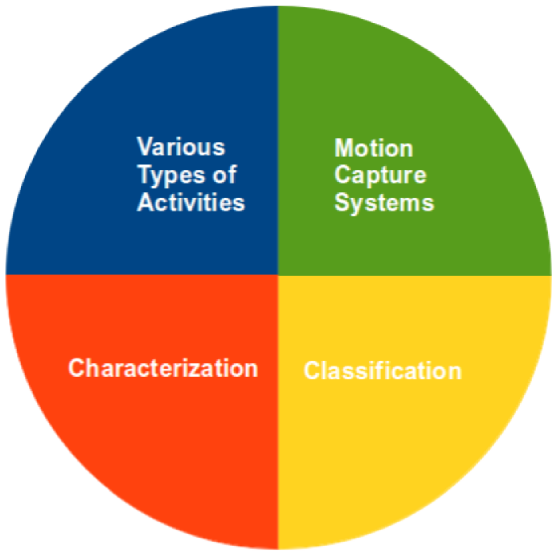
A Nonlinear Dynamics Approach to Human Activity Recognition Using Inertial Sensors

Pérez-Xochicale Miguel Angel

Internal Research Conference Presentation
EECE School
10th March 2015

Why is HAR a challenging task?



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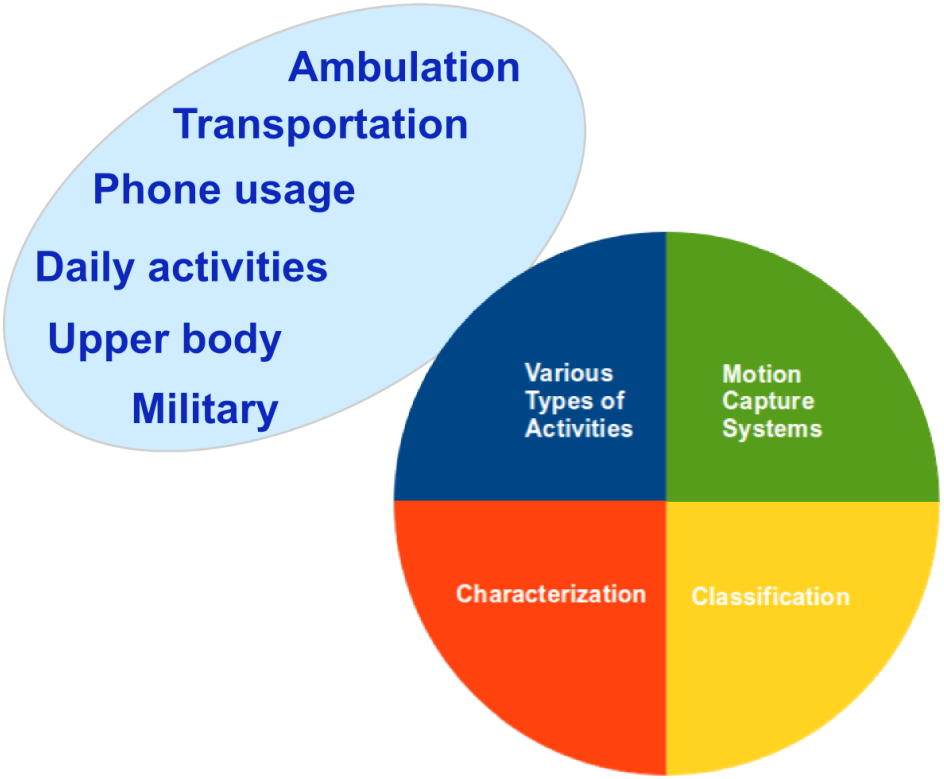

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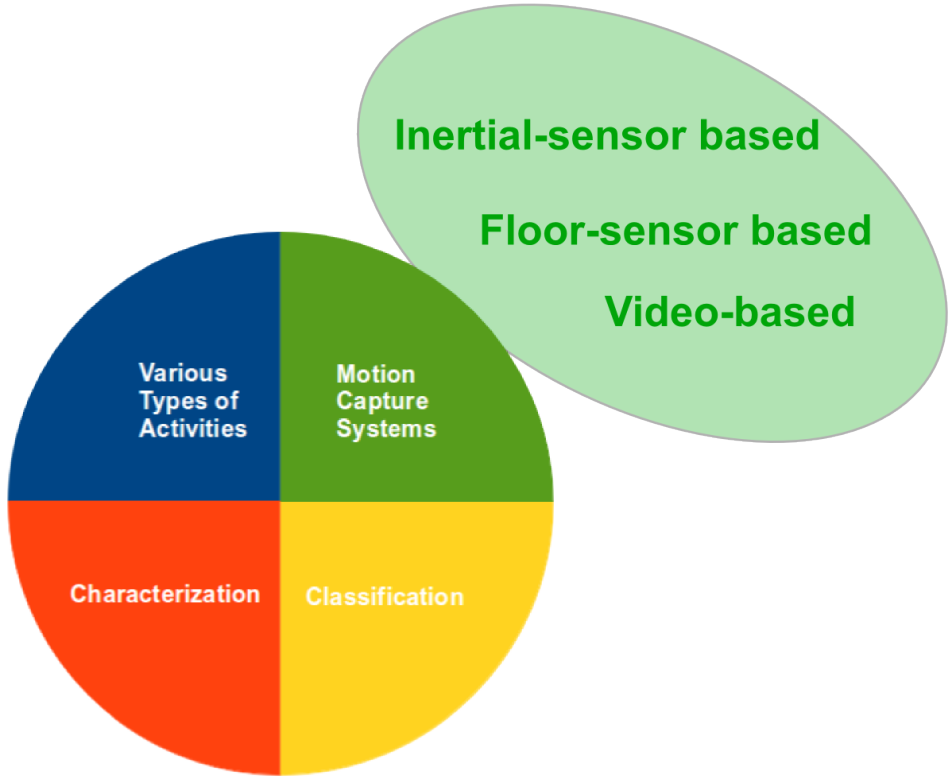

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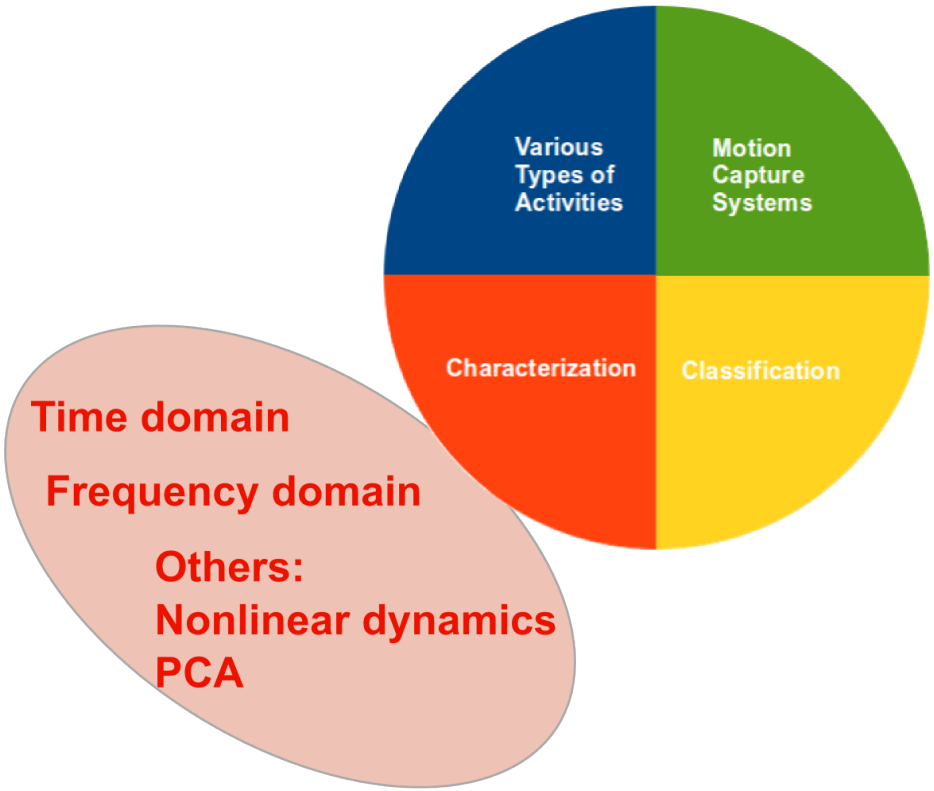

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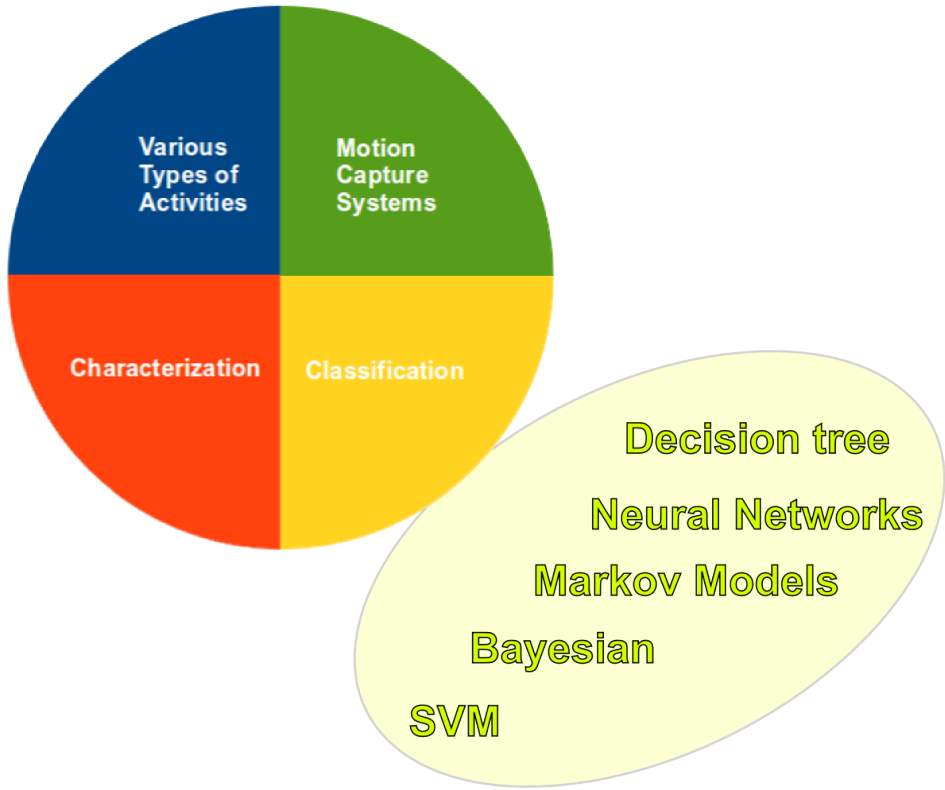

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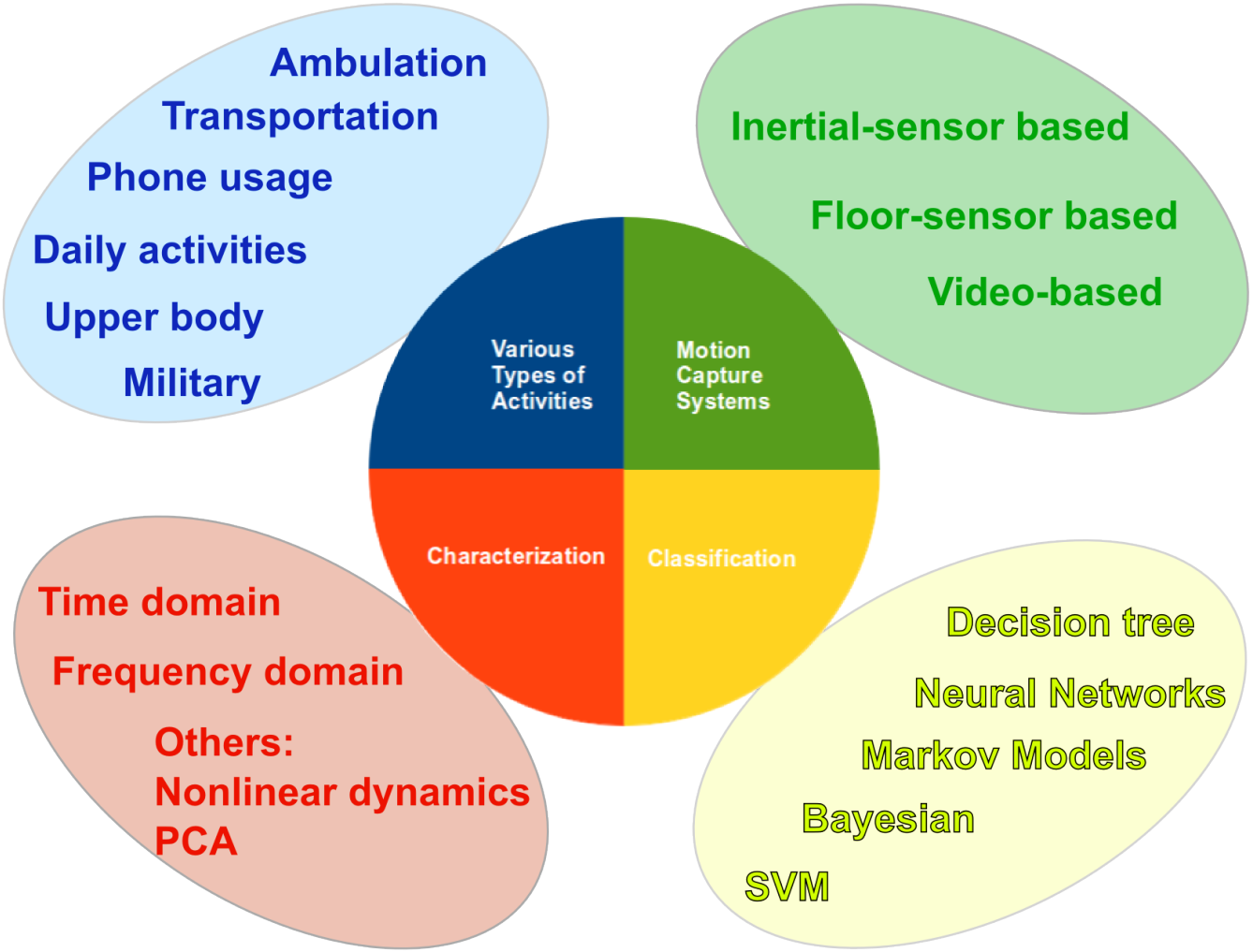
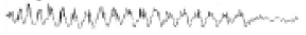
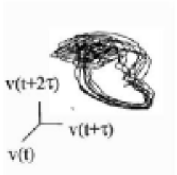
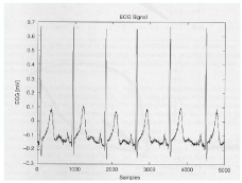


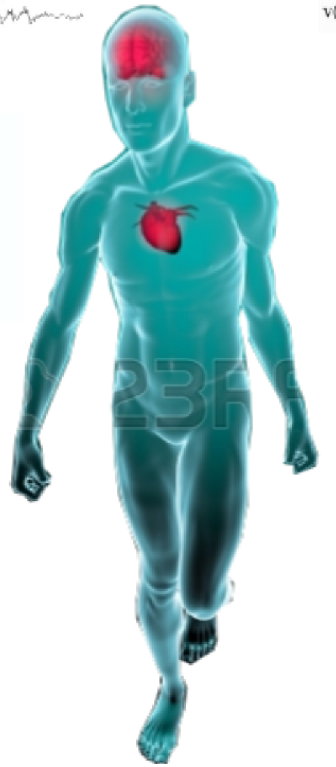
Study of electrophysiological time series

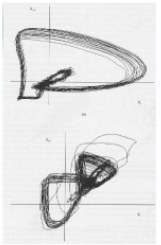




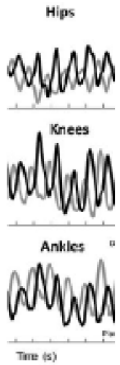
Korn et al (2003)

