Computation as a Window into Linguistic Cognition

Aniello De Santo
he/him

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anielloedesanto.github.io/UM24.pdf
aniello.desanto@utah.edu

University of Michigan, Ann Arbor
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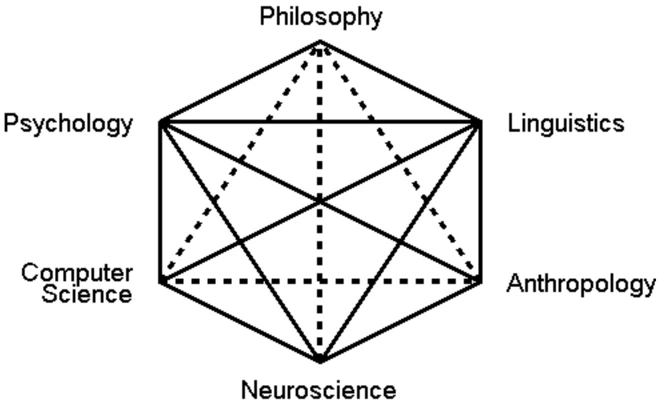
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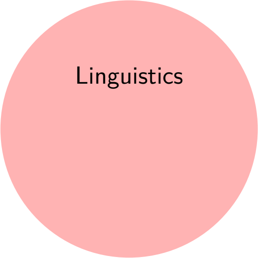
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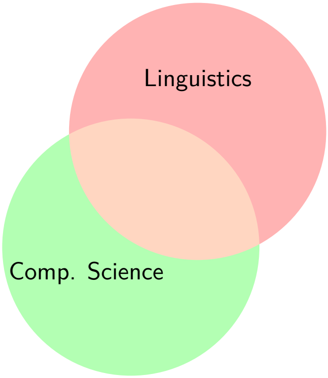
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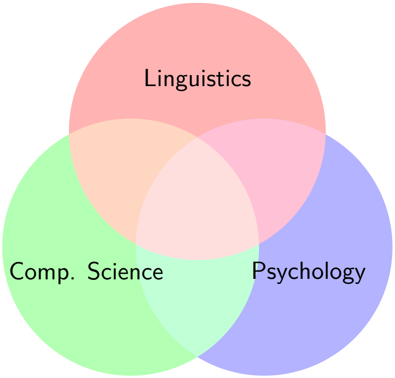
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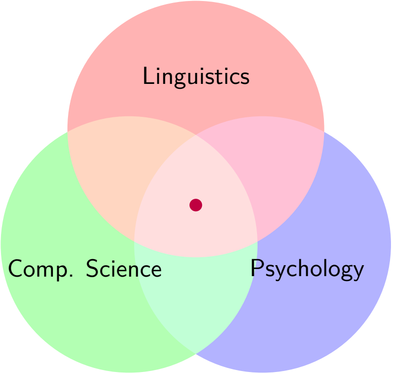

- Theory building (De Santo & Rawski 2022, Baggio, De Santo, Nunez 2024, Levenstein et al. 2024)
- Computational invariants in typology and acquisition
  (De Santo & Graf 2019, De Santo & Aksenova 2021, Johnson and De Santo 2023)
- Computational parallels across linguistic modules
  (Aksenova & De Santo 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 sentece processing
  (De Santo & Lee 2022b, Lee & De Santo in prep., Jacobs, De Santo, Grobol in prep.)
- Animal Cognition (De Santo & Rawski, 2021)
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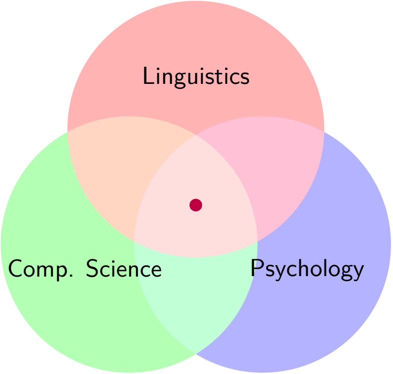

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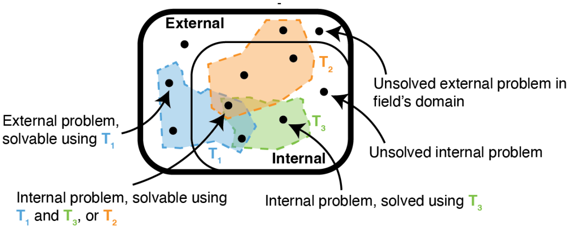
Problems and Theories[1]



Some Problems

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

[1] Levenstein, 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.*
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> *(Kaplan, 1995)*

- Invariant properties of phenomena
- Specification of verbal theories

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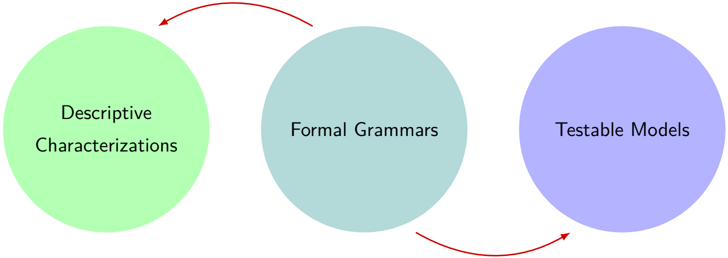
Building Bridges



Outline

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)

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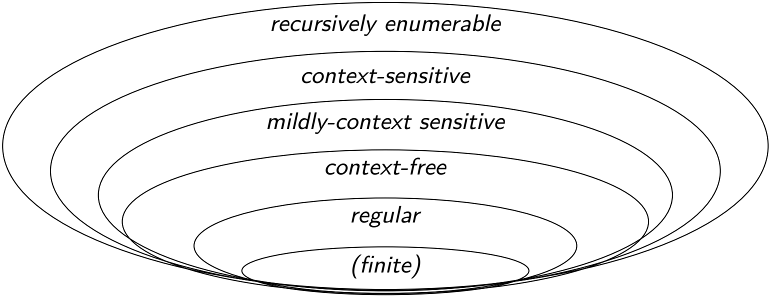
A Lens: Computational Theories of Language

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



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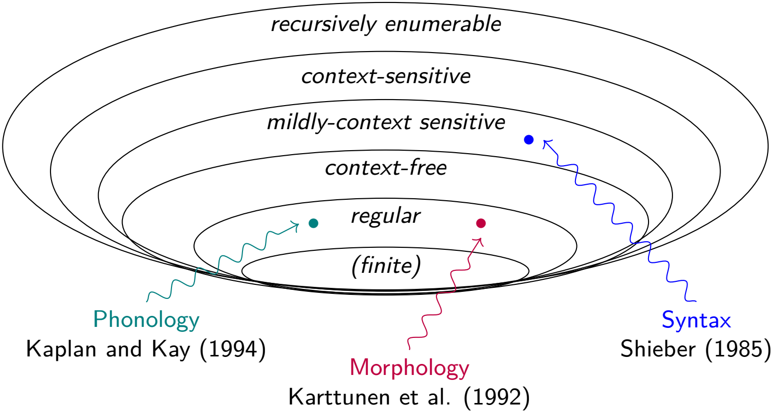
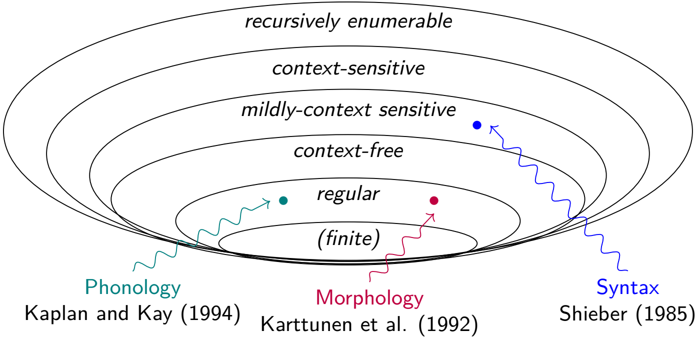


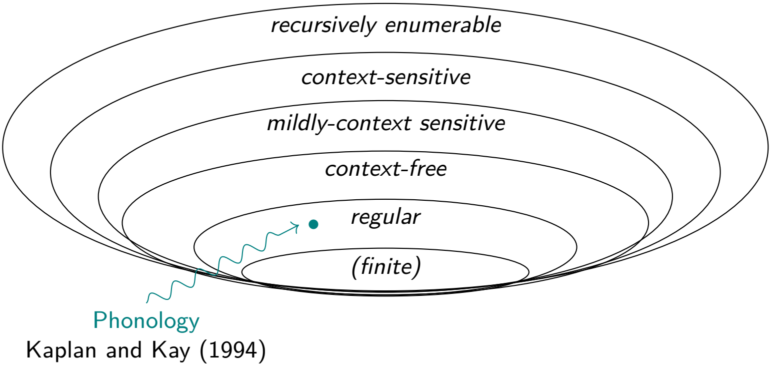
Precise Characterizations ⇒ Precise Predictions



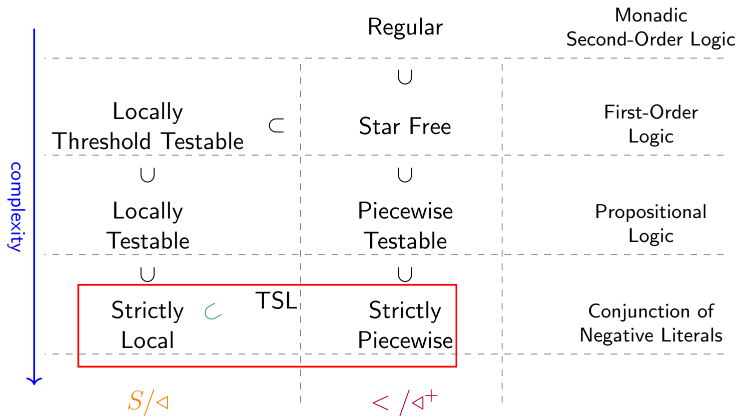
Precise predictions for:

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

Spoken Languages' Phonology as a Regular System



Beyond Monolithic Classes: Subregular Languages[2]



[2] McNaughton & Papert (1976), Heinz (2011), Chandlee & 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

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

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Example: Word-final devoicing

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- **German**: ***z**$, ***v**$,***d**$ ($ = word edge).

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Example: Intervocalic voicing

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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
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Example: Samala

*$ h a s x i n t i l a w a ʃ $

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Locality Over Tiers

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- **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 TSL

- Let's revisit Samala Sibilant Harmony

(4) a. * ha**s**xintilawaʃ

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- What do we need to project? [+strident]
- What do we need to ban? *[+ant][−ant],*[−ant][+ant]

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

Example: TSL Samala

s	ʃ		ʃ	ʃ

* $ h a **s** x i n t i l a w **ʃ** $

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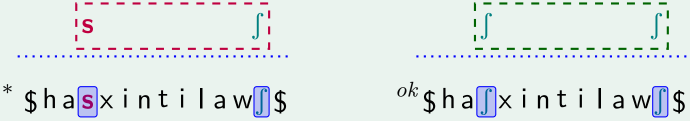
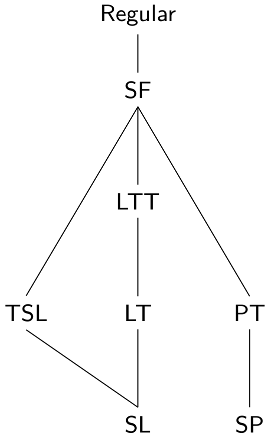


SL and TSL: So What?

*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 adjancency

- **But** typological variation is complex...
  (McMullin 2016, Mayer & Major 2018, De Santo & Graf 2019)

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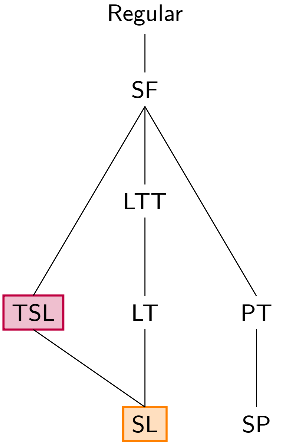

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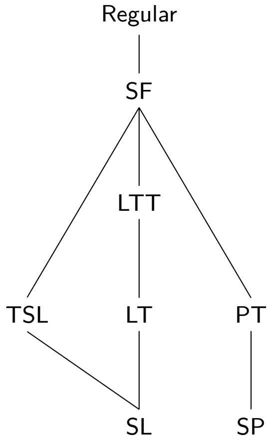
Refining the Hierarchy via Typological Insights



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[3]

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

	Base	*Causative*	
a.	uga	**s**ː-uga	"be evacuated"
b.	a**s**ːtwa	**s**-a**s**ːtwa	"settle, be levelled"

[3] Elmedlaoui (1995), Hansson (2010), McMullin (2016), De Santo (2018)

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	Base	*Causative*	
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3) Sibilant voicing harmony blocked

	Base	*Causative*	
a.	u**kz**	**s**ː-u**kz**	"recognize"
b.	**q**ːu**ʒ**ːi	**ʃ**- **q**u**ʒ**ːi	"be dislocated, broken"

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Sibilant Harmony in Imdlawn Tashlhiyt [4]

Generalization (1/2)

Sibilants must agree in anteriority and voicing.

Grammar

$T = \{$ ʒ, s, z, ʃ $\}$
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Sibilant Harmony in Imdlawn Tashlhiyt [5]

Generalization (2/2)

Voiceless obstruents block agreement in voicing.

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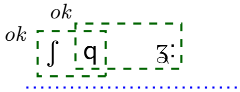

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$T = \{$ ʒ, s, z,ʃ, q$\}$
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[5] Elmedlaoui (1995), Hansson (2010), McMullin (2016), De Santo (2018)

Sibilant Harmony in IMDLAWN TASHLHIYT [5]

Generalization (2/2)

Voiceless obstruents block agreement in voicing.

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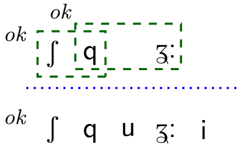

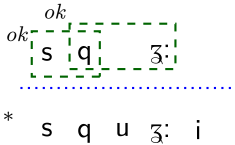

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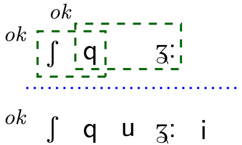

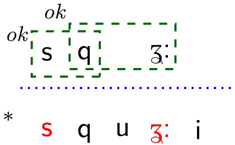

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Multi-Tier Strictly Local (MTSL) Languages (1/2)[6]

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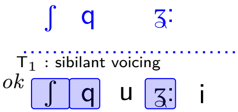

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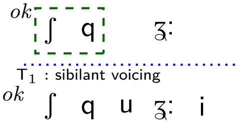

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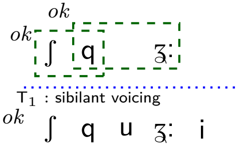

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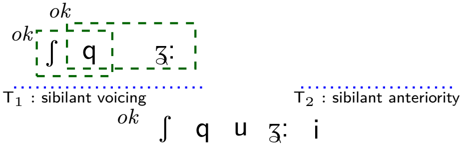

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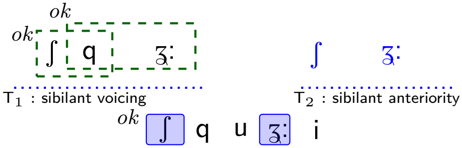

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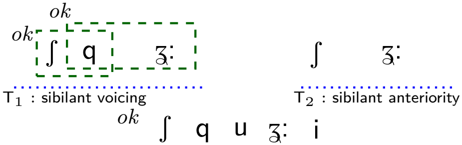

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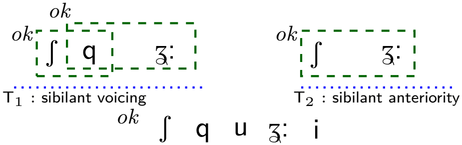

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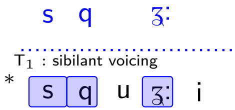

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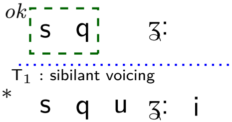

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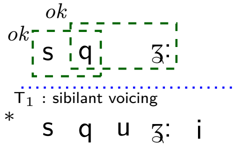

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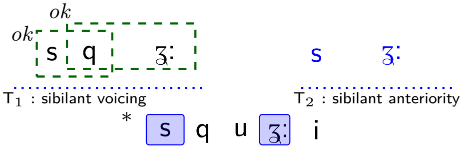

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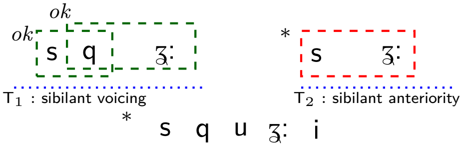

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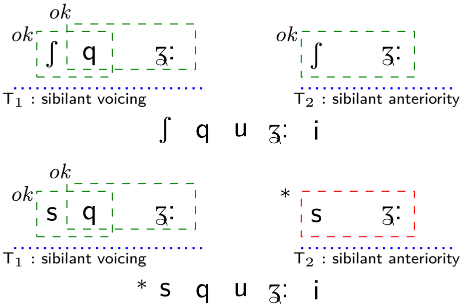
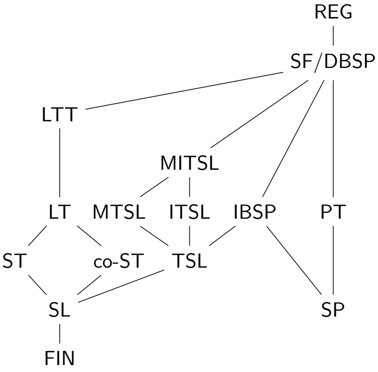
Accounting for Concurrent Processes

- 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 (De Santo & Graf 2019)



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

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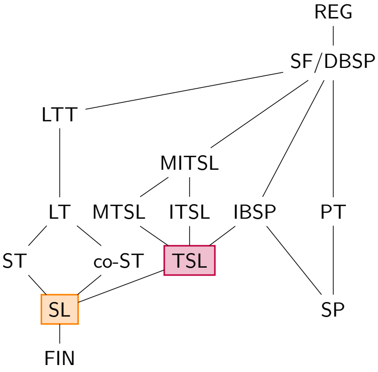
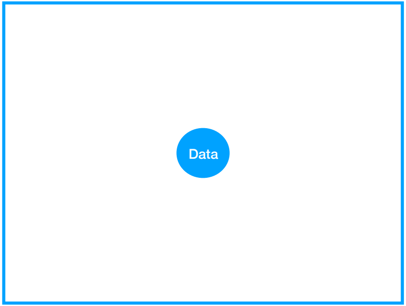


- The goal is **not** identifying a single "correct" class
- Pinpoint fundamental properties of the patterns:
  SL: $\triangleleft$, TSL: $\triangleleft_T$, ...
- What about learnability?

