What do cardiac arrest, energy harvesters, and animal networks have in common?

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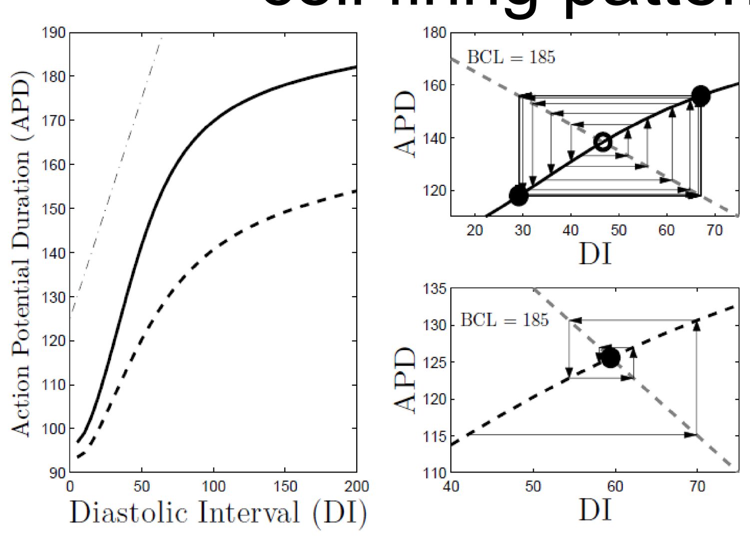
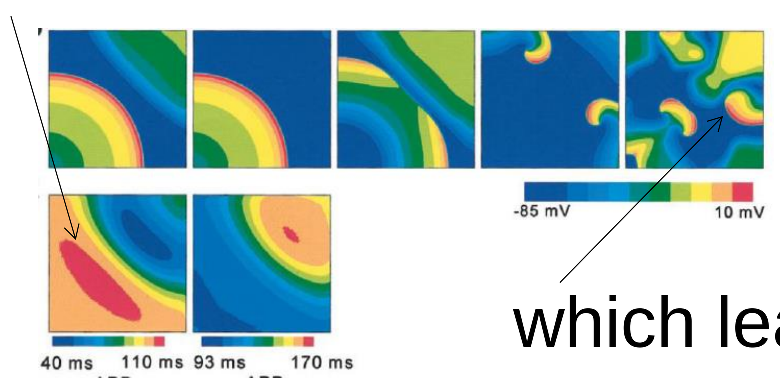
Treatment for Cardiac Arrest

Instability in cardiac cell firing patterns…



The action potential duration (APD) restitution curve (left) shows the APD as a function of the diastolic interval (DI). If the slope is larger than 1, alternation in the APDs (alternans) can develop in the tissue.

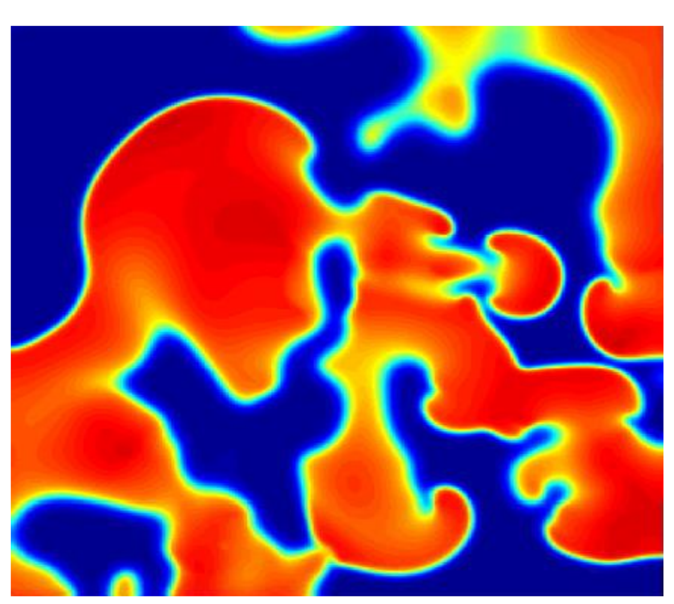
leads to Alternans…



Alternans in a 2D model of cardiac tissue can create spiral waves, causing tachycardia, an elevated heart rate.

which leads to tachycardia…

which leads to fibrillation (a.k.a. cardiac arrest)…



Spiral waves can "break up" into multiple spirals, causing fibrillation in the tissue, which interferes with normal cardiac activity. If the spiral waves are not eliminated (through e.g. defibrillation) the heart cannot pump blood effectively. Fibrillation is deadly within minutes of onset.

which is a leading cause of death in industrialized nations.

