GENERATION OF HIGH-QUALITY TETRAHEDRAL HEAD MESH MODELS FROM MRI SCANS

1

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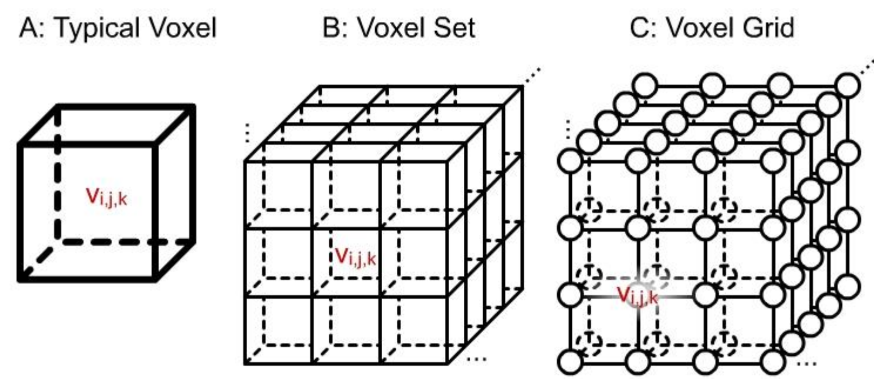
Computational Optics and Translational Imaging Lab (COTI)

OUTLINE

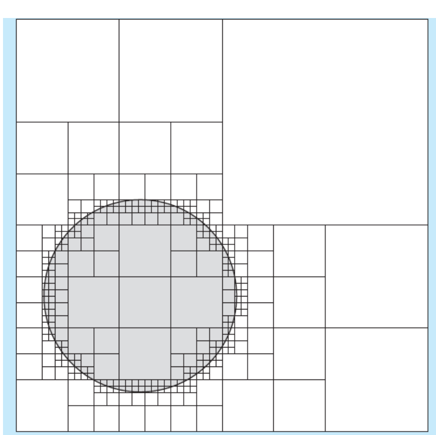
- Background
- Methodology
  - Segmenting MRI scans
  - Preprocessing the data
  - Generating and combining surface meshes for each of the tissue layers
  - Creating the final volumetric mesh
- Summary

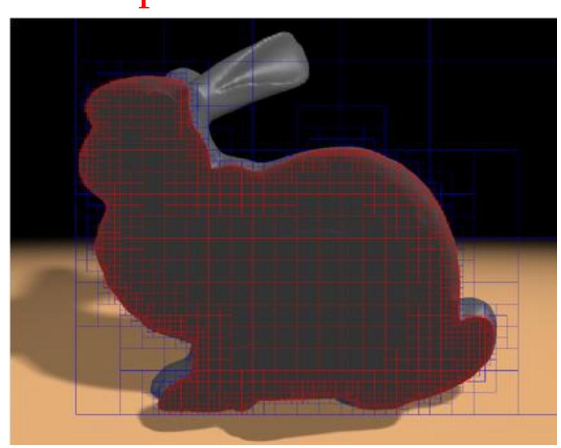
REPRESENTATION OF MEDICAL DATA (1/2)

Voxel representation:
- Most common in medical imaging
- Easiest to generate
- Large number of elements required
- Less accuracy for complex boundaries



Octree representation:
- Similar to voxel, but can adaptively refine where needed
- Less elements than the voxel representation
- Accessing the data is more complicated (recursive access)
- Boundaries still have the staircase pattern



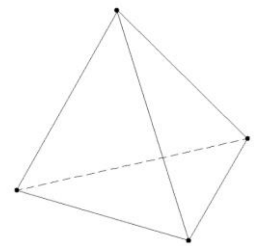


C. Dick et al. (2010)

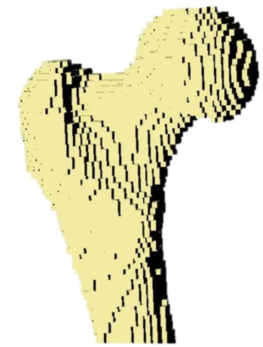
REPRESENTATION OF MEDICAL DATA (2/2)

Tetrahedral meshes

- Can represent complex boundaries
- Can be adaptively refined or coarsened
- Low memory cost
- Suitable for finite element analysis



