Towards a Computational Linking Theory for Minimalism

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CUNY GC
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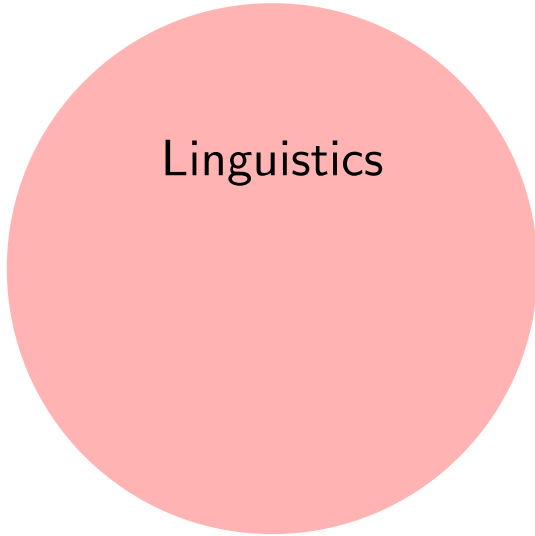
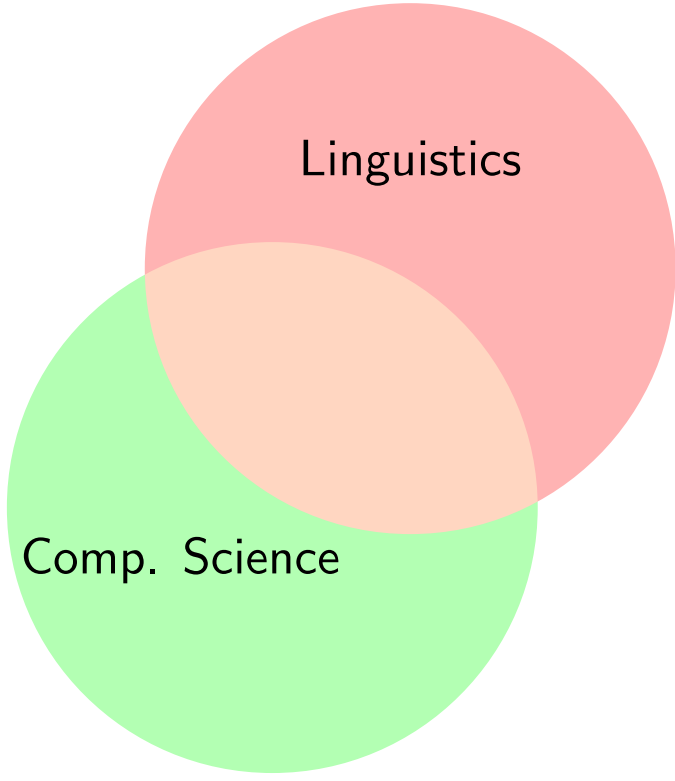

Linguistics


Linguistics
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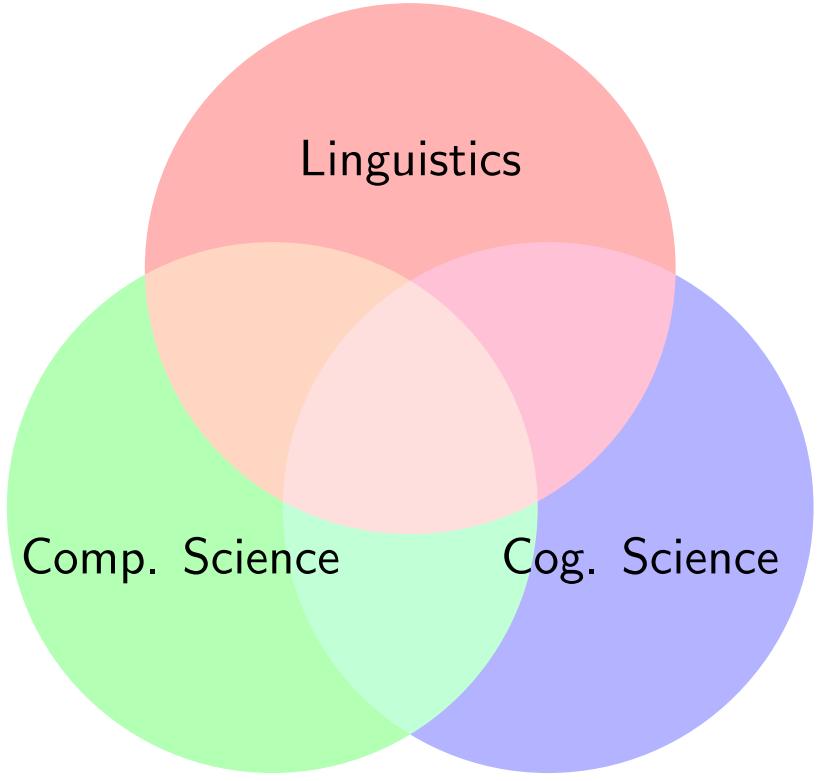
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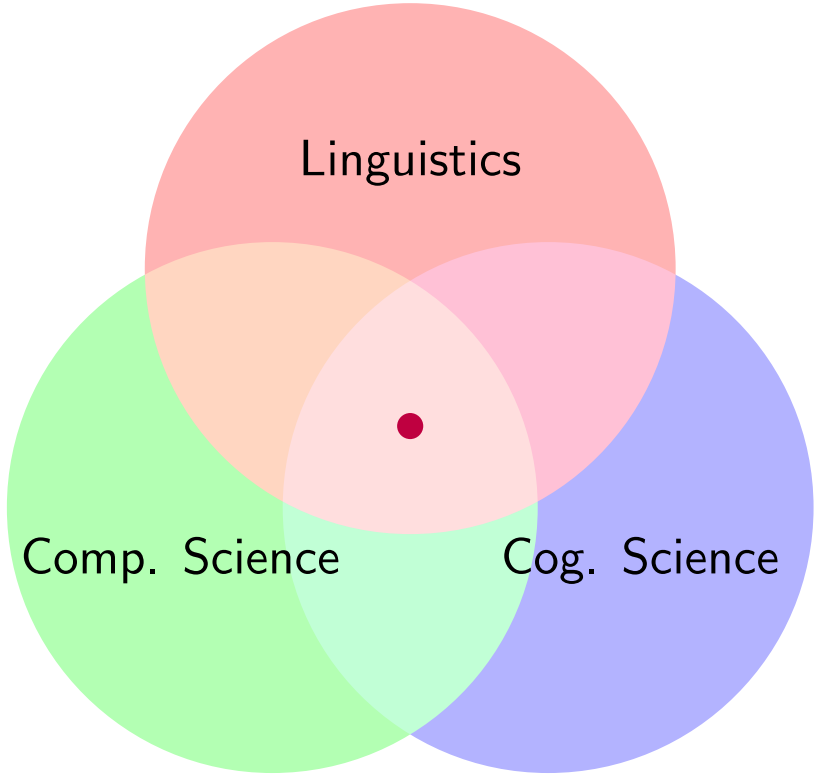

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- Evaluating/Contrasting syntactic analyses
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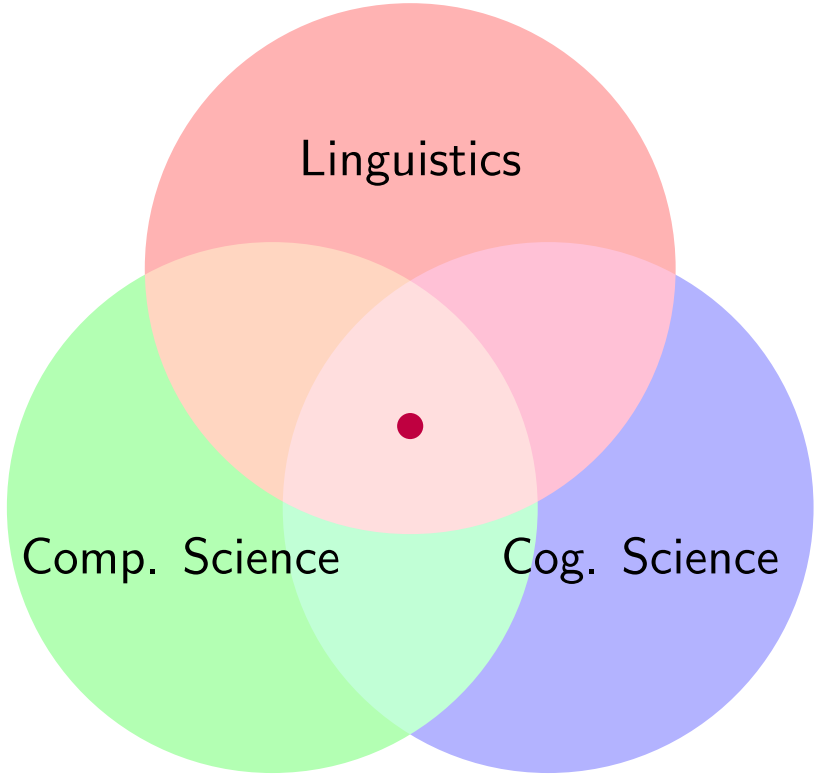

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Let's Start with Data!

Asymmetries in Italian Relative Clauses

Italian conforms to the general cross-linguistic preference for SRC over ORC (Adani et al. 2010; Arosio et al. 2018)

(1) Il cavallo che ha inseguito i leoni
The horse that has chased the lions
"The horse that chased the lions" **SRC**

(2) Il cavallo che i leoni hanno inseguito
The horse that the lions have chased
"The horse that the lions chased" **ORC**

SRC > ORC

Postverbal Subjects and Ambiguity

Italian allows for postverbal subjects, making some sentences ambiguous (De Vincenzi 1991):

(3) Il cavallo che ha inseguito il leone
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Agreement can disambiguate:

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Processing Asymmetry (De Vincenzi 1991, Arosio et al. 2018, a.o.)

SRC > ORC > ORCp

One Big Question

(How much) does grammatical structure matter in sentence processing?

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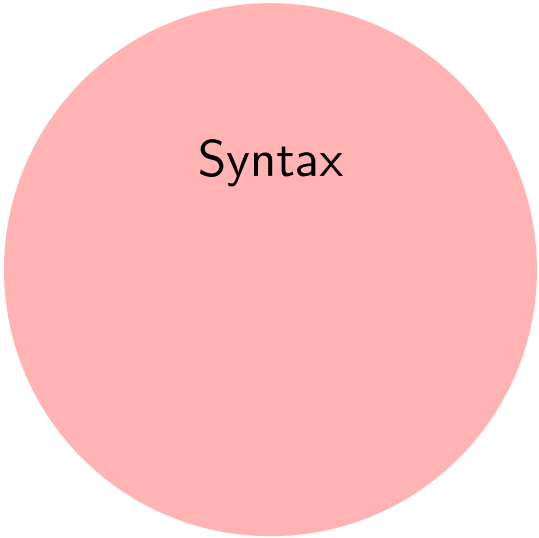

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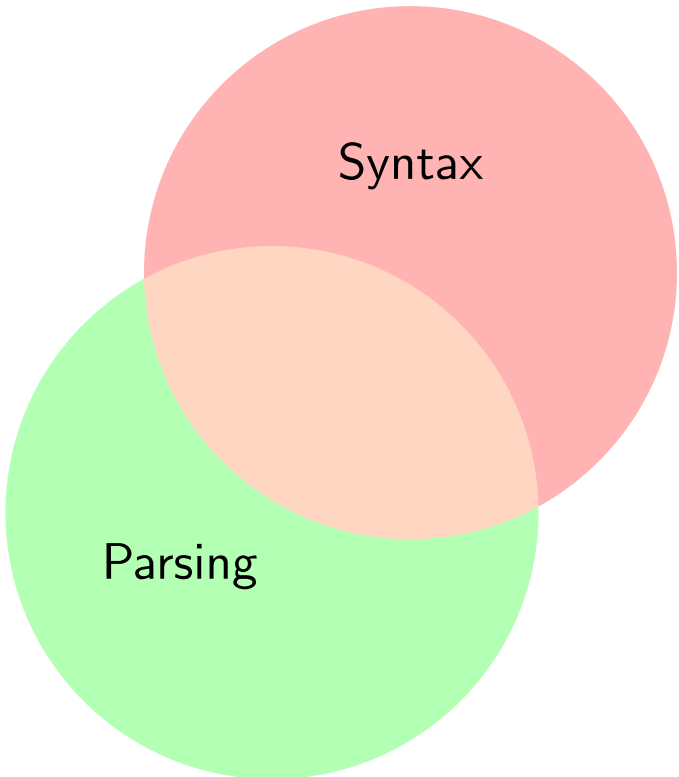

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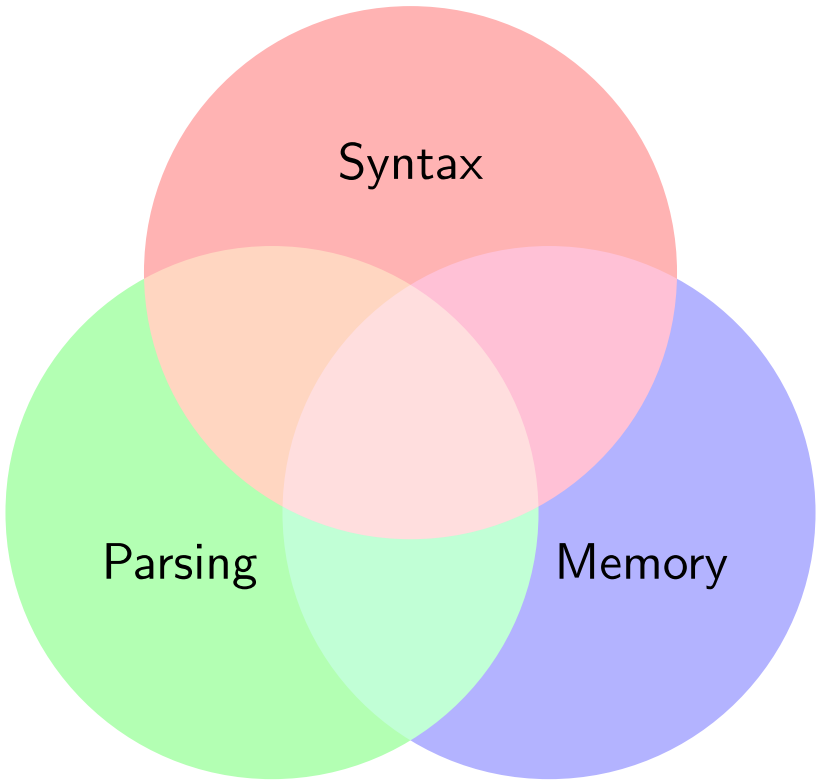

Forward to the Past

- What is the relation between grammatical operations and cognitive processes?

Derivational Theory of Complexity (Miller and Chomsky, 1963)

- Processing complexity $\sim$ length of a derivation (Fodor & Garrett 1967; Berwick & Weinberg 1983)
- Essentially: there is a **cost** to mental computations.

- What is the right notion of syntactic derivation?
- What is costly? And why?

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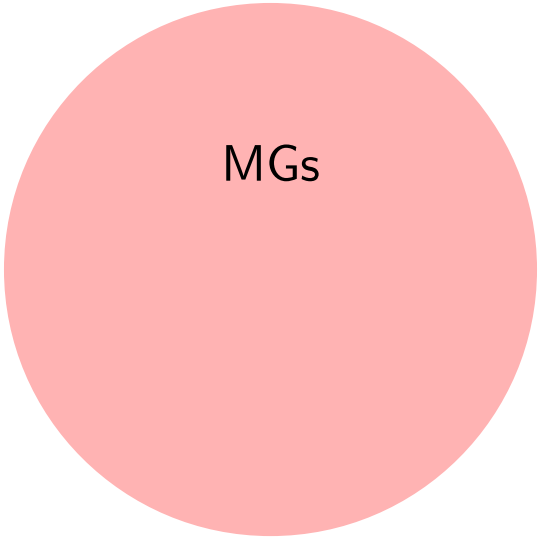

1. An explicit syntactic theory $\rightarrow$ Minimalist grammars (MGs)

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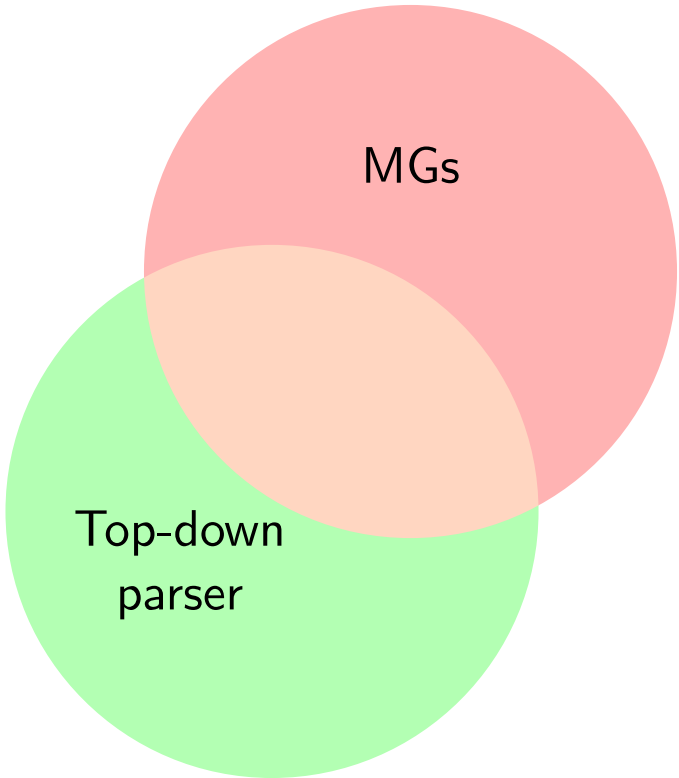

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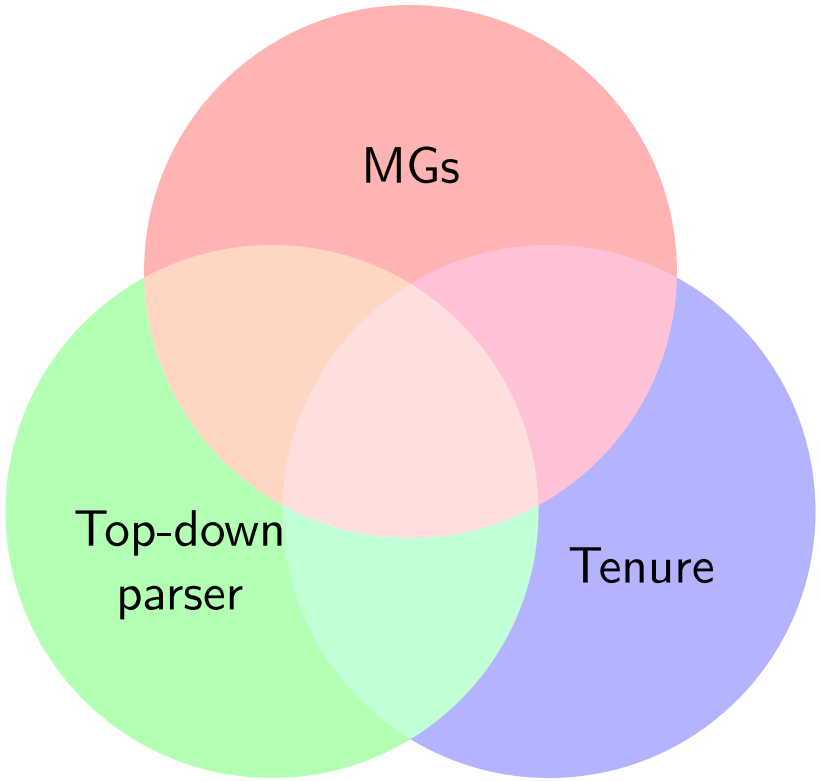

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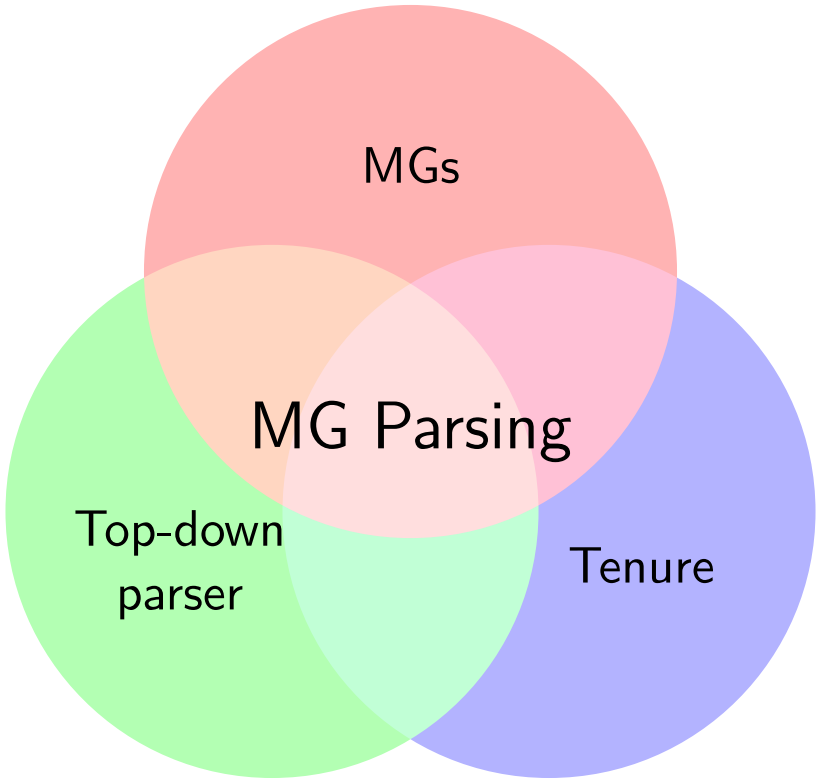

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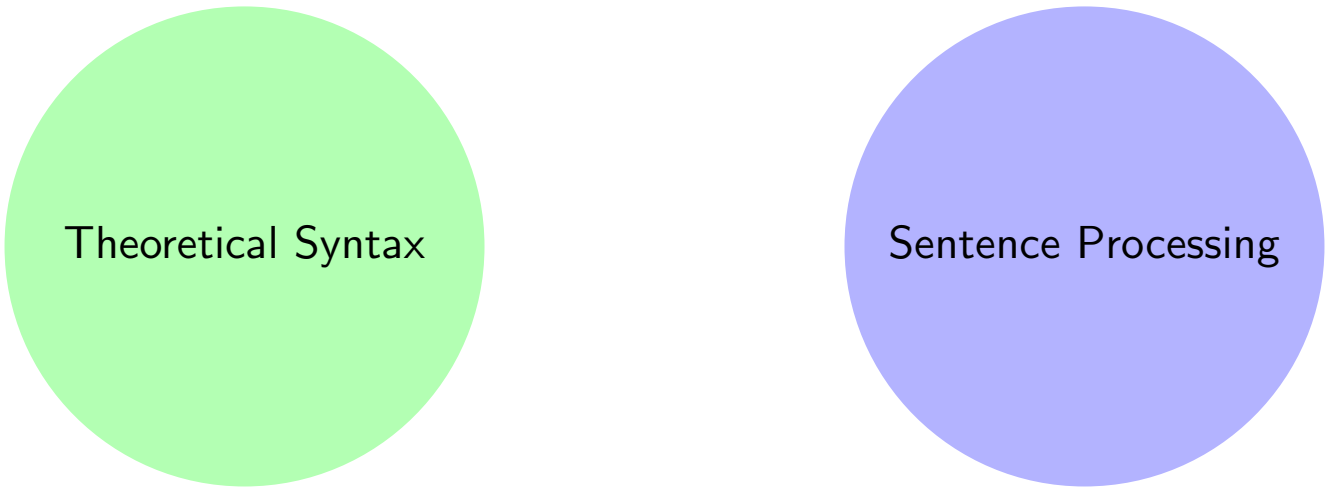
Interpretability for the win!

Building Bridges



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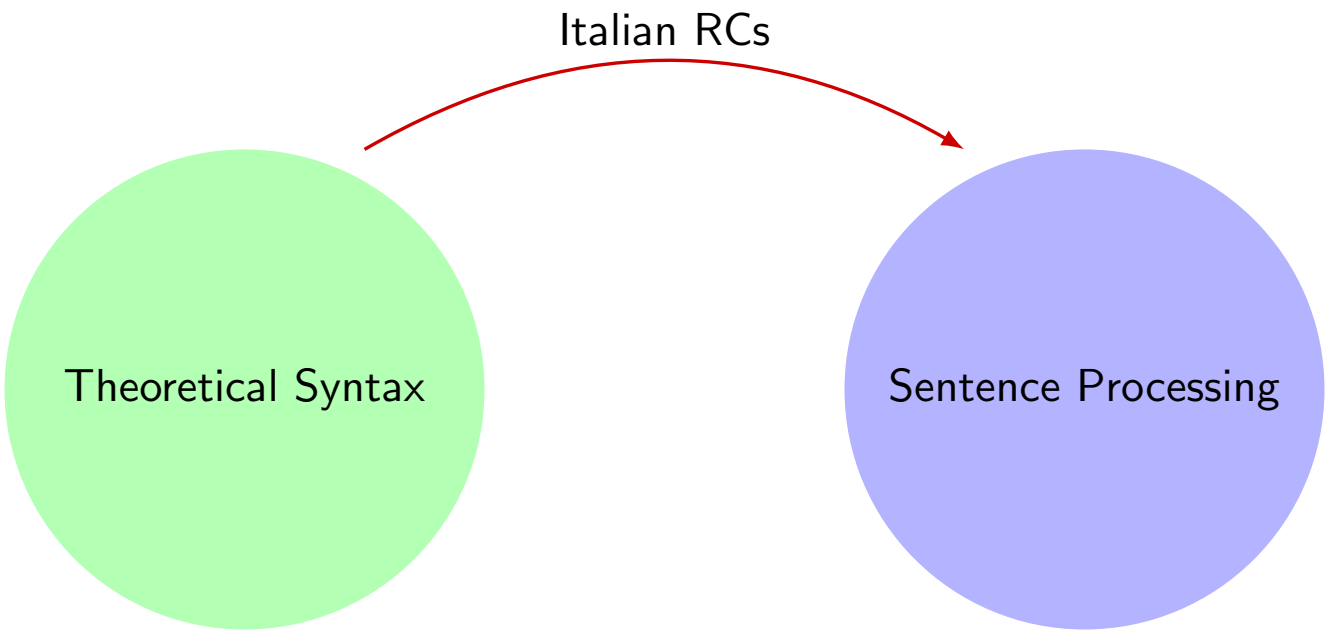

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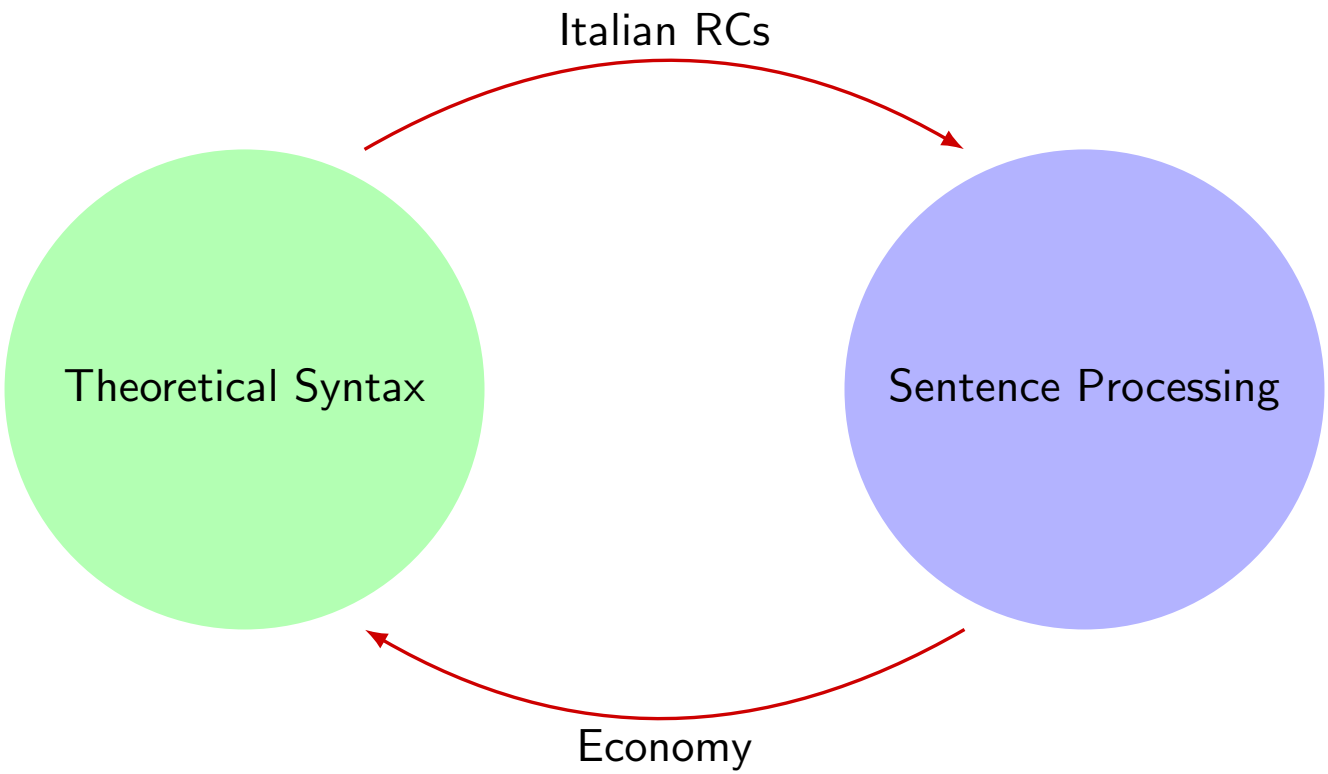


Outline

Minimalist Grammars (MGs)

We need an explicit model of syntactic structures...

