OpenMEEG

Biomag 2010 Satellite:

Analysis toolboxes for MEG data

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What is OpenMEEG ?

- A general package for quasistatic electromagnetics

$$\begin{aligned}\nabla\cdot(\sigma\nabla V) &= f \quad \text{in domain}\\ \sigma\nabla V\cdot\mathbf{n} &= g \quad \text{on domain boundary}\end{aligned}$$

- Boundary Element discretization: σ piecewise constant
- Especially targeted at EEG and MEG
- Especially targeted at Forward Problems

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- A general package for quasistatic electromagnetics

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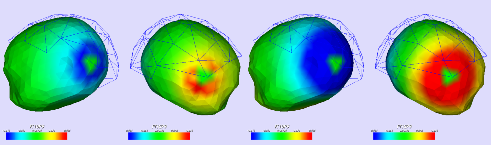
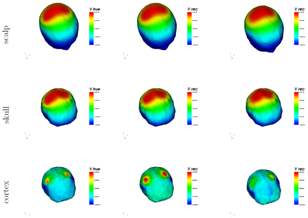
- Boundary Element discretization: σ piecewise constant
- Especially targeted at EEG and MEG
- Especially targeted at Forward Problems

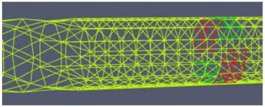
Our aim: make you want to use it !

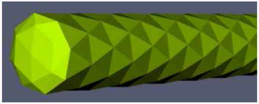
Not limited to EEG and MEG

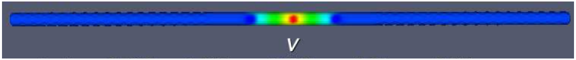


- Electrical Impedance Tomography
- Cortical Mapping
- ECoG
- Functional Electrical Stimulation
- Intracortical electrodes

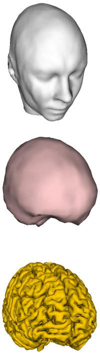








OpenMEEG may not solve all your needs



⊖ No geometry processing

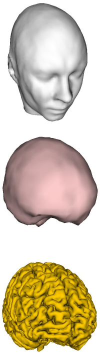
(Image segmentation, Mesh generation)

⊖ Does not handle anisotropic conductivities

⊖ Inverse problems: limited scope

⊖ No graphical functionalities

OpenMEEG may not solve all your needs



⊖ No geometry processing

(Image segmentation, Mesh generation)

⊖ Does not handle anisotropic conductivities

⊖ Inverse problems: limited scope

⊖ No graphical functionalities

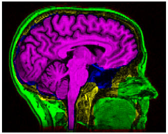
⇒ **Use OpenMEEG for what it's meant for ! (Forward Problem)**

Developers' goal:
make OpenMEEG easy to integrate into other packages.
(and goal of this Satellite: to foster communication !)

OpenMEEG facts

Methodology

- Galerkin Boundary element formulation
- Symmetric Boundary Element Method, involving both Potential V and normal current $\sigma\partial_{\mathbf{n}}V$ as unknowns



$$
\begin{array}{cc}
\mathrm{nH} &
\begin{bmatrix}
(\sigma_1+\sigma_2)\mathsf{N}_{11} & -2\mathsf{D}^*_{11} & -\sigma_2\mathsf{N}_{12} & \mathsf{D}^*_{12} & & & \\
-2\mathsf{D}_{11} & (\sigma_1^{-1}+\sigma_2^{-1})\mathsf{S}_{11} & \mathsf{D}_{12} & -\sigma_2^{-1}\mathsf{S}_{12} & & & \\
-\sigma_2\mathsf{N}_{21} & \mathsf{D}^*_{21} & (\sigma_2+\sigma_3)\mathsf{N}_{22} & -2\mathsf{D}^*_{22} & -\sigma_3\mathsf{N}_{23} & \mathsf{D}^*_{23} & \\
\mathsf{D}_{21} & -\sigma_2^{-1}\mathsf{S}_{21} & -2\mathsf{D}_{22} & (\sigma_2^{-1}+\sigma_3^{-1})\mathsf{S}_{22} & \mathsf{D}_{23} & -\sigma_3^{-1}\mathsf{S}_{23} & \\
 & & -\sigma_3\mathsf{N}_{32} & \mathsf{D}^*_{32} & (\sigma_3+\sigma_4)\mathsf{N}_{33} & -2\mathsf{D}^*_{33} & \cdots \\
 & & \mathsf{D}_{32} & -\sigma_3^{-1}\mathsf{S}_{32} & -2\mathsf{D}_{33} & (\sigma_3^{-1}+\sigma_4^{-1})\mathsf{S}_{33} & \cdots \\
 & & & & \vdots & \vdots & \ddots
\end{bmatrix}
\cdot
\begin{bmatrix}
\mathbf{v}_1 \\ \mathbf{p}_1 \\ \mathbf{v}_2 \\ \mathbf{p}_2 \\ \mathbf{v}_3 \\ \mathbf{p}_3 \\ \vdots
\end{bmatrix}
=
\begin{bmatrix}
\sigma_1^{-1}\mathsf{N}_{1sources} \\ \mathsf{D}_{1sources} \\ 0 \\ 0 \\ 0 \\ 0 \\ \vdots
\end{bmatrix}
.\mathbf{s} \quad \mathrm{nvS}
\\
 & \begin{array}{ccccccc} \mathrm{nv1} & \mathrm{nf1} & \mathrm{nv2} & \mathrm{nf2} & \mathrm{nv3} & \mathrm{nf3} & \qquad\qquad \mathrm{nvS} \end{array}
\end{array}
$$