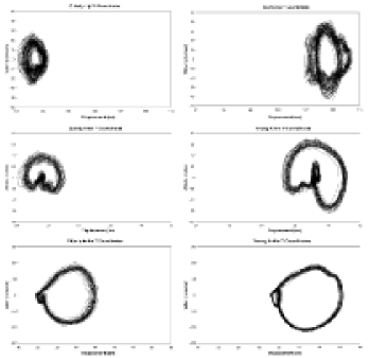






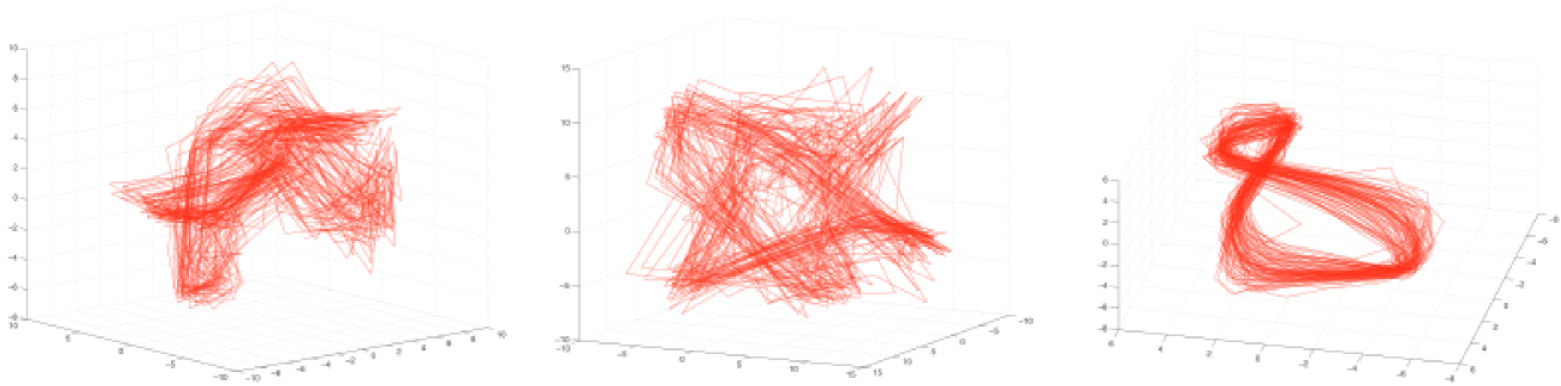
Fojt et al (1998)





Buzzi et al (2013)

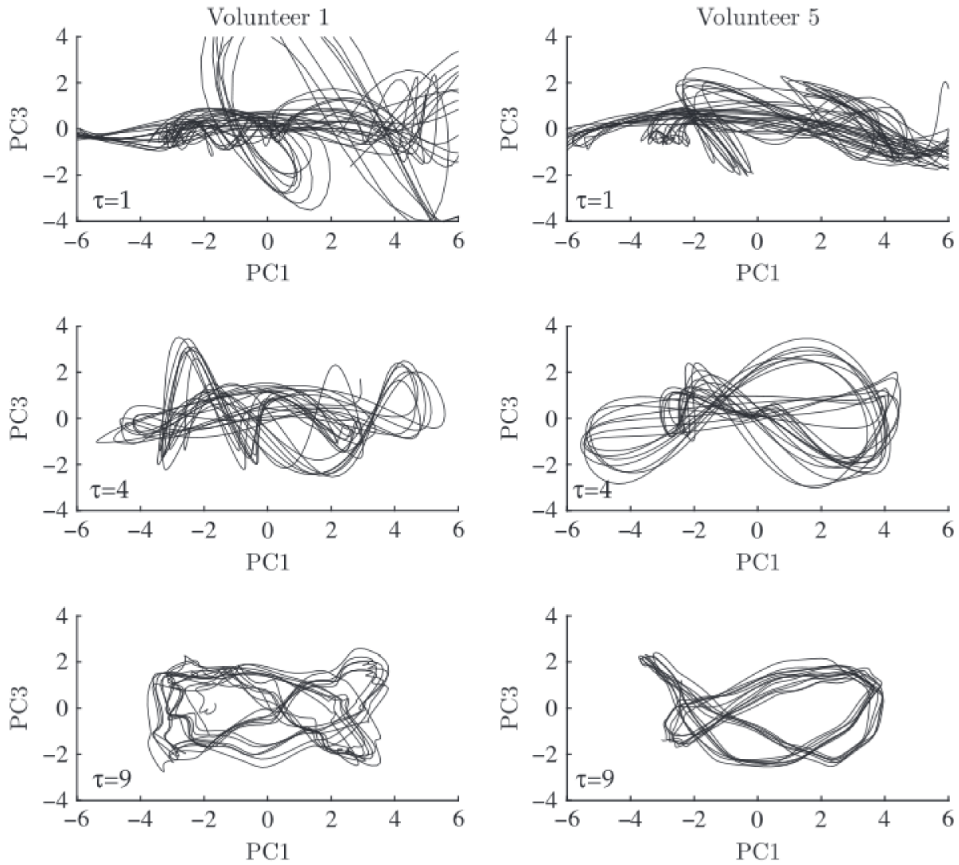
Time Series Classification



Jordan et at (2013)

Reconstructed state spaces for walking (left), running (middle), and biking (right) from noisy accelerometer data.

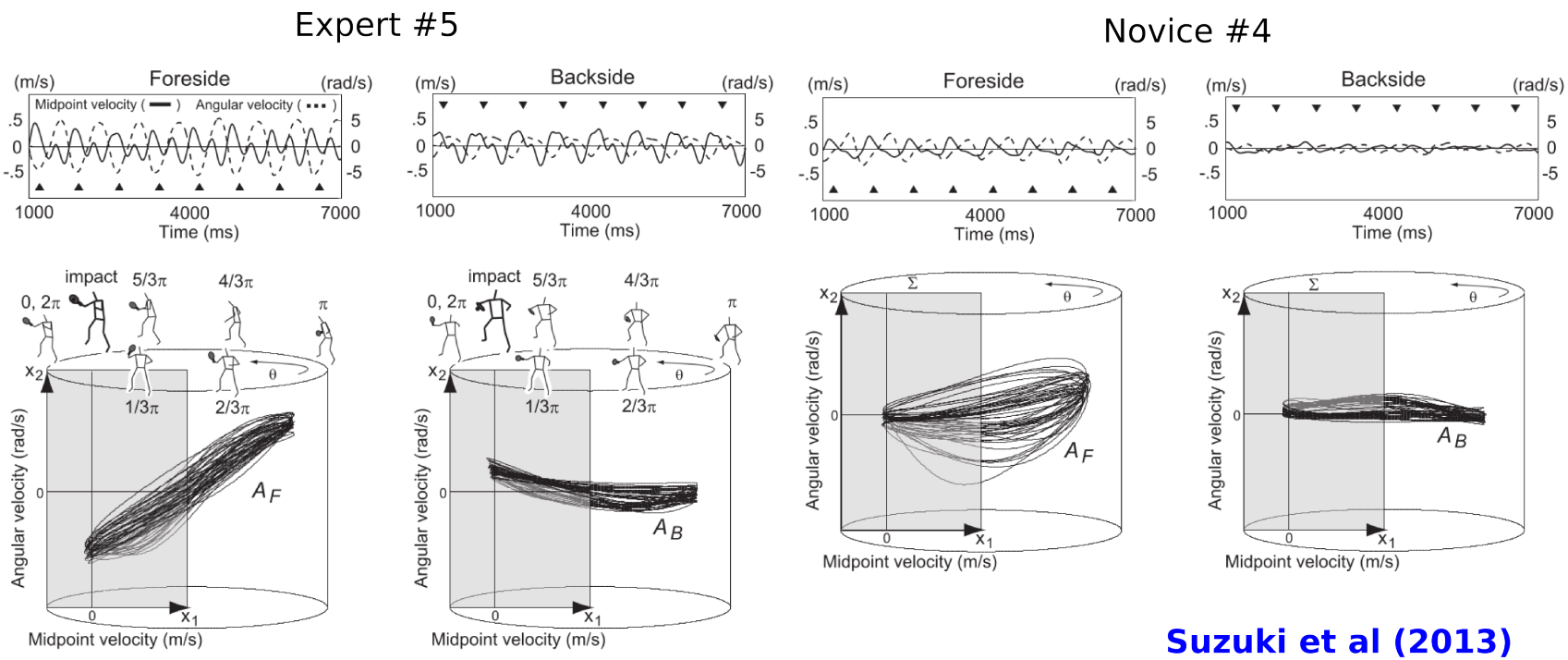
Gait Identification



Sama et al (2013)

Reconstruction of the trajectory of the first and third PC for two indivials.

Dexterity of Tennis Players



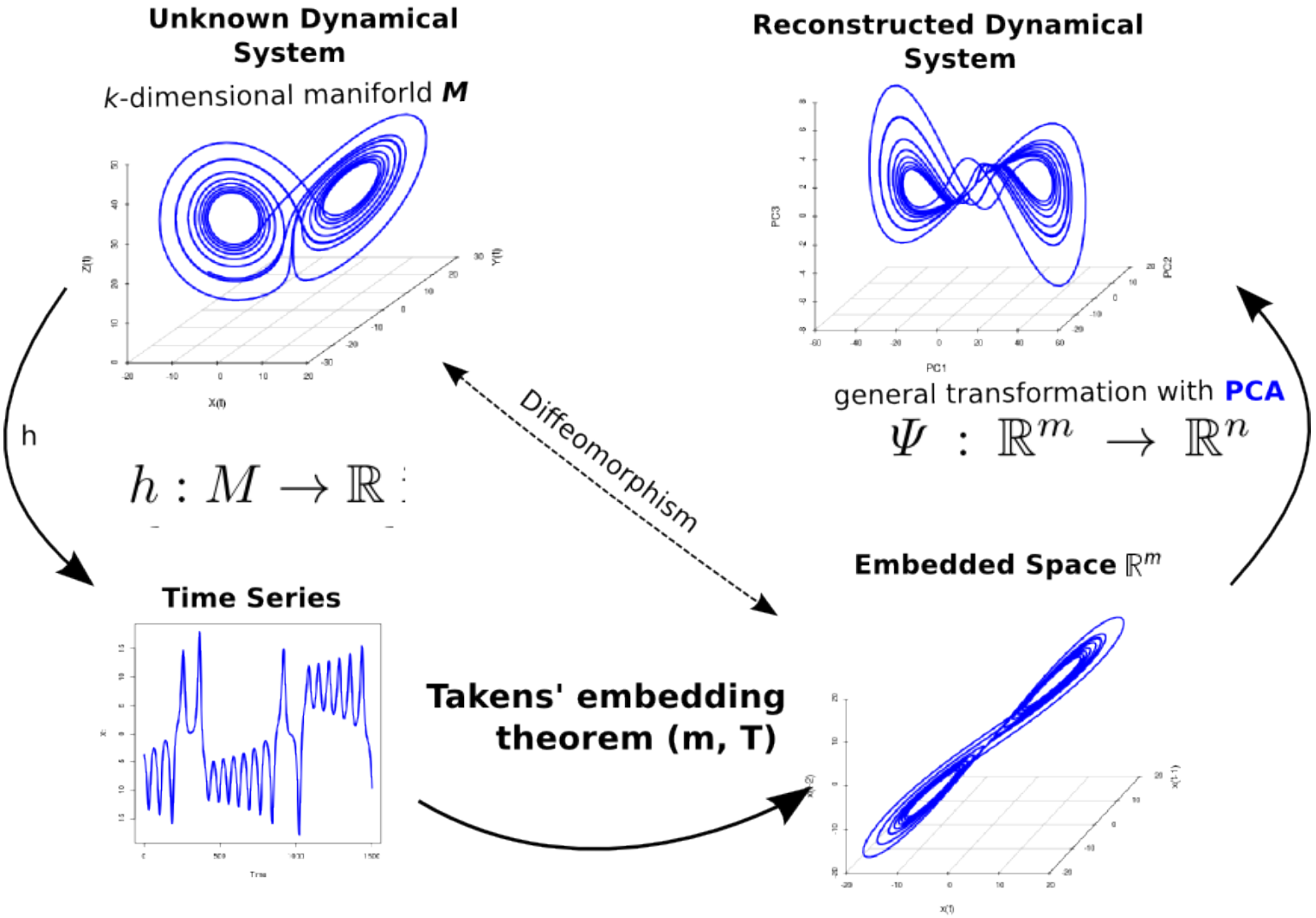
Suzuki et al (2013)

Time series and hyper-cylindrical phase space from Expert #5 and Novice #4.

Research Questions

- How the reconstructed state space can quantify the dexterity of human body activities?
- Is the Takens's Theorem the best tool to quantify Human Activities in terms of the reconstruct the state space?
- Which concepts from nonlinear dynamics can be used to characterize human body activities?

The Reconstructed State Space



Takens' Theorem (1981)

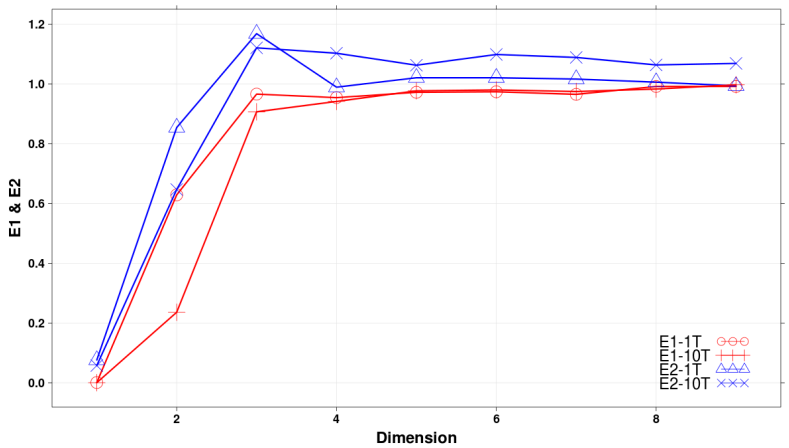
According to Takens' Theorem, the reconstructed state space in m **embedding dimension** with τ **embedding delay** of the original system is given by

$$\overline{x(t)} = (x(t), x(t-\tau), x(t-2\tau), ..., x(t-(m-1)\tau).$$

Takens' Theorem, also knows as time-delay embeddings method, states that for a large enough m to unfold the attractor and $\tau > 0$ chosen to maximize the information content of $x(t)$, this method provides a one-to-one reconstruction of the true dimension k system ($\mathbb{R}^k$).

Minimum embedding parameters

Cao (1997) proposed a method based on the false neighbor method to determine the minimum embedding dimmension from time-series based on Taken's theorem.
Fraser et al (1985) used the mutual information method for the choice of the delay embedding.



The values E1 and E2 from Lorenz attractor **Cao (1997)**

Time-Delay Embedding Example

Lorenz System

$$\begin{aligned} \frac{dx}{dt} &= \sigma(x-y), \\ \frac{dx}{dt} &= x(\rho-z)-y, \\ \frac{dx}{dt} &= xy-\beta z. \end{aligned}$$

