Outline of today's lecture

Lecture 4: Context-free grammars and parsing

- Generative grammar
- Simple context free grammars
- Simple chart parsing with CFGs
- Probabilistic CFGs
- Formalism power requirements

Parsing

Modelling syntactic structure of phrases and sentences.

Why is it useful?

- as a step in assigning semantics
- checking grammaticality
- applications: e.g. produce features for classification in sentiment analysis
- lexical acquisition

Generative grammar

a formally specified grammar that can generate all and only the acceptable sentences of a natural language

Internal structure:

the big dog slept

can be bracketed

((the (big dog)) slept)

constituent a phrase whose components form a coherent unit

The internal structures are typically given labels, e.g. *the big dog* is a noun phrase (NP) and *slept* is a verb phrase (VP)

Context free grammars

1. a set of non-terminal symbols (e.g., S, VP);
2. a set of terminal symbols (i.e., the words);
3. a set of rules (productions), where the LHS (mother) is a single non-terminal and the RHS is a sequence of one or more non-terminal or terminal symbols (daughters);

   ```
   S -> NP VP
   V -> fish
   ```

4. a start symbol, conventionally S, which is a non-terminal.

Exclude empty productions, NOT e.g.:

NP -> ϵ

A simple CFG for a fragment of English

rules

```
S -> NP VP
VP -> VP PP
VP -> V
VP -> V NP
VP -> V VP
NP -> NP PP
PP -> P NP
```

lexicon

```
V -> can
V -> fish
NP -> fish
NP -> rivers
NP -> pools
NP -> December
NP -> Scotland
NP -> it
NP -> they
P -> in
```

Analyses in the simple CFG

they fish

(S (NP they) (VP (V fish)))

they can fish

(S (NP they) (VP (V can) (VP (V fish))))

(S (NP they) (VP (V can) (NP fish)))

they fish in rivers

(S (NP they) (VP (VP (V fish))
(PP (P in) (NP rivers))))

Analyses in the simple CFG

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they fish in rivers

(S (NP they) (VP (VP (V fish))
(PP (P in) (NP rivers))))

Structural ambiguity without lexical ambiguity

they fish in rivers in December

```
(S (NP they)
   (VP (VP (VP (V fish))
               (PP (P in) (NP rivers)))
         (PP (P in) (NP December))))
```

```
(S (NP they)
   (VP (VP (V fish))
         (PP (P in) (NP rivers)
                   (PP (P in) (NP December)))))
```

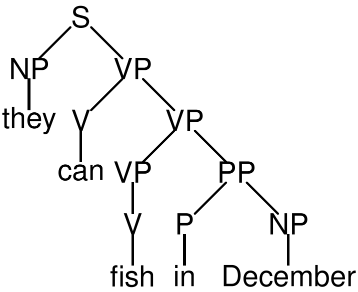
Structural ambiguity without lexical ambiguity

they fish in rivers in December

```
(S (NP they)
   (VP (VP (VP (V fish))
               (PP (P in) (NP rivers)))
        (PP (P in) (NP December))))

(S (NP they)
   (VP (VP (V fish))
        (PP (P in) (NP rivers)
                   (PP (P in) (NP December)))))
```

Parse trees




```
(S  (NP  they)
    (VP  (V  can)
         (VP  (VP  (V  fish))
              (PP  (P  in)
                   (NP  December)))))
```

Chart parsing

chart store partial results of parsing in a vector

edge representation of a rule application

Edge data structure:

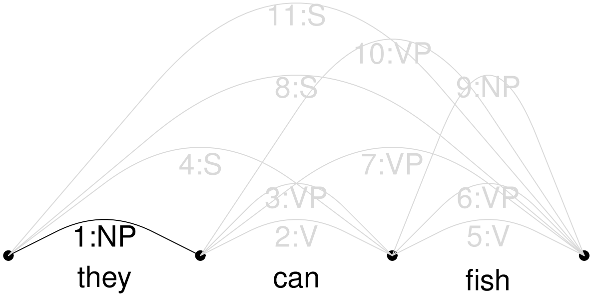
[*id*,*left_vtx*, *right_vtx*,*mother_category*, *dtrs*]

```
. they . can . fish .
0       1     2      3
```

