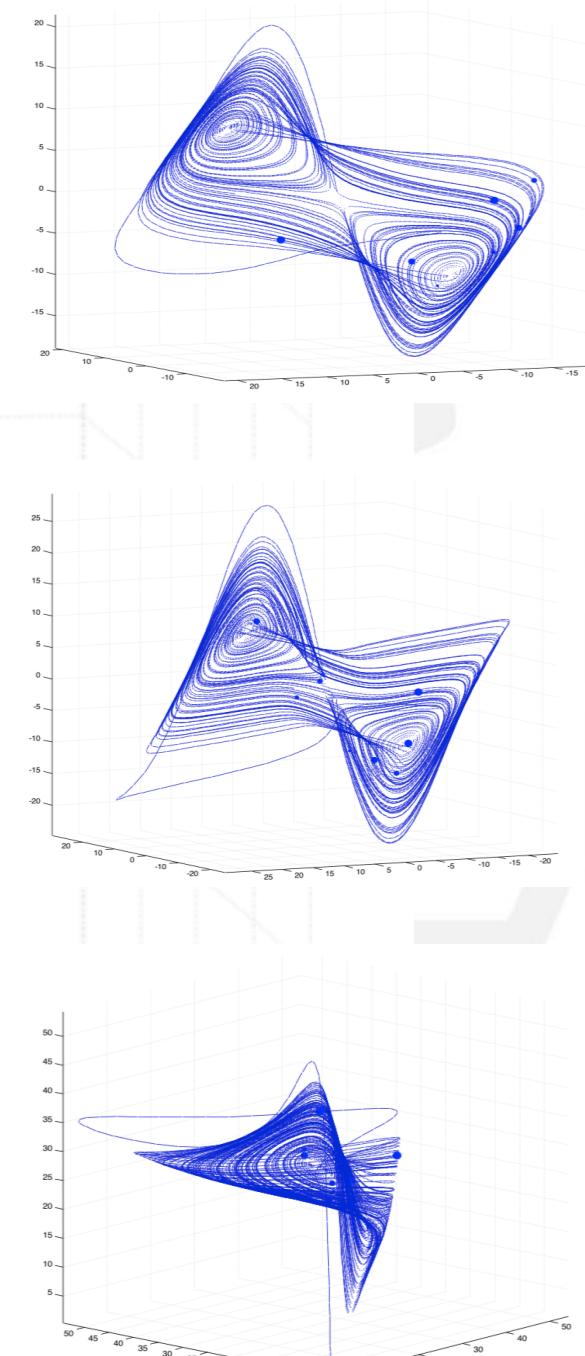
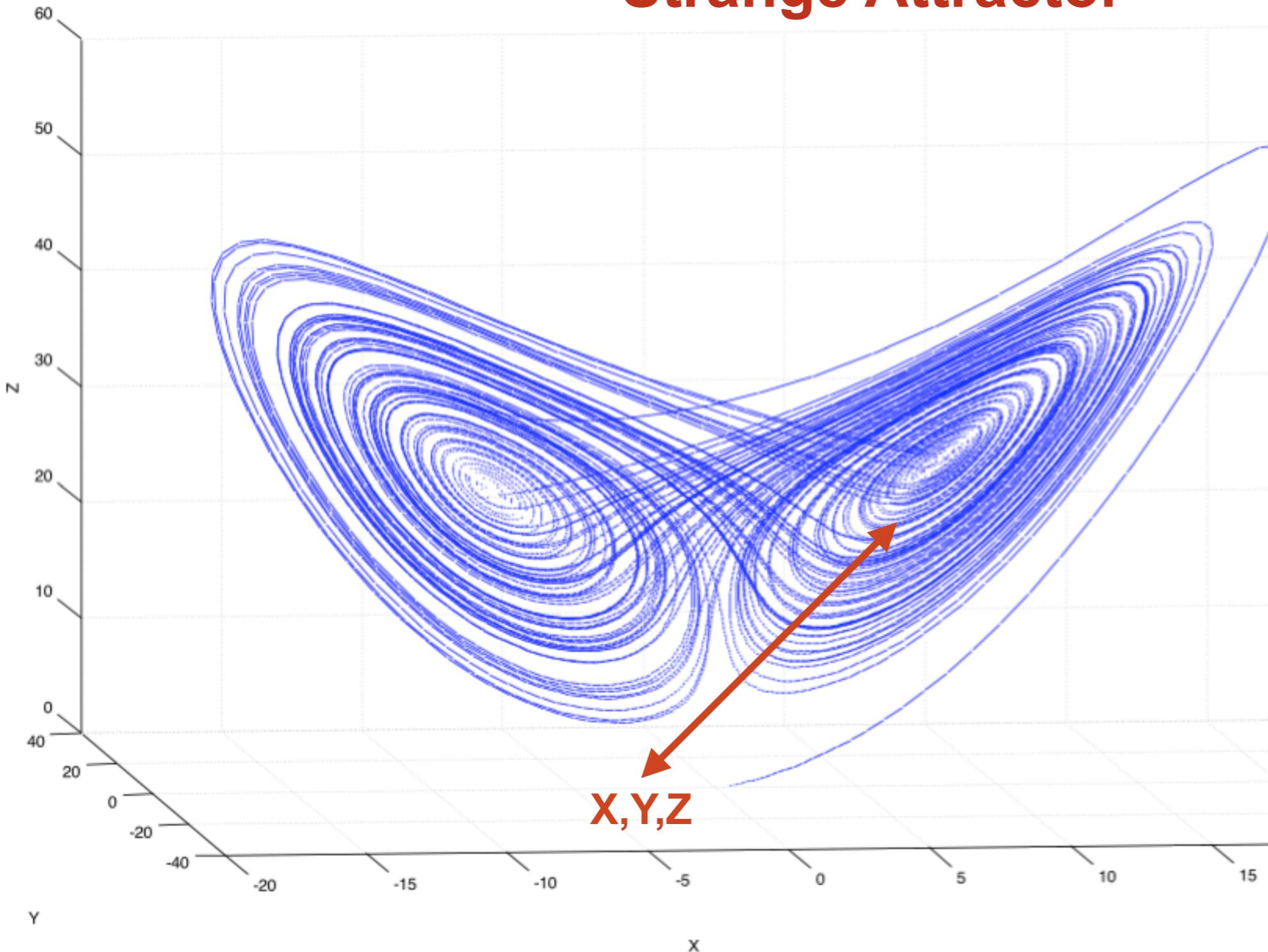
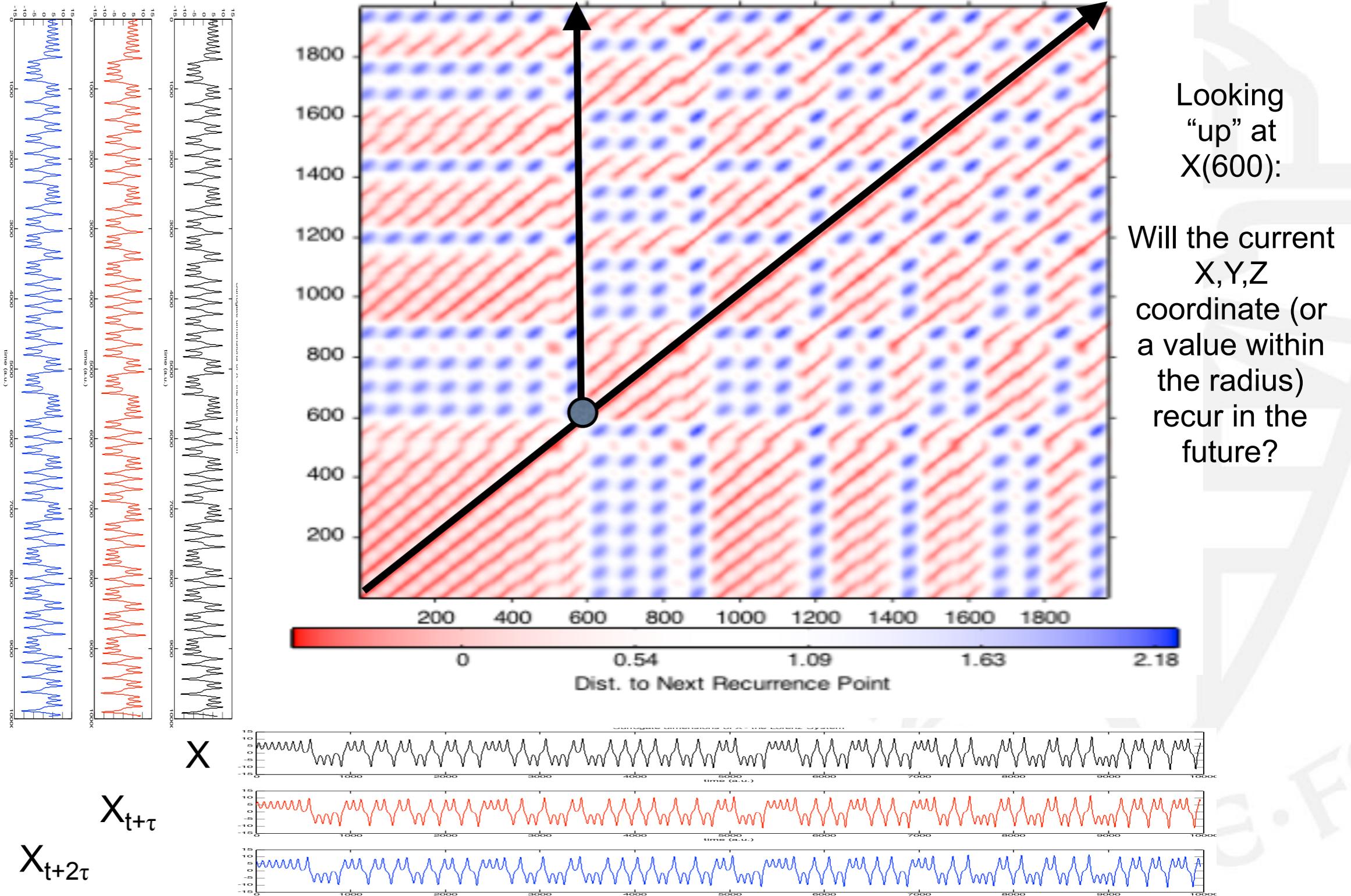


Lorenz system – X,Y,Z State space Strange Attractor

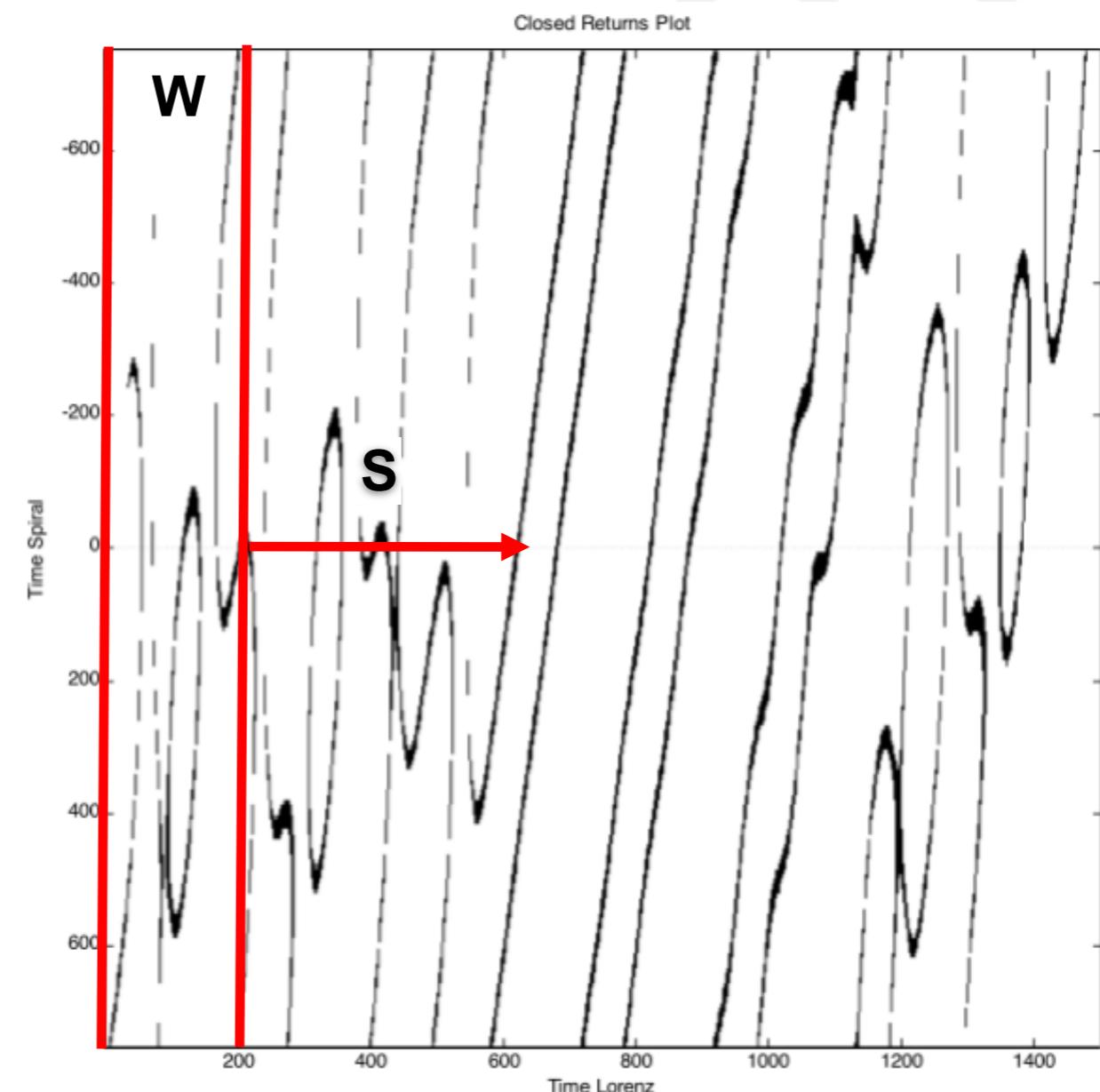
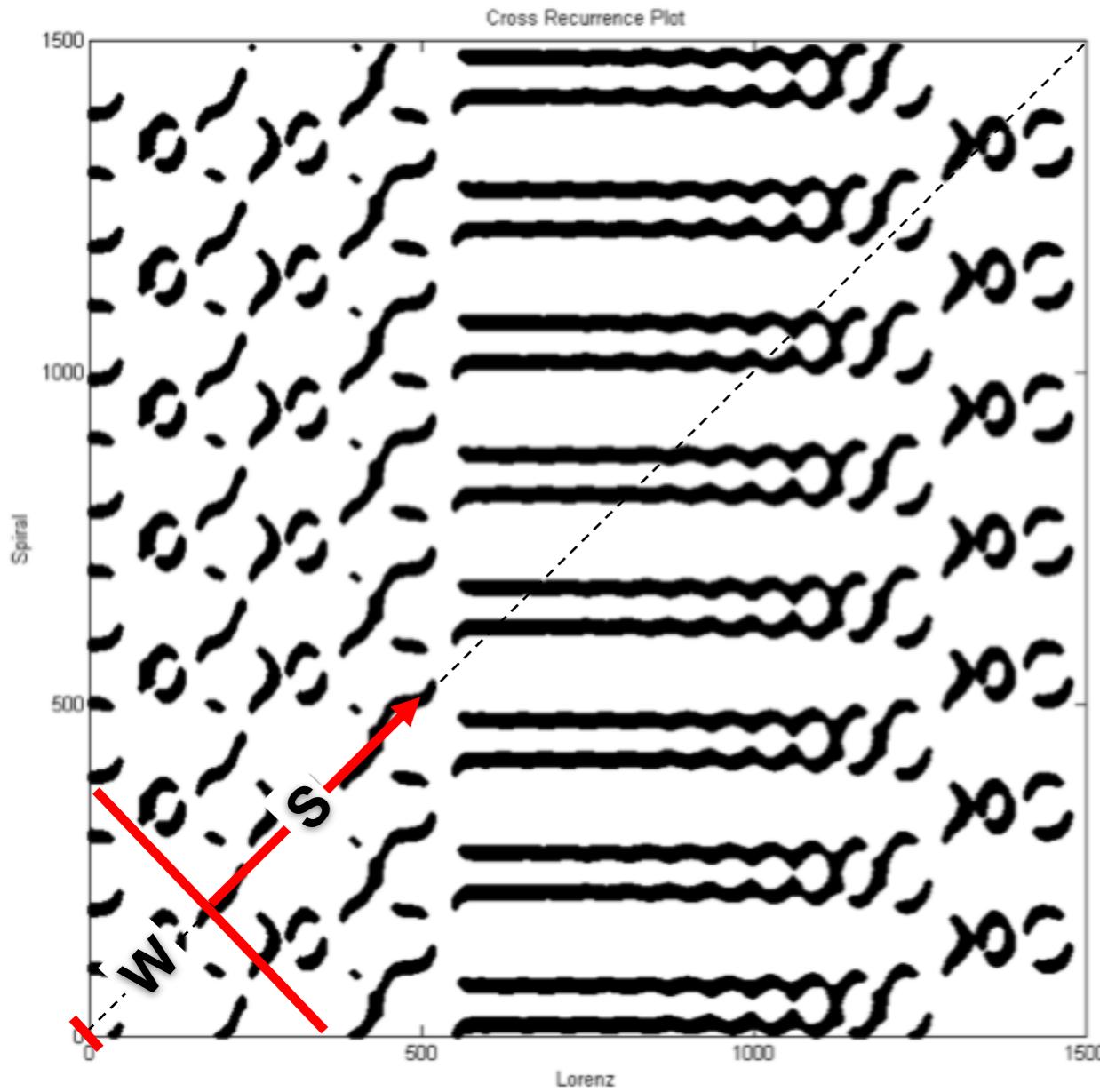


