

Source localization in MEEG (Magneto-Encephalography) requires appropriate electrophysiological modeling of the head. **Conductivity of tissues in the vicinity of the sources is especially influential on the MEEG forward fields[1]**. Although white matter anisotropy can be inferred from Diffusion-Weighted MRI[2], it is rarely incorporated into MEEG head models. The widely used Boundary Element Methods can only deal with piecewise constant conductivities, therefore ruling out white matter anisotropy. The purpose of this paper is to **extend the BEM framework to incorporate white matter anisotropy by treating anisotropic conductivity as a perturbation of an isotropic one**.

1 The forward EEG problem

The **forward EEG problem** simulates on the scalp the electric potential V generated by a source (in our case a dipole J_p).

□ writing Σ the conductivity tensor, the potential V satisfies the

$$\text{Poisson equation: } \begin{cases} \nabla \cdot (\Sigma \nabla V) = \nabla \cdot J_p & \text{in the head volume} \\ (\Sigma \nabla V) \cdot n = 0 & \text{on the scalp boundary} \end{cases}$$

□ numerical methods: FEM and BEM.

The symmetric BEM[3] is more accurate than the FEM[4] and other BEM[5] for isotropic media.

2 From tensor to fibers

Let Σ be a conductivity tensor of an isotropic medium + a fiber f oriented \mathbf{n}_f , with radius r_f ,

$$\Sigma = \sigma \mathbf{I} + (\sigma_f - \sigma) \mathbf{n}_f \mathbf{n}_f^T \chi_f$$

$$\chi_f(x) = \begin{cases} 1 & \text{if } x \in f \\ 0 & \text{if } x \notin f \end{cases}$$

We propose to discretize the fiber into N weighted points:

$$\Delta_N(\chi_f) = \frac{\pi r_f^2}{N} \sum_{k=1}^N \delta_k$$

Writing $\epsilon_f = (\sigma_f - \sigma) \frac{\pi r_f^2}{N}$, Σ becomes: $\sigma \mathbf{I} + \epsilon_f \mathbf{n}_f \mathbf{n}_f^T \sum_{k=1}^N \delta_k$

Bibliography

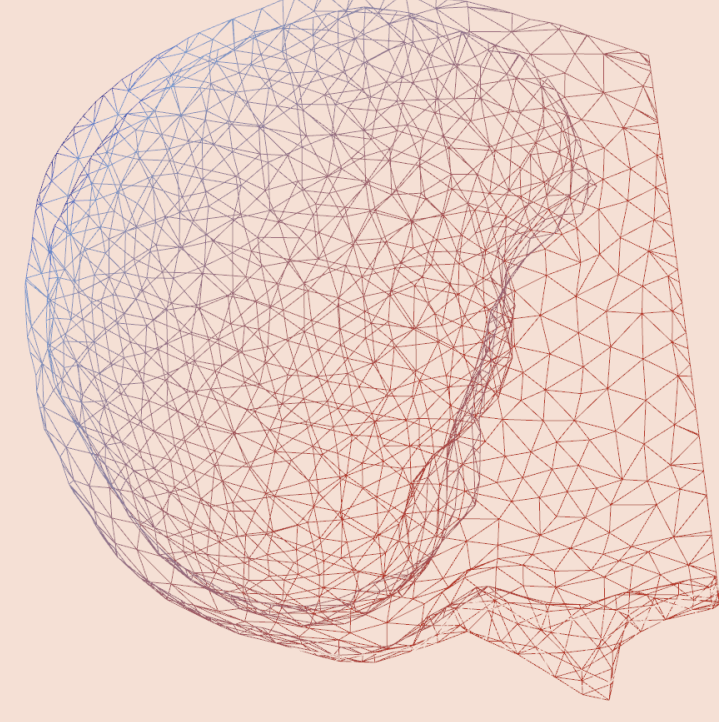
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3 Handling local anisotropy with BEM

The **Poisson equation** becomes: $\sigma \Delta V + \nabla \cdot \sum_{k=1}^N \delta_k \epsilon_f \mathbf{n}_f \mathbf{n}_f^T \nabla V = \nabla \cdot \mathbf{J}_p$
Solving this problem iteratively yields:

$$\sigma \Delta V^{n+1} = \nabla \cdot \left(\mathbf{J}_p - \sum_{k=1}^N \delta_k \epsilon_f \mathbf{n}_f \partial_{\mathbf{n}_f} V^n \right), \text{ with } V^0 = 0$$

First iteration ($V^0 = 0$) just solves an isotropic problem. From this solution we compute the 'currents' at fibers location with BEM internal operators (using OpenMEEG available at [7]). The system is then solved adding the **red dipoles**.

