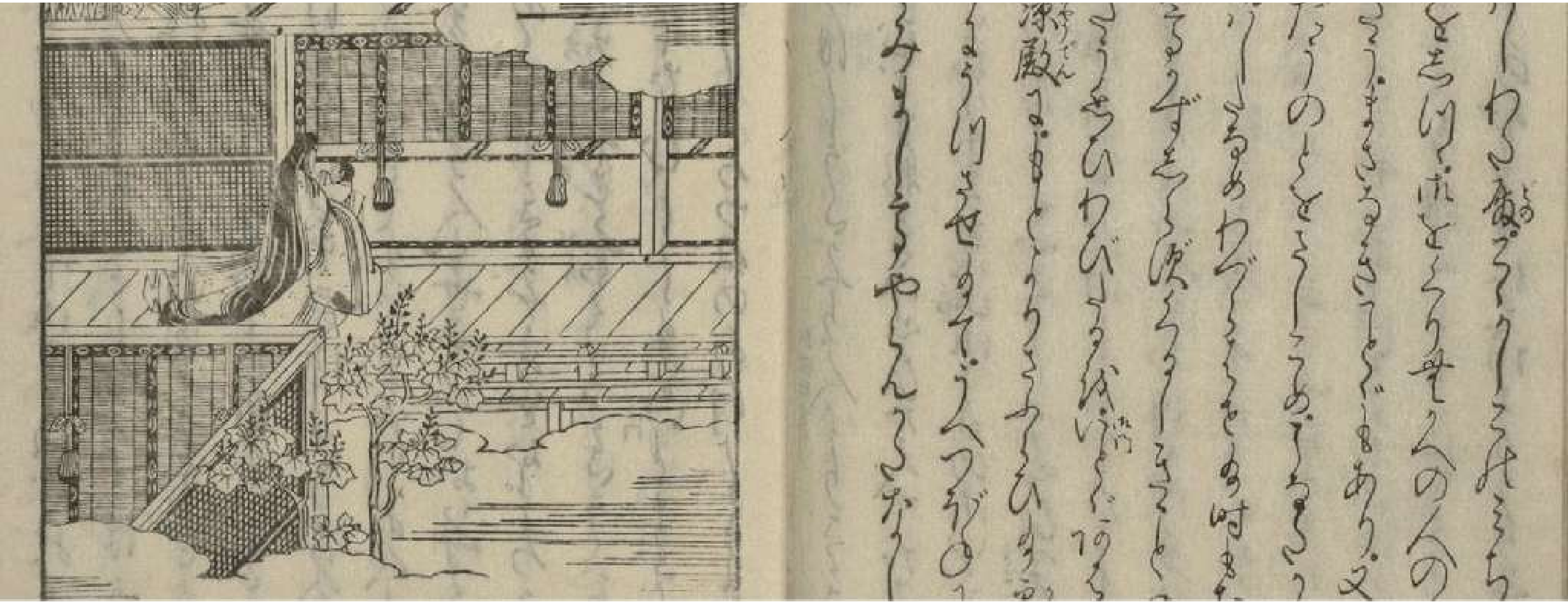


Natural Language Processing

Info 159/259

Lecture 13: Constituency syntax (March 3, 2020)

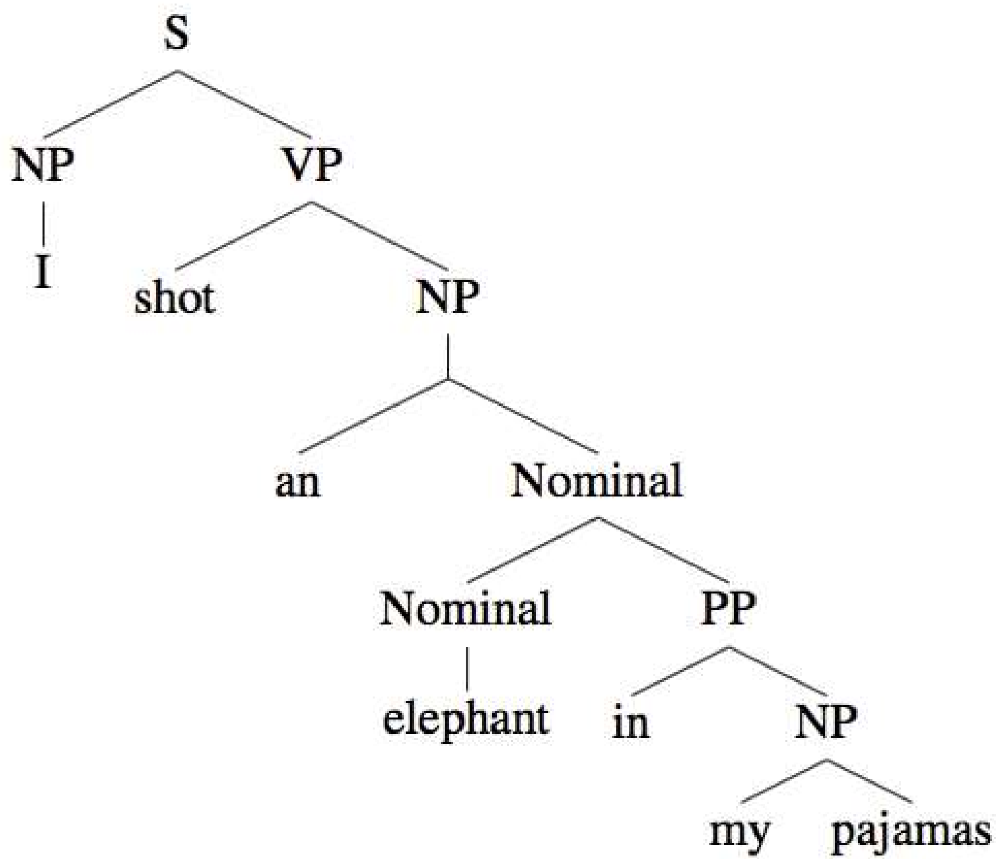
David Bamman, UC Berkeley

Syntax

- With syntax, we’re moving from labels for discrete items — documents (sentiment analysis), tokens (POS tagging, NER) — to the structure between items.

PRP VBD DT NN IN PRP$ NNS

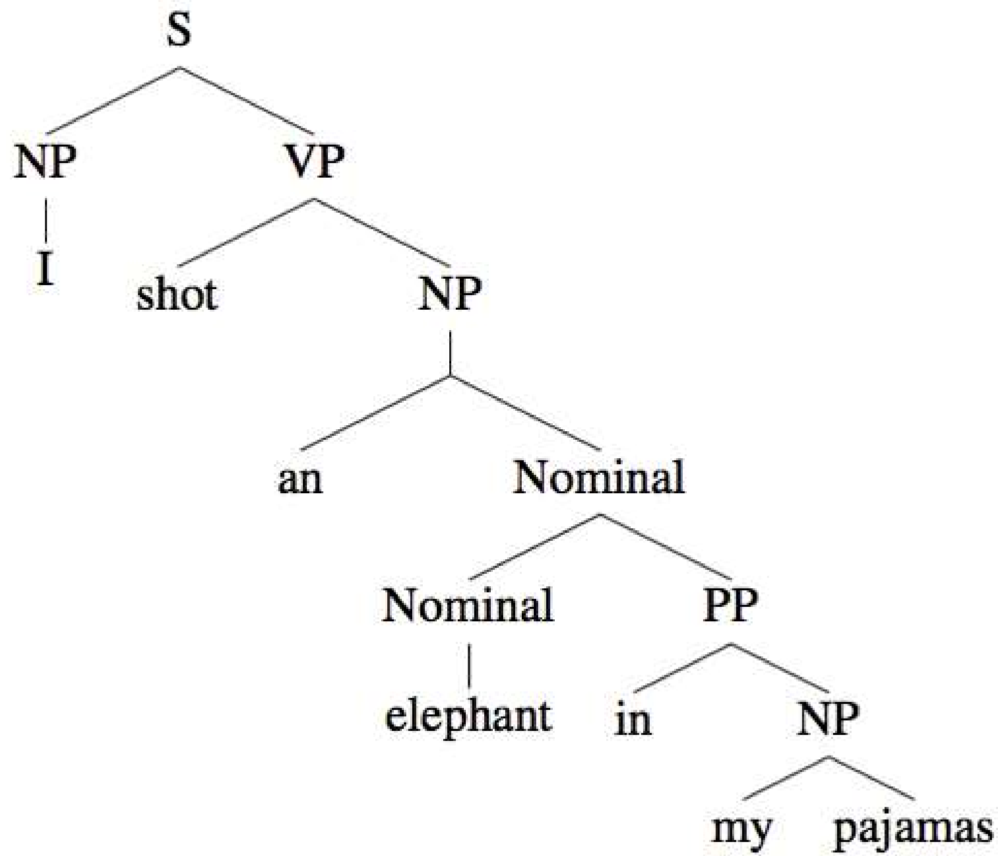
I shot an elephant in my pajamas



PRP VBD DT NN IN PRP$ NNS

I shot an elephant in my pajamas

Why is syntax important?

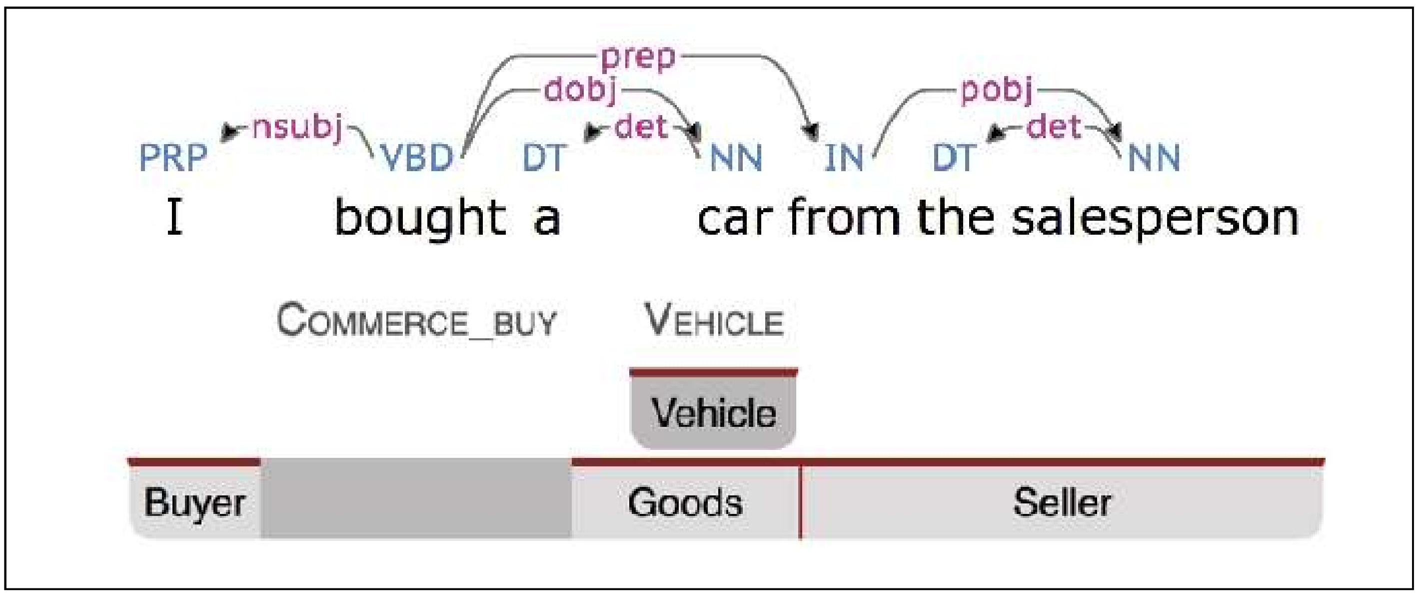


Why is POS important?

- POS tags are indicative of syntax
- POS = cheap multiword expressions [(JJ|NN)+ NN]
- POS tags are indicative of pronunciation ("I contest the ticket" vs "I won the contest"

Why is syntax important?

- Foundation for semantic analysis (on many levels of representation: semantic roles, compositional semantics, frame semantics)



http://demo.ark.cs.cmu.edu

Why is syntax important?

- Strong representation for discourse analysis (e.g., coreference resolution)

Bill VBD Jon; he was having a good day.

