Shamo : A tool for electromagnetic modeling of the head

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Head current modeling in neuroscience

Electroencephalography (EEG)

- Electroencephalogram = Recorded scalp potential induced by brain activity
- Diagnose epilepsy, sleep disorders…
- Source reconstruction = Inverse problem

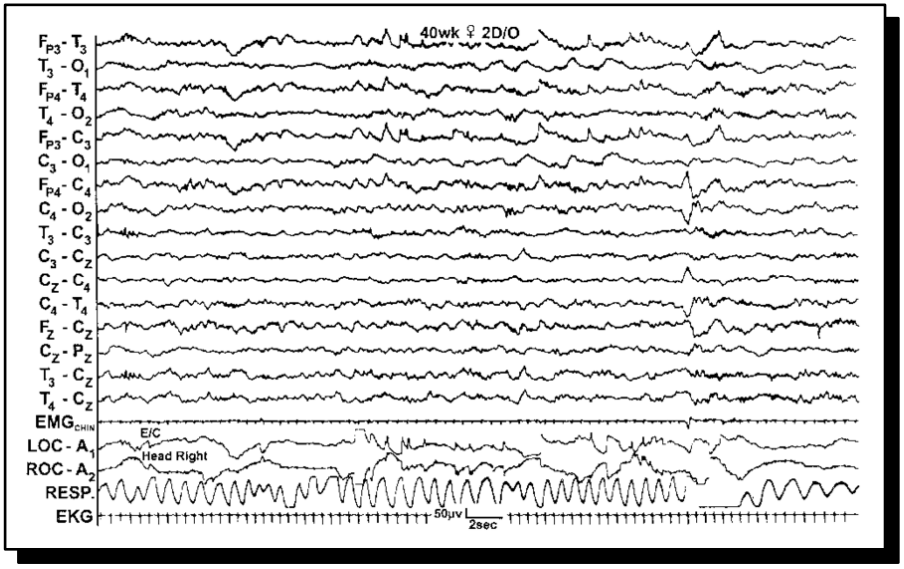
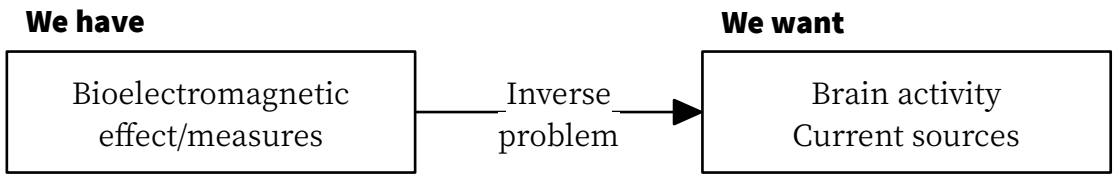


Fig. 1 **An example of an electroencephalogram [1].**



[1] M. Scher, *"Ontogeny of EEG sleep from neonatal through infancy periods"*, Handbook of Clinical Neurology, pp. 111-129, 2011.

Head current modeling in neuroscience

Transcranial direct current stimulation (tDCS)

- Neuro-modulation = Modification of neuron activation potential
- Used in stroke recovery, memory enhancement…
- Injected current < 3 mA
- Current modeling = Forward problem

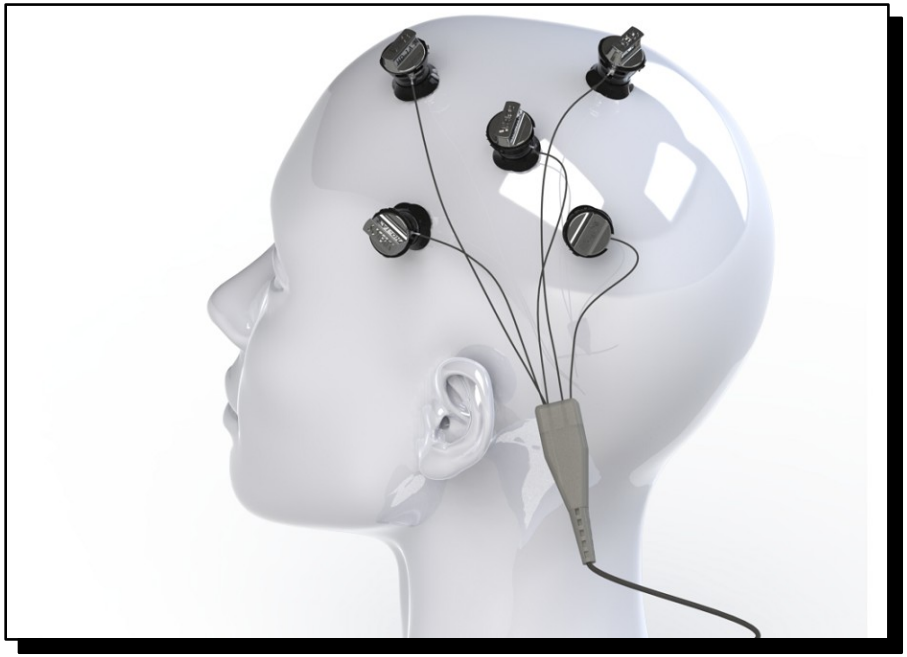
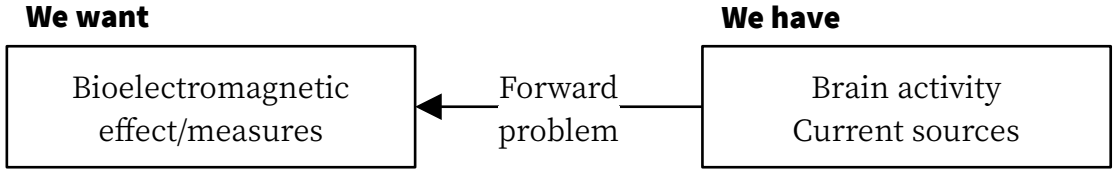


Fig. 2 An example of tDCS electrodes montage [2].