Learning Multiple TSL Grammars [8]

Problem:

- Unrestricted Hypothesis Spaces



[8] McMullin, Aksenova, De Santo (2020), De Santo & Aksenova (2021)

Learning Multiple TSL Grammars [9]

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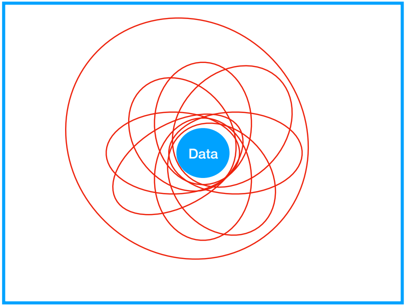

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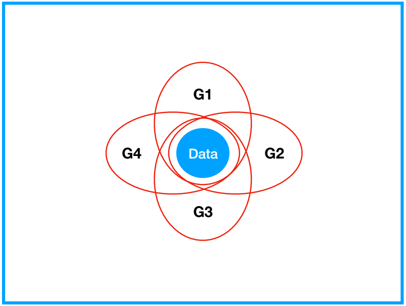
Learning Multiple TSL Grammars [10]

Solution:

- Structural priors



De Santo & Aksenova (2021):

$\Rightarrow$ Assume relativized locality!

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

[10] McMullin, Aksenova, De Santo (2020), De Santo & Aksenova (2021)

Learning Multiple TSL Grammars [10]

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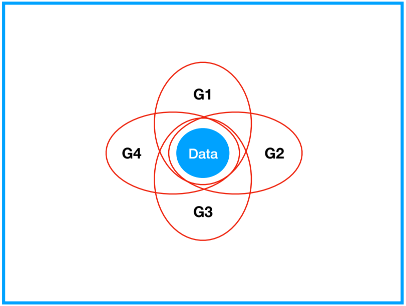

De Santo & Aksenova (2021):

⇒ Assume relativized locality!

- tiers (but not their content)
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- characteristic sample!

Results

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

[10] McMullin, Aksenova, De Santo (2020), De Santo & Aksenova (2021)

Evaluating Convergence in Real World Scenarios

	SP	SL	TSL	MTSL	MITSL
Word-final devoicing					
T	✗	✓	✓	✓	✓
A	68%	100%	100%	100%	100%
N_1	58%	100%	100%	100%	100%
Single vowel harmony without blocking					
T	✓	✗	✓	✓	✓
A	100%	83%	100%	100%	100%
N_2	100%	72%	100%	100%	100%
Single vowel harmony with blocking					
T	✗	✗	✓	✓	✓
A	84%	89%	100%	100%	99%
Several vowel harmonies without blocking					
T	✓	✗	✓	✓	✓
A	100%	69%	100%	100%	100%
Several vowel harmonies with blocking					
T	✗	✗	✓	✓	✓
A	76%	59%	100%	100%	99%
N_3	76%	70%	67%	95%	99%
Vowel harmony and consonant harmony without blocking					
T	✓	✗	✗	✓	✓
A	100%	64%	74%	100%	100%
Vowel harmony and consonant harmony with blocking					
T	✗	✗	✗	✓	✓
A	83%	64%	69%	100%	100%
Unbounded tone plateauing					
T	✓	✗	✗	✗	✓
A	100%	85%	90%		100%
Two locally-driven long-distance assimilations (ITSL restrictions)					
T	✗	✗	✗	✗	✓
A					100%

Johnson & De Santo (2023)

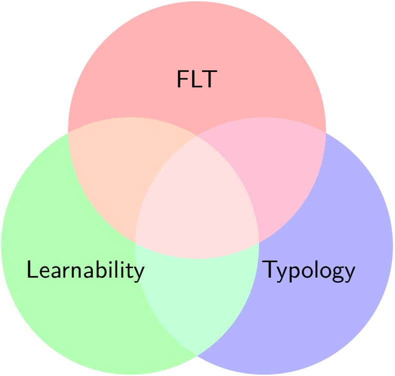
(T)heoretical expectations and performance of 5 subregular learners on (A)rtificial and simplified (N)atural language input data-sets. N_1: German; N_1: Finnish; N_1: Turkish.

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.)

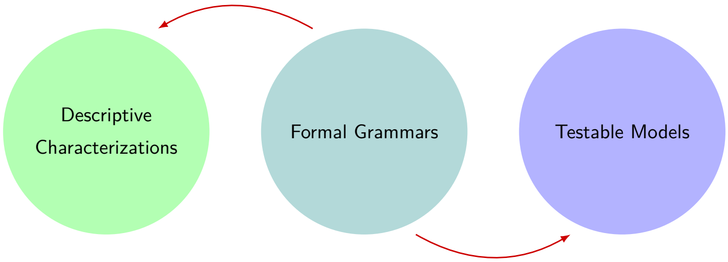
Interim Summary [cont.]



The Tip of the Iceberg:

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

Building Bridges



Outline

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 ≈ Grammaticality judgments

Gradience in Acceptability Judgments

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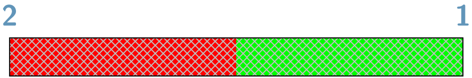
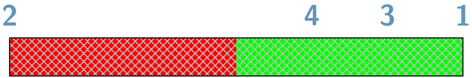


Gradience in Acceptability Judgments

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?



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Gradient Acceptability and Categorical Grammars

Acceptability judgments are not binary but *gradient*:

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

(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**!

(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**!

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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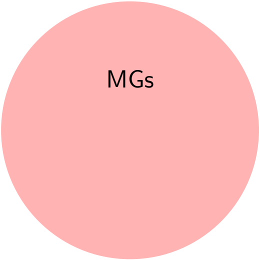
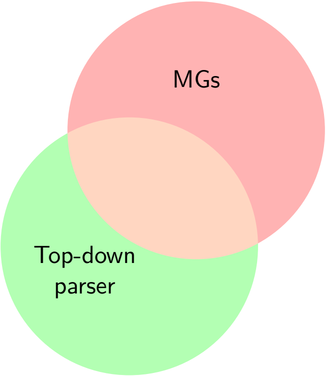
A Formal Model of Sentence Processing



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

A Formal Model of Sentence Processing



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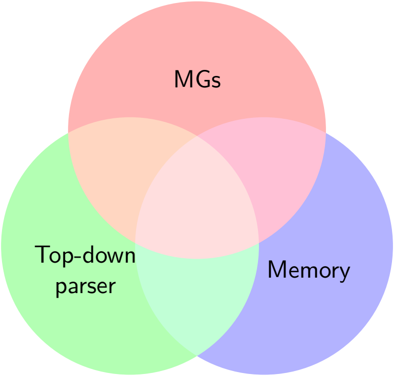

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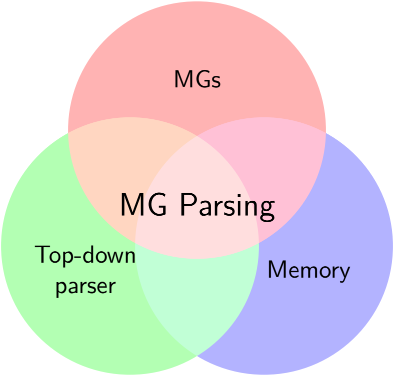

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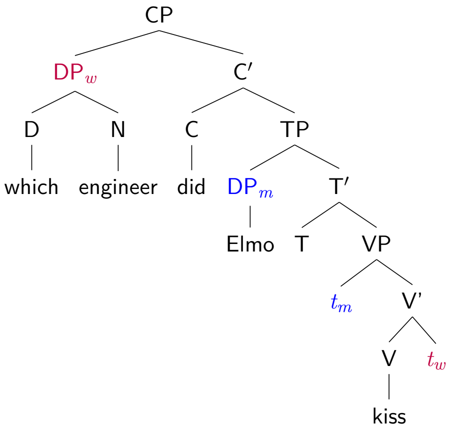
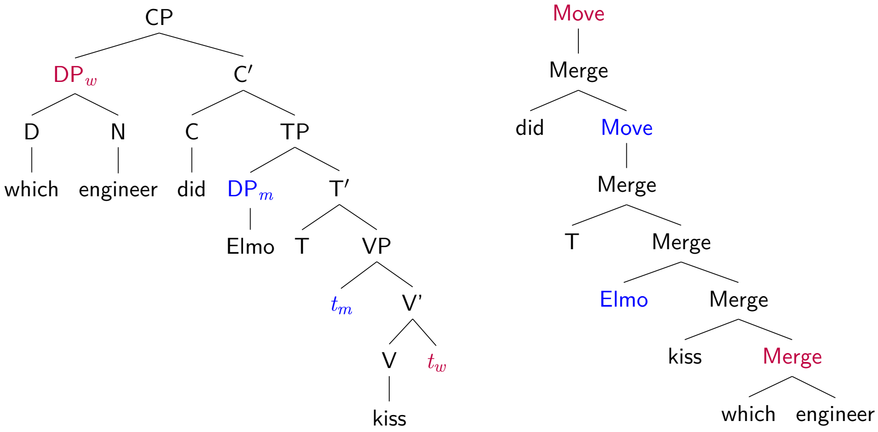
Interpretability for the win!

Minimalist Grammars (MGs) & Derivation Trees



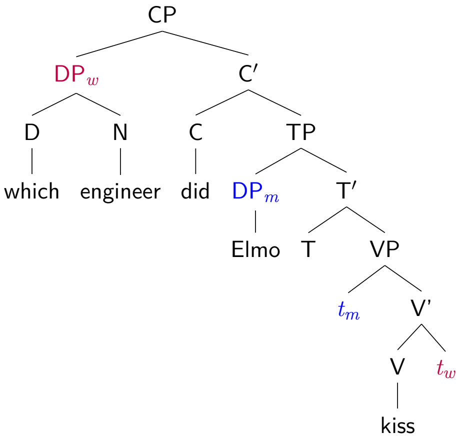
Phrase Structure Tree

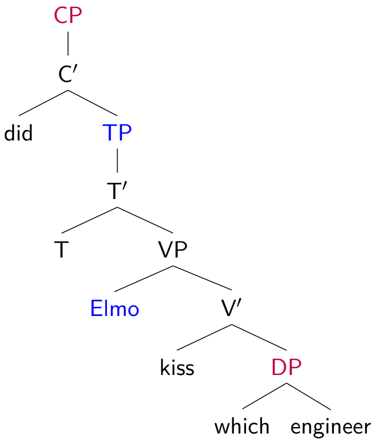
Minimalist Grammars (MGs) & Derivation Trees



Phrase Structure Tree **Derivation Tree**

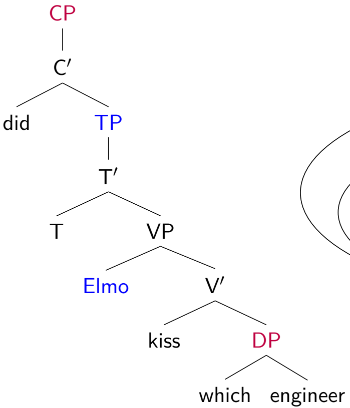
MG Syntax: Derivation Trees

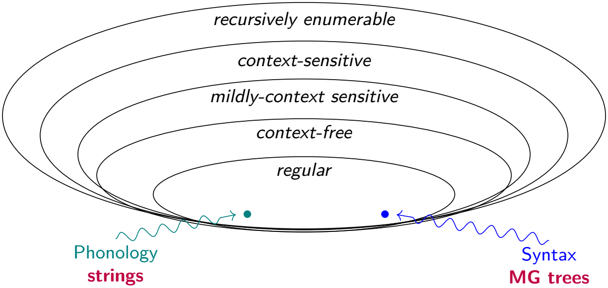




Phrase Structure Tree **Derivation Tree**

Regular Tree Languages[11]

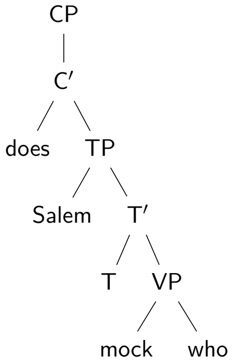




[11] Thatcher (1967), Kobele et al. (2007), Stabler (2013)

The Job of a Parser

Who does Salem mock?



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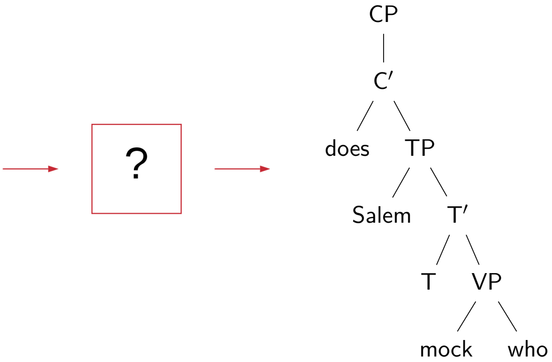

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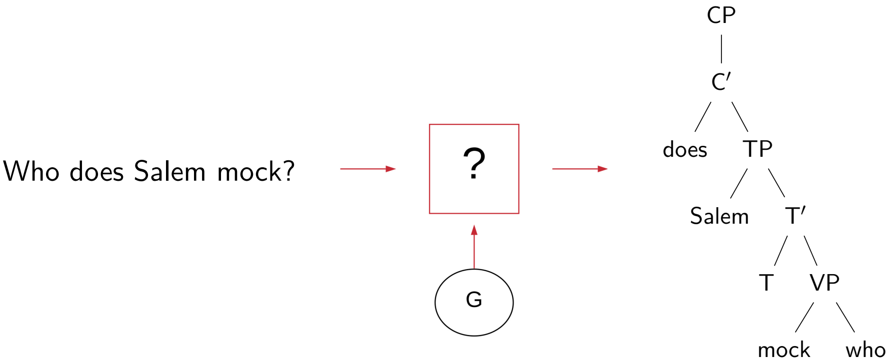

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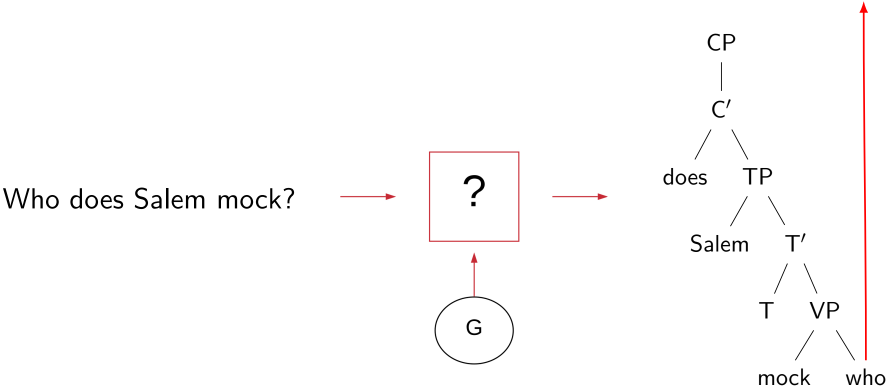

