CutFEM forward modeling for EEG-Sourceanalysis

*[1]Tim Erdbrügger; [1]Andreas Westhoff; [2]Jan-Ole Radecke; [2]Rebekka Lencer; [1]Joachim Gross; [3]Sampsa Pursiainen; [4]Christian Engwer; [1]Carsten Wolters

[1]Institute for Biomagnetism and Biosignal Analysis, University of Münster, Germany

[2]Dept. of Psychiatry and Psychotherapy, University of Lübeck, Germany

[3]Computing Sciences Unit, Faculty of Information Technology and Communication Sciences, Tampere University, Finland

[4]Institute for Analysis and Numerics, University of Münster , Germany

t_erdb01@uni-muenster.de

IBB Institute for Biomagnetism and Biosignalanalysis

WWU MÜNSTER

Introduction

Performing EEG source analysis requires a solution to its forward problem, computed e.g. via the finite element method (FEM).

Creating a high quality FEM mesh is an involved process that can be simplified by using an unfitted finite element approach where the geometry is disentangled from the mesh.

This study introduces one such approach, CutFEM[1], for EEG. It makes use of level set functions to represent compartments by cutting a background mesh into pieces. This approach allows for arbitrarily touching surfaces.

Compared to the already existing unfitted discontinuous Galerkin (UDG[2]) method it features simpler FEM-subspaces and a ghost penalty based stabilization.

Here, we tested CutFEM in a multi-layer sphere scenario and performed source analysis in a realistic model.

II. FEM formulation

$$\nabla\cdot\sigma\nabla u = f, \quad \text{in } \bigcup_i \Omega_i$$
$$\langle \sigma\nabla u, n\rangle = 0, \quad \text{on } \partial\bar{\Omega}$$