[2] *"4x1 – Soterix Medical"*, Soterixmedical.com, 2022.



Finite element modeling in neuroscience

Fig. 3 **A zoomed in view of a raw T1-weighted MRI from the BrainWeb dataset [3].**

[3] B. Aubert-Broche, M. Griffin, G. Pike, A. Evans and D. Collins, *"Twenty New Digital Brain Phantoms for Creation of Validation Image Data Bases"*, IEEE Transactions on Medical Imaging, vol. 25, no. 11, pp. 1410-1416, 2006.

Finite element modeling in neuroscience

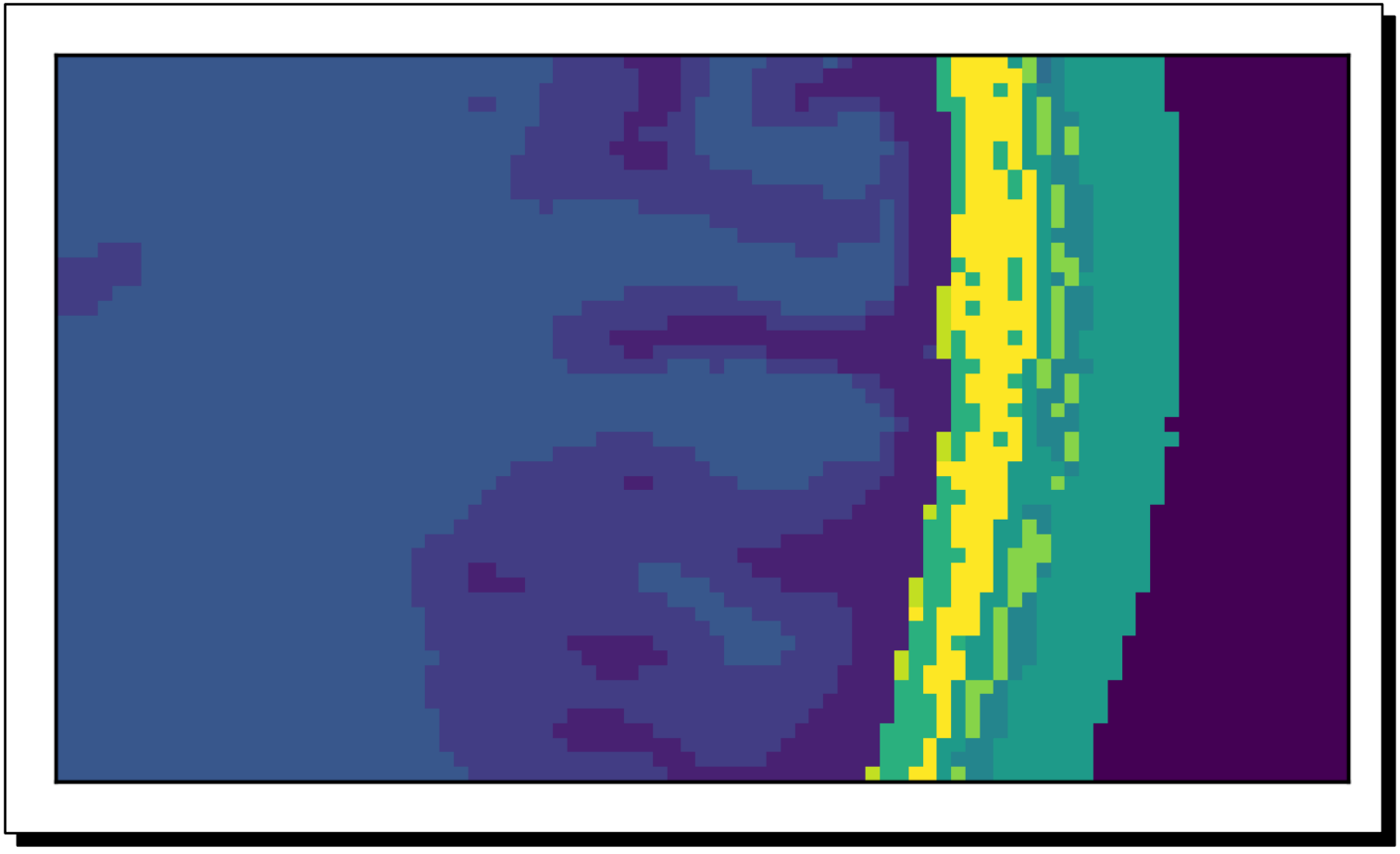


Fig. 4 **A zoomed in view of the segmented MRI from the BrainWeb dataset [3].**

[3] B. Aubert-Broche, M. Griffin, G. Pike, A. Evans and D. Collins, *"Twenty New Digital Brain Phantoms for Creation of Validation Image Data Bases"*, IEEE Transactions on Medical Imaging, vol. 25, no. 11, pp. 1410-1416, 2006.

