Introduction to Syntax and Parsing
ACS 2015/16
Stephen Clark
L6: Combinatory Categorial Grammar

UNIVERSITY OF CAMBRIDGE

Long-Range Dependencies

- A central problem for a theory of grammar:
  - "elements of sentences which belong together at the level of semantics or interpretation may be separated by unboundedly much intervening material" (Steedman)
- Obvious example in English is the relative clause construction:
  - *a woman whom Warren likes*
  - *a woman whom Dexter thinks that Warren likes*
  - ...

UNIVERSITY OF CAMBRIDGE

The Relative Clause Construction

- Relative clause construction:
  - *a woman whom Warren likes*

$$\frac{a\ woman}{NP} \quad \frac{whom}{?} \quad \frac{Warren}{NP} \quad \frac{likes}{(S\backslash NP)/NP}$$

- *whom Warren likes* should be $NP\backslash NP$
- so *whom* should be $(NP\backslash NP)/X$ for some X to be determined

“Non-Constituents” in CCG

$$
\begin{array}{cccc}
\textit{a woman} & \textit{whom} & \textit{Warren} & \textit{likes} \\
\hline
NP & (NP\backslash NP)/X & NP & (S\backslash NP)/NP
\end{array}
$$

- Could *Warren likes* be a constituent?
- The coordination test for constituency suggests so:
  - *Warren likes but Dexter detests contemporary dance*
- So what is its type?
  - how about S/NP?
  - in which case the type of *whom* is $(NP\backslash NP)/(S/NP)$

UNIVERSITY OF CAMBRIDGE

Deriving “Non-Constituents”

$$
\begin{array}{cccc}
a\ woman & whom & Warren & likes \\
\hline
NP & (NP\backslash NP)/(S/NP) & NP & (S\backslash NP)/NP \\
\cline{3-4}
 & & \multicolumn{2}{c}{\text{NOT ALLOWED}\quad <}
\end{array}
$$

- Can’t combine *Warren* and *likes* using application rules
- Need two new rules: type-raising and composition

Type-Raising

$$
\begin{array}{cccc}
\textit{a woman} & \textit{whom} & \textit{Warren} & \textit{likes} \\
\hline
NP & (NP\backslash NP)/(S/NP) & NP & (S\backslash NP)/NP \\
 & & \overline{}^{\,>\mathbf{T}} & \\
 & & S/(S\backslash NP) &
\end{array}
$$

- Subject NP becomes a functional category
- In general: $NP \Rightarrow T/(T\backslash NP)$
  - T is a variable; in practice, for both linguistic and practical parsing reasons, we'd want to limit T to a particular set of types
- Other categories can be type-raised, too, and we can have backward, as opposed to forward, type-raising

Forward Composition

$$
\begin{array}{cccc}
a\ woman & whom & Warren & likes \\
\hline
NP & (NP\backslash NP)/(S/NP) & NP & (S\backslash NP)/NP \\
 & & \overline{S/(S\backslash NP)}^{\,>\mathbf{T}} & \\
 & & \multicolumn{2}{c}{\overline{\qquad\qquad S/NP \qquad\qquad}^{\,>\mathbf{B}}}
\end{array}
$$

- Composition allows us to “get inside” a functional category
- In general: $X/Y\ \ Y/Z \Rightarrow X/Z$

UNIVERSITY OF CAMBRIDGE

CCG Derivation for Relative Clause

$$
\begin{array}{cccc}
\textit{a woman} & \textit{whom} & \textit{Warren} & \textit{likes} \\
\hline NP & (NP\backslash NP)/(S/NP) & NP & (S\backslash NP)/NP \\
 & & \overline{S/(S\backslash NP)}^{\;>\mathbf{T}} & \\
 & & \multicolumn{2}{c}{\overline{\qquad S/NP \qquad}^{\;>\mathbf{B}}} \\
 & \multicolumn{3}{c}{\overline{\qquad\qquad NP\backslash NP \qquad\qquad}^{\;>}} \\
\multicolumn{4}{c}{\overline{\qquad\qquad\qquad NP \qquad\qquad\qquad}^{\;<}}
\end{array}
$$

“Spurious” Ambiguity

$$
\begin{array}{ccc}
\textit{Warren} & \textit{likes} & \textit{the woman} \\
\hline
NP & (S\backslash NP)/NP & NP \\
\xrightarrow{\quad\quad\quad}{>}\mathbf{T} & & \\
S/(S\backslash NP) & & \\
\hline
\multicolumn{2}{c}{S/NP \quad >\mathbf{B}} & \\
\hline
\multicolumn{3}{c}{S \quad >}
\end{array}
$$

- Type-raising and composition can be used to analyse simple sentences with no long-range dependencies
- A different derivation results, *but the interpretation is the same* (hence so-called “spurious ambiguity”)