- Many factors contribute to pronominal coreference (including the specific verb above), but syntactic subjects > objects > objects of prepositions are more likely to be antecedents

Why is syntax important?

Linguistic typology; relative positions of subjects (S), objects (O) and verbs (V)

SVO	English, Mandarin	I grabbed the chair
SOV	Latin, Japanese	I the chair grabbed
VSO	Hawaiian	Grabbed I the chair
OSV	Yoda	Patience you must have
…	…	…

Sentiment analysis

"Unfortunately I already had this exact picture tattooed on my chest, but this shirt is very useful in colder weather."

[overlook1977]

Question answering

What did Barack Obama teach?

Barack Hussein Obama II (born August 4, 1961) is the 44th and current President of the United States, and the first African American to hold the office. Born in Honolulu, Hawaii, Obama is a graduate of Columbia University and Harvard Law School, where he served as president of the *Harvard Law Review*. He was a community organizer in Chicago before earning his law degree. He worked as a civil rights attorney and taught constitutional law at the University of Chicago Law School between 1992 and 2004.

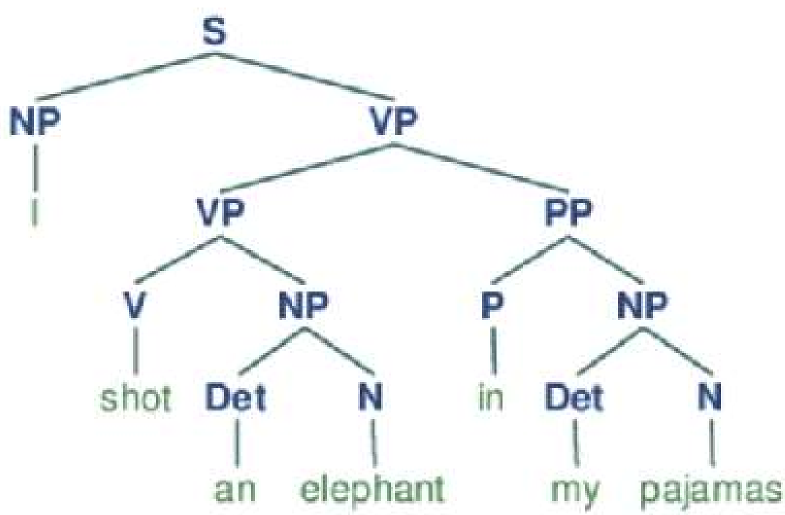
Syntax

- Syntax is fundamentally about the hierarchical structure of language and (in some theories) which sentences are grammatical in a language

words → phrases → clauses → sentences

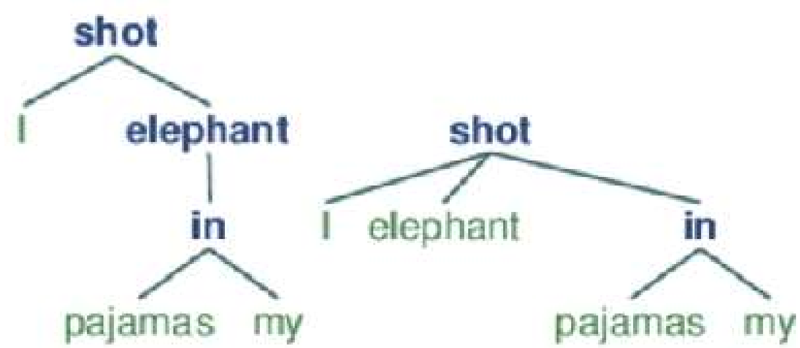
Formalisms

Phrase structure grammar
(Chomsky 1957)



today

Dependency grammar
(Mel’čuk 1988; Tesnière 1959; Pāṇini)



Mar 17

Constituency

- Groups of words ("constituents") behave as single units
- "Behave" = show up in the same distributional environments

context

everyone likes	______________	
a bottle of	______________	is on the table
	______________	makes you drunk
a cocktail with	______________	and seltzer

from POS 2/20

Parts of speech

- Parts of speech are categories of words defined distributionally by the morphological and syntactic contexts a word appears in.

from POS 2/20

Syntactic distribution

- Substitution test: if a word is replaced by another word, does the sentence remain grammatical?

Kim saw the	elephant	before we did
	dog	
	idea	
	*of	
	*goes	

Bender 2013

from POS 2/20

Syntactic distributions

three parties from Brooklyn	arrive
a high-class spot such as Mindy's	attracts
the Broadway coppers	love
they	sit

Jurafsky and Martin 2017

Syntactic distributions

grammatical only when the entire phrase is present, not an individual word in isolation

three parties from Brooklyn	arrive
a high-class spot such as Mindy's	attracts
the Broadway coppers	love
they	sit

Jurafsky and Martin 2017

Syntactic distributions

I'd like to fly from Atlanta to Denver

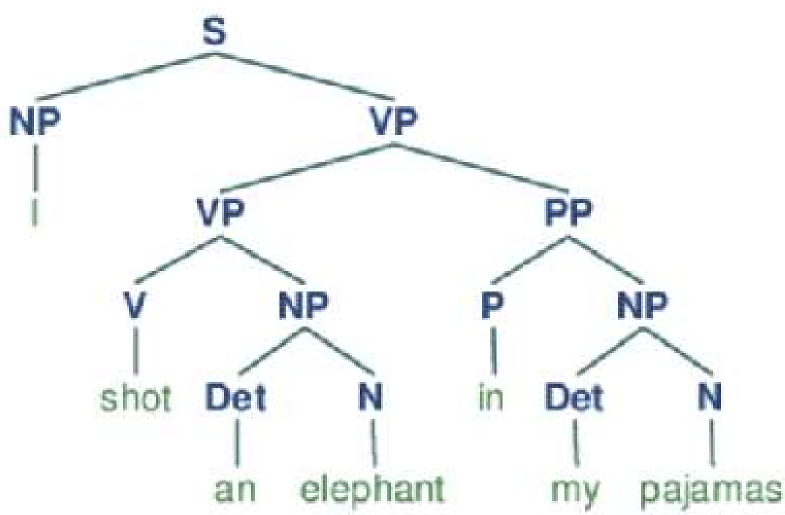
^ ^ ^ ^

$\boxed{\text{on September seventeenth}}$

Formalisms

Phrase structure grammar

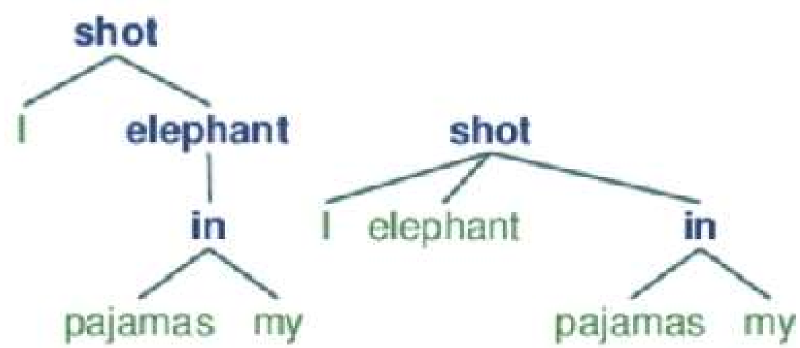
(Chomsky 1957)



today

Dependency grammar

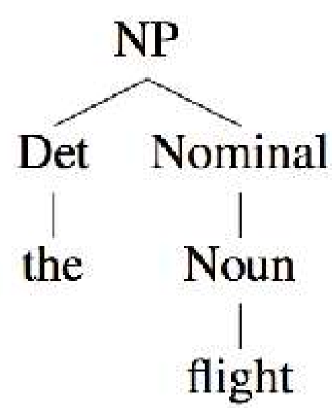
(Mel'čuk 1988; Tesnière 1959; Pāṇini)



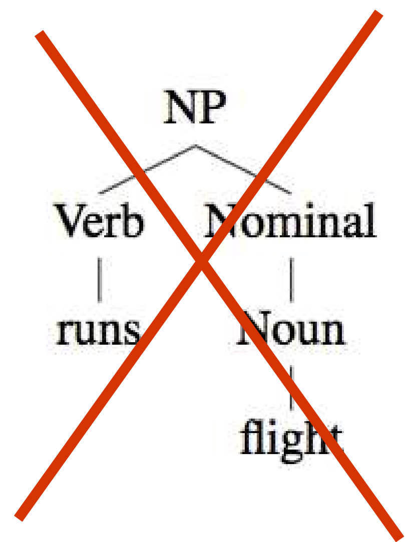
Mar 17

Context-free grammar

- A CFG gives a formal way to define what meaningful constituents are and exactly how a constituent is formed out of other constituents (or words). It defines valid structure in a language.



NP → Det Nominal



NP → Verb Nominal

Context-free grammar

A context-free grammar defines how symbols in a language combine to form valid structures

NP	→	Det Nominal
NP	→	ProperNoun
Nominal	→	Noun | Nominal Noun
Det	→	a | the
Noun	→	flight

non-terminals

lexicon/
terminals

Context-free grammar

N	Finite set of non-terminal symbols	NP, VP, S
Σ	Finite alphabet of terminal symbols	the, dog, a
R	Set of production rules, each $A \rightarrow \beta$ $\beta \in (\Sigma, N)$	S → NP VP Noun → dog
S	Start symbol	

Infinite strings with finite productions

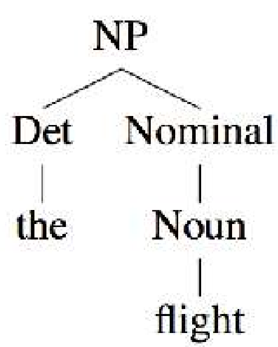
Some sentences go on

Infinite strings with finite productions

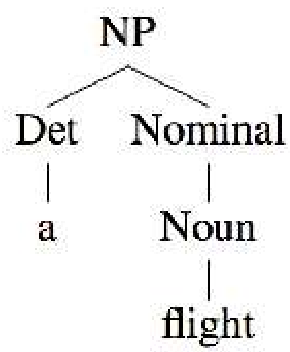
- This is the house
- This is the house that Jack built
- This is the cat that lives in the house that Jack built
- This is the dog that chased the cat that lives in the house that Jack built
- This is the flea that bit the dog that chased the cat that lives in the house the Jack built
- This is the virus that infected the flea that bit the dog that chased the cat that lives in the house that Jack built

Derivation

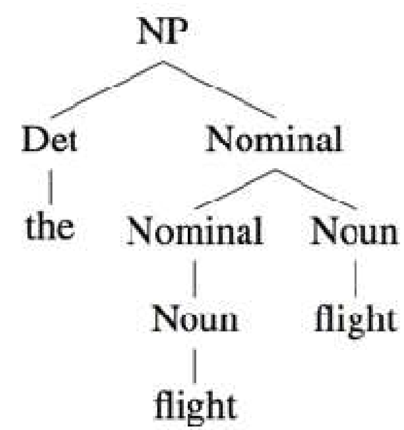
Given a CFG, a derivation is the sequence of productions used to generate a string of words (e.g., a sentence), often visualized as a parse tree.



the flight



a flight



the flight flight

Language

The formal language defined by a CFG is the set of strings derivable from S (start symbol)

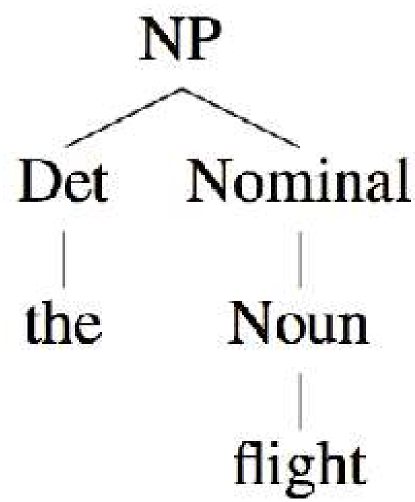
Noun	→	*flights* | *breeze* | *trip* | *morning*
Verb	→	*is* | *prefer* | *like* | *need* | *want* | *fly*
Adjective	→	*cheapest* | *non-stop* | *first* | *latest*
		| *other* | *direct*
Pronoun	→	*me* | *I* | *you* | *it*
Proper-Noun	→	*Alaska* | *Baltimore* | *Los Angeles*
		| *Chicago* | *United*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

Figure 11.2 The lexicon for $\mathscr{L}_0$.

