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The CKY algorithm part 2: Probabilistic parsing

Syntactic analysis/parsing

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Sara Stymne
Department of Linguistics and Philology

Based on slides from Marco Kuhlmann

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Recap: The CKY algorithm

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The CKY algorithm

The CKY algorithm is an efficient bottom–up parsing algorithm for context-free grammars.

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?

Restrictions

- The CKY algorithm as we present it here can only handle rules that are at most binary: $C \rightarrow w_i$, $C \rightarrow C_1\ C_2$, $(C \rightarrow C_1)$
- 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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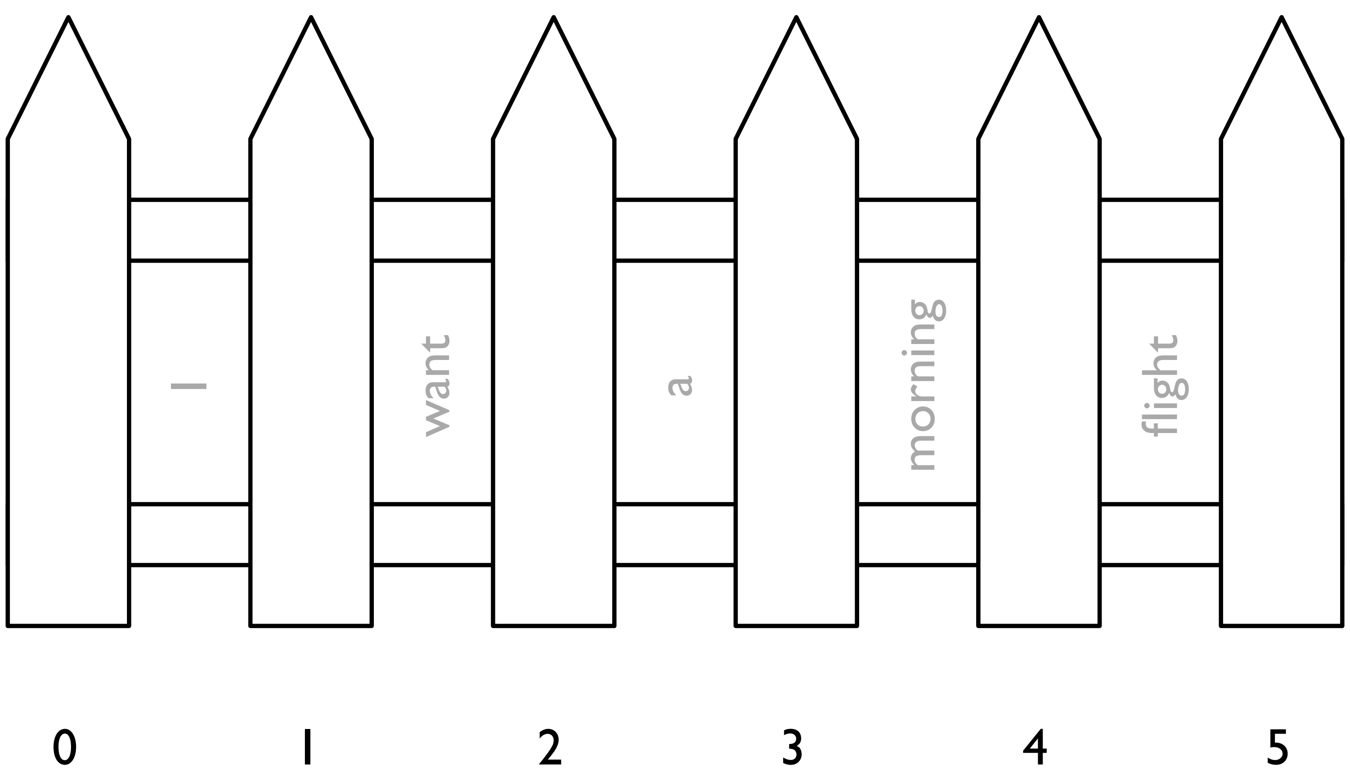
Fencepost positions

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.



Implementation

- The implementation uses a three-dimensional array *chart*.
- 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*.

