Lecture 16:
English Syntax & CFGs

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(most slides from Marine Carpuat)

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Today's Agenda

- From sequences to **trees**
- Syntax
  - Constituent, Grammatical relations, Dependency relations
- Formal Grammars
  - Context-free grammar
  - Dependency grammars
- Treebanks

sýntaxis (setting out or arranging)

- The ordering of words and how they group into phrases
  - [[the old man] [is yawning]]
  - [[the old] [man the boats]]

credit: Lori Levin

Syntax and Grammar

- Goal of syntactic theory
  - “explain how people combine words to form sentences and how children attain knowledge of sentence structure”
- Grammar
  - implicit knowledge of a native speaker
  - acquired without explicit instruction
  - minimally able to generate all and only the possible sentences of the language

[Philips, 2003]

Syntax vs. Meaning

"Colorless green ideas sleep furiously."

— Noam Chomsky (1957)

You can tell that the words are in the right order.

- ...and that "colorless" and "green" modify "ideas"
- ...and that ideas sleep
- ...and that the sleeping is done furiously
- ...and that it sounds like an English sentence, even if you can't imagine what it means.
- Contrast with: "sleep green furiously ideas colorless"

credit: Lori Levin

But isn't meaning more important?

[send [the text message from James] [to Sharon]]

[translate [the message] [from Hindi] [to English]]

- When you say these to your phone, you want it to respond appropriately.
- We will see that syntax helps you find the meaning.

adapted from: Lori Levin

Syntax in NLP

- Syntactic analysis often a key component in applications
  - Grammar checkers
  - Dialogue systems
  - Question answering
  - Information extraction
  - Machine translation
  - …

Two views of syntactic structure

- Constituency (phrase structure)
  - Phrase structure organizes words in nested constituents

- Dependency structure
  - Shows which words depend on (modify or are arguments of) which on other words

CONSTITUENCY PARSING & CONTEXT FREE GRAMMARS

Constituency

- Basic idea: groups of words act as a single unit
- Constituents form coherent classes that behave similarly
  - With respect to their internal structure: e.g., at the core of a noun phrase is a noun
  - With respect to other constituents: e.g., noun phrases generally occur before verbs

Constituency: Example

- The following are all noun phrases in English…

Harry the Horse	a high-class spot such as Mindy's
the Broadway coppers	the reason he comes into the Hot Box
they	three parties from Brooklyn

- Why?
  - They can all precede verbs
  - They can all be preposed/postposed
  - …

Grammars and Constituency

- For a particular language:
  - What are the "right" set of constituents?
  - What rules govern how they combine?
- Answer: not obvious and difficult
  - That's why there are many different theories of grammar and competing analyses of the same data!
- Our approach
  - Focus primarily on the "machinery"

Finite-State/Regular Grammars

- You've already seen one class of grammars: **regular expressions**
  - A pattern like `^[a-z][0-9]$` corresponds to a grammar which **accepts** (matches) some strings but not others.
  - Can regular languages define *infinite* languages?
  - Can regular languages define *arbitrarily complex* languages?

Finite-State/Regular Grammars

- You've already seen one class of grammars: **regular expressions**
  - A pattern like `^[a-z][0-9]$` corresponds to a grammar which **accepts** (matches) some strings but not others.
  - Can regular languages define *infinite* languages? Yes, e.g.: a*
  - Can regular languages define *arbitrarily complex* languages? No. Cannot match all strings with matched parentheses (recursion/arbitrary nesting).

Context-Free Grammars

- Context-free grammars (CFGs)
  - Aka phrase structure grammars
  - Aka Backus-Naur form (BNF)
- Consist of
  - Rules
  - Terminals
  - Non-terminals

Context-Free Grammars

- Terminals
  - We'll take these to be words (for now)
- Non-Terminals
  - The constituents in a language (e.g., noun phrase)
- Rules
  - Consist of a single non-terminal on the left and any number of terminals and non-terminals on the right

