Strong Lexicalization of Tree-Adjoining Grammars

Andreas Maletti[1] and Joost Engelfriet[2]

[1] IMS, Universität Stuttgart, Germany

[2] LIACS, Leiden University, The Netherlands

maletti@ims.uni-stuttgart.de

Jeju, Korea — July 10, 2012

Universität Stuttgart

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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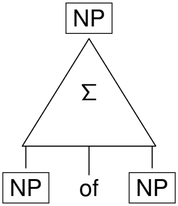
TAG — Syntax

Definition (JOSHI et al. 1969)

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

- substitution productions
- adjunction productions

Example (substitution production)



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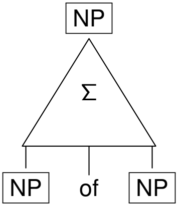

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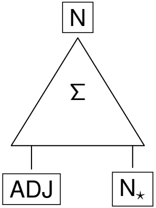

TAG — Example Derivation

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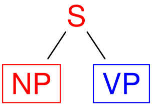

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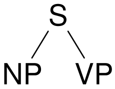

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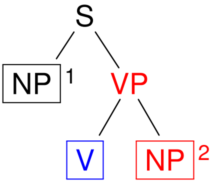

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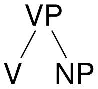

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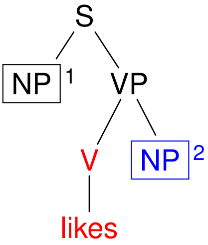

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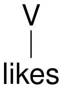

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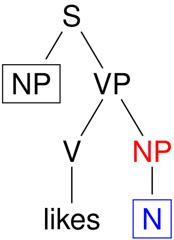

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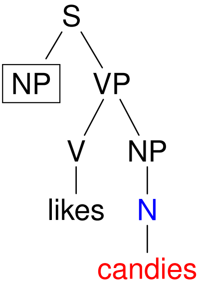

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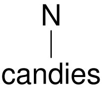

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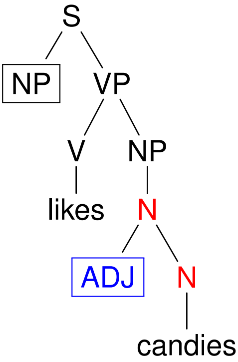

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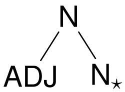

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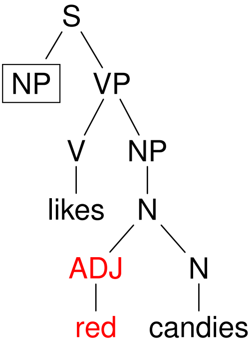


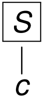
Used substitution production

TAG — Semantics

Definition (generated language)

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

TAG — More Than CFG



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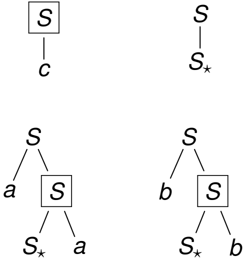

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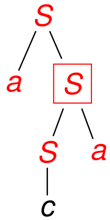

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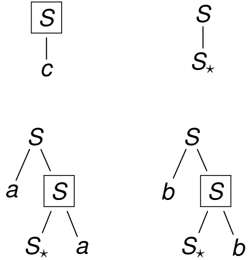

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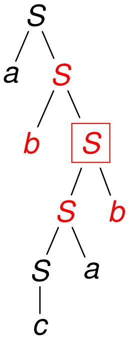

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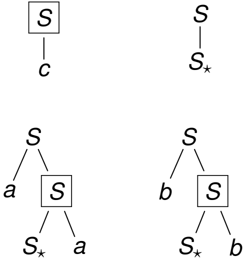

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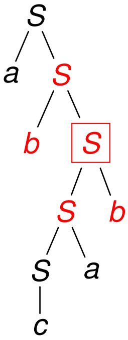

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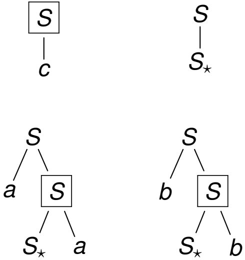

String language

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

TAG — Lexicalization

Definition

A TAG is lexicalized if each production contains a lexical item

Theorem (SCHABES 1990)

