INSTITUTE OF VISUAL COMPUTING

TU Graz

SCIENCE
PASSION
TECHNOLOGY

Visual Fingerprints of Vibration Signals Using Time Delay Embeddings

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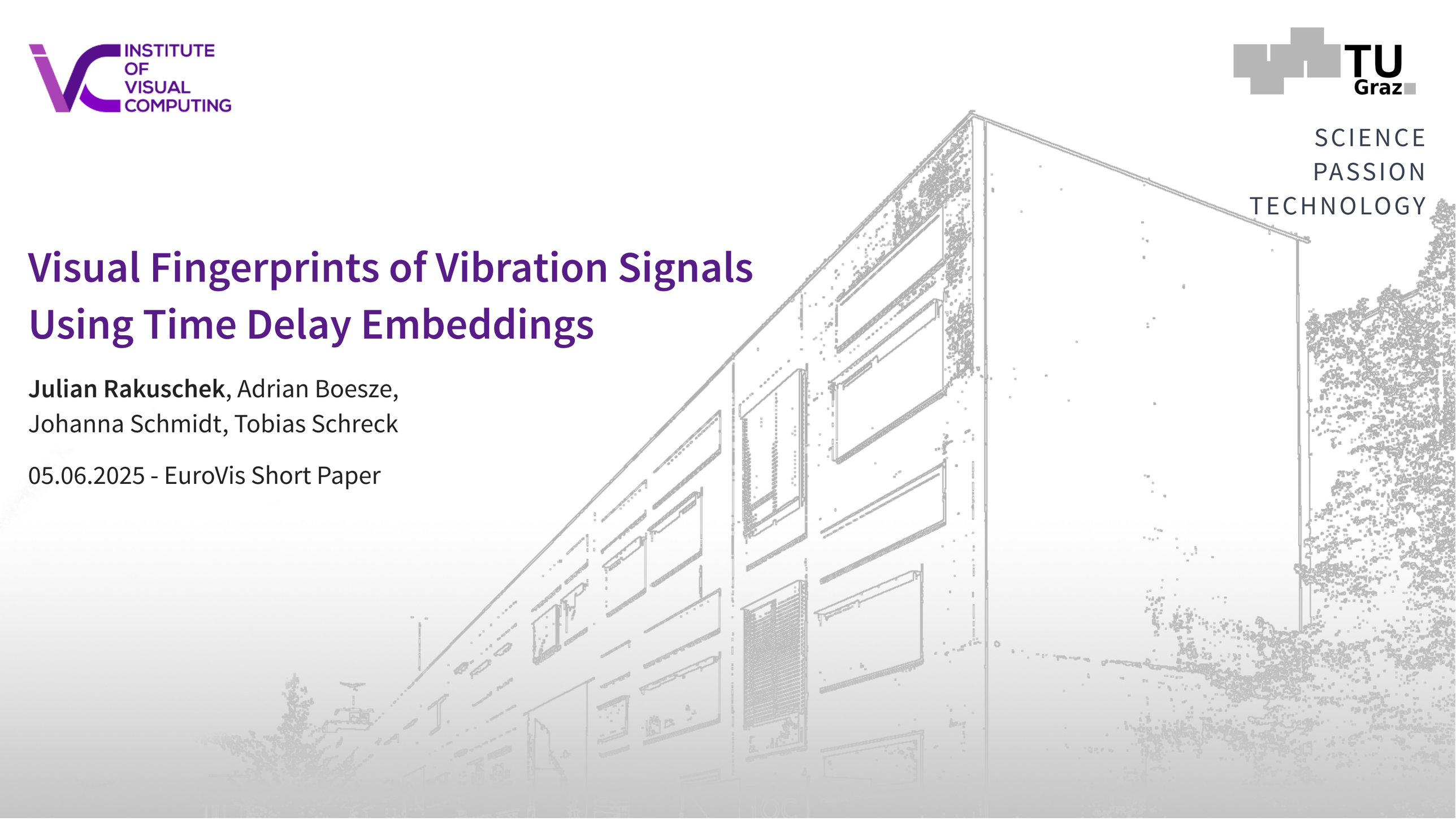
Johanna Schmidt, Tobias Schreck

05.06.2025 - EuroVis Short Paper



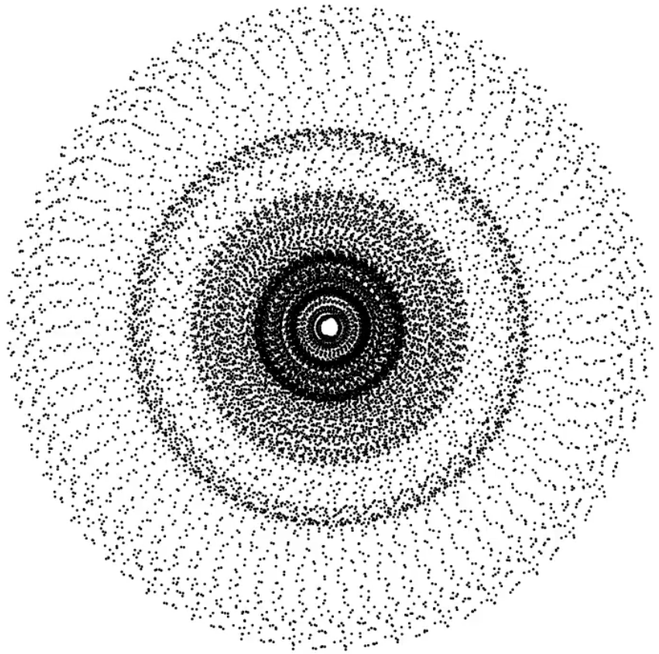
The Problem with Vibrations

Can you tell the difference?

A hidden signal

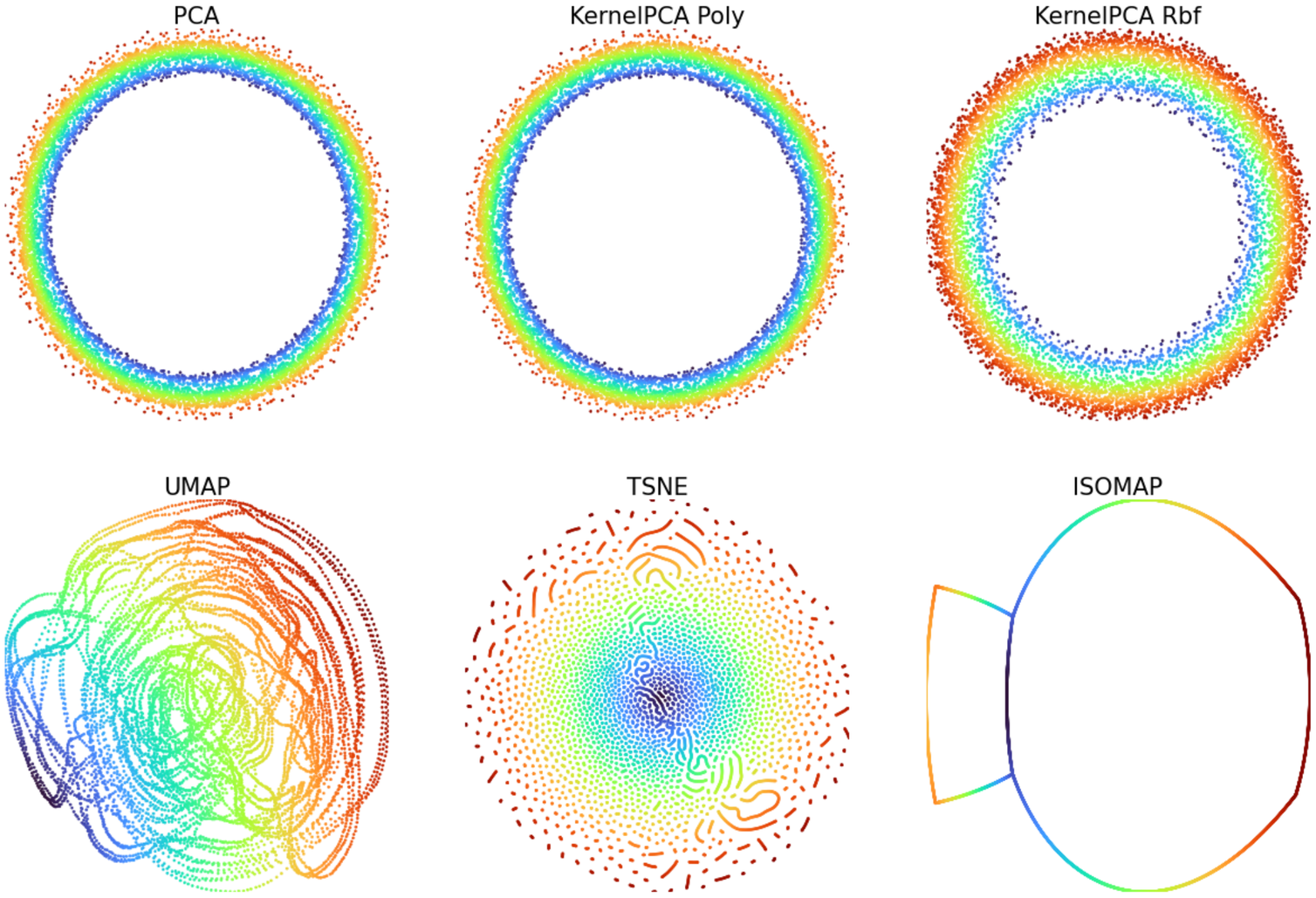
You cannot see the hidden signal with a line chart.

