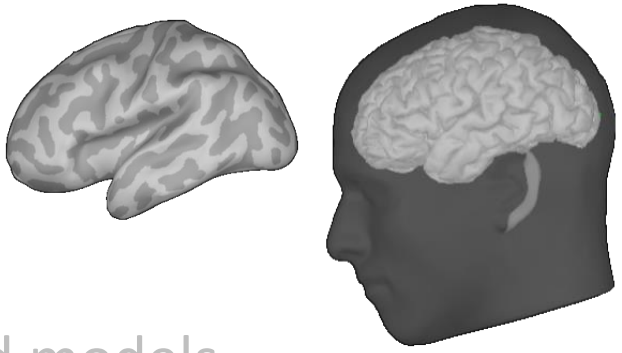
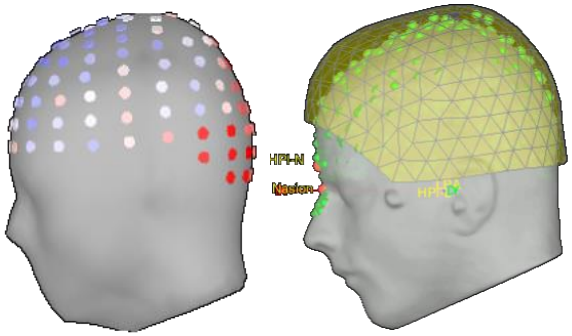
Open-source software for anatomy processing in MEG/EEG/iEEG/fNIRS source imaging

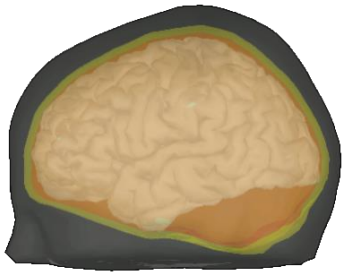
François Tadel - PracticalMEEG 2019

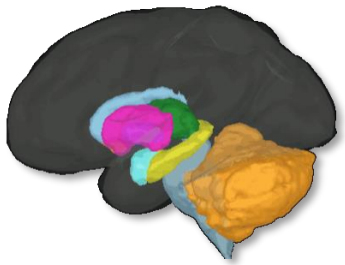
Source estimation requires…

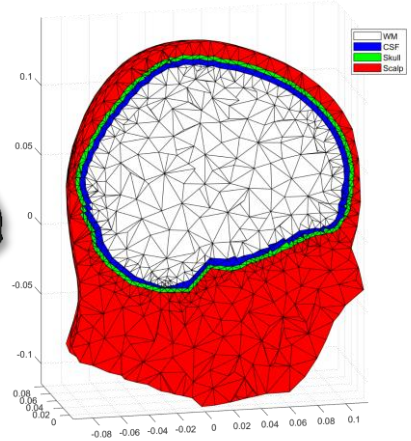


- Cortex surface (pial or grey-white)
  Source space
- Scalp and skull surfaces
  Registration anatomy-sensors, BEM head models
- Additional structures: cerebellum, sub-cortical
  Source models with different types of constraints
- Tetrahedral/hexahedral head mesh
  FEM head models



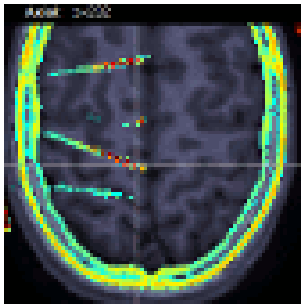






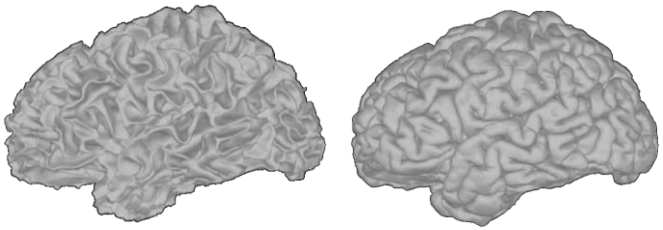
Other anatomy processes

- Co-registration between subjects
  Group-analysis
- Registration to MNI space
  Atlases, comparison with literature
- Subject volume co-registration (T1 MRI, T2, CT, DTI…)
  sEEG/ECoG contact localization
- Anonymization / De-identification
  Data sharing

