Abnormal Breathing Detection With Computational Topology

What is the Shape of a Wheeze?

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Joined work with Saba Emrani, Hamid Krim

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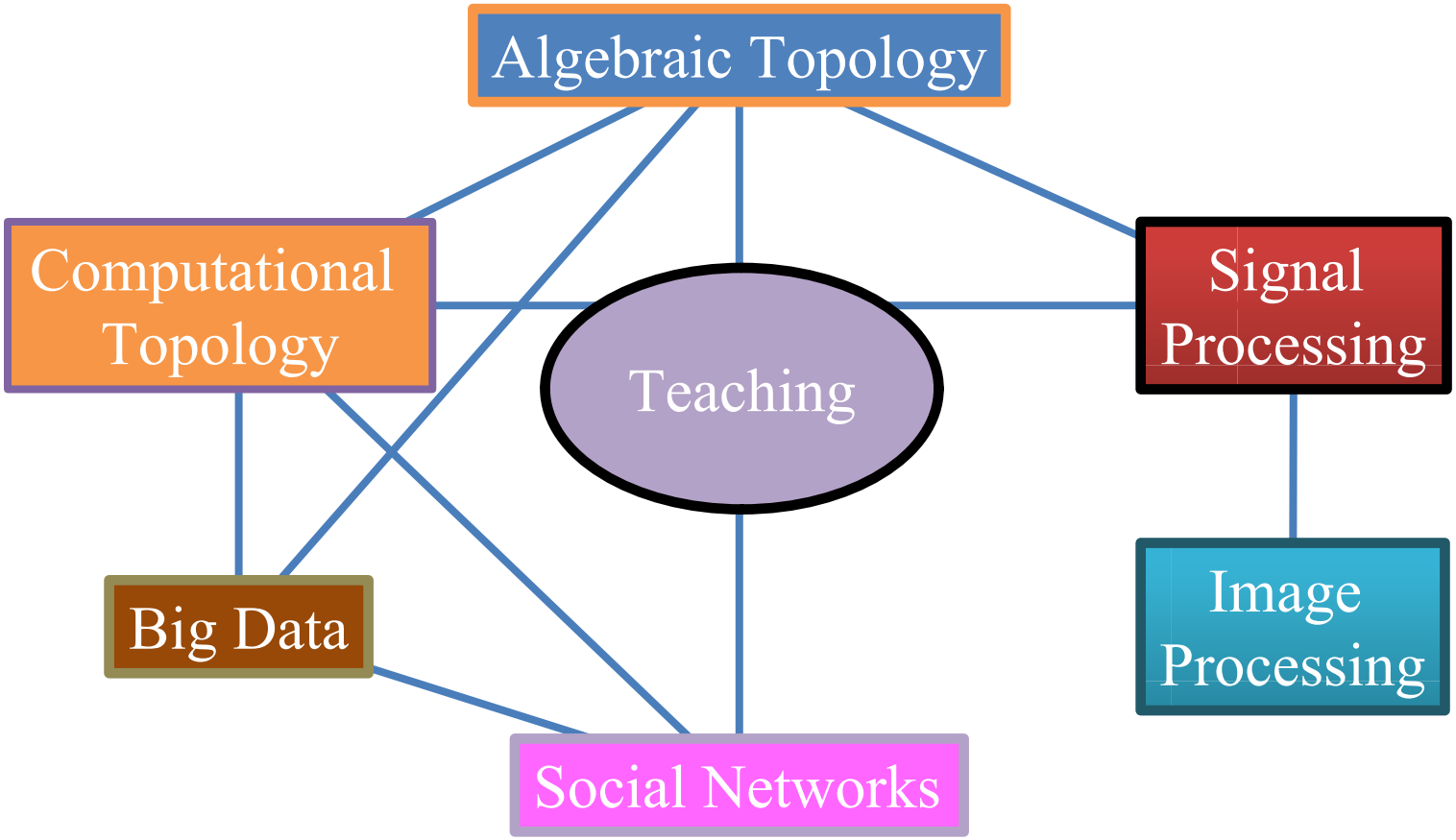
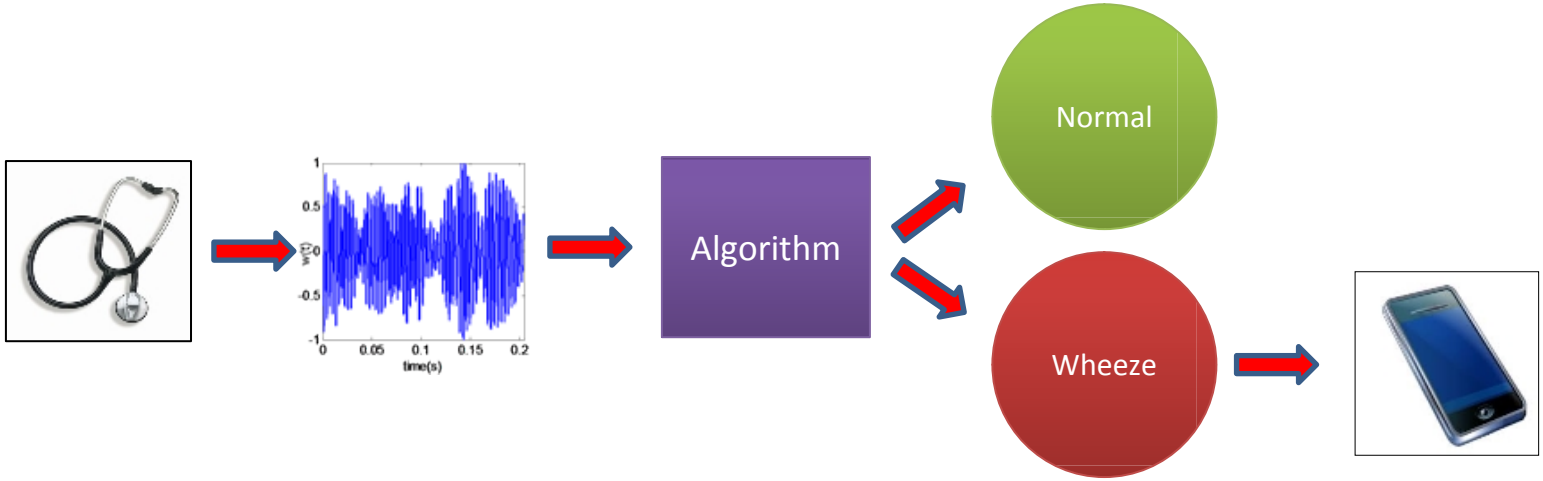
Interests