Finite element modeling in neuroscience

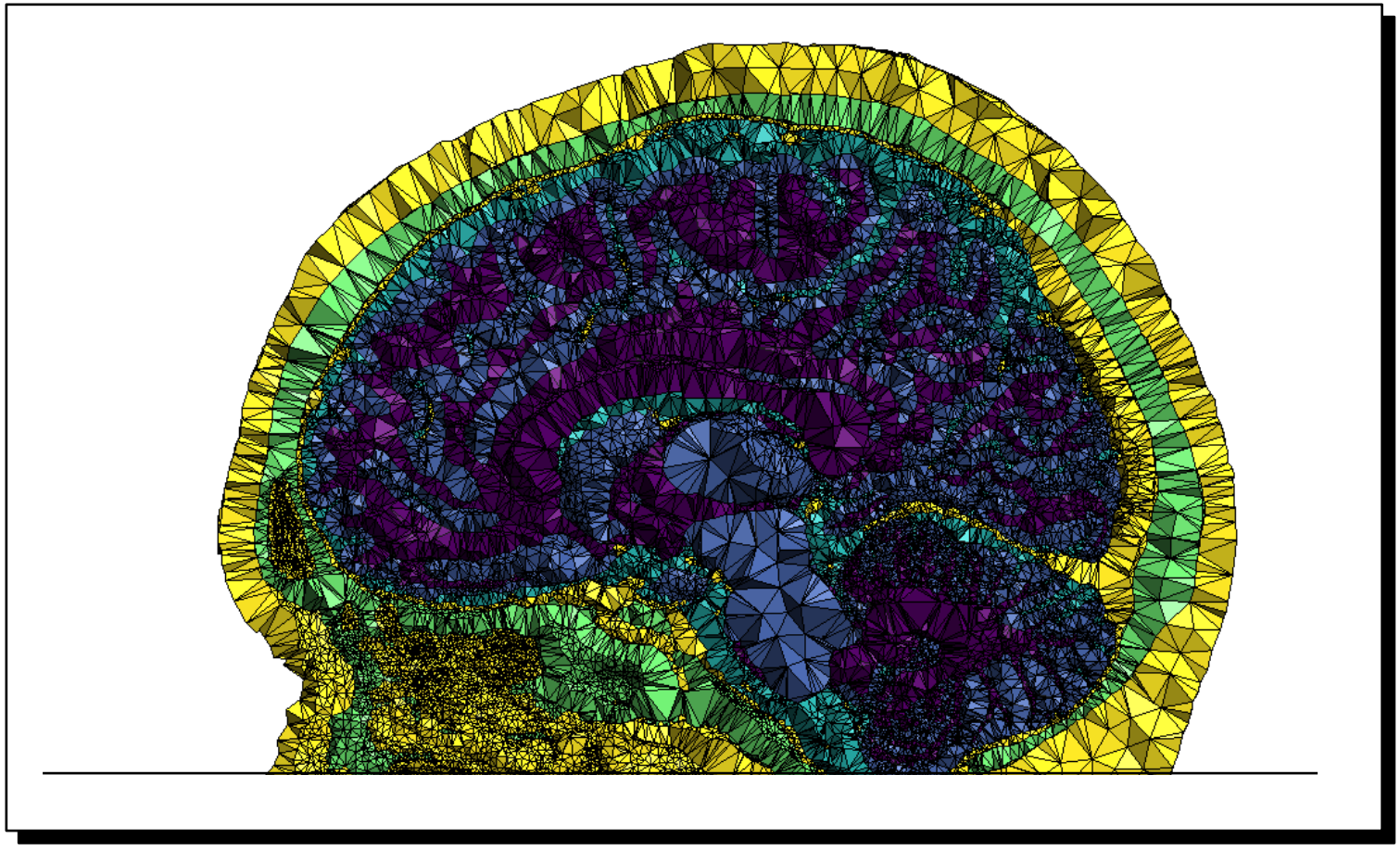


Fig. 5 **A sagittal cut of the tetrahedral mesh built from the segmented MIDA model with 5 tissues [4].**

[4] M. Iacono et al., *"MIDA: A Multimodal Imaging-Based Detailed Anatomical Model of the Human Head and Neck"*, PLOS ONE, vol. 10, no. 4, p. e0124126, 2015.

