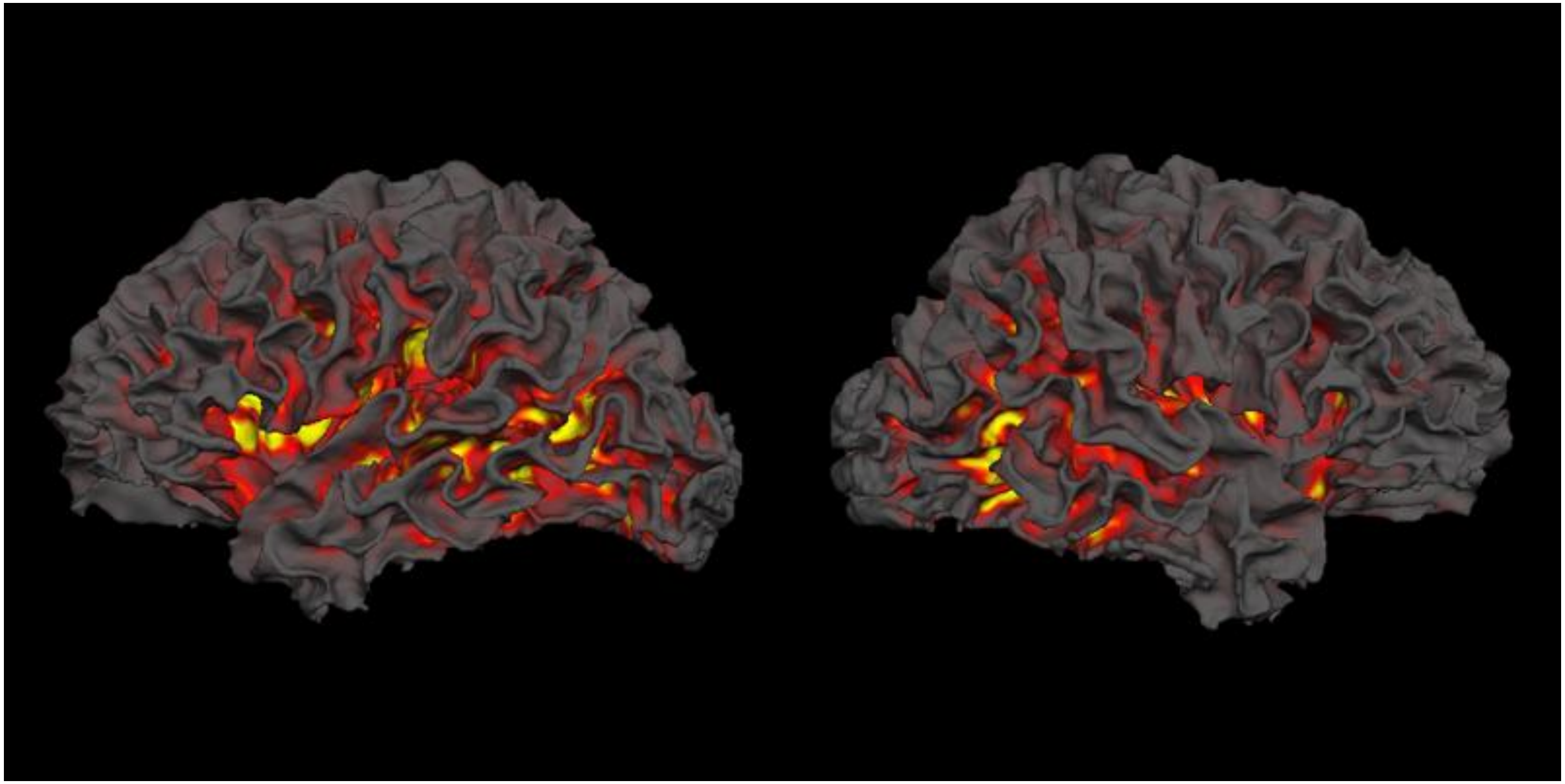
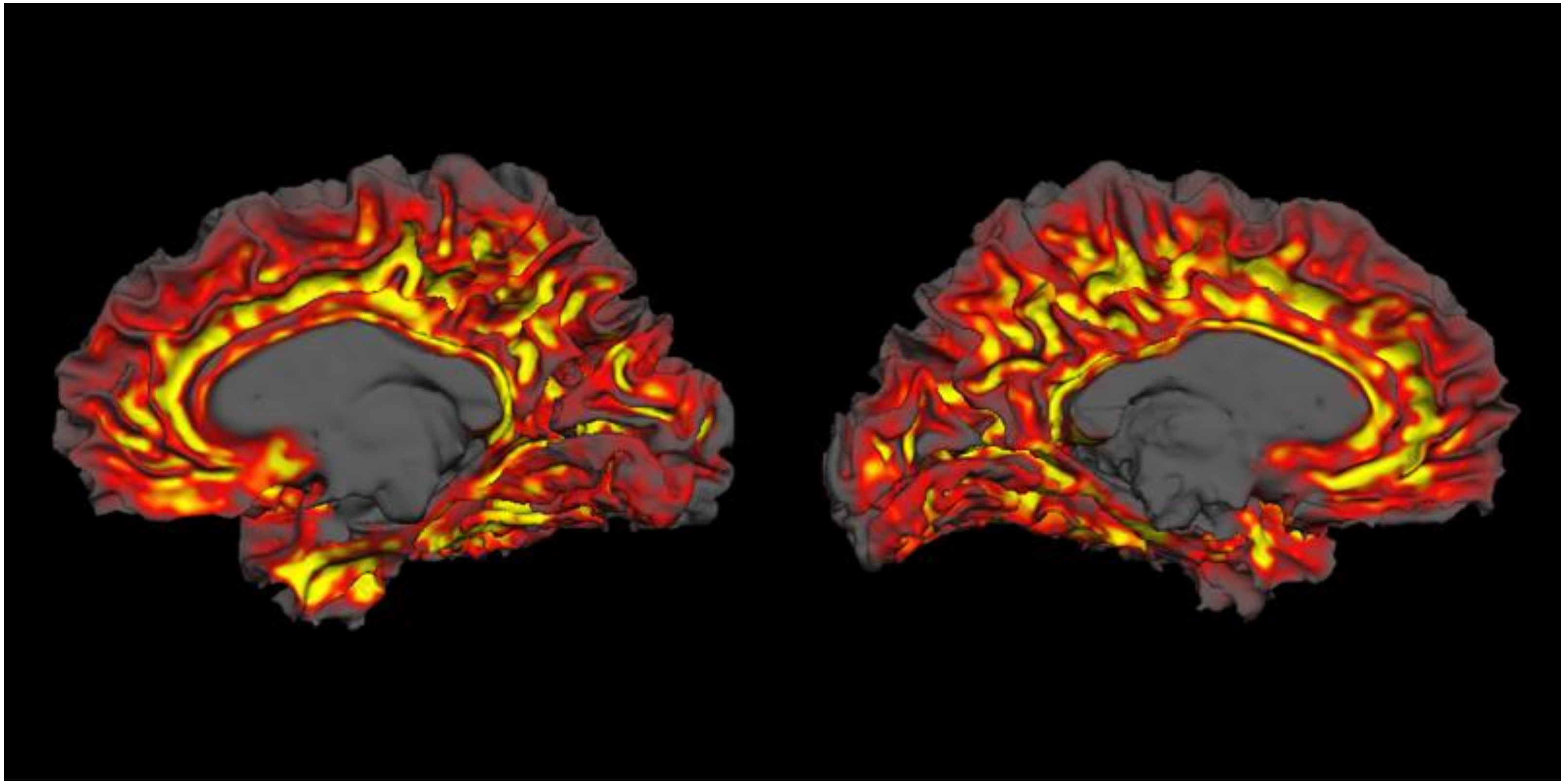


right hemisphere

left hemisphere

Relative Difference Measure – outside view

Human sensitivity analysis



right hemisphere left hemisphere

Relative Difference Measure – inside view

Conclusions

- Anisotropic volume conduction influences source strength and source orientation estimation more than source location estimation.
- Local conductivity properties in the vicinity of the source crucially influence source estimation.
- Model errors both on a local and a global scale are not Gaussian.

Thanks to:

Institut für Biomedizinische Technik und Informatik

Daniel Güllmar
Lars Flemming
Jörg Schreiber
Annegret Böttner

Hannes Nowak
Michael Eiselt
Frank Gießler
Hartmut Brauer
Jürgen R. Reichenbach

Ceon Ramon
Paul H. Schimpf
David S. Tuch
Van J. Wedeen
John S. George
John W. Belliveau

The SimBio Team:

Carsten Wolters
Alfred Anwander
Thomas Knösche
Matthias Dümpelmann
…

Financial support: European Union, German Ministry of Science