Computational Linguistics

CSC 485/2501
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8

8. Mildly Context-Sensitive Grammar Formalisms

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Based on slides by David Smith, Dan Klein, Stephen Clark and Eva Banik

Combinatory Categorial Grammar

Combinatory Categorial Grammar (CCG)

- Categorial grammar (CG) is one of the oldest grammar formalisms
- *Combinatory* Categorial Grammar now well established and computationally well founded (Steedman, 1996, 2000)
  - Account of syntax; semantics; prosody and information structure; automatic parsers; generation

Combinatory Categorial Grammar (CCG)

- CCG is a lexicalized grammar
- An elementary syntactic structure – for CCG a lexical category – is assigned to each word in a sentence

  walked: S\NP "give me an NP to my left and I return a sentence"
- A small number of rules define how categories can combine
  - Rules based on the combinators from Combinatory Logic

CCG Lexical Categories

- Atomic categories: S , N , NP , PP , . . . (not many more)
- Complex categories are built recursively from atomic categories and slashes, which indicate the directions of arguments
- Complex categories encode subcategorisation information
  - intransitive verb: S \NP *walked*
  - transitive verb: (S \NP)/NP *respected*
  - ditransitive verb: ((S \NP)/NP)/NP *gave*
- Complex categories can encode modification
  - PP nominal: (NP \NP)/NP
  - PP verbal: ((S \NP)\(S \NP))/NP

Simple CCG Derivation

$$
\begin{array}{cccl}
\mathit{interleukin-10} & \mathit{inhibits} & \mathit{production} & \\
\hline
NP & (S\backslash NP)/NP & NP & \\
\cline{2-3}
 & \multicolumn{2}{c}{S\backslash NP} & > \\
\cline{1-3}
\multicolumn{3}{c}{S} & <
\end{array}
$$

$>$ forward application

$<$ backward application

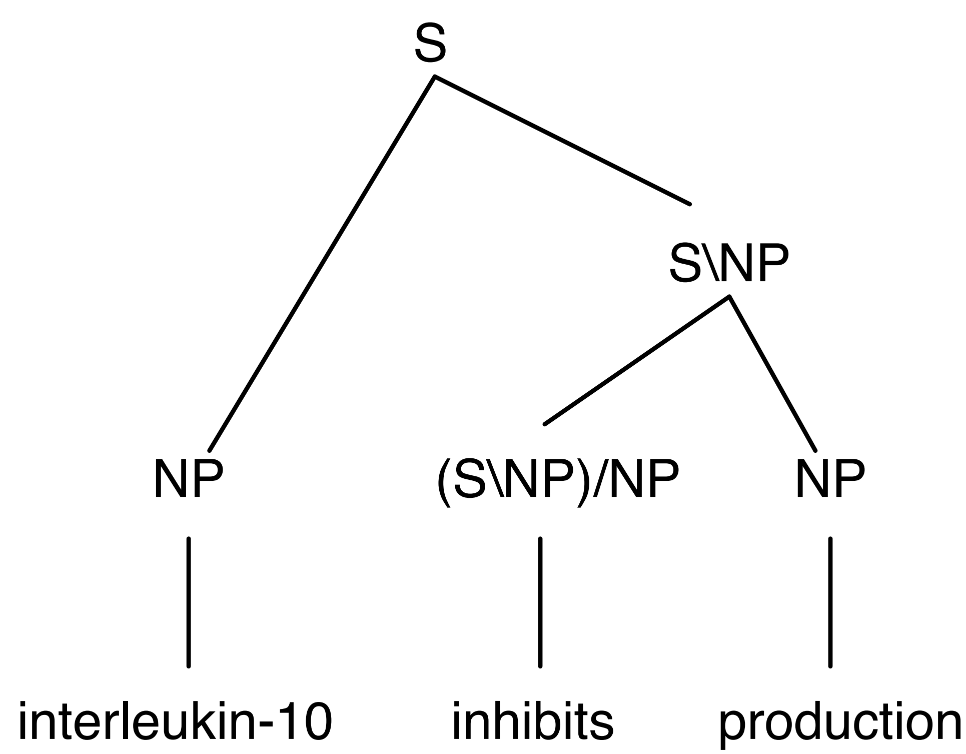
Function Application Schemata

- Forward ($>$) and backward ($<$) application:

$$
\begin{array}{rcll}
X/Y \quad Y & \Rightarrow & X & (>) \\
Y \quad X\backslash Y & \Rightarrow & X & (<)
\end{array}
$$

