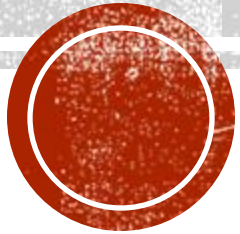
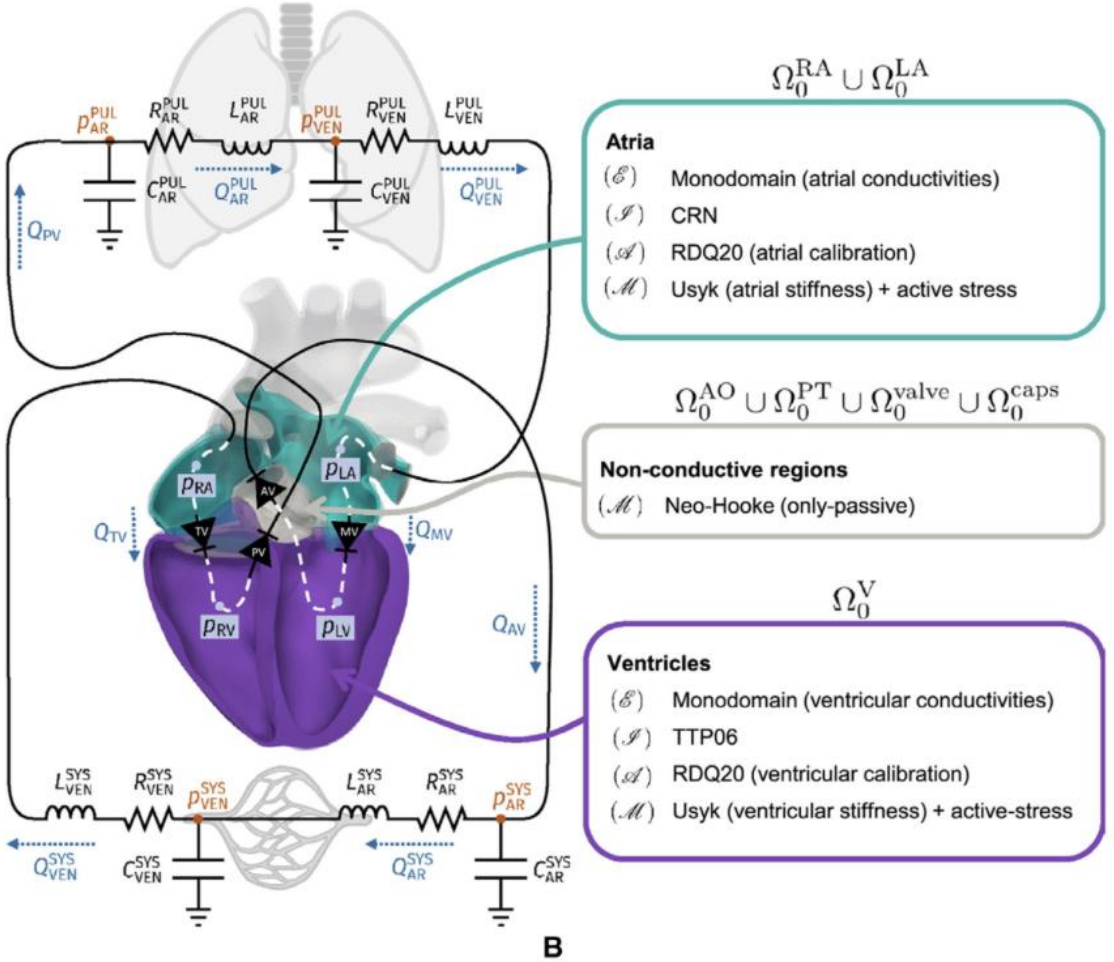
CARDIAC MESH GENERATOR



Vinay Jani

BACKGROUND – DIGITAL TWINS

- Digital Twins are virtual representations of a patient with real-time updates of phenotypic data for precision medicine.
- These involve the generation of 3D models. However, generation of said models has many problems, including:
  - Lack of standardization
  - No co-registration of multiple views
  - Imaging Data (CT, MRI) are 2D.



