Neurociencia de Sistemas

- Clase 1. Introducción
- Clase 2. Registros extracelulares y Spike sorting.
- Clase 3. Procesado de información visual.
- Clase 4. Percepción y memoria.
- Clase 5. Decodificación – Teoría de la información.
- Clase 6. Electroencefalografía – Análisis de tiempo-frecuencia y Wavelets.
- Clase 7. Potenciales evocados – Análisis de ensayo único.
- Clase 8. Dinámica no-lineal – Sincronización.

CENTRE FOR
Systems Neuroscience

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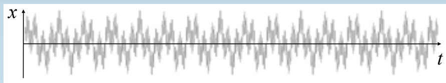
Slides

https://www.df.uba.ar/es/academica/programa-de-profesores-visitantes

Basic linear analysis



- ✓Distribution
- ✓Mean
- ✓Variance
- ✓Stationarity

✓Fourier Transform

$$X(t) = \int_{-\infty}^{\infty} x(t)\, e^{-i\omega t}\, dt \equiv \langle x(t), e^{-i\omega t} \rangle$$

Chaos and non-linear analysis

- ✓It may give more information
- ✓Is not just limited to chaotic systems
- ✓It is cool!

- ✓More complex
- ✓Interpretations are more difficult
- ✓Very easy to make pitfalls!!!

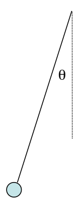
Phase space representation

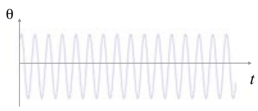
$$\theta = A\cos(\omega t + \phi)$$

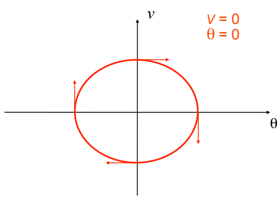
$$\ddot{\theta} + \omega^2\theta = 0$$

$$\ddot{\theta} + \omega^2 \sin\theta = 0$$

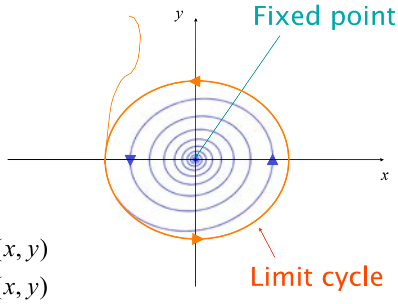
$$\dot{\theta} = v$$
$$\dot{v} = -\omega^2 \sin\theta$$





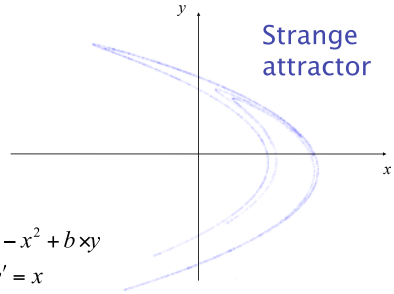


Attractors



$$\dot{x} = f(x, y)$$
$$\dot{y} = g(x, y)$$

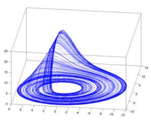
Attractors



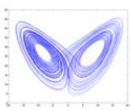
$$x' = 1.4 - x^2 + b \times y$$
$$y' = x$$

Toy models

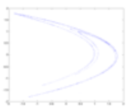
✓ Rossler
$$\begin{cases} \dot{x} = y + z \\ \dot{y} = x + 0.2\,y \\ \dot{z} = 0.2 + z(x - 5.7) \end{cases}$$



✓ Lorenz
$$\begin{cases} \dot{x} = 10(-x + y) \\ \dot{y} = 28x - y - x\,z \\ \dot{z} = x\,y - 2.66\,z \end{cases}$$

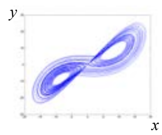


✓ Henon
$$\begin{cases} x' = 1.4 - x^2 + b \times y \\ y' = x \end{cases}$$

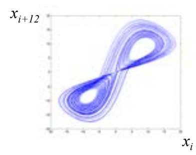


Time delay embedding

$$\begin{cases} \dot{x} = 10(-x + y) \\ \dot{y} = 28x - y - x\,z \\ \dot{z} = x\,y - 2.66\,z \end{cases}$$