Implementation: preterminal rules

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

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Implementation: 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
```

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Question

How do we need to extend the code in order to handle unary rules $C \rightarrow C_l$?

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Unary rules

```
for each max from 1 to n
  for each min from max - 1 down to 0
    // First, try all binary rules as before.
    ...
    // Then, try all unary rules.
    for each syntactic category C
      for each unary rule C -> C1
        if chart[min][max][C1] then
          chart[min][max][C] = true
```

new bounds!

Question

This is not quite right.

Why, and how could we fix the problem?

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Structure

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

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Probabilistic parsing

What is the most probable parse tree?

- The number of possible parse trees grows rapidly with the length of the input.
- But not all parse trees are equally useful.

  Example: I booked a flight from Los Angeles.
- In many applications, we want the 'best' parse tree, or the first few best trees.
- Special case: 'best' = 'most probable'

Probabilistic context-free grammars

A probabilistic context-free grammar (PCFG) is a context-free grammar where

- each rule *r* has been assigned a probability *p*(*r*) between 0 and 1
- the probabilities of rules with the same left-hand side sum up to 1

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Example

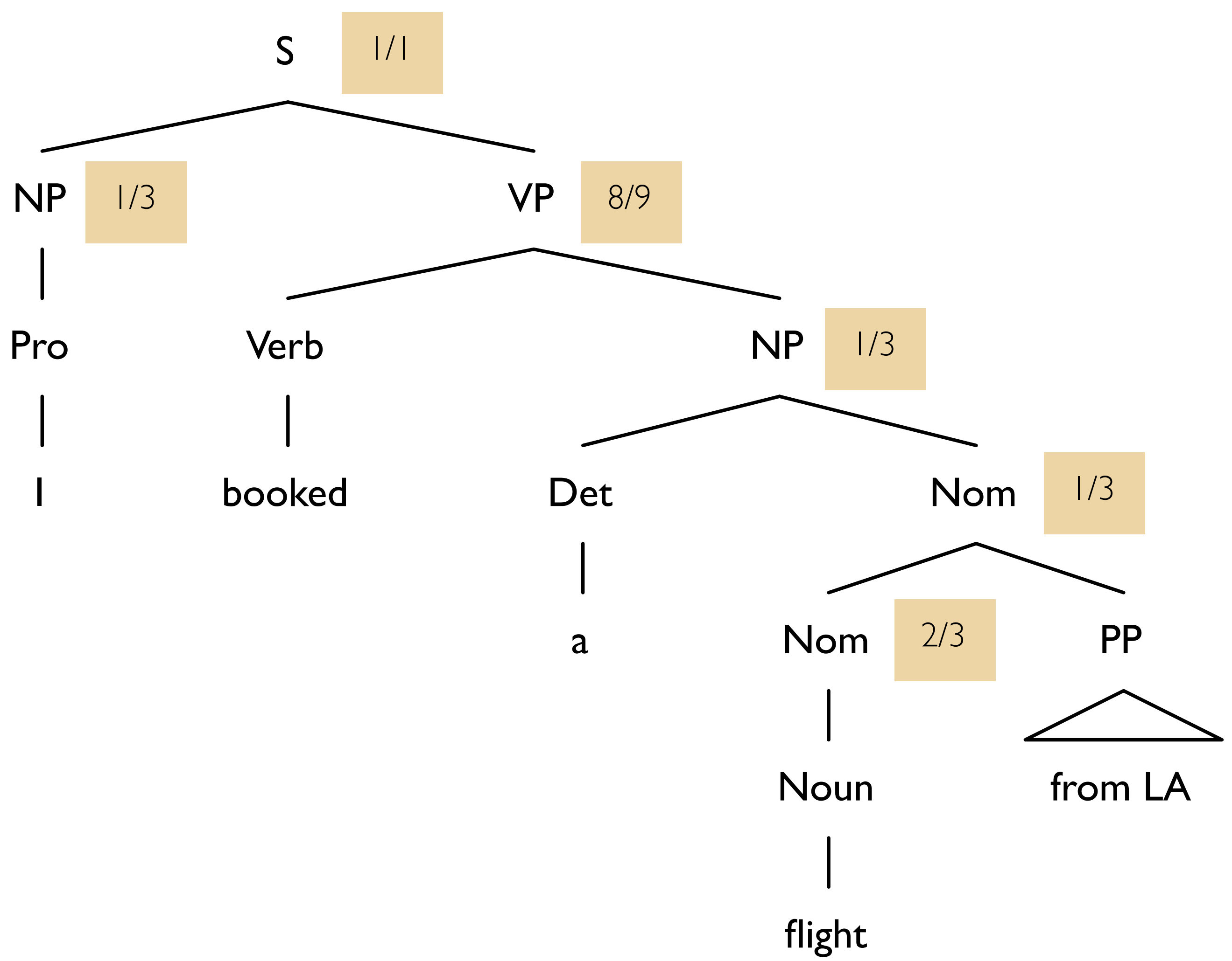
Made up probabilities!

Rule	Probability
S → NP VP	1
NP → Pronoun	1/3
NP → Proper-Noun	1/3
NP → Det Nominal	1/3
Nominal → Nominal PP	1/3
Nominal → Noun	2/3
VP → Verb NP	8/9
VP → Verb NP PP	1/9
PP → Preposition NP	1

The probability of a parse tree

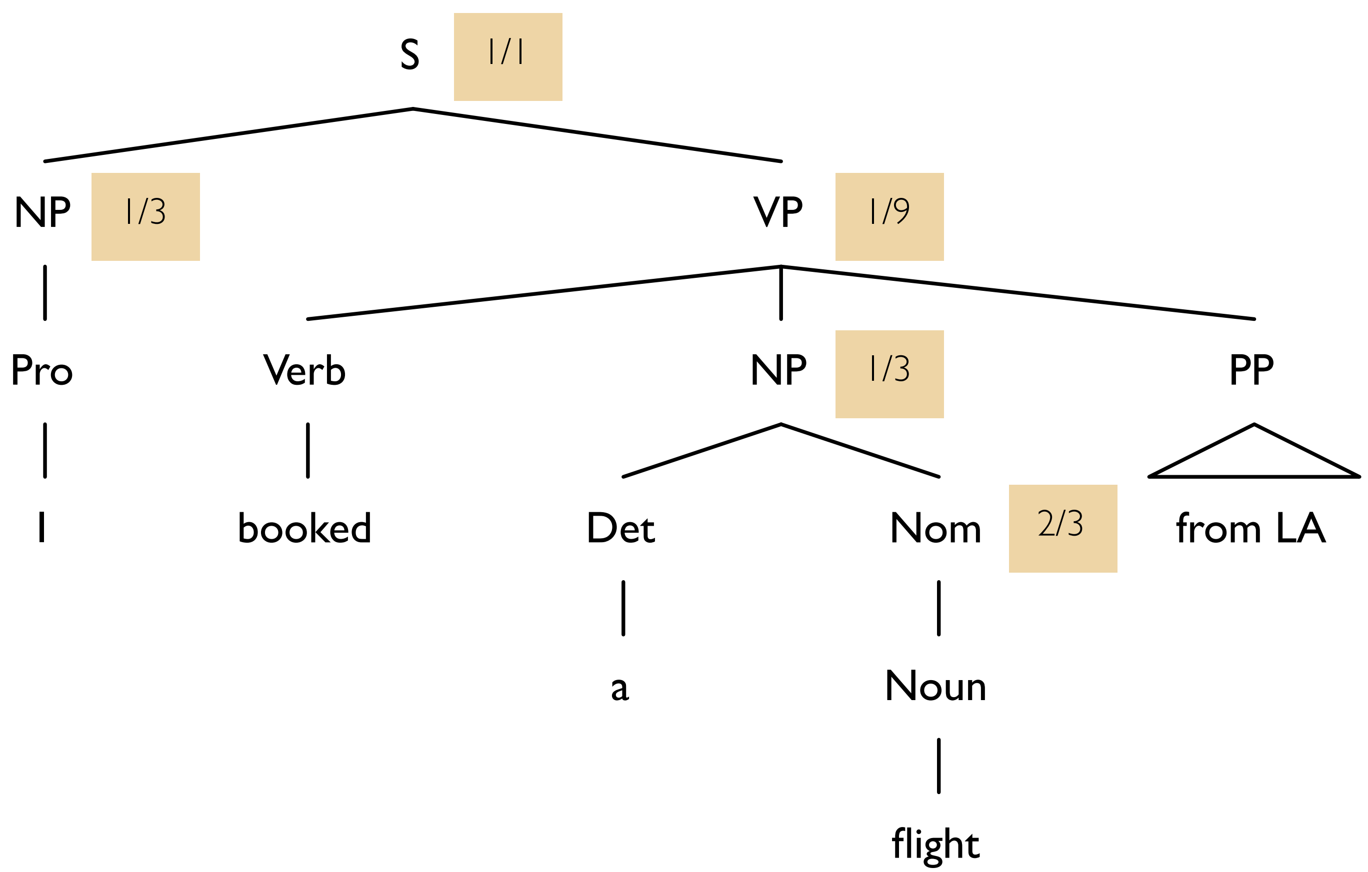