- Bottom-up

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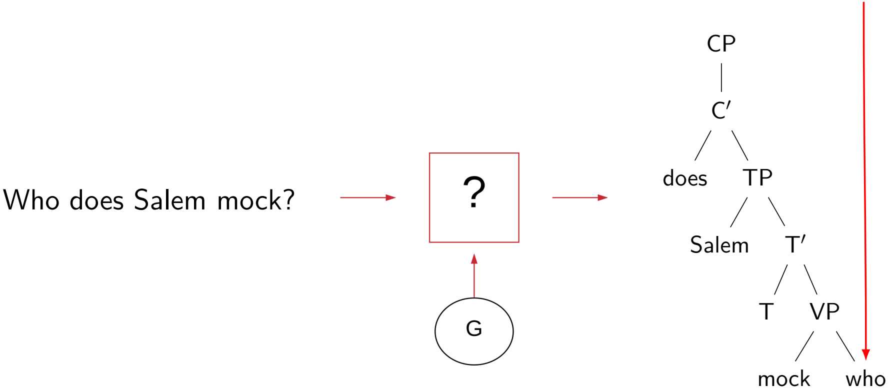

- Bottom-up
- Top-down

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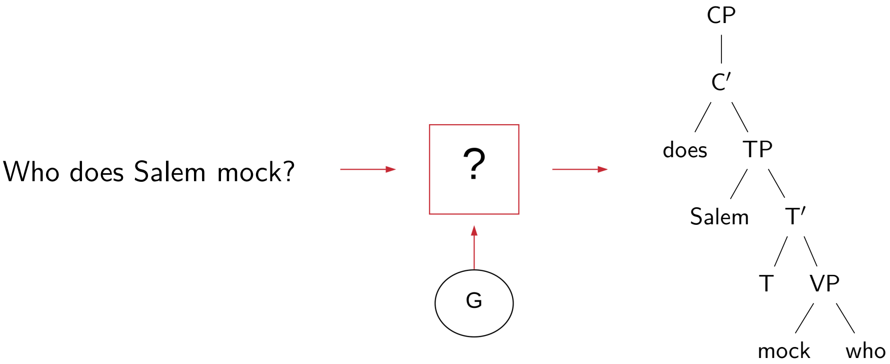

- Bottom-up
- Top-down (Stabler, 2013)
  - Psychologically plausible(-ish)

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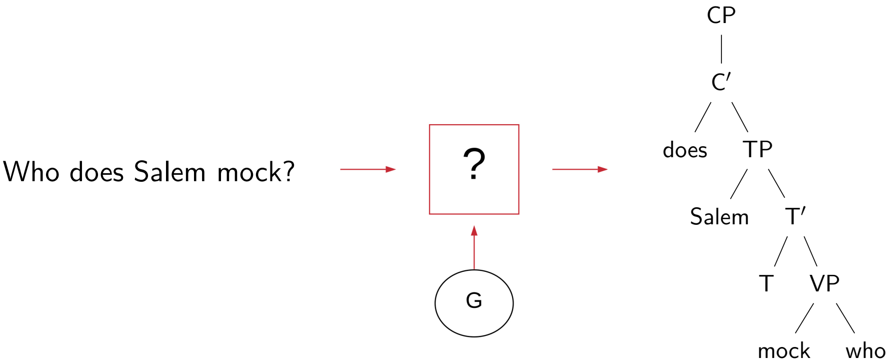

- Bottom-up
- Top-down (Stabler, 2013)
  - Psychologically plausible(-ish)
  - Assumption: Parser as an oracle!

Incremental Top-Down Parsing: The Intuition

Who does Salem mock?

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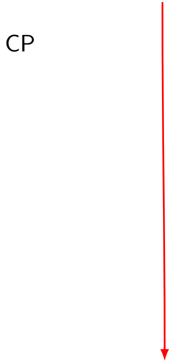

Who does Salem mock?

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

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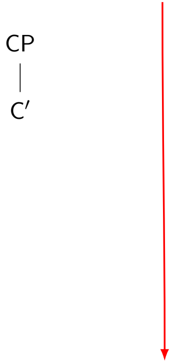

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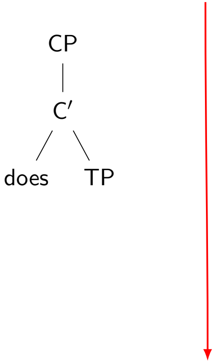

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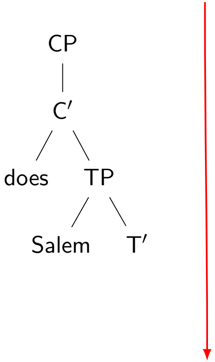

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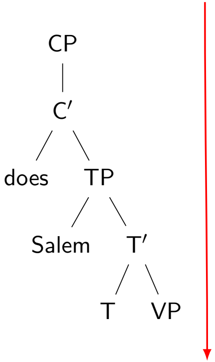

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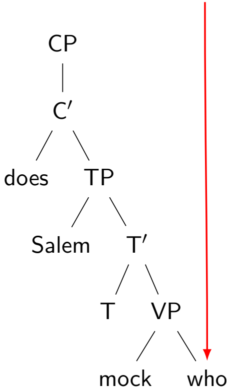

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Memory-Based Complexity Metrics

- **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
$\Rightarrow$ Intuitively, the length of its movement dependency!

- Formalized into offline **complexity metrics**

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

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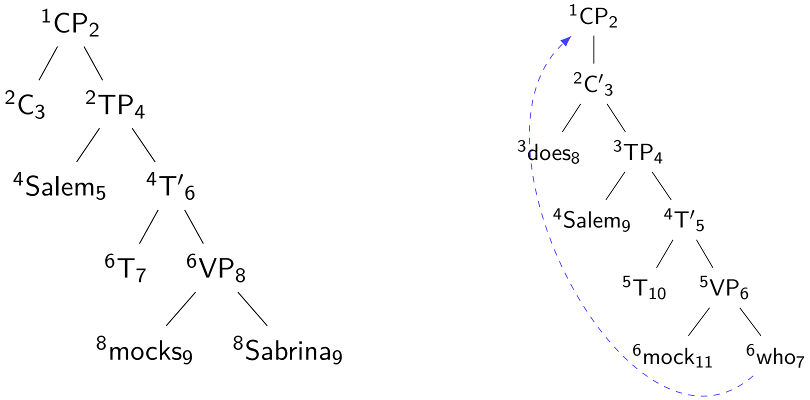
Contrasting Derivations

MaxTenure $= 2$ **MaxTenure** $= 5$



Summary of the Approach

A Computational Linking Hypothesis (De Santo 2020; in prep.)

Grammar $\rightleftarrows$ MG Parser Effort $\rightleftarrows$ 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

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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 at 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.	✓

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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.	✓
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	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
Subj. | Non Isl.	>	Obj. | Non Isl.	✓
Subj. | Non Isl.	>	Obj. | Isl.	✓
Subj. | Non Isl.	>	Subj. | Isl.	✓
Obj. | Non Isl.	>	Obj. | Isl.	✓
Obj. | Non Isl.	>	Subj. | Isl.	✓
Obj. | Isl.	>	Subj. | Isl.	×

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

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Obj. | Non Isl.	>	Obj. | Isl.	✓
Obj. | Non Isl.	>	Subj. | Isl.	✓
Obj. | Isl.	>	Subj. | Isl.	×

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Obj./Non Island	14/*do*	19
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Obj./Island	23/*T2*	22
Subj./Island	15/*do*	20

Subject Island: Case 2

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

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

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

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

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

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

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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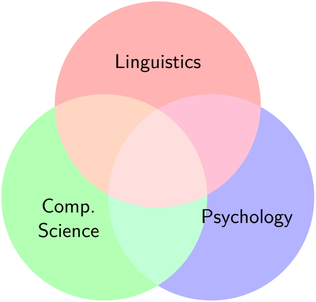
Outline

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

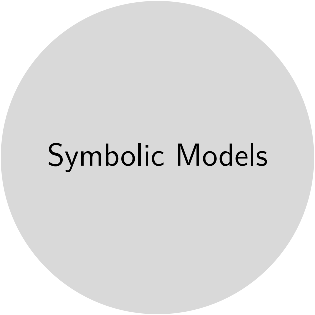
Embracing Multidisciplinarity



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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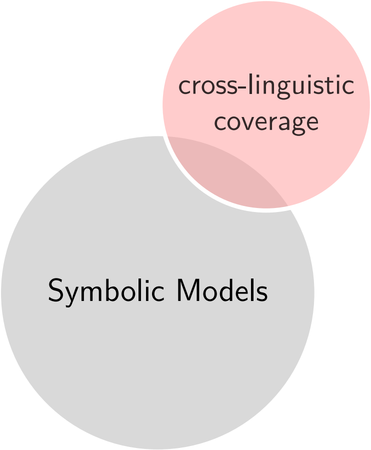

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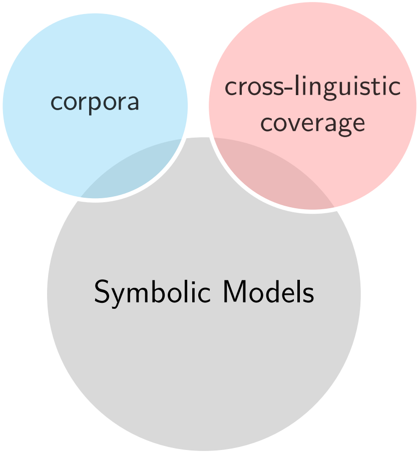
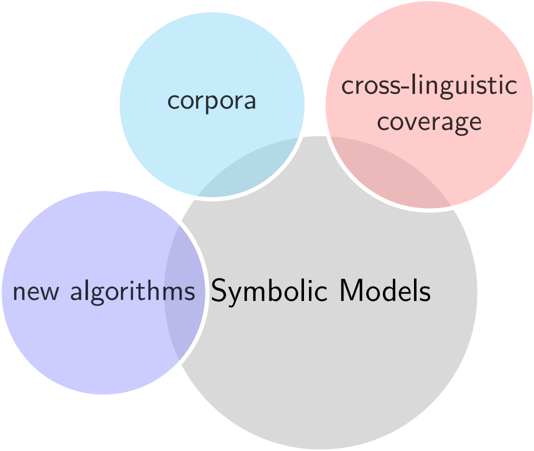


Looking Ahead: A Collaborative Enterprise



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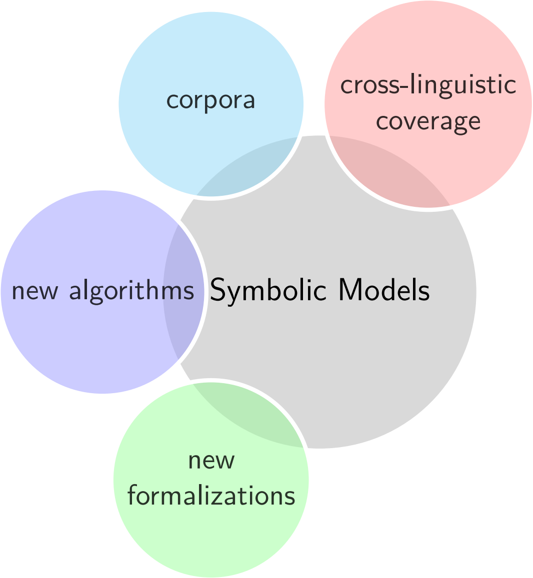

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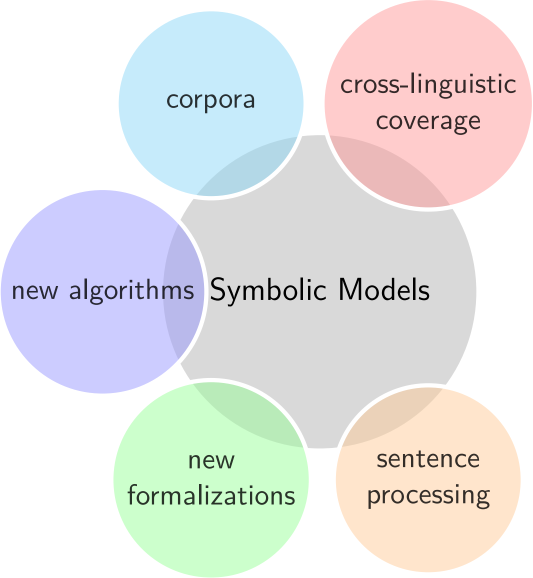

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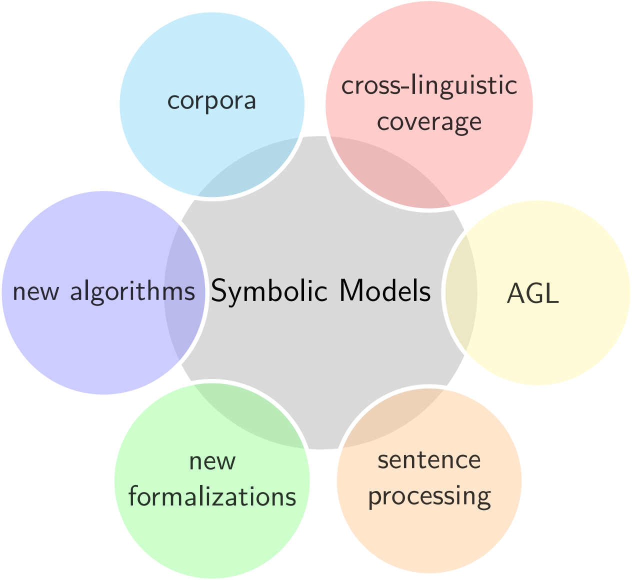

Looking Ahead: A Collaborative Enterprise

Looking Ahead: A Collaborative Enterprise

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2 **De Santo, A.** (2019). Testing a Minimalist grammar parser on Italian relative clause asymmetries. In *Proceedings of CMCL 2019*, June 6 2019, Minneapolis, Minnesota.

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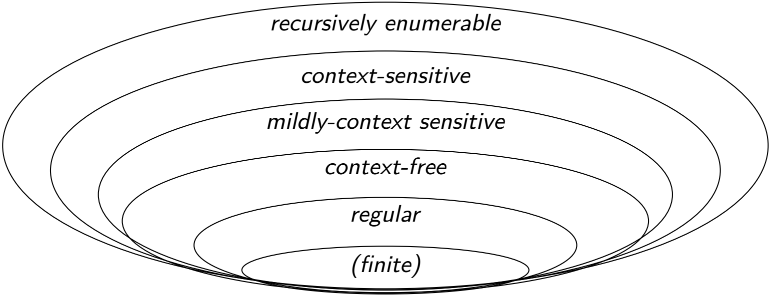
Appendix

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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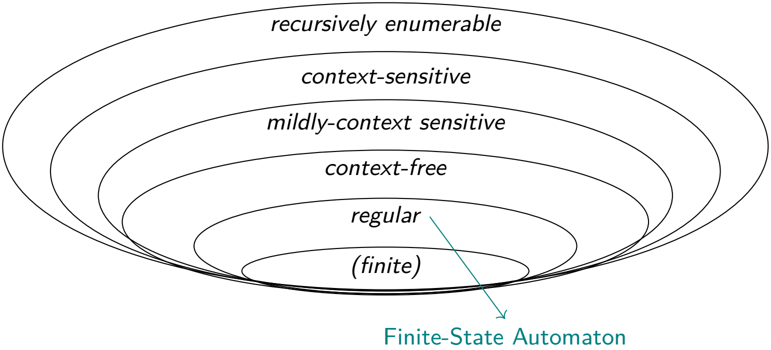

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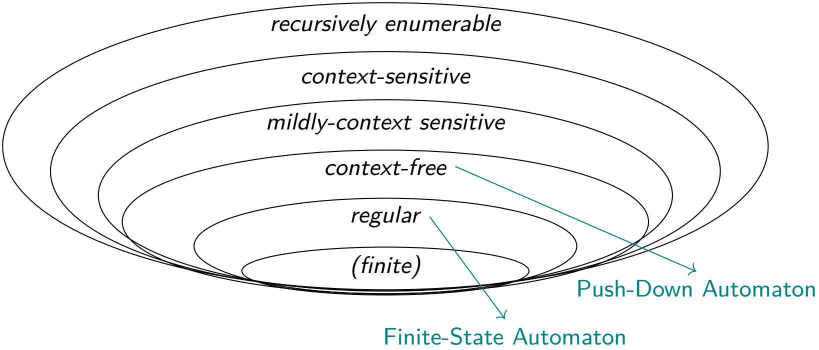

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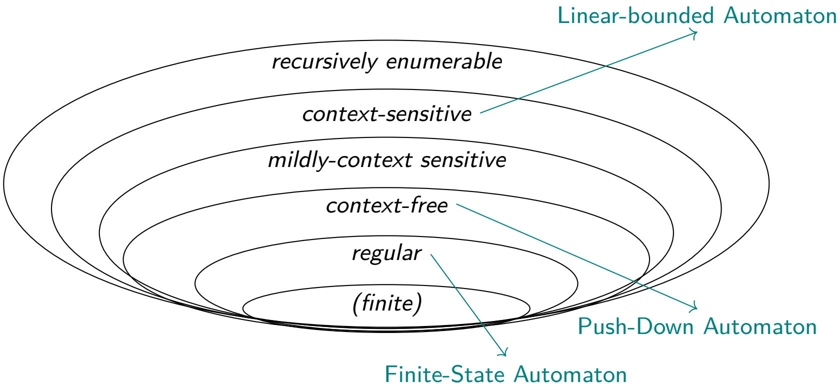

