L95: Natural Language Syntax and Parsing
4) Categorial Grammars

Paula Buttery

Dept of Computer Science & Technology, University of Cambridge

Reminder:

For statistical parsing we need:

- a grammar,
- a parsing algorithm,
- a scoring model for parses,
- an algorithm for finding best parse.

- Parsing **efficiency** is dependent on the parsing and best-parse algorithms.
- Parsing **accuracy** is dependent on the grammar and scoring model.

- Often there is a trade-off between using a more sophisticated (and perhaps less robust) grammar formalism at the expense of efficiency.

Reminder:

For statistical parsing we need:

- a grammar,
- a parsing algorithm,
- a scoring model for parses,
- an algorithm for finding best parse.

- Parsing **efficiency** is dependent on the parsing and best-parse algorithms.
- Parsing **accuracy** is dependent on the grammar and scoring model.

- Often there is a trade-off between using a more sophisticated (and perhaps less robust) grammar formalism at the expense of efficiency.

Reminder:

For statistical parsing we need:

- a grammar,
- a parsing algorithm,
- a scoring model for parses,
- an algorithm for finding best parse.

- Parsing **efficiency** is dependent on the parsing and best-parse algorithms.
- Parsing **accuracy** is dependent on the grammar and scoring model.

- Often there is a trade-off between using a more sophisticated (and perhaps less robust) grammar formalism at the expense of efficiency.

CCG parsers exist that are robust and efficient

- **Combinatory Categorial Grammars** parsers exist that are robust and efficient (Clark & Currans 2007) `https://github.com/chrzyki/candc`
- CCGs provide a mapping between syntactic structure and predicate-argument structure

- The C&C parser uses a discriminative model over complete parses
- A **supertagging** phase is needed before parsing commences

First, reminder of a CCG?

CCG parsers exist that are robust and efficient

- **Combinatory Categorial Grammars** parsers exist that are robust and efficient (Clark & Currans 2007) `https://github.com/chrzyki/candc`
- CCGs provide a mapping between syntactic structure and predicate-argument structure

- The C&C parser uses a discriminative model over complete parses
- A **supertagging** phase is needed before parsing commences

First, reminder of a CCG?

Categorial grammars are **lexicalized grammars**

In a **classic categorial grammar** each symbol in the alphabet is associated with a finite number of **types**.

- Types are formed from primitive types using two operators, $\backslash$ and $/$.
- If P_r is the set of **primitive types** then the set of all types, T_p, satisfies:
  - $P_r \subset T_p$
  - if $A \in T_p$ and $B \in T_p$ then $A \backslash B \in T_p$
  - if $A \in T_p$ and $B \in T_p$ then $A/B \in T_p$
- Note that it is possible to arrange types in a hierarchy: a type A is a *subtype* of B if A occurs in B (that is, A is a subtype of B iff $A = B$; or ($B = B_1 \backslash B_2$ or $B = B_1/B_2$) and A is a subtype of B_1 or B_2).

Categorial grammars are **lexicalized grammars**

- A relation, $\mathcal{R}$, maps symbols in the alphabet Σ to members of T_p.
- A grammar that associates at most one type to each symbol in Σ is called a **rigid grammar**
- A grammar that assigns at most k types to any symbol is a **k-valued grammar**.
- We can define a classic categorial grammar as $G_{cg} = (\Sigma, P_r, S, \mathcal{R})$ where:
  - Σ is the alphabet/set of terminals
  - P_r is the set of primitive types
  - S is a distinguished member of the primitive types $S \in P_r$ that will be the root of complete derivations
  - $\mathcal{R}$ is a relation $\Sigma \times T_p$ where T_p is the set of all types as generated from P_r as described above

Categorial grammars are **lexicalized grammars**

A string has a valid parse if the types assigned to its symbols can be combined to produce a derivation tree with root S.

Types may be combined using the two rules of **function application**:

- FORWARD APPLICATION is indicated by the symbol $>$:

$$\frac{A/B \qquad B}{A} >$$

- BACKWARD APPLICATION is indicated by the symbol $<$:

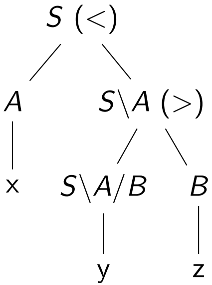
$$\frac{B \qquad A\backslash B}{A} <$$

Categorial grammars are **lexicalized grammars**

Derivation tree for the string *xyz* using the grammar $G_{cg} = (\Sigma, P_r, S, \mathcal{R})$ where:

$$
\begin{aligned}
Pr &= \{S, A, B\} \\
\Sigma &= \{x, y, z\} \\
S &= S \\
\mathcal{R} &= \{(x, A), (y, S\backslash A/B), (z, B)\}
\end{aligned}
$$

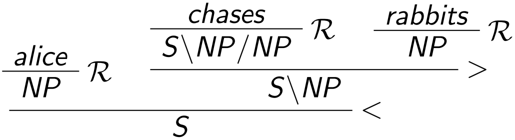
$$
\dfrac{\dfrac{x}{A}\,\mathcal{R} \qquad \dfrac{\dfrac{y}{S\backslash A/B}\,\mathcal{R} \qquad \dfrac{z}{B}\,\mathcal{R}}{S\backslash A}\,>}{S}\,<
$$

