

Quantifying **dynamic structures** of caregiver-child **interactions**: **Number talk** as a case study

Shirley Duong

Cognitive Talk Series

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Parents
Promoting
Early
Learning







MomSpeech	InfantSpeech	MomObject	BabyObject	Notes
			1 00:00:00:000 00:00:03:728 (banana, .)	00:00:00:000 00:00:00:000 (Mom and baby starts to play drinking tea game)
1 00:00:09:075 00:00:11:855 (Thanks. What is this? [Russian])			2 00:00:03:729 00:00:05:148 (banana, pitcher)	00:00:00:418 00:00:00:418 (BabyLocation code: m = near mom. p = near playset. w = walking between locations.)
			3 00:00:07:194 00:00:11:021 (banana, cup)	
		00:00:10:710 00:00:21:450 (cup, .)	4 00:00:11:022 00:00:21:450 (banana, .)	00:00:15:733 00:00:25:251 (Eating banana)
2 00:00:14:322 00:00:15:840 (It's tea?)				
3 00:00:16:929 00:00:20:058 (No... I want coffee. [Russian]. Bring me some coffee.)			5 00:00:21:384 00:00:25:812 (banana, cup)	
4 00:00:29:997 00:00:33:805 ({}[Russian])			6 00:00:25:813 00:00:26:465 (banana, .)	
			7 00:00:26:466 00:00:29:930 (banana, pitcher)	
			8 00:00:29:931 00:00:30:722 (banana, .)	
			9 00:00:30:723 00:00:39:830	

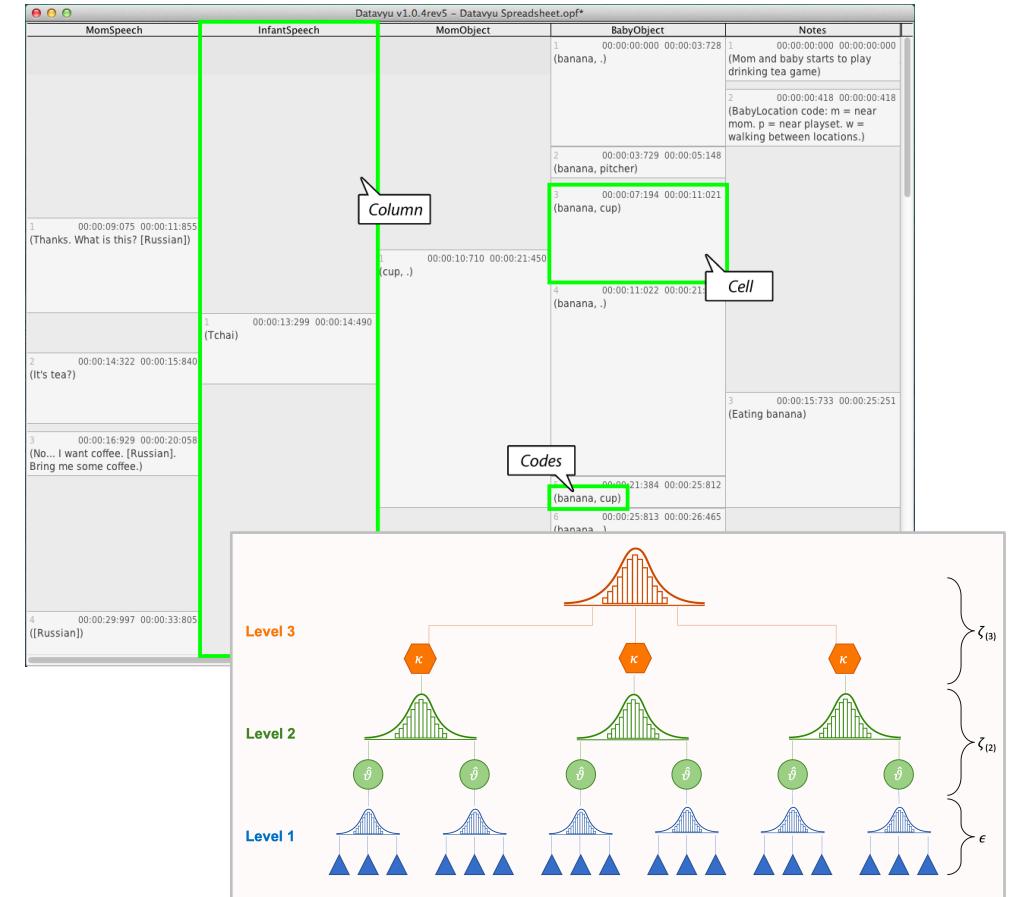


Image sources: Weekend Images Inc.; [Datavyu](#); Mathias Harrer's [bookdown](#) on meta analysis in R



What is this called? This is a...

What happened here?



What happened here?



- The dyad oriented themselves to the grocery shopping activity and selected roles to play

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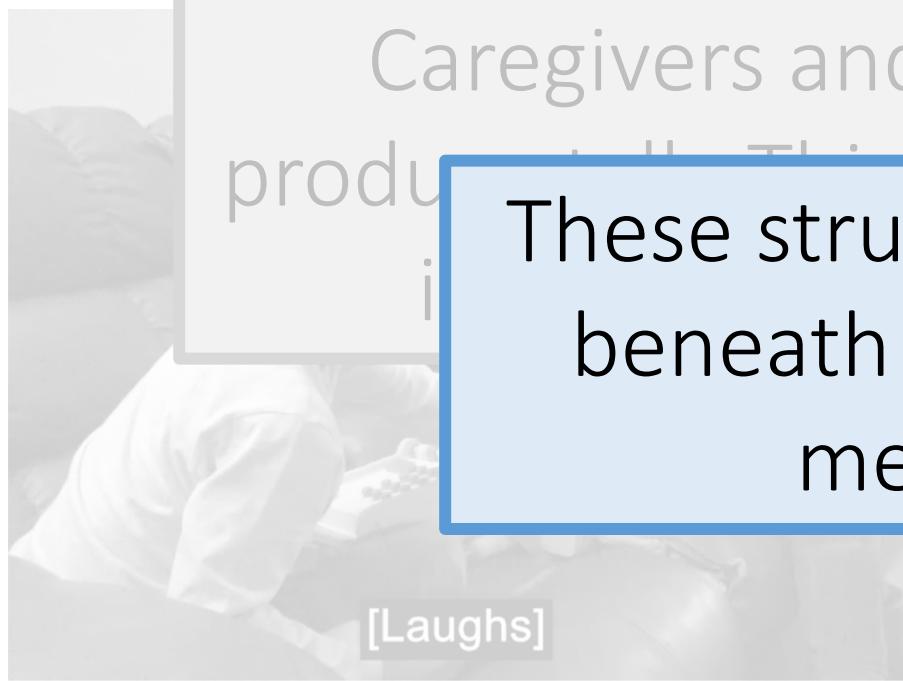
What happened here?

Caregivers and children ***collaboratively*** produce talk. This joint process may be evident in certain **conversational structures**.



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What happened here?



These structures may be **hidden** beneath common **frequency** measures of talk.

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How can we uncover reciprocal, complex, and dynamic structures of caregiver-child conversations?

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By using **cross-recurrence quantification analysis** (CRQA)!

Basic science question:
Specific **mechanisms** driving
the relation between dyadic
conversations and child
development



Real-life application:
Guidance and **resources**
based on the “**realities** and
complexities” of caregiver-
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FRED ROGERS CENTER
for early learning and children's media
at Saint Vincent College



Research questions

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1. What is cross-recurrence quantification analysis (CRQA)?

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2. Case study: What can CRQA help us uncover about dyadic interactions about number during pretend play in the home?

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1. What is cross-recurrence quantification analysis (CRQA)?
2. Case study: What can CRQA help us uncover about dyadic interactions about number during pretend play in the home?
3. Does CRQA offer additional insight into dyadic interactions *beyond* counts of input?

RQ1: What is cross-recurrence quantification?

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- Data analysis method that allows researchers to visualize and quantify the frequency and duration of **repeated events** (i.e., recurrences) of **two dynamical systems** (e.g., two speakers).

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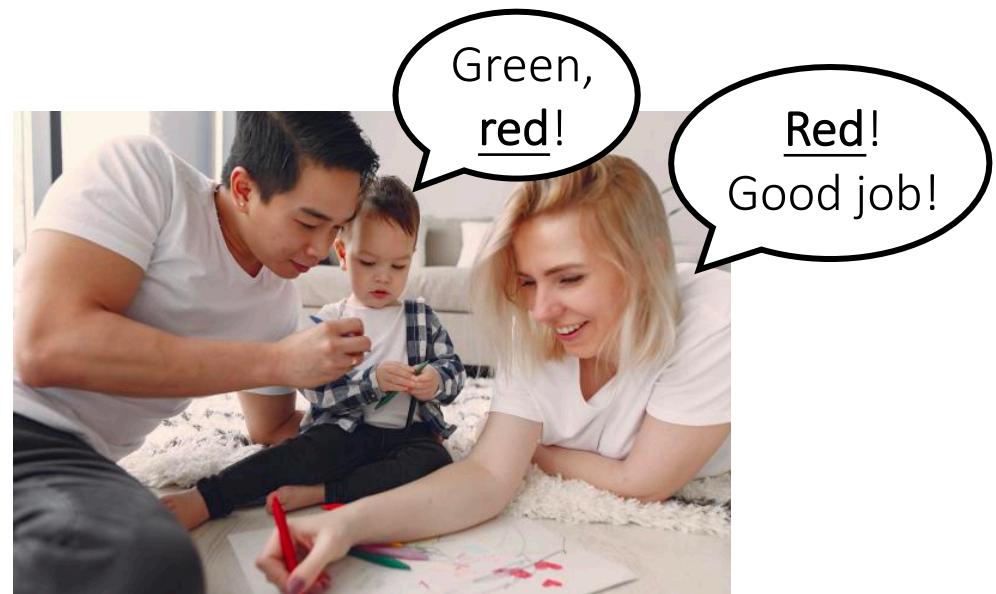


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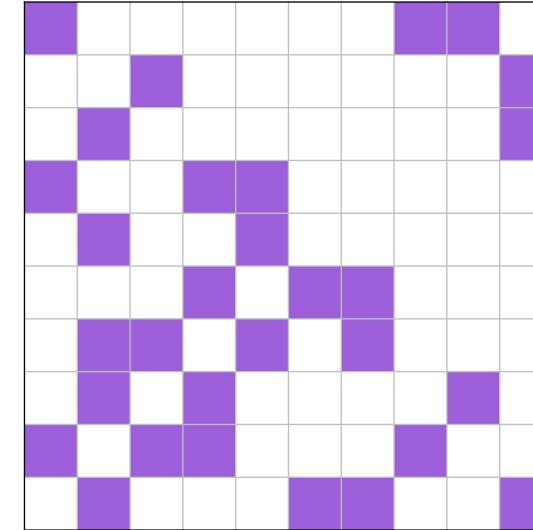
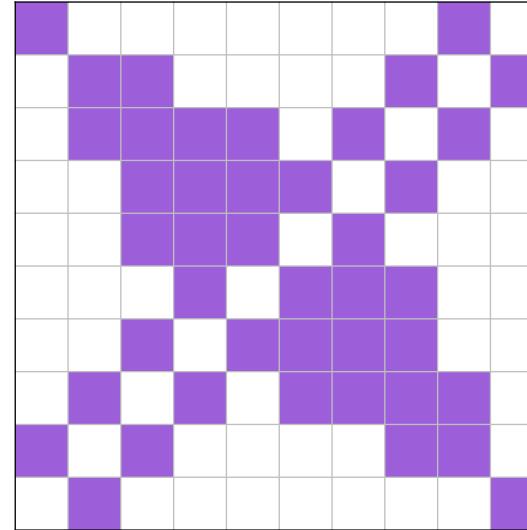
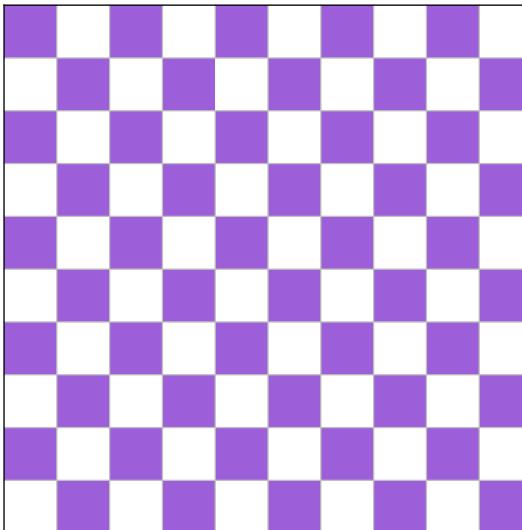


RQ1: Basic steps of cross-recurrence quantification

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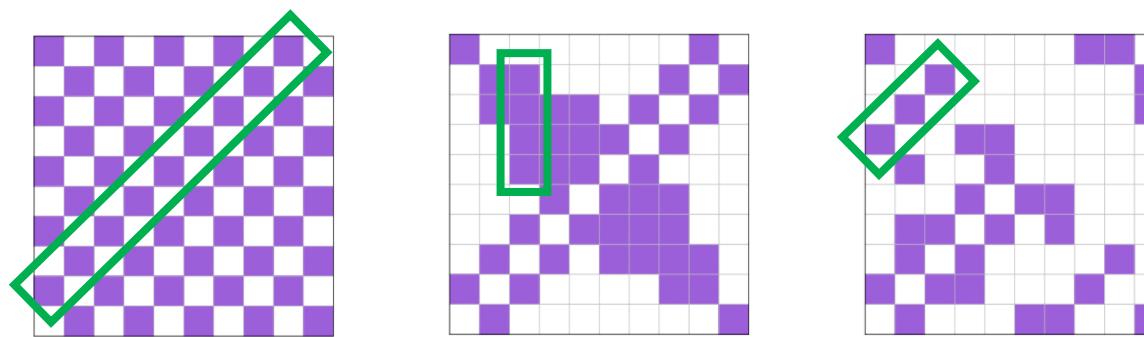
1. Create a **recurrence plot** (RP) that describes the *behavior* of two systems (e.g., speakers in this case)

RQ1: Example recurrence plots



RQ1: Basic steps of cross-recurrence quantification

1. Create a **recurrence plot** (RP) that describes the *behavior* of two systems (e.g., speakers in this case)
2. Quantify **structures** on the RP, i.e., the *number* and *length* of recurrences



RQ2: Case study

RQ2: Case study – Participants

- 124 caregiver-child dyads (*Mean child age = 4.40 years, SD = .30 years*) enrolled in the **Parents Promoting Early Learning** study



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 - Relatively highly educated (74% had at least a Bachelor's degree)
- Family yearly household income varied (*Mean = \$106,170, SD = \$69,114, Median = \$98,500, Range = \$5,000-\$350,000*)



RQ2: Case study – Observations of pretend play

- Dyads interacted with grocery store toys for ~8 minutes each



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RQ2: Case study – Observations of pretend play

- Dyads interacted with grocery store toys for ~8 minutes each
- Interactions were videotaped and transcribed verbatim
- Transcripts were coded for the occurrence (and types) of **number talk (NT)**, utterances about math concepts such as identifying numerals, counting, labeling sets, arithmetic, etc.



RQ2: CRQA – Generating a recurrence plot

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<i>Speaker</i>	<i>Utterance</i>
Parent (P)	Okay, can I have chocolate please?
Child (C)	A two or one?
P	Two.
P	How much are two?
C	One, two, three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen.
P	Thirteen?
P	Hmm.
C	You don't have enough.
P	Or thirteen cents?
C	Thirteen cents.
P	Okay, so I have a ten and a ten so that's twenty.
P	That's twenty cents.
C	You don't have enough.
P	So, if I give you my twenty cents, you have to give me- that's thirteen.
P	You have to give me seven pennies in there that you can count out.

RQ2: CRQA – Generating a recurrence plot

<i>Speaker</i>	<i>Utterance</i>	<i>P event series</i>	<i>C event series</i>
Parent (P)	Okay, can I have chocolate please?	3	6
Child (C)	A two or one?	2	1
P	Two.	1	2
P	How much are two?	1	2
C	One, two, three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen.	2	1
P	Thirteen?	1	2
P	Hmm.	3	6
C	You don't have enough.	5	4
P	Or thirteen cents?	1	2
C	Thirteen cents.	2	1
P	Okay, so I have a ten and a ten so that's twenty.	1	2
P	That's twenty cents.	1	2
C	You don't have enough.	5	4
P	So, if I give you my twenty cents, you have to give me- that's thirteen.	1	2
P	You have to give me seven pennies in there that you can count out.	1	2

Derive two event series from the transcript

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P	Or thirteen cents?	1	2
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P	Okay, so I have a ten and a ten so that's twenty.	1	2
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P	You have to give me seven pennies in there that you can count out.	1	2

Event series codes:

- **1 = using NT**
- **2 = listening to NT**
- All other = using non-NT or listening to non-NT for each speaker

RQ2: CRQA – Generating a recurrence plot

<i>Time point n (t_n)</i>	<i>P event series</i>	<i>C event series</i>
1	3	6
2	2	1
3	1	2
4	1	2
5	2	1

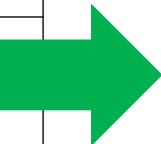
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Create an $n \times n$ matrix for every possible pair of time points,

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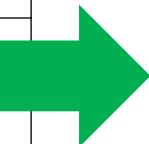
C event series

Create an $n \times n$ matrix for every possible pair of time points,

		<i>Code</i>				
		1	2	3	4	5
<i>Code</i>	<i>Time point n (t_n)</i>	t_5				
		t_4				
<i>Code</i>	<i>Time point n (t_n)</i>	t_3				
		t_2				
<i>Code</i>	<i>Time point n (t_n)</i>	t_1				
		3	2	1	1	2
		<i>P event series</i>	<i>t₁</i>	<i>t₂</i>	<i>t₃</i>	<i>t₄</i>

RQ2: CRQA – Generating a recurrence plot

<i>Time point n (t_n)</i>	<i>P event series</i>	<i>C event series</i>
1	3	6
2	2	1
3	1	2
4	1	2
5	2	1



C event series

Create an $n \times n$ matrix for every possible pair of time points,

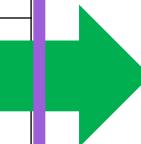
	<i>Code</i>				
t_5	1				
t_4	2				
t_3	2				
t_2	1				
t_1	6				

	3	2	1	1	2
<i>P event series</i>					<i>Code</i>
t_1	3	2	1	1	2

RQ2: CRQA – Generating a recurrence plot

<i>Time point n (t_n)</i>	<i>P event series</i>
1	3
2	2
3	1
4	1
5	2

<i>C event series</i>
6
1
2
2
1



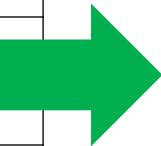
C event series

Create an $n \times n$ matrix for every possible pair of time points,

<i>Code</i>	1	2	3	4	5	<i>Code</i>
t_5						
t_4						
t_3						
t_2						
t_1	6					
	3	2	1	1	2	<i>Code</i>
	t_1	t_2	t_3	t_4	t_5	
<i>P event series</i>						

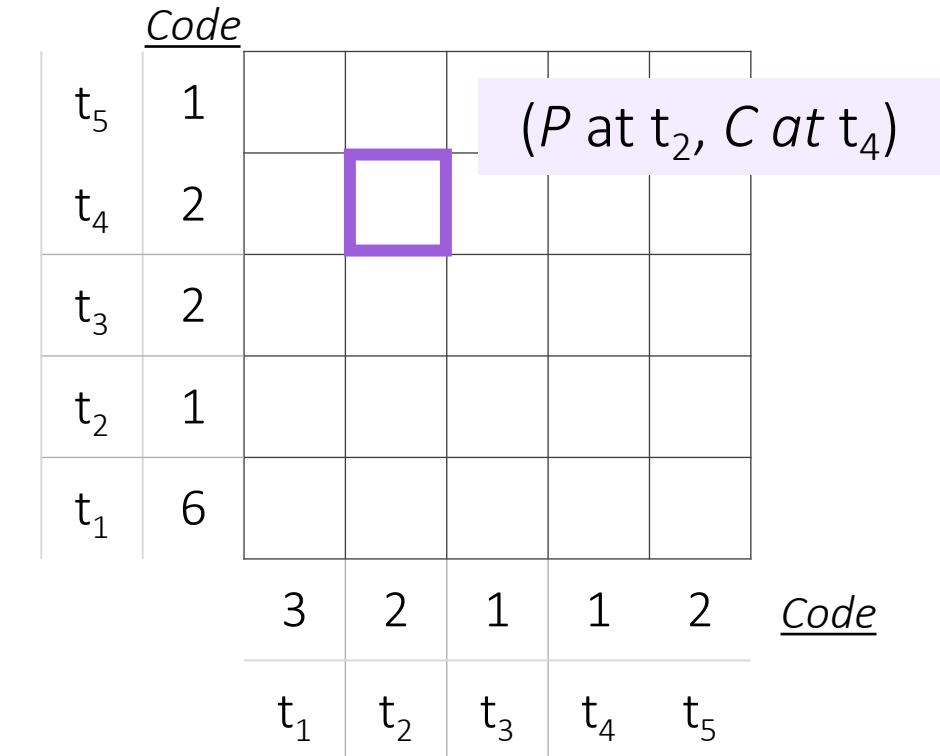
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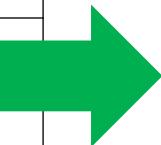
C event series