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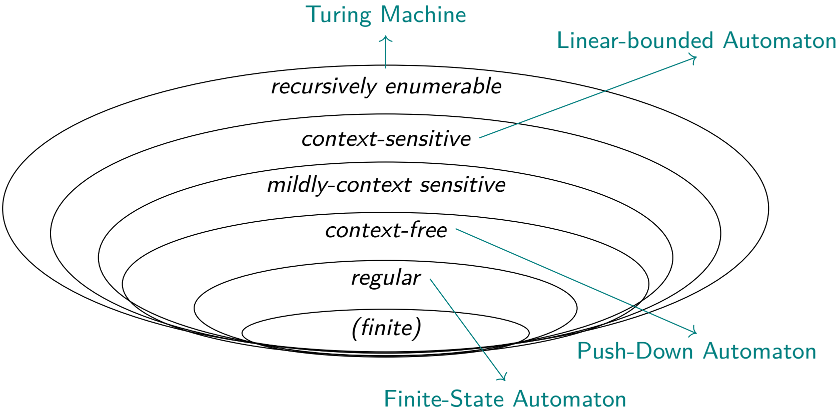

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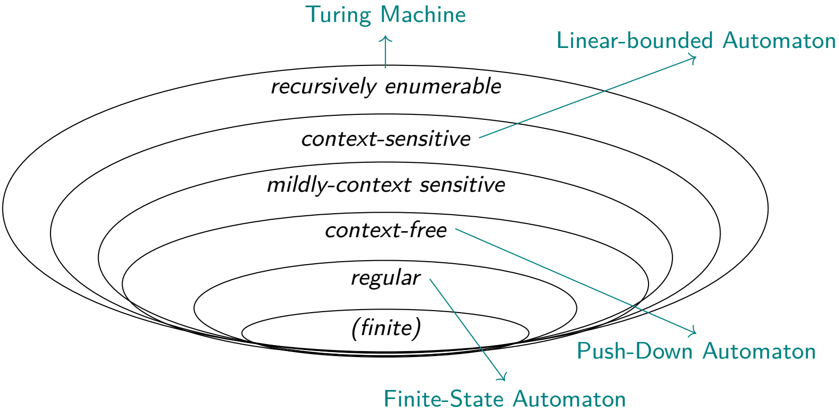
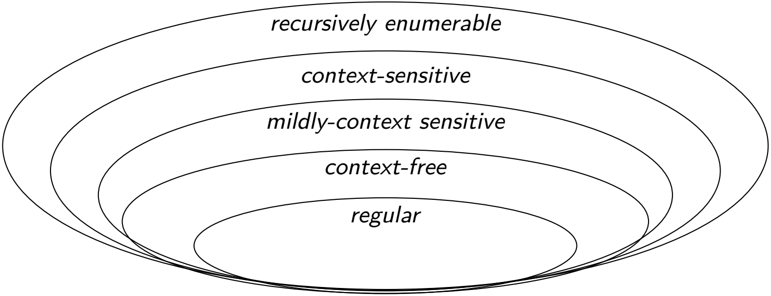


Automata theoretic classes seem to presuppose [...] specific classes of recognition mechanisms, raising questions about whether these are necessarily relevant to the cognitive mechanisms under study.

Rogers & Pullum 2011

Cross-domain Parallels



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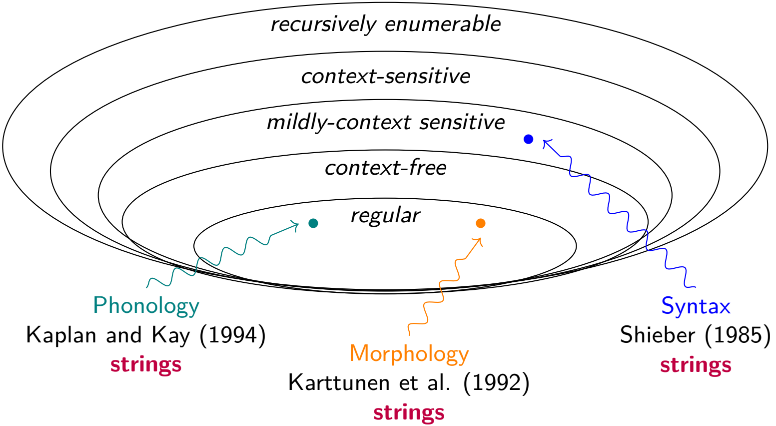

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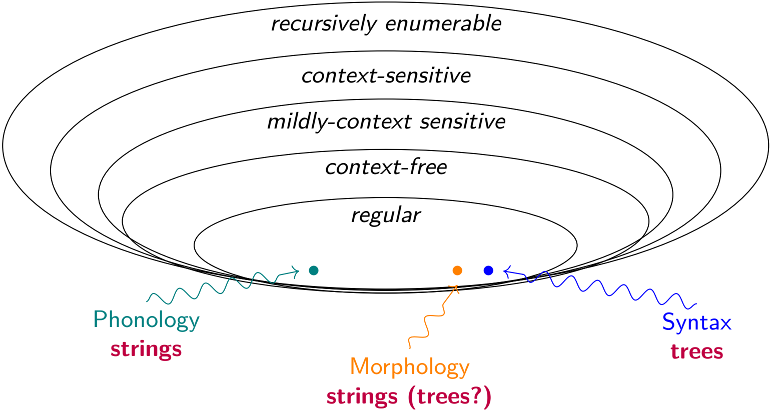

Some Insights

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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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

- Merge is a **feature-driven** operation:
  category feature N^-, D^-, ...
  selector feature N^+, D^+, ...
- Subcategorization as formalized by Merge is **strictly local**.

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's	cat
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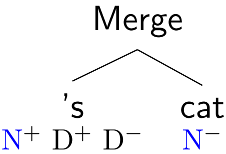

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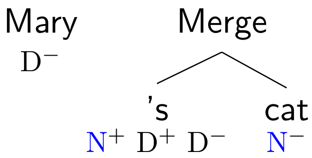

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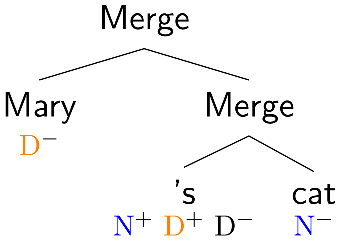
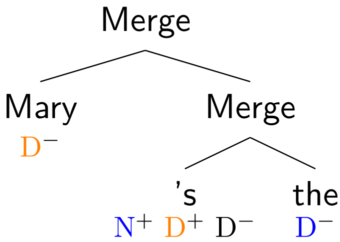
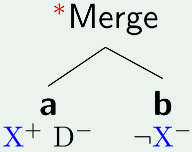


Merge is SL (Graf 2012)



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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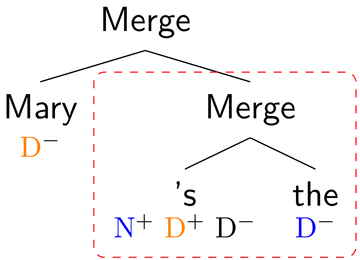

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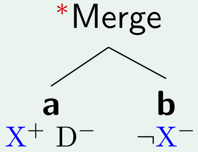

Interim Summary

	Local	**Data Structure**
Phonology	?	?
Syntax	?	?

Local phenomena modeled by n-grams of bounded size:

- computationally very simple
- learnable from positive examples of strings/trees
- plausible cognitive requirements

Interim Summary

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	Local	**Non-local**	**Data Structure**
Phonology	**SL**	?	**Strings**
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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
c. *LHLLHL
d. LHHHHL

Example

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....

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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**
- Ban: **HLH**

Example

^{ok}**L H L L L L** ***L H L L H L**

Accounting for Context [cont.]

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H

ok **L H** L L L L

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H L

. . . .

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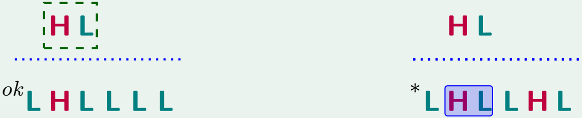

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Example

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TSL for Phonology

Most non-local dependencies in phonology are TSL

- Linguistically natural (Goldsmith 1976)
- Captures wide range of phonotactic dependencies (McMullin 2016)
- Provably correct and efficient learning algorithms (Jardine and McMullin 2017)
- Rules out unattested patterns (cf. Lai 2015, Aksenova et al. 2016, Graf & De Santo 2019, a.o.)

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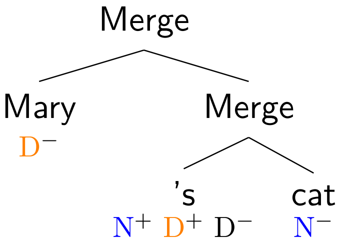
What about syntax?

Non-Local Dependencies in Syntax

Let's stick to core operations:

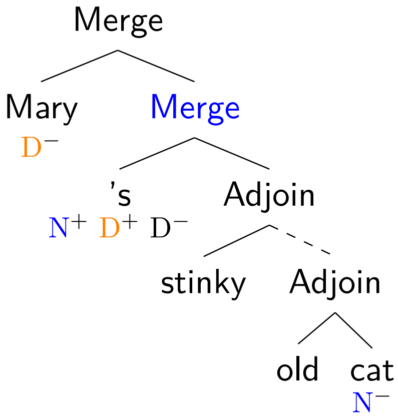
- Move
- Merge?



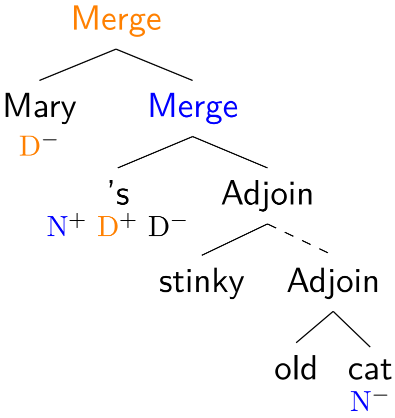
Non-Local Dependencies in Syntax

Let's stick to core operations:

- Move
- **Merge**: Unbounded adjunction
  Frey and Gärtner (2002); Graf (2017)



TSL over Trees: Projecting Tiers



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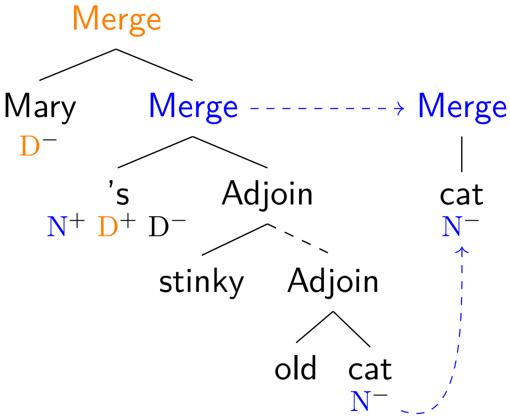

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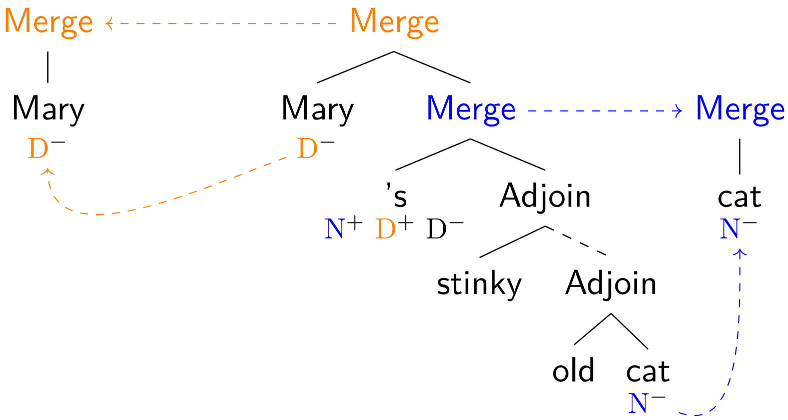
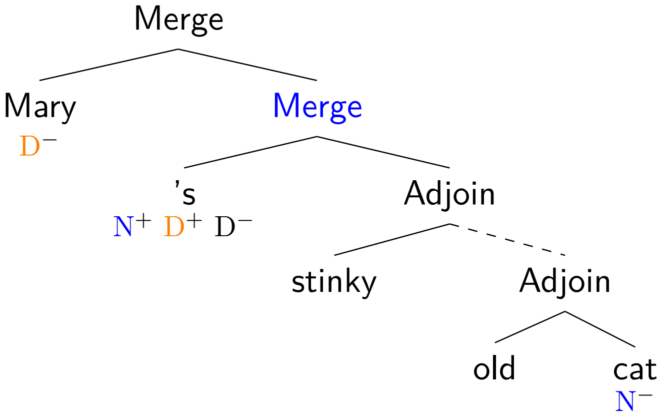


Merge with Adjunction is TSL



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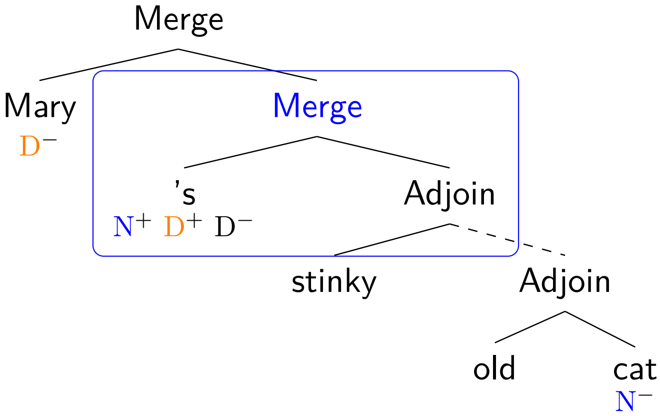

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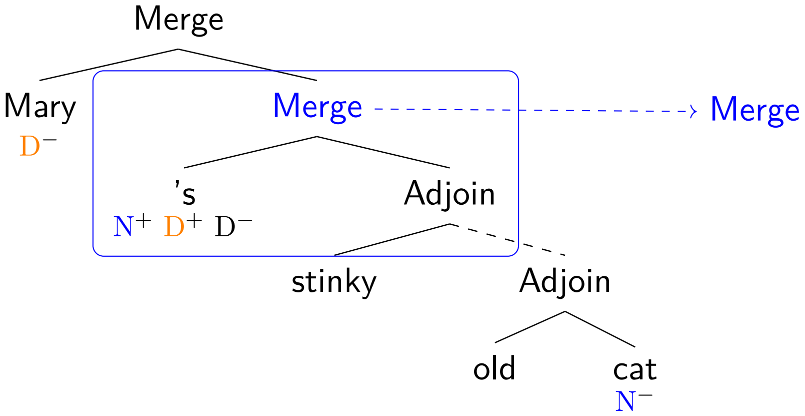

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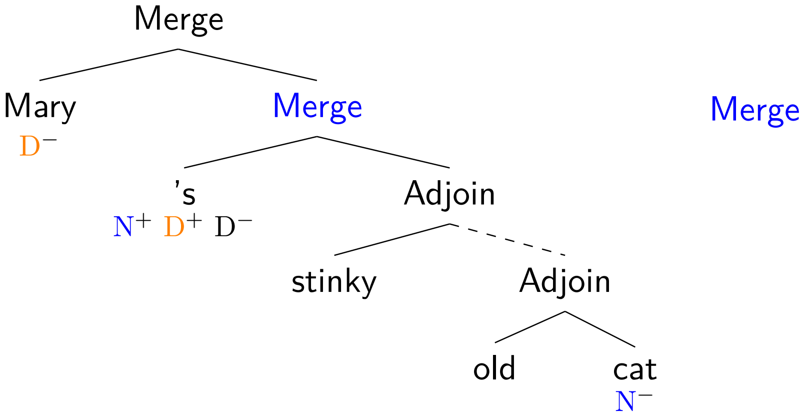

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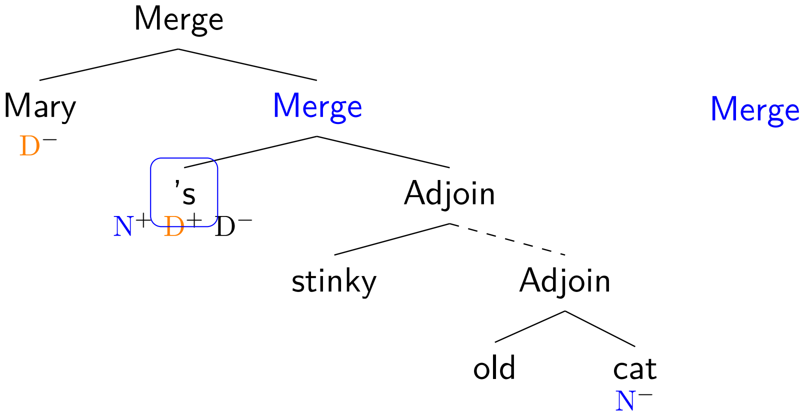