Limitations of the method

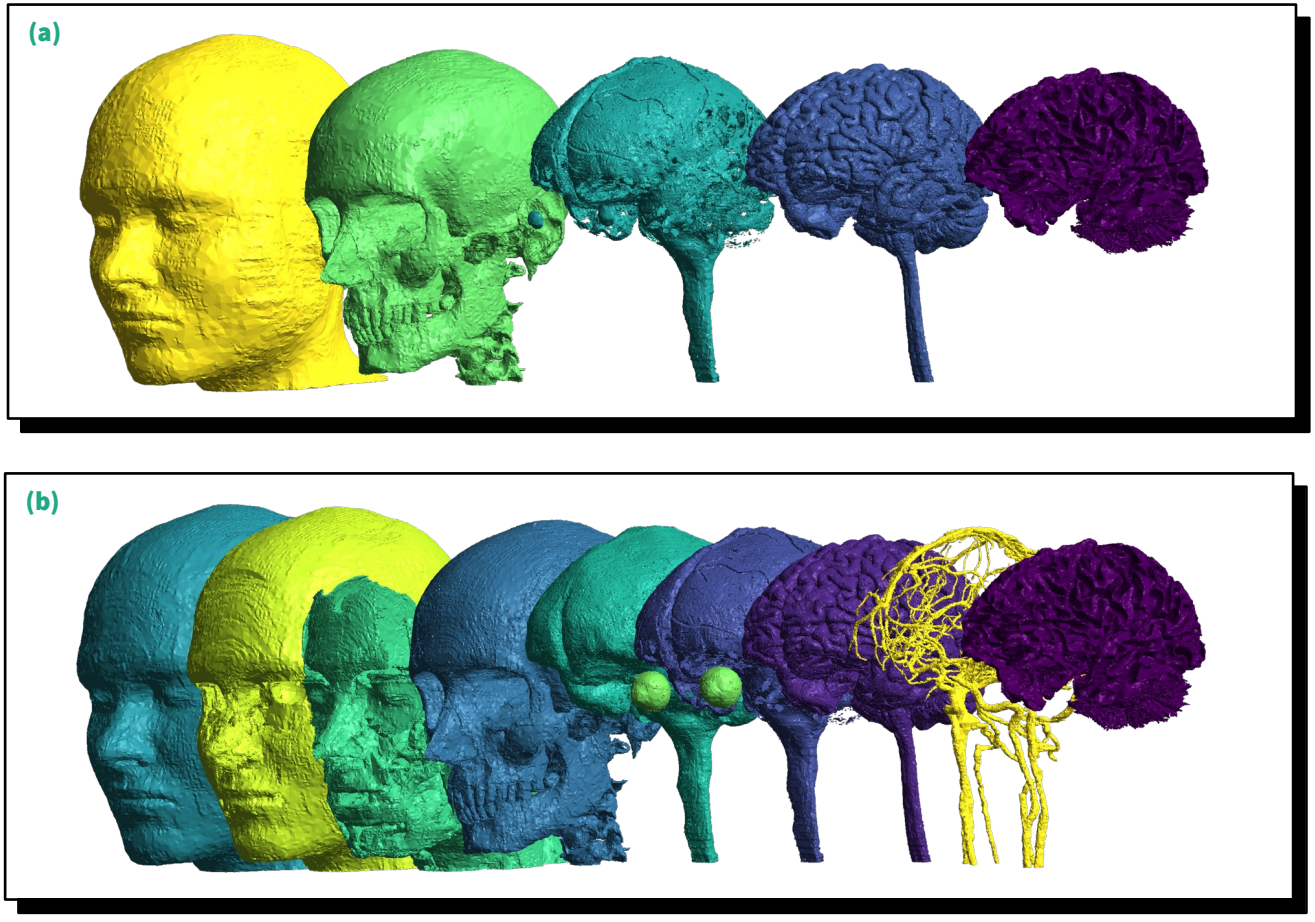


Fig. 6 **(a) A 5 tissue classes mesh and (b) a 10 tissue classes mesh built from the MIDA model [4].**

[4] M. Iacono et al., *"MIDA: A Multimodal Imaging-Based Detailed Anatomical Model of the Human Head and Neck"*, PLOS ONE, vol. 10, no. 4, p. e0124126, 2015.