[Kybic, Clerc et al, IEEE T Medical Imaging, 2005: *A Common Formalism for the integral formulations of the forward EEG problem*]

OpenMEEG facts

Software

- C++ Source code, started in 2006
- Multiplatform (binaries, cmake, Subversioning)
- Matlab i/o
- Python wrapping, Fieldtrip integration, etc.
- Open-source, CeCiLL-B license
  - Similar to, and compatible with GPL
  - **Citation duty**

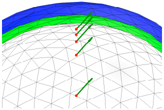
    [Gramfort, Papadopoulo, Olivi, Clerc, *OpenMEEG: opensource software for quasistatic bioelectromagnetics*, Biomedical Engineering Online, 2010, 9:45]

    [Kybic, Clerc et al., *A Common Formalism for the integral formulations of the forward EEG problem*, IEEE T Medical Imaging, 2005 Jan;24(1):12-28.]

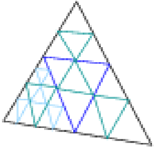
    More at: `http://openmeeg.gforge.inria.fr/`

Why use OpenMEEG ?

State of the art accuracy.



- more unknowns (V and $\sigma\partial_{\mathbf{n}}V$)
- domain-oriented
- adaptive numerical integration



Accuracy compared to analytical solutions using

$$RDM(g_{\mathrm{n}}, g_{\mathrm{a}}) = \left\| \frac{g_n}{\|g_n\|} - \frac{g_a}{\|g_a\|} \right\| \in [0,2] \ ,$$

and

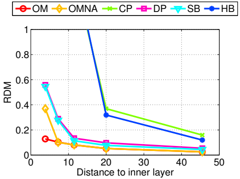
$$MAG(g_n, g_a) = \frac{\|g_n\|}{\|g_a\|} \ .$$

Accuracy comparison for EEG

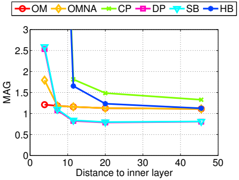
BEM solvers tested:

OM	OpenMEEG
OMNA	OM non adaptive
CP	Fieldtrip / CP
DP	Fieldtrip / Dipoli
SB	Simbio
HB	Helsinki BEM

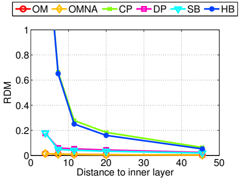
EEG
(regular meshes)



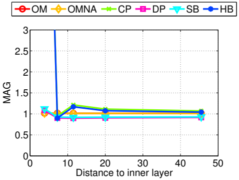
RDM 162 points/interface



MAG 162 points/interface



RDM 642 points/interface



MAG 642 points/interface

Accuracy comparison for EEG

BEM solvers tested:

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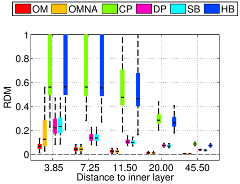
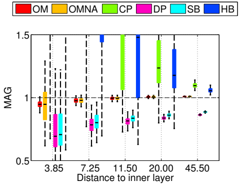
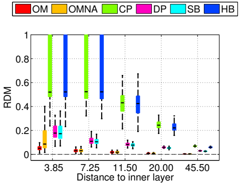
EEG
(100 random meshes)



