



Computation as a Window into Linguistic Cognition

Aniello De Santo

he/him

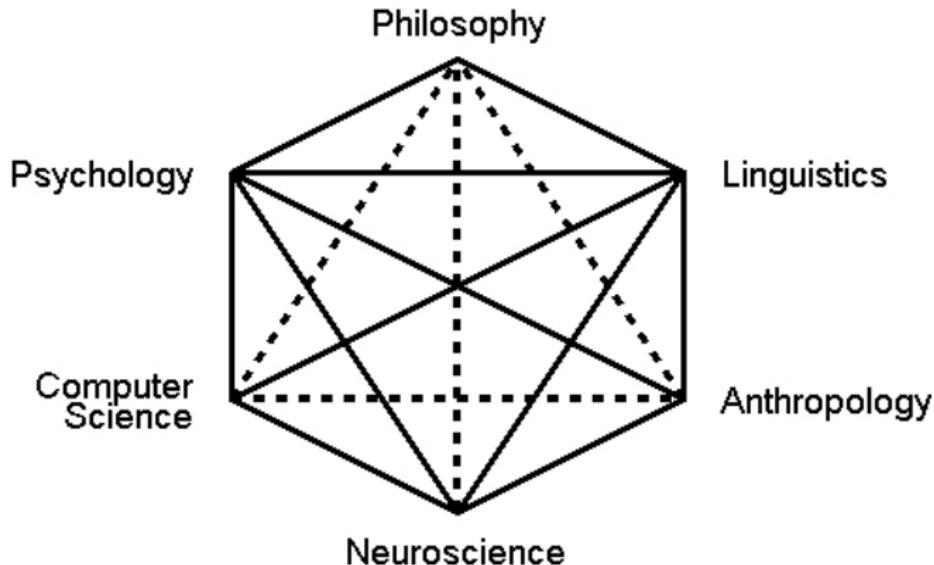
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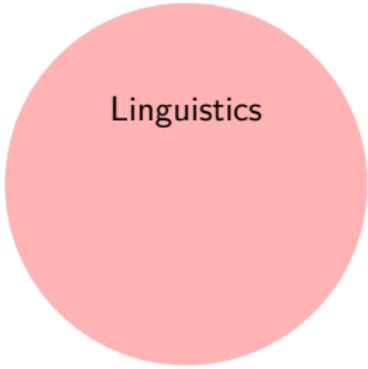
aniellodesanto.github.io/UM24.pdf

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February 2024





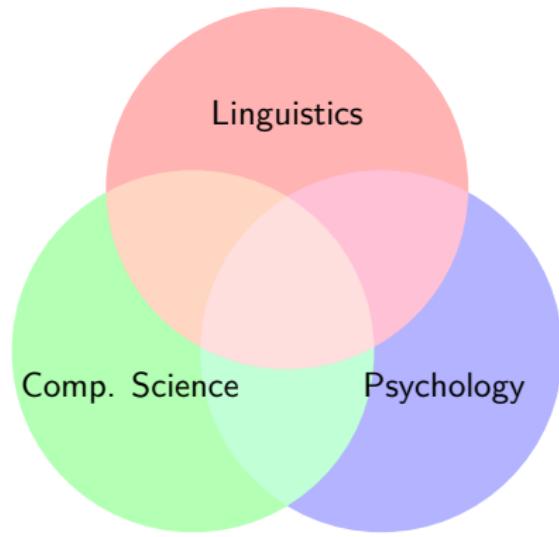


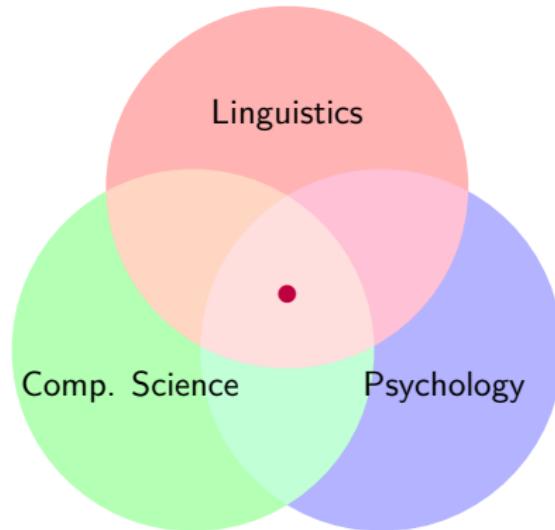
Linguistics

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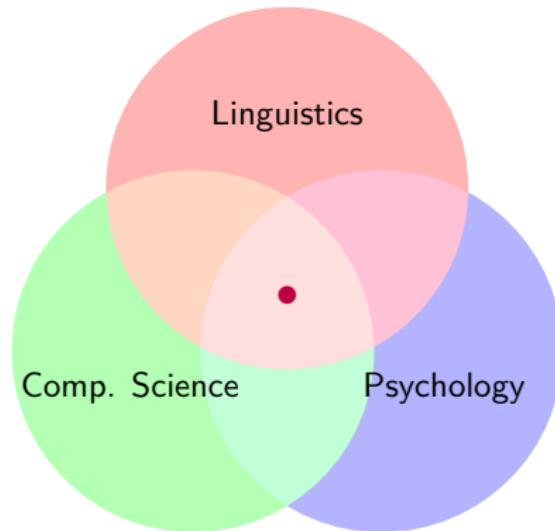
A Venn diagram consisting of two overlapping circles. The left circle is light green and labeled "Comp. Science". The right circle is light red and labeled "Linguistics". The two circles overlap in the center, representing the intersection of the two fields.

Comp. Science



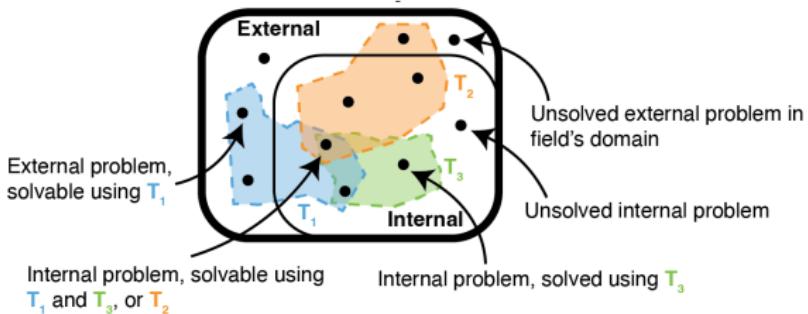


- ▶ **Theory building** (De Santo & Rawski 2022, Baggio, De Santo, Nunez 2024, Levenstein et al. 2024)
- ▶ **Computational invariants in typology and acquisition**
(De Santo & Graf 2019, De Santo & Aksenova 2021, Johnson and De Santo 2023)
- ▶ **Computational parallels across linguistic modules**
(Aksenova & De Santo 2017, Graf & De Santo 2020, De Santo 2018, Miller & De Santo 2023, a.o.)
- ▶ **Memory traces of processing generalized quantifiers** (De Santo et al. 2019, De Santo & Drury 2020)
- ▶ **Modeling processing difficulty** (De Santo 2019, 2021, 2022, a.o.)
- ▶ **Gradience in acceptability judgment** (De Santo 2020)
- ▶ **Evaluating/Contrasting syntactic analyses**
(De Santo & Shafiei 2019, Lee & De Santo 2022, Del Valle & De Santo 2023, a.o.)
- ▶ **Locality and Economy Considerations** (De Santo & Lee 2022a)
- ▶ **Online/Offline effects in sentence processing**
(De Santo & Lee 2022b, Lee & De Santo in prep., Jacobs, De Santo, Grobel in prep.)
- ▶ **Animal Cognition** (De Santo & Rawski, 2021)
- ▶ **Mapping syntactic and prosodic constituents** (Vu, De Santo, Dolatian 2022)
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Problems and Theories¹



Some Problems

- ▶ what are the core representations?
- ▶ what do they tell us about processing?
- ▶ what do they tell us about learning?

¹Levenstein, De Santo, ..., et al. (2024), Guest & Martin (2021), a.o.

Computation and Theory Building

[...] this is a confusion of two quite separate issues, **simulation and explanation**. [...] What we are **really** interested in [...] is explanation — in developing models that help us **understand how it is that people behave** that way, not merely demonstrating that we can build an artifact that behaves similarly.

(Kaplan, 1995)

- ▶ Invariant properties of phenomena
- ▶ Specification of verbal theories

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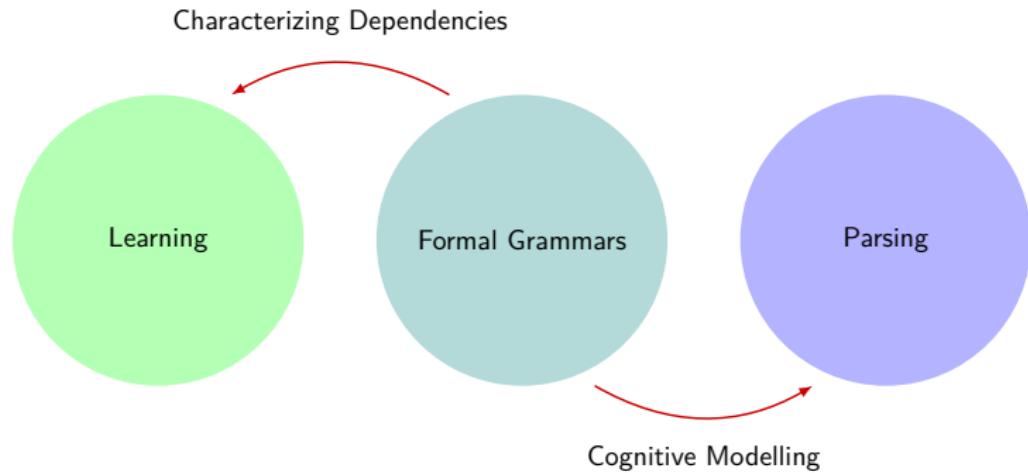
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Building Bridges



Building Bridges



Outline

- 1 Theory Building**
- 2 Linguistics and Formal Language Theory**
- 3 MG Parsing as a Model of Gradience**
- 4 Conclusion**

Theories from Data?

Theories of linguistic representations from typological/empirical observations?

*The problem that we cannot deduce [...] theories from data is a limitation, or **perhaps an attribute**, of all empirical science [...] Still, one may abduce hypotheses [...] Abduction is **reasoning from observations** [...] It consists of two steps: generating candidate **hypotheses** (abduction proper), and selecting the “best” explanatory one[s] (inference to the **best explanation**).*

(van Roji & Baggio 2020, pg. 9)

Theories from Data?

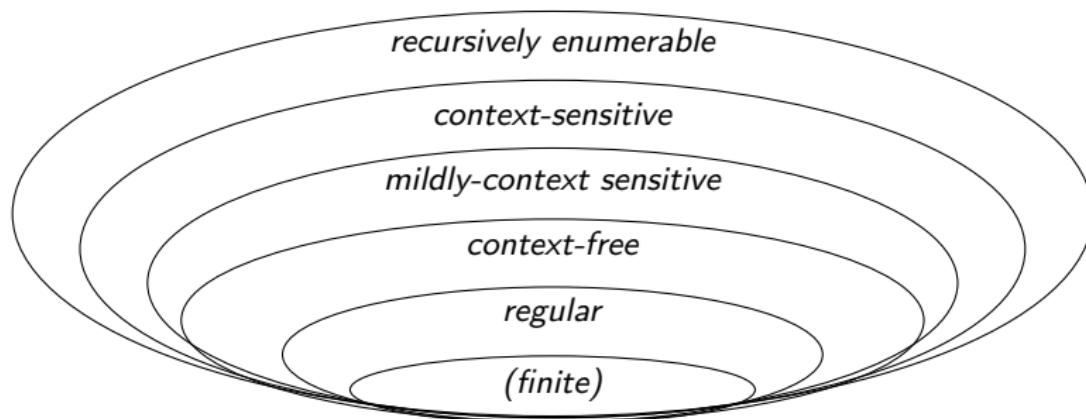
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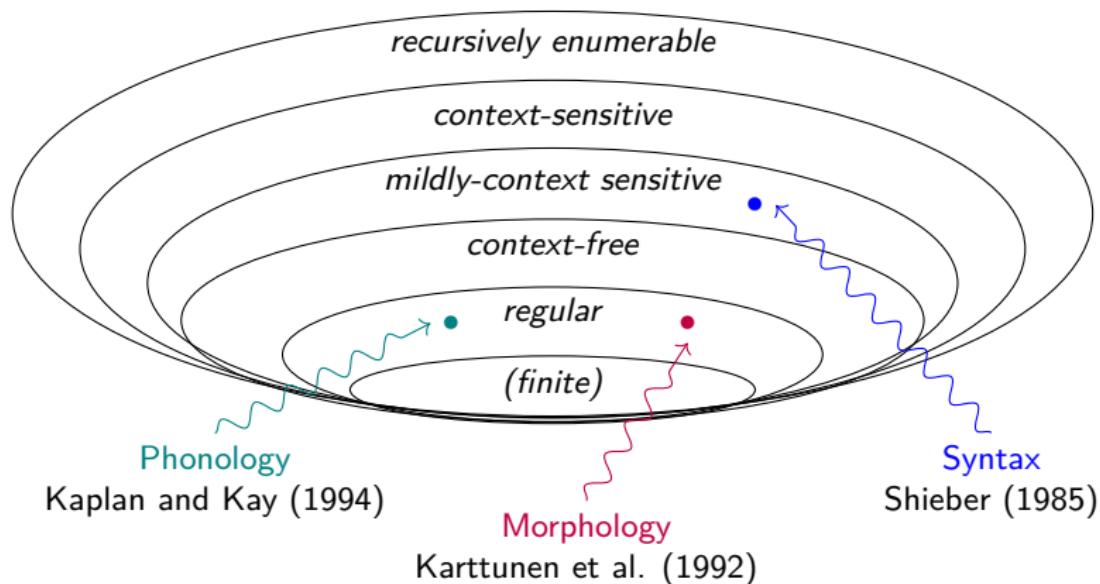
A Lens: Computational Theories of Language

Stringsets can be classified according to the requirements of the grammars that generate them.

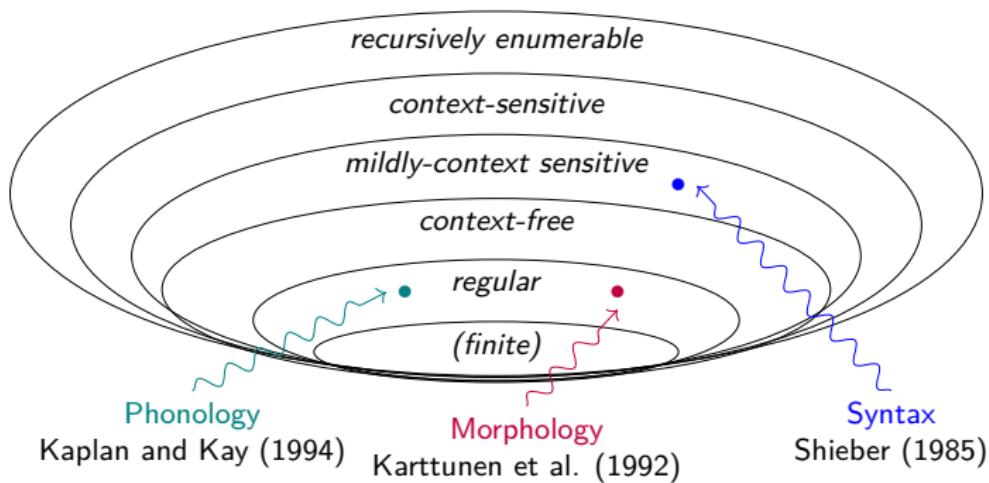


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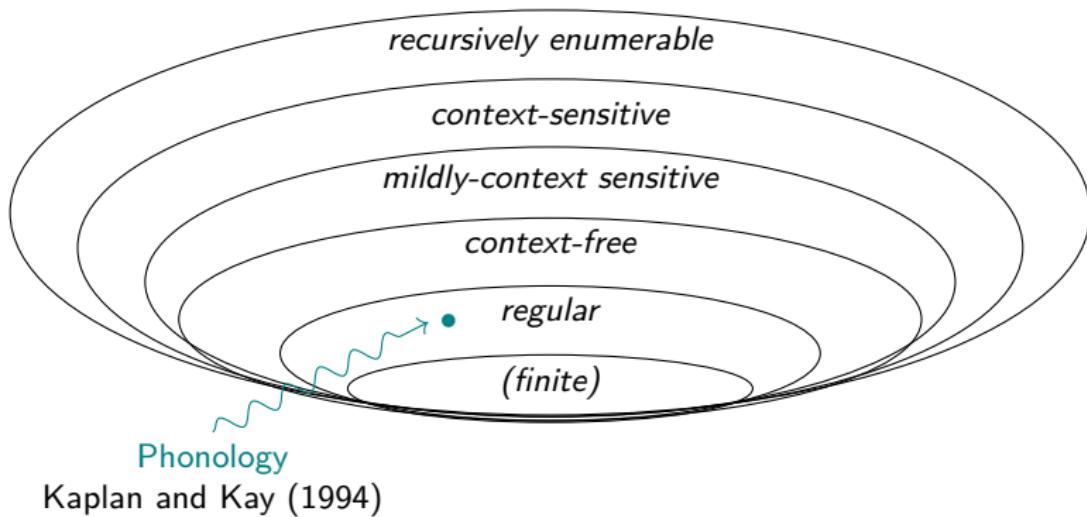
Precise Characterizations \Rightarrow Precise Predictions



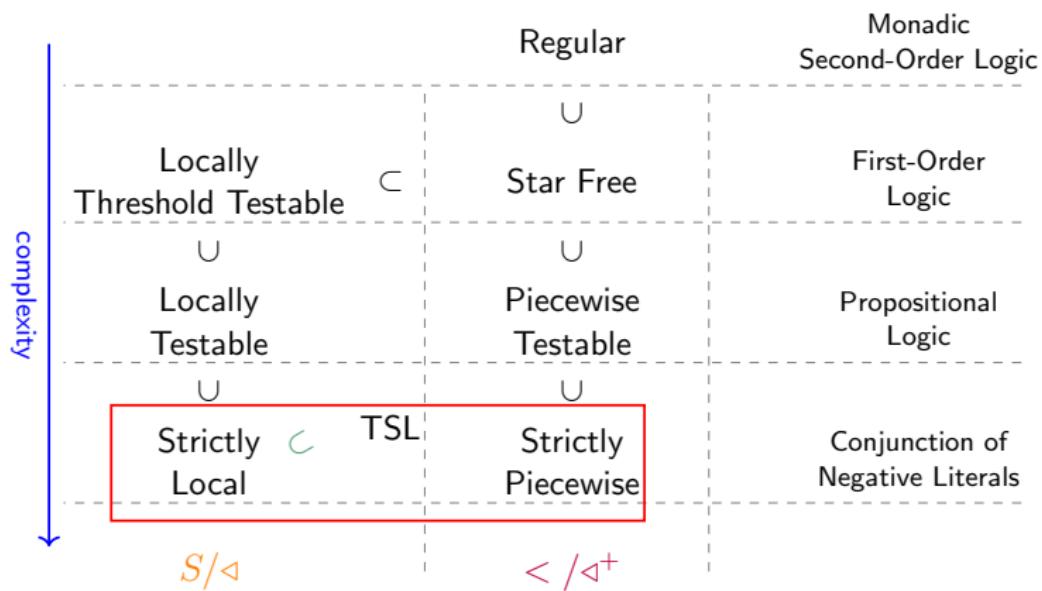
Precise predictions for:

- ▶ typology \rightarrow e.g. no center embedding in phonology
- ▶ learnability \rightarrow e.g. no Gold learning for regular languages
- ▶ cognition \rightarrow e.g. finitely bounded working memory

Spoken Languages' Phonology as a Regular System



Beyond Monolithic Classes: Subregular Languages²



²McNaughton & Papert (1976), Heinz (2011), Chandee & Heinz (2014), De Santo & Graf (2019), De Santo & Rawski (2022), a.o.

Local Phonotactic Dependencies

1 Word-final devoicing

Forbid voiced segments at the end of a word

- (1) a. * rad
- b. rat

1 Intervocalic voicing

Forbid voiceless segments in between two vowels

- (2) a. * faser
- b. fazer

These patterns can be described by **strictly local** (SL) constraints.

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Local Dependencies in Phonology are SL

Example: Word-final devoicing

- ▶ Forbid voiced segments at the end of a word: *[+voice]\$
- ▶ **German:** *z\$, *v\$, *d\$ (\$ = word edge).

\$ r a **d** \$ \$ r a t \$

Example: Intervocalic voicing

- ▶ Forbid voiceless segments in-between two vowels: *V[-voice]V
- ▶ **German:** *ase, *ise, *ese, *isi, ...

\$ f a **s** e r \$ \$ f a z e r \$

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Unbounded Dependencies Are Not SL

► Samala Sibilant Harmony

Sibilants must not disagree in anteriority.

(Applegate 1972)

- (3) a. * hasxintilawaʃ
- b. * haʃxintilawaſ
- c. haʃxintilawaʃ

Example: Samala

* \$ h a ſ x i n t i l a w a ſ \$

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Example: Samala

* \$ h a [S x i n t i l a w a ʃ] \$

\$ h a [ʃ x i n t i l a w a ʃ] \$

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 |-----|
 |-----|
\$ h a [ʃ x i n t i l a w a s] \$
 |-----|
 |-----|

► **But:** Sibilants can be arbitrarily far away from each other!

* \$ s t a j a n o w o n w a ʃ \$

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Locality Over Tiers

* \$|**s**t a j a n o w o n w a **f**|\$

- ▶ Sibilants can be arbitrarily far away from each other!
- ▶ **Problem:** SL limited to locality domains of size n ;

Tier-based Strictly Local (TSL) Grammars (Heinz et al. 2011)

- ▶ Projection of selected segments on a tier T (Goldsmith 1976)
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- ▶ Unbounded dependencies are local over **tiers**

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Unbounded Dependencies are TSL

- ▶ Let's revisit Samala Sibilant Harmony

- (4) a. * hasxintilawaʃ
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c. haʃxintilawaʃ

- ▶ What do we need to project? [+strident]
- ▶ What do we need to ban? *[+ant][−ant], * [−ant][+ant]
I.E. *ſs, *ſ3, *zſ, *z3, *ſſ, *3ſ, *ſz, *3z

Example: TSL Samala

ſ ſ ſ ſ

.....

* \$ haſxintilawſ \$ *ok* \$ haʃxintilawſ \$

Unbounded Dependencies are TSL

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I.E. *sʃ, *sʒ, *zʃ, *zʒ, *ʃs, *ʒs, *ʃz, *ʒz

Example: TSL Samala



* \$ha[s]xintilawaʃ\$



ok \$haʃ[xintilawaʃ]\$

SL and TSL: So What?

*Descriptive characterizations focus on the **nature of the information** [...] that is needed in order to distinguish [...] a pattern*

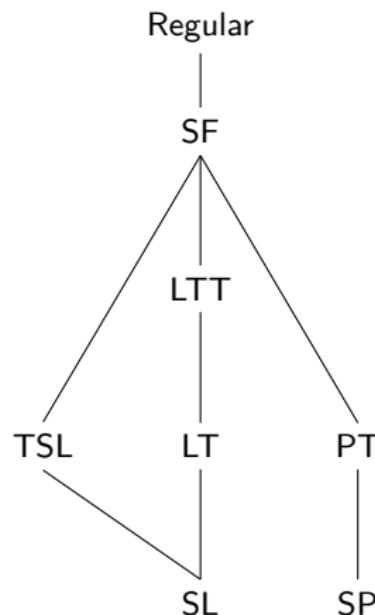
Rogers & Pullum (2011)

Invariants (De Santo & Rawski 2022)

- ▶ SL: adjacency
- ▶ TSL: relativized adjacency

▶ **But** typological variation is complex...

(McMullin 2016, Mayer & Major 2018, De Santo & Graf 2019)



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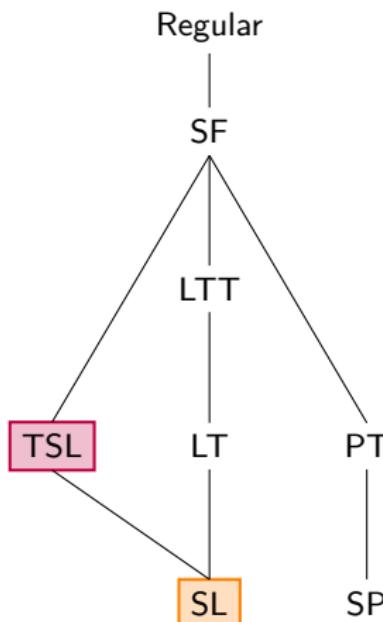
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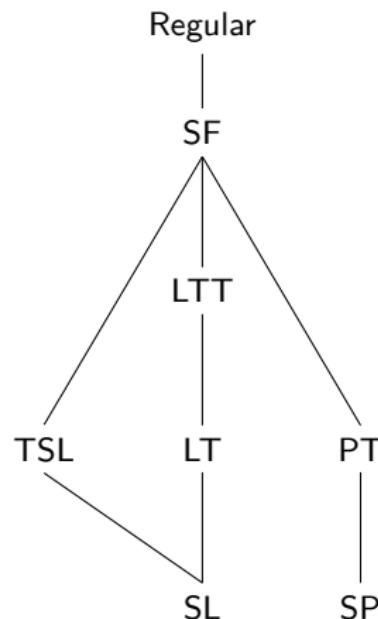
(McMullin 2016, Mayer & Major 2018, De Santo & Graf 2019)



Refining the Hierarchy via Typological Insights

Observation

TSL is not closed under intersection
(De Santo & Graf, 2019)



- ▶ We want to also account for multiple processes
So we can cover the complete phonotactics of a language
- ▶ Multiple non-interacting processes in attested patterns

Concurrent Processes

Sibilant Harmony in IMDLAWN TASHLHIYT (McMullin2016)

- 1) Underlying causative prefix /s(:)-/

Base Causative

- a. uga **s:**-uga "be evacuated"
- b. a**s**:twa **s**-**a****s**:twa "settle, be levelled"

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- 3) Sibilant voicing harmony blocked

Base Causative

- a. ukz **s**:ukz "recognize"
- b. q:uʒ:i ſ- quʒ:i "be dislocated, broken"

Sibilant Harmony in IMDLAWN TASHLHIYT

Generalization (1/2)

Sibilants must agree in anteriority and voicing.

Grammar

$$T = \{ \emptyset, s, z, \emptyset \}$$

$$S = \{ *s\emptyset, *s\emptyset, *s\emptyset, *z\emptyset, *z\emptyset, *z\emptyset, *z\emptyset, *z\emptyset, *z\emptyset, *z\emptyset \}$$

* z m: ʒ d a w |

ok ʒ m: ʒ d a w |

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z \emptyset

* $[z]$ m: \emptyset d a w |

ok \emptyset m: \emptyset d a w |

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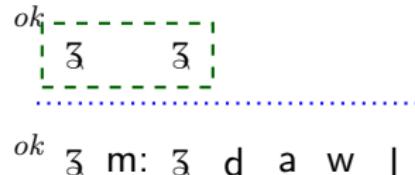
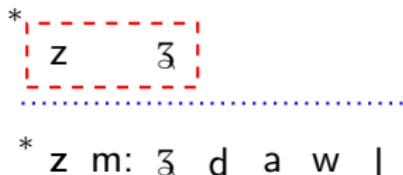
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Sibilant Harmony in IMDLAWN TASHLHIYT

Generalization (2/2)

Voiceless obstruents block agreement in voicing.

Grammar

$$T = \{ \text{ʒ}, \text{s}, \text{z}, \textʃ, \text{q} \}$$

$$S = \{ *s\text{ʒ}, *s\text{z}, *s\textʃ, *ʒ\text{s}, *ʃ\text{s}, *z\text{s}, *z\textʃ, *ʒ\text{ʒ}, *ʃ\text{ʒ}, *ʒ\text{ʃ}, *ʒ\text{z} \}$$

ok ʃ q u ʒ: i * s q u ʒ: i

Sibilant Harmony in IMDLAWN TASHLHIYT

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$\textʃ$ q ʒ̥

ok ʃ [q] u ʒ̥ i

* s q u ʒ̥ i

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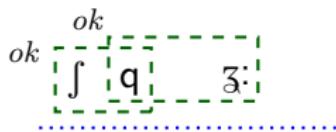
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ok /ʃ/ [q] u /ʒ:/ [dʒ]

* s q u /ʒ:/ [dʒ]

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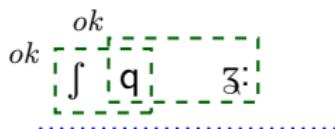
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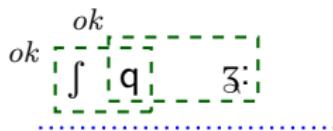
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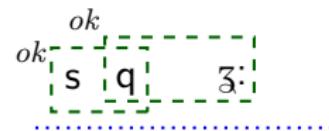
Grammar

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$$S = \{ *s\emptyset, *s\emptyset, *s\emptyset, *\emptyset s, *\emptyset s, *z\emptyset, *z\emptyset, *\emptyset z, *\emptyset z, *z\emptyset, *z\emptyset, *\emptyset z \}$$



ok /ʃ q u ʒ: i



* /s q u ʒ: i

Sibilant Harmony in IMDLAWN TASHLHIYT

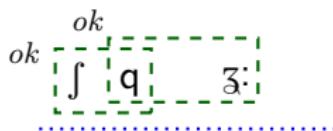
Generalization (2/2)

Voiceless obstruents block agreement in voicing.

