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Transition-based dependency parsing

Syntactic analysis/parsing

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Based on slides from Marco Kuhlmann

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Overview

- Arc-factored dependency parsing
  - Collins' algorithm
  - Eisner's algorithm
- Evaluation of dependency parsers
- Transition-based dependency parsing
  - The arc-standard algorithm
- Projectivity
- Reordering and oracles

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Transition-based dependency parsing

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Transition-based dependency parsing

- Eisner’s algorithm runs in time $O(|w|^3)$.
  This may be too much if a lot of data is involved.
- Idea: Design a dumber but really fast algorithm and let the machine learning do the rest.
- Eisner’s algorithm searches over many different dependency trees at the same time.
- A transition-based dependency parser only builds *one* tree, in *one* left-to-right sweep over the input.

Transition-based dependency parsing

- The parser starts in an initial configuration.
- At each step, it asks a guide to choose between one of several transitions (actions) into new configurations.
- Parsing stops if the parser reaches a terminal configuration.
- The parser returns the dependency tree associated with the terminal configuration.

Generic parsing algorithm

```
Configuration c = parser.getInitialConfiguration(sentence)

while c is not a terminal configuration do

     Transition t = guide.getNextTransition(c)

     c = c.makeTransition(t)

return c.getGraph()
```

Variation

Transition-based dependency parsers differ with respect to the configurations and the transitions that they use.

The arc-standard algorithm

The arc-standard algorithm

- The arc-standard algorithm is a simple algorithm for transition-based dependency parsing.
- It is very similar to shift–reduce parsing as it is known for context-free grammars.
- It is implemented in most practical transition-based dependency parsers, including MaltParser.

Configurations

A configuration for a sentence $w = w_1 \ldots w_n$ consists of three components:

- a buffer containing words of *w*
- a stack containing words of *w*
- the dependency graph constructed so far

Configurations

- Initial configuration:
  - All words are in the buffer.
  - The stack is empty.
  - The dependency graph is empty.
- Terminal configuration:
  - The buffer is empty.
  - The stack contains a single word.

Configurations, with root

- Initial configuration:
  - All words are in the buffer.
  - The stack contains the ROOT word.
  - The dependency graph is empty.
- Terminal configuration:
  - The buffer is empty.
  - The stack contains the ROOT word.

Possible transitions

- shift (sh): push
  the next word in the buffer onto the stack
- left-arc (la): add an arc
  from the topmost word on the stack, s_1,
  to the second-topmost word, s_2, and pop s_2
- right-arc (ra): add an arc
  from the second-topmost word on the stack, s_2,
  to the topmost word, s_1, and pop s_1

Terminology

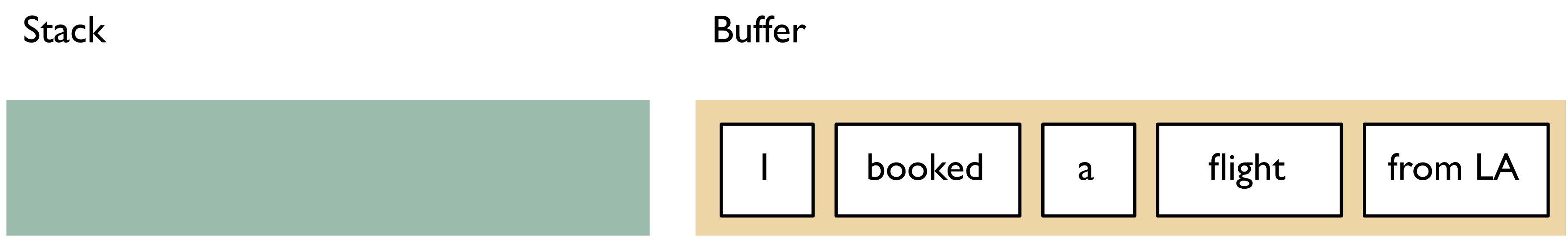
- Stack
  - S - the full stack
  - σ - partial stack
  - [σ|i|j] - a generic stack σ, with elements i,j on top (opening to right)
- Buffer
  - B - full buffer
  - β - partial buffer
  - [i|β] - buffer with element i as the first element (opening to left)

Configurations and transitions

- Initial configuration: ([],[0,…,n],[])
- Terminal configuration: ([i],[],A)
- shift (sh):
  $(\sigma,[i|\beta],A) \Rightarrow ([\sigma|i],\beta,A)$
- left-arc (la):
  $([\sigma|i|j],B,A) \Rightarrow ([\sigma|j],B,A \cup \{j,l,i\})$
- right-arc (ra):
  $([\sigma|i|j],B,A) \Rightarrow ([\sigma|i],B,A \cup \{i,l,j\})$

