

Memory Usage as a Measure of Structural Complexity in Minimalist Parsing

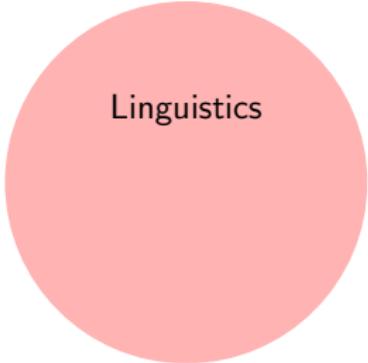
Aniello De Santo

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aniello.desanto@stonybrook.edu

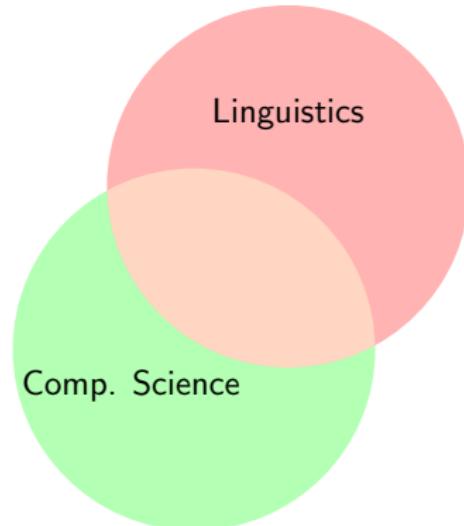
Get the slides!

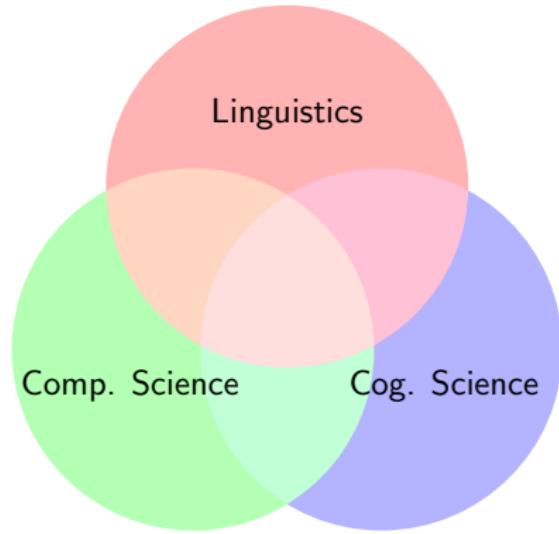
University of Utah
Jan 14, 2020

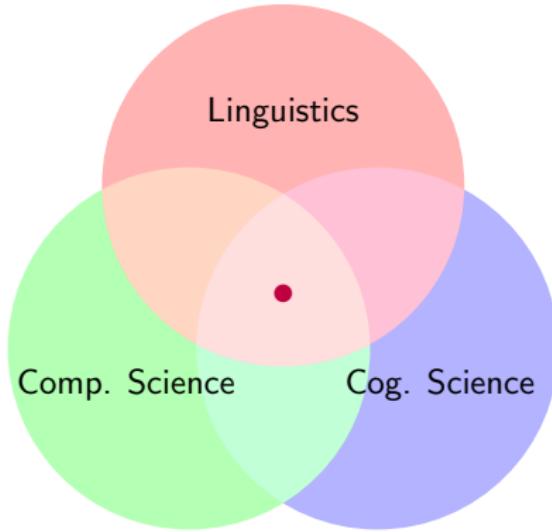




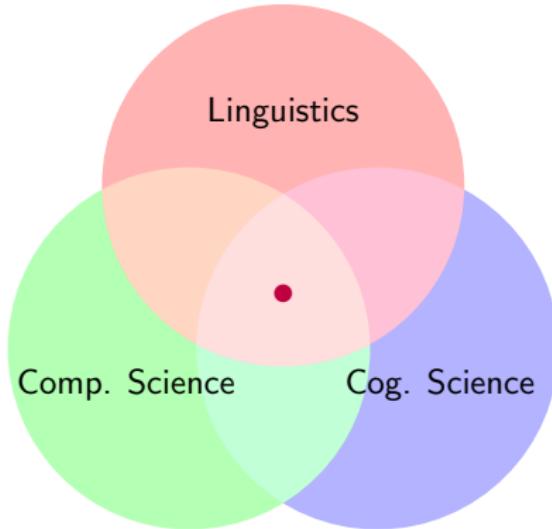
Linguistics







- ▶ Modeling processing difficulty (De Santo 2019, De Santo in prep.)
- ▶ Cross-linguistic variation
(De Santo & Shafiei 2019, De Santo & Zhang in prep.)
- ▶ Gradience in acceptability judgments (De Santo 2020)
- ▶ Computational parallels across linguistic modules
(Aksanova & De Santo 2017, De Santo & Graf 2019)
- ▶ Constraints in acquisition (De Santo 2018, Graf & De Santo 2020)
- ▶ Animal Cognition (De Santo & Rawski, to appear)



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Let's Start with a Puzzle!

Asymmetries in Italian Relative Clauses

Italian speakers conform 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
The horse that has chased the lion
- a. "The horse that chased the lion" **SRC**
 - b. "The horse that the lion chased" **ORCp**

SRC > ORCp

Agreement can disambiguate:

- (4) Il cavallo che hanno inseguito i leoni
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“The horse that the lions chased” **ORC**
- (4) Il cavallo che hanno inseguito i leoni
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Processing Asymmetry (De Vincenzi 1991, Arosio et al. 2018, a.o.)

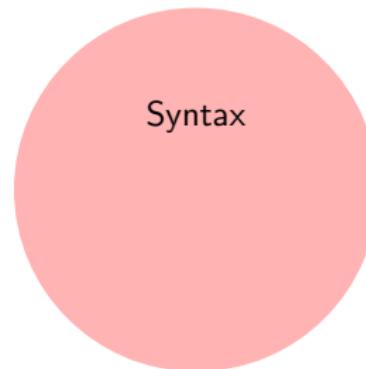
SRC > ORC > ORCp

One Big Questions

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

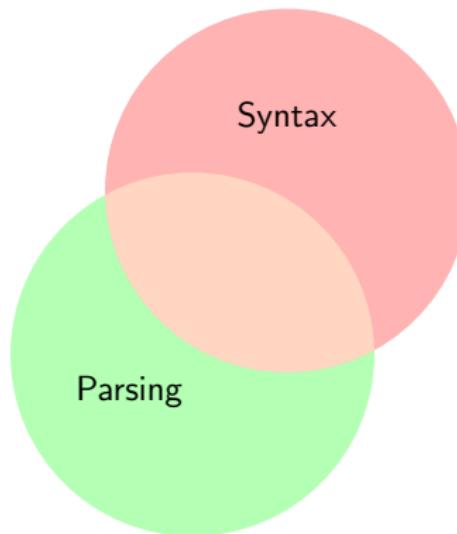
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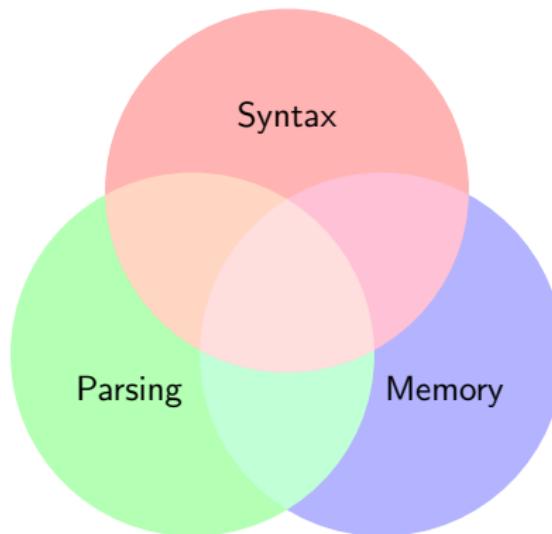
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One Big Questions

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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?

Forward to the Past

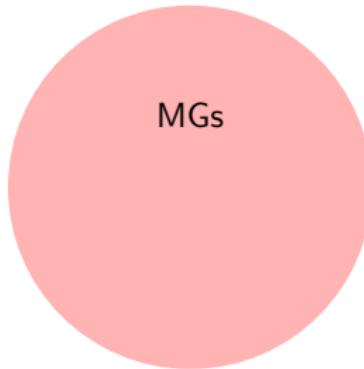
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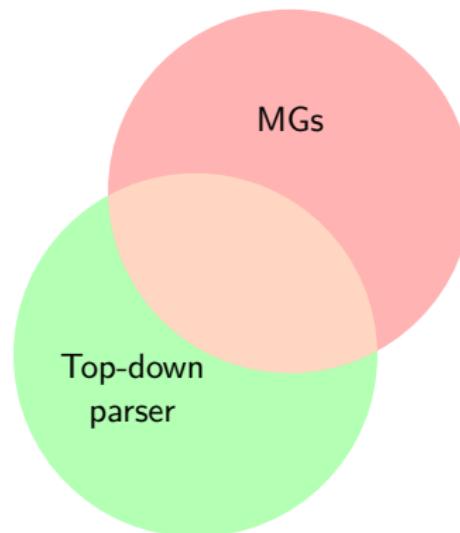
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A Formal Model of Sentence Processing



- 1 An explicit syntactic theory → Minimalist grammars (MGs)

A Formal Model of Sentence Processing



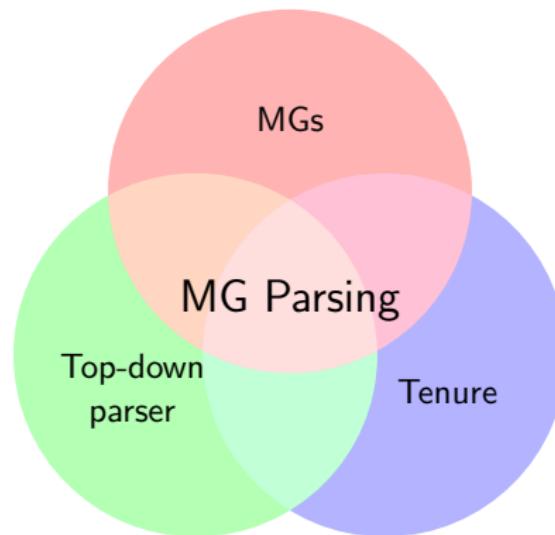
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- 2 A theory of how structures are built → top-down parser

A Formal Model of Sentence Processing



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A Formal Model of Sentence Processing



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If you want to understand it, you can understand it!

