CS 2731 Introduction to Natural Language Processing

Session 21: Dependency parsing

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University of Pittsburgh | School of Computing and Information

Course logistics

- No reading quizzes for the rest of the semester
- **Optional** discussion forum on the "Bender Rule" and the dominance of English in NLP for 7 points extra credit (**due Mon 11-13 at 12pm**)
- Homework 4 is due **this Thu 11-09**
- Basic working project system **due next Thu 11-16**

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- Su Lin Blodgett, author of Blodgett et al. 2020, "Language (Technology) is Power" paper is giving a talk at CMU
  - 12:30-1:50pm, this Fri 11-10 in CMU Posner Hall A35
  - Let Michael know if you're interested in going

Overview: Dependency parsing

- Syntax review
- Dependency grammar
  - Kinds of dependency in English
  - Dependencies and semantic roles
  - Dependency treebanks
- Dependency parsing
  - Transition-based dependency parsing
  - Projectivity
  - Evaluation
  - Tools and resources

Review: syntax

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

Slide adapted from Chris Manning

Ambiguity: prepositional phrase attachment

Scientists count whales from space

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.

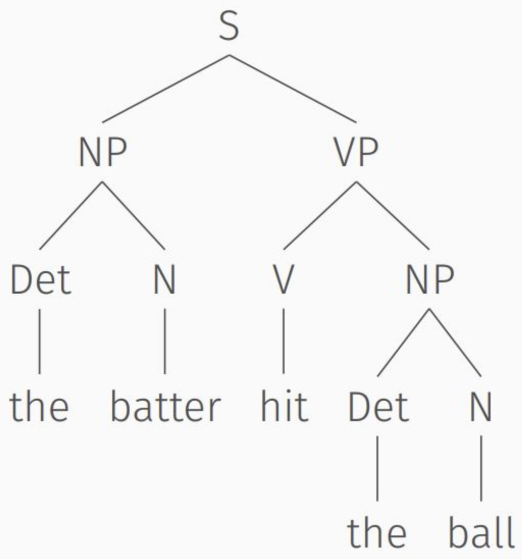
The 71-year-old president performed "exceedingly well" on cognitive screening, which is not

Slide adapted from Chris Manning

Review: different perspectives on syntax

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



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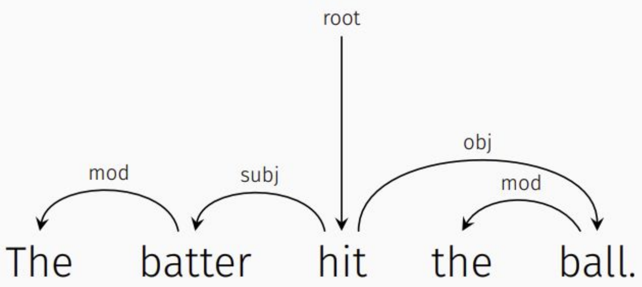
Dependency Grammar Is Based On Bilexical Dependencies

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



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Dependency grammar

Words Relate to Other Words

Words relate to other words:

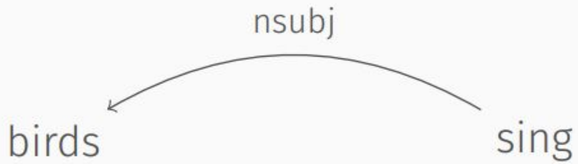
- Nouns can be subjects or objects of verbs
- Adjectives can be modifiers of nouns
- Adverbs can be modifiers of verbs, adjectives, and other adverbs

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

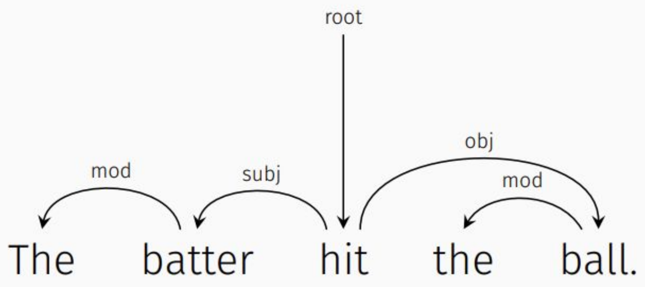
Head provides the basic content (meaning, grammatical content)

