Syntax Analysis/ Parsing

Sentence

- Sequence of words which defines syntactic structure of a sentence
- Focused on examining how the syntactic structure of a sentence can be computed
- For this, we consider 2 things:
  1. Grammar
  2. Parsing technique

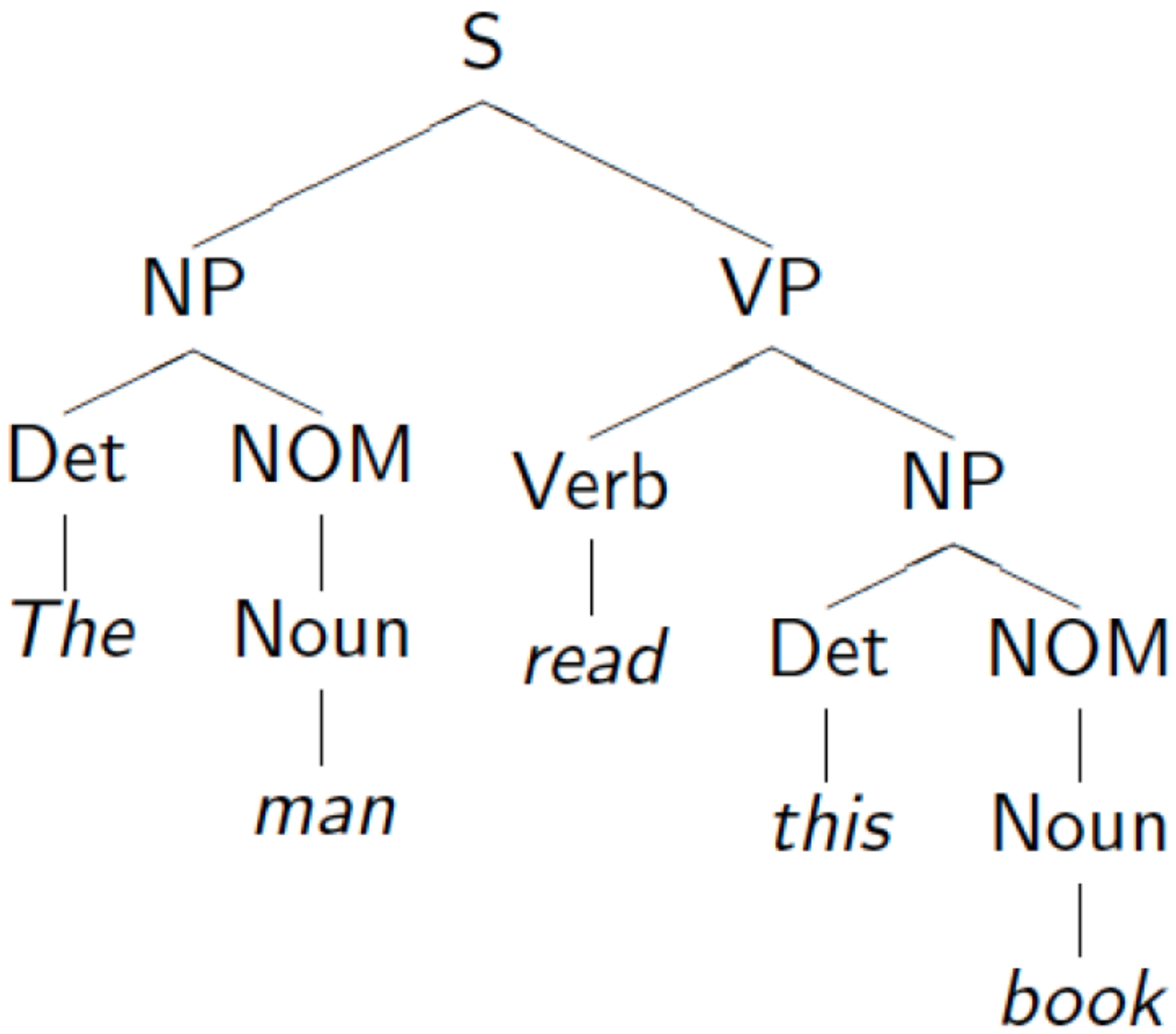
What is Syntax?

- Refers to the way words are arranged together, and the relationship between then.

Parse Tree

- Way of representing how a sentence is broken into its major subparts and how those subparts are broken up in turn

Parse/ Syntax Tree - An Example



Defining Notions: Constituent

Constituent

- Group of words which acts as a single unit - phrases, clauses etc.

Usually named based on the word that heads the constituent

- *The **man** from Pune* is a NP because head man is a noun
- *extermely **clever*** is an AP as head clever is an adjective
- ***Up** the hill* is a PP as head Up is a preposition
- ***saw** the moon* is a VP as head saw is a verb

Modeling Constituency

Context-free grammar - The most common way of modeling constituency

Modeling Constituency

Context-free grammar - The most common way of modeling constituency

Consists of production Rules

These rules express the ways in which the symbols of the language can be grouped and ordered together

Modeling Constituency

Example:

Noun phrase can be composed of either a Proper Noun or a determiner (Det) followed by a Nominal; a Nominal can be more than one nouns

NP →Det Nominal

NP →ProperNoun

Nominal → Noun | Noun Nominal

CFG for Languages

CFG for Languages

$CFG: G = (T, N, S, R)$

- T: set of terminals
- N: set of non-terminals
  - For NLP, we distinguish out a set $P \subset N$ of pre-terminals, which always rewrite as terminals
- S : start symbol
- R: Rules/productions of the form $X \rightarrow \gamma$, $X \in N$ and $\gamma \in (T \cup N)*$

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Terminals and pre-terminals

Terminals mainly correspond to words in the language while pre-terminals mainly correspond to POS categories

CFG for Languages

Example

NP →Det Nominal

NP →ProperNoun

Nominal → Noun | Noun Nominal

CFG for Languages

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NP →Det Nominal

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Now, these can be combined with other rules, that express facts about a lexicon.

Det → a

Det → the

Noun → flight

CFG as a generator

NP →Det Nominal

NP →ProperNoun

Nominal → Noun | Noun Nominal

Det → a

Det → the

Noun → flight

Generating : a flight

NP → Det Nominal→Det Noun→a Noun → a flight

- Thus a CFG can be used to randomly generate a series of strings
- This sequence of rule expansions is called derivation of string of words, represented as a tree

CFGs and Grammaticality

- A CFG defines a formal language = set of all sentences (string of words) that can be derived by the grammar

- Sentences in this set are said to be **grammatical**
- Sentences outside this set are said to be **ungrammatical**

Derivation

Definition. :

The transformation of a string of grammar symbols by replacing a non-terminal by the corresponding right hand side of its production is called a **derivation**.

Example :

The grammar G = ({list}, {id, , },list,{ list->list, id , list->id})

A derivation is traced out as follows :

list -> **list**, id

-> **list**, id, id

-> id, id, id

The set of all possible terminal strings that can be derived from the start symbol of a CFG is the **language** generated by the CFG.

Formal Definition

Language :

The language L(G) generated by a context free grammar G is defined as :

$$L(G) = \{ w \mid S \Rightarrow w , \ w \in T^* \ \}$$

Strings in L(G) are called sentences of G.

Sentential form :

A string α, α Є (N U T) * , such that S -> α, is called a sentential form of G.

Basic Concepts in Parsing

Instead of choosing the nonterminal to be replaced, in an arbitrary fashion, it is possible to make an uniform choice at each step

- replace the leftmost nonterminal in a sentential form
- replace the rightmost nonterminal in a sentential form

The corresponding derivations are known as leftmost and rightmost derivations respectively.

Given a sentence w of a grammar G, there are several distinct derivations for w.

What is Parsing?

