Speech and Language Processing

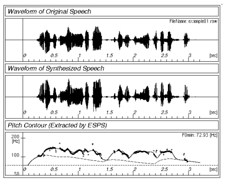
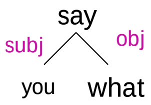
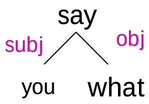
Formal Grammars

Chapter 10

Today

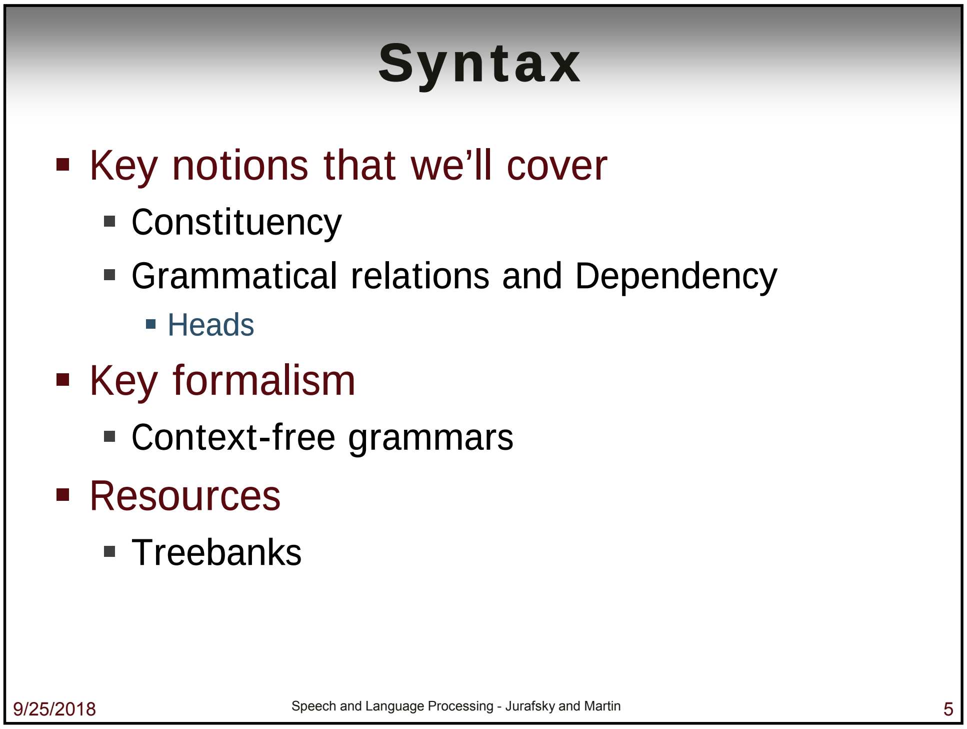
- Formal Grammars
  - Context-free grammar
  - Grammars for English
  - Treebanks
  - Dependency grammars

Simple View of Linguistic Analysis

Phonology		⇔	/waddyasai/
Morphology	/waddyasai/	⇔	what did you say
Syntax	what did you say	⇔	
Semantics		⇔	P[λx. say(you, x)]

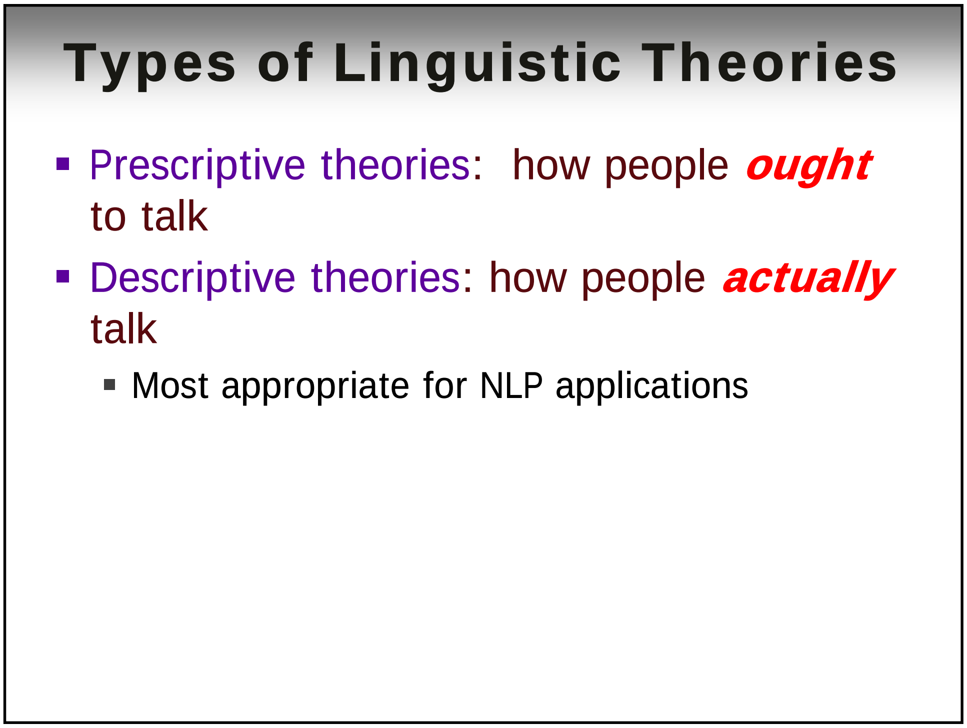
Syntax

- Grammars (and parsing) are key components in many applications
  - Grammar checkers
  - Dialogue management
  - Question answering
  - Information extraction
  - Machine translation



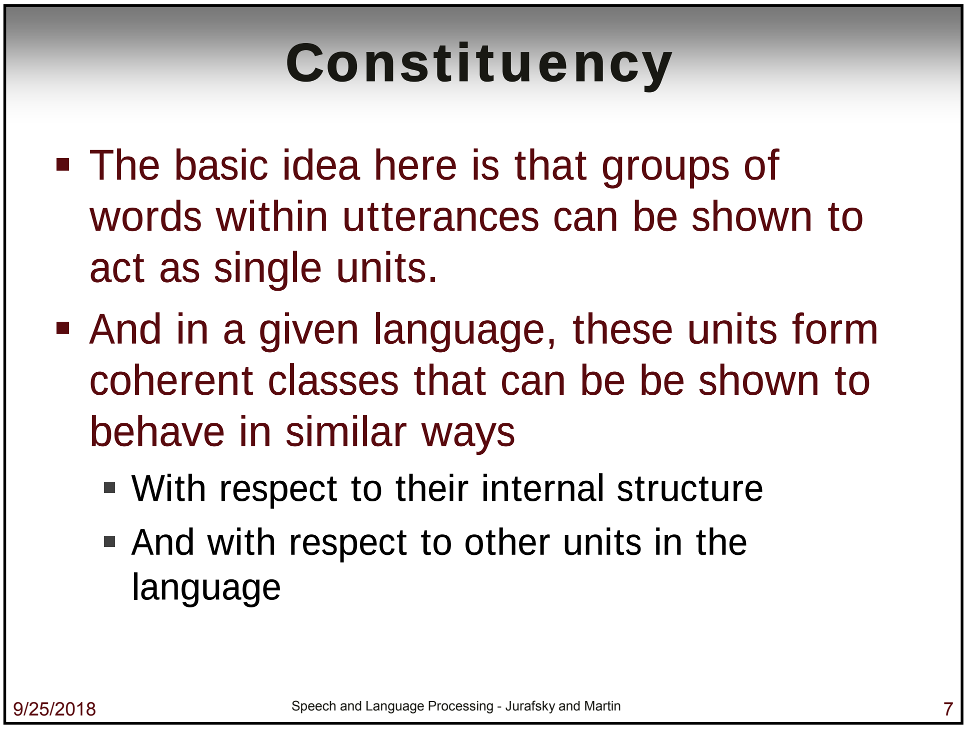
Syntax

- Key notions that we’ll cover
  - Constituency
  - Grammatical relations and Dependency
    - Heads
- Key formalism
  - Context-free grammars
- Resources
  - Treebanks



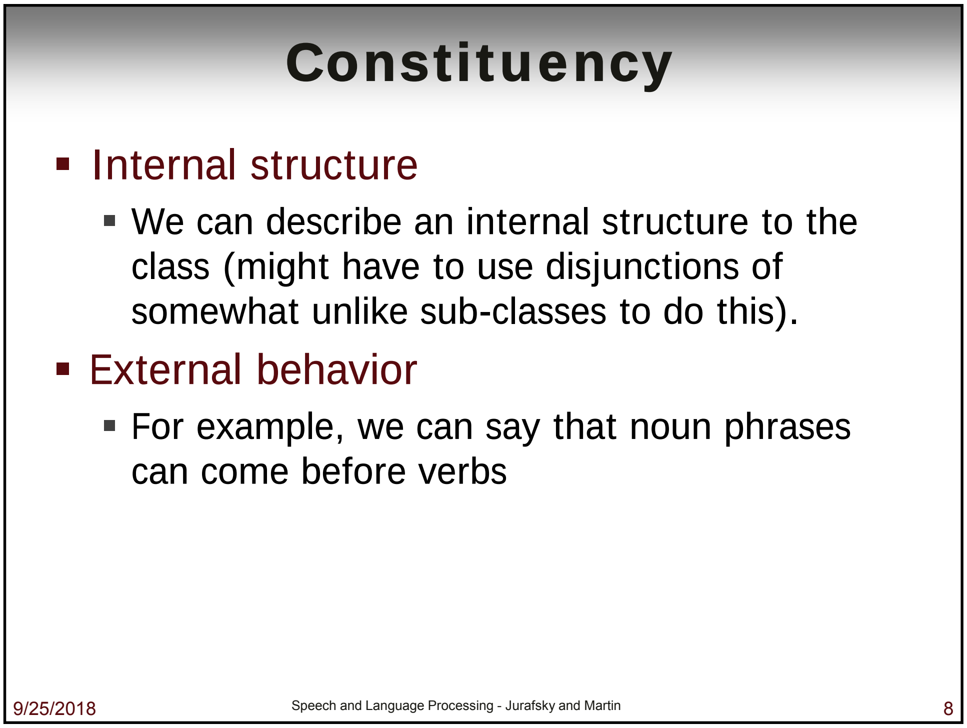
Types of Linguistic Theories

- Prescriptive theories: how people ***ought*** to talk
- Descriptive theories: how people ***actually*** talk
  - Most appropriate for NLP applications



