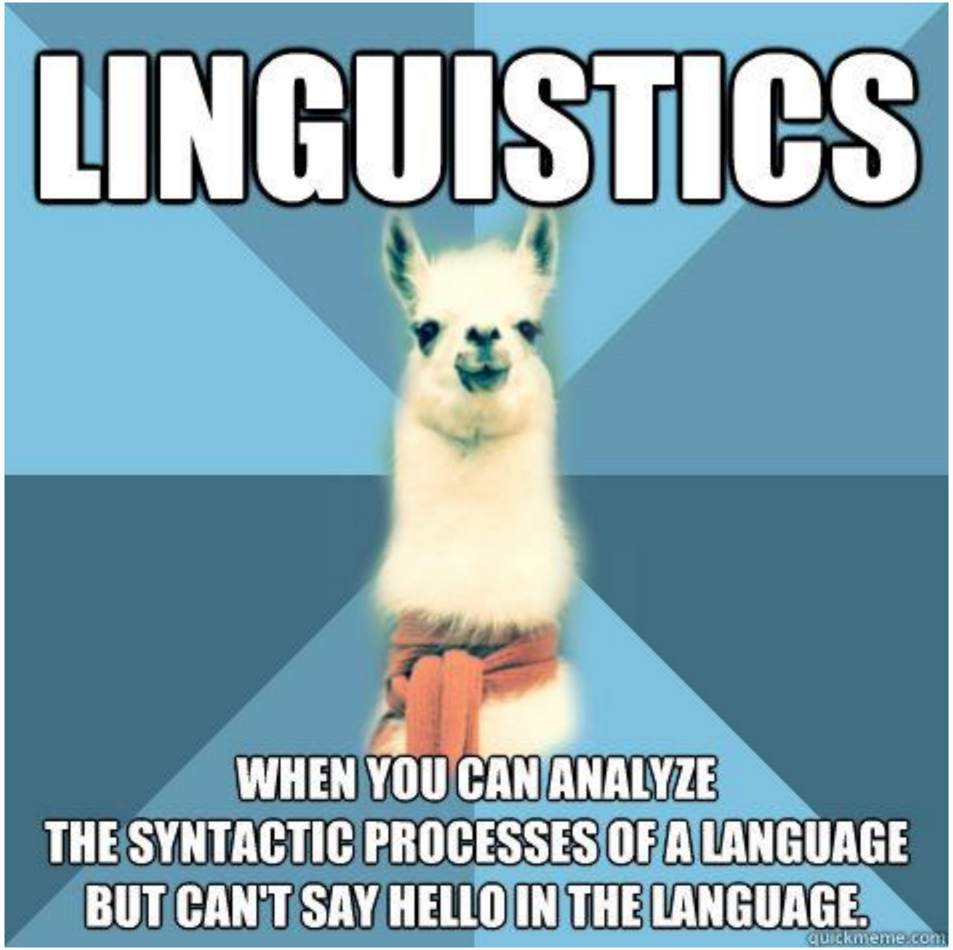

LINGUISTICS
WHEN YOU CAN ANALYZE
THE SYNTACTIC PROCESSES OF A LANGUAGE
BUT CAN'T SAY HELLO IN THE LANGUAGE.
quickmeme.com

Source:
http://www.quickmeme.com/meme/tbt

CS 2731
Introduction to Natural Language Processing

Session 22: Dependency parsing

Michael Miller Yoder

November 10, 2025

University of Pittsburgh | School of Computing and Information

Course logistics: project

- Project progress report **due this Thu Nov 13**
- Part 1: Task and dataset
  - Address the questions on basic dataset statistics, as well as how you will use your dataset to address your task
  - If you do not have a “traditional” dataset, present rough equivalents
- Part 2: Some kind of a result
  - Options: Baseline system evaluation on your dataset, a result from your own system, an example output from your system
- Part 3: Open questions and challenges
  - Need any help or additional resources?
- Check class OpenAI API usage here, updated weekly by Michael

Course logistics: homework

- Homework 4 is **due next Thu Nov 20**
  - More Hugging Face, this time BERT-based models for part-of-speech tagging

Review: What is the input and output format of sequence labeling tasks?

Overview: Dependency parsing

- What is syntax?
- Dependency grammar
  - Kinds of dependency in English
  - Dependencies and semantic roles
  - Dependency treebanks
- Dependency parsing
  - Transition-based dependency parsing
  - Projectivity
  - Evaluation
  - Tools and resources

What is syntax and why is it useful?

Syntax is Sentence and Phrase Structure

- Syntax concerns the patterns according to which words are combined to form phrases and sentences.
- It is distinct from morphology (how morphemes combine to form words) and semantics (what sentences mean) but is related to both.
- *Colorless green ideas sleep furiously.*

Slide credit: David Mortensen

Syntax is the Door to Semantics

- To arrive at a semantic interpretation of a sentence, you have to know its syntax
- Parallel with programming languages
    - Semantics different from syntax (form versus function)
    - But semantics follows from syntax

Slide credit: David Mortensen

Who Did What to Whom?

If you want to know who did what to whom with what thing having what properties, you must have access to syntax in some form.

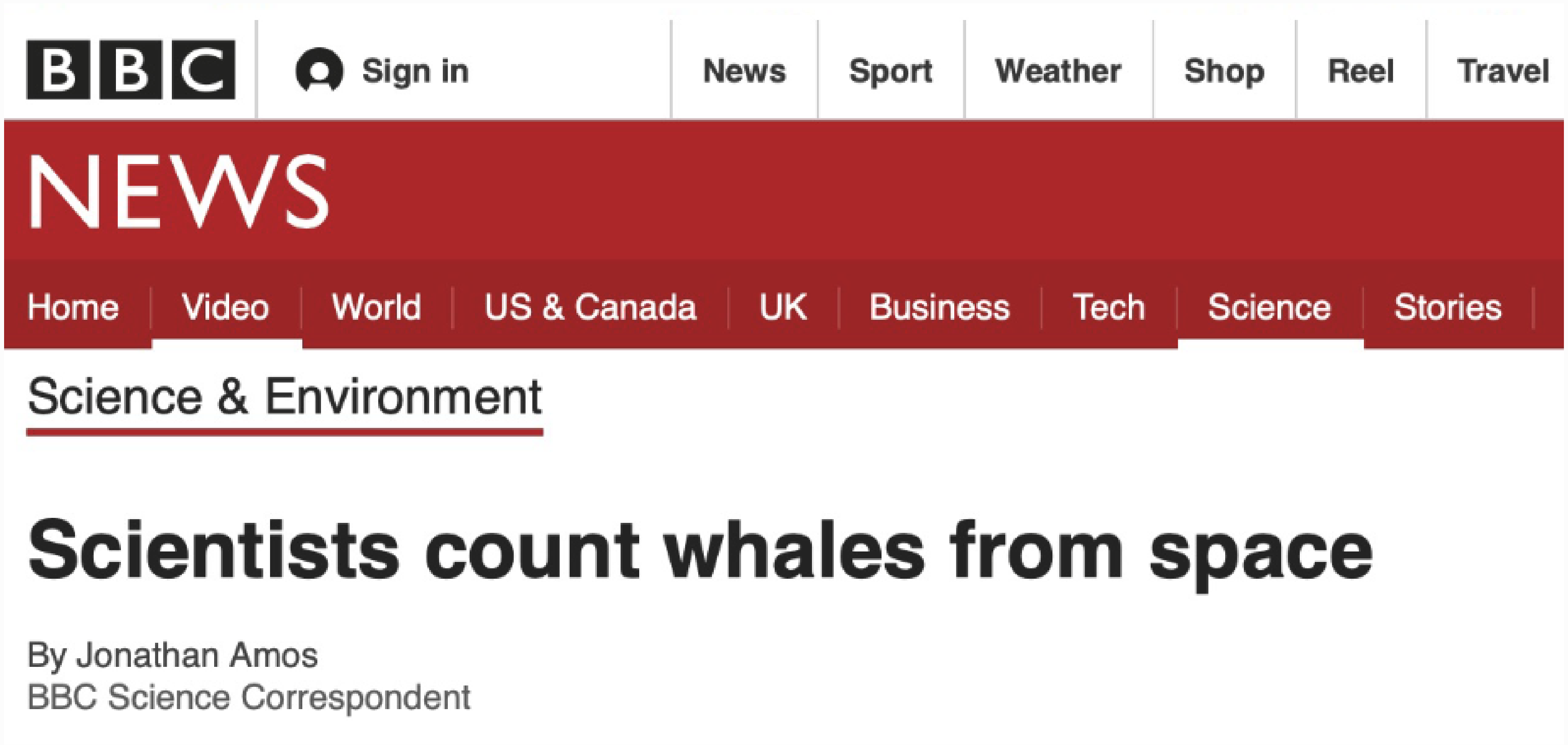
Slide credit: David Mortensen

Why do we need sentence structure (syntax)?

- Humans communicate complex ideas by composing words together into bigger units to convey complex meanings
- Human listeners need to work out what modifies (attaches to) what
- A model needs to understand sentence structure in order to be able to interpret language correctly
- Sometimes syntax can be ambiguous!

Slide adapted from Chris Manning

Ambiguity: prepositional phrase attachment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Science & Environment

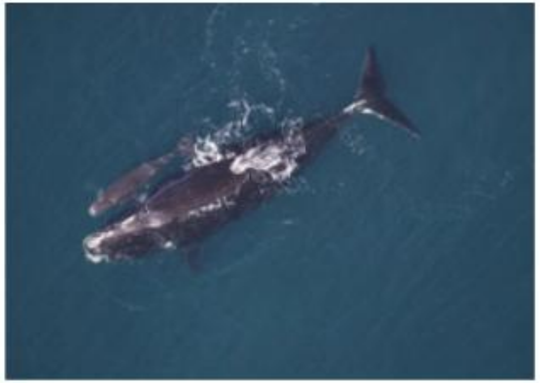
Scientists count whales from space

By Jonathan Amos
BBC Science Correspondent

Slide adapted from Chris Manning

Ambiguity: prepositional phrase attachment

Scientists count whales from space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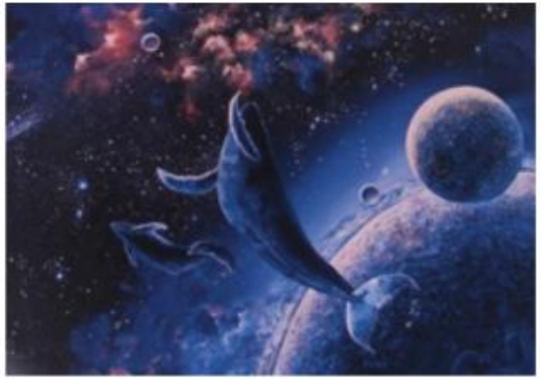
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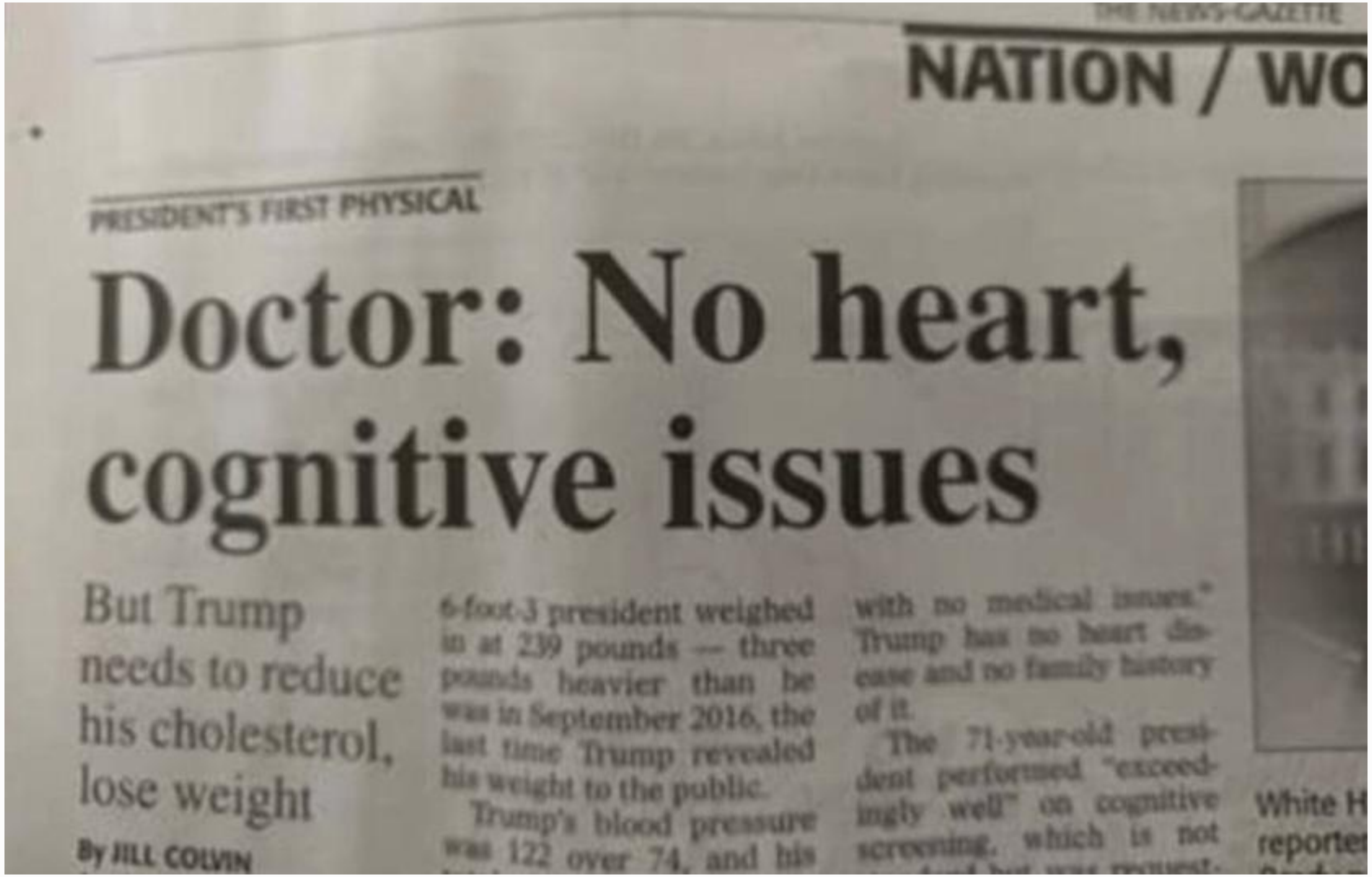
Slide adapted from Chris Manning