Classical Categorial Grammar

- 'Classical' Categorial Grammar only has application rules
- Classical Categorial Grammar is context free



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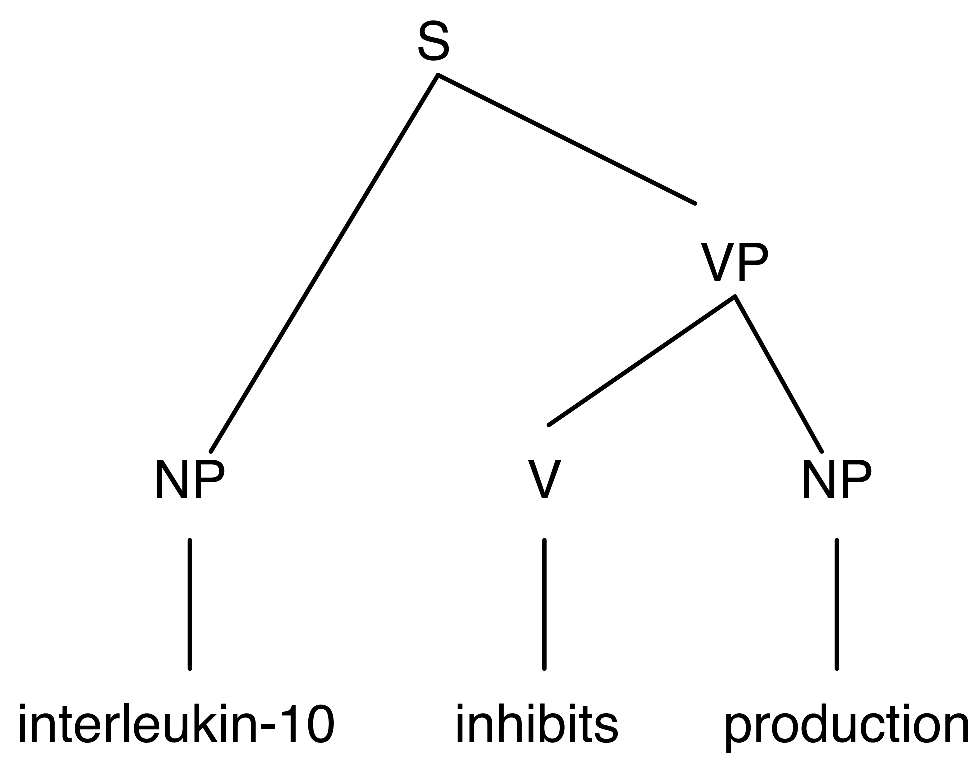


Extraction out of a Relative Clause

$$\frac{The}{NP/N} \quad \frac{company}{N} \quad \frac{which}{(NP\backslash NP)/(S/NP)} \quad \frac{Microsoft}{NP} \quad \frac{bought}{(S\backslash NP)/NP}$$

Extraction out of a Relative Clause

$$
\begin{array}{ccccc}
\textit{The} & \textit{company} & \textit{which} & \textit{Microsoft} & \textit{bought} \\
\overline{NP/N} & \overline{N} & \overline{(NP\backslash NP)/(S/NP)} & \overline{NP} & \overline{(S\backslash NP)/NP} \\
 & & & \overline{S/(S\backslash NP)}^{>\mathbf{T}} &
\end{array}
$$

$>\mathbf{T}$ type-raising

Extraction out of a Relative Clause

$$\dfrac{\textit{The}}{NP/N} \quad \dfrac{\textit{company}}{N} \quad \dfrac{\textit{which}}{(NP\backslash NP)/(S/NP)} \quad \dfrac{\dfrac{\dfrac{\textit{Microsoft}}{NP}}{S/(S\backslash NP)}{>}\mathbf{T} \quad \dfrac{\textit{bought}}{(S\backslash NP)/NP}}{S/NP}{>}\mathbf{B}$$

$>$ **T** type-raising

$>$ **B** forward composition

Extraction out of a Relative Clause

$$
\begin{array}{ccccc}
\mathit{The} & \mathit{company} & \mathit{which} & \mathit{Microsoft} & \mathit{bought} \\
\overline{NP/N} & \overline{N} & \overline{(NP\backslash NP)/(S/NP)} & \overline{NP} & \overline{(S\backslash NP)/NP} \\
 & & & \overline{S/(S\backslash NP)}^{>\mathbf{T}} & \\
 & & & \multicolumn{2}{c}{\overline{S/NP}^{>\mathbf{B}}} \\
 & & \multicolumn{3}{c}{\overline{NP\backslash NP}^{>}}
\end{array}
$$