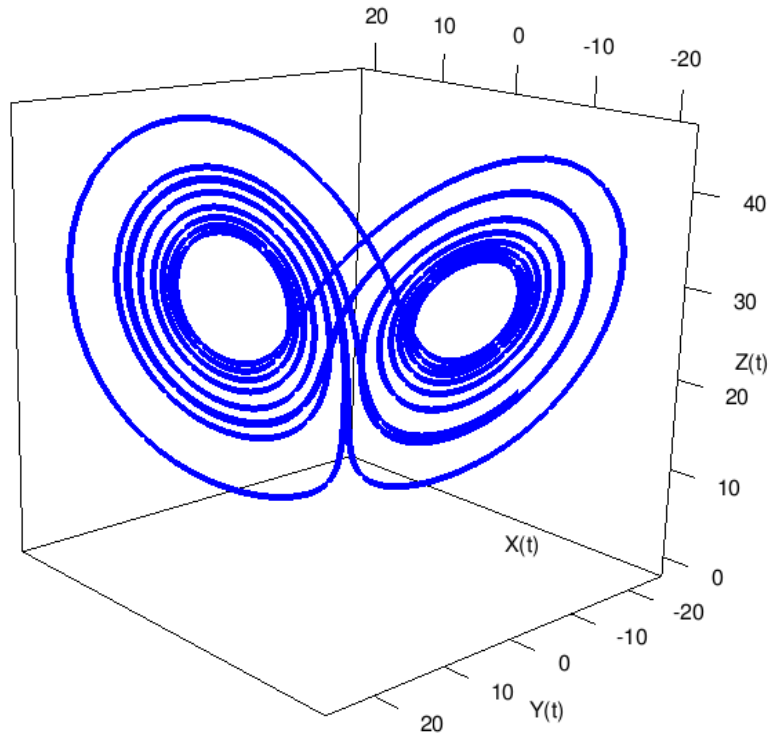


Figure: $\sigma = 10$, $\rho = 28$ and $\beta = 3/8$

Time-Delay Embedding Example

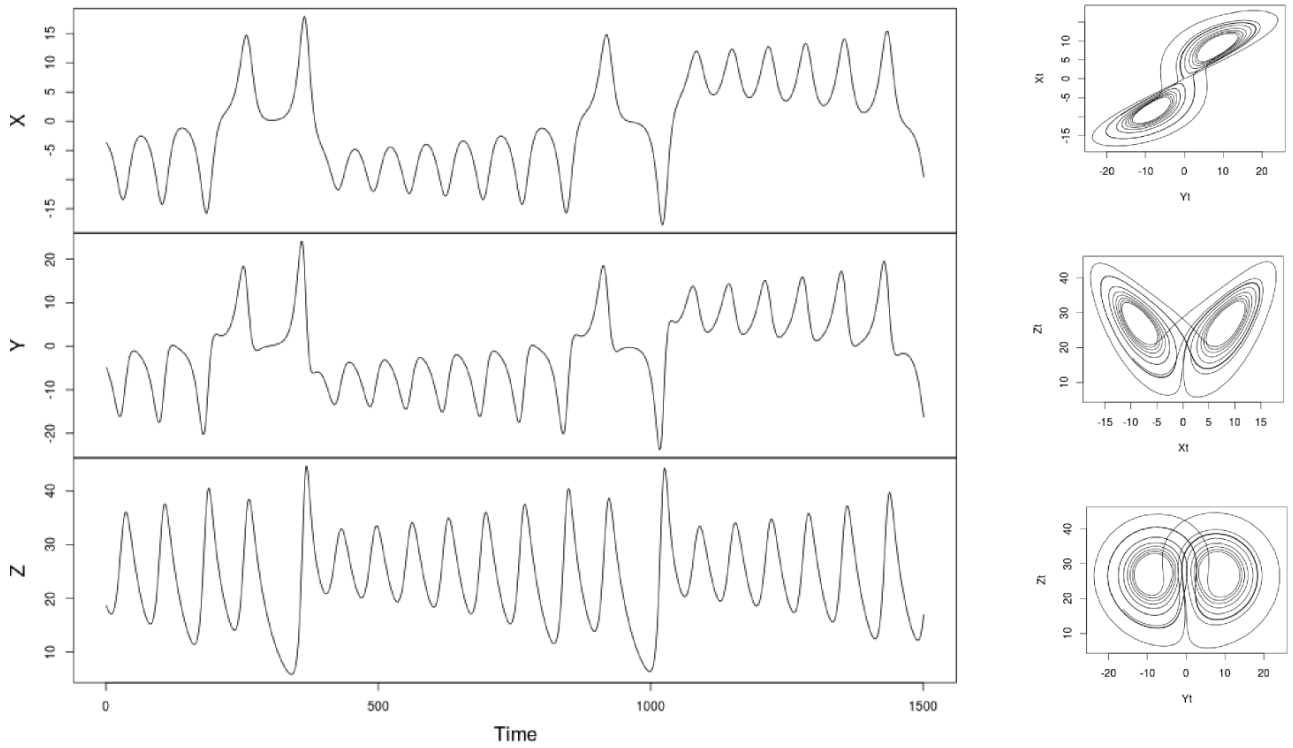


Figure: Time series of the Lorenz System and 2D manifolds

Time-Delay Embedding Example

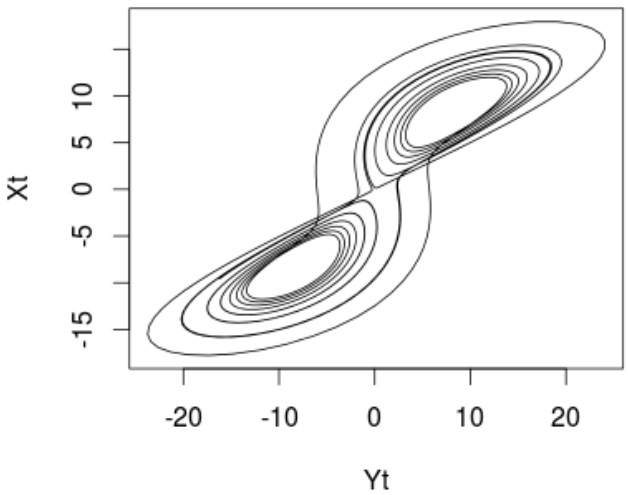
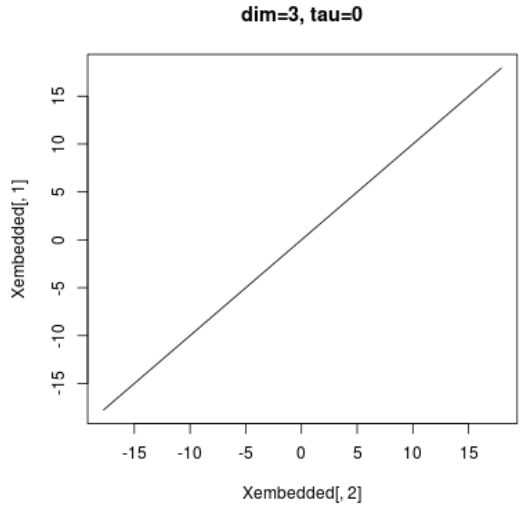
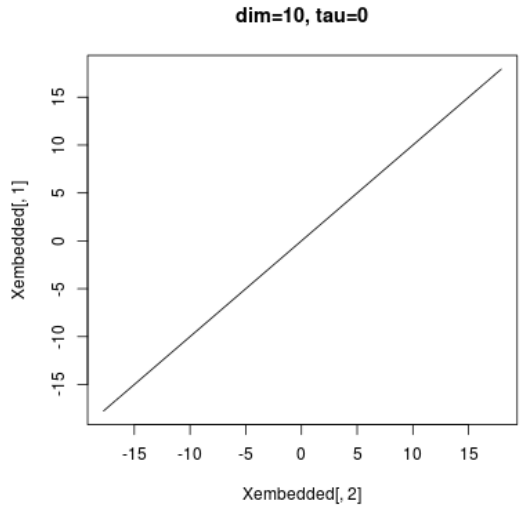


Figure: Original Manifold





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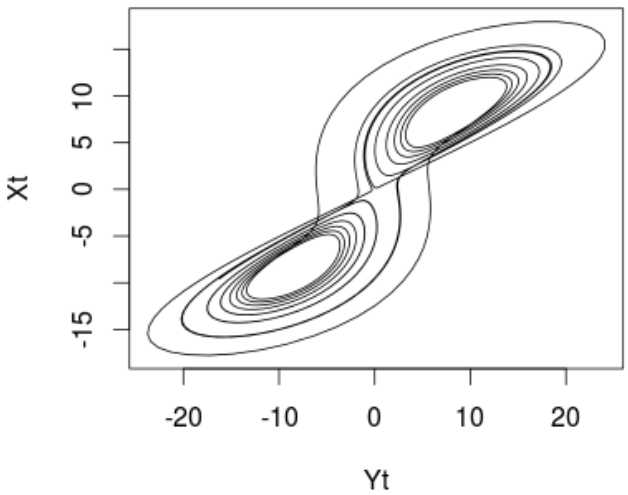

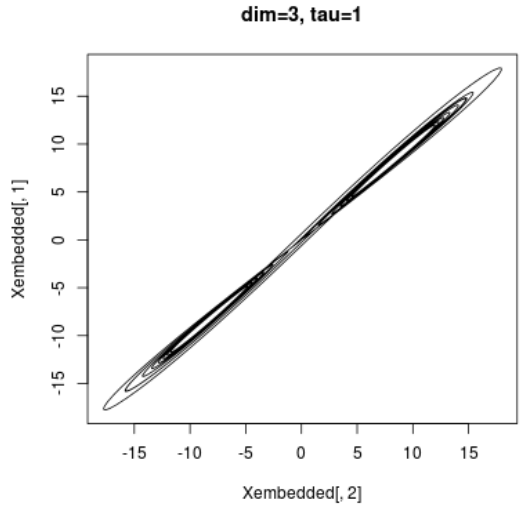

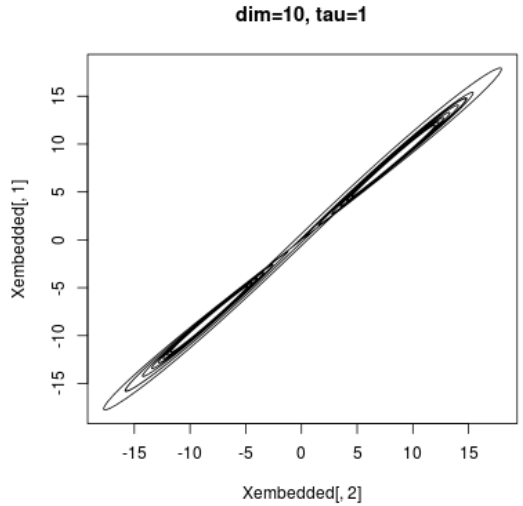

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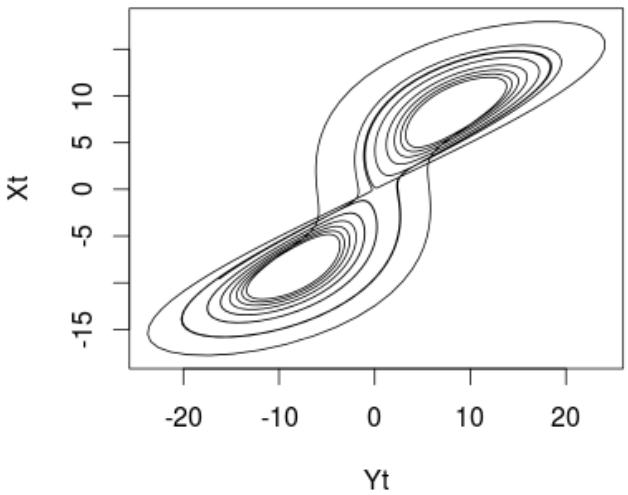

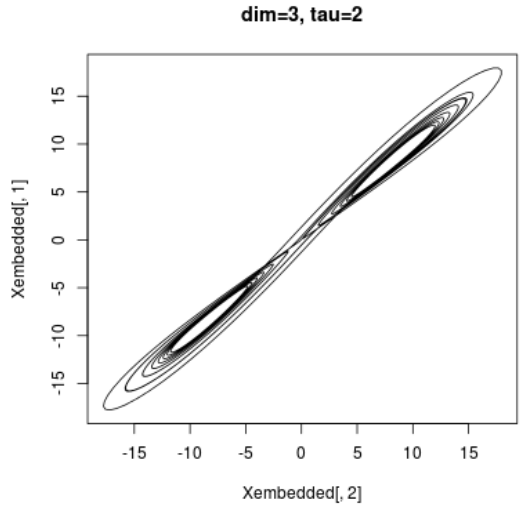

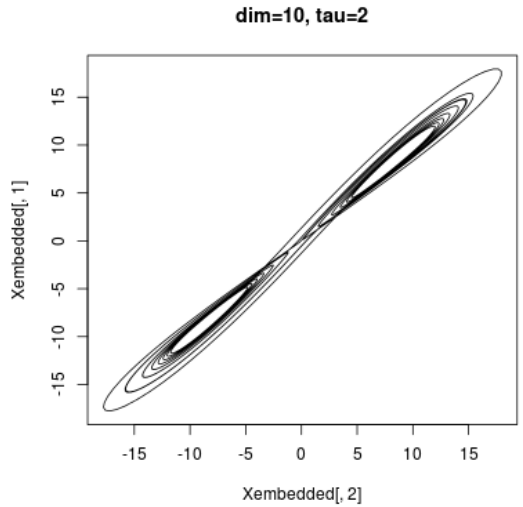

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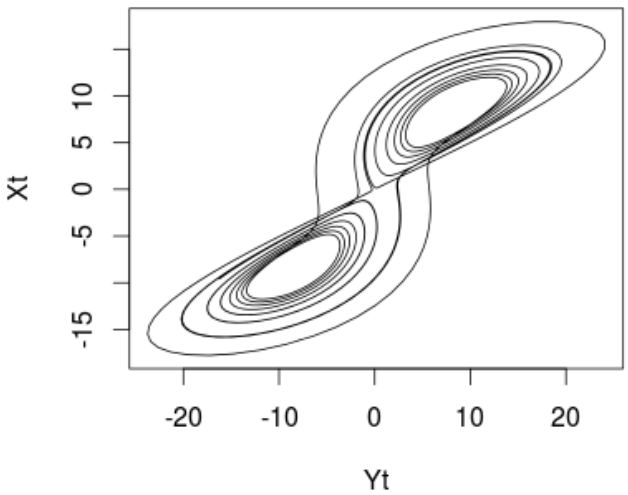

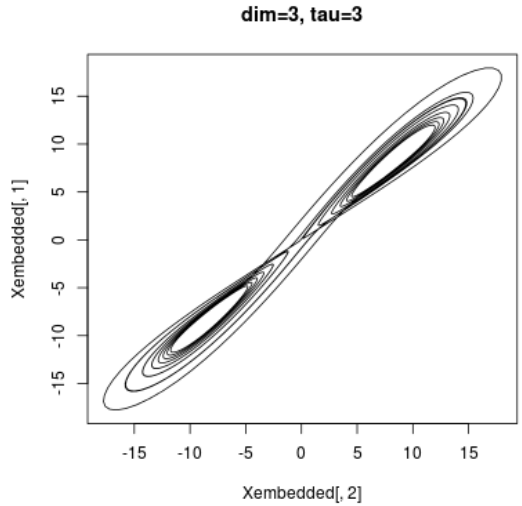

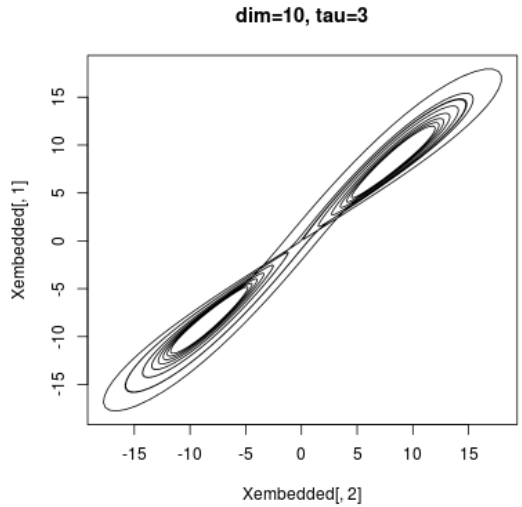

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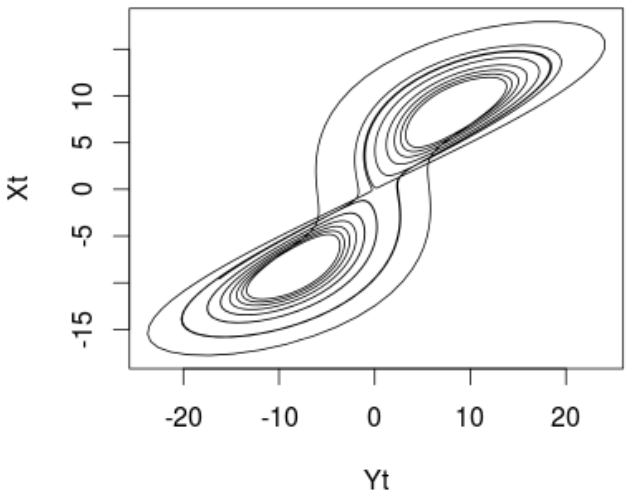

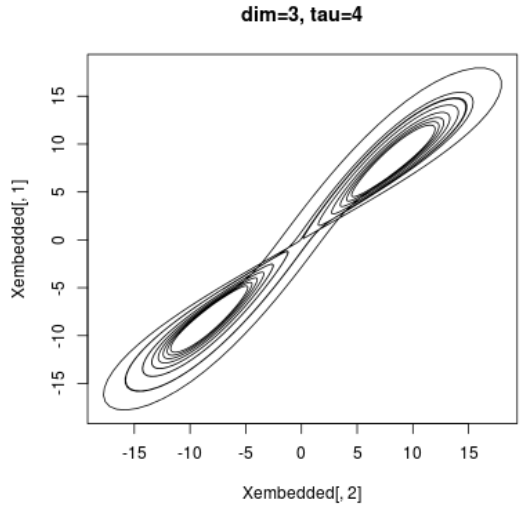

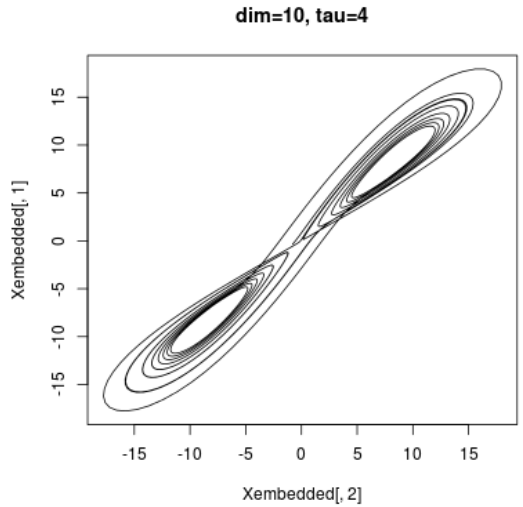

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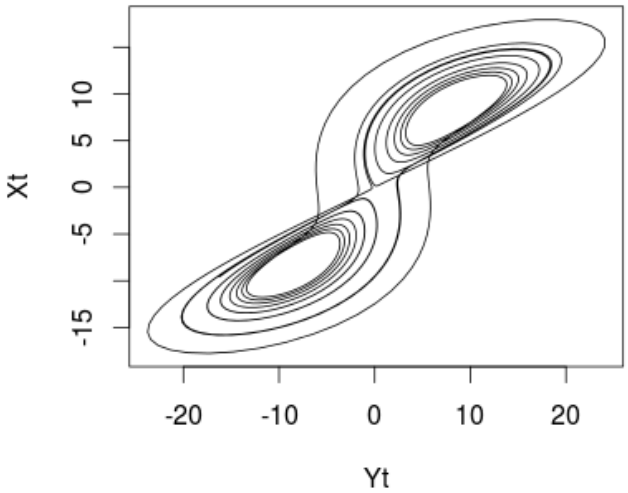

