Computational Phonology Workshop

Introduction & Tutorial

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Outline

Computational View of Language

In formal language theory, string sets are classified according to their formal complexity.

$$\text{regular} < \text{context-free} < \text{mildly context-sensitive} < \cdots$$

Phonology

Morphology

Syntax

Computational View of Language

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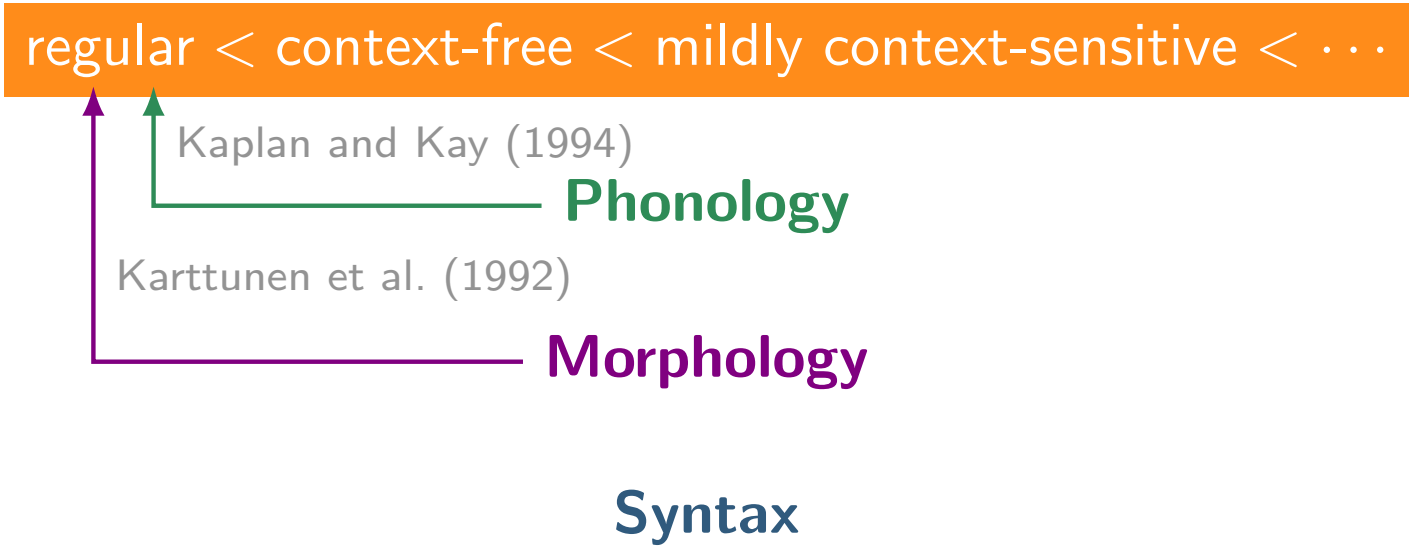

