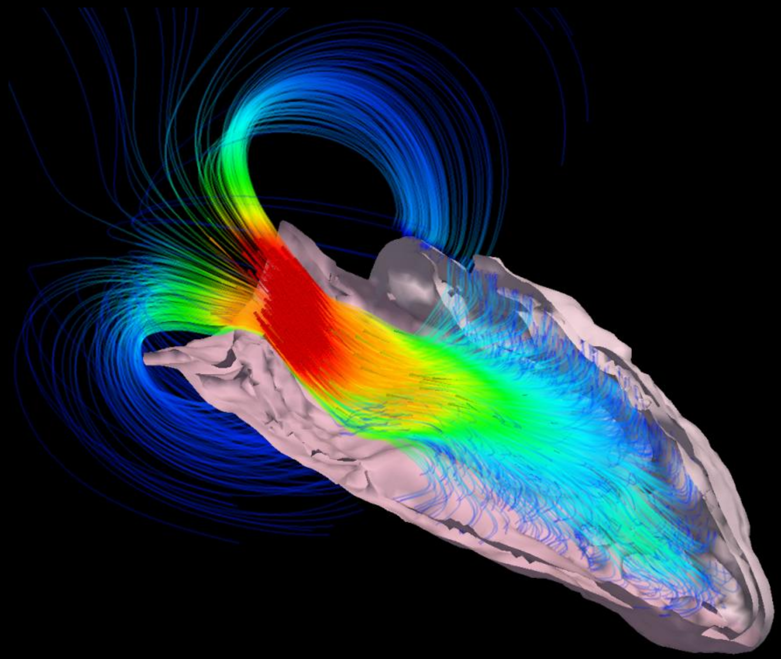
Fluid Flow Analysis for Cardiovascular Diagnostics



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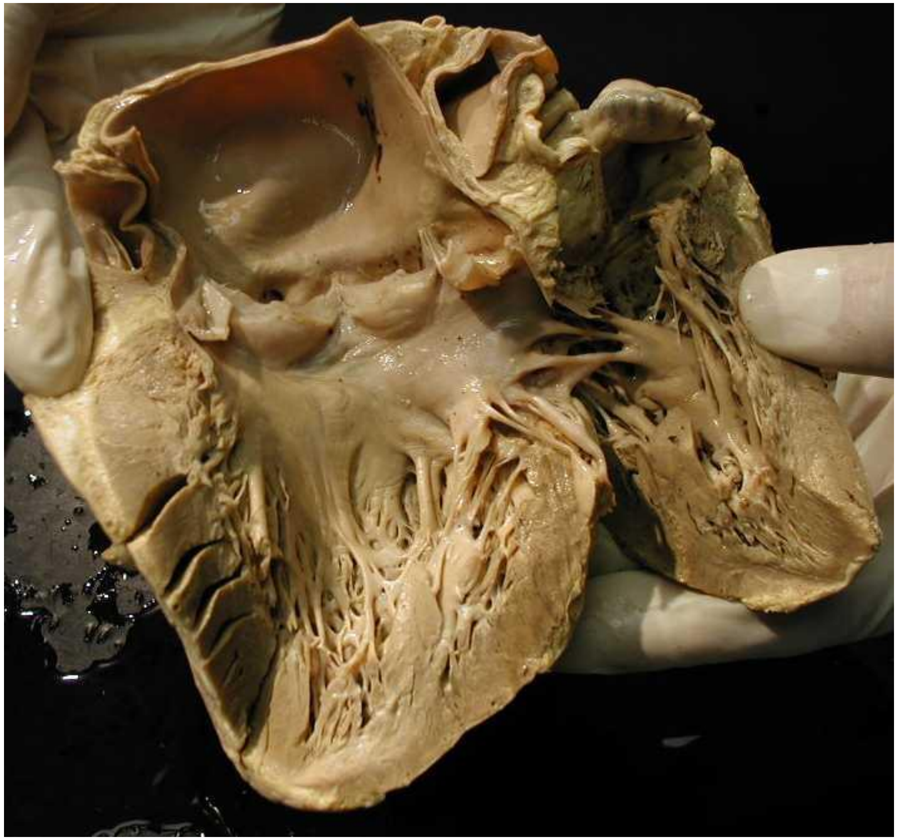
Problem

