Quantifying the Dynamics of Interpersonal Interaction: A Primer on Cross-Recurrence Quantification Analysis using R

Moreno I. Coco (micoco@psicologia.ulisboa.pt)
Faculdade de Psicologia, Universidade de Lisboa
Alameda da Universidade, Lisboa, 1649-013, Portugal

Rick Dale (rdale@ucmerced.edu)
Cognitive and Information Sciences, University of California
Merced, 5200 North Lake Rd., Merced, CA 95343

Keywords: cognitive dynamics; cross-recurrence quantification analysis; R-tutorial; interpersonal interaction; statistical methods

Objectives and Scope

Humans live in a very interactive context, requiring very frequent exchange of information with con-specifics, which itself requires subtle temporal calibration of linguistic and non-linguistic activities. Over the last decade, the dynamics of interpersonal interaction has become a growing topic in cognitive science, precisely because of the important implications that interpersonal dynamics carry on shaping our 'social cognitive system.' Research on this topic has helped us understand, for example, how overt behavior such as body sway and eye movements of interacting individuals converge or diverge in various ways (Shockley, Santana, & Fowler, 2003; Richardson & Dale, 2005), whether temporal 'calibration' occurs over multiple behavioral scales (Louwerse, Dale, Bard, & Jeuniaux, 2012); as well as, developmental child-caregiver dynamics (Yu & Smith, 2013).

Many important advances on this research topic have been possible through the application of concepts and statistical methods, which provide quantification for the dynamic structure of cognitive responses observed when individuals interact. Recurrence Quantification Analysis (RQA) is one of such framework, and has received growing attention for research on interpersonal dynamics. Conceptually, RQA makes it possible to quantify how, and the extent to which, a signal is revisiting a similar state in time (Marwan, Carmen Romano, Thiel, & Kurths, 2007). When RQA is applied on two different streams of the same information, such as the eye-movement trajectories of two interlocutors, it takes the name of Cross-Recurrence Quantification Analysis (C/RQA). C/RQA can be used, for example, to examine the temporal organization of eye-movement trajectories of dyads of interlocutors as they complete a communicative task, and establish their attentional correspondence, their feedback dynamics (e.g., leader-follower lag), as well as examine how experimental variables might foster or disrupt such synchronism. In a sense, this makes C/RQA a very comprehensive time series technique for obtaining new descriptive statistics, and some have referred to it as a sort of generalized nonlinear cross-correlation function (Marwan et al., 2007).

In this tutorial, cognitive scientists from different fields, and at different stages of their career (from graduates students to senior scientists) will learn a dynamical systems framework to interpret and understand interpersonal interaction, and acquire the analytical principles of C/RQA, which helps framing this approach.

Tutorial format and pre-requisites

In this half-day tutorial, we aim to achieve two main goals: (1) a basic understanding of C/RQA and its applicability to research in cognitive science, (2) a primer, hands-on, of C/RQA to behavioral data using the package M. I. Coco and Dale (2014) in R.

We begin the tutorial by illustrating how C/RQA developed within the literature in cognitive science, and explain how this methodology can offer more than traditional approaches based on aggregation (M. Coco & Dale, 2014).

Then, we present the theoretical backbone of C/RQA in more details, and show-cast its applicability to various kinds of data, mostly relevant to language, from non-verbal behavior such as eye-movements, to transcripts drawn from speech. We focus on applications of C/RQA to categorical data, such as sequences of eye-movement fixation, or lyrics from songs, and explain how a Recurrence Plot (RP), the core component of C/RQA, is built from them. From the Recurrence Plot, we subsequently describe the different measures that can be computed on it, such as *recurrence rate*, *determinism*, etc., as well as guiding the participants to interpret the implications of such measurement on the understanding of cognitive processes. Just to give a flavor of what RQA could do, in Figure 1 we show a RP built on an extract of the lyrics from the song 'Call me maybe' by Carly Jepsen using the `crqa` package. The points along the diagonals are the sequence of words in the extract, that are repeated in time. In practice, along the diagonals we quantify how much, and for how long, is the system (in this case a sequence of words) synchronizing with itself. In C/RQA, we follow the same logic, but instead of looking at the synchronism of a time-series with itself, we want to discover the temporal dynamics of coupling between two different time-series.