Computational View of Language

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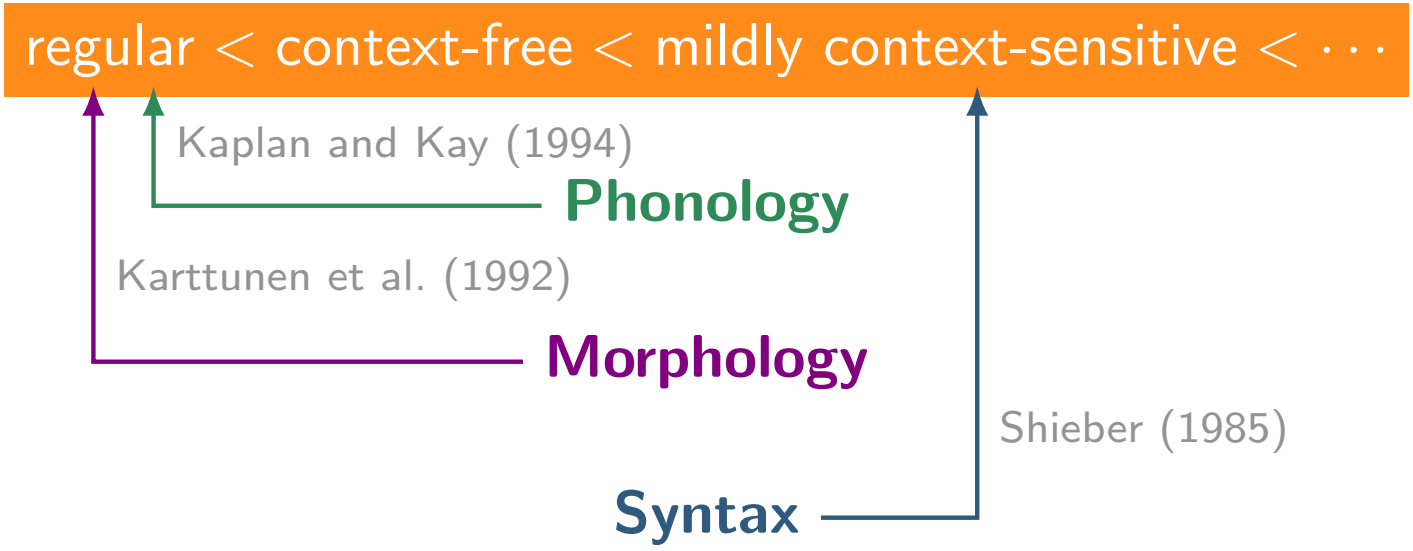

Implications of Formal Complexity

Heinz and Idsardi (2011, 2013) highlight the implications:

- different typology
  center embedding, crossing dependencies
- different memory architecture
  flat & finite VS unbounded nested stacks
- different learning algorithms
  much harder for syntax

Too Many Patterns are Regular

- **Problem**
  - All phonological and morphological patterns are regular.
  - But not all regular patterns occur in phonology.
- Regularity is **too loose an upper bound**.

Example

- First-last consonant harmony
- Every word with a plosive contains an open syllable
- Word with at least 3 suffixes must have exactly 5 prefixes

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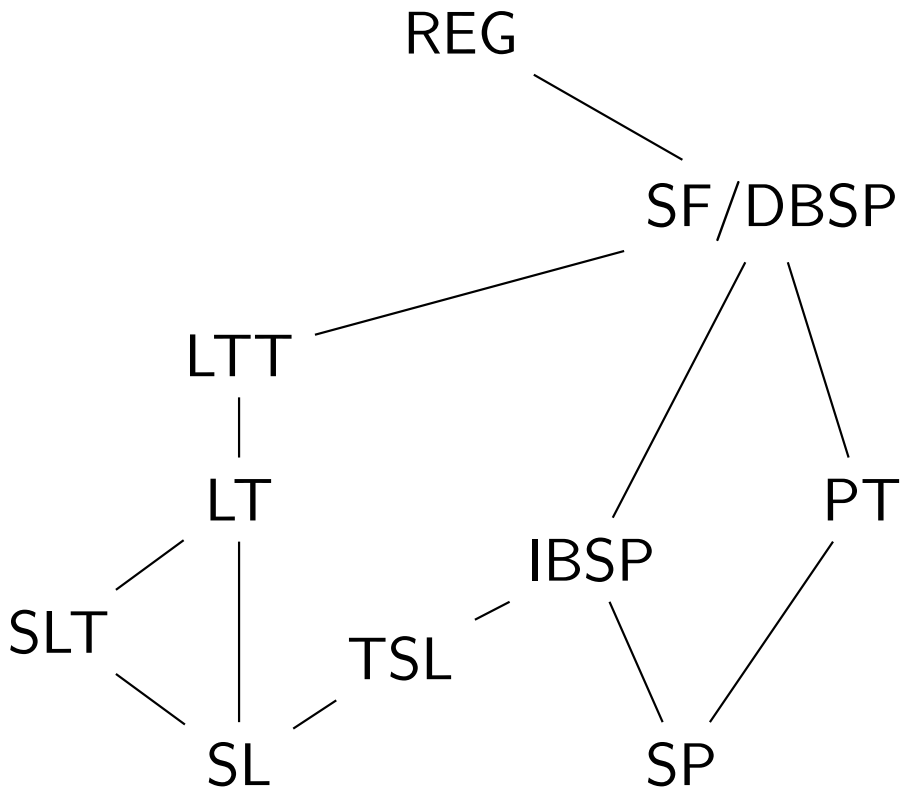
Subregular Languages

