



Minimalist Parsing as a Psycholinguistic Model

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CompLang
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Let's Start with Data!

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"

ORC_p

SRC > ORC_p

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The horse that has chased the lion

a. “The horse that chased the lion”

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b. “The horse that **the lion** chased”

ORC_p

SRC > ORC_p

Agreement can disambiguate:

(4) Il cavallo che hanno inseguito i leoni

The horse that have chased the lions

“The horse that the lions chased”

ORC_p

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

Forward to the Past

The relation between grammatical operations and cognitive processes?

A realistic grammar should [...] contribute to the explanation of linguistic behavior and to our larger understanding of the human faculty of language.

(Bresnan 1978: pg. 58)

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

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One Big Question

Which aspects of grammar influence sentence processing?

One Big Question

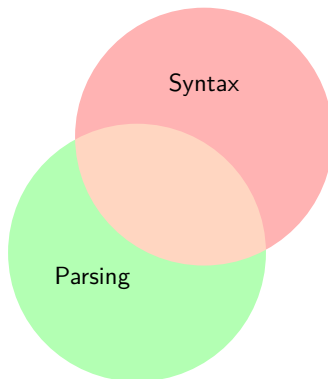
Which aspects of grammar influence sentence processing?



Syntax

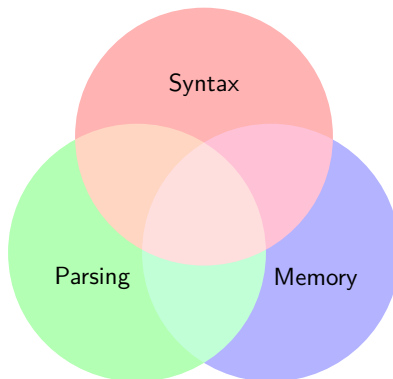
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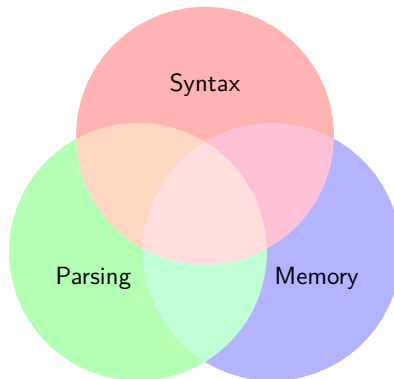


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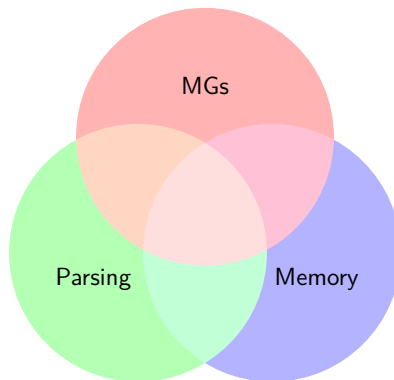
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A Formal Model of Sentence Processing

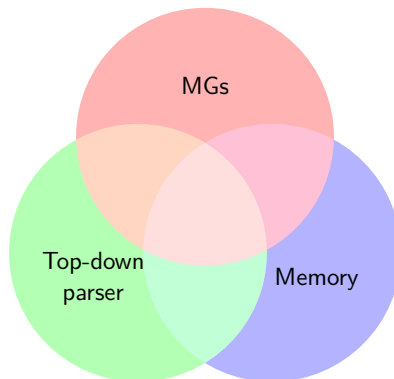


A Formal Model of Sentence Processing



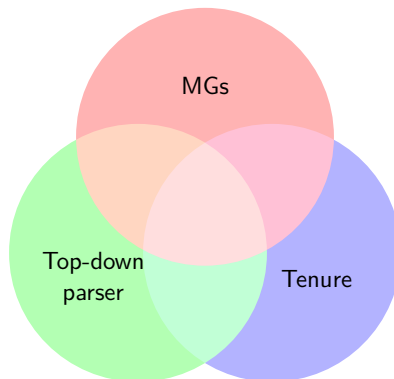
- 1 An explicit syntactic theory → Minimalist grammars (MGs)

A Formal Model of Sentence Processing



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

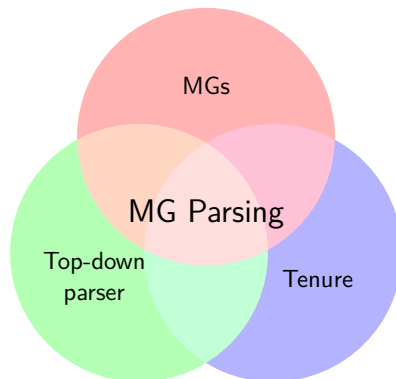
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- 3 A psychologically grounded linking theory → tenure

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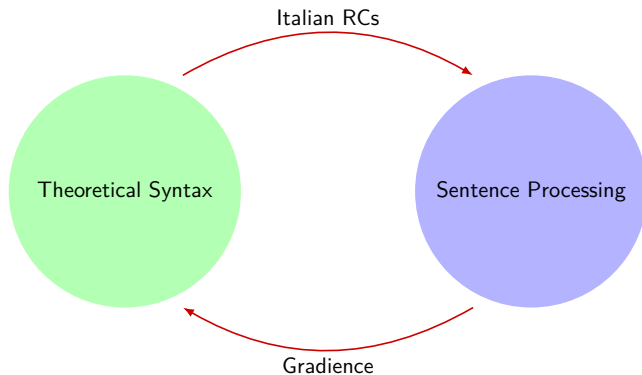
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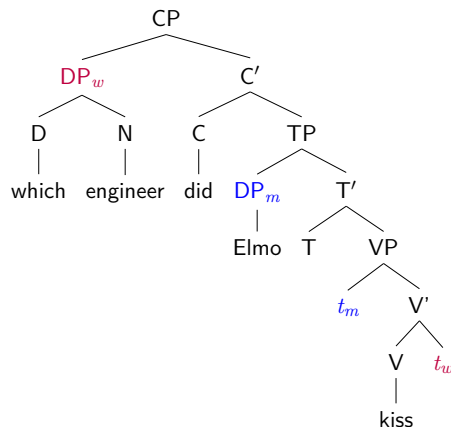
Building Bridges



Outline

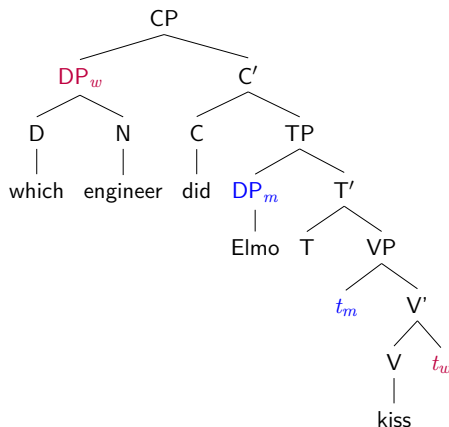
- 1 Parsing Minimalist Grammars
- 2 Case Study: Italian Postverbal Subjects
- 3 Case Study: Gradience in Island Effects (in English)
- 4 Conclusion

