CyberCardia: Compositional, Approximate, and Quantitative Reasoning for Medical CPS

CyberCardia

Stony Brook University · Fraunhofer USA · R·I·T Rochester Institute of Technology 1829 · Penn Engineering · Georgia Tech · FDA · University of Maryland 1856 · Carnegie Mellon University

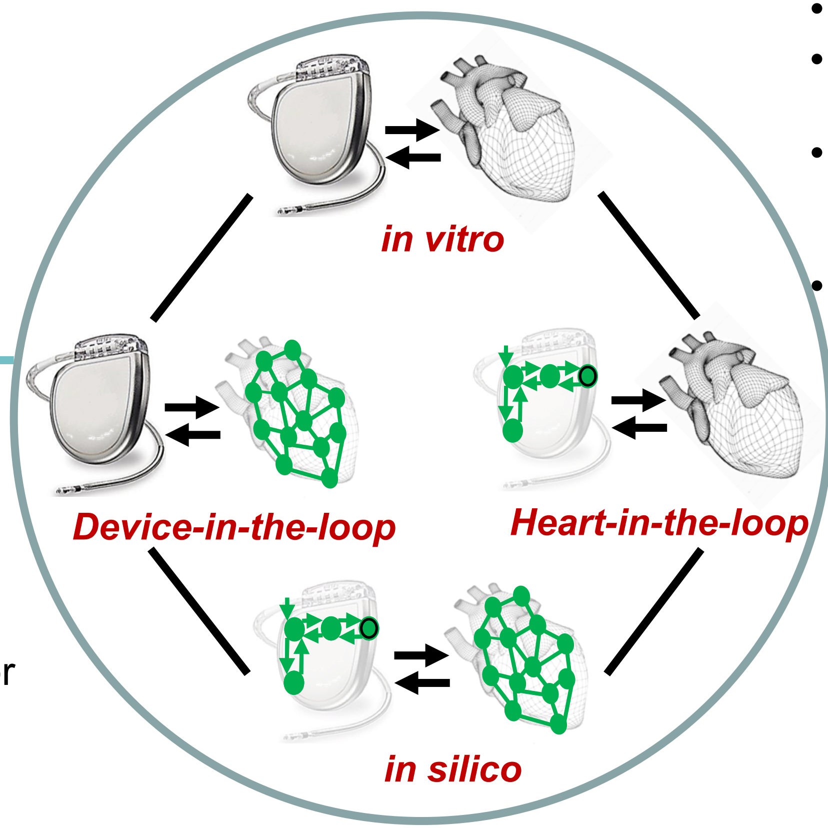
Challenge:

- Closed-loop verification of ICDs
- Patient-specific device programming
- Accurate heart & device modeling

Solution:

- Compositional, quantitative and approximate reasoning
- Lagrangian reachability analysis
- Finite-element method for accurate heart modeling

Project info: NSF CNS 1446832, Stony Brook University, **Scott Smolka, Lead PI,** sas@cs.stonybrook.edu, https://cybercardia.cs.stonybrook.edu/



Scientific Impact:

- Model-based clinical trials
- Quantitative verification of medical devices
- Patient-specific therapy guidance and device configuration
- Patient heart model in electronic health record

Broader Impact:

- More reliable cardiac device V&V
- Interdisciplinary undergrad workshops
- Outreach to middle, high school students
- Cross-disciplinary course development

