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Collins' and Eisner's algorithms

Syntactic analysis (5LN455)

2014-12-15

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Based on slides from Marco Kuhlmann

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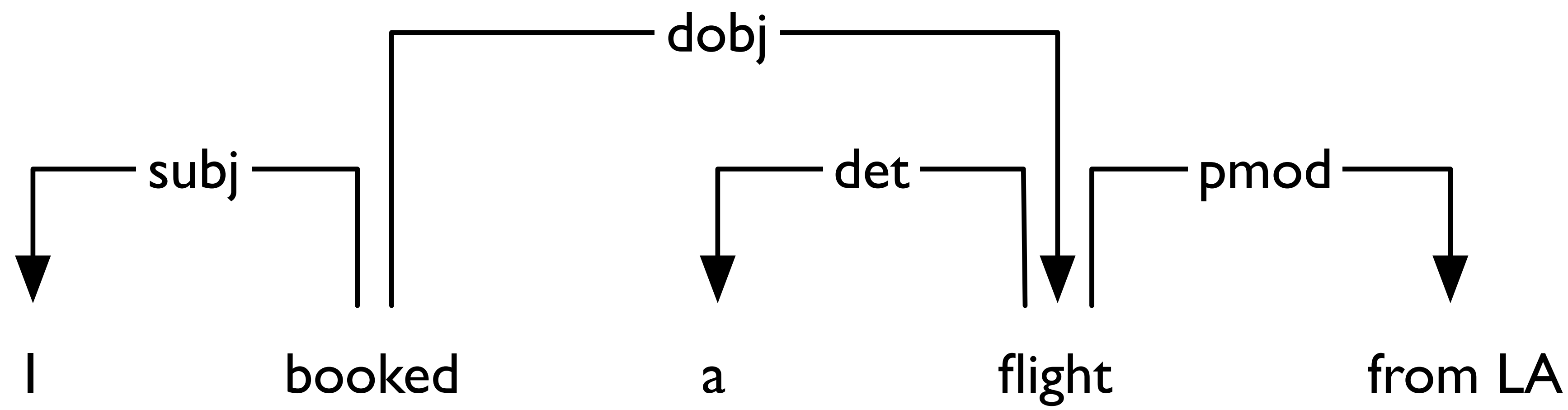
Recap: Dependency trees



- In an arc $h \rightarrow d$, the word h is called the head, and the word d is called the dependent.
- The arcs form a rooted tree.

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Recap: Scoring models and parsing algorithms

Distinguish two aspects:

- Scoring model:
  How do we want to score dependency trees?
- Parsing algorithm:
  How do we compute a highest-scoring dependency tree under the given scoring model?

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Recap: The arc-factored model

- To score a dependency tree, score the individual arcs, and combine the score into a simple sum.

  $\text{score}(t) = \text{score}(a_1) + \ldots + \text{score}(a_n)$

- Define the score of an arc $h \rightarrow d$ as the weighted sum of all features of that arc:

  $\text{score}(h \rightarrow d) = f_1 w_1 + \ldots + f_n w_n$

Recap: Example features

- ‘The head is a verb.’
- ‘The dependent is a noun.’
- ‘The head is a verb
  and the dependent is a noun.’
- ‘The head is a verb
  and the predecessor of the head is a pronoun.’
- ‘The arc goes from left to right.’
- ‘The arc has length 2.’

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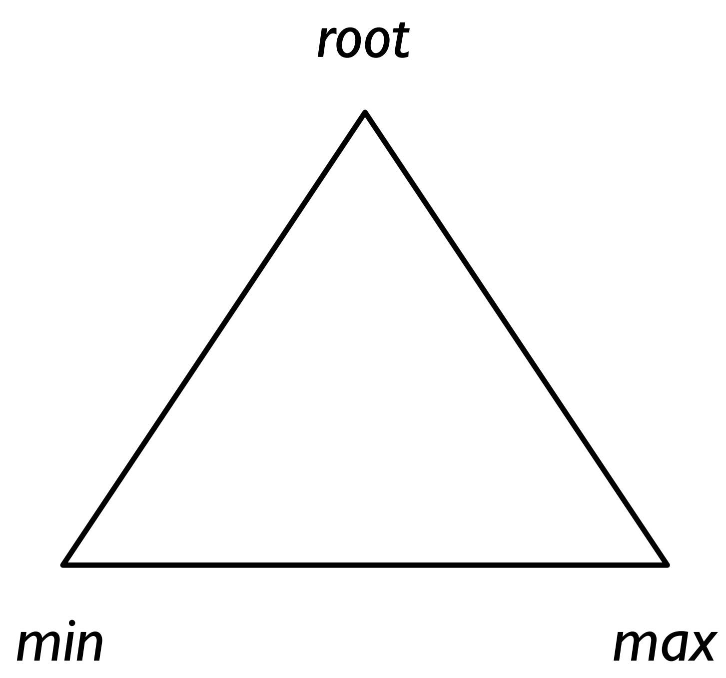
Training using structured prediction

- Take a sentence *w* and a gold-standard dependency tree *g* for *w*.
- Compute the highest-scoring dependency tree under the current weights; call it *p*.
- Increase the weights of all features that are in *g* but not in *p*.
- Decrease the weights of all features that are in *p* but not in *g*.

Collin’s algorithm

- Collin’s algorithm is a simple algorithm for computing the highest-scoring dependency tree under an arc-factored scoring model.
- It can be understood as an extension of the CKY algorithm to dependency parsing.
- Like the CKY algorithm, it can be characterized as a bottom-up algorithm based on dynamic programming.

Signatures



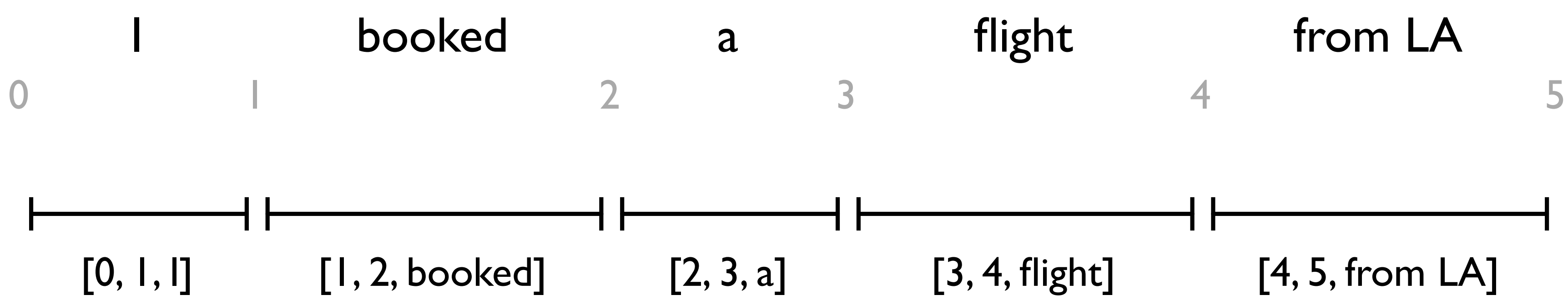
[*min*, *max*, *root*]

Initialization

I	booked	a	flight	from LA

0 1 2 3 4 5

Initialization



Adding a left-to-right arc

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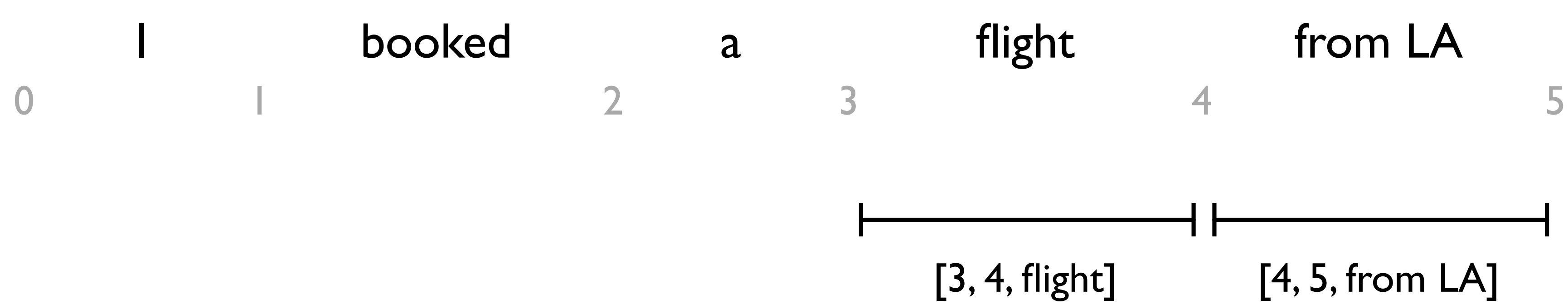
Adding a left-to-right arc



