Syntax & Grammars

Instructor: Wei Xu
Ohio State University

Some slides adapted from Ray Mooney, Marine Carpuat, Nathan Schneider, Michael Collins

What’s next in the class?

- From sequences to **trees**

- Syntax
  - Constituent, Grammatical relations, Dependency relations

- Formal Grammars
  - Context-free grammar
  - Dependency grammar

sýntaxis (setting out or arranging)

- The ordering of words and how they group into phrases
  - [[students][[cook and serve][grandparents]]]
  - [[students][[cook][and][serve grandparents]]]

Students Cook & Serve Grandparents

On Thursday, September 9, Gorman School hosted the first annual Grandparent's Day.

All Grandparents were invited to a school wide pancake breakfast. Upper grade students served as excellent chefs, as well as taking responsibility for serving the food and the clean up after-

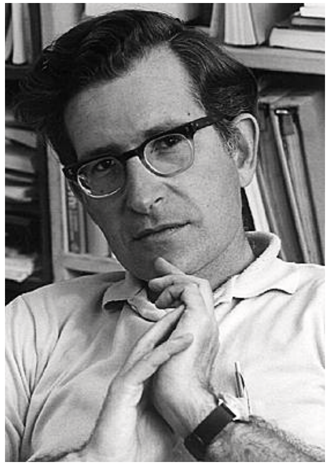
Syntax and Grammar

- Goal of syntactic theory
  - “explain how people combine words to form sentences and how children attain knowledge of sentence structure”

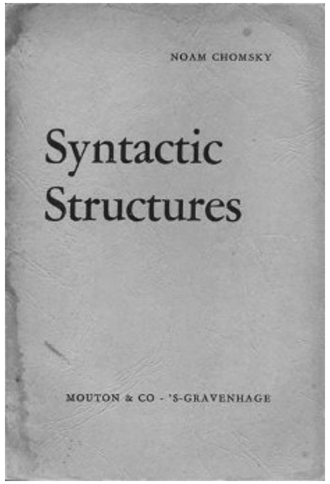
- Grammar
  - implicit knowledge of a native speaker
  - acquired without explicit instruction
  - minimally able to generate all and only the possible sentences of the language

Colin Phillips, “Syntax”, 2003

Syntax vs. Semantics



“Colorless green ideas sleep furiously.”
— Noam Chomsky (1957)

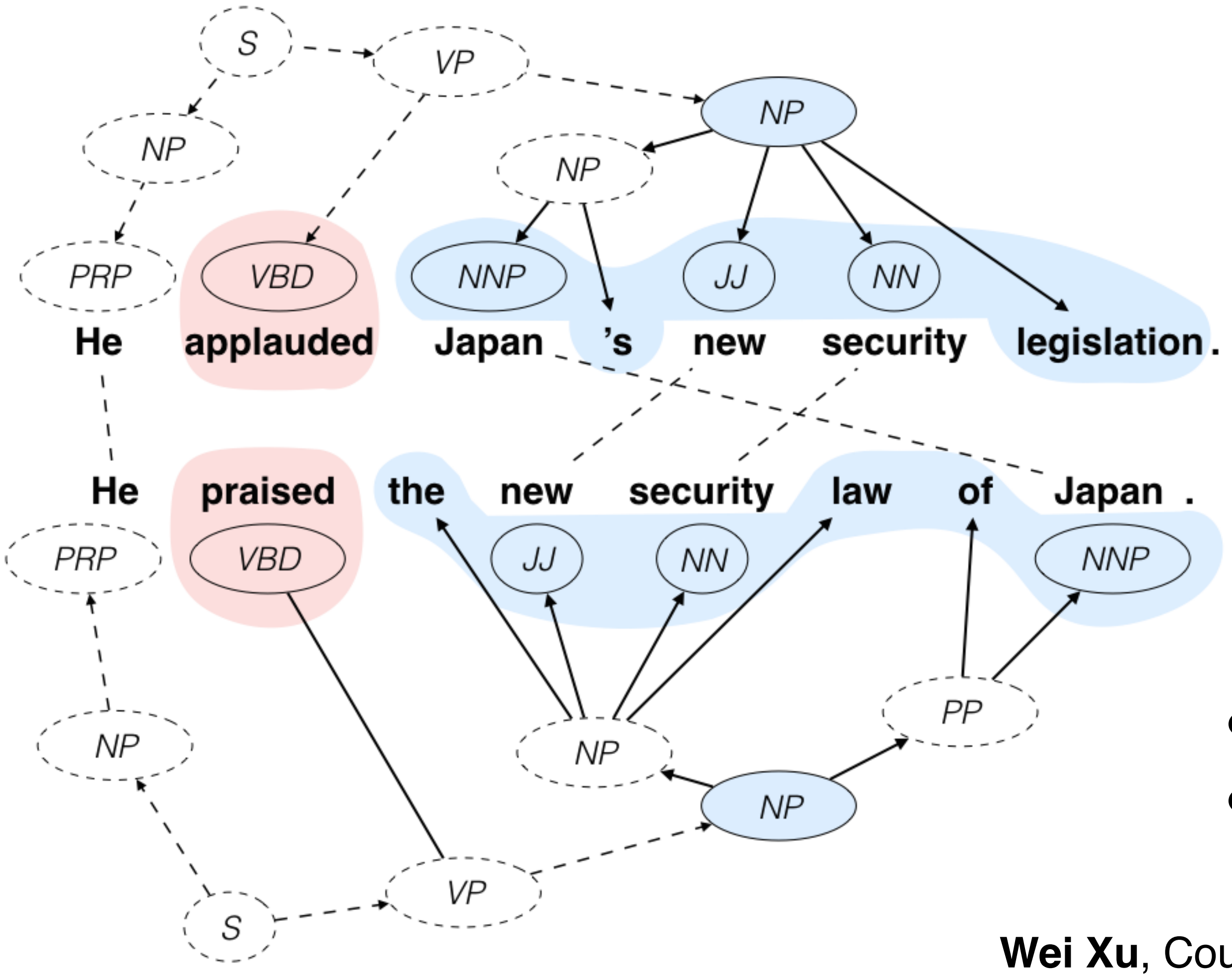


Contrast with: “sleep green furiously ideas colorless”

Syntax in NLP Applications

- Syntactic analysis is often a key component in applications
  - Grammar Checkers
  - Natural Language Generation:
    e.g. Sentence Compression, Fusion, Simplification, …
  - Information Extraction
  - Machine Translation
  - Question Answering
  - …

An Example: Sentence Simplification



- current state-of-the-art system
- syntactic machine translation techniques

Wei Xu, Courtney Napoles, Ellie Pavlick, Quanze Chen, Chris Callison-Burch.
"Optimizing Statistical Machine Translation for Simplification" in TACL (2016)

Another Example: Machine Translation

- English word order is *subject – verb – object*
- Japanese word order is *subject – object – verb*

English: IBM bought Lotus
Japanese: *IBM Lotus bought*

English: Sources said that IBM bought Lotus yesterday
Japanese: *Sources yesterday IBM Lotus bought that said*

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

Syntax

Constituency Grammars

Constituency

- Basic idea: groups of words act as a single unit

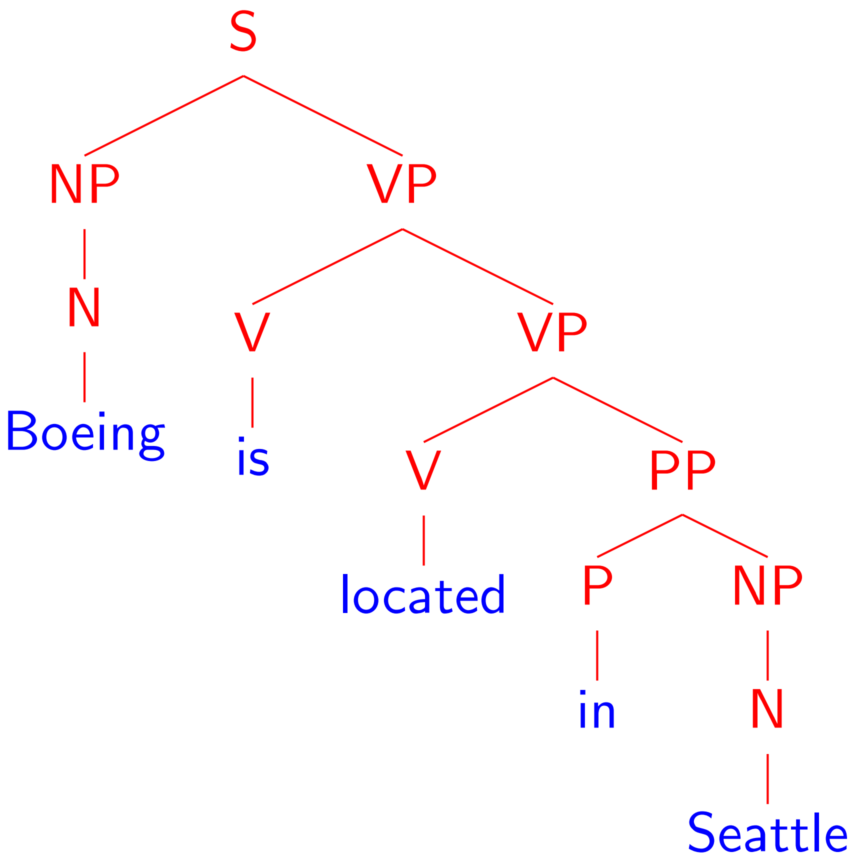
- Constituents form coherent classes that behave similarly
  - with respect to their internal structure:
    e.g. at the core of a noun phrase is a a noun
  - with respect to other constituents:
    e.g. noun phrases generally occur before verbs

Parsing (Syntactic Structure)

INPUT:

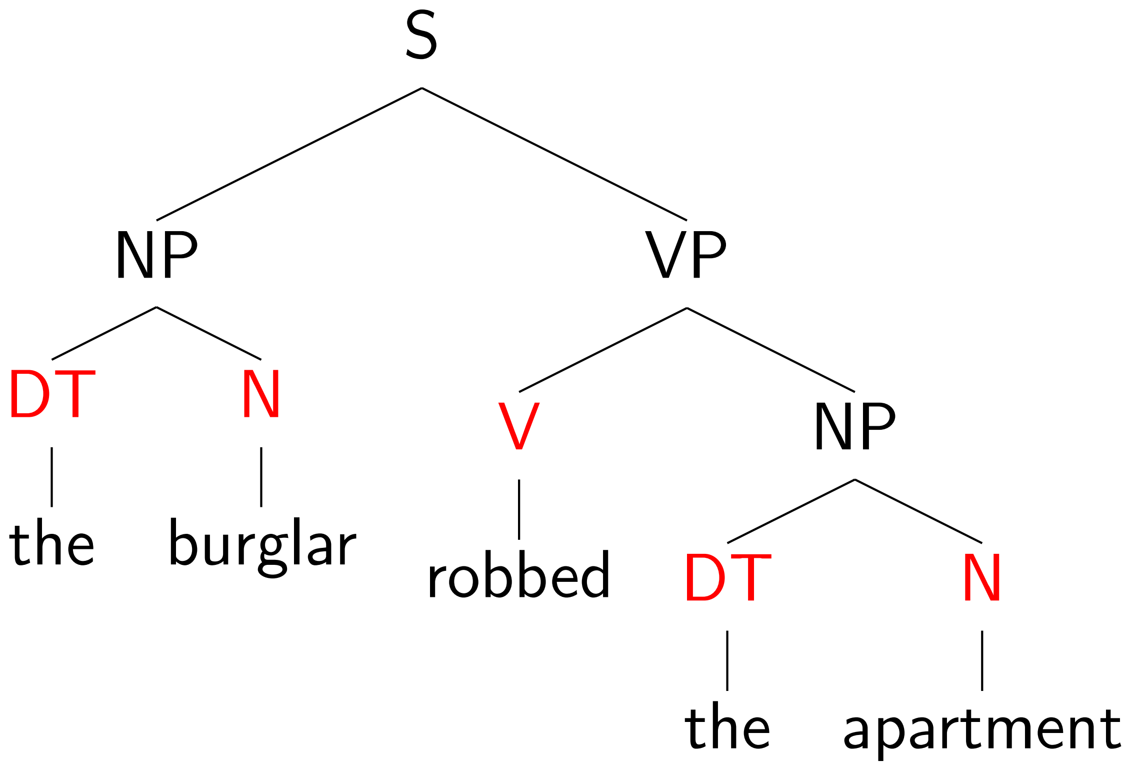
Boeing is located in Seattle.

