Categorical Recurrence Analysis of Child Language

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Abstract

Coordination between conversation partners occurs at multiple levels, including choice of syntactic structure. A number of outstanding questions concerning the origin of this coordination require novel analytic techniques. Here we introduce and adapt a widely applied dynamical analysis, recurrence analysis. We use this method to explore lexical and syntactic coordination between children and caregivers in conversation. Results indicate that children and caregivers coordinate sequences of syntactic classes, and that this coordination diminishes over development.

Introduction

Quite a bit of research has been devoted to analyzing children's developing language and the kind of input available for its acquisition. Recently, for example, some research has suggested that caregivers may issue contrastive responses to a child's ungrammatical utterances, serving both to model how a structure should be used and as evidence that the child has erred (e.g., Chouinard & Clark, 2003). Accompanying this is the growing evidence that positive statistical information available in the input is sufficient to drive considerable generalization for learning grammatical structure (e.g., Lewis & Elman, 2001; Reali & Christiansen, 2003). All this research makes the broad and surely sensible assumption that the language use of children and caregivers is following a path of alignment or coordination: Statistical input and contingent responses in a conversation, if effective, shape the language of both the child and caregiver toward "syntactic coordination."

This assumption has a strong and a weak interpretation. In the weak and clearly trivial version, coordination merely refers to the child coming to use the particular language spoken by the caregiver. In the strong version, it implies that within individual interactions there is a process of coordination taking place. The child (and/or parent) is inclined to produce sequences of syntactic classes, during a conversation, that match those being heard. Research on adult conversation has lately suggested that a wide variety of behavior is coordinated in this way during social interaction. For syntactic structures particularly, for example, Branigan, Pickering and Cleland (2000) recently demonstrated that, in a picture-description dialogue, participants often repeat syntactic structures employed by another member of the conversation (see Garrod & Pickering, 2004 for a review). Research on preverbal vocalization also suggests that coordination may be a crucial characteristic of the language-learning task. For example, Goldstein, King and West (2003) recently demonstrated experimentally that maternal responses contingent on infant vocalization increase their quantity and quality. These timely caregiver interactions perhaps provide clues that, as grammar learning proceeds, there may also be a process of syntactic coordination.

The strong assumption therefore has important theoretical consequences. Recently, Garrod and Pickering (2004) have argued that dialogue is such a fluid and seemingly simple task for us because it is steeped in coordination mechanisms found in many cognitive processes during social interaction. The coordination assumptions about language input during acquisition, both weak and strong versions, complement this discussion by pursuing the extent to which coordination occurs and changes at a syntactic level of description in child-caregiver interaction. Although the weak assumption can be corroborated easily by simple observation of child and caregiver, the strong version remains a tricky issue to quantify. For this reason, it is important to pursue novel means of analyzing child-directed and child-produced language.

This paper presents an approach toward strong coordination by employing *recurrence analysis*, a technique used in a variety of disciplines. The analysis reveals global structural patterns of child and caregiver language alignment during interaction. By "global," we mean drawing general quantitative measures, with minimal dependence on statistical assumptions, describing the extent to which a bout of child-caregiver interaction involves language structures that are more or less similar to each other. Doing so provides a quantification of syntactic coordination between interlocutors in transcripts of naturalistic dialogue. The method is based on analyzing ordered sequences of measurements, and can be extended easily to comparing how two ordered sequences of measurements involve patterns of recurrence. The ordered sequences of concern here, of course, are time series of syntactic class usage by child and caregiver. The approach therefore provides a window on how structures used by the child "recur" in those used by caregiver (and vice versa).

The basic approach is given a technical introduction below, followed by two analyses of corpora drawn from the CHILDES database (MacWhinney, 2000).

