Recognition and Parsing for Tree Adjoining Grammars

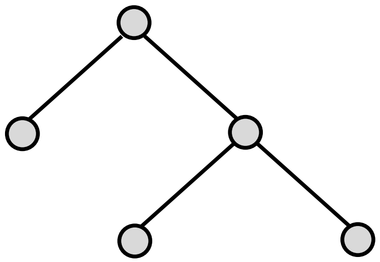
Giorgio Satta
University of Padua
satta@dei.unipd.it

Outline

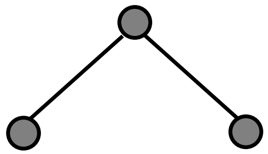
- preliminaries
- basic tabular techniques
- selected topics
- other advanced techniques
- computational/generative complexity trade-off

Sample TAG

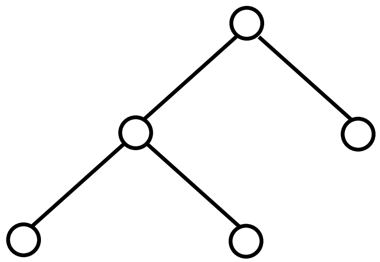
$$G = (V_N, V_\Sigma, S, I, A)$$



Grey $\in$ *Init*

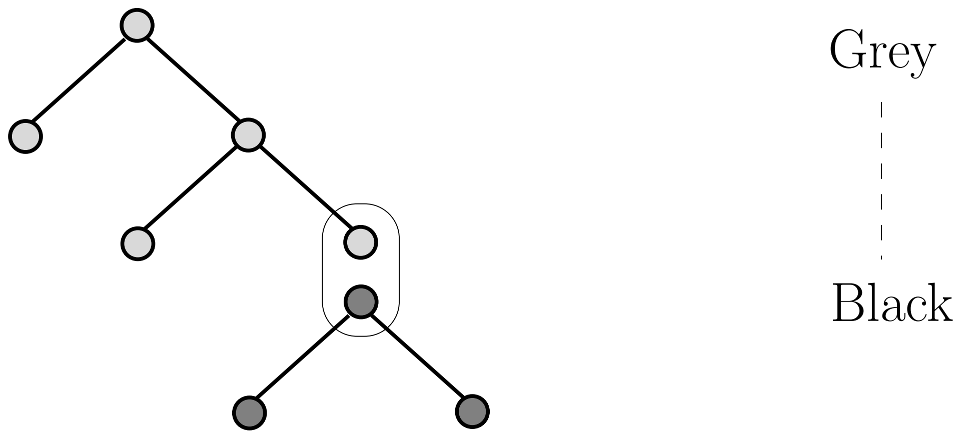


Black $\in$ *Init*

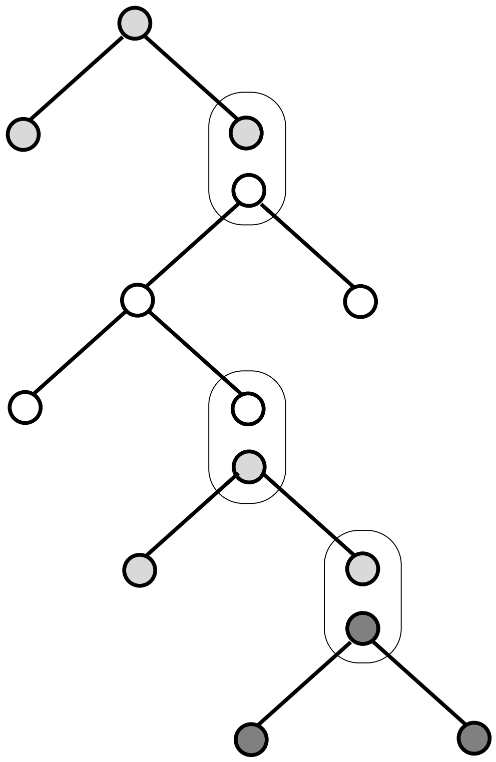


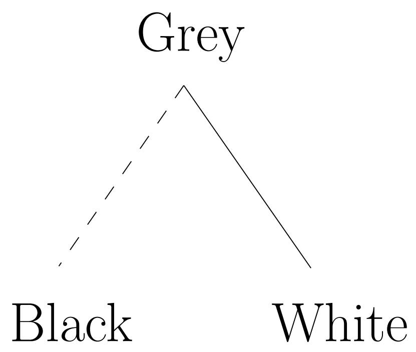
White $\in$ *Aux*

Sample derivation



Sample derivation (cont'd)





Outline

- preliminaries
- **basic tabular techniques**
  - bottom up, binary TAG
  - bottom up, general case
  - bottom up (derived tree)
  - top down
- selected topics
- other advanced techniques
- computational/generative complexity trade-off

Bottom Up on Derivation Trees

(Vijay-Shanker & Joshi, 1985)

Algorithm:

- visit each elementary tree bottom up
- visit derivation tree bottom up

In the presentation we assume:

