A UT/ORNL PARTNERSHIP
NATIONAL INSTITUTE FOR COMPUTATIONAL SCIENCES
NICS

Numerical Simulation of a Coupled Electro-Mechanical Heart Model

Henian Xia, Kwai Wong, Wenjun Ying, and Xiaopeng Zhao

National Institute for Computational Sciences

University of Tennessee

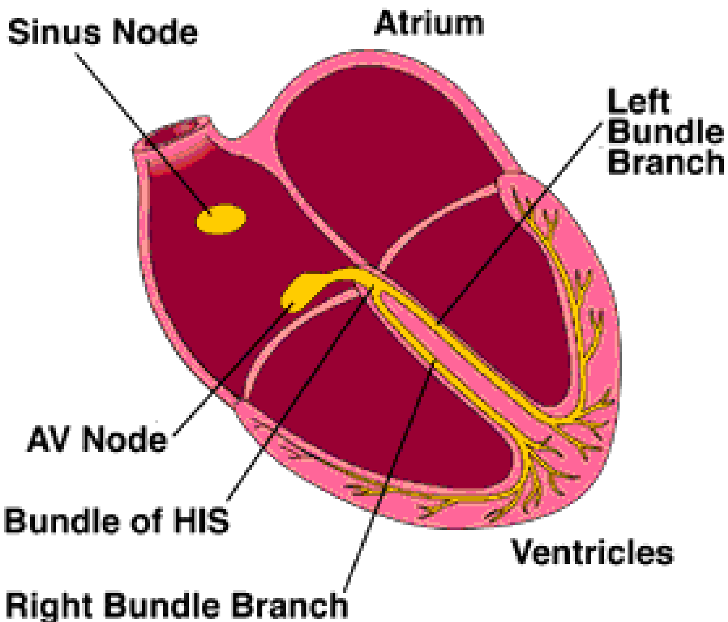
Michigan Technological University

MichiganTech

NSF

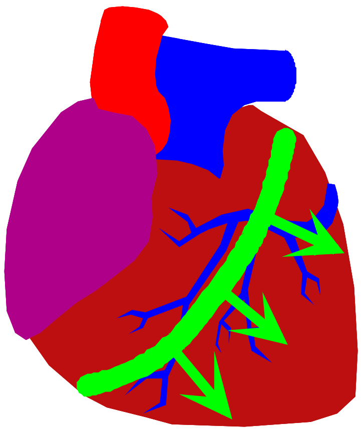
Goal: Understand the dynamics of Sudden Cardiac Arrest

- **Heart: An electro-mechanical pump**
- **Pumps 2,000 gallons of blood**
- **Beats 100,000 times/day**
- **2.5 billion times in lifetime**

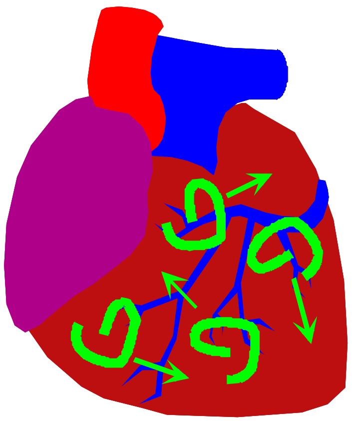


http://heartpoint.com

- **Sudden Cardiac Arrest: Not a heart attack**
- **Occur rapidly without warning**
- **A dynamical disease, that affects anyone, regardless of age, gender, and physical fitness**



Normal Rhythm



Sudden Cardiac Arrest

Model: Electrical + Physiological + Mechanical

$$\frac{dV}{dt} = -(I_{stim} + I_{Na} + I_{K1} + I_{Kr} + I_{Ks} + I_{to} + I_{Kp} + I_{NaK} + I_{NaCa} + I_{Nab} + I_{Cab} + I_{pCa} + I_{Ca} + I_{CaK})$$

Model at global level: a system of PDEs describing the interactions of the electromechanical and physiological actions.

Model at cellular level: a set of ODEs describing the change of voltage and ionic currents.

$$\nabla \cdot (\mathbf{D}(\mathbf{C})\nabla V) = C_m(\mathbf{C})\frac{\partial V}{\partial t} + I_m(\mathbf{C})$$

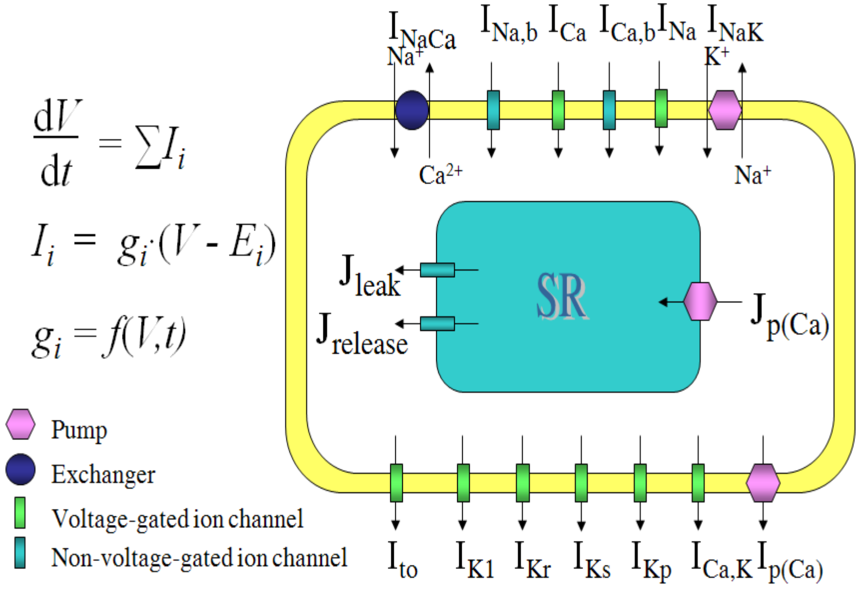
$$T^{MN} = \frac{1}{2}\left(\frac{\partial W}{\partial E_{MN}} + \frac{\partial W}{\partial E_{NM}}\right) + T_a C^{MN}$$

