Shamo v1.0 – Stochastic electromagnetic head modelling made easy

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Introduction

Electromagnetic modelling of the head is a key step for source reconstruction (EEG/MEG) and brain stimulation (tDCS/tMS). Building an accurate subject specific head model requires both geometric and physical properties of the tissues.

- **Geometry:** Spatial distribution of the tissue compartments, as extracted from structural images.
- **Physical properties:** Electrical conductivity of biological tissues has been shown to vary across subjects. McCann *et al.* [1] provide useful information about their distribution and uncertainty.

We introduce a Python 3 package: *"shamo"*. It can perform mesh generation, electromagnetic simulations and sensitivity analysis.
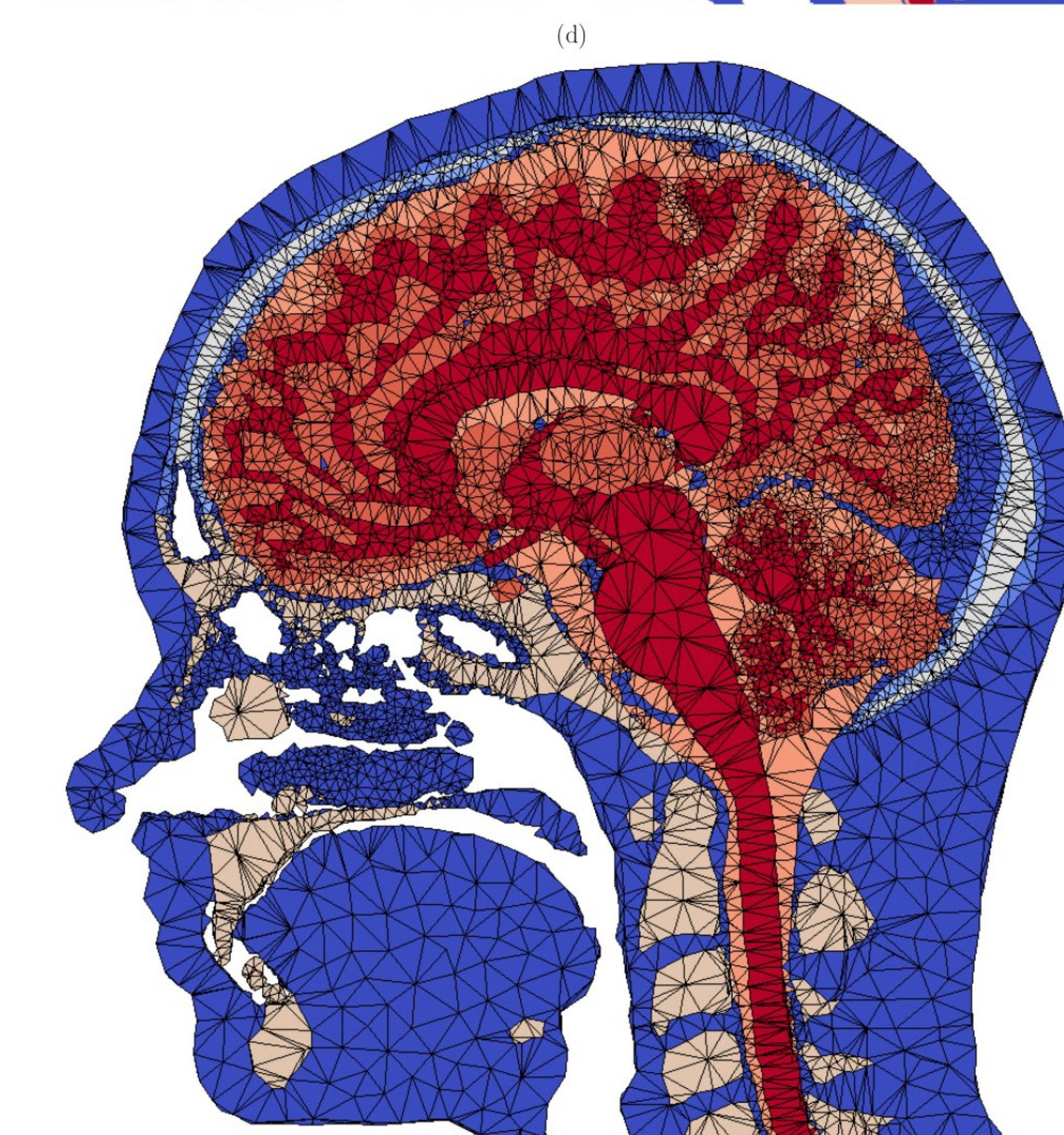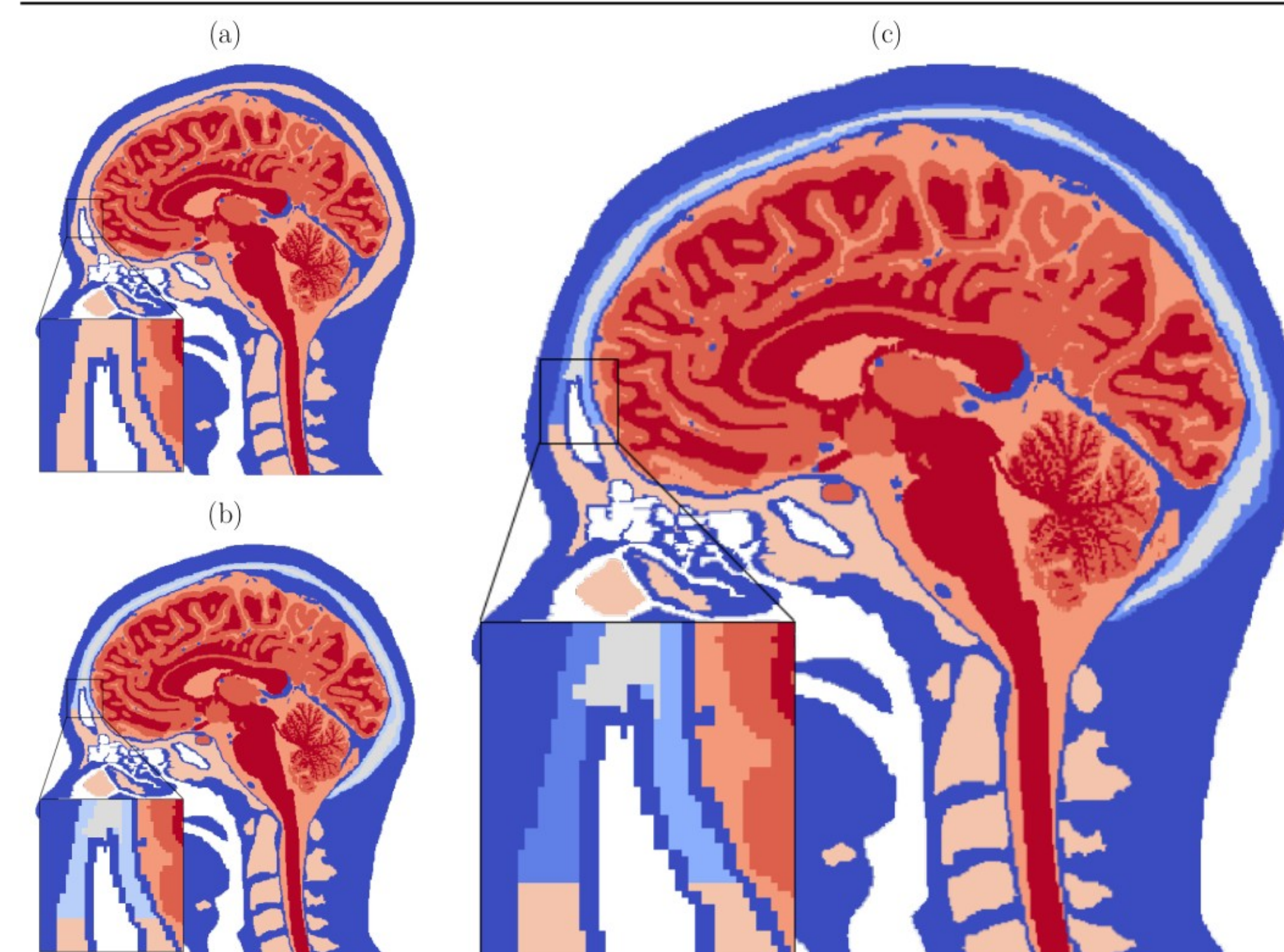
Material and methods

