Applications of Biomedical Computing in the Heart

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Center for Integrative Biomedical Computing (CIBC)

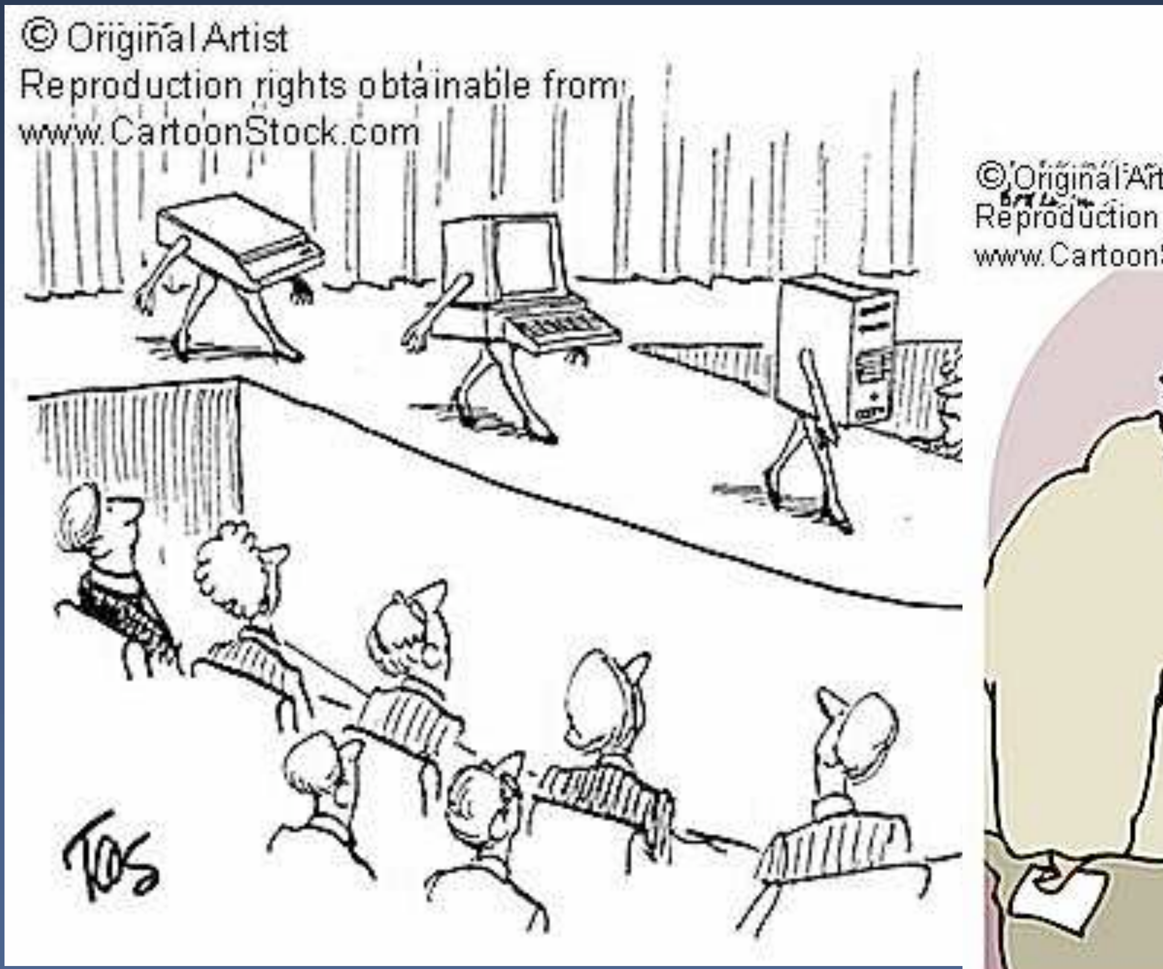
University of Utah

Utah NCRR Center

Goals

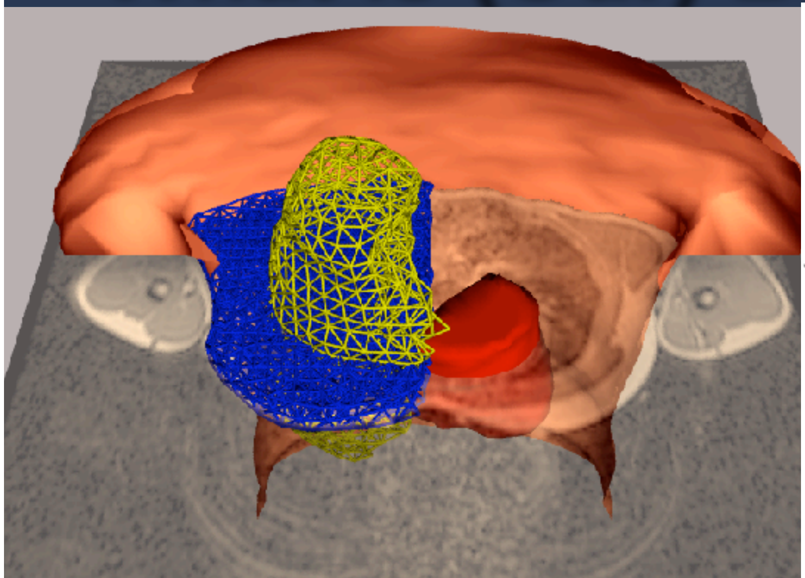
- Produce **cutting edge software** for biomedical researchers
- Develop **new techniques and algorithms** in image processing, geometric modeling, simulation and visualization
- Carry out **original research** in segmentation, bioelectric field simulation, and visualization

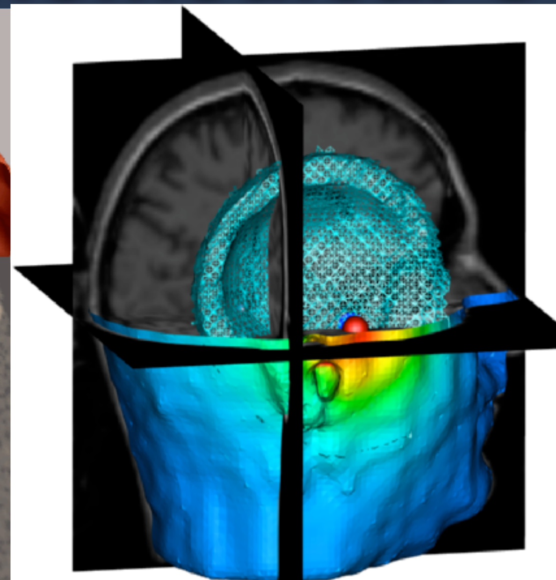
Computer Modeling

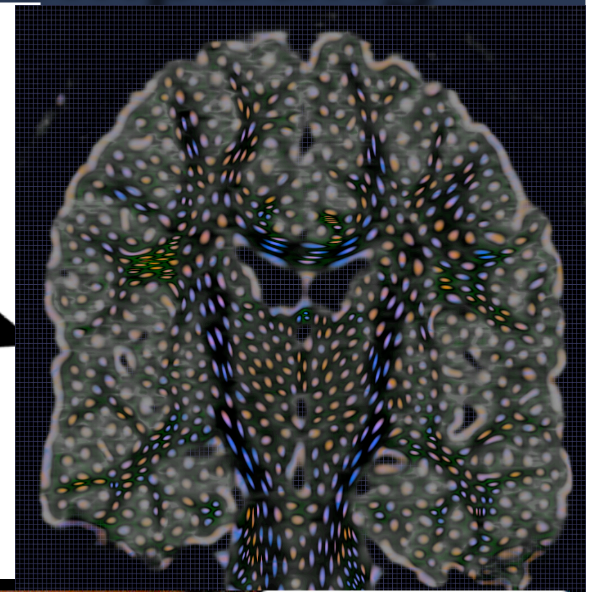


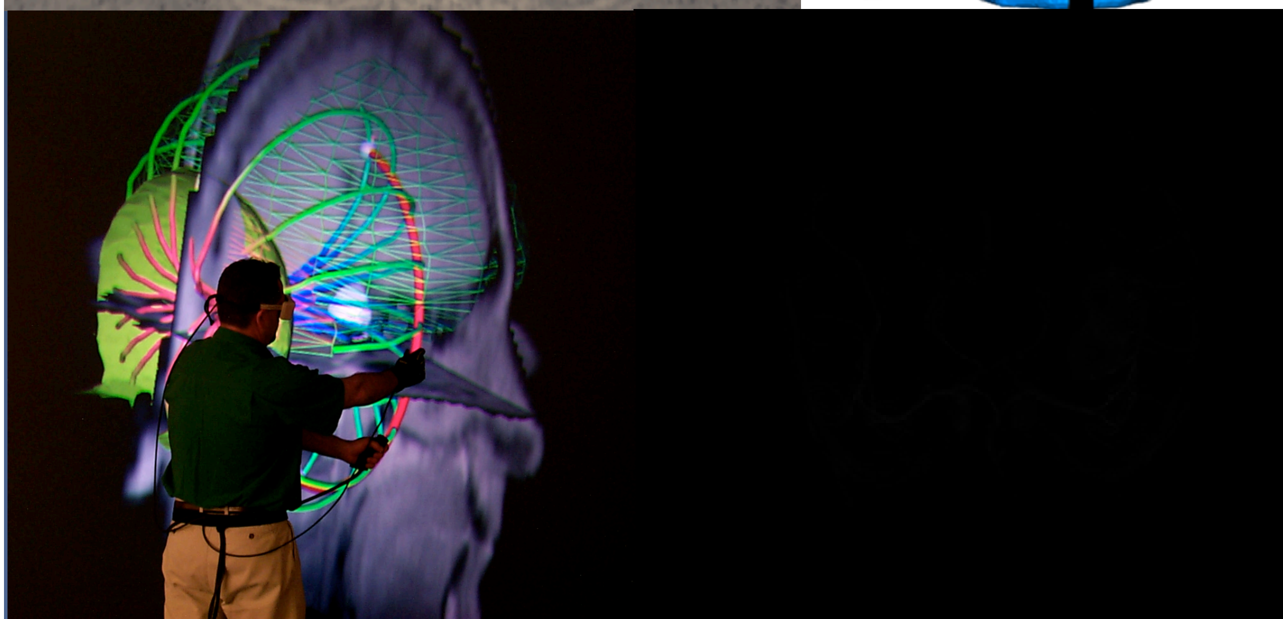
"It's very user-friendly, once it gets to know you."

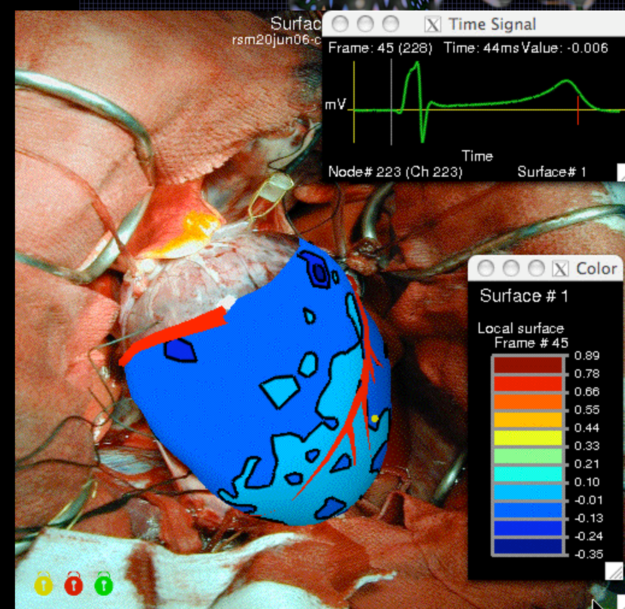
What is (Our) Biomedical Computing?



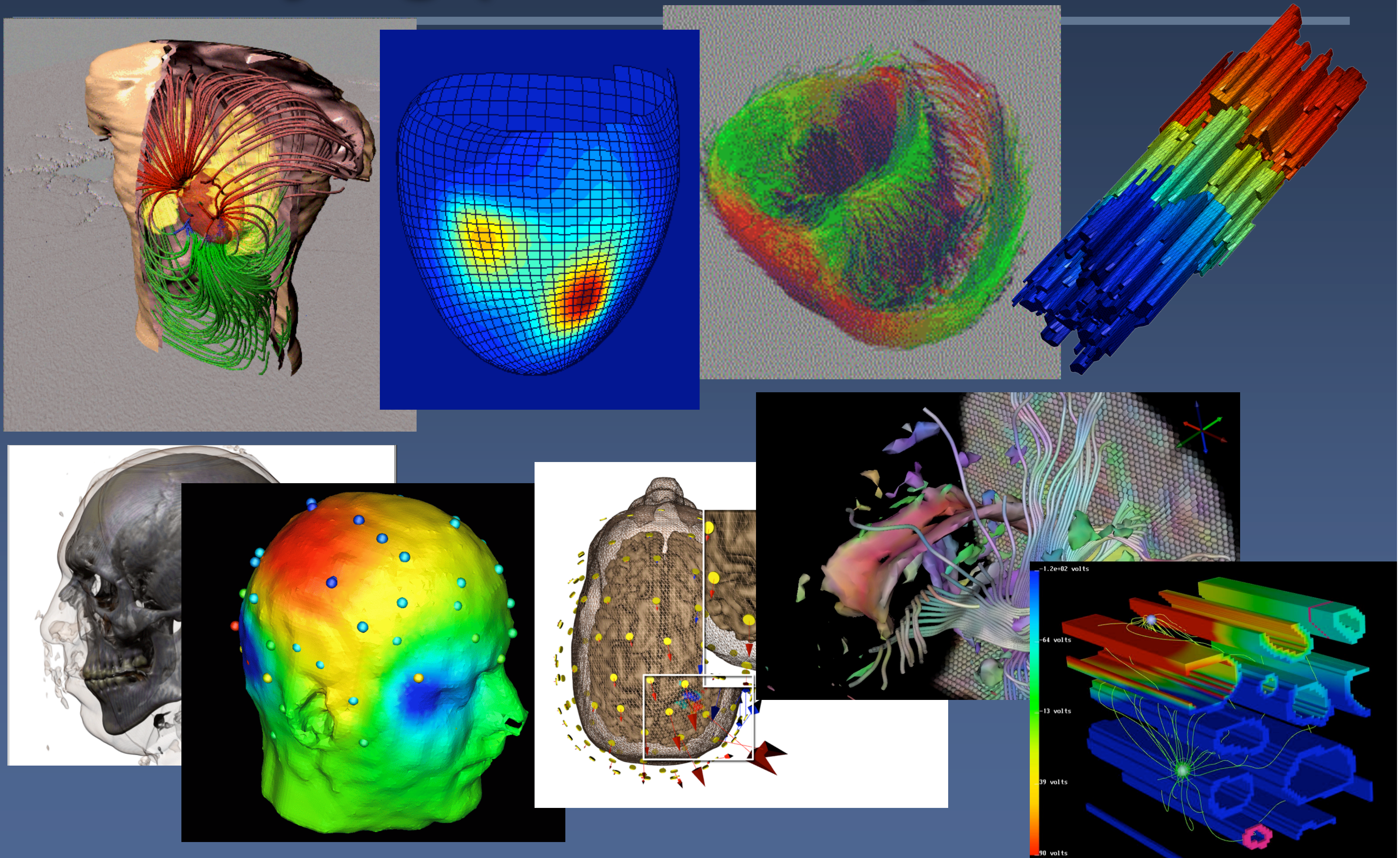








Identifying (Biomedical) Problems



Nobel Prize Problems

Structure of voltage gated potassium channels:

- Rod MacKinnon (Chemistry)
- Computation for image reconstruction for x-ray diffraction and mass spectrometry data

Discovery of water channels

- Peter Agre (Chemistry)
- Augmentation by bioinformatics for identification of water channel genes

Magnetic resonance imaging

- Lauterbur and Mansfield (Physiology)
- Mathematical and computational techniques for inferring structure and image

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How to Pick a Problem

Interesting

- Compelling, relevant, personal
- Structure-Function relationship

Feasible

- Simple enough to have a solution
- Complicated enough to grow

Supported by good and plentiful data

- Experimental partner (who trusts computers)

Translational/Clinical impact

- Sex appeal and fundability

Heart vs Brain Physiology

Cells:
- 8 billion
- fairly homogeneous

Tissue structure:
- syncitial

Function:
- It's only a pump!