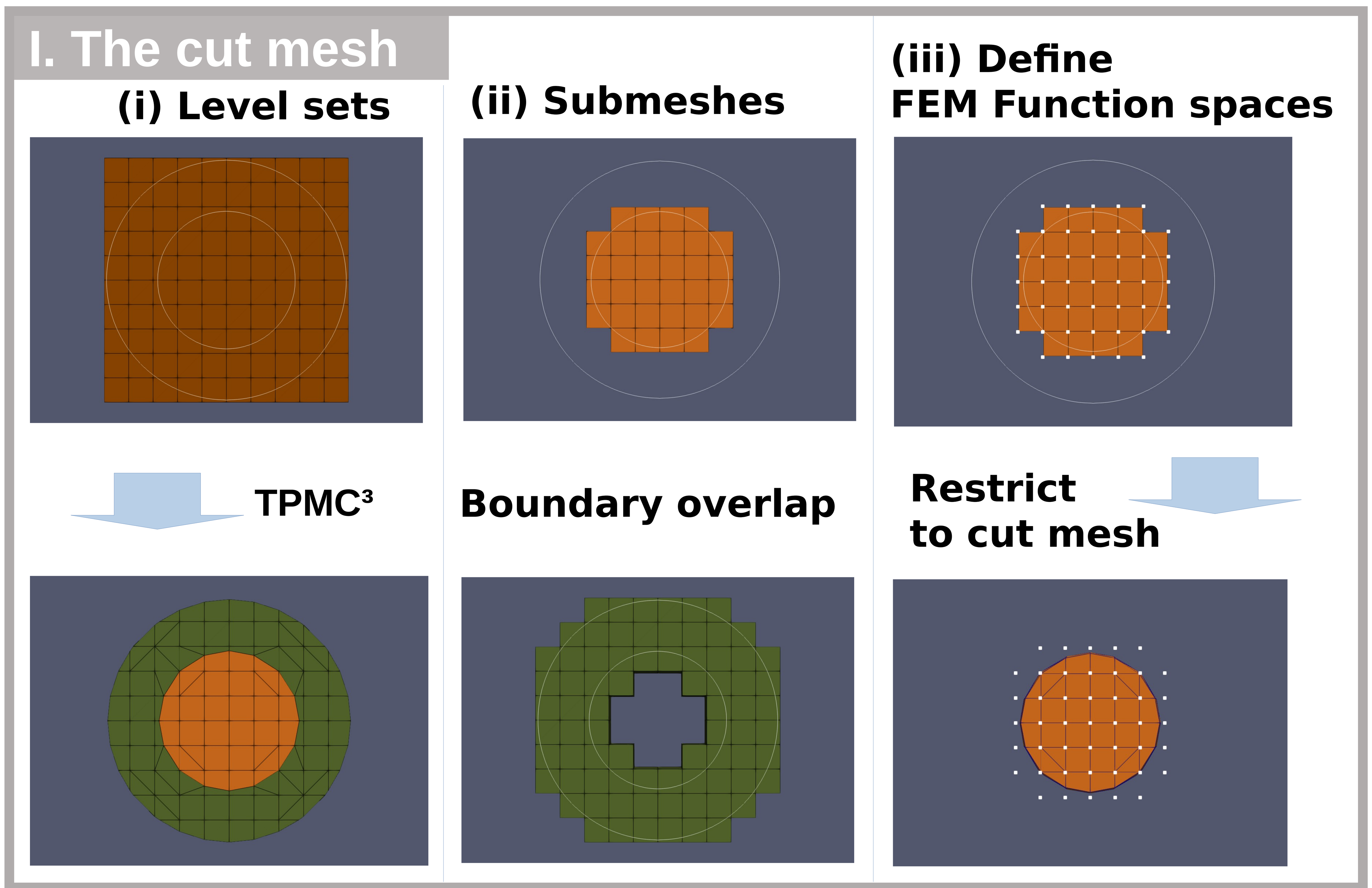
Standard EEG forward problem

$$[\![u]\!] = 0, \quad \text{on } \Gamma$$
$$[\![\sigma\nabla u]\!] = 0, \quad \text{on } \Gamma.$$

Continuous potential
Charge conservation

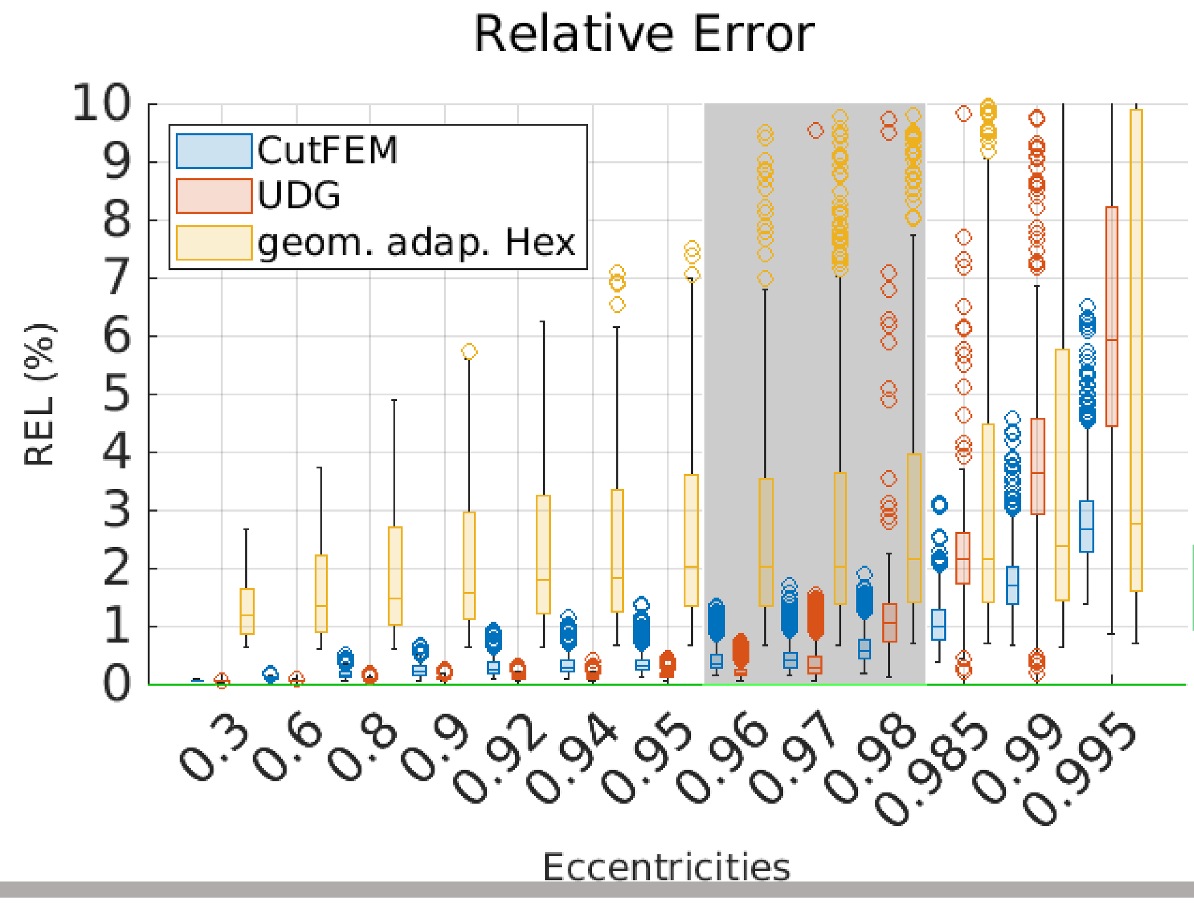
- Jump conditions are enforced weakly through Nitsche coupling[1]
- Ghost penalty is used to stabilize deformed cut cells