OUTPUT:



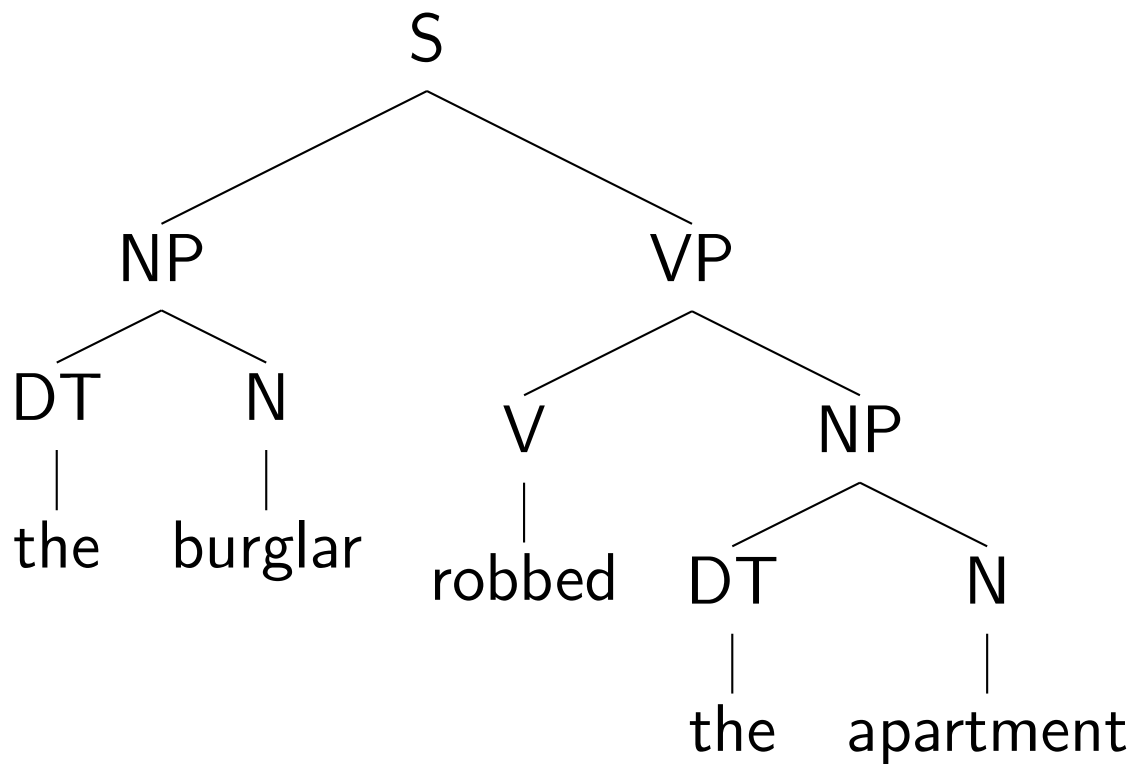
The Information Conveyed by Parse Trees

(1) Part of speech for each word
(N = noun, V = verb, DT = determiner)



The Information Conveyed by Parse Trees (continued)

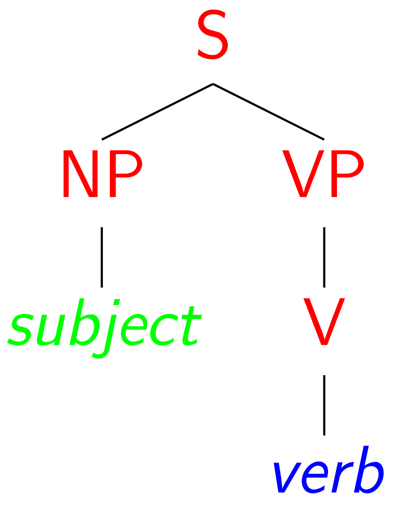
(2) Phrases

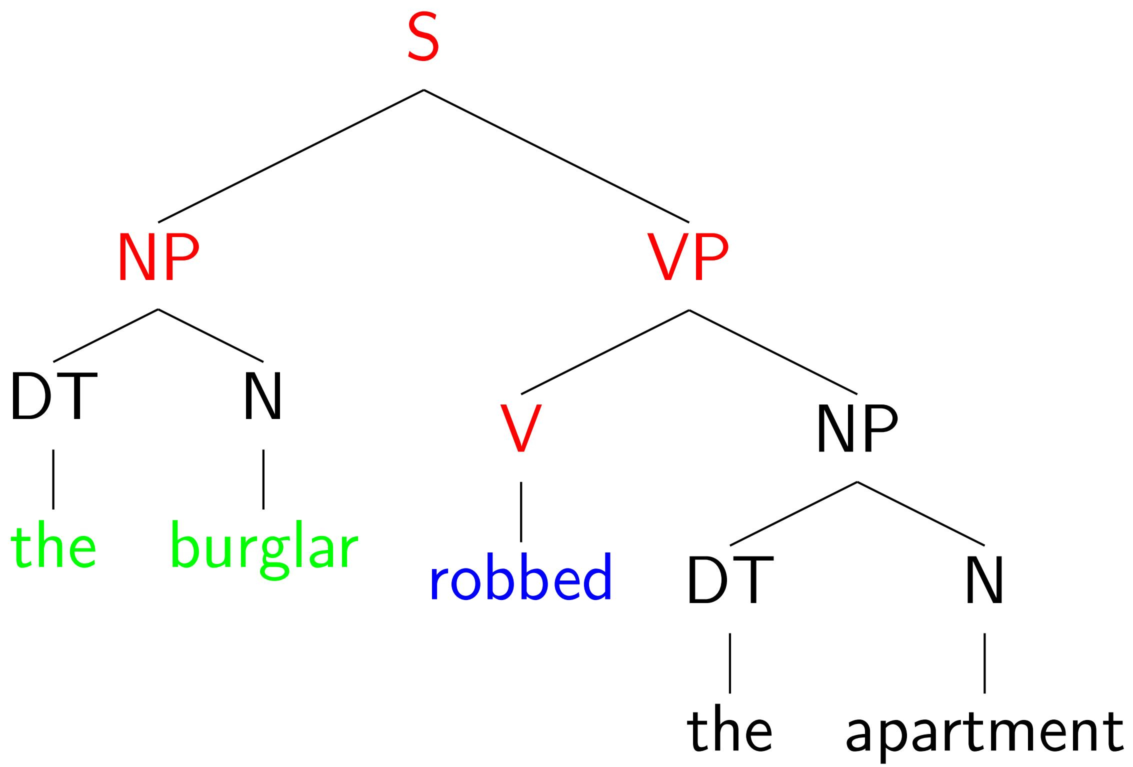


Noun Phrases (NP): "the burglar", "the apartment"
Verb Phrases (VP): "robbed the apartment"
Sentences (S): "the burglar robbed the apartment"

The Information Conveyed by Parse Trees (continued)

(3) Useful Relationships





⇒ “the burglar” is the subject of “robbed”

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!

Syntactic Formalisms

- Work in formal syntax goes back to Chomsky's PhD thesis in the 1950s

The idea of basing a grammar on constituent structure dates back to Wilhem Wundt (1890).

- Examples of current formalisms: minimalism, lexical functional grammar (LFG), head-driven phrase-structure grammar (HPSG), tree adjoining grammars (TAG), categorial grammars

Regular Grammar

- 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.

- **Q:** Can regular languages define infinite languages?

- **Q:** Can regular languages define arbitrarily complex languages?

Regular Grammar

- 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.

- **Q:** Can regular languages define infinite languages?

  Yes, e.g. a*

- **Q:** Can regular languages define arbitrarily complex languages?

  No. Cannot match all strings with matched parentheses or in $a^n b^n$ forms in general (recursion/arbitrary nesting).

https://en.wikipedia.org/wiki/Pumping_lemma_for_regular_languages

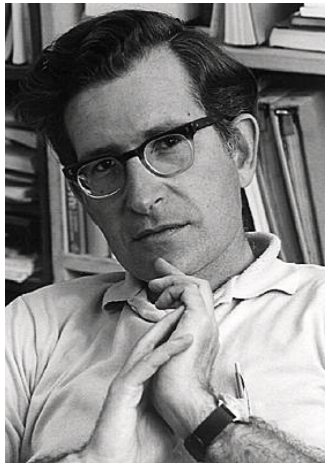
English is not a regular language

- There are certain types of sentences in English that look like $a^n b^n$
  - For example, “The dog that the man that the cat saw kicked barked” could be extended indefinitely.

- If syntax were regular, we should be able to reach a length after which we can just insert nouns, without adding the corresponding verb (by the Pumping Lemma).
  - For example, “The dog that the man that the cat that the rat that the mouse _____ feared saw kicked barked”

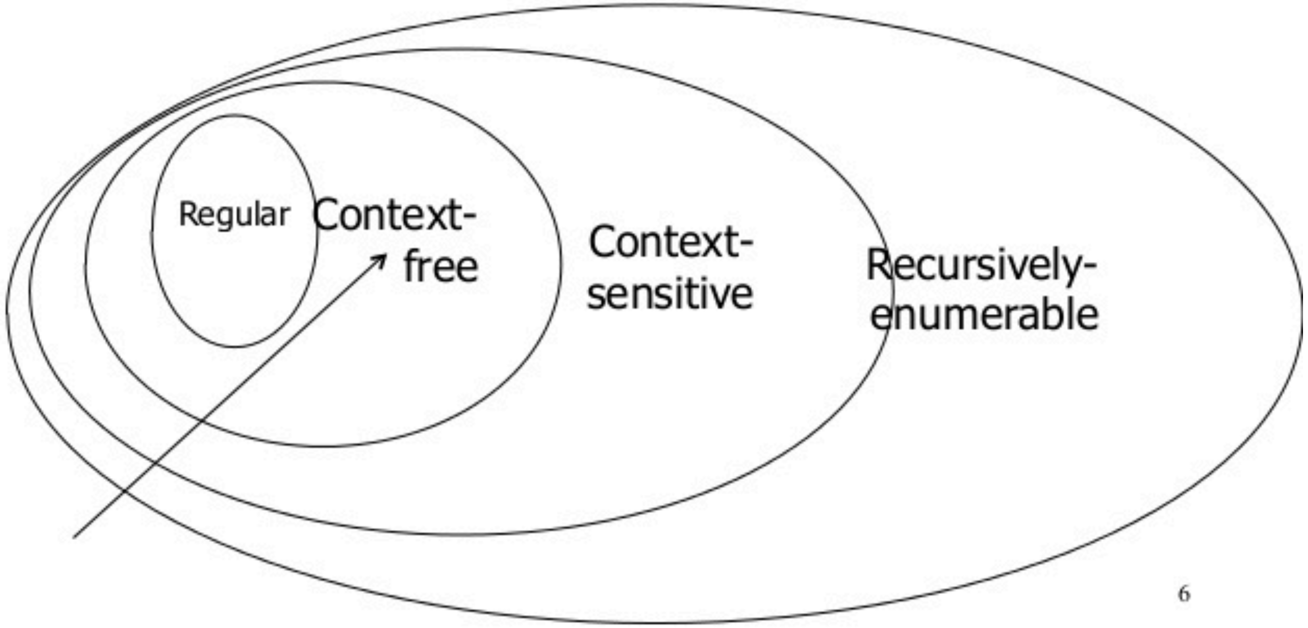
Noah Chomsky. 1956. The range of adequacy of various types of grammars.

The Chomsky Hierarchy



- Hierarchy of classes of formal languages

One language is of greater generative power or complexity than another if it can define a language that other cannot define. Context-free grammars are more powerful than regular grammars.



Context-Free Grammars

a.k.a phrase structure grammars,
Backus-Naur form (BNF)

Hopcroft and Ullman, 1979

A context free grammar $G = (N, \Sigma, R, S)$ where:

- N is a set of non-terminal symbols
- Σ is a set of terminal symbols
- R is a set of rules of the form $X \to Y_1 Y_2 \ldots Y_n$ for $n \geq 0$, $X \in N$, $Y_i \in (N \cup \Sigma)$
- $S \in N$ is a distinguished start symbol

A Context-Free Grammar for English

N = {S, NP, VP, PP, DT, Vi, Vt, NN, IN}
S = S
Σ = {sleeps, saw, man, woman, telescope, the, with, in}

$R =$

S	$\rightarrow$	NP	VP
VP	$\rightarrow$	Vi	
VP	$\rightarrow$	Vt	NP
VP	$\rightarrow$	VP	PP
NP	$\rightarrow$	DT	NN
NP	$\rightarrow$	NP	PP
PP	$\rightarrow$	IN	NP

Vi	$\rightarrow$	sleeps
Vt	$\rightarrow$	saw
NN	$\rightarrow$	man
NN	$\rightarrow$	woman
NN	$\rightarrow$	telescope
DT	$\rightarrow$	the
IN	$\rightarrow$	with
IN	$\rightarrow$	in

Note: S=sentence, VP=verb phrase, NP=noun phrase, PP=prepositional phrase, DT=determiner, Vi=intransitive verb, Vt=transitive verb, NN=noun, IN=preposition

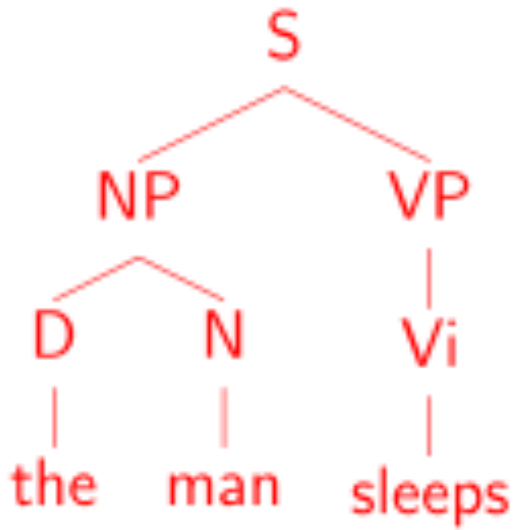
Left-Most Derivations

A left-most derivation is a sequence of strings $s_1 \ldots s_n$, where

- $s_1 = S$, the start symbol
- $s_n \in \Sigma^*$, i.e. s_n is made up of terminal symbols only
- Each s_i for $i = 2 \ldots n$ is derived from s_{i-1} by picking the left-most non-terminal X in s_{i-1} and replacing it by some β where $X \rightarrow \beta$ is a rule in R

For example: [S], [NP VP], [D N VP], [the N VP], [the man VP], [the man Vi], [the man sleeps]

Representation of a derivation as a tree:



An Example

DERIVATION	RULES USED
S	

An Example

DERIVATION	RULES USED
S	
	S $\rightarrow$ NP VP
NP VP	

An Example

DERIVATION	RULES USED
S	
	S $\rightarrow$ NP VP
NP VP	
	NP $\rightarrow$ DT N
DT N VP	

An Example

DERIVATION	RULES USED
S	
	S $\rightarrow$ NP VP
NP VP	
	NP $\rightarrow$ DT N
DT N VP	
	DT $\rightarrow$ the
the N VP	

