Introduction to Tree Adjoining Grammar

Natural Language Syntax with TAG

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DGfS-CL Fall School 2011

1st week, 1st session
Aug 29, 2011

Overview: First week

1. Going beyond Context-Free Grammar (Monday)
2. Formal definition of TAG (Tuesday)
3. TAG and natural languages (Wednesday)
4. TAG parsing (Thursday)
5. Extensions of TAG (Friday)

Overview: Second week

1. Principles underlying the shape of elementary trees
2. XTAG-analyses of raising/control
3. XTAG-analyses of extraction
4. How to implement an LTAG
5. How to run and test an LTAG

Outline

1. Organizational issues
2. CFG and natural languages
   - Context-Free Grammars
   - Are Natural Languages Context-Free?
   - Mild Context-Sensitivity
3. Tree Substitution Grammar
   - Definition
   - Properties
4. Adjunction

Organizational issues

- Course web page:
  `http://www.sfb991.uni-duesseldorf.de/a02/dgfs-11`
- Requirements for obtaining 4 ETCS credits:
  - Participation in each class
  - Solving at least 75% of the exercises
  - Writing a short essay (4 pages) or solving an implementation task

Context-Free Grammars

Context-Free Grammar (CFG)

- Disjoint sets of terminals and non-terminals
- A non-terminal start symbol
- A set of rewriting rules stating how to replace a non-terminal by a sequence of non-terminal and terminal symbols.

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$\mathrm{S} \rightarrow \mathrm{a\ S\ b} \quad \mathrm{S} \rightarrow \mathrm{ab}$

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Example

S $\rightarrow$ a S b   S $\rightarrow$ ab

Generates the string language $\{a^n b^n \mid n \geq 1\}$.

CFG language

Definition (CFG language)

Let $G = \langle N, T, P, S \rangle$ *be a CFG. The (string) language* $L(G)$ *of* G *is the set* $\{w \in T^* \mid S \stackrel{*}{\Rightarrow} w\}$ *where*

- *for* $w, w' \in (N \cup T)^*$: $w \Rightarrow w'$ *iff there is a* $A \to \alpha \in P$ *and there are* $v, u \in (N \cup T)^*$ *such that* $w = vAu$ *and* $w' = v\alpha u$.

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- *$\stackrel{*}{\Rightarrow}$ is the reflexive transitive closure of $\Rightarrow$:*
  - *$w \stackrel{0}{\Rightarrow} w$ for all $w \in (N \cup T)^*$, and*
  - *for all $w, w' \in (N \cup T)^*$: $w \stackrel{n}{\Rightarrow} w'$ iff there is a v such that $w \Rightarrow v$ and $v \stackrel{n-1}{\Rightarrow} w'$.*
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A language is called context-free iff it is generated by a CFG.

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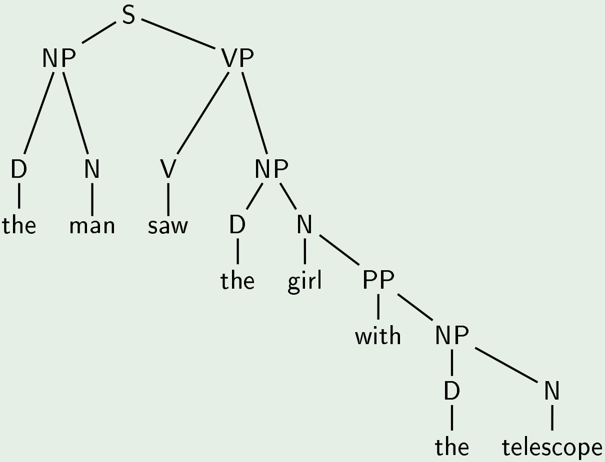
[Hopcroft and Ullman, 1979]

CFG Natural Language Example

Sample CFG $G_{telescope}$

- Nonterminals: $\{S, NP, VP, PP, N, V, P, D\}$
- Terminals: {the, man, telescope, saw, girl, with, John}
- Productions:

$$
\begin{array}{lcl lcl}
S & \rightarrow & NP\ VP & NP & \rightarrow & D\ N \\
VP & \rightarrow & VP\ PP \mid V\ NP & N & \rightarrow & N\ PP \\
PP & \rightarrow & P\ NP & & & \\
N & \rightarrow & \text{man} \mid \text{girl} \mid \text{telescope} & D & \rightarrow & \text{the} \\
N & \rightarrow & \text{John} & P & \rightarrow & \text{with} \\
V & \rightarrow & \text{saw} & & &
\end{array}
$$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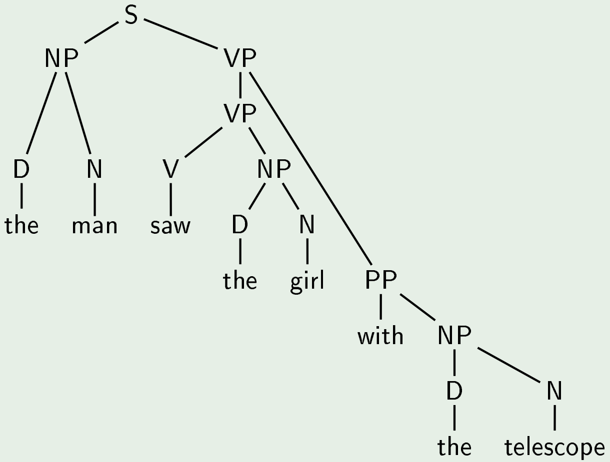
Example derivation



