COMP5046
Natural Language Processing

Lecture 7: Dependency Parsing

Semester 1, 2019
School of Computer Science
The University of Sydney, Australia

THE UNIVERSITY OF SYDNEY

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0 LECTURE PLAN

Lecture 7: Parsing

1. **Linguistic Structure**
2. Dependency Structure
3. Dependency Parsing Algorithms
4. Transition-based Dependency Parsing
5. Deep Learning-based Dependency Parsing

What is Syntax and Parsing

- Language is ***more than just a "bag of words"?***
- Grammatical rules ***apply to categories and groups of words***, not individual words.

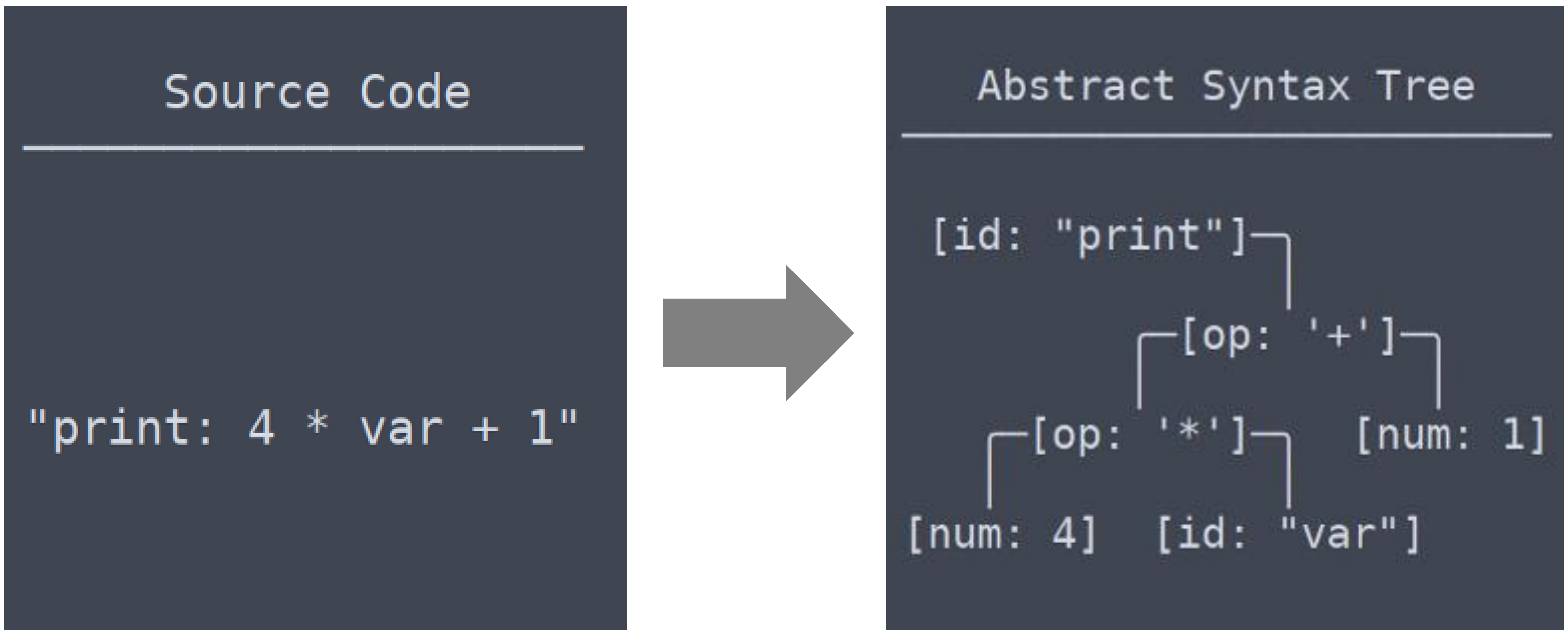
- ***Example*** – a sentence includes ***a subject*** and ***a predicate***.
  The ***subject*** is noun phrase and the ***predicate*** is a verb phrases.
  - Noun phrase: The lecture, Caren, He
  - Verb phrase: started, had dinner, went away

Parsing

- Associating tree structures to a sentence, given a grammar
  (Context Free Grammar or Dependency Grammar)

Linguistic Structure

Parsing Computer Language



1 Linguistic Structure

Parsing Natural Language (Human Language)

It is much difficult than parsing computer language

Why?

- *No **types** for words*
- *No **brackets** around phrases*
- *Ambiguity!*

Syntactic Ambiguities

Grammars are declarative

- *They don’t specify how the parse tree will be constructed*

Ambiguity

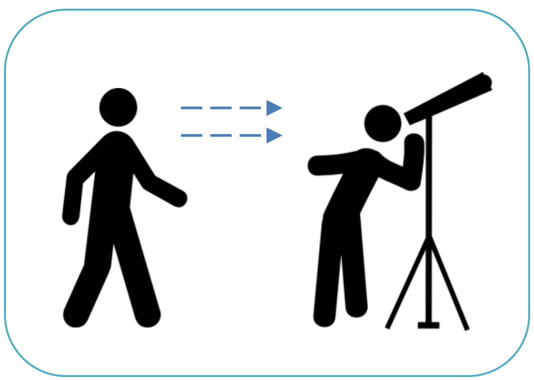
1. *Prepositional Phrase (PP) attachment ambiguity*
2. *Verb attachment ambiguity*
3. *Anaphoric Ambiguity*
4. *Coordination Scope*
5. *Particles or Prepositions*
6. *Gerund or adjective*

1 Linguistic Structure

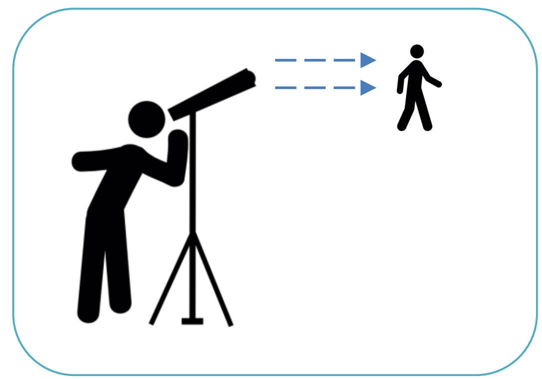
Syntactic Ambiguities – PP attachment Ambiguity

I saw the man <u>with the telescope</u>

I saw the man with the telescope

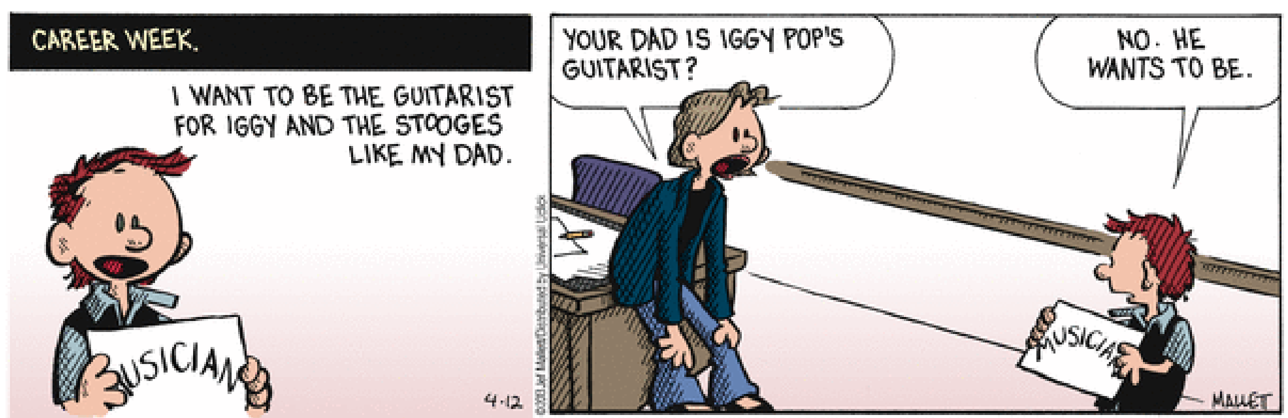


I saw the man with the telescope



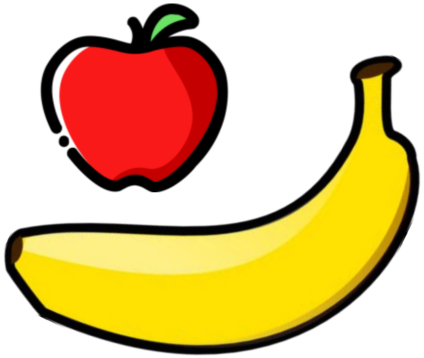
Syntactic Ambiguities – PP attachment Ambiguity Multiply

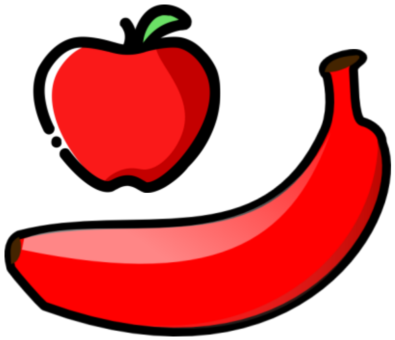
- A key parsing decision is how we 'attach' various constituents
  - *PPs, adverbial or participial phrases, infinitives, coordinations*



Syntactic Ambiguities – Coordination Scope Ambiguity

I ate red apples and bananas





1 Linguistic Structure

Syntactic Ambiguities - Gaps

She never saw a dog and did not smile

1 Linguistic Structure

Syntactic Ambiguities – Particles or Prepositions

- Some verbs are followed by adverb particles.
  (e.g. put on, take off, give away, bring up, call in)

She ran up a large bill

- *Some particles are detached from the verb and put after the object.*

He called the doctor in

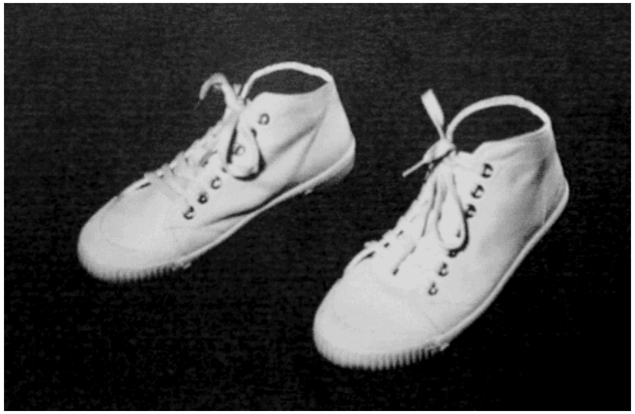
Difference between an adverb particle and a preposition.

- *the **particle** is closely tied to its verb to form idiomatic expressions*
- *the **preposition** is closely tied to the noun or pronoun it modifies.*

1 Linguistic Structure

Syntactic Ambiguities – Gerund or Adjective

***Dancing shoes** can provide nice experience*



1 Linguistic Structure

Where do we use Parsing?