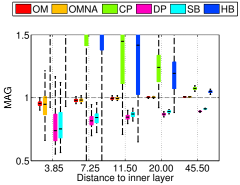
RDM 600 points/interface



MAG 600 points/interface



RDM 800 points/interface



MAG 800 points/interface

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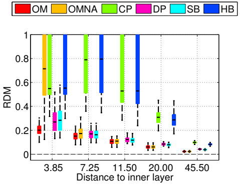
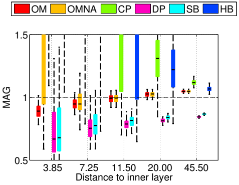
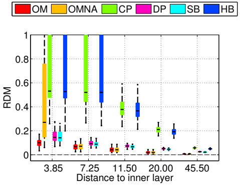


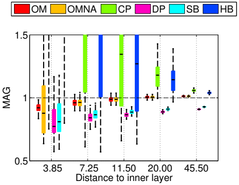
RDM with 1500 unknowns



MAG with 1500 unknowns



RDM with 3000 unknowns



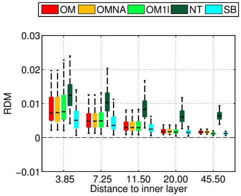
MAG with 3000 unknowns

Accuracy comparison for MEG

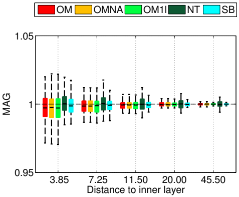
BEM solvers tested:

OM	OpenMEEG
OMNA	OM non adaptive
OM1l	OM one layer
NT	Nolte
SB	Simbio

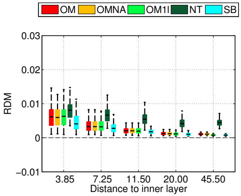
MEG, radial gradiometers
(100 random meshes)



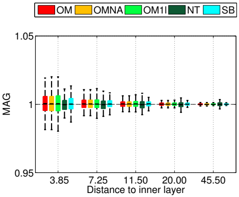
RDM with 600 unknowns



MAG with 600 unknowns



RDM 800 points/interface



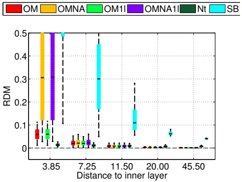
MAG 800 points/interface

Accuracy comparison for MEG

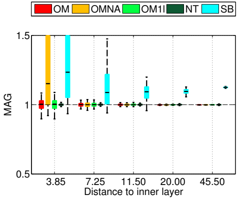
MEG, non-radial gradiometers
(100 random meshes)

BEM solvers tested:

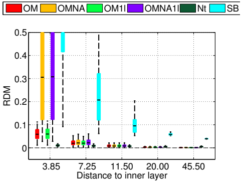
OM	OpenMEEG
OMNA	OM non adaptive
OM1l	OM one layer
NT	Nolte
SB	Simbio



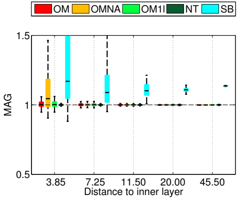
RDM with 600 unknowns



MAG with 600 unknowns



RDM 800 points/interface



MAG 800 points/interface

Computation time for EEG

BEM solvers tested:

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CP	Fieldtrip / CP
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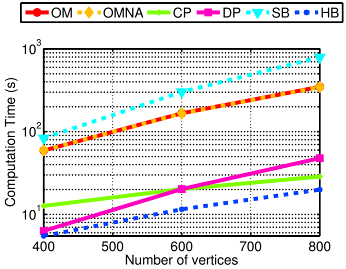
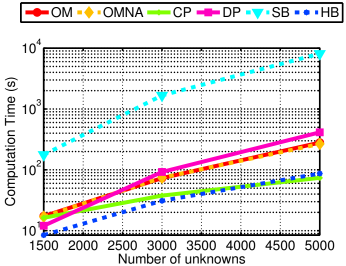
as a function of number of vertices



as a function of number of unknowns



How to use OpenMEEG

First define:

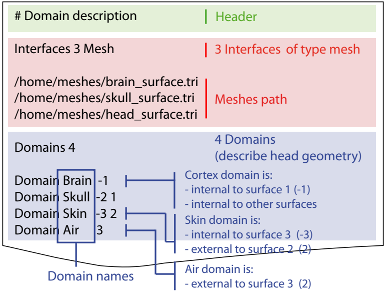
- **Head model**
  - closed nested meshes (any number)
  - conductivities
- **Sensor model**
  - EEG: positions projected to scalp surface
  - MEG: positions and weights (→ mag. or grad.)
- **Source model**
  - list of dipole positions and moments
  - surface describing dipole positions, normal to surface.

