Intelligent Systems (AI-2)

Computer Science cpsc422, Lecture 26

Learning Goals for today's class

You can:

- Provide a formal definition of a PCFG
- Apply a PCFG to compute the probability of a parse tree of a sentence as well as the probability of a sentence
- Describe the content of a treebank
- Describe the process to identify a head of a syntactic constituent
- Compute the probability distribution of a PCFG from a treebank

Lecture Overview

- Recap English Syntax and Parsing
- Key Problem with parsing: Ambiguity
- Probabilistic Context Free Grammars (PCFG)
- Treebanks and Grammar Learning

Key Constituents: Examples

Head

NP → N
NP → Det N

	(Specifier)	X	(Complement)
• Noun phrases (NP)	• (Det) the	N cat	(PP) on the table
• Verb phrases (VP)	• (Qual) never	V eat	(NP) a cat
• Prepositional phrases (PP)	• (Deg) almost	P in	(NP) the net
• Adjective phrases(AP)	• (Deg) very	A happy	(PP) about it
• Sentences (S)	• (NP) a mouse	(-) --	(VP) ate it

Context Free Grammar (CFG)

- **4-tuple** (non-term., term., productions, start)
- (N, Σ, P, S)
- P is a set of rules *A*→α; *A*∈**N**, α∈(Σ∪N)*

