Language Technology (2021)

Syntactic analysis

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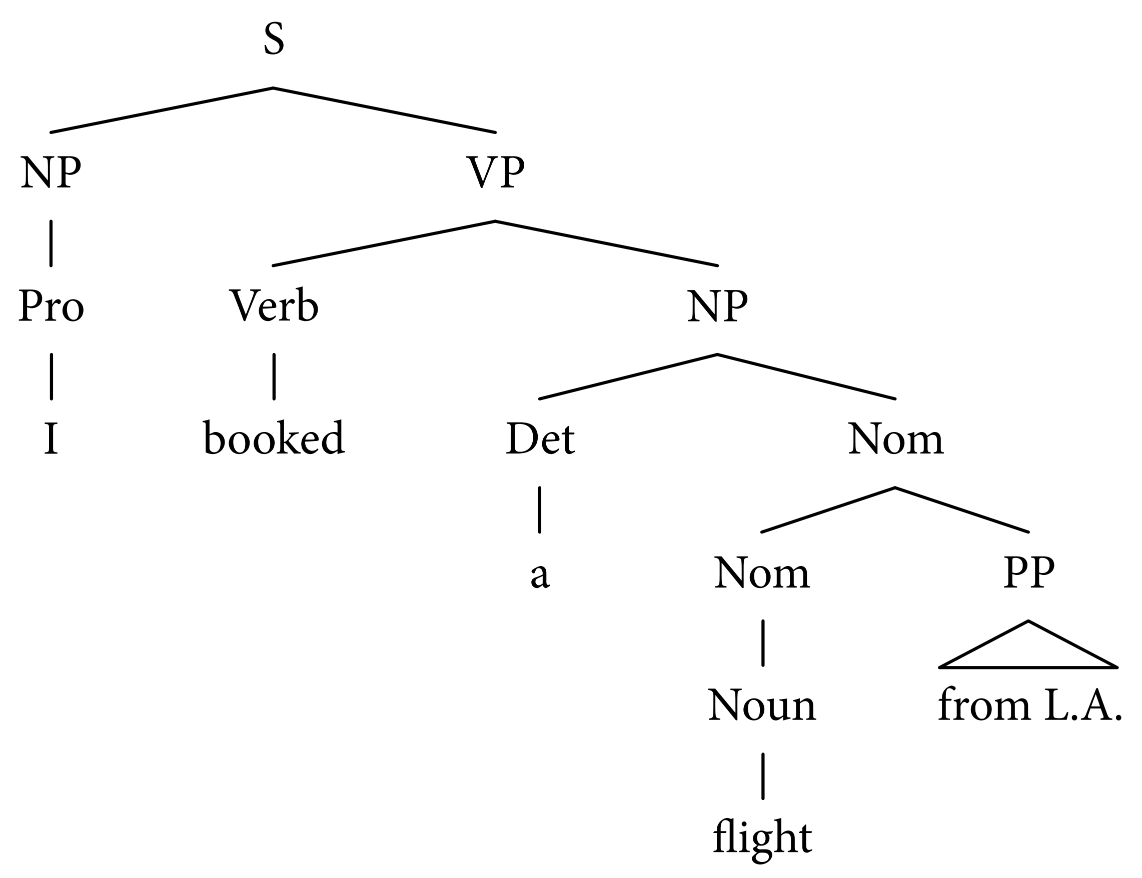
Syntactic analysis

- **Syntactic analysis** or **syntactic parsing** is the task to map a sentence to a formal representation of its syntactic structure.
- The syntactic structure of a sentence provides important clues about the meaning of the sentence.

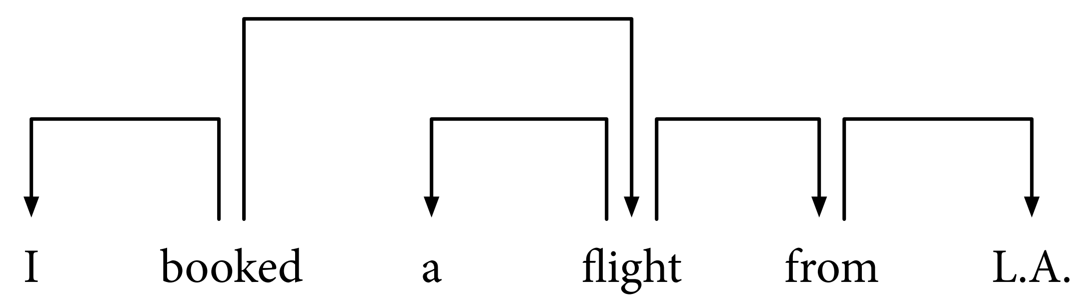
  example application: information extraction

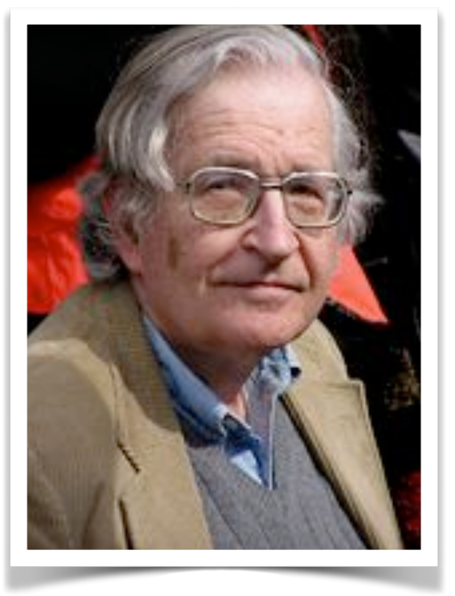
Different syntactic representations

Phrase structure tree

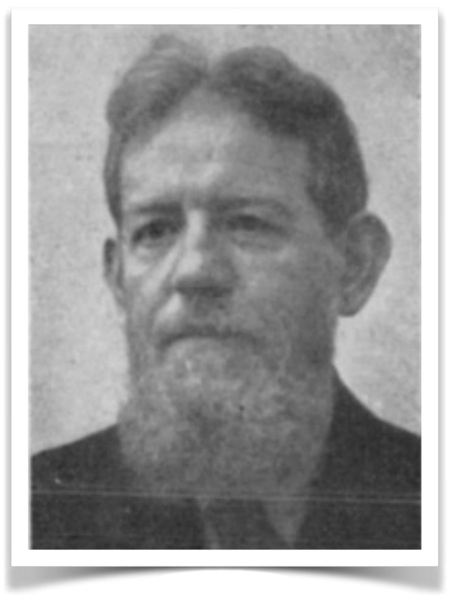


Dependency tree





Noam Chomsky



Lucien Tesnière

Source: Wikimedia Commons [1] [2]

Information extraction

- **Information extraction (IE)** is the task of extracting structured information from running text.

- More specifically, the term ‘structured information’ refers to **named entities** and **semantic relations** between those entities.

  persons, organisations, companies – *X* is-leader-of *Y*, *X* bought *Y*

JEOPARDY!

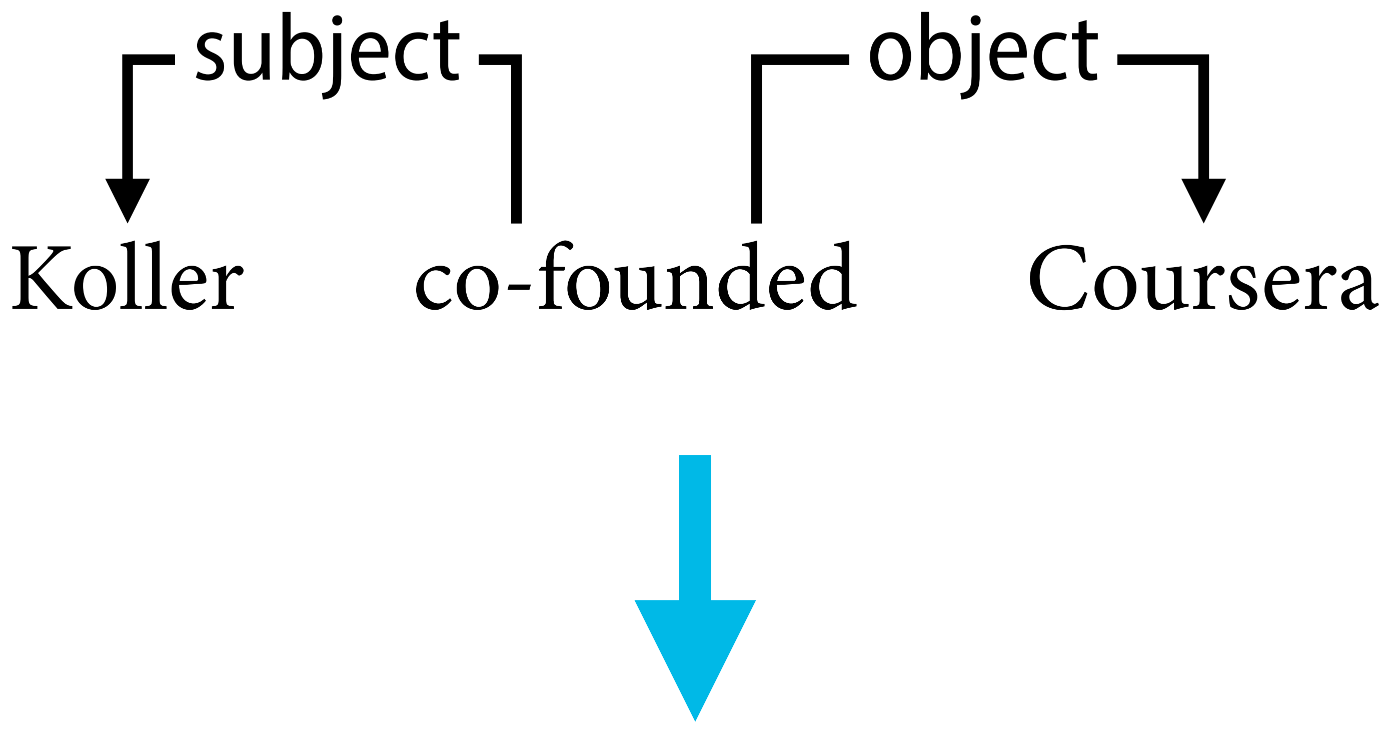
This Stanford University alumnus co-founded educational technology company Coursera.

Source: MacArthur Foundation

SPARQL query against DBPedia

```
SELECT DISTINCT ?x WHERE {
  ?x dbo:almaMater dbr:Stanford_University.
  dbr:Coursera dbo:foundedBy ?x.
}
```

Syntactic structure, semantic relations



```
dbr:Coursera dbo:foundedBy dbr:Daphne_Koller
```

Algorithmic approaches to syntactic analysis

- **Exhaustive search**

  Cast parsing as a combinatorial optimisation problem over the set of target representations (trees).

  CKY algorithm

- **Greedy search**

  Casts parsing as a sequence of classification problems: at each point in time, predict one of several parser actions.

  transition-based dependency parsing

Google Research Blog

The latest news from Research at Google

Announcing SyntaxNet: The World's Most Accurate Parser Goes Open Source

Thursday, May 12, 2016

Posted by Slav Petrov, Senior Staff Research Scientist

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This lecture

- Introduction to syntactic analysis
- Parsing to phrase structure trees
    - Context-free grammars
    - Parsing with probabilistic context-free grammars
- Parsing to dependency trees
    - Transition-based dependency parsing

Context-free grammars

Phrases and syntactic heads

- Words within sentences form groupings called **phrases**.

  Kim read [a book]. Kim read [a very interesting book about grammar].

- Each phrase is projected by a **syntactic head**, which determines its internal structure and external distribution.

  [The <u>war</u> on drugs] is controversial. / *[The <u>battle</u> on drugs] is controversial.

  [The <u>war</u> on drugs] is controversial. / *[The <u>war</u> on drugs] are controversial.

Context-free grammars

- Phrases can be combined to form larger phrases. This gives rise to a hierarchical structure.
- The phrase structure of a sentence can be described using **context-free grammars**.
- The main ingredient of a context-free grammar is a set of rules that describe how phrases are structured.