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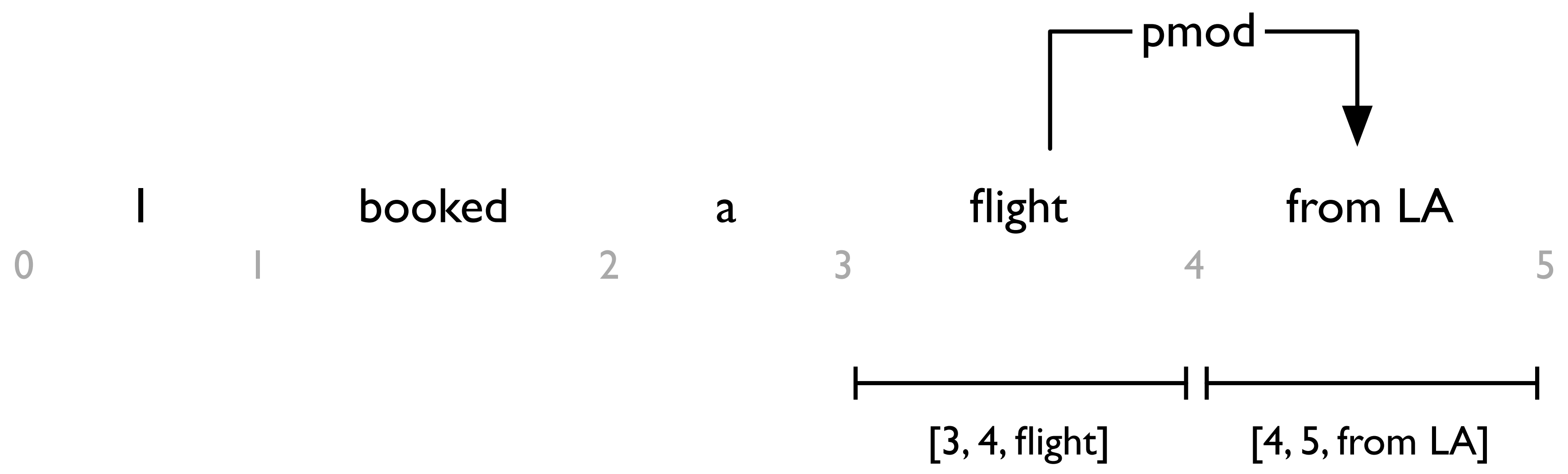
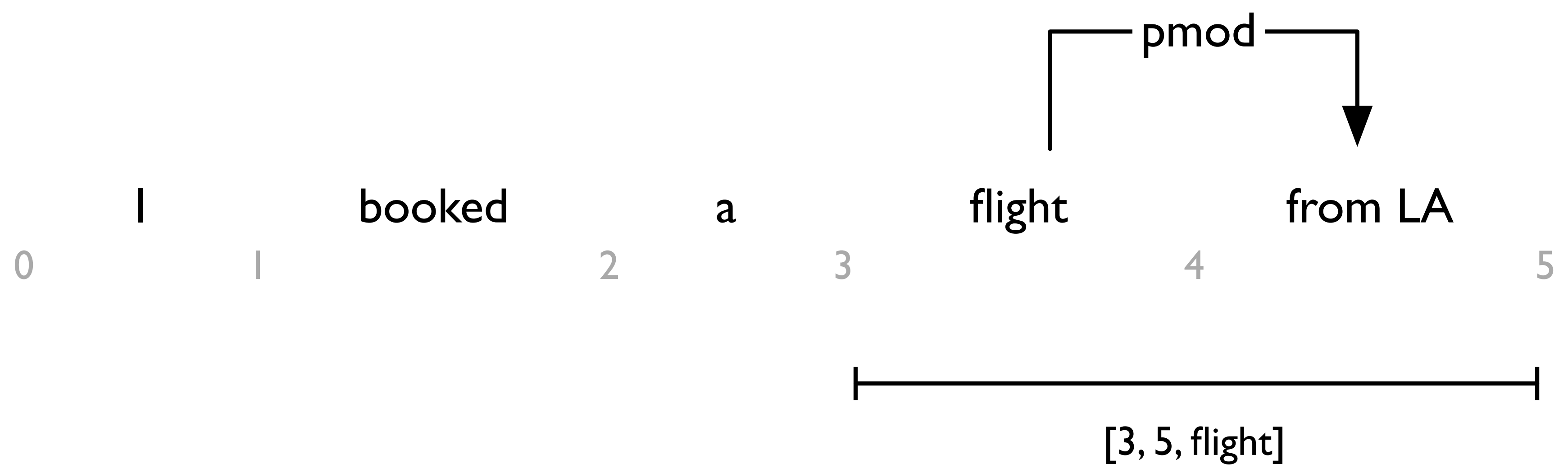


Collins’ algorithm

Adding a left-to-right arc



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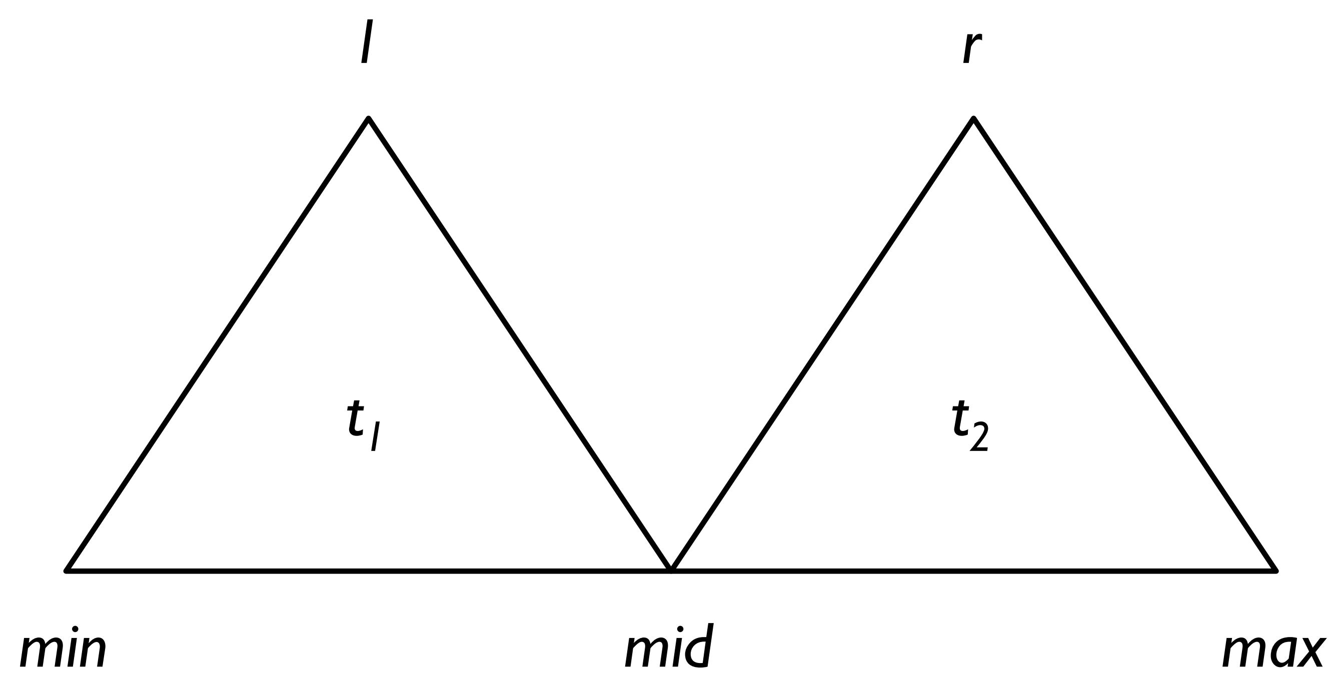

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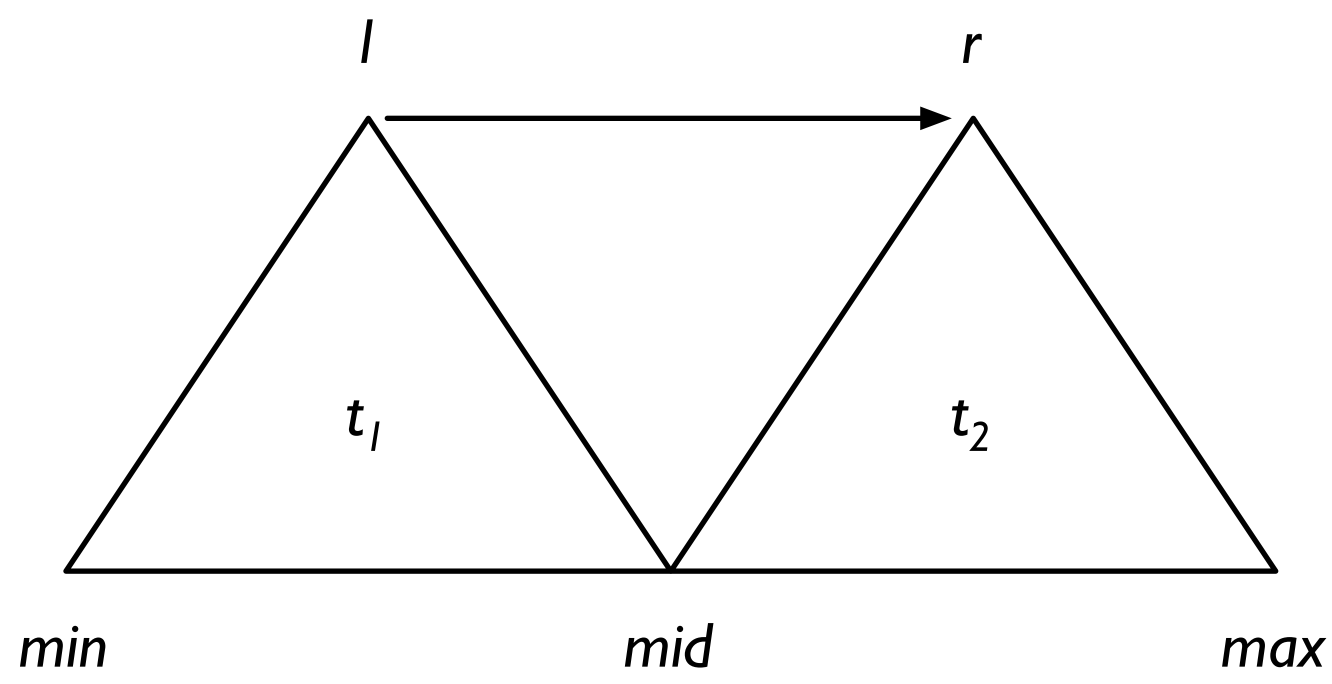

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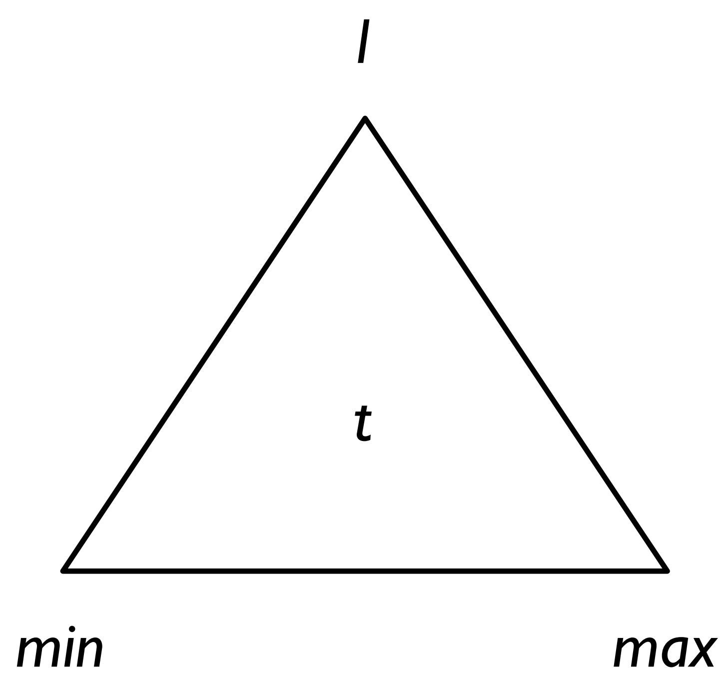