- The process of taking a string and a grammar and returning all possible parse trees for that string
- That is, find all trees, whose root is the start symbol S, which cover exactly the words in the input
- Give rise to two search strategies: **top-down** (goal-oriented) and **bottom-up** (data-directed)

Grammar Rewrite Rules

S → NP VP
S → Aux NP VP
S → VP
NP → Det NOM
NOM → Noun
NOM → Noun NOM
VP → Verb
VP → Verb NP

Det → *that* | *this* | *a* | *the*
Noun → *book* | *flight* | *meal* | *man*
Verb → *book* | *include* | *read*
Aux → *does*

Parse :**The man read this book**

Derivation:

S→ NP VP

Derivation:

S→ **NP** VP

S→ **Det NOM** VP

Derivation:

S→ NP VP

S→ **Det** NOM VP

S→ **The** NOM VP

Derivation:

S→ NP VP

S→ Det NOM VP

S→ The **NOM** VP

S→ The **Noun** VP

Derivation:

S→ NP VP

S→ Det NOM VP

S→ The NOM VP

S→ The **Noun** VP

S→ The **man** VP

Derivation:

S→ NP VP

S→ Det NOM VP

S→ The NOM VP

S→ The Noun VP

S→ The man **VP**

S→ The man **Verb NP**

Derivation:

S→ NP VP

S→ Det NOM VP

S→ The NOM VP

S→ The Noun VP

S→ The man VP

S→ The man **Verb** NP

S→ The man **read** NP

Derivation:

S→ NP VP

S→ Det NOM VP

S→ The NOM VP

S→ The Noun VP

S→ The man VP

S→ The man Verb NP

S→ The man read **NP**

S→ The man read **Det NOM**

Derivation:

S→ NP VP

S→ Det NOM VP

S→ The NOM VP

S→ The Noun VP

S→ The man VP

S→ The man Verb NP

S→ The man read NP

S→ The man read **Det** NOM

S→ The man read **this** NOM

Derivation:

S→ NP VP

S→ Det NOM VP

S→ The NOM VP

S→ The Noun VP

S→ The man VP

S→ The man Verb NP

S→ The man read NP

S→ The man read Det NOM

S→ The man read this **NOM**

S→ The man read this **Noun**

Derivation:

S→ NP VP

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S→ The man read NP

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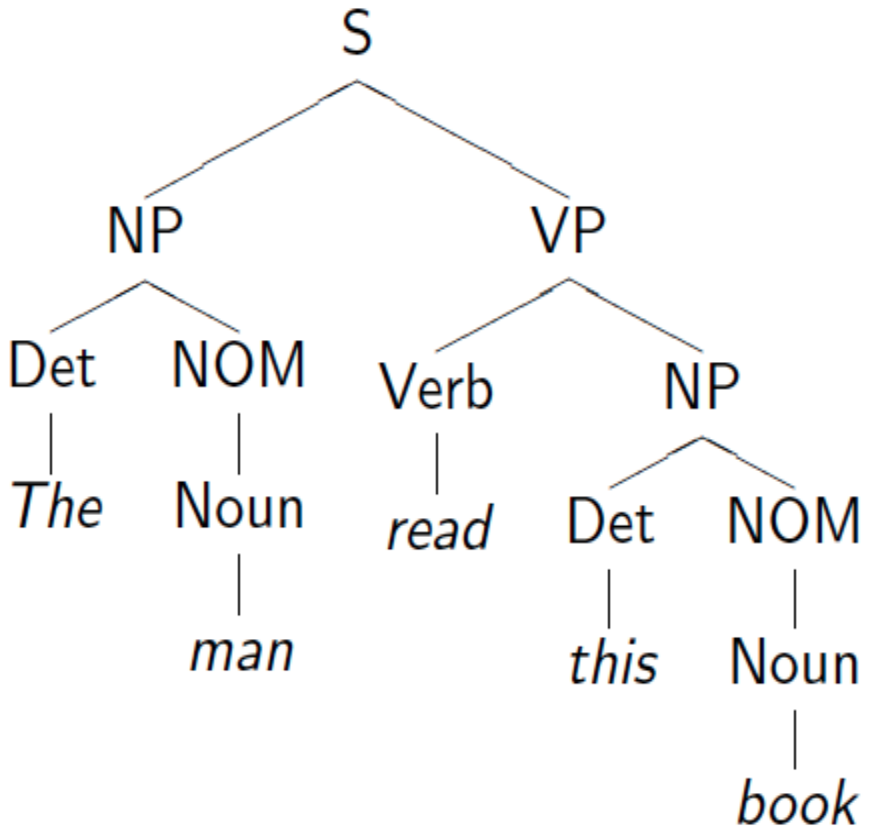
S→ The man read this NOM

S→ The man read this **Noun**

S→ The man read this **book**

Parse Tree

S → NP VP
→ Det NOM VP
→ *The* NOM VP
→ *The* Noun VP
→ *The man* VP
→ *The man* Verb NP
→ *The man read* NP
→ *The man read* Det NOM
→ *The man read this* NOM
→ *The man read this* Noun
→ *The man read this book*



Parsing Strategies

1. Top-Down
2. Bottom Up

Top-Down Parsing

- Searches for a parse tree by trying to build upon the root node S down to the leaves
- Start by assuming that the input can be derived by the designated start symbol S
- Find all trees that can start with S, by looking at the grammar rules with S on the left-hand side
- Trees are grown downward until they eventually reach the POS categories at the bottom
- Trees whose leaves fail to match the words in the input can be rejected

Top-Down Parsing

Sentence : Book that flight

Grammar

S → NP VP
S → Aux NP VP
S → VP
NP → Pronoun
NP → Proper-Noun
NP → Det Nominal
Nominal → Noun
Nominal → Nominal Noun
Nominal → Nominal PP
VP → Verb
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PP → Prep NP

Lexicon

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

Top Down Parsing

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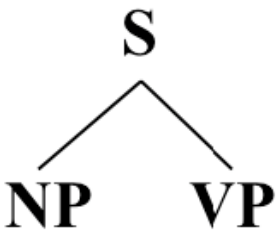

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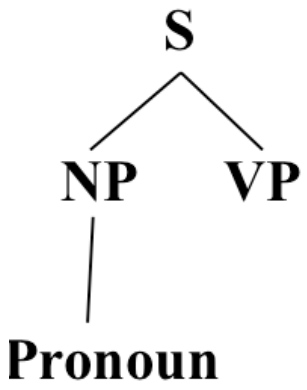

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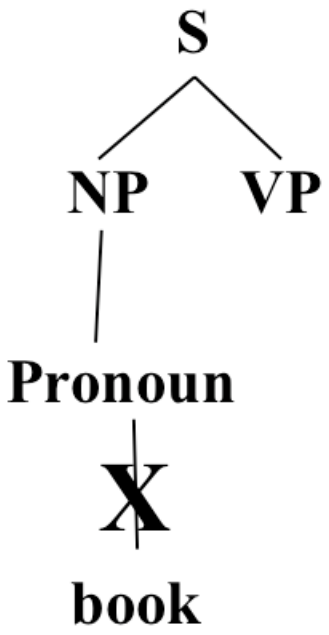

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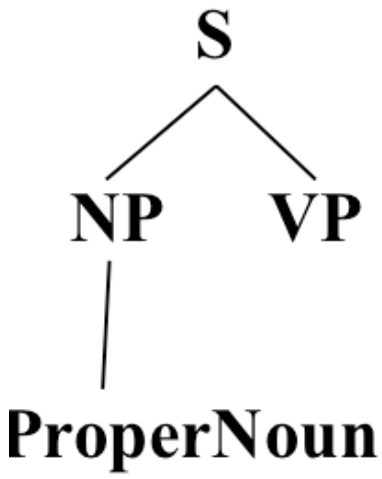

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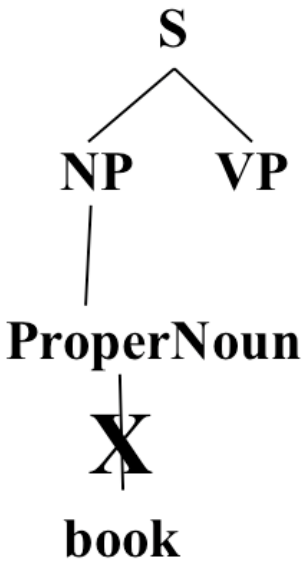

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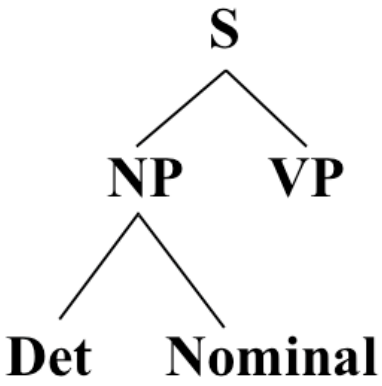

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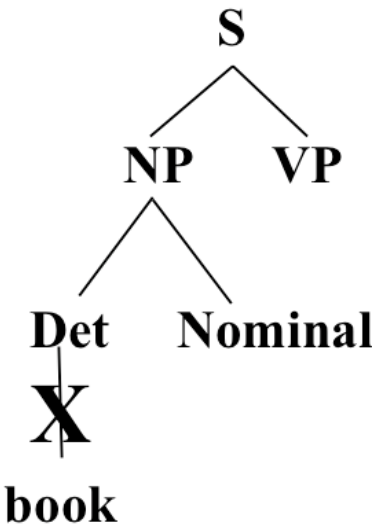

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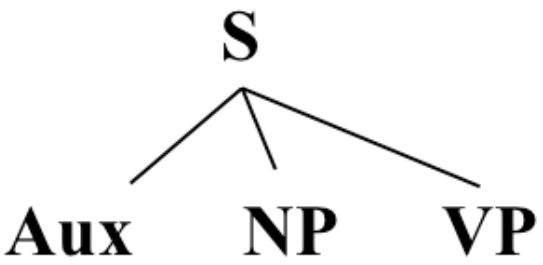