Processing Asymmetries All the Way Down

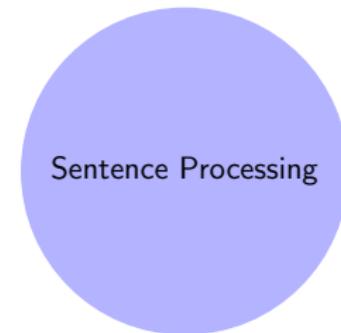
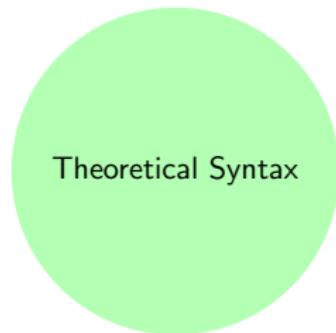
Not Just Italian:

- ▶ English, German, ...
- ▶ Korean, Japanese, ...
- ▶ Mandarin Chinese
- ▶ Persian
- ▶

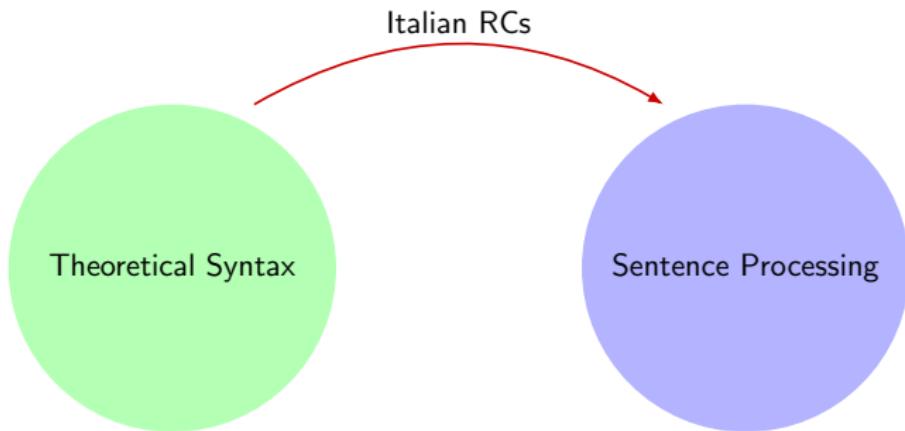
Not Just RCs:

- ▶ Right > center embedding
- ▶ Crossing > nested dependencies
- ▶ SC-RC > RC-SC
- ▶ Attachment ambiguities
- ▶ ...

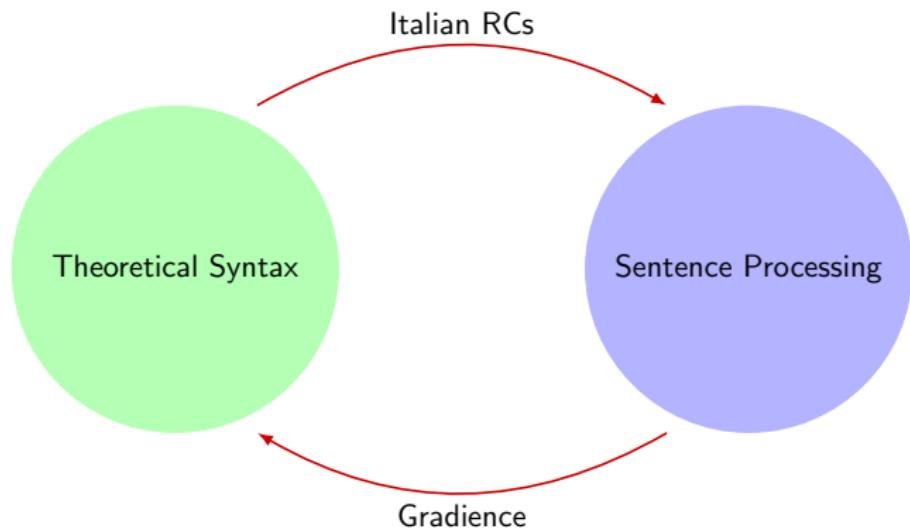
Building Bridges



Building Bridges



Building Bridges



Outline

- 1** Parsing Minimalist Grammars
- 2** Case Study: Italian Postverbal Subjects
- 3** Case Study: Gradience in Island Effects (in English)
- 4** Conclusion

Minimalist Grammars (MGs)

We need an explicit model of syntactic structures...



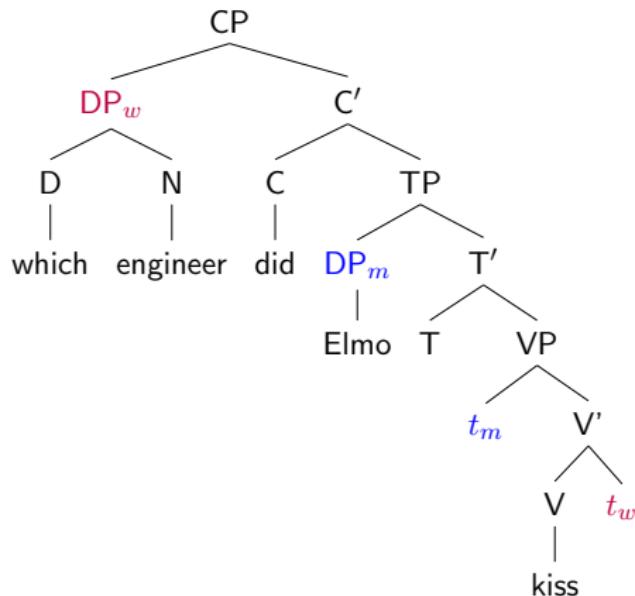
Ed Stabler

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

Technical details!

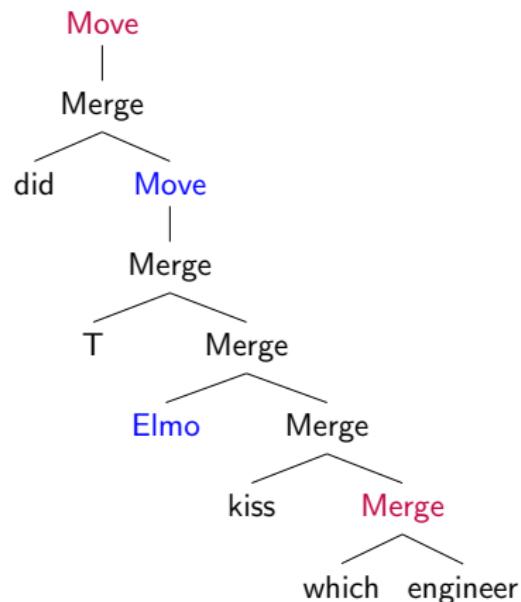
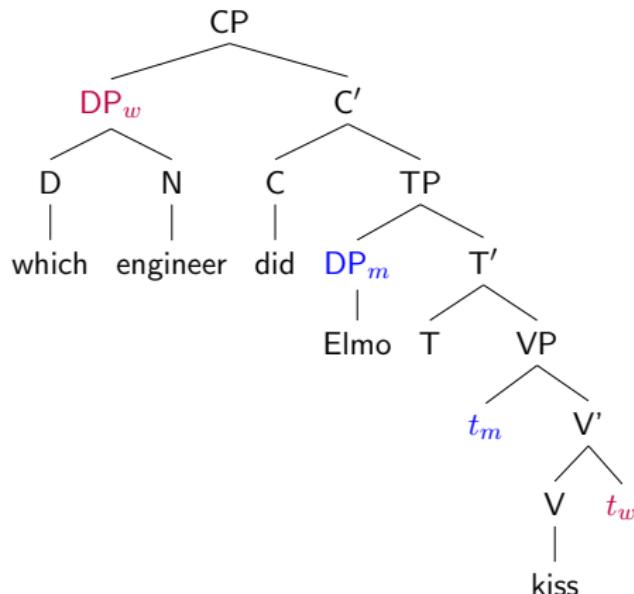
- ▶ Weakly equivalent to MCFGs
- ▶ Essentially: CFGs with a more complicated mapping from trees to strings

MG Syntax: Derivation Trees



Phrase Structure Tree

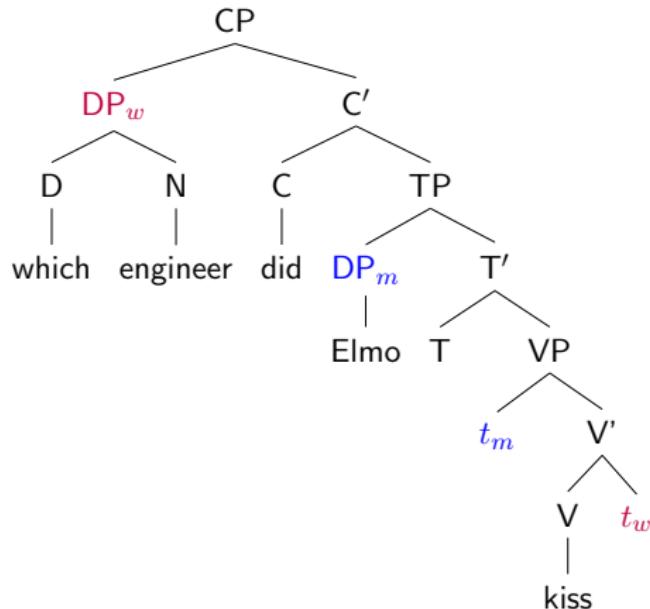
MG Syntax: Derivation Trees



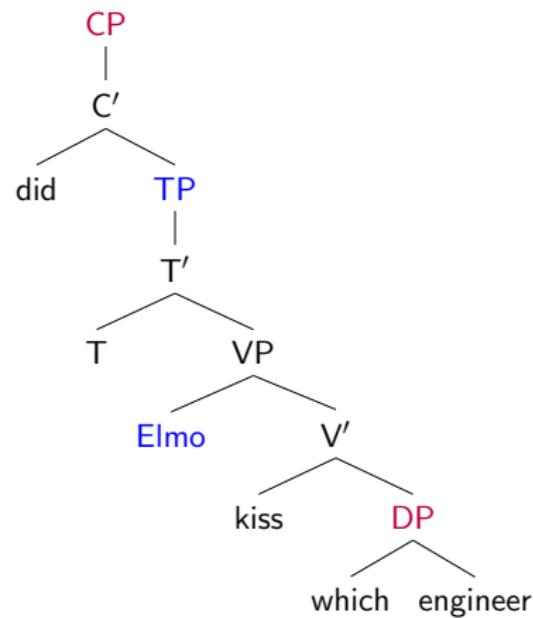
Phrase Structure Tree

Derivation Tree

MG Syntax: Derivation Trees



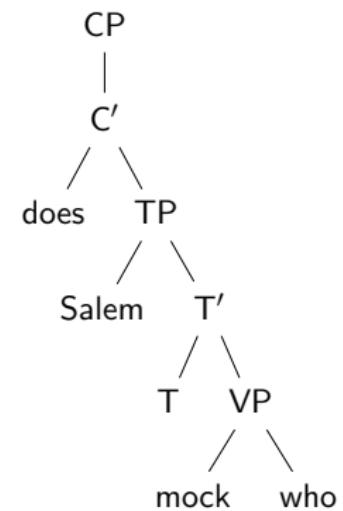
Phrase Structure Tree



Derivation Tree

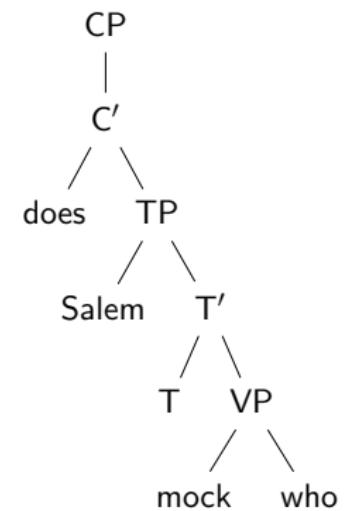
The Job of a Parser

Who does Salem mock?