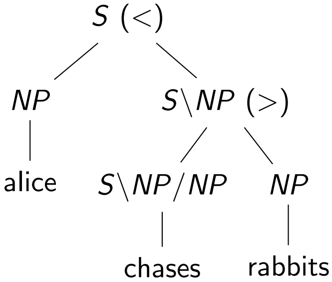


Categorial grammars are **lexicalized grammars**

Derivation tree for the string *Alice chases rabbits* using the grammar $G_{cg} = (\Sigma, P_r, S, \mathcal{R})$ where:

$$
\begin{aligned}
Pr &= \{S, NP\} \\
\Sigma &= \{alice, chases, rabbits\} \\
S &= S \\
\mathcal{R} &= \{(alice, NP), (chases, S\backslash NP/NP), \\
&\quad (rabbits, NP)\}
\end{aligned}
$$





Combinatory categorial grammars **extend** classic CG

Combinatory categorial grammars use **function composition** rules in addition to function application:

- FORWARD COMPOSITION is indicated by the symbol $> B$:

$$\frac{X/Y \qquad Y/Z}{X/Z} > B$$

- BACKWARD COMPOSITION is indicated by the symbol $< B$:

$$\frac{Y\backslash Z \qquad X\backslash Y}{X\backslash Z} < B$$

They also use **type-raising** rules (only applies to NP, PP, $S[adj]\backslash NP$):

$$\frac{X}{T/(T\backslash X)}\ T$$

$$\frac{X}{T\backslash(T/X)}\ T$$

- Also backward crossed composition and co-ordination (see Steedman)

CCG examples...

Lexicalised grammar parsers have three steps

Parsing with lexicalised grammar formalisms has the following pipeline:

1. Lexical **categories are assigned** to each word in the sentence
2. Parser combines the categories together to **form legal structures**
3. The **highest scoring derivation** is found according to some model

For C&C:

1. Uses a **supertagger** (log-linear model using words and PoS tags in a 5-word window)
2. Uses the CKY chart parsing algorithm to derive all legal structures
3. Uses Viterbi to find best parse (log-linear model to score parses based on their features)

- *CCGBank derived from the Penn Treebank is used to train the scoring models*

Lexicalised grammar parsers have three steps

Parsing with lexicalised grammar formalisms has the following pipeline:

1. Lexical **categories are assigned** to each word in the sentence
2. Parser combines the categories together to **form legal structures**
3. The **highest scoring derivation** is found according to some model

For C&C:

1. Uses a **supertagger** (log-linear model using words and PoS tags in a 5-word window)
2. Uses the CKY chart parsing algorithm to derive all legal structures
3. Uses Viterbi to find best parse (log-linear model to score parses based on their features)

- *CCGBank derived from the Penn Treebank is used to train the scoring models*

The C&C parser uses a supertagger

Two stage tagging using **log-linear model**:

$$P(tag|context) = \frac{1}{Z} \exp^{\sum_i \lambda_i f_i(tag, context)}$$

where λ_i is the weight of the ith feature, f_i (and Z is a normalising factor)

- context is **5-word window** surrounding target word
- features are
  - words and POS tags in the context window
  - two previously assigned categories
- $\approx$ 400 lexical categories
- baseline for task is $\approx$ 72% (compare to normal POS tagging $\approx$ 90%)
- One tag per word yields $\approx$ 92% — improve by assigning all categories whose probability is within some factor β of the highest probability category

The C&C parser uses CKY and Viterbi

- Build a packed chart of all the trees using CKY.
- Parses are scored according to their features (**feature forest**)
- Discriminative parser: $P(tree|words) = \frac{1}{Z_W} \exp^{\lambda.F(tree)}$
  where $\lambda.F(tree) = \sum_i \lambda_i f_i(tree)$ and λ_i is the weight of the ith feature, f_i (and Z_W is a normalising factor)
- Train λ by maximising log-likelihood over the training data (minus a prior term to prevent overfitting)
- Use CKY and Viterbi when decoding to find the best parse.
- Packing requires that any rule based features are **local**—confined to a single rule application.

The C&C parser uses CKY and Viterbi

- Build a packed chart of all the trees using CKY.
- Parses are scored according to their features (**feature forest**)
- Discriminative parser: $P(tree|words) = \frac{1}{Z_W} \exp^{\lambda.F(tree)}$
  where $\lambda.F(tree) = \sum_i \lambda_i f_i(tree)$ and λ_i is the weight of the ith feature, f_i (and Z_W is a normalising factor)
- Train λ by maximising log-likelihood over the training data (minus a prior term to prevent overfitting)
- Use CKY and Viterbi when decoding to find the best parse.
- Packing requires that any rule based features are **local**—confined to a single rule application.

The C&C parser uses CKY and Viterbi

- Build a packed chart of all the trees using CKY.
- Parses are scored according to their features (**feature forest**)
- Discriminative parser: $P(tree|words) = \frac{1}{Z_W} \exp^{\lambda.F(tree)}$
  where $\lambda.F(tree) = \sum_i \lambda_i f_i(tree)$ and λ_i is the weight of the ith feature, f_i (and Z_W is a normalising factor)
- Train λ by maximising log-likelihood over the training data (minus a prior term to prevent overfitting)
- Use CKY and Viterbi when decoding to find the best parse.
- Packing requires that any rule based features are **local**—confined to a single rule application.

C&C scores parses according to their features

The features used in the C&C scoring model include:

- features encoding local trees (that is two combining categories and the result category)
- features encoding word-lexical category pairs at the leaves of the derivation
- features encoding grammatical dependencies, including the distance between them

CKY CCG parse example...