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The CKY algorithm part 1: Recognition

Syntactic analysis (5LN455)

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Mostly based on slides from Marco Kuhlmann

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Recap: Parsing

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Parsing

The automatic analysis of a sentence
with respect to its syntactic structure.

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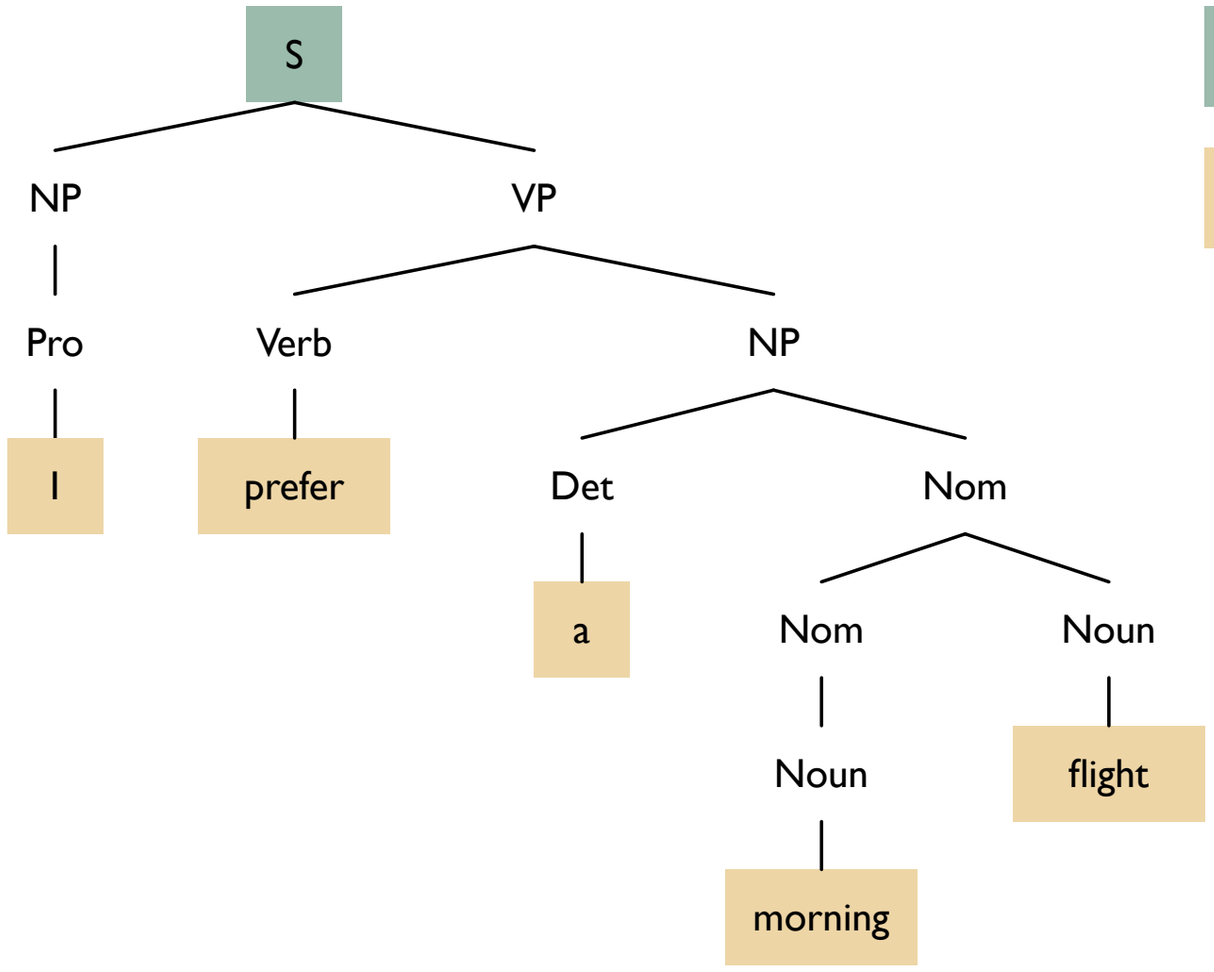
Phrase structure trees



root (top)

leaves (bottom)