Ambiguity: coordination scope



THE NEWS-GAZETTE

NATION / WO

PRESIDENT'S FIRST PHYSICAL

Doctor: No heart, cognitive issues

But Trump needs to reduce his cholesterol, lose weight

By JILL COLVIN

6-foot-3 president weighed in at 239 pounds — three pounds heavier than he was in September 2016, the last time Trump revealed his weight to the public.

Trump's blood pressure was 122 over 74, and his

with no medical issues." Trump has no heart disease and no family history of it.

The 71-year-old president performed "exceedingly well" on cognitive screening, which is not

White H
reporte

Slide adapted from Chris Manning

Different perspectives on syntax

There are Two Major Approaches to Syntax in NLP

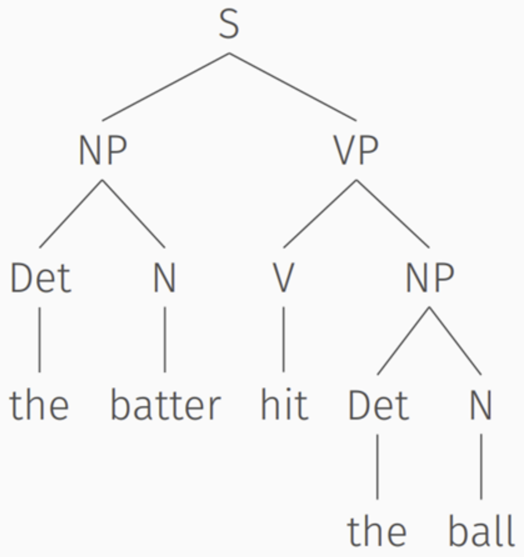
Two approaches:

- Syntax means taking sentences, dividing them into phrases and dividing those phrases into smaller phases until you arrive at individual words, yielding a tree of “constitutents”
- Syntax means taking sentences and characterizing the relationships between pairs of words in the sentence, yielding a tree or graph of “heads” and “dependents”

Slide credit: David Mortensen

Phrase Structure Grammar is also Called Constituency Grammar

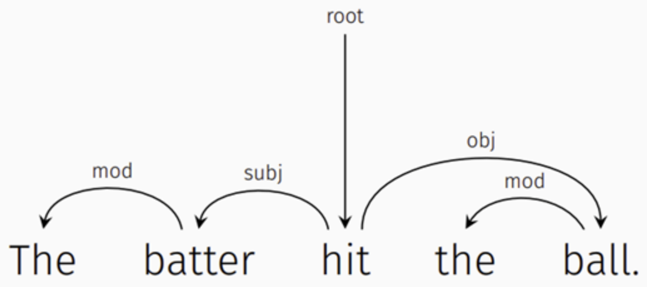
- The first approach is called PHRASE STRUCTURE GRAMMAR or CONSTITUENCY GRAMMAR.
- Basic unit — constituent
- Used by the parsers in the interpreters/compilers of most programming languages



Slide credit: David Mortensen

Dependency Grammar Is Based On Bilexical Dependencies

- The second approach is called DEPENDENCY GRAMMAR.
- Basic element — BILEXICAL DEPENDENCY
- Especially useful for many contemporary NLP tasks



Slide credit: David Mortensen

Dependency grammar

Words Relate to Other Words

Words relate to other words:

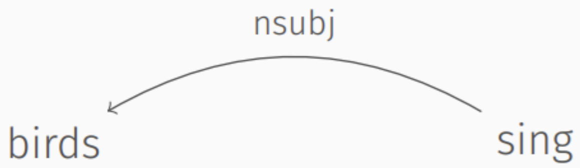
- Nouns can be subjects or objects of verbs
- Adjectives can be modifiers of nouns
- Adverbs can be modifiers of verbs, adjectives, and other adverbs

Dependency grammar seeks to capture these relations (subject, obect, modifier, etc.)

Slide credit: David Mortensen

The Bilexical Dependency is the Basic Unit of Dependency Grammar

The basic unit in dependency grammar is a bilexical dependency, a “link” between two words: a head (governor) and a dependent



Slide credit: David Mortensen

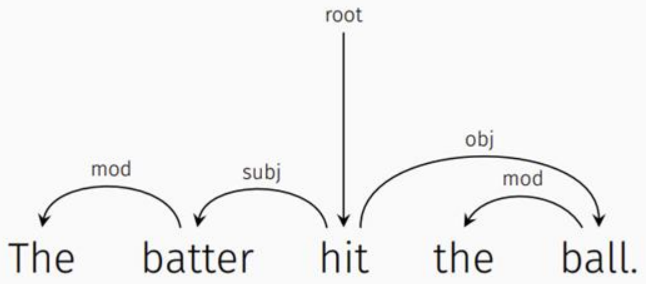
Dependents Contribute to the Meaning of Heads

Head	provides the basic content (meaning, grammatical content)
Dependent	modifies or serves as an argument of the head

Slide credit: David Mortensen

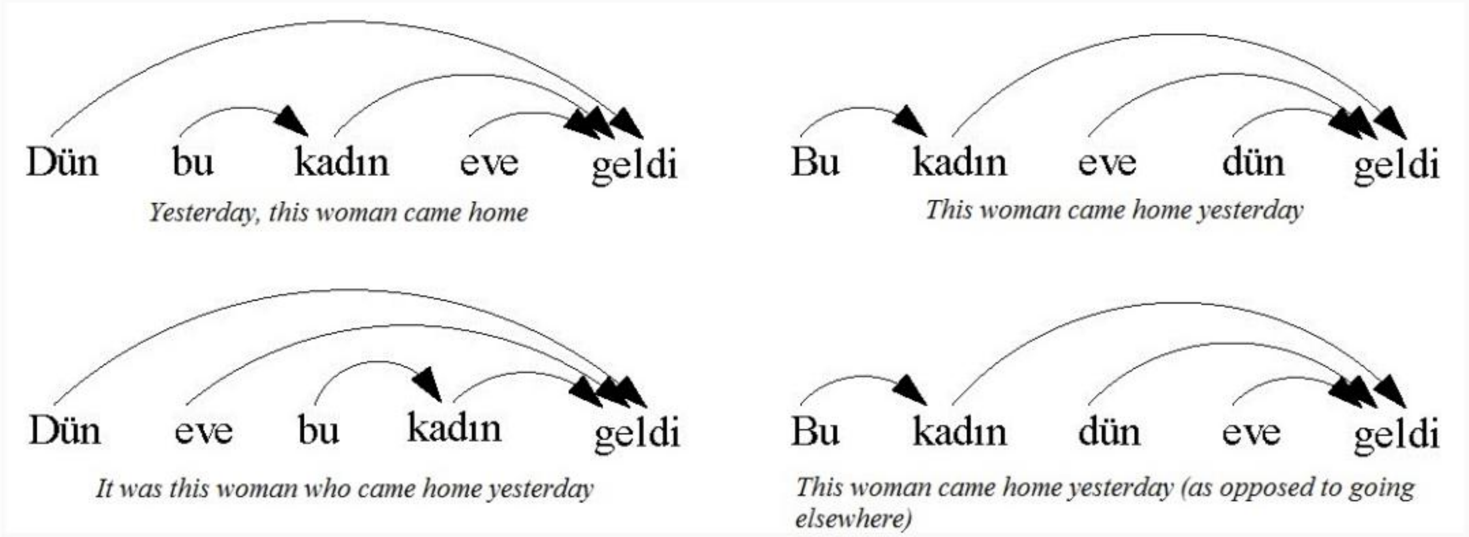
Dependencies Form a Tree

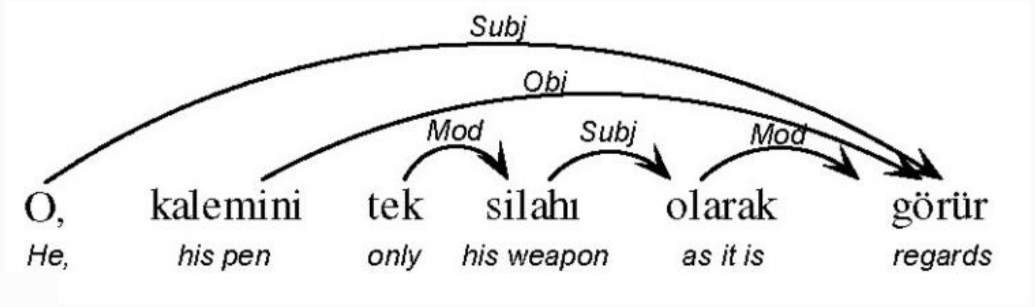
- Typically, the head of a sentence is a verb
- Every word is the dependent of one head
- The head verb is a dependent of ROOT



