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
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

[Diagram of brain activity superposition]
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

forward model
physiological source
electrical current
body tissue
tissue conductivity
observed
potential or field

inverse model

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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 homogeneous
- 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

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

FEM is the most accurate numerical method
Computationally more expensive

Volume conductor: FDM

Finite Difference Method
easy to compute
not very
Volume conductor: FDM

\[
I_1 + I_2 + I_3 + I_4 = 0
\]

\[
V = \frac{\Delta V_1}{R_1} + \frac{\Delta V_2}{R_2} + \frac{\Delta V_3}{R_3} + \frac{\Delta V_4}{R_4} = 0
\]

\[
(V_1 - V_0)R_1 + (V_2 - V_0)R_2 + (V_3 - V_0)R_3 + (V_4 - V_0)R_4 = 0
\]

unknown potential \( V_i \) at each node
linear equation for each node
approx. \( 100 \times 100 \times 100 = 1,000,000 \) 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

Methods implemented in FieldTrip

```matlab
% File: my_script.m

% my function
myfunc = @(x) mymath(x);

% my method
mymethod = 'my_method';

% my operator
myoperator = 'my_op';

% my solver
mysolver = 'my_solver';

end
```
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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 $\rightarrow$ magnetic field

MEG volume conduction

Only tiny fraction of current passes through the poorly conductive skull
Therefore skull and skin are usually neglected in MEG model

Similarities between EEG and MEG

Identical source model
Similar volume conductor model
Identical inverse methods apply!
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Source analysis: overview

forward model

- Physiological source
  - Electrical current

- Body tissue
  - Volume conductor

- Observed potential or field

inverse model

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)
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

Methods implemented in FieldTrip

```matlab
% Design experiment
% Measure brain activity
% Data analysis
% - Preprocessing etc.
% - Time frequency analysis
% Prepare necessary geometric objects
% Compute forward model
% Source analysis
```

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

FieldTrip functions:
- `ft_sourceanalysis`
- `ft_sourceanalysis(fft_definestrial)`
- `ft_sourceanalysis(fft_sourcemodel)`
- `ft_sourceanalysis(fft_sourcemodelfield)"
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