Constituency

- The basic idea here is that groups of words within utterances can be shown to act as single units.
- And in a given language, these units form coherent classes that can be be shown to behave in similar ways
  - With respect to their internal structure
  - And with respect to other units in the language

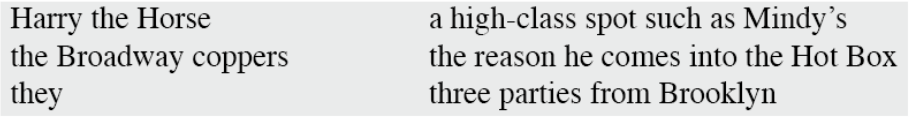


Constituency

- Internal structure
  - We can describe an internal structure to the class (might have to use disjunctions of somewhat unlike sub-classes to do this).
- External behavior
  - For example, we can say that noun phrases can come before verbs

Constituency

- For example, it makes sense to the say that the following are all ***noun phrases*** in English...

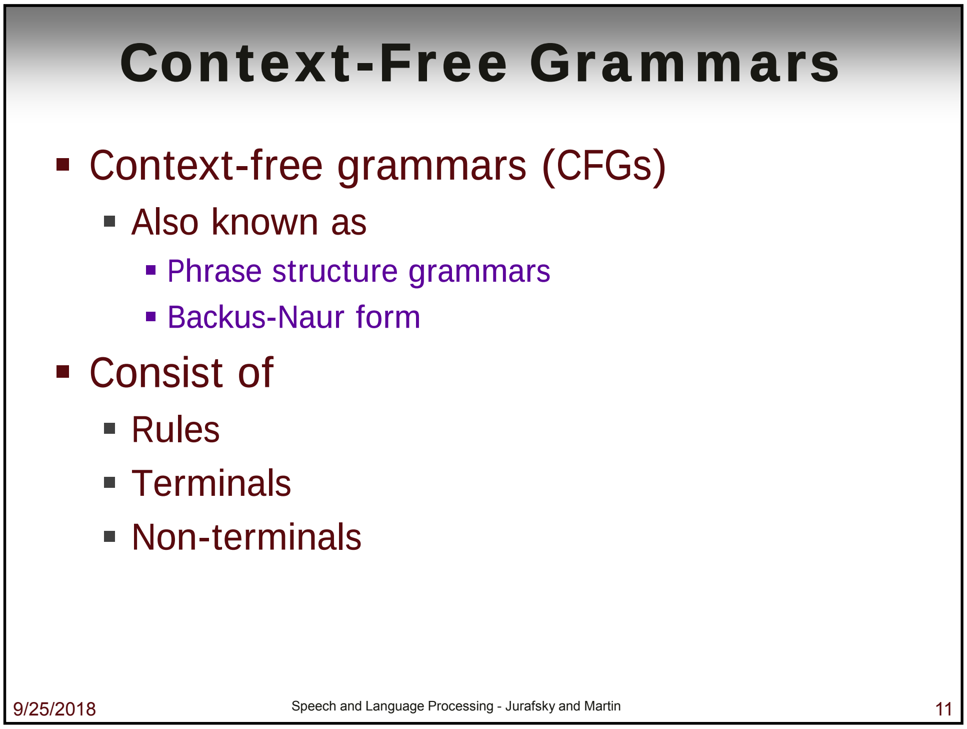


Harry the Horse	a high-class spot such as Mindy's
the Broadway coppers	the reason he comes into the Hot Box
they	three parties from Brooklyn

- Why? One piece of evidence is that they can all precede verbs.
  - This is external evidence

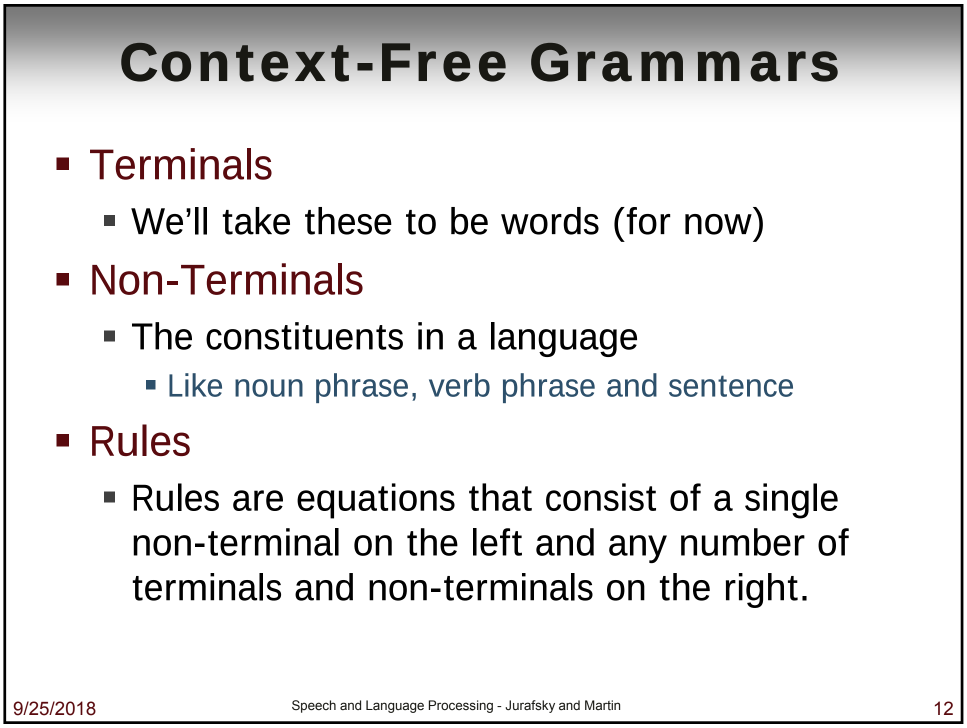
Grammars and Constituency

- Of course, there's nothing easy or obvious about how we come up with right set of constituents and the rules that govern how they combine...
- That's why there are so many different theories of grammar and competing analyses of the same data.
- The approach to grammar, and the analyses, adopted here are very generic (and don't correspond to any modern linguistic theory of grammar).



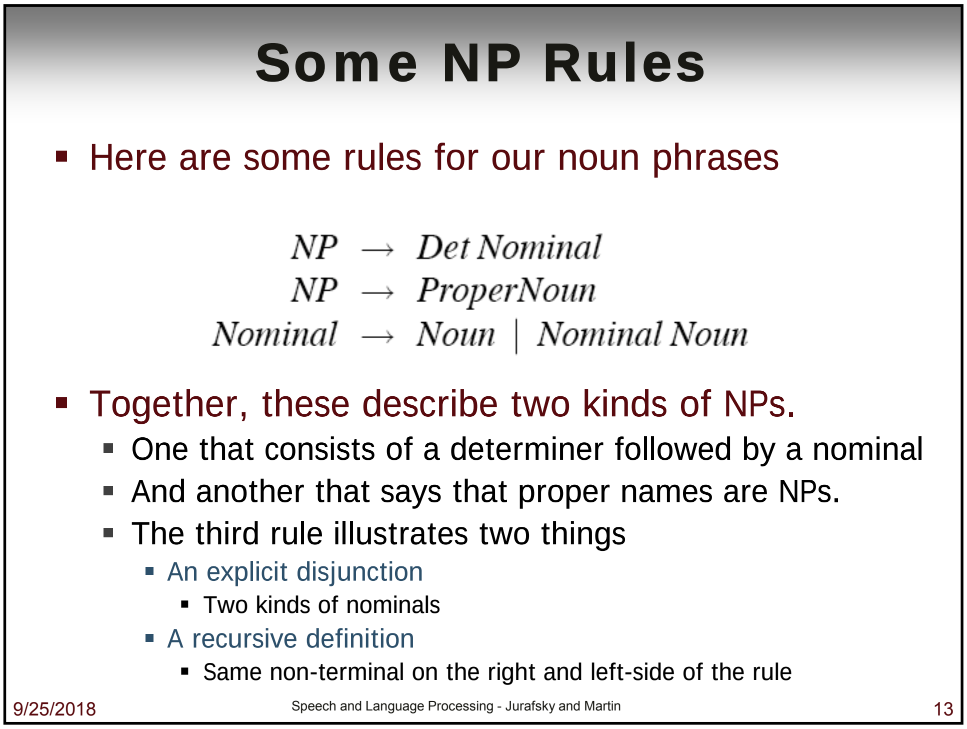
Context-Free Grammars

- Context-free grammars (CFGs)
  - Also known as
    - Phrase structure grammars
    - Backus-Naur form
- 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
    - Like noun phrase, verb phrase and sentence
- Rules
  - Rules are equations that consist of a single non-terminal on the left and any number of terminals and non-terminals on the right.