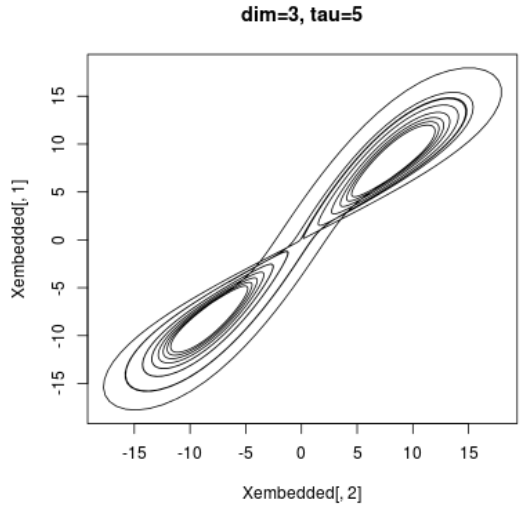

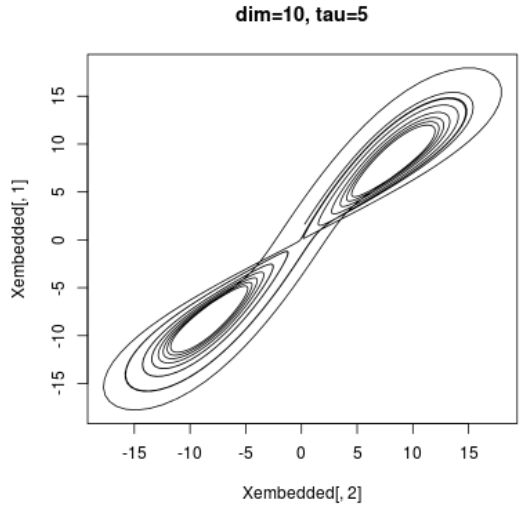

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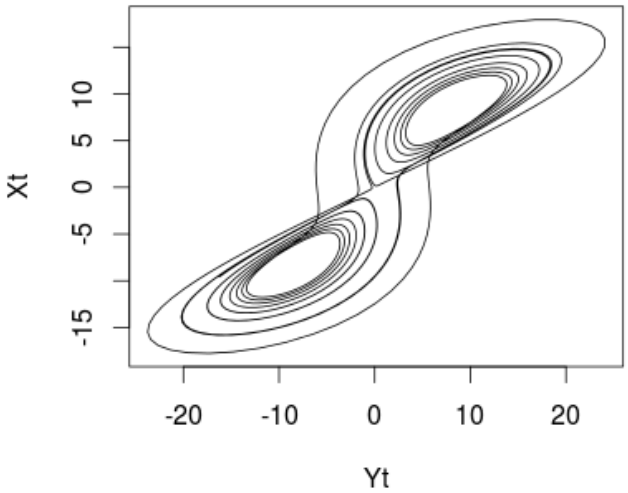

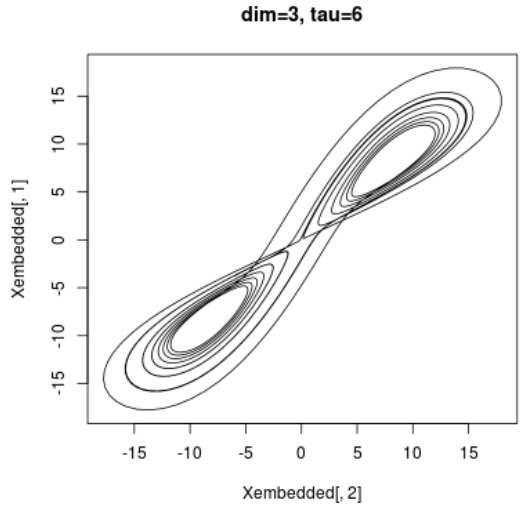

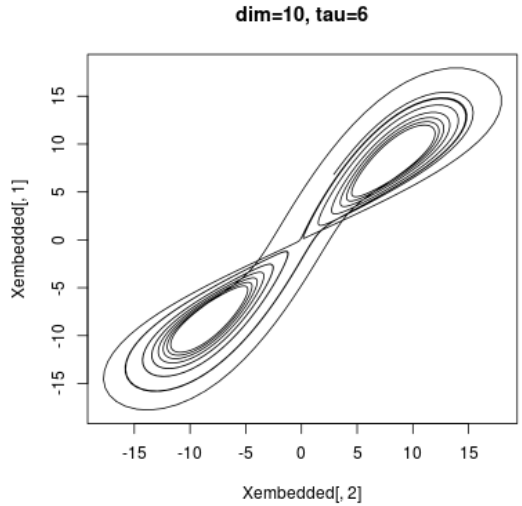

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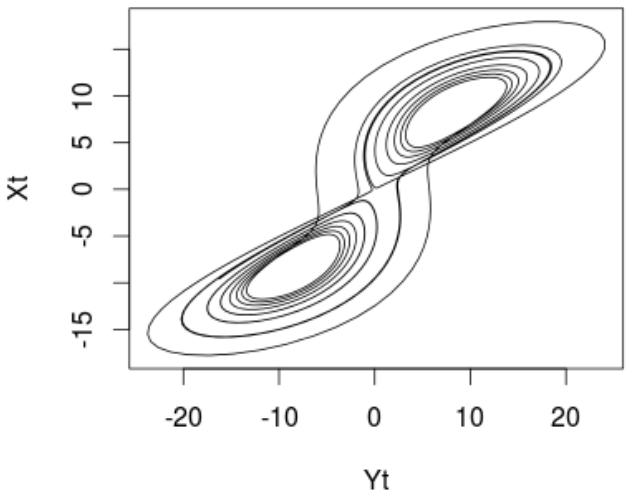

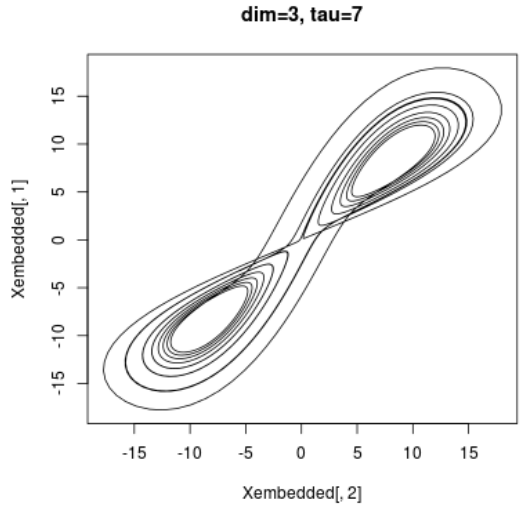

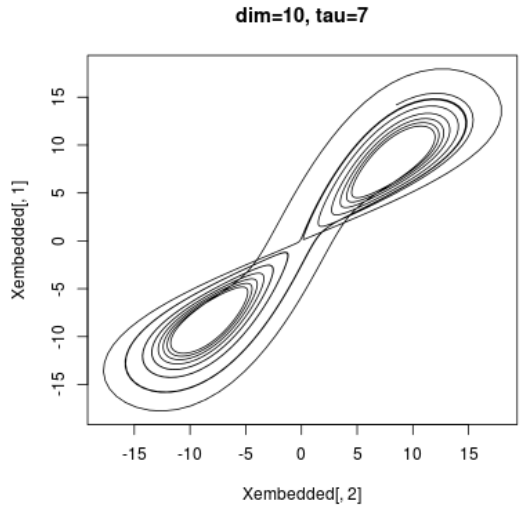

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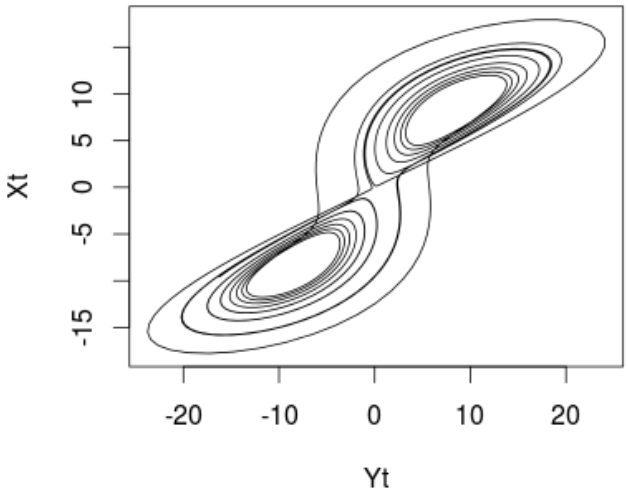

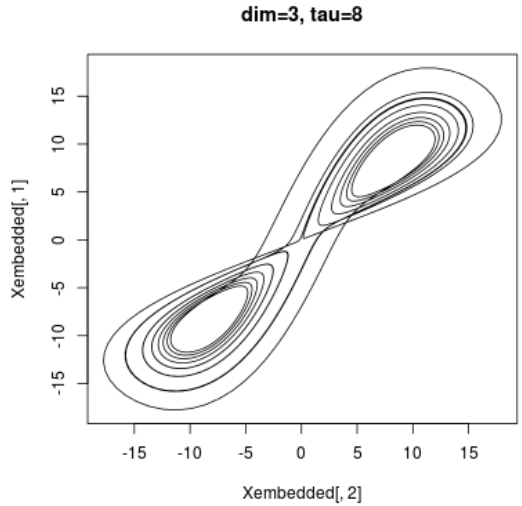

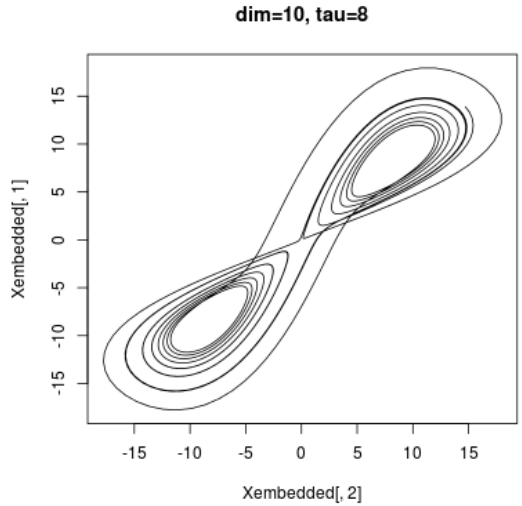

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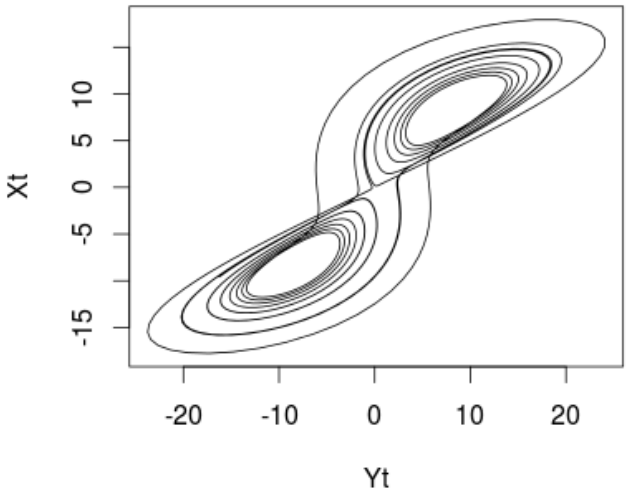

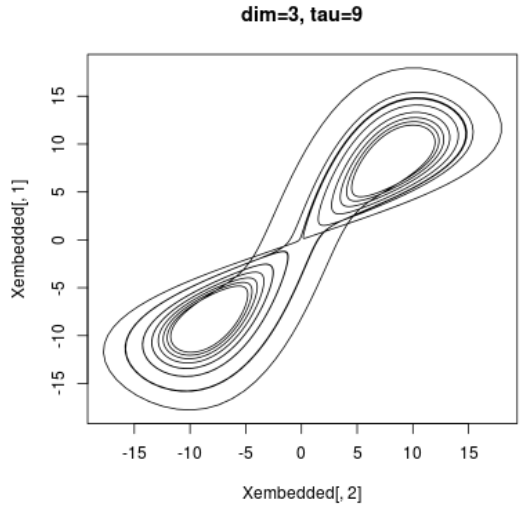

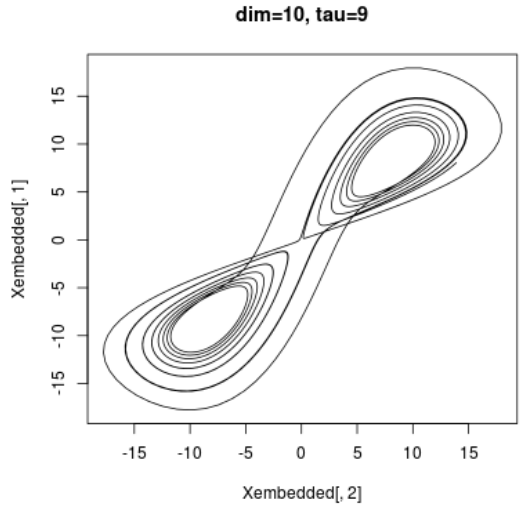

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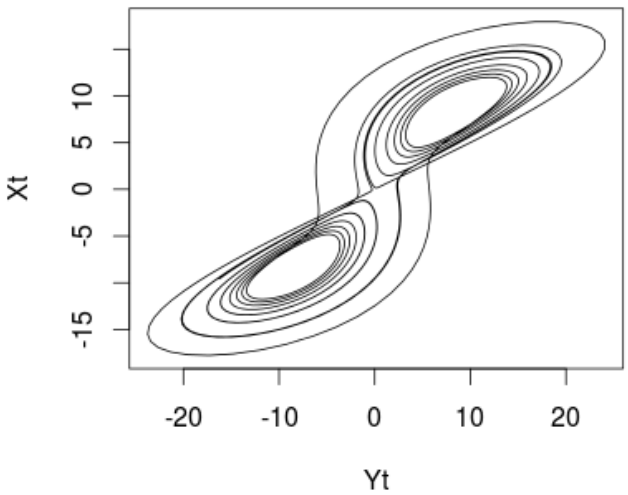