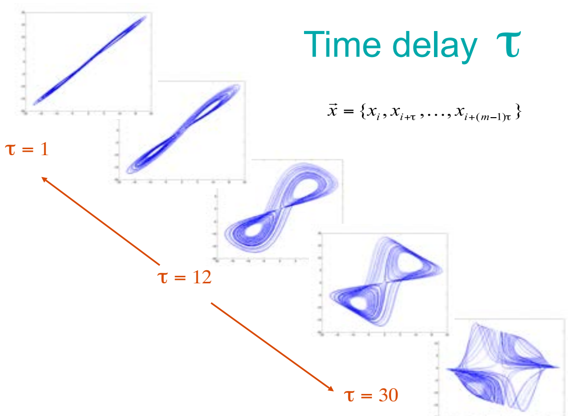


$$\vec{x} = \{x_i, x_{i+\tau}, \ldots, x_{i+(m-1)\tau}\}$$



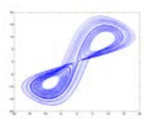
Time delay τ

$$\vec{x} = \{x_i, x_{i+\tau}, \ldots, x_{i+(m-1)\tau}\}$$



Embedding dimension *m*

$$\vec{x} = \{x_i, x_{i+\tau}, \ldots, x_{i+(m-1)\tau}\}$$

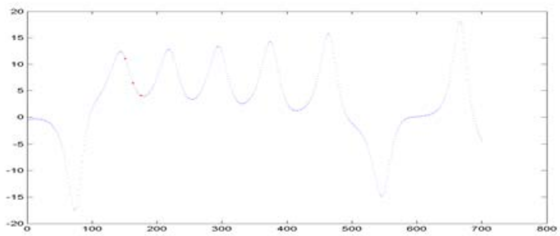


✓ Increase until unfold the attractor

Embedding parameters

$$\vec{x} = \{x_i, x_{i+\tau}, \ldots, x_{i+(m-1)\tau}\}$$

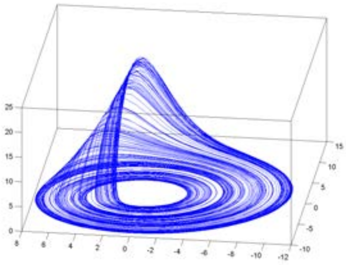
τ: time delay
m: embedding dimension



✓ Rather than τ or *m* alone, what matters is ***m*τ**

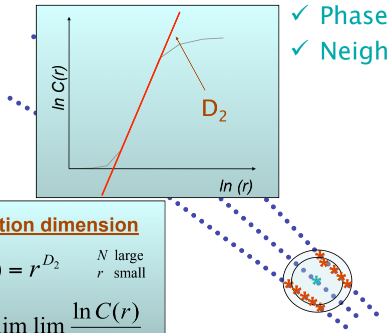
Nonlinear measures

✓ Phase space



Nonlinear measures

✓ Phase space
✓ Neighbors



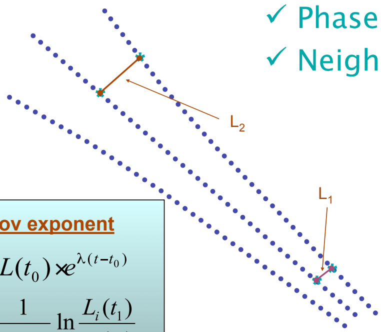
Correlation dimension

$$C(r) = r^{D_2} \quad \begin{matrix} N \text{ large} \\ r \text{ small} \end{matrix}$$

