FORMAL GRAMMARS

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(mostly from: Speech and Language Processing - Jurafsky and Martin)

Today

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

Syntax

- By grammar, or syntax, we have in mind the kind of implicit knowledge of your native language that you had mastered by the time you were 3 years old without explicit instruction
- Not the kind of stuff you were later taught in “grammar” school

Syntax

- Why should you care?
- 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

Constituency

- The basic idea here is that **groups of words** within utterances can be shown to act as **single units** → *constituent*
- 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
- 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
- Non-terminals
  - The *constituents*
    - Like noun phrase, verb phrase
  - The *pre-terminals* (e.g., POS tags)
  - A special symbol: S to start from
- Rules
  - a single non-terminal → any number of terminals and non-terminals

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

The L_0 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

The L_0 Grammar

GRAMMAR LEXICON

$$
\begin{aligned}
Noun &\rightarrow flights \mid breeze \mid trip \mid morning \mid \ldots \\
Verb &\rightarrow is \mid prefer \mid like \mid need \mid want \mid fly \\
Adjective &\rightarrow cheapest \mid non-stop \mid first \mid latest \\
&\quad \mid other \mid direct \mid \ldots \\
Pronoun &\rightarrow me \mid I \mid you \mid it \mid \ldots \\
Proper\text{-}Noun &\rightarrow Alaska \mid Baltimore \mid Los\ Angeles \\
&\quad \mid Chicago \mid United \mid American \mid \ldots \\
Determiner &\rightarrow the \mid a \mid an \mid this \mid these \mid that \mid \ldots \\
Preposition &\rightarrow from \mid to \mid on \mid near \mid \ldots \\
Conjunction &\rightarrow and \mid or \mid but \mid \ldots
\end{aligned}
$$

Pre-terminals (POS tags)

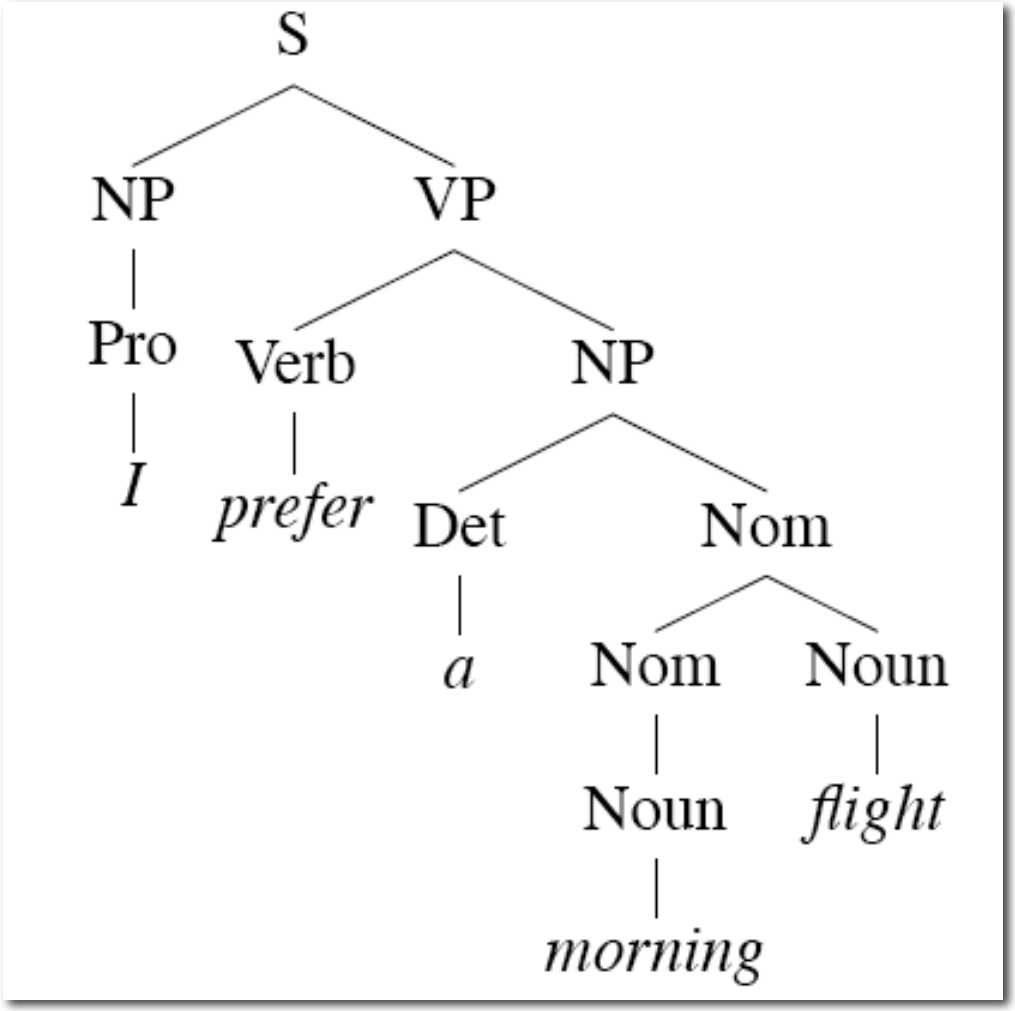
Terminals (words)