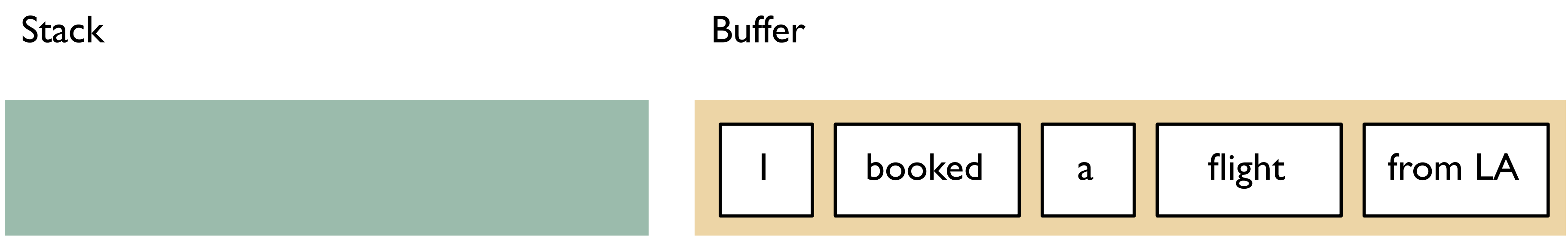
The arc-standard algorithm

Example run



I booked a flight from LA

Example run

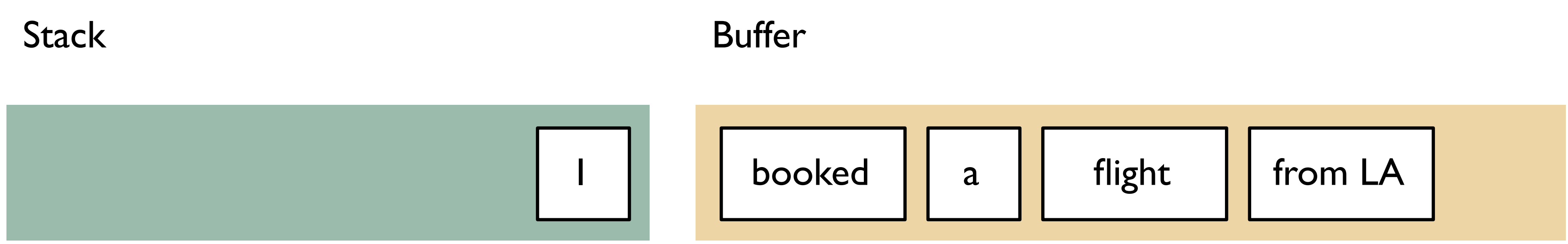


I booked a flight from LA

sh

The arc-standard algorithm

Example run



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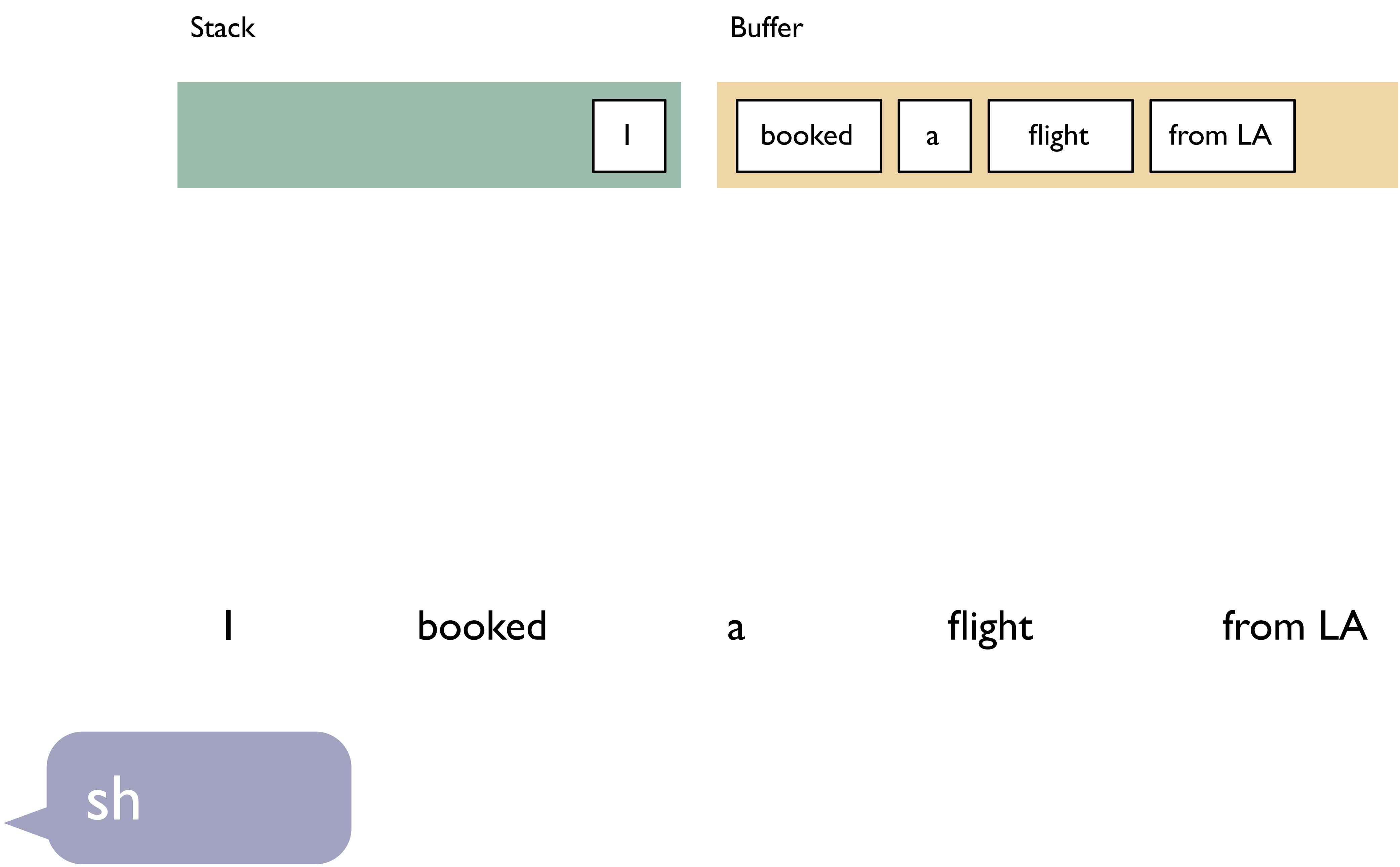
Stack
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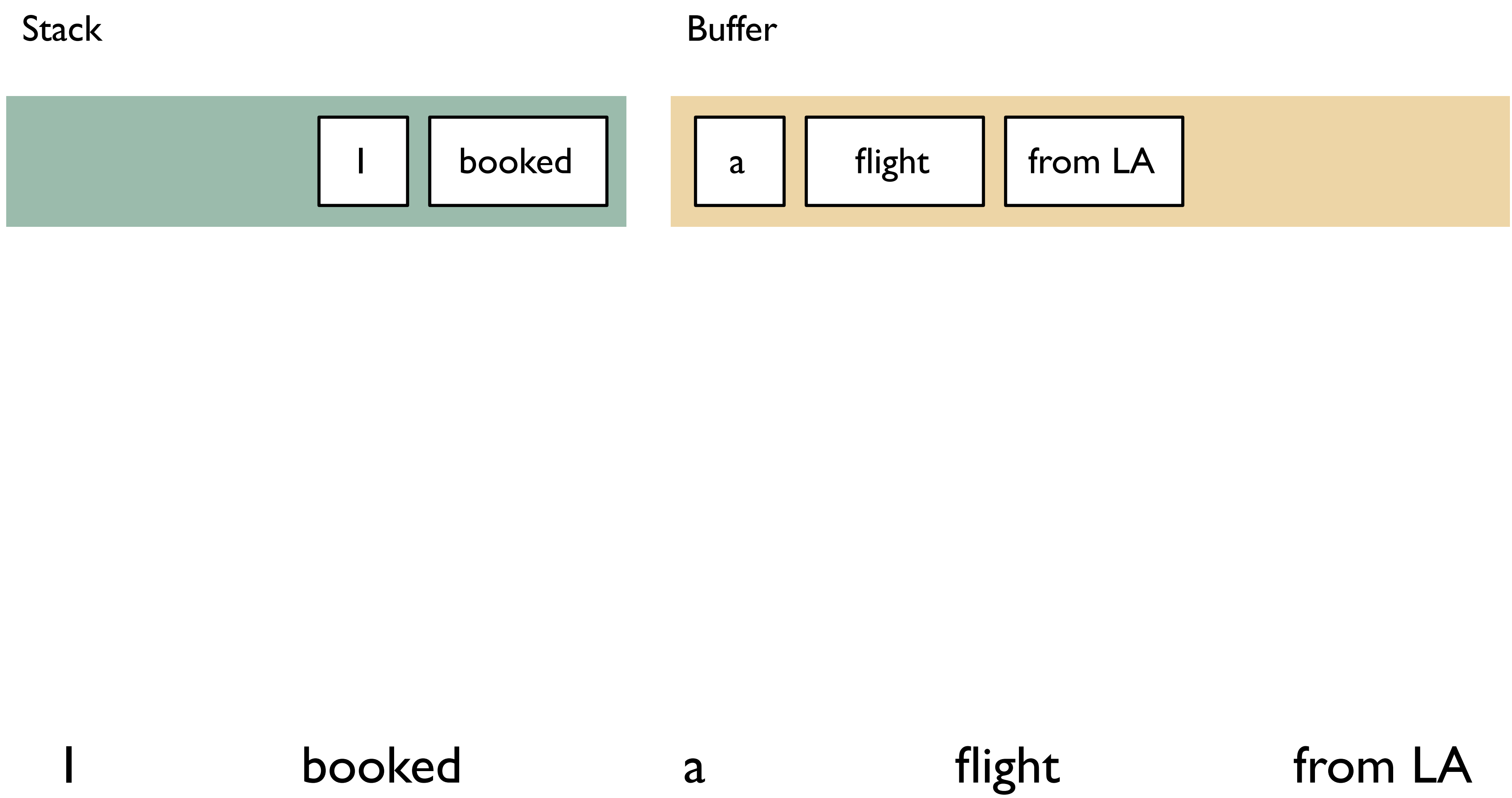
The arc-standard algorithm

Example run



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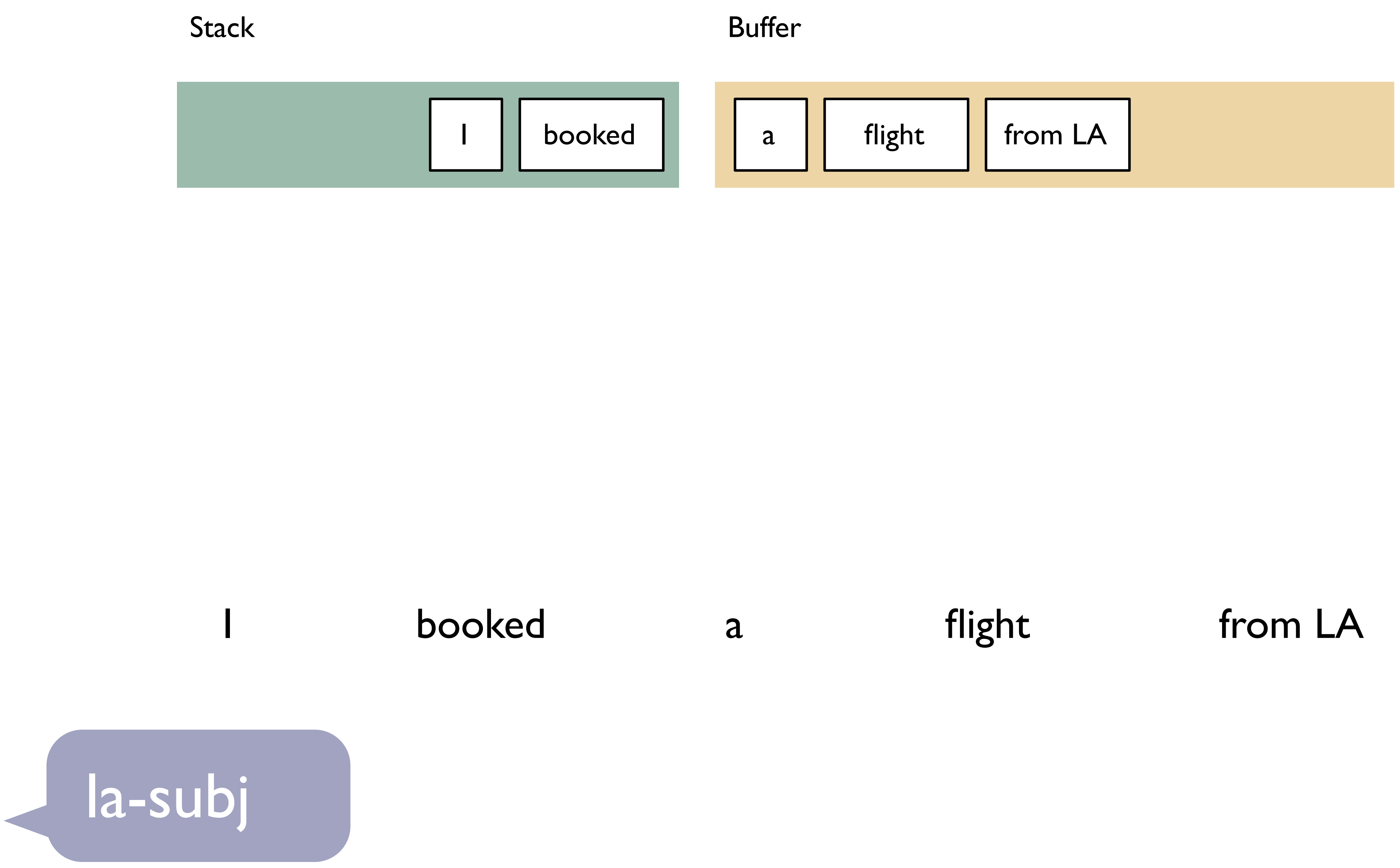
Example run