Create an $n \times n$ matrix for every possible pair of time points,



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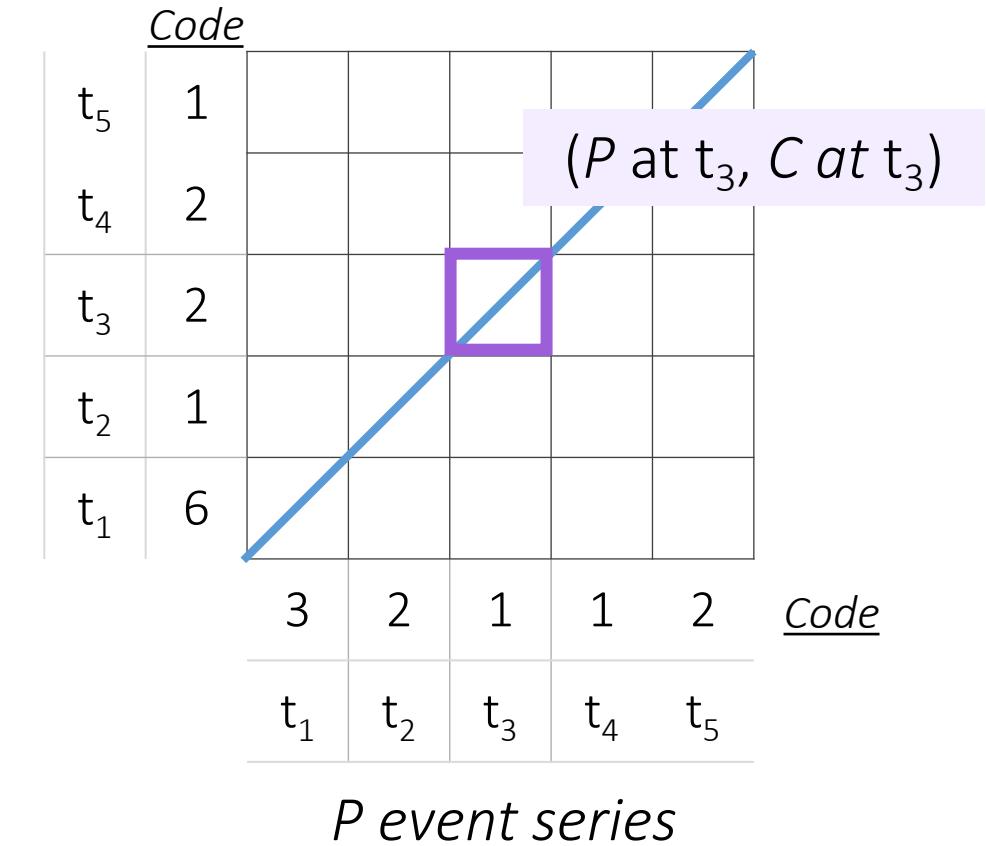
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1	3	6
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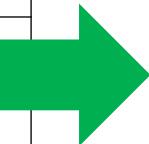
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(blue line = line of incidence)

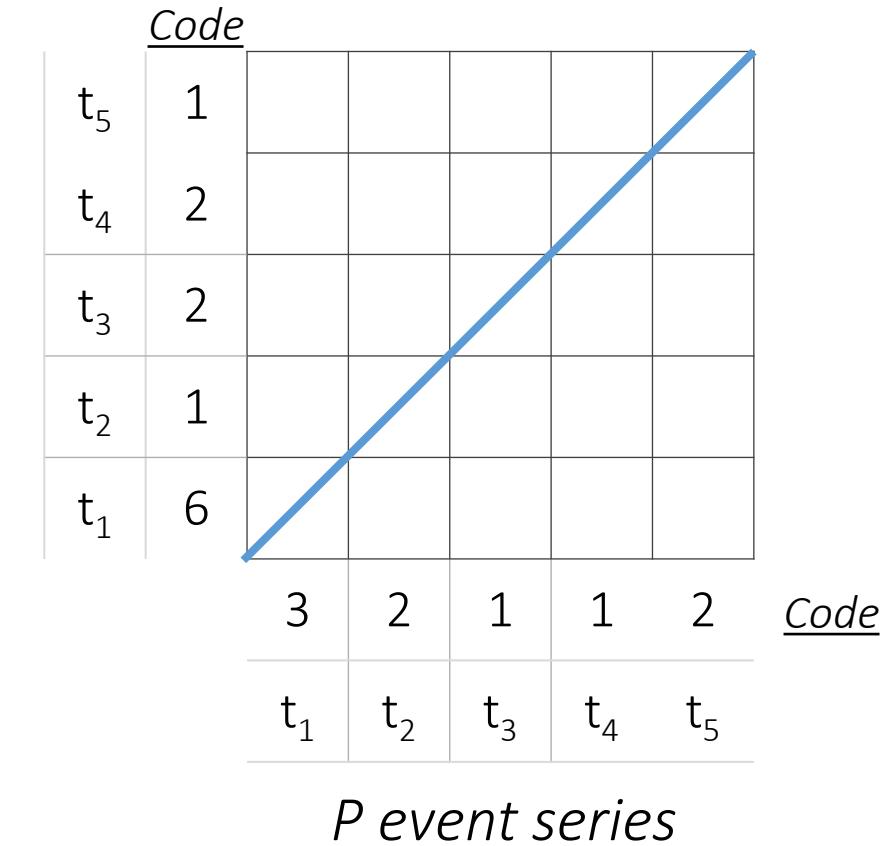


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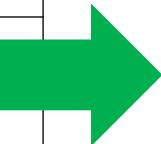
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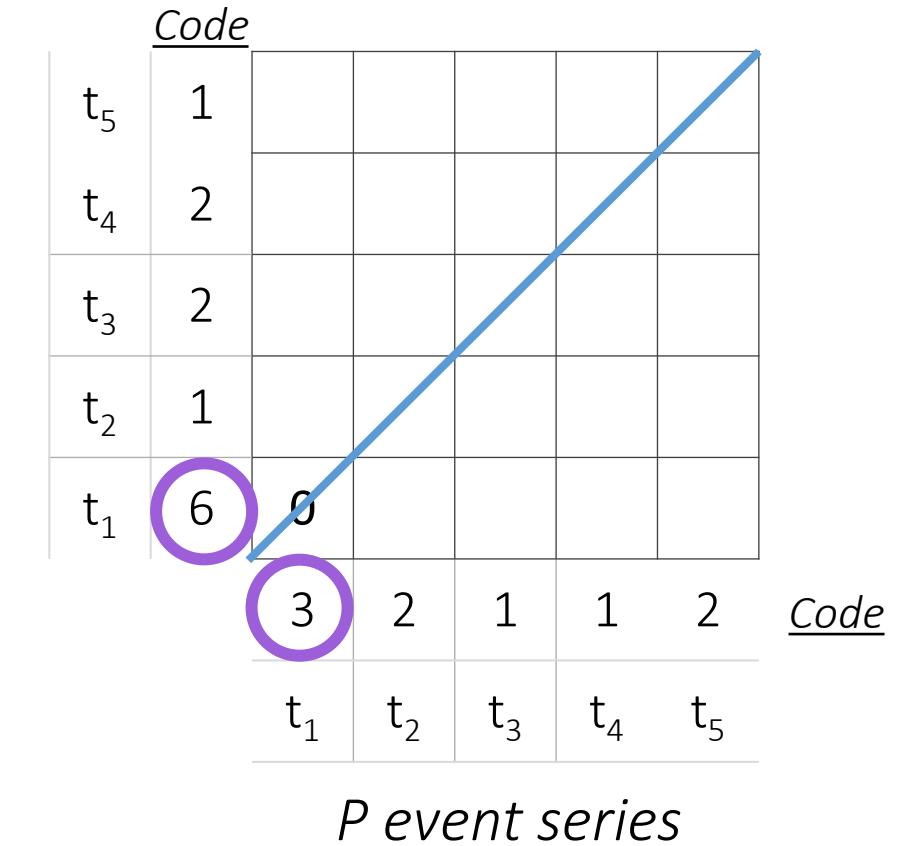
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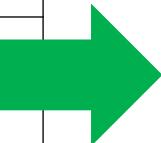
C event series



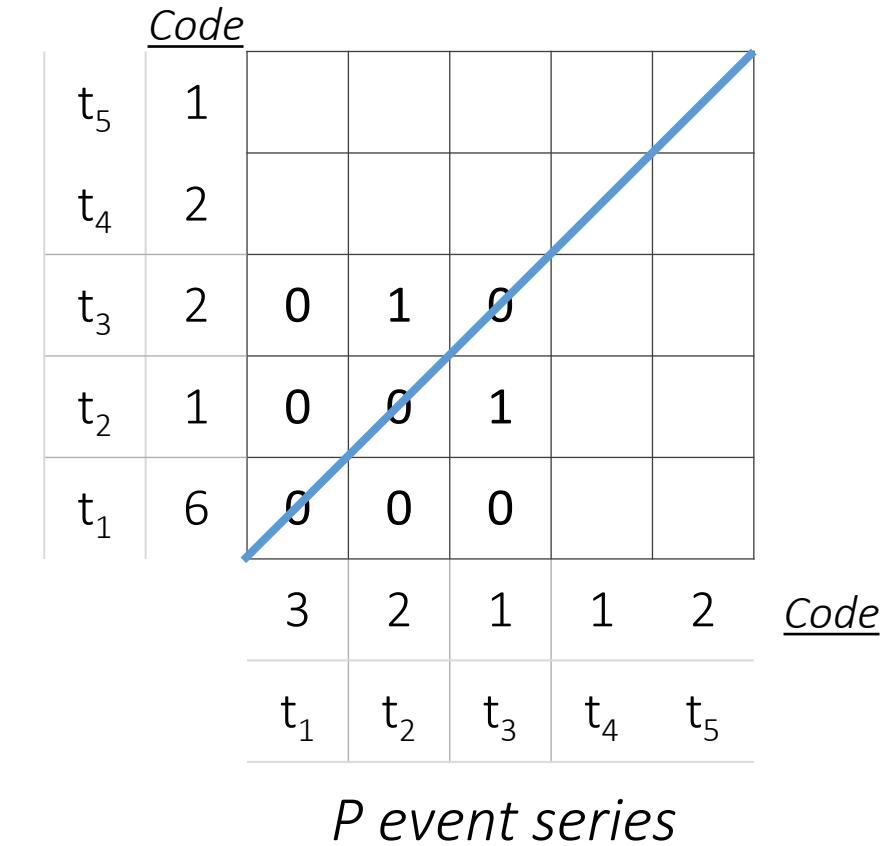
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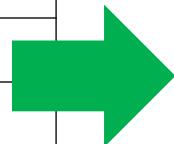
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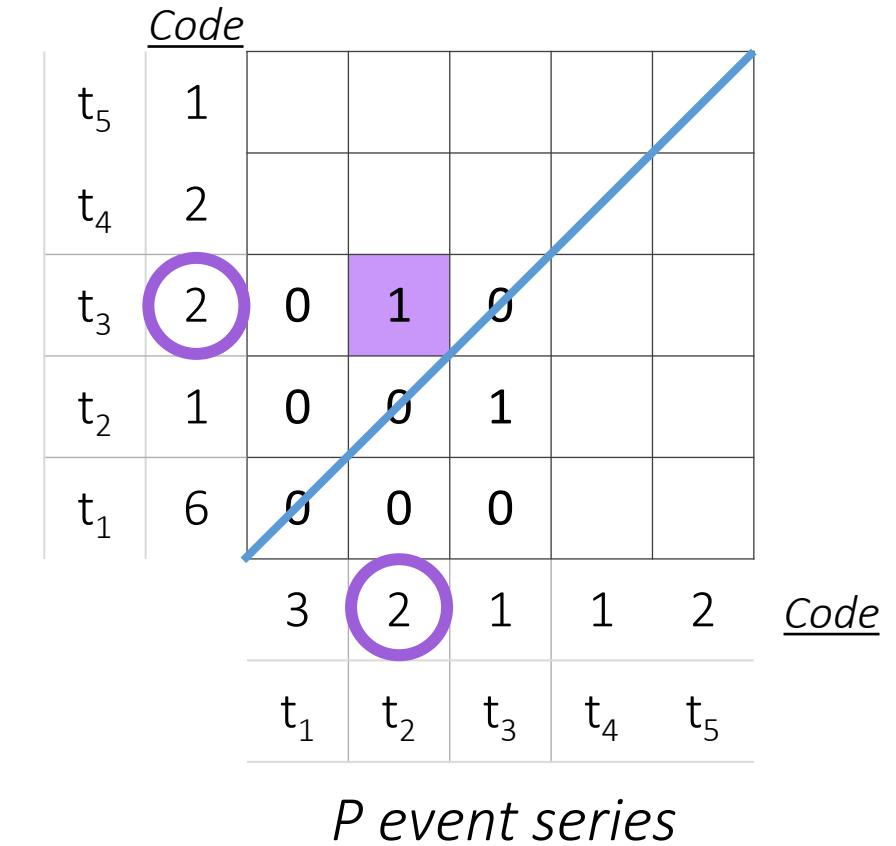
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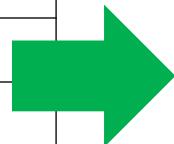
C event series



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1	3	6
2	2	1
3	1	2
4	1	2
5	2	1



C event series

	<i>Code</i>				
t_5	1	0	0	1	1
t_4	2	0	1	0	0
t_3	2	0	1	0	0
t_2	1	0	0	1	1
t_1	6	0	0	0	0

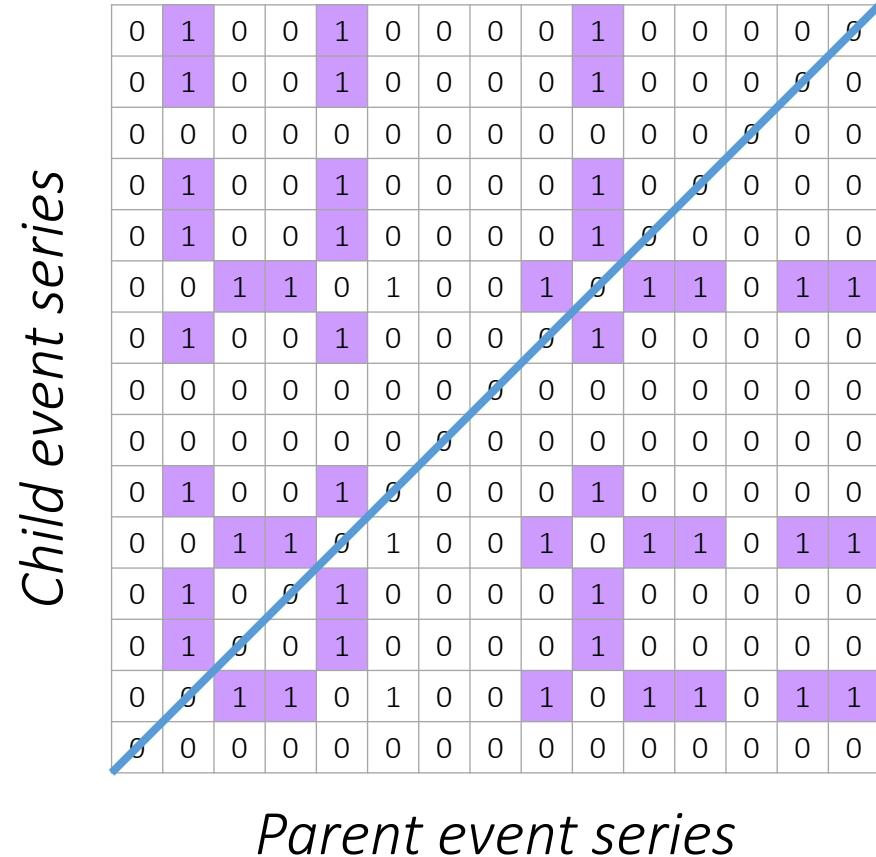
P event series

Code

$t_1 \quad t_2 \quad t_3 \quad t_4 \quad t_5$

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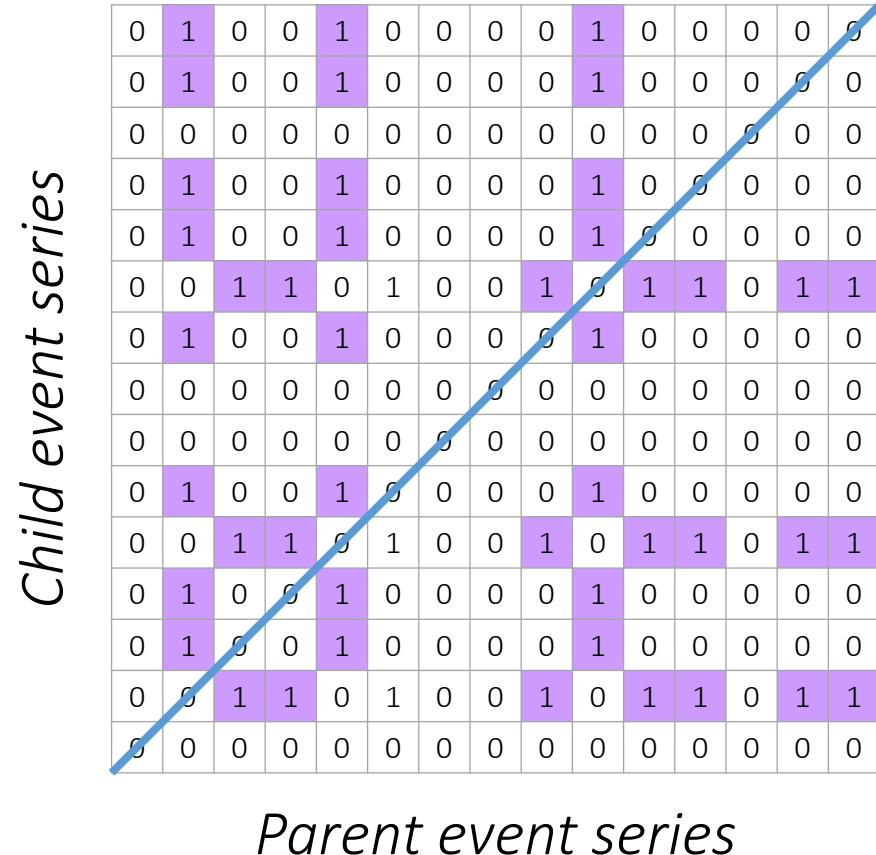


RQ2: CRQA – Generating a recurrence plot

Yay, we have our RP! 



RQ2: CRQA – Quantifying NT structures on the RP



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Recurrence rate (RR) =

% of recurrent points (purple 1s) on the RP

RQ2: CRQA – Quantifying NT structures on the RP

0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
0	0	1	1	0	1	0	0	0	1	0	1	1	0	1	1	0
0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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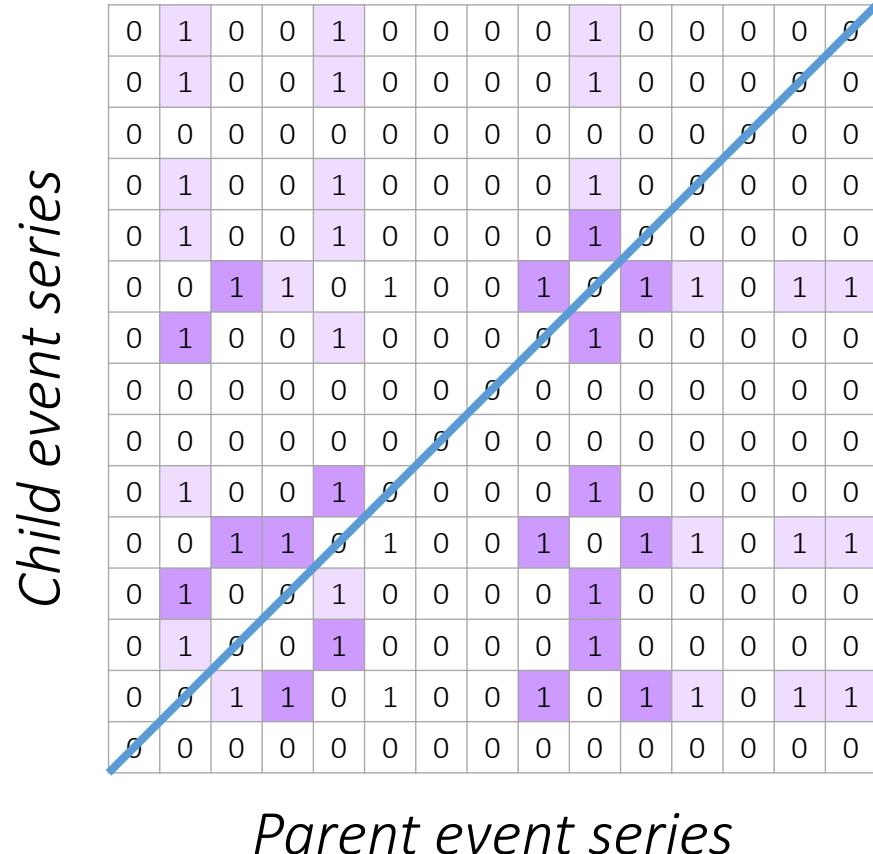
Recurrence rate (RR) =

% of recurrent points (purple 1s) on the RP

How often do parent and child NT co-occur?

What is the extent to which dyads reciprocate each others' NT?