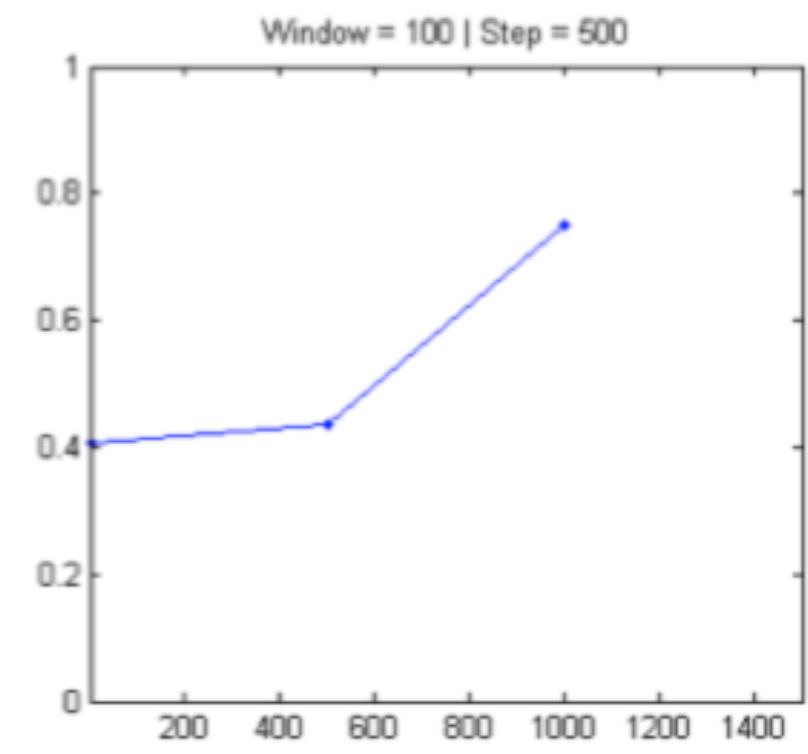
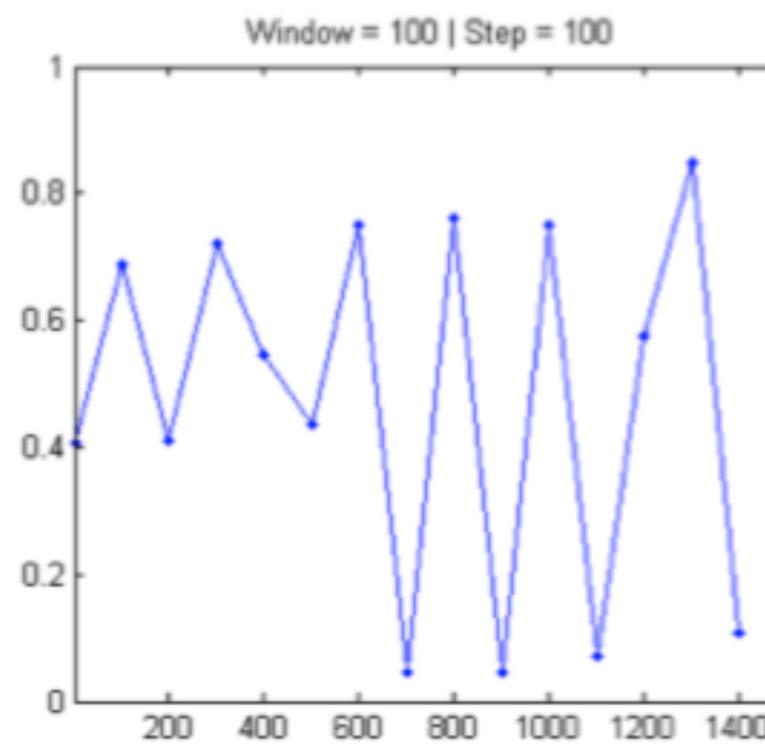
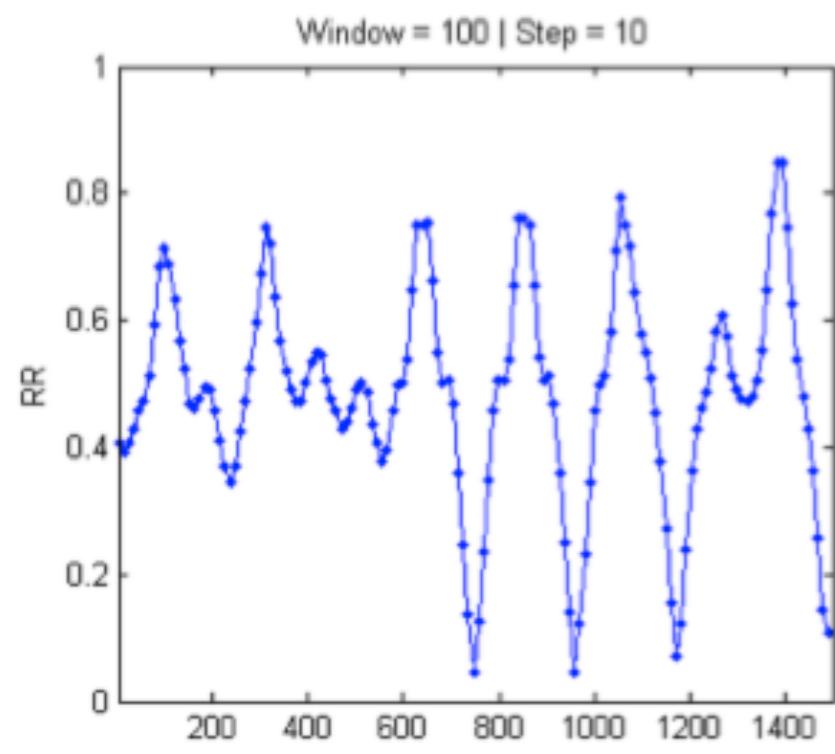
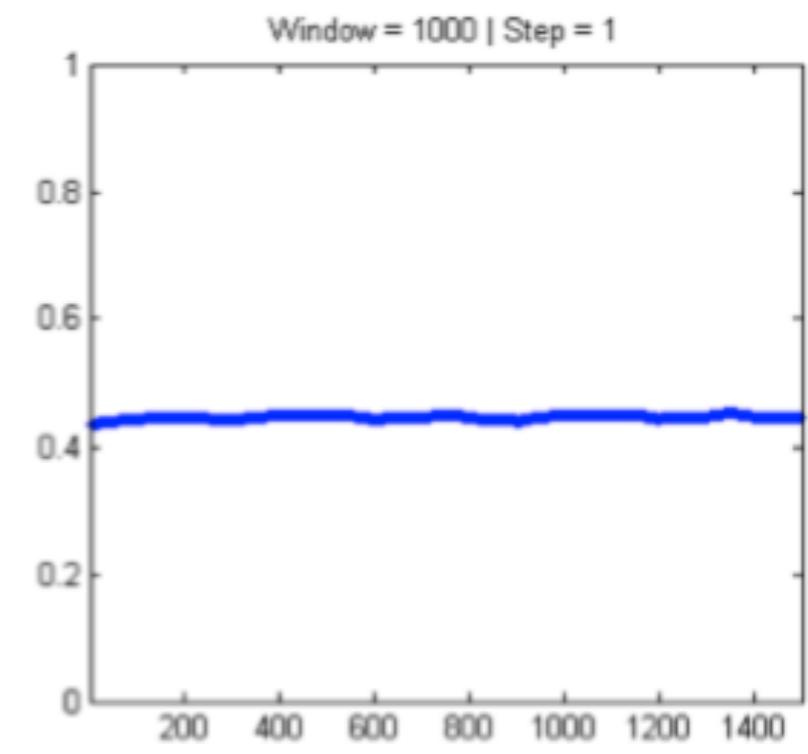
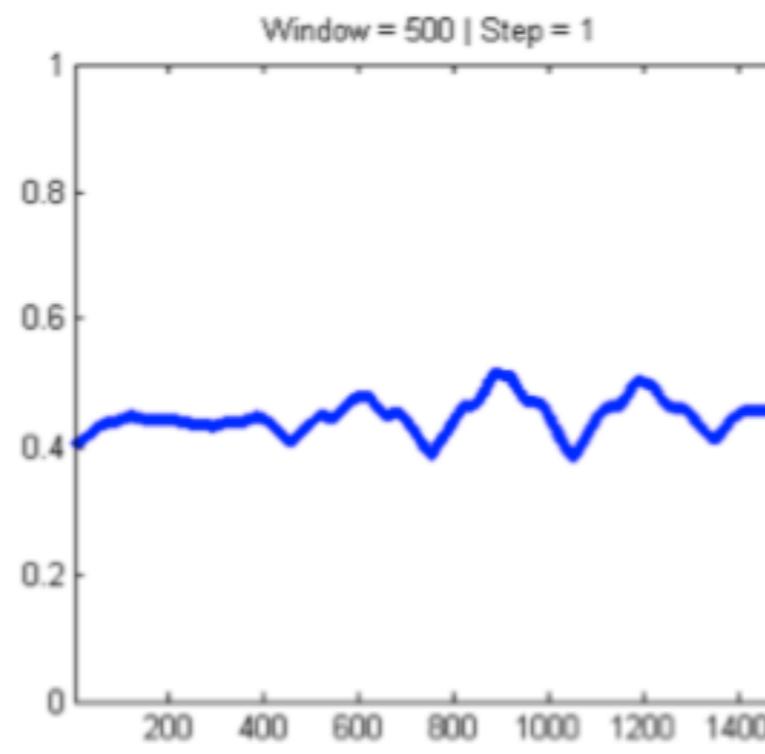
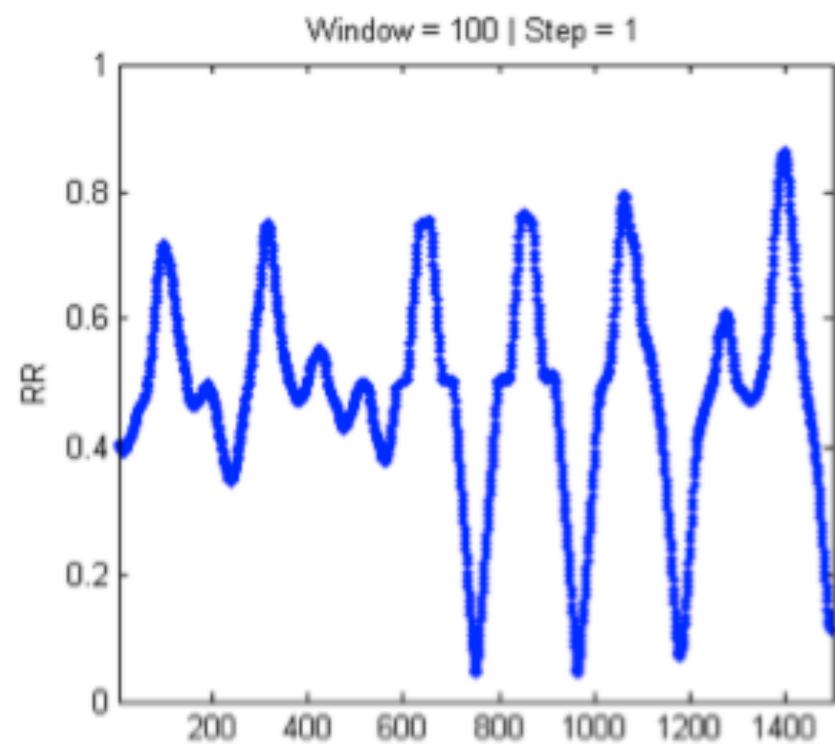
Recurrence Quantification



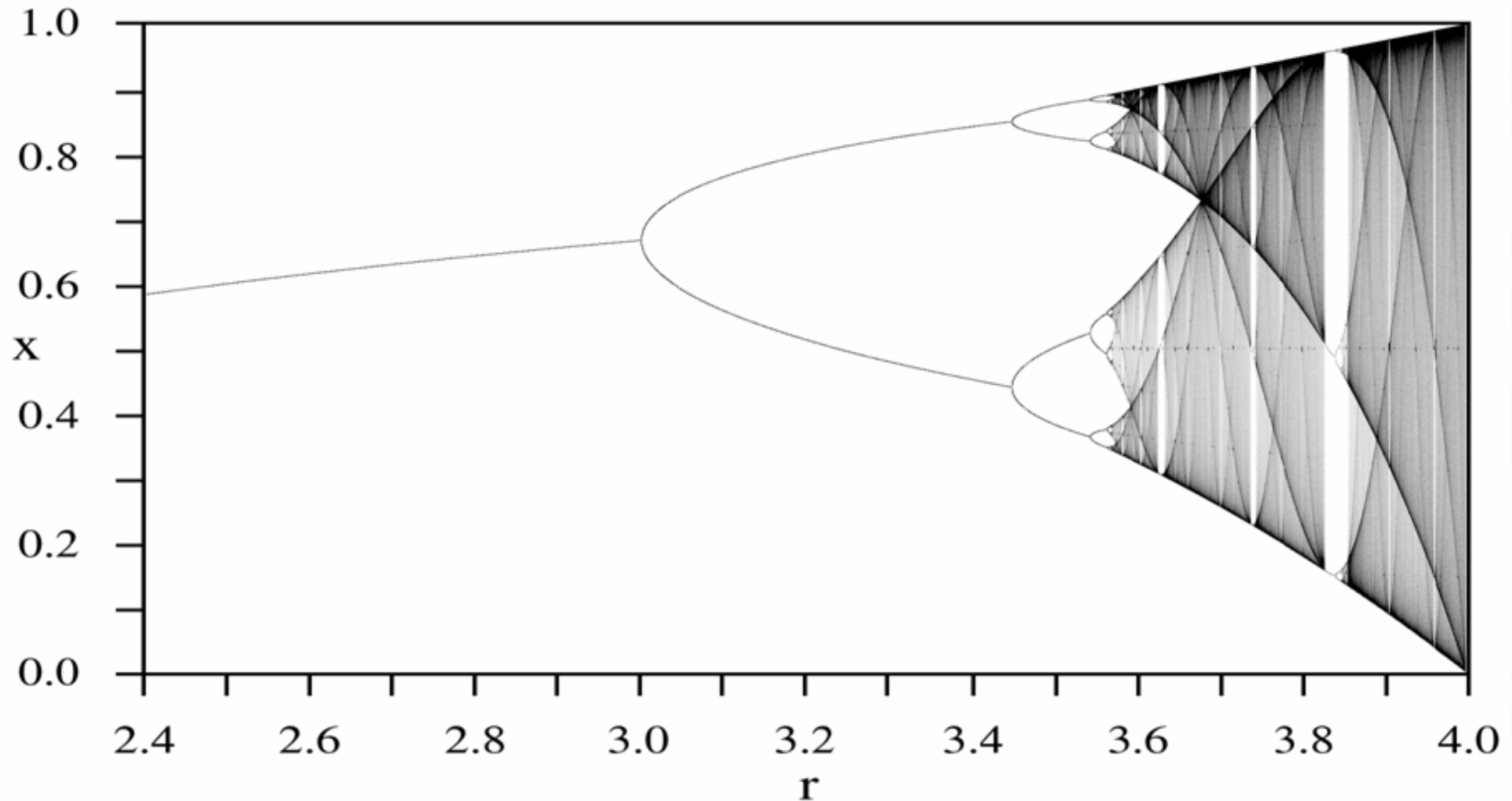
Lagged RQA

move a window of size W in S steps across LOI



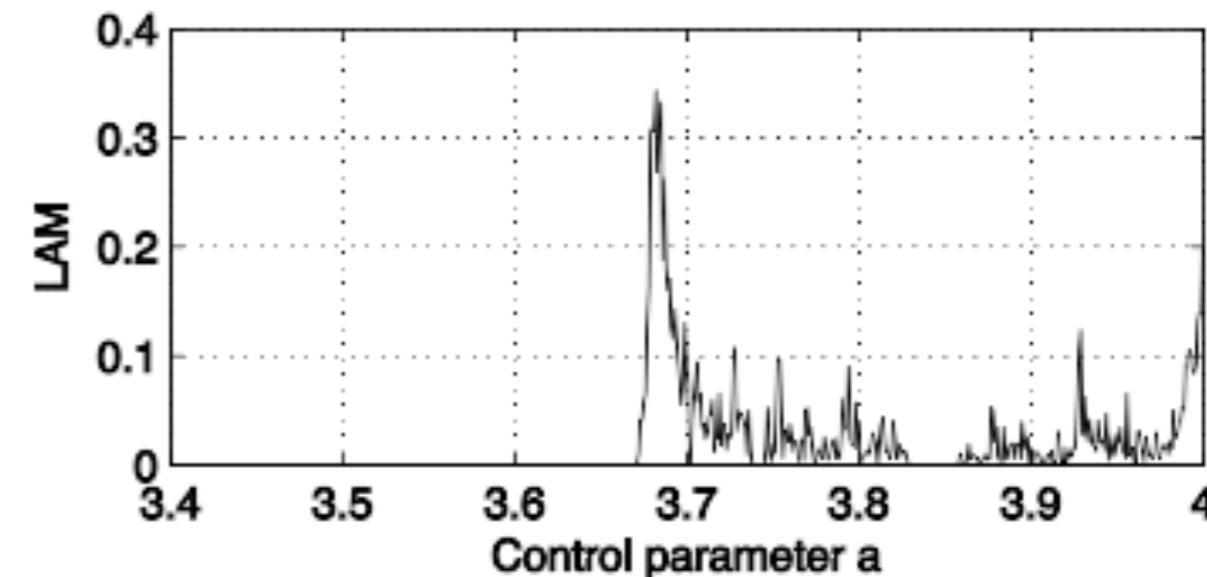
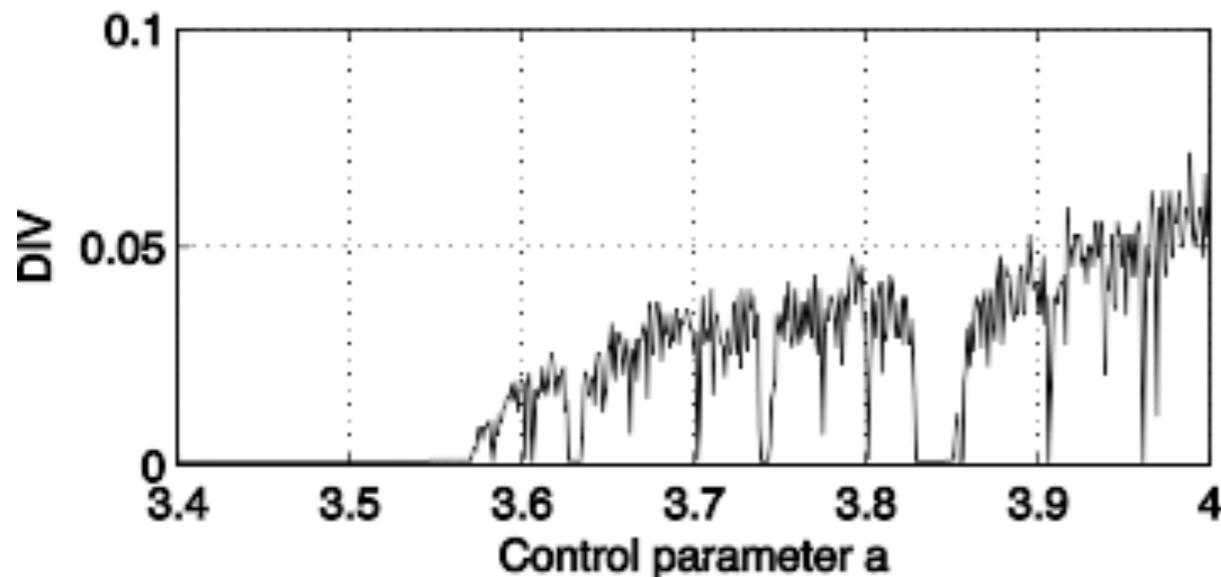
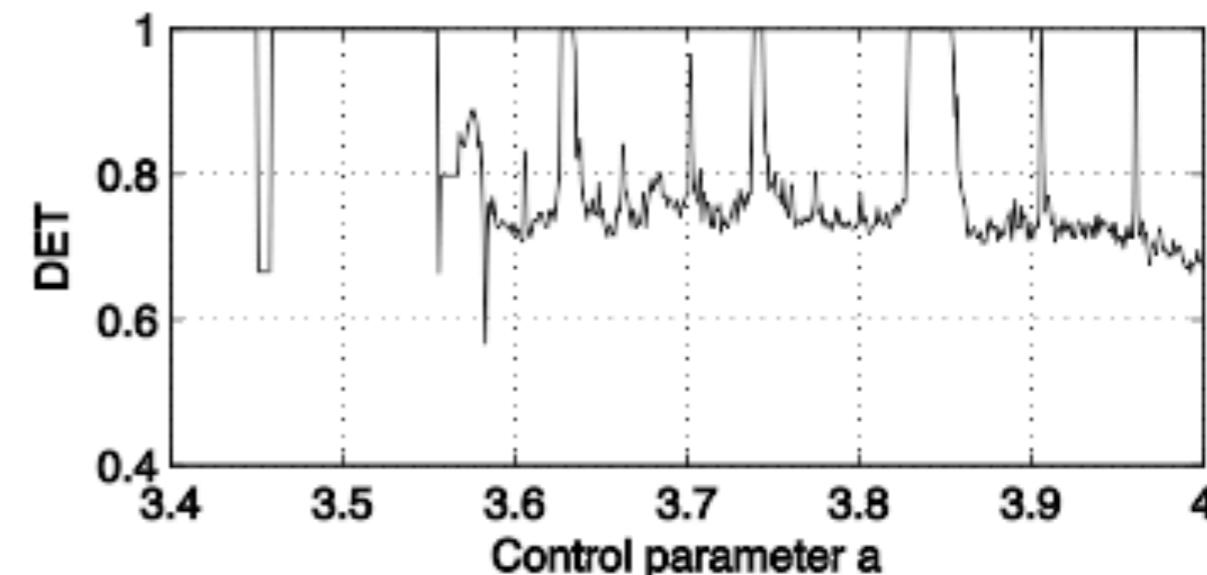
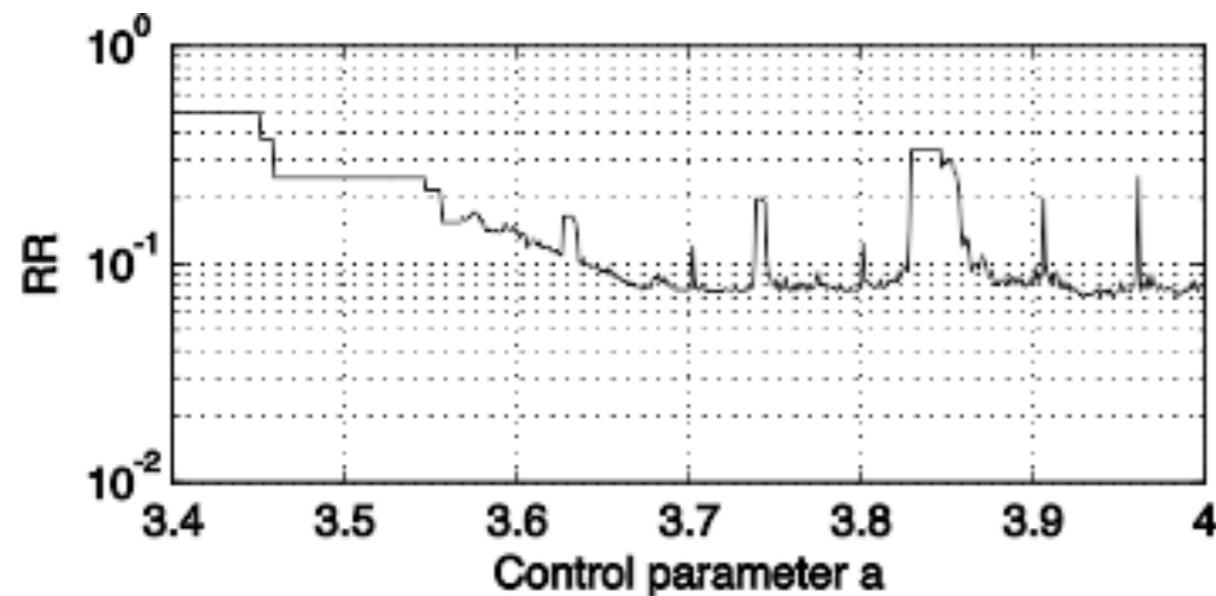


Logistic map – Transitions revealed by lagged RQA



Logistic map – Transitions revealed by lagged RQA

note: $a = r$ in bifurcation diagram on previous slide



Further reading

- The paper by Marwan et al in Physics Reports tells you everything you wanted to know... and more.



