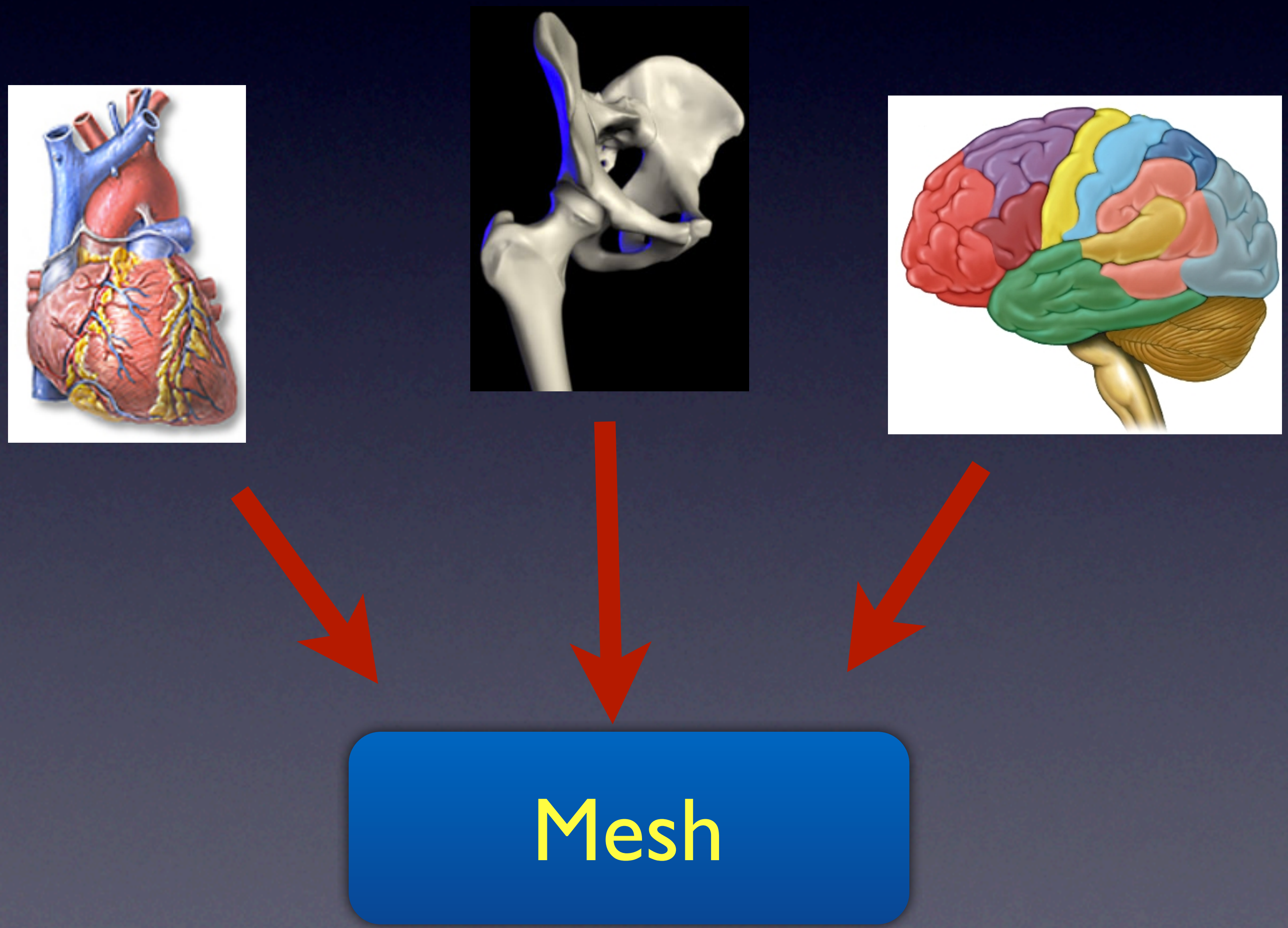
Case Study IV: Geometrical Modeling of the heart and the head

Moritz Dannhauer

Motivation

- Geometrical modeling for simulation



Content

- Meshing
- BioMesh3D
- new Meshing Approach: Cleaver

Pipeline

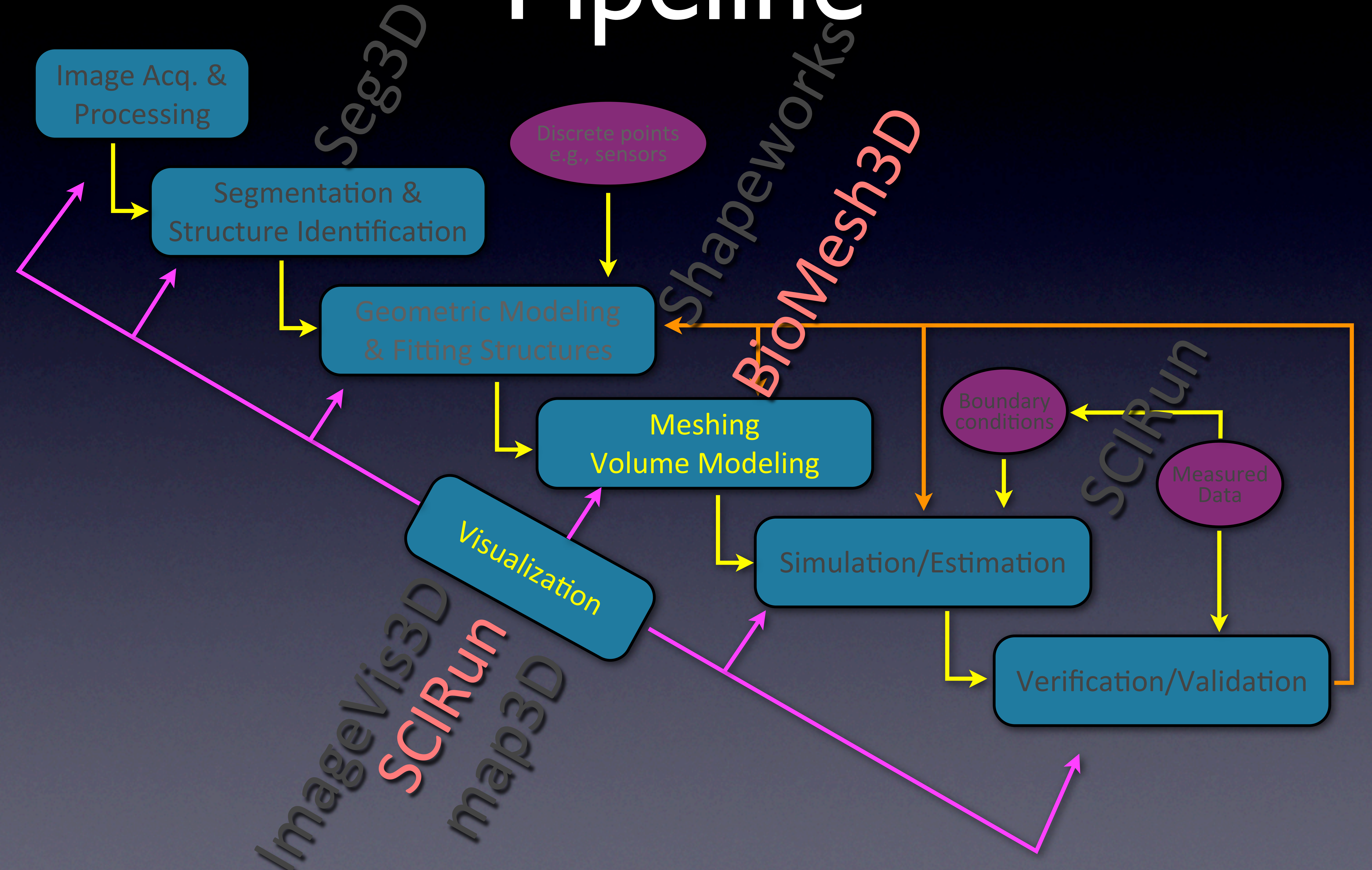
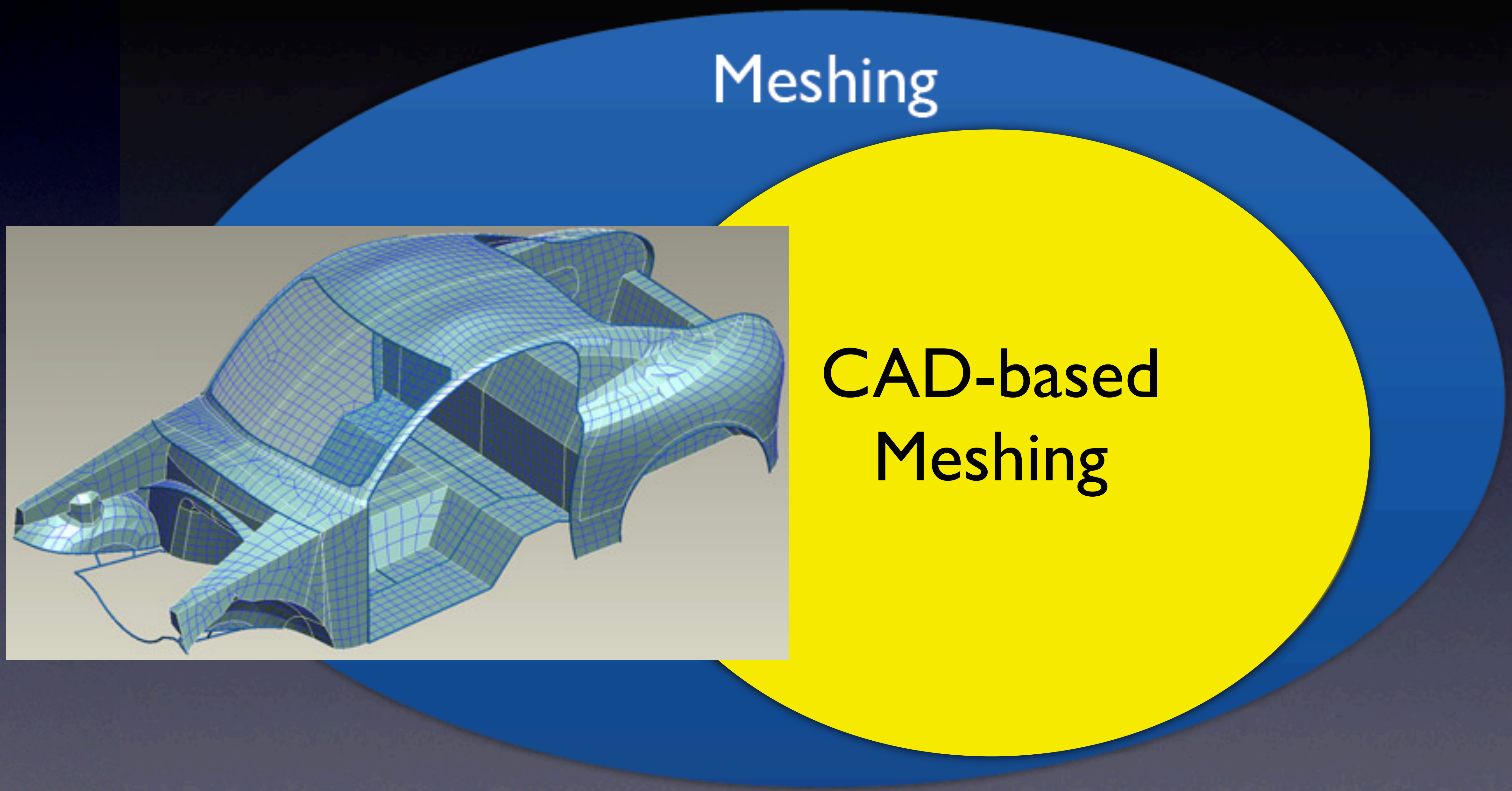
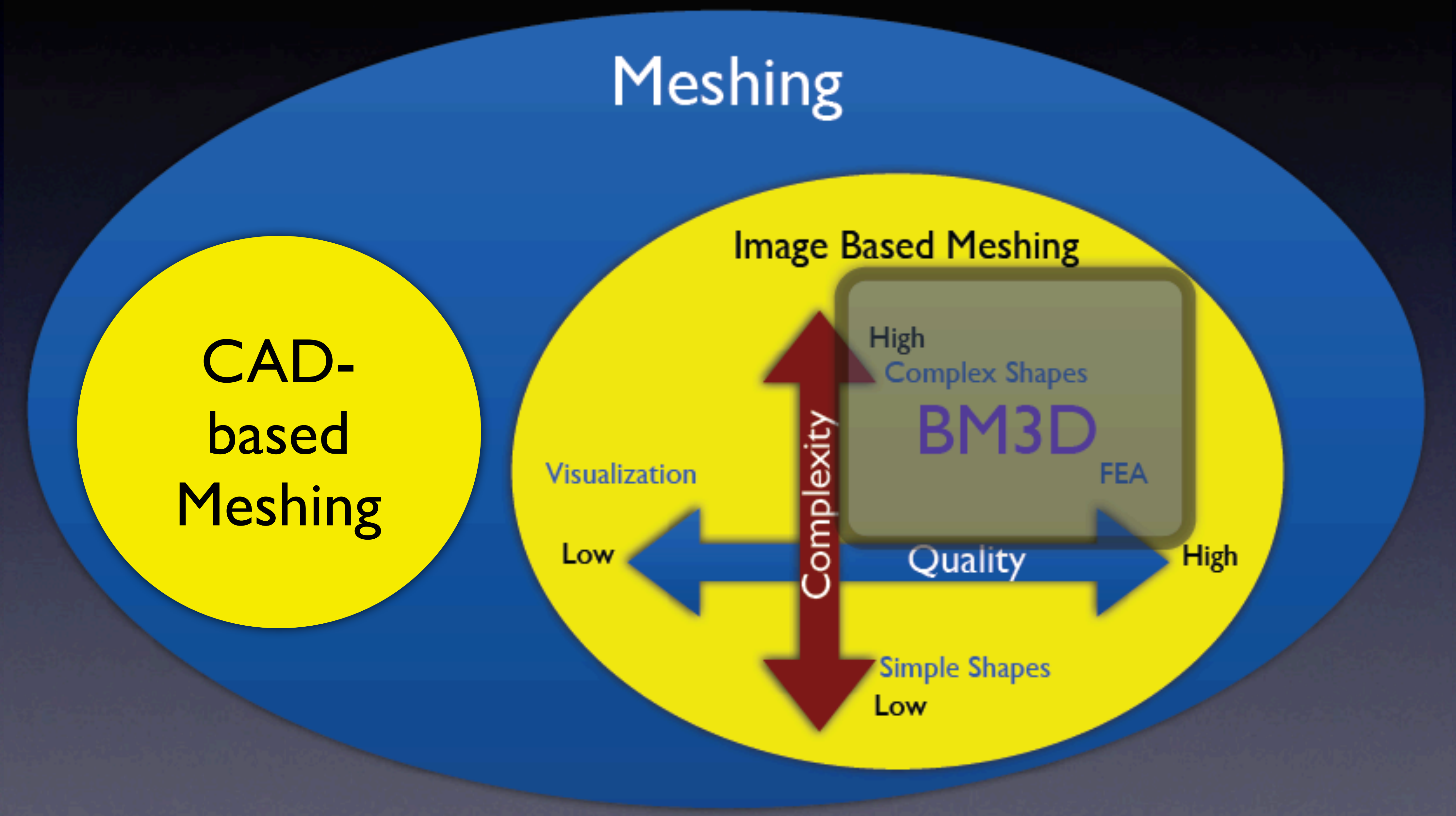