Slide credit: David Mortensen

Dependencies are useful for languages with free word order

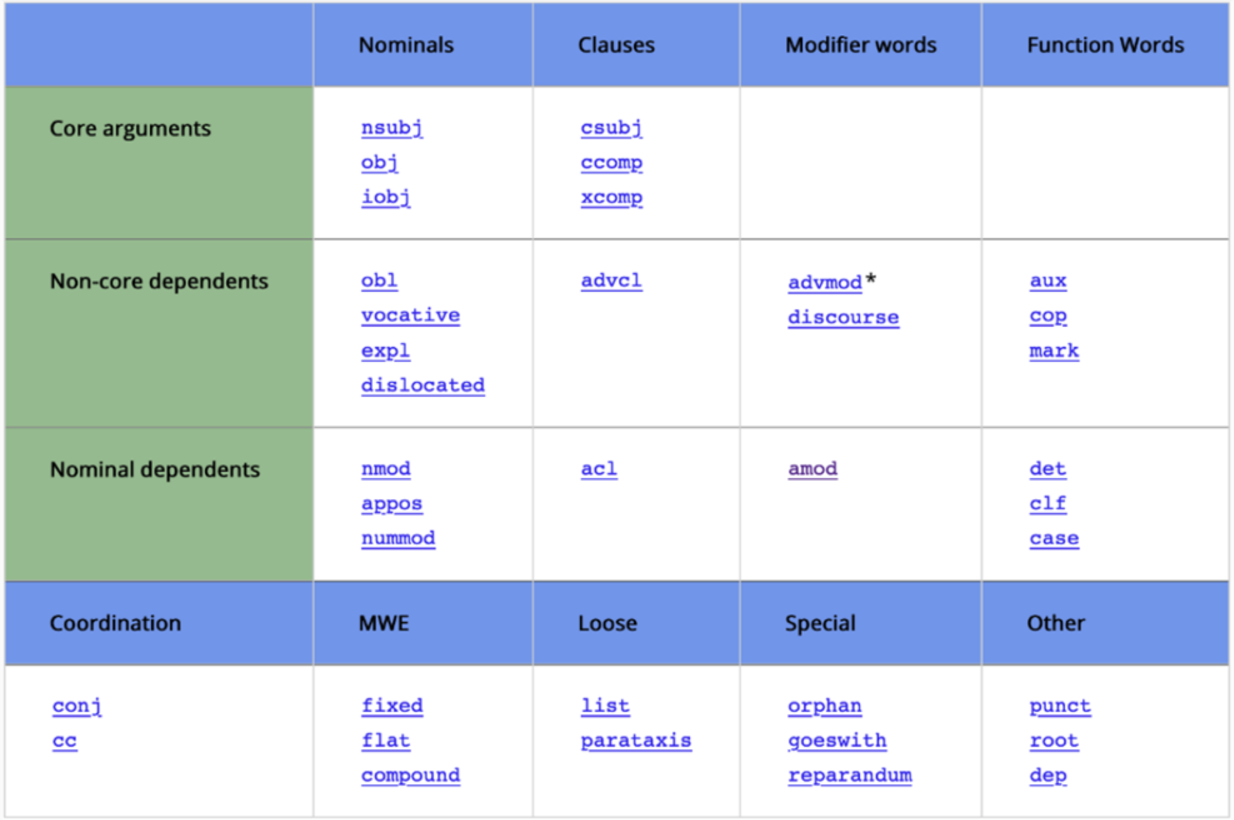

Dün bu kadın eve geldi
Yesterday, this woman came home
Bu kadın eve dün geldi
This woman came home yesterday
Dün eve bu kadın geldi
It was this woman who came home yesterday
Bu kadın dün eve geldi
This woman came home yesterday (as opposed to going elsewhere)



Slide adapted from David Mortensen

Kinds of dependency in English

Dependency Relations for Universal Dependencies



	Nominals	Clauses	Modifier words	Function Words
Core arguments	nsubj	csubj		
	obj	ccomp		
	iobj	xcomp		
Non-core dependents	obl	advcl	advmod*	aux
	vocative		discourse	cop
	expl			mark
	dislocated			
Nominal dependents	nmod	acl	amod	det
	appos			clf
	nummod			case

Coordination	MWE	Loose	Special	Other
conj	fixed	list	orphan	punct
cc	flat	parataxis	goeswith	root
	compound		reparandum	dep

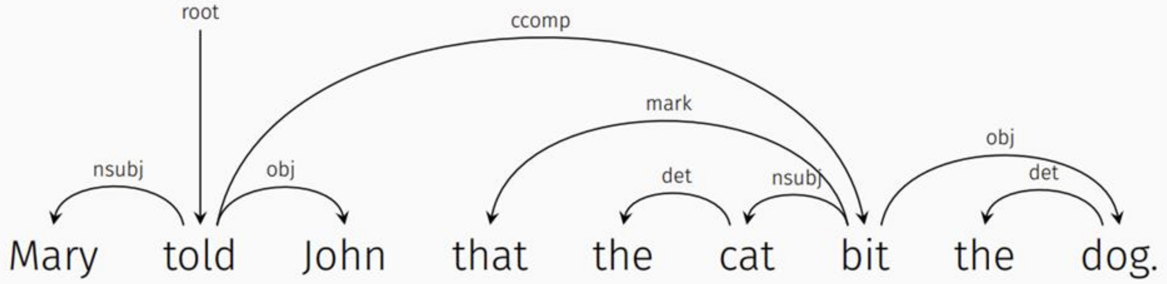
Slide credit: David Mortensen

Six Dependency Relations Common in English

nsubj	the subject noun of a verb
obj	the object of a verb
ccomp	the complement of a verb
amod	the adjectival modifier of a noun
det	the determiner of a noun
mark	a word marking a clause as subordinate

Slide credit: David Mortensen

An Illustration of Six UD Relations



Slide credit: David Mortensen

Dependencies and who did what to whom?

Semantic Roles Are Important to NLP

Often, in NLP, we want to know the semantic roles (thematic roles) of the noun phrases in a sentence.

Agent	the doer of an action
Patient	the one to whom an action is done
Instrument	that with which an action is done
	etc.

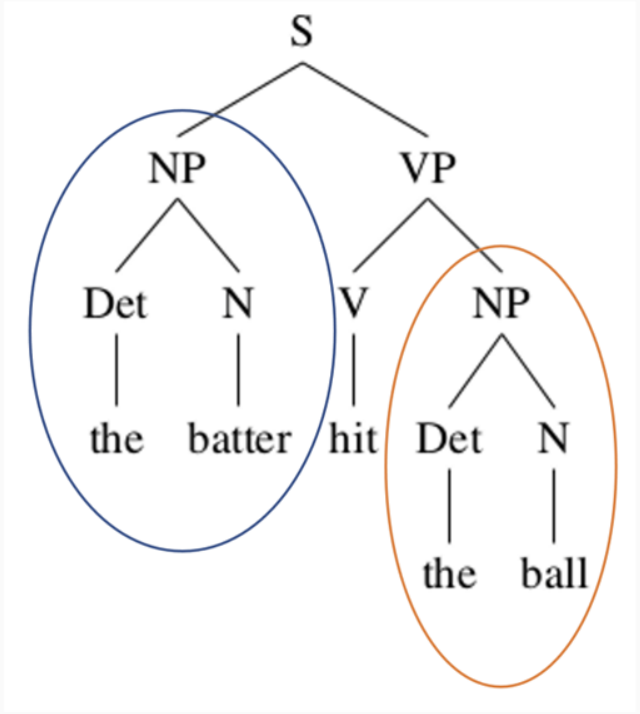
Slide credit: David Mortensen

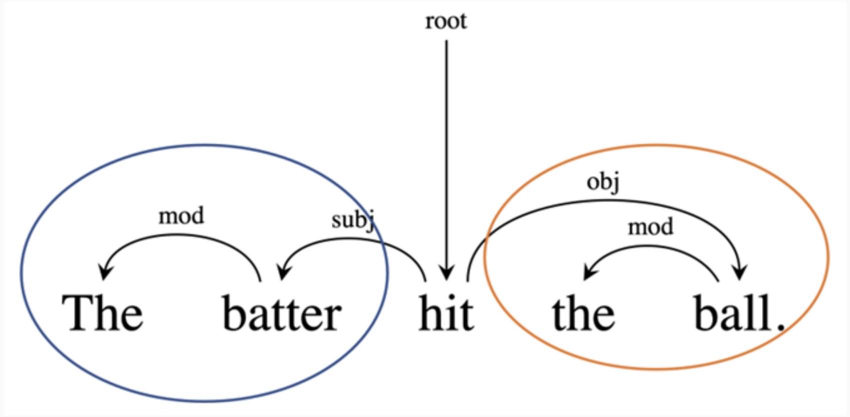
Semantic Roles are Related to but not Identical to, Grammatical Relation

- These are not the same as subject, object, etc.
- However, there is a function from grammatical relations like subject and object to thematic roles
- Syntax $\Rightarrow$ grammatical relations $\Rightarrow$ semantic/thematic roles

Slide credit: David Mortensen

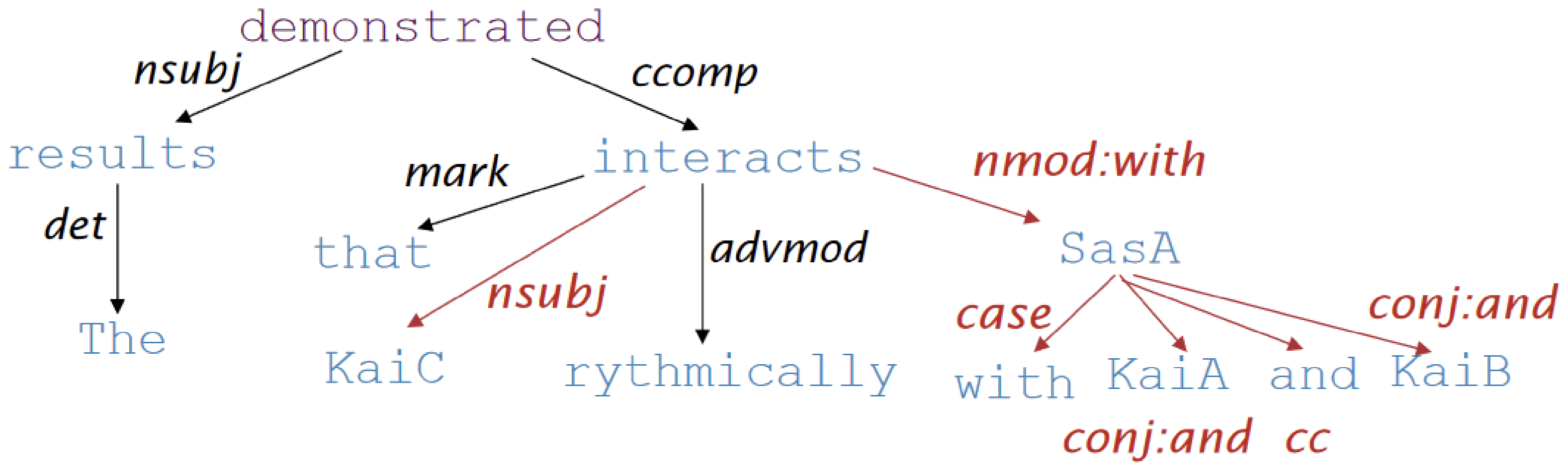
Dependency Trees Encode Grammatical Relations Directly





Slide credit: David Mortensen

Practical example: extracting protein-protein interaction



KaiC ←nsubj interacts nmod:with → SasA

KaiC ←nsubj interacts nmod:with → SasA conj:and→ KaiA

KaiC ←nsubj interacts nmod:with → SasA conj:and→ KaiB

[Erkan et al. EMNLP 07, Fundel et al. 2007, etc.]

Slide adapted from Chris Manning

Dependency treebanks

Proper Ambivalence toward Treebanks

Why you should have great respect for treebanks

Why you should be cautious around treebanks

Slide credit: David Mortensen

Why You Should Respect Treebanks

Treebanks require great skill

- Expert linguists make thousands of decisions
- Many annotators must remember all of the decisions and use them consistently, including knowing which decision to use
- The “coding manual” containing all of the decisions is hundreds of pages long

Treebanks take many years to make

- Writing the coding manual, training coders, building user-interface tools, etc., all take a lot of time
- So does the actual coding of the data and quality assurance

Treebanks are expensive

Somebody has to secure funding for these projects

Slide credit: David Mortensen

You Should Be Cautious around Treebanks

- They are **too big to fail**
- The are **produced under pressure** of time and funding
- Although most of the decisions are made by experts, **most of the coding is done by non-experts**

Slide credit: David Mortensen

Universal Dependencies Treebanks

- Over 200 treebanks in almost 100 languages
- UD annotation scheme
- Standard, easy to process, U-CONLL file format
- Despite attempts at standardization, considerable variation in conventions, quality

Slide credit: David Mortensen

Dependency parsing

Dependency Tree: Definition

Let $\mathbf{x} = [x_1, \ldots, x_n]$ be a sentence. We add a special ROOT symbol as "x_0".

A dependency tree consists of a set of tuples $[p, c, \ell]$ where

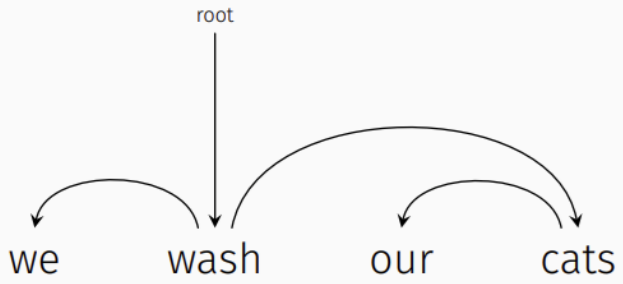
- $p \in \{0, \ldots, n\}$ is the index of a *parent*.
- $c \in \{1, \ldots, n\}$ is the index of a *child*.
- $\ell \in \mathcal{L}$ is a label.

Different annotation schemes define different label sets $\mathcal{L}$, and different constraints on the set of tuples. Most commonly:

- The tuple is represented as a directed edge from x_p to x_c with label ℓ.
- The directed edges form an directed tree with x_0 as the root (sometimes denoted as ROOT).

