Adaptive Sampling of Cardiac Action Potentials for a Best Fit Ellipse

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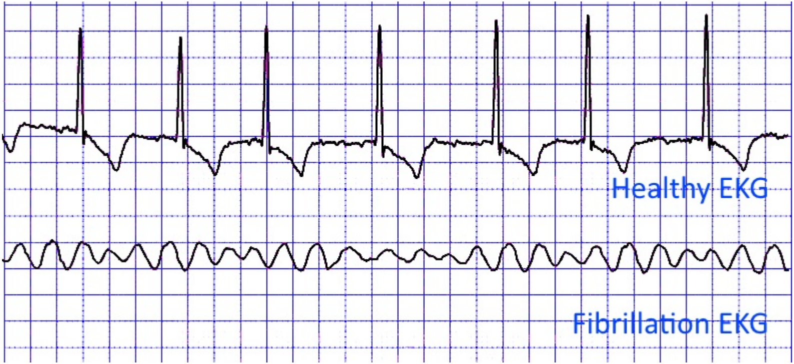
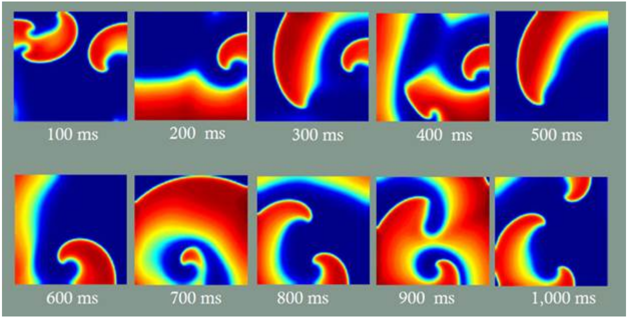
Motivation

- Fibrillation and treatment: large electric shocks
- Drug therapies don't work! (Pratt and Moye, 1995)
- Another idea: do more with less



Motivation

- Small electric shocks instead of one big one
- more understanding as a math/physics problem (since math is easier than biology)



The model

Fenton et. al., 2002

$$\frac{\partial V_m}{\partial t} = D\nabla^2 V_m - \frac{I_{ion} + I_{stim}}{C_m}$$

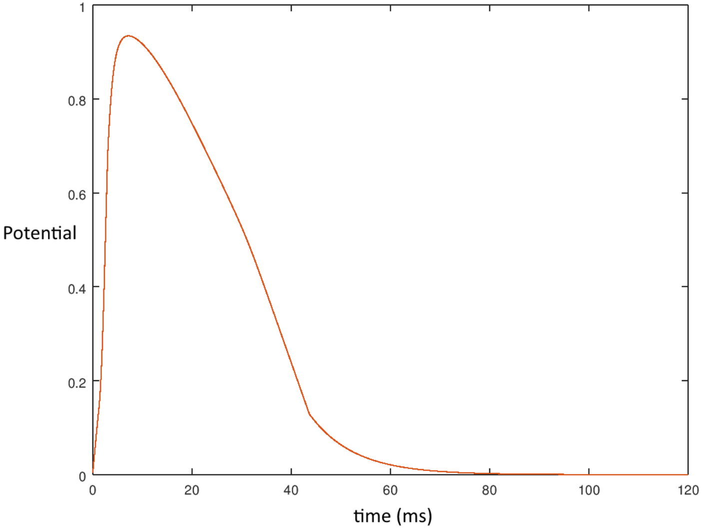
$$I_{fi} = \frac{-\nu p(V_m - V_c)(1 - V_m)}{\tau_d}$$