The probability of a parse tree is defined as the product of the probabilities of the rules that have been used to build the parse tree.

Example



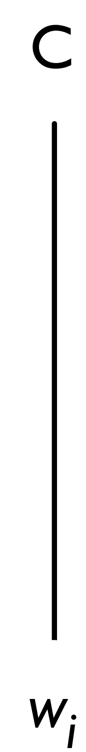
Probability: 16/729

Example



Probability: 6/729

Small trees



Small trees

w_i

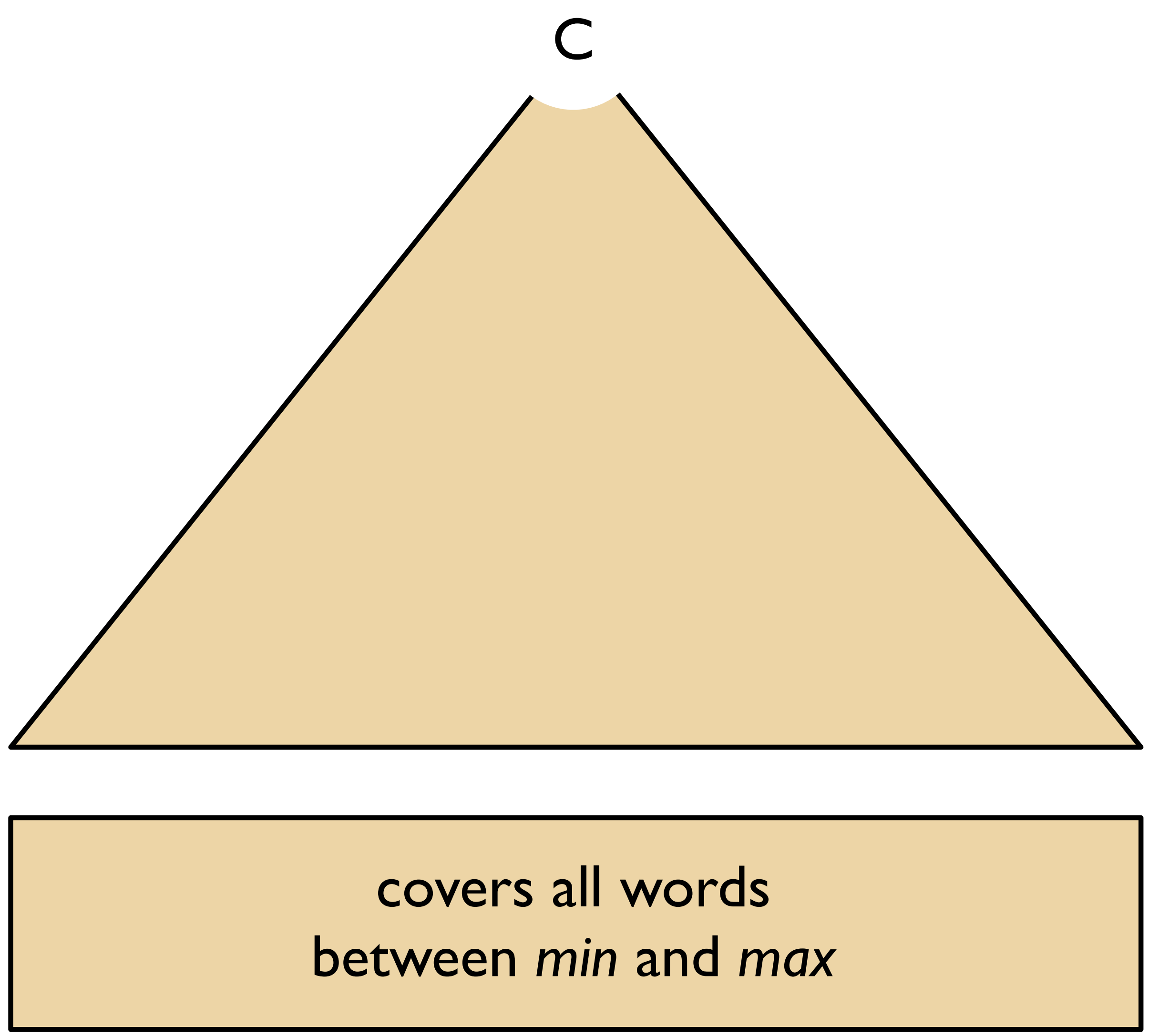
Small trees

$C \rightarrow w_i$

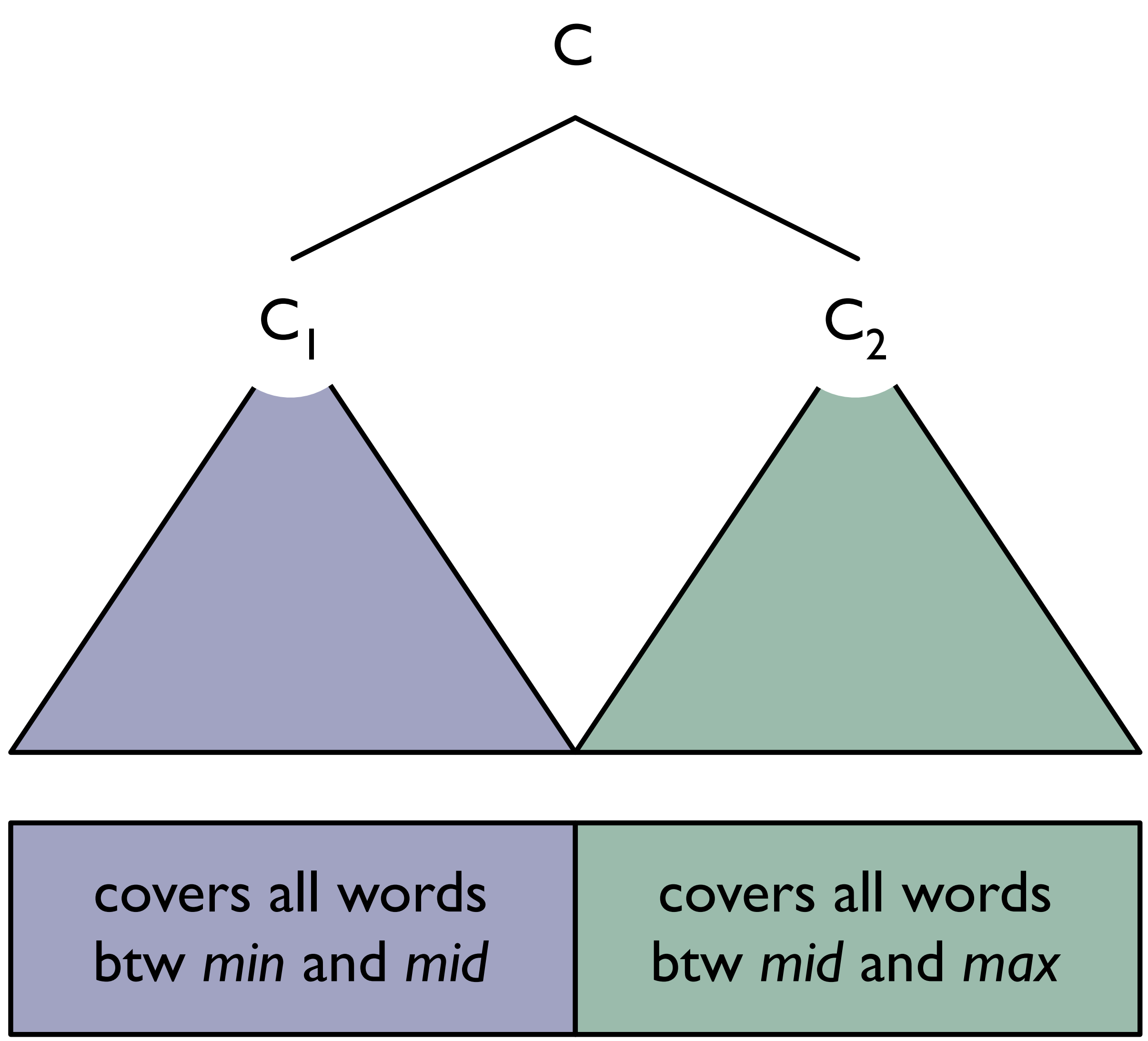
Apply each rule for w_i

w_i

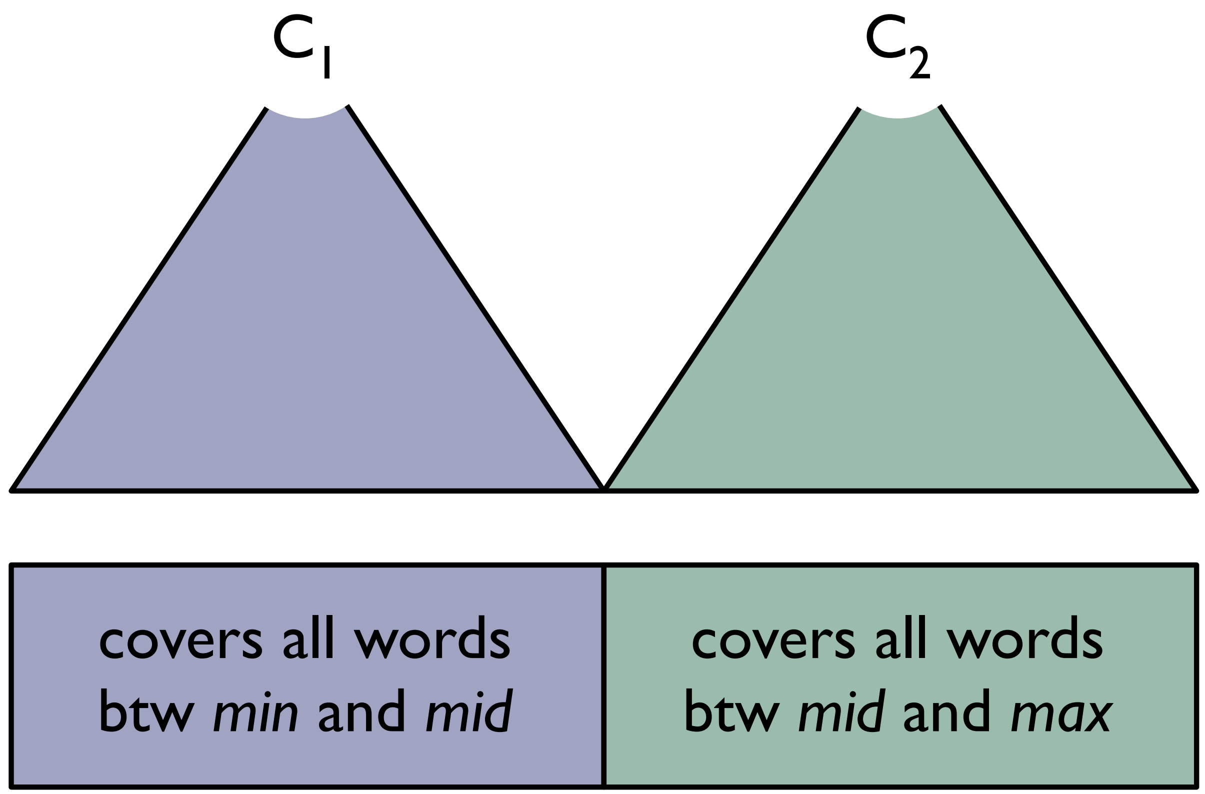
Small trees



Big trees


C
C1
C2
covers all words btw min and mid
covers all words btw mid and max

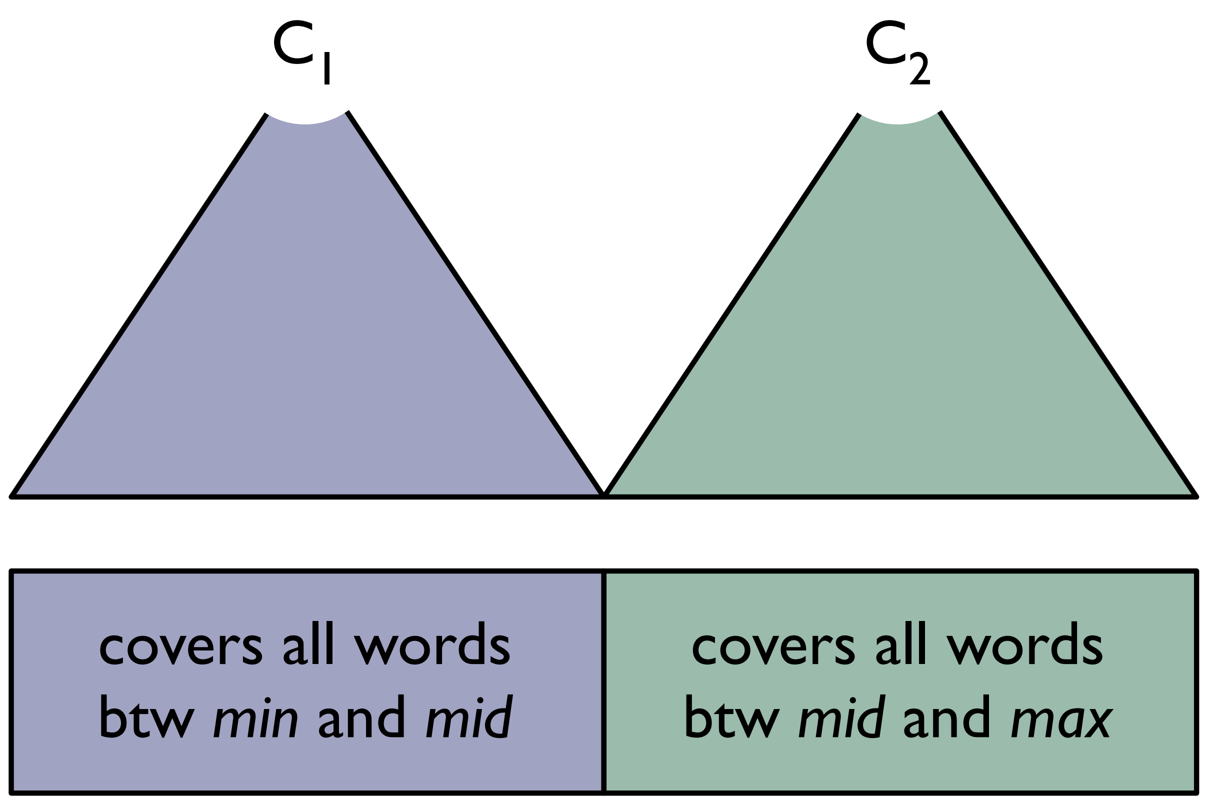
Big trees


C1
C2
covers all words btw *min* and *mid*
covers all words btw *mid* and *max*

Big trees

$C \rightarrow C_1\ C_2$

Choose the most probable rule!



Idea

- For trees built using preterminal rules:
  Find a most probable rule. (apply all rules!)
- For trees built using binary rules:
  Find a binary rule *r* and a split point *mid* such that
  $p(r) \times p(t_1) \times p(t_2)$ is maximal, where
  t_1 is a most probable left subtree and
  t_2 is a most probable right subtree.

Implementation

- Instead of an array with Boolean values, we now have an array with probabilities, i.e., *floats*.
- When all is done, we want to have
  chart[*min*][*max*][*C*] = *p*
  if and only if a most probable parse tree with signature [*min*, *max*, *C*] has probability *p*.

Preterminal rules

