Forward (and inverse) modeling of MEG data

Robert Oostenveld

Donders Institute for Brain, Cognition and Behaviour
Radboud University Nijmegen, The Netherlands

NatMEG, Karolinska Institutet, Stockholm

Radboud University Nijmegen

Overview

- Motivation and background
- Forward modeling
  - Source model
  - Volume conductor model
    - Analytical (spherical model)
    - Numerical (realistic model)
  - Comparison EEG and MEG
- Inverse modeling
  - Single and multiple dipole fitting
  - Distributed source models
  - Spatial filtering

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Motivation 1

Strong points of EEG and MEG
- Temporal resolution (~1 ms)
- Characterize individual components of ERP
- Oscillatory activity
- Disentangle dynamics of cortical networks

Weak points of EEG and MEG
- Measurement on outside of brain
- Overlap of components
- Low spatial resolution

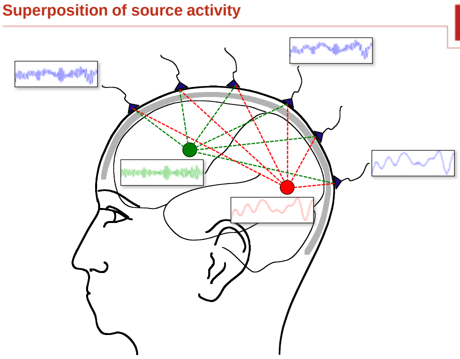
Motivation 2

If you find a ERP/ERF component, you want to characterize it in physiological terms
- Time or frequency are the "natural" characteristics
- "Location" requires interpretation of the scalp topography

Forward and inverse modeling helps to interpret the topography

Forward and inverse modeling helps to disentangle overlapping components

Superposition of source activity



Superposition of source activity

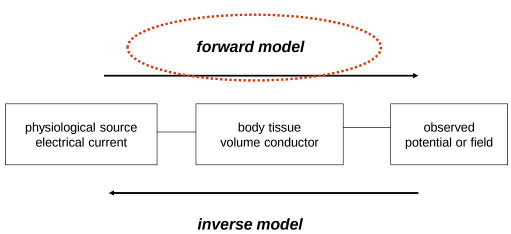
Varying “visibility” of each source to each channel

Timecourse of each source contributes to each channel

The contribution of each source depends on its “visibility”

Activity on each channel is a superposition of all source activity

Source modelling: overview



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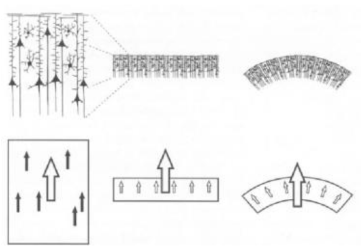
Equivalent current dipoles



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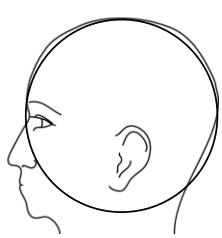
Volume conductor

electrical properties of tissue

geometrical description that approximates the head

describes how the currents flow, not where they originate from



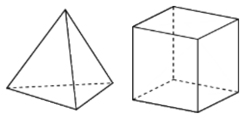
Volume conductor

Computational methods for volume conduction problem that allow for realistic geometries

- Boundary Element Method (BEM)
- Finite Element Method (FEM)
- Finite Difference Method (FDM)

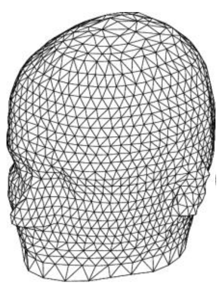
Geometrical description

- triangles
- tetraeders
- voxels



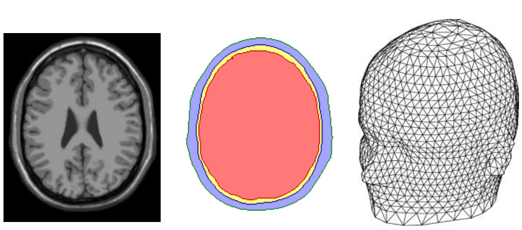
Volume conductor: BEM

Boundary Element Method
- description of geometry by compartments
- each compartment is
  - homogenous
  - isotropic
- important tissues
  - skin
  - skull
  - brain
  - (CSF)
- triangulated surfaces as boundaries



Volume conductor: BEM

construction of geometry
- segmentation in different tissue types



Volume conductor: BEM

construction of geometry
- segmentation in different tissue types
- extract surface description
- downsample to reasonable number of triangles

computation of model
- independent of source model
- only one lengthy computation
- fast during application to real data

can (almost) be arbitrary complex
- ventricles
- holes in skull

Volume conductor: FEM

Tesselation of 3D volume in tetraeders
Large number of elements
Simplify the tesselation in regions were less accuracy is required
Each tetraeder can have its own conductivity

FEM is the most accurate numerical method
Computationally more expensive

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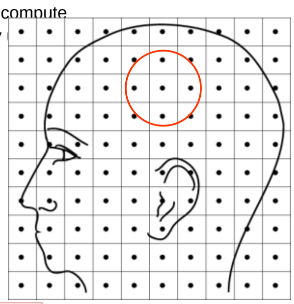
Volume conductor: FDM