TAG can strongly lexicalize CFG and themselves

Widespread myth

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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 $A(x_1, \dots, x_k) \to r$ — *productions*
    - $A \in N_k$
    - $r \in C_{N \cup \Sigma}(\{x_1, \dots, x_k\})$

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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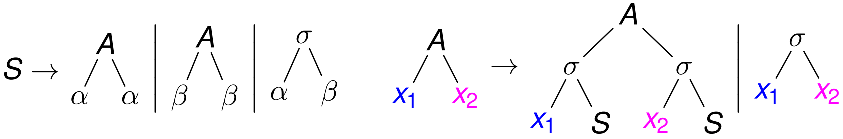

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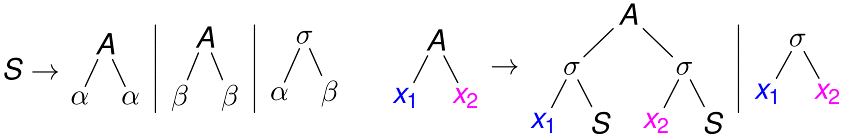

CFTG — Derivation Example

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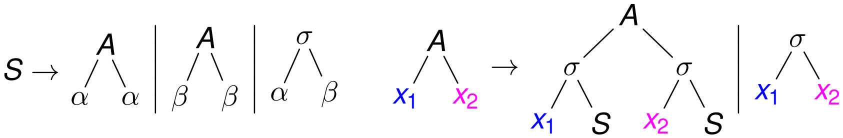

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$$S \to A(\alpha, \alpha) \mid A(\beta, \beta) \mid \sigma(\alpha, \beta) \qquad A(x_1, x_2) \to A(\sigma(x_1, S), \sigma(x_2, S)) \mid \sigma(x_1, x_2)$$

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

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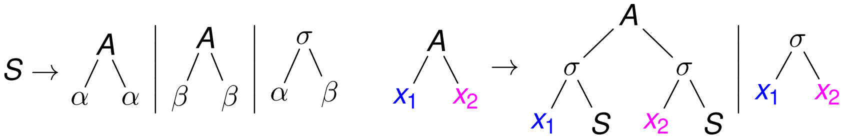

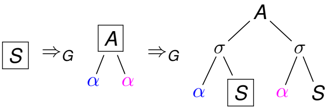

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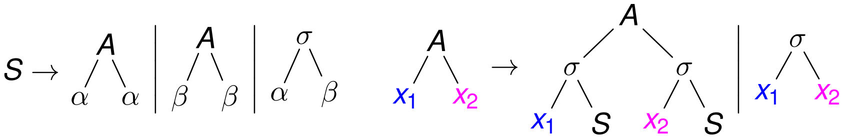

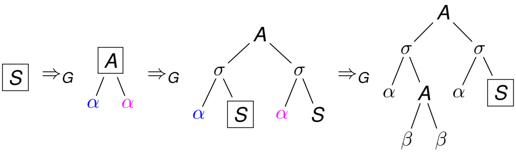

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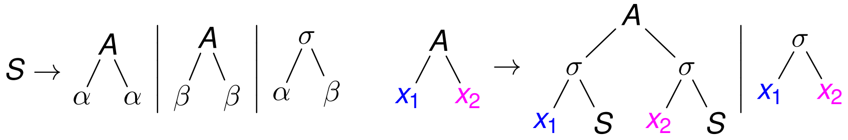

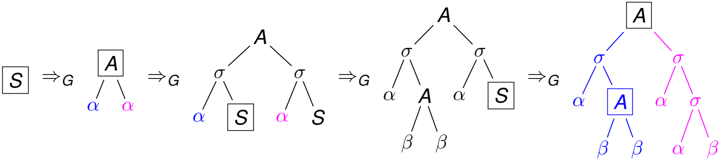

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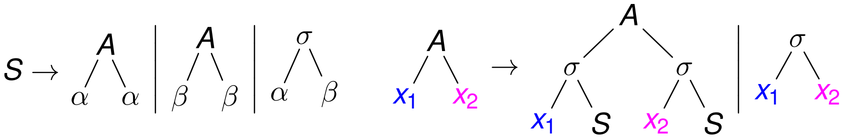