An Example

DERIVATION	RULES USED
S	$S \rightarrow NP\ VP$
NP VP	$NP \rightarrow DT\ N$
DT N VP	$DT \rightarrow$ the
the N VP	$N \rightarrow$ dog
the dog VP	

An Example

DERIVATION	RULES USED
S	$S \rightarrow NP\ VP$
NP VP	$NP \rightarrow DT\ N$
DT N VP	$DT \rightarrow the$
the N VP	$N \rightarrow dog$
the dog VP	$VP \rightarrow VB$
the dog VB	

An Example

DERIVATION	RULES USED
S	
NP VP	S $\rightarrow$ NP VP
DT N VP	NP $\rightarrow$ DT N
the N VP	DT $\rightarrow$ the
the dog VP	N $\rightarrow$ dog
the dog VB	VP $\rightarrow$ VB
the dog laughs	VB $\rightarrow$ laughs

An Example

DERIVATION

S

NP VP

DT N VP

the N VP

the dog VP

the dog VB

the dog laughs

RULES USED

S $\rightarrow$ NP VP

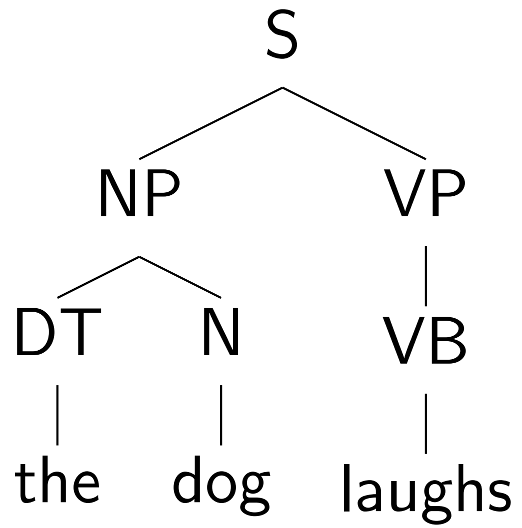
NP $\rightarrow$ DT N

DT $\rightarrow$ the

N $\rightarrow$ dog

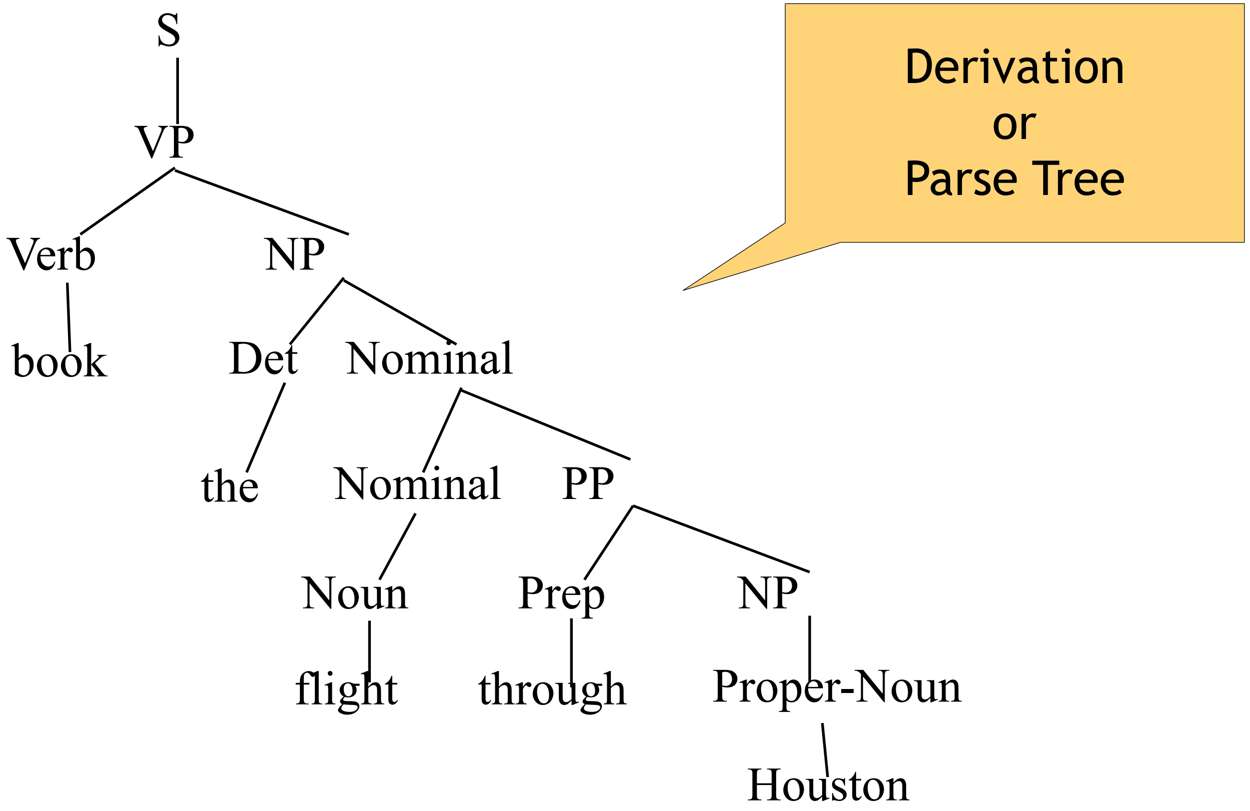
VP $\rightarrow$ VB

VB $\rightarrow$ laughs



Sentence Generation

- Sentences are generated by recursively rewriting the start symbol using the production rules in a CFG until only terminal symbols remain.



Parsing

- Given a string of terminals and a CFG, determine if the string can be generated by the CFG:
  - also return a parse tree for the string
  - also return all possible parse trees for the string

Properties of CFGs

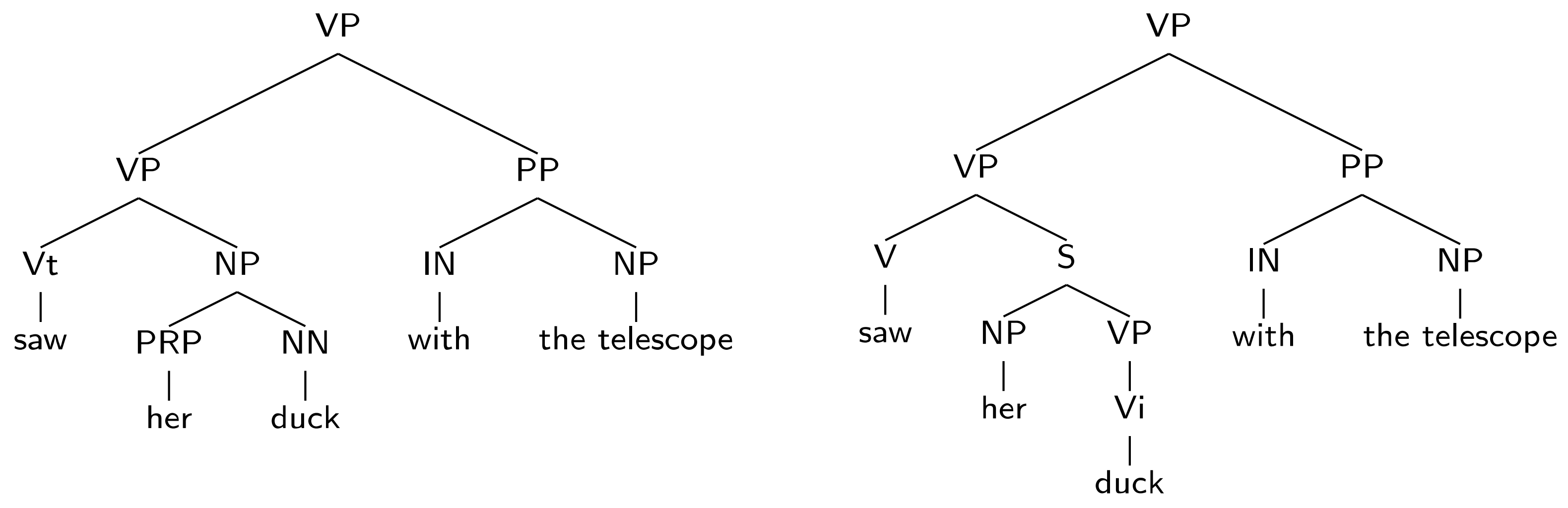
- A CFG defines a set of possible derivations
- A string $s \in \Sigma^*$ is in the *language* defined by the CFG if there is at least one derivation that yields s
- Each string in the language generated by the CFG may have more than one derivation ("ambiguity")