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N. Marwan et al. / Physics Reports 438 (2007) 237–329

Table 2

Comparison of RQA measures based on diagonal (DET , L and L_{\max}) and vertical structures (LAM , TT and V_{\max}) regarding periodic-chaos/chaos-periodic transitions (PC/CP), chaos–chaos transitions (band merging—BM and inner crisis—IC) and laminar states

Measure	PC/CP transitions	BM and IC	Laminar states
DET	Increases	—	—
L	Increases	—	—
L_{\max}	Increases	—	—
LAM	Drops to zero	—	Increases
TT	Drops to zero	Increases	Increases
V_{\max}	Drops to zero	Increases	Increases

Order Patterns Recurrence Plot

- Sort of “filter”: not recurrences of values, but order patterns

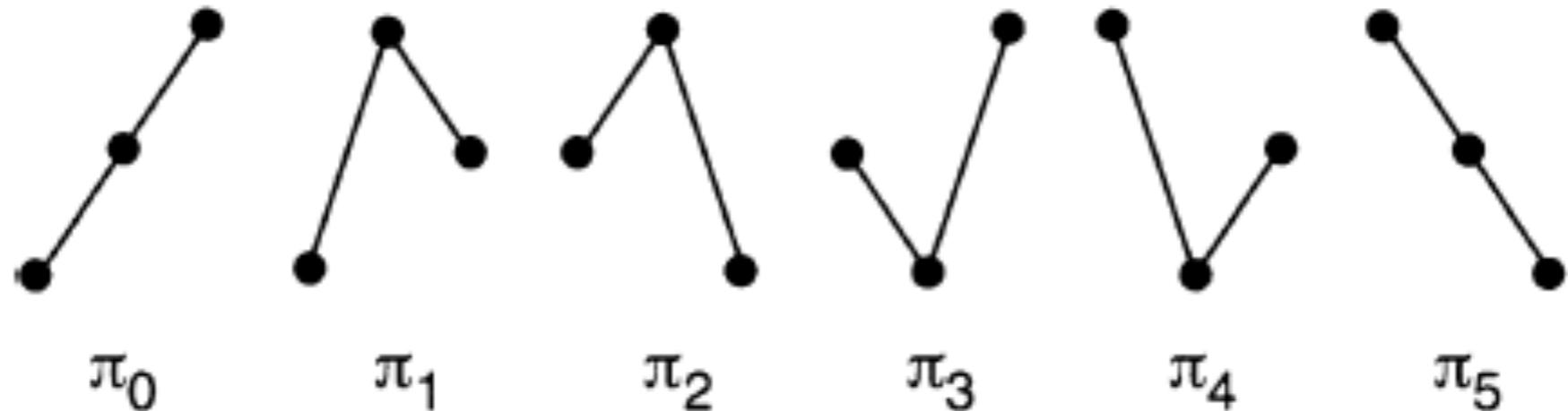
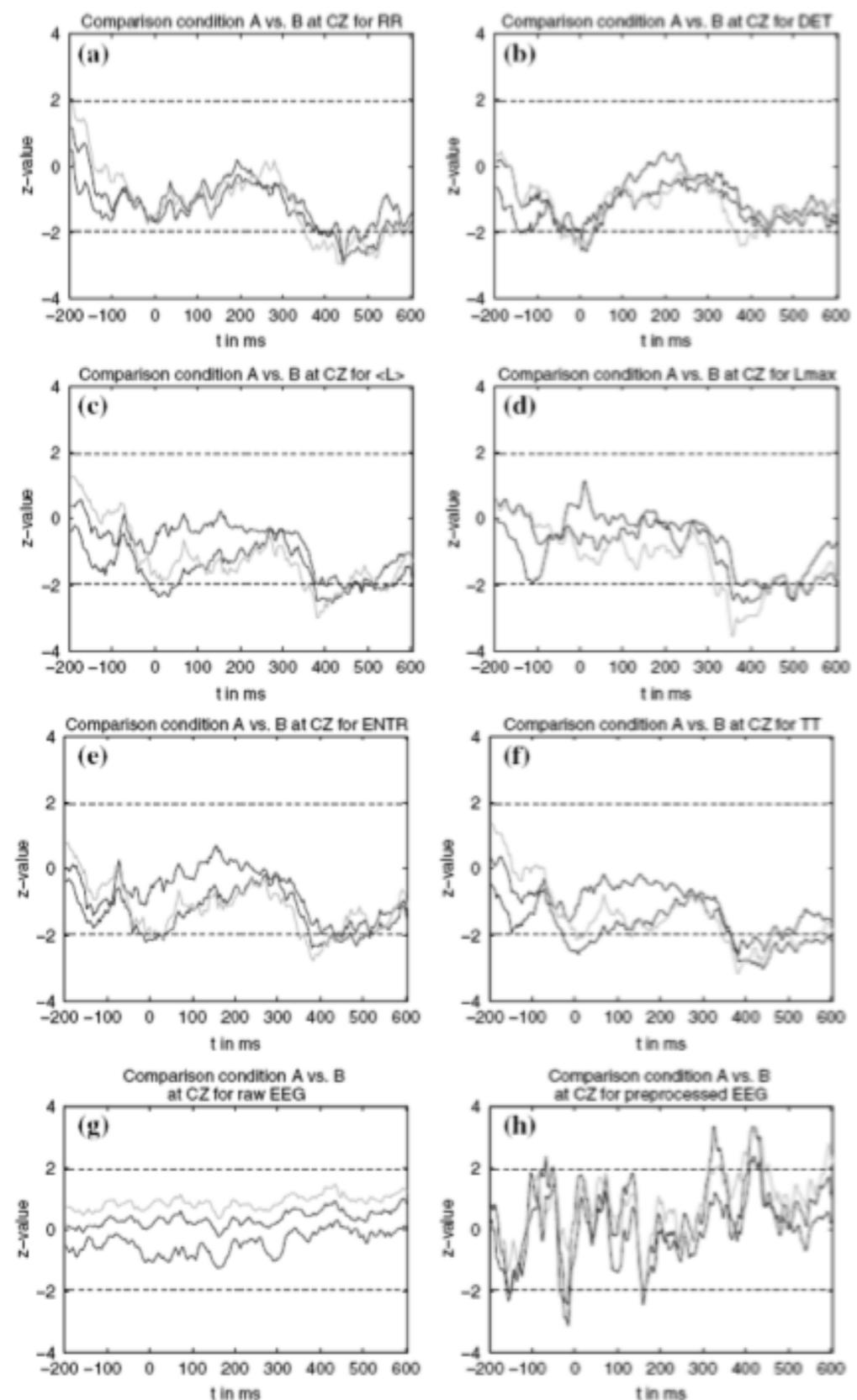
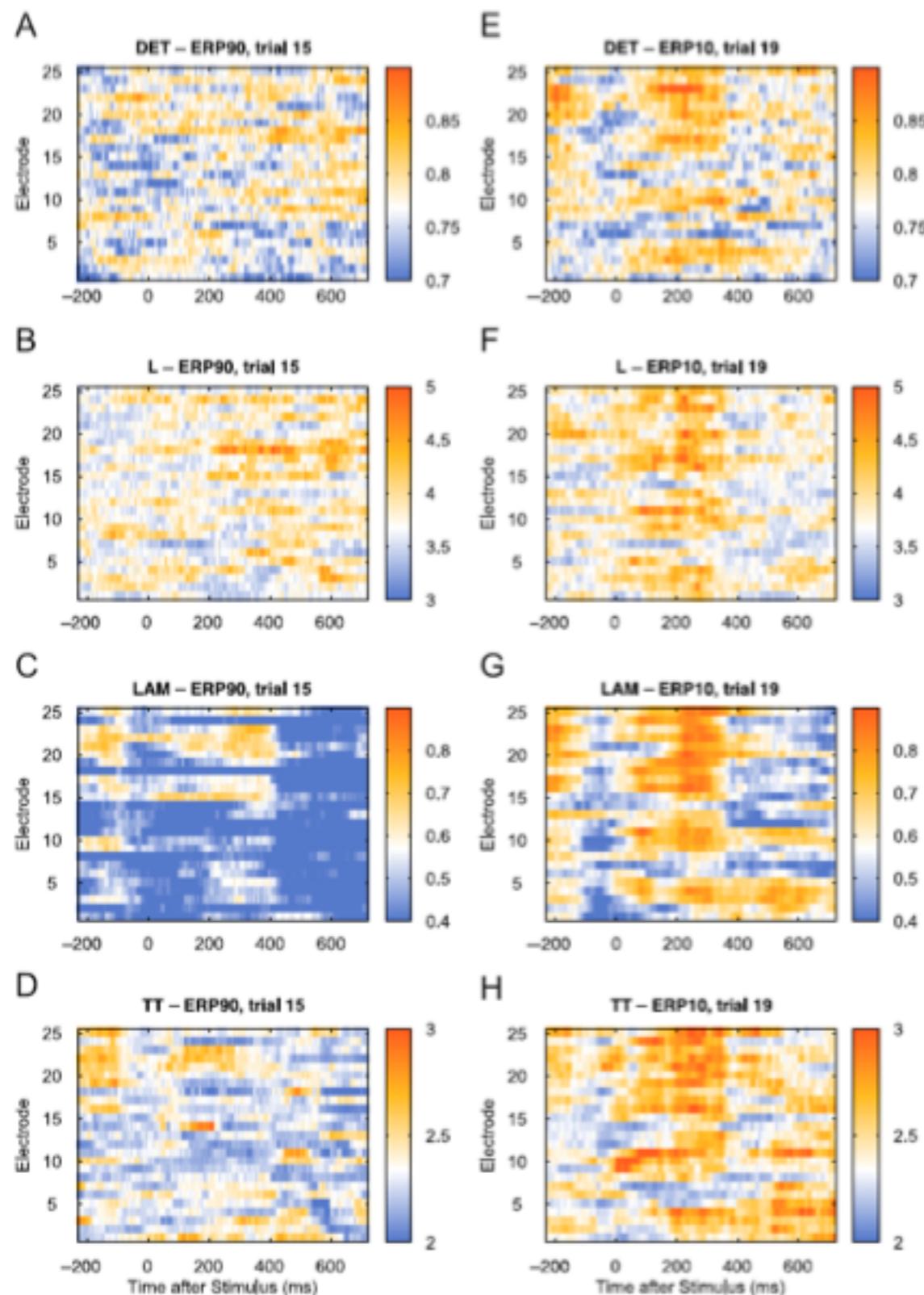


Fig. 2 Order patterns for dimension $d = 3$ (tied ranks $u_i = u_{i+\tau}$ are assumed to be rare)

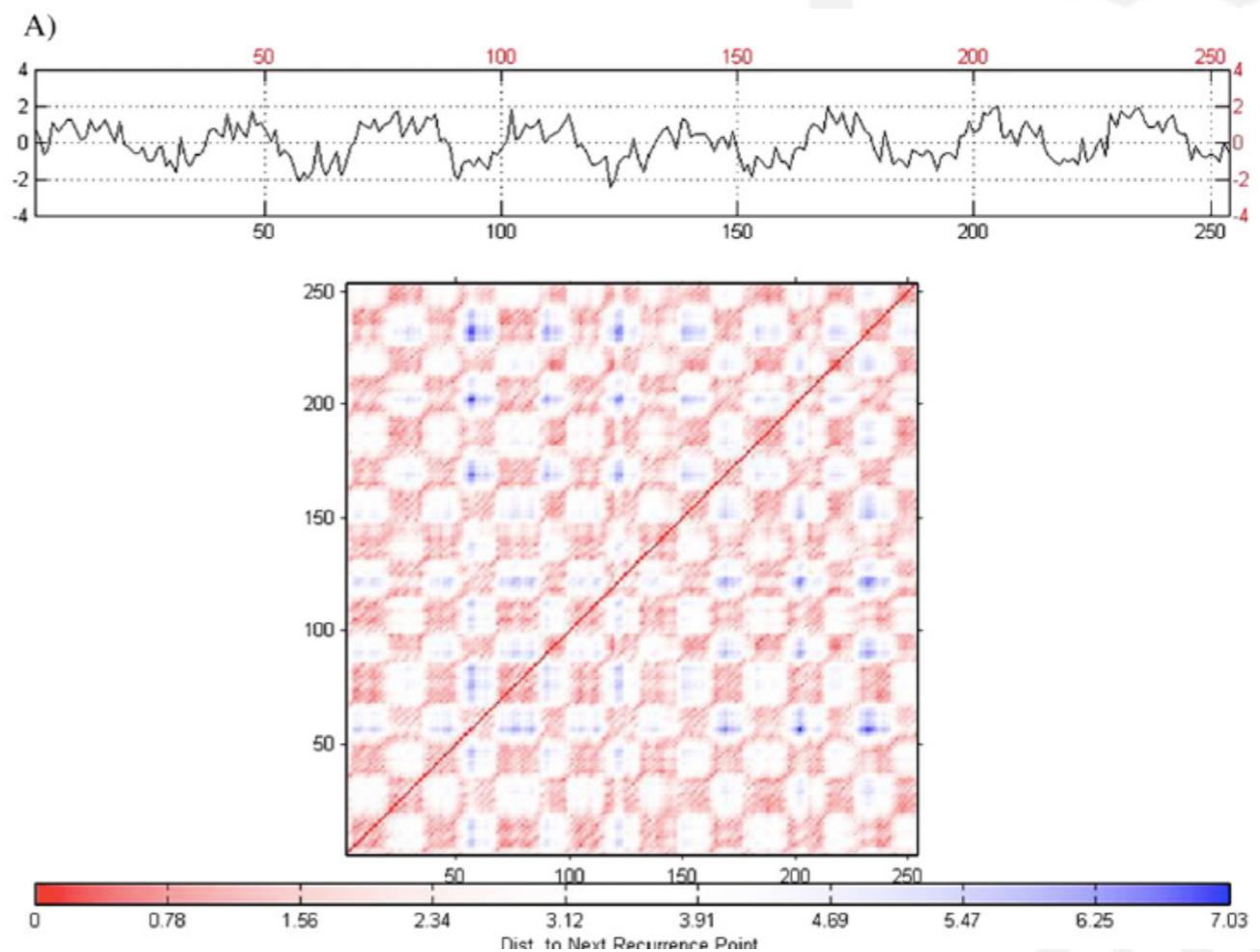
Order patterns recurrence plots in the analysis of ERP data

Stefan Schinkel · Norbert Marwan ·
Jürgen Kurths



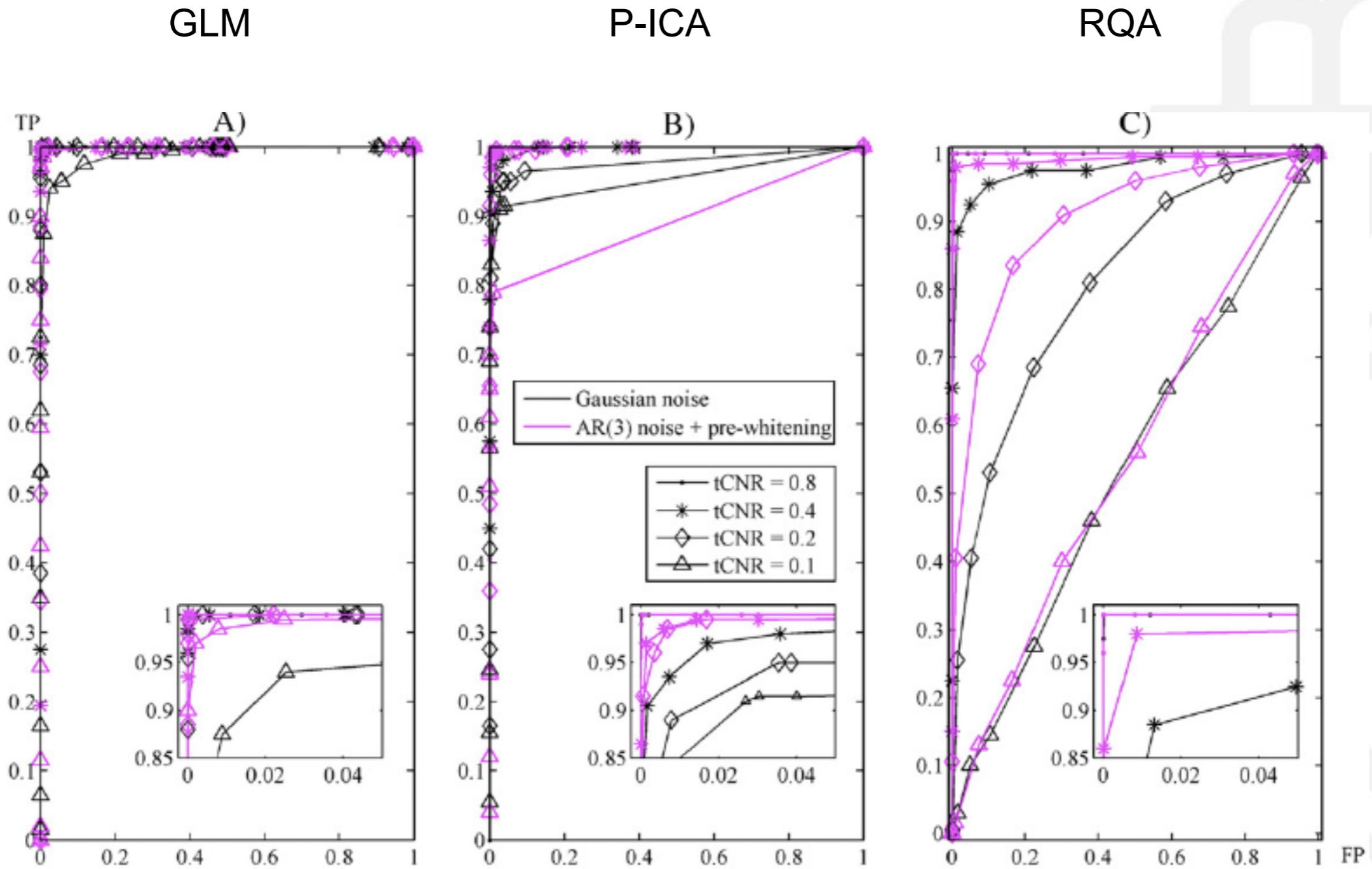
Model-free analysis of brain fMRI data by recurrence quantification

Marta Bianciardi,^a Paolo Sirabella,^b Gisela E. Hagberg,^a Alessandro Giuliani,^c
Joseph P. Zbilut,^d and Alfredo Colosimo^{b,*}



Comparison of RQA with GLM and P-ICA

Ability of three analyses to distinguish between noises in fMRI signal (ROC analysis)



Bianciardi, M., Sirabella, P., Hagberg, G. E., Giuliani, A., Zbilut, J. P., & Colosimo, A. (2007). Model-free analysis of brain fMRI data by recurrence quantification. *NeuroImage*, 37(2), 489-503. doi:10.1016/j.neuroimage.2007.05.025

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Summary

RQA^(TM) - now comes with an errorbar

Physics Letters A 373 (2009) 2245–2250

Contents lists available at ScienceDirect

Physics Letters A

www.elsevier.com/locate/pla

 ELSEVIER



Confidence bounds of recurrence-based complexity measures

Stefan Schinkel ^{a,*}, N. Marwan ^{a,b}, O. Dimigen ^c, J. Kurths ^{b,d}

<http://www.agnld.uni-potsdam.de/~schinkel>

Schinkel, S., Marwan, N., Dimigen, O., & Kurths, J. (2009). Confidence bounds of recurrence-based complexity measures. *Physics Letters A*, 373(26), 2245-2250. Elsevier B.V. doi:10.1016/j.physleta.2009.04.045

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Complexity Methods for Behavioural Science

Cross-Recurrence Quantification Analysis
and other flavours of RP's



Rescaling *before* Reconstruction

- You could also rescale the time series *before* you do the reconstruction:
- **Max distance** -> unit scale $X_{\text{unit}} = (X - \min(X)) / (\max(X) - \min(X))$

Scale of 0-1 (in package *casnet* you can use the **elascer** function)

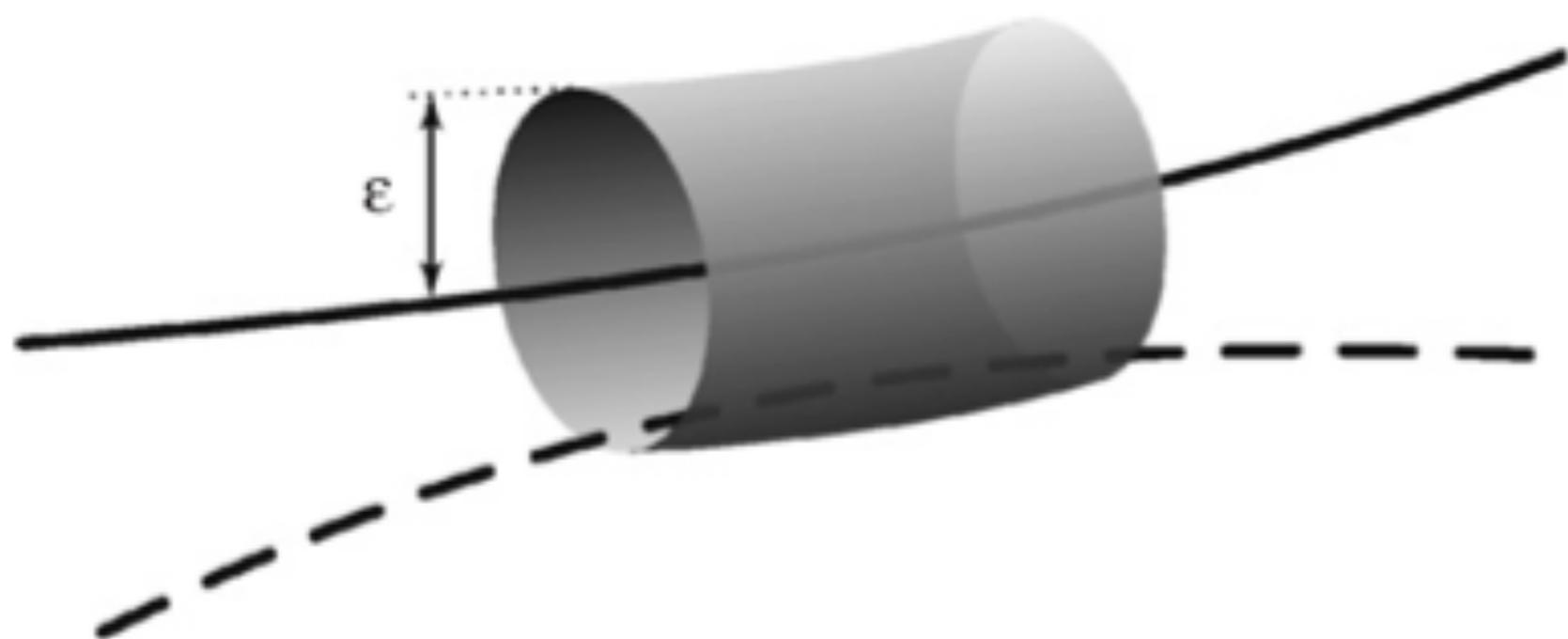
- **Mean distance** -> z-score $X_z = (X - \text{mean}(X)) / \text{std}(X)$

Z-score scale (in package *casnet* you can use the **ts_standardise** function with: **adjustN = FALSE**)