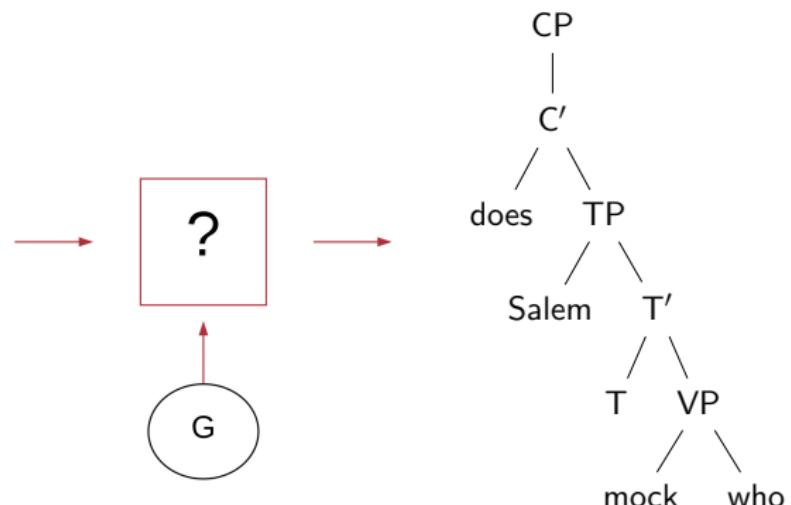
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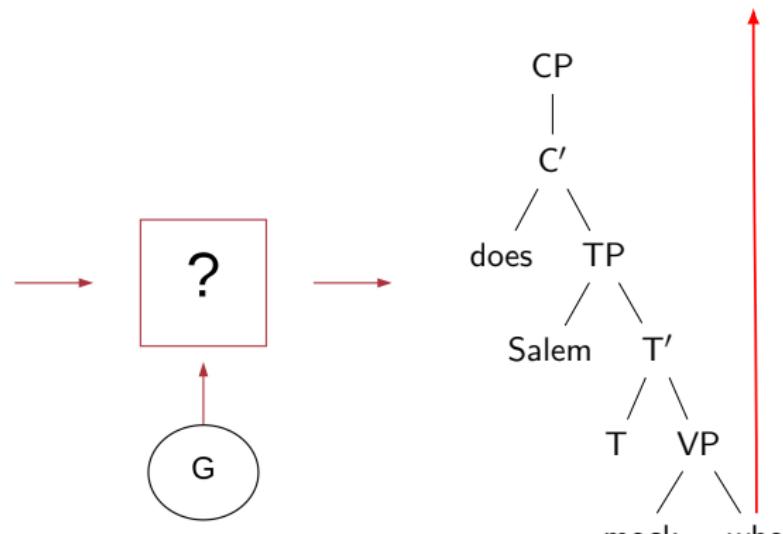
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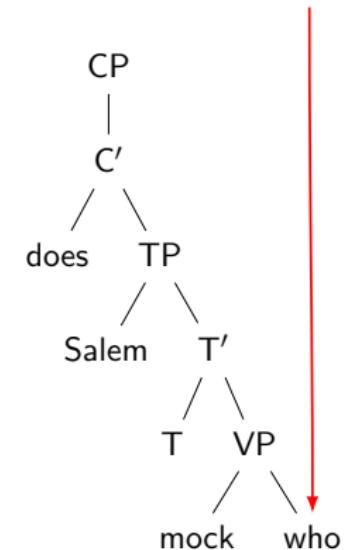
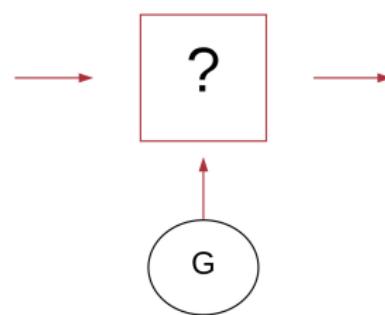
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► Bottom-up

The Job of a Parser

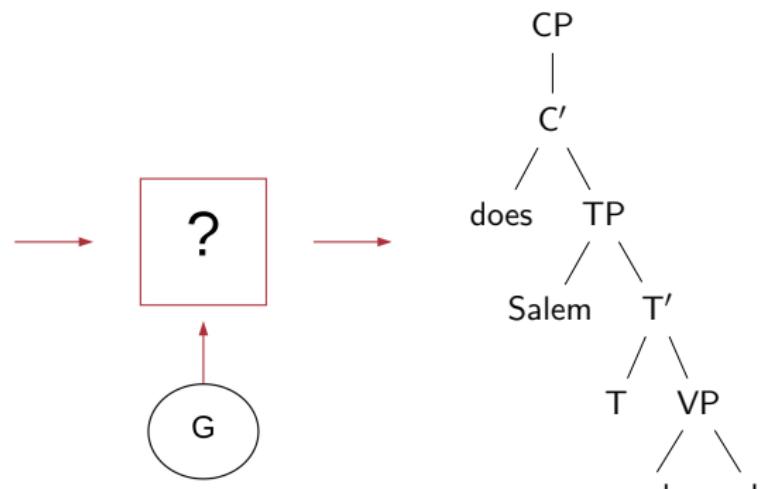
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- ▶ Bottom-up
- ▶ Top-down

The Job of a Parser

Who does Salem mock?



- ▶ Bottom-up
- ▶ Top-down
 - ▶ Psychologically plausible
 - ▶ We can build bottom-up grammars top-down!

Top-Down Parsing: The Intuition

Who does Salem mock?

Top-Down Parsing: The Intuition

CP

Who does Salem mock?



- ▶ Builds the structure from top to bottom
- ▶ Takes elements in and out of memory
- ▶ Complexity of the structure \approx how much memory is used!

Top-Down Parsing: The Intuition

CP
|
C'

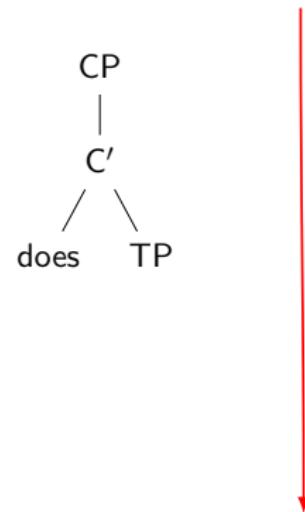


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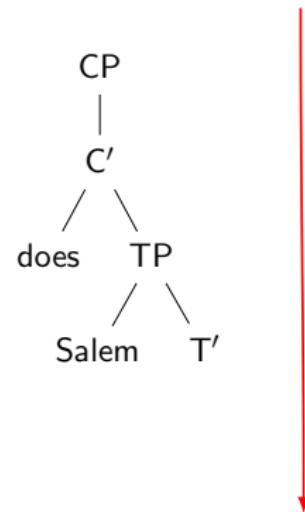
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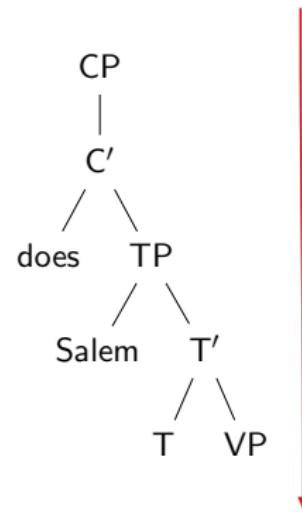
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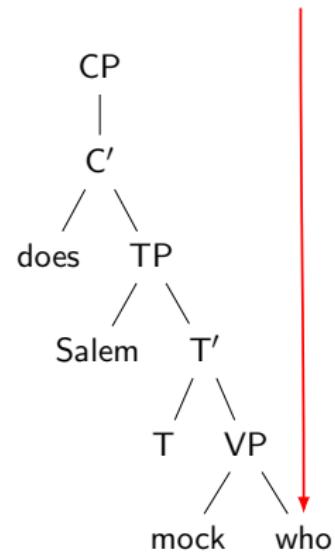
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Incremental Top-Down Parsing

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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1CP

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1CP_2

|

$^2C'$

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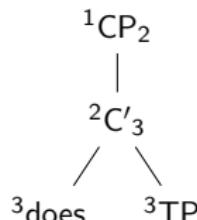
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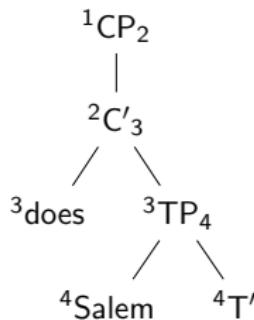
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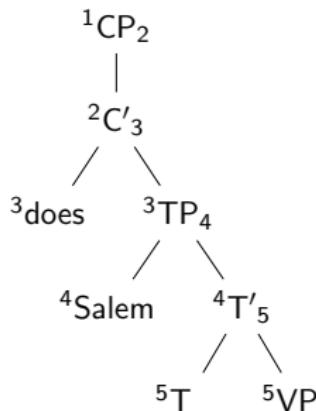
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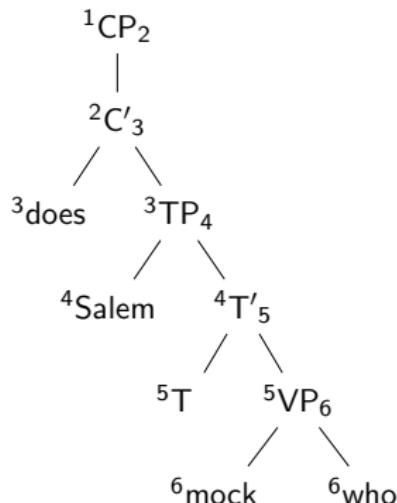
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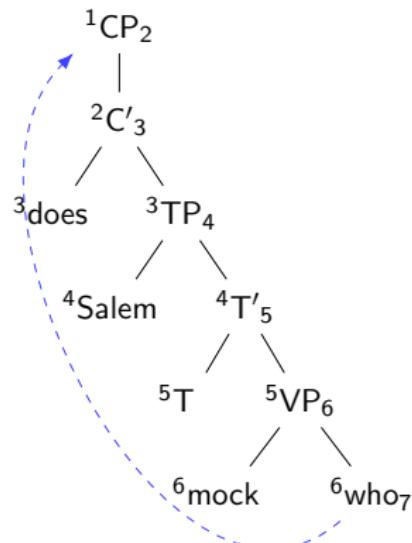
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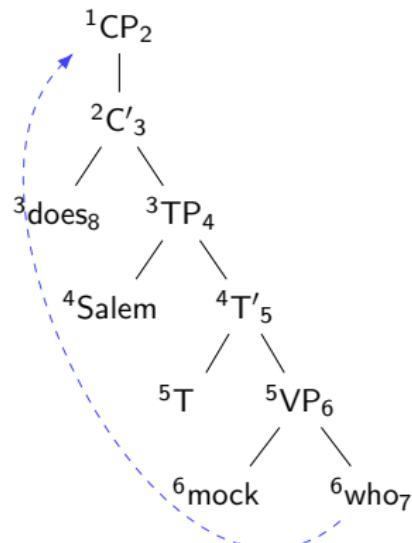
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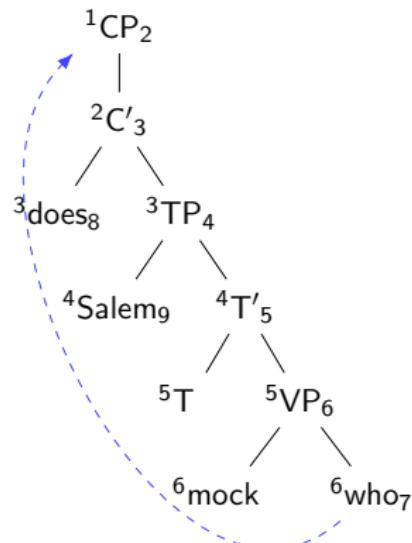
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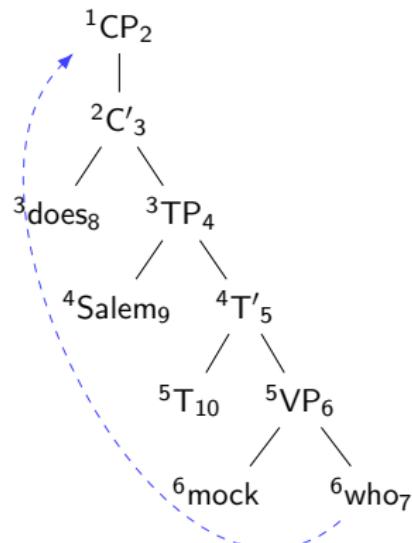
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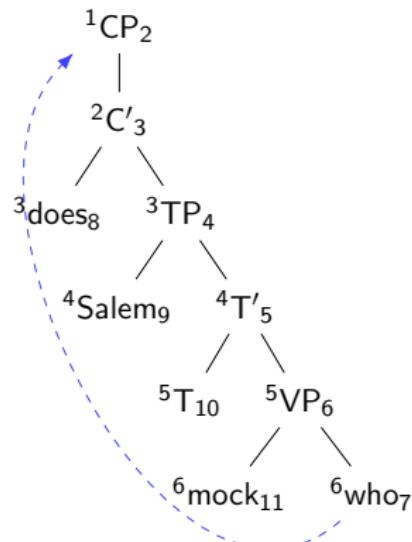
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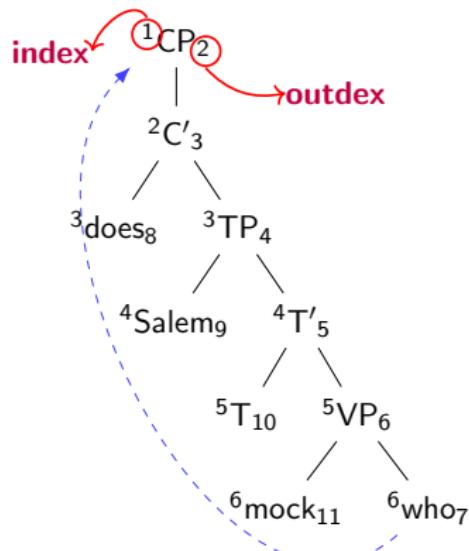
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- ▶ String-driven recursive descent parser (Stabler 2013)