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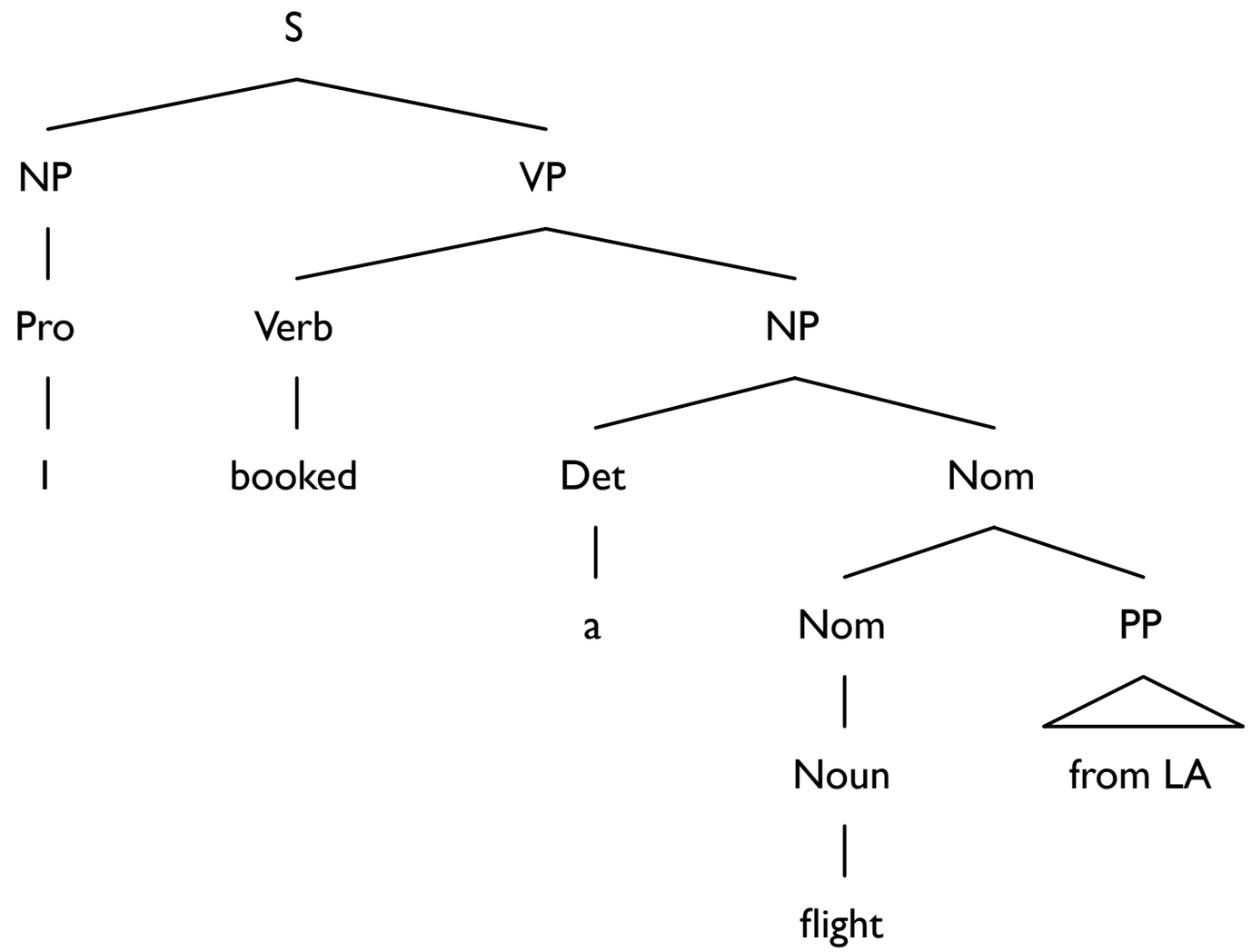
Ambiguity



