Retrieving structures from memory causes difficulty during incremental processing

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Based on Shain et al. 2016

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Introduction

- **Hypothesis:** Memory access in incremental parsing causes reading time delays.
- Predicted by a number of theories of sentence processing (e.g. Gibson 2000; Johnson-Laird 1983).
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Conclusion

- Memory retrieval effects exist in human sentence processing.

Acknowledgments

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So why are we still working on this?

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  - **Constructed stimuli:** Strong effects
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Experimental setup: The Natural Stories corpus

- Experiments used Natural Stories corpus (Futrell et al. in prep):
  - Constructed-natural stimuli:
    - Fluent narrative text
    - Memory-intensive constructions
  - SPR data collected
  - 10 texts, 10257 words, 181 subjects, 848,207 events
- Partitioned into exploratory (1/3) and confirmatory (2/3) corpora
- First evaluated all predictors on exploratory using LME regression.
- All results are in spillover 1 position.

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The Dependency Locality Theory: Background

- DLT (Gibson 2000): Difficulty by dependency length (# discourse referents (DR))
- Intuition: Older things are harder to access in memory
- For simplicity, DR = nouns and finite verbs
- **Integration cost** is sum of:
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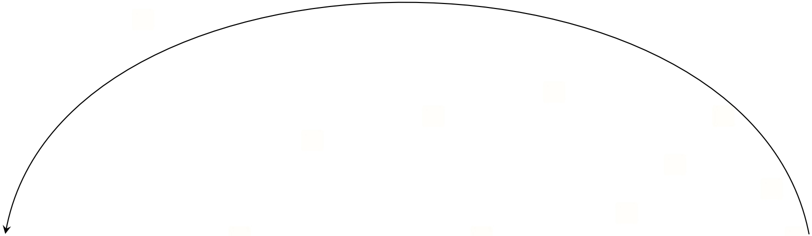
The Dependency Locality Theory: Example



Yesterday, the **person supervisors** and **co-workers caught** stealing **millions fled.**

Dependency length = 4 (4 intervening DR (bold))

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	β (ms)	p-value
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Reliable broad-coverage DLT effect

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DLT (modified)	1.13	4.87e-10

Reliable broad-coverage DLT effect

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Left-corner parsing

- Popular model of sentence processing
- Rosenkrantz and Lewis (1970), Johnson-Laird (1983), Abney and Johnson (1991), Gibson (1991), Resnik (1992), Stabler (1994), Lewis and Vasishth (2005), and van Schijndel, Exley, and Schuler (2013)

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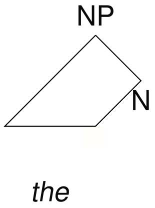

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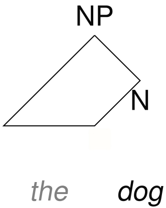

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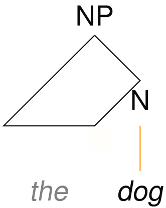

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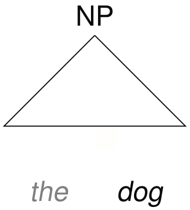

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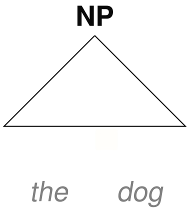

Left-corner parsing

- Many plausible predictor implementations (see Shain et al. 2016)
- Best predictor on exploratory: “no fork”
  - Top sign must be recalled from memory
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Left corner (no-fork)	3.88	2.33e-14

Reliable broad-coverage left corner effect

Left-corner parsing: Results

- No-fork estimate (3.88ms) is entire effect.
- DLT effect has a large range (12) but is usually small (95th percentile = 2).
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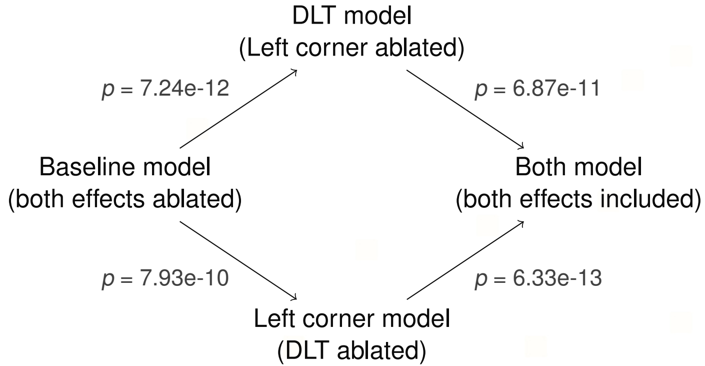

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- Both effects improve significantly over baseline and over each other.

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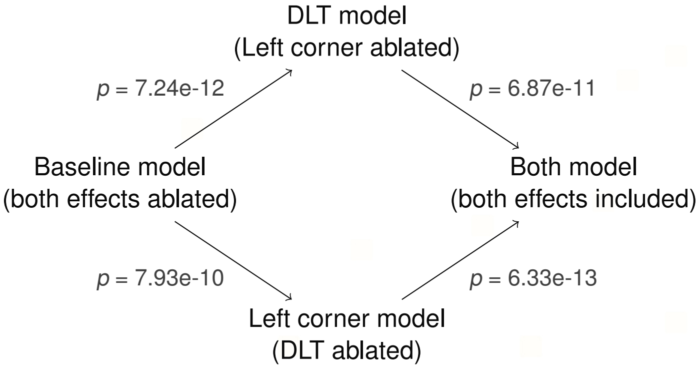

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How general are these effects?

