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ELECTROCARDIAC DEFIBRILLATION MODELING

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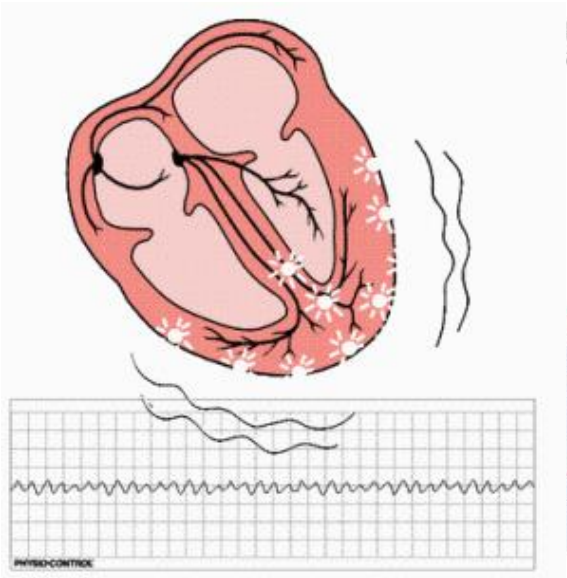
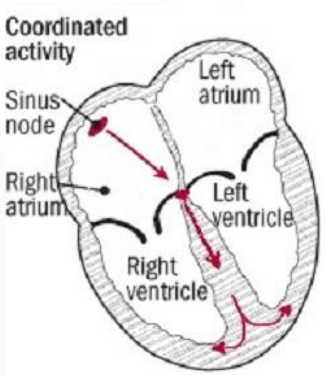
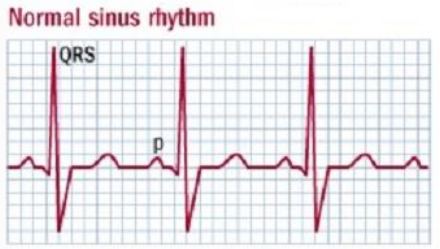
Motivation

— Cardiac Fatal Diseases

- Sudden cardiac death (SCD): unexpectedly, spontaneously death from heart arrest.
- Ventricular fibrillation (VF): uncoordinated contraction of the muscle of the ventricles.
- Fibrillation is a turbulent electrical state, causing death if not treated.







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Defibrillation

— Treatment for fibrillation

- Strong electrical shock
- Electrical shock/heart boundaries

  - gives virtual electrodes
- Resets the electrical wave of the heart to its normal routine.

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Goals

- Understand role of virtual electrodes in terminating fibrillation.
  - Defibrillation simulations
  - Analysis of filaments interacting with virtual electrodes

- LEAP as well as normal defibrillating voltages

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Main Results

- Defibrillation electrical shock creates the virtual electrodes in realistic heart geometry.
- Virtual electrodes appears primarily near the epi/endocardium cardiac surfaces and large blood vessels play a secondary but still important. However, small blood vessels appear to have smaller role.
- Strong shock defibrillation extends polarized region to terminate fibrillation.
- LEAP defibrillation:
  - Extensive filament motion during LEAP as possible contributor to LEAP defibrillation.
- Sensitivity of the simulations to the conductivity values and blood vessel walls.

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Resources for Computing

- LIred and Handy cluster (IACS at SBU)
  - 8 hours using 192 processors for 10ms defibrillation simulation

- Possible role of GPU speed up, collaborating with cyber heart community as chaste upgrade.

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Defibrillation Modeling

- Chaste
  - Bidomain with a Bath problem
  - finite element method

- Two currents added to Chaste
  - Electroporation
  - Asymmetric response

- Blood vessel wall model (inter/outer wall)

