Lecture 8:
What’s the matter with CFGs?
How can we learn from our mistakes?

Professor Robert C. Berwick
berwick@csail.mit.edu

Menu
• What’s wrong with CFGs?
• Featuritis – how do we know which features to use? Ans: we will see how to learn them (in a bit)
• The Slash ’N Burn Strategy: fillers & gaps
• What’s wrong with PCFGs?
• Learning parameters for language models: the EM method
  • First: cone heads
  • Hot today – hot tamale
Agreement features example 1

% start S
S -> NP[NUM=?n] VP[NUM=?n]
# NP expansion productions
NP[NUM=?n] -> N[NUM=?n]
NP[NUM=?n] -> PropN[NUM=?n]
NP[NUM=pl] -> N[NUM=pl]
# VP expansion productions

Det[NUM=sg] -> 'this' | 'every'
Det[NUM=pl] -> 'these' | 'all'
Det -> 'the' | 'some' | 'several'
PropN[NUM=sg]-> 'Kim' | 'Jody'
N[NUM=sg] -> 'dog' | 'girl' | 'car' | 'child'
N[NUM=pl] -> 'dogs' | 'girls' | 'cars' | 'children'
IV[TENSE=pres, NUM=sg] -> 'disappears' | 'walks'
TV[TENSE=pres, NUM=sg] -> 'sees' | 'likes'

Parse *Kim likes children*
Trace showing bottom-up combination & feature checking as each left-hand nonterminal phrase is built

Feature Bottom Up Predict Combine Rule:
| [-----]    .    .| [0:1] PropN[NUM='sg'] -> 'Kim' *
Feature Bottom Up Predict Combine Rule:
| [-----]    .    .| [0:1] NP[NUM='sg'] -> PropN[NUM='sg'] *
Feature Bottom Up Predict Combine Rule:
Feature Bottom Up Predict Combine Rule:
|   [-----] . [1:2] TV[NUM='sg', TENSE='pres'] -> 'likes' *
Feature Bottom Up Predict Combine Rule:
Feature Bottom Up Predict Combine Rule:
|   [-----] . [2:3] NP[NUM='pl'] leading 'children' *

End of trace: NP, VP, S checked

Feature Bottom Up Predict Combine Rule:
| .    [-----] . [2:3] NP[NUM='pl'] -> N[NUM='pl'] *
Feature Bottom Up Predict Combine Rule:
Feature Single Edge Fundamental Rule:
| .    [----------] . [1:3] VP[NUM='sg', TENSE='pres'] -> TV[NUM='sg', TENSE='pres'] NP[] *
Feature Single Edge Fundamental Rule:
| [--------------] . [0:3] S[] -> NP[NUM='sg'] VP[NUM='sg'] *
More challenging: German

<table>
<thead>
<tr>
<th>Case</th>
<th>Masc</th>
<th>Fem</th>
<th>Neut</th>
<th>Plural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom</td>
<td>der</td>
<td>die</td>
<td>das</td>
<td>die</td>
</tr>
<tr>
<td>Gen</td>
<td>des</td>
<td>der</td>
<td>des</td>
<td>der</td>
</tr>
<tr>
<td>Dat</td>
<td>dem</td>
<td>der</td>
<td>dem</td>
<td>den</td>
</tr>
<tr>
<td>Acc</td>
<td>den</td>
<td>die</td>
<td>das</td>
<td>die</td>
</tr>
</tbody>
</table>

Morphological Paradigm for the German definite Article

a. Die Katze sieht den Hund
   the.NOM.FEM.SG cat.3.FEM.SG see.3.SG the.ACC.MASC.SG dog.3.MASC.SG
b. *Die Katze sieht dem Hund
   the.NOM.FEM.SG cat.3.FEM.SG see.3.SG the.DAT.MASC.SG dog.3.MASC.SG
c. Die Katze hilft dem Hund
   the.NOM.FEM.SG cat.3.FEM.SG help.3.SG the.DAT.MASC.SG dog.3.MASC.SG
d. *Die Katze hilft den Hund
   the.NOM.FEM.SG cat.3.FEM.SG help.3.SG the.ACC.MASC.SG dog.3.MASC.SG

