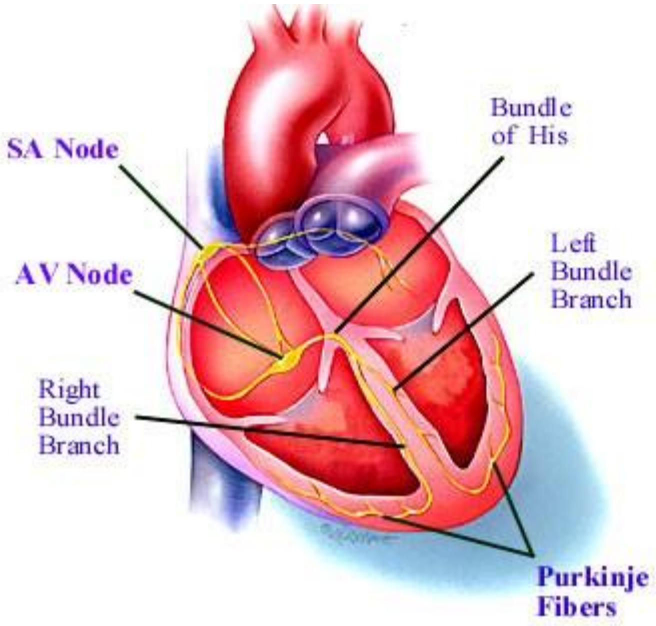
A Cellular Automata Model for Dynamics and Control of Cardiac Arrhythmias

Danny Gallenberger

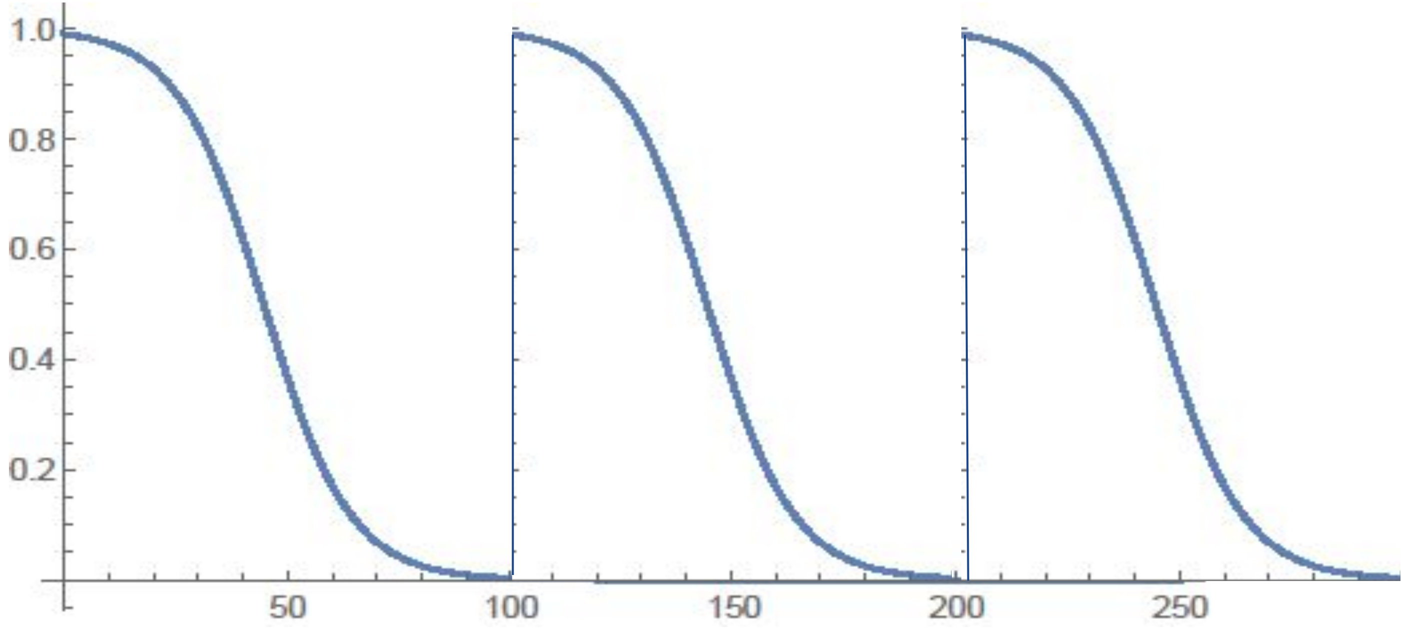
Electrophysiology of the Heart

- Four chambers
- Heartbeat driven by electrical signal
- As signal passes through each chamber, the heart contracts