Generativity

- 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



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** is the process of taking a string and a grammar and returning a (multiple?) parse tree(s) for that string

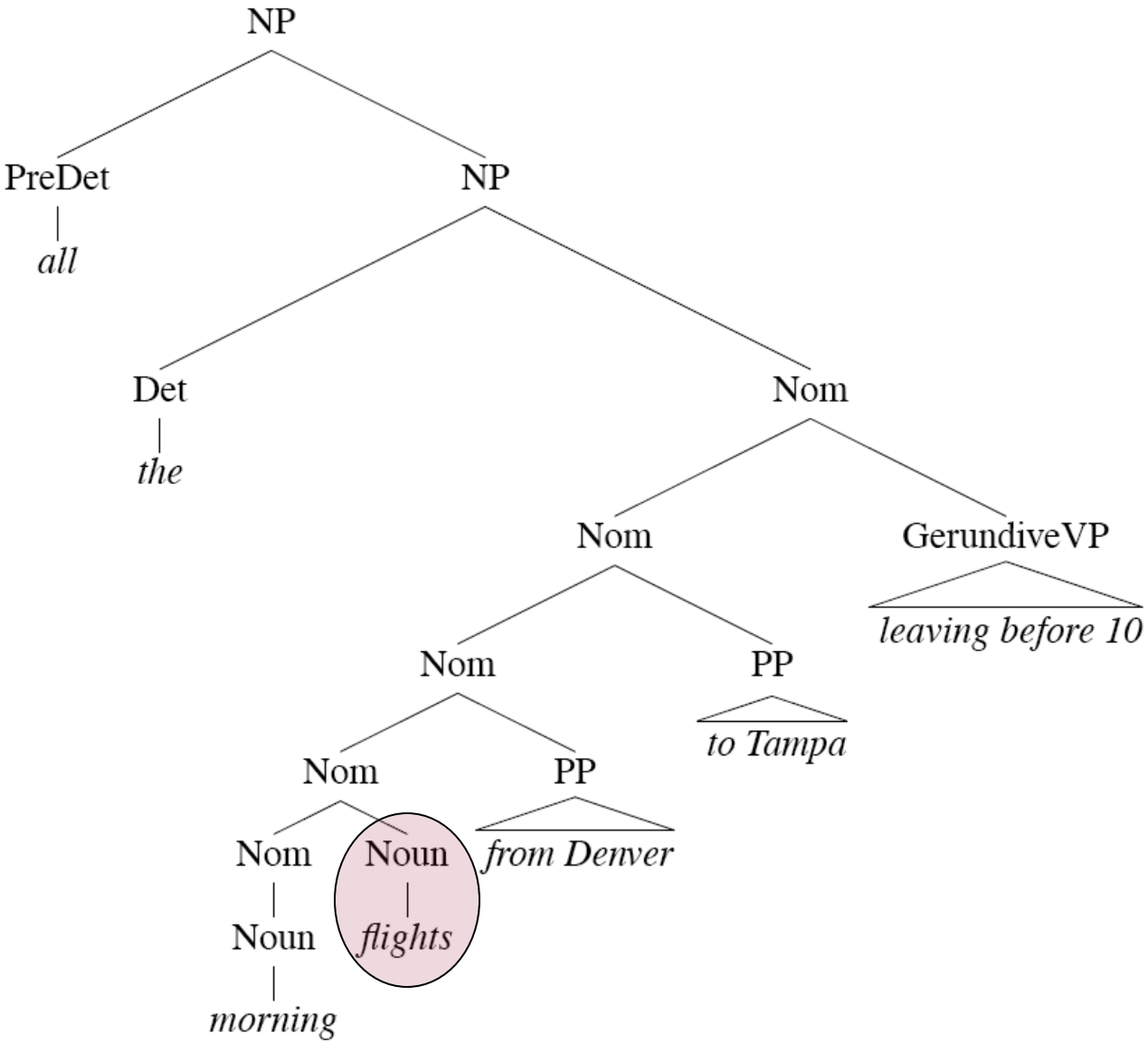
Noun Phrases

- 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 critical 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.