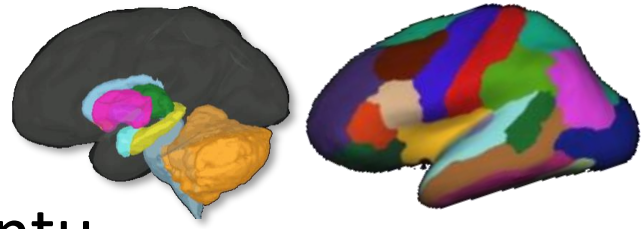

Cortex surface

FreeSurfer

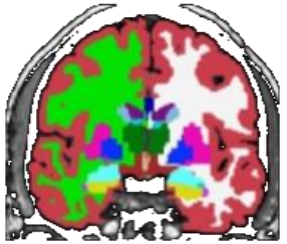


- Cortex mesh: Pial, grey-white
- Registration with FSAverage atlas
  Spherical parametrization based on curvature

- Many surface and volume atlases, thickness
  Brodmann, Desikan-Killiany, Destrieux, PALS, Yeo…

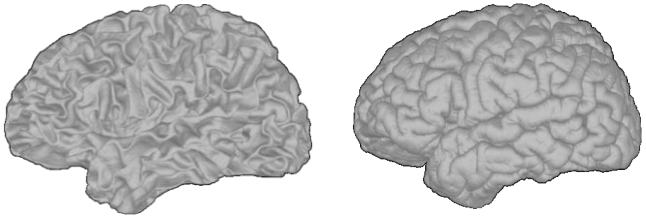


- Linux and MacOS: Native binaries
- Windows: VirtualBox or WSL/Ubuntu
- 12-24 hrs/subject, very stable
- https://surfer.nmr.mgh.harvard.edu/

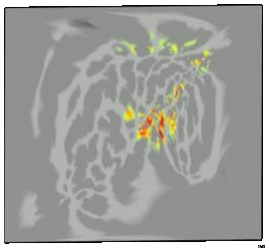


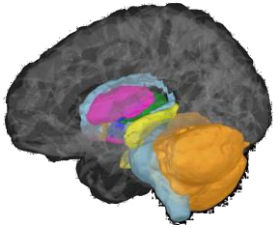
Cortex surface

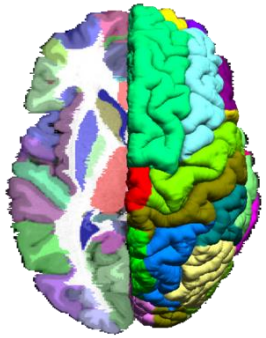
BrainSuite



- Cortex mesh: Pial, grey-white
  Better cortex growth model than FS
- Realistic skull and scalp meshes
- Registration with BCI-DNI atlas (USC-UCLA)
  Square parametrization based on curvature
- Surface and volume atlases (SVReg)
- Great visualization (tractography)
- Windows, MacOS, Linux binaries (C++)
- 1-2 hrs/subj, may require manual tuning
- http://brainsuite.org

