# Modeling Supraventricular Tachycardia Using Dynamic Computer-Generated Left Atrium

Melanie Little, Brandon Wyatt, Avery Campbell, Gavin McIntosh, Bryant Wyatt
Department of Mathematics at Tarleton State University

## Introduction

The leading cause of death globally is heart disease, followed by strokes. Supraventricular Tachycardias (SVT), though not in itself deadly, is a leading cause of strokes, heart attacks, and heart failure. Therefore, one could argue that SVT is indirectly a leading global killer [1-7]. SVT is a term used to describe all cardiac arrhythmias where the atria beat too rapidly or out of sync with the ventricles. This out-of-sync beating between the atria and the ventricles can cause blood to pool in the atria creating clots that can then travel to the brain or coronary arteries resulting in a stroke or heart attack. SVT events also significantly reduce the stroke volume of the heart. If they persist for extended periods of time they can cause a permanent reduction in ejection fraction, possibly resulting in congestive heart failure. Currently, catheter ablation is the standard practice for treating cardiac arrhythmias [6, 16, 18, 19].

Radiofrequency catheter ablation and three-dimensional mapping techniques have greatly improved over the last ten years allowing doctors to perform amazing procedures on beating hearts. But the heart is a multi-dimensional nonlinear dynamical system, making it extremely difficult to predict precisely what outcome will result from changes to the system such as those introduced by ablation lesions. Hence, most ablations are limited to educated guesses that doctors hope will result in positive outcomes. This work will use computational mathematics to move catheter ablations from an art into a science [6, 20-22].

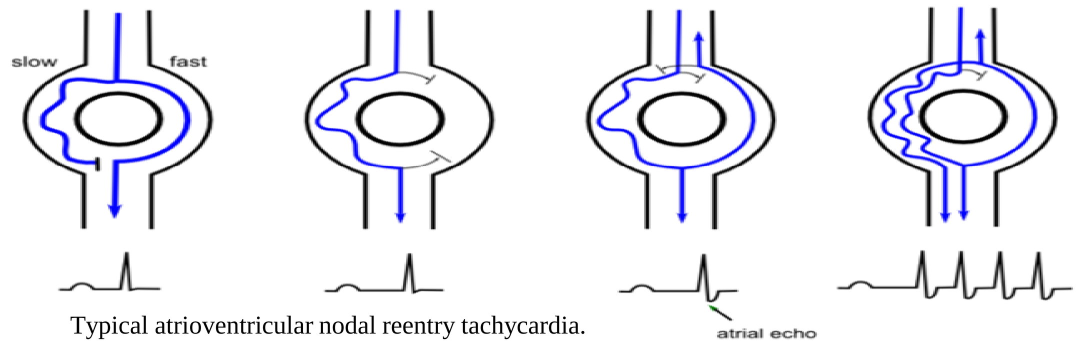
## Tachycardias

For detailed information on our initial developments through one and two-dimensional phases please see our website.

Website

Normal EKG rhythm.