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

Those flights

*This flights

*Those flight

*=wrong sentence

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

Verb Phrases

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

$VP \rightarrow Verb$ 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

- 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 and complements.
- Modern grammars may have 100s or 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]$_{TO\text{-}VP}$
- …

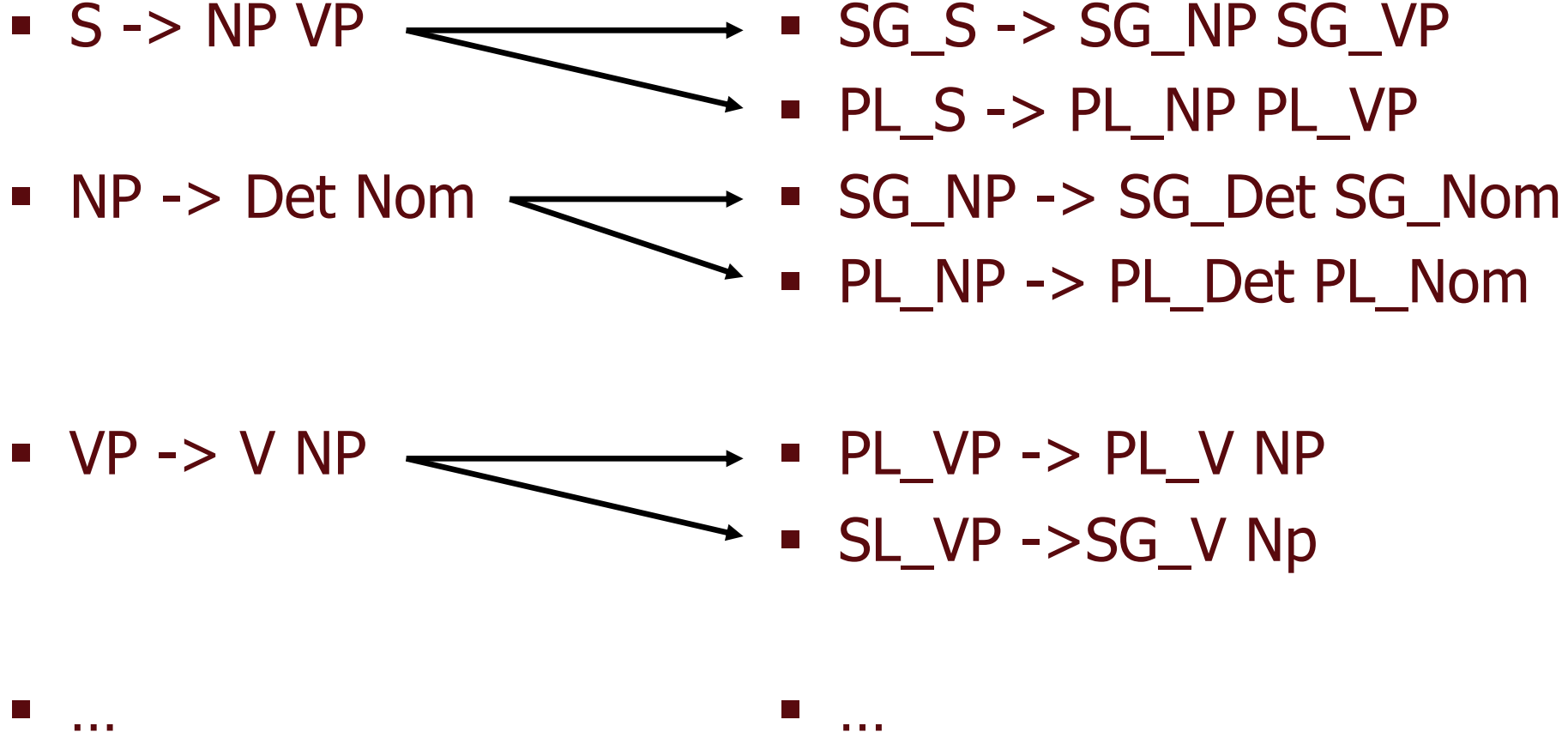
Subcategorization

- *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

Possible CFG Solution

- Possible solution for agreement and subcategorization: create ad-hoc sub-classes