'Simple' agreement grammar for German - not complex agr feature

# Singular determiners
# masc
Det[CASE=nom, AGR=[GND=masc,PER=3,NUM=sg]] -> 'der'
Det[CASE=dat, AGR=[GND=masc,PER=3,NUM=sg]] -> 'dem'
Det[CASE=acc, AGR=[GND=masc,PER=3,NUM=sg]] -> 'den'
...
# fem
Det[CASE=nom, AGR=[GND=fem,PER=3,NUM=sg]] -> 'die'
Det[CASE=dat, AGR=[GND=fem,PER=3,NUM=sg]] -> 'der'
Det[CASE=acc, AGR=[GND=fem,PER=3,NUM=sg]] -> 'die'
# Plural determiners
Det[CASE=nom, AGR=[PER=3,NUM=pl]] -> 'die'
...
Nouns
N[AGR=[GND=fem,PER=3,NUM=sg]] -> 'Katze'
N[AGR=[GND=fem,PER=3,NUM=pl]] -> 'Katzen'
Noun-Verb agreement in ‘case’

S -> NP[CASE=nom, AGR=?a] VP[AGR=?a]

VP[AGR=?a] -> IV[AGR=?a]

... TV[OBJCASE=dat, AGR=[NUM=sg, PER=1]] -> 'folge' | 'helfe'
TV[OBJCASE=dat, AGR=[NUM=sg, PER=2]] -> 'folgst' | 'hilfst'

Folgst/follow
Hilfst/help

ich folge den Katzen

6.863J/9.611J Fall 2012  Lecture 8
Features to detect inversions

Many kinds of ‘displaced’ phrases

<table>
<thead>
<tr>
<th>Name</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Topicalization</td>
<td>This guy, I want XXX to solve the problem</td>
</tr>
<tr>
<td>(2) Wh-question</td>
<td>Who did I want XXX to solve the problem?</td>
</tr>
<tr>
<td>(3) PP-fronting</td>
<td>From which book did the students get the answer XXX?</td>
</tr>
<tr>
<td>(4) Passive</td>
<td>All the ice-cream was eaten XXX</td>
</tr>
<tr>
<td>(5) Right-node raising</td>
<td>I read XXX yesterday a book about China.</td>
</tr>
<tr>
<td>(6) Aux-inversion</td>
<td>Will the guy eat the ice-cream?</td>
</tr>
<tr>
<td>(7) Relative clause</td>
<td>The guy that John saw XXX</td>
</tr>
<tr>
<td>(8) Gapping</td>
<td>I chased XXX and Mary killed XXX a rabid dog.</td>
</tr>
</tbody>
</table>
Questions about displaced phrases

• What kinds of phrases?
• What are configurations for displacement?
• What is ‘distance’ of displacement?
• How can we encode this?

The key configuration: c-command($X,Y$):
the first branching node that dominates $X$
also dominates $Y$

Constraint 1: Fillers must c-command their
‘gaps’ (positions from which they are displaced)
Figure 3: Displaced phrases must c-command the canonical positions from which they are displaced. Here, in the sentence "This student I want to solve the problem", this student has been displaced from its position as the Subject of to solve, as indicated by the empty element with an index $i$. The displaced NP with index $i$ c-commands the empty element’s position.

1. Add new nonterminal rules that map NPs, Ss, PPs, etc. to the empty string, $\varepsilon$. This corresponds to an expansion of a phrase that is then "unpronounced" or silent. For example, for NP we will have the rule, $\text{NP} \Rightarrow \varepsilon$. Informally, we will call the position of the empty phrase a "gap." (In fact, this is not exactly the NP expansion rule we want, and we’ll have to modify it slightly as described below.)