A context-free grammar

Rule	Example
S → NP VP	I + want a morning flight
NP → Pronoun	I
NP → Proper-Noun	Los Angeles
NP → Det Nominal	a flight
Nominal → Nominal Noun	morning flight
Nominal → Noun	flights
VP → Verb	do
VP → Verb NP	want + a flight
VP → Verb NP PP	leave + Boston + in the morning
VP → Verb PP	leaving + on Thursday
PP → Preposition NP	from + Los Angeles

Context-free grammars, formal definition

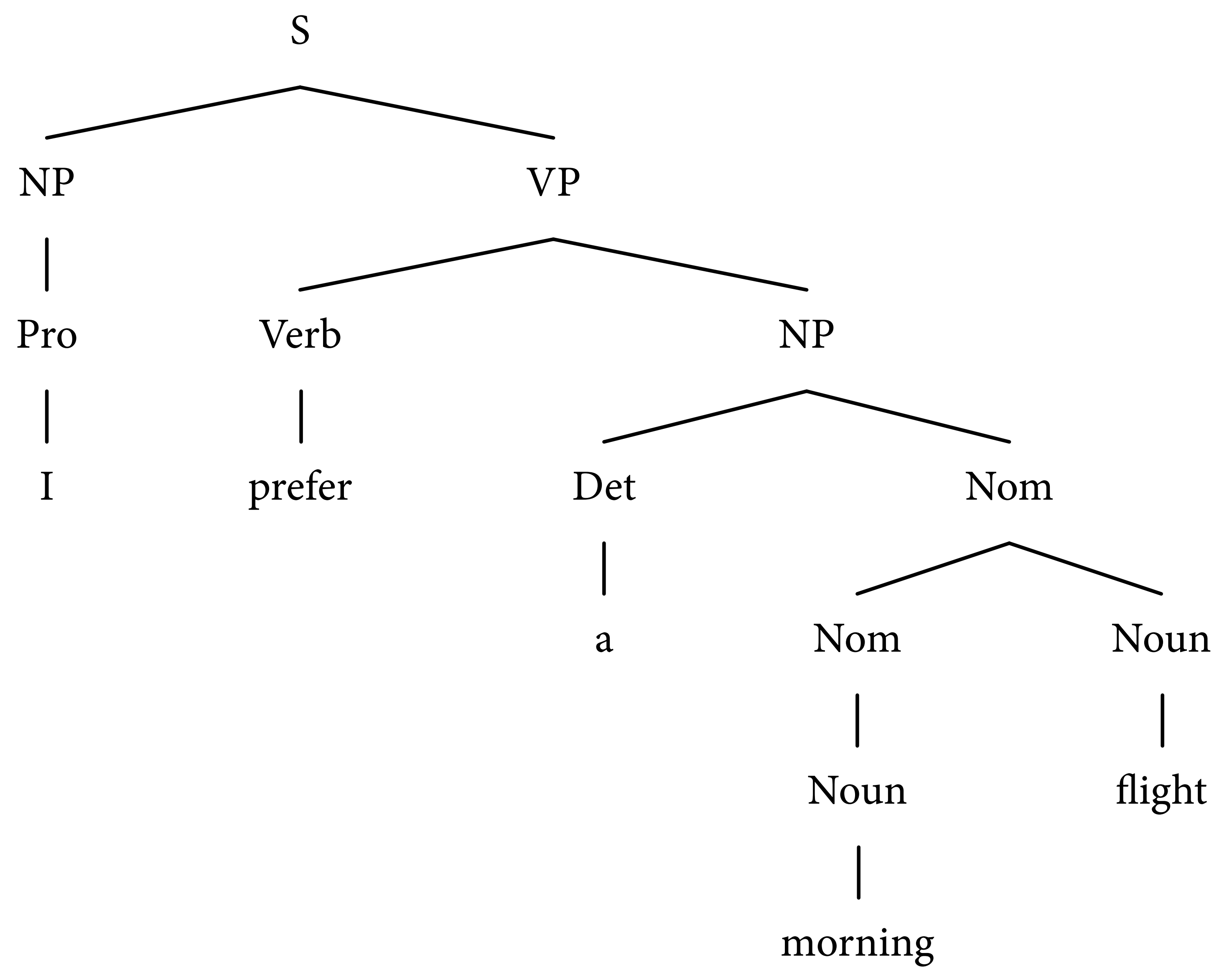
N	a set of nonterminals (phrase labels)
T	a set of terminals (words)
P	a finite set of rules or productions
S	a distinguished nonterminal symbol called the start symbol

Notation for rules

$$\overset{\text{left-hand side}}{\overset{\downarrow}{\mathrm{S}}} \rightarrow \mathrm{NP}\ \underset{\text{right-hand side}}{\underset{\uparrow}{\mathrm{VP}}}$$

‘A sentence (S) consists of a noun phrase (NP) and a verb phrase (VP).’

Phrase structure tree



Limitations of context-free grammars

- Context-free grammars can model many important aspects of natural language syntax.

  linguistic creativity, nested structures

- But there are other aspects that they do not model adequately, or are unable to model at all.

  agreement, crossing dependencies

Subject–verb agreement

- In English, a verb and its grammatical subject need to agree with respect to number.

  *[A flight] [leave Boston in the morning]

- The rules of our example grammar do not capture this regularity. The grammar **overgenerates**.

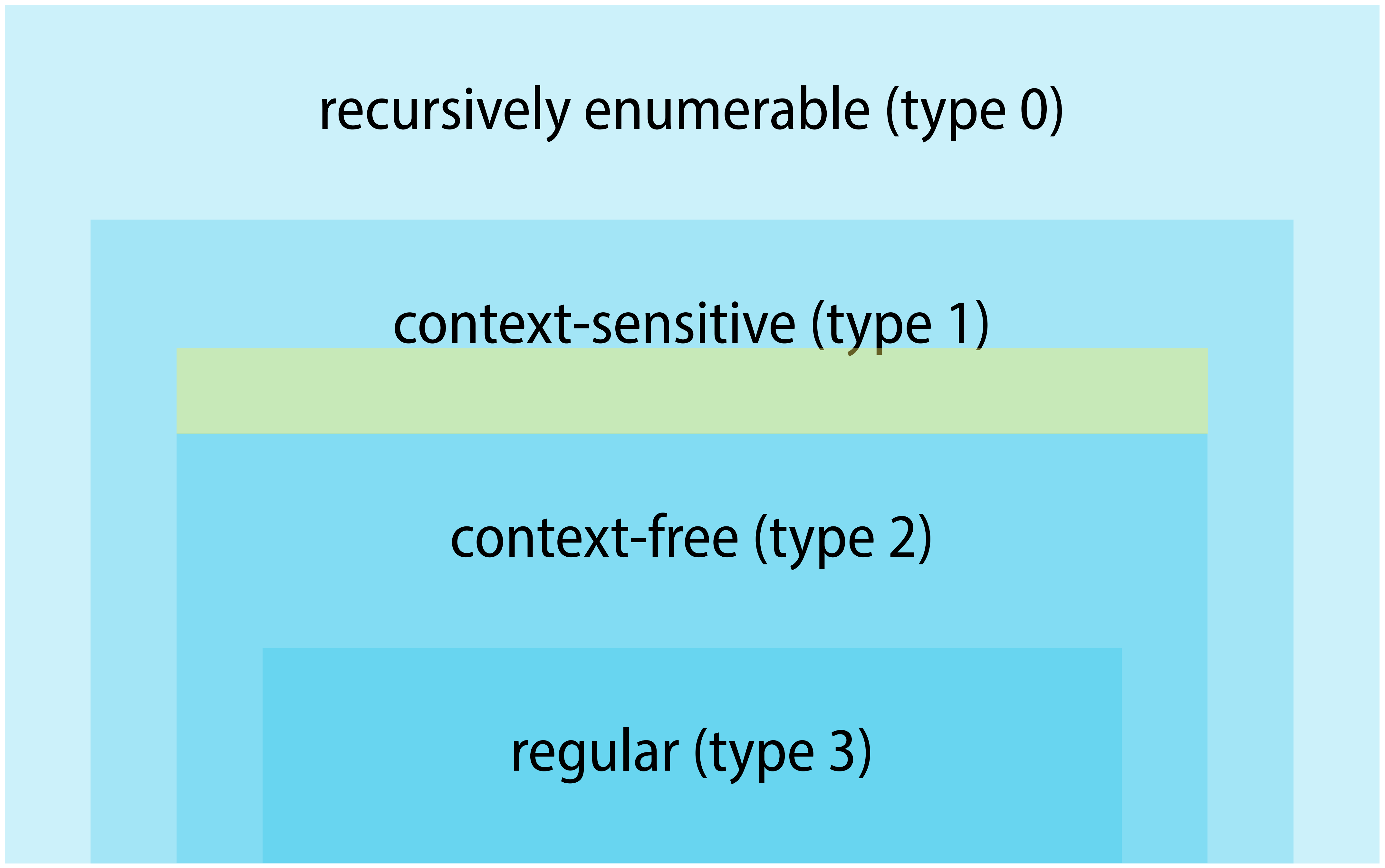
Subject–verb agreement

One way to solve the problem with overgeneration is to specialise the rules of the grammar with respect to number:

Rule	Example
S → NP[sg] VP[sg]	this flight + leaves on Monday
NP[sg] → Det[sg] Nom[sg]	this + flight
VP[sg] → Verb[sg] PP	leaves + on Monday
NP[pl] → Det[pl] NP[pl]	these + flights

However, this makes the size of grammar explode.

Chomsky hierarchy



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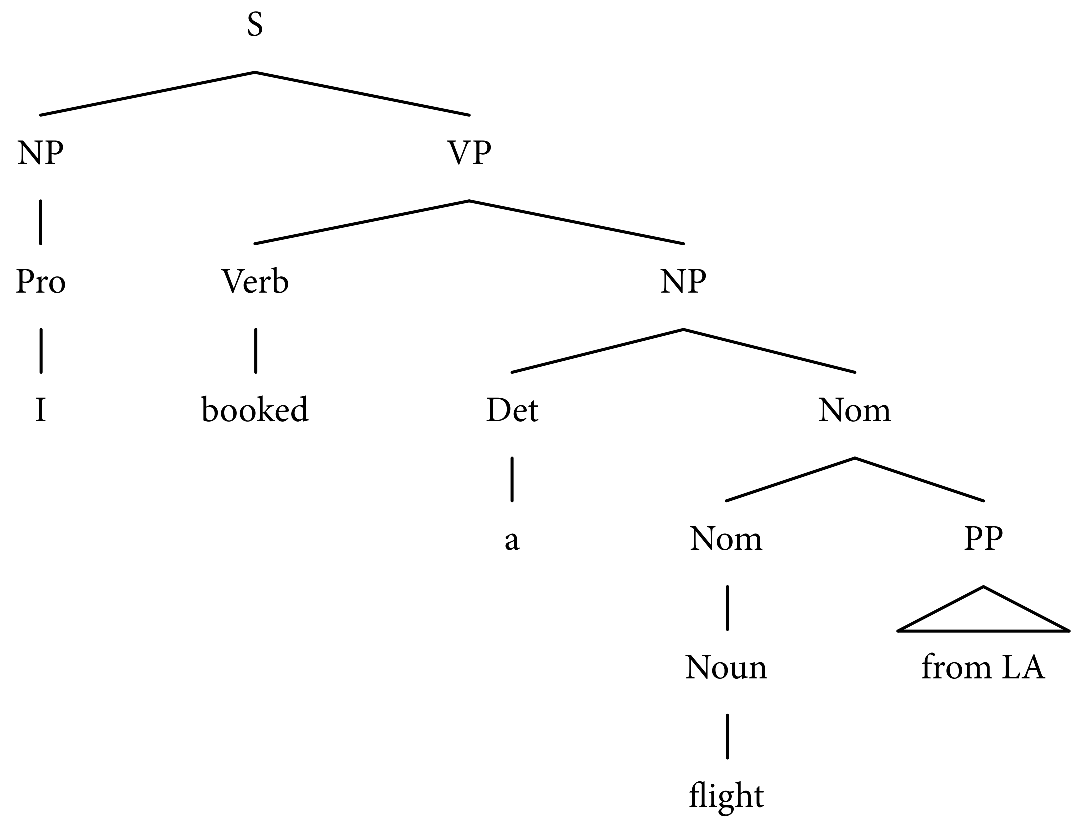
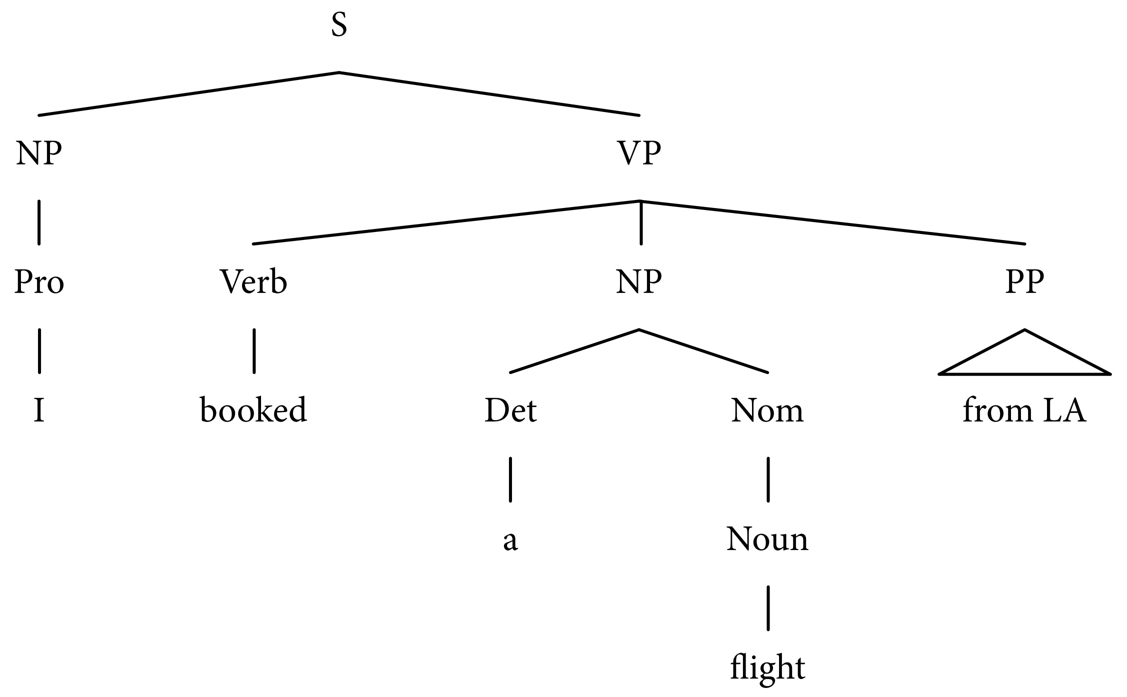
Parsing with probabilistic context-free grammars