Coorey et. al. NPJ Digital Med. 2022

BACKGROUND – MESH GENERATION AND FINITE ELEMENT ANALYSIS

Image Co-Registration and Universal Coordinate Transformation

$$\begin{bmatrix} P_x \\ P_y \\ P_z \\ 1 \end{bmatrix} = \begin{bmatrix} X_x & \Delta_i & Y_x & \Delta_j & 0 & S_x \\ X_y & \Delta_i & Y_y & \Delta_j & 0 & S_y \\ X_z & \Delta_i & Y_z & \Delta_j & 0 & S_z \\ 0 & & 0 & & 0 & 1 \end{bmatrix} \begin{bmatrix} i \\ j \\ 0 \\ 1 \end{bmatrix} = M \begin{bmatrix} i \\ j \\ 0 \\ 1 \end{bmatrix}$$

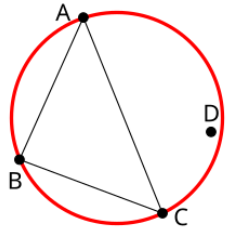
absolute coordinates

pixel spacing; direction cosines

image indices

Mesh Generation and Delaunay Triangulation

$$\begin{vmatrix} A_x & A_y & A_x^2 + A_y^2 & 1 \\ B_x & B_y & B_x^2 + B_y^2 & 1 \\ C_x & C_y & C_x^2 + C_y^2 & 1 \\ D_x & D_y & D_x^2 + D_y^2 & 1 \end{vmatrix}$$



$$= \begin{vmatrix} A_x - D_x & A_y - D_y & (A_x - D_x)^2 + (A_y - D_y)^2 \\ B_x - D_x & B_y - D_y & (B_x - D_x)^2 + (B_y - D_y)^2 \\ C_x - D_x & C_y - D_y & (C_x - D_x)^2 + (C_y - D_y)^2 \end{vmatrix} > 0$$

Parameter Optimization: Elliptic PDEs

$$\alpha x_{\xi\xi} - 2\beta x_{\xi\eta} + \gamma x_{\eta\eta} = -I^2(Px_\xi + Qx_\eta)$$

$$\alpha y_{\xi\xi} - 2\beta y_{\xi\eta} + \gamma y_{\eta\eta} = -I^2(Py_\xi + Qy_\eta)$$