An Example Grammar

Grammar Rules			Examples
S	→	*NP VP*	I + want a morning flight
NP	→	*Pronoun*	I
	|	*Proper-Noun*	Los Angeles
	|	*Det Nominal*	a + flight
Nominal	→	*Nominal Noun*	morning + flight
	|	*Noun*	flights
VP	→	*Verb*	do
	|	*Verb NP*	want + a flight
	|	*Verb NP PP*	leave + Boston + in the morning
	|	*Verb PP*	leaving + on Thursday
PP	→	*Preposition NP*	from + Los Angeles

CFG: Formal definition

N a set of **non-terminal symbols** (or **variables**)

Σ a set of **terminal symbols** (disjoint from N)

R a set of **rules** or productions, each of the form $A \rightarrow \beta$,
where A is a non-terminal,
β is a string of symbols from the infinite set of strings $(\Sigma \cup N)*$

S a designated **start symbol**

Three-fold View of CFGs

- Generator

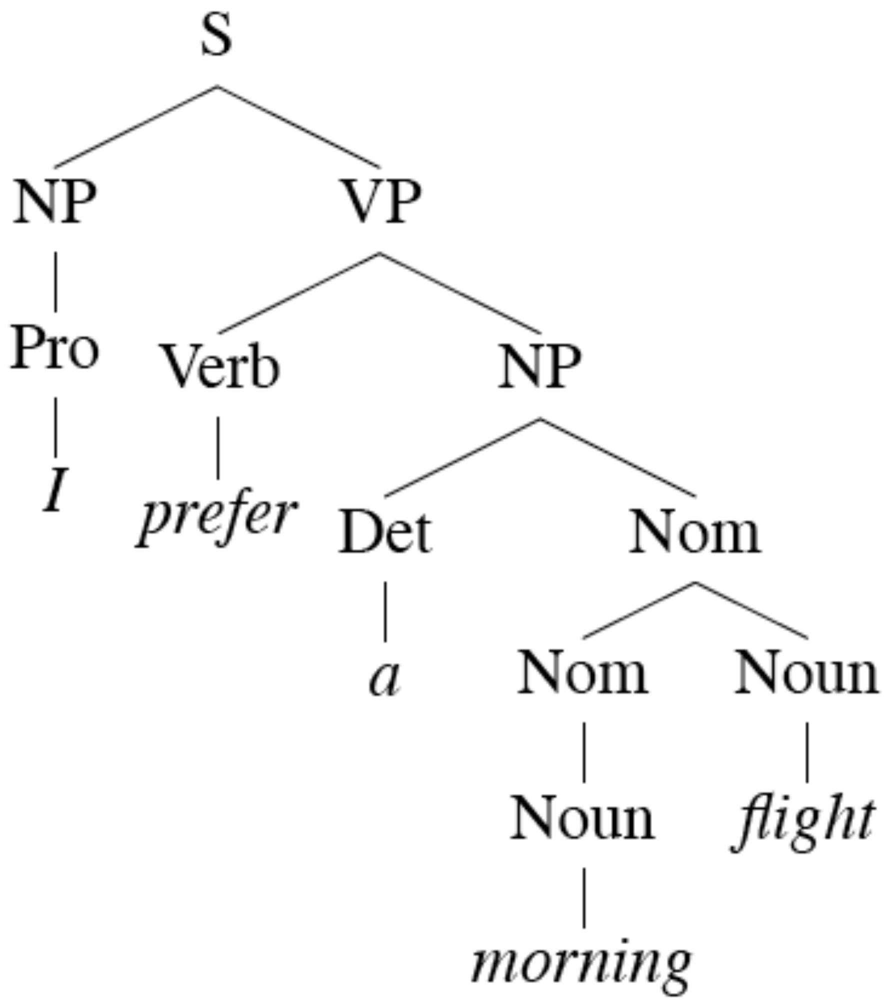
- Acceptor

- Parser

Derivations and Parsing

- A **derivation** is a sequence of rules applications that
  - Covers all tokens in the input string
  - Covers only the tokens in the input string
- **Parsing**: given a string and a grammar, recover the derivation
  - Derivation can be represented as a parse tree
  - Multiple derivations?

Parse Tree: Example



An English Grammar Fragment

- Sentences

- Noun phrases
  - Issue: agreement
- Verb phrases
  - Issue: subcategorization

Sentence Types

- Declaratives: A plane left.