Minimalist Grammars (MGs) & Derivation Trees

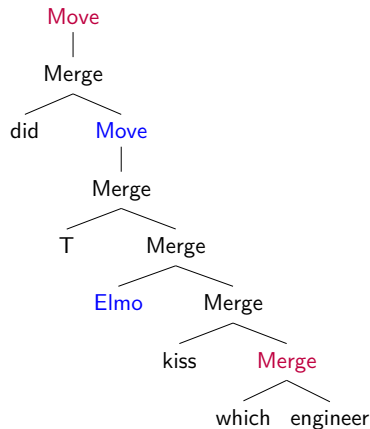


Phrase Structure Tree

Minimalist Grammars (MGs) & Derivation Trees

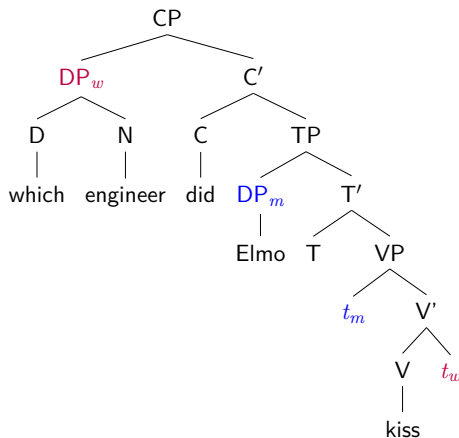


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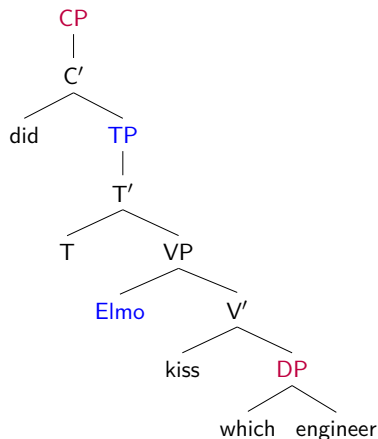


Derivation Tree

MG Syntax: Derivation Trees



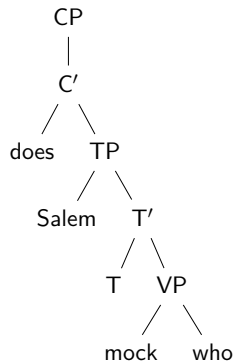
Phrase Structure Tree



Derivation Tree

The Job of a Parser

Who does Salem mock?

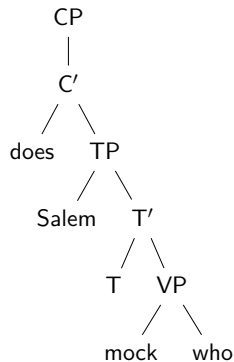


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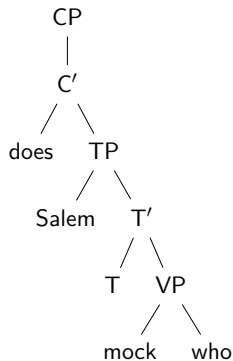
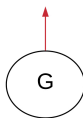


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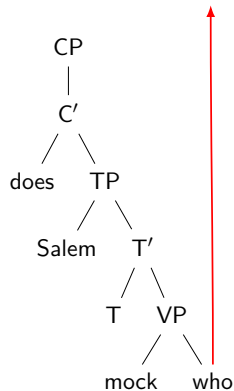
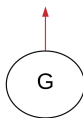
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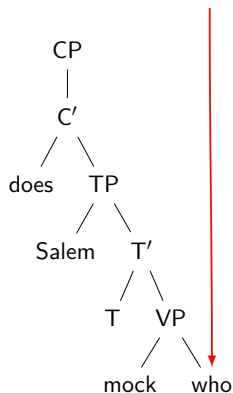
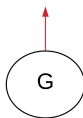
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► Bottom-up

The Job of a Parser

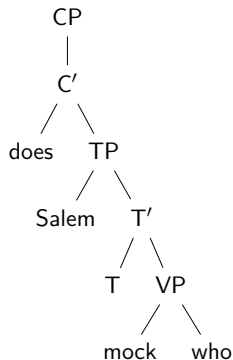
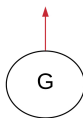
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- ▶ Bottom-up
- ▶ Top-down

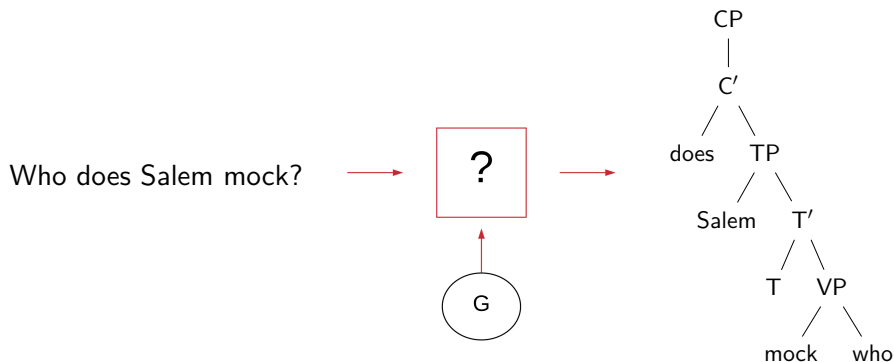
The Job of a Parser

Who does Salem mock?



- ▶ Bottom-up
- ▶ Top-down
 - ▶ Psychologically plausible(-ish)

The Job of a Parser



- ▶ Bottom-up
- ▶ Top-down
 - ▶ Psychologically plausible(-ish)
 - ▶ Insight: We can build lexicalized grammars top-down!
 - ▶ Assumption: Parser as an oracle!

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 an out of memory
- ▶ Complexity of the structure \approx how much memory is used!

Top-Down Parsing: The Intuition

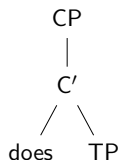
CP
|
C'

Who does Salem mock?

