CSE 517
Natural Language Processing
Winter 2019

Dependency Parsing
And Other Grammar Formalisms

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Dependency Grammar

For each word, find one parent.

Child Parent

A child is dependent on the parent.

- A child is an argument of the parent.
- A child modifies the parent.

I shot an elephant

For each word, find one parent.

Child Parent

A child is dependent on the parent.

- A child is an argument of the parent.
- A child modifies the parent.

I shot an elephant in my pajamas

For each word, find one parent.

Child Parent

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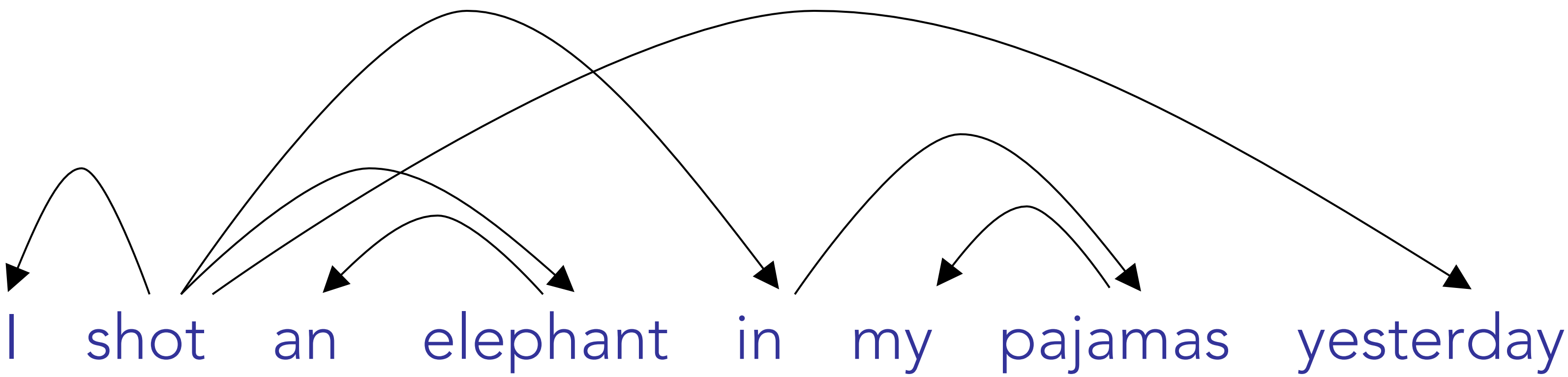
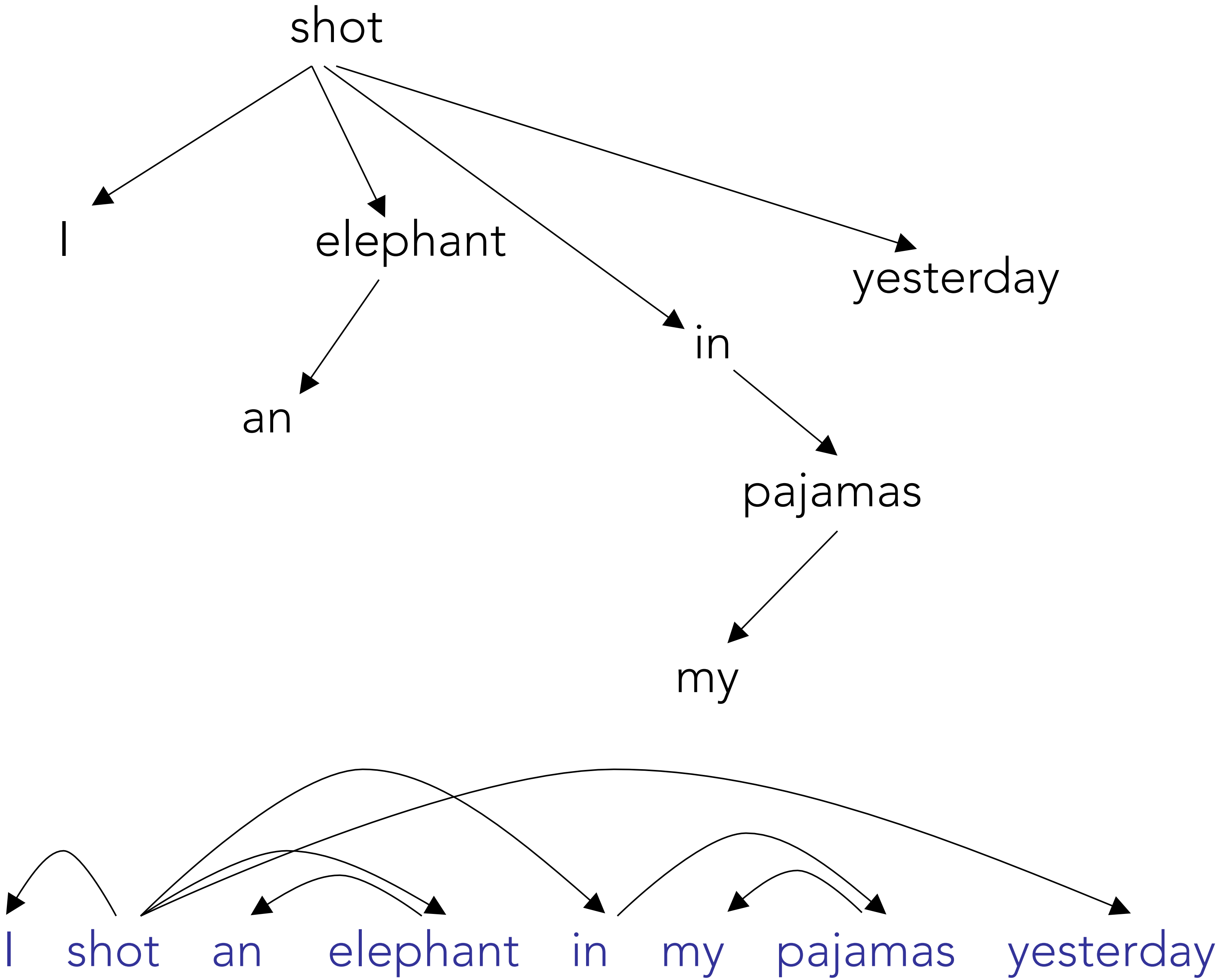
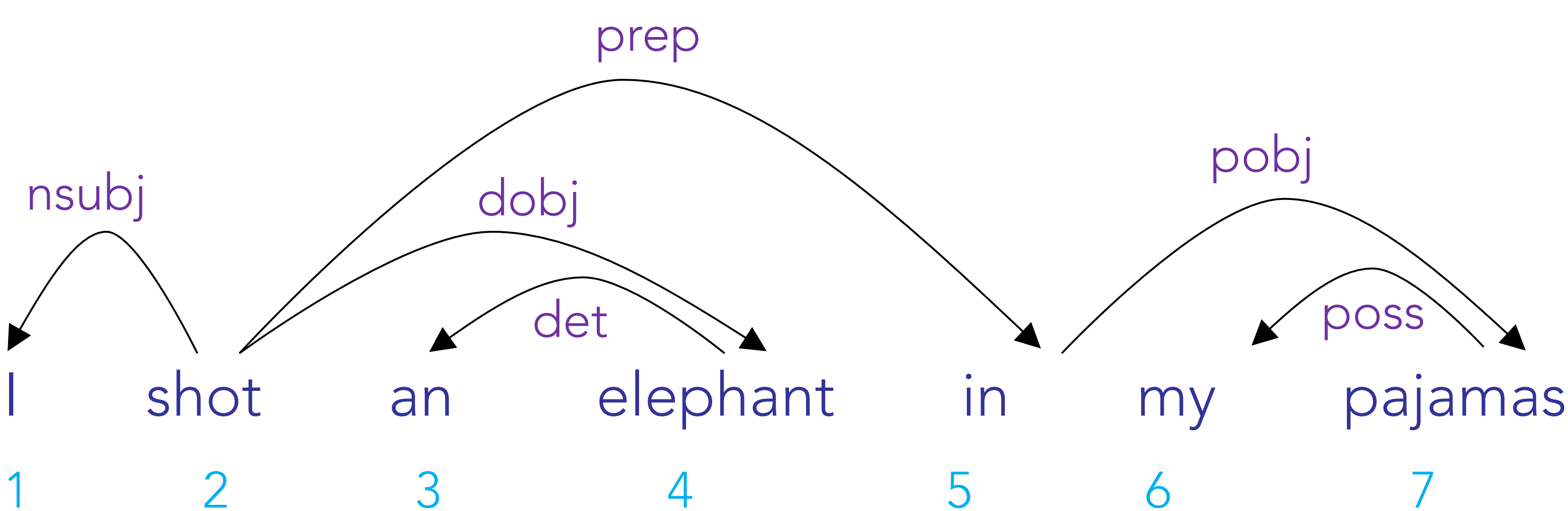



shot
I
elephant
an
in
pajamas
my
yesterday
I shot an elephant in my pajamas yesterday

Typed Depedencies

nsubj(shot-2, i-1)
root(ROOT-0, shot-2)
det(elephant-4, an-3)
dobj(shot-2, elephant-4)

prep(shot-2, in-5)
poss(pajamas-7, my-6)
pobj(in-5, pajamas-7)



CFG vs Dependency Parse I

- Both are context-free.
- Both are used frequently today, but dependency parsers are more recently popular.

- CKY Parsing algorithm:
  - O (N^3) using CKY & unlexicalized grammar
  - O (N^5) using CKY & lexicalized grammar (O(N^4) also possible)
- Dependency parsing algorithm:
  - O (N^5) using naïve CKY
  - O (N^3) using Eisner algorithm
  - O (N^2) based on minimum directed spanning tree algorithm (arborescence algorithm, aka, Edmond-Chu-Liu algorithm – see edmond.pdf)
- Linear-time O (N) Incremental parsing (shift-reduce parsing) possible for both grammar formalisms

CFG vs Dependency Parse II

- CFG focuses on "**constituency**" (i.e., phrasal/clausal structure)
- Dependency focuses on "**head**" relations.

- CFG includes non-terminals. CFG edges are not typed.
- No non-terminals for dependency trees. Instead, dependency trees provide "dependency types" on edges.