Limitations of the method

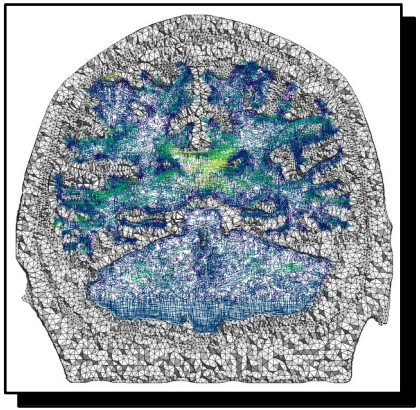


Fig. 7 **A cut of the anisotropic conductivity tensor of white matter.**

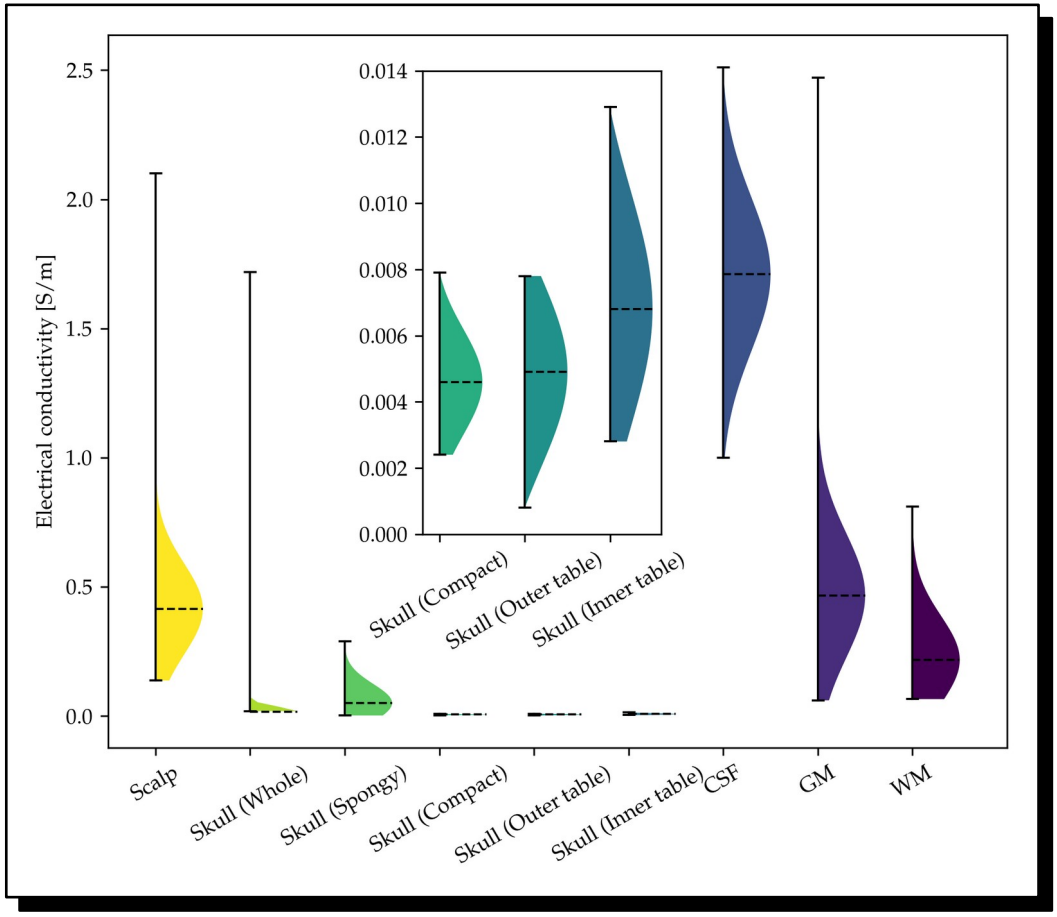


Fig. 8 **The distributions of the electric conductivity of the different tissues composing the head as reported by McCann *et al.* [5].**

[5] H. McCann, G. Pisano and L. Beltrachini, *"Variation in Reported Human Head Tissue Electrical Conductivity Values"*, Brain Topography, vol. 32, no. 5, pp. 825-858, 2019.

How to overcome these limitations ?

Shamo to the rescue !

Shamo to the rescue

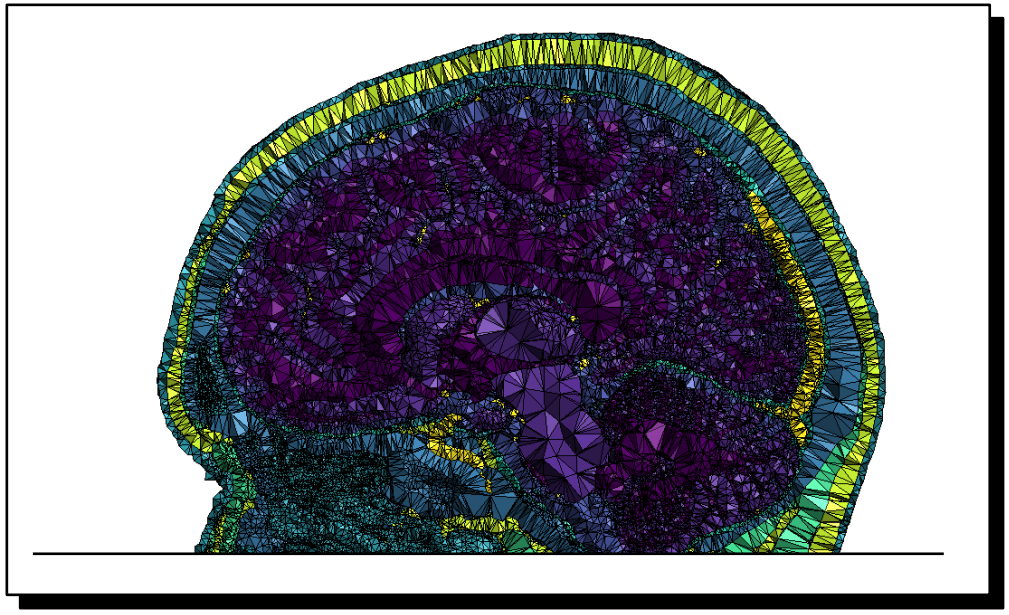


Fig. 9 **A sagittal cut of the tetrahedral mesh built from the segmented MIDA model with 10 tissues [4].**