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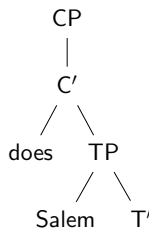
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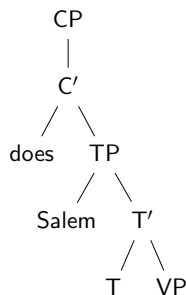
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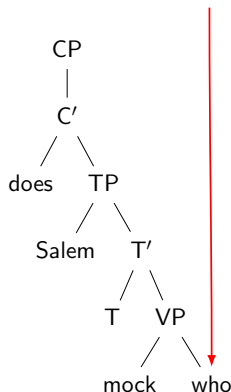
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Incremental Top-Down Parsing

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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$$\begin{array}{c} {}^1CP_2 \\ | \\ {}^2C' \end{array}$$

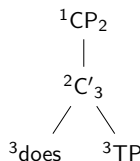
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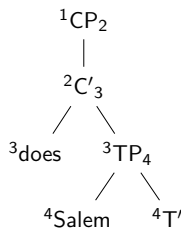
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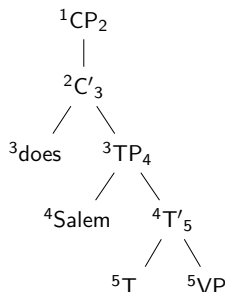
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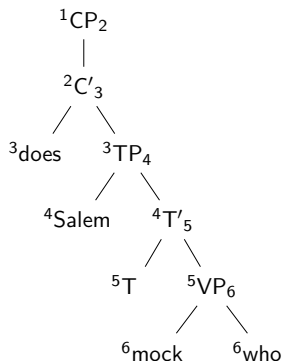
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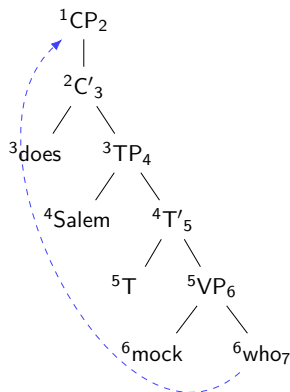
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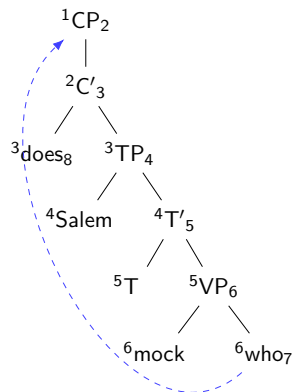
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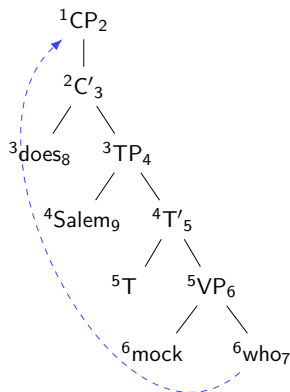
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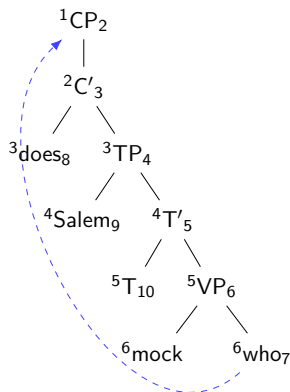
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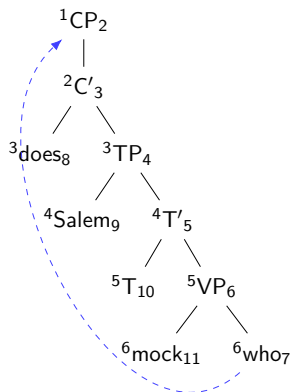
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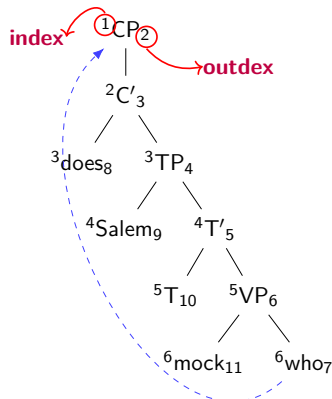
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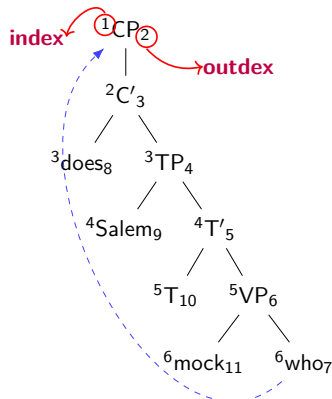
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Index and Outdex are our connection to memory!

Memory-Based Complexity Metrics

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

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!

- 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

Memory-Based Complexity Metrics

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

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!

- Formalized into **complexity metrics**

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Processing Asymmetries All the Way Down

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

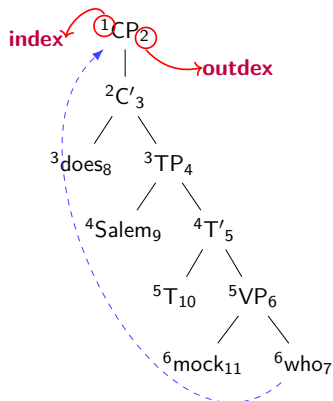
Across Many Constructions

- ▶ 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)
- ▶ RC attachment in Mandarin, Korean, Japanese (De Santo & Lee in prep.)

Across Languages

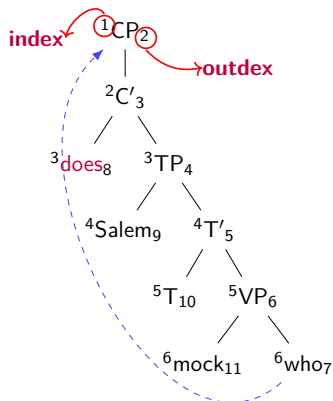
- ▶ English, German, Italian
- ▶ Korean, Japanese, Mandarin Chinese
- ▶ Persian, ...

Computing Metrics: An Example



Tenure how long a node is kept in memory

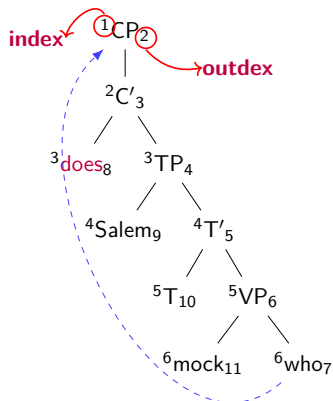
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$$\text{Tenure}(\text{does}) = 8 - 3 = 5$$

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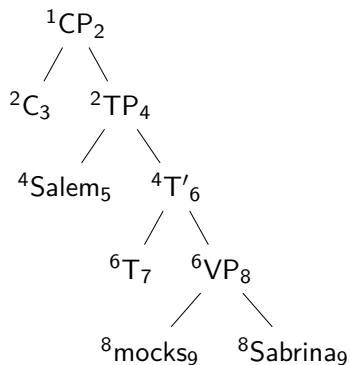
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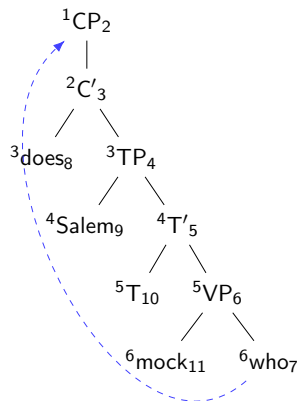
$$\mathbf{MaxTenure} = \max\{\mathbf{Tenure}(\text{does}), \mathbf{Tenure}(\text{Salem}), \dots\} = 5$$