- ▶ ● 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



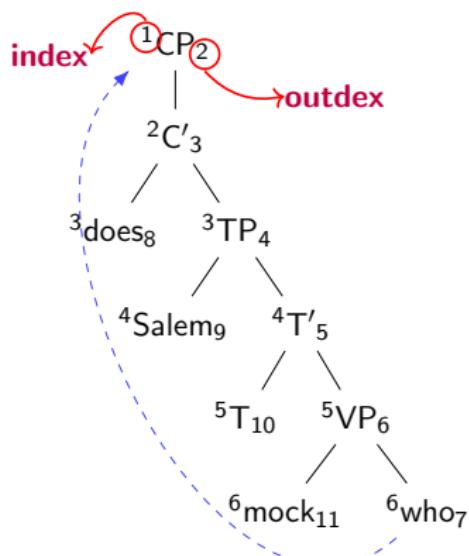
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Index and Outdex are our connection to memory!

Memory-Based Complexity Metrics

- ▶ **Memory usage** (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 $\sum_{m \in M} \text{size}(m)$

Ranked $\langle \text{MaxTenure}, \text{SumSize} \rangle$



Greg Kobele



Sabrina Gerth



John Hale

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Empirical Coverage!

<MAXT,SUMS> makes correct predictions cross-linguistically!

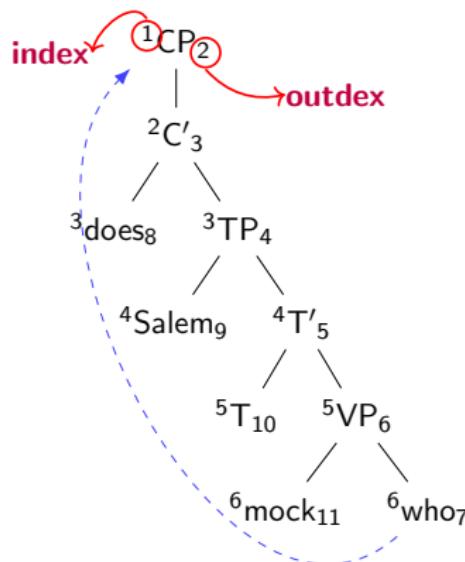
Across Many Constructions

- ▶ Right > center embedding (Kobele et al. 2012)
- ▶ Crossing > nested dependencies (Kobele et al. 2012)
- ▶ SC-RC > RC-SC (Graf & Marcinek 2014)
- ▶ SRC > ORC (Graf et al. 2017)
- ▶ Postverbal subjects in Italian (De Santo 2019)
- ▶ Persian attachment ambiguities (De Santo & Shafiei 2019)
- ▶ Gradient acceptability (De Santo 2020)

Across Languages

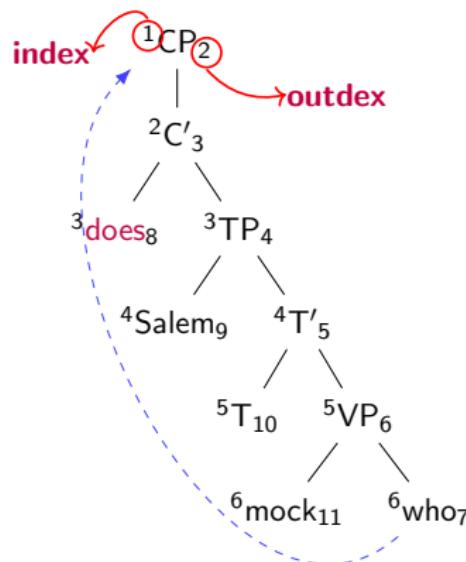
- ▶ English, German, Italian
- ▶ Korean, Japanese
- ▶ Mandarin Chinese
- ▶ Persian

Computing Metrics: An Example



Tenure how long a node is kept in memory

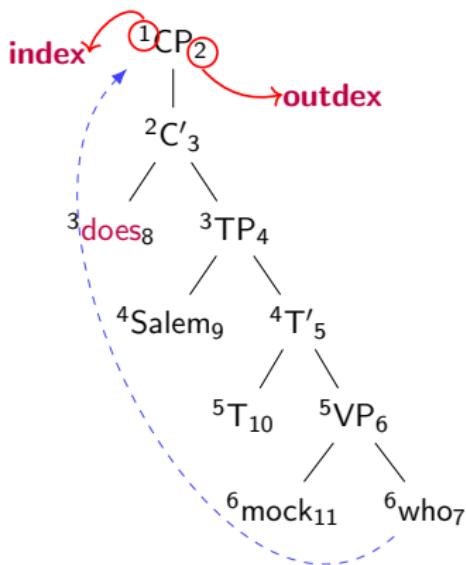
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$$\text{Tenure}(does) = 8 - 3 = 5$$

Computing Metrics: An Example



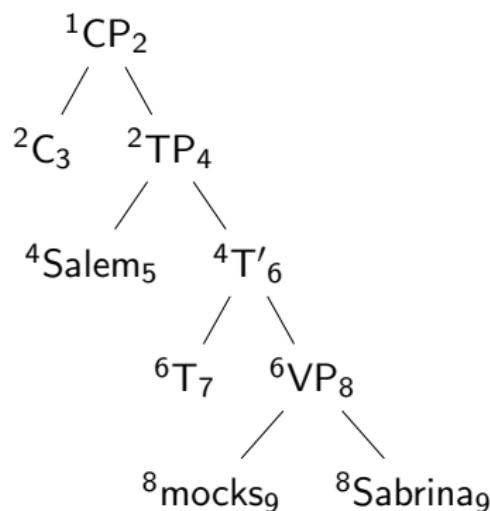
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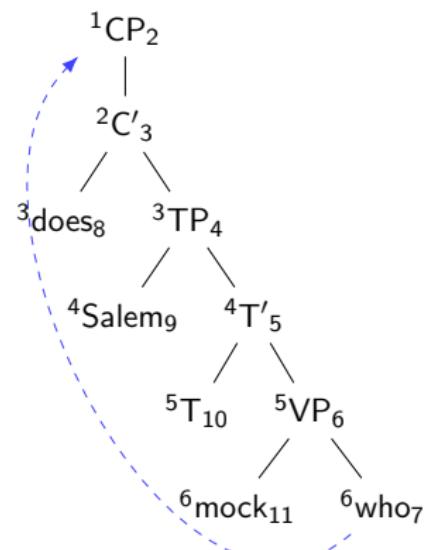
$$\text{MaxTenure} = \max\{\text{Tenure}(does), \text{Tenure}(Salem), \dots\} = 5$$

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 in processing. The scripts integrate well with a LaTeX-centric workflow, following the ideal of OpenScience 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)

- 1 Pick two competing derivations
- 2 Evaluate metrics over each
 - ▶ Lowest score means easiest!
- 3 Compare parser's prediction to experimental data

Remember!

If you want to understand it, you can understand it!

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
⇒ Top-down parser
- ▶ Complexity Metrics
⇒ MaxTenure and SumSize

Degrees of freedom: Syntactic analyses

- 1 RC constructions → (Kayne 1994)
- 2 Postverbal subjects → (Belletti & Leonini 2004)

Modeling Assumptions

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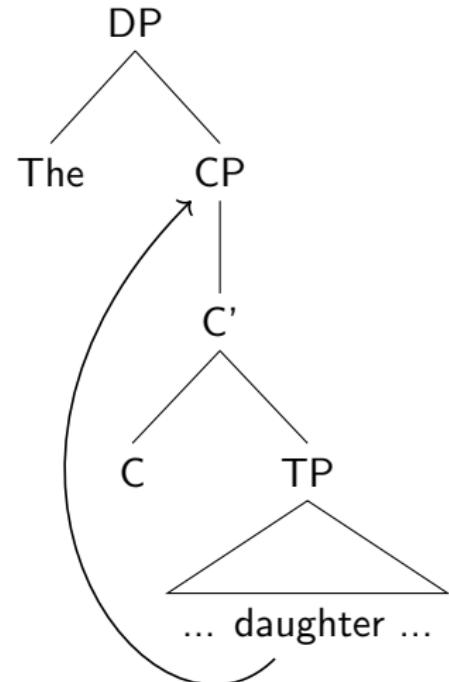
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Kayne's Promotion Analysis (Kayne 1994)

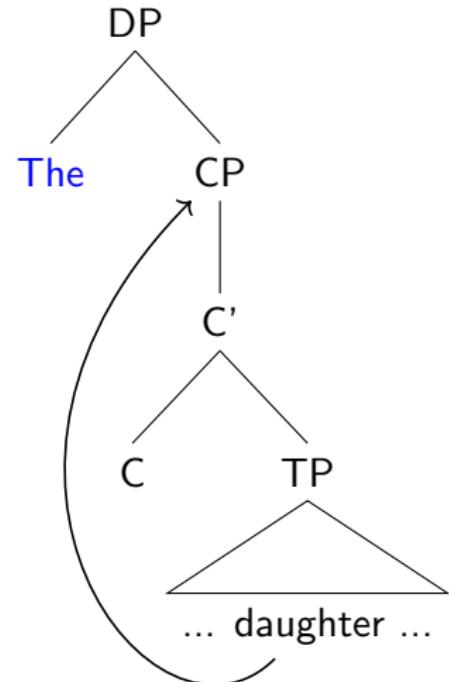
- ▶ RC is selected by an external D^0
- ▶ the RC head is a nominal constituent
- ▶ the RC head raises from its base position to [Spec, CP]



$[_{DP} \text{The} [_{CP} \text{daughter}_i [\text{that } t_i \text{ was on the balcony}]]]$