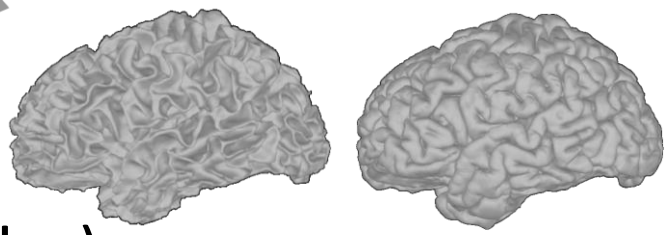




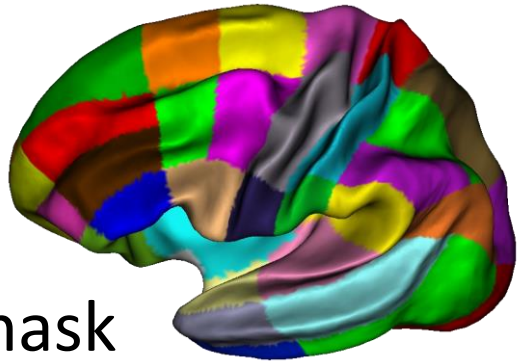


Cortex surface

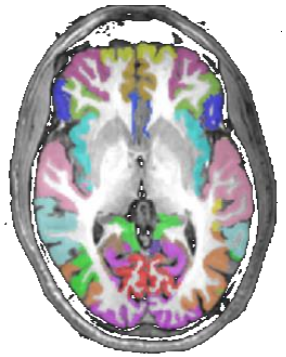
BrainVISA



- Cortex mesh: Pial, grey-white
- Surface and volume atlas (MarsAtlas)
  Better parcellation than FS atlases for ROI source analysis
  Inter-operable with FreeSurfer



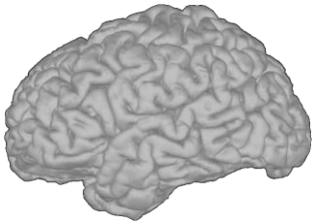
- No easy solution for group analysis
- Linux binaries (C++, Python)
- 2 hrs/subj, may require editing brain mask
- Future developments and support?
- http://brainvisa.info
  https://meca-brain.org/software/marsatlas/

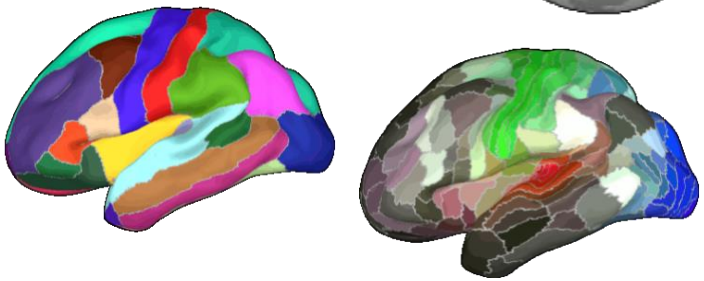


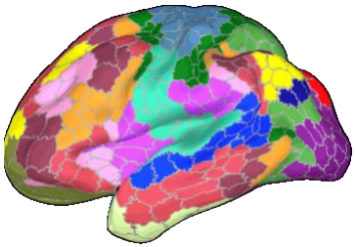
Cortex surface

CAT12

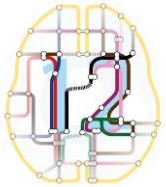
- Cortex mesh: Pial surface only
- Registration with FSAverage atlas
  Spherical parametrization based on curvature
- Many surface atlases, cortical thickness
  All the FS atlases, HCP MMP1, Schaefer 2018
- SPM12 toolbox (MATLAB)
  Integrated with Brainstorm
- 1 hr/subj
- Recent project, actively supported
- http://www.neuro.uni-jena.de/cat/