Slide credit: David Mortensen

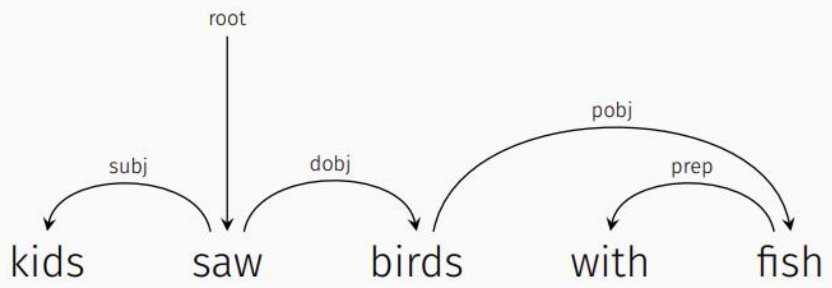
Example



"Bare bones" dependency tree.

Slide credit: David Mortensen

Labels



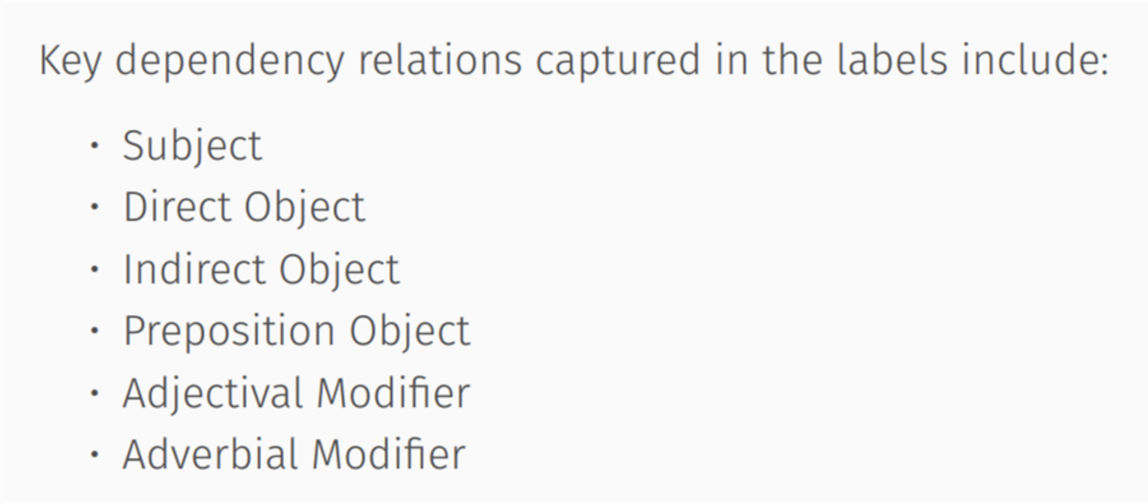
Key dependency relations captured in the labels include:

- Subject (arrow from predicate/main verb to subject)
- Direct Object (arrow from verb to object)
- Indirect Object (arrow from verb to object)
- Preposition Object (arrow from main noun to object of the preposition)
- Adjectival Modifier (arrow from noun to modifying adjective)
- Adverbial Modifier (arrow from noun to modifying adverb)

Slide credit: David Mortensen

Practice: parse these sentences

1. Enraged cow injures farmer with ax.
2. Hospitals are sued by seven foot doctors.
3. The woman saw the man with the telescope.



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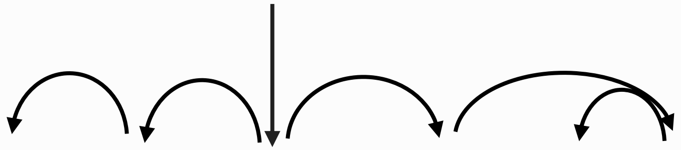

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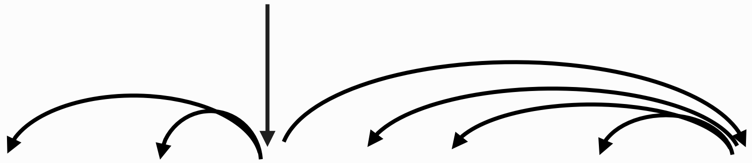
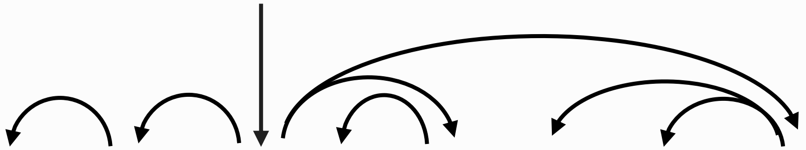


2. Hospitals are sued by seven foot doctors.



3. The woman saw the man with the telescope.

Two approaches to dependency parsing

Transition-based parsing

- Proceed through a sequence of actions, building up a representation step by step
- The representation, and any step, depends on the representations that came before

Graph-based parsing

- Start with probabilities for each edge
- Apply some sort of dynamic programming

Slide adapted from David Mortensen

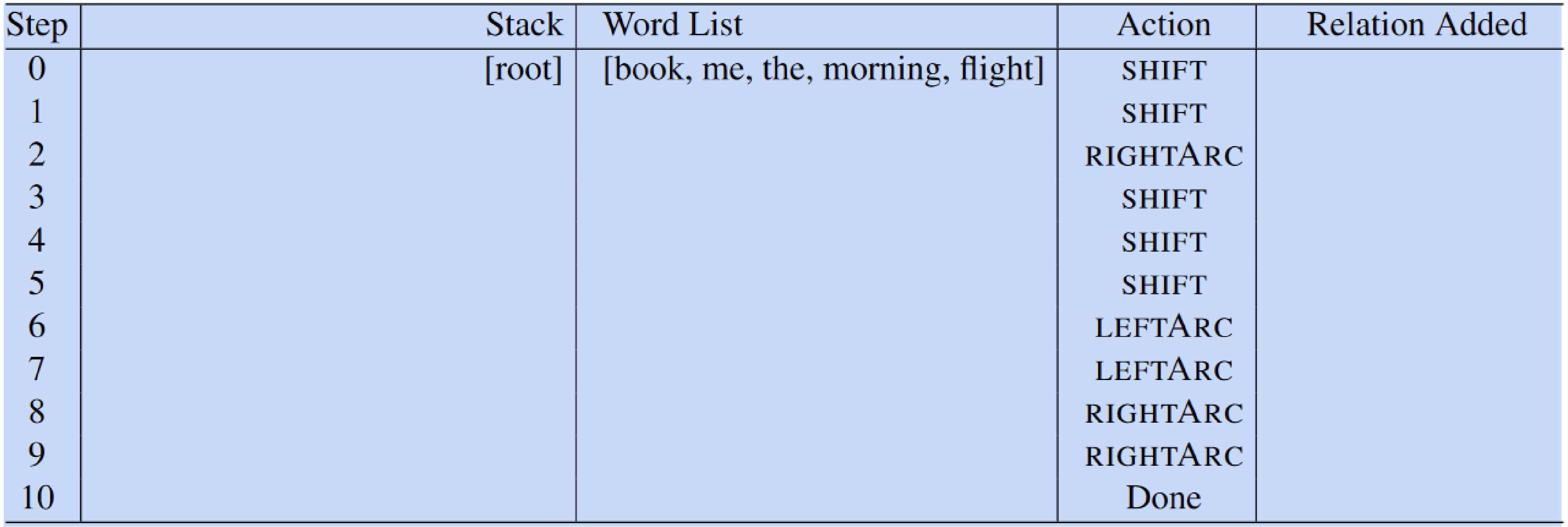
Transition-based dependency parsing

Transition-based dependency parsing

- Process input from left-to-right once, making a sequence of greedy parsing decisions
- Represents the current state/configuration of the parse:
    - Stack
    - Buffer
    - Current set of relations
- In arc-standard parsing, possible actions are:
    - SHIFT: move first word in the buffer to the stack
    - LEFT-ARC: draw an arc from word in the top of the stack to second word in the stack; remove dependent word (second word)
    - RIGHT-ARC: draw an arc from second word in the stack to the top of the stack; remove dependent word (top of the stack)

Slide adapted from David Mortensen

Example of transition-based parsing

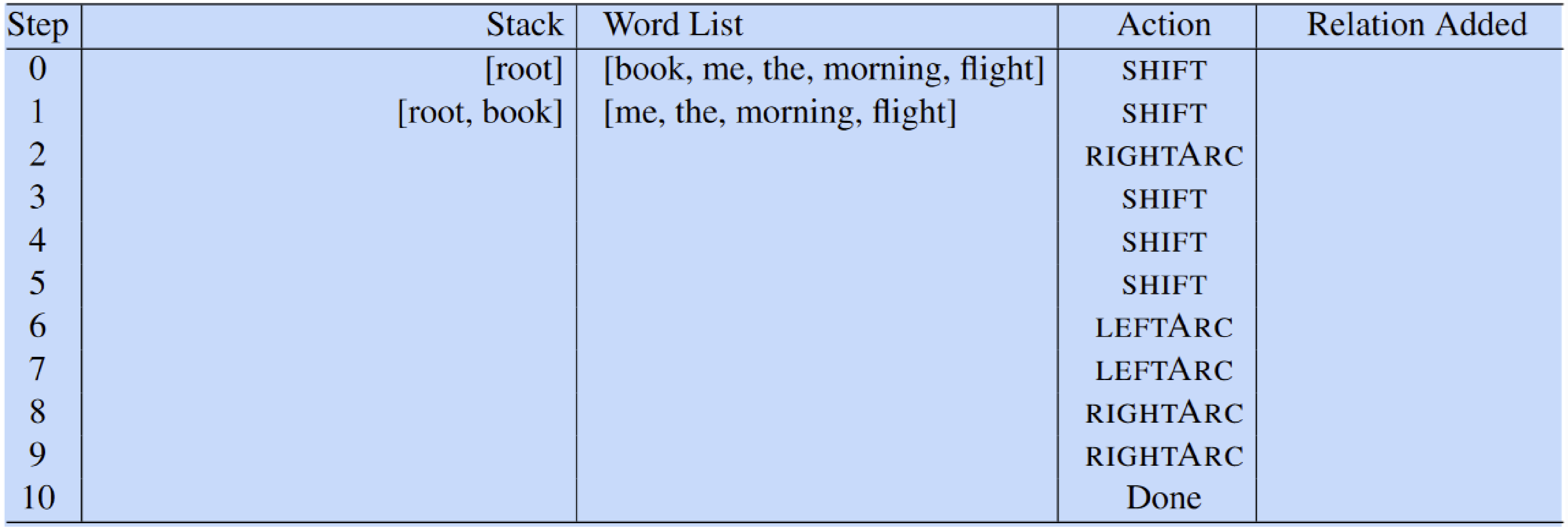


Step	Stack	Word List	Action	Relation Added
0	[root]	[book, me, the, morning, flight]	SHIFT	
1			SHIFT	
2			RIGHTARC	
3			SHIFT	
4			SHIFT	
5			SHIFT	
6			LEFTARC	
7			LEFTARC	
8			RIGHTARC	
9			RIGHTARC	
10			Done	

Figure 18.6 Trace of a transition-based parse.