$$\alpha = x_\eta^2 + y_\eta^2$$

$$\beta = x_\eta x_\xi + y_\xi y_\eta$$

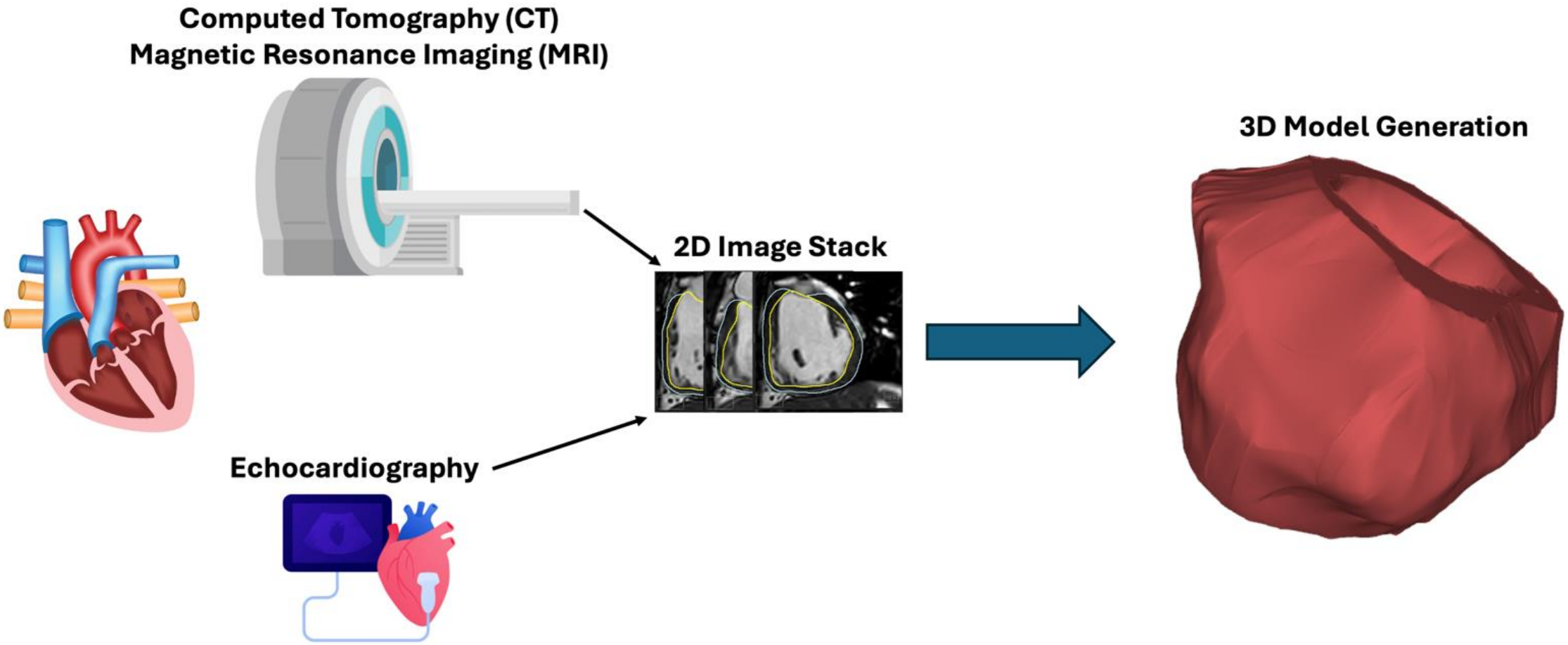
$$\gamma = x_\xi^2 + y_\xi^2$$

$$I = \frac{\delta(x,y)}{\delta(\xi,\eta)} = y_\eta x_\xi - y_\xi x_\eta$$