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

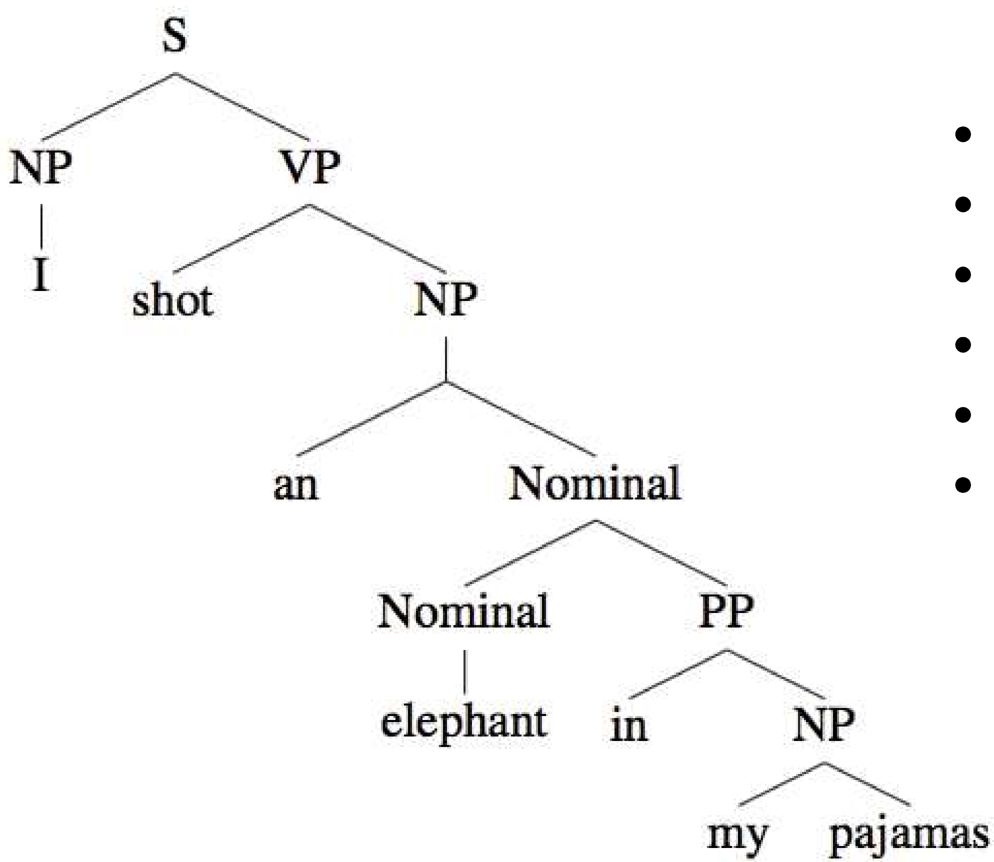
Figure 11.3 The grammar for $\mathscr{L}_0$, with example phrases for each rule.

Bracketed notation



[$_{NP}$ [$_{Det}$ the] [$_{Nominal}$ [$_{Noun}$ flight]]]

Constituents



Every internal node is a phrase

- my pajamas
- in my pajamas
- elephant in my pajamas
- an elephant in my pajamas
- shot an elephant in my pajamas
- I shot an elephant in my pajamas

Each phrase could be replaced by another of the same type of constituent

S → VP

- Imperatives
- “Show me the right way”

$S \rightarrow NP\ VP$

- Declaratives
- "The dog barks"

S → Aux NP VP

- Yes/no questions
- “Will you show me the right way?”
- Question generation: subject/aux inversion
    - “the dog barks” ⇛ “is the dog barking”
    - S → NP VP ⇛ S → Aux NP VP

$S \rightarrow$ Wh-NP VP

- Wh-subject-question
- “Which flights serve breakfast?”

Nominal → Nominal PP

- An elephant [$_{PP}$ in my pajamas]
- The cat [$_{PP}$ on the floor] [$_{PP}$ under the table] [$_{PP}$ next to the dog]

Relative clauses

- A relative pronoun (that, which) in a relative clause can be the subject or object of the embedded verb.
- A flight [$_{\text{RelClause}}$ that serves breakfast]
- A flight [$_{\text{RelClause}}$ that I got]
- Nominal → RelClause
- RelClause → (who | that) VP

Verb phrases

VP	→	Verb	disappear
VP	→	Verb NP	prefer a morning flight
VP	→	Verb NP PP	prefer a morning flight on Tuesday
VP	→	Verb PP	leave on Tuesday
VP	→	Verb S	I think [$_{S}$ I want a new flight]
VP	→	Verb VP	want [$_{VP}$ to fly today]

Not every verb can appear in each of these productions

Verb phrases

VP	→	Verb	*I filled
VP	→	Verb NP	*I exist the morning flight
VP	→	Verb NP PP	*I exist the morning flight on Tuesday
VP	→	Verb PP	*I filled on Tuesday
VP	→	Verb S	*I exist [$_S$ I want a new flight]
VP	→	Verb VP	* I fill [$_{VP}$ to fly today]

Not every verb can appear in each of these productions

Subcategorization

- Verbs are compatible with different complements
  - Transitive verbs take direct object NP (“I filled the tank”)
  - Intransitive verbs don’t (“I exist”)

Subcategorization

- The set of possible complements of a verb is its subcategorization frame.

VP	→	Verb VP	* I fill [$_{VP}$ to fly today]
VP	→	Verb VP	I want [$_{VP}$ to fly today]

Coordination

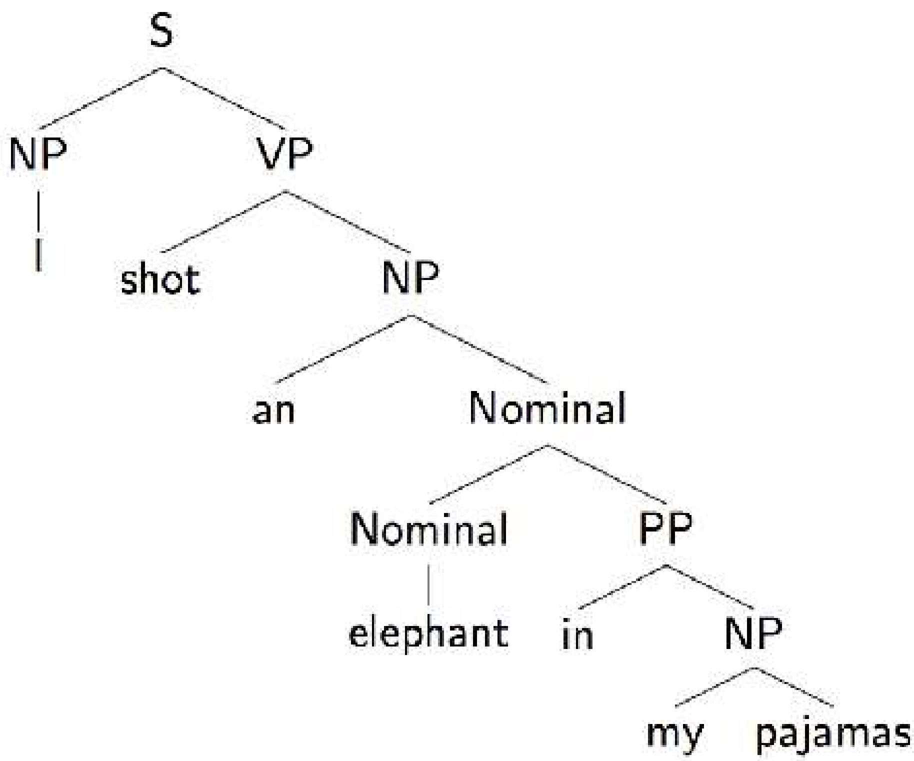
NP	→	NP and NP	the dogs and the cats
Nominal	→	Nominal and Nominal	dogs and cats
VP	→	VP and VP	I came and saw and conquered
JJ	→	JJ and JJ	beautiful and red
S	→	S and S	I came and I saw and I conquered

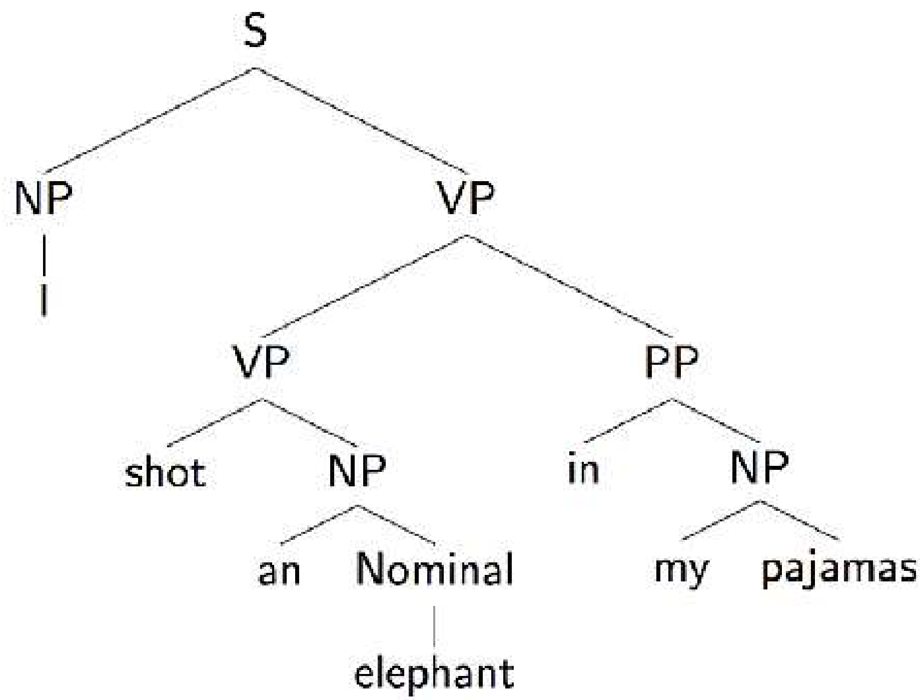
Coordination here also helps us establish whether a group of words forms a constituent

S	→	NP VP
VP	→	Verb NP
VP	→	VP PP
Nominal	→	Nominal PP
Nominal	→	Noun
Nominal	→	Pronoun
PP	→	Prep NP
NP	→	Det Nominal
NP	→	Nominal
NP	→	PossPronoun Nominal

Verb	→	shot
Det	→	an | my
Noun	→	pajamas | elephant
Pronoun	→	I
PossPronoun	→	my

I shot an elephant in my pajamas


S
NP
VP
I
shot
NP
an
Nominal
Nominal
PP
elephant
in
NP
my
pajamas

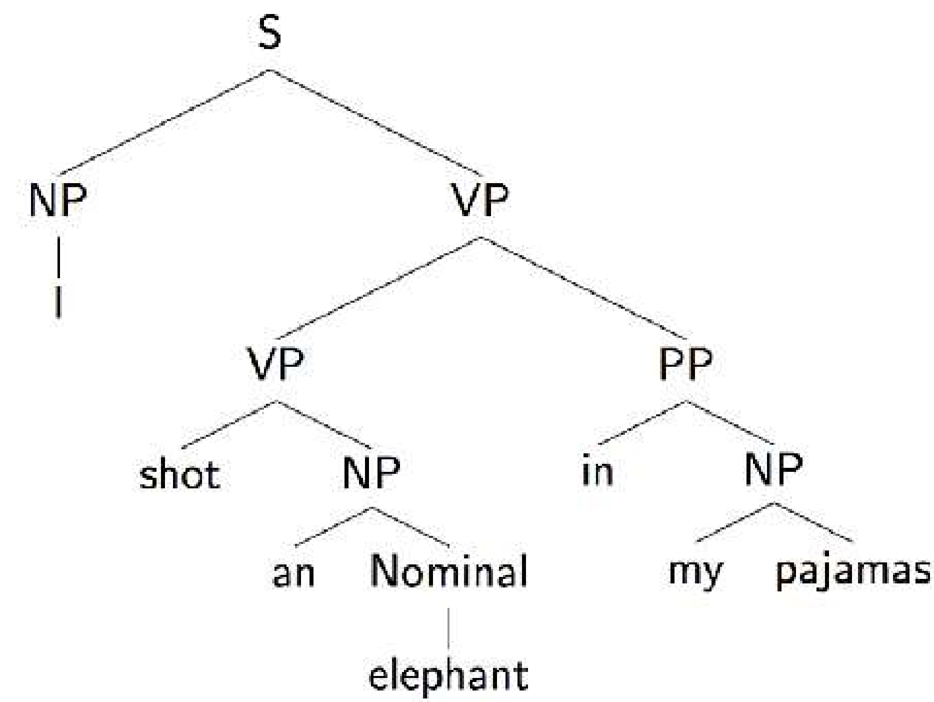

S
NP
VP
I
VP
PP
shot
NP
in
NP
an
Nominal
my
pajamas
elephant

Evaluation

Parseval (1991):
Represent each tree as a collection of tuples:

$<l_1, i_1, j_1>, \ldots, <l_n, i_n, j_n>$

- l_k = label for kth phrase
- i_k = index for first word in kth phrase
- j_k = index for last word in kth phrase

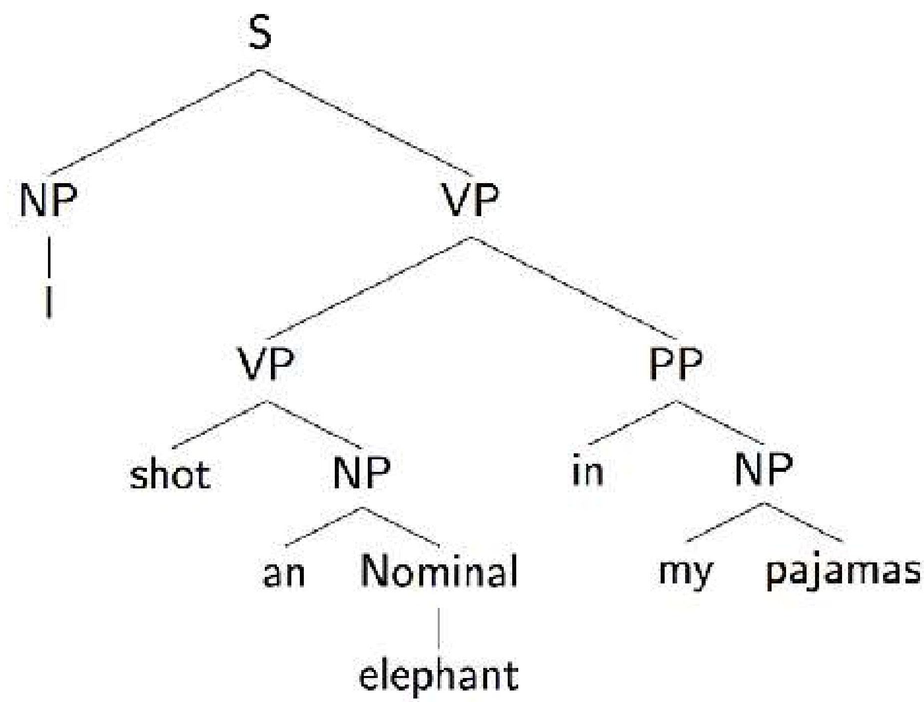


Smith 2017

Evaluation

I$_1$ shot$_2$ an$_3$ elephant$_4$ in$_5$ my$_6$ pajamas$_7$

- <S, 1, 7>
- <NP, 1,1>
- <VP, 2, 7>
- <VP, 2, 4>
- <NP, 3, 4>
- <Nominal, 4, 4>
- <PP, 5, 7>
- <NP, 6, 7>



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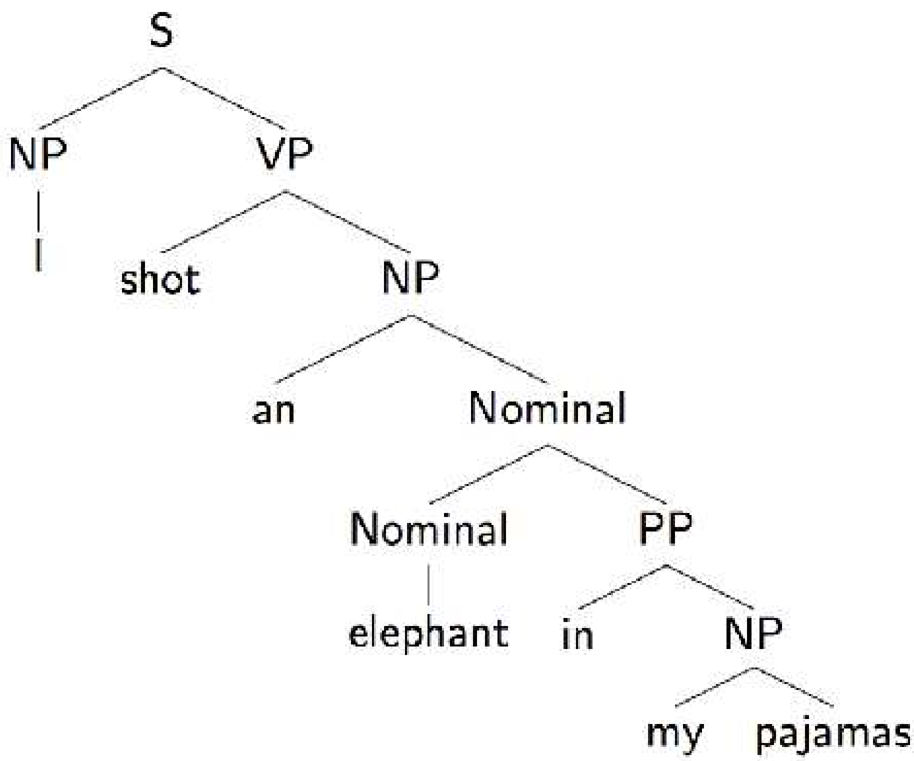
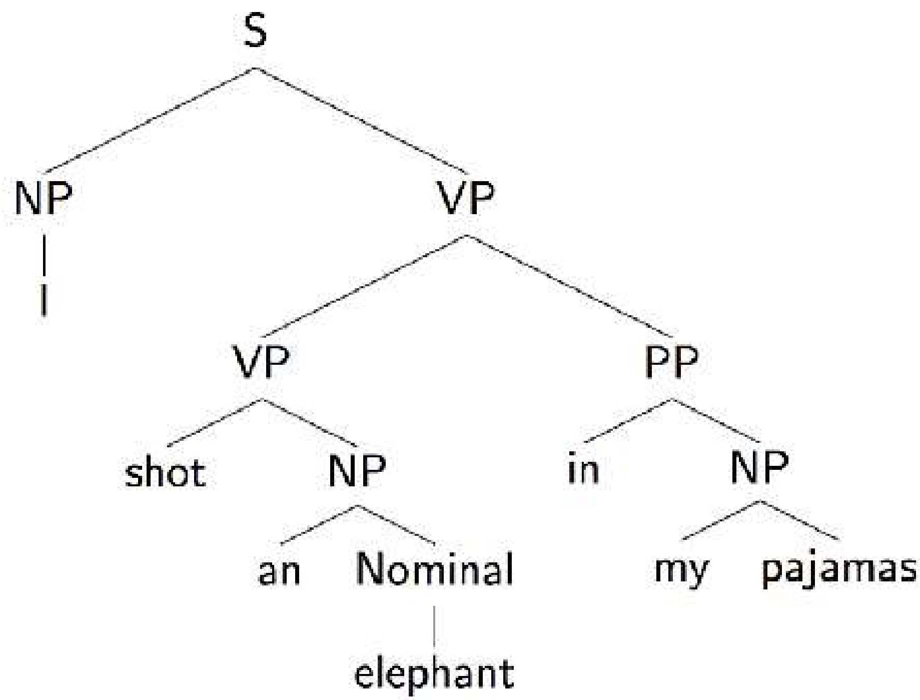

S
NP
VP
I
shot
NP
an
Nominal
Nominal
PP
elephant
in
NP
my
pajamas


S
NP
VP
I
VP
PP
shot
NP
in
NP
an
Nominal
my
pajamas
elephant

Evaluation

I_1 $shot_2$ an_3 $elephant_4$ in_5 my_6 $pajamas_7$

- <S, 1, 7>
- <NP, 1,1>
- <VP, 2, 7>
- <VP, 2, 4>
- <NP, 3, 4>
- <Nominal, 4, 4>
- <PP, 5, 7>
- <NP, 6, 7>

- <S, 1, 7>
- <NP, 1,1>
- <VP, 2, 7>
- <NP, 3, 7>
- <Nominal, 4, 7>
- <Nominal, 4, 4>
- <PP, 5, 7>
- <NP, 6, 7>

Smith 2017

Evaluation

Calculate precision, recall, F1 from these collections of tuples

- Precision: number of tuples in tree 1 also in tree 2, divided by number of tuples in tree 1
- Recall: number of tuples in tree 1 also in tree 2, divided by number of tuples in tree 2

Smith 2017

Evaluation

I_1 $shot_2$ an_3 $elephant_4$ in_5 my_6 $pajamas_7$

- <S, 1, 7>
- <NP, 1,1>
- <VP, 2, 7>
- <VP, 2, 4>
- <NP, 3, 4>
- <Nominal, 4, 4>
- <PP, 5, 7>
- <NP, 6, 7>

- <S, 1, 7>
- <NP, 1,1>
- <VP, 2, 7>
- <NP, 3, 7>
- <Nominal, 4, 7>
- <Nominal, 4, 4>
- <PP, 5, 7>
- <NP, 6, 7>

Smith 2017

CFGs

- Building a CFG by hand is really hard
- To capture all (and only) grammatical sentences, need to exponentially increase the number of categories (e.g., detailed subcategorization info)

Verb-with-no-complement	→	disappear
Verb-with-S-complement	→	said
VP	→	Verb-with-no-complement
VP	→	Verb-with-S-complement S

CFGs

Verb-with-no-complement	→	disappear
Verb-with-S-complement	→	said
VP	→	Verb-with-no-complement
VP	→	Verb-with-S-complement S

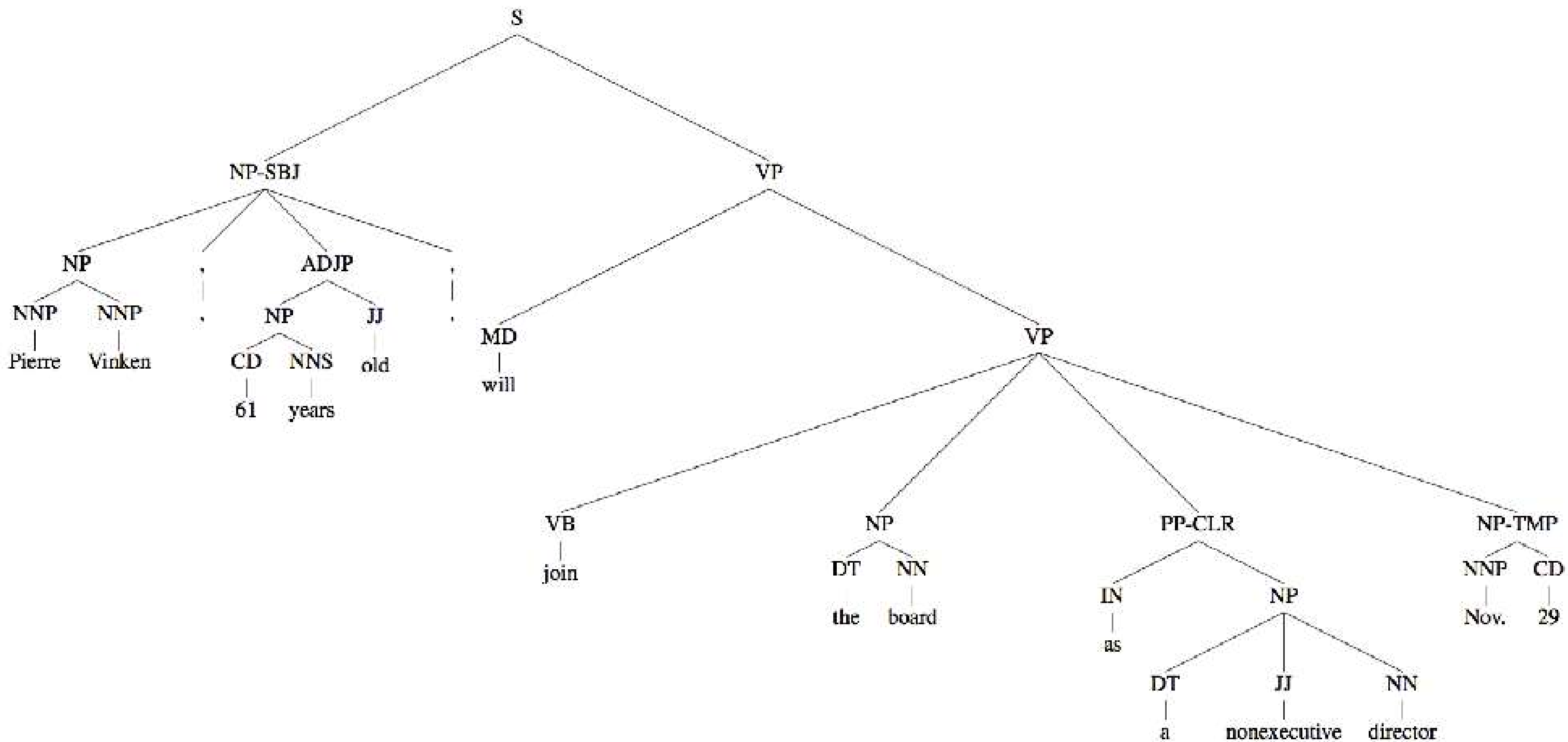
- disappear
- said he is going to the airport
- *disappear he is going to the airport