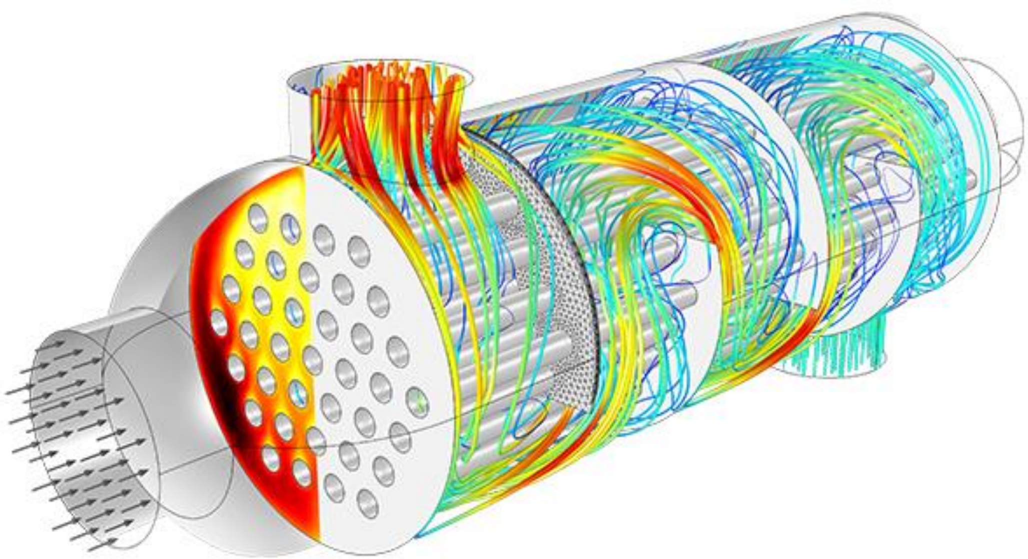
Tetrahedral element

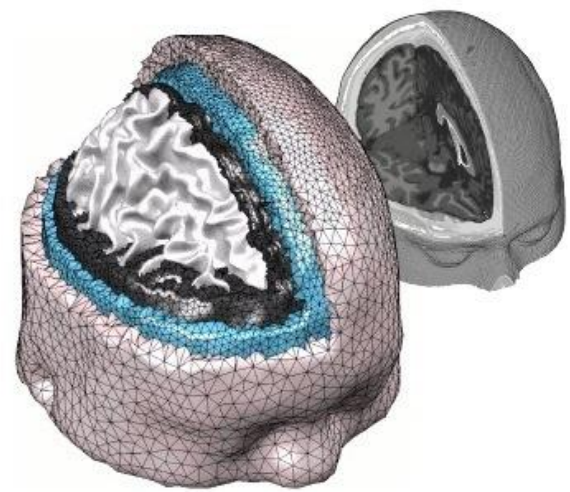


Voxel representation

Tetrahedral mesh

P.G. Young et al. (2008)

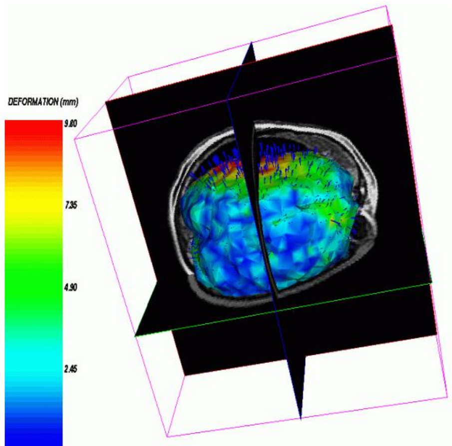




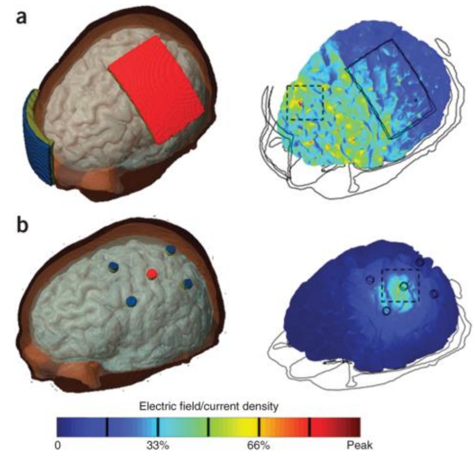
Colin27 head mesh model

Q. Fang (2010)

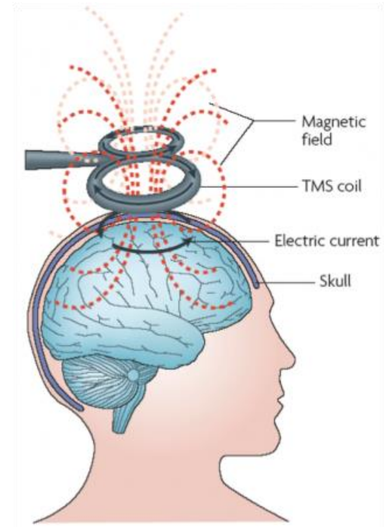
NEUROLOGICAL APPLICATIONS



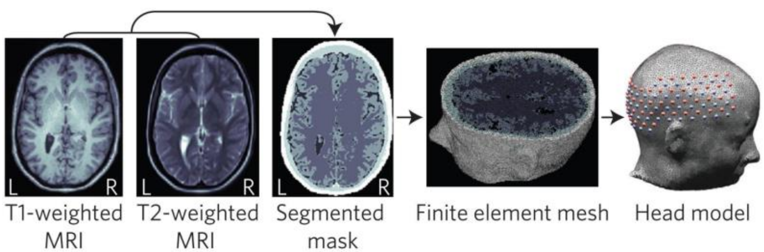
Simulating deformation for neurosurgery
(Warfield et al., 2000)

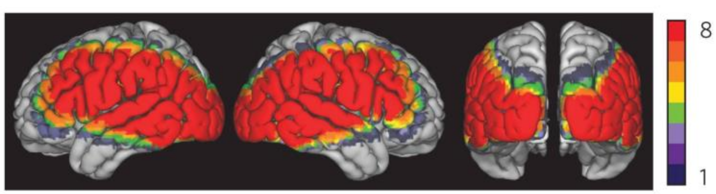


Simulation of transcranial direct current stimulation (tDCS)
(Dayan et al., 2013)

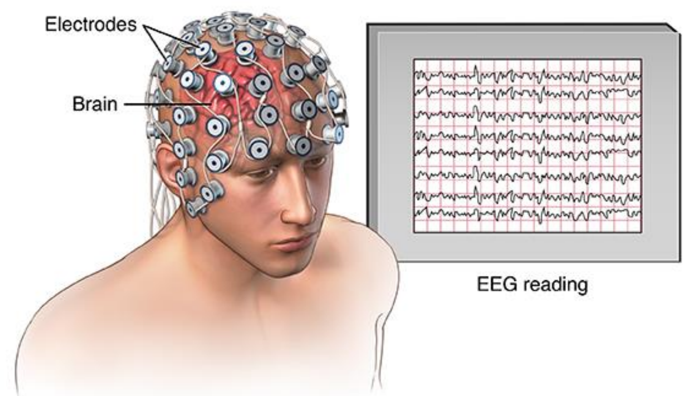


Transcranial magnetic stimulation (TMS)