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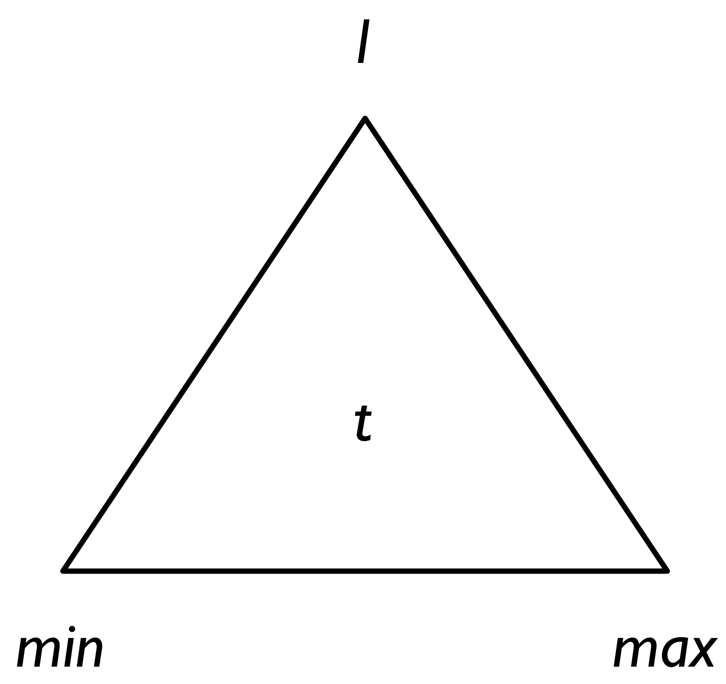
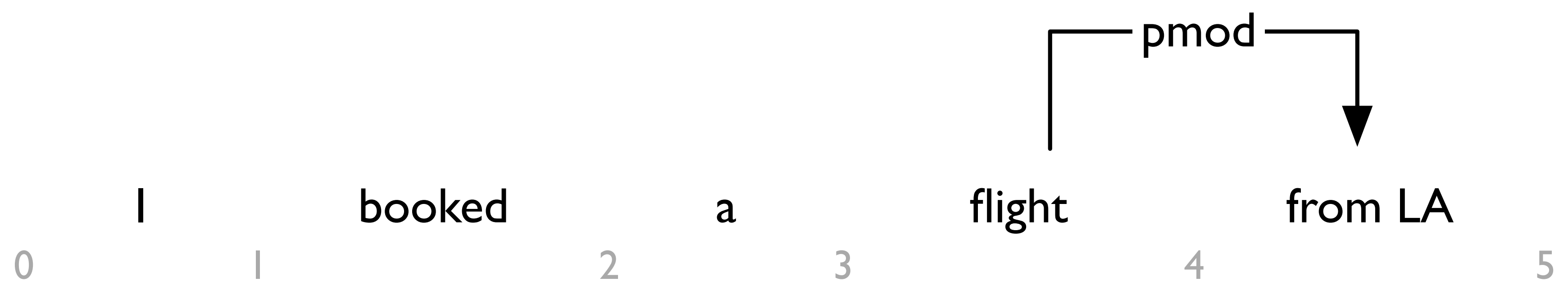


$$\text{score}(t) = \text{score}(t_1) + \text{score}(t_2) + \text{score}(l \rightarrow r)$$

Adding a left-to-right arc

```
for each [min, max] with max - min > 1 do
  for each l from min to max - 2 do
    double best = score[min][max][l]
    for each r from l + 1 to max - 1 do
      for each mid from l + 1 to r do
        t1 = score[min][mid][l]
        t2 = score[mid][max][r]
        double current = t1 + t2 + score(l → r)
        if current > best then
          best = current
    score[min][max][l] = best
```

Adding a right-to-left arc



Collins’ algorithm

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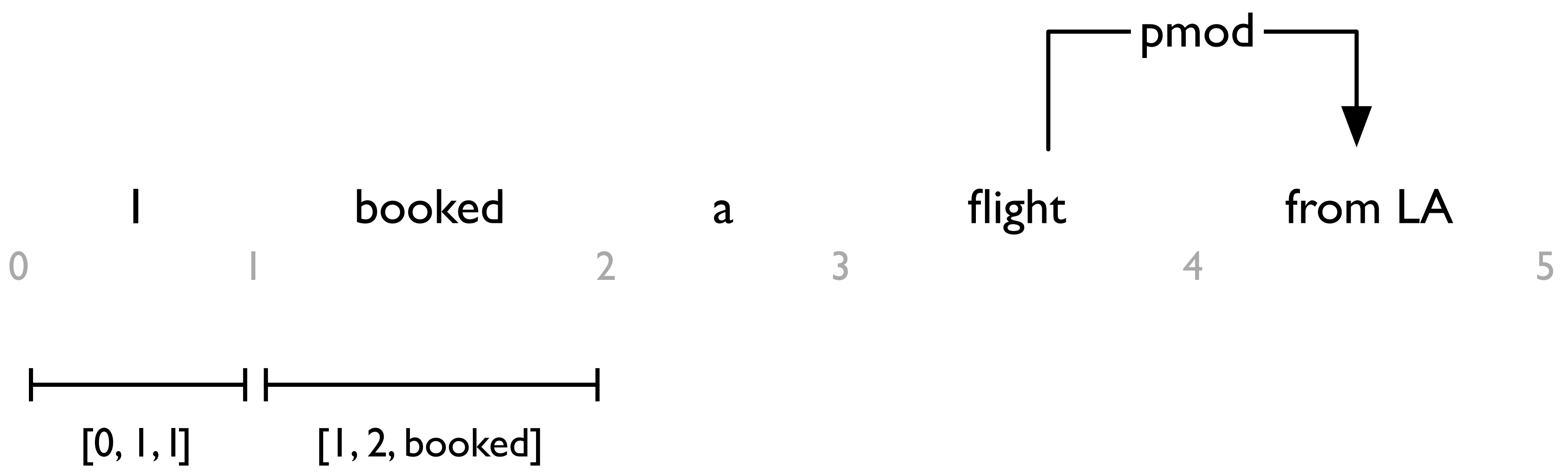

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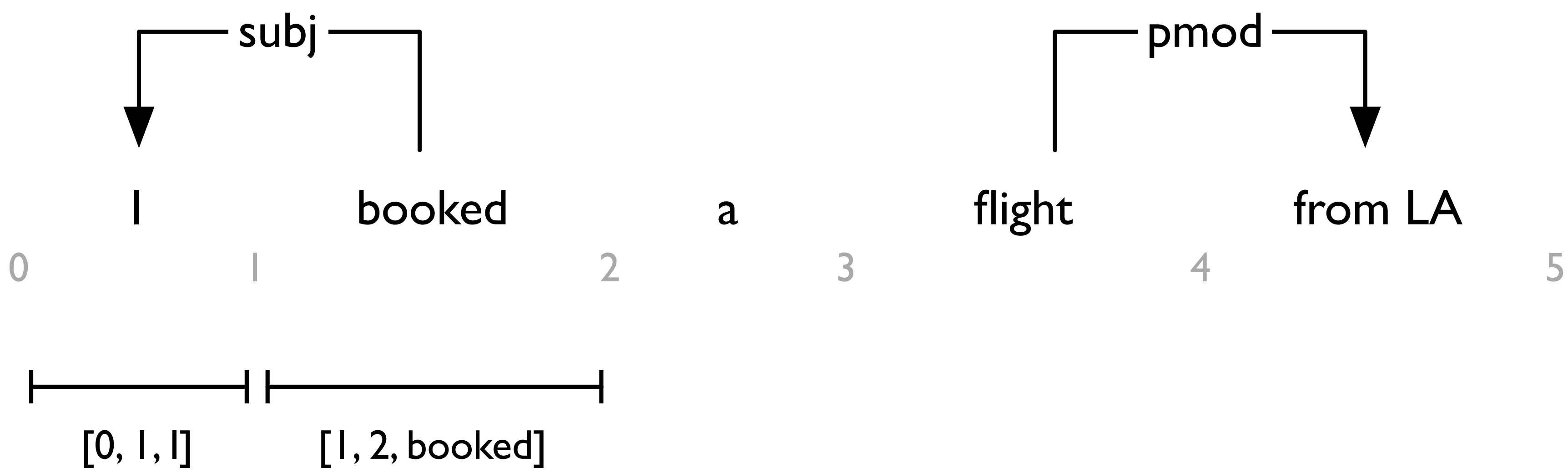

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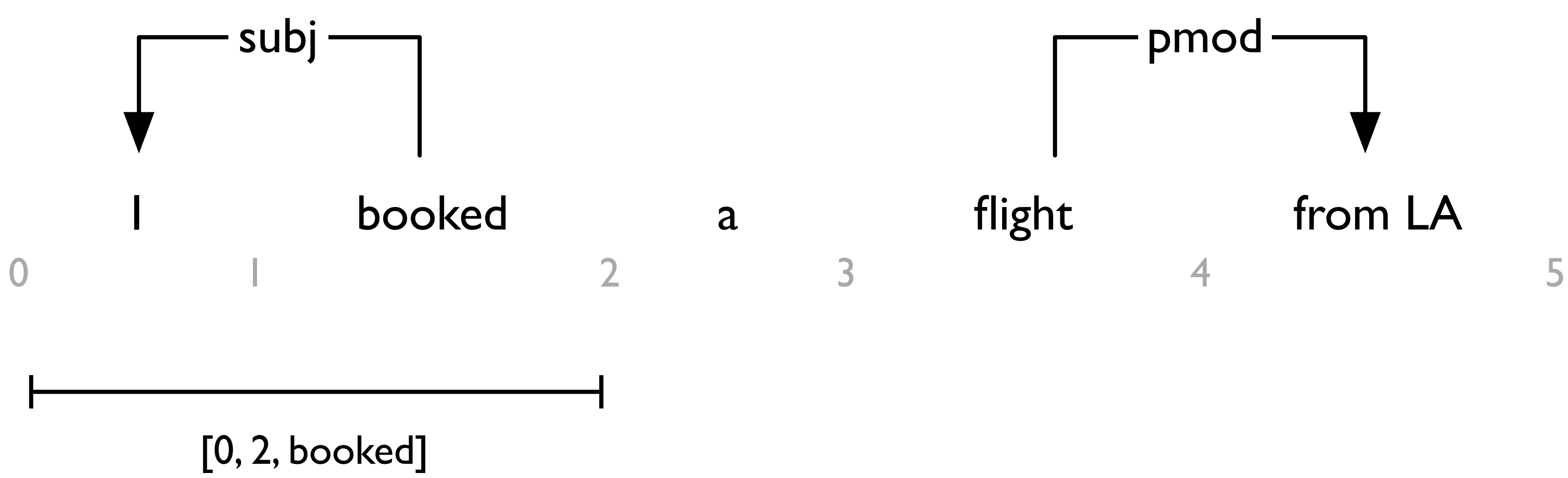