$$D_2 = \lim_{r \to o} \lim_{N \to \infty} \frac{\ln C(r)}{\ln r}$$

Nonlinear measures

✓ Phase space
✓ Neighbors



Lyapunov exponent

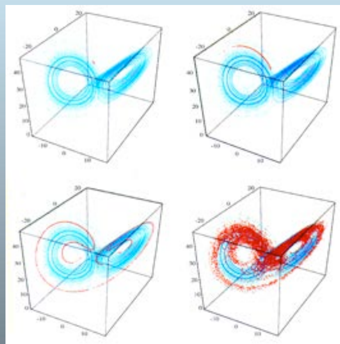
$$L(t) = L(t_0) \times e^{\lambda(t-t_0)}$$

$$\lambda_i = \frac{1}{t_1 - t_0} \ln \frac{L_i(t_1)}{L_i(t_0)}$$

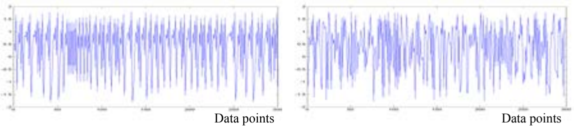
Chaotic attractors

- ✓ Fractal dimension
  - ✓ self-similarity
- ✓ At least 1 positive lyapunov exponent
  - ✓ sensitivity to initial conditions

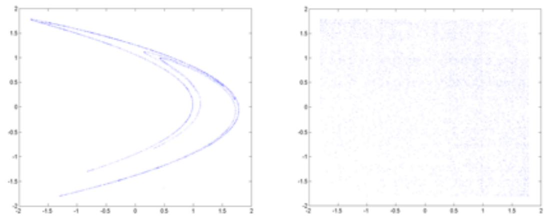
Sensitivity to initial conditions



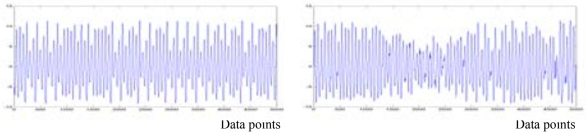
Are they different?



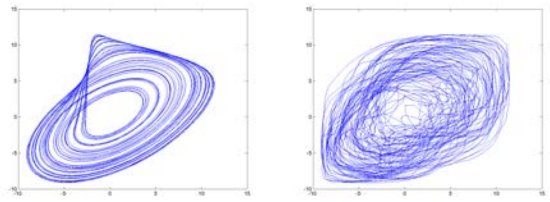
Phase space reconstruction



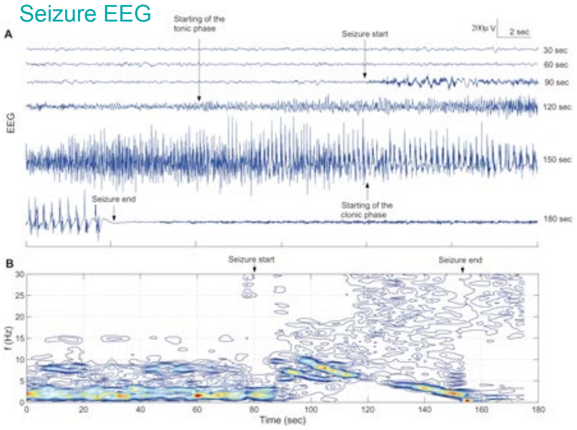
Are they different?



Phase space reconstruction



Seizure EEG



A personal approach to non-linear analysis…

- ✓ Visual inspection
- ✓ Stationarity
- ✓ Basic linear analysis (Power spectrum)
- ✓ Finding of a good embedding (m,τ)
- ✓ Setting of parameters (e.g. nr. Nearest neighbors)
- ✓ Use of the Non-linear method
- ✓ Does it give more information?
- ✓ Carefull with the interpretation

Synchronization

Why synchronization?

In the EEG:

- Communication between distant brain areas.
- Functional connectivity.
- Quantify different brain states.
- Basic mechanism of epilepsy.

At single cell level:

- Bottom up processes (in vision).
- Alternative coding (instead of firing rates).