Cells:
- 100 billion
- very diverse

Tissue structure:
- Network with many links

Function:
- It's a brain!

Heart vs Brain Computing

Cells:
- HH formalism
- + stochastic
- + EC coupling

Tissue structure:
- Discrete models, cellular automata, bidomain

Function:
- Electrical, mechanical, statistical models

Cells:
- HH formalism
- + stochastic
- + synapse

Tissue structure:
- Discrete models, circuits, neural nets

Function:
- Electrical, chemical, network, and cognitive models

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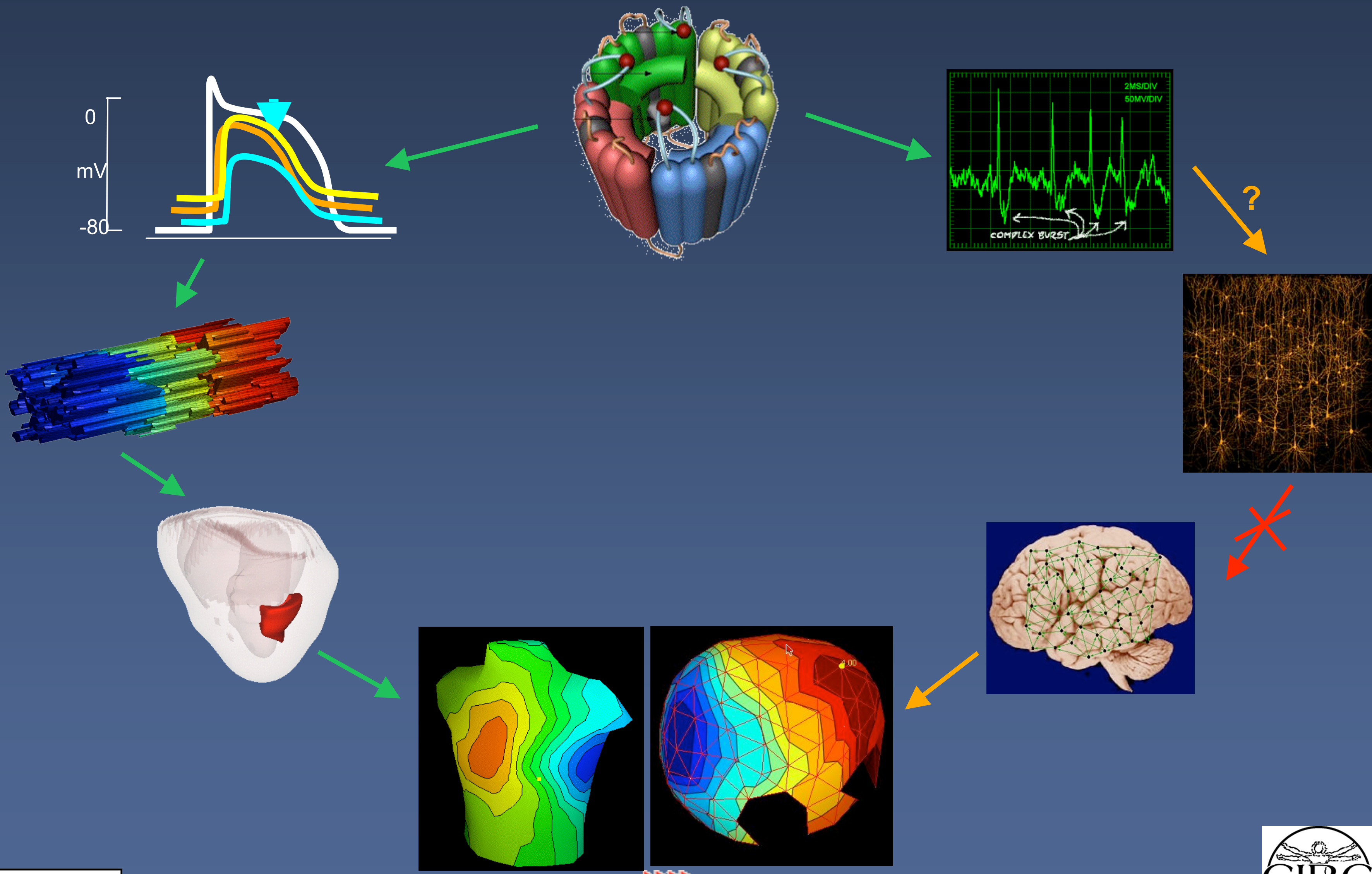
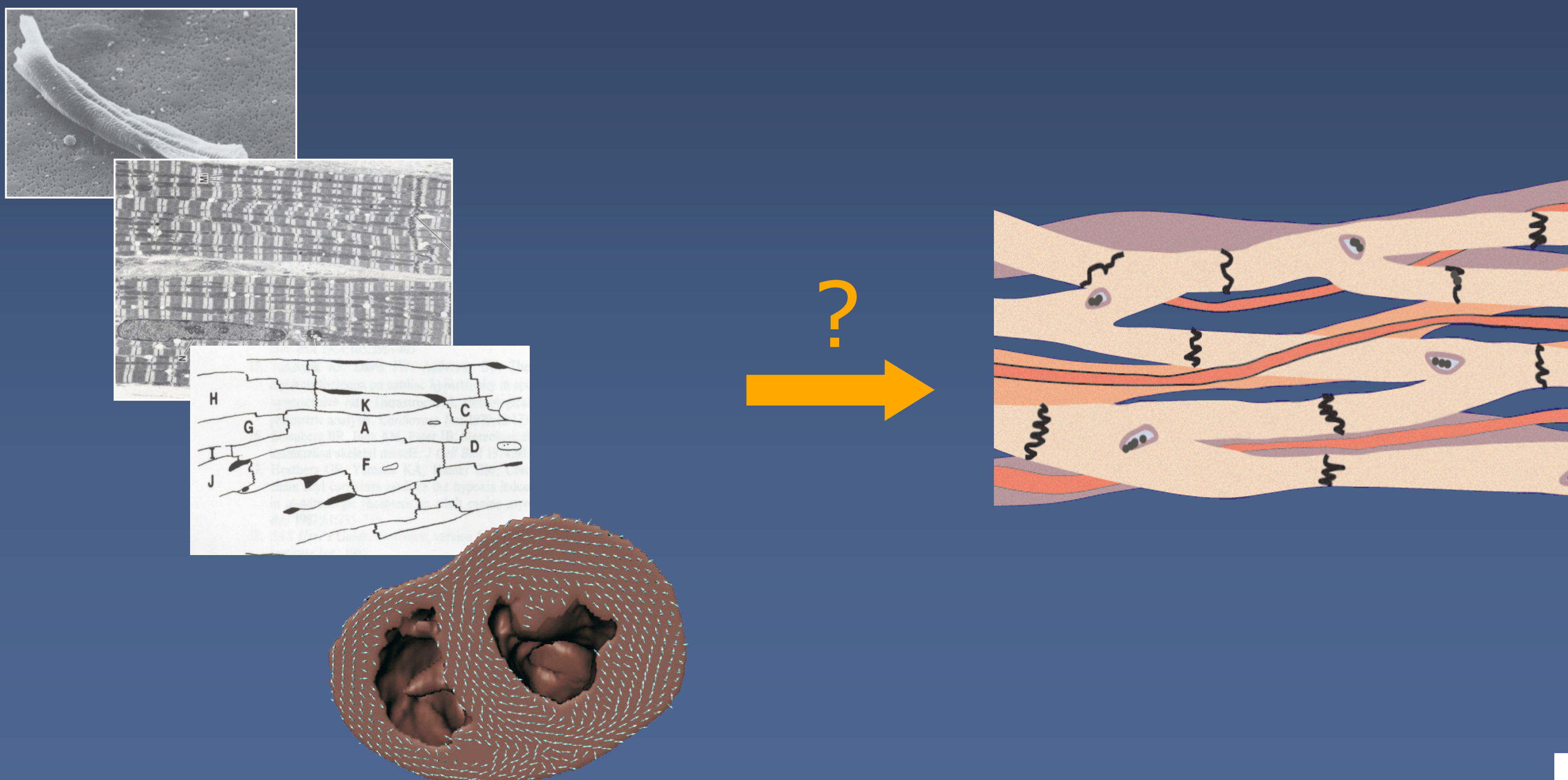
Heart vs Brain (Multi)Scalability

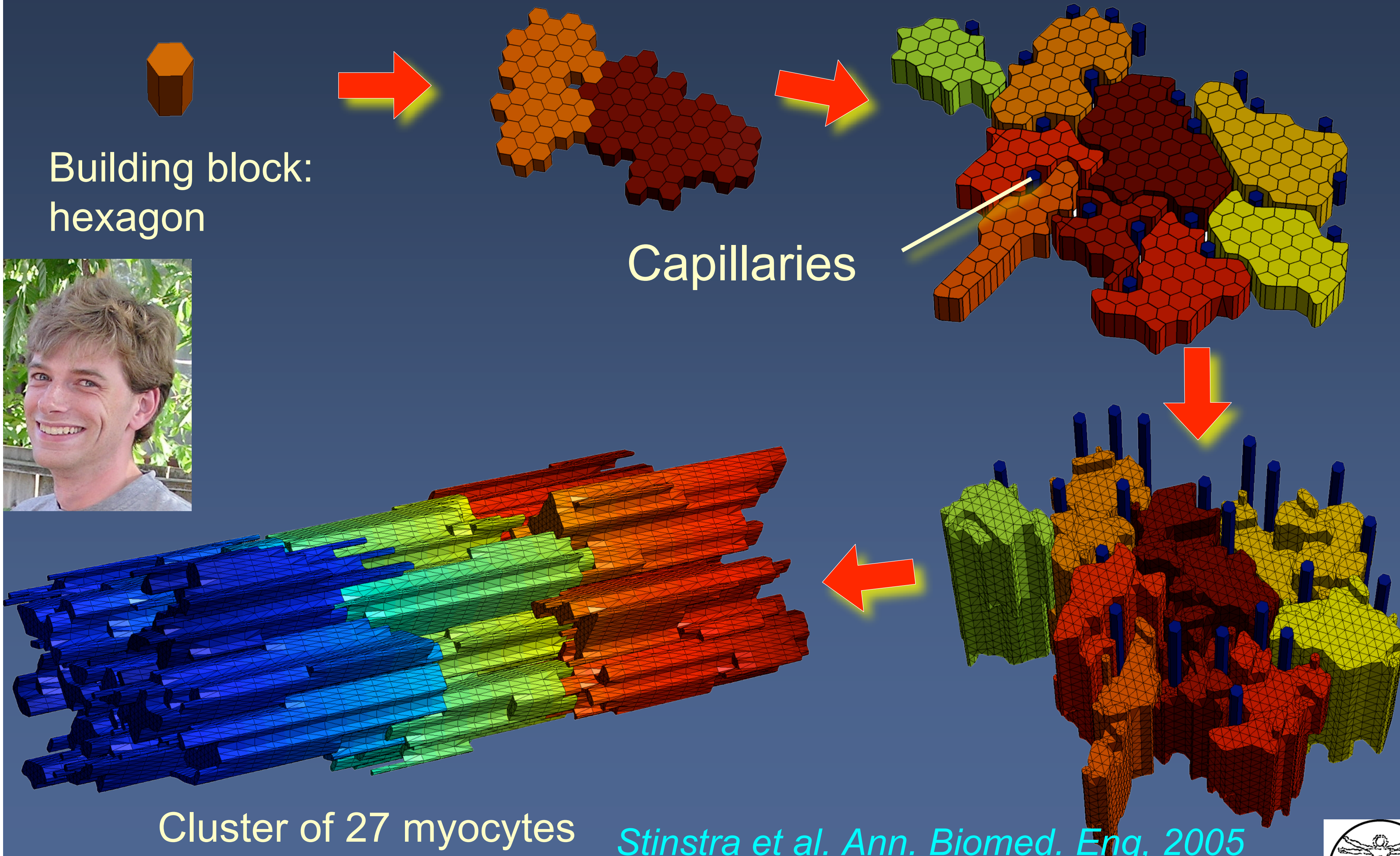


Example 1: Modeling Tissue Structure

How do we incorporate realistic structure and function into heart tissue models ?