- Dependency types encode "**grammatical roles**" like
  - nsubj -- nominal subject
  - dobj – direct object
  - pobj – prepositional object
  - nsubjpass – nominal subject in a passive voice

CFG vs Dependency Parse III

- Can we get “heads” from CFG trees?
  - Yes. In fact, modern statistical parsers based on CFGs use hand-written “head rules” to assign “heads” to all nodes.
- Can we get constituents from dependency trees?
  - Yes, with some efforts.

- Can we transform CFG trees to dependency parse trees?
  - Yes, and transformation software exists. (stanford toolkit based on [de Marneffe et al. LREC 2006])
- Can we transform dependency trees to CFG trees?
  - Mostly yes, but (1) dependency parse can capture ***non-projective*** dependencies, while CFG cannot, and (2) people rarely do this in practice

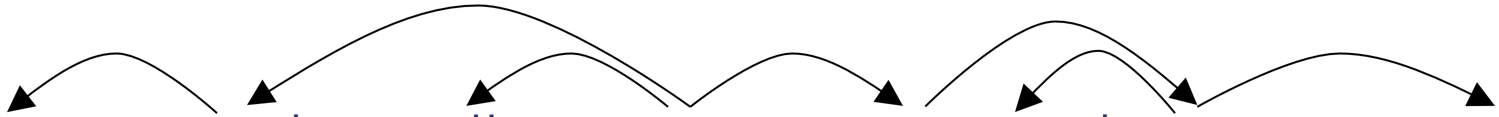
Non Projective Dependencies

- Mr. Tomash will remain as a director emeritus.
- A hearing is scheduled on the issue today.

Non Projective Dependencies

- Projective dependencies: when the tree edges are drawn directly on a sentence, it forms a tree (without a cycle), and there is no crossing edge.

- Projective Dependency:
- Eg:



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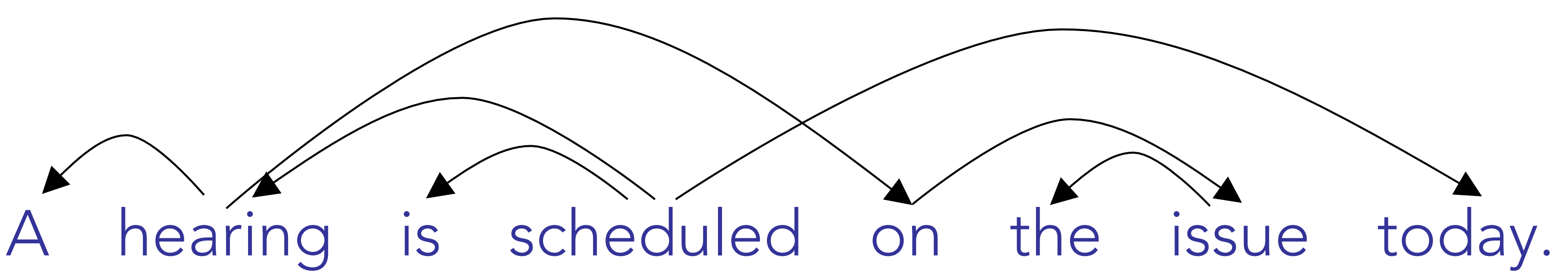
Non Projective Dependencies

- Projective dependencies: when the tree edges are drawn directly on a sentence, it forms a tree (without a cycle), and there is no crossing edge.
- Non-projective dependency:

- Eg:



Non Projective Dependencies

- which word does “on the issue” modify?
  - We scheduled a meeting on the issue today.
  - A meeting is scheduled on the issue today.
- CFGs capture only projective dependencies (why?)

Coordination across Constituents

- Right-node raising:
  - [[She bought] and [he ate]] bananas.
- Argument-cluster coordination:
  - I give [[you an apple] and [him a pear]].
- Gapping:
  - She likes sushi, and he sashimi

➔ CFGs don’t capture coordination across constituents:

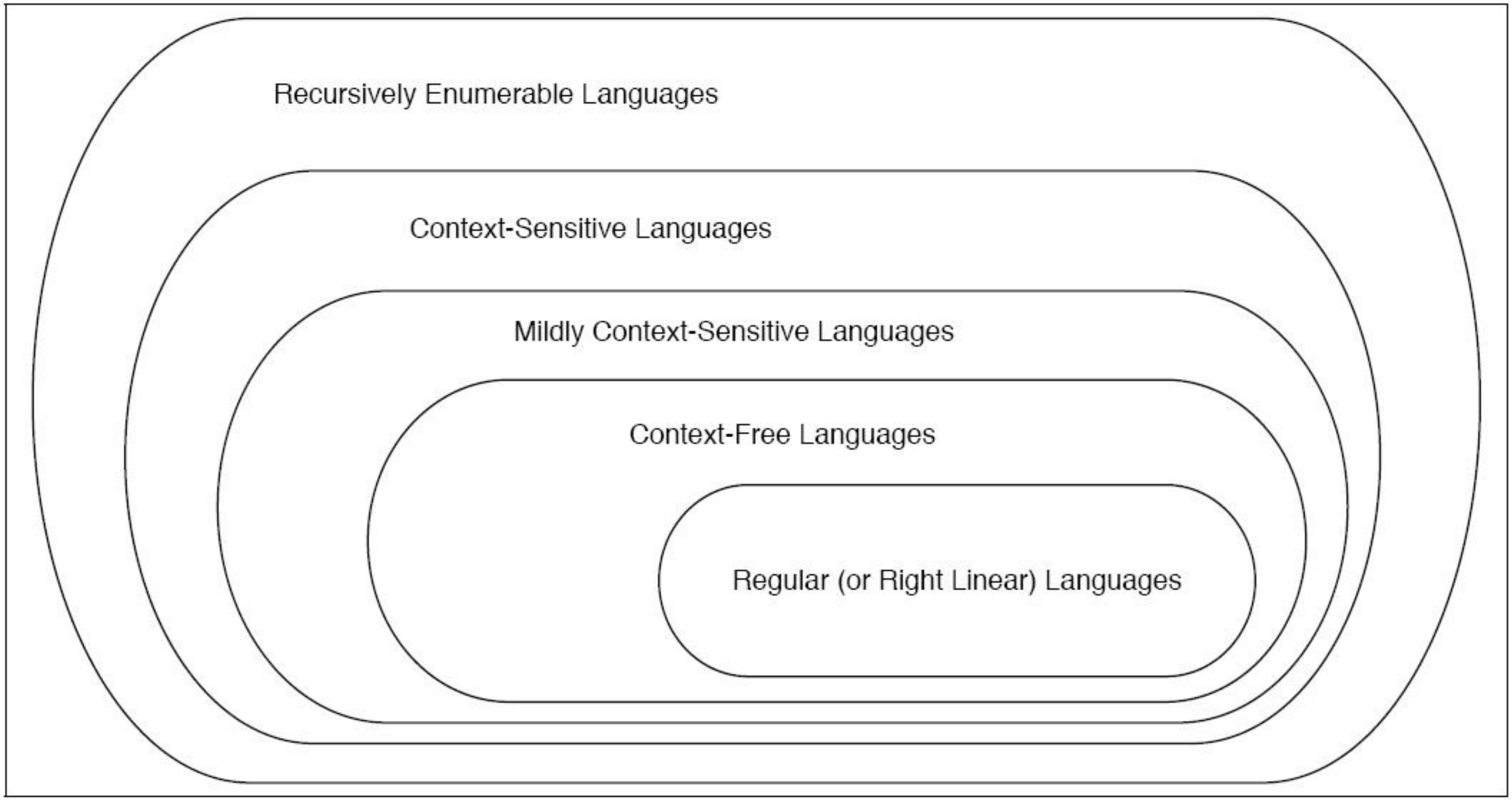
Coordination across Constituents

- She bought and he ate bananas.
- I give you an apple and him a pear.

Compare above to:

- She bought and ate bananas.
- She bought bananas and apples.
- She bought bananas and he ate apples.

The Chomsky Hierarchy



The Chomsky Hierarchy

Type	Common Name	Rule Skeleton	Linguistic Example
0	Turing Equivalent	$\alpha \rightarrow \beta$, s.t. $\alpha \neq \epsilon$	HPSG, LFG, Minimalism
1	Context Sensitive	$\alpha A \beta \rightarrow \alpha \gamma \beta$, s.t. $\gamma \neq \epsilon$	
–	Mildly Context Sensitive		TAG, CCG
2	Context Free	$A \rightarrow \gamma$	Phrase-Structure Grammars
3	Regular	$A \rightarrow xB$ or $A \rightarrow x$	Finite-State Automata

- Head-Driven Phrase Structure Grammar (HPSG) (Pollard and Sag, 1987, 1994)
- Lexical Functional Grammar (LFG) (Bresnan, 1982)
- Minimalist Grammar (Stabler, 1997)

- Tree-Adjoining Grammars (TAG) (Joshi, 1969)
- Combinatory Categorial Grammars (CCG) (Steedman, 1986)