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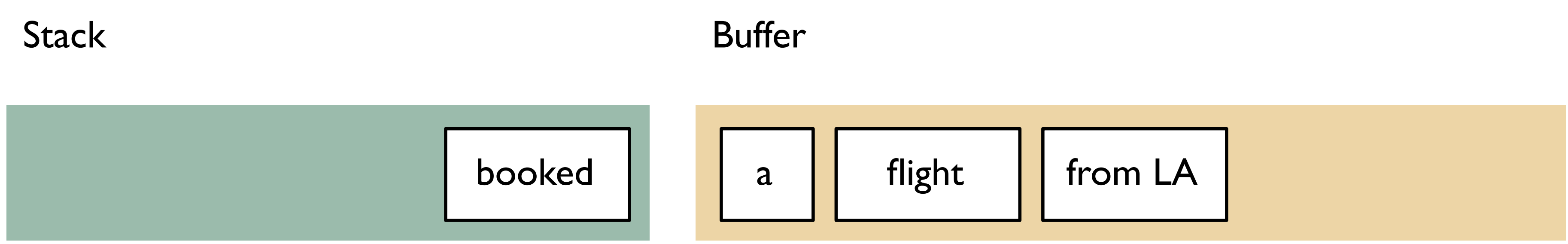
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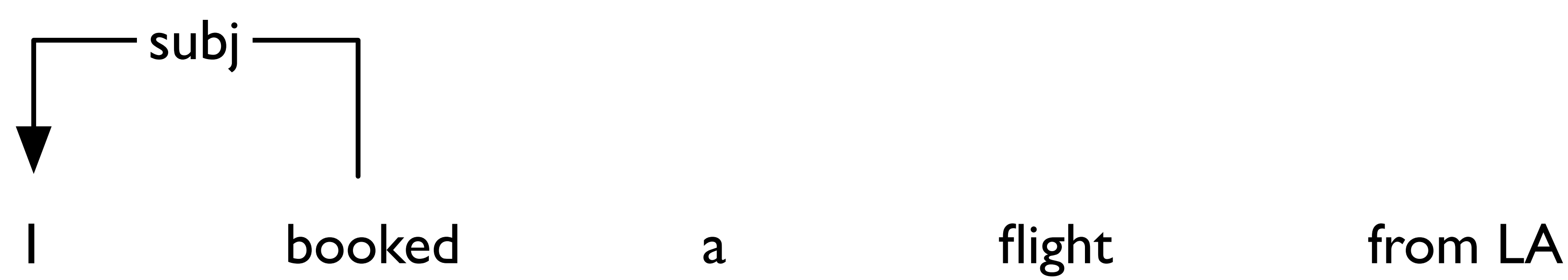
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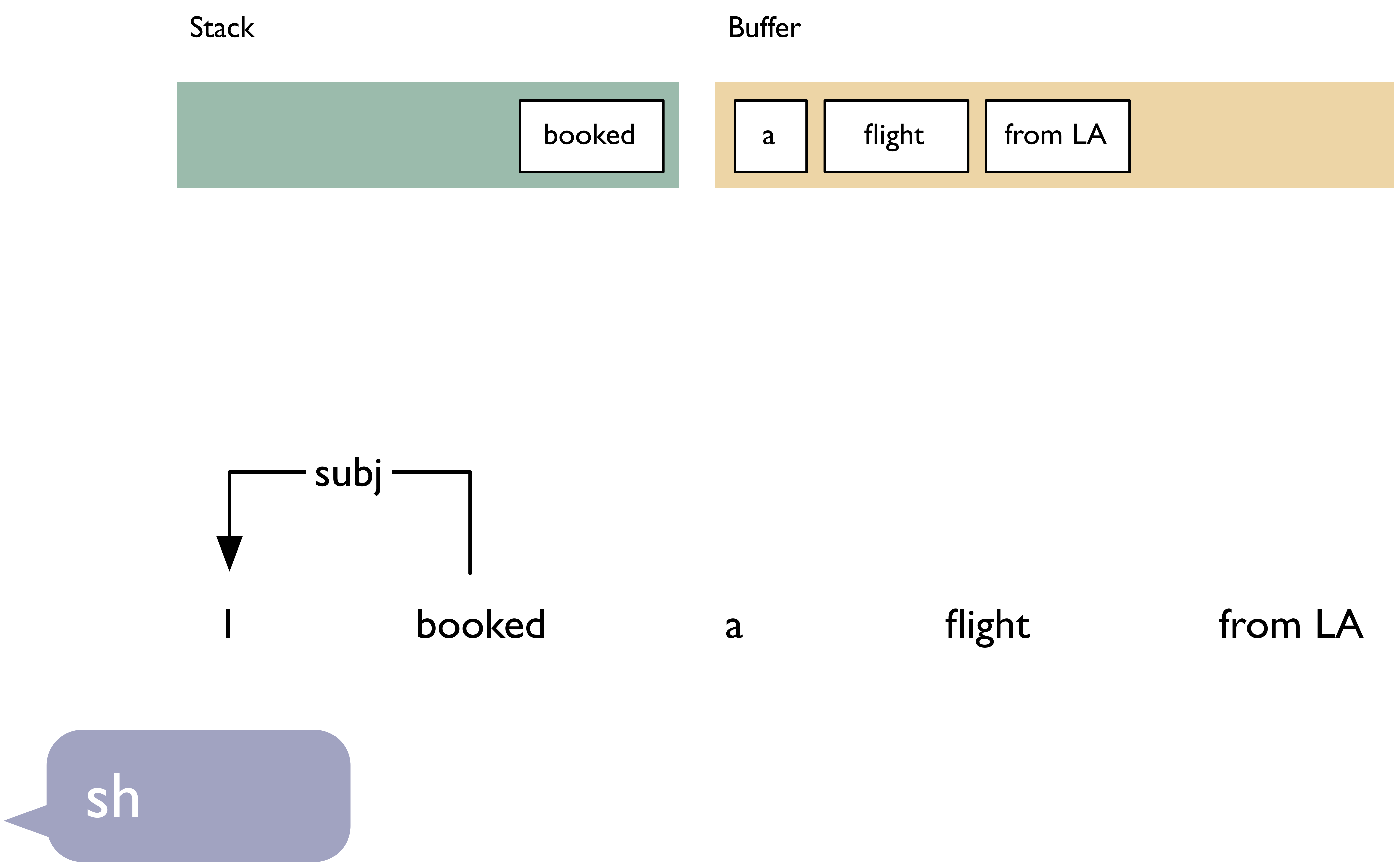
Example run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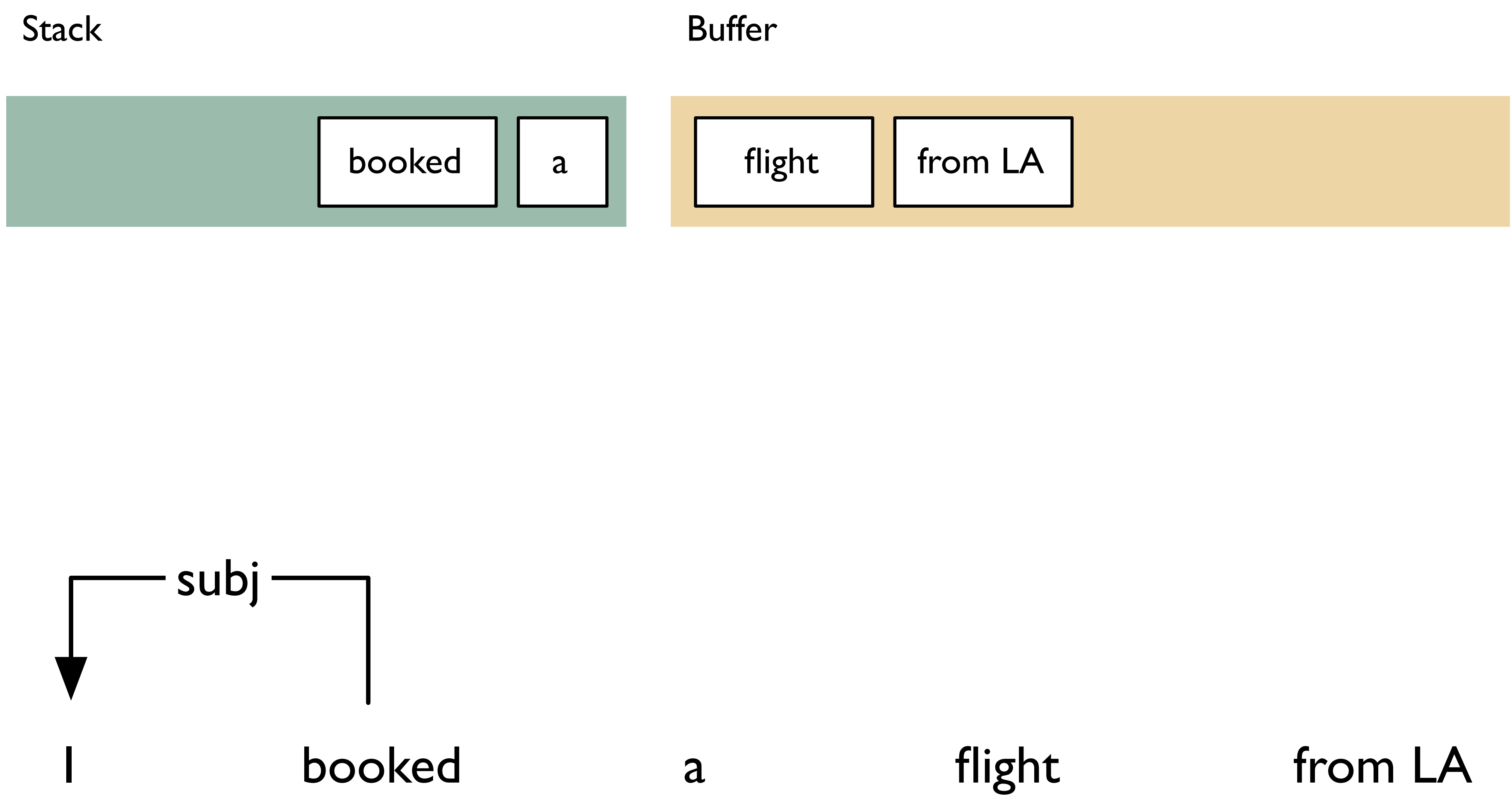
Example run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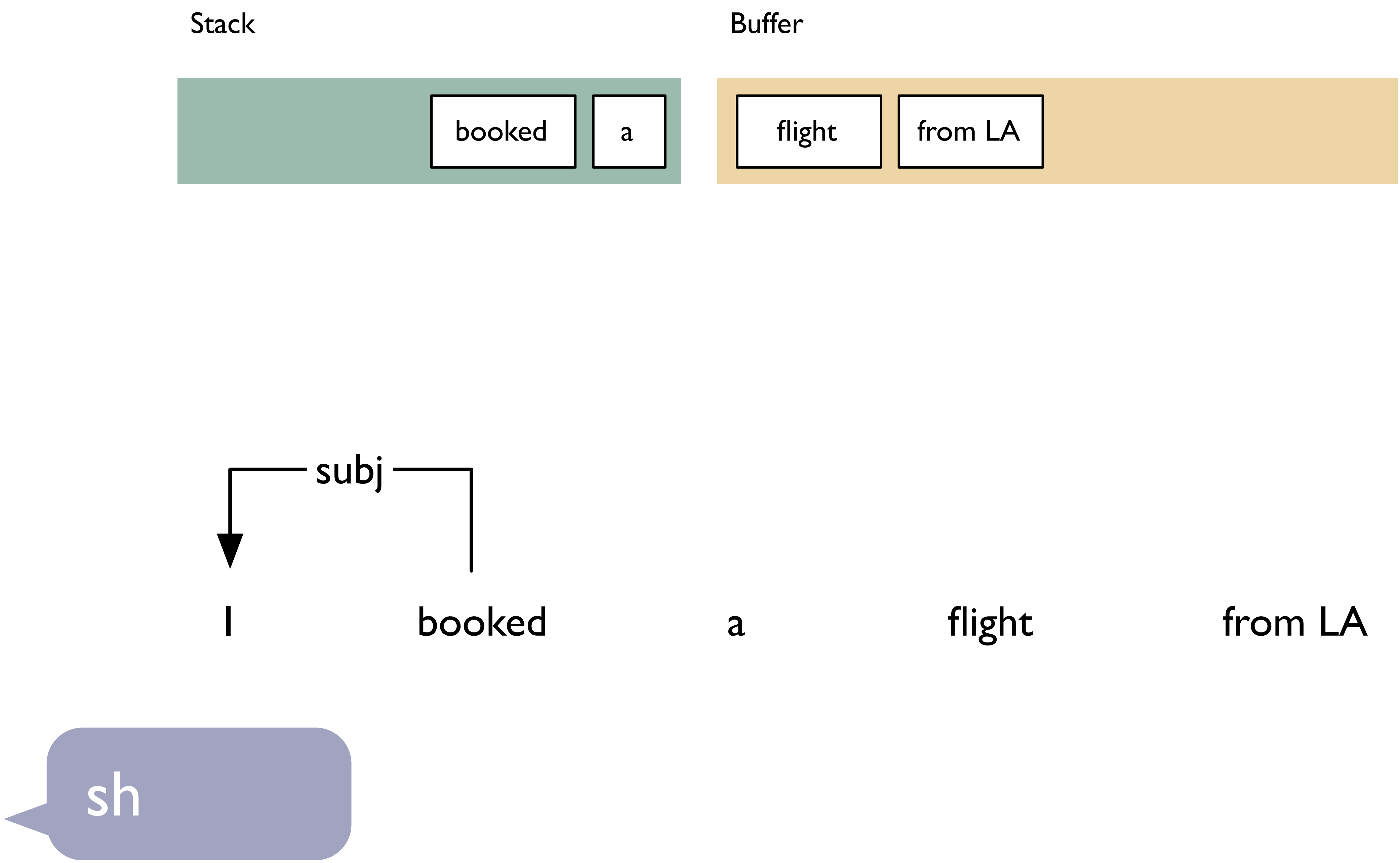
The arc-standard algorithm