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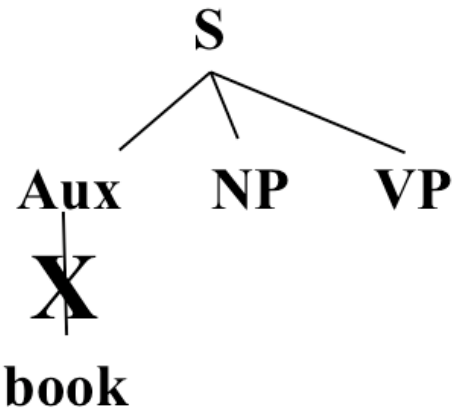

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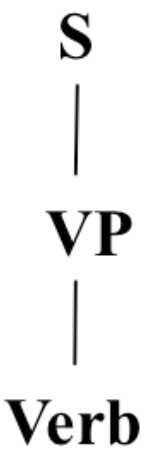

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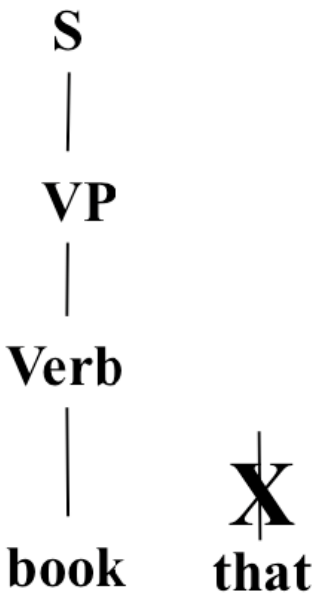

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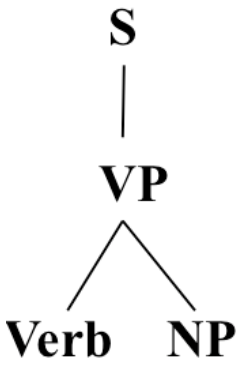

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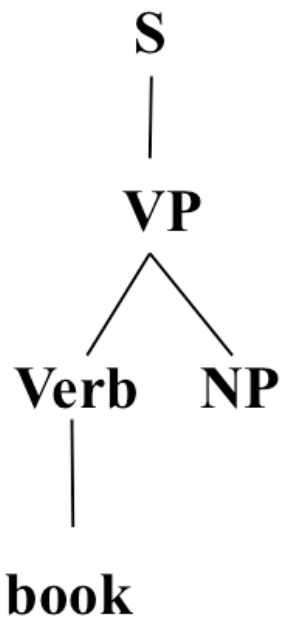

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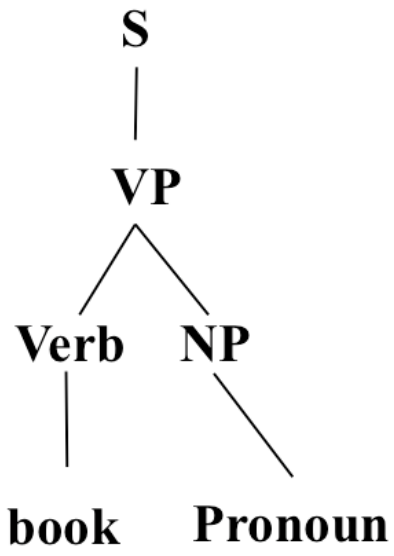

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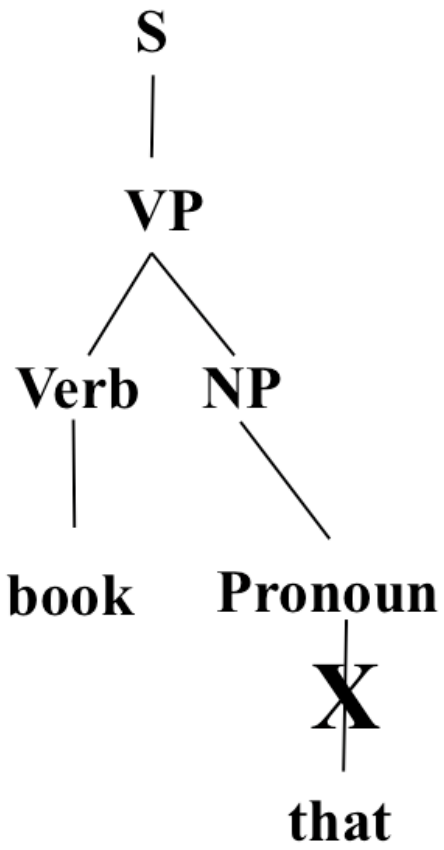

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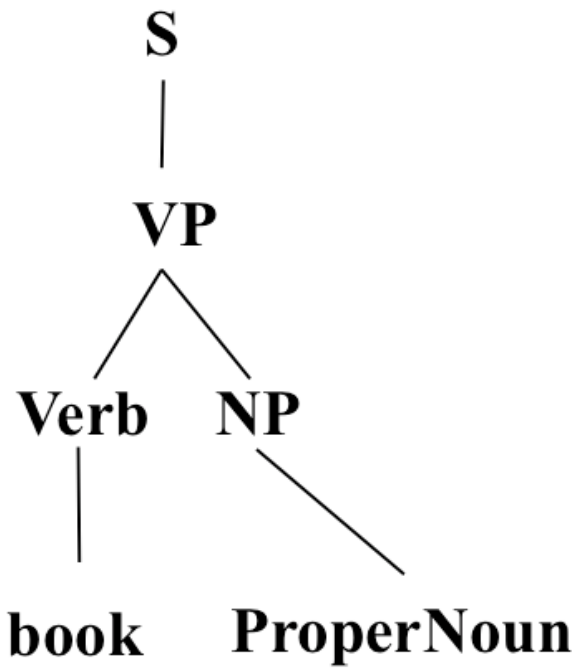
Lexicon

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

Top Down Parsing



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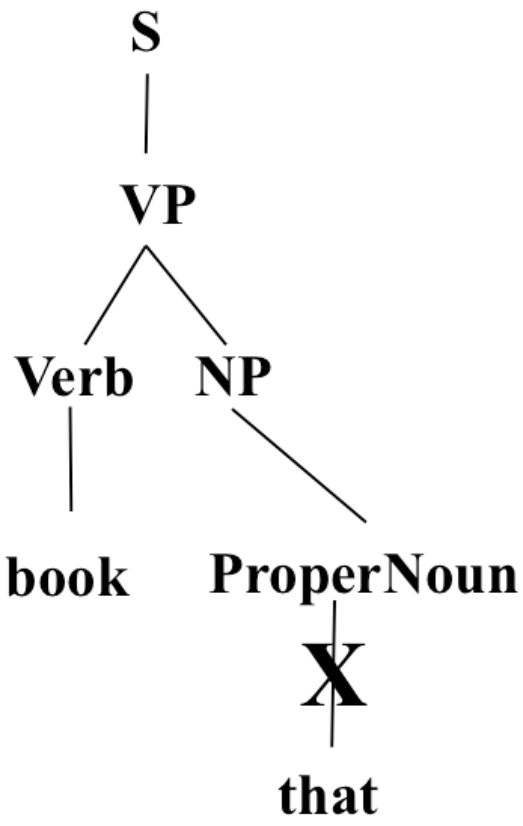

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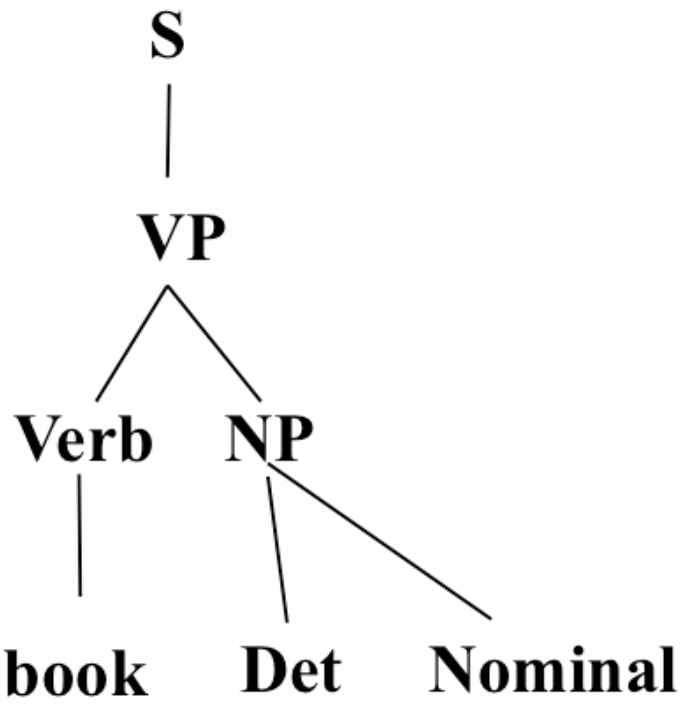