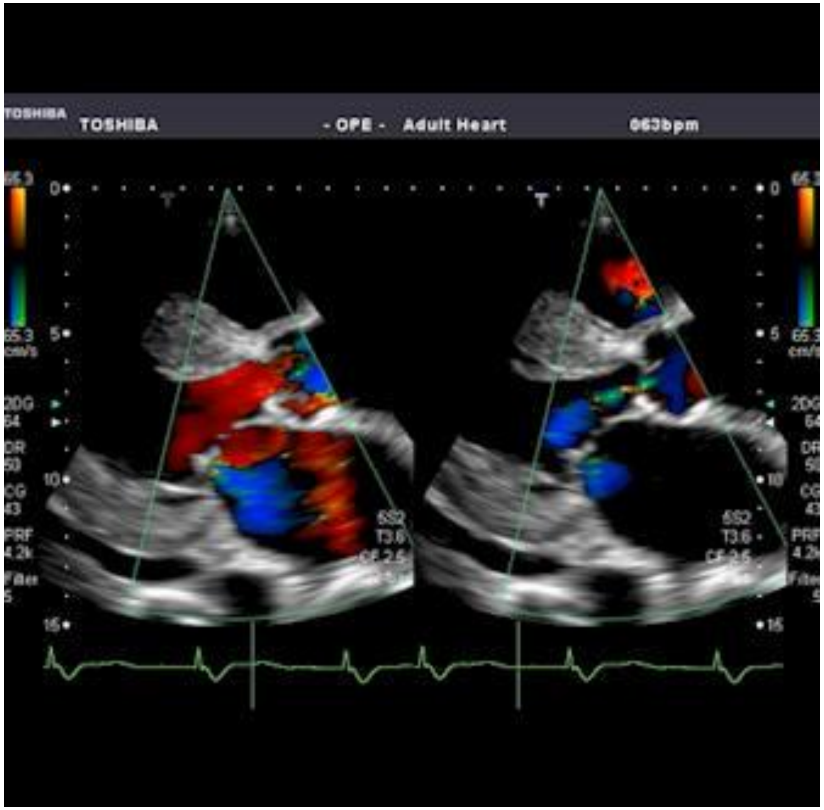
- After someone survives a heart attack, portions of the heart wall tissue dies, and so the walls will not move correctly.
- If the heart walls are too weak, blood may get stuck inside the heart and clot, leading to a stoke.
- Doctors want to be able to look a patient's heart, and determine if they are at risk of clotting/stroke, so they want to see how blood is flowing within the heart.



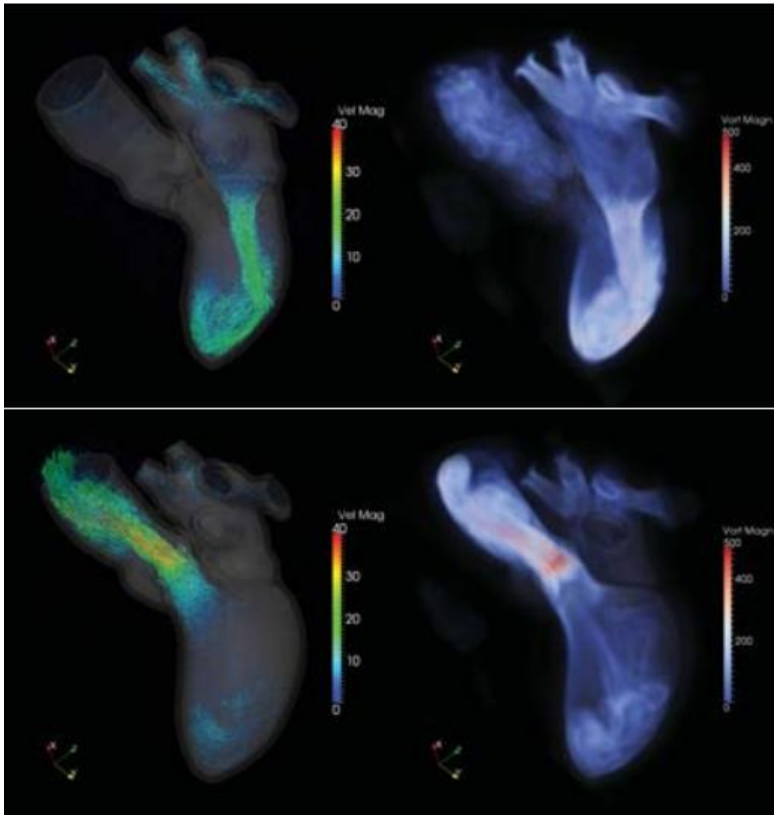
http://biology.clc.uc.edu

Visualizing Blood Flow

Ultrasound Images



Fluid Simulation



(Mihalef, 2009)