CFG Solution for Agreement

- It works and stays within the power of CFGs
- But it's ugly and it doesn't scale because of the interaction among the various constraints explodes the number of rules in our grammar
- CFGs appear to be just about what we need to account for a lot of basic syntactic structure in
- Other solutions:
  - Feature-based grammars

    S→NP VP

    <NP AGREEMENT>=<VP AGREEMENT>

    A feature associated to NP and VP
  - LFG, HPSG, Construction grammar, XTAG, etc.
  - No solution!

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

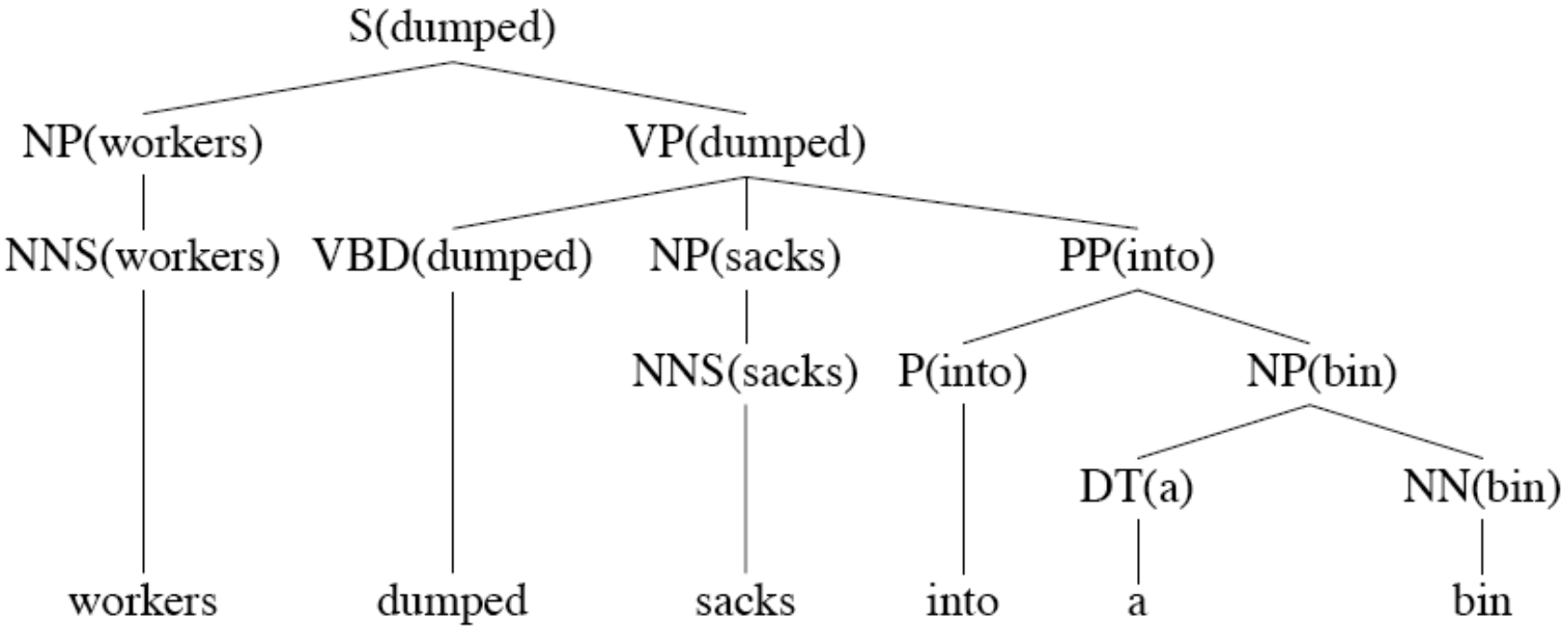
- Such grammars tend to be very flat due to the fact that they tend to avoid recursion.
  - To ease the annotators burden
- For example, the Penn Treebank has 4500 different rules for VPs. Among them...