$N = \{X \; Y\}$ $\Sigma = \{a \; b \; c\}$ $P =$

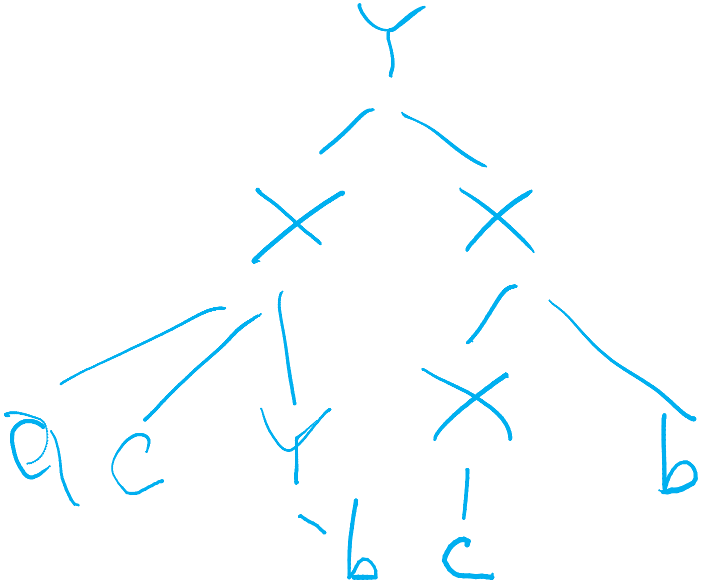
$X \to Xb$

$Y \to XX$

$X \to acY$

$X \to c$

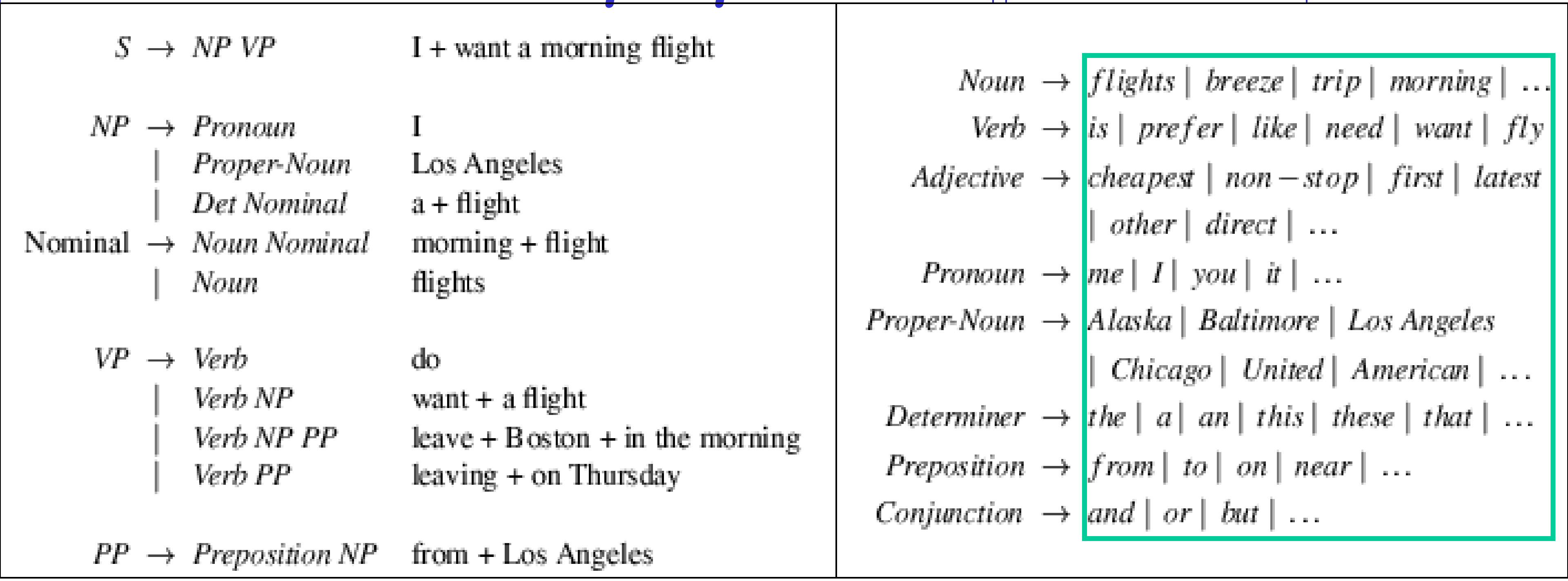
$Y \to b$



CFG Example

Grammar with example phrases

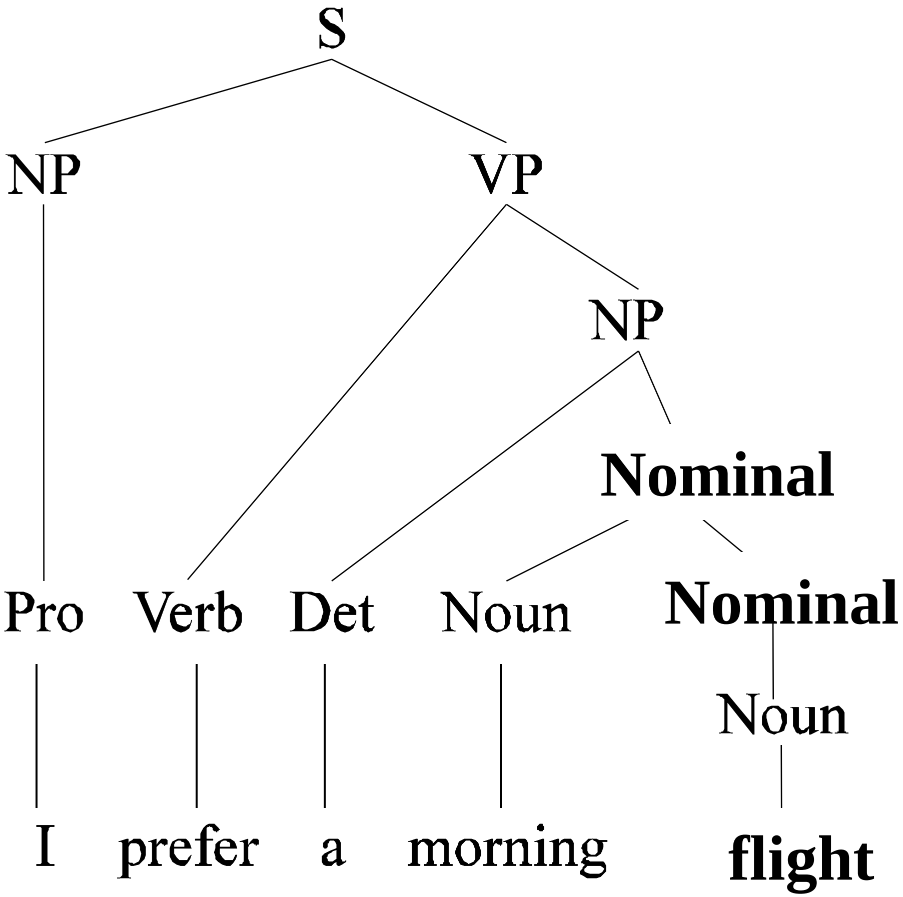
Lexicon



S	→	*NP VP*	I + want a morning flight
NP	→	*Pronoun*	I
	|	*Proper-Noun*	Los Angeles
	|	*Det Nominal*	a + flight
Nominal	→	*Noun Nominal*	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

Noun → *flights* | *breeze* | *trip* | *morning* | …
Verb → *is* | *prefer* | *like* | *need* | *want* | *fly*
Adjective → *cheapest* | *non* − *stop* | *first* | *latest*
| *other* | *direct* | …
Pronoun → *me* | *I* | *you* | *it* | …
Proper-Noun → *Alaska* | *Baltimore* | *Los Angeles*
| *Chicago* | *United* | *American* | …
Determiner → *the* | *a* | *an* | *this* | *these* | *that* | …
Preposition → *from* | *to* | *on* | *near* | …
Conjunction → *and* | *or* | *but* | …