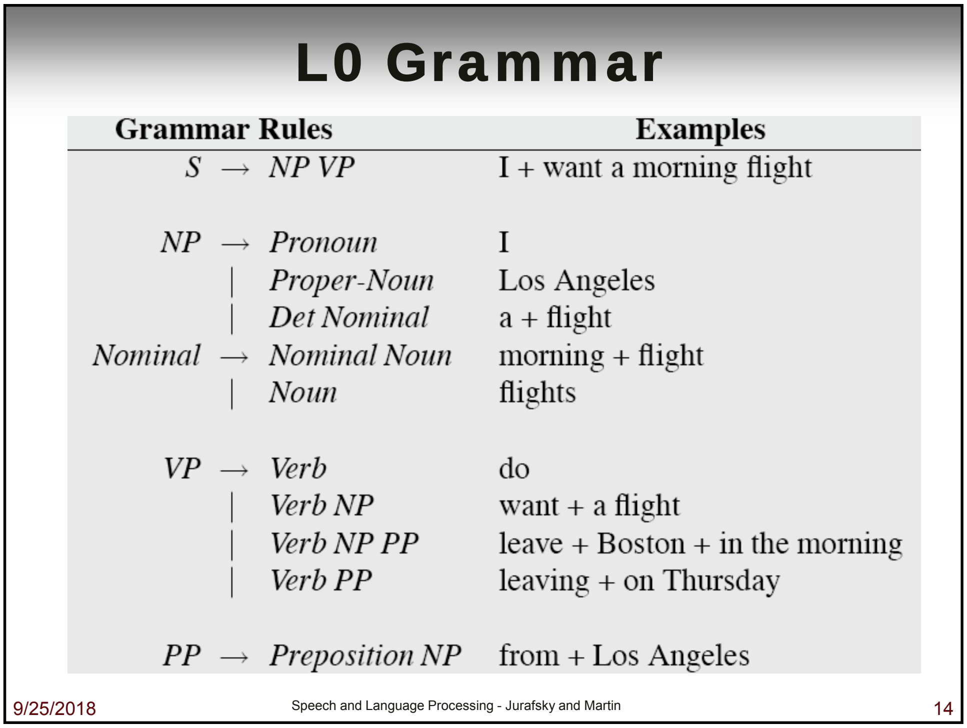


Some NP Rules

- Here are some rules for our noun phrases

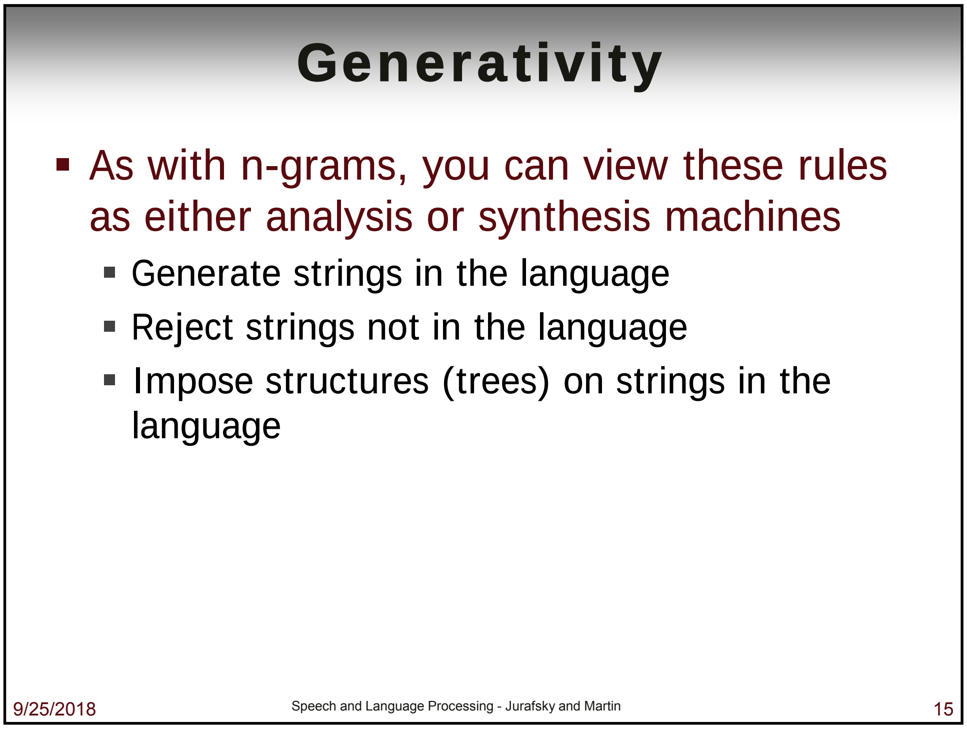
$$\begin{aligned} NP &\rightarrow Det\ Nominal \\ NP &\rightarrow ProperNoun \\ Nominal &\rightarrow Noun \mid Nominal\ Noun \end{aligned}$$

- Together, these describe two kinds of NPs.
  - One that consists of a determiner followed by a nominal
  - And another that says that proper names are NPs.
  - The third rule illustrates two things
    - An explicit disjunction
      - Two kinds of nominals
    - A recursive definition
      - Same non-terminal on the right and left-side of the rule



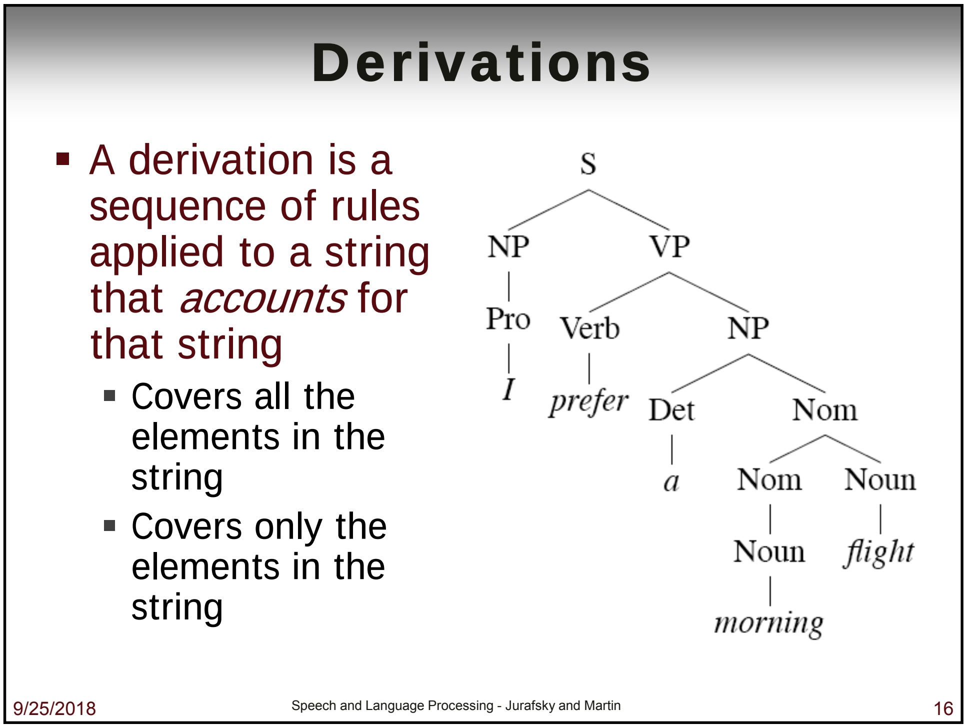
L0 Grammar

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



Generativity

- As with n-grams, you can view these rules as either analysis or synthesis machines
  - Generate strings in the language
  - Reject strings not in the language
  - Impose structures (trees) on strings in the language



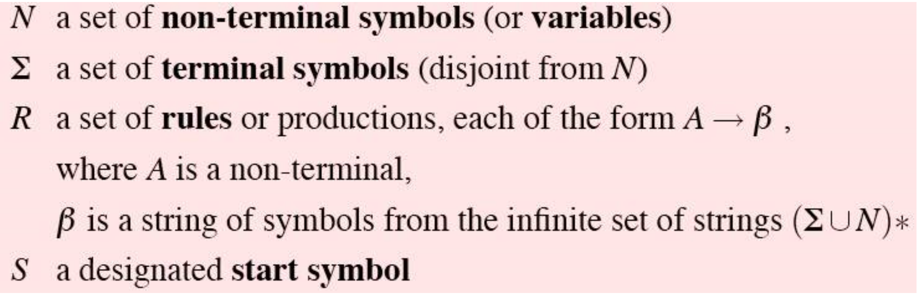
Derivations

- A derivation is a sequence of rules applied to a string that *accounts* for that string
  - Covers all the elements in the string
  - Covers only the elements in the string