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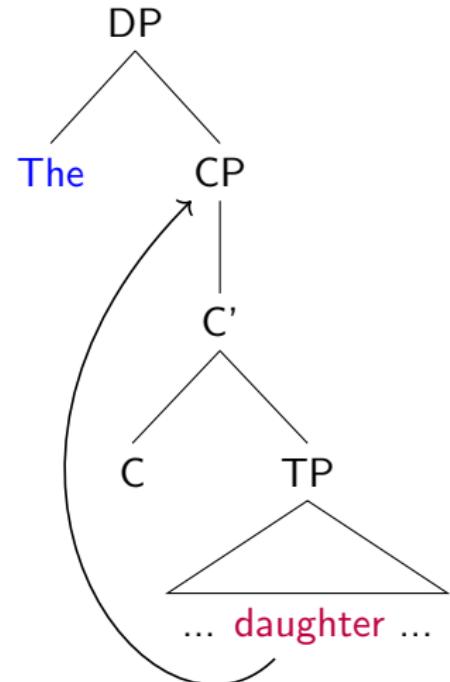
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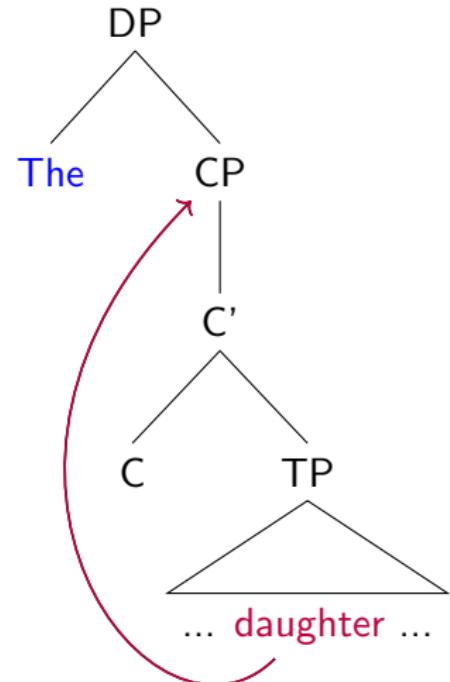
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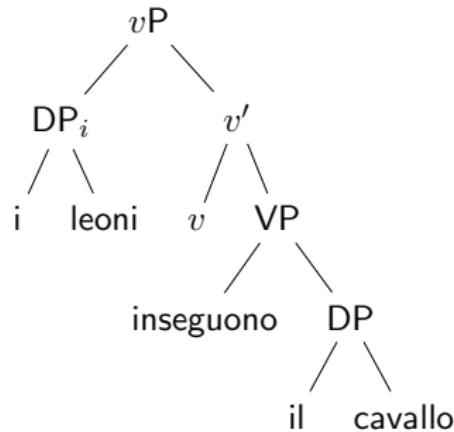
Postverbal Subjects (Belletti & Leonini 2004)

- (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



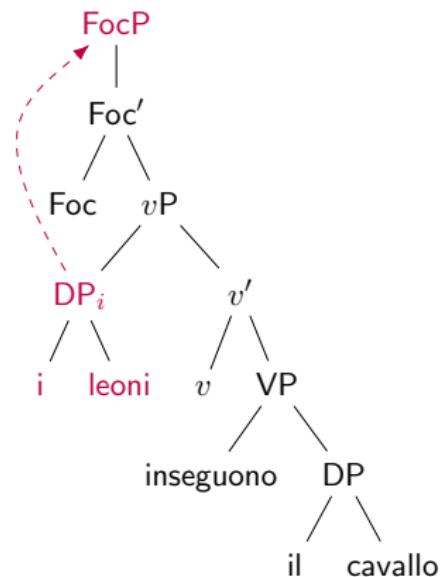
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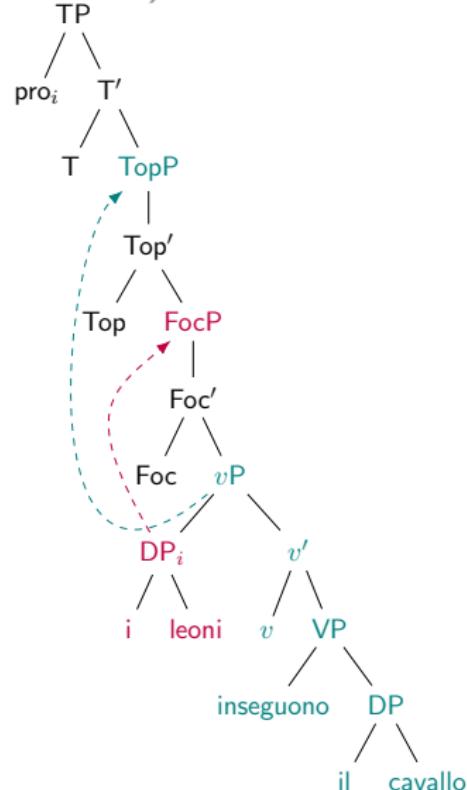
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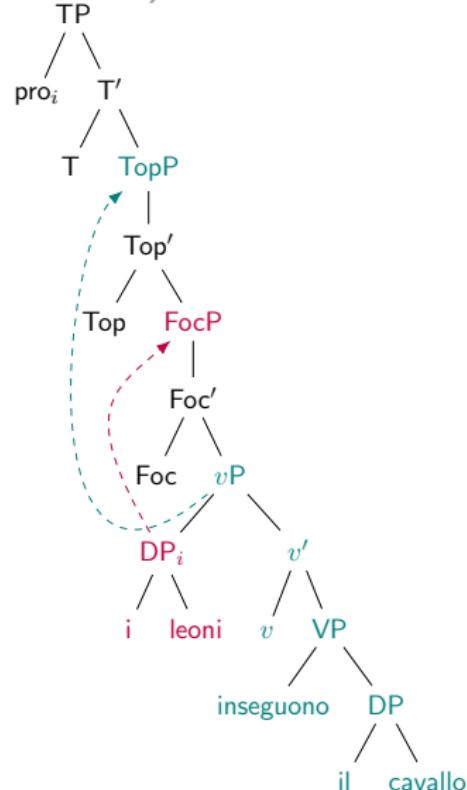
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Modeling Results

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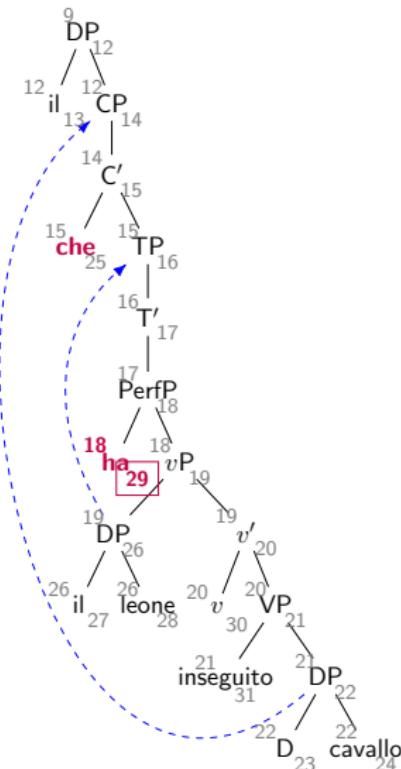
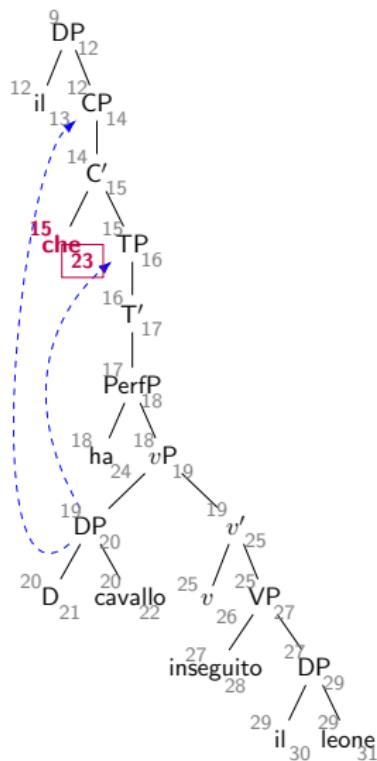
	SRC	>	ORC	>	ORCp
MaxTenure	8/che		11/ha		16/Foc
SumSize	18		24		31

Modeling Results

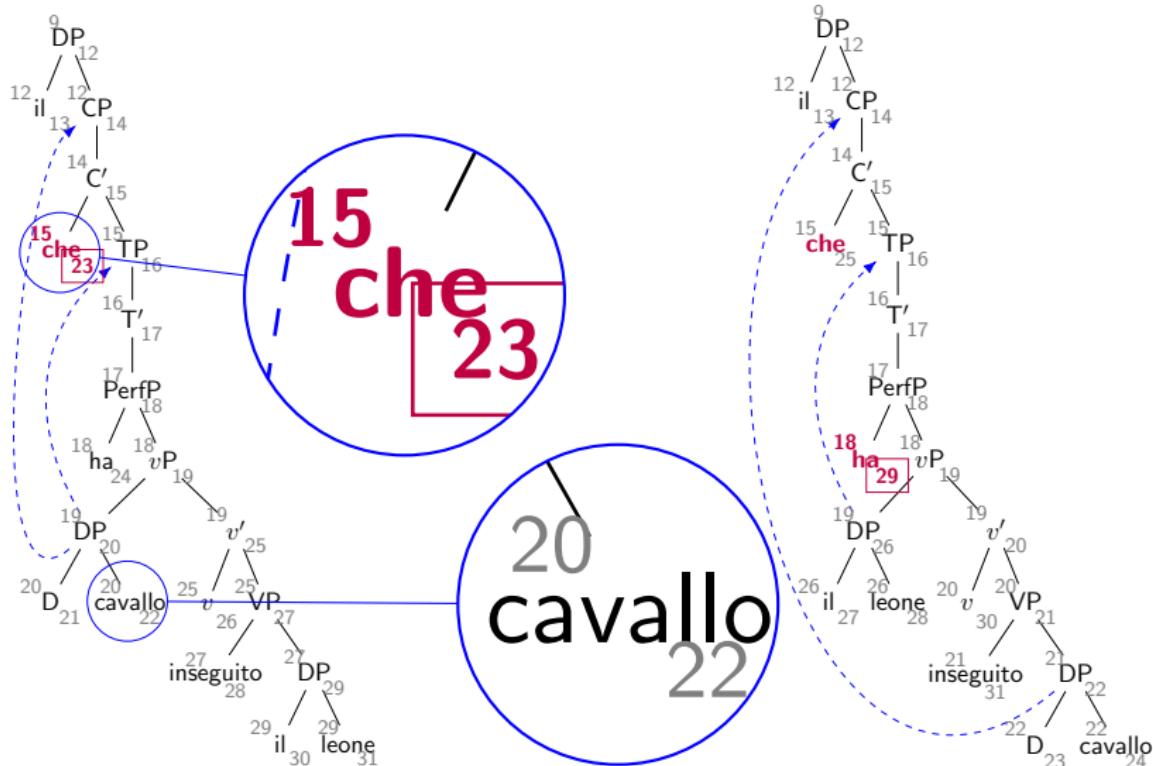
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MaxTenure	8/che		11/ha		16/Foc	✓
SumSize	18		24		31	✓