Syntactic ambiguity

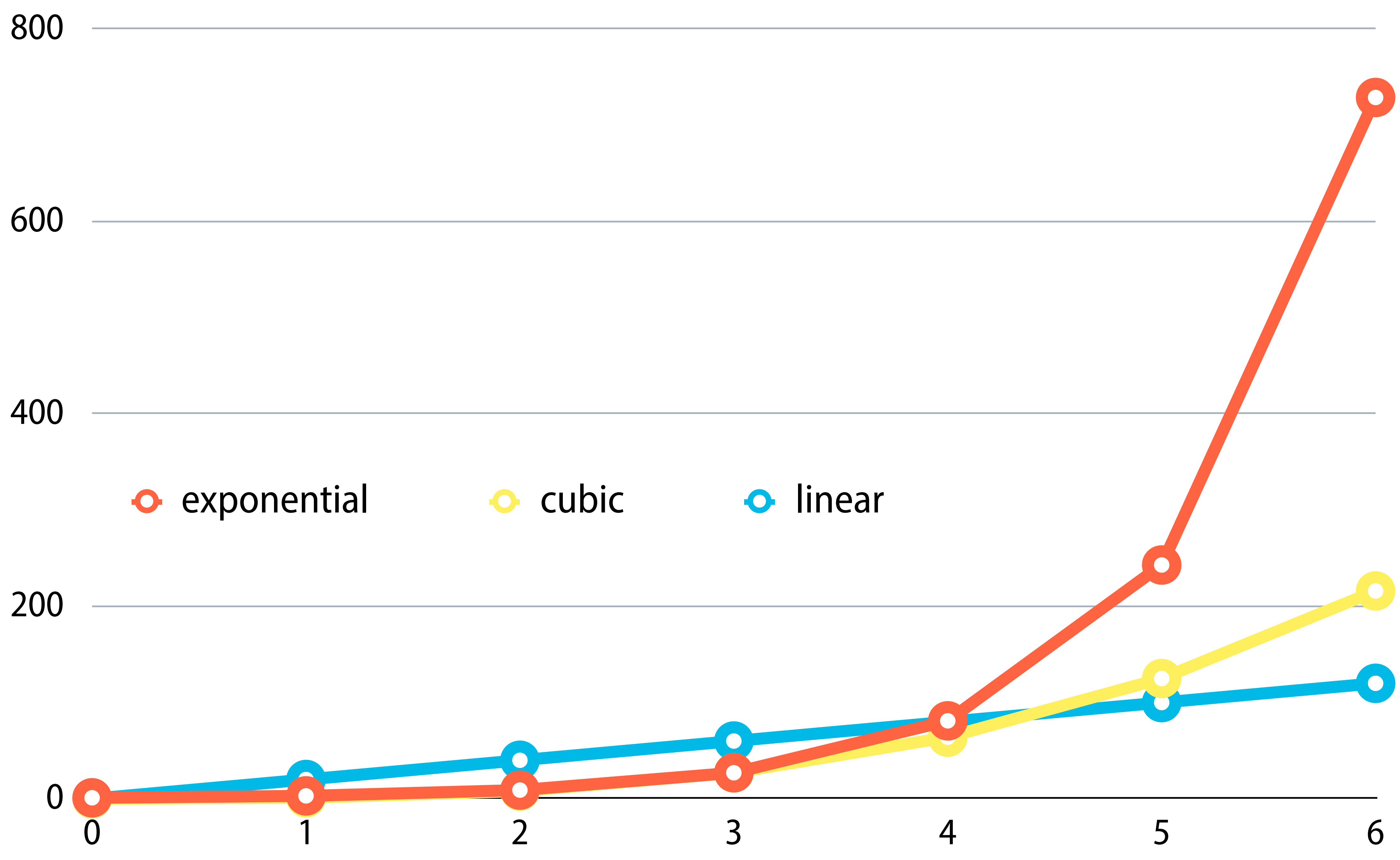




The PP modifies ‘flight’.

The PP modifies ‘booked’.

Combinatorial explosion



Probabilistic grammars

- The number of possible parse trees grows exponentially with the length of the sentence.
- But not all parse trees are equally relevant, and in many applications, we just want to find the most probable parse tree.

Probabilistic context-free grammar

A **probabilistic context-free grammar (PCFG)** is a context-free grammar with the following additional properties:

- Every rule r has been assigned a probability $P(r)$.
- The total probability of all rules with the same left-hand side is 1.

Probabilistic context-free grammar

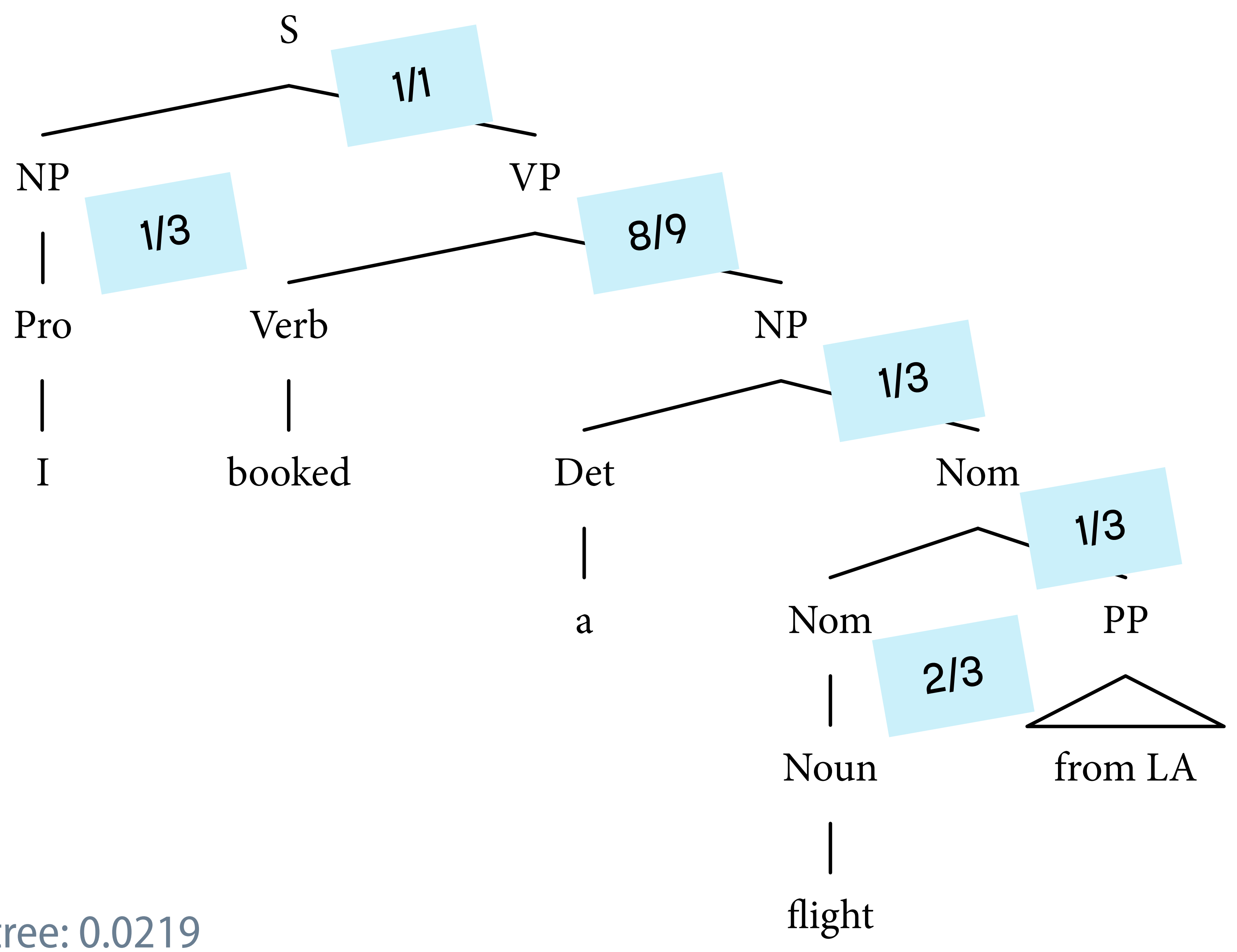
Rule	Probability
S → NP VP	1/1
NP → Pronoun	1/3
NP → Proper-Noun	1/3
NP → Det Nominal	1/3
Nominal → Nominal PP	1/3
Nominal → Noun	2/3
VP → Verb NP	8/9
VP → Verb NP PP	1/9
PP → Preposition NP	1/1

The probability of a parse tree

The probability of a parse tree t is defined as the product of the probabilities of the rules that appear in t:

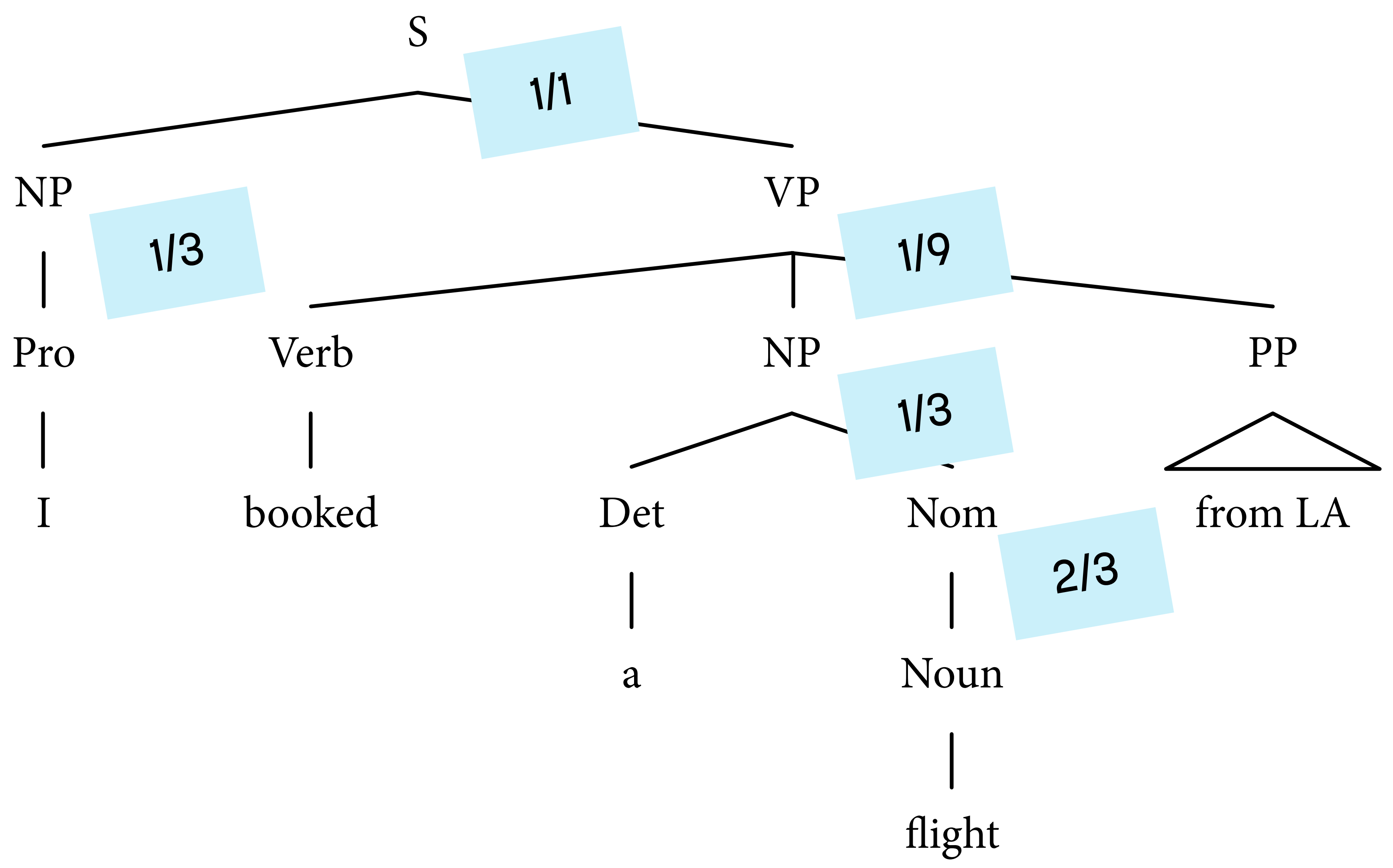
$$P(t) = \prod_{r \in t} P(r)$$

Probability of a parse tree



Probability of this tree: 0.0219

Probability of a parse tree



Probability of this tree: 0.0082

The CKY algorithm

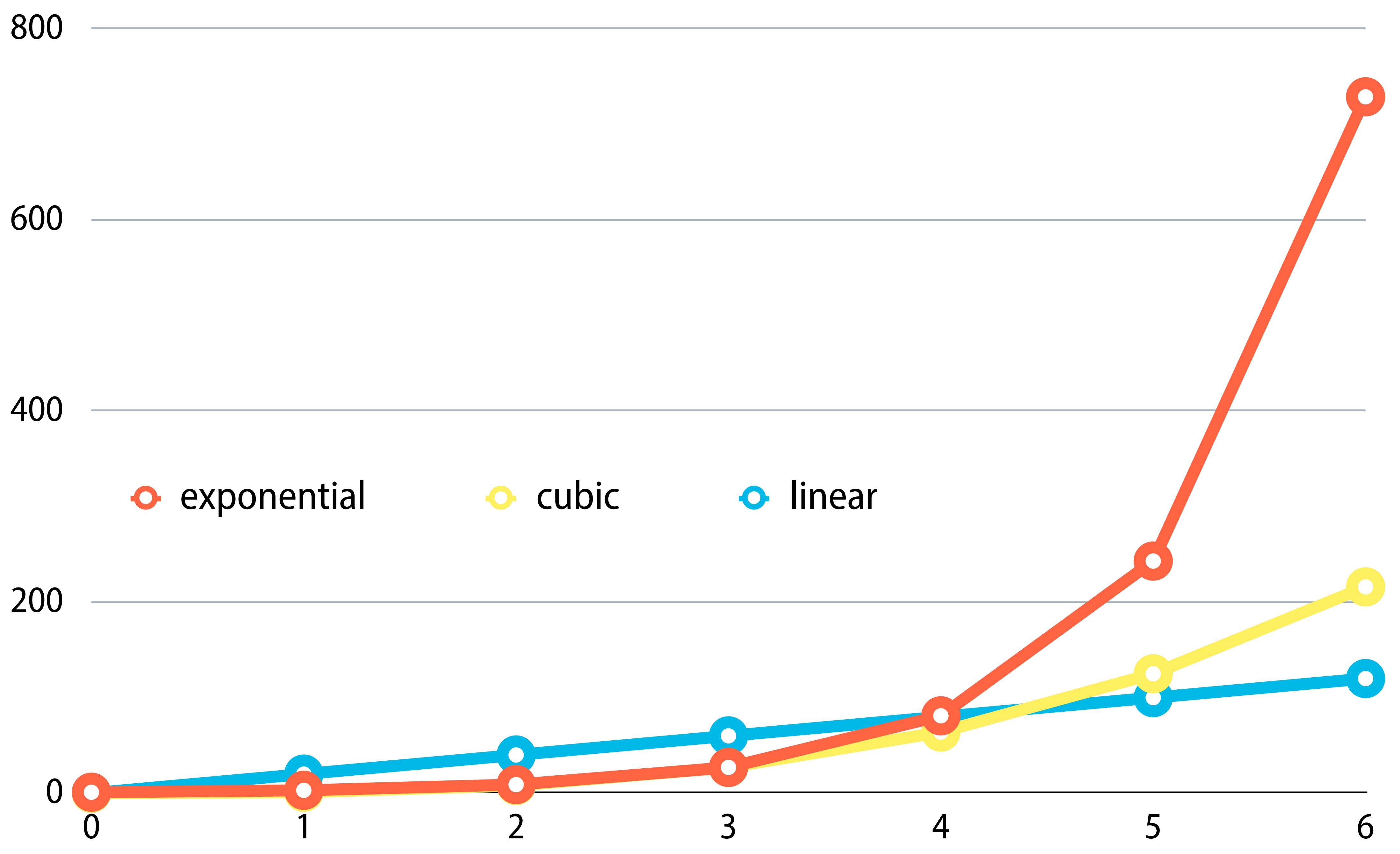
- We need an efficient algorithm that can find the most probable parse tree, much like the Viterbi algorithm for POS tagging.

  efficient = runtime is at most polynomial in the length of the sentence

- One such algorithm is (the probabilistic extension of) the **Cocke–Kasami–Younger (CKY) algorithm**.

  advanced material

Combinatorial explosion



Treebanks

- Until the mid-1990s, syntactic parsers used large, hand-written grammars created by linguistic experts.
- Modern parsers are learned from corpora of syntactic analyses called **treebanks**.

  Penn Treebank, Swedish Treebank, Universal Dependencies Project

Penn Treebank

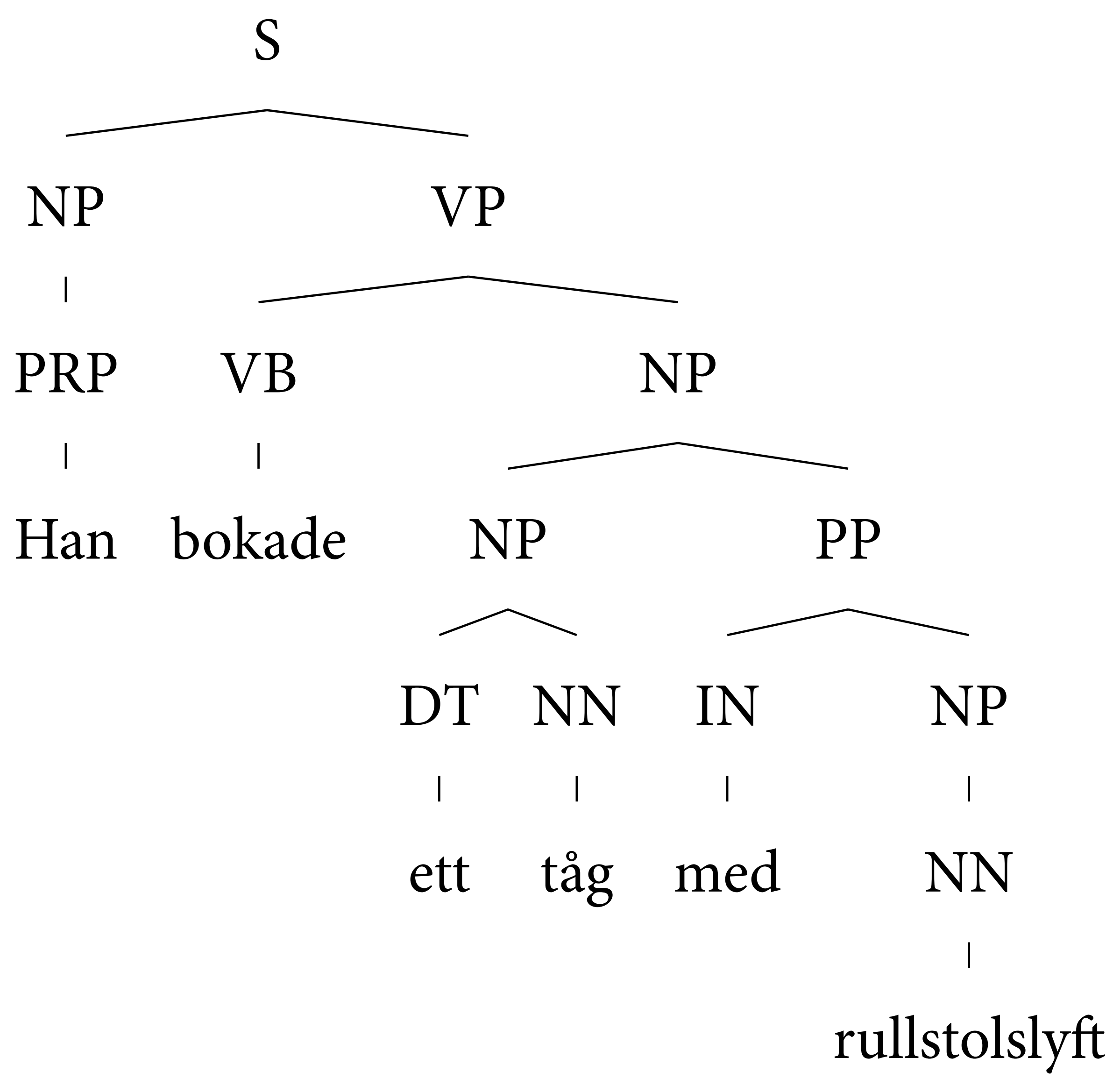
```
( (S
    (NP-SBJ
      (NP (NNP Pierre) (NNP Vinken) )
      (, ,)
      (ADJP
        (NP (CD 61) (NNS years) )
        (JJ old) )
      (, ,) )
    (VP (MD will)
      (VP (VB join)
        (NP (DT the) (NN board) )
        (PP-CLR (IN as)
          (NP (DT a) (JJ nonexecutive) (NN director) ))
        (NP-TMP (NNP Nov.) (CD 29) )))
    (. .) ))
```