***Syntactic Analysis** checks*
whether the generated tokens form a meaningful expression

- *We need to understand sentence structure in order to be able to interpret language correctly*
- *Humans communicate complex ideas by composing words together into bigger units to convey complex meanings*
- *We need to know what is connected to what*

- *Grammar Checking*
- *Question Answering*
- *Machine Translation*
- *Information Extraction*
- *Chatbot*

… and many others

1 Linguistic Structure

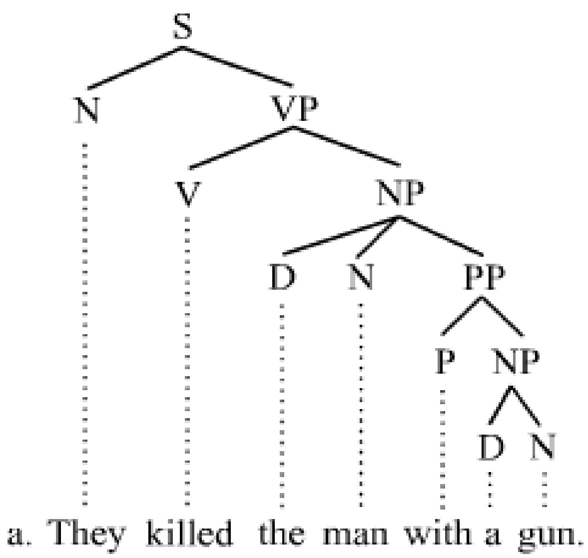
Two main views of linguistic structure

Constituency Grammar *(a.k.a context-free grammar, phrase structure grammar)*
- *Noam Chomsky (1928 -)*
- *Immediate constituent analysis*

Dependency Grammar
- *Lucien Tesniere (1893 – 1954)*
- *Functional dependency relations*

Two main views of linguistic structure

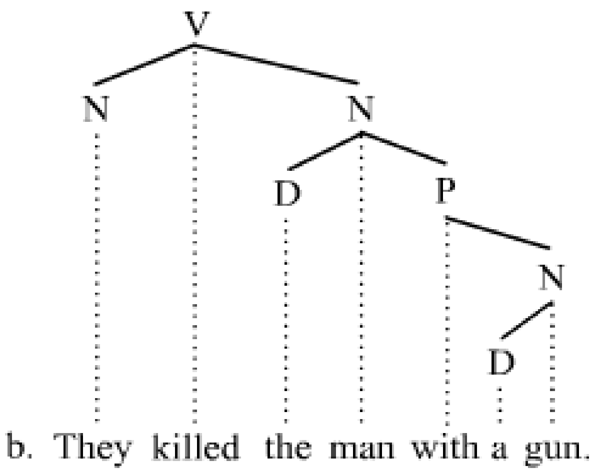
Constituency Parsing



Constituency grammars

One-to-one-or-more correspondence. For every word in a sentence, there is at least one node in the syntactic structure that corresponds to that word.

Dependency Parsing



Dependency grammars

one-to-one relation; for every word in the sentence, there is exactly one node in the syntactic structure that corresponds to that word

Constituency Grammar

- *A **basic observation about syntactic structure** is that groups of words can act as single units*
- *Such groups of words are called **constituents***
- *Constituents tend to have **similar internal structure**, and behave similarity with respect to other units*

Examples

- *noun phrases (NP)*
  - she, the house, Robin Hood and his merry men, etc.
- verb phrases (VP)
  - blushed, loves Mary, was told to sit down and be quiet, lived happily ever after
- prepositional phrases (PP)
  - on it, with the telescope, through the foggy dew, etc.

A sample context-free grammar

I prefer a morning flight

1. *Starting unit: words are **given a category (part-of-speech)***
2. *Combining words into **phrases with categories***
3. *Combining phrases into **bigger phrases** recursively*

1 Linguistic Structure

A sample context-free grammar

1. *Starting unit: words are given a category (part-of-speech)*
2. *Combining words into phrases with categories*
3. *Combining phrases into bigger phrases recursively*

I, prefer, a, morning, flight

PRP VBP DT NN NN

A sample context-free grammar

I, prefer, a, morning, flight

PRP *VBP* *DT* *NN* *NN*

Grammar rule	Example
S → NPVP	I + want a morning flight
NP → Pronoun	I
NP → Proper-Noun	Sydney
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 + Melbourne + in the morning
VP → Verb PP	leaving + on Thursday
PP → Preposition NP	from + Sydney

A sample context-free grammar

1. *Starting unit: words are given a category (part-of-speech)*
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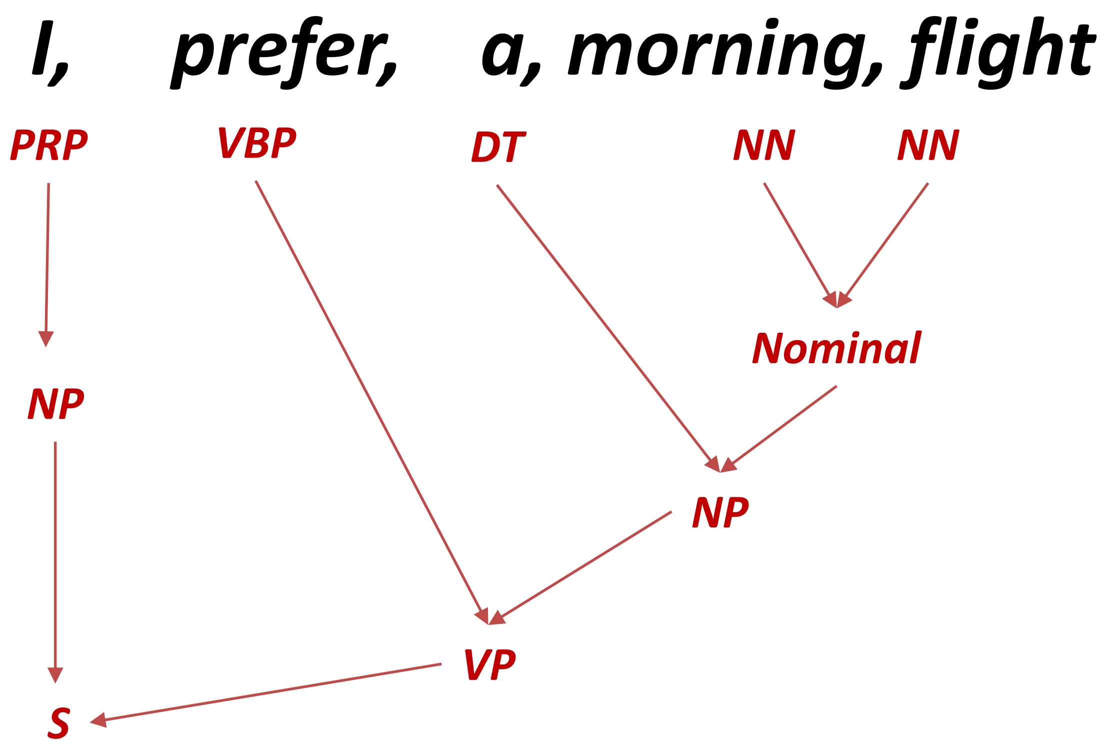
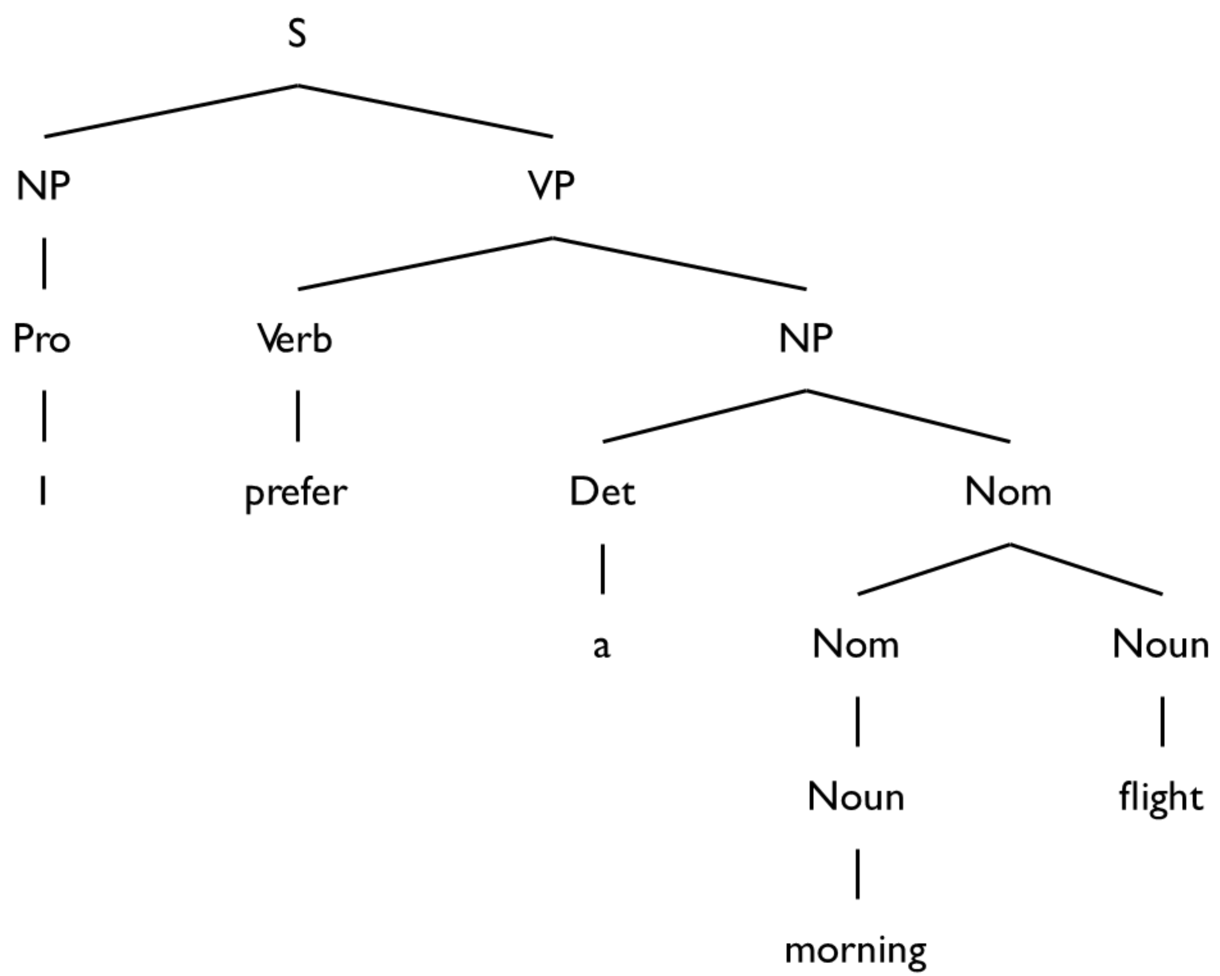
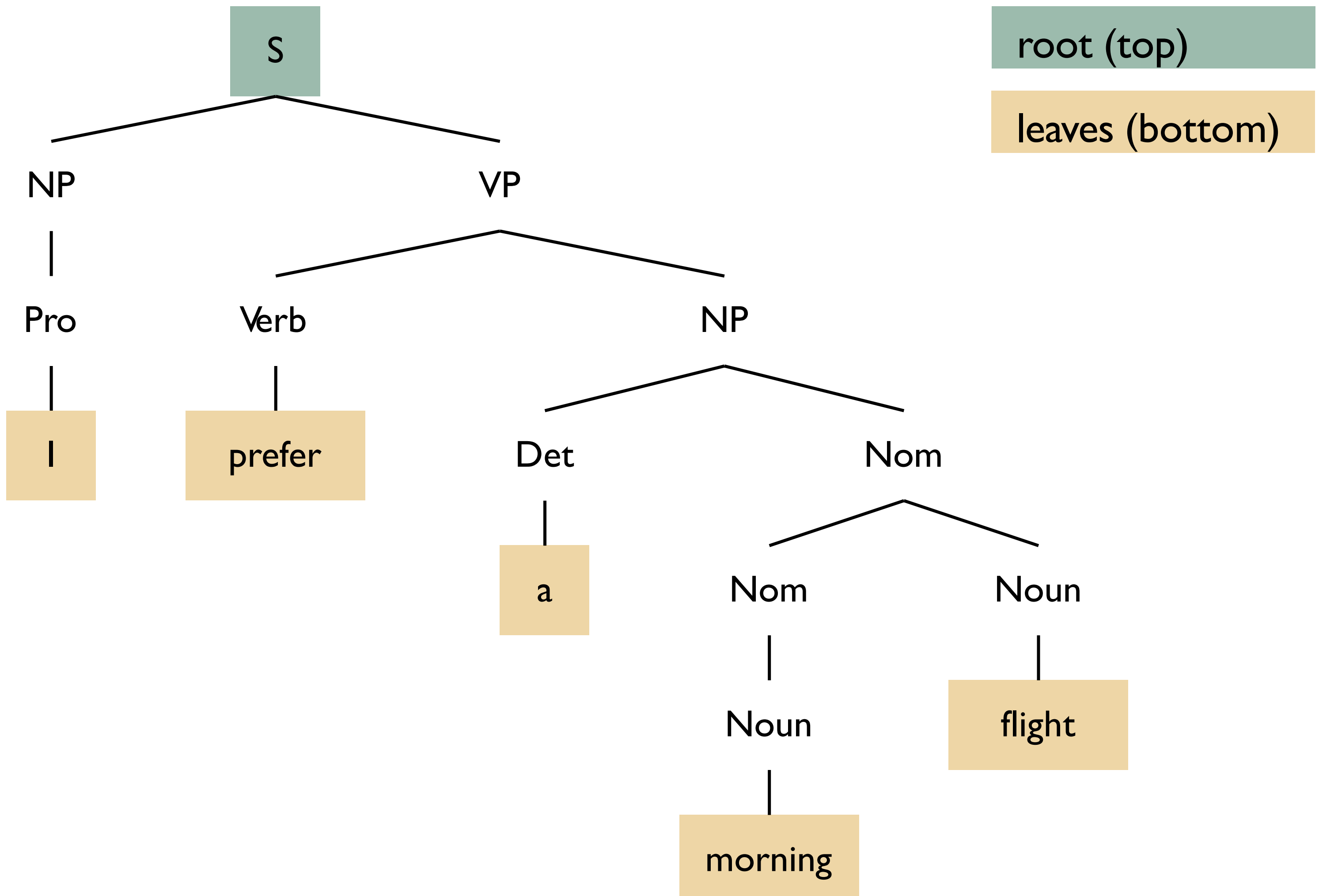