The Idea: Vibration → Point Cloud

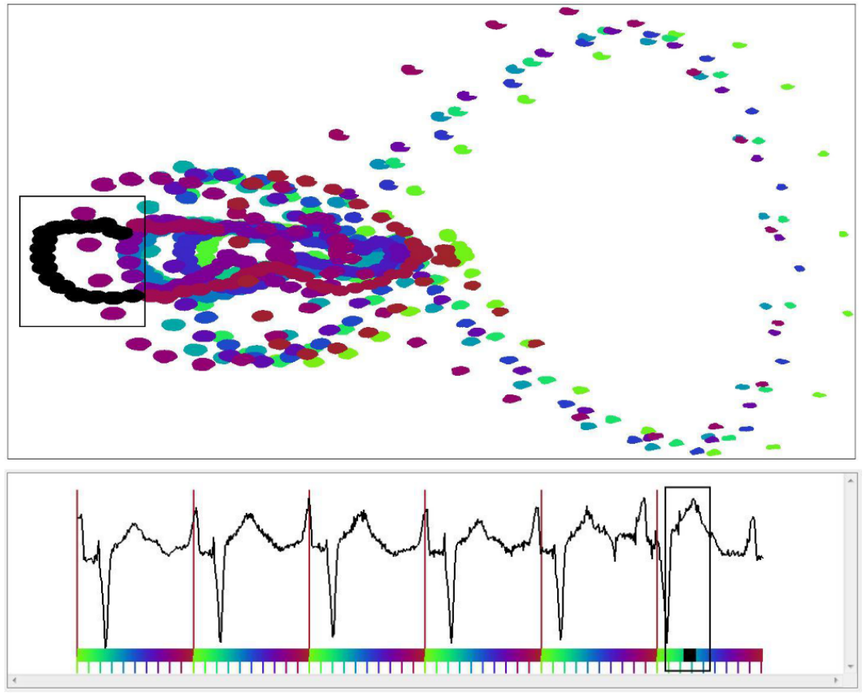


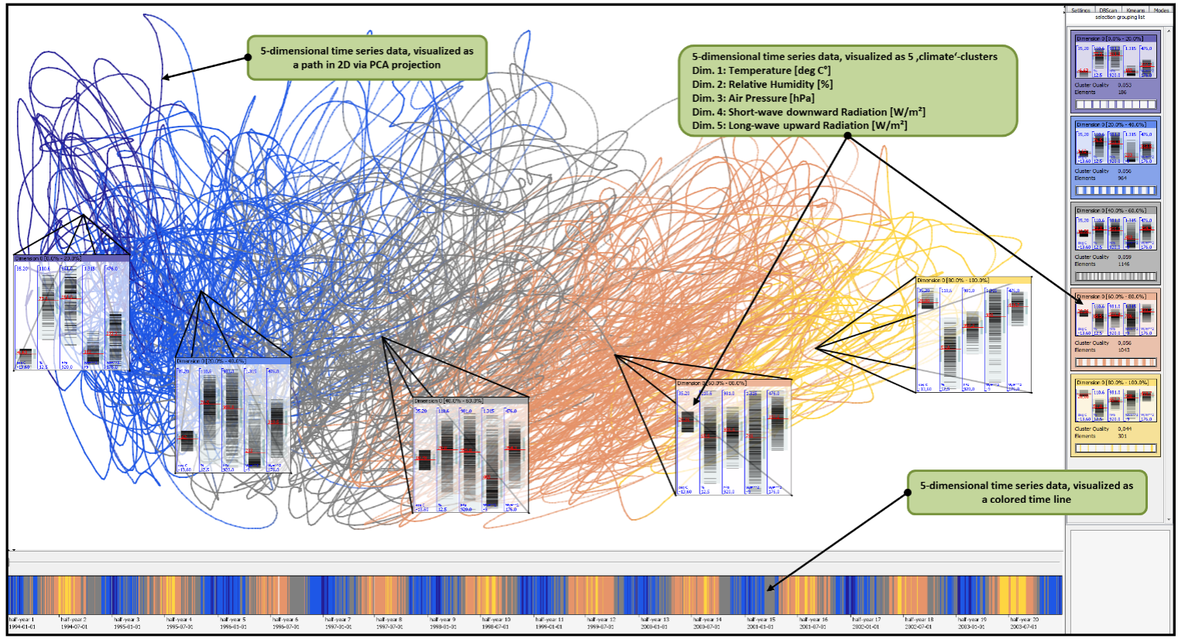
1. Sliding Window View
2. Apply PCA

Vibration Fingerprints



Projecting Time Series has been explored already



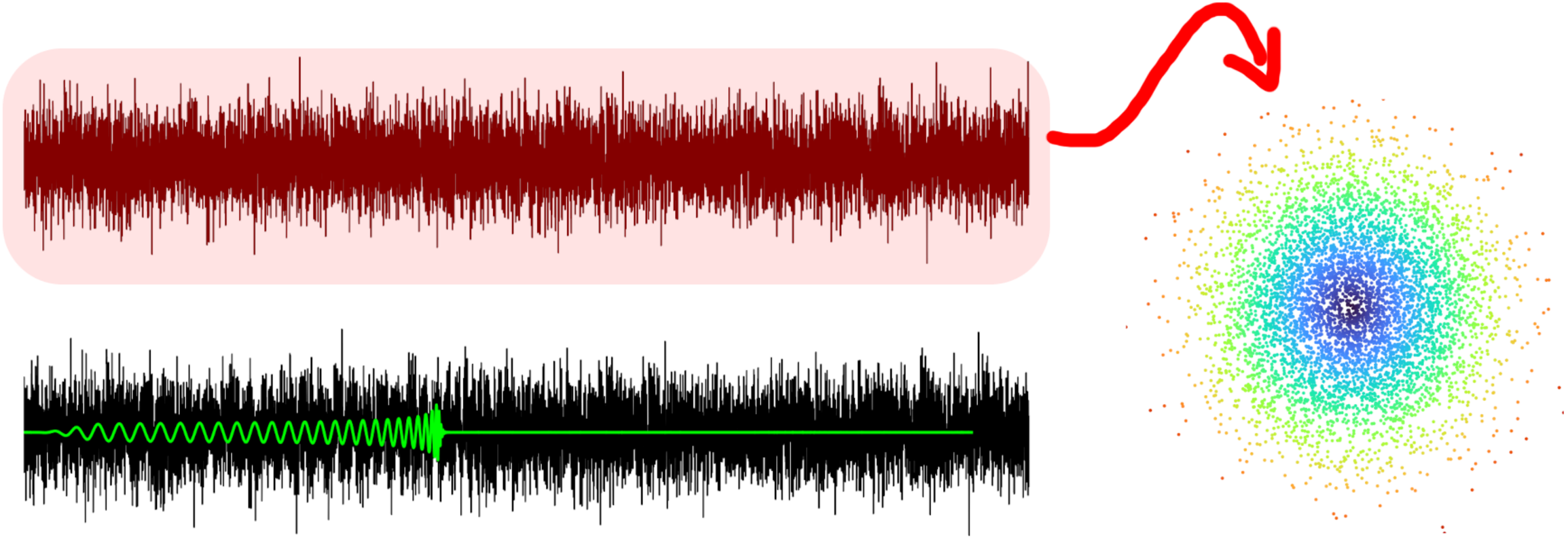


M. Ward et al. "Visual Exploration of Time-Series Data with Shape Space Projections" Computer Graphics Forum 30 (2011)

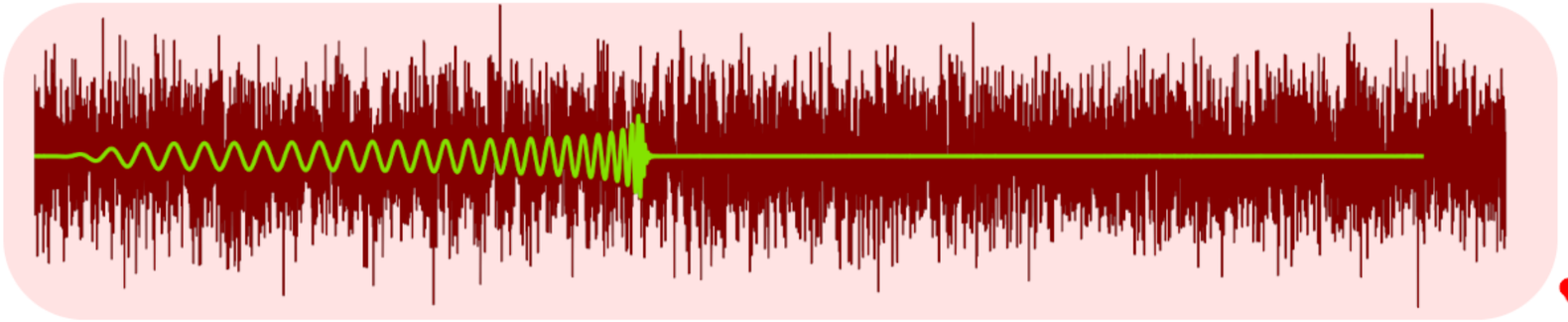
J. Bernard et al. "TimeSeriesPaths : Projection-Based Explorative Analysis of Multivariate Time Series Data" 20 (2012): 97-106

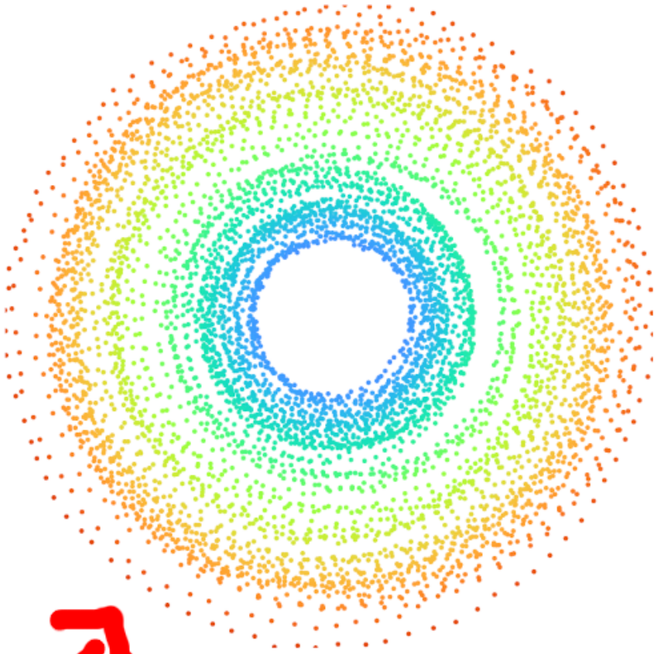
But not with Vibrations!

Noise is not exciting ...

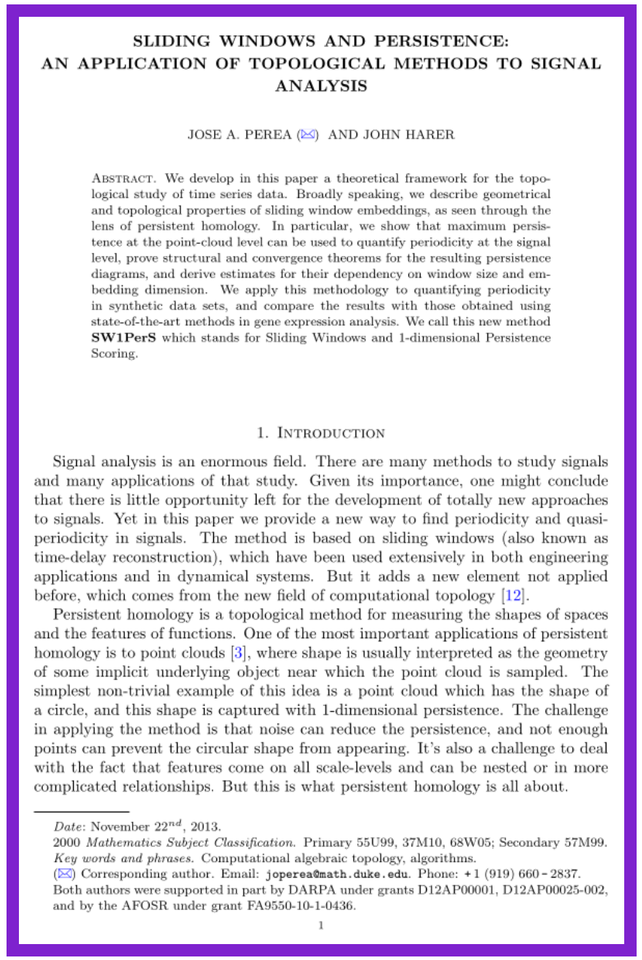


... but oscillations result in circles!





Grounded in Theory



SLIDING WINDOWS AND PERSISTENCE:
AN APPLICATION OF TOPOLOGICAL METHODS TO SIGNAL ANALYSIS

JOSE A. PEREA (✉) AND JOHN HARER

Abstract. We develop in this paper a theoretical framework for the topological study of time series data. Broadly speaking, we describe geometrical and topological properties of sliding window embeddings, as seen through the lens of persistent homology. In particular, we show that maximum persistence at the point-cloud level can be used to quantify periodicity at the signal level, prove structural and convergence theorems for the resulting persistence diagrams, and derive estimates for their dependency on window size and embedding dimension. We apply this methodology to quantifying periodicity in synthetic data sets, and compare the results with those obtained using state-of-the-art methods in gene expression analysis. We call this new method **SW1PerS** which stands for Sliding Windows and 1-dimensional Persistence Scoring.

1. Introduction

Signal analysis is an enormous field. There are many methods to study signals and many applications of that study. Given its importance, one might conclude that there is little opportunity left for the development of totally new approaches to signals. Yet in this paper we provide a new way to find periodicity and quasi-periodicity in signals. The method is based on sliding windows (also known as time-delay reconstruction), which have been used extensively in both engineering applications and in dynamical systems. But it adds a new element not applied before, which comes from the new field of computational topology [12].

Persistent homology is a topological method for measuring the shapes of spaces and the features of functions. One of the most important applications of persistent homology is to point clouds [3], where shape is usually interpreted as the geometry of some implicit underlying object near which the point cloud is sampled. The simplest non-trivial example of this idea is a point cloud which has the shape of a circle, and this shape is captured with 1-dimensional persistence. The challenge in applying the method is that noise can reduce the persistence, and not enough points can prevent the circular shape from appearing. It's also a challenge to deal with the fact that features come on all scale-levels and can be nested or in more complicated relationships. But this is what persistent homology is all about.