- binary trees
- no node labeled by ε

BU: Representation

Let the input string be

$$w = a_1 \; a_2 \; a_3 \; \cdots \; a_n$$

An **index** for w is an integer i, $0 \leq i \leq n$, denoting a cut of w

$$[0] \; a_1 \; [1] \; a_2 \; [2] \; a_3 \; \cdots \; a_{n-1} \; [n-1] \; a_n \; [n]$$

BU: Representation (cont'd)

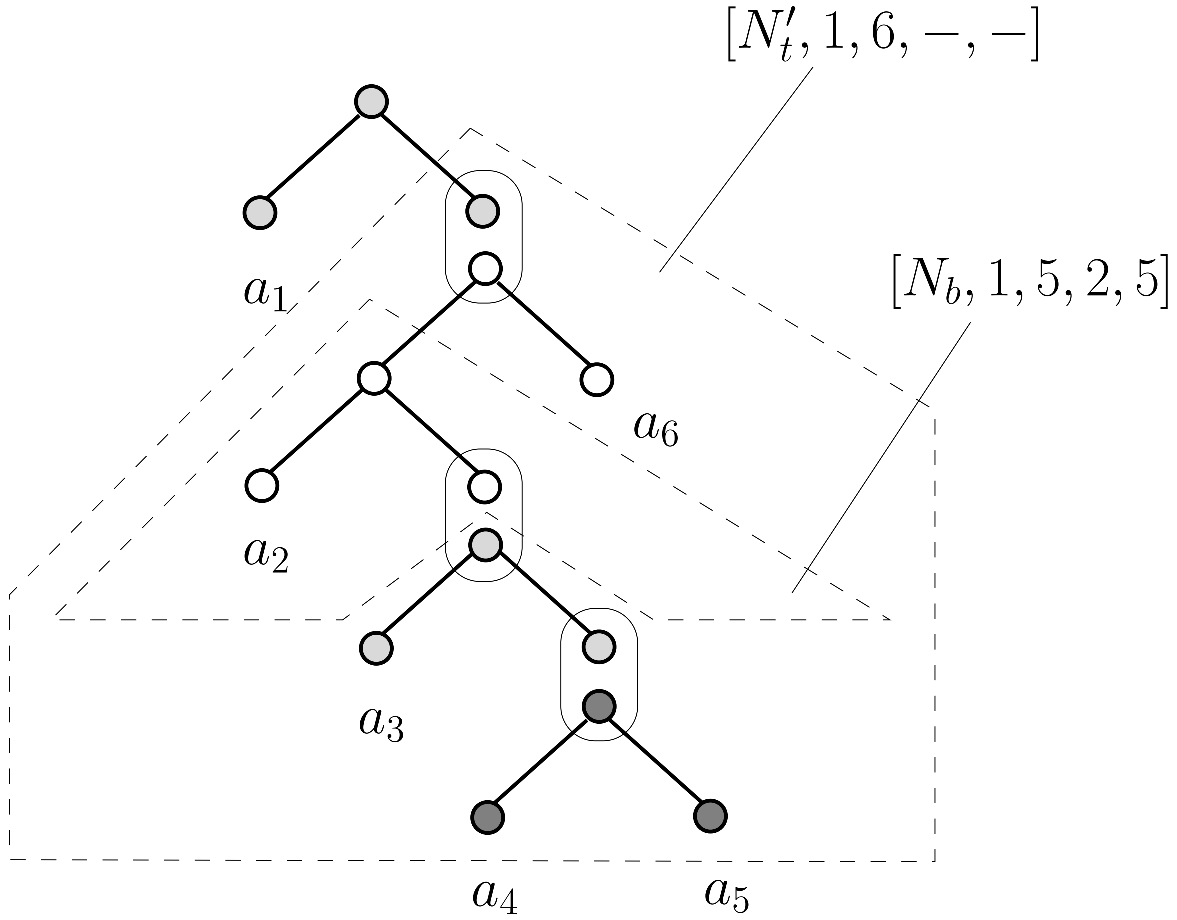
An **item** is a tuple

$$[N_X, i, j, f_1, f_2]$$

denoting a complete subtree of an elementary tree (with possible substitutions and adjunctions):

- N is the root of the subtree, spanning from index i to index j
- foot of subtree spans from index f_1 to index f_2; $f_1 = f_2 = -$ if there is no foot
- $X \in \{b, t\}$ records whether adjunction has been already checked ($X = t$) or not ($X = b$)