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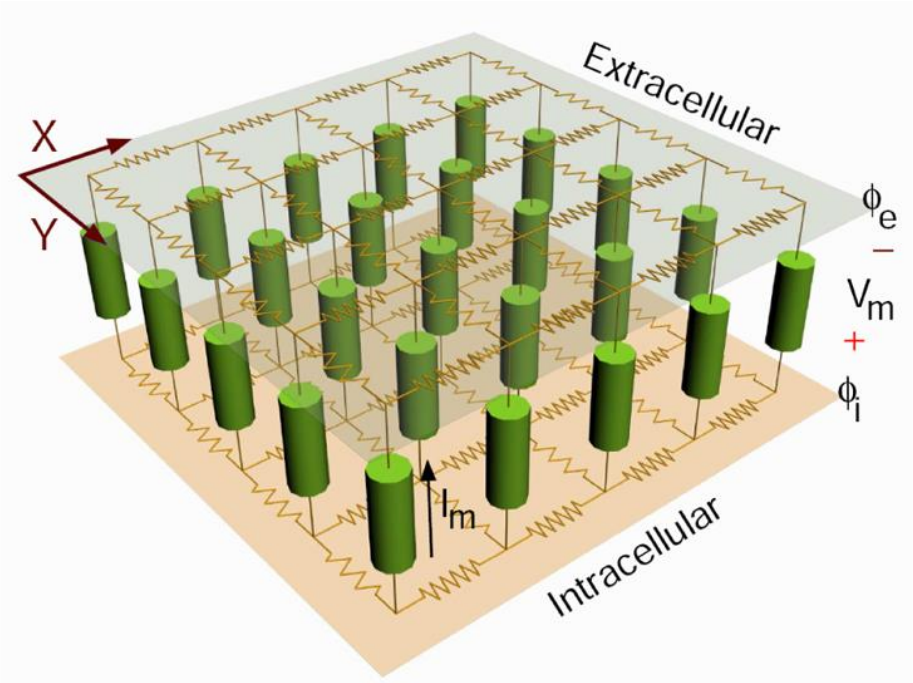
Cardiac Model for Defibrillation Simulation — Bidomain Model

- Most complete computationally tractable cardiac tissue model.
- Explicit account for both extracellular and intracellular domains.
- Able to model unequal anisotropy ratios and defibrillation.



ϕ_i, ϕ_e: intracellular, extracellular potential

V_m: transmembrane voltage

$V_m = \phi_i - \phi_e$

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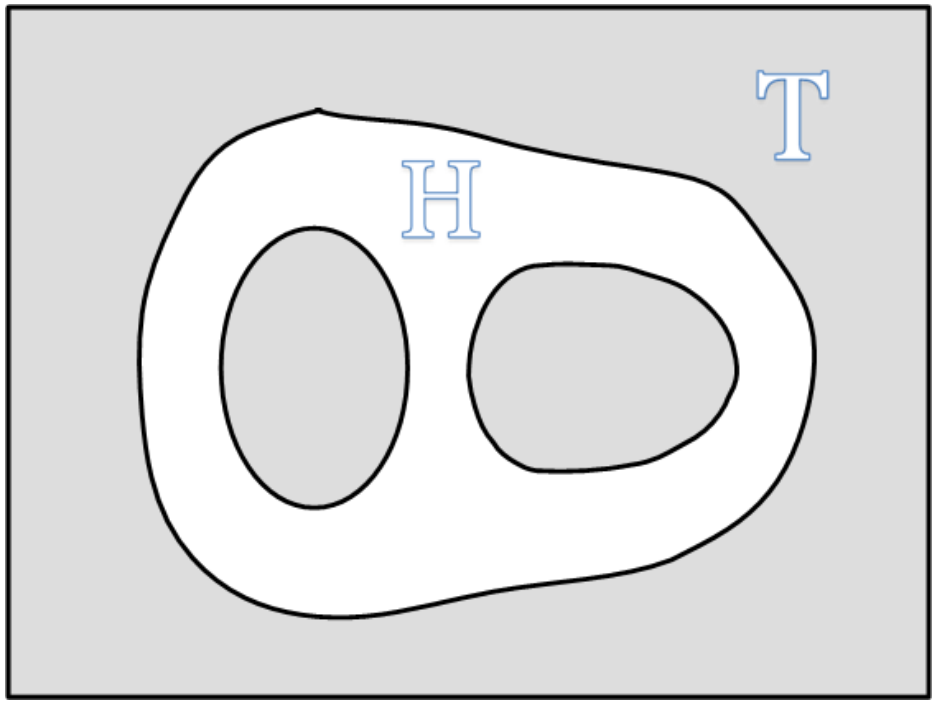
Cardiac Model for Defibrillation Simulation

— Bidomain with a Conductive Bath

- Solution domain $\Omega = \mathbb{H} \cup \mathbb{T}$.
- Heart tissue region $\mathbb{H}$ composed of overlapping intracellular and extracellular spaces.
- Perfusing bath region $\mathbb{T}$.
- Bath potential ϕ_t in $\mathbb{T}$
- Electrodes act on the bath boundary only.



