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# An empirical evaluation of free BEM solvers for M/EEG forward modeling



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## Objective

■ Evaluate the accuracy of available BEM solvers for M/EEG forward modeling with realistic head models.

## The M/EEG forward problem

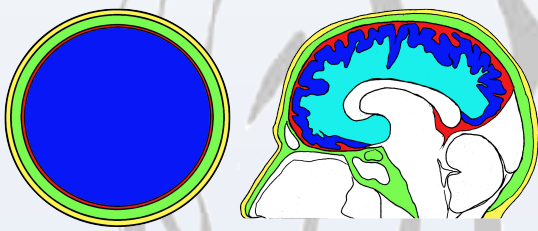
### Objective

Predict what is measured by M/EEG sensors due to a configuration of current generators within the head.

### Challenge

Analytical solutions exist for simple models such as sphere models. With realistic head models, numerical solvers are required. BEM solvers are adapted to models with piecewise constant conductivities.

### Sphere models vs. realistic models



## Why compare BEM solvers?

- BEM solvers are based on **different mathematical formulations**.
- For a given formulation, **implementation details** vary:
  - Galerkin methods vs collocation methods
  - Precision in numerical integrations
  - Adaptive vs. non adaptive integration procedures

## Experimental setting

### Software packages tested

- **OpenMEEG** with and without adaptive integration (**OM** and **OMNA**) [1,2,3]: Symmetric BEM with P1-P0 elements.
- **BEMCP (CP)** [Phillips 00]: standard BEM + ISA with constant collocation
- **Helsinki BEM (HB)** [Stenroos et al. 07]: same as BEMCP
- **Simbio (SB)** [Zanow et al. 95]: std. BEM + ISA with linear collocation
- **Dipoli (DP)** [Oostendorp et al. 89]: same as Simbio

### Model considered

- **3 nested shells**: inner skull, outer skull and skin surfaces (radii 88, 92, 100).
- **5 dipoles** at different distances from the inner skull: direction (1, 0, 1)
- **regular and random meshes**
- a **random mesh** with  $N$  vertices is obtained by meshing the convex hull of  $10N$  points randomly sampled on the unit sphere followed by decimation.

## Simulation study: Comparison results for EEG

### Precision measures

- Numerical solution  $g_n$
- Analytical solution  $g_a$
- Relative Difference Measure (RDM):

$$RDM(g_n, g_a) = \left\| \frac{g_n}{\|g_n\|} - \frac{g_a}{\|g_a\|} \right\|$$

Should be close to 0

- Magnitude (MAG):

$$MAG(g_n, g_a) = \|g_n\| / \|g_a\|$$

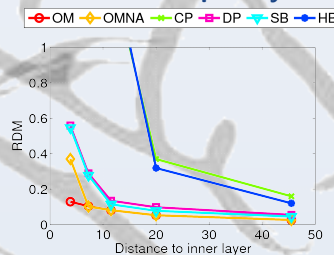
Should be close to 1

- With **random meshes** RDMs and MAGs are computed with **100 repetitions** of the experiment.

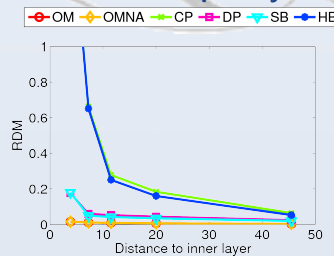
- **Note**: MEG accuracy relies on EEG solutions via the Biot et Savart law

### With standard meshes

#### 162 vertices per layer

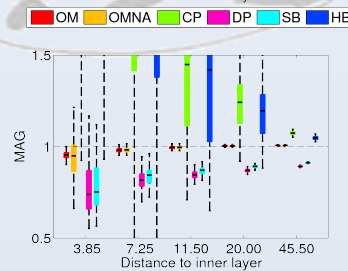
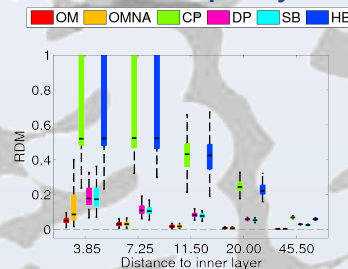


#### 642 vertices per layer



### With random meshes

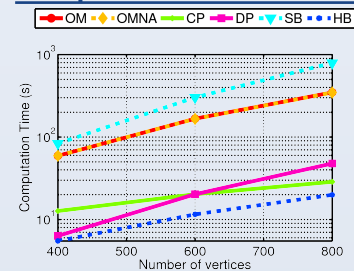
#### 800 vertices per layer



■ **OpenMEEG is the most accurate solver** with regular meshes.

■ **OpenMEEG with adaptive integration is the most robust** to imperfect meshing.

### Computation times



## Technical details

- **OpenMEEG** is **opensource** (Linux, Windows, Mac OS X)
- **OpenMEEG** is written in C++ and can be used from **Python** and **Matlab** using the Fieldtrip toolbox
- Experiments have been performed with Fieldtrip
- <http://openmeeg.gforge.inria.fr>
- [openmeeg-info@lists.gforge.inria.fr](mailto:openmeeg-info@lists.gforge.inria.fr)

## References

- [1] Gramfort A., Papadopoulou T., Olivi E., Clerc M. **OpenMEEG: opensource software for quasistatic bioelectromagnetics**, submitted.
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- [3] Kybic J., Clerc M., Abboud T., Faugeras O., Keriven R., Papadopoulou T. **A Common Formalism for the Integral Formulations of the Forward EEG Problem**, IEEE Transactions on Medical Imaging, 2005