  $S \rightarrow NP\ VP$
- Imperatives: Leave!

  $S \rightarrow VP$
- Yes-No Questions: Did the plane leave?

  $S \rightarrow Aux\ NP\ VP$
- WH Questions: When did the plane leave?

  $S \rightarrow WH\text{-}NP\ Aux\ NP\ VP$

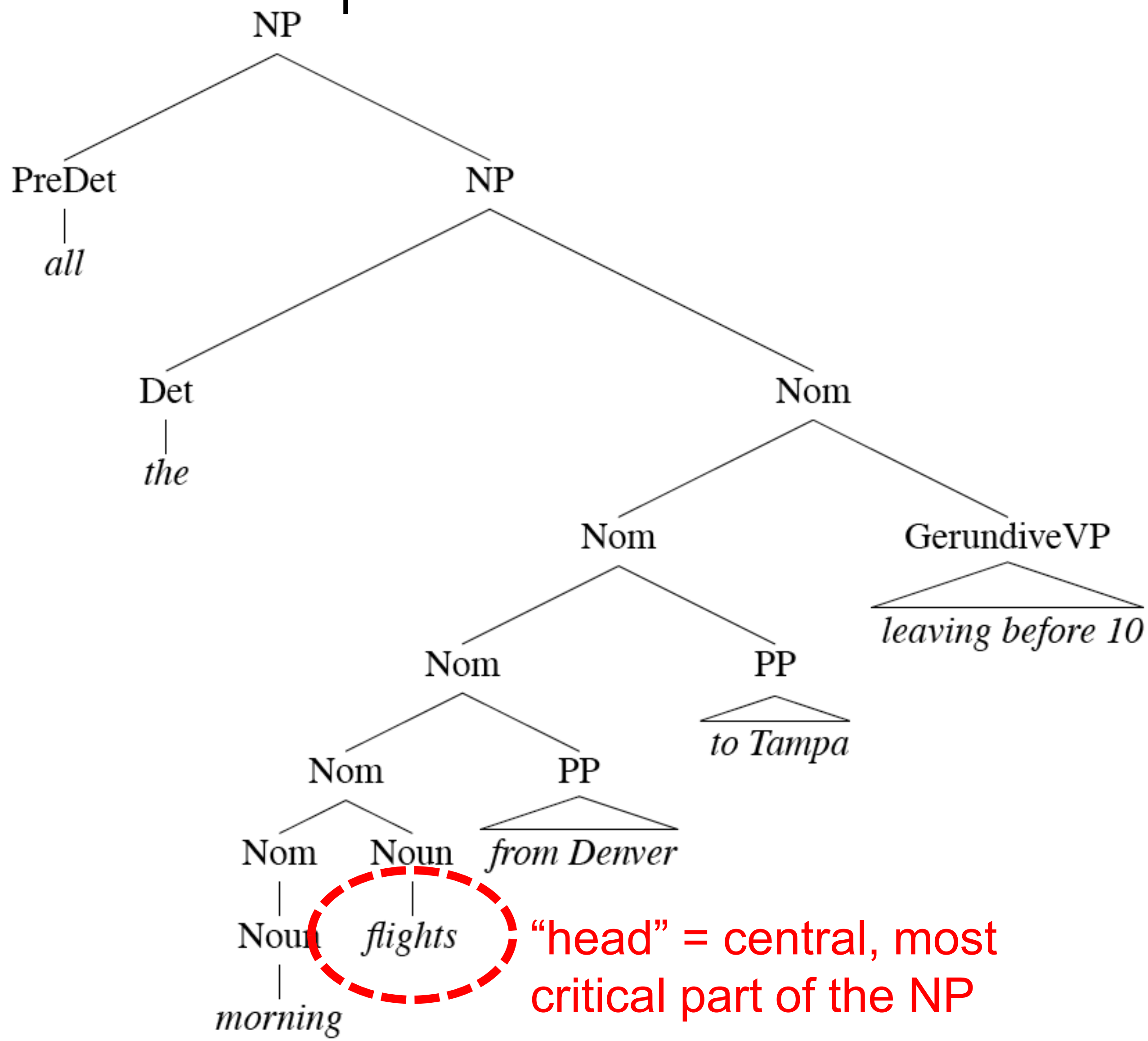
Noun Phrases

- We have seen rules such as

$$
\begin{aligned}
NP &\rightarrow Det\ Nominal \\
NP &\rightarrow ProperNoun \\
Nominal &\rightarrow Noun \mid Nominal\ Noun
\end{aligned}
$$