Date: November 22nd, 2013.
2000 *Mathematics Subject Classification.* Primary 55U99, 37M10, 68W05; Secondary 57M99.
Key words and phrases. Computational algebraic topology, algorithms.
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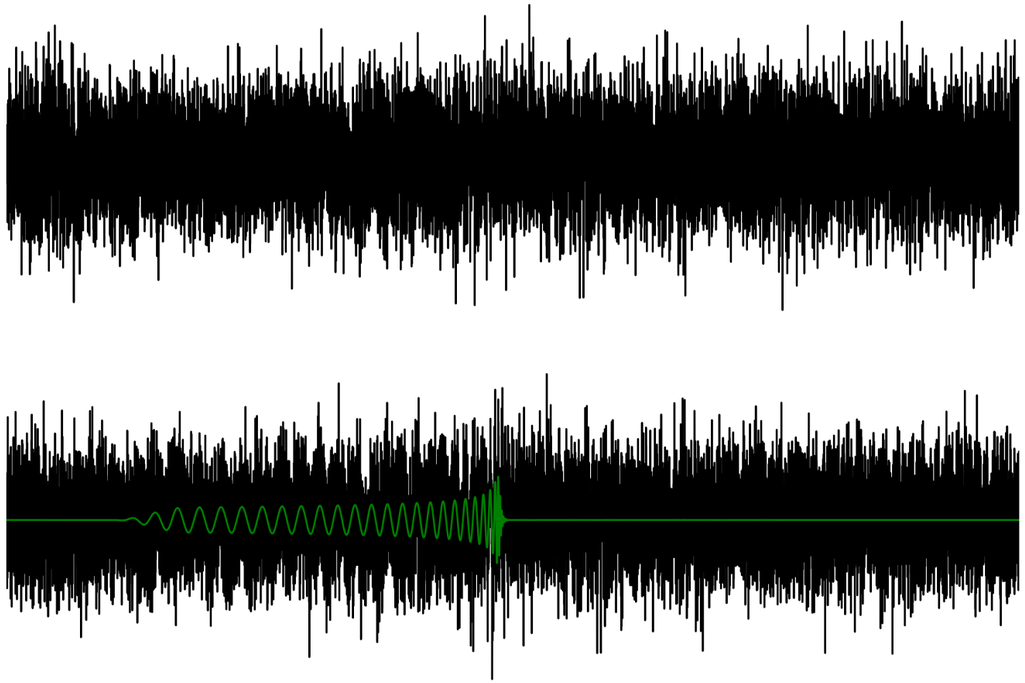
Both authors were supported in part by DARPA under grants D12AP00001, D12AP00025-002, and by the AFOSR under grant FA9550-10-1-0436.

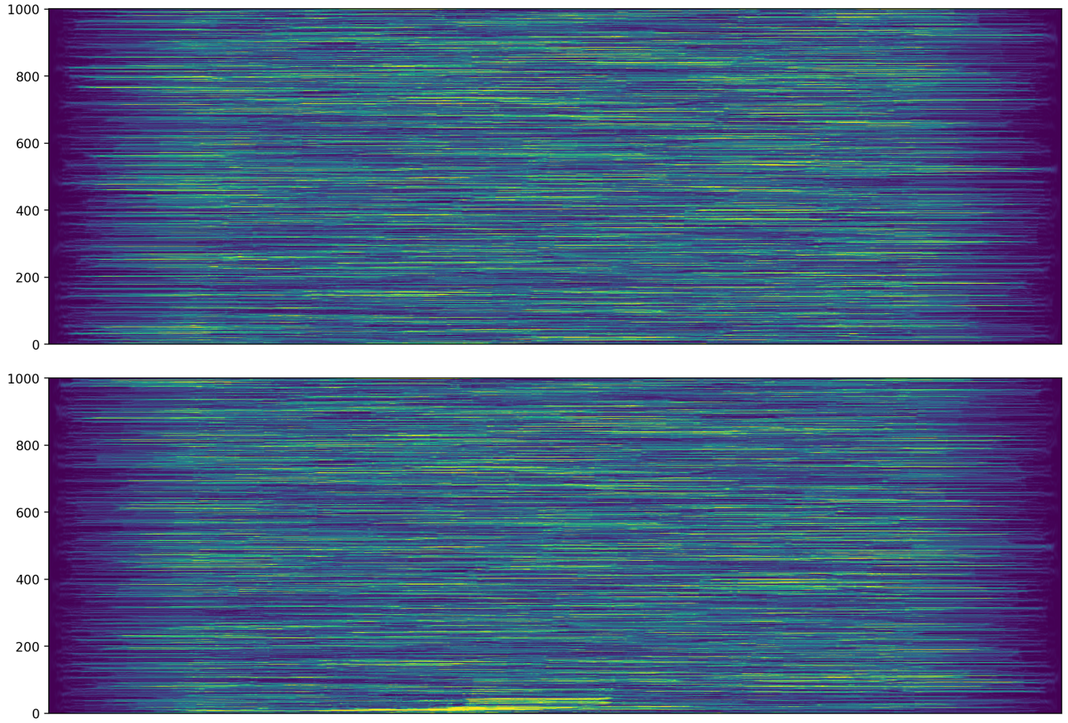
Sliding Windows and Persistence: An Application of Topological Methods to Signal Analysis

Jose Perea and John Harer, Foundations of Computational Mathematics (2015).

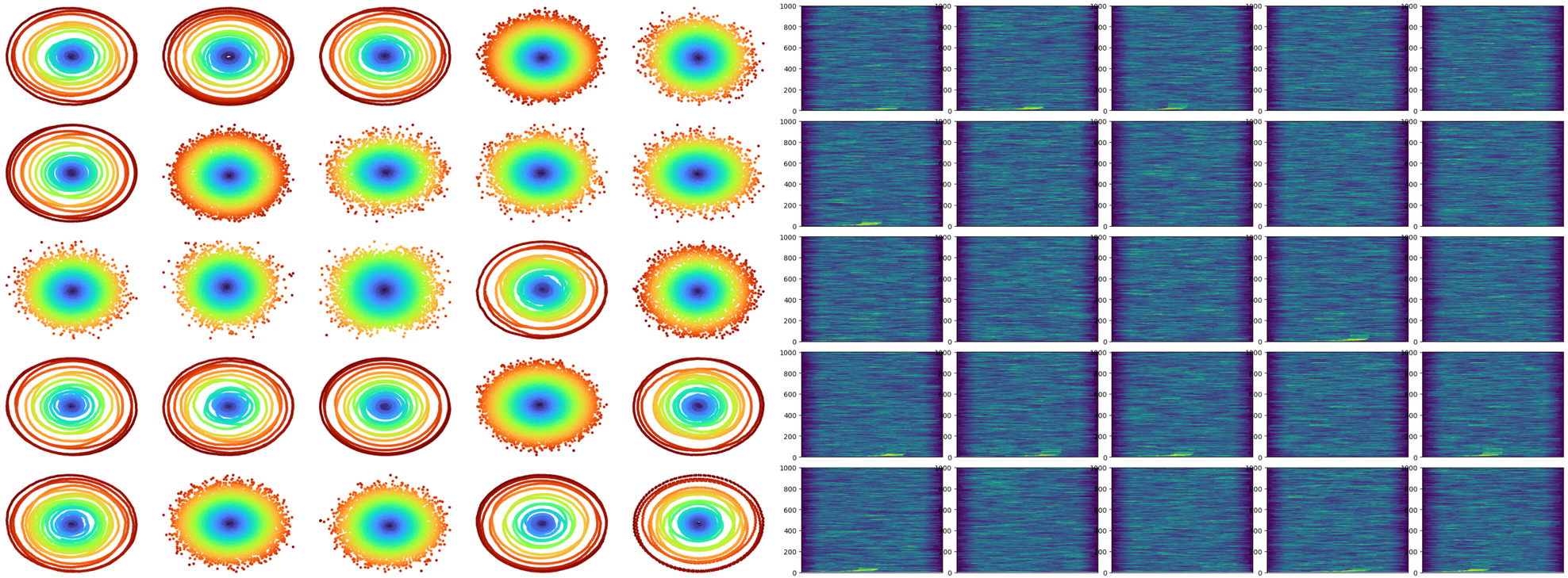
They explained: Why the circles?