Why CFG is not enough

... for modeling natural language:

1. only atomic non-terminals
2. only weak lexicalization
3. expressive power is too low

Why CFG is not enough (1) - Atomic non-terminals

$S \rightarrow NP\ VP$	$NP \rightarrow John$	$NP \rightarrow Mary$	
$VP \rightarrow V$	$VP \rightarrow V\ NP$	$V \rightarrow sleeps$	$V \rightarrow likes$

Possible derivation:

$S \Rightarrow NP\ VP \Rightarrow John\ VP \Rightarrow John\ V \Rightarrow John\ sleeps$

$S \stackrel{*}{\Rightarrow} John\ likes\ Mary$

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How to treat subcategorization frames, number agreement, and case marking?

(1) a. Kim depends on Sandy.
*Kim depends Sandy.
*Kim depends.
b. *The children depends on Sandy.
c. Kim depends on her/*she.

Why CFG is not enough (1)

How to treat subcategorization frames, number agreement, and case marking?

$\Longrightarrow$ encode the necessary information into the non-terminal symbols

$$
\begin{array}{ll}
NP_{3sg-nom} \rightarrow John & NP_{3sg-acc} \rightarrow Mary \\
V_{3sg-itr} \rightarrow sleeps & V_{3sg-tr} \rightarrow likes \\
S \rightarrow NP_{3sg-nom}\ VP_{3sg-itr} & S \rightarrow NP_{3sg-nom}\ VP_{3sg-tr} \\
VP_{3sg-itr} \rightarrow V_{3sg-itr} & VP_{3sg-tr} \rightarrow V_{3sg-tr}\ NP_{3sg-acc}
\end{array}
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$S \rightarrow NP_{3sg-nom}\ VP_{3sg-itr}$	$S \rightarrow NP_{3sg-nom}\ VP_{3sg-tr}$
$VP_{3sg-itr} \rightarrow V_{3sg-itr}$	$VP_{3sg-tr} \rightarrow V_{3sg-tr}\ NP_{3sg-acc}$

$S \overset{*}{\Rightarrow} John\ likes\ Mary$

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Drawback: Every possible combination of subcategorization frame, number agreement, and case marking necessitates its own rule (let alone the number of non-terminal symbols).

Why CFG is not enough (1)

$\Longrightarrow$ grammar writing is tedious and error prone
$\Longrightarrow$ generalizations very hard to express

Remedy: feature structures instead of atomic non-terminal symbols, unification, underspecification

Why CFG is not enough (2) - Only weak lexicalization

Lexicalization

In a lexicalized grammar, each element of the grammar contains at least one lexical item (terminal symbol).

G_1: $S \rightarrow SS$, $S \rightarrow a$
G_2: $S \rightarrow aS$, $S \rightarrow a$

- **Computationally interesting:** the number of analyses for a sentence is finite (if the grammar is finite of course).
- **Linguistically interesting:** each lexical item allows for of certain syntactic constructions, which one would like to associate with it.

Why CFG is not enough (2)

Lexicalizing a CFG:

- Greibach normal form: $A \rightarrow aB_1 \dots B_k$ $(k \geq 0)$
- weak lexicalization: string language is preserved
- strong lexicalization: tree structure is preserved

Question

Can CFGs be lexicalized such that the set of trees remains the same (strong lexicalization)?

Answer

No. Only weak lexicalization (same string language).

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Cross-serial dependencies in Dutch

(2) ... dat Wim Jan Marie de kinderen zag helpen leren zwemmen
... that Wim Jan Marie the children saw help teach swim
'... that Wim saw Jan help Marie teach the children to swim'

Why CFG is not enough (3)

Swiss German

(3) … das mer em Hans es huus hälfed aastriiche
… that we Hans_{Dat} house_{Acc} helped paint
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- Swiss German uses case marking and displays cross-serial dependencies.
- [Shieber, 1985] shows that Swiss German is not context-free.

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$$\Downarrow$$

We need extensions of CFG in order to describe all NL phenomena!

CFG: Mild context-sensitivity (1)

Idea [Joshi, 1985]: characterize the amount of context-sensitivity necessary for natural languages.