Sources of Ambiguity

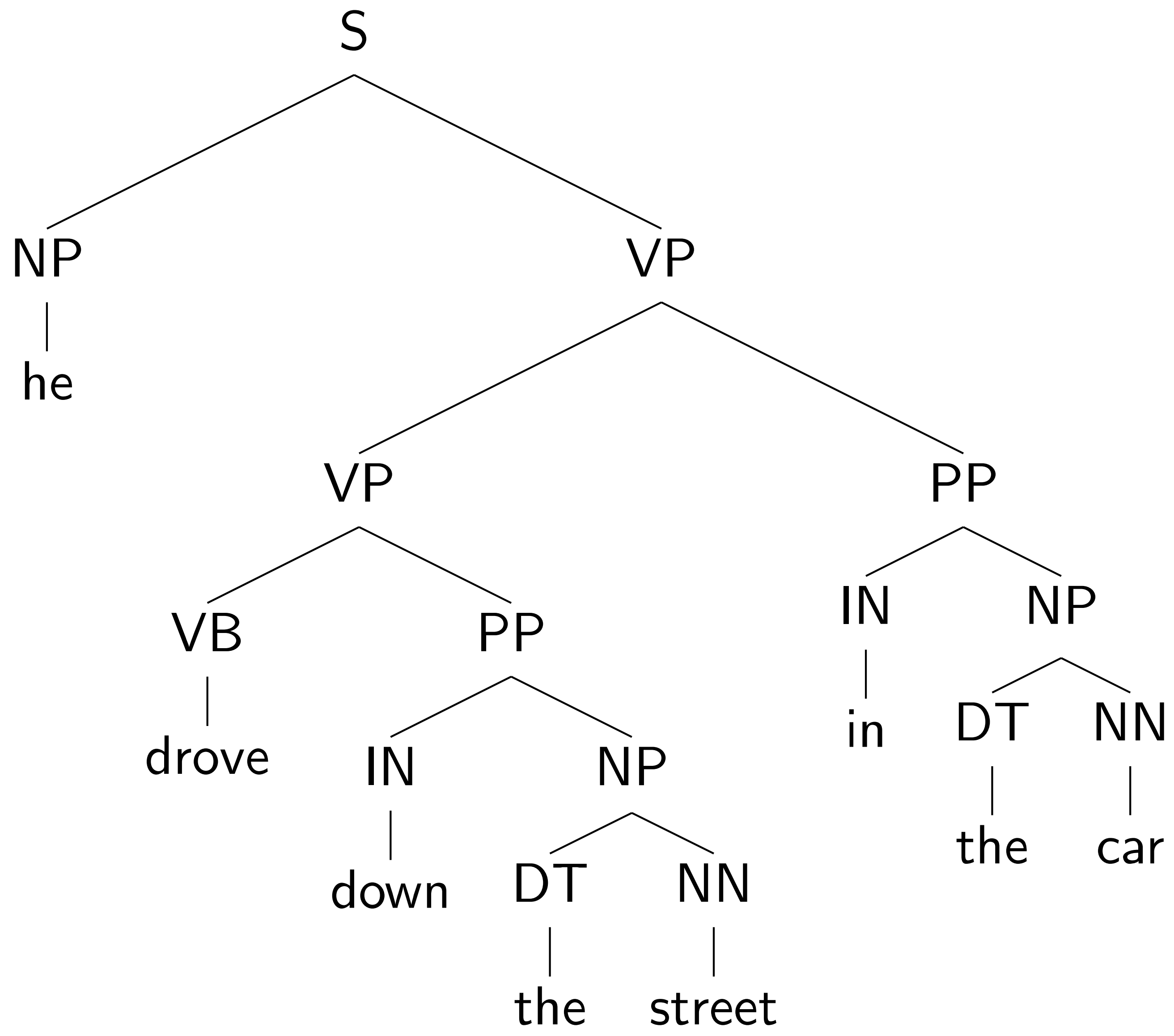
- Part-of-Speech ambiguity

  NN $\rightarrow$ duck

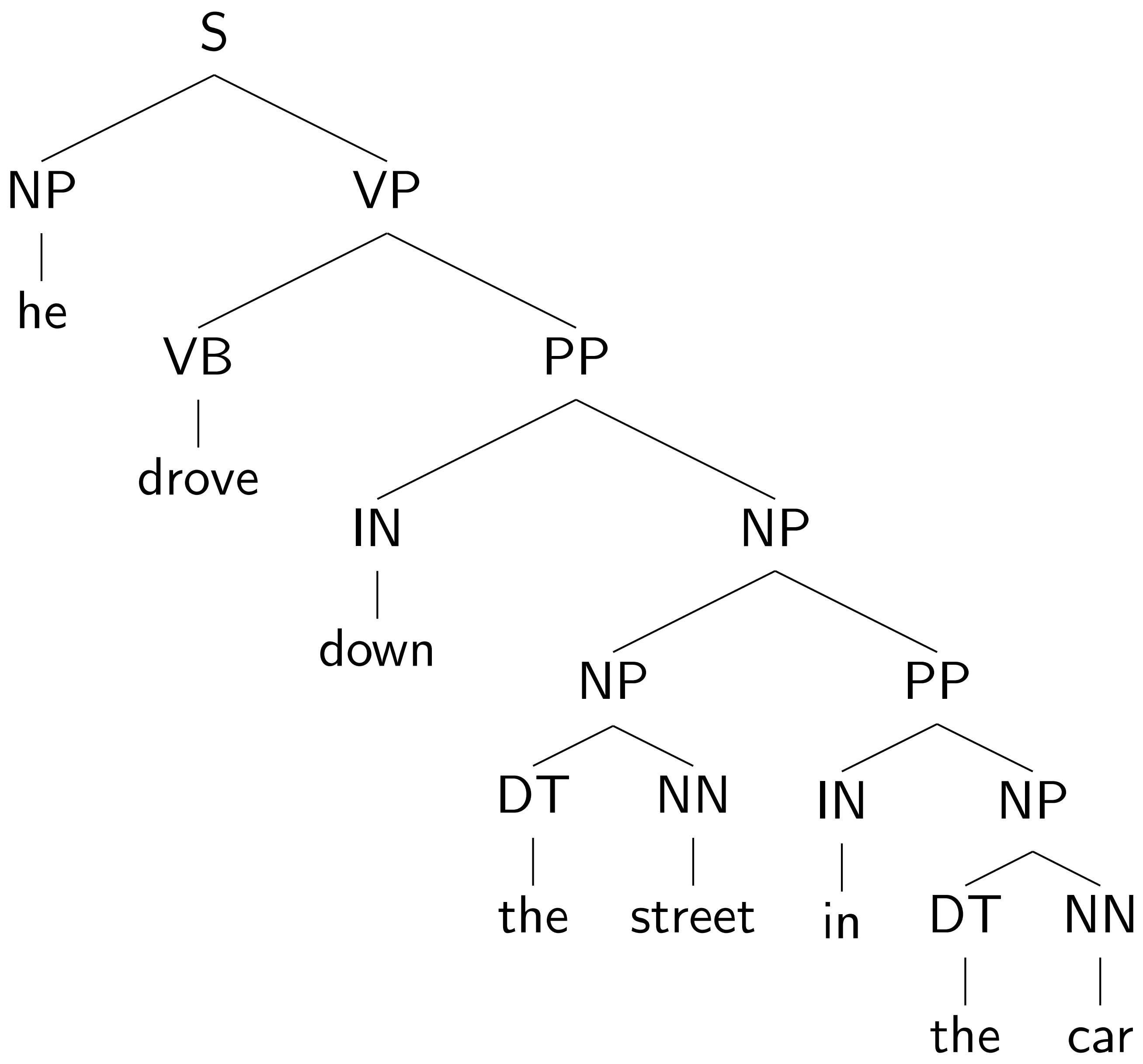
  Vi $\rightarrow$ duck



An Example of Ambiguity

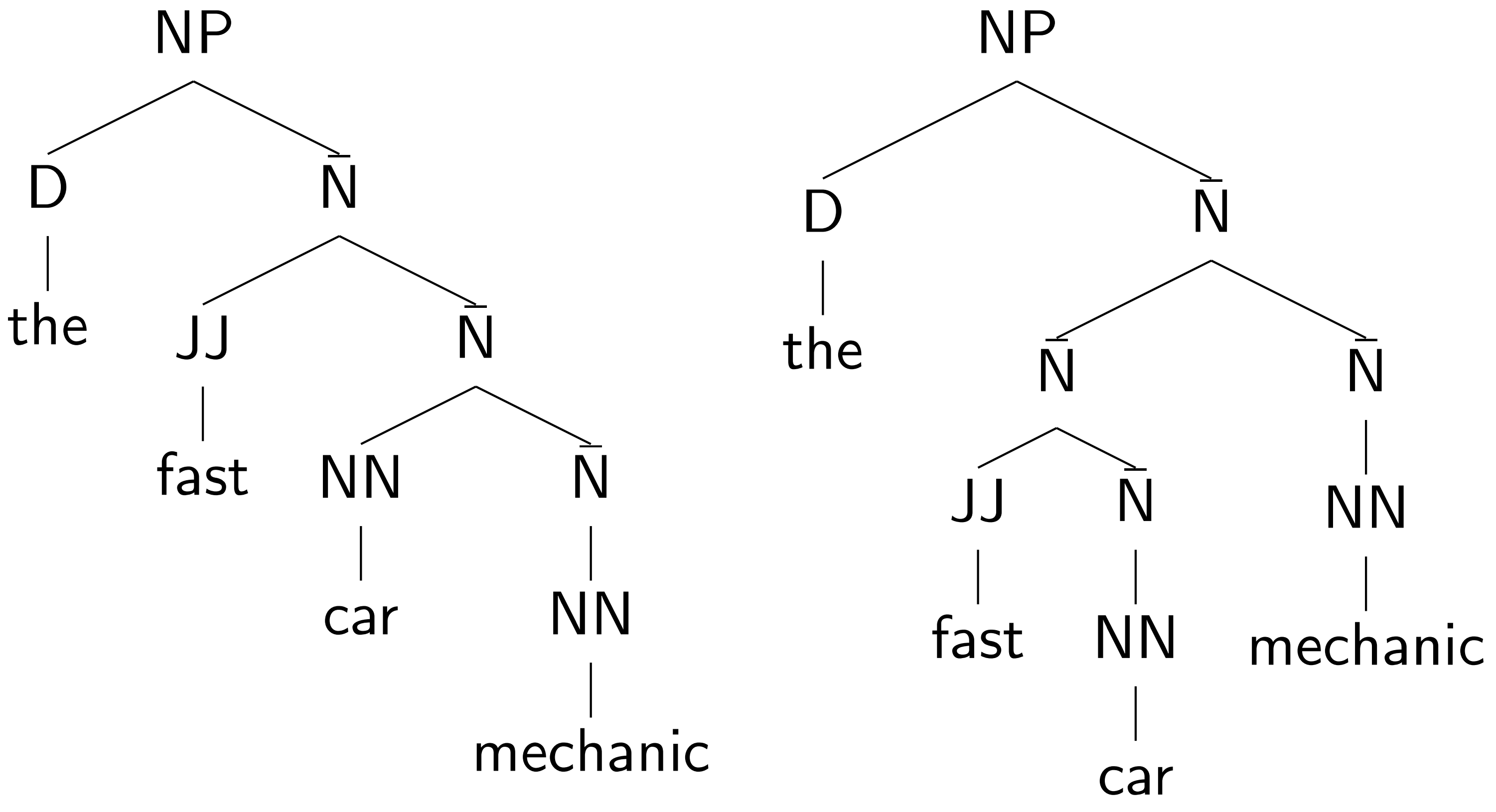


An Example of Ambiguity (continued)



Sources of Ambiguity: Noun Premodifiers

- Noun premodifiers:



Two analyses for: John was believed to have been shot by Bill

Issues with CFGs

- Ambiguity
- addressing some grammatical constraints requires complex CFGs that do not compactly encode.
- some aspects of natural language syntax may not be captured by CFGs and require context-sensitivity

Swiss-German:

...de Karl d'Maria em Peter de Hans laat hälfe lärne schwüme

English:

...Charles lets Mary help Peter to teach John to Swim

- Regardless, good enough for most applications!
  (and many other alternative grammars exist)

Syntax

Dependency Grammars

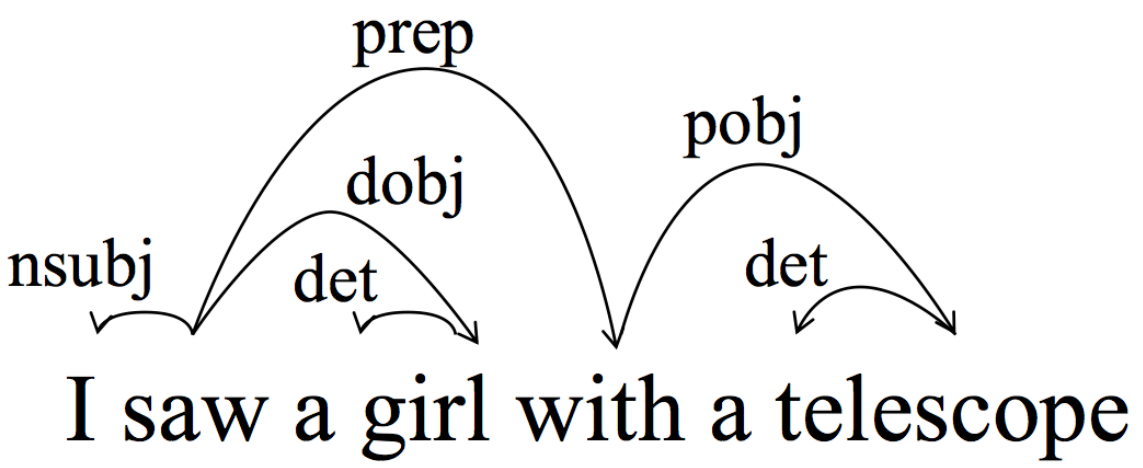
Dependency Grammars

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

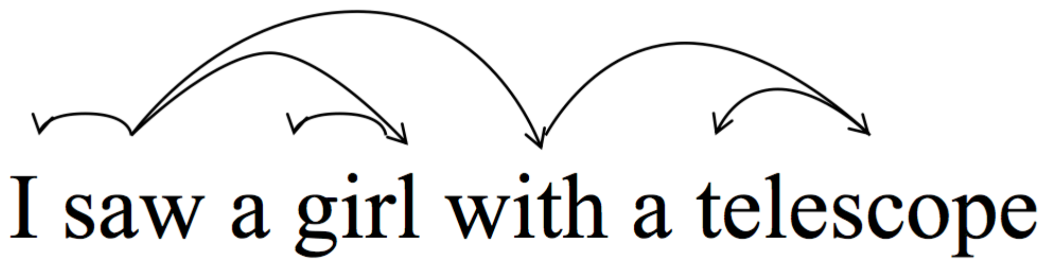
- In dependency grammar, a parse is a graph (usually a tree) where:
  - Nodes represent words
  - Edges represent dependency relations between words

Dependencies

- Typed: Label indicating relationship between words

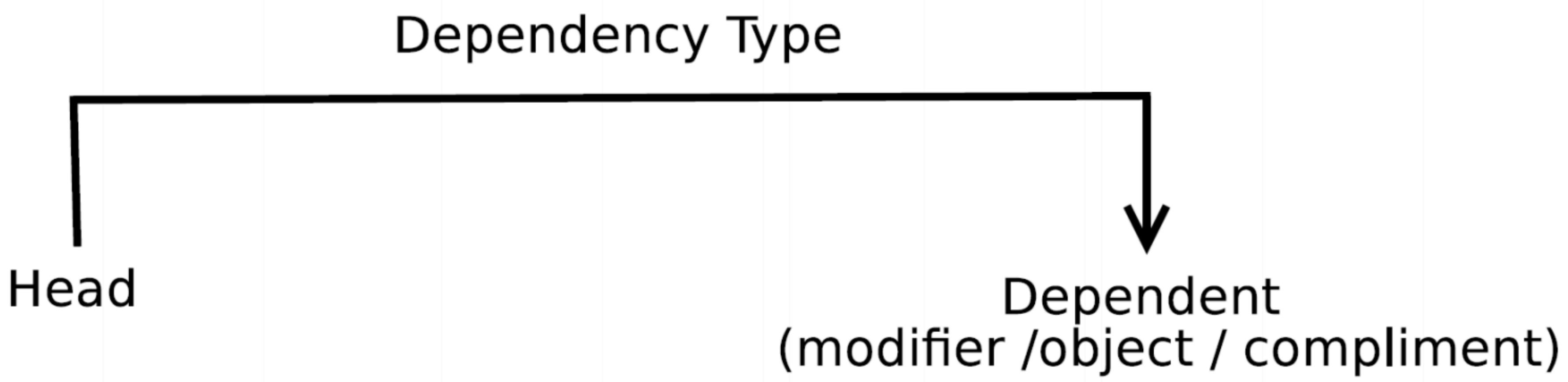


- Untyped: Only which words depend



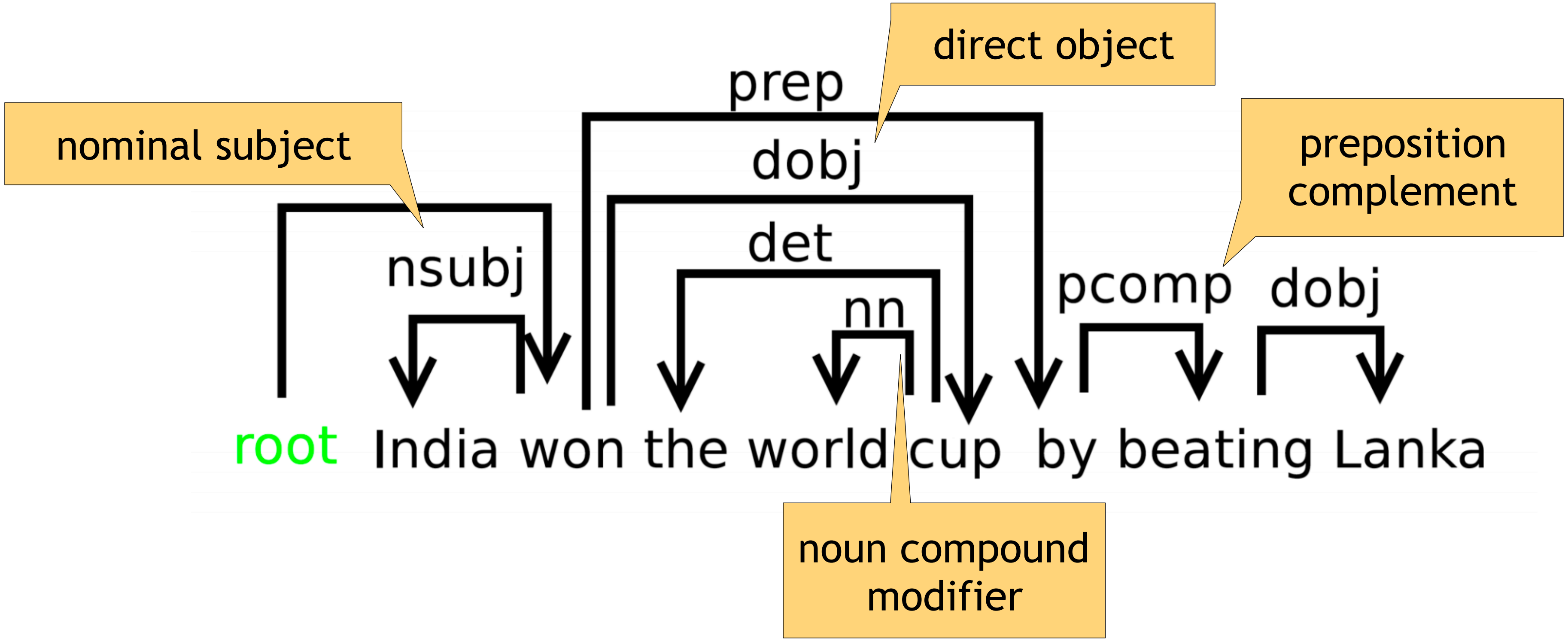
Dependency Grammars

- Syntactic Structure = Lexical items linked by binary asymmetrical relations called dependencies



Example Dependency Grammars

- Syntactic Structure = Lexical items linked by binary asymmetrical relations called dependencies



Syntax

English Grammar in a Nutshell

Product Details (from Amazon)
Hardcover: 1779 pages
Publisher: Longman; 2nd Revised edition
Language: English
ISBN-10: 0582517346
ISBN-13: 978-0582517349
Product Dimensions: 8.4 x 2.4 x 10 inches
Shipping Weight: 4.6 pounds

An English Grammar Fragment

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

Sentence Types

- Declaratives:

  S → NP VP   A plane left.

