A Sphere Model for Atrial Fibrillation

Tigany Zarrouk & Mattia Gaggi

Supervisor: Kim Christensen. Condensed Matter Theory Group—Imperial College London

Objectives

1. Replicate original model of Atrial Fibrillation (AF) from Christensen *et al.*
2. Incorporate restitution of heart cells into the model.
3. Model on more realistic morphology via translating model onto a sphere and adding restitution.
4. Analyse to see if there is enhanced risk with the new model, using new morphology and model basis, to create a more accurate AF model.

Introduction

- Atrial Fibrillation (AF) is a type of cardiac arrhythmia and one of the major causes of stroke and heart failure. AF is also the most widespread cardiac condition, with over 30 millions of people worldwide suffering from it. In the UK, expenses related to this disease account for more than **1%** of the total budget of the National Health Service, which is more than **800** million pounds. Atrial fibrillation usually manifests itself in patients affected through alterations of the normal cardiac rhythm lasting short periods of time (also called fibrillation episodes).

Phenomenology of Atrial Fibrillation

- Each heart beat originates as an electric signal in the sinoatrial (SA) node that propagates first into the atria, then through the atrioventricular (AV) node, through Purkinje fibres and finally from the ventricular endocardium to the ventricular epicardium. The electric signal is conducted in the cardiac muscle cells thanks to the polarisation mechanism of the cell membrane.
- When the electric impulse propagates a single muscle cell goes through three stages:
  - *Excitable state*: the muscle cell is at rest with a negative built up potential.
  - *Excited state*: the muscle cell is excited by its excited neighbours and the Voltage of the cell is at its peak.
  - *Refractory state* :the muscle cell goes through a phase during which it can't be excited again - this period is called *refractory period)*.
- Where the refractory period depends on the last time a cell was excited and is always fixed to a constant.
- AF is correlated to the amount of **fibrosis** in the cardiac tissue which generates a process called reentry.
  During reentry the electric signal wavefront propagation breaks. It has been shown a clear link between fibrosis and AF Even though many treatments have been developed, the mechanisms behind this condition are not completely understood and AF remains a major topic in medical research.
  The current research revolves around three possible approaches:

Our research is based on expanding on the work done by Kim Christensen on CA (Cellular Automata) models [1].

Results: Connectome

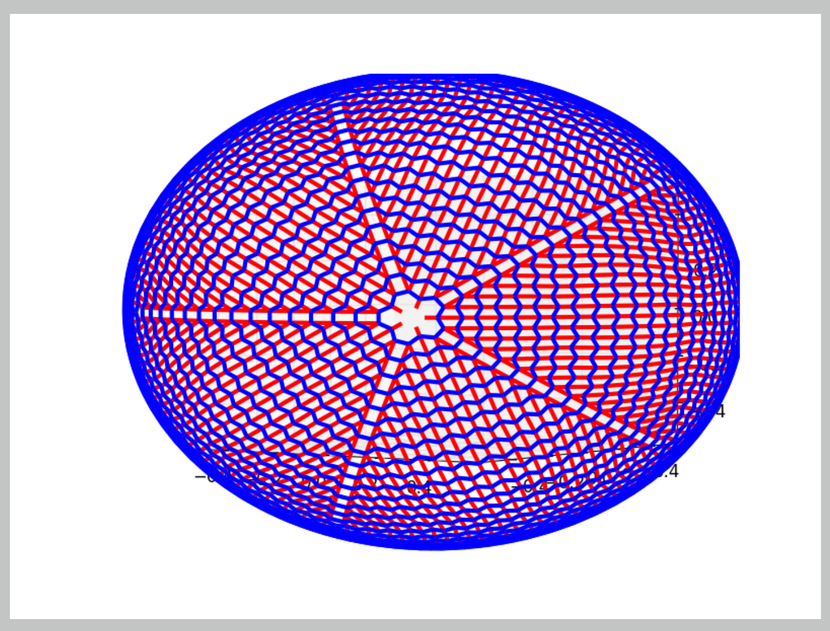

Figure 1: Hemisphere of possible connections defined on the sphere model. Each vertex corresponds to a face. Longitudinal connections are in red, transversal are in blue. Starts from a single pentagon on the icosphere and then can be seen to propagate outwards.

