Patient specific simulation of brain stimulation using the unfitted discontinuous galerkin method

Andreas Nüßing[1,2,3], Carsten H. Wolters[1], Heinrich Brinck[2], Christian Engwer[3]

andreas.nuessing@uni-muenster.de

[1]Institute for Biomagnetism and Biosignal Analysis, University of Münster, Germany
[2]Westphalian University of Applied Sciences, Germany
[3]Institute for Computational and Applied Mathematics, University of Münster, Germany

Introduction

Patient specific brain stimulation is a useful tool for understanding and improving brain stimulation. It can help to better understand the current flow and its distribution during stimulation. Combined with optimization methods in can help targeting specific brain areas.[1]
Patient specific simulation increases the accuracy of a simulation by taking the individual head anatomy of a patient into account. The anatomy can be obtained from a multimodal quasi-non-invasive MRI image. For an accurate approximation of the different tissue compartments, several methods construct triangulation of the segmented MRI image.
The **unfitted discontinuous Galerkin** method works directly on a level set representation of the segmented image.

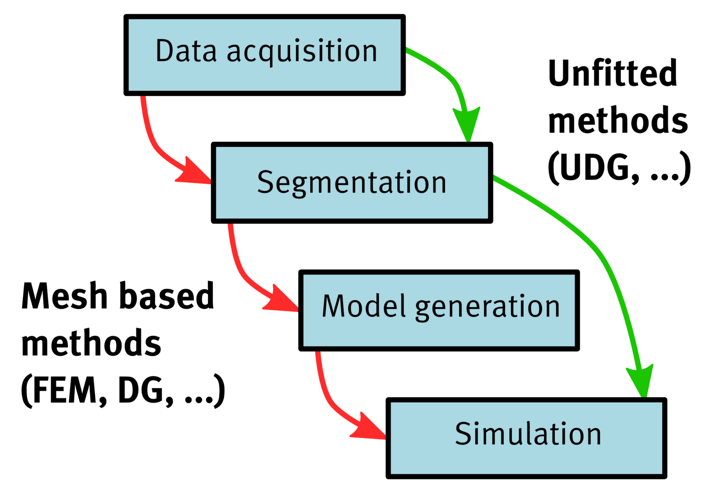
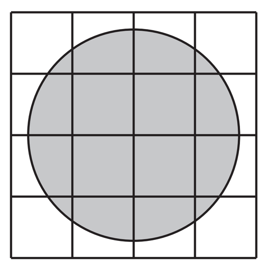


Figure 1: General pipeline of a patient specific simulation

Unfitted Discontinuous Galerkin

Discontinous Galerkin method (DG) The DG method is similar to the finite element method. We solve the Poisson equation $\nabla \cdot \sigma \nabla U = 0$ on a conforming mesh. We use element local polynomial basis functions which might be discontinuous over element boundaries. Continuity is imposed weakly by a penalty term.
Unfitted discontinuous Galerkin method (UDG)[2] The UDG method uses a structured mesh which does not resolve the geometry. The geometry is given as level sets and the elements of the mesh are restricted to the different domains.



Reciprocal Evaluation

We compare the DG method on a conforming mesh with the unfitted DG method using the **reciprocal EEG forward problem**[3]. Using a multilayer sphere model we can compare the methods with an **analytical solution**. Both models have comparable number of degrees of freedom (∼ 200k)

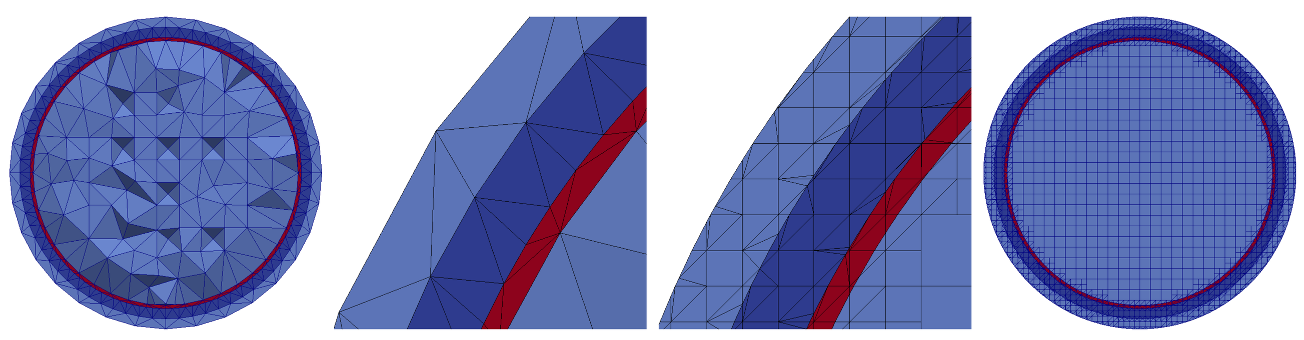


Figure 3: Multilayer sphere model used for the DG (left) and UDG (right) simulation

