Natural Language Processing 1

Lecture 3: Modelling structure: morphology and syntax

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Outline of today's lecture

Morphology and finite state techniques

Formal grammars and syntactic parsing

Outline.

Morphology and finite state techniques

Formal grammars and syntactic parsing

Stems and affixes

- morpheme: the minimal information carrying unit
- affix: morpheme which only occurs in conjunction with other morphemes
- words made up of stem (more than one for compounds) and zero or more affixes.
  e.g., *dog+s*, *book+shop+s*
- *slither*, *slide*, *slip* etc have somewhat similar meanings, but *sl-* not a morpheme.

Affixation

- **suffix**: *dog +s*, *truth +ful*
- **prefix**: *un+ wise* (derivational only)
- **infix**: Arabic stem *k_t_b*: *kataba* (he wrote); *kotob* (books)
  In English: *sang* (stem *sing*): not productive
  e.g., (maybe) *absobloodylutely*
- **circumfix**: not in English
  German *ge+kauf+t* (stem *kauf*, affix *ge-t*)

Productivity

productivity: whether affix applies generally, whether it applies to new words
sing, *sang*, *sung*
ring, *rang*, *rung*
BUT: *ping*, *pinged*, *pinged*
So this infixation pattern is not productive:
sing, *ring* are irregular

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Inflectional morphology

- e.g., plural suffix *+s*, past participle *+ed*
- sets slots in some paradigm
  e.g., tense, aspect, number, person, gender, case
- inflectional affixes are not combined in English
- generally fully productive (except irregular forms)
  e.g., *texted*

Derivational morphology

- e.g., *un-*, *re-*, *anti-*, *-ism*, *-ist* etc
- broad range of semantic possibilities, may change part of speech
- indefinite combinations
  e.g., *antiantidisestablishmentarianism*
  anti-anti-dis-establish-ment-arian-ism
- generally semi-productive: e.g., *escapee*, *textee*, *?dropee*, *?snoree*, **cricketee* (* and ?)
- zero-derivation: e.g. *tango*, *waltz*

Guess the structure...

- ruined
- settlement
- inventive
- archive
- unionised

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Internal structure and ambiguity

Morpheme ambiguity: stems and affixes may be individually ambiguous: e.g. *dog* (noun or verb), *+s* (plural or 3persg-verb)

Structural ambiguity: e.g., *shorts* or *short -s*
unionised could be *union -ise -ed* or *un- ion -ise -ed*

Bracketing: *un- ion -ise -ed*

- **((un- ion) -ise) -ed*
- *un- ((ion -ise) -ed)*

Using morphological processing in NLP

- compiling a full-form lexicon
- stemming for IR (not linguistic stem)
- lemmatization, i.e. morphological analysis:
  - finding stems and affixes as a precursor to parsing (often inflections only)
- generation
  - Morphological processing may be bidirectional: i.e., parsing and generation.

```
party + PLURAL <-> parties
sleep + PAST_VERB <-> slept
```

Compiling a full form lexicon

run
runs
ran
running

Compiling a full form lexicon

run
runs
ran
running

Бегаю
Бегу
Бегаешь
Бежишь
Бегает
Бежит
Бегаем
Бежим
Бегаете
Бежите
Бегают
Бегут

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Morphological processing

Surface form mapped to stem(s) and affixes (or abstractions of affixes):

OPTION 1	*pinged / ping-ed*
OPTION 2	*pinged / ping PAST_VERB* *pinged / ping PSP_VERB* *sang / sing PAST_VERB* *sung / sing PSP_VERB*

Lexical requirements for morphological processing

- affixes, plus the associated information conveyed by the affix

  ```
  ed PAST_VERB
  ed PSP_VERB
  s PLURAL_NOUN
  ```

- irregular forms, with associated information similar to that for affixes

  ```
  began PAST_VERB begin
  begun PSP_VERB begin
  ```

- stems with syntactic categories
  e.g. to avoid *corpus* being analysed as *corpu -s*