Extraction out of a Relative Clause

$$
\begin{array}{ccccc}
\mathit{The} & \mathit{company} & \mathit{which} & \mathit{Microsoft} & \mathit{bought} \\
\hline
NP/N & N & (NP\backslash NP)/(S/NP) & NP & (S\backslash NP)/NP \\
\multicolumn{2}{c}{\overline{\qquad\qquad\qquad}{>}} & & \overline{\qquad\quad}{>}\mathbf{T} & \\
\multicolumn{2}{c}{\color{blue}{NP}} & & S/(S\backslash NP) & \\
 & & & \multicolumn{2}{c}{\overline{\qquad\qquad\qquad}{>}\mathbf{B}} \\
 & & & \multicolumn{2}{c}{S/NP} \\
 & & \multicolumn{3}{c}{\overline{\qquad\qquad\qquad\qquad\qquad}{>}} \\
 & & \multicolumn{3}{c}{NP\backslash \color{blue}{NP}} \\
\multicolumn{5}{c}{\overline{\qquad\qquad\qquad\qquad\qquad\qquad\qquad}{<}} \\
\multicolumn{5}{c}{NP}
\end{array}
$$

Forward Composition and Type-Raising

- Forward composition ($>_{\mathbf{B}}$):

$$X/Y \quad Y/Z \quad \Rightarrow \quad X/Z \qquad (>_{\mathbf{B}})$$

- Type-raising ($\mathbf{T}$):

$$\begin{aligned} X &\Rightarrow T/(T\backslash X) \qquad (>_{\mathbf{T}}) \\ X &\Rightarrow T\backslash(T/X) \qquad (<_{\mathbf{T}}) \end{aligned}$$

- Extra combinatory rules increase the weak generative power to mild context -sensitivity

"Non-constituents" in CCG – Right Node Raising

$$
\begin{array}{cccccc}
\textit{Google} & \textit{sells} & \textit{but} & \textit{Microsoft} & \textit{buys} & \textit{shares} \\
\hline
NP & (S\backslash NP)/NP & conj & NP & (S\backslash NP)/NP & NP \\
\overline{}{>}\mathbf{T} & & & \overline{}{>}\mathbf{T} & & \\
S/(S\backslash NP) & & & S/(S\backslash NP) & &
\end{array}
$$

$>\mathbf{T}$ type-raising

"Non-constituents" in CCG – Right Node Raising

Google	*sells*	*but*	*Microsoft*	*buys*	*shares*
NP	$(S\backslash NP)/NP$	$conj$	NP	$(S\backslash NP)/NP$	NP
$S/(S\backslash NP)$ $>\mathbf{T}$			$S/(S\backslash NP)$ $>\mathbf{T}$		
S/NP $>\mathbf{B}$			S/NP $>\mathbf{B}$		