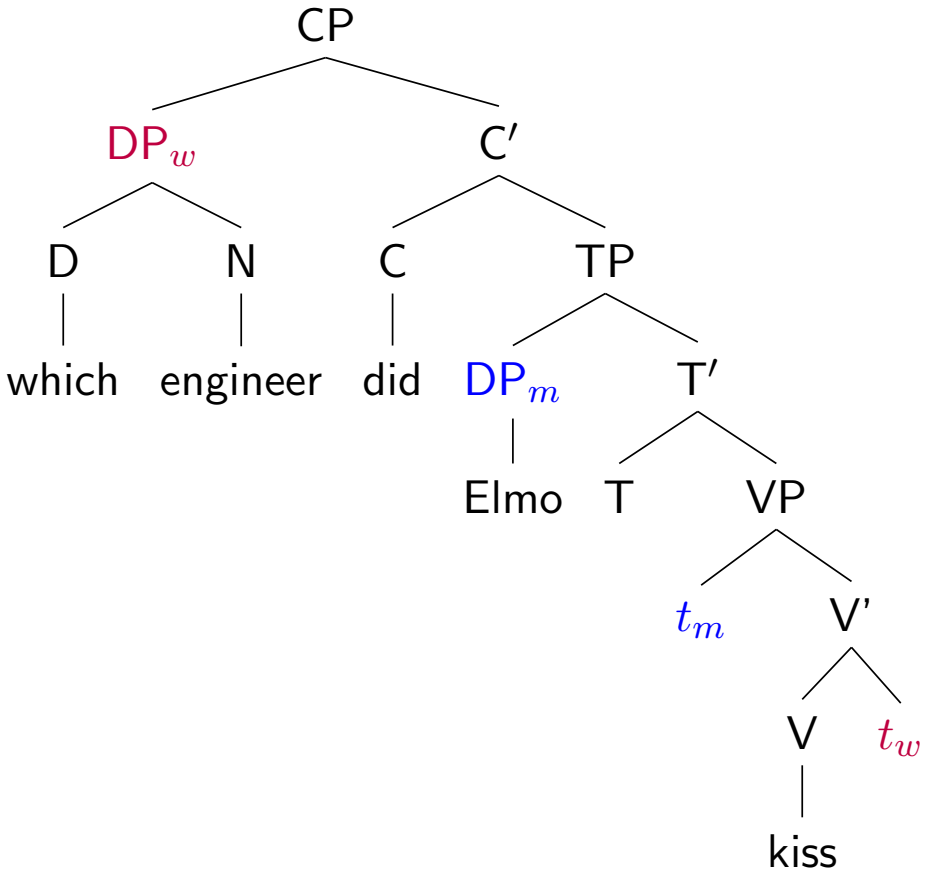
Ed Stabler

- Minimalist grammars (**MGs**): a formalization of Chomskyan syntax
  (Chomsky 1995; Stabler 1997)

Technical details!

- Weakly equivalent to MCFGs
- Essentially: CFGs with a more complicated mapping from trees to strings

MG Syntax: Derivation Trees



Phrase Structure Tree

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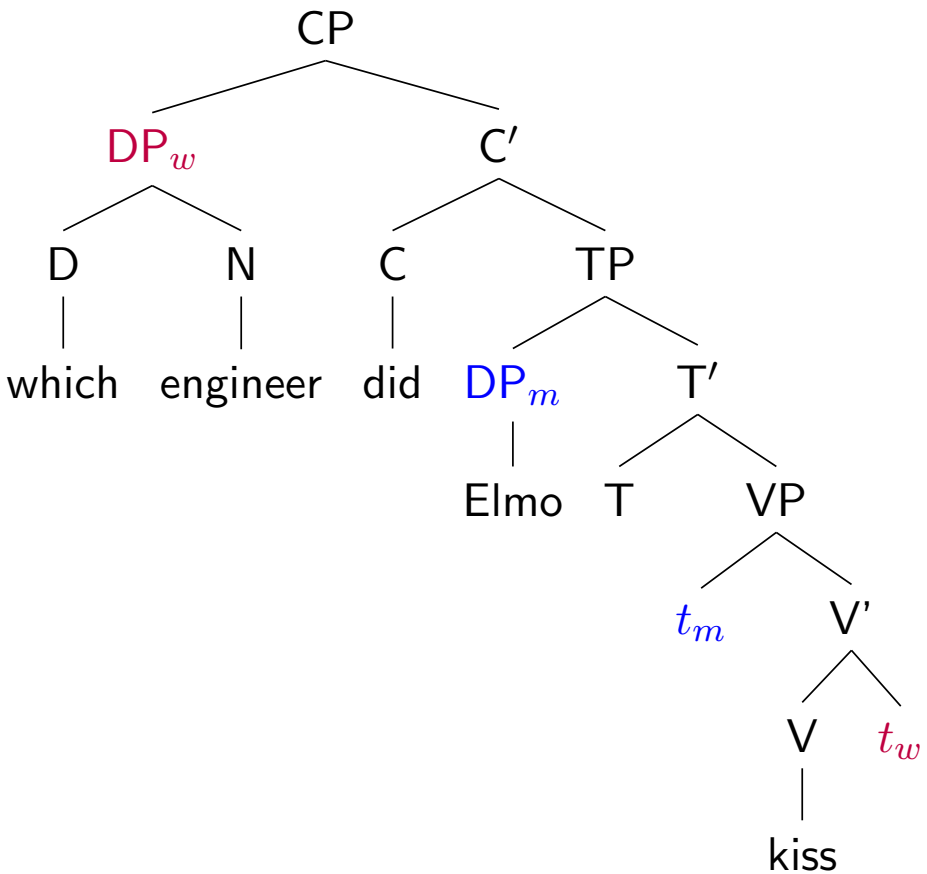

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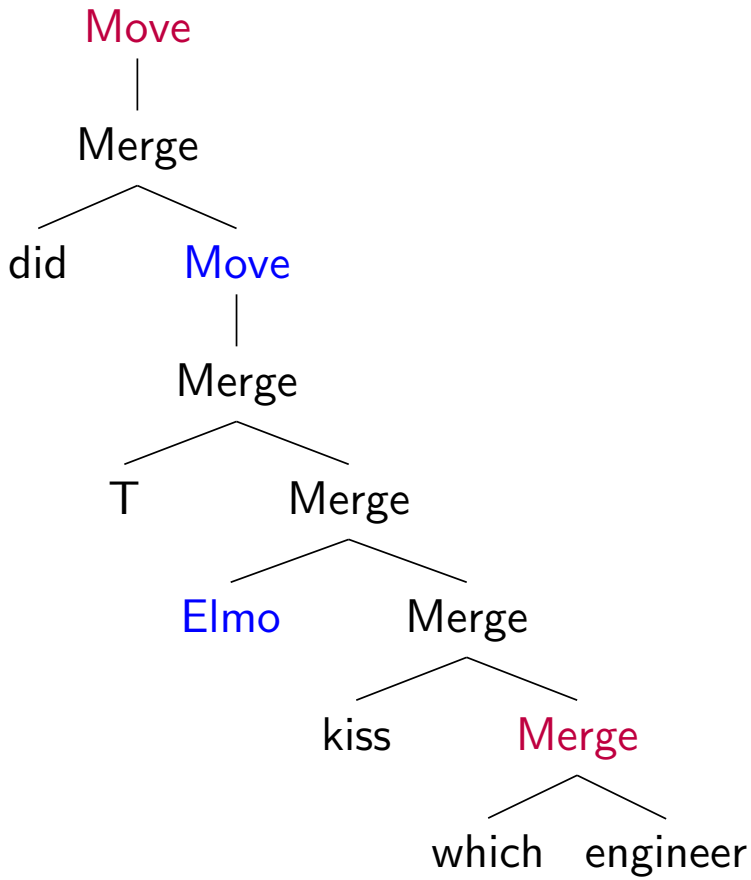

Derivation Tree

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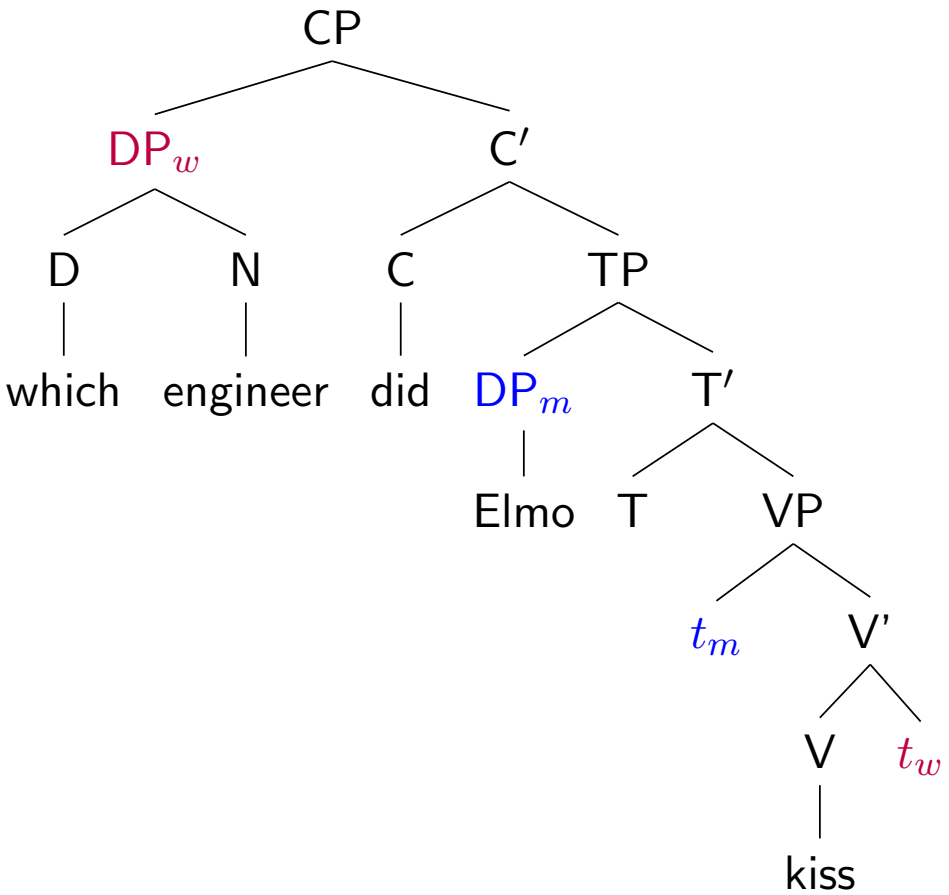

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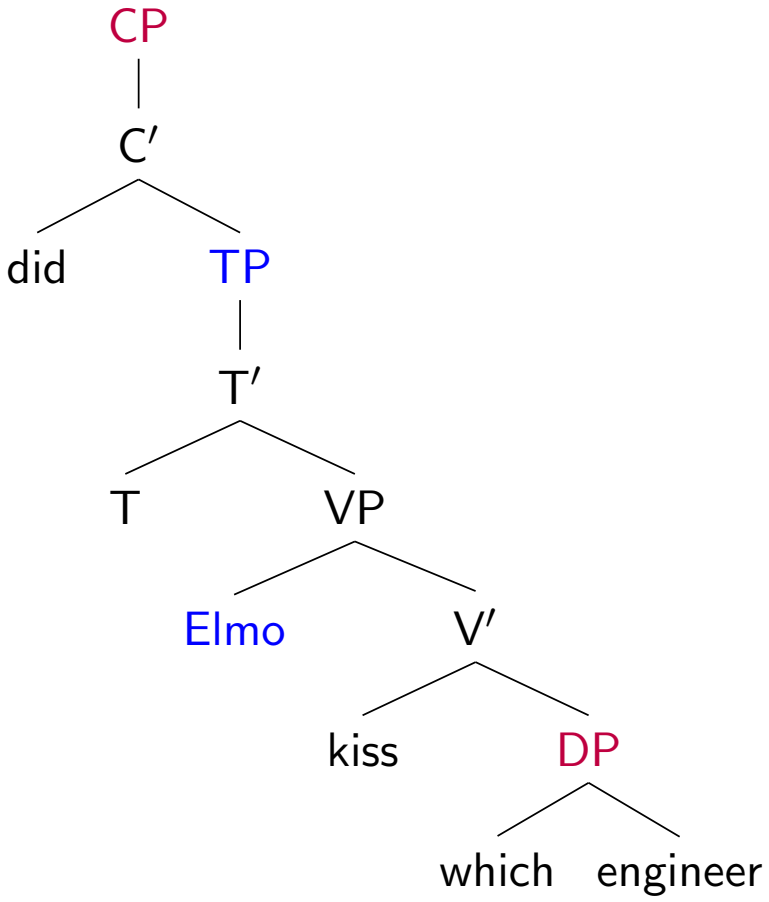
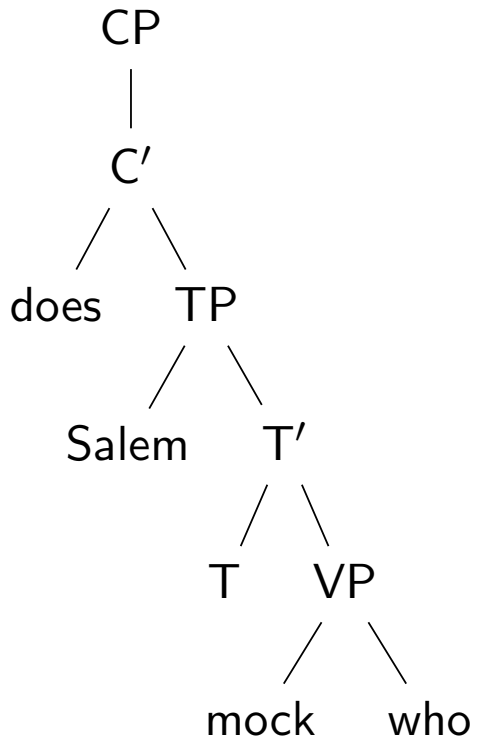


Derivation Tree

The Job of a Parser

Who does Salem mock?



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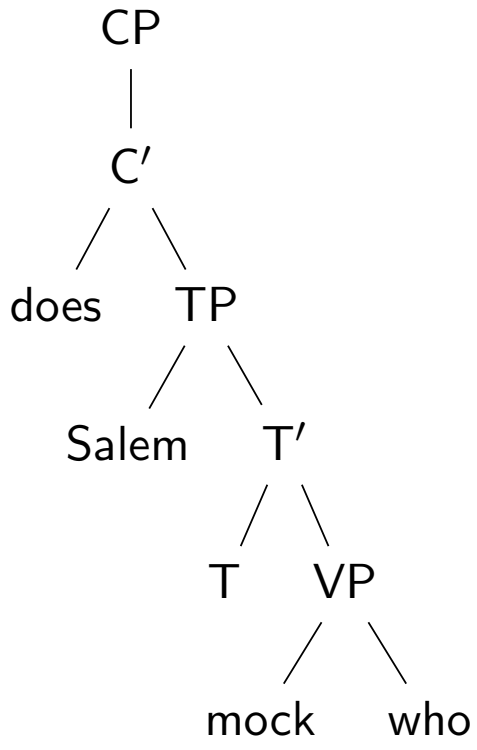

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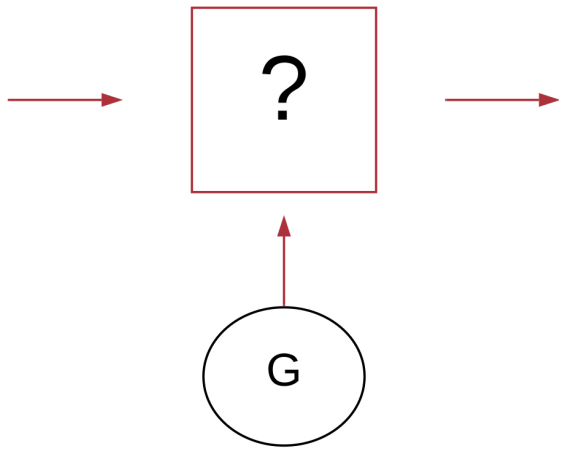

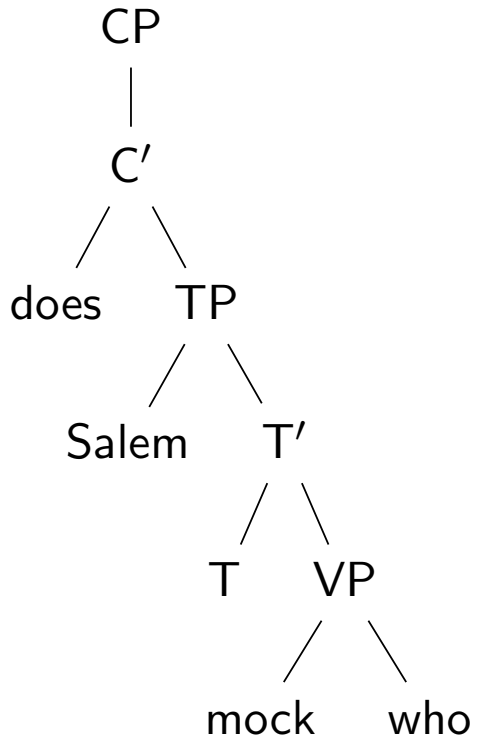

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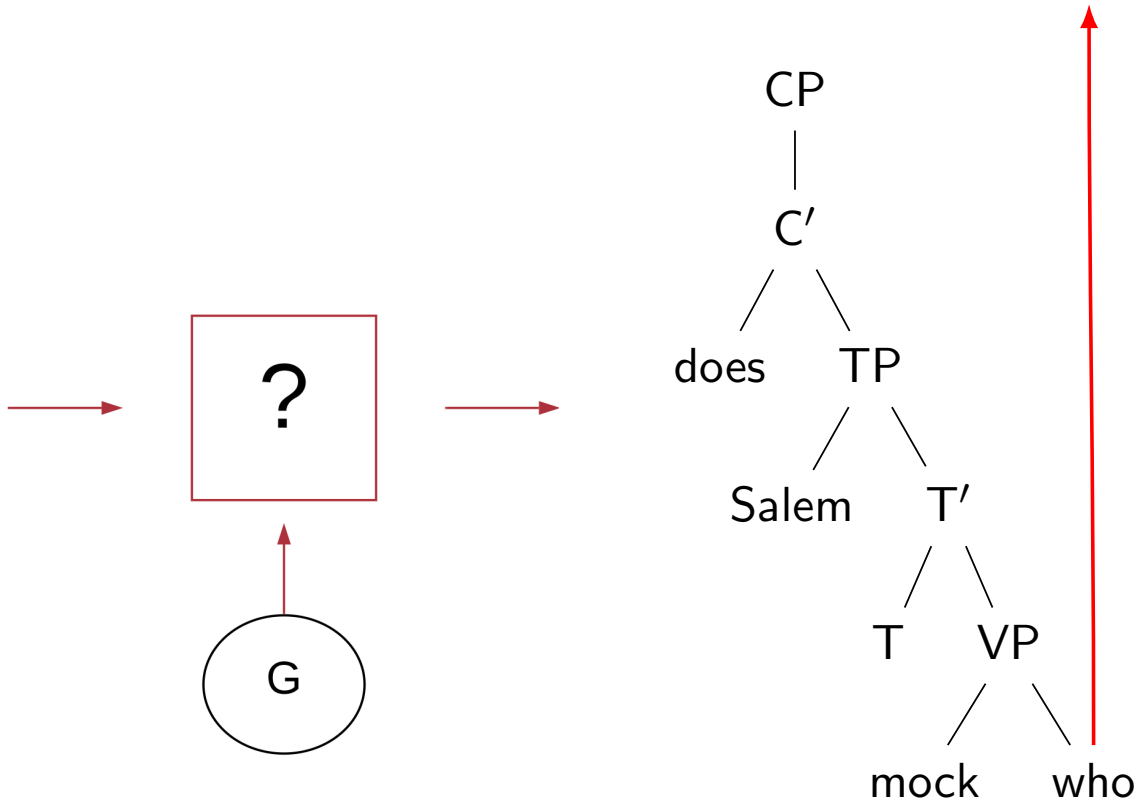

- Bottom-up

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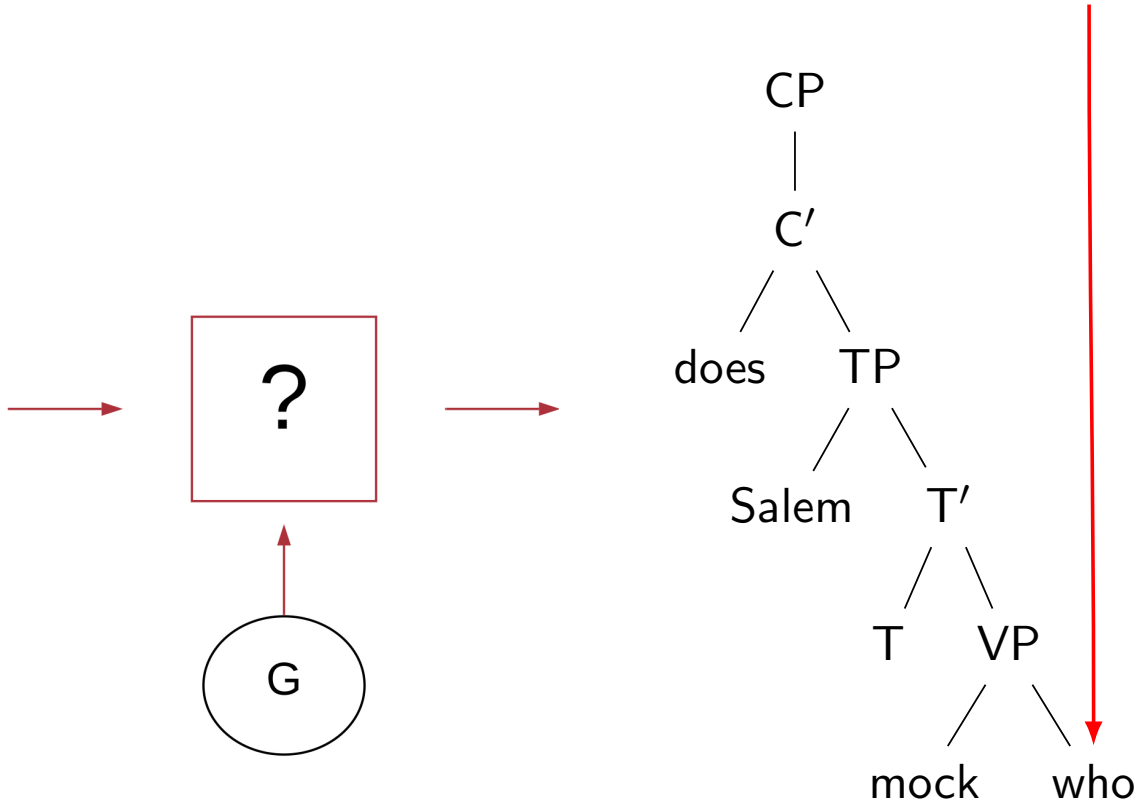
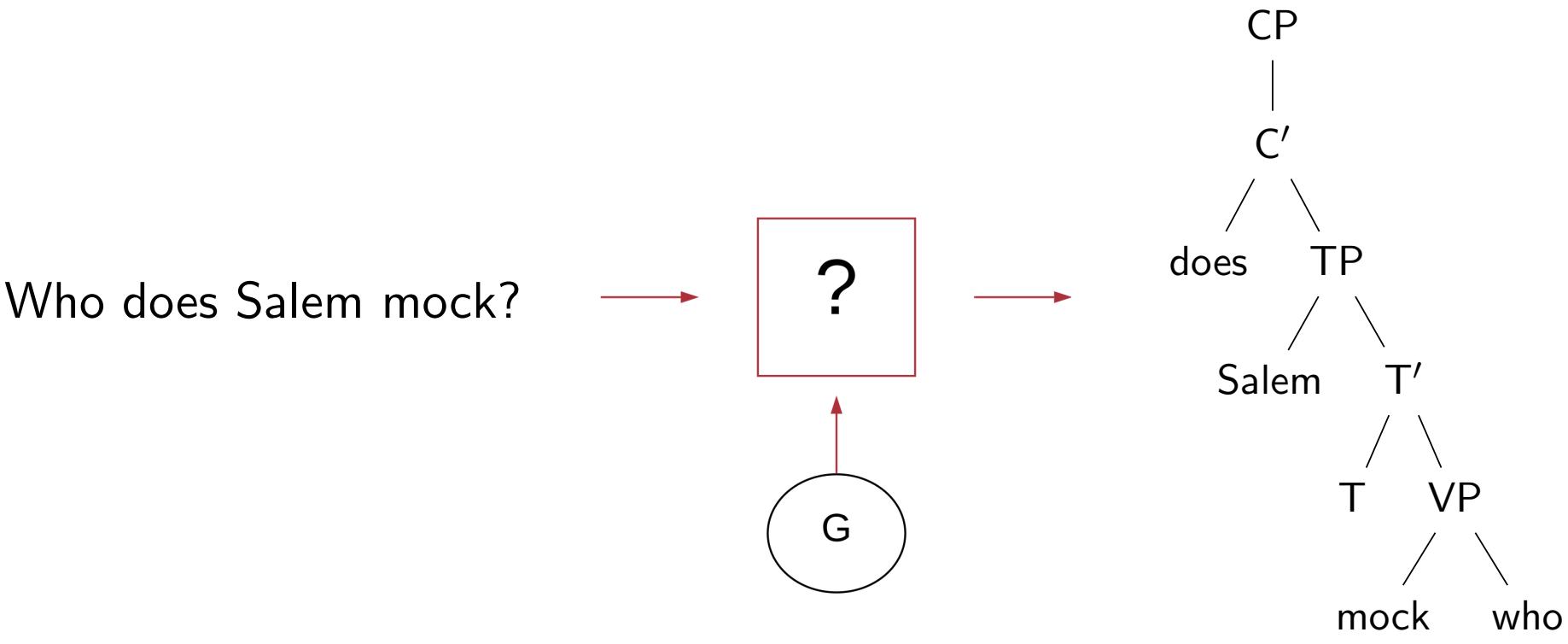


- Bottom-up
- Top-down

The Job of a Parser



- Bottom-up
- Top-down
  - Psychologically plausible(-ish)
  - We can build bottom-up grammars top-down!
  - Big idealization: Parser as an oracle!

Top-Down Parsing: The Intuition

Who does Salem mock?

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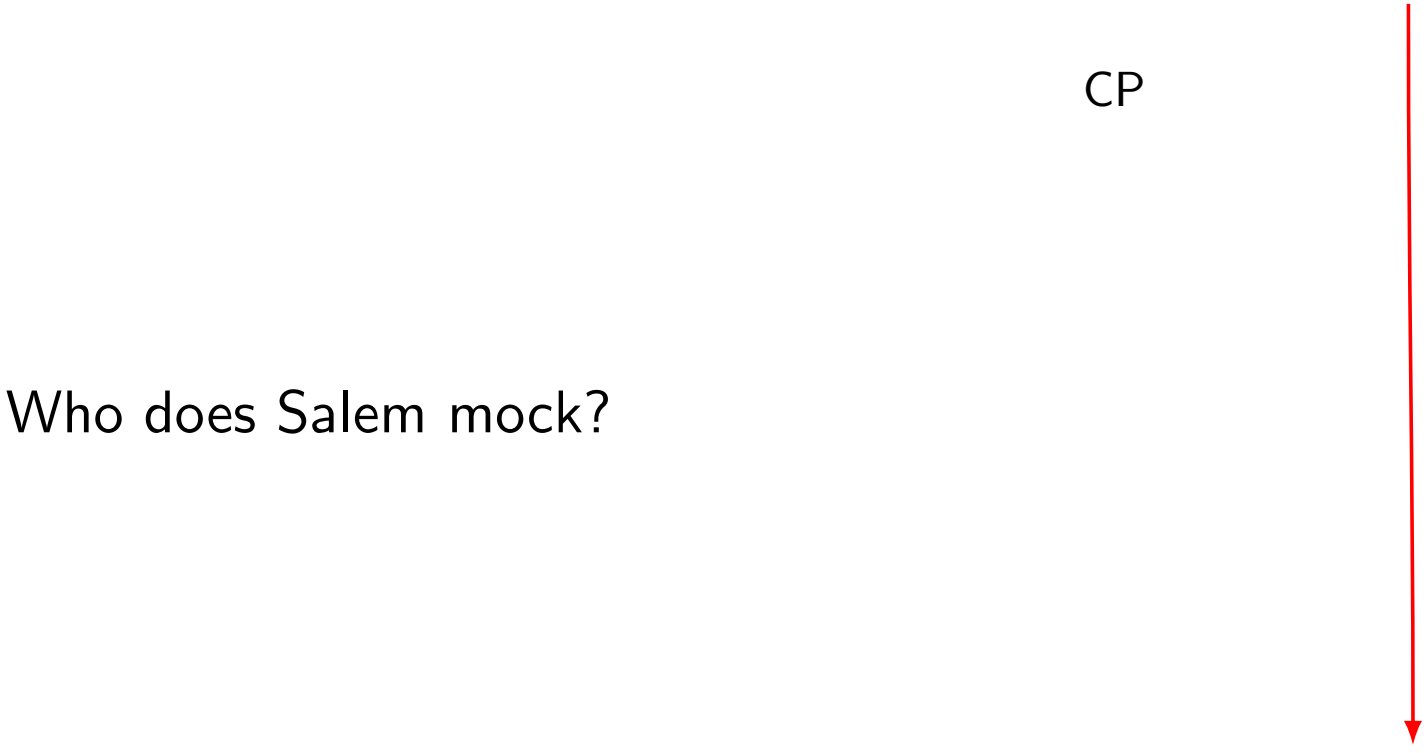

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- Takes elements in an out of memory
- Complexity of the structure $\approx$ how much memory is used!