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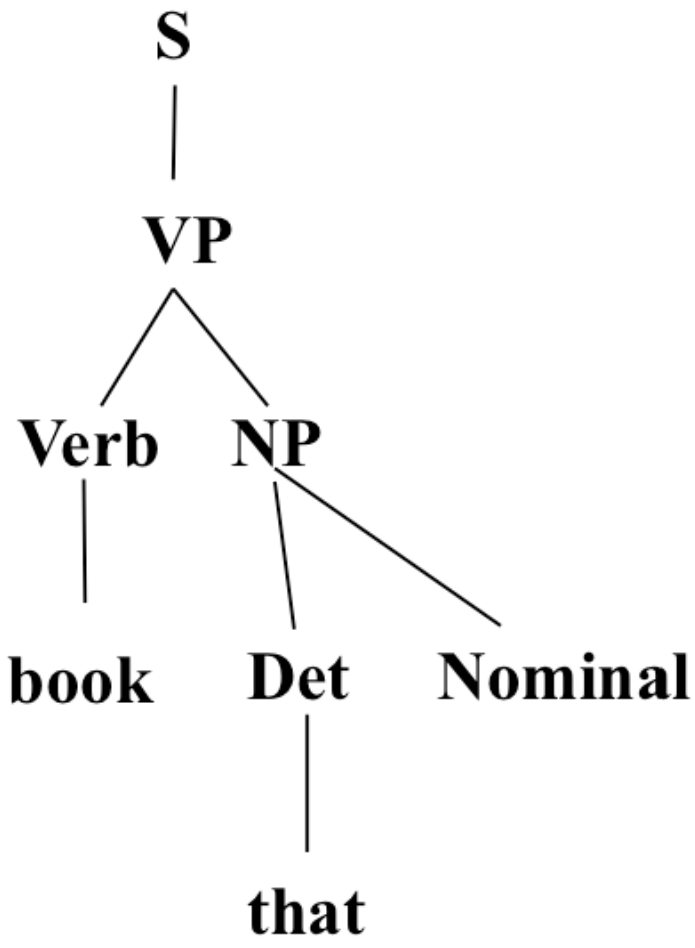

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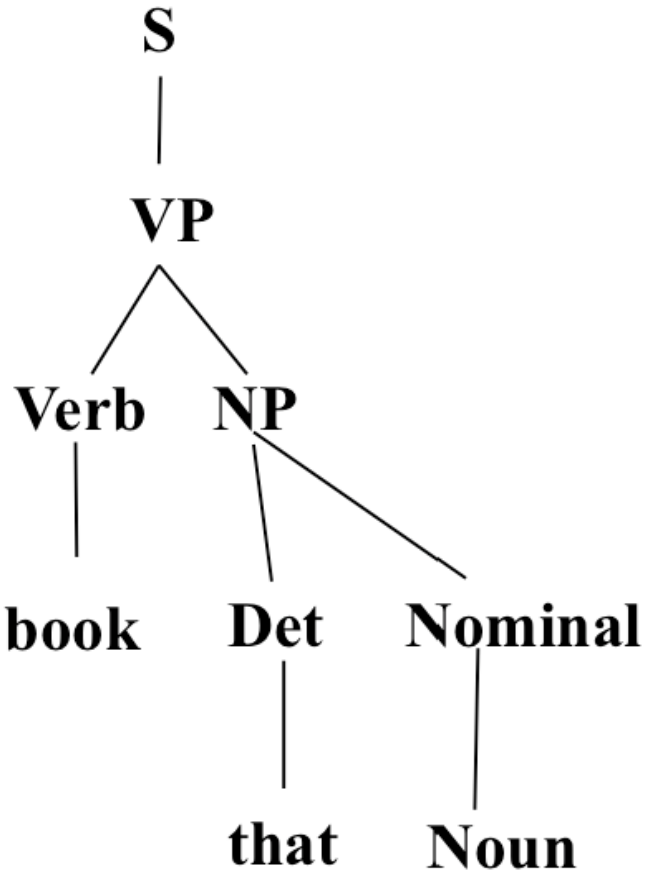

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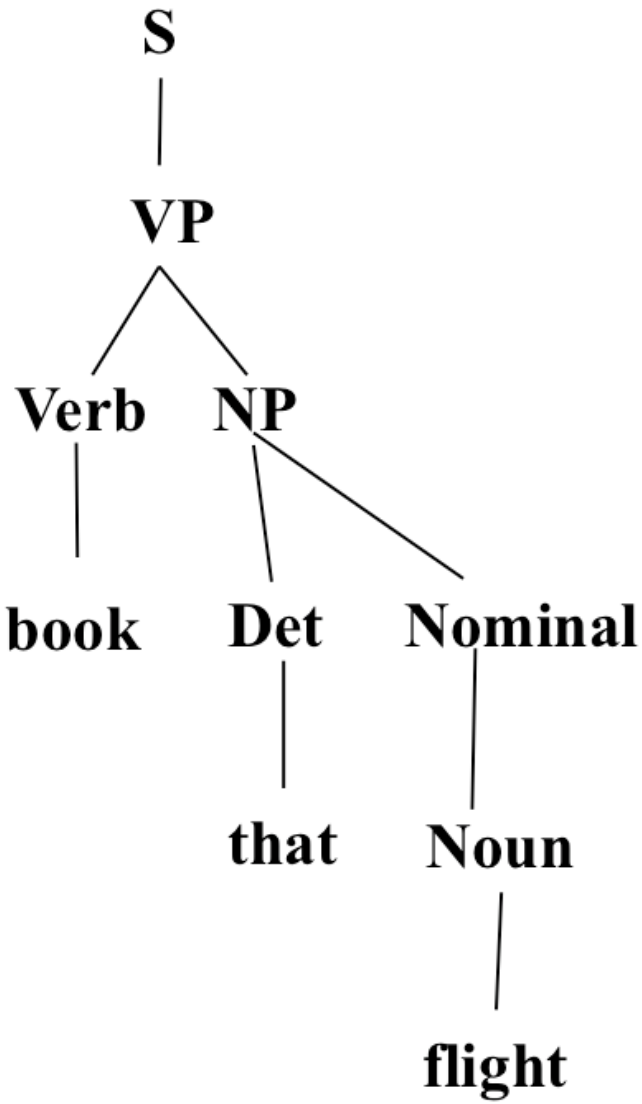

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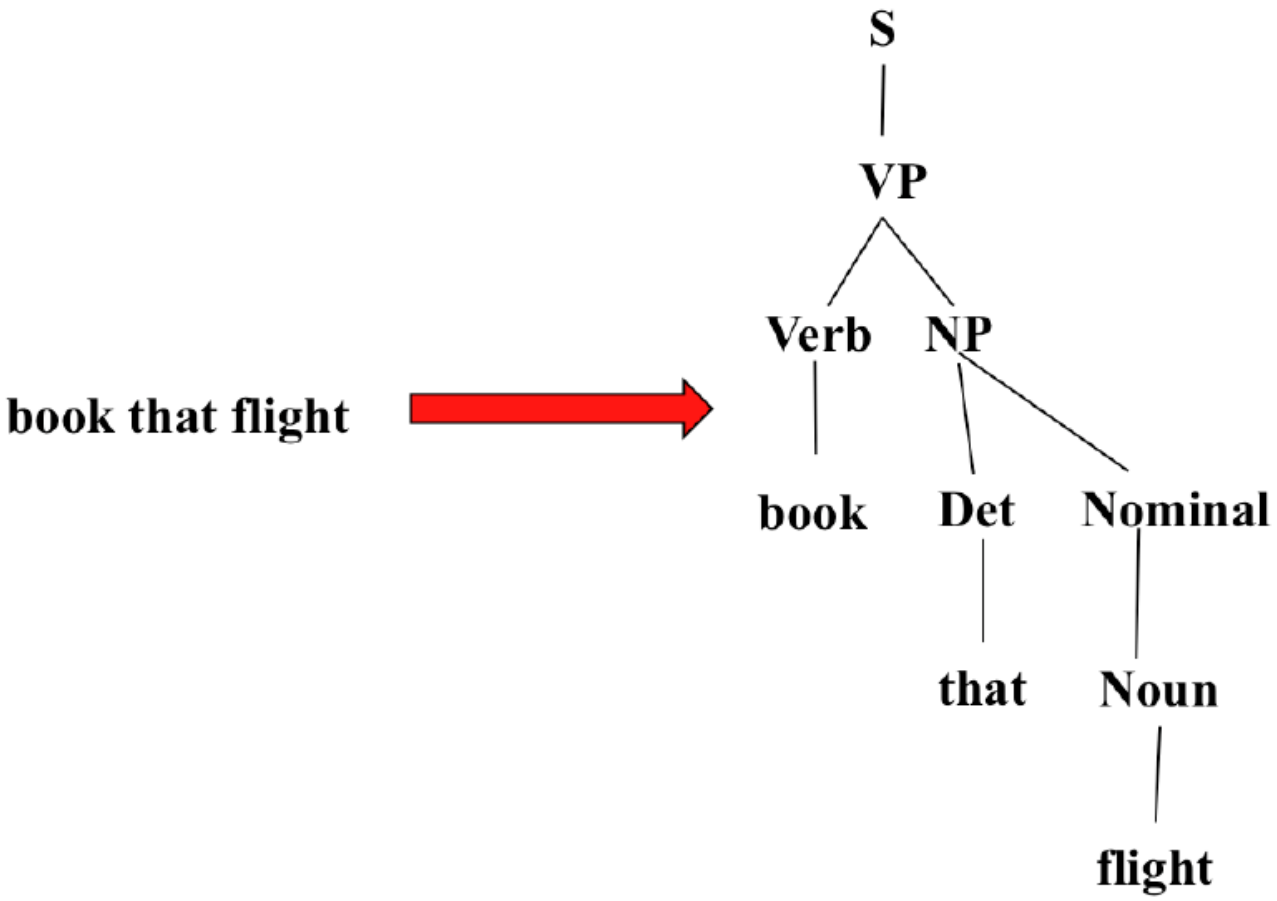

Bottom-Up Parsing

Bottom-Up Parsing

- The parser starts with the words of the input, and tries to build trees from the words up, by applying rules from the grammar one at a time
- Parser looks for the places in the parse-in-progress where the right-hand-side of some rule might fit.