Recurrence Analysis

The past 20 years have seen a family of techniques emerge in the physical sciences that allows global analysis of time series produced by dynamical systems. Global dynamical analyses generate informative parameters concerning a time series and the process generating it. For example, computing the Lyapunov exponent from a time series of measurements (e.g., the weather) provides an indication of

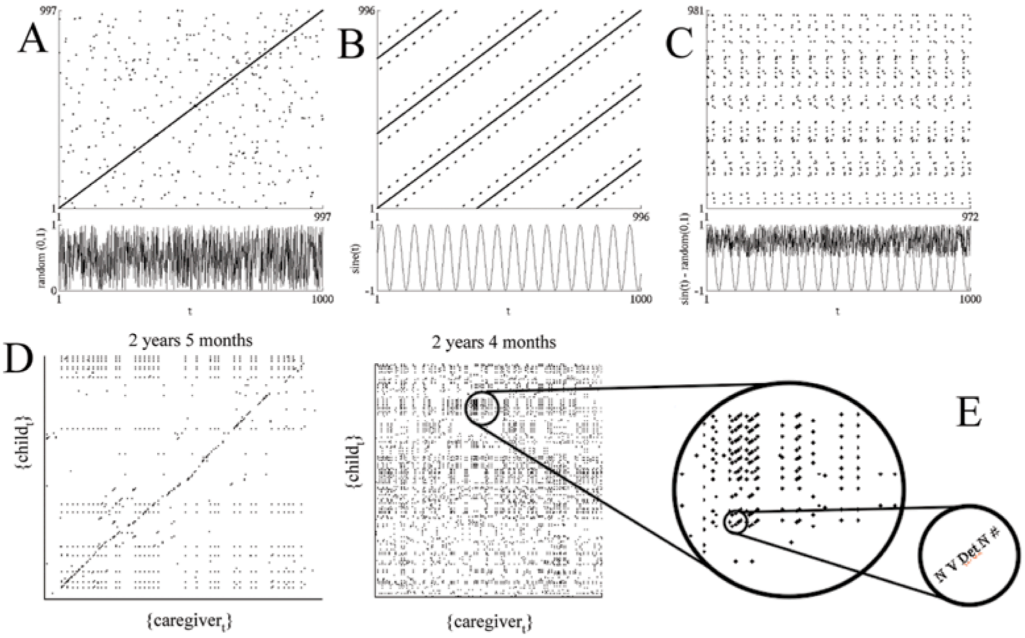

Figure 1: (A) Random series [0, 1]. (B) Sine wave *RP*. C: *CRP* between sine and random series. (D) Lexical *CRP* for Abe at 2 years 5 months. (E) Syntactic class *CRP* for Naomi. Zooming reveals diagonal structures. Their points represent syntactic recurrence. The relevant sequence is shown, with # as end-of-sentence.

the how two trajectories diverge in the system through time (e.g., chaotic systems; see Broer, Krauskopf & Vegter, 2001 for a recent volume on such analyses). Many of these informative global techniques require that certain assumptions be met about the dynamical system and the observed time series (e.g., stationarity; see Eckmann, Kamphorst & Ruelle, 1987 for a discussion). To overcome these limitations, Eckmann et al. (1987) offered a diagnostic technique permitting easily constructed visualizations of a time series to gain insight into the dynamical system from which it is drawn. The technique is free from the assumptions more sophisticated analyses require. For example, the Lyaponuv and other parameters require that a time series be of sufficient (typically extensive) length to be reliably computed. Recurrence analysis is not bound by this assumption (see also Webber & Zbilut, 1994).

The foundation of recurrence analysis can be easily laid out. Consider a time series of scalar measurements $\{x_t\}$, with $t = 1,\ldots, N$. An ordered sequence of vectors or "windows" of size m can be constructed from this time series, referred to as the "embedded" time series, $\xi\{x_t\}$ [1]

$$\xi\{x_t\} = \{\mathbf{x}_1, \ldots, \mathbf{x}_{N-m+1}\}, \text{ where } \mathbf{x}_i = (x_i, \ldots, x_{i+m-1})$$

By comparing each pair of vectors in the embedded time series, a recurrence plot (*RP*) is constructed out of the points (i,j) where $i, j = 1, \ldots, N - m + 1$, when the i^{th} and j^{th} vectors are sufficiently "close" or similar. An *RP* is therefore a set of points (i,j) that visualizes how the dynamical system is revisiting certain paths in the system's trajectory.

$$RP = \{(i,j) \mid d(\mathbf{x}_i,\mathbf{x}_j) < \varepsilon\}, \text{ where } \mathbf{x}_i, \mathbf{x}_j \in \xi\{x_t\}$$