Spelling rules

- English morphology is essentially concatenative
  - irregular morphology — inflectional forms have to be listed
- regular phonological and spelling changes associated with affixation, e.g.
  - *-s* is pronounced differently with stem ending in *s*, *x* or *z*
  - spelling reflects this with the addition of an *e* (*boxes* etc)
- in English, description is independent of particular stems/affixes

e-insertion

e.g. *box^s* to *boxes*

$$\varepsilon \rightarrow \mathrm{e} / \left\{ \begin{array}{c} \mathrm{s} \\ \mathrm{x} \\ \mathrm{z} \end{array} \right\} \hat{}\ \_\ s$$

- map 'underlying' form to surface form
- mapping is left of the slash, context to the right
- notation:

_	position of mapping
ε	empty string
^	affix boundary — stem ^ affix

- same rule for plural and 3sg verb
- formalisable/implementable as a finite state transducer

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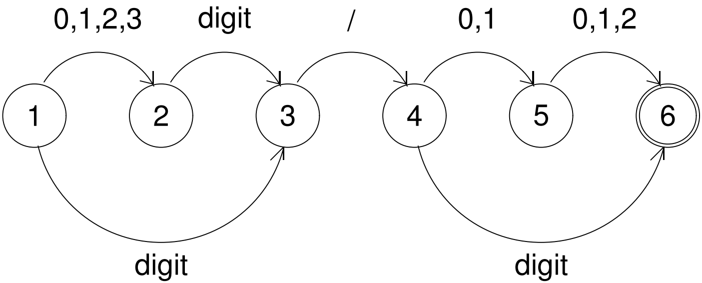
Finite state automata for recognition

day/month pairs: e.g. 12/2, 1/12 etc.



- non-deterministic — after input of ‘2’, in state 2 and state 3.
- double circle indicates accept state
- accepts e.g., 11/3 and 3/12
- also accepts 37/00 — overgeneration

e-insertion

e.g. *box^s* to *boxes*

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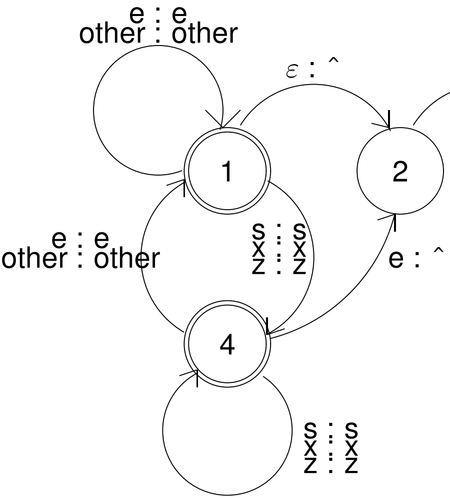
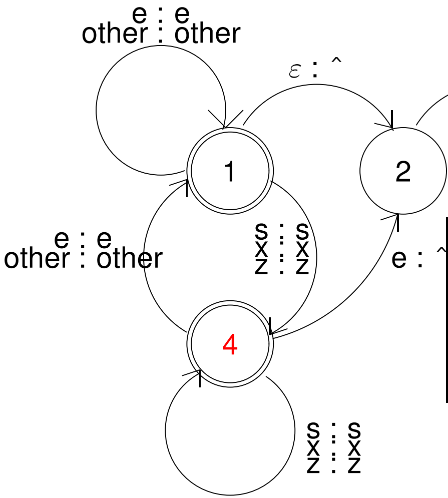
Finite state transducer



$$\varepsilon \rightarrow e/ \left\{\begin{array}{c} s\\ x\\ z \end{array}\right\} \hat{}\ \_\ s$$

surface : underlying
c a k e s ↔ c a k e ^ s
b o x e s ↔ b o x ^ s

Analysing *b o x e s*



Input: b o x e s
Accept output: b o x ^ s
Accept output: b o x e s
Input: b o x e ϵ s
Accept output: b o x e ^ s

Using FSTs

- FSTs assume tokenization (word boundaries) and words split into characters. One character pair per transition!
- **Analysis**: return character list with affix boundaries, so enabling lexical lookup.
- **Generation**: input comes from stem and affix lexicons.
- One FST per spelling rule: either compile to big FST or run in parallel.
- FSTs do not allow for internal structure:
  - can't model *un- ion -ize -d* bracketing.

How is morphological processing implemented?