Contrasting Derivations

MaxTenure = 2



MaxTenure = 5



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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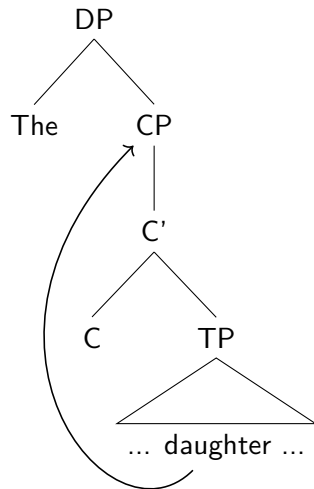
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Kayne's Promotion Analysis (Kayne 1994)

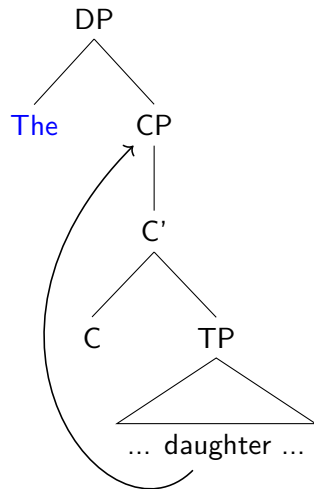
- ▶ RC is selected by an external D^0
- ▶ the RC head is a nominal constituent
- ▶ the RC head raises from its base position to [Spec, CP]



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

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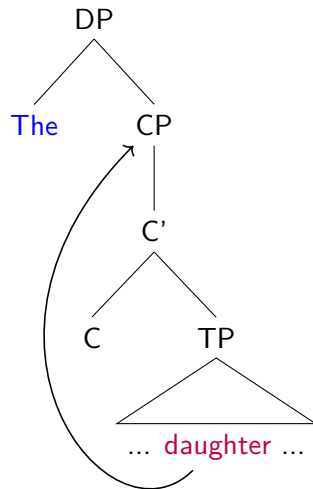
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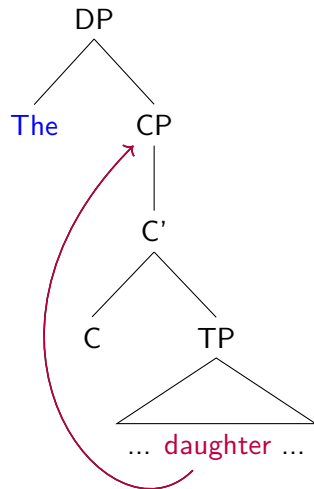
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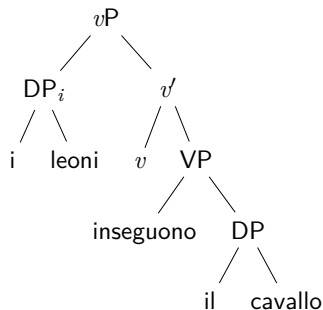


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Postverbal Subjects (Belletti & Leonini 2004)

- (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

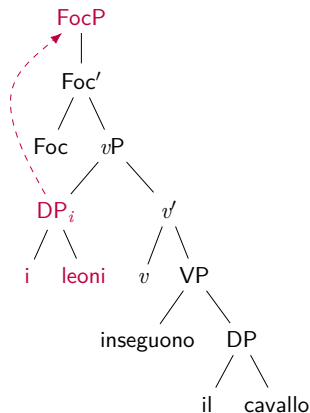
Postverbal Subjects (Belletti & Leonini 2004)

- (6) 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!

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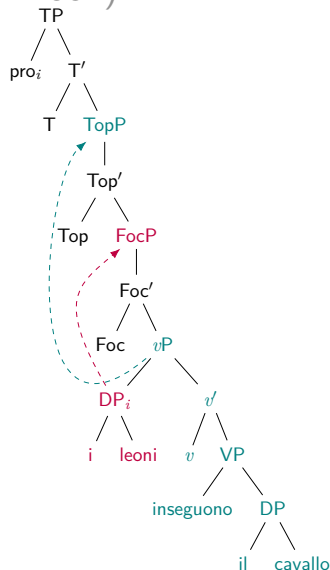
Postverbal Subjects (Belletti & Leonini 2004)

- (7) Inseguono il cavallo i leoni
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Technical details!

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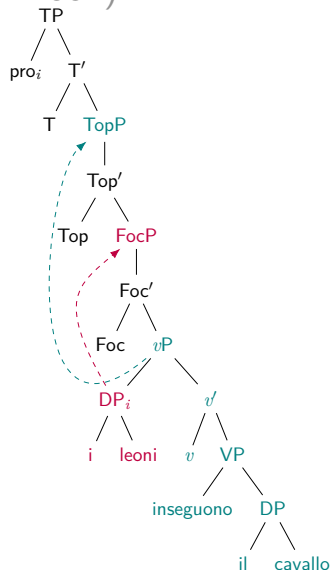
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Modeling Results

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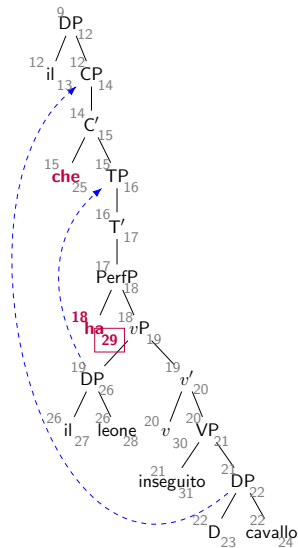
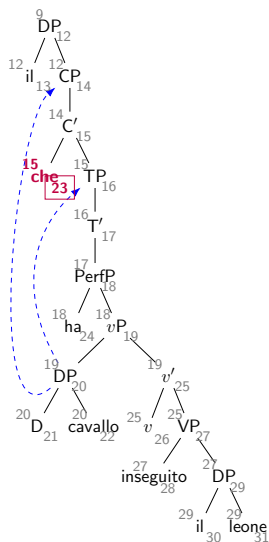
	SRC	>	ORC	>	ORCp
MaxTenure	8/che		11/ha		16/Foc
SumSize	18		24		31

