A Global Measure for Dyadic Symmetry in a Dynamic Model of Mother-Child Heart Rate Synchrony

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Summary

- The Notion of Symmetry
- Computation of Symmetry
  - Simulated Time Series Example
  - Windowed Cross-Correlation
  - Mahalanobis Distance
  - Computation of a Global Measure
- Symmetry in Practice
  - Symmetry in Dyadic Heart Rate Variability
- Conclusions and Future Directions

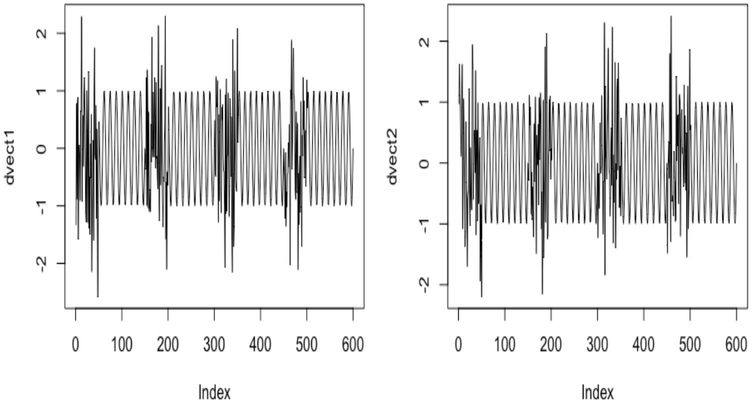
Symmetry as Reflective of Human Interaction

- The dynamic nature of human interaction is inherently complex and the burden is on methodologists to parse out the structures, processes, and characteristics of human interaction
  - Synchrony can be thought of as a behavioral coordination between two individuals (Boker, Xu, Rotondo, & King, 2002)
    - The synchrony process involves covariation between time series and can be represented visually with a cross-correlation function (Butler, 2011)
  - Symmetry is created by mirroring phenomenon that occur between two interacting individuals (Ashenfelter, Boker, Waddell, & Vitanov (2009))
    - Can be thought of as relatedness between time points
    - Symmetry here is thought to reflect temporal displacement/translation, although there may be other kinds of symmetry inherent in this system (Rosen, 1983)

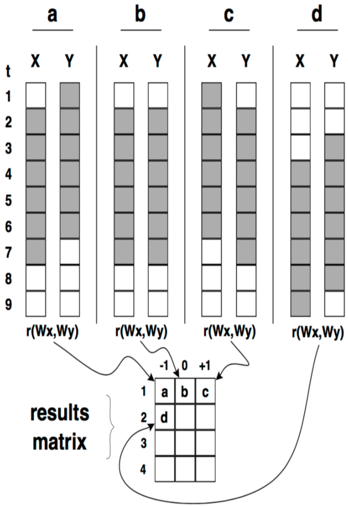
Symmetry Formation / Symmetry Breaking

- Symmetry formation is perpetuated by the human tendency to make use of symmetry in situations where similarity might be fruitful (Boker and Rotondo, 2002)
- Symmetry breaking can occur with a shift in context and is attributed with providing informational surprise (Boker and Rotondo, 2002)
  - Approximate Symmetry Transformation (Rosen, 1983)
  - Possible Outcomes After Perturbation:
    - Stability ("damped out")
    - Lability (still in range)
    - Instability (Spontaneous Symmetry Breaking)

