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Dependency grammar and dependency parsing

Syntactic analysis (5LN455)

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Based on slides from Marco Kuhlmann

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Mid-course evaluation

- Mostly positive
  - Good lectures and slides
  - Good with small exercises during lectures
  - Good assignments
- Main negative points:
  - Air in Turing
  - Parallel with semantic analysi
- Final evaluation at end of course, student portal

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Overview

- Dependency parsing in general
- Arc-factored dependency parsing
  - Collins' algorithm
  - Eisner's algorithm
- Transition-based dependency parsing
  - The arc-standard algorithm
- Evaluation of dependency parsers

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Dependency grammar

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Dependency grammar

- The term ‘dependency grammar’ does not refer to a specific grammar formalism.
- Rather, it refers to a specific way to describe the syntactic structure of a sentence.

The notion of dependency

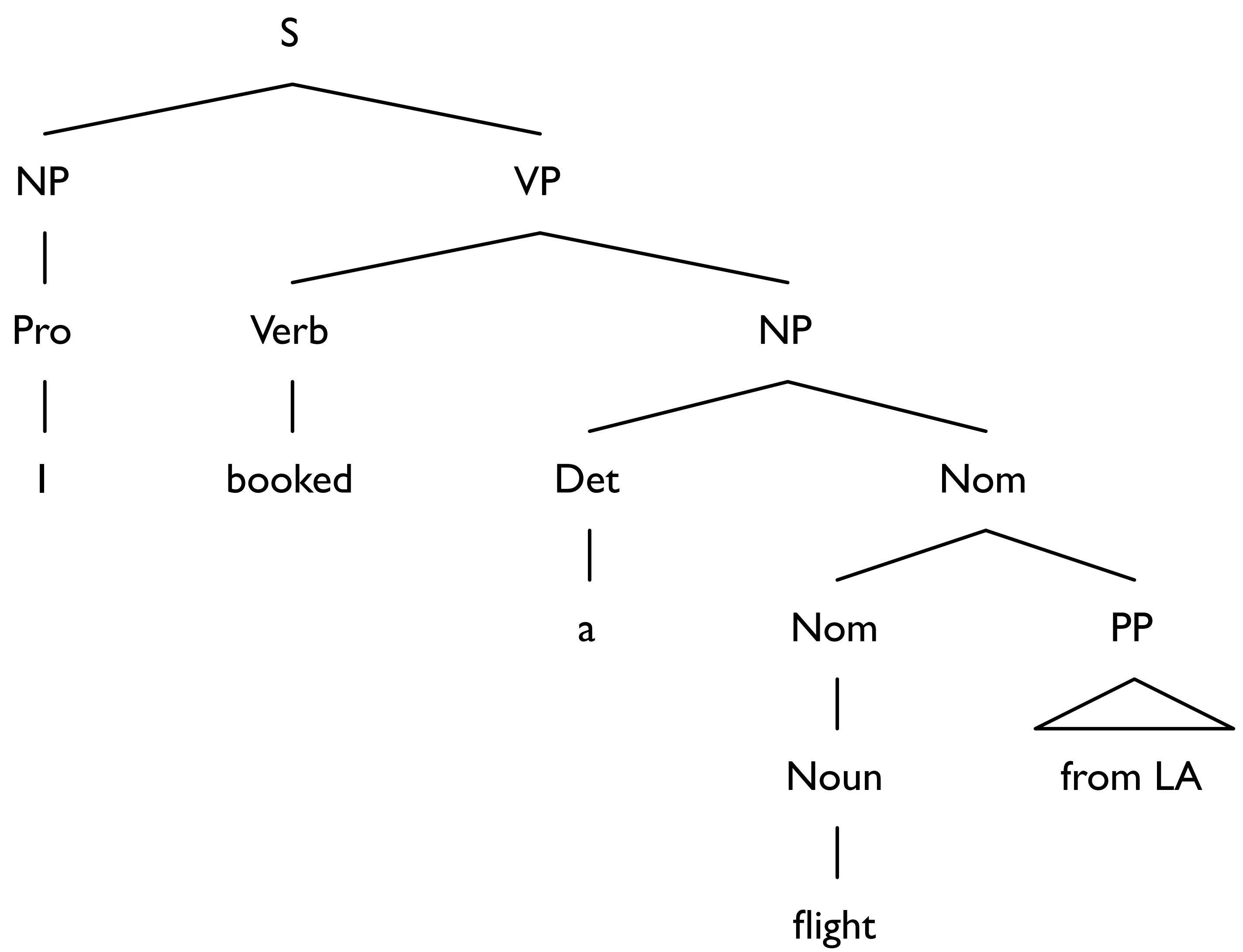
- The basic observation behind constituency is that groups of words may act as one unit.

  Example: noun phrase, prepositional phrase

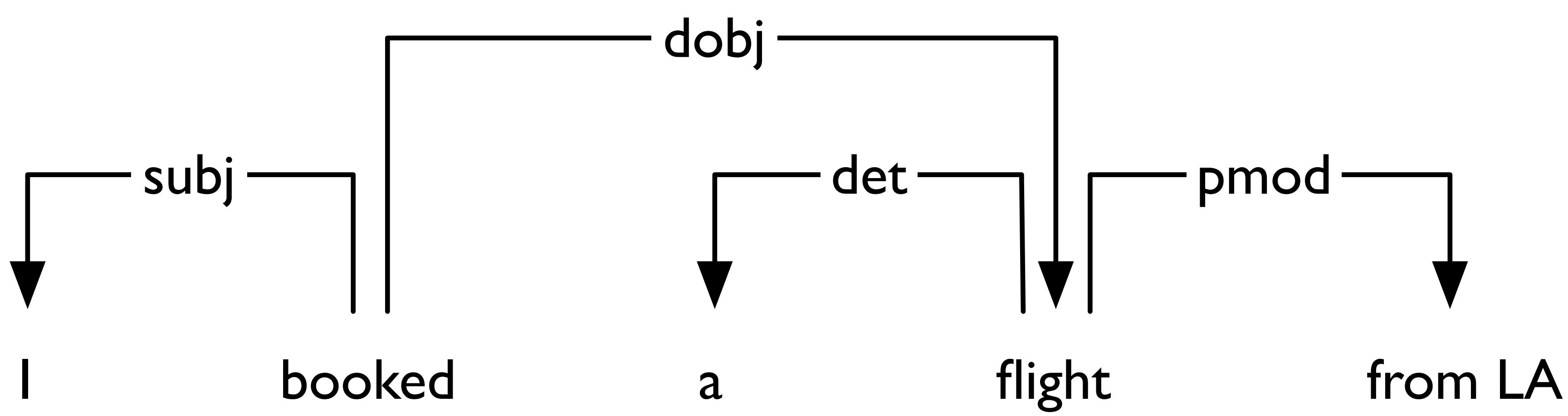
- The basic observation behind dependency is that words have grammatical functions with respect to other words in the sentence.

  Example: subject, modifier

Phrase structure trees



Dependency trees



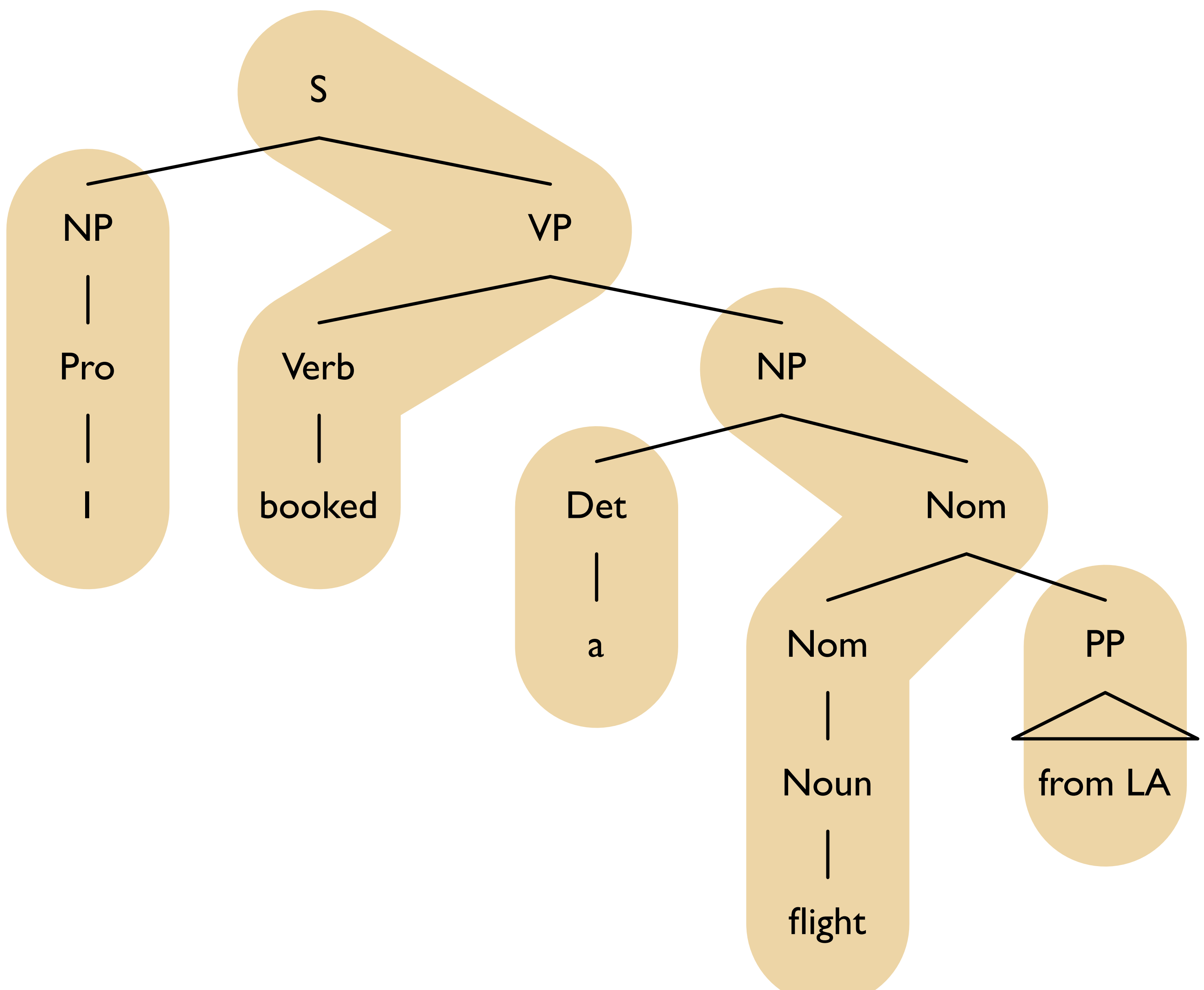
- In an arc $h \rightarrow d$, the word h is called the head, and the word d is called the dependent.
- The arcs form a rooted tree.