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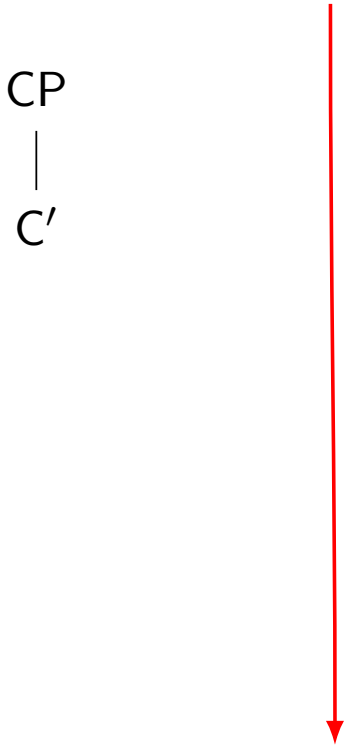

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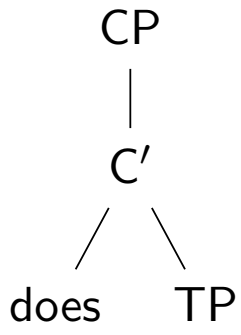

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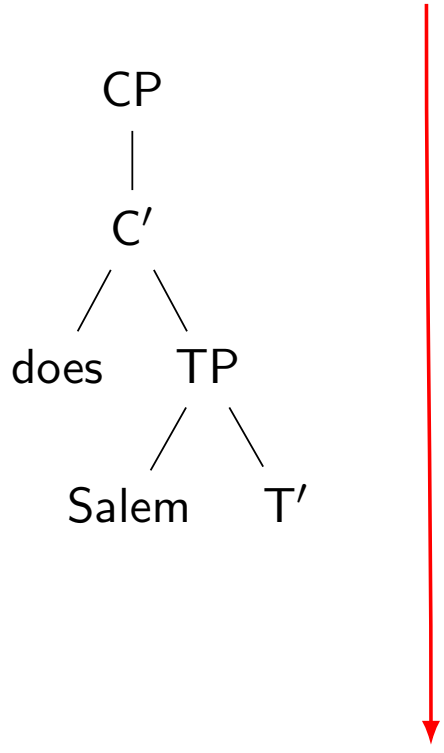

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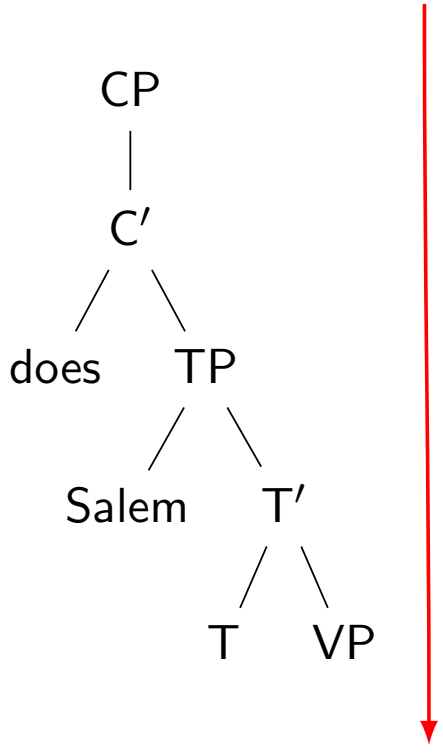

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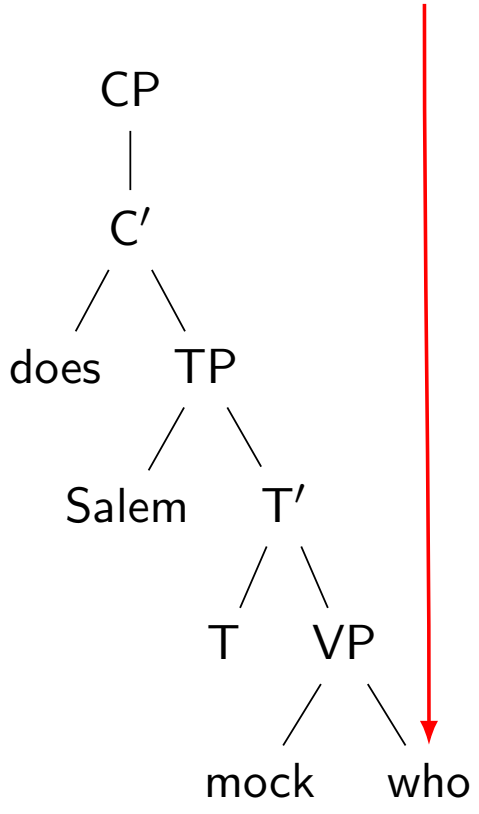

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Incremental Top-Down Parsing

Technical details!

- String-driven recursive descent parser (Stabler 2013)

- • Who • does • Salem • T • mock

step 1 CP is conjectured
step 2 CP expands to C′
step 3 C′ expands to does and TP
step 4 TP expands to Salem and T′
step 5 T′ expands to T and VP
step 6 VP expands to mock and who
step 7 who is found
step 8 does is found
step 9 Salem is found
step 10 T is found
step 11 mock is found

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[1]CP

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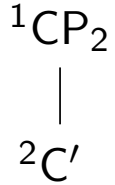

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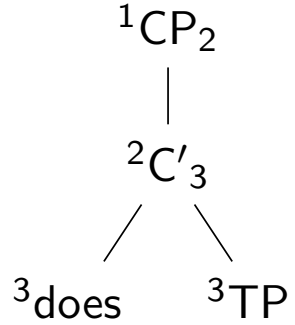

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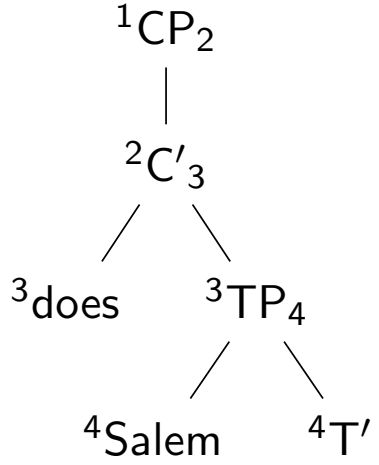

Incremental Top-Down Parsing

Technical details!

- String-driven recursive descent parser (Stabler 2013)

- • Who • does • Salem • T • mock

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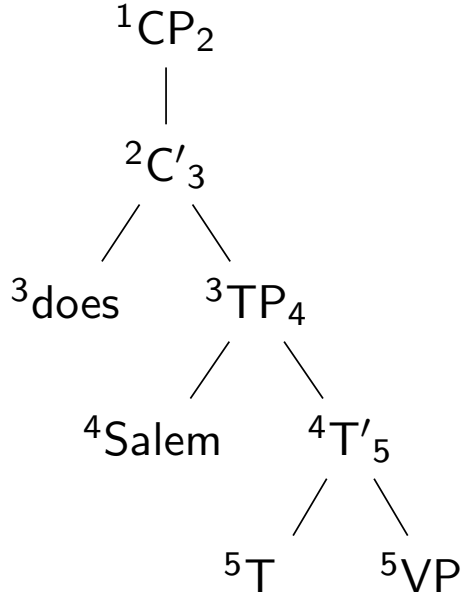

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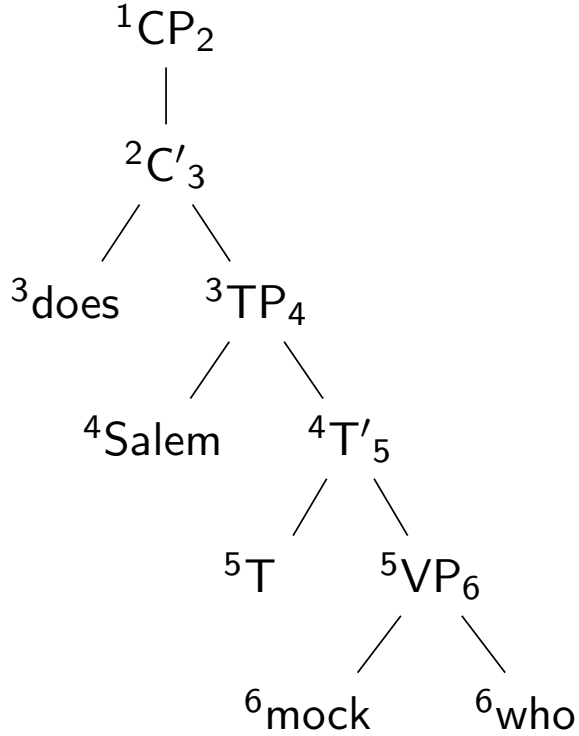

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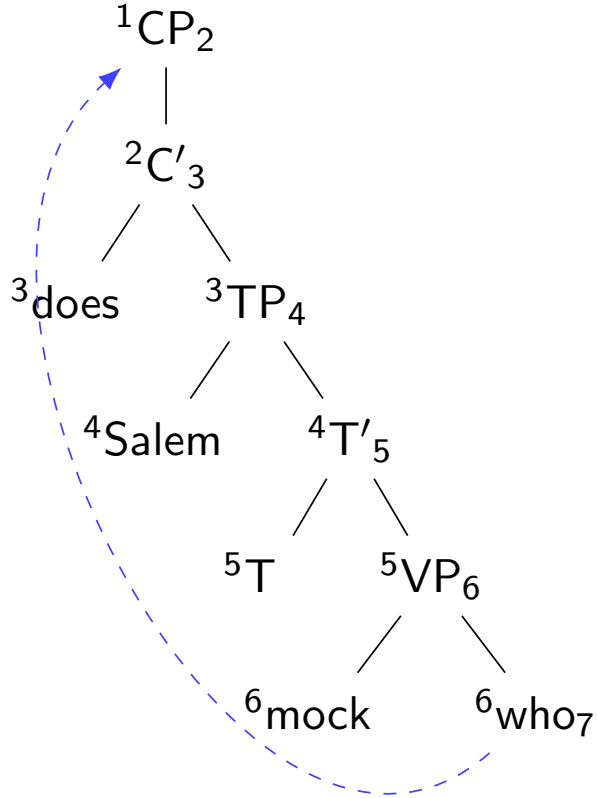

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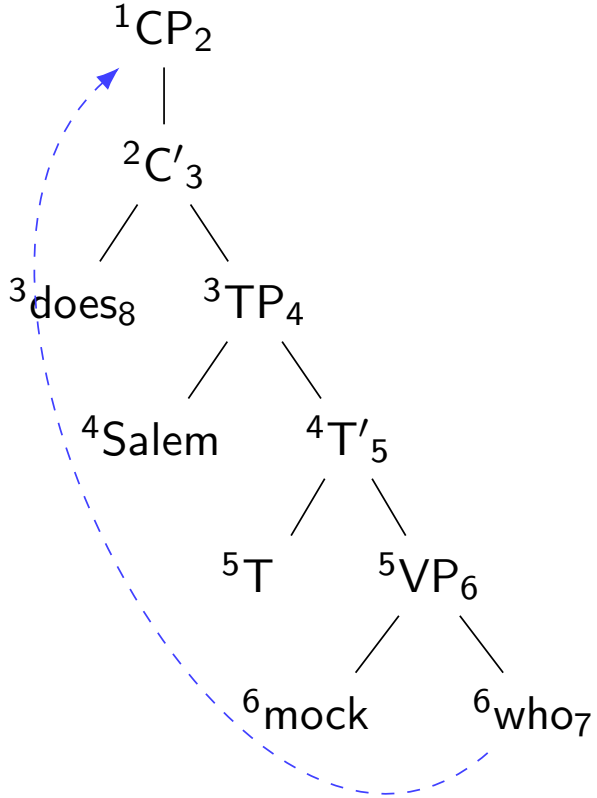

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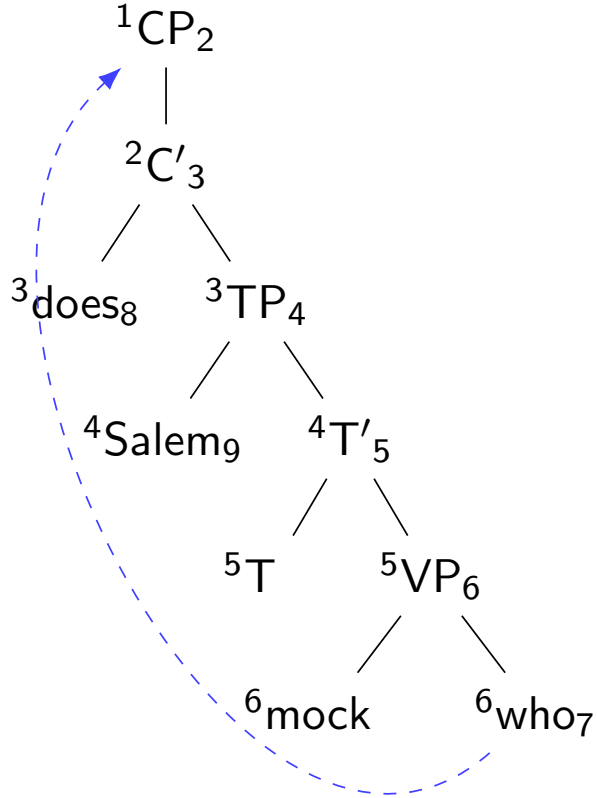

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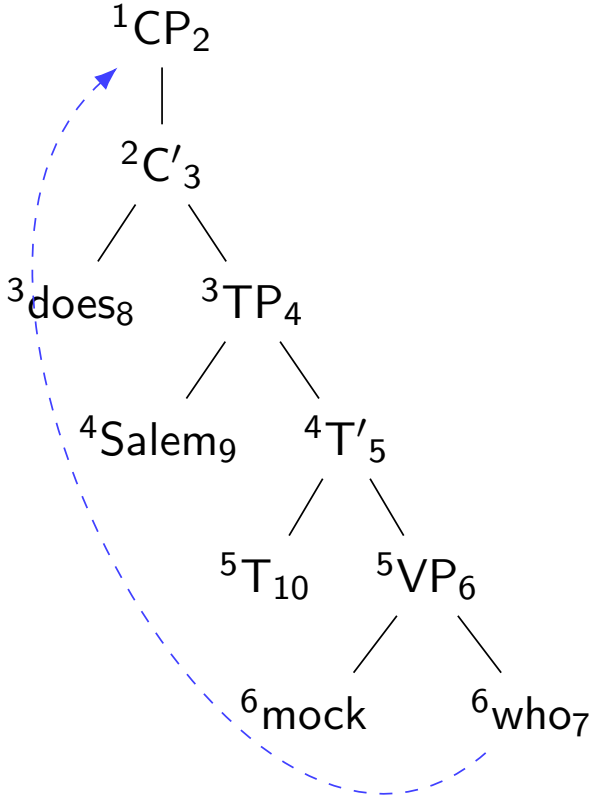

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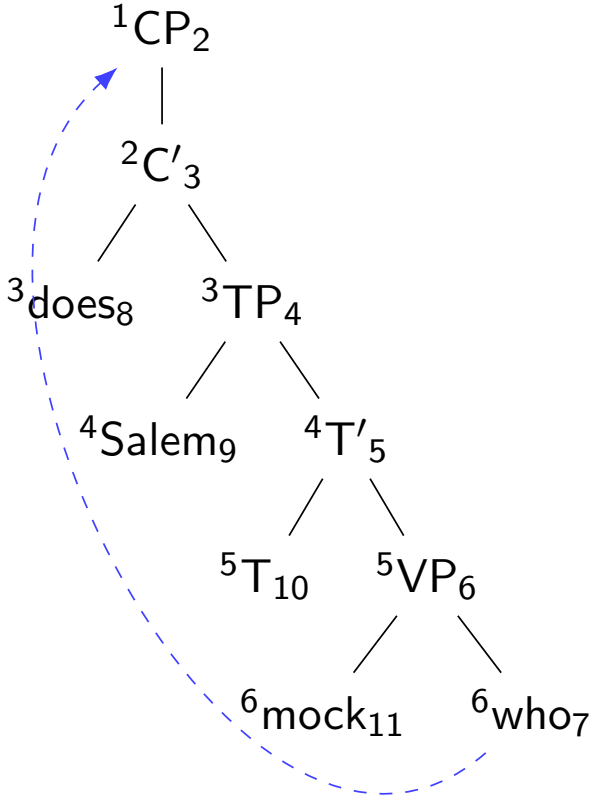

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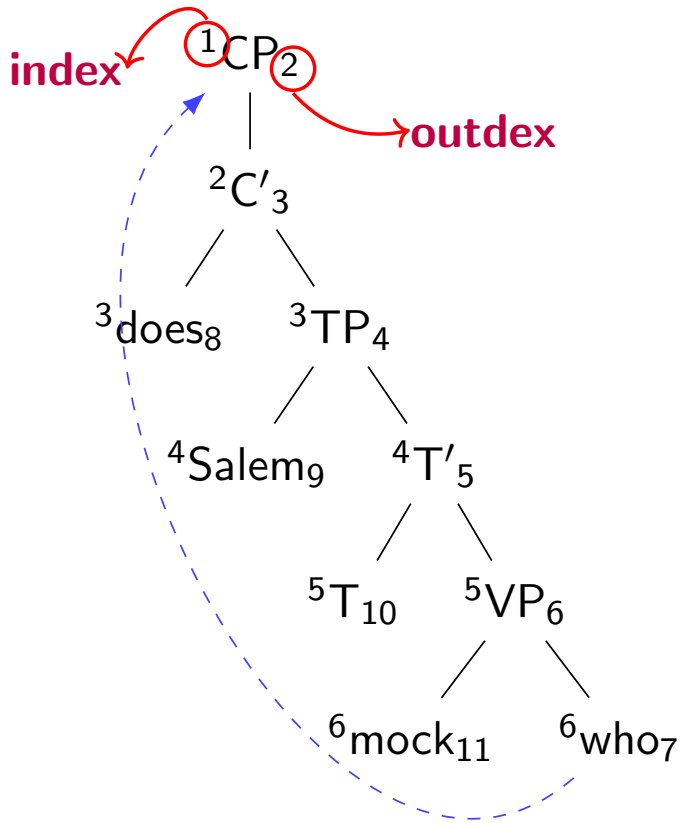

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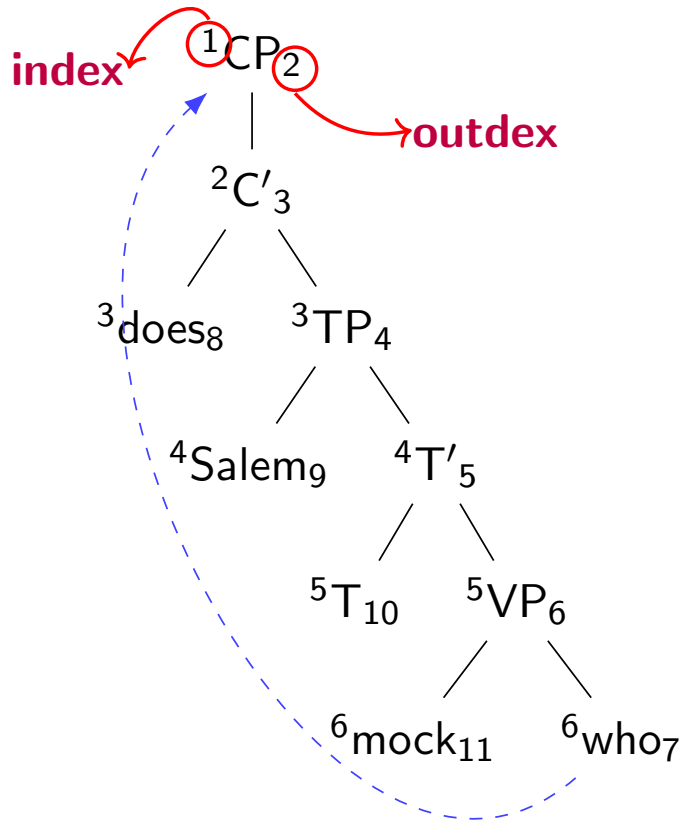

Index and Outdex are our connection to memory!

Memory-Based Complexity Metrics

- **Memory usage** (Gibson 1998, Kobele et al. 2012):

Tenure How long a node is kept in memory

Size How much information is stored in a node

⇒ Intuitively, the length of its movement dependency!

- These can be formalized into **complexity metrics**

MaxTenure $max(\{\text{tenure-of}(n) | n \text{ a node of the tree}\})$

SumSize $\sum_{m \in M} size(m)$

Ranked $\langle MaxTenure, SumSize \rangle$

Greg Kobele

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Processing Asymmetries All the Way Down

<MaxT,SumS> makes correct predictions cross-linguistically!

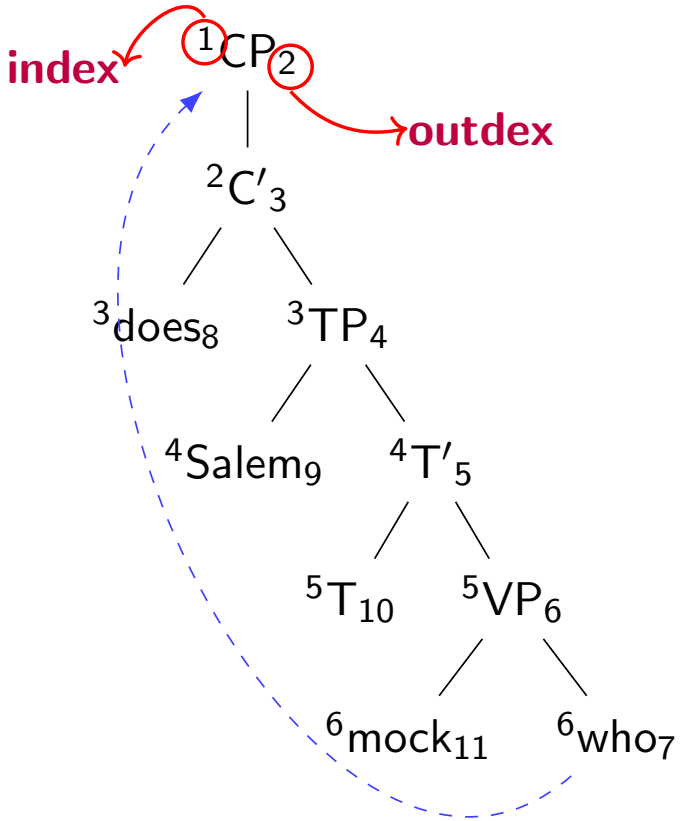
Across Constructions

- Right > center embedding (Kobele et al. 2012)
- Crossing > nested dependencies (Kobele et al. 2012)
- SC-RC > RC-SC, SRC > ORC (Graf et al. 2017)
- Postverbal subjects in Romance
  (De Santo 2019, 20, Del Valle & De Santo 2023)
- Attachment ambiguities
  (De Santo & Shafiei 2019, Lee & De Santo 2022)
- Gradient acceptability (De Santo 2020)
- Structural Priming (De Santo 2020, 2021)

Across Languages

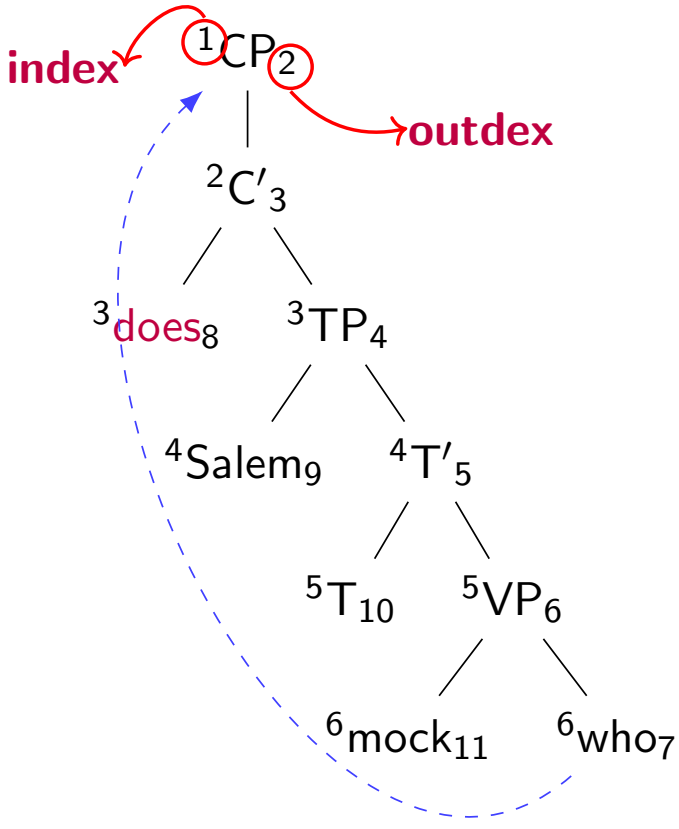
- English, German, Italian, Spanish, French, Korean, Japanese, Mandarin Chinese, Basque, Turkish, Persian, ...

Computing Metrics: An Example



Tenure how long a node is kept in memory

Computing Metrics: An Example



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Tenure($does$) $= 8 - 3 = 5$

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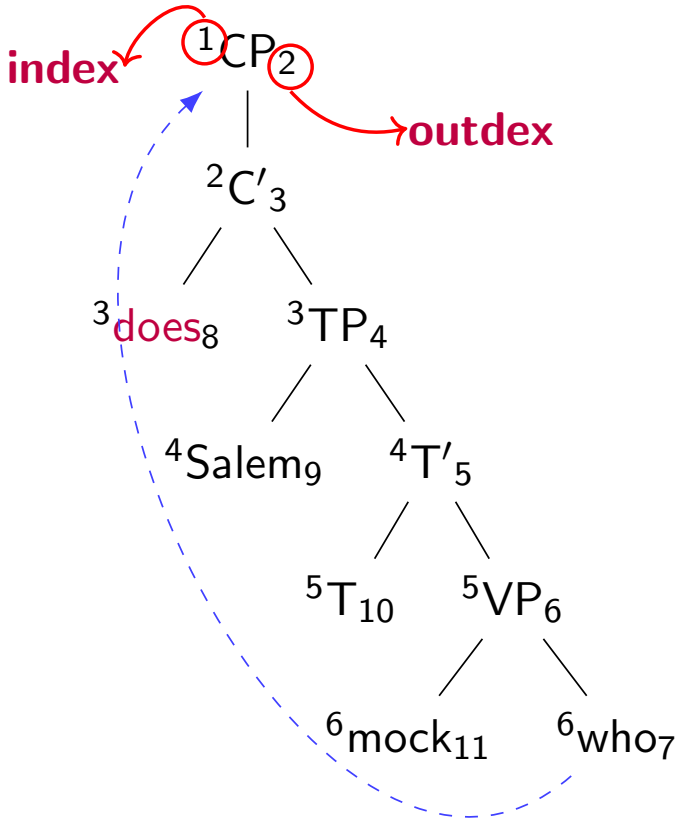


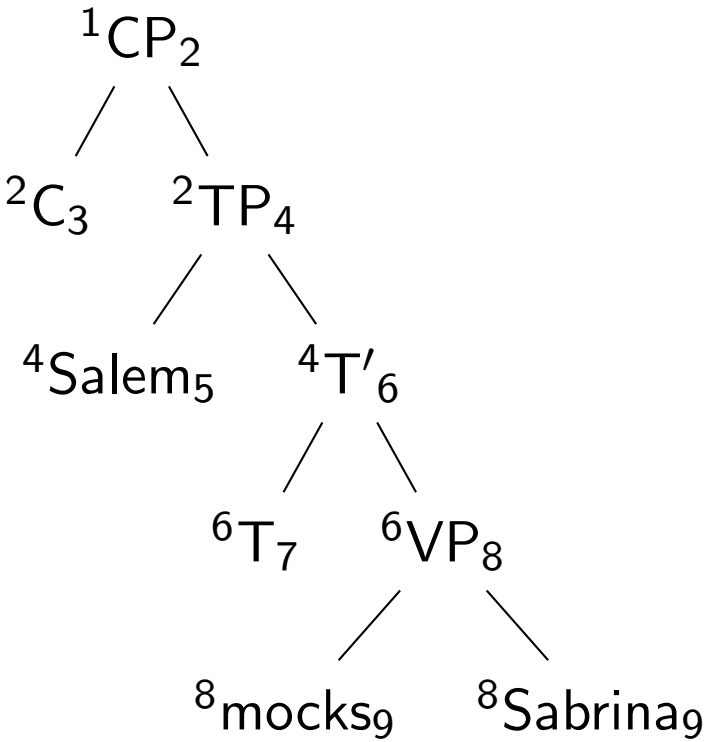
Tenure how long a node is kept in memory

Tenure($does$) $= 8 - 3 = 5$

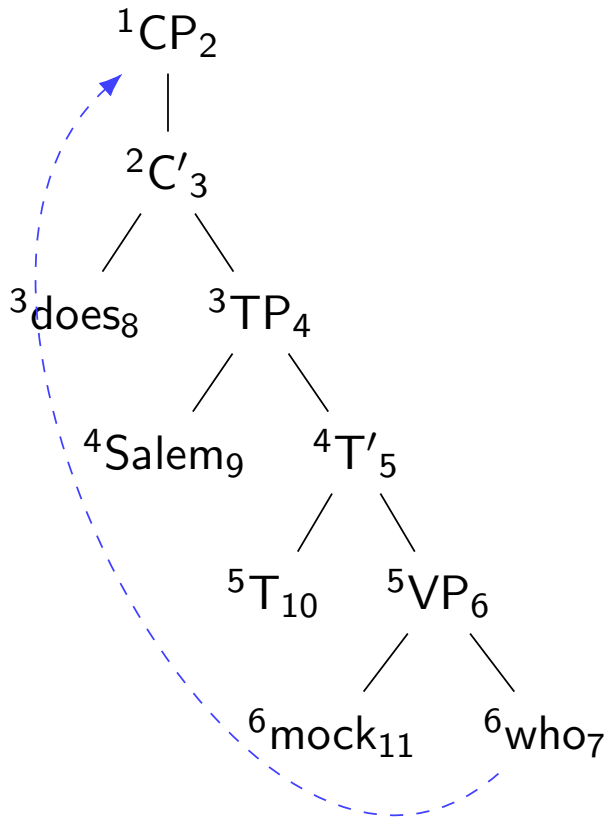
MaxTenure $= max\{$**Tenure**$(does)$, **Tenure**$(Salem), \dots\} = 5$

Contrasting Derivations

MaxTenure $= 2$



MaxTenure $= 5$



Automatizing Helps!

mgproc: A Python Package for MG Processing Research

This is a collection of Python3 scripts to facilitate the investigation of human processing from the perspective of Minimalist grammars (MGs).

Background

MGs were developed in Stabler (1997) as a formalization of Chomsky's Minimalist program. A top-down parser for MGs is defined in Stabler (2013) and has been implemented in a number of languages. A number of subsequent works have successfully used this parser to make predictions about relative difficulty in sentence processing. Good starting points with a review of the previous literature are Gerth (2015) and Graf et al. (to appear).

- Gerth, Sabrina: Memory Limitations in Sentence Comprehension
- Graf, Thomas, James Monette, and Chong Zhang (to appear): Relative Clauses as a Benchmark for Minimalist Parsing (link to be added soon)
- Stabler, Edward (1997): Derivational Minimalism
- Stabler, Edward (2013): Two Models of Minimalist, Incremental Syntactic Analysis

Quick Start Guide

With *mgproc* you can easily compare MG derivation trees with respect to thousands of complexity m
processing. The scripts integrate well with a LaTeX-centric workflow, following the ideal of OpenScie
publication form a cohesive unit. Usually a parsed derivation tree is specified by four files. Assuming
`foo`, we have:

- Open source ⇒ in prep. for *Journal of Open Source Software*
- User-friendly!
- Easy to modify!

Summary of the Approach

General Idea

(Kobele et al. 2012; Gerth 2015; Graf et al. 2017; De Santo 2020)

1. Pick two competing derivations for a processing contrast
2. Annotate derivation trees and compute metrics
3. Evaluate metrics over each
   - Lowest score means easiest!
4. Compare parser's prediction to experimental data

Remember!