Algebraic Topology
Computational Topology
Teaching
Signal Processing
Big Data
Image Processing
Social Networks

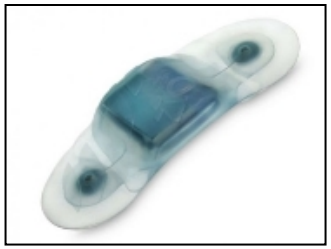
Overview

1. Wheeze Detection
2. Computational Topology (Persistence)

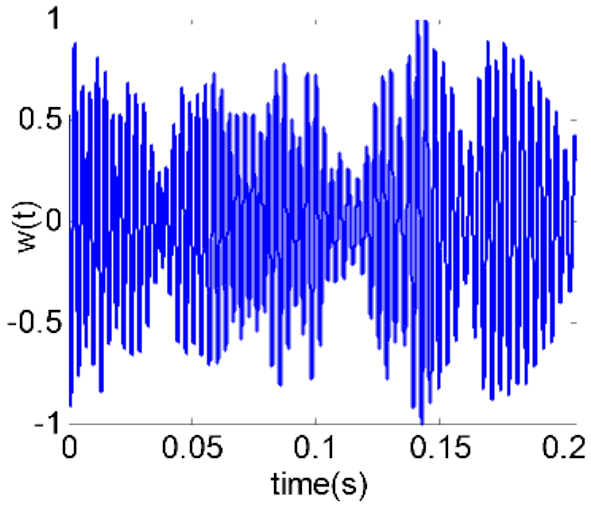
Wheeze Detection Problem Statement



Wearable Device
Harvesting body heat



Discovering things by accident



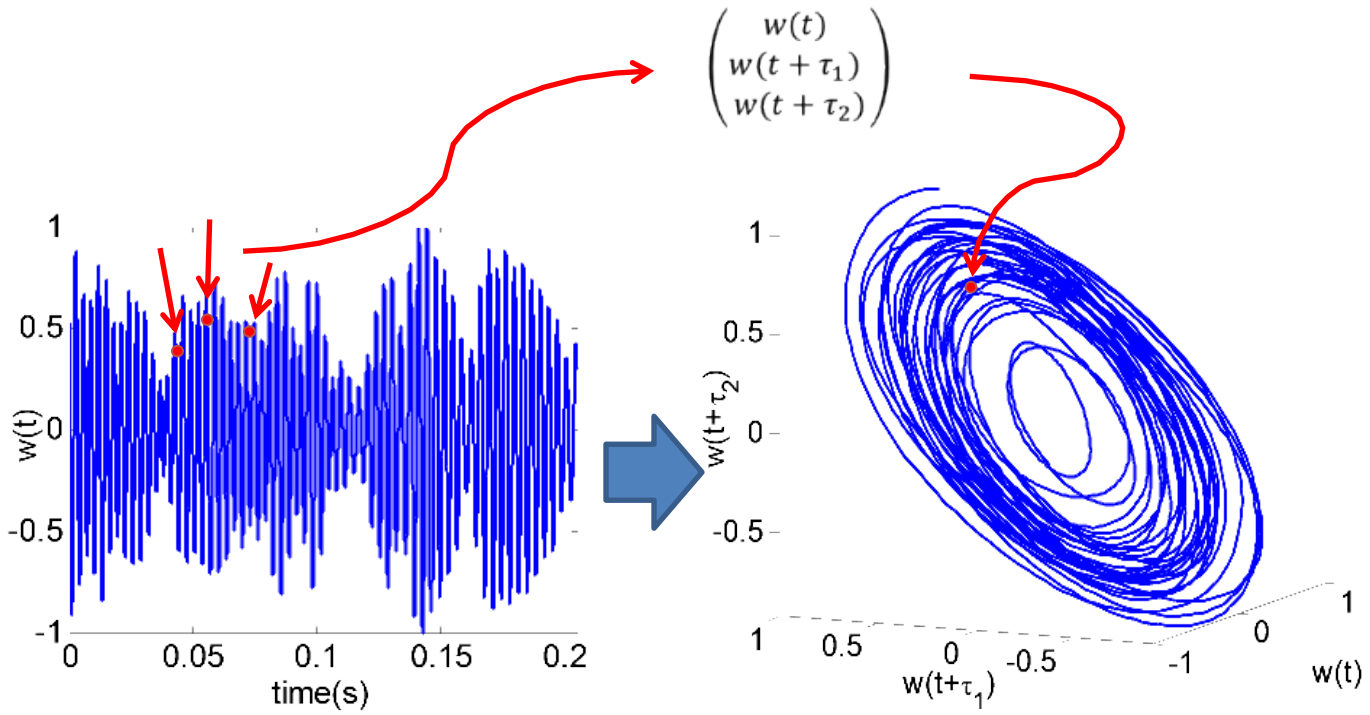
Normalized Signal
in time domain

- Using Short Time Fourier Tra
- Accurate but not effi
- U
- Packet Decomposition(WPD)
- icient but not accurate …

… This thing seems periodic … Wait a minute! …

How about we use Computational Topology!