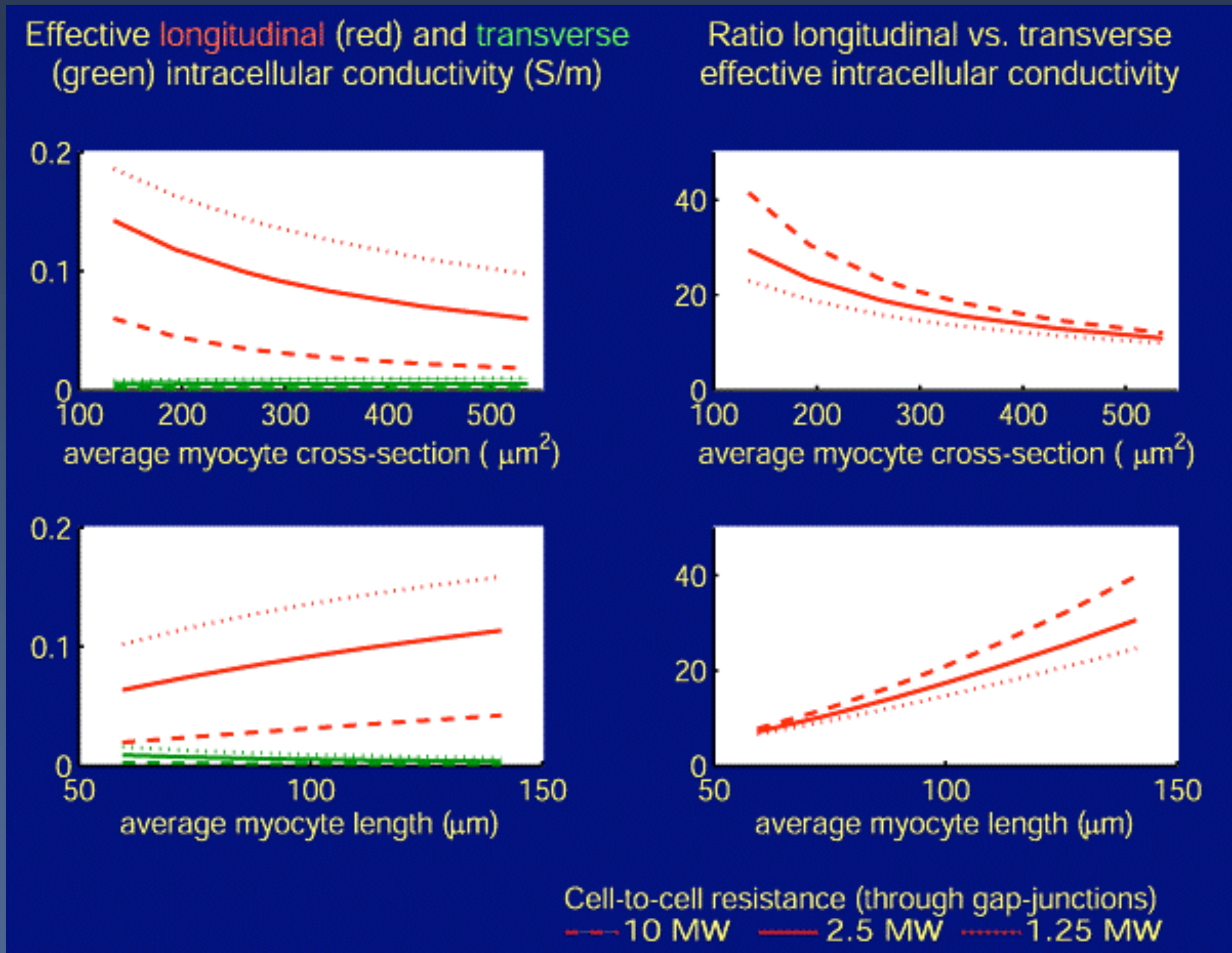


Myocardial Structure



Stinstra et al. Ann. Biomed. Eng, 2005

Passive Tissue Properties



Propagation during ischemia

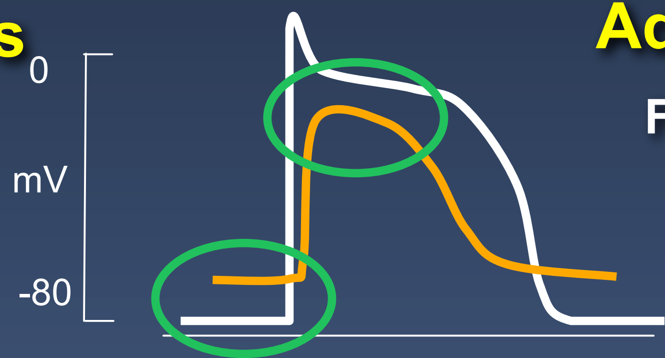
Competing Factors

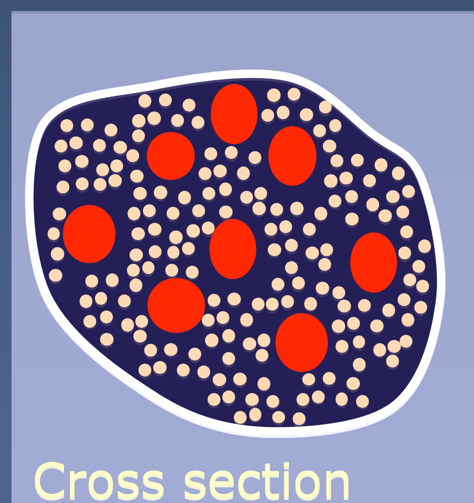
Elevated $[K^+]_e$

- brings resting closer to threshold
- reduces charging current
- accelerates activation

Reduced AP amplitude

- reduces potential difference between cells
- slows down spread of activation





Additional Compexity

Fluid shift

- capillaries collapse
- water enters cells
- reduces extracellular space
- reduces tissue conductivity
- slows spread of activation

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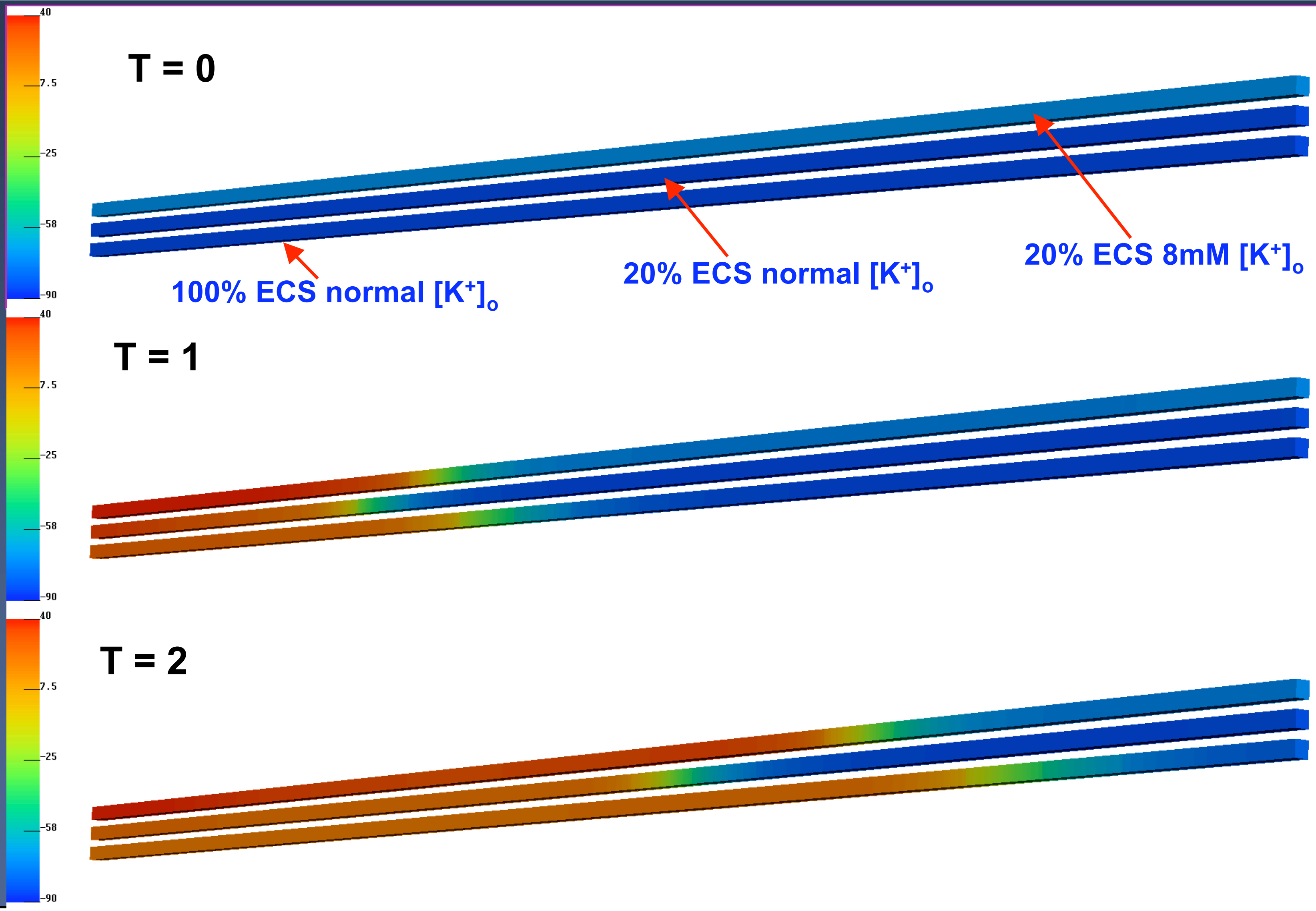
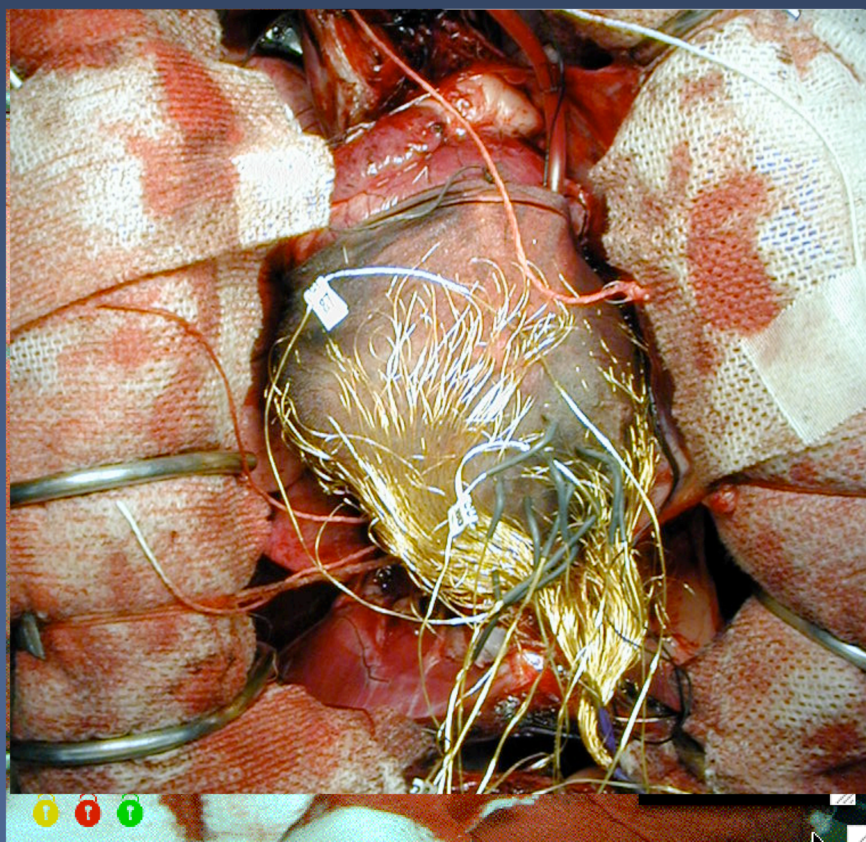
Propagation during Ischemia