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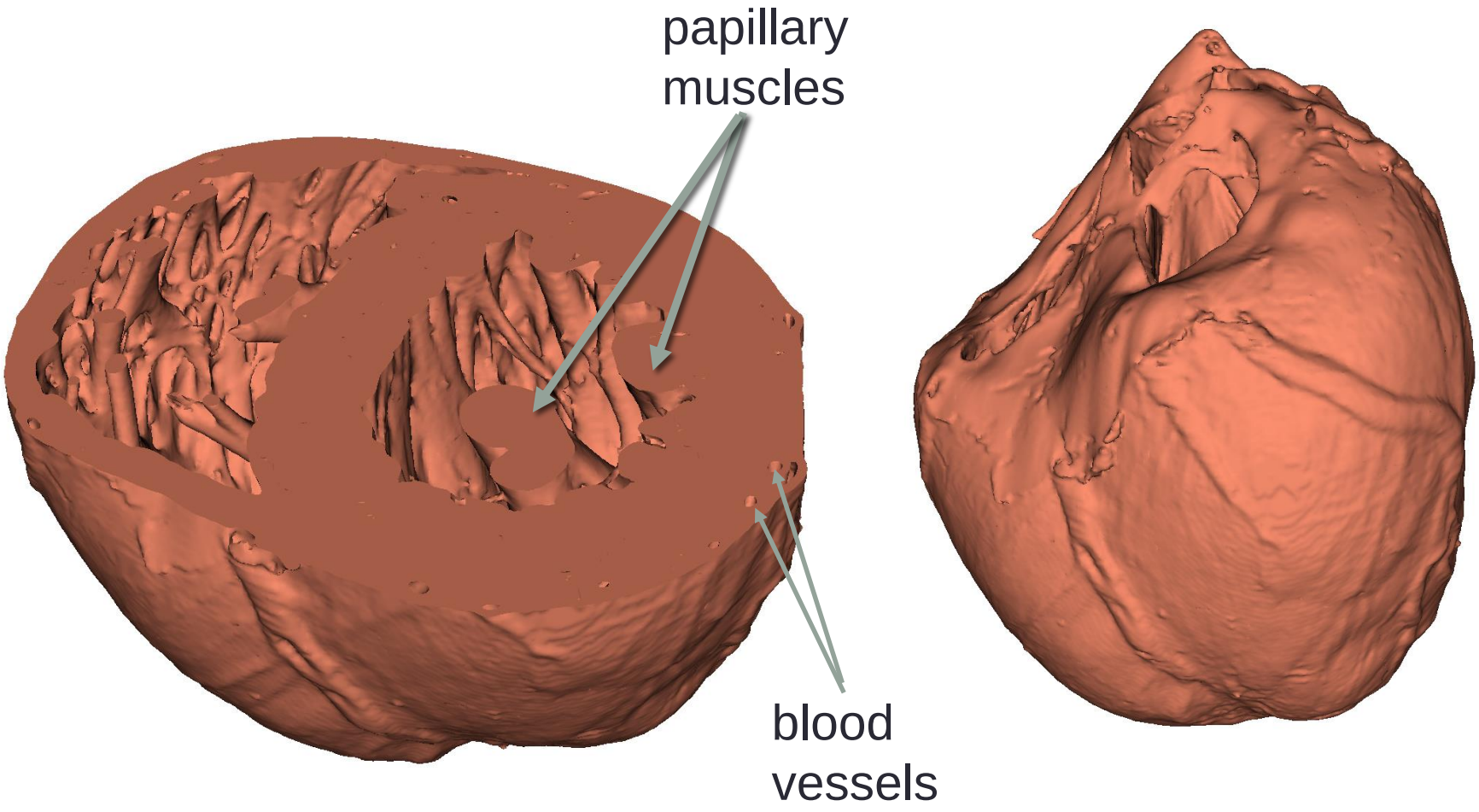
Oxford Rabbit Heart – High Resolution Tetrahedral Mesh (40M) Reconstructed from MRI data