- rule-based methods, e.g. the Porter stemmer
  - part of NLTK toolkit
  - used in the practical
- probabilistic models for morphological segmentation
- neural models with character-level input
  (discussed later in the course)

Outline.

Morphology and finite state techniques

Formal grammars and syntactic parsing

Why is syntax important?

- Last time we saw models of word sequences – n-grams
- Why is this insufficient?
- Because language has long-distance dependencies:

  The computer which I had just put into the machine room on the fifth floor is crashing.

- We want models that can capture these dependencies.

Syntactic 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

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)

Phrases and substitutability

- POS categories indicate which *words* are substitutable. For e.g., substituting adjectives:

  I saw a red cat

  I saw a sleepy cat

- Phrasal categories indicate which *phrases* are substitutable. For e.g., substituting noun phrases:

  Dogs sleep soundly
  My next-door neighbours sleep soundly
  Green ideas sleep soundly

- Examples of phrasal categories: Noun Phrase (NP), Verb Phrase (VP), Prepositional Phrase (PP), etc.

  We want to capture substitutability at the phrasal level!

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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.:

$$\text{NP} \texttt{ -> } \epsilon$$

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))))

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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))
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Structural ambiguity without lexical ambiguity

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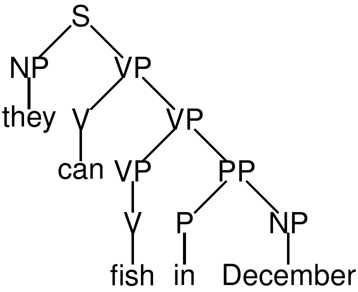

Parse trees




```
(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:

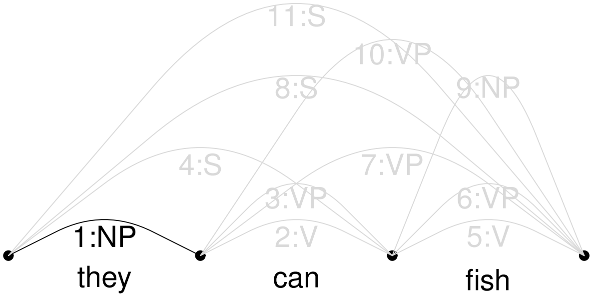
[*id*,*left_vtx*, *right_vtx*,*mother_category*, *dtrs*]

```
. 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



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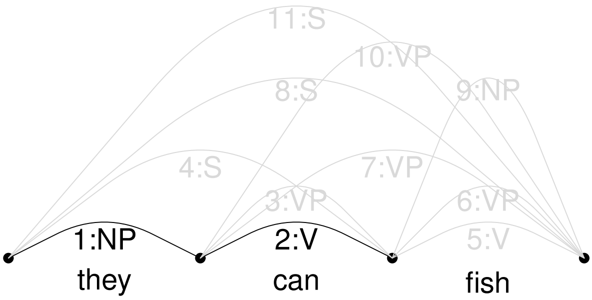

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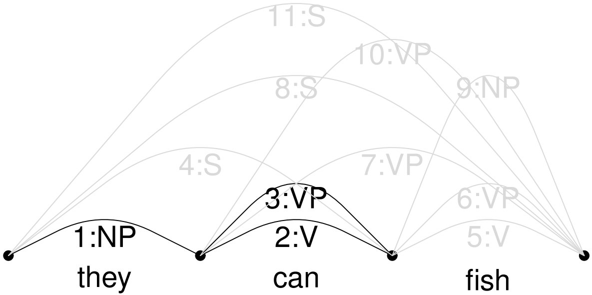

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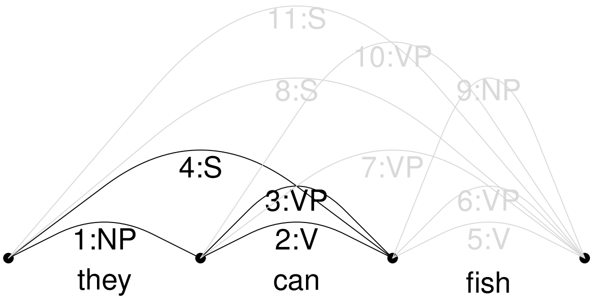