Heads in phrase structure grammar

- In phrase structure grammar, ideas from dependency grammar can be found in the notion of heads.
- Roughly speaking, the head of a phrase is the most important word of the phrase: the word that determines the phrase function.

Examples: noun in a noun phrase, preposition in a prepositional phrase

Heads in phrase structure grammar



The history of dependency grammar

- The notion of dependency can be found in some of the earliest formal grammars.
- Modern dependency grammar is attributed to Lucien Tesnière (1893–1954).

- Recent years have seen a revived interest in dependency-based description of natural language syntax.

Linguistic resources

- Descriptive dependency grammars exist for some natural languages.
- Dependency treebanks exist for a wide range of natural languages.
- These treebanks can be used to train accurate and efficient dependency parsers.

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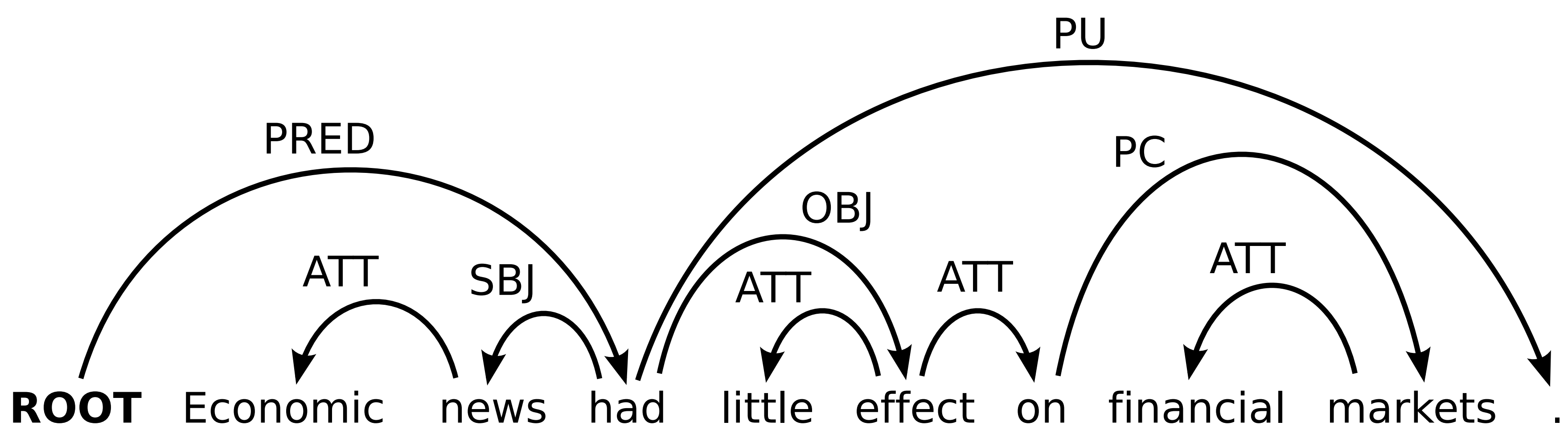
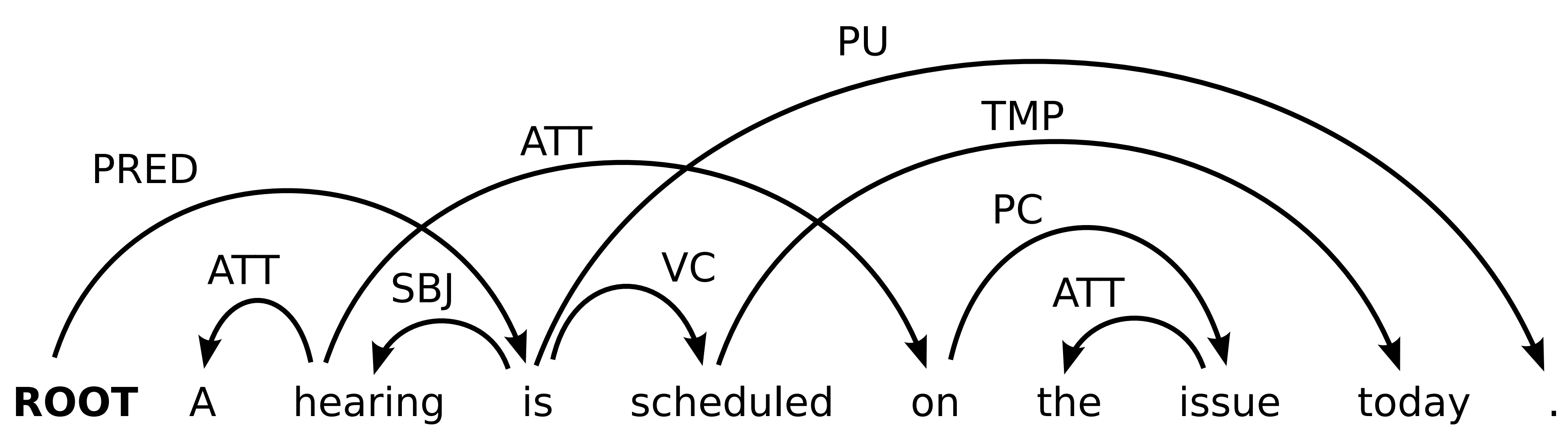
Projectivity

- An important characteristic of dependency trees is projectivity
- A dependency tree is projective if:
  - For every arc in the tree, there is a directed path from the head of the arc to all words occurring between the head and the dependent (that is, the arc (i,l,j) implies that $i \rightarrow^* k$ for every k such that $\min(i, j) < k < \max(i, j)$)

Projective and non-projective trees





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Projectivity and dependency parsing

- Many dependency parsing algorithms can only handle projective trees
- Non-projective trees do occur in natural language
  - How often depends on the language (and treebank)

Projectivity in the course

- The algorithms we will discuss in detail during the lectures will only concern projective parsing
- Non-projective parsing:
  - Seminar 2: Pseudo-projective parsing
  - Other variants mentioned briefly during the lectures
  - You can read more about it in the course book!

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Arc-factored dependency parsing

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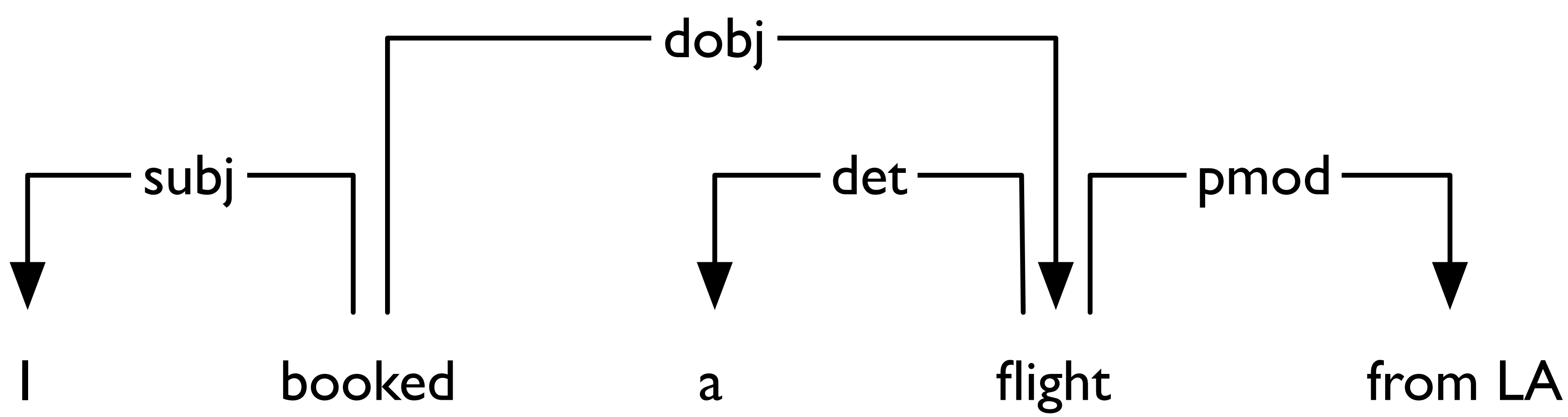
Ambiguity

Just like phrase structure parsing, dependency parsing has to deal with ambiguity.



Ambiguity

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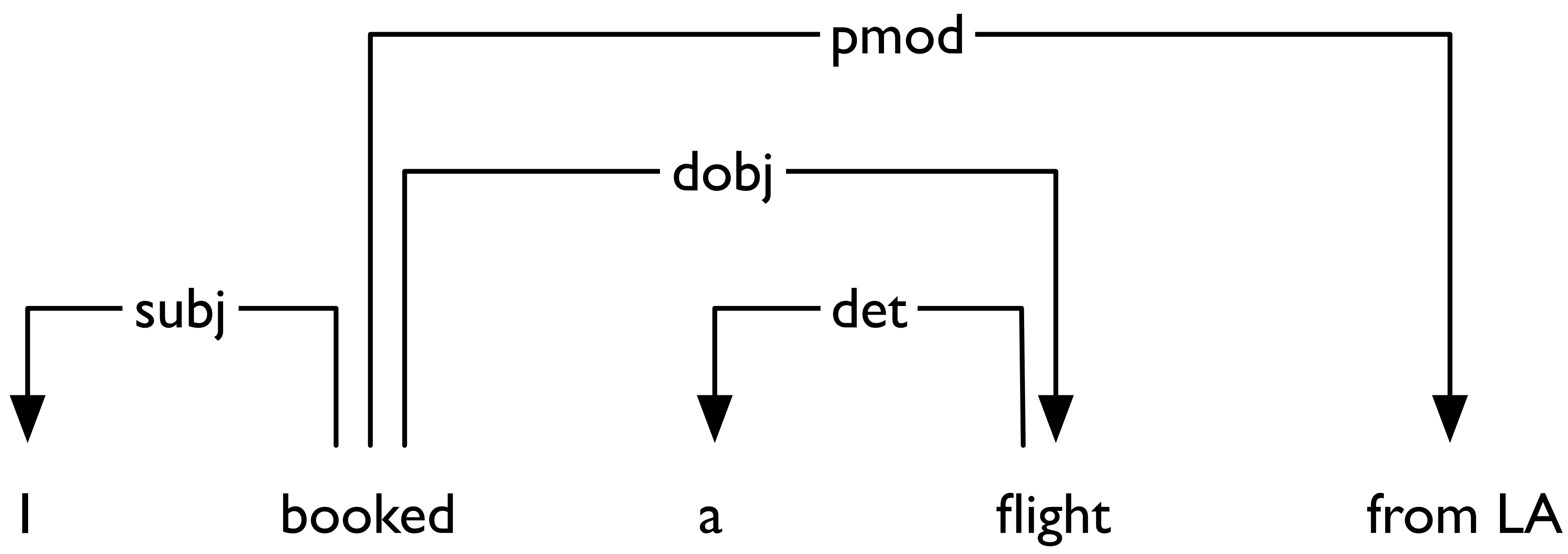

Disambiguation

- We need to disambiguate between alternative analyses.
- We develop mechanisms for scoring dependency trees, and disambiguate by choosing a dependency tree with the highest score.