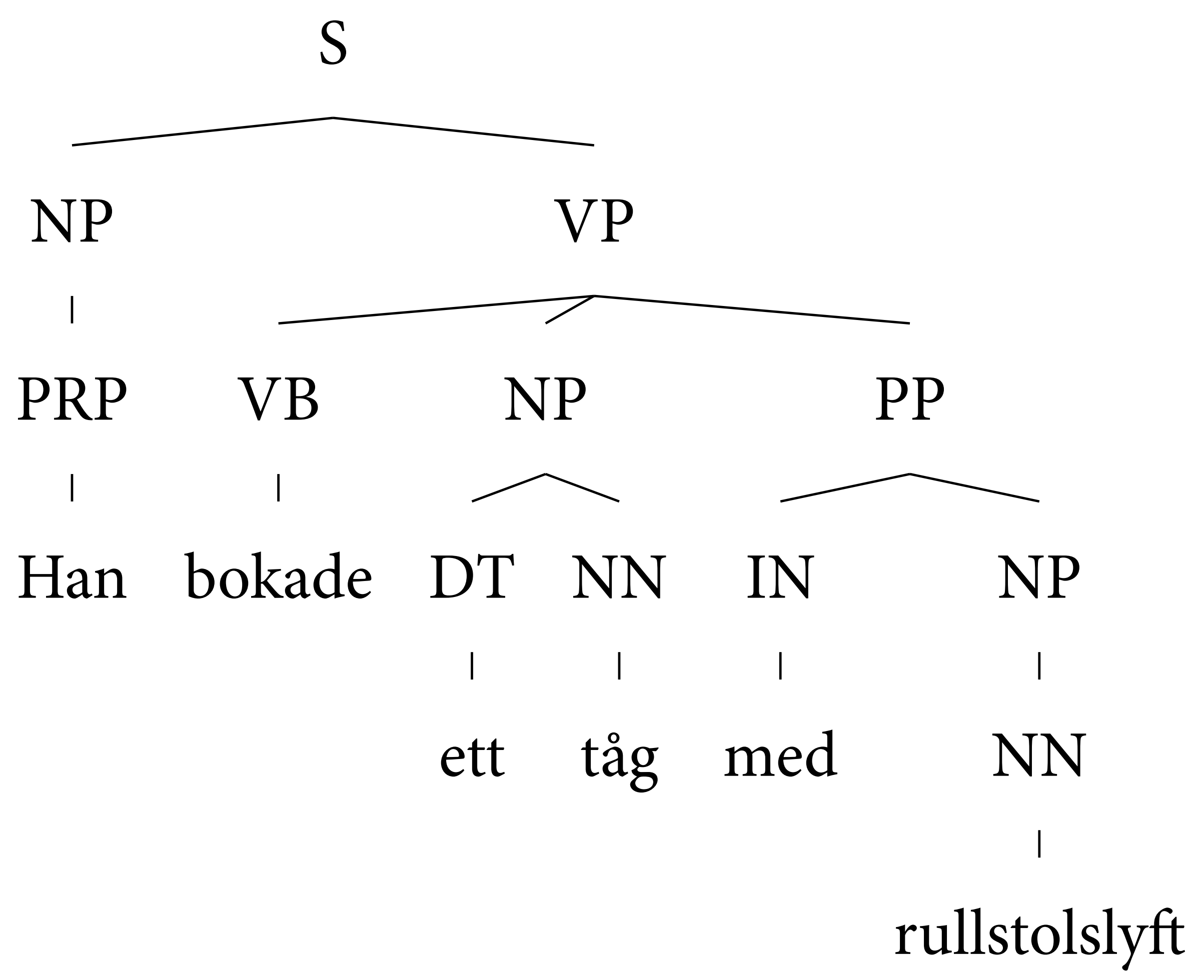
Grammar rule	Phrase
S → NP-SBJ VP .	Pierre Vinken … Nov. 29.
NP-SBJ → NP , ADJP ,	Pierre Vinken, 61 years old,
VP → MD VP	will join the board …
NP → DT NN	the board

Estimation of rule probabilities

- Given a phrase structure treebank, the rule probabilities of a PCFG can be obtained using maximum likelihood estimation.
- To do this, we divide the count for a certain rule by the count for all rules that share the same left-hand side.

Sample exam question: Estimate rule probabilities





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Transition-based dependency parsing

Algorithmic approaches

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  Cast parsing as a combinatorial optimisation problem over the set of target representations (trees).

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- **Greedy search**

  Cast parsing as a sequence of classification problems: at each point in time, predict one of several parser actions.

  transition-based dependency parsing

Dependency parsing as classification

- In Section 3 we have seen how part-of-speech tagging can be broken down into a sequence of classification problems.

  part-of-speech tagging with the multi-class perceptron

- In this section we will see how the same idea can be applied to dependency parsing.

- Instead of POS tags, the classifier will predict **transitions** that take the parser from one **configuration** to another.

  moves, states

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Transition-based dependency parsing

- The parser starts in the **initial configuration**.
- It then calls the classifier, which predicts the transition that the parser should make to move to the next configuration.
- This process is repeated until the parser reaches a **terminal configuration**.

Configurations

A parser configuration consists of three parts:

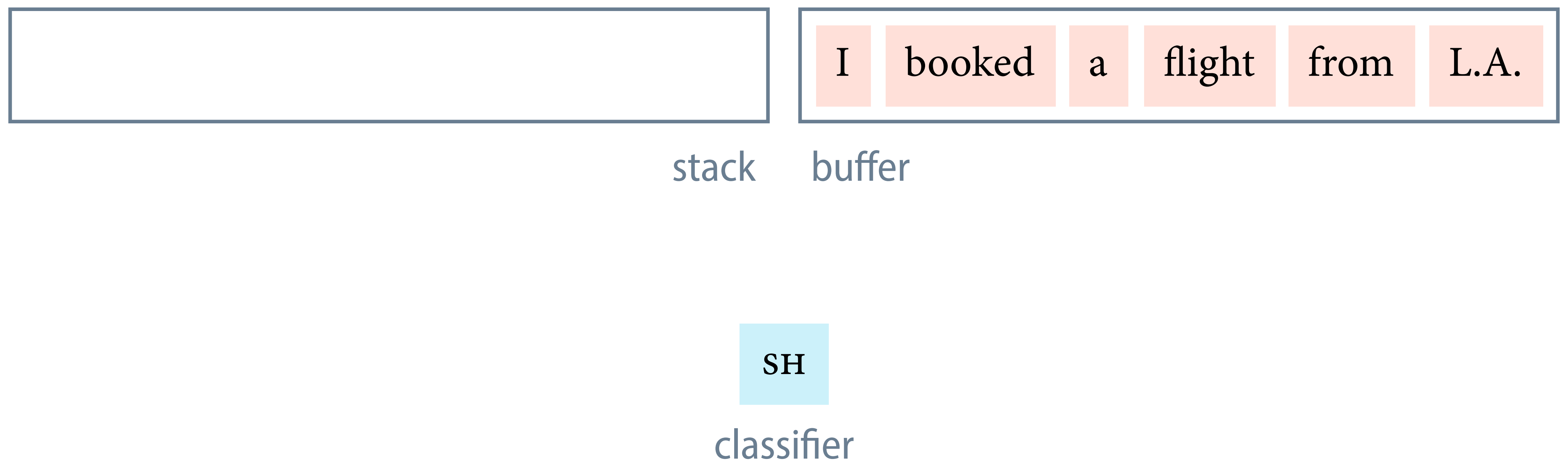
- A **buffer**, which contains those words in the sentence that still need to be processed. Initially, the buffer contains all words.
- A **stack**, which contains those words in the sentence that are currently being processed. Initially, the stack is empty.
- A **partial dependency tree**. Initially, this tree contains all the words of the sentence, but no dependency arcs.

Transitions

- The **shift transition (SH)** removes the frontmost word from the buffer and pushes it to the top of the stack.
- The **left-arc transition (LA)** creates a dependency from the topmost word on the stack to the second-topmost word, and removes the second-topmost word.
- The **right-arc transition (RA)** creates a dependency from the second-topmost word on the stack to the topmost word, and removes the topmost word.

Transition-based dependency parsing, example

I booked a flight from L.A.



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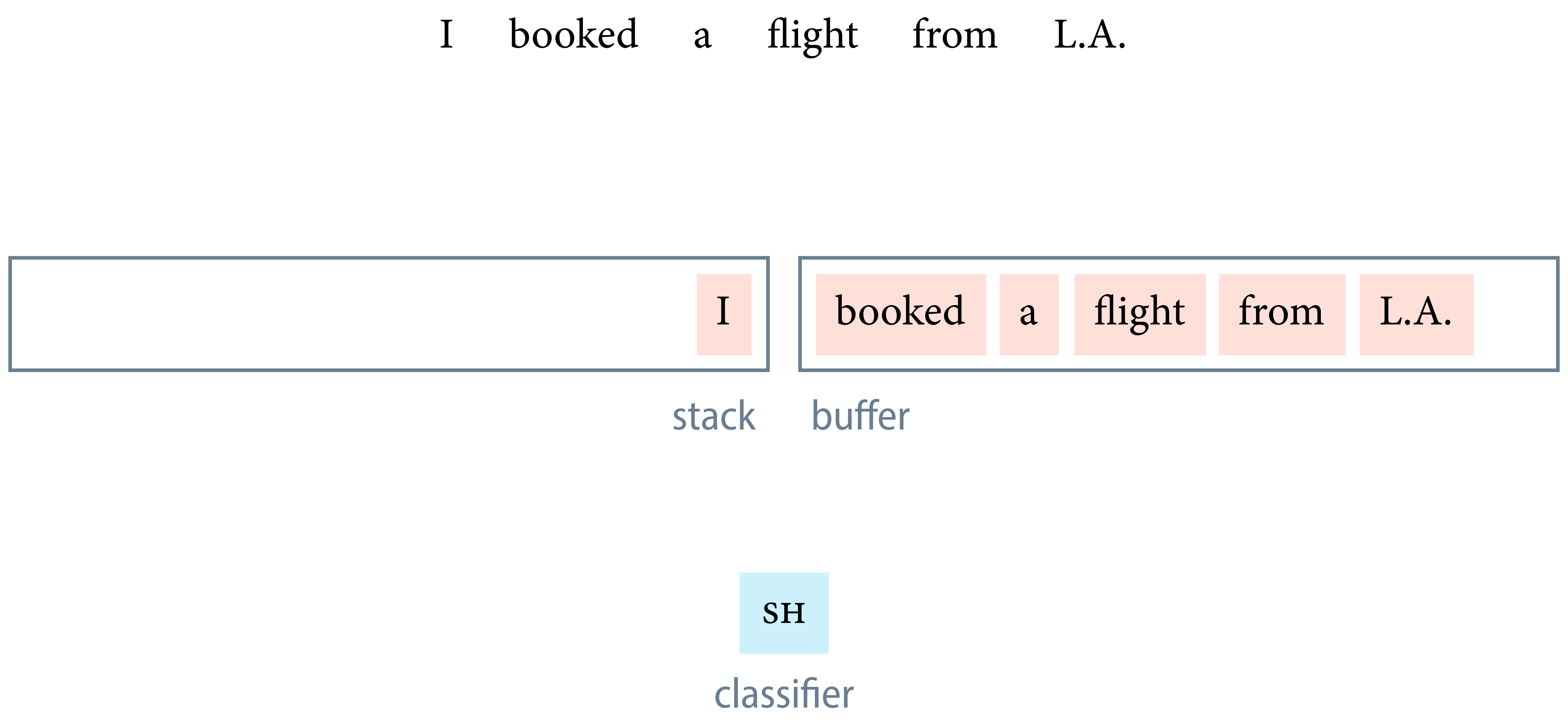

