A Descriptive Characterization of Multicomponent Tree Adjoining Grammars

Laura Kallmeyer
SFB 441, University of Tübingen
laura.kallmeyer@linguist.jussieu.fr

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Structure of the talk

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Tree Adjoining Grammars (LTAG): Tree-rewriting system: set of elementary trees with two operations:

- **adjunction**: replacing an internal node with a new tree. The new tree is an auxiliary tree and has a special leaf, the foot node.
- **substitution**: replacing a leaf with a new tree. The new tree is an initial tree.

(1) John sometimes laughs

```
S
  /\  
/   \ 
NP    VP
  |    |  
NP  ADV VP  V
   |  |  |
  John sometimes  laughs
```

derived tree:

```
S
  /\  
/   \ 
NP    VP
  |    |  
NP  ADV VP  V
   |  |  |
  John sometimes  laughs
```
**TAG (3)**

**Derivation tree**: unordered tree that records how elementary trees were put together.

![Derivation Tree](image)

Derivation trees

- are context-free
- determine uniquely the derived tree
- abstract away from derivation order differences that are not relevant for the derived tree or the derivation tree
- are usually the output of parsing
- serve as interface between syntax and semantics

**MCTAG: Standard definition (1)**

**Multi-Component TAG (MCTAG)**: contains sets of elementary trees. In each derivation step, all trees from one set are added simultaneously.

An MCTAG is

- **tree-local** if all nodes the elements of a set attach to must belong to the same elementary tree
- **set-local** if all nodes the elements of a set attach to must belong to the same elementary tree set
- **non-local** otherwise
MCTAG: Standard definition (2)

Sample derivation:

\[
\begin{align*}
S' & \rightarrow WH S \\
S & \rightarrow WH S \\
S & \rightarrow NP V NP
\end{align*}
\]

MCTAG: Standard definition (3)

Problem with simultaneity requirement in standard MCTAG definition:

- in order to check whether a tree is in the language of the grammar, one has to check all possible derivations including all possible derivation orders ⇒ no abstraction from derivation orders as in TAG derivation trees

Goal: give an MCTAG definition that abstracts away from differences in derivation orders that do not yield different substitutions and adjunctions.
MCTAG: Standard definition (4)

MCTAG derivation trees are defined (Weir 88) only for tree-local and set-local MCTAG:

- each node in the derivation tree corresponds to an elementary tree set
- each edge corresponds to the simultaneous adjunctions of all members of a tree set
- the edges are equipped with tuples of node addresses; each address is a combination of a tree and a node position

MCTAG: Standard definition (5)

MCTAG derivation tree for *whom does John buy a picture of*

```
  ⟨buy⟩
  ⟨⟨buy, 1⟩, ⟨buy, 2222⟩⟩
  ⟨whom, picture⟩
```

MCTAG derivation trees are context-free. (Tree-local and set-local MCTAG are linear context-free rewriting systems (LCFRS).)

Problem: such derivation trees are not possible for non-local MCTAG variants (e.g., non-local MCTAG, Vector MCTAG with Dominance Links V-TAG)
Descriptive characterization of MCTAG (1)

Goal: find a derivation structure that exists for all multicomponent derivations and give a constraint-based characterization of the structures the grammar licenses.

Each MCTAG derivation is a TAG derivation if simultaneous adjunctions and substitutions are performed one after the other.

Define the TAG derivation tree of an MCTAG derivation as the derivation tree of the corresponding TAG derivation.

Then an MCTAG can be characterized via the TAG derivation trees it licences.

Descriptive characterization of MCTAG (2)

Example: TAG derivation tree for whom does John buy a picture of

```
   buy
   1   2
        \   / 222
          whom  picture
```

This TAG derivation tree is allowed because

- both trees from the set \{whom, picture\} occur in the derivation tree (multicomponent),
- there is no dominance relation between whom and picture (simultaneity), and
- whom and picture even have the same mother node (tree-locality)
Descriptive characterization of MCTAG (3)

**Lemma:** Let $G$ be an MCTAG. Let $D$ be a derivation tree in the corresponding TAG. $D$ is a TAG derivation tree in $G$ iff it satisfies (MC1)–(MC3) explained in the following.