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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?

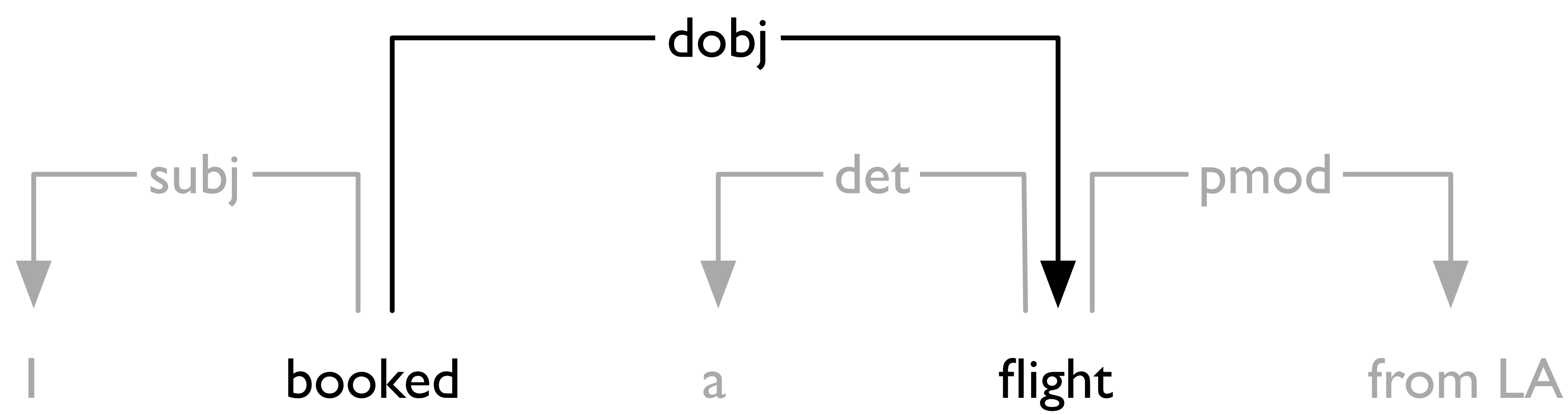
The arc-factored model

- Split the dependency tree t into parts $p_1, \dots, p_n$,
score each of the parts individually,
and combine the score into a simple sum.

  $$\text{score}(t) = \text{score}(p_1) + \dots + \text{score}(p_n)$$

- The simplest scoring model is
the arc-factored model, where
the scored parts are the arcs of the tree.

Features



- To score an arc, we define features that are likely to be relevant in the context of parsing.
- We represent an arc by its feature vector.

Examples of features

Examples of features

- ‘The head is a verb.’

Examples of features

- ‘The head is a verb.’
- ‘The dependent is a noun.’

Examples of features

- ‘The head is a verb.’
- ‘The dependent is a noun.’
- ‘The head is a verb
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Examples of features

- ‘The head is a verb.’
- ‘The dependent is a noun.’
- ‘The head is a verb
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- ‘The head is a verb
  and the predecessor of the head is a pronoun.’

Examples of features

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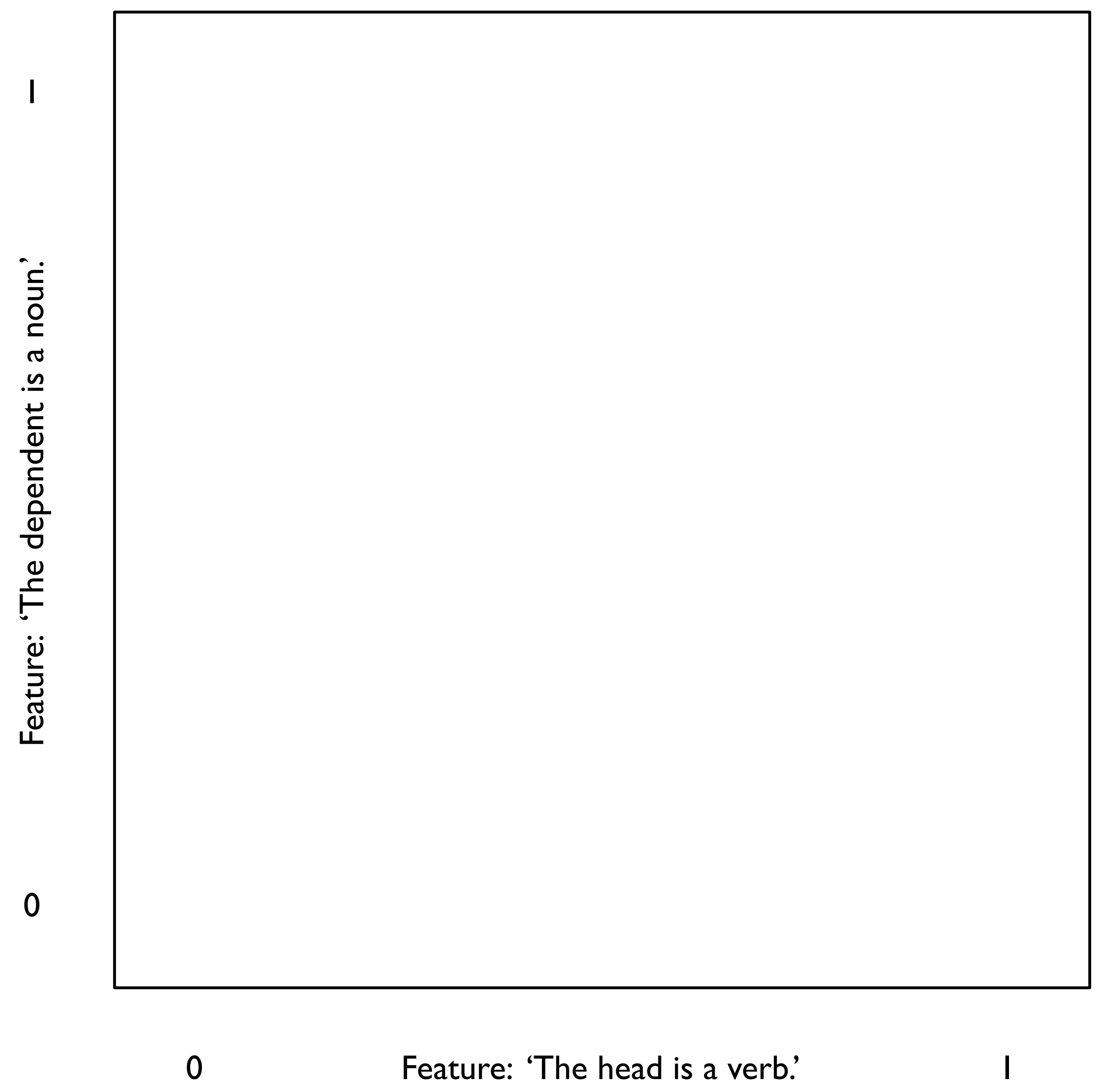
- ‘The head is a verb
  and the predecessor of the head is a pronoun.’
- ‘The arc goes from left to right.’

Examples of features

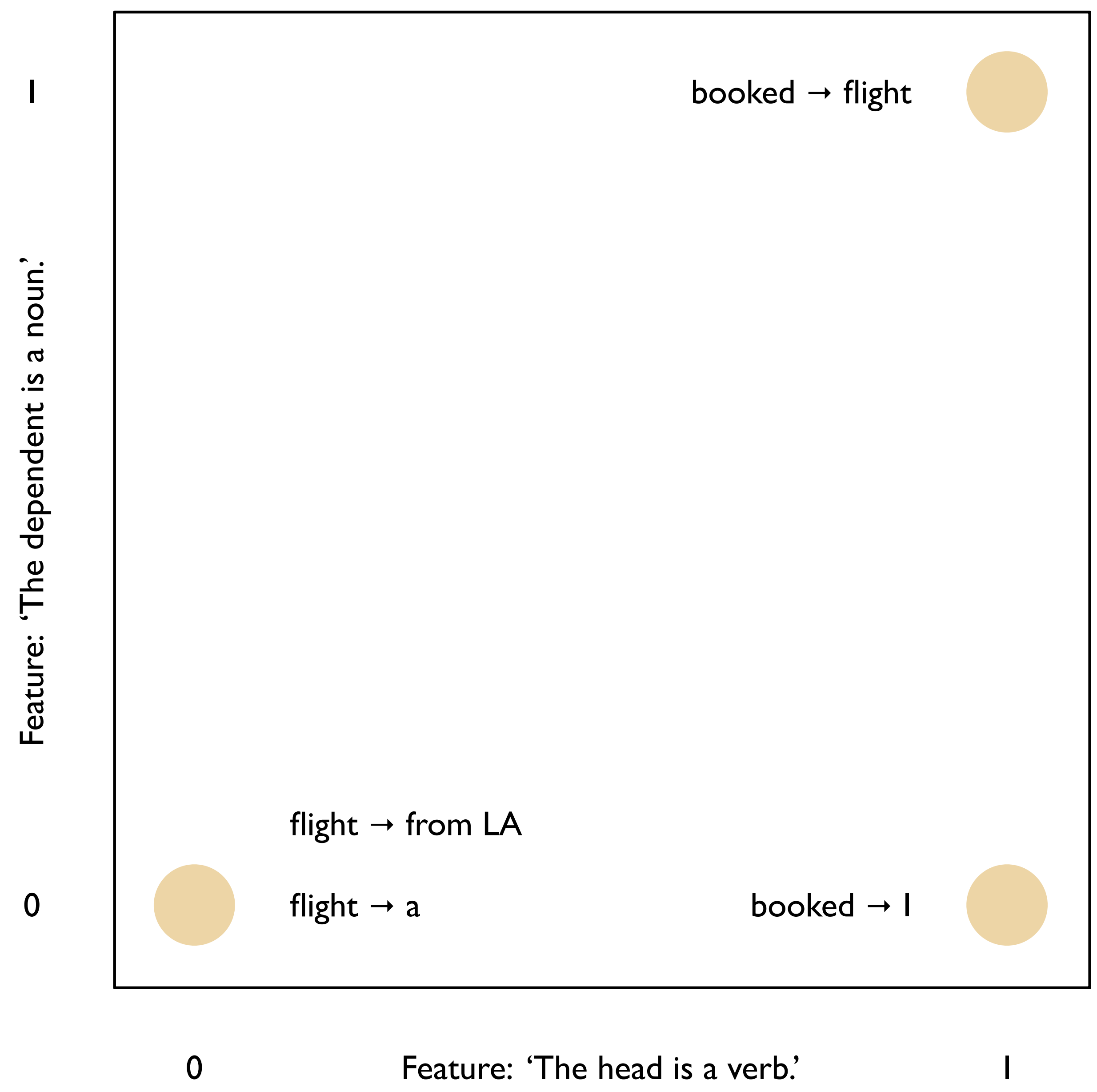
- ‘The head is a verb.’
- ‘The dependent is a noun.’
- ‘The head is a verb
  and the dependent is a noun.’
- ‘The head is a verb
  and the predecessor of the head is a pronoun.’
- ‘The arc goes from left to right.’
- ‘The arc has length 2.’