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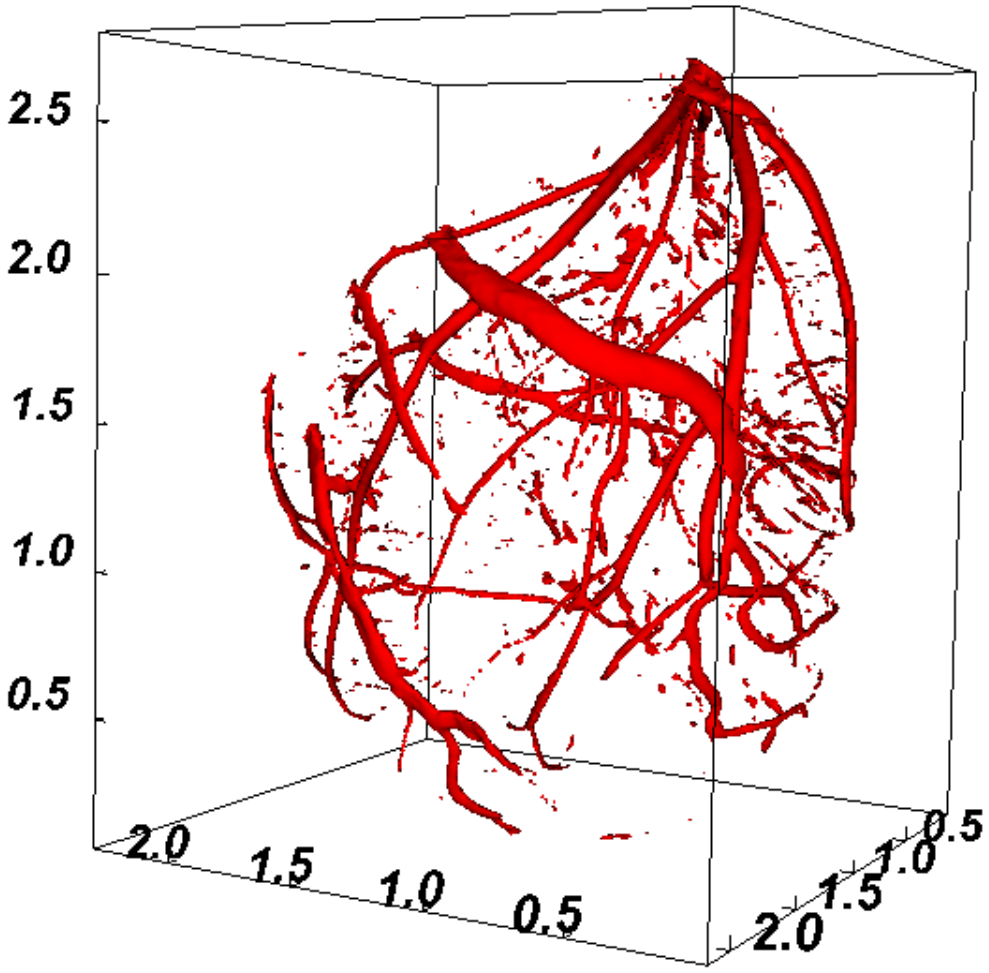
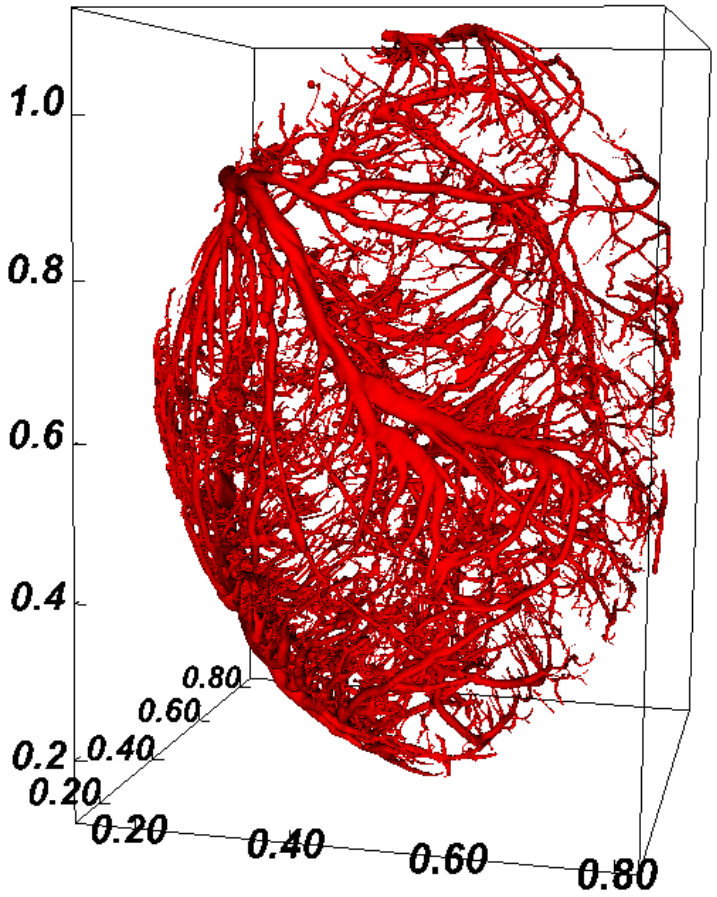
Blood vessels of Rabbit heart from Chaste tetrahedral mesh (left) vs. Rat vasculature (right)