Real vs Simulated Heart

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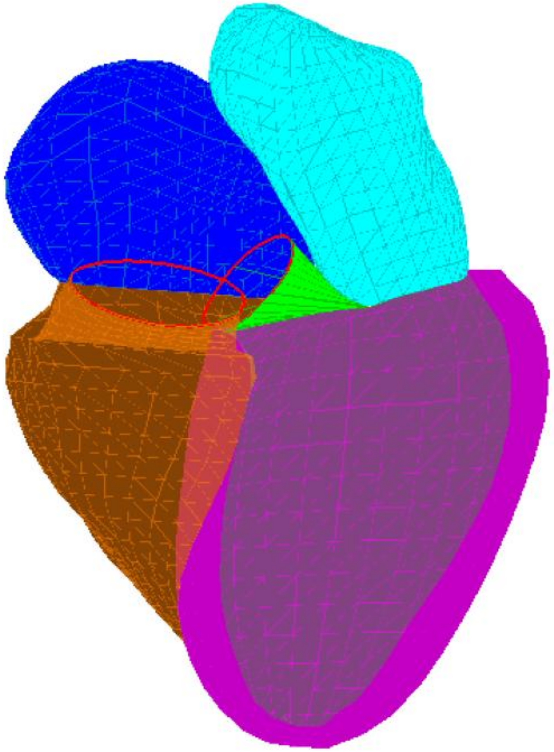
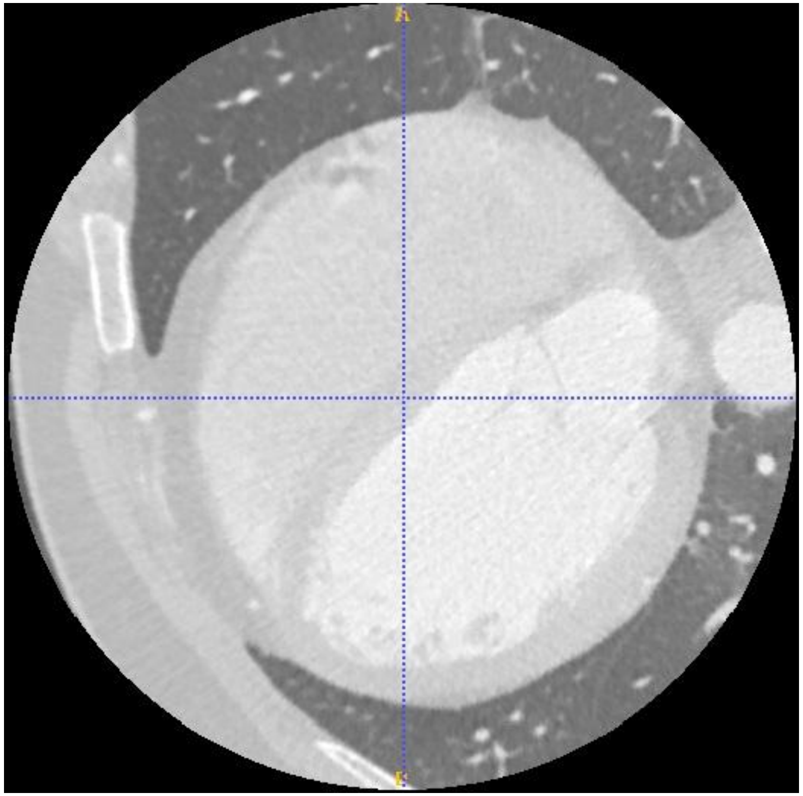