Feature vectors



Arc-factored dependency parsing

Feature vectors



Implementation of feature vectors

- We assign each feature a unique number.
- For each arc, we collect the numbers of those features that apply to that arc.
- The feature vector of the arc is the list of those numbers.

Example: [1, 2, 42, 313, 1977, 2008, 2010]

Feature weights

- Arc-factored dependency parsers require a training phase.
- During training, our goal is to assign, to each feature f_i, a feature weight w_i.
- Intuitively, the weight w_i quantifies the effect of the feature f_i on the likelihood of the arc.

How likely is is that we will see an arc with this feature in a useful dependency tree?

Feature weights

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

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

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*.

Training using structured prediction

- Training involves repeatedly parsing (treebank) sentences and refining the weights.
- Hence, training presupposes an efficient parsing algorithm.

Higher order models

- The arc-factored model is a first-order model, because scored subgraphs consist of a single arc.
- An nth-order model scores subgraphs consisting of (at most) n arcs.
- Second-order: siblings, grand-parents
- Third-order: tri-siblings, grand-siblings
- Higher-order models capture more linguistic structure and give higher parsing accuracy, but less efficient

Parsing algorithms

- Projective parsing
  - Inspired by the CKY algorithm
    - Collins' algorithm
    - Eisner's algorithm
- Non-projective parsing:
  - Minimum spanning tree (MST) algorithms

Graph-based parsing

- Arc-factored parsing is an instance of graph-based dependency parsing
- Because it scores the dependency graph (tree)
- Graph-based models are often contrasted with transition-based models (next week)
- There are also grammar-based methods, which we will not discuss

Summary

- The term ‘arc-factored dependency parsing’ refers to dependency parsers that score a dependency tree by scoring its arcs.
- Arcs are scored by defining features and assigning weights to these features.
- The resulting parsers can be trained using structured prediction.
- More powerful scoring models exist.

Overview

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  - Eisner's algorithm
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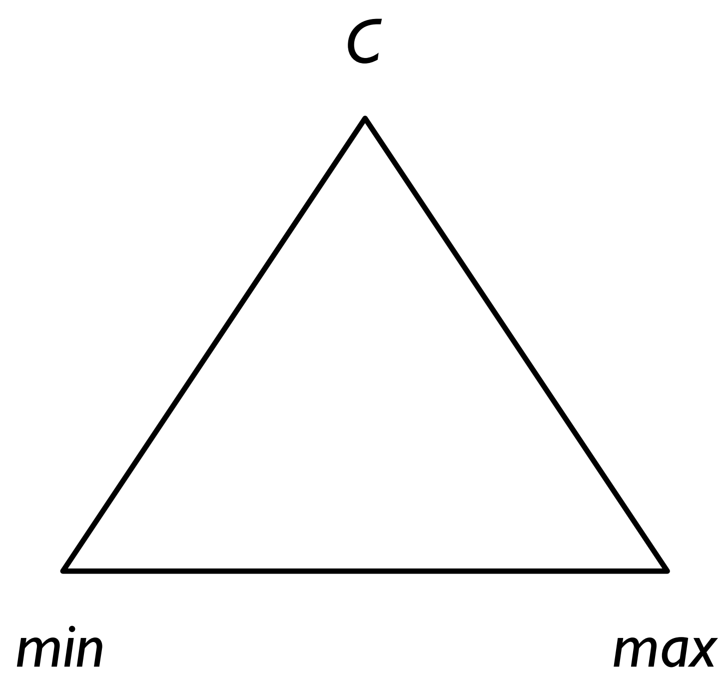
- Dependency treebanks
- Evaluation of dependency parsers

Collins’ algorithm

Collins' algorithm

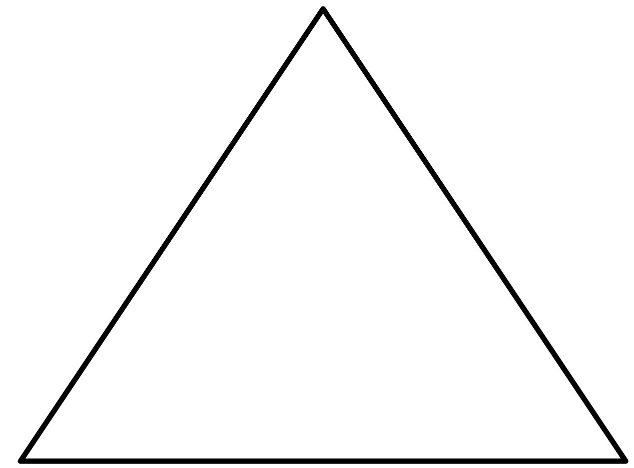
- Collin's algorithm is a simple algorithm
for computing the highest-scoring dependency
tree under an arc-factored scoring model.
- It can be understood as an extension
of the CKY algorithm to dependency parsing.
- Like the CKY algorithm, it can be characterized
as a bottom-up algorithm
based on dynamic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

Signatures, CKY



[min, max, C]

Signatures, Collins’



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

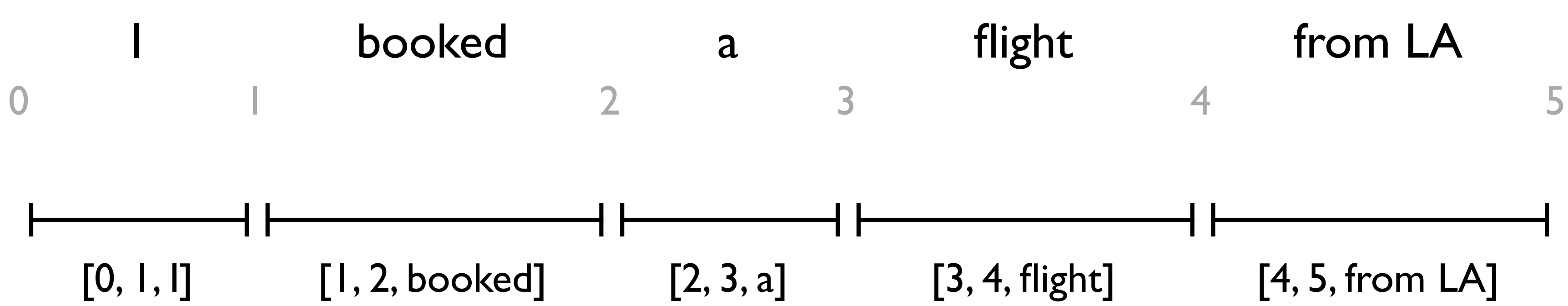
Initialization

I	booked	a	flight	from LA

0 1 2 3 4 5

Collins' algorithm

Initialization



Adding a left-to-right arc

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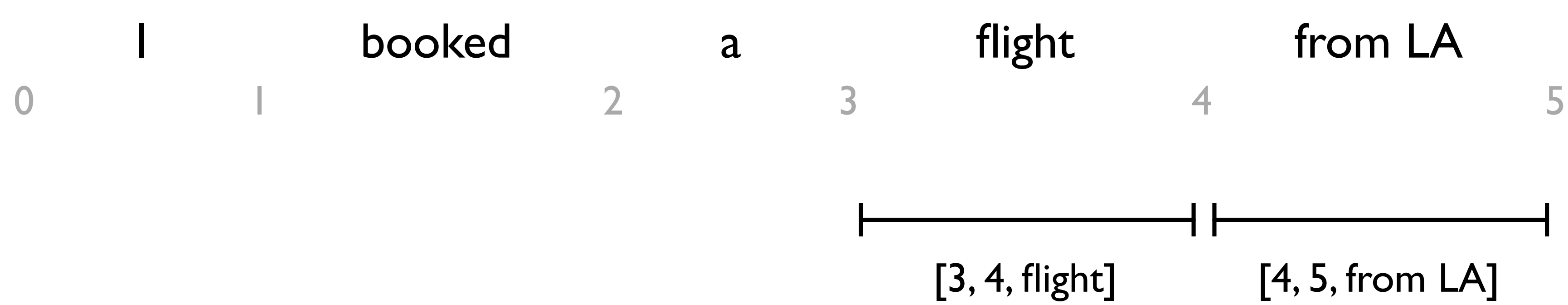
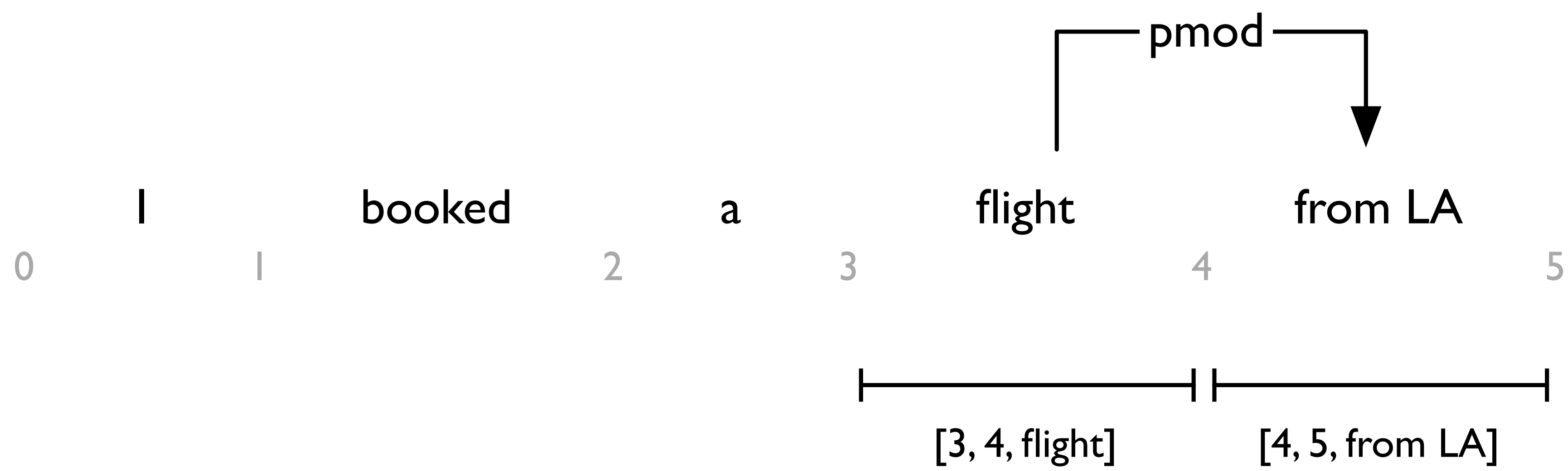
Collins' algorithm