1D Model

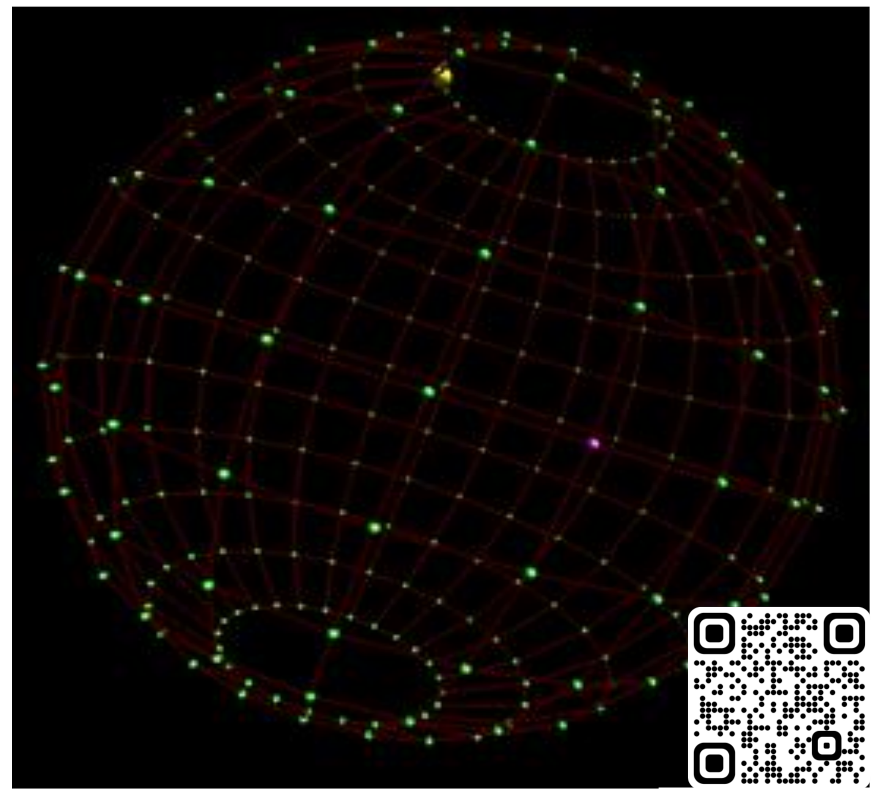



Typical atrioventricular nodal reentry tachycardia.

2D Reentry

## Non-Linear Dynamical System

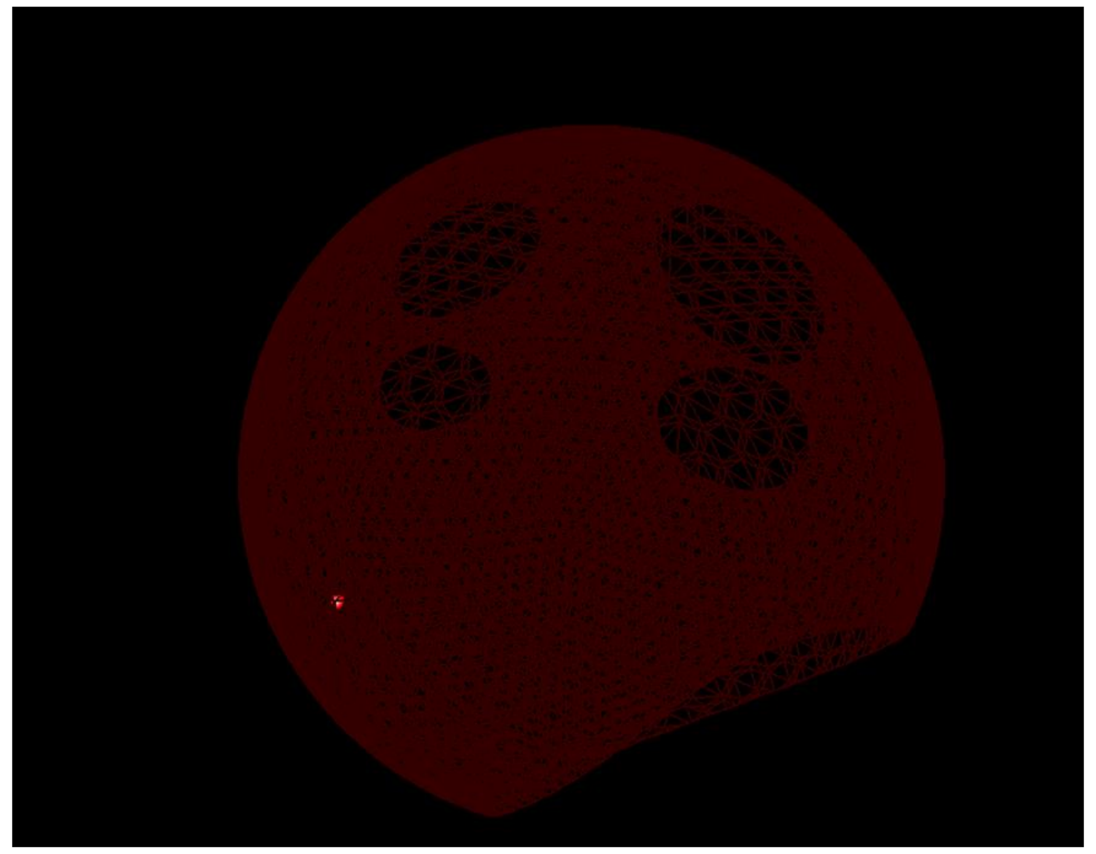
SVT events can produce chaotic outcomes that are impossible to predict analytically and must be numerically simulated and propagated through time with the aid of high-speed computers. Doctors and biomedical researchers need the help of the computational mathematics community to create a computer-generated dynamical model of the atria that they can perform experiments on [6, 8, 15, 17-19, 24-26]. This research has combined the mathematics of dynamical systems and parallel processing to create such a computer model. The model beats in real-time and is adjustable down to the individual muscle level. The essentials of the model are represented to the right. Again, for a more in-depth discussion please see our website.