RQ2: CRQA – Quantifying NT structures on the RP



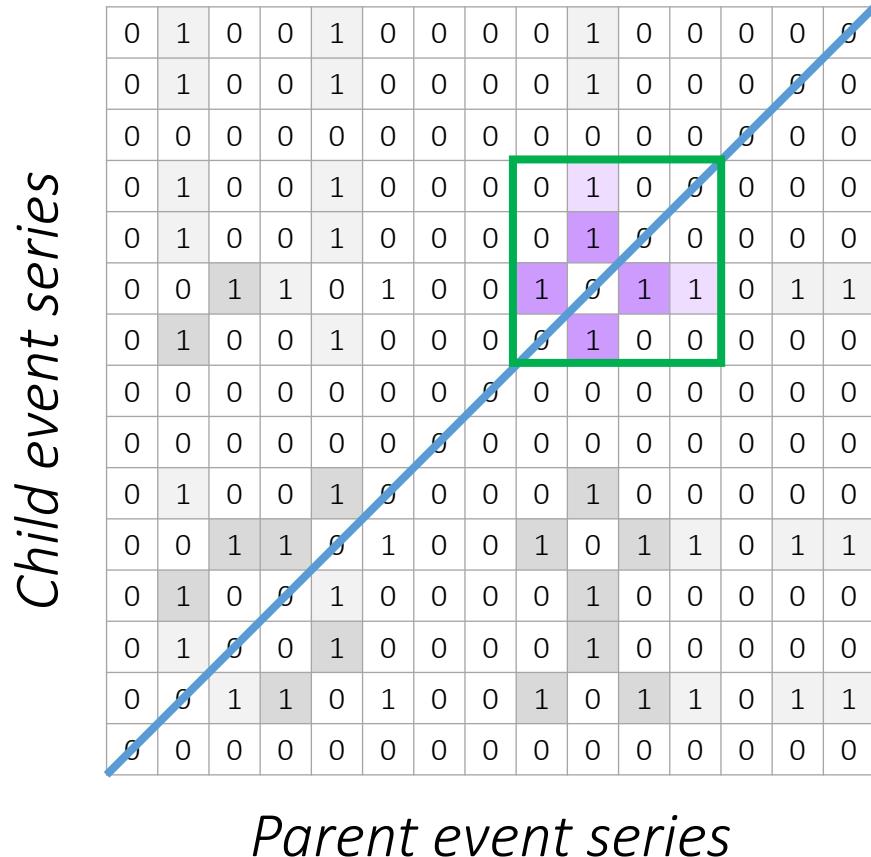
Determinism (DET) = % of recurrent points
that make up diagonal lines of at least 2
utterances

RQ2: CRQA – Quantifying NT structures on the RP

Determinism (DET) = % of recurrent points
that make up diagonal lines of at least 2
utterances

*When dyads reciprocate each other's NT,
how often do they do so in “back and forth”
exchanges?*

RQ2: CRQA – Quantifying NT structures on the RP

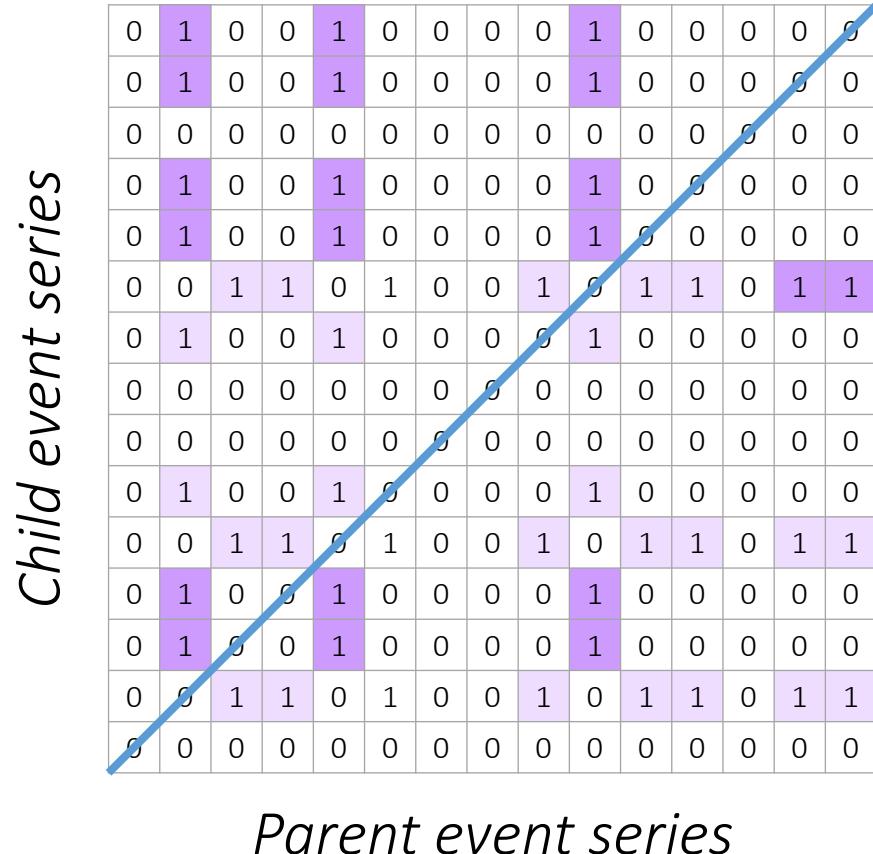


Determinism (DET) = % of recurrent points
that make up diagonal lines of at least 2

Speaker	Utterance
P	Or thirteen cents?
C	Thirteen cents.
P	Okay, so I have a ten and a ten so that's twenty.
P	That's twenty cents.

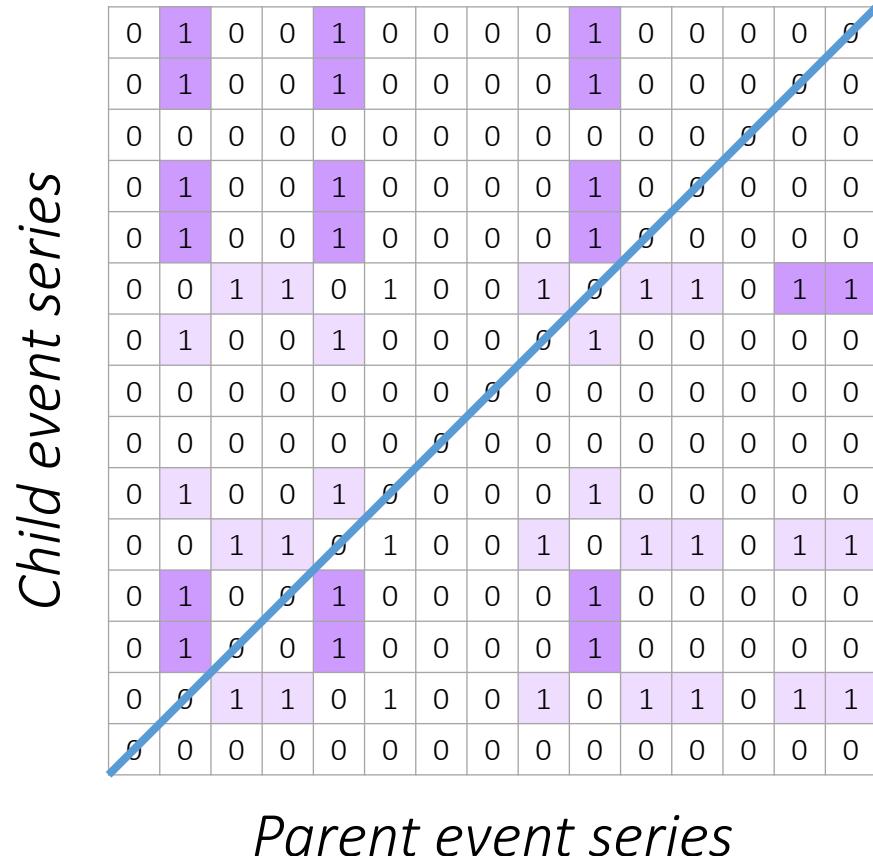
now often do they do so in “back and forth”
exchanges?

RQ2: CRQA – Quantifying NT structures on the RP



Laminarity (LAM) = % of recurrent points
that make up vertical lines of at least 2
utterances

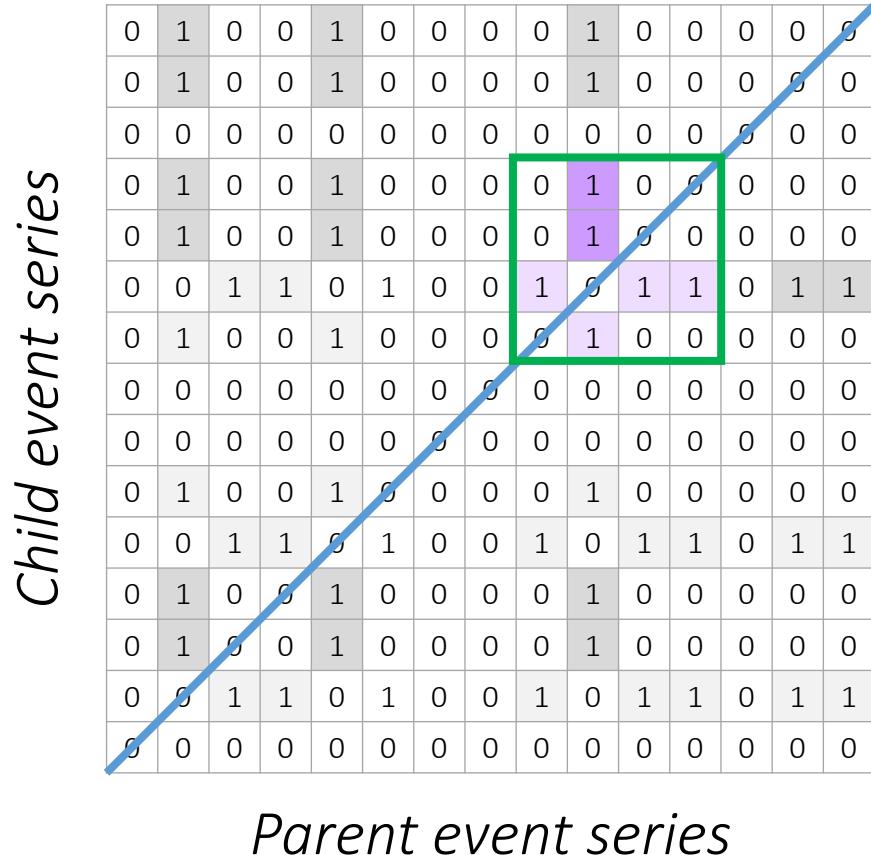
RQ2: CRQA – Quantifying NT structures on the RP



Laminarity (LAM) = % of recurrent points that make up vertical lines of at least 2 utterances

When speakers reciprocate each other's NT, how often do they do so in consecutive utterances?

RQ2: CRQA – Quantifying NT structures on the RP



Laminarity (LAM) = % of recurrent points

Speaker	Utterance
P	Or thirteen cents?
C	Thirteen cents.
P	Okay, so I have a ten and a ten so that's twenty.
P	That's twenty cents.

other's NT,
how often do they do so in consecutive
utterances?

RQ2: CRQA – Quantifying NT structures on the RP

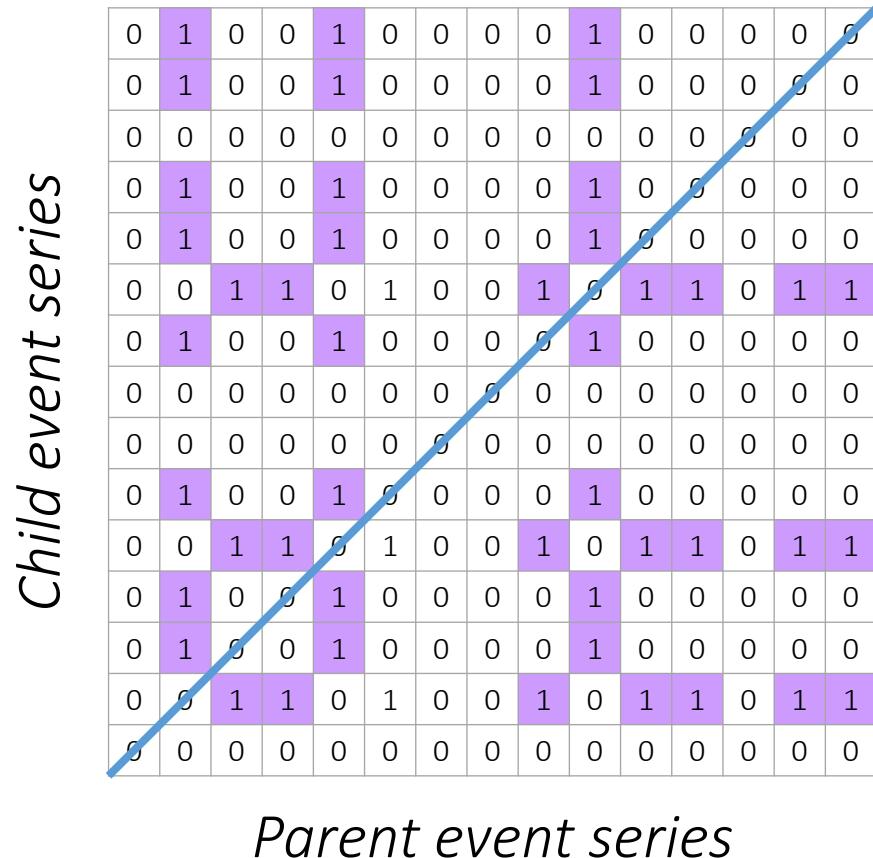
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0	0	1	1	0	1	0	0	0	1	0	1	1	0	1	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Repeat this process...

- Generate event series
- Create RP
- Quantify structures in the RP

For every dyadic interaction ☺

RQ2: CRQA – Quantifying NT structures on the RP

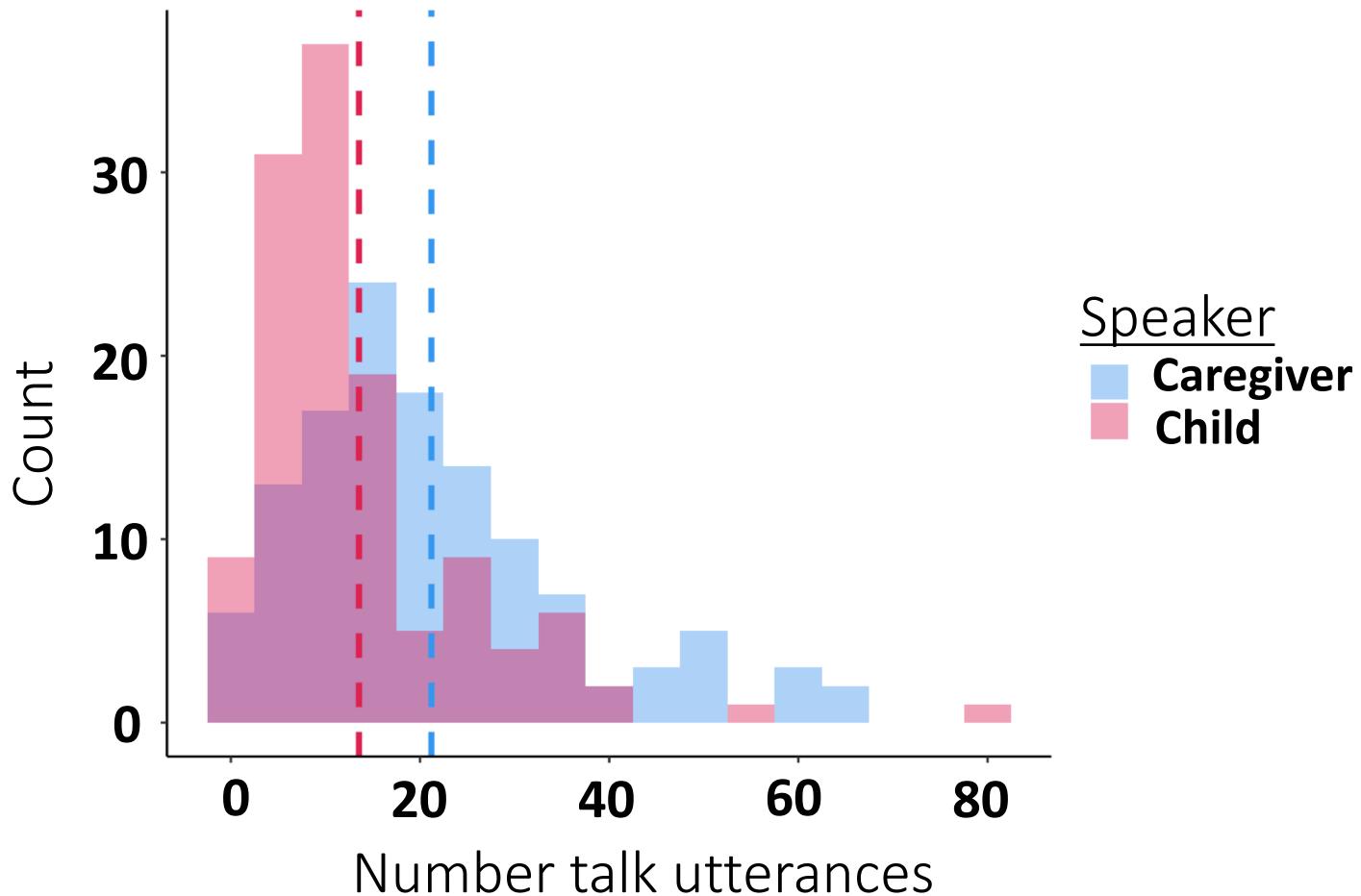


Some useful packages/functions
(programming language):

- **['crqa'](#)**: Recurrence Quantification for Categorical and Continuous Time Series (R)
- **['nonlinearTseries'](#)**: Nonlinear Time Series Analysis (R)
- **['PyRQA'](#)**: Recurrence analysis in a massively parallel manner... (Python)
- **[Toolbox of RP and RQA](#)** (MATLAB)

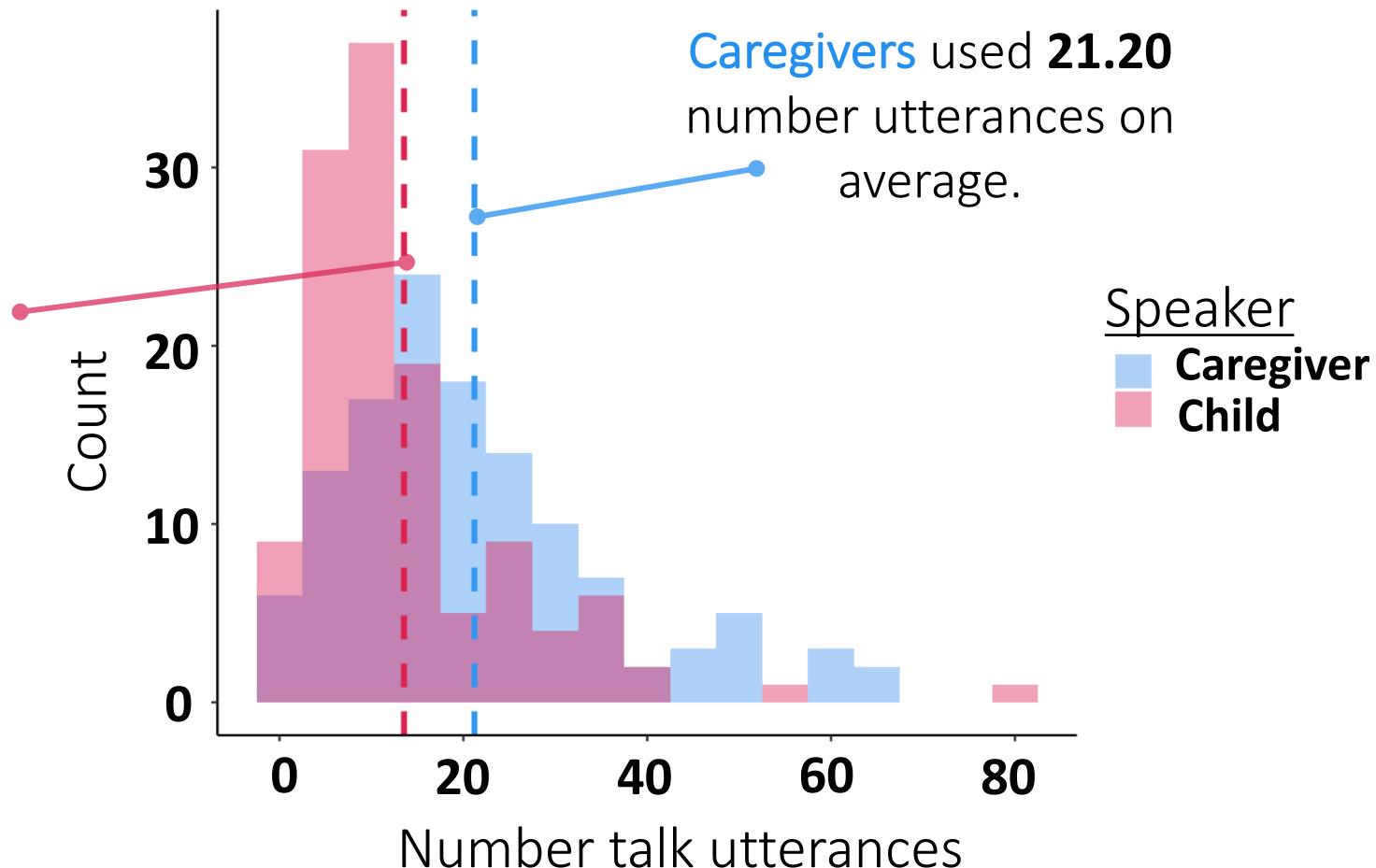
RQ2: Variability in caregiver-child NT

RQ2: Variability in caregiver-child NT



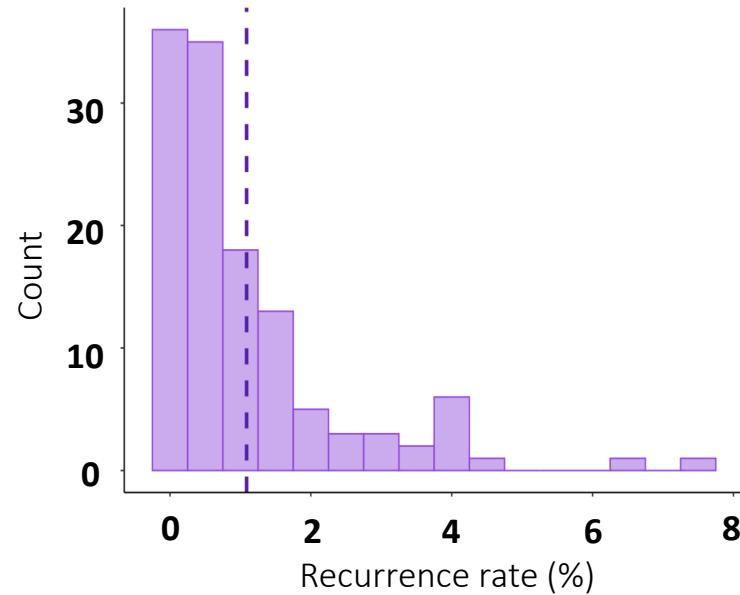
RQ2: Variability in caregiver-child NT

Children used
13.55 number
utterances on
average.