Bottom-Up Parsing

book that flight

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Noun

book that flight

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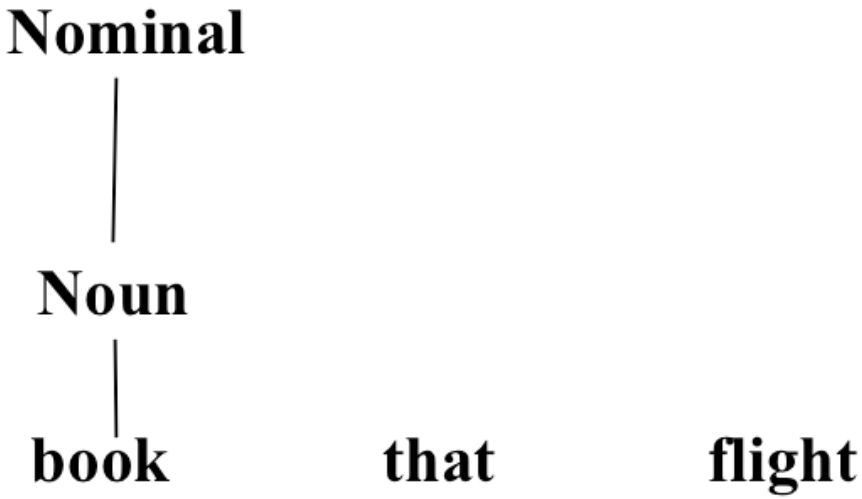

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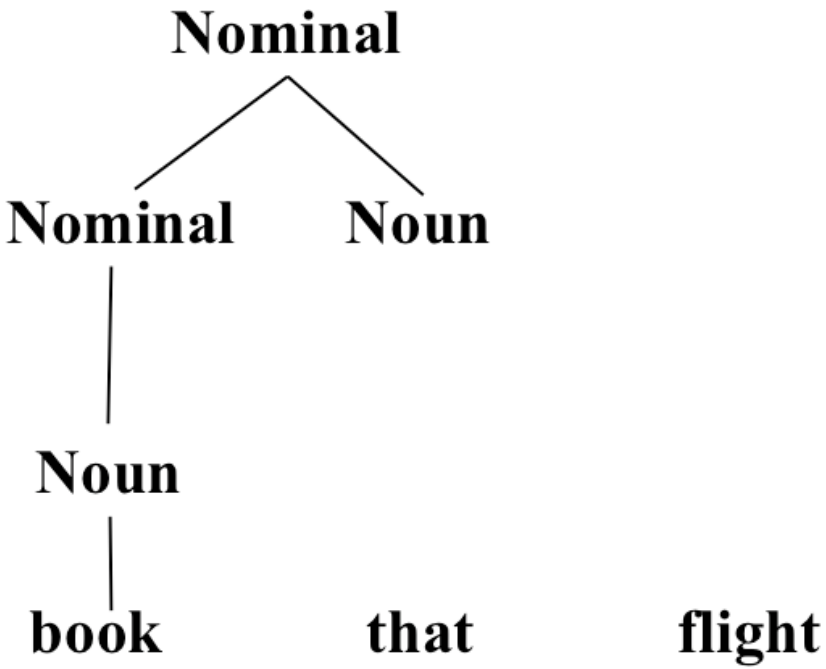

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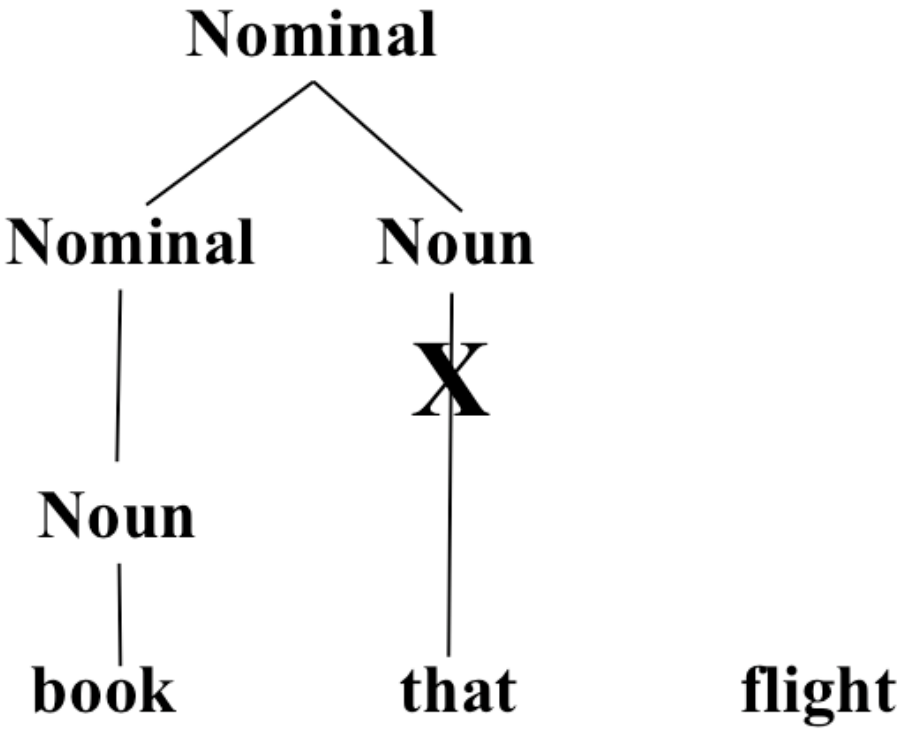

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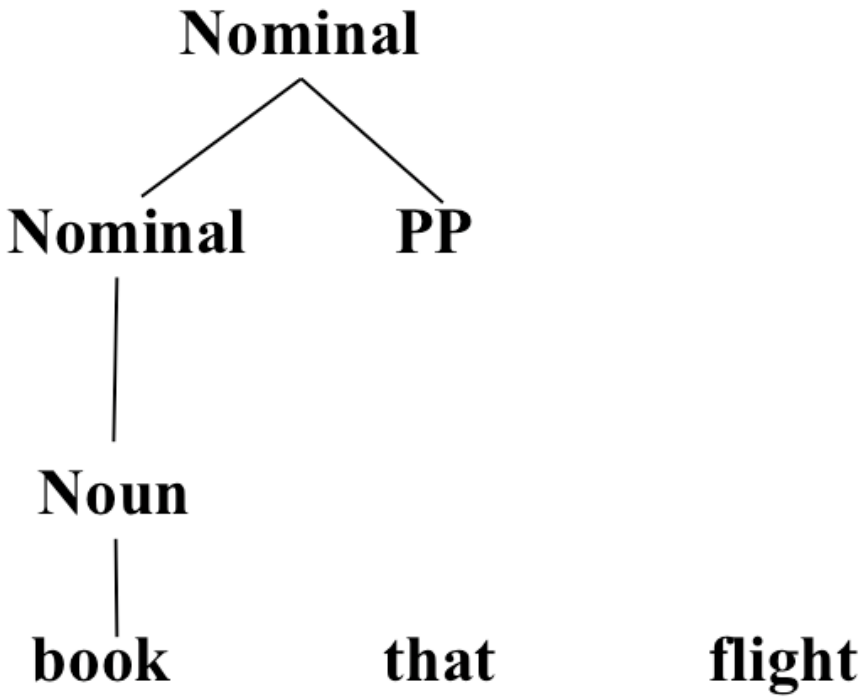