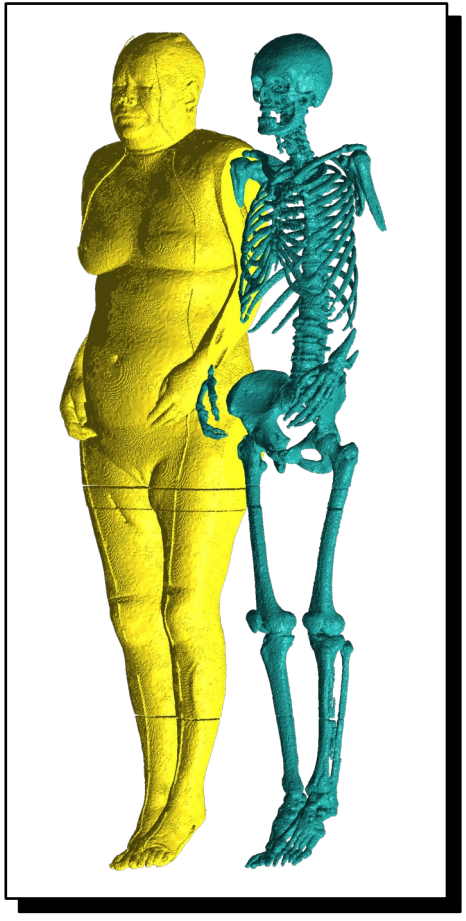
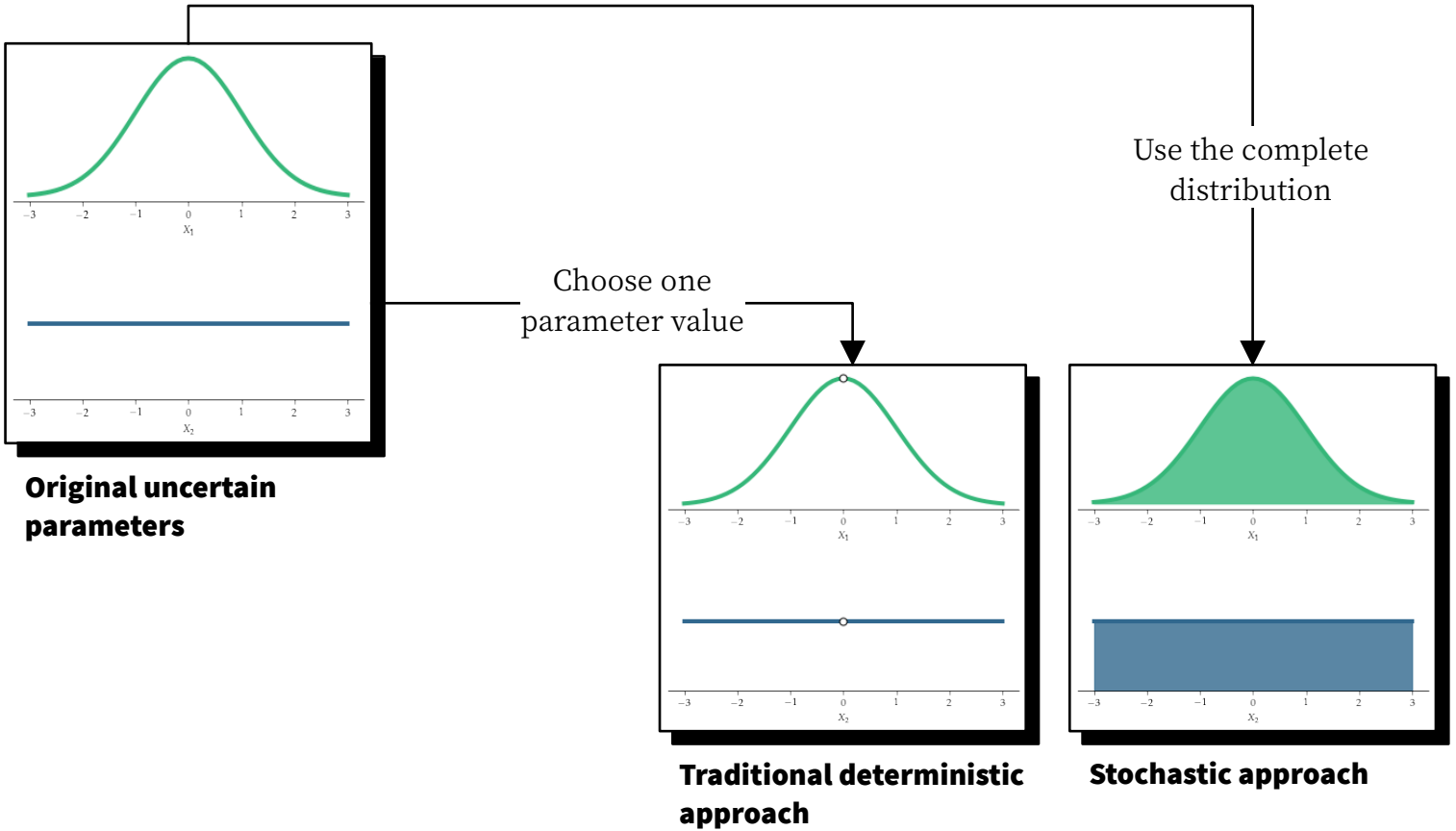


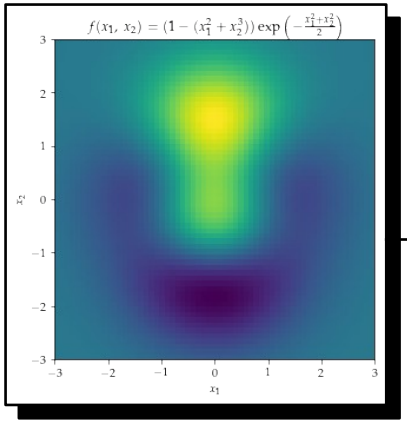
Fig. 10 **A mesh built from a segmented version of the Visual Human Project [6].**

[4] M. Iacono et al., *"MIDA: A Multimodal Imaging-Based Detailed Anatomical Model of the Human Head and Neck"*, PLOS ONE, vol. 10, no. 4, p. e0124126, 2015. ☒
[6] *"The Visible Human Project - Applications"*, Nlm.nih.gov, 2022. ☒