Shamo pipelines can be split into different modules:

- **Finite elements generation:** Several methods are available and are built upon **CGAL** [3] and **Gmsh** [4]. It allows for the inclusion of any number of tissues and fields in the model.
  - Mesh from a segmented image (directly from a labelled voxel 3D volume).
  - Mesh from already extracted compartment surfaces.
  - Mesh reduction by merging already meshed tissue compartments.
- **Electromagnetic simulation:** Shamo uses **GetDP** [5] to define and solve the physical problems (e.g. EEG or tDCS forward model).
- **Surrogate modelling:** To build a simple model suited for sensitivity analysis, shamo uses Gaussian processes as implemented in **Scikit-learn** [6].
- **Sensitivity analysis:** In shamo, Sobol indices are obtained with **SALib** [7].

In addition, shamo can be ran on a PC or on HPC infrastructure (particularly useful for the surrogate modelling) and mesh fields can be exported into NifTI format images.

Tissue			Parameters (Sm^{-1})			
Name	Abbr.	Color	Min.	Max.	Mean	Std.
Scalp	SCP		0.1370	2.1000	0.4137	0.1760
Skull (Whole)	SKL		0.0182	1.7180	0.0160	0.0190
Skull (Spongy)	SKL SPG		0.0012	0.2890	0.0497	0.0735
Skull (Compact)	SKL CPT		0.0024	0.0079	0.0046	0.0016
Skull (Outer table)	SKL OCPT		0.0008	0.0078	0.0049	0.0029
Skull (Inner table)	SKL ICPT		0.0028	0.0129	0.0068	0.0036
Cerebrospinal fluid	CSF		1.0000	2.5100	1.7100	0.2981
Gray matter	GM		0.0600	2.4700	0.4660	0.2392
White matter	WM		0.0646	0.8100	0.2167	0.1703

Tab. 1: On the left part, the tissues used throughout the other figures with their corresponding colors – On the right part, values of the electrical conductivity of the tissues defining the probability distributions [1].