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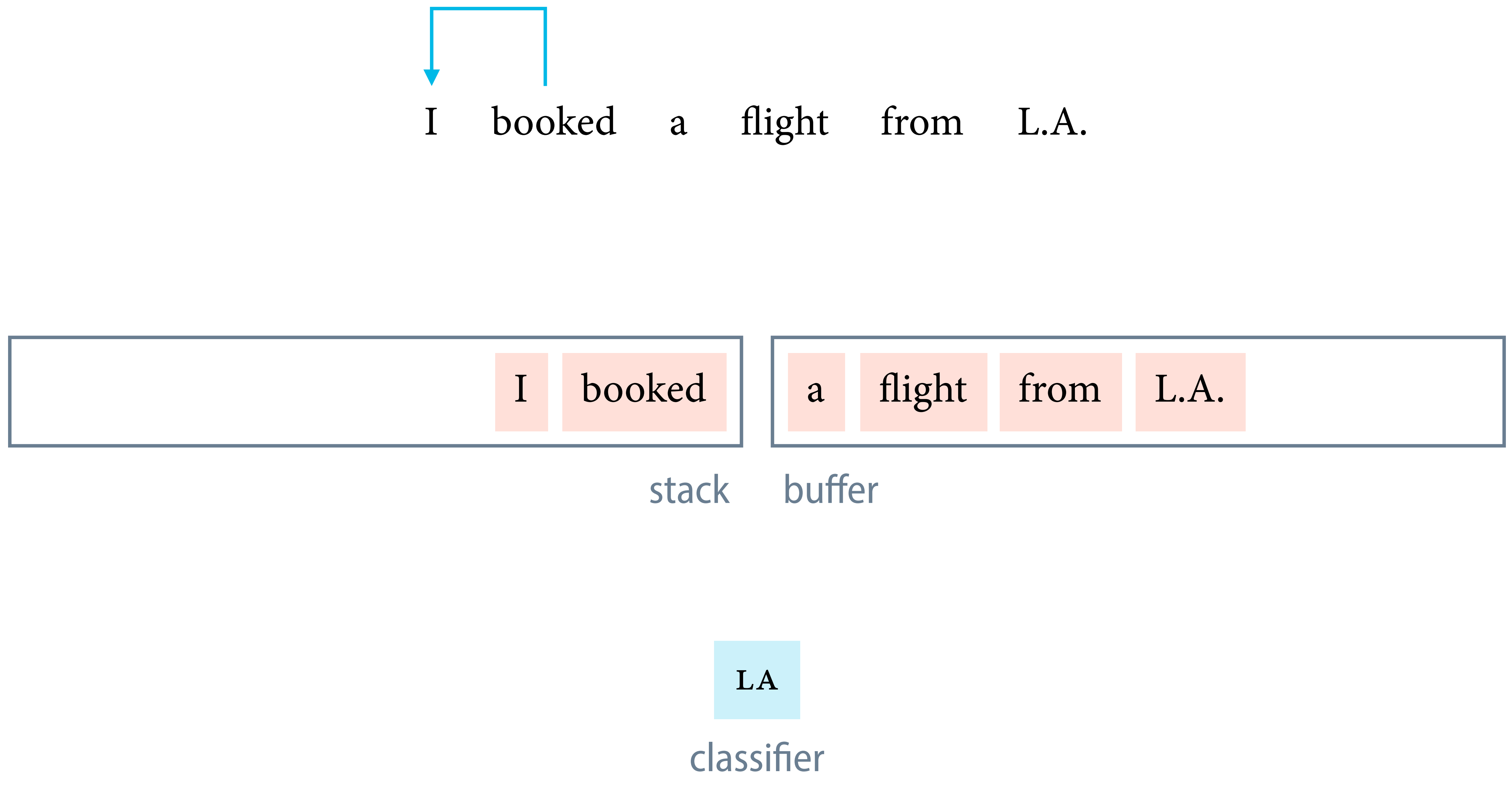

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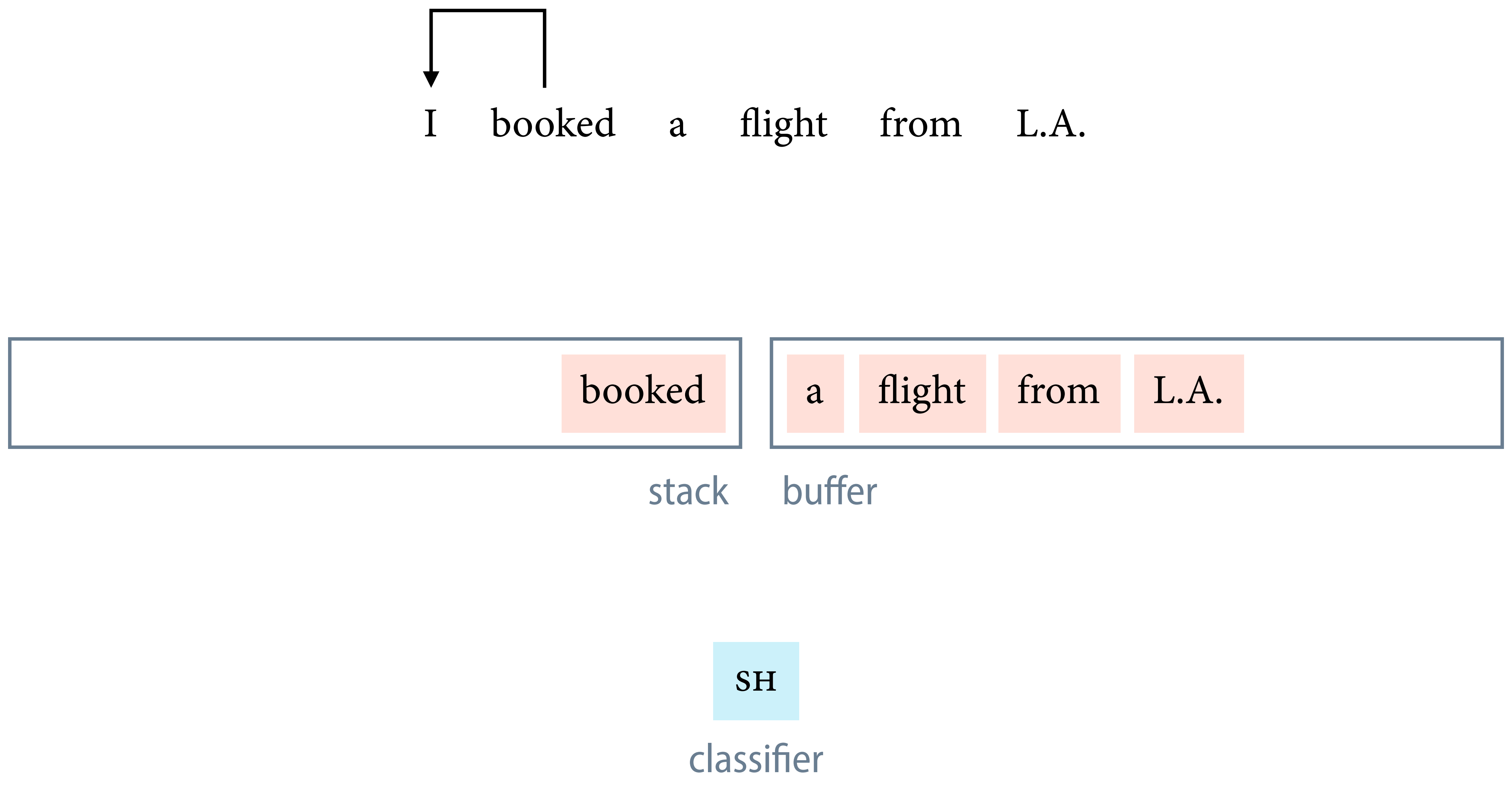
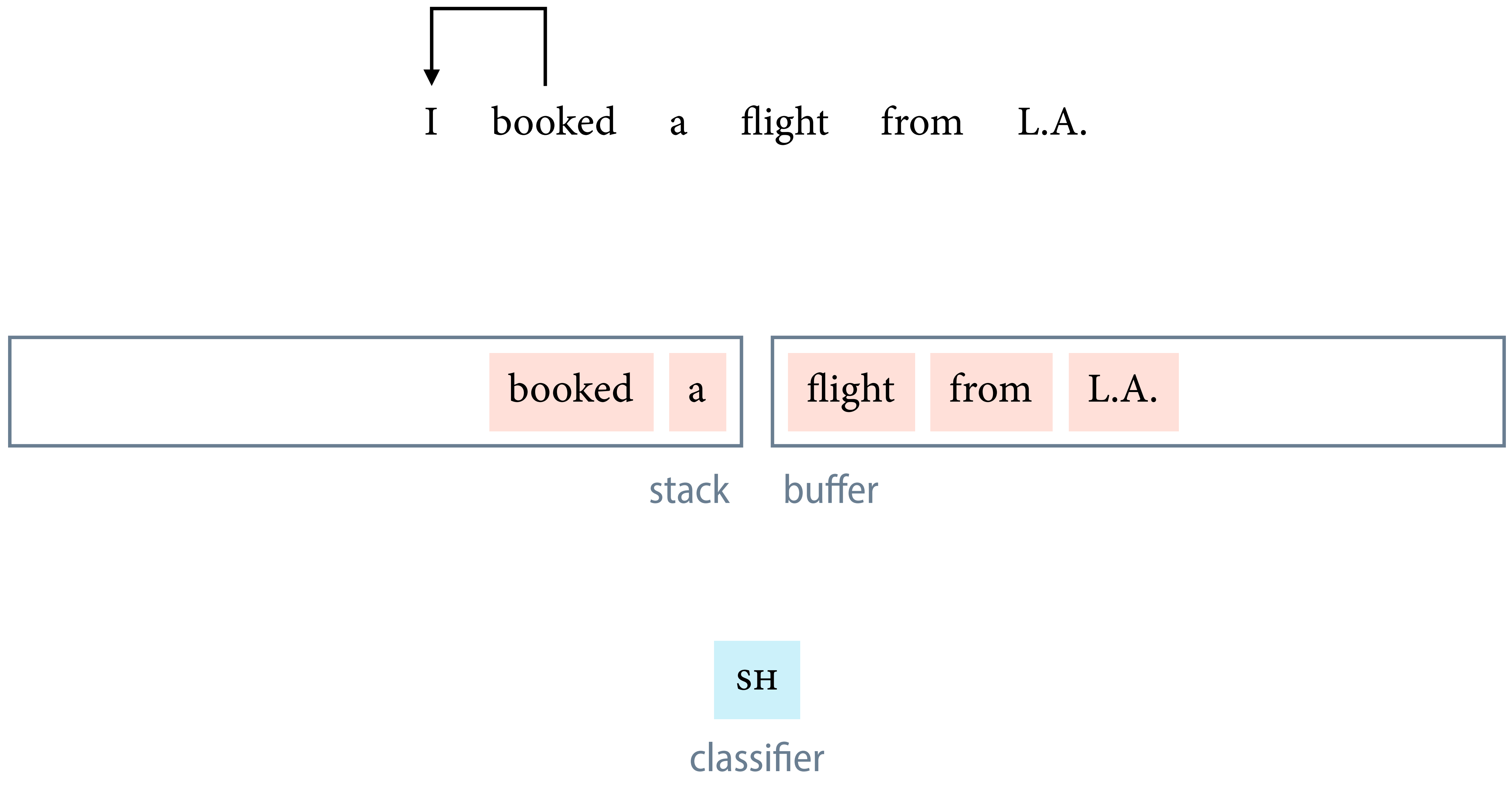