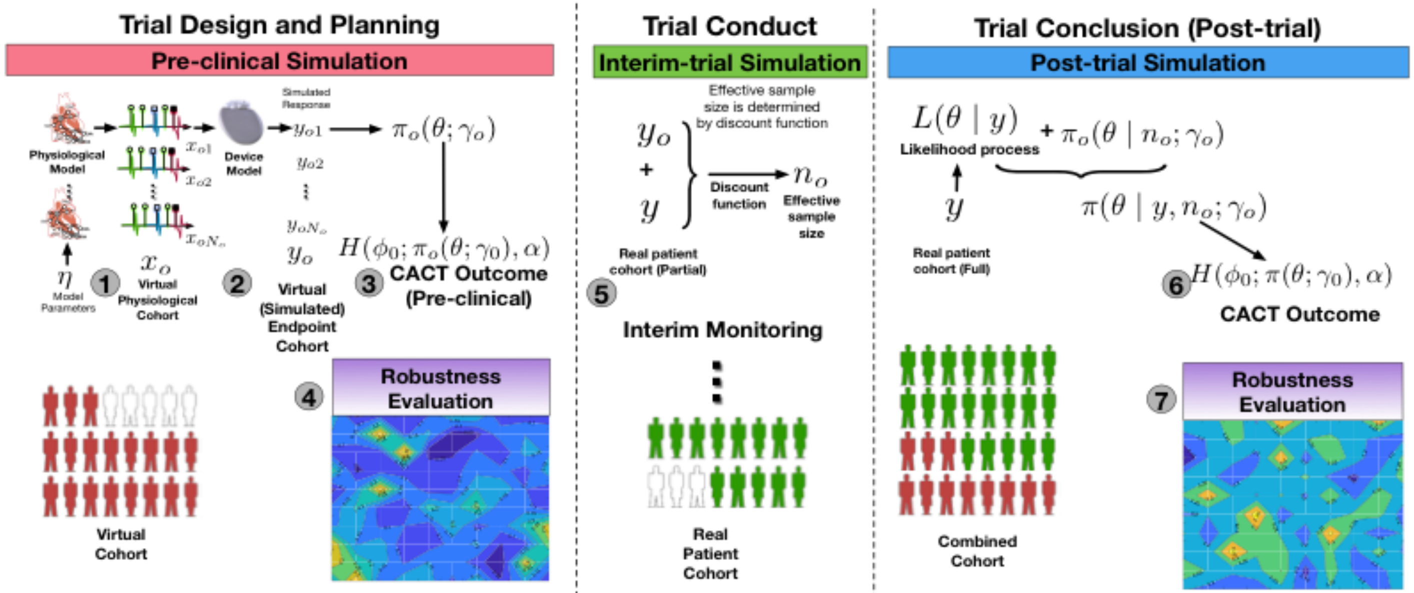
Example Project Outcomes Past 12 Months

- Computer-Aided Clinical Trials
- Automated MRI to Finite-Element Mesh
- Real-Time High-Performance Computing
- Runtime-Assured Autonomy
- Interdisciplinary Undergrad Workshop

Computer-aided Clinical Trials for Medical Devices

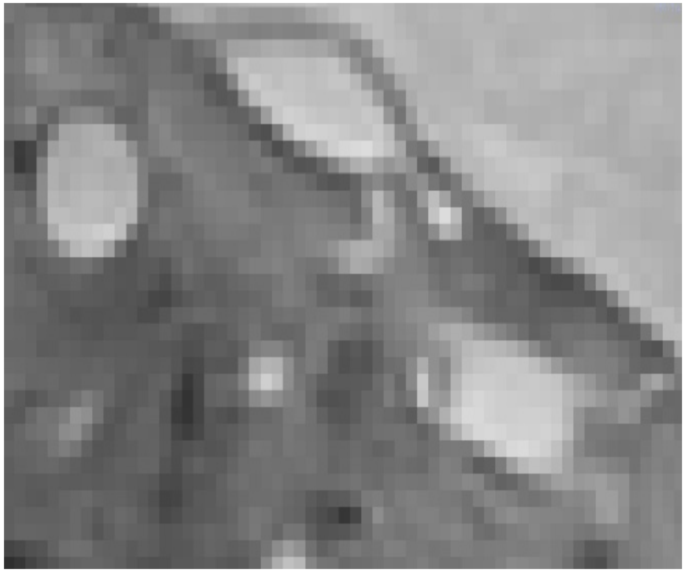
Rahul Mangharam and Kuk Jang, U. Penn

Problem: Medical device clinical trials cost $10-$20M, take 4-6 years and over 30% fail

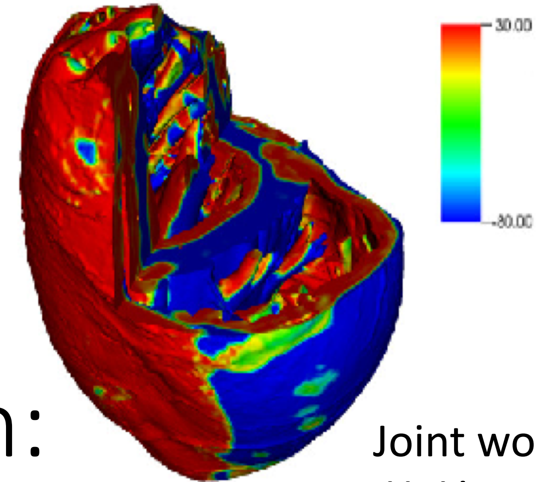


We investigate:

How can modeling and simulation of the physiology and devices be used as regulatory-grade evidence prior to and after a clinical trial?



