Lexicalized Tree Adjoining Grammar

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FRVŠ MŠMT FR97/2011/G1
Introduction
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- Some Important TAG Properties
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Motivation

Motivation is of linguistic and formal nature.

- Elementary objects are trees - structured objects and not strings.
- Structured objects are related with strong generative capacity. ⇒ More relevant to linguistic description.
- TAG allow factoring recursion from the statement of linguistic dependencies
- Lexicalization of grammar formalism.
Tree-Adjoining Grammars (TAG)

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- TAG allow factoring recursion from the statement of linguistic dependencies
- Lexicalization of grammar formalism.

- TAG is tree-generating system ⇒ the set of trees constitute the object language
- One well known normal form of grammars - Greibach Normal Form (GNF) is a kind of lexicalization.
Introduction

Tree Adjoining Grammar

Some Important TAG Properties

Lexicalized Tree Adjoining Grammar
## Definition

Tree Adjoining Grammar (TAG) is a quintuple \( (T, N, I, A, S) \).

- \( T \ldots \) a finite set of terminal symbols
- \( N \ldots \) a finite set of nonterminal symbols; \( T \cap N = \emptyset \)
- \( I \ldots \) a finite set of initial trees
  - An initial tree is a phrase structure tree
- \( A \ldots \) a finite set of auxiliary trees
  - An auxiliary tree is a phrase structure tree that has a leaf nonterminal node that is the same as its root symbol
- \( S \ldots \) start symbol, \( S \in N \)
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- Trees in \(I\) and \(A\) are called **elementary trees**.
- Parsing is done by two operations: **substitution** and **adjunction**.
An example of an initial and an auxiliary tree

- A nonterminal symbol marked by * is the foot node of an auxiliary tree.
- A nonterminal symbol marked by ↓ is a nonterminal node for substitution.
Substitution of an initial tree $T_1$ into a tree $T_2$ is to replace a substitution node in $T_2$ with $T_1$. 
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Example

```
  S
   /\  \
  NP  VP
   /\     \
  NP  V  NP
   /    /\  \
  John likes NP
```

$T_1$  $T_2$
Substitution of an initial tree $T_1$ into a tree $T_2$ is to replace a substitution node in $T_2$ with $T_1$.

Example

```
S
  NP↓  VP
  NP  V  NP↓
  John likes
```

```
S
  NP  VP
  NP  V  NP↓
     John likes
```

$T_1$  $T_2$
Adjoining an auxiliary tree $T_1$ into a tree $T_2$ is to inset $T_1$ into $T_2$ at the node that is the same as the root (and the foot) of $T_1$. 
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Example

\[
\begin{array}{c}
S \\
\downarrow \\
NP \quad \text{VP} \\
\downarrow \\
\text{John} \quad \text{V} \\
\downarrow \\
\text{walks} \\
\end{array}
\quad
\begin{array}{c}
\text{VP} \\
\downarrow \\
\text{VP}^* \\
\downarrow \\
\text{PREP} \quad \text{NP} \\
\downarrow \\
\text{in} \quad \text{NP} \\
\end{array}
\]

$T_2$ $T_1$
Adjoining an auxiliary tree $T_1$ into a tree $T_2$ is to inset $T_1$ into $T_2$ at the node that is the same as the root (and the foot) of $T_1$.

Example

```
S
  /\         \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \       \�
```
Adjoining an auxiliary tree $T_1$ into a tree $T_2$ is to inset $T_1$ into $T_2$ at the node that is the same as the root (and the foot) of $T_1$.

Example

$T_1$ is adjoined at VP in $T_2$
Adjunction (Adjoining)

- Any adjunction on a node marked for substitution is disallowed.

Adjoining Constraints

to have more precision for specifying which auxiliary trees can be adjoined at a given node.

1. **Selective Adjunction** (S A(T)) - only members of a set $T \subseteq A$ of auxiliary trees can be adjoined on the given node, the adjunction of an auxiliary is not mandatory on the given node.

2. **Null Adjunction** (N A) - disallows any adjunction on the given node.

3. **Obligatory Adjunction** (O A(T)) - an auxiliary tree member of the set $T \subseteq A$ must be adjoined on the given node.

- These constraints on adjoining are needed for formal reasons in order to obtain some closure properties.
Derivation in TAG

This tree yields the sentence Yesterday a man saw Mary and is derived from the following elementary trees:
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Derivation in TAG

\[
\begin{align*}
\beta_{\text{yest}} &: \quad S \\
& \quad \text{Ad} \\
& \quad S^* \\
& \quad \text{yesterday} \\
\end{align*}
\]

\[
\begin{align*}
\alpha_{a} &: \quad D \\
& \quad \alpha \\
\end{align*}
\]

\[
\begin{align*}
\alpha_{\text{man}} &: \quad \text{NP} \\
& \quad \text{D} \\
& \quad N \\
& \quad \text{man} \\
\end{align*}
\]

\[
\begin{align*}
\alpha_{\text{saw}} &: \quad \text{VP} \\
& \quad \text{V} \\
& \quad \text{NP}_1 \\
& \quad \text{saw} \\
\end{align*}
\]

\[
\begin{align*}
\alpha_{\text{Mary}} &: \quad \text{NP} \\
& \quad \text{N} \\
& \quad \text{Mary} \\
\end{align*}
\]

The order in which the derivation tree is interpreted has no impact on the resulting derived tree.
Derivation tree for *Yesterday a man saw Mary.*
Derivation tree for *Yesterday a man saw Mary*.