Finite Difference Method
- easy to compute
- not very



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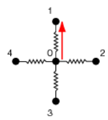
Volume conductor: FDM



$$\left.\begin{array}{l} I_1 + I_2 + I_3 + I_4 = 0 \\ V = I*R \end{array}\right\} \Longrightarrow$$

$$\Delta V_1/R_1 + \Delta V_2/R_2 + \Delta V_3/R_3 + \Delta V_4/R_4 = 0 \quad \Longrightarrow$$

$$(V_1-V_0)/R_1 + (V_2-V_0)/R_2 + (V_3-V_0)/R_3 + (V_4-V_0)/R_4 = 0$$

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Volume conductor: FDM

unknown potential Vi at each node

linear equation for each node

- approx. 100x100x100 = 1.000.000 linear equations
- just as many unknown potentials

add a source/sink

- sum of currents is zero for all nodes, except
- sum of current is I+ for a certain node
- sum of current is I- for another node

solve for unknown potential

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Methods implemented in FieldTrip

```
mri             = ft_read_mri(filename);

cfg             = [];
cfg.output      = {'brain','skull','scalp'};
segmentedmri    = ft_volumesegment(cfg, mri);

cfg             = [];
cfg.tissue      = {'brain','skull','scalp'};
cfg.numvertices = [3000 2000 1000];
bnd             = ft_prepare_mesh(cfg,segmentedmri);
```

```
cfg             = [];
cfg.method      = 'concentricspheres';
...
headm
```

```
cfg             = [];
cfg.method      = 'bemcp';
...
head
```

```
cfg             = [];
cfg.method      = 'simbio';
...
headmodel       = ft_prepare_headmodel(cfg, segmentedmri);
```

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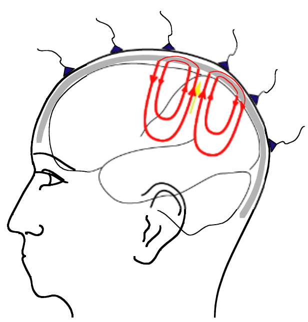
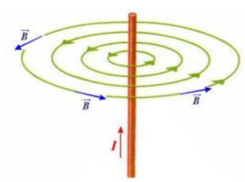
EEG volume conduction

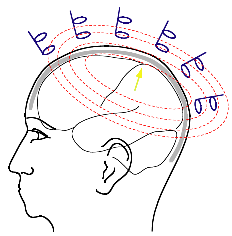


EEG volume conduction

Potential difference between electrodes corresponds to current flowing through skin
Only tiny fraction of current passes through skull
Therefore the model should describe the skull and skin as accurately as possible

Electric current → magnetic field





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MEG volume conduction

Only tiny fraction of current passes through the poorly conductive skull

Therefore skull and skin are usually neglected in MEG model

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Similarities between EEG and MEG

Identical source model

Similar volume conductor model

Identical inverse methods apply!

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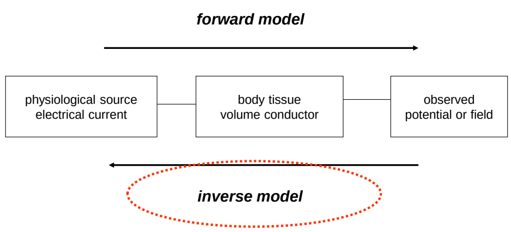
Source analysis: overview



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Inverse methods

Single and multiple dipole models
- Minimize error between model and measured potential/field

Distributed dipole models
- Perfect fit of model to the measured potential/field
- Additional constraint on sources
  - Maximal smoothness (LORETA)
  - Minimum power (L2)
  - Minimum amplitude (L1)

Spatial filtering
- Compute the filter output at every location
- Scan the whole brain with a single dipole
  - Beamforming (e.g. LCMV, SAM, DICS)
  - Multiple Signal Classification (MUSIC)

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Inverse methods

Single and multiple dipole models
Assume a small number of sources

Distributed dipole models
Assume activity everywhere

Spatial filtering
Assume that the timecourses of different sources are uncorrelated

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Methods implemented in FieldTrip

```
cfg   = [];
       .
source = ft_dipolefitting(cfg, data);
```

```
cfg   = [];
cfg.method = 'mne';
so
```

```
cfg   = [];
cfg.method = 'dics';
sou
```

```
cfg   = [];
cfg.method = 'lcmv';
       .
       .
       .
source = ft_sourceanalysis(cfg, data);
```

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Procedure for source reconstruction

1. *Design experiment*
2. *Measure brain activity*
3. *Data analysis*
   - *Preprocessing etc.*
   - *Time frequency analysis*
4. *Prepare necessary geometric objects*
5. *Compute forward model*
6. *Source analysis*

```
ft definetrial
ft preprocessing
ft rejectartifact
```

```
ft freqanalysis
ft timelockanalysis
```

```
ft prepare headmodel
ft prepare sourcemodel
ft prepare leadfield
```

```
ft sourceanalysis
```

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