Slide adapted from Jurafsky & Martin

Example of transition-based parsing



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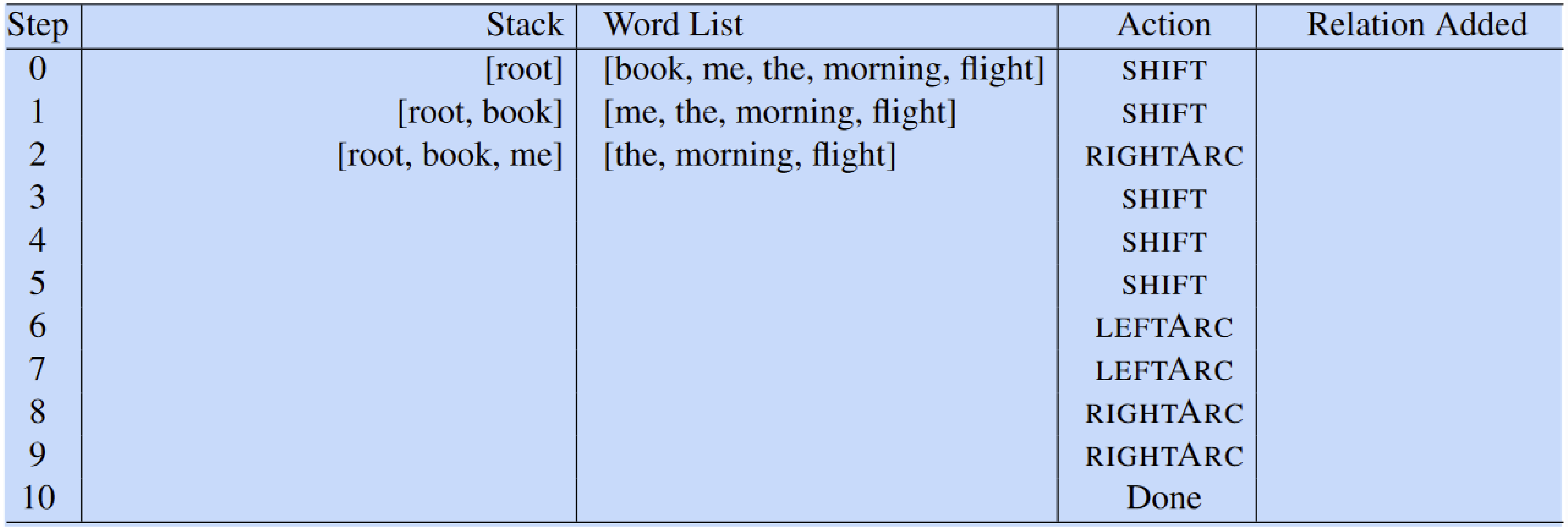

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1	[root, book]	[me, the, morning, flight]	SHIFT	
2	[root, book, me]	[the, morning, flight]	RIGHTARC	
3			SHIFT	
4			SHIFT	
5			SHIFT	
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10			Done	

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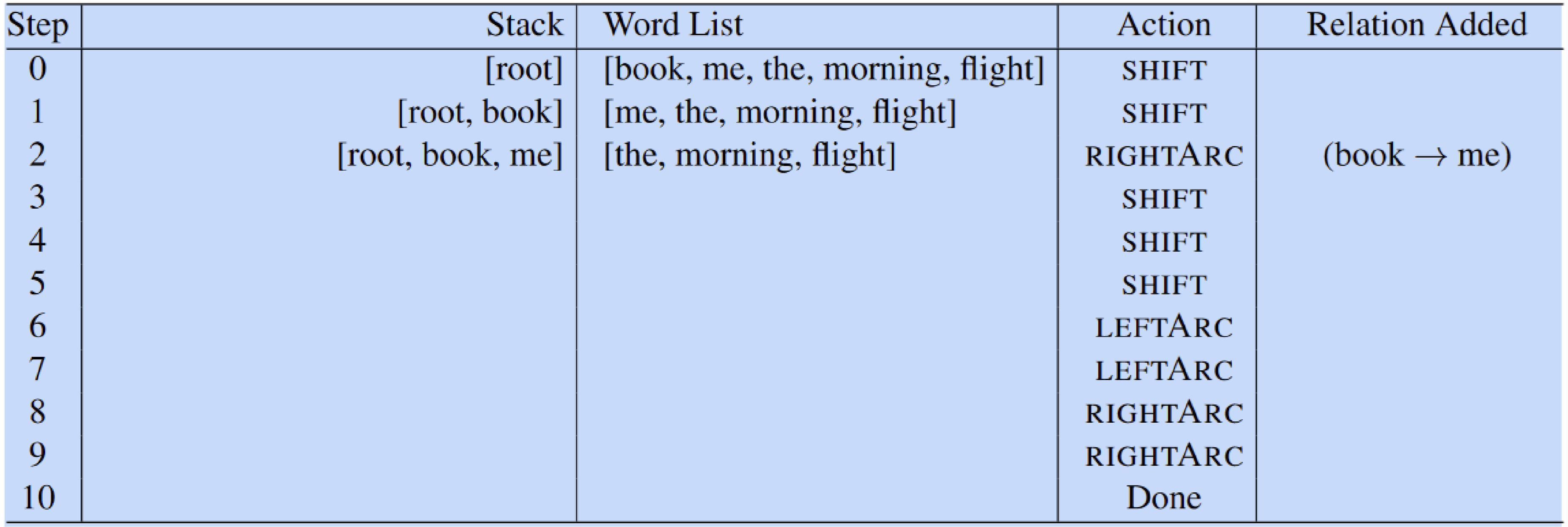

Step	Stack	Word List	Action	Relation Added
0	[root]	[book, me, the, morning, flight]	SHIFT	
1	[root, book]	[me, the, morning, flight]	SHIFT	
2	[root, book, me]	[the, morning, flight]	RIGHTARC	(book $\rightarrow$ me)
3			SHIFT	
4			SHIFT	
5			SHIFT	
6			LEFTARC	
7			LEFTARC	
8			RIGHTARC	
9			RIGHTARC	
10			Done	

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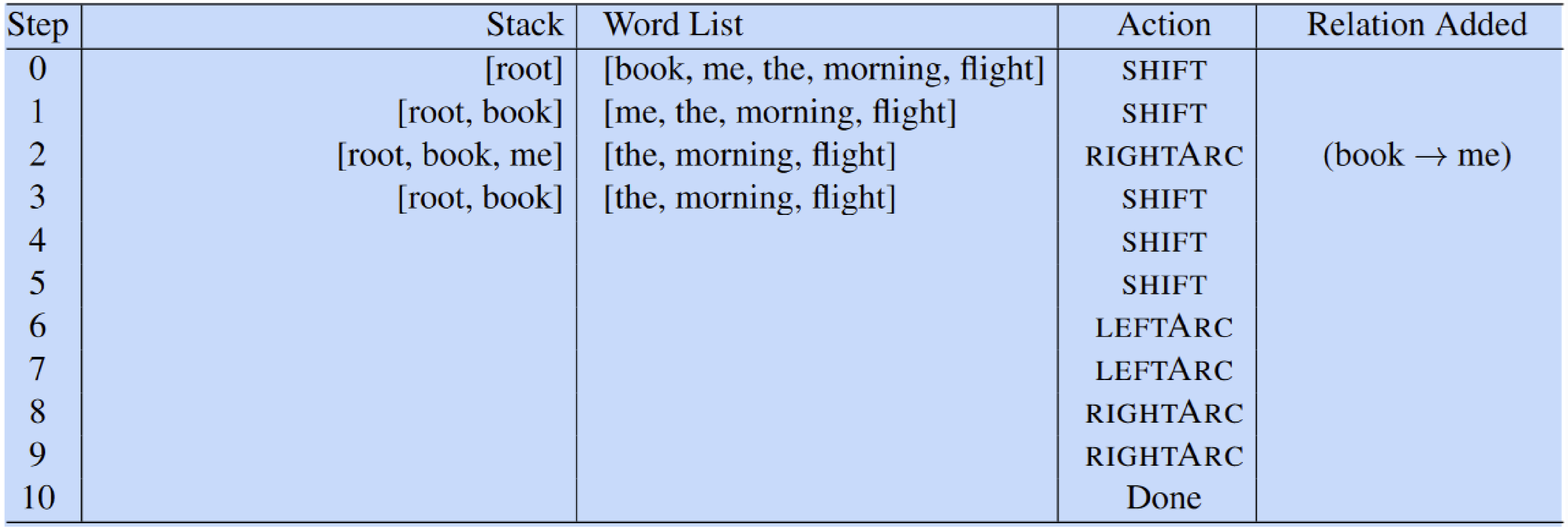

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2	[root, book, me]	[the, morning, flight]	RIGHTARC	(book $\rightarrow$ me)
3	[root, book]	[the, morning, flight]	SHIFT	
4			SHIFT	
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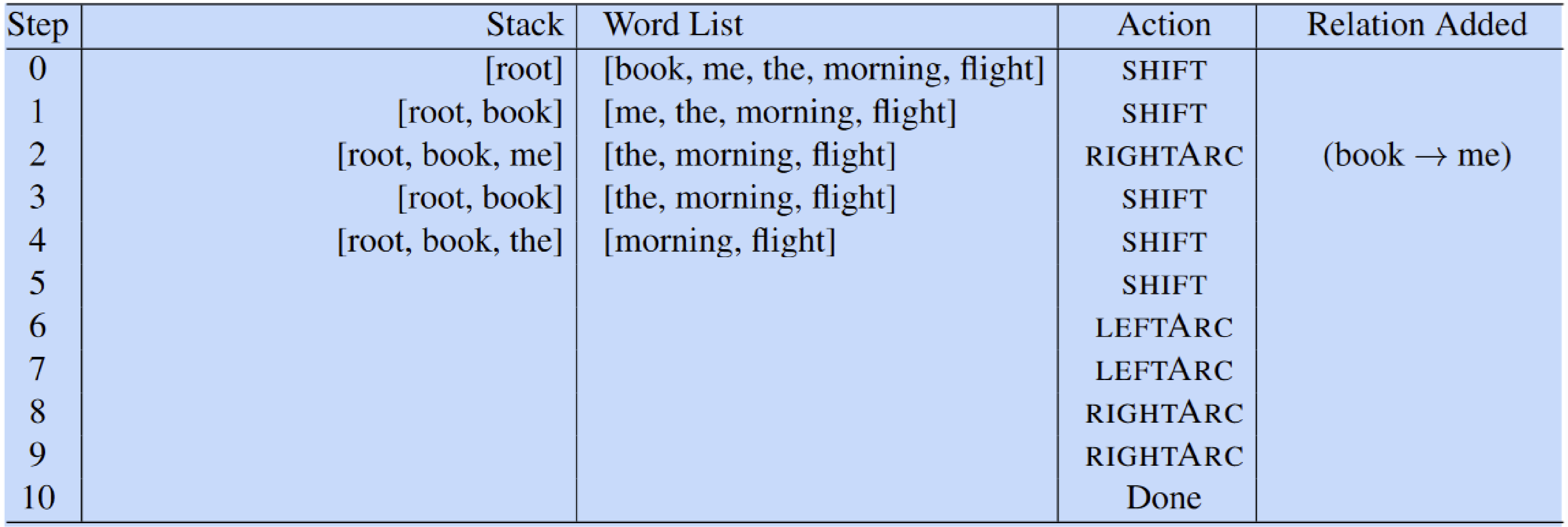

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1	[root, book]	[me, the, morning, flight]	SHIFT	
2	[root, book, me]	[the, morning, flight]	RIGHTARC	(book → me)
3	[root, book]	[the, morning, flight]	SHIFT	
4	[root, book, the]	[morning, flight]	SHIFT	
5			SHIFT	
6			LEFTARC	
7			LEFTARC	
8			RIGHTARC	
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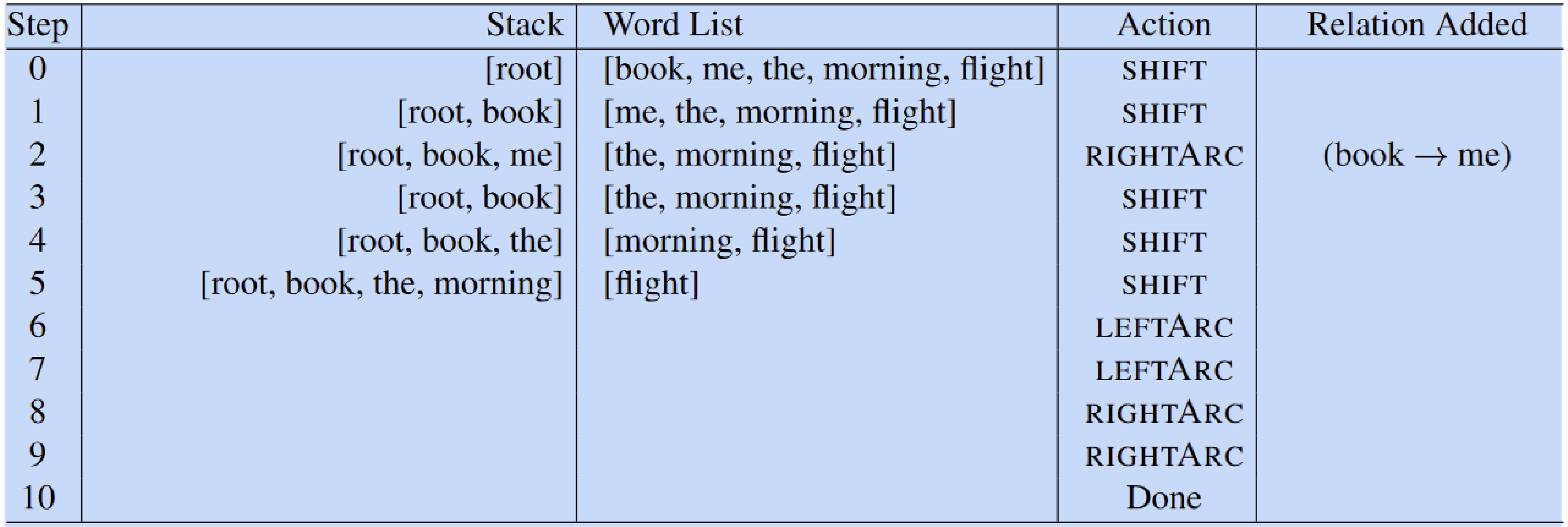