- Imperatives:

  S → VP   Leave!

- Yes-No Questions:

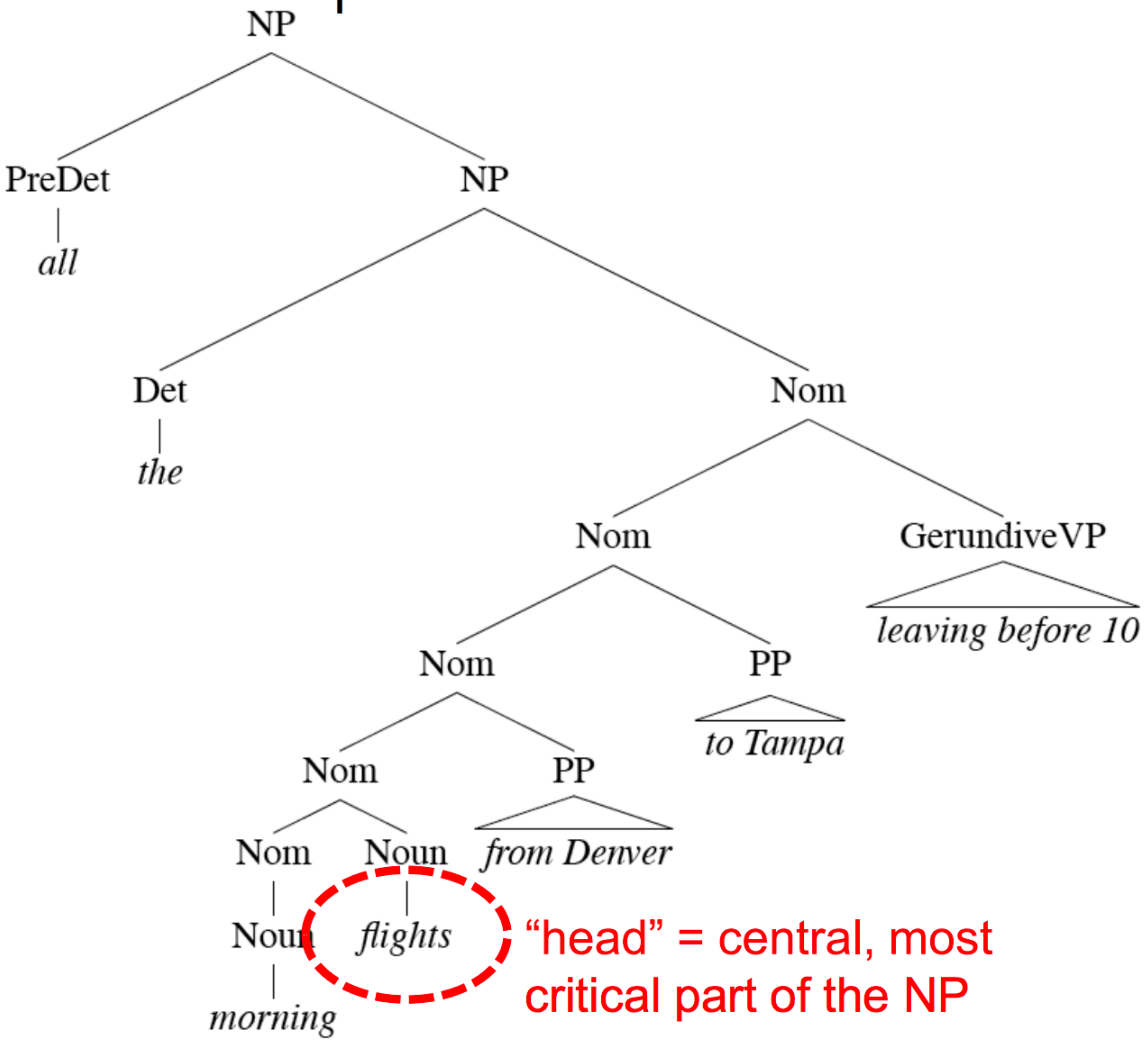
  S → Aux NP VP   Did the plane leave?

- WH Questions:

  S → WH–NP Aux NP VP   When did the plane leave?

Noun Phrases

- can be complicated
  - Determiners
  - Pre-modifiers
  - Post-modifiers



Determiners

- Noun phrases can start with determiners...
- Determiners can be
  - simple lexical items: the, this, a, an, etc. a car
  - simple possessives John's car
  - complex recursive versions John's sister's husband's son's car

Pre-modifiers

- Come before the head
- Examples:
  - Cardinals, ordinals, etc. three cars
  - Adjectives large car
- Ordering constraints:

three large cars vs. large three cars

Post-modifiers

- Come after the head
- Three kinds:
  - Prepositional phrases from Seattle
  - Non-finite clauses arriving before noon
  - Relative clauses that serve breakfast
- Similar recursive rules to handle these:
  - Nominal → Nominal PP
  - Nominal → Nominal GerundVP
  - Nominal → Nominal RelClause

Agreement Issues

- Agreement: constraints that hold among various constituents
- For example, subjects must agree with their verbs on person and number:

  I am cold. You are cold. He is cold.
  * I are cold * You is cold. *He am cold.

- Requires separate productions for each combination in CFG:

  S → NP1stPersonSing VP1stPersonSing
  S → NP2ndPersonSing VP2ndPersonSing
  NP1stPersonSing → …
  VP1stPersonSing → …
  NP2ndPersonSing → …
  VP2ndPersonSing → …

Other Agreement Issues

- Pronouns have case (e.g. nominative, accusative) that must agree with their syntactic position.

I gave him the book.	* I gave he the book.
He gave me the book.	* Him gave me the book.

- Many languages have gender agreement.

Los Angeles	* Las Angeles
Las Vegas	* Los Vegas

Verb Phrases

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

  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 Issues

- Specific verbs take some types of arguments but not others.
  - Transitive verb: “found” requires a direct object

    John found the ring. * John found.
  - Intransitive verb: “disappeared” cannot take one

    John disappeared. * John disappeared the ring.
  - “gave” takes both a direct and indirect object

    John gave Mary the ring. * John gave Mary. * John gave the ring.
  - “want” takes an NP, or non-finite VP or S

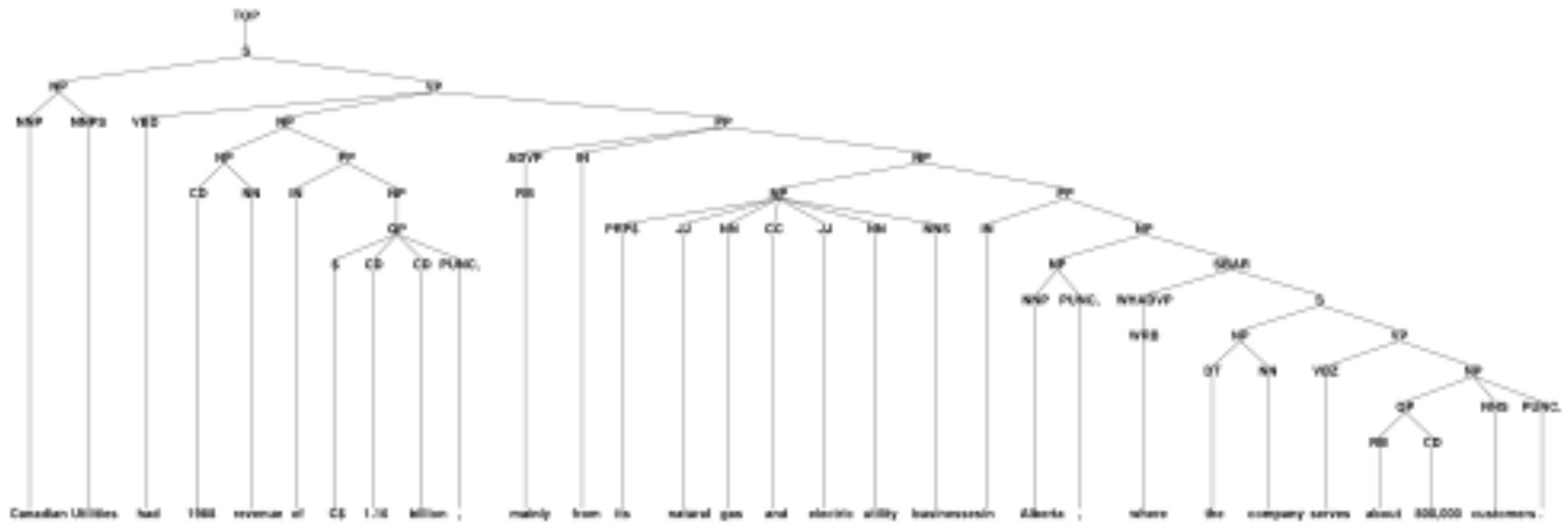
    John wants a car. John wants to buy a car.
    John wants Mary to take the ring. * John wants.

- Subcategorization frames specify the range of argument types that a given verb can take.

Data: Penn Treebank

- Penn WSJ Treebank = 50,000 sentences with associated trees
- Usual set-up: 40,000 training sentences, 2400 test sentences

An example tree:



Data: Penn Treebank

- Treebanks implicitly define a grammar for the language
- Penn Treebank has 4500 different rules for VPs, including…
    - VP → BD PP
    - VP → VBD PP PP
    - VP → VBD PP PP PP
    - VP → VBD PP PP PP PP

Summary

- Two views of syntactic structures
  - Constituency grammars (in particular, Context Free Grammars)
  - Dependency grammars

- Can be used to capture various facts about the structure of language (but not all!)

Syntax

Parsing

Parsing

- Given a string of terminals and a CFG, determine if the string can be generated by the CFG:
  - also return a parse tree for the string
  - also return all possible parse trees for the string

- Must search space of derivations for one that derives the given string.
  - Top-Down Parsing
  - Bottom-Up Parsing

Simple CFG for ATIS English

Grammar

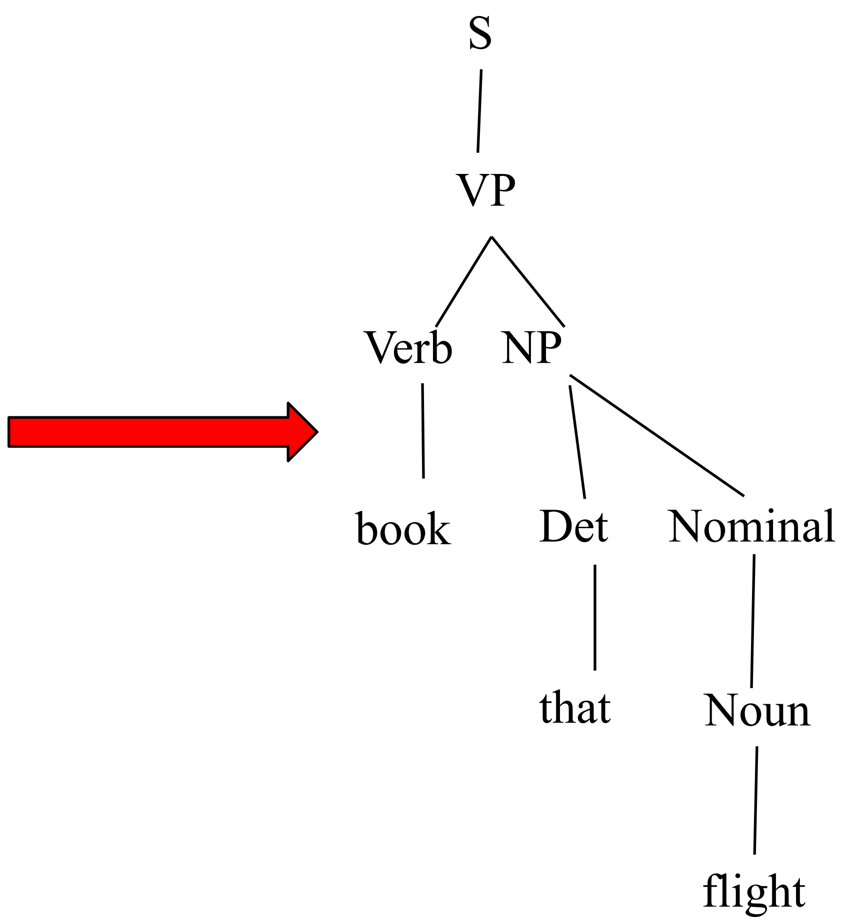
$S \rightarrow NP\ VP$
$S \rightarrow Aux\ NP\ VP$
$S \rightarrow VP$
$NP \rightarrow Pronoun$
$NP \rightarrow Proper\text{-}Noun$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow Noun$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow Verb$
$VP \rightarrow Verb\ NP$
$VP \rightarrow VP\ PP$
$PP \rightarrow Prep\ NP$