Often forgotten: hierarchy of **subregular languages**
(McNaughton and Papert 1971; Rogers et al. 2010; Ruiz et al. 1998; Rogers and Pullum 2011; Heinz et al. 2011; Graf 2016)



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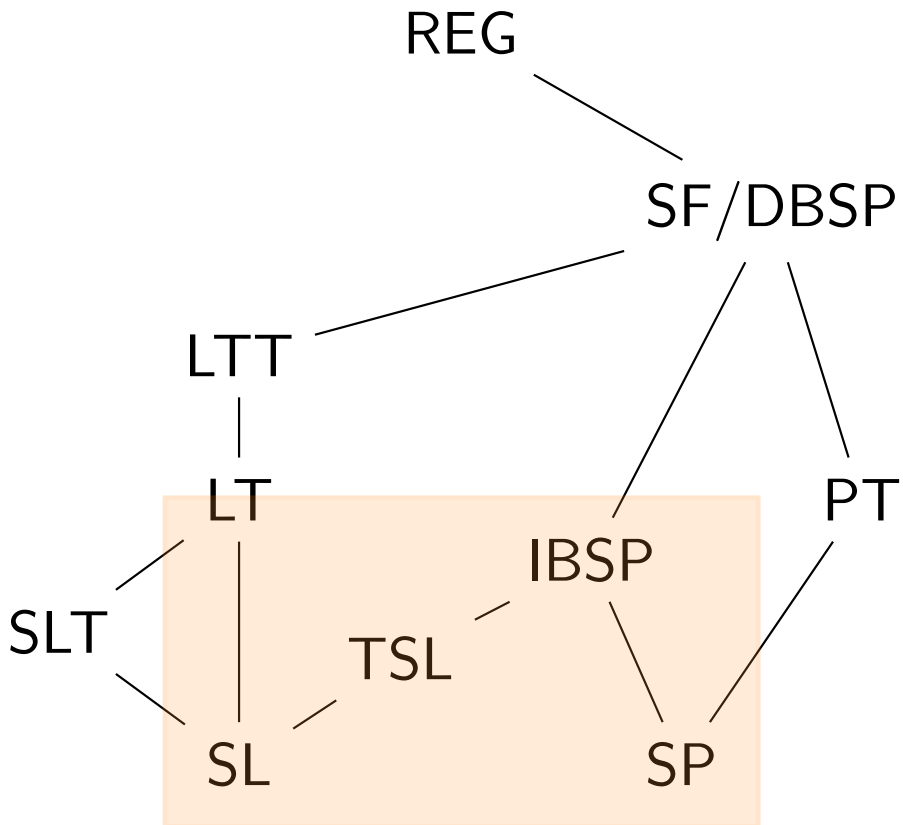