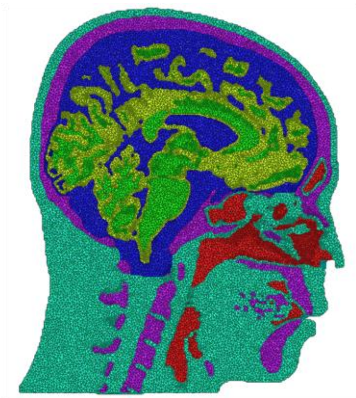


Mapping brain functions through functional near-infrared spectroscopy (fNIRS)
(Eggebrecht et al., 2014)



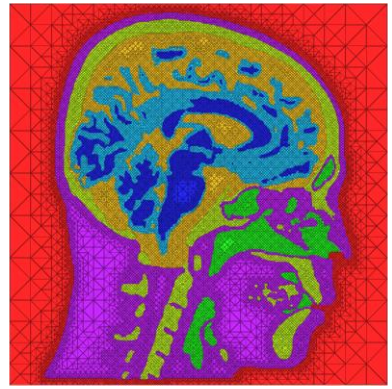
Electroencephalogram (EEG)
(Adebimpe et al., 2016)

EXISTING MESHING WORKFLOWS



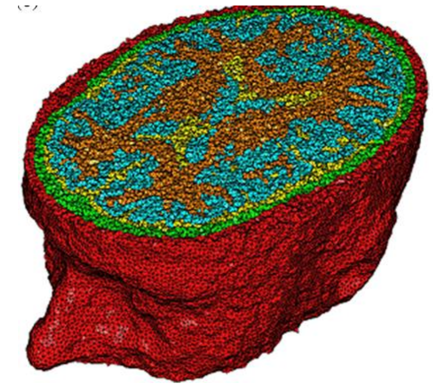
Biomesh3D
- 8-12 hrs
- Robustness issues

(Callahan et al., 2007)



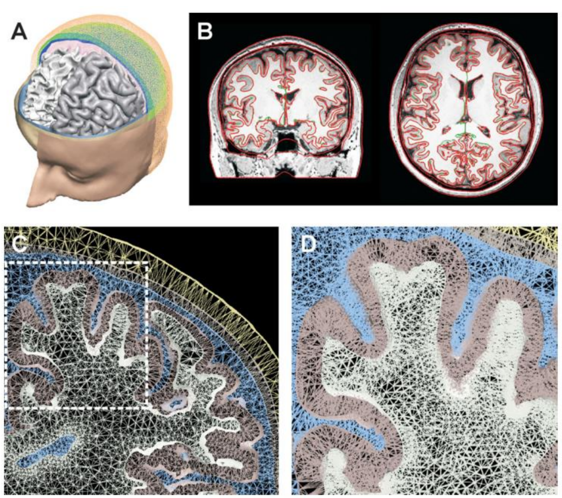
Cleaver
- ~Few minutes
- Large number of elements
- Not much control on element size
- Memory requirements are high

(Bronson et al. , 2012)



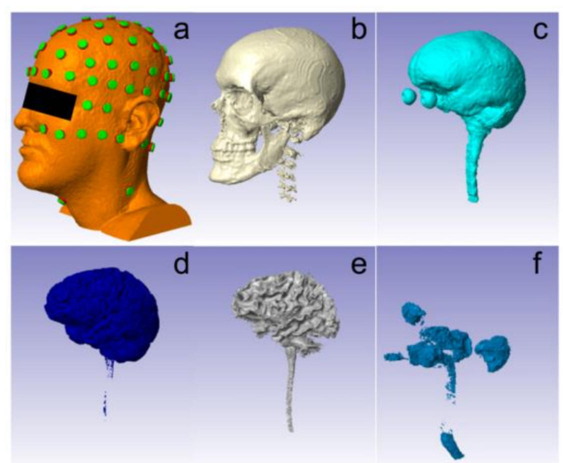
CGAL
- ~5 min
- Robust
- Accuracy of boundaries

(Fabri & Pion, 2009)



Mri2Mesh
- Accurate boundaries
- ~2-3 hours
- Input flexibility

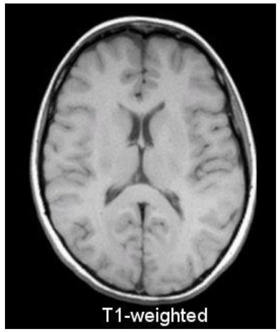
(Windhof et al., 2013)



ScanIP
- Large number of elements
- ~2-3 hours
- Not open-source

(Huang et al., 2013)

MESH GENERATION FROM A SEGMENTED VOLUME (1/2)



White matter (WM)

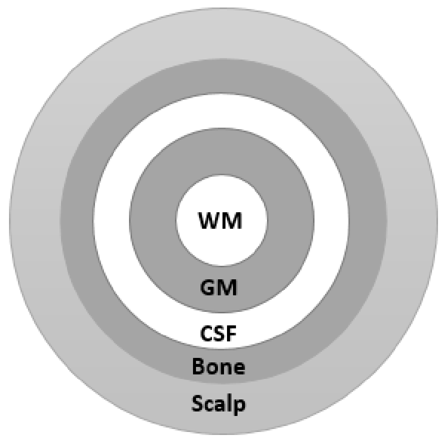
Grey matter (GM)

Cerebrospinal fluid (CSF)

Bone

Scalp

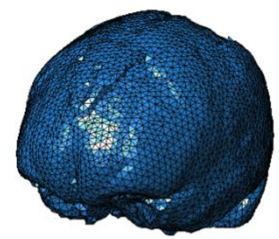
1. Segment MRI scans
(SPM, FSL, BrainSuite etc.)