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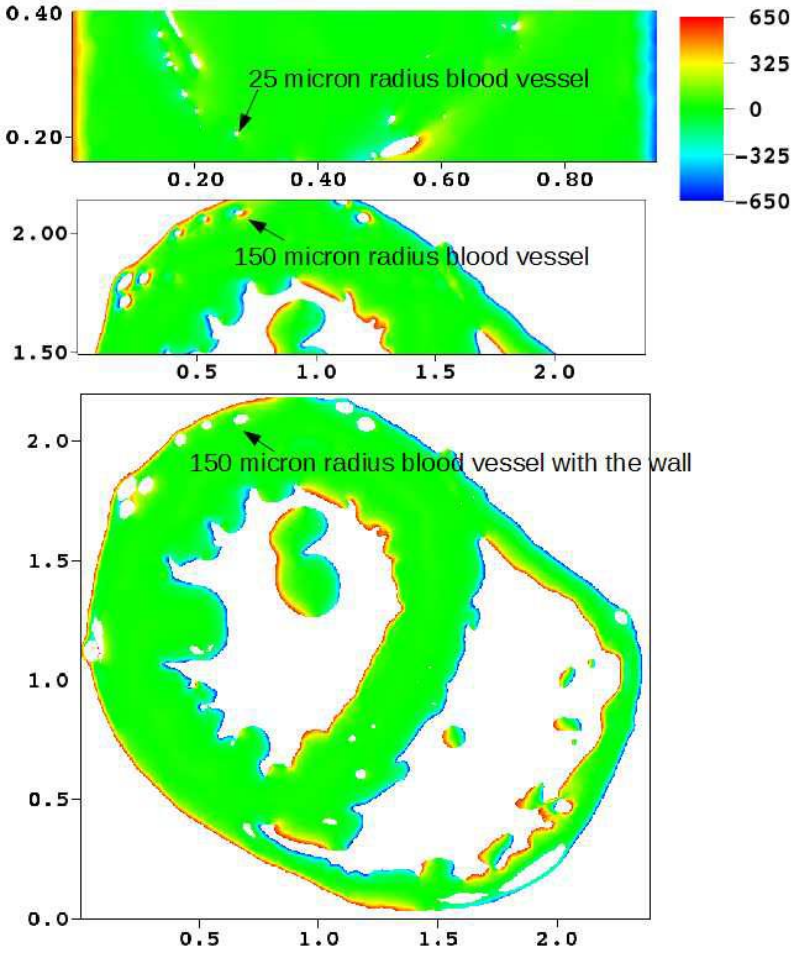
Isotropic simulations with Rat and Rabbit



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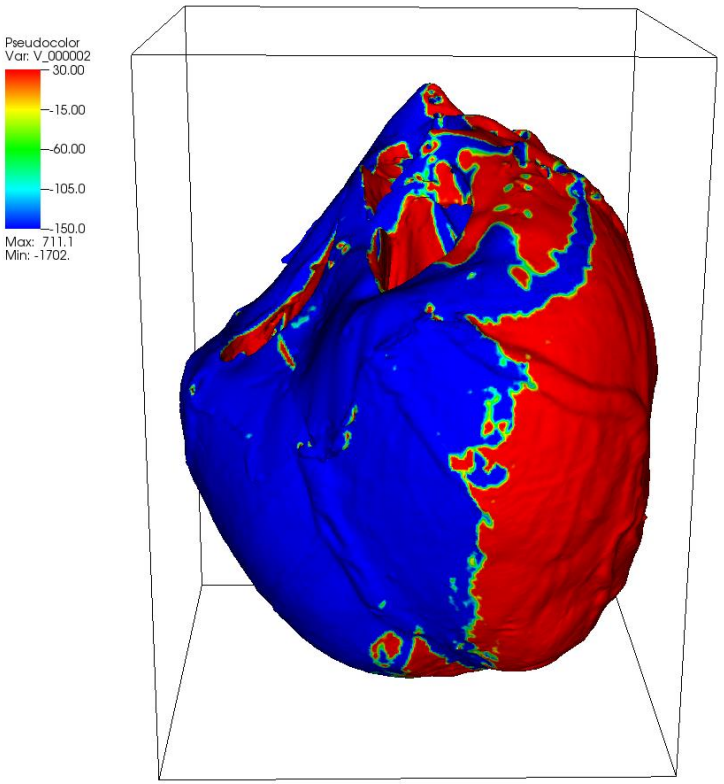
Defibrillation Simulation —Bidomain with Bath Problem



- Computational domain (2.4x2.4x3.2cm) in a model of cardiac tissue contained in a conductive bath.
- The color represents transmembrane voltage and the Initial voltage is -83 mV.
- Use of physiological parameters.
- Duration of shock: 1 ms
- Shock strength: 50V/cm
- The electrodes are placed at the bath boundary surfaces
  x = min x and x = max x.

