Forward and Inverse Modeling of EEG and MEG data

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Biophysical source modelling: overview

**Forward model**

- Physiological source
- Electrical current
- Body tissue
- Volume conductor
- Observed potential or field

**Inverse model**
Overview

Motivation and background

**Forward modeling**
- Source model
- Volume conductor model

Inverse modeling
What produces the electric current
Equivalent current dipoles
Overview

Motivation and background
Forward modeling
  Source model
    Volume conductor model
Inverse modeling
Volume conductor

described electrical properties of tissue

describes geometrical model of the head

describes how the currents flow, not where they originate from

same volume conductor for EEG as for MEG, but also for tDCS, tACS, TMS, ...
Volume conductor

Computational methods for volume conduction problem that allow for realistic geometries

- **BEM**  \( \text{Boundary Element Method} \)
- **FEM**  \( \text{Finite Element Method} \)
- **FDM**  \( \text{Finite Difference Method} \)
Volume conductor: Boundary Element Method

Each compartment is homogenous isotropic

Important tissues
- skin
- skull
- brain
  (CSF)

Triangulated surfaces describe boundaries
Volume conductor: Boundary Element Method

Construction of geometry
  segmentation in different tissue types
  extract surface description
  downsample to reasonable number of triangles
Volume conductor: Boundary Element Method

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 also include more complex geometrical details
  ventricles
  holes in skull
Volume conductor: Finite Element Method

Tessellation of 3D volume in tetraeders or hexaheders
Volume conductor: Finite Element Method

tetraeders

hexaheders
Volume conductor: Finite Element Method

Tesselation of 3D volume in tetraeders or hexaheders

Each element can have its own conductivity

FEM is the most accurate numerical method but computationally quite expensive

Geometrical processing not as simple as BEM
Volume conductor: Finite Difference Method

Easy to compute

Not very useful
Volume conductor: Finite Difference Method

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

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

\[ V = I \times R \]
Volume conductor: Finite Difference Method

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
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
MEG measures magnetic field over the scalp

Magnetic field itself is not distorted by skull but also from the volume currents. Only tiny fraction of current passes through skull, therefore the model can ignore the skull and...
MEG volume conduction compared to EEG

EEG is measurement on scalp
potential difference due to volume currents

MEG field not affected by head
- magnetic field due to primary current (source)
- magnetic field due to secondary (volume) currents
Overview

Motivation and background
Forward modeling
  Source model
  Volume conductor model
  EEG versus MEG

Inverse modeling
Biophysical source modelling: overview

**forward model**

- physiological source
  - electrical current
- body tissue
  - volume conductor
- observed
  - potential or field

**inverse model**
Inverse localization: demo
Inverse methods

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

Distributed source models
Perfect fit of model to the measured potential/field
Additional constraint on source smoothness, power or amplitude

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