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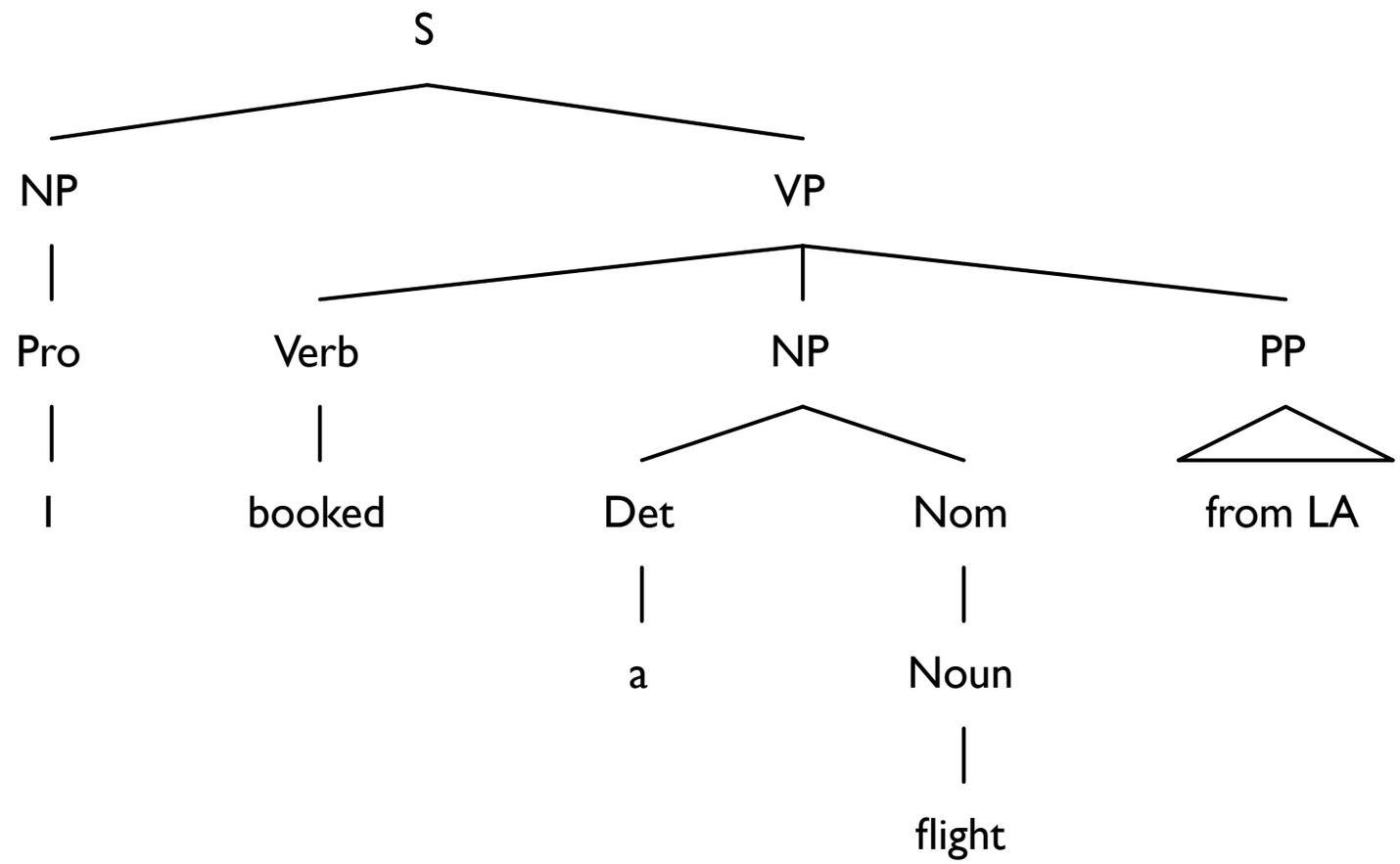
Ambiguity



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Parsing as search

- Parsing as search:
  search through all possible parse trees for a given sentence
- bottom–up:
  build parse trees starting at the leaves
- top–down:
  build parse trees starting at the root node

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Overview of the CKY algorithm

- The CKY algorithm is an efficient bottom-up parsing algorithm for context-free grammars.
- It was discovered at least three (!) times and named after Cocke, Kasami, and Younger.
- It is one of the most important and most used parsing algorithms.

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Applications

The CKY algorithm can be used to compute many interesting things.
Here we use it to solve the following tasks:

- **Recognition:**
  Is there any parse tree at all?

- **Probabilistic parsing:**
  What is the most probable parse tree?

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Restrictions

- The CKY algorithm as we present it here can only handle rules that are at most binary:
  $C \rightarrow w_i$, $C \rightarrow C_1$, $C \rightarrow C_1\ C_2$.
- This restriction is not a problem theoretically, but requires preprocessing (binarization) and postprocessing (debinarization).
- A parsing algorithm that does away with this restriction is Earley's algorithm (J&M 13.4.2).

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Restrictions - details

- The CKY algorithm originally handles grammars in CNF (Chomsky normal form):
  $C \rightarrow w_i$, $C \rightarrow C_1\ C_2$, $(S \rightarrow \varepsilon)$
- ε is normally not used in natural language grammars
- We also allow unit productions, $C \rightarrow C_1$
  - Extended CNF
  - Easy to integrate into CNF, easier grammar conversions

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Conventions

- We are given a context-free grammar *G* and a sequence of word tokens $w = w_1 \ldots w_n$.
- We want to compute parse trees of *w* according to the rules of *G*.
- We write *S* for the start symbol of *G*.

