Whole Heart Computational Modeling

Allen X. Manning
Alabama A&M University
Research Alliance in Math and Science
Computational Sciences and Engineering, Oak Ridge National Laboratory
Mentors: Dr. Richard C. Ward; Kara L. Kruse M.S.E.
Faculty Advisors: Dr. Cathy Qian, Dr. Zhengtao Deng
https://info.ornl.gov/sites/rams09/a_manning/Pages/default.aspx

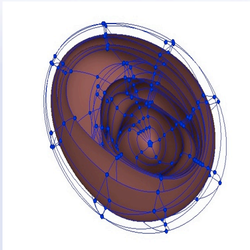


Figure 3: Heart mesh and surfaces rendered on *Continuity 6.3b*.

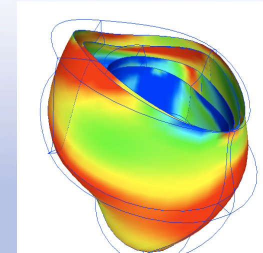


Figure 4: heart mesh and biomechanics rendered on *Continuity* 6.3b.

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

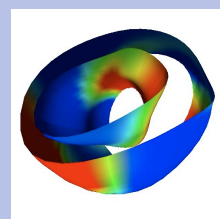


Figure 1. Heart electrophysiology model with rounded coarse mesh orientation.

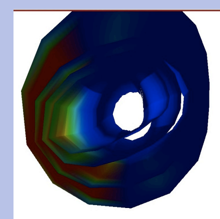
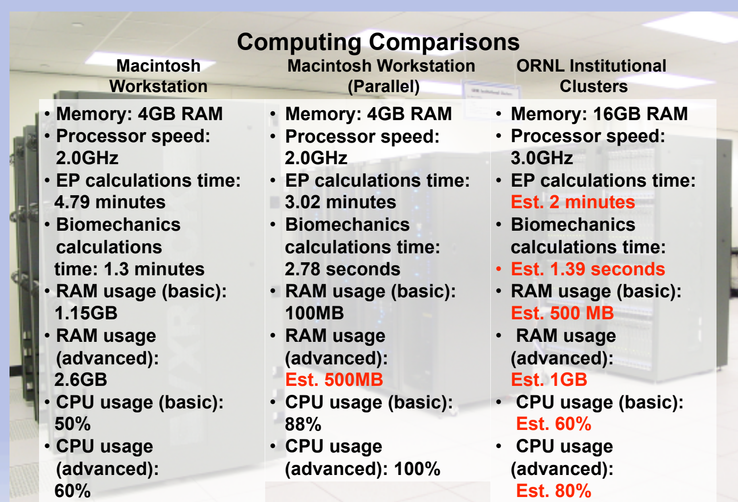


Figure 2. Heart electrophysiology model with linear fine mesh orientation.



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.

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

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