OpenMEEG commands available through

- **Command-line** interface
- **Python** scripts
- **Matlab/Fieldtrip** integration

Data structure

*.geom - Geometry description file



```
# Domain description

Interfaces 3 Mesh

/home/meshes/brain_surface.tri
/home/meshes/skull_surface.tri
/home/meshes/head_surface.tri

Domains 4

Domain Brain -1
Domain Skull -2 1
Domain Skin -3 2
Domain Air 3
```

Header

3 Interfaces of type mesh

Meshes path

4 Domains (describe head geometry)

Cortex domain is:
- internal to surface 1 (-1)
- internal to other surfaces

Skin domain is:
- internal to surface 3 (-3)
- external to surface 2 (2)

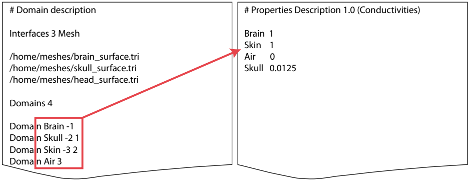
Air domain is:
- external to surface 3 (2)

Domain names

Sample geometry file

*.geom - Geometry description file

*.cond - Conductivity description file

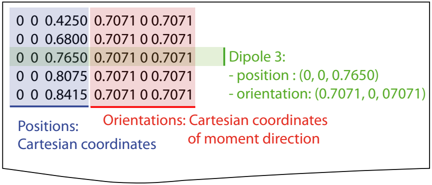


```
# Domain description

Interfaces 3 Mesh

/home/meshes/brain_surface.tri
/home/meshes/skull_surface.tri
/home/meshes/head_surface.tri

Domains 4

Domain Brain -1
Domain Skull -2 1
Domain Skin -3 2
Domain Air 3
```

```
# Properties Description 1.0 (Conductivities)

Brain  1
Skin   1
Air    0
Skull  0.0125
```

Sample conductivity file

Dipoles positions and orientations description file



```
0  0  0.4250  0.7071 0 0.7071
0  0  0.6800  0.7071 0 0.7071
0  0  0.7650  0.7071 0 0.7071
0  0  0.8075  0.7071 0 0.7071
0  0  0.8415  0.7071 0 0.7071
```

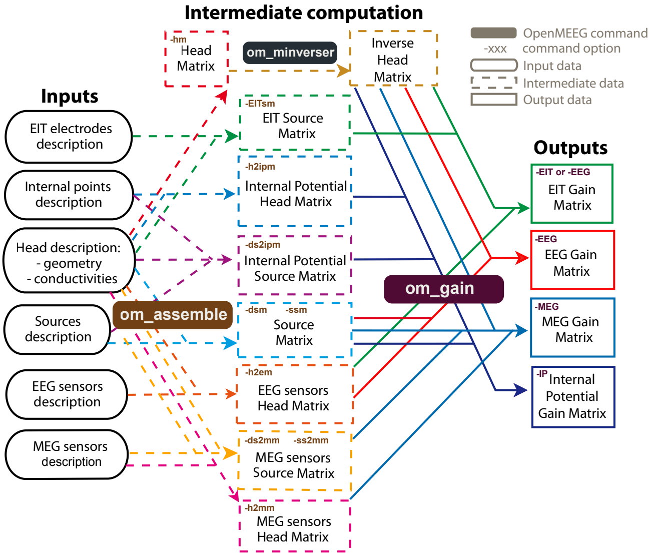
Dipole 3:
- position : (0, 0, 0.7650)
- orientation: (0.7071, 0, 07071)

Positions: Cartesian coordinates

Orientations: Cartesian coordinates of moment direction

Sample source file

Generating Lead-Fields



Intermediate computation

-hm Head Matrix

om_minverser

Inverse Head Matrix

OpenMEEG command

-xxx command option

Input data

Intermediate data

Output data

Inputs

EIT electrodes description

Internal points description

Head description:
- geometry
- conductivities

Sources description

EEG sensors description

MEG sensors description

om_assemble

-EITsm EIT Source Matrix

-h2ipm Internal Potential Head Matrix

-ds2ipm Internal Potential Source Matrix

-dsm -ssm Source Matrix

-h2em EEG sensors Head Matrix

-ds2mm -ss2mm MEG sensors Source Matrix

-h2mm MEG sensors Head Matrix

om_gain

Outputs

-EIT or -EEG EIT Gain Matrix

-EEG EEG Gain Matrix

-MEG MEG Gain Matrix

-IP Internal Potential Gain Matrix

Example scripts

EEG gain matrix:

```
om_assemble -HeadMat head.geom head.cond head.hm
om_assemble -SSM head.geom head.cond sources.tri head.ssm
om_assemble -h2em head.geom head.cond head.eegsensors head.h2em
om_minverser head.hm head.hm_inv
om_gain -EEG head.hm_inv head.ssm head.h2em head.gain
```

