Dependency Parsing

Feb 3, 2026

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Outline

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Understanding linguistic structure

- So far we have focused on how NLP deals with word meanings.
- But language goes beyond individual words.
- **Linguistic structure** is equally important for capturing how words combine together to create meaning.

Understanding linguistic structure

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1. Part of Speech (POS)
2. Dependency grammar

1. Part-of-Speech (POS)

- A word's POS determines how words fit into a sentence.
- POS is also called lexical category.
- Main POS categories (in English):
  - **N**___: reindeer, game, government
  - **V**___: play, run, believe
  - **A**___: fun, beautiful
  - **A**___: well, heavily
  - **P**___: on, into
  - **A**___/**D**___: a, the, some
  - **C**___: and, or

How do we identify POS?

- Examples:
  - *This car is very interesting.*
  - *This car mooked fast.*
  - *This nony car mooked fast.*
- We usually identify POS by:
  - **Morphology:** how a word changes form (e.g., verbs mark tense: *play* $\rightarrow$ *play***ed**, sometimes irregularly: *go* $\rightarrow$ *went*)
  - **Distribution:** where a word appears in a sentence (e.g., nouns after articles, verbs after subjects)

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2. From words to phrases

- Words combine into constituents based on POS:
  - **the reindeer** = article + noun = noun phrase
  - **play games** = verb + noun phrase = verb phrase
- Constituents combine based on **phrasal category**:
  - **Noun Phrase** + **Verb Phrase** = Sentence

Structure over meaning

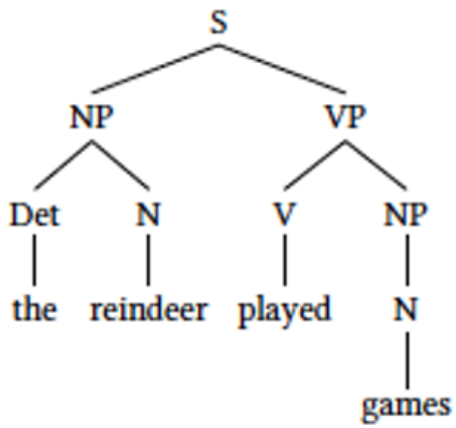
- Chomsky (1957): *"Colorless green ideas sleep furiously"*
- Nonsensical meaning, but:
  - Correct lexical and phrasal categories
  - Grammatically well-formed
- Syntax is about **structure**, not always meaning.

Understanding linguistic structure 1: Constituency

- **Constituency grammar**
- A linguistic theory that analyzes sentences as nested constituents (e.g., noun phrases, verb phrases).
- Also known as phrase structure grammar

Lexicon:
N → *reindeer, dragon, lunch, game, evening, morning*
V(trans) → *play, eat*
V(intrans) → *run, swim, dance*
Adj → *fun, beautiful, interesting*
Det → *the, a, some, many*
P → *for, in, to, at*

Phrase structure rules:
S → NP VP
VP → V(trans) NP
VP → V(intrans)
NP → Det (A*) N
NP → N
NP → NP PP
PP → P NP



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Frameworks for analyzing grammar

- Linguists formalize sentence structure using grammar frameworks:
  - Phrase Structure Grammar

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Frameworks for analyzing grammar

- Linguists formalize sentence structure using grammar frameworks:
  - Phrase Structure Grammar (linguistics)
  - **Dependency Grammar (widely used in NLP)**

Understanding linguistic structure 2: Dependency

- Dependency grammar shows that syntactic structure consists of relationships between lexical items, normally binary asymmetric relations ("arrows") called **dependencies**.
- Dependency structure shows which words depend on (modify, attach to, or are arguments of) which other words.