PROBLEM STATEMENT

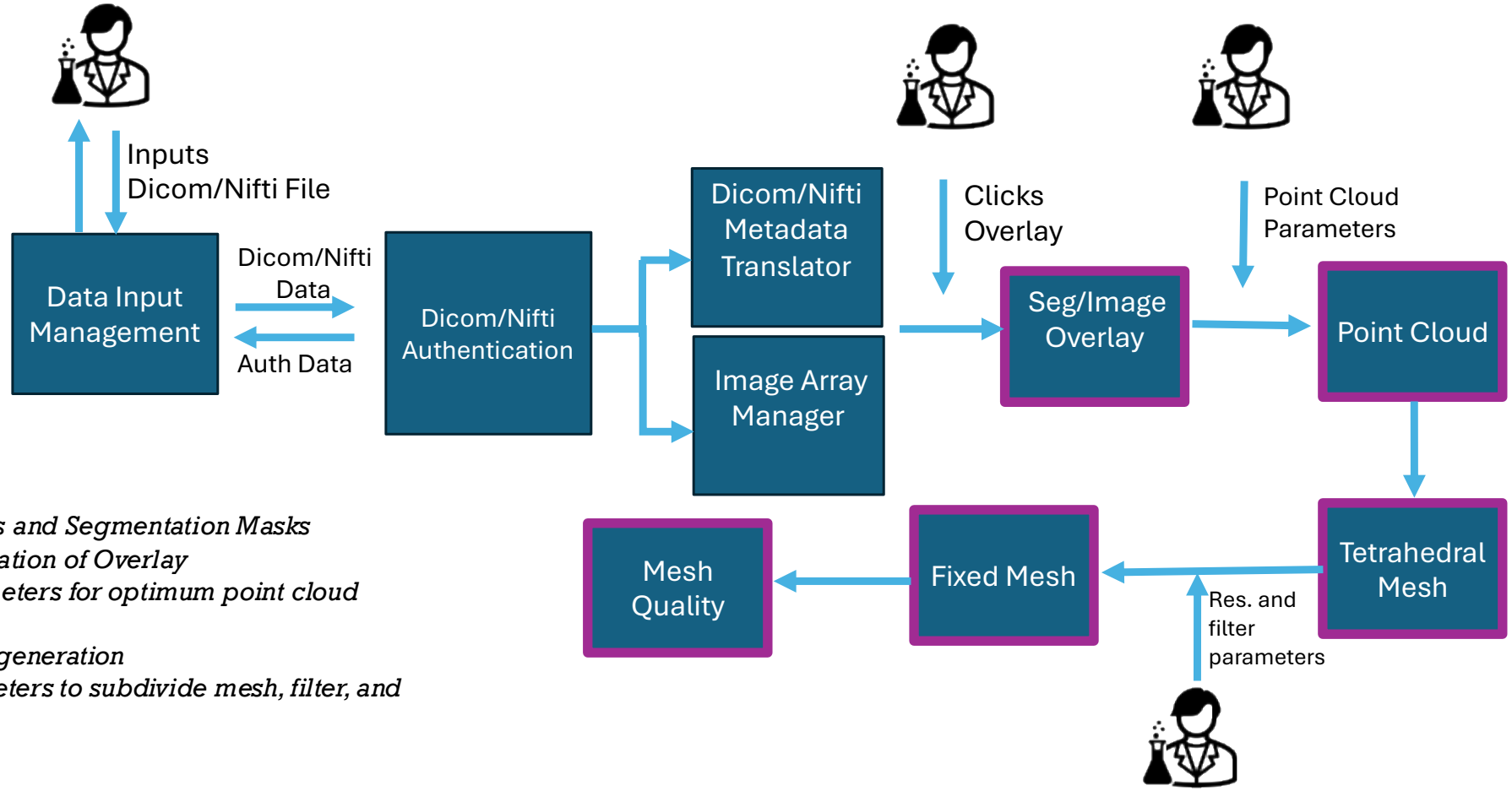
- A means to visualize and generate 3D models from cardiac MRI data , which can colocalize views and is easily accessible does not exist

