Strong Lexicalization of Tree-Adjoining Grammars

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Tree-Adjoining Grammars

Motivation

- mildly context-sensitive formalism
- productions express local dependencies
- but can realize global dependencies

Applications

- TAG for English [XTAG Research Group 2001]
- lexicalized TAG for German [Kallmeyer et al. 2010]

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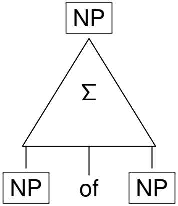
TAG — Syntax

Definition (Joshi et al. 1969)

$G = (N, \Sigma, S, R)$ tree-adjoining grammar (TAG) with finite set R

- substitution rules
- adjunction rules

Example (Substitution rule)



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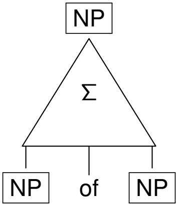

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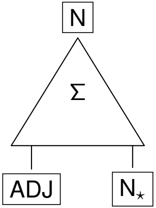

TAG — Example Derivation

S

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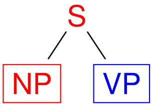

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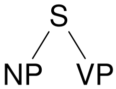

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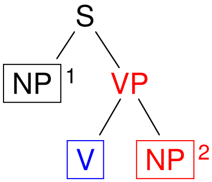

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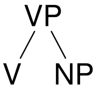

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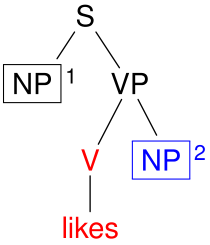

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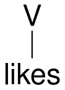

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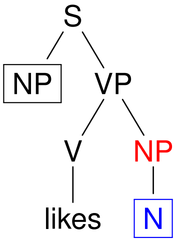

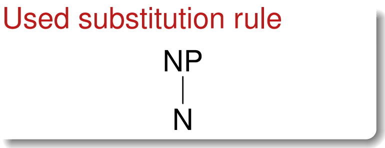

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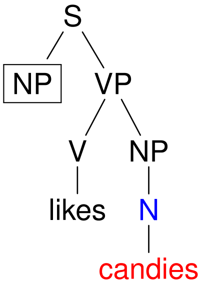

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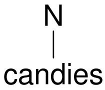

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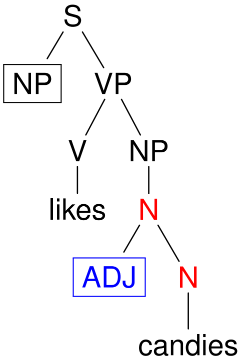
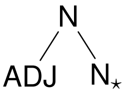


Used adjunction rule



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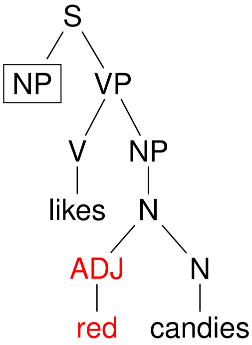


Used substitution rule

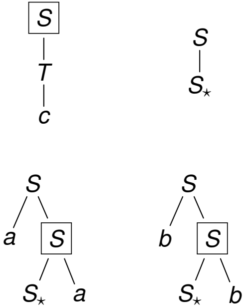
TAG — Semantics

Definition (Generated language)

$$L(G) = \{t \in T_\Sigma \mid S \Rightarrow_G^* t\}$$

TAG — More Than CFG

Example (Productions)



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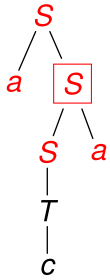

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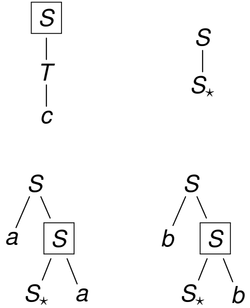

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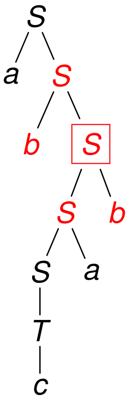

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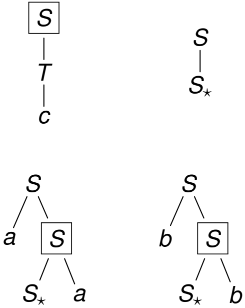

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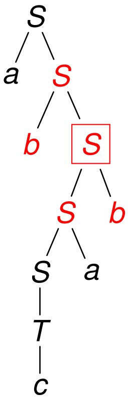