Cortical surface

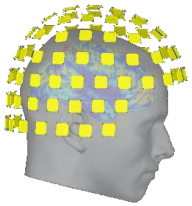


SPM12

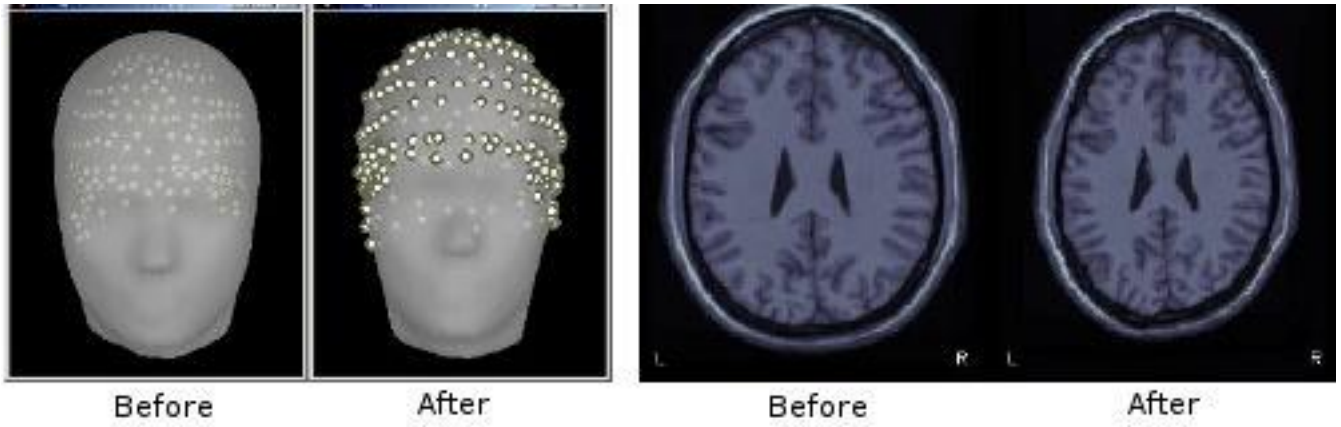
- Canonical surfaces:
  SPM MNI template warped to fit the shape of the individual brain
- Based on SPM MNI normalization
- Pial, inner skull, outer skull, head
- No individual atlas registration

- MATLAB, integrated with Brainstorm and FieldTrip
- Takes a few minutes, very stable

https://github.com/neurodebian/spm12/blob/master/spm_eeg_inv_mesh.m

Cortical surface  Brainstorm

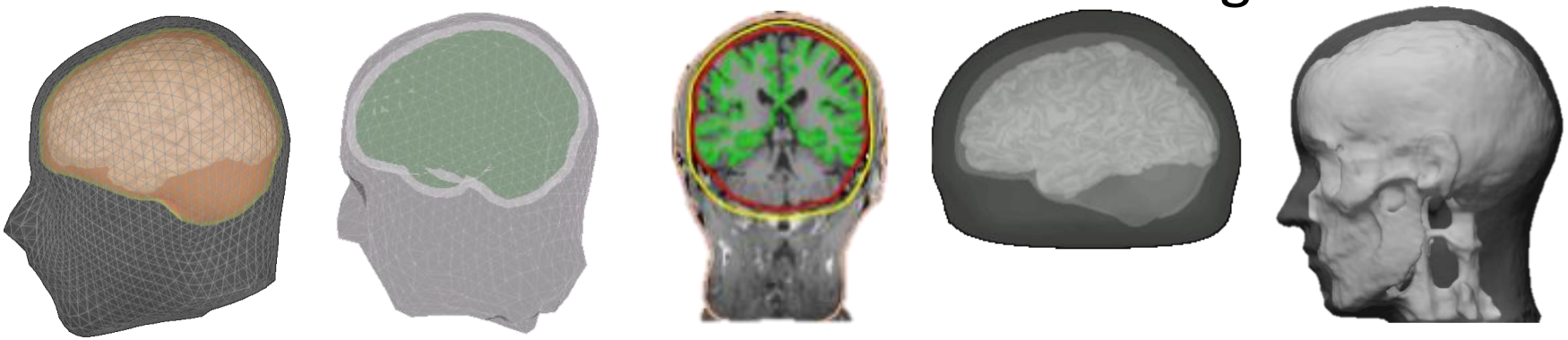
- MNI template processed with FreeSurfer 6, and warped to fit digitized individual head shape
- MATLAB, takes a few minutes
- Quality depends on quality of head shape



https://neuroimage.usc.edu/brainstorm/Tutorials/TutWarping

BEM: Head and skull surfaces

- Brainstorm (follows OpenMEEG recommendations)
  https://neuroimage.usc.edu/brainstorm/Tutorials/TutBem
- FieldTrip (uses SPM tissue segmentation)
  http://www.fieldtriptoolbox.org/tutorial/headmodel_eeg_bem/
- MNE-Python (FreeSurfer watershed, Linux/MacOS)
  https://mne.tools/stable/auto_tutorials/source-modeling/plot_forward.html
- EEGLAB/NFT: https://sccn.ucsd.edu/nft/
- SPM12: Canonical surfaces
- BrainSuite: Too realistic for BEM modelling