Lexicon

Det $\rightarrow$ the | a | that | this
Noun $\rightarrow$ book | flight | meal | money
Verb $\rightarrow$ book | include | prefer
Pronoun $\rightarrow$ I | he | she | me
Proper-Noun $\rightarrow$ Houston | NWA
Aux $\rightarrow$ does
Prep $\rightarrow$ from | to | on | near | through

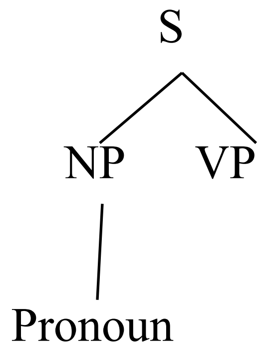
Parsing Example

book that flight

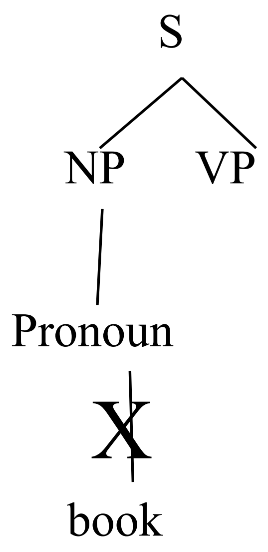


Top Down Parsing

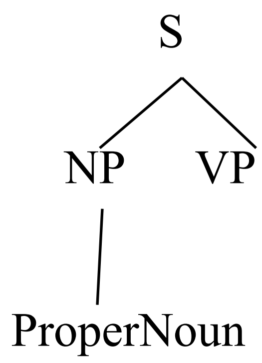
- Start searching space of derivations for the start symbol.



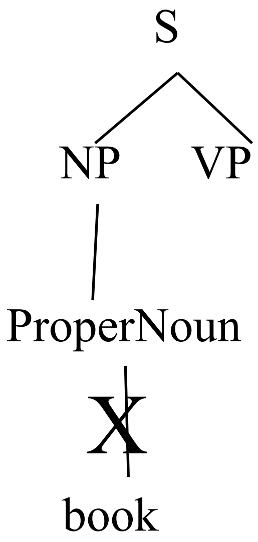
Top Down Parsing



Top Down Parsing



Top Down Parsing



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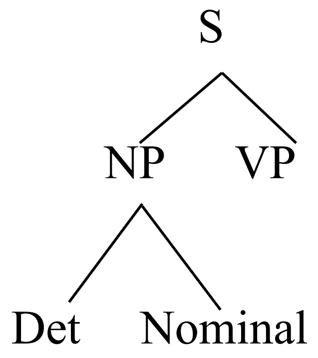
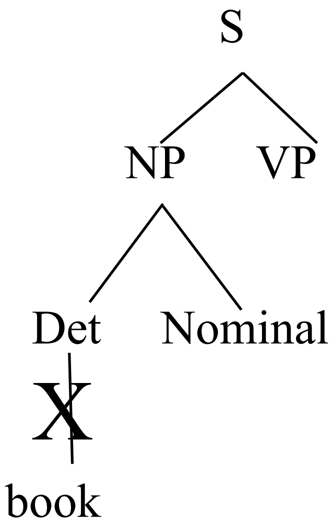
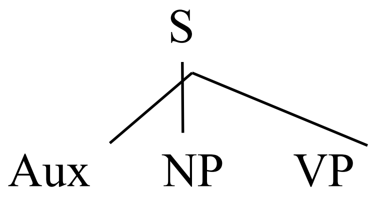


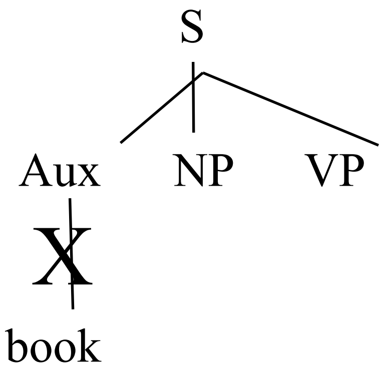
Top Down Parsing



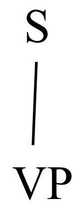
Top Down Parsing



Top Down Parsing



Top Down Parsing



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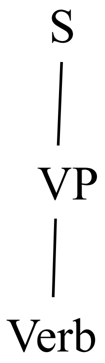

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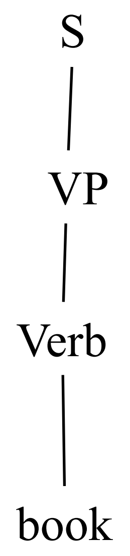

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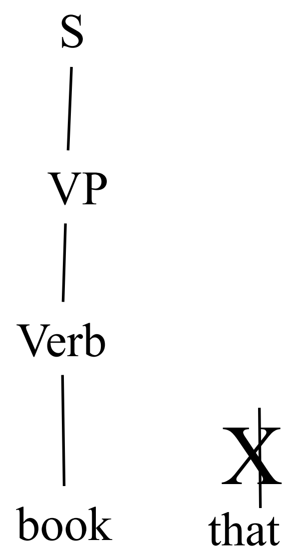

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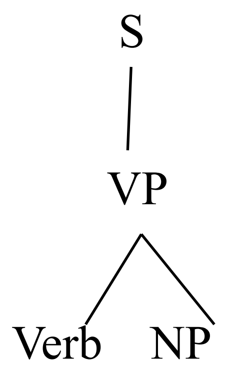

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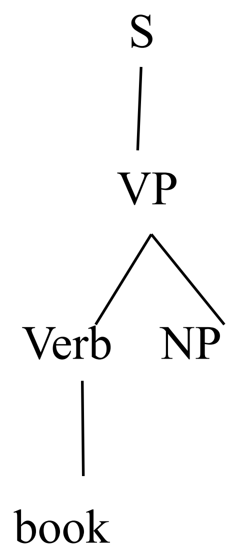

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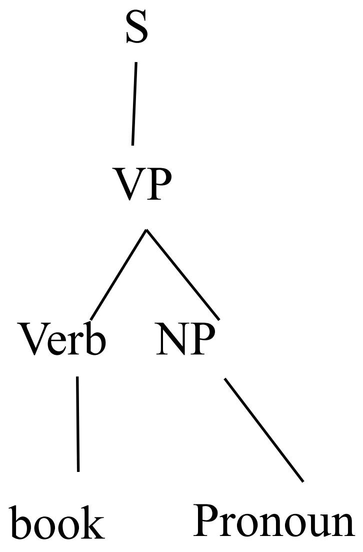

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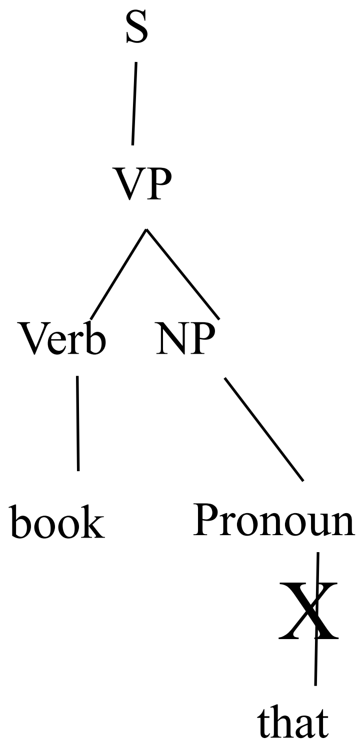

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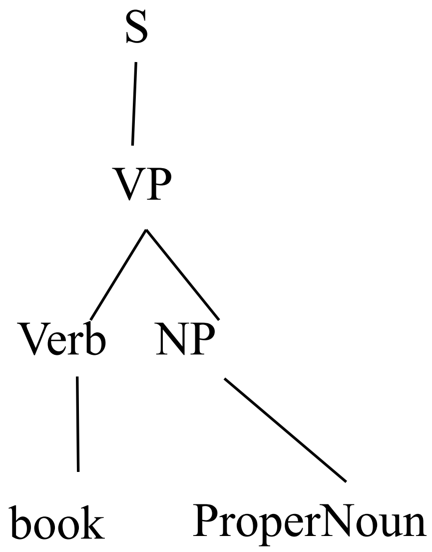

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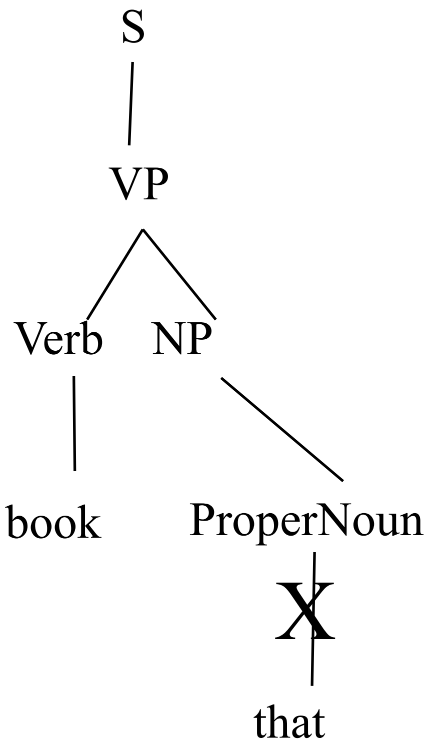

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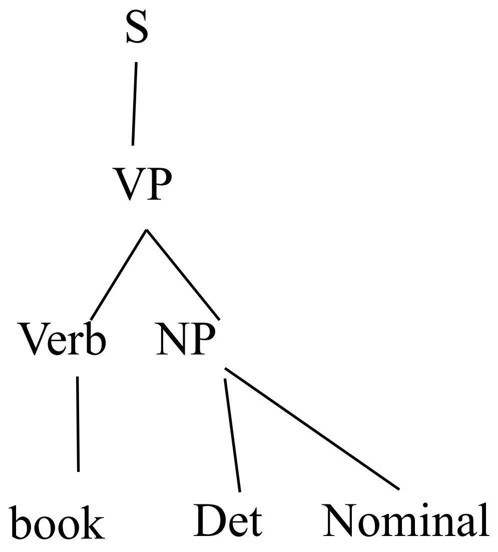

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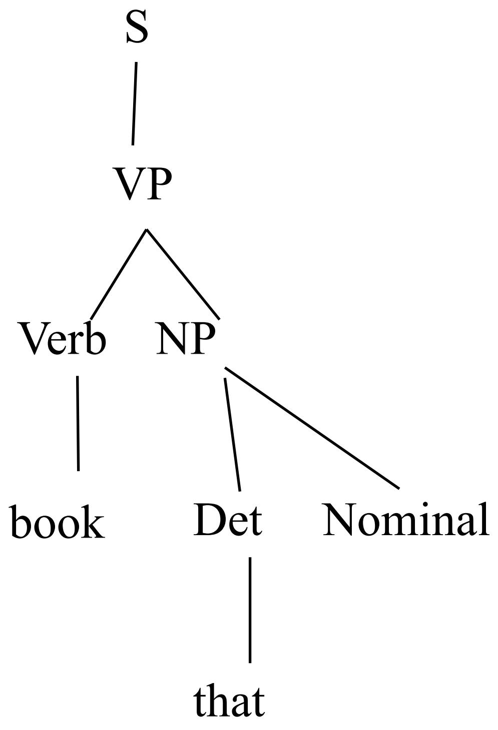

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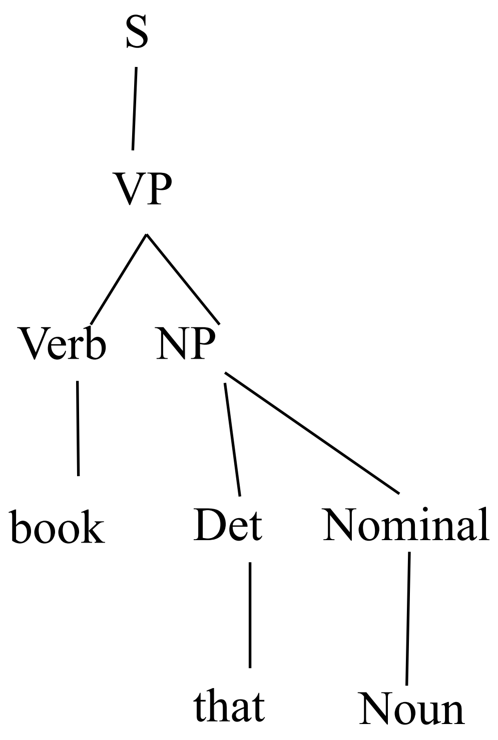

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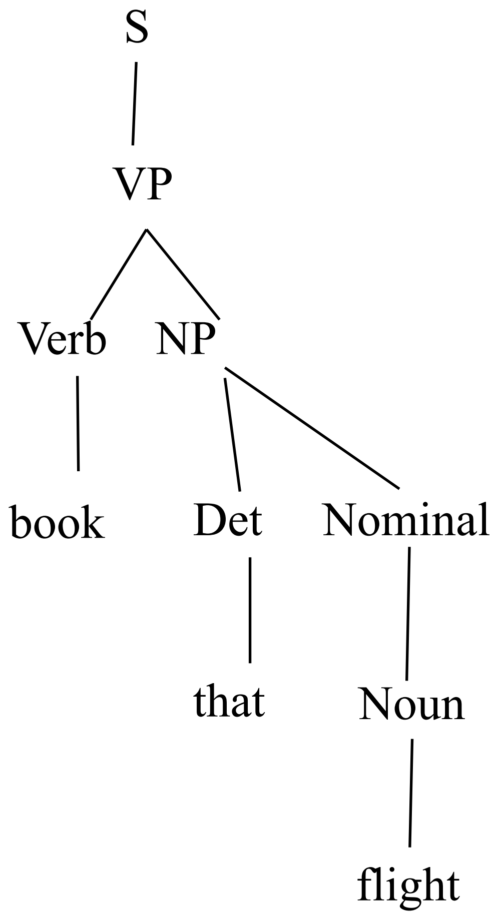


Bottom Up Parsing

- Start searching space of reverse derivations from the terminal symbols in the string.