Time delay embedding of Signals



Signal(wheeze) in time domain

3D delay embedding

Delay Embedding

- Suppose that $x : I \to \mathbb{R}$ is a time series where I is an interval of the reals. Consider a set of delay indices

$$\theta_1, \theta_2, \theta_3, ..., \theta_{m-1}$$

The m dimensional delay embedding of x is:

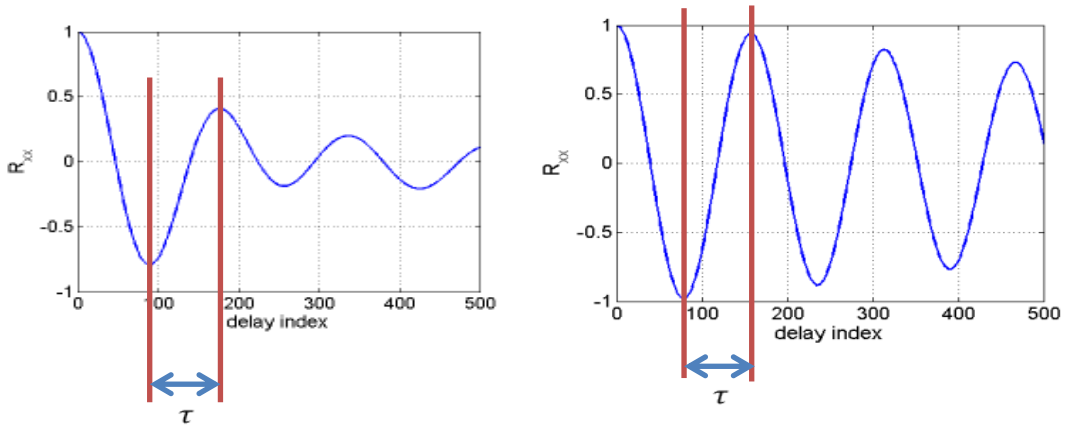
$$X(t) = (x(t), x(t+\theta_1), x(t+\theta_2), ..., x(t+\theta_{m-1}))$$

- This notion was used by Takens to explore strange attractors in dynamical systems.

Choosing the Delay

- Use an autocorrelation like (ACL) function to choose a proper delay time:

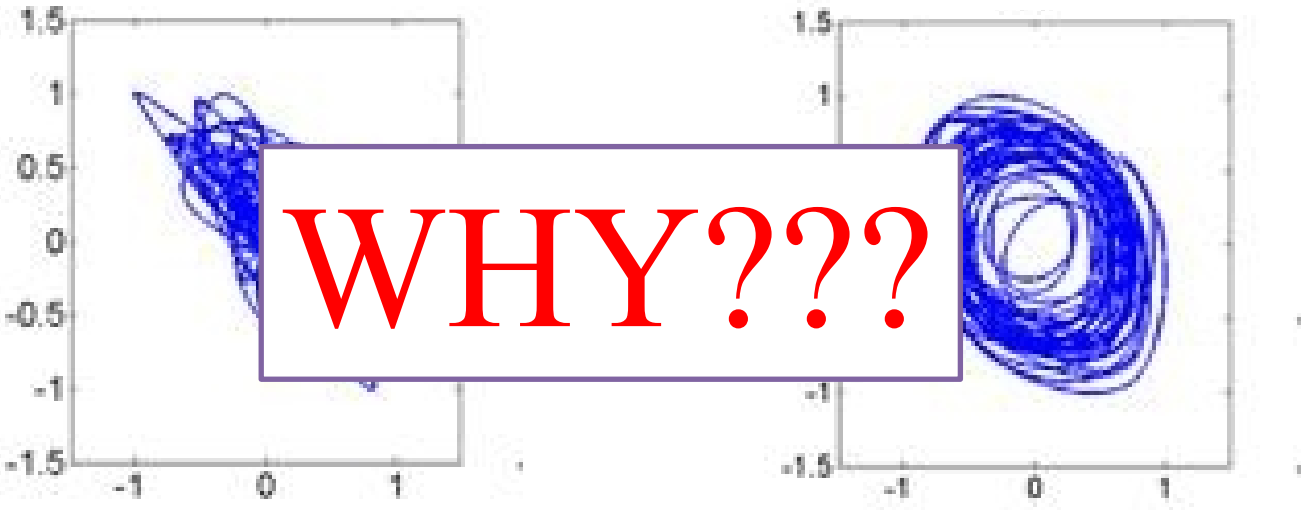
$$R_{xx}(t) = \sum_{k} x(k+t)x(k)$$



Normal

Wheezing

Wheeze vs Normal



WHY???