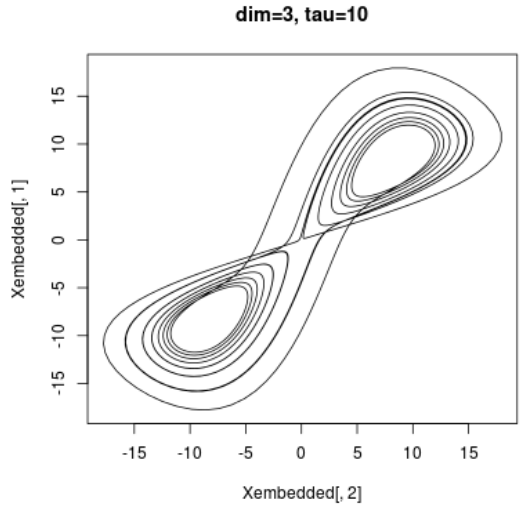

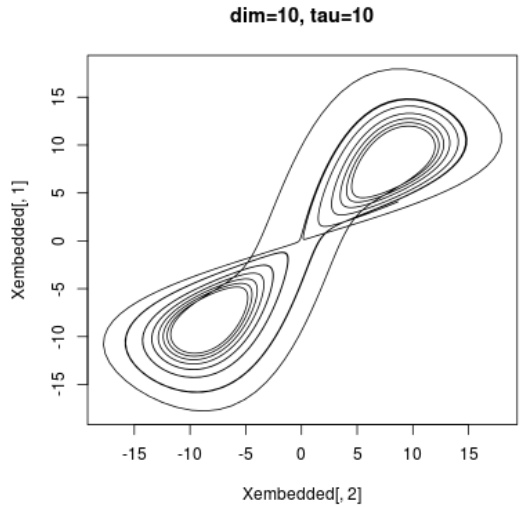

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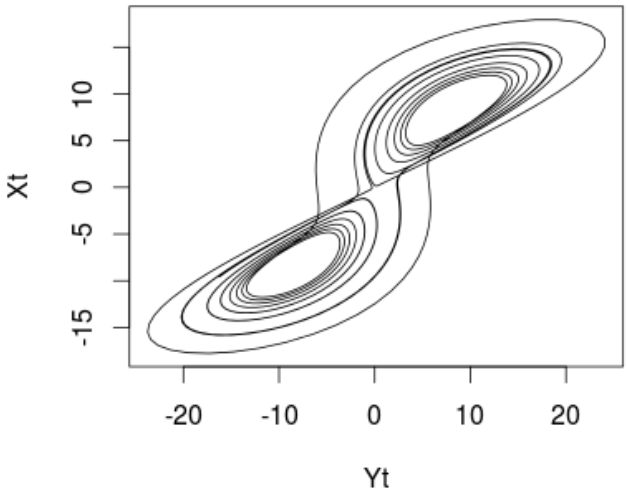
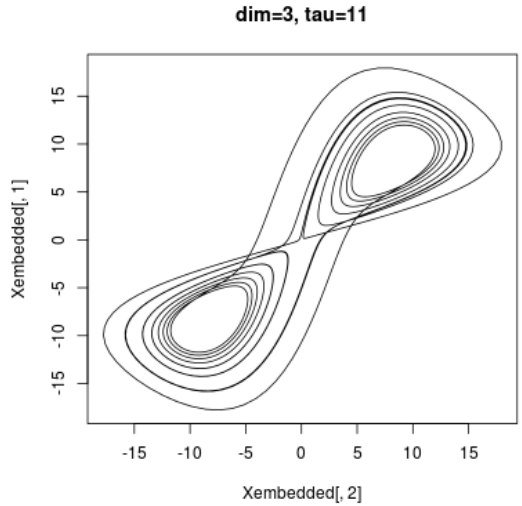




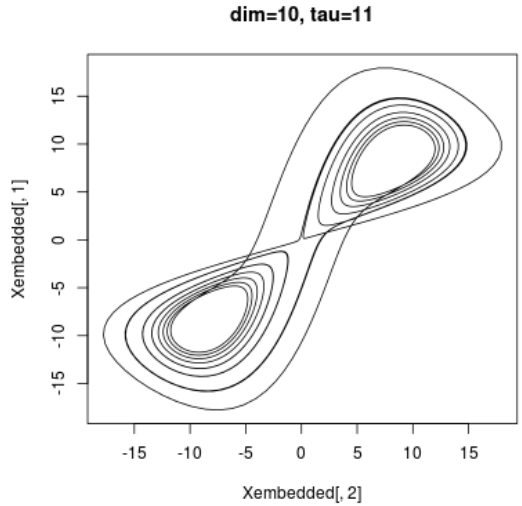
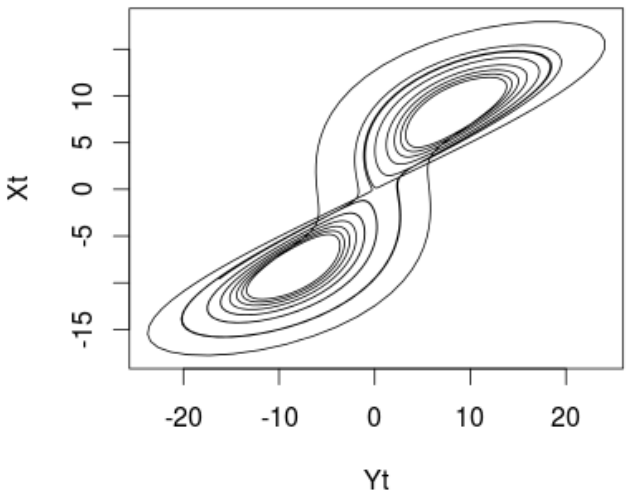
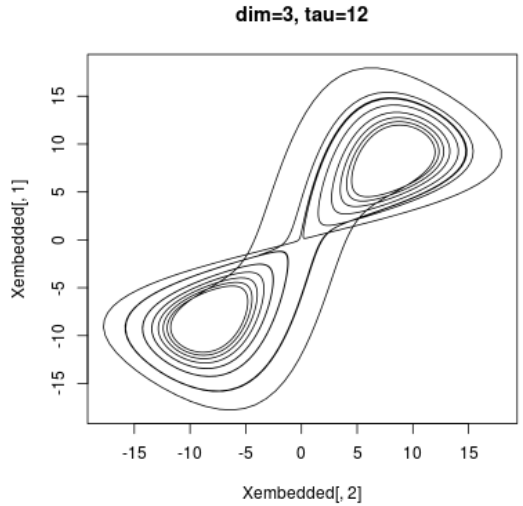


Figure: Original Manifold

Time-Delay Embedding Example





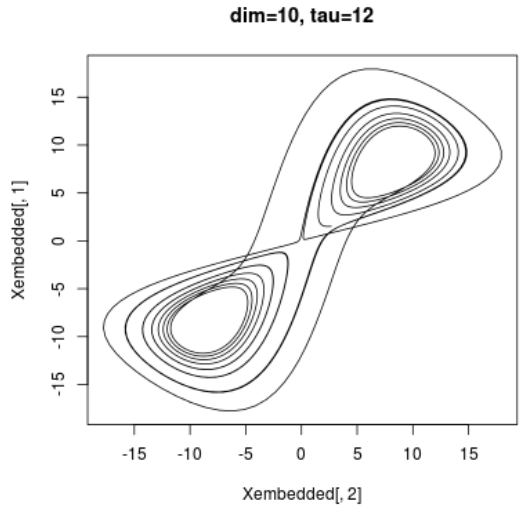
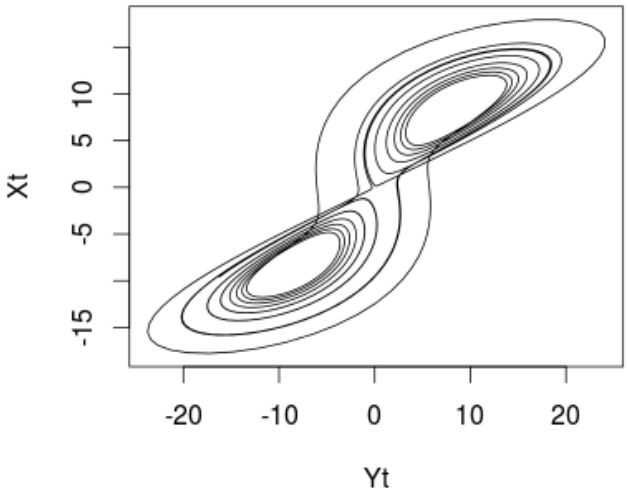
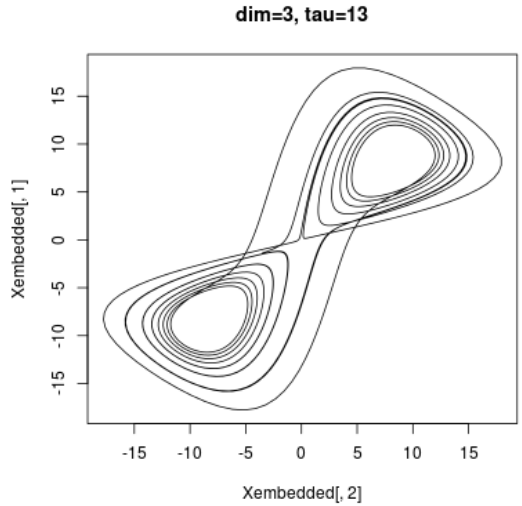


Figure: Original Manifold

Time-Delay Embedding Example





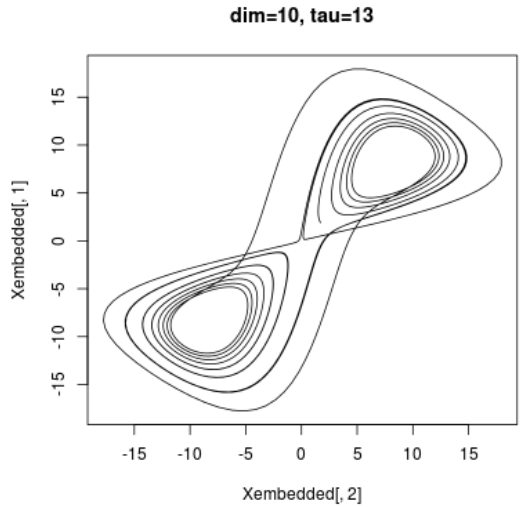


Figure: Original Manifold

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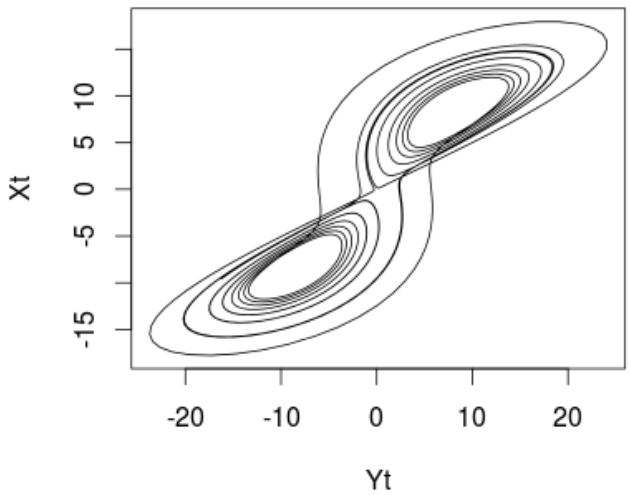
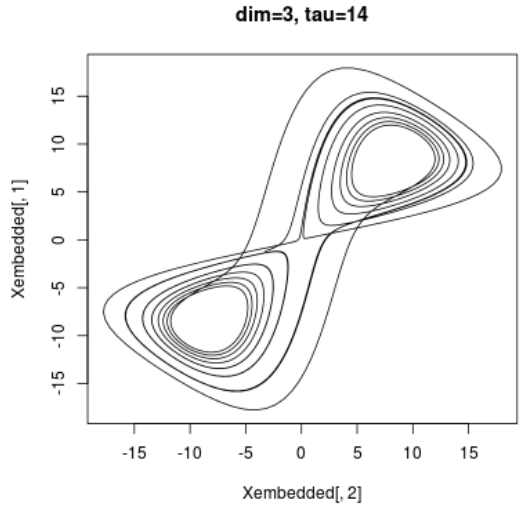




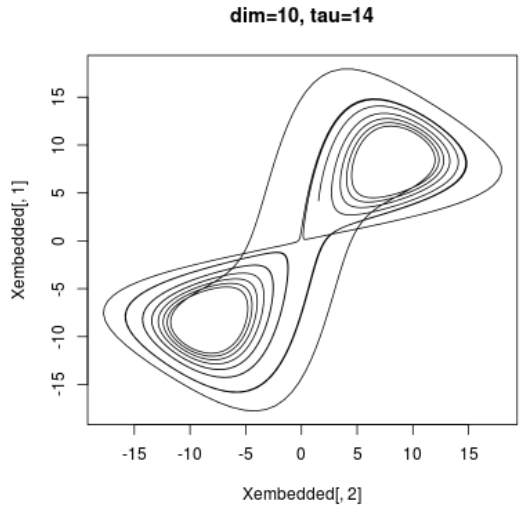
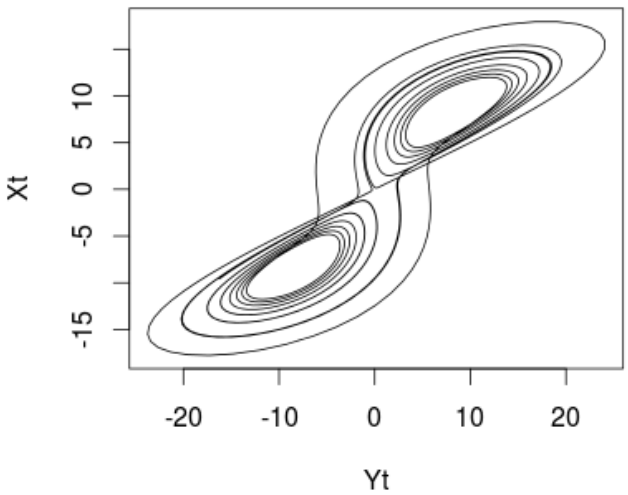
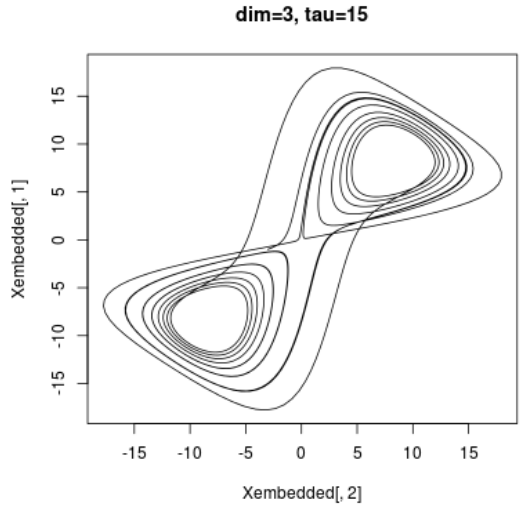


Figure: Original Manifold

Time-Delay Embedding Example





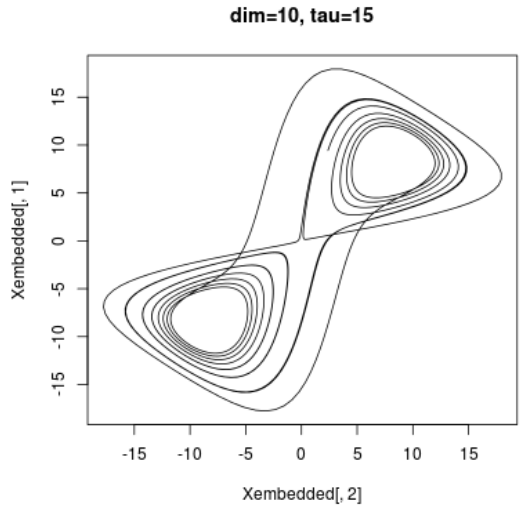


Figure: Original Manifold

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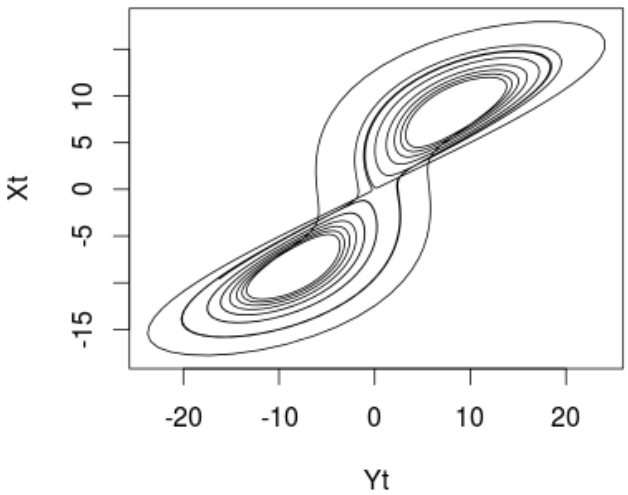