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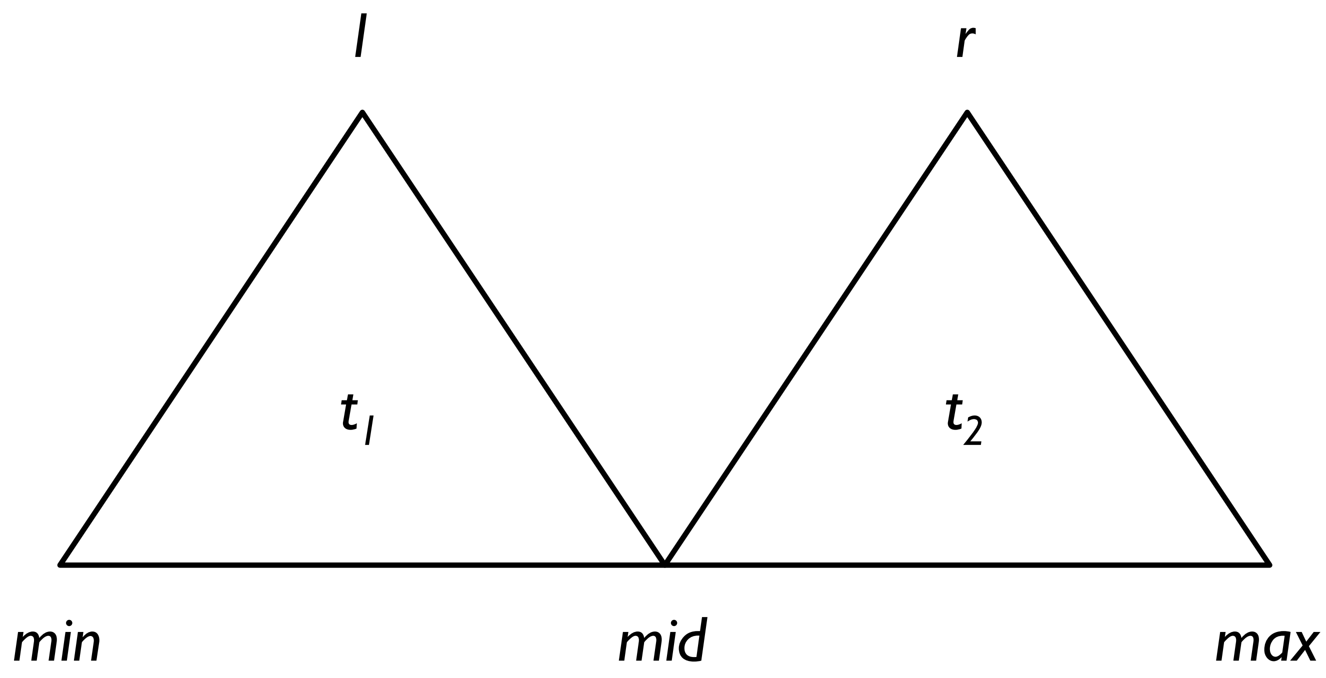

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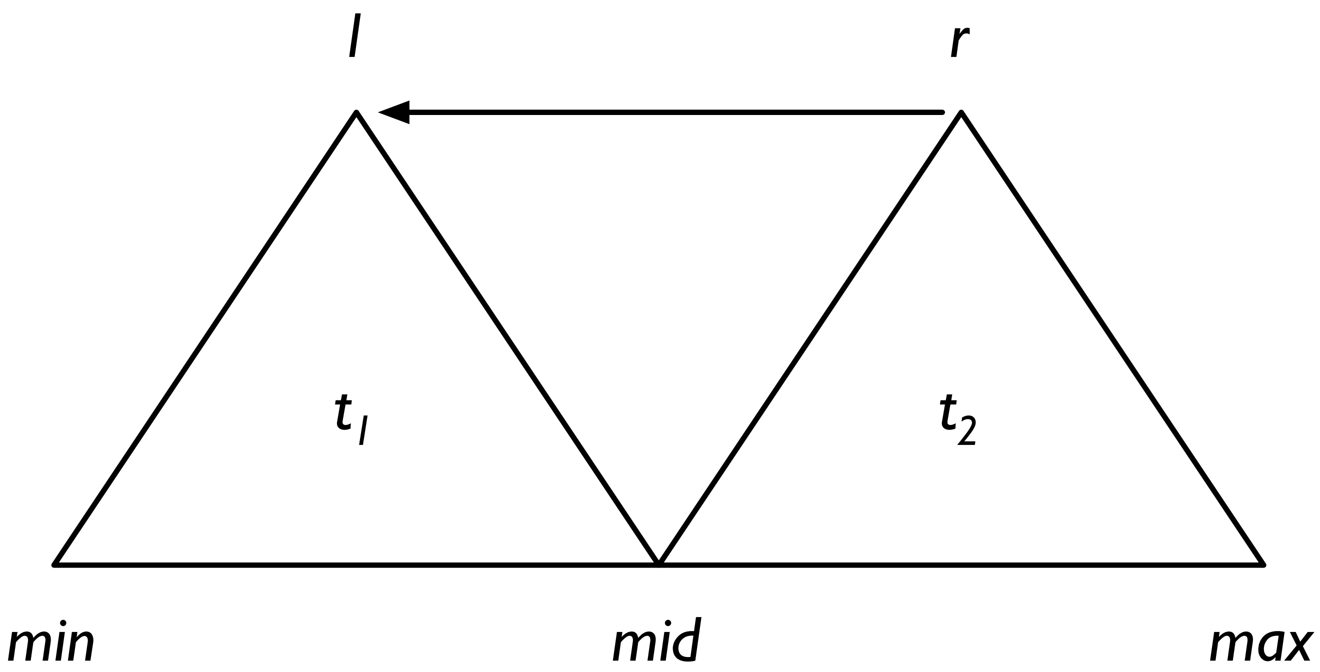

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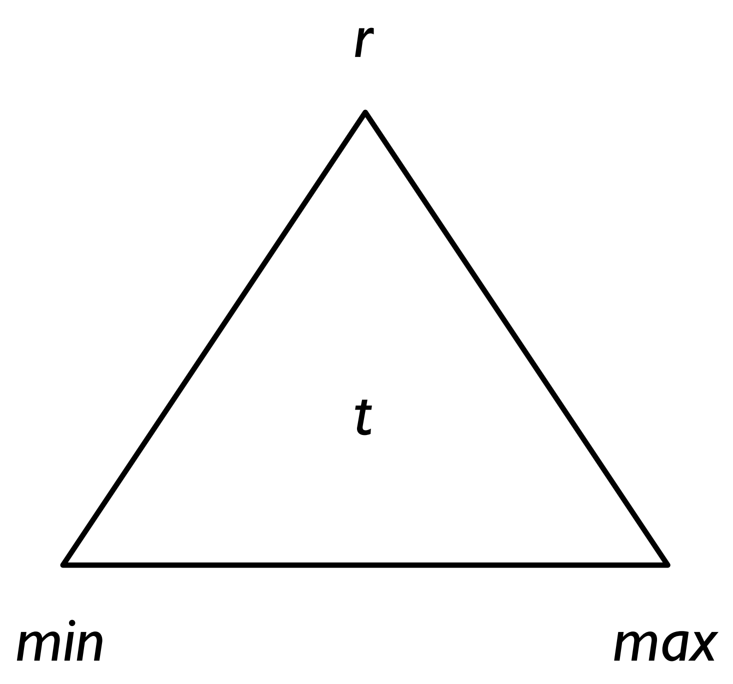

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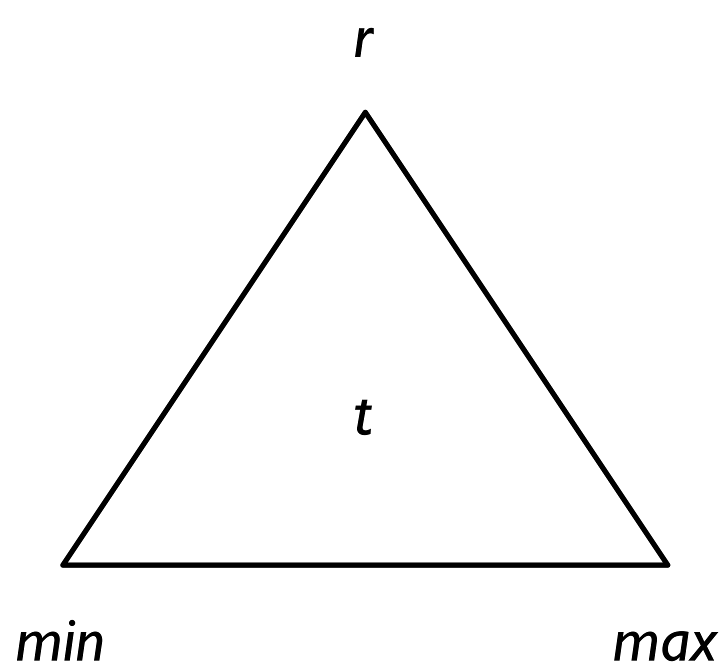

$$\text{score}(t) \;=\; \text{score}(t_1) + \text{score}(t_2) + \text{score}(r \rightarrow l)$$