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2	[root, book, me]	[the, morning, flight]	RIGHTARC	(book → me)
3	[root, book]	[the, morning, flight]	SHIFT	
4	[root, book, the]	[morning, flight]	SHIFT	
5	[root, book, the, morning]	[flight]	SHIFT	
6			LEFTARC	
7			LEFTARC	
8			RIGHTARC	
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10			Done	

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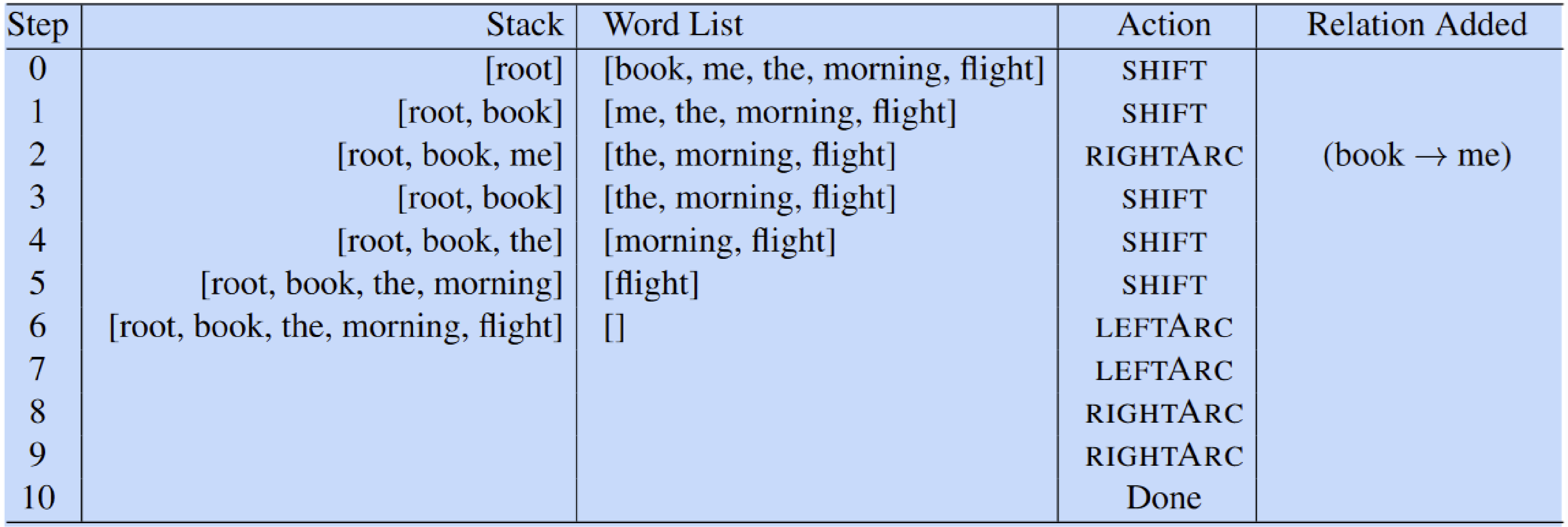
Slide adapted from Jurafsky & Martin

Example of transition-based parsing



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2	[root, book, me]	[the, morning, flight]	RIGHTARC	(book $\rightarrow$ me)
3	[root, book]	[the, morning, flight]	SHIFT	
4	[root, book, the]	[morning, flight]	SHIFT	
5	[root, book, the, morning]	[flight]	SHIFT	
6	[root, book, the, morning, flight]	[]	LEFTARC	
7			LEFTARC	
8			RIGHTARC	
9			RIGHTARC	
10			Done	

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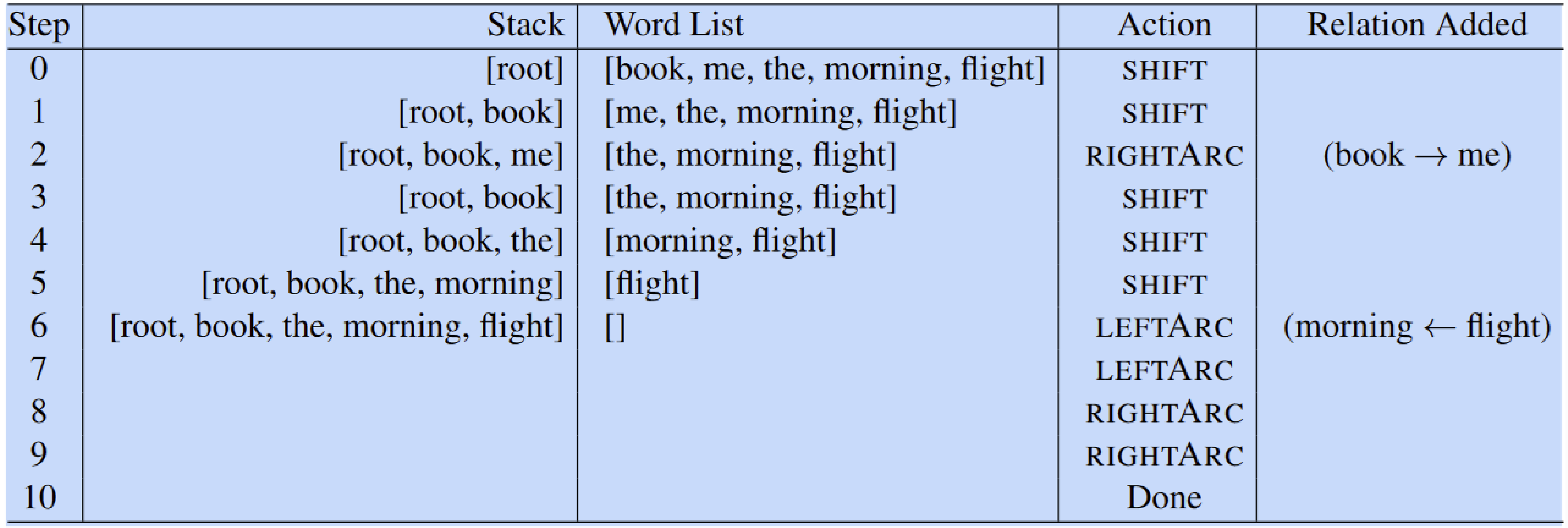
Example of transition-based parsing



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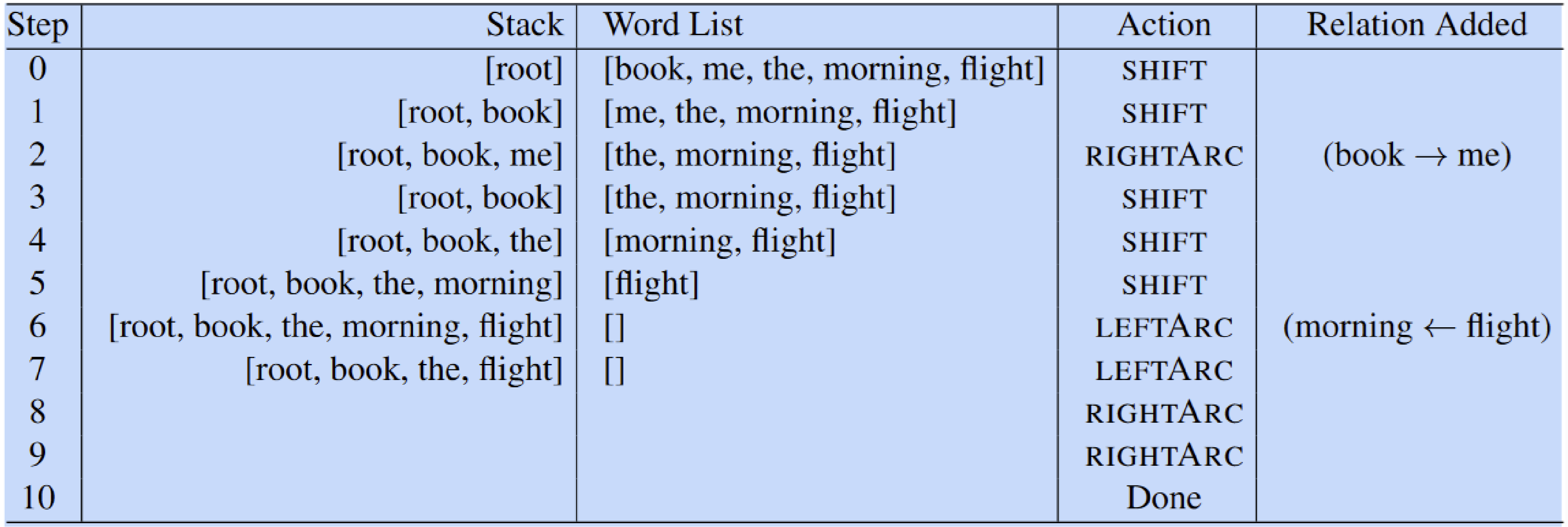
1	[root, book]	[me, the, morning, flight]	SHIFT	
2	[root, book, me]	[the, morning, flight]	RIGHTARC	(book $\rightarrow$ me)
3	[root, book]	[the, morning, flight]	SHIFT	
4	[root, book, the]	[morning, flight]	SHIFT	
5	[root, book, the, morning]	[flight]	SHIFT	
6	[root, book, the, morning, flight]	[]	LEFTARC	(morning $\leftarrow$ flight)
7			LEFTARC	
8			RIGHTARC	
9			RIGHTARC	
10			Done	

Figure 18.6 Trace of a transition-based parse.

Slide adapted from Jurafsky & Martin

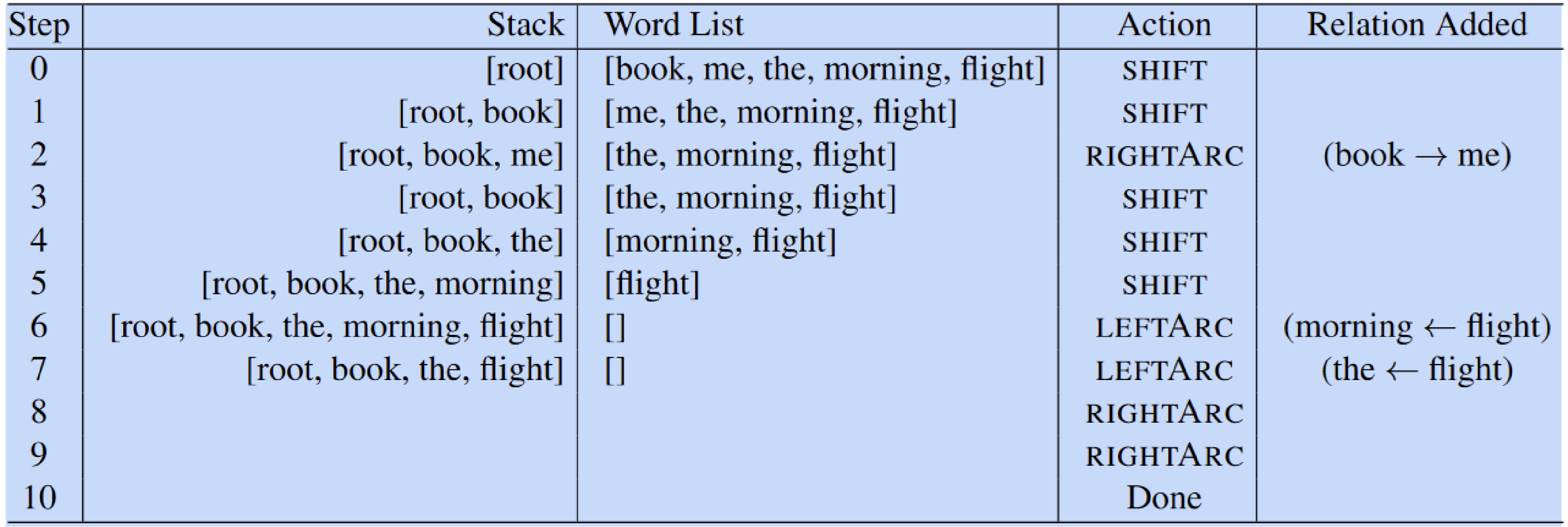
Example of transition-based parsing



Step	Stack	Word List	Action	Relation Added
0	[root]	[book, me, the, morning, flight]	SHIFT	
1	[root, book]	[me, the, morning, flight]	SHIFT	
2	[root, book, me]	[the, morning, flight]	RIGHTARC	(book $\rightarrow$ me)
3	[root, book]	[the, morning, flight]	SHIFT	
4	[root, book, the]	[morning, flight]	SHIFT	
5	[root, book, the, morning]	[flight]	SHIFT	
6	[root, book, the, morning, flight]	[]	LEFTARC	(morning $\leftarrow$ flight)
7	[root, book, the, flight]	[]	LEFTARC	
8			RIGHTARC	
9			RIGHTARC	
10			Done	

Figure 18.6 Trace of a transition-based parse.