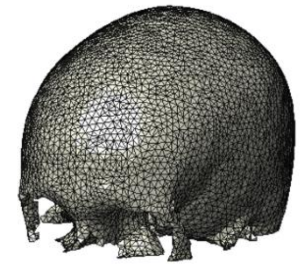
2. Pre-process segmented volumes to ensure brain layers don't intersect
(Iso2Mesh)

WM

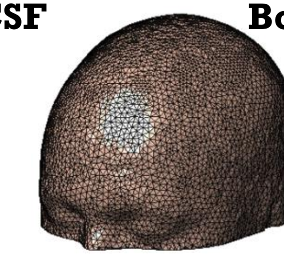
GM



CSF



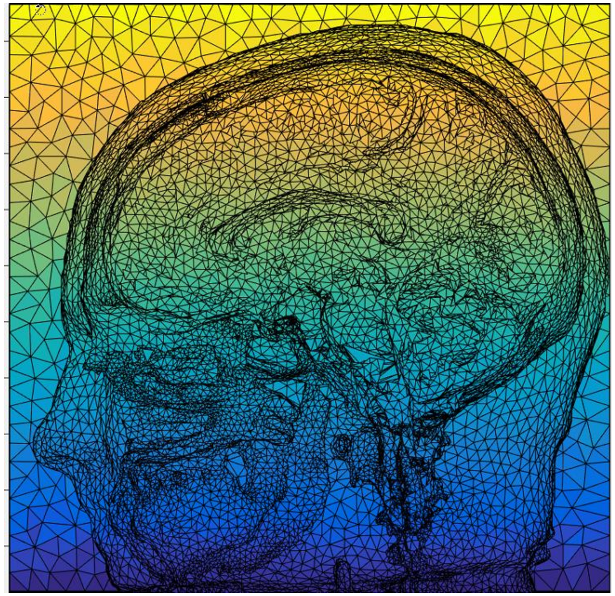
Bone



Scalp

3. Grayscale surface mesh extraction using ε-sampling
(CGAL)

MESH GENERATION FROM A SEGMENTED VOLUME (2/2)



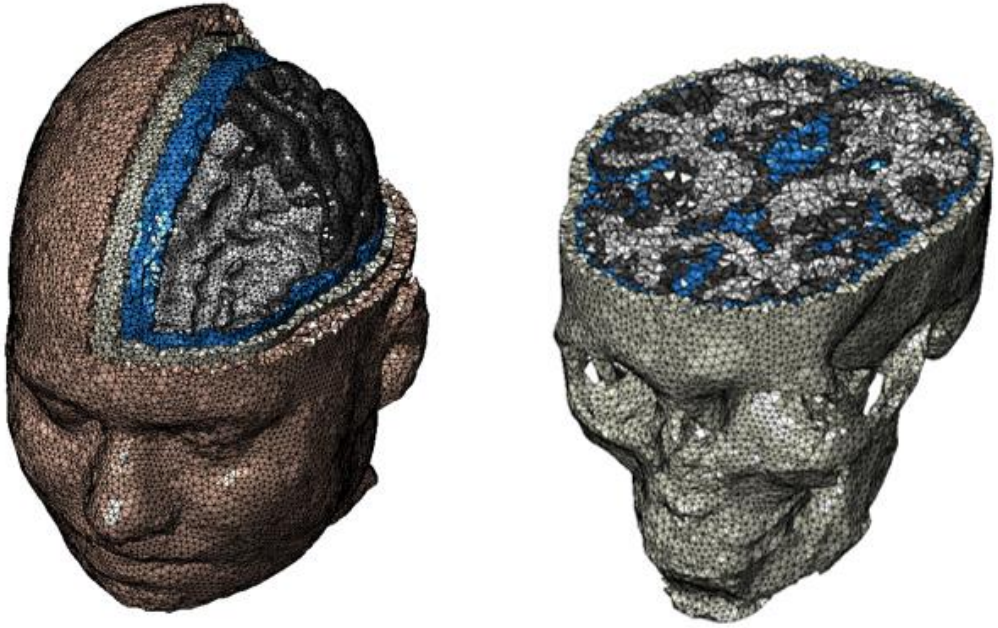
4. Generate a merged surface mesh
(Cork)

5. Generate tetrahedral mesh using defined parameters

(TetGen)

6. Label different tissue regions

(Iso2Mesh)