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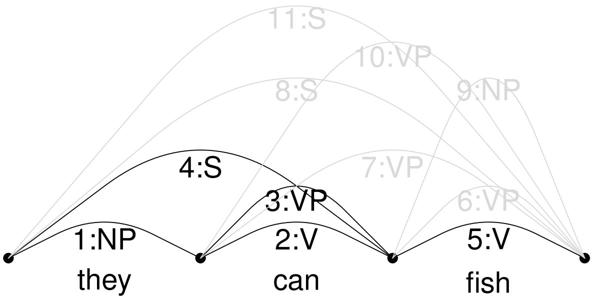
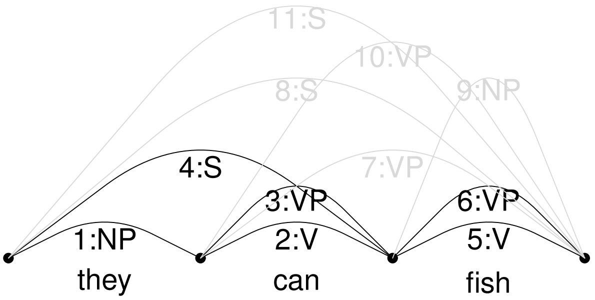
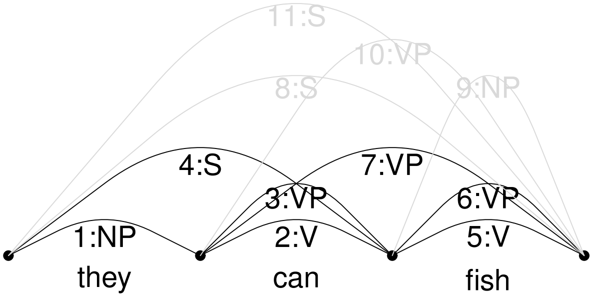


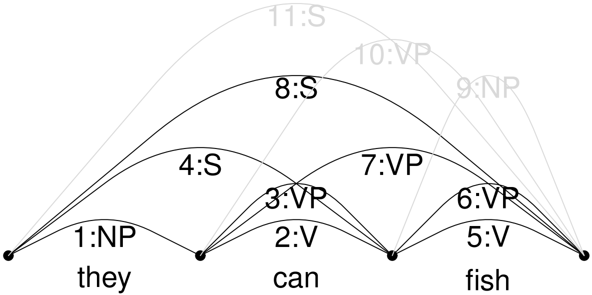
Bottom up parsing: edges



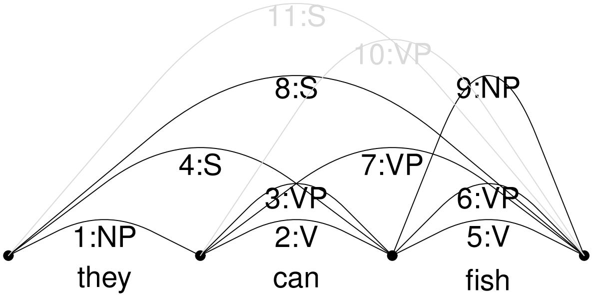
Bottom up parsing: edges



Bottom up parsing: edges



Bottom up parsing: edges



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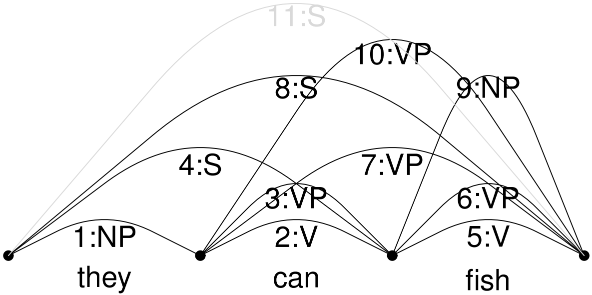

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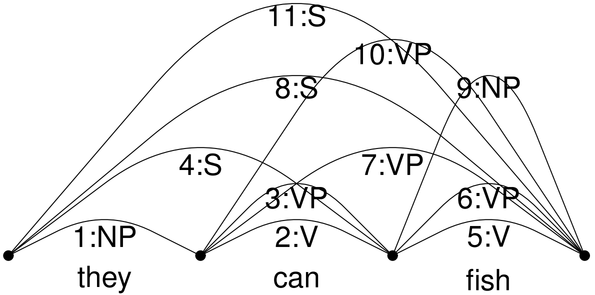


A bottom-up chart parser

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,$dtrs_1$] ...