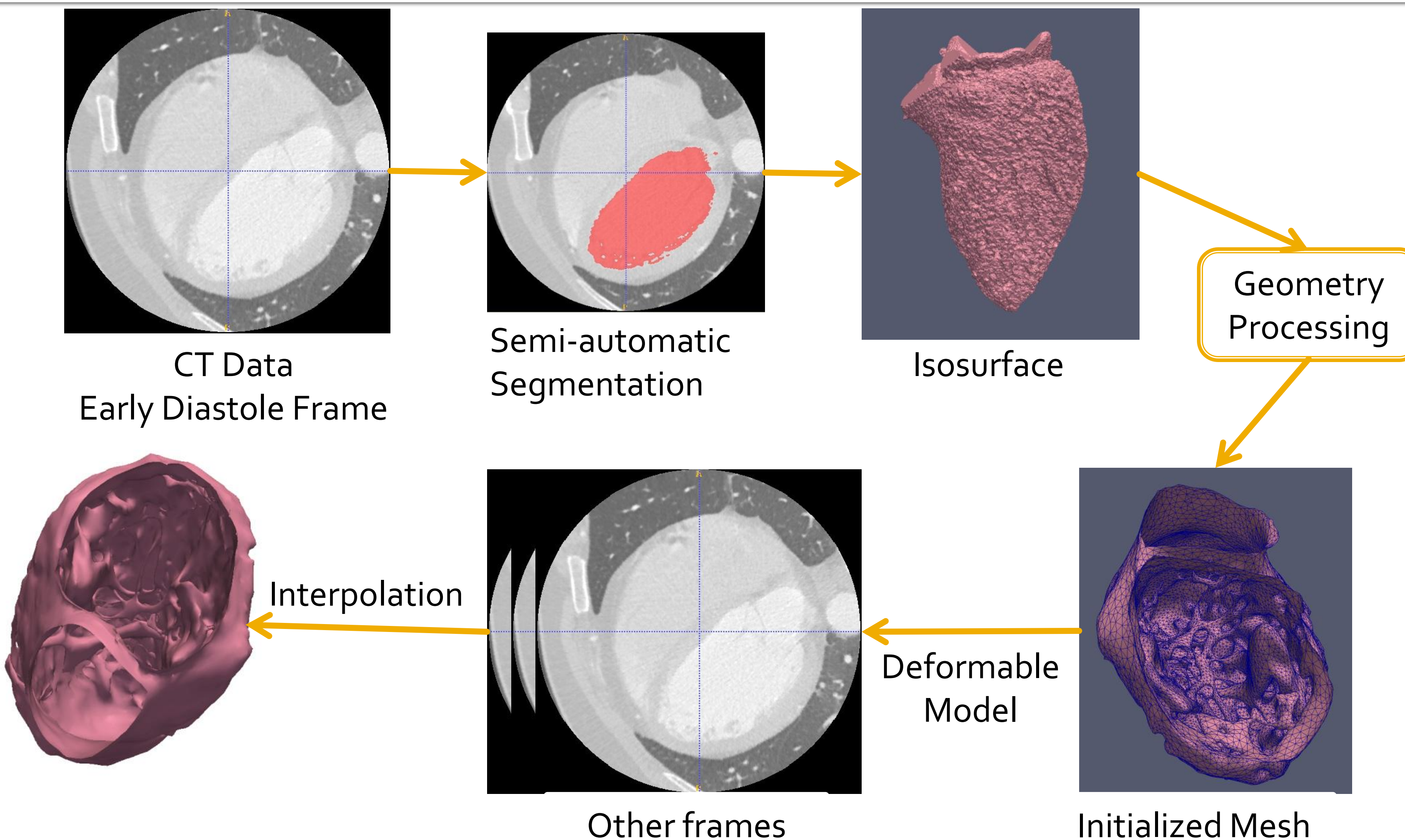
[Y. Zheng TMI'08]

CT Technology

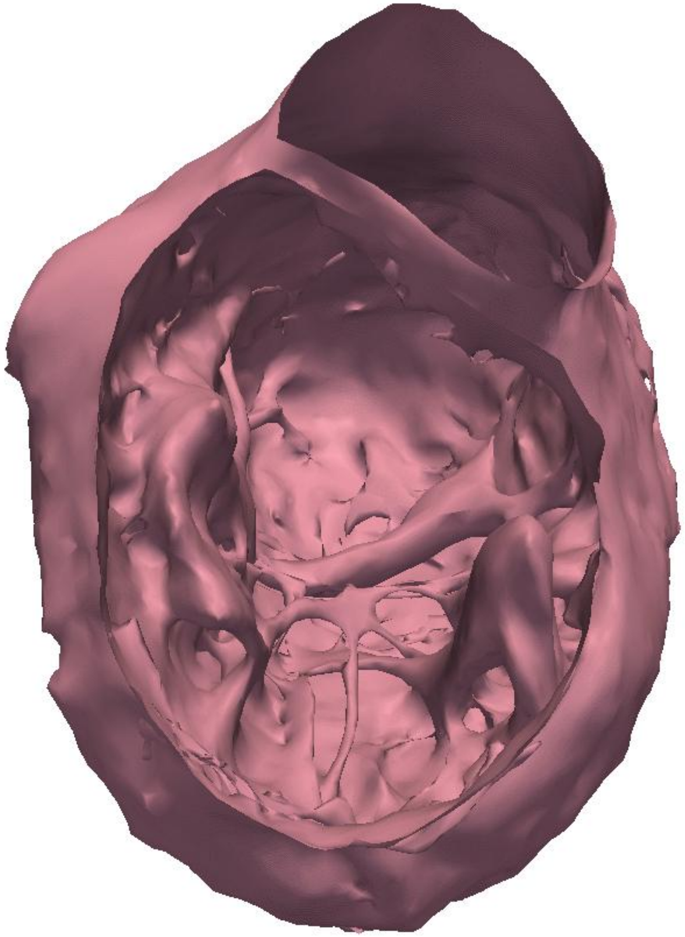
- 320-MDCT scanner
- Isotropic 0.5mm volumetric resolution
- 10 3D frames during a cardiac cycle
- Each frame 512*512*320