Example run



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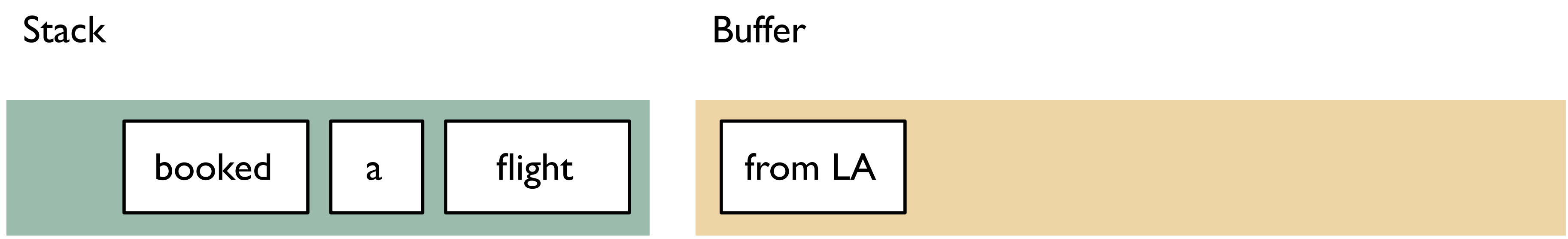
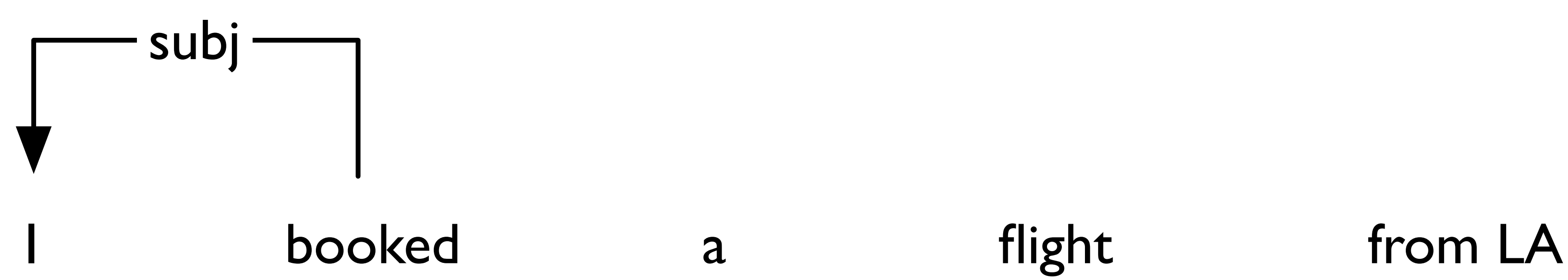
The arc-standard algorithm

Example run





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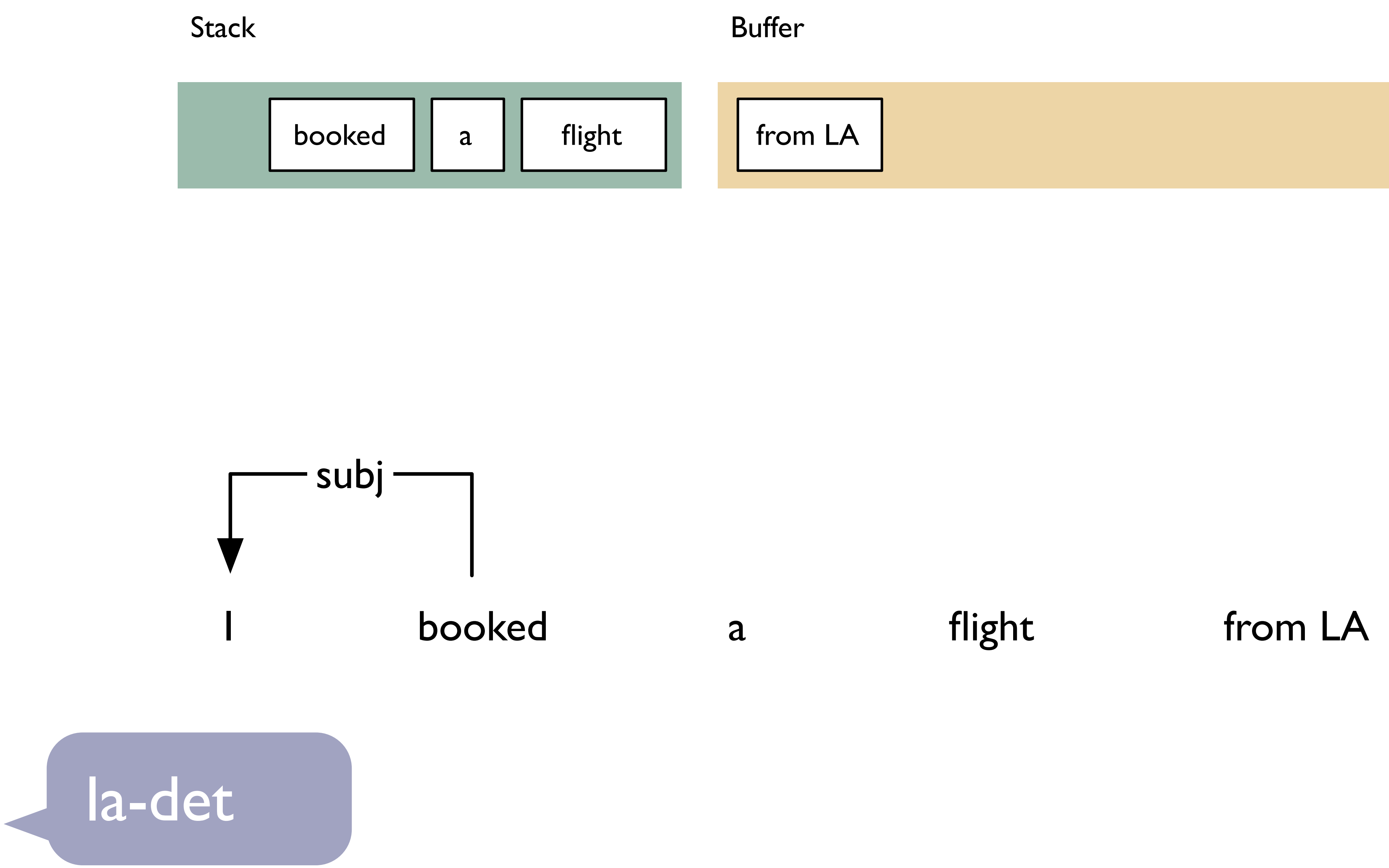
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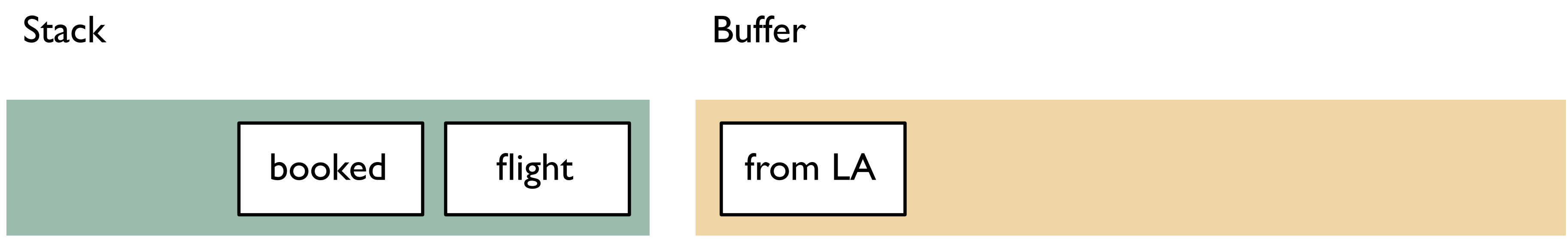
Example run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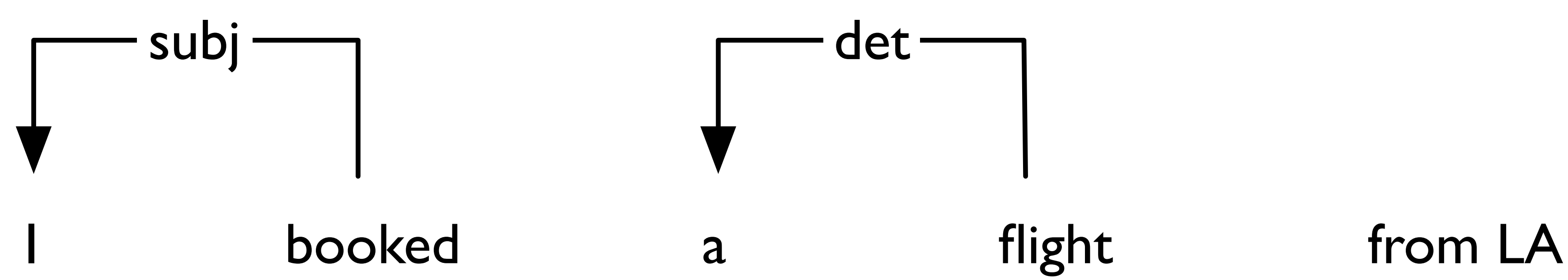
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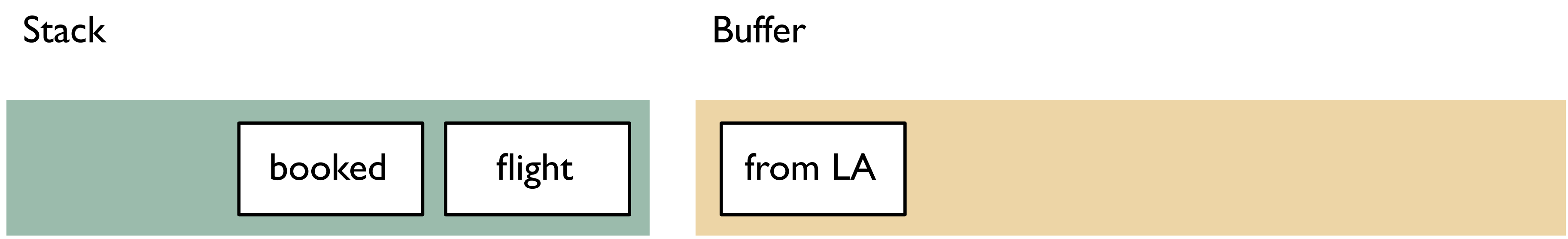
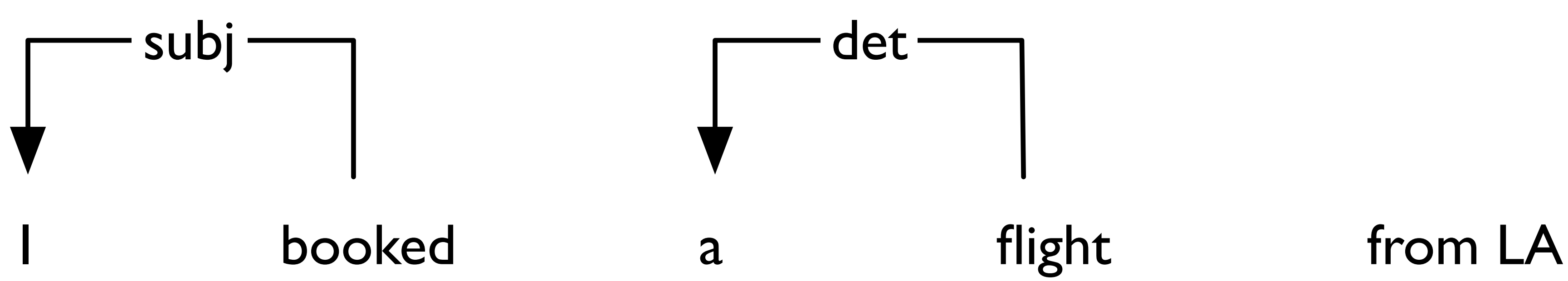
The arc-standard algorithm