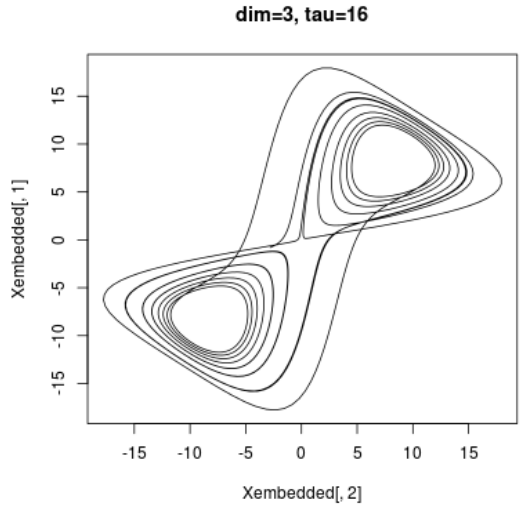

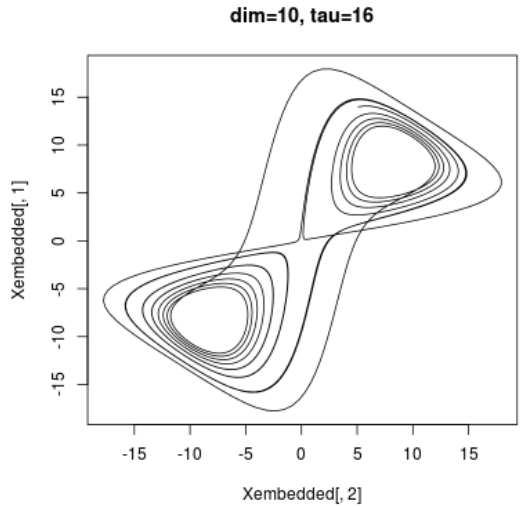

Figure: Original Manifold

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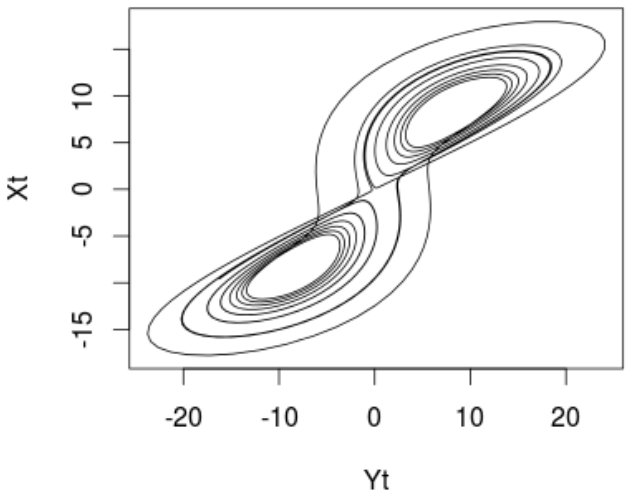

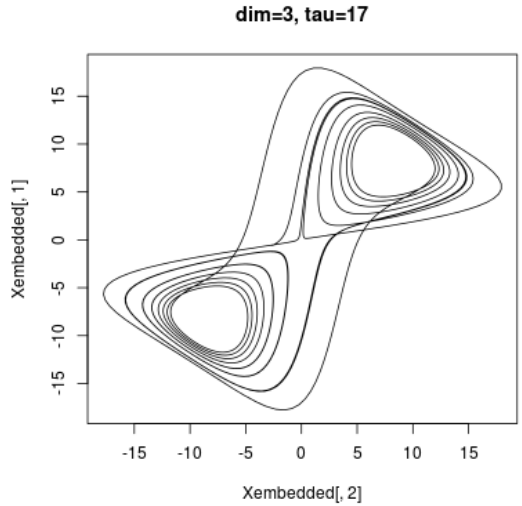

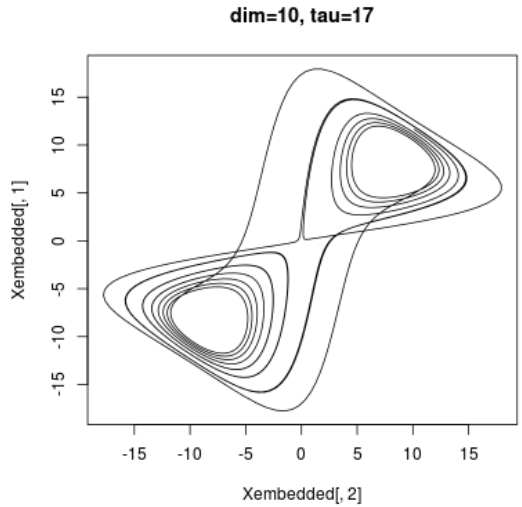

Figure: Original Manifold

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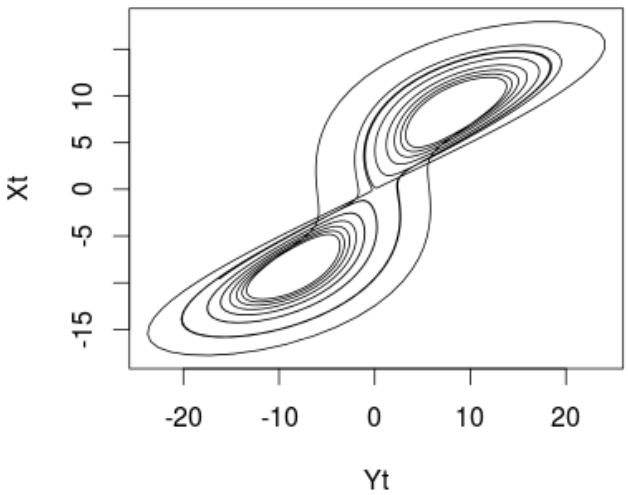

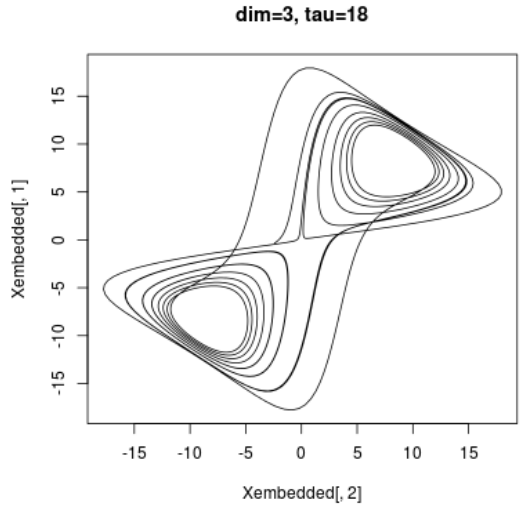

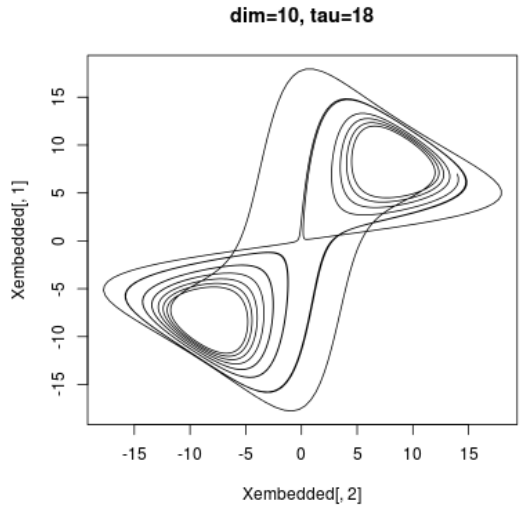

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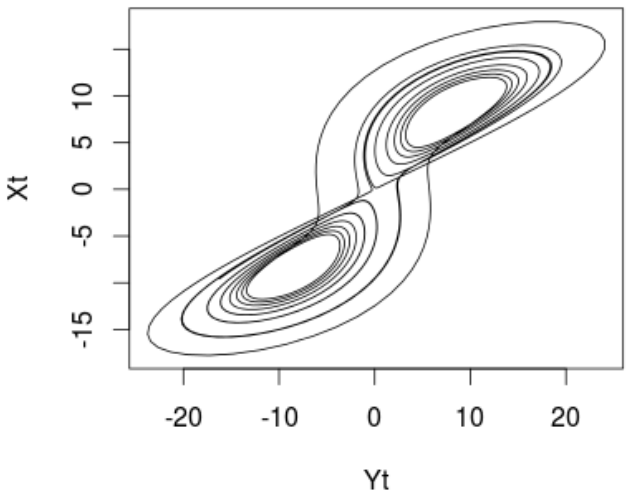
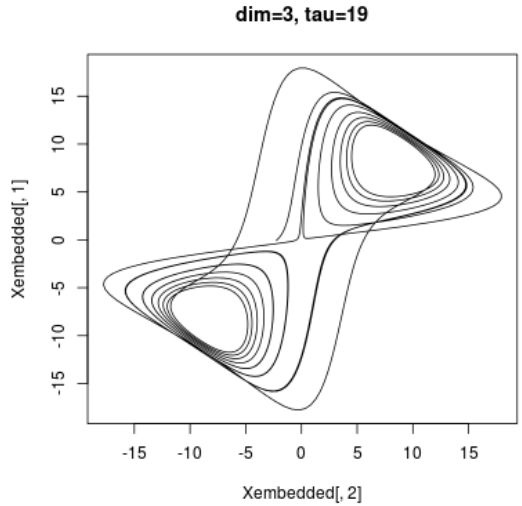




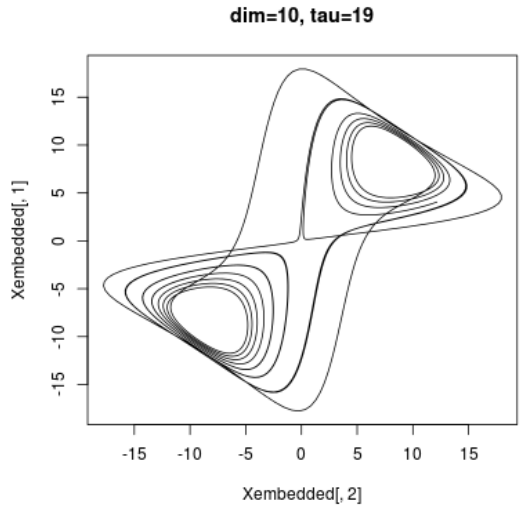
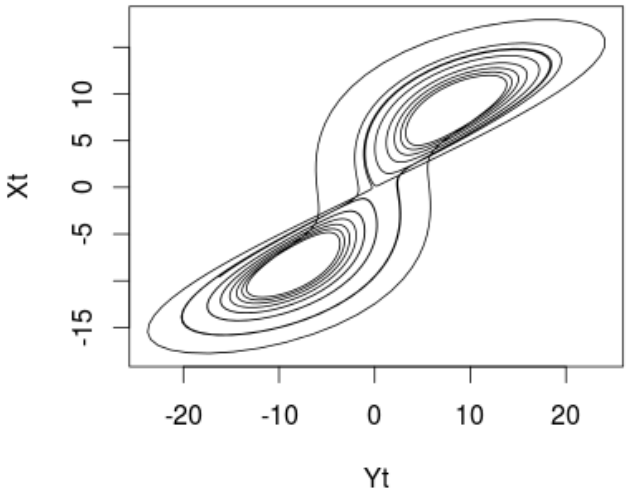
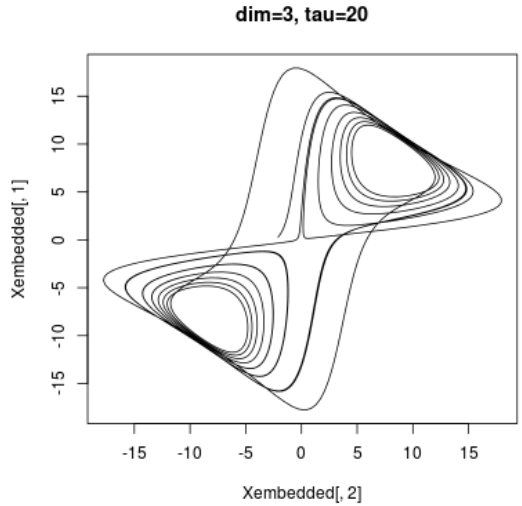
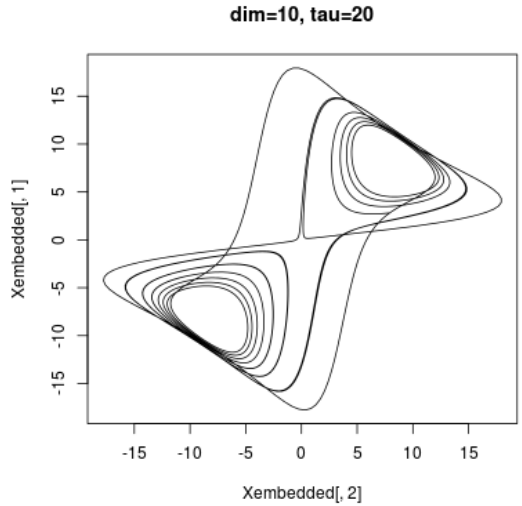


Figure: Original Manifold

Time-Delay Embedding Example







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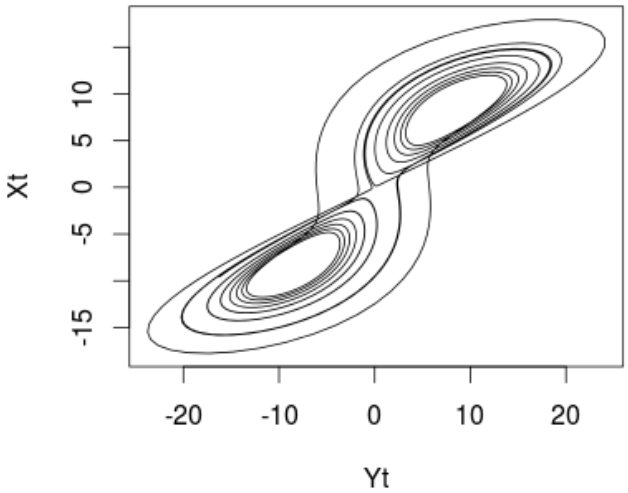
Time-Delay Embedding Example



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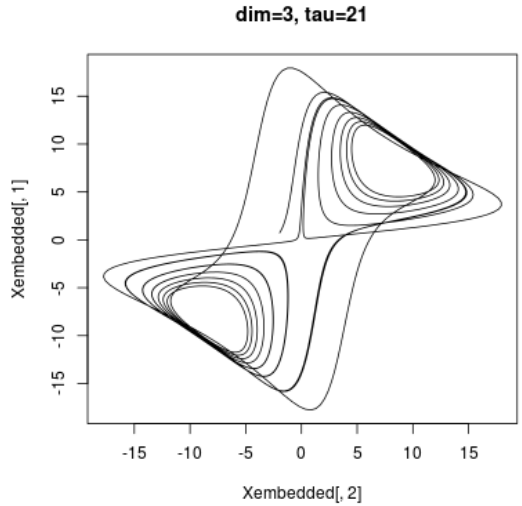
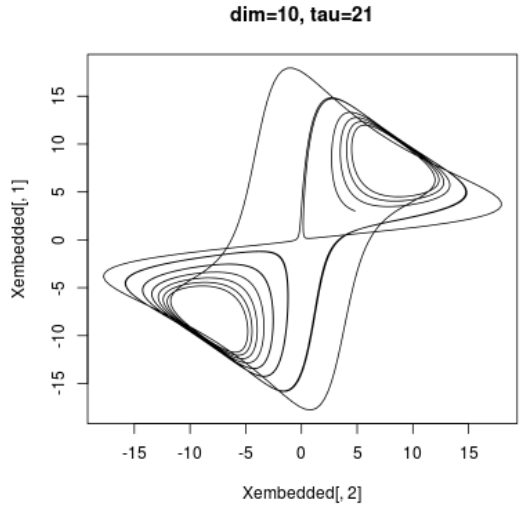
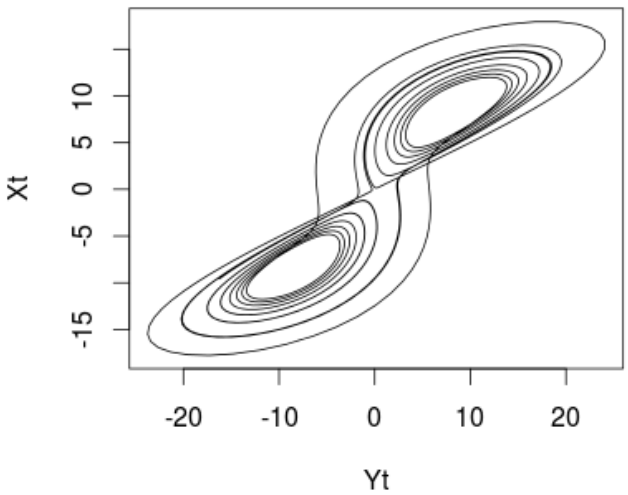
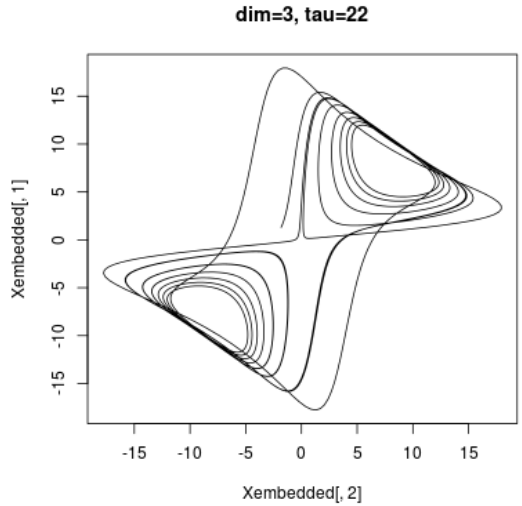