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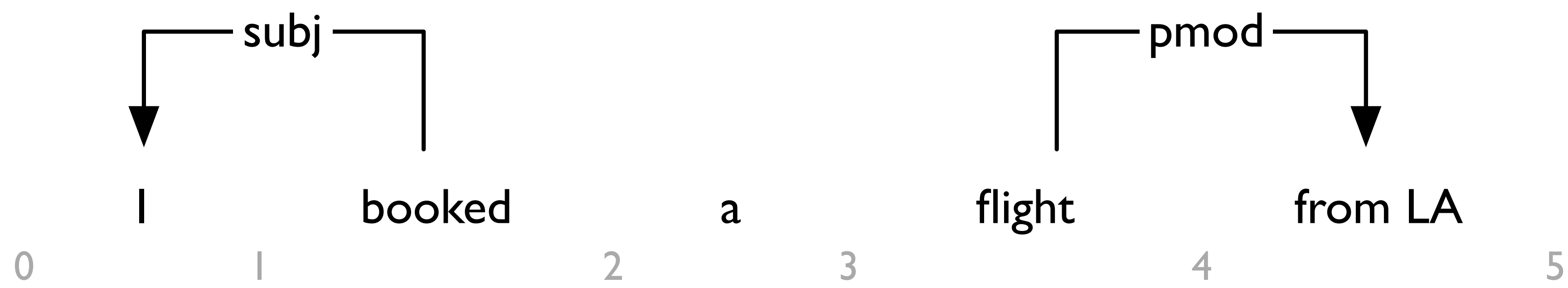
```

Finishing up



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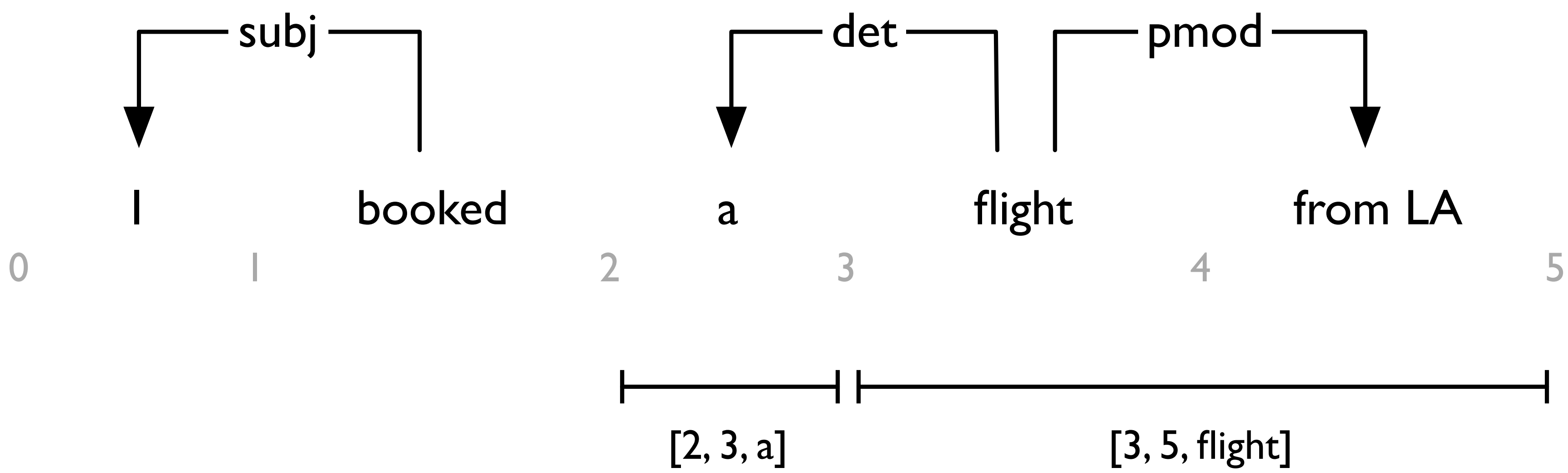
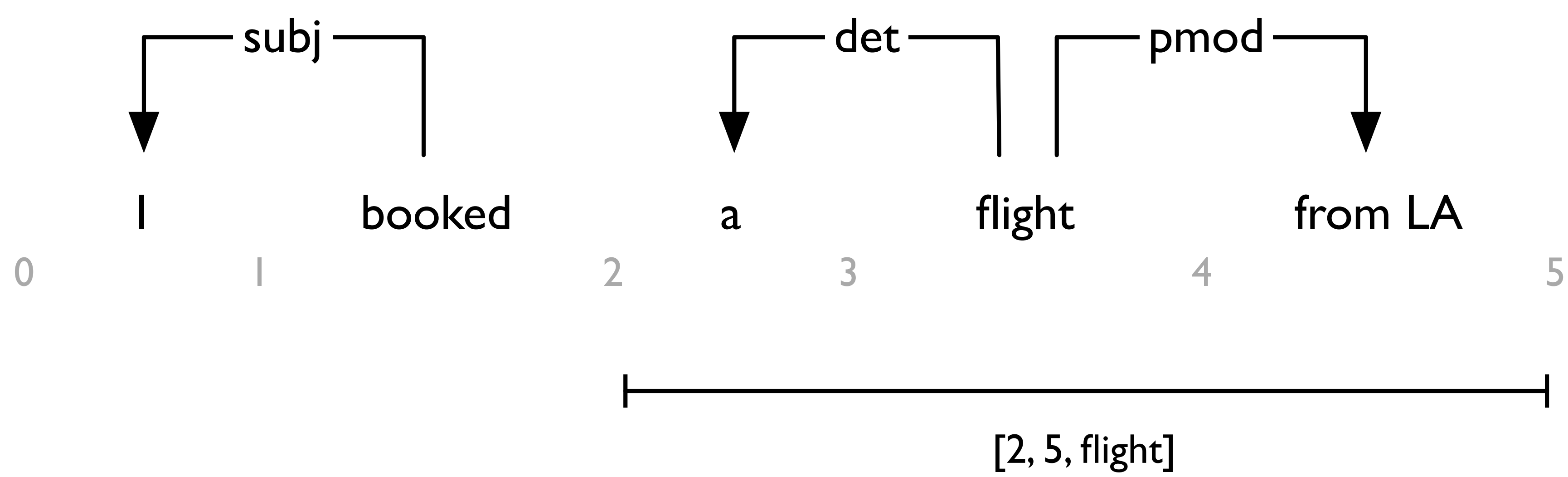


Collins' algorithm

Finishing up



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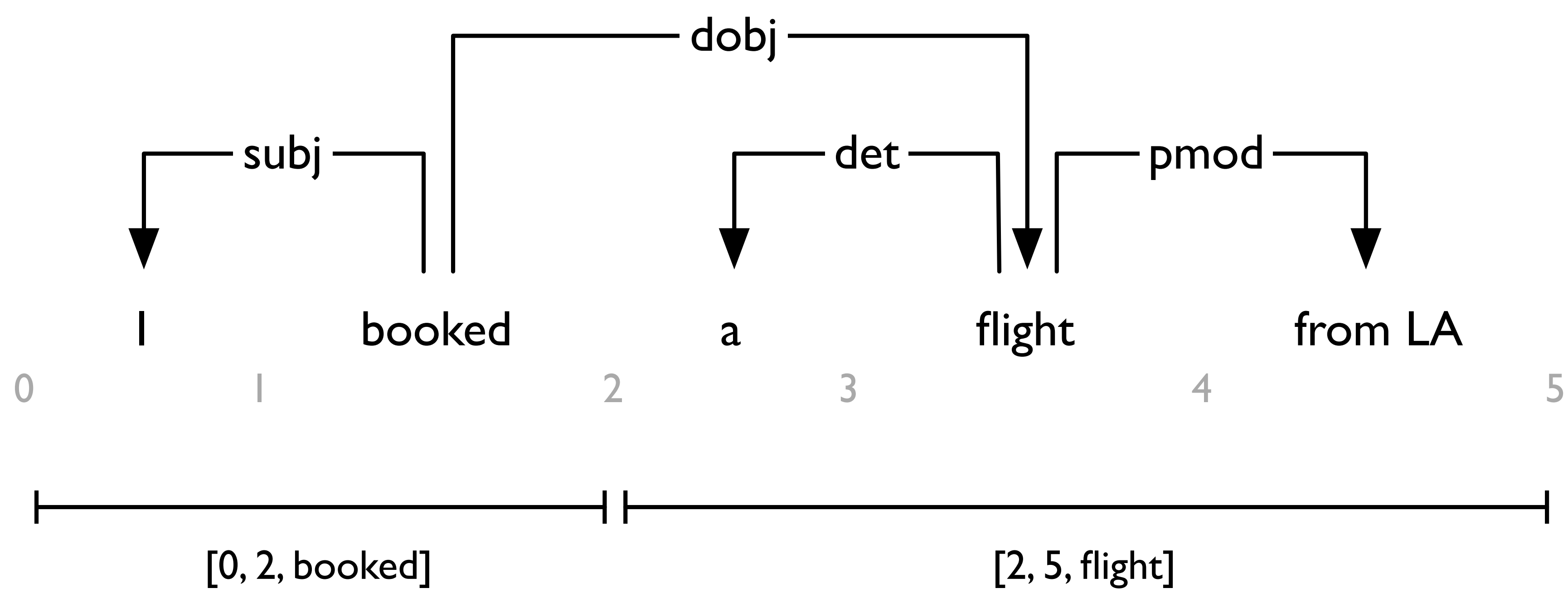

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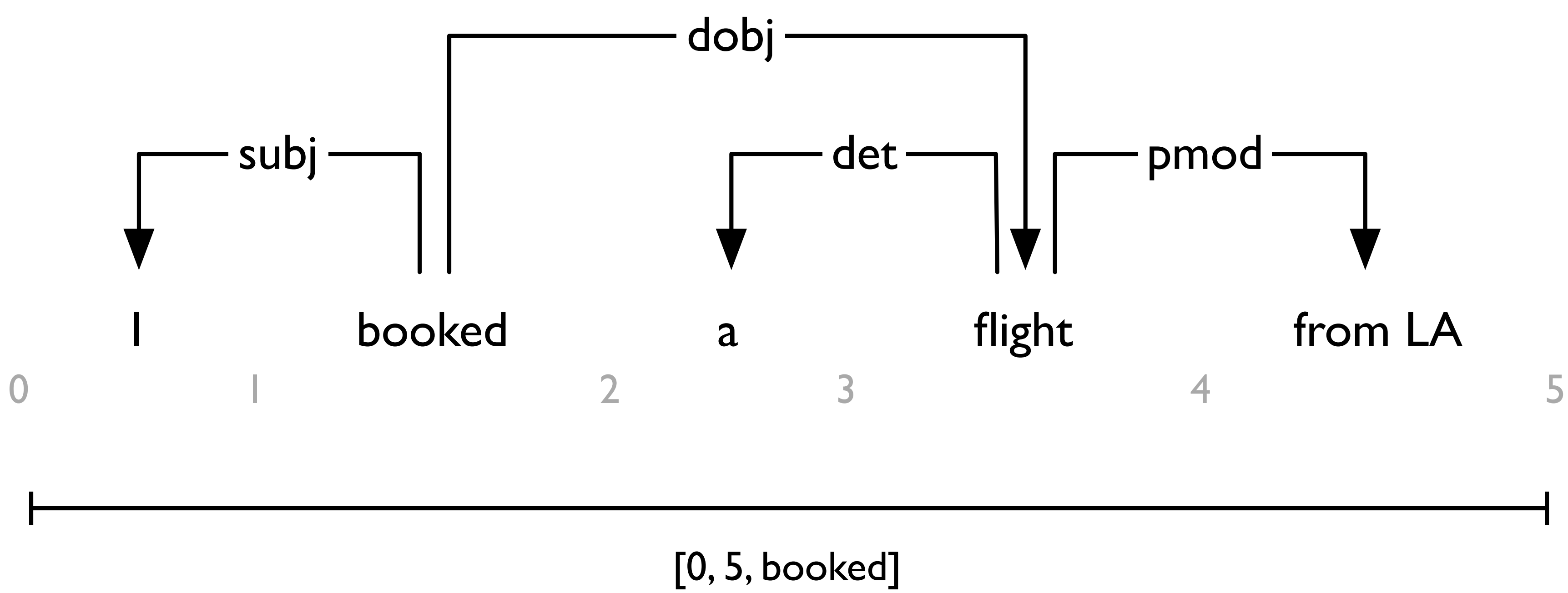

Complexity analysis

- Space requirement:
  $O(|w|^3)$
- Runtime requirement:
  $O(|w|^5)$

Extension to the labeled case

- It is important to distinguish dependencies of different types between the same two words.

  Example: subj, dobj

- For this reason, practical systems typically deal with labeled arcs.

- The question then arises how to extend Collins’ algorithm to the labeled case.

Naive approach

- Add an innermost loop that iterates over all edge labels in order to find the combination that maximizes the overall score.