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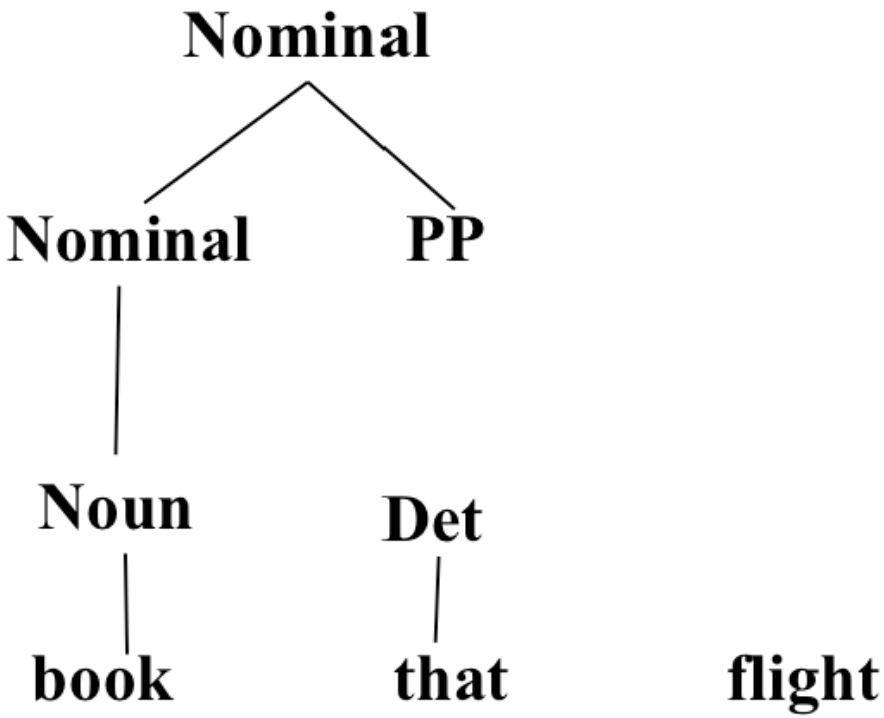

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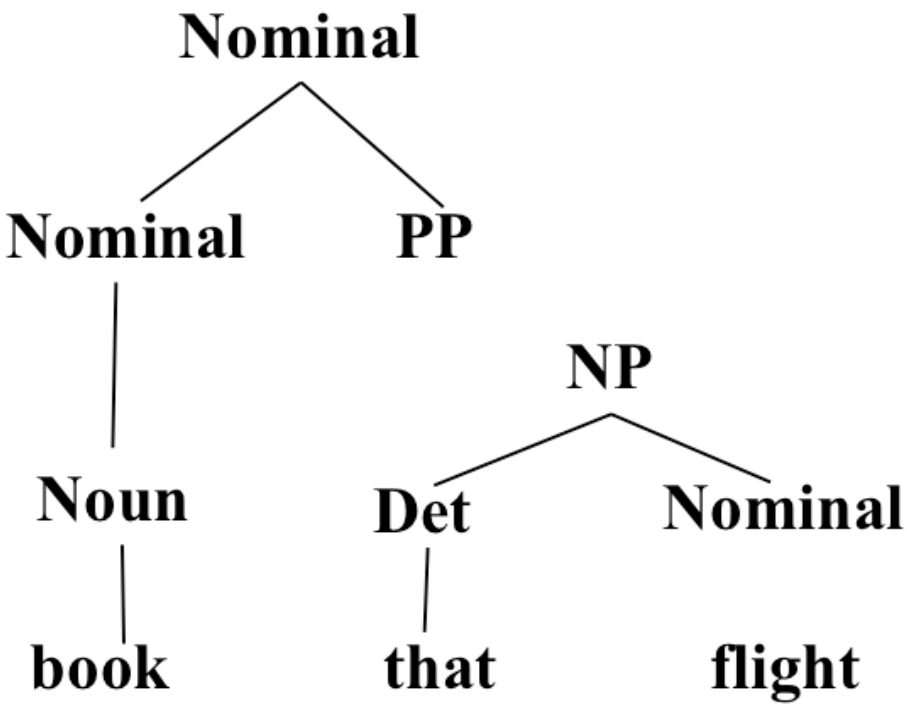

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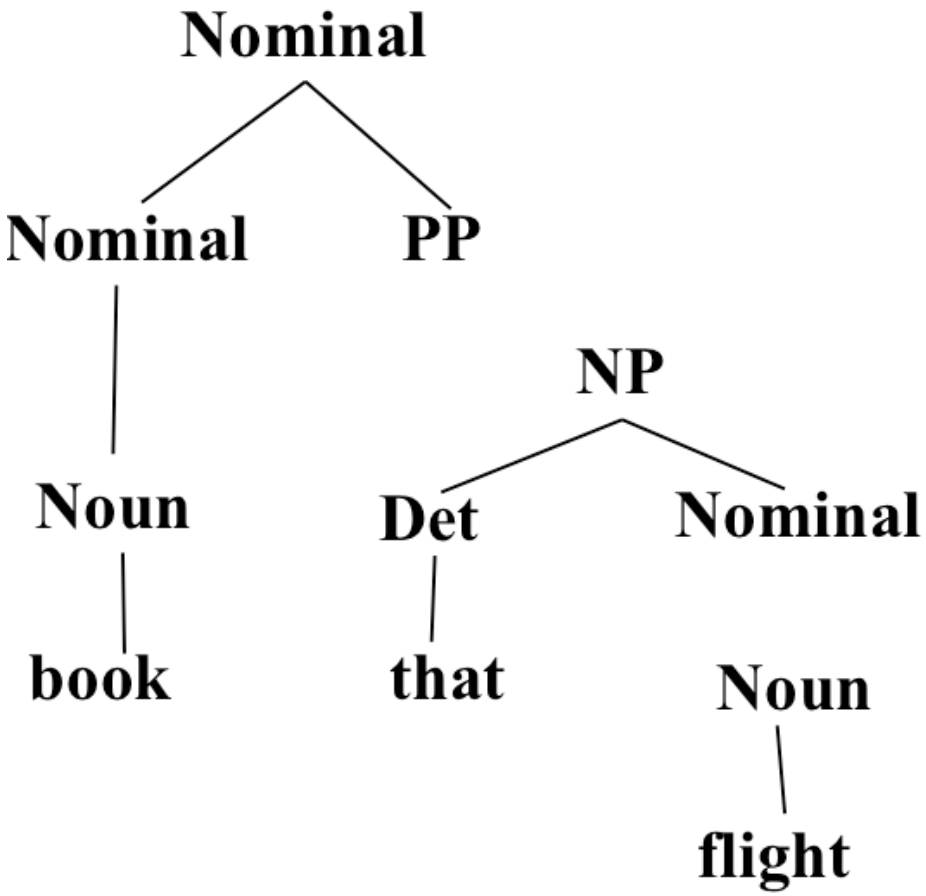

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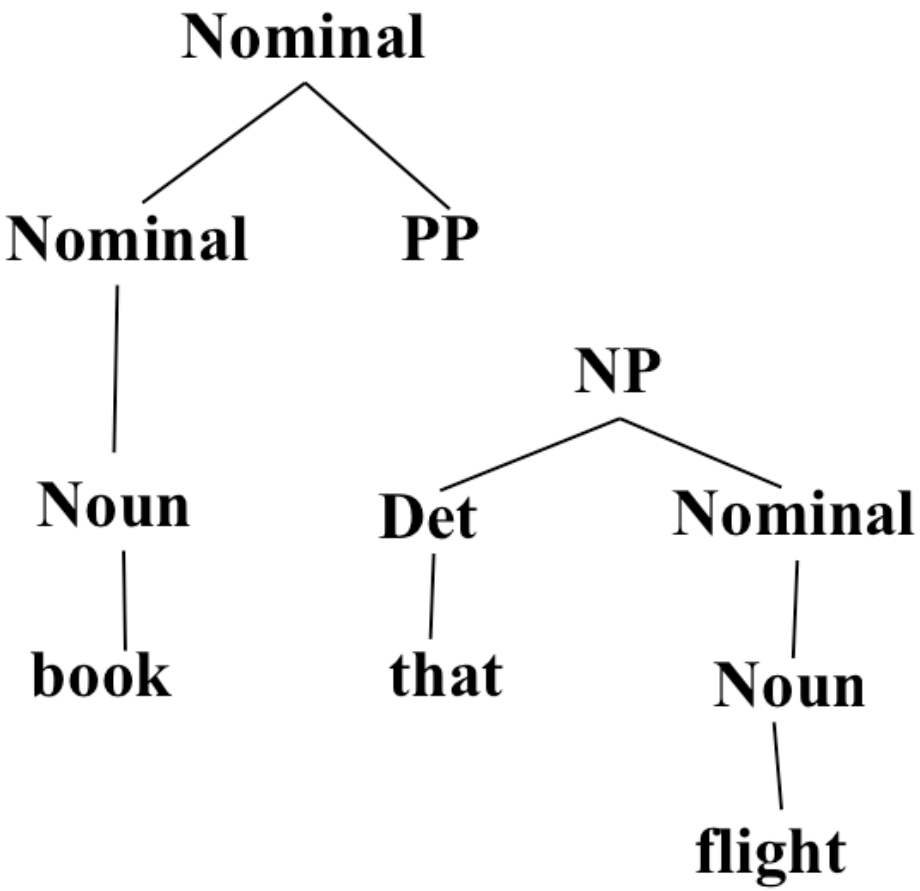