S
NP
VP
Pro
Verb
NP
I
prefer
Det
Nom
a
Nom
Noun
Noun
flight
morning

Definition

- More formally, a CFG consists of



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

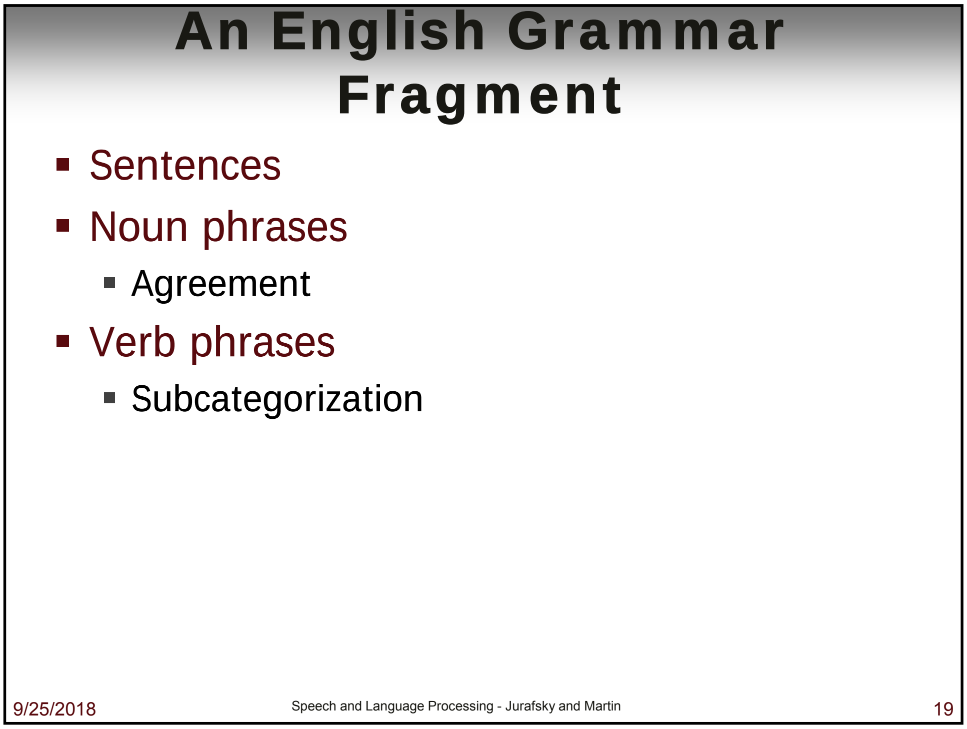
Σ a set of **terminal symbols** (disjoint from N)

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**

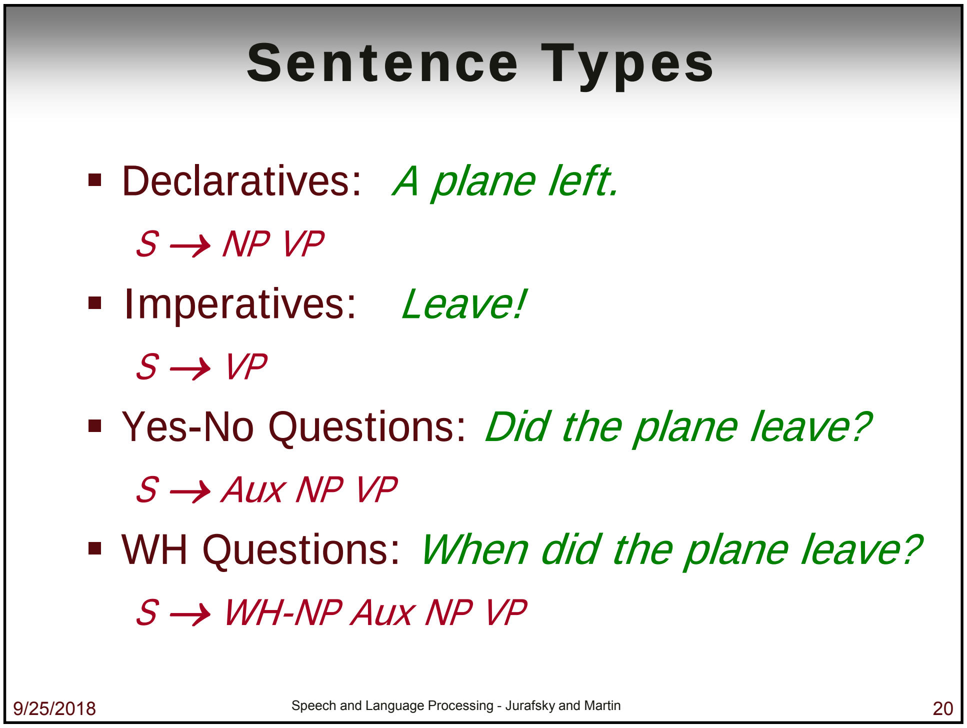
Parsing

- Parsing is the process of taking a string and a grammar and returning a (multiple?) parse tree(s) for that string
  - There are languages we can capture with CFGs that we can't capture with regular expressions
  - There are properties that we can capture that we can't capture with n-grams



An English Grammar Fragment

- Sentences
- Noun phrases
  - Agreement
- Verb phrases
  - Subcategorization



Sentence Types

- Declaratives: *A plane left.*

  S → NP VP
- Imperatives: *Leave!*

  S → VP
- Yes-No Questions: *Did the plane leave?*

  S → Aux NP VP
- WH Questions: *When did the plane leave?*

  S → WH-NP Aux NP VP

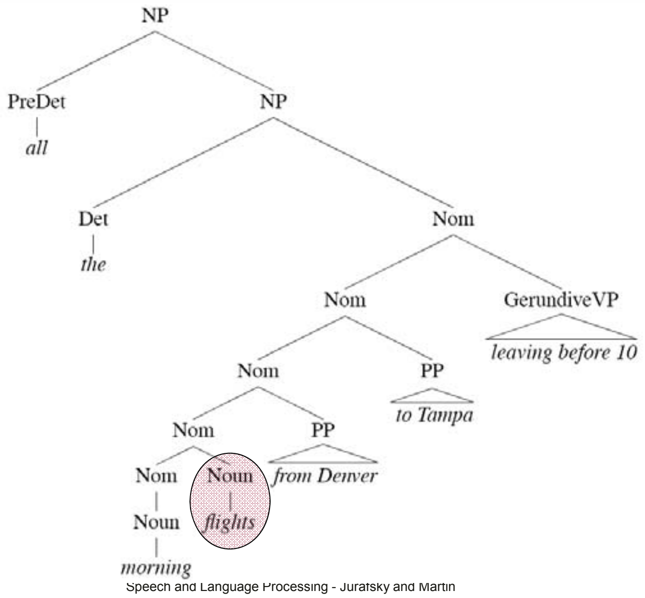
Noun Phrases

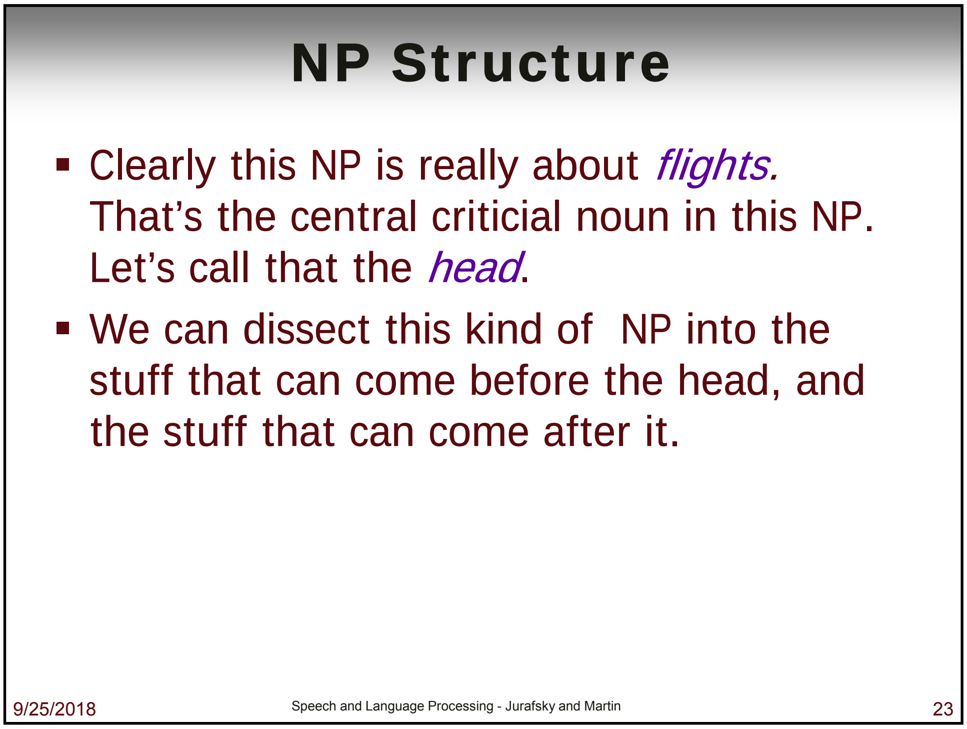
- Let's consider the following rule in more detail...