```
for each wi from left to right
  for each preterminal rule C -> wi
    chart[i - 1][i][C] = p(C -> wi)
```

Binary rules

```
for each max from 2 to n
  for each min from max - 2 down to 0
    for each syntactic category C
      double best = undefined
      for each binary rule C -> C1 C2
        for each mid from min + 1 to max - 1
          double t1 = chart[min][mid][C1]
          double t2 = chart[mid][max][C2]
          double candidate = t1 * t2 * p(C -> C1 C2)
          if candidate > best then
            best = candidate
      chart[min][max][C] = best
```

Question

How should we treat unary rules?

One more question

The only thing that we have done so far is to compute the *probability* of the most probable parse tree. But how does that parse tree look like?

Backpointers

- When we find a new best parse tree, we want to remember how we built it.
- For each element *t* = *chart*[*min*][*max*][*C*], we also store backpointers to those elements from which *t* was built.
- Besides the ordinary chart of floats, we also have a backpointer chart

Preterminal rules

```
for each wi from left to right
  for each preterminal rule C -> wi
    chart[i - 1][i][C] = p(C -> wi)
    backpointerChart[i-1][i][C] = (C -> wi, i, i-1)
```

Backpointers

```
double best = undefined
Backpointer backpointer = undefined
...
if candidate > best then
  best = candidate
  // We found a better tree; update the backpointer!
  backpointer = (C -> C1 C2, min, mid, max)
...
chart[min][max][C] = best
backpointerChart[min][max][C] = backpointer
```

Implementation ideas