Derivations as Trees



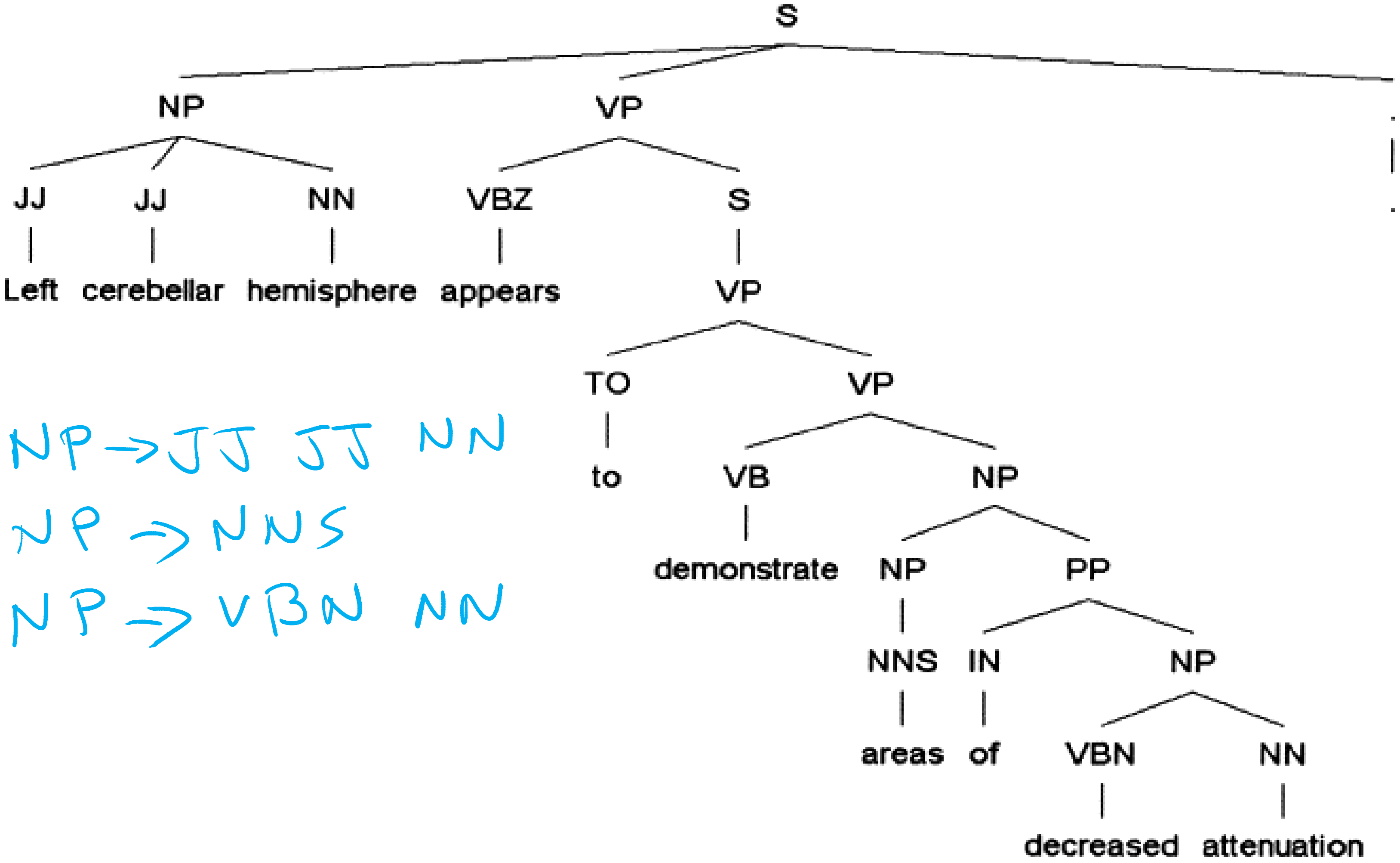
S → *NP VP*

NP → *Pronoun*
| *Proper-Noun*
| *Det Nominal*
Nominal → *Noun Nominal*
| *Noun*

VP → *Verb*
| *Verb NP*
| *Verb NP PP*
| *Verb PP*

PP → *Preposition NP*

Example of relatively complex parse tree



NP -> JJ JJ NN

NP -> NNS

NP -> VBN NN

Journal of the American Medical Informatics Association, 2005, Improved Identification of Noun Phrases in Clinical Radiology Reports Using a High-Performance Statistical Natural Language Parser Augmented with the UMLS Specialist Lexicon

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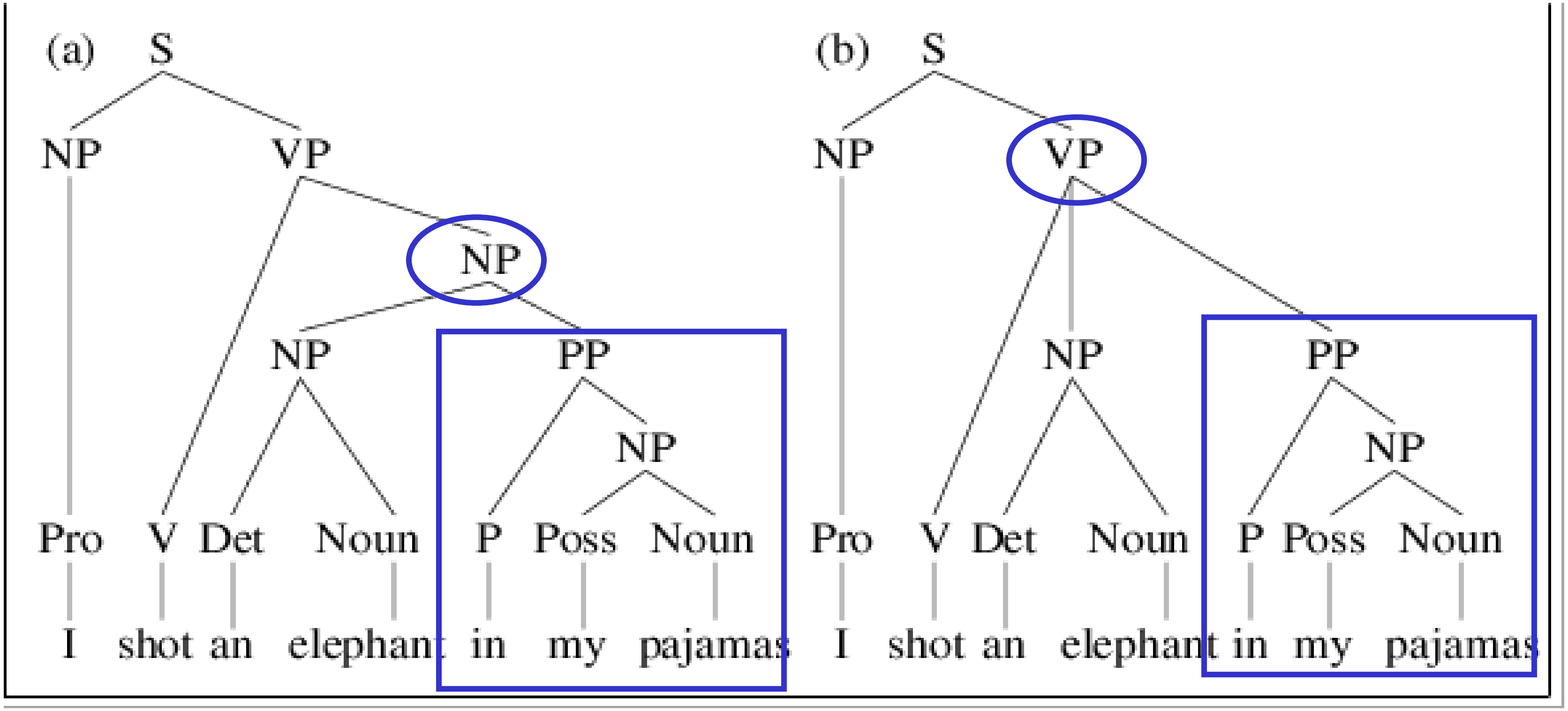
- **Key Problem with parsing: Ambiguity**
- Probabilistic Context Free Grammars (PCFG)
- Treebanks and Grammar Learning

Structural Ambiguity (Ex. 1)

VP -> V NP ; NP -> NP PP
VP -> V NP PP

"I shot an elephant in my pajamas"



Structural Ambiguity (Ex.2)

“I saw Mary passing by cs2”

```
(ROOT
  (S
    (NP (PRP I))
    (VP (VBD saw)
      (S
        (NP (NNP Mary))
        (VP (VBG passing)
          (PP (IN by)
            (NP (NNP cs2)))))))
```

“I saw Mary passing by cs2”

```
(ROOT
  (S
    (NP (PRP I))
    (VP (VBD saw)
          (NP (NNP Mary))
          (S
              (VP (VBG passing)
                   (PP (IN by)
                      (NP (NNP cs2)))))))
```

Structural Ambiguity (Ex. 3)