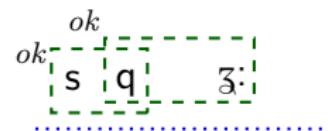
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ok \emptyset \emptyset \emptyset \emptyset \emptyset



* $\textcolor{red}{s}$ \emptyset \emptyset \emptyset \emptyset

Multi-Tier Strictly Local (MTSL) Languages (1/2)

Sibilant Harmony in IMDLAWN TASHLHIYT (Revisited)

Voiceless obstruents block agreement in voicing:

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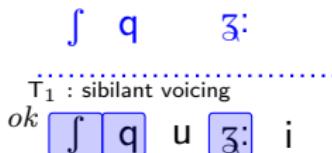
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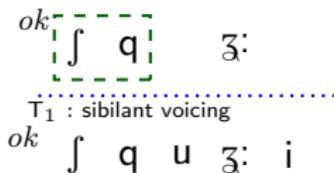


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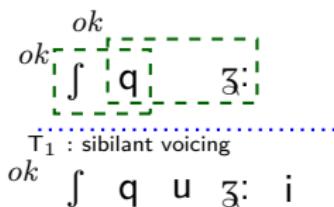


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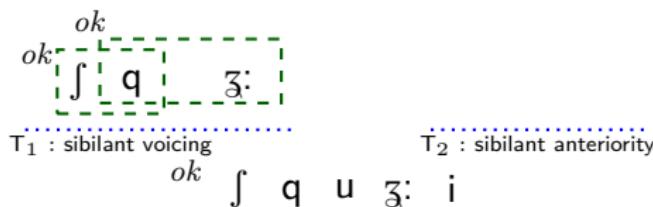
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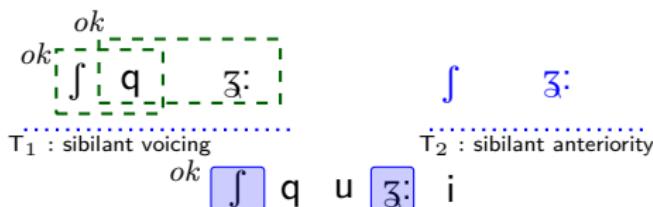
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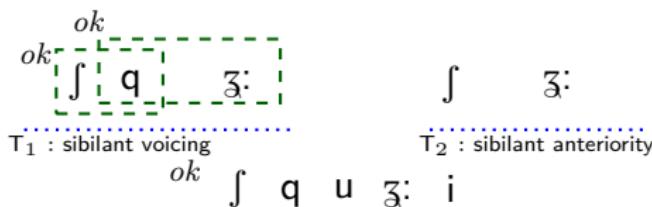
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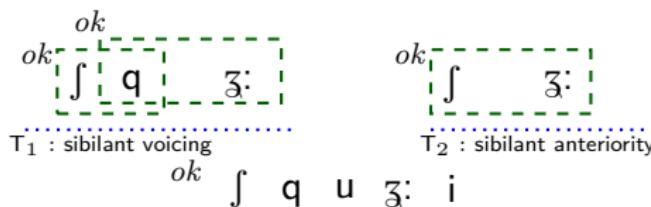
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Multi-Tier Strictly Local (MTSL) Languages (2/2)

Sibilant Harmony in IMDLAWN TASHLHIYT (Revisited)

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* s q u ʒ: i

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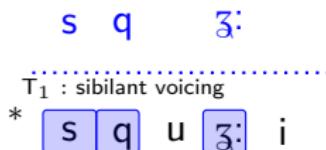
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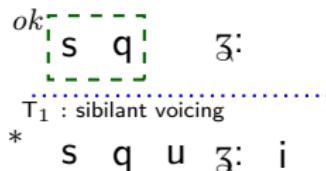
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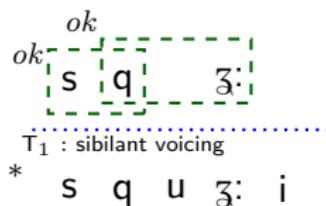
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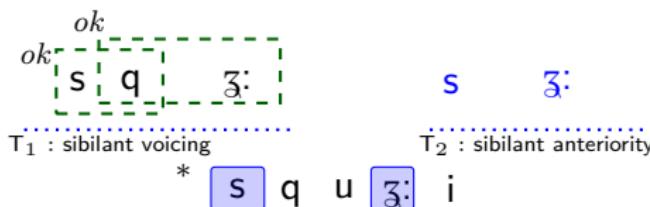
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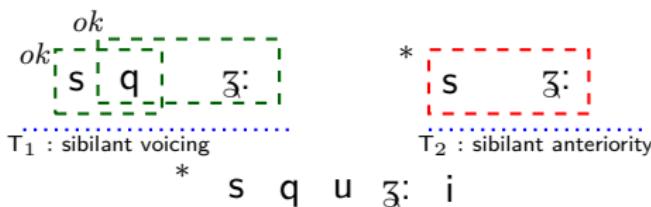
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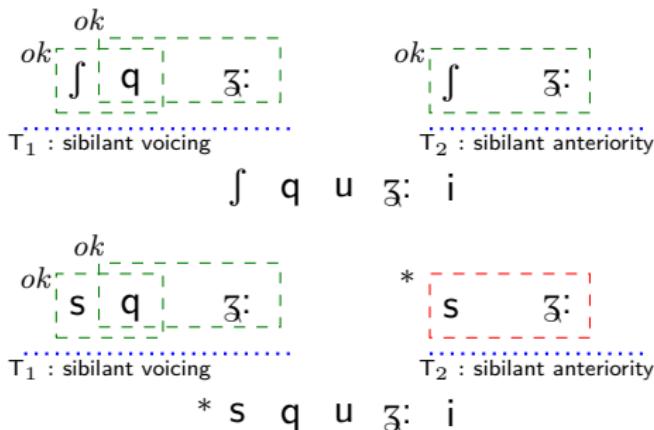
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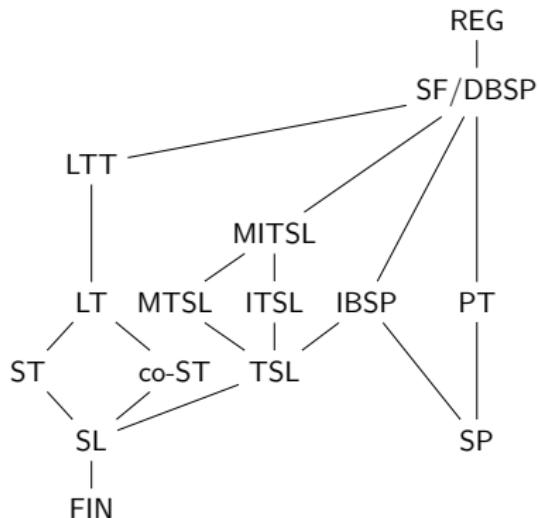
Accounting for Concurrent Processes

- ▶ MTSL: TSL closure under intersection
(De Santo & Graf, 2019)



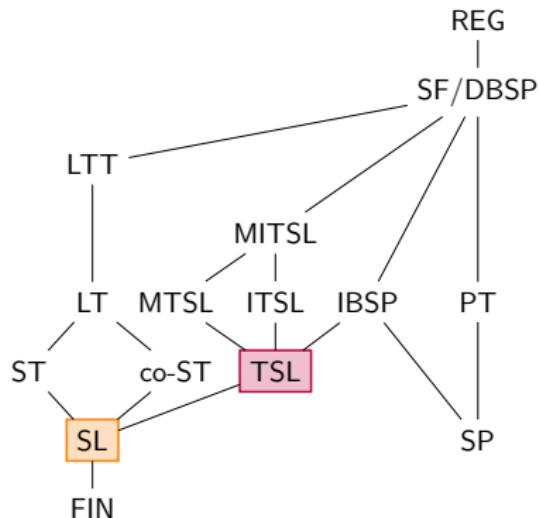
- ▶ Intersection closure accounts for multiple concurrent processes
- ▶ Can characterize the complete phonotactics of a language

A Plethora of Combination



- ▶ The goal is **not** identifying a single “correct” class
- ▶ Pinpoint fundamental properties of the patterns:
SL: \triangleleft , TSL: \triangleleft_T , ...

A Plethora of Combination

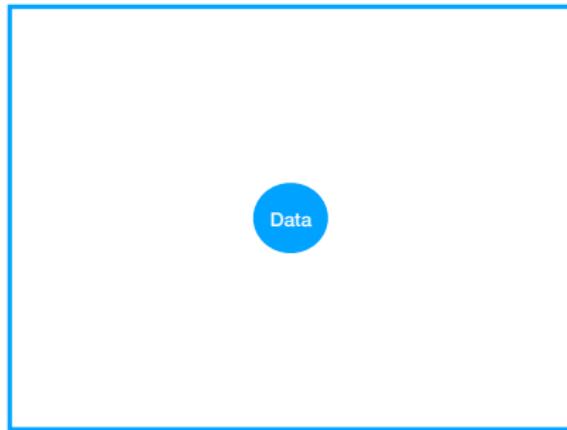


- ▶ The goal is **not** identifying a single “correct” class
- ▶ Pinpoint fundamental properties of the patterns:
SL: \triangleleft , TSL: \triangleleft_T , ...
- ▶ What about learnability?

Learning Multiple TSL Grammars

Problem:

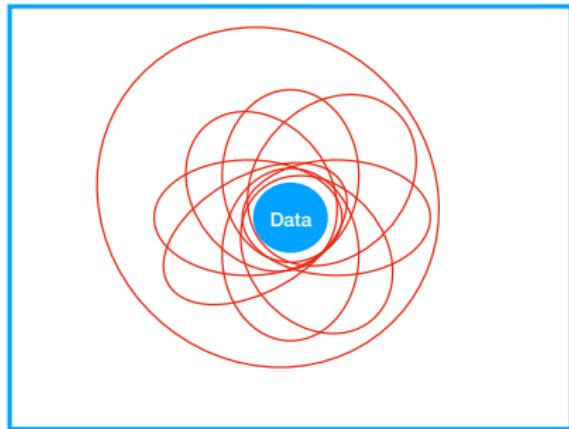
- ▶ Unrestricted Hypothesis Spaces



Learning Multiple TSL Grammars

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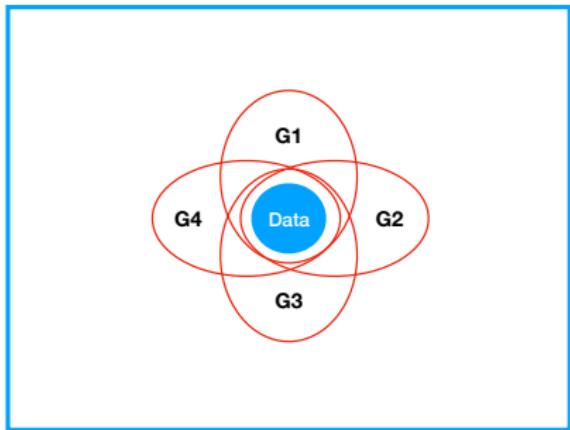
- ▶ Unrestricted Hypothesis Spaces



Learning Multiple TSL Grammars

Solution:

- ▶ Structural priors



Efficient Learning of MTS defense?

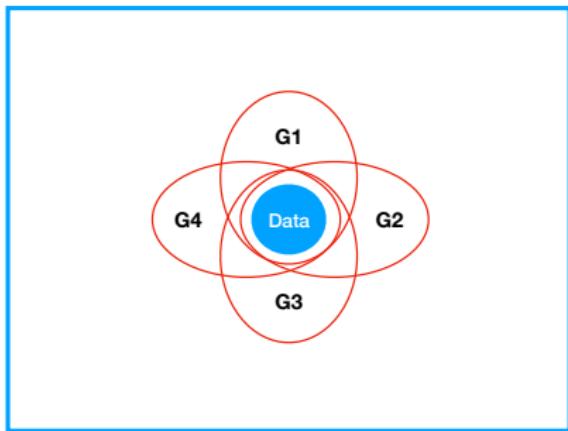
De Santo & Aksanova (2021):
⇒ Assume relativized locality!

- ▶ tiers (but not their content)
- ▶ local tier constraints
- ▶ characteristic sample!

Learning Multiple TSL Grammars

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Efficient Learning of MTSL?

De Santo & Aksanova (2021):
⇒ Assume relativized locality!

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Results

- ▶ No a priori information on the content of tiers/constraints
- ▶ Guaranteed convergence in polynomial time and data

Evaluating Convergence in Real World Scenarios

	SP	SL	TSL	MTSL	MITSL
Word-final devoicing					
T	X	✓	✓	✓	✓
A	68%	100%	100%	100%	100%
N ₁	58%	100%	100%	100%	100%
Single vowel harmony without blocking					
T	✓	X	✓	✓	✓
A	100%	83%	100%	100%	100%
N ₂	100%	72%	100%	100%	100%
Single vowel harmony with blocking					
T	X	X	✓	✓	✓
A	84%	89%	100%	100%	99%
Several vowel harmonies without blocking					
T	✓	X	✓	✓	✓
A	100%	69%	100%	100%	100%
Several vowel harmonies with blocking					
T	X	X	✓	✓	✓
A	76%	59%	100%	100%	99%
N ₃	76%	70%	67%	95%	99%
Vowel harmony and consonant harmony without blocking					
T	✓	X	X	✓	✓
A	100%	64%	74%	100%	100%
Vowel harmony and consonant harmony with blocking					
T	X	X	X	✓	✓
A	83%	64%	69%	100%	100%
Unbounded tone plateauing					
T	✓	X	X	X	✓
A	100%	85%	90%		100%
Two locally-driven long-distance assimilations (ITSL restrictions)					
T	X	X	X	X	✓
A					100%

(T)heoretical expectations and performance of 5 subregular learners on (A)rtificial and simplified (N)atural language input data-sets. N₁: German; N₂: Finnish; N₃: Turkish.

Johnson & De Santo (2023)

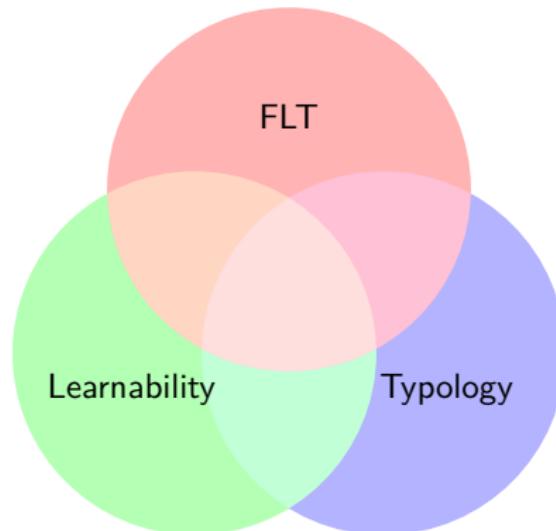


Interim Summary

SL and TSL for Spoken Phonotactics

- ▶ Linguistically natural (Goldsmith 1976)
- ▶ Captures (properties of a) wide range of (spoken) phonotactic dependencies (McMullin 2016, De Santo & Graf 2019)
What about sign? (Rawski 2017, Rawski forth.)
- ▶ Provably correct and efficient learning algorithms
(De Santo & Aksenova 2021, Johnson & De Santo u.r.)
- ▶ Predictions for human learning
(Lai 2015, Avcu & Hestevic 2021, De Santo & Gutierrez in prep.)
- ▶ Generalizes beyond phonotactics
(Aksenova & De Santo 2017, Graf & De Santo 2019, a.o.)

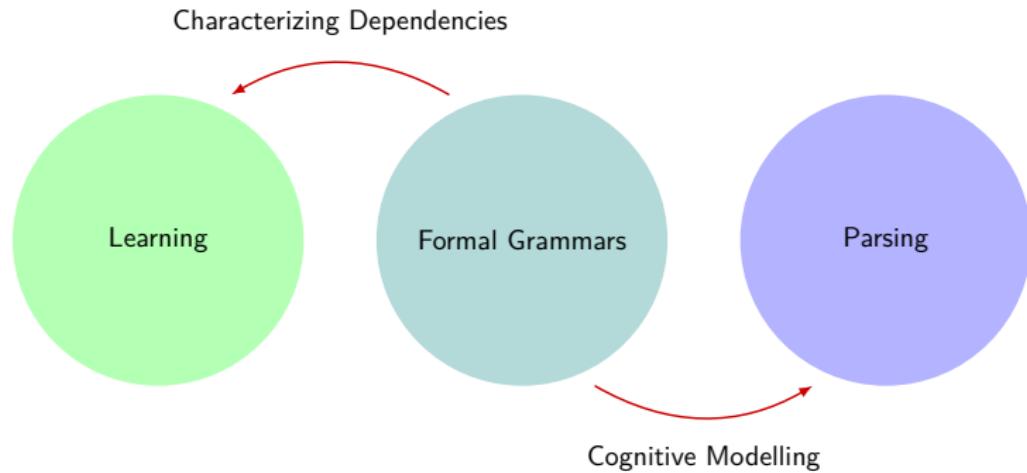
Interim Summary [cont.]



The Tip of the Iceberg:

- ▶ Cross-linguistic/cross-domain typological analysis
- ▶ Artificial language learning experiments
- ▶ New algorithms
- ▶ New mathematical insights

Building Bridges



Outline

- 1 Theory Building**
- 2 Linguistics and Formal Language Theory**
- 3 MG Parsing as a Model of Gradience**
- 4 Conclusion**

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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Acceptability judgments \approx Grammaticality judgments

Gradience in Acceptability Judgments

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Gradience in Acceptability Judgments

- 1 **What** do you think that John bought *t*?
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- 3 **Who** *t* thinks that John bought a car?
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Gradience in Acceptability Judgments

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



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)

(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!

Building Linking Hypothesis

We need to link categorical grammars, processing difficulty, and gradience **explicitly!**

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Forward to the Past

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

Derivational Theory of Complexity (Miller and Chomsky, 1963)

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

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

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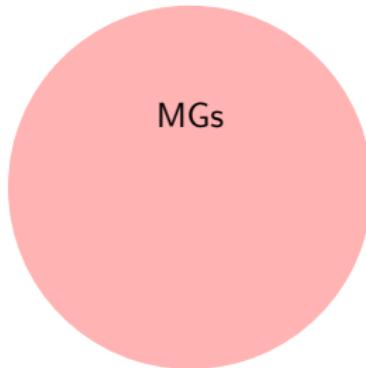
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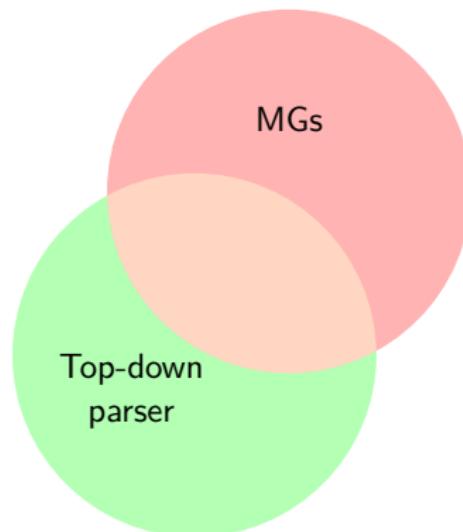
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A Formal Model of Sentence Processing



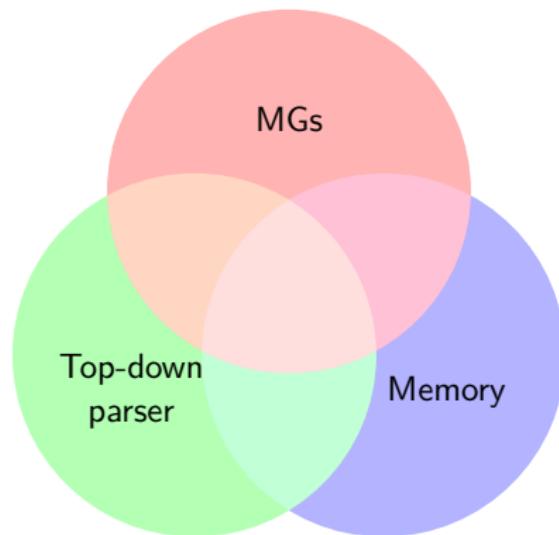
- 1 An explicit syntactic theory → Minimalist grammars (MGs)

A Formal Model of Sentence Processing



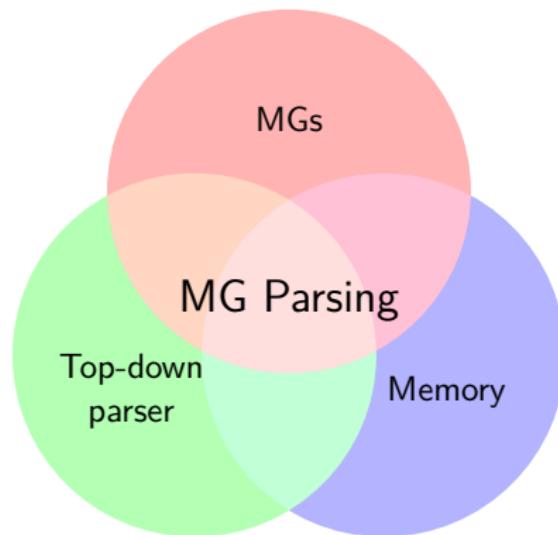
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A Formal Model of Sentence Processing



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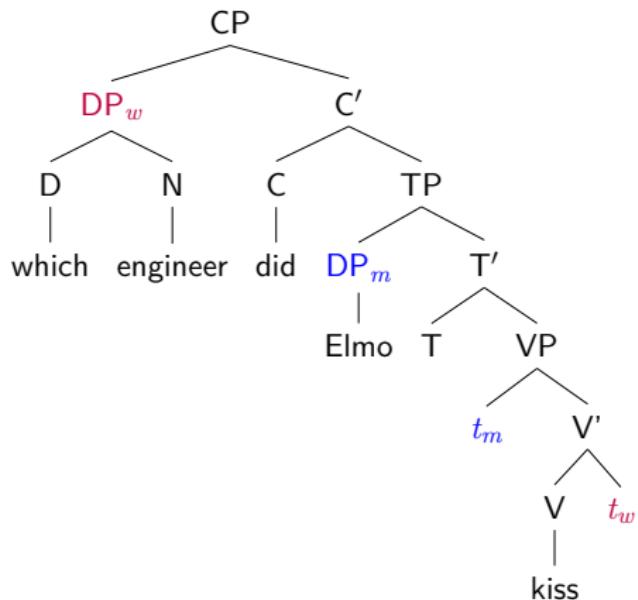
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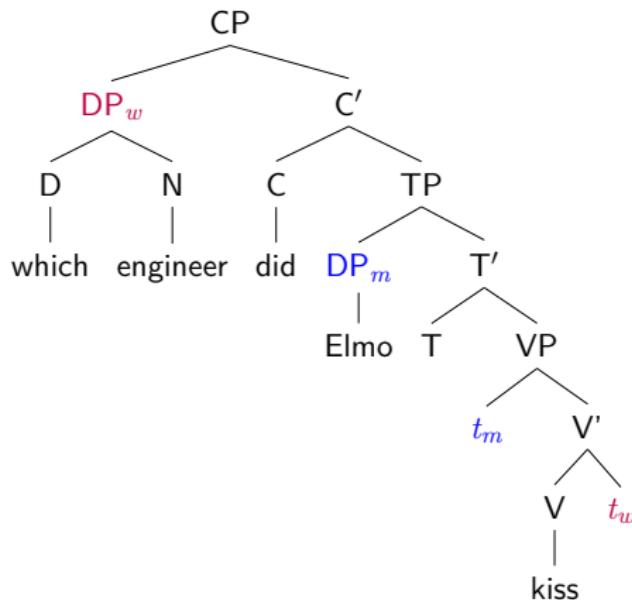
Interpretability for the win!

Minimalist Grammars (MGs) & Derivation Trees

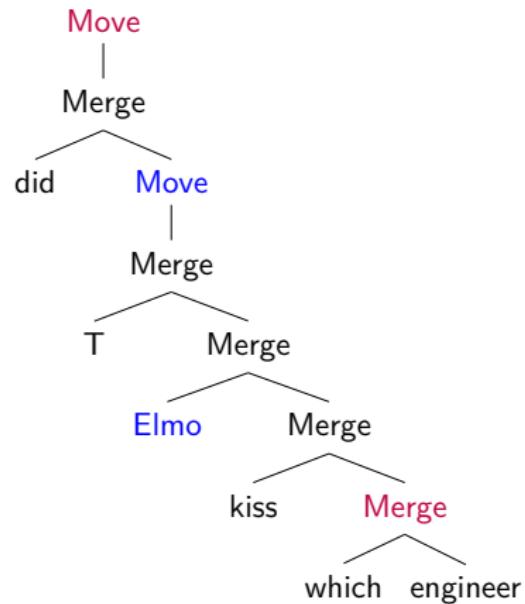


Phrase Structure Tree

Minimalist Grammars (MGs) & Derivation Trees

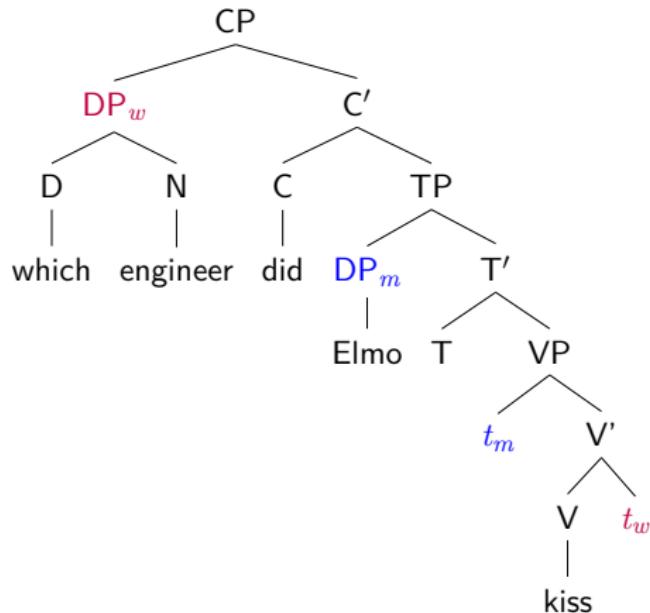


Phrase Structure Tree



Derivation Tree

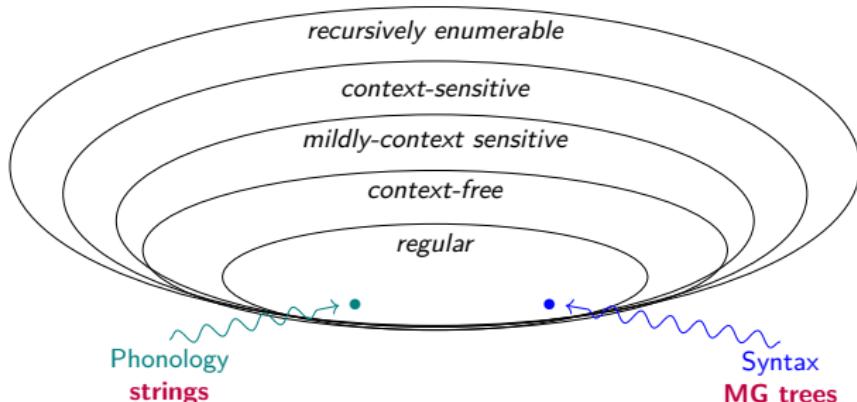
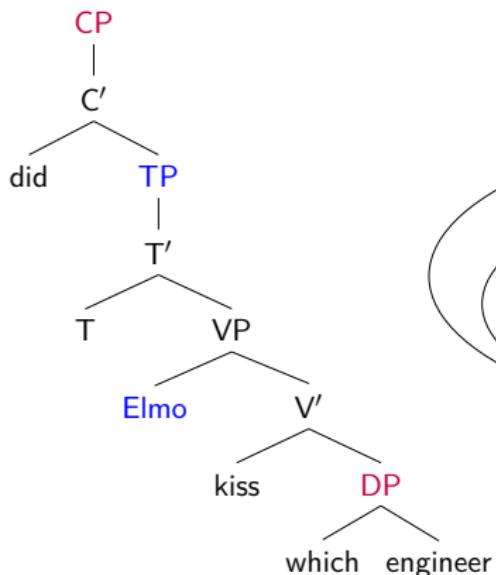
MG Syntax: Derivation Trees



Phrase Structure Tree

Derivation Tree

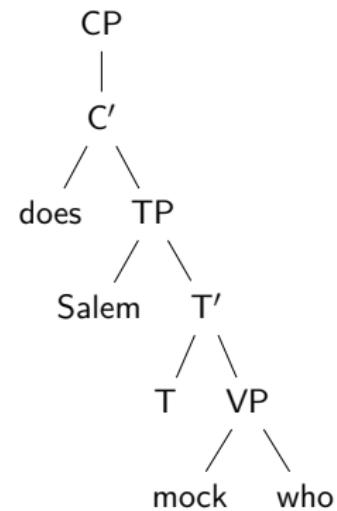
Regular Tree Languages³



³ Thatcher (1967), Kobele et al. (2007), Stabler (2013)

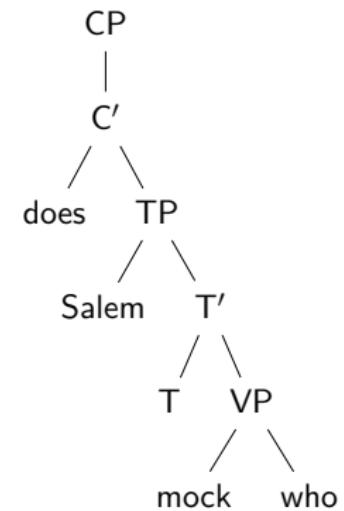
The Job of a Parser

Who does Salem mock?



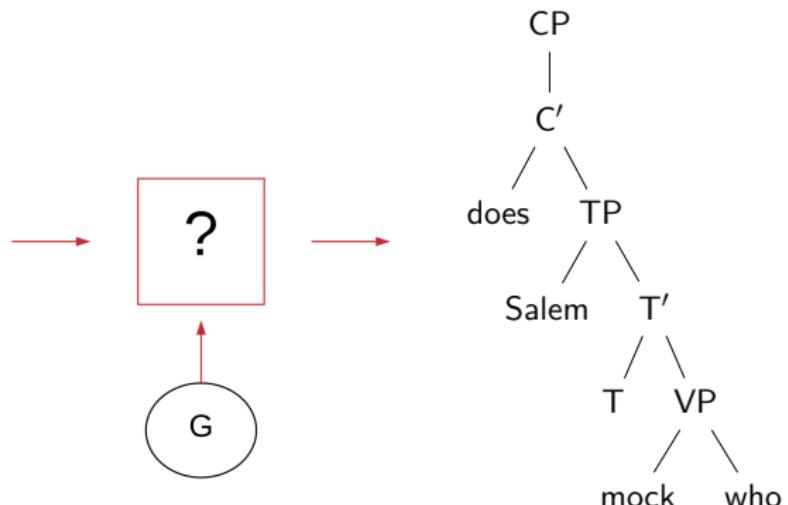
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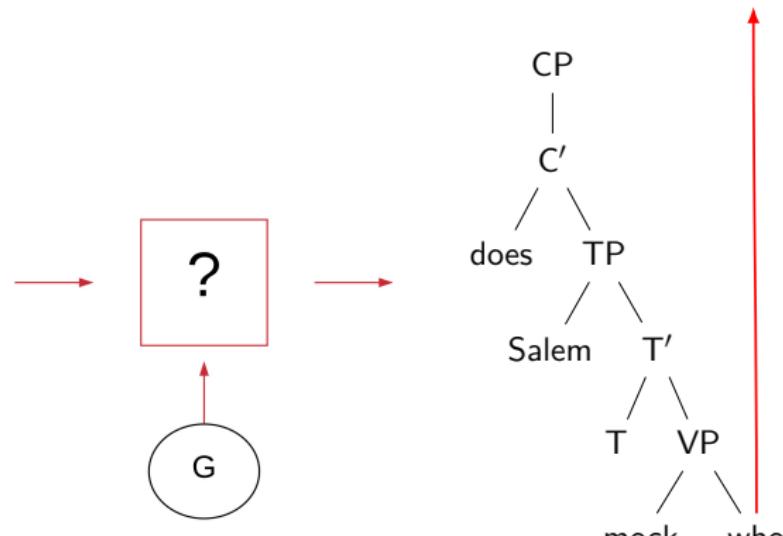
The Job of a Parser

Who does Salem mock?



The Job of a Parser

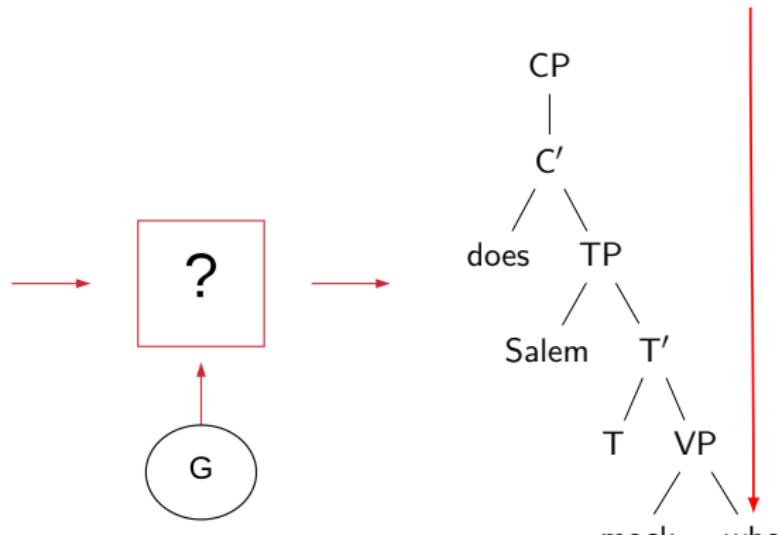
Who does Salem mock?