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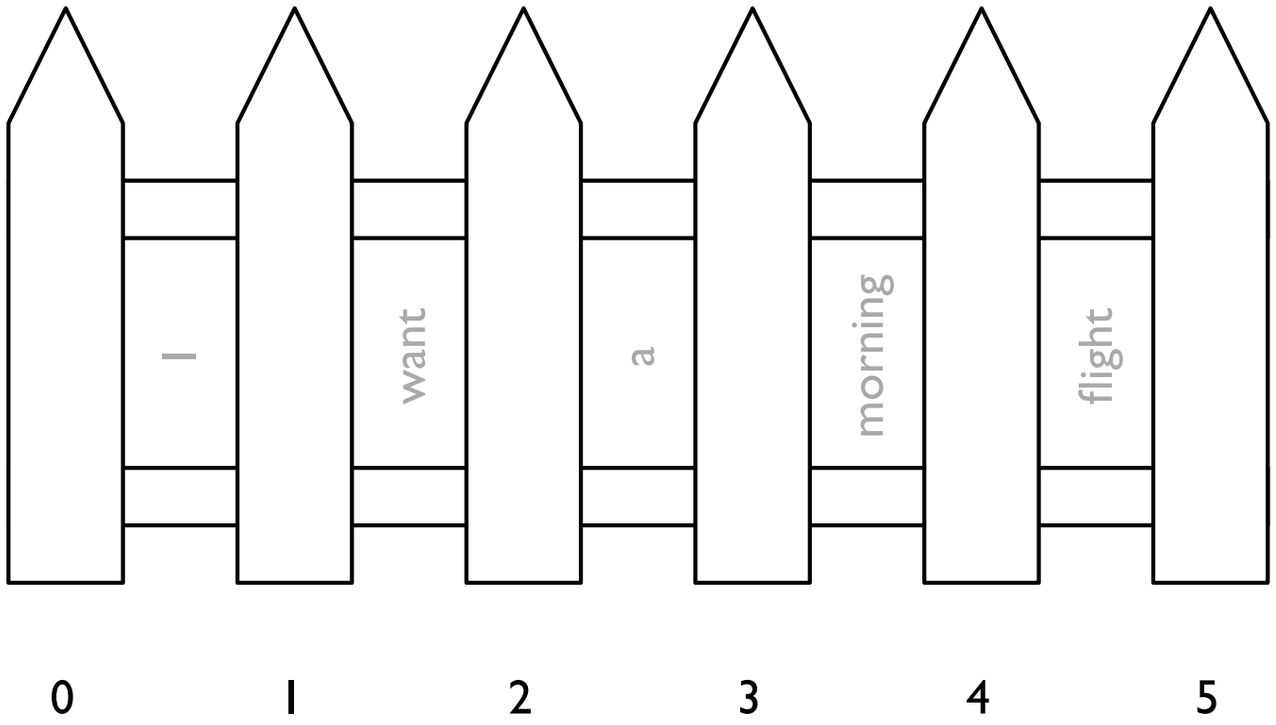
Fencepost positions

We view the sequence *w* as a fence with *n* holes,
one hole for each token w_i ,
and we number the fenceposts from 0 till *n*.



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Structure

- Is there any parse tree at all?
- What is the most probable parse tree?

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Recognition