Image Acq. & Processing
Seg3D
Segmentation & Structure Identification
Discrete points e.g., sensors
Geometric Modeling & Fitting Structures
Shapeworks
BioMesh3D
Meshing Volume Modeling
Boundary conditions
SCIRun
Measured Data
Simulation/Estimation
Verification/Validation
Visualization
ImageVis3D
SCIRun
map3D

Meshing



Meshing



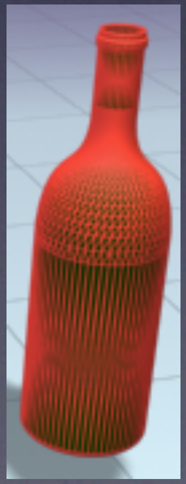
Meshing
CAD-based Meshing
Image Based Meshing
High
Complex Shapes
BM3D
Visualization
FEA
Complexity
Low
Quality
High
Simple Shapes
Low

Three Scenarios

- Low detail models

- Medium detail models

- High detail models



Challenges of Meshing

irregular features

multi-material

adaptive mesh

run time

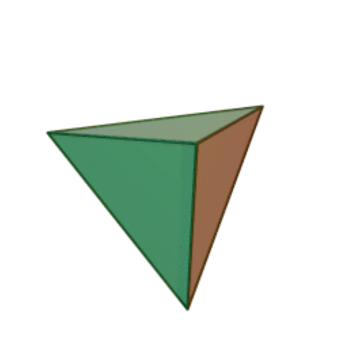
small meshes

etc.

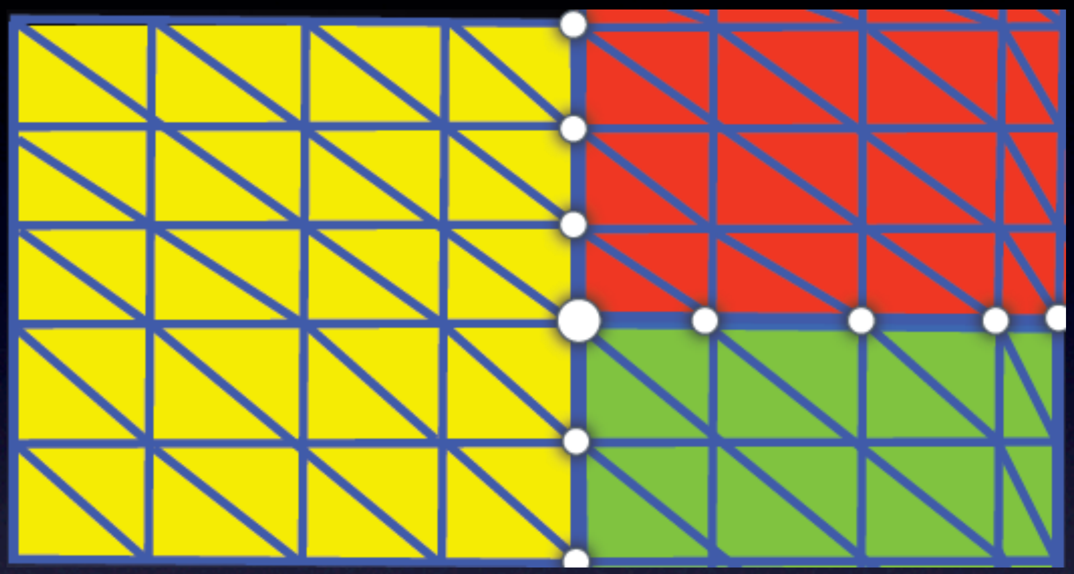
What is BioMesh3D?

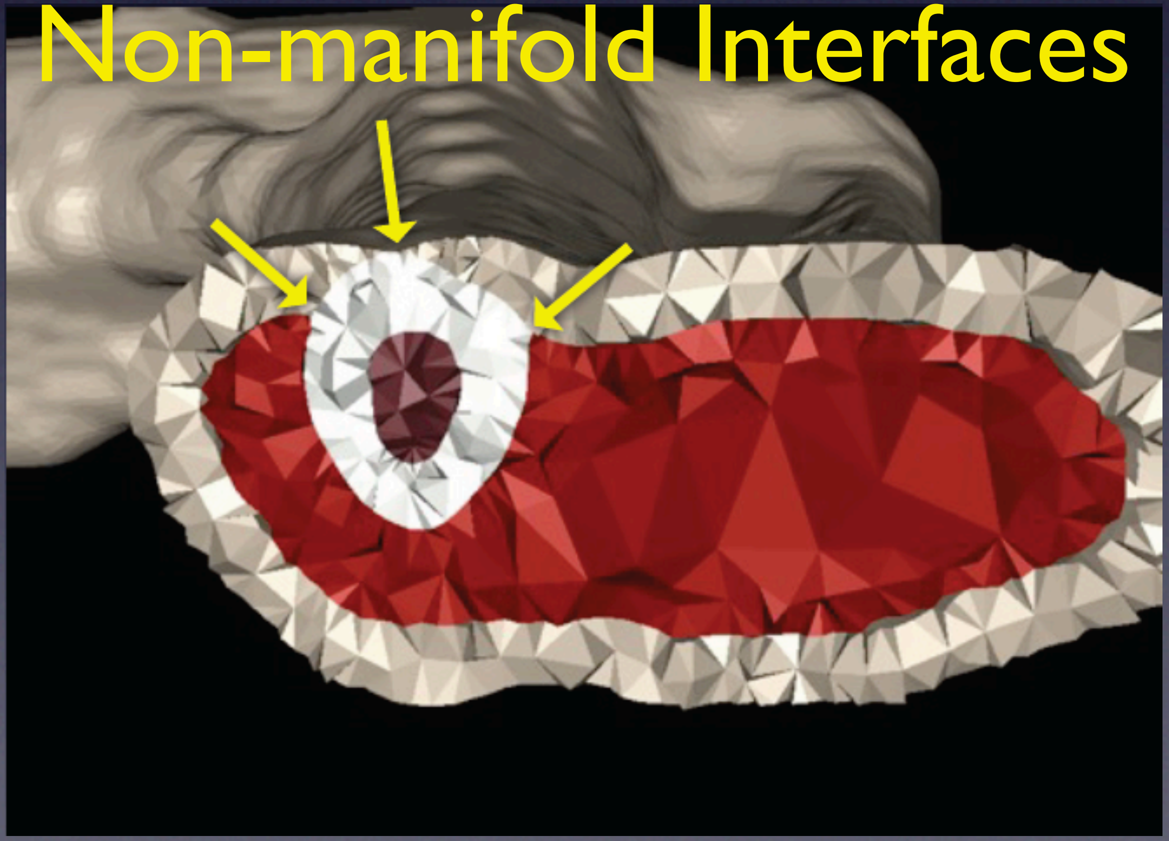
- Tetrahedral conforming volume meshing
- Adaptive, multi material, subvoxel accuracy
- Goal: Determine accurate boundary surfaces
- Tetrahedralization (external): TetGen