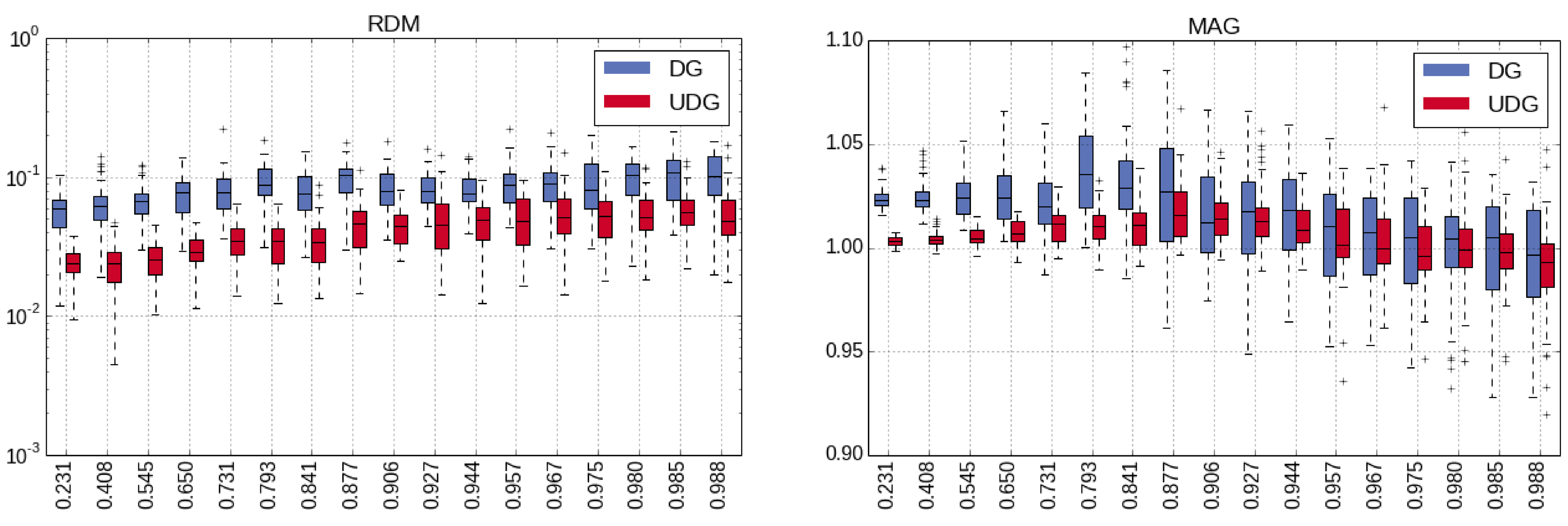


Figure 4: RDM (left) and MAG (right) errors for DG (blue) and UDG (red) method

We use **4 layers** with conductivities from outer to inner compartment: 0.33, 0.0042, 1.79 and 0.33 S/m. We generate 50 random dipoles on each of 16 eccentricities in the inner compartment. The potential is measured at 100 electrodes on the outer surface and compared to the analytic solution. The error is measured as

$$\mathrm{RDM}(U_{num}, U_{ana}) = \left\| \frac{U_{num}}{\|U_{num}\|} - \frac{U_{ana}}{\|U_{ana}\|} \right\| \in [0, 2] \qquad \mathrm{MAG}(U_{num}, U_{ana}) = \frac{\|U_{num}\|}{\|U_{ana}\|} \in [0, \infty)$$

with an optimal RDM value of 0 and an optimal MAG value of 1. The results show a comparable or even higher accuracy for UDG.

Conclusion and Outlook

We presented first promising results of the application of the UDG method for brain stimulation and the EEG forward problem. It shows higher (RDM) or at least comparable (MAG) accuracy to a DG method on a conforming mesh.
We are currently investigating a smoothing procedure based on constrained mean curvature flow. In addition, an evaluation in a TDCS optimization scheme can be worthwhile.