Automated MRI to finite element mesh: widely useful

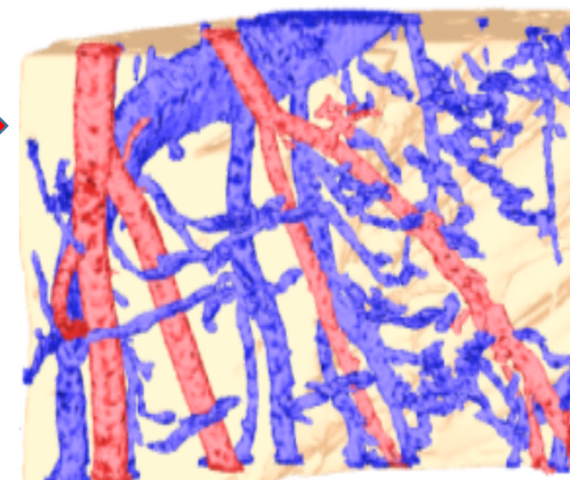


Joint work:
H. Lim,
J. Glimm,
R. Gray,
M. Bishop

Applied to cardiac fibrillation Studies (LEAP)

1. Gray scale to black/white
2. Smooth boundary mesh
3. Outer blood vessel wall
4. Volume mesh
5. Mesh quality

Public domain + new algorithms

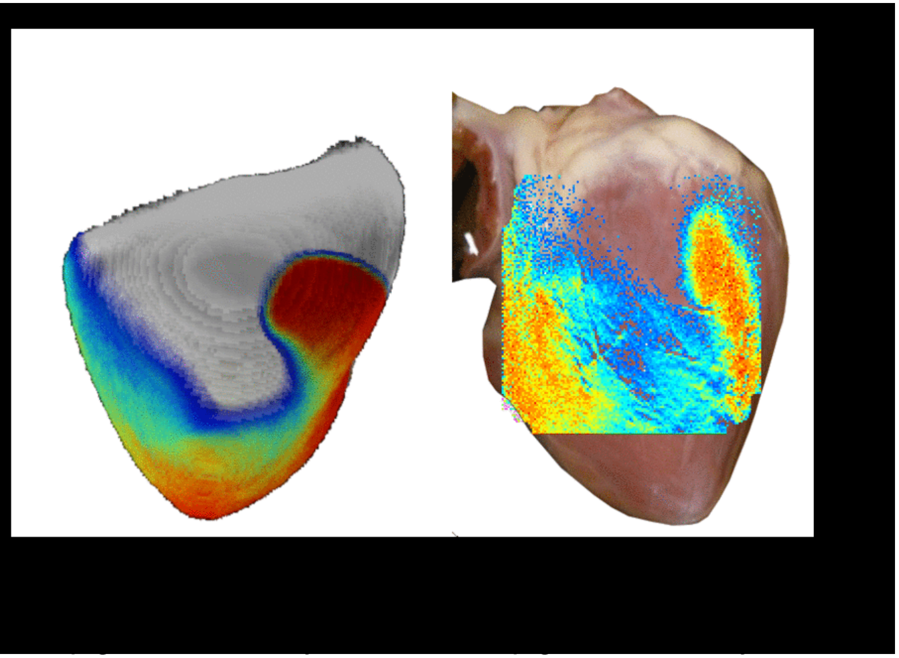


Real-Time, Interactive, High-Performance Computing (without the need for supercomputers)

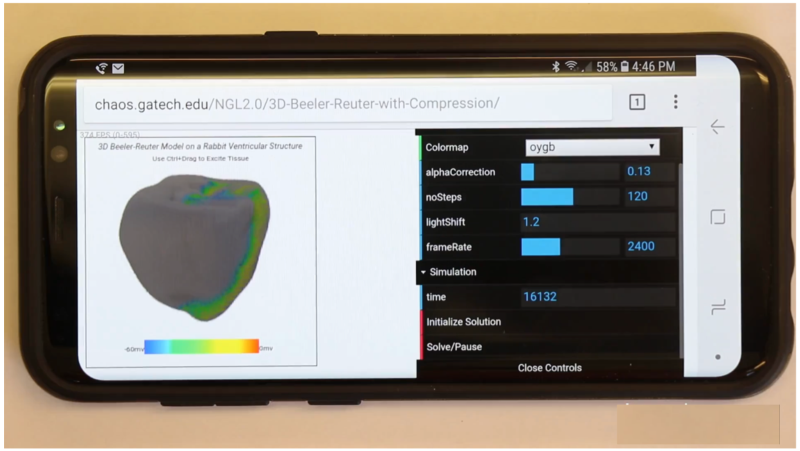
A GPU library for Large-Scale Simulations on PCs and even Cellphones

Flavio Fenton, Georgia Tech

Interactive simulations of cardiac electrical activity in accurate 3D structures are now possible in real time via the GPU. Opens the door to close-loop feedback control.