Example run





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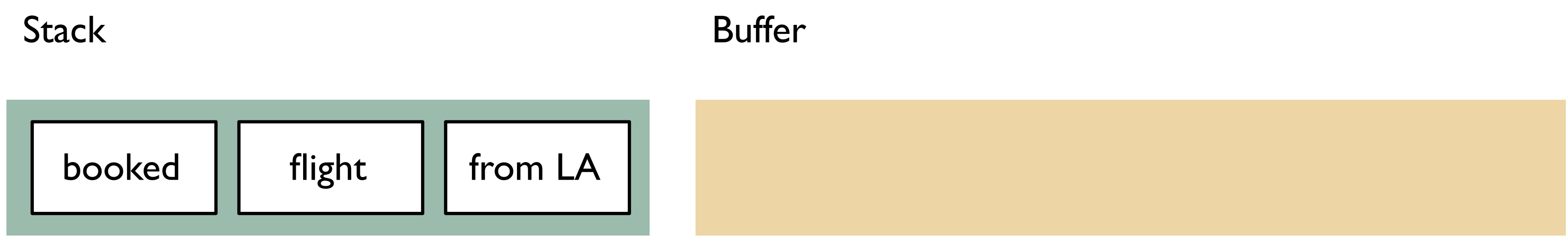
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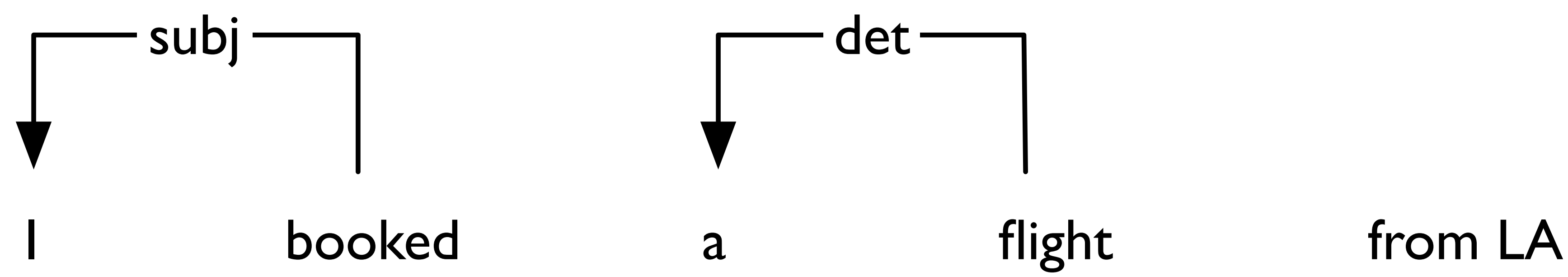
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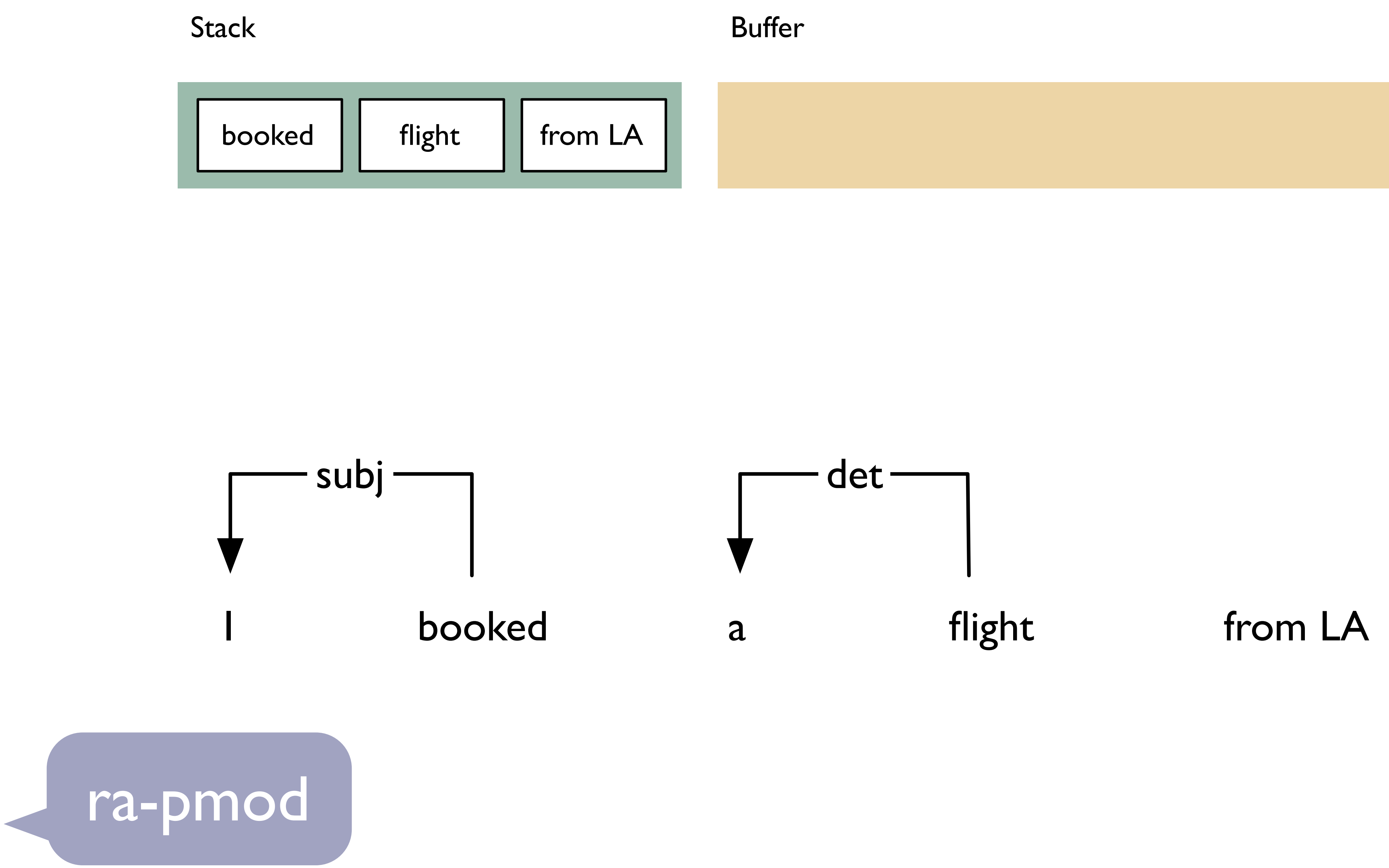
The arc-standard algorithm