  NP → Det Nominal

- Most of the complexity of English noun phrases is hidden in this rule.
- Consider the derivation for the following example
  - *All the morning flights from Denver to Tampa leaving before 10*

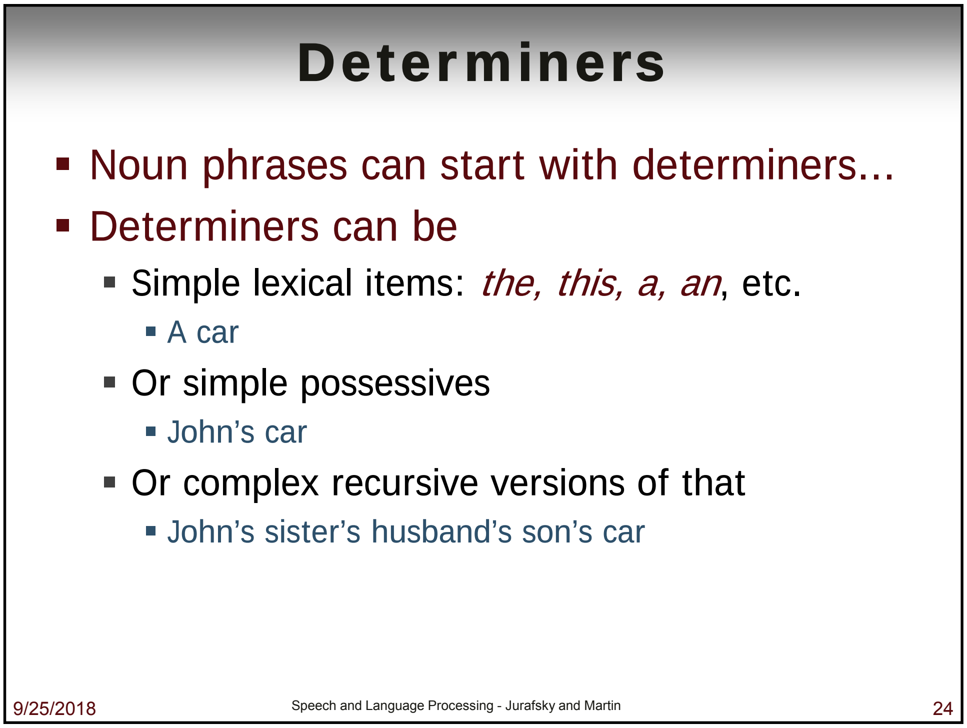
Noun Phrases





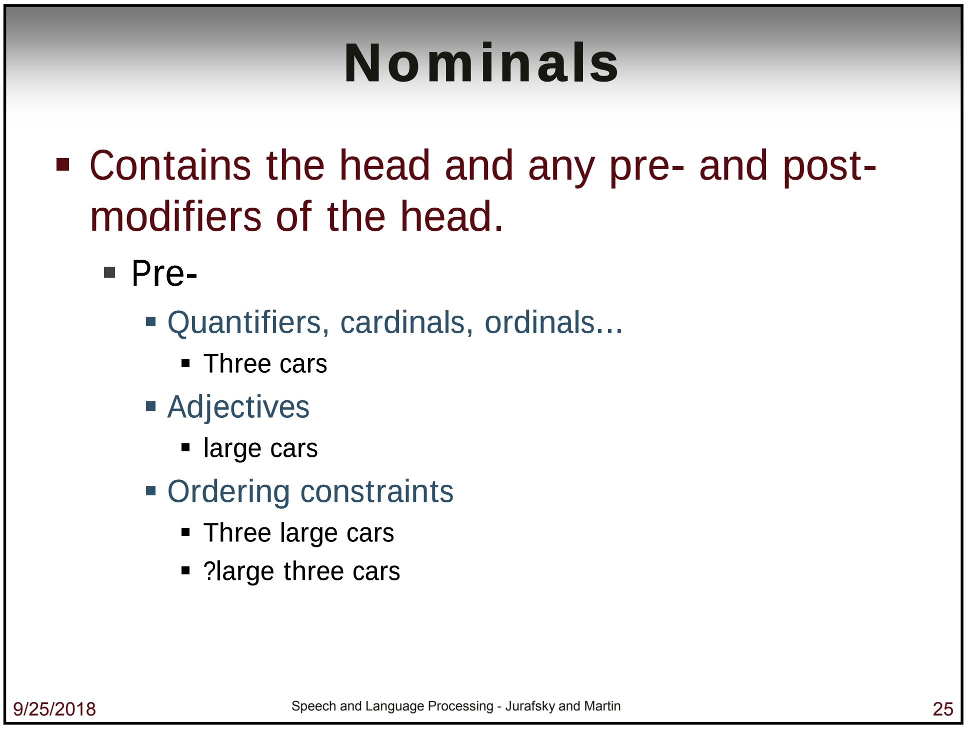
NP Structure

- Clearly this NP is really about *flights.* That’s the central criticial noun in this NP. Let’s call that the *head*.
- We can dissect this kind of NP into the stuff that can come before the head, and the stuff that can come after it.



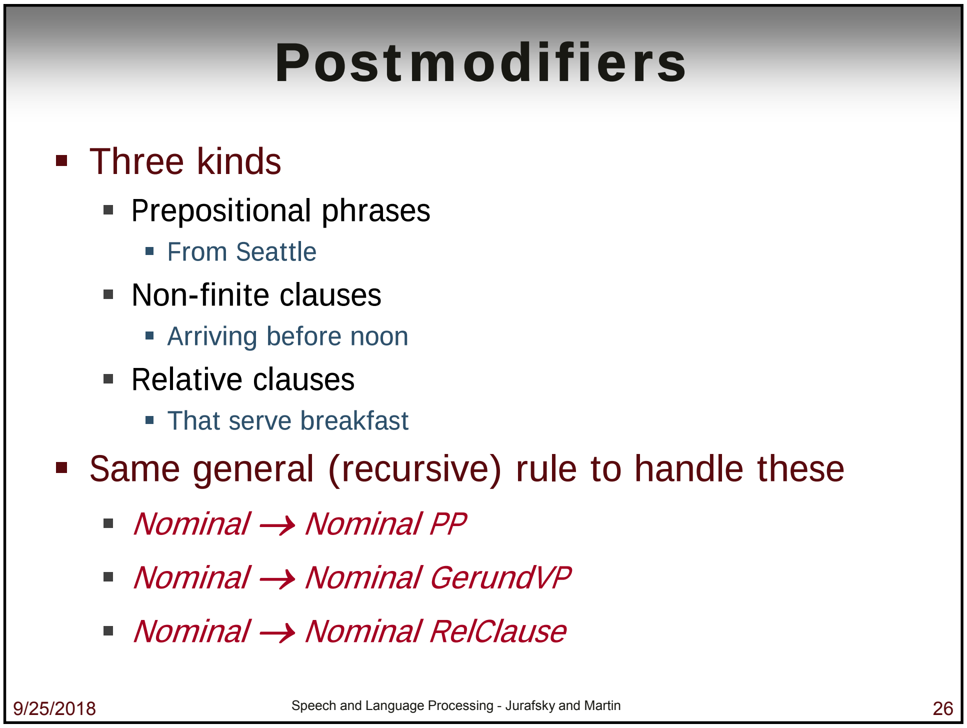
Determiners

- Noun phrases can start with determiners...
- Determiners can be
  - Simple lexical items: *the, this, a, an*, etc.
    - A car
  - Or simple possessives
    - John’s car
  - Or complex recursive versions of that
    - John’s sister’s husband’s son’s car



Nominals

- Contains the head and any pre- and post-modifiers of the head.
  - Pre-
    - Quantifiers, cardinals, ordinals...
      - Three cars
    - Adjectives
      - large cars
    - Ordering constraints
      - Three large cars
      - ?large three cars



Postmodifiers

- Three kinds
  - Prepositional phrases
    - From Seattle
  - Non-finite clauses
    - Arriving before noon
  - Relative clauses
    - That serve breakfast
- Same general (recursive) rule to handle these
  - *Nominal* → *Nominal PP*
  - *Nominal* → *Nominal GerundVP*
  - *Nominal* → *Nominal RelClause*

Agreement

- By ***agreement***, we have in mind constraints that hold among various constituents that take part in a rule or set of rules
- For example, in English, determiners and the head nouns in NPs have to agree in their number.

This flight	*This flights
Those flights	*Those flight

Problem

- Our earlier NP rules are clearly deficient since they don't capture this constraint
  - *NP → Det Nominal*
    - Accepts, and assigns correct structures, to grammatical examples (*this flight*)
    - But its also happy with incorrect examples (*these flight)
  - Such a rule is said to *overgenerate.*
  - We'll come back to this in a bit

NP Constituency: Review

- NPs can all appear before a verb:
  - Some big dogs and some little dogs are going around in cars…
  - Big dogs, little dogs, red dogs, blue dogs, yellow dogs, green dogs, black dogs, and white dogs are all at a dog party!
  - I do not
- But individual words can’t always appear before verbs:
  - *little are going…
  - *blue are…
  - *and are
- Must be able to state generalizations like:
  - Noun phrases occur before verbs

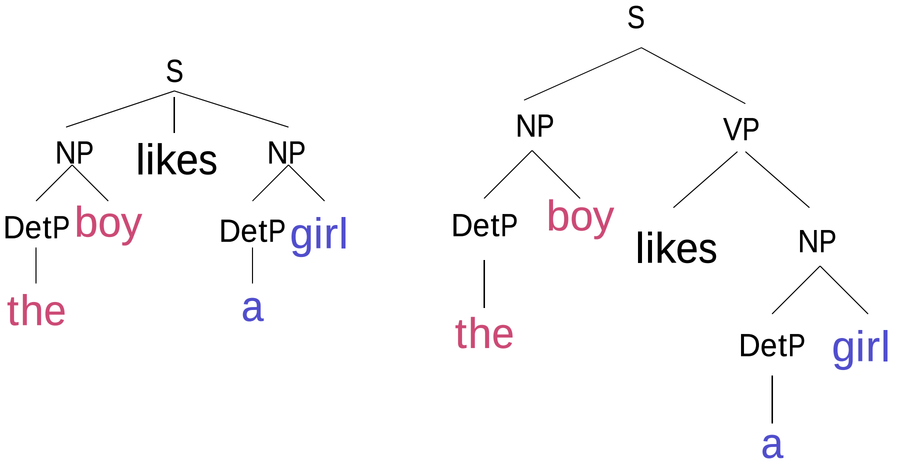
PP Constituency

- Preposing and postposing:
  - Under a tree is a yellow dog.
  - A yellow dog is under a tree.
- But not:
  - *Under, is a yellow dog a tree.
  - *Under a is a yellow dog tree.
- Prepositional phrases notable for ambiguity in attachment
  - I saw a man on a hill with a telescope.