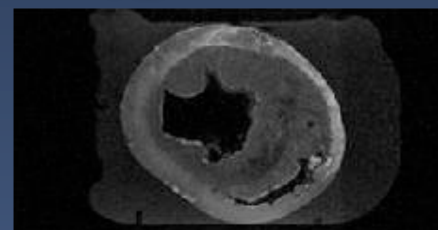
Example 2: Ischemia Modeling

Electrophysiology Experiments

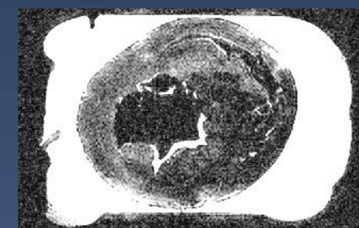


Cardiac Imaging

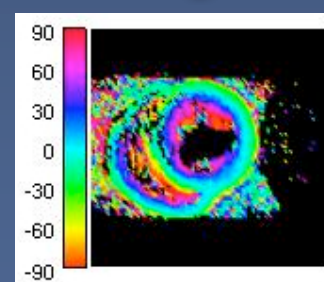
T1



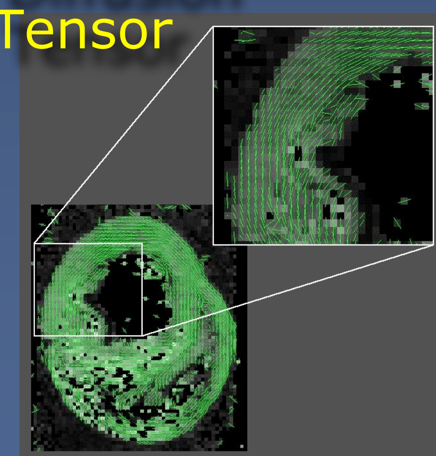
T2



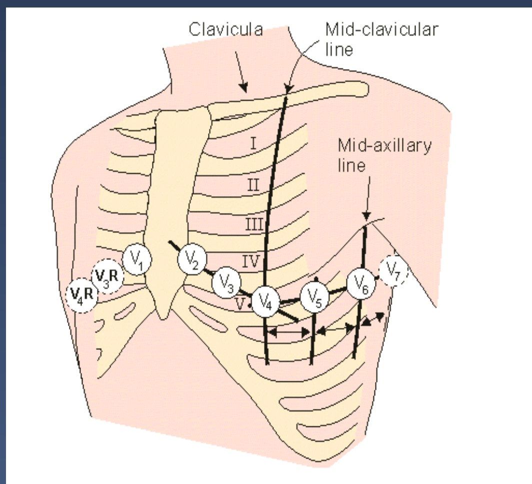
Fiber Angle

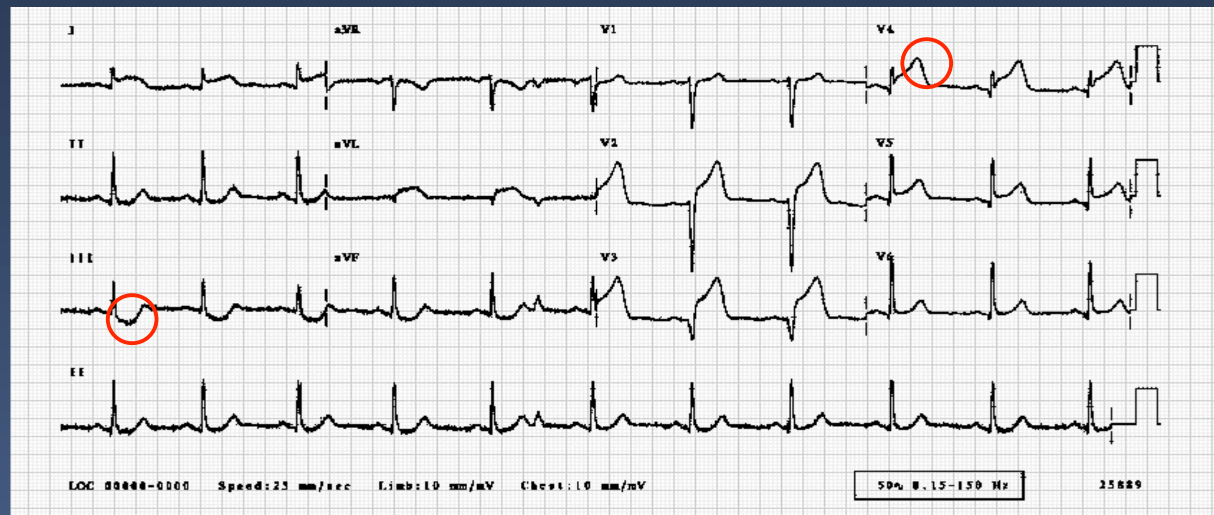


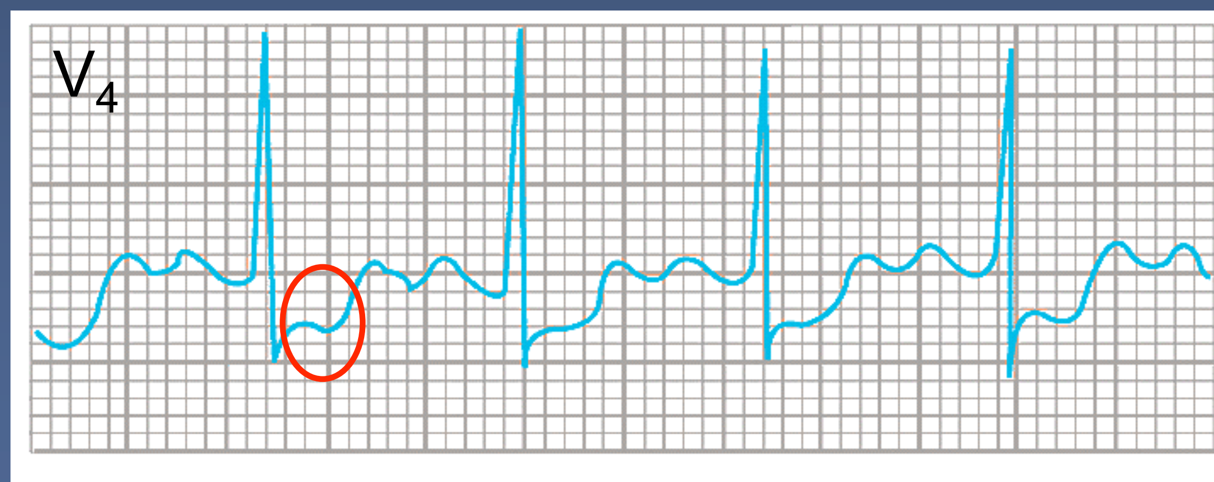
Diffusion Tensor



Transmural and Subendocardial Ischemia







Problem: Diagnosing Ischemia

Clinical challenge:

- ECG: fast by equivocal
- Enzymes: more robust but slow and lack spatial information