M. Meyer et. al, IEEE, 2008



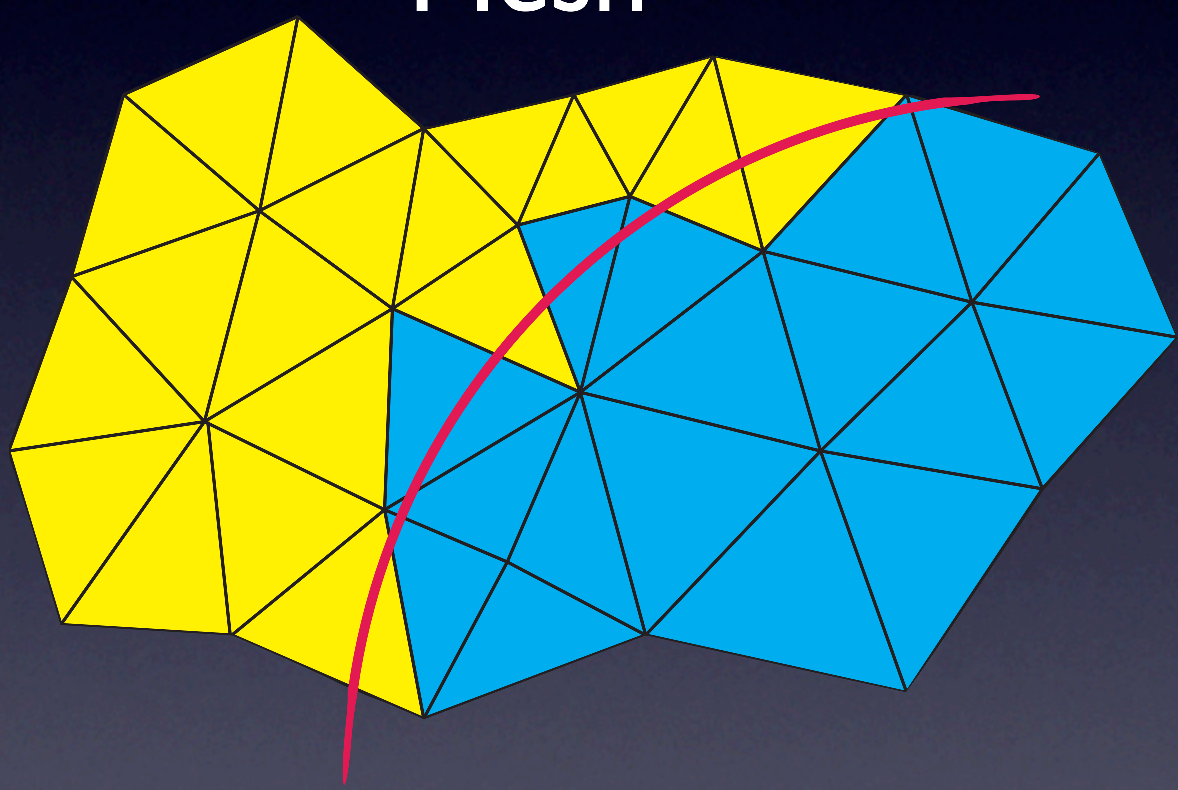
Meshing in Biology



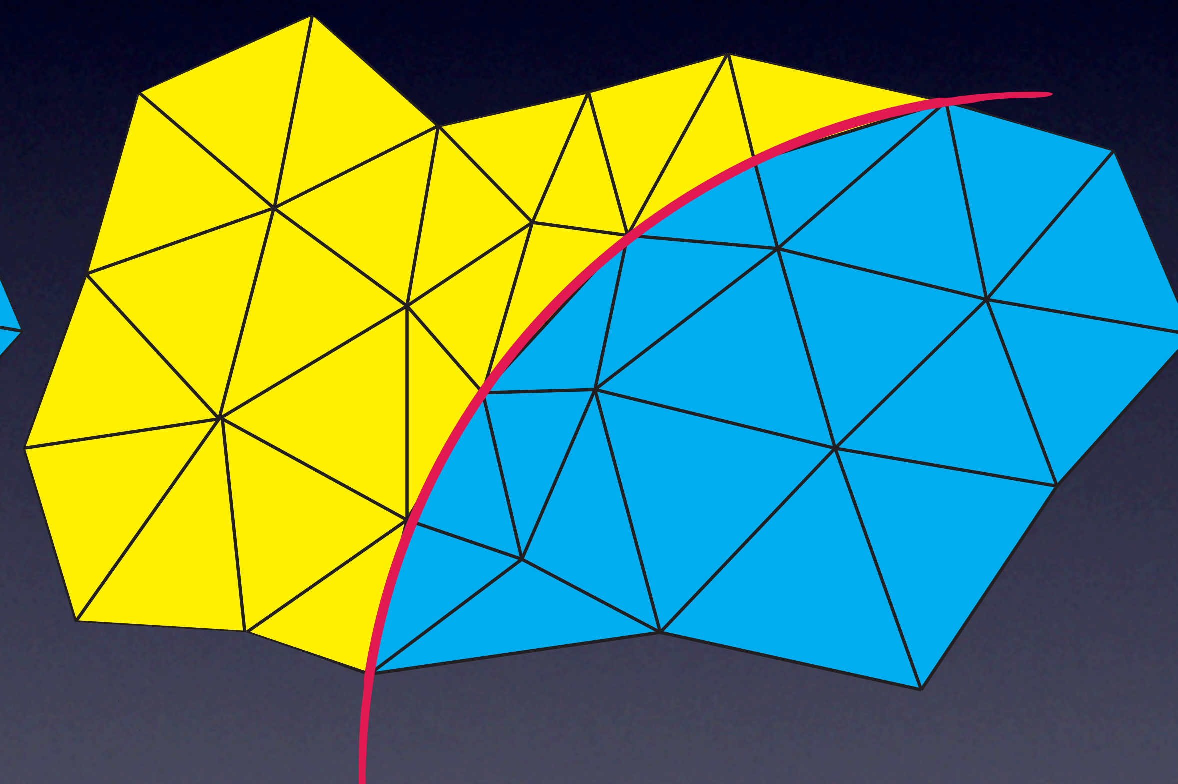


Conformal Meshing

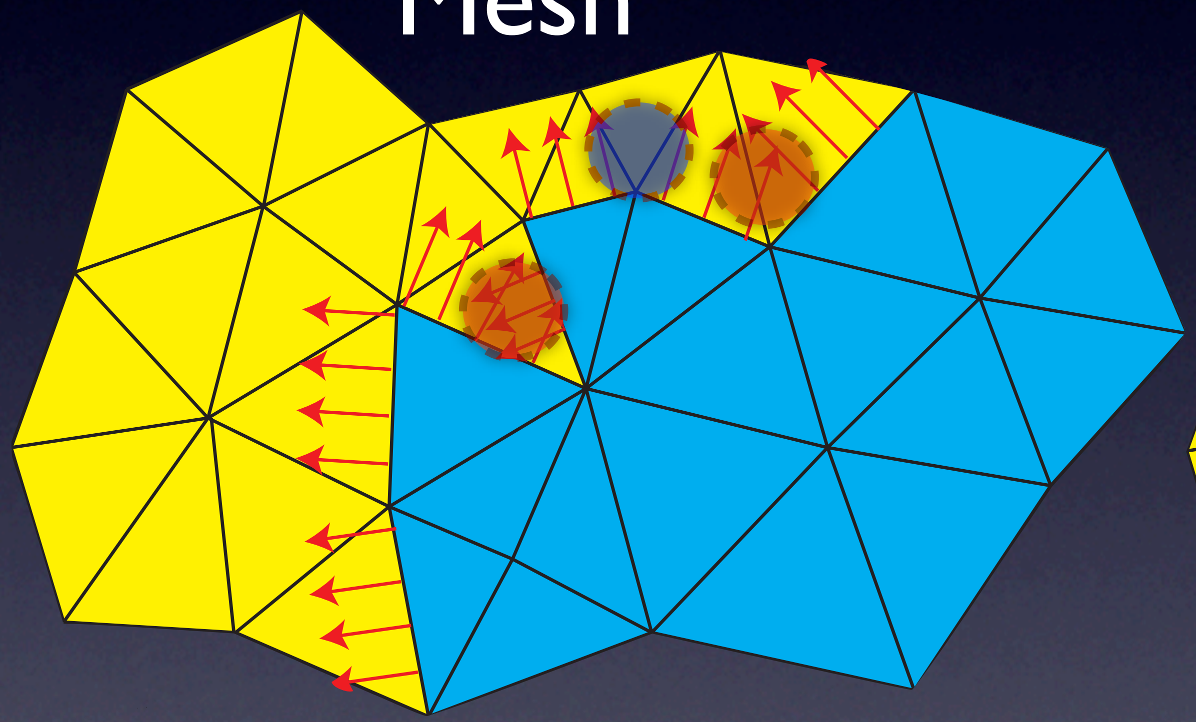
Non-Conformal Mesh



Conformal Mesh

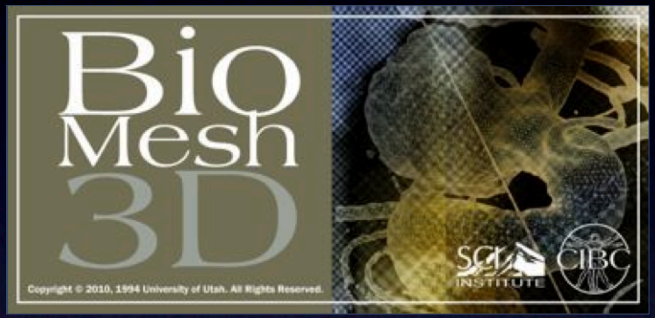


Conformal Meshes better?

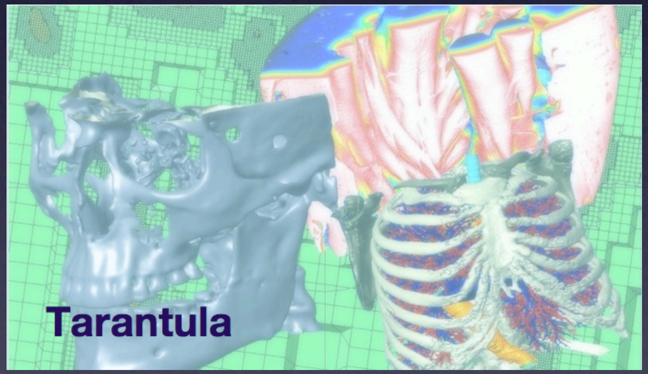


Still an open question!

Meshing packages



CGAL

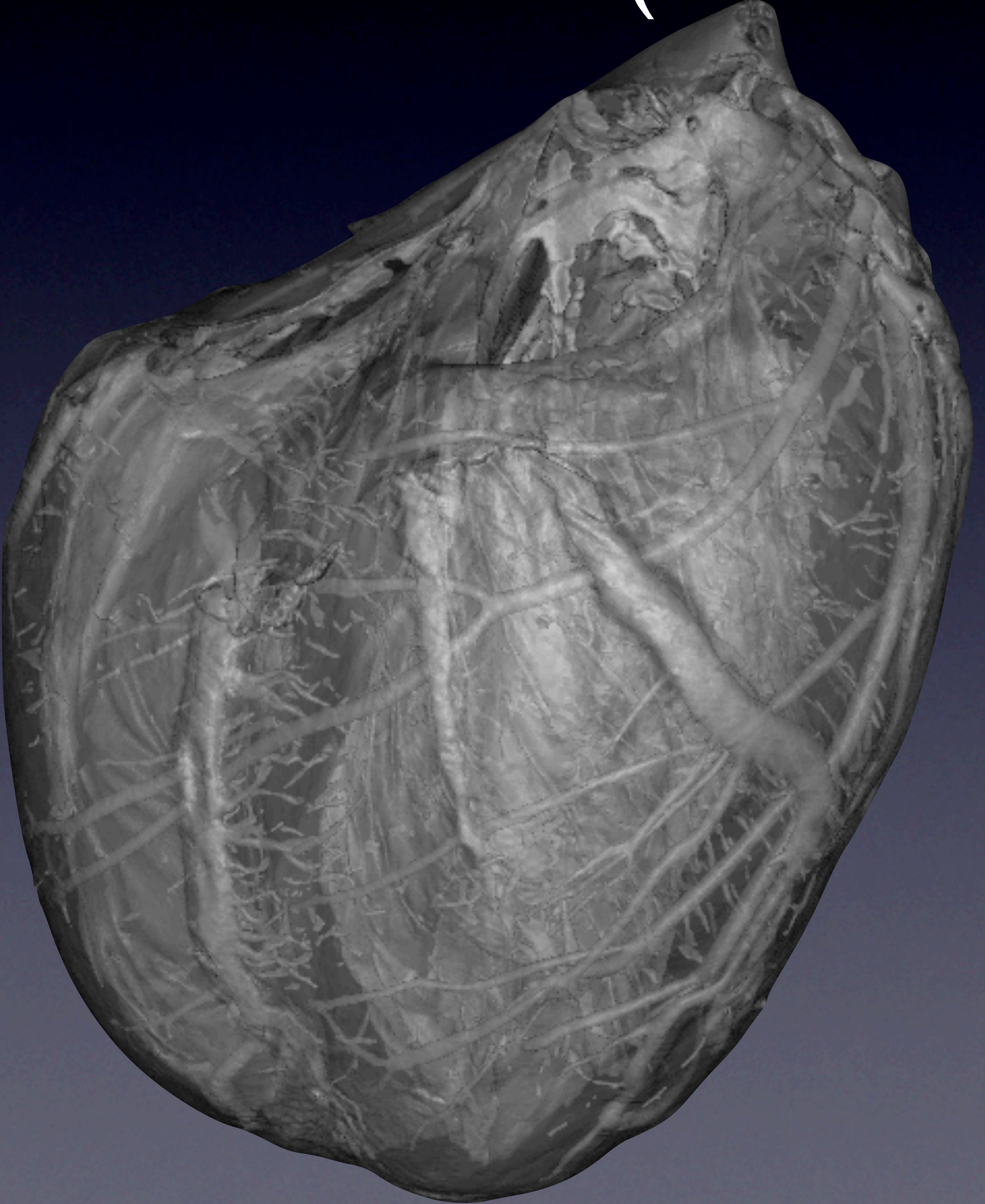


TetrUSS VGRID

and many more ...

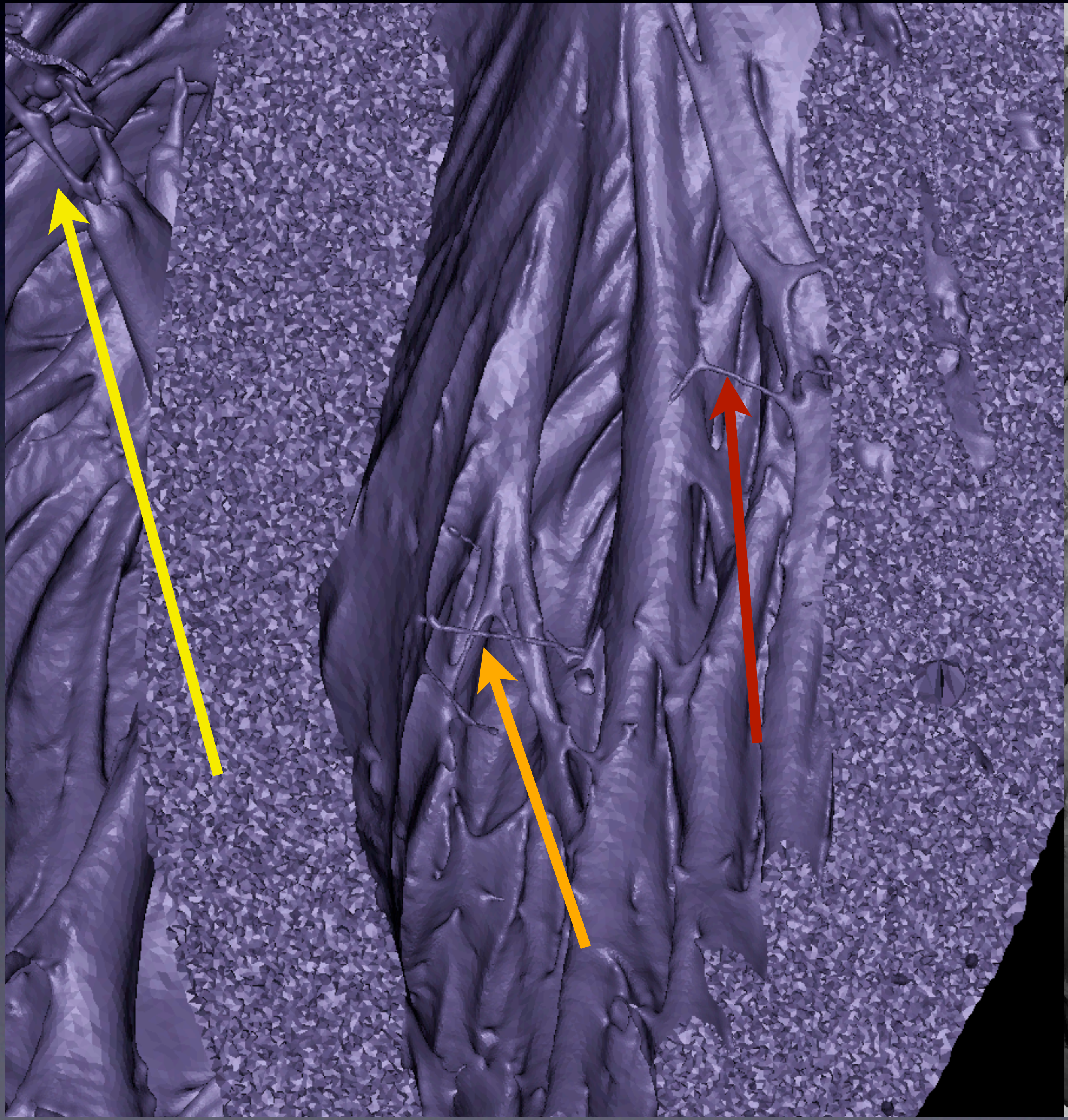
Example - Heart

- Oxford Rabbit Heart (BioMesh3D)