PROPOSED PIPELINE FOR MODEL GENERATION



USE CASES

User Profile: Non-programmer user who uses patient specific cardiac studies and simulations



1. User Inputs Dicoms and Segmentation Masks
2. User clicks visualization of Overlay
3. User selects parameters for optimum point cloud generation
4. User selects mesh generation
5. User inputs parameters to subdivide mesh, filter, and fix mesh

METHODOLOGY

Overlay and Image Processing

DICOMS AND SEGMENTATIONS → defImportDicomSeries Import and Localize pixels defGetMasks- Import and Localize Mask Pixels → defgetMaskOverlay Overlay segmentations with image stack

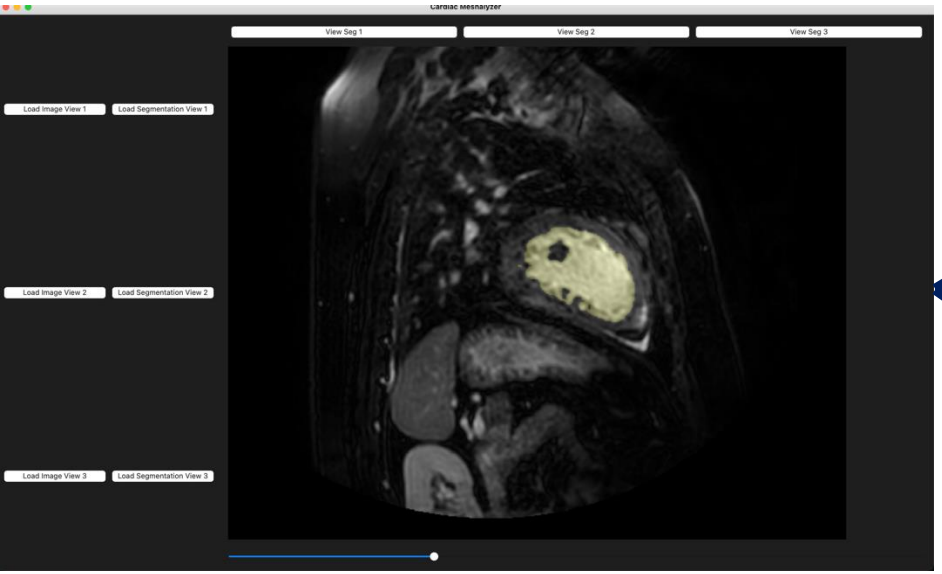
Point Cloud Generation

Processed Pixel Matricies from above → defGeneratePointCloud Generates, Cleans, and Vizualizes Point Cloud → defSavePointCloud Saves a ply of point cloud