First iterative three-dimensional model.

3D Model

## Ideal Left Atrium

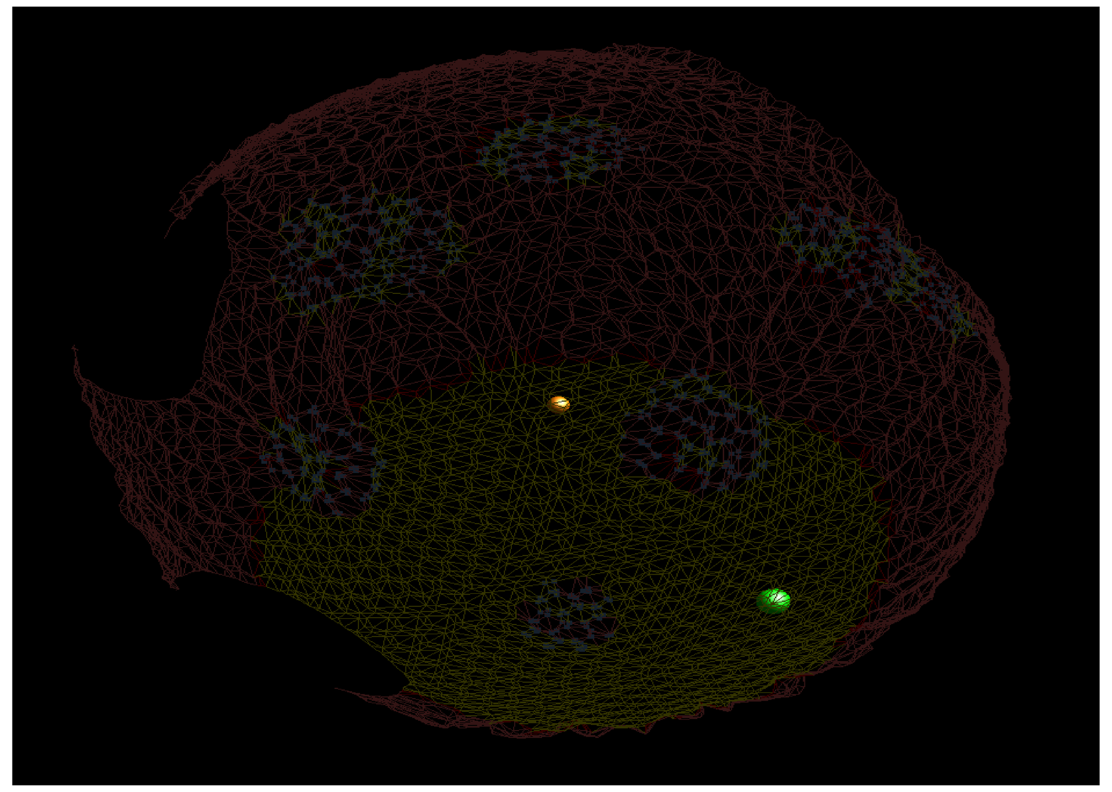


Posterior wall of the idealized left atria, showing the four pulmonary veins.

The majority of cardiac arrhythmia are caused by malfunctions that occur in the left atrium [6, 8, 16-19, 24-26]. Hence, a large part of our work is focused on the left atrium. Here we present our model of the left atrium idealized by removing non-critical components.