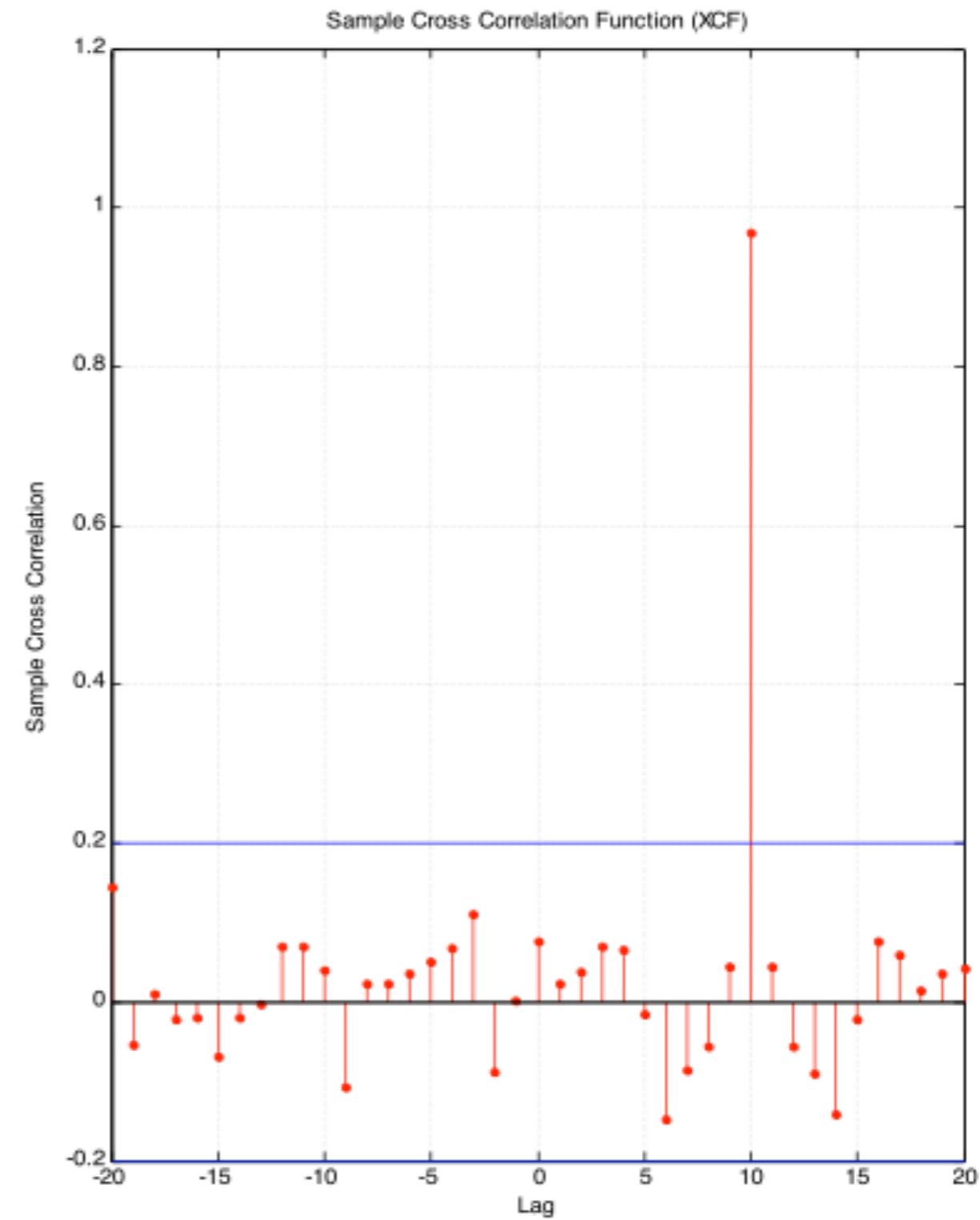
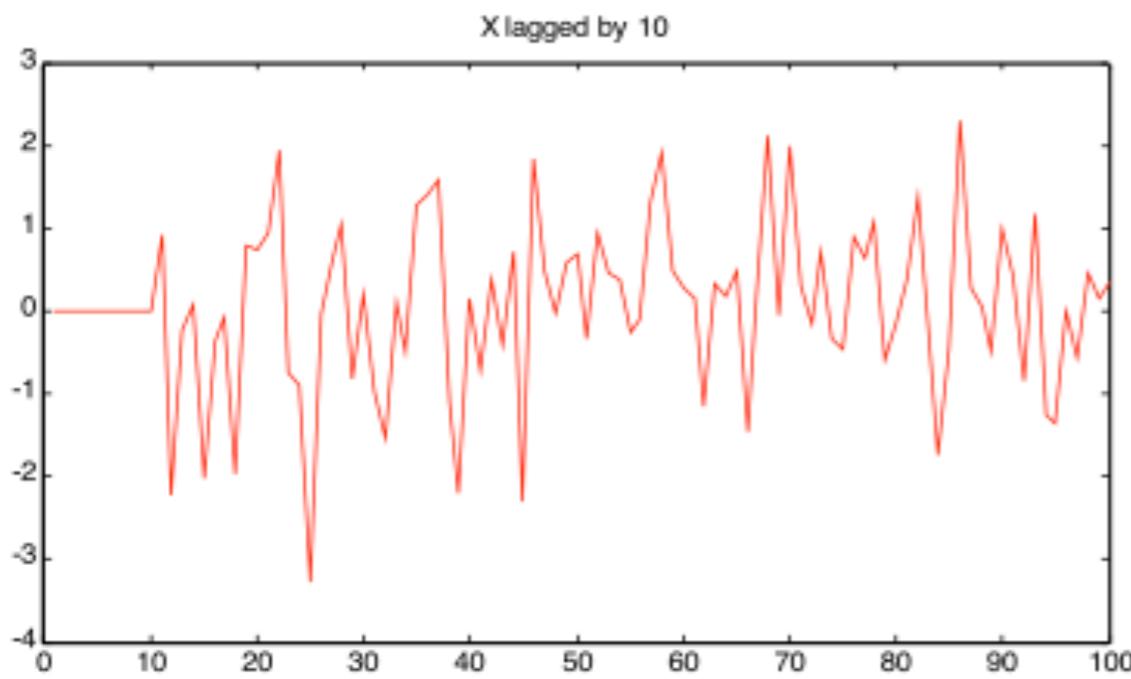
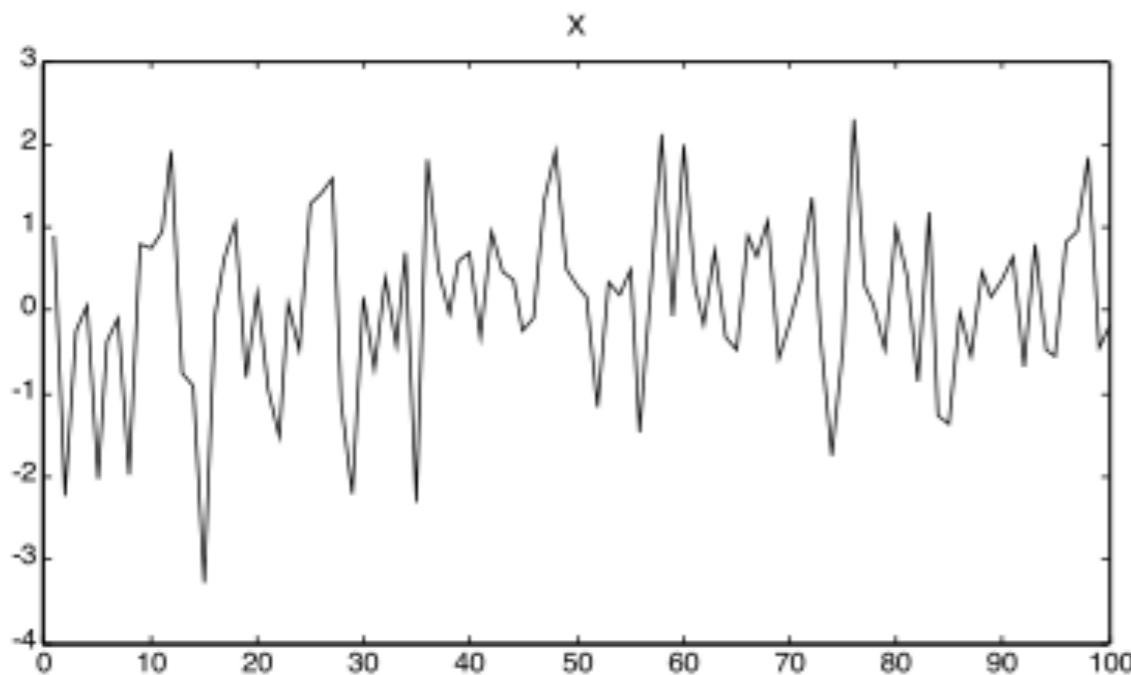


Within radius / threshold = shared trajectory

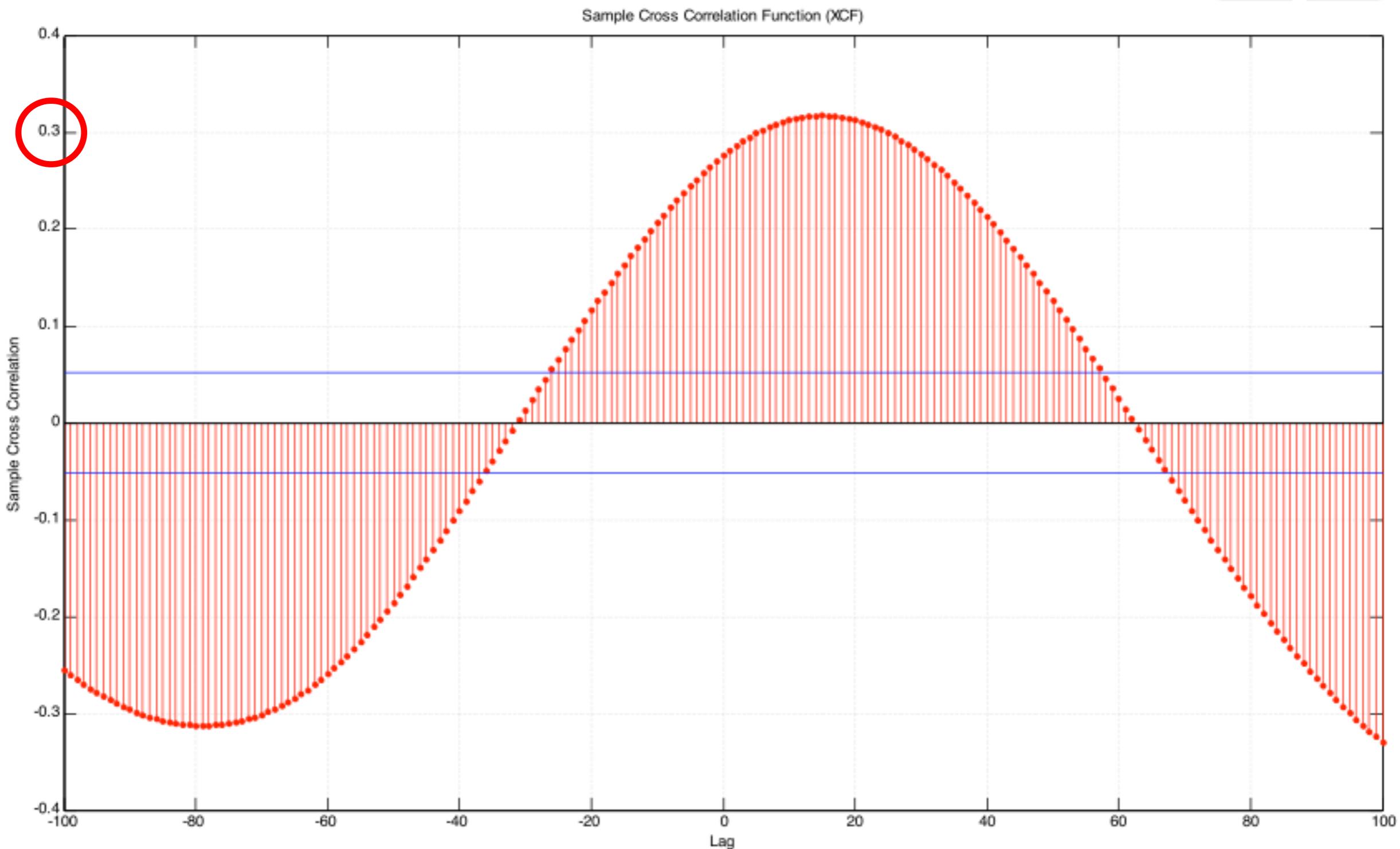
N. Marwan et al. / Physics Reports 438 (2007) 237–329



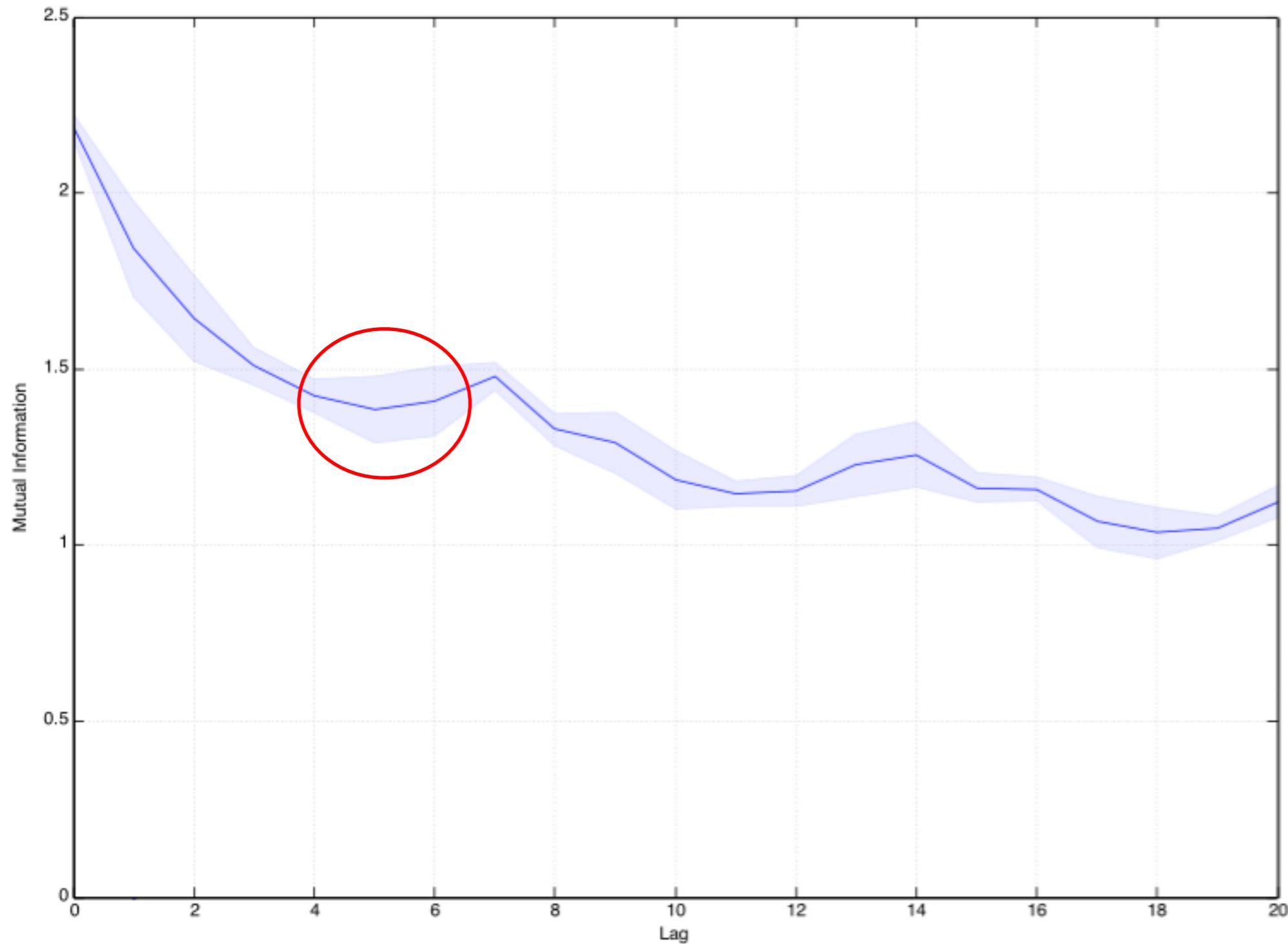
Intuitive notion of synchronisation – Cross Correlation

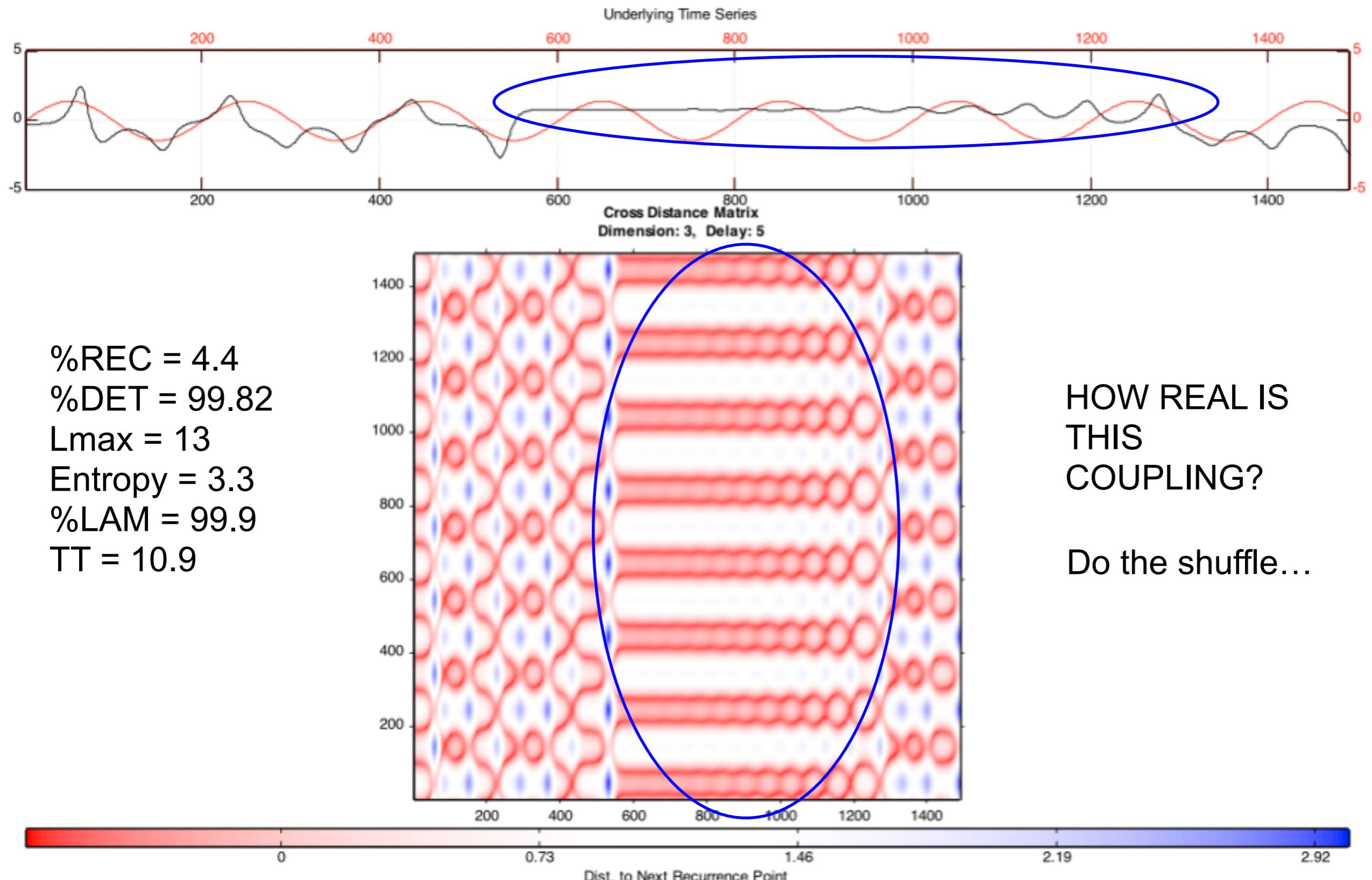


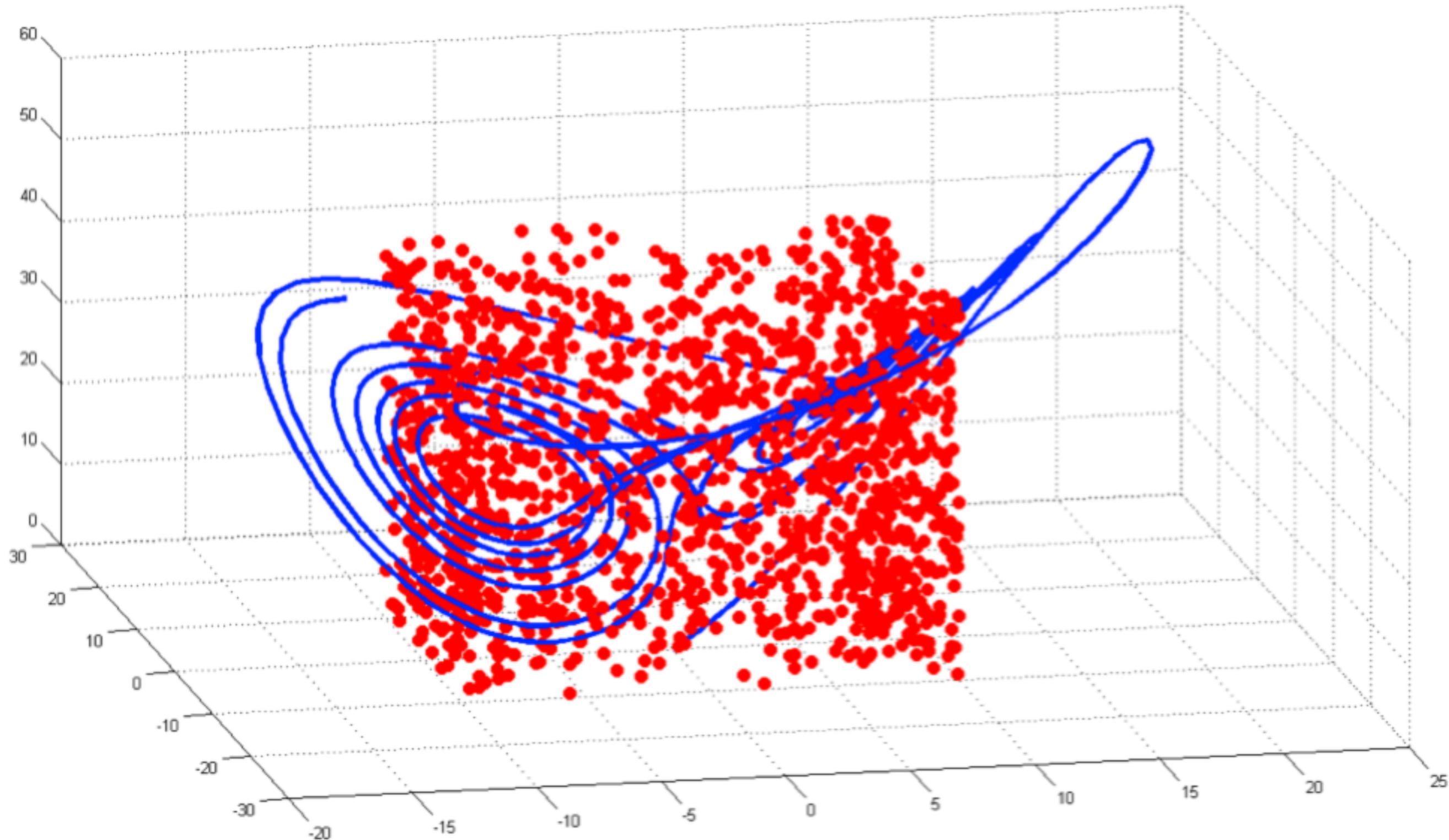
Intuitive notion of synchronisation – Cross Correlation