► Bottom-up

The Job of a Parser

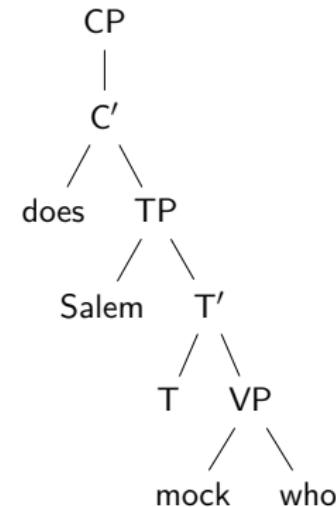
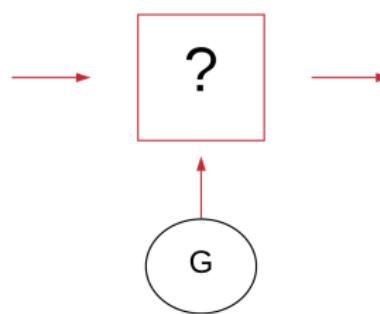
Who does Salem mock?



- ▶ Bottom-up
- ▶ Top-down

The Job of a Parser

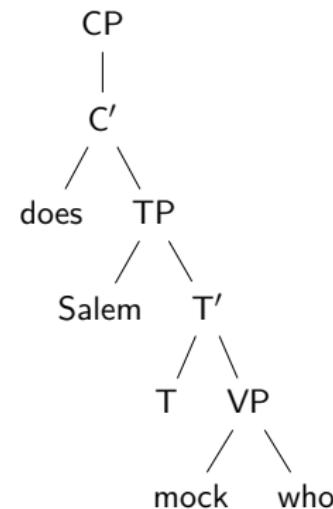
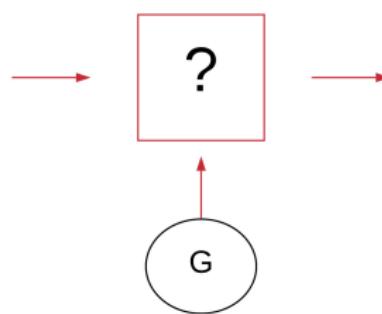
Who does Salem mock?



- ▶ Bottom-up
- ▶ Top-down (Stabler, 2013)
 - ▶ Psychologically plausible(-ish)

The Job of a Parser

Who does Salem mock?



- ▶ Bottom-up
- ▶ Top-down (Stabler, 2013)
 - ▶ Psychologically plausible(-ish)
 - ▶ Assumption: Parser as an oracle!

Incremental Top-Down Parsing: The Intuition

Who does Salem mock?

Incremental 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!

Incremental Top-Down Parsing: The Intuition

CP
|
C'

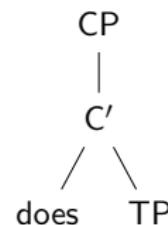


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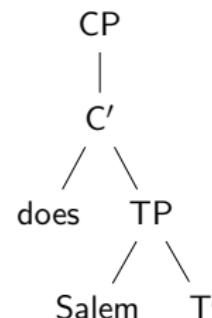
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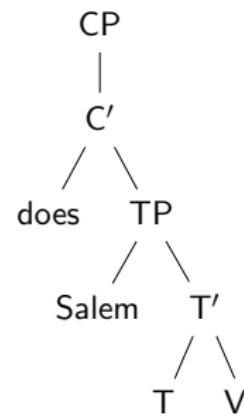
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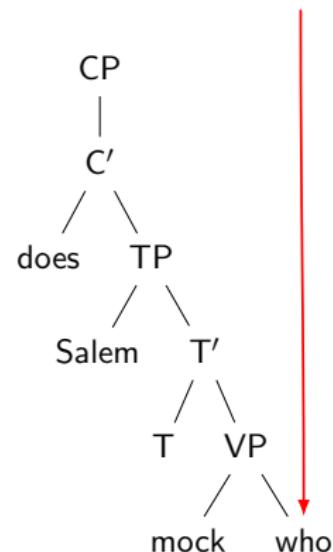
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Memory-Based Complexity Metrics

► **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 offline **complexity metrics**

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

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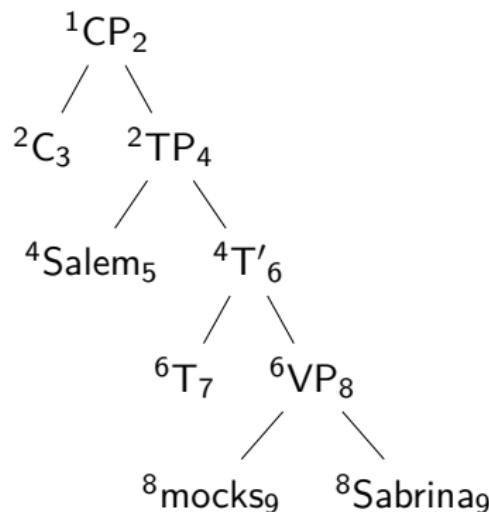
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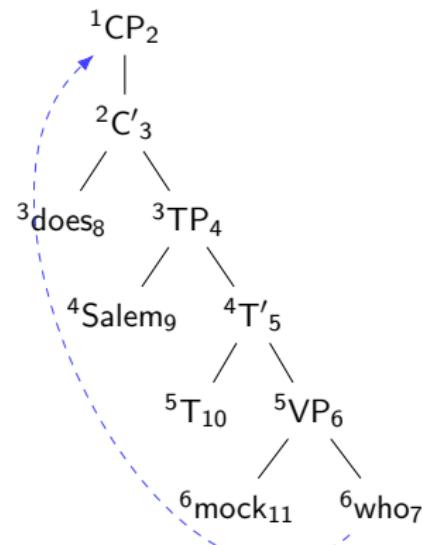
MaxTenure $\max(\{\text{tenure-of}(n) \mid n \text{ a node of the tree}\})$

Contrasting Derivations

MaxTenure = 2



MaxTenure = 5



Summary of the Approach

A Computational Linking Hypothesis (De Santo, 2020)

Grammar \rightleftharpoons MG Parser Effort \rightleftharpoons Gradience

General Idea

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

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

A Proof of Concept: Back to Island Effects

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

Results in pairwise comparisons ideal for the MG parser

A Proof of Concept: Back to Island Effects

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Gradience in Islands: Sprouse et al. (2012)

A factorial design for islands effects:

- 1 GAP POSITION: Matrix vs. Embedded
- 2 STRUCTURE: Island vs. Non-Island
(Kluender & Kutas 1993)

Results in pairwise comparisons ideal for the MG parser

A Proof of Concept: Back to Island Effects

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

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Sprouse et al. (2012)

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*?

GAP POSITION × STRUCTURE

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

Modeling Results (De Santo 2020)

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

Modeling Results (De Santo 2020)

Island Type	Spouse et al. (2012)		MG Parser
Subj. Island 1	Subj. Non Isl.	>	Obj. Non Isl. ✓
	Subj. Non Isl.	>	Obj. Isl. ✓
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	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

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

Processing Asymmetries All the Way Down

A variety of processing insights!

Across Many Constructions

- ▶ Right > center embedding (Kobele et al. 2012)
- ▶ Crossing > nested dependencies (Kobele et al. 2012)
- ▶ SRC > ORC
(Graf et al. 2017; De Santo 2020; Fiorini, Chang, De Santo 2023)
- ▶ Priming/Stacked RCs (De Santo 2020, 2022)
- ▶ Postverbal subjects
(De Santo 2019, 2021; Del Valle & De Santo 2023)
- ▶ Persian attachment ambiguities (De Santo & Shafiei 2019)
- ▶ RC attachment preferences
(De Santo & Lee 2022; Lee & De Santo 2023)

Across Languages

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

Summary

Gradience from a categorical MG grammar?

- ▶ The **first** (quantitative) model of this kind!
- ▶ Overall, a success! ⇒ **just** from structural differences!
- ▶ Outlier is expected (and makes predictions!)

The tip of the iceberg!

- ▶ Modulate range of dependencies
- ▶ Other examples of gradience
- ▶ Cognitive vs. grammatical constraints? (Ferrara-Boston 2012)
- ▶ Syntactic constraints ~ pruning the parsing space
(Stabler 2013, Graf & De Santo 2020)
- ▶ Economy principles (De Santo & Lee 2022)

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Outline

- 1 Theory Building**
- 2 Linguistics and Formal Language Theory**
- 3 MG Parsing as a Model of Gradience**
- 4 Conclusion**

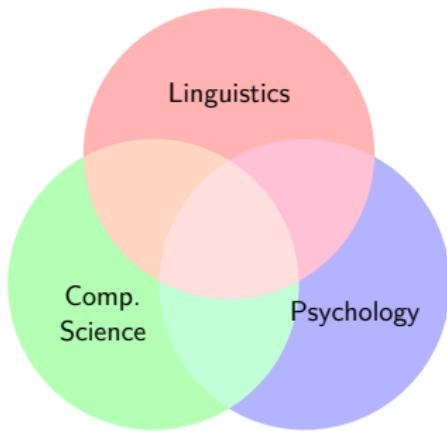
From the Trees (back) to the Forest

[...] this is a confusion of two quite separate issues, **simulation and explanation**. [...] What we are **really** interested in [...] is explanation — in developing models that help us **understand how it is that people behave** that way, not merely demonstrating that we can build an artifact that behaves similarly.

(Kaplan, 1995)

- ▶ Invariant properties of phenomena
- ▶ Implementations of verbal theories

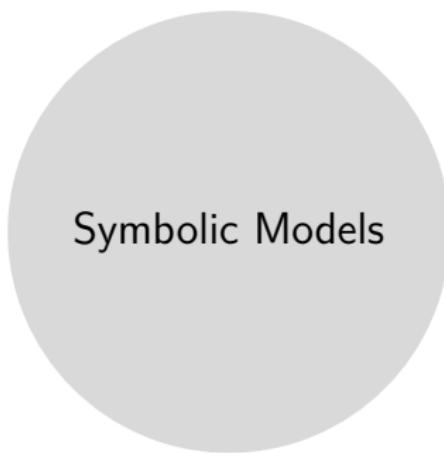
Embracing Multidisciplinarity



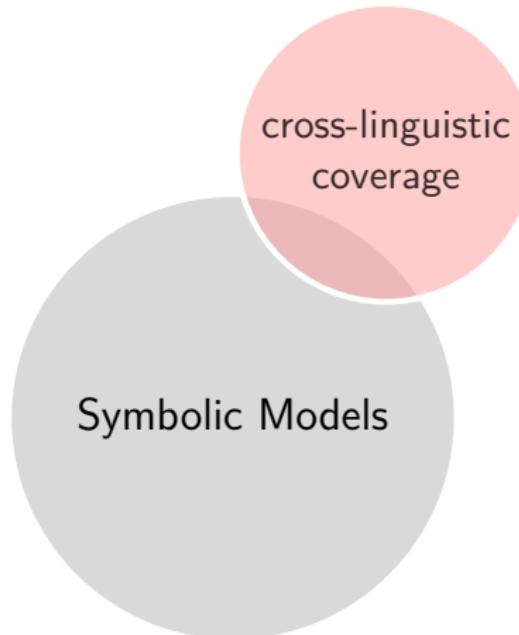
Within the program of research proposed here, joint work by linguists, computer scientists, and psychologists could lead to a deeper scientific understanding of the role of language in cognition.

(Bresnan 1978: pg. 59)

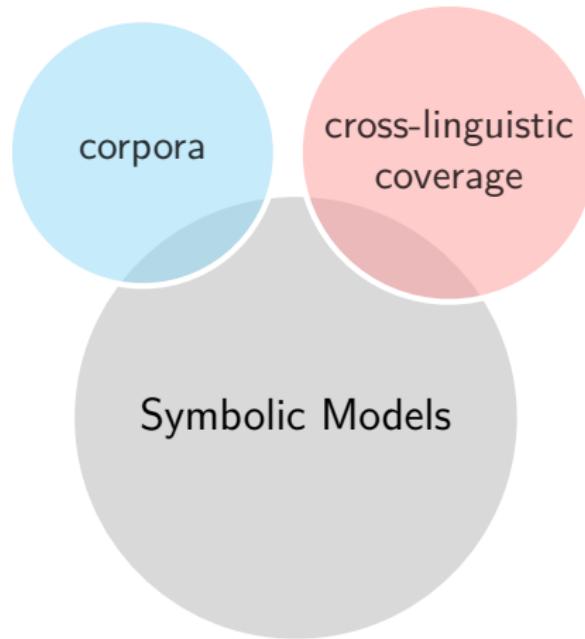
Looking Ahead: A Collaborative Enterprise



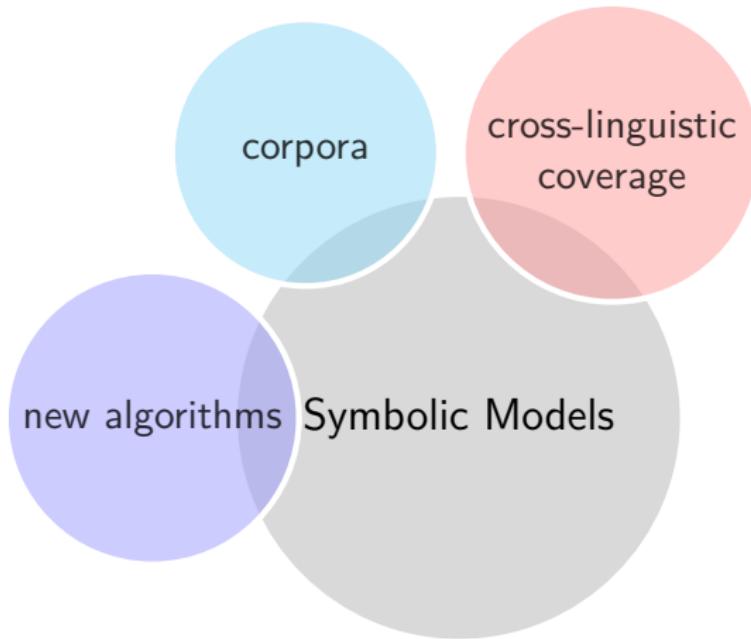
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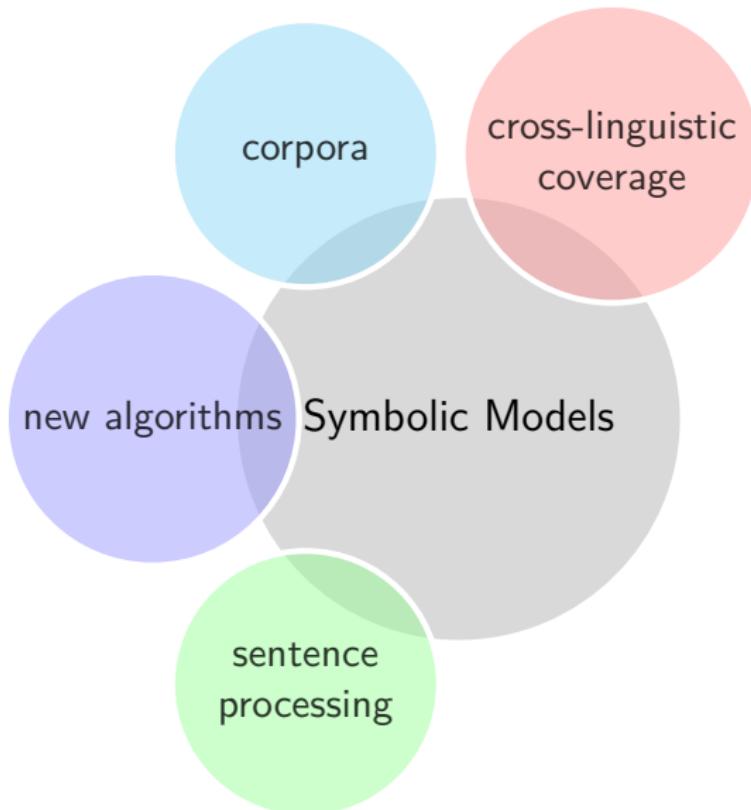
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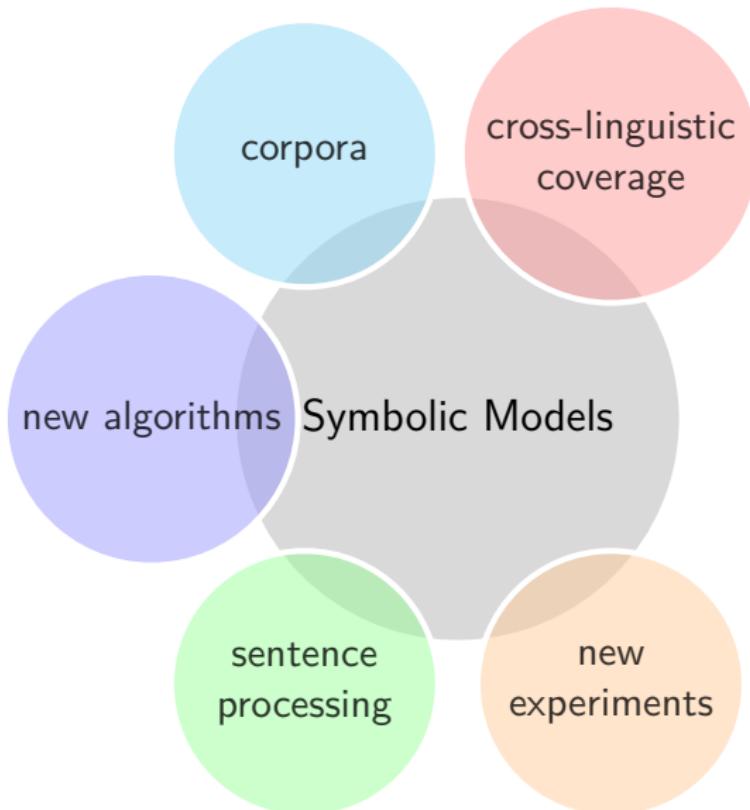
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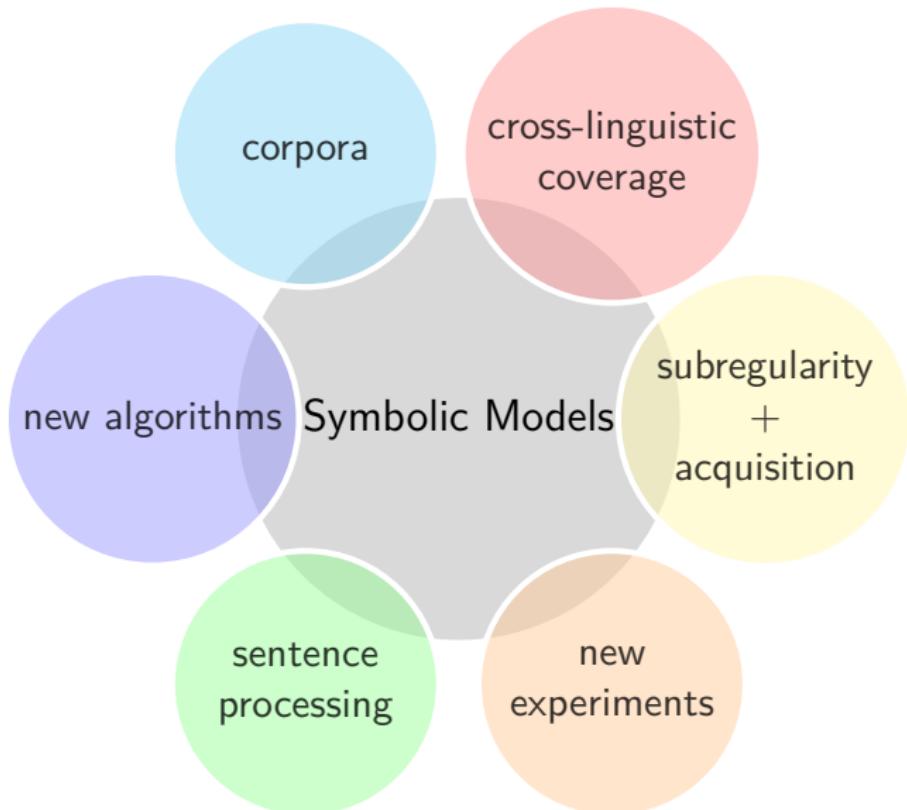
Looking Ahead: A Collaborative Enterprise



Looking Ahead: A Collaborative Enterprise



Looking Ahead: A Collaborative Enterprise



Looking Ahead: A Collaborative Enterprise



Looking Ahead: A Collaborative Enterprise



Selected References I

- 1** Applegate, R.B. 1972. Ineseno chumash grammar. Doctoral Dissertation, University of California,Berkeley.
- 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. In *Proceedings of SCiL 2020*, Jan 2-5, New Orleans.
- 4** De Santo, A. & Aksenova, A. (2021). Learning Interactions of Local and Non-Local Phonotactic Constraints from Positive Input. In *Proceedings of SCiL*
- 5** De Santo, A. and Graf, T. 2019. Structure sensitive tier projection: Applications and formal properties. *Proceedings of FG*.
- 6** De Santo, A. & Rawski, J. (2022). Mathematical Linguistics and Cognitive Complexity. In *Handbook of Cognitive Mathematics* (pp. 1-38).
- 7** Graf, T. and Monette, J. and Zhang, C. (2017). Relative Clauses as a Benchmark for Minimalist Parsing. *Journal of Language Modelling*.
- 8** Kobele, G.M., Gerth S., and Hale. J. (2012). Memory resource allocation in top-down minimalist parsing. In *Formal Grammar*, pages 32–51. Springer.
- 9** Stabler, E.P. (2013). Bayesian, minimalist, incremental syntactic analysis. *Topics in Cognitive Science* 5:611–633.

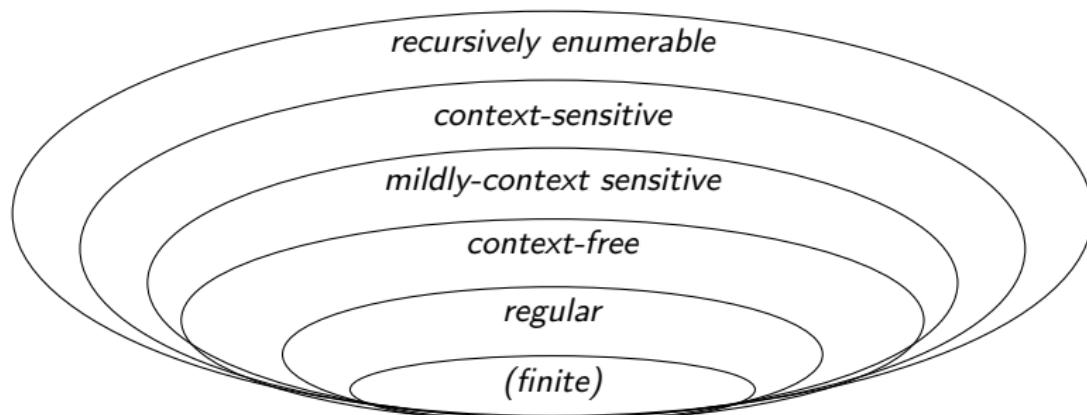
Appendix

Kaplan's Full Quote

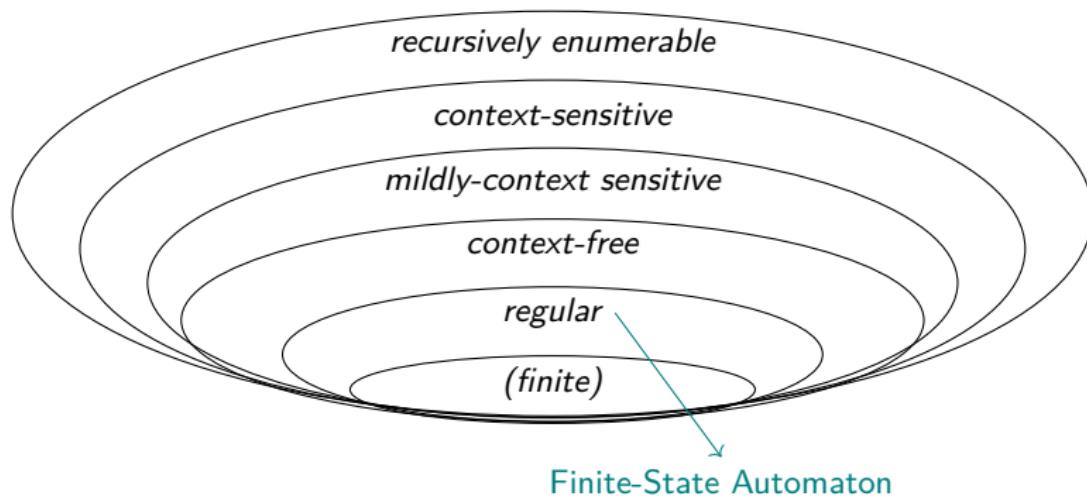
[...] this is a confusion of two quite separate issues, simulation and explanation. As scientists, we are not merely interested in simulating human behavior [...] What we are really interested in [...] is explanation — in developing models that help us **understand how it is that people behave** that way, not merely demonstrating that we can build an artifact that behaves similarly. [...] We should look for modular theories that account for the observed interactions in terms of the interleaving of information from separate, scientifically comprehensible systems

(Kaplan, 1995)

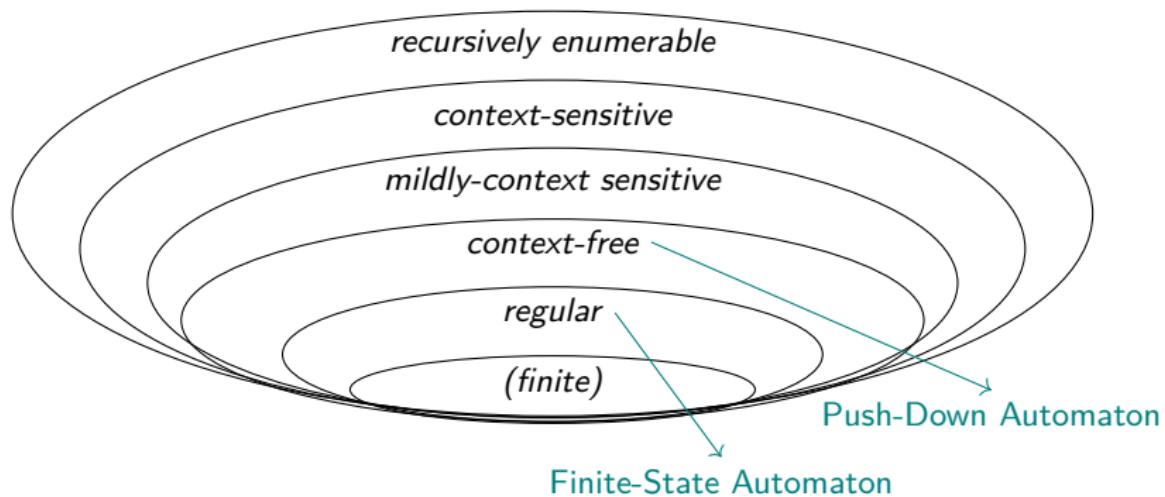
Chomsky Hierarchy and Automata Theory



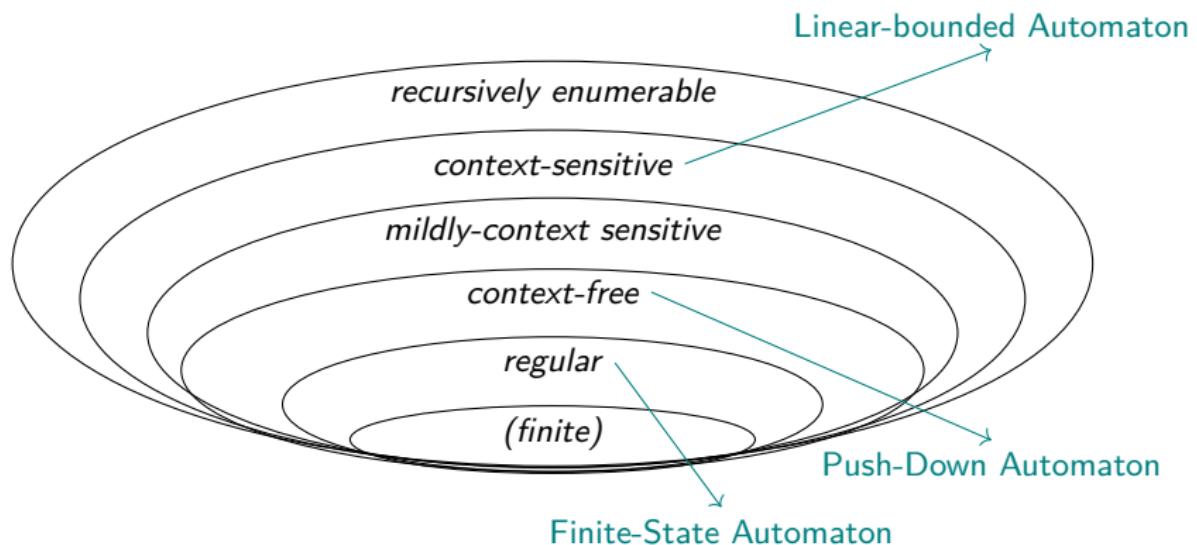
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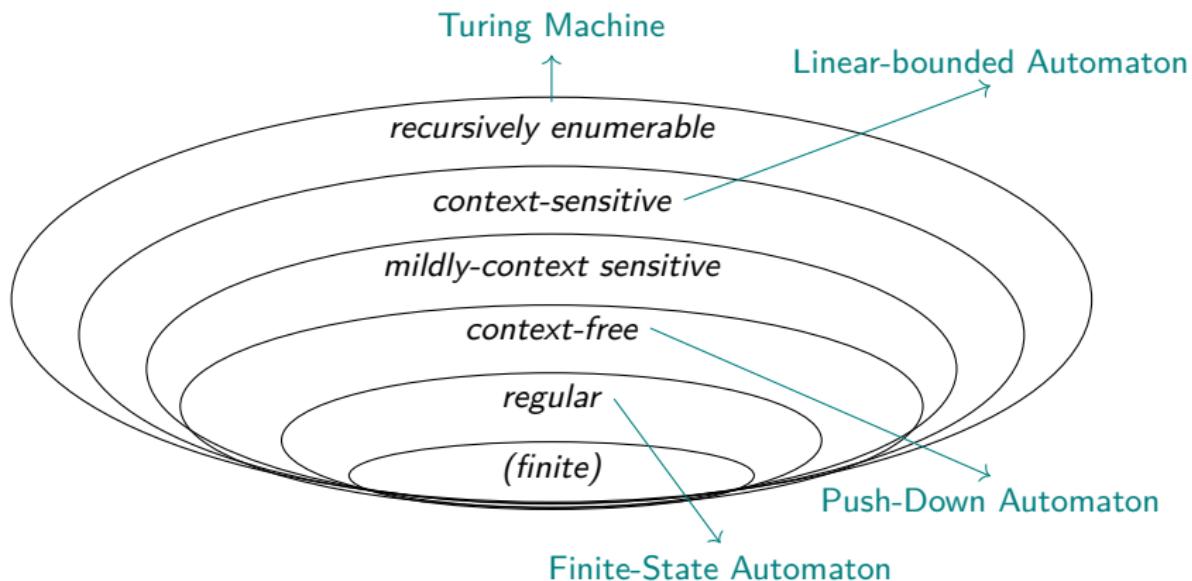
Chomsky Hierarchy and Automata Theory