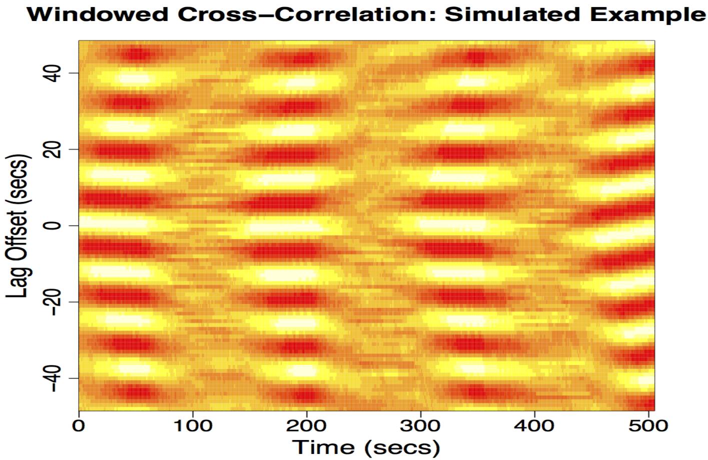
Graphical Depictions of Simulated Data



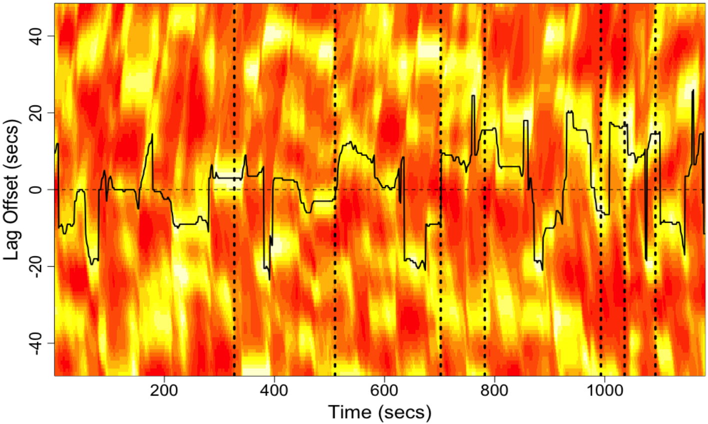
Windowed Cross-Correlations: Window Shifting



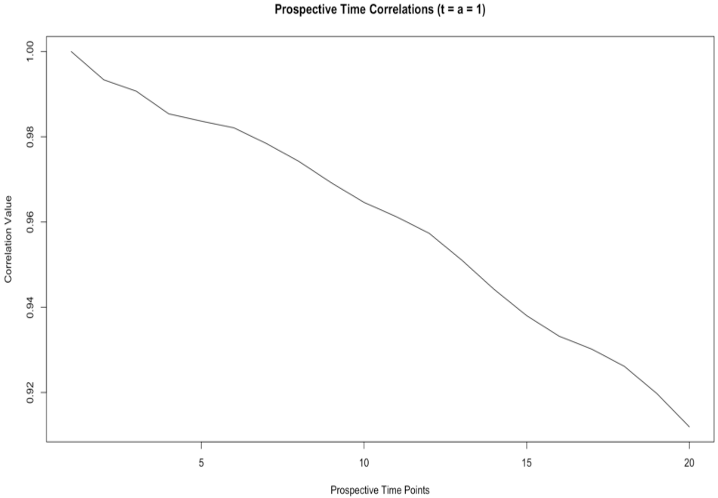
Windowed Cross-Correlation Plot For Simulated Data



Example of a More Complex Windowed Cross-Correlation Plot



A Plot of Prospective Correlations



The Prospective Correlation Matrix

$$\begin{bmatrix} r_{a_1a_1} & r_{a_1a_2} & r_{a_1a_3} & & r_{a_1a_{1+b}} \\ r_{a_2a_2} & r_{a_2a_3} & r_{a_2a_4} & \cdots & r_{a_2a_{2+b}} \\ r_{a_3a_3} & r_{a_3a_4} & r_{a_3a_5} & & r_{a_3a_{3+b}} \\ & \vdots & & \ddots & \vdots \\ r_{a_ia_i} & r_{a_ia_{i+1}} & r_{a_ia_{i+b}} & \cdots & r_{a_ia_{i+b}} \end{bmatrix}$$

where

a_i	is the ith time point
b	is the number of time points ahead of a_i correlated with a_i
$r_{a_ia_{i+b}}$	is the correlation of a_i with a_{i+b}

(Notice that the first column of the matrix is all 1's)

Bivariate Mahalanobis Distance: Concept and Calculation

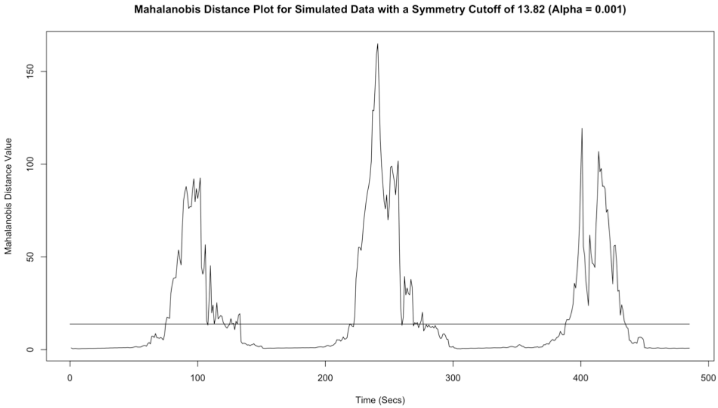
$$D_i^2 = (x_i - \mu)' \, \Sigma^{-1} \, (x_i - \mu)$$

where

x_i	is *i*th row of the data matrix x
μ	is a vector of the mean values of the columns of x
Σ	is the covariance matrix of x
D_i^2	is the Mahalanobis distance for the *i*th row of x

- In outlier detection, Mahalanobis distance values are generally compared to chi-squared values with alpha at .001 and (with two variables) 2 degrees of freedom (Mahalanobis, 1930; Meyers, Gamst, and Guarino, 2013)