VP Constituency

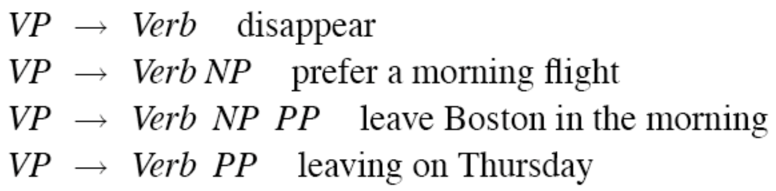
- Existence of VP is a linguistic (i.e., empirical) claim, not a methodological claim
- Syntactic evidence
  - VP-fronting (and quickly clean the carpet he did!)
  - VP-ellipsis (He cleaned the carpet quickly, and so did she)
  - Adjuncts can occur before and after VP, but not ***in*** VP (He often eats beans, *he eats often beans)

VP Constituency



Verb Phrases

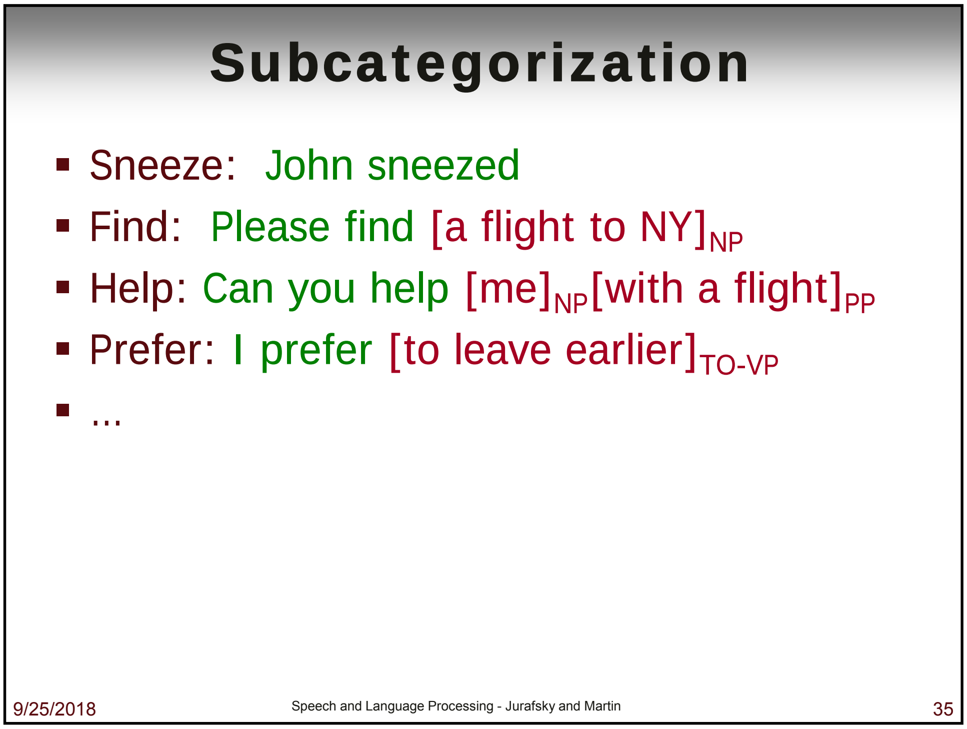
- English *VP*s consist of a head verb along with 0 or more following constituents which we'll call *arguments*.



VP	→	*Verb*	disappear
VP	→	*Verb NP*	prefer a morning flight
VP	→	*Verb NP PP*	leave Boston in the morning
VP	→	*Verb PP*	leaving on Thursday

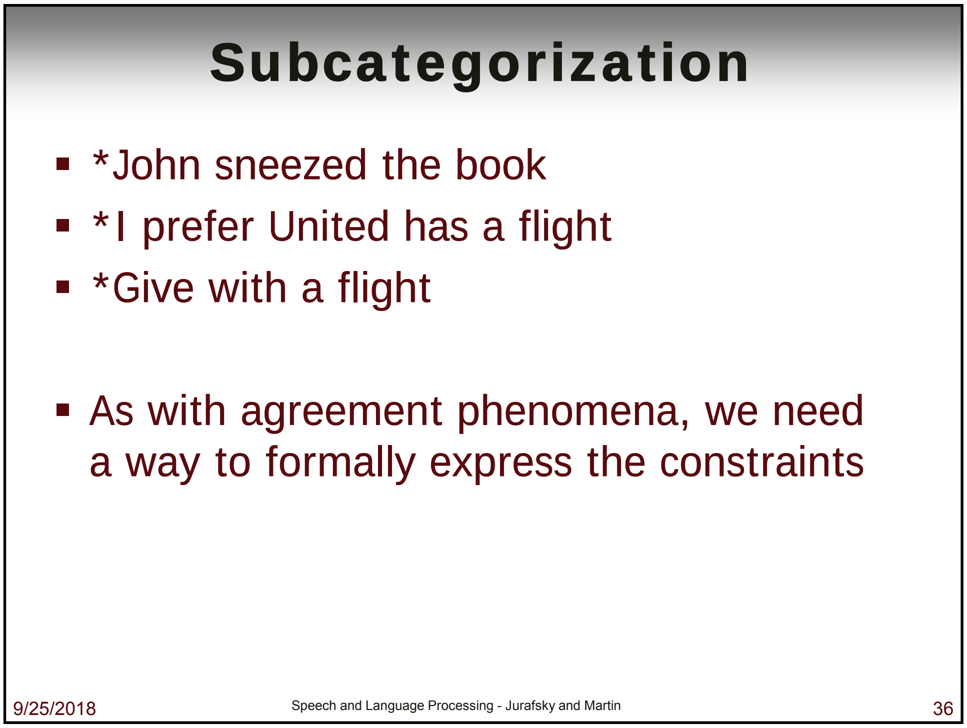
Subcategorization

- But, even though there are many valid VP rules in English, not all verbs are allowed to participate in all those VP rules.
- We can subcategorize the verbs in a language according to the sets of VP rules that they participate in.
- This is a modern take on the traditional notion of transitive/intransitive.
- Modern grammars may have 100s or such classes.



Subcategorization

- Sneeze: John sneezed
- Find: Please find [a flight to NY]$_{NP}$
- Help: Can you help [me]$_{NP}$[with a flight]$_{PP}$
- Prefer: I prefer [to leave earlier]$_{TO\text{-}VP}$
- ...



Subcategorization

- *John sneezed the book
- *I prefer United has a flight
- *Give with a flight
- As with agreement phenomena, we need a way to formally express the constraints

Why?

- Right now, the various rules for VPs *overgenerate*.
  - They permit the presence of strings containing verbs and arguments that don’t go together
  - For example
  - VP -> V NP therefore

    Sneezed the book is a VP since “sneeze” is a verb and “the book” is a valid NP

Possible CFG Solution

- Possible solution for agreement.
- Can use the same trick for all the verb/VP classes.

- SgS -> SgNP SgVP
- PlS -> PlNp PlVP
- SgNP -> SgDet SgNom
- PlNP -> PlDet PlNom
- PlVP -> PlV NP
- SgVP ->SgV Np
- …

CFG Solution for Agreement

- It works and stays within the power of CFGs
- But its ugly
- And it doesn’t scale all that well because of the interaction among the various constraints explodes the number of rules in our grammar.

The Point

- CFGs appear to be just about what we need to account for a lot of basic syntactic structure in English.
- But there are problems
  - That can be dealt with adequately, although not elegantly, by staying within the CFG framework.
- There are simpler, more elegant, solutions that take us out of the CFG framework (beyond its formal power)
  - LFG, HPSG, Construction grammar, XTAG, etc.
  - Prior edition explores the unification approach

Treebanks

- Treebanks are corpora in which each sentence has been paired with a parse tree (presumably the right one).
- These are generally created
  - By first parsing the collection with an automatic parser
  - And then having human annotators correct each parse as necessary.
- This generally requires detailed annotation guidelines that provide a POS tagset, a grammar and instructions for how to deal with particular grammatical constructions.

Penn Treebank

- Penn TreeBank is a widely used treebank.

- Most well known is the Wall Street Journal section of the Penn TreeBank.
  - 1 M words from the 1987-1989 Wall Street Journal.