Yes, this is also detectable with spectrograms, but ...



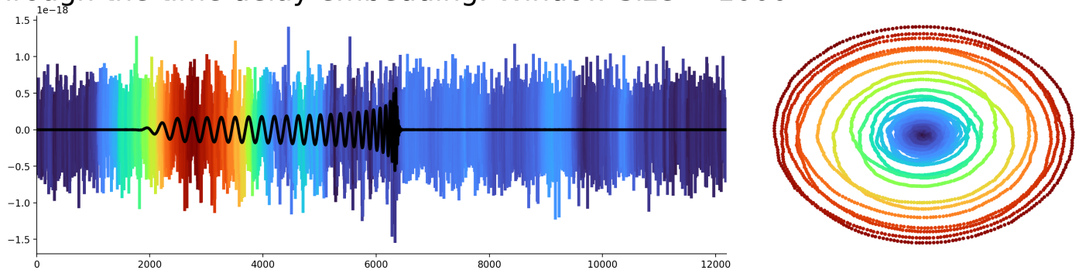


... the TDE is suitable to gain an overview!

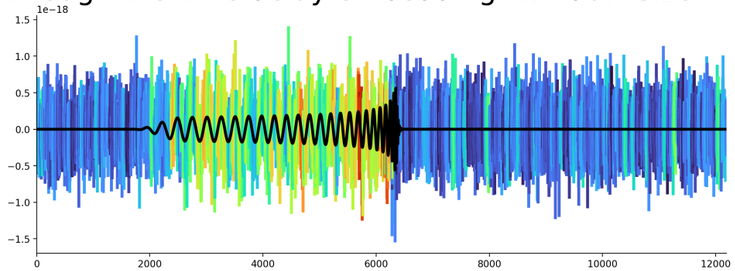


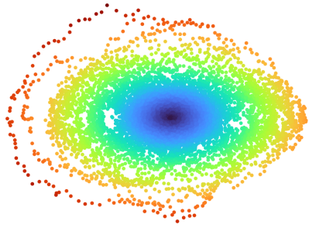
Why the coloring?

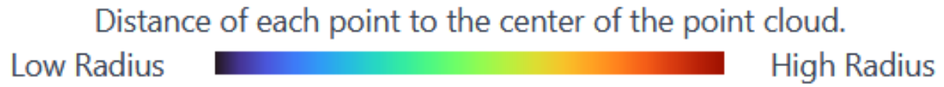
The hidden signal (black) in the noise is revealed through the time delay embedding. Window Size = 1000



The hidden signal (black) in the noise is revealed through the time delay embedding. Window Size = 70







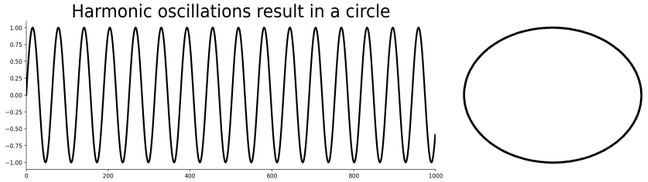
Through the turbo coloring, the fingerprint guides users towards vibrations within the signal.

Press "Arrow Down" to see other colormaps

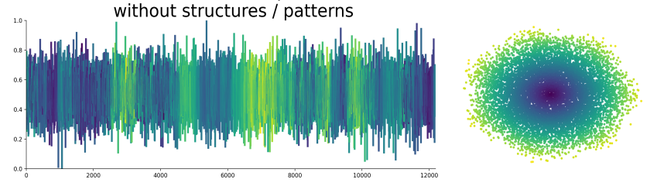
Vibration Fingerprints

Viridis

Harmonic oscillations result in a circle



Pure noise results in a point cloud without structures / patterns



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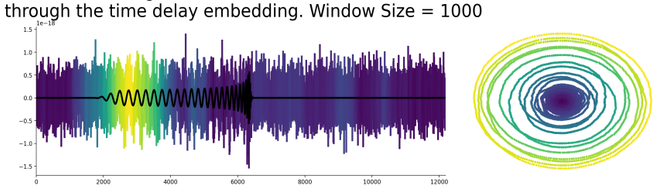

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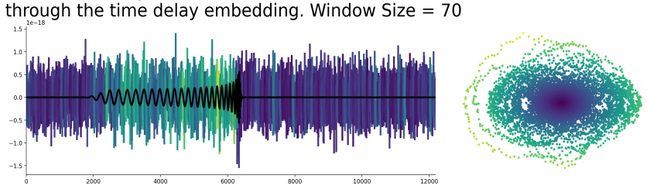
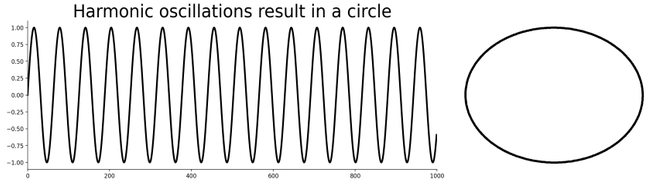
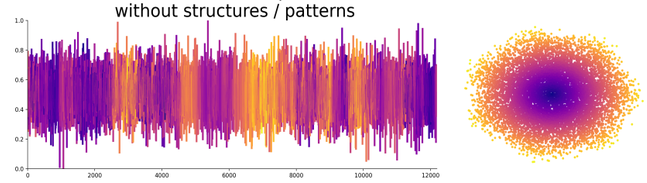


Plasma

Harmonic oscillations result in a circle



Pure noise results in a point cloud without structures / patterns



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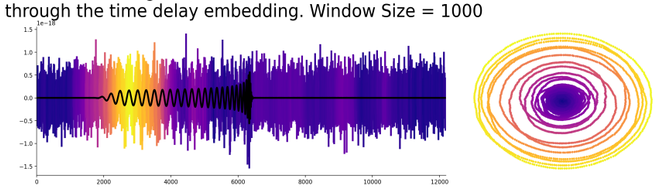

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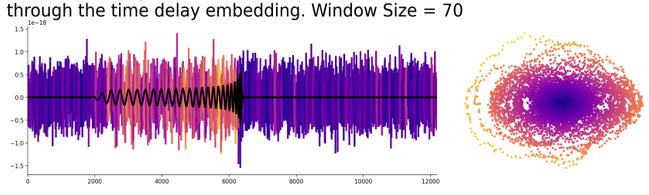
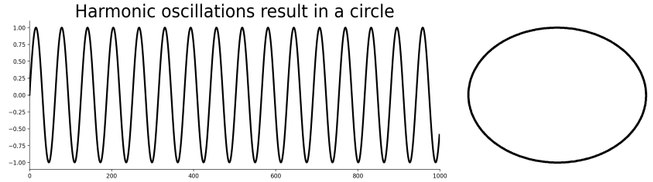
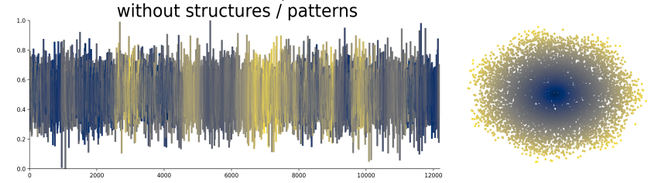


Cividis

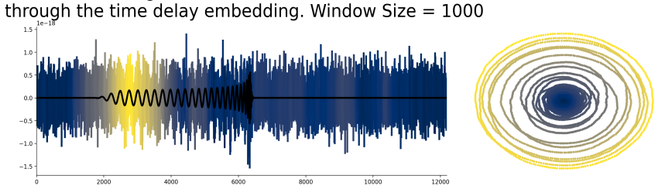
Harmonic oscillations result in a circle



Pure noise results in a point cloud without structures / patterns



The hidden signal (black) in the noise is revealed through the time delay embedding. Window Size = 1000