Treebanks

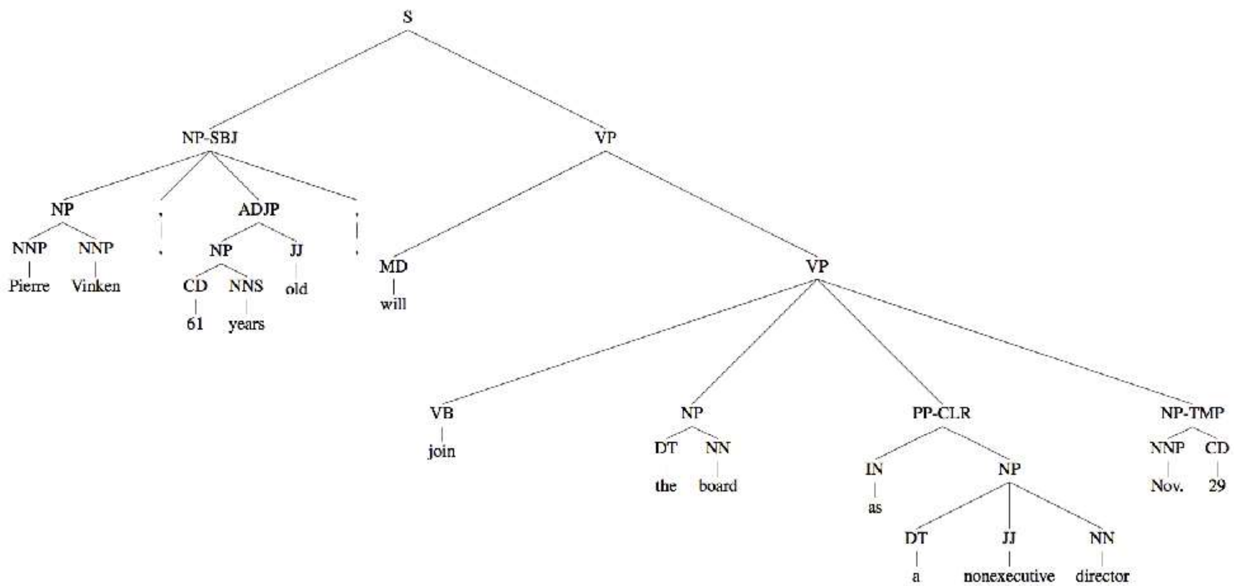
- Rather than create the rules by hand, we can annotate sentences with their syntactic structure and then extract the rules from the annotations

- Treebanks: collections of sentences annotated with syntactic structure

Penn Treebank



Penn Treebank



NP	→	NNP NNP
NP-SBJ	→	NP , ADJP ,
S	→	NP-SBJ VP
VP	→	VB NP PP-CLR NP-TMP

Example rules extracted from this single annotation

Penn Treebank

NP → DT JJ NN
NP → DT JJ NNS
NP → DT JJ NN NN
NP → DT JJ JJ NN
NP → DT JJ CD NNS
NP → RB DT JJ NN NN
NP → RB DT JJ JJ NNS
NP → DT JJ JJ NNP NNS
NP → DT NNP NNP NNP NNP JJ NN
NP → DT JJ NNP CC JJ JJ NN NNS
NP → RB DT JJS NN NN SBAR
NP → DT VBG JJ NNP NNP CC NNP
NP → DT JJ NNS , NNS CC NN NNS NN
NP → DT JJ JJ VBG NN NNP NNP FW NNP
NP → NP JJ , JJ `` SBAR '' NNS

Jurafsky and Martin 2017

CFG

- A basic CFG allows us to check whether a sentence is grammatical in the language it defines
- Binary decision: a sentence is either in the language (a series of productions yields the words we see) or it is not.
- Where would this be useful?

PCFG

- Probabilistic context-free grammar: each production is also associated with a probability.

- This lets us calculate the probability of a parse for a given sentence; for a given parse tree T for sentence S comprised of n rules from R (each A → β):

$$P(T, S) = \prod_{i}^{n} P(\beta \mid A)$$

PCFG

N	Finite set of non-terminal symbols	NP, VP, S
Σ	Finite alphabet of terminal symbols	the, dog, a
R	Set of production rules, each $A \rightarrow \beta$ [p] $p = P(\beta \mid A)$	$S \rightarrow NP\ VP$ $Noun \rightarrow dog$
S	Start symbol	

PCFG

$$\sum_{\beta} P(A \to \beta) = 1$$

(equivalently)

$$\sum_{\beta} P(\beta \mid A) = 1$$

Estimating PCFGs

How do we calculate $P(A \rightarrow \beta)$?

Estimating PCFGs

$$\sum_{\beta} P(\beta \mid A) = \frac{C(A \rightarrow \beta)}{\sum_{\gamma} C(A \rightarrow \gamma)}$$

(equivalently)

$$\sum_{\beta} P(\beta \mid A) = \frac{C(A \rightarrow \beta)}{C(A)}$$

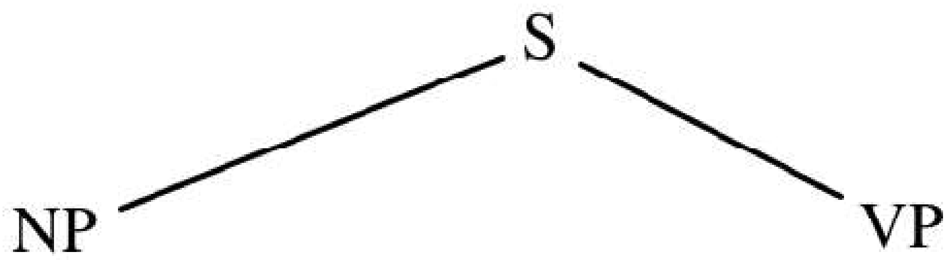
A		β	P(β | NP)
NP	→	NP PP	0.092
NP	→	DT NN	0.087
NP	→	NN	0.047
NP	→	NNS	0.042
NP	→	DT JJ NN	0.035
NP	→	NNP	0.034
NP	→	NNP NNP	0.029
NP	→	JJ NNS	0.027
NP	→	QP -NONE-	0.018
NP	→	NP SBAR	0.017
NP	→	NP PP-LOC	0.017
NP	→	JJ NN	0.015
NP	→	DT NNS	0.014
NP	→	CD	0.014
NP	→	NN NNS	0.013
NP	→	DT NN NN	0.013
NP	→	NP CC NP	0.013

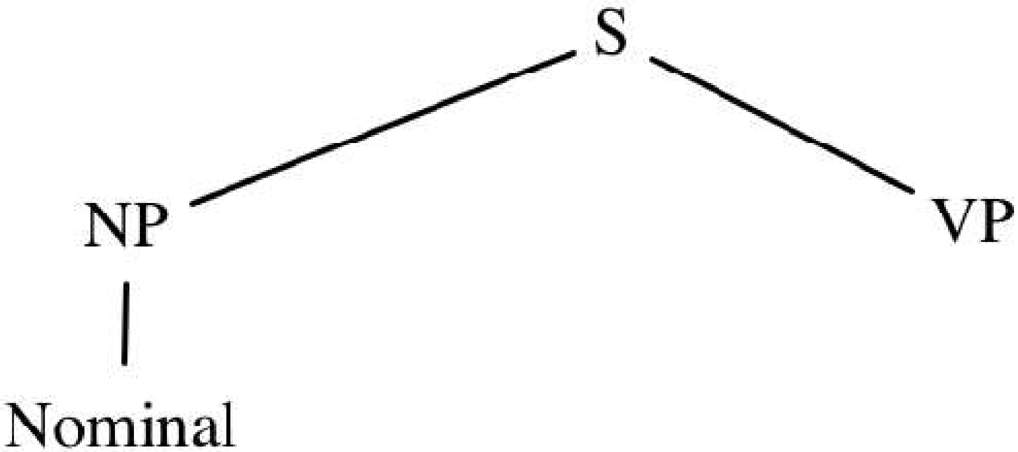
PCFGs

- A CFG tells us whether a sentence is in the language it defines
- A PCFG gives us a mechanism for assigning scores (here, probabilities) to different parses for the same sentence.