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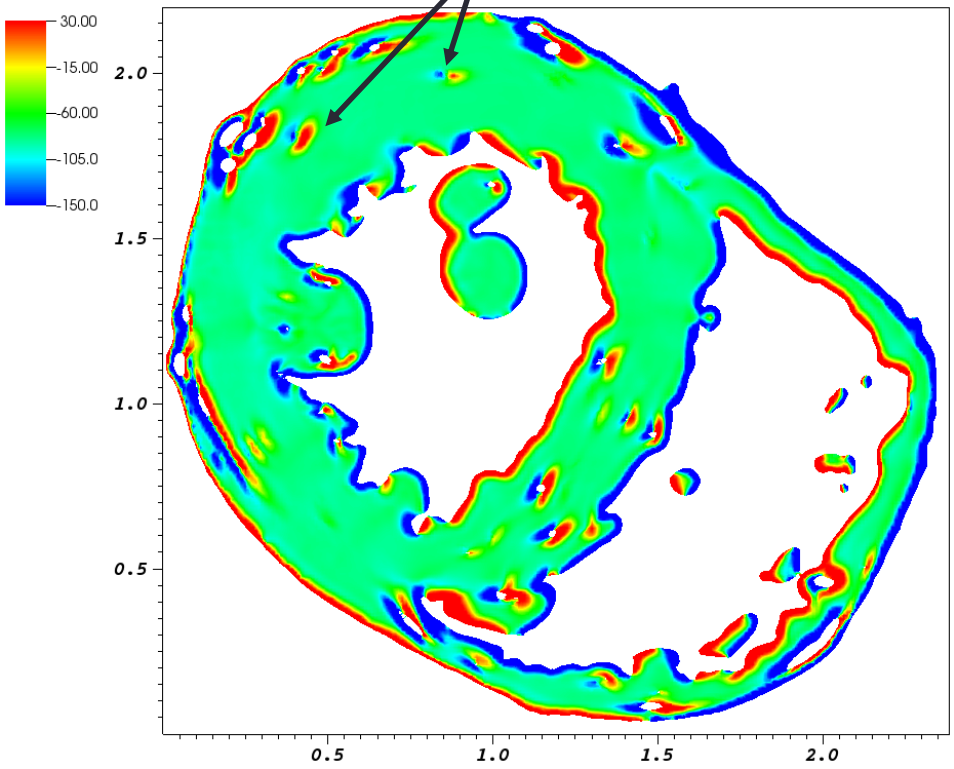
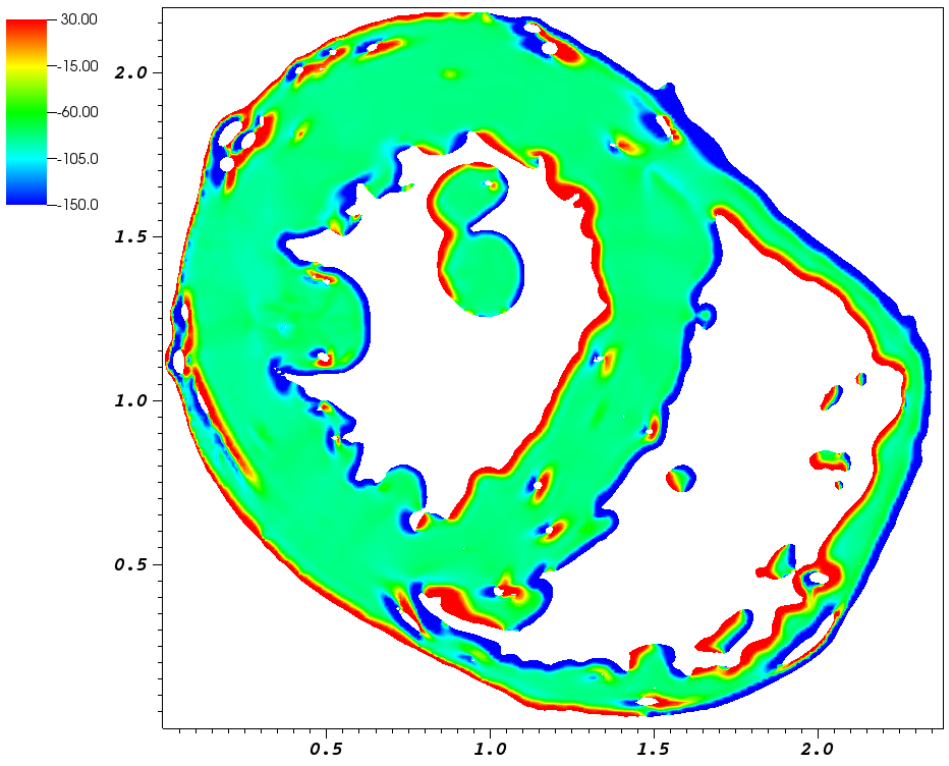
Sensitivity to the blood vessel wall