Adding a left-to-right arc



Collins' algorithm

Adding a left-to-right arc



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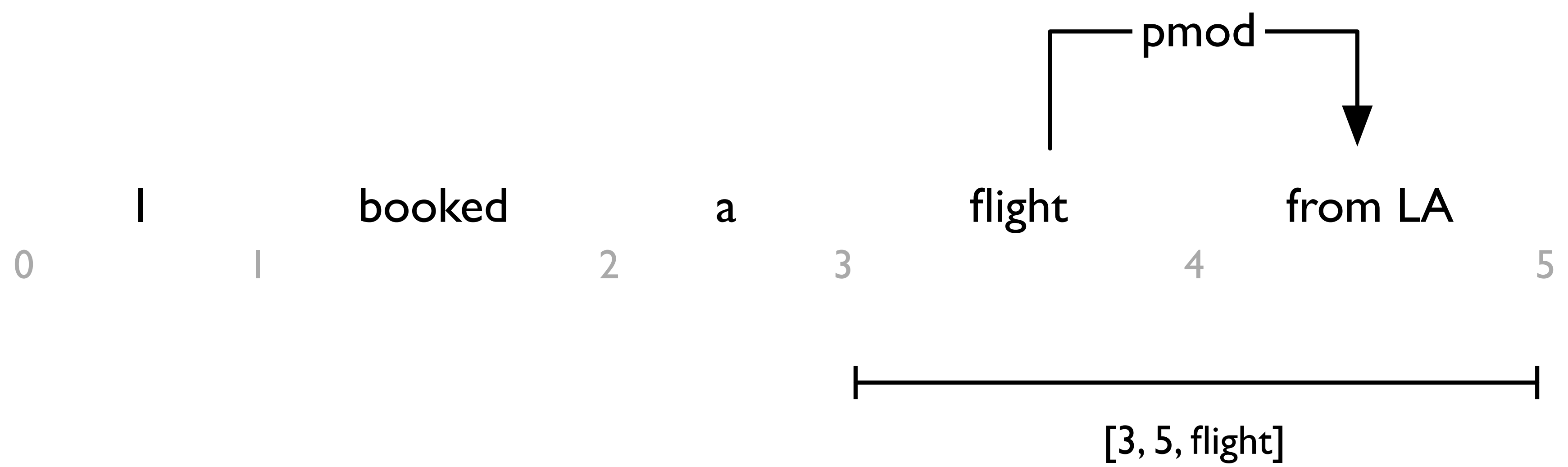

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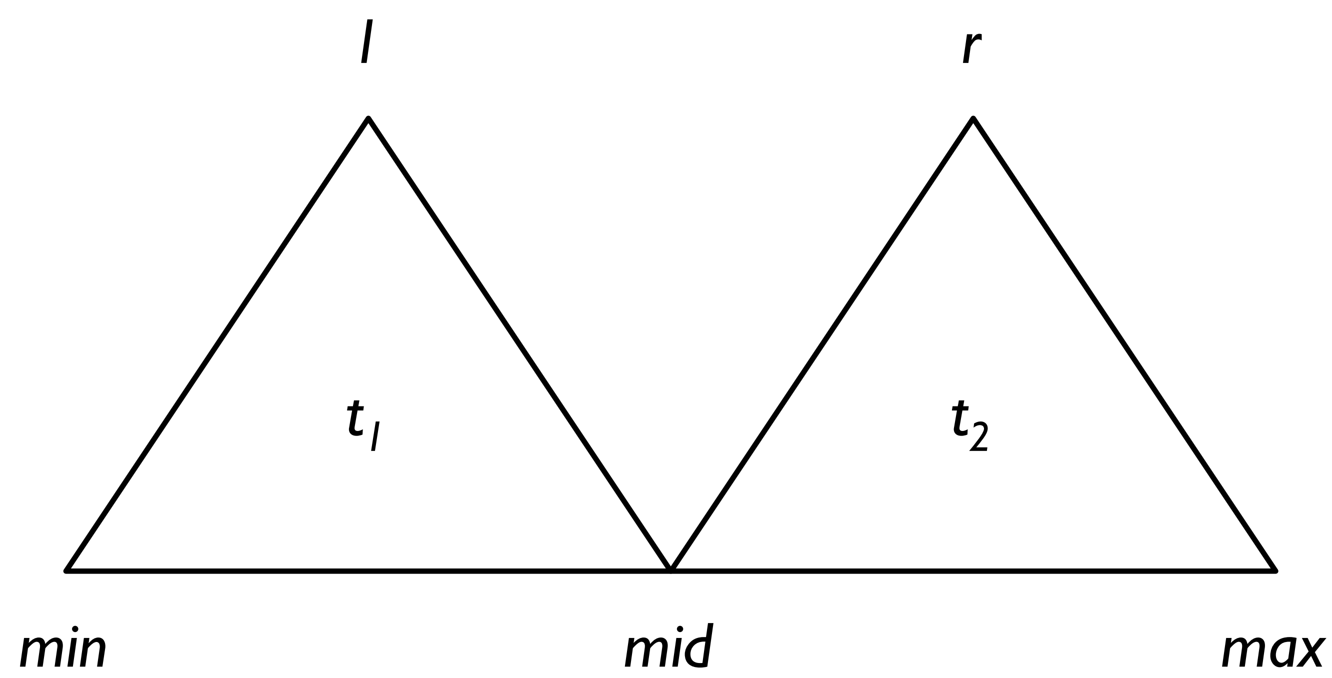

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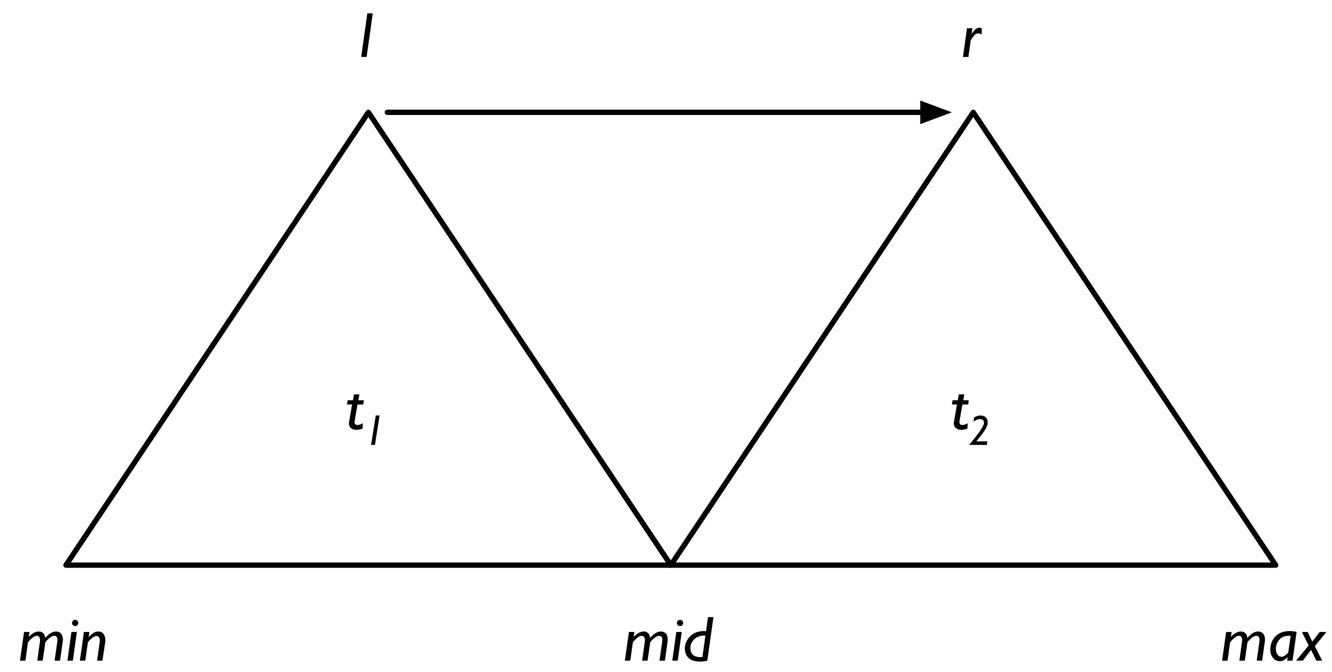

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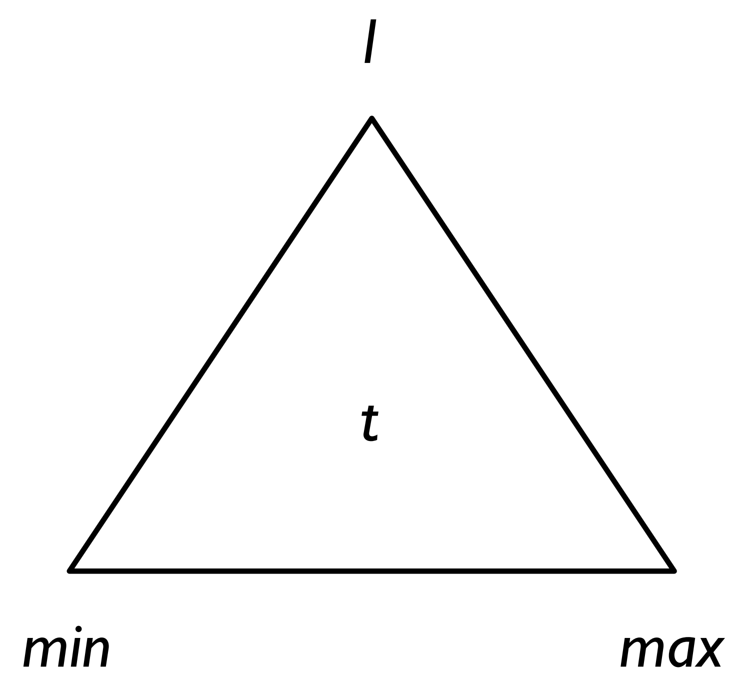