$>$ **T** type-raising
$>$ **B** forward composition

"Non-constituents" in CCG – Right Node Raising

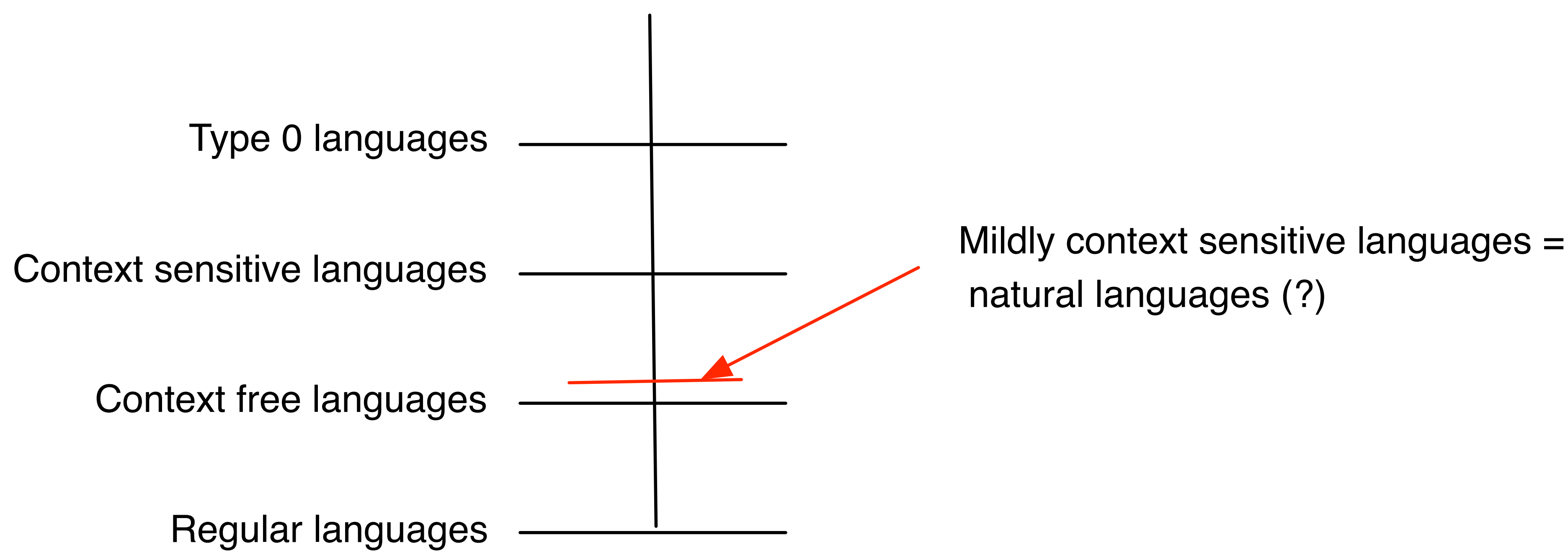
$$
\begin{array}{cccccc}
\mathit{Google} & \mathit{sells} & \mathit{but} & \mathit{Microsoft} & \mathit{buys} & \mathit{shares} \\
\hline
NP & (S\backslash NP)/NP & conj & NP & (S\backslash NP)/NP & NP \\
\cline{1-1}\cline{4-4}
S/(S\backslash NP)\ {>}\mathbf{T} & & & S/(S\backslash NP)\ {>}\mathbf{T} & & \\
\cline{1-2}\cline{4-5}
\multicolumn{2}{c}{S/NP\ {>}\mathbf{B}} & & \multicolumn{2}{c}{S/NP\ {>}\mathbf{B}} & \\
\cline{1-5}
\multicolumn{5}{c}{S/NP\ {<}\Phi{>}} &
\end{array}
$$

"Non-constituents" in CCG – Right Node Raising

$$
\begin{array}{cccccc}
\textit{Google} & \textit{sells} & \textit{but} & \textit{Microsoft} & \textit{buys} & \textit{shares} \\
\overline{NP} & \overline{(S\backslash NP)/NP} & \overline{conj} & \overline{NP} & \overline{(S\backslash NP)/NP} & \overline{\color{blue}{NP}} \\
\overline{S/(S\backslash NP)}{>}\mathbf{T} & & & \overline{S/(S\backslash NP)}{>}\mathbf{T} & & \\
\multicolumn{2}{c}{\overline{\qquad\qquad S/NP \qquad\qquad}{>}\mathbf{B}} & & \multicolumn{2}{c}{\overline{\qquad\qquad S/NP \qquad\qquad}{>}\mathbf{B}} & \\
\multicolumn{5}{c}{\overline{\qquad\qquad\qquad\qquad S/\color{blue}{NP} \qquad\qquad\qquad\qquad}{<}\Phi{>}} & \\
\multicolumn{6}{c}{\overline{\qquad\qquad\qquad\qquad\qquad S \qquad\qquad\qquad\qquad\qquad}{>}}
\end{array}
$$

Combinatory Categorial Grammar

- CCG is *mildly* context sensitive
- Natural language is provably non-context free
- Constructions in Dutch and Swiss German (Shieber, 1985) require more than context free power for their analysis
    - these have *crossing* dependencies (which CCG can handle)



CCG Semantics

- Categories encode argument sequences
- Parallel syntactic combinator operations and lambda calculus semantic operations