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Derived Tree
A tree built by composition of two others trees.

- the derived tree does not give enough information to determine how it was constructed
- adjunction and substitution are considered in a TAG derivation
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Derivation Tree

It is an object that specifies uniquely how a derived tree was constructed.
Introduction

Tree Adjoining Grammar

Some Important TAG Properties

Lexicalized Tree Adjoining Grammar
Tree Set of a TAG $T_G$

- Defined as the set of completed initial trees derived from some $S$-rooted initial trees.

$$T_G = \{ t \mid t \text{ is derived from some } S\text{-rooted initial tree} \}$$

- Note that completed initial tree is an initial tree with no substitution nodes.
Tree Sets and String Languages

Tree Set of a TAG $T_G$

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Tree String language of a TAG $L_G$

- Defined as the set of yields of all trees in the tree set.

$$L_G = \{ w | w \text{ is the yield of some } t \text{ in } T_G \}$$
Some Properties of the Tree Sets and String Languages

- All closure properties of context-free languages (CFL) also hold for tree-adjoining languages (TAL).
- $CFL \subset TAL$
- TAL can be parsed in polynomial time.
- Tree-adjoining grammars generate some context-sensitive languages.
Consider the following TAG $G_1 = (\{a, e, b\}, \{S\}, \{\alpha_6\}, \{\beta_2\}, S)$:

**Example**

\[\alpha_6: \quad S \quad \beta_2: \quad S_{NA}\]

\[\quad e \quad a \quad S \quad \quad \quad S_{NA}^{*} \quad b\]
Example

Consider following TAG $G_1 = (\{a, e, b\}, \{S\}, \{\alpha_6\}, \{\beta_2\}, S)$

- $\alpha_6$: $S$
- $\beta_2$: $S_{NA}$

$G_1$ generates the language $L_1 = \{a^n eb^n | n \geq 1\}$
Example

Consider following TAG $G_1 = (\{a, b, c, d, e\}, \{S\}, \{\alpha_6\}, \{\beta_3\}, S)$

$\alpha_6$: $S$

$\beta_3$: $S_{\text{NA}}$

$e$

$a S d$

$b S_{\text{NA}} c$
Example

Consider following TAG $G_1 = (\{a, b, c, d, e\}, \{S\}, \{\alpha_6\}, \{\beta_3\}, S)$

\[
\begin{align*}
\alpha_6: & \quad S \\
\beta_3: & \quad S_{\text{NA}} \\
& \quad e \\
& \quad a \quad S \quad d \\
& \quad b \quad S_{\text{NA}}^* \quad c \\
\end{align*}
\]

- $G_1$ generates the language $L_1 = \{a^n b^n e c^n d^n | n \geq 1\}$
Some properties of the Tree Sets and String Languages: Example 2

Example

Some derived trees of $G_2$

- $S_{NA}\ a\ S\ d$
- $b\ S^*_{NA}\ c$
Some Properties of the Tree Sets and String Languages: Example 2

Example

Some derived trees of \( G_2 \)

\[
\begin{align*}
S_{NA} & \\
\quad \vdash a \quad S \quad d \\
\quad \quad \vdash b \quad S^*_{NA} \quad c \\
\quad \quad \quad \vdash e \\
S_{NA} & \\
\quad \vdash a \quad S_{NA} \quad \vdash d \\
\quad \quad \vdash a \quad S_{NA} \quad \vdash c \\
\quad \quad \quad \vdash b \quad S_{NA} \quad \vdash e
\end{align*}
\]
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Lexicalized Grammar

- Each elementary structure is associated with a lexical item.
- The grammar consists of *lexicon*, where:
  - each lexical item is associated with a finite number of structures and
  - there are operations which tell how these structures are composed.
Lexicalized Tree Adjoining Grammar (LTAG)

Definition

- A grammar is **lexicalized** if it consists of a finite set of structures each associated with a lexical item.
- Each lexical item is called the **anchor** of the corresponding structure.
- Grammar contains an operation or operations for composing the structure.
- LTAG is a TAG in which every elementary (initial and auxiliary) tree is anchored with a lexical item.

Notes

- The **anchor** must be overt (= not empty string).
- The structures defined by the lexicon are called **elementary structures**.
- Structures built up by combination of others are called **derived structures**.
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The definition of Lexicalized Grammar implies the following proposition:

**Proposition**

Lexicalized grammars are finitely ambiguous.
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**Proposition**
Lexicalized grammars are finitely ambiguous.

Further, this closure property holds:

**Closure under lexicalization**
TAGs are closed under lexicalization.
Conclusion

Notes

- Lexicalization of grammars is of linguistic and formal interest.
- Rules should not be separated from their lexical realization.
- By using TAGs we can lexicalize the CFGs.
- Substitution and adjunction gives this possibility to lexicalize CFG.
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Thank you for your attention!
End