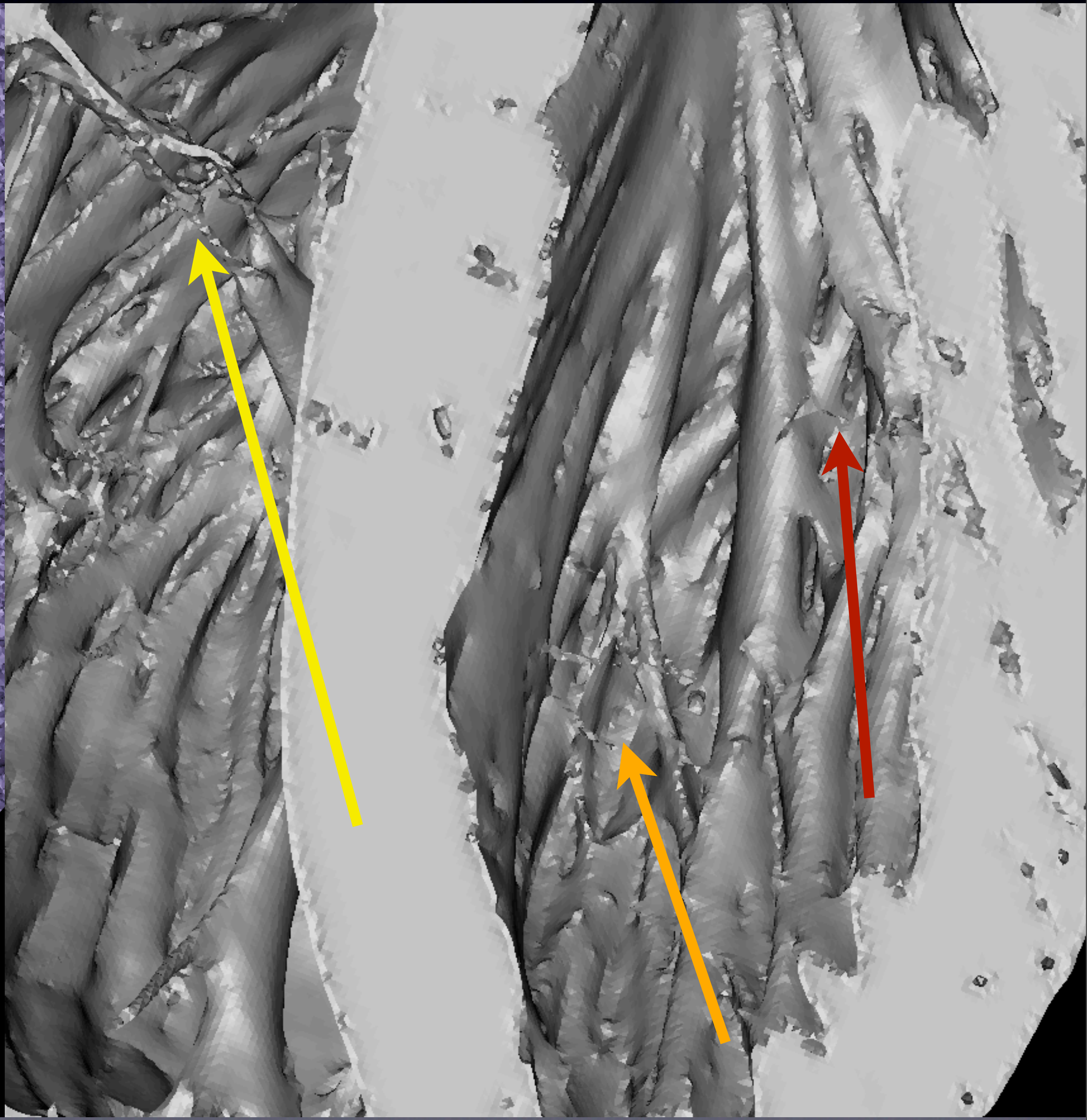


Cross Section of Heart

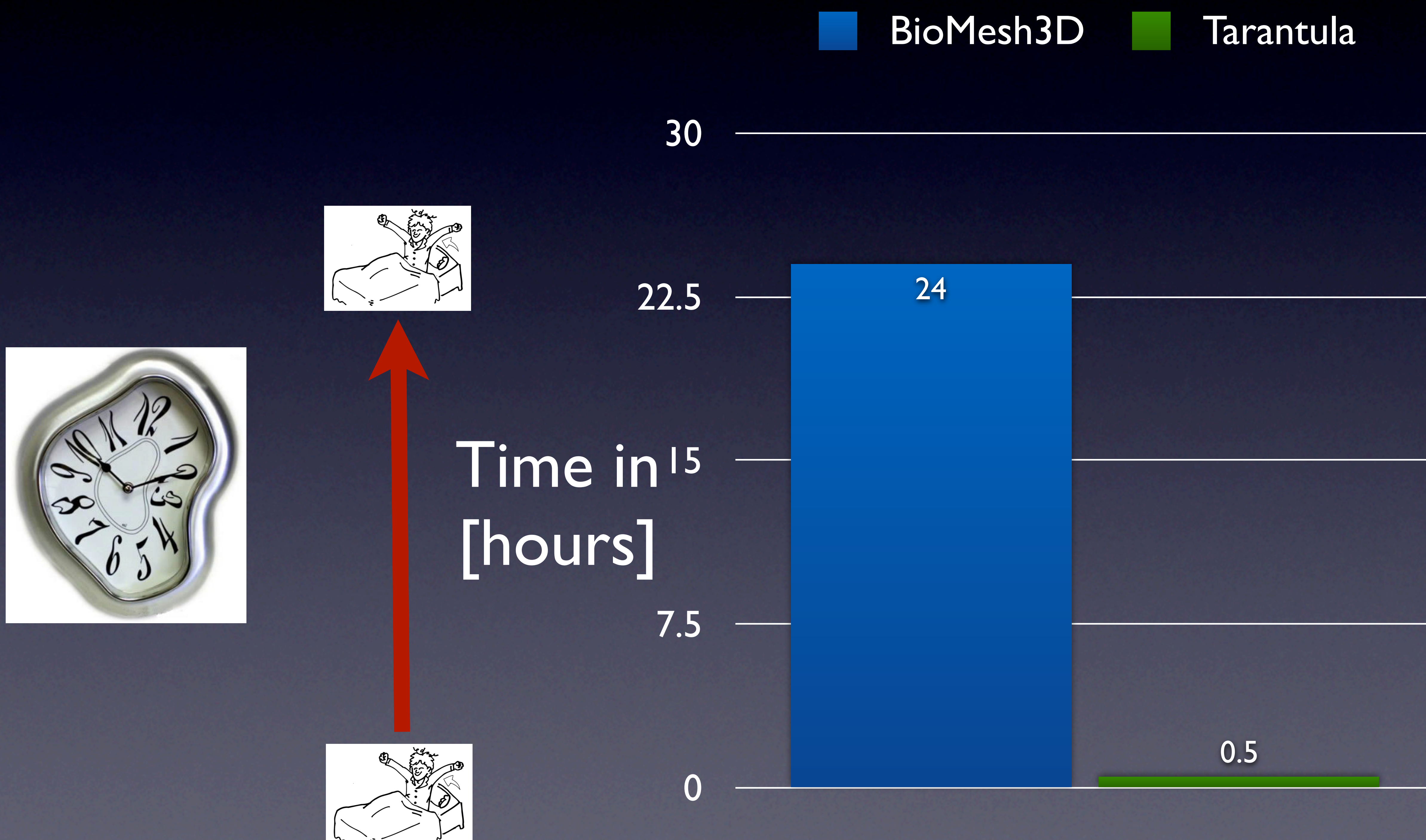
BioMesh3D



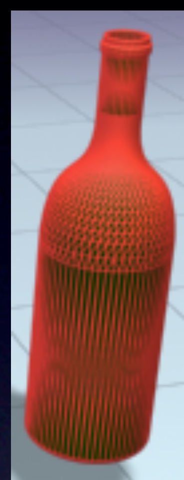
Tarantula



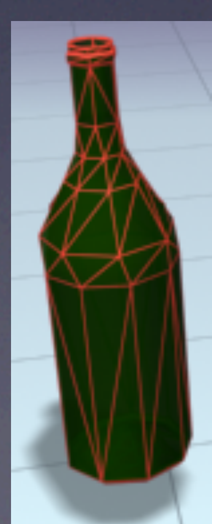
Comparison - Run Time

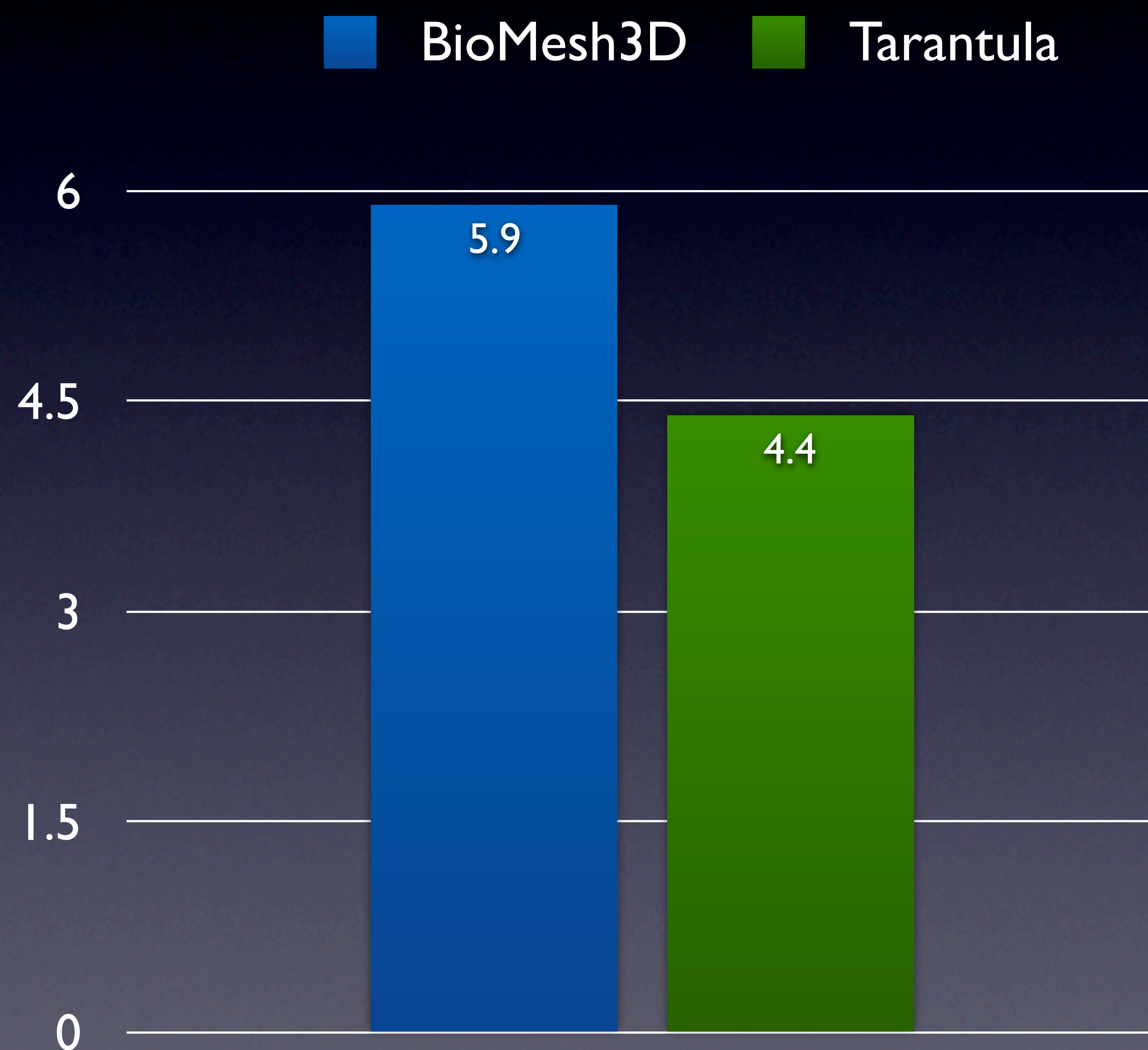


Comparison - Complexity