Interpretability for the win!

Reminder: Asymmetries in Italian Relative Clauses

(1) Il cavallo che ha inseguito i leoni
The horse that has chased the lions
"The horse that chased the lions" **SRC**

(2) Il cavallo che i leoni hanno inseguito
The horse that the lions have chased
"The horse that the lions chased" **ORC**

(4) Il cavallo che hanno inseguito i leoni
The horse that have chased the lions
"The horse that the lions chased" **ORCp**

Processing Asymmetry (De Vincenzi 1991, Arosio et al. 2018, a.o.)

SRC > ORC > ORCp

Modeling Assumptions

Reminder:

- Parsing strategy
  $\Rightarrow$ Top-down parser
- Complexity Metrics
  $\Rightarrow$ MaxTenure and SumSize

Degrees of freedom: Syntactic analyses

1. RC constructions $\rightarrow$ (Kayne 1994)
2. Postverbal subjects $\rightarrow$ (Belletti & Leonini 2004)

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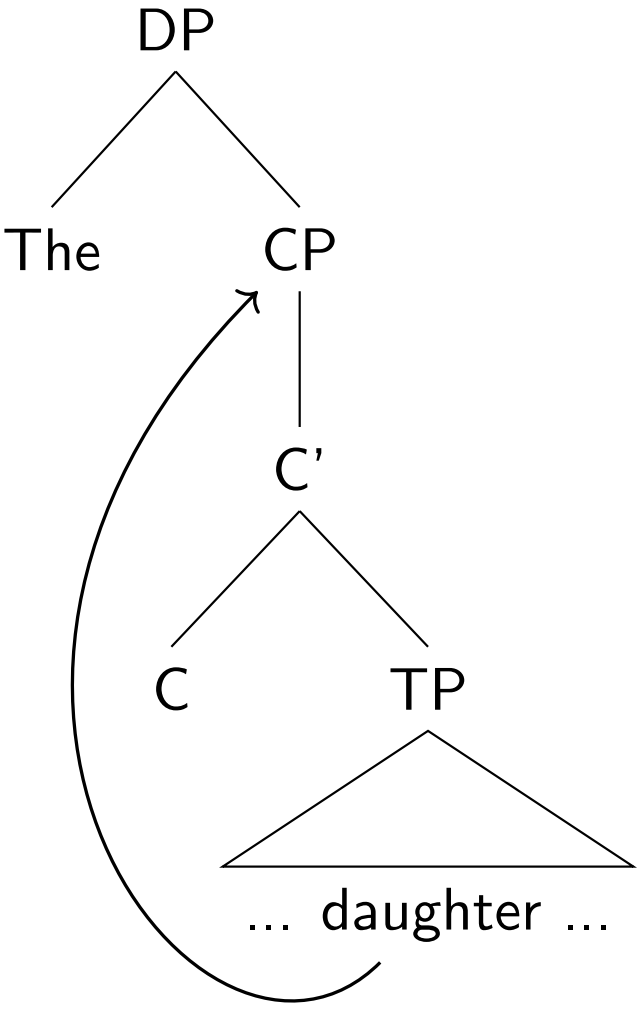
- RC is selected by an external D^0
- the RC head is a nominal constituent
- the RC head raises from its base position to [Spec, CP]



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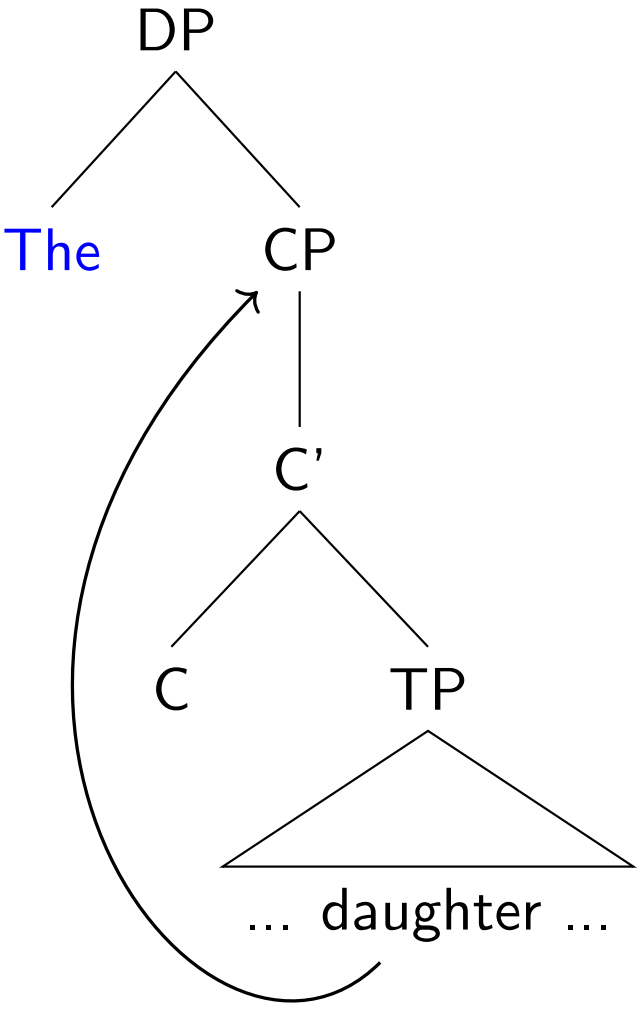

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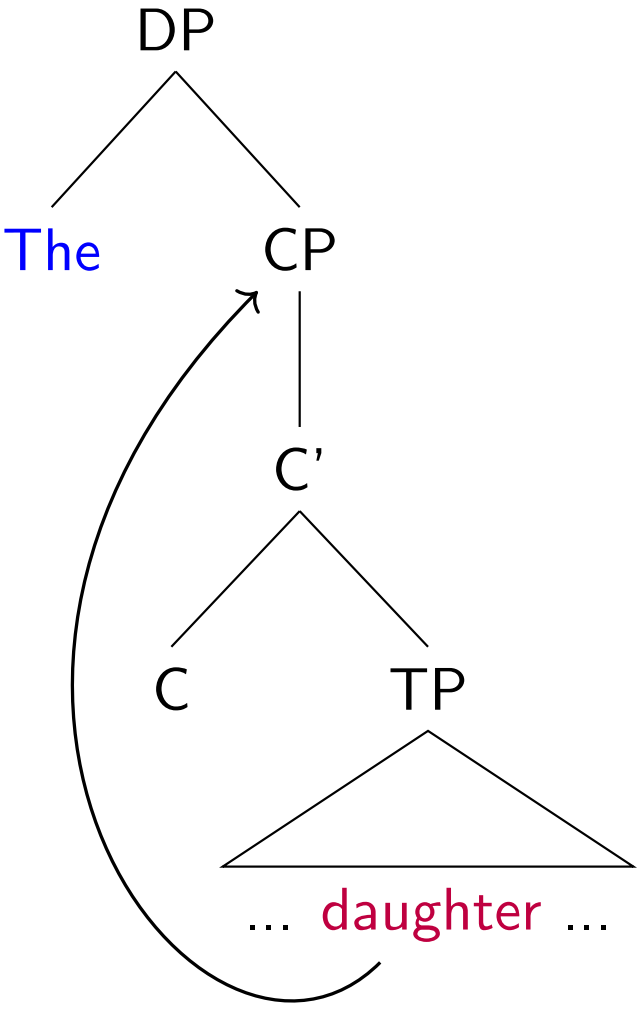

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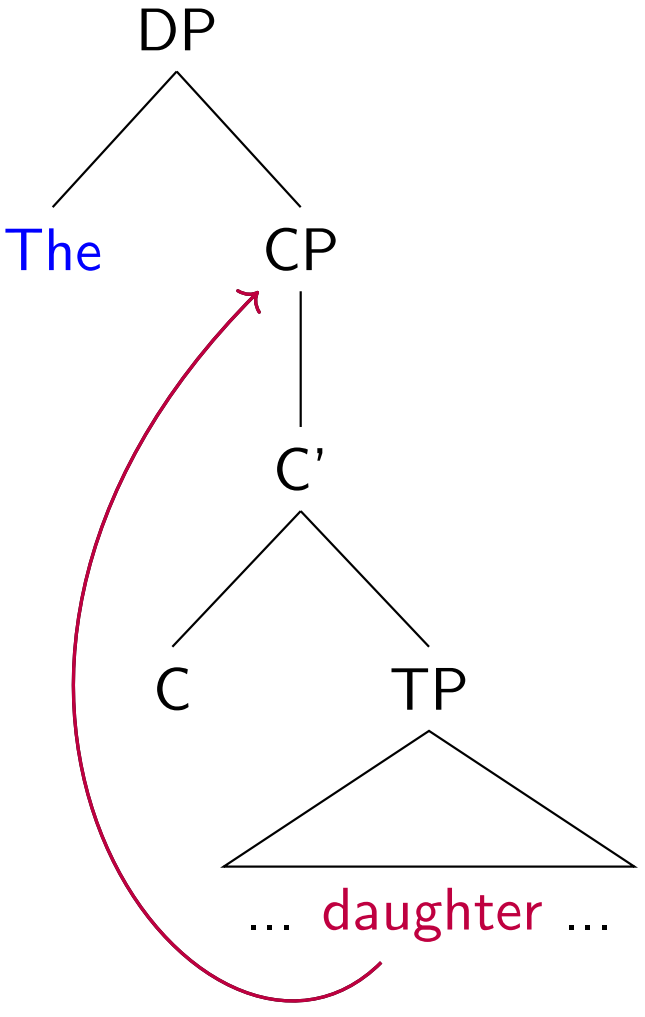

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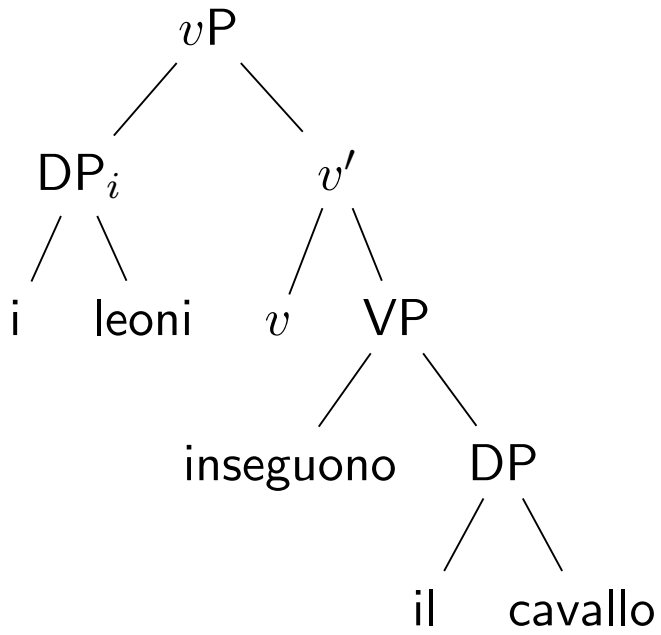
Postverbal Subjects (Belletti & Leonini 2004)

(5) Inseguono il cavallo i leoni
Chase the horse the lions
"The lions chase the horse"

- the subject DP raises to Spec, FocP
- The whole vP raises to Spec,TopP

Technical details!

- an expletive *pro* is base generated in Spec,TP



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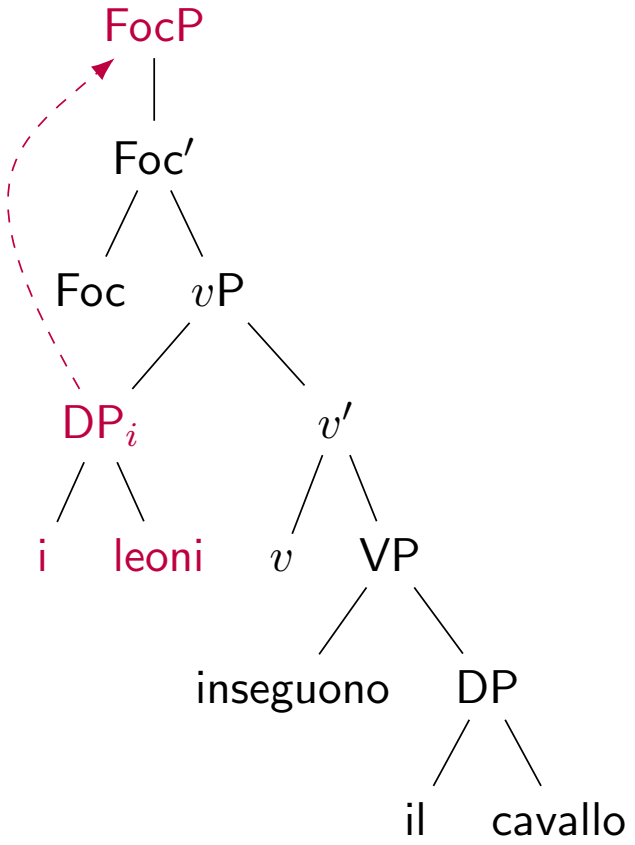

Postverbal Subjects (Belletti & Leonini 2004)

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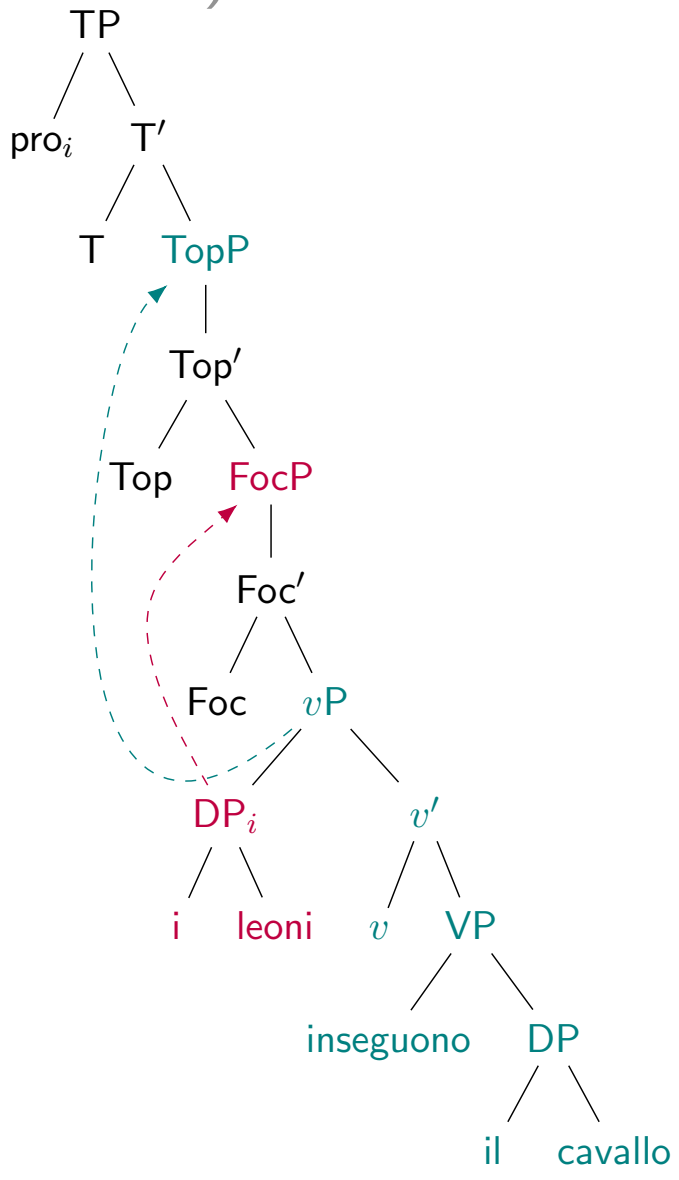

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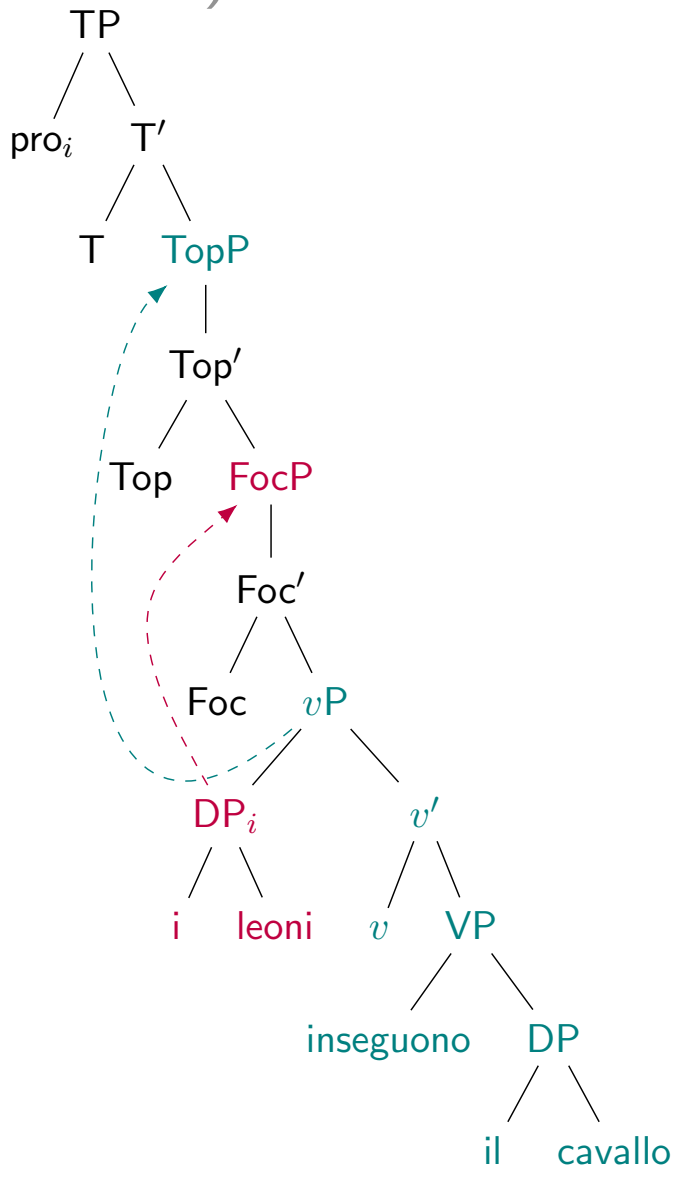

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SumSize	18		24		31

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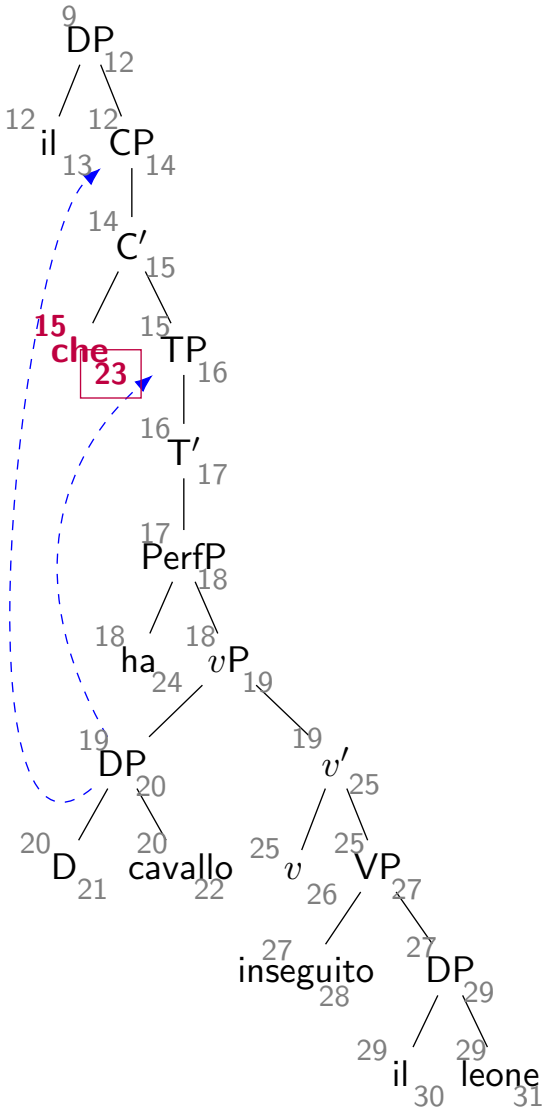
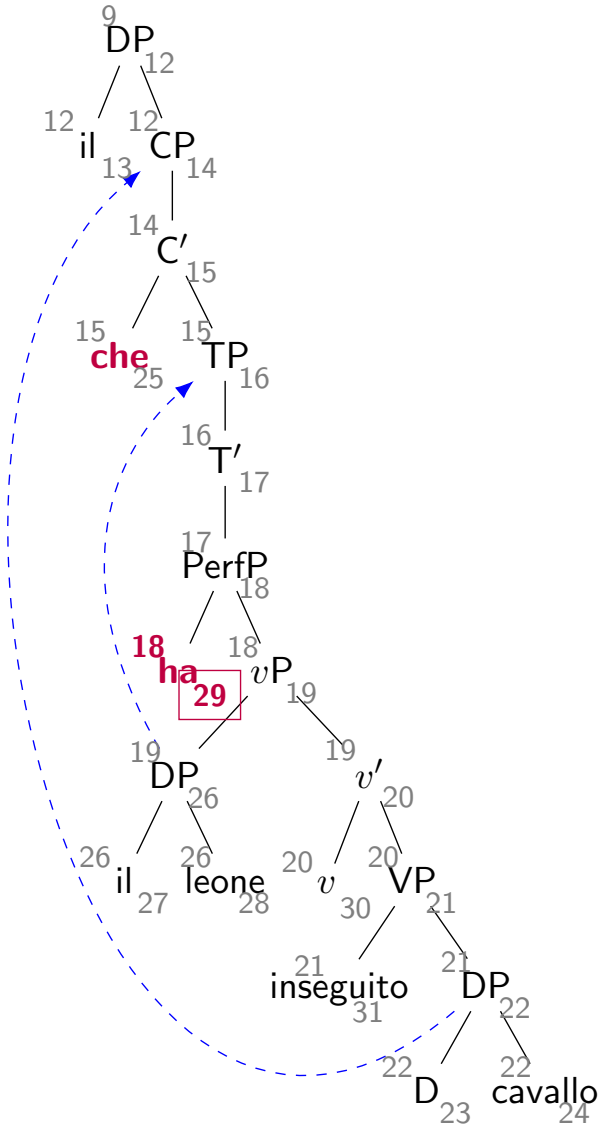
SumSize	18		24		31	✓

Results: SRC > ORC





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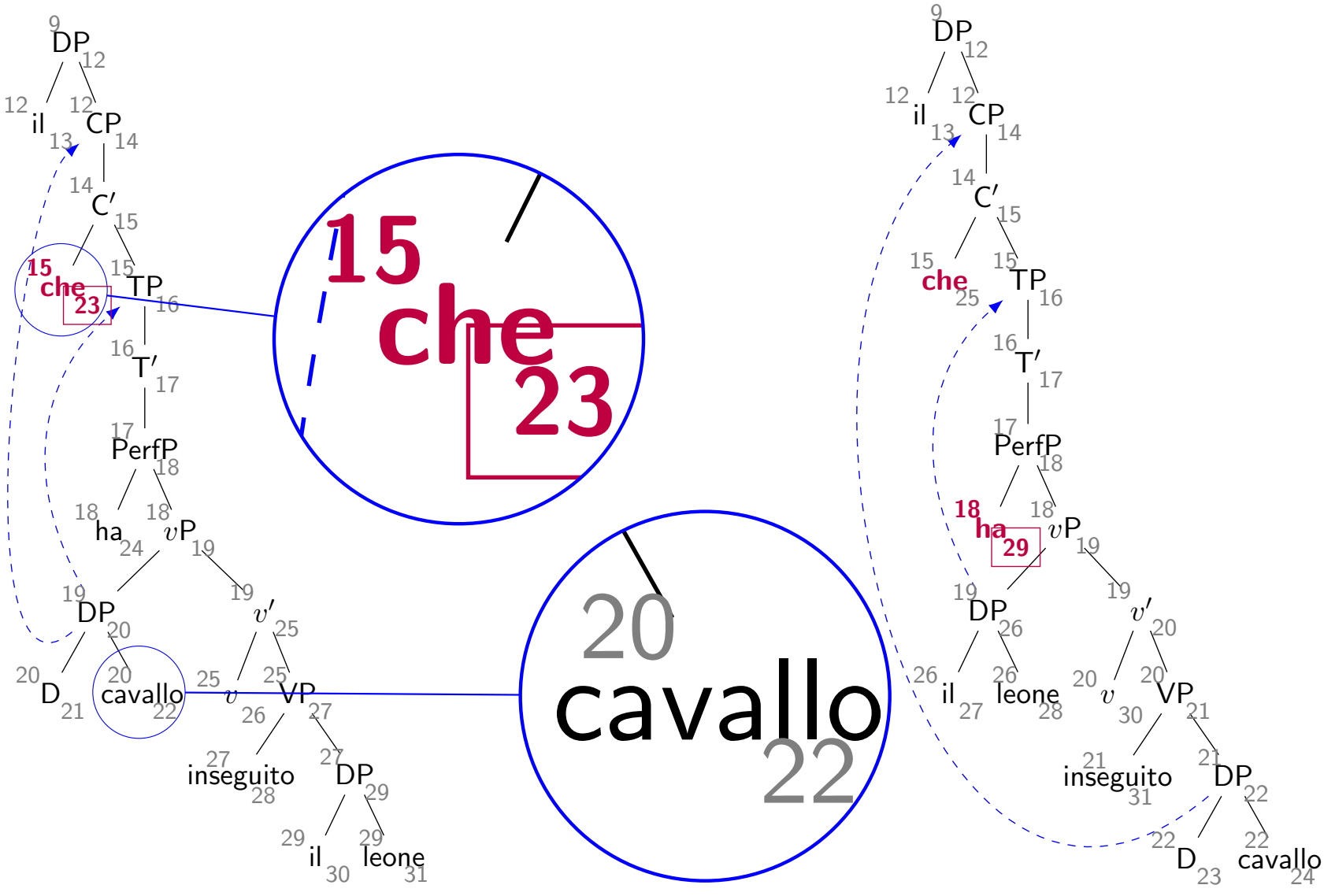

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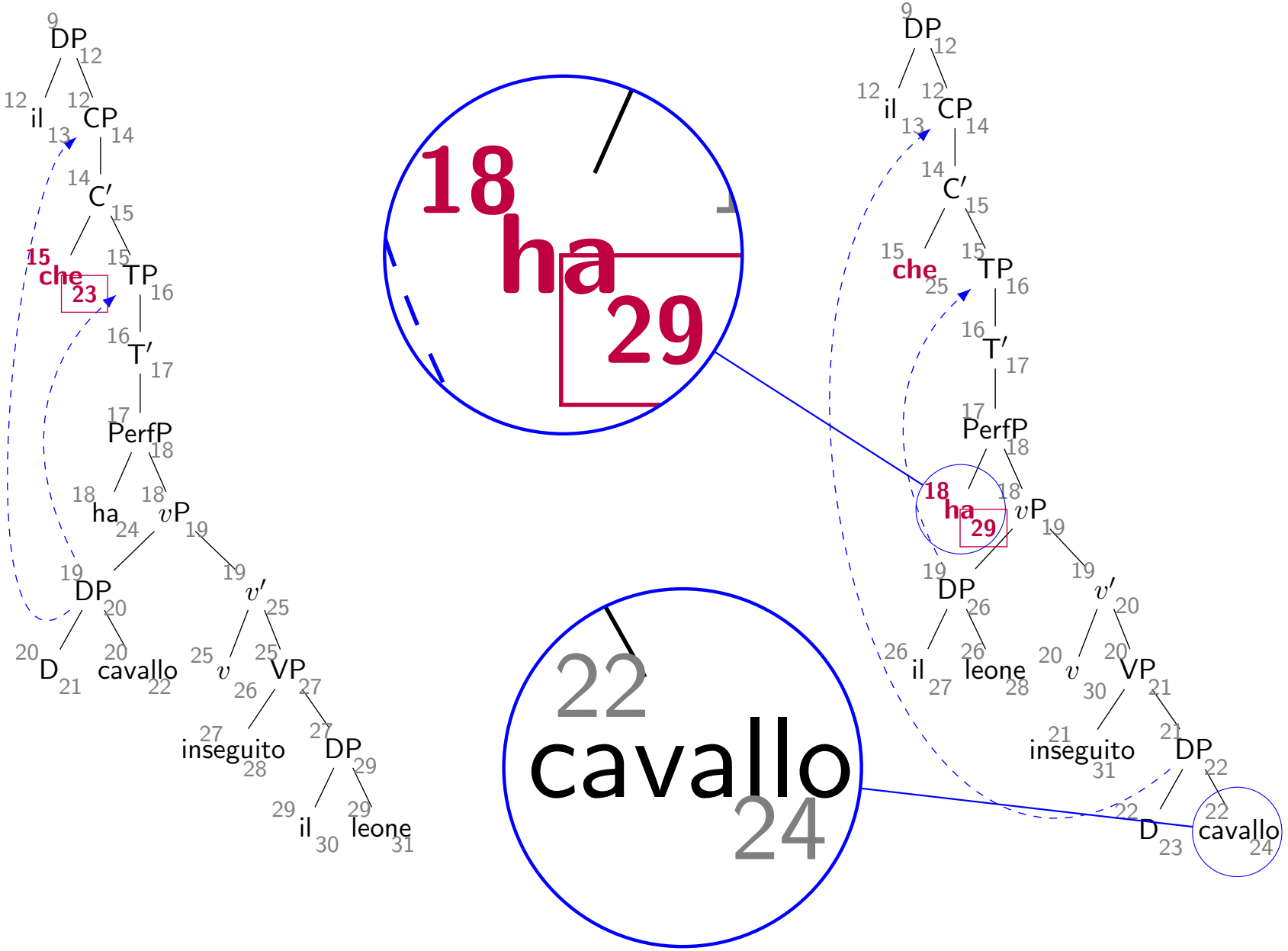
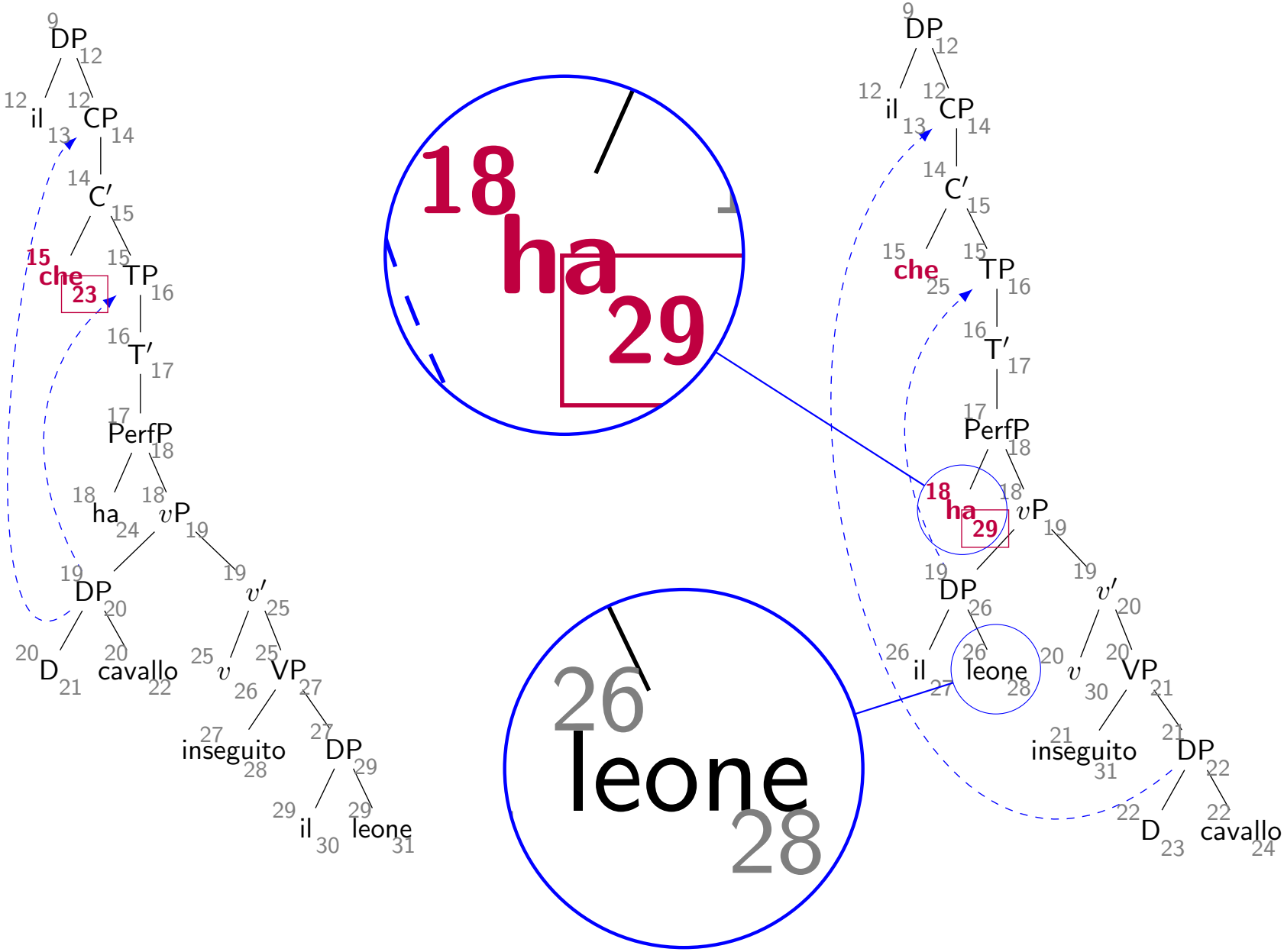


Results: SRC > ORC



Some Additional Results (De Santo 2019, 2021)

Clause Type	**<MaxTenure,SumSize>**
obj. SRC > ORC	✓
obj. SRC > ORCp	✓
obj. ORC > ORCp	✓
subj. SRC > ORC	✓
subj. SRC > ORCp	✓
subj. ORC > ORCp	✓
matrix SVO > VOS	✓
VS unacc > VS unerg	✓

Table: Predictions of the MG parser by contrast.