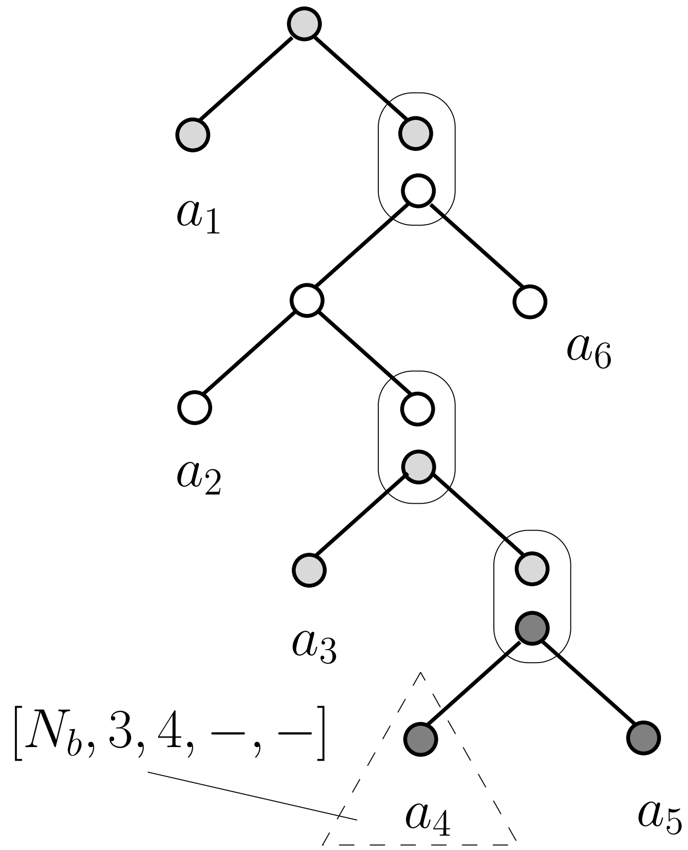
Example



BU: Steps

Init$_1$

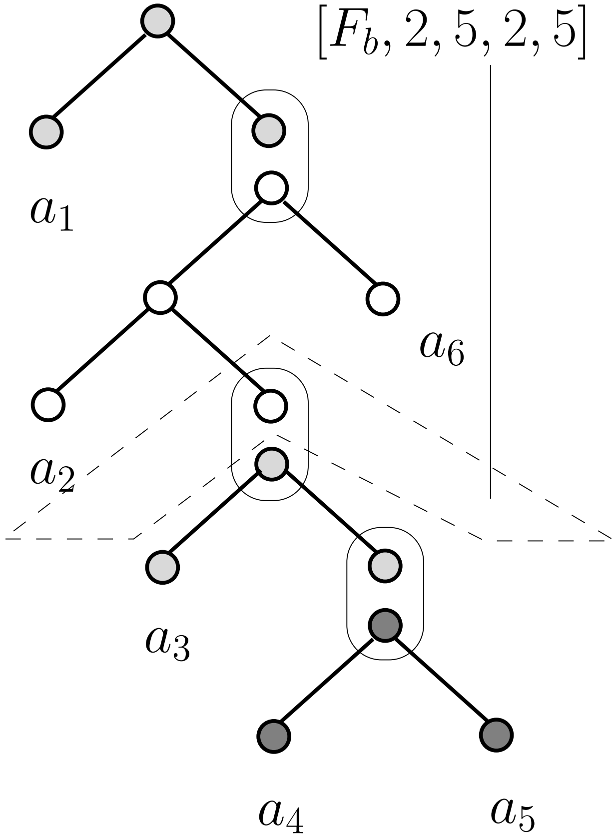
$$\frac{a_i = Labl(N)}{[N_b, i-1, i, -, -]}$$



BU: Steps (cont'd)

Init$_2$

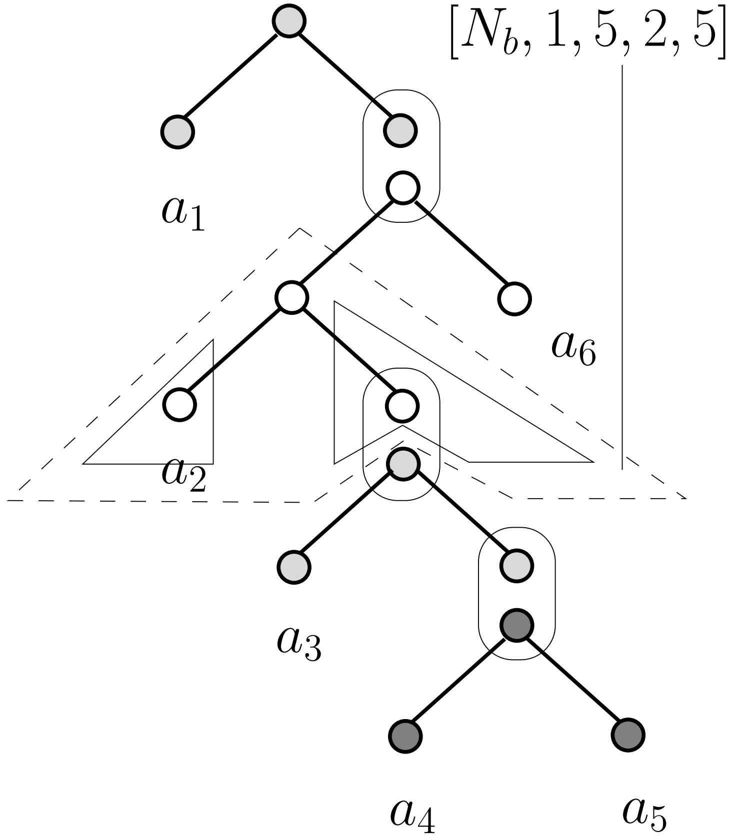
$$\frac{F = Foot(\beta) \quad \forall i, j \in \{0..n\},\ i < j}{[F_b, i, j, i, j]}$$