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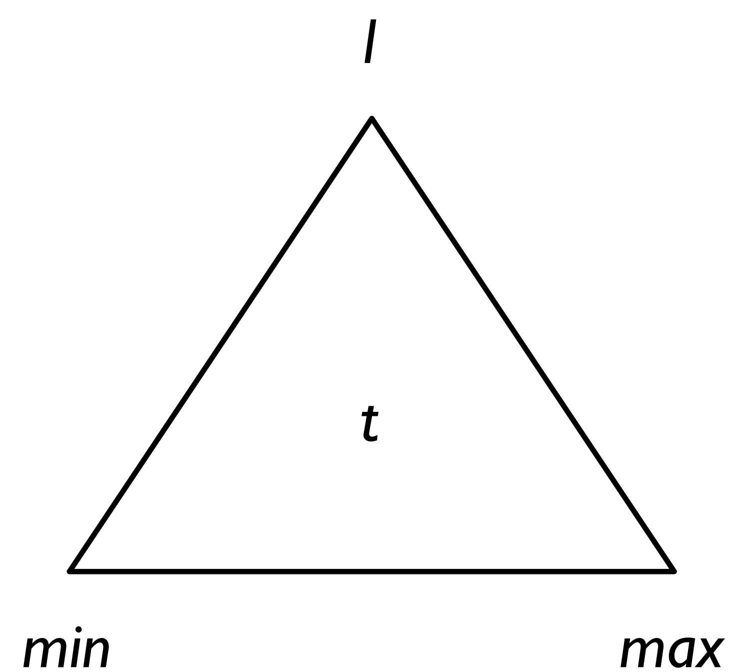
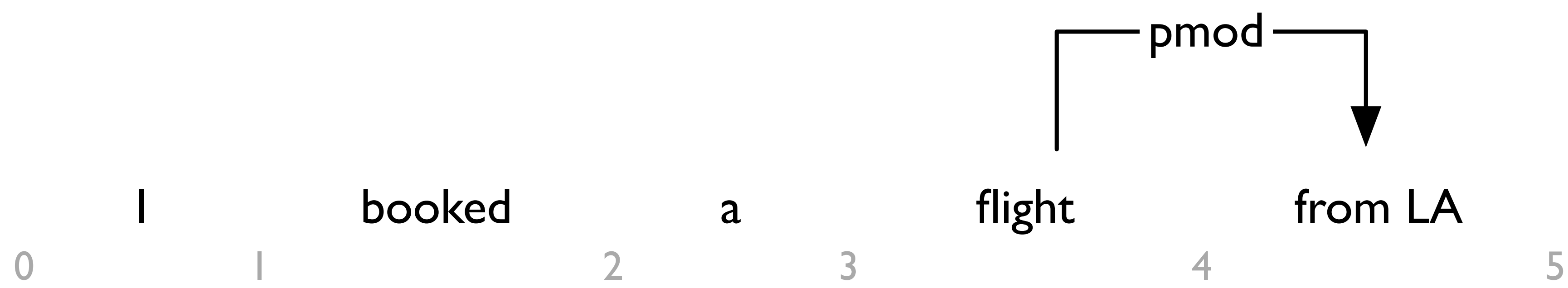


$$\text{score}(t) = \text{score}(t_1) + \text{score}(t_2) + \text{score}(l \to r)$$

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



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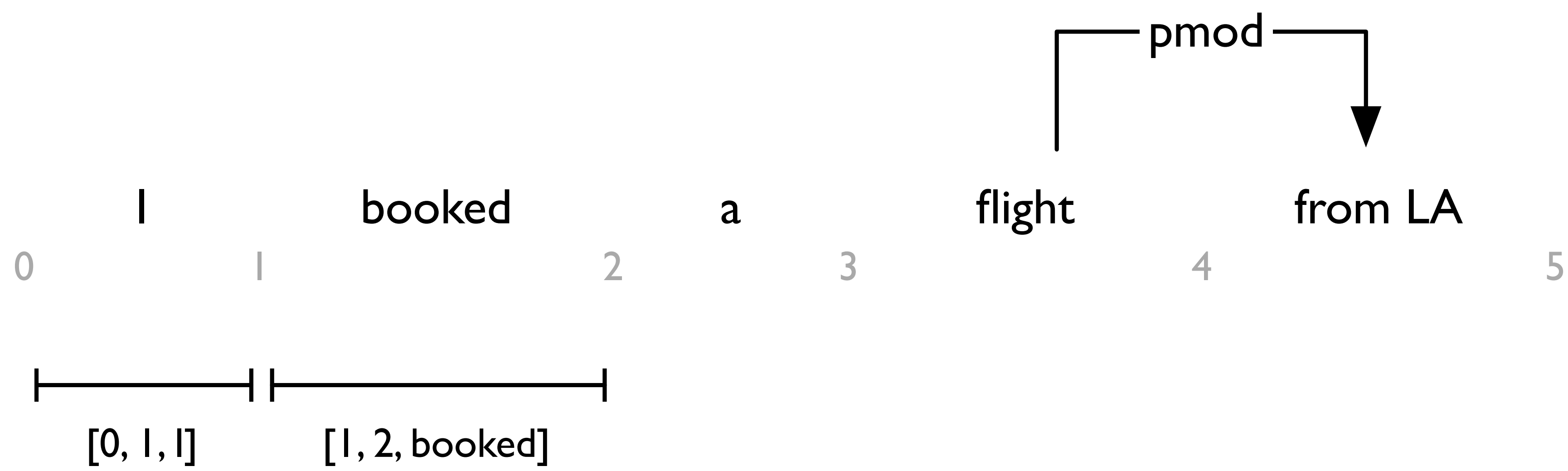

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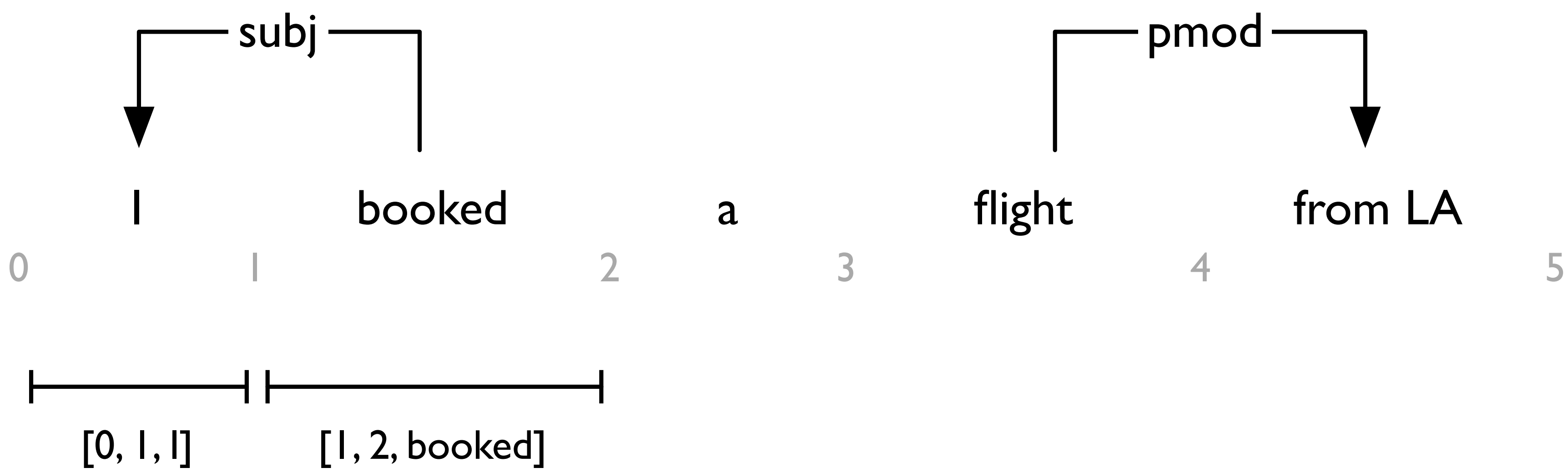
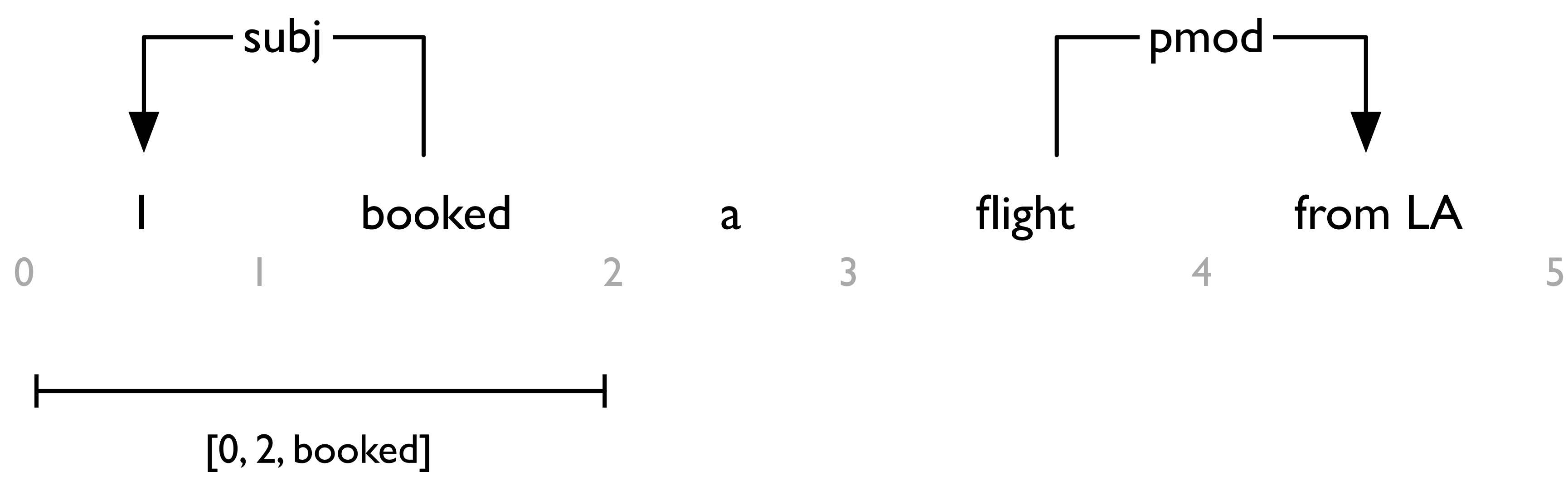