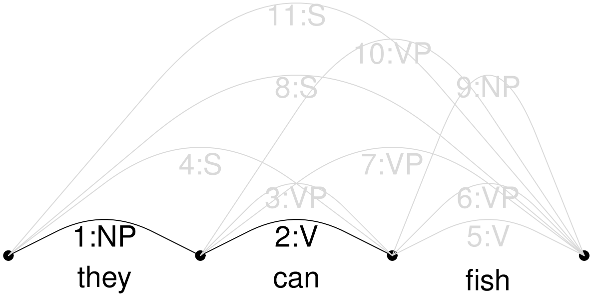
Fragment of chart:

id	left	right	mother	daughters
1	0	1	NP	(they)
2	1	2	V	(can)
3	1	2	VP	(2)
4	0	2	S	(1 3)

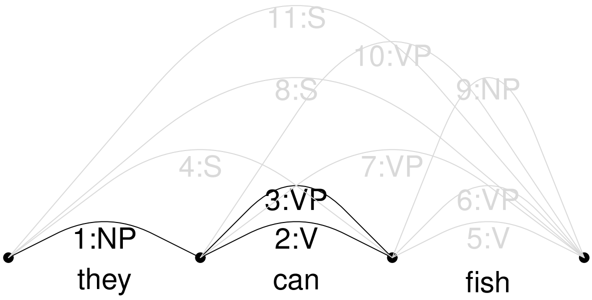
Bottom up parsing: edges



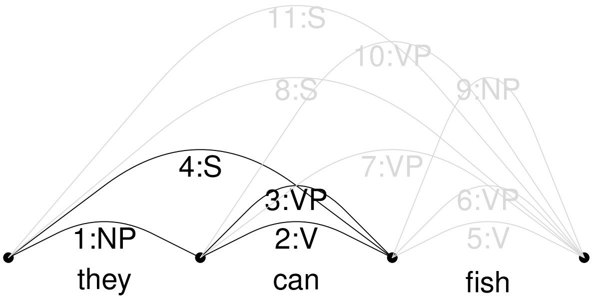
Bottom up parsing: edges



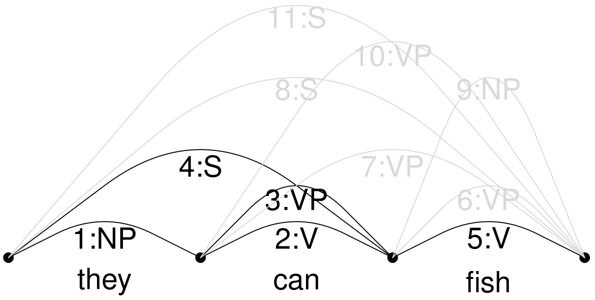
Bottom up parsing: edges



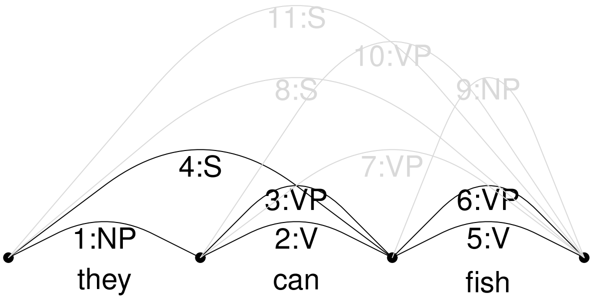
Bottom up parsing: edges



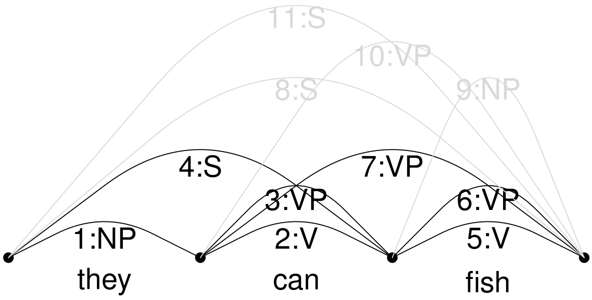
Bottom up parsing: edges



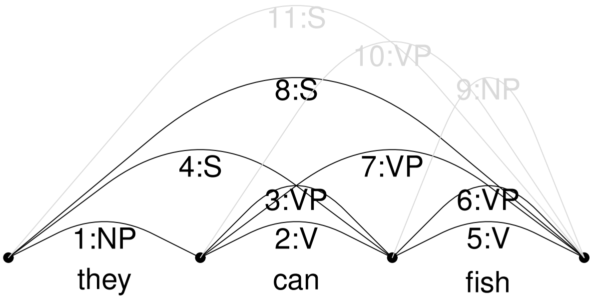
Bottom up parsing: edges