A sample context-free grammar



1 Linguistic Structure

A sample context-free grammar



Treebanks

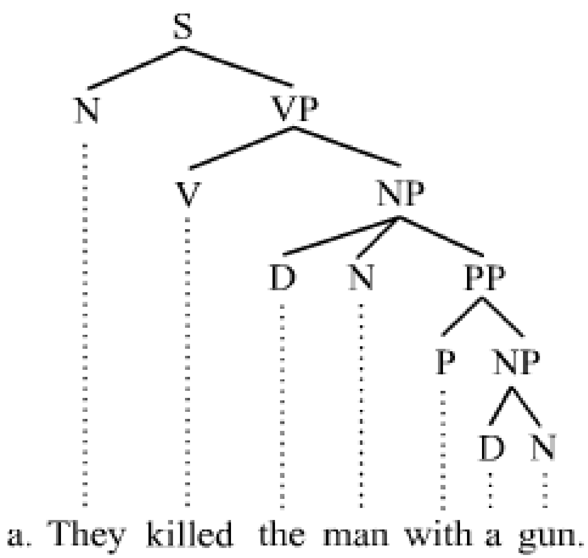
Corpora where each sentence is annotated with a parse tree

- *Treebanks are generally created by*
  - *parsing texts with an existing parser*
  - *having human annotators correct the result*
- *This requires detailed annotation guidelines for annotating different grammatical constructions*
- *Penn Treebank is a popular treebank for English (Wall Street Journal section)*

```
( (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) )))
    (. .) ))
```

Two main views of linguistic structure

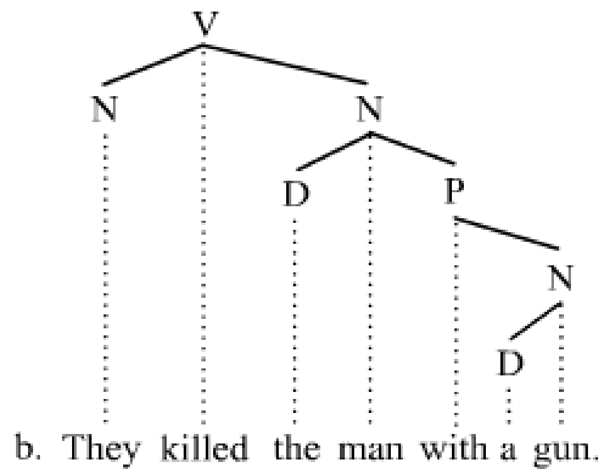
Constituency Parsing



Constituency grammars

One-to-one-or-more correspondence. For every word in a sentence, there is at least one node in the syntactic structure that corresponds to that word.

Dependency Parsing



Dependency grammars

one-to-one relation; for every word in the sentence, there is exactly one node in the syntactic structure that corresponds to that word

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Dependency Structure

Syntactic structure*: lexical items linked by binary asymmetrical relations (“arrows”) called* ***dependencies***

compound

Red ***Hat***

modifier *head*

Red – **modifier**, dependent, child, subordinate

Hat - **head**, governor, parent, regent

Compound – **dependency relations** (e.g. subject, prepositional object, etc)

**Head* *determines the syntactic/semantic category of the construct*

The arrows are commonly typed with the name of* ***grammatical relations*

2 Dependency Structure

Dependency Relations

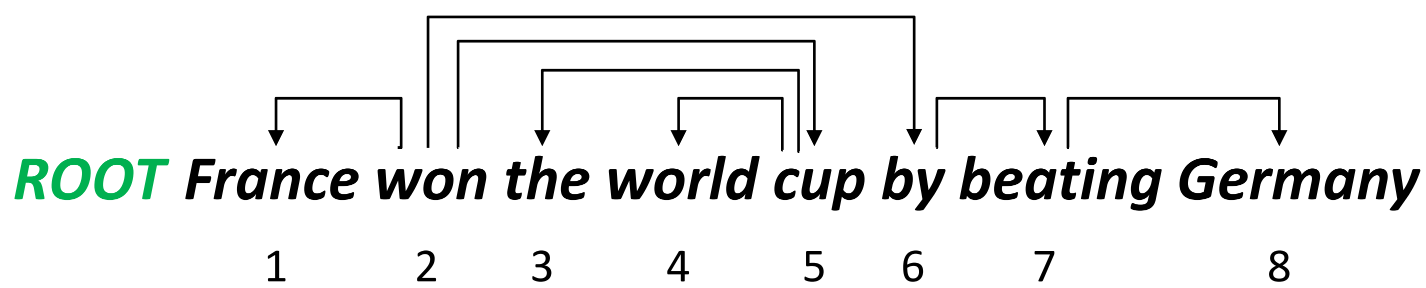
*The following list shows the 37 universal **syntactic relations** used in UD v2. (de Marneffe et al. 2014).*

- acl: clausal modifier of noun (adjectival clause)
- advcl: adverbial clause modifier
- advmod: adverbial modifier
- amod: adjectival modifier
- appos: appositional modifier
- aux: auxiliary
- case: case marking
- cc: coordinating conjunction
- ccomp: clausal complement
- clf: classifier
- compound: compound
- conj: conjunct
- cop: copula
- csubj: clausal subject
- dep: unspecified dependency
- det: determiner
- discourse: discourse element
- dislocated: dislocated elements
- expl: expletive
- fixed: fixed multiword expression
- flat: flat multiword expression
- goeswith: goes with
- iobj: indirect object
- list: list
- mark: marker
- nmod: nominal modifier
- nsubj: nominal subject
- nummod: numeric modifier
- obj: object
- obl: oblique nominal
- orphan: orphan
- parataxis: parataxis
- punct: punctuation
- reparandum: overridden disfluency
- root: root
- vocative: vocative
- xcomp: open clausal complement

Universal Dependency Relations: *http://universaldependencies.org/u/dep/index.html*

Dependency Structure

Example



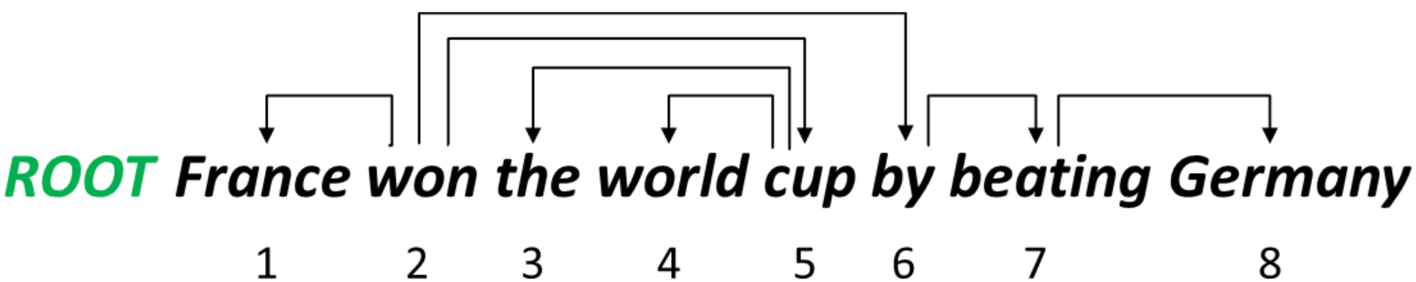
2 Dependency Structure

Dependency Parsing

- Represents Lexical/syntactic dependencies between words
  - A sentence is parsed by choosing for each word what other word (including ROOT) is it a dependent of

Dependencies form a tree (connected, acyclic, single-head)

- ***How to make the dependencies a tree - Constraints***
  - Only one word is a dependent of ROOT (the main predicate of a sentence)
  - Don’t want cycles A → B, B → A



Dependency Grammar/Parsing History

Panini's grammar (4th century BCE)
The notion of dependencies between grammatical units

Ibn Maḍāʾ (12th century)
The first grammarian to use the term dependency in the grammatical sense

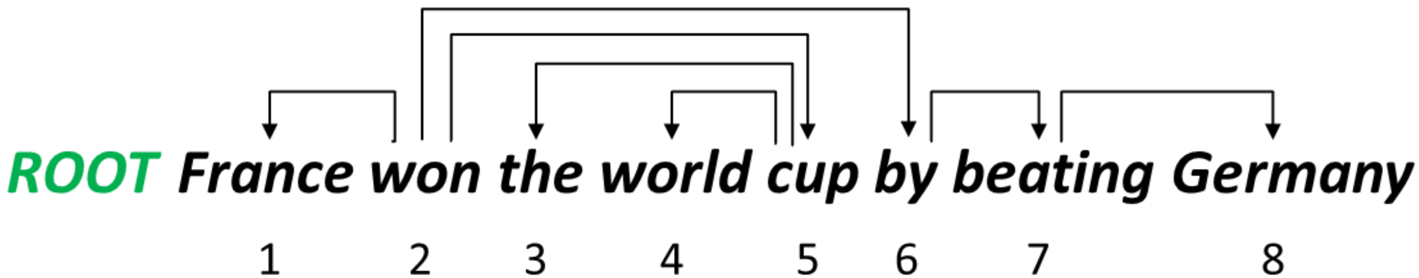
Sámuel Brassai, Franz Kern, Heimann Hariton Tiktin (1800 - 1930)
The dependency seems to have coexisted side by side with that of phrase structure

Lucien Tesnière (1959)
Was dominant approach in "East" in 20th Century (Russia, China, …)
Good for free-er word order languages

David Hays (1962)
The great development surrounding dependency-based theories has come from computational linguistics

2 Dependency Structure

Dependency Grammar/Parsing



Some people draw the arrows one way; some the other way!