- For each step of the original algorithm, we now need to make $|L|$ steps, where L is the set of all labels.

Smart approach

- Before parsing, compute a table that lists, for each head–dependent pair (h, d), the label that maximizes the score of arcs $h \rightarrow d$.
- During parsing, simply look up the best label in the precomputed table.
- This adds (not multiplies!) a factor of $|L||w|^2$ to the overall runtime of the algorithm.

Summary

- Collins’ algorithm is a CKY-style algorithm for computing the highest-scoring dependency tree under an arc-factored scoring model.
- It runs in time $O(|w|^5)$.
  This may not be practical for long sentences.

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Eisner’s algorithm

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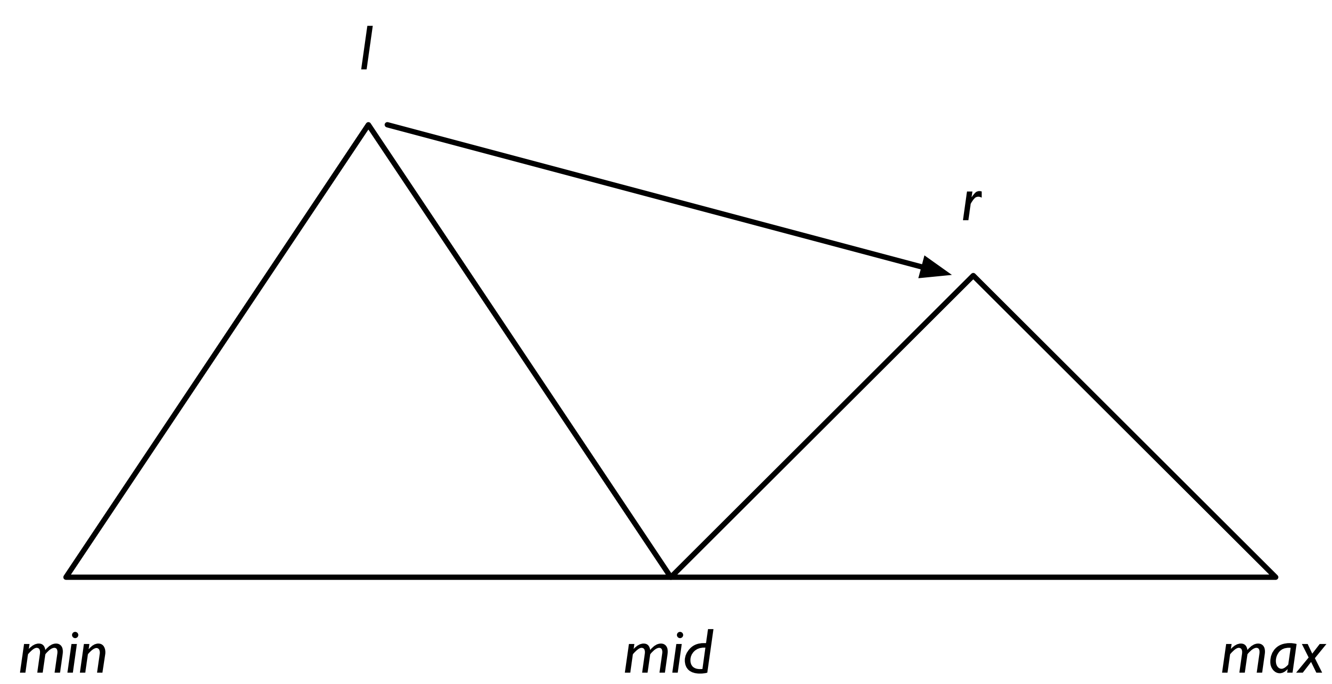
Eisner's algorithm

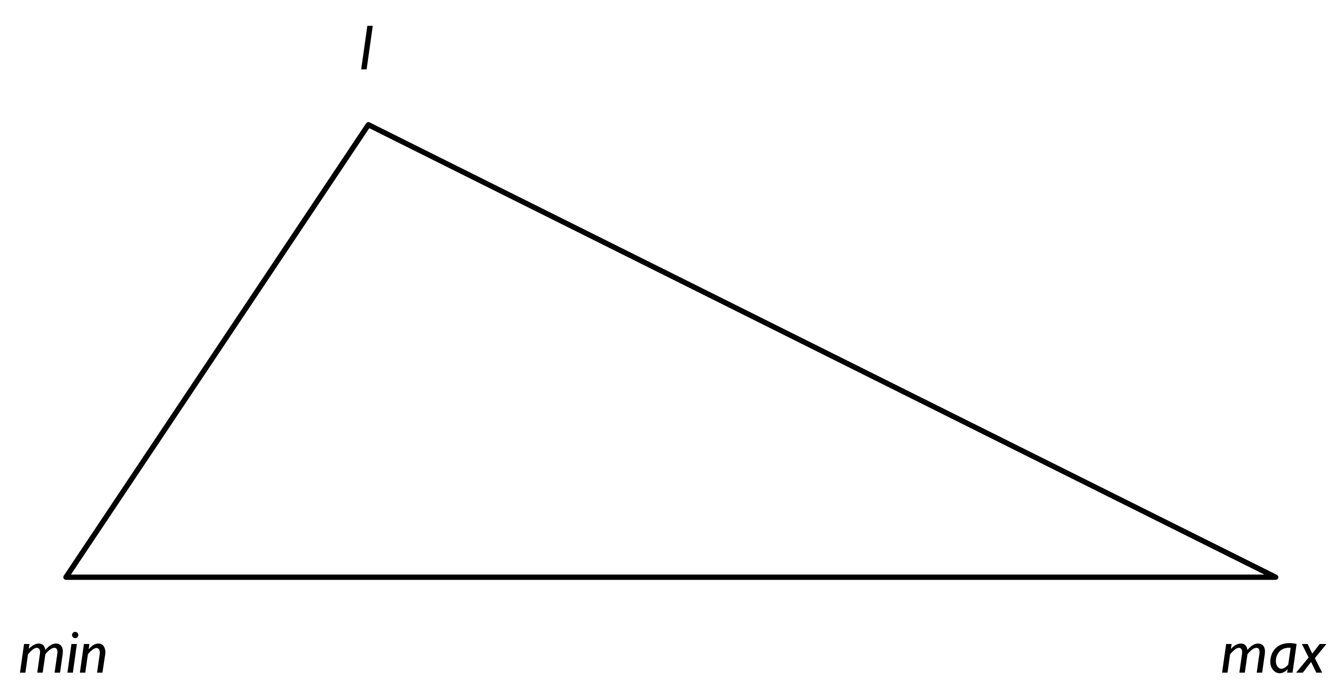
- With its runtime of $O(|w|^5)$, Collins' algorithm may not be of much use in practice.
- With Eisner's algorithm we will be able to solve the same problem in $O(|w|^3)$.