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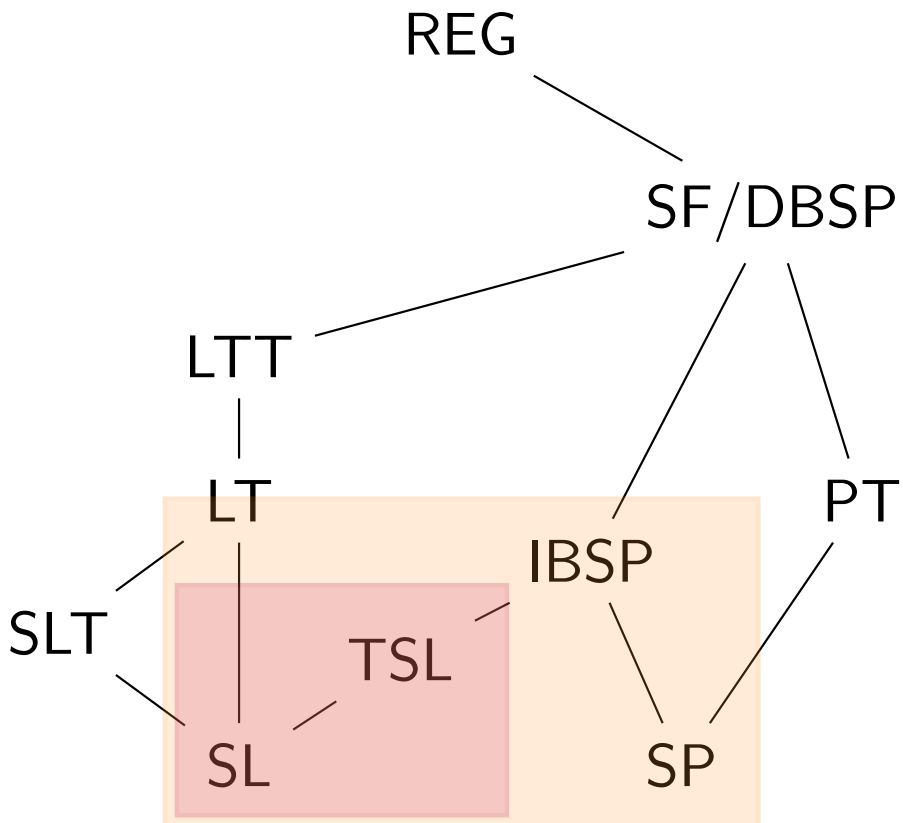

SL: Strictly Local

- SL formalizes **local dependencies**.
- SL grammars are collections of markedness constraints that are
  - hard/non-violable,
  - locally bounded.

Strictly Local Grammars & Languages

SL_n grammar finite set of forbidden n-grams

SL_n language all strings except those with forbidden n-grams

Example: SL Constraints

Process	Constraint	Forbidden n-grams
Word-final devoicing	*[+voice]⋉	z⋉, v⋉, . . .
Intervocalic voicing	*V[-voice]V	asa, asi, . . . , isa, isi, . . . , afa, afi, . . . , ifa, ifi, . . . ,
CV template	*⋊V	⋊a, ⋊i, . . .
	*CC	pp, pb, . . . bp, bb, . . .
	*VV	aa, ai, . . . , ia, ii, . . .
	*C⋉	p⋉, b⋉, . . .

SL is Too Weak

- SL grammars only handle unbounded dependencies.
- But some processes in phonology are unbounded.

Samala Sibilant Harmony (Heinz 2015:16)

ʃtojonowonowaʃ

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Samala Sibilant Harmony (Heinz 2015:16)