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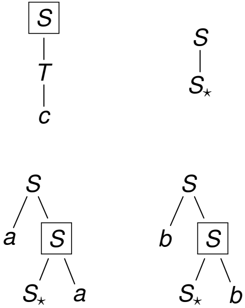

String language

$$\{wcw \mid w \in \Sigma^*\}$$

TAG — Lexicalization

Definition

A TAG is lexicalized if each production contains a lexical item

Theorem (SCHABES 1990)

TAG can stronly lexicalize CFG and themselves

Widespread myth

- JOSHI, SCHABES: Tree-adjoining grammars and lexicalized grammars. *Tree Automata and Languages.* North-Holland 1992
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Overview

Context-free Tree Grammar

Definition (Rounds 1969)

(N, Σ, S, P) context-free tree grammar (CFTG)

- ranked alphabet N — *nonterminals*
- ranked alphabet Σ — *terminals*
- $S \in N_0$ — *start nonterminal*
- P is a finite set of $A(x_1, \ldots, x_k) \to r$ — *productions*
  - $A \in N_k$
  - $r \in C_{N \cup \Sigma}(\{x_1, \ldots, x_k\})$

CFTG — Example

Example

CFTG (N, Σ, S, P)

- $N = \{S^{(0)}, A^{(2)}\}$
- $\Sigma = \{\alpha^{(0)}, \beta^{(0)}, \sigma^{(2)}\}$

Productions

$$S \to A(\alpha, \alpha) \mid A(\beta, \beta) \mid \sigma(\alpha, \beta)$$

$$A(x_1, x_2) \to A(\sigma(x_1, S), \sigma(x_2, S))$$

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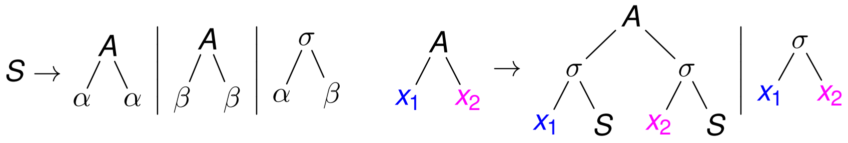

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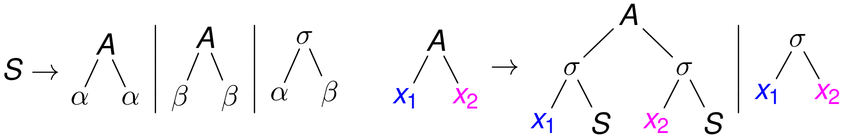

CFTG — Derivation Example

Example

$$S \rightarrow A(\alpha, \alpha) \;\Big|\; A(\beta, \beta) \;\Big|\; \sigma(\alpha, \beta) \qquad A(x_1, x_2) \rightarrow A(\sigma(x_1, S), \sigma(x_2, S)) \;\Big|\; \sigma(x_1, x_2)$$

$\boxed{S}$

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$$\boxed{S} \Rightarrow_G \boxed{A}(\alpha, \alpha)$$

CFTG — Derivation Example

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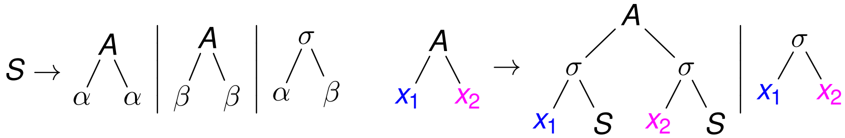

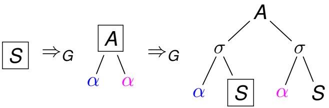

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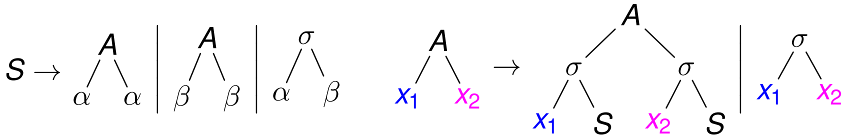