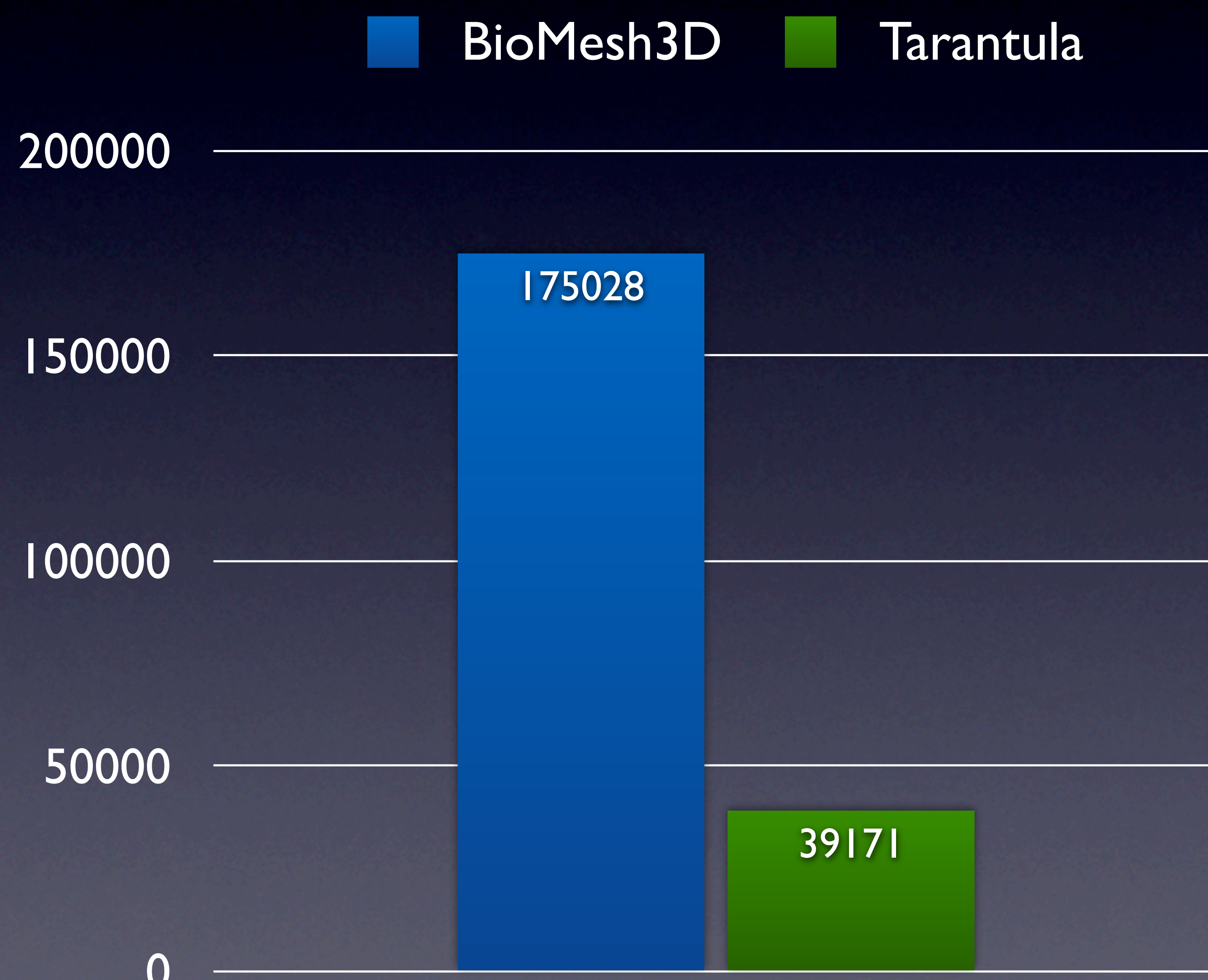
Mesh nodes in [xMillion]





Comparison - Adaptivity

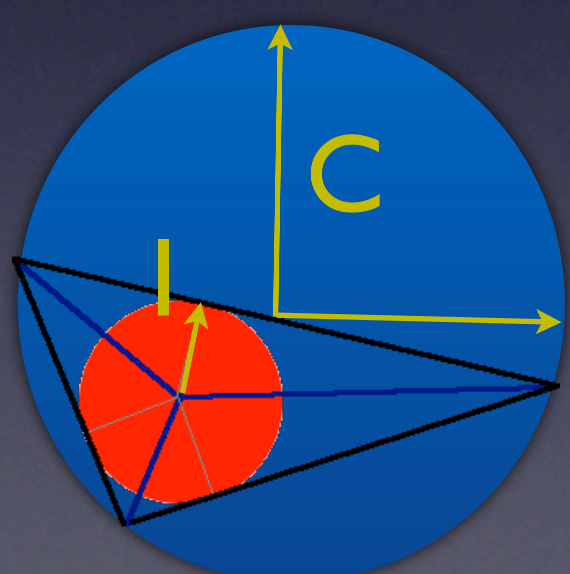
Size variability of FE - Stddev. of Volumes in [uM^3]

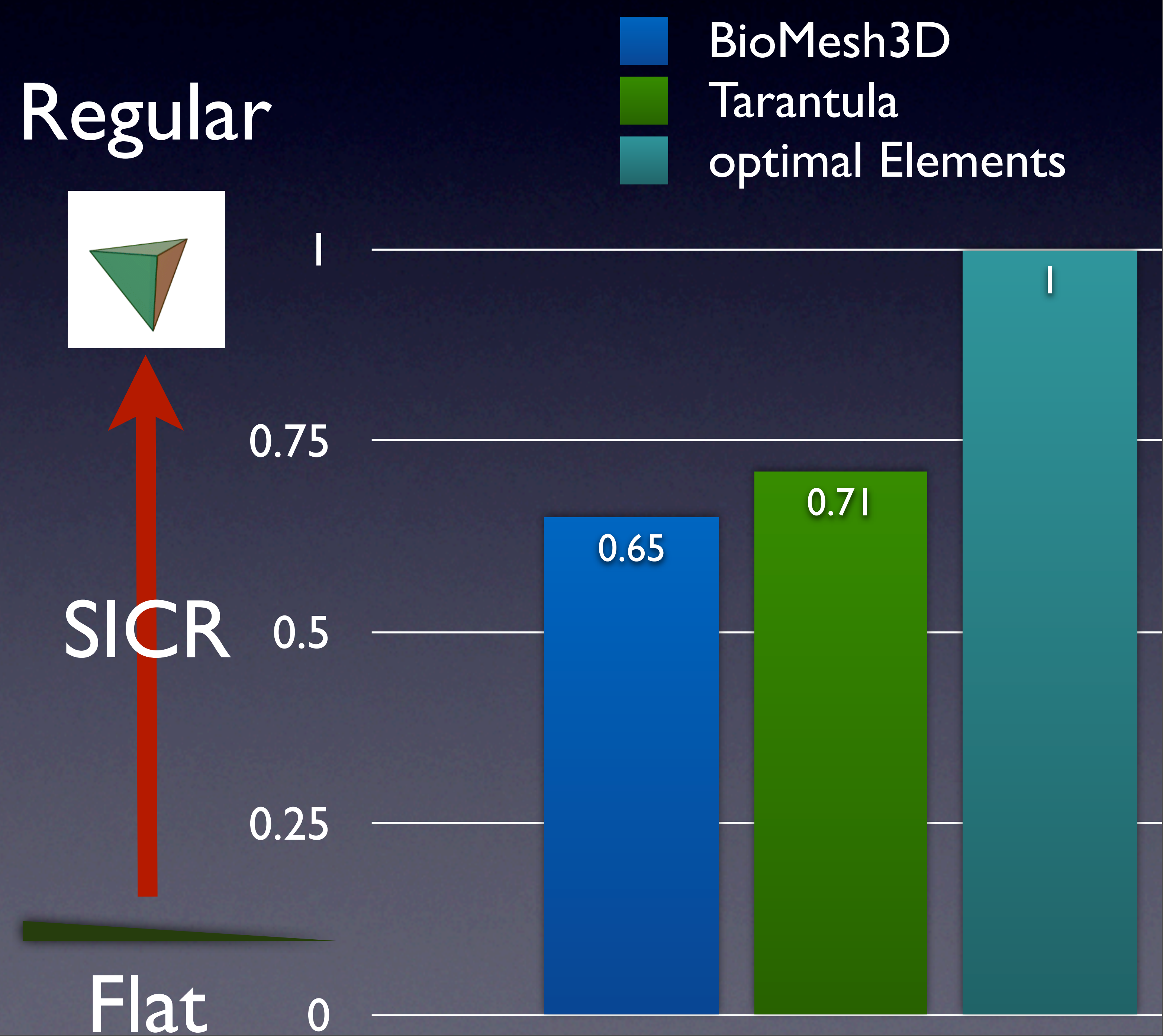


Comparison - Element Quality

scaled inscribed (I) to circumscribed ratio (C) (SICR)