Recognizer

A computer program that can answer the question

Is there any parse tree at all
for the sequence *w* according to the grammar *G*?

is called a recognizer.

In practical applications one also wants
a concrete parse tree, not only an answer
to the question whether such a parse tree exists.

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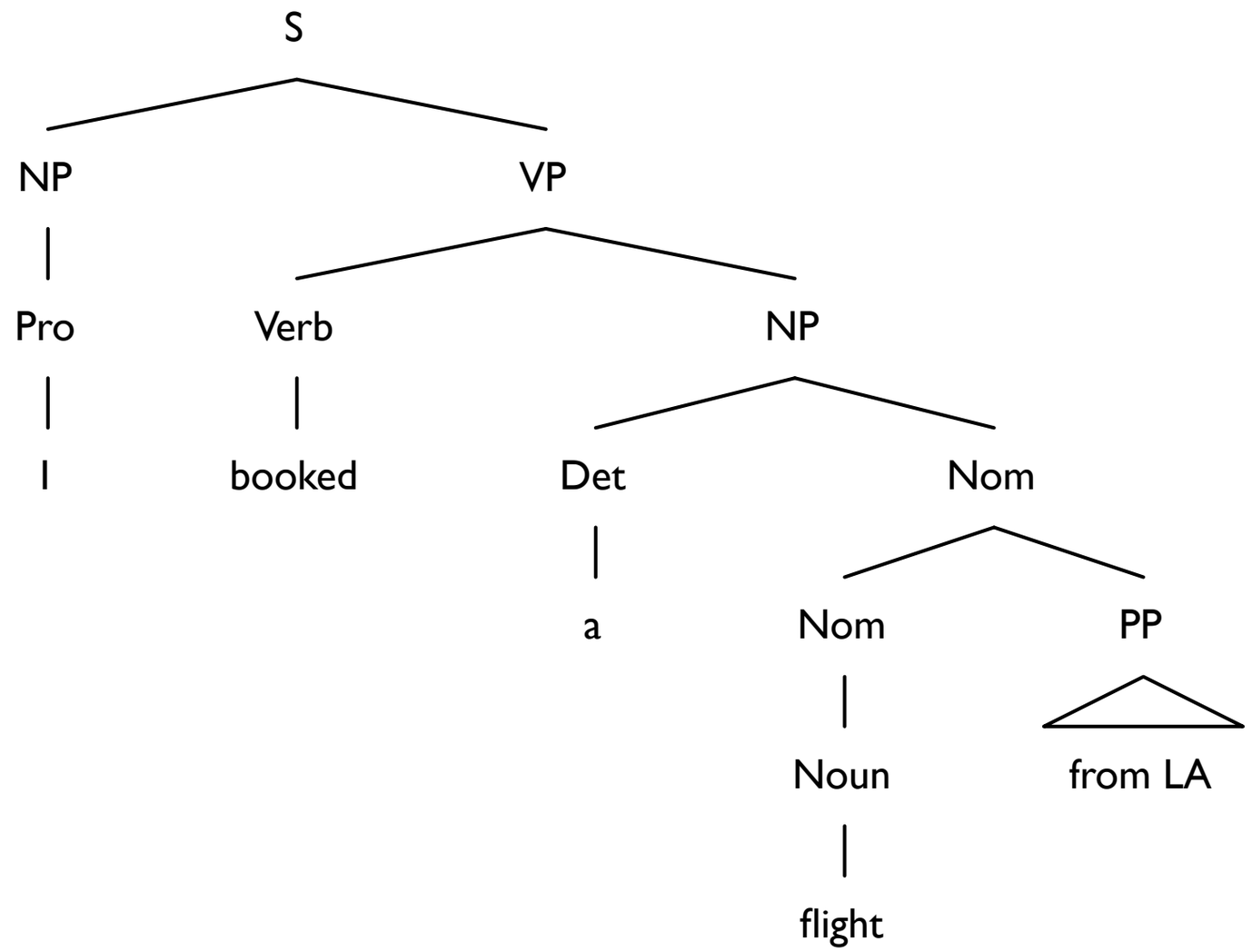
Parse trees