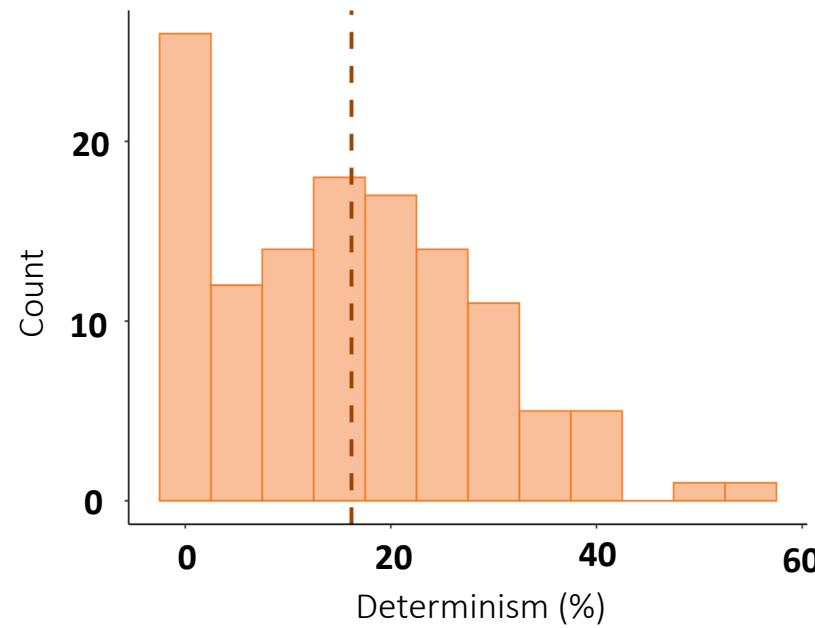
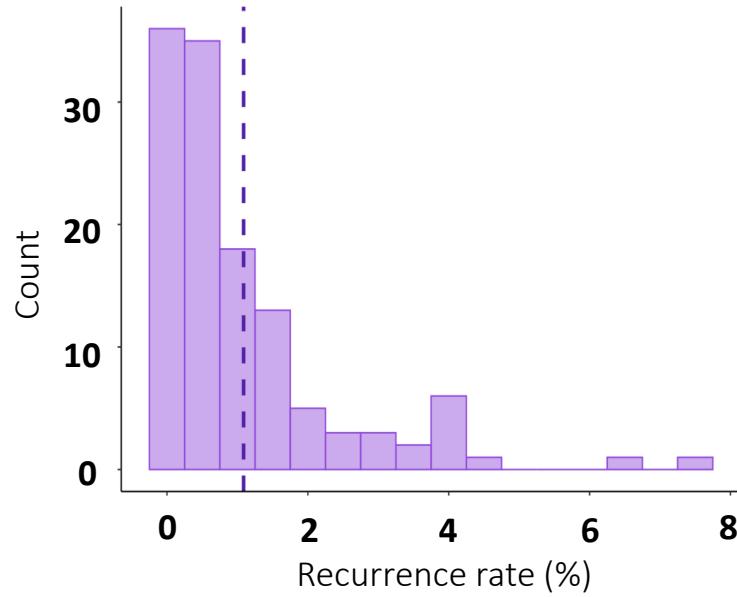


RQ2: Variability in NT reciprocity

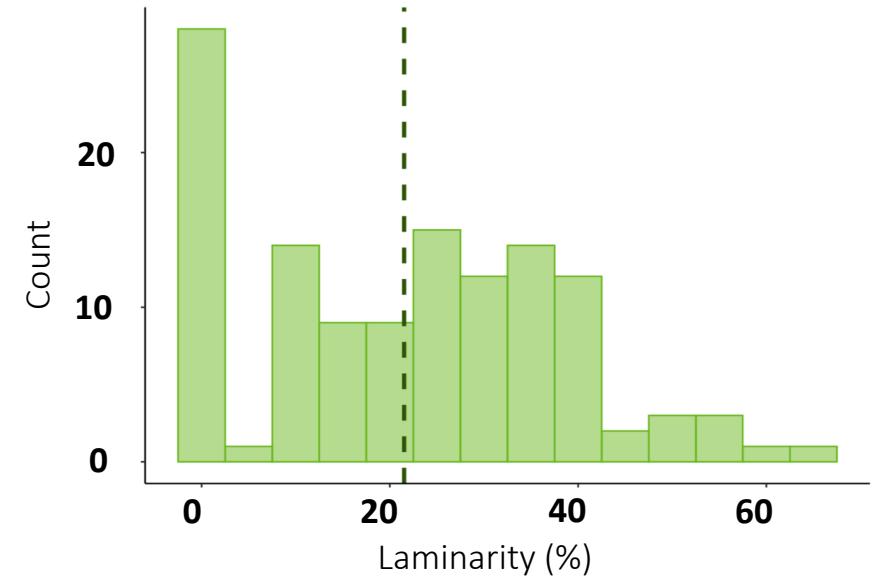
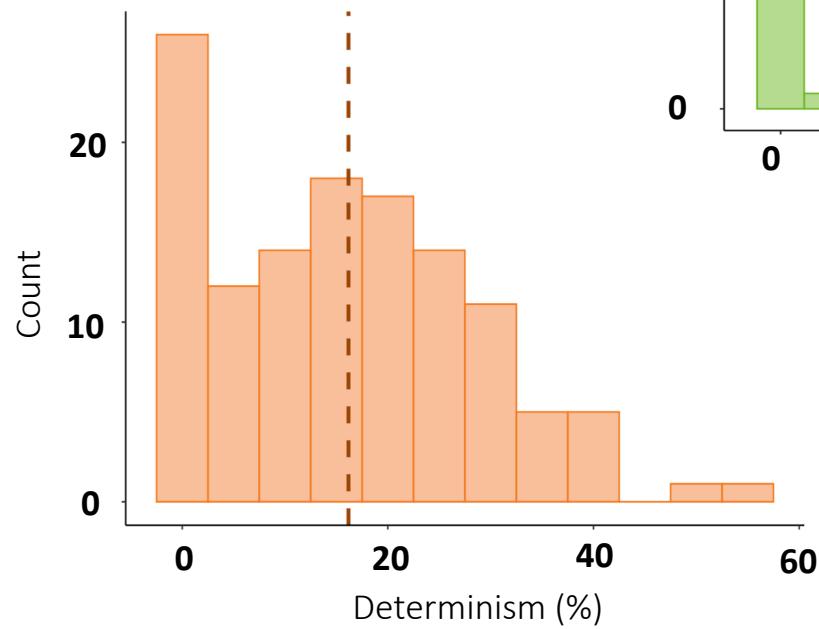
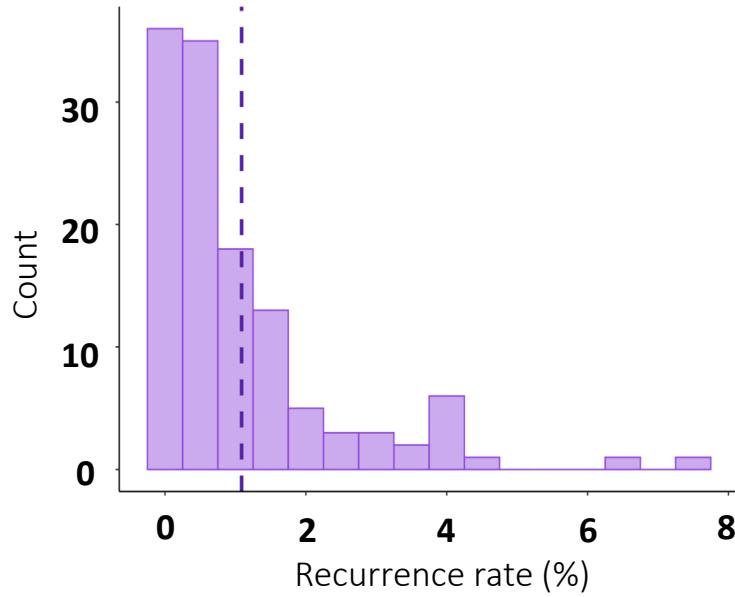
RQ2: Variability in NT reciprocity



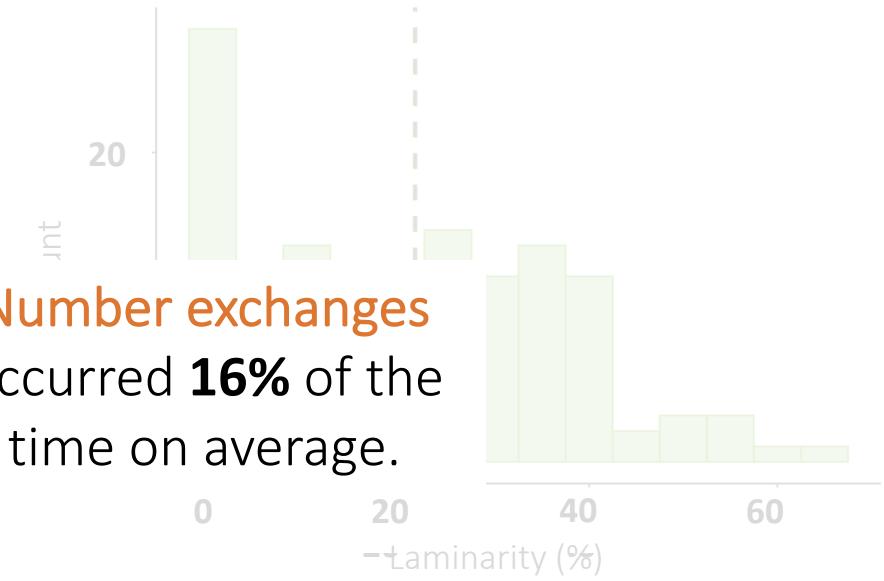
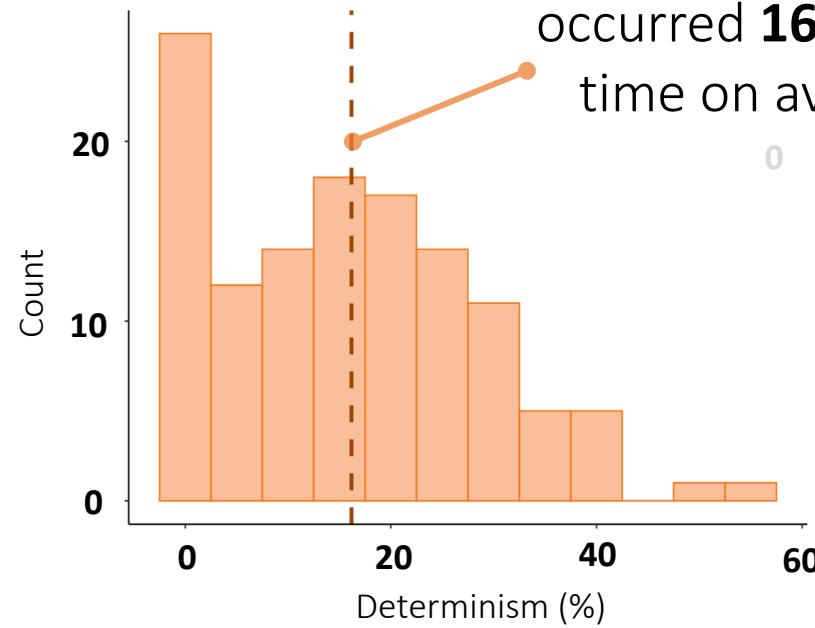
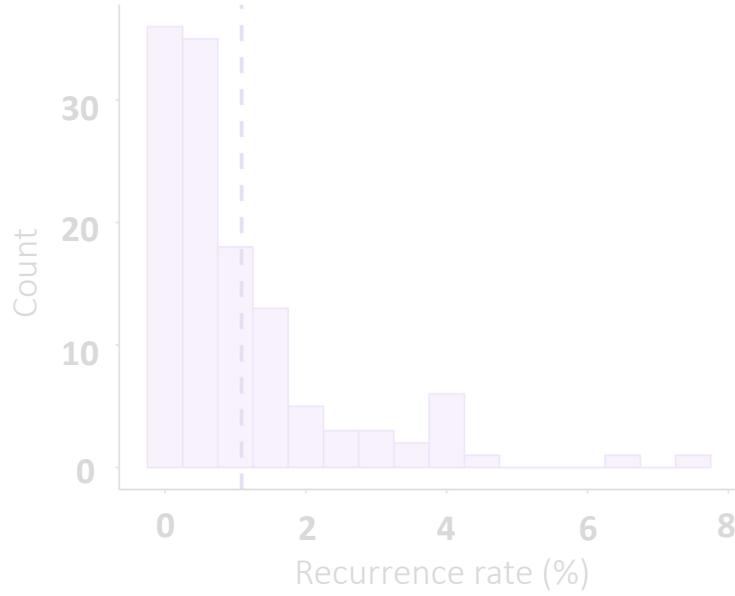
RQ2: Variability in NT reciprocity



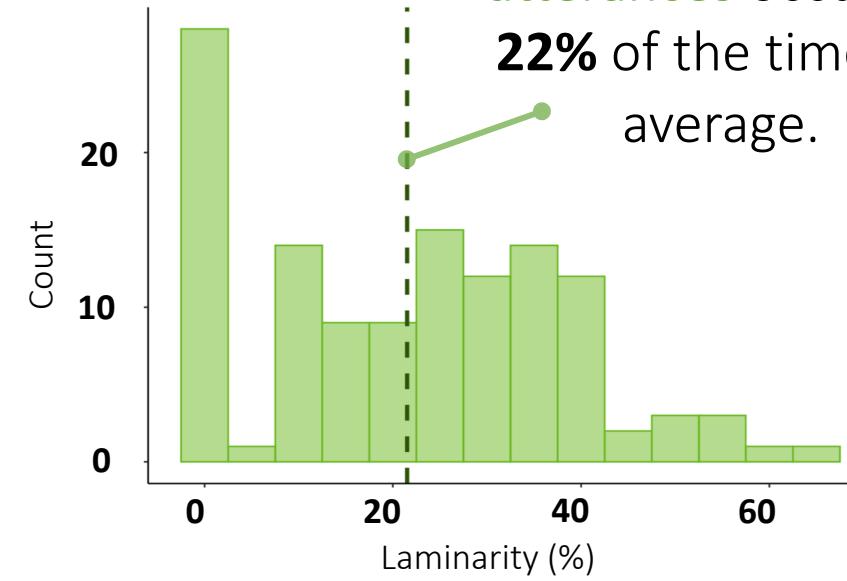
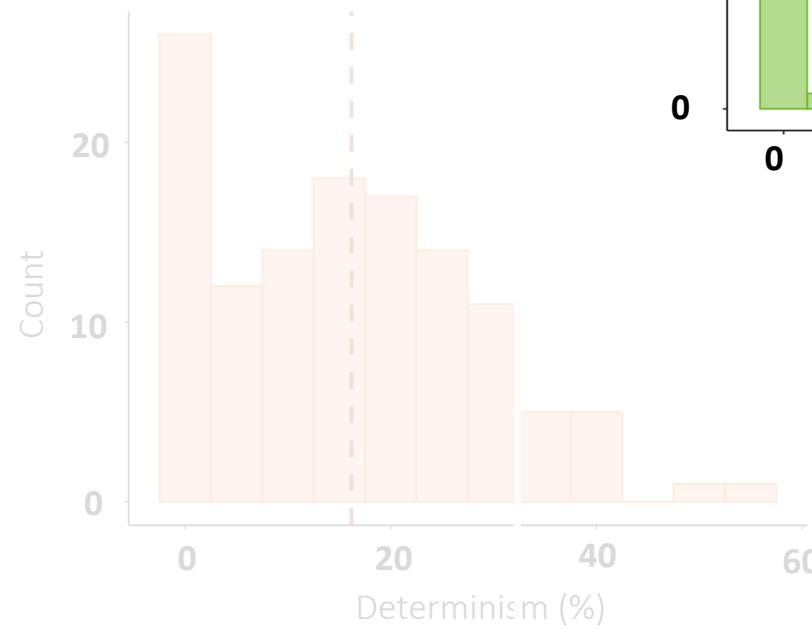
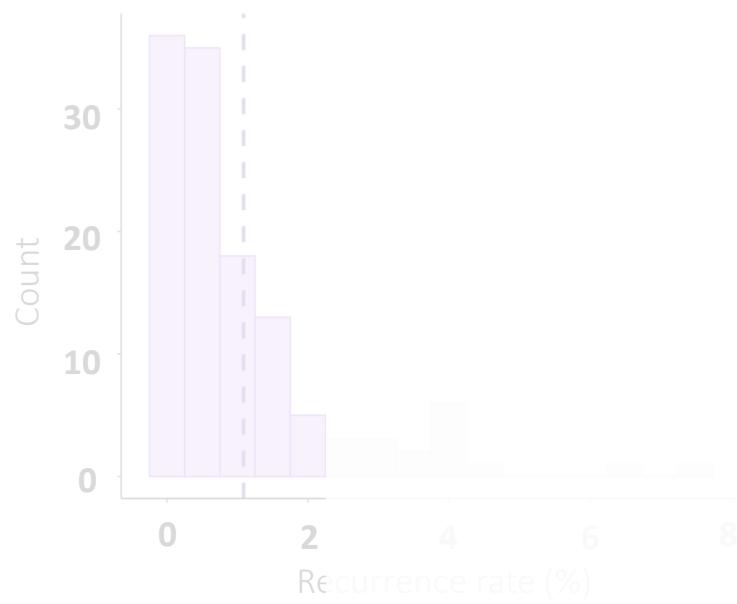
RQ2: Variability in NT reciprocity



RQ2: Variability in NT reciprocity



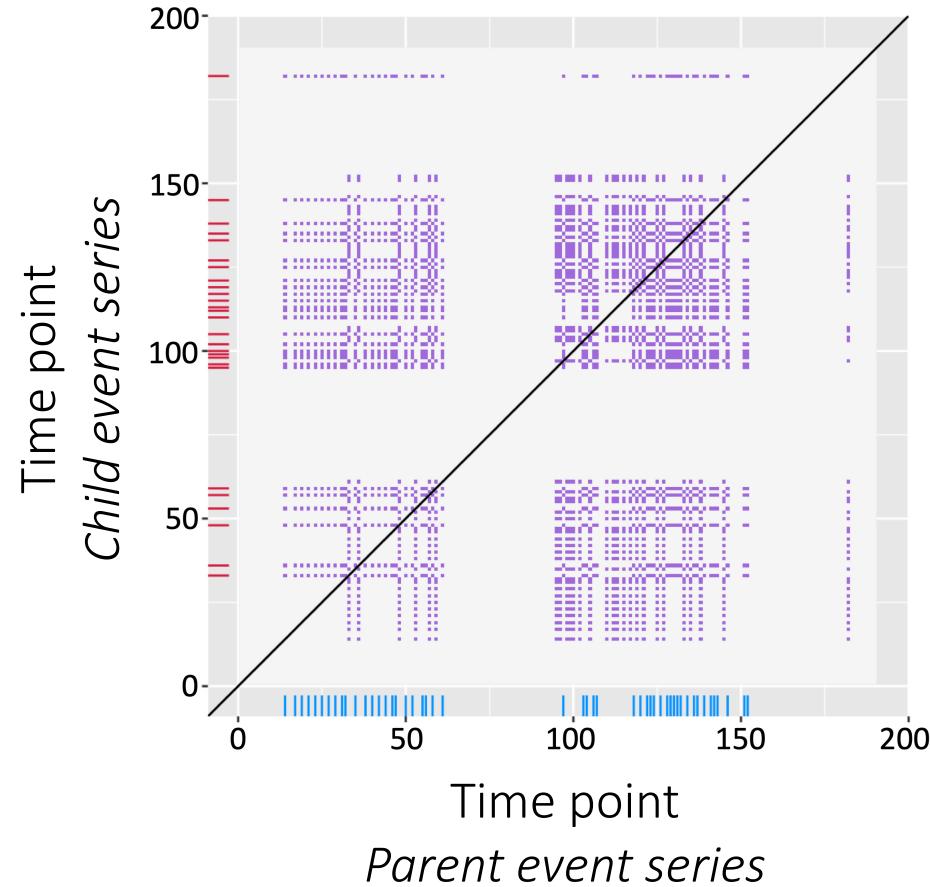
RQ2: Variability in NT reciprocity



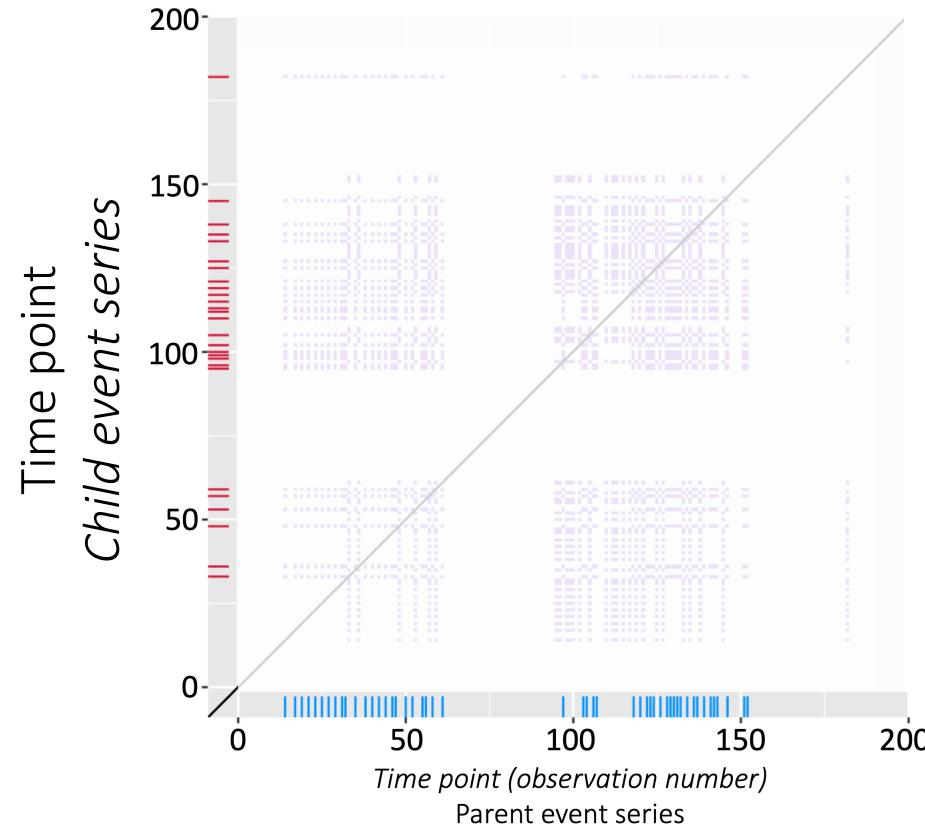
Consecutive number
utterances occurred
22% of the time on
average.