Collins' algorithm

Adding a right-to-left arc



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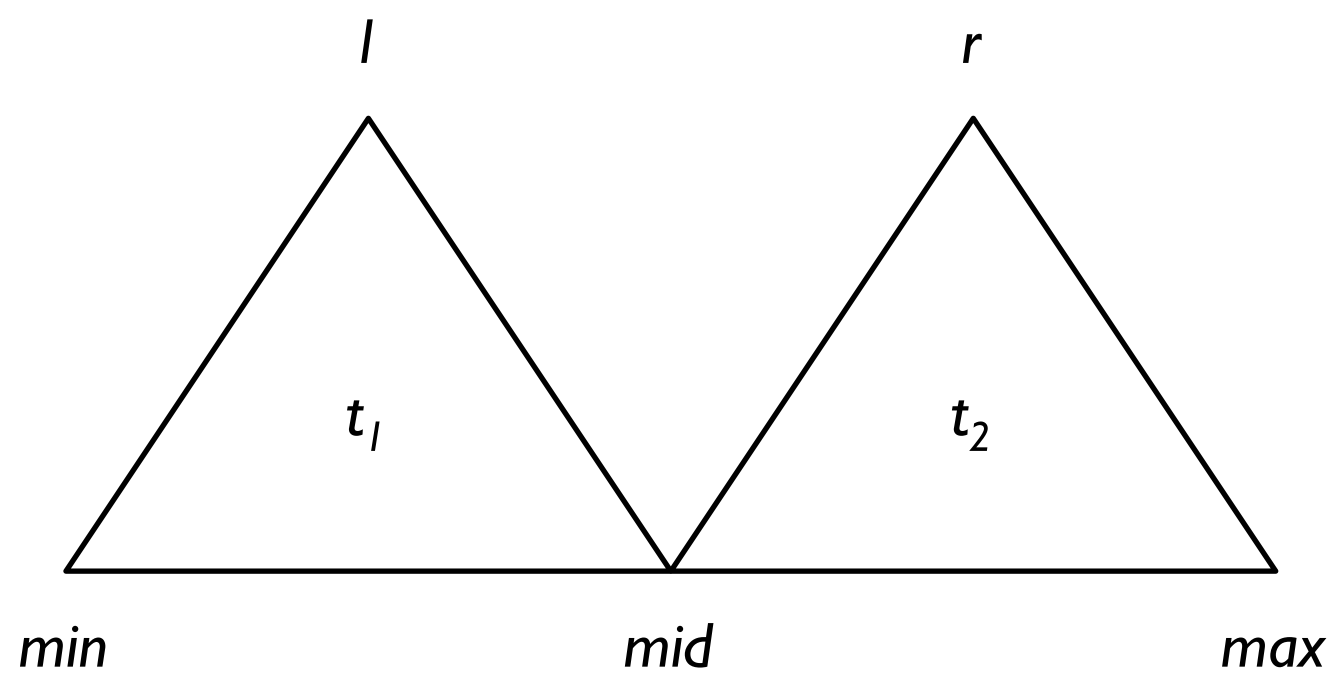

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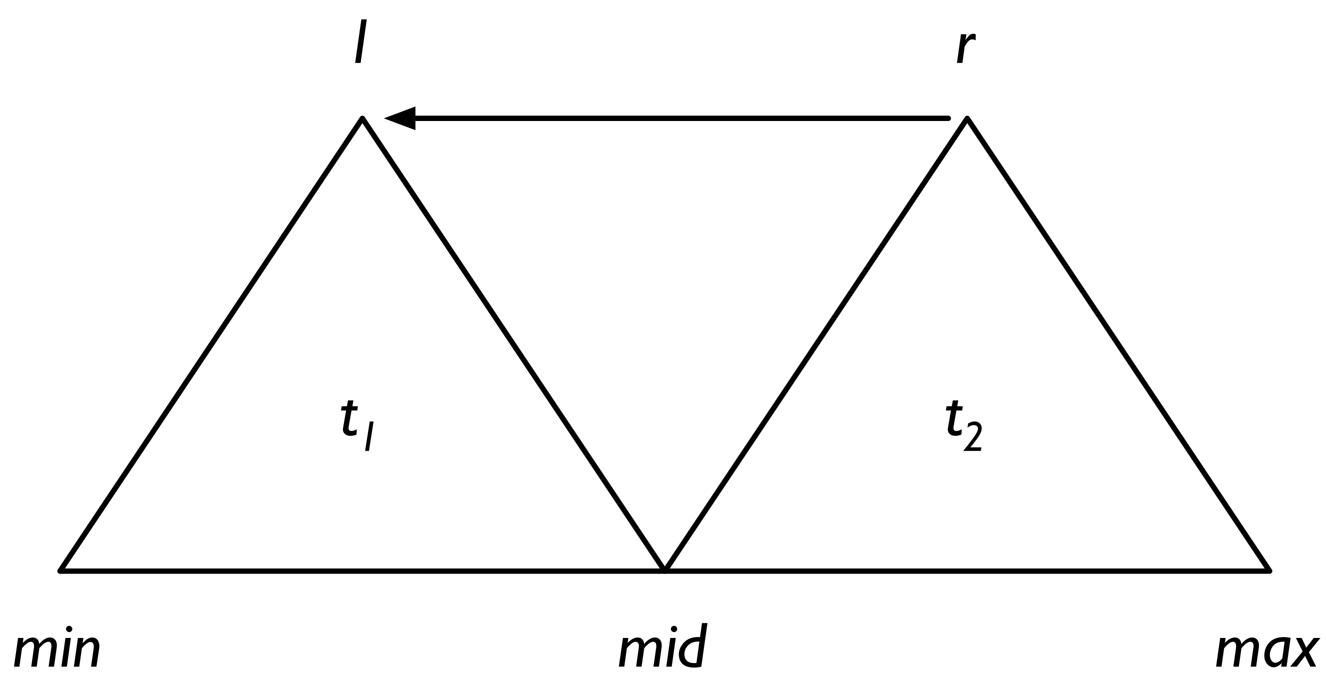

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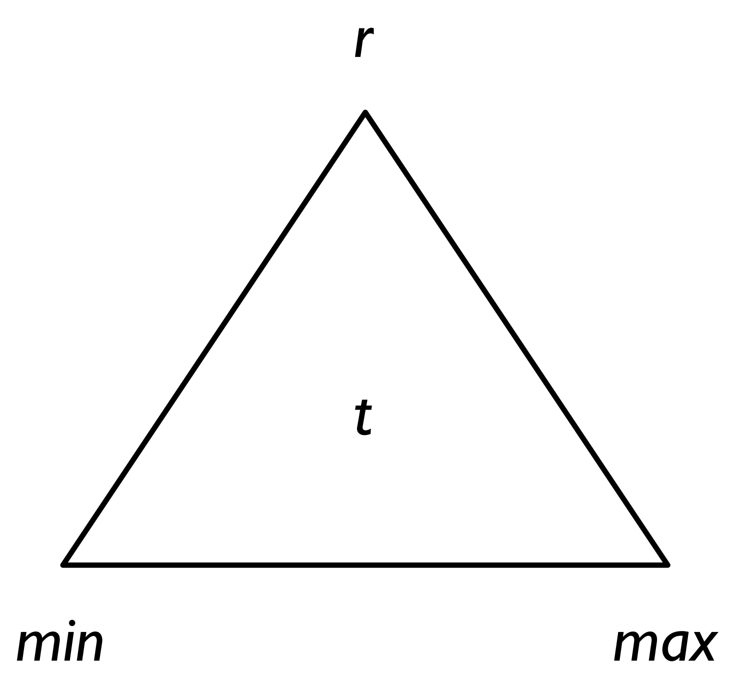

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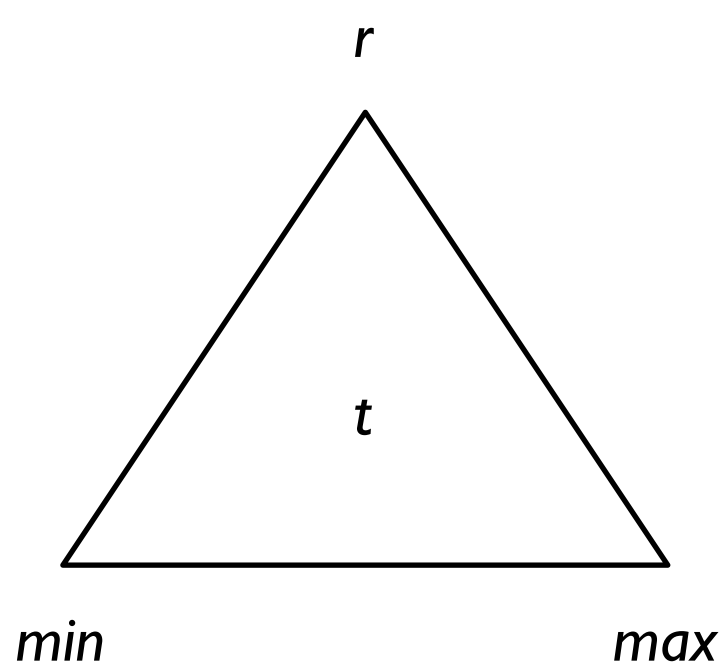

$$\text{score}(t) = \text{score}(t_1) + \text{score}(t_2) + \text{score}(r \rightarrow l)$$