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Preterminal rules and inner rules

- preterminal rules:
  rules that rewrite a part-of-speech tag to a token, i.e. rules of the form $C \rightarrow w_i$.

  Pro → I, Verb → booked, Noun → flight

- inner rules:
  rules that rewrite a syntactic category to other categories: $C \rightarrow C_1\ C_2$, $C \rightarrow C_1$.

  S → NP VP, NP → Det Nom, NP → Pro

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Recognizing small trees

$$C \rightarrow w_i$$

w_i

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Recognizing small trees

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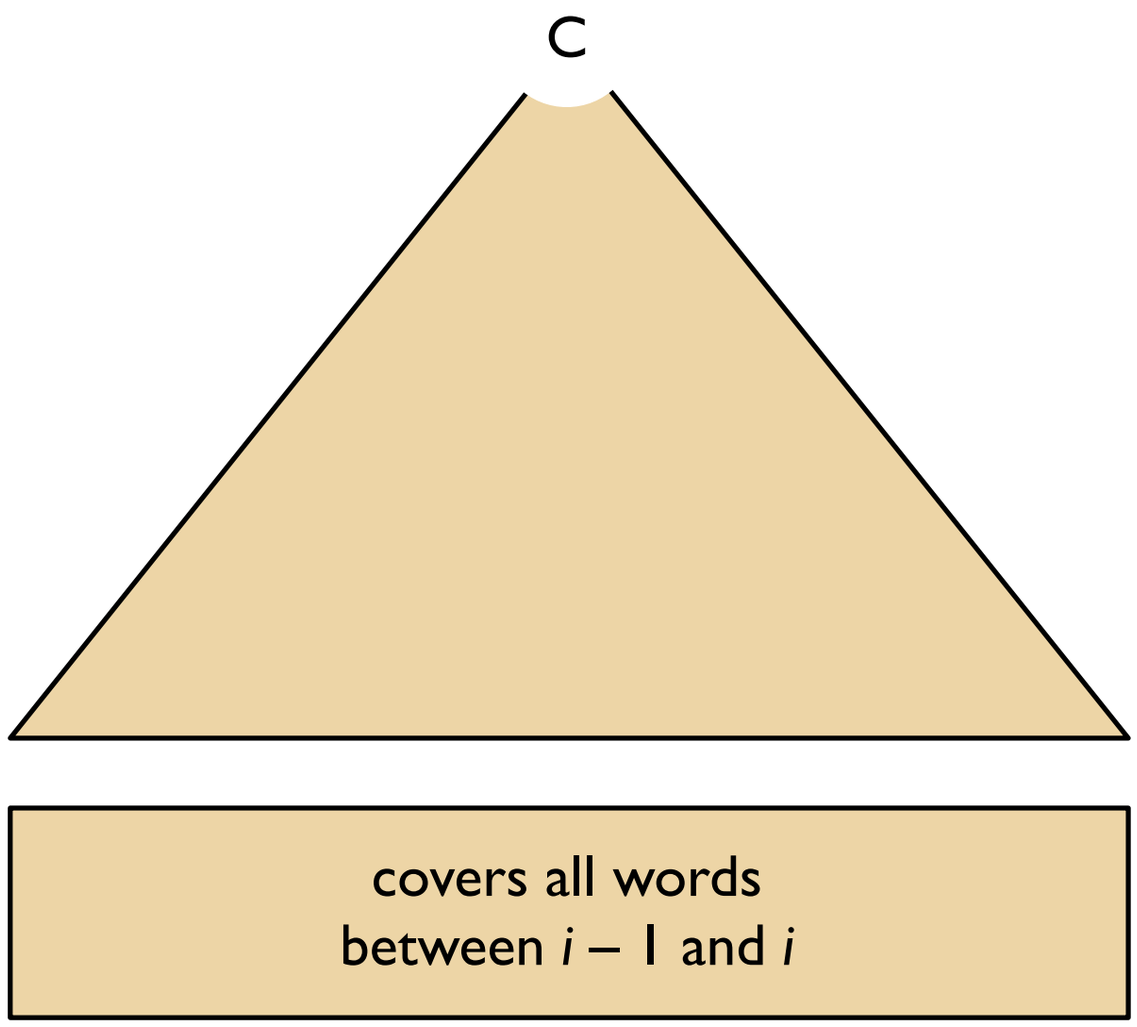
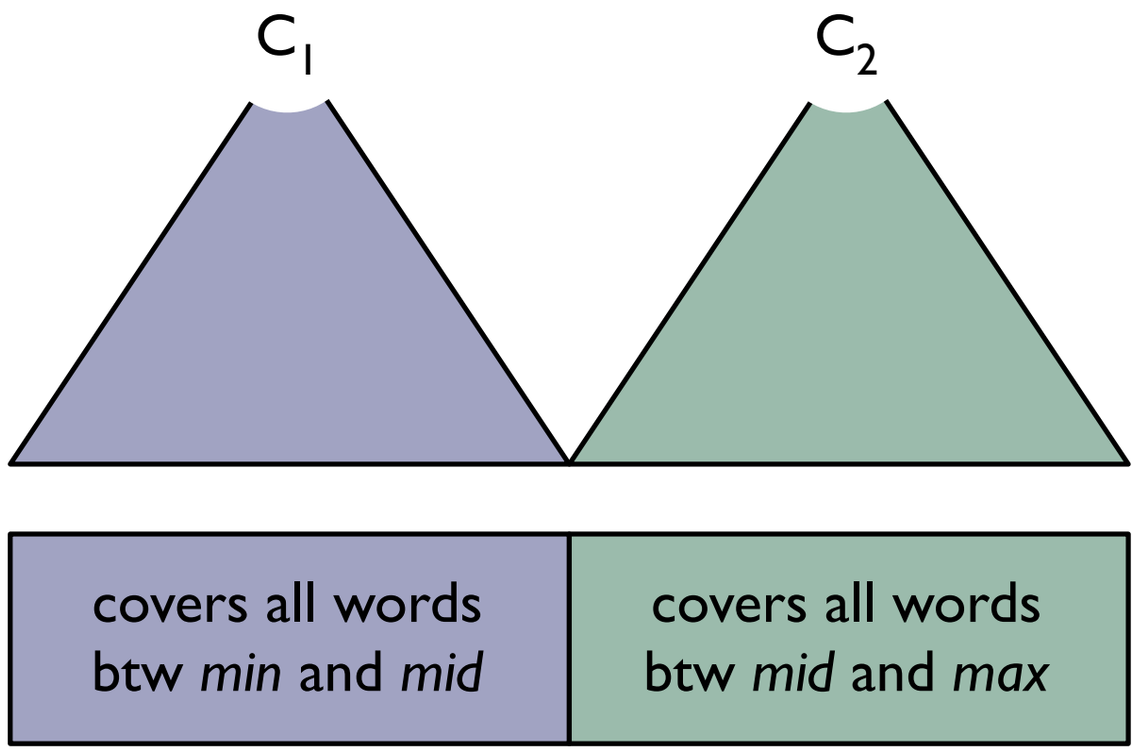
Recognizing small trees