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

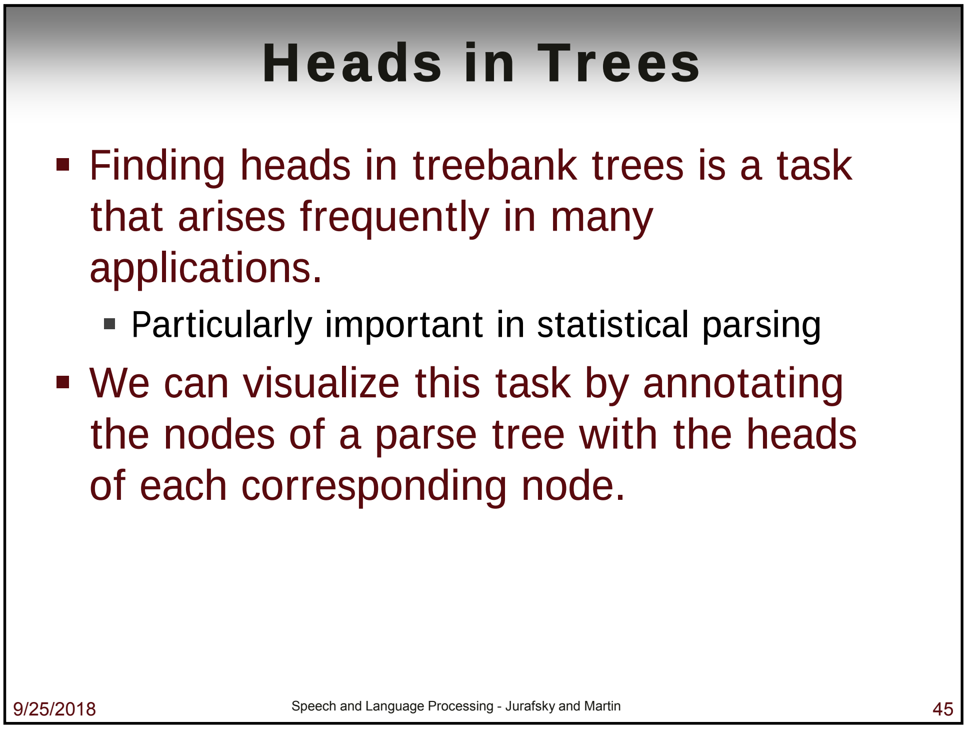
Treebank Grammars

- Treebanks implicitly define a grammar for the language covered in the treebank.
- Simply take the local rules that make up the sub-trees in all the trees in the collection and you have a grammar.
- Not complete, but if you have decent size corpus, you'll have a grammar with decent coverage.

Treebank Grammars

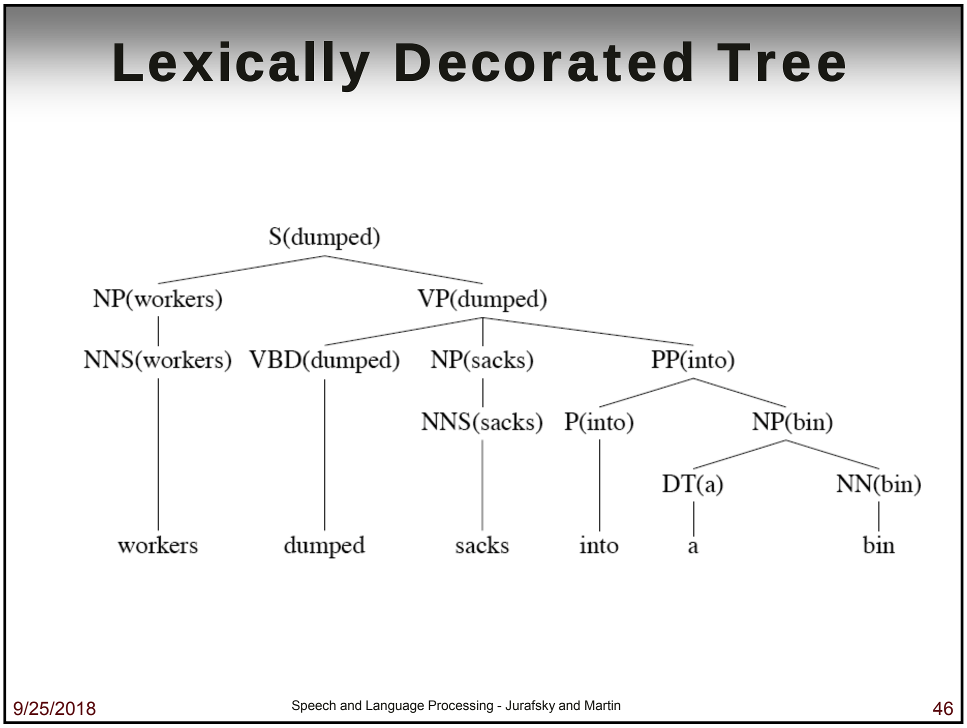
- Such grammars tend to be very flat due to the fact that they tend to avoid recursion.
  - To ease the annotators burden
- For example, the Penn Treebank has 4500 different rules for VPs. Among them...

```
VP → VBD PP
VP → VBD PP PP
VP → VBD PP PP PP
VP → VBD PP PP PP PP
```



Heads in Trees

- Finding heads in treebank trees is a task that arises frequently in many applications.
  - Particularly important in statistical parsing
- We can visualize this task by annotating the nodes of a parse tree with the heads of each corresponding node.

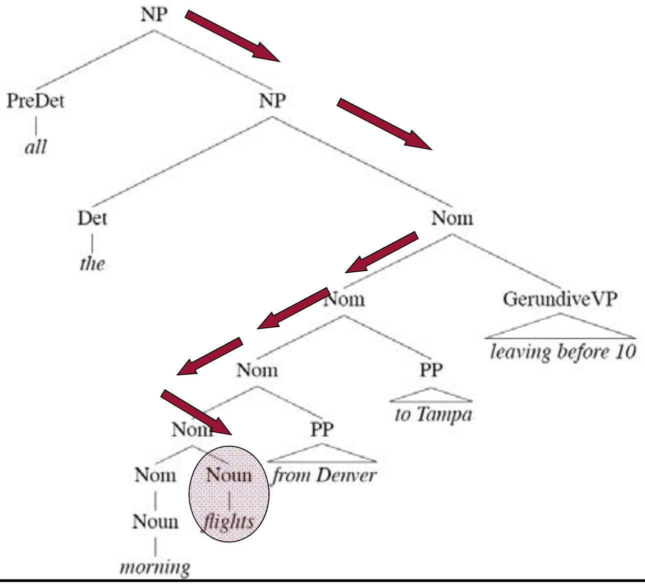


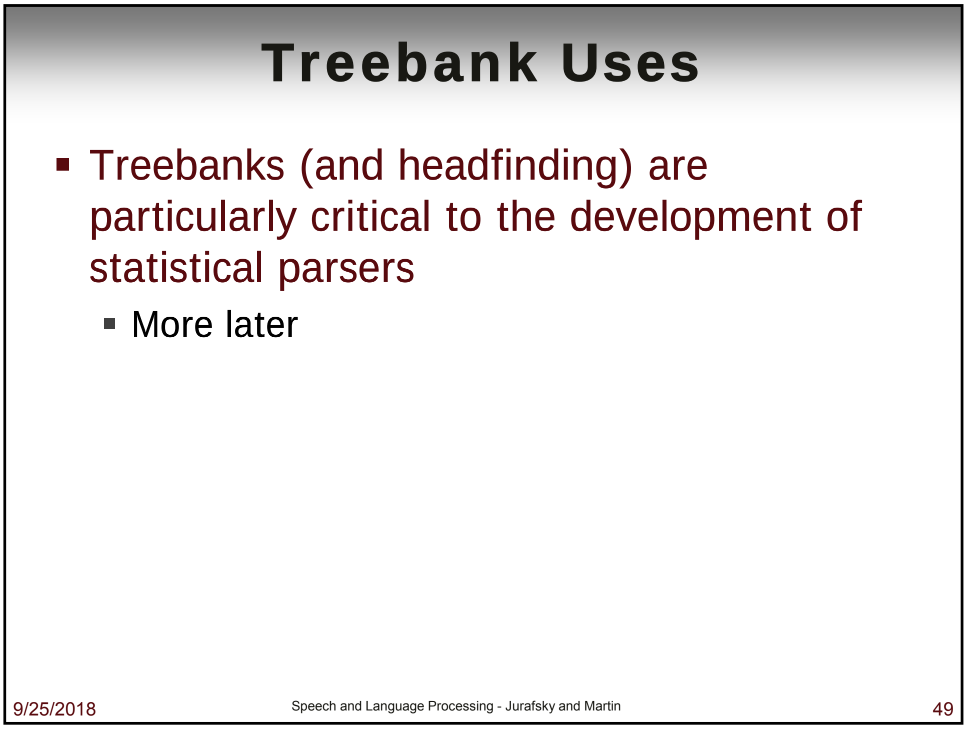
Lexically Decorated Tree

Head Finding

- The standard way to do head finding is to use a simple set of tree traversal rules specific to each non-terminal in the grammar.