Can we find better ways of terminating the spiral waves that cause fibrillation?

D. Wilson and J. Moehlis. An energy-optimal methodology for synchronization of excitable media. *SIAM Journal on Applied Dynamical Systems* 13.2 (2014): 944-957.
D. Wilson and J. Moehlis. Towards a more efficient implementation of low energy antifibrillation pacing. In preparation.

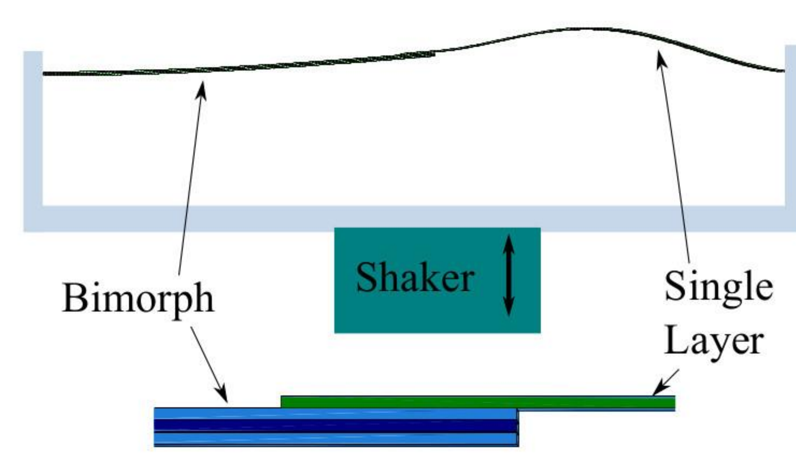
Can we remove the instability to prevent cardiac arrest before it starts?

D. Wilson and J. Moehlis. Extending phase reduction to excitable media: theory and applications. To appear in *SIAM Review.*