Tetrahedral Mesh

Point Cloud from above → defgeneratetetramesh Delauney Triangulation → defclean_tetra_mesh Poisson Smoothing and Subdivison defsavemesh- saves as VTK

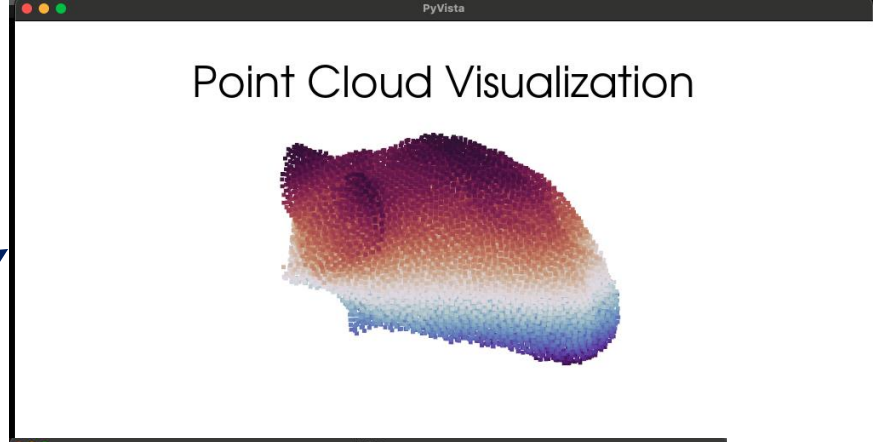
OUTPUTS DEMO

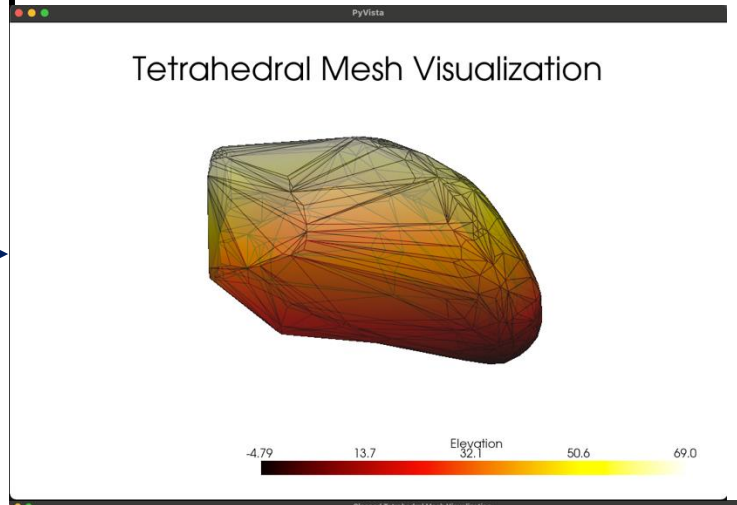


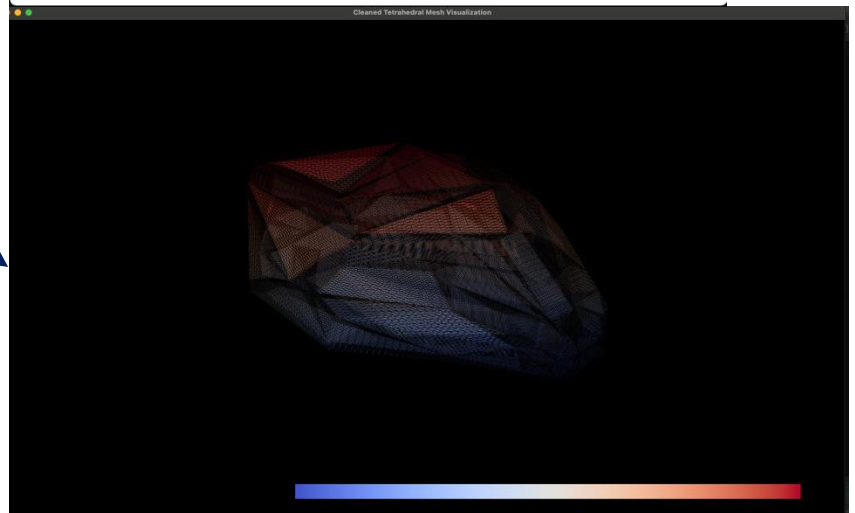
Point Cloud

Initial Tetra Mesh

Cleaned Tetra Mesh



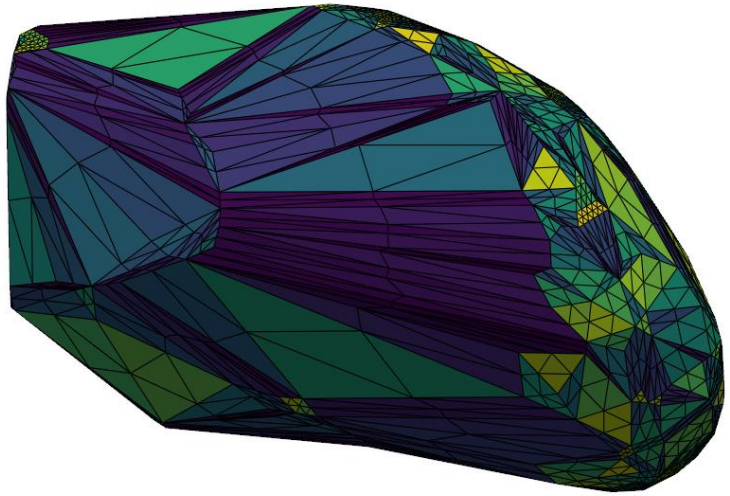




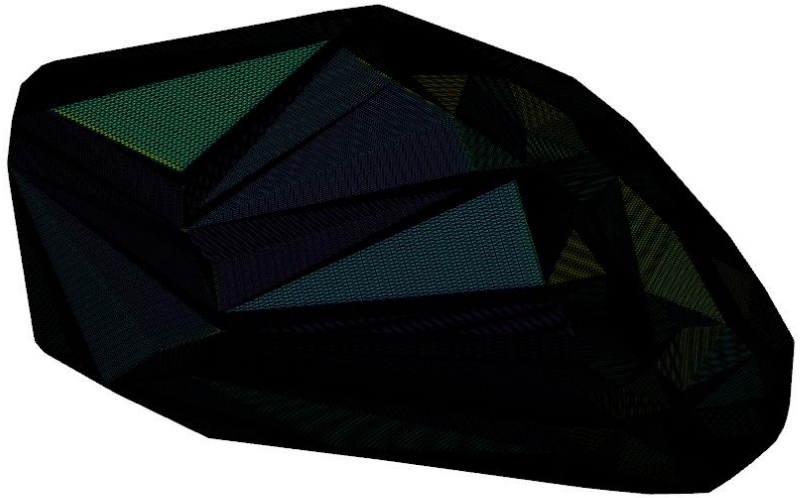
RESULTS

- **Speed – Can make mesh in less than 1 second and perform a 100 Poisson iterations with 5 subdivisions in less than 10 seconds**
- **Filtering and cleaning methods allow for increased resolution**