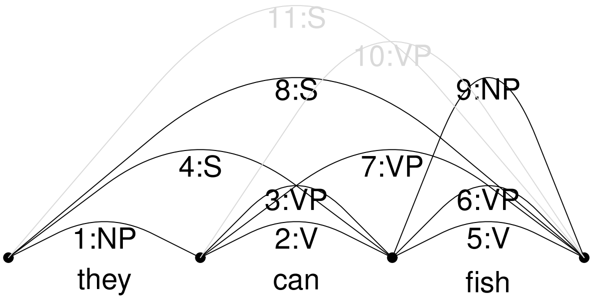
Bottom up parsing: edges



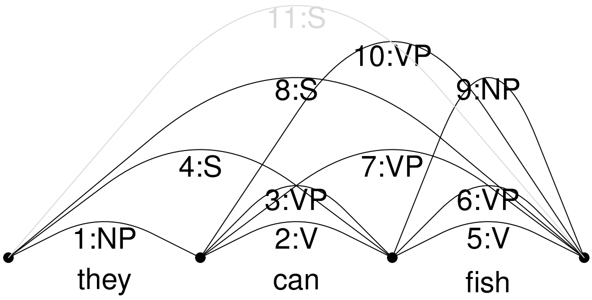
Bottom up parsing: edges



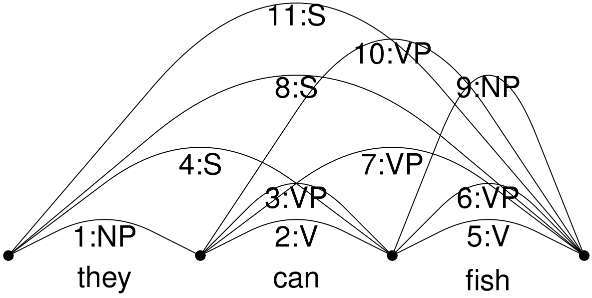
Bottom up parsing: edges



Bottom up parsing: edges



Bottom up parsing: edges



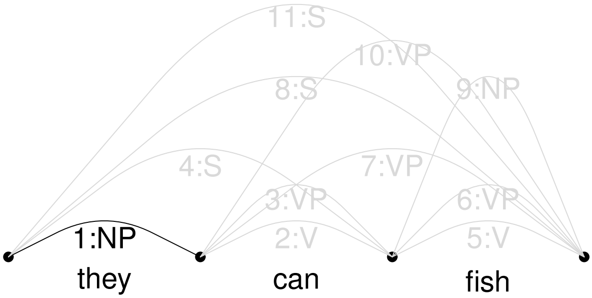
A bottom-up passive chart parser

Parse:
Initialize the chart
For each word *word*, let *from* be left vtx,
to right vtx and *dtrs* be (*word*)
For each category *category*
lexically associated with *word*
Add new edge *from*, *to*, *category*, *dtrs*
Output results for all spanning edges