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3. are polynomially parsable, and
4. their string languages are of constant growth. (the length of the words generated by the grammar grows in a linear way, e.g., $\{a^{2^n} \mid n \geq 0\}$ does not have that property)

TSG: Definition (1)

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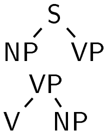
$S \rightarrow NP\ VP$

$VP \rightarrow V\ NP$



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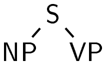
S $\rightarrow$ NP VP



VP $\rightarrow$ V NP

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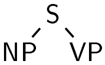
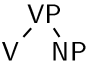
VP → V NP





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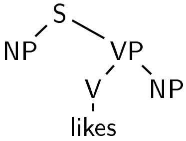

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- internal nodes labeled with non-terminals, and
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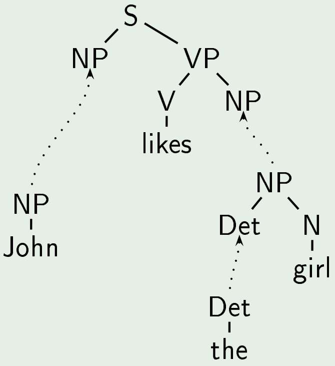
We build larger trees by substitution:

- Pick a non-terminal leaf (substitution node)
- Replace it with a tree the root node of which has the same label

TSG: Definition (3)

Substitution example



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Definition (Tree Substitution Grammar)

A Tree Substitution Grammar (TSG) is a tuple $G = \langle N, T, S, I \rangle$ where

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Every tree in I *is called an* elementary tree*.*
G *is called* lexicalized *if every tree in* I *has at least one leaf with a label from* T*.*

TSG: Definition (5)

TSG derivation step

- select a node with a non-terminal label A,
- pick a fresh instance of an elementary tree with root label A from the grammar,
- and substitute the node for the new tree.

Definition (TSG language)

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4. *The string language of G is $\{w \mid \text{there is a } \gamma \in L_T(G) \text{ such that } w = yield(\gamma)\}$.*

TSG: Properties (1)

In spite of the larger domains of locality, the following holds:

Proposition (Equivalence of CFG and TSG)

CFG and TSG are weakly equivalent. Furthermore, except for some relabeling of the nodes, they are even strongly equivalent.

TSG: Properties (2)

CFG $\Rightarrow$ TSG

Every CFG can be immediately written as a TSG with every production being understood as a tree with a single root and a daughter for every righthand side symbol

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CFG ⇒ TSG

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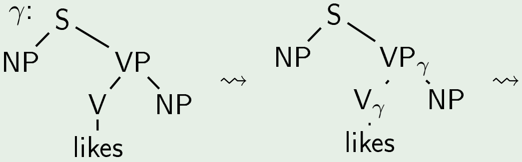
TSG ⇒ CFG

In order to construct an equivalent CFG for a given TSG, we have to encode the dependencies between nodes from the same tree within the non-terminal symbols.



$$\mathrm{S} \rightarrow \mathrm{NP}\ \mathrm{VP}_\gamma$$
$$\mathrm{VP}_\gamma \rightarrow \mathrm{V}_\gamma\ \mathrm{NP}$$
$$\mathrm{V}_\gamma \rightarrow \text{likes}$$

TSG: Properties (4)

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- Nevertheless they offer an extended domain of locality

$\Longrightarrow$ They capture more generalizations than CFGs!

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- TSGs are used in the context of data-oriented parsing (DOP) [Bod, 1995].
- Lexicalized TSGs can be extracted from treebanks and used for probabilistic parsing [Post and Gildea, 2009].
- [Cohn et al., 2009] also induce Probabilistic Tree Substitution Grammars from treebanks and use them successfully for parsing.

Adjunction (1)

Tree Adjoining Grammars (TAG)

[Joshi et al., 1975, Joshi and Schabes, 1997]:

- Tree-rewriting grammar.
- Extension of CFG that allows to replace not only leaves but also internal nodes with new trees.
- Can generate the copy language.

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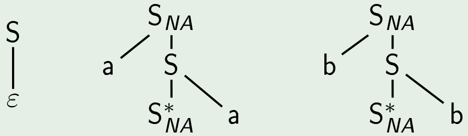
TAG for the copy language



Adjunction (2)

TAG derivation of *abab*

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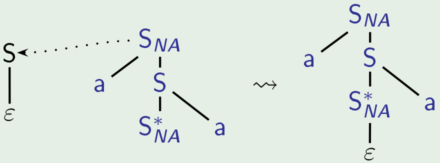

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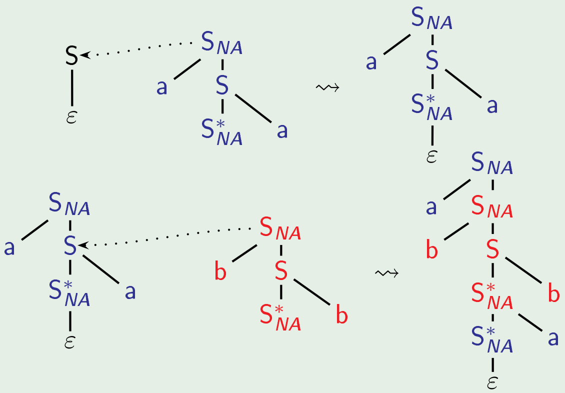

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