No Smoothing or Filtering

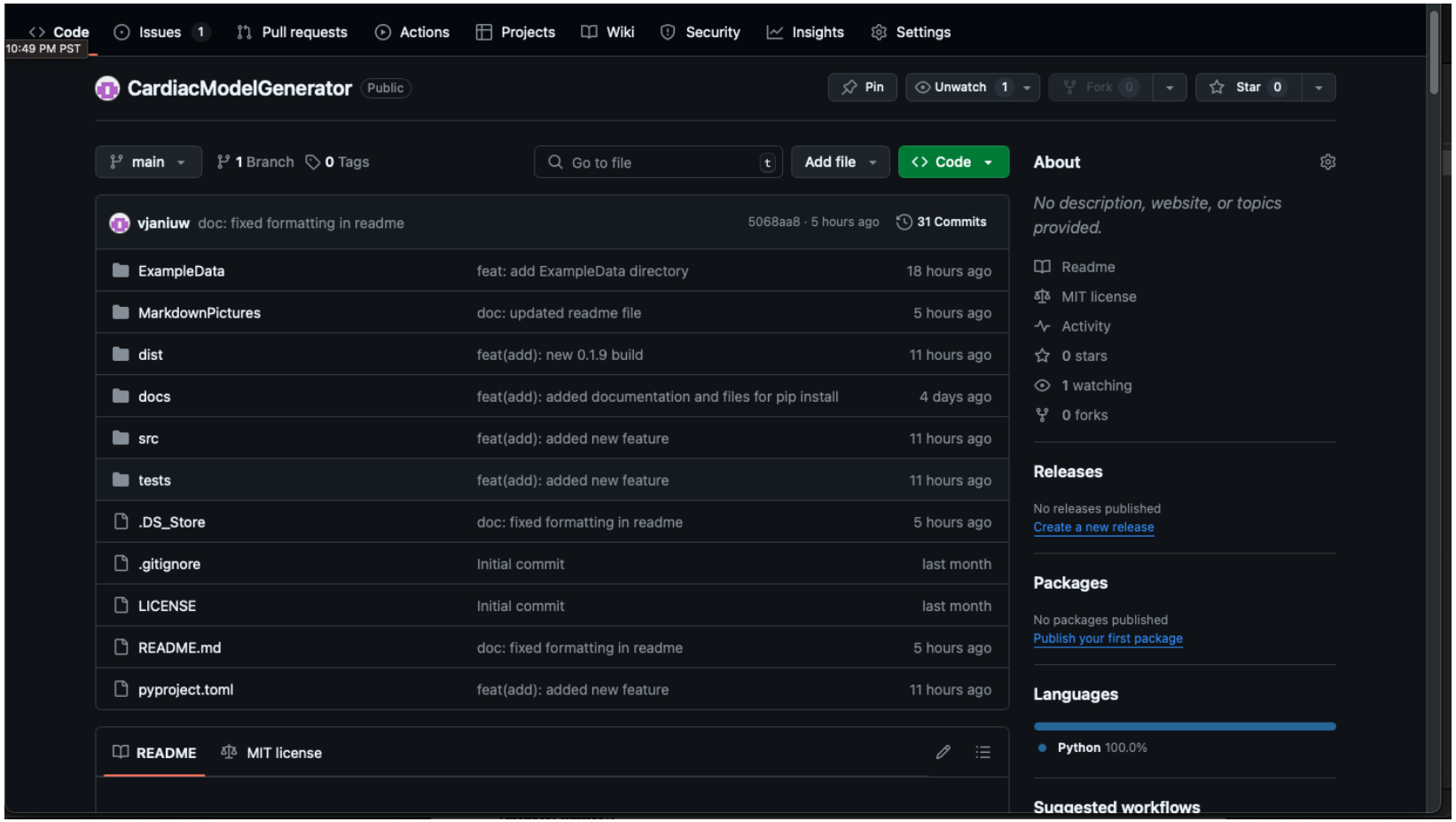


New Smoothing/Subdivision Algorithm



PROJECT STRUCTURE

CardiacModelGenerator/
- ExampleData/
- MarkdownPictures/
- dist/
- docs/
- src/
- tests/
- .gitignore
- LICENSE
- README.md
- pyproject.toml