Adding a right-to-left arc

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        if current > best then
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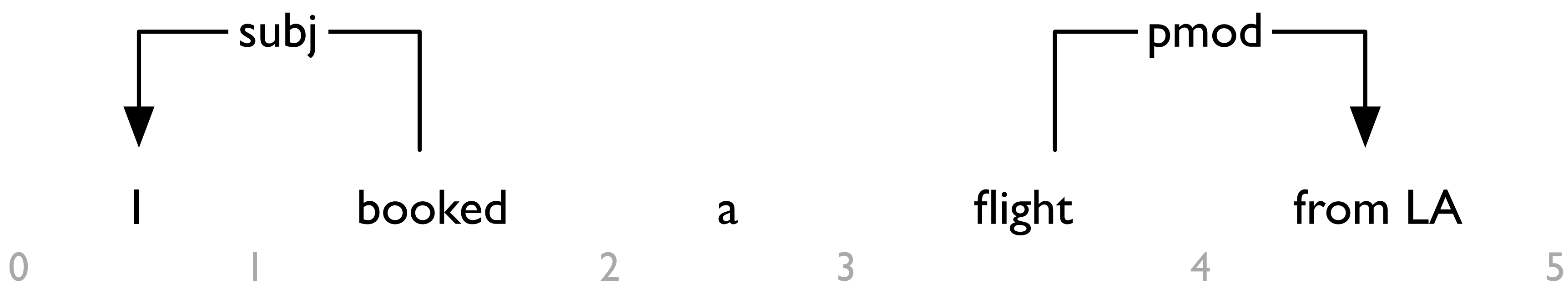
    score[min][max][r] = best
```

Finishing up



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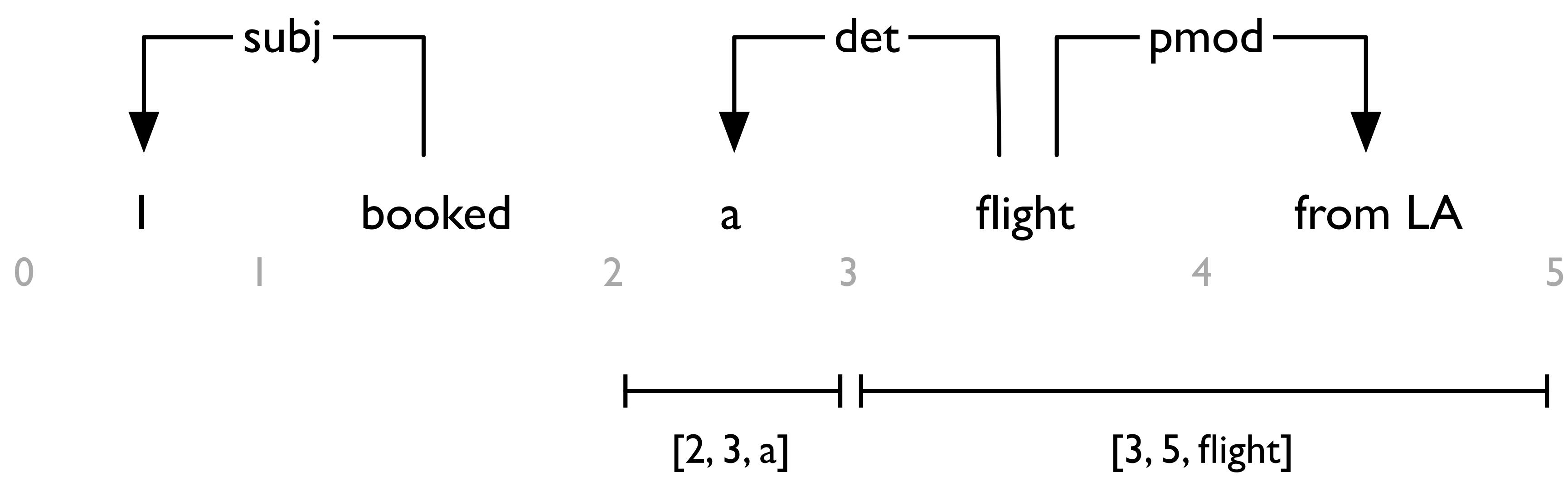
Collins' algorithm

Finishing up



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Collins' algorithm

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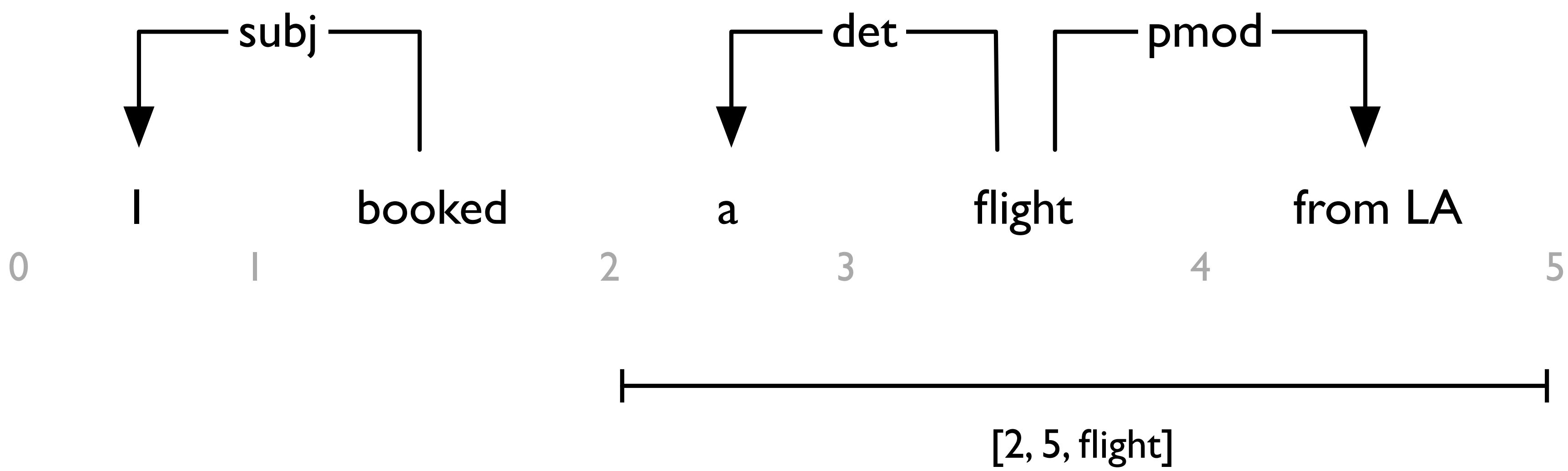

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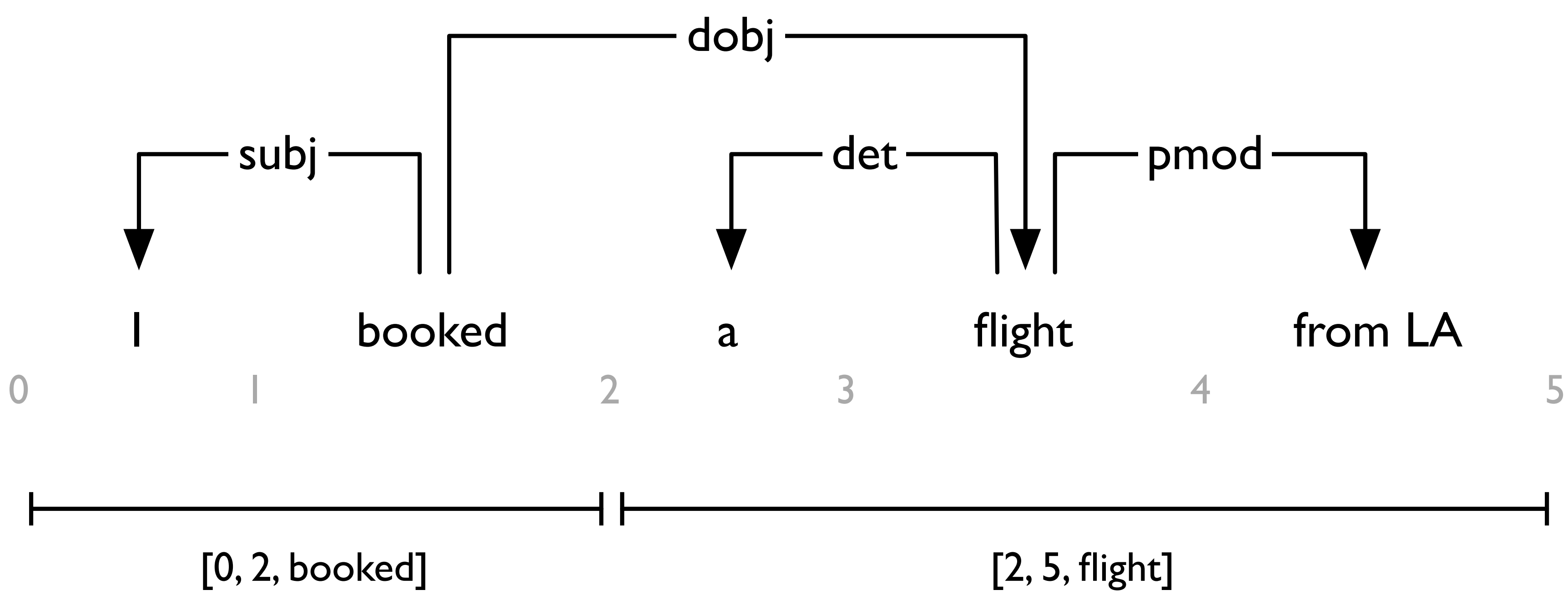

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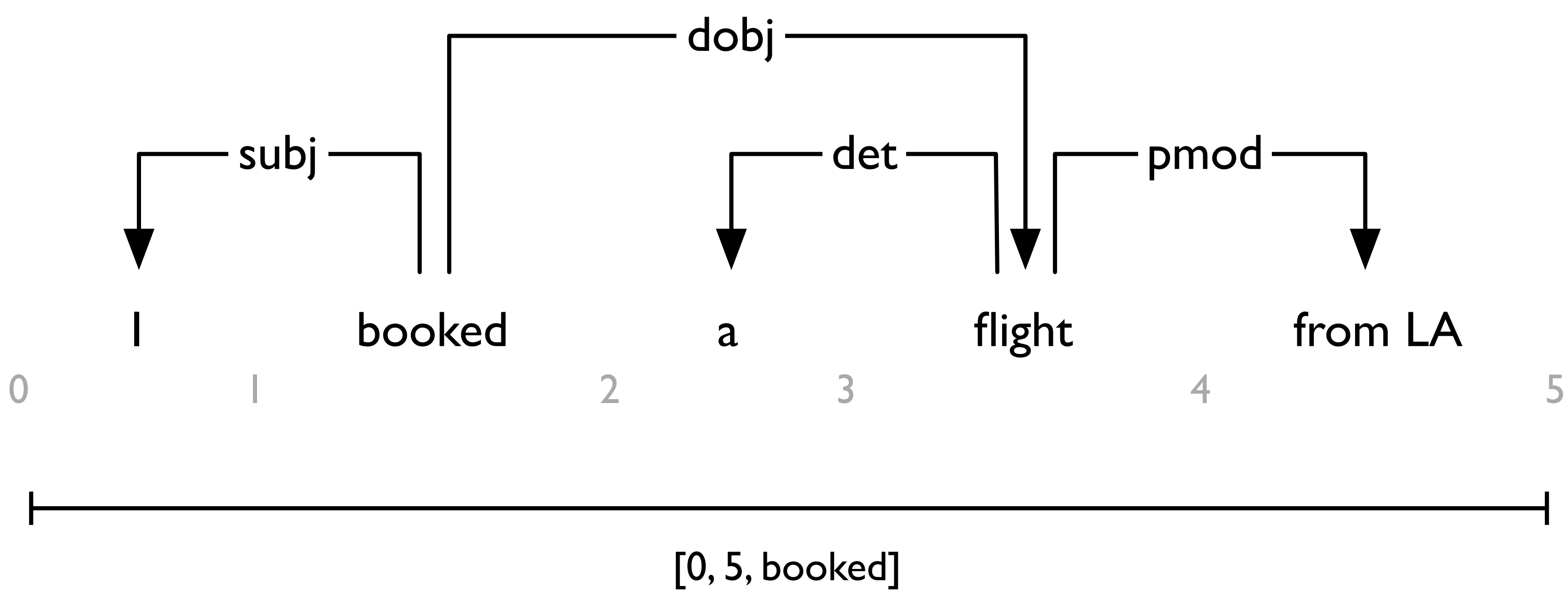

Complexity analysis

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

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.