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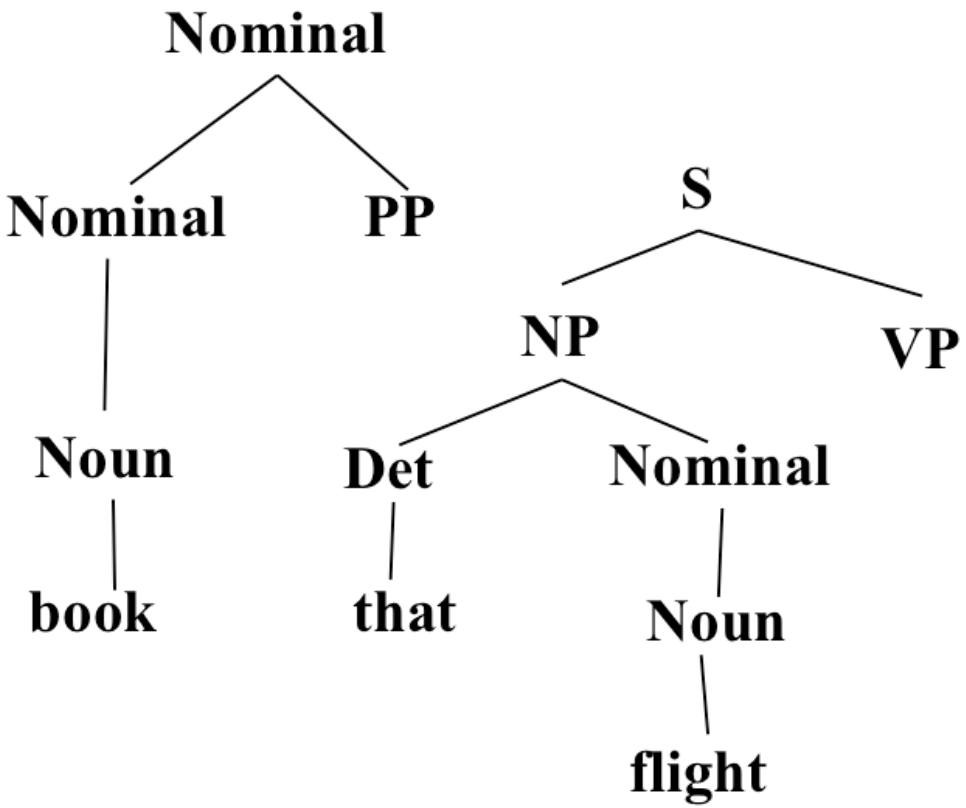

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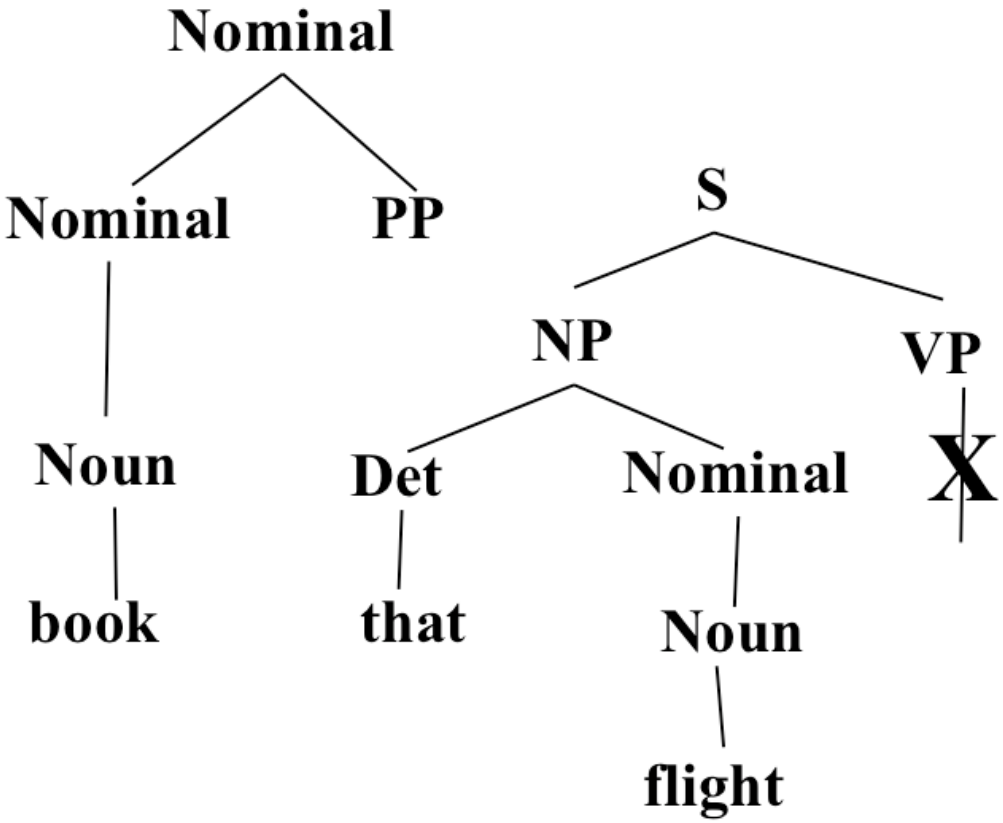

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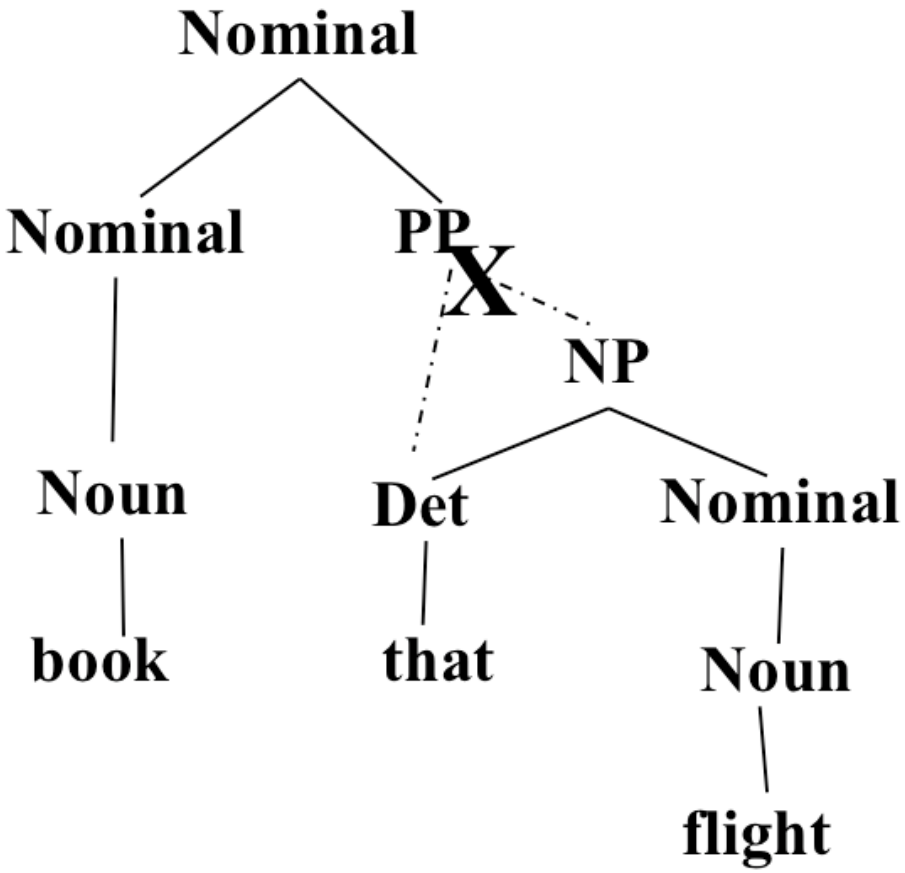

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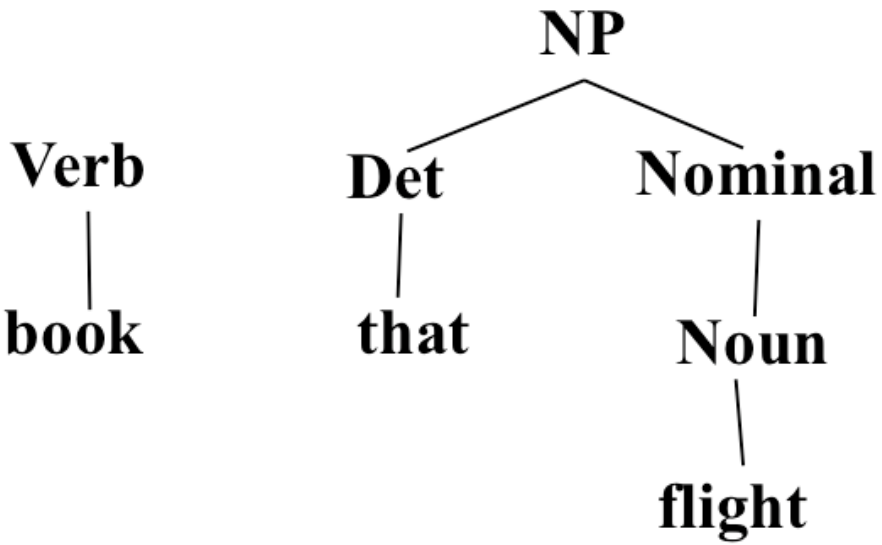