Recognizing big trees

$$C \rightarrow C_1\ C_2$$



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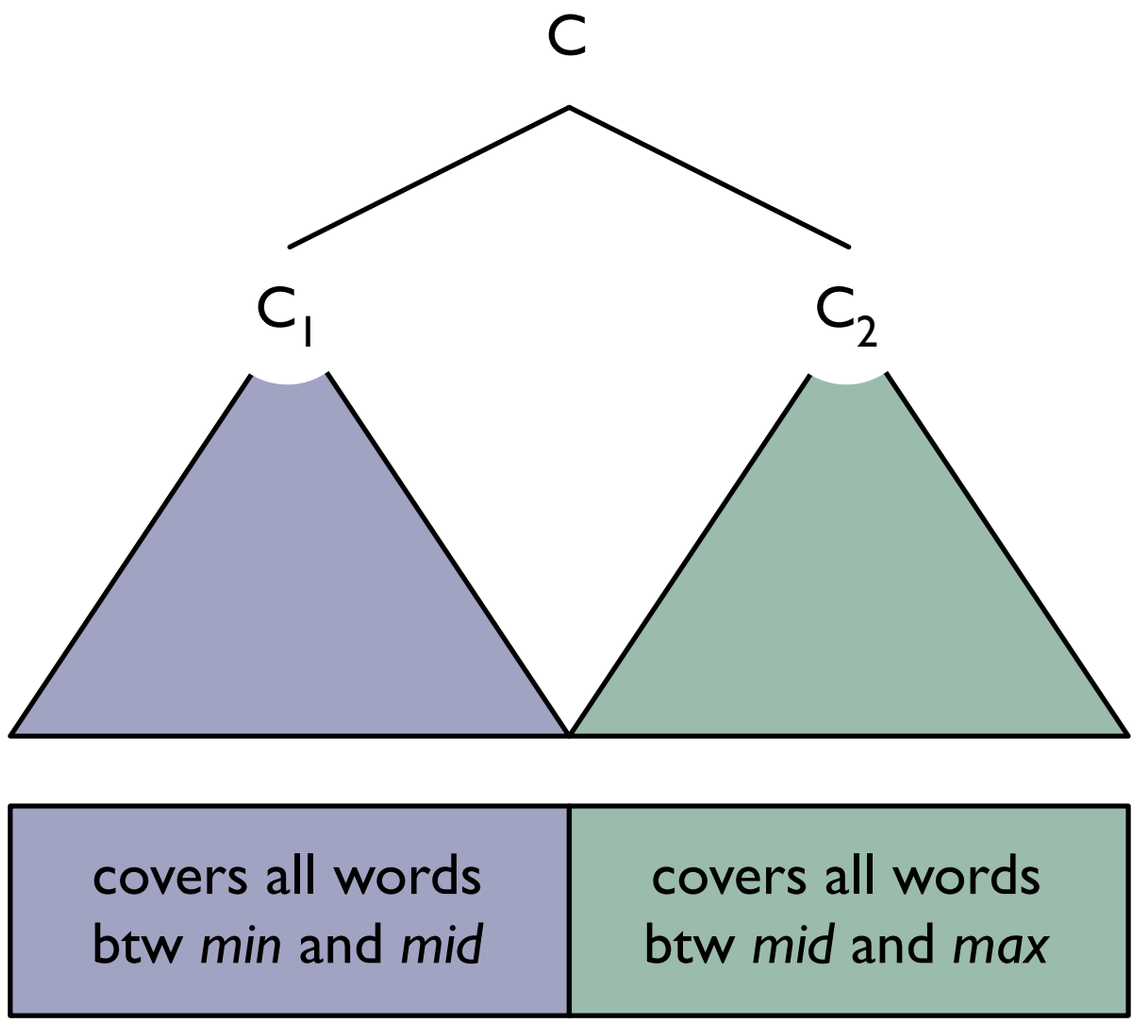
Recognizing big trees