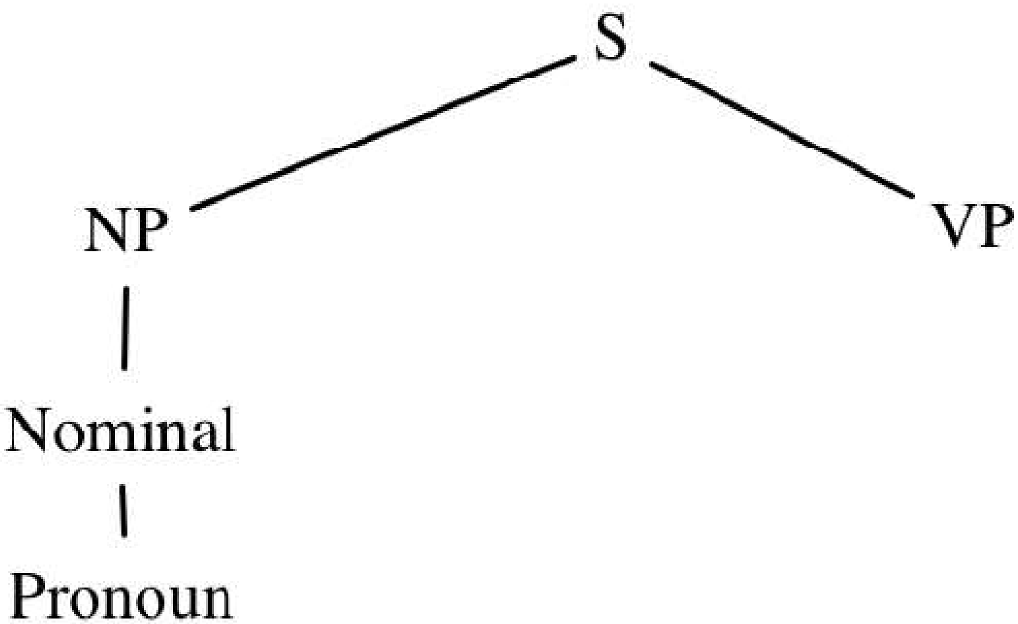
S

$$P(\mathrm{NP}\ \mathrm{VP} \mid \mathrm{S})$$

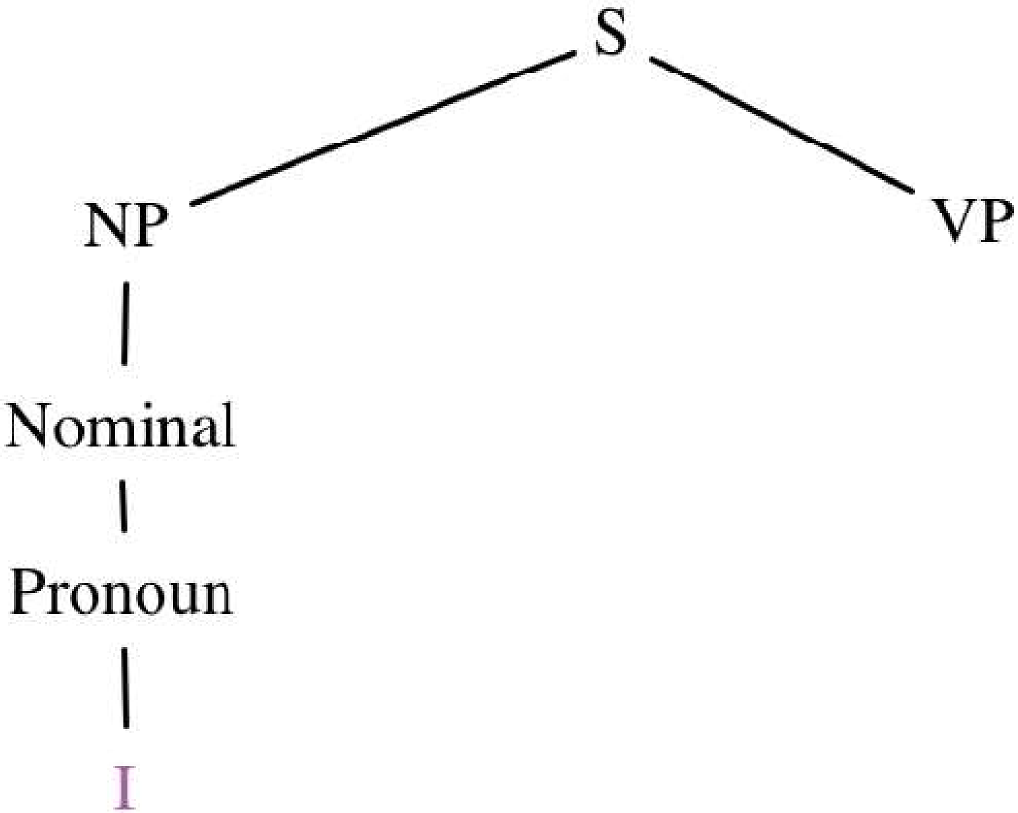




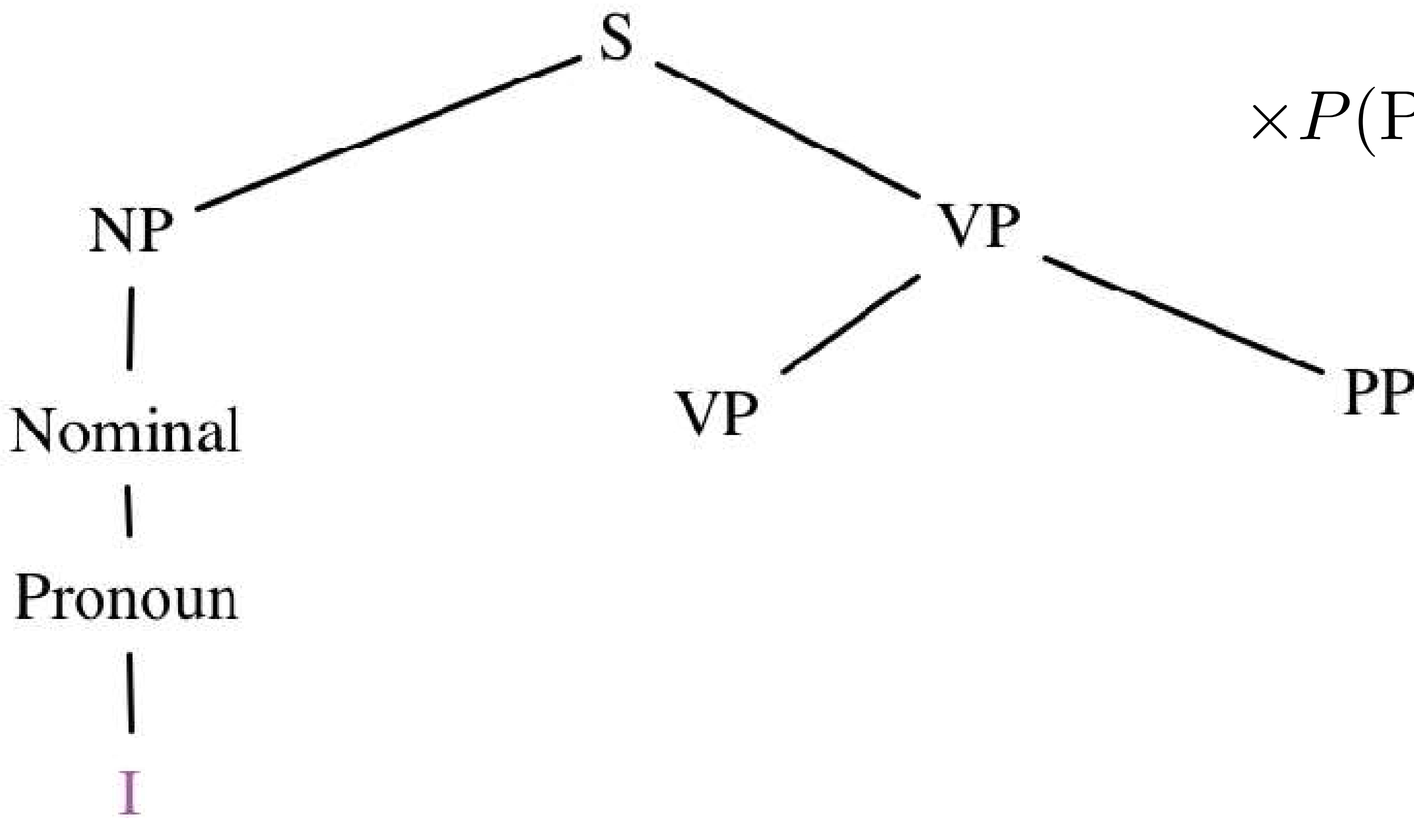
$$P(\text{NP VP} \mid \text{S})$$
$$\times P(\text{Nominal} \mid \text{NP})$$



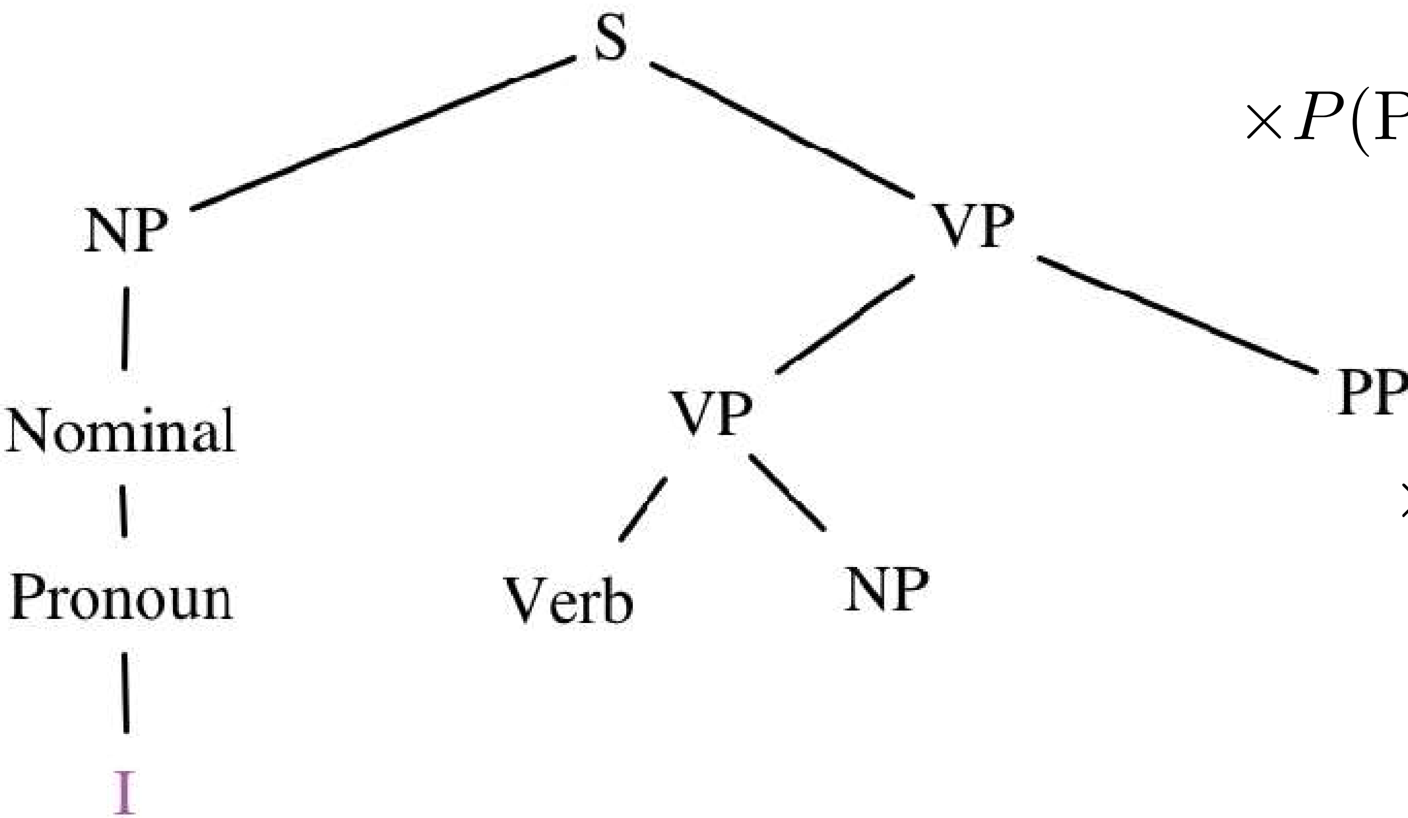
$$P(\mathrm{NP\ VP} \mid \mathrm{S}) \times P(\mathrm{Nominal} \mid \mathrm{NP}) \times P(\mathrm{Pronoun} \mid \mathrm{Nominal})$$



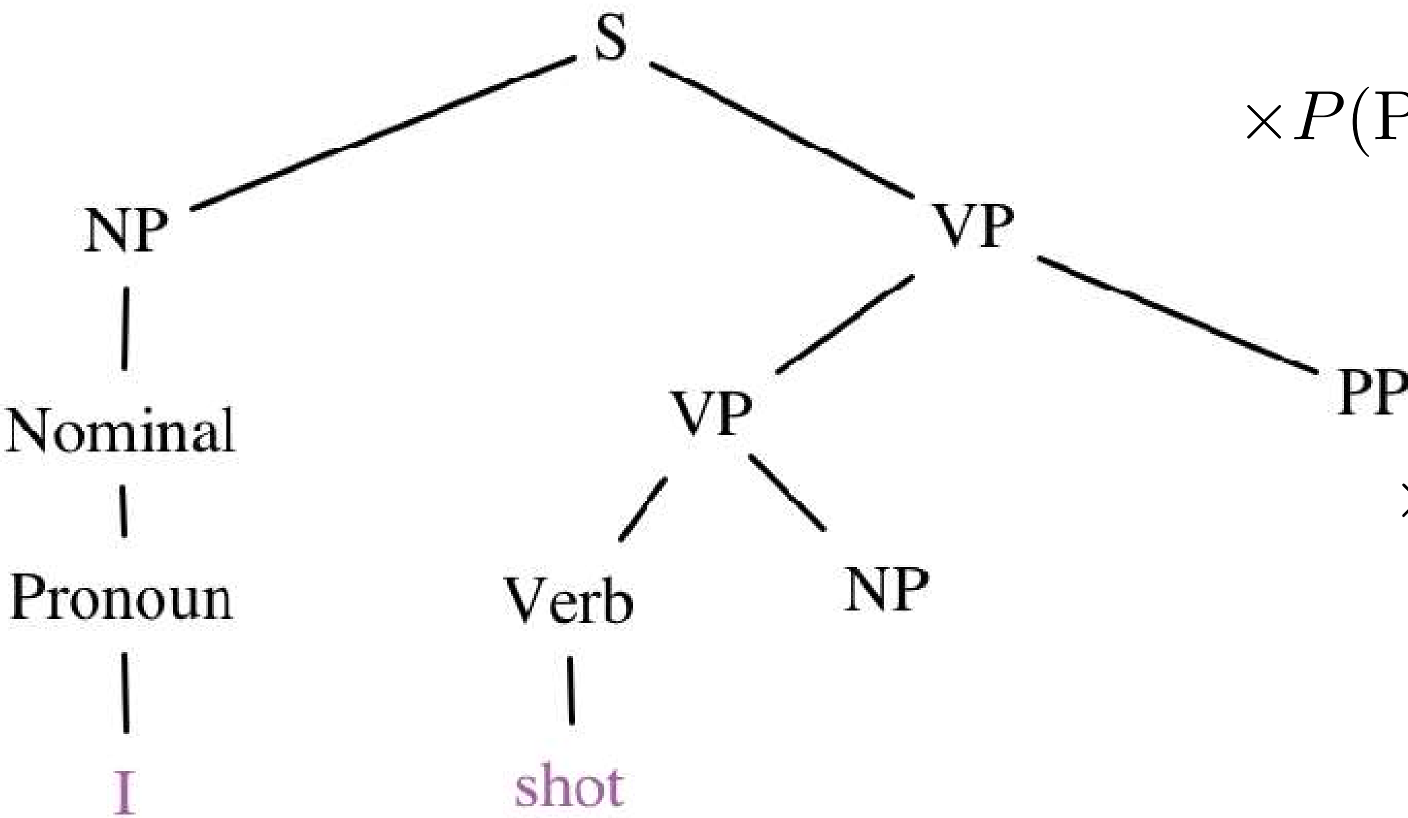
$$
\begin{aligned}
&P(\text{NP VP} \mid \text{S}) \\
&\times P(\text{Nominal} \mid \text{NP}) \\
&\times P(\text{Pronoun} \mid \text{Nominal}) \\
&\times P(\text{I} \mid \text{Pronoun})
\end{aligned}
$$