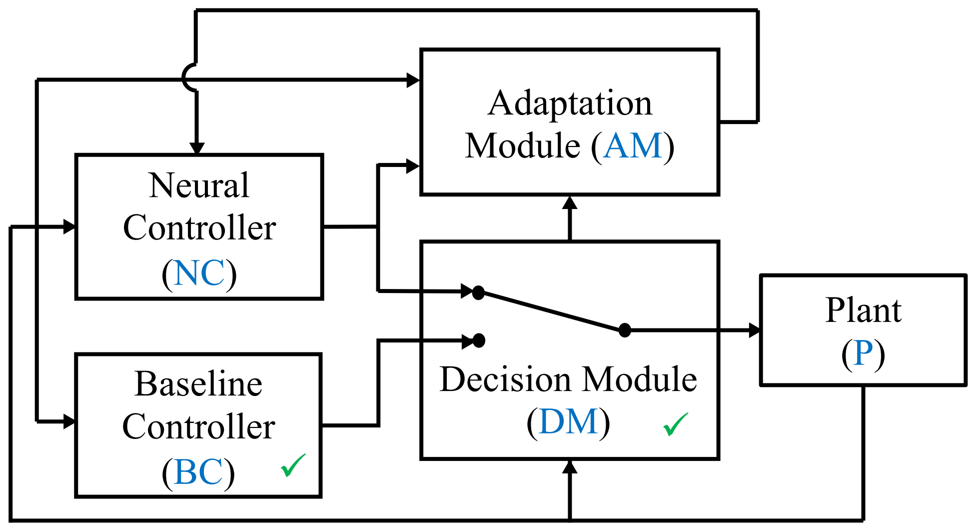


A supercomputer in your pocket!



This interactive simulation (on a phone) of a 3D rabbit heart in arrhythmia runs at:
7 billion differential equations per second

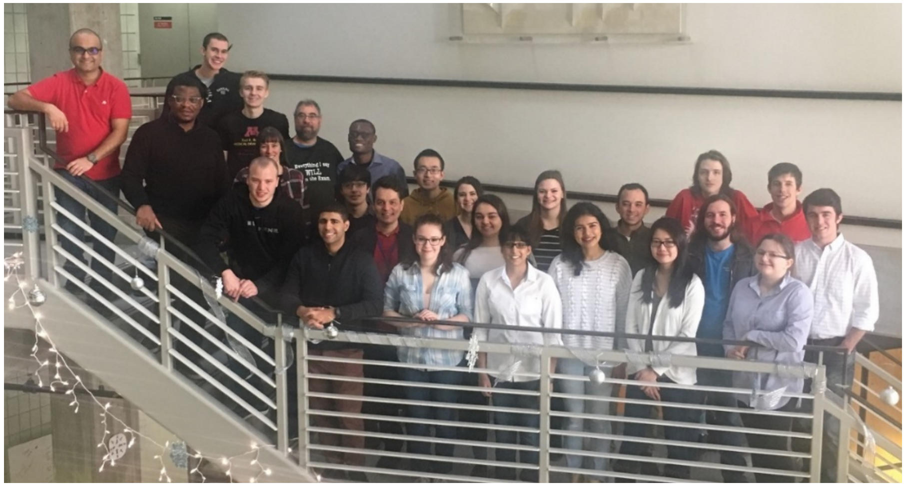
Runtime-Assured Autonomy



- Neural Simplex Architecture [Grosu, Smolka et al. 2018]
- Neural Controller (NC) is a DNN
- Adaptation Module (AM) uses Deep Reinforcement Learning for online retraining of NC
- Reverse switching from BC to NC to assure mission completion

Interdisciplinary Undergraduate Workshop on Excitable Systems

- **Weeklong workshop at RIT**
  - *Active learning* (teams)
  - *Multiple modes of learning* (analytical, computational, laboratory)
- **January 2019 workshop:** 24 students
  - *Diversity*: 13 female, 1 non-binary-gender, 3 AALANA, 1 veteran
  - *Diversity of majors*: biology, chemistry, computing, engineering, mathematics, physics majors
  - *Diversity of locations*: Bowdoin (ME) to Harvey Mudd (CA)
  - *Diversity of schools types*: Essex County (NJ) Community College to Harvard



"I really enjoyed how we viewed these problems from so many different angles."