2. Add new nonterminal rules corresponding to the introduction of displaced phrase, along with new nonterminal names to keep track of the "link" between the displaced phrase and the place where the empty phrase is. This is done by taking a regular nonterminal, say, $S$ or $VP$, and then creating an additional new non-terminal that has a "slash" in it, with a non-terminal name after the slash that stands for the kind of phrase that has been displaced, and so will eventually expand out as the empty string $\varepsilon$ somewhere below in the expansion of the regular nonterminal. For example, given the "vanilla" rule with nonterminals, $S \Rightarrow \text{NP VP}$, then we can create a "slash" nonterminal: $\text{VP/ NP}$, which denotes the fact that somewhere below in the subtree headed by $VP$, the rule $\text{NP} \Rightarrow \varepsilon$ must be applied. Of course, it must be the case that there is an NP that gets "paired up" with this unpronounced NP (the "filler" for the "gap). So the new, additional rule for expanding $S$ looks like this: $S \Rightarrow \text{NP VP/ NP}$. Here, it is tacitly assumed that the first NP (the Subject) is in fact the "filler" for the "gap" that is represented by the slashed nonterminal $\text{VP/ NP}$.

3. Therefore, whenever a "slash rule" introduces the possibility of a displaced phrase, one must not only add the initial slashed nonterminal and rule, e.g., $\text{VP/ NP}$, one must also add a chain of such rules that terminate in the expansion of NP as $\varepsilon$. For example, given that we have added a new rule $S \Rightarrow \text{NP VP/ NP}$, one must also add rules that expand $\text{VP/ NP}$ with the slash "passed on" beneath the VP. For example, if we have the vanilla rule expanding $VP$ as, say, $VP \text{ NP}$, then we must also add a new rule and slash nonterminal, $\text{VP/ NP} \Rightarrow \text{VB NP/ NP}$, indicating that the NP "gap" (denoted by the slash) has been passed down to the NP on the right. Finally, we have the rule that terminates the 'chain' of slashed rule expansions as $\varepsilon$. For example, in our example sentence, "this student I want to solve the problem", where "this student" has been displaced from its position as the subject of to solve, we...
But never this:

Relative clause
The c-command constraint is central for ‘variable binding’ in human language

S
   NP  VP
     he  V  NP
        likes  John

S
   NP  VP
     he  V  NP
        thinks  S
           NP  VP
                 he  V  NP
                    likes  John

‘he’ cannot be ‘John’

‘he’ can be ‘John’ = "coreference"

S
   NP  VP
     he  V  NP
        ordered  sushi
          Max  V  NP
            said  IP
               he  NP

S
   NP  VP
     Ta  shuo  IP
       NP  VP
         Max  V  NP
           order-ASP  sushi

How do children learn that a particular interpretation must be absent? (How do they pick up on nothing in signal?)

他說，約翰命令壽司
Why can ‘he’ be Max in this sentence?

C-command constraint on variable binding resembles environment frames in programming languages
Constraint on displacement #2: distance

This is OK… what displaced….

Constraint #2: distance

This is NOT OK… what displaced how far?
Blocked! Can’t cross two “environment domains”
Can only go to adjacent domain

One more distance example
What about apparently long-distance links?

A CFG challenge: can you do this with ‘slash’ categories (1 person has, in 20 yrs)

JOHN GAVE MARY AND BILL TO FRED BOOKS THAT LOOKED REMARKABLY SIMILAR
JOHN HUMMED AND MARY SANG AT EQUAL VOLUMES
JOHN HUMMED AND MARY SANG THE SAME TUNE
I HAVE BEEN WONDERING WHETHER BUT WOULD NOT WANT TO STATE THAT YOUR THEORY IS CORRECT
I CAN TELL YOU WHEN BUT I CAN NOT TELL YOU WHY BILL LEFT ME I LIKE BUT BILL DOES NOT LIKE TO VISIT NEW CITIES
JOHN HAS CLAIMED BUT I DO NOT BELIEVE THAT BILL IS A COMMunist
MARY USED TO BE AND BILL STILL IS VERY SUSPICIOUS
MARY SAID SHE WOULD AND BILL ACTUALLY DID EAT A RAW EGGPLANT
BILL MAY BE AND JOHN CERTAINLY IS A WEREWOLF
BILL OFFERED AND MARY GAVE JOHN A CADILLAC
BILL CAUGHT AND MARY KILLED THE RABID DOG
THE WOMAN WHO WAS HERE BELIEVED THAT THE MAN WAS ILL
THE WOMAN BELIEVED THAT THE GUY WHO WAS HERE WAS ILL
THE WOMAN BELIEVED THAT THE GUY WAS ILL WHO WAS HERE
Figure 4: An example of how the PTB annotates displaced phrases. Here the sentence is a topicalized form, The SEC will probably vote on the proposal early next June, he said. Note the empty phrase under the final S, labeled as a T indexed with a 1. This means it is linked to the S which has been displaced to the front, which also has the index 1, along with a topic annotation, -TPC-.