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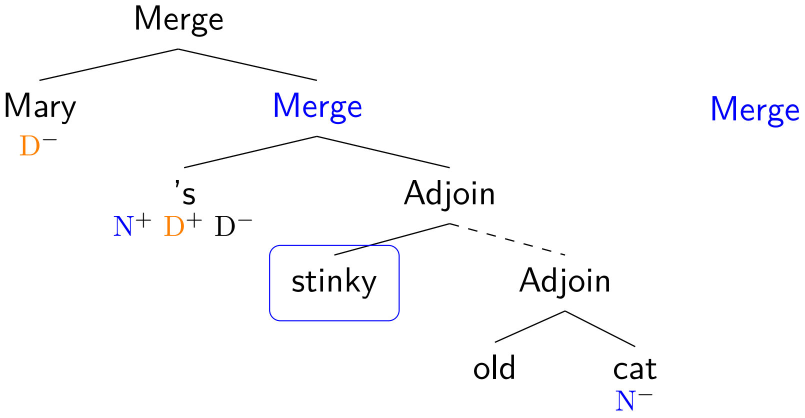

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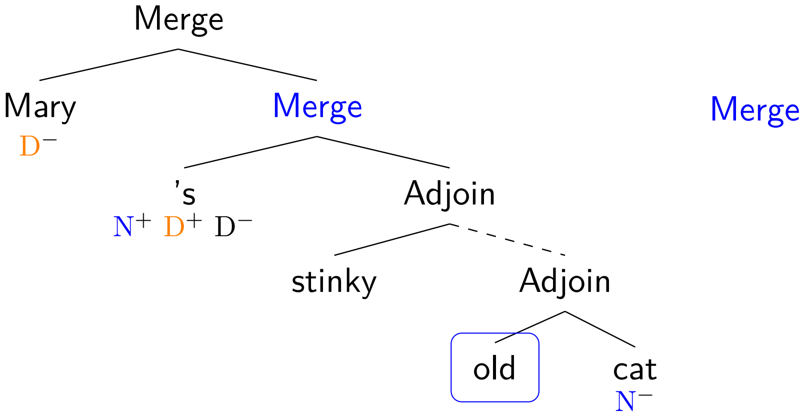

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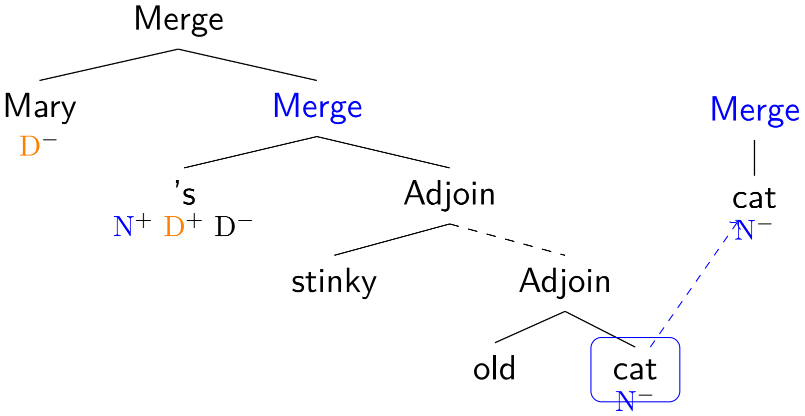

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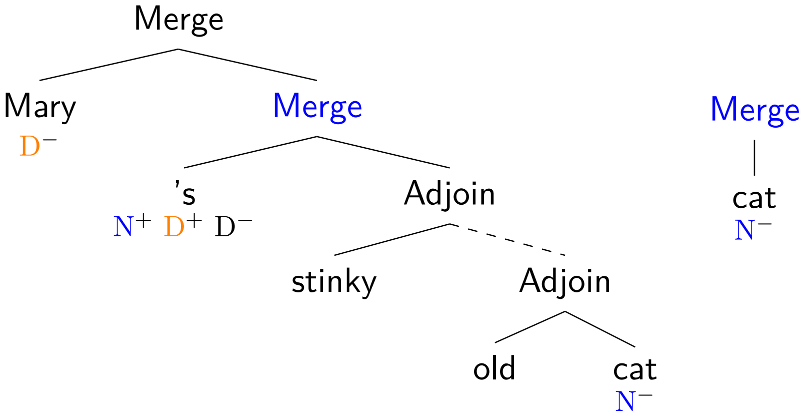

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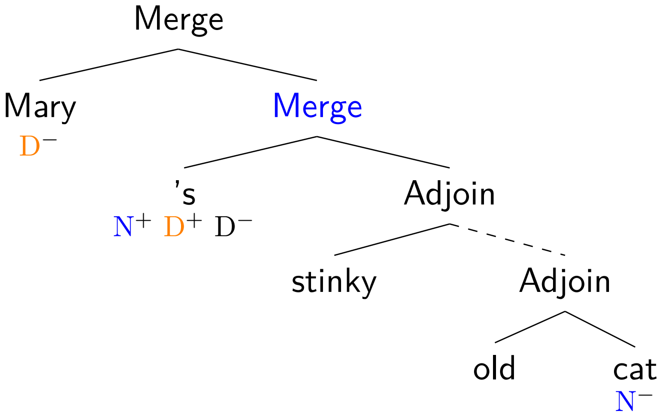

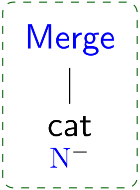

A TSL grammar for Merge

1. Project **Merge** iff a child has X^+ (e.g. $X = N$)
2. Project any node which has X^- (e.g. $X = N$)
3. No Merge without exactly one LI among its daughters.

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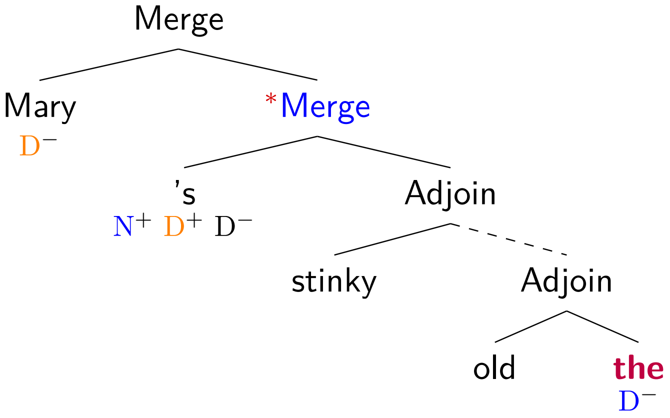

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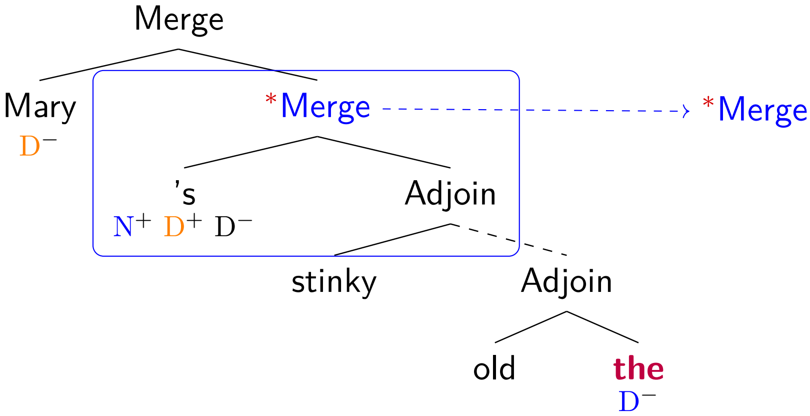

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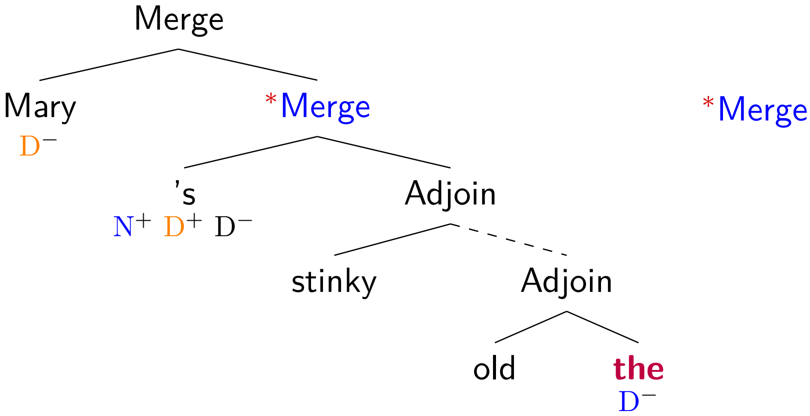

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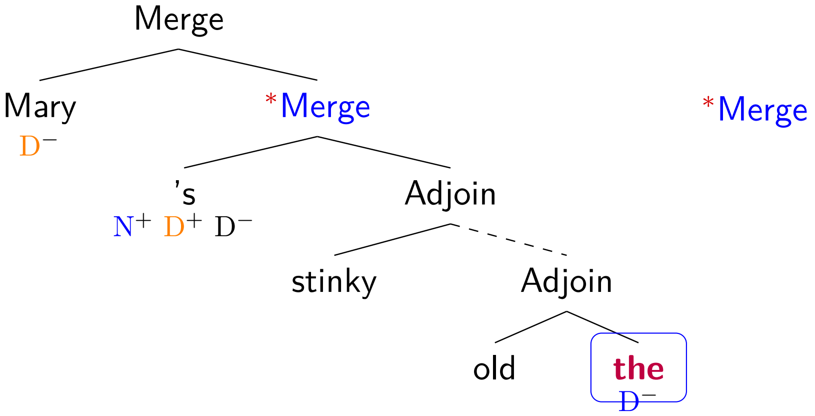

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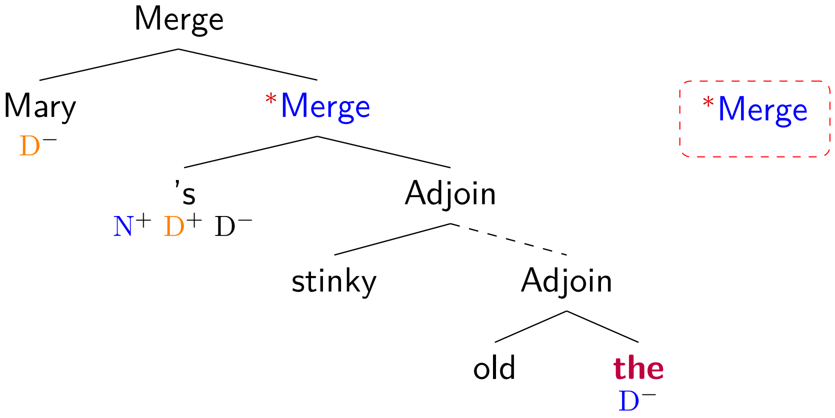

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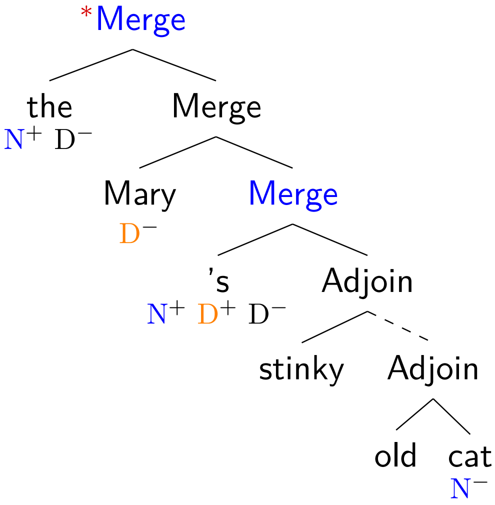

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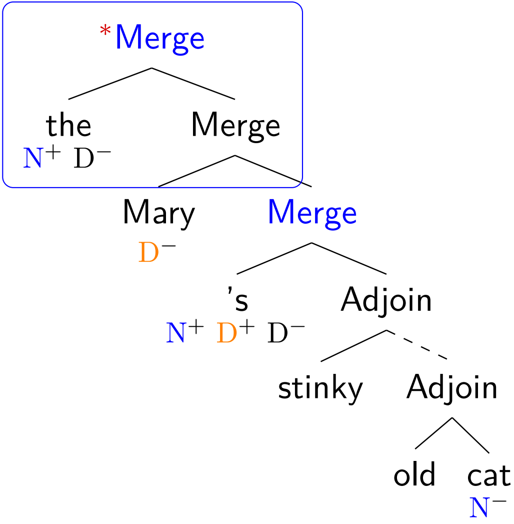

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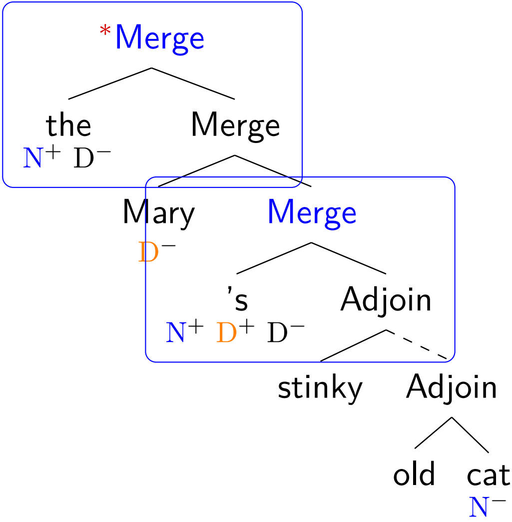

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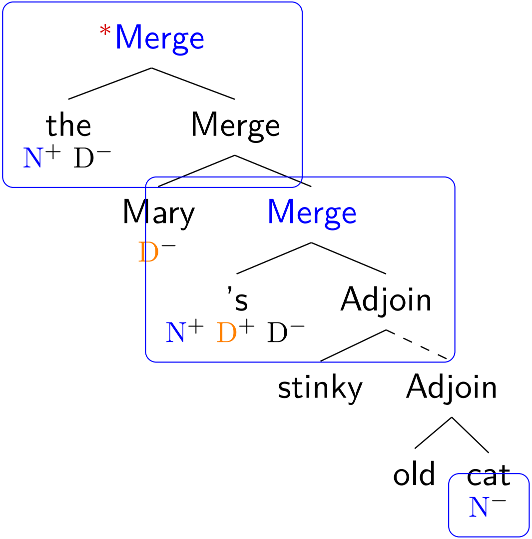

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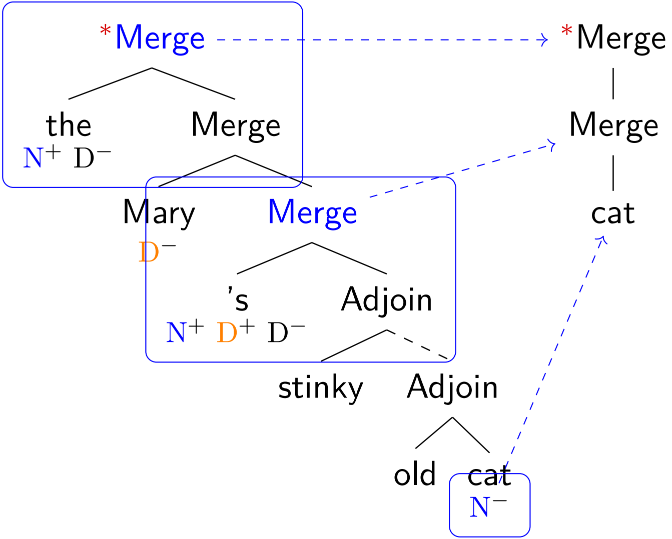

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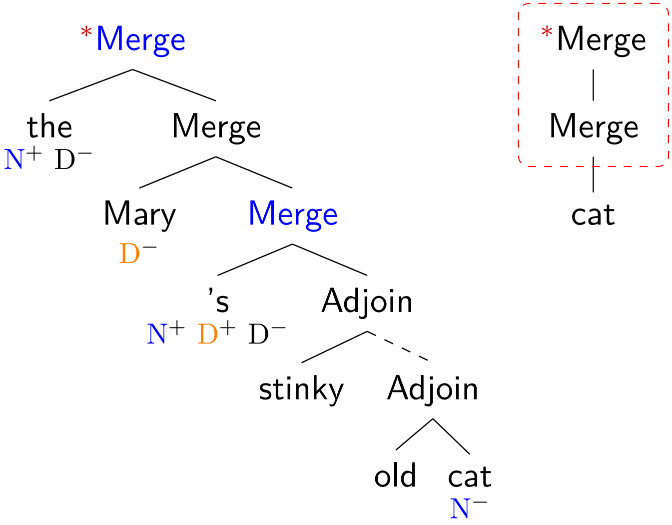

Parallels Between Phonology And Syntax

	Local	Non-local
Phonology	?	?
Syntax	?	?