Linear measures of synchronization

- Cross-correlation

$$c_{xy}(\tau) = \frac{1}{N-\tau} \sum_i \frac{x_i - \bar{x}}{\sigma_x} \times \frac{y_{i+\tau} - \bar{y}}{\sigma_y}$$

- Coherence

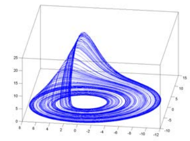
$$C_{xy}(\omega) = (\mathcal{F}x)(\omega)\,(\mathcal{F}y)^*(\omega)$$

$$\Gamma_{xy}(\omega) = \frac{\left|\langle C_{xy}(\omega)\rangle\right|}{\sqrt{\langle C_{xx}(\omega)\rangle}\sqrt{\langle C_{yy}(\omega)\rangle}}$$

Lorenz driven by a Rossler

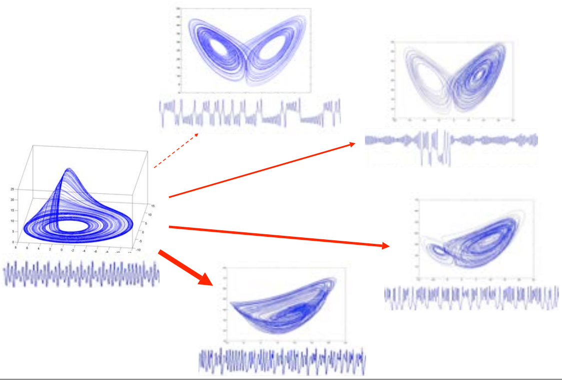
$$\begin{cases} \dot{x}_1 = x_2 + x_3 \\ \dot{x}_2 = x_1 + 0.2x_2 \\ \dot{x}_3 = 0.2 + x_3(x_1 - 5.7) \end{cases}$$

$$\begin{cases} \dot{y}_1 = 10(-y_1 + y_2) \\ \dot{y}_2 = 28y_1 - y_2 - y_1 y_3 + Cx_2^{\,2} \\ \dot{y}_3 = y_1 y_2 - 2.66\, y_3 \end{cases}$$

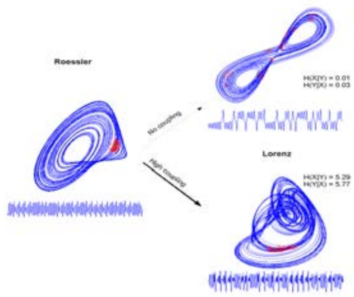


Coupling

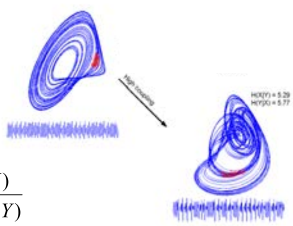
Lorenz driven by a Rossler



Non-linear interdependencies



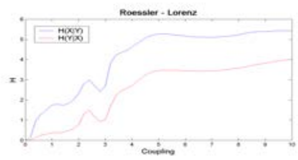
Equations

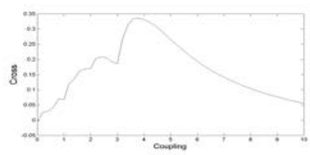


$$S^{(k)}(X|Y) = \frac{1}{N} \sum_{n=1}^{N} \frac{R_n^{(k)}(X)}{R_n^{(k)}(X|Y)}$$

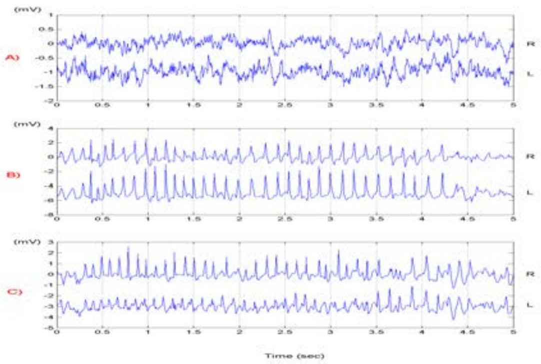
$$H^{(k)}(X|Y) = \frac{1}{N} \sum_{n=1}^{N} \log \frac{R_n(X)}{R_n^{(k)}(X|Y)}$$