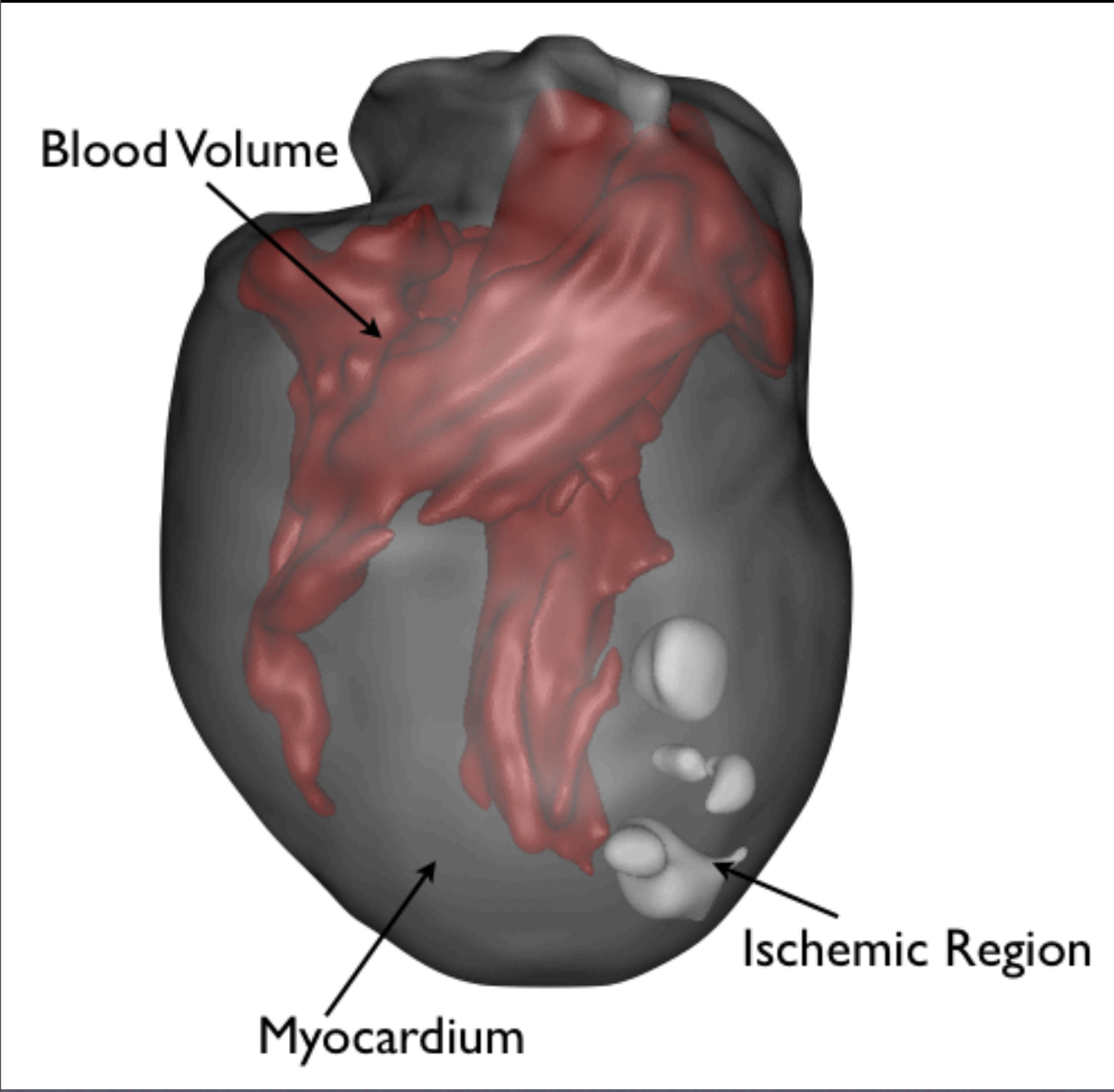
SICR= 3*I/C

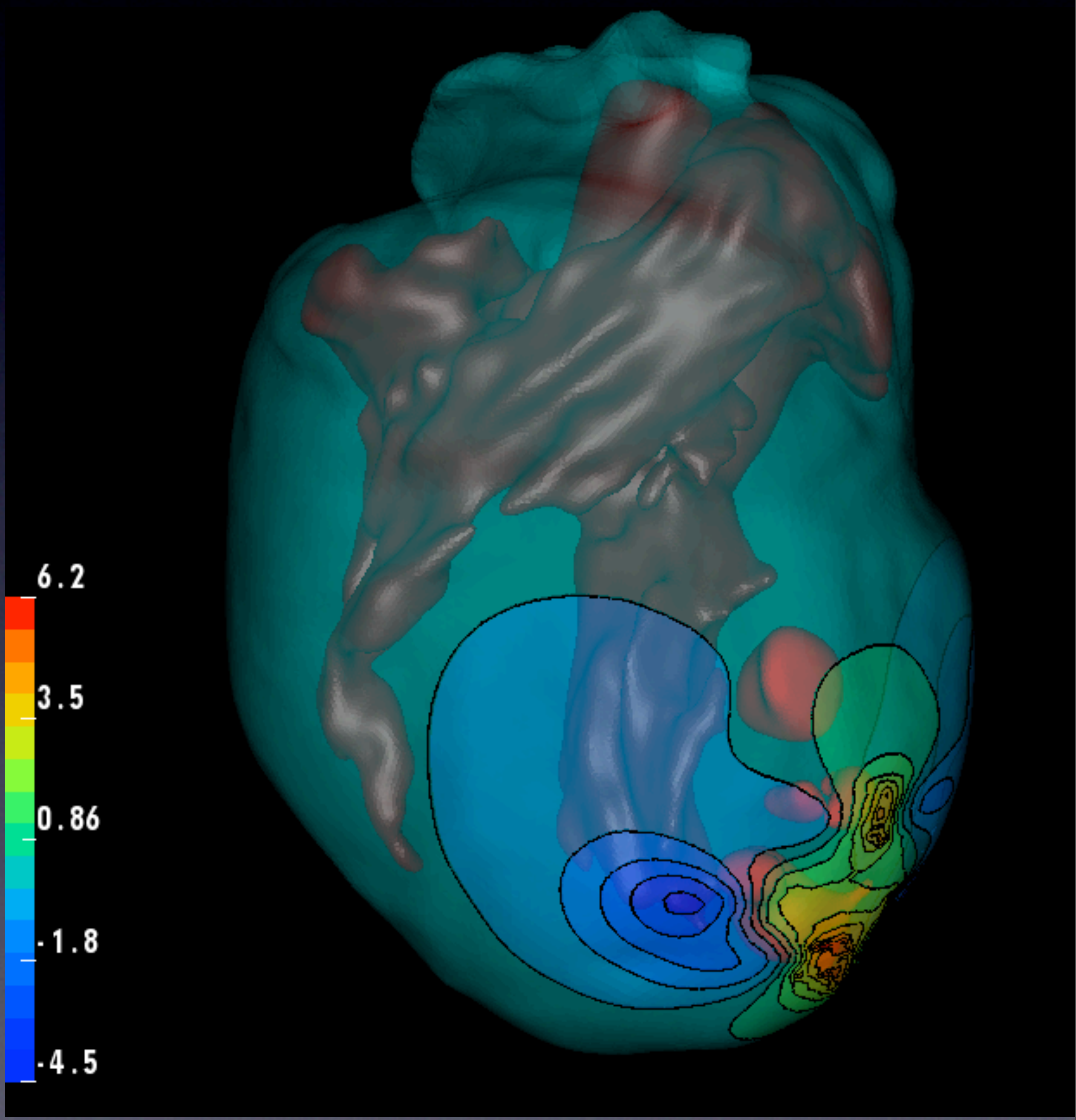




BioMesh3D-Pros/Cons

Single Time Point





- Pro: Local refinement
- Con: Reaction/Diffusion

BioMesh3D - Properties

Pros:

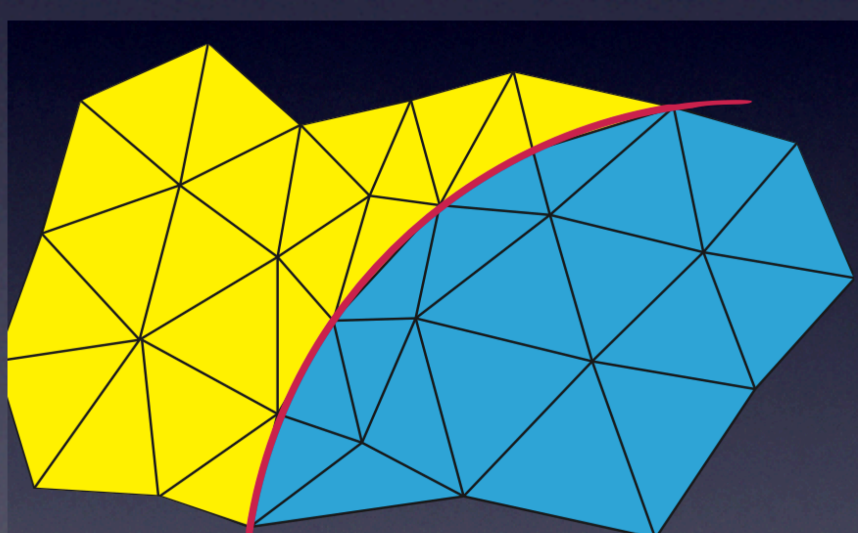
+ Conforming
+ Highly Adaptive
+ Preserve smooth/ small features

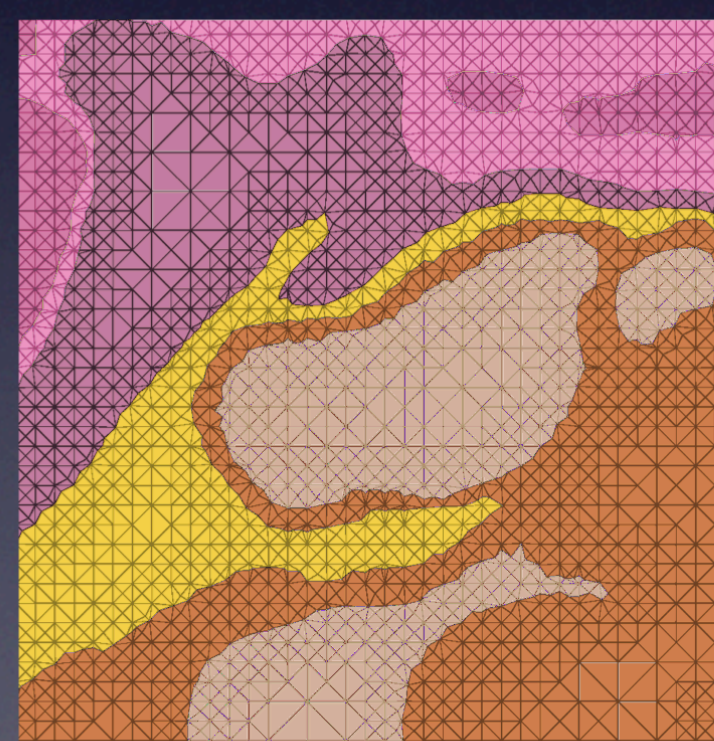
Cons:

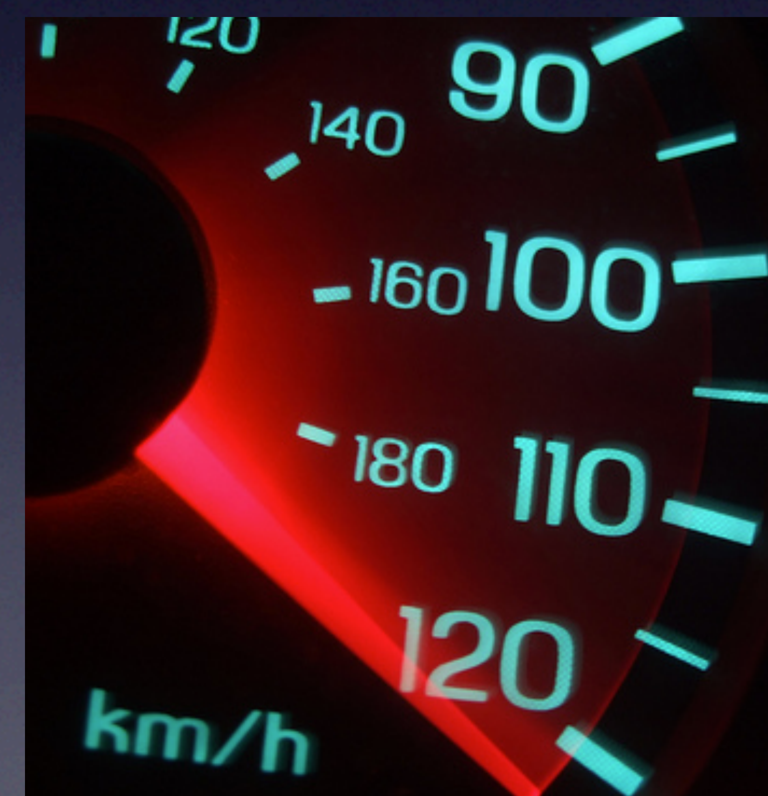
- Robustness
- Usability
- Run time
- Sufficient node density
- Element Quality

New meshing Approach: "Cleaver"

min(SICR)>=const



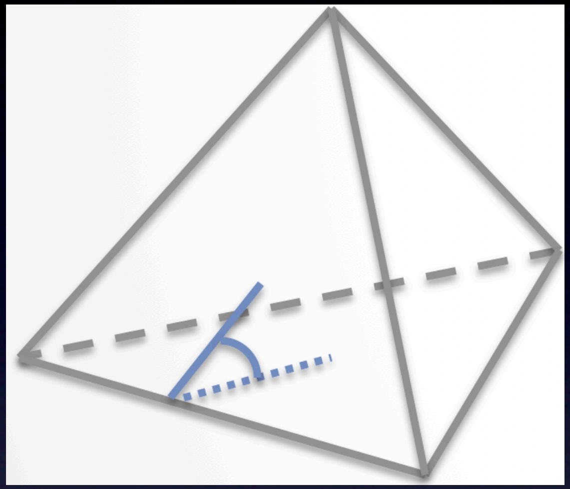


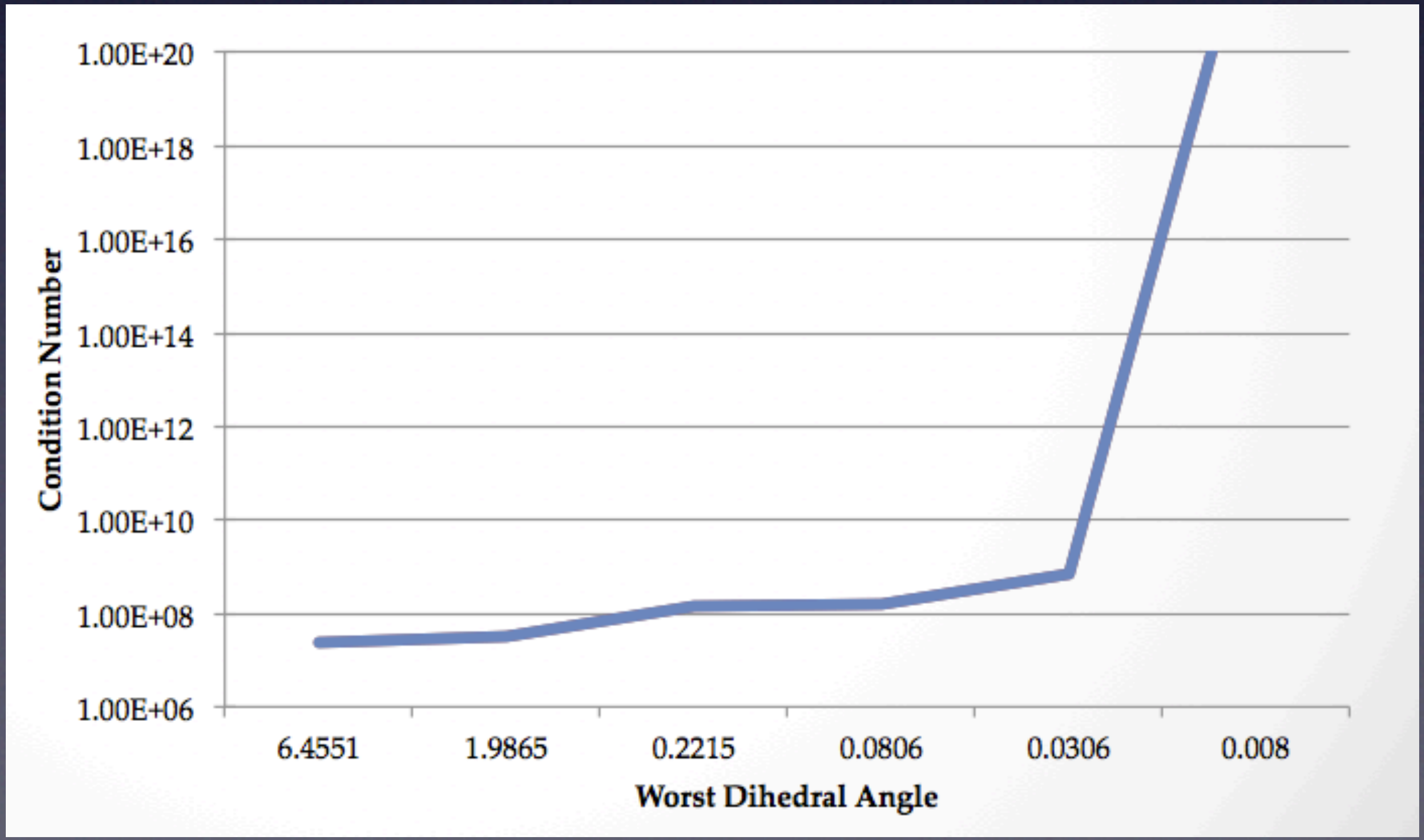


"Lattice Cleaving: Conforming Tetrahedral Meshes of Multimaterial Domains with Bounded Quality"
Bronson, J., Levine, J., and Whitaker, R.
To appear in Proceedings of the 21st International Meshing Roundtable (San Jose, CA, Oct 7 - 10, 2012)