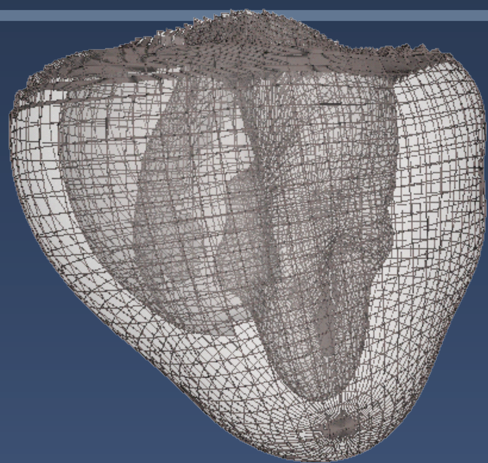
Unavoidably multiscale

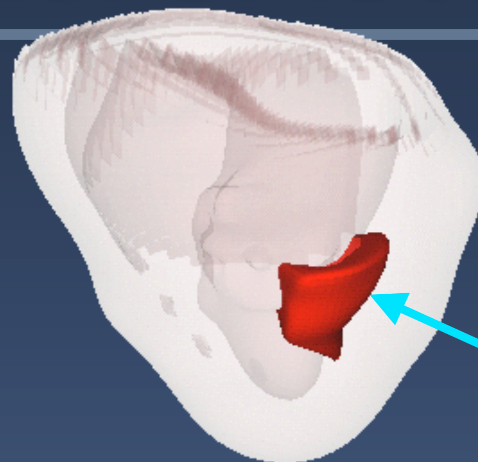
- Cellular, tissue, volume conductor

Impact

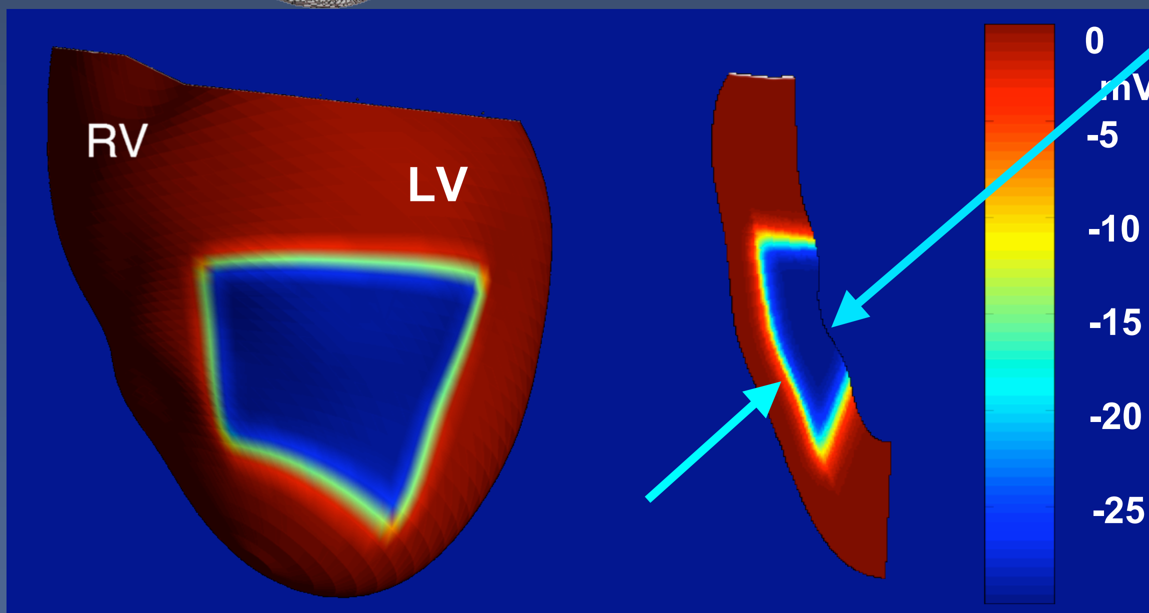
- Enormous

Geometric Model of Ischemia





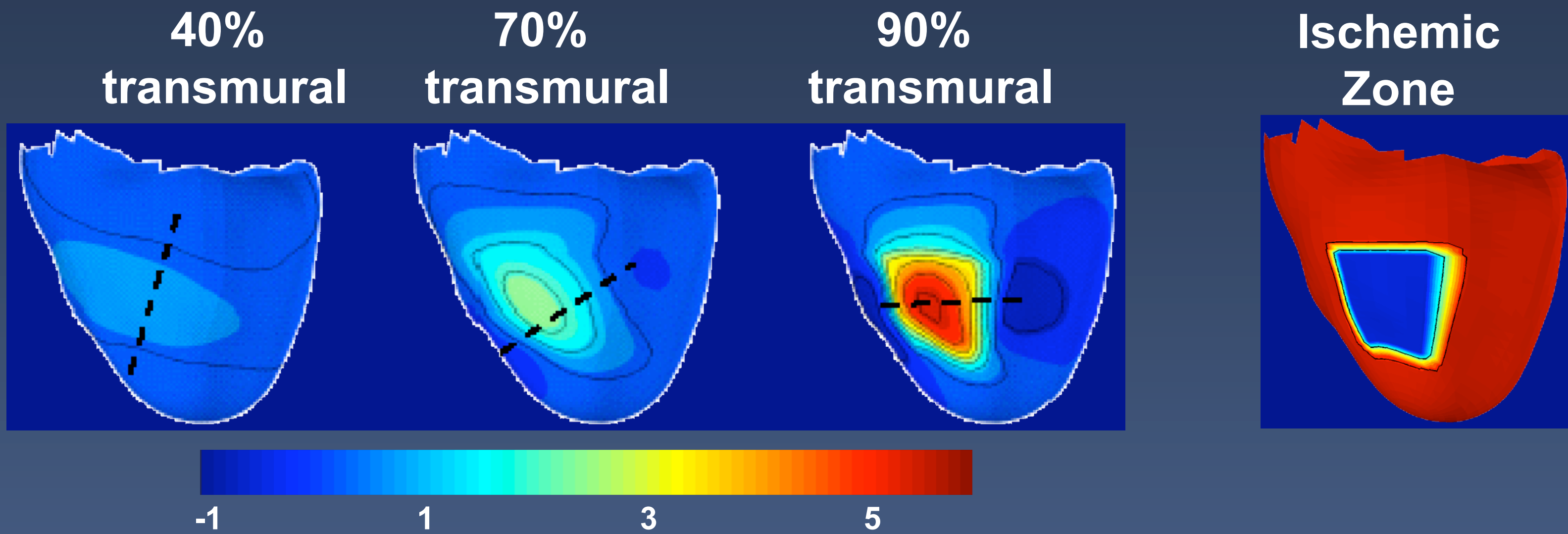
Ischemic Zone



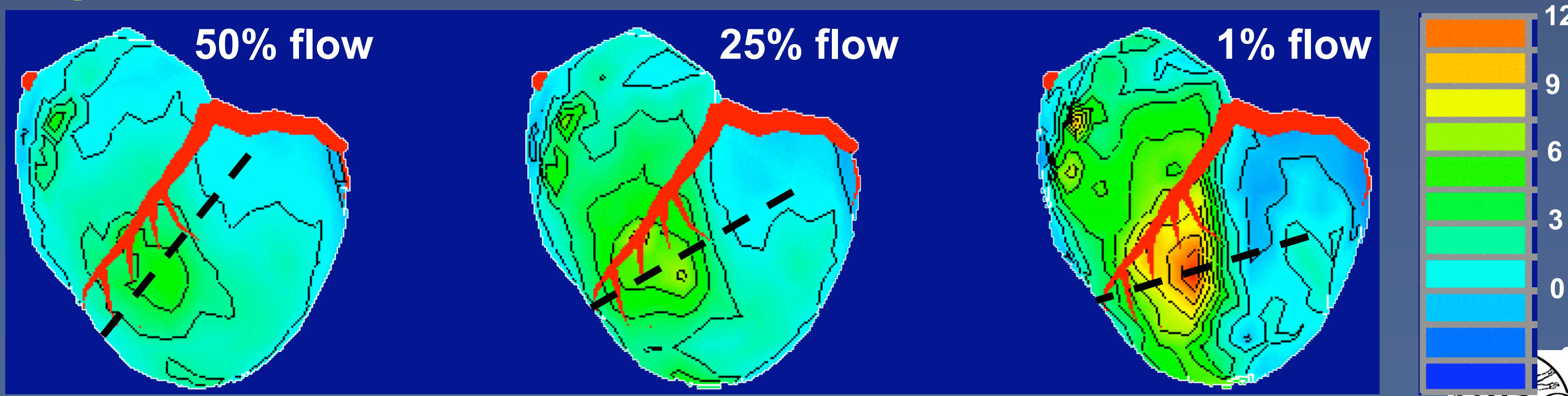
Hopenfeld et al. JCE, 15:1200, 2004

Results: Extent of Ischemia

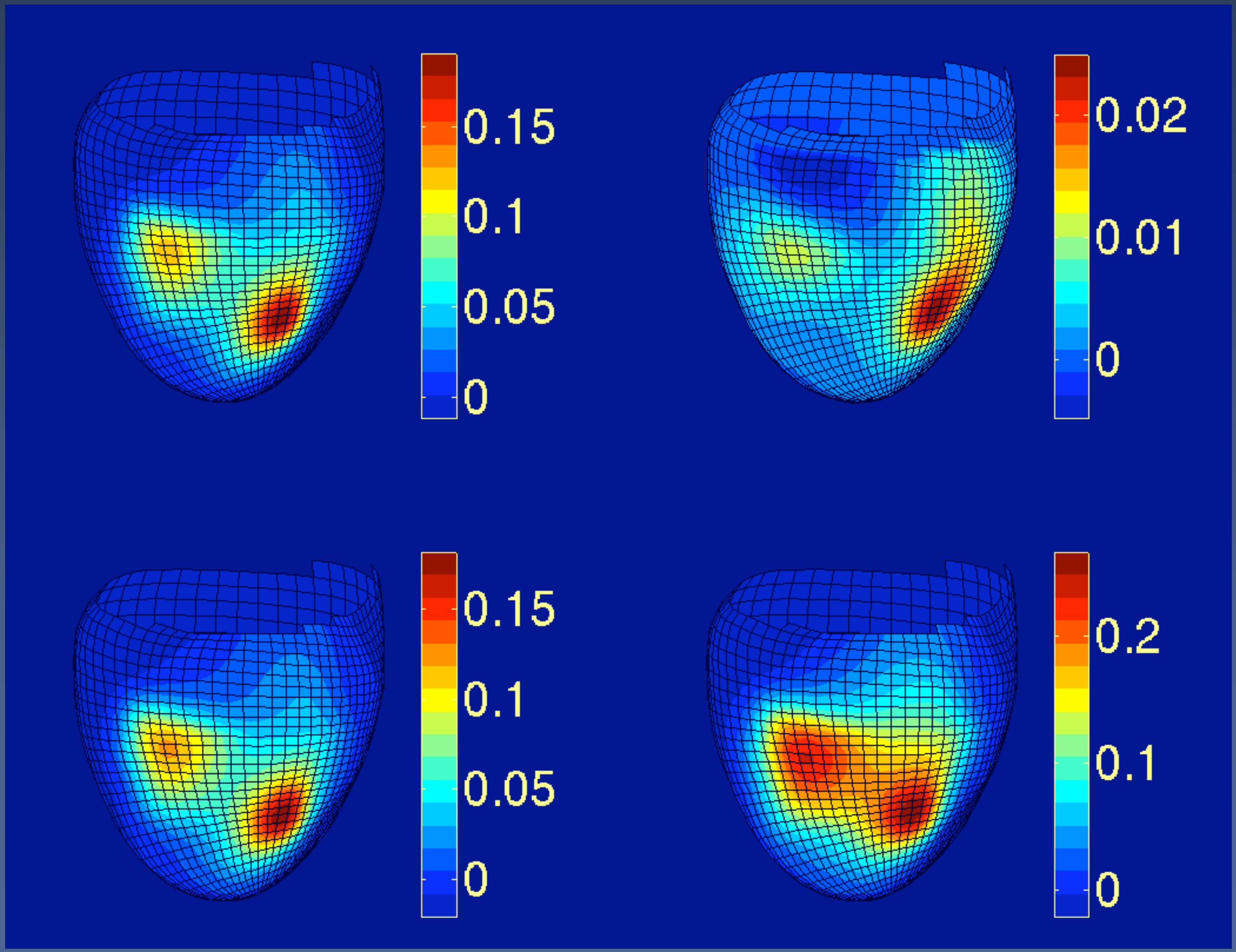
Simulations



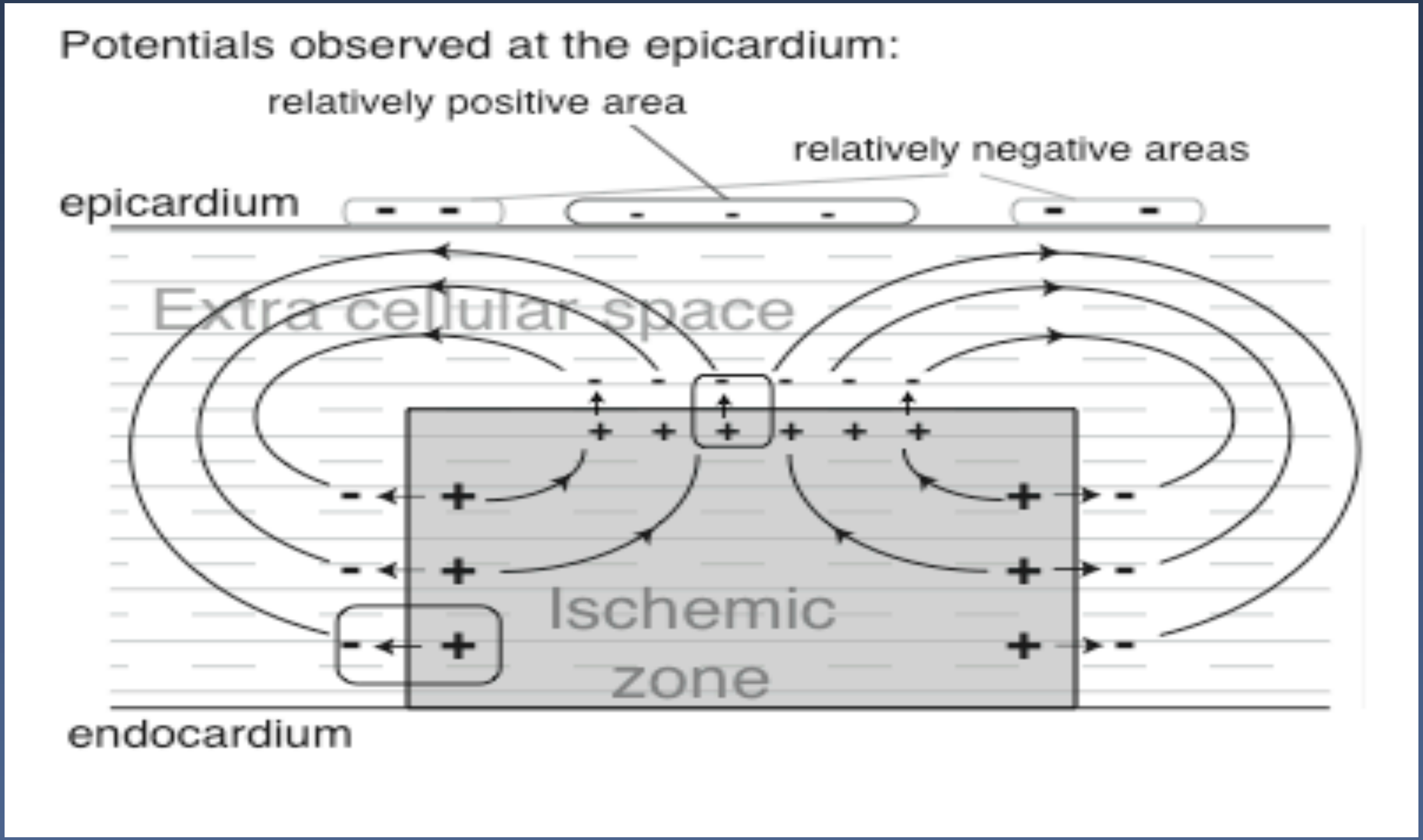
Experiments



Effect of Conductivity during Ischemia



Mechanism of ST Shifts



- Depends strongly on anisotropy
- Requires detailed geometry

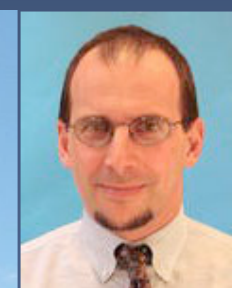
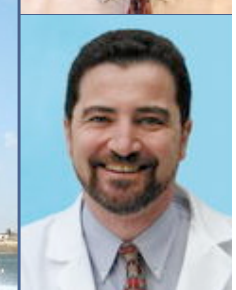
Example 3: Defibrillation Modeling

Patient-Specific Modeling of Defibrillation in Children

Children's Hospital Boston:
John Triedman, Assoc. Prof. Pediatrics
Matt Jolley, Pediatrics Fellow
Frank Cecchin, Assist. Prof. Pediatrics

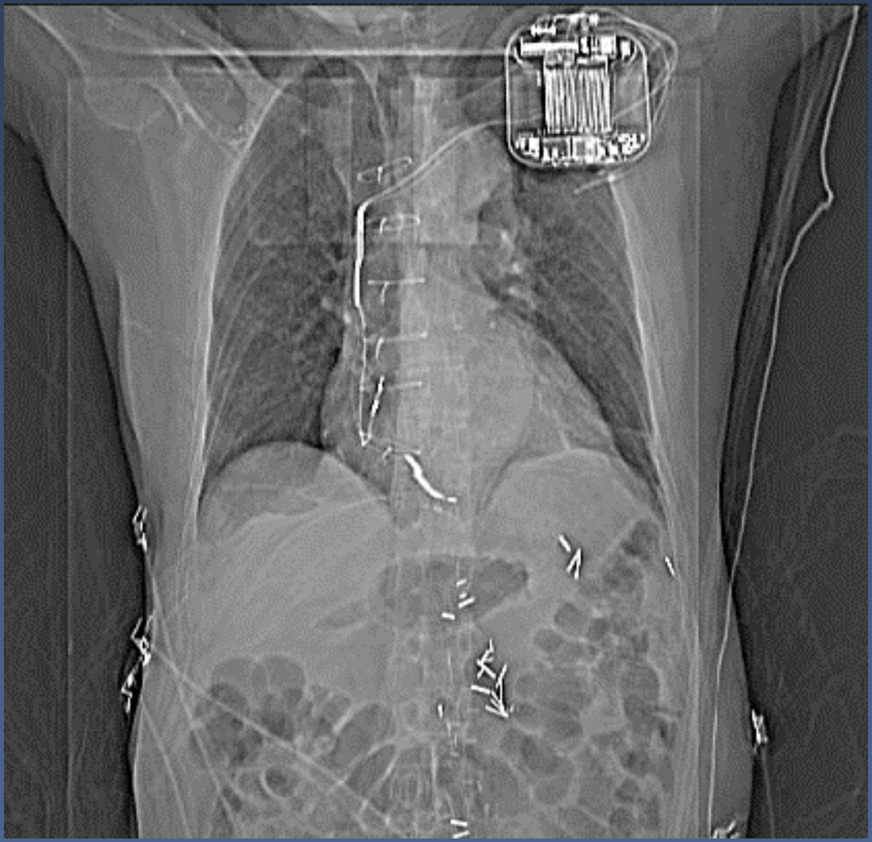
LMI/SPL/NAMIC at Brigham and Women's Hospital
C.F. Westin
Raul San Jose
Kilian Pohl
Steve Pieper
Gordon Kindlmann



