

Whole Heart Computational Modeling

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https://info.ornl.gov/sites/rams09/a_manning/Pages/default.aspx

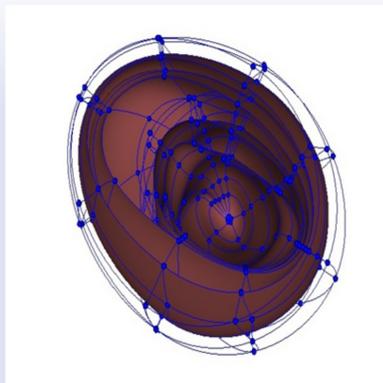


Figure 3: Heart mesh and surfaces rendered on Continuity 6.3b.

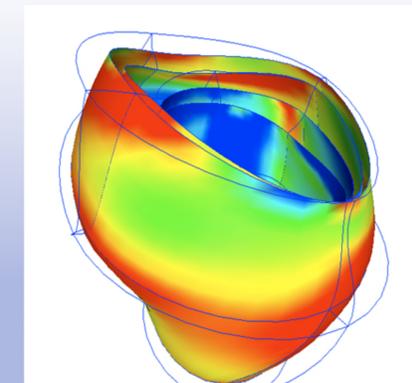


Figure 4: heart mesh and biomechanics rendered on Continuity 6.3b.

Background

In biomedical research today, simulation is a powerful tool in helping scientists solve complex cardiac problems. Finite element software *Continuity* developed by the University of California San Diego helps solve some of these problems. *Continuity* implements interconnected, multi-scale models including biomechanics, electrophysiology, and the underlying cellular mechanisms of cardiac myocytes. Problem solving is conducted on an iMac using Linux, a Linux workstation, and on the ORNL Institutional Cluster (OIC).

Continuity Heart Simulations

- Electrophysiology (EP) simulation:
 - FitzHugh-Nagumo models
 - Luo – Rudy cell models
 - Arrhythmia models
- Biomechanical (BM) simulation:
 - Simulate the basic heart functions
 - Ventricular pressure
 - Simulated atria pressure and volume
 - Mitral and Tricuspid valve resistance
 - Stress and strain analysis
- Cellular Models:
 - Supports EP and BM models
 - Emphasis on calcium concentration (BM)
 - Sarcomere properties (BM)
 - Transmembrane voltage (EP)
 - Membrane capacitance (EP)

Computing Resources

- Electrophysiological, biomechanical, and cellular models
 - Solved on Linux, Macintosh, or PC workstation
- Complex problems planned for ORNL Institutional Cluster
- Rendering high-capacity problems
 - Port coding to GUI-based *Continuity*
 - Requires RAM of 4 to 8GB

Continuity Finite Elements

- Heart specific finite elements problem solving environment
- Heart models optimally use quadratic and cubic functions
- Elemental and nodal orientation key for representation

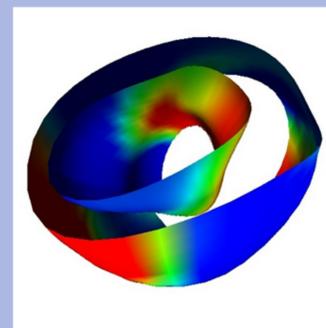


Figure 1. Heart electrophysiology model with rounded coarse mesh orientation.

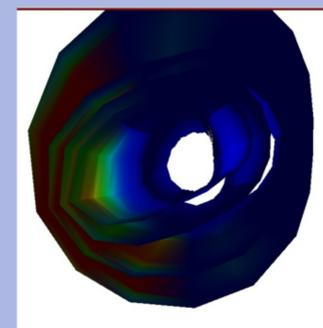


Figure 2. Heart electrophysiology model with linear fine mesh orientation.

Results

- Electrophysiology (FitzHugh-Nagumo model)
 - Tensor conductivity difference: stimulus current difference
 - Stimulus time effects rendering of stimulus paths
- Biomechanics (stress/strain analysis)
 - Ventricular pressure: time dependent
 - Coefficients of strain: minimal effects
 - Mitral and tricuspid valve resistance: minimal effects
 - Sarcomere length: big stress/strain determinant
 - Calcium concentration: minimal effects

Conclusions/Future Research

- Faster OIC calculations
 - Extensive data calculations
 - More factors of heart functions calculated
- Mesh building must be accurate
- **Biomechanical:**
 - Stress vs. strain analysis determine tissue integrity
- **Electrophysiological:**
 - Cellular loop basis of stimulus current propagation
 - Tensor conductivity is critical
- **Future Research:**
 - Advance in EP and BM OIC computing
 - Simulate heart anomalies by model or by properties
 - Simulate Luo-Rudy Cell model

References

- Netter, Frank H. *Cardiovascular Anatomy*. New Jersey: Novartis, 1997.
- Kilner, Philip J., Yang, Guang-Zhong, Wilkes, John A., Mohiaddin, Raad H., Firmin, David N., Yacoub, Magdi H. "Asymmetric redirection of flow through the heart." *Nature* 13 Apr. 2000: 759.
- Baker, A.J., Pepper, D.W. *Finite Elements 123*. A.J. Baker and D.W. Pepper, 1990.
- Luo, C.H., Rudy, Y. A model of the ventricular cardiac action potential. *Depolarization, Repolarization, and Interaction*. Cleveland: Circulation Research, 1991.

Computing Comparisons

Macintosh Workstation	Macintosh Workstation (Parallel)	ORNL Institutional Clusters
• Memory: 4GB RAM	• Memory: 4GB RAM	• Memory: 16GB RAM
• Processor speed: 2.0GHz	• Processor speed: 2.0GHz	• Processor speed: 3.0GHz
• EP calculations time: 4.79 minutes	• EP calculations time: 3.02 minutes	• EP calculations time: Est. 2 minutes
• Biomechanics calculations time: 1.3 minutes	• Biomechanics calculations time: 2.78 seconds	• Biomechanics calculations time: Est. 1.39 seconds
• RAM usage (basic): 1.15GB	• RAM usage (basic): 100MB	• RAM usage (basic): Est. 500 MB
• RAM usage (advanced): 2.6GB	• RAM usage (advanced): Est. 500MB	• RAM usage (advanced): Est. 1GB
• CPU usage (basic): 50%	• CPU usage (basic): 88%	• CPU usage (basic): Est. 60%
• CPU usage (advanced): 60%	• CPU usage (advanced): 100%	• CPU usage (advanced): Est. 80%

Figure 5. Photo of ORNL institutional clusters via <http://oic.ornl.gov>.