Interpreting Cardiovascular Data with Mathematics

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Why is this important?

- Cardiovascular disease affects **7 million people** in the UK and costs the NHS nearly **£9 billion a year**
- Drugs may have **gender-related therapeutic or adverse effects**, but these are not usually reflected in diagnostic or monitoring guidelines
- The NHS routinely collects **large volumes** of electrocardiogram (ECG) data which provides information on cardiac performance
- Standard metrics focus on key points in the signal, but disregard the clinical **importance of the ECG waveform shape**

Figure 1: The non-invasive, simple recording of an ECG (left) and a typical ECG output (right)

How can maths help?

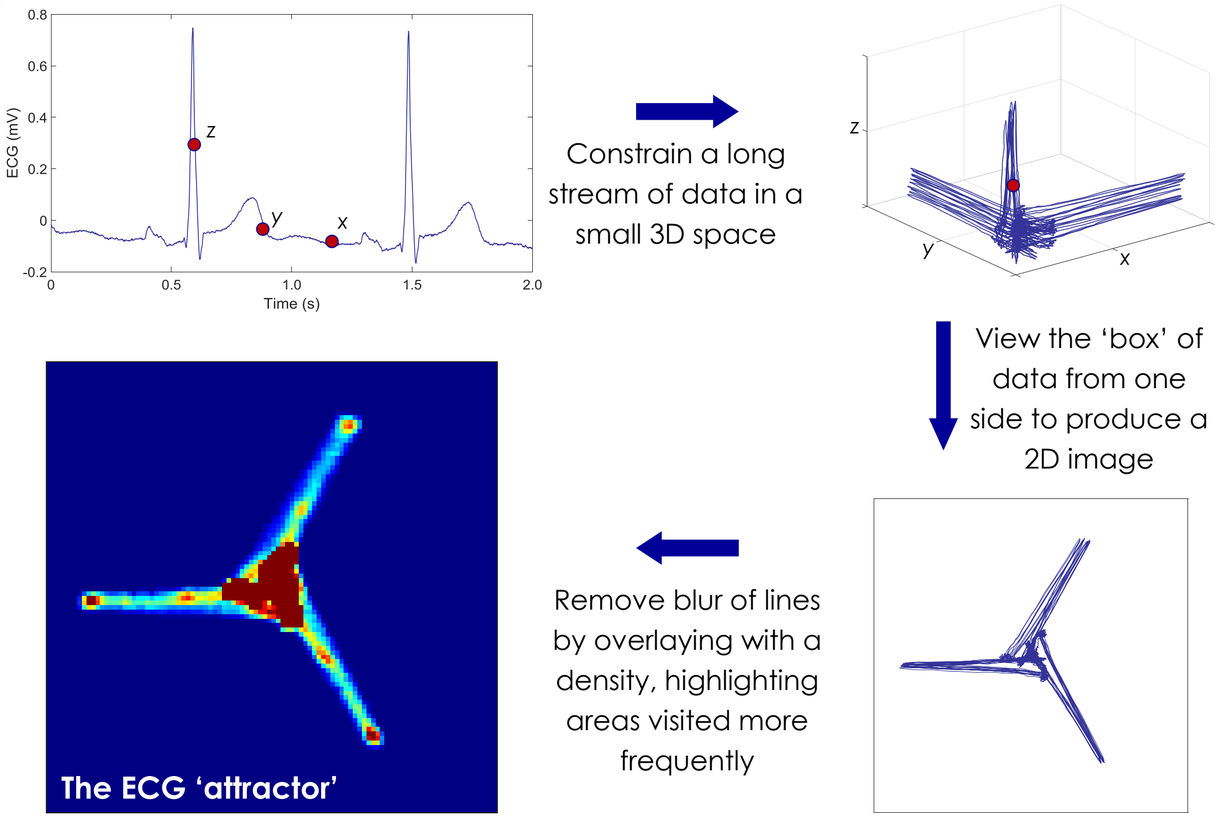


Figure 2: From ECG to attractor: The four steps of attractor reconstruction

- **Attractor reconstruction** encapsulates all of the information in the shape of the ECG waveform in an easily visualised two dimensional image called an 'attractor'
- We extract **attractor measures** that define an attractor's size, shape and symmetry
- As the shape of the ECG waveform changes, its attractor will change, giving us **new information from a routine signal**
- Attractor measures can be entered into **machine learning** to develop a model which can classify ECG signals for a specific question