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



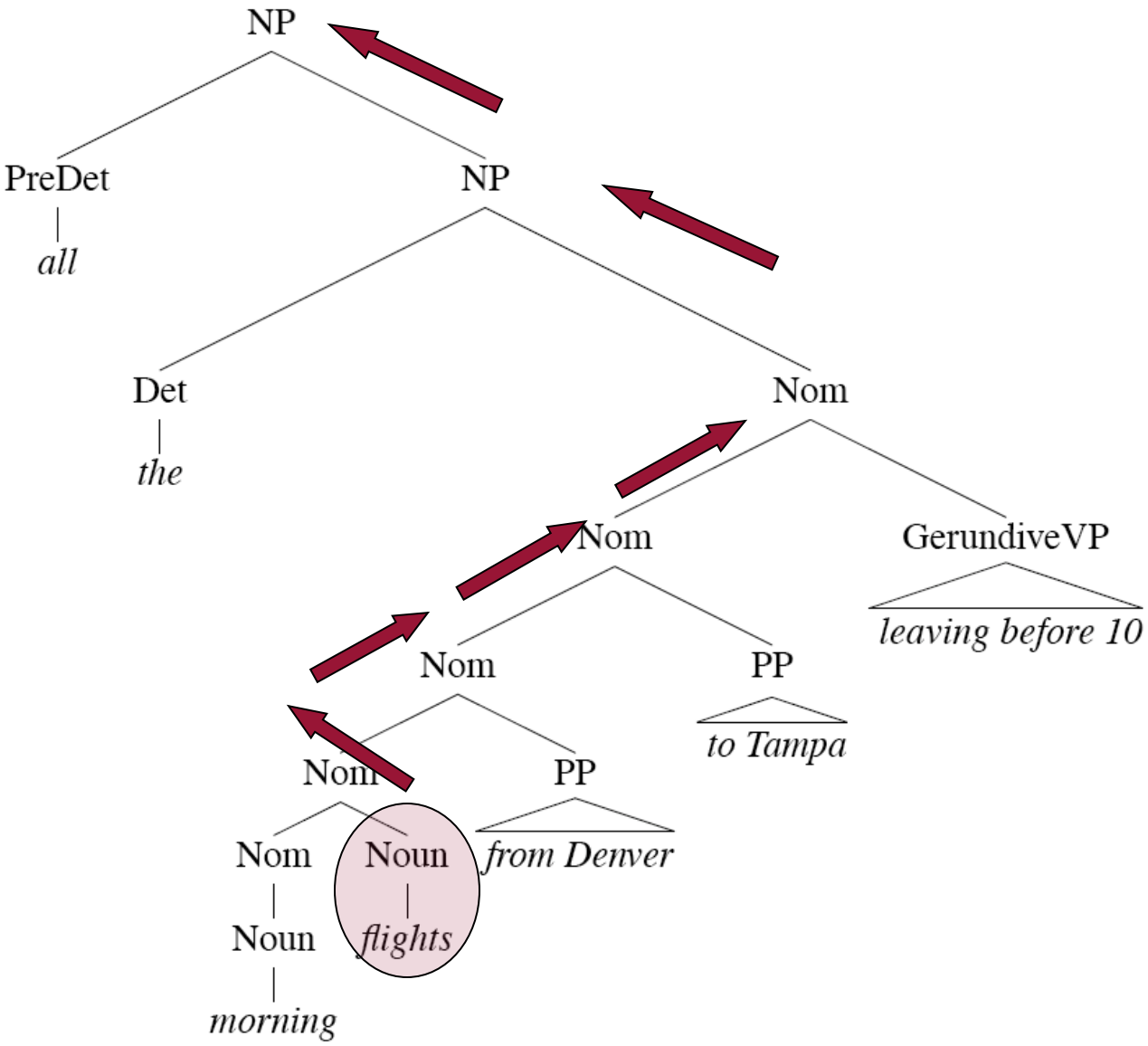
Head Finding

- 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.
  - such traversal rules are "encoded" into *lexicalized grammar rules* (more on that later…)
  - Derived from lexicalized treebanks
  - E.g.:

    VP(dumped) → VDB(dumped) NP(sacks) PP(into)

    means that in VP → VDB NP PP, the head of VDB goes to VP

Noun Phrases



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.