Modeling Results

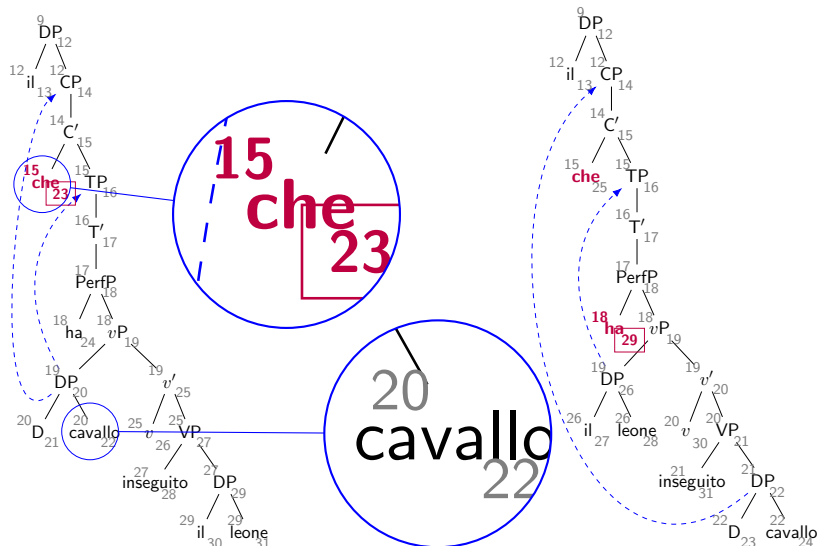
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	SRC	>	ORC	>	ORCp	
MaxTenure	8/che		11/ha		16/Foc	✓
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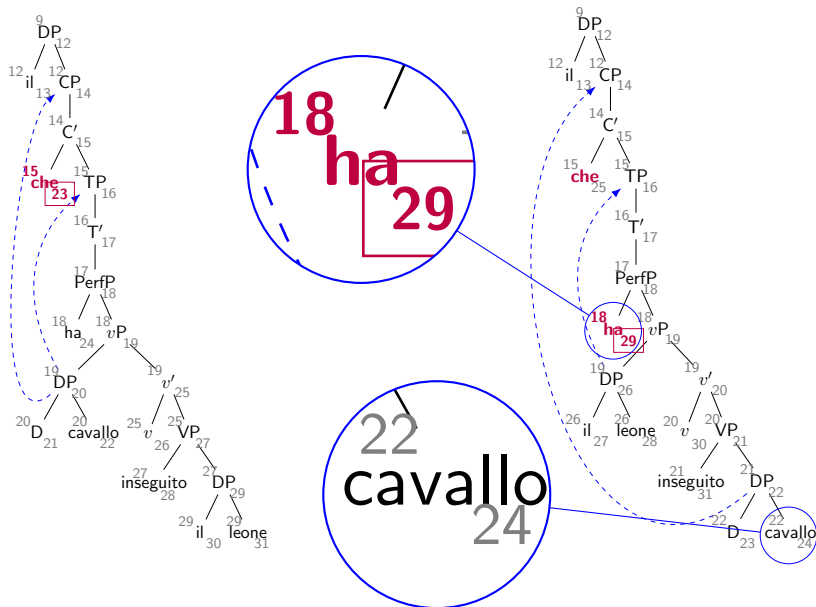
Results: SRC > ORC



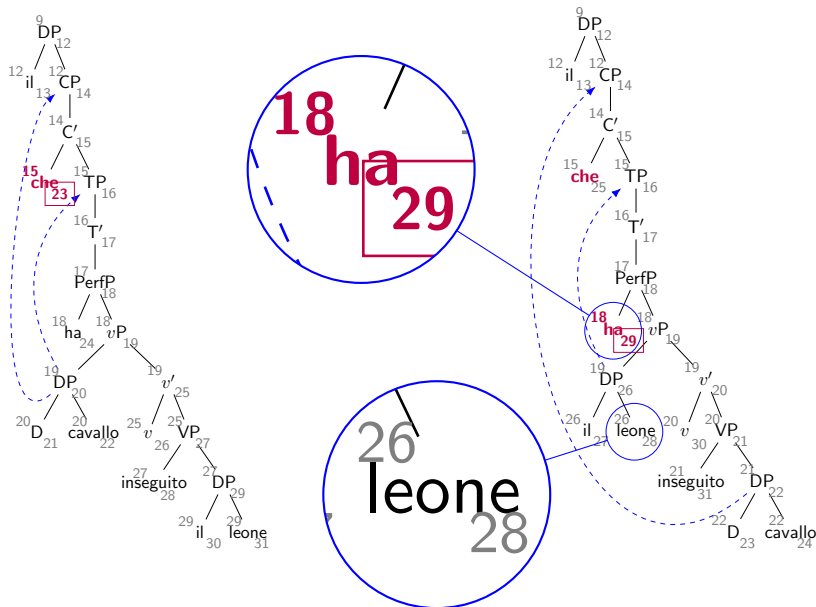
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Summary of Results (De Santo 2019)

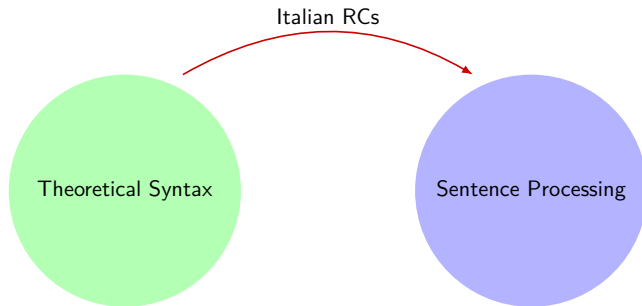
Clause Type	<MaxTenure,SumSize>
obj. SRC > ORC	✓
obj. SRC > ORCp	✓
obj. ORC > ORCp	✓
subj. SRC > ORC	✓
subj. SRC > ORCp	✓
subj. ORC > ORCp	✓
matrix SVO > VOS	✓
VS unacc > VS unerg	✓

Table: Predictions of the MG parser by contrast.

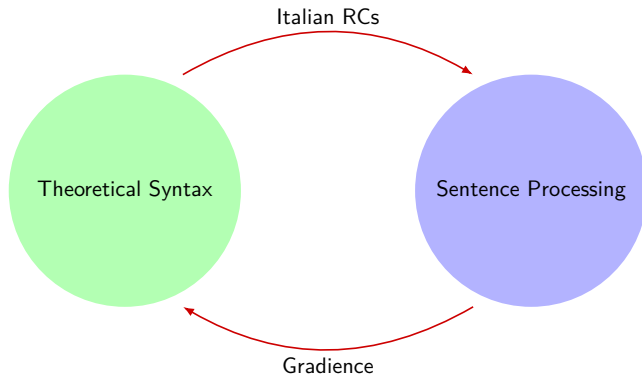
Interim Summary

- ▶ Asymmetries in Italian postverbal subject constructions
 - ▶ Derived just from **(fine-grained) structural differences!**
- ▶ $\langle \text{MAXT}, \text{SUMS} \rangle$ 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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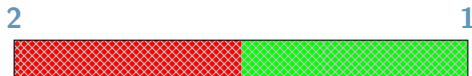
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Acceptability judgments \approx Grammaticality judgments

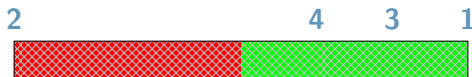
Gradience in Acceptability Judgments

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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 grammaticality** [...] 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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(Quantitative) Models of Gradiance

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 gradiance!