Inner function

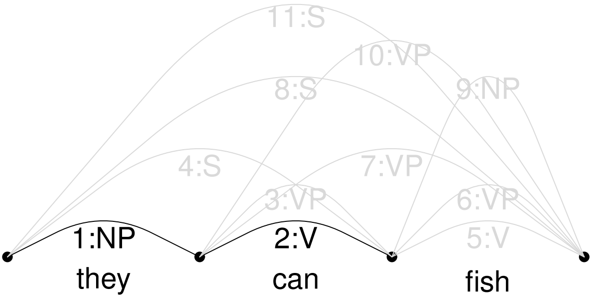
Add new edge *from*, *to*, *category*, *dtrs*:
Put edge in chart: [*id*,*from*,*to*, *category*,*dtrs*]
For each *rule* $lhs \rightarrow cat_1 \ldots cat_{n-1}, category$
Find sets of contiguous edges
$[id_1, from_1, to_1, cat_1, dtrs_1] \ldots$
$[id_{n-1}, from_{n-1}, from, cat_{n-1}, dtrs_{n-1}]$
(such that $to_1 = from_2$ etc)
For each set of edges,
Add new edge $from_1$, *to*, *lhs*, $(id_1 \ldots id)$

Parse construction



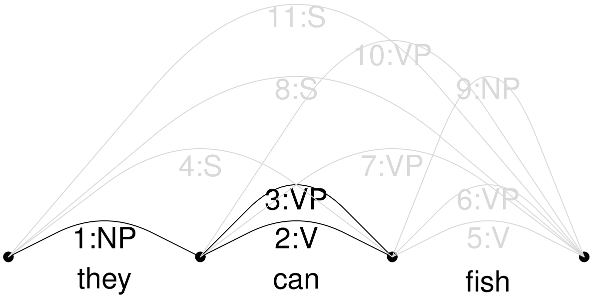
word = they, categories = {NP}
Add new edge 0, 1, NP, (they)
Matching grammar rules: {VP→V NP, PP→P NP}
No matching edges corresponding to V or P

Parse construction



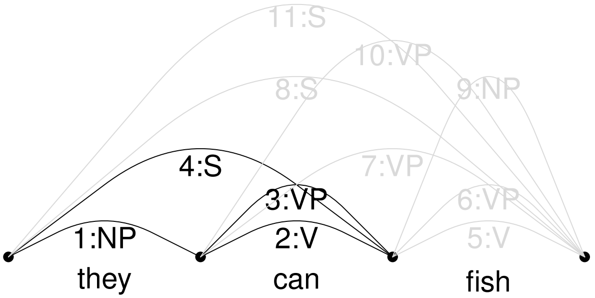
word = can, categories = {V}
Add new edge 1, 2, V, (can)
Matching grammar rules: {VP→V}
recurse on edges {(2)}

Parse construction



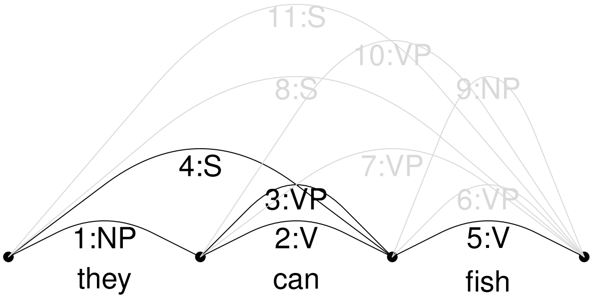
Add new edge 1, 2, VP, (2)
Matching grammar rules: {S→NP VP, VP→V VP}
recurse on edges {(1,3)}

Parse construction



Add new edge 0, 2, S, (1, 3)
No matching grammar rules for S
Matching grammar rules: {S→NP VP, VP→V VP}
No edges for V VP