In the above equation, d is a distance metric, for example Euclidean distance, and ε a threshold specifying how close two vectors must be to register a point (i,j) to the plot. An *RP* can have widely varying features depending on its time series. Fig. 1 illustrates some plots, revealing what Eckmann et al. (1987) originally referred to as differing "textures." Fig. 1C presents a cross-recurrence plot (*CRP*), a simple extension of the above technique to compare recurrent vectors between two different time series (e.g., Marwan & Kurths, 2002).

$$CRP = \{(i,j) \mid d(\mathbf{x}_i,\mathbf{y}_j) < \varepsilon\}, \text{ where } \mathbf{x}_i \in \xi\{x_t\}, \mathbf{y}_i \in \xi\{y_t\}$$

By quantifying the number and nature of recurrence points in an *RP* or *CRP*, one draws a global measure of the dynamical system generating the time series. For example, Fig. 1A is a plot of uniform white noise between 0 and 1, and exhibits little structure beyond the line of incidence (LOI; where $i = j$, and $d = 0 < \varepsilon$). Fig. 1B is a plot of a time series drawn from a sine wave function, and contains highly regular structures in the form of diagonal lines. Zbilut and Webber (1992; Webber & Zbilut, 1994) devised a supplementary technique called recurrence quantification analysis (RQA) consisting of a suite of measures extracted from *RPs*. The simplest example is percent recurrence (*%REC*), the percentage of points registered on the plot. This is computed by dividing the total points by the number of possible points: $\| RP \| / (N - m + 1)^2$. Diagonal structures on an *RP* are also informative, indicating periods of high regularity where stretches of the time series are recurrent. In Fig. 1B for example, almost all the points in the plot fall along diagonal structures, indicating the regularity of the sine wave itself.

This basic process of embedding a time series and subjecting that embedding to analysis is a means of manipulating data sequences that is used in a number of disciplines. Among others, these include molecular biology (Von Heijne, 1987), natural language processing and computational linguistics (see Manning & Schütze, 1999, for a review), and physiology (Webber & Zbilut, 1994). In psychology, Riley, Balasubramaniam, and Turvey (1999)

[1] For simplicity, we omit discussion of the additional parameter of lag. See Marwan (2003) for extensive discussion.

and Balasubramaniam, Riley, and Turvey (2000) investigated the dynamics of posture under differing conditions. Also, *CRPs* of bodily movements between conversation partners unveil postural coordination during dialogue (Shockley, Santana, & Fowler, 2003).

Categorical Recurrence Analysis

Recurrence analysis so far requires scalar measurements that permit the use of a continuous metric, such as a Euclidean distance metric. A non-continuous, categorical comparison of embedded vectors, however, allows this method to be applied to a range of cognitive phenomena. The time series evaluated may therefore be at a higher-order timescale, such as words or gaze fixations on certain objects. For example, the time series may consist of musical notes, with each unique element labeled numerically, thus obtaining a time series of numeric states.

$$A\ B\#\ C\ F\ A\ \ldots \Rightarrow 1,\ 2,\ 3,\ 4,\ 1,\ \ldots$$

To build a categorical *RP*, we compare directly any two vectors from the embedded time series using a 0-threshold function. This comparison generates a *comparison vector*, $\mathbf{c}_{ij}$, whose elements are 1 or 0, 1 representing a non-recurring numeric state and 0 representing a recurring one.

$$\mathbf{c}_{ij} = \Theta \mid \mathbf{x}_i - \mathbf{x}_j \mid,\ where \begin{cases} c_k = 1 \ \ if \ \ \mid x_{ik} - x_{jk} \mid \ > \ 0 \\ c_k = 0 \ \ if \ \ \mid x_{ik} - x_{jk} \mid \ = \ 0 \end{cases}$$

To generate an *RP* or *CRP* for our purposes, a fixed set C of comparison vectors serves as a metric. In the continuous application above, a point (i,j) is a member of the *RP* or *CRP* only if the vectors are sufficiently close according to a continuous distance metric and threshold. In the categorical case, only if $\mathbf{c}_{ij}$ is within this set C of relevant comparison vectors will point (i,j) be added to the *RP* or *CRP*.

$$RP/CRP = \{(i,j) \mid \mathbf{c}_{ij} \in C\}$$

Such a categorical technique invites analysis of time series from behavioral phenomena at a coarser timescale. Along with the continuous version, it admits of a number of benefits for analyzing psychological sequences (see Dale, Spivey, & Richardson, in preparation; Richardson & Dale, in press). In particular, the categorical nature allows selection of more complex set metrics to investigate recurrence in behavioral phenomena (see Table 1).