ʃtojonowonowaʃ
*stojonowonowaʃ
*ʃtojonowonowas

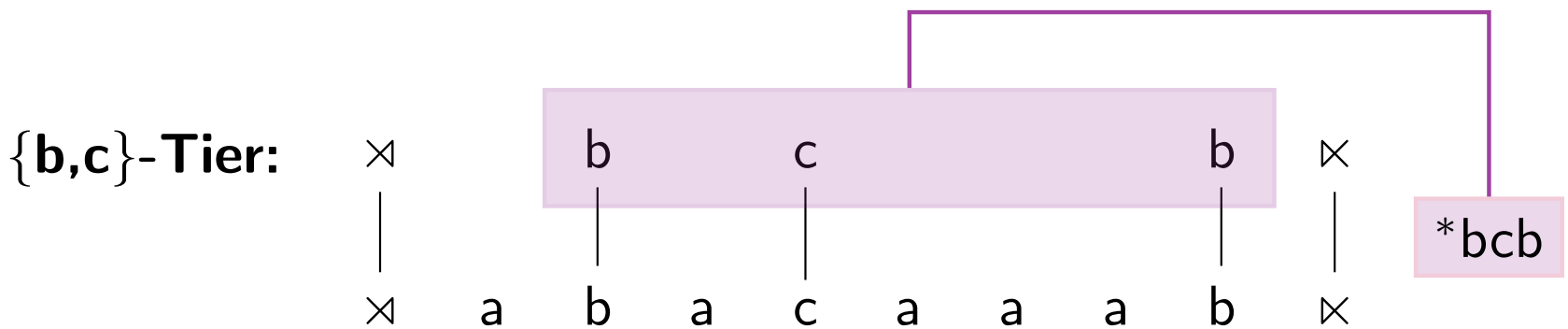
TSL: Tier-Based Strictly Local

We can make Samala SL-like if we **create new locality domains**.

Tier-Based Strictly Local Grammars & Languages

TSL_n grammar finite set of forbidden n-grams + tier alphabet

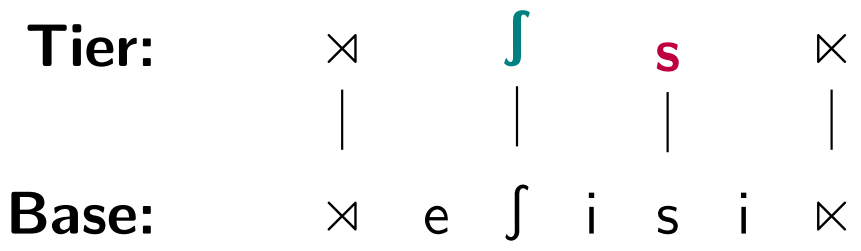
TSL_n language all strings except those with forbidden n-grams over tier

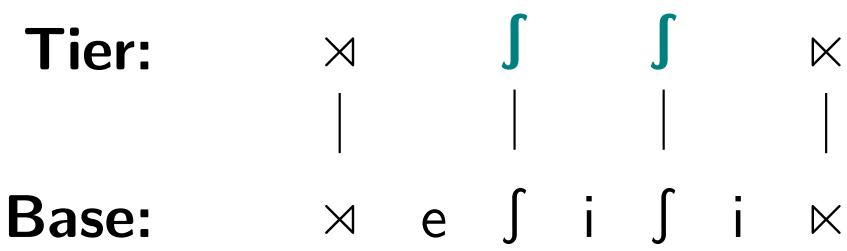


Example: Sibilant Harmony

Constraint	**Forbidden tier-n-grams**
***[α ant] $\cdots$ [$-\alpha$ ant]**	**ʃs, sʃ**

Tier contains all sibilants



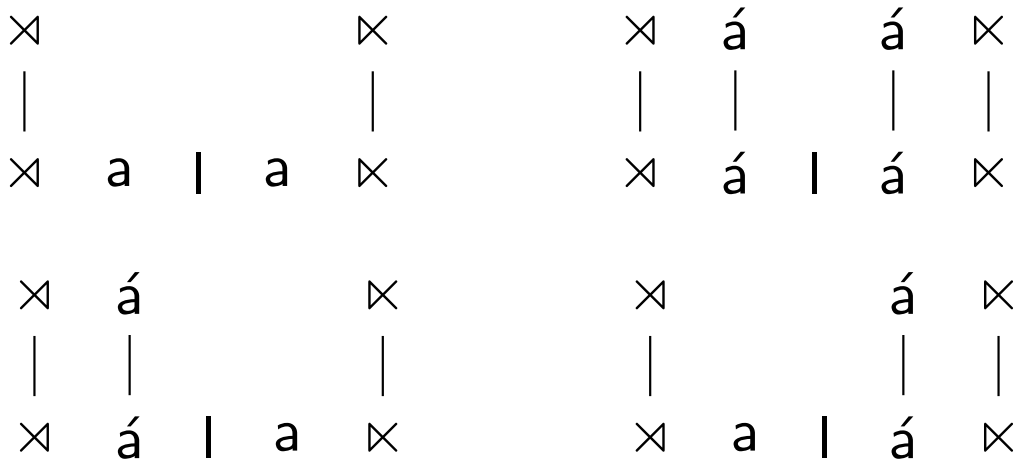


Example: Stress Assignment

Culminativity every word has exactly one primary stress

Tier contains segments with primary stress

n-**grams** **śś** and ⋊⋉



A Non-TSL Pattern: Sour Grapes Harmony

Sour Grapes vowel harmony applies only if it can apply to the whole word (i.e. there is no blocker)