**(MC1)** The root of $D$ is an initial tree and all other nodes are trees from tree sets in $G$ such that for all tree sets $\Gamma$ and for all $\gamma_1, \gamma_2 \in \Gamma$: $\gamma_1$ is a node in $D$ iff $\gamma_2$ is a node in $D$.

*(All trees from $\Gamma$ must be used.)*

Example:

\[
\begin{array}{c}
\alpha \\
A \\
B \\
e \\
\end{array}
\left\{ \begin{array}{c}
\beta_a \\
A \\
a \\
A_{NA} \\
b \\
B_{NA} \\
\beta_b \\
B \\
\end{array} \right\}
\]

not possible:

\[
\begin{array}{c}
\alpha_0 \\
\beta_a \\
\end{array}
\]

(only one tree from the tree set used)

---

Descriptive characterization of MCTAG (4)

**(MC2)** For all elementary tree sets $\Gamma$ and for all $\gamma_1, \gamma_2 \in \Gamma$, $\gamma_1 \neq \gamma_2$: $\gamma_1$ does not dominate $\gamma_2$.

*(Otherwise $\gamma_2$ would be attached to a tree derived from $\gamma_1$)*

Example:

\[
\begin{array}{c}
\alpha \\
A \\
B \\
e \\
\end{array}
\left\{ \begin{array}{c}
\beta_a \\
A \\
a \\
A_{NA} \\
b \\
B_{NA} \\
\beta_b \\
B \\
\end{array} \right\}
\]

not possible:

\[
\begin{array}{c}
\alpha_1 \\
\beta_a \\
\beta_b \\
\end{array}
\]

(trees from the same tree set adjoined into each other)
Descriptive characterization of MCTAG (5)

(MC3) For all pairwise different elementary tree sets \( \Gamma_1, \Gamma_2, \ldots, \Gamma_n \), \( n \geq 2 \): there are no \( \gamma_1^{(i)}, \gamma_2^{(i)} \in \Gamma_i \), \( 1 \leq i \leq n \) such that \( \gamma_1^{(i)} \) dominates \( \gamma_2^{(n)} \) and \( \gamma_1^{(i)} \) dominates \( \gamma_2^{(i-1)} \) for \( 2 \leq i \leq n \).

(The \( \Gamma_i \) must be added one after the other.)

Example:

\[
\begin{array}{c}
\alpha \\
\text{A} \\
\text{B}
\end{array} \quad \frac{\begin{array}{c}
\beta_a \\
A\text{A}_N\text{A}^{*} \\
\beta_b \\
B\text{B}_N\text{A}^{*}
\end{array}}{\beta_c \\
A\text{A}_N\text{A}^{*} \\
\beta_d \\
B\text{B}_N\text{A}^{*}}
\]

(not possible: \( \beta_a \) added before \( \beta_c \) but \( \beta_d \) added before \( \beta_b \) \( \Rightarrow \) neither \( \{\beta_a, \beta_b\} \) nor \( \{\beta_c, \beta_d\} \) can be added first)

Descriptive characterization of MCTAG (6)

(MC1) = multicomponent sets: all trees of an elementary set must be used.

(MC2), (MC3) = simultaneity: the trees of an elementary set must be added one after the other to different nodes in an already derived tree.

An MCTAG \( G \) is a non-local MCTAG iff for each derivation tree \( D \):
\( D \) is a TAG derivation tree in \( G \) iff \( D \) satisfies (MC1)–(MC3).
Local MCTAG variants (1)

An MCTAG $G$

- is **tree-local** iff for each derivation tree $D$:
  
  $D$ is a TAG derivation tree in $G$ iff $D$ satisfies (MC1)–(MC3) and
  
  *(TL)* for all elementary tree sets $\{\gamma_1, \ldots, \gamma_n\}$ occurring in $D$: $\gamma_1 \ldots \gamma_n$ have a unique mother node in $D$.