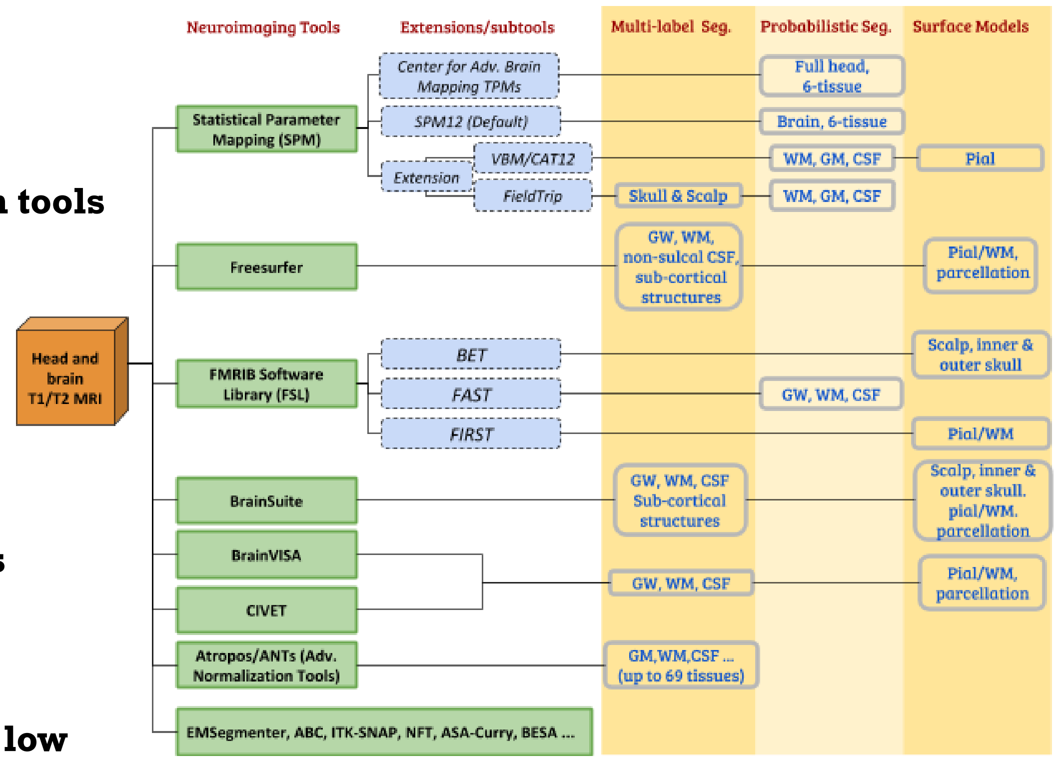


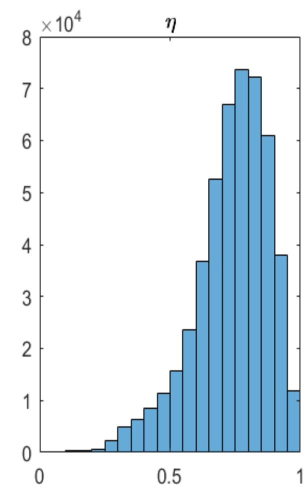
RESULTS

- **Can use a wide range of segmentation tools**
- **High-quality elements**
- **Open-source**
- **Processing times of ~1 min**
- **Fine-grained control on element sizes**
- **Smooth and accurate boundaries**
- **Generate accurate brain models with low number of elements**

(400k – 1M elements vs. 6-7 M in other meshing tools)

- **Generalizable to other animal brains**

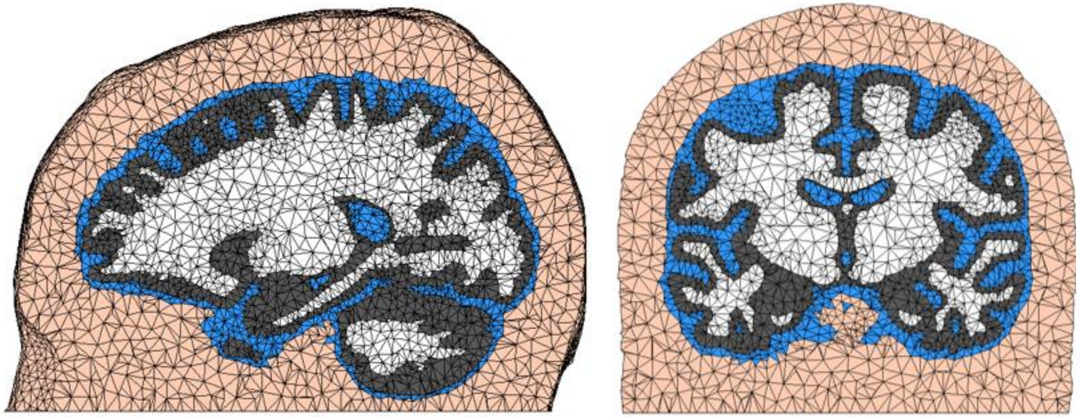




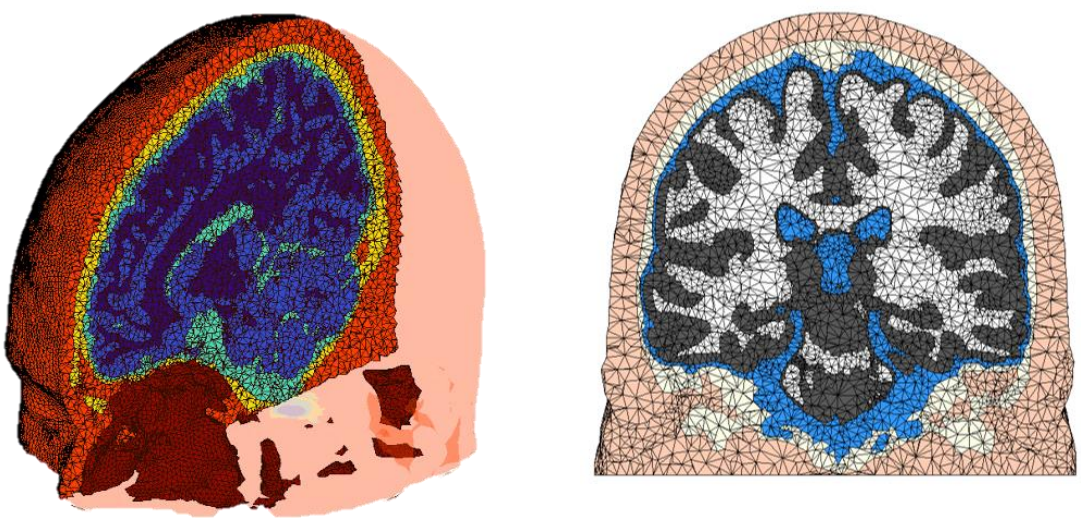
Joe-Liu quality metric

*P. Tran & Q. Fang, Neuroimage. (submission pending)