RQ3: CRQA metrics vs. frequencies of NT

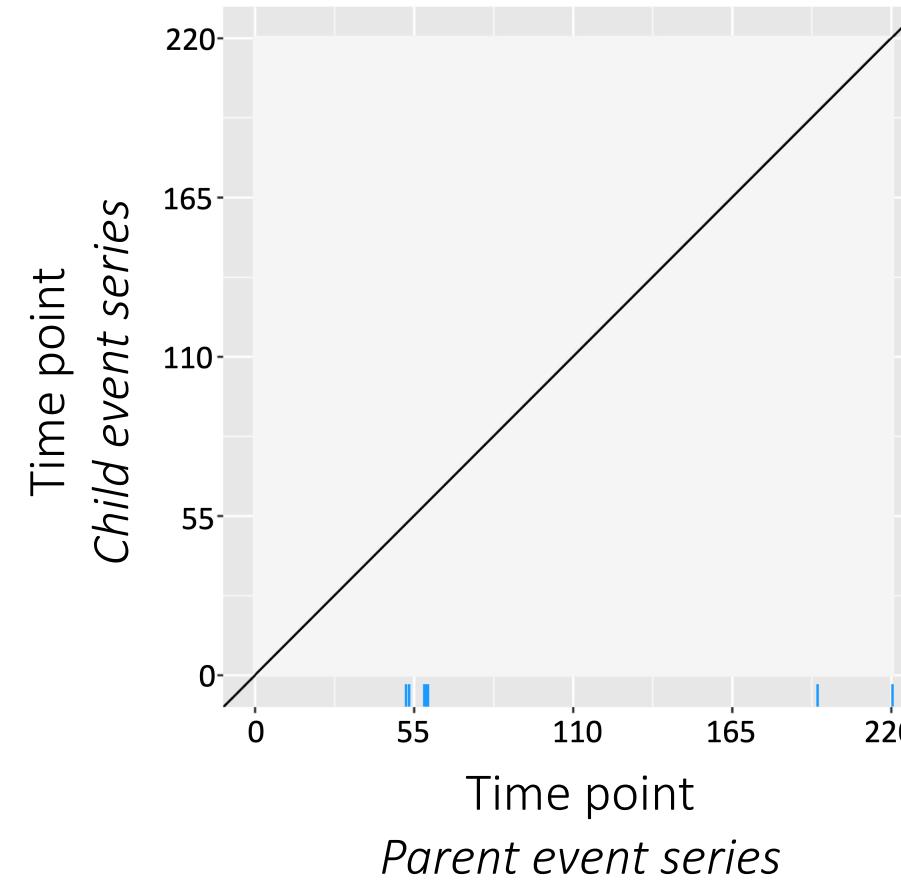
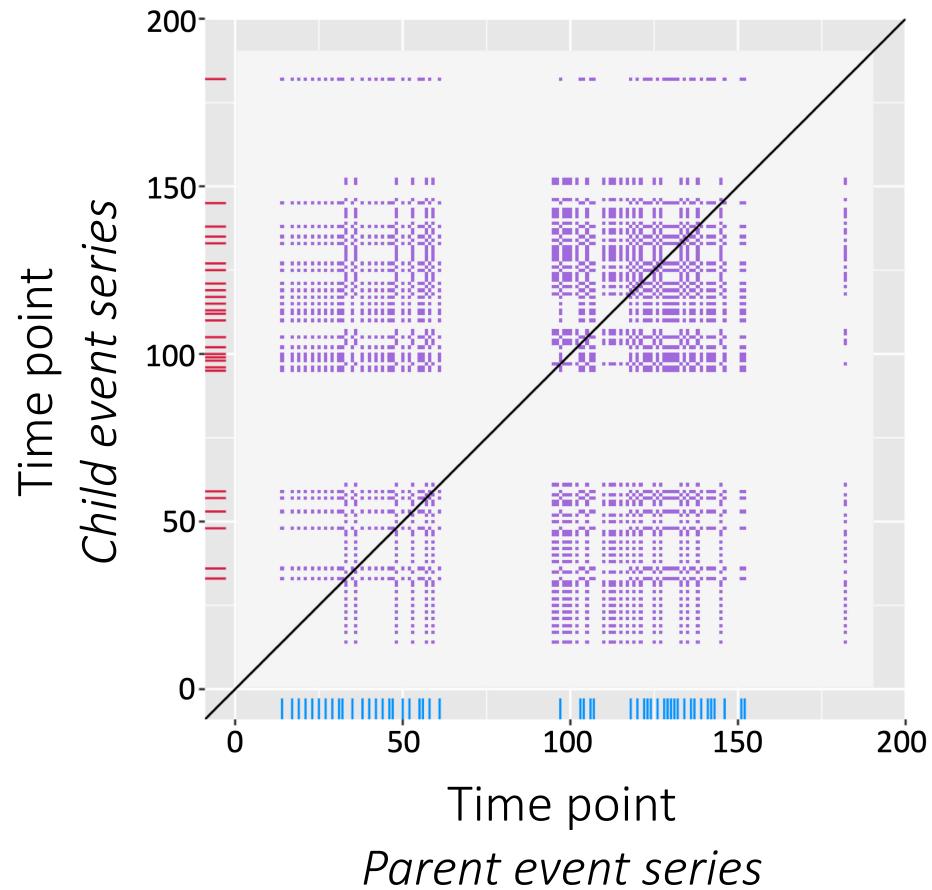
RQ3: CRQA metrics vs. frequencies of NT



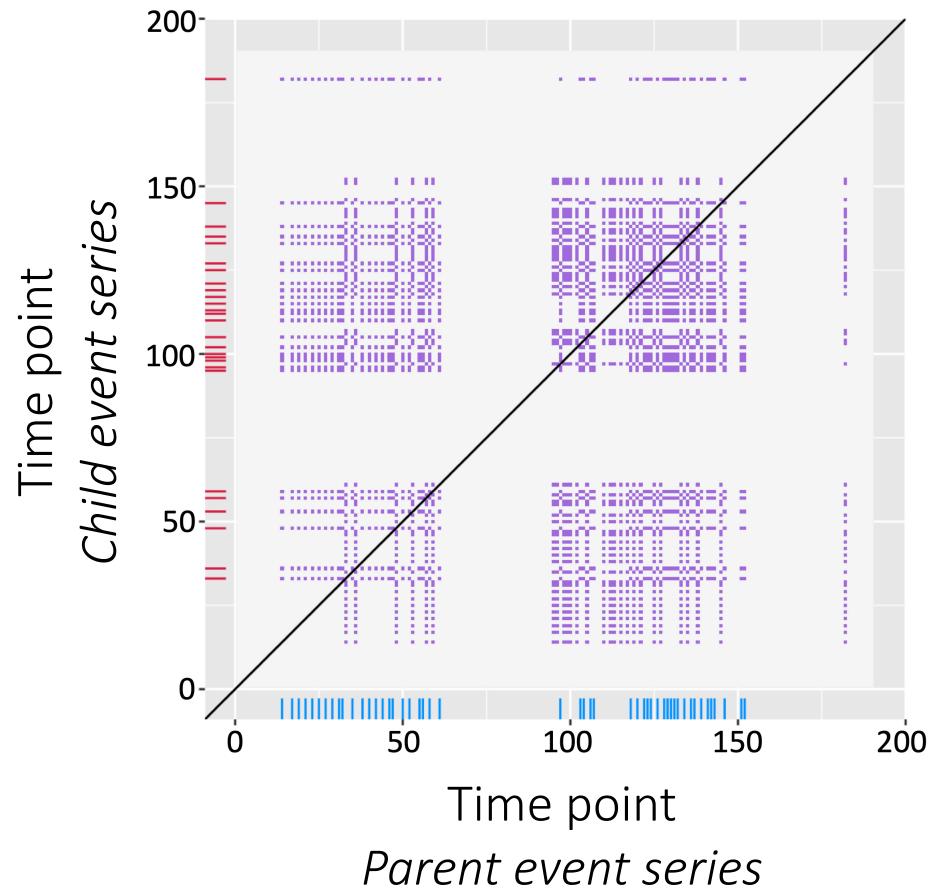
RQ3: CRQA metrics vs. frequencies of NT



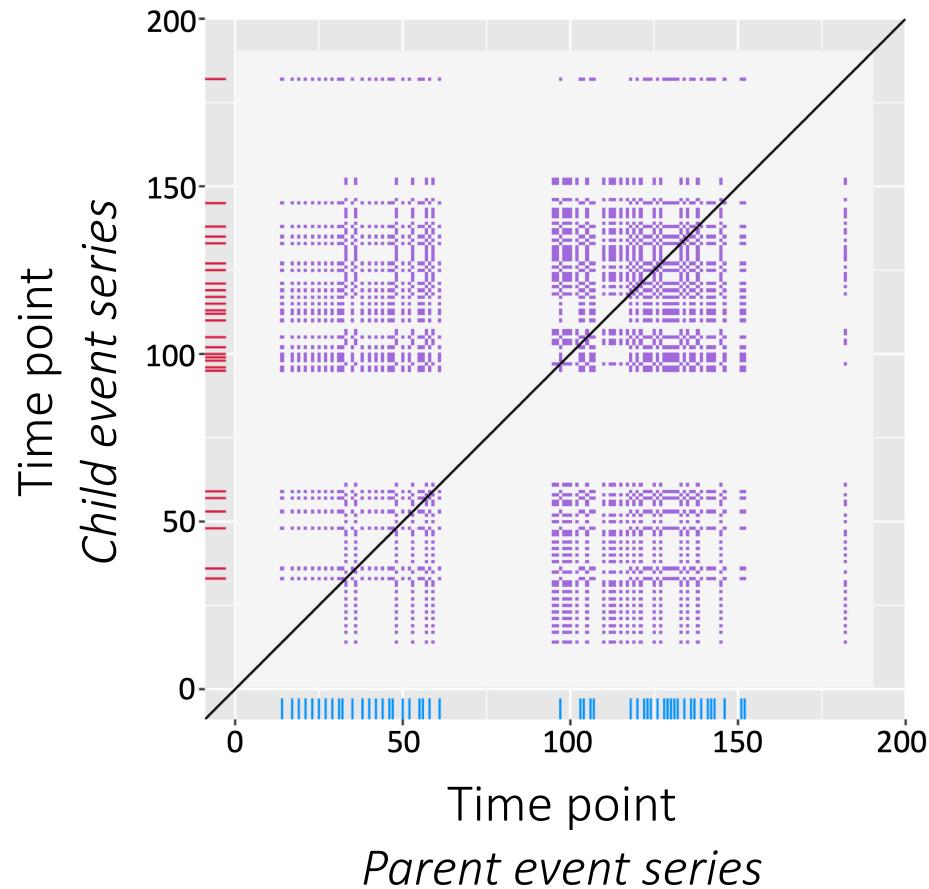
RQ3: Descriptive analysis



RQ3: Descriptive analysis



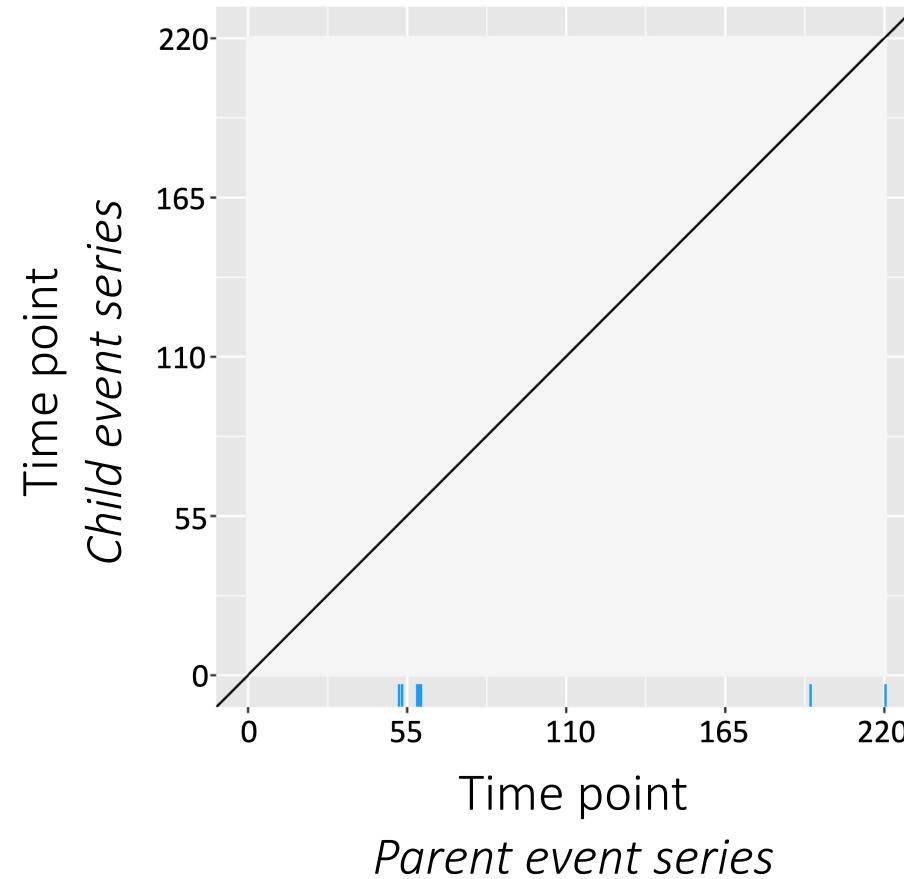
RQ3: Descriptive analysis



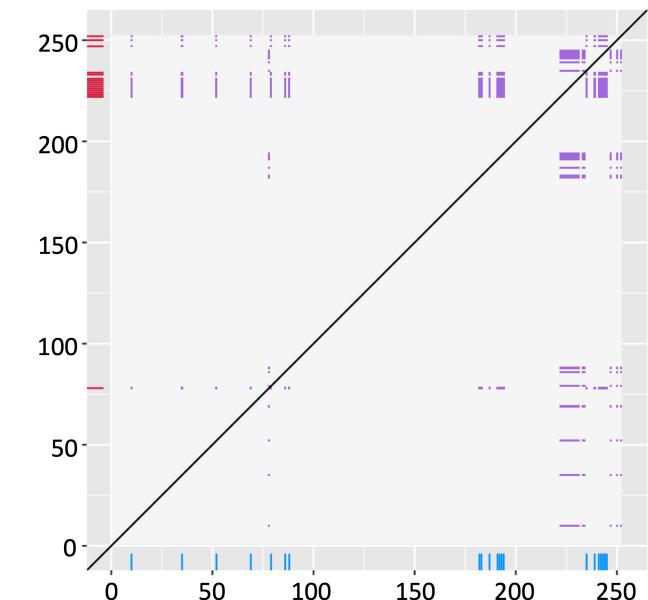
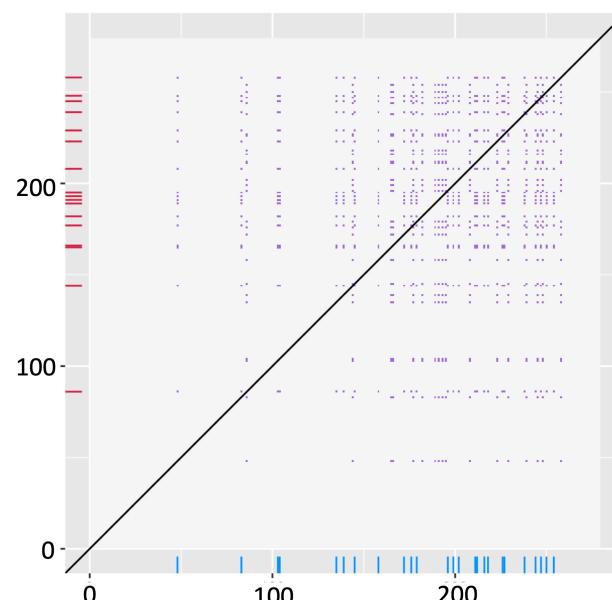
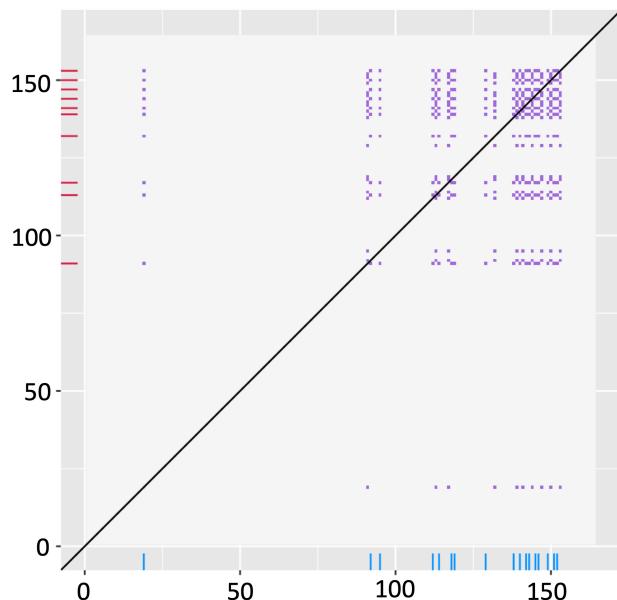
Above average quantities and reciprocity of number talk!

RQ3: Descriptive analysis

Extremely low quantities
and NO reciprocation of
number talk!