— Virtual Electrodes by Externally Applied Electrical Shock

virtual electrodes near small blood vessels without vessel wall model



Without Wall (1S/m)



With Wall (0.01S/m ; 1S/m)

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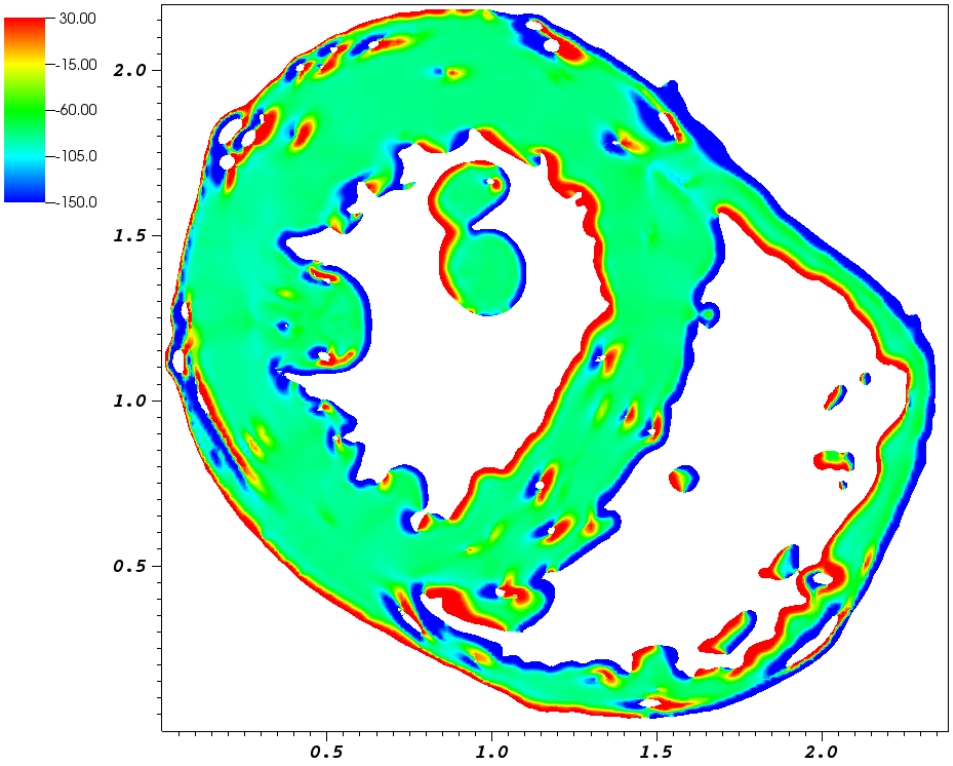
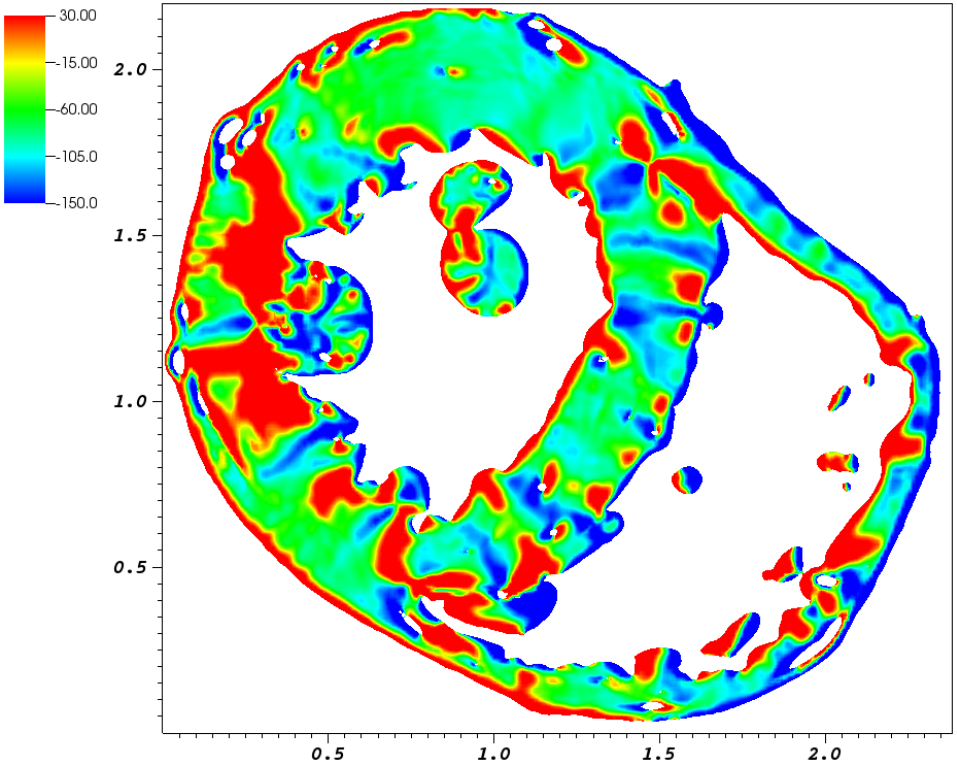
Sensitivity to Conductivity values