MEG gain matrix

```
om_assemble -HeadMat head.geom head.cond head.hm
om_assemble -DSM head.geom head.cond sources.dip head.dsm
om_assemble -h2mm head.geom head.cond head.squids head.h2mm
om_assemble -ds2mm sources.dip head.squids head.ds2mm
om_minverser head.hm head.hm_inv
om_gain -MEG head.hm_inv head.dsm head.h2mm head.ds2mm head.gain
```

OpenMEEG with Python (EEG leadfield)

```python
import openmeeg as om
# Load data
cond_file = ’om_demo.cond’
geom_file = ’om_demo.geom’
dipole_file = ’cortex.dip’
electrodes_file = ’eeg_electrodes.txt’

geom = om.Geometry()
geom.read(geom_file,cond_file)
dipoles = om.Matrix()
dipoles.load(dipole_file)
electrodes = om.Sensors()
electrodes.load(electrodes_file)

# Compute forward problem (Build Gain Matrices)
gauss_order = 3 # Numerical integration order

hm        = om.HeadMat(geom, gauss_order)
hminv     = hm.inverse()
dsm       = om.DipSourceMat(geom, dipoles, gauss_order)
h2em      = om.Head2EEGMat(geom, electrodes)
gain_eeg = om.GainEEG(hminv, dsm, h2em)
```

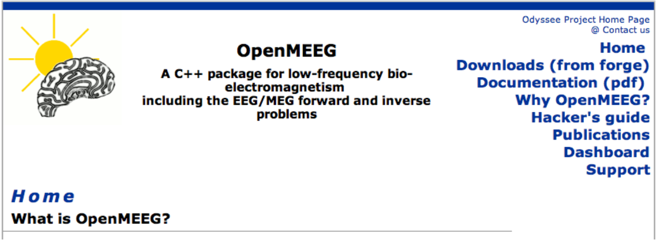
OpenMEEG with Fieldtrip (EEG leadfield)

```
%% The structure for the BEM volume conduction model
%% Each layer mesh is indexed by k
% vol.bnd(k).pnt : contains vertices for mesh "k"
% vol.bnd(k).tri : contains triangles for mesh "k"
%% Set the conductivities of each domain
% vol.cond       : contains conductivities

%% EEG electrodes
% sens.pnt        : contains locations of electrodes

%% Positions of the dipoles
% pos             : contains locations of dipoles

%% Compute the BEM
% choose BEM method (OpenMEEG, BEMCP or Dipoli)
cfg.method = 'openmeeg';
% Compute the BEM matrix
vol = ft_prepare_bemmodel(cfg, vol);
cfg.vol = vol;
cfg.grid.pos = pos;
cfg.elec = sens;
% Compute leadfield (no orientation constraint)
lf_openmeeg = ft_prepare_leadfield(cfg);
```

How to download OpenMEEG

Latest release (March 25, 2010): **OpenMEEG 2.0**

- From the forge:
  `http://openmeeg.gforge.inria.fr/`



Odyssee Project Home Page
@ Contact us

OpenMEEG

A C++ package for low-frequency bio-electromagnetism including the EEG/MEG forward and inverse problems

Home

What is OpenMEEG?

- anonymous download of source code:
  svn checkout svn://scm.gforge.inria.fr/svn/openmeeg
- or download binaries for your OS
  Supported OS: Windows, Linux, Mac OS X

For more info

- Talks (Wednesday):

W-4.1	*The symmetric BEM: bringing in more variables for better accuracy*
W-4.3	*The adjoint method for general EEG and MEG sensor-based lead field*

- Posters (Wednesday):

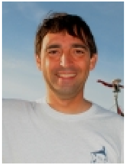
W-I T3-11	*Domain decomposition for coupling finite and boundary element methods*
W-I T3-6	*Evaluation of free BEM solvers for accurate M/EEG forward modeling*

- Subscribe to `openmeeg-info@lists.gforge.inria.fr` at `http://lists.gforge.inria.fr/mailman/listinfo/openmeeg-info`
- Contact the developers

Maureen Clerc

Alexandre Gramfort

Emmanuel Olivi



Théo Papadopoulo