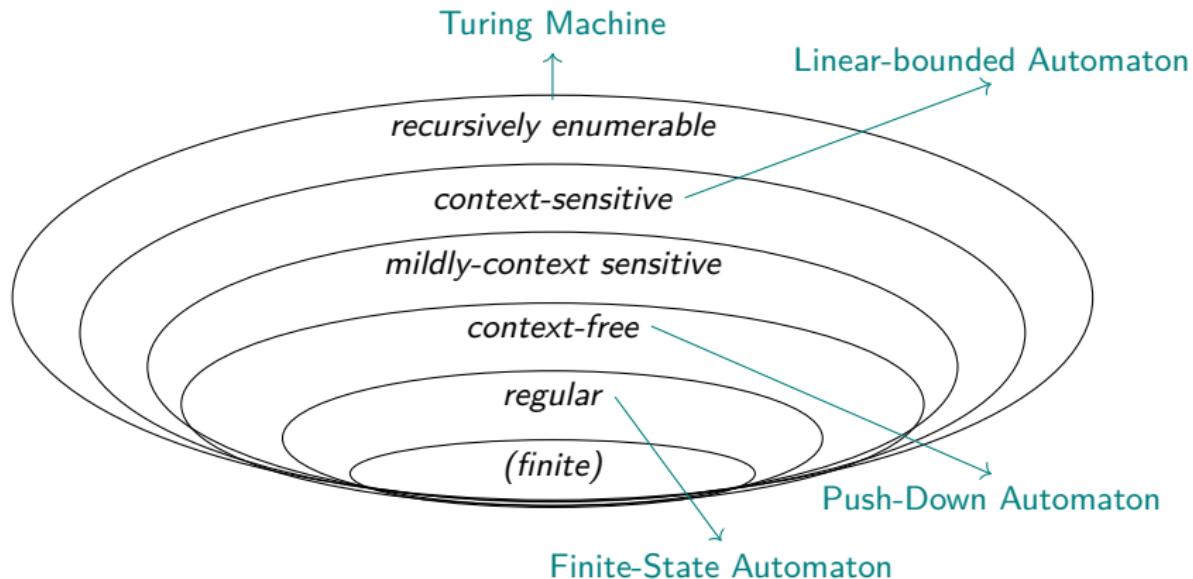
Chomsky Hierarchy and Automata Theory



Chomsky Hierarchy and Automata Theory



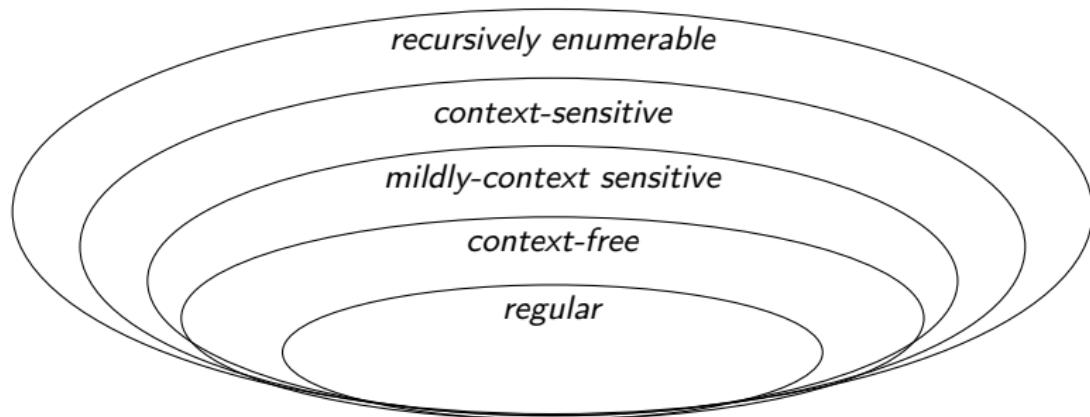
Chomsky Hierarchy and Automata Theory



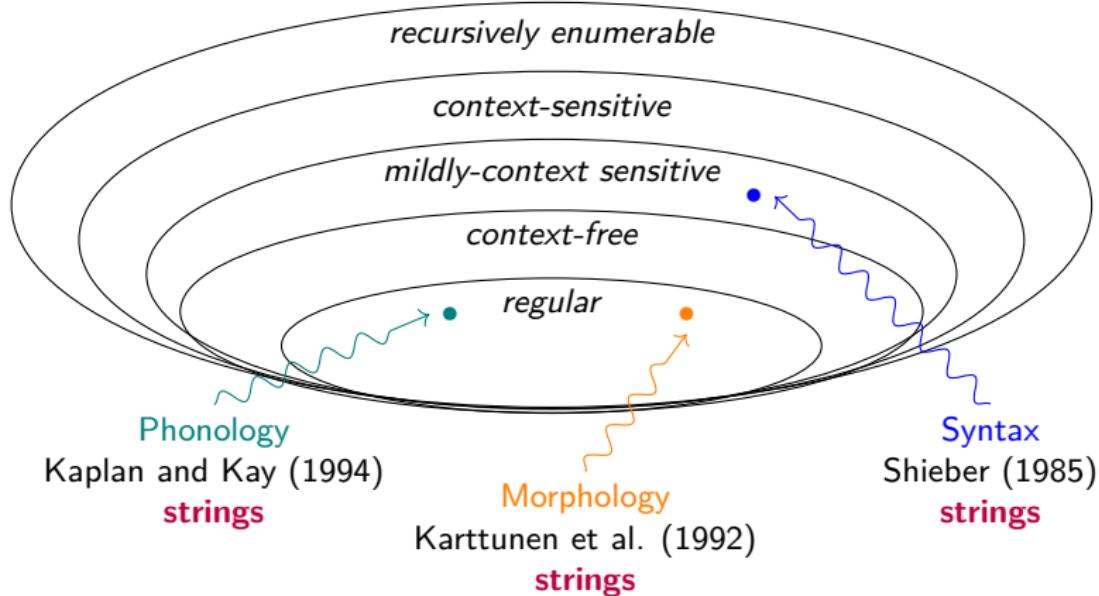
Automata theoretic classes seem to presuppose [...] specific classes of recognition mechanisms, raising questions about whether these are necessarily relevant to the cognitive mechanisms under study.

Rogers & Pullum 2011

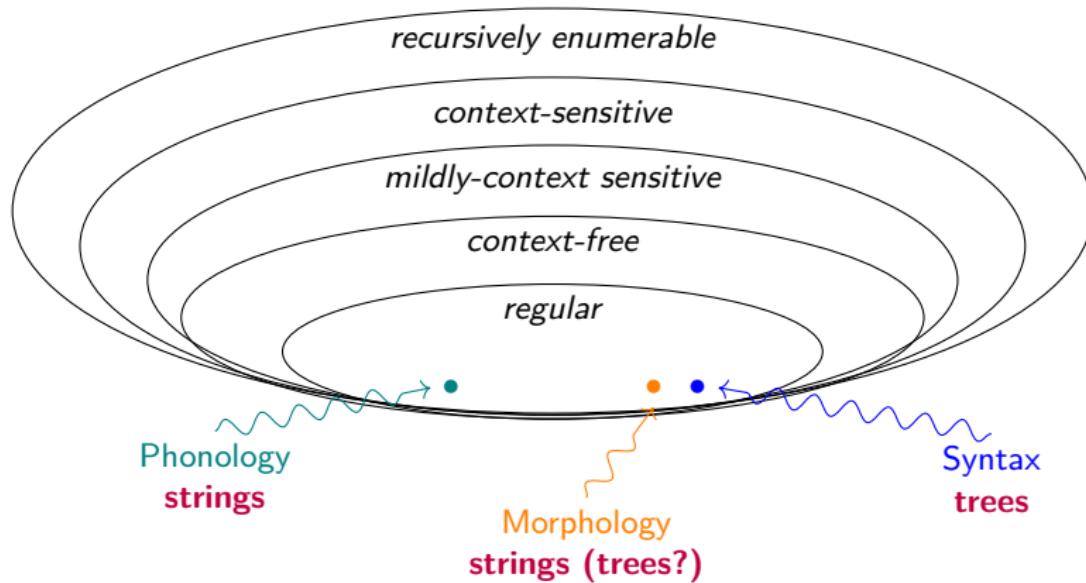
Cross-domain Parallels



Cross-domain Parallels



Cross-domain Parallels



Some Insights

Parallels between phonology and syntax?

- ▶ What would a computational linguist tell you?
Well, it depends!
- ▶ What will I show you?
They are fundamentally similar!

The Take-Home Message

- ▶ Two kind of dependencies: local and non-local
- ▶ The core mechanisms are the same cross-domain
- ▶ That is: linguistic dependencies are **local** over the right structural representations

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The Take-Home Message

- ▶ Two kind of dependencies: local and non-local
- ▶ The core mechanisms are the same cross-domain
- ▶ That is: linguistic dependencies are **local** over the right structural representations

Some Insights

Parallels between phonology and syntax?

- ▶ What would a computational linguist tell you?
Well, it depends!
- ▶ What will I show you?
They are fundamentally similar!

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- ▶ **Two kind of dependencies:** local and non-local
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What about Syntax?

We need a model for syntax ...

- ▶ Minimalist grammars (MGs) are a formalization of Minimalist syntax. (Stabler 1997, 2011)
- ▶ Operations: **Merge** and **Move**
- ▶ Adopt Chomsky-Borer hypothesis:
Grammar is just a finite list of feature-annotated lexical items

Local dependencies in syntax

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category feature N^- , D^- , ...
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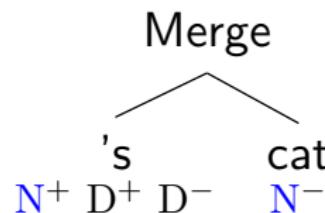
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's cat
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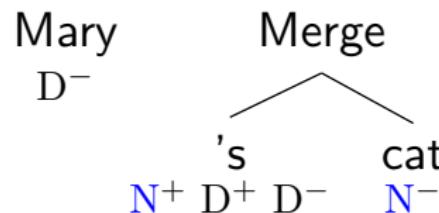
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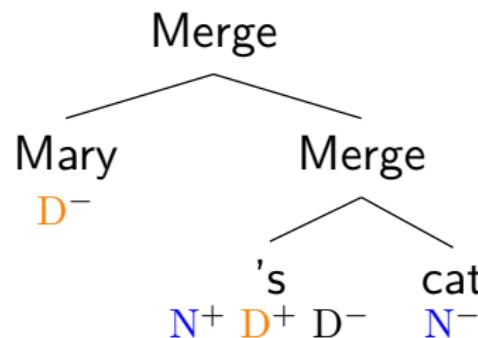
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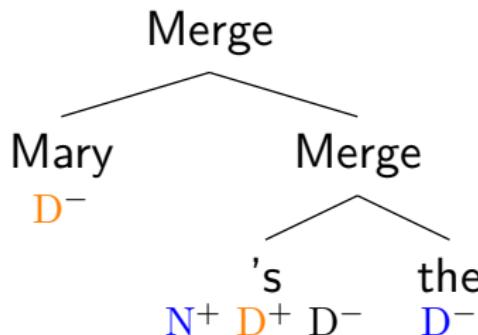
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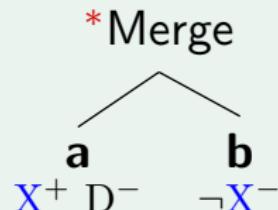


Merge is SL (Graf 2012)

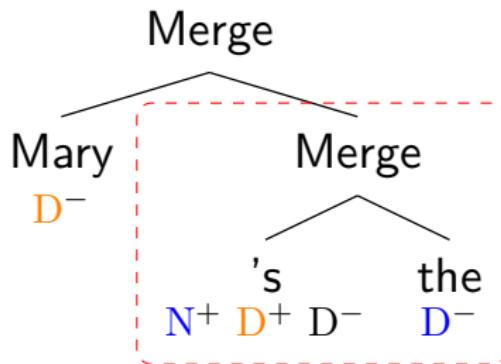


SL constraints on Merge

- ▶ We lift constraints from **string *n*-grams** to **tree *n*-grams**
- ▶ We get SL constraints over subtrees.

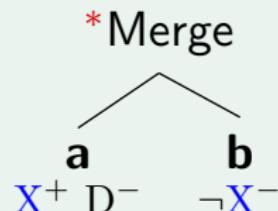


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Interim Summary

	Local	Data Structure
Phonology	?	?
Syntax	?	?

Local phenomena modeled by n -grams of bounded size:

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TSL Phonology: Accounting for Context

► Unbounded Tone Plateauing in Luganda (UTP)

No L may occur within an interval spanned by H.
(Hyman 2011)

- (7) a. **LHLLLL**
b. **LLLLHL**
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L H L L H L
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Example

The diagram illustrates the constraint against tone plateauing. It shows two rows of tones. The top row has a dashed red box around the sequence "L H L L H L". The bottom row shows the same sequence with an asterisk (*) preceding it, indicating it is a prohibited form.

L H L L H L
* L H L L H L

Accounting for Context [cont.]

A TSL analysis for UTP (De Santo and Graf 2017):

- ▶ Project every **H**; project **L** iff immediately follows **H**
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- ▶ Captures wide range of phonotactic dependencies (McMullin 2016)
- ▶ Provably correct and efficient learning algorithms (Jardine and McMullin 2017)
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(cf. Lai 2015, Aksanova et al. 2016, Graf & De Santo 2019, a.o.)

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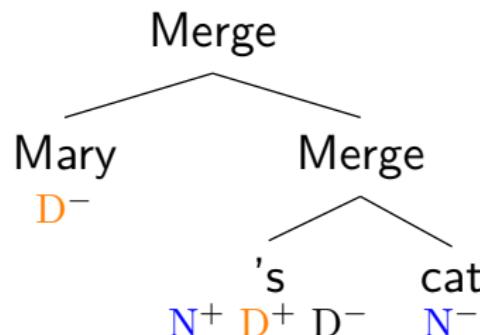
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Non-Local Dependencies in Syntax

Let's stick to core operations:

- ▶ Move
- ▶ Merge?

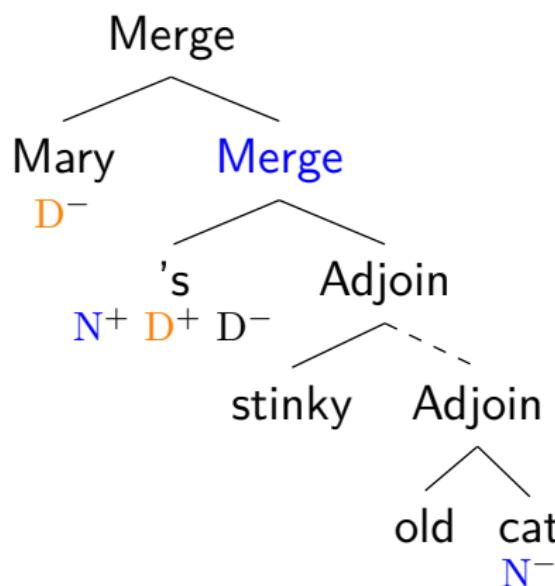


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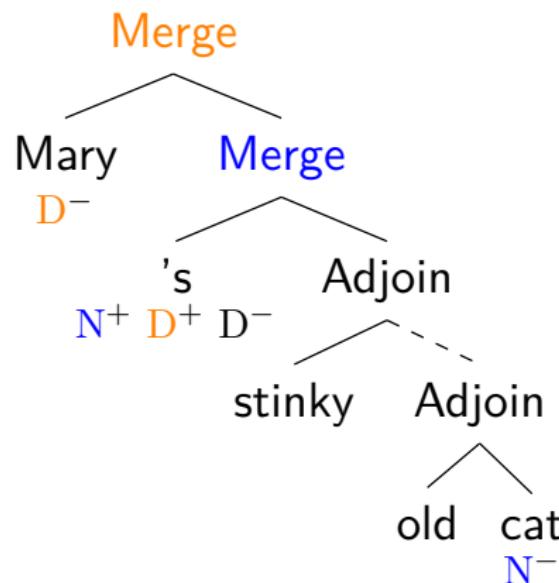
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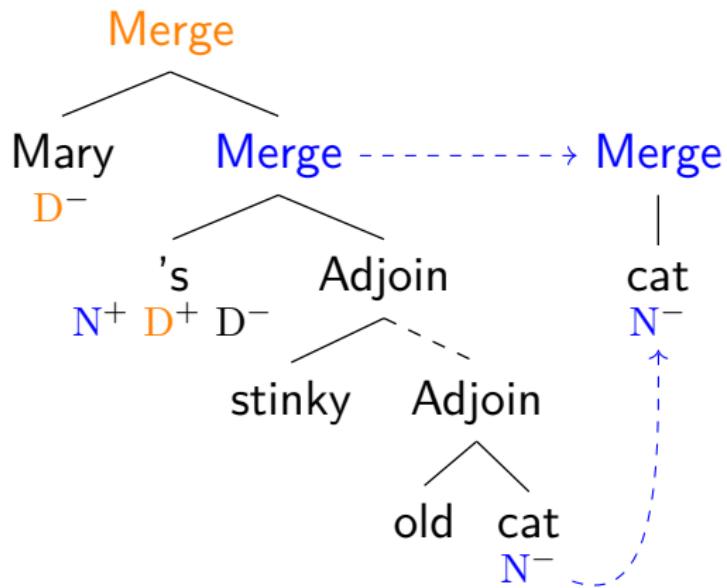
Frey and Gärtner (2002); Graf (2017)



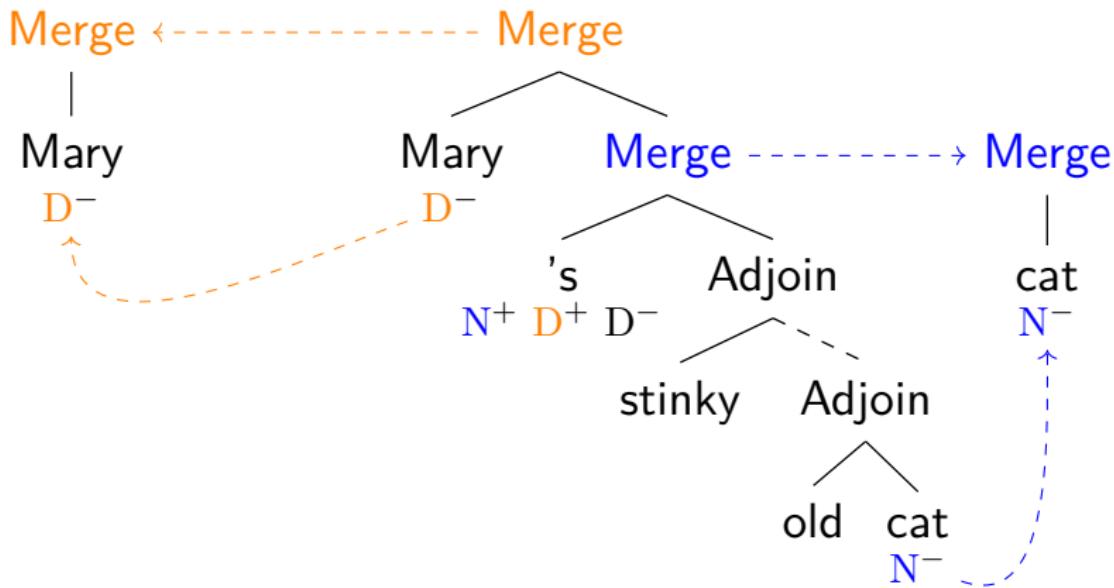
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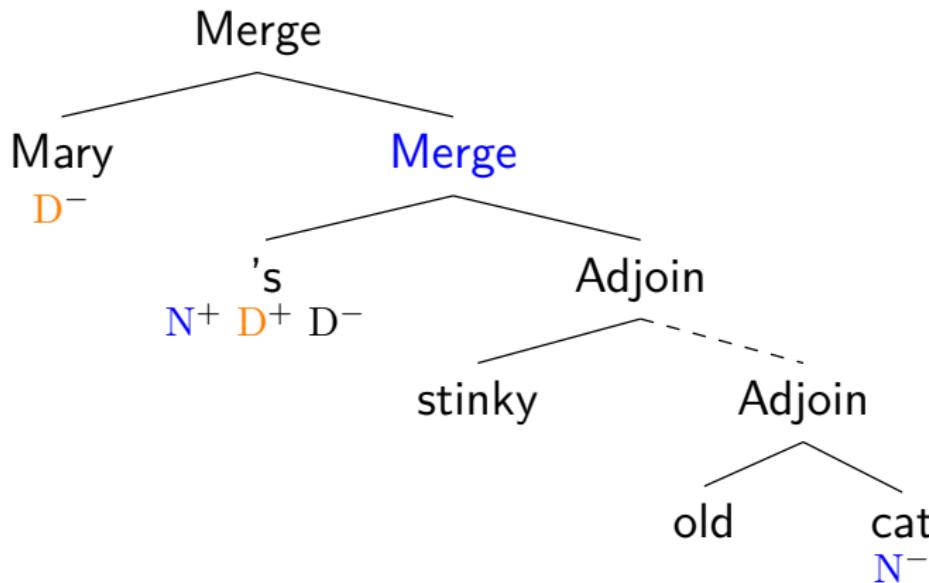
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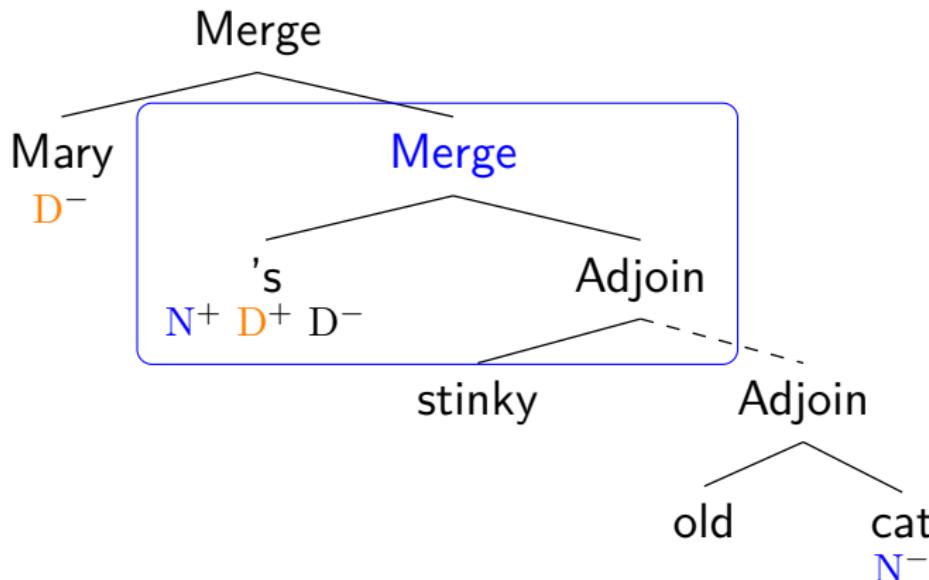