Electrophysiology of the Heart

Transmembrane Potential

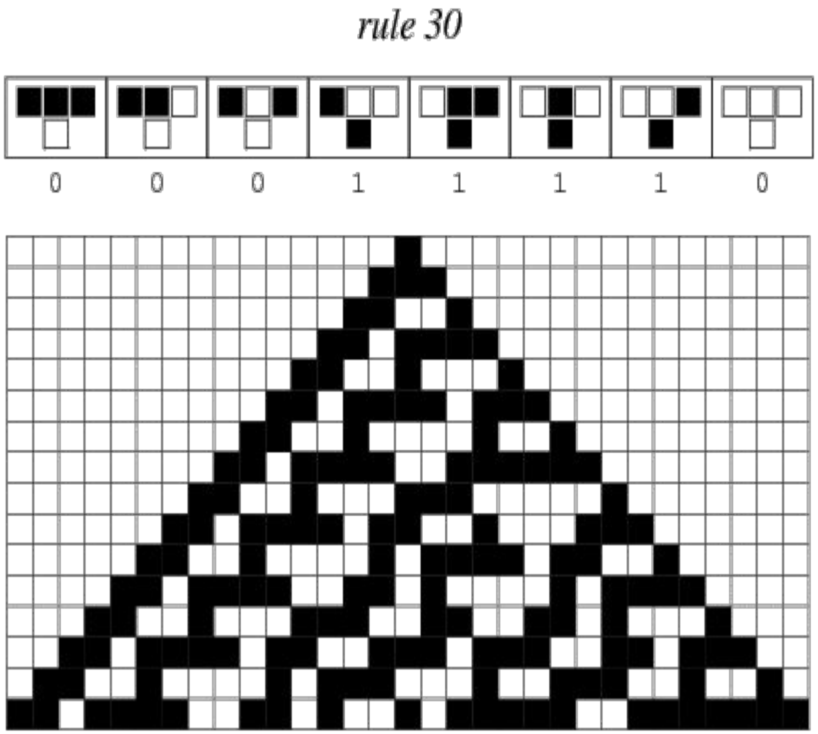


Action potential (V)

Time (ms)

Cellular Automata

- A two-dimensional grid of cells
- Each cell changes state based on specific rules, usually determined by the states of neighboring cells.



Research Task

Develop a cellular automata model to study the propagation of electrical waves in the heart, and use the model to explore cardiac arrhythmias and possible control algorithms to eliminate arrhythmias.

Through this model, we can simulate what an electrical wave looks like as it is propagated through the heart.