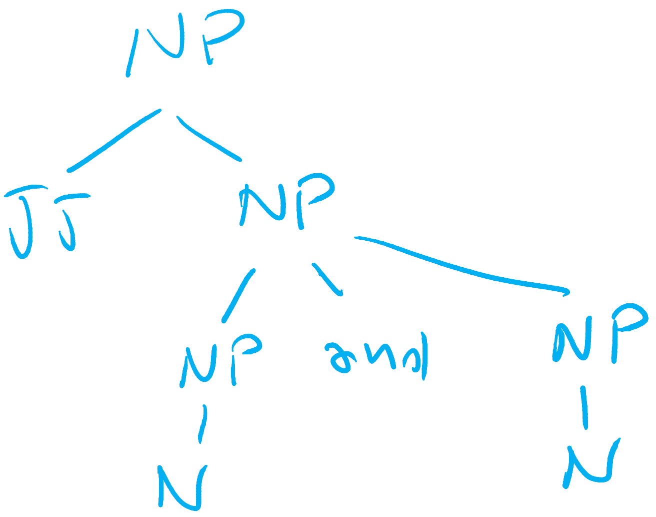
JJ N N

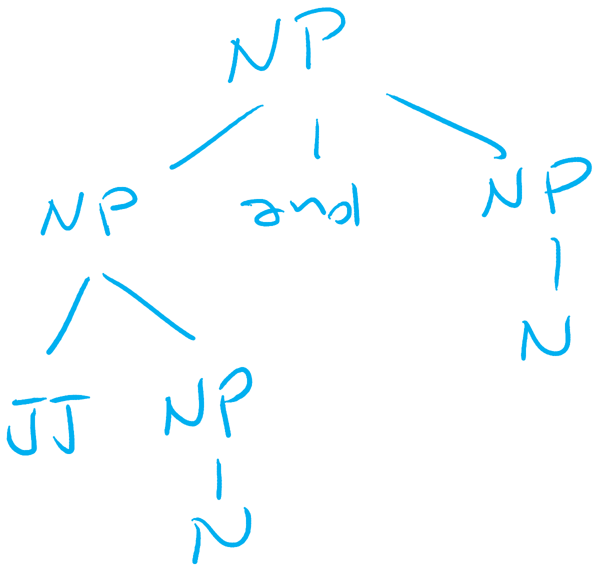
- **Coordination “new students and profs”**

NP -> NP and NP

NP -> JJ NP

NP -> N





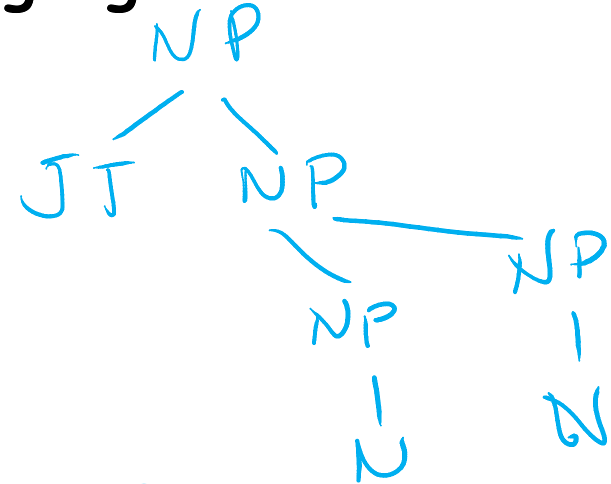
Structural Ambiguity (Ex. 4)

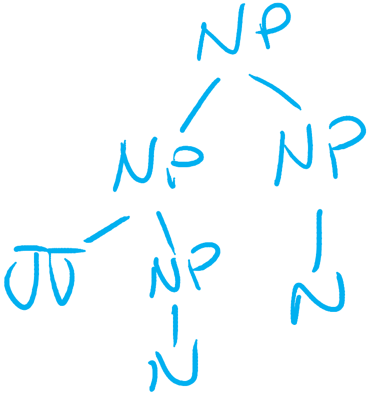
- **NP-bracketing "French language teacher"**

NP → JJ NP

NP → N

NP → NP NP





Lecture Overview

- Recap English Syntax and Parsing
- Key Problem with parsing: Ambiguity
- **Probabilistic Context Free Grammars (PCFG)**
- Treebanks and Grammar Learning (acquiring the probabilities)
- Intro to Parsing PCFG

Probabilistic CFGs (PCFGs)

- **GOAL: assign a probability to parse trees and to sentences**
- **Each grammar rule is augmented with a conditional probability**
- **If these are all the rules for VP and .55 is P(VP->Verb | VP)**

VP -> Verb	.55
VP -> Verb NP	.40
VP -> Verb NP NP	??

- **What should ?? be ?**

A. 1

B. 0

C. 0.05

D. 0.42

E. None of the above

Probabilistic CFGs (PCFGs)