Shamo to the rescue

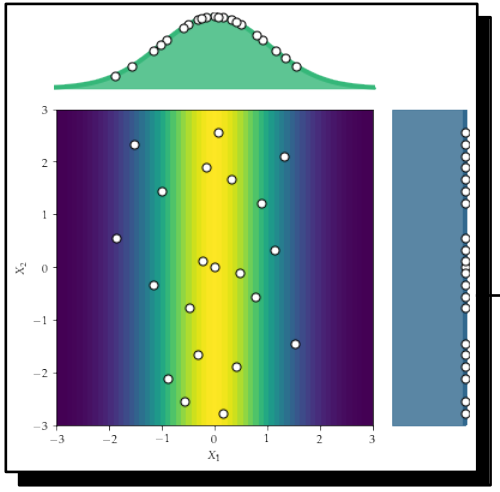


Shamo to the rescue



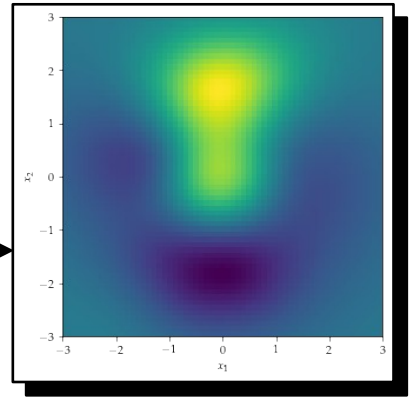
Real model

Sample



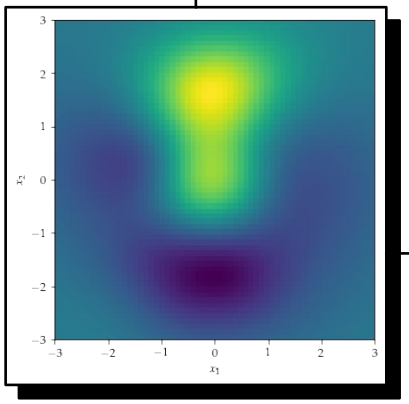
Parameters space sampled with a Halton sequence

Fit



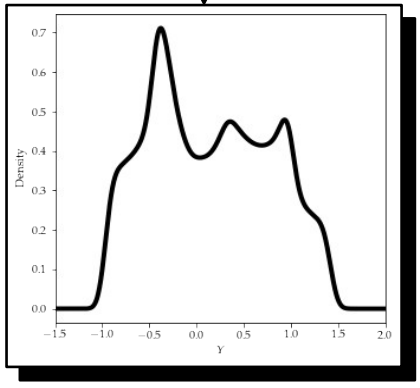
Gaussian process regressor output

Shamo to the rescue

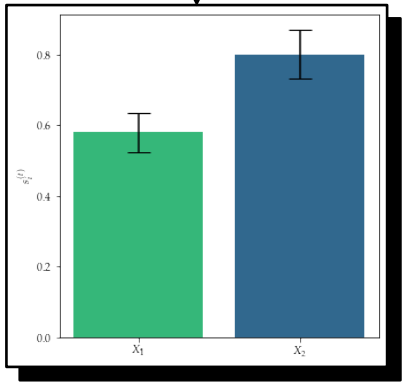


Gaussian process Regressor output

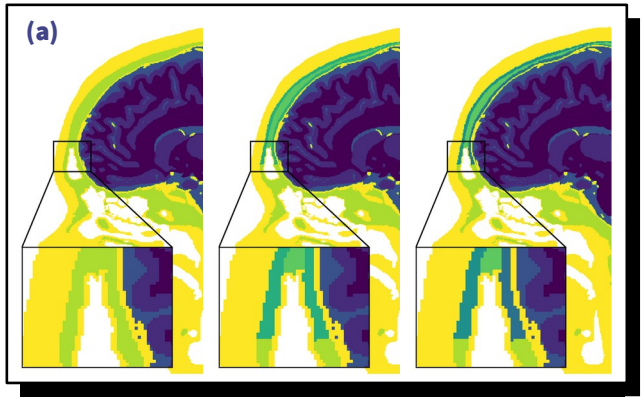
Uncertainty quantification



Sensitivity analysis



Applications : EEG



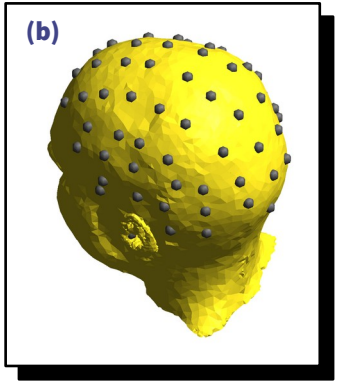
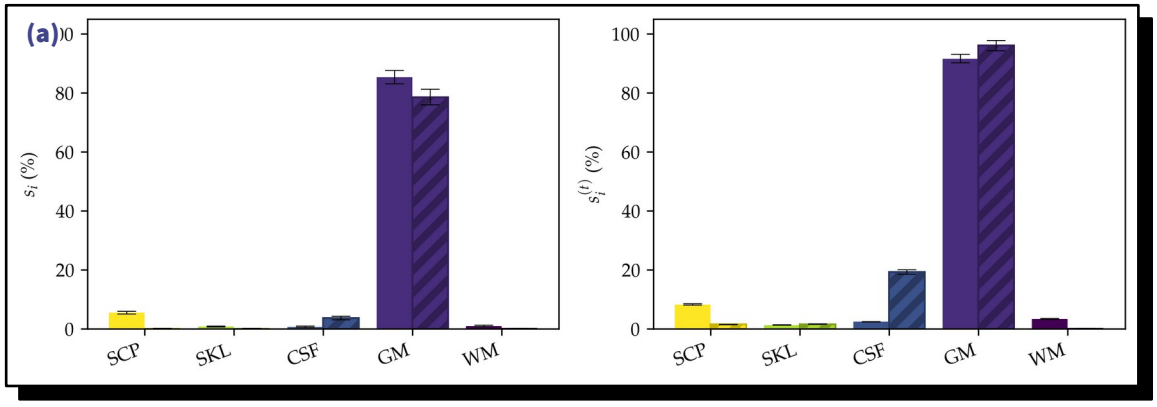


Fig. 11 **(a) A sagittal cut the 3 segmented skull models [7] and (b) the electrodes placed on the scalp.**