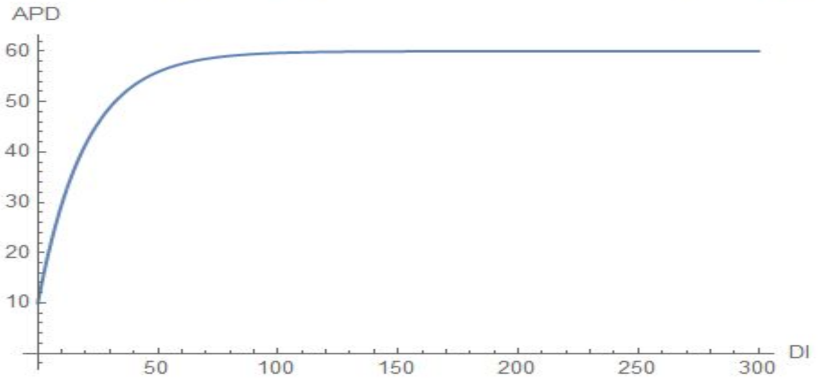
Research Steps

---

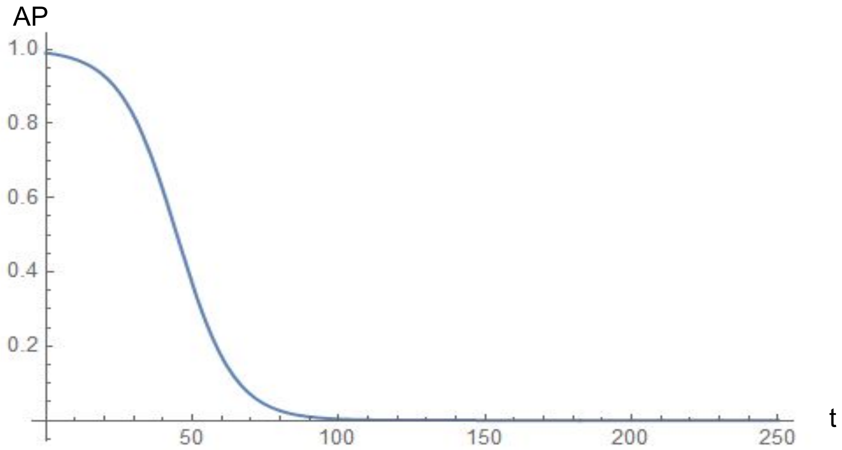
1. Explicitly write out the Mathematica simulation provided in an easy-to-understand fashion. Separate out variables and equations.
2. Use MATLAB to recreate the Mathematica simulation.
3. Translate MATLAB code into C.
4. GPU implementation.
5. Implement various control mechanisms to remedy arrhythmias.

Diagrams

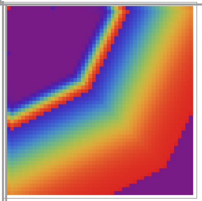
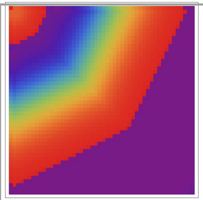
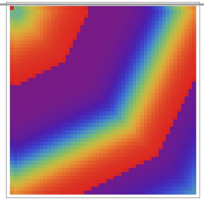
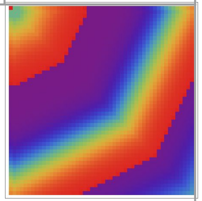
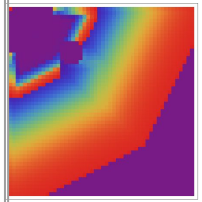
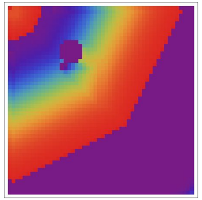
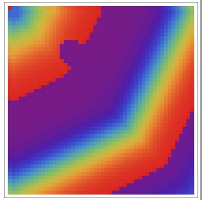
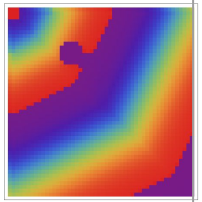
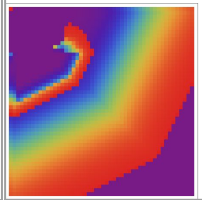
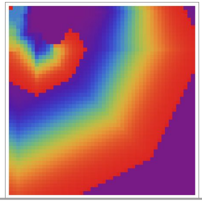
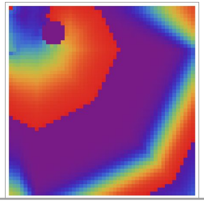
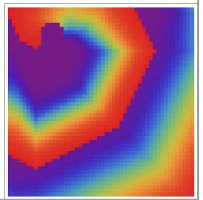
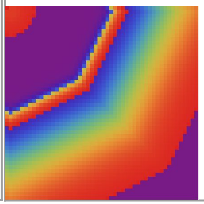
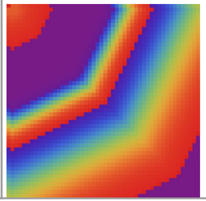
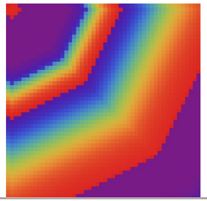
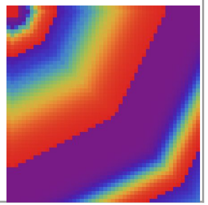
- Restitution curve
  - $f(D_n) = A_{max} - A_0 e^{-Dn/\tau}$
  - $f(D_n) = 60 - 50e^{-Dn/20}$
  - Unstable for $f'(D_n) > |1|$