BEM: Forward model

- FieldTrip / SPM
  - OpenMEEG: https://openmeeg.github.io/ (all OS)
  - bemcp (Matlab)
  - dipoli (Linux only)
- Brainstorm
  - OpenMEEG: Automatic download and full integration
  - Integration with FieldTrip ft_prepare_leadfield
- MNE-Python
  - Reimplementation in Python of Matti Hamalainen's code

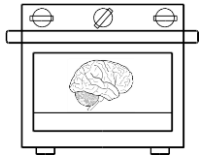
FEM: Volumetric meshes

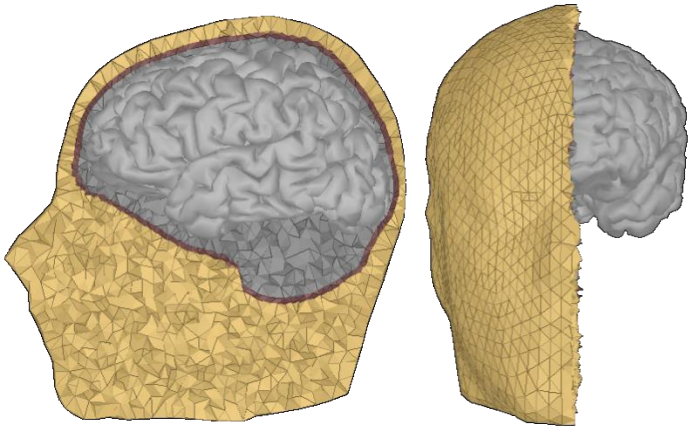
Brainstorm: Tetrahedral meshes only

- **Iso2mesh**: surf2mesh on the BEM meshes (< 1 min)
  All OS: Based on Matlab, uses CGAL and TetGen
  http://iso2mesh.sourceforge.net
- **ROAST**: Matlab, uses SPM + iso2mesh (20-30min)
  https://www.parralab.org/roast
- **SimNibs**: Matlab+Python, all OS
  - headreco: SPM12/CAT (2-3 hrs)
  - mri2mesh: FSL/FreeSurfer (20 hrs)

  https://simnibs.github.io

Under development

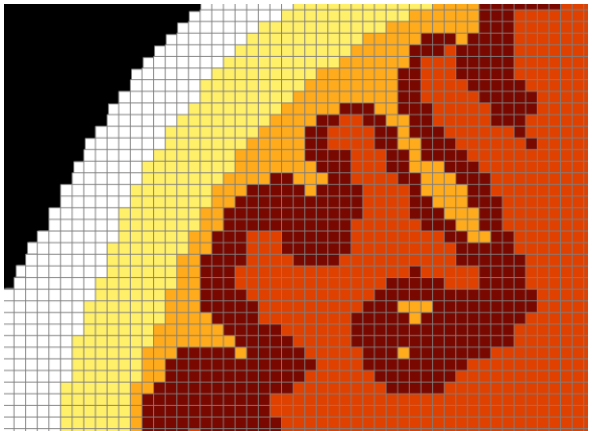


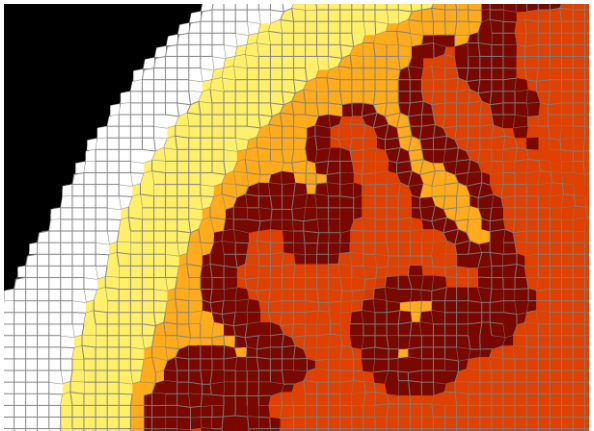


FEM: Volumetric meshes

FieldTrip: Hexahedral or tetrahedral meshes

- **Hexahedral**: Tissue classification with SPM, then conversion to geometry-adapted hexahedral mesh
  Used in the FieldTrip-SimBio FEM pipeline
  http://www.fieldtriptoolbox.org/tutorial/headmodel_eeg_fem/
- **Iso2mesh**: Tissue classification with SPM, then tetrahedral meshing with iso2mesh