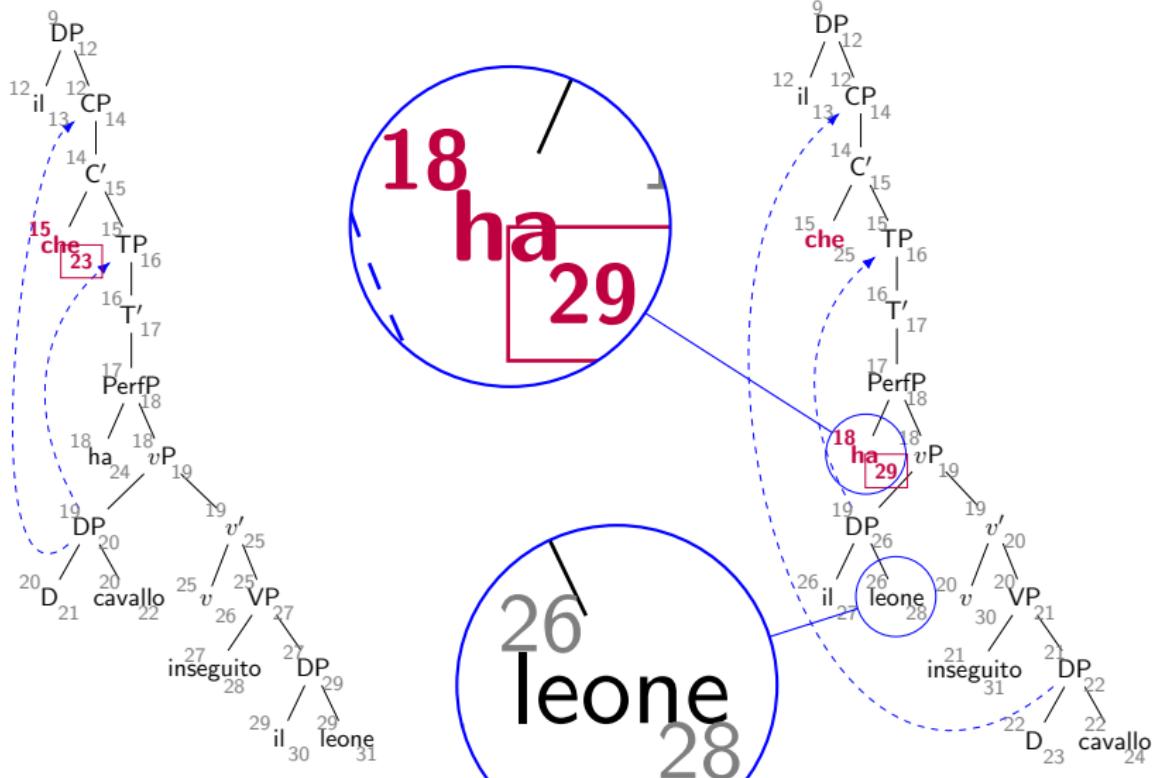
Results: SRC > ORC



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Results: SRC > ORC



Summary of Results (De Santo 2019)

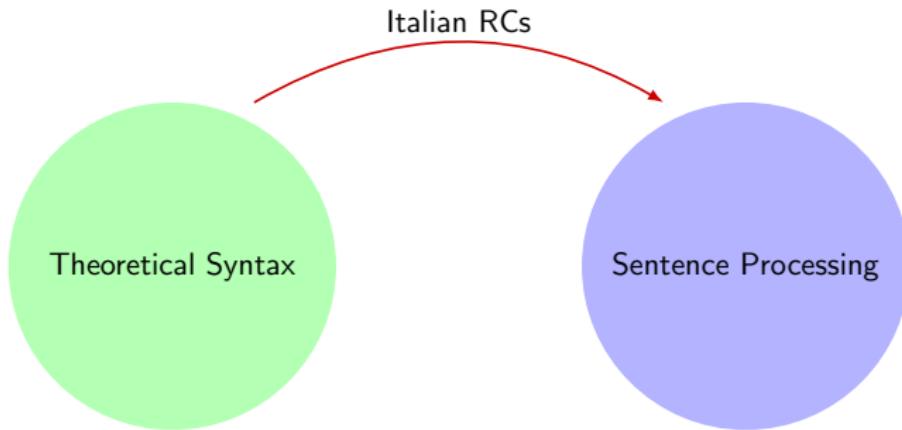
Clause Type	<MaxTenure,SumSize>
obj. SRC > ORC	✓
obj. SRC > ORCp	✓
obj. ORC > ORCp	✓
subj. SRC > ORC	✓
subj. SRC > ORCp	✓
subj. ORC > ORCp	✓
matrix SVO > VOS	✓
VS unacc > VS unerg	✓

Table: Predictions of the MG parser by contrast.

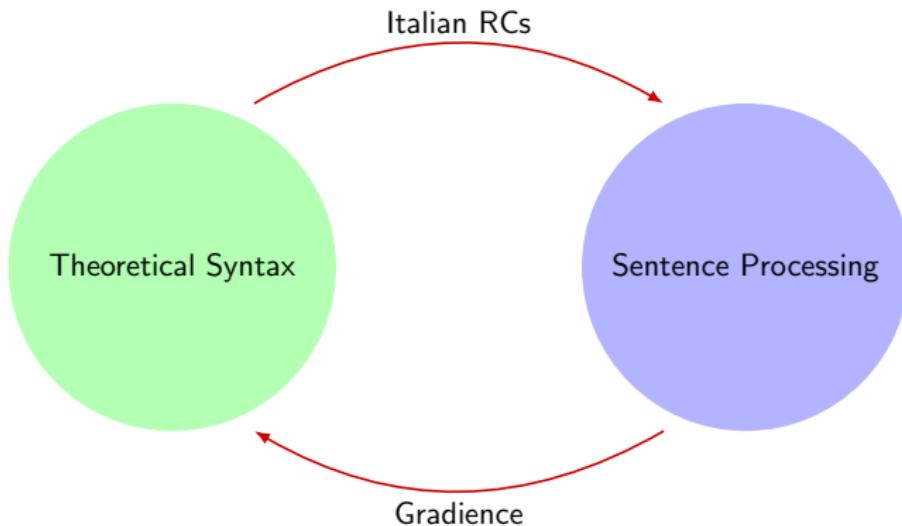
Interim Summary

- ▶ Asymmetries in Italian postverbal subject constructions
 - ▶ Derived just from **(fine-grained) structural differences!**
 - ▶ **Ongoing:** expand range of syntactic analyses;
 - ▶ **Ongoing:** cross-linguistic comparisons.
- ▶ $\langle \text{MAXT}, \text{SUMS} \rangle$ gives consistent results!
 - ▶ Right vs. center embedding, attachment ambiguities, relative clause preferences
 - ▶ English, German, Korean, Japanese, Persian, Mandarin Chinese
 - ▶ More?

Moving on



Moving on



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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One way to test the adequacy of a grammar proposed for [language] L is to determine whether or not the sequences that it generates are actually grammatical, i.e., acceptable to a native speaker.

(Chomsky 1957)

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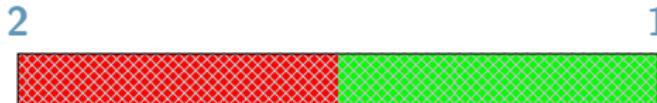
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Acceptability judgments ≈ Grammaticality judgments

Gradience in Acceptability Judgments

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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.

(Chomsky 1975: 131-132)

But mainstream syntactic theories rely on categorical grammars!

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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
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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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Modeling Gradience with an MG Parser

The model is the same as before

- 1 A formal model of syntax → Minimalist grammars (MGs)
- 2 A theory of how structures are built → MG parser
- 3 A linking theory: higher memory cost ⇒ lower acceptability

- ▶ Sensitive to fine-grained structural differences!
- ▶ Minimal, pairwise comparisons are maximally interpretable!

A proof-of-concept:

- ▶ Variation of Island effects in English (Sprouse et al. 2012)

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)



Jon Sprouse

Results in pairwise comparisons ideal for the MG parser

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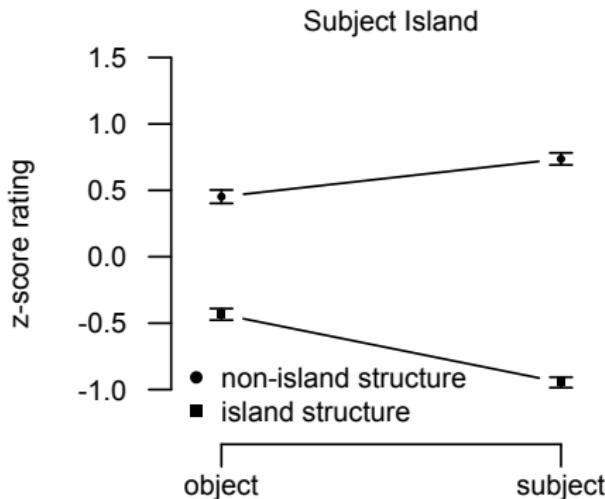
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Results in pairwise comparisons ideal for the MG parser

Deriving Pairwise Comparisons



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

Sprouse et 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

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GAP POSITION × STRUCTURE

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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.	✓
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	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.	✓

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.	✓

TL;DR

Success in all
cases but one!

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	Clause Type	MaxT	SumS
Subj. — Non Isl.	> Obj. — Non Isl.	✓	Obj./Non Island	14/do	19
Subj. — Non Isl.	> Obj. — Isl.	✓	Subj./Non Island	11/do	14
Subj. — Non Isl.	> Subj. — Isl.	✓	Obj./Island	23/T2	22
Obj. — Non Isl.	> Obj. — Isl.	✓	Subj./Island	15/do	20
Obj. — Non Isl.	> Subj. — Isl.	✓			
Obj. — Isl.	> Subj. — Isl.	✗			

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Obj. — Non Isl.	> Obj. — Isl.	✓	Subj./Island	15/do	20
Obj. — Non Isl.	> Subj. — Isl.	✓			
Obj. — Isl.	> Subj. — Isl.	✗			

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

Spouse 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/ <i>C</i>	9
Emb. — Non Isl.	11/ <i>do</i>	14
Matrix — Isl.	11/ <i>T_{RC}</i>	9
Emb. — Isl.	17/ <i>T_{RC}</i>	20

Summary

Gradience from a categorical MG grammar?

- ▶ The **first** (quantitative) model of this kind!
- ▶ Overall, a success! ⇒ **just** from structural differences!
- ▶ Outlier is expected assuming grammaticalized constraints.

The tip of the iceberg!

- ▶ Modulate range of dependencies
- ▶ Other examples of gradience
- ▶ Cognitive vs. grammatical constraints? (Ferrara-Boston 2012)
- ▶ Probing industrial-level language models
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From the Trees (back) to the Forest



- ▶ Fully specified parsing model allows for precise predictions
- ▶ Tight connection with current generative syntax
- ▶ Successful on a variety of cross-linguistic constructions
- ▶ + insights about the structure of the grammar

Not Just Theoretical Insights!