A Comparison of Symmetric and Nonsymmetric Moments



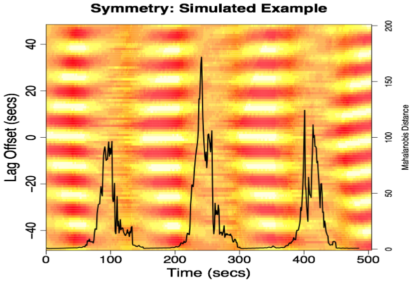
A Global Measure of Symmetry

$$G = \frac{S}{T}$$

where

- G is the global percentage of symmetry in the system
- S is the number of Mahalanobis distance values that fall below the threshold
- T is the total number of Mahalanobis distance values in the system

Mahalanobis Distance Plot and Symmetry Values for Simulated Data



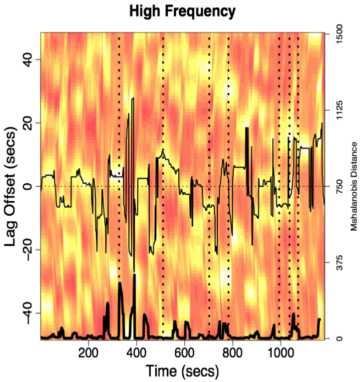
Global Symmetry Values for Simulated Data

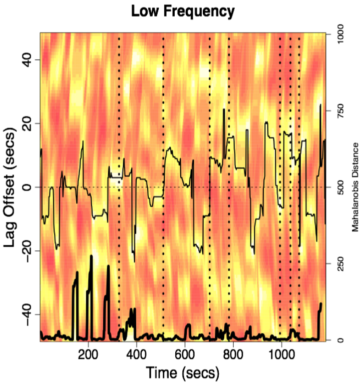
Alpha (α)	Chi-Square (X^2)	Symmetry (G)
.05	5.99	0.53
.025	7.38	0.55
.001	13.82	0.66

Strange Situation Procedure

- 2-hour lab session
- mother-child dyads were subject to the eight episodes of the Strange Situation paradigm (Ainsworth & Bell, 1970)
- Heart-rate collected by electro-cardiogram (ECG) - sampled at 300 Hz
- low-frequency (LF) and high frequency (HF) components collected
  - HF reflects parasympathetic nervous system
  - LF reflects sympathetic nervous system
  - LF-to-HF ratio reflects sympathovagal balance

Mahalanobis Distance Plot: High and Low Frequency Heart Rate Measures





Symmetry Computation: How and Low Frequency Heart Rate Measures

Global Symmetry Values for High Frequency

Alpha (α)	Chi-Square (X^2)	Symmetry (G)
.05	5.99	0.58
.025	7.38	0.62
.001	13.82	0.75

Global Symmetry Values for Low Frequency

Alpha (α)	Chi-Square (X^2)	Symmetry (G)
.05	5.99	0.54
.025	7.38	0.55
.001	13.82	0.73

Future Directions

- Use the robust mean and covariance matrix to compute the Mahalanobis distance values
- Refine chosen parameters for this context:
  - Wsize, or the size of the window for the windowed cross-correlation
  - b, or the number of prospective correlated time points
  - a, or the reference time point
- Use box-counting dimension techniques to determine a cutoff for nonsymmetric moments that is specific to each set of cross-correlations
- Configure a value that best represents symmetry in a given system
- Develop an algorithm that pinpoints moments of symmetry formation and symmetry breaking

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References

Ainsworth, M. D. S., & Bell, S. M. (1970). Attachment, exploration, and separation: Illustrated by the behavior of one-year-olds in a Strange Situation. *Child Development, 41*(1), 49.67.

Ashenfelter, K. T., Boker, S. M., Waddell, J. R., & Vitanov, N. (2009). Spatiotemporal symmetry and multifractal structure of head movements during dyadic conversation. *Journal of Experimental Psychology: Human Perception and Performance, 35*(4), 1072-1091.

Boker, S. M. & Rotondo, J. L. (2002). Symmetry building and symmetry breaking in synchronized movement. In M. Stamenov & V. Gallese (Eds.), *Mirror neurons and the evolution of brain and language* (pp. 163-171). Amsterdam: John Benjamins.

Crandell, L. E., Fitzgerald, H. E., & Whipple, E. E. (1997). Dyadic synchrony in parent-child interactions: A link with maternal representations of attachment relationships. *Infant Mental Health Journal, 18*(3), 247-264.

LaFrance, M. (1985). Postural mirroring and intergroup relations. *Personality and Social Psychology Bulletin, 11*(2), 207-217.

Mahalanobis, P. C. (1930). On the generalized distance in statistics. *Journal of Asiatic Society of Bengal, 2*(1), 541-588.

Mandelbrot, B. B. (1967). How long is the coast of Britain? *Science,* 156. 636-638.

Meyers, L. S., Gamst, G., & Guarino, A. J. (2013). *Applied Multivariate Research*. Sage.

Pascal, B. (1941). *Pensées: The provincial letters.* The Modern Library.

Rosen, J. (1983). *A symmetry primer for scientists*. John Wiley & Sons, Inc.