Left Atrium Normal

## Left Atrial Micro-Reentrant Flutters



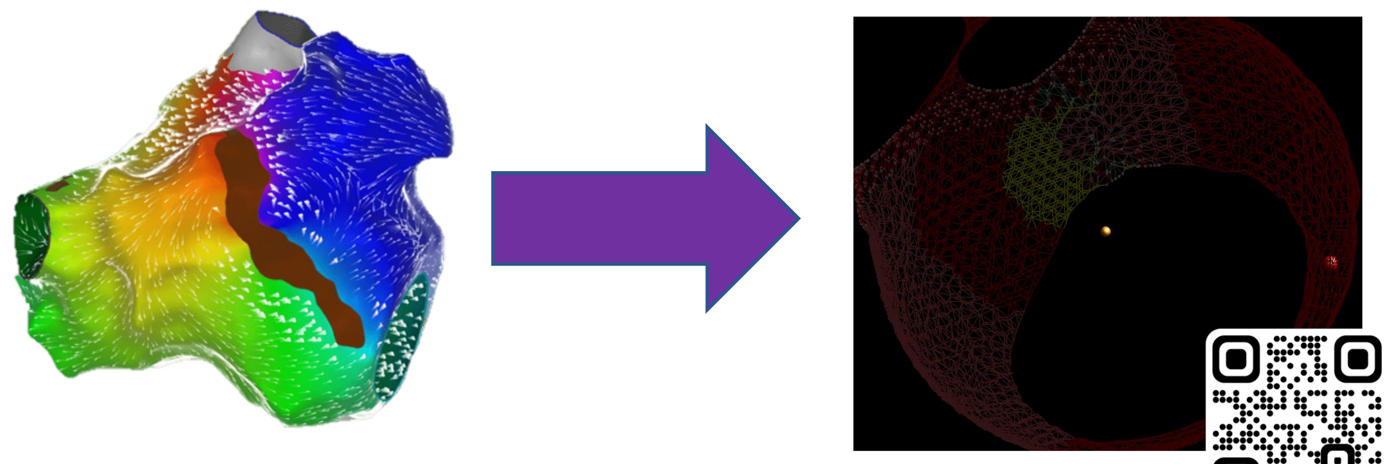
Micro-Reentrant atrial flutters.

The model here simulates an accurate atrial flutter induced by a slowed action potential and shorter recharge and contraction duration represented by the circles pictured at the left.

Micro-Reentries

## Man Made Isthmus

In many cases patients must return for repeated ablation procedures, this can be the result of ineffective ablations or spawning of new arrhythmias from those ablated areas. Isthmus regions are typically the result.