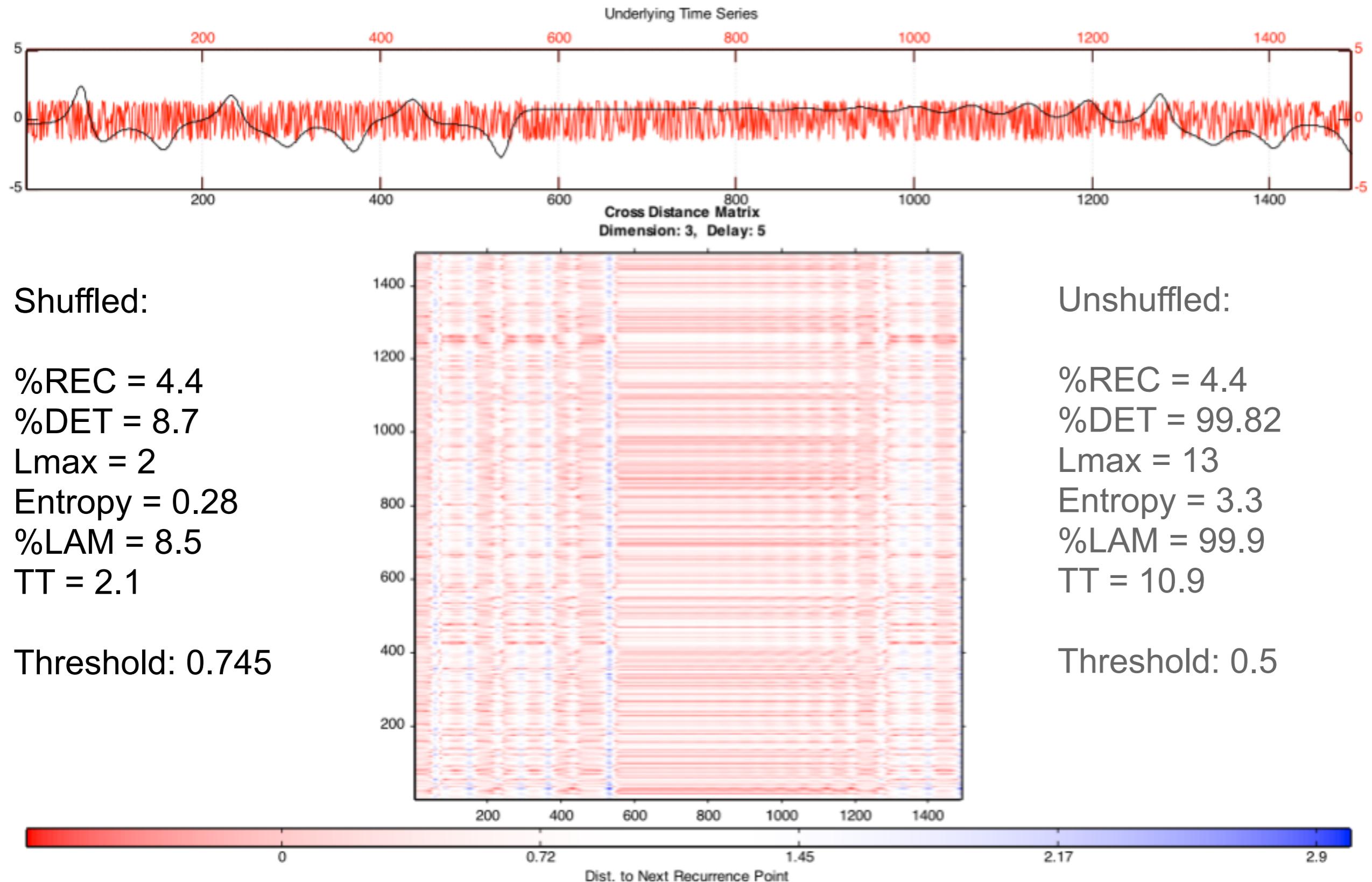


Lorenz and Spiral – Mutual Information









Some Applications

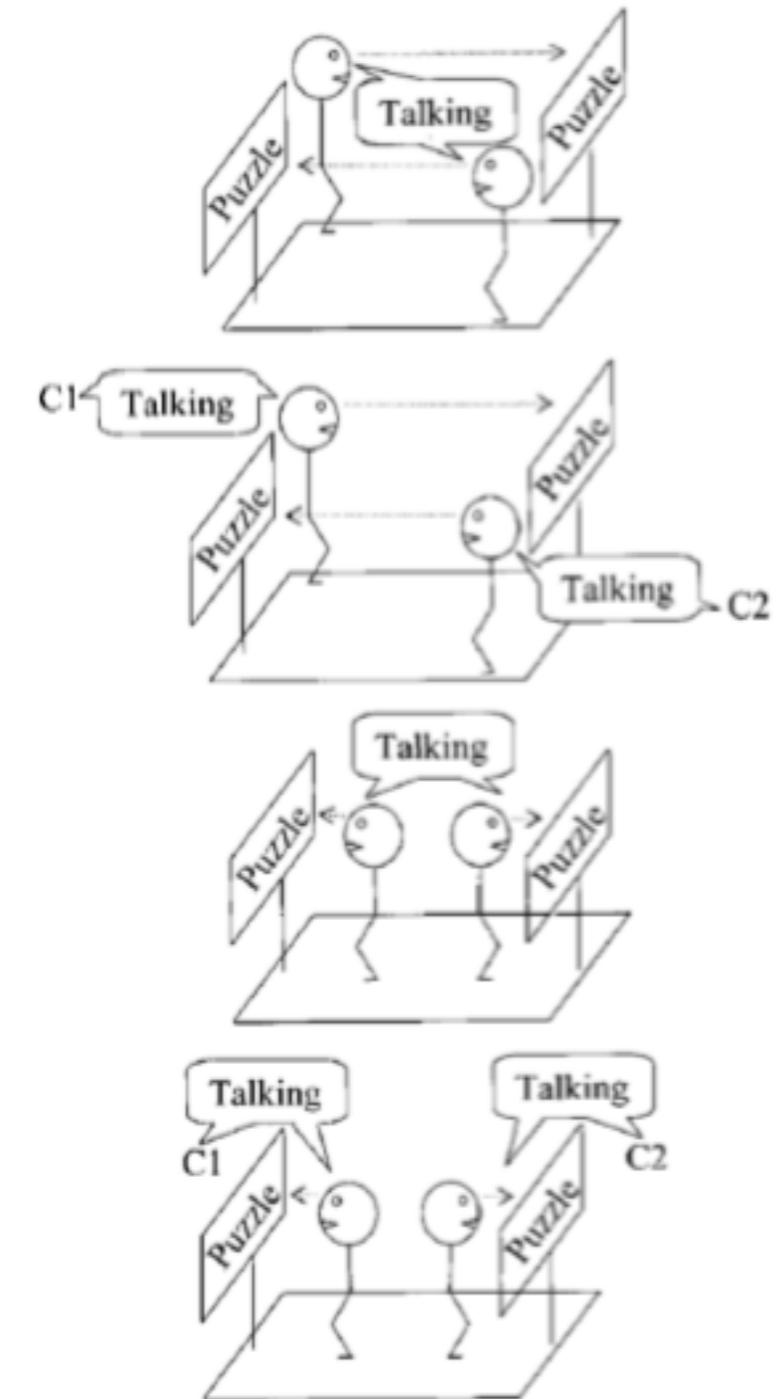
- Coupling of postural sway through communication
- Coupling of language development between infant and caretaker
- Coupling of eye movements to communication



Coupling of postural sway through communication

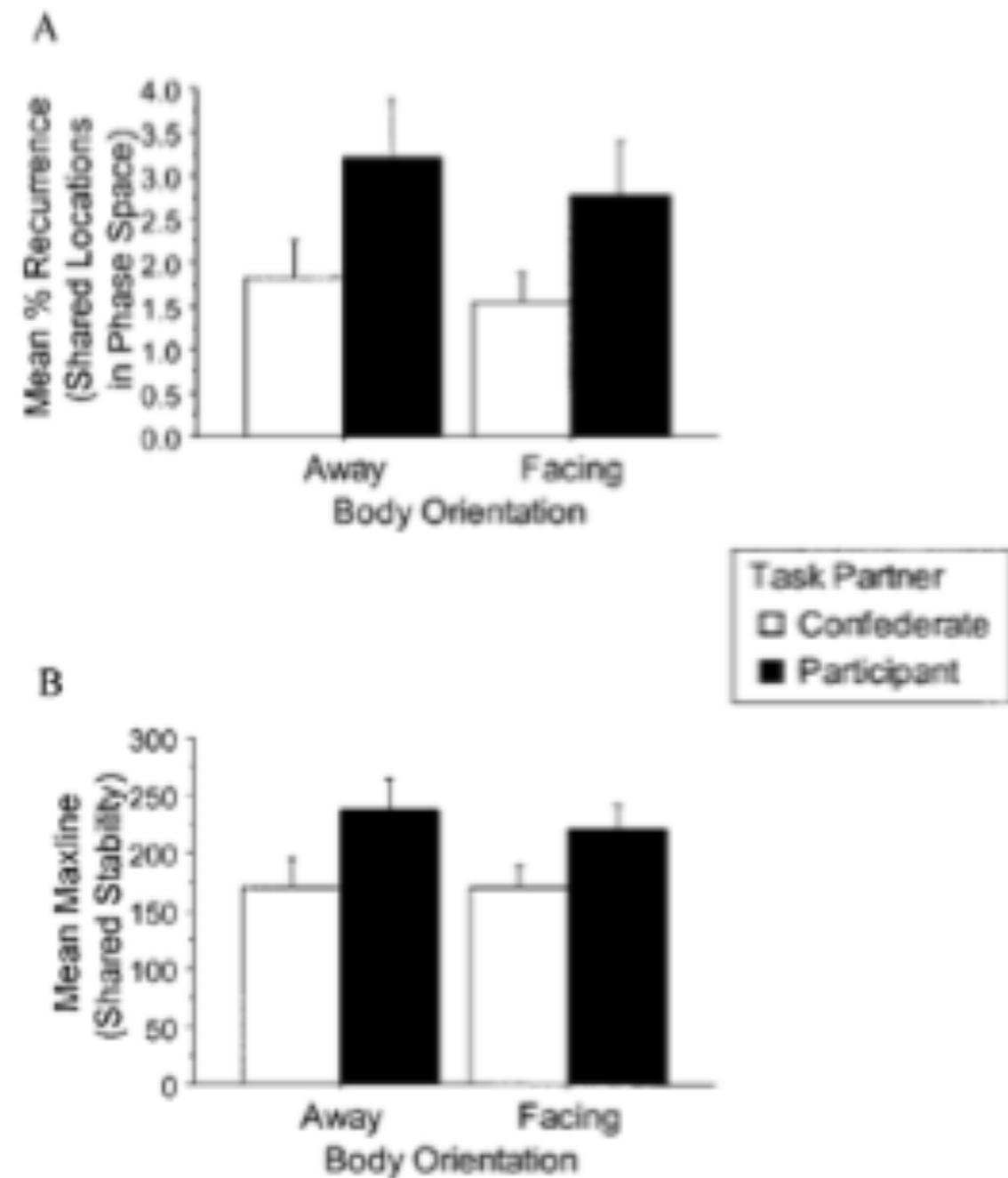
- Postural sway measured by force plate

- Level of direct communication manipulated by talking directly or to confederate / visibility



Coupling of postural sway through communication

Speech can be a “coupling tool” for coordination of previously autonomous bodies



Shockley, K., Santana, M-V., Fowler, C. (2003). Mutual Interpersonal Postural Constraints Are Involved in Cooperative Conversation. *Journal of Experimental Psychology: Human Perception and Performance*, 29, 326-323.

Coupling of language development between infant and caretaker

Dale, R., & Spivey, M.J. (2006). Unraveling the dyad: Using recurrence analysis to explore patterns of syntactic coordination between children and caregivers in conversation. *Language Learning*, 56(3), 391–430

Rick Dale has introduced some interesting applications of Recurrence Analysis:

- CRQA on categorical/nominal data
- “LOS”-profile, as a measure of who’s leading and who’s trailing

Categorical (C)RQA:

- The RP’s of the poems are an example of recurrence plots on categorical data. The recurring values represent an arbitrary category.
- Dale examined transcriptions of conversations between children and caregivers (CHILDES). The unit of analysis was syntactic structure

The RQA parameters become extremely simple, no need for estimation:

Lag = 1, Embedding = 1, Threshold / Radius = 0

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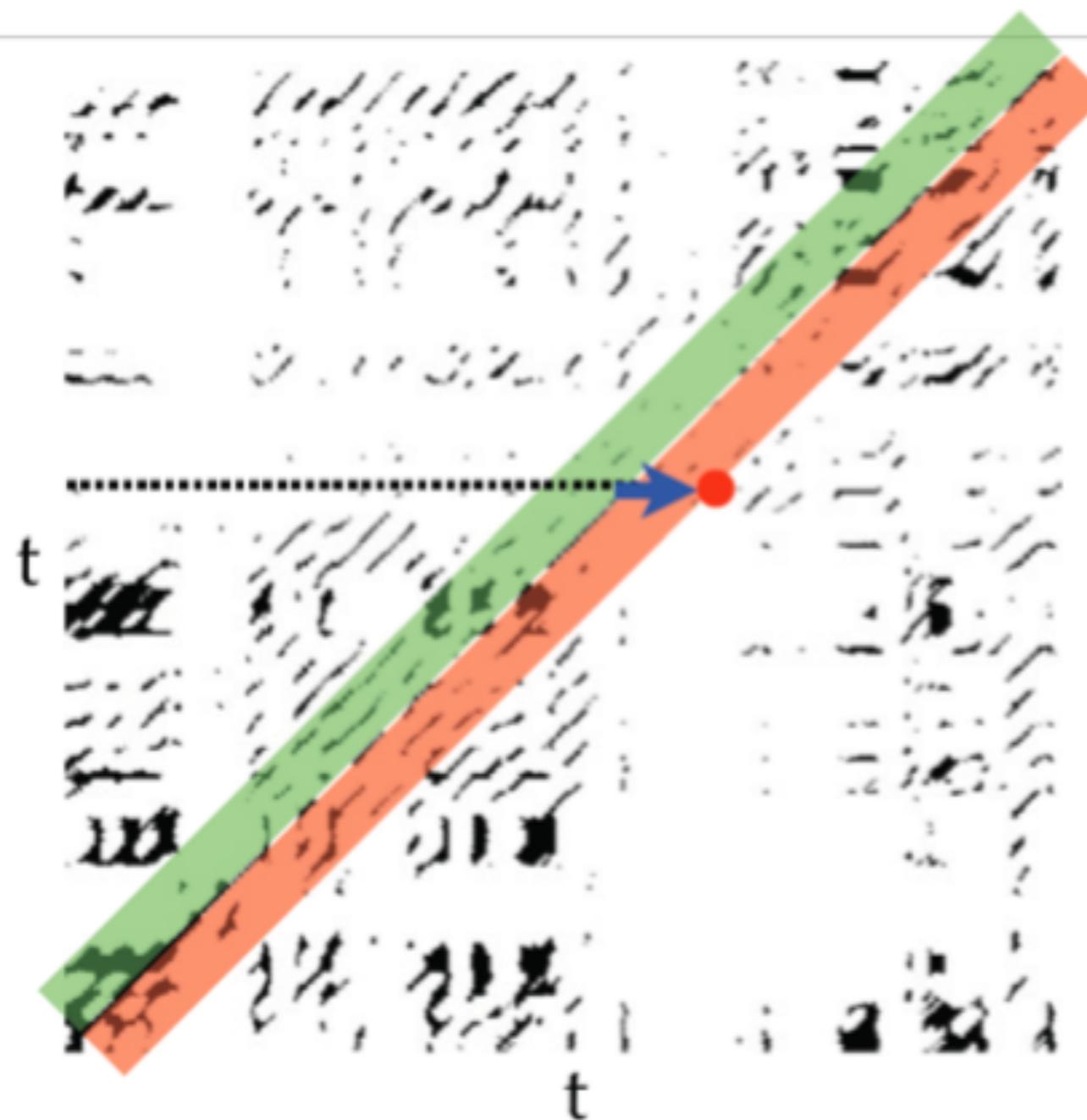
Radboud University Nijmegen



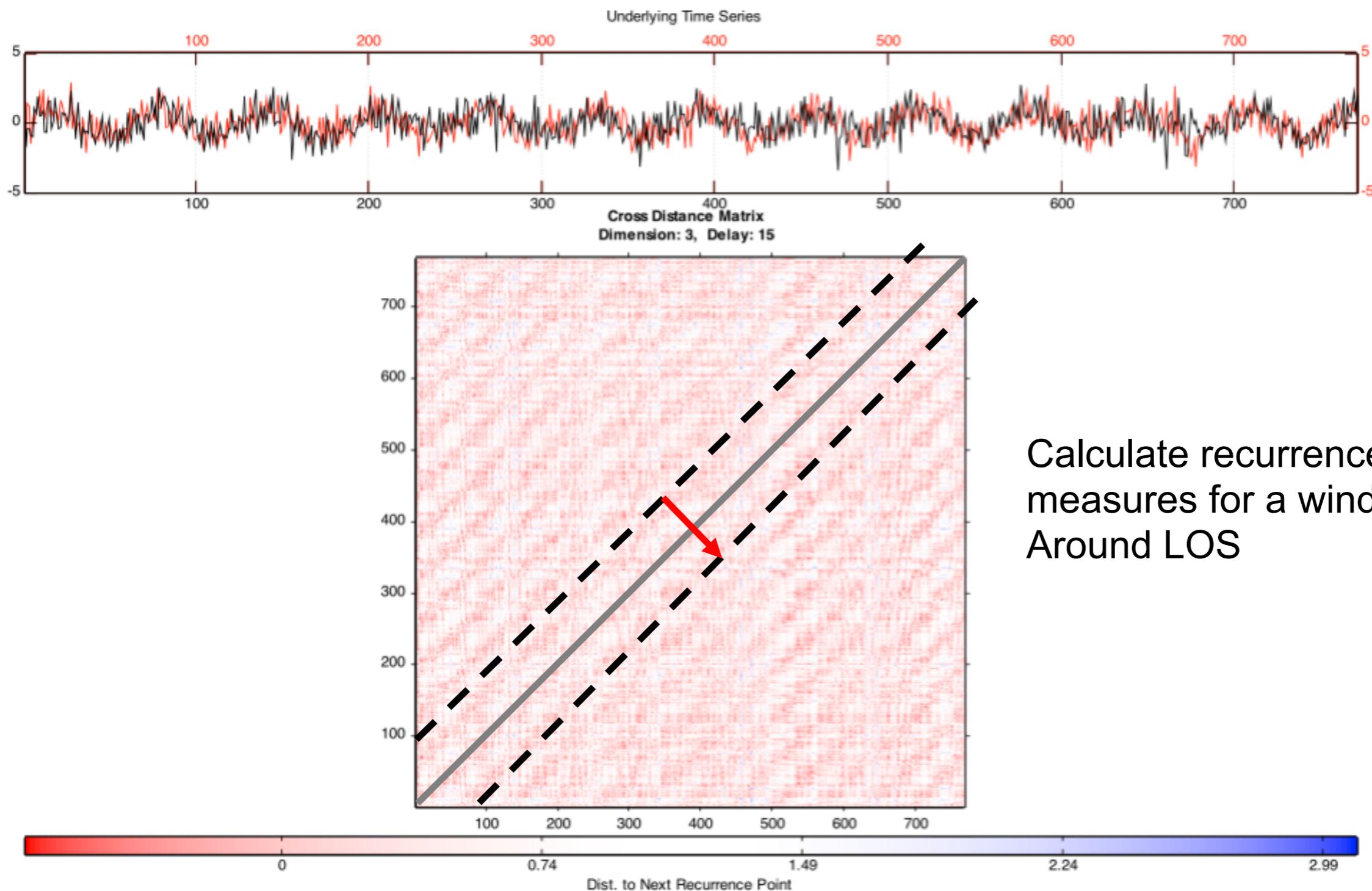
Who leads?