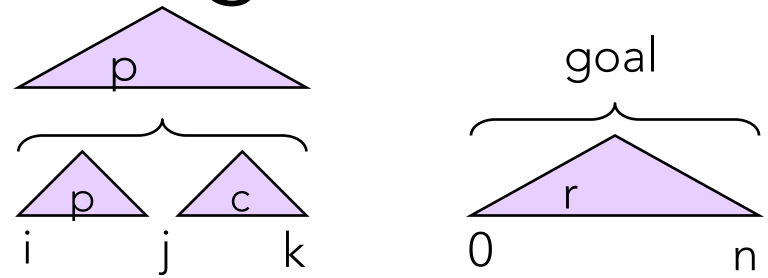
Advanced Topics

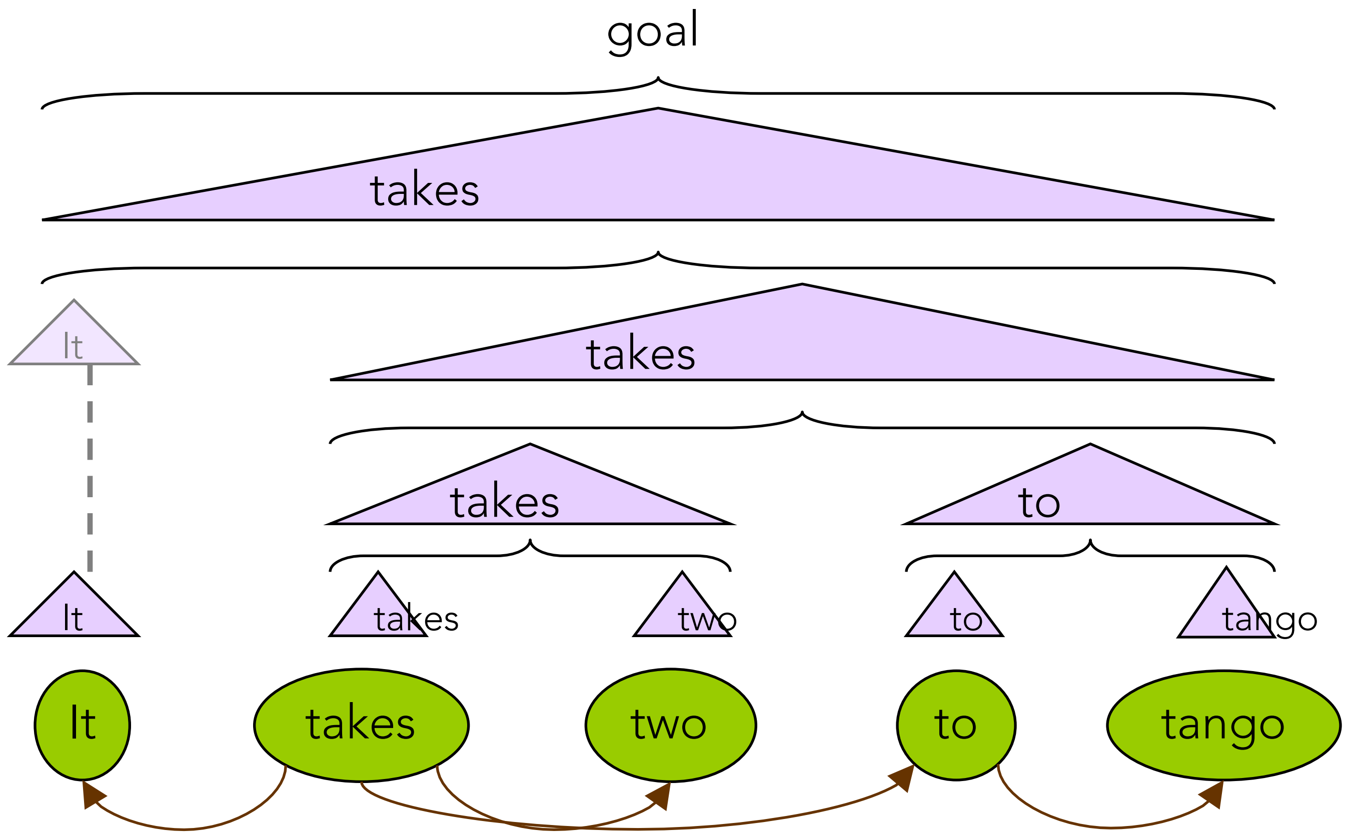
- Eisner's Algorithm -

Naïve CKY Parsing

$O(n^5N^3)$ if N nonterminals

$O(n^5)$ combinations





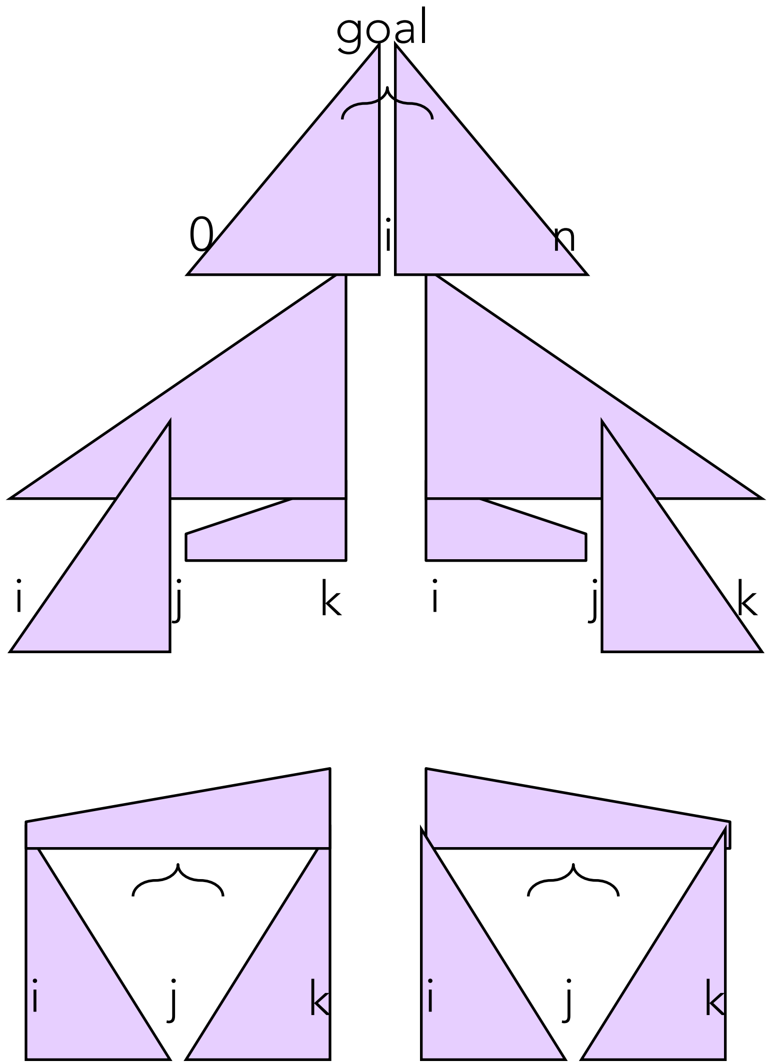
slides from Eisner

Eisner Algorithm (Eisner & Satta, 1999)

This happens only once as the very final step

Without adding a dependency arc

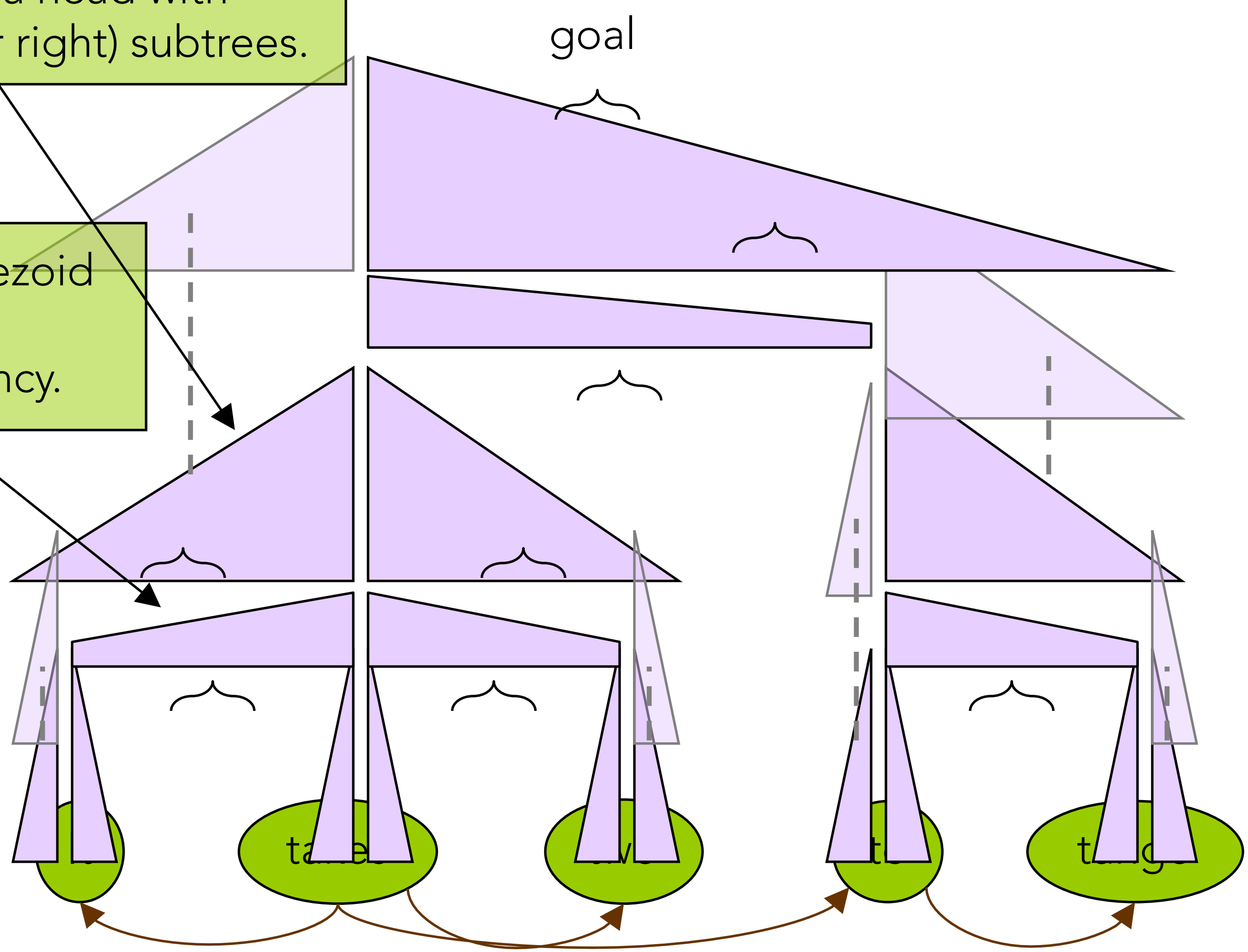
When adding a dependency arc (head is higher)



Eisner Algorithm (Eisner & Satta, 1999)

A triangle is a head with some left (or right) subtrees.

One trapezoid per dependency.