	longitudinal	transverse	longitudinal	transverse
Intracellular	0.175	0.019	0.174	0.019
Extracellular	0.7	0.07	0.625	0.236

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Motion of Filaments

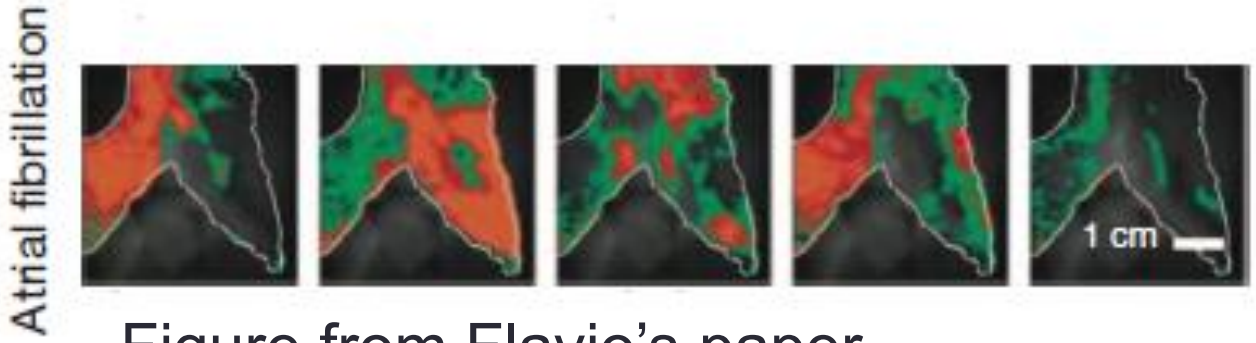
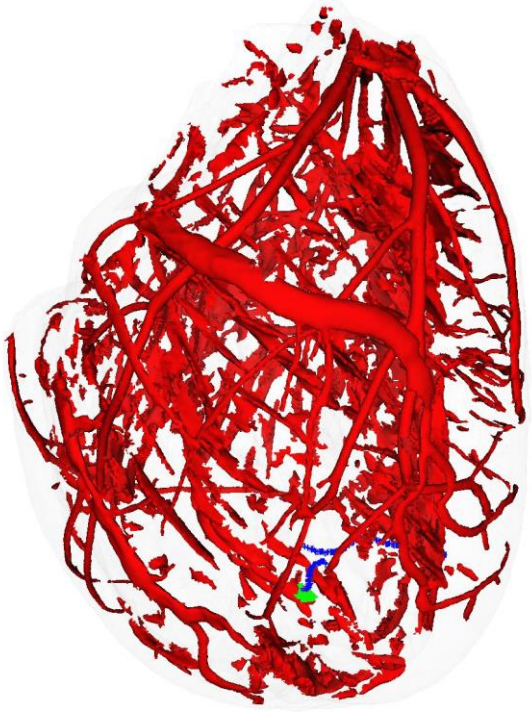


Figure from Flavio's paper



Filaments (blue curves) dynamics interacting with blood vessels and heart surfaces (green dots) and so virtual electrodes.

Filament data from Rick and Pras

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Four LEAP scenarios

1. Distributed sources for virtual electrodes
2. Dynamic motion of the filaments
3. Near virtual electrode scroll motion
4. Filament tension

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Future Plans

- LEAP defibrillation studies to differentiate among multiple possible mechanisms

- Consider dog or pig models
  - Larger animals
  - Experimental data