- is **set-local** iff for each derivation tree $D$:
  
  $D$ is a TAG derivation tree in $G$ iff $D$ satisfies (MC1)–(MC3) and
  
  *(SL)* for all elementary tree sets $\{\gamma_1, \ldots, \gamma_n\}$ occurring in $D$: there is an elementary tree set $\Gamma$ such that for all $1 \leq i \leq n$ there is a $t_i \in \Gamma$ that is the mother node of $\gamma_i$.

Local MCTAG variants (2)

**Tree-local MCTAG with Shared Nodes** (SN-MCTAG, Kallmeyer 05):

Idea: after adjunction of some $\beta$ into an elementary $\gamma$, the root and foot node of $\beta$ belong to both trees, $\beta$ and $\gamma$.

$\Rightarrow$ A further adjunction at the root or the foot of $\beta$ can be considered being an adjunction to $\gamma$.

In combination with tree-locality, this extends the generative capacity of TAG.
**Local MCTAG variants (3)**

Sample SN-MCTAG derivation: scrambling in German

... dass \([es]_1\) der Mechaniker \([t_1\ zu\ reparieren]\) verspricht

... that it the mechanic to repair promises

‘... that the mechanic promises to repair it’

\[
\begin{align*}
&\text{VP} \\
&\quad \text{NP}_{nom} \quad \text{VP}^* \quad \text{verspricht} \quad \text{NP}_{acc} \quad \text{zu\ reparieren} \\
&\Rightarrow \quad \text{NP}_{nom} \quad \text{VP} \quad \text{verspricht} \\
&\quad \text{NP}_{acc} \quad \text{zu\ reparieren}
\end{align*}
\]

**Local MCTAG variants (4)**

TAG derivation tree: \(\epsilon\)-\(es\)

is daughter of \(\text{reparieren}\)

and \(es\) is adjoined to the

root of a daughter of \(\text{reparieren}\).
**Local MCTAG variants (5)**

$G$ is an SN-MCTAG iff for each derivation tree $D$: $D$ is a TAG derivation tree in $G$ iff $D$ satisfies (MC1)–(MC3) and

**(SN-TL)** for all elementary tree sets $\{\gamma_1, \ldots, \gamma_n\}$ occurring in $D$: there is a $\gamma$ such that for $1 \leq i \leq n$:

- either $\gamma$ is the mother of $\gamma_i$,
- or there is a daughter $\gamma'$ of $\gamma$ such that $\gamma_i$ is linked to $\gamma'$ by a sequence of adjunctions at root or foot nodes.

**Non-local MCTAG variants (1)**

**Dominance Links**: Constraints of the form $f \geq n$ where $f$ is a foot node in some $\beta$, $n$ an internal node in some $\gamma$ such that $\beta$ and $\gamma$ belong to the same elementary tree set.

A dominance link $f \geq n$ means that whenever using this set in a derivation, in the final derived tree, the node $f$ must dominate $n$ (or anything adjoined to $n$).

- Dominance links are interesting only in non-local MCTAG variants since in a local variant dominance links can be simulated choosing appropriate node labels.
- Dominance links add a restriction on the derived trees. But a corresponding constraint for the possible TAG derivation trees can be formulated.
Non-local MCTAG variants (2)

Example of a derivation with dominance links:

\[
\begin{aligned}
\text{TAG derivation tree: } & \text{es is ad-
\text{jointed to the spine of verspricht which is adjoined to reparieren at a node that dominates the substi-
\text{tution site of } \epsilon\text{-es.}} \\
\end{aligned}
\]

Non-local MCTAG variants (3)

We define: in a derivation tree \( \beta_1 \) spine-dominates \( \beta_n \) iff either \( \beta_1 = \beta_n \) or there are \( \beta_2, \ldots, \beta_{n-1} \) and positions \( p_1, \ldots, p_{n-1} \) on the spines of \( \beta_1, \ldots, \beta_{n-1} \) resp. such that \( \beta_{i+1} \) is adjoined to \( \beta_i \) at position \( p_i \) for \( 1 \leq i < n \).