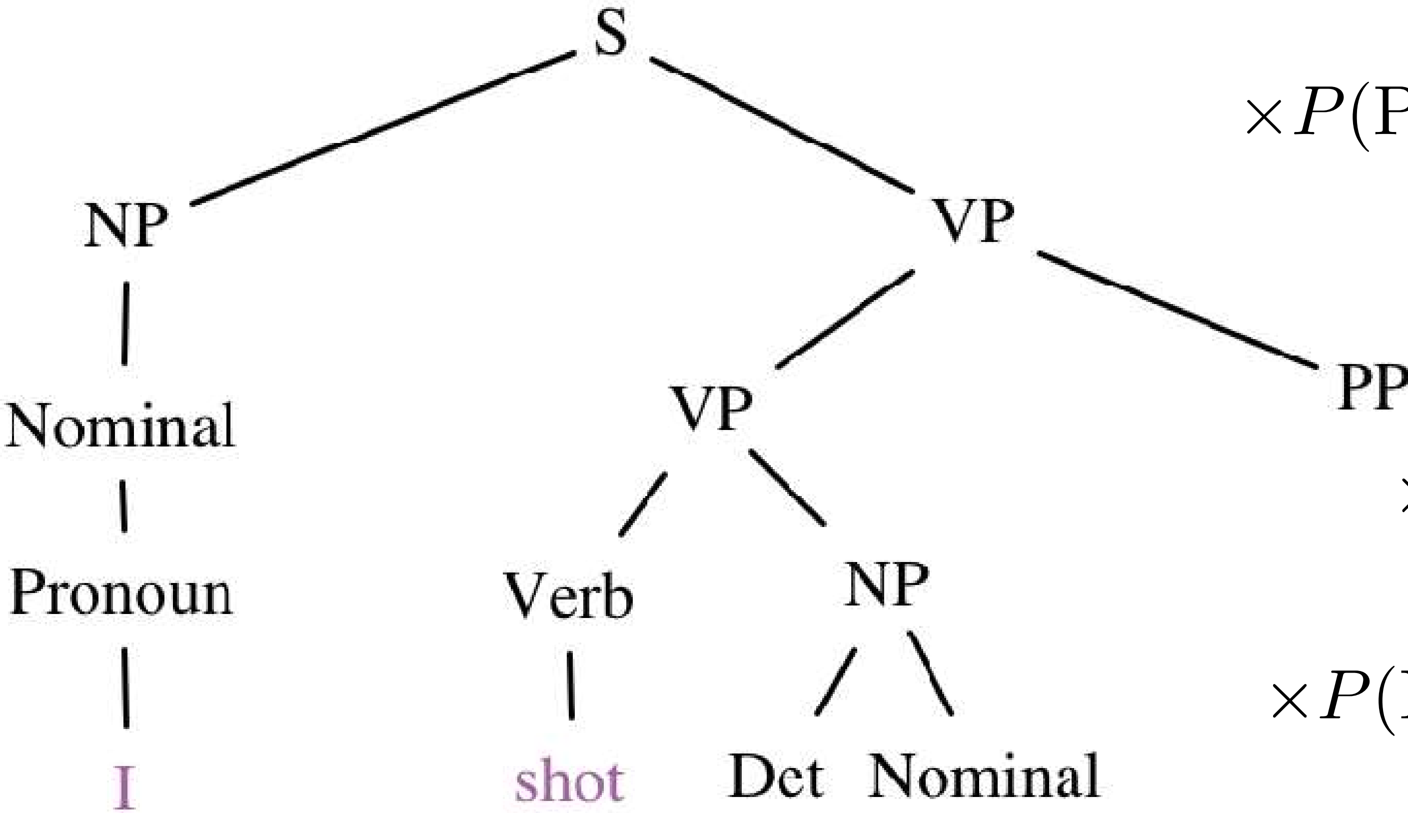
$$P(\text{NP VP} \mid \text{S})$$
$$\times P(\text{Nominal} \mid \text{NP})$$
$$\times P(\text{Pronoun} \mid \text{Nominal})$$
$$\times P(\text{I} \mid \text{Pronoun})$$
$$\times P(\text{VP PP} \mid \text{VP})$$



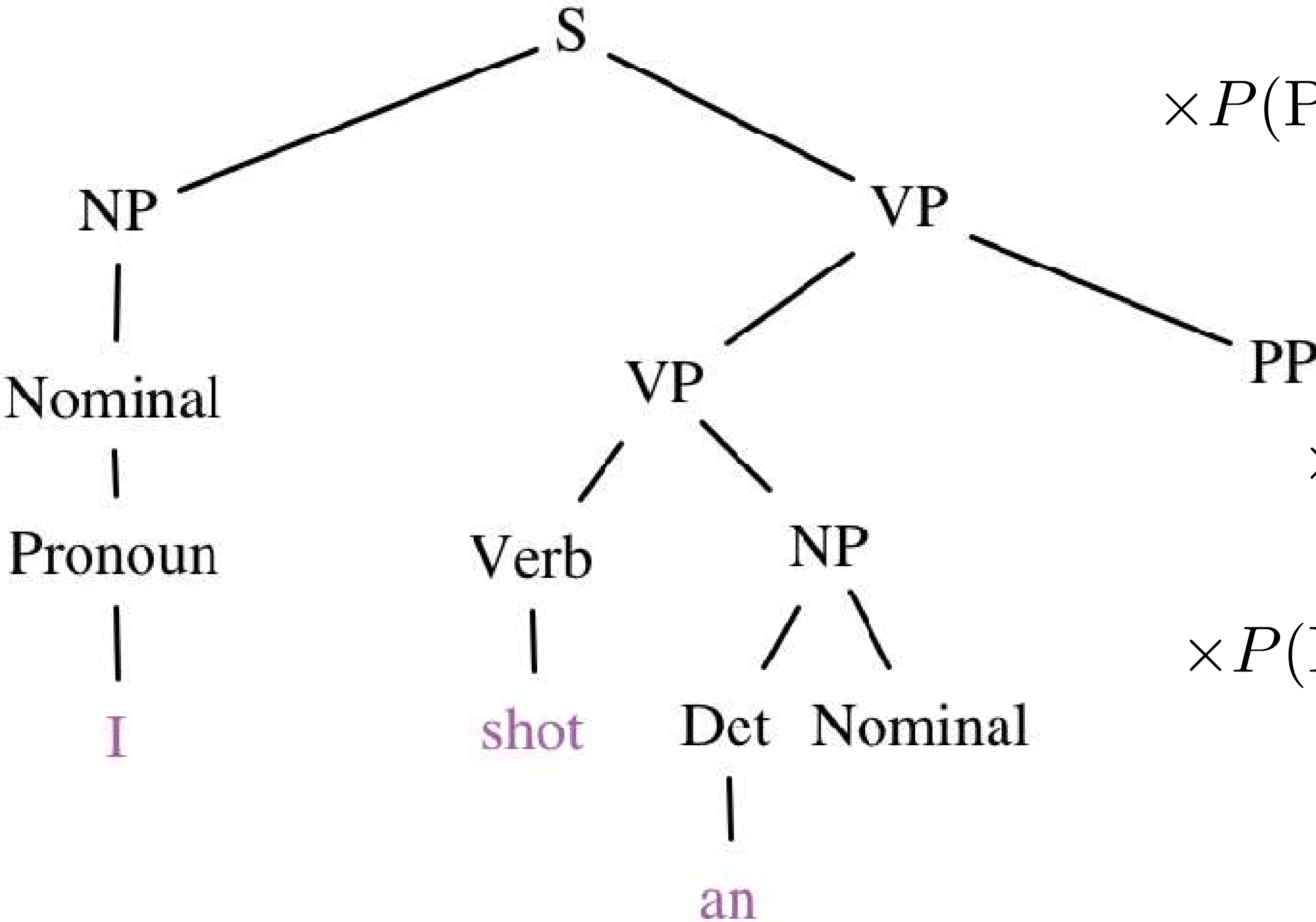
$$P(\text{NP VP} \mid \text{S})$$
$$\times P(\text{Nominal} \mid \text{NP})$$
$$\times P(\text{Pronoun} \mid \text{Nominal})$$
$$\times P(\text{I} \mid \text{Pronoun})$$
$$\times P(\text{VP PP} \mid \text{VP})$$
$$\times P(\text{Verb NP} \mid \text{VP})$$



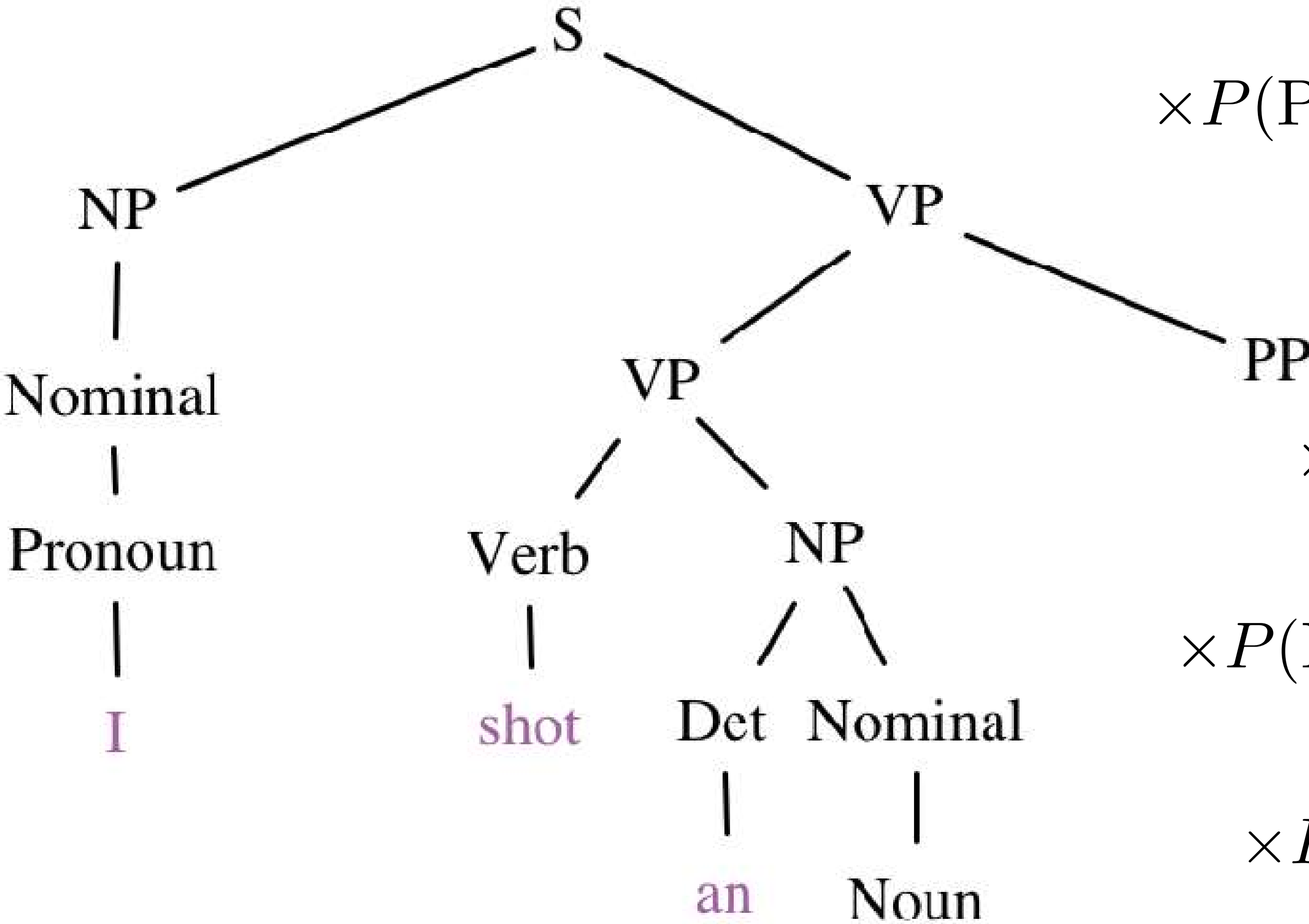
$$P(\text{NP VP} \mid \text{S})$$
$$\times P(\text{Nominal} \mid \text{NP})$$
$$\times P(\text{Pronoun} \mid \text{Nominal})$$
$$\times P(\text{I} \mid \text{Pronoun})$$
$$\times P(\text{VP PP} \mid \text{VP})$$
$$\times P(\text{Verb NP} \mid \text{VP})$$
$$\times P(\text{shot} \mid \text{Verb})$$