DUNE Framework

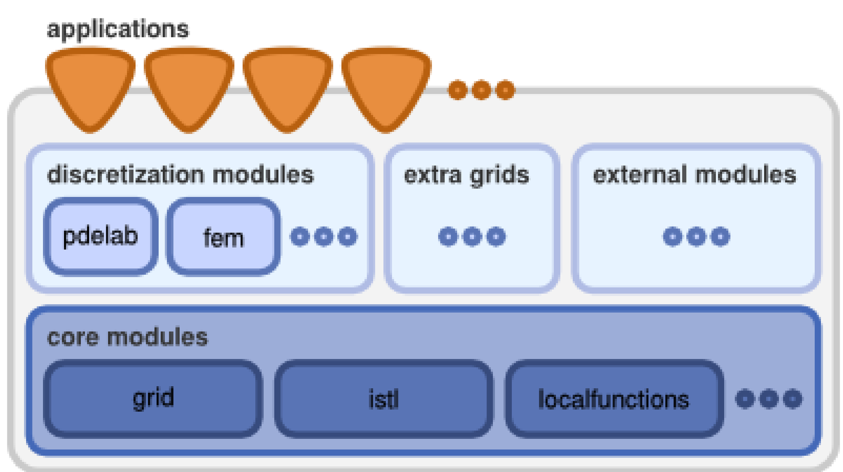


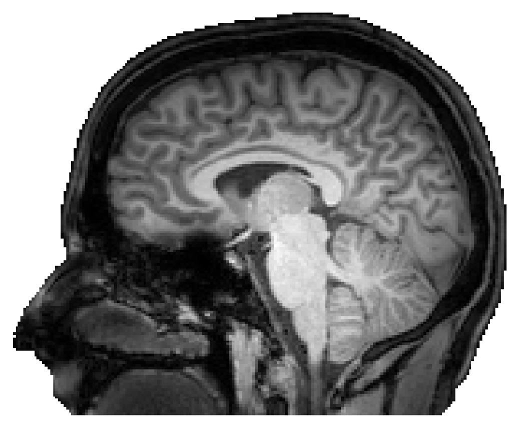
Figure 2: The modular structure of the DUNE library

DUNE = Distributed and Unified Numerics Environment
http://www.dune-project.org

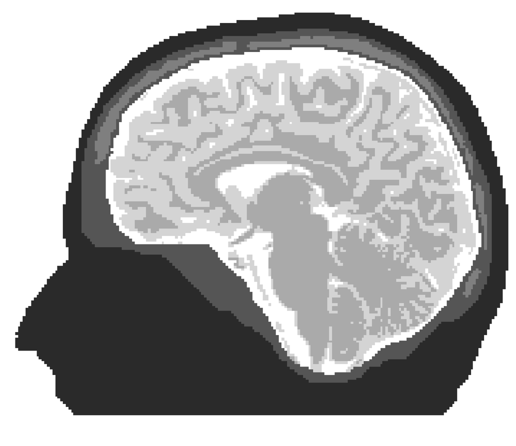
- C++ **open source library** for the discretization and solution of partial differential equations
- modular structure, general interfaces

Realistic Head Model

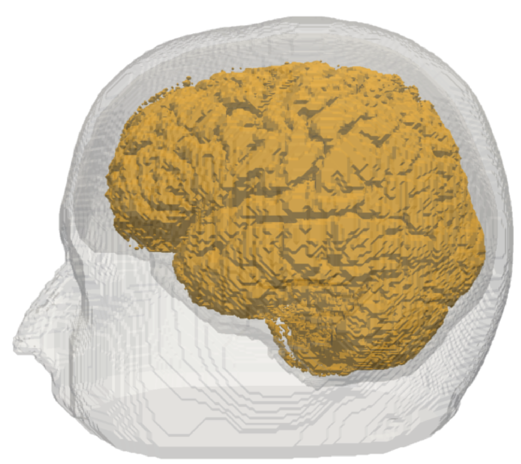
We test the UDG method for a TDCS stimulation on a 4 compartment isotropic head model with the same conductivities as for the evaluation part. The level sets are generated artificially from a voxel segmentation.