BU: Steps (cont'd)

Complete$_1$ (3 cases)

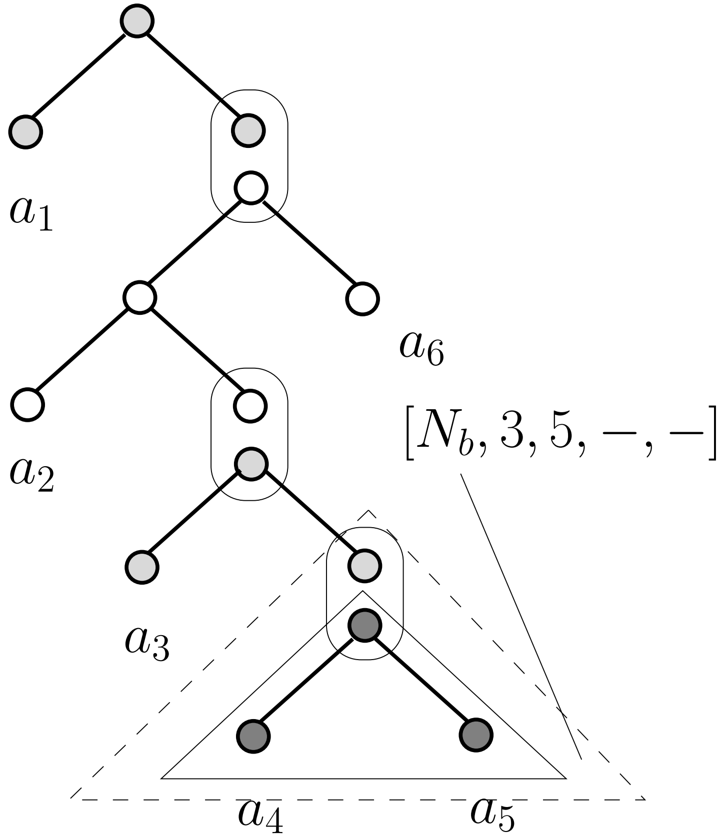
$$\frac{\begin{array}{c} Childr(N) = N'N'' \\ [N'_t, i, k, -, -] \\ [N''_t, k, j, f_1, f_2] \end{array}}{[N_b, i, j, f_1, f_2]}$$



BU: Steps (cont'd)

Substitute

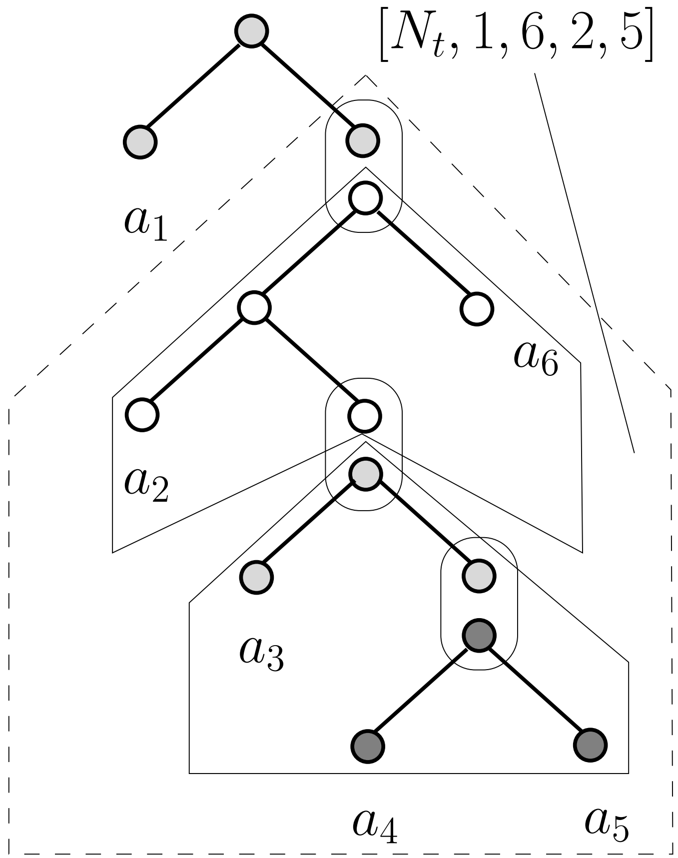
$$\frac{\begin{array}{c} R = Root(\alpha) \\ \alpha \in Sbst(N) \\ [R_t, i, j, -, -] \end{array}}{[N_t, i, j, -, -]}$$



BU: Steps (cont'd)