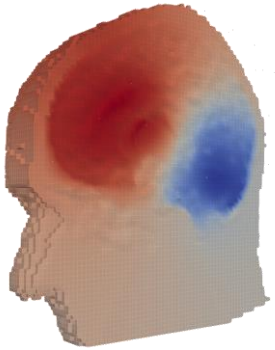


Meshing libraries

- Iso2mesh: http://iso2mesh.sourceforge.net
- CGAL: https://www.cgal.org/
- TetGen: http://wias-berlin.de/software/tetgen/
- Netgen: https://ngsolve.org/
- Gmsh: http://gmsh.info/
- MeshFix: https://sourceforge.net/projects/meshfix/
- VGrid: http://vgrid.simbio.de/
- GetDP: http://getdp.info/

- MeshLab: http://www.meshlab.net/
- Paraview: https://www.paraview.org
- Salome: https://www.salome-platform.org/

FEM: Forward model



FieldTrip / SimBio

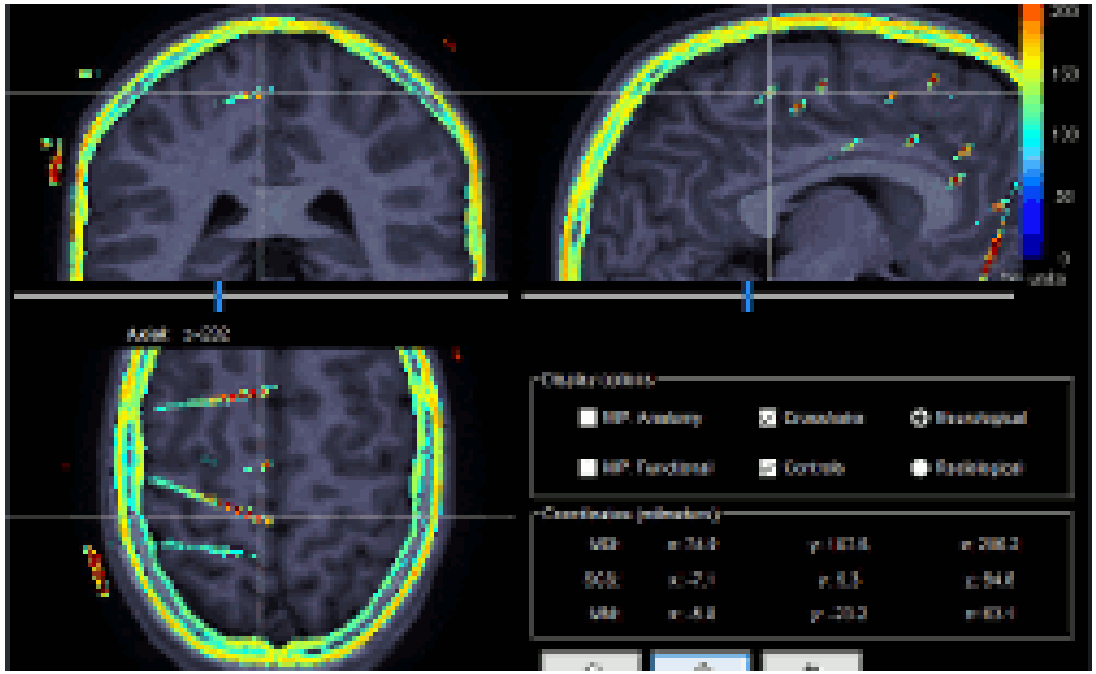
- https://www.mrt.uni-jena.de/simbio
- Vorwerk J, Oostenveld R, Piastra MC, Magyari L, Wolters CH The FieldTrip-SimBio pipeline for EEG forward solutions, BioMedical Engineering OnLine, 2018

Brainstorm / DUNEuro

- http://duneuro.org/
- Work in progress: Uni Münster (Christian Engwer, Sophie Schrader, Carsten Wolters), USC (Takfarinas Medani, Richard Leahy), UT Houston (Juan Garcia-Prieto, John Mosher)

