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

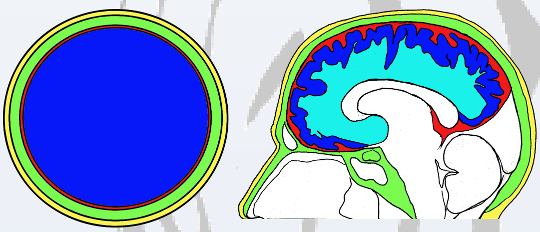
Objective

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

Challenge

Analytical solutions exists 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?

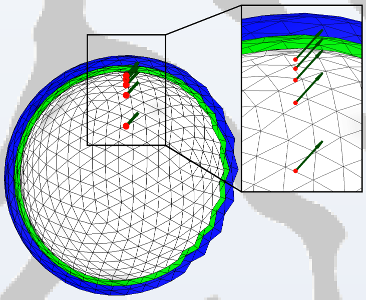
- BEM solvers are based on **different mathematical formulations**.
- For a given formulation, **implementation details** vary:
  - **Galerkin** methods vs **collocation** methods
  - Precision in **numerical integrations**
  - **Adaptive vs. non adaptive integration** procedures

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):

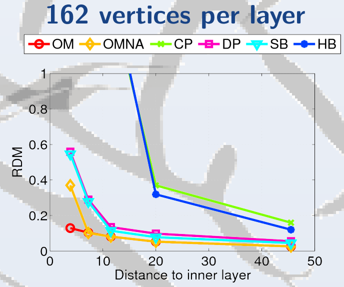
$$MAG(g_n, g_a) = \|g_n\| / \|g_a\|$$

Should be **close to 1**

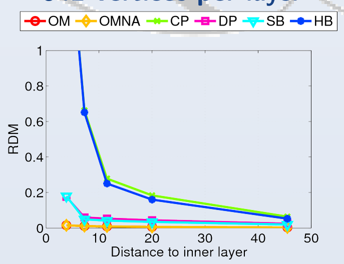
- With **random meshes** RDMs and MAGs are computed with **100 repetitions** of the experiment.
- **Note:** MEG accuracy relies on EEG solutions via the Biot et Savart law

With standard meshes

162 vertices per layer

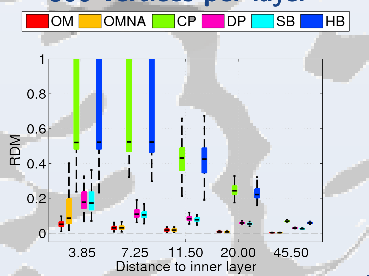


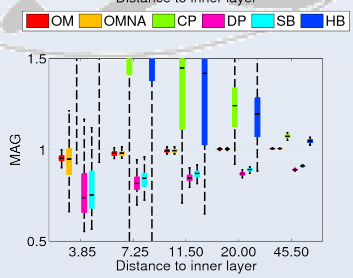
642 vertices per layer



With random meshes

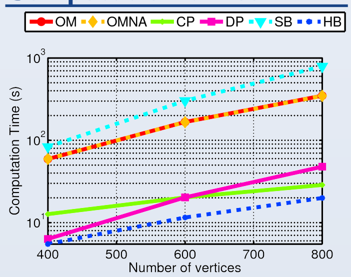
800 vertices per layer





- **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

References

[1] Gramfort A., Papadopoulo T., Olivi E., Clerc M. **OpenMEEG: opensource software for quasistatic bioelectromagnetics**, submitted.

[2] Gramfort A. **Mapping, timing and tracking cortical activations with MEG and EEG: Methods and application to human vision**, PhD thesis 2009.

[3] Kybic J., Clerc M., Abboud T., Faugeras O., Keriven R., Papadopoulo T. **A Common Formalism for the Integral Formulations of the Forward EEG Problem**, IEEE Transactions on Medical Imaging, 2005