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



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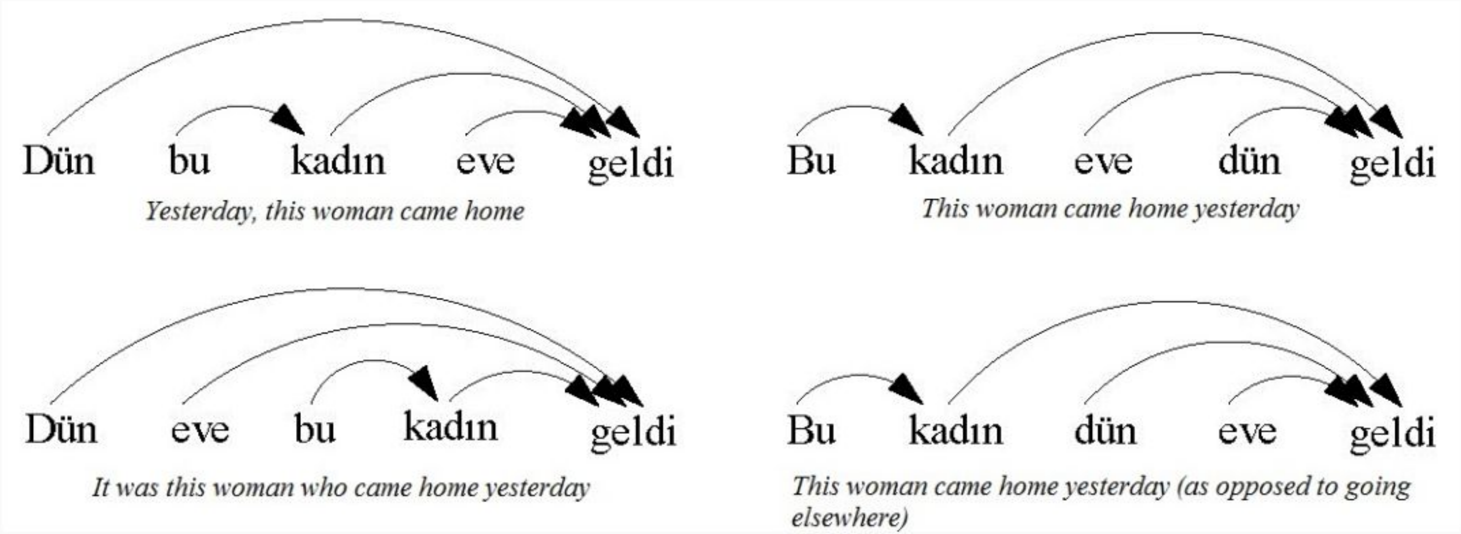
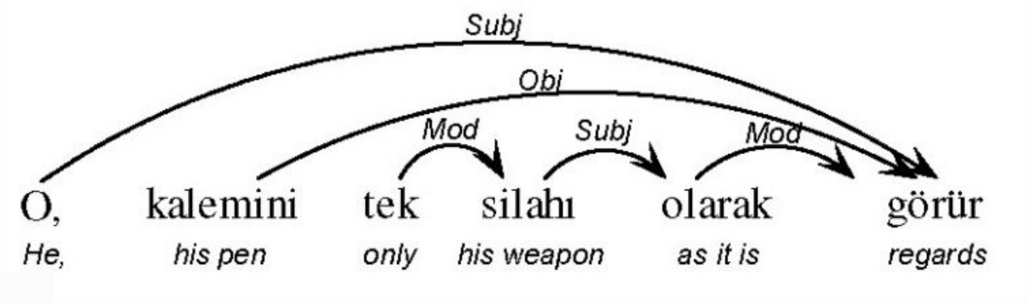
Dependencies are useful for languages with free word order