Non-Wheeze

Wheeze

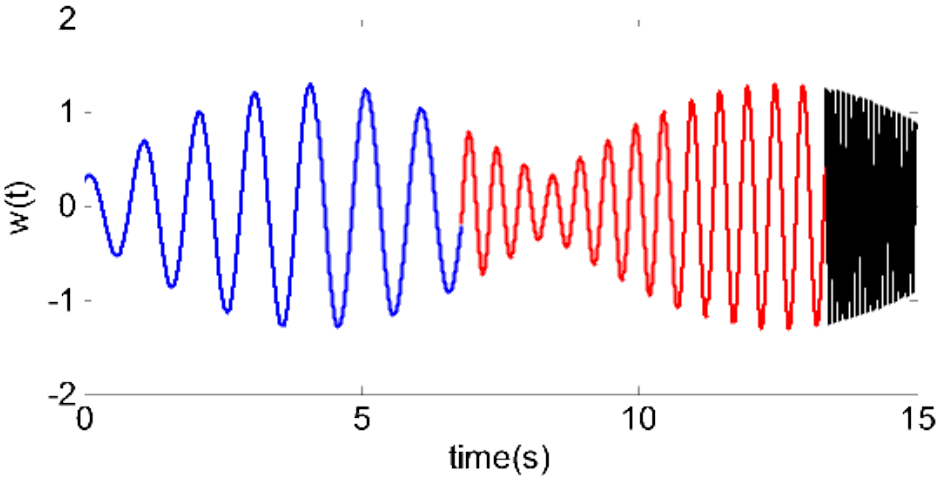
The Model

$$w(t) = \sum_{i=1}^{n} g_i,$$

$$g_i(t) = \begin{cases} w_i(t) & t_{i-1} \le t < t_i \\ 0 & \text{otherwise} \end{cases}$$

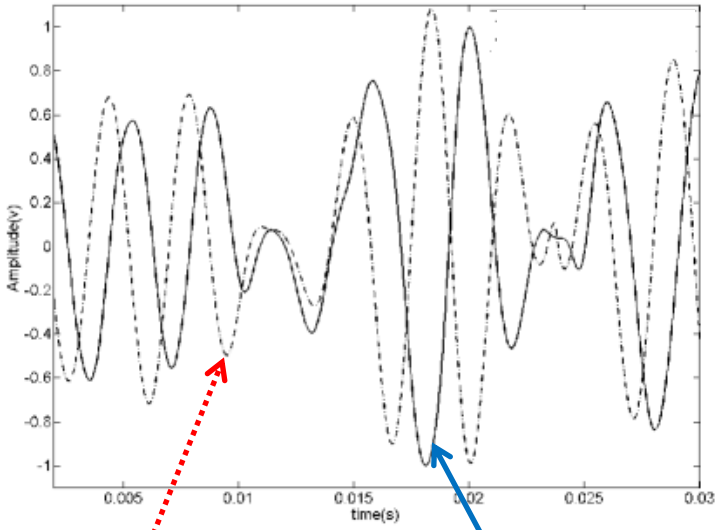
$$w_i(t) = A_i \sin(\frac{2\pi}{T_i} + \phi_i)$$