```
#  defaultdict is a suitable datastructure for charts!
    pi = defaultdict(float)
    bp = defaultdict(tuple)
#  Recognize all parse trees built with with preterminal rules.
#  Recognize all parse trees built with binary rules.

#  "S" is not always the top category, the below is a simplification
return backtrace(bp[0, n, "S"], bp);
```

Backtrace

Convenient to use recursion to retrieve the tree!

```
# assume backppointers are tuples:

# Preterminal: (C, w, min, max)

# Binary: (C, C1, C2, min, mid, max)

backtrace(bpChart, bp):

    if length(bp) == 4:  #preterminal rule

        return tree for C, w

    else if length(bp) == 6 #binary rule

        return tree for C, backtrace(left subtree), backtrace(right
        subtree)
```

Assignment 1: CKY parsing

- Tips:
  - During development: use print statements to make sure your code does what you think it should
  - Use a small test set, and possibly a small grammar during dvelopment. The parser is slow
  - Start on the assignment now! Do not leave it until the last week!

Advanced models

- The CKY model is used in many competitive parsers
- To improve performance the grammar is often modified, e.g. by
  - Parent annotation
  - Lexicalized rules

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Summary

- The CKY algorithm is an efficient parsing algorithm for context-free grammars.
- Today, we have used it for probabilistic parsing: The task of computing the most probable parse tree for a given sentence.

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Coming up

- Next Tuesday:
  - Lecture on treebanks and PCFGs
- Next Friday:
  - Earley's algorithm
  - Tuesday Feb 6:
    - Advanced PCFG parsing (~ 45 minutes)
    - Time for supervision (~ 45 minutes)
    - bring your questions on paper, or your laptop

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Own work

- Reading:
  - CKY: J&M 14.1, 14.2
  - Treebanks: J&M12.4, 14.3, 14.7
- Work on assignments
  - Start working on assignment 1: CKY
  - Start thinking about assignment 2 and project
  - Contact me if you need help
  - You can also ask questions during lectures and breaks

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Deadlines

- Ordinary deadlines
  - Assignment 1: 18-02-16
  - Assignment 2: 18-03-07
  - Assignment 3: 18-03-23
  - Project proposal: 18-02-26
  - Project report: 18-03-23
  - Oral project discussion (for pairs): 18-03-22
- Resubmission deadline
  - All assignments: 18-04-20
- Assignments will only be graded in connection with each deadline
- In case of special circumstances, contact me BEFORE the deadline it concerns!