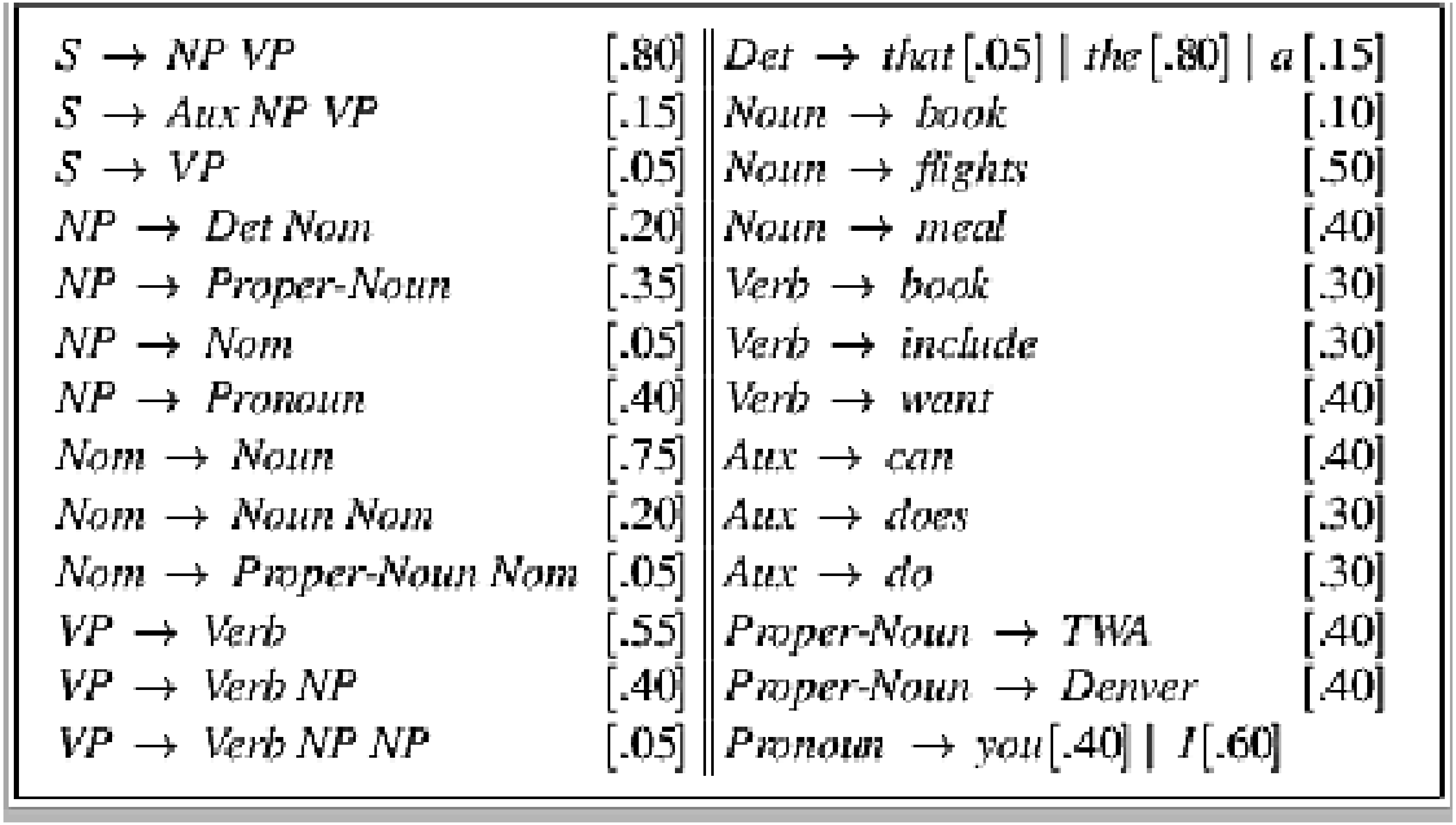
- **GOAL: assign a probability to parse trees and to sentences**
- **Each grammar rule is augmented with a conditional probability**

  - **The expansions for a given non-terminal sum to 1**

VP -> Verb	.55	P(VP -> Verb | VP)
VP -> Verb NP	.40	P(VP -> Verb NP | VP)
VP -> Verb NP NP	.05	P(VP -> Verb NP NP | VP)

Formal Def: 5-tuple (N, Σ, P, S, D)

Sample PCFG



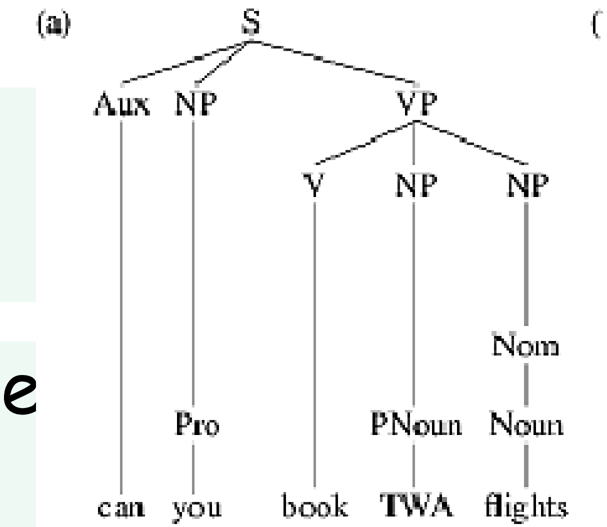
S	→ *NP VP*	[.80]	*Det*	→ *that* [.05] | *the* [.80] | *a* [.15]	
S	→ *Aux NP VP*	[.15]	*Noun*	→ *book*	[.10]
S	→ *VP*	[.05]	*Noun*	→ *flights*	[.50]
NP	→ *Det Nom*	[.20]	*Noun*	→ *meal*	[.40]
NP	→ *Proper-Noun*	[.35]	*Verb*	→ *book*	[.30]
NP	→ *Nom*	[.05]	*Verb*	→ *include*	[.30]
NP	→ *Pronoun*	[.40]	*Verb*	→ *want*	[.40]
Nom	→ *Noun*	[.75]	*Aux*	→ *can*	[.40]
Nom	→ *Noun Nom*	[.20]	*Aux*	→ *does*	[.30]
Nom	→ *Proper-Noun Nom*	[.05]	*Aux*	→ *do*	[.30]
VP	→ *Verb*	[.55]	*Proper-Noun*	→ *TWA*	[.40]
VP	→ *Verb NP*	[.40]	*Proper-Noun*	→ *Denver*	[.40]
VP	→ *Verb NP NP*	[.05]	*Pronoun*	→ *you* [.40] | *I* [.60]	

PCFGs are used to….

- **Estimate Prob. of parse tree**

A. Sum of the probs of all the rules applied

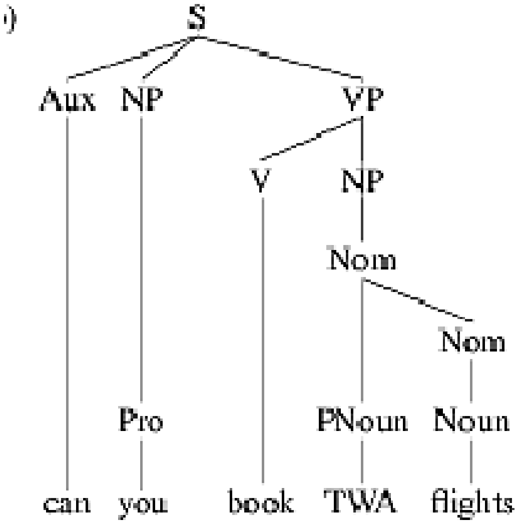
B. Product of the probs of all the rules applied



- **Estimate Prob. of a sentence**

A. Sum of the probs of all the parse trees

B. Product of the probs of all the parse trees



PCFGs are used to….