Piece-wise Sinusoidal



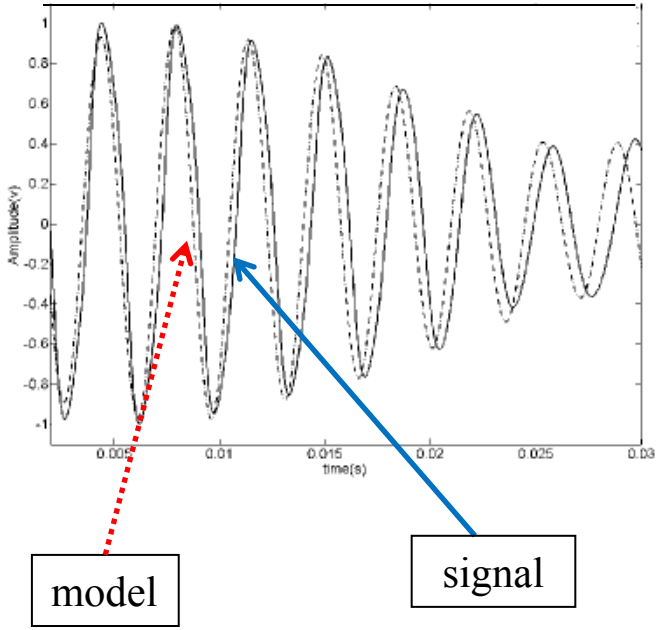
Model vs True Signals

Non-Wheeze



$d_{GH}(M, NW) \approx 9.7\%(\text{P}-\text{P})$

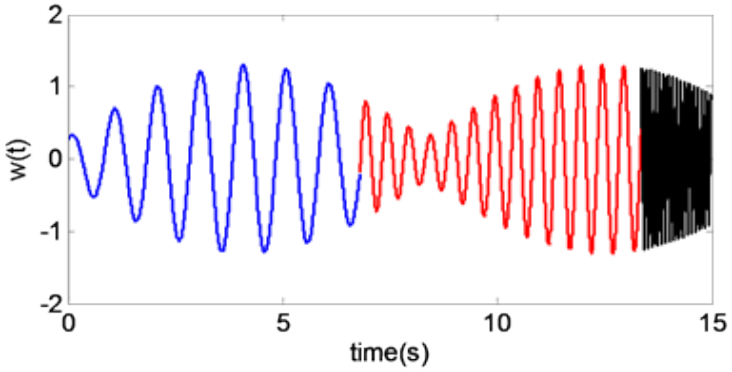
Wheeze



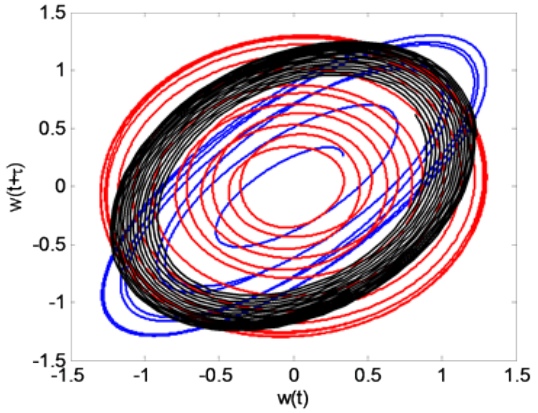
$d_{GH}(M, W) \approx 0.84\%(\text{P}-\text{P})$