- ▶ The human parser outperforms our fastest parsers

From the Trees (back) to the Forest

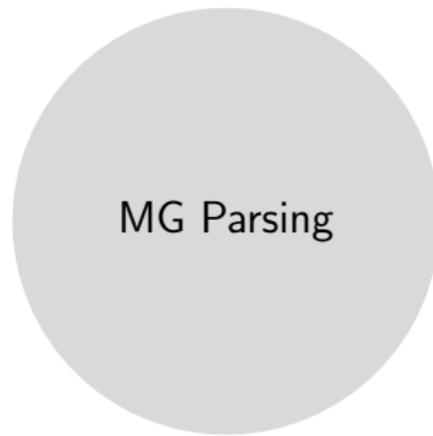


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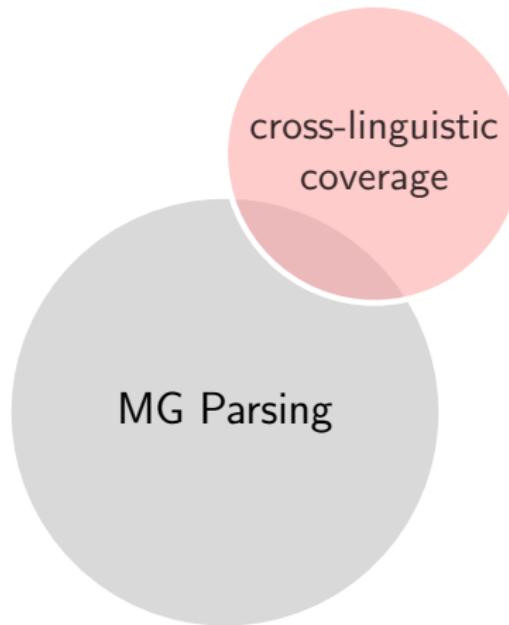
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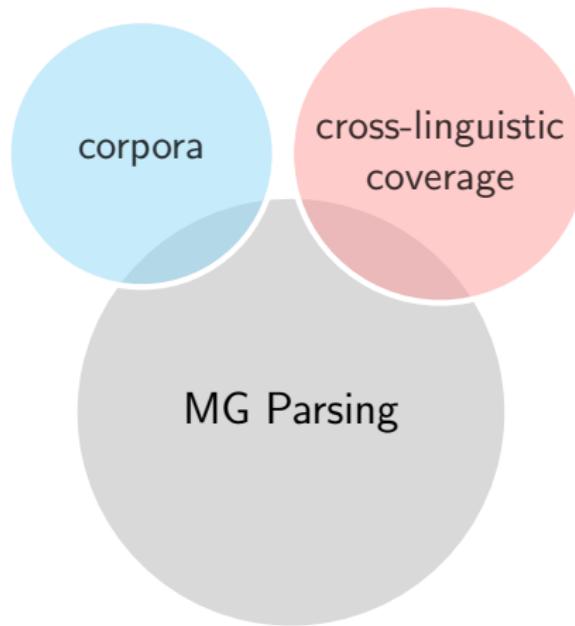
Looking Ahead: A Collaborative Enterprise



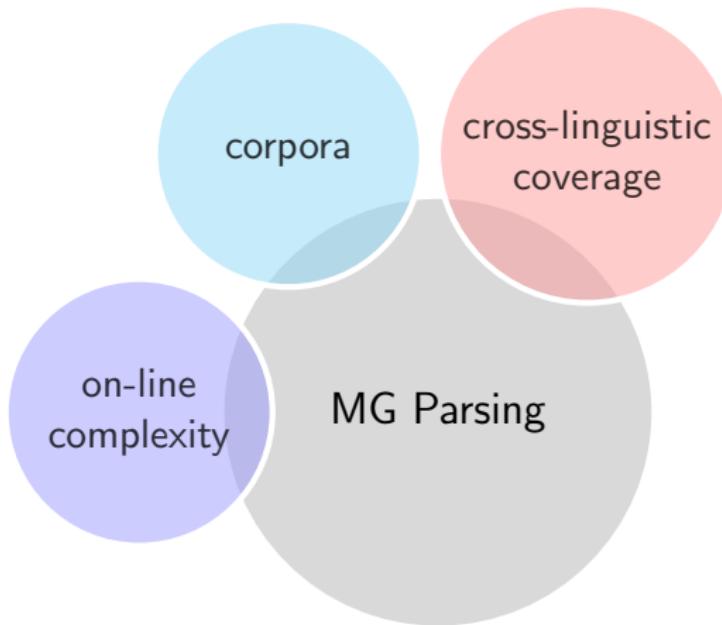
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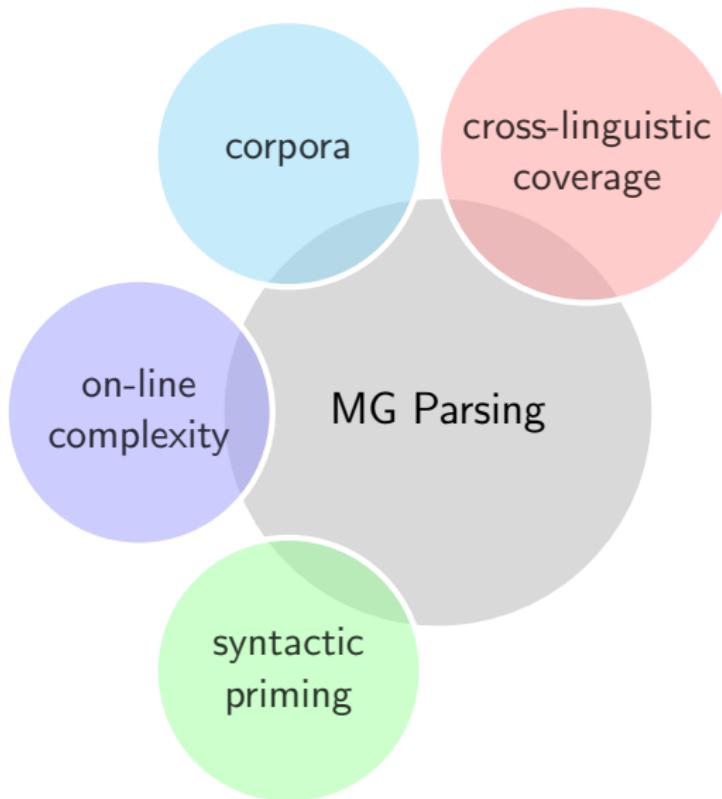
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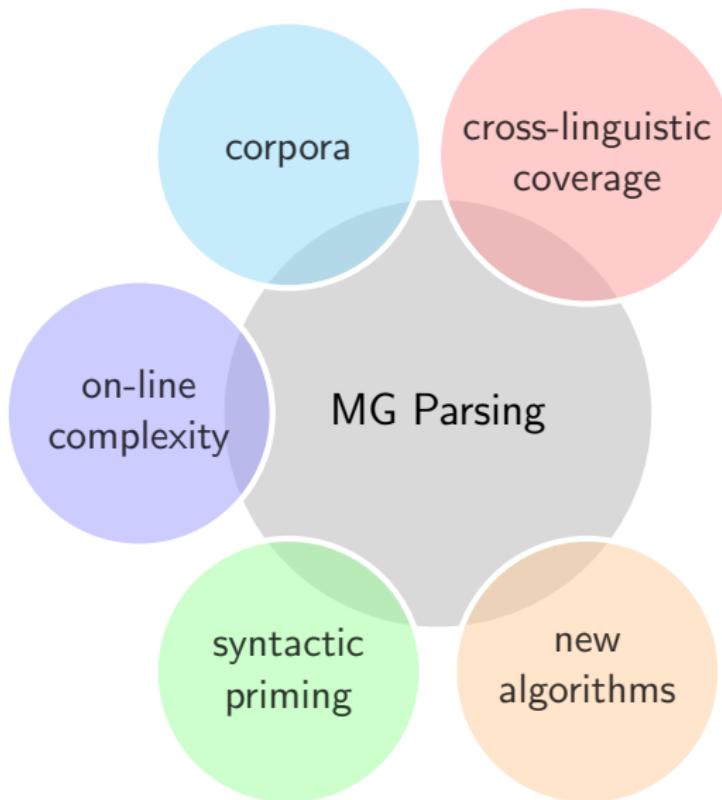
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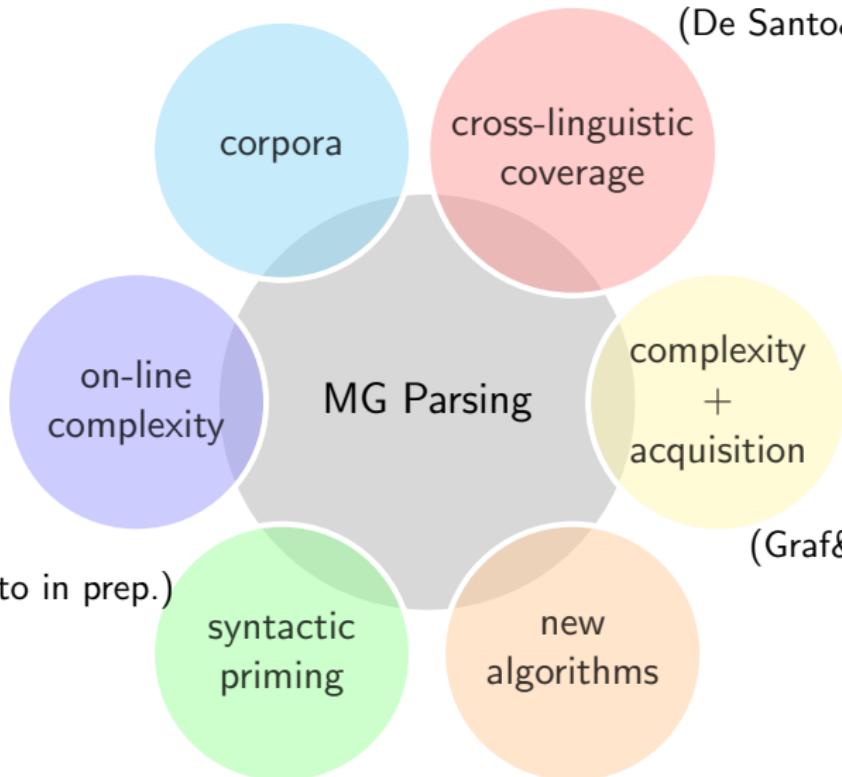


Looking Ahead: A Collaborative Enterprise



Looking Ahead: A Collaborative Enterprise

(De Santo&Shafiei 2019)



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

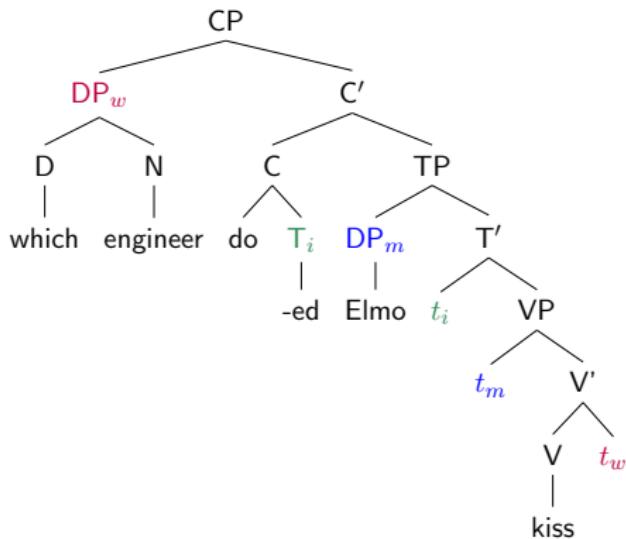
3 Simple parsing algorithms

- ▶ Variant of a recursive descent parser for CFGs
⇒ cf. TAG (Rambow & Joshi, 1995; Demberg, 2008)