In the last section of the tutorial, we provide the participants with a practical hands-on, coding session, using `R`. In particular, we will provide participants with worked-out instruction sheets written in Markdown, a marked-up language

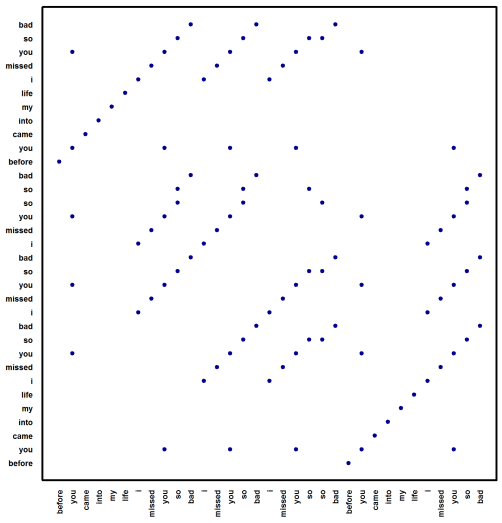

Figure 1: Recurrence Plot for speech extract: *before you came into my life I missed you so bad, I missed you so bad I missed you so so bad before you came into my life I missed you so bad* from the song 'Call me maybe' by Carly Jepsen.
RR: Percentage of points in the plot = 8.81%; **L**: Average length of diagonal lines = 4.87; **maxL**: Longest diagonal = 11; **DET**: Percentage of the points on diagonal lines = 81.25%; **ENTR**: Entropy distribution of diagonal lines = 0.92

which makes possible to integrate R-code, its output, and explanation within the same document (using `knitR`).

It would be preferable if tutorial participants have already basic familiarity with `R`. However, no specific knowledge of the `crqa` package is required. Participants are also expected to bring their laptops with R installed (`http://cran.r-project.org/`), along with the `crqa` package, so that they can actively participate to the hands-on session. We are agnostic as to the editor you should use to compile R. R-Studio (`http://www.rstudio.com/`) is becoming a popular choice because it provides a cross-platform environment, and several other features. However, also simple editing softwares, such as EMACS, can work.

Instructors

Moreno I. Coco is an Independently Funded Post-Doctoral Researcher at the University of Lisbon, Department of Psychology. His research interests span the cognitive science on a variety of topics, such as psycholinguistics, visual cognition and more recently, dialogue. His work combines experimental data collection with experimental modeling. He is an avid user, and active developer of R (e.g., `crqa`), and has been invited to organize hands-on workshops on analyzing eye-tracking data (his primary expertise) using R. He will mostly cover the hands-on part of the tutorial.

Rick Dale is an Associate Professor at the University of California, Merced. He is a full rounded cognitive scientist with interests and expertise in a wide range of areas of research, from interpersonal dynamics to deception. His research aims at quantifying cognitive dynamics during human communication, focusing on language use and evolution, as well as its intimate relation with action. In the context of C/RQA, he has pioneered the use of such method to quantify cognitive mechanisms of alignment, initially eye-movements, then extended to a wider range of cognitive responses. He will mostly cover the theoretical part of this tutorial.

Both instructors have given together a week-long postgraduate workshop on C/RQA (29th April - 2nd May, 2014) at the School of Philosophy, Psychology and Language Sciences (University of Edinburgh).

Table 1: Tutorial Schedule

Time	Content
9am - 10am	**Theory**: C/RQA in cognitive science research.
10am - 11am	**Application**: C/RQA for categorical time-series.
11am - 12am	**Hands-on**: C/RQA on eye-movement and speech data.

Tutorial Structure

The participants of this tutorial will be guided through practical research examples and hands-on activities (including data analysis) to understand the theoretical principles of CRQA. A detailed schedule is provided in Table 1.

References

Coco, M., & Dale, R. (2014). Cross-recurrence quantification analysis of behavioral streams: An r package. *Quantitative Psychology and Measurement*, *5*, 510.

Coco, M. I., & Dale, R. (2014). crqa: Cross-recurrence quantification analysis for categorical and continuous time-series [Computer software manual]. Retrieved from `http://CRAN.R-project.org/package=crqa` (R package version 1.0.5)

Louwerse, M. M., Dale, R., Bard, E. G., & Jeuniaux, P. (2012). Behavior matching in multimodal communication is synchronized. *Cognitive Science*, *36*(8), 1404–1426.

Marwan, N., Carmen Romano, M., Thiel, M., & Kurths, J. (2007). Recurrence plots for the analysis of complex systems. *Physics Reports*, *438*(5), 237–329.

Richardson, D. C., & Dale, R. (2005). Looking to understand: The coupling between speakers' and listeners' eye movements and its relationship to discourse comprehension. *Cognitive Science*, *29*, 39–54.

Shockley, K., Santana, M., & Fowler, C. (2003). Mutual interpersonal postural constraints are involved in cooperative conversation. *Journal of Experimental Psychology Human Perception and Performance*, *29*, 326-332.

Yu, C., & Smith, L. B. (2013). Joint attention without gaze following: human infants and their parents coordinate visual attention to objects through eye-hand coordination. *PloS one*, *8*(11), e79659.