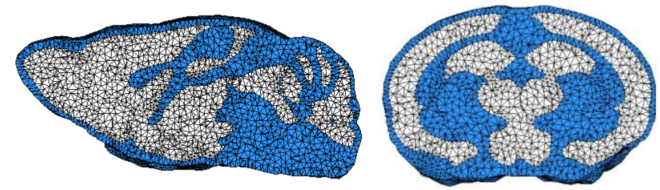
SOME BRAIN MESHING RESULTS



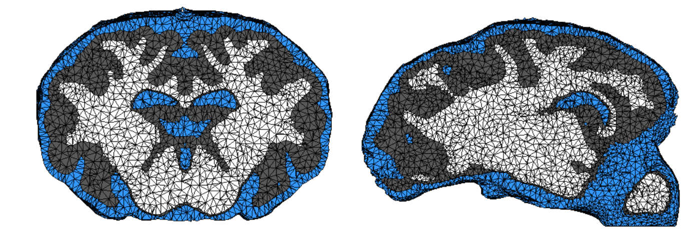
Mesh resulting from a FSL segmentation



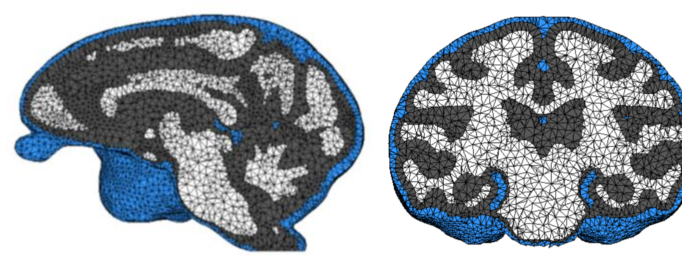
Tetrahedral mesh of the Colin27 atlas



Mouse brain

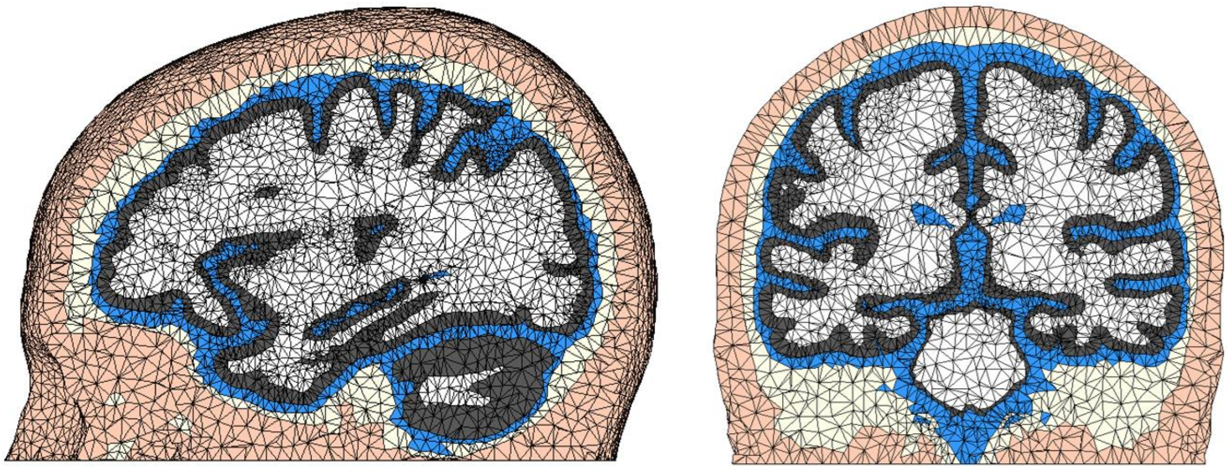


Ovine brain

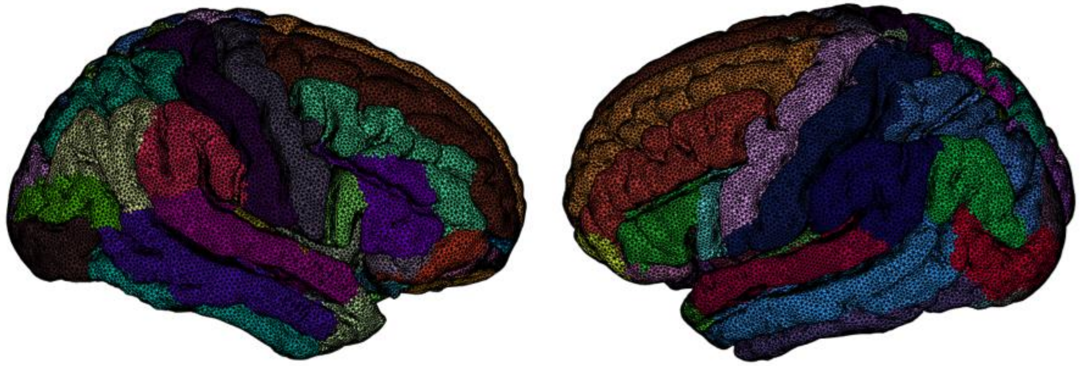


Baboon brain

WORKFLOW USING CORTICAL SURFACES



Tetrahedral mesh generated from FreeSurfer surfaces and SPM segmentation outputs for a 30-34 years-old average brain.



Parcellated tetrahedral mesh of (a) the right hemisphere and (b) the left hemisphere of the 30-34 years old atlas from the Neurodevelopmental MRI database. The cortical surfaces and parcellation data were derived using BrainSuite.