Results: Sphere and Previous model

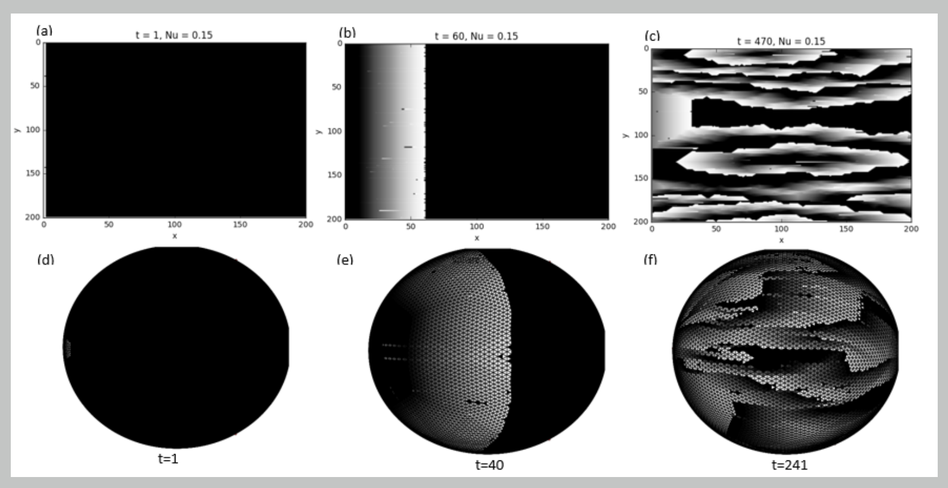

Figure 2: Figures of: Christensen *et al.*'s model at times of t=1, t=60 and t=470,for a, b and c, respectively, and the sphere model at times of t=1, t=41 and t=241 for d, e and f respectively. Normal wavefront propagation seen starting from pentagonal node in the leftmost figures.In figure e, the excitation wavefront propagates around the sphere, mimicking Christensen *et al.*'s model, b. On the right, chaotic, fibrillatory activity has arisen from reentry circuit spontaneously manifesting itself in c and f.

Implementing Restitution

In Christensen *et al.*'s model, the refractory period of each muscle cell was always fixed, this is not what happens in a real heart. In a real heart the refractory period depends on the heart beat rate and on the last time each cell it was excited. The relationship between refractory period and heart beat rate is called restitution.

Model on a Sphere

- In research by Fedotov, a cellular automaton model was constructed on the surface of a triangulated sphere to model spiral rotor waves on a closed, heterogeneous surface [2]. It was shown that both a decrease in refractory period and conduction velocity from a "healthy" myocardium state, where no irregular excitation waves above 300bpm are observed, resulted in an area where spiral waves were formed. In addition, a multi-electrode system was created to study the localization of AF sources by simulated electrograms.

Results: Figure

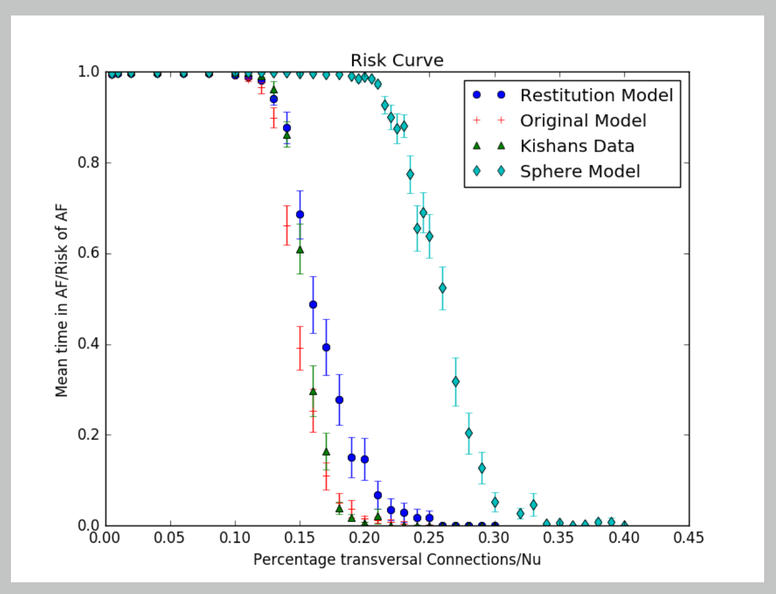

Figure 3: Figure of the Risk Curve of all the systems analysed. Y-axis: probablility of a realisation being in AF, x-axis: value of ν, the probability of a transversal connection between cells

Conclusion

- A simplified mechanism of AF had been achieved by Christensen *et al.'s* model through the modelling of heart muscle fibre connectivity while incorporating the effects of fibrosis. This model was improved upon by the additon of the restitution process, making AF more risky. By translating the model to a sphere, the steady growth of heart muscle fibres from the sino-atrial node could be replicated, while simulating a more realisitc morphology of the atria. The risk of AF was seen to be higher, than with the original model. Verification of this model can be achieved with the analysis of the proportion of fibrosis in atrial heart tissue.

References

[1] Kim Christensen, Kishan A. Manani, and Nicholas S. Peters.
Simple model for identifying critical regions in atrial fibrillation.
Phys. Rev. Lett., 114:028104, Jan 2015.