# PCMI Project:
# Resetting Reentrant Excitation Oscillations in Different Geometries

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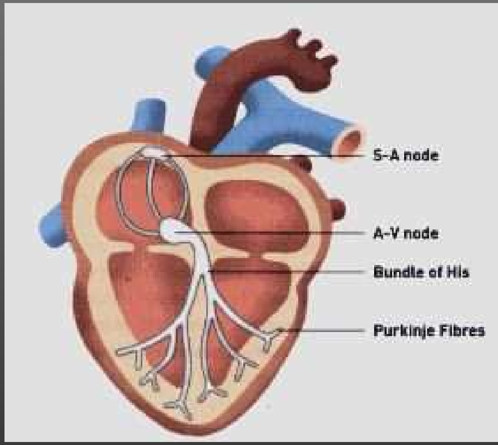
# motivation...




- normal rhythm is set by cells in SA node
- excitation spreads via conduction system
- cardiac tissue is excitable...
  $\star$ large enough perturbation from rest
  $\Longrightarrow$ action potential
  $\Longrightarrow$ refractory period

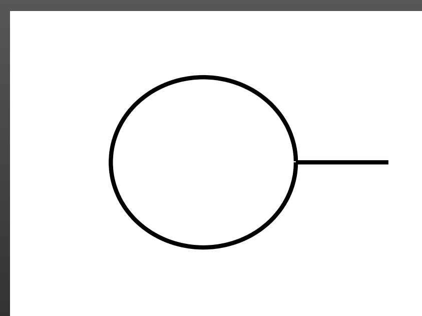
- Reentrant Tachycardia...
  $\star$ a conduction pathway loops onto itself $\longrightarrow$ self-sustained oscillation of excitation
  $\star$ rapid heart rate determined by time it takes excitation to travel around the loop
- Goal...
  $\star$ deliver stimulus to area, utilizing refractory properties, to annihilate tachycardia

# mechanism for annihilation of tachycardia...

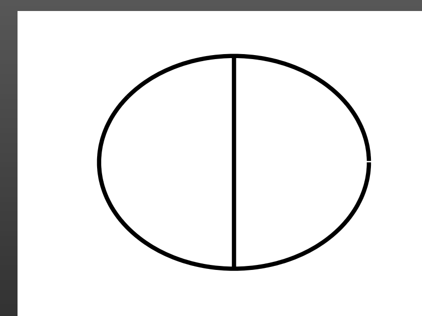
- consequences of refractory property of 1D excitable media...
  - a stimulus delivered...
    $\star$ early in the refractory period will produce 0 new waves
    $\star$ after the refractory period will produce 2 new waves
    $\star$ in just the right spot will produce only 1 new wave
  - two waves colliding head on will be annihilated by the refractory periods
- simple picture of tachycardia....
  - represent the loop in the conduction system as a 1D ring of excitable media
  - the tachycardia is a traveling wave of excitation on the 1D ring
  - the above observations provide a mechanism for both
    the annihilation and phase resetting of tachycardia
    $\star$ can create phase resetting curves to characterize and study the behavior

## the project...

- Goal: to explore this phenomena on different geometries
  - ring with a tail



  - ring with a chord



- Fitzhugh-Nagumo was the suggested model for excitability
  - boundary conditions will be challenging for complicated geometries

$\Longrightarrow$ so, we took a different approach in modeling excitability...

# Red-Blue-White model of excitation...

⋆ a number of discrete cells on a ring

⋆ each cell can be in one of four states

⋆ the state of each cell is updated every discrete time step

⋆ each state is assigned an arbitrary numerical value

- resting: $0$
- excited: $+10$
- absolutely refractory: $-\infty$
- relatively refractory: $-c$ .. $-1$

⋆ input variables...
$b =$ length of absolute refractory period
$c =$ length of relative refractory period
$N =$ how many cells on a ring

★ show movie of pulse on a ring with $N = 50, b = 5, c = 5$

## adding a stimulus...

- $s =$ strength of the stimulus (note: $s \geq 1$)
- $t_s =$ time, or phase, at which the stimulus is applied to the ring
- if the stimulus is delivered to...

  $(i)$ absolutely refractory cell $\longrightarrow$ no response

  $(ii)$ resting cell $\longrightarrow 2$ new waves propagate in opposite directions

  $(iii)$ relatively refractory cell...