Why do we need dependency structure?

e.g., *I saw the man with the telescope.*

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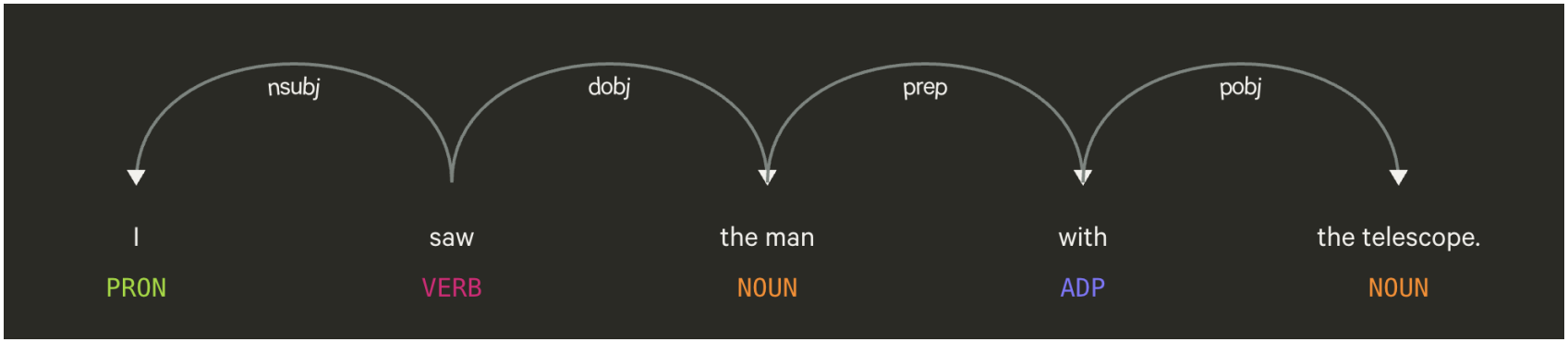

- Readers/Listeners/NLP models need to work out what modifies (attaches to) what.

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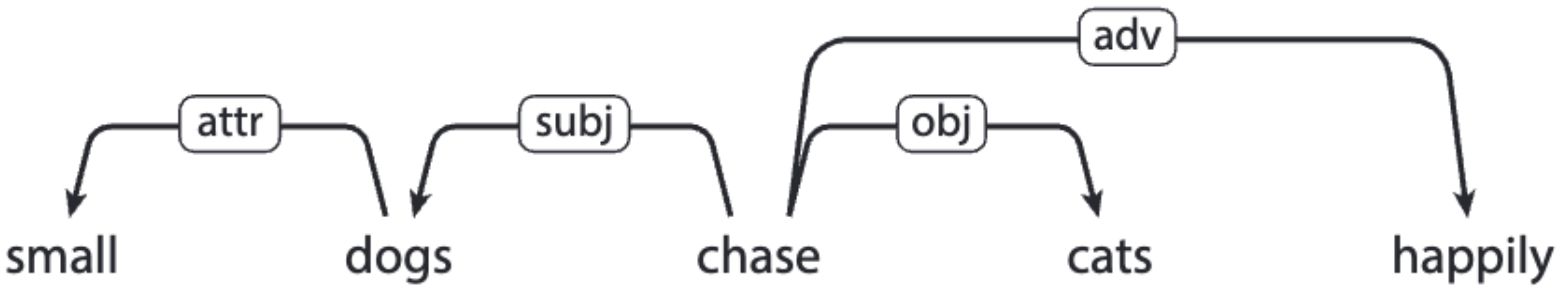
Dependency grammar and dependency structure

Dependency grammar shows that syntactic structure (of a sentence) consists of relations between lexical items, normally binary asymmetric relations ("arrows") called dependencies.



Sourced from: De Marneffe, M. C., & Nivre, J. (2019). *Dependency grammar*. *Annual Review of Linguistics*, 5(1), 197–218. Figure 1.