Why Sour Grapes isn't TSL

- All vowels **V** must be on the vowel harmony tier.
- The blocker **B** must be on the same tier in order to block it.
- But there is no bound on the number of vowels per tier.
- The tier thus may have the shape

$$\cdots \mathbf{V}\ \mathbf{V}\ \mathbf{V} \cdots \mathbf{B} \cdots$$

- **B** can be arbitrarily far away from **VVV** $\Rightarrow$ not a local relation
- But we need to know whether **B** is on the tier in order to determine the well-formedness of **VVV**.

More Patterns Beyond TSL?

A few other patterns may go beyond TSL.

- **Non-Final RHOL**
  - discussed in **Hyunah Baek's talk**
  - a minor extension of TSL suffices
- **Multiple Harmony**
  - discussed in **Alëna Aksënova's talk**
  - is actually TSL due to important restrictions

Complexity of Phonology

- All local phonological constraints are SL.
- All segmental long-distance constraints are TSL.
- Suprsegmental constraints (tone, stress) may go beyond TSL. (Graf 2010a,b; Jardine 2015)
- TSL avoids instances of OT overgeneration:
  - cannot generate *sour-grapes* or *majority rules* patterns
  - does not allow *agreement by proxy*
  - explains why consonant harmony is unbounded or transvocalic, but never transconsonantal (McMullin and Hansson 2015)

Cognitive Implications

- SL and TSL languages are **learnable** from positive data. (Heinz et al. 2012; Jardine and Heinz 2016)
  - UG: specifies upper bound on size of n-grams
  - memorize which sequences have not been seen so far
  - induce tier (more complex)
  - learning input can be relatively small
- What cognitive resources are required?
  - Only memorization of the last n segments of a specific type
  - For most processes $n \leq 3$, and for all $n \leq 7$
  - Fits **within bounds of human working memory**

Interim Summary: Phonotactics

- Natural languages have **TSL phonotactics**.
- gives tighter bound on typology
- solves poverty of stimulus by greatly simplifying learning
- reduces cognitive resource requirements

Next

- phonological mappings
- SL & TSL syntax

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- SL & TSL syntax

Phonological Mappings

- So far we have only considered phonotactics.
- But mappings from underlying representations to surface forms can be studied, too.
- Regular mappings are enough.
  (Kaplan and Kay 1994)
- What about subregular mappings?

Input Strictly Local Mappings

Input Strictly Local (ISL)

- Move through string from left to right.
- Rewrite x as y based on previous n symbols in input string.
- Output is **not considered**!

A Note on TSL

Every TSL_n grammar can be decomposed into

1. an **ISL_1** function (the tier projection), and
2. an SL_n grammar.

An Interesting Puzzle

- What happens if we use an ISL_k function for tier projection?
- Addressed in **Aniello De Santo**'s talk

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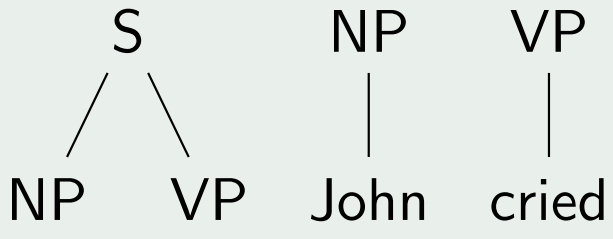
(Tier-Based) Strictly Local Syntax

- SL tree grammars are common in computational linguistics: **context-free grammars**
- By adding tier projection, we get TSL tree grammars.