Time-Delay Embedding Example





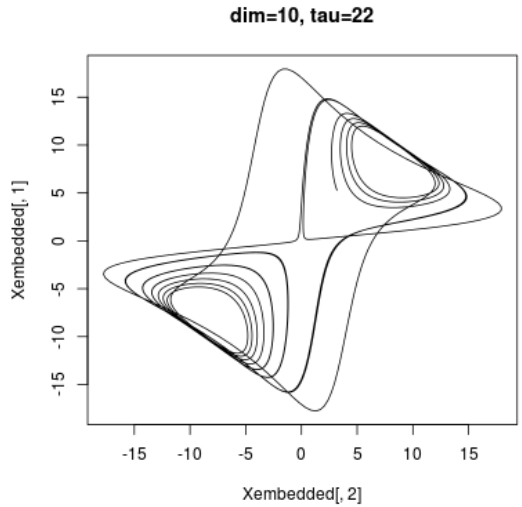
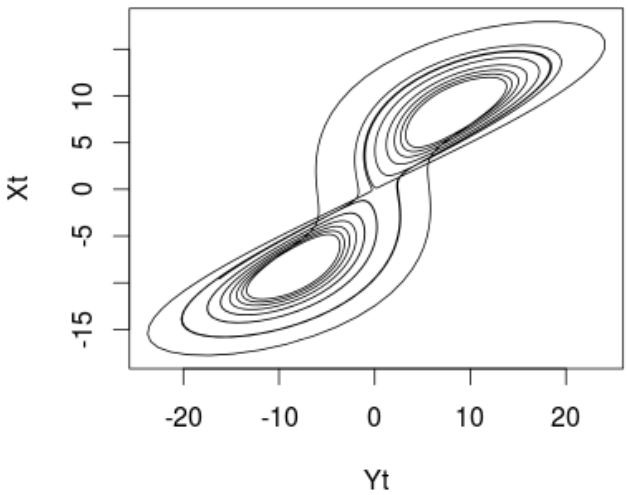
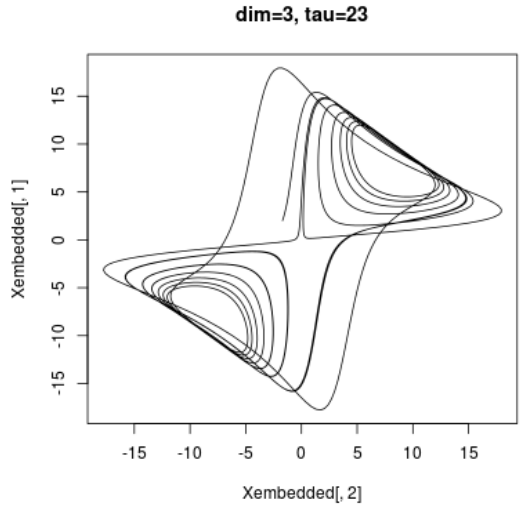


Figure: Original Manifold

Time-Delay Embedding Example





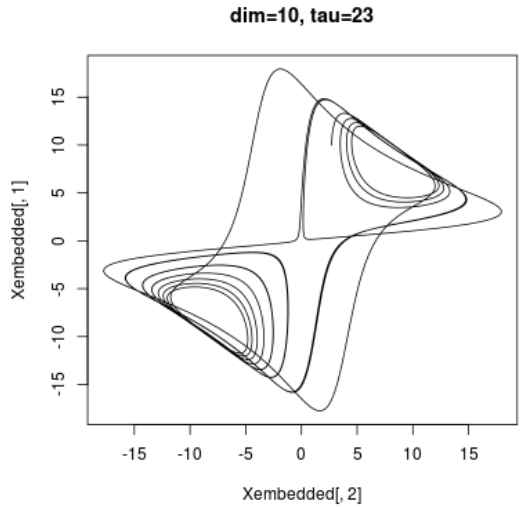
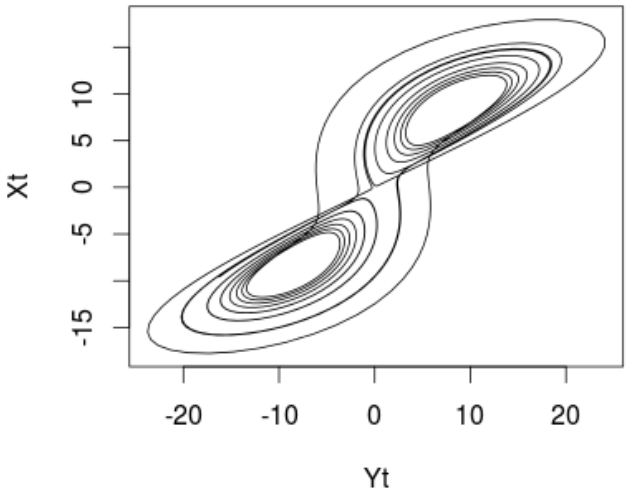
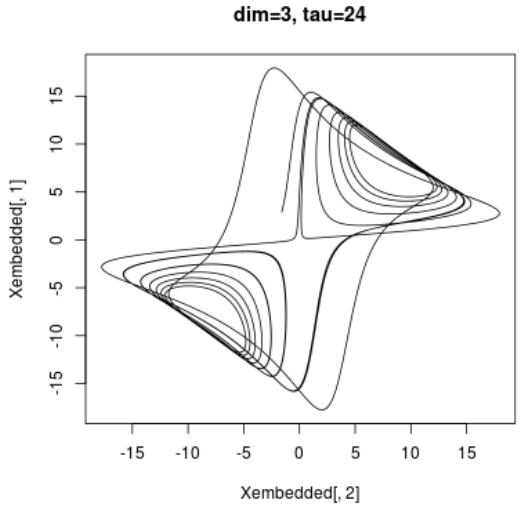


Figure: Original Manifold

Time-Delay Embedding Example





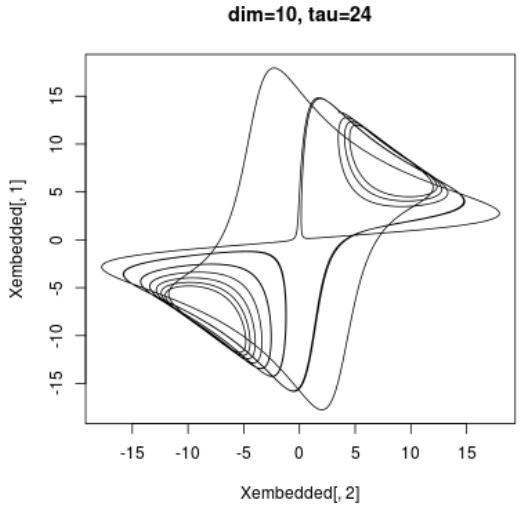


Figure: Original Manifold

Time-Delay Embedding Example

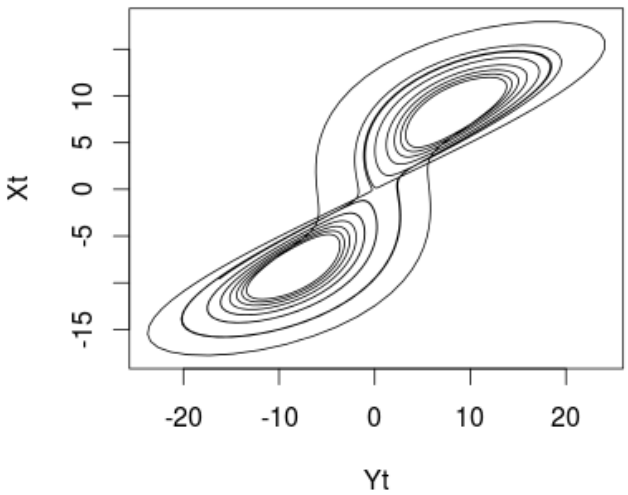


Figure: Original Manifold

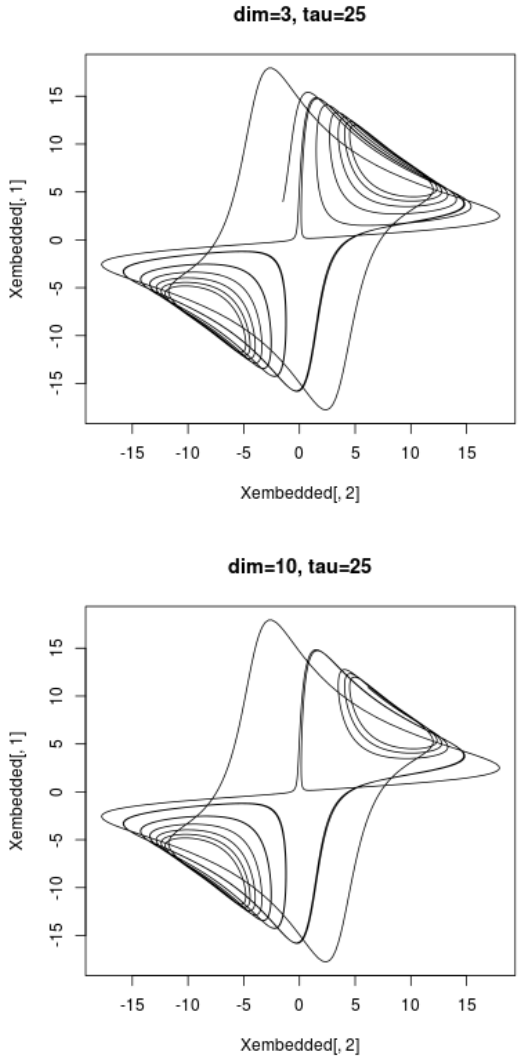


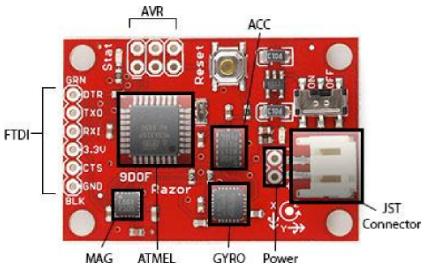
Figure: Reconstructed Manifold

My goals this month

- Determine the technique(s) to quantify the dexterity of Salsa Dancers based on the analysis of the reconstructed state space.
- Submit a paper in The International Symposium on Wearable Computers (ISWC). Deadline: April 10th, 2015.


DECIMUS Class in C++

9DOF Razor IMU



Accelerometer **X Y Z |m|**

Magnetometer **X Y Z |m|**

Gyroscope **X Y Z |m|**

Yaw
Pitch
Roll

DECIMUS Class in C++

*time-**D**elay **E**mbedding theorem for*
*Re**C**onstructing state spaces*
*Using **I**nertial **M**easurement **U**nit**S***

Time-Delay Embedding Parameters

```
DataAnalysis.Set_SpaceReconstructionParameters(50,10,5); // (lengthwindowframe, dim, tau)
```

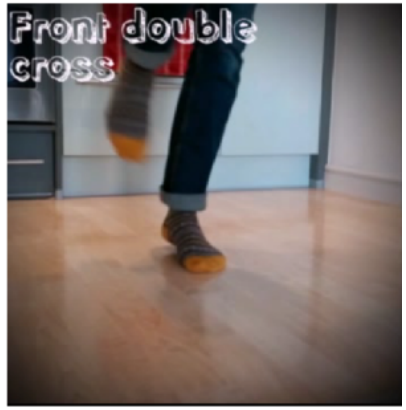
Decimus DataAnalysis
Kind: *Variable* definition
Decl.: main.cpp :66 Show uses
DataAnalysis Object

Principal Component Analysis

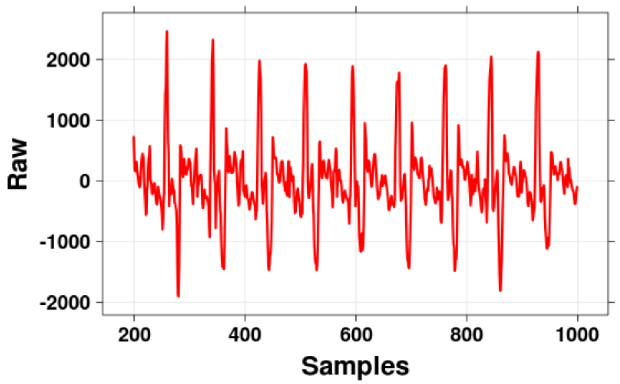
```
mat A;

 A= EmbeddedMatrix.t() * EmbeddedMatrix; // generate a symmetric matrix --- mat B = A.t()*A;


vec eigval_original, eigval;
mat eigvec_original, eigvec, transformedData;
eig_sym(eigval_original, eigvec_original, A.t(), "dc"); // divide-and-conquer

eigval = flipud(eigval_original);
eigvec = fliplr(eigvec_original);
transformedData = fliplr(eigvec_original).t()*EmbeddedMatrix.t();

cout << "DIY:eigenvalues \n" << eigval << endl;
cout << "DIY:eigenvectors \n" << eigvec << endl;
cout << "DIY:transformedData \n" << transformedData << endl;
```