Interim Summary

- <MaxT,SumS> gives surprisingly good results!
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    → "just" **(fine-grained) structural differences**!
  - RC preferences, attachment ambiguities, ...
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  - Expand range of syntactic constructions/analyses (De Santo 2021, De Santo & Shafiei 2019, in prep.)
  - Cross-linguistic comparison (Del Valle & De Santo, in prep; Fiorini, Chang, De Santo, u.r.)

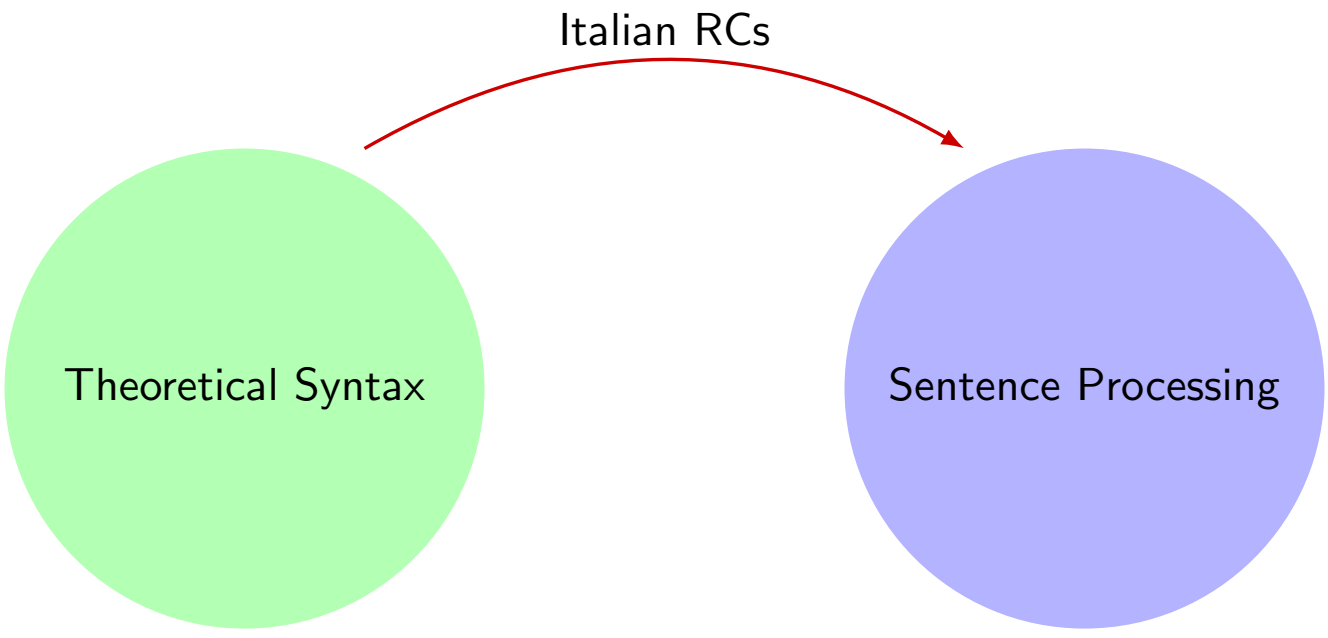
Nazila Shafiei

Dan Del Valle

Matteo Fiorini

Jillian Chang

Moving on



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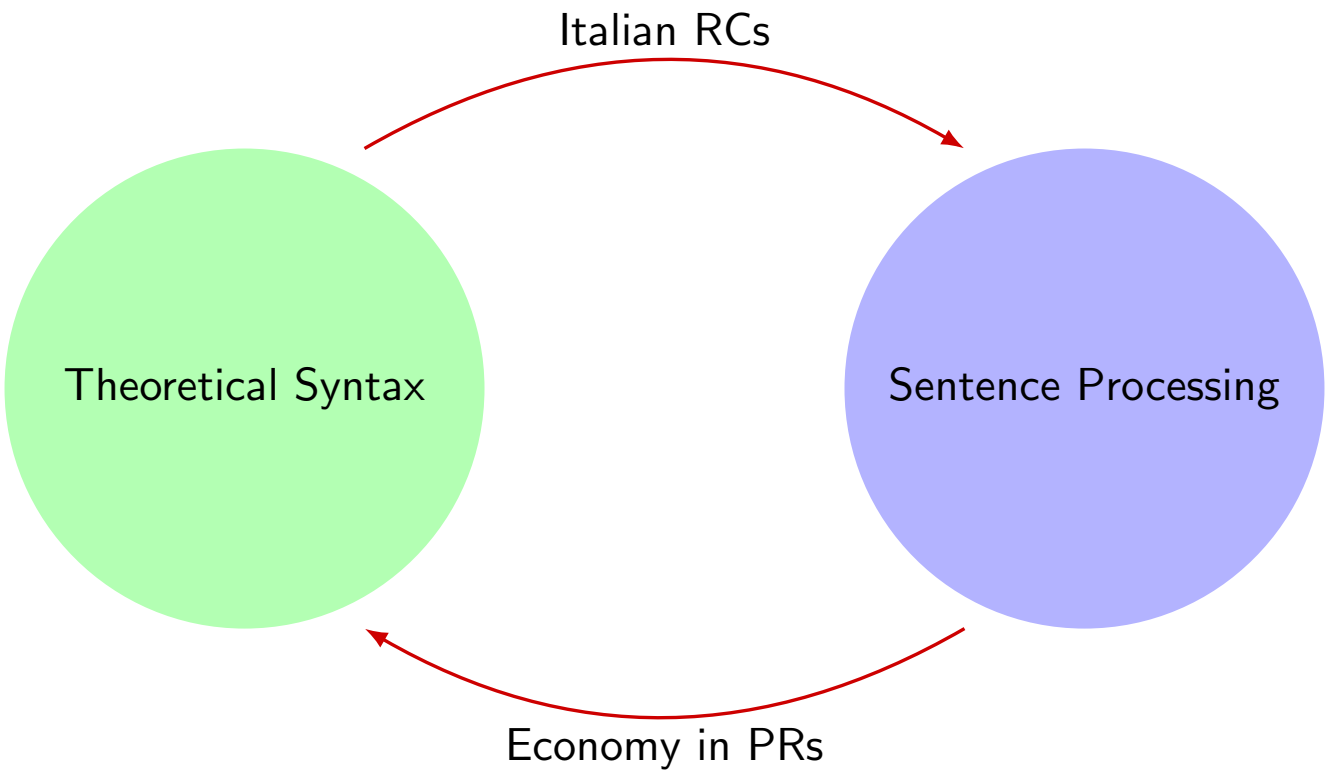
Italian RCs
Theoretical Syntax
Sentence Processing
Economy in PRs

The Role of Economy

- Economy considerations ubiquitous in Generative syntax
  (Chomsky 1995, Collins 2001, Boskovic and Messick 2017, a.o.)

But:

- What is the relevant notion of cost?
- What does simplicity mean in practice?
- Do fine-grained syntactic details matter?

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So Young Lee

Attachment and Relative Clauses (RC)

- They saw the daughter of the actress that was on the balcony

  NP_1 **The daughter** was on the balcony — HA

  NP_2 **The actress** was on the balcony — LA

English: **LA** interpretation

- Late Closure (Frazier 1978),
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Universal locality principles?

- Spanish: **HA** interpretation
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    (Cuetos & Mitchell 1988, Mitchell & Cuetos 1991)
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A Complex Cross-Linguistic Scenario

HA vs LA languages?

RC preferences cross-linguistically affected by a variety of factors

- Syntactic environment
  (Fernandez 2003, Gibson et al. 1996, De Vincenzi and Job 1993)
- Prosodic effects (Teira and Igoa 2007, Hemforth et al. 2015)
- Lexical-semantic properties of the DPs
  (MacDonald et al. 1994, Gilboy et al. 1995)
- Online vs. Offline Differences
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None of these fully accounts for the LA vs HA variation

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(5) (Io) Ho visto **[la nonna della ragazza che gridava]**
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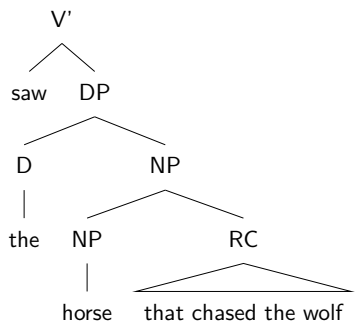

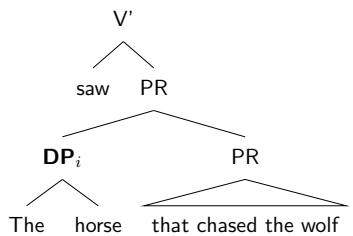

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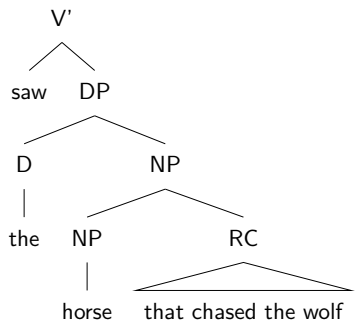

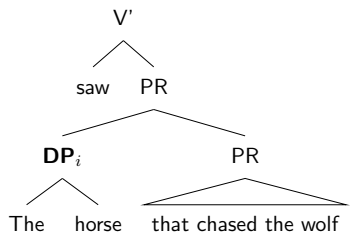

- RCs are NP-modifiers and denote properties of entities
- PRs are complements of VPs and denote events/situations
  - **Only** compatible with a **HA** reading!

So What? PRs and Attachment Preferences

- The grandma of the girl that was screaming
  - RC: HA
  - RC: LA
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The Pseudo-Relative First Hypothesis (Grillo & Costa 2014)

All else being equal:

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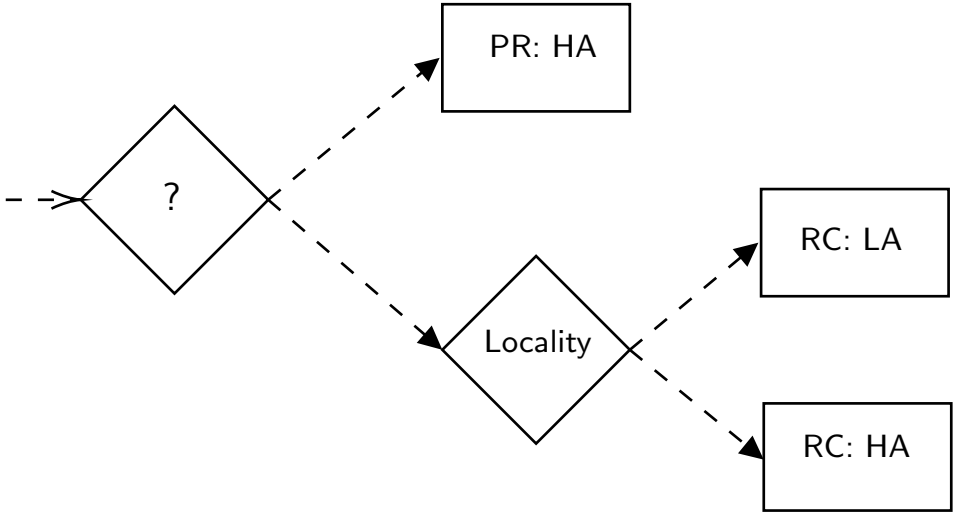

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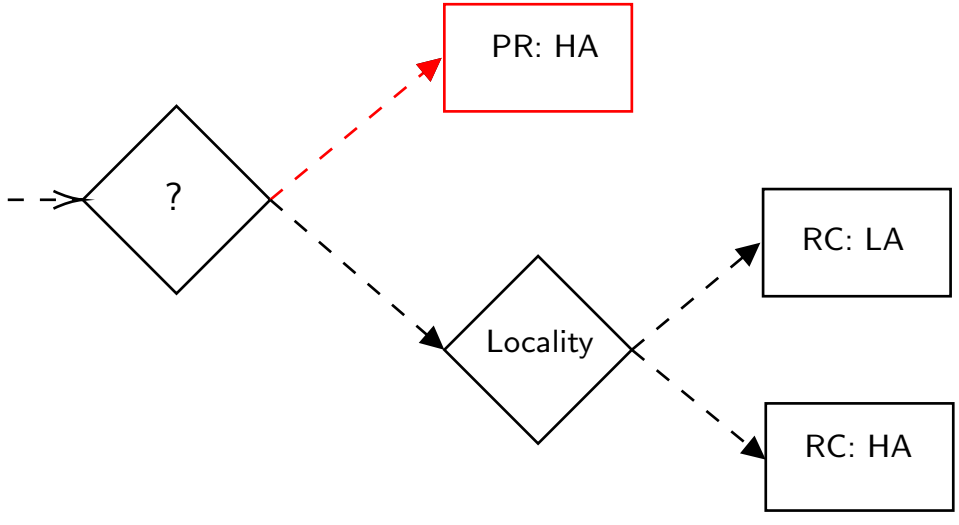

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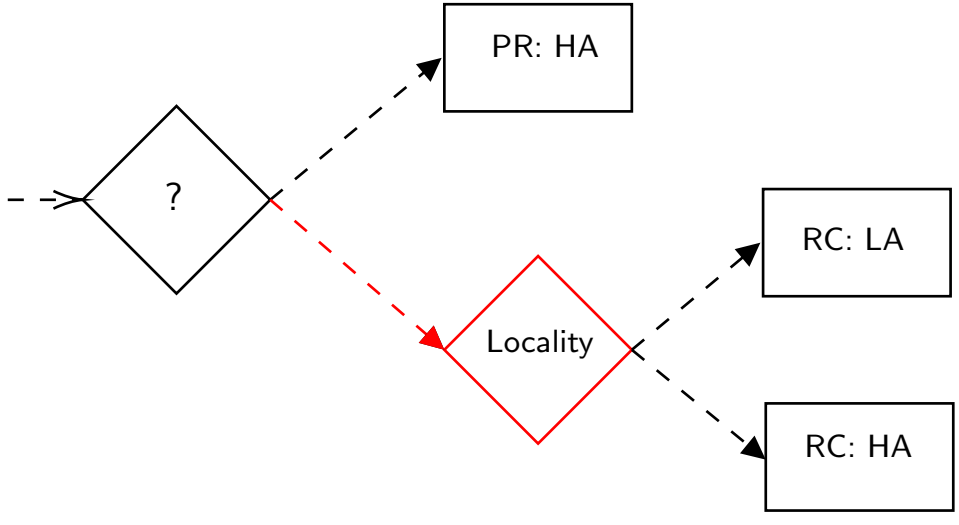

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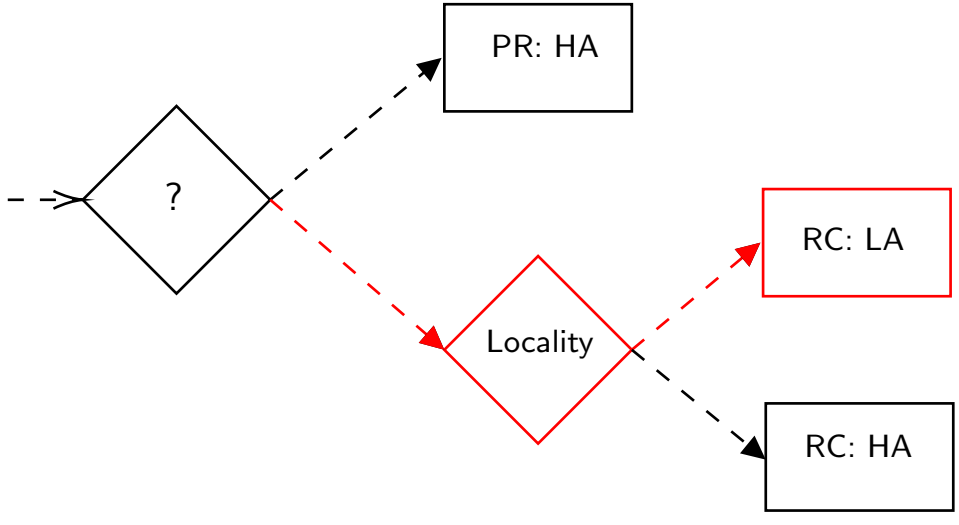

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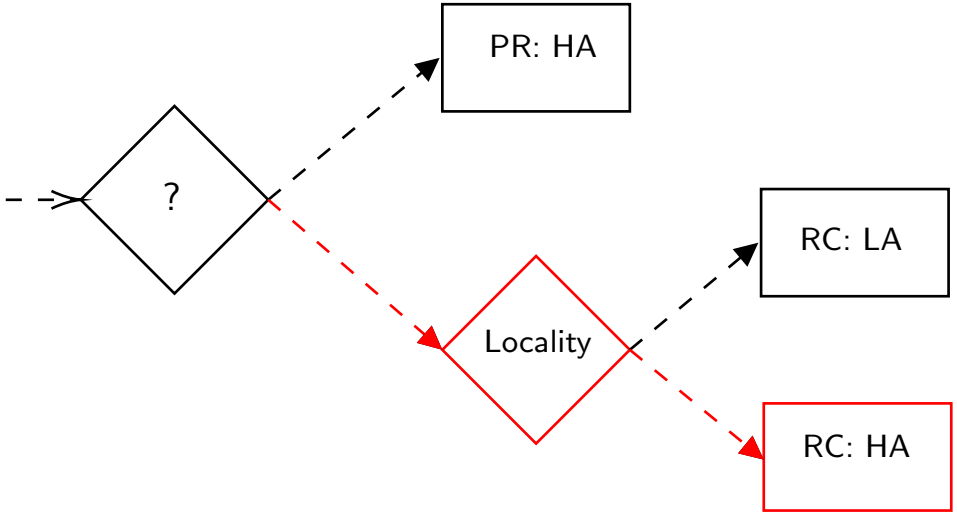

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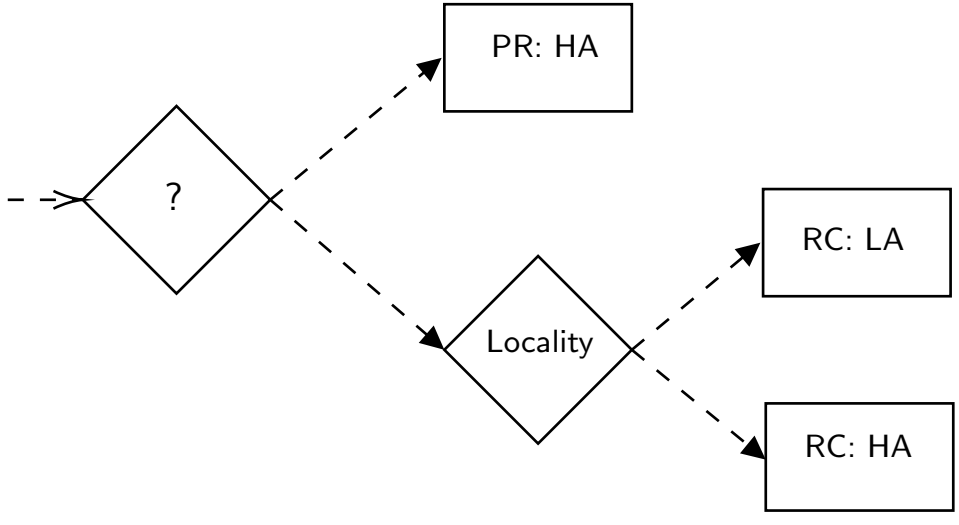

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(57) **Stimuli Experiment II**

a. PR/ RC CONDITION: PR-VERBS
Gianni ha visto il figlio del medico che correva.
G. saw the son of the doctor running.

b. RC ONLY CONDITION: STATIVE VERBS
Gianni vive con il figlio del medico che correva.
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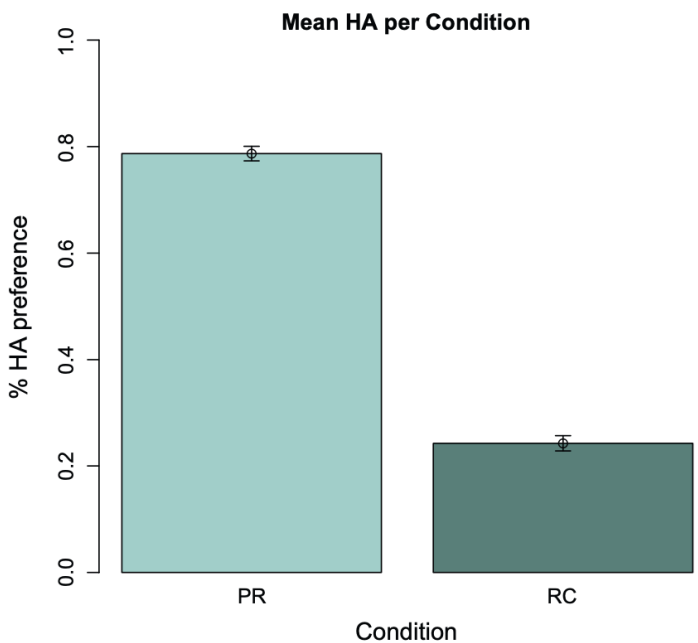
Percentage of high attachment preferences.

Eventive	Stative
78.6%	24.2%



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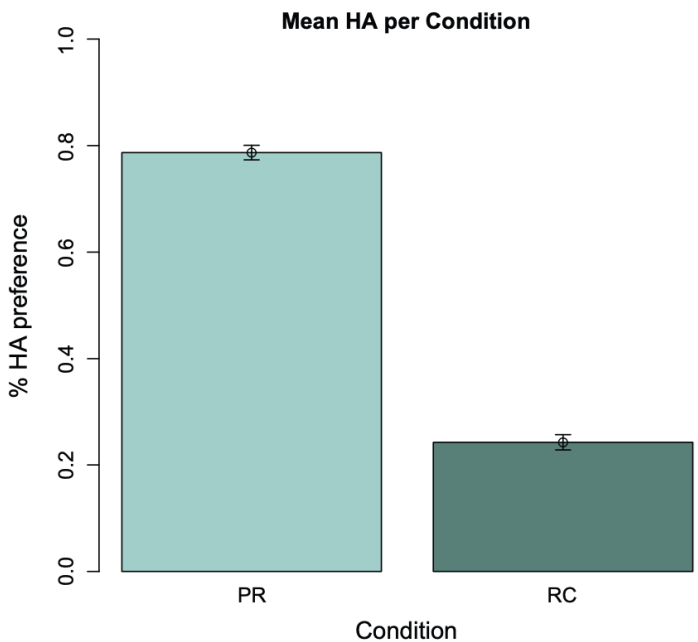

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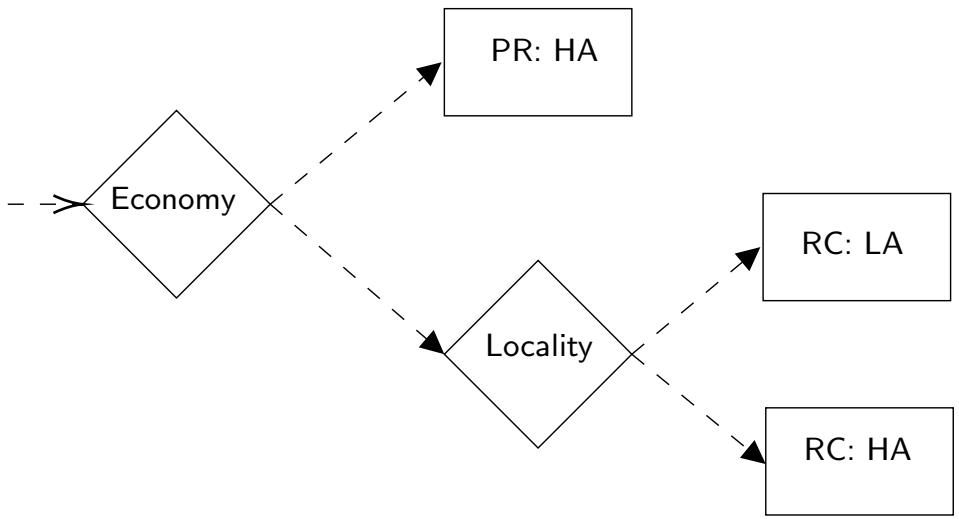
PR-First: Why?

Question

Why should PRs be preferred?



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- RCs: richer and more articulated functional domain

Can we evaluate structural economy quantitatively?

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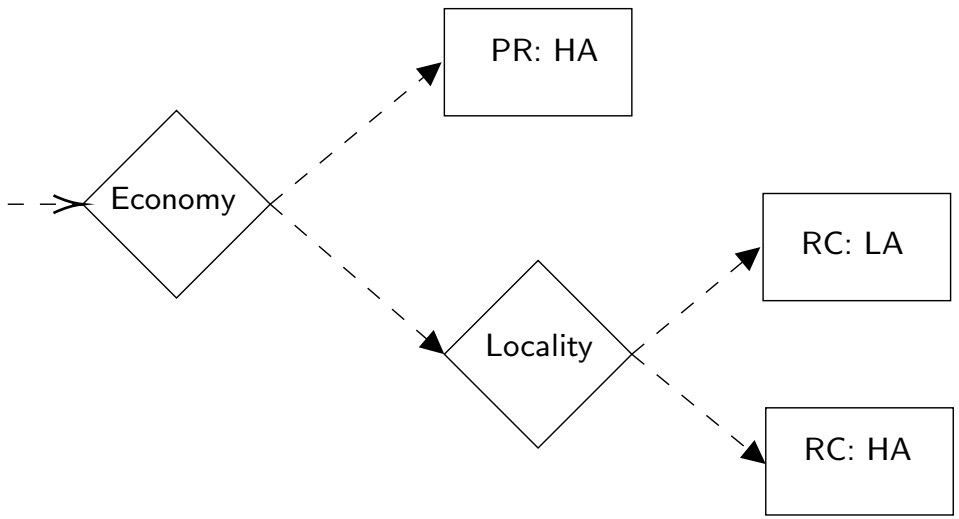

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Modeling PR-First

Why should PRs be easier/preferred?

- Can we evaluate structural economy quantitatively?
- Do different syntactic choices matter?