Are these effects widespread, or are they driven by particular contexts?

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	β-ms	p-value
DLT (modified) (N/V removed)	0.353	0.141
Left corner (no-fork) (N/V removed)	1.17	1.72e-05

- Left corner effect survives even when nouns and verbs are filtered out.
- DLT effect does not.

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- Possibly semantics vs. syntax?
  - DLT has access to semantic information like head/dependent, referential status, etc. Left corner does not.
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- Separate contributions might indicate separate mechanisms for (semantic) dependency construction vs. retrieval of syntactic derivations.

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Appendix: Experimental setup

- Filtered out sentence starts/ends (leaving 768,023 events)
- Models evaluated via likelihood ratio test (LRT)
- Reading times transformed by Box and Cox (1964) ($\lambda \approx 0.63$)
- **Baseline:**
  `boxcox(readingTime) ~ sentencePosition + wordLength + 5GramSurp + pcfgSurp + (1 + sentenceID + sentencePosition + wordLength + 5GramSurp + pcfgSurp + mainEffect | subject) + (1 | word) + (1 | sentenceID)`
- All predictors z-score normalized prior to evaluation
- β values above are divided by standard deviation and backtransformed into ms, only valid at mean
- Predictors computed over trees in Generalized Categorial Grammar (GCG) (Nguyen, van Schijndel, and Schuler 2012)
  - Automatically reannotated from Penn Treebank-style gold and hand-corrected
  - Contains implicit dependency and memory store representations, can be used to calculate all predictors from single source

The DLT variants

- In this study, we consider 3 additional broad-coverage modifications of the DLT:
  - **DLT-V**: *Verbs are more expensive*. Non-finite verbs receive a cost of 1 (instead of 0) and finite verbs receive a cost of 2 (instead of 1).
  - **DLT-C:** *Coordination is less expensive*. Dependencies out of coordinate structures skip preceding conjuncts. Dependencies with intervening coordinations just use heaviest conjunct.
  - **DLT-M:** *Exclude modifier dependencies*. Dependencies to preceding modifiers are ignored.
- Modifications can be applied in any combination, yielding 8 implementation variants of the DLT for this study.
- Best variant was DLT-C and DLT-M together.

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- Best variant was DLT-C and DLT-M together.

The DLT variants

- In this study, we consider 3 additional broad-coverage modifications of the DLT:
  - **DLT-V**: *Verbs are more expensive*. Non-finite verbs receive a cost of 1 (instead of 0) and finite verbs receive a cost of 2 (instead of 1).
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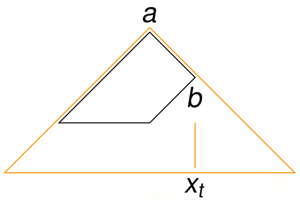
Left-corner parsing: Fork decision



No-fork (shift + match): Word satisfies b. a is complete.

$$\frac{a/b \quad x_t}{a}\; b \rightarrow x_t. \qquad (-F)$$

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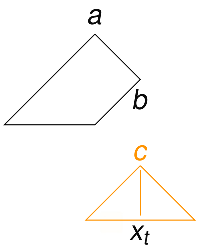
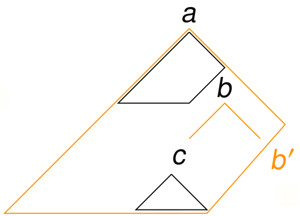


Yes-fork (shift): Word does not satisfy b, fork off new complete category c.

$$\frac{a/b \quad x_t}{a/b \quad c} \; b \xrightarrow{+} c \ldots ; \quad c \rightarrow x_t. \tag{+F}$$

Left-corner parsing: Join decision



Yes-join (predict + match): Complete category c satisfies b while predicting b'. Store updates from $\langle \ldots, a/b, c \rangle$ to $\langle \ldots, a/b' \rangle$.

$$\frac{a/b \quad c}{a/b'} \; b \rightarrow c \; b'. \tag{+J}$$

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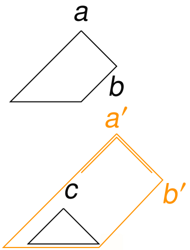

No-join (predict): Complete category c does not satisfy b. Predict new a' and b' from c. Store updates from $\langle \ldots, a/b, c \rangle$ to $\langle \ldots, a/b, a'/b' \rangle$.

$$\frac{a/b \quad c}{a/b \quad a'/b'}\; b \xrightarrow{+} a' \ldots ; \quad a' \to c\; b'. \qquad (\text{–J})$$

Appendix: Left-corner predictors

- Memory effects are predicted when signs must be recalled by left-corner parser, but implementation details matter.
- We implemented 3 families of left-corner predictors:
  - **EMBD:** *End of embedded region.* True if –F+J or end of carrier, false otherwise.

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  - Number of words
  - Number of DLT discourse referents
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Appendix: Full results

		Exploratory corpus				Confirmatory corpus			
		β	β-ms	t-value	p-value	β	β-ms	t-value	p-value
Best	**NoF-S1**	1.23e-4	1.29	6.66	1.45e-10	1.46e-4	1.54	8.15	2.33e-14
Best	**DLT-CM-S1**	1.11e-4	1.16	5.85	1.42e-8	9.63e-5	1.10	6.48	4.87e-10
Canon	**REINST-S1**	1.17e-4	1.23	6.33	1.60e-9	1.35e-4	1.43	8.01	5.77e-14
Canon	**DLT-S1**	8.04e-5	0.846	4.51	1.03e-05	6.04e-05	0.634	4.50	1.11e-05