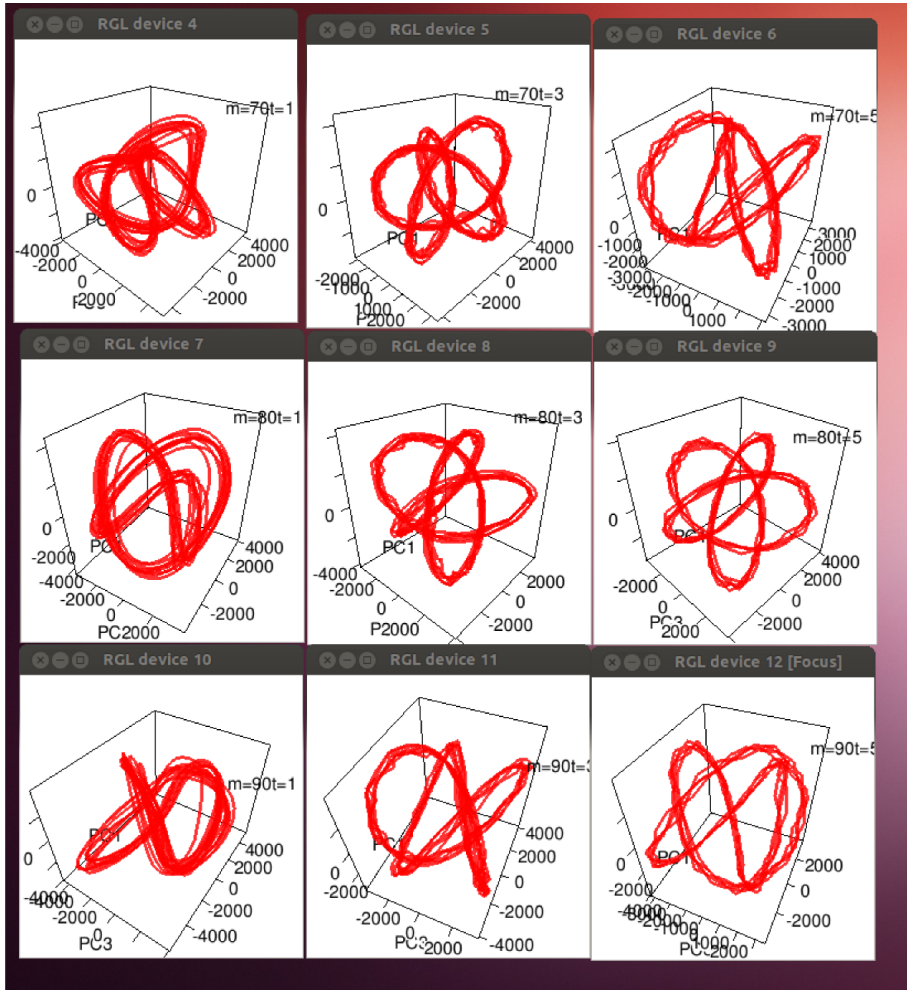
IMU, Axes and C++ Class

Seven Beginner Salsa Feet Patterns

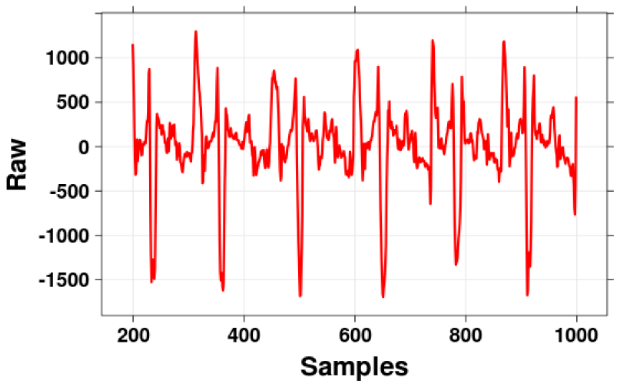


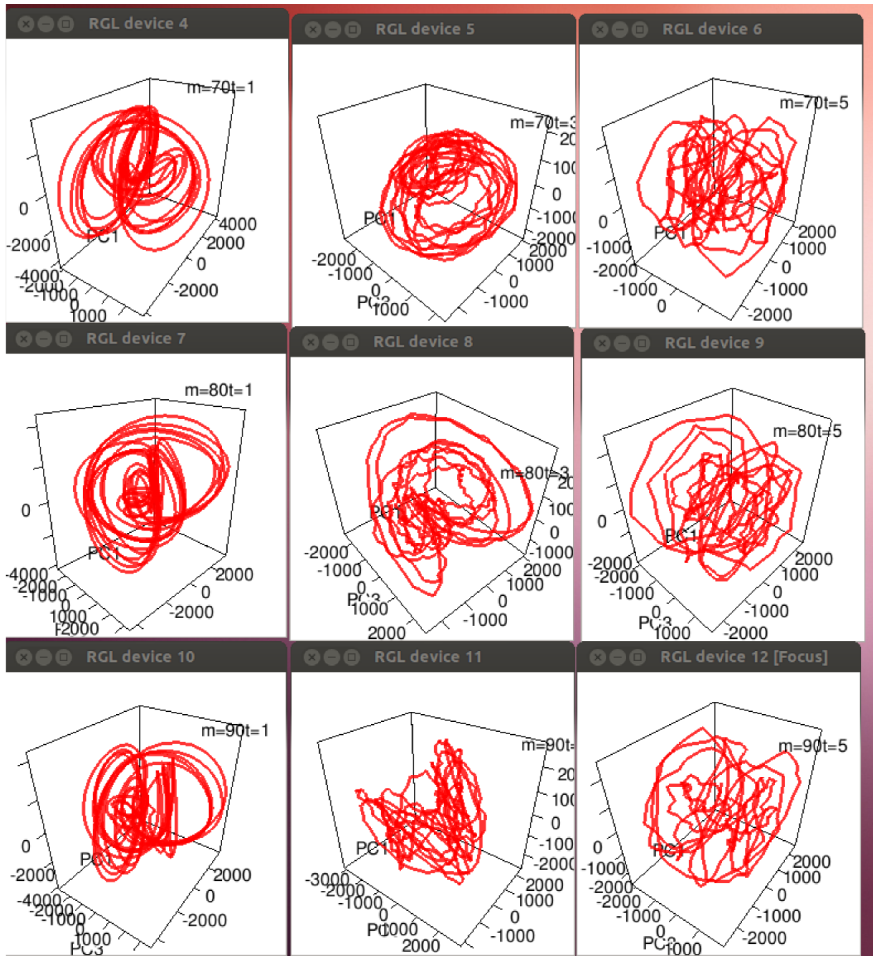
RSS for Feet Pattern 2
Participan 0 (Woman)- IMU1 GYR Z



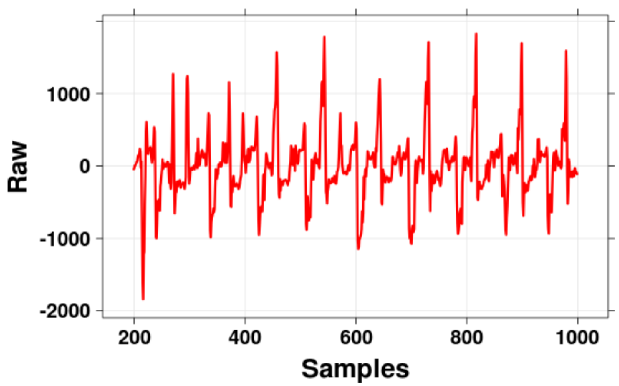


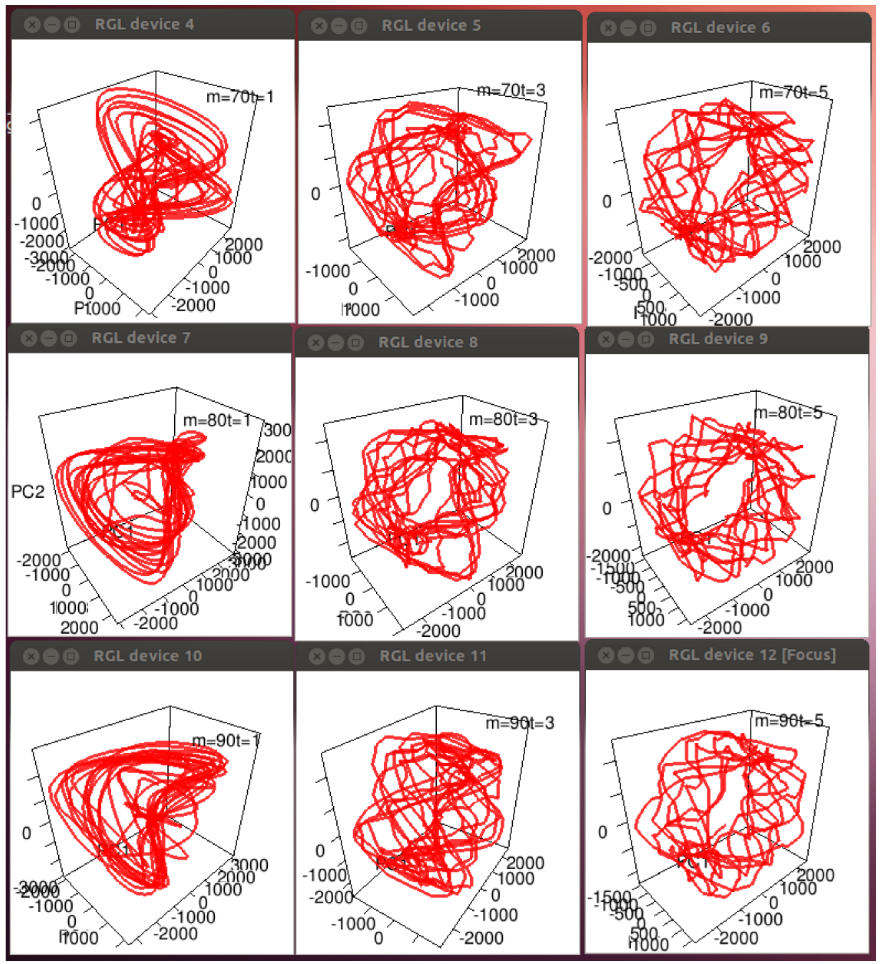
RSS for Feet Pattern 2
Participan 1 (Woman) - IMU1 GYR Z



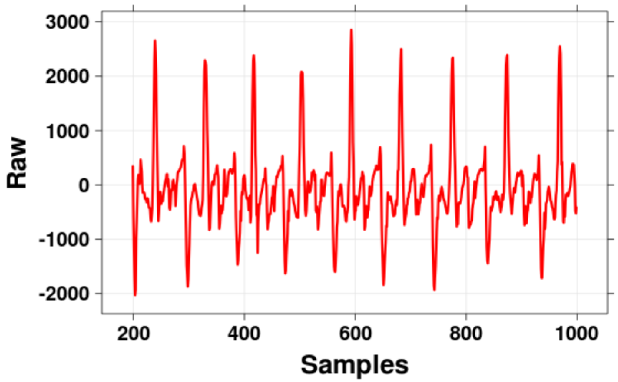


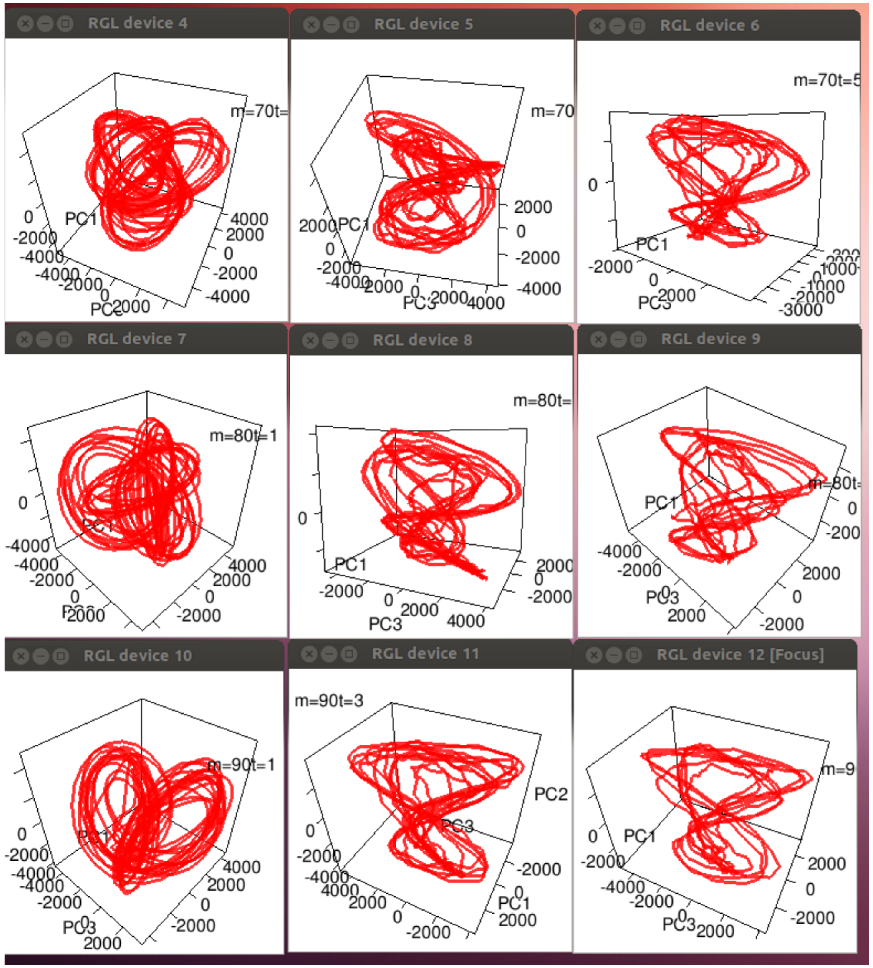
RSS for Feet Pattern 2
Participan 2 (Man) - IMU1 GYR Z



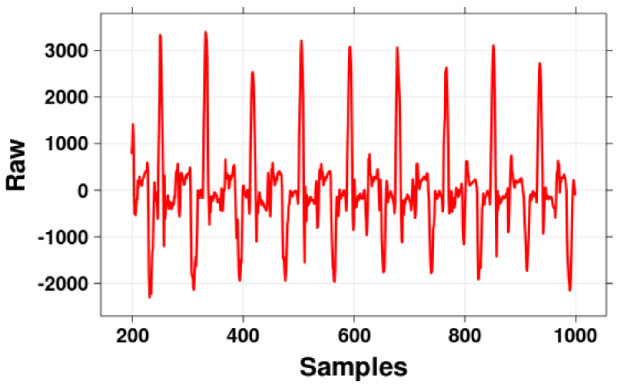


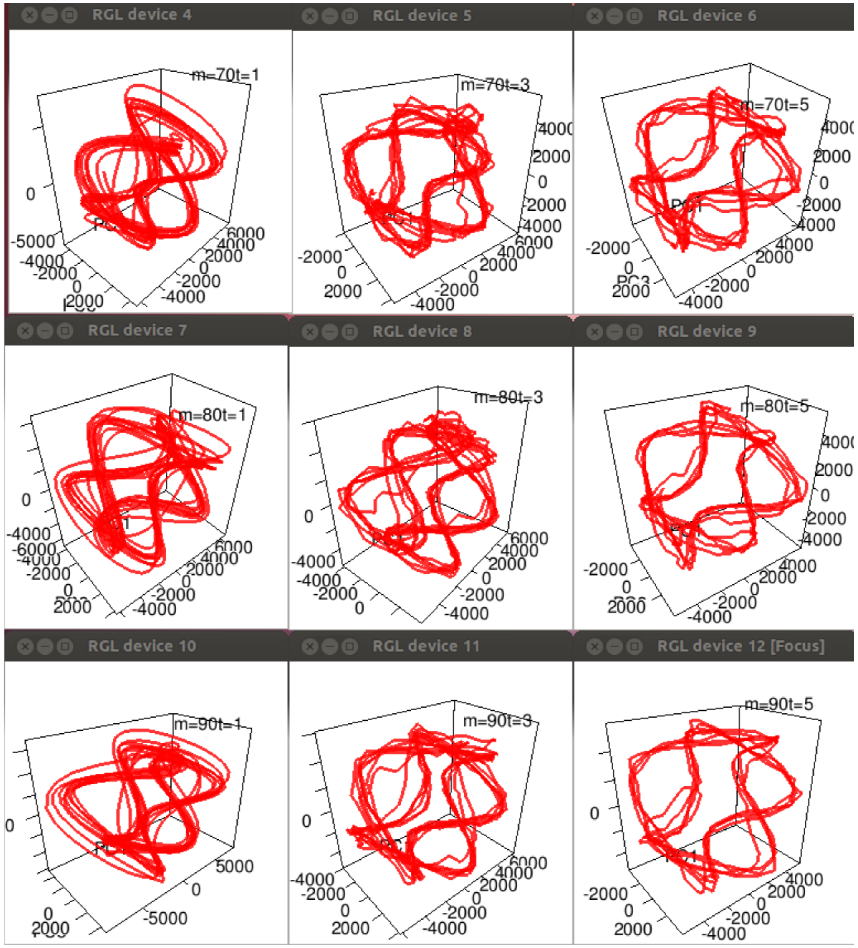
RSS for Feet Pattern 2
Participan 3 (Man) - IMU1 GYR Z



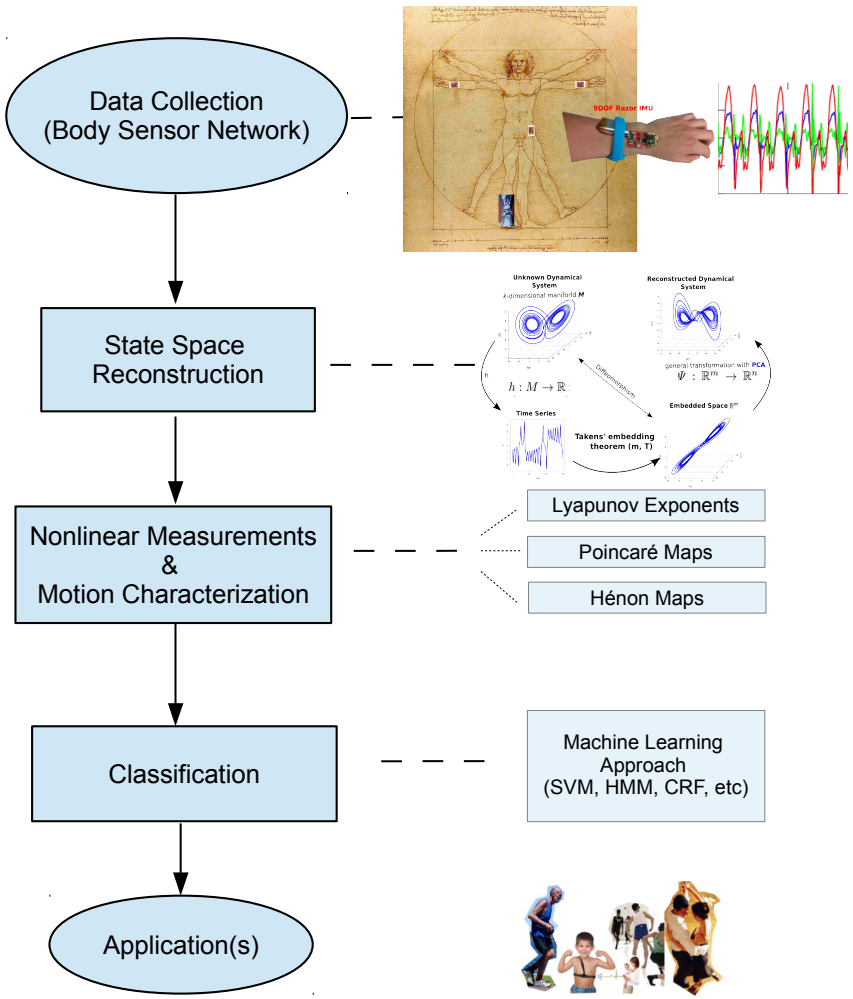


RSS for Pattern 2
Participan 4 (Man) - IMU1 GYR Z





PhD Framework



QUESTIONS?

Pérez-Xochicale Miguel Angel
E-Mail: perez.xochicale@gmail.com
Homepage: https://sites.google.com/site/perezxochicale/

A Nonlinear Dynamics Approach to Human Activity Recognition Using Inertial Sensors

Pérez-Xochicale Miguel Angel

Internal Research Conference Presentation
EECE School
10th March 2015