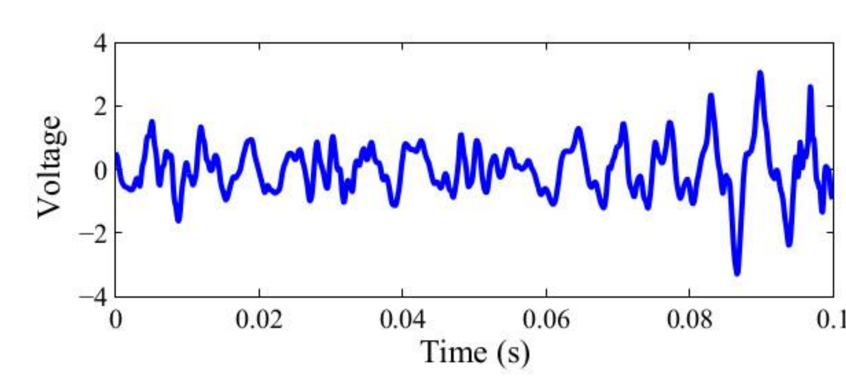
Energy Harvesting

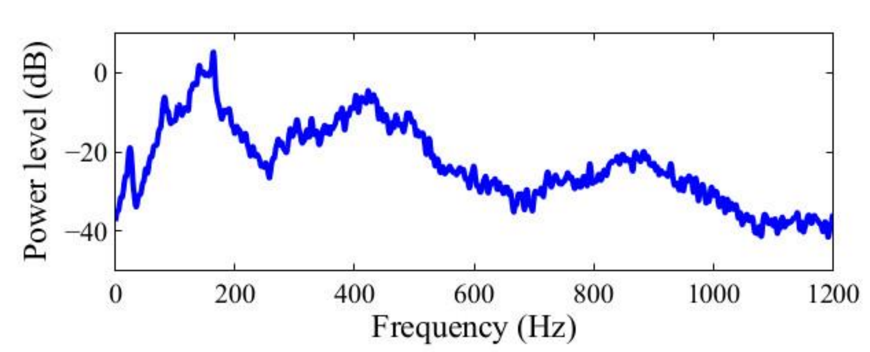
Devices which use ambient energy sources to create electrical power are known as energy harvesters. There are many places in our world for which there is energy in the form of vibrations that goes unused. Moreover, often there is a desire to mount a sensor and wireless transmitter in a place which is very difficult to get power to. Vibrational energy harvesters can provide a solution to this problem.

Frequently, ambient vibrations have a time varying frequency content, which makes it difficult to harvest with a resonant energy harvester. Incorporating nonlinear characteristics can decrease the frequency sensitivity. In this device an asymmetric buckled beam with piezoelectric elements is used for energy harvesting.

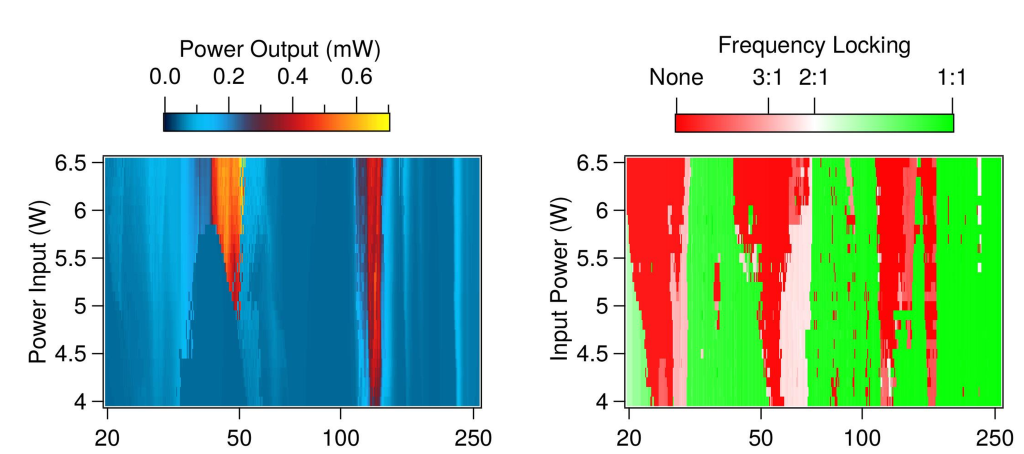


System behaves chaotically for certain frequencies:





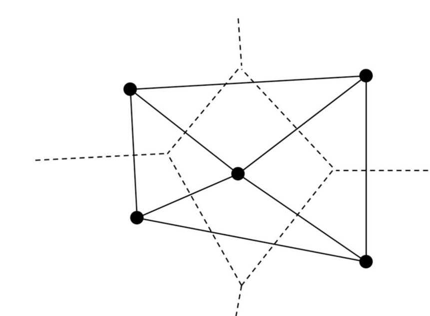
Areas of high power are associated with a lack of frequency locking between input and output:



L. Van Blarigan and J. Moehlis, A broadband vibrational energy harvester. *Applied Physics Letters*, 100:253904, 2014.

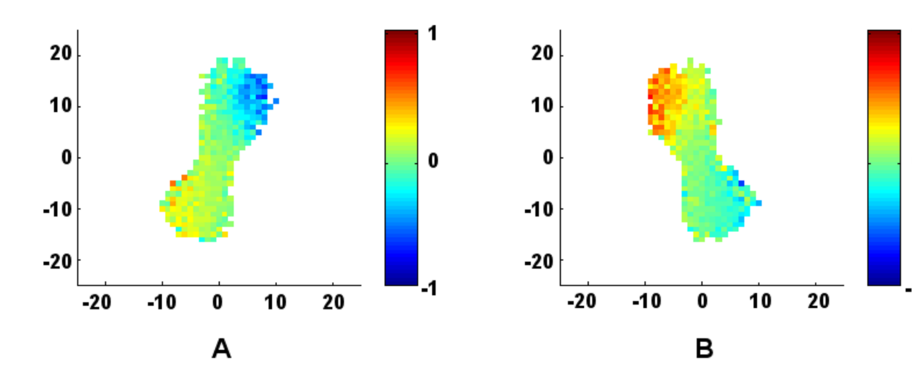
Networked Animal Behavior

Schools of fish and flocks of birds are examples of self-organized animal groups that arise through social interactions among individuals. Here, the communication topology is described by Delaunay triangulation, which is defined by each individual's Voronoi neighbors. We find that in the Delaunay-based model an individual who is perturbed is capable of triggering a cascade of responses, ultimately leading to the group changing direction. This phenomenon has been seen in self-organized animal groups in both experiments and nature.



(←) Network topology is defined by a nearest-neighbor model. Swarm cohesion is maintained by a balance of attraction and repulsion.

(Below) Heat map shows regions of influence: rightward influence in blue, and leftward influence in red.

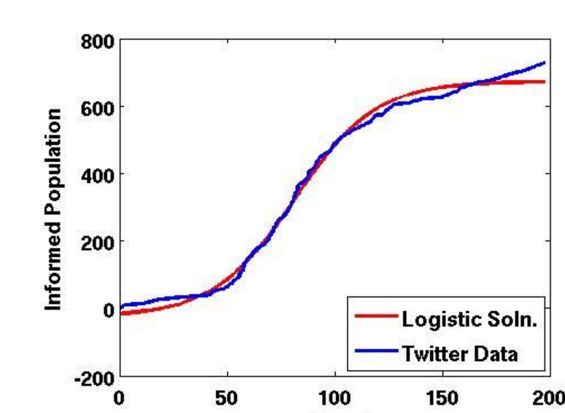


Over time, according to a simple nearest neighbor model, the swarm has a tendency to settle to a diagonal configuration with leaders at the head of the pack, which helps explain the "flying vee" flocking formation.

A. Kolpas, M. Busch, H. Li, I.D. Couzin, L. Petzold, J. Moehlis. How the Spatial Position of Individuals Affects Their Influence on Swarms: A Numerical Comparison of Two Popular Swarm Dynamics Models. PLoS ONE 8(3): e58525, 2013.

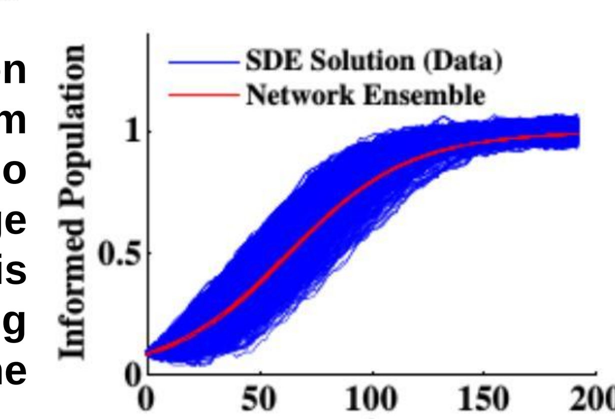
Hashtag Adoption in Twitter

Cascade phenomena of information sharing is often observed in human networks, too.



(←) Real Twitter hashtag adoption curve (blue), vs. an average adoption curve predicted by the Twitter network structure (red).