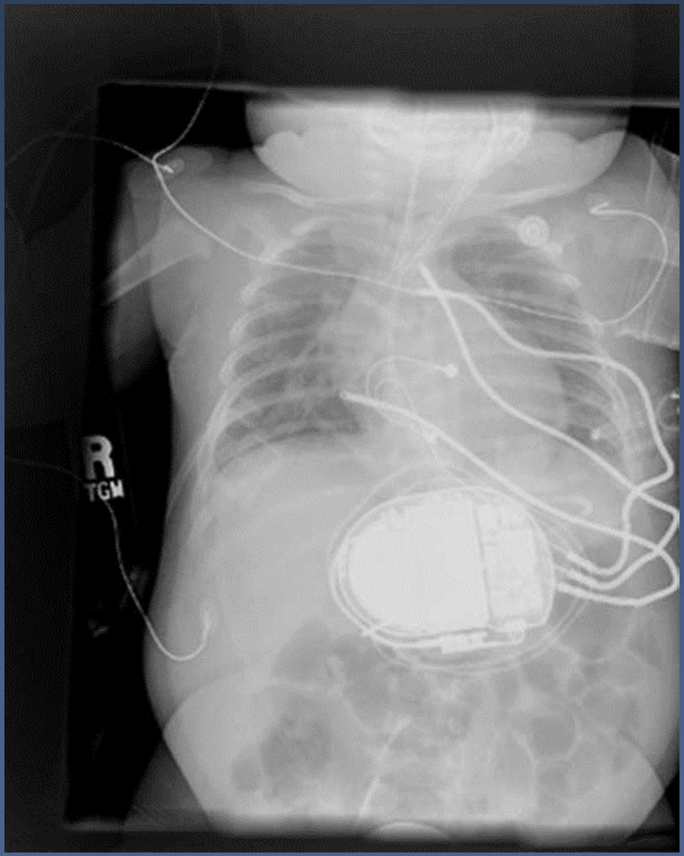



The Problem

ICD Placement in Children

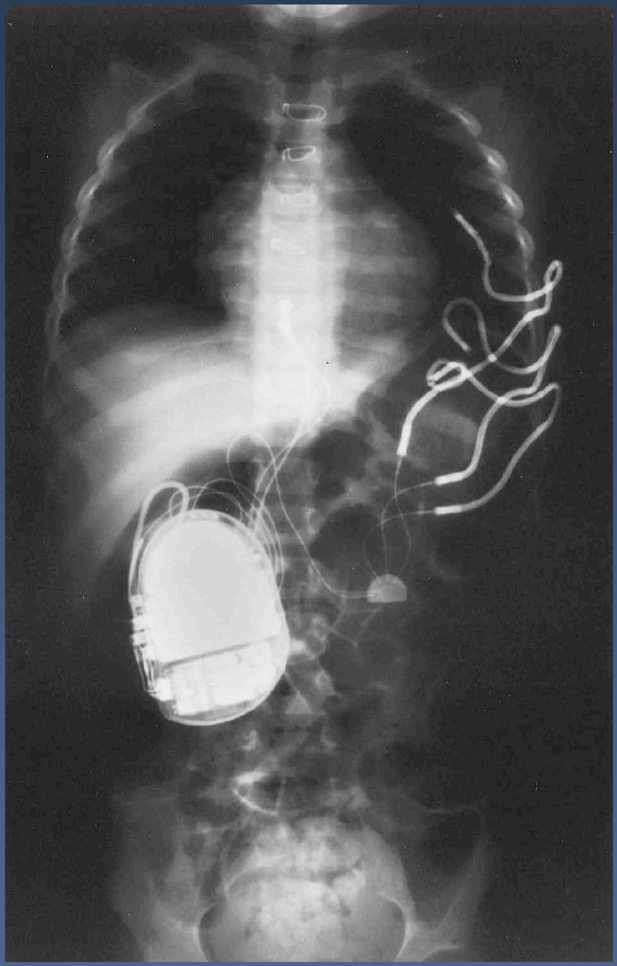


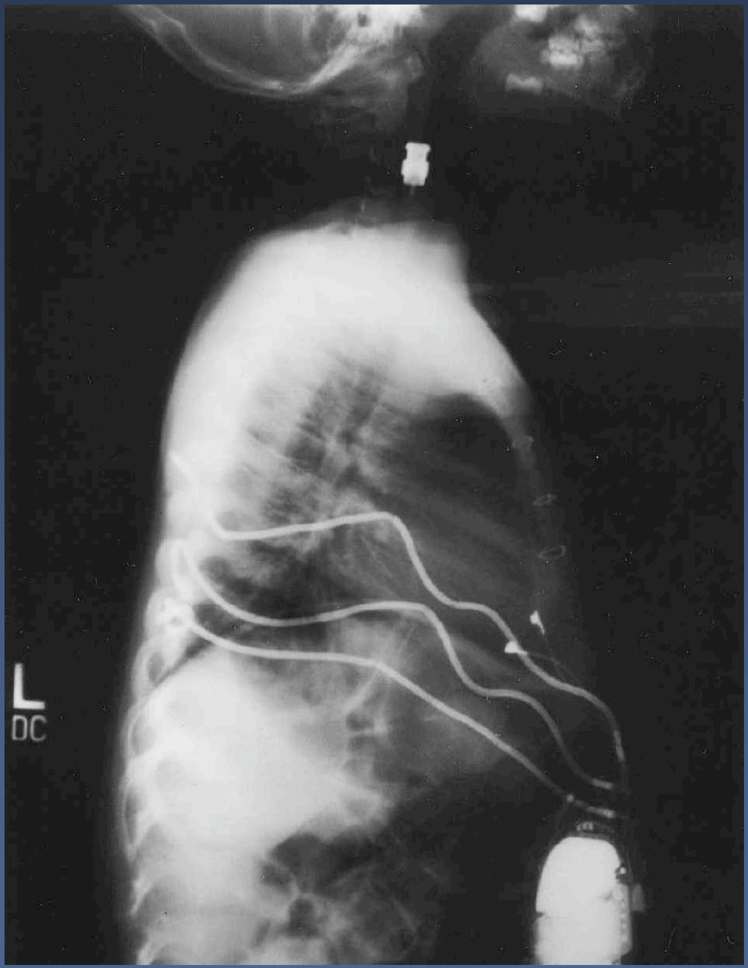
Adult



Child

Examples Developed at CHB

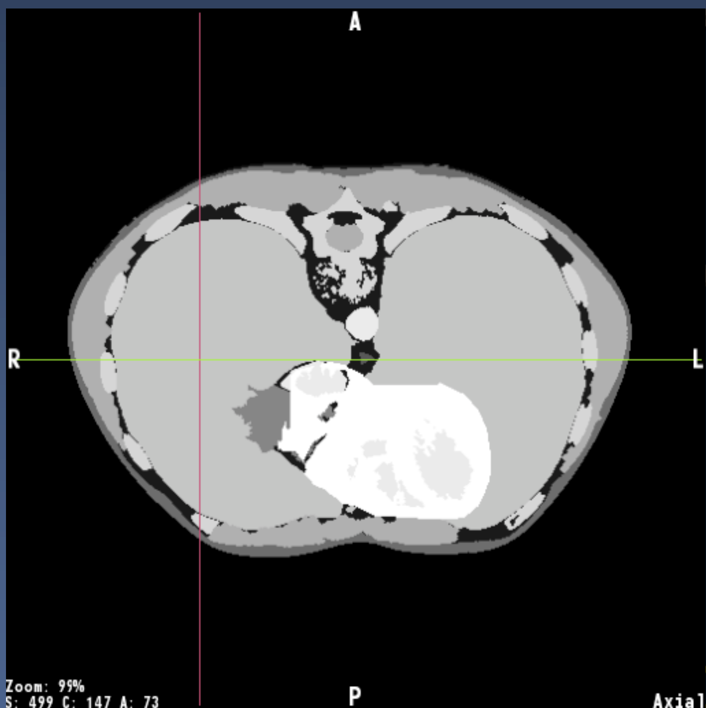


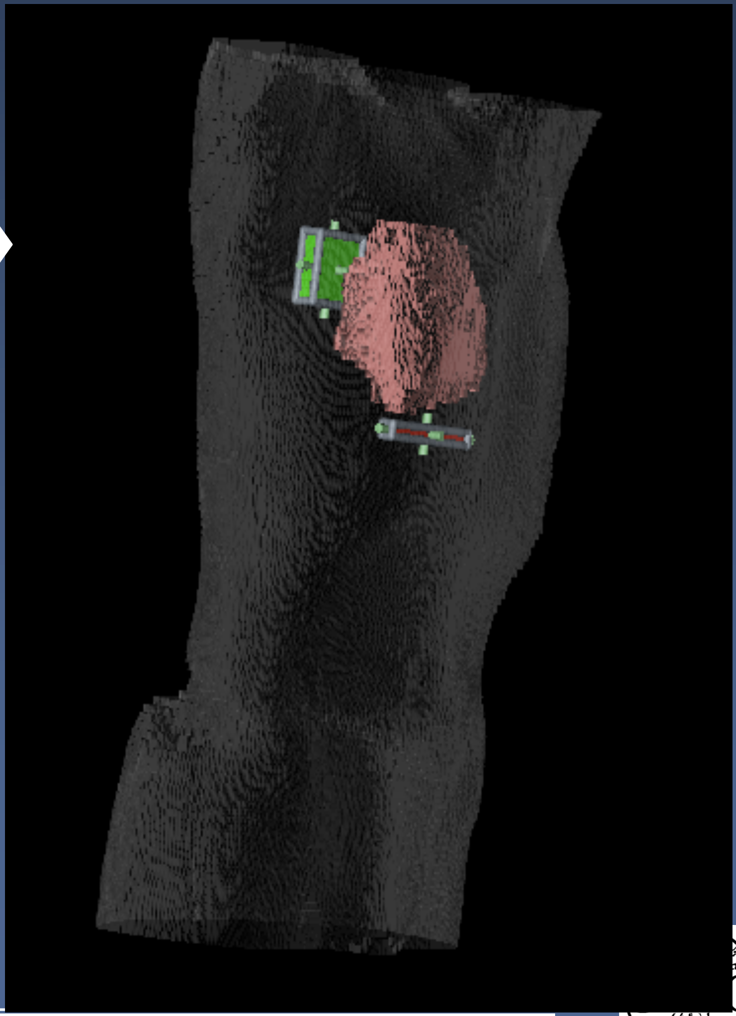


Berul *et al*, 2001

Goal: Simulate Defibrillation

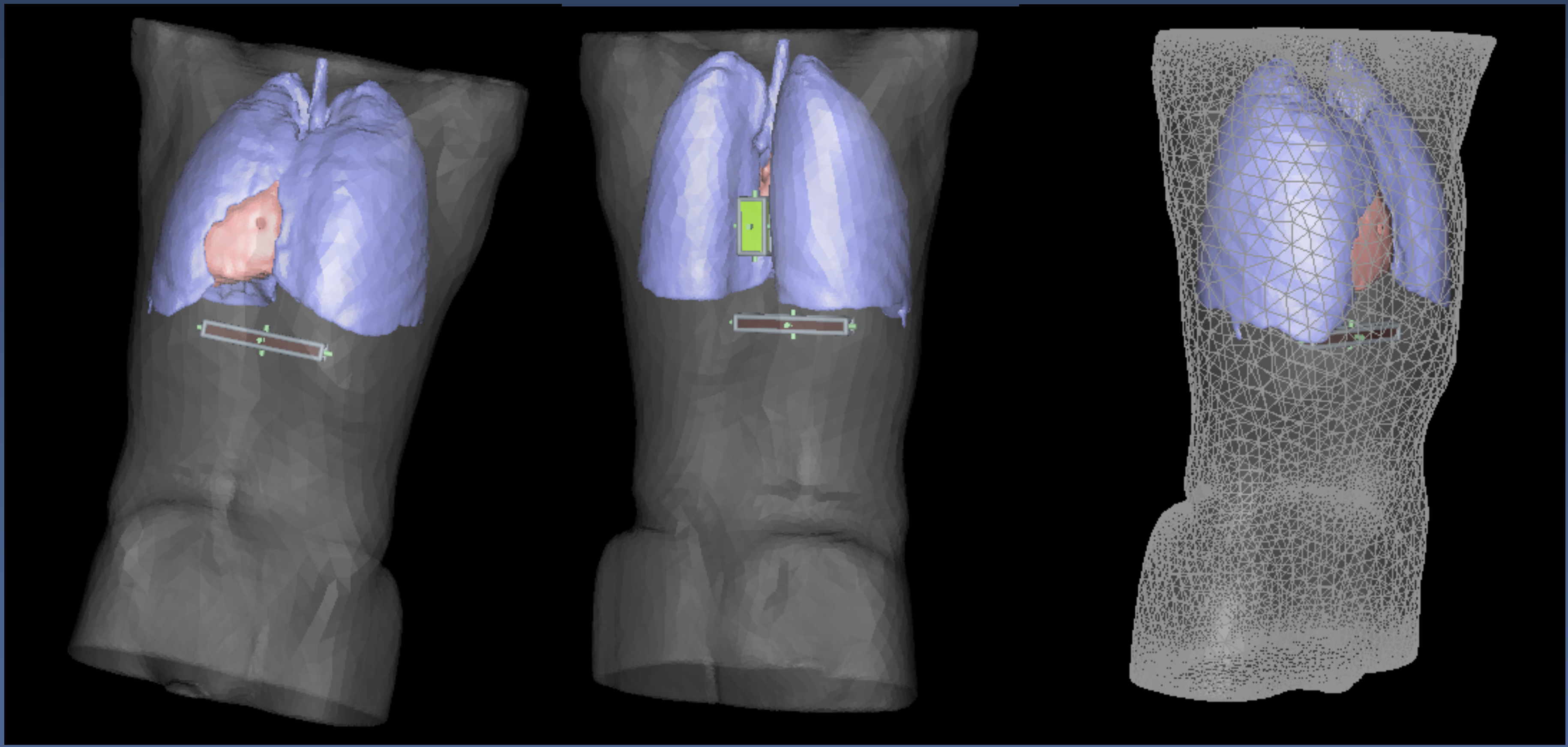
Patient specific models necessary



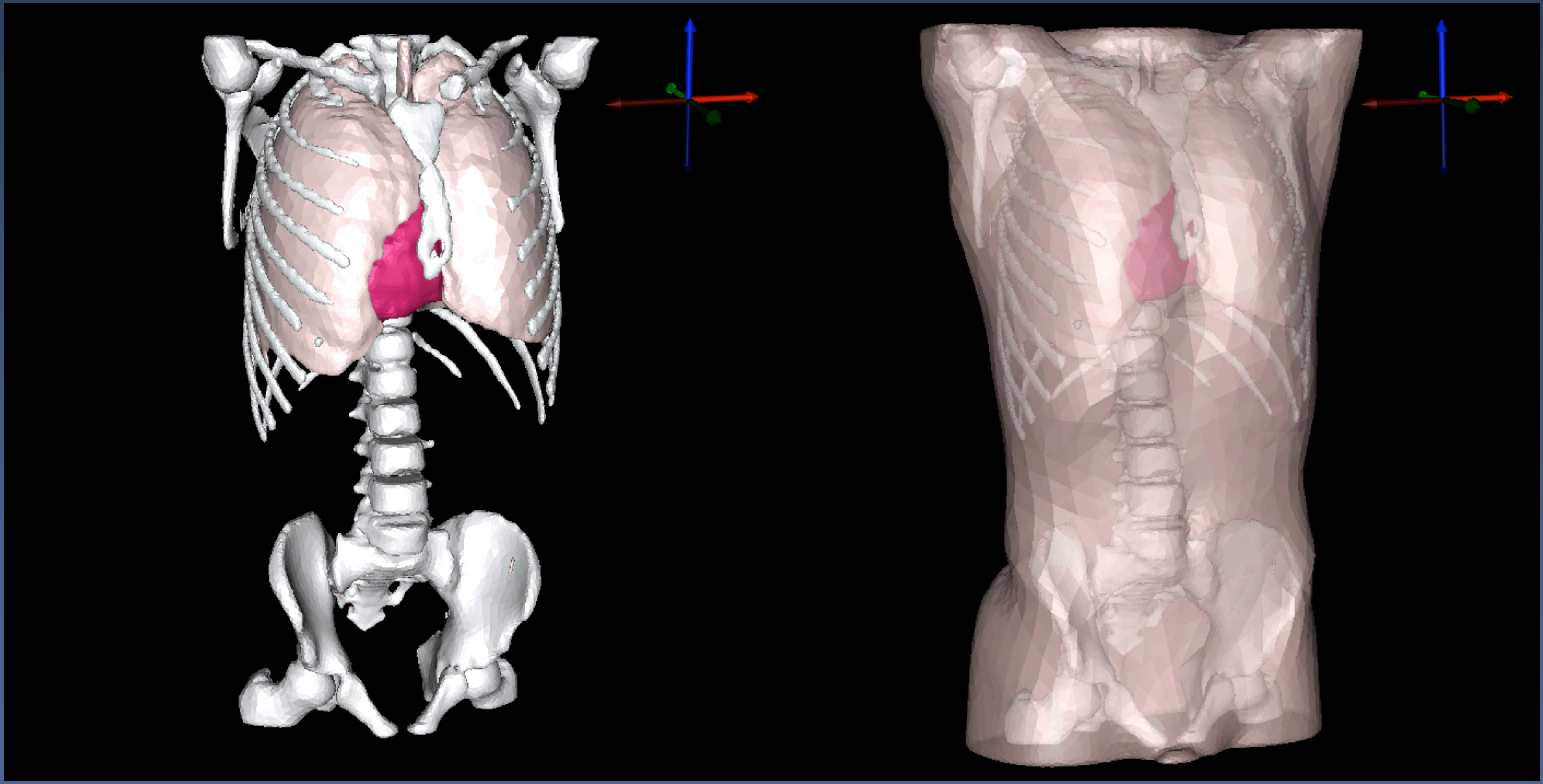


Model Construction Pipeline

From segmented images to tet mesh

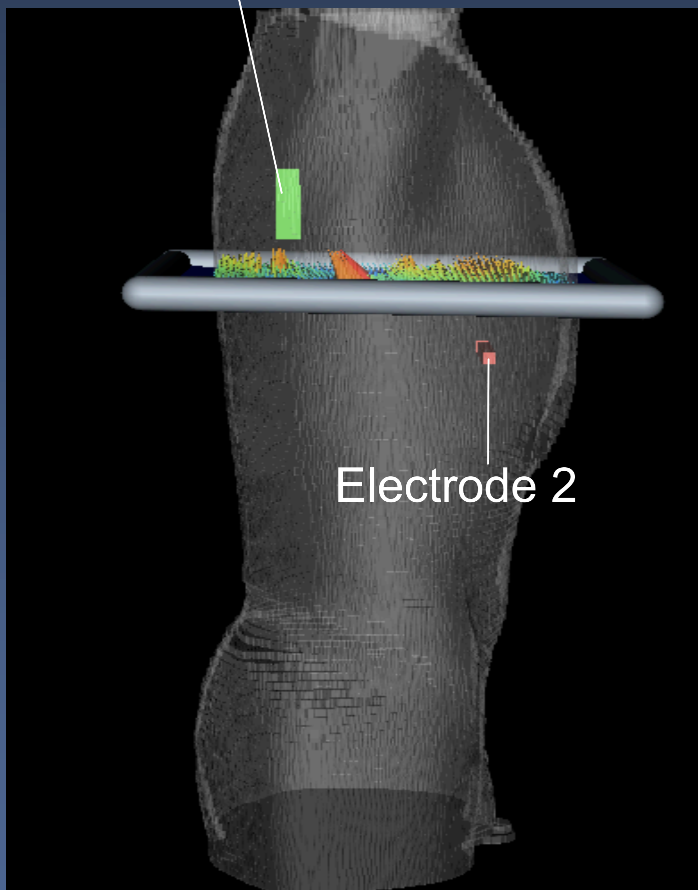