UNIVERSITY OF CAMBRIDGE

Generalised Forward Composition

- Some linguistic phenomena suggest the need for additional combinatory rules, eg:

I offered, and may give, a flower to a policeman

- Need to coordinate *offered* and *may give*, which means we need to make *may give* a constituent:

$$(S\backslash NP)/(S\backslash NP) \;\; ((S\backslash NP)/PP)/NP \;\; \Rightarrow \;\; ((S\backslash NP)/PP)/NP \;\; ?$$

Generalised Forward Composition

$$X/Y \quad (\ldots(Y/Z)/W)/\ldots \Rightarrow_{\mathbf{B}^n} (\ldots(X/Z)/W)/\ldots$$

- Can now combine *may* and *give*:

$$\cfrac{\cfrac{\mathit{may}}{(S\backslash NP)/VP} \quad \cfrac{\mathit{give}}{(VP/PP)/NP}}{((S\backslash NP)/PP)/NP}{>}\mathbf{B}^n$$

where $VP = S\backslash NP$

Argument Cluster Coordination

give a teacher an apple and a policemen a flower

- Looks like we need to coordinate *a teacher an apple* and *a policeman a flower*
- Can *a teacher an apple* really be a constituent?!
- Yes, if we allow backward type-raising and composition rules (once we allow these the derivation drops out)

Forward and Backward Type-Raising

$$X \Rightarrow_{\mathbf{T}} T/(T\backslash X) \qquad \text{forward}$$

$$X \Rightarrow_{\mathbf{T}} T\backslash(T/X) \qquad \text{backward}$$

Argument Cluster Coordination

$$
\begin{array}{cccccc}
\textit{give} & \textit{a teacher} & \textit{an apple} & \textit{and} & \textit{a policeman} & \textit{a flower} \\
\hline
DTV & NP & NP & conj & NP & NP \\
 & \overline{TV\backslash DTV}^{<\mathbf{T}} & \overline{VP\backslash TV}^{<\mathbf{T}} & & \overline{TV\backslash DTV}^{<\mathbf{T}} & \overline{VP\backslash TV}^{<\mathbf{T}}
\end{array}
$$

where $VP = S\backslash NP$, $TV = (S\backslash NP)/NP$, $DTV = ((S\backslash NP)/NP)/NP$

- Now we need a rule to combine $TV\backslash DTV$ and $VP\backslash TV$

Argument Cluster Coordination

$$
\begin{array}{cccccc}
\textit{give} & \textit{a teacher} & \textit{an apple} & \textit{and} & \textit{a policeman} & \textit{a flower} \\
\hline
DTV & NP & NP & conj & NP & NP \\
 & \overline{TV\backslash DTV}^{<\mathbf{T}} & \overline{VP\backslash TV}^{<\mathbf{T}} & & \overline{TV\backslash DTV}^{<\mathbf{T}} & \overline{VP\backslash TV}^{<\mathbf{T}} \\
 & \multicolumn{2}{c}{\overline{VP\backslash DTV}^{<\mathbf{B}}} & & \multicolumn{2}{c}{\overline{VP\backslash DTV}^{<\mathbf{B}}} \\
 & \multicolumn{5}{c}{\overline{VP\backslash DTV}^{<\Phi>}} \\
\multicolumn{6}{c}{\overline{VP}^{<}}
\end{array}
$$

where $VP = S\backslash NP$, $TV = (S\backslash NP)/NP$, $DTV = ((S\backslash NP)/NP)/NP$

- Backward Composition ($< \mathbf{B}$):

$$Y\backslash Z \quad X\backslash Y \quad \Rightarrow_{\mathbf{B}} \quad X\backslash Z$$

UNIVERSITY OF CAMBRIDGE

Backward Crossed Composition

I shall buy today and cook tomorrow some mushrooms

- *buy today* and *cook tomorrow* need to be constituents
- *buy* has category $(S\backslash NP)/NP$ and *today* has category $(S\backslash NP)\backslash(S\backslash NP)$
- No rule so far allows us to combine these; but this one will:

$$Y/Z \quad X\backslash Y \quad \Rightarrow_{\mathbf{B}} \quad X/Z \qquad (< \mathbf{B}_x)$$

$$VP/NP \quad VP\backslash VP \quad \Rightarrow_{\mathbf{B}} \quad VP/NP$$

UNIVERSITY OF CAMBRIDGE

Another Combinatory Rule

- Forward-Crossed Composition:

$$X/Y \;\; Y\backslash Z \Rightarrow_{\mathbf{B_x}} X\backslash Z$$

- Generalised Foward-Crossed Composition:

$$X/Y \; (\ldots(Y\backslash Z)\backslash W)\backslash \ldots \Rightarrow_{\mathbf{B_x}^n} (\ldots(X\backslash Z)\backslash W)\backslash \ldots$$