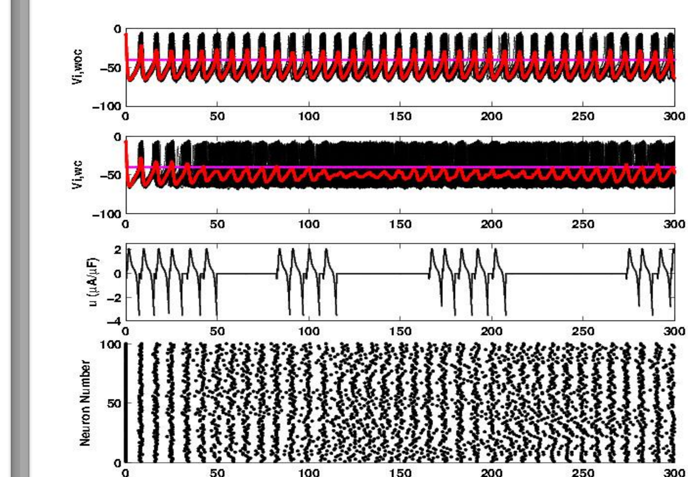
(→) The data distribution (blue) is synthesized from the data via Monte Carlo simulation. The average network behavior (red) is capable of approximating the mean behavior of the data.



M. Busch and J. Moehlis, A nonparametric adaptive nonlinear statistical filter. Proceedings of the 53rd IEEE Conference on Decision and Control (CDC), Los Angeles, CA, 2014.

Other Projects

Controlling Neural Populations

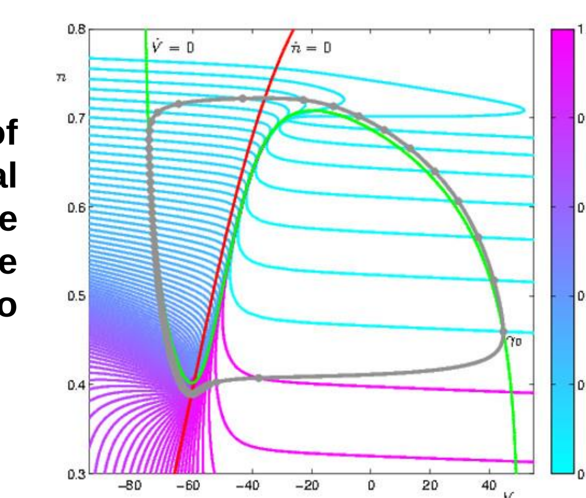


A proposed control method desynchronizes neural activity by maximizing the system's Lyapunov exponent. This study was motivated by deep brain stimulation treatment of Parkinson's disease.

D. Wilson and J. Moehlis, Optimal chaotic desynchronization for neural populations. *SIAM Journal on Applied Dynamical Systems*, 13:944-957, 2014.
D. Wilson and J. Moehlis, Locally optimal extracellular stimulation for chaotic desynchronization of neural population. *Journal of Computational Neuroscience, 37:243-257, 2014.*

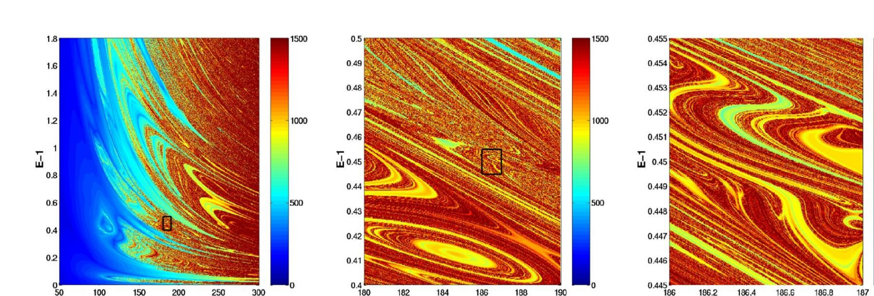
Nonlinear Oscillators: Isochrons

Numerical computation of isochrons for a neural oscillator model allows one to understand the phase dynamics in response to inputs.



H. Osinga and J. Moehlis, A continuation method for computing global isochrons. *SIAM Journal on Applied Dynamical Systems*, 9:1201-1228, 2010.

Shear Flow Turbulence



Fractal turbulent lifetimes are found for a model for shear flow turbulence as a function of Reynolds number and perturbation size.

J. Moehlis, B. Eckhardt, and H. Faisst, Fractal lifetimes in the transition to turbulence, *Chaos*, 14:S11, 2004

Acknowledgements

Research Group Members:
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