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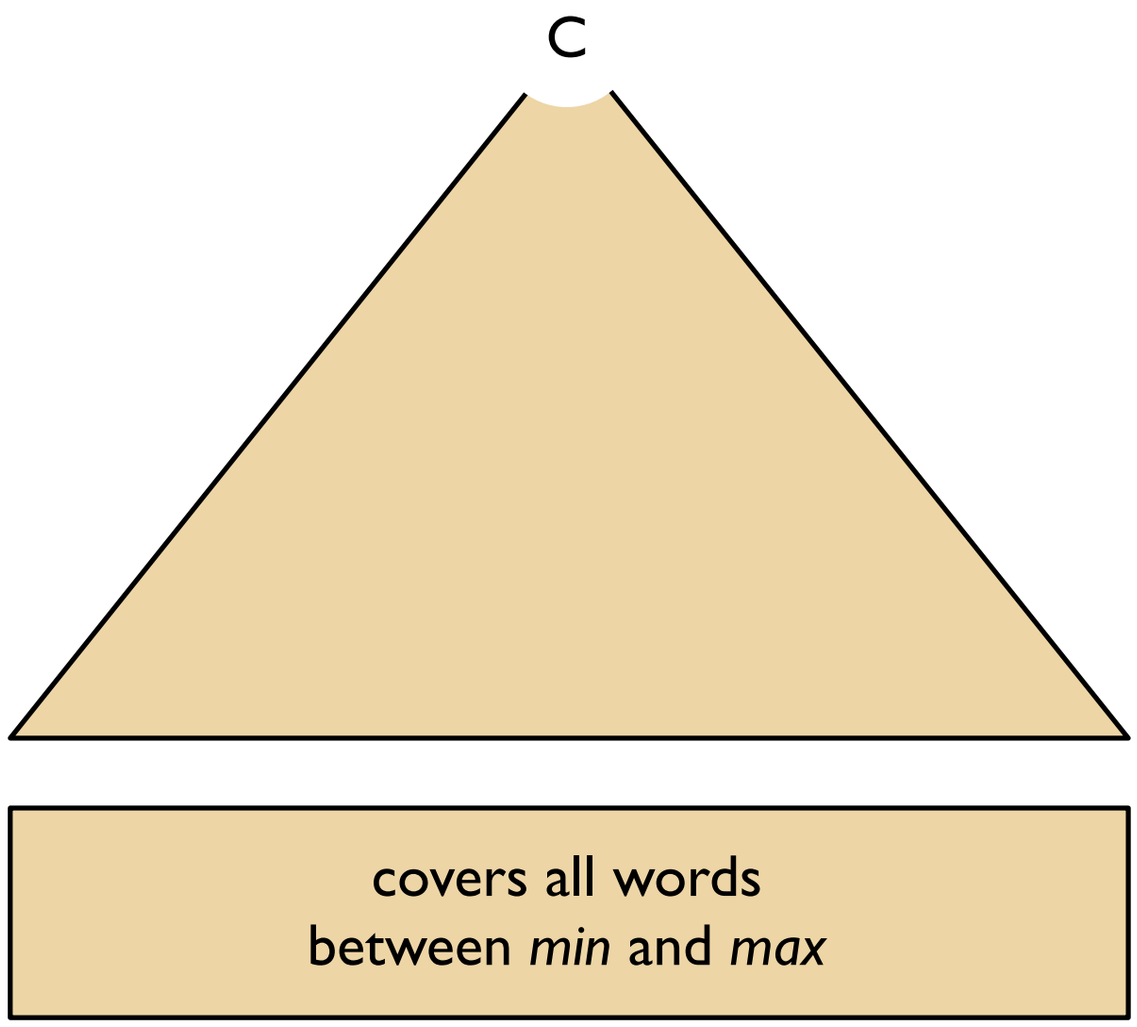
Recognizing big trees



Questions

- How do we know that we have recognized that the input sequence is grammatical?
- How do we need to extend this reasoning in the presence of unary rules: $C \rightarrow C_1$?

Signatures

- The rules that we have just seen are independent of a parse tree's inner structure.
- The only thing that is important is how the parse tree looks from the 'outside'.
- We call this the signature of the parse tree.
- A parse tree with signature [*min*, *max*, *C*] is one that covers all words between *min* and *max* and whose root node is labeled with *C*.

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Questions

- What is the signature of a parse tree for the complete sentence?
- How many different signatures are there?
- Can you relate the runtime of the parsing algorithm to the number of signatures?

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Implementation

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Data structure

- The implementation represents signatures by means of a three-dimensional array *chart*.
- Initially, all entries of *chart* are set to *false*. (This is guaranteed by Java.)
- Whenever we have recognized a parse tree that spans all words between *min* and *max* and whose root node is labeled with *C*, we set the entry *chart*[*min*][*max*][*C*] to *true*.

Preterminal rules

```
for each w_i from left to right
  for each preterminal rule C -> w_i
    chart[i - 1][i][C] = true
```

Binary rules

```
for each max from 2 to n
  for each min from max - 2 down to 0
    for each syntactic category C
      for each binary rule C -> C1 C2
        for each mid from min + 1 to max - 1
          if chart[min][mid][C1] and chart[mid][max][C2] then
            chart[min][max][C] = true
```

Numbering of categories

- In order to use standard arrays, we need to represent syntactic categories by numbers.
- He we write *m* for the number of categories; we number them from 0 till *m* – 1.
- We choose our numbers such that the start symbol *S* gets the number 0.

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Implementation

Skeleton code

```
// int n = number of words in the sequence

// int m = number of syntactic categories in the grammar

// int s = the (number of the) grammar's start symbol

boolean[][][] chart = new boolean[n + 1][n + 1][m]

// Recognize all parse trees built with with preterminal rules.

// Recognize all parse trees built with inner rules.

return chart[0][n][s]
```

Questions

- In what way is this algorithm bottom–up?
- Why is that property of the algorithm important?
- How do we need to extend the code in order to handle unary rules $C \rightarrow C_1$?

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Summary

- The CKY algorithm is an efficient parsing algorithm for context-free grammars.
- Today: Recognizing whether there is any parse tree at all.
- Next time: Probabilistic parsing – computing the most probable parse tree.

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Reading

- Recap of the introductory lecture:
  J&M chapter 13 up to and including 13.3
- CKY recognition:
  J&M section 13.4.1