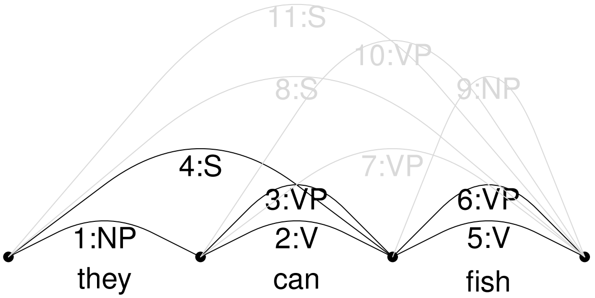
Parse construction



word = fish, categories = {V, NP}
Add new edge 2, 3, V, (fish)
Matching grammar rules: {VP→V}
recurse on edges {(5)}

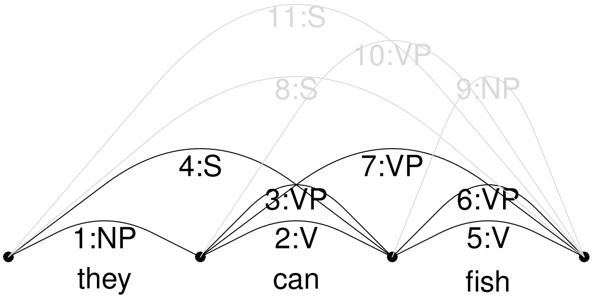
NB: fish as V

Parse construction



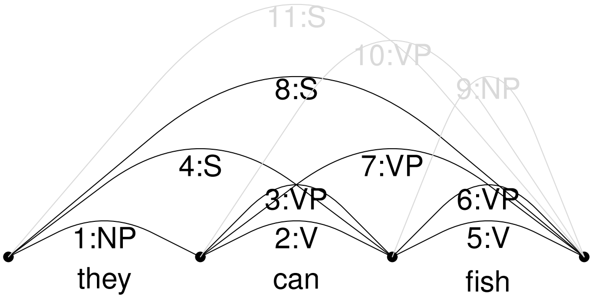
Add new edge 2, 3, VP, (5)
Matching grammar rules: {S →NP VP, VP →V VP}
No edges match NP
recurse on edges for V VP: {(2,6)}

Parse construction



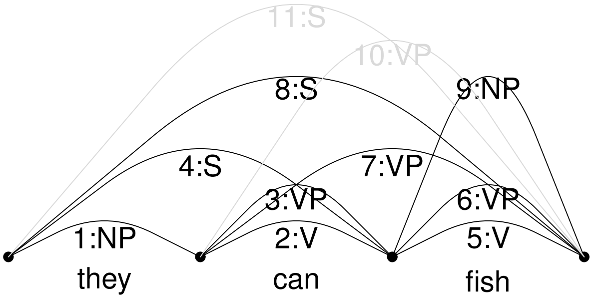
Add new edge 1, 3, VP, (2, 6)
Matching grammar rules: {S→NP VP, VP→V VP}
recurse on edges for NP VP: {(1,7)}

Parse construction



Add new edge 0, 3, S, (1, 7)
No matching grammar rules for S
Matching grammar rules: {S→NP VP, VP →V VP}
No edges matching V