Table 1: Some example metrics

C	Description	Interpretation
$\{(0)\}$	1 recurrent item	Repetition of one word
$\{(0, 1, 0)\}$	Different element between 2 of the same	Novel word in a 2-word "frame"
$\{(1, 0, 1)\}$	Recurring element between 2 different elements	Word occurring in novel context
$sum(\mathbf{c}_{ij}) < a$	At least m - a elements must be the same	At least m - a words in a sequence the same in the same ordered places

Analysis 1: Lexical Coordination

We first explore coordination of *word* sequences between children and caregivers in conversation. Time series of words (tokens such as "dog" or "the") are translated into numeric states, and recurrence points on plots are drawn when two ordered words are the same between child and caregiver (metric of $C = \{(0,\ 0)\}$). Following this analysis, we can compare a second set of results based on syntactic *class* recurrence to discern whether pure lexical patterns are driving any syntactic coordination that categorical recurrence analysis reveals.

Materials

We selected three English corpora from the CHILDES database (MacWhinney, 2000): Brown's Sarah (Brown, 1973), Kuczaj's Abe (Kuczaj, 1976), and Sachs' Naomi (Sachs, 1983). These three corpora were used recently by Chouinard and Clark (2003) for the reasons we choose them here: The sample sizes are relatively large, numerous, and drawn at regular intervals. Each sample was turned into two separate time series, one for word usages by the child and another for the caregiver. Numeric labels composing the time series for each sample therefore stood for individual lexical tokens. The four most common of these from Sarah's samples are shown in Table 2.

Table 2: Frequent lexical items

Lexical form	Numeric identifier
"you"	11
"I"	68
"a"	51
"the"	39

Procedure

Plot generation We used the Matlab CRP Toolbox (Marwan & Kurths, 2002) to compute cross-recurrence plots between child and caregiver. *CRPs* were constructed from the time series using a bigram categorical metric ($C = \{(0,0)\}$). For each child's time series from sample k, $\{child_t\}_k$, we generated a cross-recurrence plot with the caregiver's time series drawn from the same sample, $\{caregiver_t\}_k$. This plot reveals bigram alignment of word usage between caregiver and child within the same discourse context, namely, in the same conversation. In addition, for every time series from sample k (a conversation at a particular time), we also generated a plot of the child's series $\{child_t\}_k$ crossed with the caregiver's from the sample $k+1$ (a conversation at another time), one step ahead in development, $\{caregiver_t\}_{k+1}$. This allows recurrence analysis within the same interaction, then analysis of syntactic coordination between child and caregiver outside that interaction. Both groups of plots will generate recurrence, but by comparing them we reveal whether patterns of word usage that are recurrent between caregiver and child are influenced by the context of the given conversation.

Analysis We chose two RQA measures to explore (used in both analyses). These measures are generated by analyzing the number and nature of recurrence points in the plots of our conversation samples. As a first measure, the simplest comparison between conversation types is of the overall recurrence of the plot (*%REC*). To compute this measure, we simply take the number of points in the plot divided by the area of the plot. Percentage recurrence represents the raw amount of coordination between a child's and caregiver's word sequences. This global quantity therefore indicates the extent to which child and caregiver coordinate word bigrams across the whole time series.

As our second measure, we used the temporal information of the plot to investigate what temporal range the recurrence points are falling into. Because each recorded point on a cross-recurrence plot represents a revisitation between two temporal indices (i and j), we can measure how the points' indices are organized in the plot. For example, if a large density of points appears near the LOI, it indicates that alignment occurs within the specific temporal context of ongoing conversation.[2] In this case, we chose a window of +/- 50 words outside the line of incidence of the plot, and computed how many points fall in that range, then divided it by the total possible points of that band along the LOI. This obtains another percentage score ($\%DREC_{50}$), but is determined by the temporal proximity of the points. This also allows us some basis for comparing this measure to the simplest, *%REC*.[3]

Results

An example cross-recurrence plot is presented in Fig. 1D. In this earlier age sample, extensive lexical recurrence occurs along the line of incidence, indicating consistent lexical bigrams used in ongoing conversational context between child and caregivers. Each corpus sample generated two such plots, for same- and other-conversation conditions, and we consider each measure based on these plots individually.