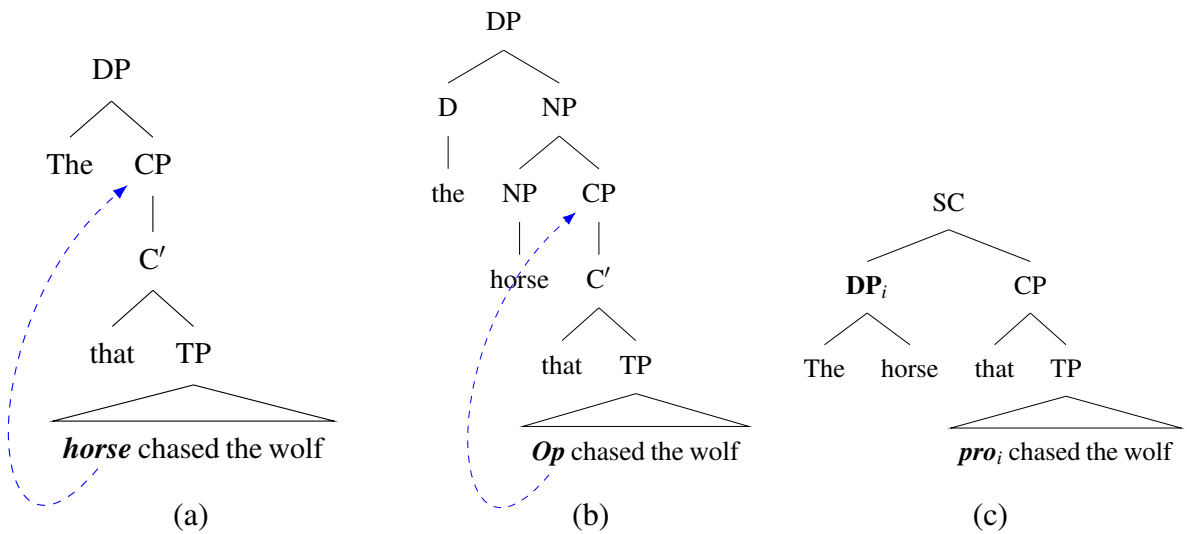

Figure 2: Sketches of the *(a)* RC with Promotion, *(b)* RC with Wh-movement, and *(c)* PR analyses for the sentence *The horse that the wolf chased*.

Modeling Results (De Santo & Lee, 2022b)

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TI/Dr: The Value of Formal Models

A fully specified model of syntactic cost:

- Allows evaluation of economy definitions
- Shows that syntactic choices affect "cost" in unexpected ways
- Suggest ways to narrow down the space of plausible accounts

Beyond these results

- Cross-linguistic and cross-analysis validation
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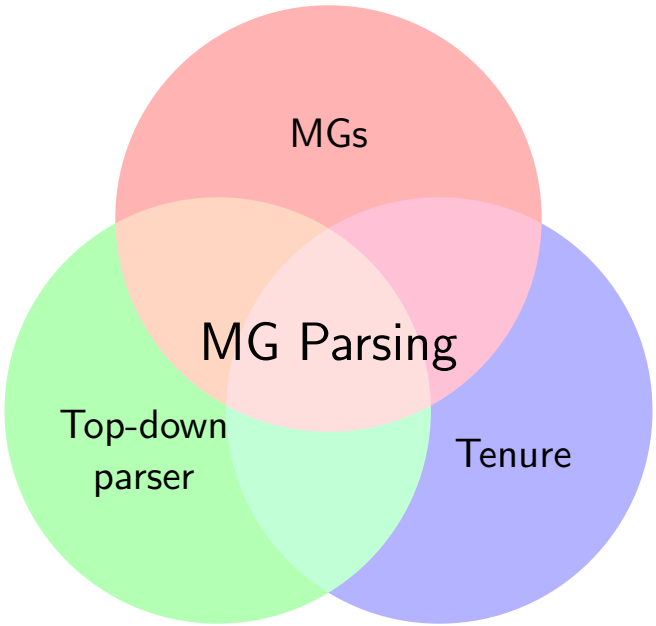
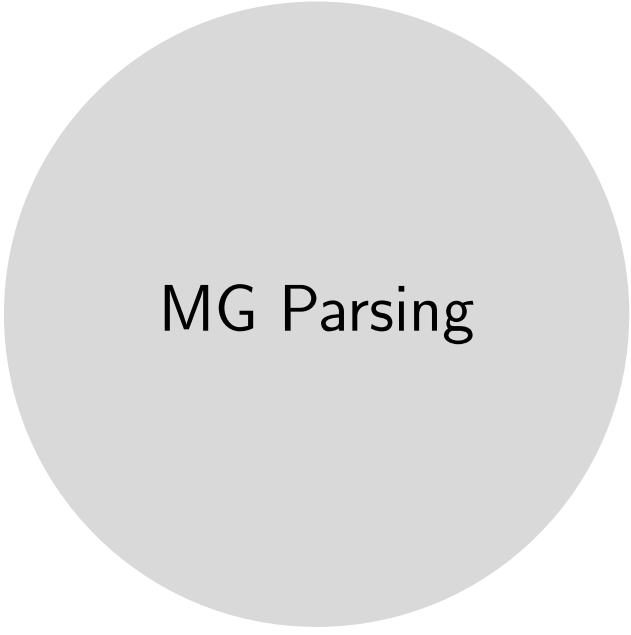
From the Trees (back) to the Forest



Within the program of research proposed here, joint work by linguists, computer scientists, and psychologists could lead to a deeper scientific understanding of the role of language in cognition.

(Bresnan 1978: pg. 59)

Looking Ahead: A Collaborative Enterprise



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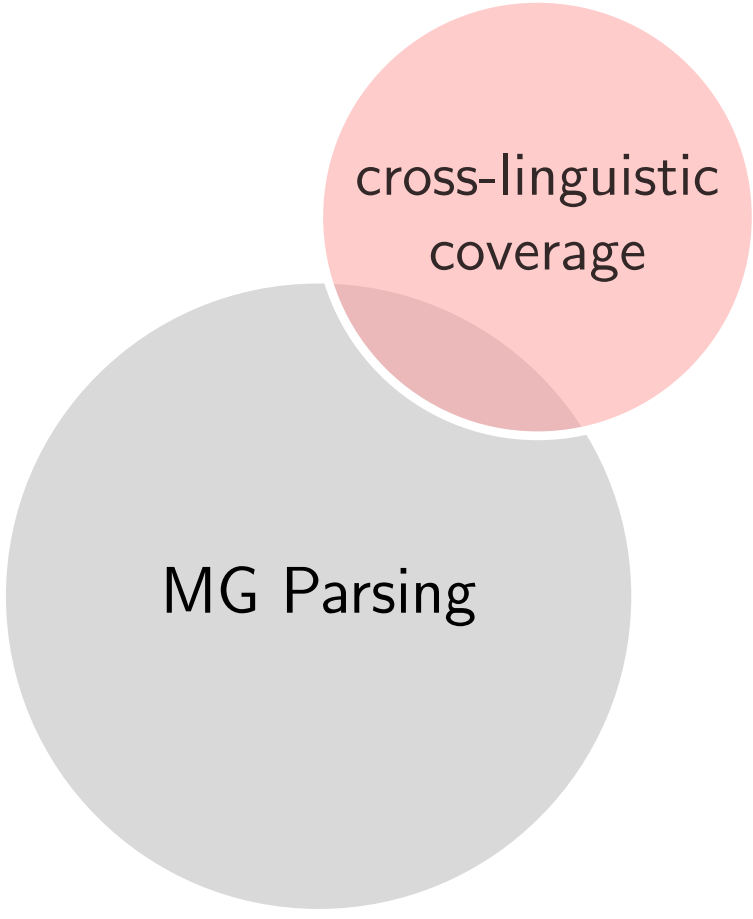

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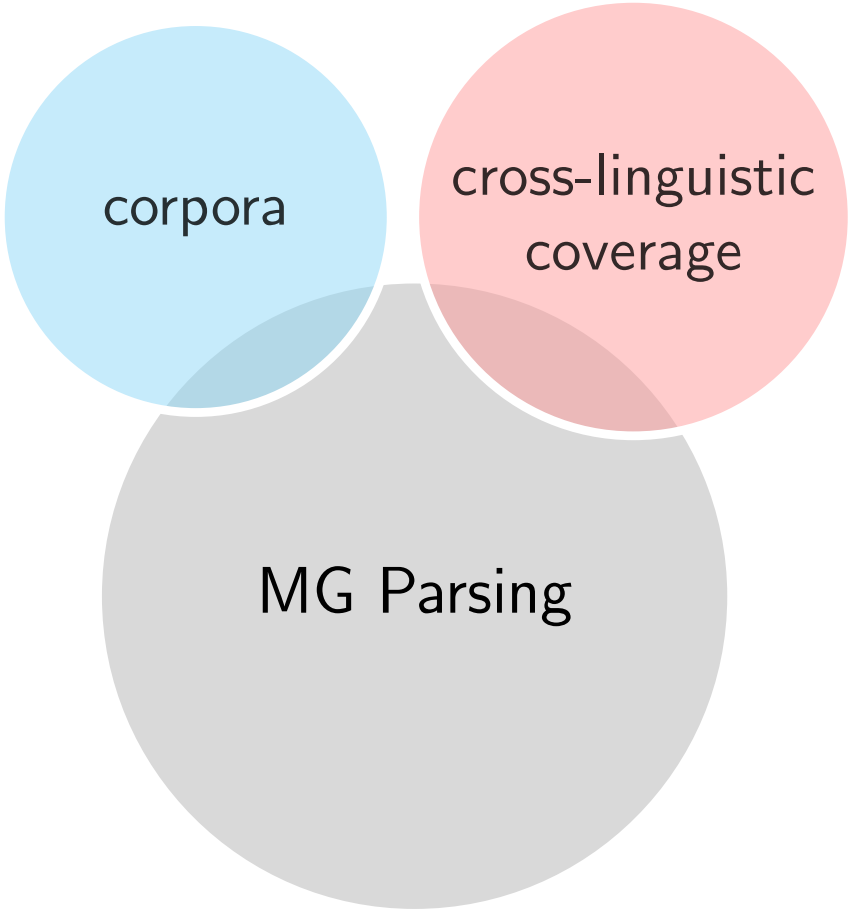
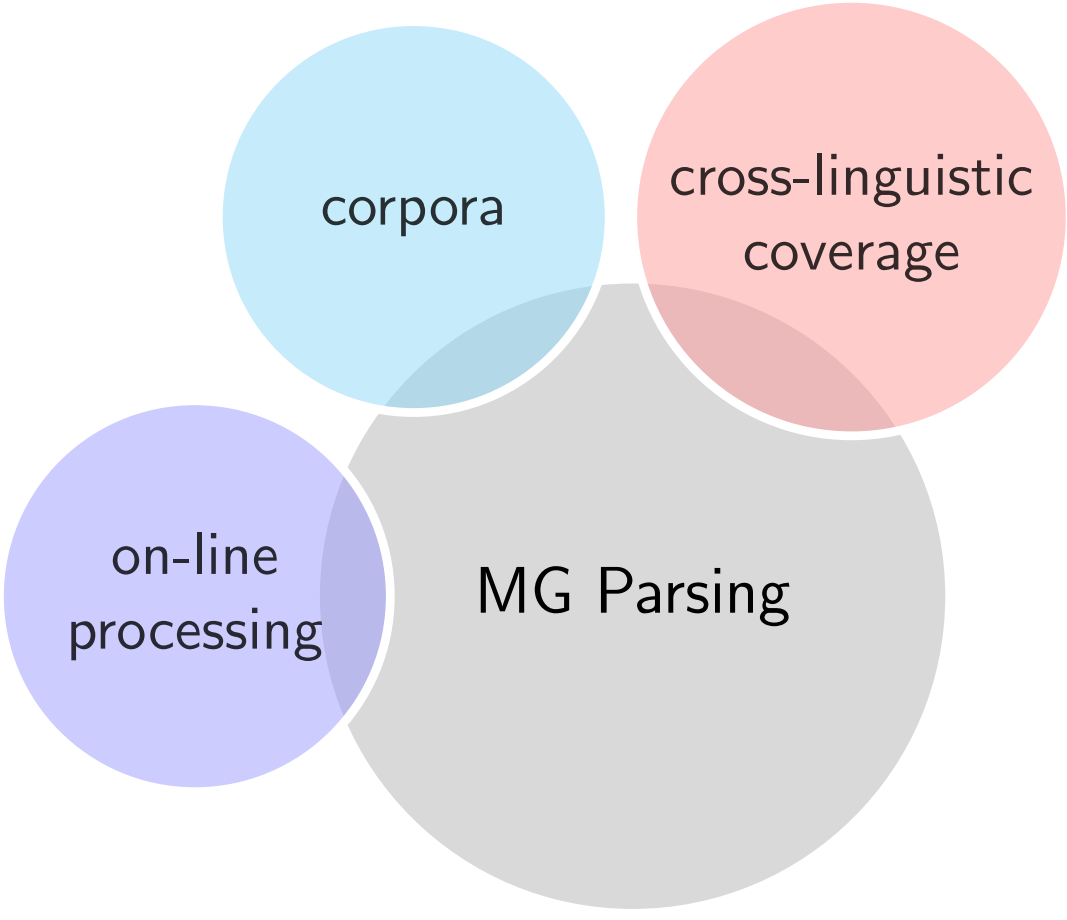
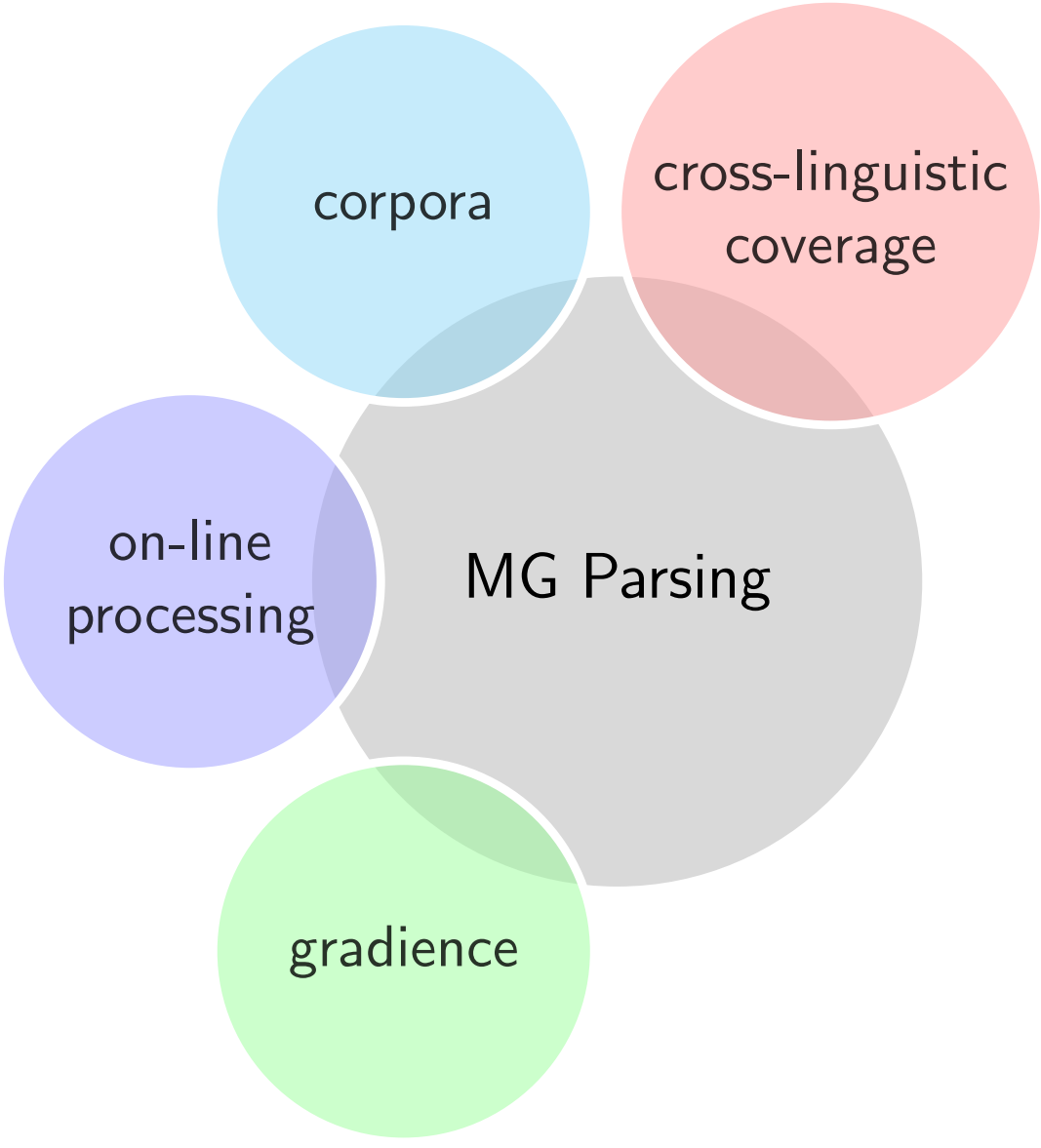


Looking Ahead: A Collaborative Enterprise



Looking Ahead: A Collaborative Enterprise



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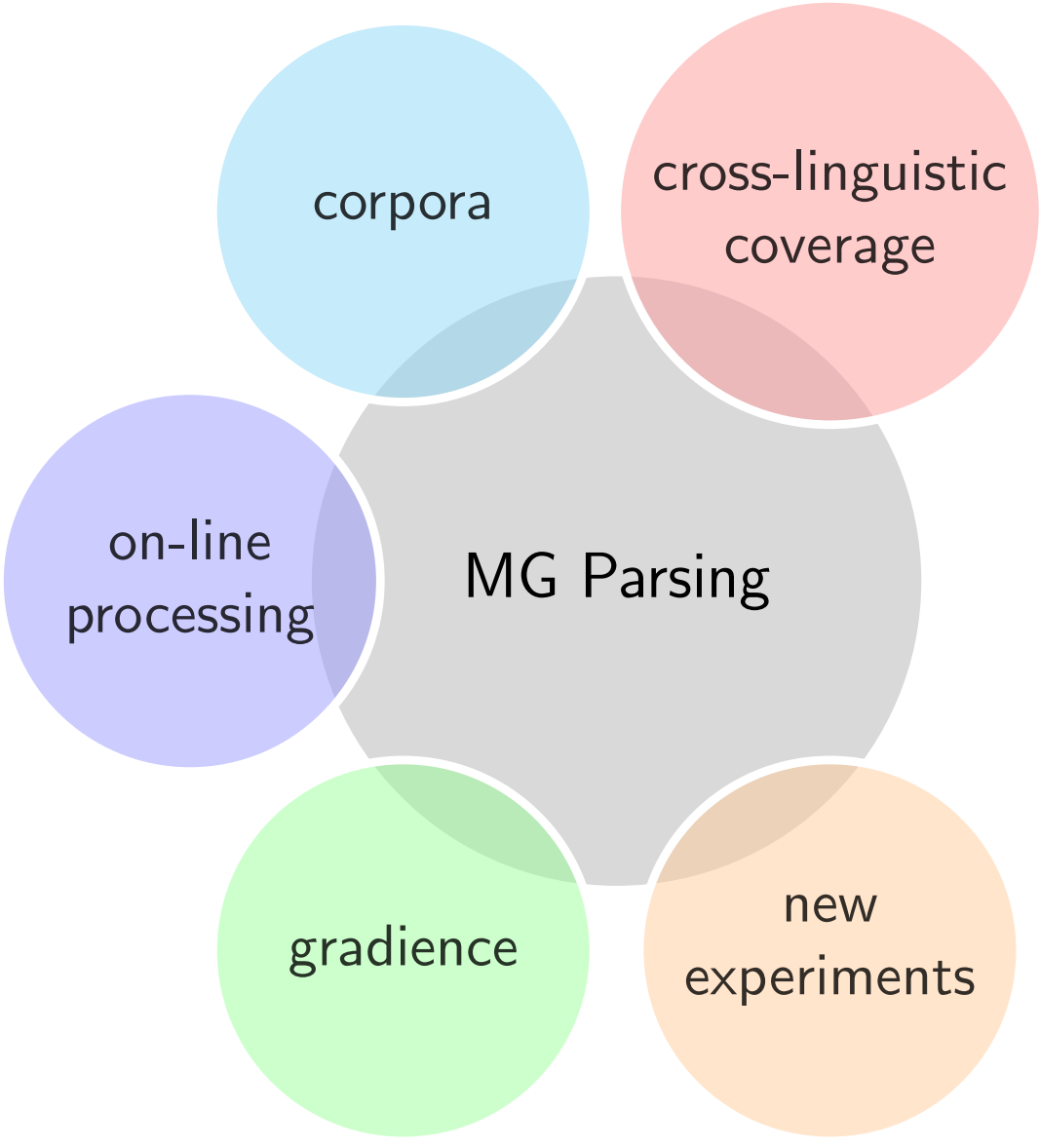

Looking Ahead: A Collaborative Enterprise

Looking Ahead: A Collaborative Enterprise












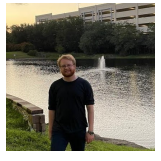

corpora

cross-linguistic coverage

on-line processing

MG Parsing

subregularity + acquisition

gradience

new experiments

Looking Ahead: A Collaborative Enterprise

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Appendix

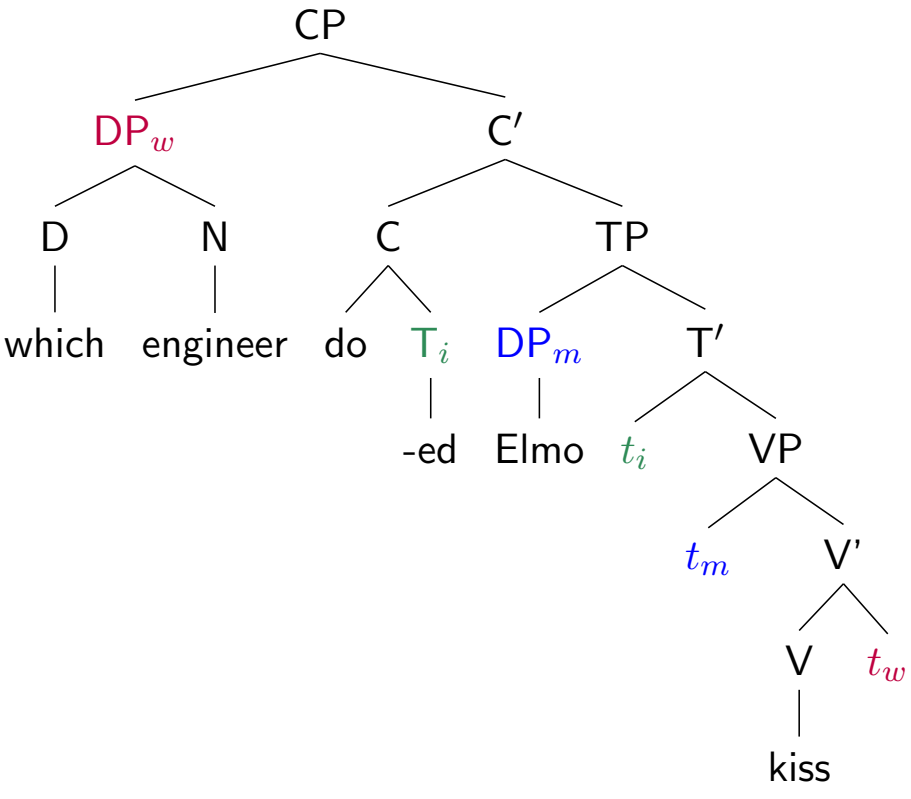
Why MGs?

1. Vast analytical coverage
   - MGs handle virtually all analyses in the generative literature
2. Centrality of derivation trees
   - MGs can be viewed as CFGs with a more complicated mapping from trees to strings
3. Simple parsing algorithms
   - Variant of a recursive descent parser for CFGs
     $\Rightarrow$ cf. TAG (Rambow & Joshi, 1995; Demberg, 2008)

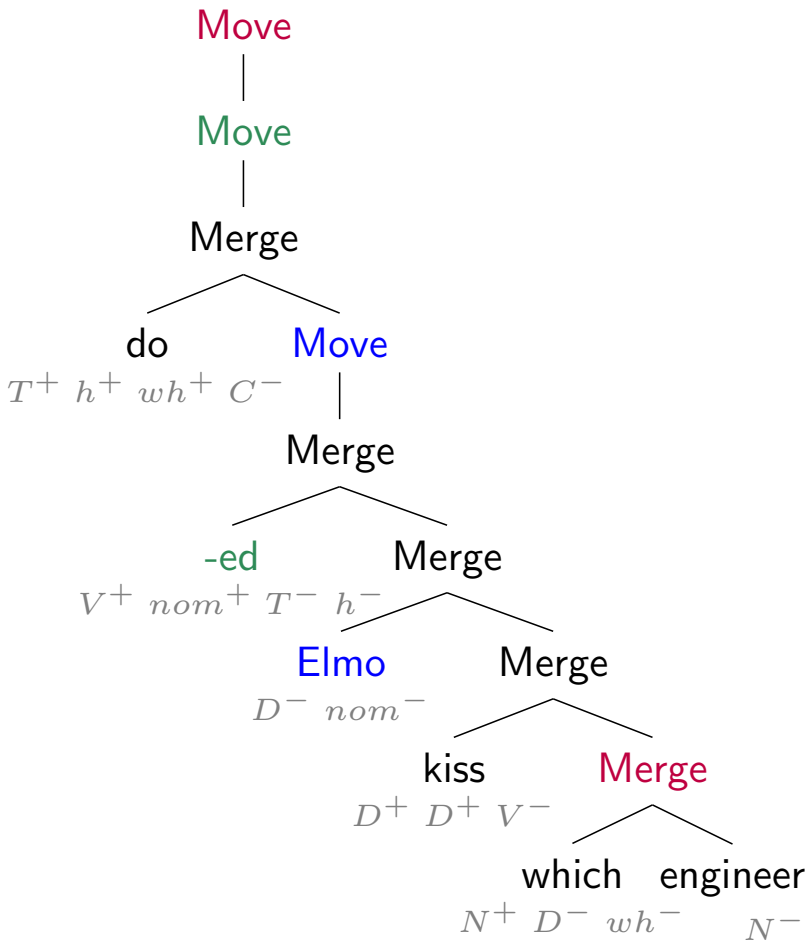
Some Important Properties of MGs

- MGs are weakly equivalent to MCFGs and thus mildly context-sensitive. (Harkema 2001, Michaelis 2001)
- But we can decompose them into two finite-state components: (Michaelis et al. 2001, Kobele et al. 2007, Monnich 2006)
  - a regular language of well-formed derivation trees
  - an MSO-definable mapping from derivations to phrase structure trees
- **Remember:** Every regular tree language can be re-encoded as a CFG (with more fine-grained non-terminal labels). (Thatcher 1967)

Fully Specified Derivation Trees



Phrase Structure Tree



Derivation Tree

Technical Fertility of MGs

MGs can accommodate the full syntactic toolbox:

- sidewards movement (Stabler, 2006; Graf 2013)
- affix hopping (Graf 2012; Graf2013)
- clustering movement (Gartner & Michaelis 2010)
- tucking in (Graf 2013)
- ATB movement (Kobele 2008)
- copy movement (Kobele 2006)
- extraposition (Hunter &Frank 2014)
- Late Merge (Kobele 2010; Graf 2014)
- Agree (Kobele 2011; Graf 2011)
- adjunction (Fowlie 2013; Hunter 2015)
- TAG-style adjunction (Graf 2012)

Why These Metrics?

- These complexity metrics are all related to **storage cost** (cf. Gibson, 1998)
- We could implement alternative ones (cf. Ferrara-Boston, 2012)
  - number of bounding nodes / phases
  - surprisal
  - feature intervention
  - status of discourse referents
  - integration, retrieval, ...
- We want to keep the model **simple** (but not **trivial**):
  - Tenure and Size only refer to the geometry of the derivation
  - they are sensitive the specifics of tree-traversal (cf. node-count; Hale, 2001)

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  - Tenure and Size only refer to the geometry of the derivation
  - they are sensitive the specifics of tree-traversal (cf. node-count; Hale, 2001)

Results across Constructions (De Santo 2019)

Clause Type	<MaxTenure,SumSize>
obj. SRC > ORC	✓
obj. SRC > ORCp	✓
obj. ORC > ORCp	✓
subj. SRC > ORC	✓
subj. SRC > ORCp	✓
subj. ORC > ORCp	✓
matrix SVO > VOS	✓
VS unacc > VS unerg	✓

Table: Predictions of the MG parser by contrast.

Results across Analyses (De Santo 2021)

		SRC < ORC		SRC < ORCp		ORC < ORCp	
Postverbal	**RC Type**	MaxT	SumS	MaxT	SumS	MaxT	SumS
Smuggling	Promotion	✓	✓	✓	✓	✓	✓
	Wh-movement	✓	✓	✓	✓	✓	✓
	Extraposition	✓	✓	✓	✓	✓	✓
	DP analysis	✓	✓	✓	✓	✓	✓
Scrambling	Promotion	✓	✓	✓	✓	✓	✓
	Wh-movement	✓	✓	✓	✓	✓	✓
	Extraposition	✓	✓	✓	✓	tie	tie
	DP analysis	✓	✓	✓	✓	tie	tie

Table: Predictions of the MG parser for the RC contrast by analysis.

Italian Subjects: Probing the Results

Clause Type	MaxT	SumS
obj. SRC	8/*che*	18
obj. ORC	11/*ha*	24
obj. ORCp	16/*Foc*	31
subj. SRC	21/v'	37
subj. ORC	21/v'	44
subj. ORCp	28/v'	56
matrix SVO	3/*ha*/v'	7
matrix VOS	7/*Top*/*Foc*	11
VS unacc	2/vP	3
VS unerg	7/*Top*/*Foc*	11

Table: Summary of MaxT (*value*/*node*) and SumS by construction. Obj. and subj. indicate the landing site of the RC head in the matrix clause.

Postverbal Asymmetries: Possible Accounts?

SRC > ORC

- DLT, active-filler strategy, Competition model, ...

ORC > ORCp

- more problematic (e.g., for DLT)
- can be explained by
  1. economy of gap prediction + structural re-analysis;
  2. intervention effects + featural Relativized Minimality

Can we give a purely structural account?