$$C_m\frac{\partial V}{\partial t} = \frac{1}{\sqrt{C}}\frac{\partial}{\partial X^M}\left(\sqrt{C}D_N^M C^{NL}\frac{\partial V}{\partial X^L}\right) - kV(V-a)(V-1) - rV + I_s,$$

$$\frac{dV}{dt} = \sum I_i$$

$$I_i = g_i(V - E_i)$$

$$g_i = f(V,t)$$



$$\frac{\partial r}{\partial t} = \left(\varepsilon + \frac{\mu_1 r}{\mu_2 + V}\right)(-r - kV(V-b-1)),$$

$$\frac{\partial T_a}{\partial t} = \epsilon(V)(k_{T_a}V - T_a),$$

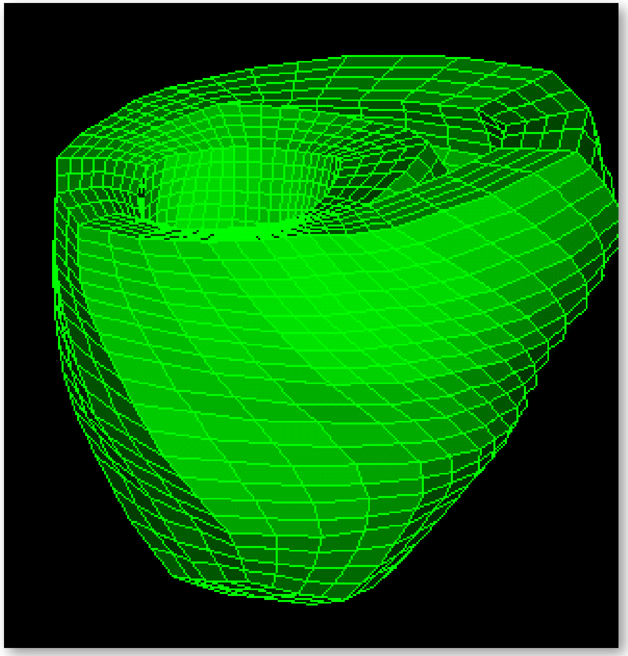
Fox et al., Am J Physiol, 2002

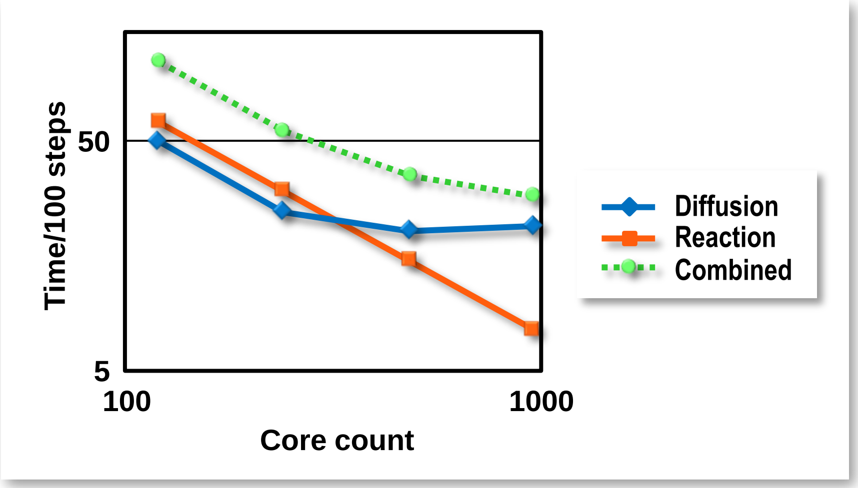
NSF

NICS

Collaborative Computational Effort: 1000+ Cores

- Collaborative research on kraken between NICS and University partners
- Transform a 2D serial research code to a multi-physics 3D parallel code (1000 + Core)
- Solve a set of diffusion reaction equations
- Mesh refinement: CUBIT
- Domain decomposition: Metis
- Efficient I/O distribution
- Finite Element scheme: 3D hexahedron
- Cell-wise reaction: Euler ischeme
- Linear solve package: Trilinos
- VTK output: VISIT used for visualization





Contact

Kwai L. WONG

Joint Institute for Computational Science
The University of Tennessee
Knoxville, TN 37996
kwong@utk.edu