%REC All three corpora showed greater recurrence in same- versus other-conversation conditions (.18% vs. .16%, $t(268) = 2.4$, $p < .05$, .22% vs. .10%, $t(180) = 6.8$, $p < .0001$, and .11% vs. .09%, $t(414) = 8.2$, $p < .0001$, for Sarah, Naomi and Abe, respectively). Raw lexical bigrams are more consistent between child and caregiver across the entire conversation.

$\%DREC_{50}$ As intuitively expected, the line-of-incidence band exhibited much more recurrence per unit length within the same conversation than otherwise (.26% vs. .16%, $t(268) = 5.3$, $p < .0001$, .32% vs. .09% $t(180) = 10.3$ $p < .0001$, and .19 vs. .09 $t(414) = 13.4$, $p < .0001$, for Sarah, Naomi, and Abe, respectively). In fact, all $\%DREC_{50}$ scores significantly exceeded *%REC* scores, indicating greater recurrence occurring along the LOI.

Developmental change All measures exhibited significant change, diminishing across samples. These results are presented in Table 3.

Table 3: Measures regressed over time

	r	
Child	*%REC*	$\%DREC_{50}$
Sarah	-.39***	-.59***
Naomi	-.31**	-.57***
Abe	-.34***	-.40***

Notes: * = p < .05, ** = p < .01, *** = p < .001

Discussion

These lexical *CRPs* generated surprisingly low *%REC*. In particular, they likely exhibit higher recurrence early in development because of the fewer lexical items used by children. The measures diminish considerably because the wider array of lexical items available for children reduces the chances of recurrent lexical bigrams. Although this initial result therefore seems obvious, it suggests that there is not *trivial* lexical coordination that might drive the syntactic coordination we explore in the following analysis.

Analysis 2: Syntactic Coordination

Materials

The same corpora were used in this analysis. However, constructed time series were composed of the *syntactic class* to which words belong. Each lexical class (noun, verb, etc.) was assigned a numeric label, generating two time series of numeric states. The four most frequent structures from Naomi's time series are shown in Table 4. This significantly restricted the number of possible numeric states occurring (e.g., we did not encode agreement in the time series), permitting considerably more recurrence patterns in the plots.

Table 4: Frequent lexical classes

Lexical form	Numeric identifier
verb	5
noun	2
pronoun	6
determiner	14

Procedure

Plot generation As in the first analysis, the same- vs. other-conversation plot types were constructed in this analysis. Of course, the *CRPs* in this analysis were based on time series of syntactic *class* usage, revealing recurrent bigrams of grammatical class rather than lexical items.

[2] Where the number of words used by child and caregiver were not equal, we approximated the "true" LOI of the conversation by examining the band of points from $(1,1)$ to (N_m,N_k), where N_m is the length of the caregiver usage, and N_k of the child.

[3] A number of window sizes were tested, and results were consistent with those presented.

Analysis Exactly the same measures were computed in the *CRPs*: *%REC* and *%DREC*$_{50}$.

Results

An example plot is shown in Fig. 1E. Though more recurrence is clearly present, there is less obvious temporal structure. Temporal patterning can only be establishing by RQA of the plots across samples. As in the first analysis, we consider each measure individually.

%REC As in lexical recurrence, all three corpora showed greater recurrence in same- versus other-conversation conditions (1.76% vs. 1.71%, $t(268) = 2.1$, $p < .05$, 2.13% vs. 1.90%, $t(180) = 2.3$, $p < .05$, and 1.74% vs. 1.69%, $t(414) = 2.0$, $p < .05$, for Sarah, Naomi and Abe, respectively). Syntactic bigrams are more consistent between child and caregiver across the same entire conversation. Even with the diminished number of numeric states and the resultant higher *%REC*, there is comparable recurrence in other-conversation plots.

%DREC$_{50}$ If syntactic coordination is present in conversation, we should expect differences in this measure. Indeed, the line-of-incidence band exhibited more recurrence within the same conversation than otherwise (1.90% vs. 1.72%, $t(268) = 4.5$, $p < .0001$, 2.26% vs. 1.87% $t(180) = 3.8$, $p < .0001$, and 1.85% vs. 1.70% $t(414) = 4.5$, $p < .0001$, for Sarah, Naomi, and Abe, respectively). In Abe's and Sarah's analyses, these measures significantly exceeded those of *%REC*, suggesting that syntactic alignment itself is stronger along temporal proximity of ongoing conversation. While Naomi's is in the appropriate direction, this was not significant.