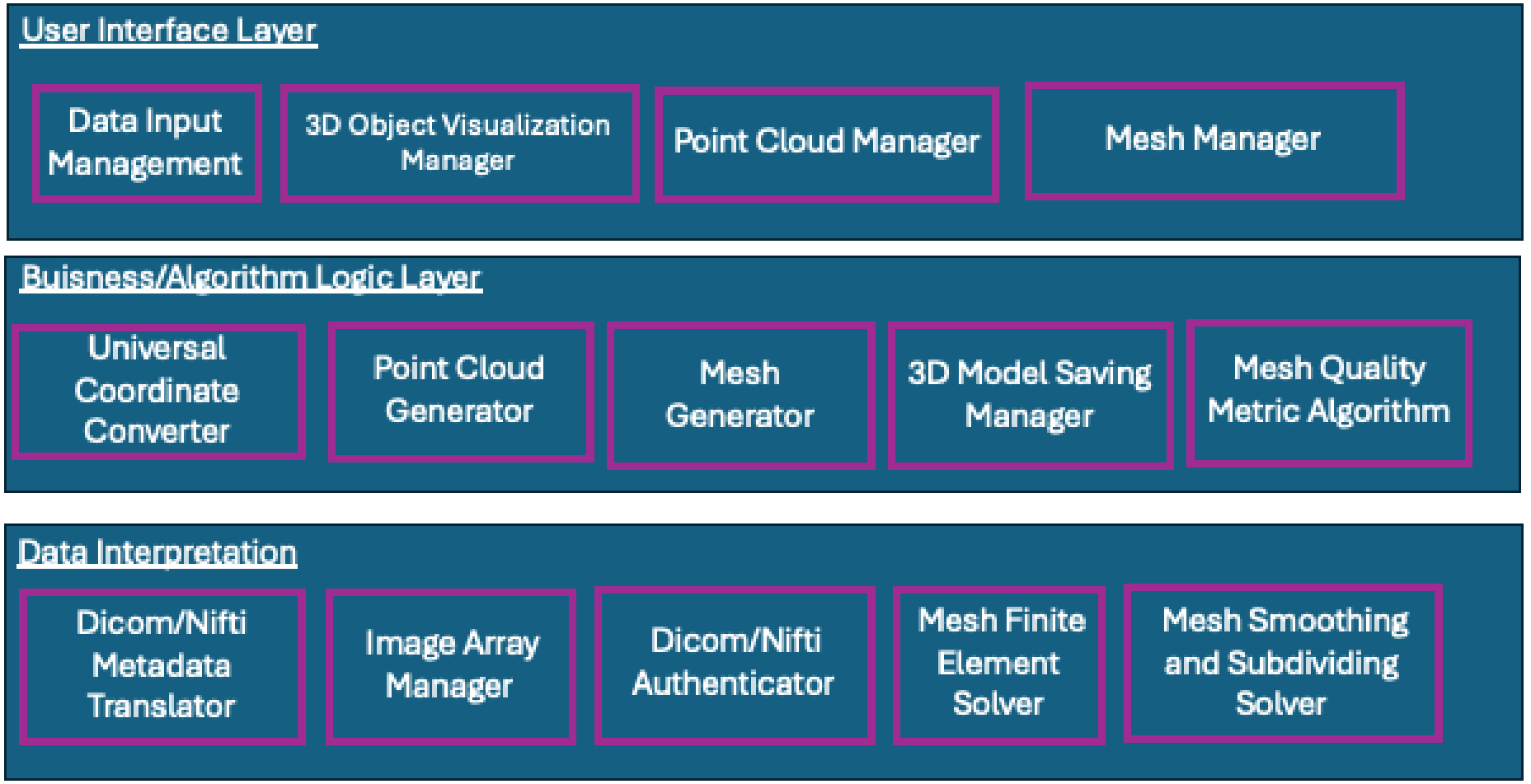
https://github.com/vjaniuw/CardiacModelGenerator

CHALLENGES

1. Object Oriented Programming with WX
2. Meshing Computationally Expensive
3. User Configurable Meshing is non-uniform
4. Co-registration of images in real coordinates
5. Image Segmentation input requires expertise
6. Rigidity of Medical Image Data

APPENDIX

DESIGN INPUTS- LAYERED ARCHITECTURE



DESIGN OUTPUT