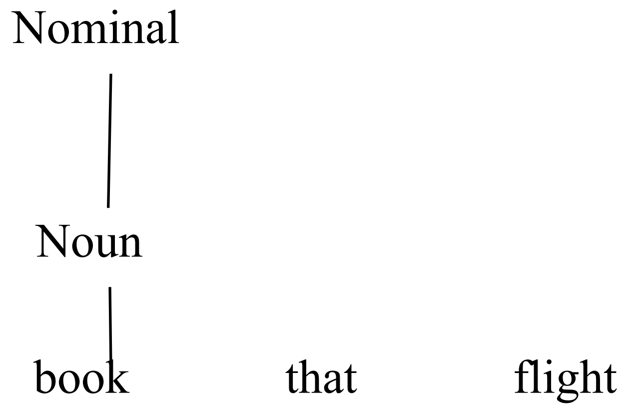
book that flight

Bottom Up Parsing

Noun

book that flight

Bottom Up Parsing



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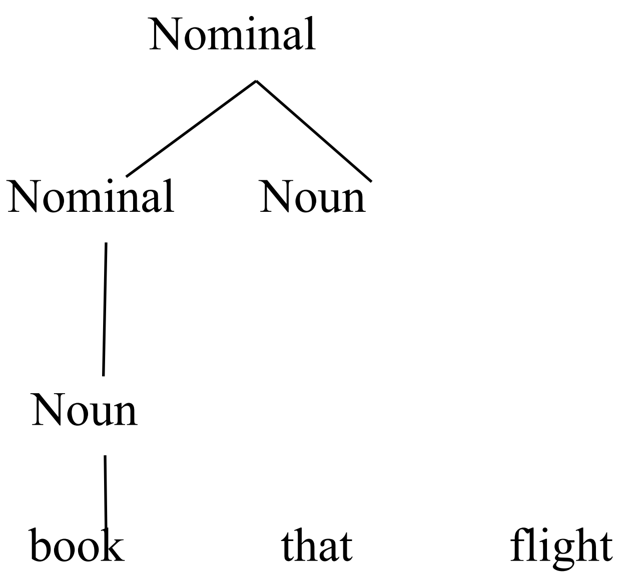

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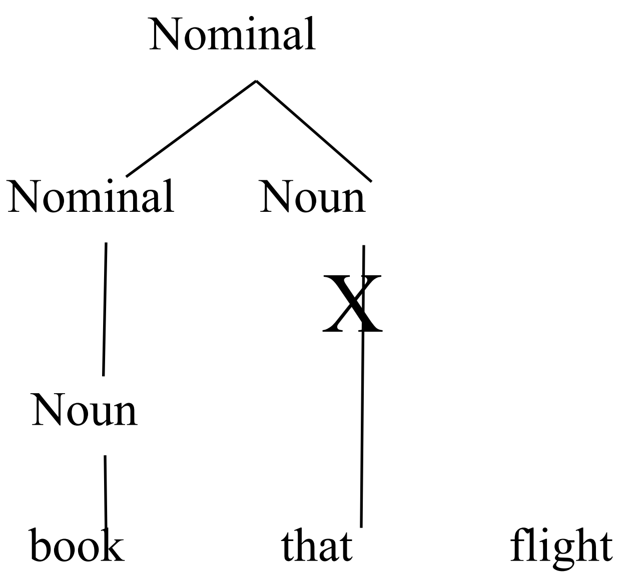

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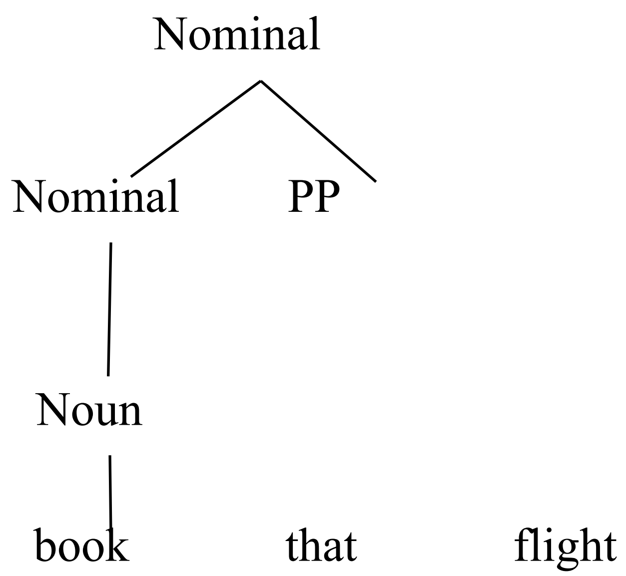

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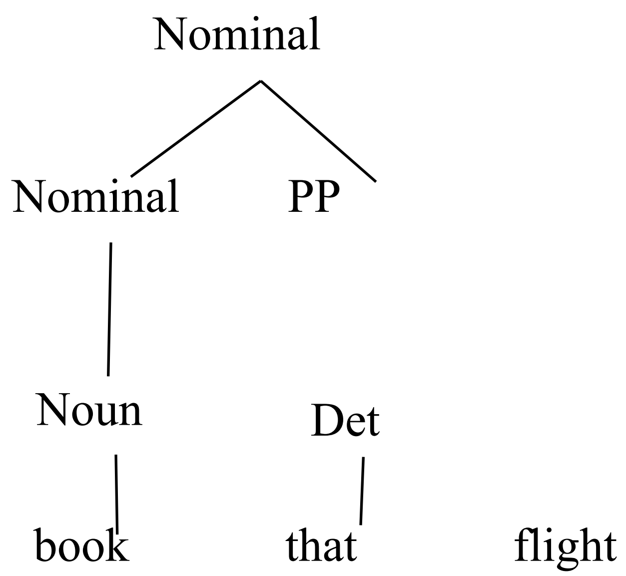

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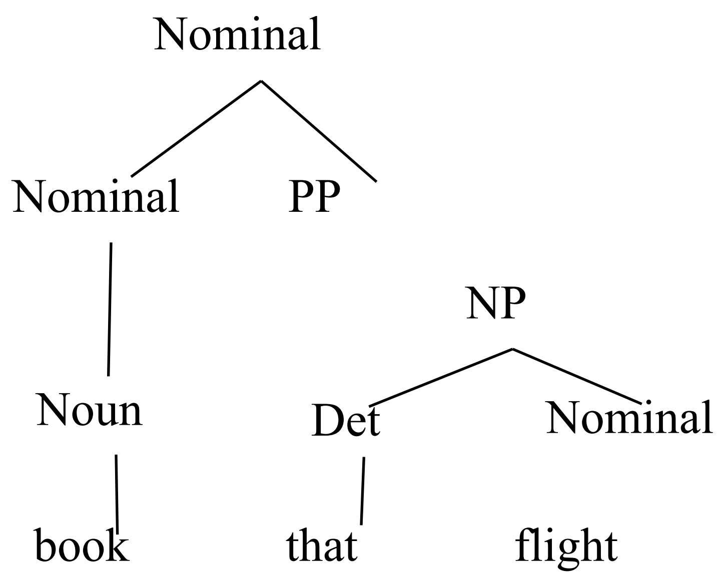

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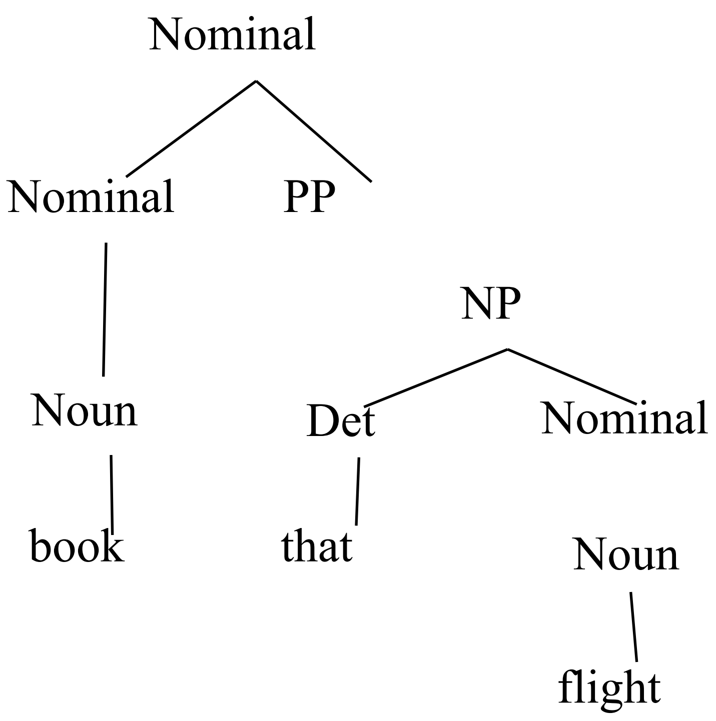

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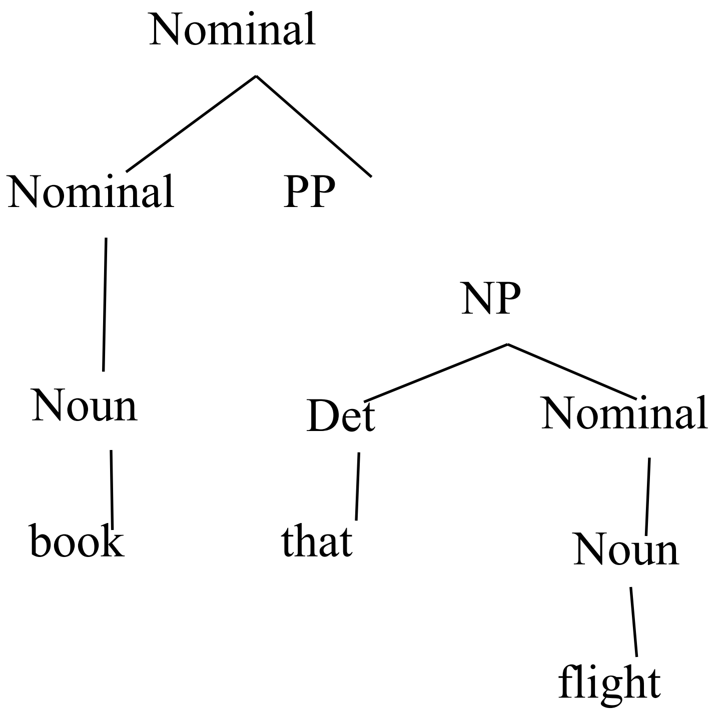

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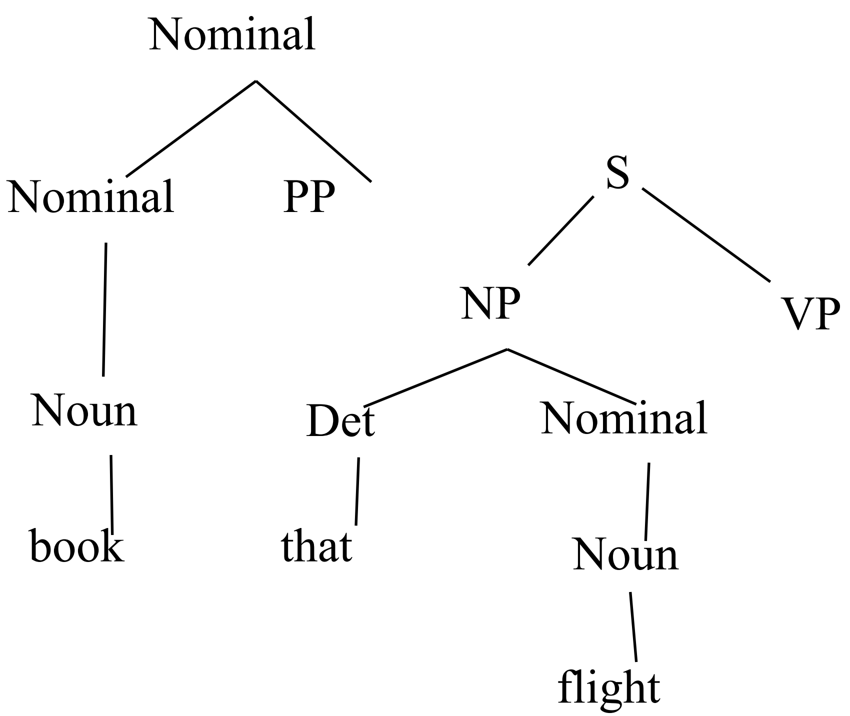