- But NPs are a bit more complex than that!
  - E.g. "All the morning flights from Denver to Tampa leaving before 10"

A Complex Noun Phrase



Determiners

- Noun phrases can start with determiners...
- Determiners can be
  - Simple lexical items: the, this, a, an, etc. (e.g., “a car”)
  - Or simple possessives (e.g., “John’s car”)
  - Or complex recursive versions thereof (e.g., John’s sister’s husband’s son’s car)

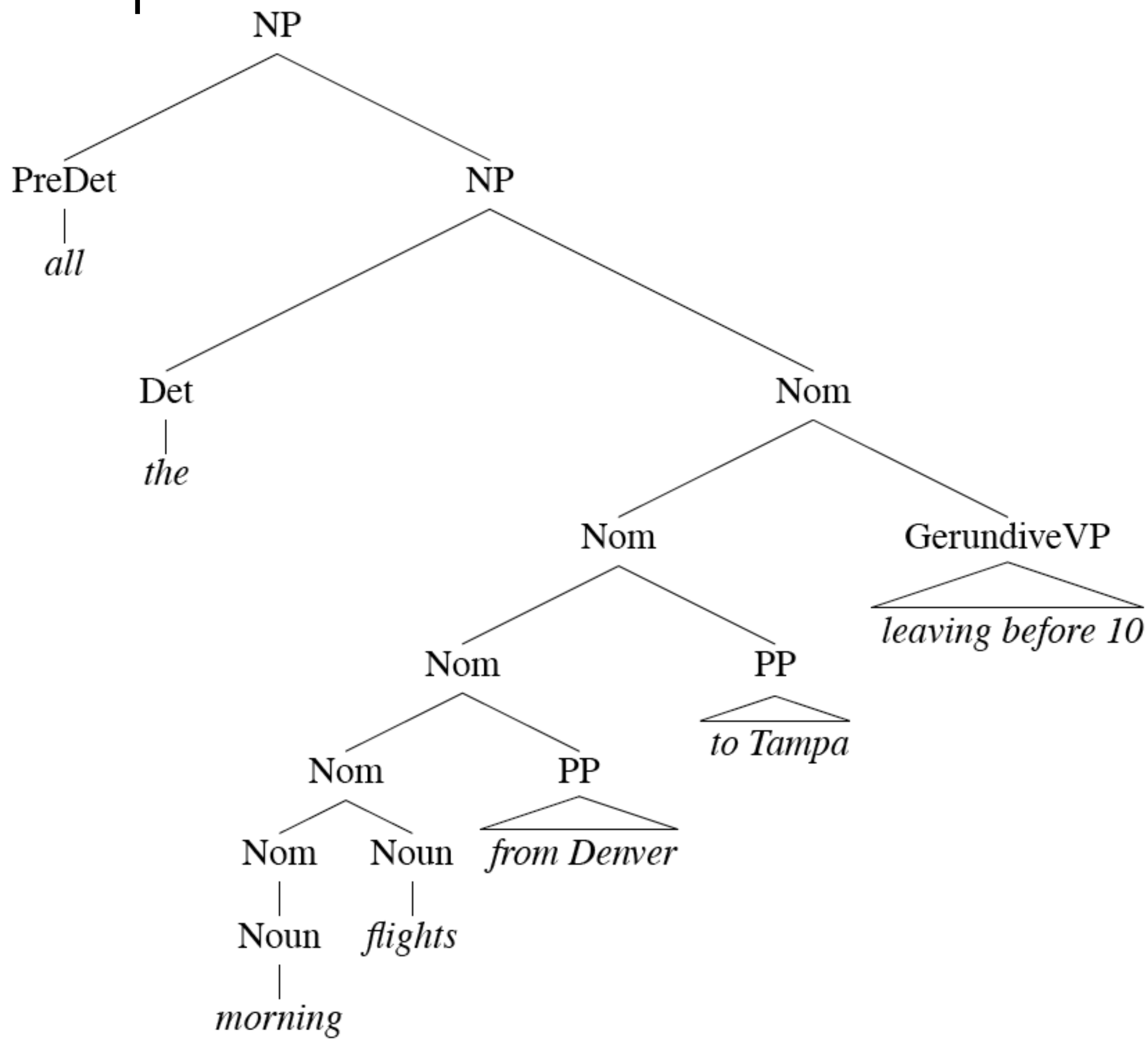
Premodifiers

- Come before the head
- Examples:
  - Cardinals, ordinals, etc. (e.g., “three cars”)
  - Adjectives (e.g., “large car”)
- Ordering constraints
  - “three large cars” vs. “?large three cars”

Postmodifiers

- Come after the head
- Three kinds
  - Prepositional phrases (e.g., “from Seattle”)
  - Non-finite clauses (e.g., “arriving before noon”)
  - Relative clauses (e.g., “that serve breakfast”)
- Similar recursive rules to handle these
  - Nominal $\rightarrow$ Nominal PP
  - Nominal $\rightarrow$ Nominal GerundVP
  - Nominal $\rightarrow$ Nominal RelClause

A Complex Noun Phrase Revisited



Subject and Object

Syntactic (not semantic):

The batter hit the ball [subject is semantic *agent*]
The ball was hit by the batter [subject is semantic *patient*]
The ball was given a whack by the batter
[subject is semantic *recipient*]
{George, the key, the wind} opened the door

Subject ≠ topic:

I just married the most beautiful woman in the world
Now **beans**, I like
As for democracy, I think it's the best form of government

credit: Lori Levin, Archna Bhatia

Subject and Object

- English subjects
  - agree with the verb
  - when pronouns, in nominative case (I/she/he/we/they)
  - omitted from infinitive clauses (I tried _ to read the book, I hoped _ to be chosen)
- English objects
  - when pronouns, in accusative case (me/her/him/us/them)