- *Tesnière had them point from head to dependent…*

Usually add a fake ROOT so every word is a dependent of precisely 1 other node

Projectivity vs Non-Projectivity

- There are no crossing dependency arcs when the words are laid out in their linear order, with all arcs above the words
- Dependencies parallel to a CFG tree must be projective
  - Forming dependencies by taking 1 child of each category as head
- But dependency theory normally does allow non-projective structures to account for displaced constituents

Dependency Structure

The rise of annotated data

- The idea of dependency structure goes back a long way
- *[Universal Dependencies: http://universaldependencies.org/ ;*
- *cf. Marcus et al. 1993, The Penn Treebank, Computational Linguistics]*

- Starting off, building a treebank seems a lot slower and less useful than building a grammar

- But a treebank gives us many things
  - Reusability of the labor
    - Many parsers, part-of-speech taggers, etc. can be built on it
    - Valuable resource for linguistics
  - Broad coverage, not just a few intuitions
  - Frequencies and distributional information
  - A way to evaluate systems

2 Dependency Structure

Dependency Conditioning Preferences

What are the sources of information for dependency parsing?

- Bilexical affinities
- Dependency distance
- Intervening material
- Valency of heads

2 Dependency Structure

Dependency Parsing

Exercise – Let's do it together!

- Simpler to parse than context-free grammars

ROOT ***I prefer the morning flight through Sydney***

ROOT ***Unionised workers are usually better paid than their non-union counterparts***

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Lecture 7: Parsing

1. Linguistic Structure
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3 Dependency Parsing Approaches

Methods of Dependency Parsing

- Dynamic programming

  Eisner (1996) gives a clever algorithm with complexity O(n3), by producing parse items with heads at the ends rather than in the middle
- Constraint Satisfaction

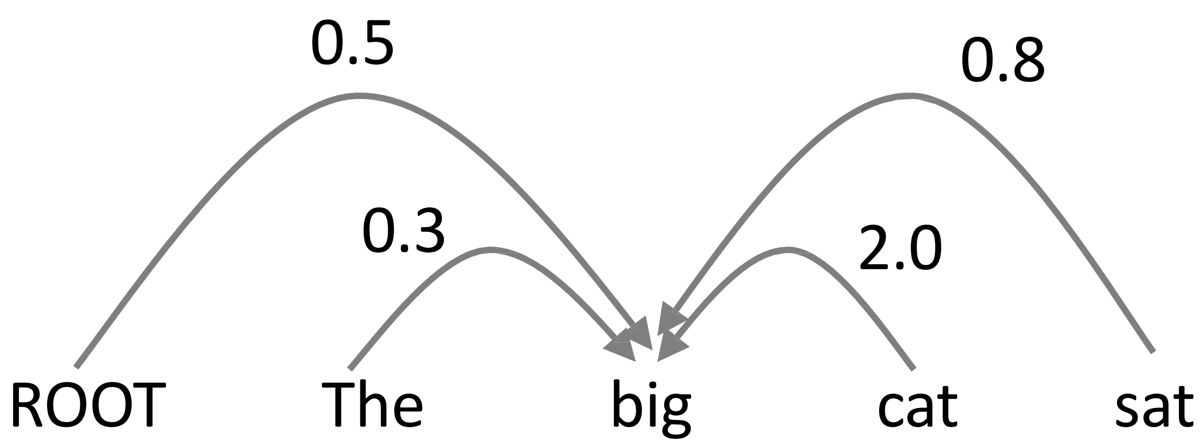
  Edges are eliminated that don't satisfy hard constraints. Karlsson (1990)
- ***Graph-based Dependency Parsing***

  Create a ***Minimum Spanning Tree*** for a sentence
  McDonald et al.'s (2005) MSTParser scores dependencies independently using an Machine Learning classifier
- ***Transition-based Dependency Parsing***
- ***Neural Network-based Dependency Parsing***

3 Dependency Parsing Approaches

Graph-based dependency parsers

- Compute a score for every possible dependency for each edge

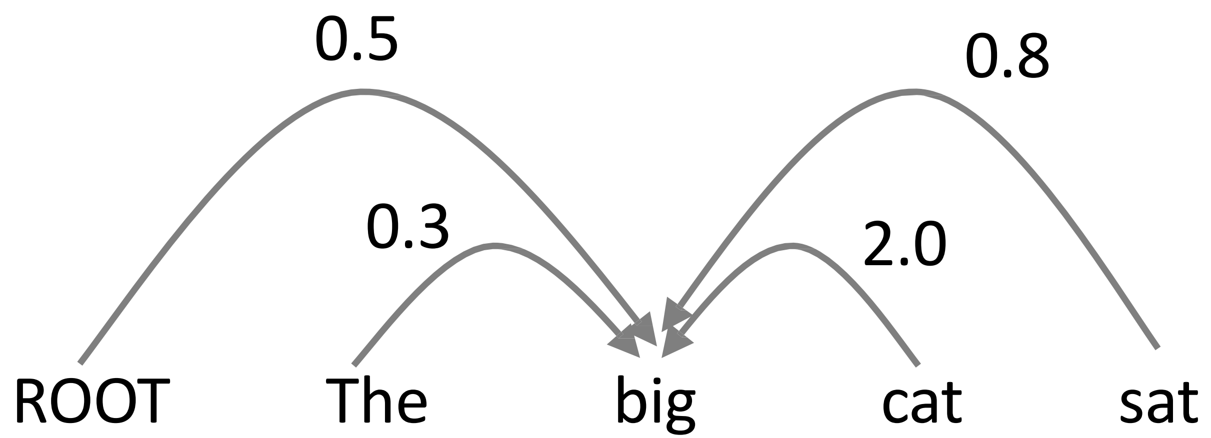


e.g., picking the head for “big”

3 Dependency Parsing Approaches

Graph-based dependency parsers

- Compute a score for every possible dependency for each edge
  - Then add an edge from each word to its highest-scoring candidate head
  - And repeat the same process for each other word



e.g., picking the head for “big”

3 Dependency Parsing Approaches

Methods of Dependency Parsing

greedy algorithm

Graph-based Dependency Parsing	***Transaction-based Dependency Parsing***
• Non-deterministic dependency parsing • Build a complete graph with directed/weighted edges • Find the highest scoring tree from a complete dependency graph	• Deterministic dependency parsing • Build a tree by applying a sequence of transition actions • Find the highest scoring action sequence that builds a legal tree

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Transition-based Parsing

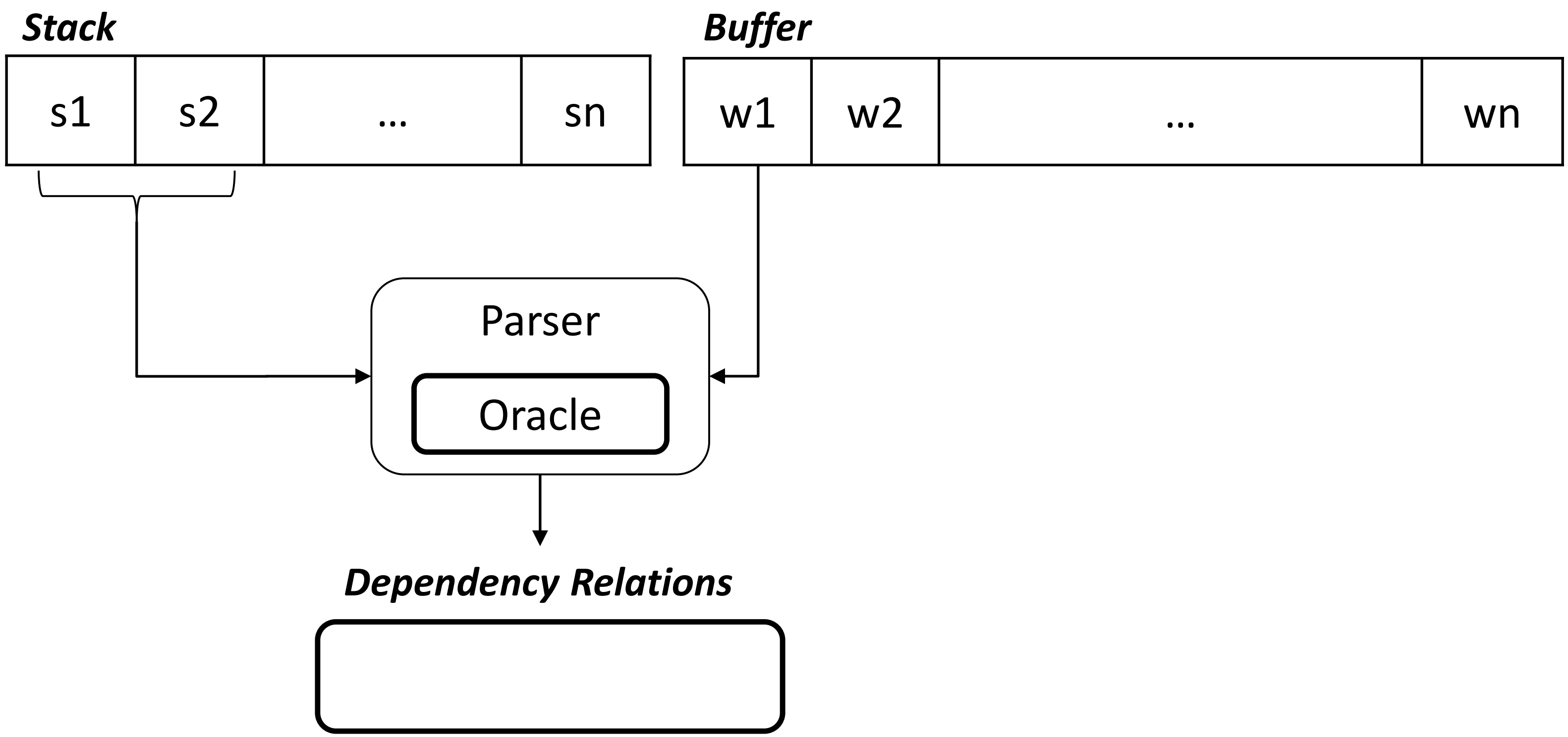
Greedy transition-based parsing

- A simple form of greedy discriminative dependency parser
- Design a dumber but really fast algorithm and let the machine learning do the rest.

- Eisner's algorithm (Dynamic Programming-based Dependency Parsing) 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

4 Transition-based Parsing

Greedy transition-based parsing



Transition-based parsing – The arc-standard algorithm

- The arc-standard algorithm is a simple algorithm for transition-based dependency parsing.
- A sequence of bottom up actions
  - Roughly like “shift” or “reduce” in a shift-reduce parser, but the “reduce” actions are specialized to create dependencies with head on left or right
- It is implemented in most practical transition- based dependency parsers, including MaltParser.