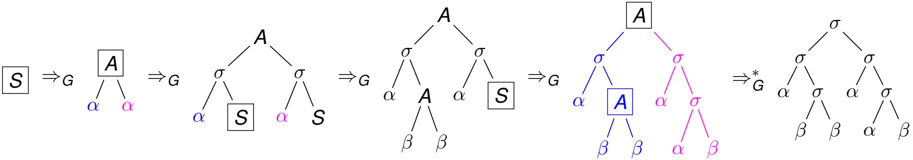

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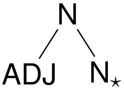
Theorem (Joshi et al. 1975 and Mönnich 1997)

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

Example (adjunction production)



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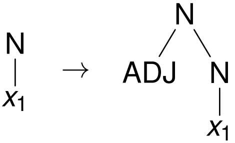

Overview

Growing Normal Form

Definition

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

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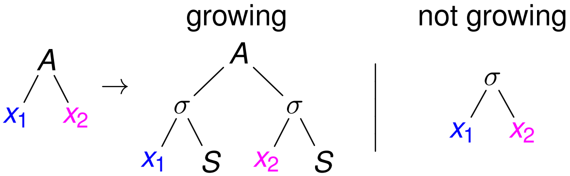

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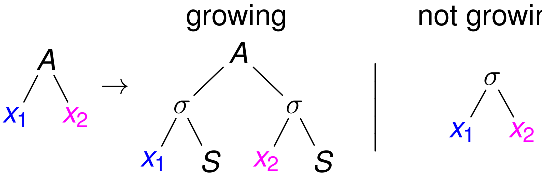

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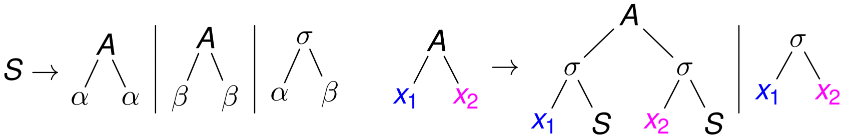

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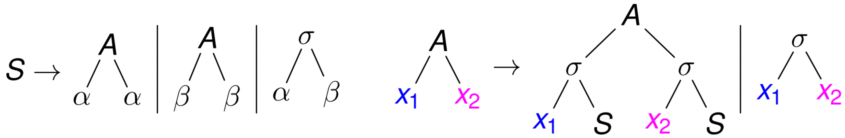
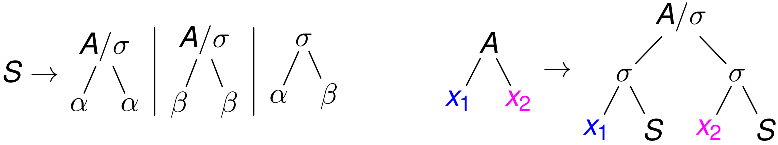


Eliminate last production:



Limited Ambiguity

Definition (frontier yield)

$\text{yd}\colon T_\Sigma \to \Sigma_0^*$

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

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

Definition (Schabes 1990)

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Monadic, Terminal, and Lexicalized Productions

Definition

Production $\ell \to r$

- monadic (terminal) if r contains ≤ 1 (resp. 0) nonterminals
- (doubly) lexicalized if r contains ≥ 1 (resp. ≥ 2) lexical items

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]
- compute closure under non-lexicalized productions □

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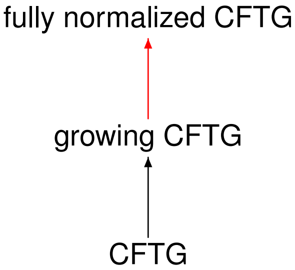

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Definition

A CFTG is lexicalized if each (non-initial) production is lexicalized

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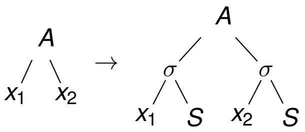
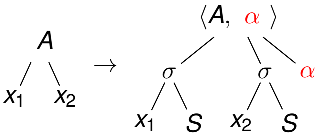
Lexicalization — Step 1

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

Input



Output



Lexicalization — Step 2

1. guess lexical item in non-lexicalized production
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3. potentially guess again
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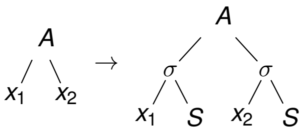

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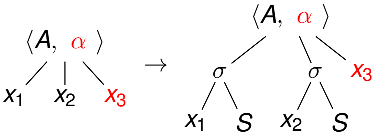