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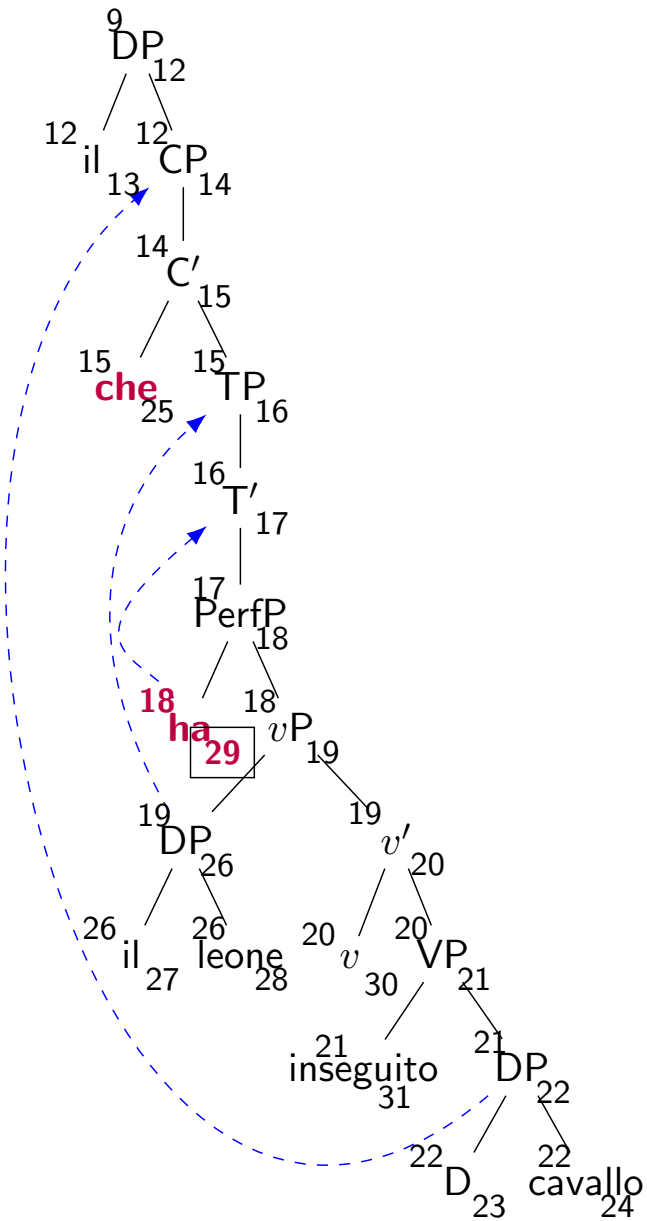
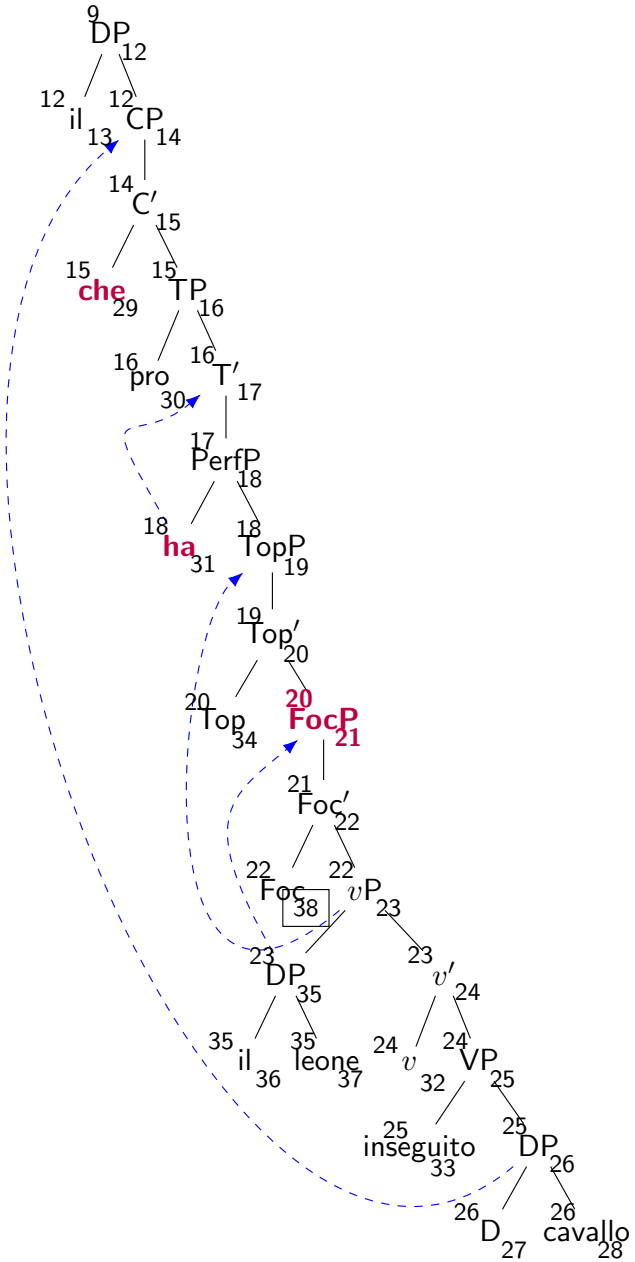
Results: ORC > ORCp





Additional Constructions

- Ambiguity in Matrix Clauses

(8) Ha chiamato Gio
Has called Giovanni

a. "He/she/it called Gio" **SVO**

b. "Gio called" **VS**

- Unaccusatives vs. Unergatives

(9) È arrivato Gio
Is arrived Gio
"Gio arrived" **Unaccusative**

(10) Ha corso Gio
Has ran Gio
"Gio ran" **Unergative**

Acceptability and Grammaticality

1. What do you think that John bought *t*?
2. *What do you wonder whether John bought *t*?

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>
> *(Chomsky 1957)*

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Acceptability judgments $\approx$ Grammaticality judgments

Gradience in Acceptability Judgments

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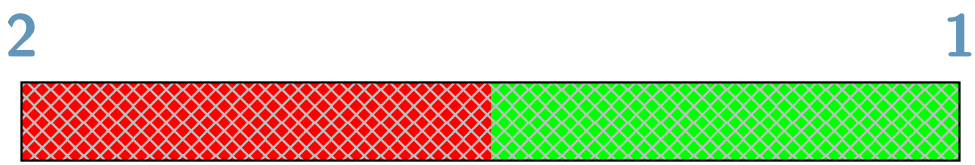
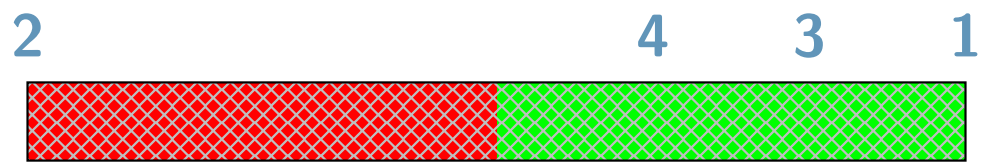
2. *What do you wonder whether John bought *t*?



Gradience in Acceptability Judgments

1. What do you think that John bought *t*?
2. *What do you wonder whether John bought *t*?
3. Who *t* thinks that John bought a car?
4. Who *t* wonders whether John bought a car?



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Gradient Acceptability and Categorical Grammars

Acceptability judgments are not binary but *gradient*:

> *An adequate linguistic theory will have to recognize degrees of grammaticalness [...] there is little doubt that speakers can fairly consistently order new utterances, never previously heard, with respect to their degree of belongingness to the language.*
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> *(Chomsky 1975: 131-132)*

But mainstream syntactic theories rely on categorical grammars!

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(Quantitative) Models of Gradience

Gradient Grammars (Keller 2000; Lau et al. 2014)

- OT-style constraint ranking
- Probabilistic grammars

Extra-grammatical Factors (Chomsky 1975; Schütze 1996)

- Processing effects
  - Plausibility
  - Working memory limitations
  - **But:** few models for quantitative predictions!

Hypothesis

We can use the MG parser to test the relation between categorical grammar, processing difficulty, and gradience!

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A Proof of Concept: Island Effects

1. What do you think that John bought *t*?
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Results in pairwise comparisons ideal for the MG parser

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Gradience in Islands: Sprouse et al. (2012)

A factorial design for islands effects:

1. Gap Position: Matrix vs. Embedded
2. Structure: Island vs. Non-Island
   (Kluender & Kutas 1993)

Results in pairwise comparisons ideal for the MG parser

A Proof of Concept: Island Effects

1. What do you think that John bought *t*? — Non-Island — Embedded
2. What do you wonder whether John bought *t*? — Island — Embedded
3. Who *t* thinks that John bought a car? — Non-Island — Matrix
4. Who *t* wonders whether John bought a car? — Island — Matrix

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Sprouse at al. (2012)

Four island types

Subject islands

- What do you think the speech about *t* interrupted the show about global warming?

Adjunct islands

- What do you laugh if John leaves *t* at the office?

Complex NP islands

- What did you make the claim that John bought *t*?

Whether islands

- What do you wonder whether John bought *t*?

Gap Position × Structure

1. Matrix vs. Embedded
2. Island vs. Non-Island

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Gap Position × Structure

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2. Island vs. Non-Island

Modeling Results (De Santo 2020)

Island Type	Sprouse et al. (2012)			MG Parser
Subj. Island 1	Subj. — Non Isl.	>	Obj. — Non Isl.	✓
	Subj. — Non Isl.	>	Obj. — Isl.	✓
	Subj. — Non Isl.	>	Subj. — Isl.	✓
	Obj. — Non Isl.	>	Obj. — Isl.	✓
	Obj. — Non Isl.	>	Subj. — Isl.	✓
	Obj. — Isl.	>	Subj. — Isl.	×
Subj. Island 2	Matrix — Non Isl.	>	Emb. — Non Isl.	✓
	Matrix — Non Isl.	>	Matrix — Isl.	✓
	Matrix — Non Isl.	>	Emb. — Isl.	✓
	Matrix — Isl.	>	Emb. — Isl.	✓
	Matrix — Isl.	>	Matrix — Isl.	✓
	Emb. — Non Isl.	>	Emb. — Isl.	✓
Adj. Island	Matrix — Non Isl.	>	Emb. — Non Isl.	✓
	Matrix — Non Isl.	>	Matrix — Isl.	✓
	Matrix — Non Isl.	>	Emb. — Isl.	✓
	Matrix — Isl.	>	Emb. — Isl.	✓
	Matrix — Isl.	>	Matrix — Isl.	✓
	Emb. — Non Isl.	>	Emb. — Isl.	✓
CNP Island	Matrix — Non Isl.	>	Emb. — Non Isl.	✓
	Matrix — Non Isl.	=	Matrix — Isl.	✓
	Matrix — Non Isl.	>	Emb. — Isl.	✓
	Matrix — Isl.	>	Emb. — Isl.	✓
	Matrix — Isl.	>	Matrix — Isl.	✓
	Emb. — Non Isl.	>	Emb. — Isl.	✓

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Island Type	Sprouse et al. (2012)			MG Parser
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	Subj. — Non Isl.	>	Obj. — Isl.	✓
	Subj. — Non Isl.	>	Subj. — Isl.	✓
	Obj. — Non Isl.	>	Obj. — Isl.	✓
	Obj. — Non Isl.	>	Subj. — Isl.	✓
	Obj. — Isl.	>	**Subj. — Isl.**	×
Subj. Island 2	Matrix — Non Isl.	>	Emb. — Non Isl.	✓
	Matrix — Non Isl.	>	Matrix — Isl.	✓
	Matrix — Non Isl.	>	Emb. — Isl.	✓
	Matrix — Isl.	>	Emb. — Isl.	✓
	Matrix — Isl.	>	Matrix — Isl.	✓
	Emb. — Non Isl.	>	Emb. — Isl.	✓
Adj. Island	Matrix — Non Isl.	>	Emb. — Non Isl.	✓
	Matrix — Non Isl.	>	Matrix — Isl.	✓
	Matrix — Non Isl.	>	Emb. — Isl.	✓
	Matrix — Isl.	>	Emb. — Isl.	✓
	Matrix — Isl.	>	Matrix — Isl.	✓
	Emb. — Non Isl.	>	Emb. — Isl.	✓
CNP Island	Matrix — Non Isl.	>	Emb. — Non Isl.	✓
	Matrix — Non Isl.	=	Matrix — Isl.	✓
	Matrix — Non Isl.	>	Emb. — Isl.	✓
	Matrix — Isl.	>	Emb. — Isl.	✓
	Matrix — Isl.	>	Matrix — Isl.	✓
	Emb. — Non Isl.	>	Emb. — Isl.	✓

TL;DR

Success in all cases but one!

Subject Island: Case 1

(11) a. What do you think the speech interrupted *t*? Obj — Non Island

b. What do you think *t* interrupted the show? Subj — Non Island

c. What do you think the speech about global warming interrupted the show about *t*? Obj — Island

d. What do you think the speech about *t* interrupted the show about global warming? Subj — Island

Sprouse et al. (2012)			MG Parser
Subj. — Non Isl.	>	Obj. — Non Isl.	✓
Subj. — Non Isl.	>	Obj. — Isl.	✓
Subj. — Non Isl.	>	Subj. — Isl.	✓
Obj. — Non Isl.	>	Obj. — Isl.	✓
Obj. — Non Isl.	>	Subj. — Isl.	✓
Obj. — Isl.	>	Subj. — Isl.	×

Clause Type	MaxT	SumS
Obj./Non Island	14/*do*	19
Subj./Non Island	11/*do*	14
Obj./Island	23/*T2*	22
Subj./Island	15/*do*	20

Subject Island: Case 1

(5) a. What do you think the speech interrupted *t*? Obj — Non Island

b. What do you think *t* interrupted the show? Subj — Non Island

c. What do you think the speech about global warming interrupted the show about *t*? Obj — Island

d. * What do you think the speech about *t* interrupted the show about global warming? Subj — Island

Sprouse et al. (2012)			MG Parser
Subj. — Non Isl.	>	Obj. — Non Isl.	✓
Subj. — Non Isl.	>	Obj. — Isl.	✓
Subj. — Non Isl.	>	Subj. — Isl.	✓
Obj. — Non Isl.	>	Obj. — Isl.	✓
Obj. — Non Isl.	>	Subj. — Isl.	✓
Obj. — Isl.	>	Subj. — Isl.	×

Clause Type	MaxT	SumS
Obj./Non Island	14/*do*	19
Subj./Non Island	11/*do*	14
Obj./Island	23/*T2*	22
Subj./Island	15/*do*	20

Subject Island: Case 2

(6) a. Who *t* thinks the speech interrupted the primetime TV show?
Matrix — Non Island

b. What do you think *t* interrupted the primetime TV show?
Emb. — Non Island

c. Who *t* thinks the speech about global warming interrupted the primetime TV show?
Matrix — Island

d. What do you think the speech about *t* interrupted the primetime TV show?
Emb. — Island

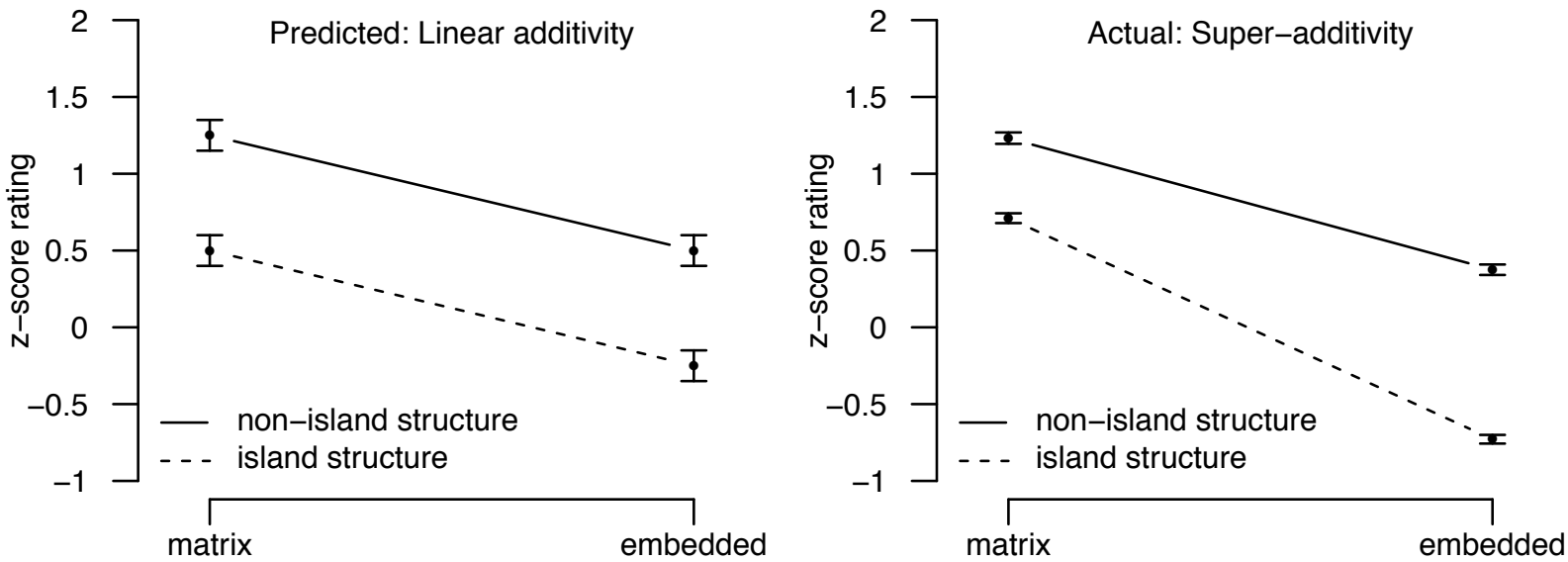
Sprouse et al. (2012)			MG Parser
Matrix — Non Isl.	>	Emb. — Non Isl.	✓
Matrix — Non Isl.	>	Matrix — Isl.	✓
Matrix — Non Isl.	>	Emb. — Isl.	✓
Matrix — Isl.	>	Emb. — Isl.	✓
Matrix — Isl.	>	Matrix — Isl.	✓
Emb. — Non Isl.	>	Emb. — Isl.	✓

Clause Type	MaxT	SumS
Matrix — Non Isl.	$5/C$	9
Emb. — Non Isl.	$11/do$	14
Matrix — Isl.	$11/T_{RC}$	9
Emb. — Isl.	$17/T_{RC}$	20

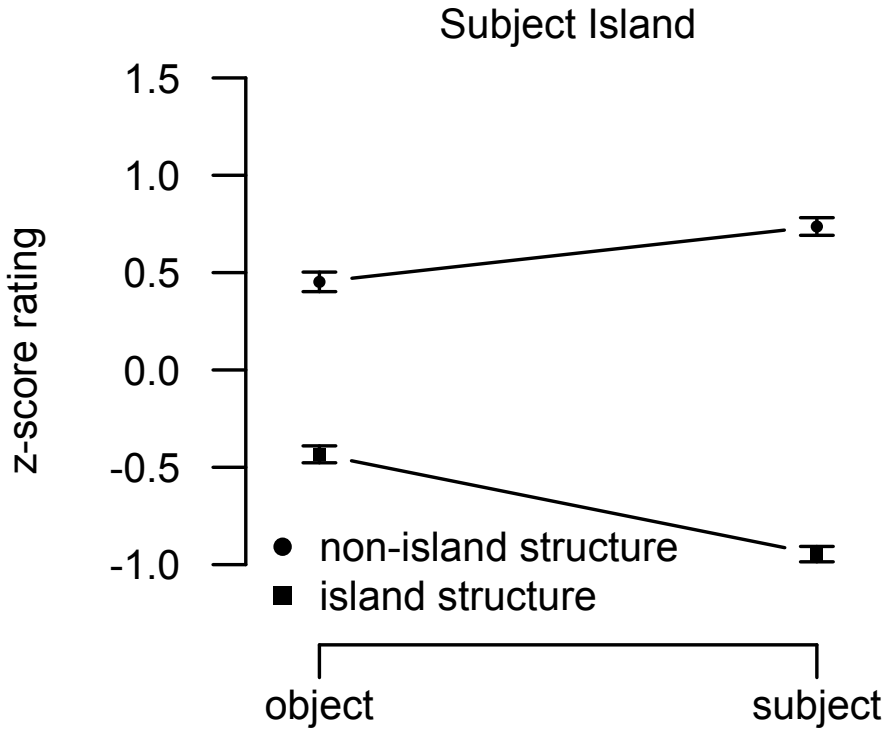
Gradience in Islands

A factorial design for islands effect:

- Gap Position × Structure



Deriving Pairwise Comparisons



- Subj — Non Island > Obj — Non Island
- Subj — Non Island > Obj — Island
- Subj — Non Island > Subj — Island
- etc.

A Caveat on Island Effects

The Goal

Can gradience in acceptability judgments arise from a categorical grammar due to processing factors?

- Sprouse et al.'s (2012) design is ideal for the MG model.

But I am not interested in island effects per se:

- Islands: grammatical or processing effects?
  (Hofmeister et al., 2012a; Sprouse et al., 2012a,b)
  - hence, not modeling super-additivity
  - spoilers: maybe we get some insights?
- Islands: syntax or semantics?
  (Truswell, 2011; Kush et al., 2018; Matchin et al., 2018)

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  - spoilers: maybe we get some insights?
- Islands: syntax or semantics?
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A Caveat on Island Effects

The Goal

Can gradience in acceptability judgments arise from a categorical grammar due to processing factors?

- Sprouse et al.'s (2012) design is ideal for the MG model.

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Models of Gradience

(At least two) theories of gradience:

- Gradience incorporated in the grammar
  (Keller 2000; Featherston 2005; Lau et al. 2014)
- Gradience due to extra-grammatical factors
  (Chomsky 1975; Schütze 1996)

The contribution of formal models?

Quantify what each approach needs to account for the data:

- Additional syntactic assumptions
- Additional complexity in acquisition, processing strategies, etc.

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Subject Islands

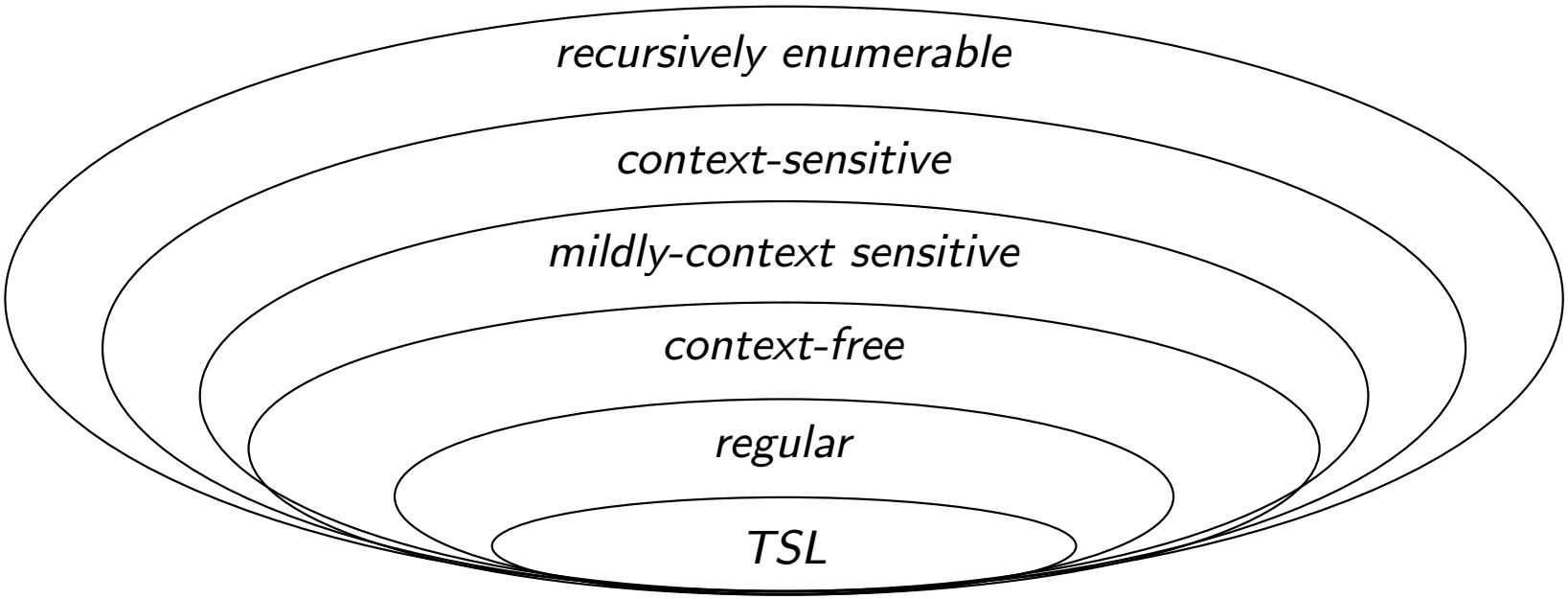
Case 1:

(7)
a. What do you think the speech interrupted *t*? Obj — Non Island
b. What do you think *t* interrupted the show? Subj — Non Island
c. What do you think the speech about global warming interrupted the show about *t*? Obj — Island
d. What do you think the speech about *t* interrupted the show about global warming? Subj — Island

Case 2:

(8)
a. Who *t* thinks the speech interrupted the primetime TV show? Matrix — Non Island
b. What do you think *t* interrupted the primetime TV show? Emb. — Non Island
c. Who *t* thinks the speech about global warming interrupted the primetime TV show? Matrix — Island
d. What do you think the speech about *t* interrupted the primetime TV show? Emb. — Island

Subregular Complexity



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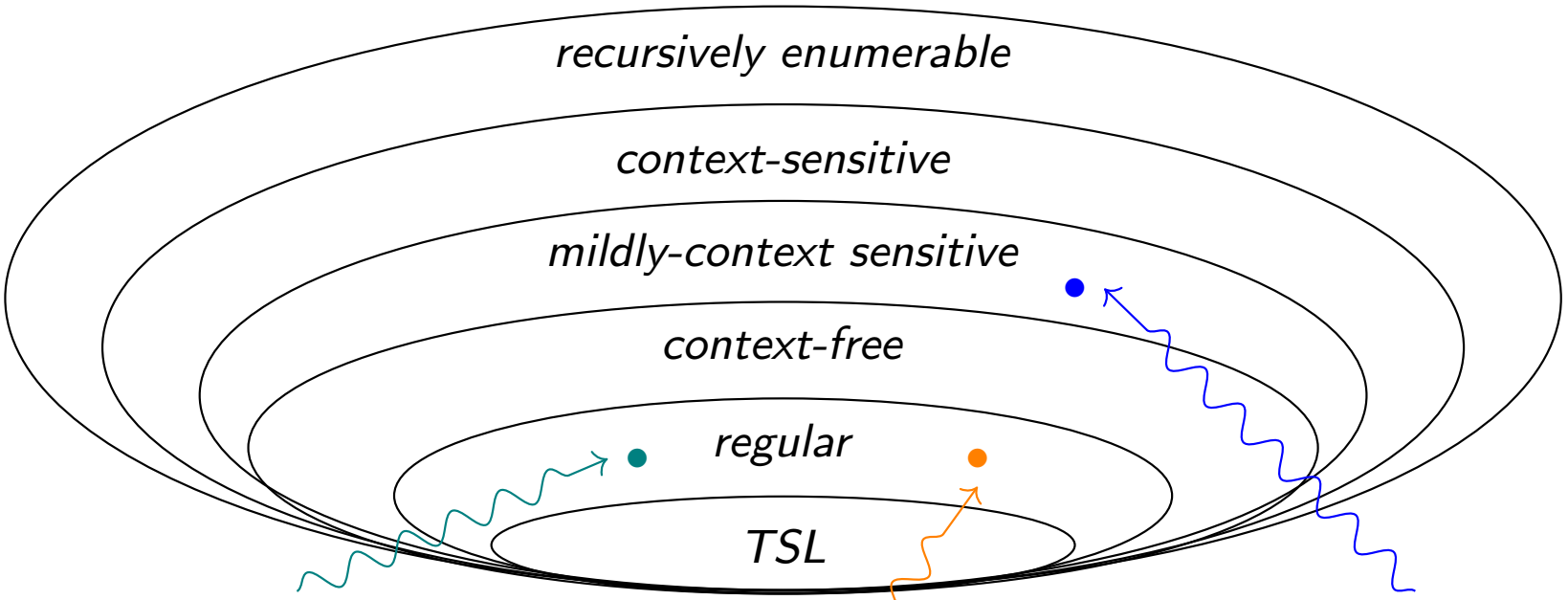
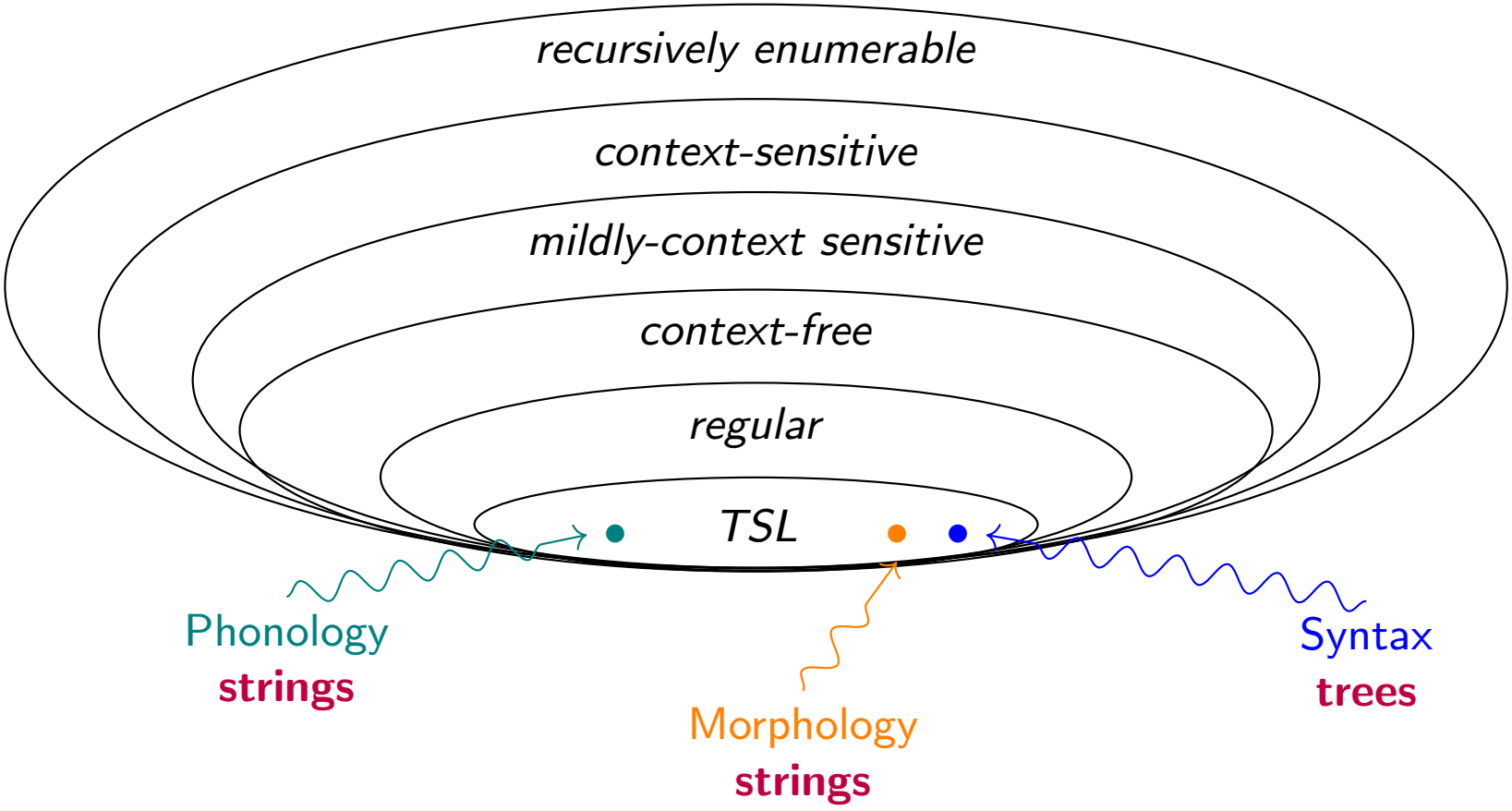


Phonology
Kaplan and Kay (1994)
strings

Morphology
Karttunen et al. (1992)
strings

Syntax
Shieber (1985)
strings

Subregular Complexity



Cognitive Parallelism

Strong Cognitive Parallelism Hypothesis

Phonology, (morphology), and syntax have the **same subregular complexity** over their respective **structural representations**.