Adjoin$_1$

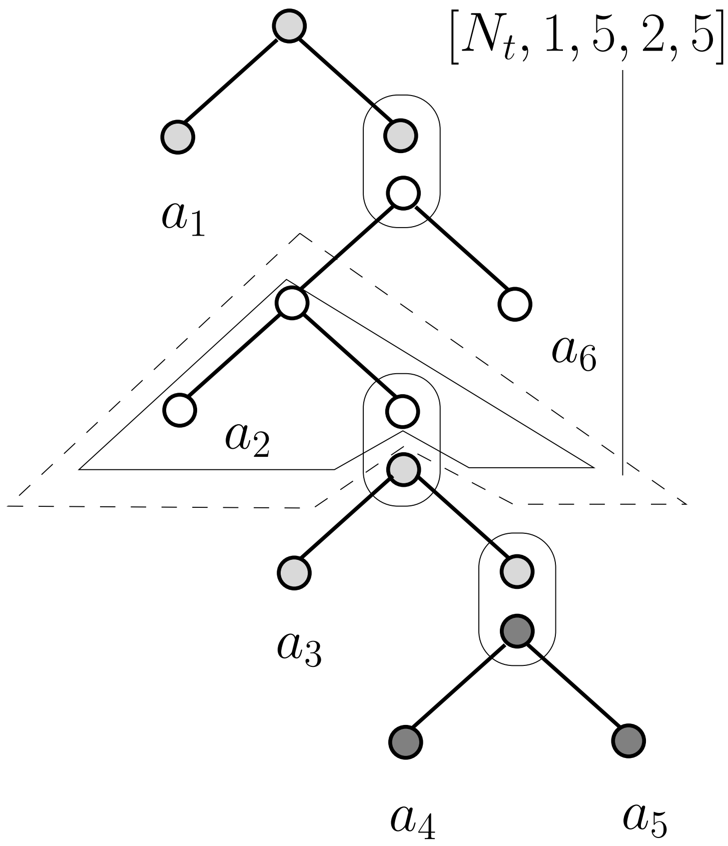
$$\frac{\begin{array}{c} R = Root(\beta) \\ \beta \in Adj(N) \\ [R_t, i, j, f_1, f_2] \\ [N_b, f_1, f_2, f_1', f_2'] \end{array}}{[N_t, i, j, f_1', f_2']}$$



BU: Steps (cont'd)

Adjoin$_2$

$$\frac{\begin{array}{c}\text{nil} \in Adj(N) \\ [N_b, i, j, f_1, f_2]\end{array}}{[N_t, i, j, f_1, f_2]}$$



BU: Data structure

Table:
a 4-dimensional table to retrieve items from their indices i, j, f_1 and f_2

Agenda:
a heap to order items w.r.t. some priority score

BU: Control

Init$_{1,2}() \rightarrow$ *Agenda*
while $I \leftarrow$ *Agenda* **do**
    $I \rightarrow$ *Table*
    Substitute$(I) \rightarrow$ *Agenda*;   **Adjoin**$_2(I) \rightarrow$ *Agenda*
    foreach I' in *Table* (adjacent to I)
        Complete$_{1,2,3}(I, I') \rightarrow$ *Agenda*
        Adjoin$_1(I, I') \rightarrow$ *Agenda*
    end
end
accept iff $[R_t, 0, n, -, -]$ in *Table* for some R root of an initial tree labeled by S

BU: Complexity

Step	time	space
Init	$\mathcal{O}(n^2)$	$\mathcal{O}(n^2)$
Complete	$\mathcal{O}(n^5)$	$\mathcal{O}(n^4)$
Substitute	$\mathcal{O}(n^2)$	$\mathcal{O}(n^2)$
Adjoin	$\mathcal{O}(n^6)$	$\mathcal{O}(n^4)$

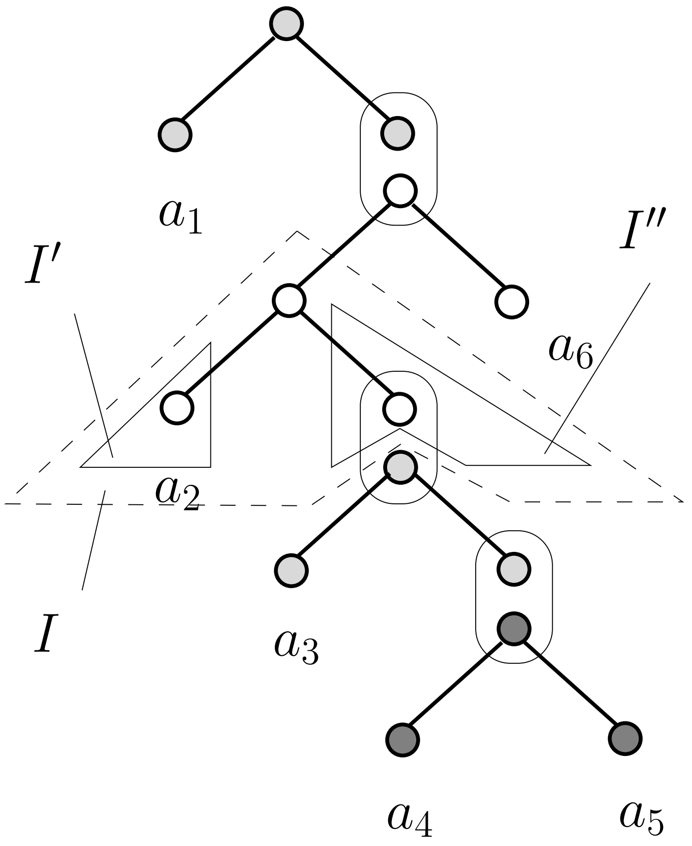
BU: Parsing

A **parse forest** for w and G is a representation of all derived trees for w in G