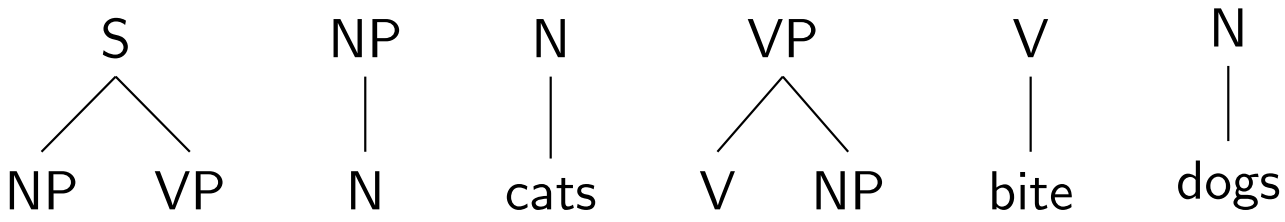
Example: CFGs as SL_2 Tree Grammars

$$\begin{aligned} S &\to NP\ VP \\ NP &\to John \\ VP &\to cried \end{aligned}$$

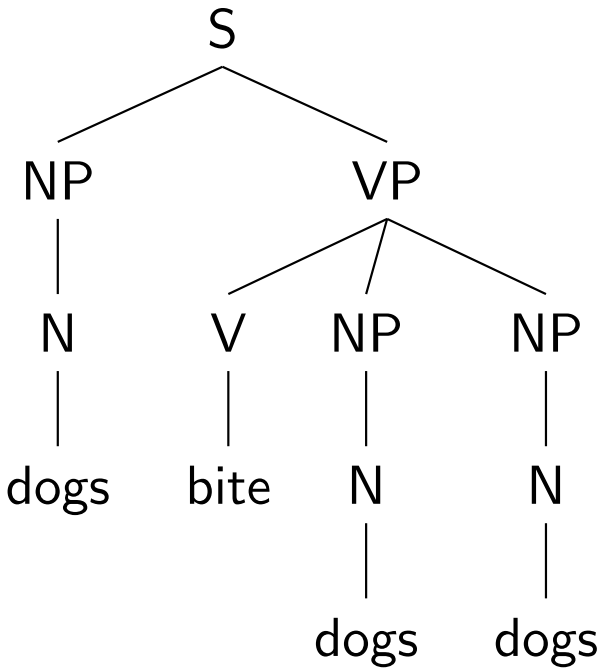


Example: An Illicit Tree

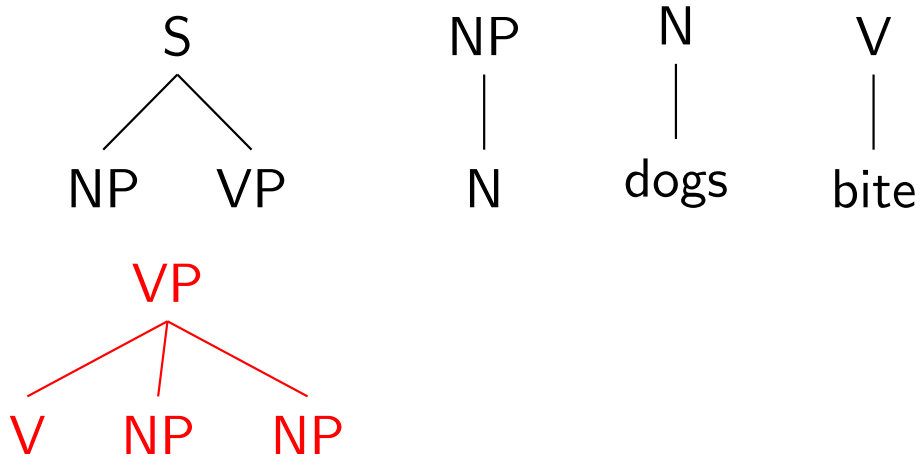
SL_2 Tree Grammar



Example Tree

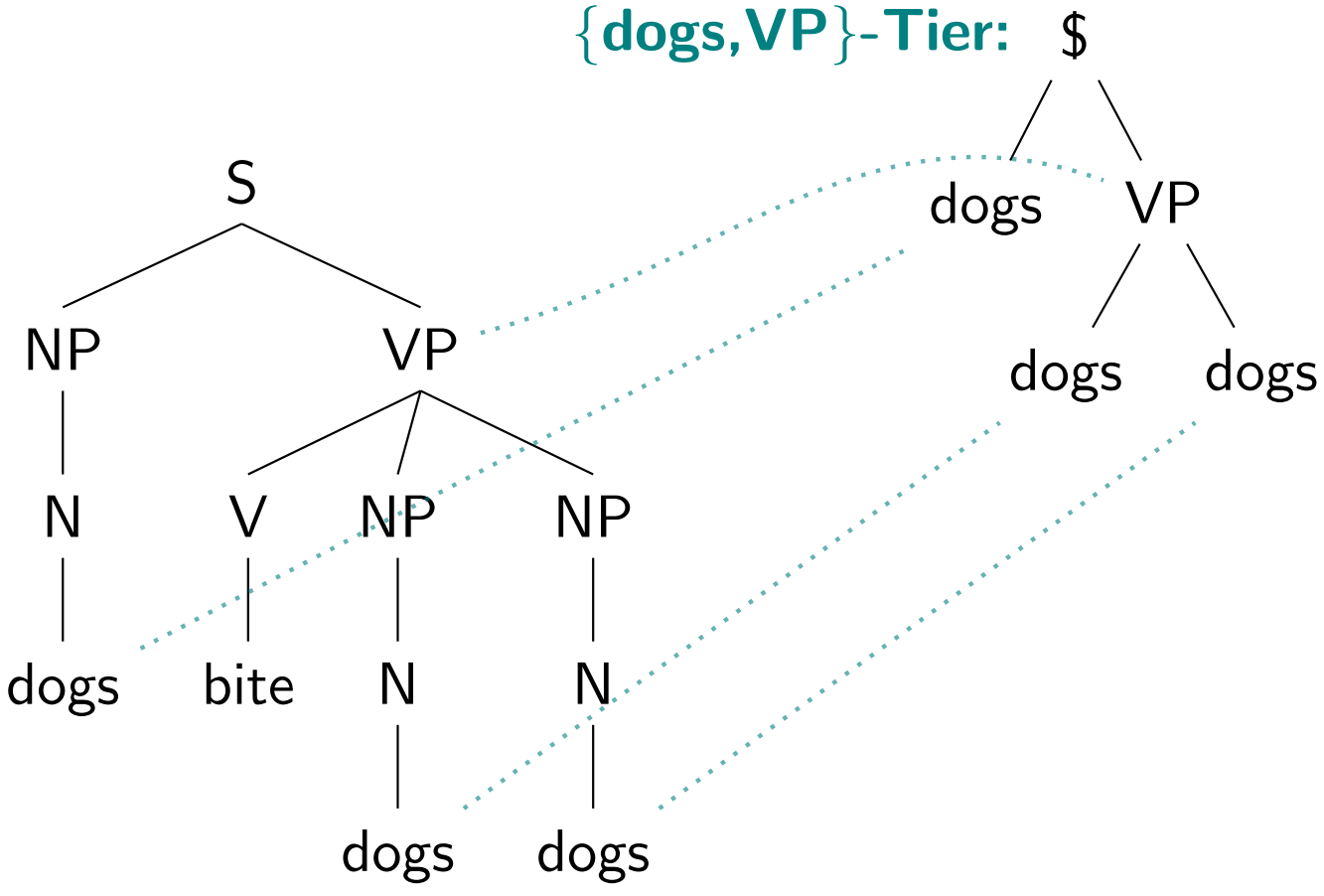


Tree Bigrams of Example Tree



Tier Projection for Trees

Just as for strings, we can project tiers for trees.
(Graf and Heinz 2016)



Towards TSL-Syntax

While TSL-Syntax is still young, it holds promise:

- movement dependencies are TSL (Graf and Heinz 2016)
- scope ambiguities in **Lei Liu's blitz talk**
- Mandarin negation in **Hongchen Wu's talk**

Conclusion

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