We gain a unified perspective on:

- typology
- learnability
- cognition

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  Finite, flat memory

Top-down Parsing + Grammaticalized Constraints?

Graf & De Santo (2019)

Sensing Tree Automata (Martens 2006) as a subregular bound on the complexity of syntactic dependencies.

- $0(b) \rightarrow b$; $1(b) \rightarrow b$
- $1(a) \rightarrow a$

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- Constraints improve parsing performance by **exponentially reducing** the search space (Stabler 2013)
- Can be pre-compiled in the MG parse schema as a deterministic **top-down filter** (De Santo & Graf, in prep.)

Stacked RCs and Parallelism Effects

English Stacked RCs (Zhang, 2017)

(9) **The horse** [$_{RC_1}$ that t chased the wolf] [$_{RC_2}$ that t kicked the elephant] . . . **ss**

(10) **The horse** [$_{RC_1}$ that the wolf chased t] [$_{RC_2}$ that t kicked the elephant] . . . **os**

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  SS << OS, OO << SO.
- But she also showed that no combination of metrics can account for these effects.
- Proposal: metric encoding memory reactivation

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Feature Reactivation

REACTIVATION For each node m_i associated to a movement feature f^-, its reactivation is $i(m_i) - o(m_{i-1})$; the index of m_i minus the outdex of the closest preceding node also associated to f^-, if it exists.

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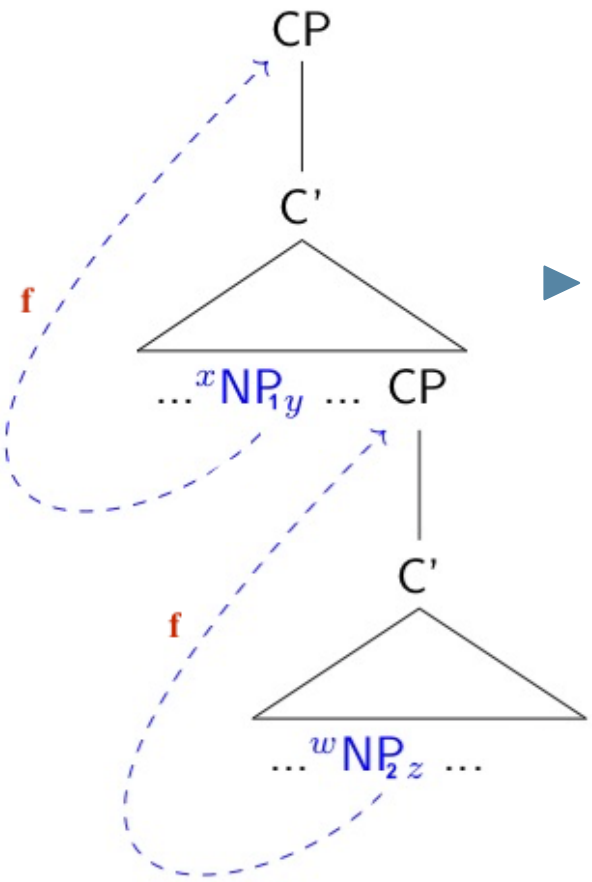

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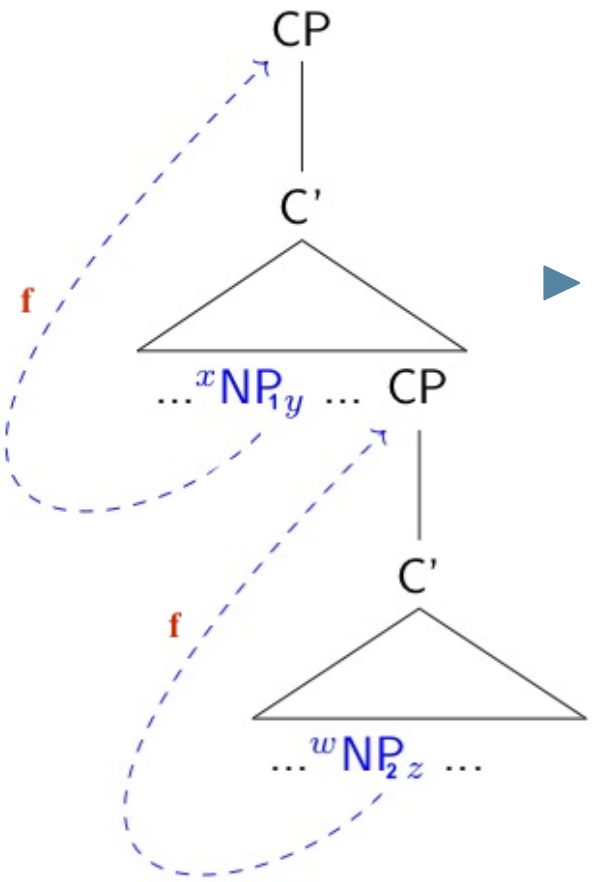

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  TENURE (NP_1) $y - x$

  TENURE (NP_2) $z - w$

  REACTIVATION(NP_2) $w - y$

Feature Reactivation: Base Metrics

- feature-associated metrics

  $\textsc{SumR}^f$ $\sum_{m_i \in M^f} i(m_i) - o(m_{i-1})$

  $\textsc{MaxR}^f$ $max(\{i(m_i) - o(m_{i-1}) | m_i \in M^f\})$

  $\textsc{AvgR}^f$ $\frac{\textsc{SumR}}{|M^f|}$

- comprehensive metrics

  $\textsc{SumR}$ $\sum_{f \in \mathcal{M}} \textsc{SumR}^f$

  $\textsc{MaxR}$ $max(\{\textsc{SumR}^f | f \in \mathcal{M}\})$

  $\textsc{AvgR}$ $\frac{\textsc{SumR}}{|\mathcal{M}|}$

Priming Effects

(13) I saw

a. $[_{RC_1}$ the horse that chased the lions $]$ **SRC**

b. and $[_{RC_2}$ the mouse that kissed the chicken $]$ **SRC**

(14) I saw

a. $[_{RC_1}$ The horse that chased the lions$]$ **SRC**

b. and $[_{RC_2}$ the mouse that the chicken kissed $]$ **ORC**

(15) I saw

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(16) I saw

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b. and $[_{RC_2}$ the mouse that the chicken kissed$]$ **ORC**

A Look at HA Languages (Grillo & Costa 2015)

Table 4
Attachment preferences and PR availability.

Language	Attachment	PRs
English	Low	*
Romanian	Low	*
Basque	Low	*
Chinese	Low	*
German (?)	High/Low	*
Russian (?)	High	*
Bulgarian (?)	High/Low	*
Norwegian (?)	Low	✓
Swedish (?)	Low	✓
Spanish	High	✓
Galician	High	✓
Dutch	High	✓
Italian	High	✓
French	High	✓
Serbo-Croatian	High	✓
Japanese	High	✓
Korean	High	✓
Greek	High	✓
Portuguese	High	✓

Figure: Survey of Attachment preferences from Grillo & Costa (2014)

PRs: Modeling Results 1

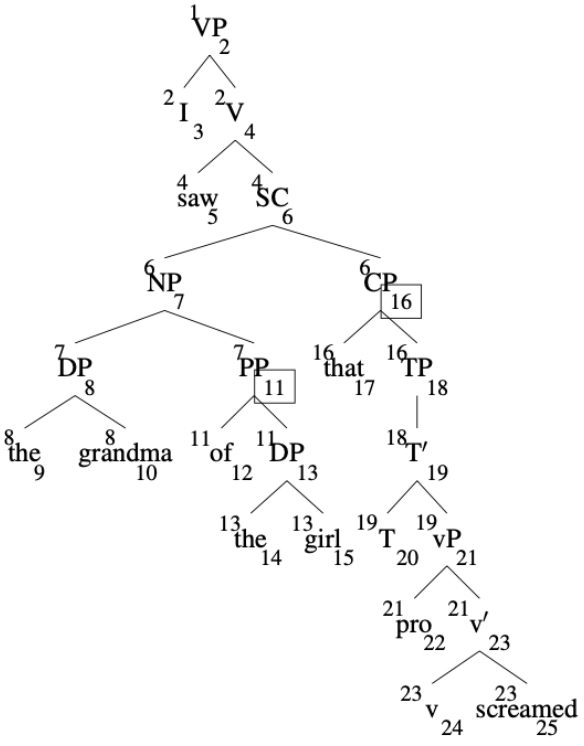


Figure 3: Annotated derivation trees for the Italian sentence *I saw the grandma of the girl that screamed*, according to a pseudo-relaive clause analysis. The tree is treated as a VP since additional structure in the matrix clause would be identical across comparisons.

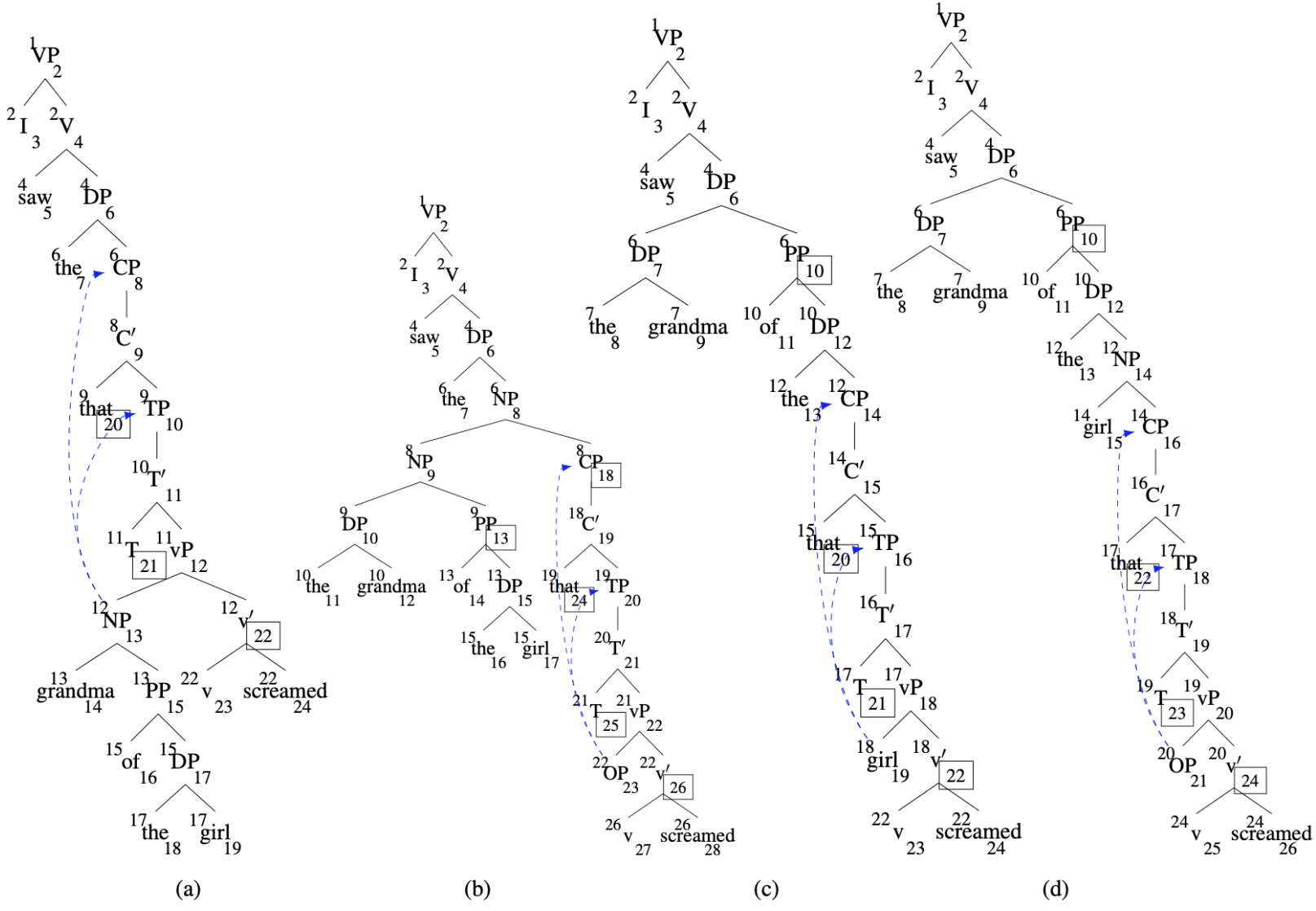
	MG Parser	
Hypothesis	**Promotion**	**Wh-mov**
PR < HA	✓	Tie
PR < LA	×	×
LA < HA	✓	✓

Table 1: Summary of the predictions made by a *pseudo-relative first* account, and corresponding parser's predictions based on MAXTENURE, as pairwise comparisons (x < y: x is preferred over y).

	MAXT	
	Promotion	**Wh-mov**
PR	10/CP	
HA	11/that	10/CP
LA	5/that	7/that

Table 2: MAXT values (*value/node*) by construction, with RCs modulated across a promotion and wh-movement analysis.

PRs: Modeling Results 2



Our Study

Question: Online effects of PR availability in Italian?

- Modulating:
  - Type of Verb: Perceptual vs. Non-perceptual
  - Attachment: HA vs. LA
- Temporal ambiguity HA/LA until # agreement on the **verb**

(2)

	Verb	Interpretation		before	target	after	
a.	PR/RC (Perceptual)	LA	Gianni vide il figlio dei medici Gianni saw the son-SG of the doctors-PL	che who	correvano were running-PL	la the	maratona marathon
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  - Type of Verb: Perceptual vs. Non-perceptual
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  - **Perceptual Verbs**: costly LA disambiguation (on verb)
  - **Non-Perceptual Verbs**: costly HA disambiguation (on verb)

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Decomposing the Hypothesis: Perceptual Verbs

- Temporal HA/LA ambiguity until # agreement on the **verb**

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Perceptual Verbs

- PR vs RC
- PR-first: HA-like interpretation is preferred
- LA disambiguation (on verb) should be costly

Decomposing the Hypothesis: Perceptual Verbs

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Non-Perceptual Verbs

- Just RC
- LA interpretation (more local) is preferred
- HA disambiguation (on verb) should be costly

Study Details: Summary of Predictions

- Temporarily ambiguous sentences modulating:
  - Type of Verb: Perceptual vs. Non-perceptual
  - Attachment: HA vs. LA

Hypothesis

Perceptual Verbs

- LA disambiguation (on verb) should be costly

Non-Perceptual Verbs

- HA disambiguation (on verb) should be costly

- 74 participants (recruited through Prolific, run on Ibex Farm)
- 24 item sets, 48 fillers
- Self-paced reading

Results: Behavioral Data

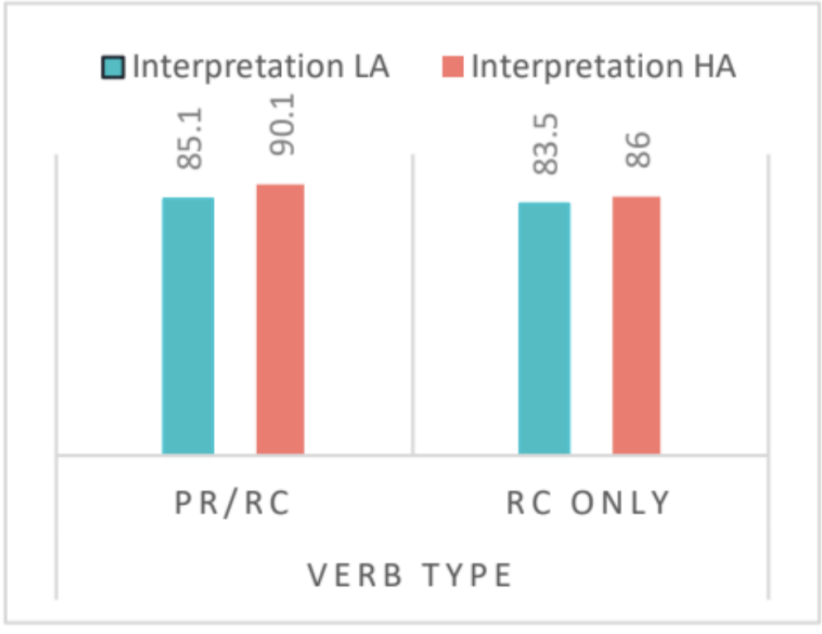
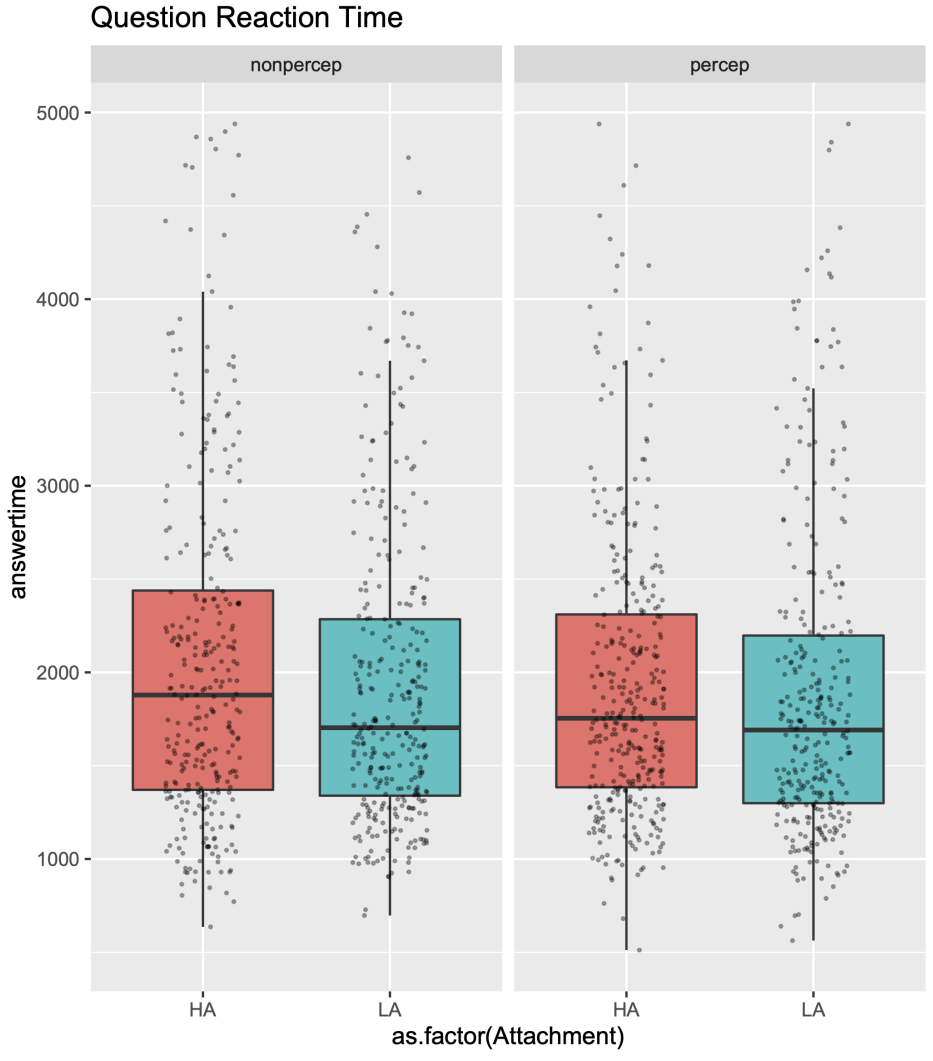
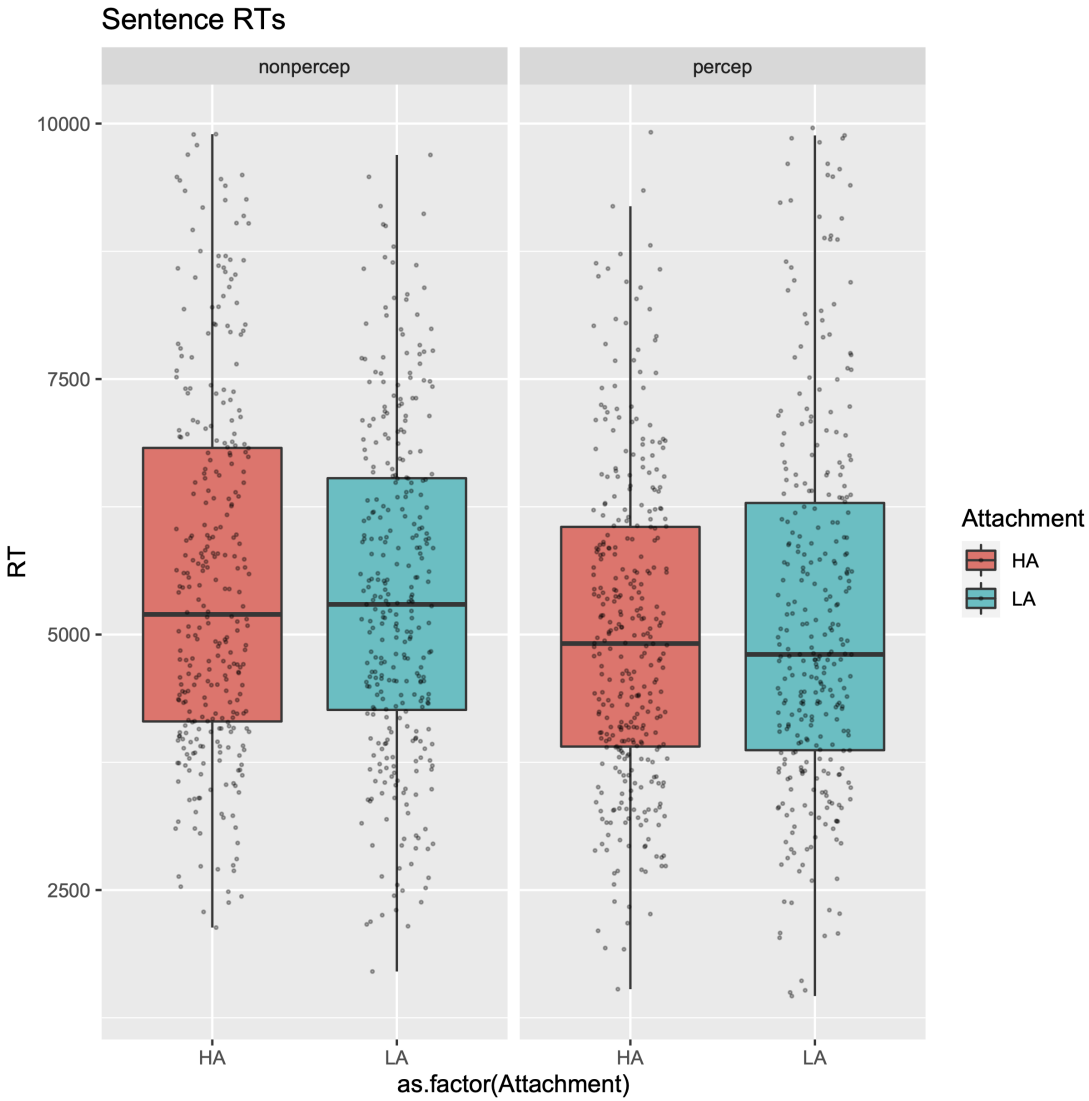


Figure 2. The results of the comprehension test



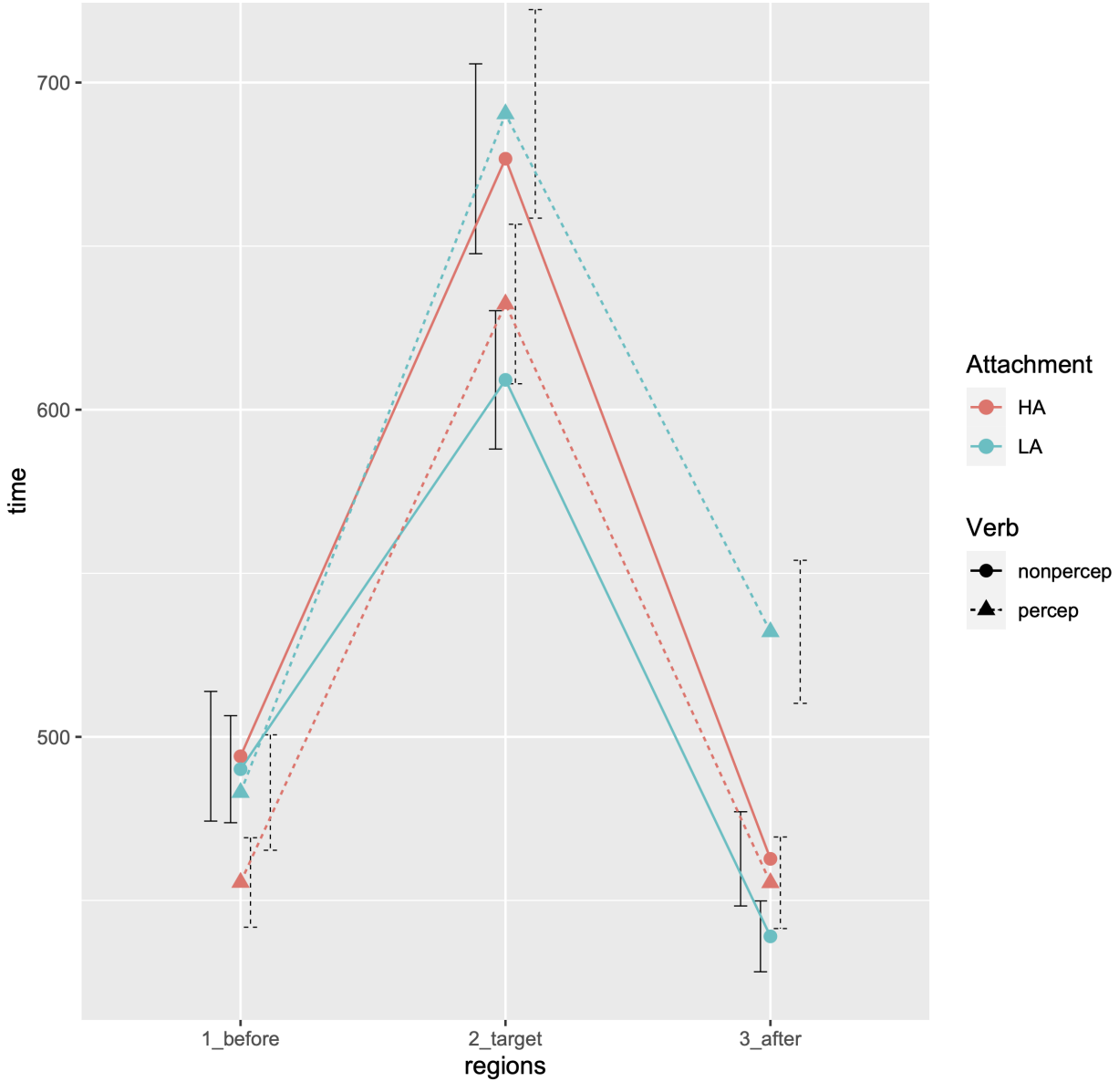
- No effect of Verb, Attachment, or Interaction

Results: Sentence Reading Time



- Effect of the Verb ($p<0.01$) and Verb*Attachment ($p<0.05$)

Results: RTs by ROI



Hypothesis

- **Percep**: LA costly
- **Non-Perc**: HA costly

- Pre-Target: No Effect
- Target: Verb*Attachment ($p < 0.01$)
- Spillover: Verb*Attachment ($p < 0.001$) and Verb ($p<0.001$)

Online Effects: Stimuli and RTs

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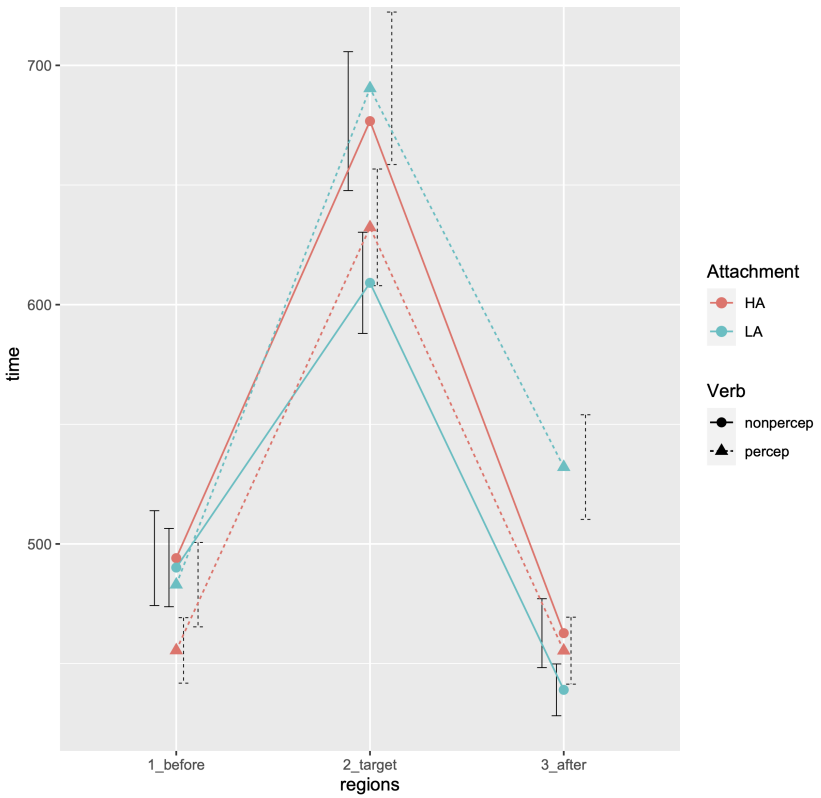

Hypothesis (@ verb)

- **Percep**: LA costly
- **Non-Perc**: HA costly

See also Aguilar et al. (2021)