We construct a parse forest P of size $\mathcal{O}(n^6)$ from which a single derived tree can be extracted in time $\mathcal{O}(n)$

To build P, whenever item I is obtained from the application of some **Step**(I', I''), store with I pair of links $[(I, I'), (I, I'')]$ (similar condition for application of unary steps)

Example



$$I \longrightarrow \langle [(I, I'), (I, I'')], \ldots \rangle$$

BU: General Grammars

If N has children $M_1, \ldots, M_q$, $q \geq 1$, use additional items

$$[N \longrightarrow M_1 \cdots M_h \bullet M_{h+1} \cdots M_q, i, j, f_1, f_2]$$

and split **Complete** into

$$\frac{\begin{array}{c}[N \longrightarrow M_1 \cdots M_h \bullet M_{h+1} \cdots M_q, i, k, f_1, f_2] \\ [(M_{h+1})_t, k, j, -, -]\end{array}}{[N \longrightarrow M_1 \cdots M_{h+1} \bullet M_{h+2} \cdots M_q, i, j, f_1, f_2]}$$

$$\frac{[N \longrightarrow M_1 \cdots M_q \bullet, i, j, f_1, f_2]}{[N_b, i, j, f_1, f_2]}$$

BU: General Grammars (cont'd)

If N is labeled by ε extend **Init**$_1$

$$\frac{\forall i \in \{0..n\}}{[N_b, i, i, -, -]}$$

Bottom Up on Derived Trees

(Vijay-Shanker & Weir, 1993)

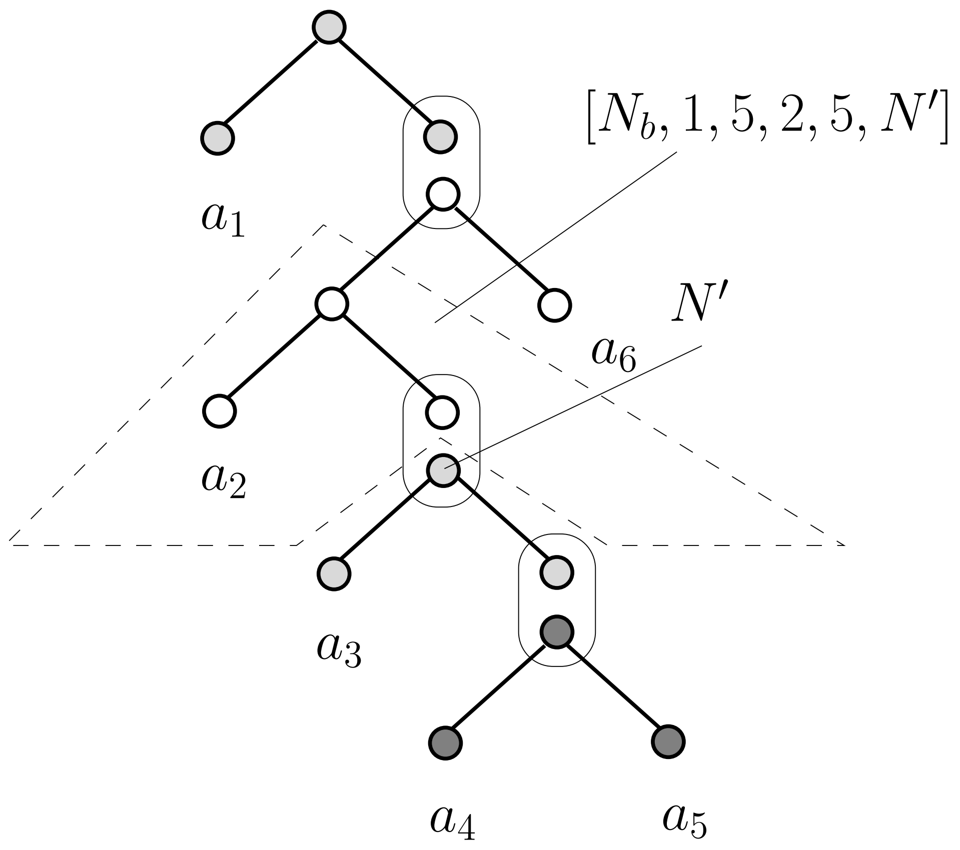
Use items

$$[N_X, i, j, f_1, f_2, N'],$$

where:

- N' is the node at which current subtree has been adjoined, if $f_1, f_2 \neq -$
- $N' = -$ if $f_1 = f_2 = -$

Example



Top Down on Derived Trees + Valid Prefix Property

(Schabes & Joshi, 1988), (Nederhof, 1997)

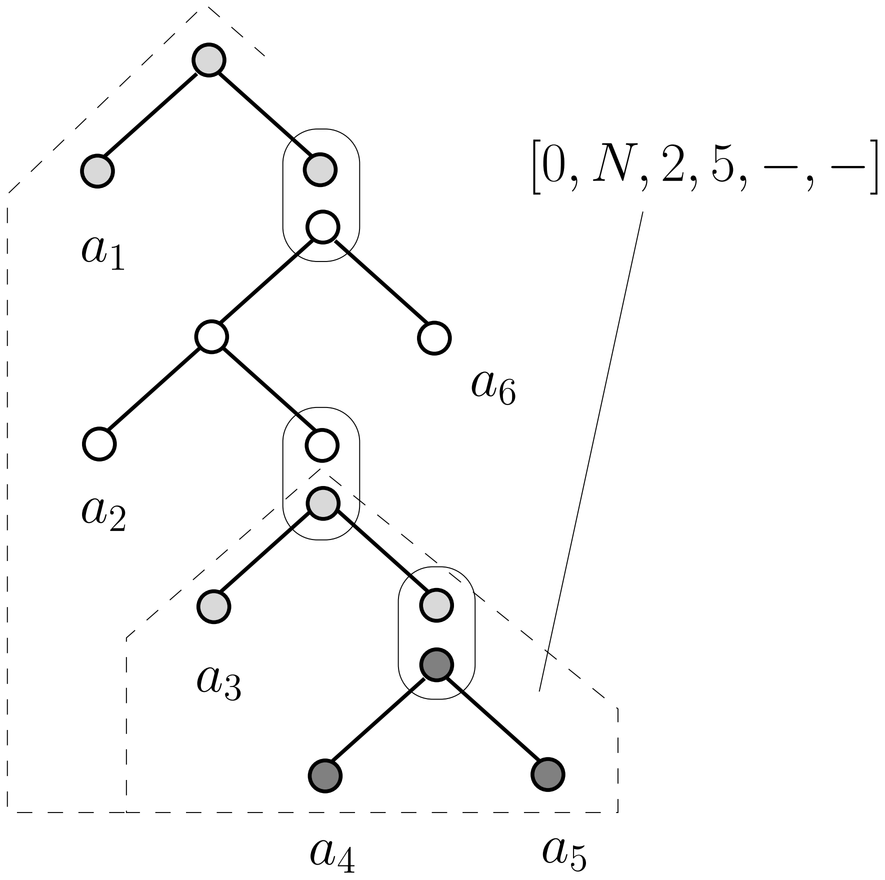
Parse input from left-to-right and detect an error as early as its position is reached

Use items

$$[h, N, i, j, f_1, f_2],$$

representing a subtree of an elementary tree γ such that γ spans the input from index h

Example



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- **selected topics**
  - guided parsing
  - supertagging
  - automata tabulation
- other advanced techniques
- computational/generative complexity trade-off

Guided Parsing

(Harbush, 1990),(Poller, 1994; Poller & Becker, 1998)

Construct a kernel context-free grammar from TAG:

- one production for each internal node
- one production for each substitution/adjunction

Algorithm:

- parse input using kernel grammar
- re-parse input BU using TAG and kernel parse forest as an oracle

Guided Parsing (cont'd)

(Barthélemy et al., 2001)

Construct a context-free grammar approximation of TAG *via* transformation to Range Concatenation Grammar (RCG):

- one production for each initial tree
- two productions for each auxiliary tree

Algorithm:

- use existing RCG guided parser
- on XTAG, three times faster than non-guided RCG parser

Supertagging

(Bangalore & Joshi, 1999)

Phase I: for each word in input, select lexicalized elementary tree (supertag) that is most likely:

- use language modeling techniques (3-grams)
- use error-driven method

Phase II: produce dependency linkages and partial parse (Lightweight Dependency Analyzer)

Supertagging (cont'd)

(Boullier, 2003)

Supertag selection using non-local generative models

- superset approximations, 100% recall
- LTAG to CFG
- LTAG to FA (dynamically constructed)

Automata tabulation

(Alonso et al., 2000)