Example run



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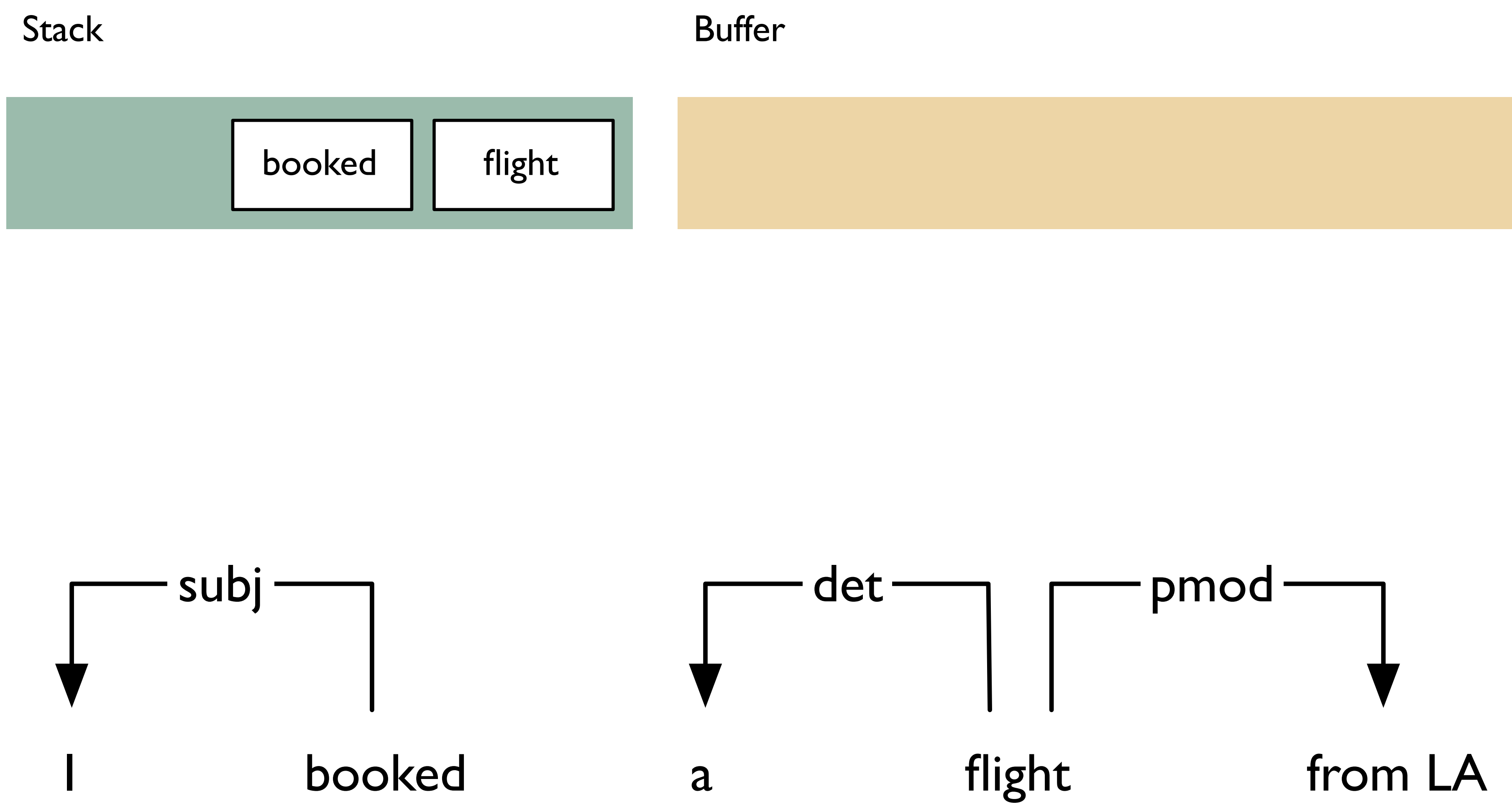
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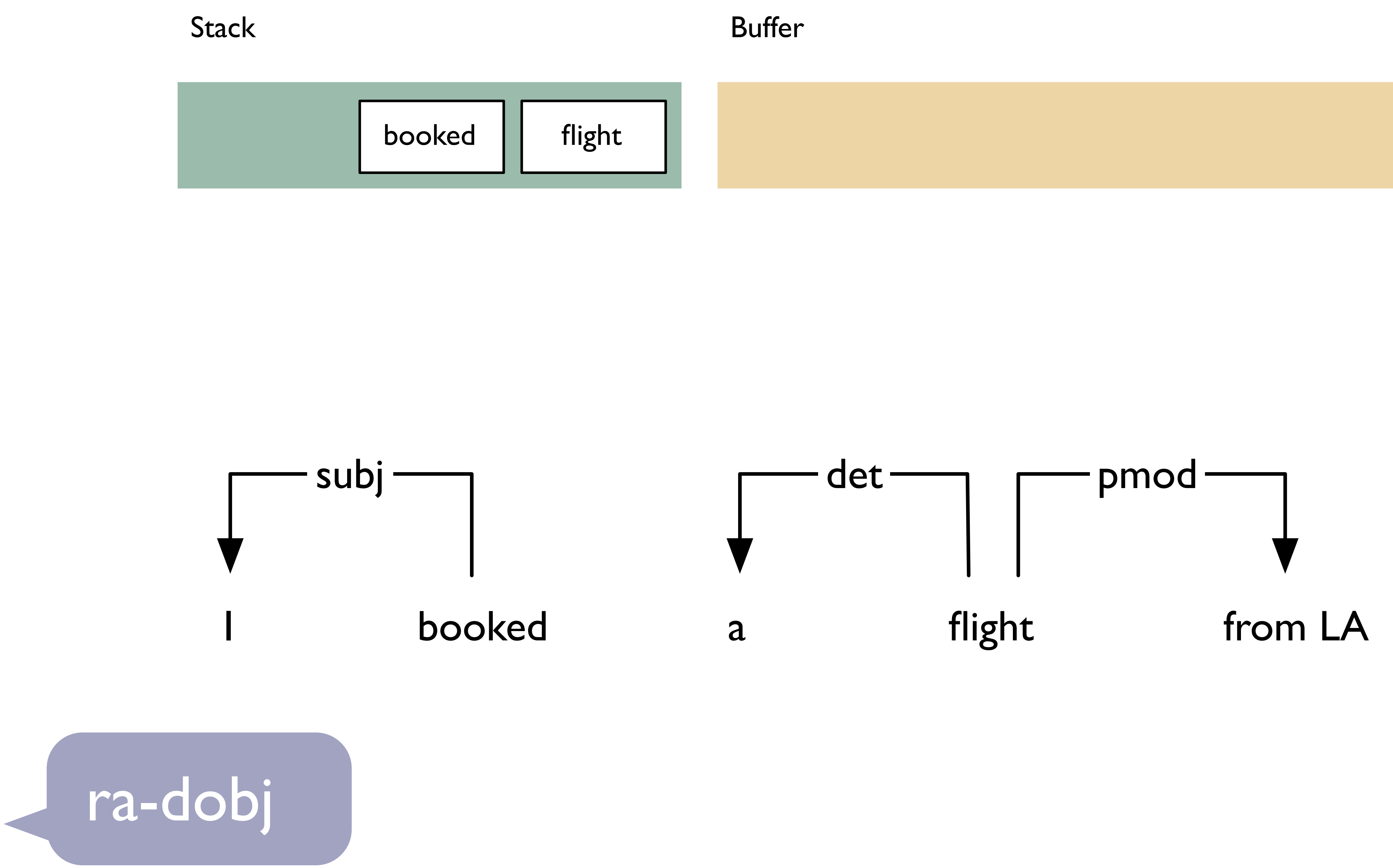
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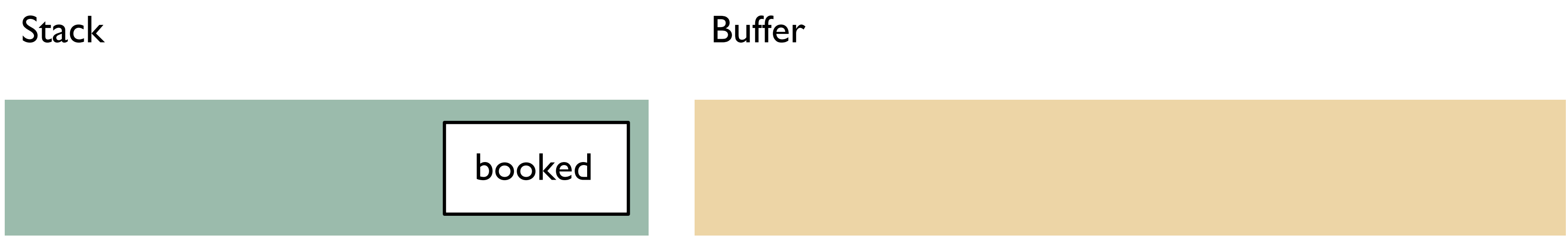
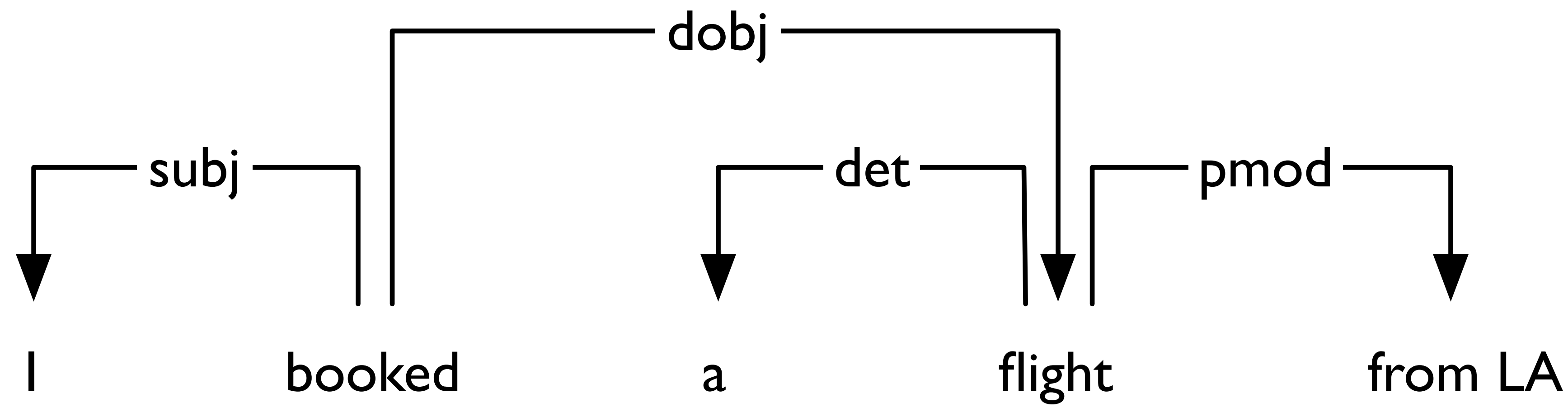
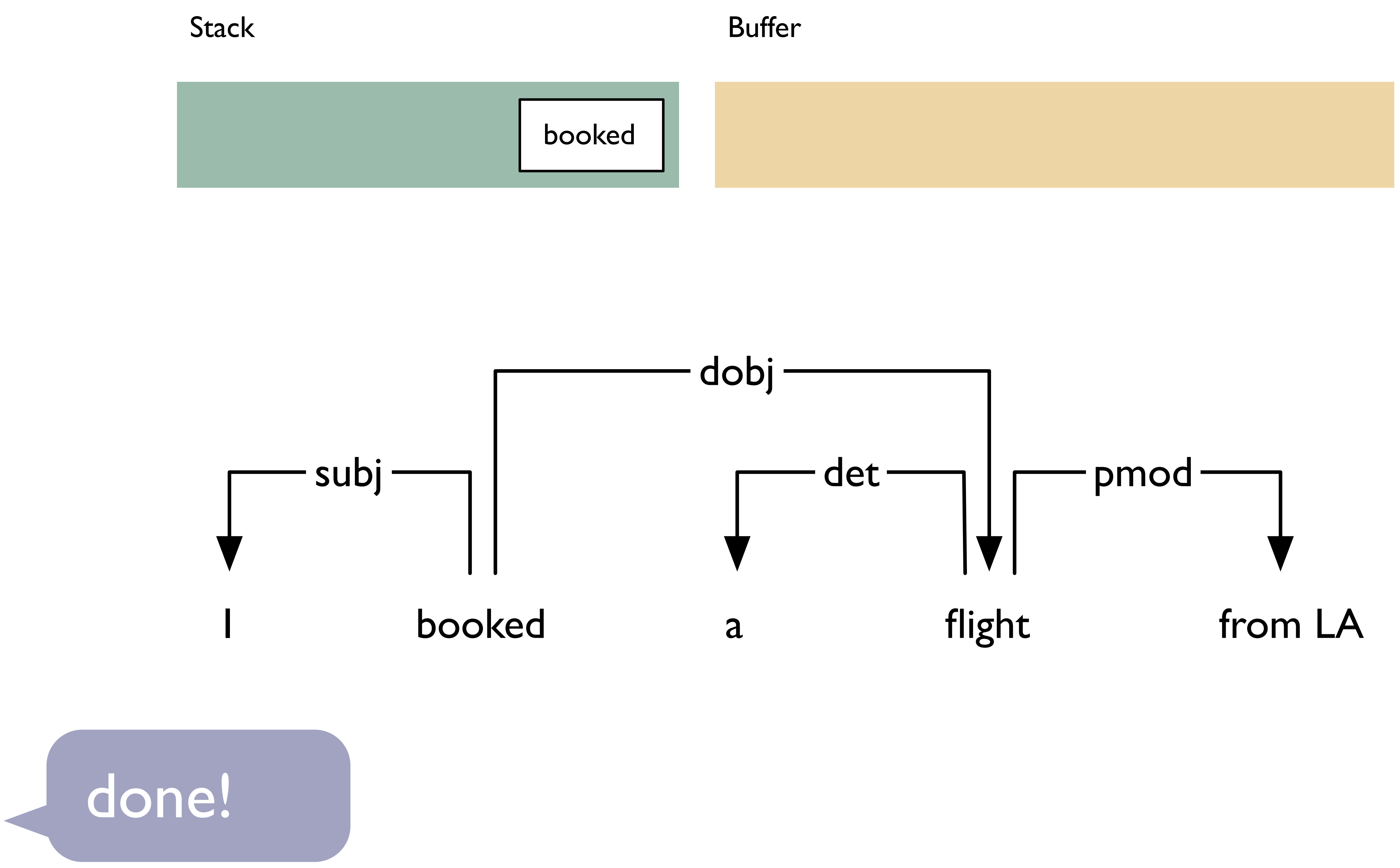
The arc-standard algorithm