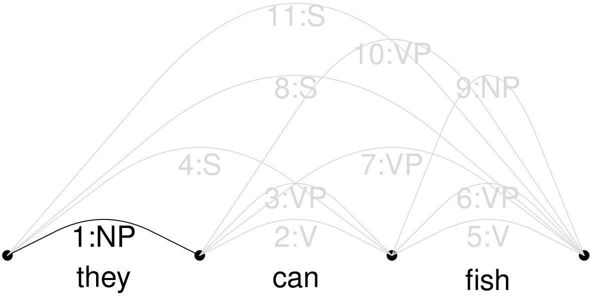
[id_{n-1},$from_{n-1}$,*from*, cat_{n-1},$dtrs_{n-1}$]

(such that $to_1 = from_2$ etc)

For each set of edges,

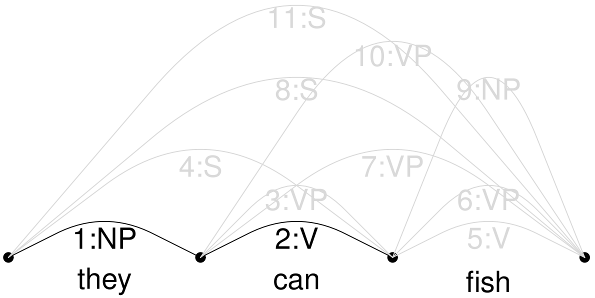
Add new edge $from_1$, *to*, *lhs*, ($id_1 \ldots id$)

Parse construction



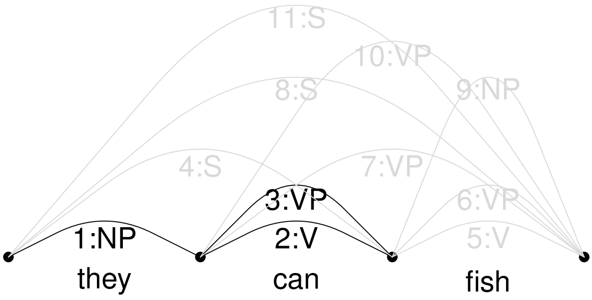
word = they, categories = {NP}
Add new edge 0, 1, NP, (they)
Matching grammar rules: {VP→V NP, PP→P NP}
No matching edges corresponding to V or P

Parse construction



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

Parse construction

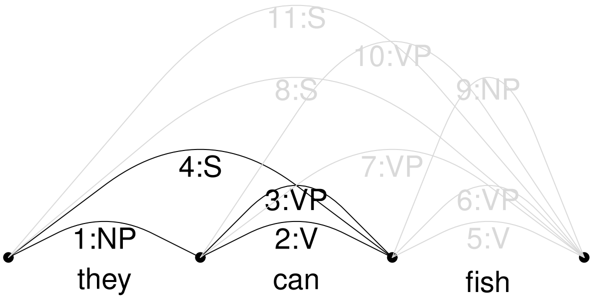


Add new edge 1, 2, VP, (2)

Matching grammar rules: {S→NP VP, VP→V VP}

recurse on edges {(1,3)}

Parse construction



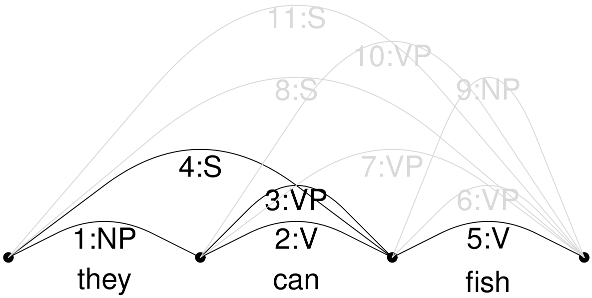
Add new edge 0, 2, S, (1, 3)