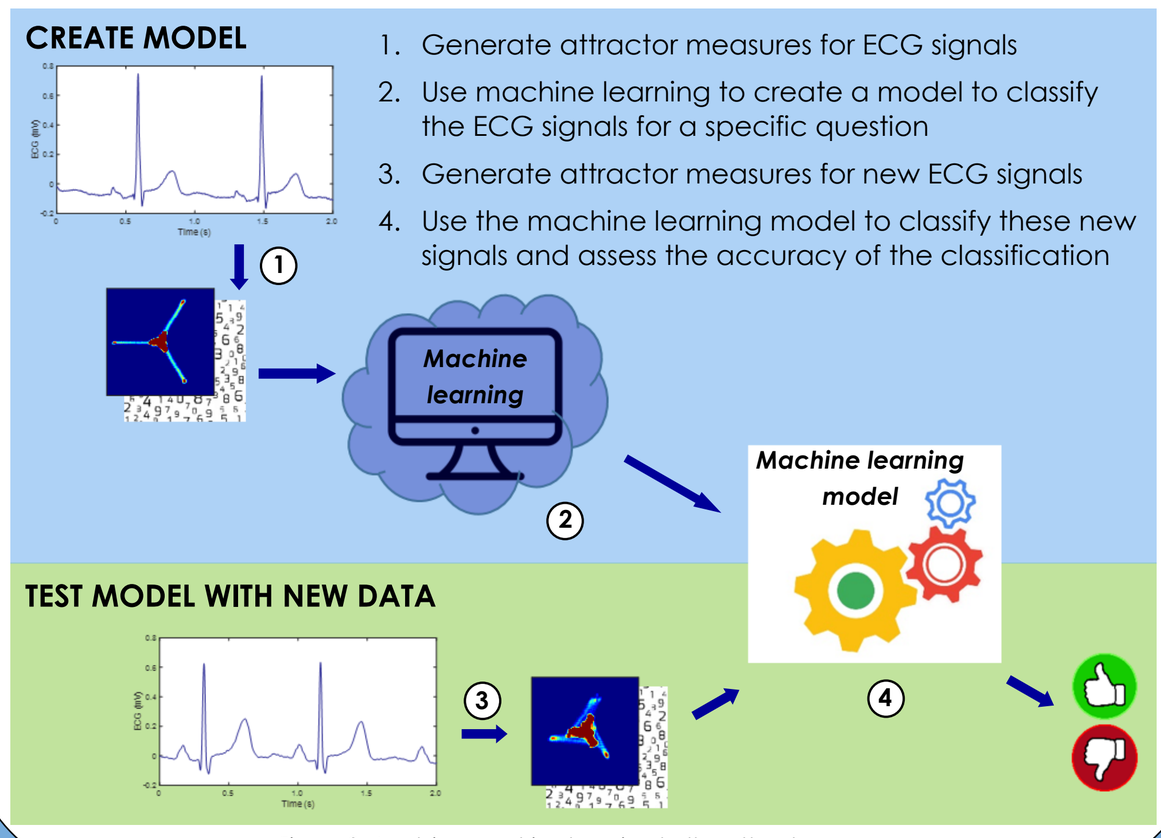


Figure 3: Applying machine learning to the attractor measures

Case study: Gender

- Attractors observed to show variability between individuals
- There are significant **attractor differences between male and female** ECG signals

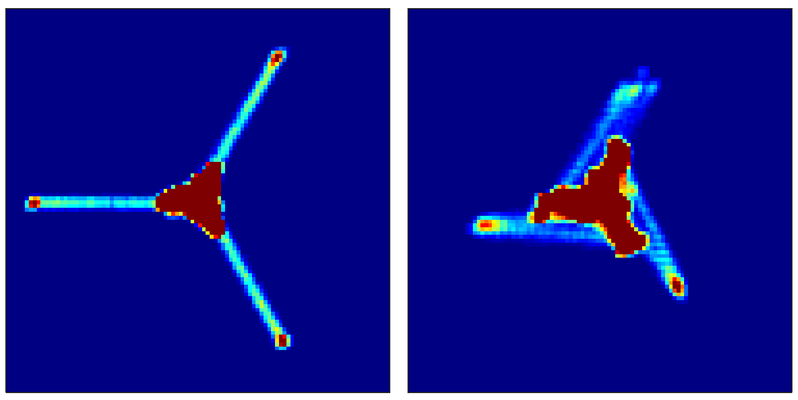


Figure 4: Typical male (left) and female (right) attractors

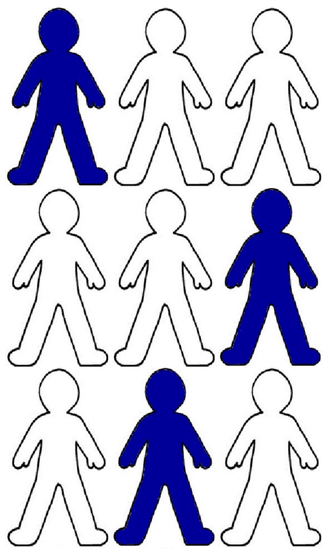
Can machine learning use the attractor measures to successfully classify ECG signals by gender?

- **Data**: 5,232 ECG signals for 22 healthy individuals taken from a publicly available database[1]. Pre- and post-drug treatment signals were available, where the drug treatment can impact cardiac function
- **Method**:
  - Reconstructed attractors and generated six attractor measures for each ECG signal
  - Six standard metrics were taken from key points in each signal to provide a comparative classification
  - Assessed the accuracy of the attractor measures to classify gender and compared this with the same classification by standard metrics

Attractor measures classified 96% of pre-treatment records correctly, and performed significantly better than the standard metrics (78%)

Similar results achieved on post-treatment ECG signals, with **attractor measures correctly classifying 93%** (standard metrics attained 74%)

What does this mean?



- Attractor reconstruction can derive **useful clinical information from existing biological big data**
- **Attractor demonstrates significant gender differences** in the ECG that have not previously been so clearly discriminated, indicating an underlying difference in physiological mechanisms
- Wider applications of the attractor include **earlier detection of a range of conditions** from the ECG
- Improved understanding of an individual's cardiovascular response, **supporting a personalised approach to detection, diagnosis and treatment**

[1] Goldberger AL, Amaral LAN, Glass L, Hausdorff JM, Ivanov PC et al. *PhysioBank, PhysioToolkit, and PhysioNet: Components of a new research resource for complex physiologic signals*. Circulation 2000;101(23):e215–e220

[2] Lyle JV, Charlton PH, Bonet-Luz E, Chaffey G, Christie M, Nandi M, Aston PJ. *Beyond HRV: Analysis of ECG Signals Using Attractor Reconstruction*. Accepted by Computing in Cardiology 2017, Volume 44