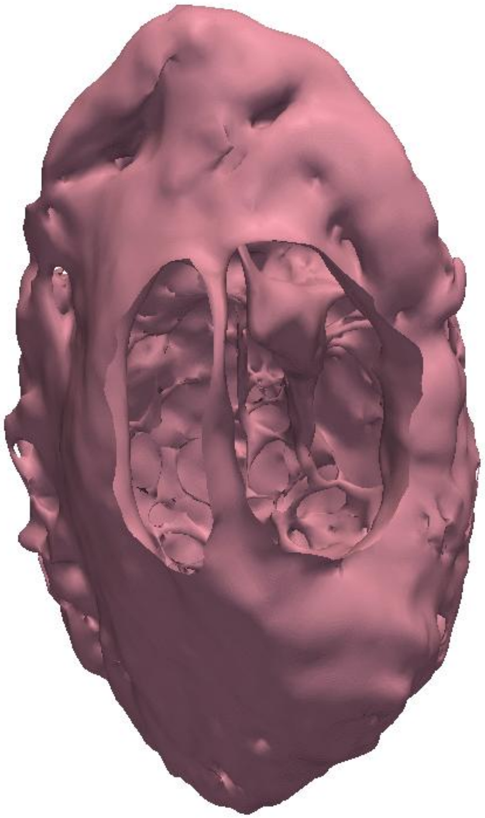
4D Cardiac Reconstruction Framework



4D Cardiac Reconstruction Results



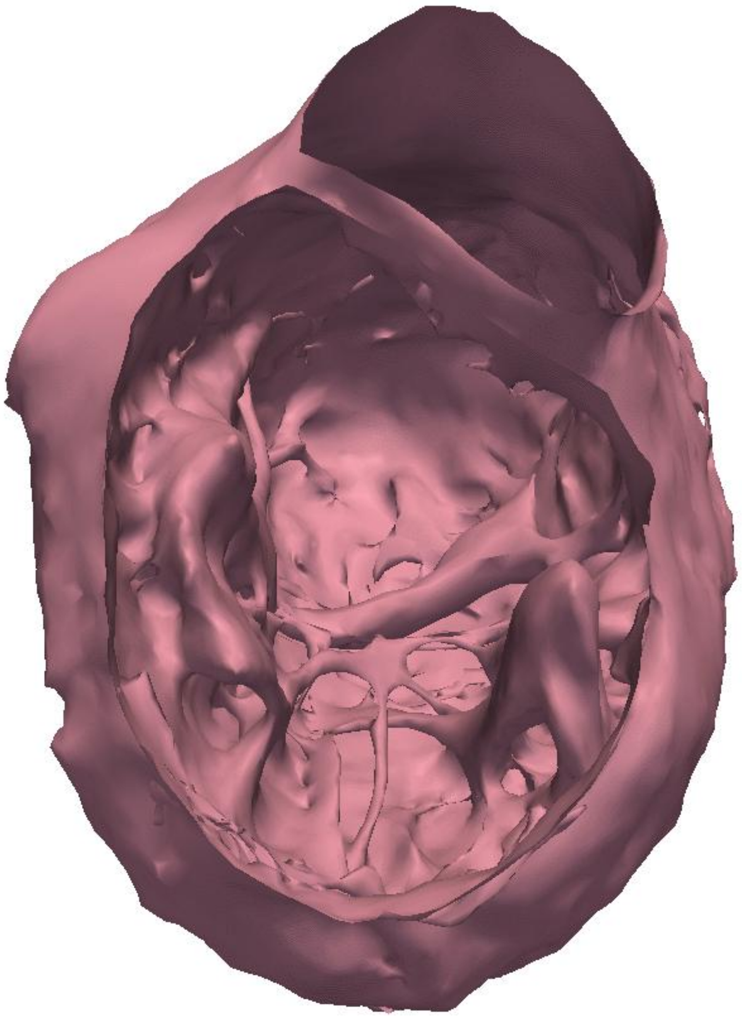
Healthy Heart



Desynchronized Heart

4D Cardiac Reconstruction

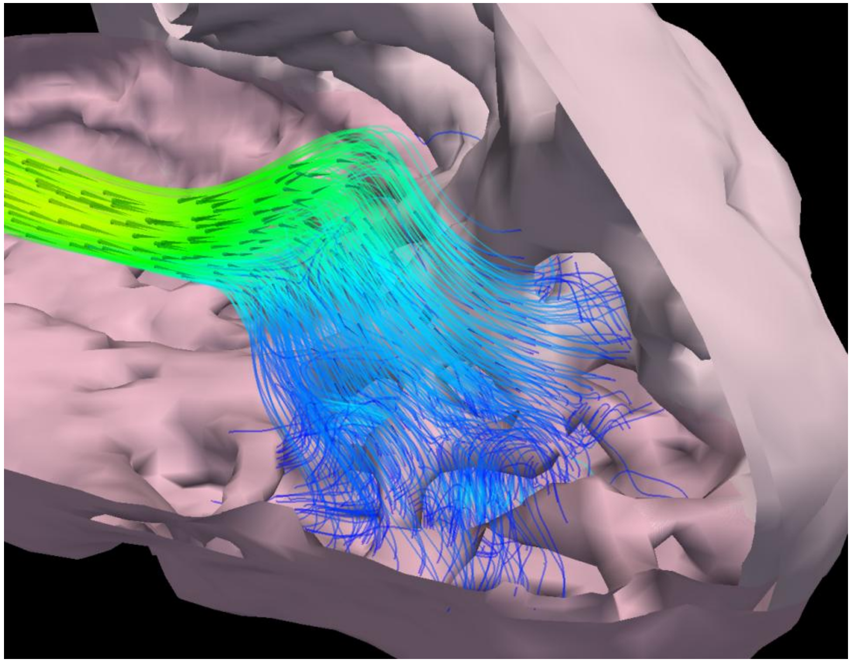
- Captured the fine detailed structure of the papillary muscle and the trabeculae