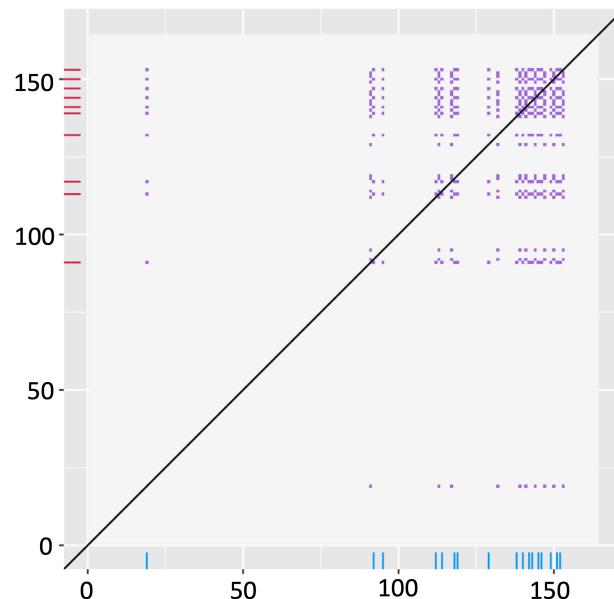


RQ3: Descriptive analysis

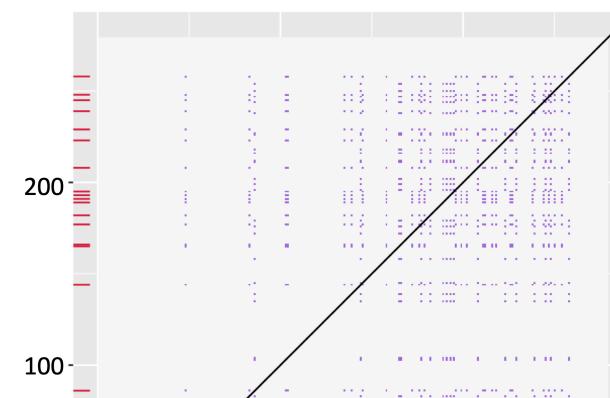


RQ3: Descriptive analysis

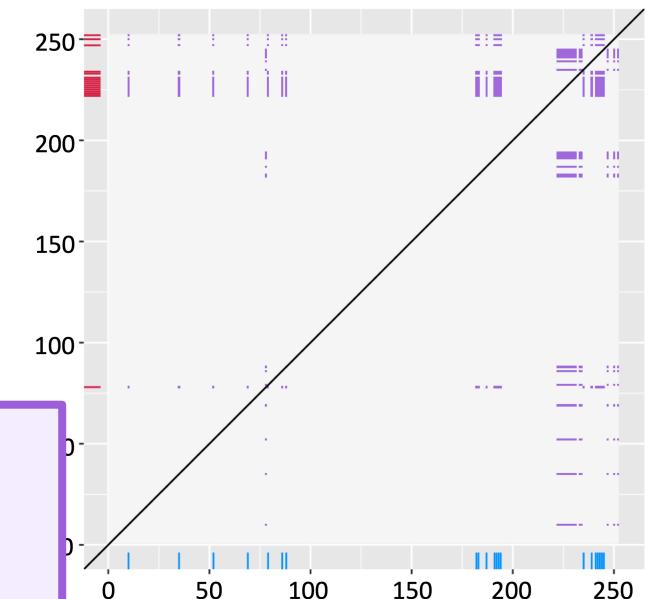
Parent NT = 17
Child NT = 10



Parent NT = 25
Child NT = 17



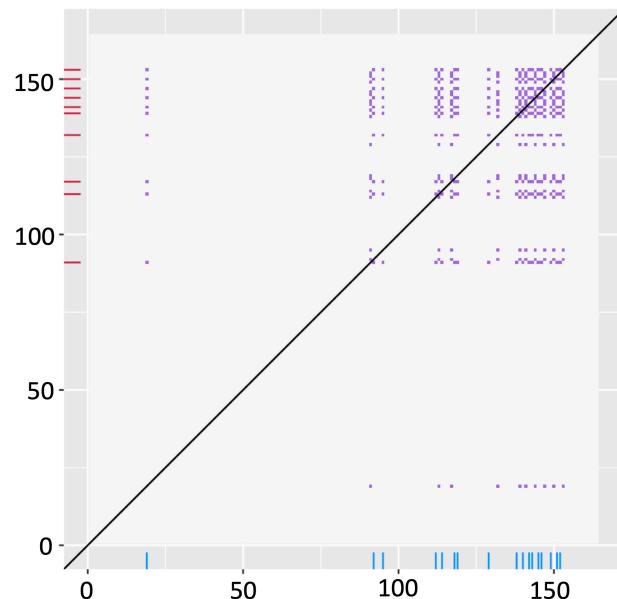
Parent NT = 23
Child NT = 6



*These parents have **similar**
frequencies of NT...*

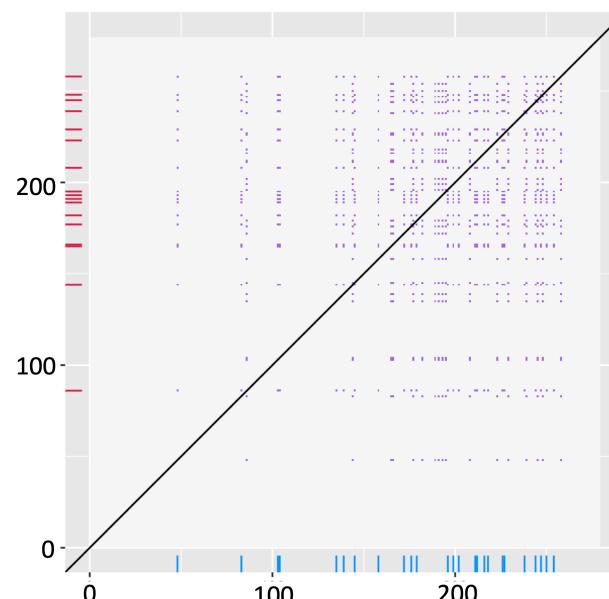
RQ3: Descriptive analysis

Longer NT exchanges,
concentrated at the end
of the conversation



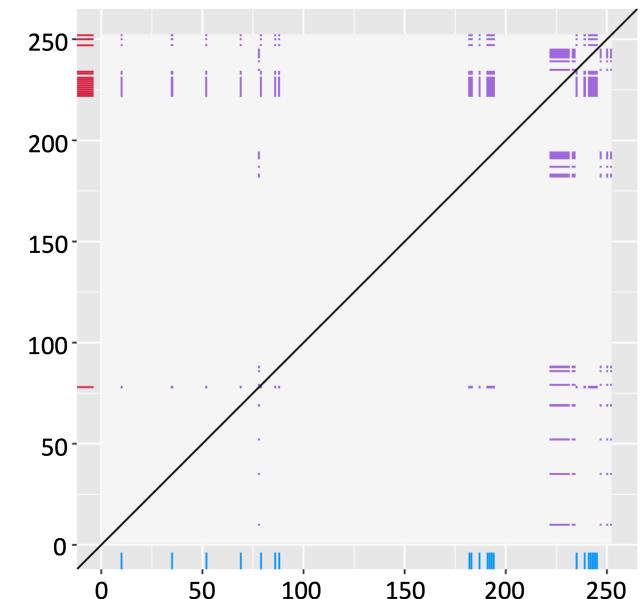
RR = 1.26
DET = 54.71
LAM = 23.53

Shorter NT exchanges,
distributed throughout
the conversation



RR = 1.09
DET = 5.18
LAM = 17.88

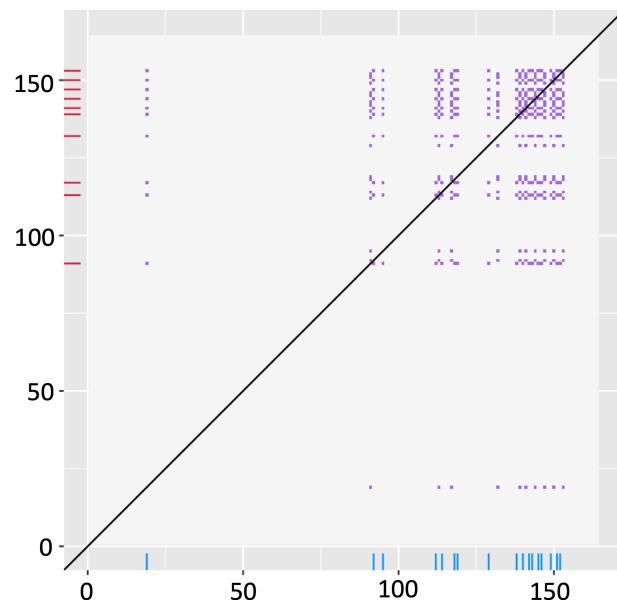
Long bouts of consecutive
NT by one speaker,
especially at the end



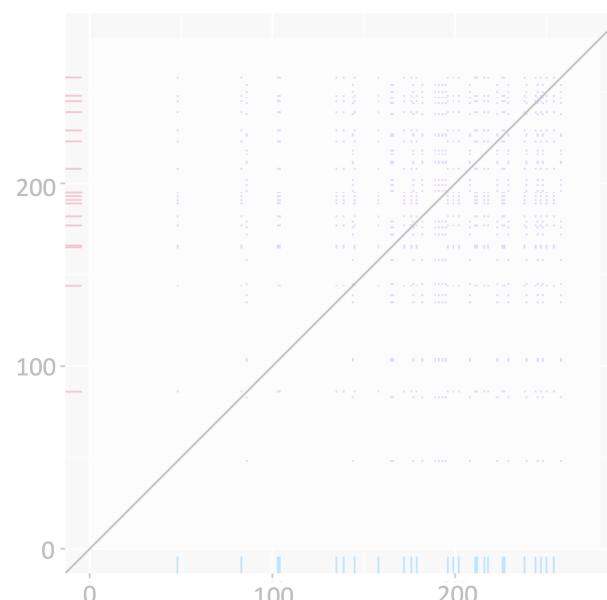
RR = 1.06
DET = 1.45
LAM = 63.69

RQ3: Descriptive analysis

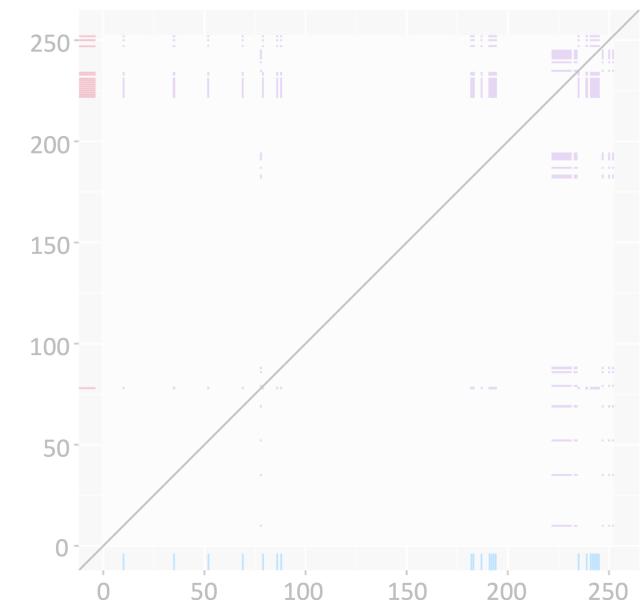
Longer NT exchanges,
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Shorter NT exchanges,
distributed throughout
the conversation

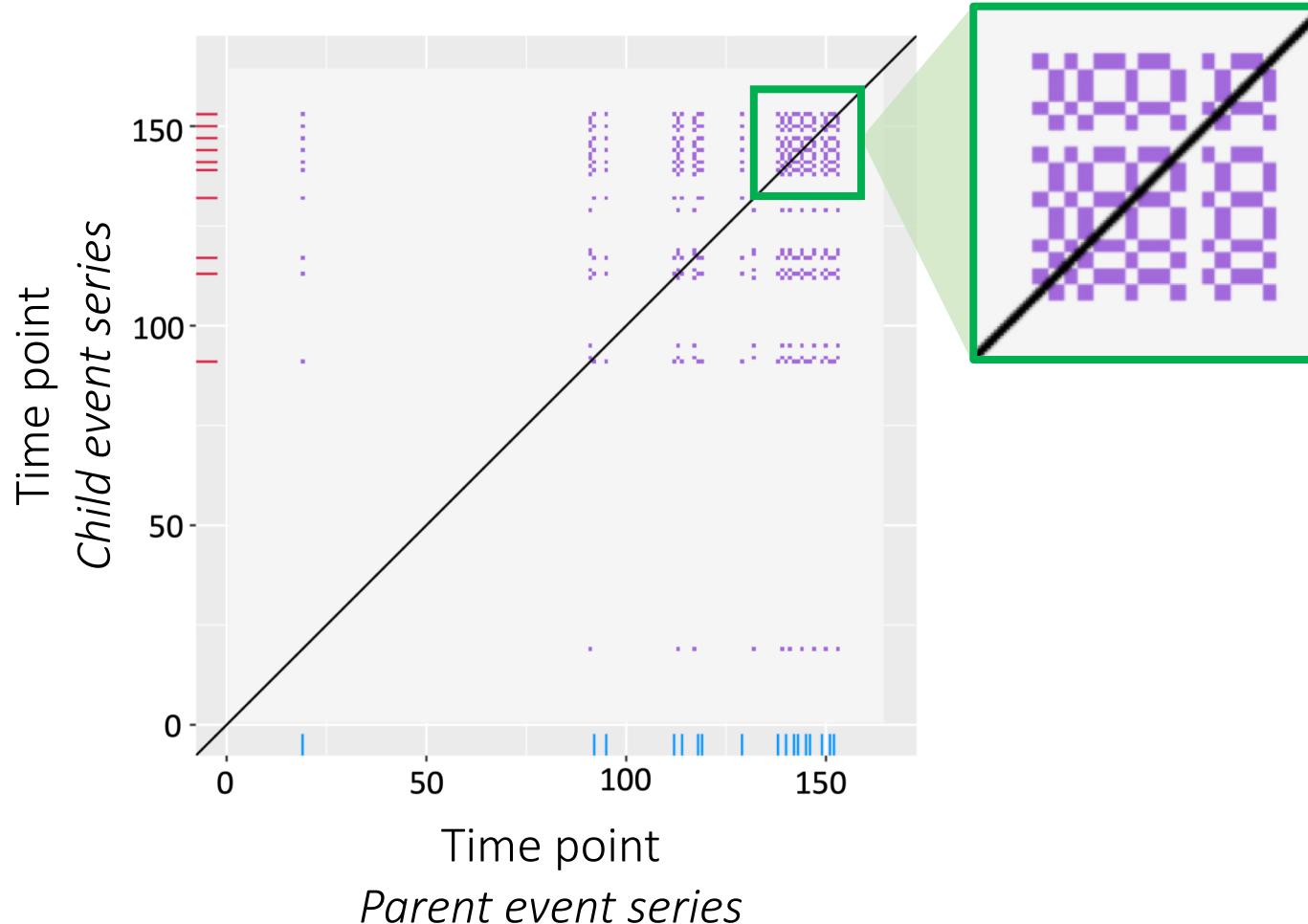


Long bouts of consecutive
NT by one speaker,
especially at the end



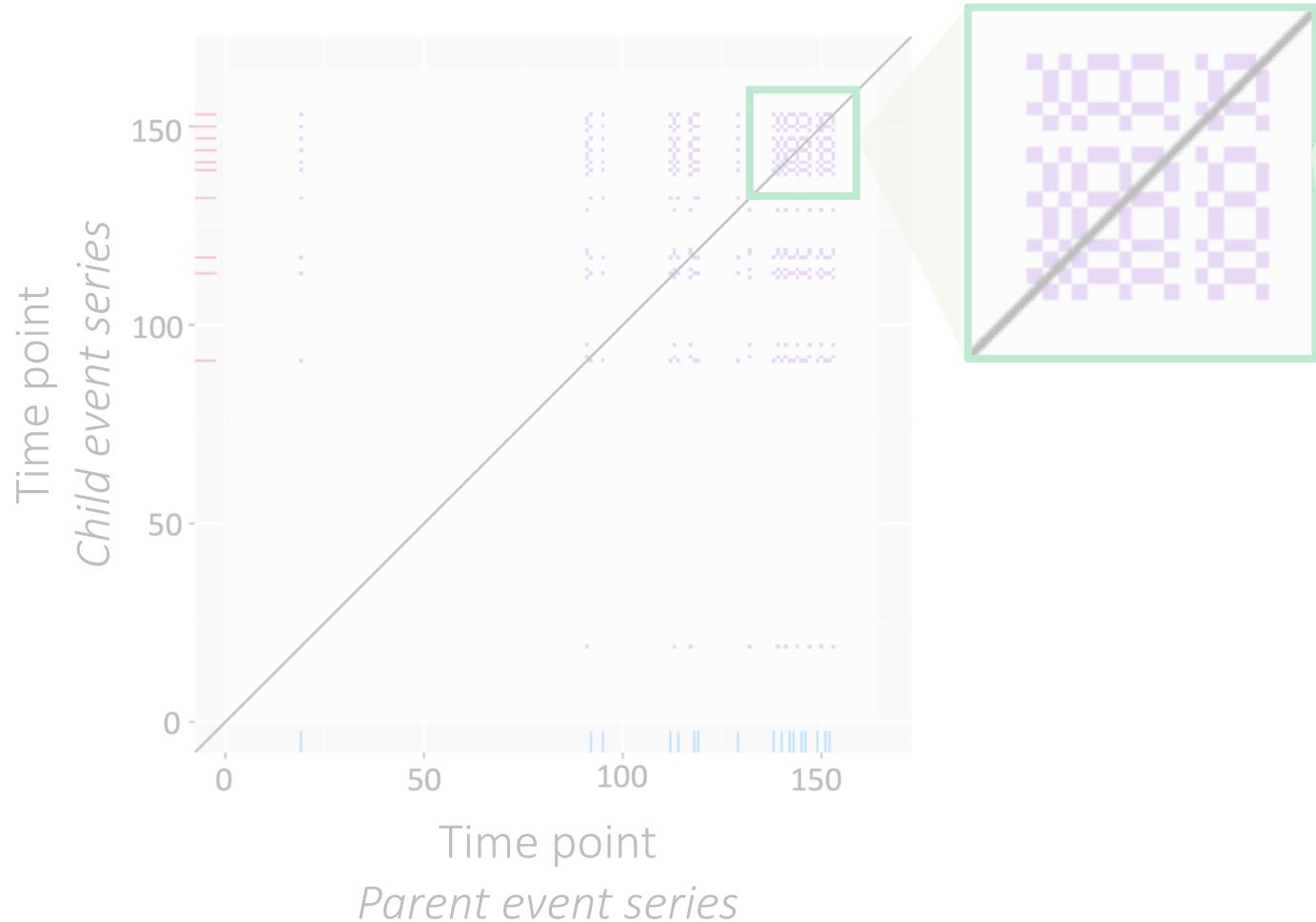
RQ3: Descriptive analysis

Longer NT exchanges, concentrated at the end



RQ3: Descriptive analysis

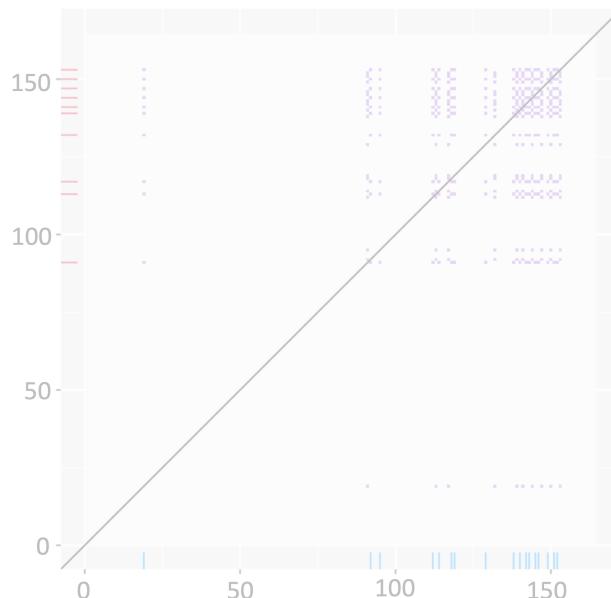
Longer NT exchanges, concentrated at the end



- P: What is one plus one?
C: Two.
- P: What is two plus two?
P: How many is there?
C: Four.
- P: Four plus two more.
P: Count them.
C: One, two, three, four, five six.
- P: Mhmm so what is it?
P: Is it six?
C: Six.
- P: Six plus four more.
P: How many is all of that together?
C: One, two, three, four five, six seven, eight, nine, ten.
- P: Good job.