Volume coregistration

Rigid registration of multiple images for one individual: various MRI sequences, CT…
Eg. Localization of sEEG/ECoG/DBS electrodes using post-implantation CT scan



Volume coregistration

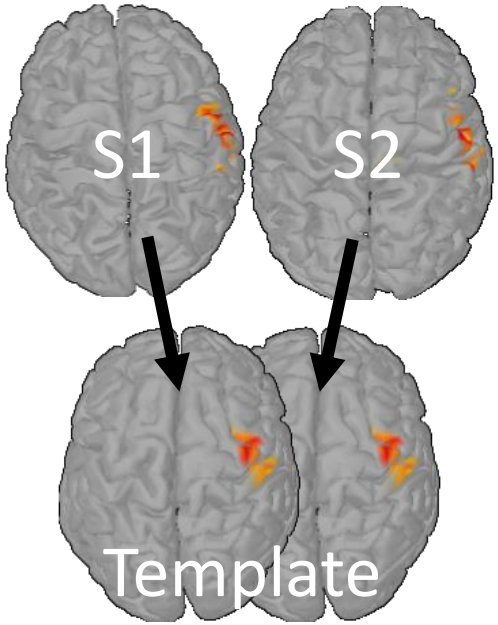
- SPM
- FreeSurfer
- BrainSuite
- BrainVISA/AIMS
- Brainstorm (based on SPM, linear registration only)

- ANTs: http://stnava.github.io/ANTs/
- AFNI: https://afni.nimh.nih.gov/
- FSL: https://fsl.fmrib.ox.ac.uk/

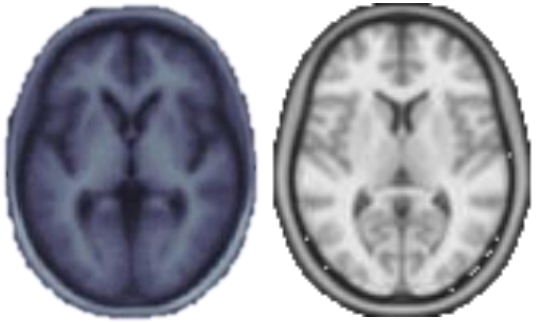
Anatomy templates

- No individual anatomy (no MRI, or poor quality)
  - Use a template matching the age range of the subjects
  - If possible adjust the template size/shape to individual measures (Brainstorm, EEGLAB/NFT)
  - Project electrodes on the template scalp surface

- Group analysis
  - Estimate sources on individual anatomy
  - Project source maps on template
  - Group statistics in the template space

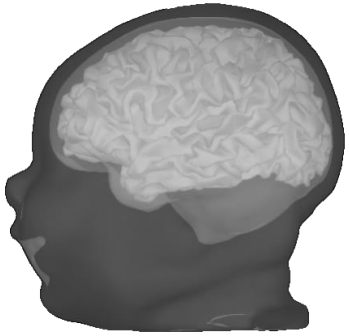


Anatomy templates

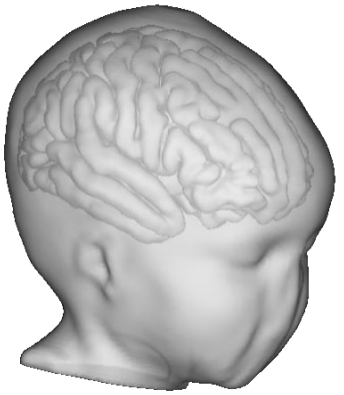


- **MNE-Python**: FSAverage (Fischl et al. 1999) | Link
- **FieldTrip**: Colin27 in MNI152 space from SPM | Link
- **Brainstorm**: Full list
  - Colin27 (FreeSurfer 5.3, BrainSuite 15b)
  - MNI ICBM152 (FreeSurfer 5.3, BrainSuite 15b)
  - FSAverage (FreeSurfer 5.3)
  - USC BCI-DNI (BrainSuite 15c) | Link
  - USCBrain (BrainSuite 17a) | Link
  - Infant 7 weeks (BrainVISA) (Kabdebon et al. 2014)
  - Oreilly 1 year (BrainVISA) (Li et al. 2015, Shi et al. 2011)