Developmental change All measures exhibited diminishing across age samples, though the patterns of significance are different across the three children. These results are presented in Table 5.

Table 5: Measures regressed over time

	r	
Child	*%REC*	*%DREC*$_{50}$
Sarah	-.06	-.23**
Naomi	-.48***	-.56***
Abe	-.07	-.32***

Discussion

Children and caregivers engage in syntactic coordination in conversation. Even though the magnitude of differences in the global measure (*%REC*) is small, they are consistently higher in the same- vs. other-conversation plots. The LOI analysis exhibits wider differences, indicating that recurrent bigrams of syntactic class are organized temporally in conversation. In addition, recurrence measures are vastly greater than in the first analysis. This supports that at least a trivial lexical patterning explanation for these results is unlikely.

General Discussion

We observed no exceptions to the general rule obtained across measures in both analyses: Same-conversation plots invariably produced greater recurrence than plots between children and their mother's usage from a separate conversation. Although the magnitudes of difference can appear small, the patterns are surprising in the second analysis given that plots represent word *class* bigrams, and not the specific lexical items used in the conversation, as in the first analysis. Moreover, the more minute figures (in particular *%REC*) from the first analysis suggest that this syntactic coordination is not driven *merely* by the coordination of individual lexical items.[4] Also, with the observation that these measures are reducing over development, it seems that early on children may be guided by the word class sequences used by caregivers (or, vice versa; Newport, Gleitman & Gleitman, 1977). A probable explanation for these data is that the sequences of word types used in these conversations are representative of a coupled process. Syntactic structures are coordinated in conversation. The interesting proviso is that this coupling is stronger at an earlier age. Whoever is responsible, caregiver or child or both, there is significant care taken in adapting word-class sequences used in conversation in early stages of development.

In fact, Sokolov (1993) discusses whether there should be expected patterns of "leading" by caregivers or children. He offered a similar analysis of corpora by investigating specific grammatical structures and how they are adapted by child and caregiver within a particular sentence window of conversation. His results are similar, though did not yet provide insight into leading or following patterns of syntactic alignment. The method presented here is capable of accomplishing this. Dale and Spivey (in preparation) have used the current method to investigate recurrence points above and below the LOI of recurrence plots. Temporal hypotheses of leading suggest that, for example, more recurrence points should occur above the LOI if the mother is using language *subsequently* aligned by the child. The current method thus offers further insights into rich temporal patterning and child-caregiver interaction.

The strong assumption, that syntactic coordination in language development occurs *within* an interaction, therefore seems to be supported by these data. Caregivers may be attuning their language to the language learner, and the language learner is picking up new skills in that context. These results provide a quantification of coordination within naturalistic conversation, and provide clues to how this alignment may be subject to developmental change.

The current findings have a few limitations. First, the method presented examines global patterns extracted from raw corpora. This does not mean that structure-specific patterns cannot be explored via categorical recurrence

[4] This is not meant to deny that the genesis of syntactic coordination could derive from the structure and organization of lexically motivated phrases (e.g., Tomasello, 2003).

analysis. Future application of this technique could target specific structures in the word-class sequences, and discover how their recurrence patterns are changing through time. This initial application of recurrence quantification analysis to child-caregiver interaction may therefore open numerous avenues of exploration concerning alignment of particular structures, and how they are organized in discourse.

Second, the methods presented here do not yet address a basic change in a child's time series across age samples: Sentence length is becoming longer. The overall reduction in recurrence measures observed in the results therefore must interact with a growing range of word class sequences. Indeed, given that later samples of child word class sequences contain fewer (but longer) sentences, the percentage recurrence *per sentence* is increasing. In fact, this makes the early samples' results here even more surprising: Despite the child's shorter utterances, there is still stronger coordination within the same conversation than otherwise.

Despite these limitations, the work presented here introduces a fairly simple technique for exploring recurrence within child-caregiver interaction. In other domains, the technique has been very useful because of its relatively few statistical assumptions (Zbilut & Webber, 1992) and amenability to very noisy datasets (see Bandt, 2004, for a related method and discussion). This categorical adaptation of recurrence analysis, and its application to language corpora here, has introduced quantification of a simple but strong hypothesis: Children and caregivers align word class sequences within conversation.