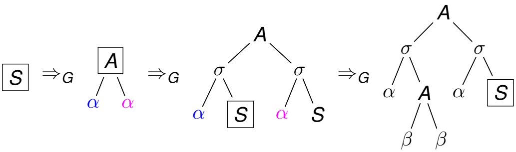

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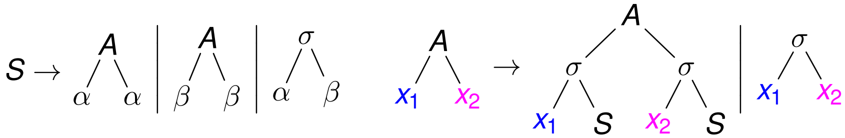

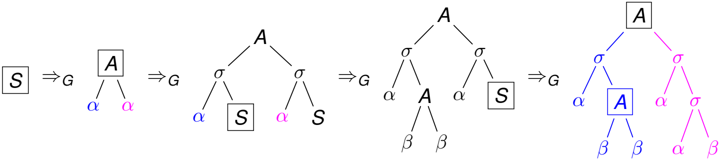

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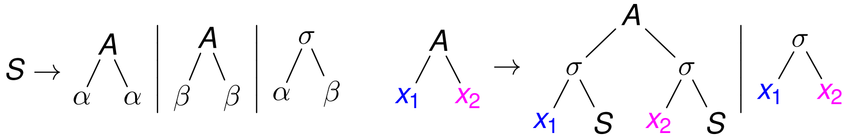

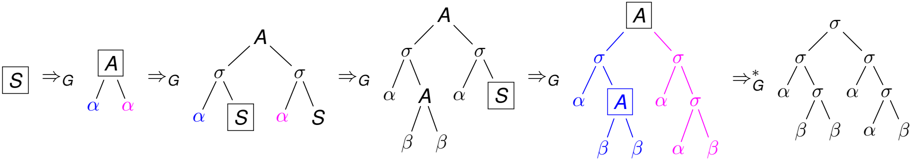

CFTG — Semantics

Definition

$$L(G) = \{t \in T_\Sigma \mid S \Rightarrow_G^* t\}$$

Theorem (JOSHI et al. 1975 and MÖNNICH 1997)

Every (non-strict) TAG can be simulated by a CFTG

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Growing Normal Form

Definition

CFTG growing if non-initial productions contain ≥ 3 non-variables

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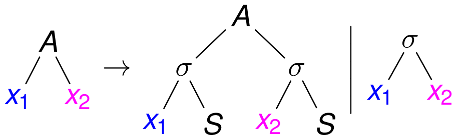

Theorem (Stamer, Otto 2007)

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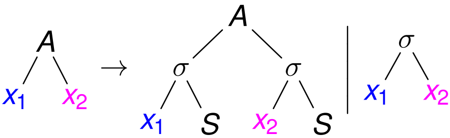

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CFTG

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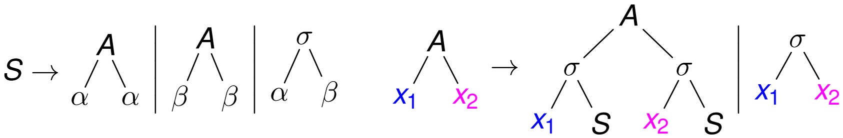

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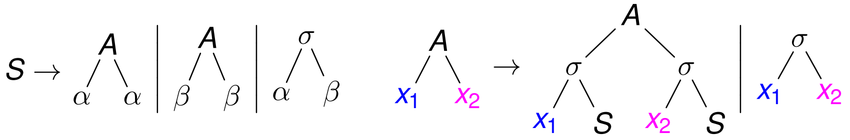
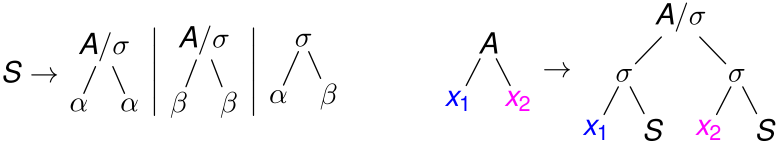


Eliminate last production:



Limited Ambiguity

Definition (Frontier yield)

yd: $T_\Sigma \to \Sigma_0^*$

$$\mathrm{yd}(\alpha) = \alpha$$

$$\mathrm{yd}(\sigma(t_1, \ldots, t_k)) = \mathrm{yd}(t_1) \cdots \mathrm{yd}(t_k)$$

Definition (Schabes 1990)

$L \subseteq T_\Sigma$ finite ambiguity if $\{t \in L \mid \mathrm{yd}(t) = w\}$ finite for all $w \in \Sigma_0^*$

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Monadic Productions

Definition

Production $\ell \to r$

- monadic if r contains ≤ 1 nonterminals
- terminal if r contains 0 nonterminals

Theorem

Every CFTG with finite ambiguity can be simulated by a CFTG

- *all (non-initial) monadic productions are lexicalized*
- *all (non-initial) terminal productions are doubly lexicalized*

Proof.