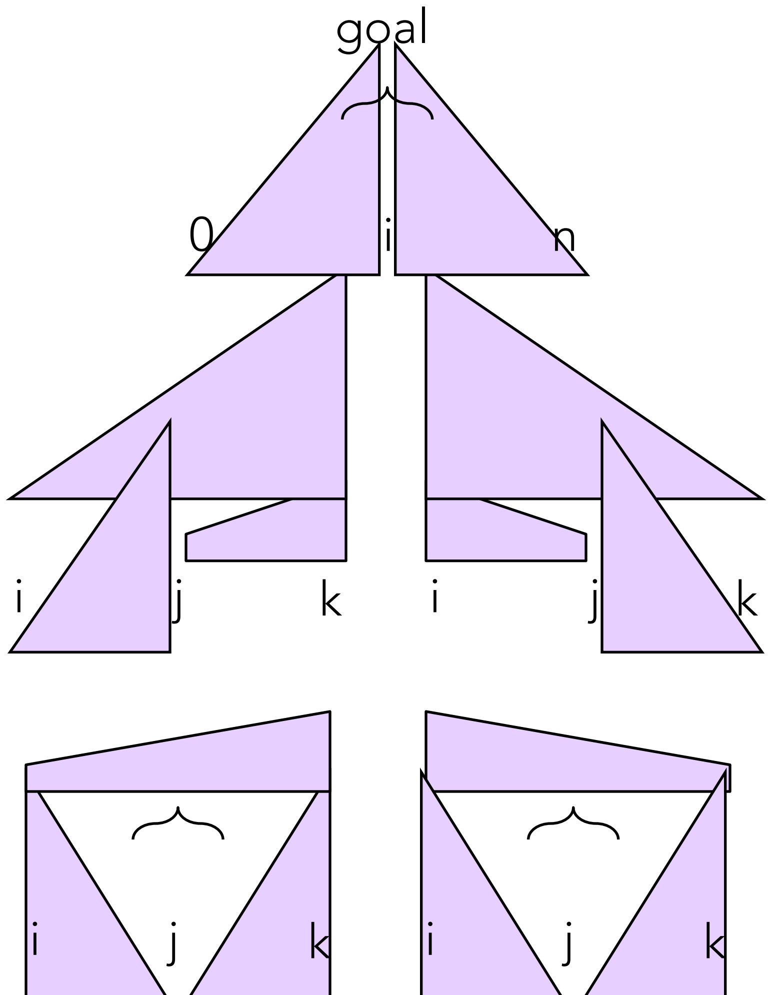


Eisner Algorithm (Eisner & Satta, 1999)

O(n) combinations

O(n³) combinations

O(n³) combinations



Gives $O(n^3)$ dependency grammar parsing

Eisner Algorithm

- Base case:

$$\forall t \in \{\trianglelefteq, \trianglerighteq, \triangleleft, \triangleright\}, \;\; \pi(i, i, t) = 0$$

- Recursion:

$$\pi(i, j, \trianglelefteq) = \max_{i \le k < j} \left(\pi(i, k, \triangleright) + \pi(k+1, j, \triangleleft) + \phi(w_j, w_i) \right)$$

$$\pi(i, j, \trianglerighteq) = \max_{i \le k < j} \left(\pi(i, k, \triangleright) + \pi(k+1, j, \triangleleft) + \phi(w_i, w_j)) \right)$$

$$\pi(i, j, \triangleleft) = \max_{i \le k < j} \left(\pi(i, k, \triangleleft) + \pi(k+1, j, \trianglelefteq) \right)$$

$$\pi(i, j, \triangleright) = \max_{i \le k < j} \left(\pi(i, k, \trianglerighteq) + \pi(k+1, j, \triangleright) \right)$$

- Final case:

$$\pi(1, n, \triangleleft\triangleright) = \max_{1 \le k < n} \left(\pi(1, k, \triangleleft) + \pi(k+1, n, \triangleright) \right)$$

Advanced Topics:

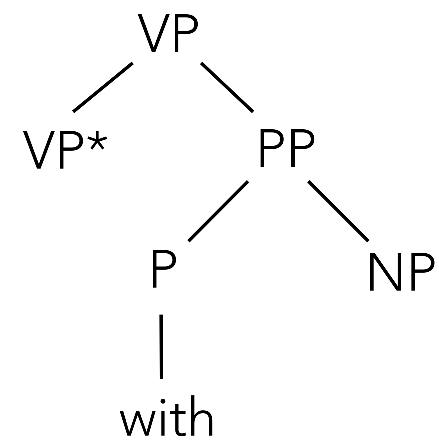
Mildly Context-Sensitive Grammar Formalisms

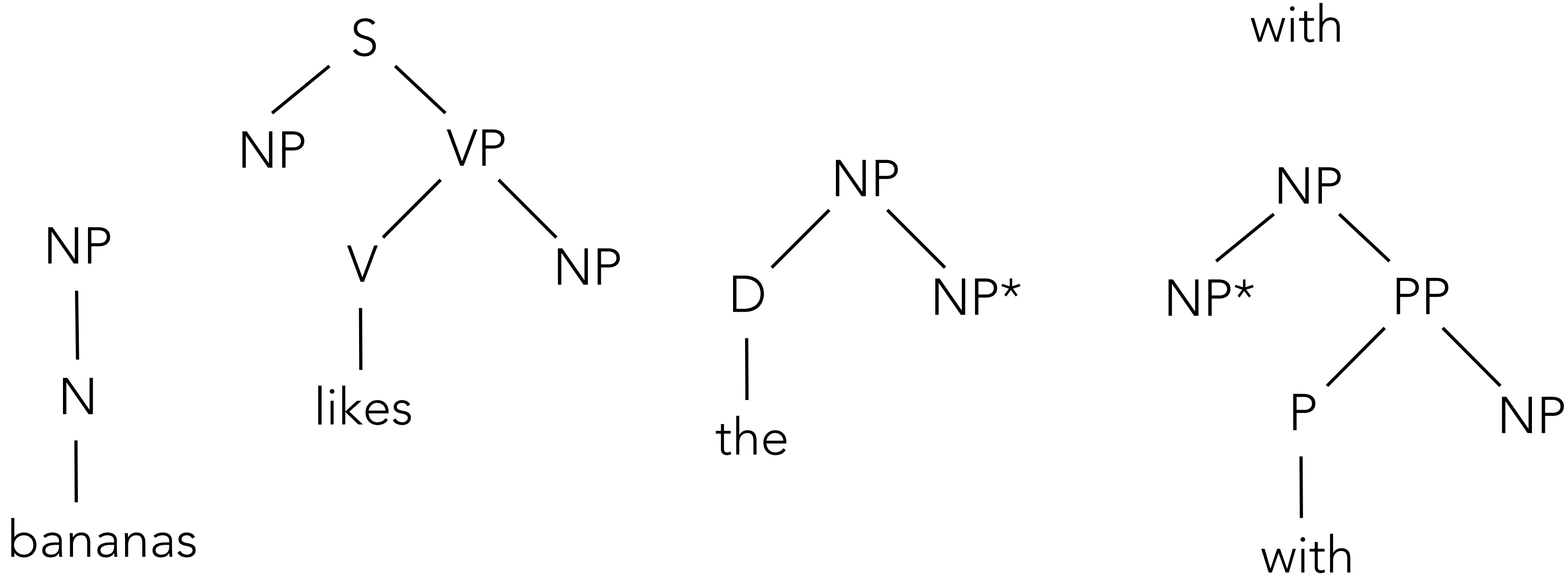
I. Tree Adjoining Grammar (TAG)

Some slides adapted from Julia Hockenmaier's

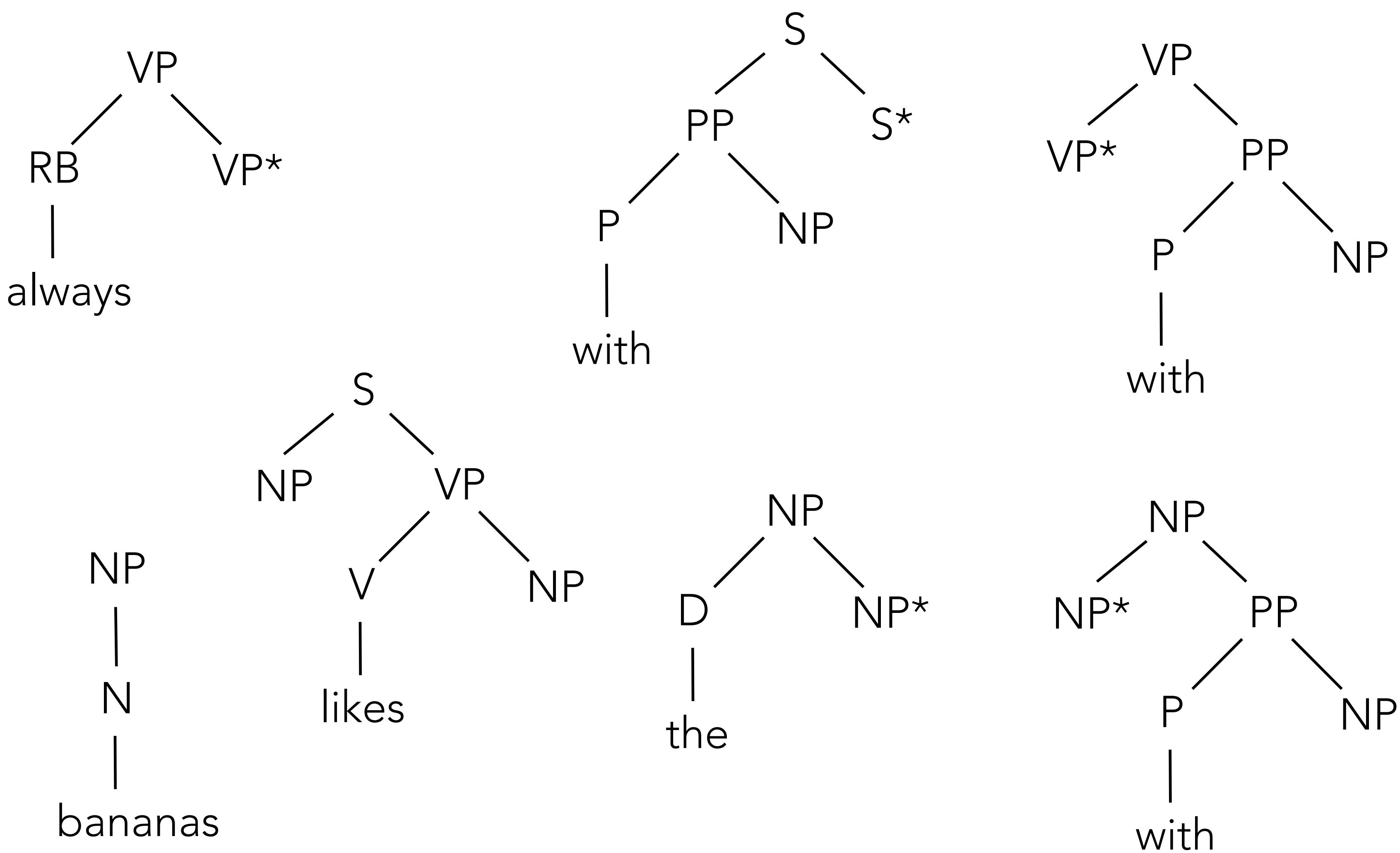
TAG Lexicon (Supertags)