4 Transition-based Parsing

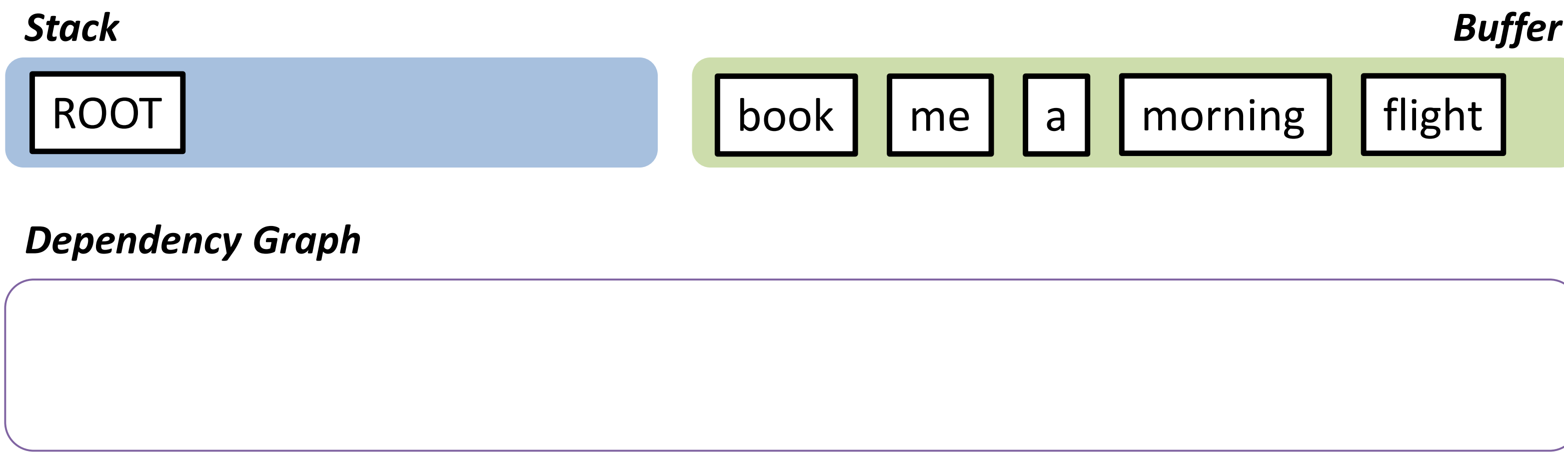
Transition-based parsing – The arc-standard algorithm

Stack

Buffer

Dependency Graph

Transition-based parsing – The arc-standard algorithm



- ***Initial configuration:***
  - All words are in the buffer.
  - The stack is empty or starts with the ROOT symbol
  - The dependency graph is empty.

Transition-based Parsing

Transition-based parsing – The arc-standard algorithm

Stack

ROOT

Buffer

book | me | a | morning | flight

Dependency Graph

Possible Transaction

Shift

- ***Push*** *the next word in buffer onto the stack*

Left-Arc

- *Add an arc* ***from the topmost word to the 2nd-topmost word*** *on the stack*
- *Remove 2nd word from stack*

Right-Arc

- *Add an arc* ***from the 2nd-topmost word to the topmost word*** *on the stack*
- *Remove the topmost word from stack*

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Transition-based parsing – The arc-standard algorithm