Slide adapted from David Mortensen

Kinds of dependency in English

Dependency Relations for Universal Dependencies

	Nominals	Clauses	Modifier words	Function Words
Core arguments	nsubj obj iobj	csubj ccomp xcomp		
Non-core dependents	obl vocative expl dislocated	advcl	advmod* discourse	aux cop mark
Nominal dependents	nmod appos nummod	acl	amod	det clf case
Coordination	**MWE**	**Loose**	**Special**	**Other**
conj cc	fixed flat compound	list parataxis	orphan goeswith reparandum	punct root dep

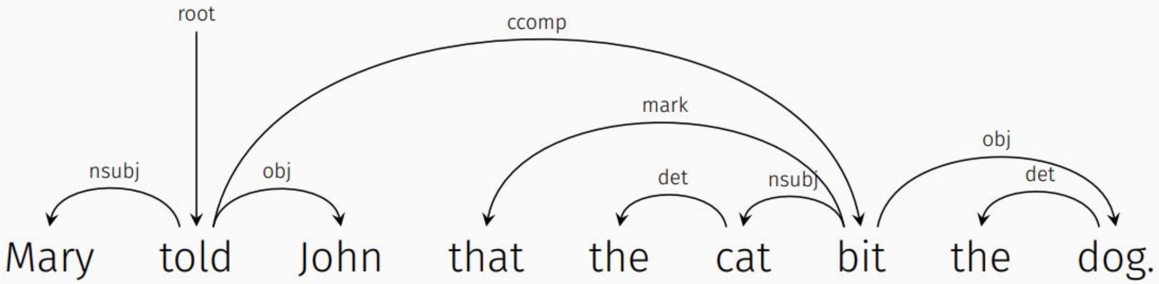
Slide credit: David Mortensen

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.

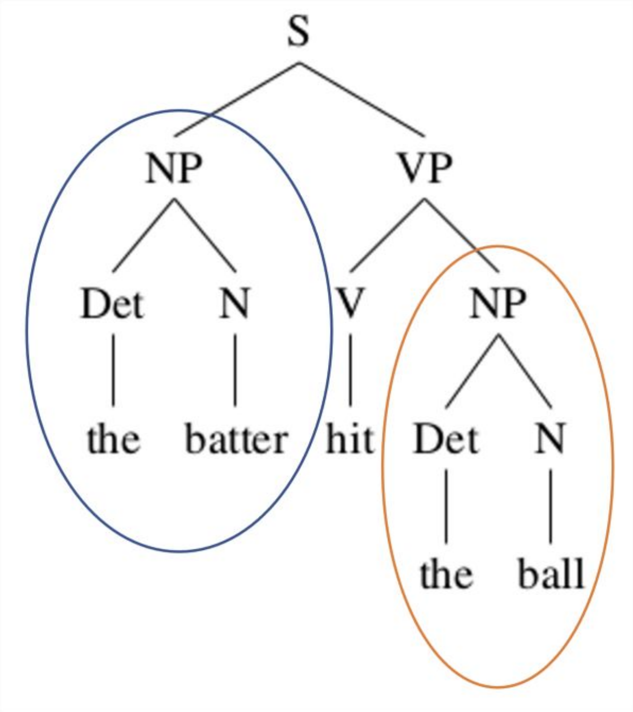
Slide credit: David Mortensen

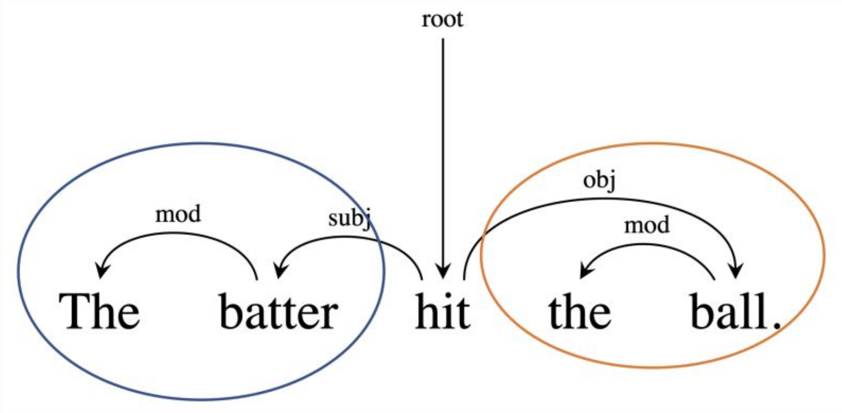
Semantic Roles are Related to but not Identical to, Grammatical Relation