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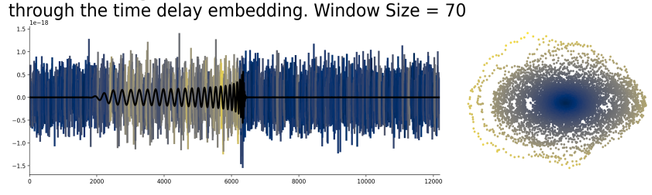
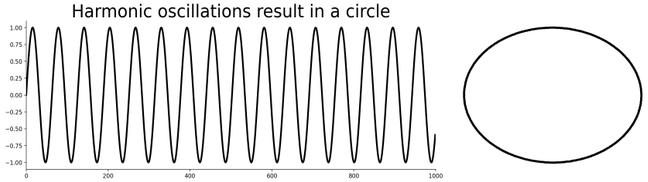


Vibration Fingerprints

Jet

Harmonic oscillations result in a circle



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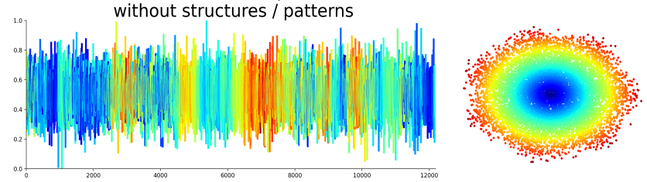

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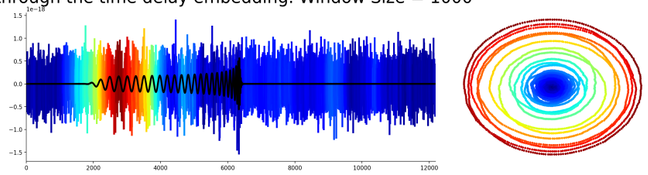
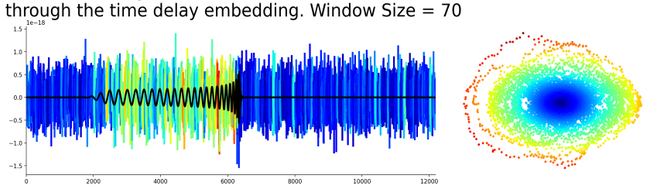
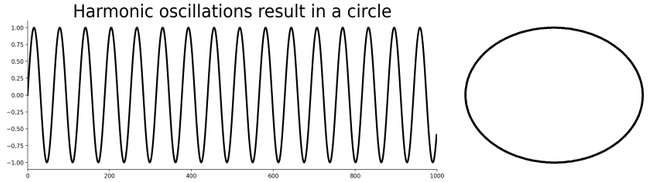


The hidden signal (black) in the noise is revealed through the time delay embedding. Window Size = 70

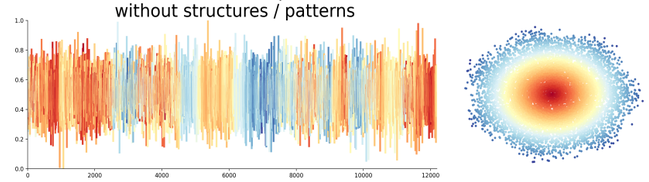


RdYlBu

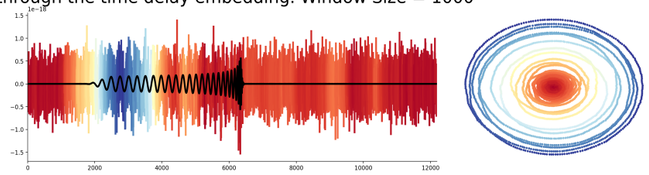
Harmonic oscillations result in a circle



Pure noise results in a point cloud without structures / patterns



The hidden signal (black) in the noise is revealed through the time delay embedding. Window Size = 1000



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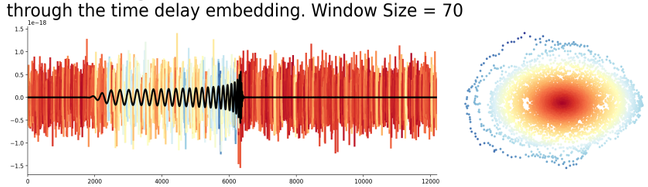
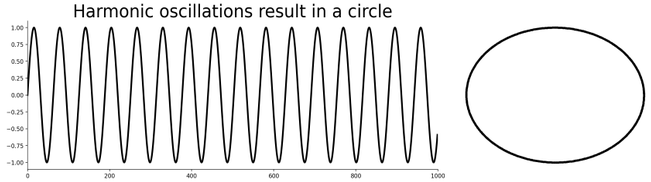
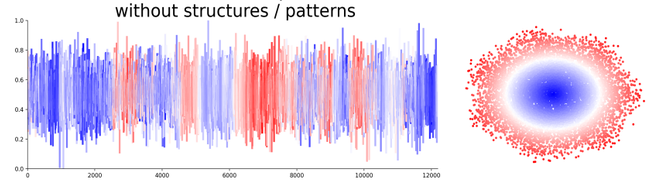


bwr

Harmonic oscillations result in a circle



Pure noise results in a point cloud without structures / patterns



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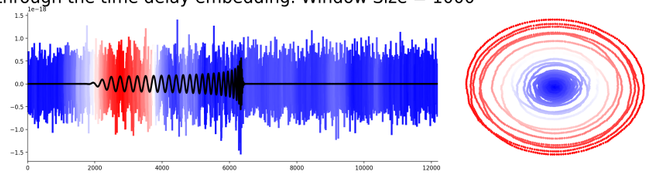

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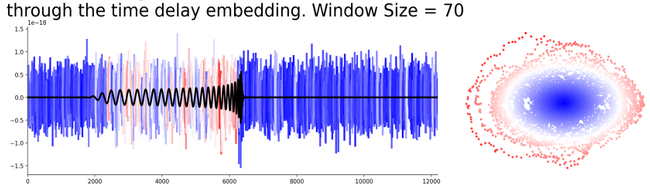
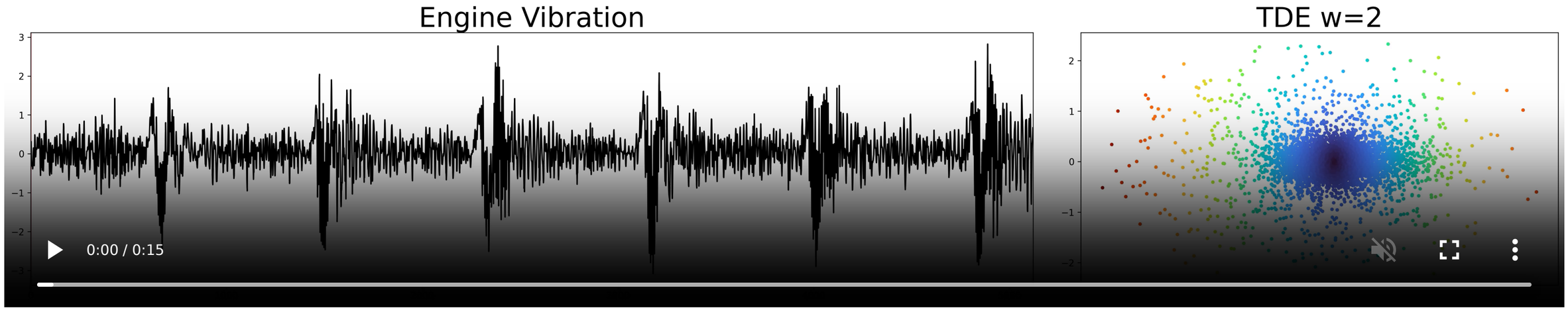
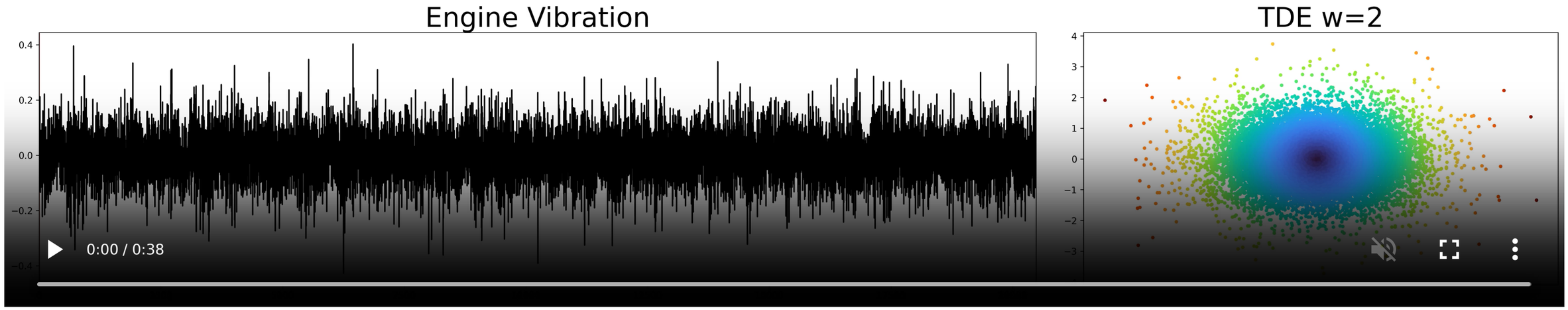