Merge with Adjunction is TSL



A TSL grammar for Merge

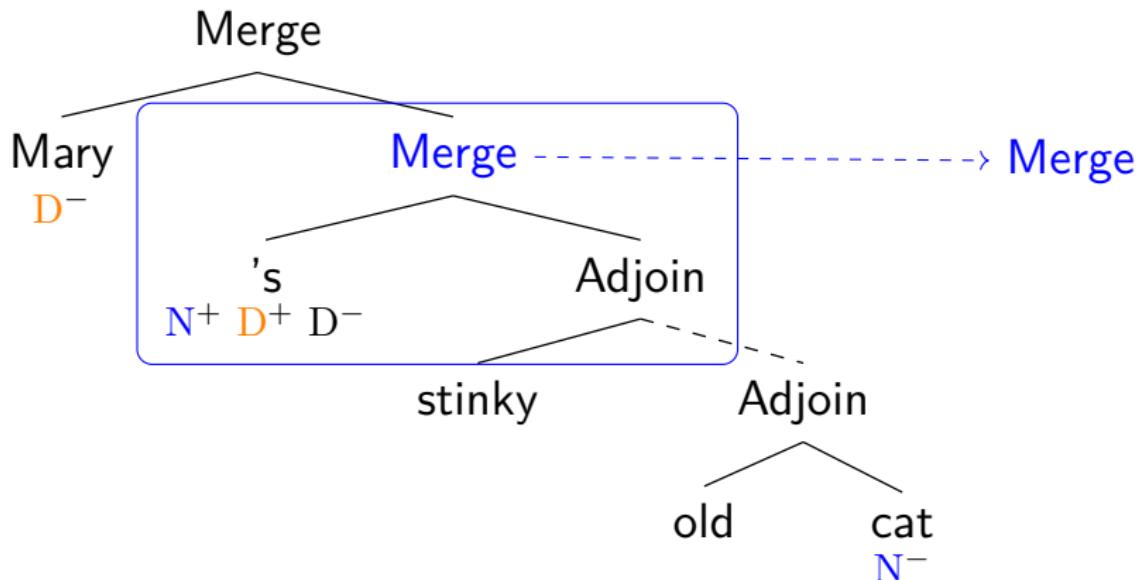
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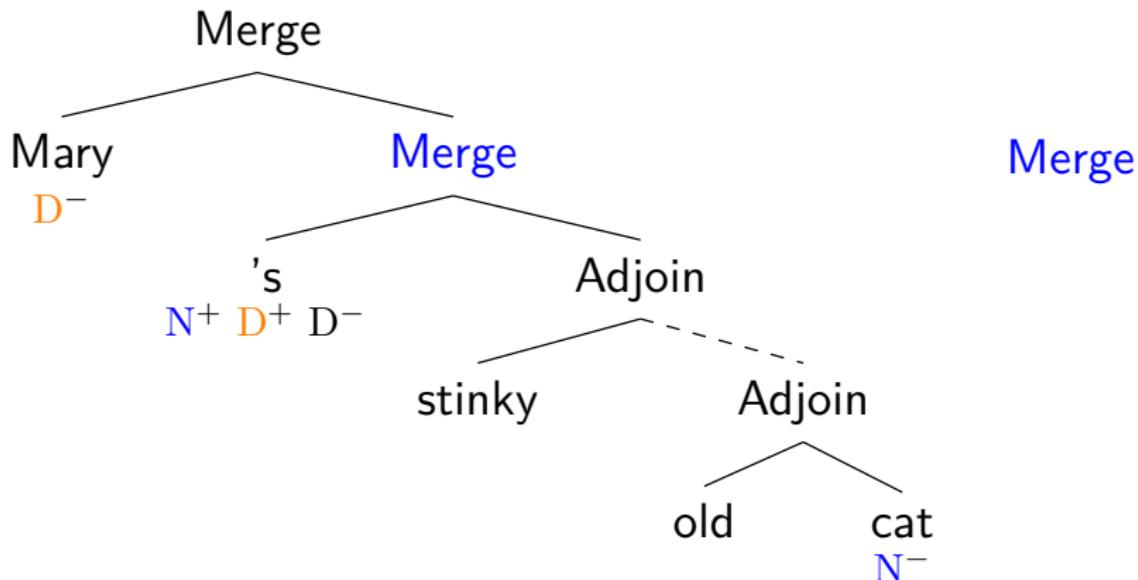
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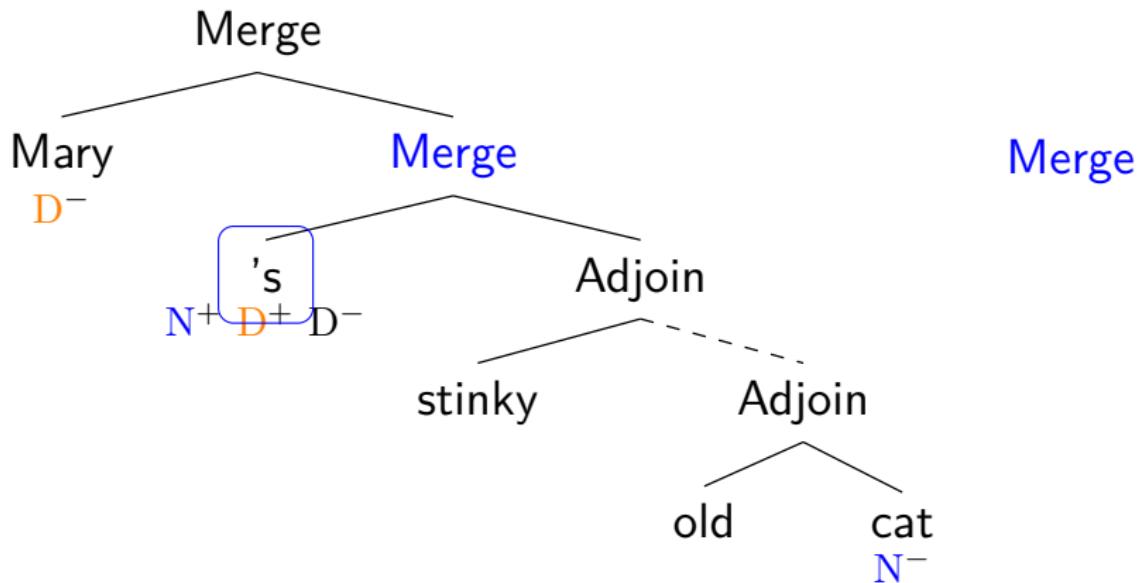
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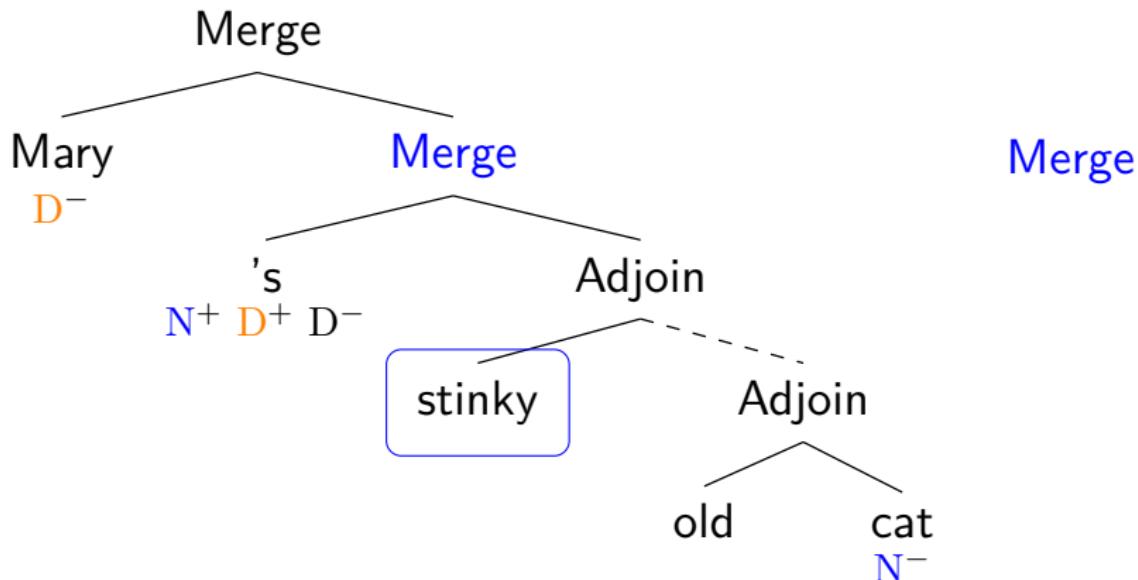
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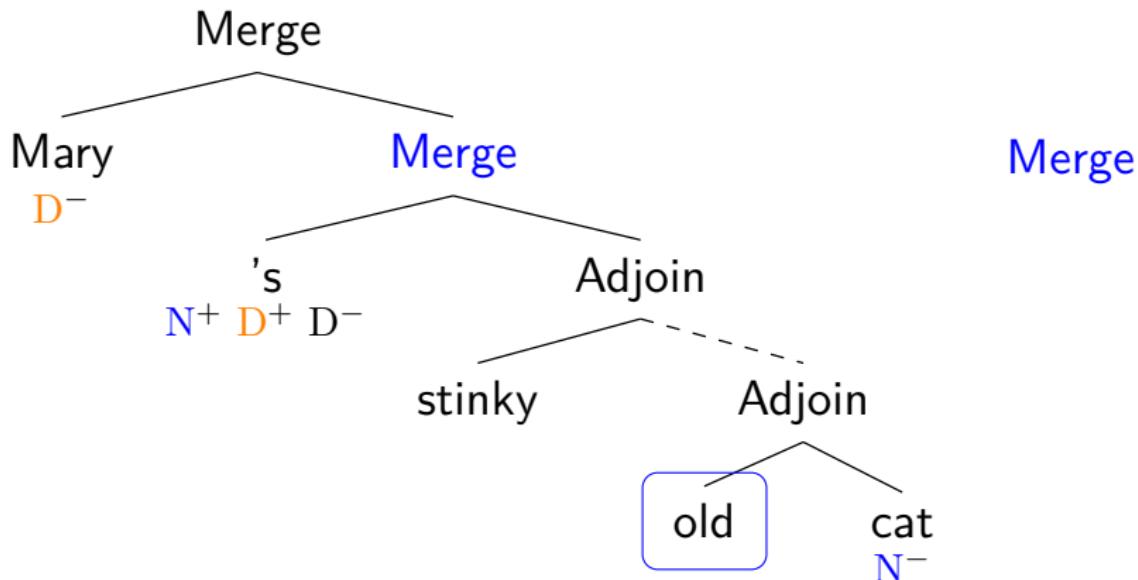
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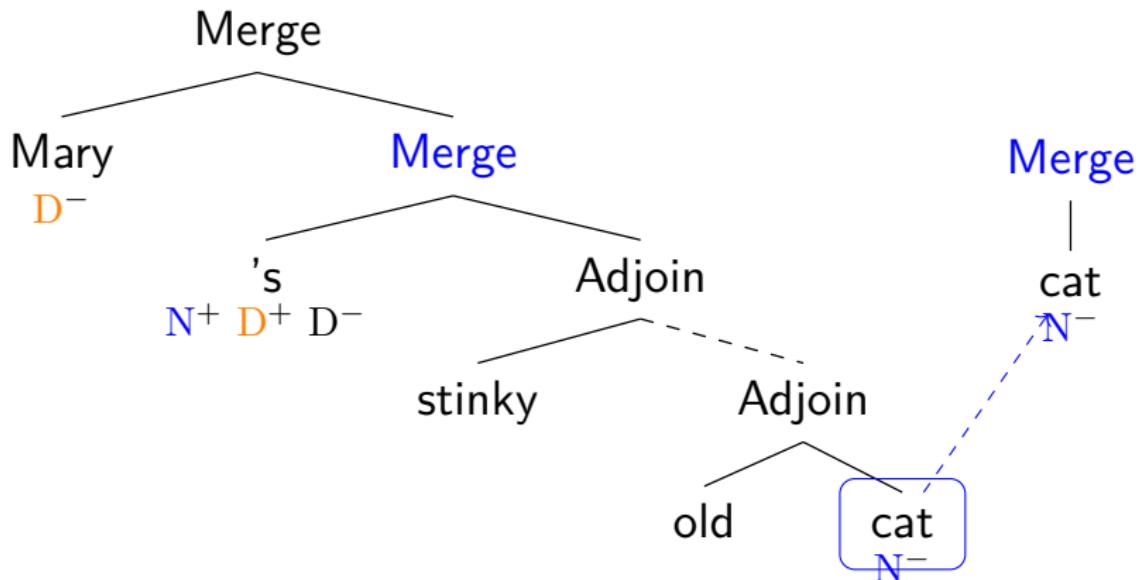
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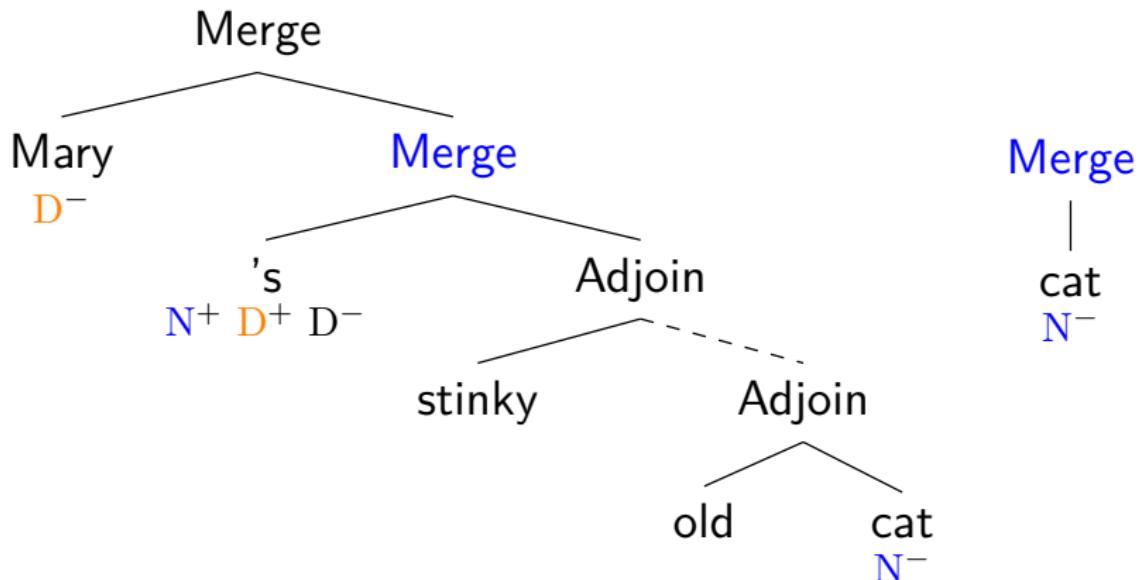
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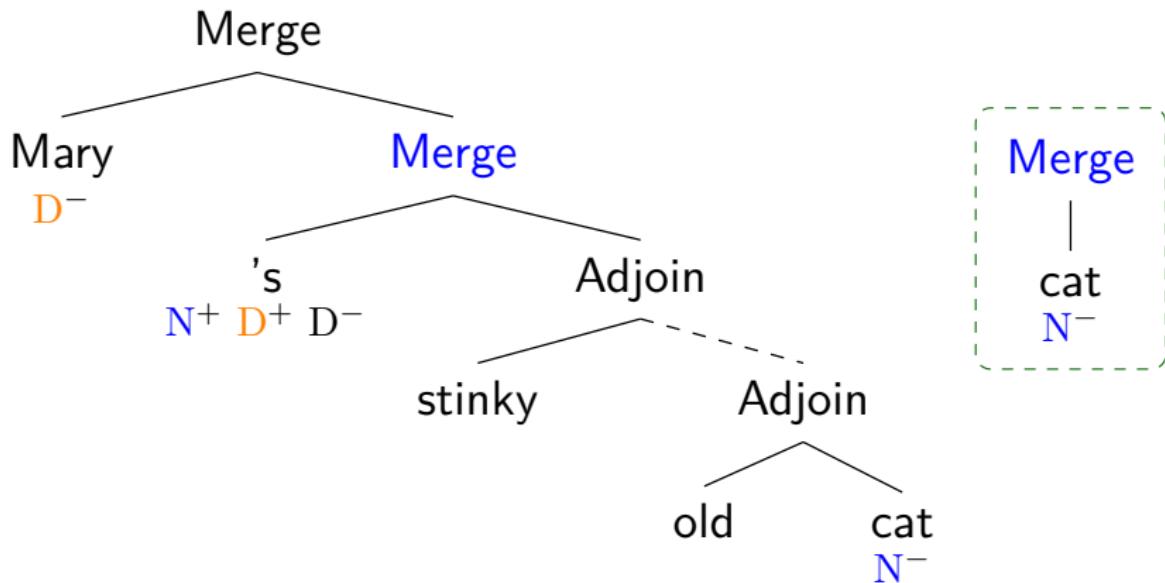
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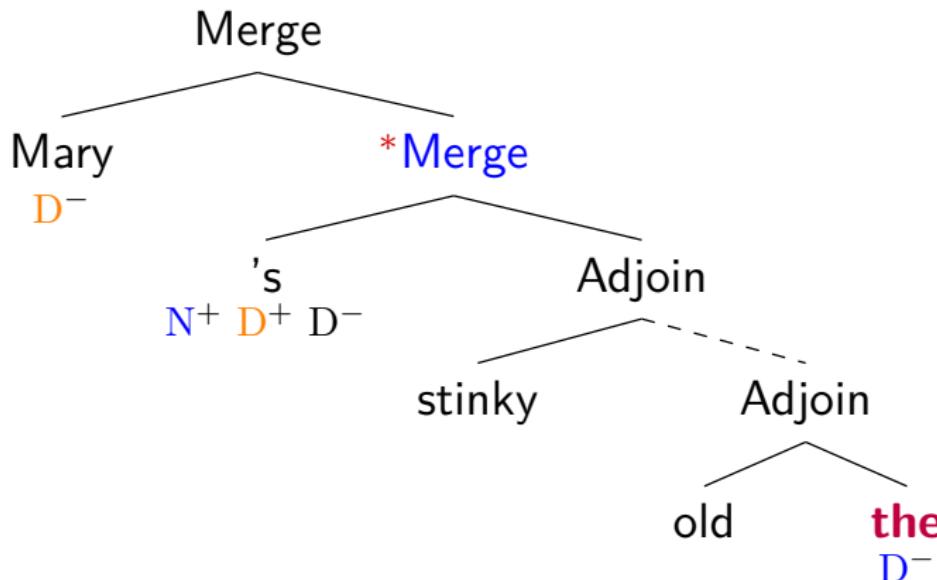
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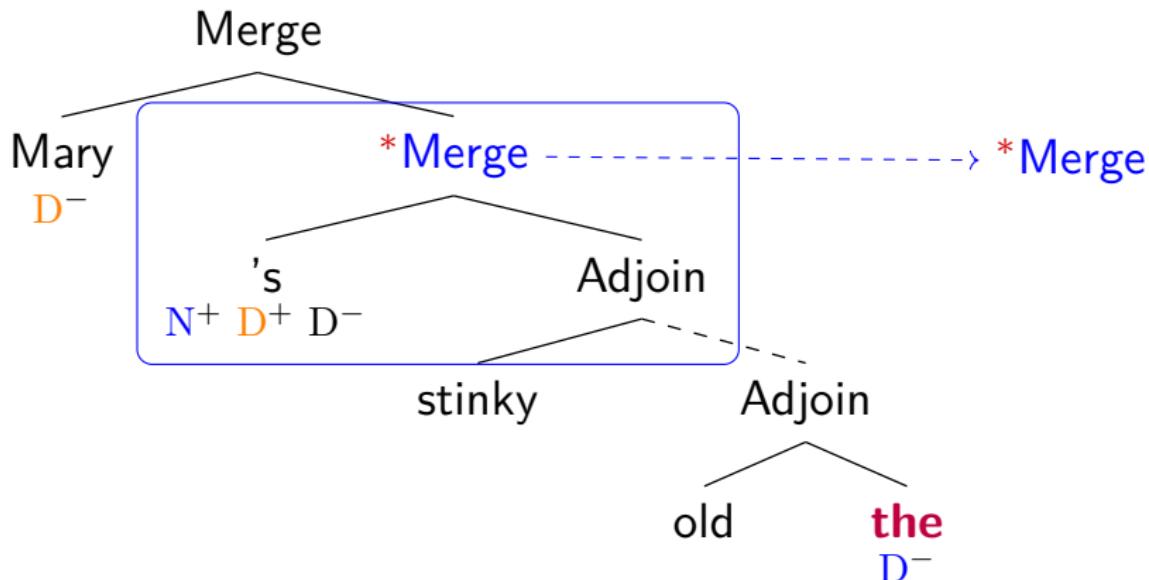
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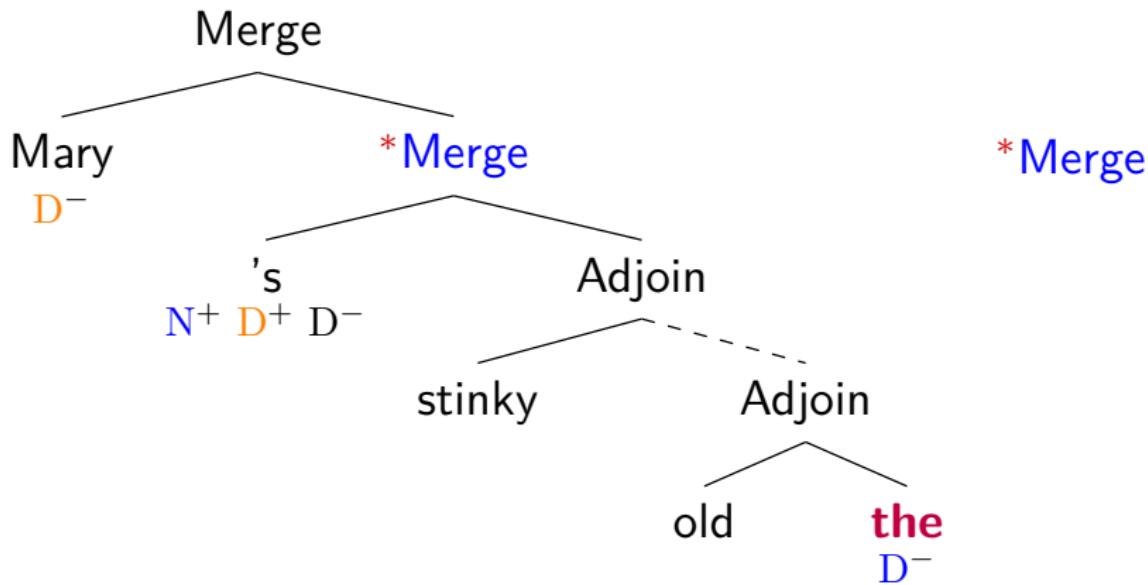
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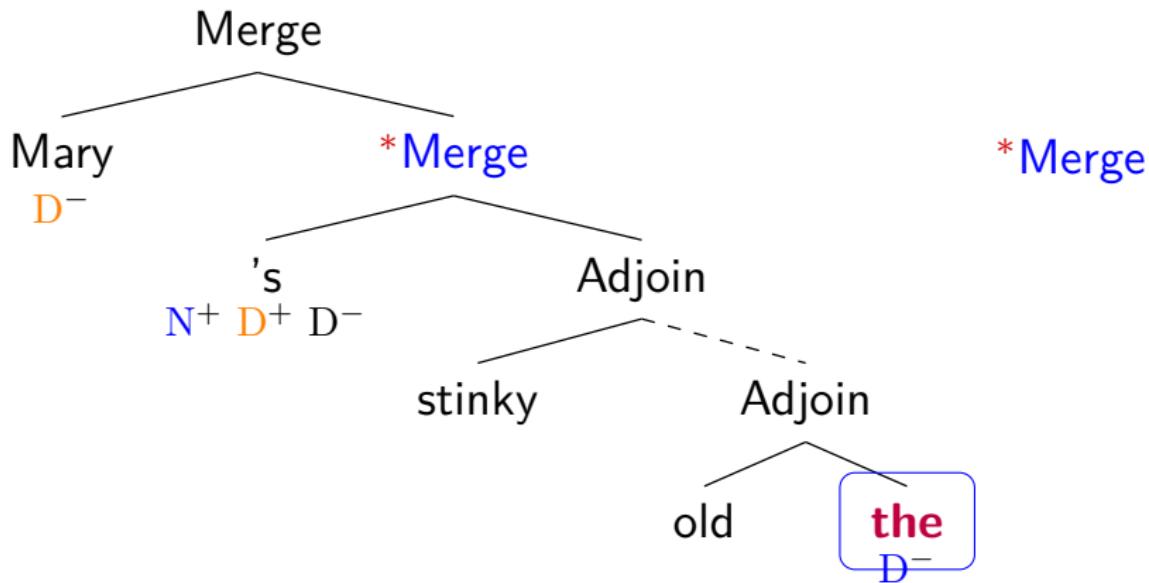
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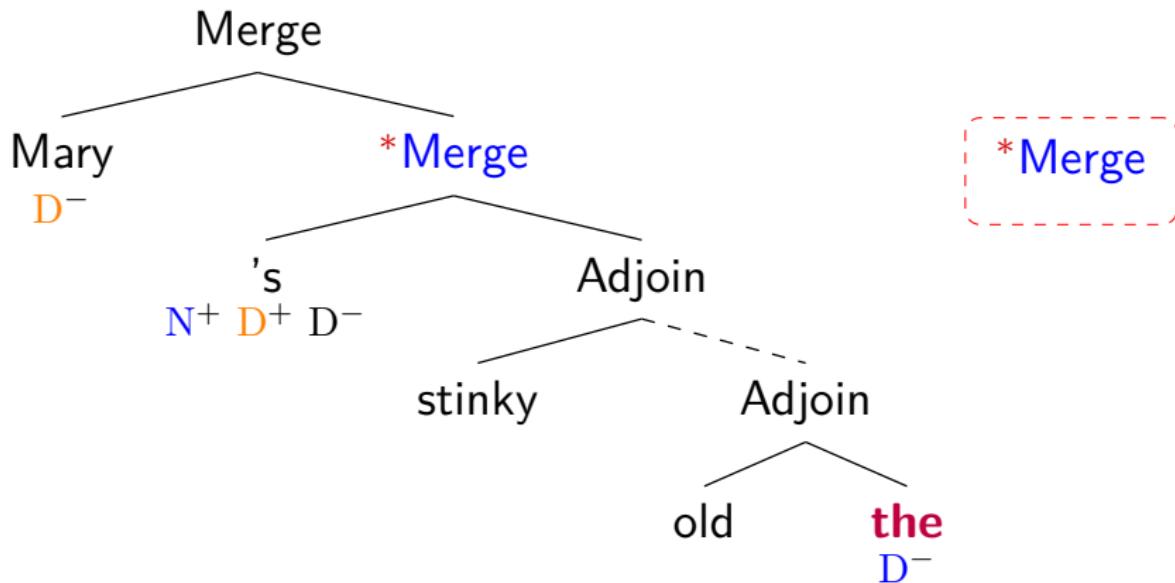
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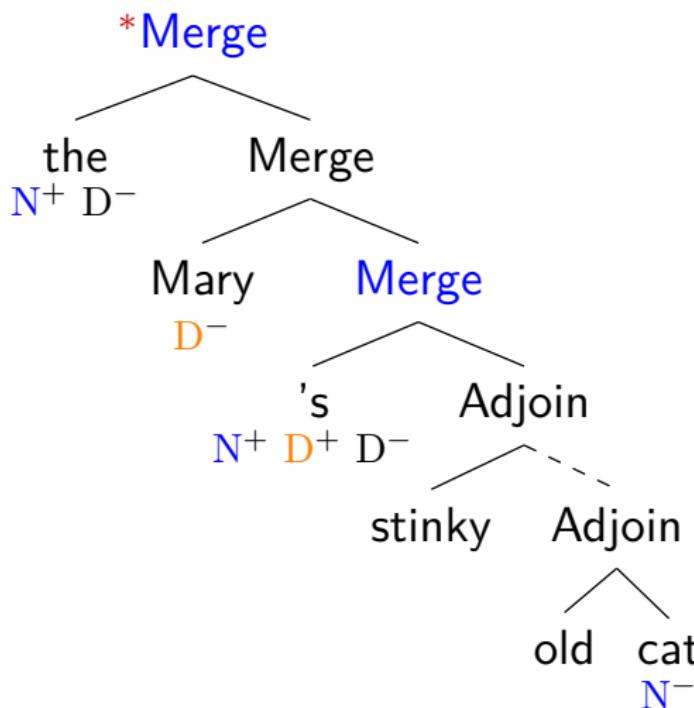
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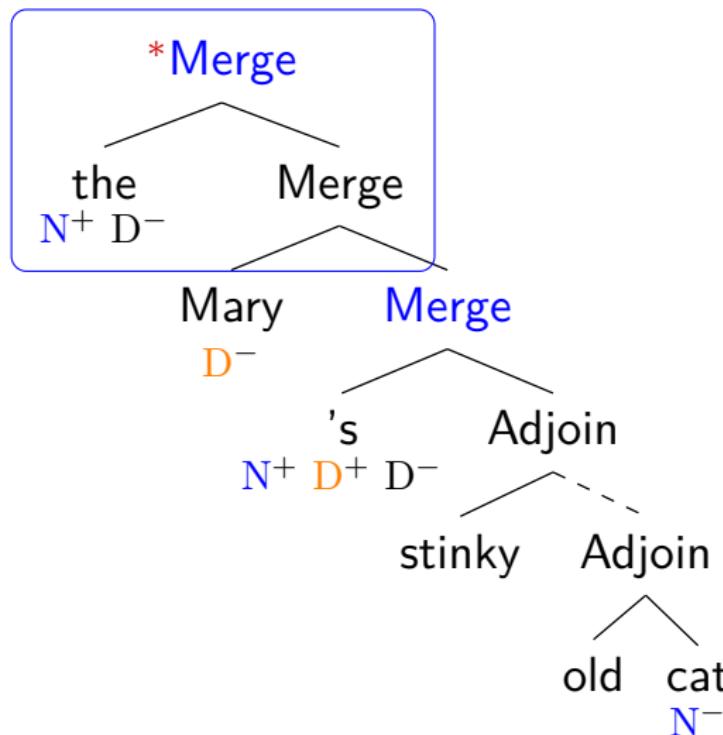
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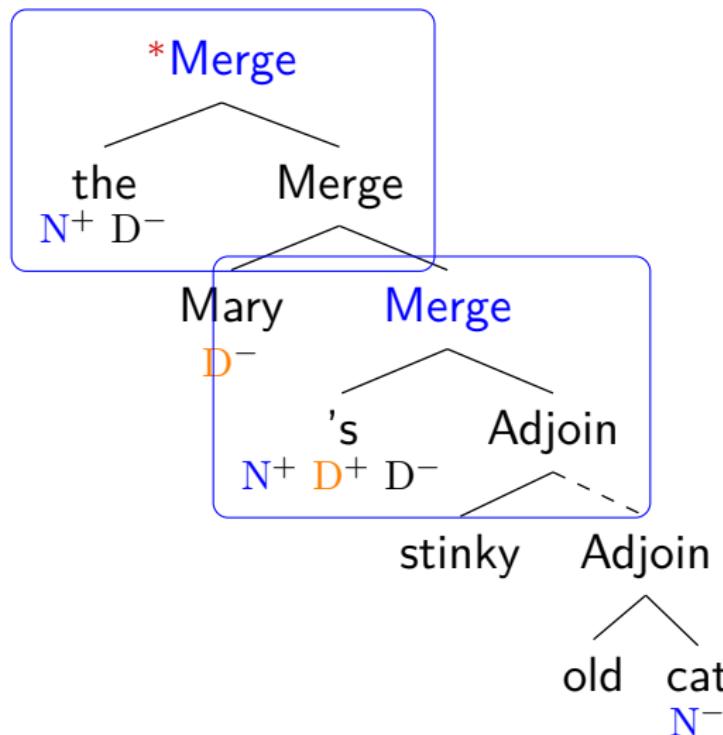
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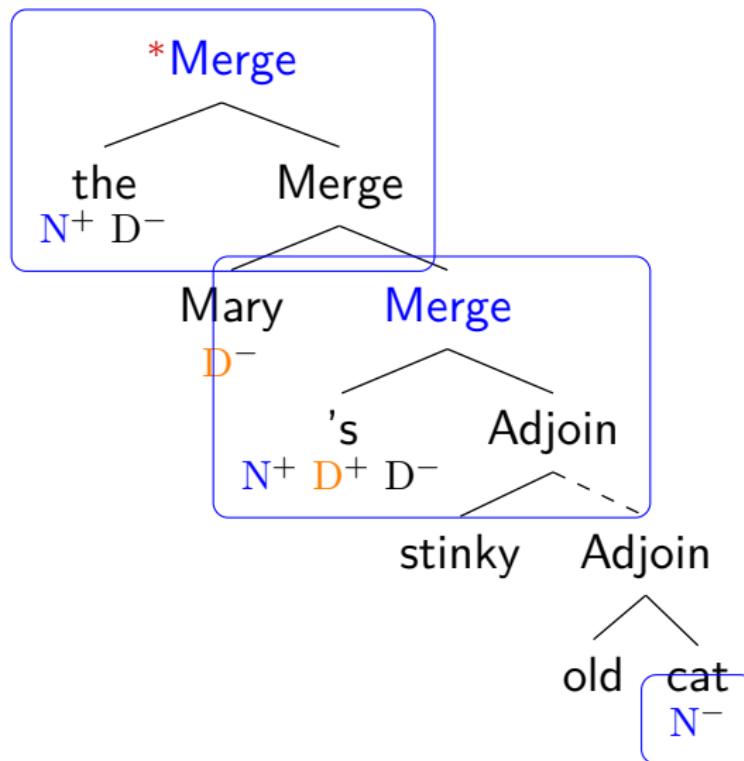
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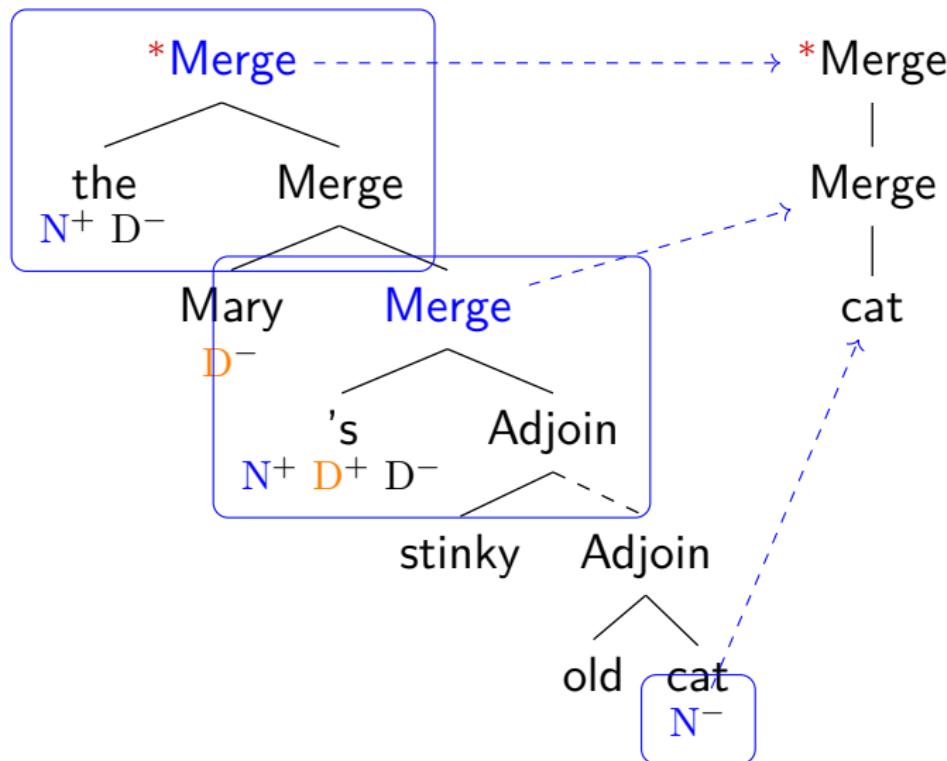
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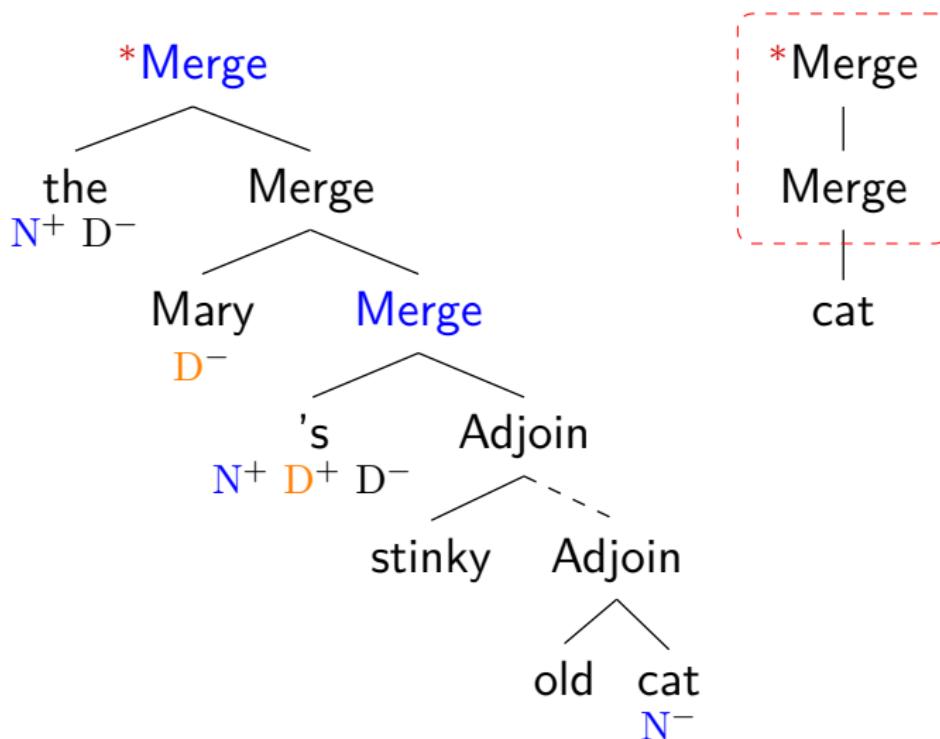
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Non-local dependencies are local over a simple relativization domain.