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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)

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A Proof of Concept: Island Effects

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2	What do you wonder whether John bought <i>t</i> ?	Island Embedded
3	Who <i>t</i> thinks that John bought a car?	Non-Island Matrix
4	Who <i>t</i> wonders whether John bought a car?	Island Matrix

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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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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. ✓

Modeling Results (De Santo 2020)

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

- (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/ <i>do</i>	19
Subj.	Non Isl.	>	Obj.	Isl.	✓	Subj./Non Island	11/ <i>do</i>	14
Subj.	Non Isl.	>	Subj.	Isl.	✓	Obj./Island	23/ <i>T2</i>	22
Obj.	Non Isl.	>	Obj.	Isl.	✓	Subj./Island	15/ <i>do</i>	20
Obj.	Non Isl.	>	Subj.	Isl.	✓			
Obj.	Isl.	>	Subj.	Isl.	×			

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Sprouse et al. (2012)				MG Parser	Clause Type	MaxT	SumS
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Subj. Non Isl.	>	Obj. Isl.		✓	Subj./Non Island	11/ <i>do</i>	14
Subj. Non Isl.	>	Subj. Isl.		✓	Obj./Island	23/ <i>T2</i>	22
Obj. Non Isl.	>	Obj. Isl.		✓	Subj./Island	15/ <i>do</i>	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

Sprouse et al. (2012)				MG Parser	Clause Type	MaxT	SumS
Matrix Non Isl.	>	Emb. Non Isl.		✓	Matrix Non Isl.	5/ <i>C</i>	9
Matrix Non Isl.	>	Matrix Isl.		✓	Emb. Non Isl.	11/ <i>do</i>	14
Matrix Non Isl.	>	Emb. Isl.		✓	Matrix Isl.	11/ <i>T_{RC}</i>	9
Matrix Isl.	>	Emb. Isl.		✓	Emb. Isl.	17/ <i>T_{RC}</i>	20
Matrix Isl.	>	Matrix Isl.		✓			
Emb. Non Isl.	>	Emb. Isl.		✓			

Summary

Gradience from a categorical MG grammar?

- ▶ The **first** (quantitative) model of this kind!
- ▶ Overall, a success! \Rightarrow **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)
- ▶ Syntactic constraints \sim pruning the parsing space (Stabler 2013)
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Summary

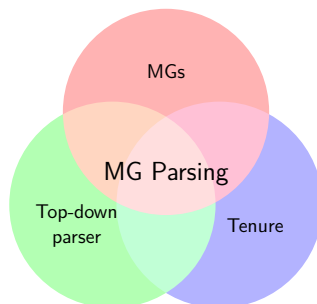
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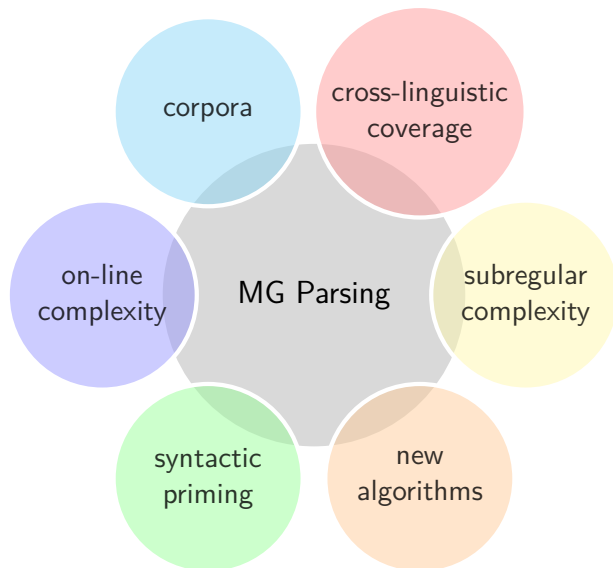
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From the Trees (back) to the Forest

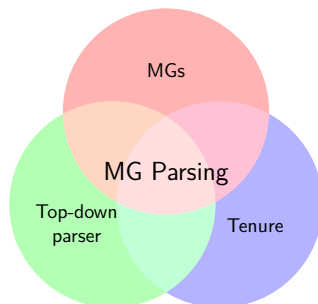


- ▶ Fully specified parsing model allows for precise predictions
- ▶ Tight connection with current generative syntax
- ▶ Successful on a variety of cross-linguistic constructions
- ▶ + insights about the structure of the grammar

Looking Ahead: A Collaborative Enterprise



From the Trees (back) to the Forest [cont.]



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)

Thank you!



Selected References I

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- 2 **De Santo, A.** (2019). Testing a Minimalist grammar parser on Italian relative clause asymmetries. In *Proceedings of CMCL 2019*, June 6 2019, Minneapolis, Minnesota.
- 3 **De Santo, A.** (2020). MG Parsing as a Model of Gradient Acceptability in Syntactic Islands. (To appear) In *Proceedings of SCiL 2020*, Jan 2-5, New Orleans.
- 4 **De Santo, A.** and Shafiei, N. (2019). On the structure of relative clauses in Persian: Evidence from computational modeling and processing effects. *Talk at the NACIL2*, April 19-21 2019, University of Arizona.
- 5 **Graf, T.** and Monette, J. and Zhang, C. (2017). Relative Clauses as a Benchmark for Minimalist Parsing. *Journal of Language Modelling*.
- 6 **Kobele, G.M.,** Gerth S., and Hale. J. (2012). Memory resource allocation in top-down minimalist parsing. In *Formal Grammar*, pages 32–51. Springer.
- 7 **Sprouse, J.,** Wagers, M. and Phillips, C. (2012). A test of the relation between working-memory capacity and syntactic island effects. *Language*.
- 8 **Stabler, E.P.** (2013). Bayesian, minimalist, incremental syntactic analysis. *Topics in Cognitive Science* 5:611–633.
- 9 **Stabler, E.P.** (1997). Derivational minimalism. In Logical aspects of computational linguistics, ed. Christian Retore, volume 1328 of Lecture Notes in Computer Science, 68–95. Berlin: Springer.