Transition-based dependency parsing, example



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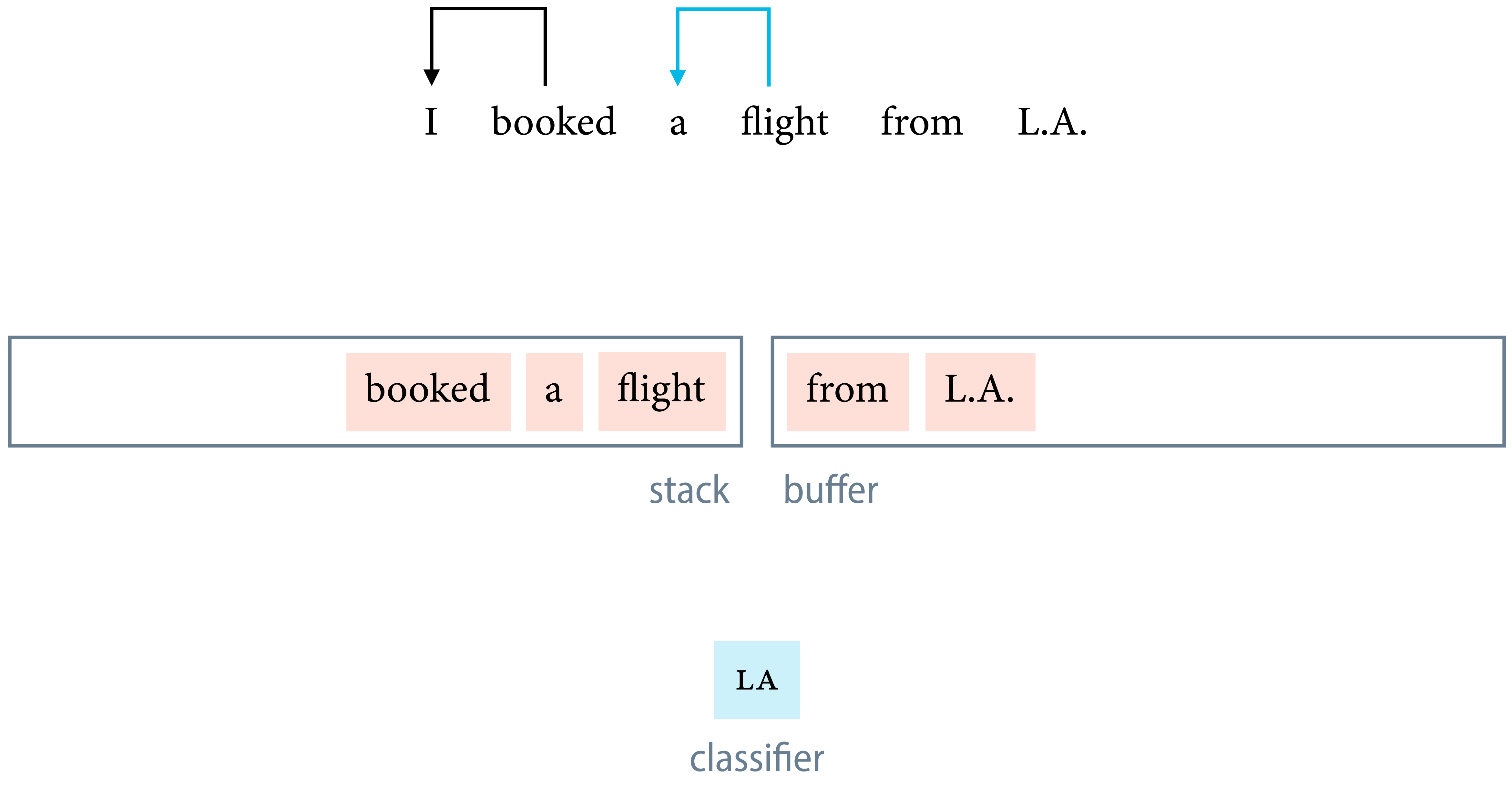

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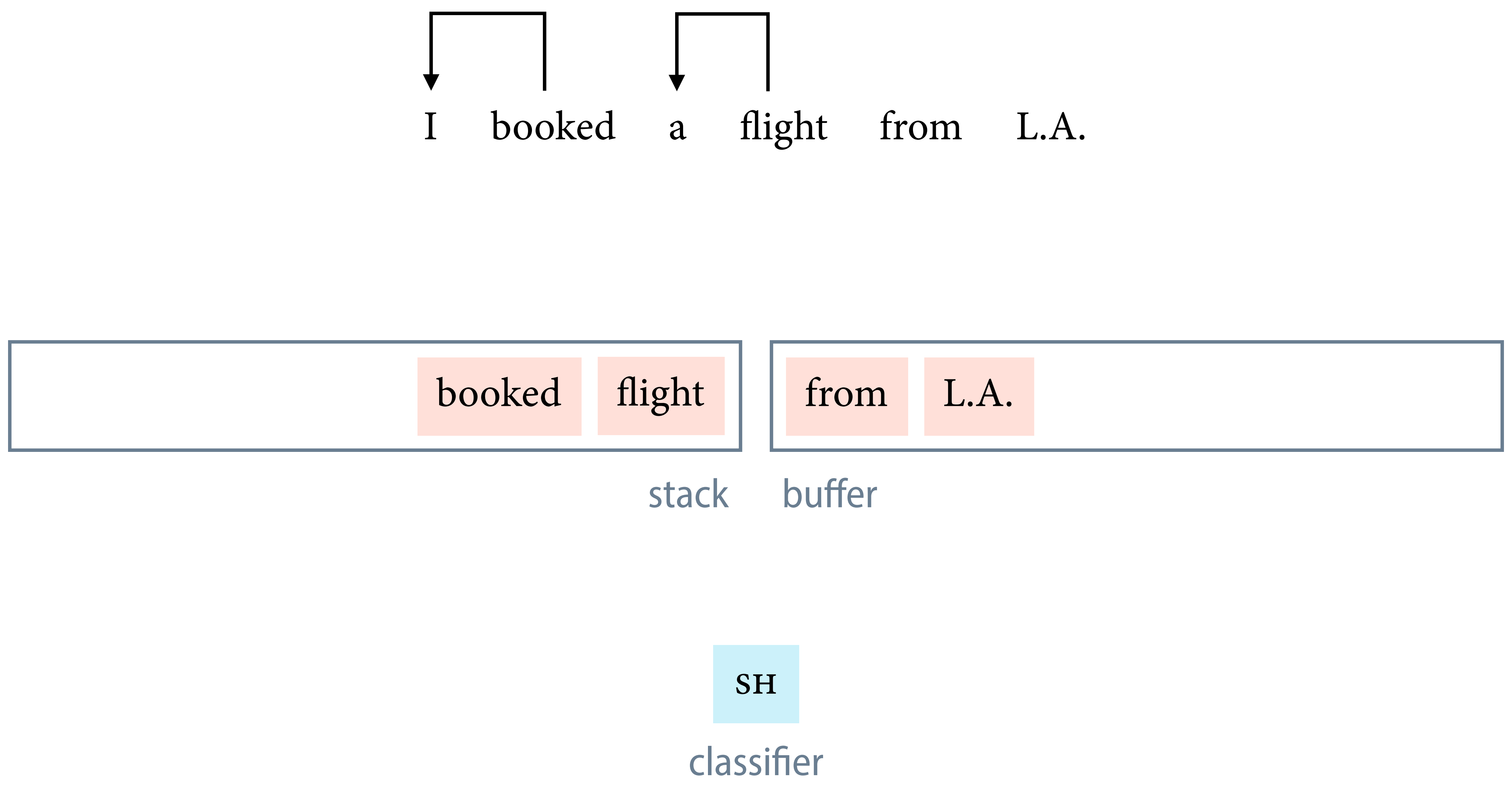

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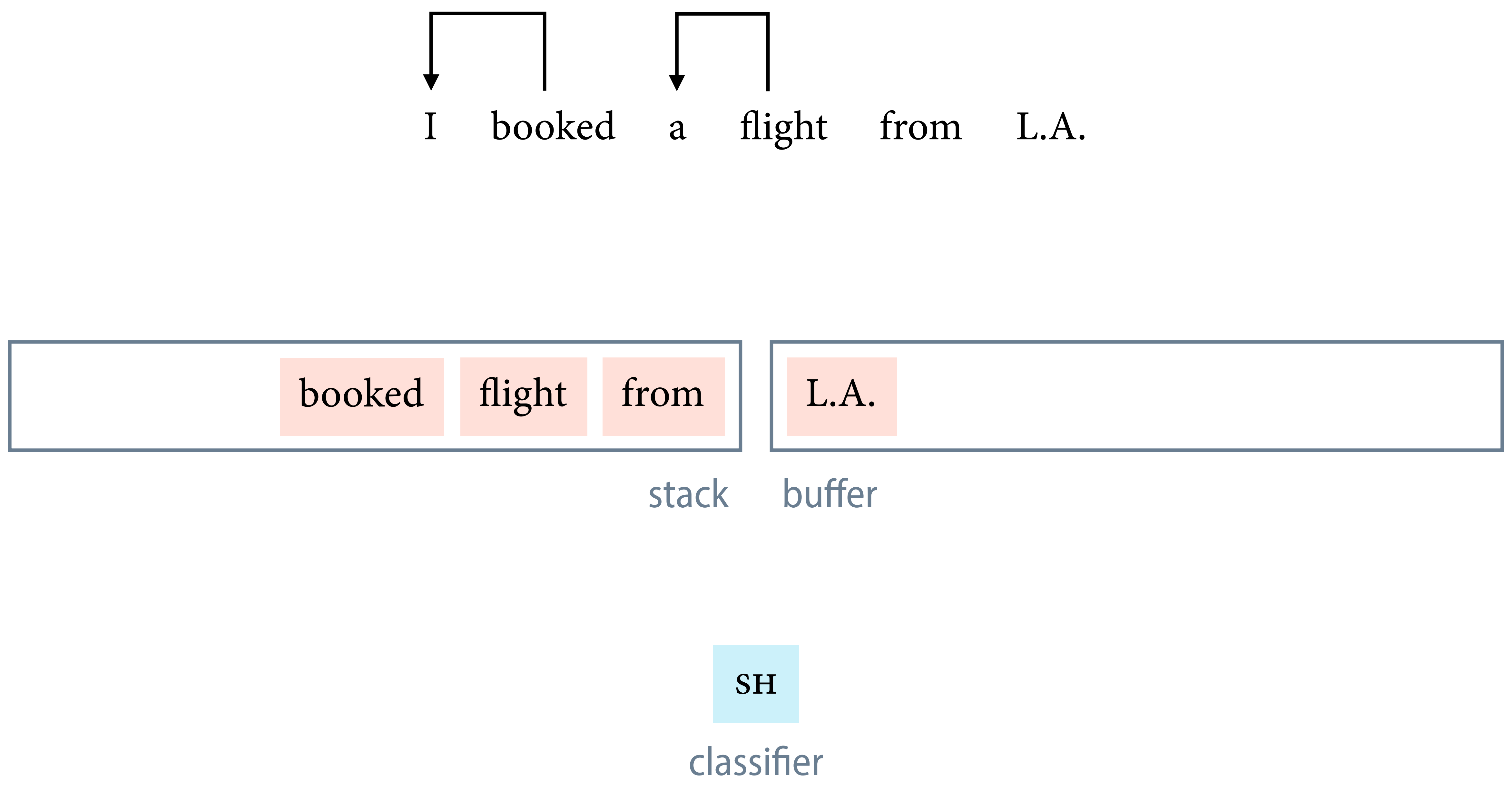

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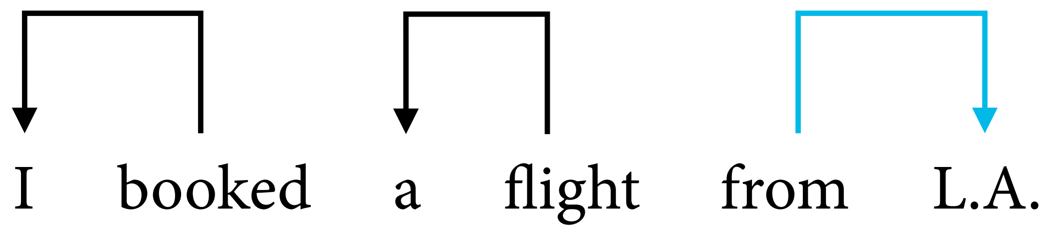