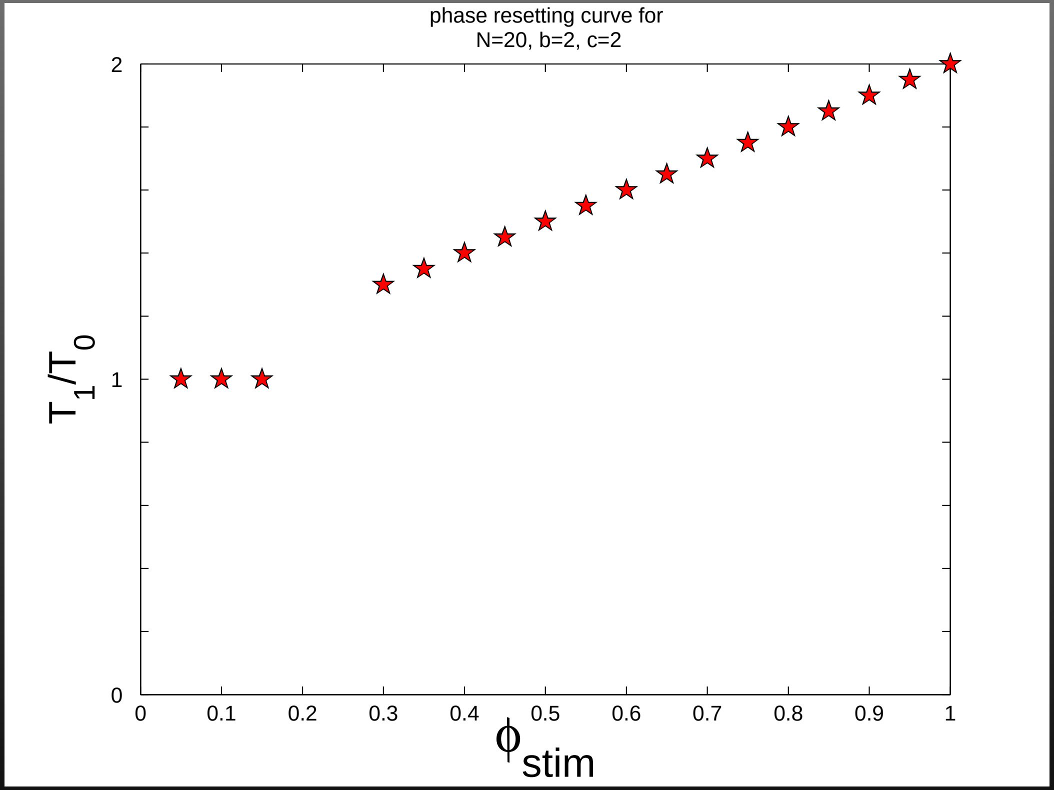
  $\star$ early in the relative refractory period $\longrightarrow$ no response
  $\star$ late in the relative refractory period $\longrightarrow 1$ new wave propagates back

★ show movies for various $t_s$ with $N = 50, b = 5, c = 5, s = 4$, and threshold=$+1$

## phase resetting curve...

- $T_0 =$ time it takes the original pulse to travel around the ring once
- $\phi_s =$ phase of the stimulus (with respect to a reference cell)
  - $\phi_s = 1/N \Rightarrow$ stim is applied to ref cell when the orig pulse is also at that point
  - $\phi_s = 1/2 \Rightarrow$ stimulus is applied when original pulse is halfway around the ring
  - $\phi_s = 3/4 \Rightarrow$ stimulus is applied when original pulse is a $\frac{3}{4}$ the way around
  - $\phi_s = (N+1)/N \Rightarrow$ same result as $\phi_s = 1/N$
- if a stimulus is applied at a given phase...
  - $T_1$ is the time since the ref point last saw a pulse to when it sees another
  - in general..
    - $T_j$ is the time at which the ref point has seen another $j$ pulses

# phase resetting curve...




- for a given $N$, $b$, $c$, and $s$, stimulate the reference cell at various phases, and calculate $T_1$
- we get the same type of curves generated by Fitzhugh-Nagumo excitability (Glass,1995)

## so what...

- why did we take this approach...
  - ★ wanted to develop a simple way to observe the behavior found in FN
    - annihilation and phase resetting
    - reproduce the phase resetting curves
  - ★ modify this simple code for different for geometries
  - ★ perhaps examine periodic stimulation
  - ★ then, moving into a continuous PDE model, we might know what to look for
- of course, there might be more interesting behavior in the PDE model, but...
  ⋆ this simple discrete model is a good way to investigate the complicated problem
  and gets us (me) thinking about the behavior of excitable media in general,
  and the corresponding rules that govern its behavior