- Tree-Adjoining Grammars (TAG) (Joshi, 1969)
- *"… super parts of speech (supertags): almost parsing"* (Joshi and Srinivas 1994)
- POS tags enriched with syntactic structure
- also used in other grammar formalisms (e.g., CCG)

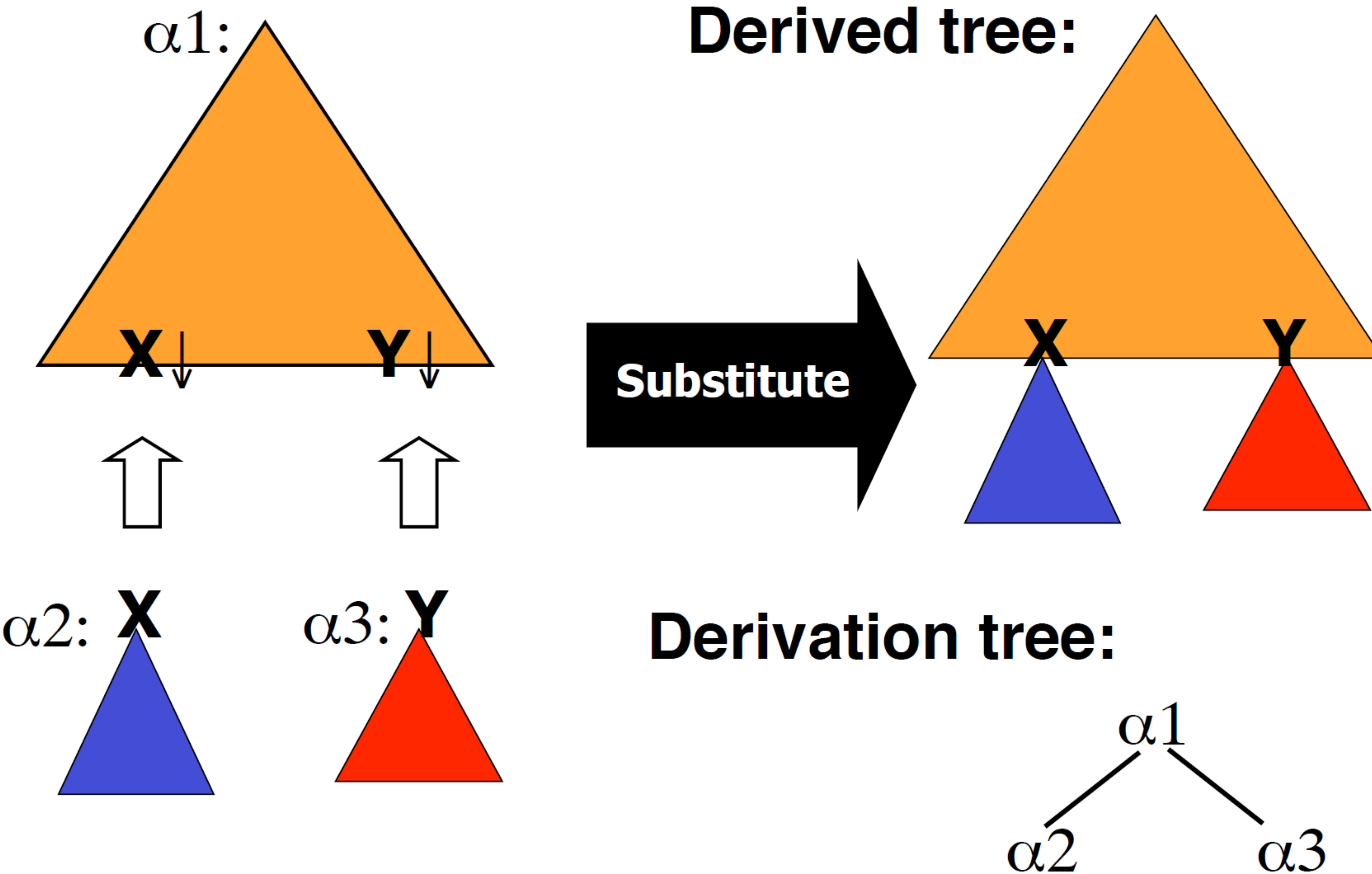




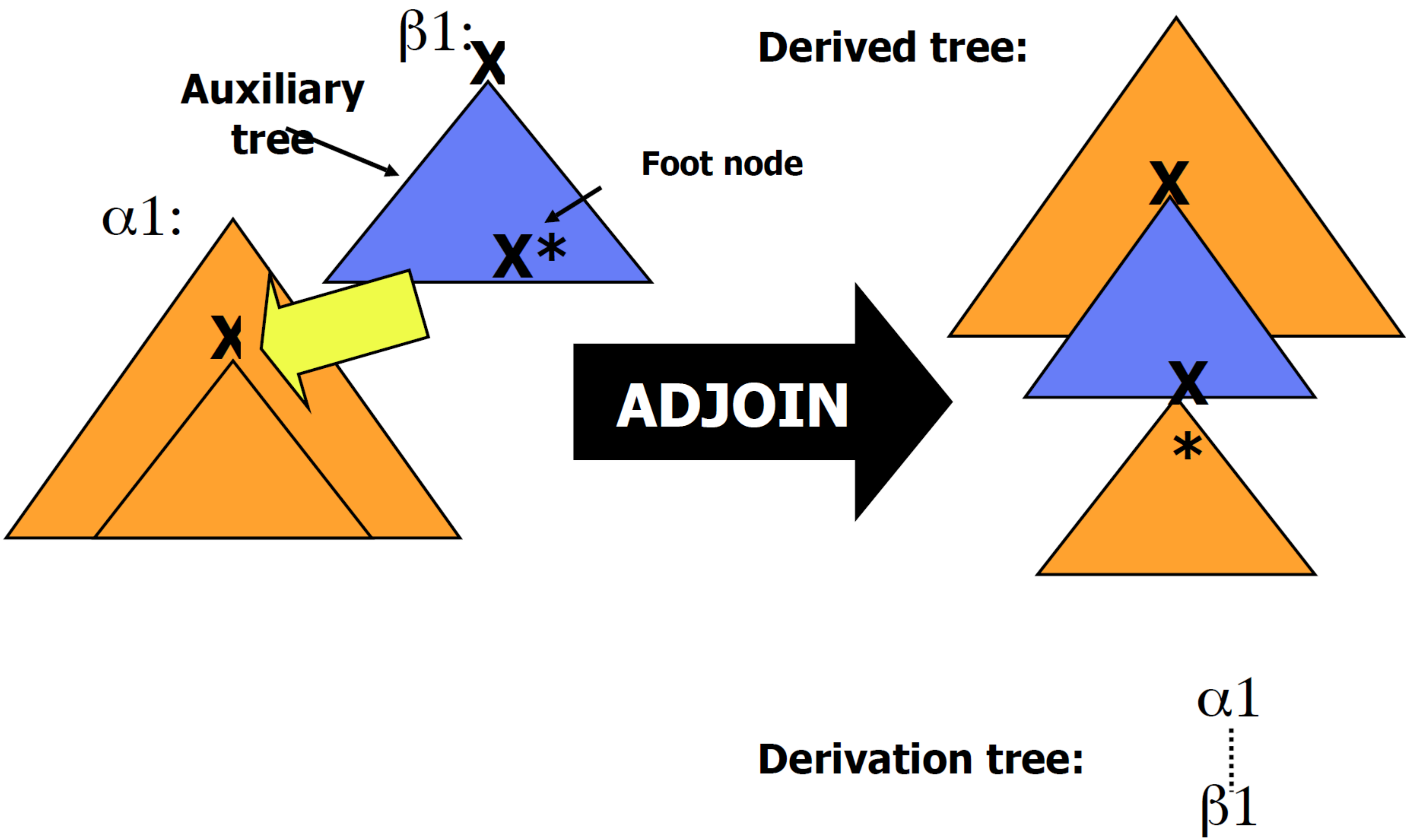
TAG Lexicon (Supertags)



TAG rule 1: Substitution

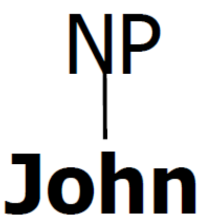


TAG rule 2: Adjunction

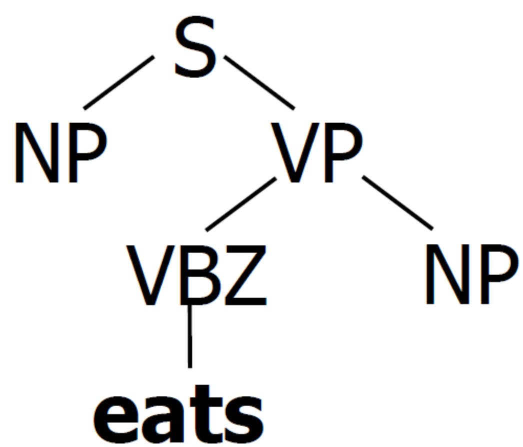


Example: TAG Lexicon

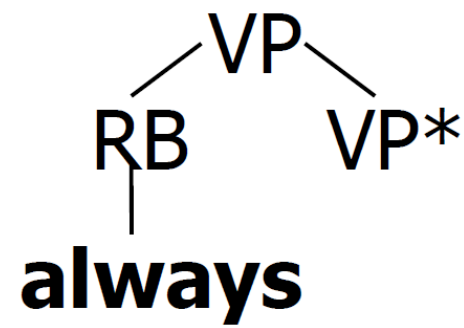
α2:



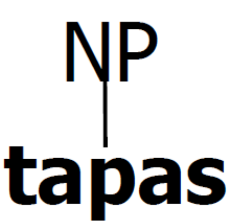
α1:



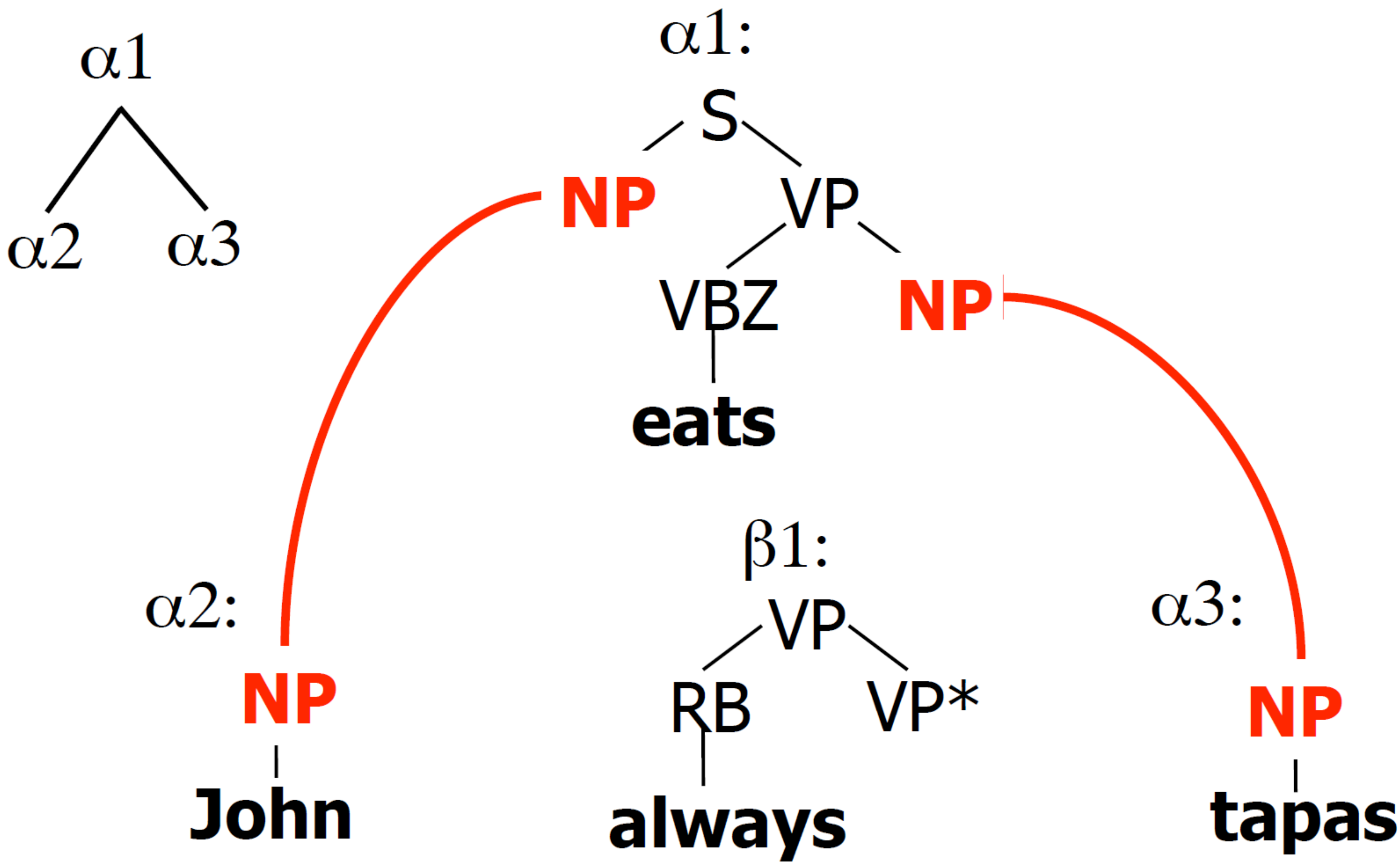
β1:



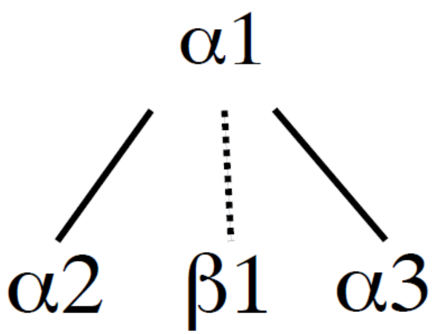
α3
:

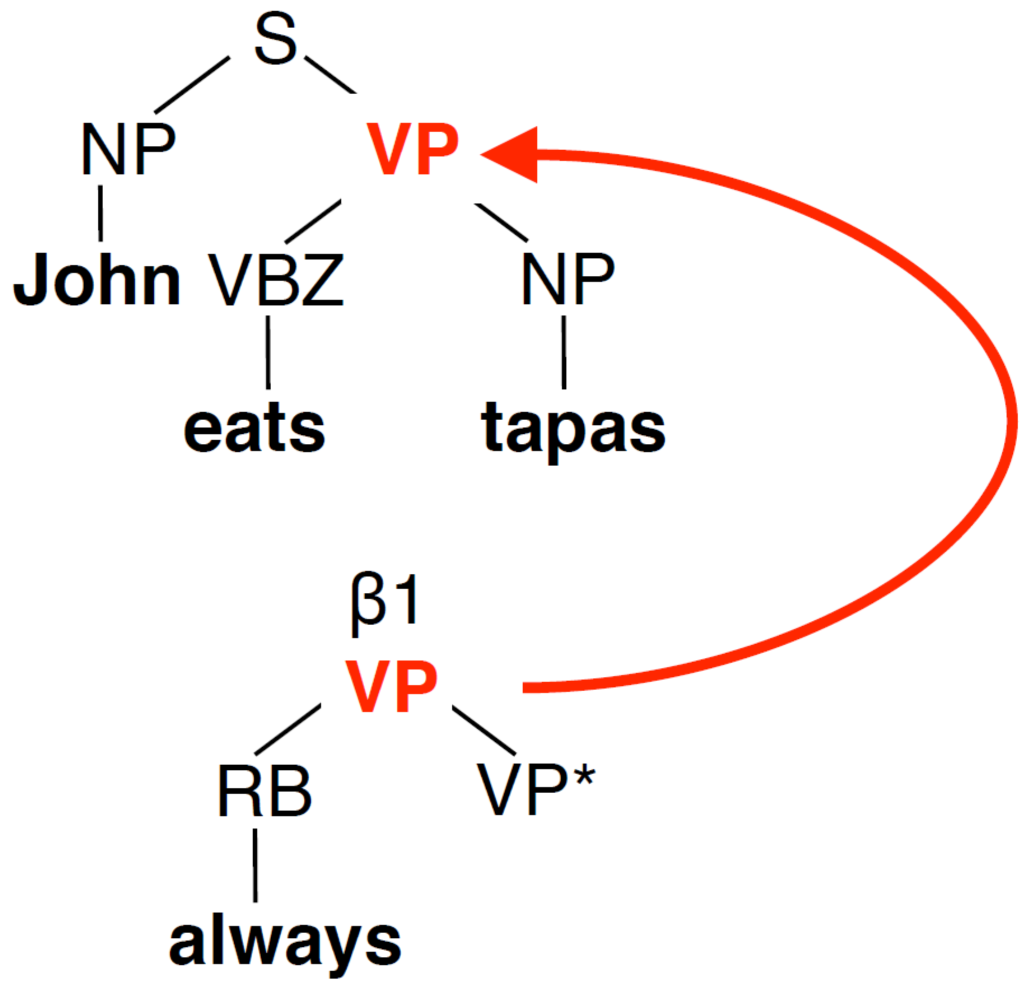


Example: TAG Derivation

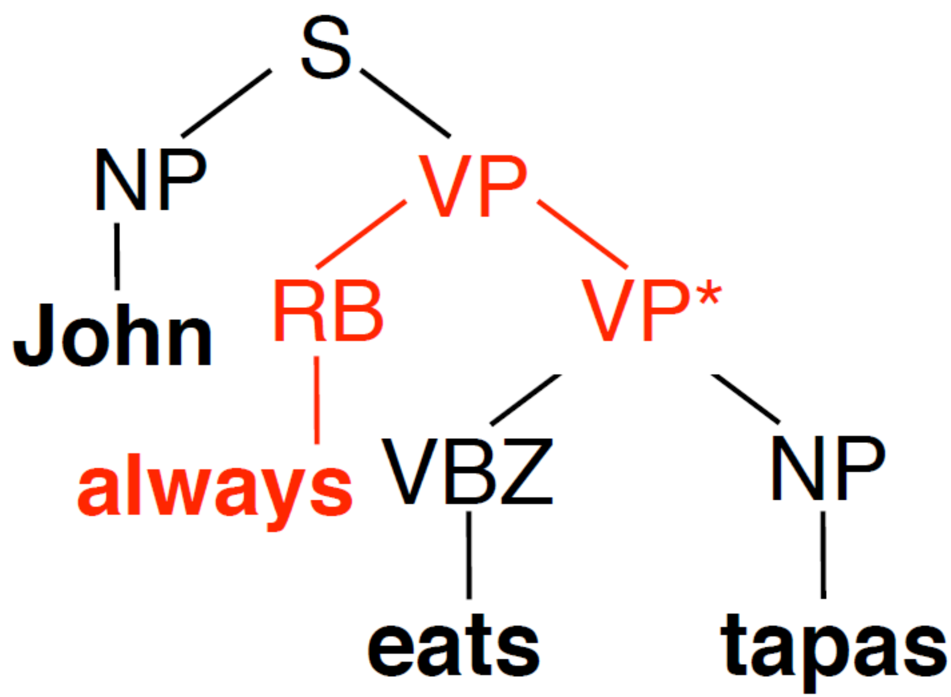


Example: TAG Derivation

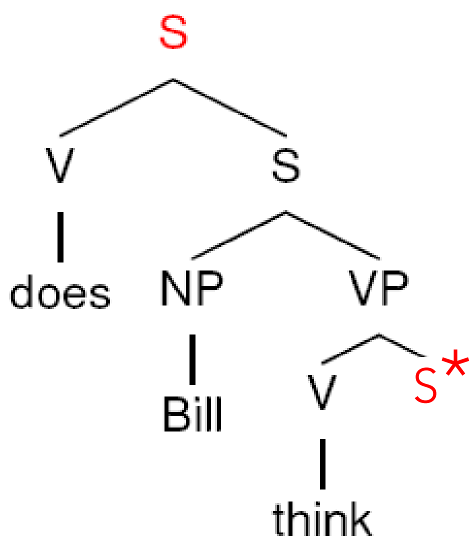


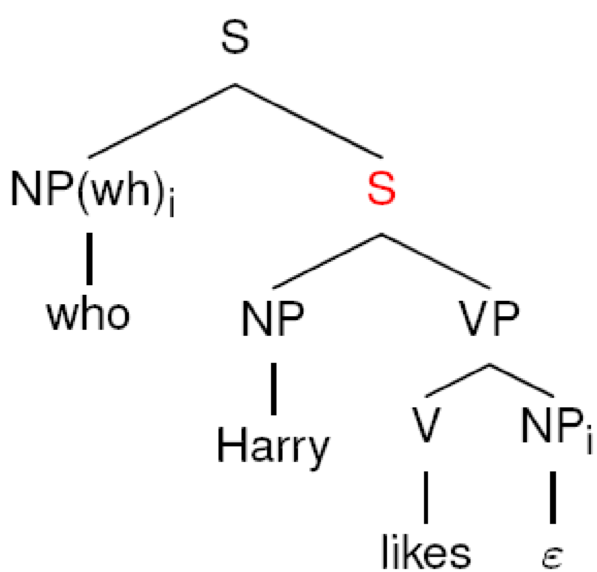


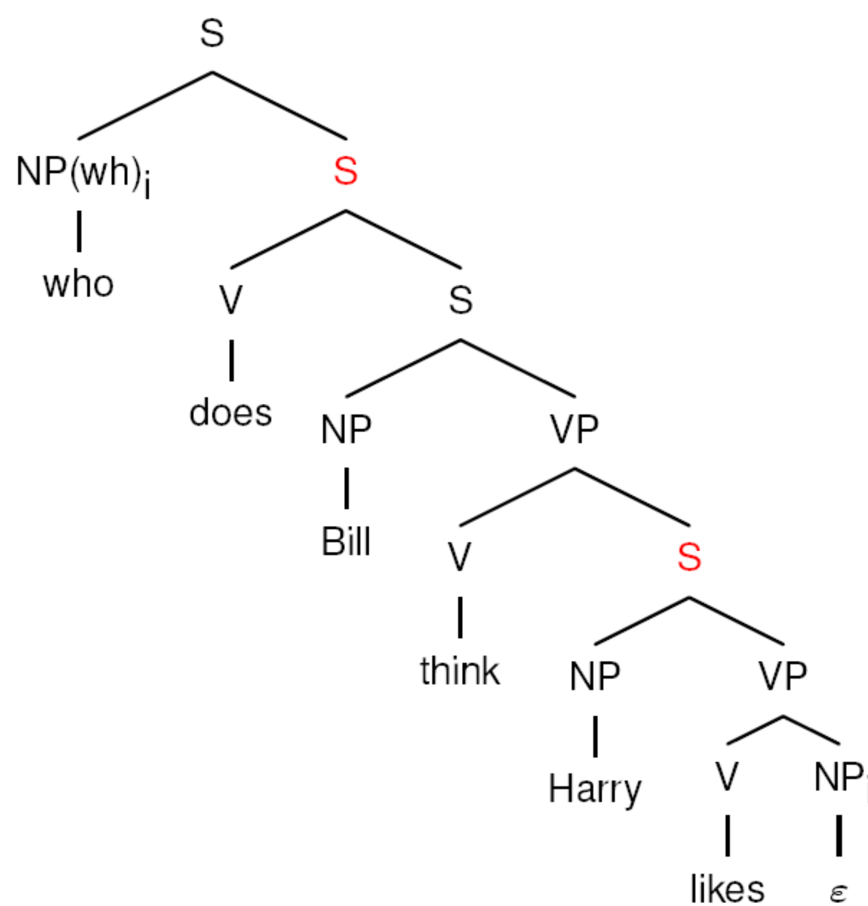
Example: TAG Derivation



(1) Can handle long distance dependencies







(2) Cross-serial Dependencies

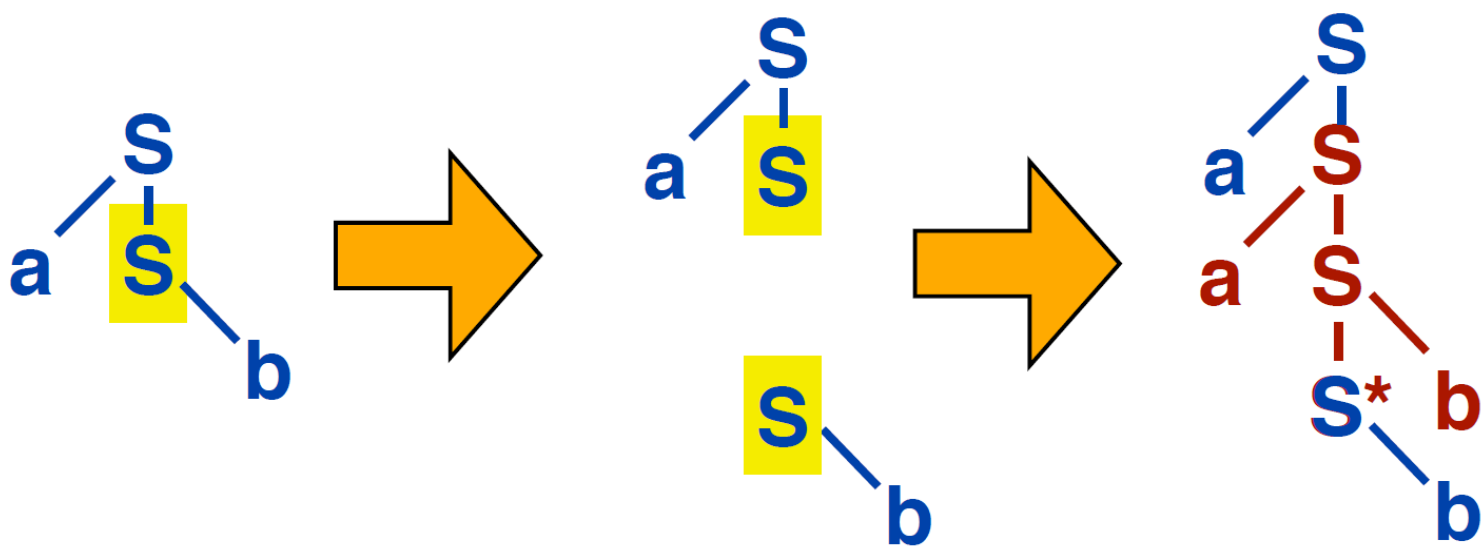
dat Jan Piet Marie de kinderen zag helpen laten zwemmen

- Dutch and Swiss-German
- Can this be generated from context-free grammar?

$a^n b^n$: Cross-serial dependencies

Elementary trees:

Deriving aabb

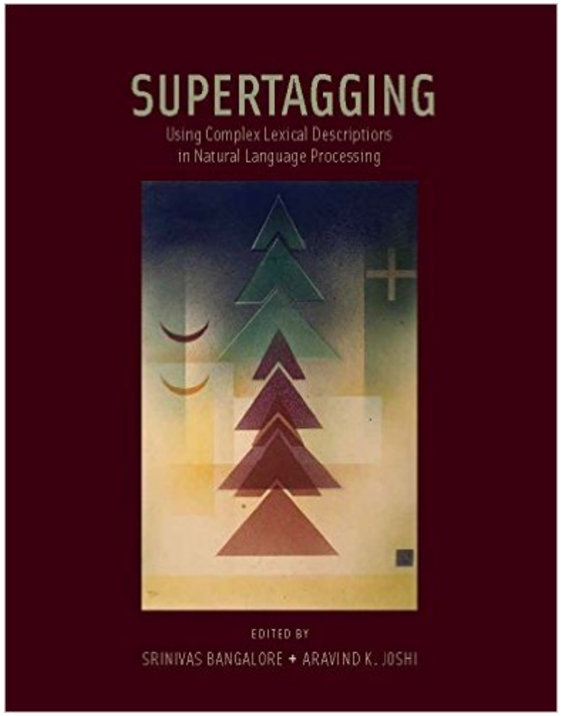


Tree Adjoining Grammar (TAG)

- TAG: Aravind Joshi in 1969
- Supertagging for TAG: Joshi and Srinivas 1994

- Pushing grammar down to lexicon.
- With just two rules: substitution & adjunction

- Parsing Complexity:
  - O(N^7)



- Xtag Project (TAG Penntree) (http://www.cis.upenn.edu/~xtag/)

- Local expert!
  - Fei Xia @ Linguistics (https://faculty.washington.edu/fxia/)

II. Combinatory Categorial Grammar (CCG)

Some slides adapted from Julia Hockenmaier's

Categories

- Categories = types
  - Primitive categories
    - N, NP, S, etc
  - Functions
    - a combination of primitive categories
    - S/NP,   (S/NP) / (S/NP),   etc
    - V, VP, Adverb, PP, etc

Combinatory Rules

- Application
  - forward application: x/y y ➔ x
  - backward application: y x\y ➔ x
- Composition
  - forward composition: x/y y/z ➔ x/z
  - backward composition: y\z x\y ➔ x\z
  - (forward crossing composition: x/y y\z ➔ x\z)
  - (backward crossing composition: x\y y/z ➔ x/z)
- Type-raising
  - forward type-raising: x ➔ y / (y\x)
  - backward type-raising: x ➔ y \ (y/x)
- Coordination <&>
  - x conj x ➔ x

Combinatory Rules 1 : Application

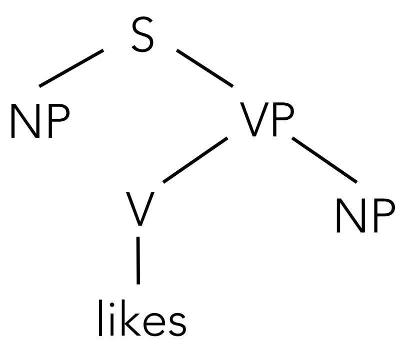
- Forward application “>”
  - X/Y   Y ➔ X
  - (S\NP)/NP   NP ➔ S\NP

- Backward application “<“
  - Y   X\Y ➔ X
  - NP   S\NP ➔ S

Function

- likes := (S\NP) / NP
  - A transitive verb is a function from NPs into predicate S. That is, it accepts two NPs as arguments and results in S.