Strong Cognitive Parallelism Hypothesis

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

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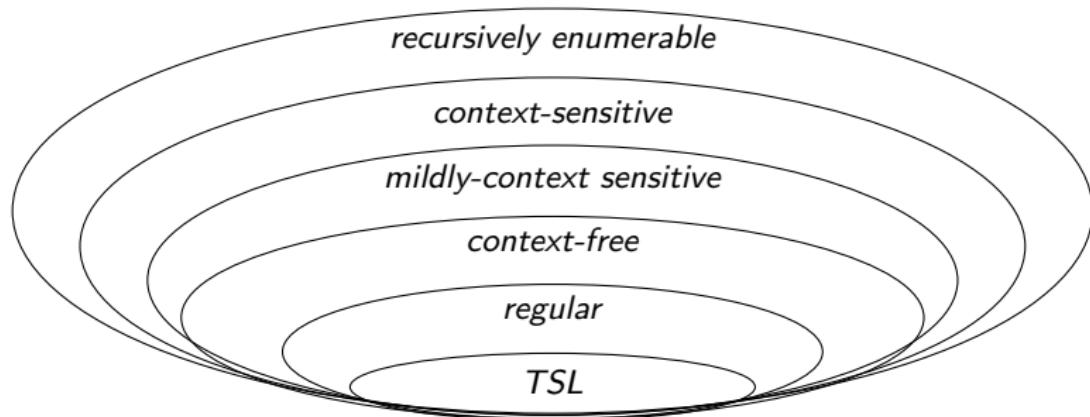
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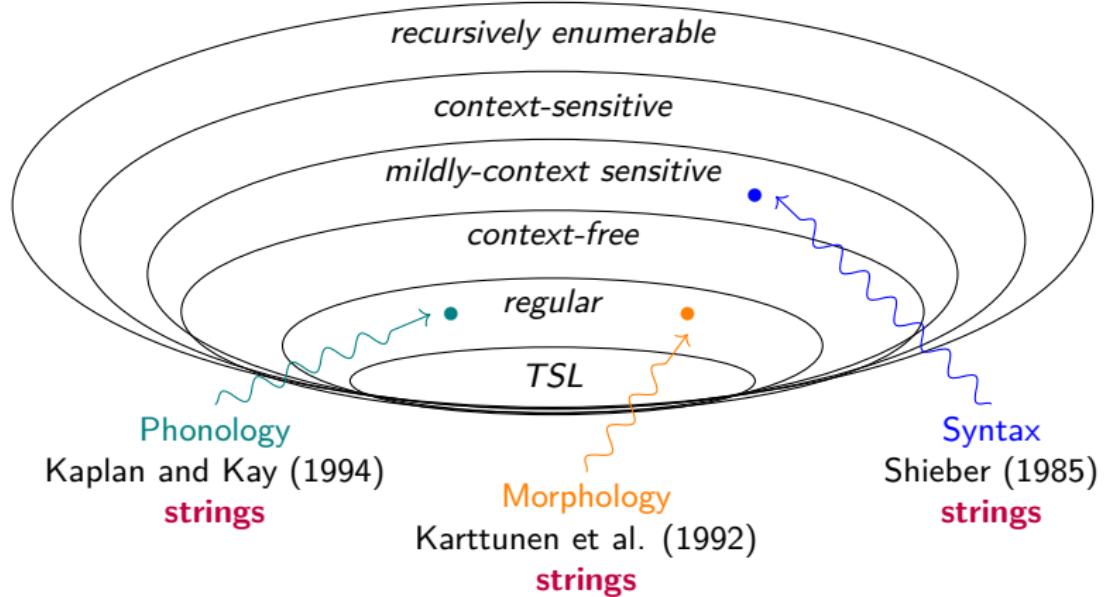
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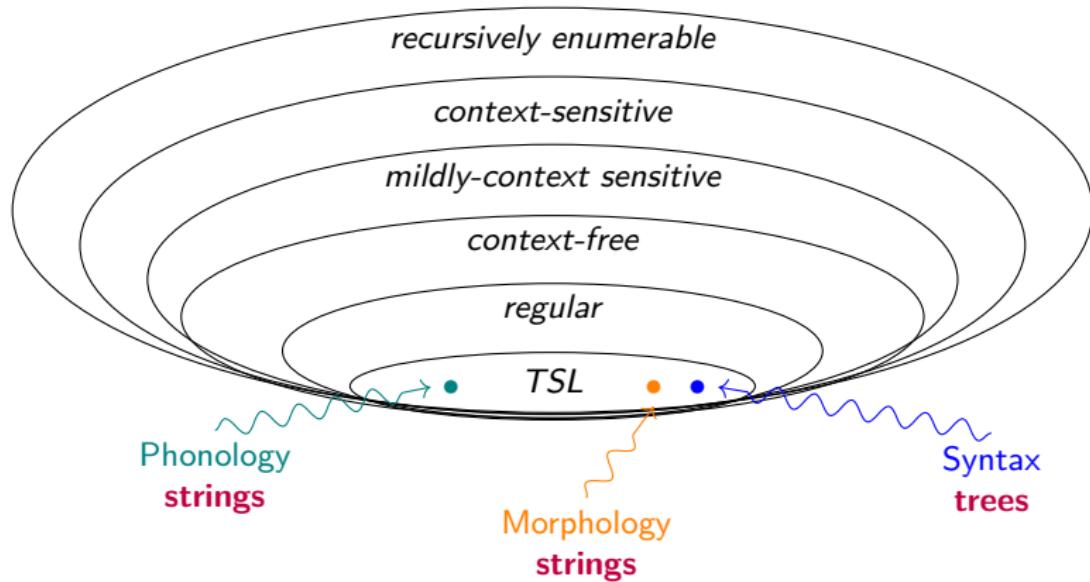
A Bird's-Eye View of the Framework



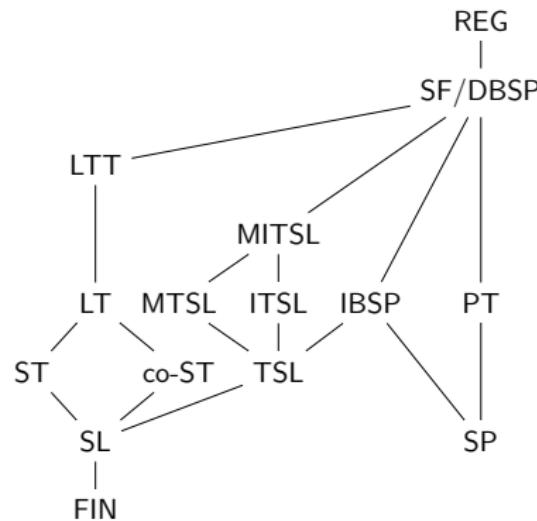
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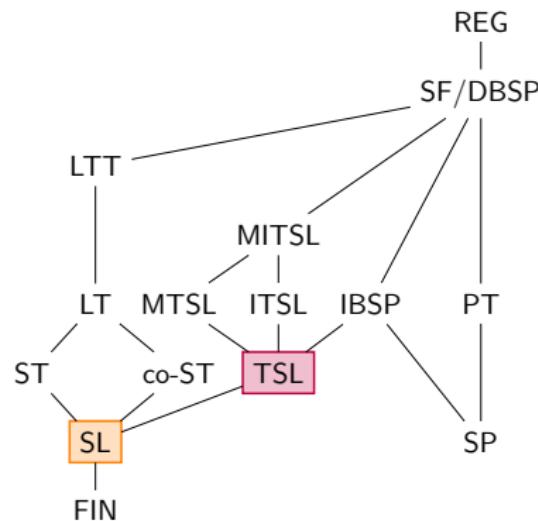


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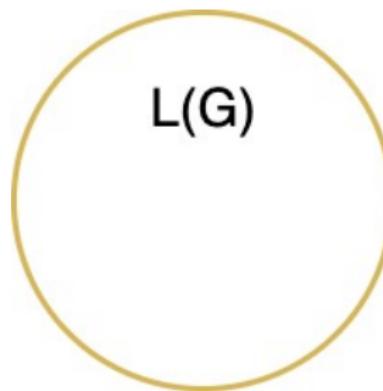
Syntax beyond Merge and Move

- ▶ regular tree languages
(Michaelis 2004; Kobele et al. 2007)
- ▶ subregular operations (Graf 2018)
- ▶ subregular dependencies/constraints
(Vu et al. 2019; Shafiei and Graf 2019)
- ▶ tree automata and parsing restrictions
(Graf & De Santo 2020)



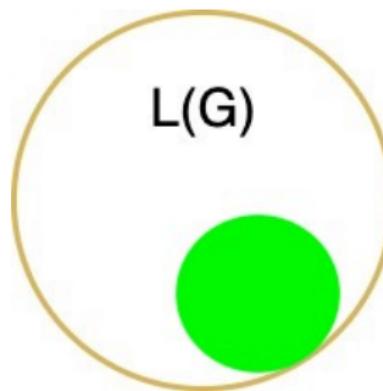
Artificial Grammar Learning (AGL)

- ▶ Can be used to test implicit learning abilities (Reber, 1976)



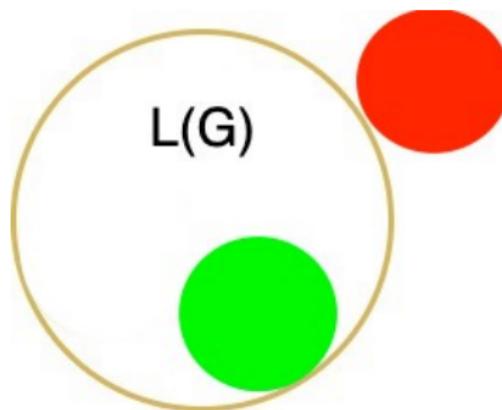
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Reber (1976)

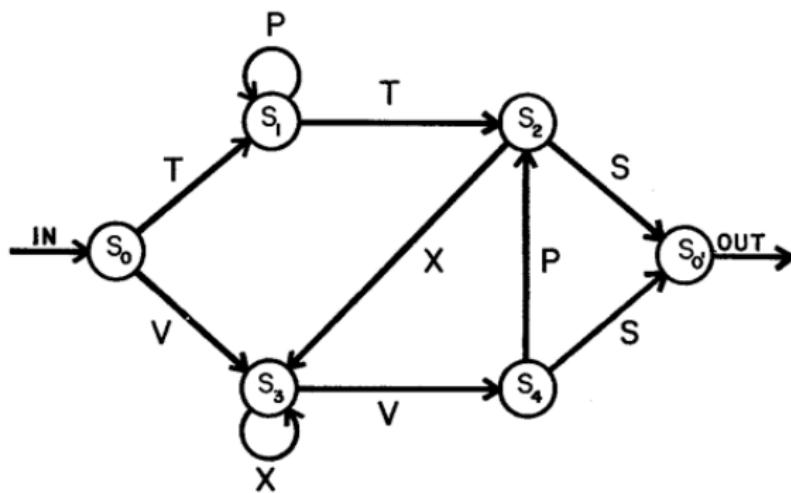


FIG. 1. Schematic state diagram of the grammar used to generate the grammatical stimulus items.

- ▶ Stimuli generated from an FST or randomly
 - ▶ 28 sentences per group, in sets of four sentences each
 - ▶ Participants asked to reproduce the sentences in a group
 - ▶ Participants informed of correct/incorrect reproductions, but not of error type

Reber (1976) [cont.]

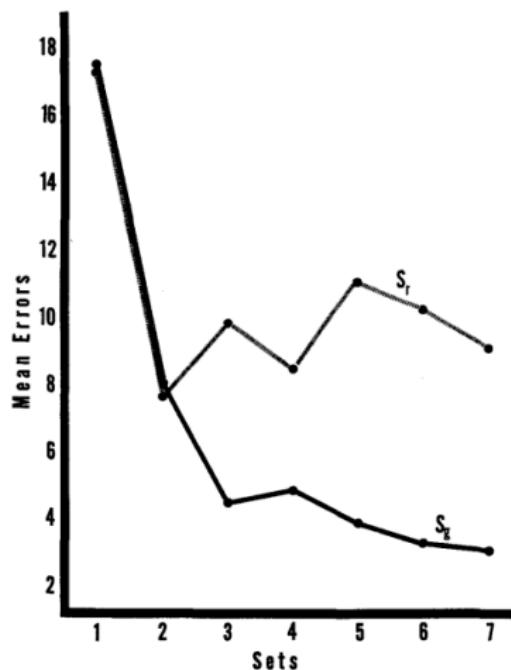
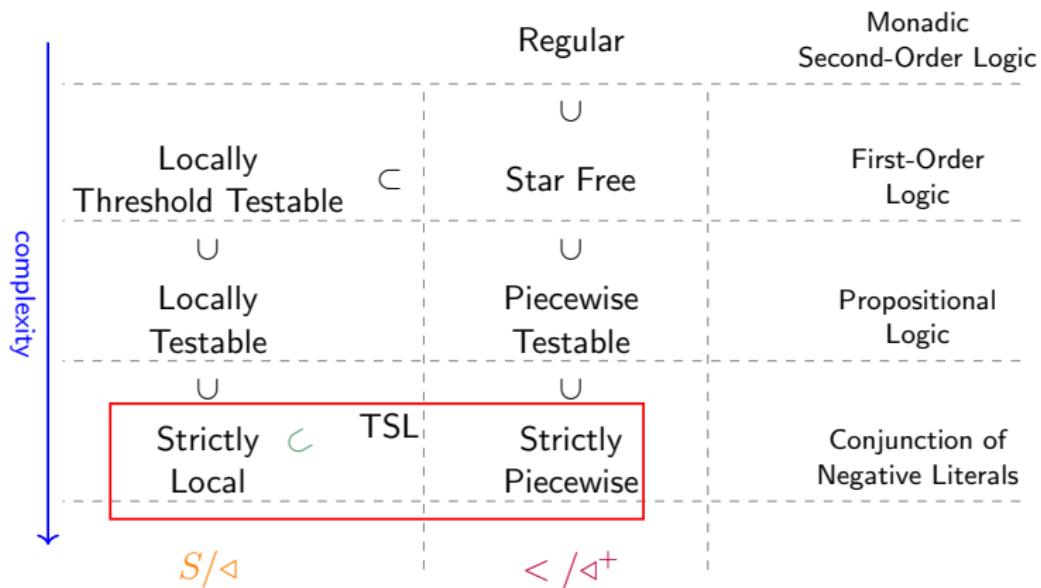


Fig. 2. Mean number of errors to criterion on each of the seven learning sets.

- ▶ Stimuli generated from an FST or randomly
 - ▶ Significant differences between learning trajectories across participant group

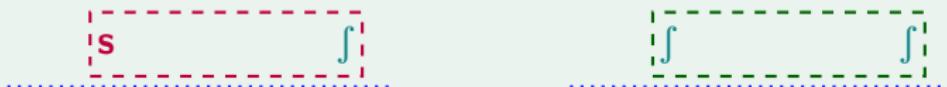
Testing Subregular Predictions



Example: Attested vs. Unattested Patterns

Attested: Unbounded Sibilant Harmony

- ▶ Every sibilant needs to harmonize



* \$hasxintilawʃ\$ *ok* \$haʃxintilawʃ\$

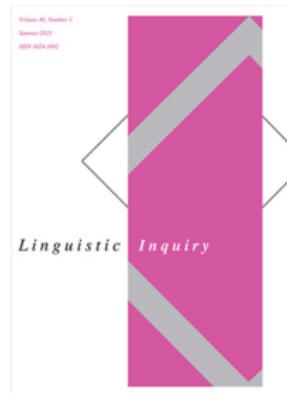
Unattested: First-Last Harmony

- ▶ Harmony only holds between initial and final segments



ok \$hasxintilawʃ\$ * \$satxintilawʃ\$

Lai (2015)



Learnable vs. Unlearnable Harmony Patterns

Regine Lai

Posted Online July 09, 2015

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Keywords: phonotactics, learnability, computational phonology,
formal theory, typology, dependencies

Lai (2015): Stimuli

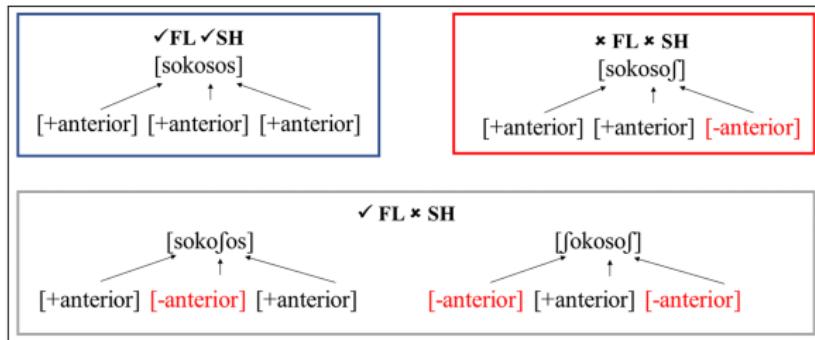


Figure 3: Comparison of SH and FL stimuli.

Lai (2015): Stimuli

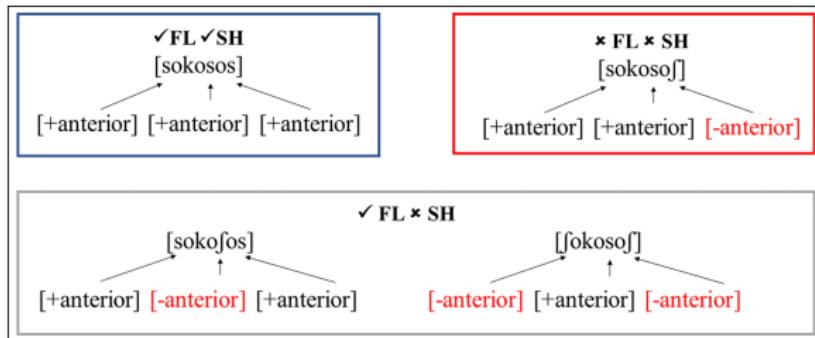


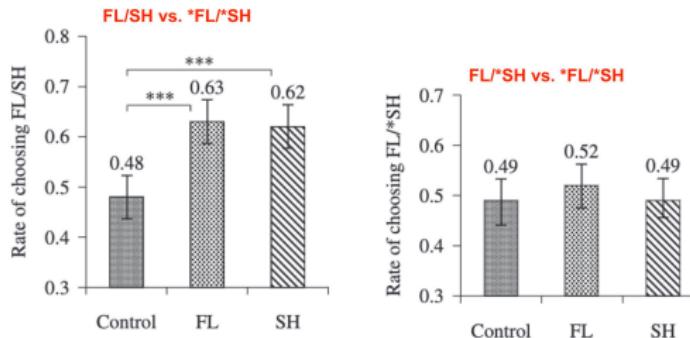
Figure 3: Comparison of SH and FL stimuli.

Table 6

Predicted results with respect to the control group for each test pairing if Sibilant Harmony and First-Last Assimilation grammars were internalized

		Pairs		
		FL/*SH vs. *FL/*SH (e.g., [s . . . ſ . . . s] vs. [s . . . s . . . ſ])	FL/SH vs. *FL/*SH (e.g., [s . . . s . . . s] vs. [s . . . s . . . ſ])	FL/SH vs. FL/*SH (e.g., [s . . . s . . . s] vs. [s . . . ſ . . . s])
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	SH	~ Control	> Control	> Control
FL	> Control	> Control	~ Control	

Lai (2015): Results

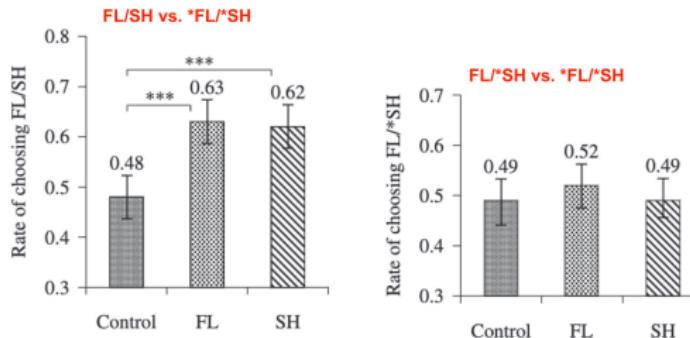
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- ▶ See Avcu and Hestvik (2020), Avcu et al. (2019) for replications

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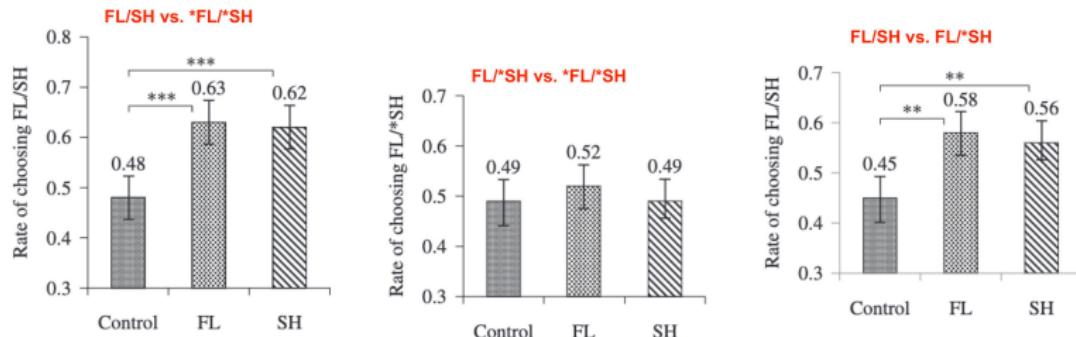
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Lai (2015): Full Results

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AGL and Syntax/Semantics

distinctions between mechanisms for recognizing non-Finite-State stringsets depend on the way in which the additional structure, beyond the string itself, is organized; these are issues that show up in the analysis of the string, not in its form as a sequence of events.

Rogers & Pullum 2011

In other words:

- ▶ Questions of complexity confounded by representations
- ▶ Questions of representations confounded by procedures

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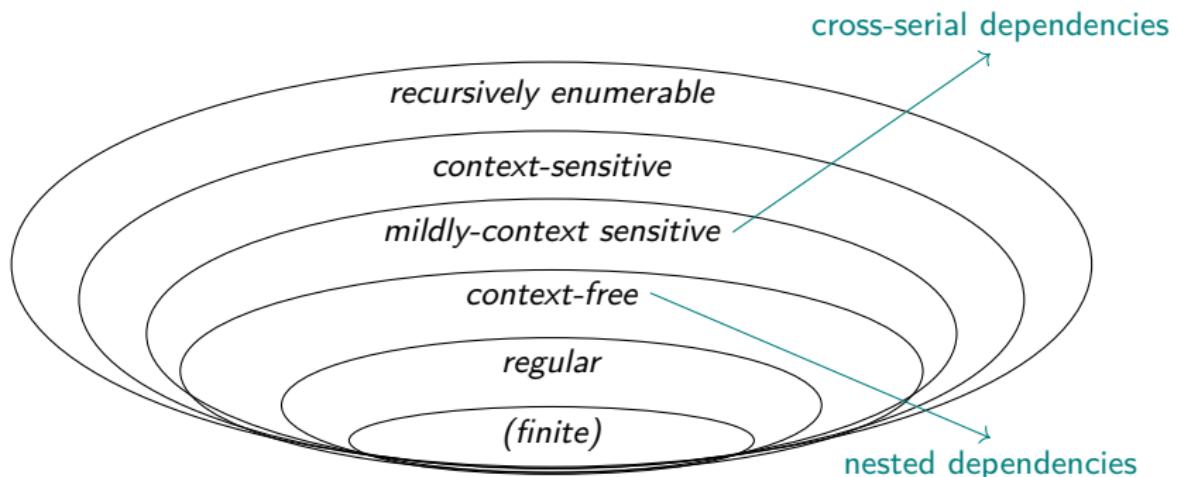
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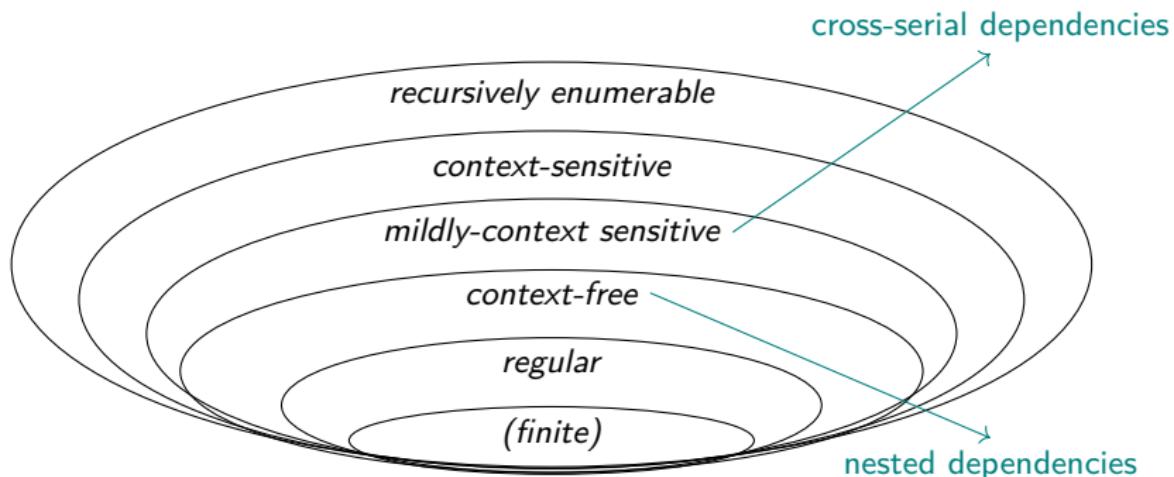
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Syntactic Expressivity



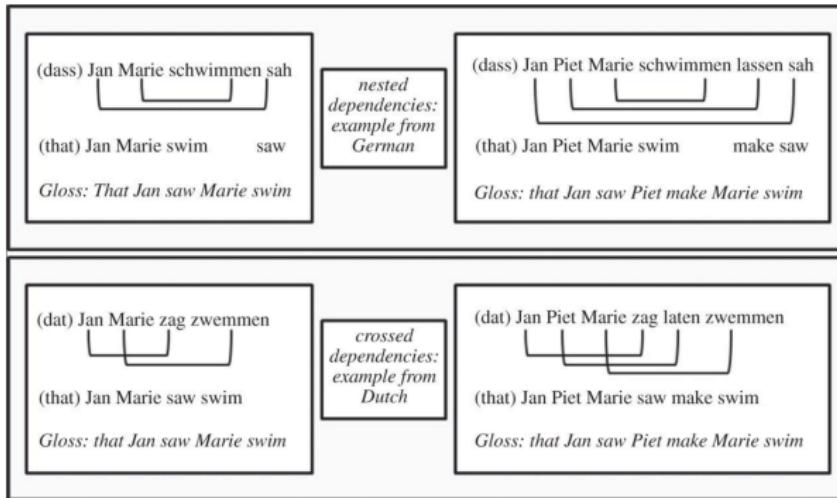
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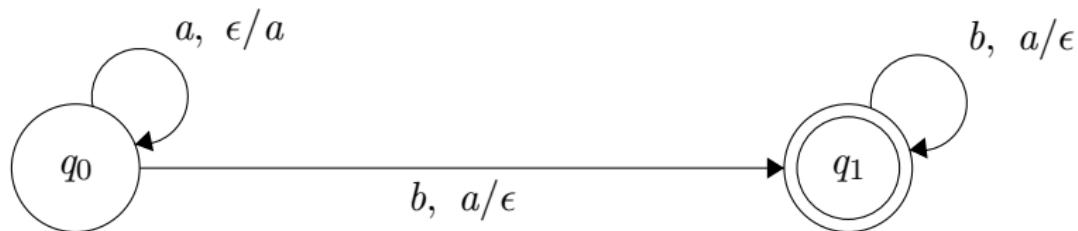
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Expressivity vs. Procedures



- ▶ cross-serial preferred over nested (Bach et al. 1986)
- ▶ against predictions from the CH?
(Chesi & Moro 2014; de Vries et al. 2012)
- ▶ BUT: this can easily be derived via processing mechanisms
(Savitch 1989; Joshi, 1990; Rainbow and Joshi, 1994)
- ▶ recognition complexity requires a precise theory of parsing cost

AGL and Syntax/Semantics [cont.]

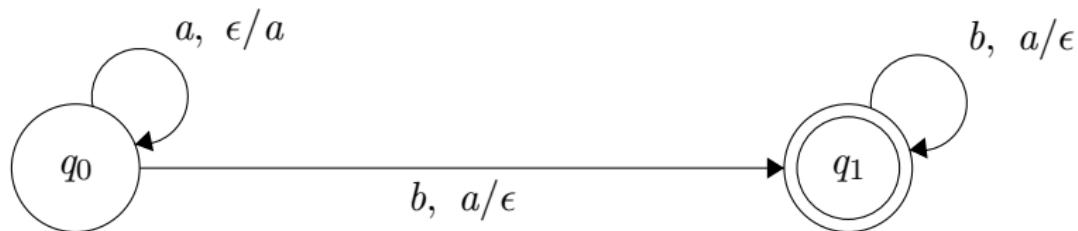


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a PDA with a single counter is enough (Counter Machines)
- ▶ Same for the language of strings of **well-nested parentheses**
- ▶ Phrase-structure analyses often depend on distinctions based
on the meaning of the strings

Complicated questions:

- ▶ What **representations** are relevant?
- ▶ How are they connected to **tasks**?
- ▶ How do we probe them?

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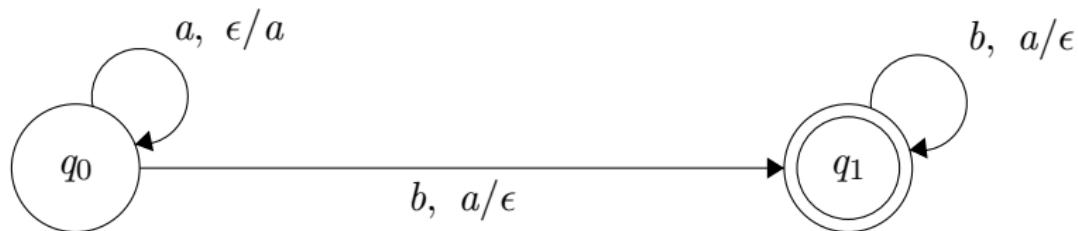


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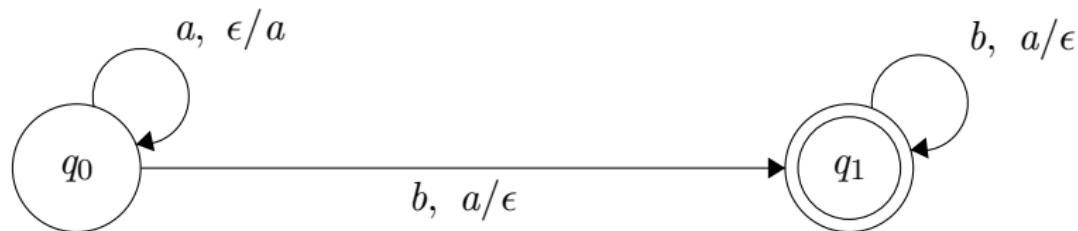


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A Plethora of Testable Predictions

Observation

- ▶ Attested patterns **A** and **B** are TSL.
- ▶ But combined pattern **A+B** is not TSL.

Prediction

- ▶ **A+B** should be harder to learn than **A** and **B**

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Morphotactics as Tier-Based Strictly Local Dependencies

Alëna Aksënova Thomas Graf Sedigheh Moradi

Example: Compounding Markers

- ▶ Russian has an infix **-o-** that may occur between parts of compounds.
- ▶ Turkish has a single suffix **-sı** that occurs at end of compounds.

(8) vod **-o-** voz **-o-** voz
water -COMP- carry -COMP- carry
'carrier of water-carriers'

(9) türk bahçe kapı **-sı** (***-Sİ**)
turkish garden gate -COMP (*-COMP)
'Turkish garden gate'



Example: Compounding Markers [cont.]

- ▶ Russian and Turkish are TSL.

	Tier₁	COMP affix and stem edges #
Russian	<i>n</i> -grams	oo, \$o, o\$
Turkish	<i>n</i> -grams	sisi, \$si, si#

- ▶ The combined pattern would yield **Ruskish**: stem^{*n+1*}-si^{*n*}
- ▶ This pattern is not regular and hence **not TSL either**.
- ▶ **Hypothesis** (Aksenova et al, 2016)
If a language allows unboundedly many compound affixes, they are **infixes**.

Testable Predictions

- ▶ Can naive subjects learn Russian-like, Turkis-like, and Ruskish-like compounding?