  - become subjects in passive sentences

credit: Lori Levin, Archna Bhatia

Agreement

- Agreement: constraints that hold among various constituents
- Example, number agreement in English

This flight	*This flights
Those flights	*Those flight
One flight	*One flights
Two flights	*Two flight

Problem

- Our NP rules don't capture agreement constraints
  - Accepts grammatical examples (this flight)
  - Also accepts ungrammatical examples (*these flight)

- Such rules **overgenerate**

Possible CFG Solution

- Encode agreement in non-terminals:
  - SgS $\rightarrow$ SgNP SgVP
  - PlS $\rightarrow$ PlNP PlVP
  - SgNP $\rightarrow$ SgDet SgNom
  - PlNP $\rightarrow$ PlDet PlNom
  - PlVP $\rightarrow$ PlV NP
  - SgVP $\rightarrow$ SgV Np

Verb Phrases

- English verb phrases consists of
  - Head verb
  - Zero or more following constituents (called arguments)
- Sample rules:

VP	$\rightarrow$	$Verb$	disappear
VP	$\rightarrow$	$Verb\ NP$	prefer a morning flight
VP	$\rightarrow$	$Verb\ NP\ PP$	leave Boston in the morning
VP	$\rightarrow$	$Verb\ PP$	leaving on Thursday

Subcategorization

- Not all verbs are allowed to participate in all VP rules
  - We can subcategorize verbs according to argument patterns (sometimes called “frames”)
  - Modern grammars may have 100s of such classes

Subcategorization

- Sneeze: John sneezed
- Find: Please find [a flight to NY]$_{NP}$
- Give: Give [me]$_{NP}$ [a cheaper fare]$_{NP}$
- Help: Can you help [me]$_{NP}$ [with a flight]$_{PP}$
- Prefer: I prefer [to leave earlier]$_{TO\text{-}VP}$
- Told: I was told [United has a flight]$_{S}$
- …

Subcategorization

- Subcategorization at work:
  - *John sneezed the book
  - *I prefer United has a flight
  - *Give with a flight
- But some verbs can participate in multiple frames:
  - I ate
  - I ate the apple
- How do we formally encode these constraints?