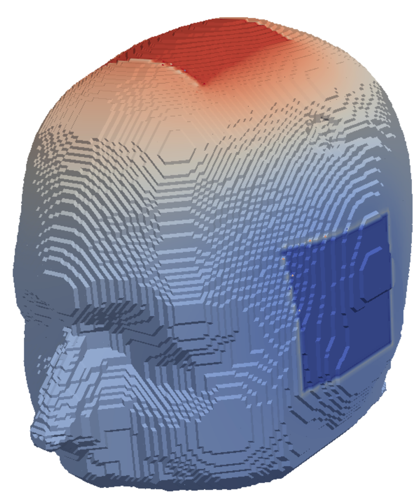
T1 MRI image



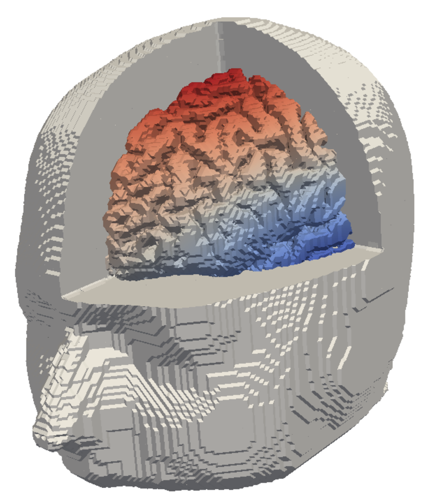
segmentation



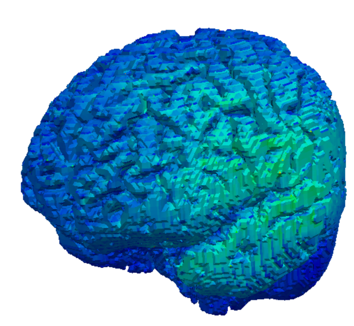
level set reconstruction



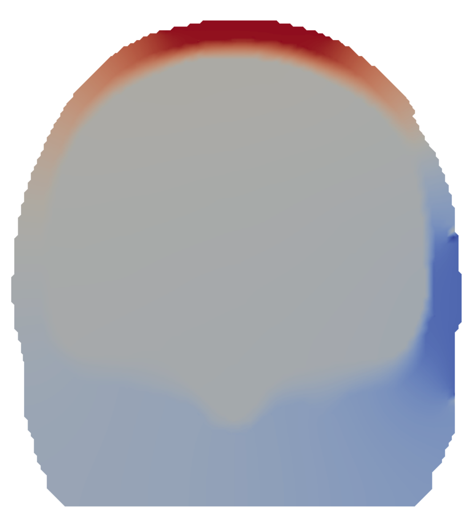
potential u



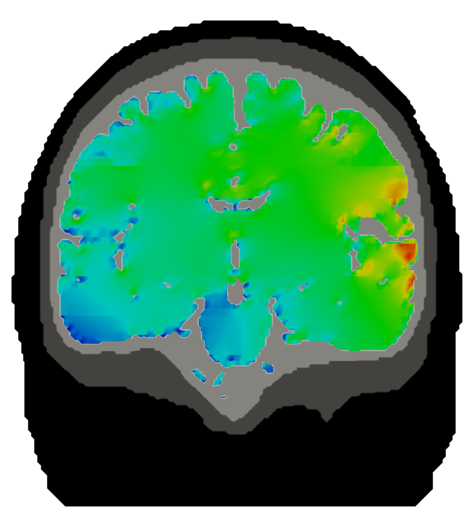
potential u



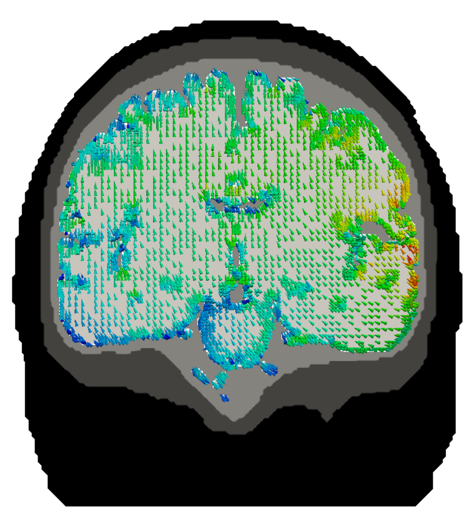
current density $|\sigma \nabla u|$



potential u



current density $|\sigma \nabla u|$



current density $\sigma \nabla u$

References

[1] S Wagner, S M Rampersad, Ü Aydin, J Vorwerk, T F Oostendorp, T Neuling, C S Herrmann, D F Stegeman, and C H Wolters. Investigation of tdcs volume conduction effects in a highly realistic head model. *Journal of Neural Engineering*, 11(1):016002, 2014.

[2] Peter Bastian and Christian Engwer. An unfitted finite element method using discontinuous Galerkin. *Internat. J. Numer. Methods Engrg.*, 79(12):1557–1576, 2009.

[3] Jan C. de Munck, Carsten H. Wolters, and Maureen Clerc. Eeg and meg: forward modeling. In Romain Brette and Alain Destexhe, editors, *Handbook of Neural Activity Measurement*, pages 192–256. Cambridge University Press, 2012. Cambridge Books Online.

contact