require rules that look something like the following, resulting in the parse structure that is displayed in Figure 3. It should be readily apparent that the sequence of new "slash: nonterminals for a chain that runs down from the introduction of the slash nonterminal – always by a rule where it is adjacent to the actual phrase that corresponds to the displaced phrase – all the way down a "spine" until it reaches a point where the phrase is "discharged" by a rule of the form XP/XP. Note: this means that the displaced phrase will always c-command a gap, as it should be in human language.

Question: what happens to the parsing time? (Hint: think about the new grammar size.)

4. It is even possible to incorporate the idea of feature values to work with the "filler and gap" idea. The method is to introduce a new feature, named GAP, which has as its value the name of the phrase that is being displaced. Then it is this GAP feature that must be given a value (by the displaced NP, S, PP, etc.), and we link displaced phrases (and fillers) to their gaps by means of this feature. This turns out to be very tricky to implement; see Figure 5. The reason is that once one posits the possibility of a GAP feature, then it is hard to keep it under control. (It must be able to handle even sentences with displacement to the right, as in I need, and he wanted, a book about economics.

For another example, in Figure 5, we show the parse tree for What did Obama eat and the corresponding parse tree using "slash" notation.

This isn't the only problem with the use of a variable to "pass around" the information about a displaced phrase. Consider example sentences where there are two displaced phrases, as mentioned earlier, where SSS denotes the place from which these sonatas has been displaced, and VVV denotes the place from which which violins is displaced:

Which violins are these sonatas too difficult to play SSS on VVV

Meaning: For wh-x, x= violins, and is it too di cult for (someone) to play these sonatas on these violins

Furthermore, examples like these illustrate that there is a third type of "unpronounced" element in some sentences, corresponding to an (arbitrary) person or thing that we can call PRO (for Pronoun, but...
Figure 5: The ordinary CFG and "slashed" CFG parse tree for the sentence,

"What did Obama eat?"

In 1995, Carl de Marcken wrote the first paper on designed a head-centric CFG for use in learning CFGs

The Slash `N Burn Answer

The problem is that one can conjoin any two or more phrases of the kind of example by using multiple "slash" features, but the same issues arise.

Returning to the violins-sonatas example with two displaced phrases, in order to represent this in an augmented CFG system, we must use

for the second, augmented name, something like VP/wh-NP/NP, where the 2nd NP in this list after the slash stands for the second, unpronounced) items, which of course cause di

If the reader is interested in a real challenge, the final kind of syntactic structure that poses a di

It should be evident that unpronounced elements need careful treatment within a CFG framework.

We'll return to this point later, but you see that language is full of empty positions after

In its augmented name, something like VP/wh-NP/NP, where the 2nd NP in this list after the slash stands for the second, unpronounced).

What did Obama eat

Note the relationship (you should know this by now: the earlier element must c-command the
“Slash” nonterminals encode state
Consequences for parsing?

How does this enforce the c-command constraint?