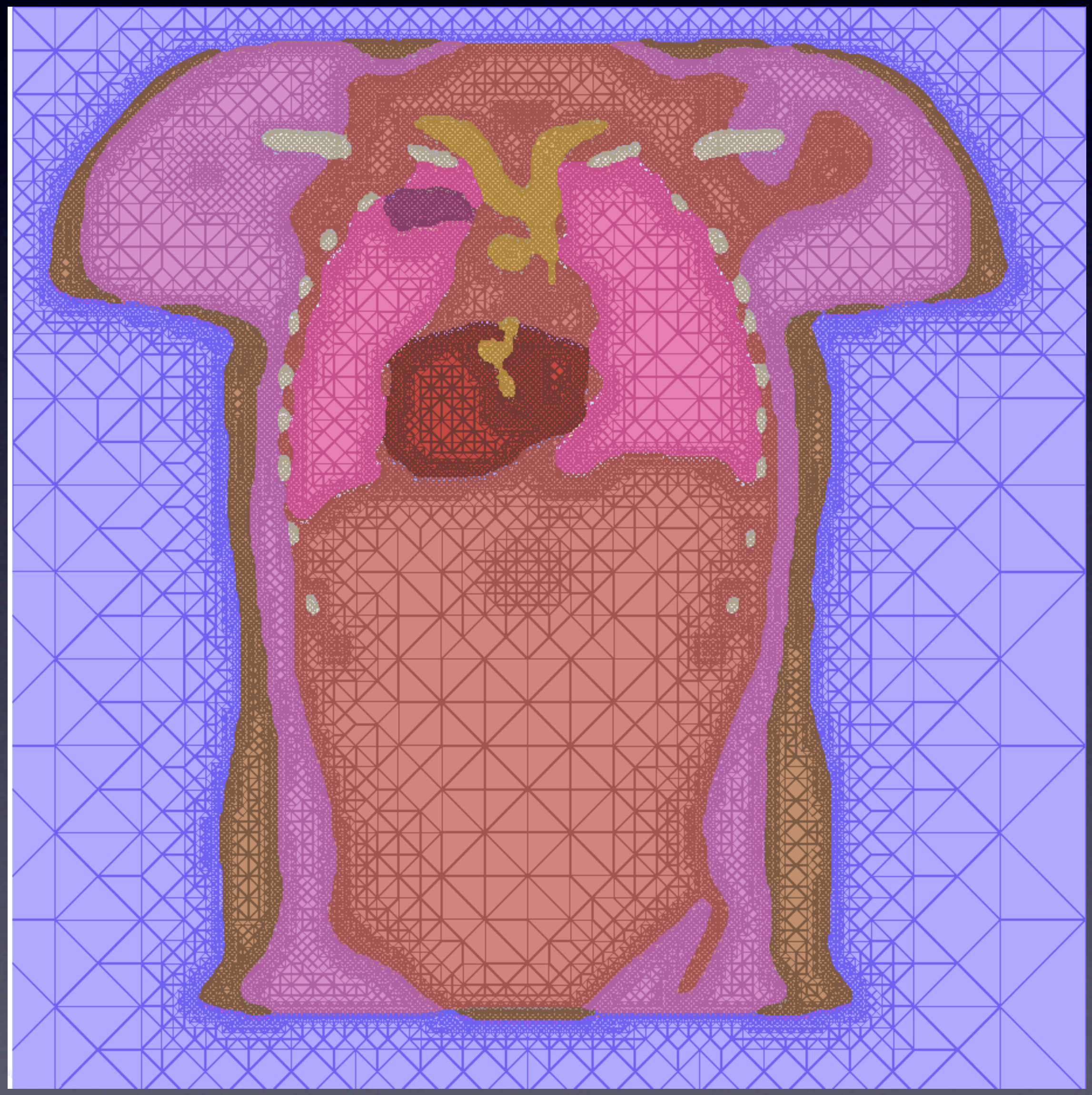
Element quality

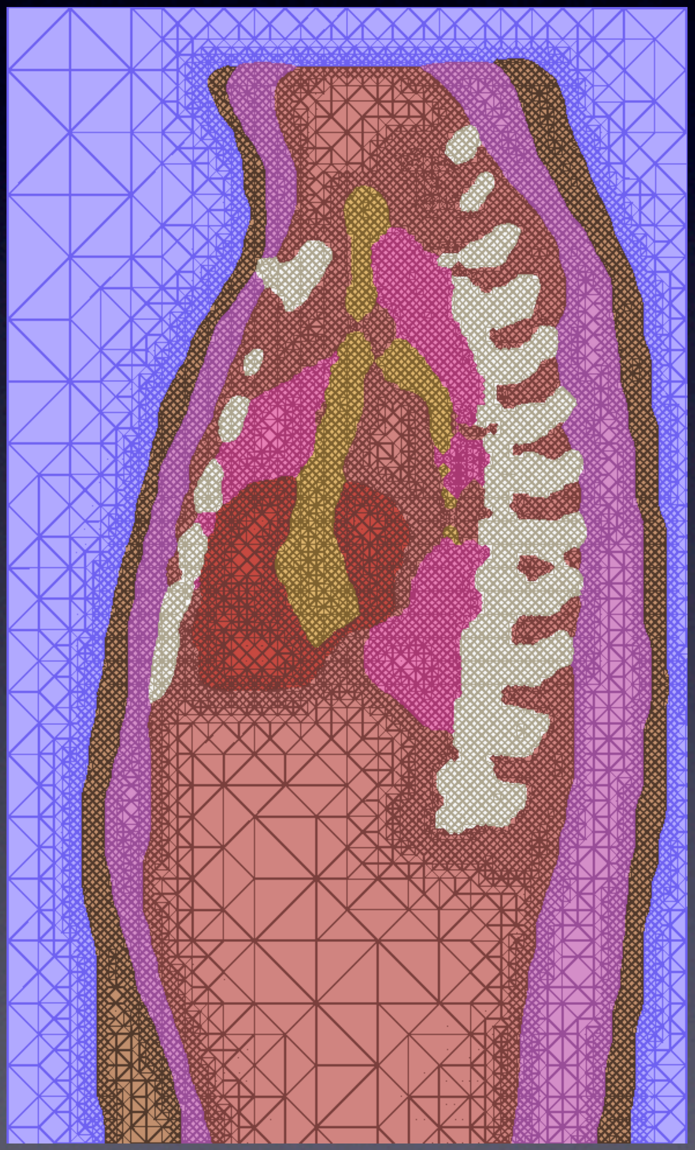
- Dihedral Angle
- Condition number





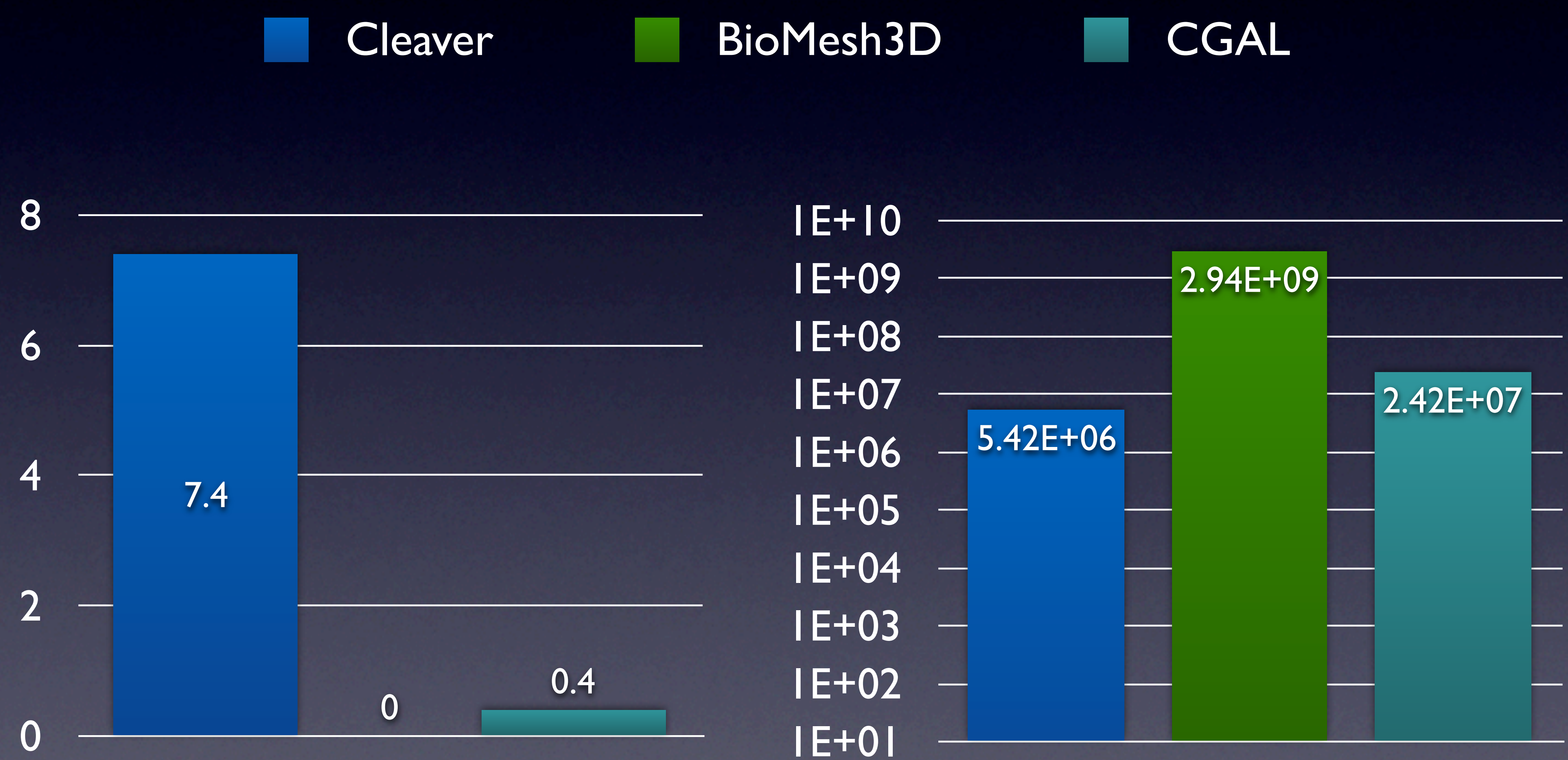
Comparison - Torso





Cleaver Mesh Result

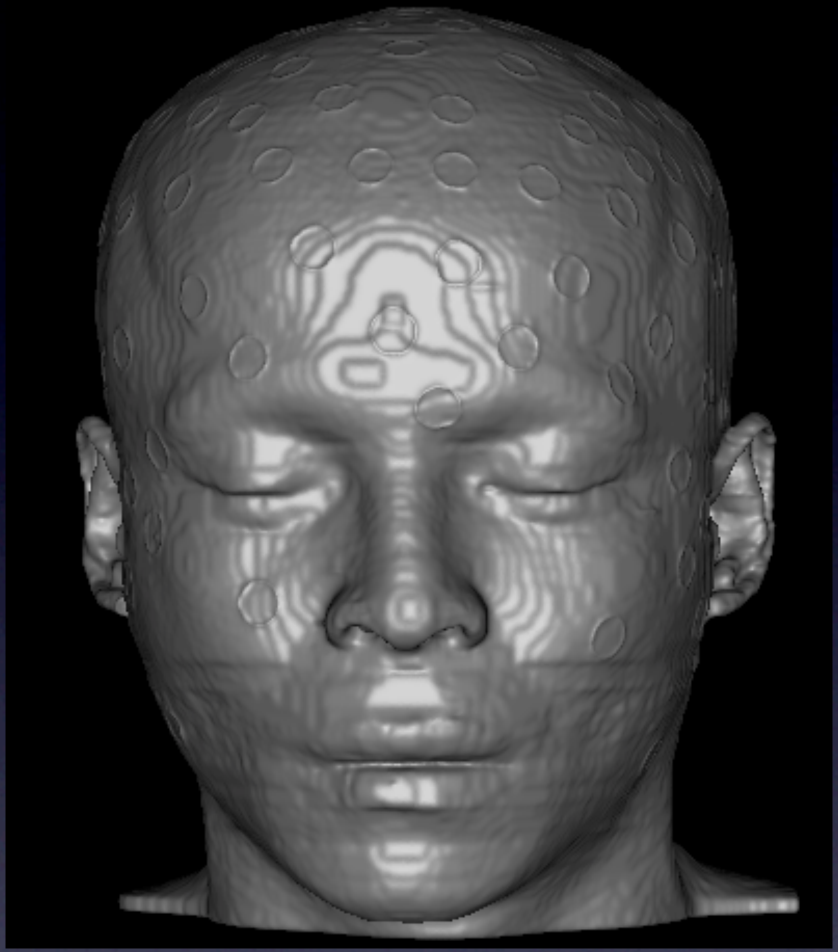
Comparison - Torso



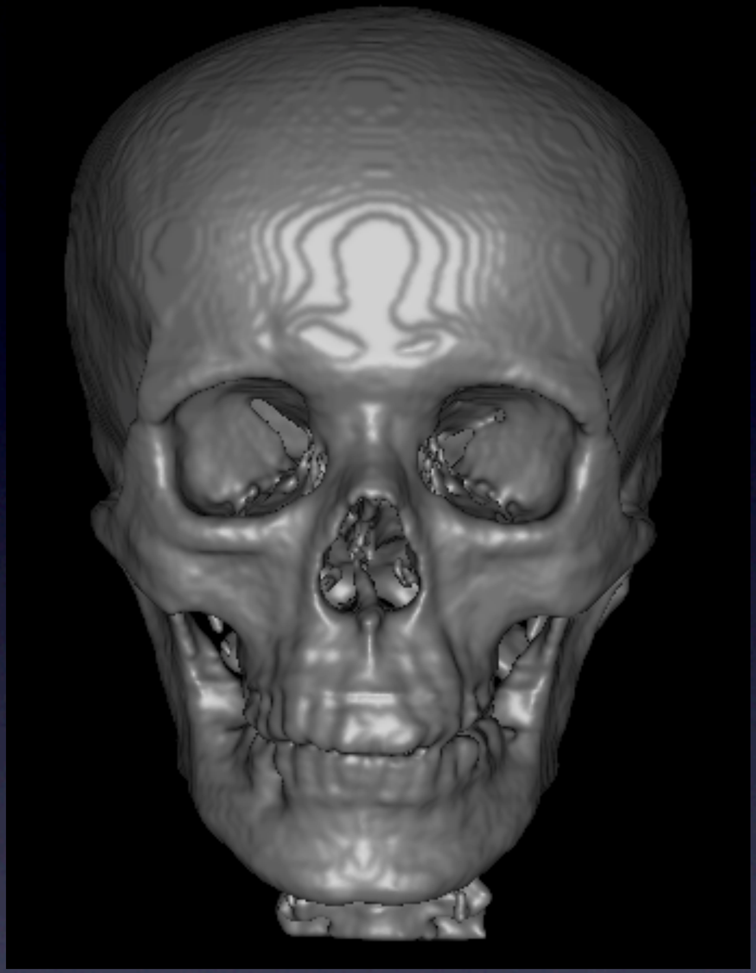
min(Dihedral Angle)

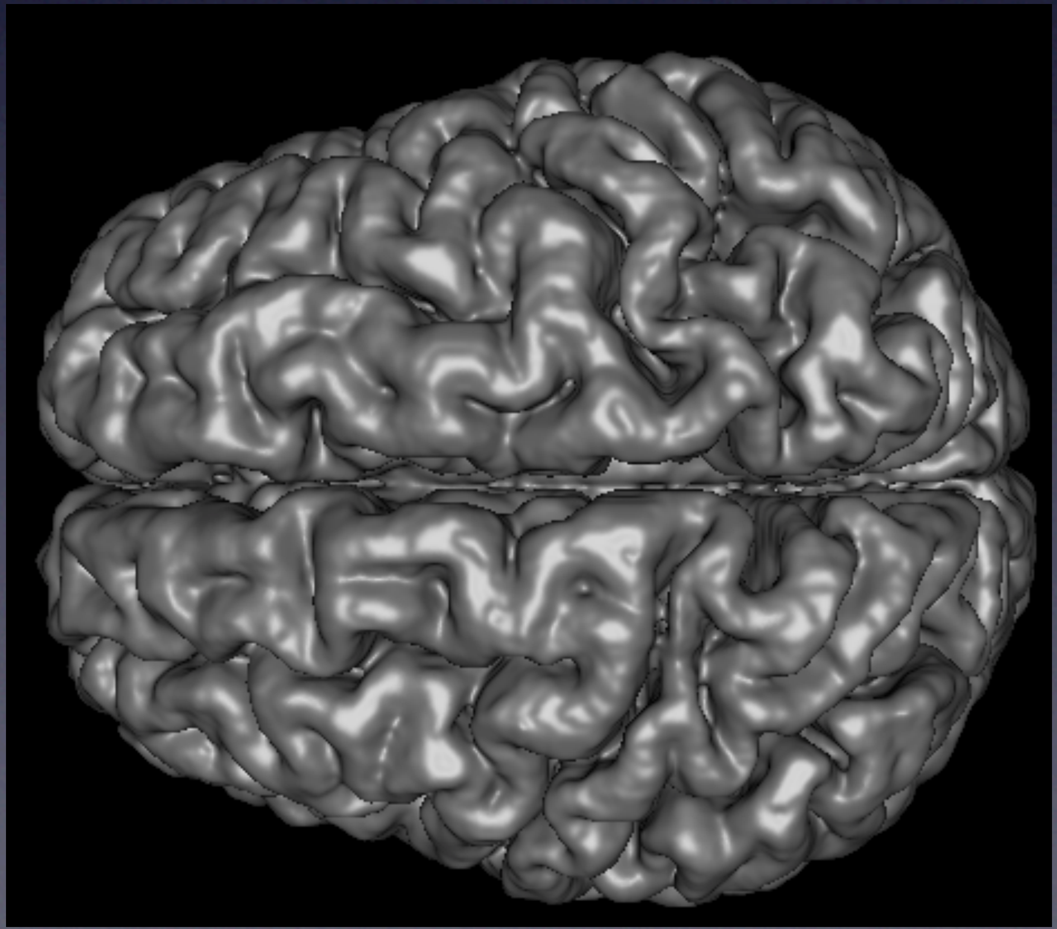