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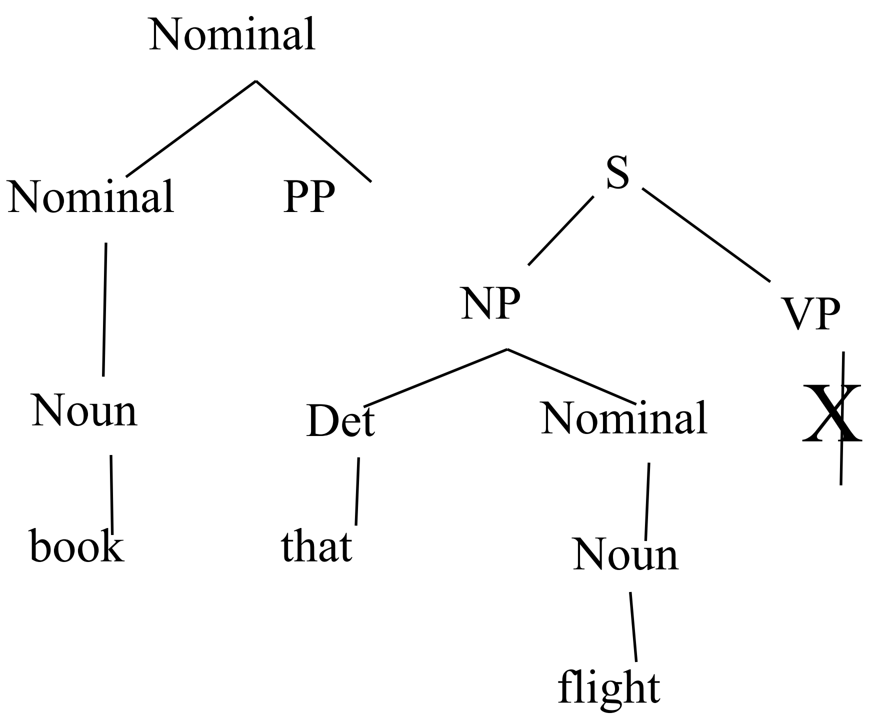

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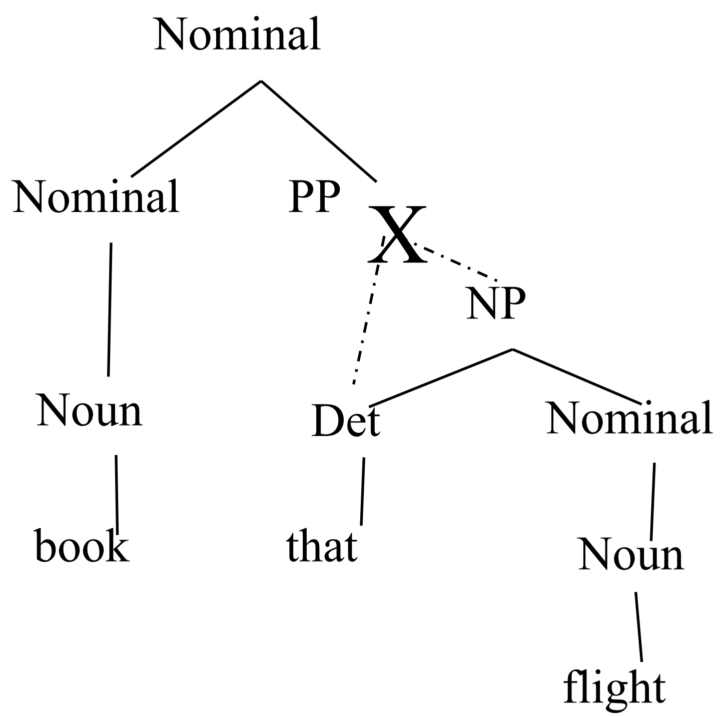

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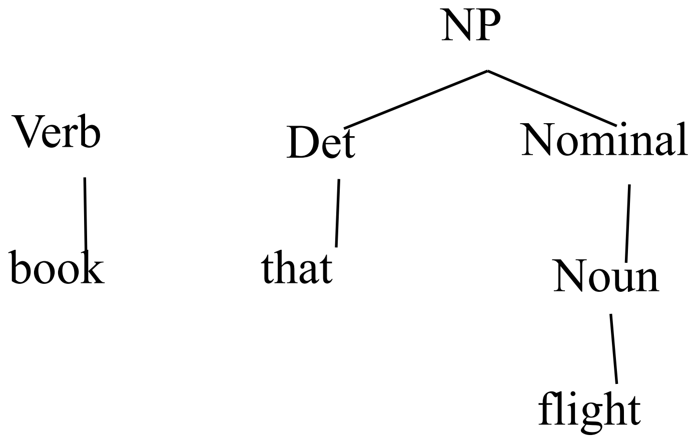

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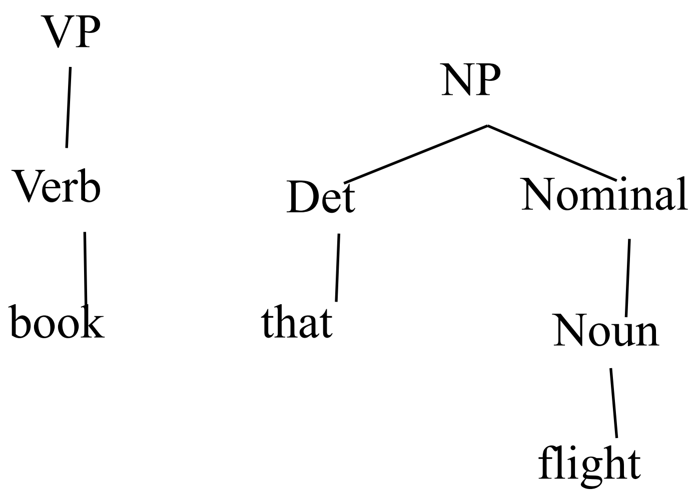

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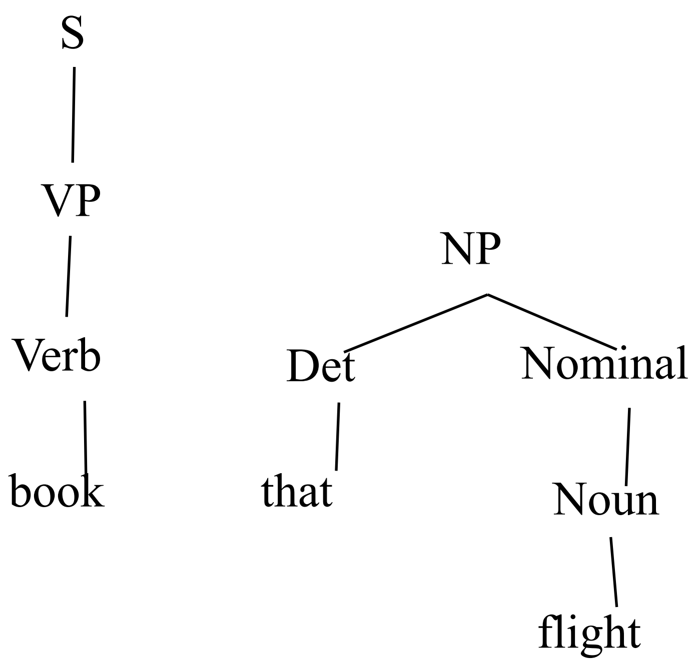

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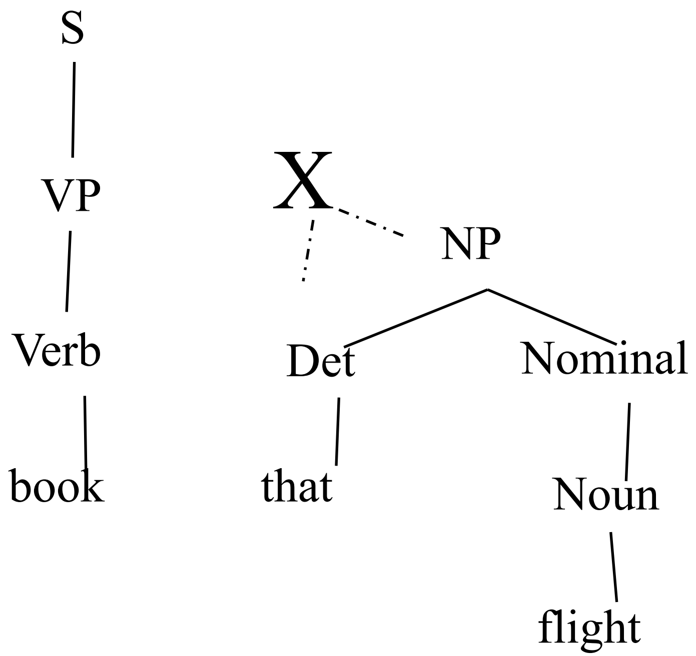

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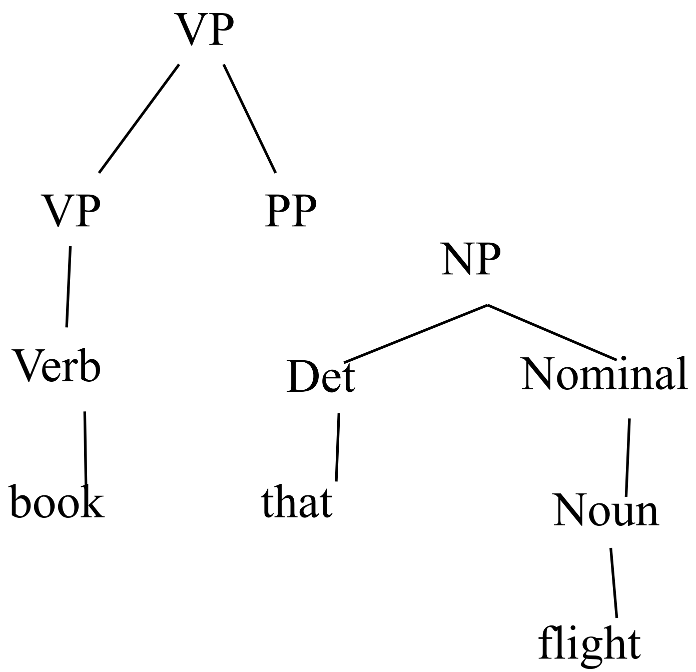

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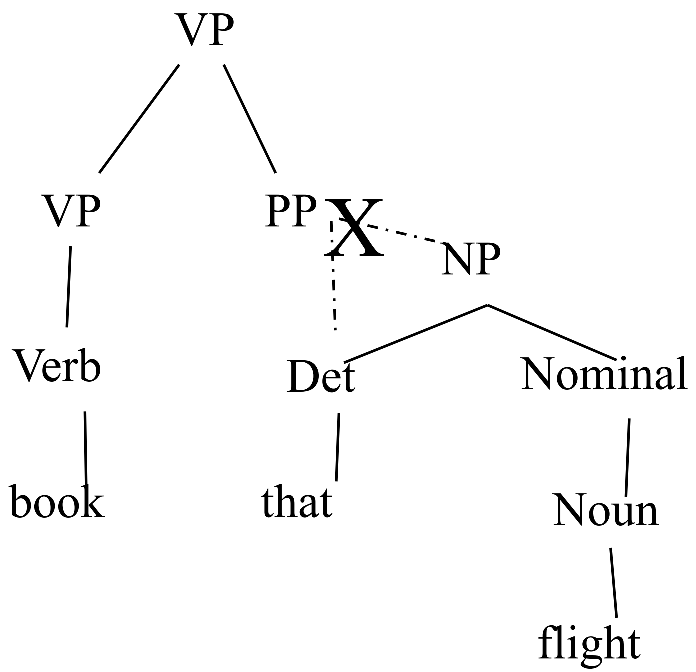

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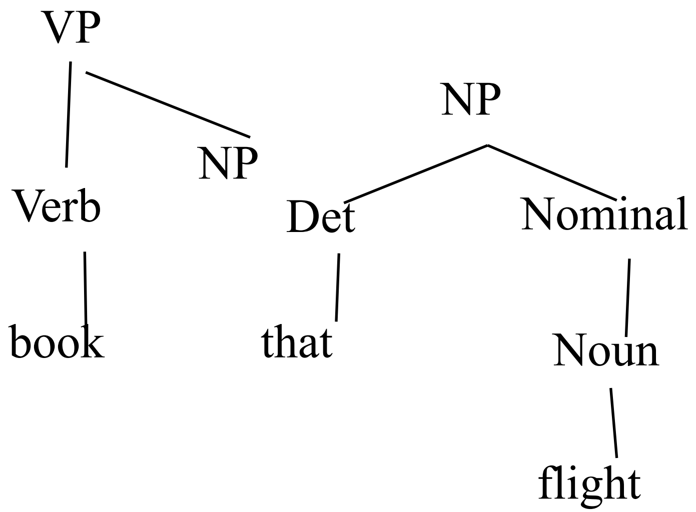

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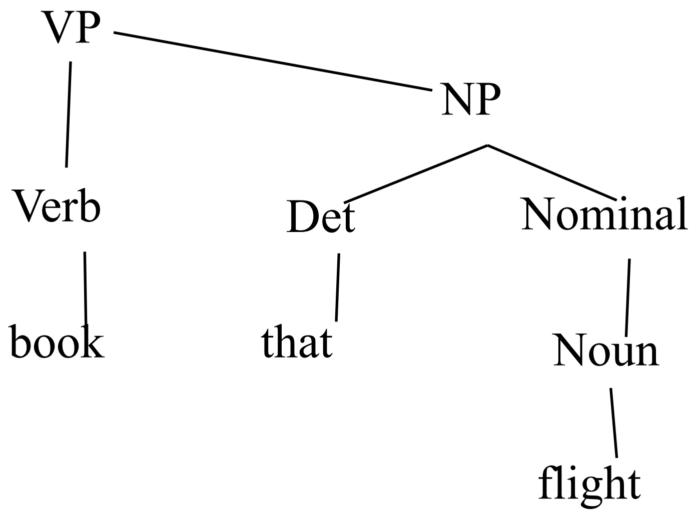

Bottom Up Parsing