Time Series
On Y-axis
leads at red dot:

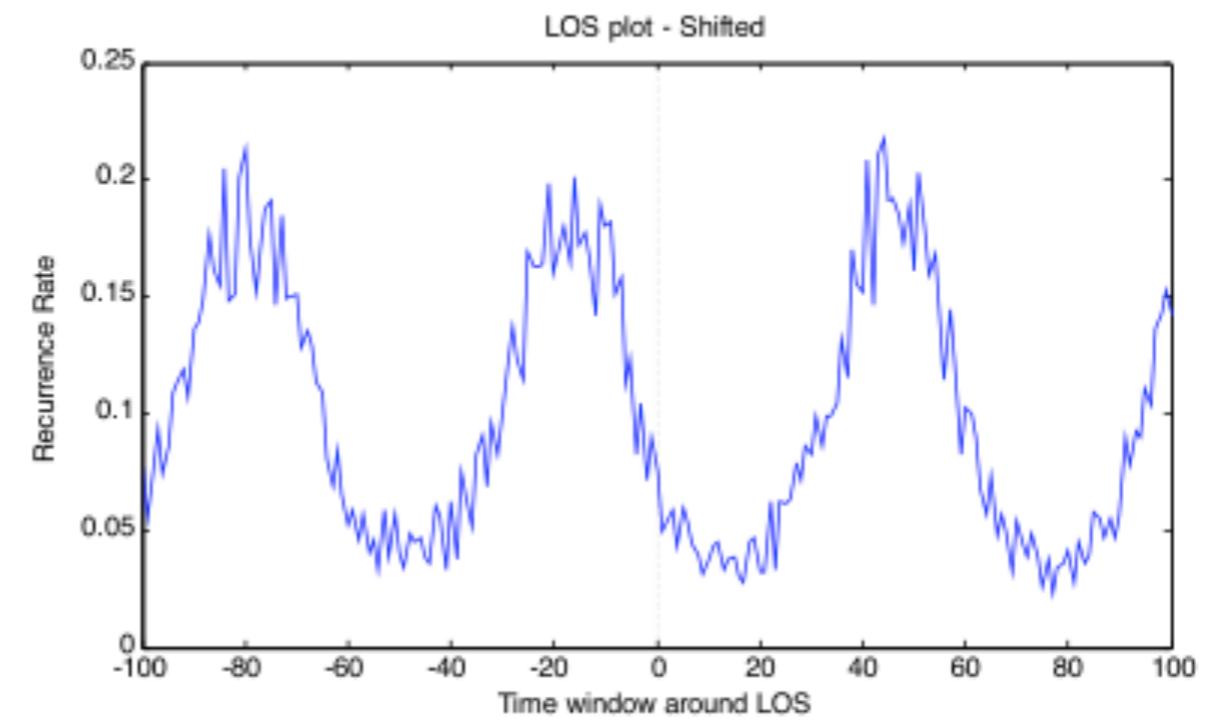
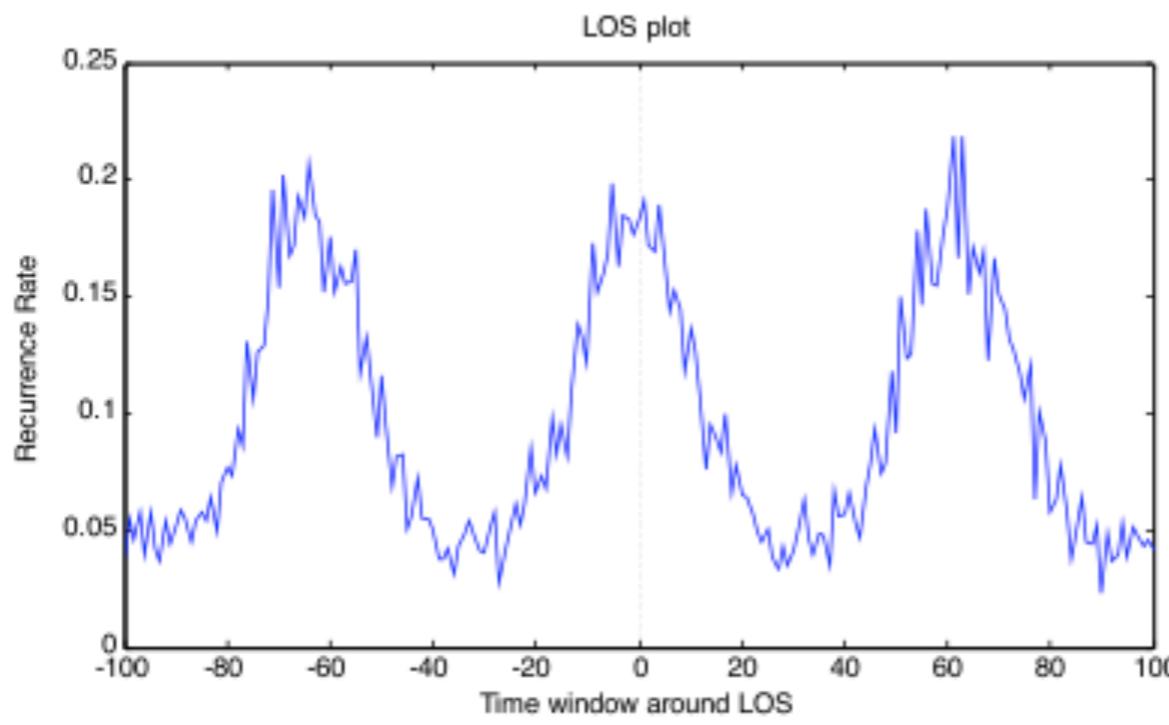
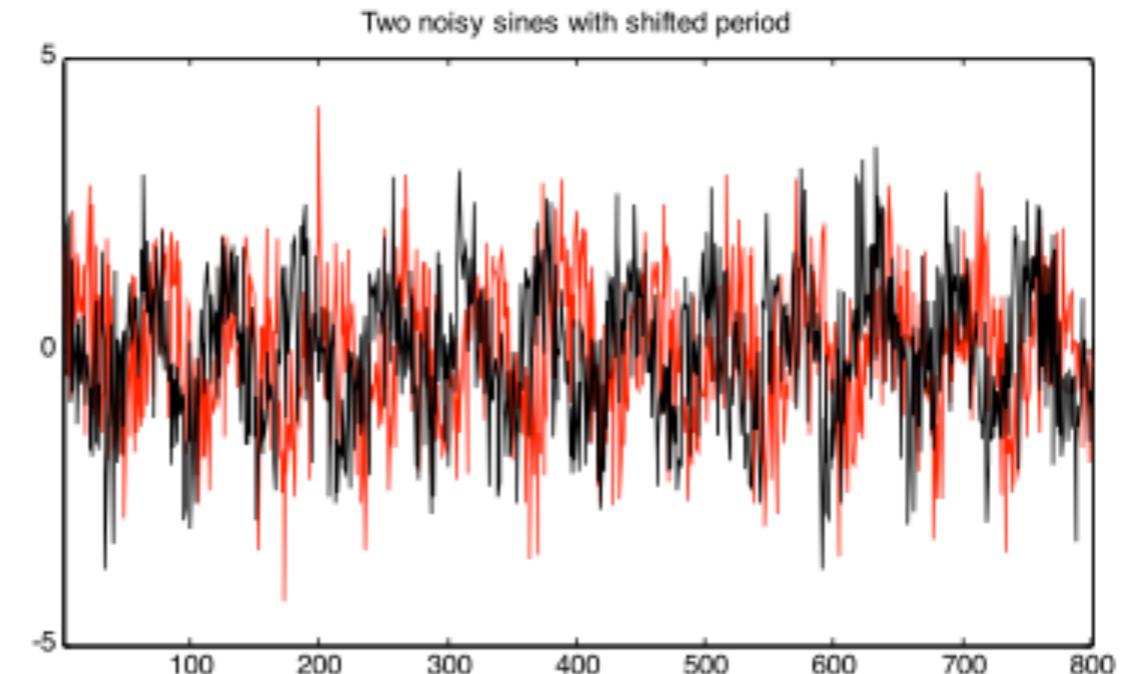
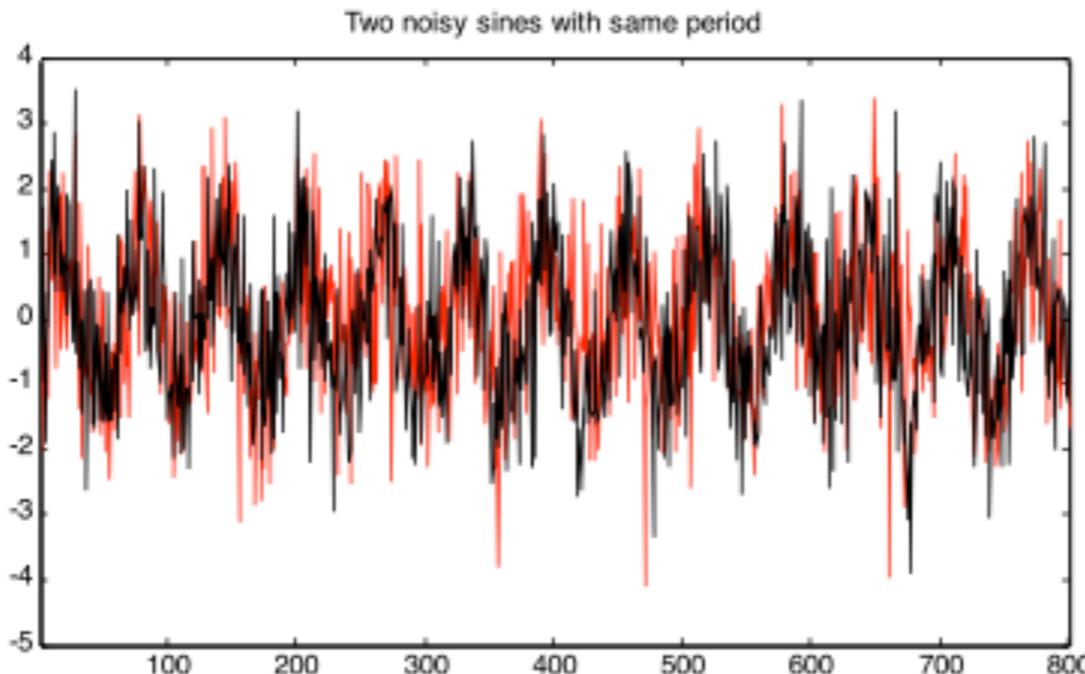
The category- / word- /
syntactic- / pattern first
occurred there,
in the X-axis series
it occurred later



Diagonal Recurrence Profile

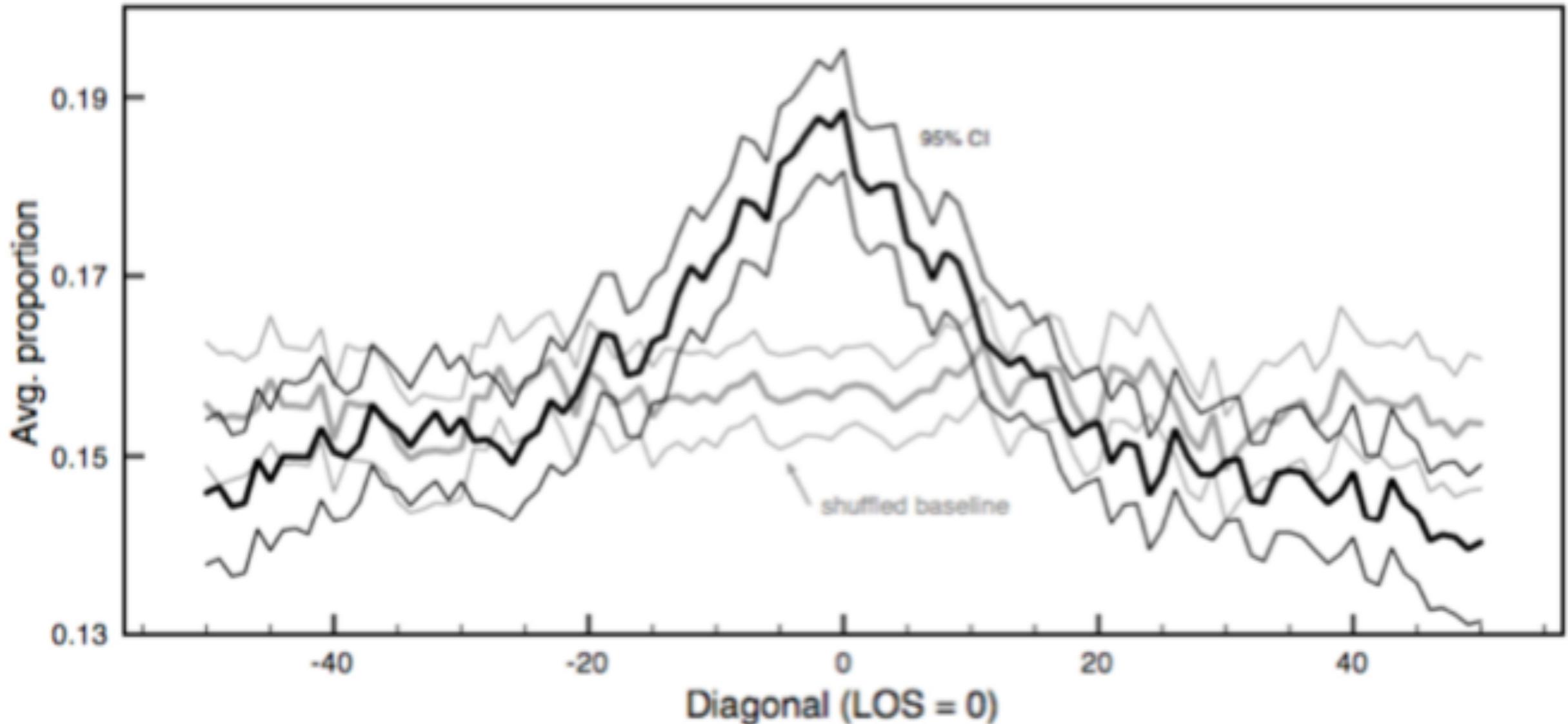


Diagonal Recurrence Profile



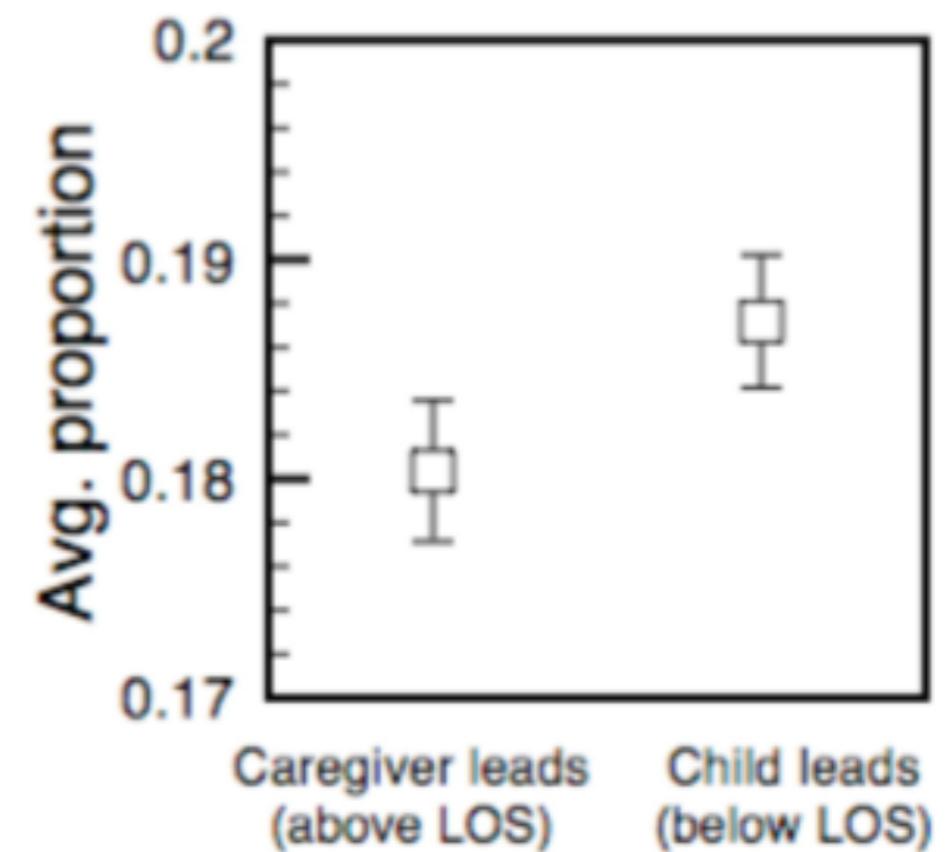
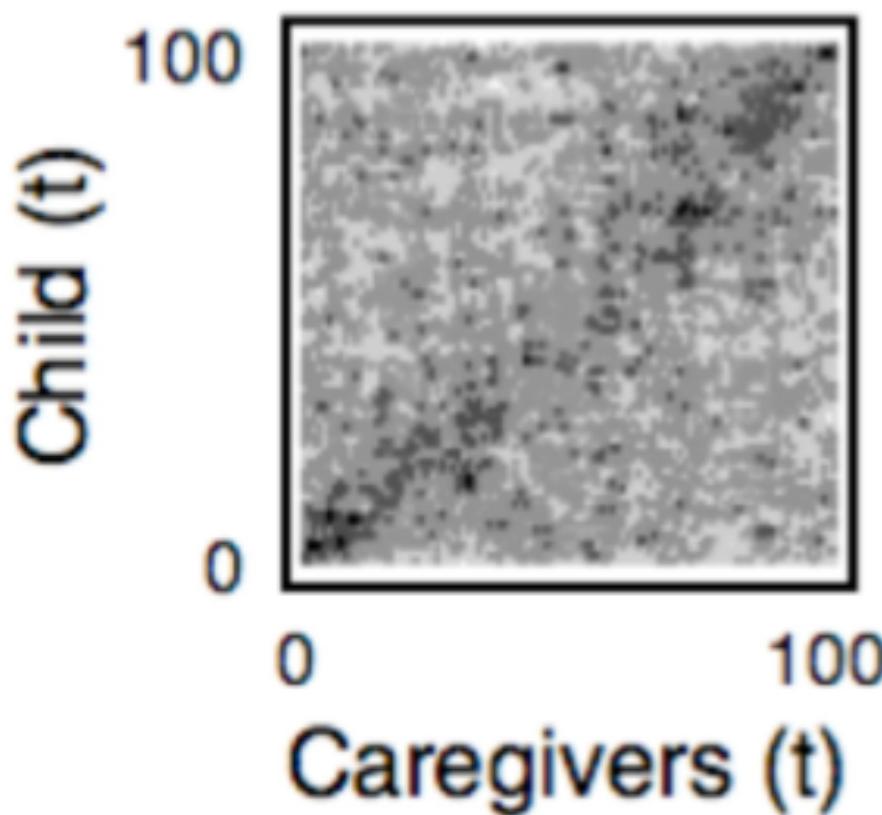
Coupling of language development between infant and caretaker

Dale, R., & Spivey, M.J. (2006). Unraveling the dyad: Using recurrence analysis to explore patterns of syntactic coordination between children and caregivers in conversation. *Language Learning*, 56(3), 391–430.



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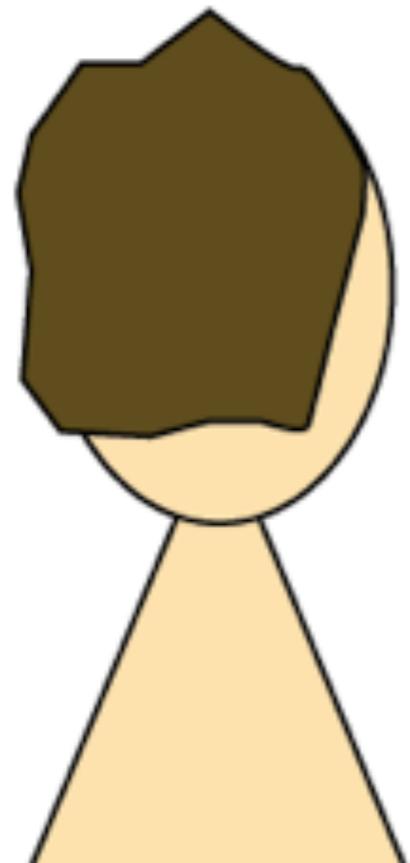


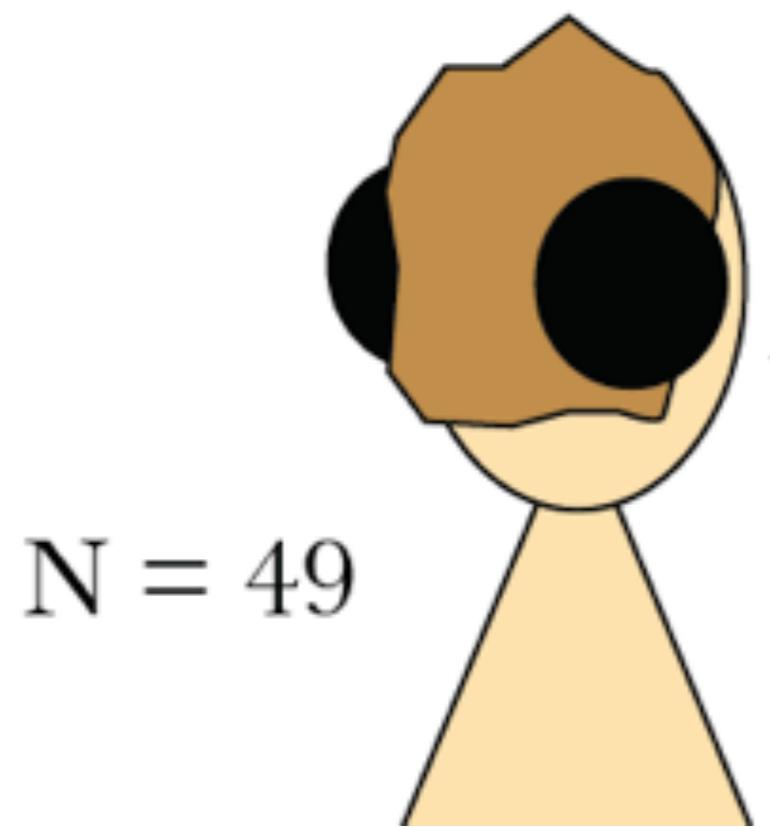
eye movement patterns...

1, 2, 2, 2, 2, 4, 4, 5, ...

“blah blah blah...”