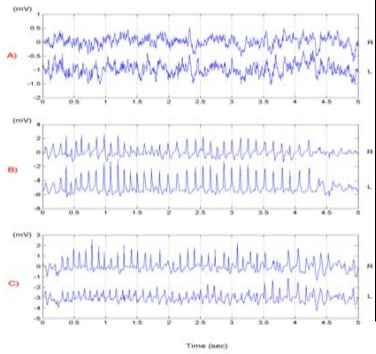
Synchronization of the coupled Roessler – Lorenz systems





Which one is more synchronized?

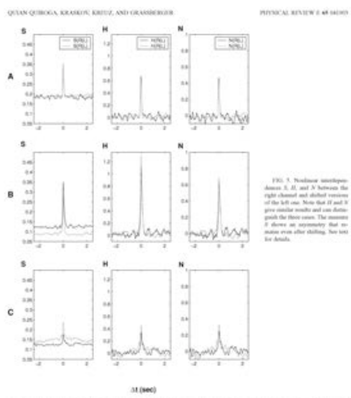




H	γ_H	γ_W	c_{XY}	Γ_{XY}	MI
0.64	0.59	0.71	0.70	0.88	?
1.20	0.71	0.80	0.79	0.86	?
0.39	0.48	0.48	0.42	0.40	?

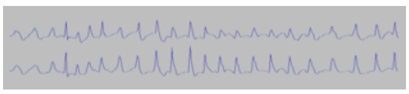
Phys Rev E, 65: 041903 (2002)

Time-shifted surrogates

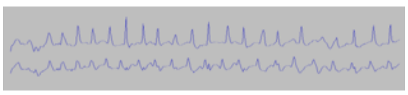


Phys Rev E, 66: 041904 (2002)

Key idea: given 2 signals, look for quasi-synchronous events.

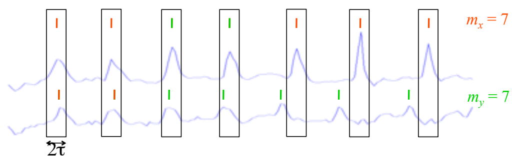


High Synchro



Low Synchro

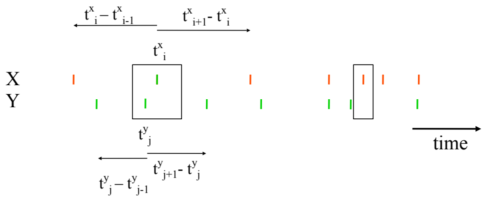
Outline of the method:



1. Detect events (e.g. local maxima)
2. Draw boxes of length 2τ around each event in X
3. Define: $C^\tau(Y|X)$: # X_i appears before Y_j
   $C^\tau(X|Y)$: # Y_j appears before X_i
4. Define: $Q_\tau = \frac{C^\tau(Y|X) + C^\tau(X|Y)}{\sqrt{m_x \times m_y}}$ $\quad q_\tau = \frac{C^\tau(Y|X) - C^\tau(X|Y)}{\sqrt{m_x \times m_y}}$

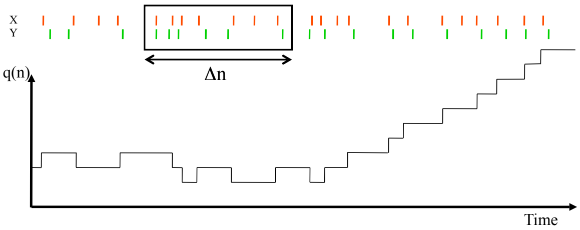
Synchronization — Time asymmetry

Automatic (and local) window τ



$$\tau_{ij} = \min\{t^x_{i+1} - t^x_i \,;\, t^x_i - t^x_{i-1} \,;\, t^y_{j+1} - t^y_j \,;\, t^y_j - t^y_{j-1}\} / 2$$