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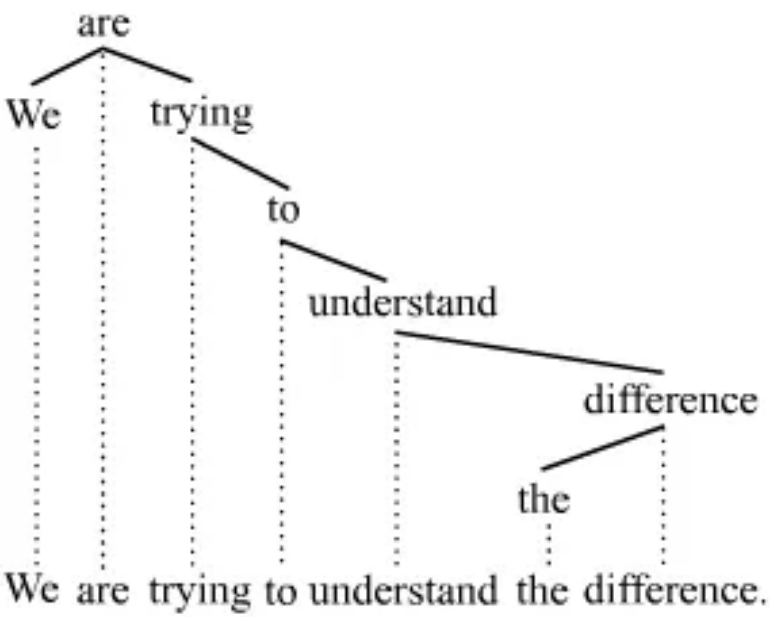
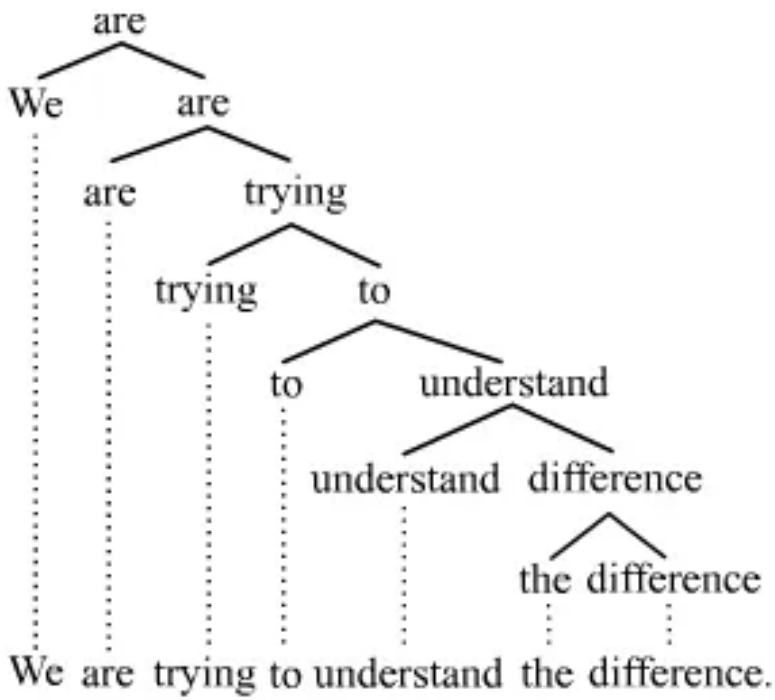
Dependency grammar vs. Constituency parsing



Dependency



Constituency (BPS)

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The arise of annotated data & Universal Dependencies tree

What is a treebank? An annotated corpus that includes syntactic or morphological structure, often in the form of parse trees.

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Milestones in treebank development:

- *Brown corpus* (1967): First general-purpose corpus; part-of-speech (PoS) tagged in 1979
- *Lancaster-IBM treebank* (Late 1980s): One of the first syntactically annotated corpora
- *The Penn treebank* (Marcus et al., 1993): Influential constituency-based treebank for English
- **Universal Dependencies (UD)**: A multilingual, cross-linguistically consistent treebank project using dependency grammar

The rise of annotated data

Starting off, building a treebank seems a lot slower and less useful than writing a grammar (by hand)

But a treebank gives us many things:

- Reusability of the labor
  - Many parser, POS taggers, and built on it
  - Valuable resource for linguistics
- Broad coverage, not just a few intuitions
- Frequencies and distributional information
- A way to evaluate NLP systems (work as a benchmark for empirical science)

Presentation 1

Matthew & Valbona: de Marneffe et al. (2021). Universal Dependencies.

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Sources of information for dependency parsing

How do we build a **parser**, once we get the dependency information?