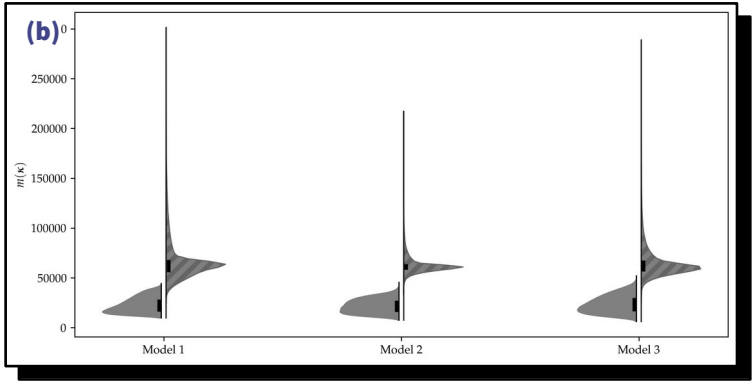


Fig. 12 **(a) The Sobol indices computed for model 1 and (b) the density of the output metric for all the models.**

[7] M. Grignard, C. Geuzaine and C. Phillips, "Shamo: A Tool for Electromagnetic Modeling, Simulation and Sensitivity Analysis of the Head", Neuroinformatics, 2022. ☒

Applications : tDCS (WIP)

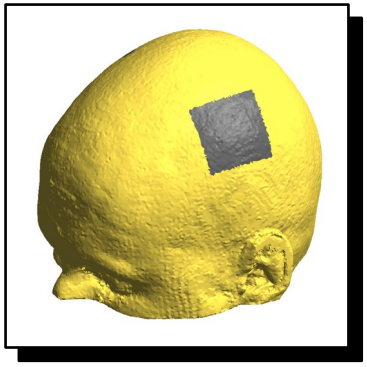
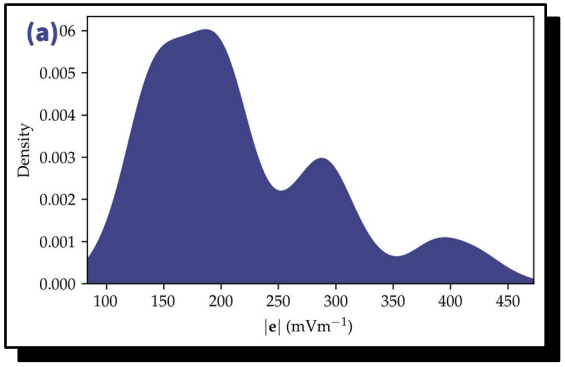
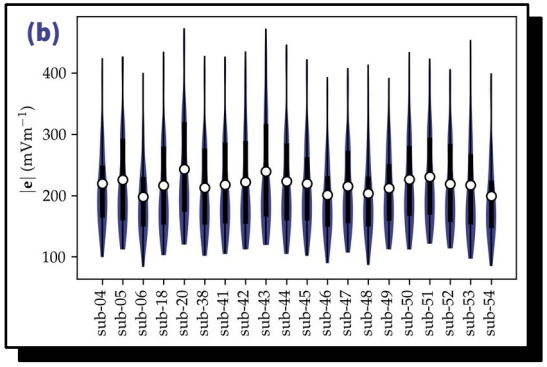
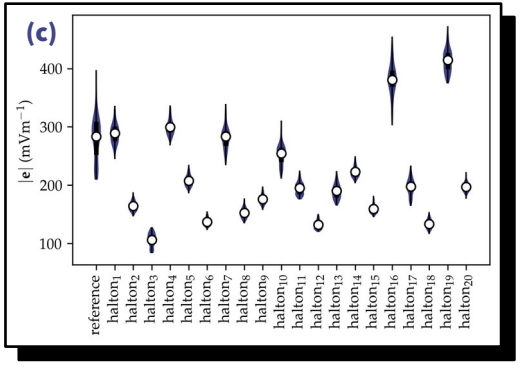


Fig. 13 The C3-C4 electrodes montage targeting the motor cortex for subject 41 from BrainWeb [3].







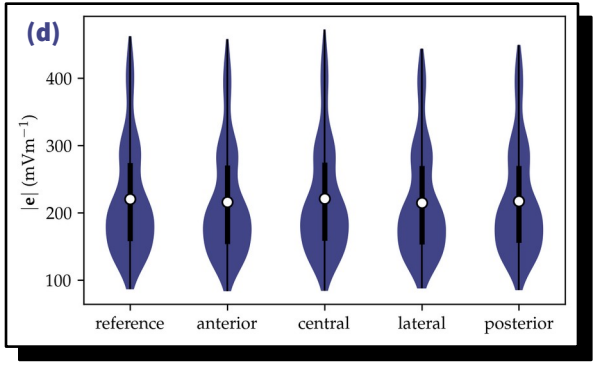


Fig. 14 The density of the computed metric (a) overall and grouped by (b) head geometry, (c) conductivity profile and (d) anode displacement for the C3-C4 electrodes montage targeting the motor cortex.

[3] B. Aubert-Broche, M. Griffin, G. Pike, A. Evans and D. Collins, *"Twenty New Digital Brain Phantoms for Creation of Validation Image Data Bases"*, IEEE Transactions on Medical Imaging, vol. 25, no. 11, pp. 1410-1416, 2006.

Conclusion

- Makes mesh generation independant from segmentation algorithm
- Makes UQ and SA easy for simulation based models
- Built upon industrial grade free open source software
- Works on both single and multi subjects studies
- Works on massively parallel infratructures

Check it out on GitHub !

Source code – Documentation – Tutorial notebooks

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