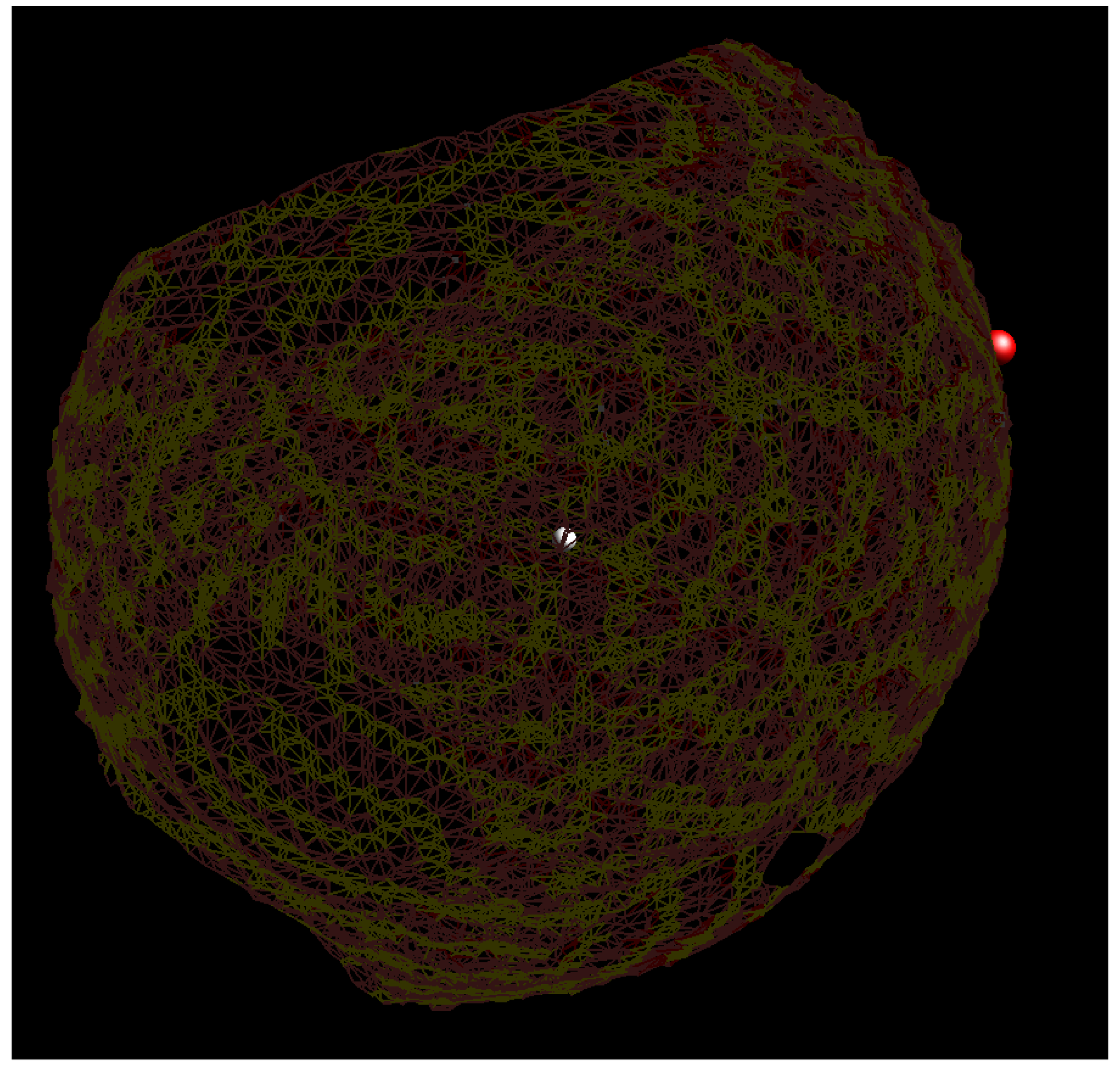


Real world map of left atria during atrial flutter created by electrophysiologist compared with idealized model.

Man Made Isthmus

## Atrial Fibrillation

Atrial fibrillation (AF) is the most prevalent cardiac arrhythmia. It is characterized by chaotic electrical signals in the atria, causing the atria to beat erratically, leading to blood stagnation and the formation of clots that may produce strokes and heart attacks [3, 4, 8]. Chaotic systems are not well understood, making AF the most elusive of all SVTs [3, 4, 8-14]. Where an electrophysiologist must place scar tissue to illuminate AF is a tricky question to answer. It needs to be more than an educated guess gained from trials run on living patients. This is where the model could prove to be most useful to doctors and researchers.