Example of transition-based parsing

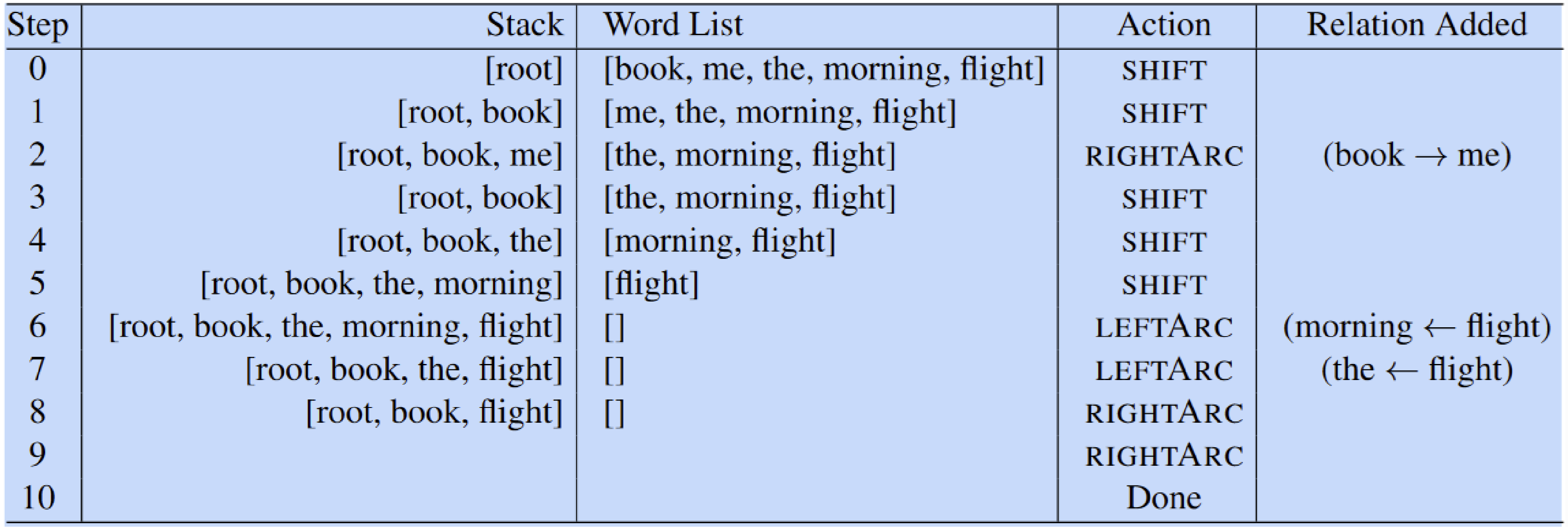


Step	Stack	Word List	Action	Relation Added
0	[root]	[book, me, the, morning, flight]	SHIFT	
1	[root, book]	[me, the, morning, flight]	SHIFT	
2	[root, book, me]	[the, morning, flight]	RIGHTARC	(book $\rightarrow$ me)
3	[root, book]	[the, morning, flight]	SHIFT	
4	[root, book, the]	[morning, flight]	SHIFT	
5	[root, book, the, morning]	[flight]	SHIFT	
6	[root, book, the, morning, flight]	[]	LEFTARC	(morning $\leftarrow$ flight)
7	[root, book, the, flight]	[]	LEFTARC	(the $\leftarrow$ flight)
8			RIGHTARC	
9			RIGHTARC	
10			Done	

Figure 18.6 Trace of a transition-based parse.

Slide adapted from Jurafsky & Martin

Example of transition-based parsing

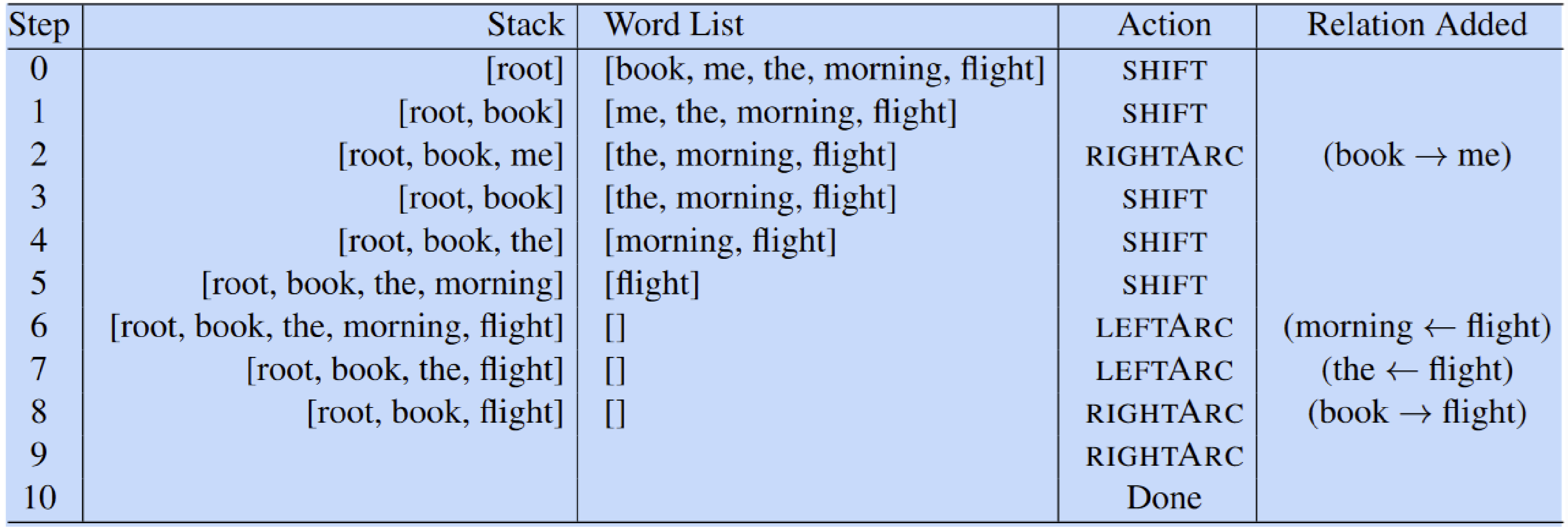


Step	Stack	Word List	Action	Relation Added
0	[root]	[book, me, the, morning, flight]	SHIFT	
1	[root, book]	[me, the, morning, flight]	SHIFT	
2	[root, book, me]	[the, morning, flight]	RIGHTARC	(book $\rightarrow$ me)
3	[root, book]	[the, morning, flight]	SHIFT	
4	[root, book, the]	[morning, flight]	SHIFT	
5	[root, book, the, morning]	[flight]	SHIFT	
6	[root, book, the, morning, flight]	[]	LEFTARC	(morning $\leftarrow$ flight)
7	[root, book, the, flight]	[]	LEFTARC	(the $\leftarrow$ flight)
8	[root, book, flight]	[]	RIGHTARC	
9			RIGHTARC	
10			Done	

Figure 18.6 Trace of a transition-based parse.

Slide adapted from Jurafsky & Martin

Example of transition-based parsing

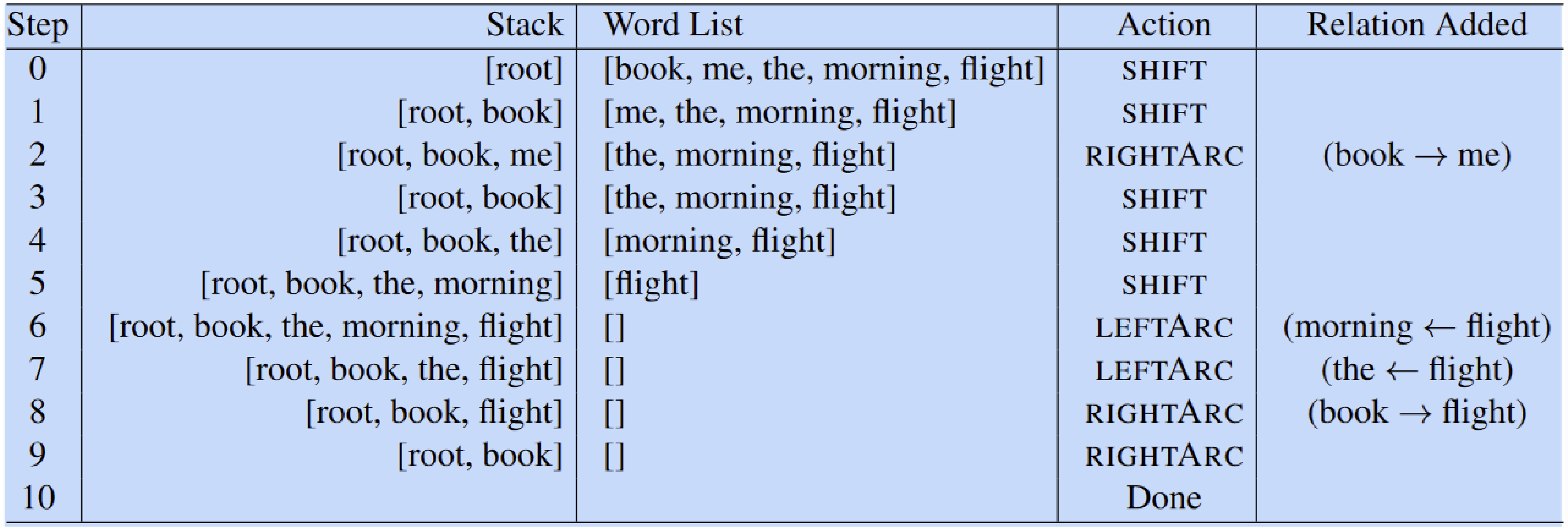


Step	Stack	Word List	Action	Relation Added
0	[root]	[book, me, the, morning, flight]	SHIFT	
1	[root, book]	[me, the, morning, flight]	SHIFT	
2	[root, book, me]	[the, morning, flight]	RIGHTARC	(book → me)
3	[root, book]	[the, morning, flight]	SHIFT	
4	[root, book, the]	[morning, flight]	SHIFT	
5	[root, book, the, morning]	[flight]	SHIFT	
6	[root, book, the, morning, flight]	[]	LEFTARC	(morning ← flight)
7	[root, book, the, flight]	[]	LEFTARC	(the ← flight)
8	[root, book, flight]	[]	RIGHTARC	(book → flight)
9			RIGHTARC	
10			Done	

Figure 18.6 Trace of a transition-based parse.