Example run





Example run


Stack
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done!

Complexity and optimality

- Time complexity is linear, O(n), since we only have to treat each word once
- This can be achieved since the algorithm is greedy, and only builds one tree, in contrast to Eisner's algorithm, where all trees are explored
- There is no guarantee that we will even find the best tree given the model, the arc-standard model.
- There is a risk of error propagation
- An advantage is that we can use very informative features, for the ML algorithm

Training a guide

Guides

- We need a guide that tells us what the next transition should be.
- The task of the guide can be understood as classification: Predict the next transition (class), given the current configuration.

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Training a guide

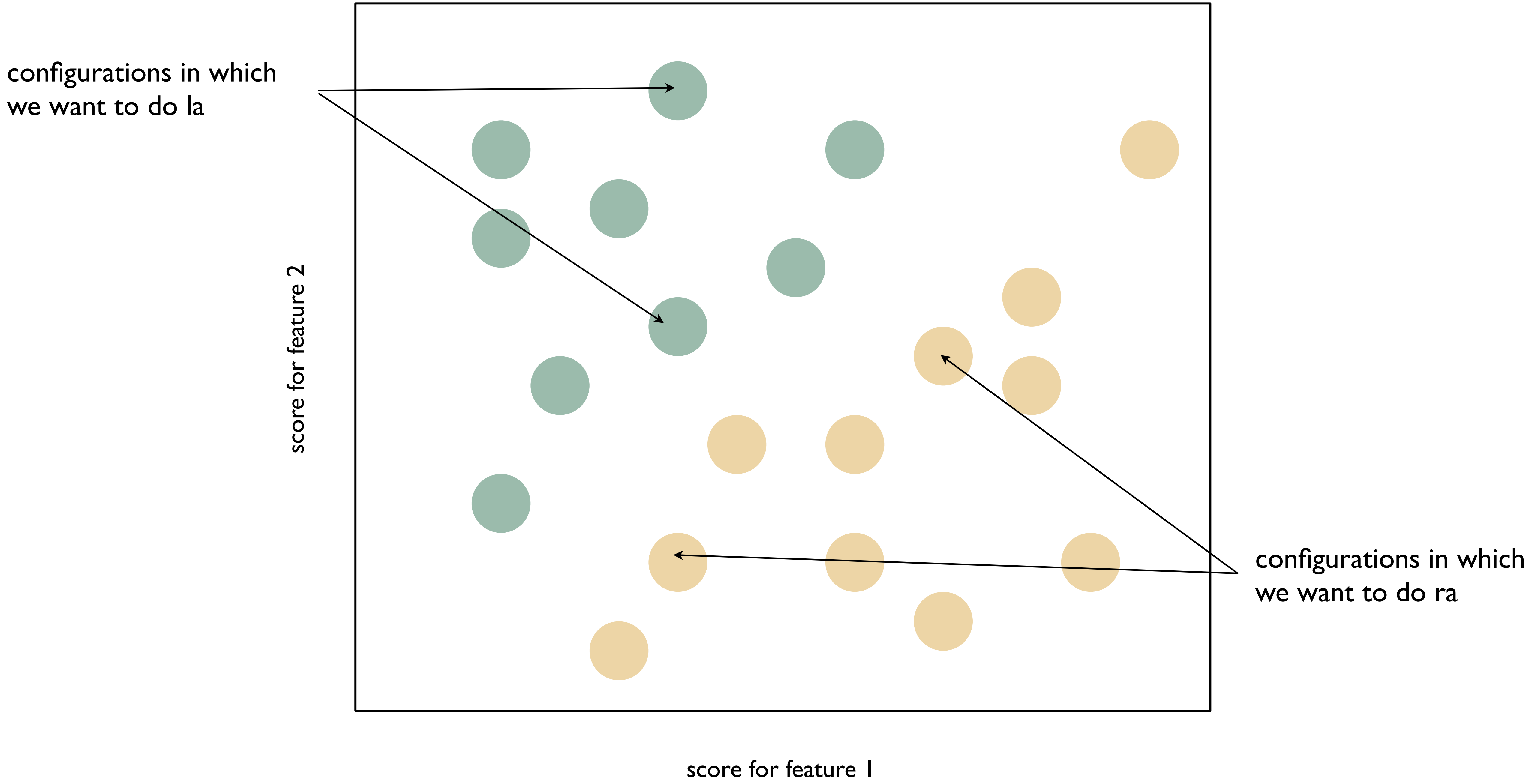
- We let the parser run on gold-standard trees.
- Every time there is a choice to make, we simply look into the tree and do 'the right thing'™. (oracle)
- We collect all (configuration, transition) pairs and train a classifier on them.
- When parsing unseen sentences, we use the trained classifier as a guide.

Training a guide

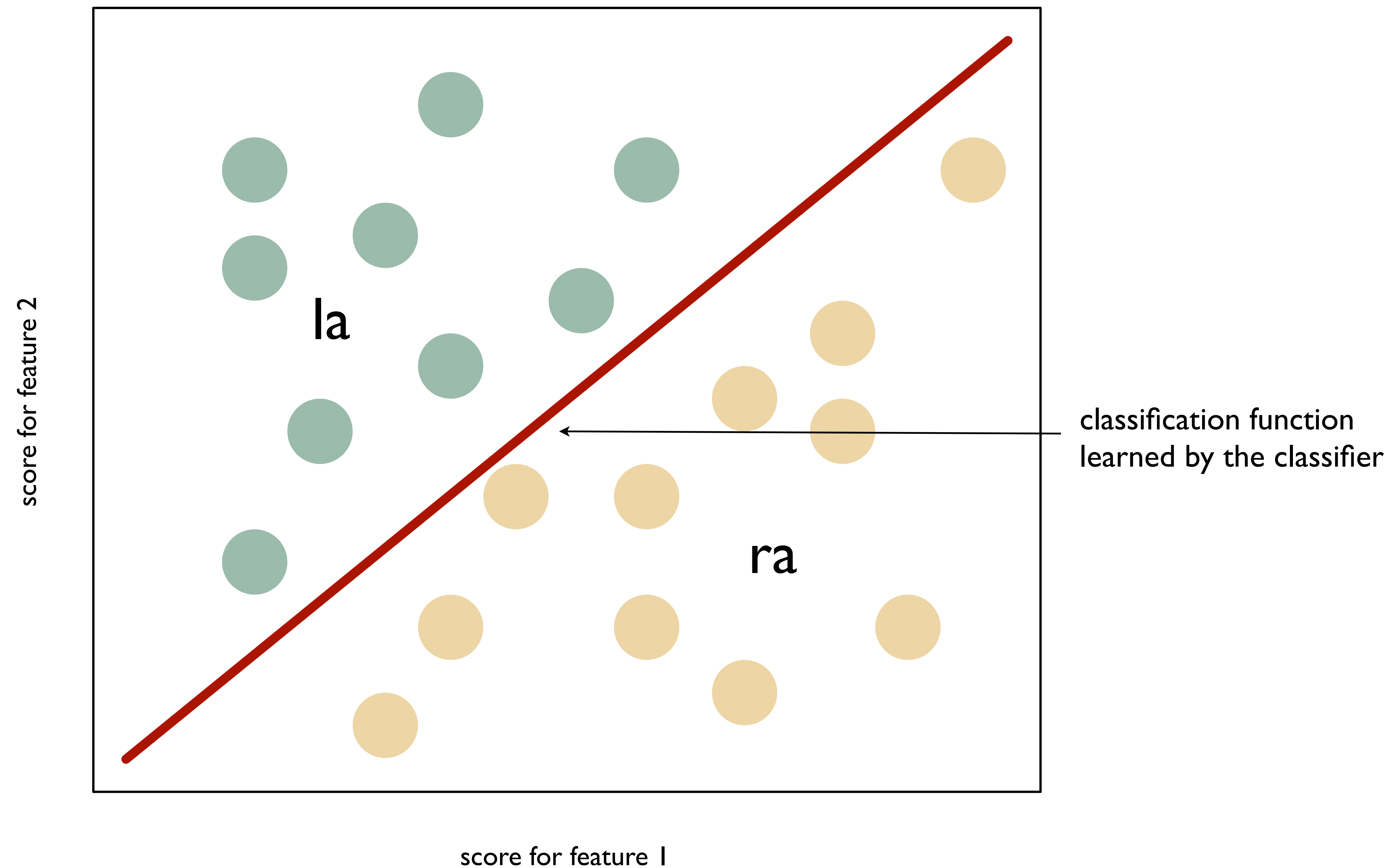
- The number of (configuration, transition) pairs is far too large.
- We define a set of features of configurations that we consider to be relevant for the task of predicting the next transition.