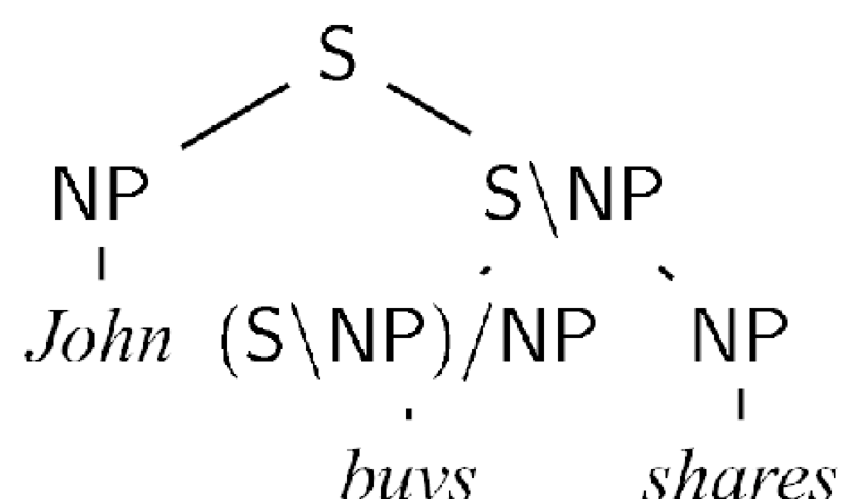
$John \vdash \mathsf{NP} : john'$

$shares \vdash \mathsf{NP} : shares'$

$buys \vdash (\mathsf{S}\backslash\mathsf{NP})/\mathsf{NP} : \lambda x.\lambda y.buys'xy$

$sleeps \vdash \mathsf{S}\backslash\mathsf{NP} : \lambda x.sleeps'x$

$well \vdash (\mathsf{S}\backslash\mathsf{NP})\backslash(\mathsf{S}\backslash\mathsf{NP}) : \lambda f.\lambda x.well'(fx)$



CCG Semantics

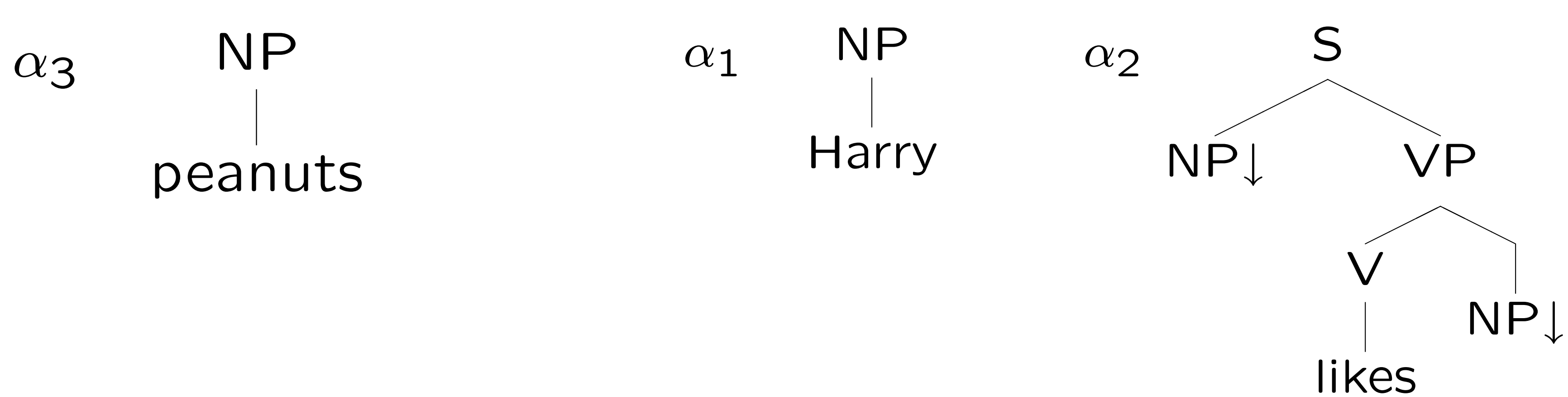
Left arg.	Right arg.	Operation	Result
X/Y : f	Y : a	Forward application	X : f(a)
Y : a	X\Y : f	Backward application	X : f(a)
X/Y : f	Y/Z : g	Forward composition	X/Z : λx.f(g(x))
X : a		Type raising	T/(T\X) : λf.f(a)

etc.