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Xu Sun
Morris Vanegas
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Yu Shi
Edward Xu

Northeastern University, Department of Chemical Engineering and Bioengineering

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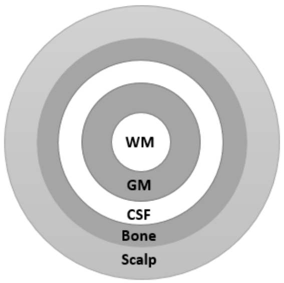
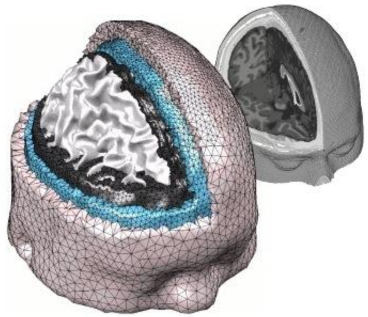
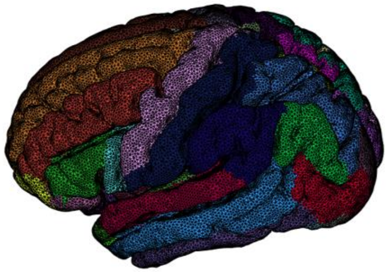
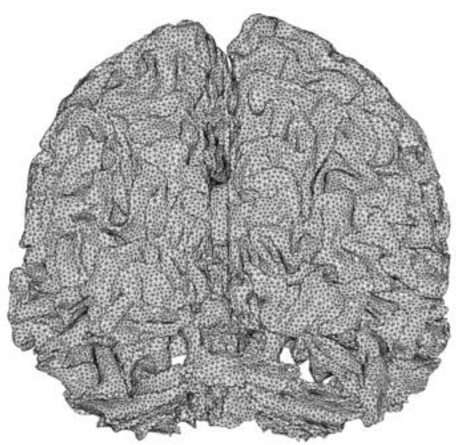
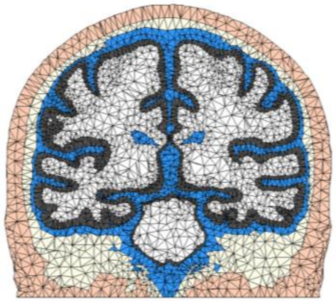
QUESTIONS