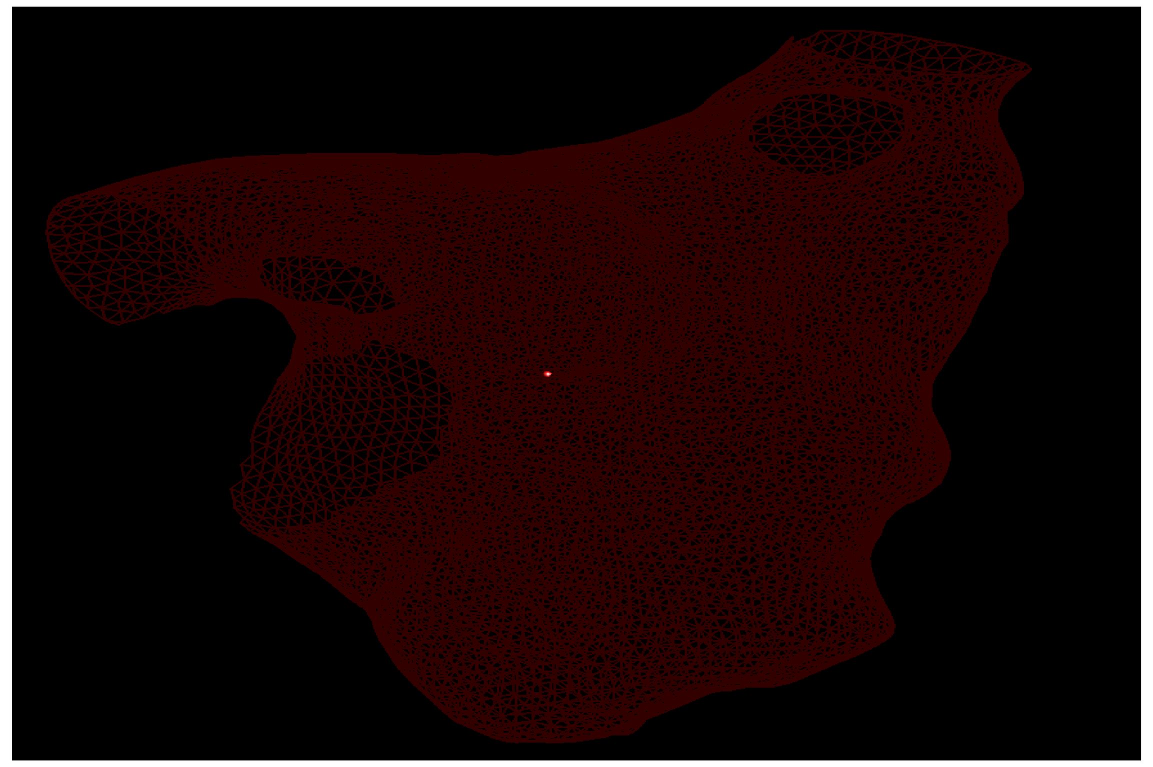


Above are manually produced areas of muscle with a slower action potential speed and quicker contraction and refractory speed. Simulations resulted in entropic outcomes, produced areas were either stimulated by the sinoatrial node or through repeated ectopic foci.

Left Atrium AF

## Patient-Specific Left Atrium

Patient-specific is the gold standard that all models aspire to become. Our system can take 3D assets and build models specific to the data; moving us closer to individualized models [8, 15-19, 24-26]. This will allow doctors to perform and test ablation procedures prior to surgery.



Hyper-realistic model of left atrium.