Parse construction

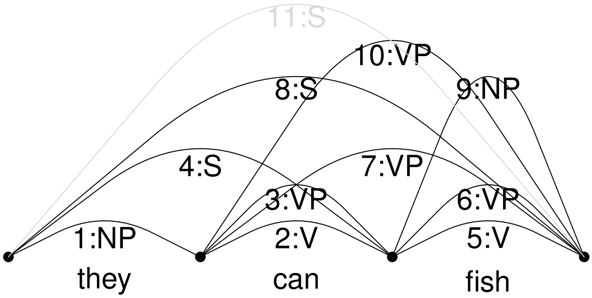


Add new edge 2, 3, NP, (fish) NB: fish as NP

Matching grammar rules: {VP→V NP, PP→P NP}

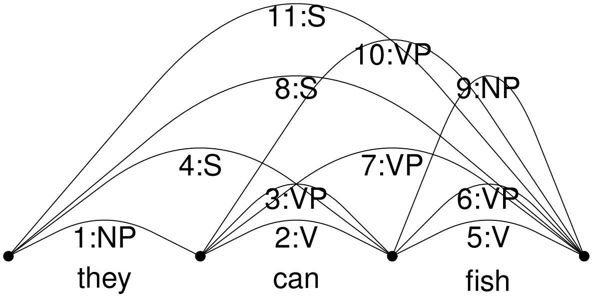
recurse on edges for V NP {(2,9)}

Parse construction



Add new edge 1, 3, VP, (2, 9)
Matching grammar rules: {S→NP VP, VP→V VP}
recurse on edges for NP VP: {(1, 10)}

Parse construction



Add new edge 0, 3, S, (1, 10)
No matching grammar rules for S
Matching grammar rules: {S→NP VP, VP→V VP}
No edges corresponding to V VP
Matching grammar rules: {VP→V NP, PP→P NP}
No edges corresponding to P NP

Resulting chart

```
. they . can . fish .
0      1     2      3
```

id	left	right	mother	daughters
1	0	1	NP	(they)
2	1	2	V	(can)
3	1	2	VP	(2)
4	0	2	S	(1 3)
5	2	3	V	(fish)
6	2	3	VP	(5)
7	1	3	VP	(2 6)
8	0	3	S	(1 7)
9	2	3	NP	(fish)
10	1	3	VP	(2 9)
11	0	3	S	(1 10)

Output results for spanning edges

Spanning edges are 8 and 11:
Output results for 8

```
(S (NP they) (VP (V can) (VP (V fish))))
```

Output results for 11

```
(S (NP they) (VP (V can) (NP fish)))
```

Note: sample chart parsing code in Java is downloadable from the course web page.

Packing

To make parsing more efficient:

- don't add equivalent edges as whole new edges
- *dtrs* is a set of lists of edges (to allow for alternatives)

about to add: [*id*,*l_vtx*, *right_vtx*,*ma_cat*, *dtrs*]
and there is an existing edge:

[*id-old*,*l_vtx*, *right_vtx*,*ma_cat*, *dtrs-old*]

we simply modify the old edge to record the new dtrs:

[*id-old*,*l_vtx*, *right_vtx*,*ma_cat*, *dtrs-old* ∪ *dtrs*]

and do not recurse on it: never need to continue computation with a packable edge.

Packing example

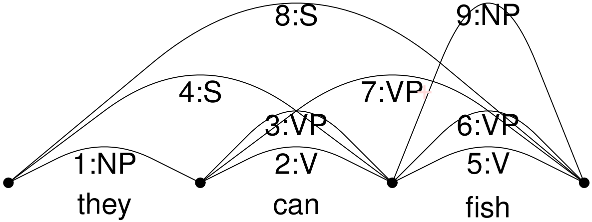
1	0	1	NP	{(they)}
2	1	2	V	{(can)}
3	1	2	VP	{(2)}
4	0	2	S	{(1 3)}
5	2	3	V	{(fish)}
6	2	3	VP	{(5)}
7	1	3	VP	{(2 6)}
8	0	3	S	{(1 7)}
9	2	3	NP	{(fish)}

Instead of edge `10 1 3 VP {(2 9)}`

`7 1 3 VP {(2 6), (2 9)}`

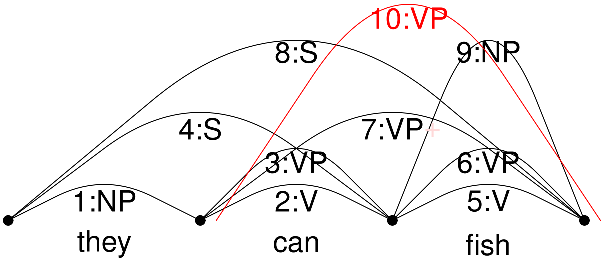
and we're done

Packing example



Both spanning results can now be extracted from edge 8.