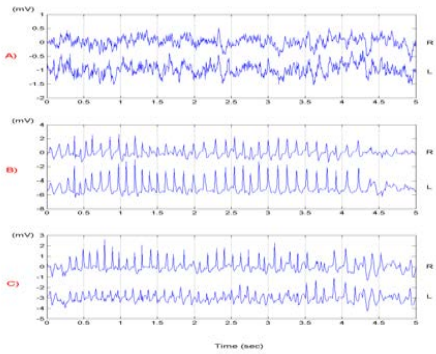
Time resolved asymmetry: $q(n) = c_n(y|x) - c_n(x|y)$



Time resolved synchronization: $Q(n) = c_n(y|x) + c_n(x|y)$

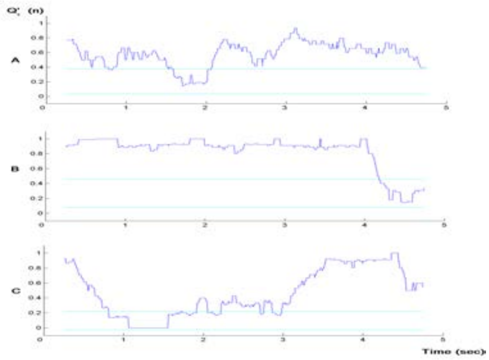
$$Q'(n) = \frac{Q(n) - Q(n - \Delta n)}{\sqrt{\Delta n_x \cdot \Delta n_y}}$$