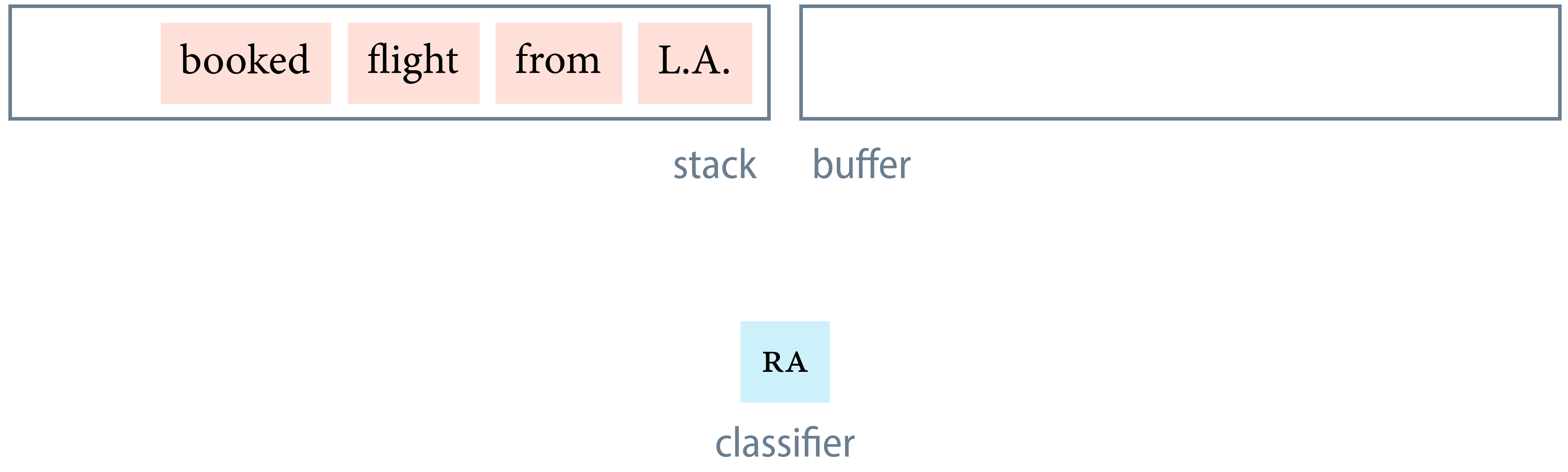

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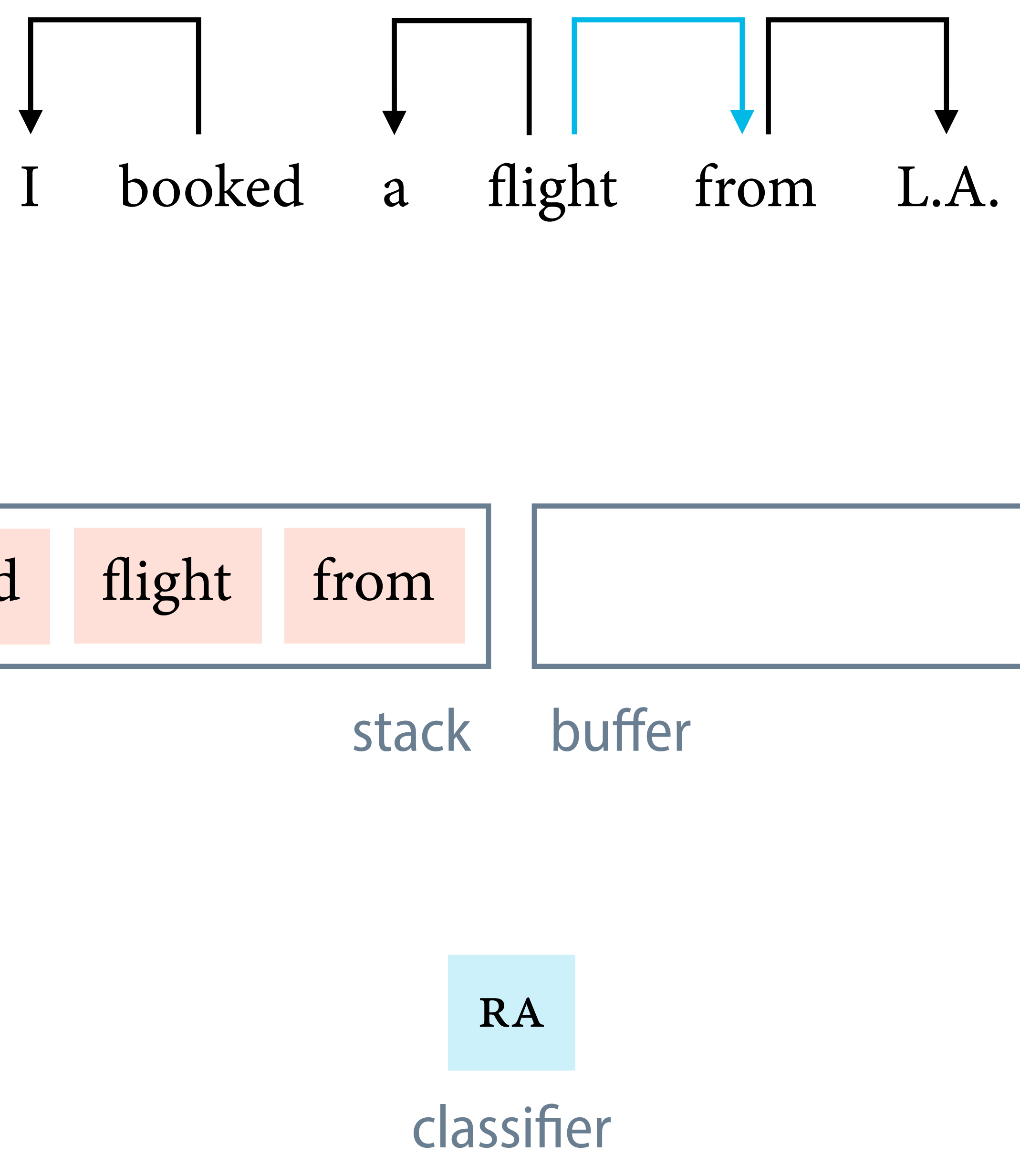

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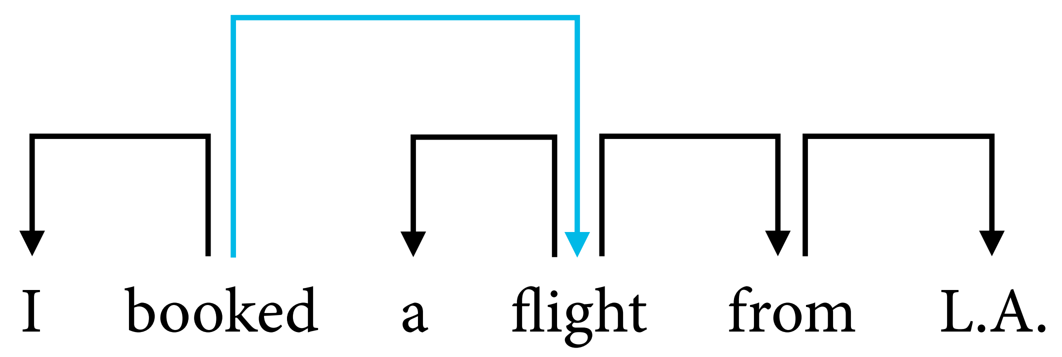

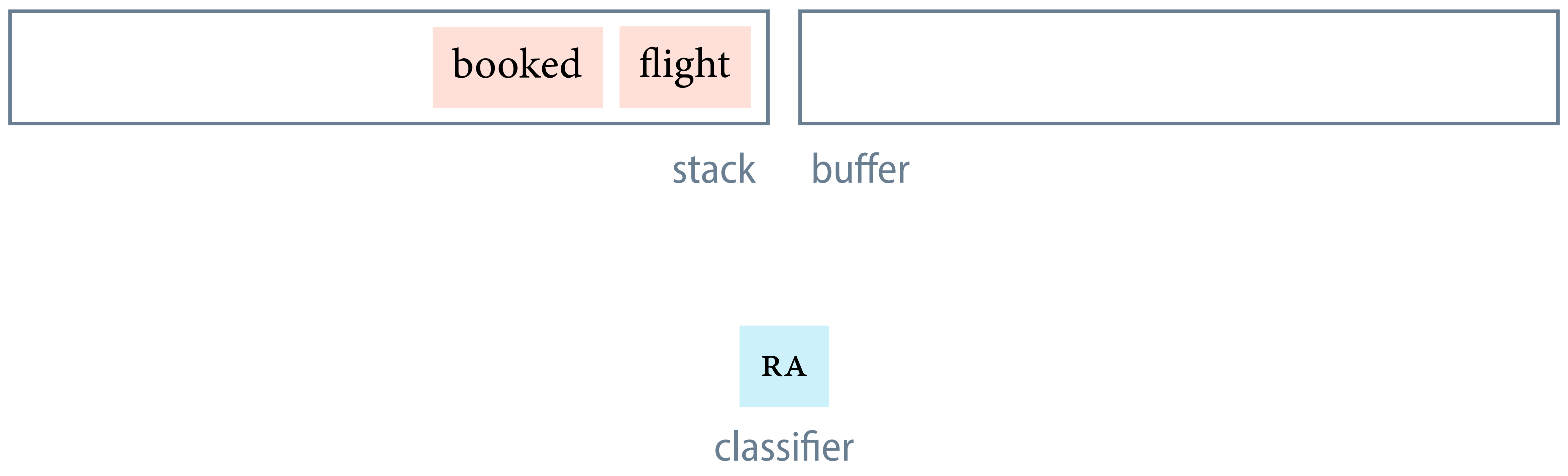

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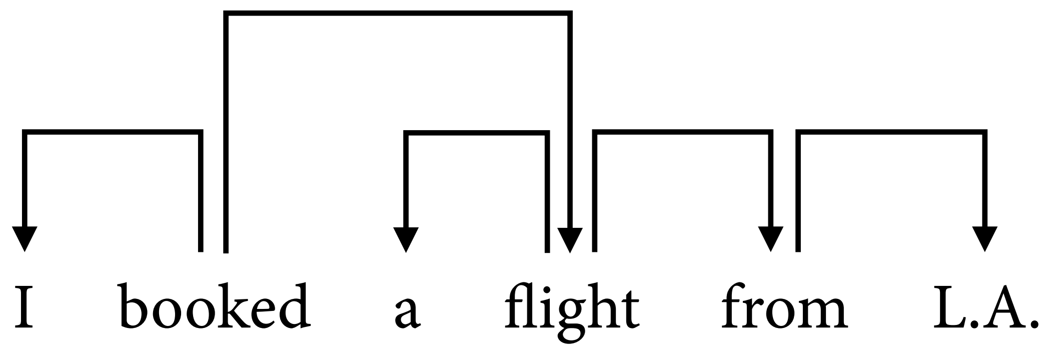
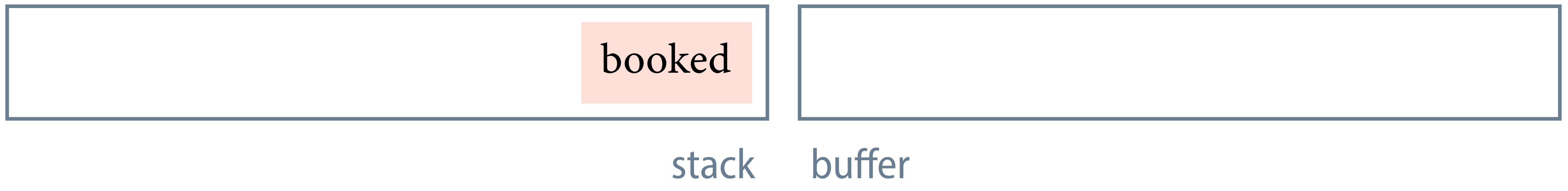




(terminal configuration)

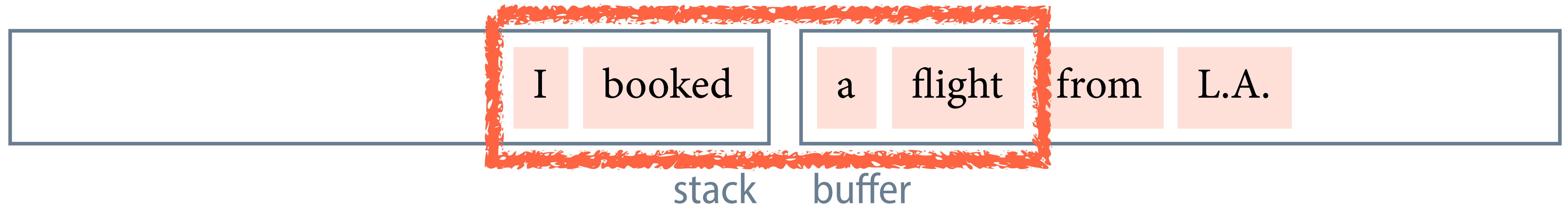
Features in transition-based dependency parsing

Features can be defined over

- the next words in the buffer
- the topmost words in the stack
- the partial dependency tree

Features in transition-based dependency parsing

I booked a flight from L.A.



Is 'booked' a verb? Can 'I' be a subject? Does 'booked' already have a subject?

Training transition-based dependency parsers

- To train a transition-based dependency parser, we need a treebank with dependency trees.
- In addition to that, we need an algorithm that tells us the gold-standard transition sequence for a tree in that treebank.

  oracle

Evaluating dependency parsers

- The **(unlabelled) attachment score** of a dependency parser is its accuracy at the task of predicting the correct head of each word.

  similar to the accuracy of a part-of-speech tagger

- When computing the **labelled attachment score**, we only give points if both the head *and* the dependency label are correct.

- The **exact match score** is the percentage of sentences in which *all* dependencies are correctly predicted.

  unlabelled = only heads, labelled = heads and labels

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