$$I_{so} = \frac{V_m(1-p)}{\tau_0} + \frac{p}{\tau_r}$$

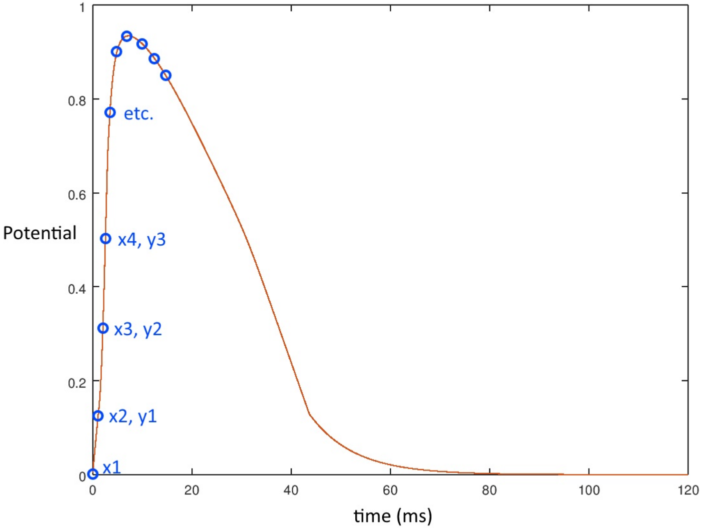
$$I_{si} \frac{-w(1 + \tanh(k(V_m - V_c^{si})))}{2\tau_{si}}$$

I_{fi}: sodium upstroke
I_{si}: calcium plateau
I_{so}: potassium downstroke
I_{stim}: stimulus current (experiment)

And when we do this...



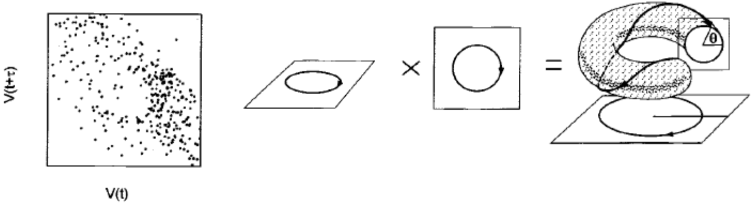
Phase space



1
0.8
0.6
0.4
0.2
0
Potential
etc.
x4, y3
x3, y2
x2, y1
x1
0
20
40
60
80
100
120
time (ms)

The model

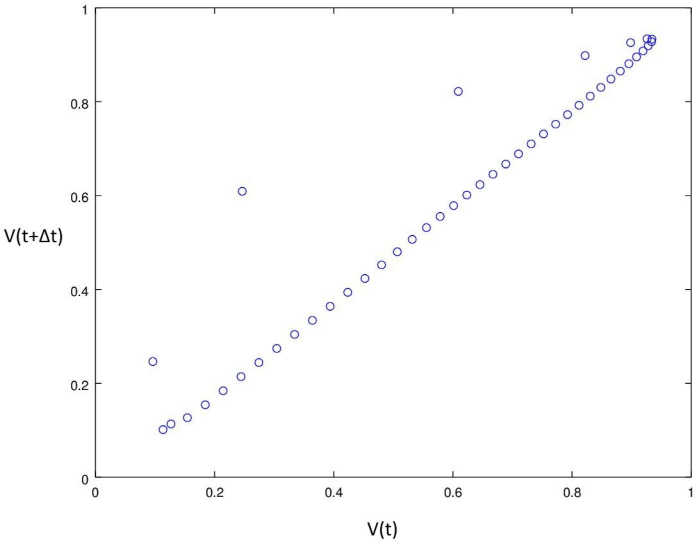
- Back away from the biology, what's happening?
- a toroidal attractor in phase space



Method

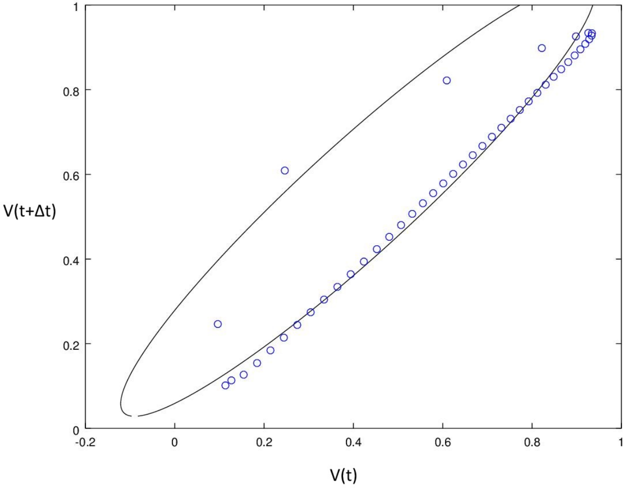
- The idea: sample discrete points on this signal
- plot into phase space as $V(t)$ against $V(t + \Delta t)$
- important consideration: choosing Δt
- cater to experimentalists!