ROOT cannot have incoming arc

Stack

ROOT

Buffer

book me a morning flight

Dependency Graph

Possible Transaction

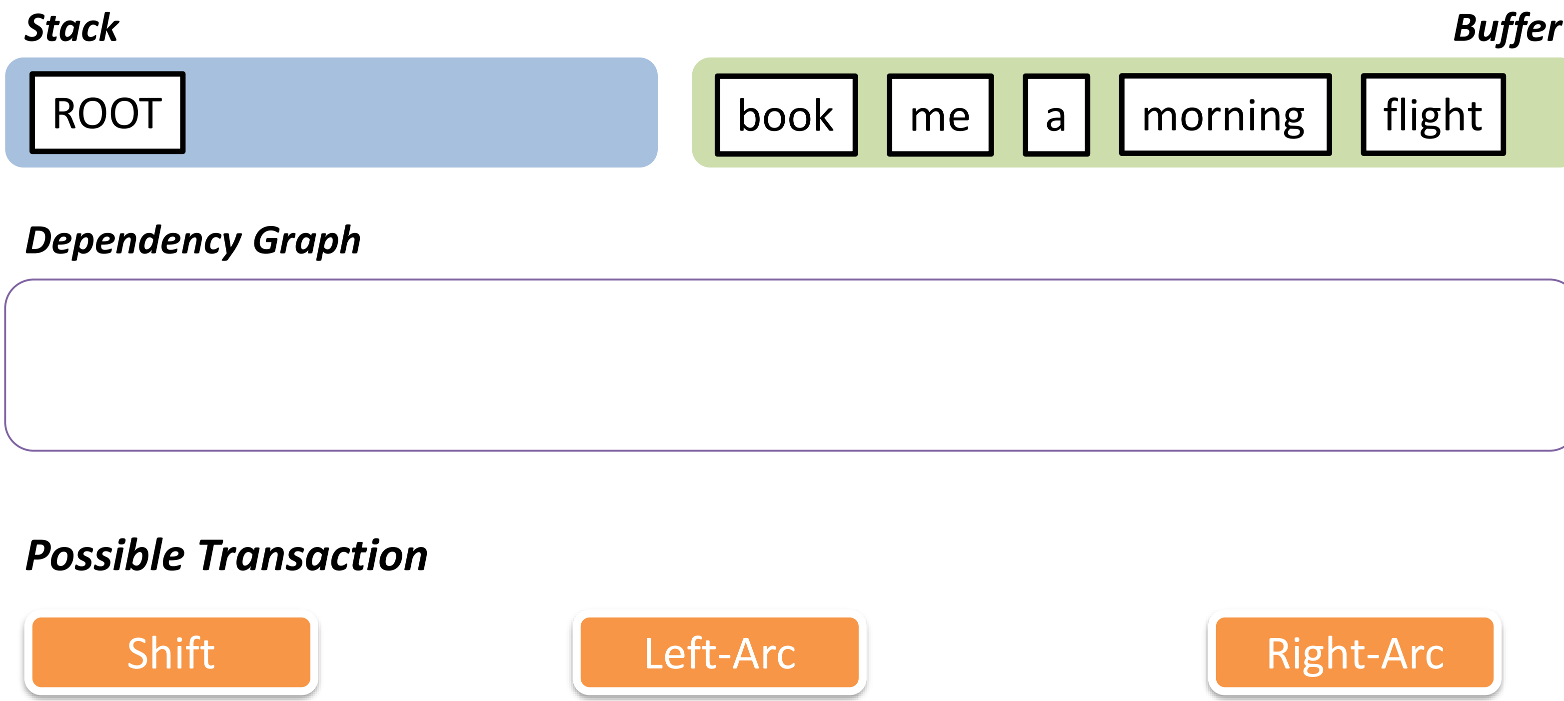
Shift

Left-Arc

Right-Arc

Left Arc and Right Arc require 2 elements in stack to be applied

Transition-based parsing – The arc-standard algorithm



4 Transition-based Parsing

Transition-based parsing – The arc-standard algorithm

Stack

ROOT | book

Buffer

me | a | morning | flight

Dependency Graph

Possible Transaction

Shift

Left-Arc

Right-Arc

4 Transition-based Parsing

Transition-based parsing – The arc-standard algorithm

Stack

ROOT | book | me

Buffer

a | morning | flight

Dependency Graph

Possible Transaction

Shift

Left-Arc

Right-Arc

Transition-based parsing – The arc-standard algorithm

Stack

ROOT | book | me

Buffer

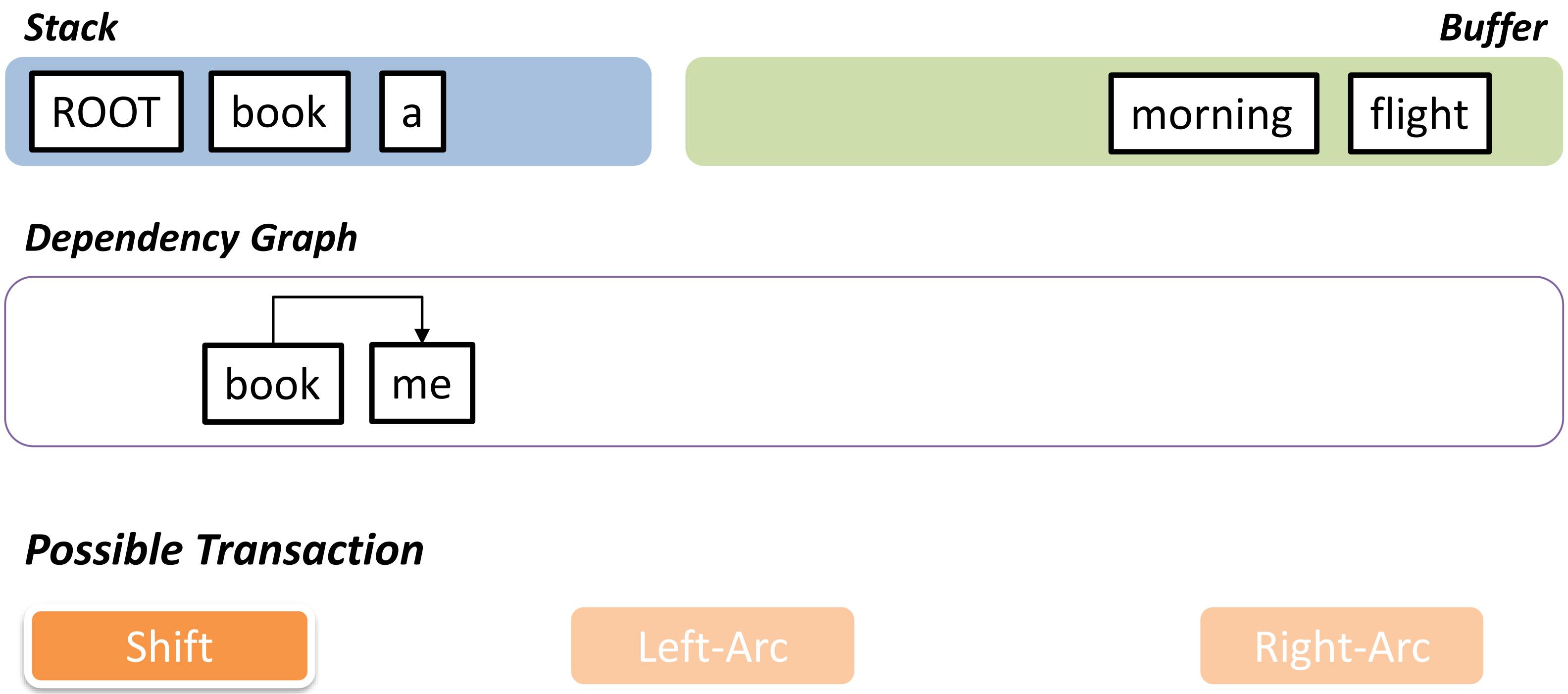
a | morning | flight

Dependency Graph

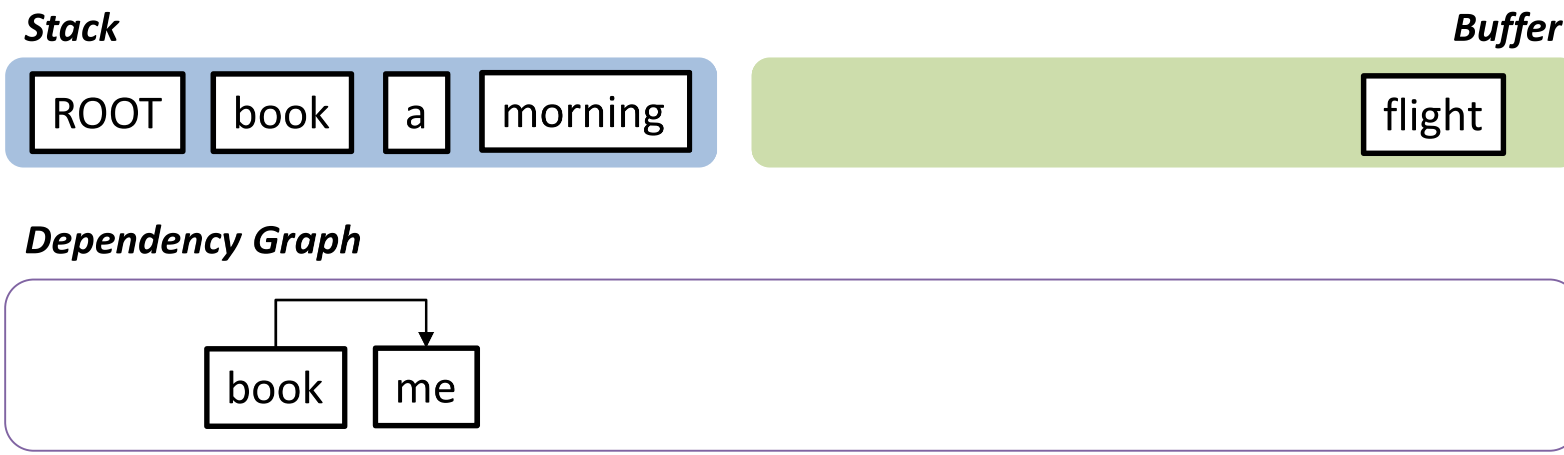
Possible Transaction

Shift   Left-Arc   **Right-Arc**

Transition-based parsing – The arc-standard algorithm



Transition-based parsing – The arc-standard algorithm



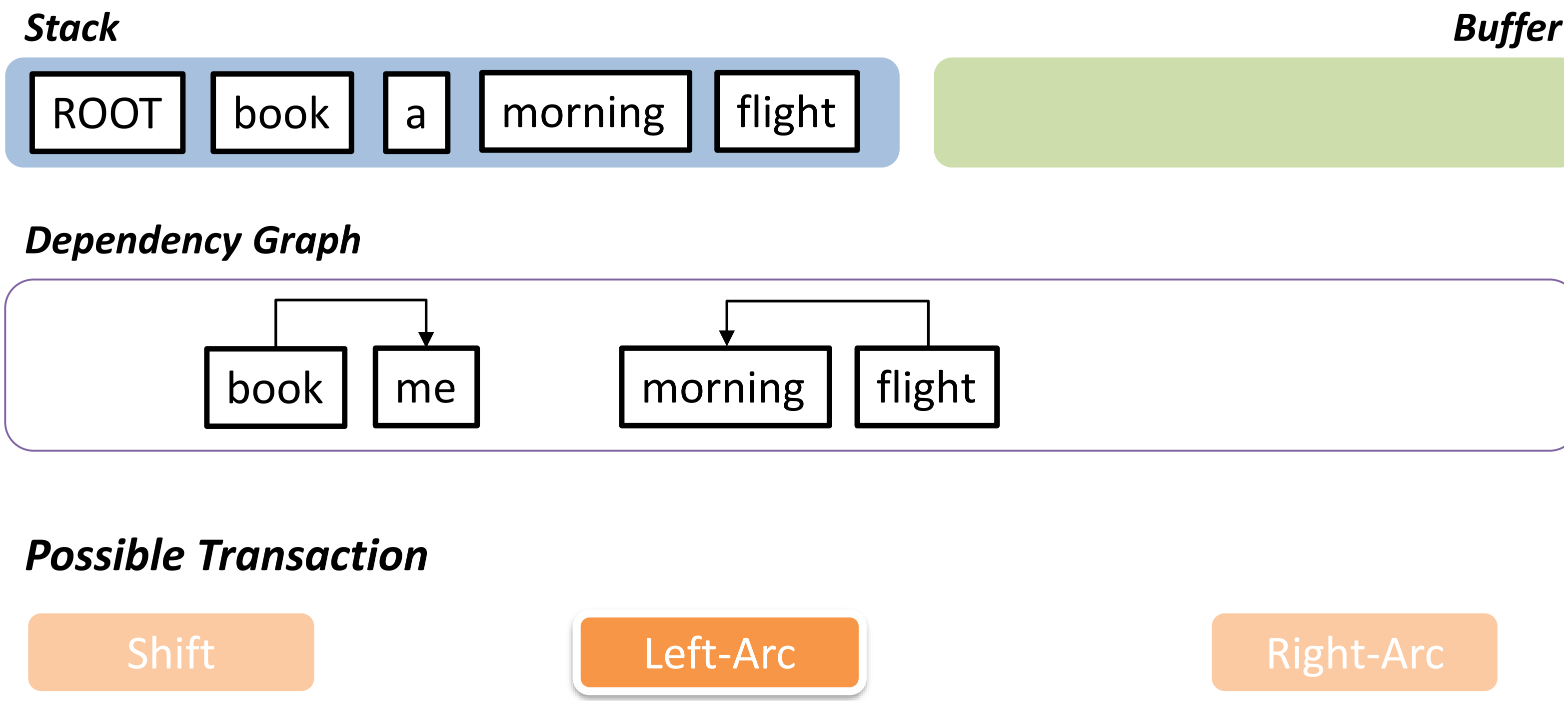
Possible Transaction

Shift

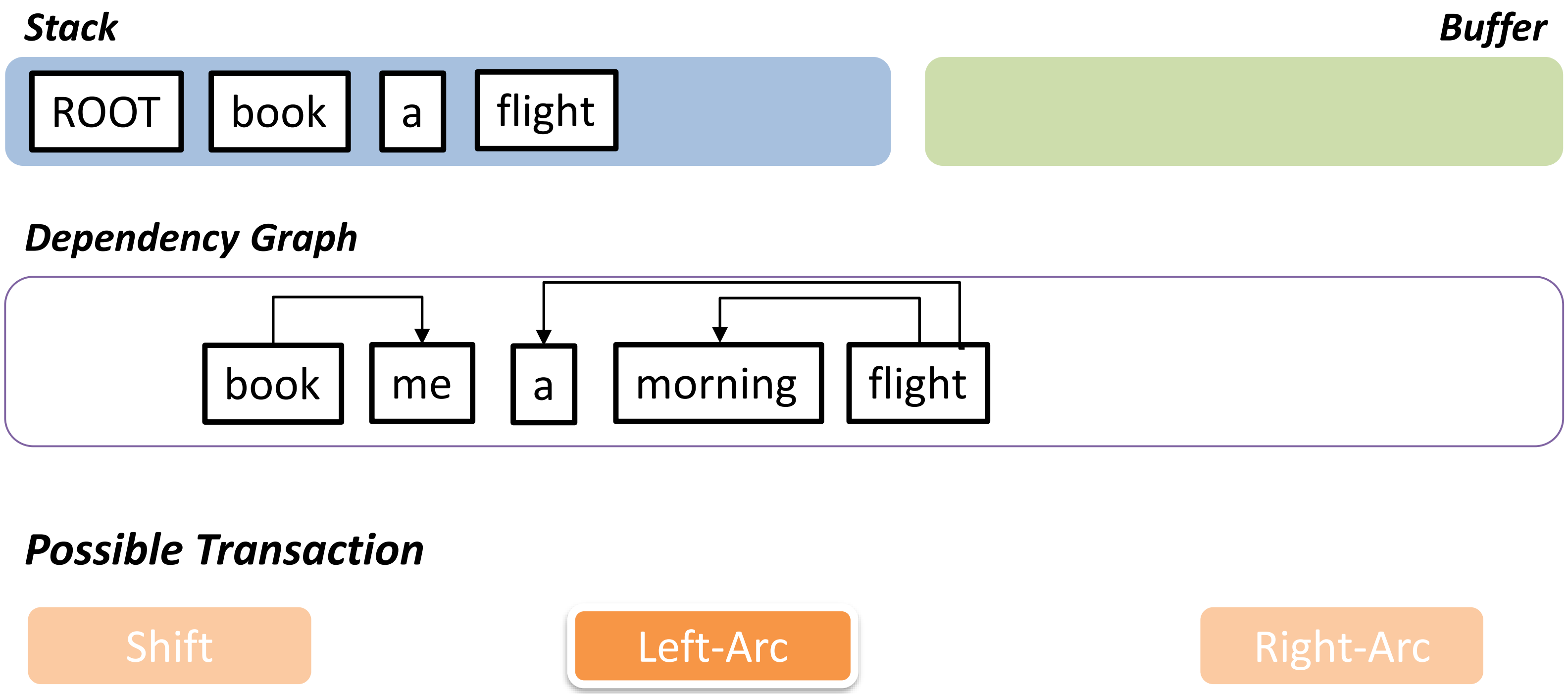
Left-Arc

Right-Arc

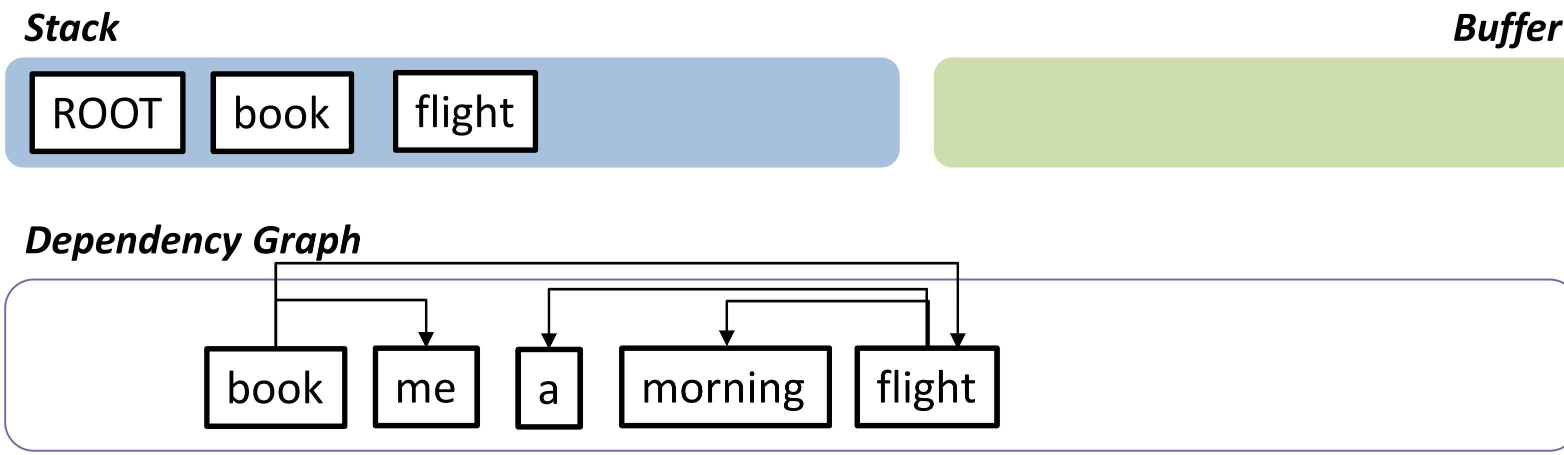
Transition-based parsing – The arc-standard algorithm