No matching grammar rules for S

Matching grammar rules: {S→NP VP, VP→V VP}

No edges for V VP

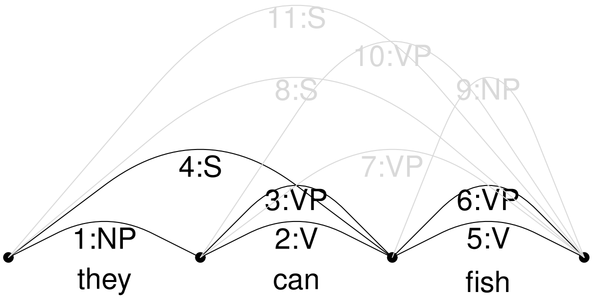
Parse construction



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

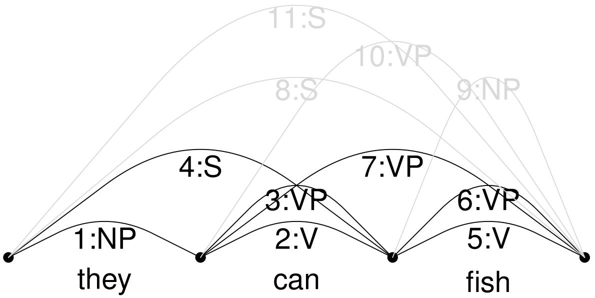
NB: fish as V

Parse construction



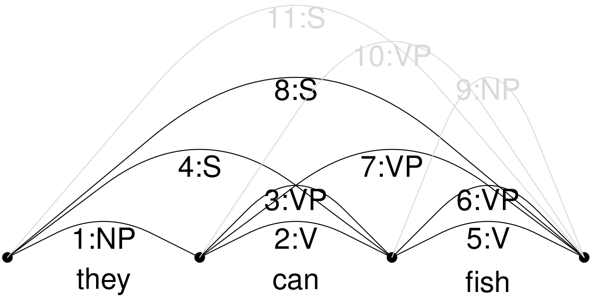
Add new edge 2, 3, VP, (5)
Matching grammar rules: {S →NP VP, VP →V VP}
No edges match NP
recurse on edges for V VP: {(2,6)}

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



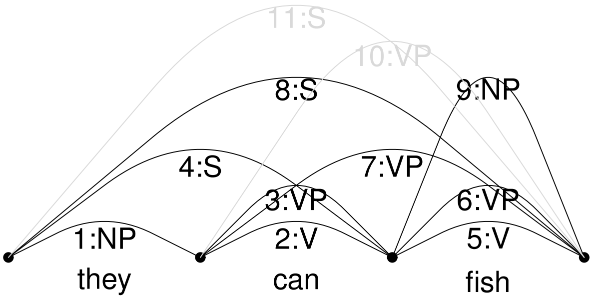
Add new edge 0, 3, S, (1, 7)

No matching grammar rules for S

Matching grammar rules: {S→NP VP, VP →V VP}

No edges matching V

Parse construction



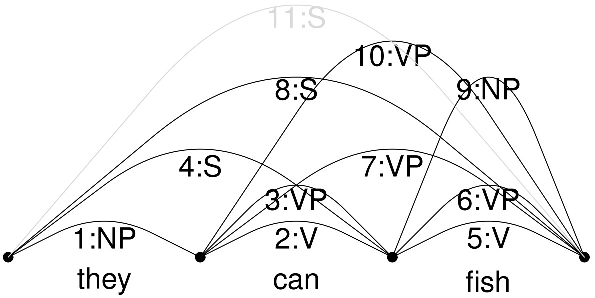
Add new edge 2, 3, NP, (fish)

NB: fish as NP

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

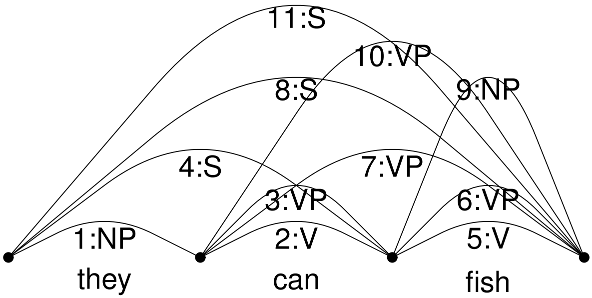
recurse on edges for V NP {(2,9)}

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)))
```

Acknowledgement

Some slides were adapted from Ann Copestake and Tejaswini Deoskar