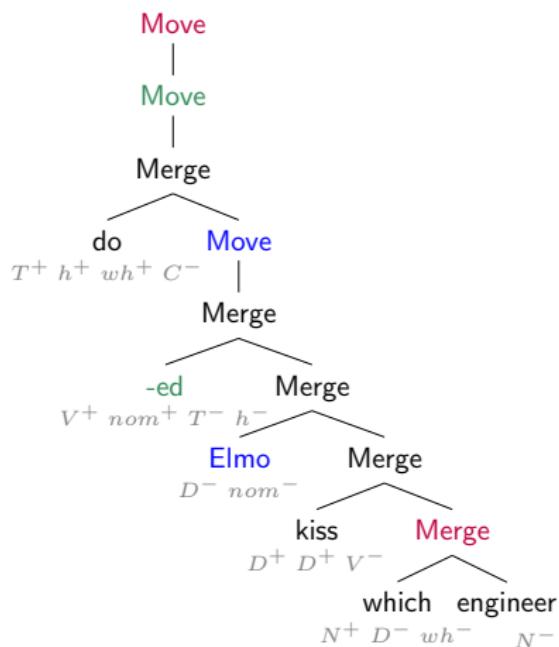
Some Important Properties of MGs

- ▶ 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:

- ▶ sideways movement (Stabler, 2006; Graf 2013)
- ▶ affix hopping (Graf 2012; Graf 2013)
- ▶ 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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Italian Subjects: Probing the Results

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

- ▶ 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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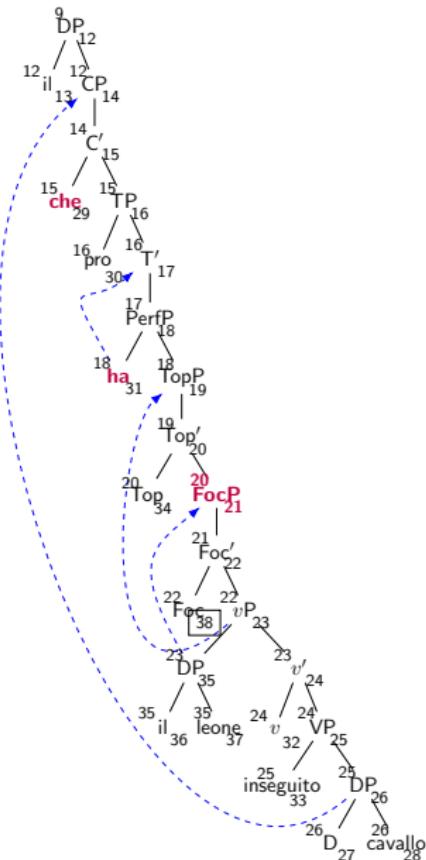
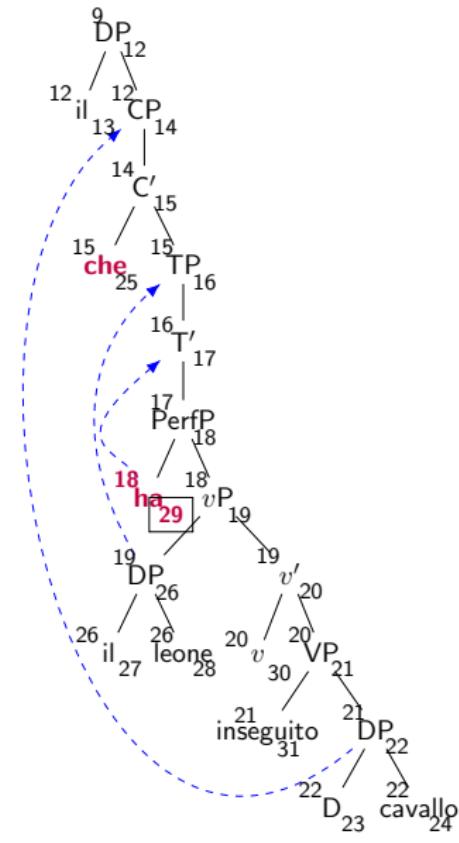
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Can we give a purely structural account?

Results: ORC > ORCp



Additional Constructions

► Ambiguity in Matrix Clauses

- (7) Ha chiamato Gio

Has called Giovanni

a. “He/she/it called Gio”

SVO

b. “Gio called”

VS

► Unaccusatives vs. Unergatives

- (8) È arrivato Gio

Is arrived Gio

“Gio arrived”

Unaccusative

- (9) Ha corso Gio

Has ran Gio

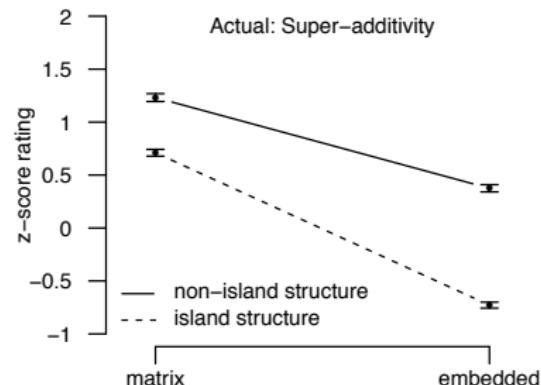
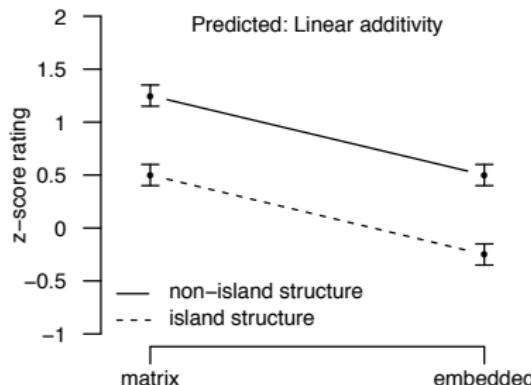
“Gio ran”

Unergative

Gradience in Islands

A factorial design for islands effect:

► GAP POSITION × STRUCTURE



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?
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Subject Islands

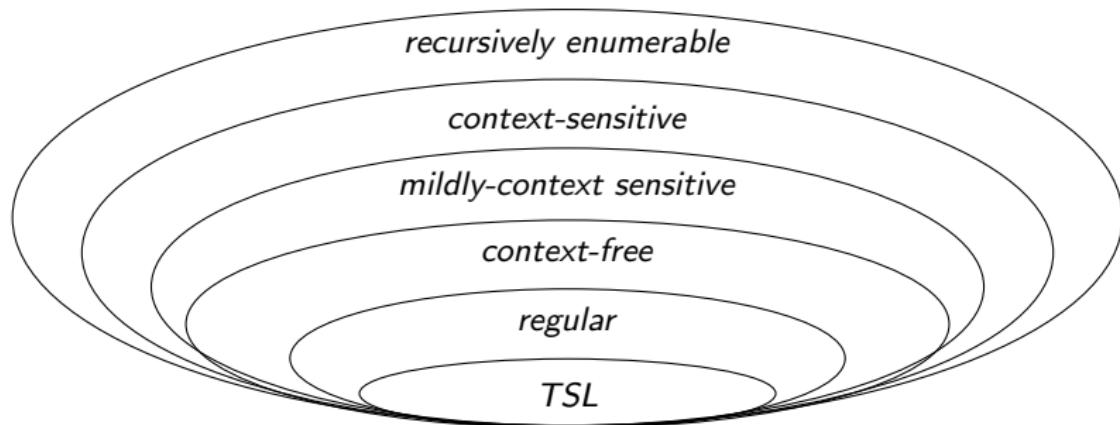
Case 1:

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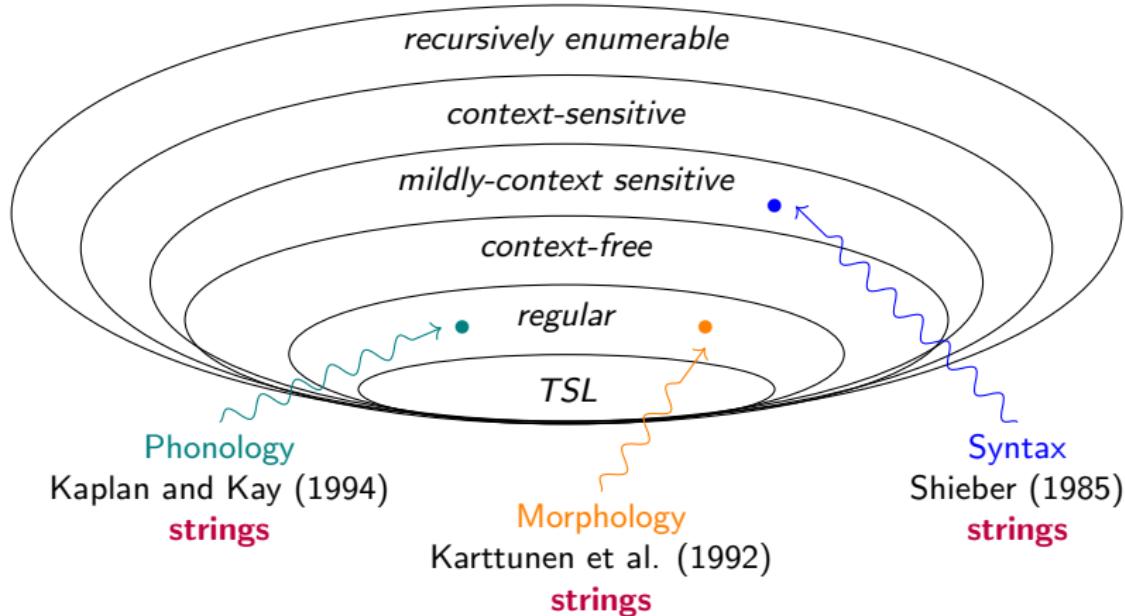
Case 2:

- (11) 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
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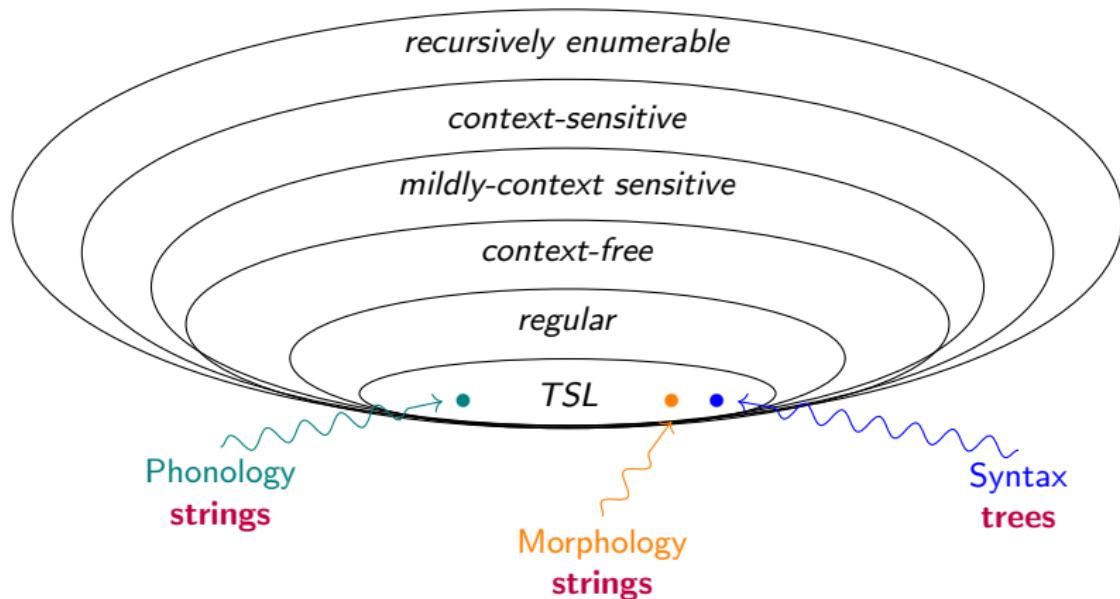
Subregular Complexity



Subregular Complexity



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:

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- ▶ learnability
- ▶ cognition

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 - Finite, flat memory