Transition-based parsing – The arc-standard algorithm



Transition-based parsing – The arc-standard algorithm



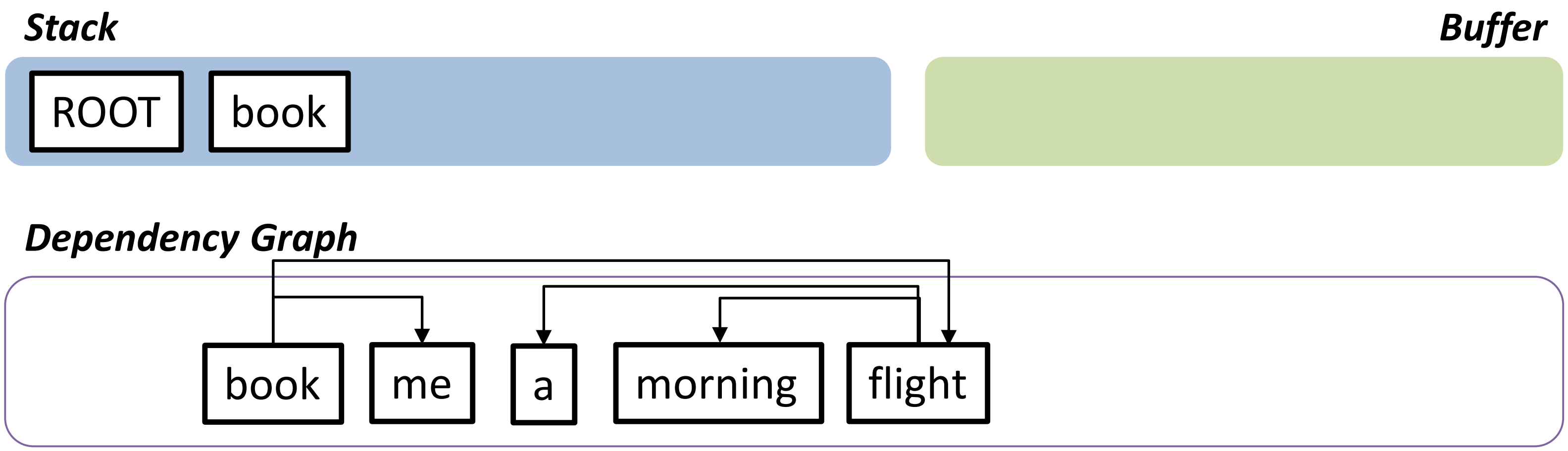
Possible Transaction

Shift

Left-Arc

Right-Arc

Transition-based parsing – The arc-standard algorithm



Possible Transaction

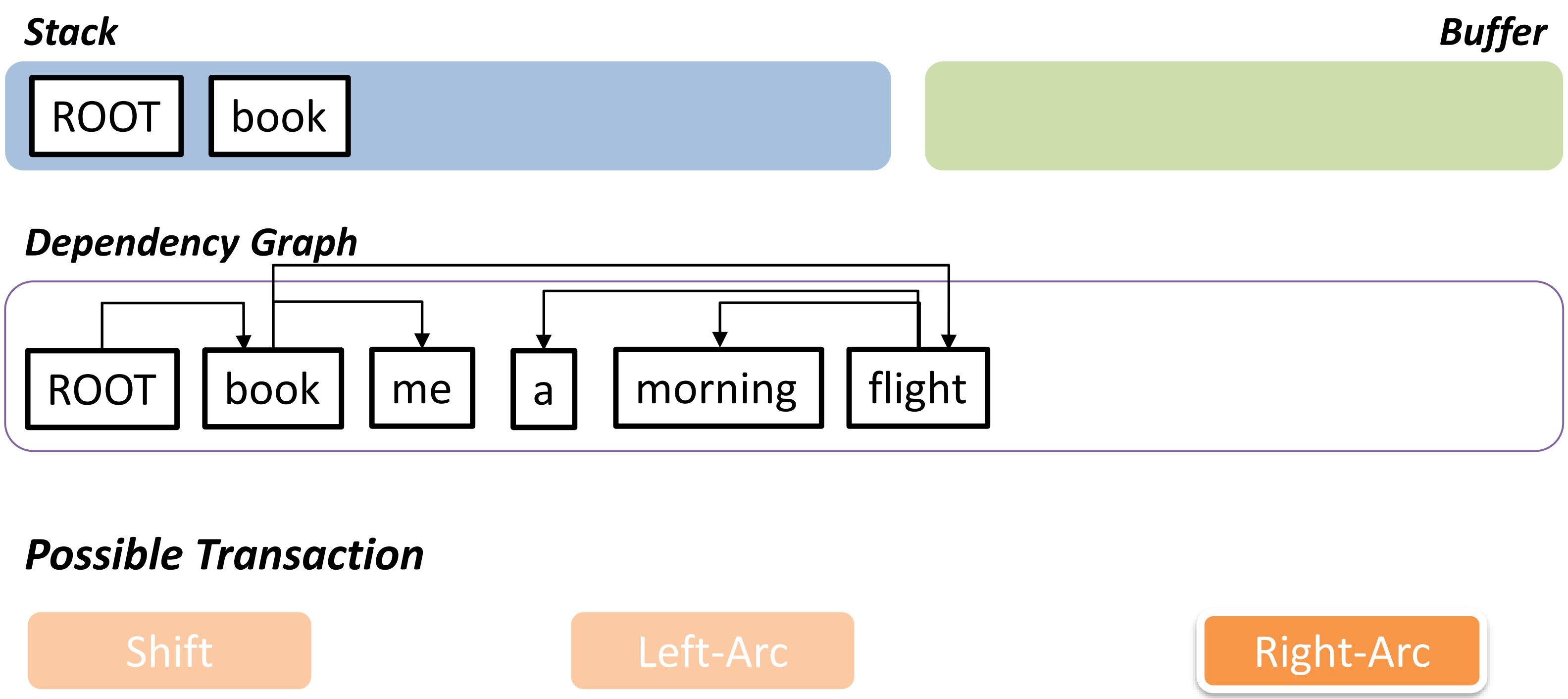
Shift

Left-Arc

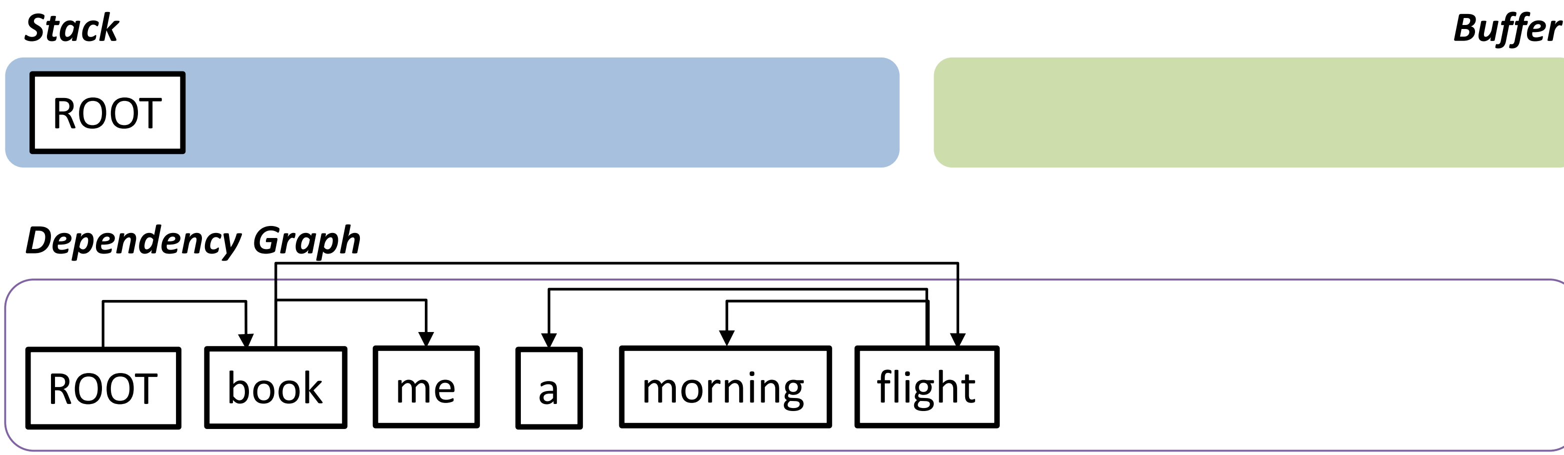
Right-Arc

4 Transition-based Parsing

Transition-based parsing – The arc-standard algorithm



Transition-based parsing – The arc-standard algorithm



- ***Terminal configuration:***
  - The buffer is empty.
  - The stack contains a single word.

Transition-based parsing – The arc-standard algorithm

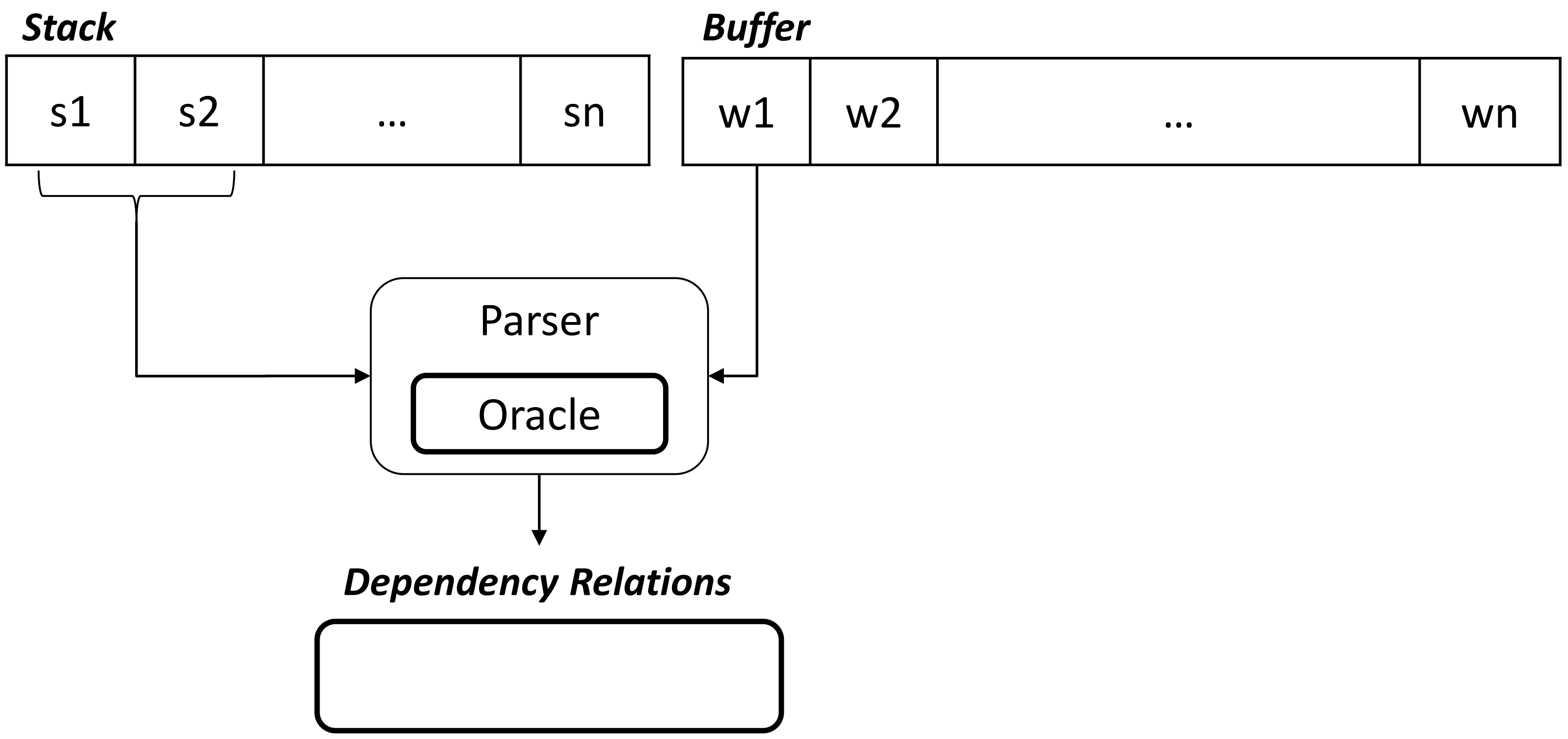
Start: σ = [ROOT], $\beta = w_1, \ldots, w_n$, A = Ø

1. Shift $\sigma, w_i|\beta, A \rightarrow \sigma|w_i, \beta, A$
2. Left-Arc$_r$ $\sigma|w_i|w_j, \beta, A \rightarrow \sigma|w_j, \beta, A \cup \{r(w_j, w_i)\}$ $\sigma|w_i|w_j, \beta, A \rightarrow$
3. Right-Arc$_r$ $\sigma|w_i, \beta, A \cup \{r(w_i, w_j)\}$

Finish: $\sigma = [w]$, β = Ø

How to choose the next action?