The only parameter: Window Size



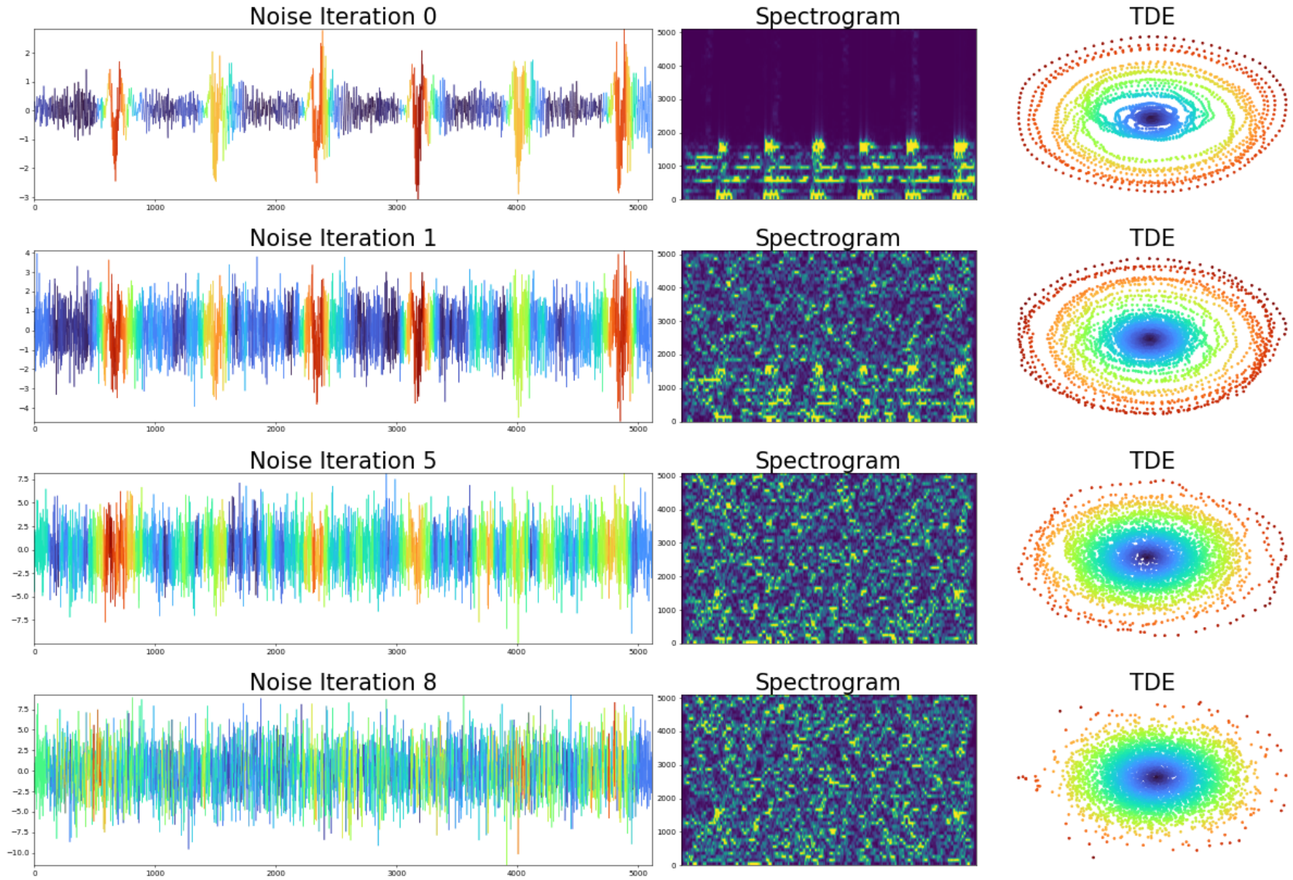
Large window sizes in general advisable

The only parameter: Window Size



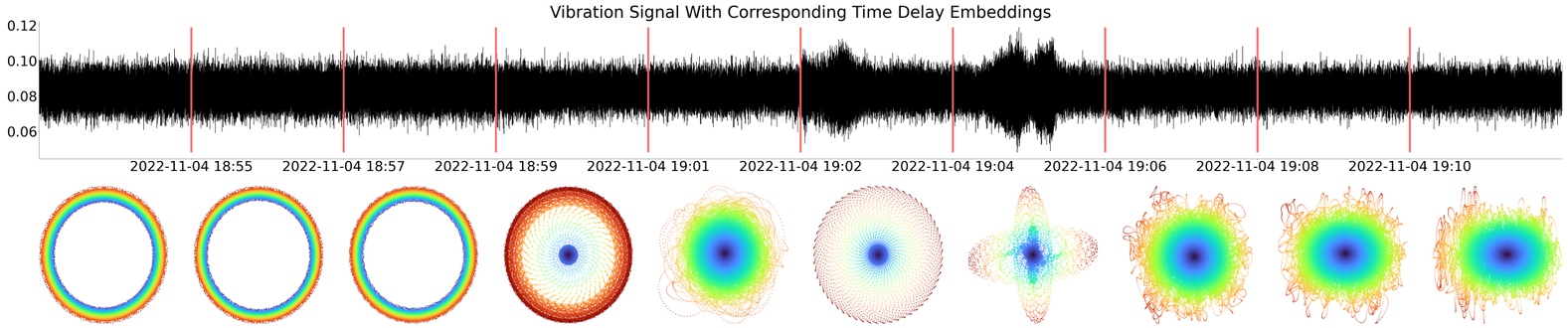
Large window sizes in general advisable

TDE under Noise Influence

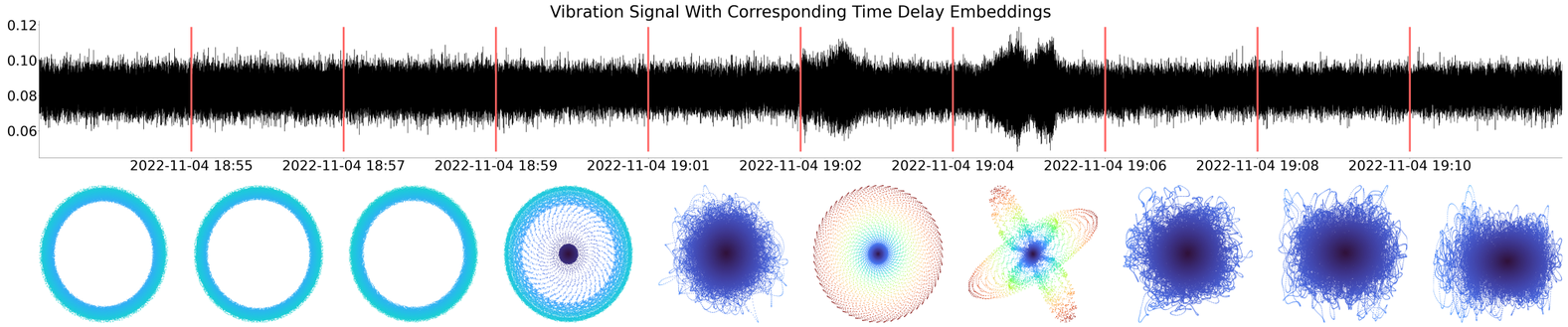


Vibration Fingerprints

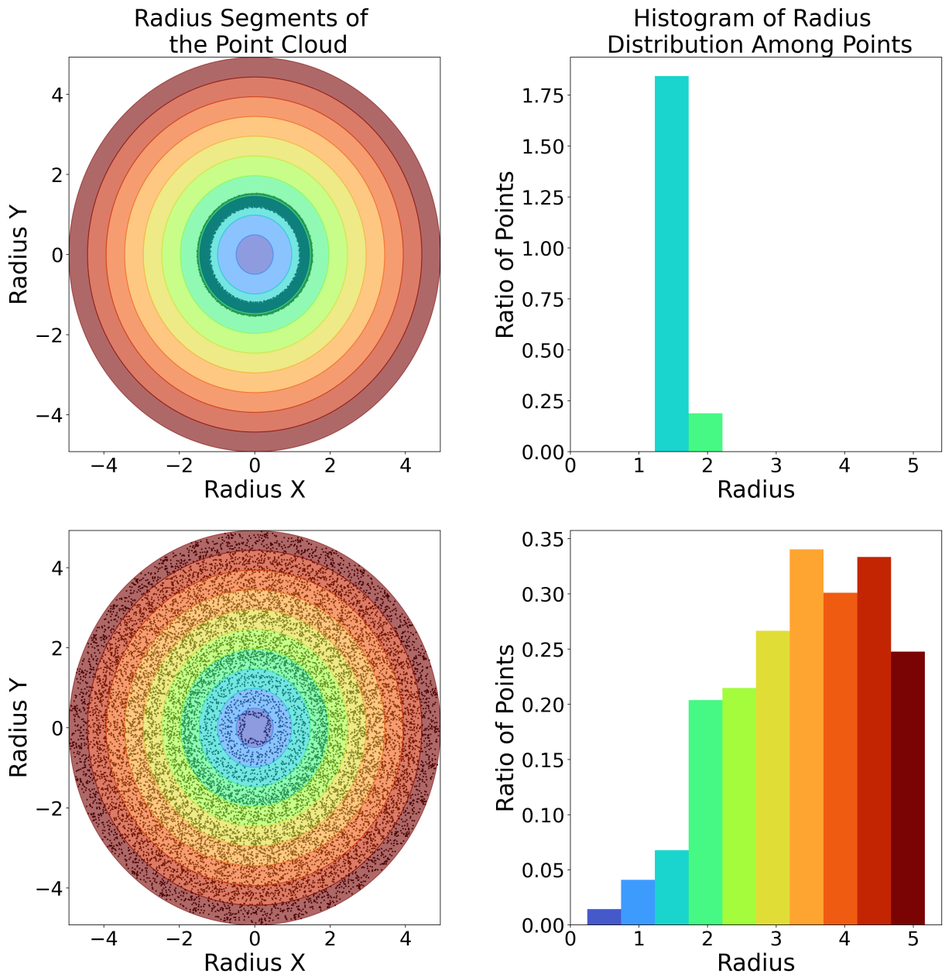
We can use the fingerprints to observe change ...



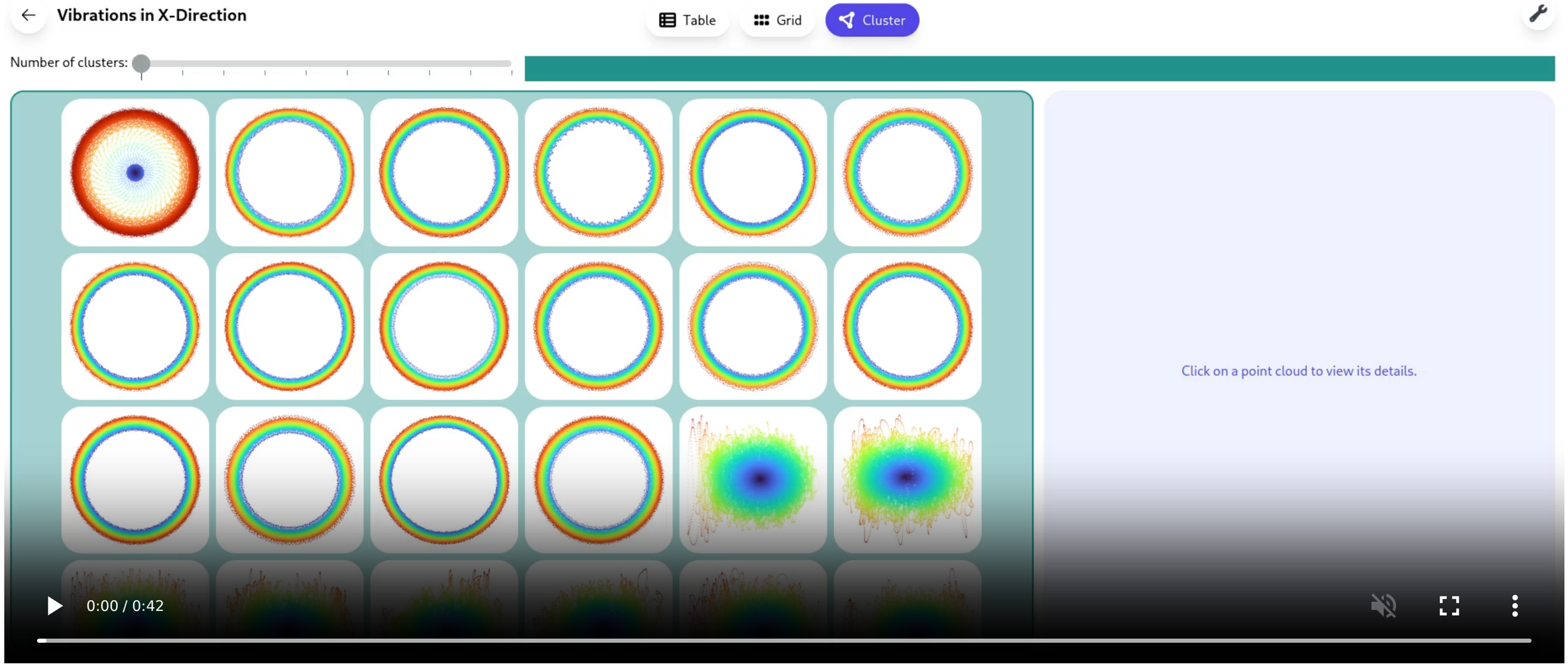
... and analyze the radii on a global scale



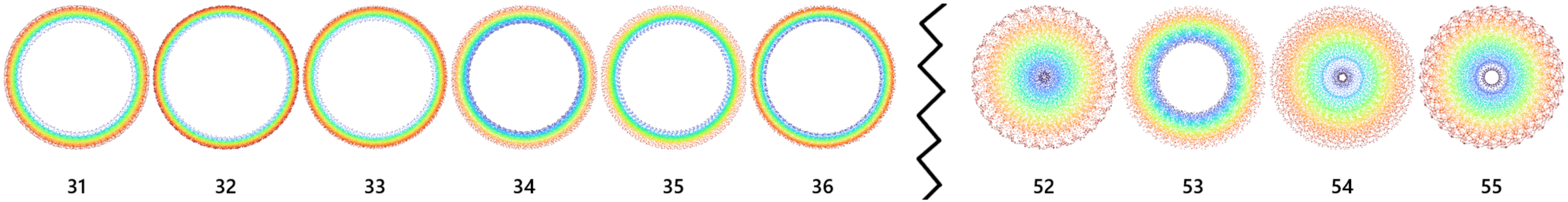
We can compare fingerprints through the radius distribution



Clustering


Vibrations in X-Direction
Table
Grid
Cluster
Number of clusters:
Click on a point cloud to view its details.
0:00 / 0:42

Observing Wear



Conclusion

- Detecting periodicity through fingerprints
- Robust to window size parameter and noise to some degree
- Applicable to detect wear

Future Work

- Scalability: Visually and computationally
- Application to stream monitoring
- Counterfactuals: Effect of data changes

Questions?

Slides:

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