Slide adapted from Jurafsky & Martin

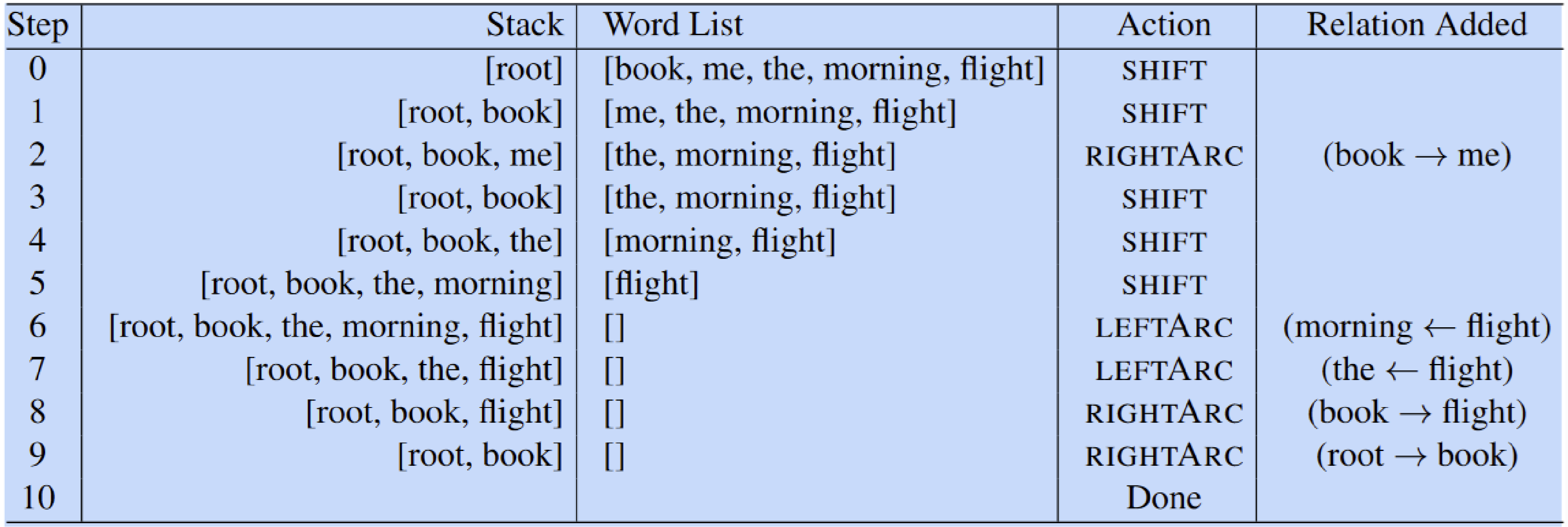
Example of transition-based parsing



Step	Stack	Word List	Action	Relation Added
0	[root]	[book, me, the, morning, flight]	SHIFT	
1	[root, book]	[me, the, morning, flight]	SHIFT	
2	[root, book, me]	[the, morning, flight]	RIGHTARC	(book → me)
3	[root, book]	[the, morning, flight]	SHIFT	
4	[root, book, the]	[morning, flight]	SHIFT	
5	[root, book, the, morning]	[flight]	SHIFT	
6	[root, book, the, morning, flight]	[]	LEFTARC	(morning ← flight)
7	[root, book, the, flight]	[]	LEFTARC	(the ← flight)
8	[root, book, flight]	[]	RIGHTARC	(book → flight)
9	[root, book]	[]	RIGHTARC	
10			Done	

Figure 18.6 Trace of a transition-based parse.

Example of transition-based parsing

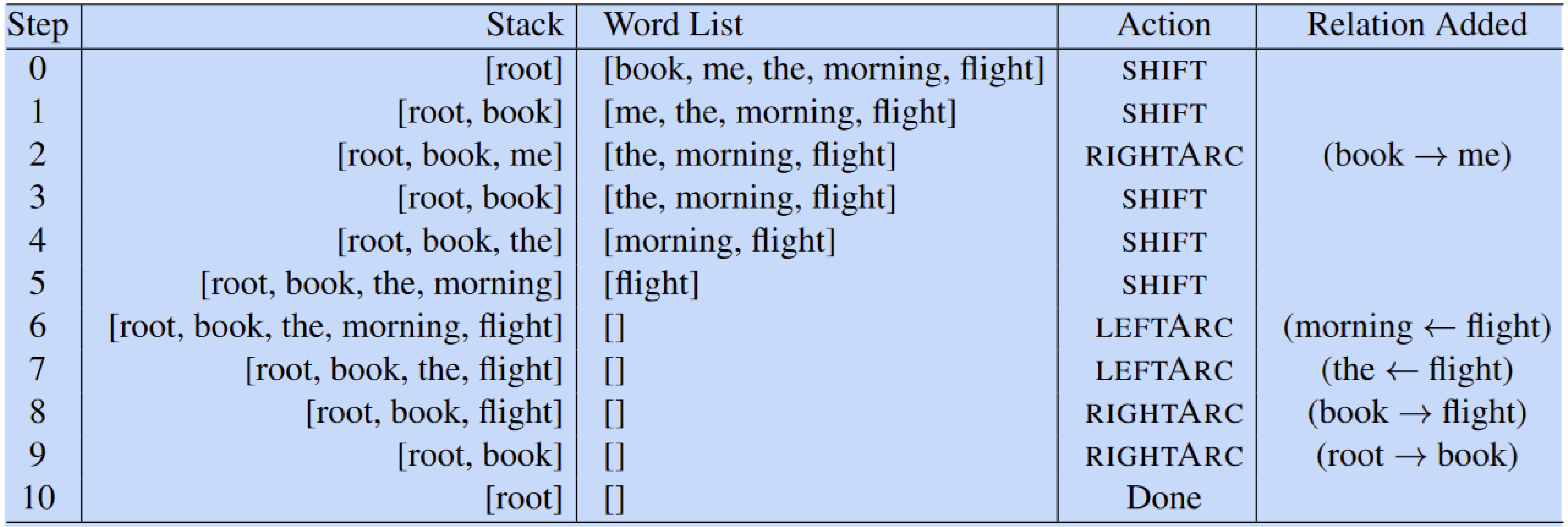


Step	Stack	Word List	Action	Relation Added
0	[root]	[book, me, the, morning, flight]	SHIFT	
1	[root, book]	[me, the, morning, flight]	SHIFT	
2	[root, book, me]	[the, morning, flight]	RIGHTARC	(book $\rightarrow$ me)
3	[root, book]	[the, morning, flight]	SHIFT	
4	[root, book, the]	[morning, flight]	SHIFT	
5	[root, book, the, morning]	[flight]	SHIFT	
6	[root, book, the, morning, flight]	[]	LEFTARC	(morning $\leftarrow$ flight)
7	[root, book, the, flight]	[]	LEFTARC	(the $\leftarrow$ flight)
8	[root, book, flight]	[]	RIGHTARC	(book $\rightarrow$ flight)
9	[root, book]	[]	RIGHTARC	(root $\rightarrow$ book)
10			Done	

Figure 18.6 Trace of a transition-based parse.

Slide adapted from Jurafsky & Martin

Example of transition-based parsing



Step	Stack	Word List	Action	Relation Added
0	[root]	[book, me, the, morning, flight]	SHIFT	
1	[root, book]	[me, the, morning, flight]	SHIFT	
2	[root, book, me]	[the, morning, flight]	RIGHTARC	(book → me)
3	[root, book]	[the, morning, flight]	SHIFT	
4	[root, book, the]	[morning, flight]	SHIFT	
5	[root, book, the, morning]	[flight]	SHIFT	
6	[root, book, the, morning, flight]	[]	LEFTARC	(morning ← flight)
7	[root, book, the, flight]	[]	LEFTARC	(the ← flight)
8	[root, book, flight]	[]	RIGHTARC	(book → flight)
9	[root, book]	[]	RIGHTARC	(root → book)
10	[root]	[]	Done	

Figure 18.6 Trace of a transition-based parse.

A Classifier Calls the Tune

How does the parser know which step to take next?

- This is a three-way **classification** problem (or, for parsing labeled dependencies, more)
- Various classifiers have been used
  - Traditional classifiers
  - Feed-forward neural nets
  - etc.
- What features? Stay tuned!

Slide credit: David Mortensen

The Core of Transition-based Parsing

- At each iteration, choose among {SHIFT, RIGHT-ARC, LEFT-ARC}.
    - Actually, among all $\mathcal{L}$-labeled variants of RIGHT- and LEFT-ARC.
- Training data: Dependency treebank trees converted into "oracle" transition sequence.
    - These transition sequences give the right tree,
    - $2 \cdot n$ pairs: $\langle state, correcttransition \rangle$.
    - Each word gets SHIFTed **once** and participates as a child in **one** ARC.

Slide credit: David Mortensen

Features for Transition Parsing Come from the Configuration

Where do the features for making parsing decisions come from?

- The words in the buffer
- The words in the stack (e.g. the roots of the trees)
- The children of these roots
- The POS tags of the words
- History of actions

Feature combinations are important:

- When parsing English, suppose that the second word in *S* is a verb and the first is a noun.
- The model should probably choose LEFT-ARC

Slide credit: David Mortensen

Example of Features: Feed-Forward Neural Transition Parser

Here are the features extracted by Chen and Manning’s (2014) feed-forward neural model for shift-reduce parsing:

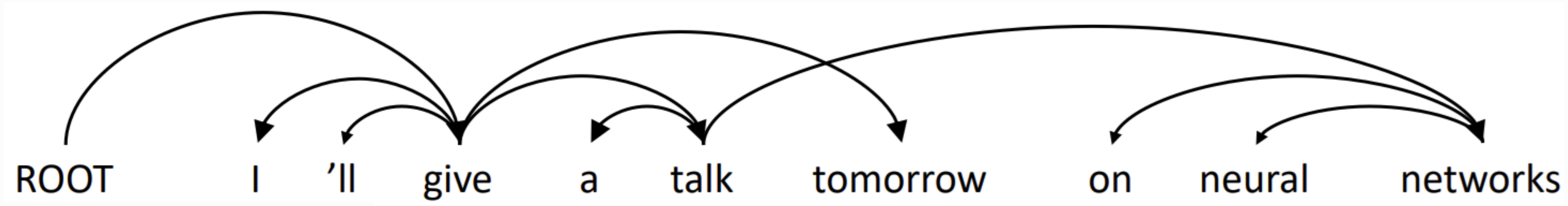
- The top three words on S and B (6 features)
  $s_1, s_2, s_3, b_1, b_2, b_3$
- The two leftmost/rightmost children of the top two words on S (8 features)
  $lc_1(s_i), lc_2(s_i), rc_1(si), rc_2(s_i)$ $i = 1, 2$
- The leftmost and rightmost grandchildren (4 features)
  $lc_1(lc_1(s_i)), rc_1(rc_1(s_i))$ $i = 1, 2$
- POS tags for all words invoked above (18 features)
- Arc labels of all children/grandchildren invoked above (12 features)

Slide credit: David Mortensen

Projectivity

Projectivity

- Definition of a projective parse: There are no crossing dependency arcs when the words are laid out in their linear order, with all arcs above the words
- Most syntactic structure is projective like this, but dependency theory normally does allow non-projective structures to account for displaced constituents
  - You can't easily get the semantics of certain constructions right without these nonprojective dependencies



Slide adapted from Chris Manning

Handling non-projectivity

- The arc-standard algorithm we just presented only builds projective dependency trees
- Possible directions to head:

    1. Just declare defeat on nonprojective arcs 🤷‍♀️

    2. Use a postprocessor to a projective dependency parsing algorithm to identify and resolve nonprojective links

    3. Add extra transitions that can model at least most non-projective structures (e.g., add an extra SWAP transition will allow any non-projectivity)

    4. Move to a parsing mechanism that does not use or require any constraints on projectivity (e.g., the graph-based MSTParser or Dozat and Manning (2017))

Slide adapted from Chris Manning

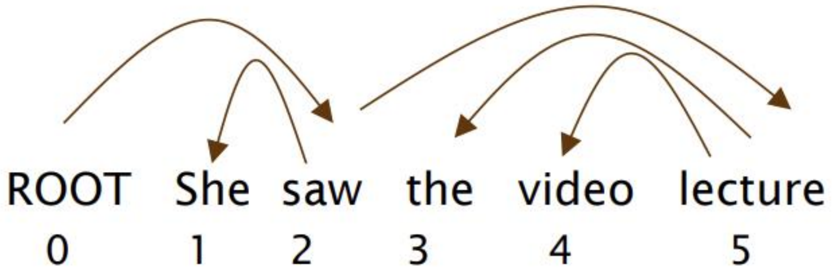
Evaluation

Dependency Parsing Evaluation

- **Unlabeled attachment score (UAS)**: Did you identify the head and the dependent correctly?
- **Labeled attachment score (LAS)**: Did you identify the head and the dependent AND the label correctly?

Slide credit: David Mortensen

Evaluation: an example



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

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

Slide adapted from Chris Manning

Tools and resources for dependency parsing

Dependency parsers

- UDPipe
  - Widely used
  - Provides parsing, morphological analysis, etc
  - A little harder to use than Stanza
- Stanza
  - New version of the classic Stanford Parser (which was in Java)
  - Pure Python
- spaCy (English)
  - Convenient Python library
  - Performs many other NLP tasks in addition to parsing
  - For the most part, is English-only

Slide adapted from David Mortensen

Wrapping up

- Syntax concerns rules for grouping and ordering words into meaningful phrases and sentences
- Constituencies and dependencies are two high-level formalisms for syntax
- The dependency grammar formalism models syntactic head-dependent relationships between words
- Dependency relationships are key to understanding who did what to whom (semantic roles)
- Key families of algorithms for dependency parsing include transition-based and graph-based parsers

Questions?