Packing example



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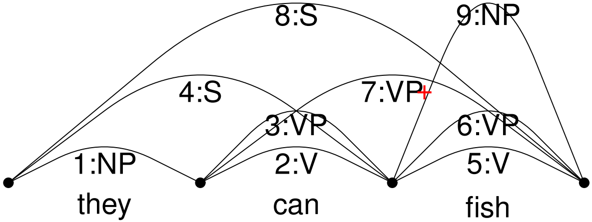
Packing example



Both spanning results can now be extracted from edge 8.

Producing n-best parses

- manual weight assignment
- probabilistic CFG — trained on a treebank
  - automatic grammar induction
  - automatic weight assignment to existing grammar
- beam-search

Why not FSA?

centre-embedding:

$$A \rightarrow \alpha A \beta$$

generate grammars of the form $a^n b^n$.
For instance:

the students the police arrested complained

However, limits on human memory / processing ability:

? the students the police the journalists criticised arrested complained

More importantly:

- Without internal structure, we can't build good semantic representations

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More importantly:

- Without internal structure, we can't build good semantic representations

Overgeneration in atomic category CFGs

- agreement: subject verb agreement. e.g., *they fish*, *it fishes*, **it fish*, **they fishes*. * means ungrammatical
- case: pronouns (and maybe *who/whom*) e.g., *they like them*, **they like they*

```
S -> NP-sg-nom VP-sg          NP-sg-nom -> he
S -> NP-pl-nom VP-pl          NP-sg-acc -> him
VP-sg -> V-sg NP-sg-acc       NP-sg-nom -> fish
VP-sg -> V-sg NP-pl-acc       NP-pl-nom -> fish
VP-pl -> V-pl NP-sg-acc       NP-sg-acc -> fish
VP-pl -> V-pl NP-pl-acc       NP-pl-acc -> fish
```

BUT: very large grammar, misses generalizations, no way of saying when we don't care about agreement.

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S  -> NP-sg-nom VP-sg          NP-sg-nom -> he
S  -> NP-pl-nom VP-pl          NP-sg-acc -> him
VP-sg -> V-sg NP-sg-acc        NP-sg-nom -> fish
VP-sg -> V-sg NP-pl-acc        NP-pl-nom -> fish
VP-pl -> V-pl NP-sg-acc        NP-sg-acc -> fish
VP-pl -> V-pl NP-pl-acc        NP-pl-acc -> fish
```

BUT: very large grammar, misses generalizations, no way of saying when we don't care about agreement.

Subcategorization

- intransitive vs transitive etc
- verbs (and other types of words) have different numbers and types of syntactic arguments:

  **Kim adored*
  **Kim gave Sandy*
  **Kim adored to sleep*
  Kim liked to sleep
  **Kim devoured*
  Kim ate
- Subcategorization is correlated with semantics, but not determined by it.

Overgeneration because of missing subcategorization

Overgeneration:

they fish fish it
(S (NP they) (VP (V fish) (VP (V fish) (NP it))))

- Informally: need slots on the verbs for their syntactic arguments.
  - intransitive takes no following arguments (complements)
  - simple transitive takes one NP complement
  - *like* may be a simple transitive or take an infinitival complement, etc

Long-distance dependencies

1. which problem did you say you don't understand?
2. who do you think Kim asked Sandy to hit?
3. which kids did you say were making all that noise?

'gaps' (underscores below)

1. which problem did you say you don't understand _?
2. who do you think Kim asked Sandy to hit _?
3. which kids did you say _ were making all that noise?

In 3, the verb *were* shows plural agreement.

* what kid did you say _ were making all that noise?

The gap filler has to be plural.

- Informally: need a 'gap' slot which is to be filled by something that itself has features.