- similar to removal of ε-productions [Hopcroft et al. 2001]
- closure under non-lexicalized productions □

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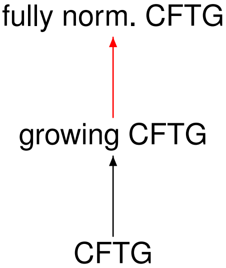


Overview

Lexicalization

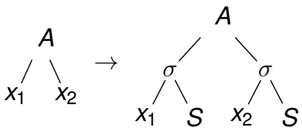
Theorem

Every CFTG with finite ambiguity can be lexicalized

Lexicalization — Step 1

1. guess lexical item in non-lexicalized production
2. transport guessed lexical item
3. potentially guess again
4. cancel in terminal production

Input



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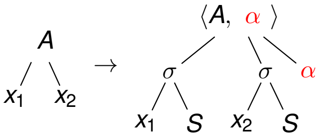

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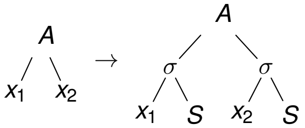

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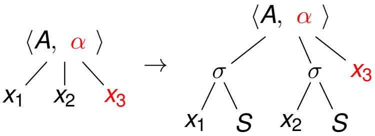

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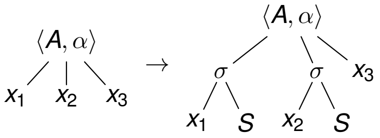

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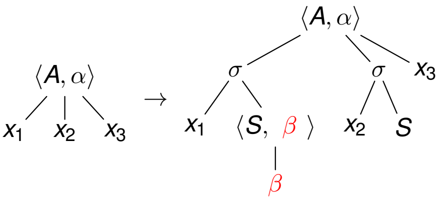

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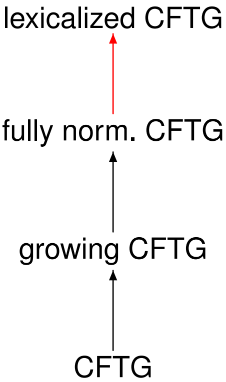
Input

$$S \to \sigma(\alpha, \alpha)$$

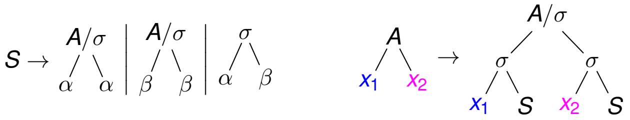
Output

$$\langle S, \alpha \rangle(x_1) \to \sigma(x_1, \alpha)$$

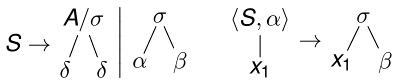
Lexicalization

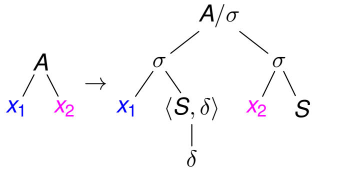


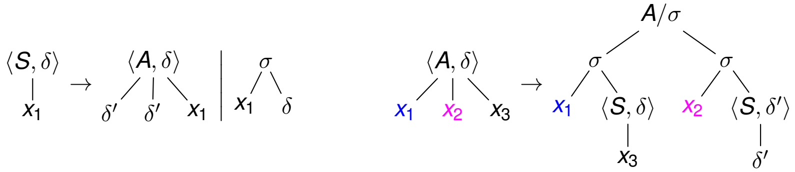
Lexicalization — Example



After lexicalization (with $\delta, \delta' \in \{\alpha, \beta\}$)







Summary

CFTG(k): CFTG with nonterminals of rank $\leq k$

Corollary

CFTG(k) are strongly lexicalized by CFTG($k+1$)

Corollary

TAG are strongly lexicalized by CFTG(2)

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Open Problem

Theorem (ENGELFRIET et al. 1980)

CFTG(k) induces infinite hierarchy of string languages

Open problem

Is the rank increase necessary for strong lexicalization?

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