Transition-based Parsing



Transition-based Parsing

How to choose the next action?

Stand back, You know machine learning!
Goal: Predict the next transition (class), given the current configuration.

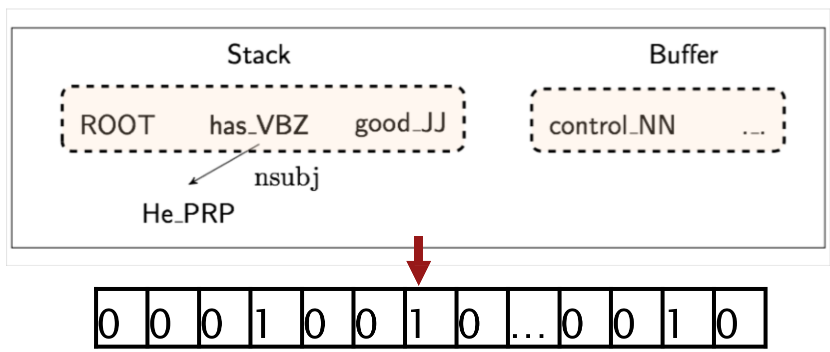
- We let the parser run on gold-standard trees.
- Every time there is a choice to make, we simply look into the tree and do 'the right thing'.
- We collect all (configuration, transition) pairs and train a classifier on them.
- When parsing unseen sentences, we use the trained classifier as a guide.

What if the number of pairs is far too large?

4 Transition-based Parsing

Feature Representation

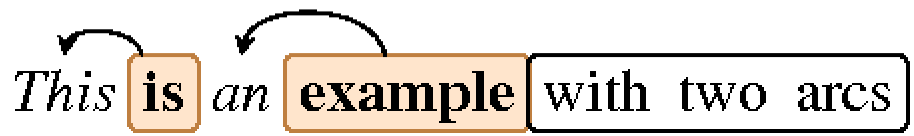
- Define a set of features of configurations that you consider to be relevant for the task of predicting the next transition.
- Example: word forms of the topmost two words on the stack and the next two words in the buffer
- Describe every configuration in terms of a feature vector.



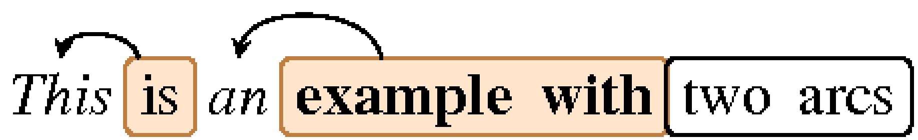
- In practical systems, we have thousands of features and hundreds of transitions.
- There are several machine-learning paradigms that can be used to train a guide for such a task
- Examples: perceptron, decision trees, support-vector machines, memory-based learning

4 Transition-based Parsing

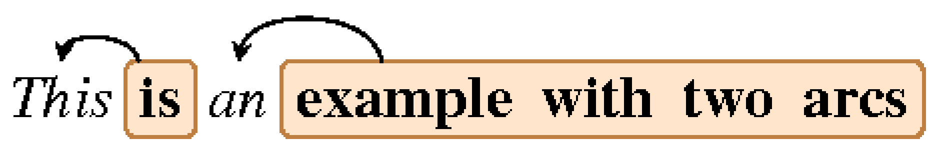
Transition-based parsing



(a) Arc-standard: *is* and *example* are eligible for arcs.



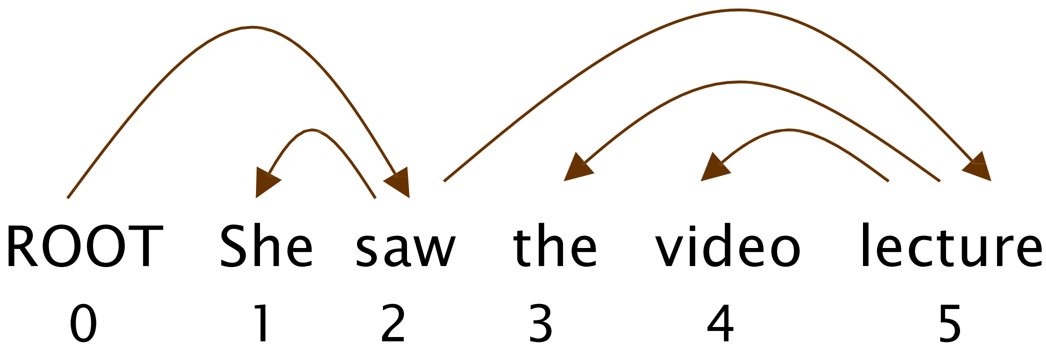
(b) Arc-eager: *example* and *with* are eligible for arcs.



(c) Easy-first: All unreduced tokens are active (bolded).

4 Transition-based Parsing

Evaluation of Dependency Parsing



$$\text{Acc} = \frac{\text{\# correct deps}}{\text{\# of deps}}$$

UAS = 4 / 5 = 80%

LAS = 2 / 5 = 40%

Gold

1	2	She	nsubj
2	0	saw	root
3	5	the	det
4	5	video	nn
5	2	lecture	obj

Parsed

1	2	She	nsubj
2	0	saw	root
3	4	the	det
4	5	video	nsubj
5	2	lecture	ccomp

0

LECTURE PLAN

Lecture 7: Parsing

1. Linguistic Structure
2. Dependency Structure
3. Dependency Parsing Algorithms
4. Transition-based Dependency Parsing
5. **Deep Learning-based Dependency Parsing**

5

Deep Learning-based Parsing

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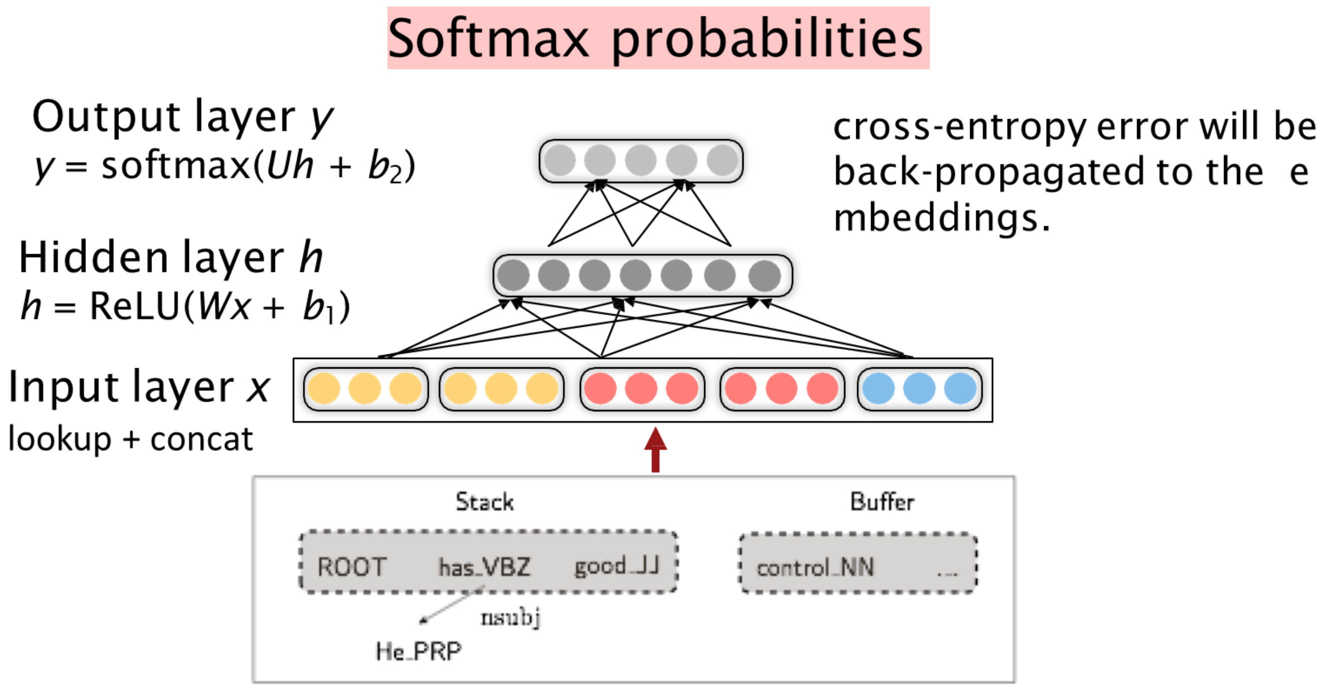
Distributed Representations

- Represent each word as a d-dimensional dense vector (i.e., word embedding)
  - Similar words are expected to have close vectors.
  - NNS (plural noun) should be close to NN (singular noguon).

- Meanwhile, part-of-speech tags (POS) and dependency labels are also represented as d-dimensional vectors.
- The smaller discrete sets also exhibit many semantical similarities

Distributed Representations



Neural Network Dependency Parsing

Accuracy and parsing speed on PTB + Stanford dependencies.

Parser	Dev		Test		Speed
	UAS	LAS	UAS	LAS	(sent/s)
standard	90.2	87.8	89.4	87.3	26
eager	89.8	87.4	89.6	87.4	34
Malt:sp	89.8	87.2	89.3	86.9	469
Malt:eager	89.6	86.9	89.4	86.8	448
MSTParser	91.4	88.1	90.7	87.6	10
Our parser	**92.0**	**89.7**	**91.8**	**89.6**	**654**

Accuracy and parsing speed on CTB

Parser	Dev		Test		Speed
	UAS	LAS	UAS	LAS	(sent/s)
standard	82.4	80.9	82.7	81.2	72
eager	81.1	79.7	80.3	78.7	80
Malt:sp	82.4	80.5	82.4	80.6	420
Malt:eager	81.2	79.3	80.2	78.4	393
MSTParser	**84.0**	82.1	83.0	81.2	6
Our parser	**84.0**	**82.4**	**83.9**	**82.4**	**936**

Chen, D., & Manning, C. (2014). A fast and accurate dependency parser using neural networks. In Proceedings of the 2014 conference on empirical methods in natural language processing (EMNLP) (pp. 740-750).

- *PTB: English Penn Treebank*
- *CTB: Chinese Penn Treebank*

/ Final Exercise

Thank you !

Any questions ?

/ Reference

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- Rao, D., & McMahan, B. (2019). Natural Language Processing with PyTorch: Build Intelligent Language Applications Using Deep Learning. " O'Reilly Media, Inc.".
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