Normal Beat

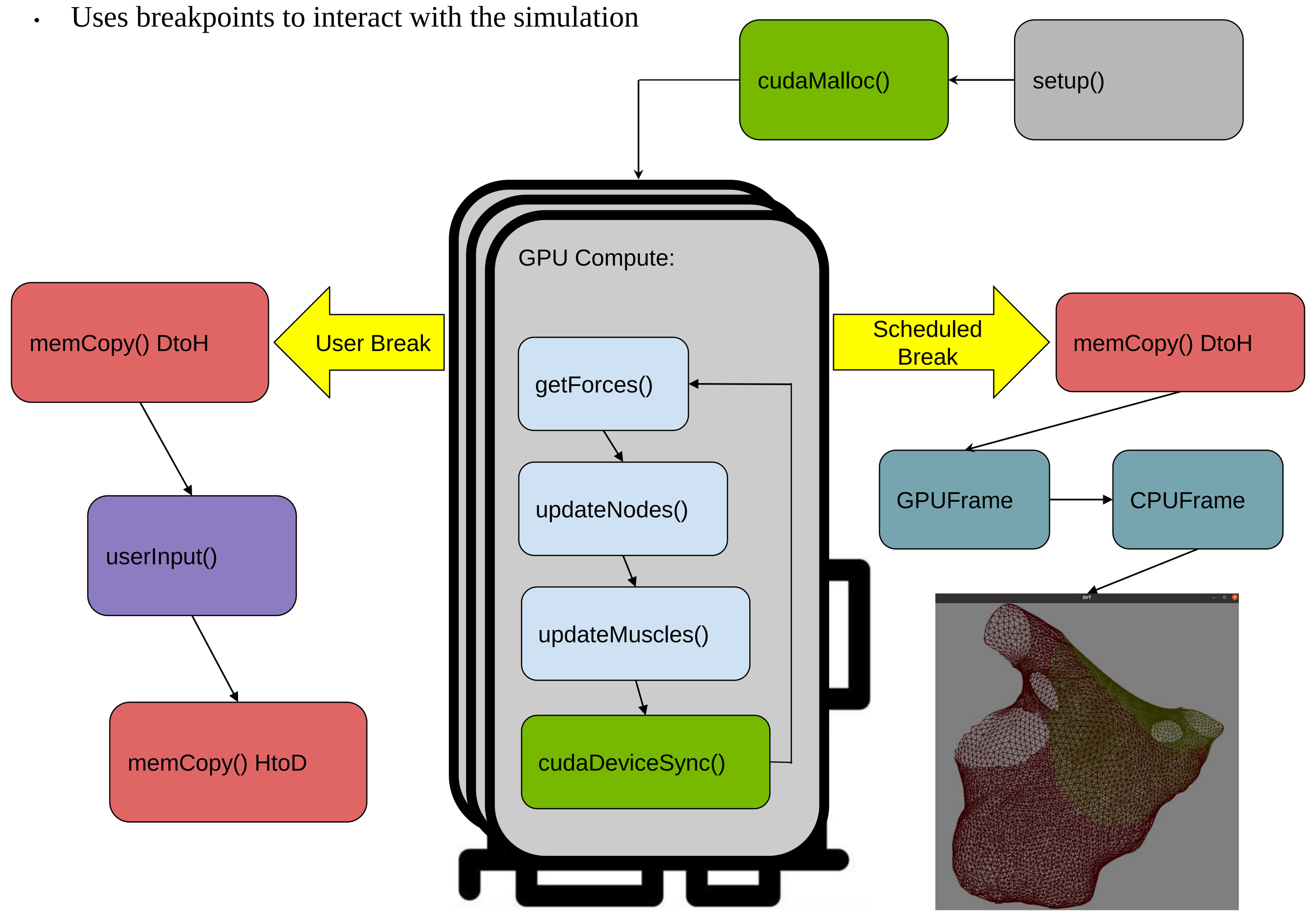
Roof Flutter

AF Model

## Methods

The code is written in C/C++ and CUDA. The simulations are accelerated on CUDA-enabled NVIDIA GPUs. Visualization and three-dimensional rendering are done in OpenGL and Blender.

- Blender-generated assets implemented with Python BPY API
- Generated nodes and muscles to lay over Blender assets
- Offloaded nodes and muscles to GPUs
- Periodic nodal dump for visualization
- Uses breakpoints to interact with the simulation




## Results and Limitations

Our model can take user-defined assets and create a model of the human heart that beats in real-time and is adjustable down to individual muscle levels. Muscle attributes can be set to send the model into arrhythmias which we are able to eliminate through simulated ablations. Our model can help electrophysiologists and researchers better understand heart arrhythmias and how to eliminate them. In public patient cases provided by Biosense Webster, we were able to validate our model by mimicking real-world cases, the first being an atrial flutter. Our limiting factor is getting enough patient data.

## Acknowledgements

We would like to thank:
The NVIDIA Corporation for partnering with us and for generous hardware donations.
The Tarleton State University Mathematics department for the use of their HPC Lab.
Presidential Excellence in Research Grant Award #0102344.
Dashon Mitchell for his continued advice and sincere help.

## References

[1] Wynsberghe DV, Carola R, Noback CR. 1995. *Human Anatomy and Physiology* (3rd ed.). McGraw-Hill, London.
[2] Dubin D. 2007. *Rapid Interpretation of EKG's: ... an Interactive Course* (6th ed.). Cover Publishing Company, Fort Myers, FL.
[3] Fogoros RN. 2012. *Electrophysiologic Testing* (5th ed.). John Wiley & Sons, Incorporated, Hoboken, NJ.
[4] Klabunde RE. 2021. *Cardiovascular Physiology Concepts.* Wolters Kluwer, Philadelphia, PA.
[5] Shen MJ, Zipes DP. 2014. Role of the autonomic nervous system in modulating cardiac arrhythmias. *Circulation research,* 114, 6 (May 2014), 1004–1021. https://doi.org/10.1161/CIRCRESAHA.113.302549.

Full reference list