- **Relativized Locality:**
  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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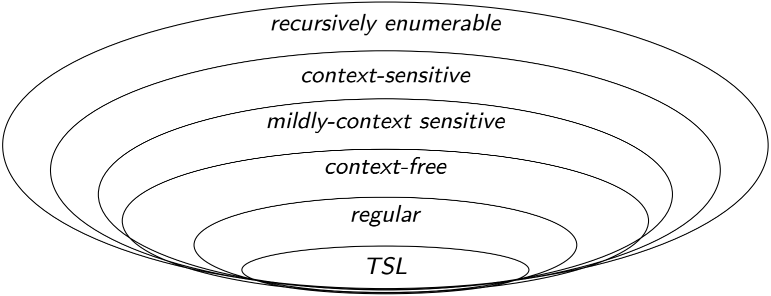
A Bird's-Eye View of the Framework



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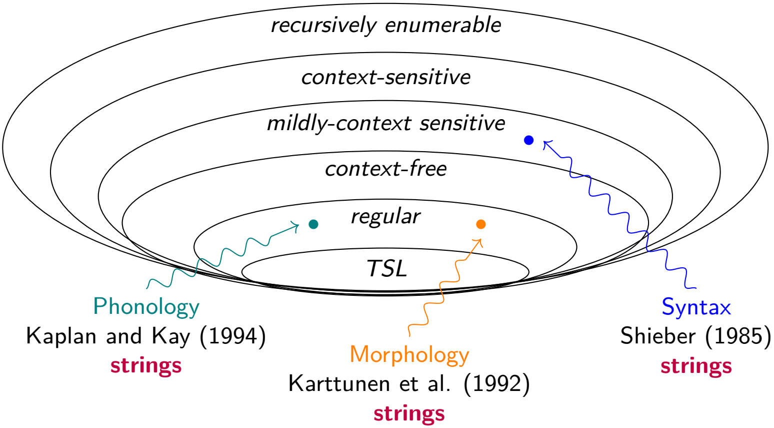

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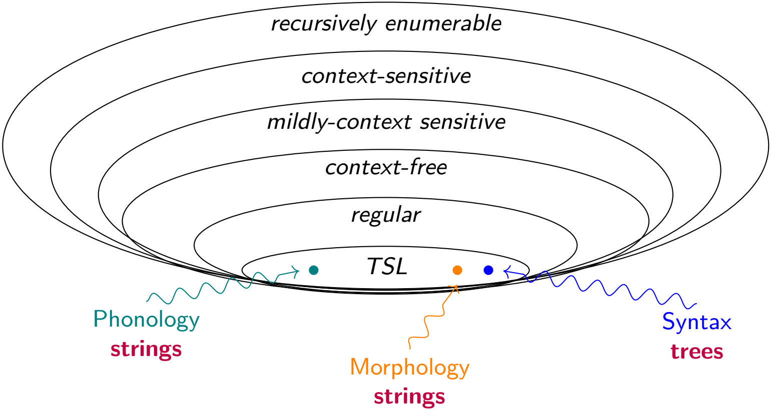
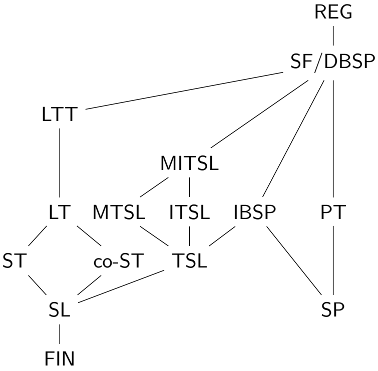


Refining the Hierarchy via Typological Insights



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  SL: $\triangleleft$, TSL: $\triangleleft_T$, etc

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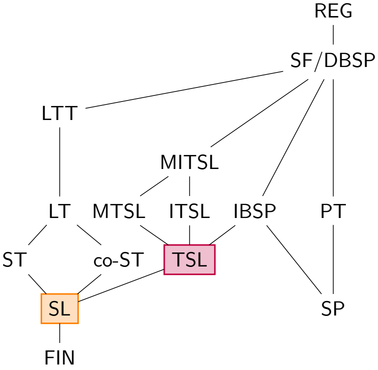

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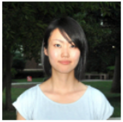
Syntax beyond Merge and Move

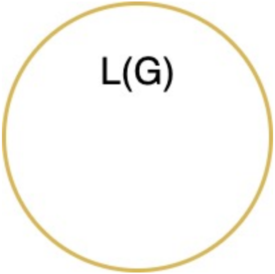
- regular tree languages
  (Michaelis 2004; Kobele et al. 2007)
- subregular operations (Graf 2018)
- subregular dependencies/constraints
  (Vu et al. 2019; Shafiei and Graf 2019)
- tree automata and parsing restrictions
  (Graf & De Santo 2020)



Artificial Grammar Learning (AGL)

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



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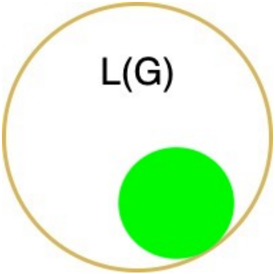

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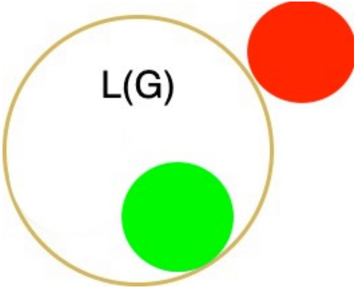


Reber (1976)

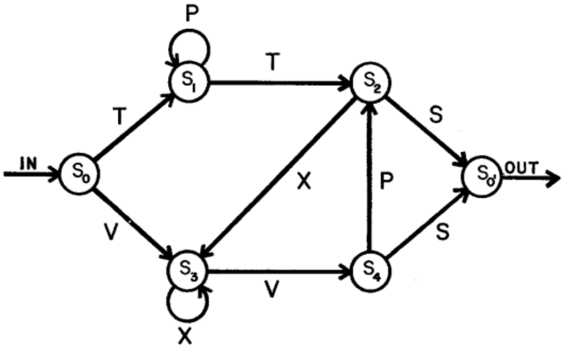


FIG. 1. Schematic state diagram of the grammar used to generate the grammatical stimulus items.

- 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.]

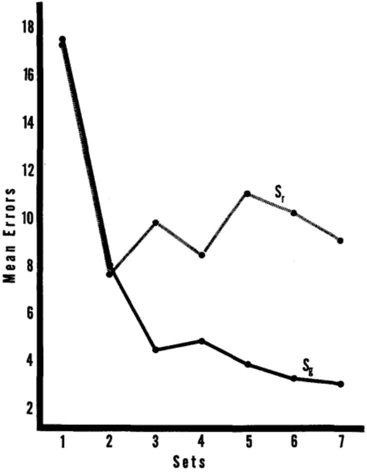
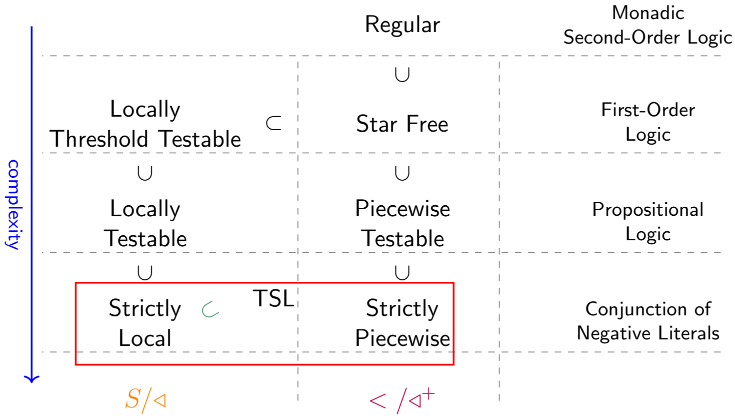


Fig. 2. Mean number of errors to criterion on each of the seven learning sets.

- 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

s ʃ ʃ ʃ

* $hasxintilawʃ$ ok $haʃxintilawʃ$

Unattested: First-Last Harmony

- Harmony only holds between initial and final segments

s ʃ s ʃ

ok $hasxintilawʃ$ * $satxintilawʃ$

Lai (2015)

Learnable vs. Unlearnable Harmony Patterns

Regine Lai

Posted Online July 09, 2015
https://doi.org/10.1162/LING_a_00188

Linguistic Inquiry
Volume 46 | Issue 3 | Summer 2015
p.425-451

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

Lai (2015): Stimuli

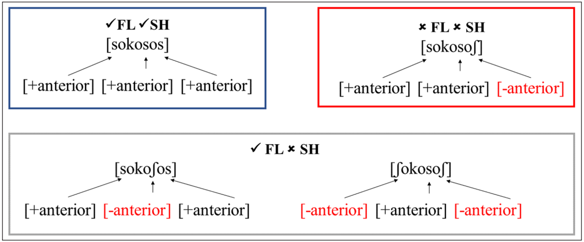


Figure 3: Comparison of SH and FL stimuli.

Lai (2015): Stimuli

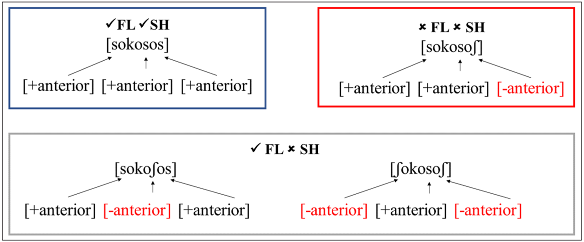
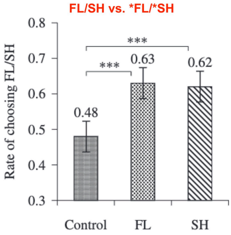


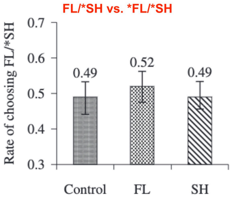
Figure 3: Comparison of SH and FL stimuli.

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		
Conditions	FL/*SH vs. *FL/*SH (e.g., [s . . . ʃ . . . s] vs. [s . . . s . . . ʃ]) Rate of FL/*SH	FL/SH vs. *FL/*SH (e.g., [s . . . s . . . s] vs. [s . . . s . . . ʃ]) Rate of FL/SH	FL/SH vs. FL/*SH (e.g., [s . . . s . . . s] vs. [s . . . ʃ . . . s]) Rate of FL/SH
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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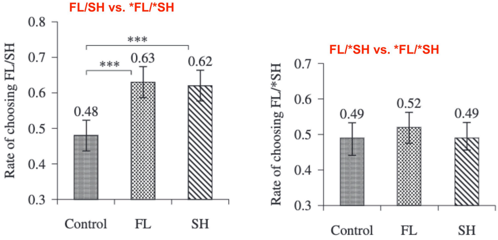

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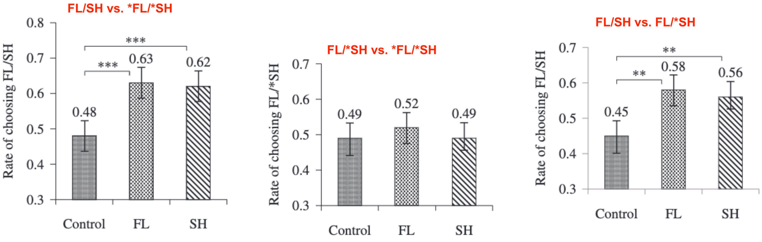
Lai (2015): Full Results



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AGL and Syntax/Semantics

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> *Rogers & Pullum 2011*

In other words:

- Questions of complexity confounded by representations
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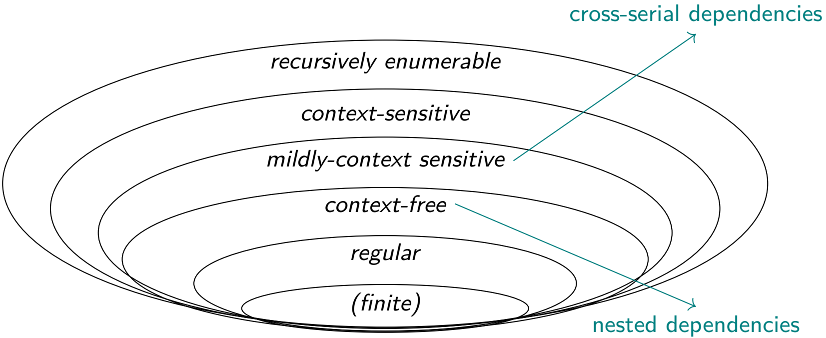

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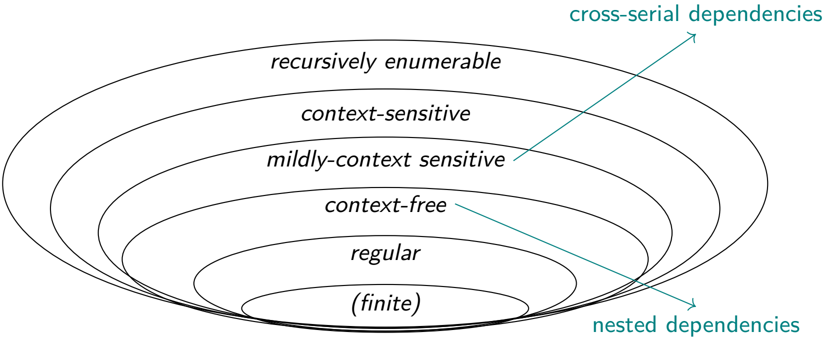

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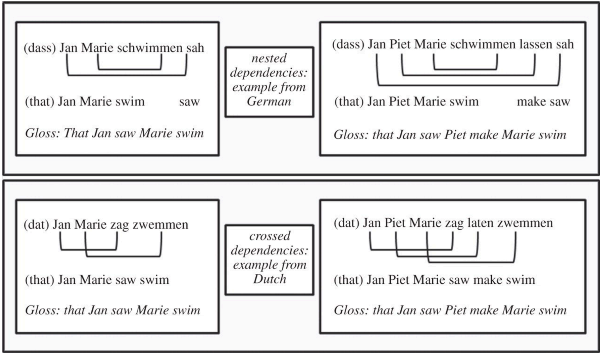
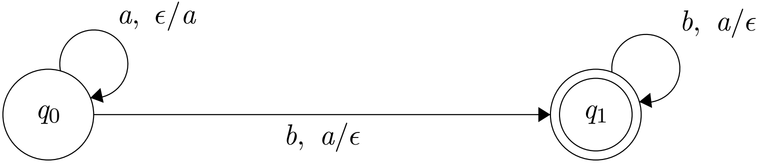


- cross-serial preferred over nested (Bach et al. 1986)
- against predictions from the CH? (Chesi & Moro 2014; de Vries et al. 2012)
- BUT: this can easily be derived via processing mechanisms (Savitch 1989; Joshi, 1990; Rainbow and Joshi,1994)
- recognition complexity requires a precise theory of parsing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

AGL and Syntax/Semantics [cont.]



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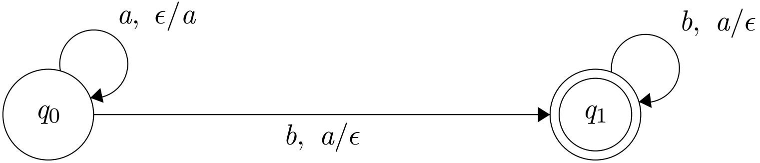

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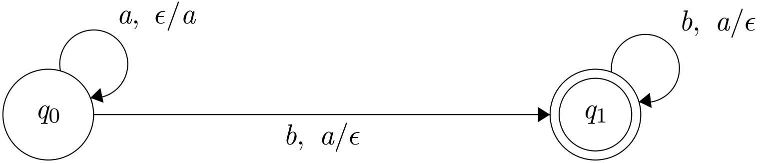

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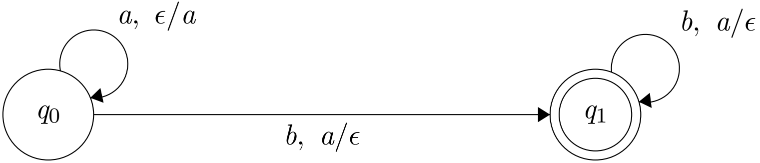

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- But combined pattern **A**+**B** is not TSL.

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)

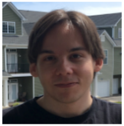
vod	**-o-**	voz	**-o-**	voz
water	-COMP-	carry	-COMP-	carry

'carrier of water-carriers'

(9)

türk	bahçe	kapı	**-sı**	(*-**sı**)
turkish	garden	gate	-COMP	(*-COMP)

'Turkish garden gate'



Example: Compounding Markers [cont.]

- Russian and Turkish are TSL.

Tier$_1$	COMP affix and stem edges #
Russian n-grams	**oo**, **$o**, **o$**
Turkish n-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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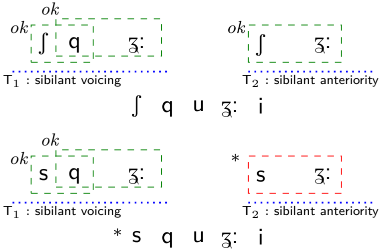
Formal Restrictions On Multiple Tiers

Alena Aksenova
Stony Brook University, alena.aksenova@stonybrook.edu

Sanket Deshmukh
Stony Brook University, sanket.deshmukh@stonybrook.edu

Testing Harmony Systems

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



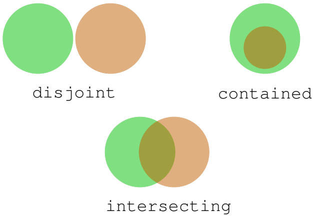
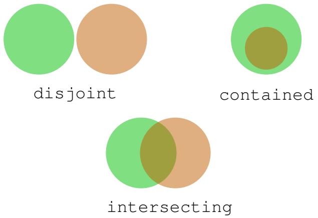


Figure 2: Theoretically possible tier alphabet relations

Testing Harmony Systems (cont.)