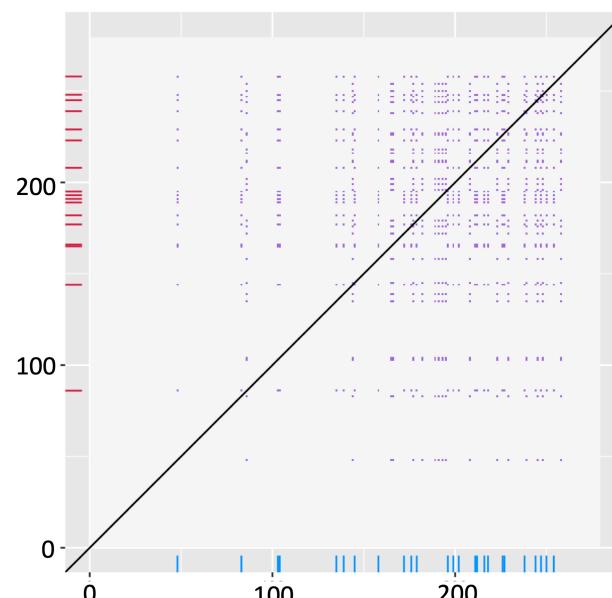
RQ3: Descriptive analysis

Longer NT exchanges,
concentrated at the end
of the conversation



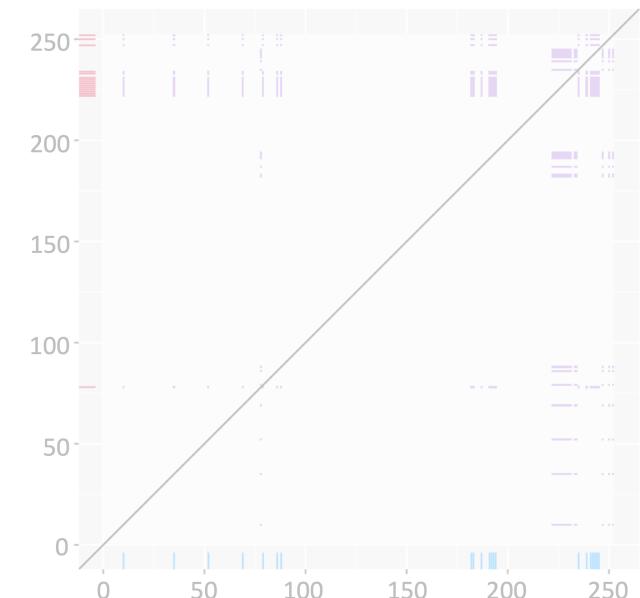
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Shorter NT exchanges,
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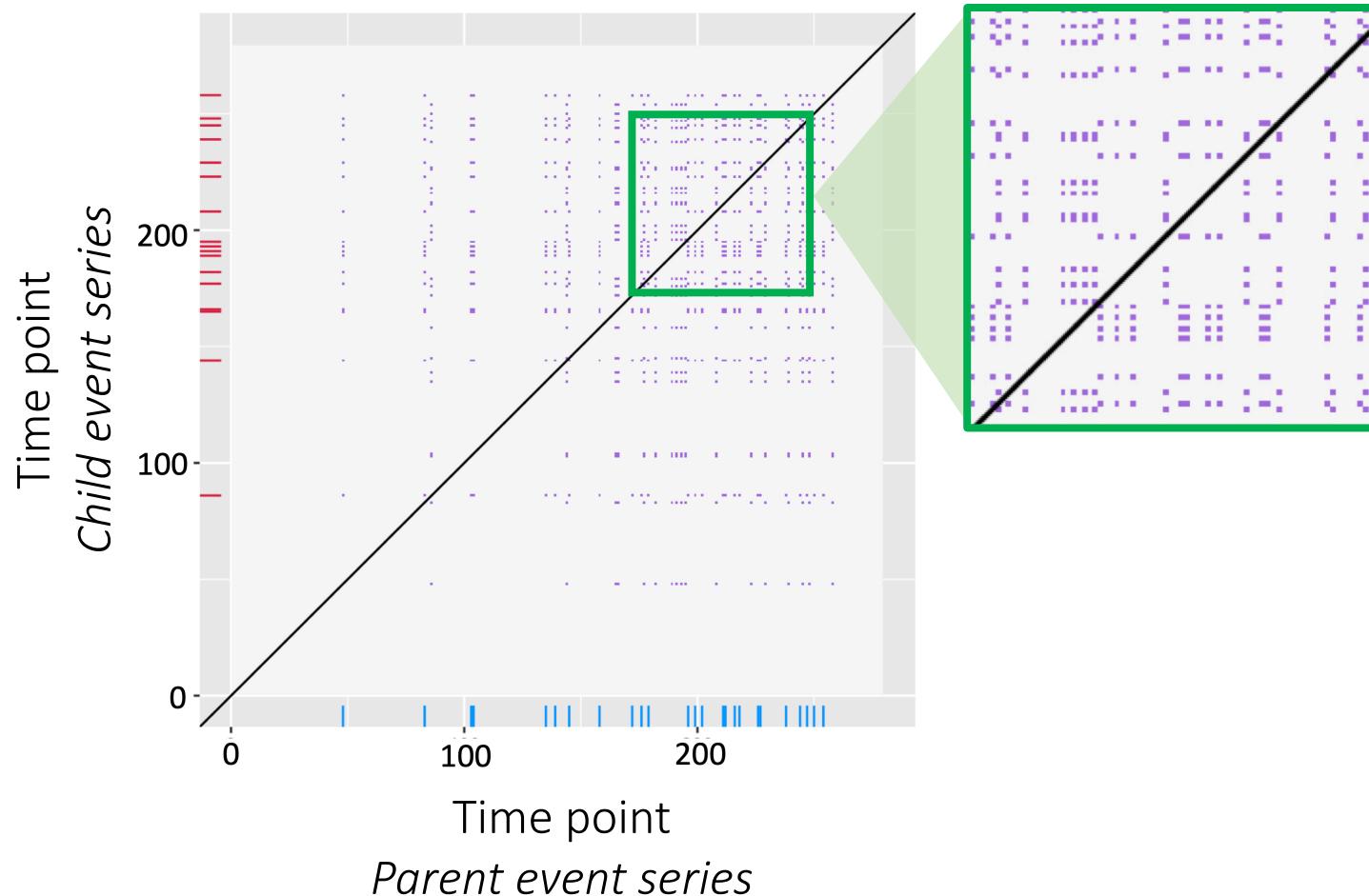
Long bouts of consecutive
NT by one speaker,
especially at the end



RR = 1.06
DET = 1.45
LAM = 63.69

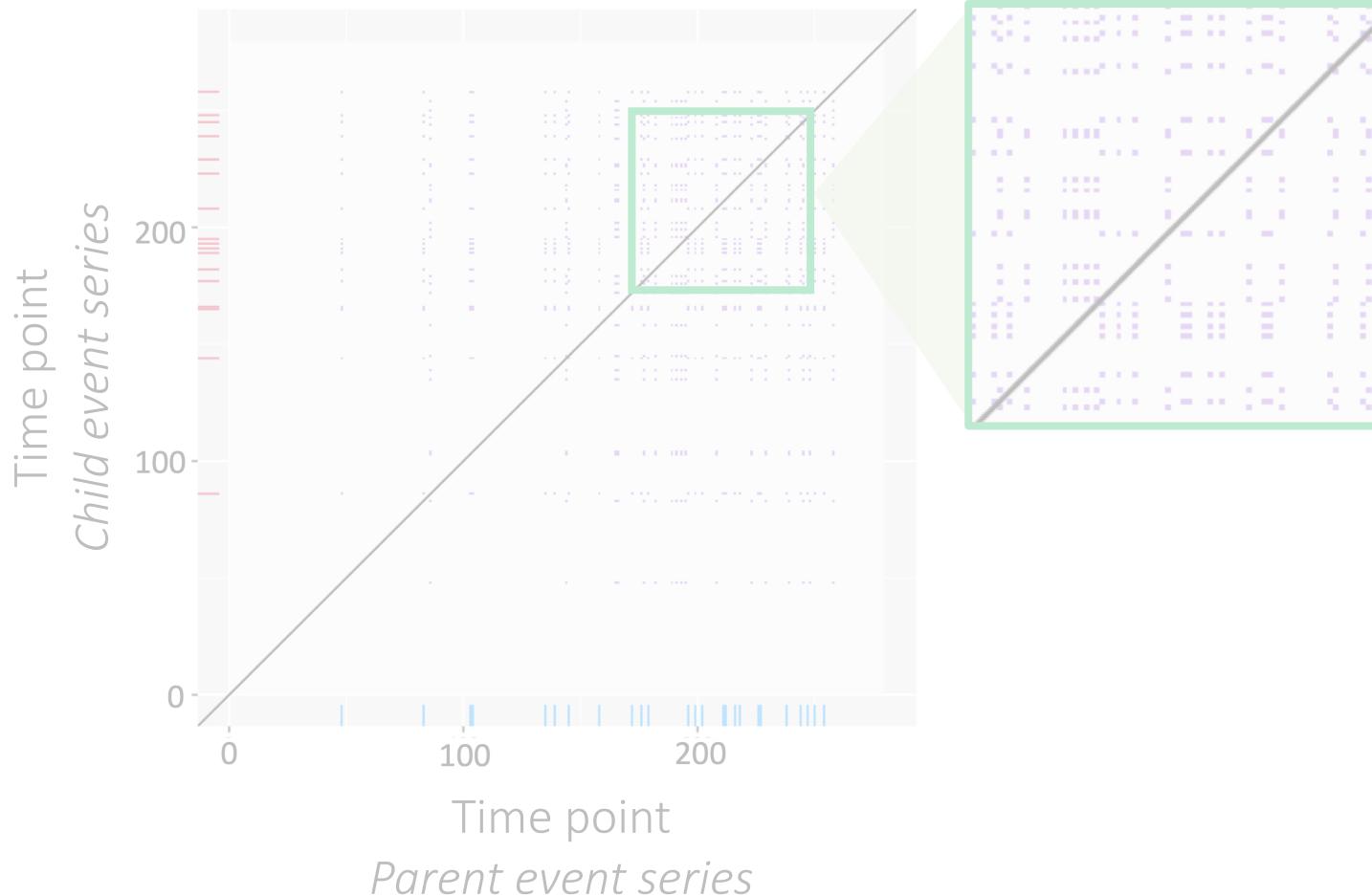
RQ3: Descriptive analysis

Shorter NT exchanges, distributed throughout the conversation



RQ3: Descriptive analysis

Shorter NT exchanges, distributed throughout the conversation



C: Three dollars.

P: Three dollars?

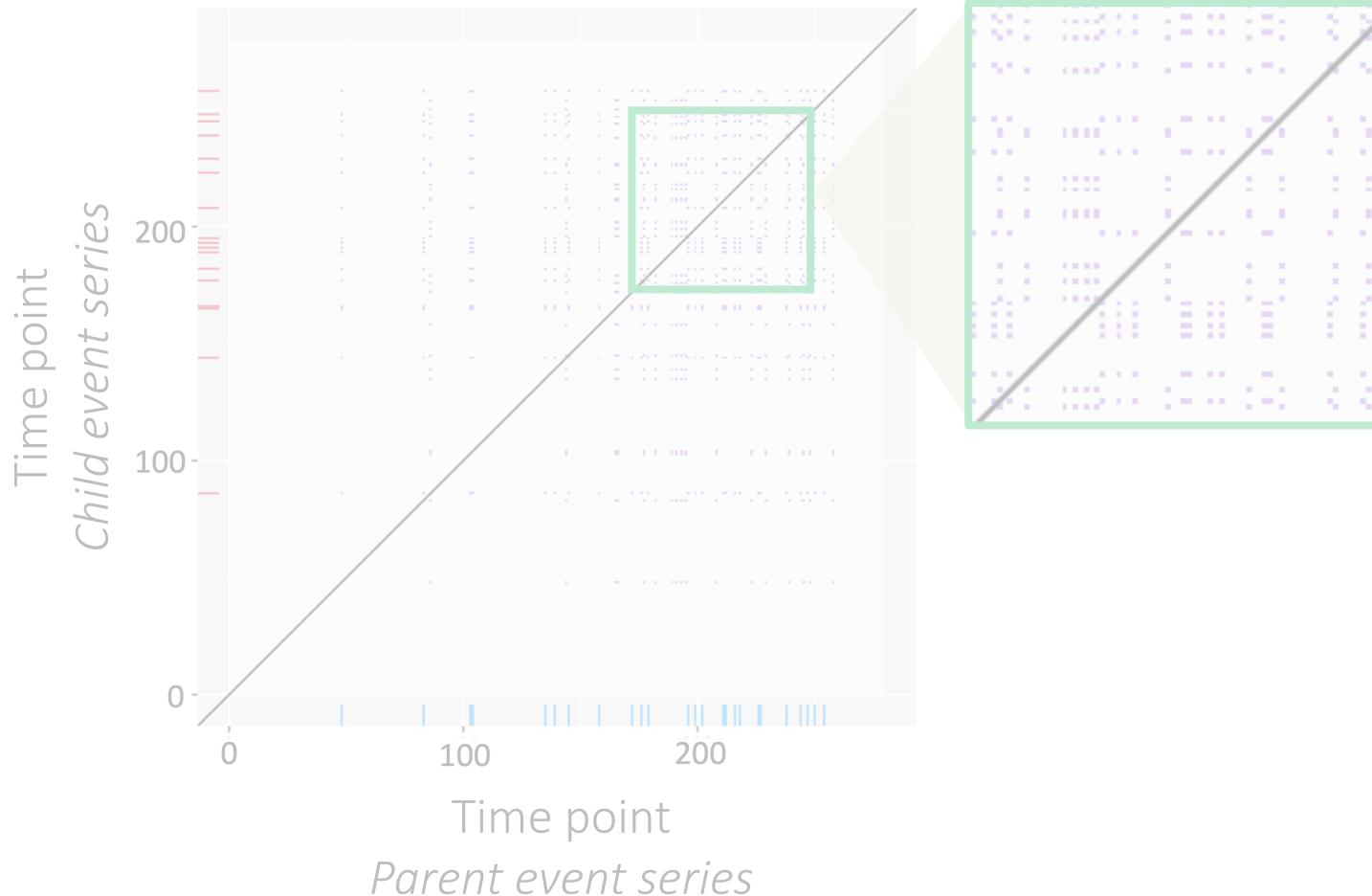
P: Okay.

P: Count how many
chicken.

C: One.

RQ3: Descriptive analysis

Shorter NT exchanges, distributed throughout the conversation

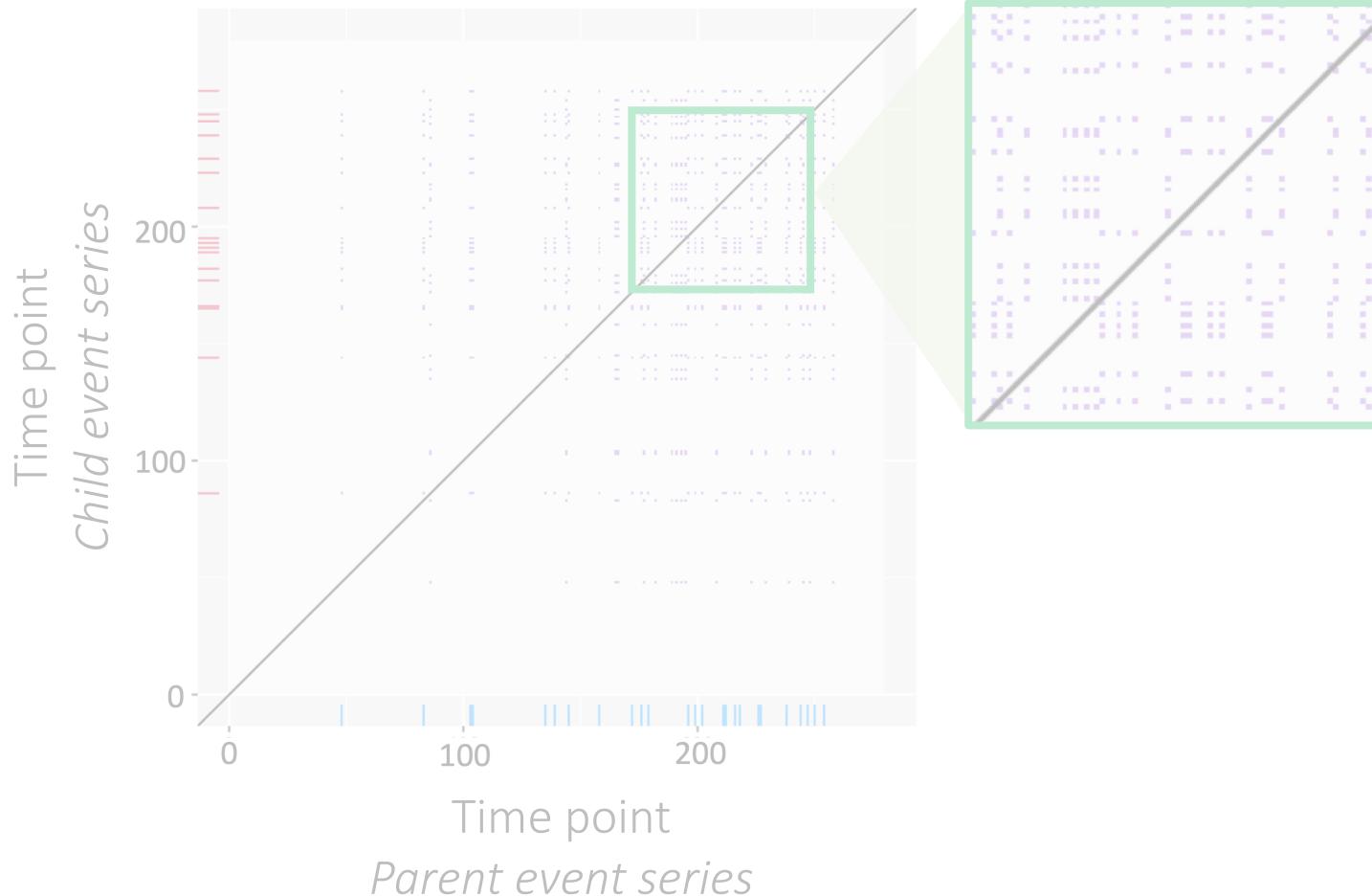


C: Three dollars.
P: Three dollars?
P: Okay.

P: Count how many
chicken.
C: One.

RQ3: Descriptive analysis

Shorter NT exchanges, distributed throughout the conversation

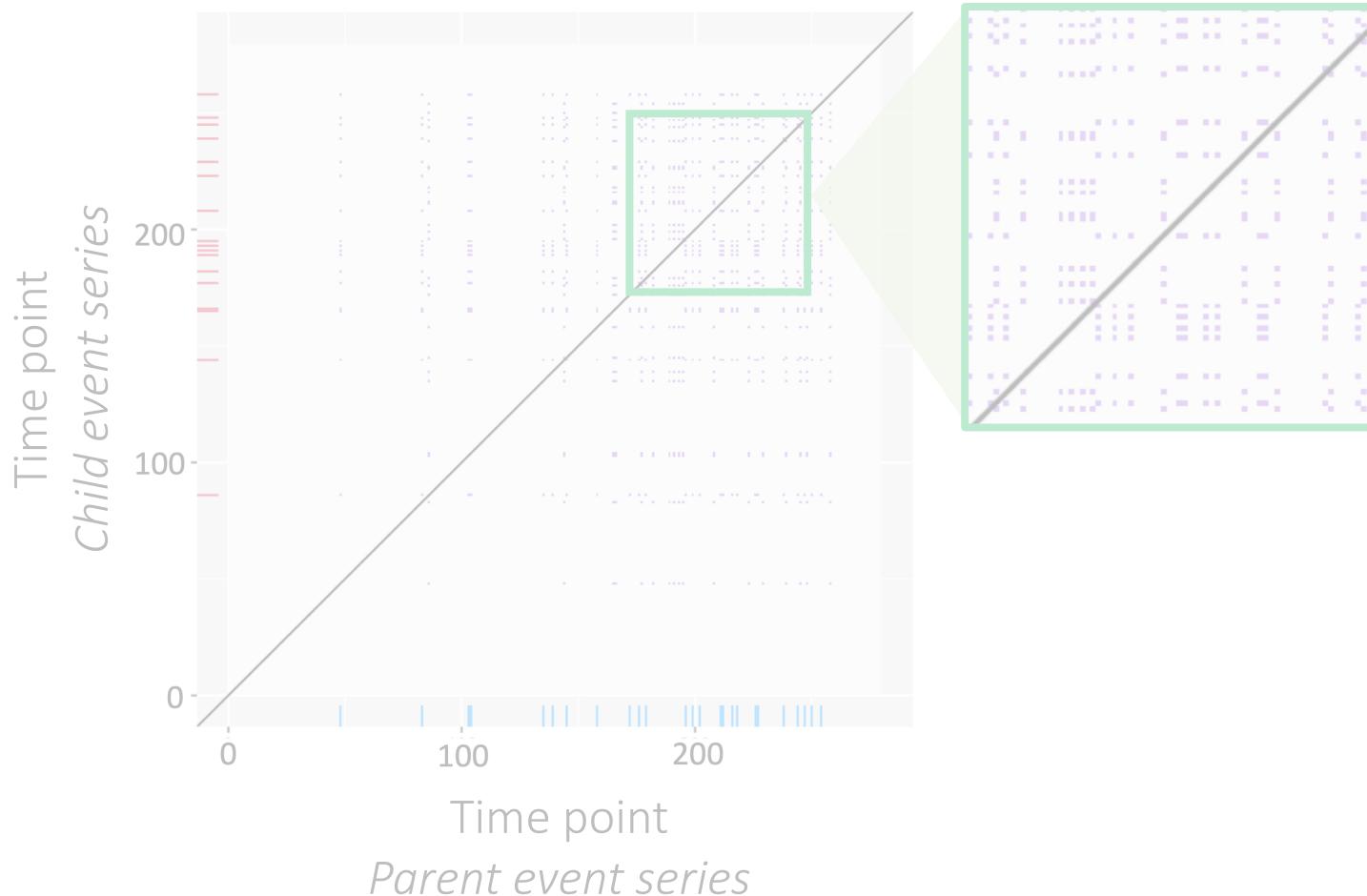


C: Three dollars.
P: Three dollars?
P: Okay.

P: Count how many
chicken.
C: One.

RQ3: Descriptive analysis

Shorter NT exchanges, distributed throughout the conversation



C: Three dollars.

P: Three dollars?

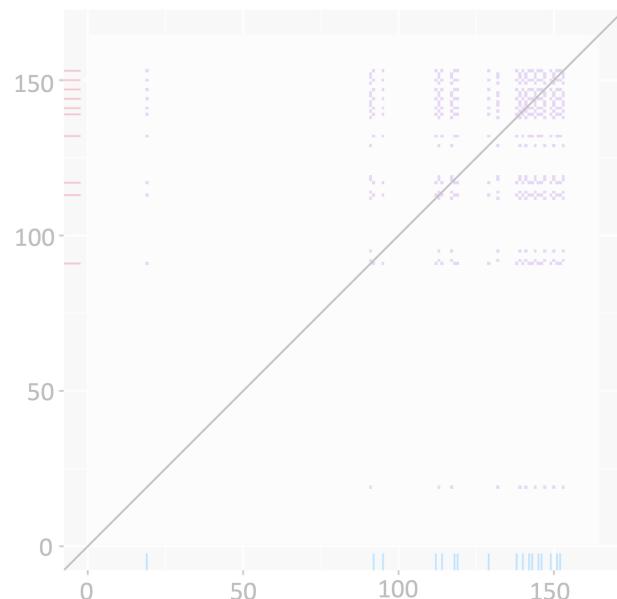
P: Okay.

P: Count how many
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C: One.