I. The cut mesh



III. Sphere results

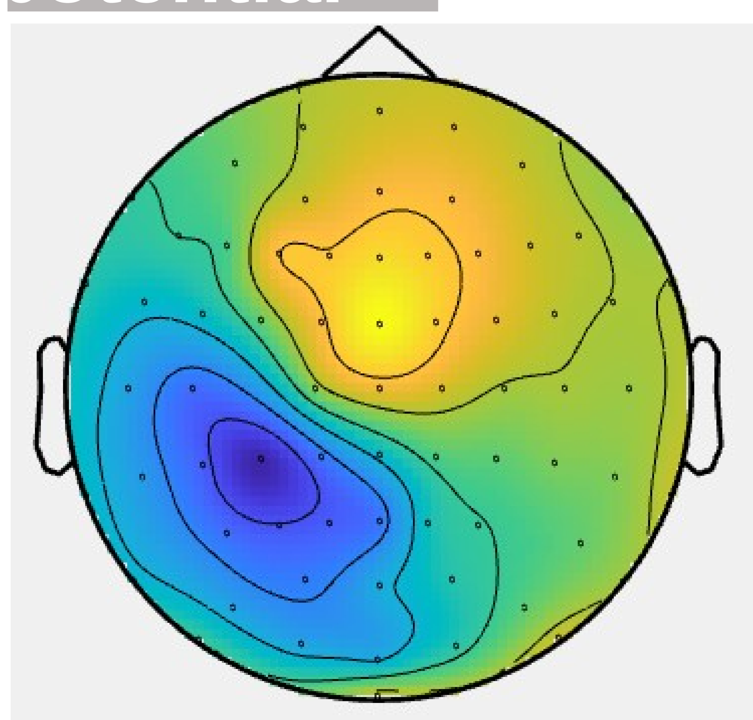
- 4 layer sphere
- geometry adapted hexahedral FEM + UDG for comparison
- 2mm CutFEM/UDG vs 1mm Hex