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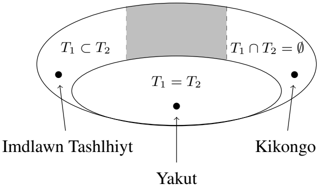


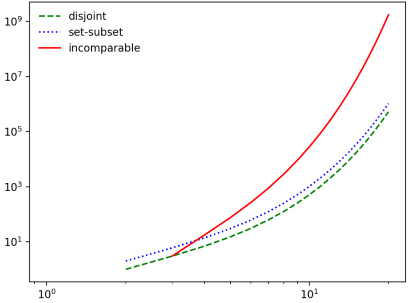
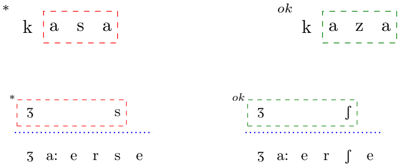


Figure 7: Growth of number of partitions of sets containing up to 20 elements (loglog scale)

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:

$$L_{loc} = \{abcd, aabcd, baacd, bcaae, \dots\}$$
$$L_{dist} = \{abacd, bacad, bcada, bcaea, \dots\}$$

What happens if we test on stimuli with similar distances?

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

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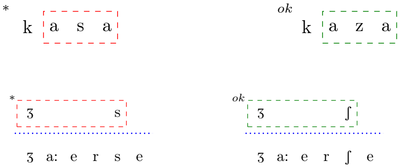

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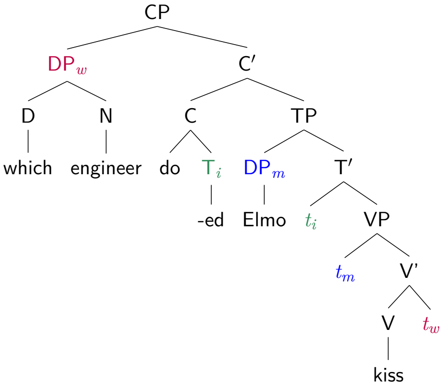
Why MGs?

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
     $\Rightarrow$ cf. TAG (Rambow & Joshi, 1995; Demberg, 2008)

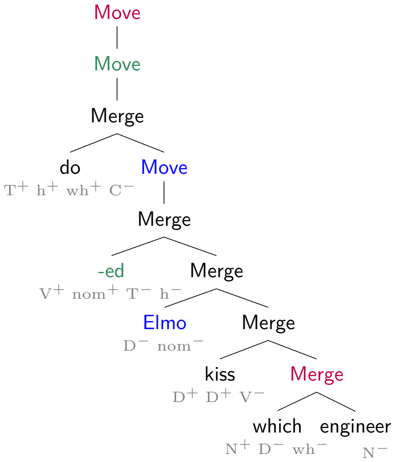
Some Important Properties of MGs

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

Fully Specified Derivation Trees



Phrase Structure Tree



Derivation Tree

Technical Fertility of MGs

MGs can accommodate the full syntactic toolbox:

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

Why These Metrics?

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

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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
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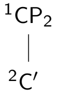

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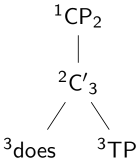

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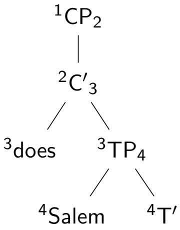

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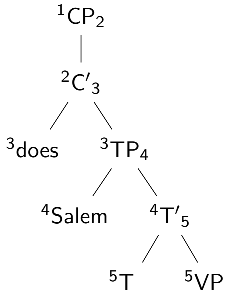

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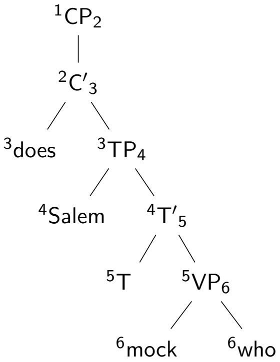

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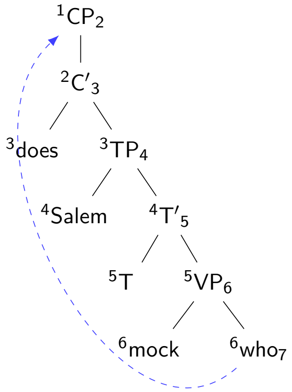

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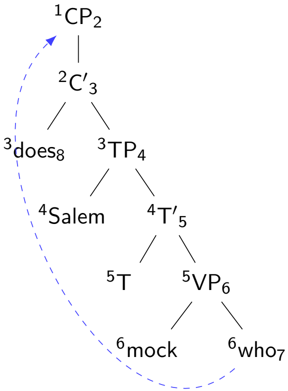

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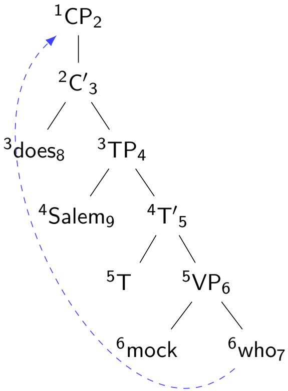

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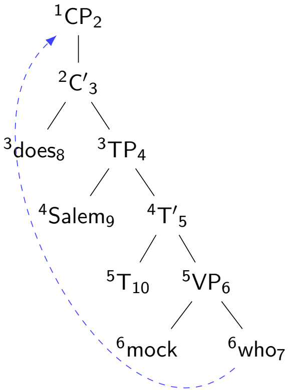

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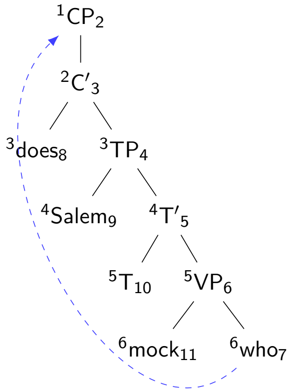

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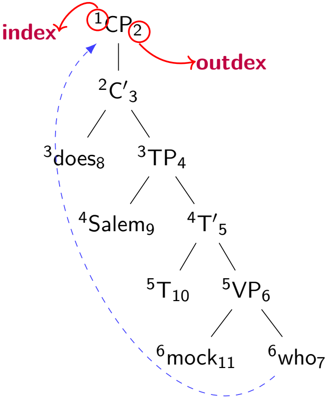

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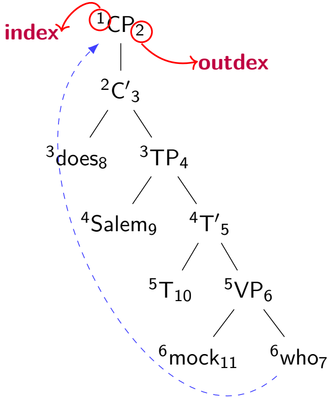
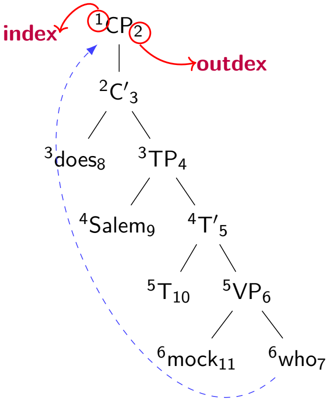


Index and Outdex are our connection to memory!

Computing Metrics: An Example



Tenure how long a node is kept in memory

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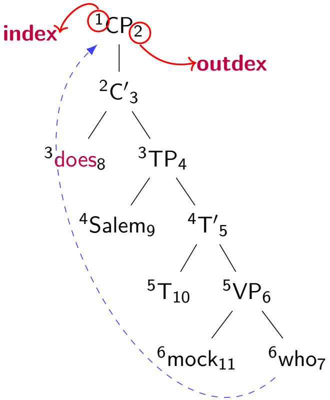

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Tenure($does$**)** $= 8 - 3 = 5$

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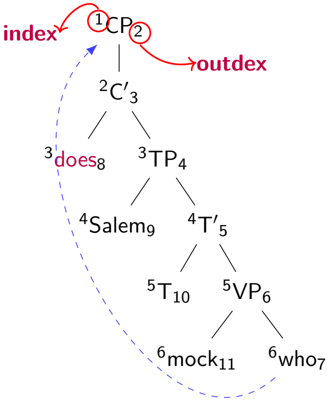

Tenure how long a node is kept in memory

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

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

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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a. "The horse that chased the lion" **SRC**

b. "The horse that the lion chased" **ORCp**

SRC > ORCp

Agreement can disambiguate:

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"The horse that chased the lions" **SRC**

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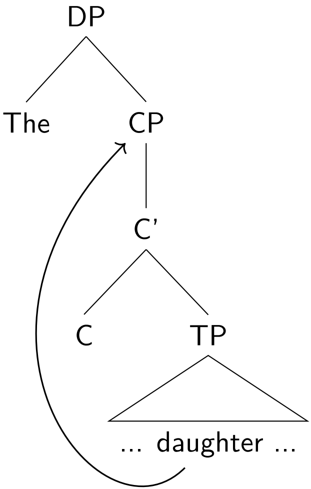
"The horse that the lions chased" **ORC**

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

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

SRC $>$ **ORC** $>$ **ORCp**

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]

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

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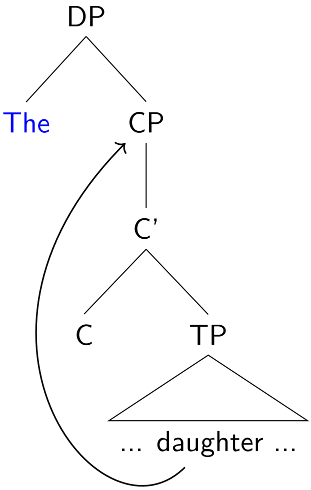

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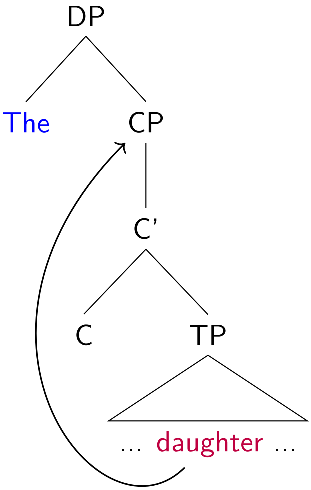

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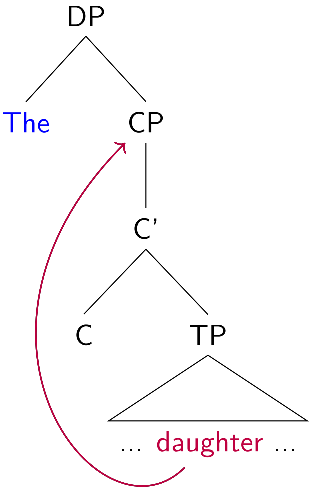
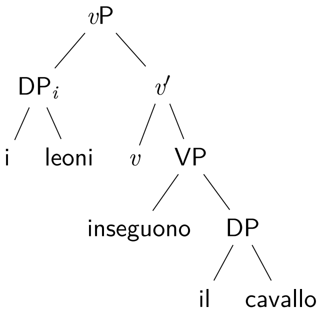


- RC is selected by an external D^0
- the RC head is a nominal constituent
- the RC head raises from its base position to [Spec, CP]

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

Postverbal Subjects (Belletti & Leonini 2004)

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



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

Technical details!

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

Postverbal Subjects (Belletti & Leonini 2004)

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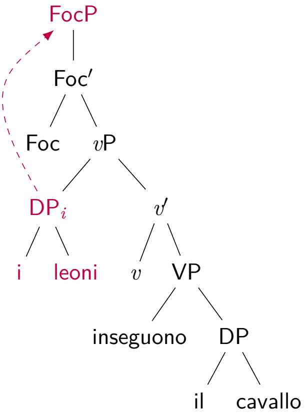

Postverbal Subjects (Belletti & Leonini 2004)

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Technical details!

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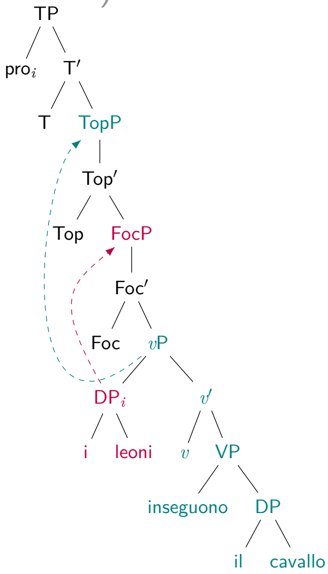

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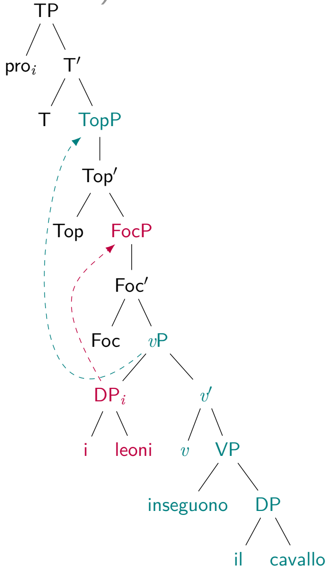

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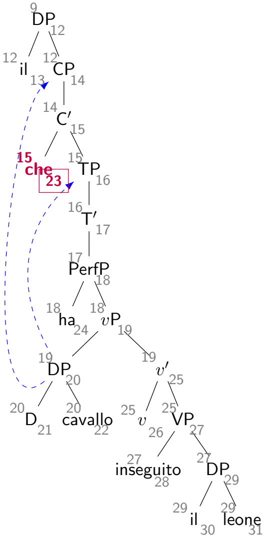
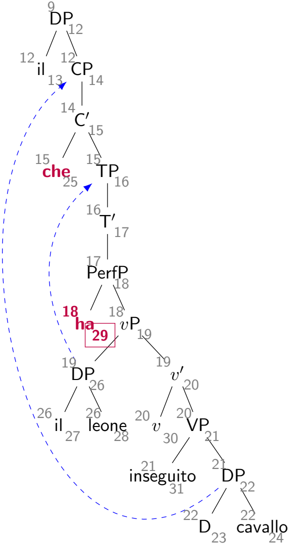
Results: SRC > ORC





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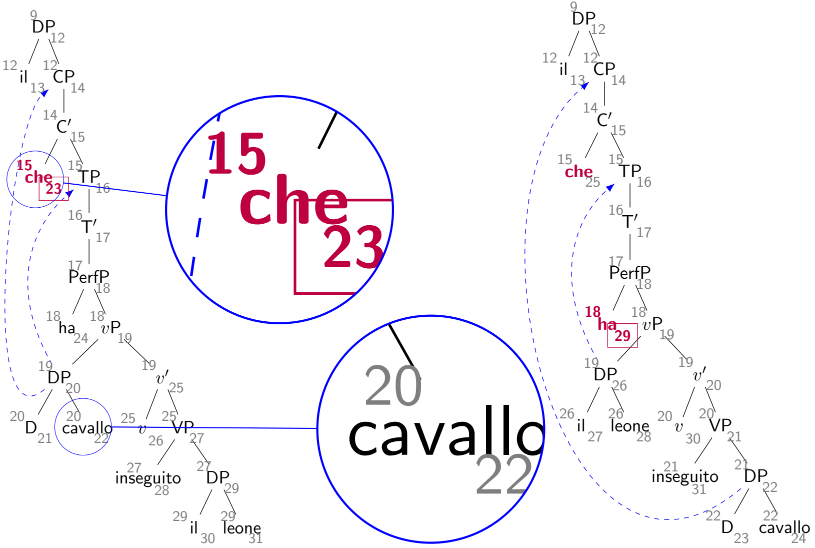

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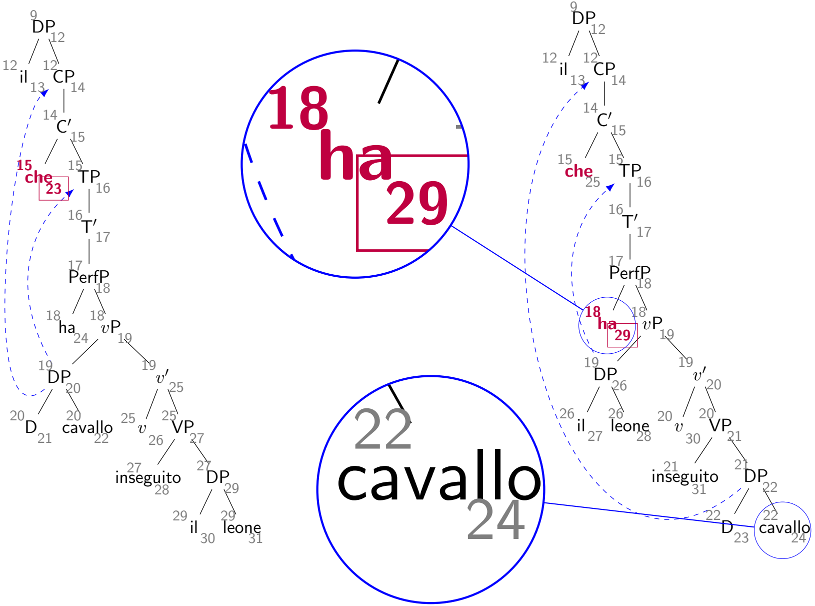

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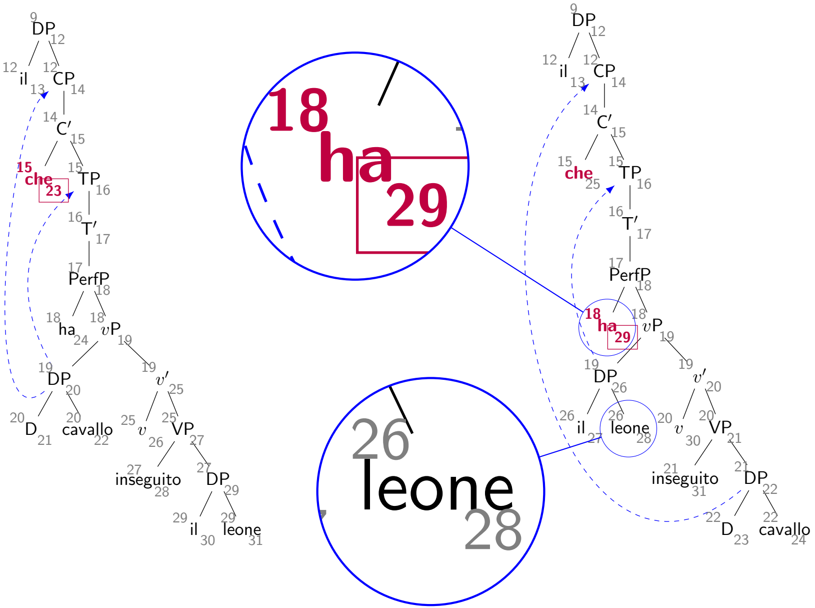

Italian Subjects: Probing the Results

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

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

Postverbal Asymmetries: Possible Accounts?