Appendix

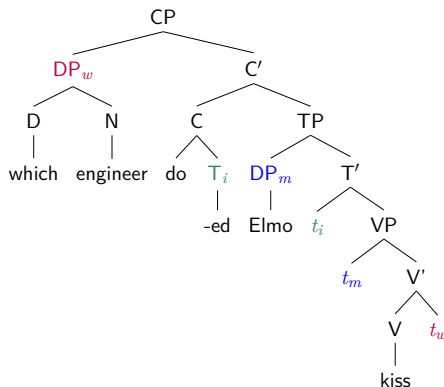
Why MGs?

- 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)

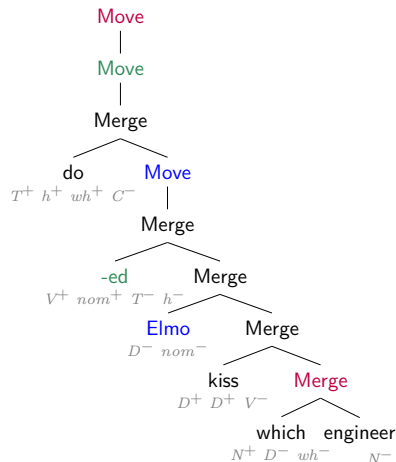
Some Important Properties of MGs

- ▶ 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; 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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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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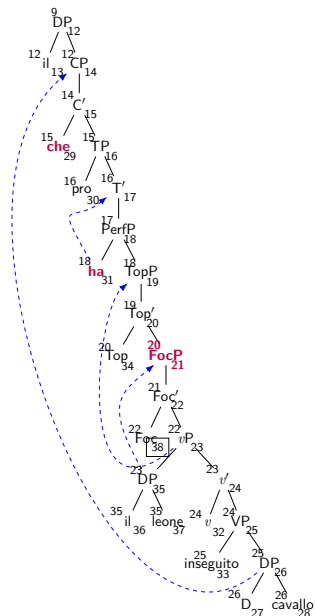
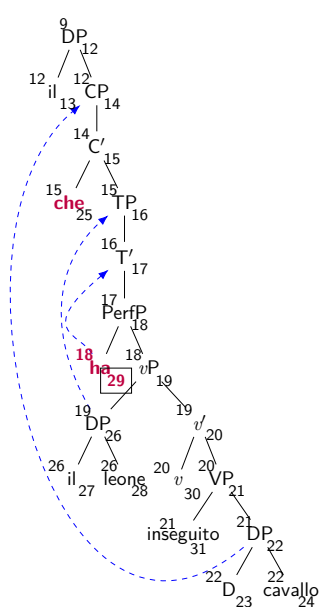
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Can we give a purely structural account?

Results: $ORC > ORC_p$



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

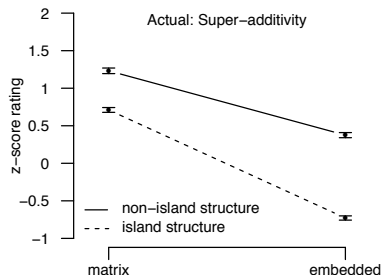
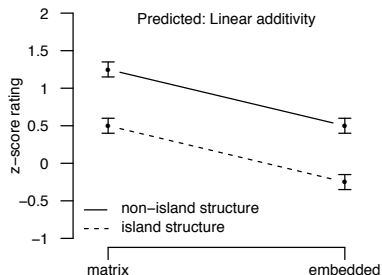
“Gio ran”

Unergative

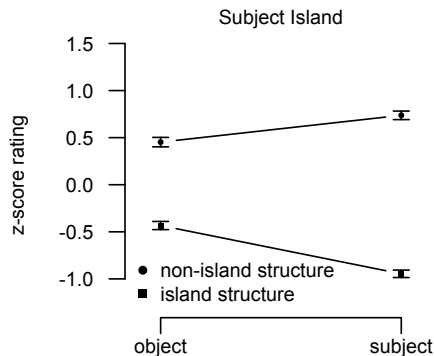
Gradience in Islands

A factorial design for islands effect:

► GAP POSITION \times 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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Models of Gradience

(At least two) theories of gradience:

- ▶ Gradience incorporated in the grammar
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- ▶ 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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Subject Islands

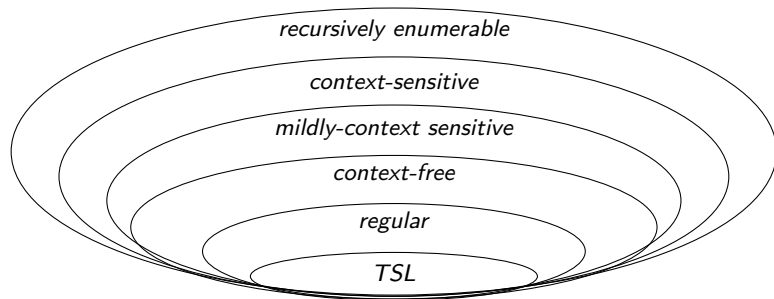
Case 1:

- (10) a. **What** do you think the speech interrupted ***t***? Obj | Non Island
b. **What** do you think ***t*** interrupted the show? Subj | Non Island
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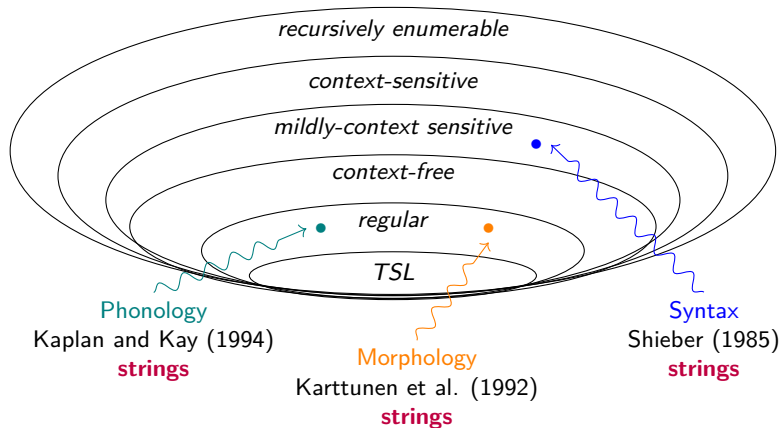
Case 2:

- (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 the primetime TV show? Matrix | Island
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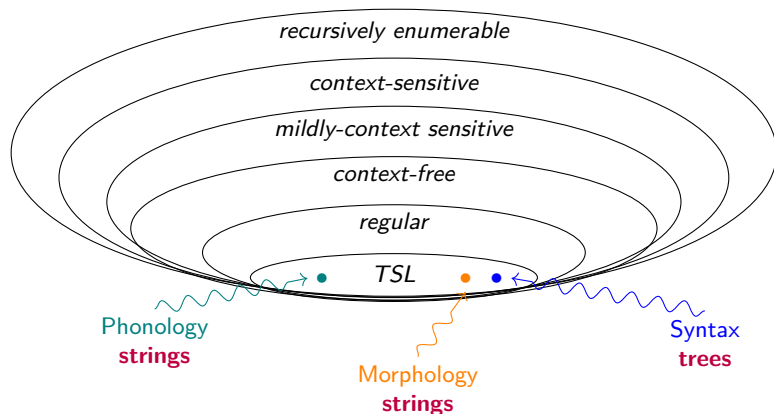
Subregular Complexity



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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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 - × Have a CP iff it dominates ≥ 3 TPs
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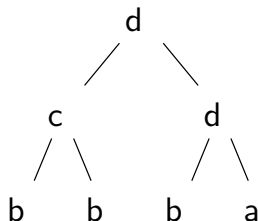
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- ▶ **cognition**

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.