References

Balasubramaniam, R., Riley, M.A. & Turvey, M.T. (2000). Specificity of postural sway to the demands of a precision task. *Gait and Posture*, 11, 12-24.

Bandt, C. (in press). Ordinal time series analysis. *Ecological Modelling*.

Branigan, H.P., Pickering, M.J. & Cleland, A.A. (2000). Syntactic co-ordination in dialogue. *Cognition*, *75*, B13-25.

Broer, H., Krauskopf, B. & Vegter, G. (2001). *Global analysis of dynamical systems: festschrift dedicated to Floris Takens*. Bristol, UK: Institute of Physics.

Brown, R. (1973). *A First Language: The Early Stages*. Cambridge, MA: Harvard University Press.

Chouinard, M.M. & Clark, E.V. (2003). Adult reformulations of child errors as negative evidence. *Journal of Child Language*, 30, 637-669.

Dale, R., Spivey, M.J. & Richardson, D.C. (in preparation). Quantifying psychological sequences: Categorical recurrence analysis.

Dale, R. & Spivey, M.J. (in preparation). Cross-recurrence analysis of child-caregiver coordination.

Eckmann, J.-P., Kamphorst, S.O., Ruelle, D. (1987). Recurrence lots of dynamical systems. Europhysics Letters, 5, 973-977.

Garrod, S. & Pickering, M.J. (2004). Why is conversation so easy? *TRENDS in Cognitive Sciences*, 8, 8-11.

Goldstein, M. H., King, A. P., & West, M. J. (2003). Social interaction shapes babbling: Testing parallels between birdsong and speech. Proceedings of the National Academy of Sciences, 100(13), 8030 - 8035.

Kuczaj, S. (1976). *-ing, -s and -ed: A study of the acquisition of certain verb inflections*. Unpublished doctoral dissertation, University of Minnesota.

Lewis, J.D., & Elman, J.L. (2001). Learnability and the statistical structure of language: Poverty of stimulus arguments revisted. *Proceedings of the 26th Annual Boston University Conference on Language Development.*

MacWhinney, B. (2000). *The CHILDES project: tools for analyzing talk*. Mahwah, NJ: Erlbaum.

Marwan, N., Kurths, J.: Nonlinear analysis of bivariate data with cross recurrence plots, *Phys. Lett. A*, 302(5-6), 2002, 299-307.

Marwan, N. (2003). *Encounters With Neighbours* . Doctoral dissertation, University of Potsdam.

Newport, E., Gleitman, H. & Gleitman, L. (1977). Mother I'd rather do it myself: some effects and non-effects of maternal speech style. In C. E. S. C. A. Ferguson (Ed.), *Talking to children: language input and interaction*. Cambridge University Press.

Reali, F. & Christiansen, M.H. (2003). Reappraising poverty of the stimulus argument: A corpus analysis approach. Paper presented at the *Boston University Conference on Language Development*.

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

Riley, M.A., Balasubramaniam, R. & Turvey, M.T. (1999). Recurrence quantification analysis of postural fluctuations. *Gait and Posture*, 9, 65-78.

Sachs, J. (1983). Talking about the there and then: The emergence of displaced reference in parent–child discourse. In K. E. Nelson (Ed.), *Children's language*, Vol. 4, Hillsdale, NJ: Lawrence Erlbaum Associates.

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

Sokolov, J. (1993). A local contingency analysis of the fine-tuning hypothesis. *Developmental Psychology*, *29*, 1008-1023.

Tomasello, M. (2003). *A usage-based theory of language*. Cambridge, MA: Harvard University Press.

Von Heijne, G. (1987). *Sequence analysis in molecular biology: Treasure trove or trivial pursuits?* San Diego, CA: Academic Press.

Webber, C.L., Jr. & Zbilut, J.P. (1994). Dynamical assessment of physiological systems and states using recurrence plot strategies. Journal of Applied Physiology, 76, 965-973.

Zbilut, J.P. & Webber, C.L., Jr. (1992). Embeddings and delays as derived from quantification of recurrence plots. *Physics Letters A*, 171, 199-203.