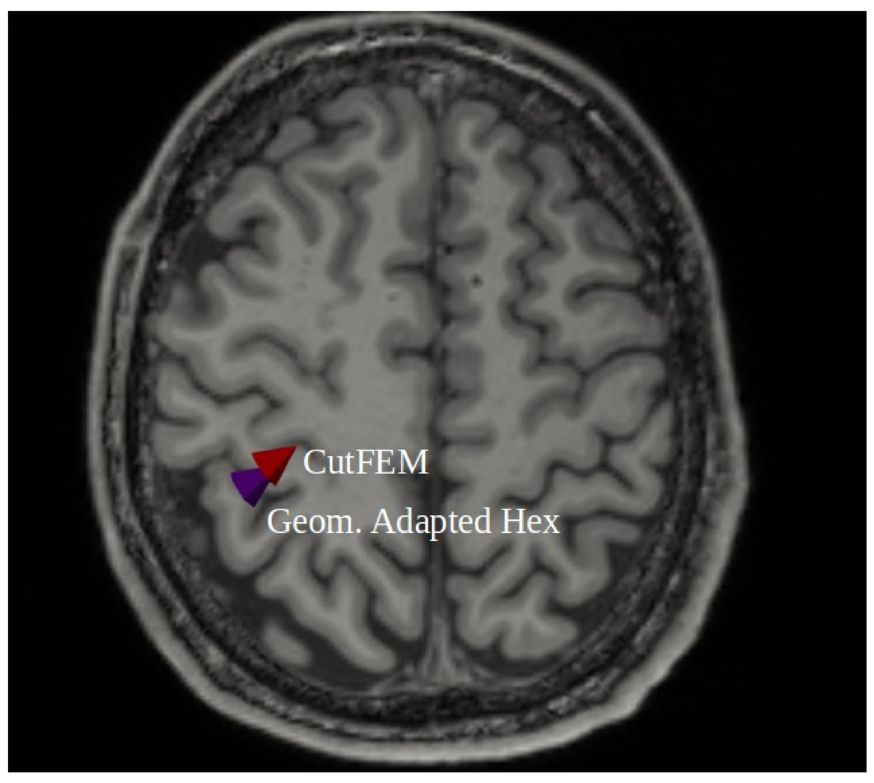


	CutFEM	UDG	Hex
number DoFs	552 985	3 601 824	3 341 280
max. RAM used	6.91 GB	64.77 GB	40.2GB
Driver setup	44s	45s	52s
Matrix assembly	319s	161s	25s
Solver setup	353s	235s	45s
Solving	1111s	2367s	1550s
Lead field	22s	20s	125s
Total time	1849s	2828s	1797s

IV. Reconstruction of somatosensory evoked potential

- electric wrist stimulation
- elicits highly focal source in somatosensory cortex
- tissue probability maps as level sets (5 compartments)
- CutFEM reconstruction is, in line with the literature, in Brodmann Area 3b, the hexahedral version locates to the back of the same gyrus.





Conclusion

In this study CutFEM was introduced to EEG source analysis. It offers a simplified meshing pipeline. Compared to the previously published UDG it is faster while maintaining a similar accuracy. CutFEM also outperforms a standard geometry adapted hexahedral mesh in sphere models.

It thus strikes a balance of numerical accuracy, computational efficiency and ability to model complex geometries that was previously not available in FEM-based EEG forward modeling.

Source analysis of somatosensory data in a realistic head model shows that this can translate to a reconstruction that is more in line with the literature than the hexahedral model.

Acknowledgements

This work was supported by the Bundesministerium für Gesundheit (BMG) as project ZMI1-2521FSB006, under the frame of ERA PerMed as project ERAPERMED2020-227 and by the Deutsche Forschungsgemeinschaft (DFG), project WO1425/10-1.

References

[1]Burman, et al. "CutFEM …", Int. Journal for Numerical Methods in Engineering '15.

[2]Nüßing, et al. "The unfitted discontinuous Galerkin method …" IEEE Trans on Biomed. Eng. '16

[3]Engwer et al. "Geometric rec. …" , TOMS '17