Fig. 1: Based on the MIDA model [2] where in (c) the skull is split into 4 distinct compartments (spongy, outer/inner tables, and rest), in (b) 3 compartments (spongy, compact and rest), and in (a) 1 compartment. Any of these anatomical models can directly serve as a basis to generate a finite element model. (d) The mesh produced from the tissues segmentation (c).
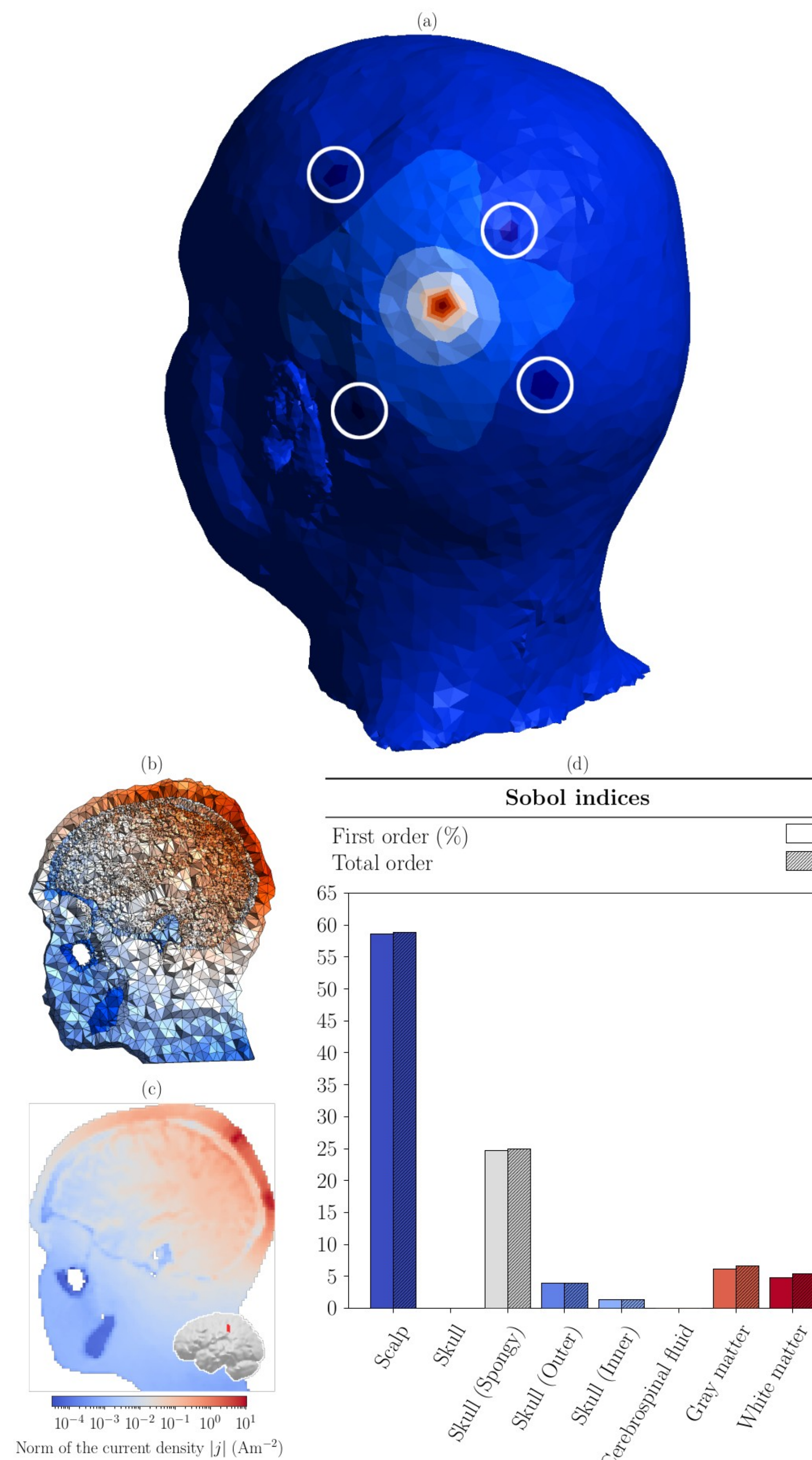
Fig. 2: A tDCS sensitivity analysis based on the probability distributions from [1] for the electrical conductivity using shamo. Electrode P3 was set as a 4mA injector and TP9, C3, P1 and O1 were set to ground. The mean current density in the ROI showed in red on (c) was used as the sensitivity metric to compute the first and total order Sobol indices (d). The scalp potential (a) and the norm of the current density (b) were computed during the process. (c) Shows a conversion from mesh data to NII.

Applications

Currently, shamo supports two applications:
- EEG forward modelling.
- (HD)tDCS current simulation as shown in Figure 2. The Sobol indices Fig. 2D points at a large sensitivity of the current intensity in the target area with the actual skin (~60%) and spongy skull (~25%) conductance.

Those applications are fully available via the API (sensitivity analysis included). Any new simulation can be easily added.

Conclusion

Shamo, a fully open source Python pakage,
- Suited for electromagnetic simulation of the head and focused on sensitivity analysis.
- Providing several easy ways to build realistic head models with a user-friendly API.
- Installable from **PYPI** and fully documented with tutorials to quickly get started.
- Extendable to specific simulations by adding new problem definitions based on **GetDP** syntax.
- Exposing similar APIs for single simulations and sensitivity analysis, allowing easy swith from fixed to probabilistic parameters in your pipeline.

Test it, use it, extend it!

Interested? Read more...

Preprint   Github   Docs

Thanks to

[1] McCan *et al.* (2019), "Variation in Reported Human Head Tissue Electrical Conductivity Values" (DOI) – [2] Iacono *et al.* (2015), "MIDA: A Multimodal Imaging-Based Detailed Anatomical Model of the Human Head and Neck" (DOI) – [3] The CGAL Project (2020), "CGAL User and Reference Manual" (URL) – [4] Geuzaine *et al.* (2009), "Gmsh: a three-dimensional finite element mesh generator with built-in pre- ad post-processing facilities" (DOI) – [5] Geuzaine (2007), "GetDP: a general finite-element solver for the de Rham complex" (DOI) – [6] Pedregosa *et al.* (2011), "Scikit-learn: Machine Learning in Python" (URL) – [7] Herman *et al.* (2020), "SALib: An open-source Python library for Sensitivity Analysis" (DOI)