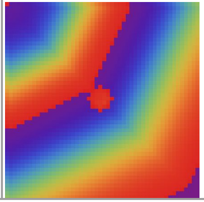
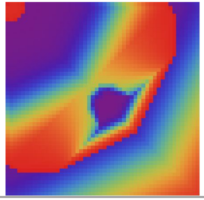
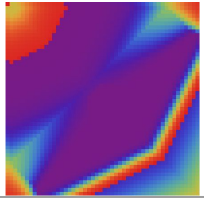
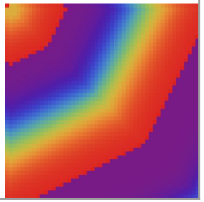
- Initial wave form
  - $f(A,t) = e^{-t/T(A)} / (c+e^{-t/T(A)})$
  - $T(A) = A / (\ln(0.9) - \ln(0.1*c))$
  - $f(t) = e^{-t/9.7025} / (0.01+e^{-t/9.7025})$
  - $T(66) \approx 9.7025$

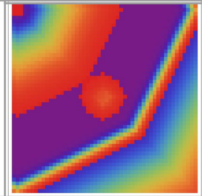
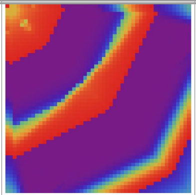
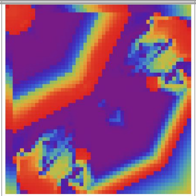
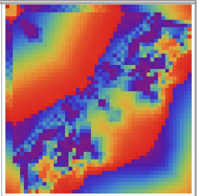


Diagrams

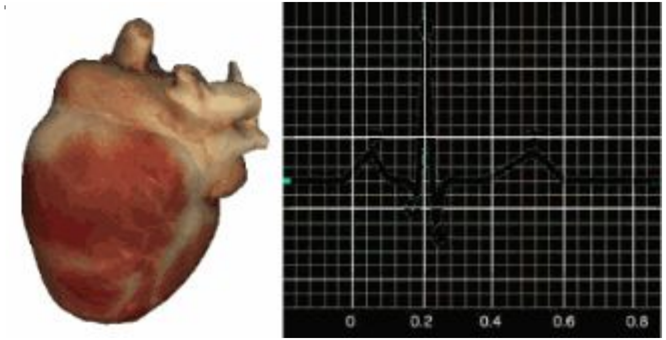
	t = 100	t = 200	t = 300	t = 400
Normal Conduction				
Normal Conduction with Scar				
Spiral Wave with Scar				
Alternans				

Diagrams

	t = 150	t = 175	t = 195	t = 400
Normal (ectopic)				

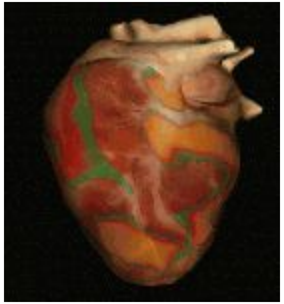
	t = 150	t = 400	t = 600	t = 800
Alternans (ectopic)				

Cardiac Arrhythmias

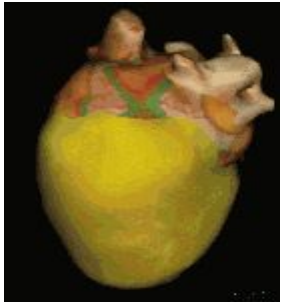


Normal rhythm

AV heart block



Ventricular fibrillation



Atrial fibrillation

Sources

- Flavio H Fenton et al. (2008) *Cardiac arrhythmia.* Scholarpedia, 3(7):1665.
- Garcia, G. & Sheth, N. (n.d.). *Understanding Cardiac Arrhythmias through Cellular Automata.* University of Tennessee, Knoxville.
- Wolfram Research, Inc., Mathematica, Version 11.3, Champaign, IL (2018).