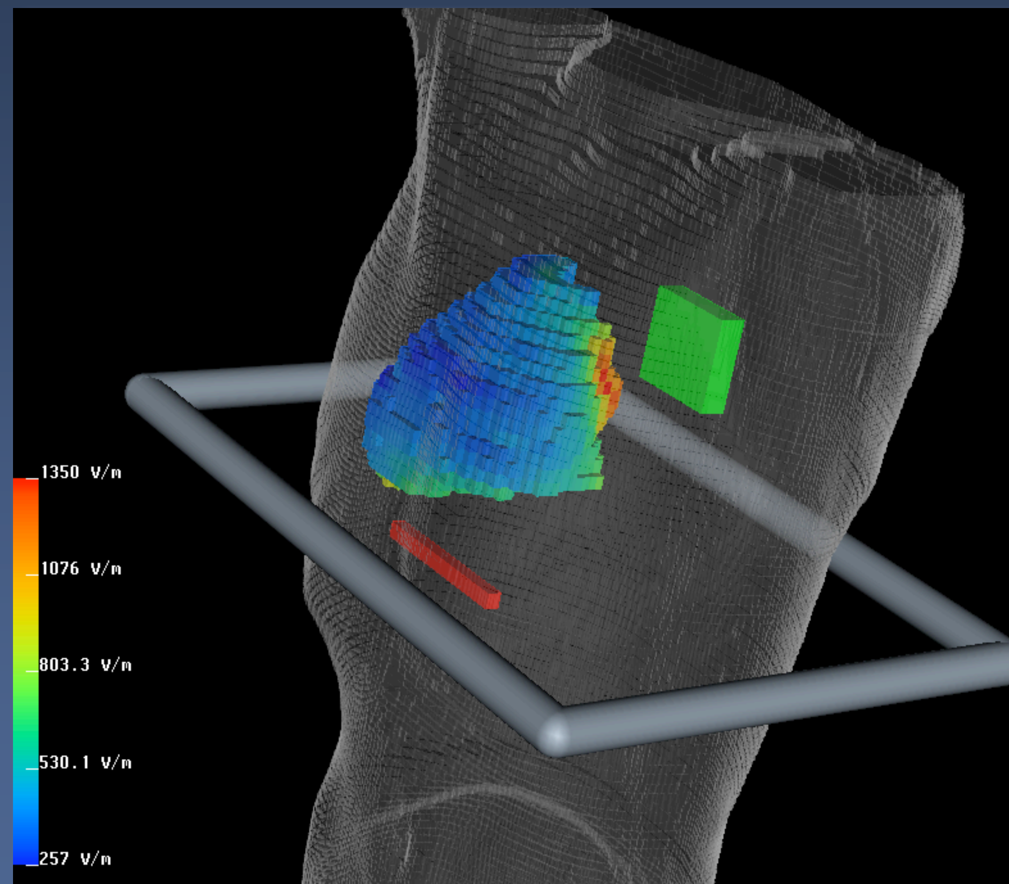
Volume Rendering



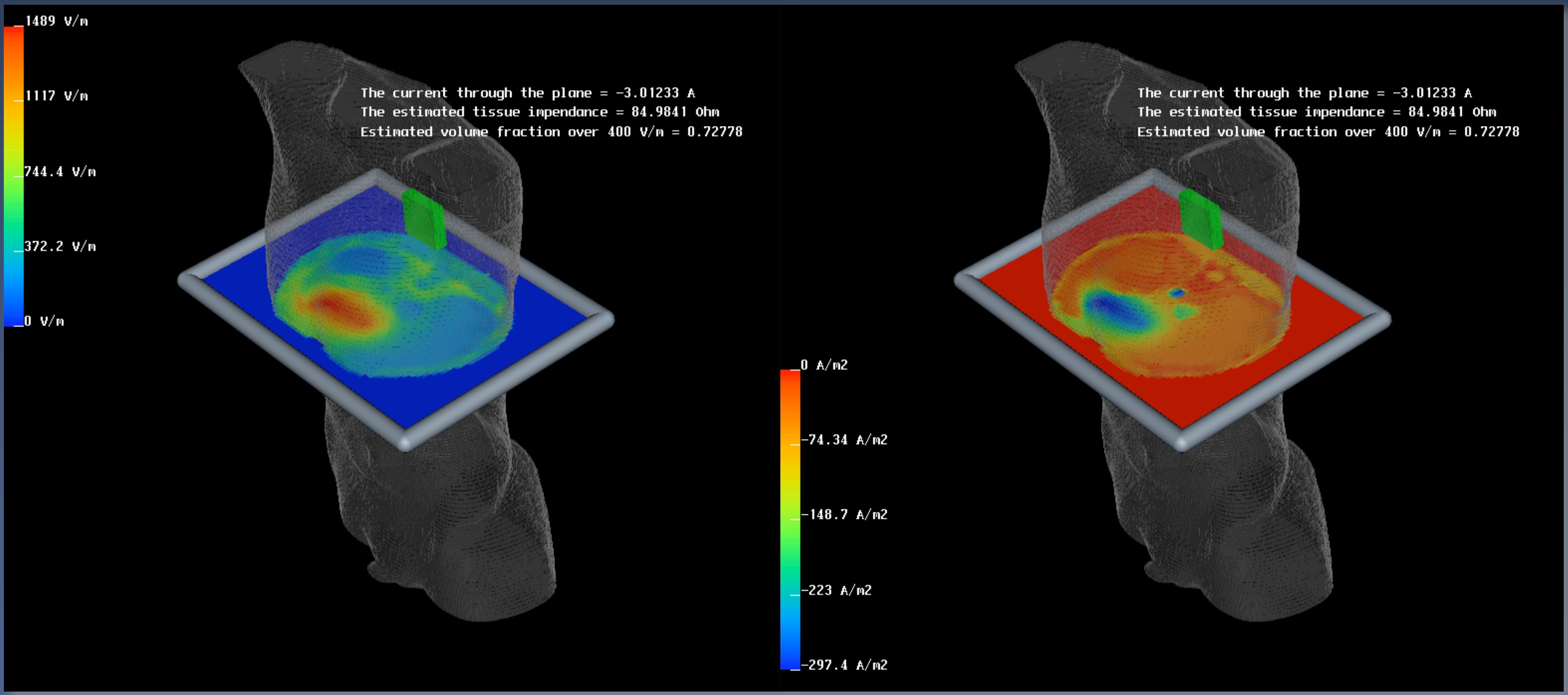
Example

Electrode 1





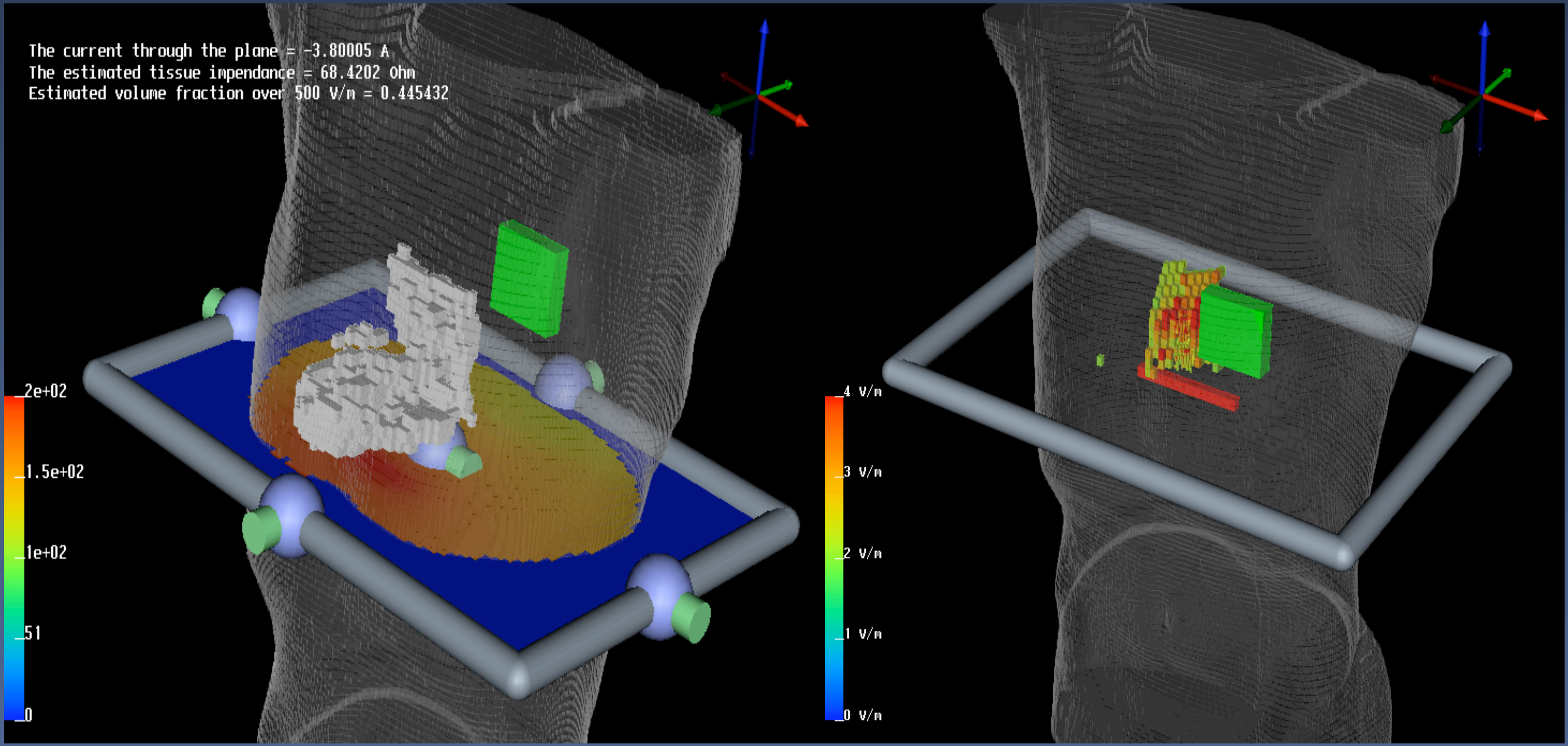
Current and Voltage



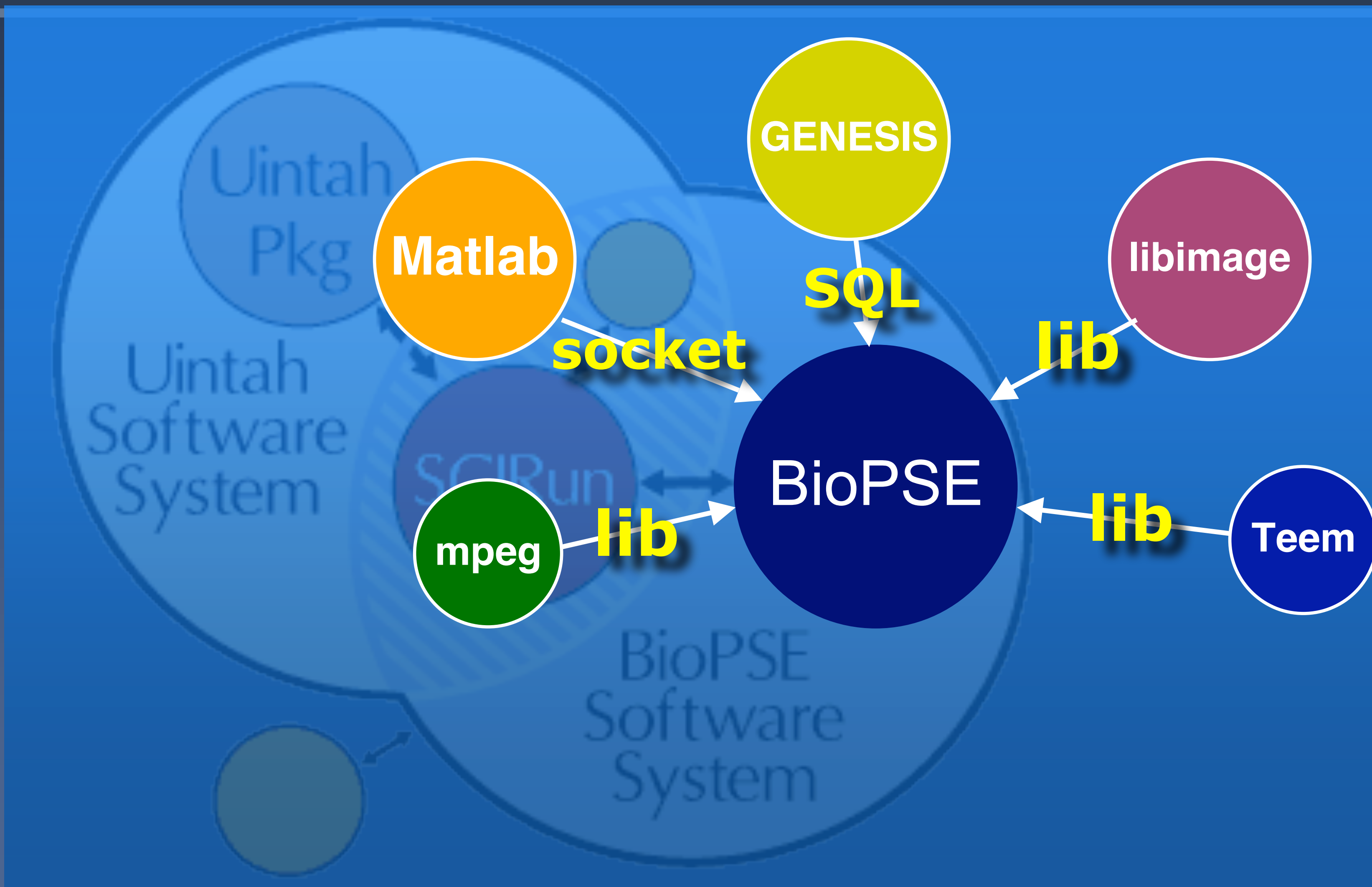
Voltage Gradient

Current Density

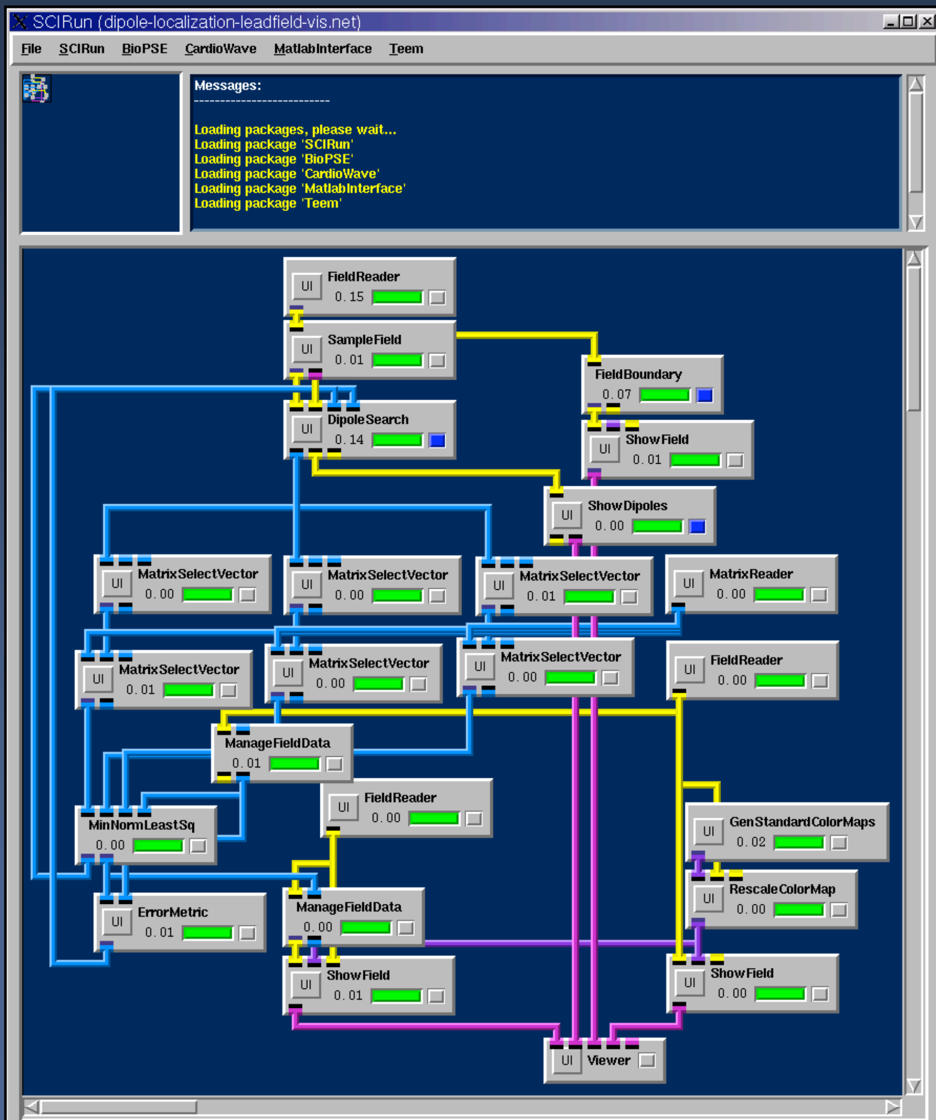
Myocardium Over Threshold

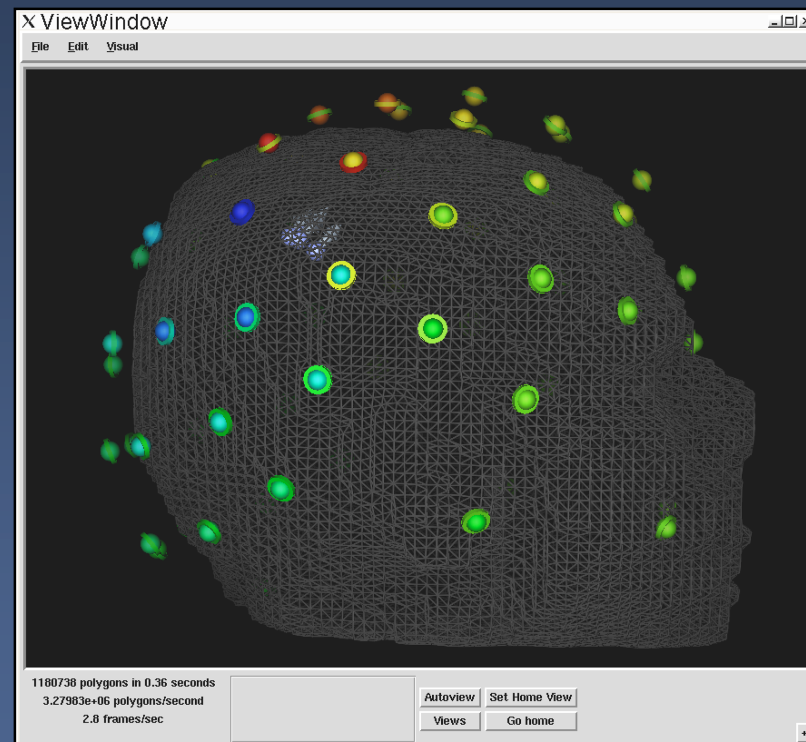


CIBC Software



SCIRun/BioPSE Networks

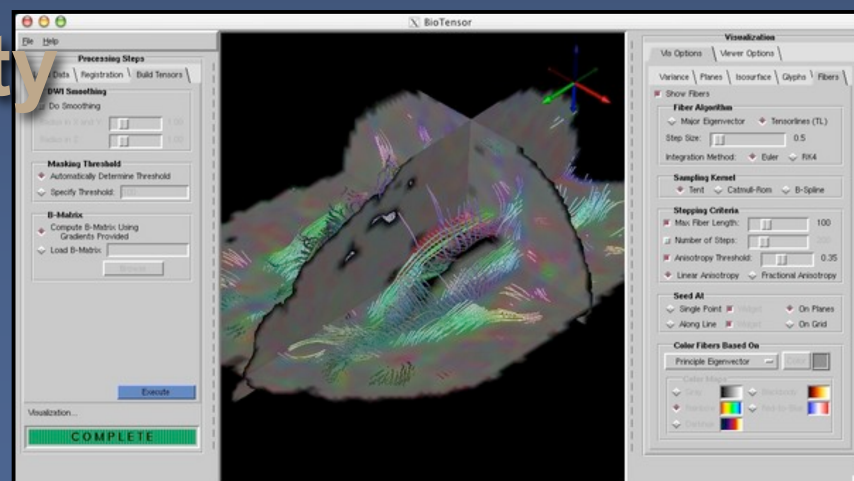




CIBC Power Apps

Problem-specific Application

- Hide complexities of dataflow
- Provide simplified graphical user interface
- Focus on specific task