Application to rat EEGs

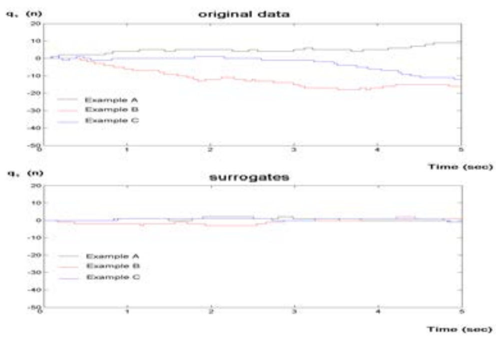


	$Q_{\tau=2}$	$Q^s_{\tau=2}$
A)	0.57	0.24
B)	0.80	0.29
C)	0.48	0.13

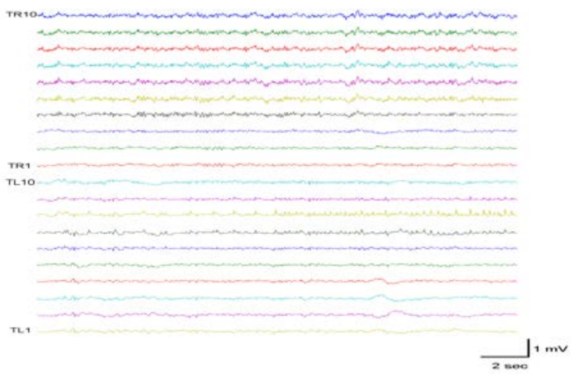
Time resolved synchronization

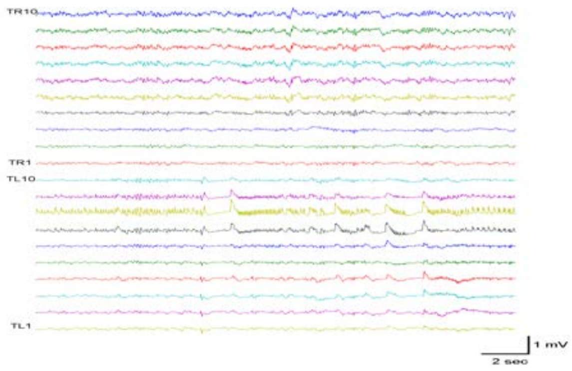


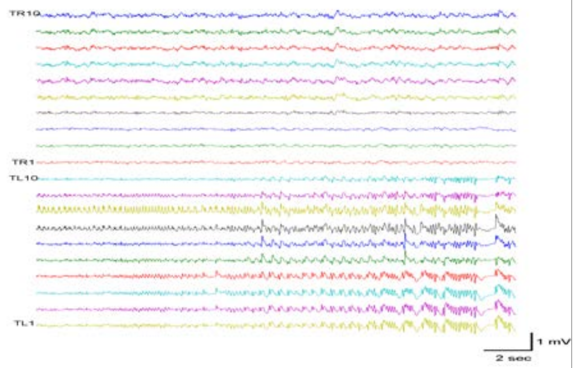
Delay asymmetry

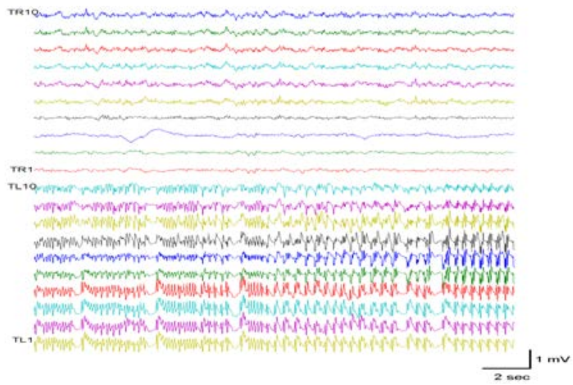


EEG of an epileptic patient

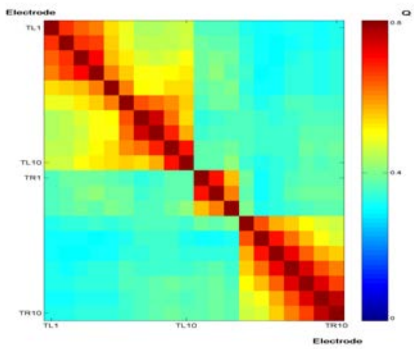




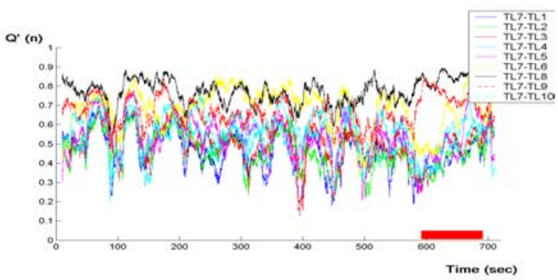




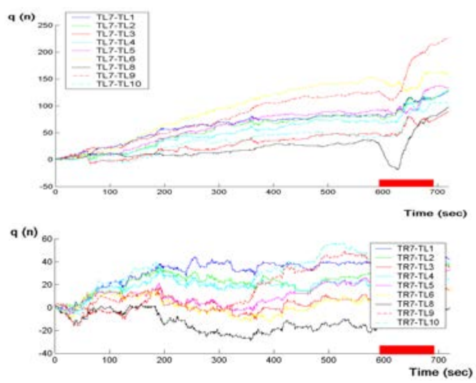
Synchronization



Time resolved synchronization



Delays



Clase 8. Dinámica no-lineal – Sincronización

Nonlinear multivariate analysis of neurophysiological signals.
Pereda E, Quian Quiroga R and Bhattacharya J
Progress in Neurobiology 77: 1-37; 2005.

Performance of different synchronization measures in real data: a case study on electroencephalographic signals.
Quian Quiroga R, Kraskov A, Kreuz T and Grassberger P
Phys. Rev. E, 65: 041903; 2002.

Event synchronization: a simple a fast method to measure synchronicity and time delay patterns.
Quian Quiroga R, Kreuz T and Grassberger P.
Phys. Rev. E, 66: 041904, 2002.

Learning driver-response relationships from synchronization patterns.
Quian Quiroga R, Arnhold J and Grassberger P.
Phys Rev. E, 61: 5142-5148; 2000. *(un ladrillo…)*

Nonlinear Time series analysis. Kantz and Schreiber *(biblia sobre métodos de caos para análisis de datos)*