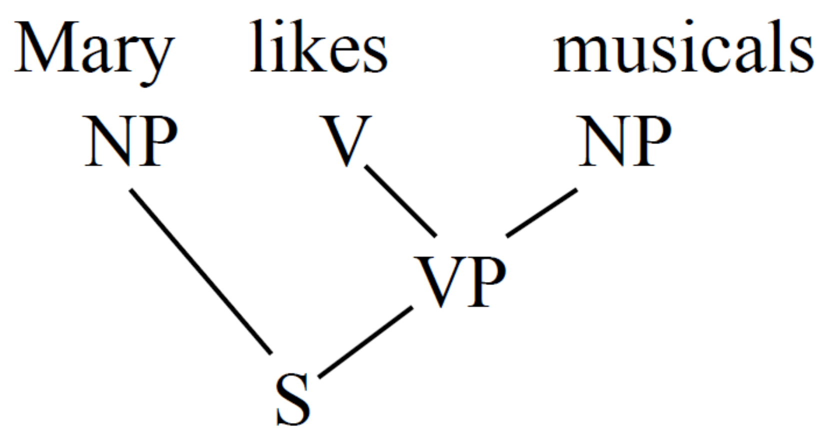
- Transitive verb: (S\NP) / NP
- Intransitive verb: S\NP
- Adverb: (S\NP) \ (S\NP)
- Preposition: (NP\NP) / NP
- Preposition: ((S\NP) \ (S\NP)) / NP



CCG Derivation:

$$
\begin{array}{ccc}
\text{Mary} & \text{likes} & \text{musicals} \\
\hline NP & \hline (S\backslash NP)/NP & \hline NP \\
 & \multicolumn{2}{c}{\overline{\quad\quad S\backslash NP \quad\quad}^{>}} \\
\multicolumn{2}{c}{\overline{\quad\quad S \quad\quad}^{<}} &
\end{array}
$$

CFG Derivation:



Combinatory Rules

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  - forward crossing composition: x/y y\z ➔ x\z
  - backward crossing composition: x\y y/z ➔ x/z
- Type-raising
  - forward type-raising: x ➔ y / (y\x)
  - backward type-raising: x ➔ y \ (y/x)
- Coordination <&>
  - x conj x ➔ x

Combinatory Rules 4 : Coordination

- X conj X ➔ X
- Alternatively, we can express coordination by defining conjunctions as functions as follows:
- and := (X\X) / X

Coordination with CCG

$$
\begin{array}{ccccc}
\text{I} & \text{loathe} & \text{and} & \text{detest} & \text{opera} \\
\overline{NP} & \overline{(S\backslash NP)/NP} & \overline{CONJ} & \overline{(S\backslash NP)/NP} & \overline{NP} \\
 & \multicolumn{3}{c}{\underline{\hphantom{(S\backslash NP)/NP \quad CONJ \quad (S\backslash NP)/NP}}\, \langle\&\rangle} & \\
 & \multicolumn{3}{c}{(S\backslash NP)/NP} & \\
 & \multicolumn{4}{c}{\underline{\hphantom{(S\backslash NP)/NP \quad CONJ \quad (S\backslash NP)/NP \quad NP}}\, >} \\
 & \multicolumn{4}{c}{S\backslash NP} \\
\multicolumn{5}{c}{\underline{\hphantom{NP \quad (S\backslash NP)/NP \quad CONJ \quad (S\backslash NP)/NP}}\, <} \\
\multicolumn{5}{c}{S}
\end{array}
$$

Examples from Prof. Mark Steedman

Coordination with CCG

$$\frac{\text{Marcel}}{NP} \quad \frac{\text{conjectured}}{(S\backslash NP)/NP} \quad \frac{\text{and}}{(X\backslash X)/X} \quad \frac{\text{proved}}{(S\backslash NP)/NP} \quad \frac{\text{completeness}}{NP}$$

- Application
  - forward application: x/y y ➔ x
  - backward application: y x\y ➔ x

Coordination with CCG

Marcel	conjectured	and	proved	completeness
NP	$(S\backslash NP)/NP$	$(X\backslash X)/X$	$(S\backslash NP)/NP$	NP

$$((S\backslash NP)/NP)\backslash((S\backslash NP)/NP) \quad >$$

$$(S\backslash NP)/NP \quad <$$

$$S\backslash NP \quad >$$

$$S \quad <$$

- Application
  - forward application: x/y y ➔ x
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Combinatory Rules

- Application
  - forward application: x/y y → x
  - backward application: y x\y → x
- Composition
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  - backward composition: y\z x\y → x\z
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- Type-raising
  - forward type-raising: x → y / (y\x)
  - backward type-raising: x → y \ (y/x)
- Coordination <&>
  - x conj x → x

Coordination with CCG

Marcel	conjectured	and	might	prove	completeness
NP	(S\NP)/NP	(X\X)/X	(S\NP)/((S\NP))	(S\NP)/NP	NP

- Application
  - forward application: x/y y ➔ x
  - backward application: y x\y ➔ x
- Composition
  - forward composition: x/y y/z ➔ x/z
  - backward composition: y\z x\y ➔ x\z
  - forward crossing composition: x/y y\z ➔ x\z
  - backward crossing composition: x\y y/z ➔ x/z

Coordination with CCG

Marcel	conjectured	and	might	prove	completeness
NP	(S\NP)/NP	(X\X)/X	(S\NP)/((S\NP))	(S\NP)/NP	NP

might prove $>_B$: (S\NP)/NP

and [might prove] $>$: ((S\NP)/NP)\((S\NP)/NP)

conjectured [and might prove] $<$: (S\NP)/NP

[conjectured and might prove] completeness $>$: S\NP

Marcel [conjectured and might prove completeness] $<$: S

- Application
  - forward application: x/y y ➔ x
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- Composition
  - forward composition: x/y y/z ➔ x/z
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Combinatory Rules

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  - backward type-raising: x ➔ y \ (y/x)
- Coordination <&>
  - x conj x ➔ x

Combinatory Rules 3 : Type-Raising

- Turns an argument into a function

- Forward type-raising: X ➔ T / (T\X)
- Backward type-raising: X ➔ T \ (T/X)

For instance…

- Subject type-raising: NP ➔ S / (S \ NP)
- Object type-raising: NP ➔ (S\NP) \ ((S\NP) / NP)

Combinatory Rules 3 : Type-Raising

I	dislike	and	Mary	likes	musicals
NP	$(S\backslash NP)/NP$	$CONJ$	NP	$(S\backslash NP)/NP$	NP

- Application
  - forward application: x/y y → x
  - backward application: y x\y → x
- Type-raising
  - forward type-raising: x → y / (y\x)
  - backward type-raising: x → y \ (y/x)
  - Subject type-raising: NP → S / (S \ NP)
  - Object type-raising: NP → (S\NP) \ ((S\NP) / NP)
- Coordination <&>
  - x conj x → x

Combinatory Rules 3 : Type-Raising

I	dislike	and	Mary	likes	musicals
NP	$(S\backslash NP)/NP$	$CONJ$	NP	$(S\backslash NP)/NP$	NP
			$: mary'$	$: \lambda x.\lambda y.like'xy$	

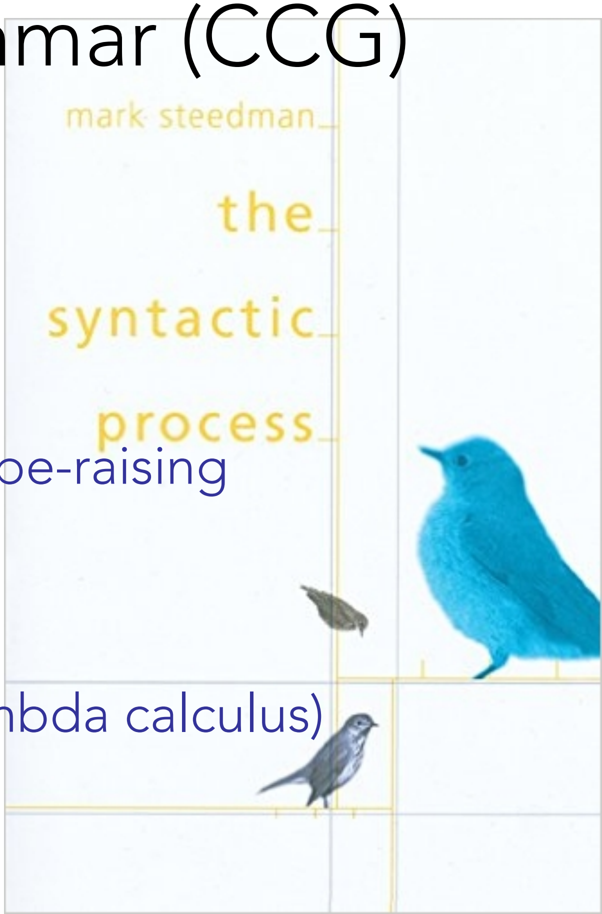
$$\dfrac{NP}{S/(S\backslash NP)}{>}T \qquad \dfrac{NP : mary'}{S/(S\backslash NP) : \lambda f.f\ mary'}{>}T$$

$$\dfrac{S/(S\backslash NP) \quad (S\backslash NP)/NP}{S/NP}{>}B \qquad \dfrac{S/(S\backslash NP) : \lambda f.f\ mary' \quad (S\backslash NP)/NP : \lambda x.\lambda y.like'xy}{S/NP : \lambda x.like'x\ mary'}{>}B$$

$$\dfrac{S/NP \quad CONJ \quad S/NP}{S/NP}{<}\&{>}$$

$$\dfrac{S/NP \quad NP}{S}{>}$$

Combinatory Categorial Grammar (CCG)



- CCG: Steedman in 1986
- Pushing grammar down to lexicon.
- With just a few rules: application, composition, type-raising
- We've looked at only syntactic part of CCG
- A lot more in the semantic part of CCG (using lambda calculus)
- Parsing Complexity:
  - O(N^6)
- Local expert!
  - Luke Zettlemoyer (https://www.cs.washington.edu/people/faculty/lsz)