- One-to-one correspondence
  - Temporal interpolation
  - ASM
  - Blood simulation

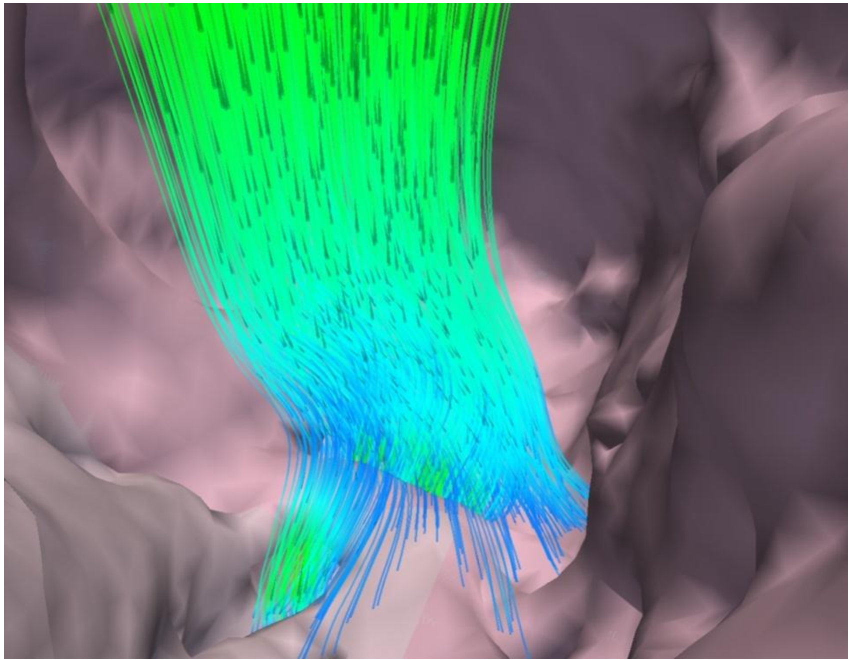


Simulating Blood Flow

- FDM, Grid size: 96x96x96
- The blood is modeled as a Newtonian fluid, with viscosity set at 4mPa*s and density set at 1060kg/m^3.
- Each two-cycle simulation took between 4-6 days to complete.