- Enhance productivity

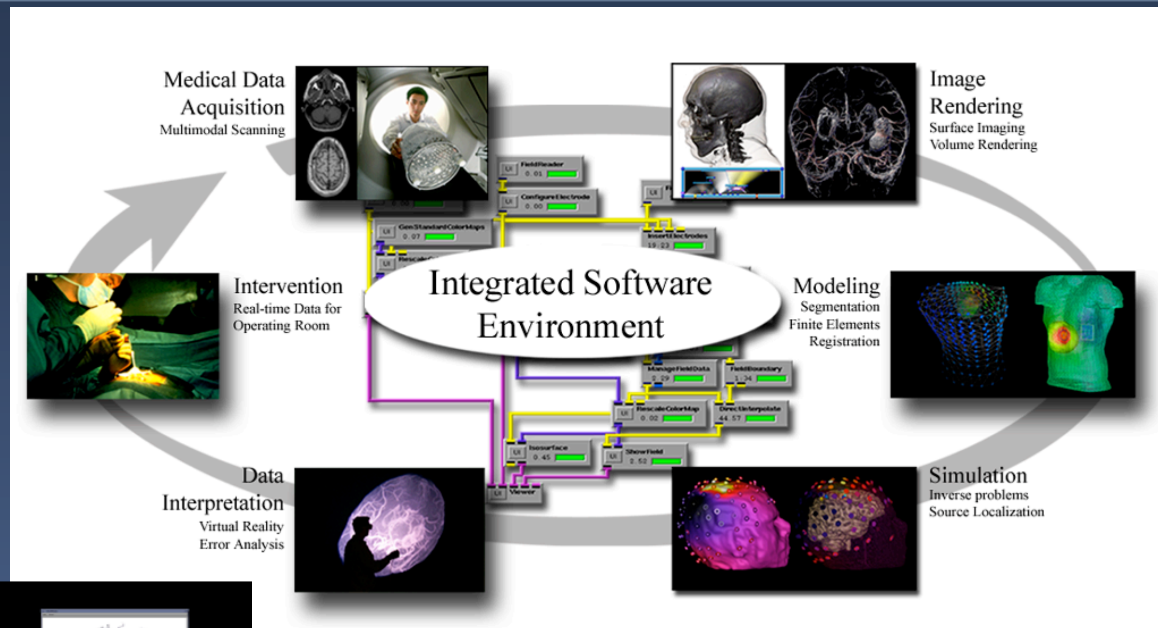


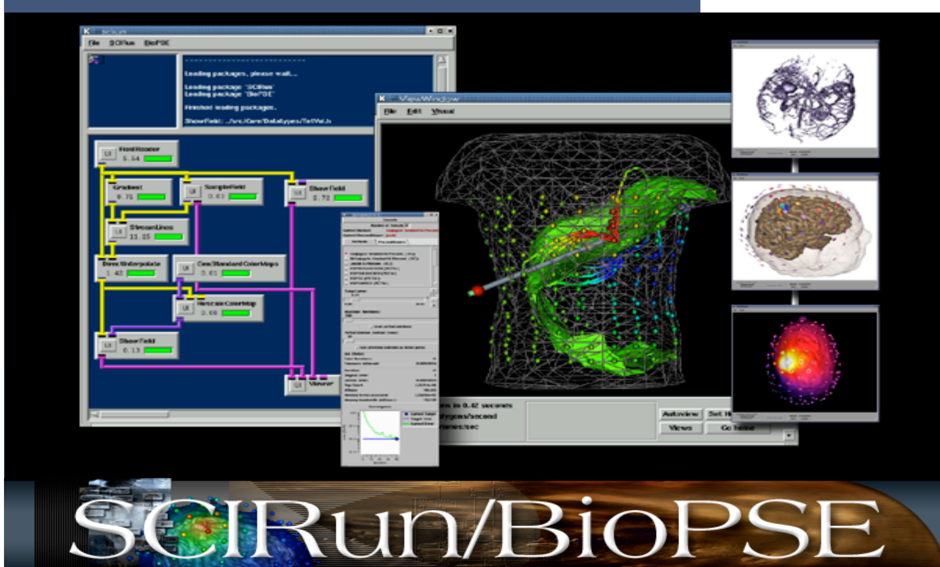
Biomedical Computing at Utah

Modeling

Simulation

Visualization





SCIRun/BioPSE

- Imaging, Modeling, Simulation, and Visualization Tools
- Modular and Extensible
- Open Source, Open Model, and Open Data

Pick Your Problem Carefully

Big Challenges Require Great People

Graduate Student and Postdoctoral Positions Open

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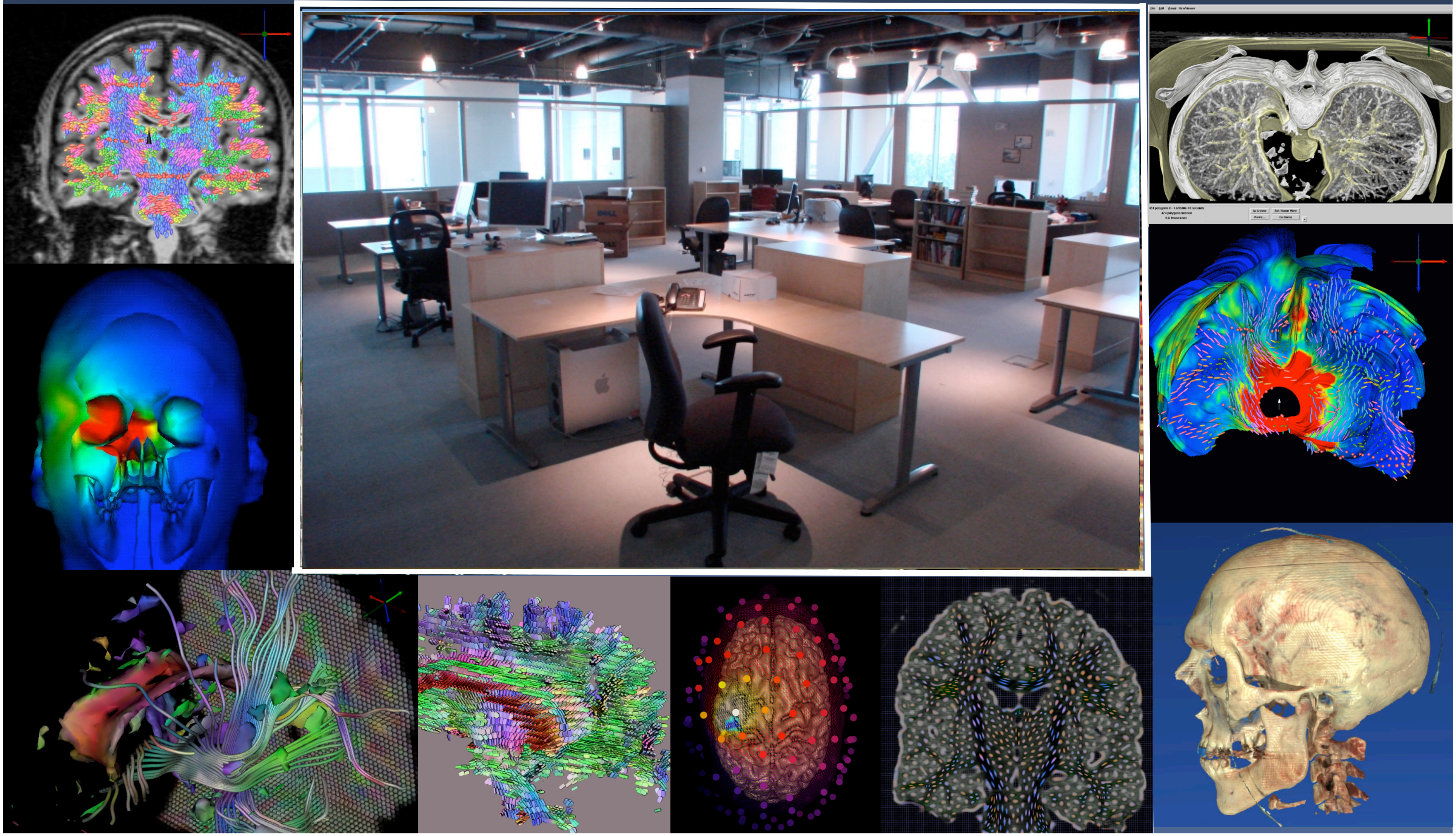

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