SRC > ORC

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

ORC > ORCp

- more problematic (e.g., for DLT)
- can be explained by
  1. economy of gap prediction + structural re-analysis;
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Can we give a purely structural account?

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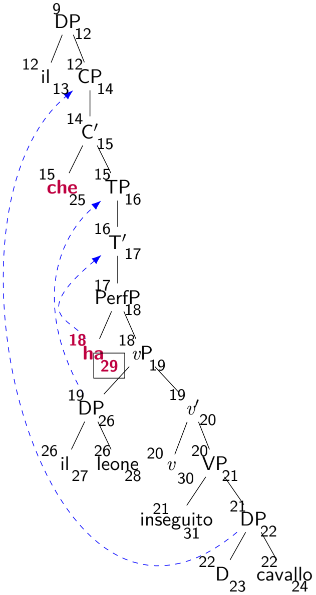
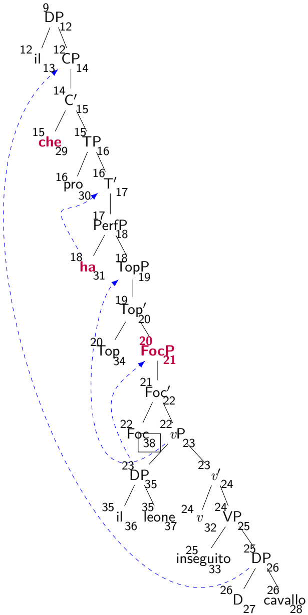




Additional Constructions

- 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**

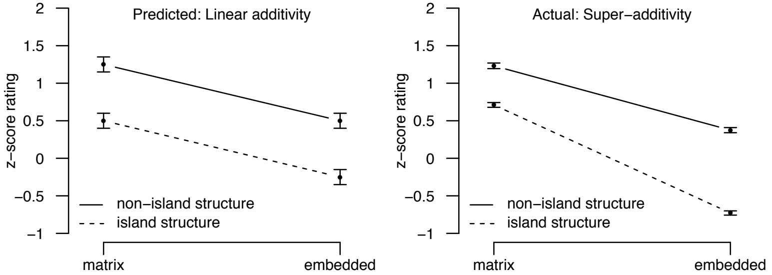
(10) Ha corso Gio
Has ran Gio

"Gio ran" **Unergative**

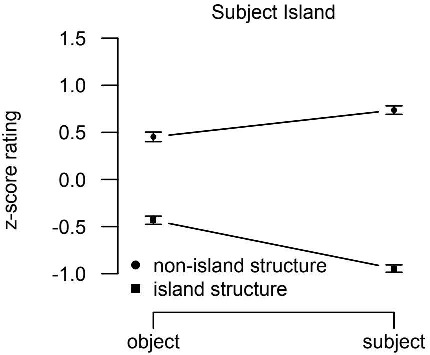
Gradience in Islands

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?
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Models of Gradience

(At least two) theories of gradience:

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

The contribution of formal models?

Quantify what each approach needs to account for the data:

- Additional syntactic assumptions
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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

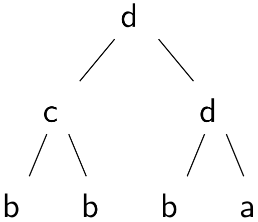
c. Who *t* thinks the speech about global warming interrupted the primetime TV show? Matrix | Island

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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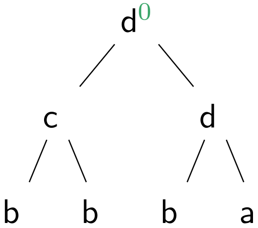

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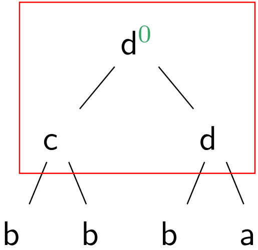

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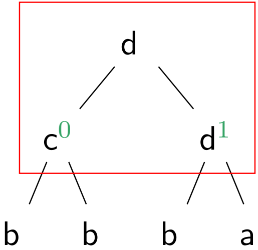

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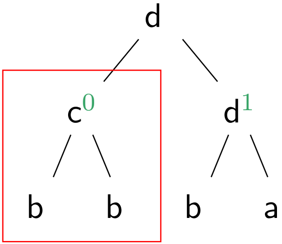

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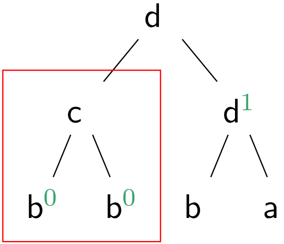

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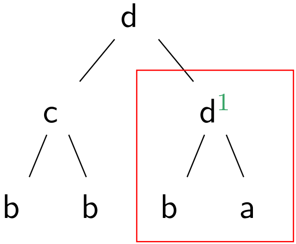

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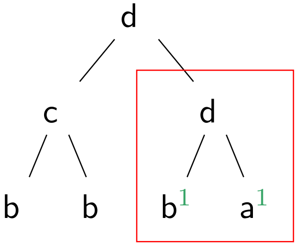

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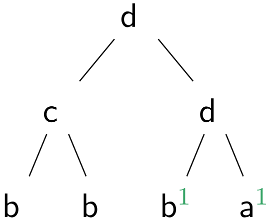

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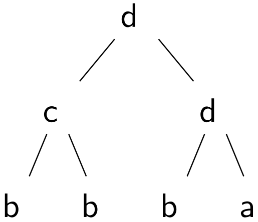

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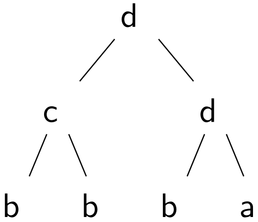

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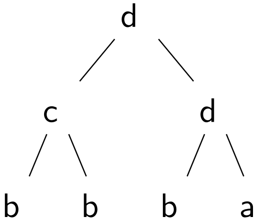

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- Constraints improve parsing performance by **exponentially reducing** the search space (Stabler 2013)
- Can be pre-compiled in the MG parse schema as a deterministic **top-down filter** (De Santo & Graf, in prep.)

Attachment and Relative Clauses (RC)

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

NP_1	**The daughter** was on the balcony	HA
NP_2	**The actress** was on the balcony	LA

English: **LA** interpretation

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

Universal locality principles?

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

HA vs LA languages?
RC preferences cross-linguistically affected by a variety of factors

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

(13) (Io) Ho visto **[la nonna della ragazza che gridava]**
(I) have seen the grandma of the girl that screaming
'I saw **[the grandma of the girl that was screaming]**"

- RC: HA
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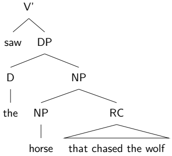
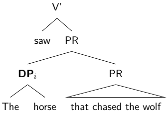
- PR





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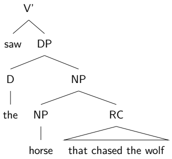

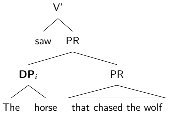

- RCs are NP-modifiers and denote properties of entities
- PRs are complements of VPs and denote events/situations
  - **Only** compatible with a **HA** reading!

So What? PRs and Attachment Preferences

- The grandma of the girl that was screaming
  - RC: HA
  - RC: LA
  - 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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Syntactic tests (Guasti 1999, Cinque 1992, Casalicchio 2013; a.o.)

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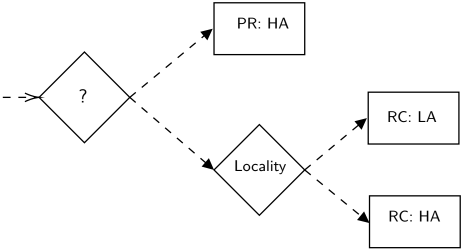

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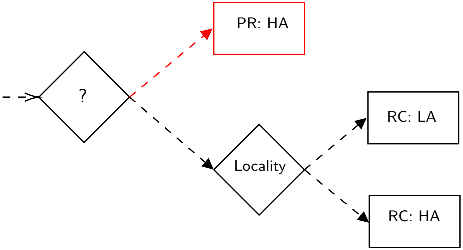

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- Appear freely with proper names, no relative pronouns, ...
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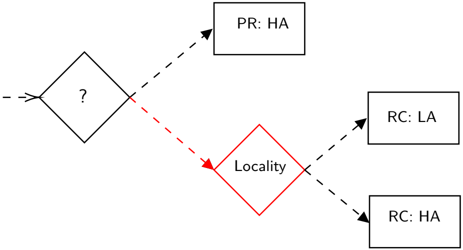

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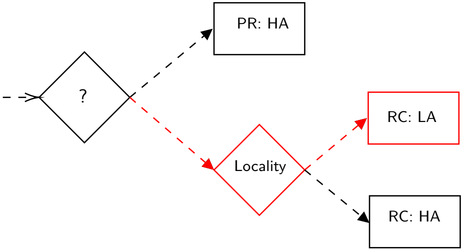

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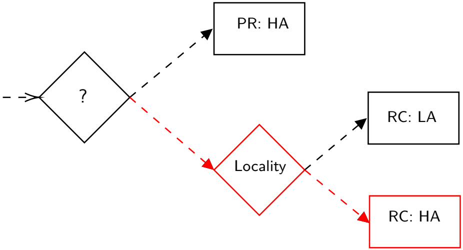

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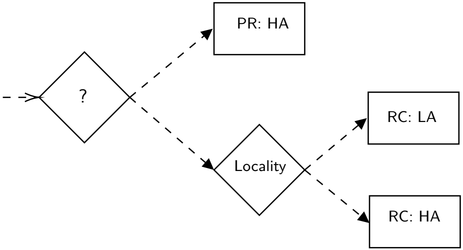

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Grillo and Costa (2014)

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

Online too!

- 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: STATIVE VERBS
Gianni vive con il figlio del medico che correva.
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Table 6
Percentage of high attachment preferences.

Eventive	Stative
78.6%	24.2%

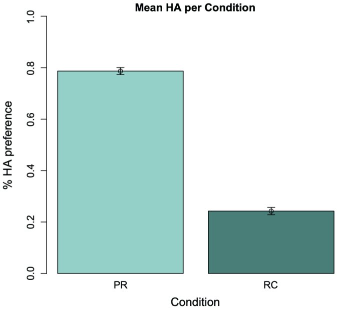

Fig. 2. Summary of attachment preference experiment 2.

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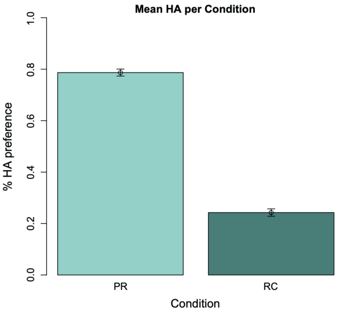

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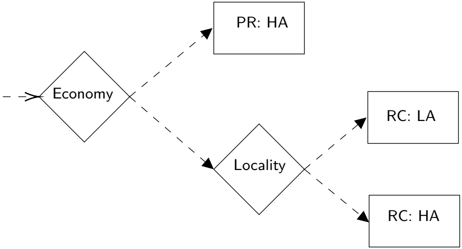
PR-First: Why?

Question

Why should PRs be preferred?



One Hypothesis: Structural Economy (Grillo & Costa 2014)

- PR structurally less complex than RC
- RCs: richer and more articulated functional domain

Can we evaluate structural economy quantitatively?

PR-First: Why?

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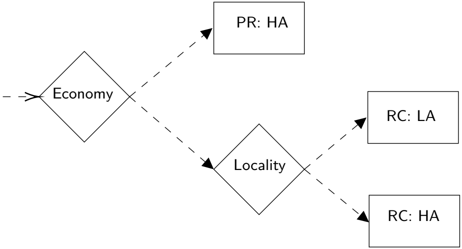

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Modeling PR-First

Why should PRs be easier/preferred?

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

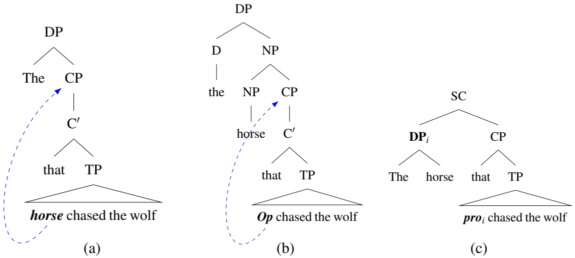

Figure 2: Sketches of the *(a)* RC with Promotion, *(b)* RC with Wh-movement, and *(c)* PR analyses for the sentence *The horse that the wolf chased*.

Modeling Results (De Santo & Lee, 2022b)

	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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- In sum:
  No immediate support for a parsing economy explanation
- LA>HA arises without explicit locality constraints!

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PR > HA	✓	Tie
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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)
  - E.g., # bounding nodes/phases, discourse referents, retrieval
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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

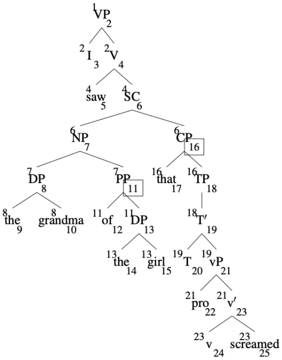


Figure 3: Annotated derivation trees for the Italian sentence *I saw the grandma of the girl that screamed*, according to a pseudo-relaive clause analysis. The tree is treated as a VP since additional structure in the matrix clause would be identical across comparisons.

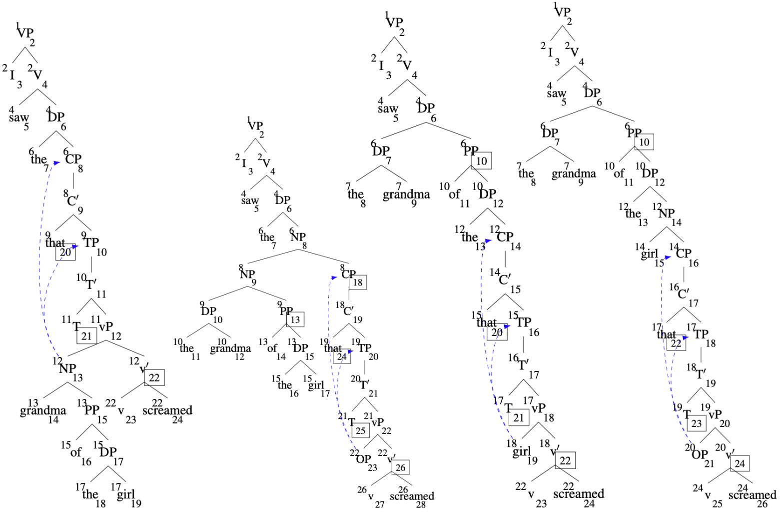
MG Parser		
Hypothesis	**Promotion**	**Wh-mov**
PR < HA	✓	Tie
PR < LA	×	×
LA < HA	✓	✓

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

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

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

PRs: Modeling Results 2



(a) (b) (c) (d)

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