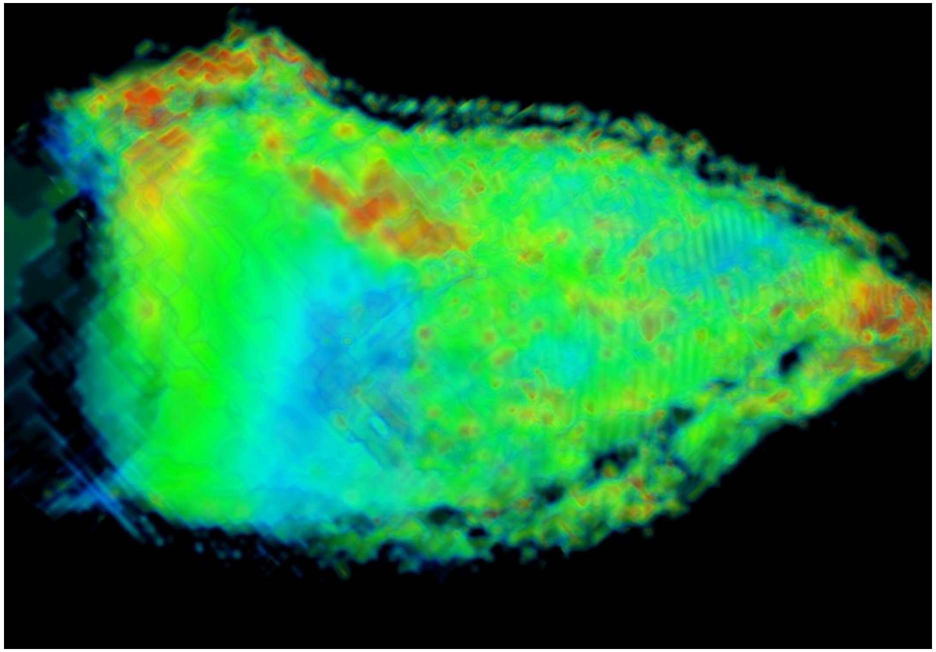
Streamlines





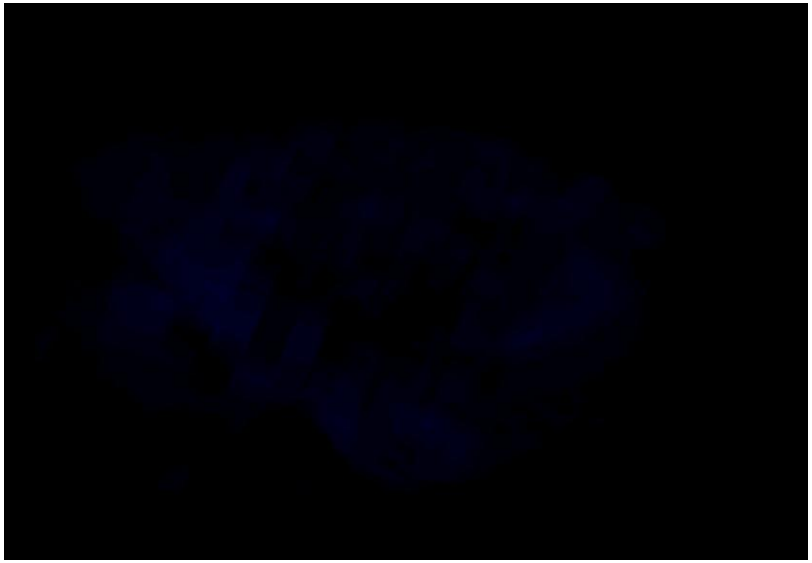
Average Residence Time

- Stagnant blood within the heart has high risk of clotting. We therefore seek a method to determine the average residence time of blood.
- Randomly generate particles within the heart at the initial time step. Each consecutive time step, use velocity field to move existing particles, and generate new particles near the valves.



Average Residence Time

Normal

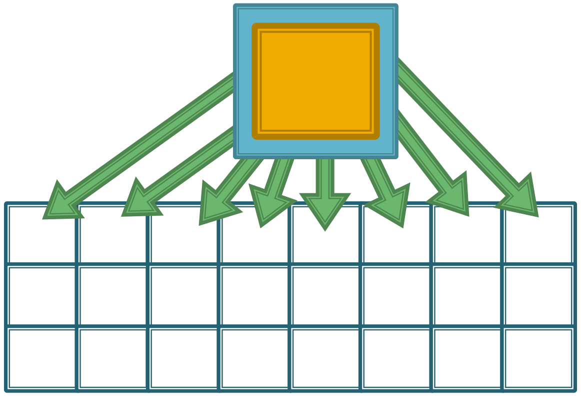


Dyssynchronized

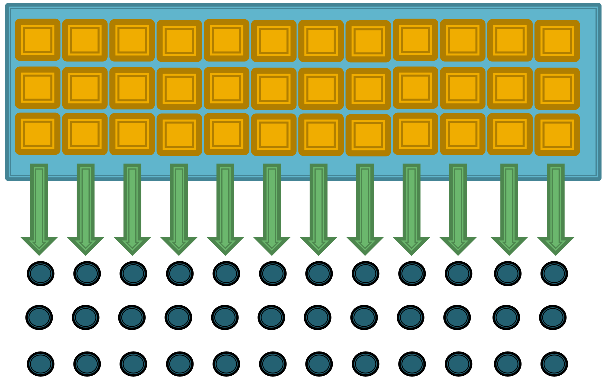
Faster Fluids

- While the previous method was very accurate, it is too slow.
- We have implemented a new particle-based (Smoothed Particle Hydrodynamics), taking advantage of massively parallel graphics processing units (GPU's) using NVIDIA's CUDA.