Why?

- As presented, the various rules for VPs overgenerate:

$$VP \rightarrow Verb \quad \text{disappear}$$
$$VP \rightarrow Verb\ NP \quad \text{prefer a morning flight}$$
$$VP \rightarrow Verb\ NP\ PP \quad \text{leave Boston in the morning}$$
$$VP \rightarrow Verb\ PP \quad \text{leaving on Thursday}$$

- John sneezed [the book]$_{NP}$
  - Allowed by the second rule…

Possible CFG Solution

- Encode agreement in non-terminals:
  - SgS → SgNP SgVP
  - PlS → PlNP PlVP
  - SgNP → SgDet SgNom
  - PlNP → PlDet PlNom
  - PlVP → PlV NP
  - SgVP → SgV Np
- Can use the same trick for verb subcategorization

Grammar Formalisms

- Linguists have invented grammar formalisms that overcome the limitations of Context-Free Grammars
  - Lexical Functional Grammar
  - Head-Driven Phrase Structure Grammar
  - Combinatory Categorial Grammar
  - Lexicalized Tree-Adjoining Grammar
  - Grammatical Framework
- We sometimes teach a class on these.

credit: Lori Levin

Recap: Three-fold View of CFGs

- Generator
- Acceptor
- Parser

Recap: why use CFGs in NLP?

- CFGs have about just the right amount of machinery to account for basic syntactic structure in English
  - Lot's of issues though...

- Good enough for many applications!
  - But there are many alternatives out there...

DEPENDENCY GRAMMARS

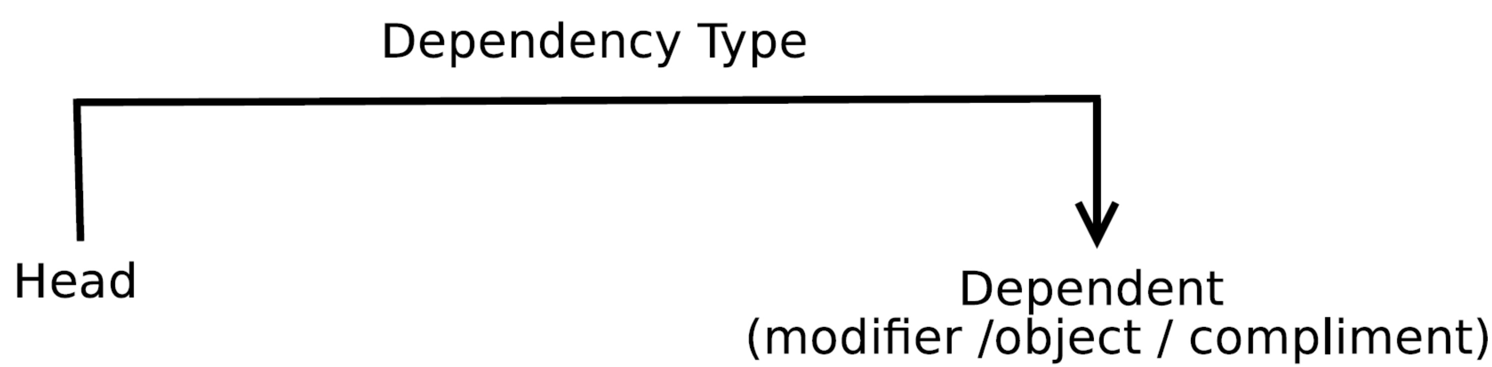
Dependency Grammars

- CFGs focus on constituents
  - Non-terminals don't actually appear in the sentence