Lexicalization — Step 3

1. guess lexical item in non-lexicalized production
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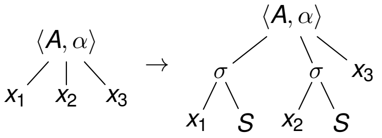
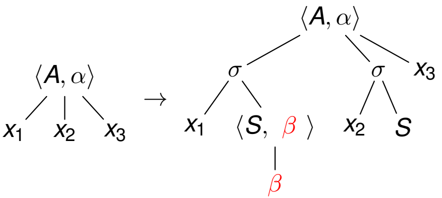
4. cancel in terminal production

Input



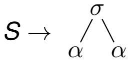
Output



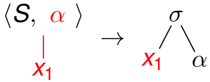
Lexicalization — Step 4

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

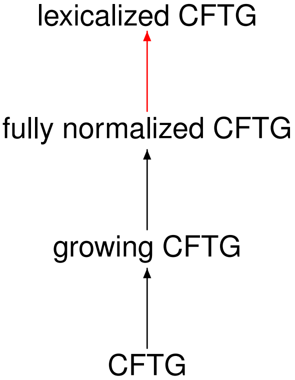
Input



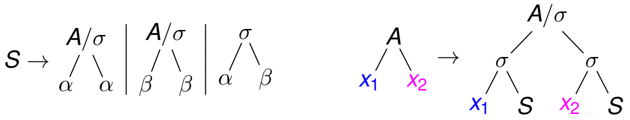
Output



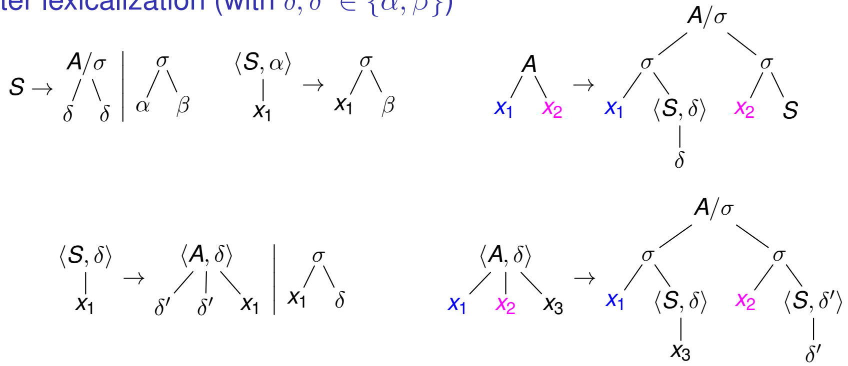
Lexicalization



Lexicalization — Example



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



Summary

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

Theorem (ENGELFRIET et al. 1980)
CFTG(k) induces infinite hierarchy of string languages

Summary

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

CFTG($k+1$)
↑
CFTG(k)
↑
...
↑
CFTG(2)
↑
CFTG(1) — includes TAG
↑
CFTG(0) — regular tree grammar

Corollary

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

Corollary

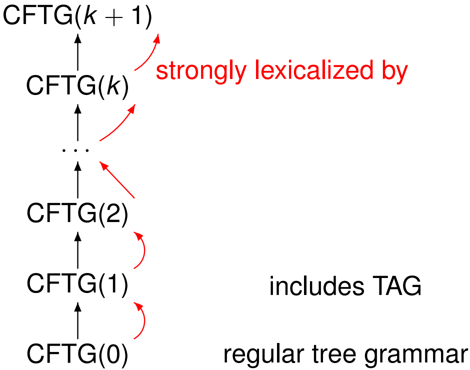
TAG are strongly lexicalized by CFTG(2)

Open problem

Rank increase necessary?

Summary

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



Corollary

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

Corollary

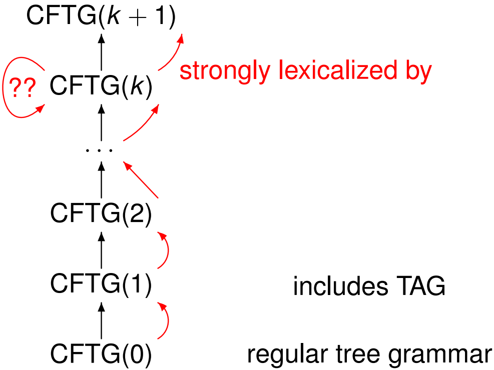
TAG are strongly lexicalized by CFTG(2)

Open problem

Rank increase necessary?

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)

Open problem

Rank increase necessary?

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