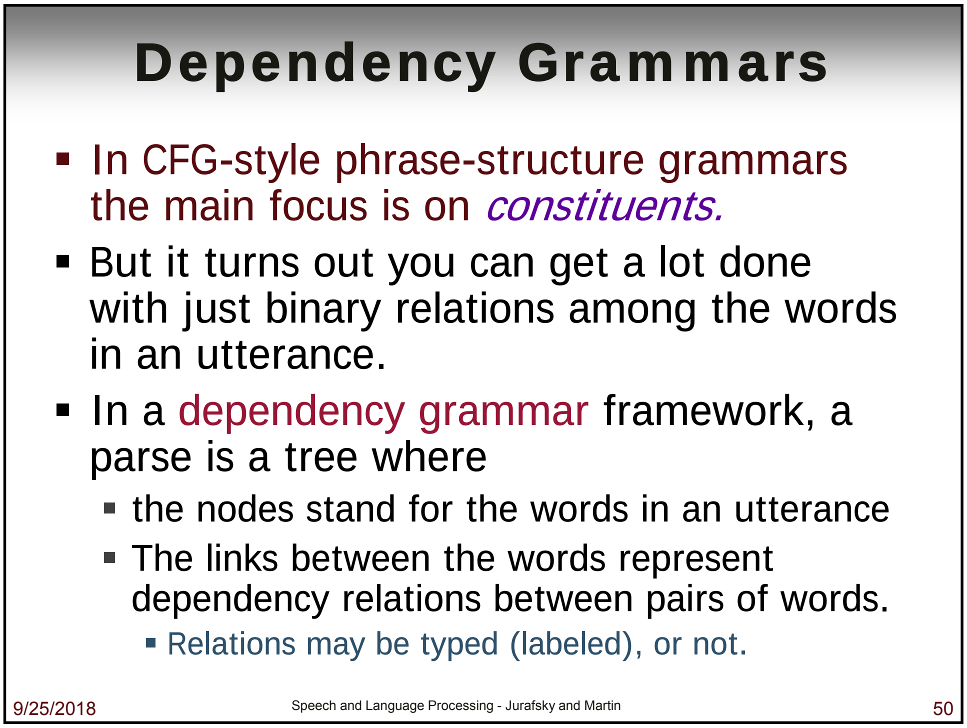
Noun Phrases





Treebank Uses

- Treebanks (and headfinding) are particularly critical to the development of statistical parsers
  - More later



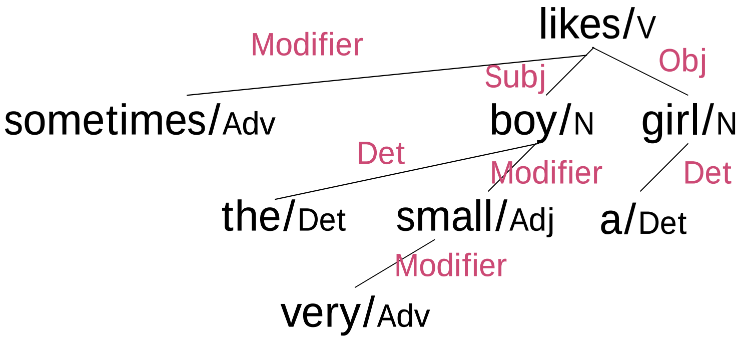
Dependency Grammars

- In CFG-style phrase-structure grammars the main focus is on *constituents.*
- But it turns out you can get a lot done with just binary relations among the words in an utterance.
- In a dependency grammar framework, a parse is a tree where
  - the nodes stand for the words in an utterance
  - The links between the words represent dependency relations between pairs of words.
    - Relations may be typed (labeled), or not.

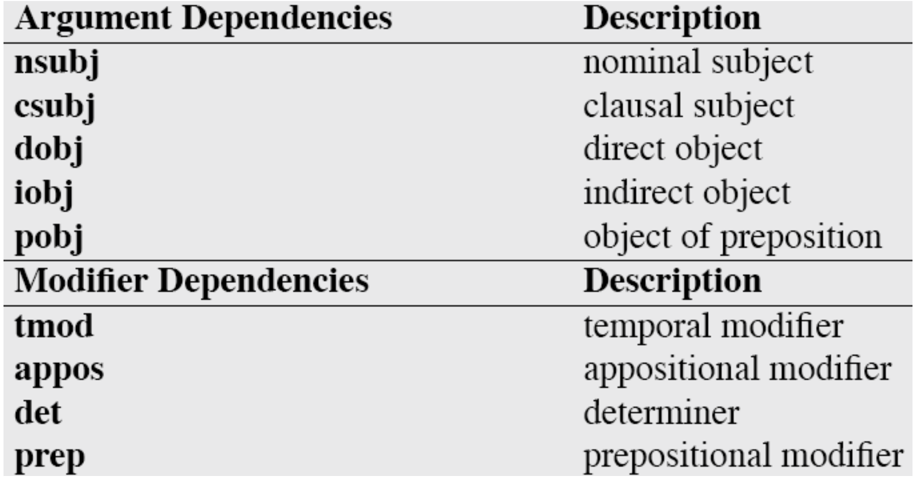
Grammatical Relations

- Types of relations between words
  - Arguments: subject, object, indirect object, prepositional object
  - Adjuncts: temporal, locative, causal, manner, ...
  - Function Words

Types of Dependency

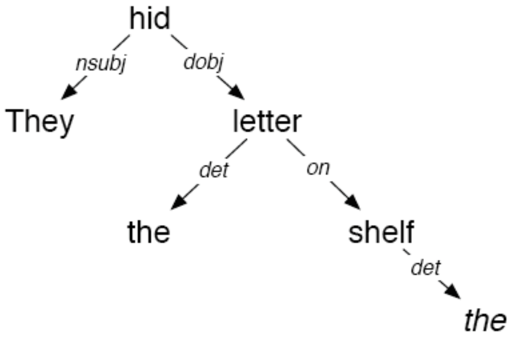


Dependency Relations



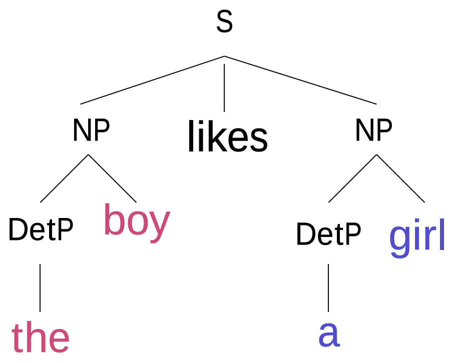
Argument Dependencies	Description
nsubj	nominal subject
csubj	clausal subject
dobj	direct object
iobj	indirect object
pobj	object of preposition
Modifier Dependencies	**Description**
tmod	temporal modifier
appos	appositional modifier
det	determiner
prep	prepositional modifier

Dependency Parse

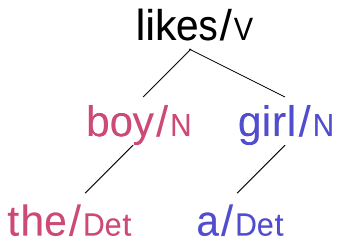


They hid the letter on the shelf

Phrase Structure and Dependency Structure



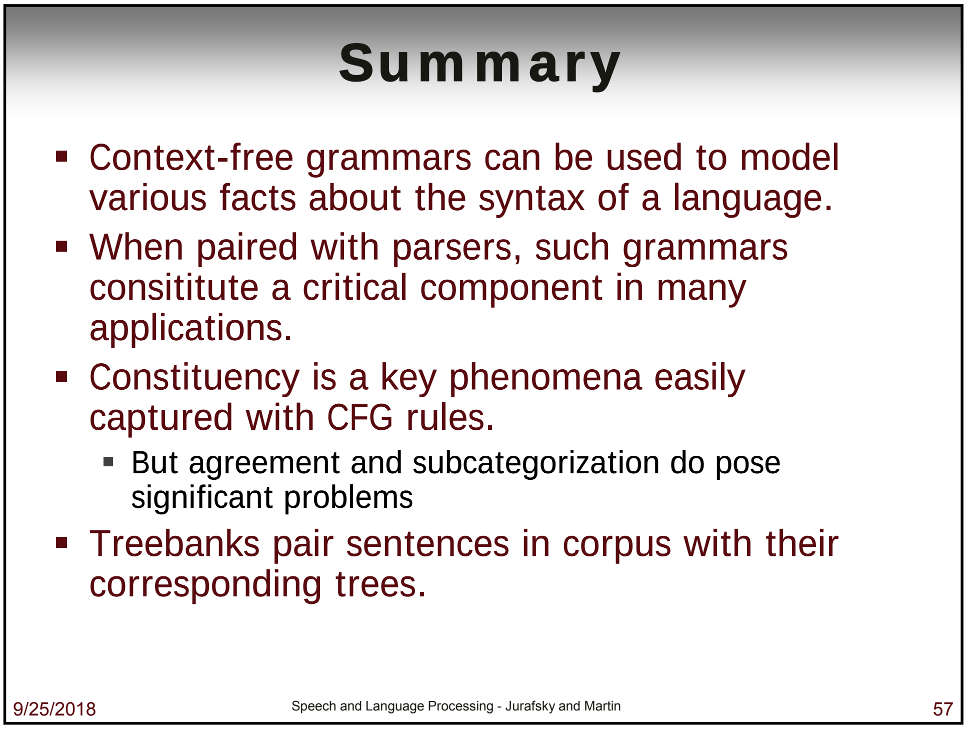
Only leaf nodes labeled with words!



All nodes are labeled with words!

Dependency Parsing

- The dependency approach has a number of advantages over full phrase-structure parsing.
  - Deals well with free word order languages where the constituent structure is quite fluid
  - Parsing is much faster than CFG-bases parsers
  - Dependency structure often captures the syntactic relations needed by later applications
    - CFG-based approaches often extract this same information from trees anyway.
- See draft J&M for new chapter



Summary

- Context-free grammars can be used to model various facts about the syntax of a language.
- When paired with parsers, such grammars consititute a critical component in many applications.
- Constituency is a key phenomena easily captured with CFG rules.
  - But agreement and subcategorization do pose significant problems
- Treebanks pair sentences in corpus with their corresponding trees.