- Estimate Prob. of parse tree

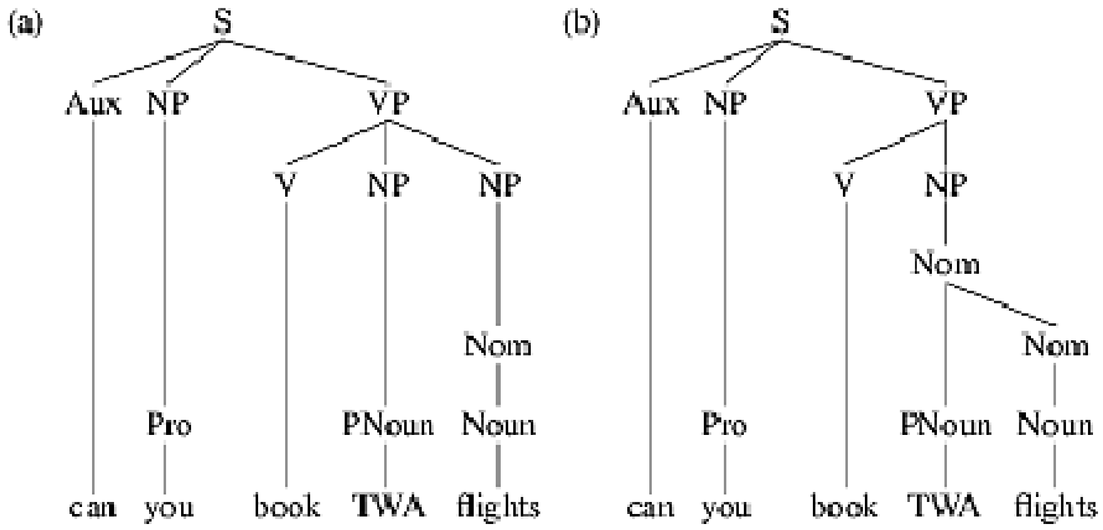
$$P(Tree) = \prod_{node \in Tree} P(\text{expansion for node})$$

- Estimate Prob. to sentences

$$P(Sentence) = \sum_{Tree \in \text{Sentence parses}} P(Tree)$$

Example

$P(Tree^a) = .15 * .4 * ... = \boxed{3.8 \cdot 10^{-7}}$ $P(Tree^b) = .15 * .4 * ... = \boxed{4.3 \cdot 10^{-7}}$



P("can you book TWA flights")

$\boxed{8.1 \cdot 10^{-7}}$

(a) →

Rules			P
S	→	Aux NP VP	.15
NP	→	Pro	.40
VP	→	V NP NP	.05
NP	→	Nom	.05
NP	→	PNoun	.35
Nom	→	Noun	.75
Aux	→	Can	.40
~~NP~~	~~→~~	~~Pro~~	.40
Pro	→	you	.40
Verb	→	book	.30
PNoun	→	TWA	.40
Noun	→	flights	.50

Rules			P
S	→	Aux NP VP	.15
NP	→	Pro	.40
VP	→	V NP	.40
NP	→	Nom	.05
Nom	→	PNoun Nom	.05
Nom	→	Noun	.75
Aux	→	Can	.40
~~NP~~	~~→~~	~~Pro~~	.40
Pro	→	you	.40
Verb	→	book	.30
Pnoun	→	TWA	.40
Noun	→	flights	.50

← (b)

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- Recap English Syntax and Parsing
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- **Treebanks and Grammar Learning (acquiring the probabilities)**