- 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





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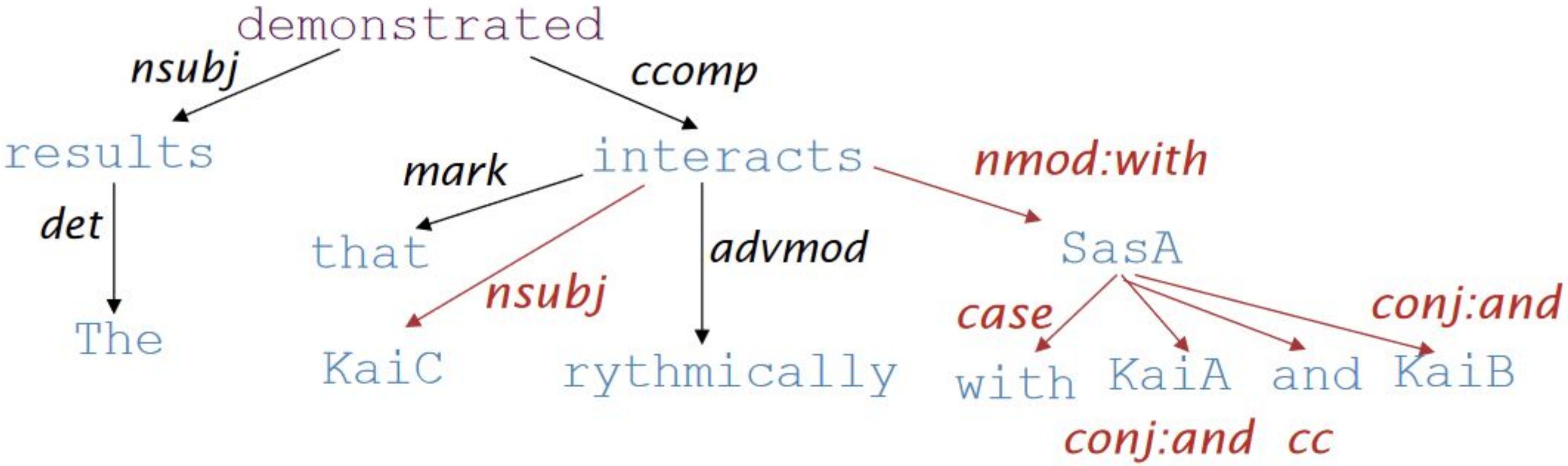
Practical example: extracting protein-protein interaction



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.]

Dependency treebanks

Dependency Treebanking Is Easy (or Easier)

Creating dependency treebanks seems to be easier that constituency treebanks:

- Simpler data structure
- More intuitive tools
- Less complicated tests

As a result, there are now many dependency treebanks.

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

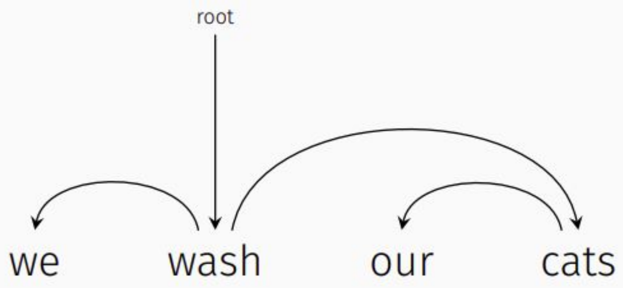
- $p \in \{0, \ldots, n\}$ is the index of a *parent*.
- $c \in \{1, \ldots, n\}$ is the index of a *child*.
- $\ell \in \mathcal{L}$ is a label.