Condition number

Comparison - Head

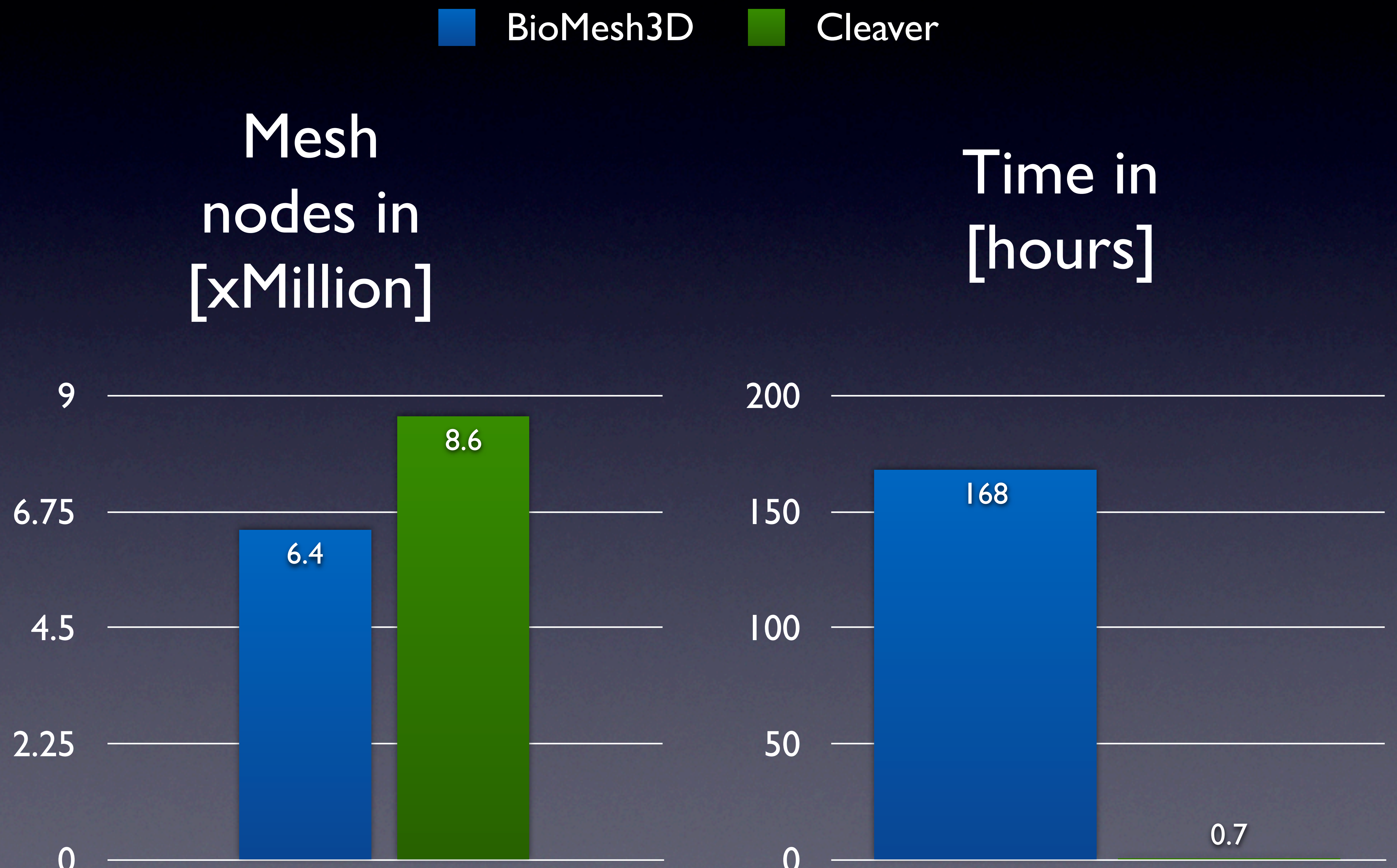


8 Materials

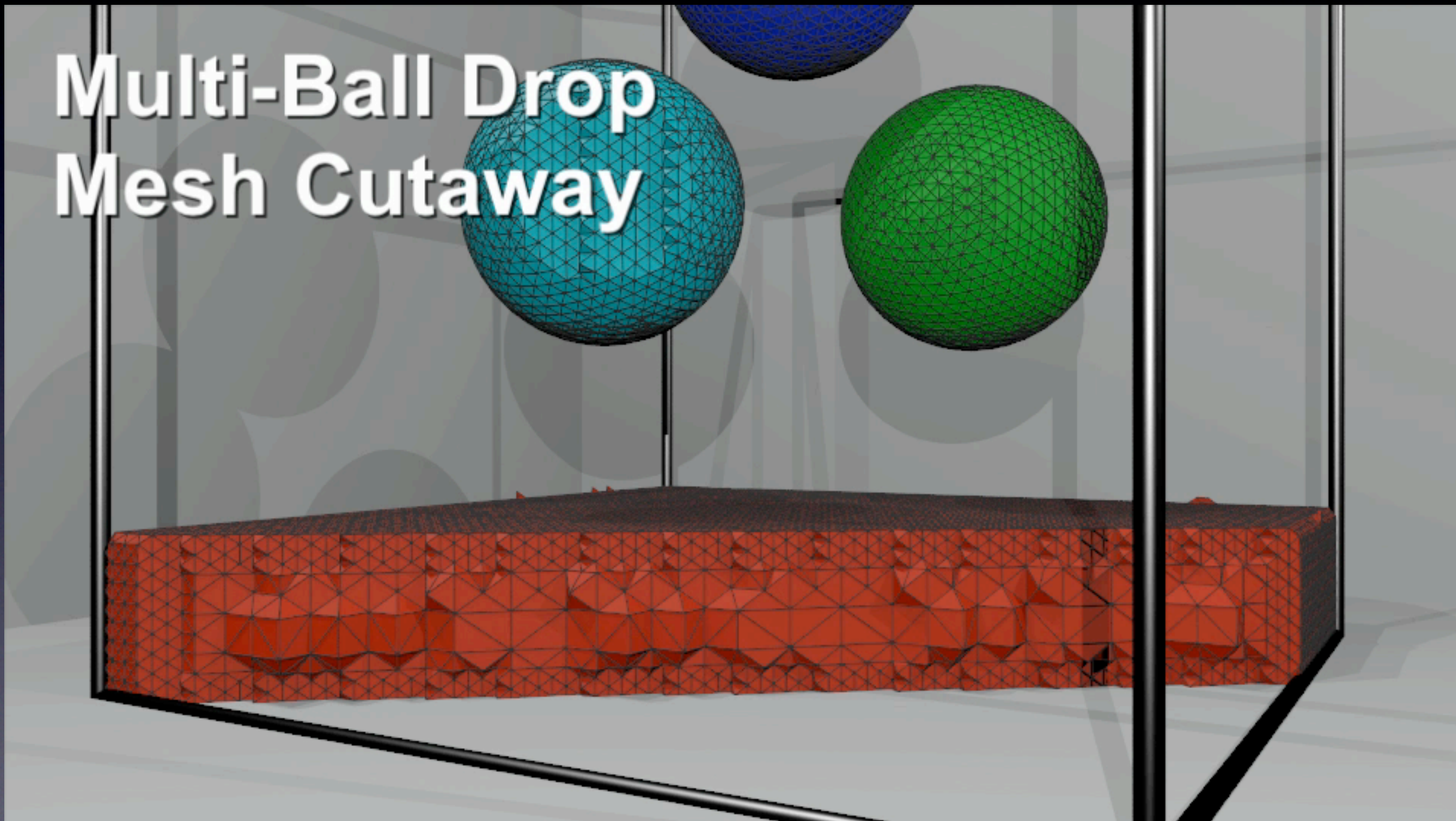




Comparison - Head



Cleaver in Action



Cleaver

- First Release: Fall 2012
- Features:
  - Incredibly fast
  - Conforming
  - Guarantees on Quality
  - Input support: SCIRun - NRRD
  - Output supports:
    - SCIRun pts/elems
    - TetGen node/eles
    - MATLAB Binaries