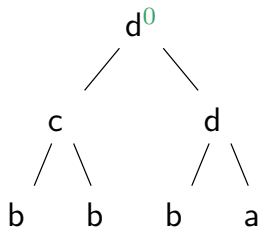
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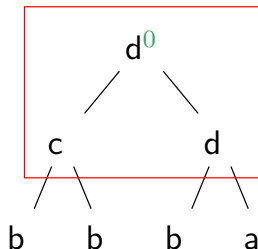
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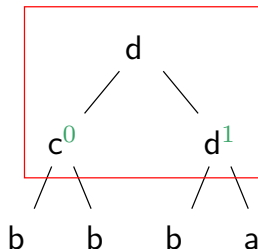
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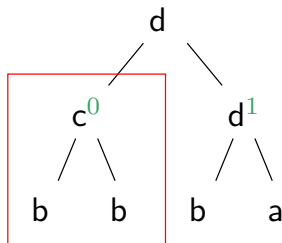
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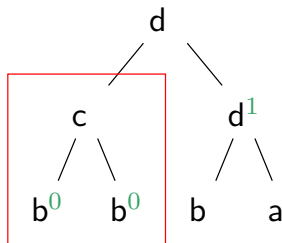
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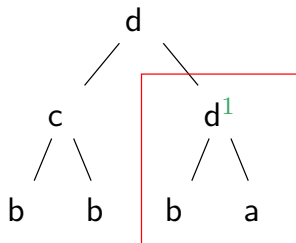
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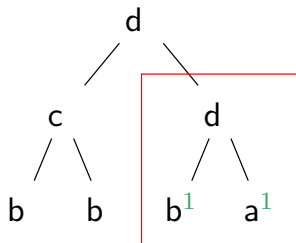
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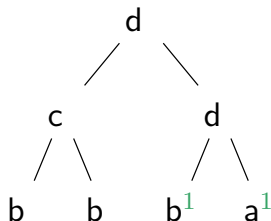
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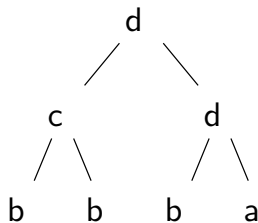
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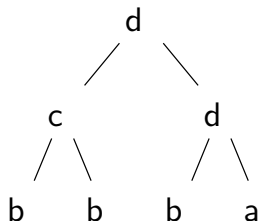
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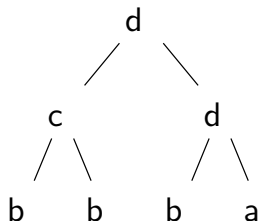
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- ▶ Some island constraints arise naturally from this perspective (e.g., Adjunct Island Constraint, SpIC, ATB movement)
- ▶ Constraints improve parsing performance by **exponentially reducing** the search space (Stabler 2013)
- ▶ Can be pre-compiled in the MG parse schema as a deterministic **top-down filter** (De Santo & Graf, in prep.)

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Stacked RCs and Parallelism Effects

English Stacked RCs (Zhang, 2017)

- (12) **The horse** [$_{RC_1}$ that **t** chased the wolf] [$_{RC_2}$ that **t** kicked the elephant] ... **ss**
- (13) **The horse** [$_{RC_1}$ that the wolf chased **t**] [$_{RC_2}$ that **t** kicked the elephant] ... **os**
- (14) **The horse** [$_{RC_1}$ that the wolf chased **t**] [$_{RC_2}$ that the elephant kicked **t**] ... **oo**
- (15) **The horse** [$_{RC_1}$ that **t** chased the wolf] [$_{RC_2}$ that the elephant kicked **t**] ... **so**

- ▶ Zhang (2017) found **parallelism effects** in stacked RC processing:
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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English Stacked RCs (Zhang, 2017)

- (12) **The horse** [RC_1 that **t** chased the wolf] [RC_2 that **t** kicked the elephant] ... **ss**
- (13) **The horse** [RC_1 that the wolf chased **t**] [RC_2 that **t** kicked the elephant] ... **os**
- (14) **The horse** [RC_1 that the wolf chased **t**] [RC_2 that the elephant kicked **t**] ... **oo**
- (15) **The horse** [RC_1 that **t** chased the wolf] [RC_2 that the elephant kicked **t**] ... **so**

- ▶ Zhang (2017) found **parallelism effects** in stacked RC processing:
SS << OS, OO << SO.
- ▶ But she also showed that no combination of metrics can account for these effects.
- ▶ Proposal: metric encoding **memory reactivation**

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.

- ▶ Assume the NPs are associated to the same movement feature f^-

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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

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

$$\text{MAXR}^f \max(\{i(m_i) - o(m_{i-1}) \mid m_i \in M^f\})$$

$$\text{AVGR}^f \frac{\text{SUMR}}{|M^f|}$$

- ▶ comprehensive metrics

$$\text{SUMR} \sum_{f \in \mathcal{M}} \text{SUMR}^f$$

$$\text{MAXR} \max(\{\text{SUMR}^f \mid f \in \mathcal{M}\})$$

$$\text{AVGR} \frac{\text{SUMR}}{|\mathcal{M}|}$$

Priming Effects

- (16) I saw
- a. [RC_1 the horse that chased the lions] **SRC**
 - b. and [RC_2 the mouse that kissed the chicken] **SRC**
- (17) I saw
- a. [RC_1 The horse that chased the lions] **SRC**
 - b. and [RC_2 the mouse that the chicken kissed] **ORC**
- (18) I saw
- a. [RC_1 the horse that the lions chased] **ORC**
 - b. and [RC_2 the mouse that kissed the chicken] **SRC**
- (19) I saw
- a. [RC_1 the horse that the lions chased] **ORC**
 - b. and [RC_2 the mouse that the chicken kissed] **ORC**