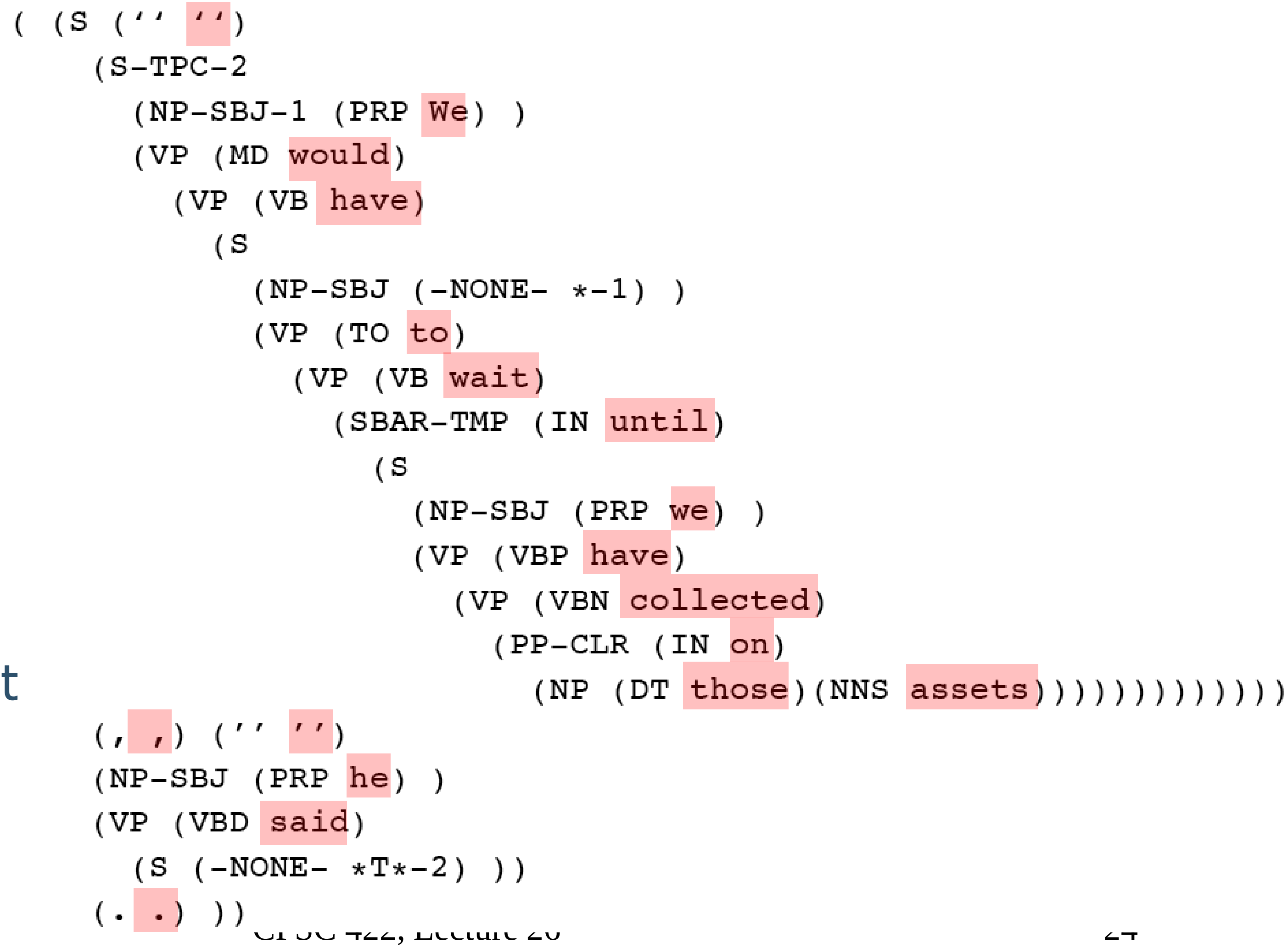
Treebanks

- Definition: corpora in which each sentence has been paired with a parse tree
- These are generally created
  - Parse collection with parser
  - human annotators revise each parse
- Requires detailed annotation guidelines
  - POS tagset
  - Grammar
  - instructions for how to deal with particular grammatical constructions.