---

The Slash `n Burn Answer

```
CP
  Comp
  I
  whNP / NP / VP
  |  |  |  |
  |  |  |  | / I'
  |  |  |  | / NP
  |  |  |  | / VP
  |  |  |  | / did
  |  |  |  | / Obama
  |  |  |  | / V
  |  |  |  | / eat
  |  |  |  | / εi
  |  |  |  | / VP/NP
  |  |  |  | / did
  |  |  |  | / Obama
  |  |  |  | / V
  |  |  |  | / NP/NP
  |  |  |  | / see
  |  |  |  | / ε
```
Feature grammar with slash feature

S[-INV] -> NP VP
S[-INV] -> NP S/NP
S[-INV] -> Adv [+NEG] S[+INV]
S[+INV] -> V[+AUX] NP VP
S[+INV]/?x -> V[+AUX] NP VP/?x
SBar -> Comp S[-INV]
SBar/?x -> Comp S[-INV]/?x
VP -> V[SUBCAT=intrans, -AUX]
VP -> V[SUBCAT=trans, -AUX] NP
VP/?x -> V[SUBCAT=trans, -AUX] NP/?x
VP -> V[SUBCAT=clause, -AUX] SBar
VP/?x -> V[SUBCAT=clause, -AUX] SBar/?x
VP -> V[+AUX] VP
VP/?x -> V[+AUX] VP/?x

V[SUBCAT=intrans, -AUX] -> 'sing'
V[SUBCAT=trans, -AUX] -> 'like'
V[SUBCAT=clause, -AUX] -> 'say'
V[+AUX] -> 'do' | 'can'
NP[-WH] -> 'you' | 'cats'
NP[+WH] -> 'who'
Adv[+NEG] -> 'rarely' | 'never'
NP/NP -> Comp -> 'that'

Using features for fillers and gaps

“Slash” feature with values NP, PP, etc.

How does this grammar obey c-command?
How does this grammar obey distance constraint?
The Problems with PCFGs

- Two: independence conditions are too strong
- They cannot model non-local dependencies

What it means to be ‘context-free’

- Expansion of a particular rule just depends on itself, not on surrounding context
- Example

<table>
<thead>
<tr>
<th></th>
<th>Pronoun</th>
<th>Not Pronoun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>91%</td>
<td>0.09%</td>
</tr>
<tr>
<td>Object</td>
<td>35%</td>
<td>66%</td>
</tr>
</tbody>
</table>

Data from Switchboard (31,021 declarative S’s)
How could we represent this choice?

\[
\begin{align*}
\text{NP} & \rightarrow \text{DT} \text{ NN} 0.28 \\
\text{NP} & \rightarrow \text{PRP} 0.25
\end{align*}
\]

But…PCFGs don’t allow conditioning on context….

We want something like this:

\[
\begin{align*}
\text{NP} & \rightarrow \text{DT} \text{ NN} 0.09 \\
\text{NP} & \rightarrow \text{PRP} 0.91 \\
\text{NP}_{\text{subject}} & \rightarrow \text{DT} \text{ NN} 0.09 \\
\text{NP}_{\text{object}} & \rightarrow \text{PRP} 0.91
\end{align*}
\]

Implementation

```
S
   /\  \
NP-S  VP-S
     /\    /
    he  V-VP NP-VP
      /\  /
     likes the guy
```

“vertical Markovization”

Is this enough? Are there problems? Can we do more?
PCFG Problem #2: not sensitive to actual words

- Wait until last moment to expand words, and this is done independent of context
- But words can help us tell which previous expansions to use…
- Eg: *ate the ice-cream with a fork/* eat the ice-cream with chocolate toppings
- One solution…

Adding lexical ‘heads’ to CF rules (De Marken, 1995)

\[
S \rightarrow NP \quad VP \\
NP \rightarrow DT \quad NN \\
\quad \text{the} \quad \text{dog} \\
VP \rightarrow V \\
\quad \text{saw} \\
\]

\[
S(\text{saw}) \rightarrow NP(\text{dog}) \quad VP(\text{saw}) \\
NP(\text{dog}) \rightarrow DT \quad NN(\text{dog}) \\
\quad \text{the} \quad \text{dog} \\
VP(\text{saw}) \rightarrow V \\
\quad \text{saw} \\
NP(\text{guy}) \rightarrow DT \quad NN(\text{guy}) \\
\quad \text{the} \\
\]

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But before we can see how to do this..

- We must develop methods for estimating probabilities of productions from pre-parsed corpus
- So far, we have just sketched MLE idea, but it won’t work w/o more clever estimation and smoothing
- First step: see how to do this with linear system, e.g., HMMs.