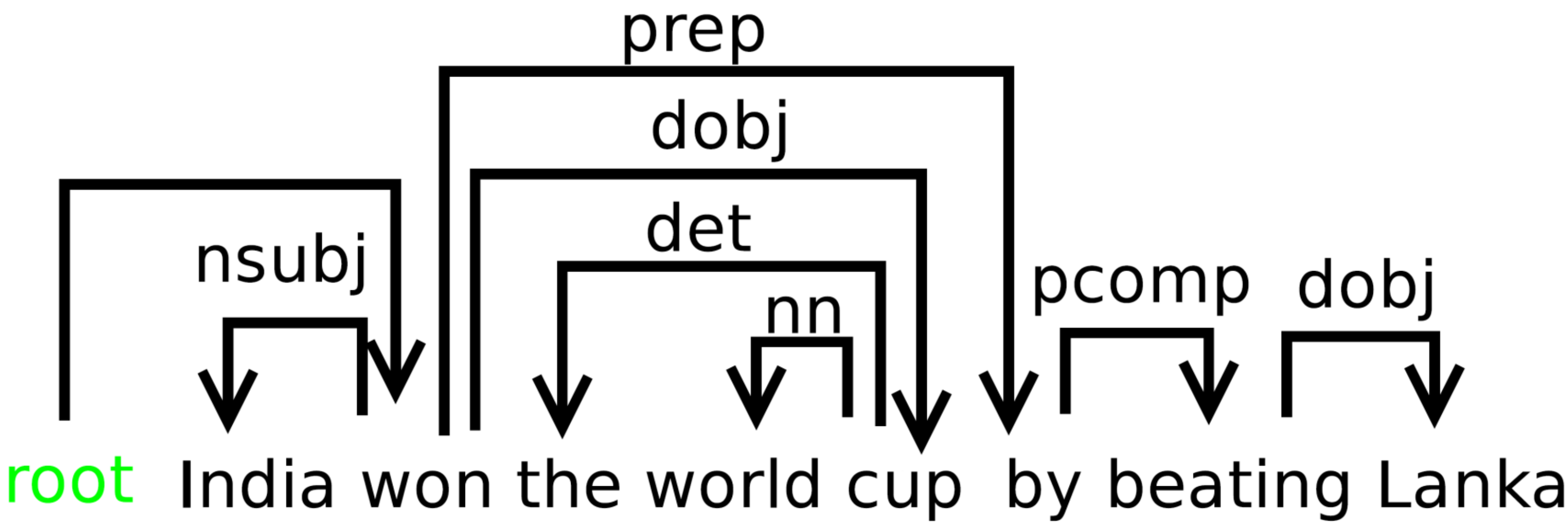
- In dependency grammar, a parse is a graph (usually a tree) where:
  - Nodes represent words
  - Edges represent dependency relations between words (typed or untyped, directed or undirected)

Dependency Grammars

- Syntactic structure = lexical items linked by binary asymmetrical relations called dependencies



Example Dependency Parse



TREEBANKS

Treebanks

- Treebanks are corpora in which each sentence has been paired with a parse tree
- These are generally created:
  - By first parsing the collection with an automatic parser
  - And then having human annotators correct each parse as necessary
- But
  - Detailed annotation guidelines are needed
  - Explicit instructions for dealing with particular constructions

Penn Treebank

- Penn TreeBank is a widely used treebank
  - 1 million words from the Wall Street Journal
- Treebanks implicitly define a grammar for the language

Penn Treebank: Example

```
( (S (‘‘ ‘‘)
    (S-TPC-2
      (NP-SBJ-1 (PRP We) )
      (VP (MD would)
        (VP (VB have)
          (S
            (NP-SBJ (-NONE- *-1) )
            (VP (TO to)
              (VP (VB wait)
                (SBAR-TMP (IN until)
                  (S
                    (NP-SBJ (PRP we) )
                    (VP (VBP have)
                      (VP (VBN collected)
                        (PP-CLR (IN on)
                          (NP (DT those)(NNS assets)))))))))))))
    (, ,) (’’ ’’)
    (NP-SBJ (PRP he) )
    (VP (VBD said)
      (S (-NONE- *T*-2) ))
    (. .) ))
```

Treebank Grammars

- Such grammars tend to be very flat
  - Recursion avoided to ease annotators burden

- Penn Treebank has 4500 different rules for VPs, including…
  - VP $\rightarrow$ VBD PP
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Summary

- Syntax & Grammar
- Two views of syntactic structures
  - Context-Free Grammars
  - Dependency grammars
  - Can be used to capture various facts about the structure of language (but not all!)
- Treebanks as an important resource for NLP