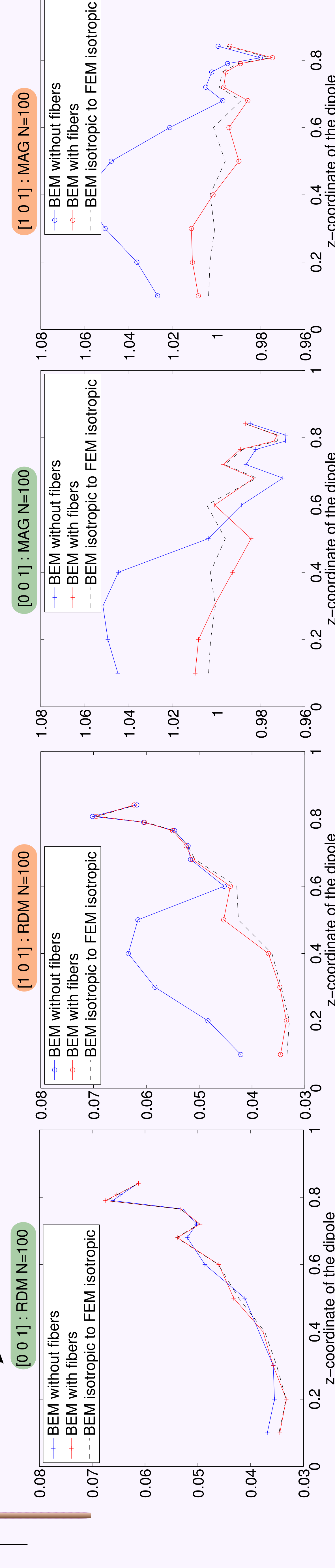
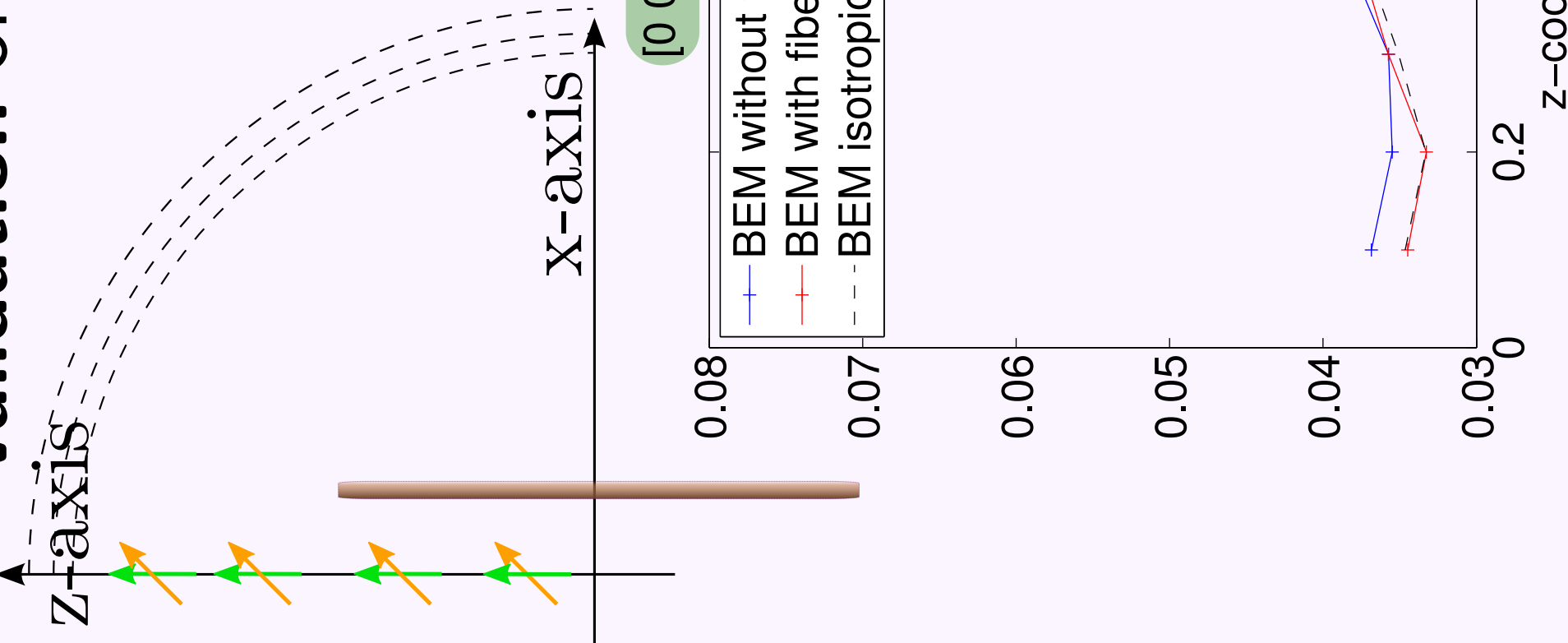


4 Experiments and Results

validation on a 3-spherical layer model using a **high resolution FEM** as reference: P1-tetrahedral elements, 590,747 nodes. **a fiber** starting at $[0.2; 0; -0.5]$, ending at $[0.2; 0; 0.5]$, $r_f = 0.04$, $\sigma_f = 10$, $N = 100$.

dipoles 24 dipoles oriented either parallel to fiber (**green arrows**) or $[1; 0; 1]$ (**orange arrows**), along the z-axis.

$$\text{errors RDM} = \left\| \frac{V_B}{\|V_B\|} - \frac{V_F}{\|V_F\|} \right\|, \text{ and MAG} = \frac{\|V_B\|}{\|V_F\|}.$$



The black dashed curve indicates the expected error between BEM and the **reference FEM**. Incorporating fibers into the BEM model significantly improves its accuracy for both RDM and MAG, especially when the dipole points toward the fiber. The red curve is closer to the black one indicating a good modeling of the anisotropy.

Conclusion

This work explores a new way of handling local anisotropy with BEM. Results have only been shown for EEG, but extension to MEG is straightforward through the Biot-Savart equation.

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