\[
\begin{aligned}
\beta_1 \\
p_1 & \leftarrow \text{position on spine} \\
\beta_2 & \ldots \\
\beta_{n-1} \\
p_{n-1} & \leftarrow \text{position on spine} \\
\beta_n \\
\end{aligned}
\]

Note that all nodes on the spines of the \( \beta_i \) dominate the foot node of \( \beta_1 \) in the derived tree.
Non-local MCTAG variants (4)

A TAG derivation tree $D$ satisfies a set of the dominance links iff 
\[\text{(Dom)}\]
for each pair $\beta, \gamma$ in $D$ such that there is a dominance link $f \geq n$ with $f$ foot node of $\beta$, $n$ an internal node in $\gamma$:

(a) $\beta$ does not dominate $\gamma$,

Otherwise $\gamma$ attached to a tree derived from $\beta \Rightarrow$ either no dominance relation between $f$ and $n$ or $n$ dominates $f$.

Non-local MCTAG variants (5)

(b) if $\gamma$ dominates $\beta$, then there is a $\beta'$ and a node $n'$ in $\gamma$ that dominates $n$ such that $\beta'$ is a daughter of $\gamma$ with position $n'$ and $\beta'$ spine-dominates $\beta$

\[
\gamma \\
\beta' \\
p' \leftarrow \text{position on spine} \\
\ldots \\
p \leftarrow \text{position on spine} \\
\beta
\]

(Then the foot node of $\beta$ dominates the foot node of $\beta'$, and the foot node of $\beta'$ dominates $n$.)
Non-local MCTAG variants (6)

(c) if $\gamma$ does not dominate $\beta$ and if $\gamma'$ is the lowest node dominating both, then there are $\gamma_1, \gamma_2$ and positions $n_1, n_2$ in $\gamma'$ such that $n_1$ dominates $n_2$ with
- $\gamma_1$ daughter of $\gamma'$ with position $n_1$, and $\gamma_2$ daughter of $\gamma'$ with position $n_2$, and
- $\gamma_1$ spine-dominates $\beta$, and $\gamma_2$ dominates $\gamma$.

\[ n_1 \text{ dominates } n_2 \rightarrow n_1 \bigg\downarrow \bigg\downarrow n_2 \]

spine dominance $\rightarrow \ldots \ldots \leftarrow \text{dominance}$

$\beta \gamma$

(Then the foot node of $\beta$ dominates the foot node of $\gamma_1$ that dominates everything attached to $n_2$.)

Non-local MCTAG variants (7)

An MCTAG $G$

- is a (non-local) MCTAG with dominance links (Becker et al. 91) iff the TAG derivation trees in $G$ satisfy (MC1)–(MC3) and (Dom).
- is a V-TAG (Rambow 94) iff the TAG derivation trees in $G$ satisfy (MC1) and (Dom).

In V-TAG, simultaneity ((MC2) and (MC3)) is not required.
Summary: MCTAG variants

Local MCTAG variants:

|      | (TL)       | (SL)       | (SN-TL) |
|------|------------|------------|---------|
| (MC1)| tree-local | set-local  | ??      |
|      | MCTAG      | MCTAG      |         |
| (MC1)| tree-local | set-local  | SN-MCTAG|
| -(MC3)| MCTAG      | MCTAG      |         |

Non-local MCTAG variants:

|      | (Dom)     |             |
|------|-----------|-------------|
| (MC1)| V-TAG     | VMC-TAG     |
|      | non-local MCTAG | non-local |
| -(MC3)| with dominance links | MCTAG     |

Conclusion

We have proposed a characterization of MCTAG via the TAG derivation trees the grammar licences.

Advantages:

- descriptive characterization of MCTAG that does not rely on the notions of derivation and simultaneity ⇒ better understanding of the formalism
- the central structure is the TAG derivation tree
- abstracts away from different derivation orders as long as the result of the derivation stays the same (i.e., abstracts away from different orders for visiting the TAG derivation tree top-down)
- allows a more systematic comparison of different MCTAG variants