Tree Adjoining Grammar

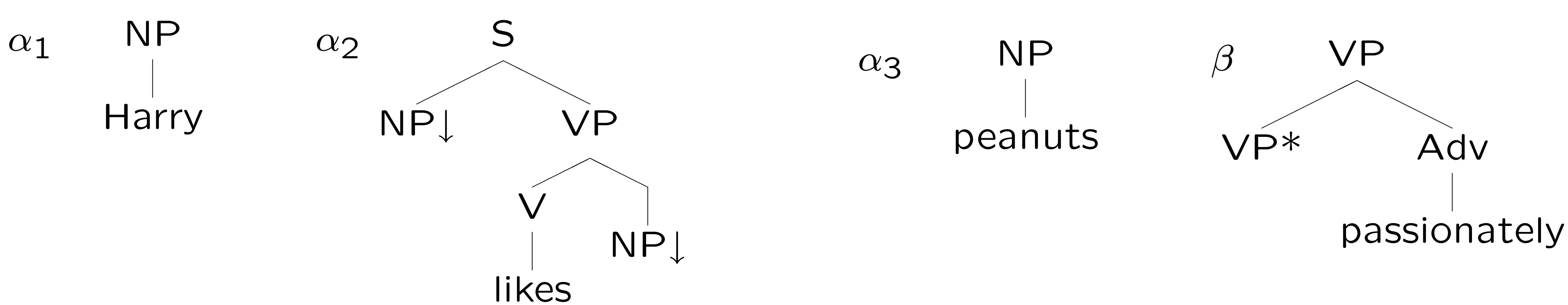
TAG Building Blocks

- Elementary trees (of many depths)
- Substitution at ↓
- Tree *Substitution* Grammar equivalent to CFG

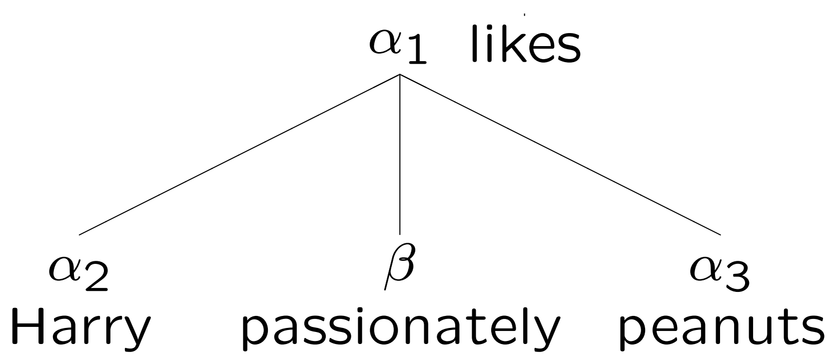


TAG Building Blocks

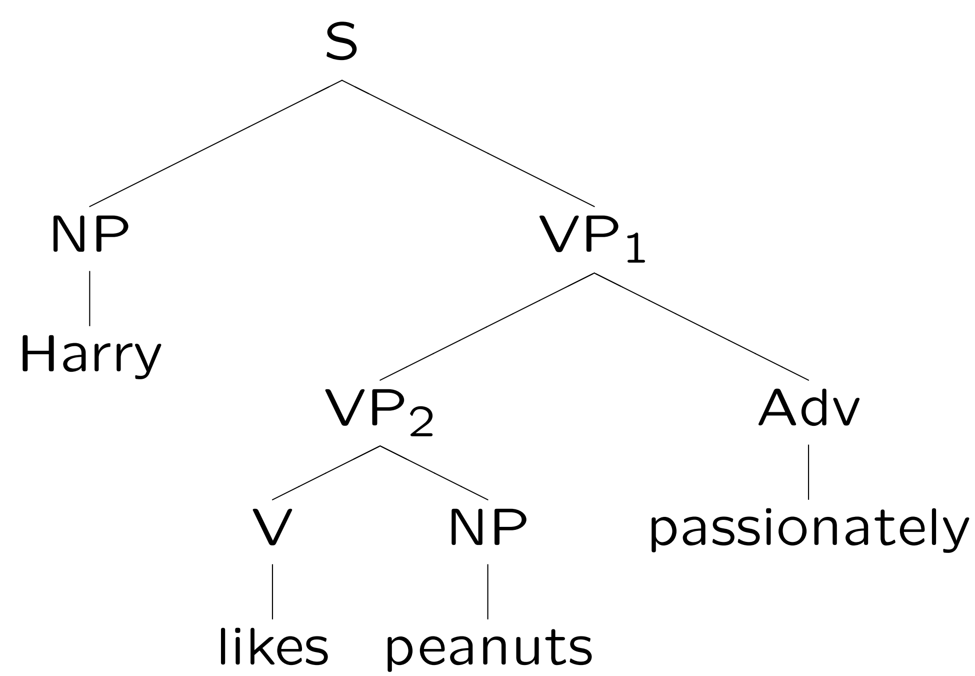
- Auxiliary trees for *adjunction*
- Adds extra power beyond CFG



Derivation Tree



Derived Tree



Semantics

$$Harry(x) \wedge likes(e, x, y) \wedge peanuts(y) \wedge passionately(e)$$