Time delay of the model

Piecewise sinusoidal



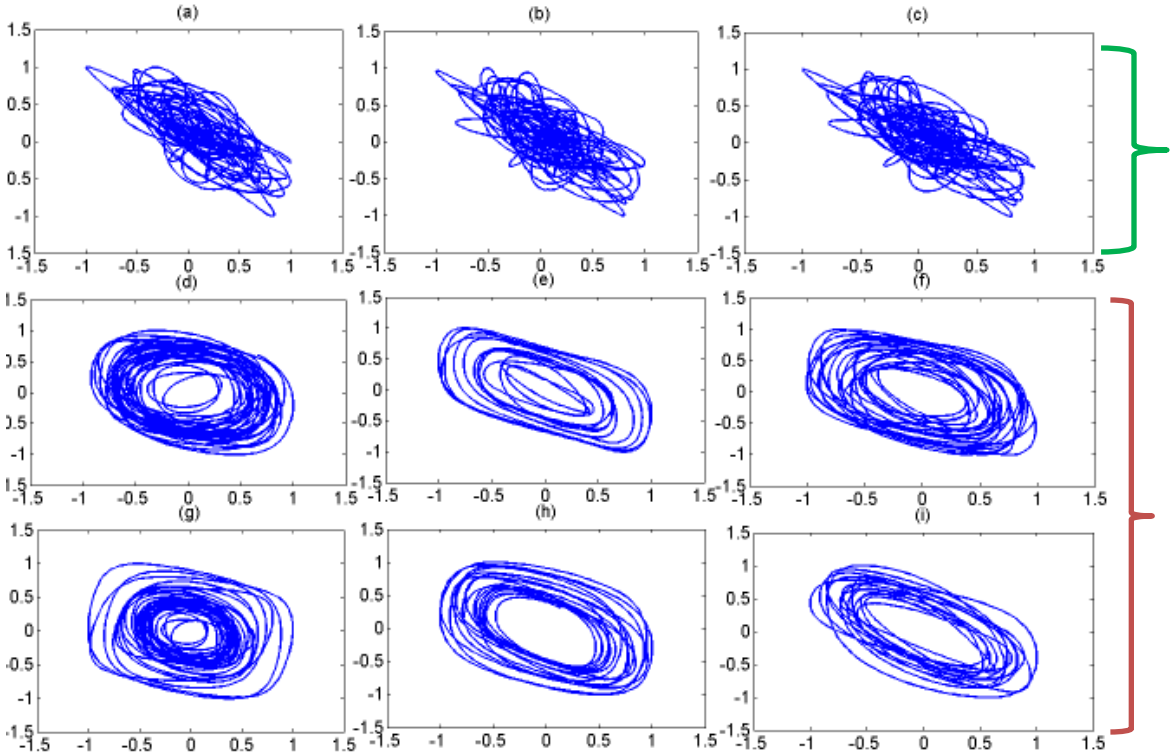
A set of concentric ellipses



Intuition

- The 2 dimensional delay embedding of piecewise sinusoidal has a hole.
- A wheeze signal is close to a piecewise sinusoidal. A normal sound is not.
- Therefore a wheeze signal has a hole! The normal sound does not.