Penn Treebank

- **Penn TreeBank is a widely used treebank.**

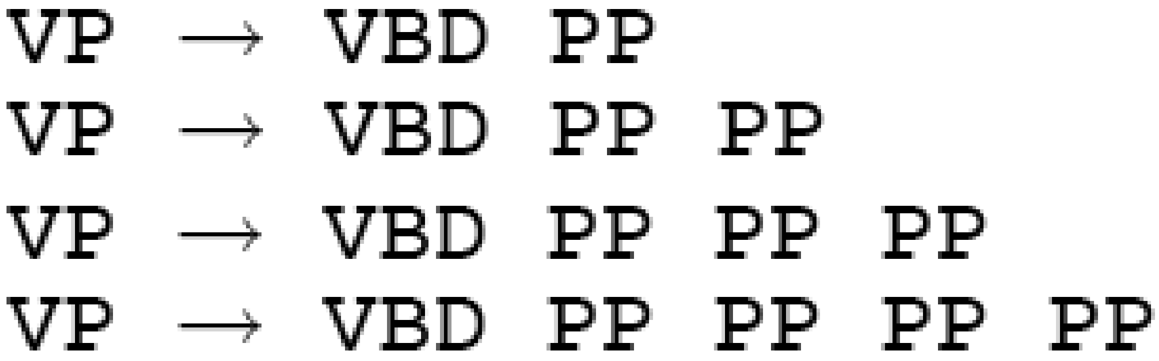
- Most well known is the Wall Street Journal section of the Penn TreeBank.
  - 1 M words from the 1987-1989 Wall Street Journal.



```
( (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

- Such grammars tend to contain lots of rules….
- For example, the Penn Treebank has 4500 different rules for VPs! Among them...



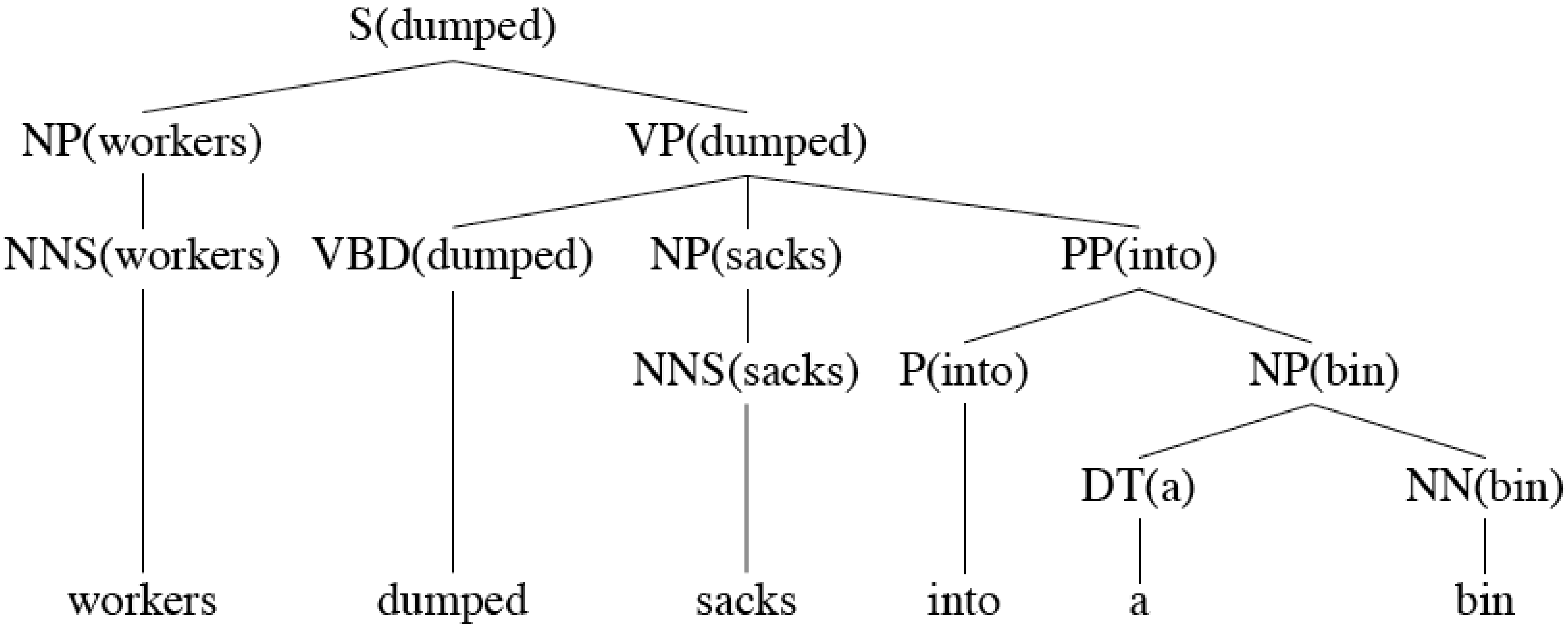
VP → VBD PP
VP → VBD PP PP
VP → VBD PP PP PP
VP → VBD PP PP PP PP

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

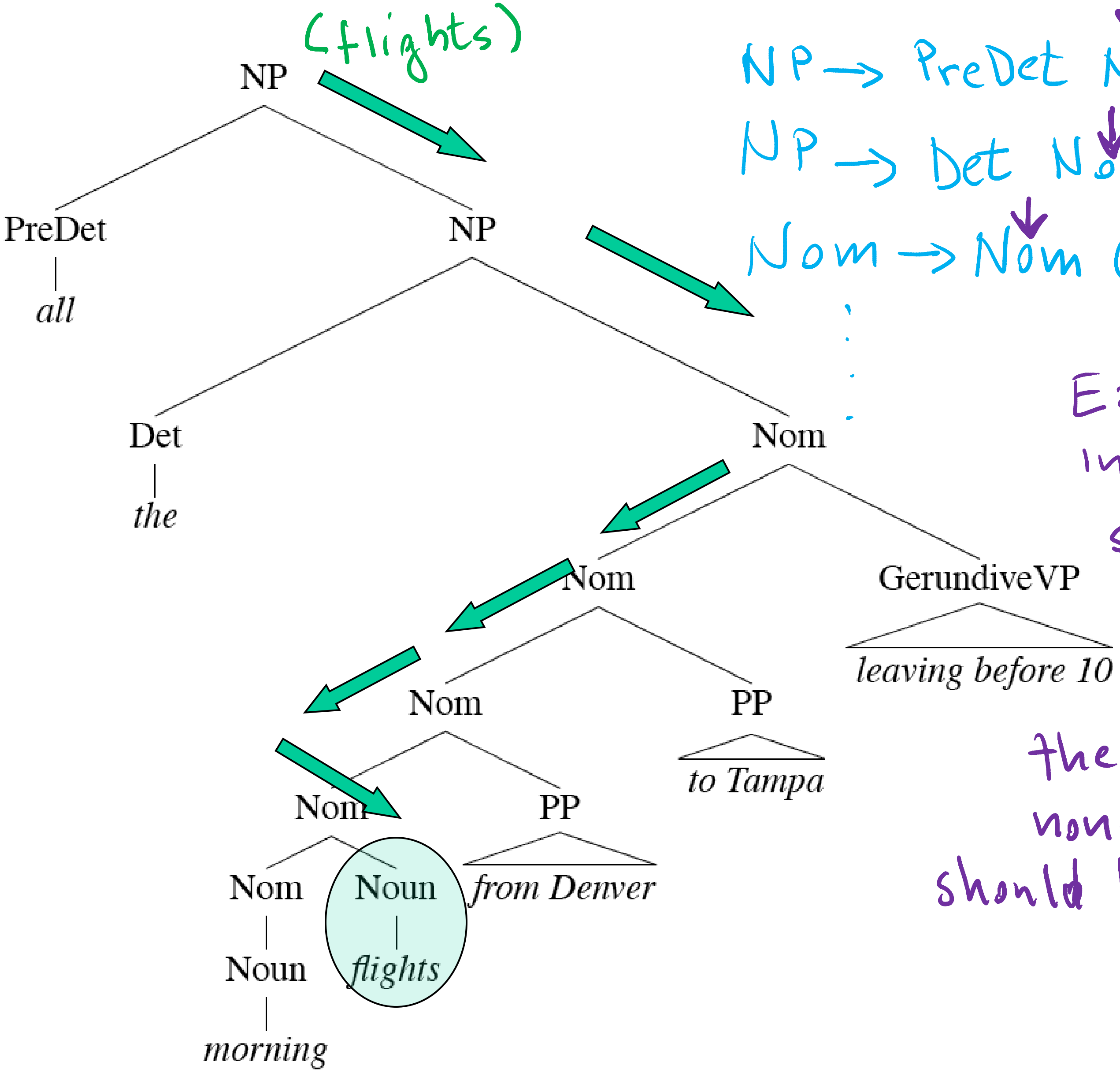


Head Finding

- 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.

- Each rule in the PCFG specifies where the head of the expanded non-terminal should be found

Noun Phrases



NP → PreDet NP

NP → Det Nom

Nom → Nom GerundiveVP

⋮

Each rule in the PCFG specifies where the head of the expanded non-terminal should be found

Acquiring Grammars and Probabilities

Manually parsed text corpora (e.g., PennTreebank)

- **Grammar**: read it off the parse trees

Ex: if an NP contains an ART, ADJ, and NOUN then we create the rule *NP -> ART ADJ NOUN*.

- **Probabilities:**

$$P(A \to \alpha | A) = \frac{count(A \to \alpha)}{\sum_{\forall \gamma} count(A \to \gamma)} = \frac{count(A \to \alpha)}{count(A)}$$

Ex: if the *NP -> ART ADJ NOUN* rule is used 50 times and all NP rules are used 5000 times, then the rule's probability is … .01

Example

If you look at all the parse trees in the bank you find three rules for NP

	How many times
① NP → ART ADJ NOUN	50
② NP → NOUN	4000
③ NP → PRONOUN	950
	5000 total # of NP expansions

P(① | NP) = 50/5000 = .01

P(② | NP) = 4000/5000 = .8

P(③ | NP) = 950/5000 = .19

$\boxed{\text{also} = 1 - (.01 + .8)}$

Next class (Nov 13)

- Parsing Probabilistic CFG: CKY parsing
- PCFG in practice: Modeling Structural and Lexical Dependencies