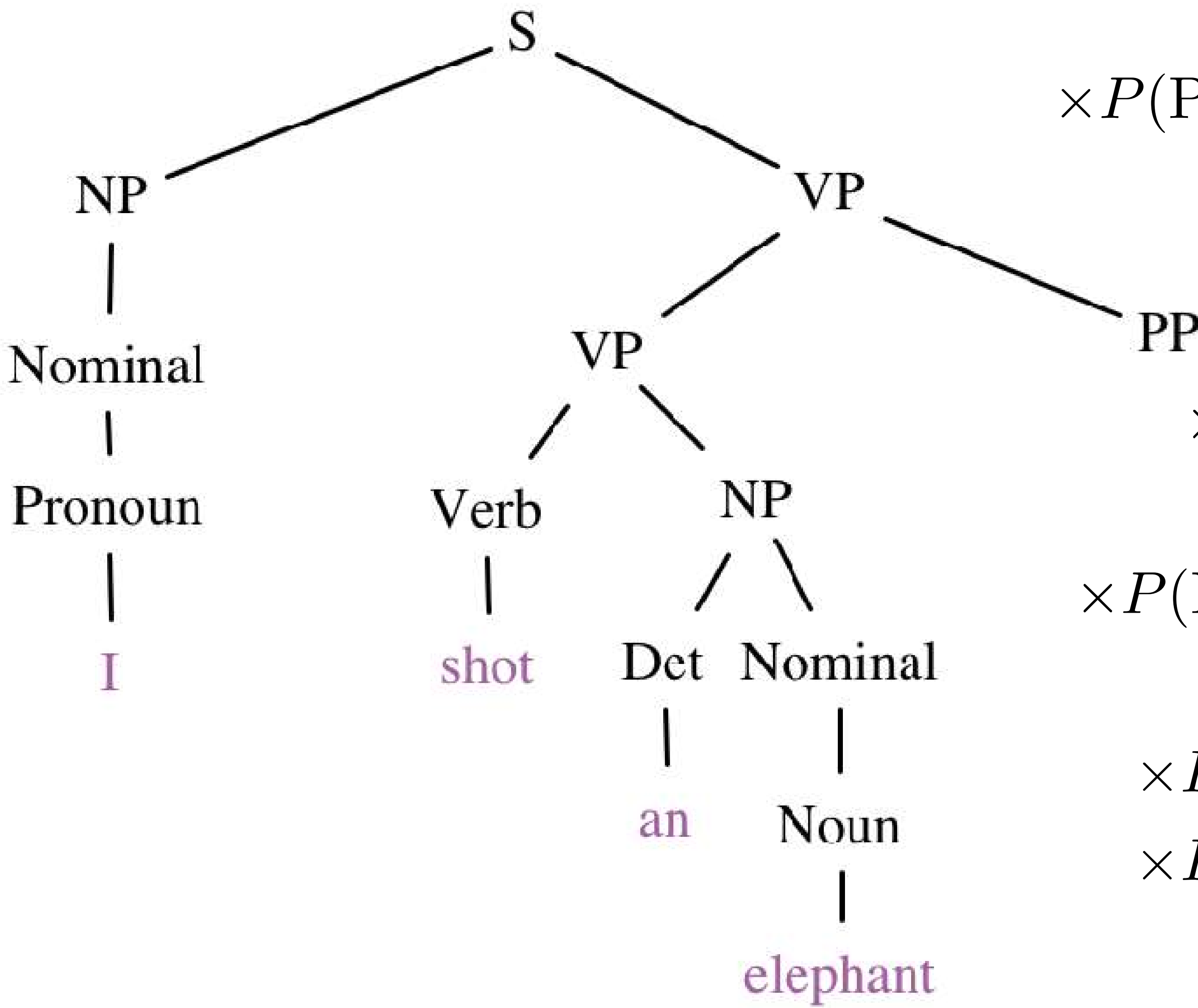
$$
\begin{aligned}
&P(\text{NP VP} \mid \text{S}) \\
&\times P(\text{Nominal} \mid \text{NP}) \\
&\times P(\text{Pronoun} \mid \text{Nominal}) \\
&\times P(\text{I} \mid \text{Pronoun}) \\
&\times P(\text{VP PP} \mid \text{VP}) \\
&\times P(\text{Verb NP} \mid \text{VP}) \\
&\times P(\text{shot} \mid \text{Verb}) \\
&\times P(\text{Det Nominal} \mid \text{NP})
\end{aligned}
$$



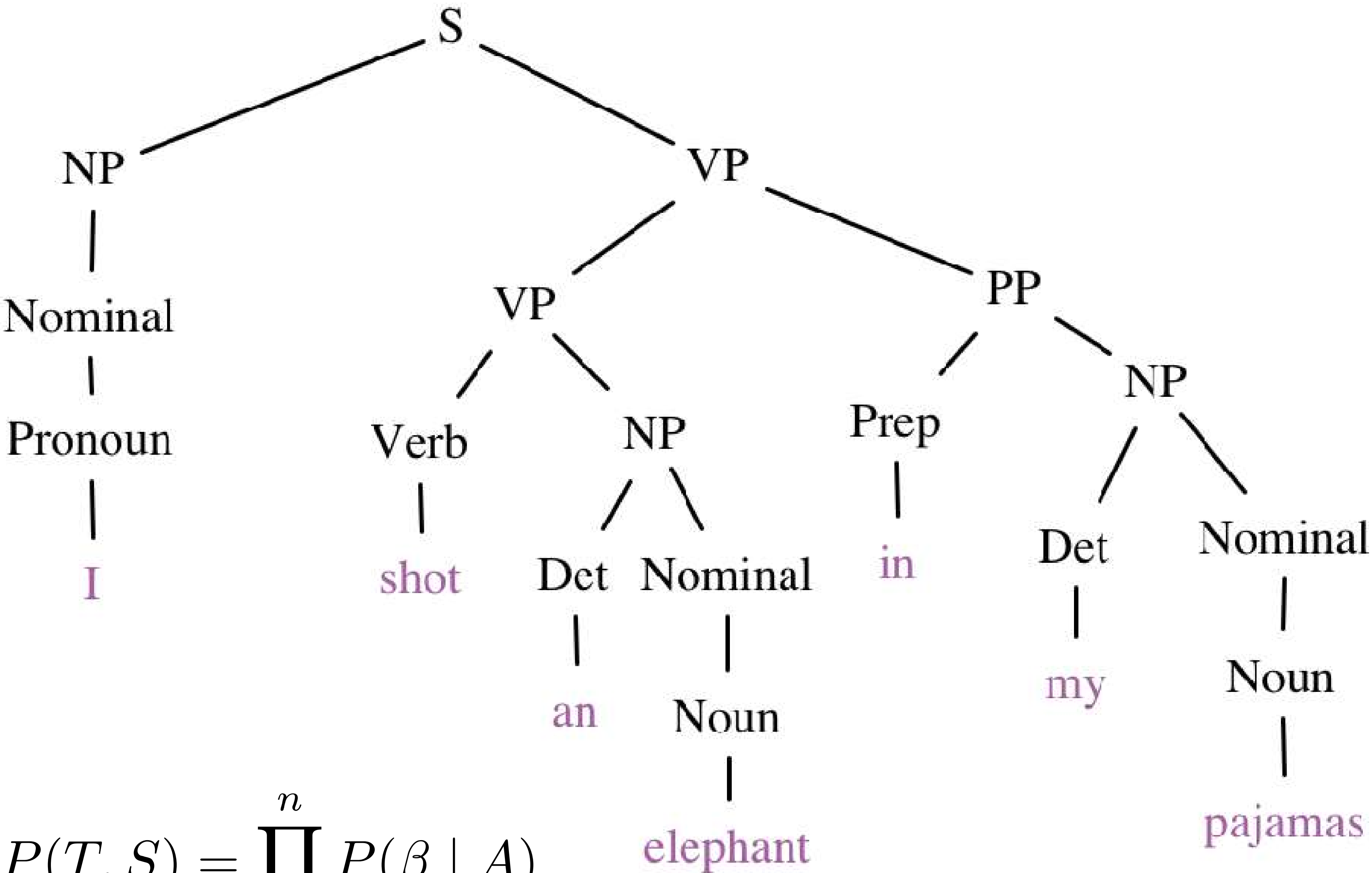
$$
\begin{aligned}
&P(\text{NP VP} \mid \text{S}) \\
&\times P(\text{Nominal} \mid \text{NP}) \\
&\times P(\text{Pronoun} \mid \text{Nominal}) \\
&\times P(\text{I} \mid \text{Pronoun}) \\
&\times P(\text{VP PP} \mid \text{VP}) \\
&\times P(\text{Verb NP} \mid \text{VP}) \\
&\times P(\text{shot} \mid \text{Verb}) \\
&\times P(\text{Det Nominal} \mid \text{NP}) \\
&\times P(\text{an} \mid \text{Det})
\end{aligned}
$$



$$P(\text{NP VP} \mid \text{S})$$
$$\times P(\text{Nominal} \mid \text{NP})$$
$$\times P(\text{Pronoun} \mid \text{Nominal})$$
$$\times P(\text{I} \mid \text{Pronoun})$$
$$\times P(\text{VP PP} \mid \text{VP})$$
$$\times P(\text{Verb NP} \mid \text{VP})$$
$$\times P(\text{shot} \mid \text{Verb})$$
$$\times P(\text{Det Nominal} \mid \text{NP})$$
$$\times P(\text{an} \mid \text{Det})$$
$$\times P(\text{Noun} \mid \text{Nominal})$$



$$P(\text{NP VP} \mid \text{S})$$
$$\times P(\text{Nominal} \mid \text{NP})$$
$$\times P(\text{Pronoun} \mid \text{Nominal})$$
$$\times P(\text{I} \mid \text{Pronoun})$$
$$\times P(\text{VP PP} \mid \text{VP})$$
$$\times P(\text{Verb NP} \mid \text{VP})$$
$$\times P(\text{shot} \mid \text{Verb})$$
$$\times P(\text{Det Nominal} \mid \text{NP})$$
$$\times P(\text{an} \mid \text{Det})$$
$$\times P(\text{Noun} \mid \text{Nominal})$$
$$\times P(\text{elephant} \mid \text{Noun})$$



$$P(T,S) = \prod_{i}^{n} P(\beta \mid A)$$

PCFGs

- A PCFG gives us a mechanism for assigning scores (here, probabilities) to different parses for the same sentence.
- But we often care about is finding the single best parse with the highest probability.