Complexity as a Magnifying Lens

- ▶ We can compare patterns and predictions across classes
- ▶ We can also compare patterns within a same class

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Formal Restrictions On Multiple Tiers

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Sanket Deshmukh

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Testing Harmony Systems

- ▶ We can also account for multiple processes
- ▶ Thus we can cover the complete phonotactics of a language

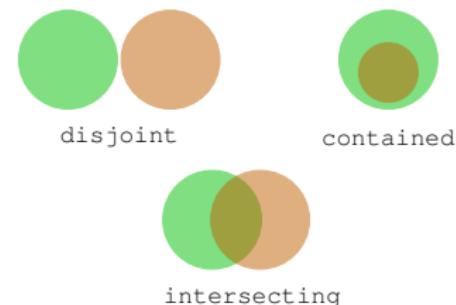
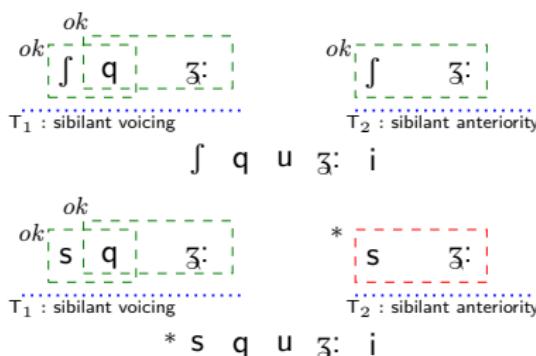


Figure 2: Theoretically possible tier alphabet relations

Testing Harmony Systems (cont.)

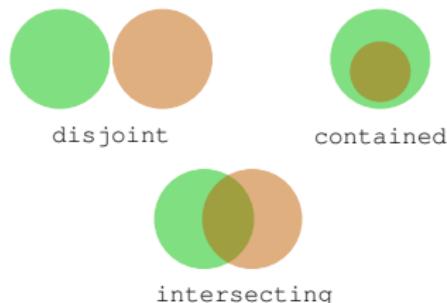


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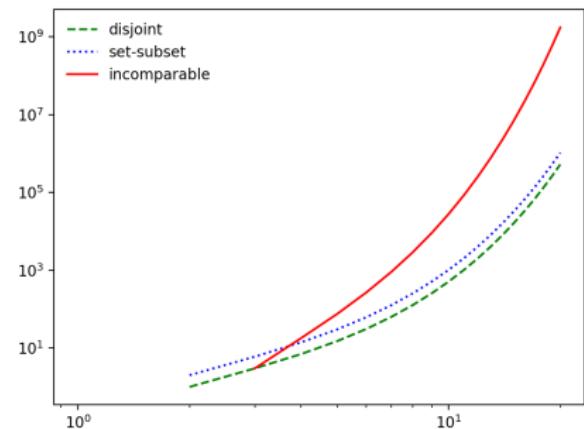
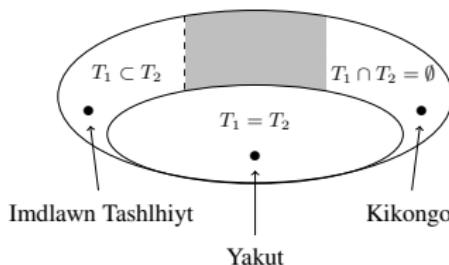
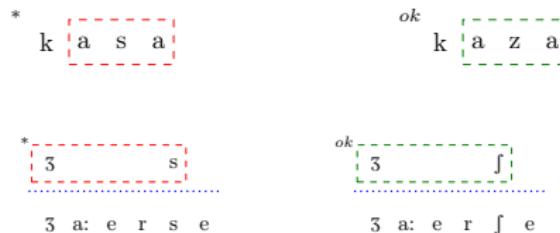


Figure 7: Growth of number of partitions of sets containing up to 20 elements (loglog scale)

The Fallacy of Generalization

- ▶ Imagine we want to test the ability to learn long-distance dependencies:



- ▶ Assuming an alphabet $\Sigma = \{a, b, c, d, e\}$, the training samples could look like the following:

$$L_{loc} = \{abcd, aabcd, baacd, bcaa, \dots\}$$

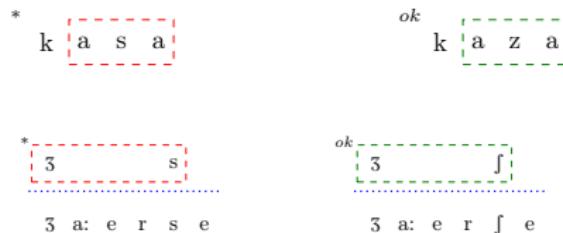
$$L_{dist} = \{abacd, bacad, bcada, bcaea, \dots\}$$

What happens if we test on stimuli with similar distances?

$$L_{test} = \{abcad, abcad, bacda, abcea, \dots\}$$

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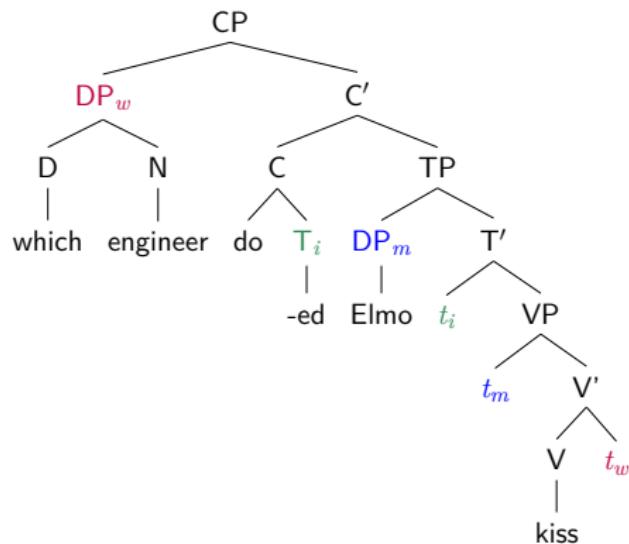
Why MGs?

- 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)

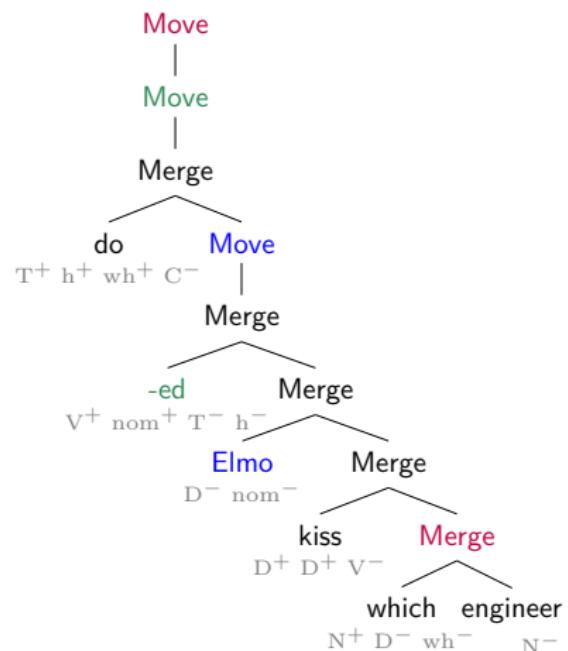
Some Important Properties of MGs

- ▶ 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
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(cf. node-count; Hale, 2001)

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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
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|
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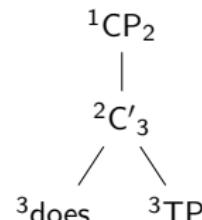
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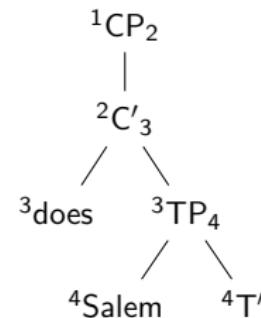
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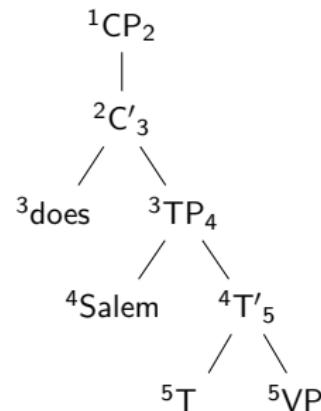
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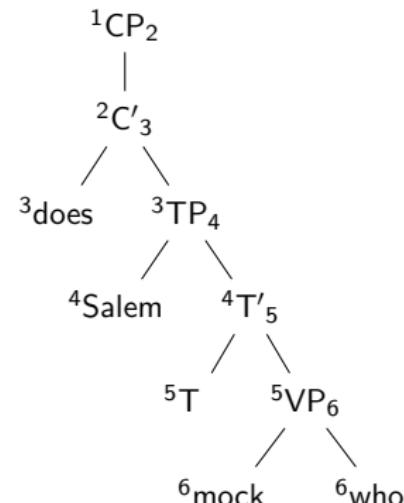
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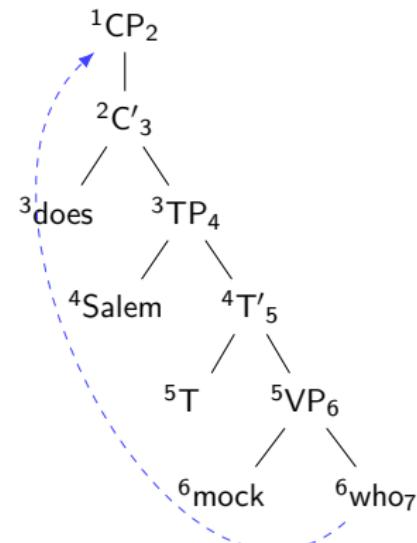
Incremental Top-Down Parsing

Technical details!

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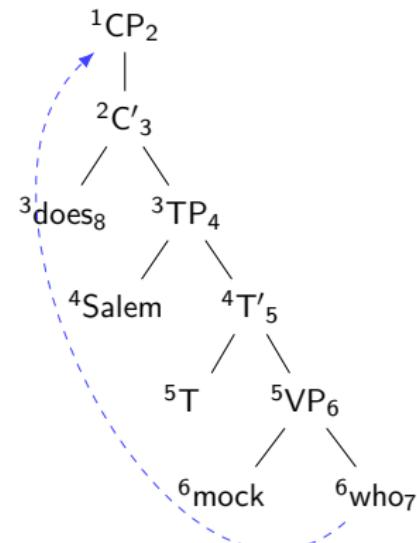
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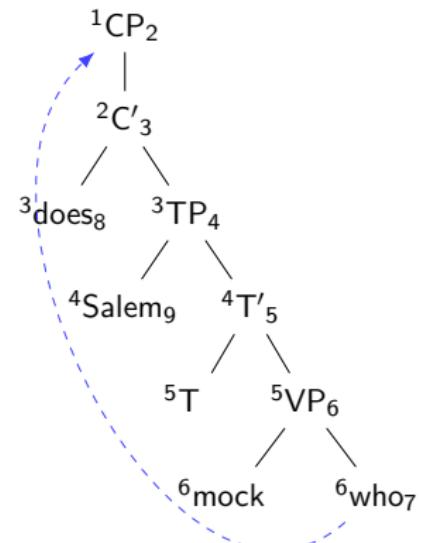
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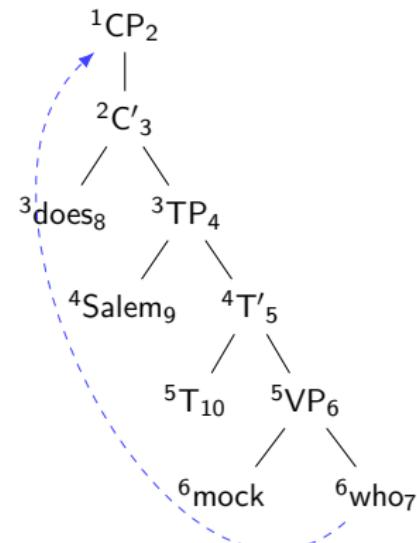
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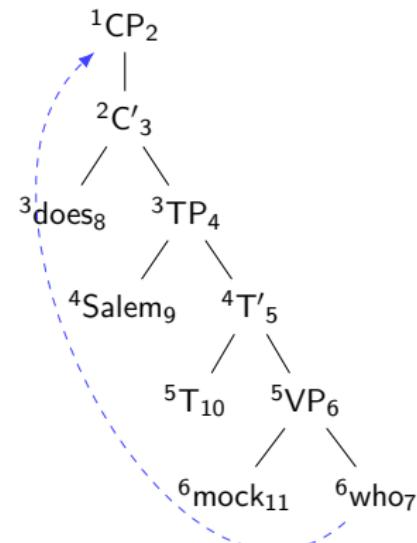
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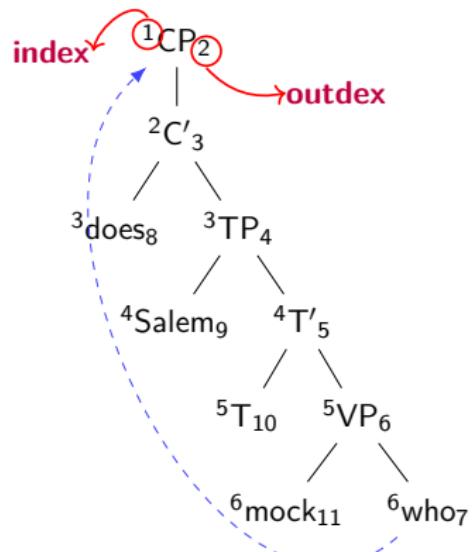
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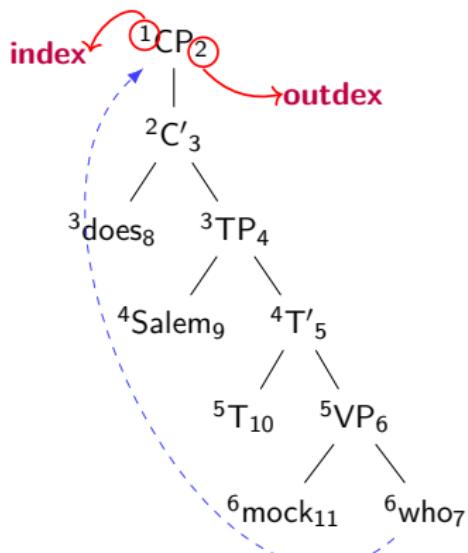
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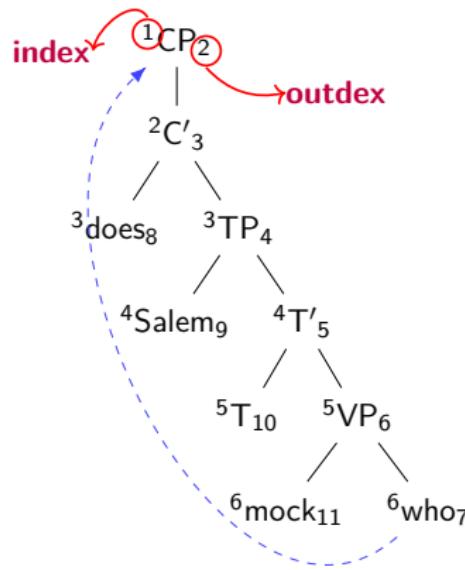
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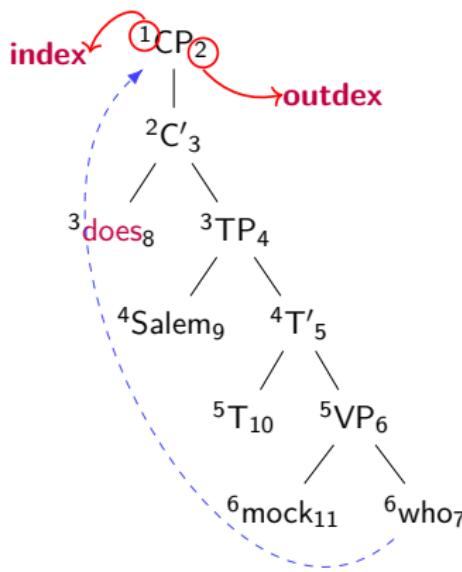
Index and Outdex are our connection to memory!

Computing Metrics: An Example



Tenure how long a node is kept in memory

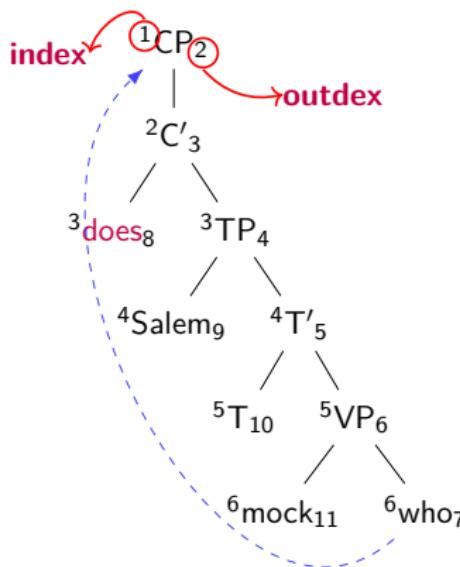
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$$\text{Tenure}(does) = 8 - 3 = 5$$

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

A Case Study: Italian Postverbal Subjects

Asymmetries in Italian Relative Clauses

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

- (10) Il cavallo che ha inseguito i leoni
The horse that has chased the lions
“The horse that chased the lions” **SRC**
- (11) 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):

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

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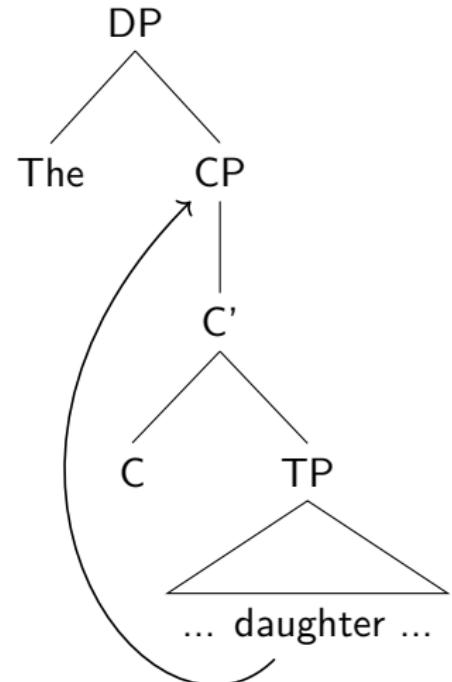
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Processing Asymmetry (De Vincenzi 1991, Arosio et al. 2018, a.o.)

SRC > ORC > ORCp

Kayne's Promotion Analysis (Kayne 1994)

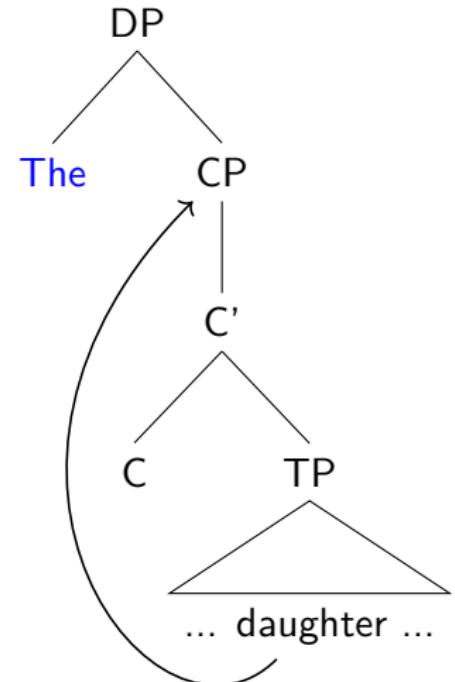
- ▶ RC is selected by an external D^0
- ▶ the RC head is a nominal constituent
- ▶ the RC head raises from its base position to [Spec, CP]



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

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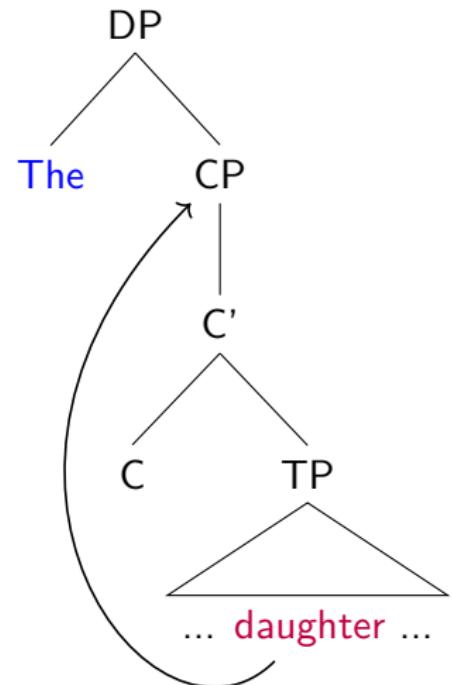
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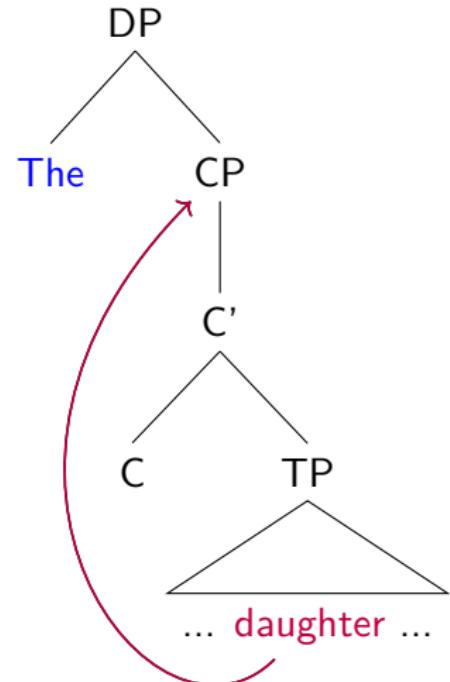
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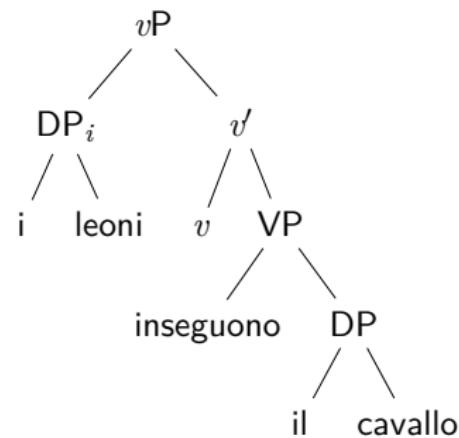
Postverbal Subjects (Belletti & Leonini 2004)

- (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



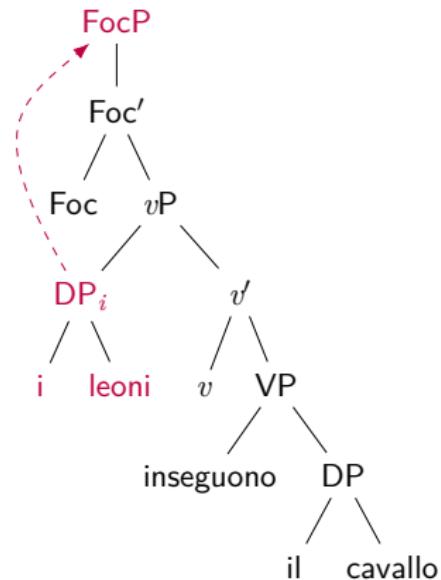
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Technical details!

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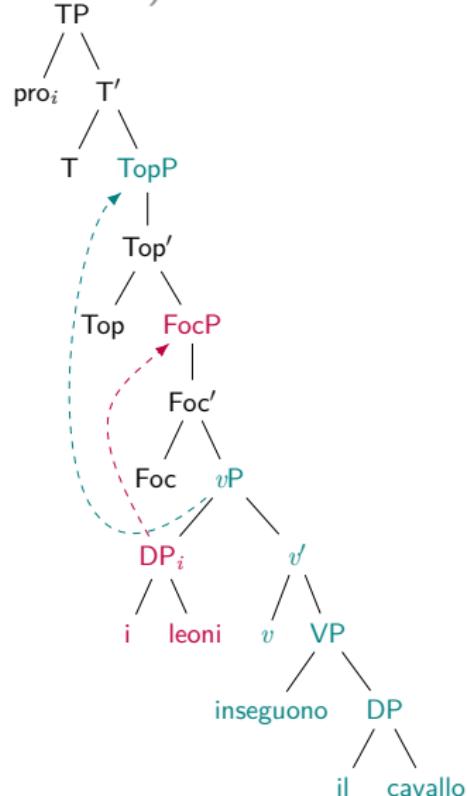
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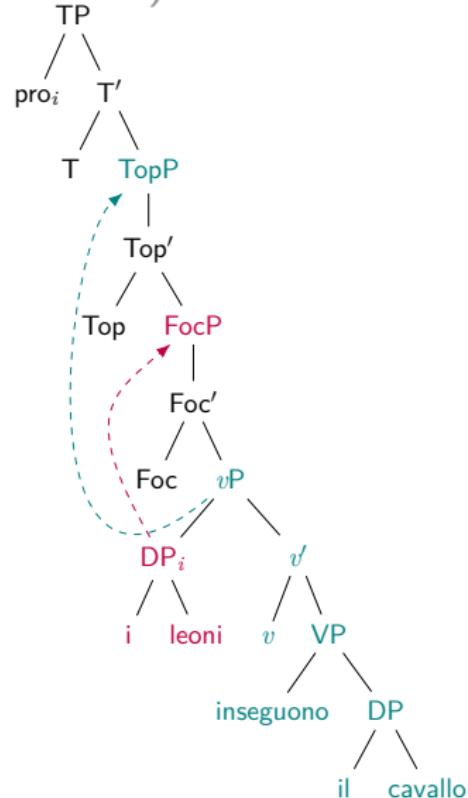
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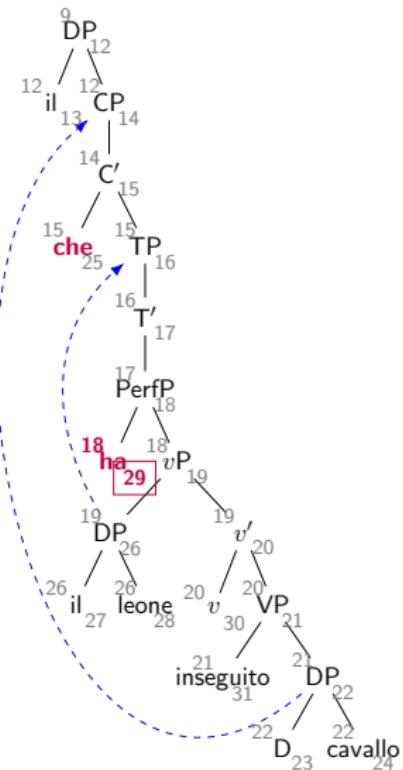
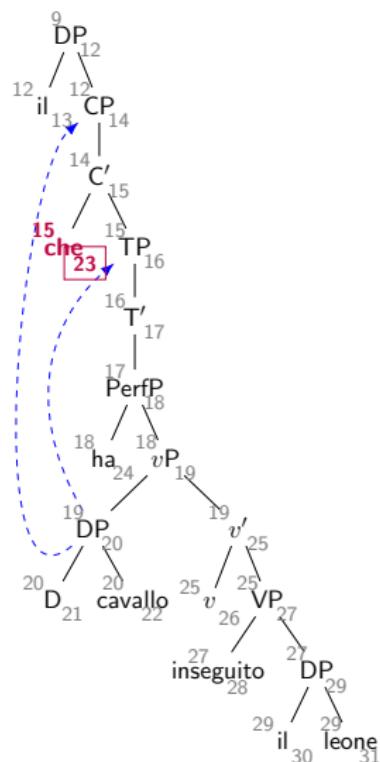
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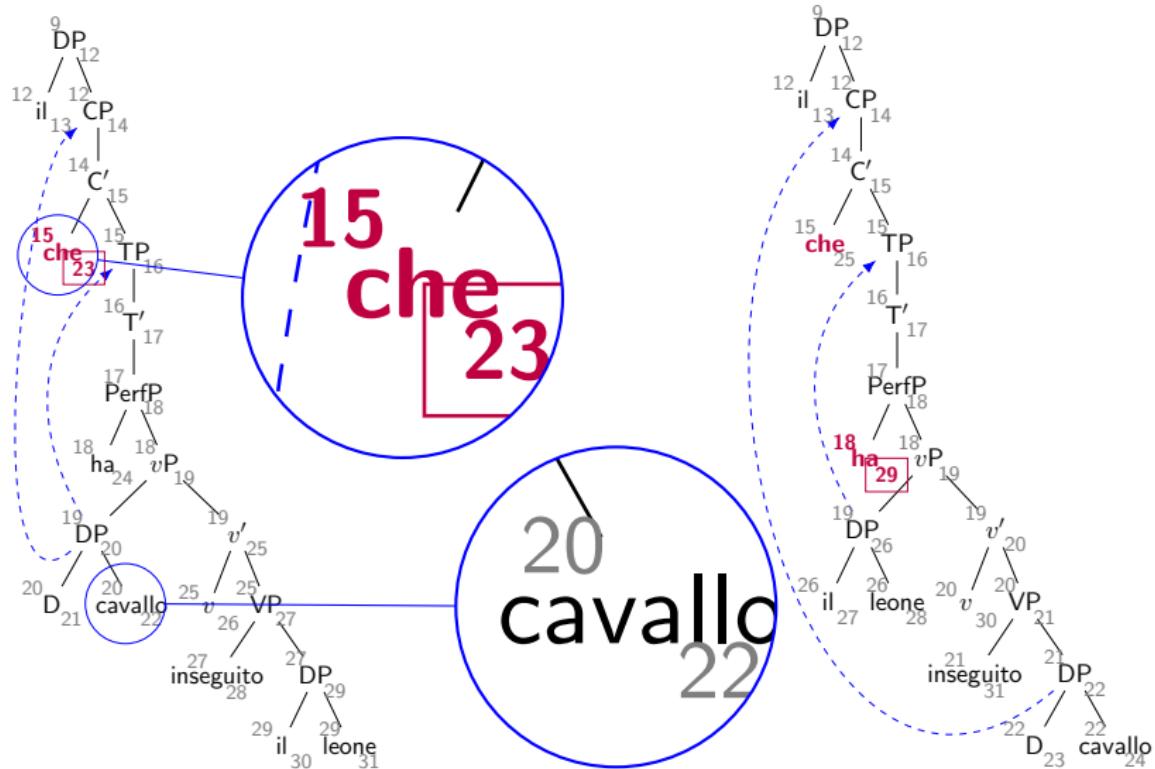
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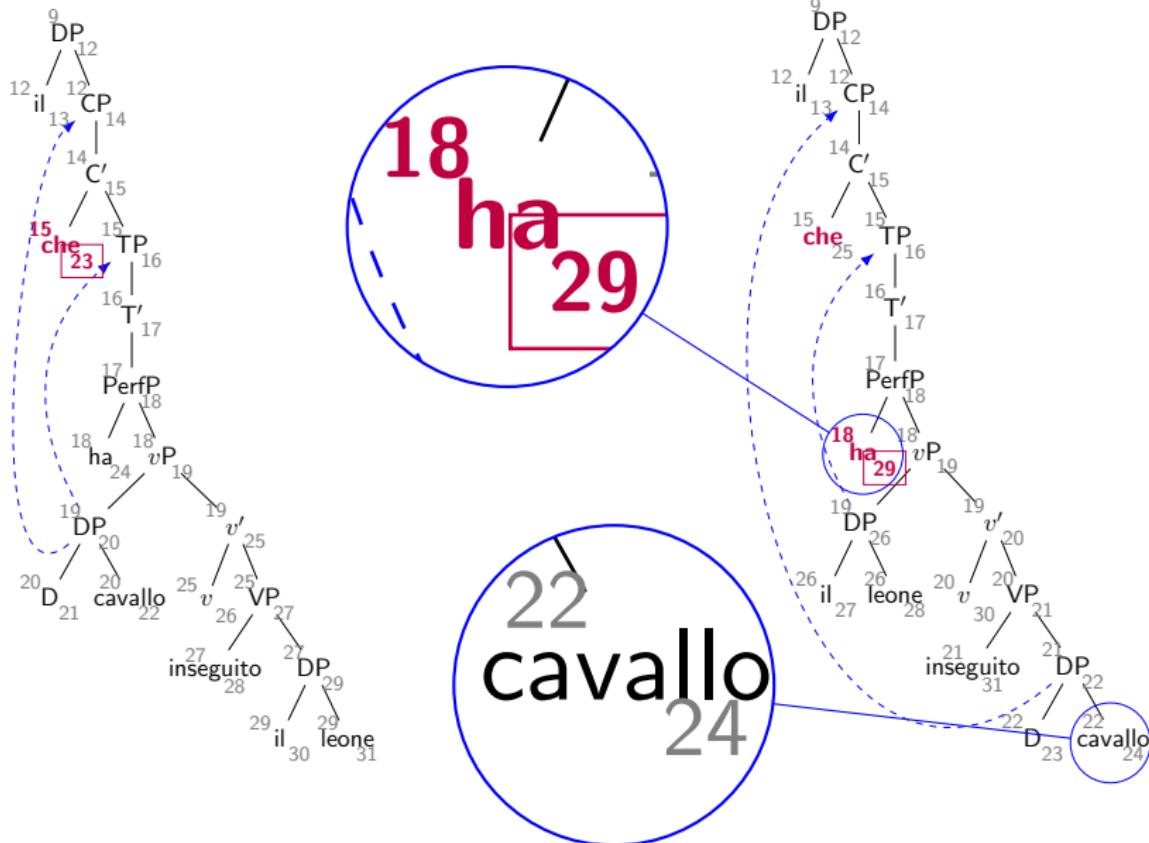
Results: SRC > ORC



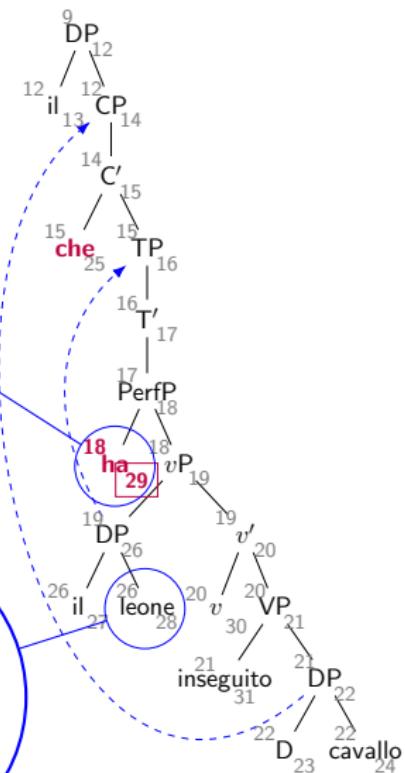
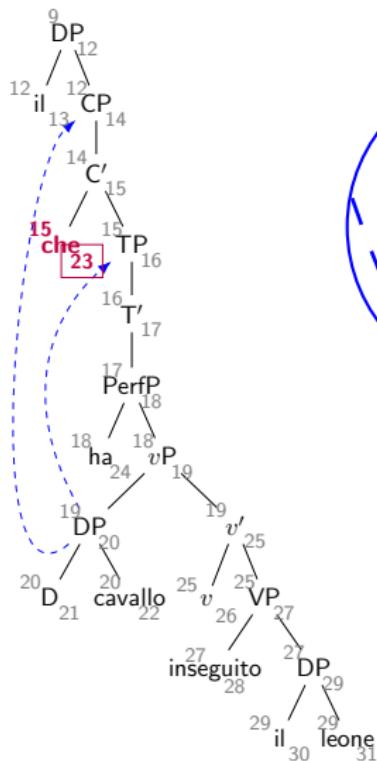
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Italian Subjects: Probing the Results

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;
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Can we give a purely structural account?