  Example: word forms of the topmost two words on the stack and the next two words in the buffer
- We can then describe every configuration in terms of a feature vector.

Training a guide



Training a guide



Training a guide

- In practical systems, we have thousands of features and hundreds of transitions.
- There are several machine-learning paradigms that can be used to train a guide for such a task.

  Examples: perceptron, decision trees, support-vector machines, memory-based learning, neural networks

Example features

	Attributes				
Adress	**FORM**	**LEMMA**	**POS**	**FEATS**	**DEPREL**
Stack[0]	X	X	X	X	
Stack[1]	X		X		
Ldep(Stack[0])					X
Rdep(Stack[0])					X
Buffer[0]	X	X	X	X	
Buffer[1]			X		
. . .					

- Combinations of addresses and attributes (e.g. those marked in the table)
- Other features, such as distances, number of children, ...

Training with neural networks

- Neural networks are a good fit for the classification tasks in transition-based features
- Features can, for instance, be extracted for each word from recurrent neural networks (RNN)
- RNNs represent each word partially by its context - useful for parsing!

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Alternative transition models

Alternatives

- The arc-standard model as I presented it, is just one example of a transition model
  - In the book you can see another version of the arc-standard model, where arcs are added between the topmost word on the stack and the topmost word on the buffer
- There are many other alternatives

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Arc-eager model

- Contains four transitions:
  - Shift
  - Reduce
  - Left-arc
  - Right-arc
- Advantage: not strictly bottom-up, can create arcs earlier than in the arc-standard model
- The model that master students will implement in assignment 3!

Arc-eager model - oracle

Algorithm 1 Standard oracle for arc-eager dependency parsing

if $c = (\sigma|i, j|\beta, A)$ and $(j, l, i) \in A_{\text{gold}}$ **then**
  $t \leftarrow$ LEFT-ARC$_l$
else if $c = (\sigma|i, j|\beta, A)$ and $(i, l, j) \in A_{\text{gold}}$ **then**
  $t \leftarrow$ RIGHT-ARC$_l$
else if $c = (\sigma|i, j|\beta, A)$ and $\exists k[k < i \wedge \exists l[(k, l, j) \in A_{\text{gold}} \vee (j, l, k) \in A_{\text{gold}}]]$ **then**
  $t \leftarrow$ REDUCE
else
  $t \leftarrow$ SHIFT
return t

- From Goldberg & Nivre, CoLING 2012
- A Dynamic Oracle for Arc-Eager Dependency Parsing

Transition models in Maltparser

- Nivre family
  - Arcs created between stack and buffer
    - arc-eager model
    - arc-standard (variant from course book)
- Stack family
  - Arcs between two topmost words on stack
    - arc-standard model (variant from slides)
    - models with swap transition (next lecture)
- Other families available as well

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Other alternatives

- Parsing with beam search
  - Instead of just keeping the 1-best tree, keep a beam of the k-best trees in each step
  - Requires scoring and ranking of transition sequences
  - Complexity: O(nk)

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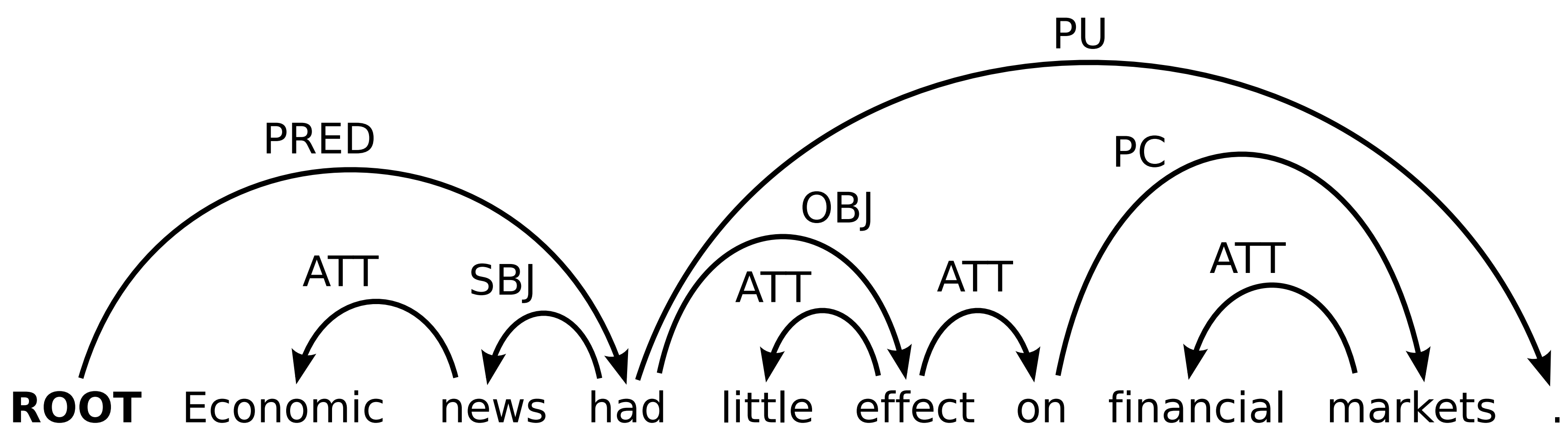
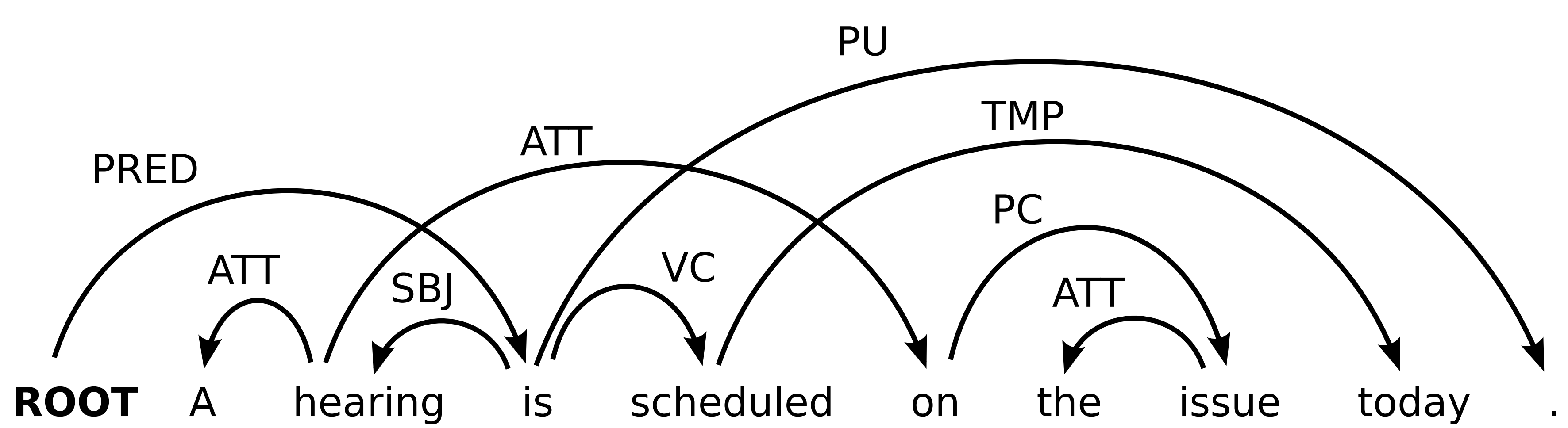
Projectivity

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





Projectivity and dependency parsing

- Many dependency parsing algorithms can only handle projective trees
  - Including all algorithms we have discussed in detail
- Non-projective trees do occur in natural language
  - How often depends on language (and treebank)

Non-projective dependency parsing

- Variants of transition-based parsing
  - Using a swap-transition (next lecture)
- Graph-based parsing
  - Minimum spanning tree algorithms
- Post processing
  - Pseudo-projective parsing (seminar 2)
  - Approximate non-projective parsing

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Summary

- In transition-based dependency parsing one does not score graphs but computations, sequences of (configuration, transition) pairs.
- In its simplest form, transition-based dependency parsing uses classification.
- One specific instance of transition-based dependency parsing is the arc-standard algorithm.

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The end of the course

- Last lecture, oracles and swap (M. de Lhoneux)
- Seminar 2, Pseudo-projective parsing
- Assignments
- Supervision on demand, mainly by email (Sara)
- Course evaluation in the student portal

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Final assignments

- Bachelors
  - Assignment 3: Disambiguation in arc-factored and transition-based parsing (Jan 12)
  - Assignment 4: Use and evaluate MaltParser (Jan 12)
- Masters:
  - Assignment 2: Summarize and discuss two research articles (Dec 18)
  - Assignment 3: Implement parts of arc-eager transition-based parser (Jan 12)
  - Project: needs to be coordinated with me ASAP! (Jan 12)