Method



Issues

What happens when we try to fit an ellipse?



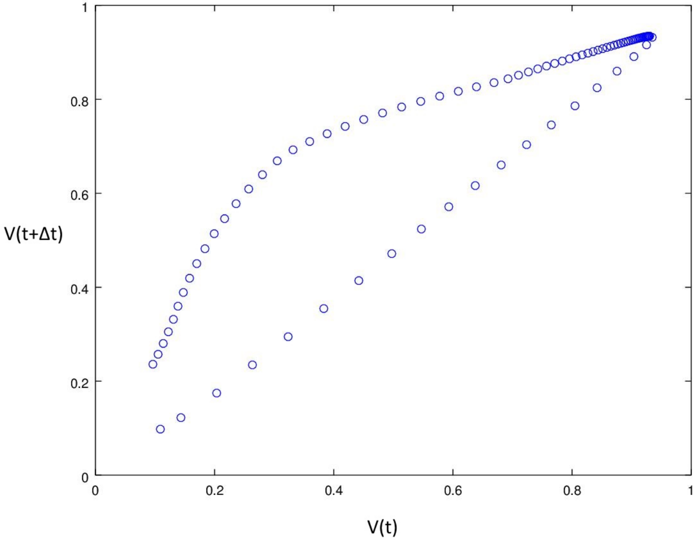
Issues

- to the computer's eyes, perfectly fine
- to a human's eyes, not so much
- the issue: point density

New method

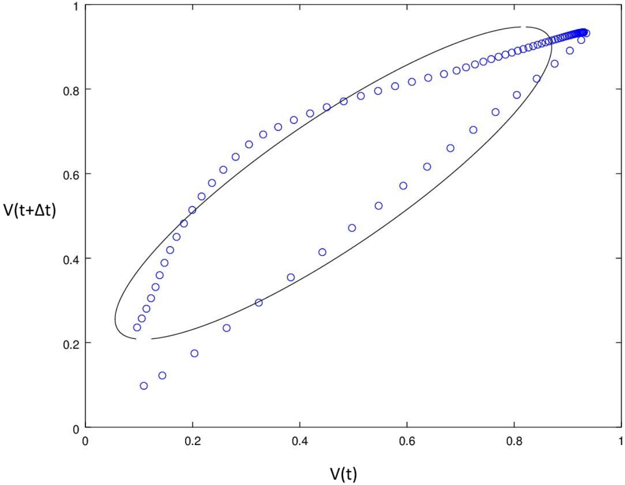
- What if we relax the conditions on Δt?
- Say, for an action potential of length N with upstroke duration n, we choose $\Delta t = \frac{n}{N}$ during the upstroke
- How does this compare to the old method?

New method



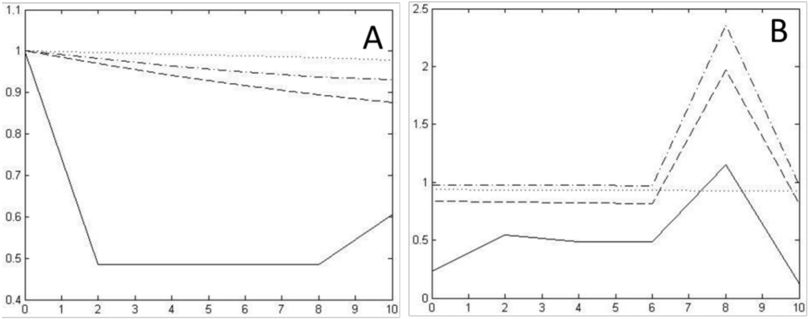
New Method

Better?



An application

- using this method to explore correlations in drug therapy
- dotted: eccentricity, dashed/dot-dashed: semimajor/minor axes, solid: termination of fibrillation



Percent Block

Summary

- make a geometric connection to raw data: represent phase space trajectories by ellipses
- interpret the data such that the geometry makes sense: choose Δt appropriately
- use the geometry to observe correlations: measure eccentricity, axis length, etc.

Future work

- How should we choose the sampling ratio?
  - static ratio based on length of upstroke?
  - dynamic ratio based on some metric in phase space?
- How many points do we need to work with?
- Application: do the best-fit ellipses provide a reliable descriptor of fibrillation termination rates? (big for the experimentalists)

Acknowledgements

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