  - Intuition: collect left and right dependents independently

Basic idea



In Collins' algorithm, adding a left-to-right arc is done in one single step, specified by 5 positions.

Basic idea



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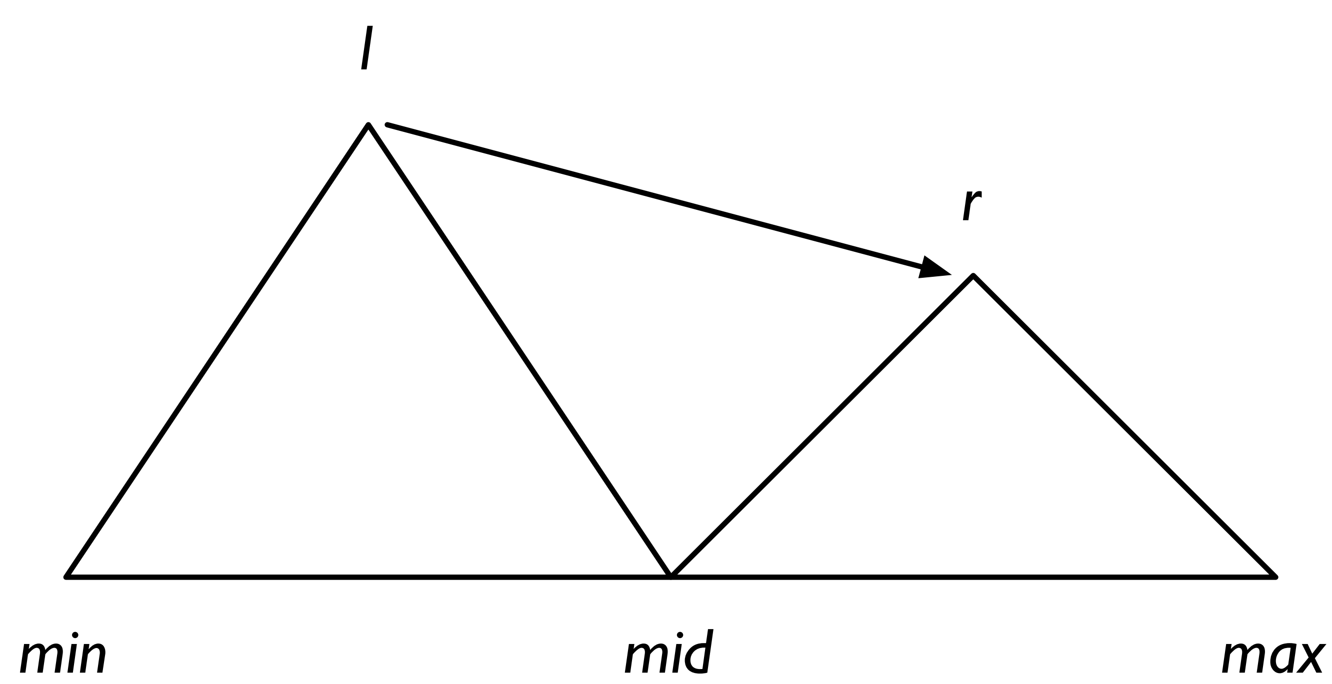

In Eisner's algorithm, the same thing is done in three steps, each one specified by 3 positions.

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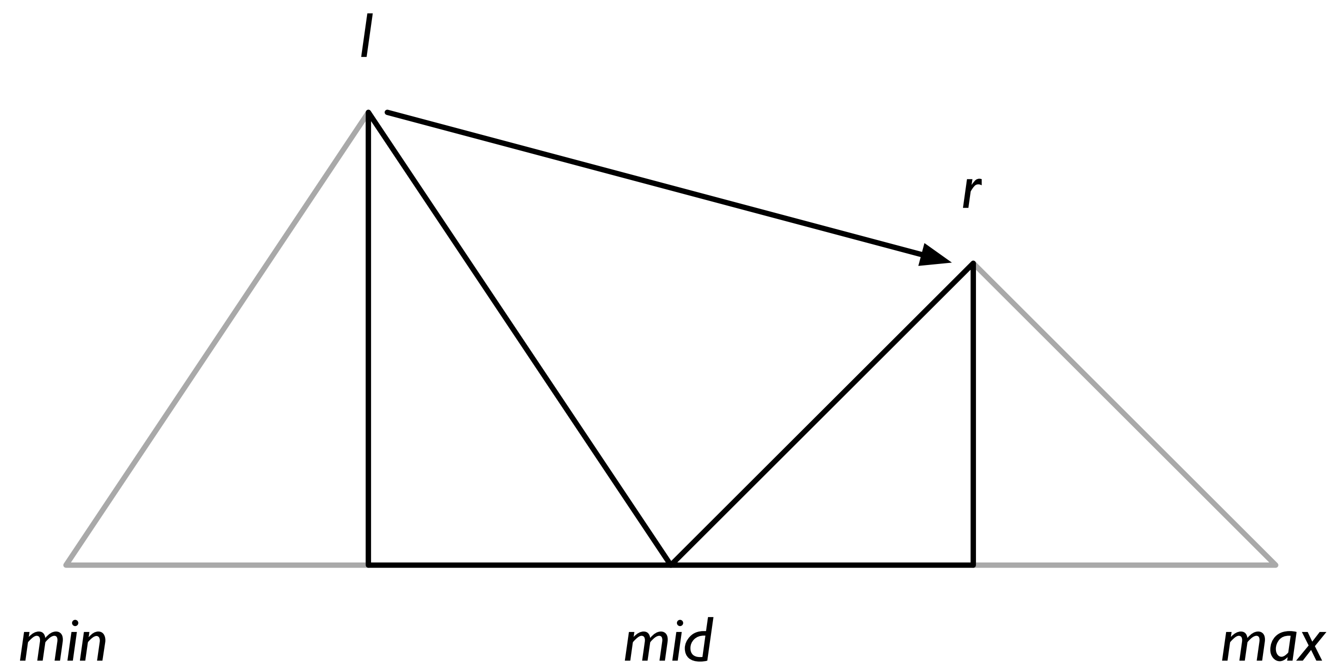

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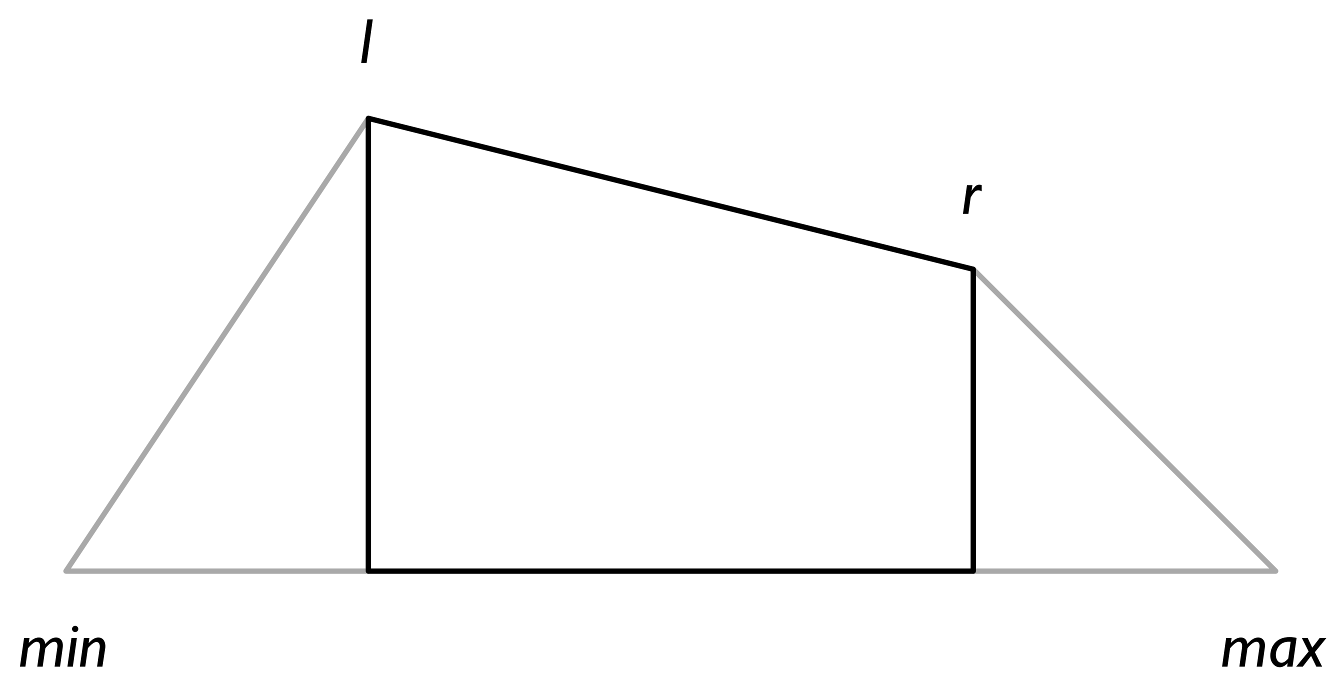

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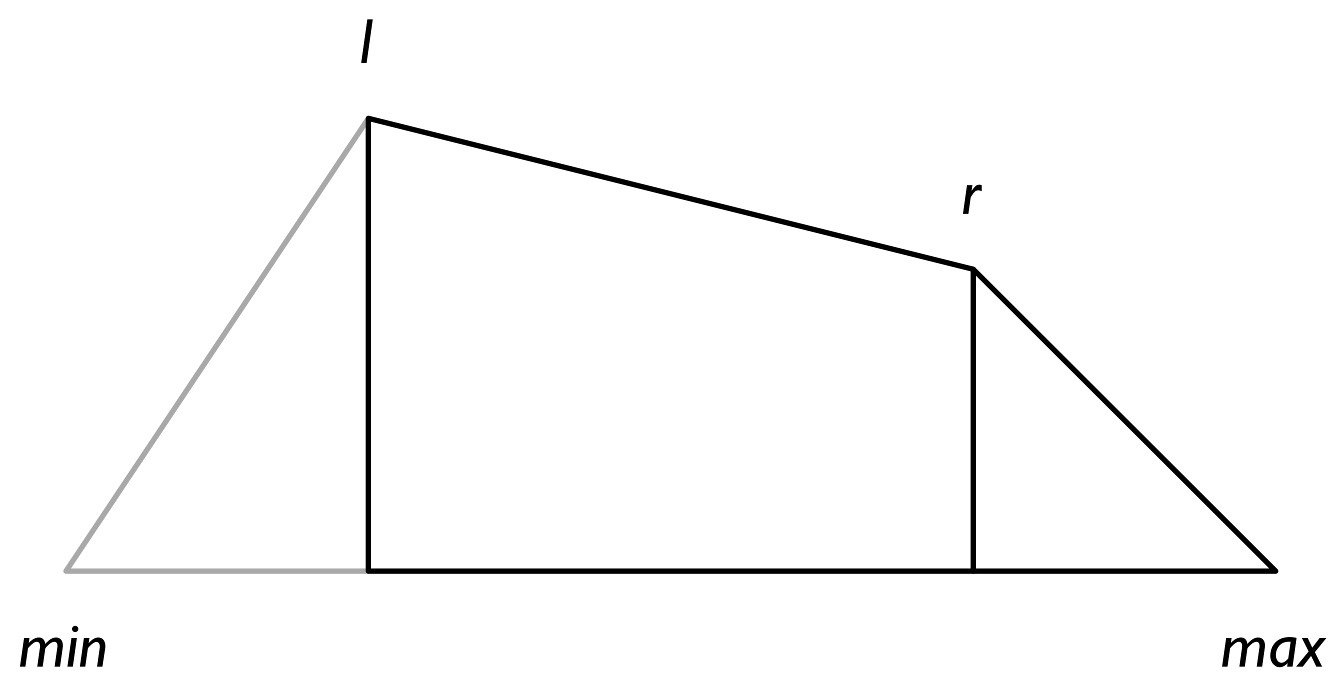

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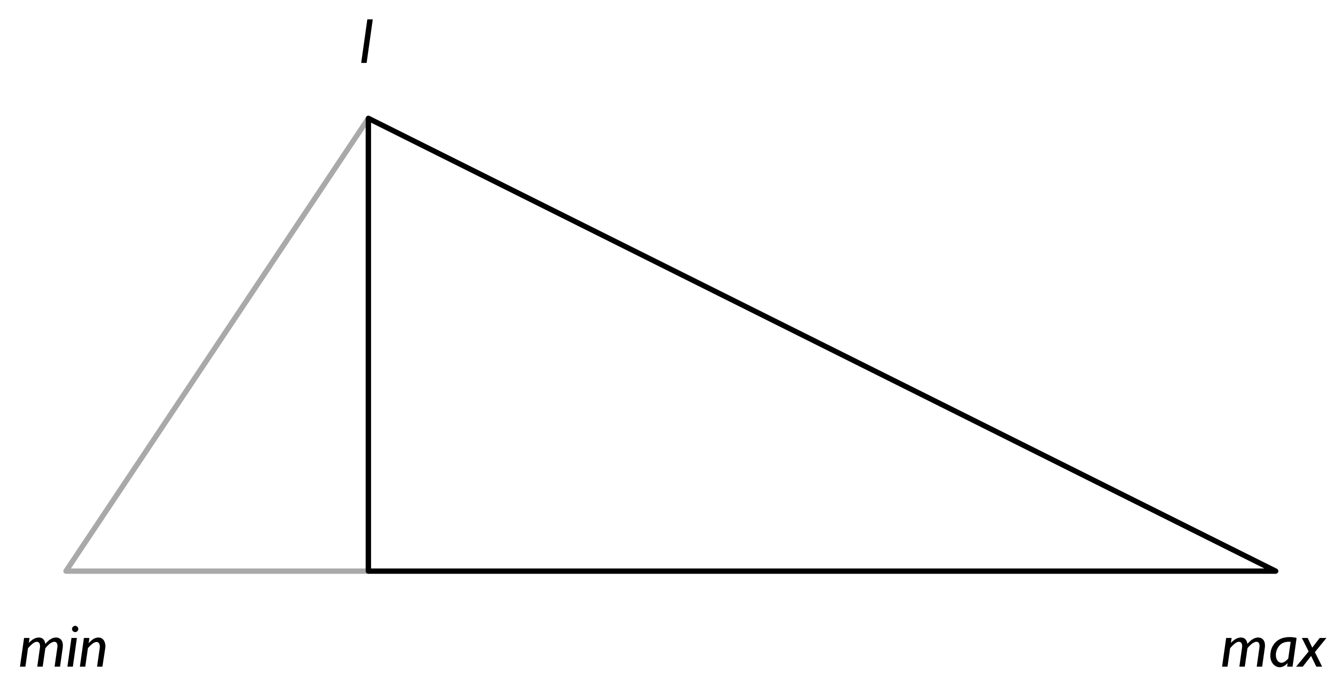

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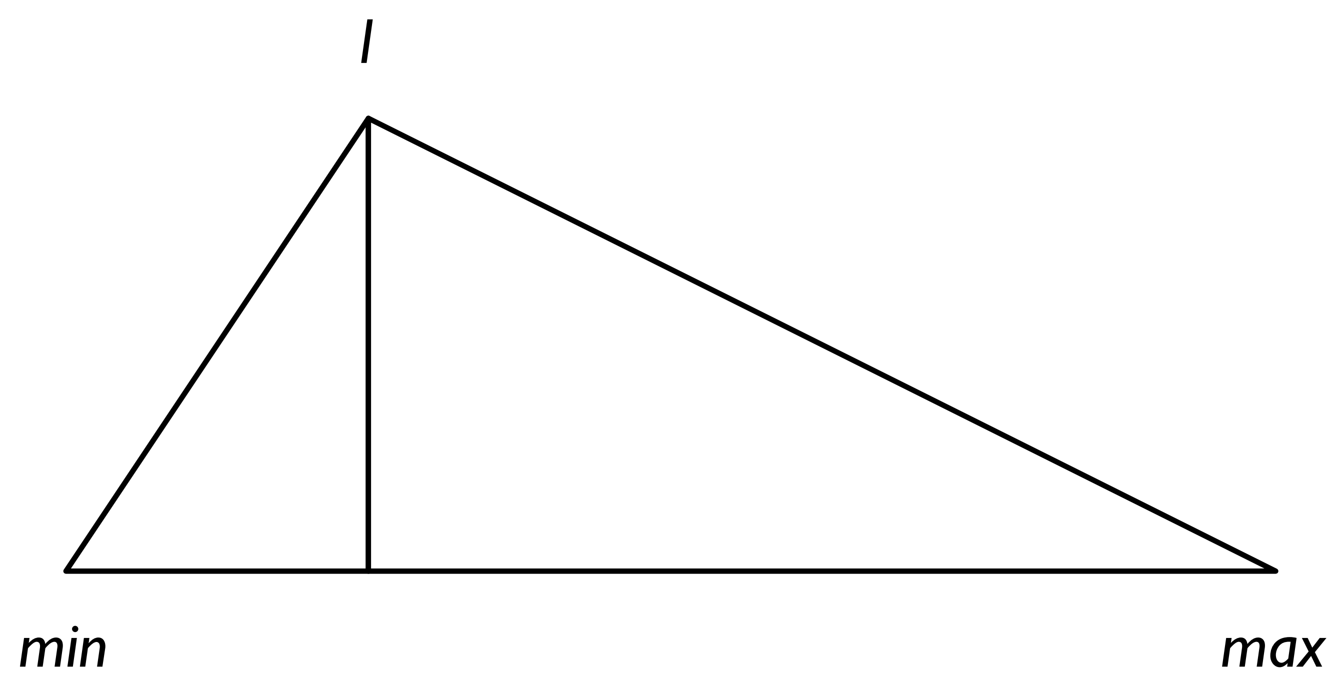

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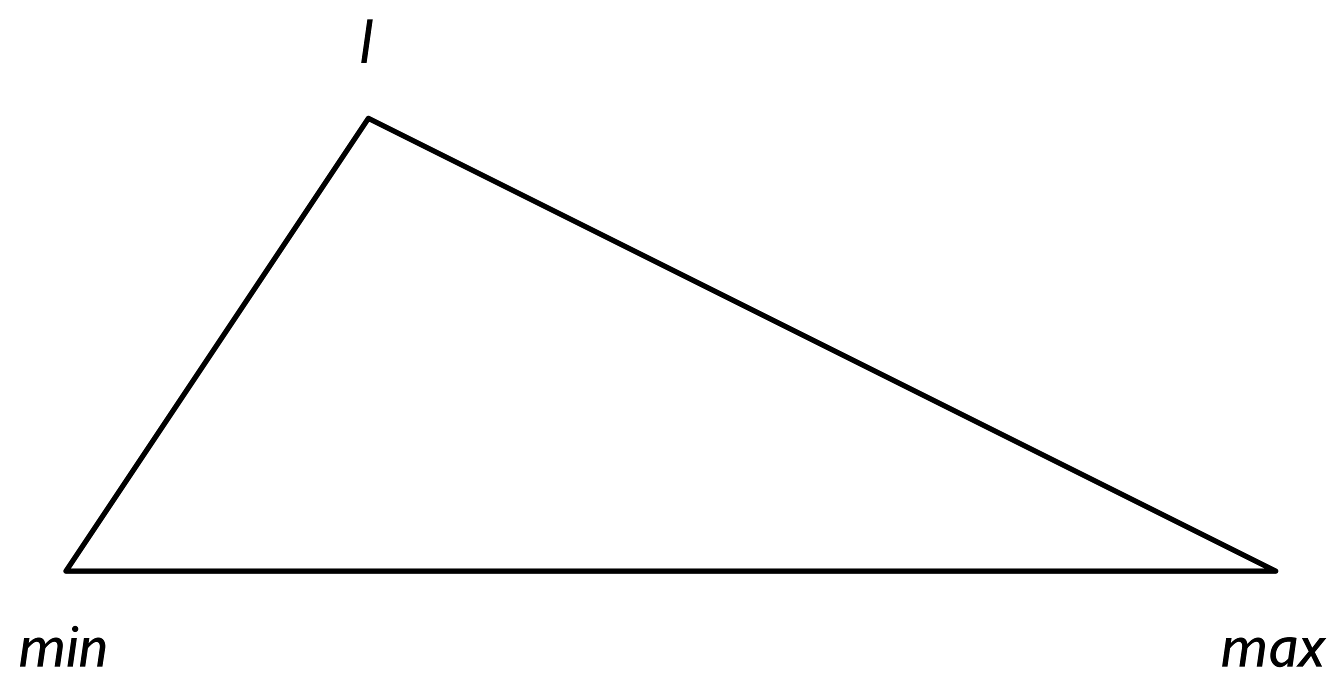

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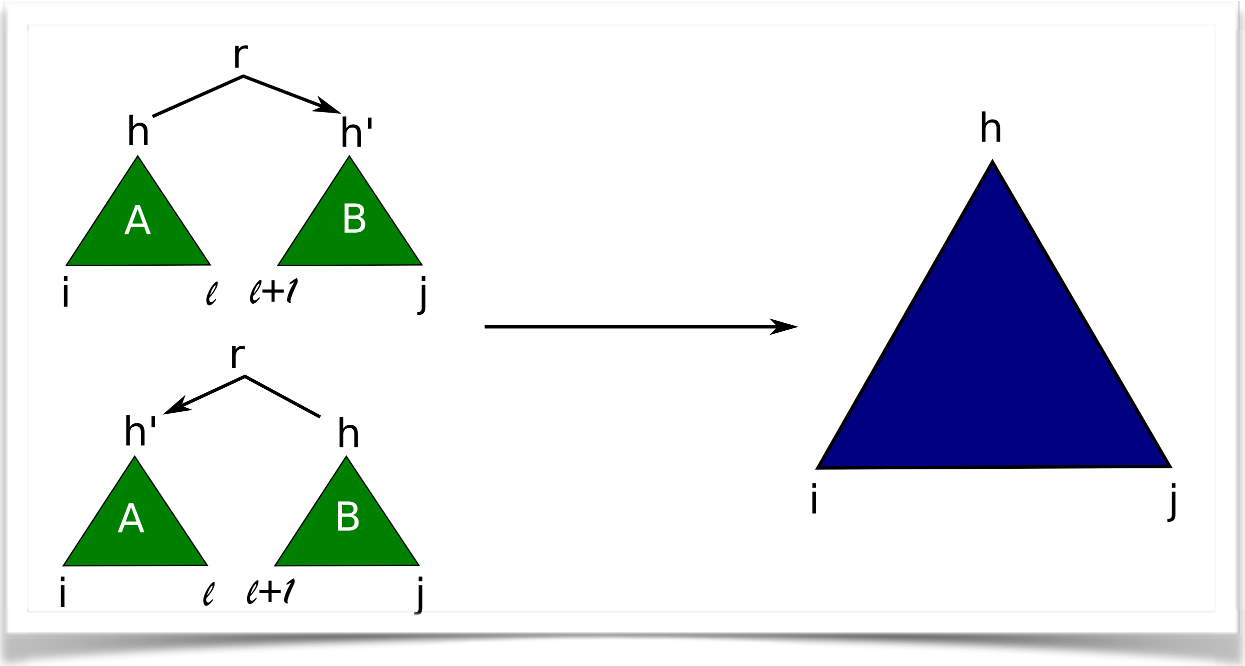