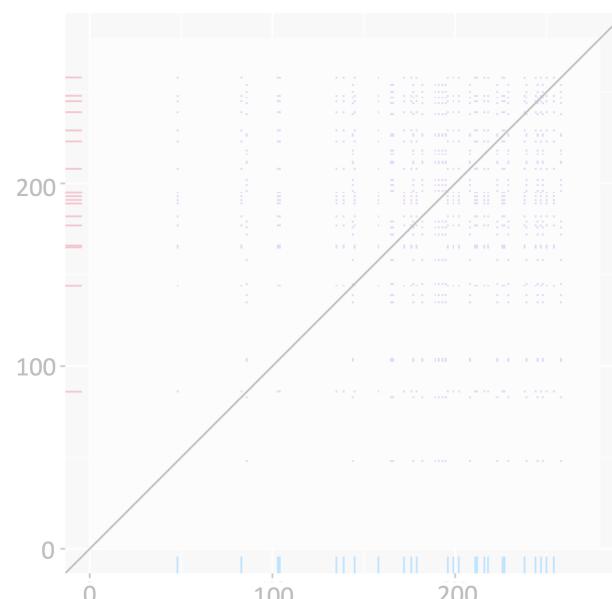
RQ3: Descriptive analysis

Longer NT exchanges,
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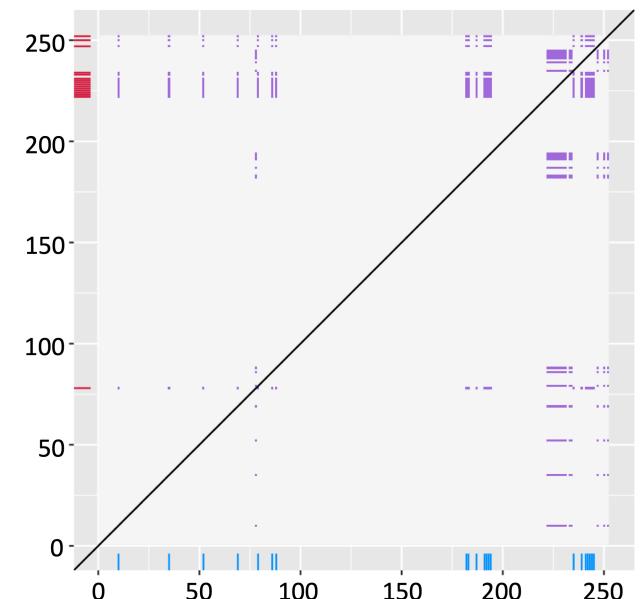
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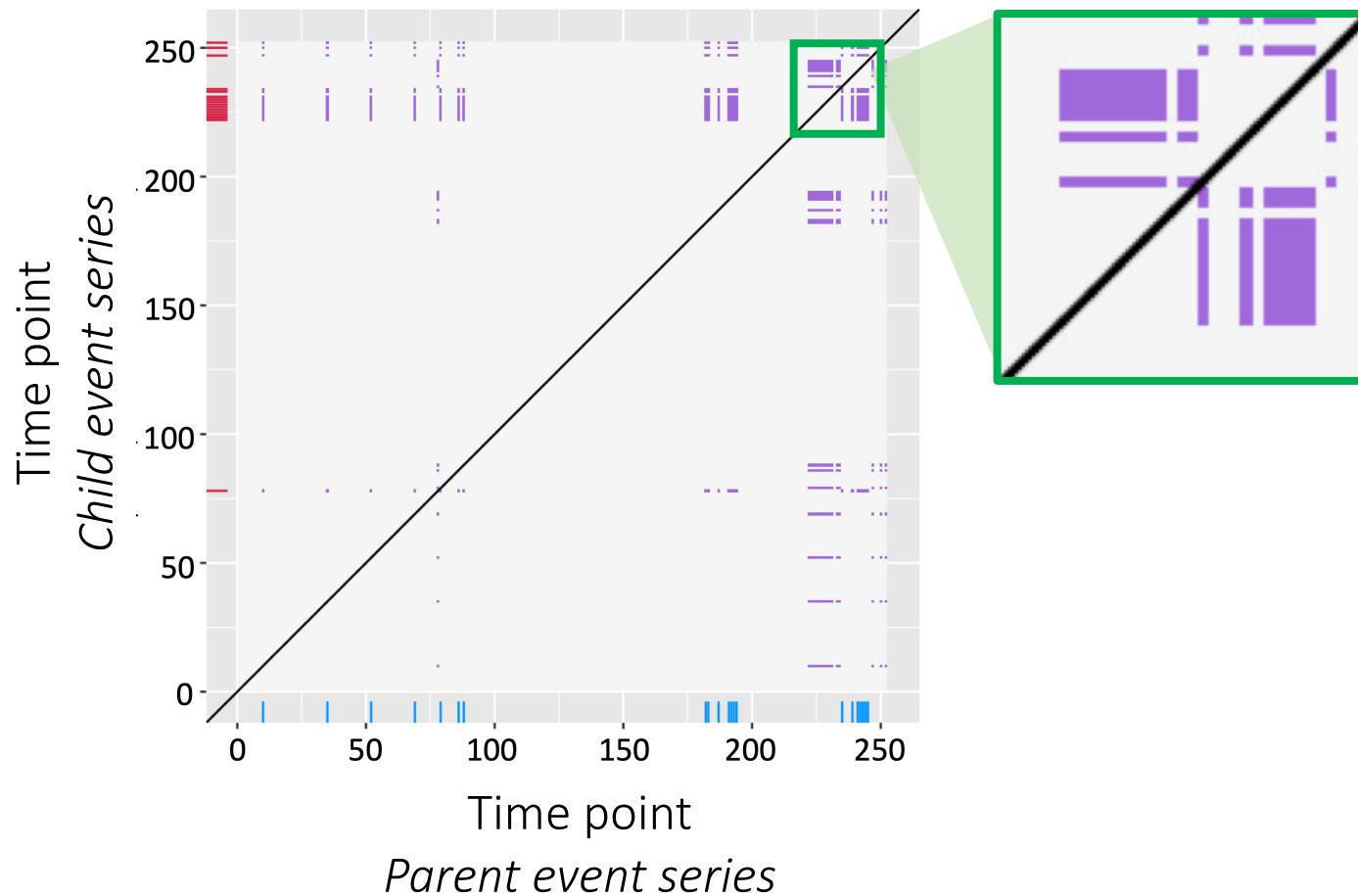
Long **bouts of consecutive**
NT by one speaker,
especially at the end



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DET = 1.45
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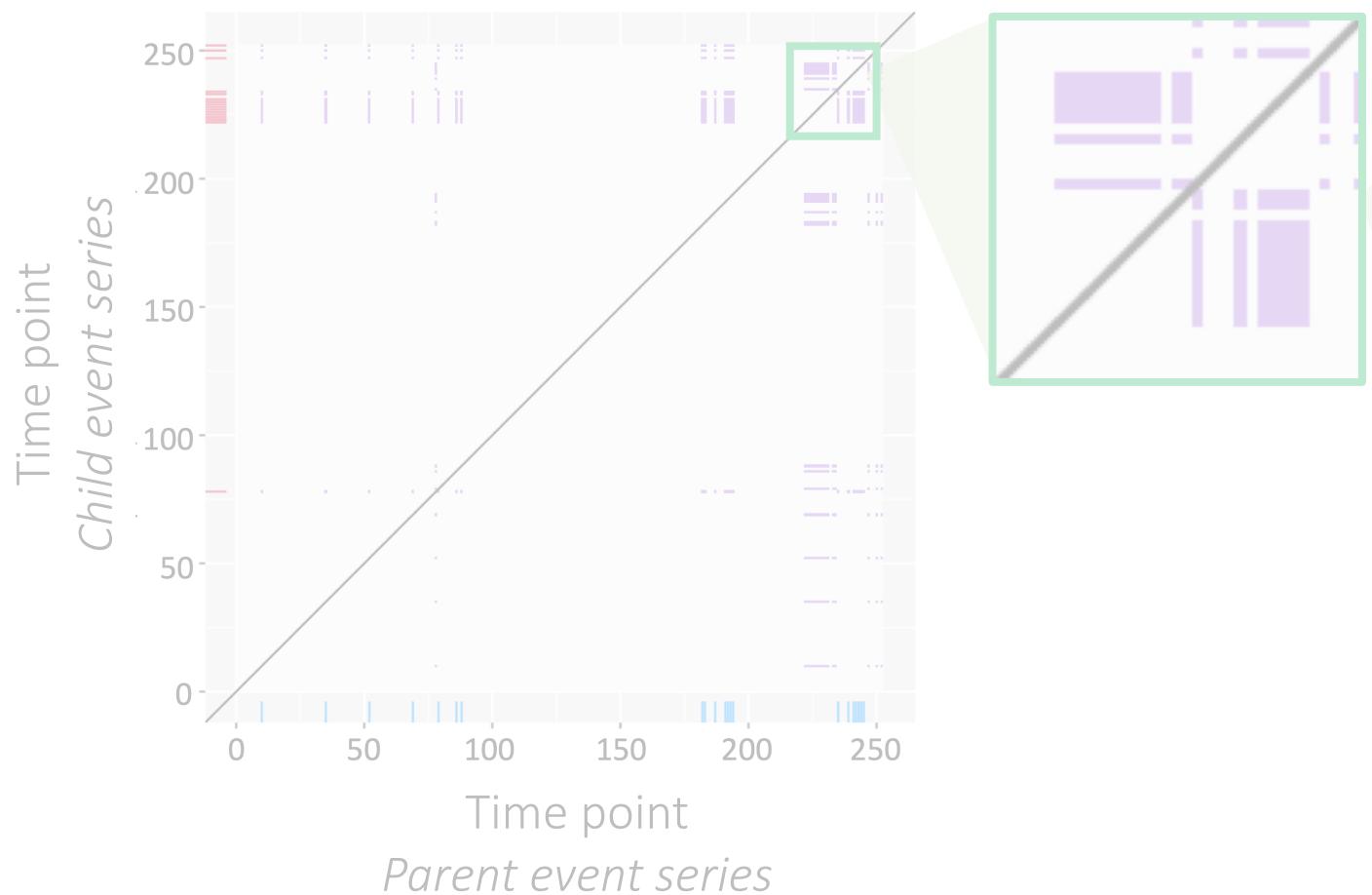
RQ3: Descriptive analysis

Long bouts of consecutive NT by one speaker at the end



RQ3: Descriptive analysis

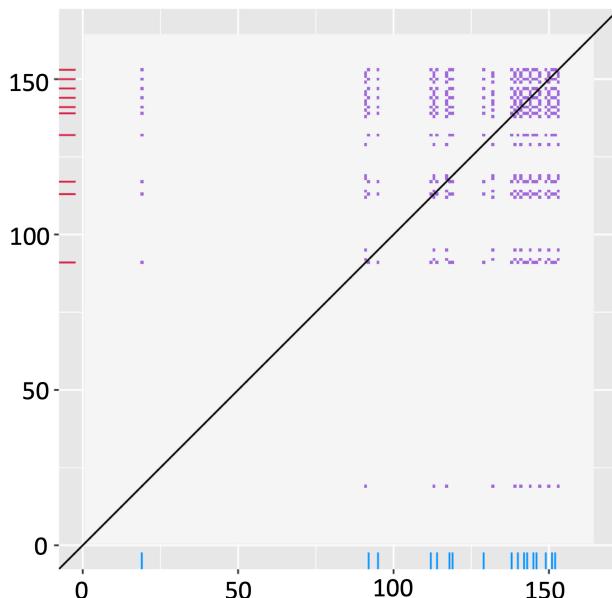
Long bouts of consecutive NT by one speaker at the end



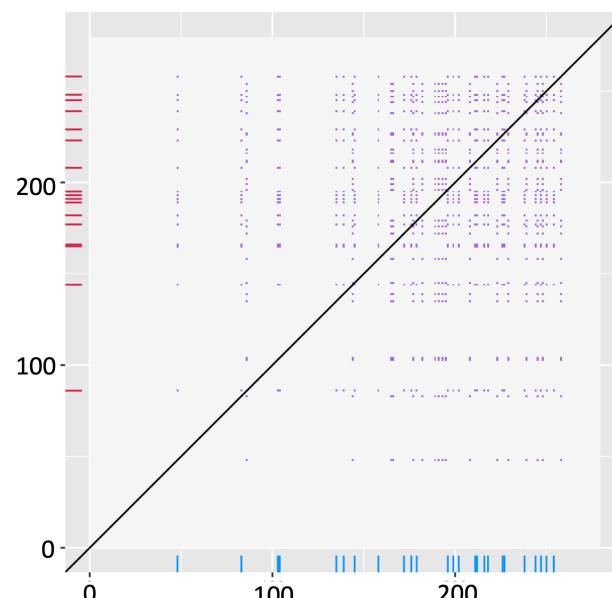
- C: [pressing buttons on the cash register] Nine, one, one.
- C: One, one.
- C: Four.
- C: Six, six.
- C: Eight.
- C: Ten.
- C: Six.
- C: Five, five, five.
- C: Six.

RQ3: Descriptive analysis

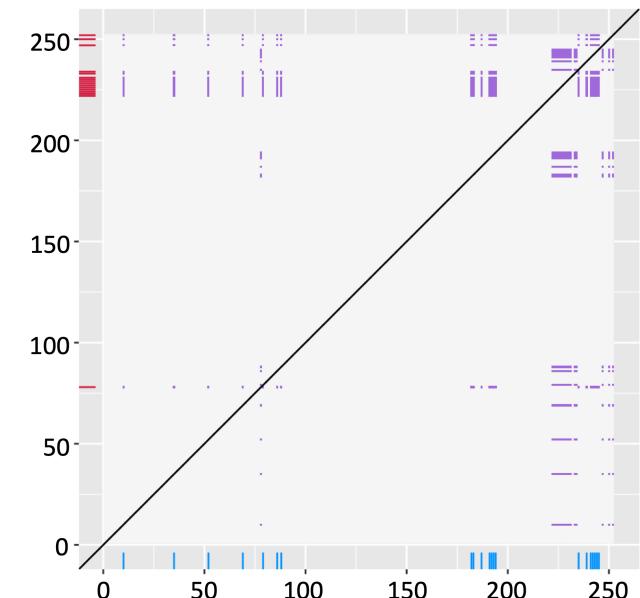
Longer NT exchanges,
concentrated at the end
of the conversation



Shorter NT exchanges,
distributed throughout
the conversation

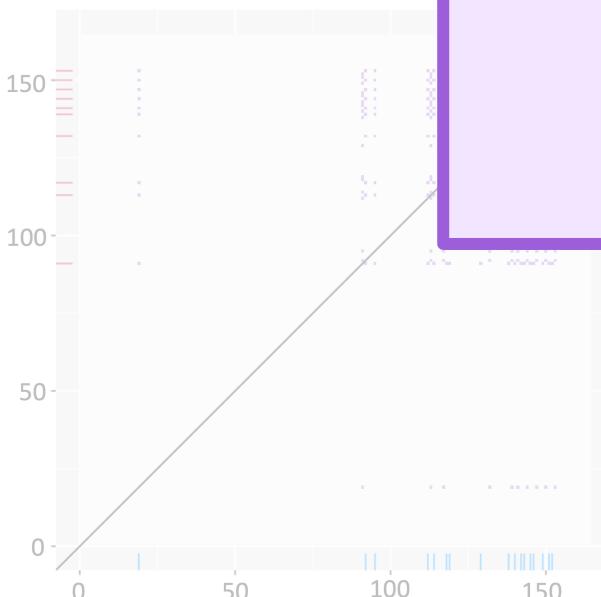


Long bouts of consecutive
NT by one speaker,
especially at the end

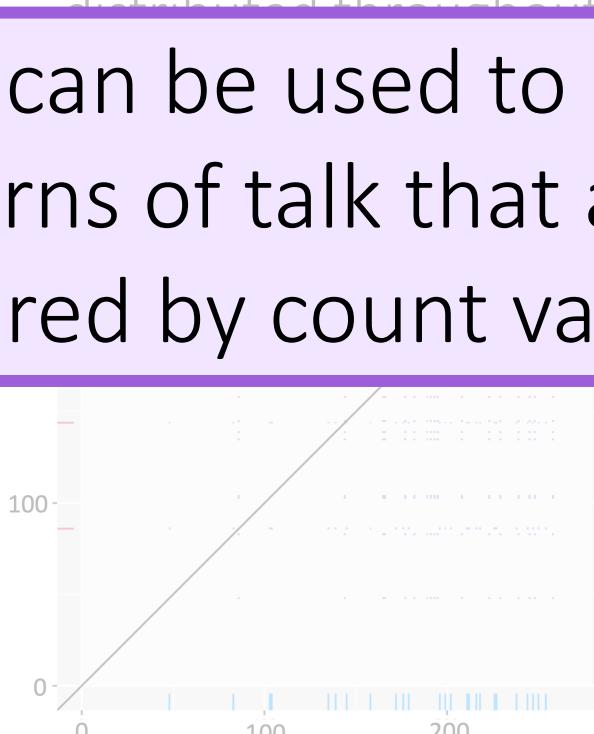


RQ3: Descriptive analysis

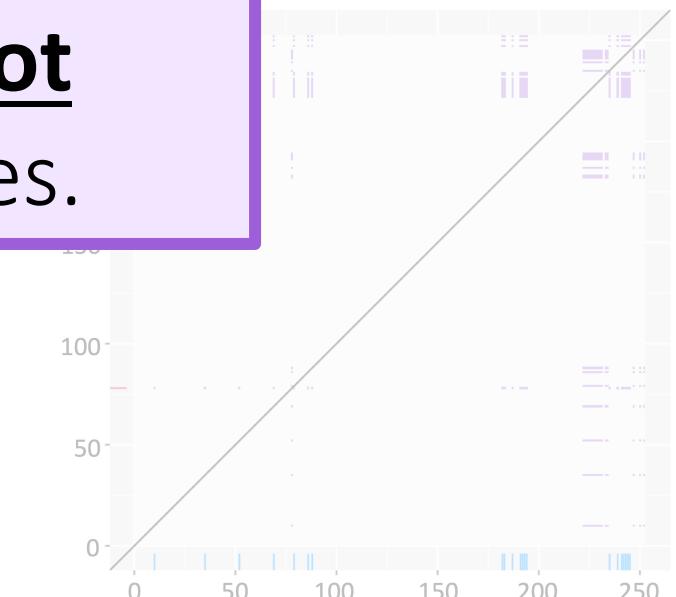
Longer NT exchanges,
concentrated at the end
of the conversation



Shorter NT exchanges,
distributed throughout the
conversation



Long bouts of consecutive
NT by one speaker,
especially at the end



CRQA can be used to uncover
patterns of talk that are **not**
captured by count variables.

In sum (math pun intended)

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- Caregiver-child (number) talk is a **collaborative** process.

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- Caregiver-child (number) talk is a **collaborative** process.
- This joint process can be described using CRQA to uncover **conversational structures**, namely the *extent* to which dyads **reciprocate** each others' talk and *how* they do so.
- These **structures vary** across dyads even when they have similar frequencies of talk.

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In sum (math pun intended)

- CRQA is a “low-cost” method for extracting additional measures of dyadic interactions beyond counts of language input.
- Combined with an in-depth, descriptive analysis, we can derive rich characterizations of caregiver-child interactions. This can help extend our knowledge of conversational practices that support child development.



FRED ROGERS CENTER
for early learning and children's media
at Saint Vincent College

EVERYDAY
INTERACTIONS
MATTER



Image sources are hyperlinked.

Thank you for listening!!! 😊

Wanna talk? Email me at shd77@pitt.edu (I'm happy to share my slides, code, and resources!)

Thanks to...

- The **Kids' Thinking Lab**  for their support and feedback!
- My comps committee members: Melissa Libertus (my awesome advisor!), Scott Fraundorf, and Tehran Davis (University of Cincinnati)

Lots of love to my study buddies,
Ketura Elie, Dani Hunter, Nicole Lobo ❤️

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More on CRQA: Assumptions?

- No assumptions about the underlying model or structure of the data
- However, the distance between any two variables must be the same
 - Continuous time series – e.g., sampling rate is constant, time between events is the same
 - Categorical event series – meanings of categories remain the same across time
- Other information?
 - More data is always better
 - Event series should be long enough that a pattern occurs at least twice*
 - How do we know if recurrent patterns are different from noise?
 - Important metrics from past work that was reviewed? It depends...

More on CRQA: Limitations?

- One limitation is that there are no significance or uncertainty metrics that are inherent to the method.
 - One way around this is to generate some pseudo- (randomized) time series from the original time series and run CRQA on them. In this case, the recurrence metrics from the pseudo time series are used as the null distribution.
- Another limitation with *categorical* CRQA has to do with "removing" time from the conversations.
 - Thus, we do not capture meaningful conversational events or cues like *pauses*.

CRQA vs. other similar methods?

- Other methods that were mentioned in reviewed papers:
 - **Cross-correlation (CC)** – measure of similarity between two time series at multiple lags
 - CC assumes that the time series are stationary (i.e., linear analysis method)
 - CRQA is non-linear and extends this “similarity” measure by quantifying *patterns* of co-visitation
 - **Lag-sequential analysis**
 - CRQA is not restricted to examining cross-recurrences at the same time or within a fixed time window before/after an event.
 - **Natural language processing (NLP) methods**
 - Using NLP to assess recurrence/coordination between dyads removes temporal information

Some limitations (+ future directions) of the case study

- Our event series coding scheme captured number utterances only if they contained a number or math word.
- We could not extract leader-follower metrics because our RPs were symmetric.
- We could look at other measures (e.g., trend – the “thinning out” of the RP or how dense the recurrence points are in a line parallel to and some distance away from the LOI).
- We could examine recurrence of NT based on categories of talk (e.g., complexity).
- We could compare the recurrence of NT to non-NT or all talk.