- Generalised case needed for the next derivation
- These rules not part of the English grammar

Cross-Serial Dependencies in Dutch

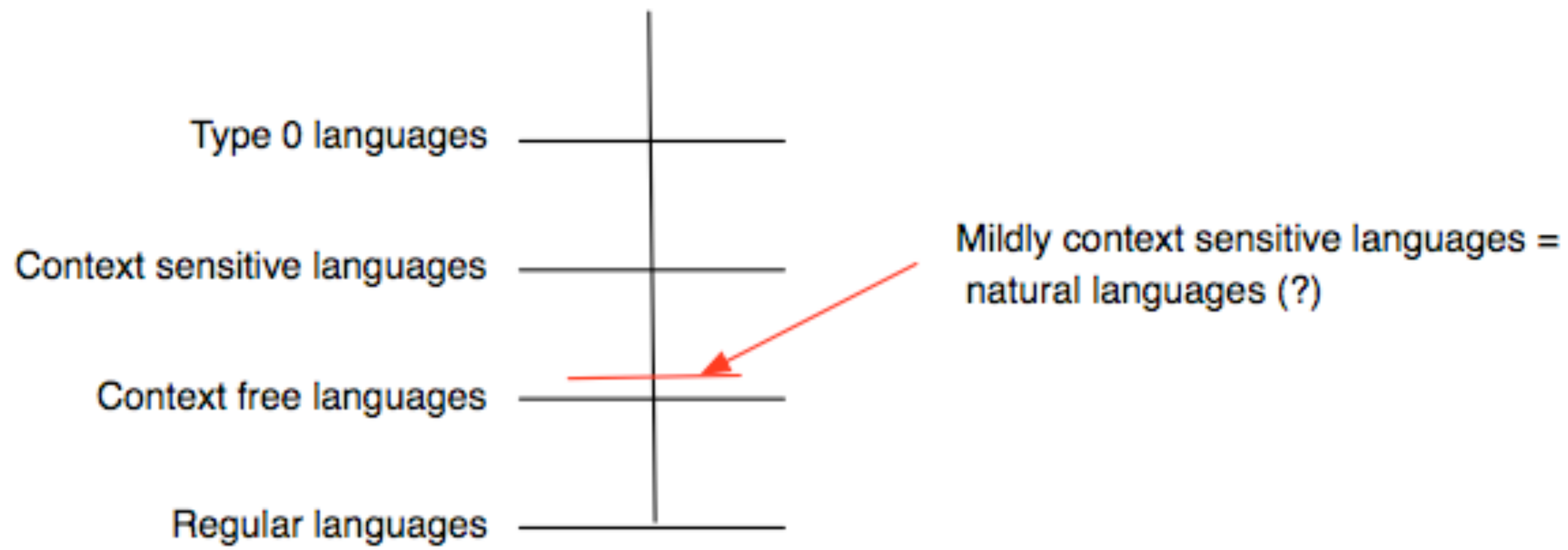
$$
\begin{array}{cccccccc}
\textit{dat} & \textit{ik} & \textit{Cecilia} & \textit{Henk} & \textit{de nijlpaarden} & \textit{zag} & \textit{helpen} & \textit{voeren} \\
\hline
 & NP_1 & NP_2 & NP_3 & NP_4 & ((S\backslash NP_1)\backslash NP_2)/VP & (VP\backslash NP_3)/VP & VP\backslash NP_4 \\
\cline{7-8}
 & & & & & & \multicolumn{2}{c}{(VP\backslash NP_3)\backslash NP_4 \quad {>}\mathbf{B}_{\times}} \\
\cline{6-8}
 & & & & & \multicolumn{3}{c}{(((S\backslash NP_1)\backslash NP_2)\backslash NP_3)\backslash NP_4 \quad {>}\mathbf{B}^2_{\times}} \\
\cline{5-8}
 & & & & \multicolumn{4}{c}{((S\backslash NP_1)\backslash NP_2)\backslash NP_3 \quad {<}} \\
\cline{4-8}
 & & & \multicolumn{5}{c}{(S\backslash NP_1)\backslash NP_2 \quad {<}} \\
\cline{3-8}
 & & \multicolumn{6}{c}{S\backslash NP_1 \quad {<}} \\
\cline{2-8}
 & \multicolumn{7}{c}{S \quad {<}}
\end{array}
$$

UNIVERSITY OF CAMBRIDGE

Mild Context Sensitivity

- It is the generalised composition rules which lead to greater-than-context free power
- A CCG with generalised composition and certain rule restrictions has the same generative power as Tree Adjoining Grammar (TAG) ("mildly context-sensitive")
- Interestingly, Kuhlman et al. show that *relaxing* some of the rule restrictions can provide a CCG with greater-than-context-free power, but with strictly less power than TAG

Mild Context Sensitivity



UNIVERSITY OF CAMBRIDGE