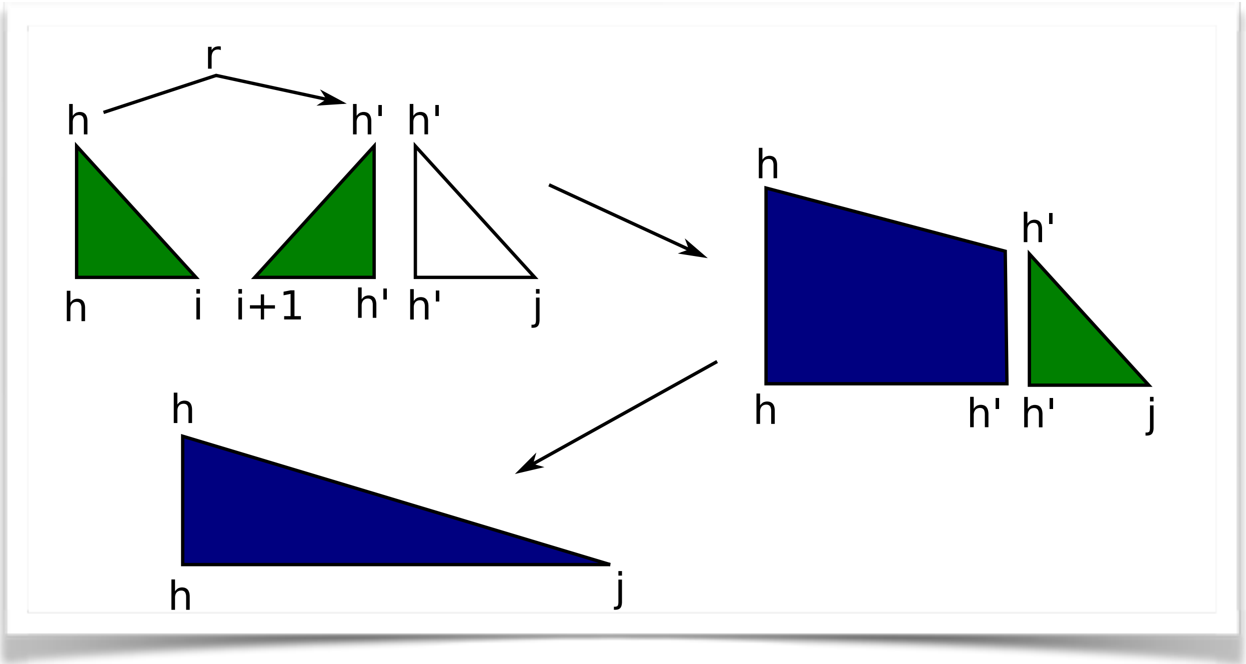
Comparison





Dynamic programming tables

- Collins':
  - [min,max,head]
- Eisner's
  - [min,max,head-side,complete]
    - head-side, binary: is head to the left or right?
    - complete, binary: is the non-head side still looking for dependents?

Pseudo code

```
for each i from 0 to n and all d,c do
  C[i][i][d][c] = 0.0
for each m from 1 to n do
  for each i from 0 to n-m do
     j = i+m
     C[i][j][←][1] = max_{i≤q<j}(C[i][q][→][0] + C[q+1][j][←][0]+score(w_j,w_i)
     C[i][j][→][1] = max_{i≤q<j}(C[i][q][→][0] + C[q+1][j][←][0]+score(w_i,w_j)
     C[i][j][←][0] = max_{i≤q<j}(C[i][q][←][1] + C[q][j][←][0])
     C[i][j][→][0] = max_{i≤q<j}(C[i][q][→][0] + C[q][j][→][1])
return [0][n][→][0]
```

Summary

- Eisner's algorithm is an improvement over Collin's algorithm that runs in time $O(|w|^3)$.
- The same scoring model can be used.
- The same technique for extending the parser to labeled parsing can be used.
- Eisner's algorithm is the basis of current arc-factored dependency parsers.