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

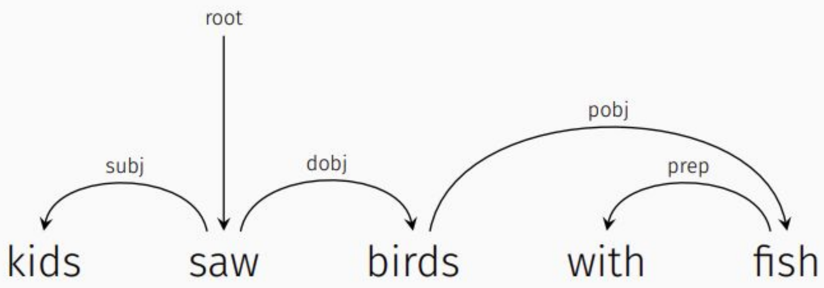
Example



“Bare bones” dependency tree.

Slide credit: David Mortensen

Labels



Key dependency relations captured in the labels include:

- Subject
- Direct Object
- Indirect Object
- Preposition Object
- Adjectival Modifier
- Adverbial Modifier

Slide credit: David Mortensen

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 (in phrase structure parsing, each constituent)
- 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
  - LEFT-ARC
  - RIGHT-ARC

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

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

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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	

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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	(morning $\leftarrow$ flight)
7	[root, book, the, flight]	[]	LEFTARC	(the $\leftarrow$ flight)
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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)
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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

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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	[root]	[]	Done	

Figure 18.6 Trace of a transition-based parse.

Slide adapted from Jurafsky & Martin

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

Transition-based Parsing: Remarks

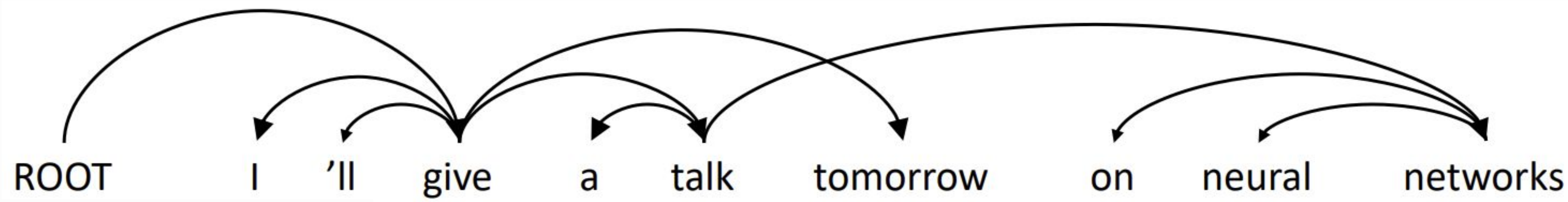
- Can also be applied to phrase-structure parsing. Keyword: “shift-reduce” parsing.
- **The algorithm for making decisions doesn’t need to be greedy; can maintain multiple hypotheses.**
    - e.g., beam search
- **Potential flaw**: the classifier is typically trained under the assumption that previous classification decisions were all correct. As yet, there is no principled solution to this problem, but there are approximations based on “dynamic oracles”.

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

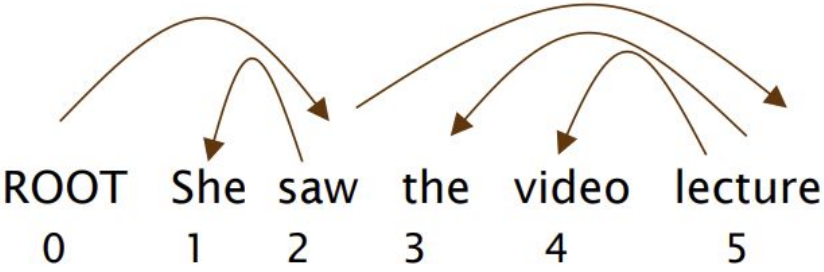
Evaluation

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



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

$$\text{UAS} = 4 / 5 = 80\%$$

$$\text{LAS} = 2 / 5 = 40\%$$

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

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

- 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?