Introduction to Syntax and Parsing
ACS 2015/16
Stephen Clark
L6: Combinatory Categorial Grammar
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
  - …
The Relative Clause Construction

- Relative clause construction:
  - a woman whom Warren likes

\[
\begin{array}{cccc}
\text{a woman} & \text{whom} & \text{Warren} & \text{likes} \\
NP & ? & NP & (S\backslash NP)/NP
\end{array}
\]

- whom Warren likes should be \( NP \backslash NP \)
- so whom should be \( (NP \backslash NP)/X \) for some \( X \) to be determined
“Non-Constiuents” in CCG

\[
\begin{align*}
\text{a woman} & \quad \text{whom} & \quad \text{Warren} & \quad \text{likes} \\
NP & \quad (NP\backslash NP)/X & \quad NP & \quad (S\backslash NP)/NP
\end{align*}
\]

- 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 \((NP\backslash NP)/(S/NP)\)
Deriving “Non-Constuients”

\[
\begin{align*}
\text{a woman} & \quad \text{whom} & \quad \text{Warren} & \quad \text{likes} \\
NP & \quad (NP \setminus NP)/(S/NP) & \quad NP & \quad (S \setminus NP)/NP \\
\text{NOT ALLOWED} & \quad < \\
\end{align*}
\]

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

\[
\begin{align*}
\text{a woman} & \quad \text{whom} \quad \text{Warren} \quad \text{likes} \\
NP & \quad (NP\backslash NP)/(S/NP) & NP & \quad (S\backslash NP)/NP \\
& \quad S/(S\backslash NP) & & \quad \Rightarrow^T
\end{align*}
\]

- 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

\[
\begin{align*}
\text{a woman} & \quad \text{whom} \\
\text{NP} & \quad (NP \backslash NP) / (S / NP) \\
\text{NP} & \quad (S \backslash NP) / NP \\
\text{S} / (S \backslash NP) & \quad \Rightarrow \text{T} \\
\text{S} / \text{NP} & \quad \Rightarrow \text{B}
\end{align*}
\]

- Composition allows us to “get inside” a functional category
- In general: \( X / Y \ Y / Z \Rightarrow X / Z \)
CCG Derivation for Relative Clause

\[
\begin{align*}
&a \text{ woman} & \text{whom} & \quad & Warren & \text{likes} \\
\frac{NP}{(NP \backslash NP)/(S/\text{NP})} & & & \frac{NP}{(S \backslash \text{NP})/\text{NP}} \\
\frac{S/(S/\text{NP})}{S/\text{NP}} & & & \frac{S/\text{NP}}{<NP \backslash NP}> \\
& & & & \frac{NP}{<NP}> \\
\end{align*}
\]
“Spurious” Ambiguity

\[
\begin{array}{c}
Warren \\
NP \\
\hline
likes \\
(S\backslash NP)/NP \\
\hline
the woman \\
NP \\
\hline
S/(S\backslash NP) \xrightarrow{\text{T}} \\
\hline
S/\text{NP} \xrightarrow{\text{B}} \\
\hline
S \\
\hline
\end{array}
\]

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

Generalised Forward Composition

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

  \[ I \text{ offered, and may give, a flower to a policeman}\]

- Need to coordinate \textit{offered} and \textit{may give}, which means we need to make \textit{may give} a constituent:

  \[ (S \backslash NP)/(S \backslash NP) \rightarrow ((S \backslash NP)/PP)/NP \]

\[ \Rightarrow ((S \backslash NP)/PP)/NP \]
Generalised Forward Composition

\[
X/Y \ (\ldots (Y/Z)/W)/\ldots \Rightarrow_{B^n} \ (\ldots (X/Z)/W)/\ldots
\]

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

\[
\frac{\text{may}}{(S'\backslash NP)/VP} \quad \frac{\text{give}}{(VP/PP)/NP} \quad \frac{}{((S'\backslash NP)/PP)/NP} \Rightarrow_{B^n}
\]

where \( VP = S'\backslash NP \)
Argument Cluster Coordination


give a teacher an apple and a policeman 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

\[ X \Rightarrow_T T/(T\setminus X) \quad \text{forward} \]

\[ X \Rightarrow_T T\setminus(T/X) \quad \text{backward} \]
Argument Cluster Coordination

\[
\begin{align*}
give & \quad a \text{ teacher} \quad an \text{ apple} \quad and \quad a \text{ policeman} \quad a \text{ flower} \\
DTV & \quad NP & \quad NP & \quad \text{conj} & \quad NP & \quad NP
\end{align*}
\]

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

\[
give \quad a \ teacher \quad an \ apple \quad and \quad a \ policeman \quad a \ flower
\]

\[
\frac{DTV}{NP} \quad \frac{NP}{<T} \quad \frac{NP}{<T} \quad \frac{NP}{<T} \quad \frac{NP}{<T}
\]

\[
\frac{TV\backslash DTV}{VP\backslash TV} \quad \frac{VP\backslash TV}{<B} \quad \frac{TV\backslash DTV}{VP\backslash TV} \quad \frac{VP\backslash DTV}{<B}
\]

\[
\frac{VP\backslash DTV}{VP\backslash DTV} \quad \frac{VP\backslash DTV}{<\Phi>}
\]

\[
\frac{VP}{<}
\]

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

- Backward Composition \( (< B) \):

\[
Y\backslash Z \quad X\backslash Y \quad \Rightarrow_B \quad X\backslash Z
\]
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 \((S \backslash NP)/(S \backslash NP)\)
- No rule so far allows us to combine these; but this one will:

\[
Y/Z \ X/Y \Rightarrow_B \ X/Z \ (< B_x)
\]

\[
VP/NP \ VP/VP \Rightarrow_B \ VP/NP
\]
Another Combinatory Rule

- Forward-Crossed Composition:
  \[ X/Y \ Y\backslash Z \Rightarrow_{B_x} X\backslash Z \]

- Generalised Foward-Crossed Composition:
  \[ X/Y (\ldots (Y\backslash Z)\backslash W)\ldots \Rightarrow_{B^n_x} (\ldots (X\backslash Z)\backslash W)\ldots \]

- Generalised case needed for the next derivation
- These rules not part of the English grammar
Cross-Serial Dependencies in Dutch

\[
\begin{array}{ccccccc}
\text{dat} & \text{ik} & \text{Cecilia} & \text{Henk} & \text{de nijlpaarden} & \text{zag} & \text{helpen} & \text{voeren} \\
NP_1 & NP_2 & NP_3 & NP_4 & (S\backslash NP_1)\backslash NP_2 & (VP\backslash NP_3)\backslash VP & VP\backslash NP_4 \\
& & & & (VP\backslash NP_3)\backslash VP & (VP\backslash NP_3)\backslash NP_4 & \quad B_x \quad \\
& & & & & (S\backslash NP_1)\backslash NP_3 & \quad B_x^2 \quad \\
& & & & & (S\backslash NP_1)\backslash NP_2 & < \\
& & & & & S\backslash NP_1 & < \\
& & & & & S & < \\
\end{array}
\]
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

- Type 0 languages
- Context sensitive languages
- Context free languages
- Regular languages

Mildly context sensitive languages = natural languages (?)