Intuition



Non-wheeze signals

$\beta_0 = 1$

$\beta_1 = 0$

Wheeze signals

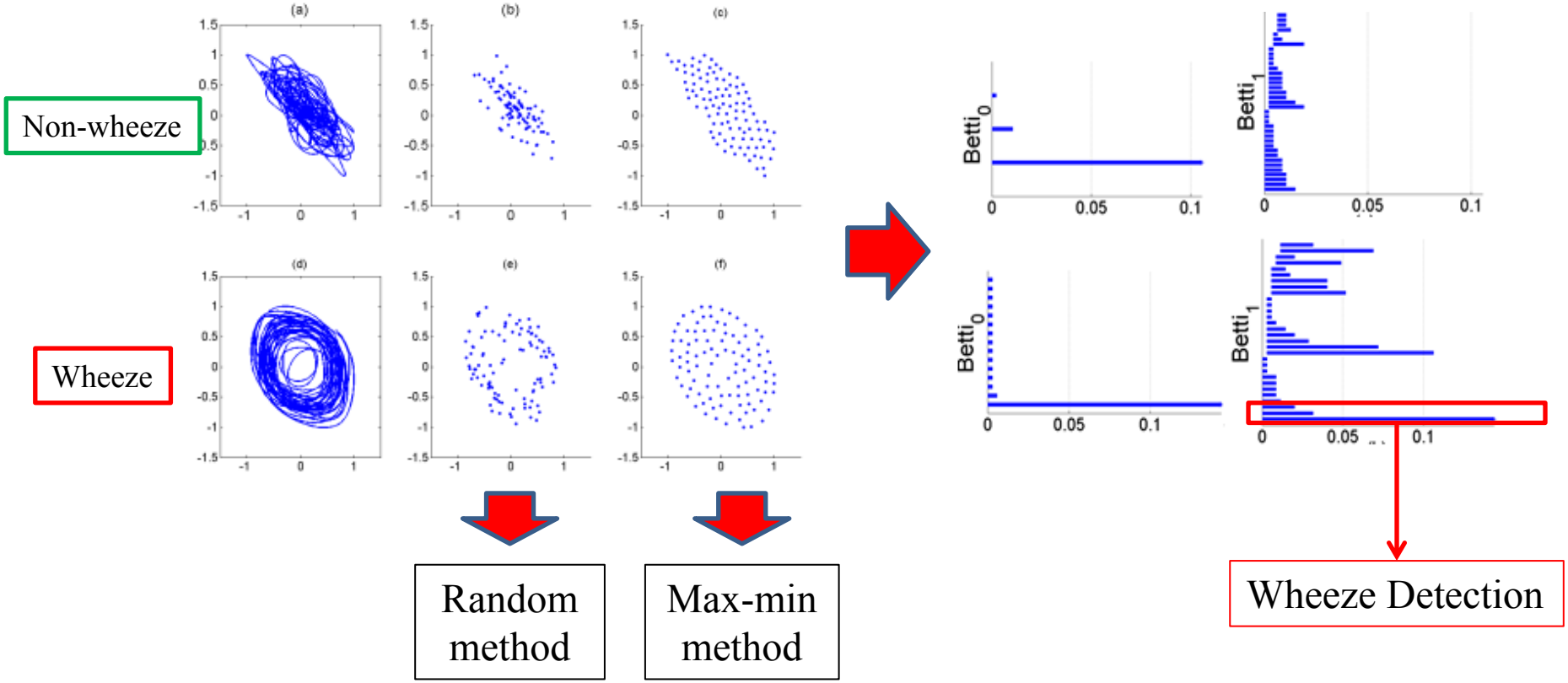
$\beta_0 = 1$

$\beta_1 = 1$

Algorithm

- We subsample our signal using random selection. (8% of the data)
- We use persistent homology to create the corresponding barcodes.
- The presence of a “1-dimensional long bar” corresponds to a wheeze detection (hole).

Algorithm

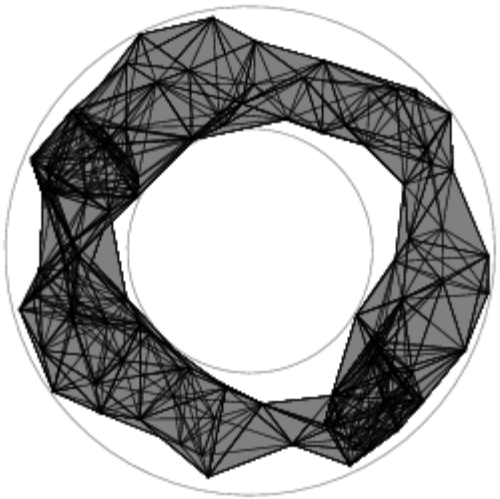

Non-wheeze
Wheeze
(a)
(b)
(c)
(d)
(e)
(f)
Random method
Max-min method
Betti0
Betti1
Wheeze Detection

Persistent Homology

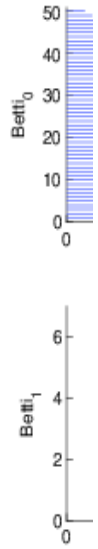
- The input of the persistent homology algorithm is a nested sequence of simplicial complexes (filtration).
- The output is a set of barcodes, i.e. a multi-set of intervals (b,d) on the plane indexed by a parameter.
- Longer bars correspond to significant features of the topological space.

From Points To Complexes

The Rips Complex



The Barcode



Conclusions

- Computational Topology can be used effectively to describe properties of dynamical systems, especially “almost periodicity”.
- There is potential for CT to be used in Signal Processing. In fact any time series can be analyzed.
- The methods are efficient, computable and scalable. They can also be parallelized.

Bibliography/Sponsors

Persistent Homology of Delay Embeddings and its Application to Wheeze Detection, Saba Emrani, Thanos Gentimis and Hamid Krim, IEEE Signal Processing Letters, Vol. 21, No.4, April 2014

Persistent Homology of Delay Embeddings, Saba Emrani, Thanos Gentimis and Hamid Krim, arxiv.org/abs/1305.3879

Thank You

Persistent Homology Barcodes