N = 4





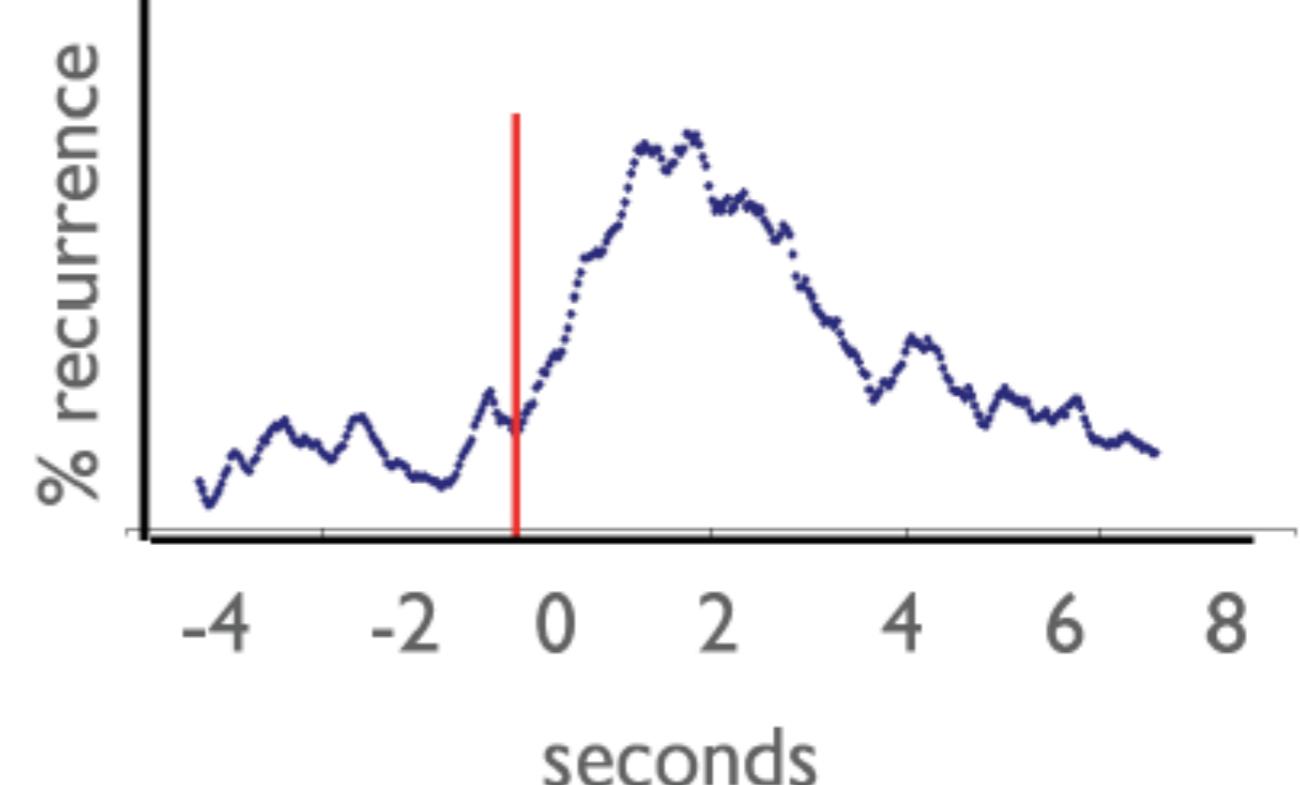
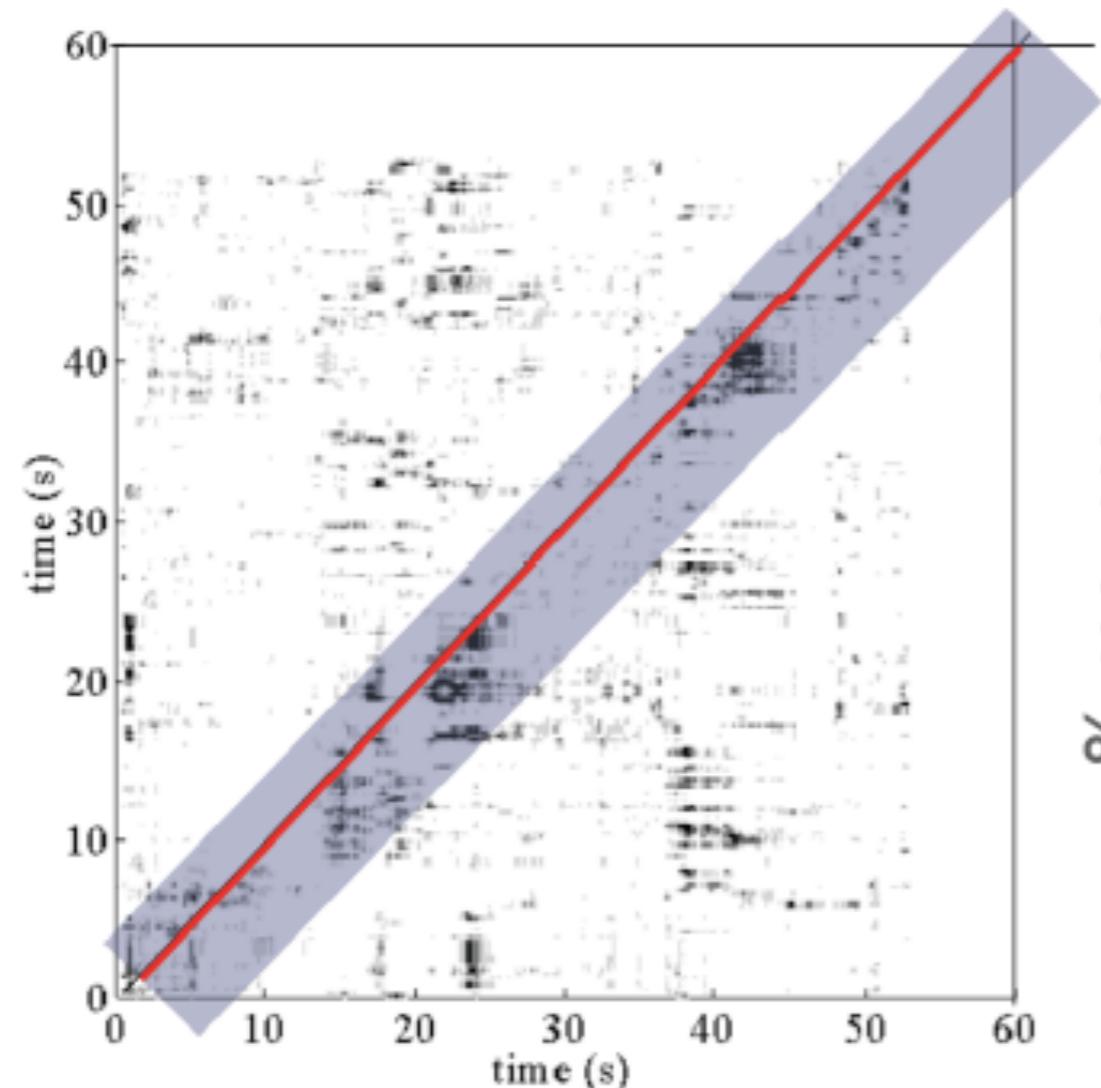
eye movement patterns...
1, 1, 1, 2, 2, 2, 2, 4, ...

“blah blah blah...”

Coupling of eye movements to communication

Richardson, D.C., Dale, R., Kirkham, N.Z. (2007). The art of conversation is coordination. *Psychological Science*, 18, 407-413.

Speaker



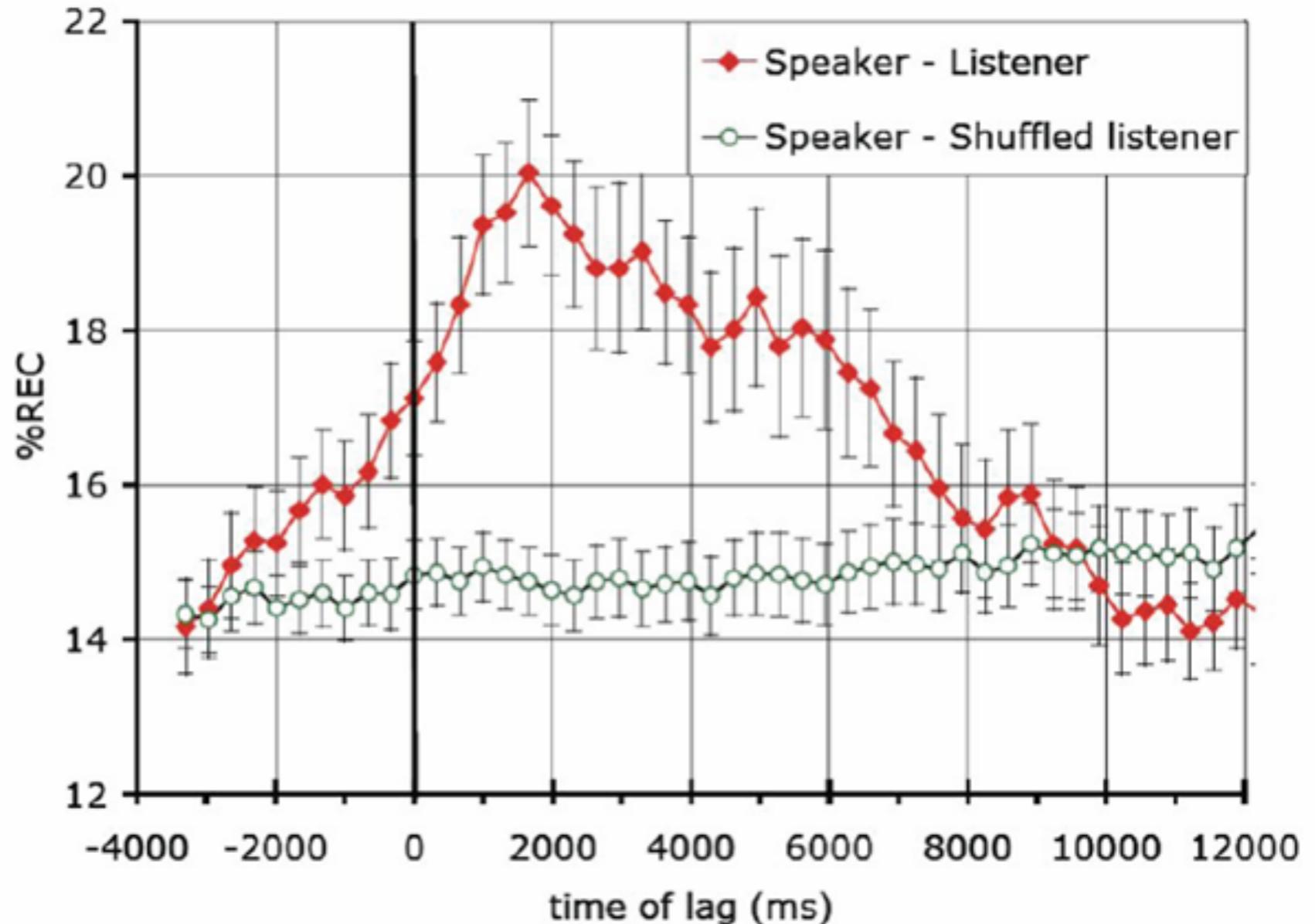
Listener

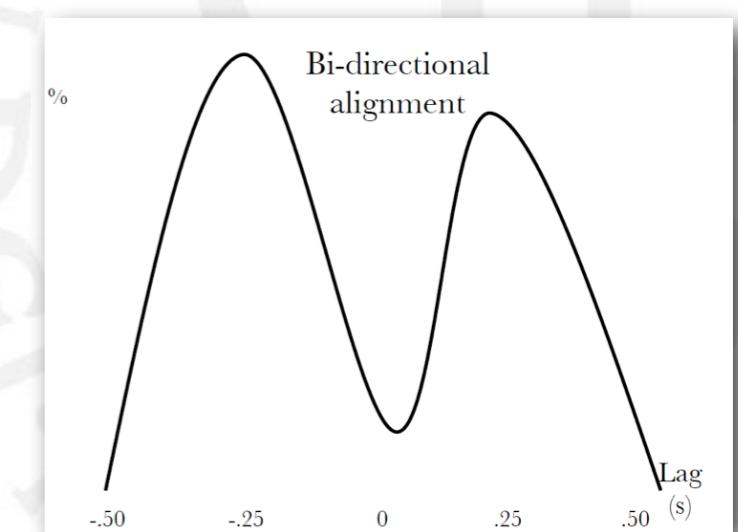
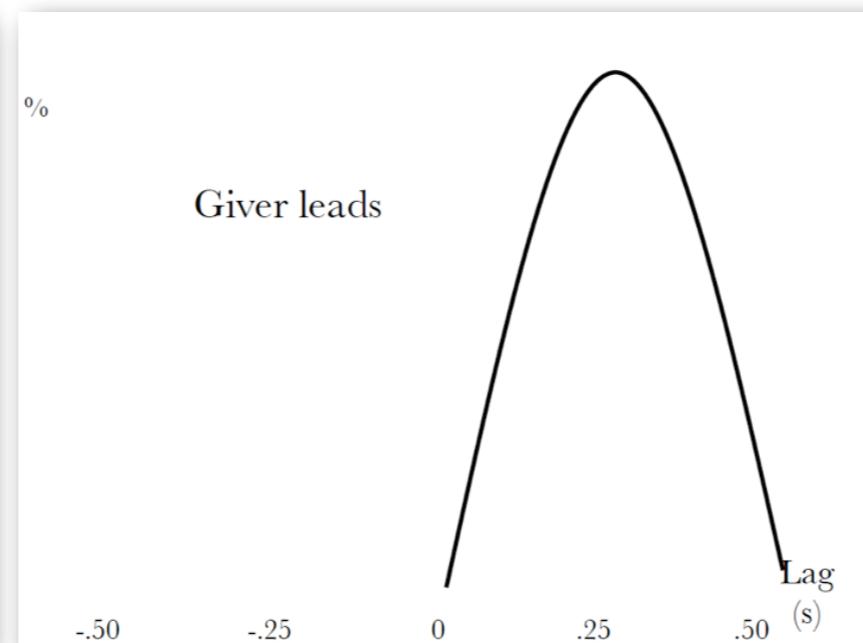
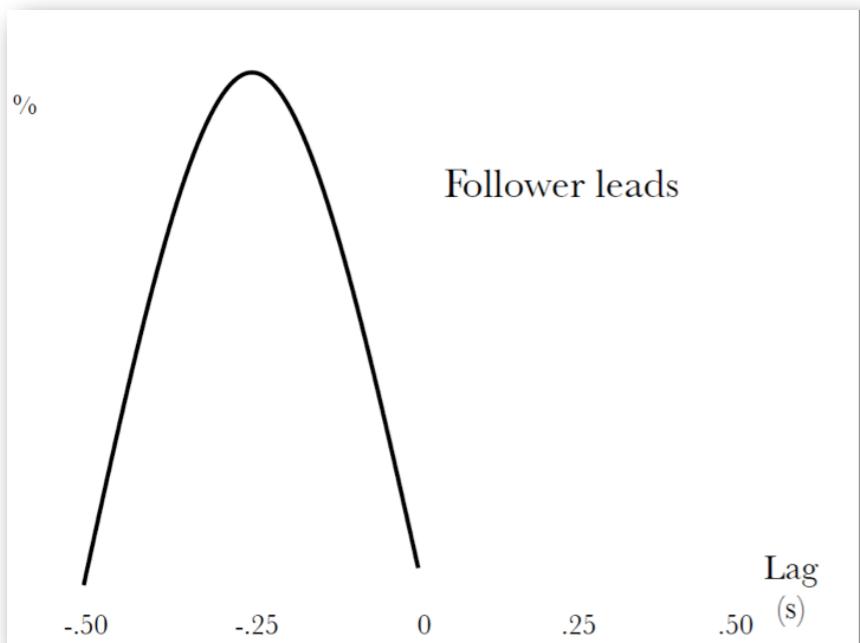
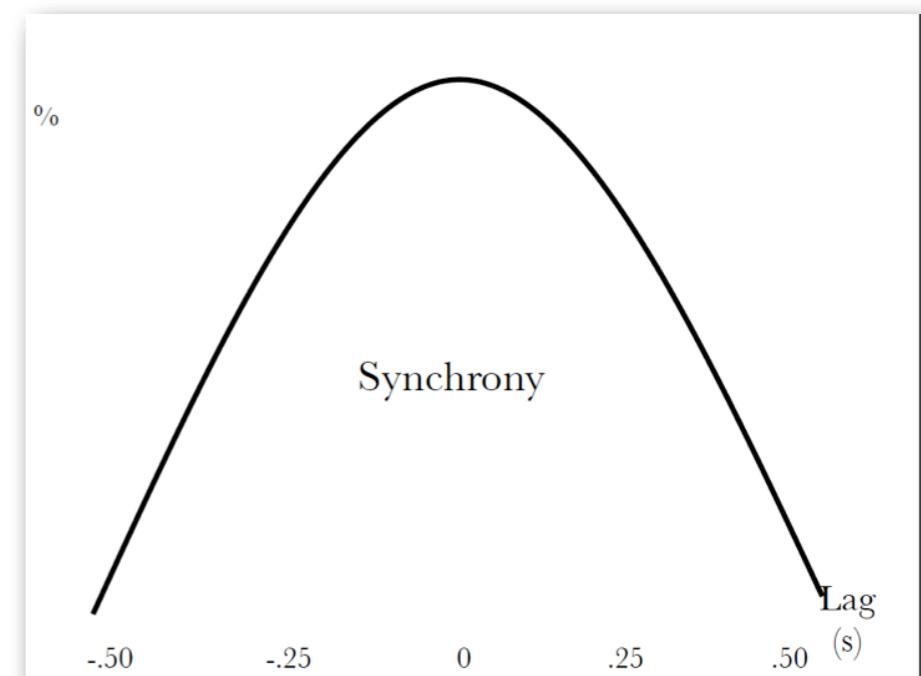
Richardson & Dale, 2005

Coupling of eye movements to communication

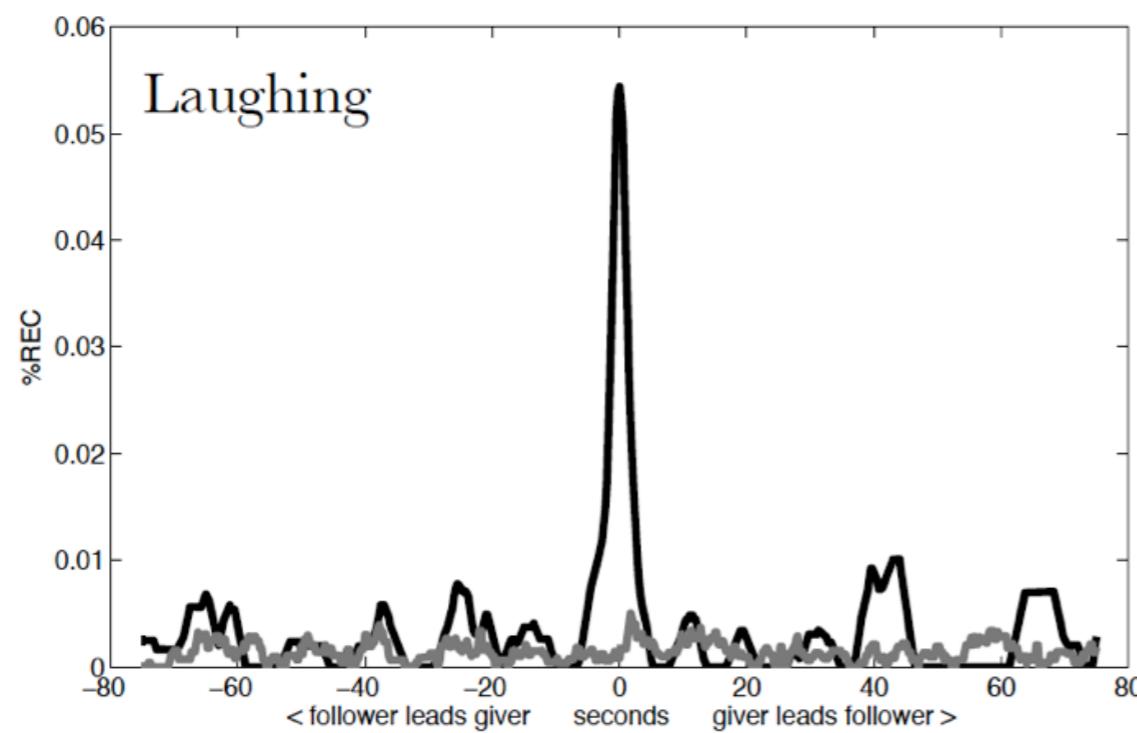
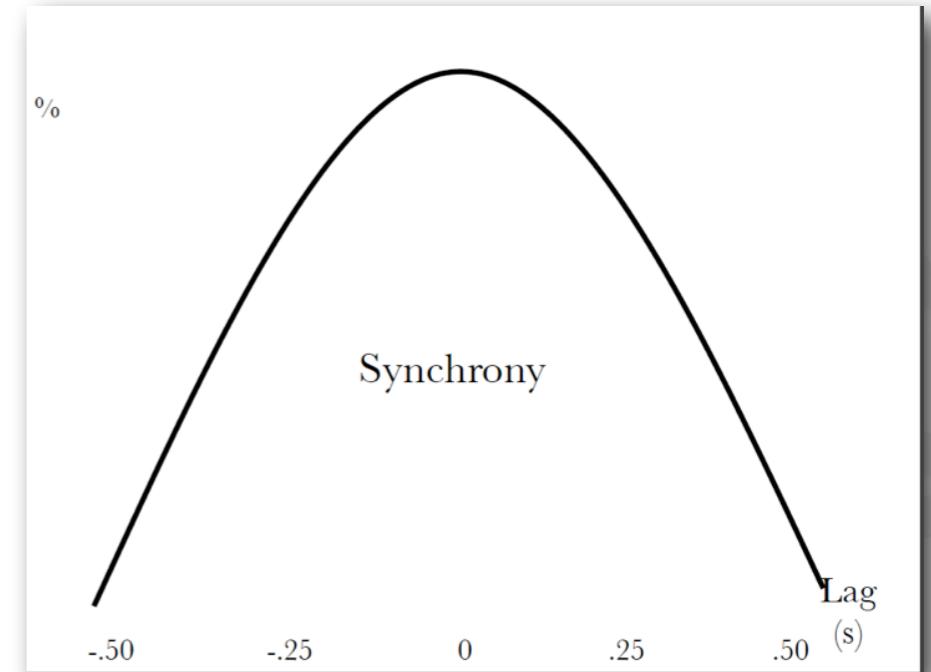
Richardson, D.C., Dale, R., Kirkham, N.Z. (2007). The art of conversation is coordination. *Psychological Science*, 18, 407-413.