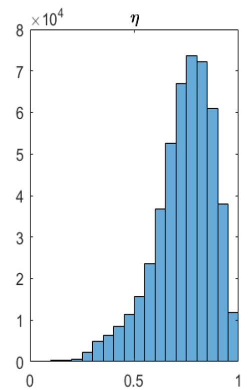


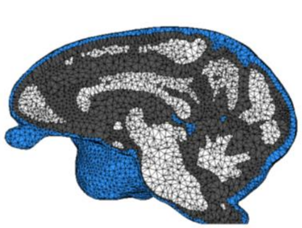


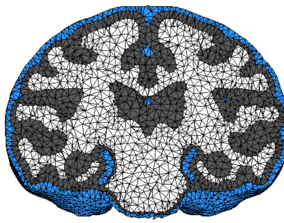




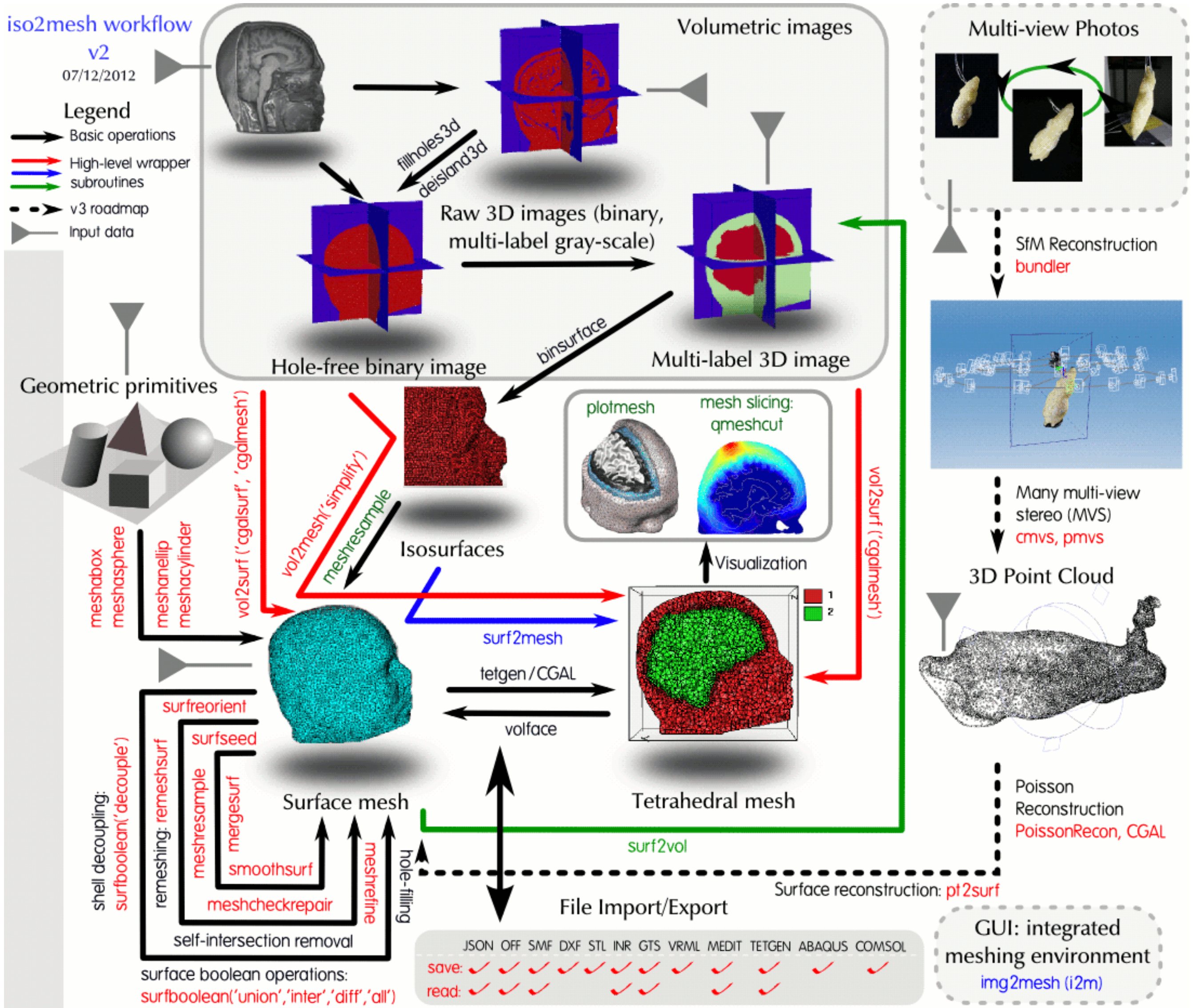




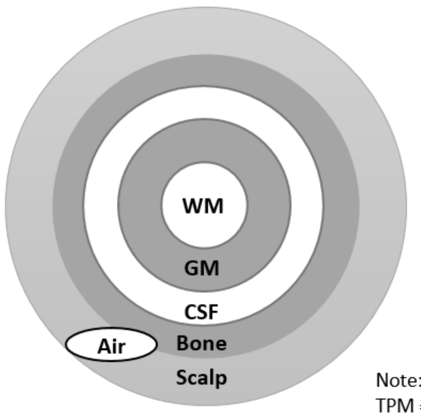


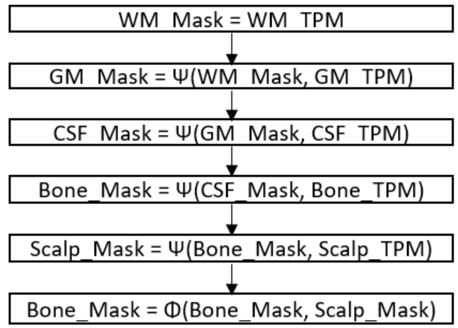


ISO2MESH


iso2mesh workflow
v2
07/12/2012
Legend
Basic operations
High-level wrapper subroutines
v3 roadmap
Input data
Volumetric images
Multi-view Photos
fillholes3d
deisland3d
Raw 3D images (binary, multi-label gray-scale)
Hole-free binary image
binsurface
Multi-label 3D image
SfM Reconstruction
bundler
Geometric primitives
plotmesh
mesh slicing: qmeshcut
Isosurfaces
Visualization
vol2surf ('cgalsurf', 'cgalmesh')
vol2mesh('simplify')
meshresample
vol2surf ('cgalmesh')
Many multi-view stereo (MVS)
cmvs, pmvs
3D Point Cloud
meshabox
meshasphere
meshanellip
meshacylinder
surf2mesh
tetgen/CGAL
volface
surfreorient
surfseed
Surface mesh
Tetrahedral mesh
Poisson Reconstruction
PoissonRecon, CGAL
surf2vol
shell decoupling: surfboolean('decouple')
remeshing: remeshsurf
meshresample
mergesurf
smoothsurf
meshcheckrepair
meshrefine
hole-filling
Surface reconstruction: pt2surf
File Import/Export
self-intersection removal
surface boolean operations:
surfboolean('union','inter','diff','all')
JSON OFF SMF DXF STL INR GTS VRML MEDIT TETGEN ABAQUS COMSOL
save:
read:
GUI: integrated meshing environment
img2mesh (i2m)

DETAILED WORKFLOW



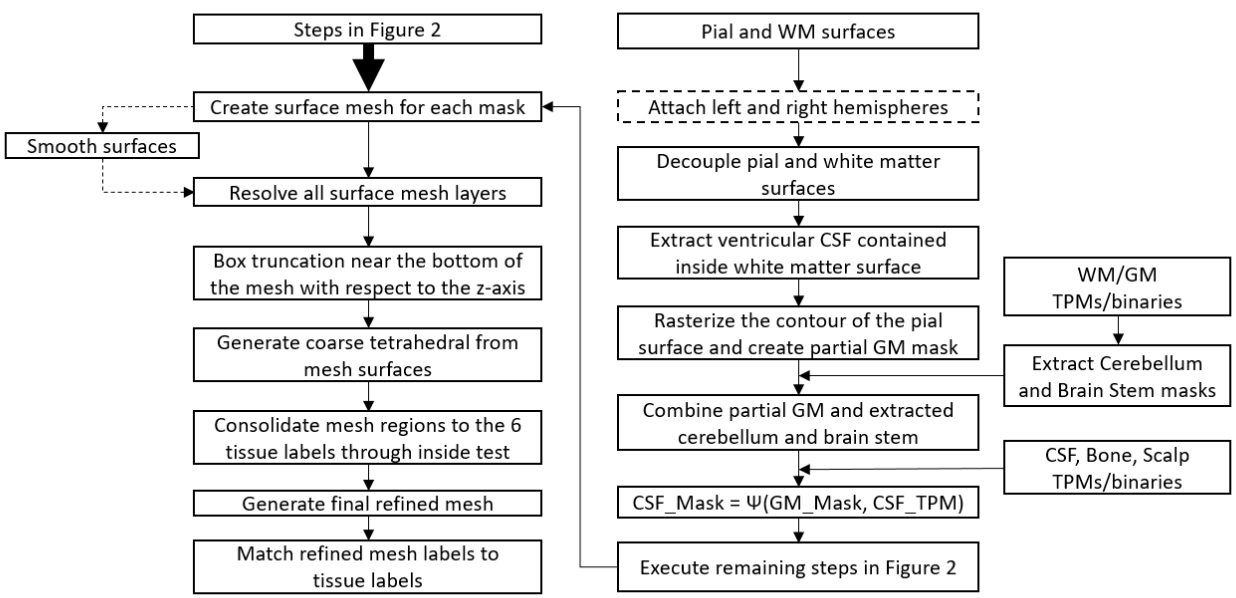


$$\Psi(A,B) = \max\{A+B, \text{max\_filter}(A)\}$$

$$\Phi(A,B) = \min\{A, \text{min\_filter}(B)\}$$

Note: Air pockets are created automatically through the scalp mask.
TPM = Tissue probability maps. Same procedure for binary values.

(a) Tissue probability maps or labeled volumes *(b) Pial and white matter surfaces available*



MESH DATABASE