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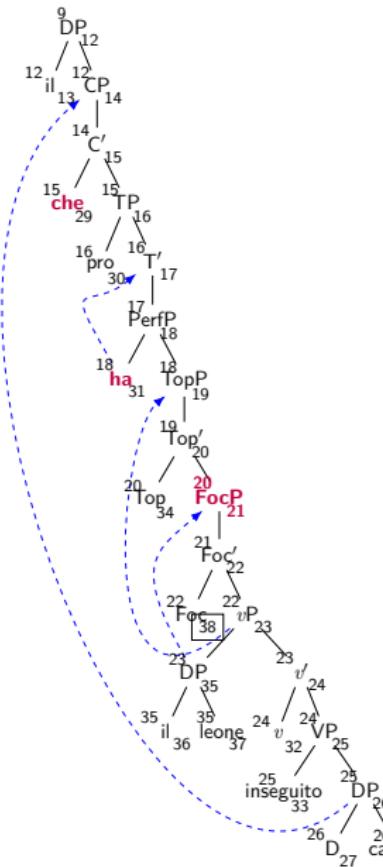
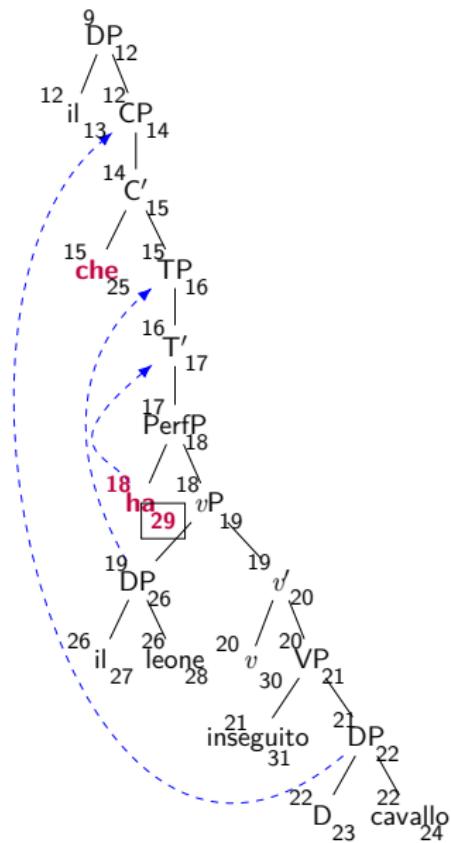
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Additional Constructions

► Ambiguity in Matrix Clauses

- (8) Ha chiamato Gio
Has called Giovanni
- a. “He/she/it called Gio” SVO
 - b. “Gio called” VS

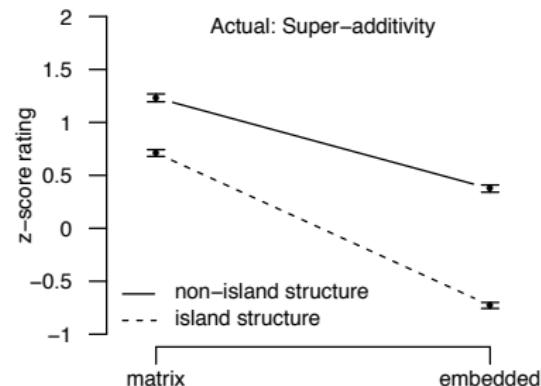
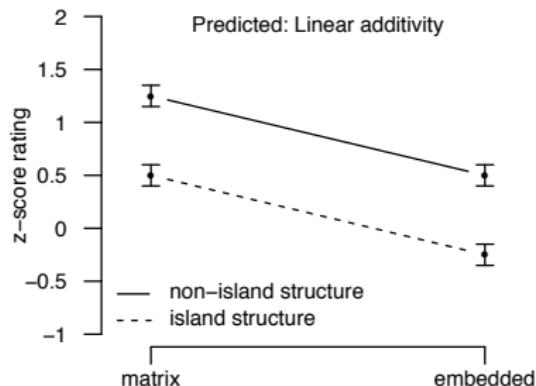
► Unaccusatives vs. Unergatives

- (9) È arrivato Gio
Is arrived Gio
“Gio arrived” Unaccusative
- (10) Ha corso Gio
Has ran Gio
“Gio ran” Unergative

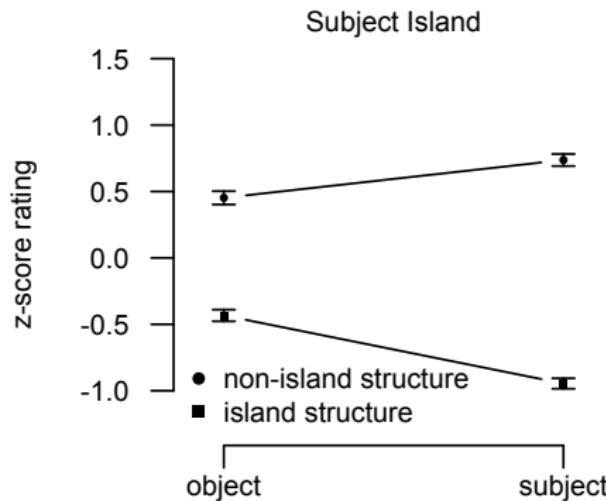
Gradience in Islands

A factorial design for islands effect:

► GAP POSITION × STRUCTURE



Deriving Pairwise Comparisons



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

A Caveat on Island Effects

The Goal

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

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

But I am not interested in island effects *per se*:

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

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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
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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:

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

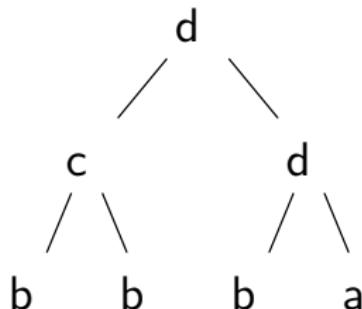
Case 2:

- (12) 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

Top-down Parsing + Grammaticalized Constraints?

Graf & De Santo (2019)

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

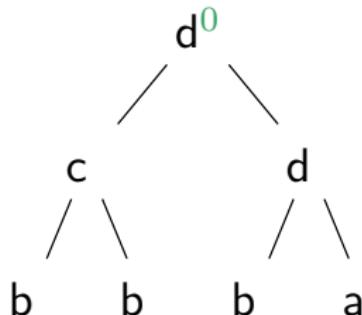


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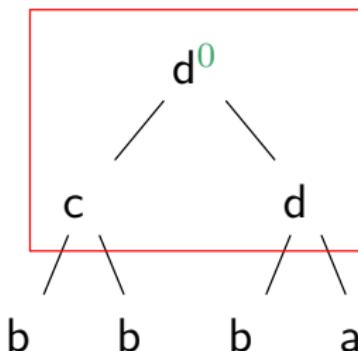


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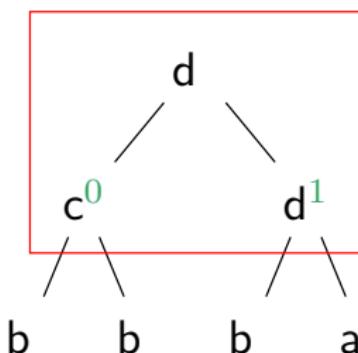


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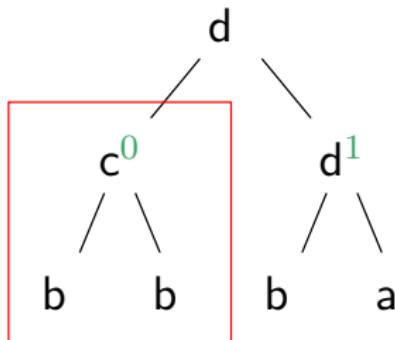


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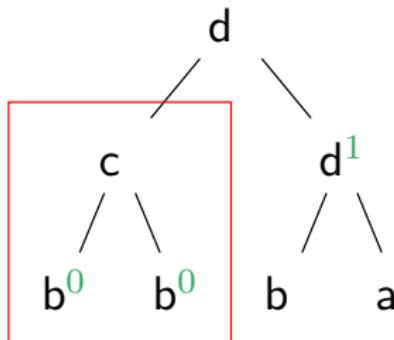


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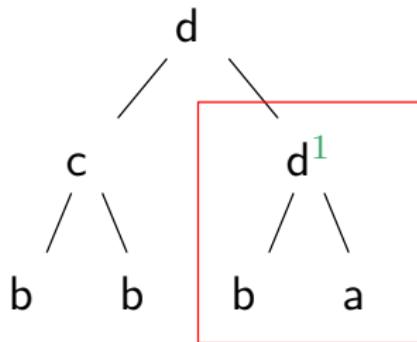


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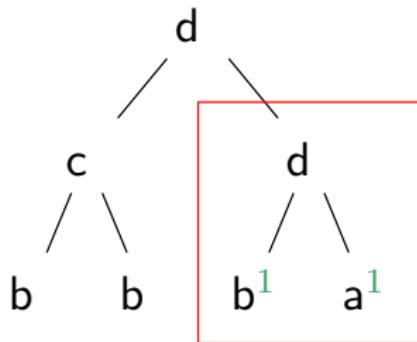


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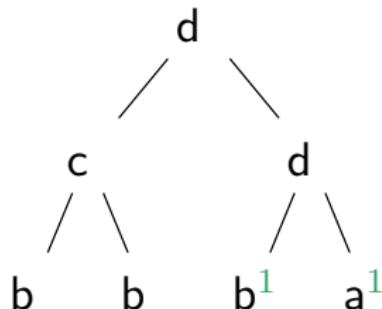


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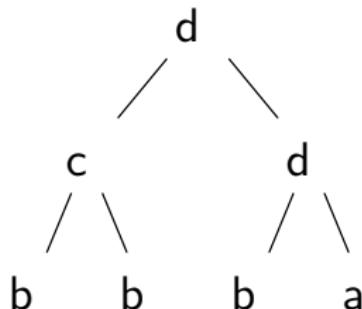


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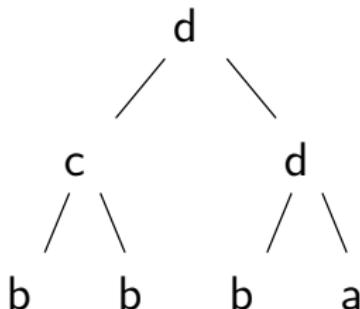
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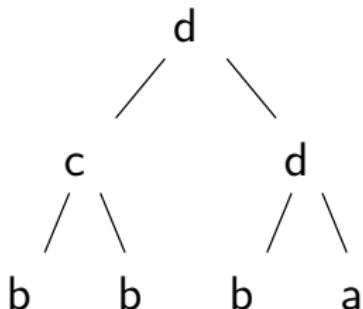
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- ▶ Constraints improve parsing performance by **exponentially reducing** the search space (Stabler 2013)
- ▶ Can be pre-compiled in the MG parse schema as a deterministic **top-down filter** (De Santo & Graf, in prep.)

Attachment and Relative Clauses (RC)

- ▶ They saw the daughter of the actress that was on the balcony
NP₁ The daughter was on the balcony HA
NP₂ The actress was on the balcony LA

English: LA interpretation

- ▶ Late Closure (Frazier 1978),
Recency (Gibson 1991, Gibson et al. 1996), ...

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Universal locality principles?

- ▶ Spanish: **HA** interpretation
 - ▶ Tuning Hypothesis
(Cuetos & Mitchell 1988, Mitchell & Cuetos 1991)
Construal (Frazier & Clifton 1996), ...

A Complex Cross-Linguistic Scenario

HA vs LA languages?

RC preferences cross-linguistically affected by a variety of factors

- ▶ Syntactic environment
(Fernandez 2003, Gibson et al. 1996, De Vincenzi and Job 1993)
- ▶ Prosodic effects (Teira and Igoa 2007, Hemforth et al. 2015)
- ▶ Lexical-semantic properties of the DPs
(MacDonald et al. 1994, Gilboy et al. 1995)
- ▶ Online vs. Offline Differences
(Fernandez 2003, Wager et al. 2009, Lourenco-Gomes et al. 2011)
- ▶ Individual WM effects (Swets et al. 2007)

None of these fully accounts for the LA vs HA variation

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Grillo & Costa: Pseudo-RCs in Italian

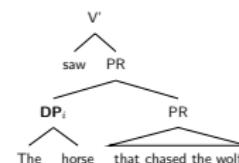
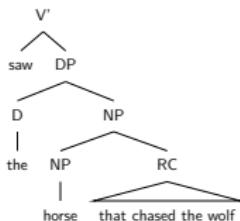
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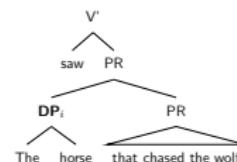
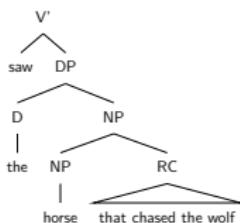
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- ▶ RC: HA
- ▶ RC: LA
- ▶ PR: ~ HA



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

So What? PRs and Attachment Preferences

- ▶ The grandma of the girl that was screaming
 - ▶ RC: HA
 - ▶ RC: LA
 - ▶ PR: HA

The Pseudo-Relative First Hypothesis (Grillo & Costa 2014)

All else being equal:

- ▶ When available: PR **preferred over** RC parse (so: ~ HA)
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Goldberg (1995), Choueiri (1997), Greweling (2002), Greweling (2007), ...

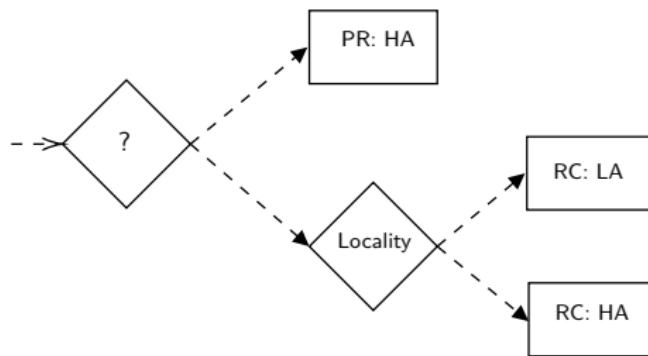
Appear freely with proper names, no relative pronouns, ...

Verb type restrictions

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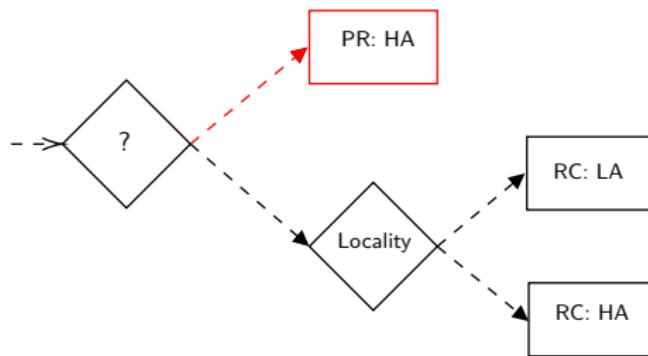


Syntactic tests (Guasti 1999, Cinque 1992, Casalicchio 2013: a.o.)

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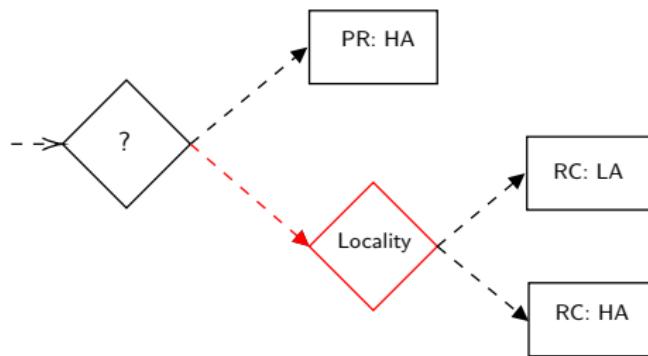


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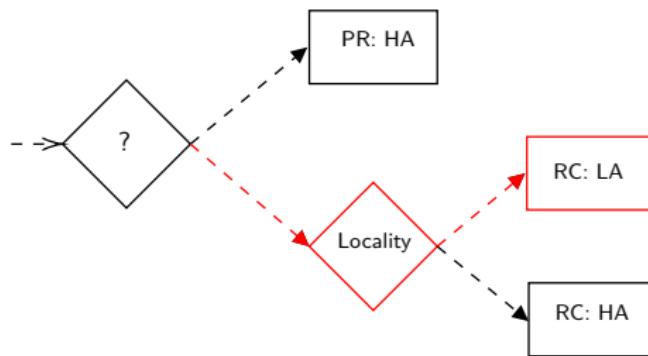


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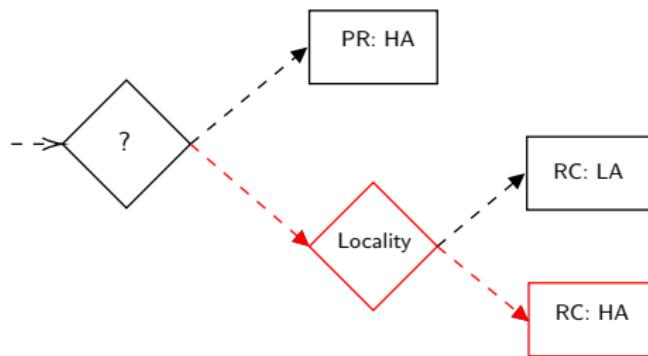


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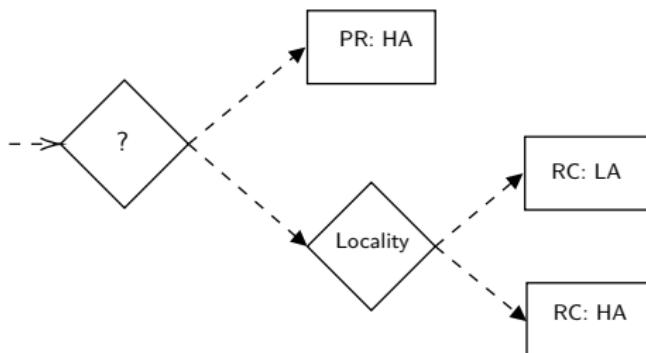


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- ▶ The daughter of the actress [that was on the balcony]
 - ▶ RC: HA
 - ▶ RC: LA
 - ▶ PR: (~) HA

Other studies

- ▶ Italian: De Santo & Lee (2022a)
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(57) Stimuli Experiment II

- a. PR/ RC CONDITION: PR-VERBS

Gianni ha visto il figlio del medico che correva.

G. saw the son of the doctor running.

- b. RC ONLY CONDITION: STATIC VERBS

Gianni vive con il figlio del medico che correva.

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Online too!

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Table 6
Percentage of high attachment preferences.

Eventive	Stative
78.6%	24.2%

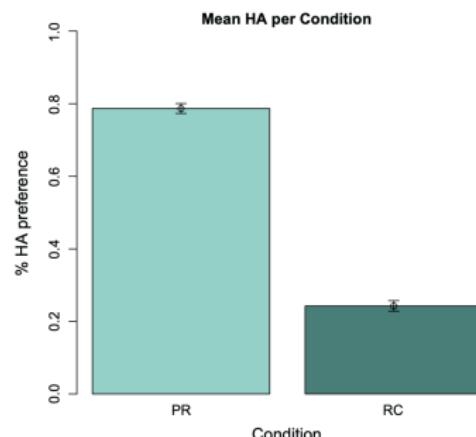


Fig. 2. Summary of attachment preference experiment 2.

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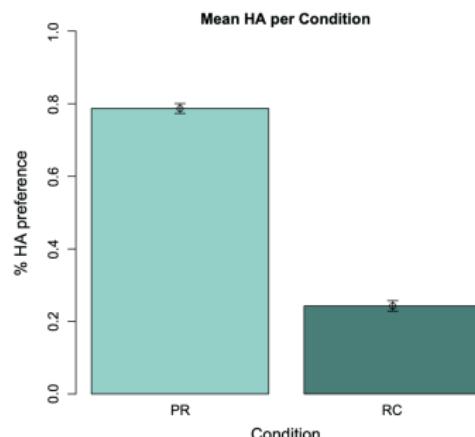
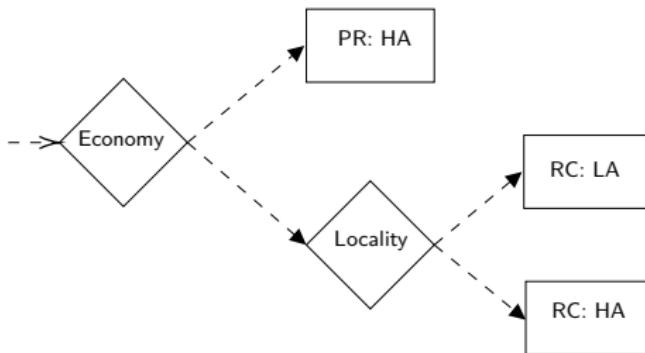


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PR-First: Why?

Question

Why should PRs be preferred?



One Hypothesis: Structural Economy (Grillo & Costa 2014)

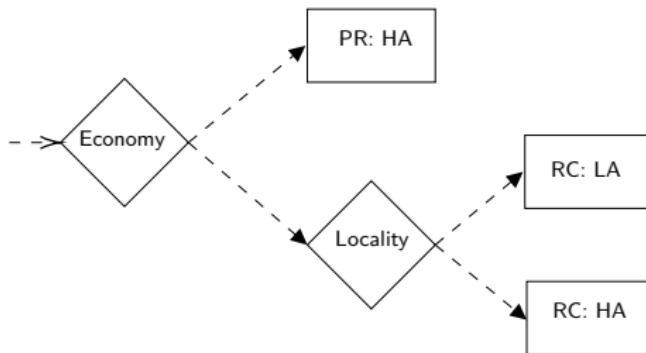
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Can we evaluate structural economy quantitatively?

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Modeling PR-First

Why should PRs be easier/preferred?

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

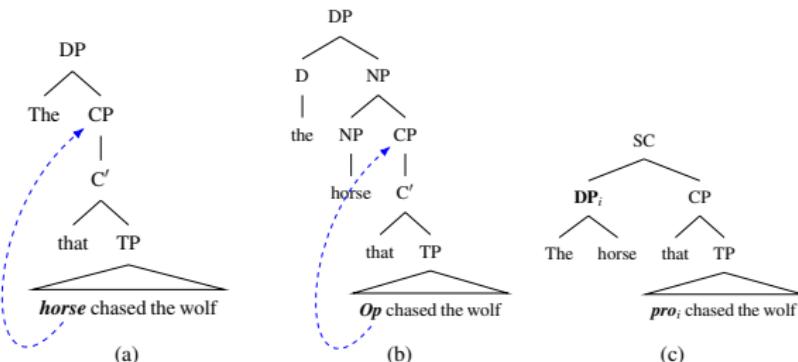


Figure 2: Sketches of the (a) RC with Promotion, (b) RC with Wh-movement, and (c) PR analyses for the sentence *The horse that the wolf chased*.

Modeling Results (De Santo & Lee, 2022b)

MG Parser: MaxT	
Hypothesis	
PR > HA	
PR > LA	
LA > HA	

- (15) (Io) Ho visto la nonna della ragazza che gridava
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- ▶ The PR> HA RC depends on syntactic choices
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TI/Dr: The Value of Formal Models

A fully specified model of syntactic cost:

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

Beyond these results

- ▶ Cross-linguistic and cross-analysis validation
- ▶ A variety of definitions for *cost* in parsing (Boston, 2012)
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E.g. Reference Theory (Altmann & Steedman 1988)
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A Look at HA Languages (Grillo & Costa 2015)

Table 4
Attachment preferences and PR availability.

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

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

PRs: Modeling Results 1

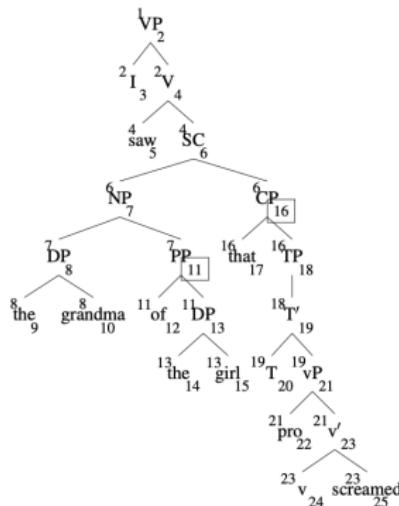


Figure 3: Annotated derivation trees for the Italian sentence *I saw the grandma of the girl that screamed*, according to a pseudo-relative clause analysis. The tree is treated as a VP since additional structure in the matrix clause would be identical across comparisons.

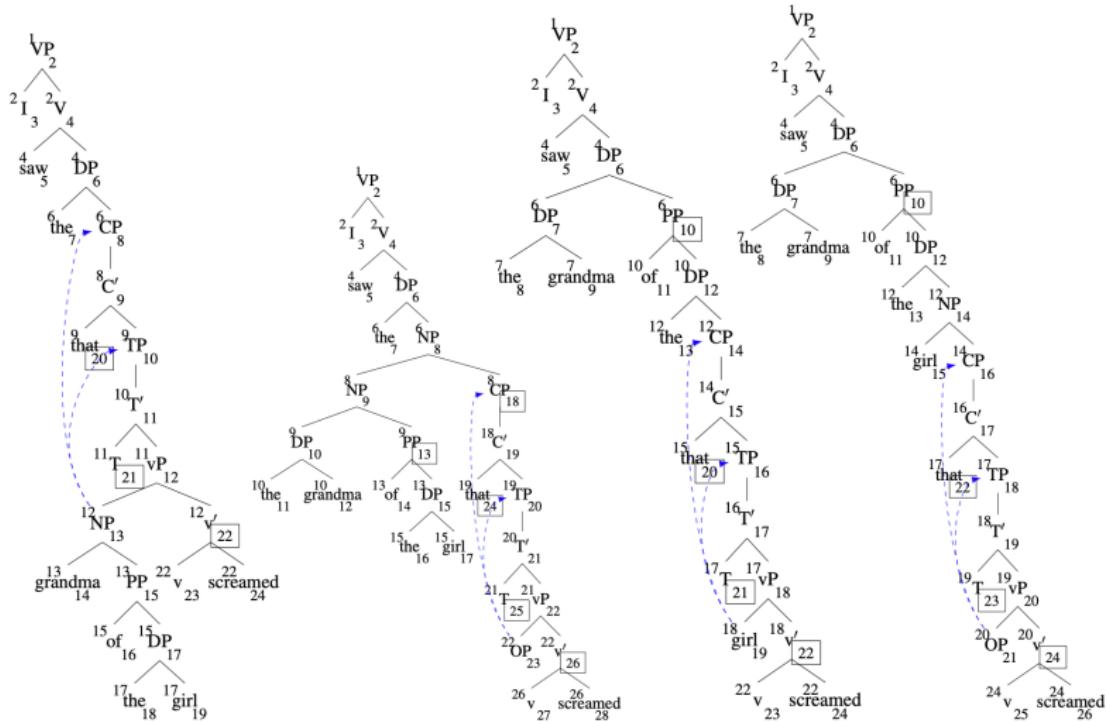
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Hypothesis	Promotion	Wh-mov
PR < HA	✓	Tie
PR < LA	✗	✗
LA < HA	✓	✓

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

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

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

PRs: Modeling Results 2



(a)

(b)

(c)

(d)

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