- CPU: Used 1 core to solve fluid equations for entire domain grid at once

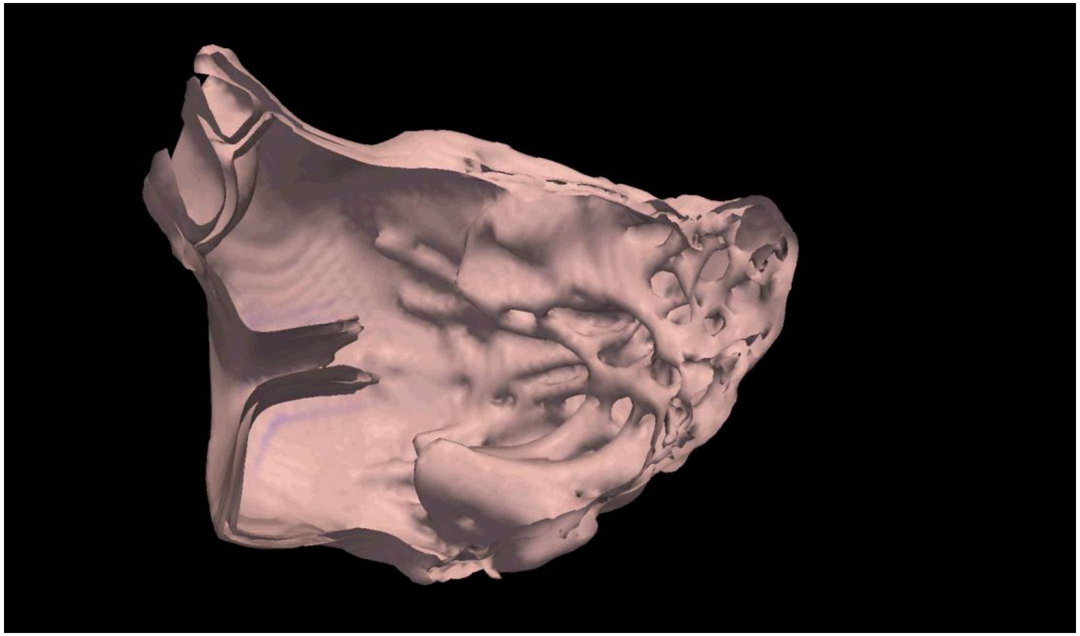


- GPU: Use 500+ cores to solve each particle individually, in parallel



Results

	FDM	SPH1	SPH2	SPH3
Speed of Sound (c)	N/A	10	20	30
dt	Adaptive	.001	.0005	.00025
Simulation Time	4 days	30 min	62 min	126 min
Ejection Fraction	.45	.42	.48	.50



Conclusions

- Using FDM, we have found interactions between the motion of the trabeculae and the blood flow, which has never been seen before.
- Using SPH, we are able to simulate cardiac blood flows that appear very close to the FDM simulations, with similar ejection fractions.
- Trabeculae/blood flow interactions currently cannot be seen when using SPH, as this method requires thickened heart walls for accurate motion at boundaries.

Proposed Task 1 – Heart Wall Segmentation

- 1 student, for approximately 12 months for total $40K, collaborating with NYU, Piedmont Heart Institute
  - Model analysis (6 months)
    - Skeletal model for more accurate motion of papillary muscle and trabeculae
    - Classification based on model analysis to aid diagnosis
  - More accurate/automatic segmentation and registration (6 months)

Proposed Task 2 – Blood Flow Simulation

- 1 student, for approximately 18 months for total $55K, collaborating with NYU, Piedmont Heart Institute
  - Development of thin wall SPH methods (7 months)
    - Capable of seeing trabeculae/blood flow interactions using SPH
  - Validation (3 months)
    - Use flow data from MRI to validate cardiac blood flow simulations
  - Automatic classification of blood flow to aid in diagnosis (potential for clotting) (9 months)

Acknowledgements

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