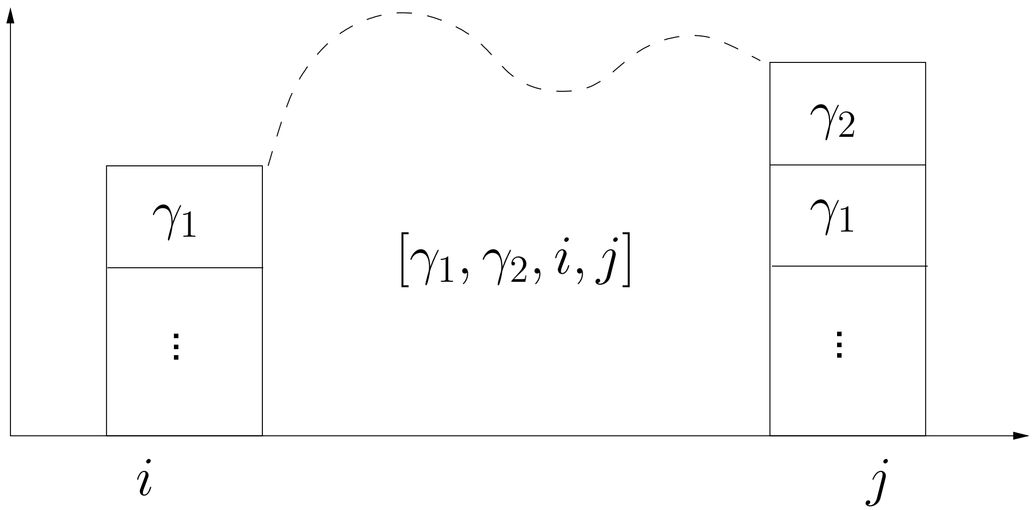
Separation between

- parsing strategy specification through operational automata
- algorithm specification through tabulation

$$2SA \longrightarrow \boxed{\text{Tabulation}} \longrightarrow \text{Parser}$$

Automata tabulation (cont'd)

- 2-stack automata abstractly specify parsing strategy
- nondeterminism is simulated through dynamic programming



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Advanced Techniques

LR parsing for TAG (Schabes & Vijay-Shanker, 1990), (Nederhof, 1998), (Prolo, 2004)

TAG parse forest represented by means of TAG (Lang, 1994) or context-free grammars (Vijay-Shanker & Weir, 1993)

Bidirectional parsing for TAG (Lavelli & Satta, 1991), (van Noord, 1994)

Parsing for 2-lexical TAG (Eisner & Satta, 2000)

Advanced Techniques (cont'd)

TAG parsing through Range Concatenation Grammars (Boullier, 2000)

TAG parsing through Boolean matrix multiplication (Rajasekaran & Yooseph, 1998)

TAG parsing through synchronous context-free grammar parsing (Guan, 1992)

TAG parsing also used to parse other formalisms, as HPSG (Kasper *et al.*, 1995), (Becker & Lopez, 2000)

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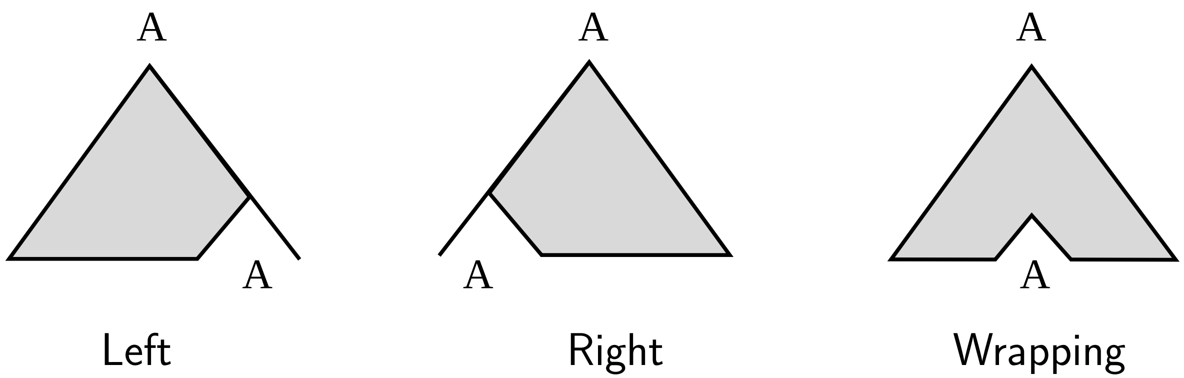
Computational/Generative Complexity Trade-Off

A **left tree** is an auxiliary tree with all nodes in its yield at the left of the foot (a **right tree** is symmetrically defined)

A **wrapping tree** is an auxiliary tree that is neither left nor right



Trade-Off (cont'd)

Parsing in $\mathcal{O}(n^3)$ (Schabes & Waters, 1993; 1995):

- no wrapping trees
- no adjunction of left (right) trees at the spine of right (left) trees

Parsing in $\mathcal{O}(n^3)$ (Rogers, 1994):

- no adjunction at the spine if this causes "recursion" of some nonterminal

These formalisms are weakly equivalent to context-free grammars

Trade-Off (cont'd)

Parsing in $\mathcal{O}(n^5)$ (Satta & Schuler, 1998):

- no more than two nodes on spine of left/right trees
- at most one adjunction of a wrapping tree at the spine of a wrapping tree

Trade-Off (cont'd)

TAG parsing asymptotically faster than $\mathcal{O}(n^6)$ implies Boolean matrix multiplication asymptotically faster than $\mathcal{O}(m^3)$ (Satta, 1994)

Result holds whenever we can adjoin at more than one site in the spine of an auxiliary tree

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