Available for group analysis



Anatomy templates

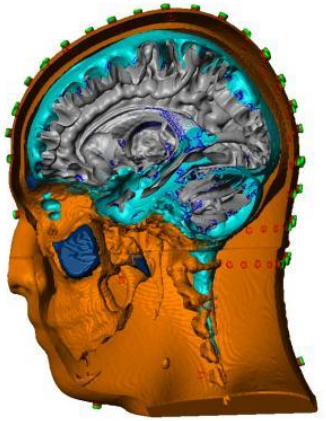


Other age ranges

- Pediatric Head Atlases: 3 atlases (0-2yr, 2-8yr, 9-18yr) https://www.pedeheadmod.net
- UNC Infant 0-1-2 Atlases (Shi F et al, PLoS ONE, 2011) https://www.med.unc.edu/bric/ideagroup/free-softwares/unc-infant-0-1-2-atlases/

FEM

- 16 Human Head CAD Models Generated with SimNIBS 2.1 from HCP https://www.nevaelectromagnetics.com/high-resolution-head-models Htet et al, Biomedical Physics & Engineering Express, 2019
- New York Head: Segmentation of MNI ICBM152 v2009 + leadfield, 2015 https://www.parralab.org/nyhead/

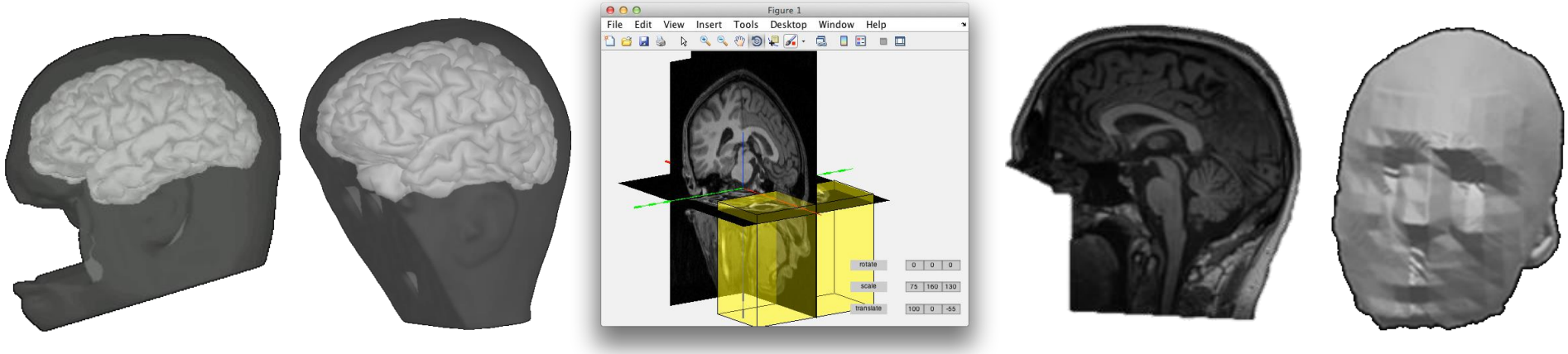


Atlases

- Exhaustive review of atlases on the Lead-DBS website: https://www.lead-dbs.org/helpsupport/knowledge-base/atlasesresources/cortical-atlas-parcellations-mni-space/

Anonymization / Defacing

- FreeSurfer / mri_deface: (integrated with Brainstorm)
  https://surfer.nmr.mgh.harvard.edu/fswiki/mri_deface
- SPM: Cut plane based on MNI registration
  Integrated with Brainstorm and FieldTrip
- FieldTrip: Interactive selection of a volume to cut
- PyDeface: https://github.com/poldracklab/pydeface
- XNAT face masking: http://nrg.wustl.edu/software/face-masking/



Commercial software

- ANT ASA
  https://www.ant-neuro.com/products/asa
- BrainVoyager
  https://www.brainvoyager.com/
- Compumedics Curry
  https://www.compumedics.com.au/products/curry