Listeners eye movements
are coupled and lagging
depending on level of
interaction in conversation



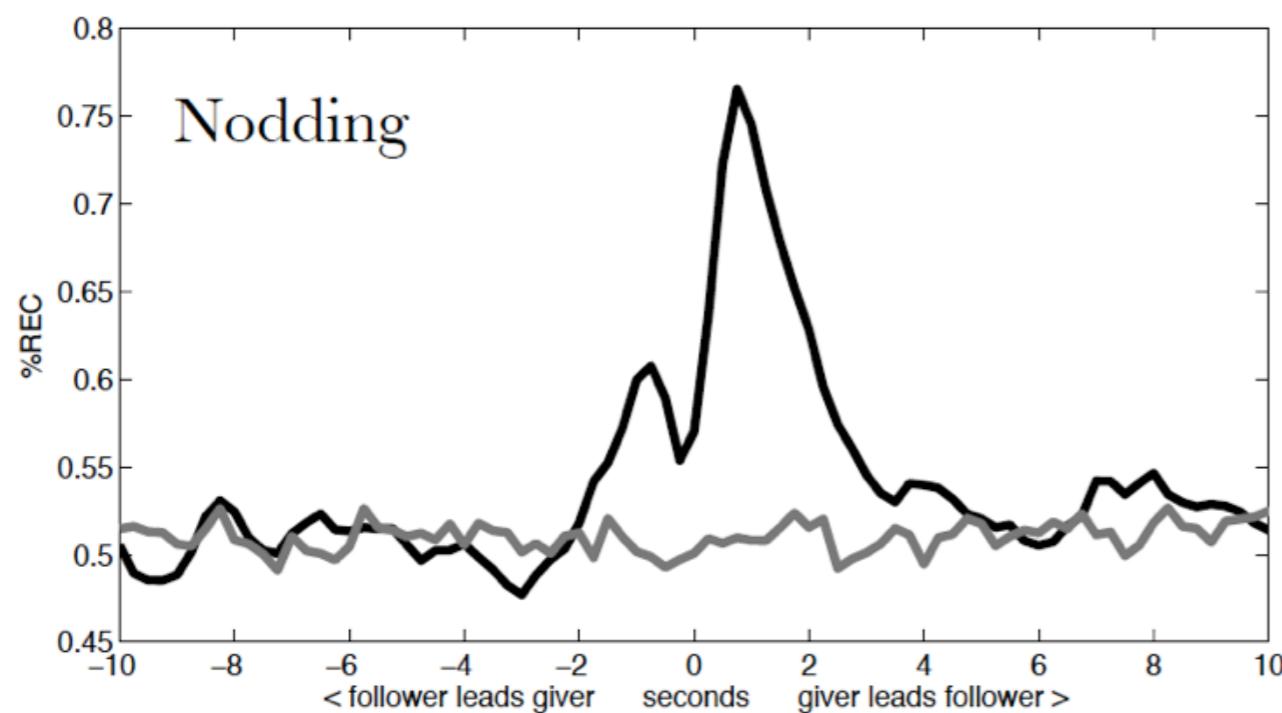
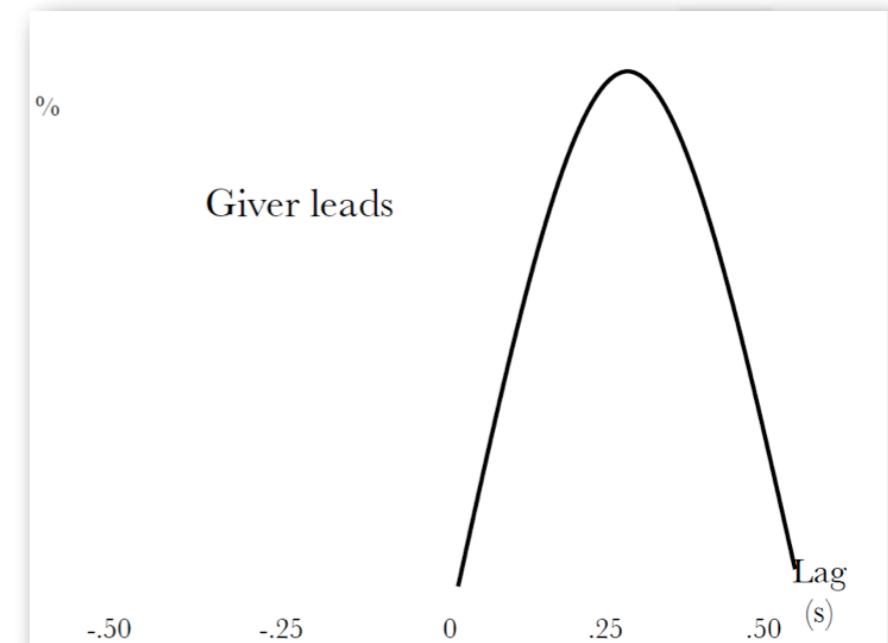


Louwerse, M. M., Dale, R., Bard, E. G., & Jeuniaux, P. (2012). Behavior matching in multimodal communication is synchronized. *Cognitive science*, 36(8), 1404–26. doi:10.1111/j.1551-6709.2012.01269.x



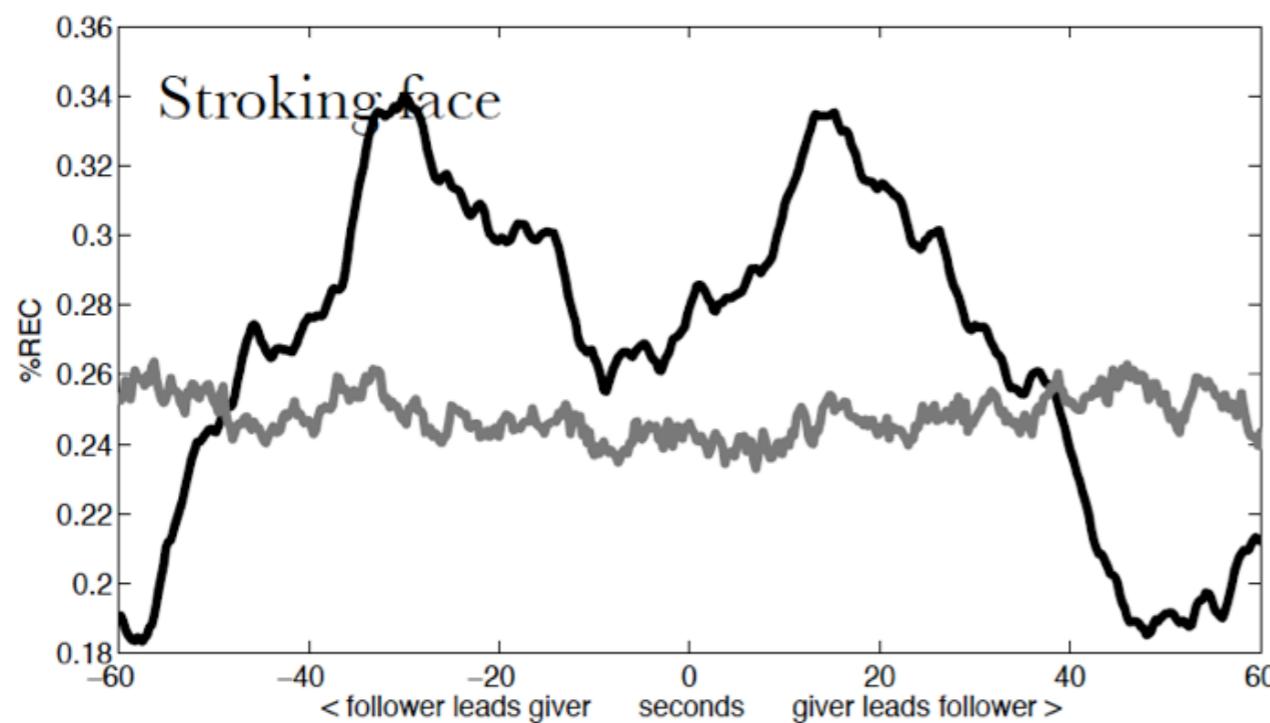
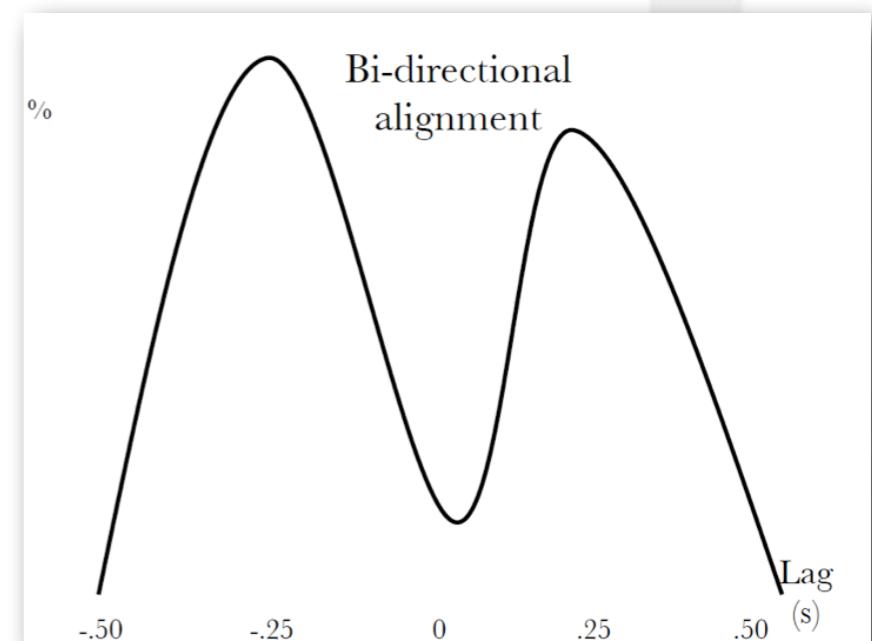
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Louwerve, Dale, et al., in prep



Louwerse, M. M., Dale, R., Bard, E. G., & Jeuniaux, P. (2012). Behavior matching in multimodal communication is synchronized. *Cognitive science*, 36(8), 1404–26. doi:10.1111/j.1551-6709.2012.01269.x

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Louwerse, Dale, et al., in prep

Research question

- **Motor coordination + Cooperation + Learning / Problem solving**
- Does the coordination of postural sway differ between typically developing children and children with a neurodevelopmental disorder, when they perform a cooperative task?
- And if so, how do they differ?
- And... why?

Participants

Typically developing children

- 183 dyads
 - $M_{age} = 10;8$ years
 - $SD = 1;00$
 - range: 8-13
- Dyad composition
~~95 boys and 88 girls~~
- Recruitment of participants

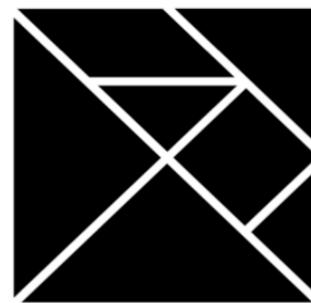
Children with a neurodevelopmental disorder

- 106 dyads
 - $M_{age} = 10;10$
 - $SD = 1;3$
 - range: 8 – 13
 - 74 boys and 32 girls.

Materials and Procedure

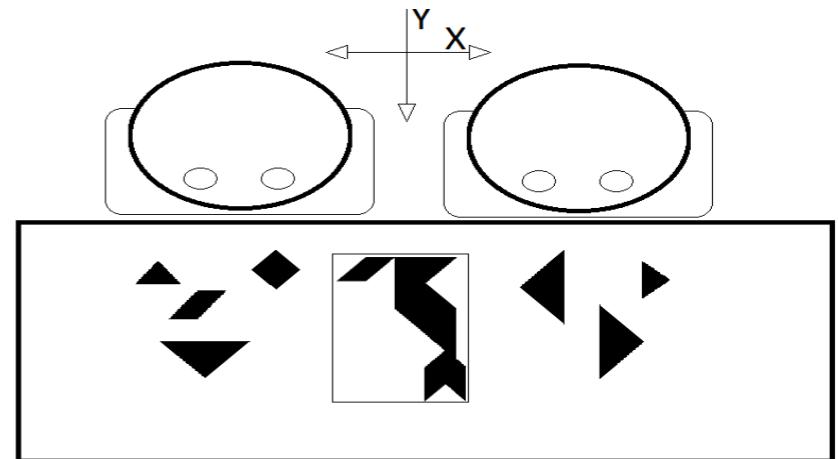
Tangram task

- Three sets of 18 puzzles
- Printed on A4 paper
- Pretest, coop, posttest



Two Nintendo Wii Balance Boards

- Simultaneously recorded postural sway
- Sampling rate 100Hz
- Records x- and y-coordinates

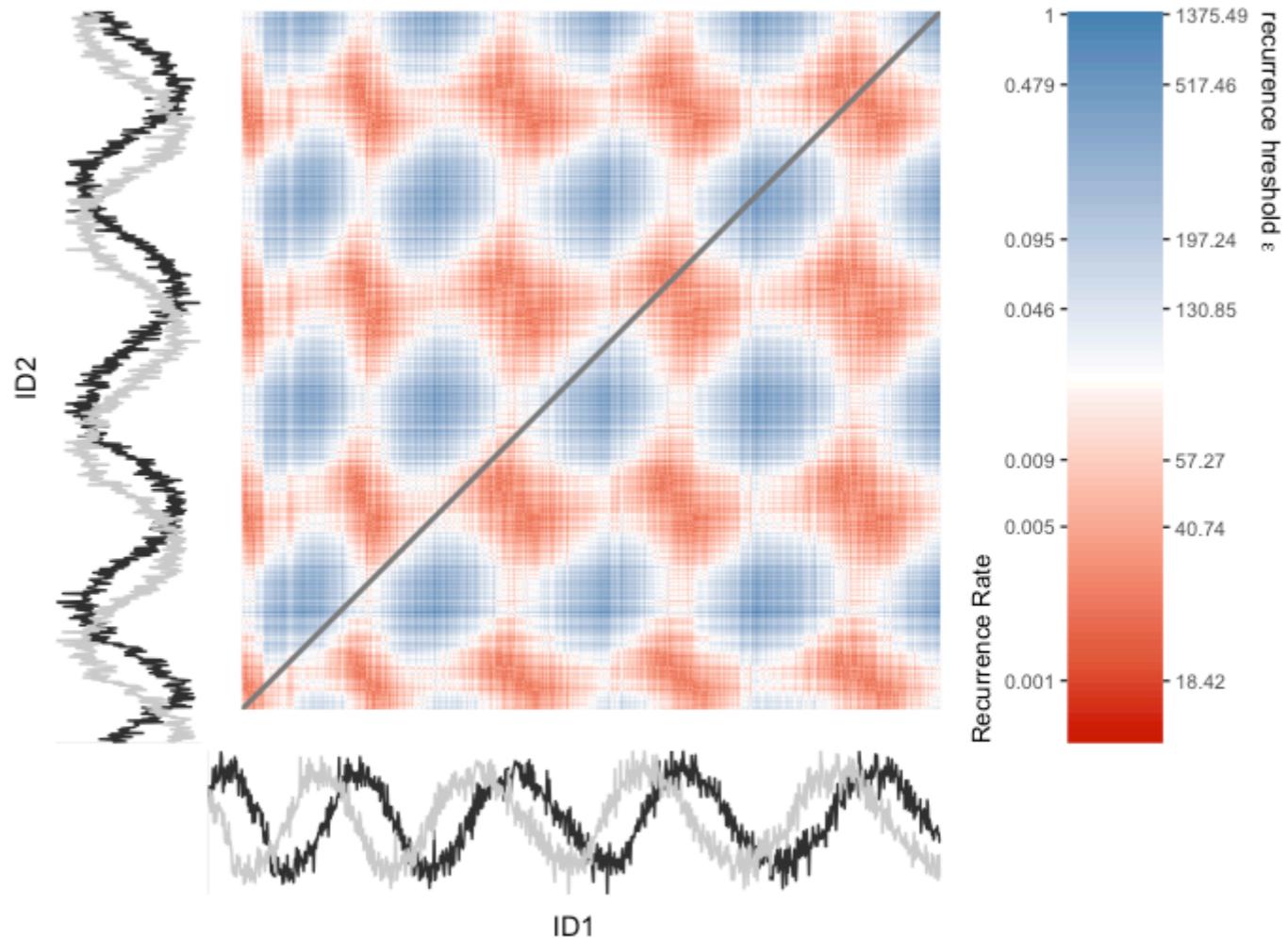


Data Preparation

- Data reduction
 - 100Hz → 5Hz
 - Time series of approximately 3,000 data points per dyad
- Displacement scores
 - $\text{Displ}_t = \sqrt{(X_{(t+1)} - X_t)^2 + (Y_{t+1} - Y_t)^2}$
- In a previous study we showed that measures obtained from surrogate and randomized timeseries differ significantly from the observed timeseries (Vink, Wijnants, Cillessen, & Bosman, 2017).

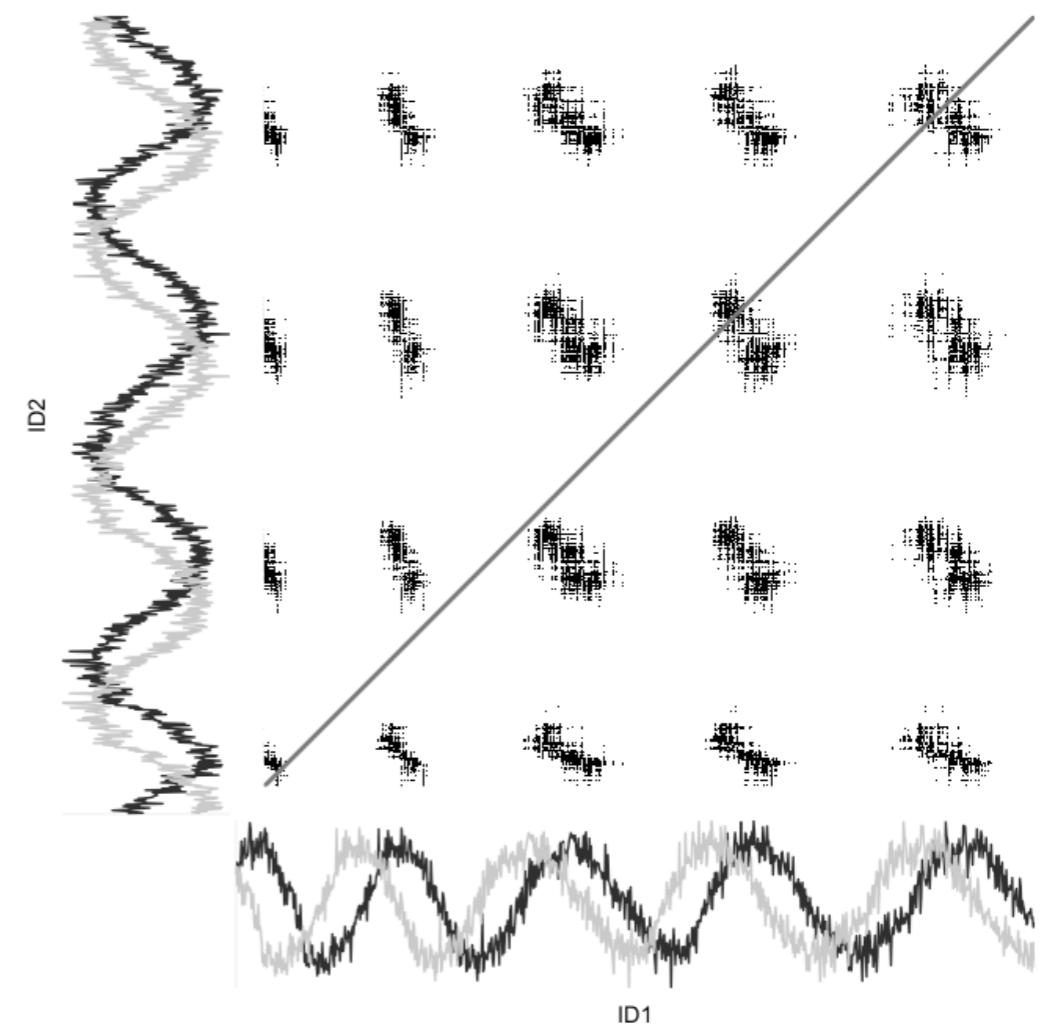
Cross Recurrence Quantification Analysis

- Can detect and quantify occurrences of synchronization in bivariate time series in reconstructed phase space (Shockley, 2005).
- Parameters used:
 - Time lag = 5 data points
 - Embedding dimension = 7
 - Recurrence rate = 5%
 - Thus, radius could vary

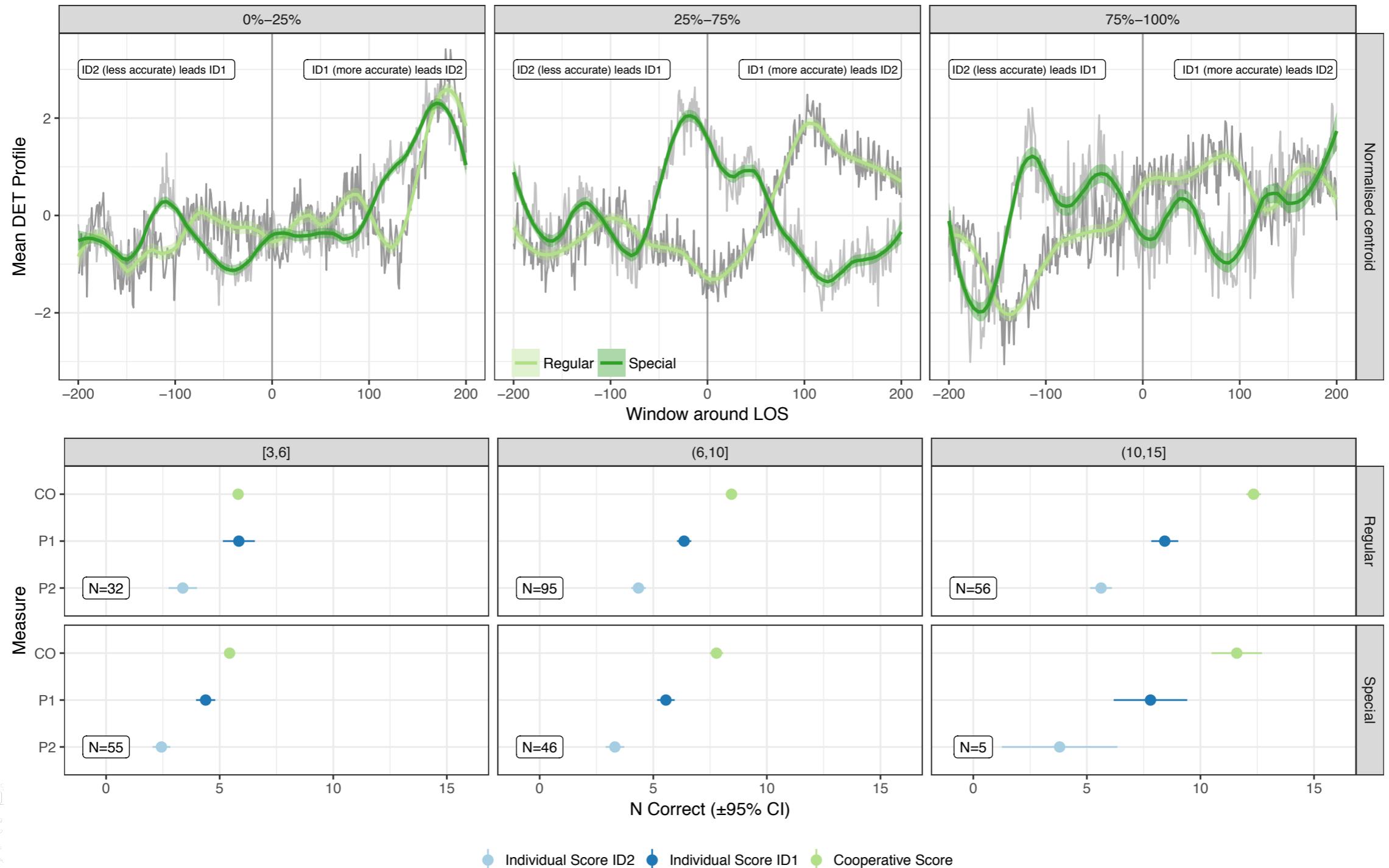


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PRE-MEASURE ACCURACY ID1 (left) > ID2 (right) [panels: percentile correct puzzles]



To summarize

- Children with a neurodevelopmental disorder and potentially comorbid postural sway disturbances performed less than their typically developing peers.
- However, their movement process (i.e., interpersonal synchronization/coordination) was similar.
- In addition, less disorder in synchrony predicted better task performance
 - This supports the view that in less restricted tasks where there is multifinality (i.e., more than one way of solving the problem):

“diversification of action is likely to occur, and complementary forms of interaction will in many cases supersede synchronous kinds of interaction” (Wallot, Mitkidis, McGraw, & Roepstroff, 2016, p. 3).