Methods of dependency parsing

There are several ways (including dynamic programming, graph algorithms, etc.) but we'll focus on the one method.

Presentation 2

Duvarakanath: Chen & Manning (2014). A Fast and Accurate Neural Dependency Parser.

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Evaluation

Gold Standard: Hand-annotated syntactic structure used for evaluating parser output.

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Example:

Word	Gold Head	Gold Label	Pred Head	Pred Label
She	2	nsubj	2	nsubj
likes	0	root	0	root
chocolate	2	obj	2	nmod
very	4	advmod	4	advmod
much	2	advmod	4	advmod

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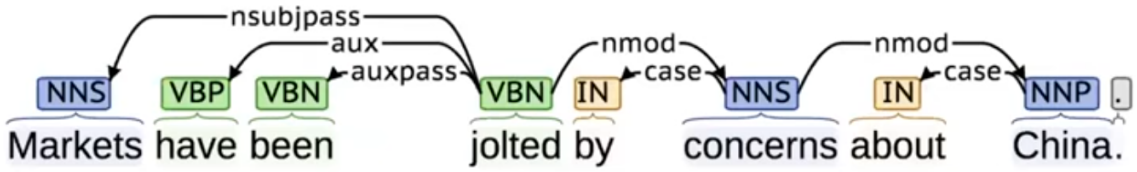
Evaluation:

- **Total dependencies:** 5
- **Correct heads (UAS):** 4 $\rightarrow$ **UAS = 4/5 = 80%**
- **Correct heads + labels (LAS):** 3 $\rightarrow$ **LAS = 3/5 = 60%**

Dependency parsing for sentence structure

- Chen and Manning (2014) showed that neural networks can accurately determine the structure of sentences, supporting meaning interpretation.



- It was the first simple, successful neural dependency parser.
- The dense representations (and non-linear classifier) let it outperform other greedy parsers in both accuracy and speed.
- This work was further developed and improved by others.

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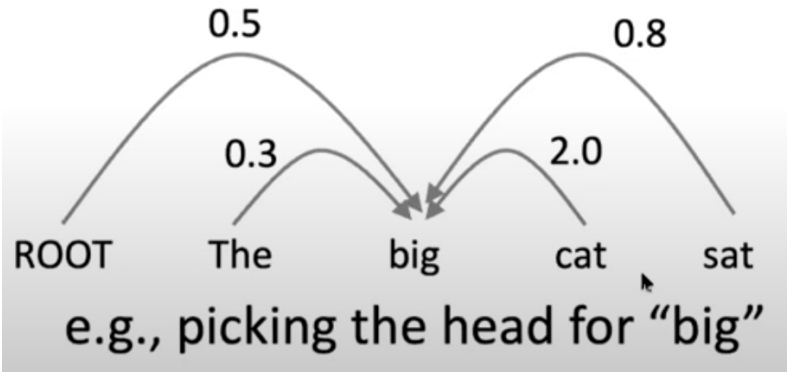
Further developments

This work was further developed and improved by others, including in particular at Google.

Graph-based dependency parsers

- Compute a score for every possible dependency (choice of head) for each word
  - Doing this well requires more than just knowing two words
  - We need good "contextual" representations of each word token
- Repeat the same process for each other word; find the best parse



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A neural graph-based dependency parser

- Dozat and Manning (2017); Dozat, Qi, and Manning (2017) - This paper revived interest in graph-based dependency parsing in a neural world
  - Designed a new scoring model (i.e., biaffine) for neural dependency parsing
- Really great results!

Method	UAS	LAS (PTB WSJ SD 3.3
Chen & Manning 2014	92.0	89.7
Weiss et al. 2015	93.99	92.05
Andor et al. 2016	94.61	92.79
Dozat & Manning 2017	**95.74**	**94.08**

- But, slower than the simple neural transition-based parsers.

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Preview

- Thursday (2/5): Lab 4 - Work with a small dataset to train dependency parser (No in-person class; **Check mycourses on time - there'll be a link for a guided video**)
- Friday (2/6): Submission deadline for **Identifying team members**
- Tuesday (2/10) RNNs, LSTMs; Presenter: Shubh Sudan