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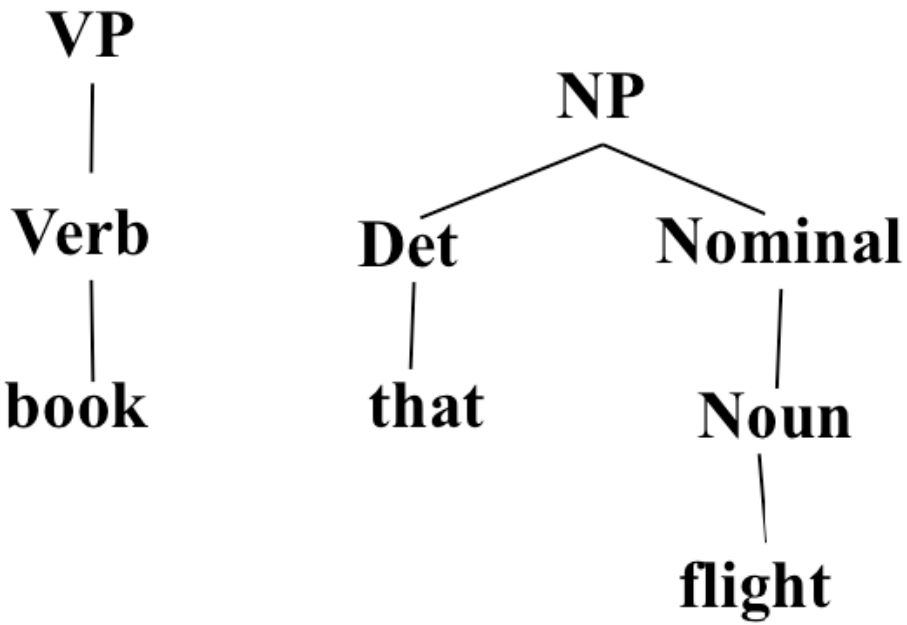

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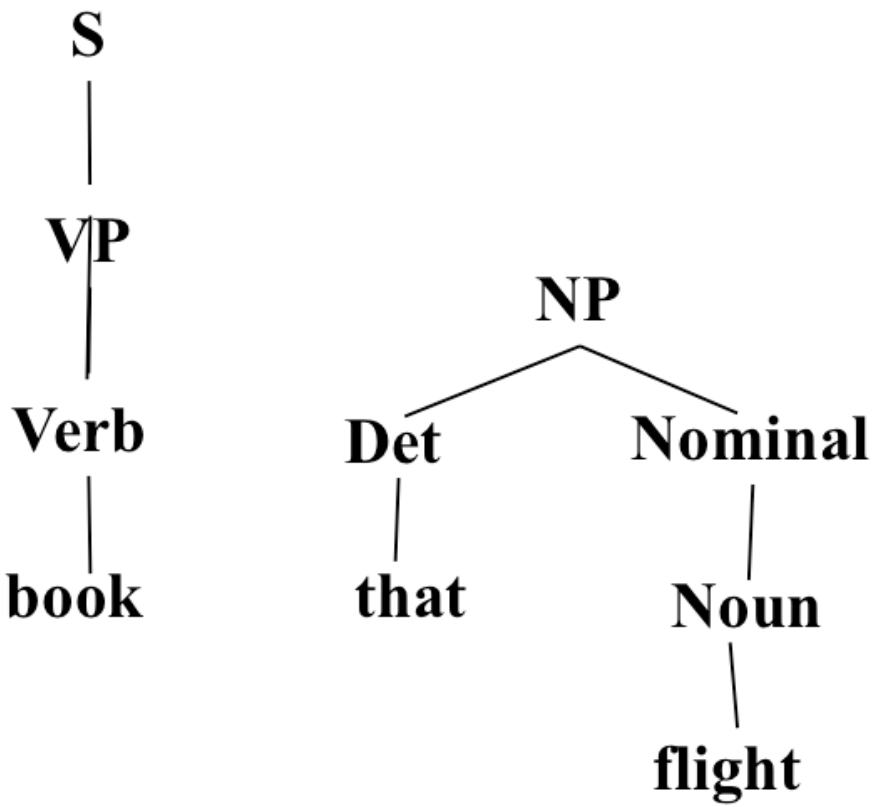

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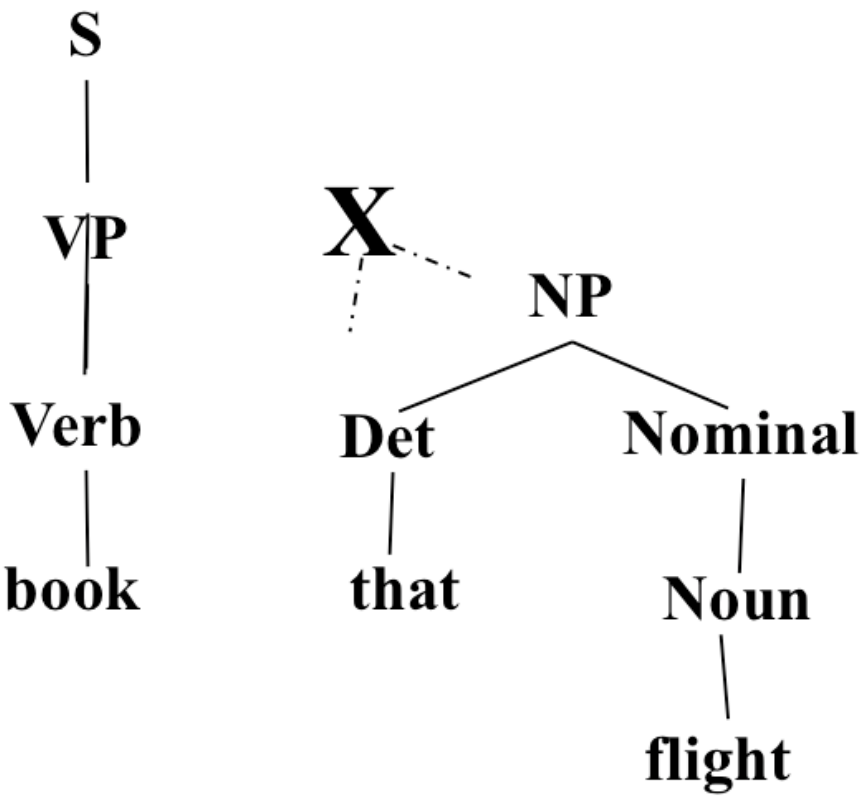

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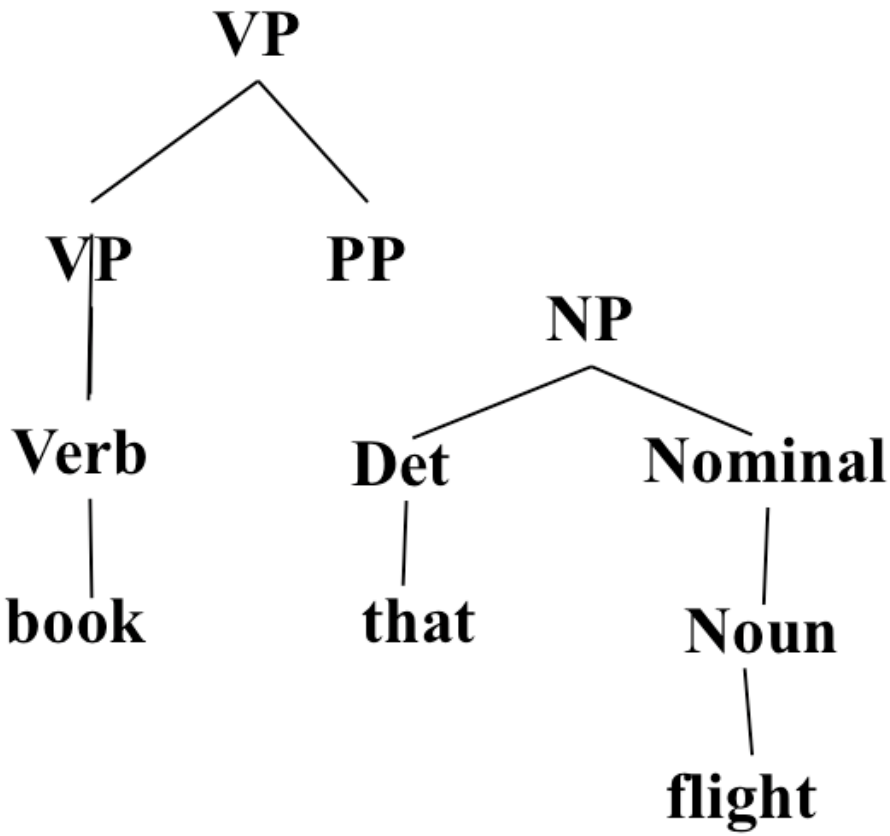

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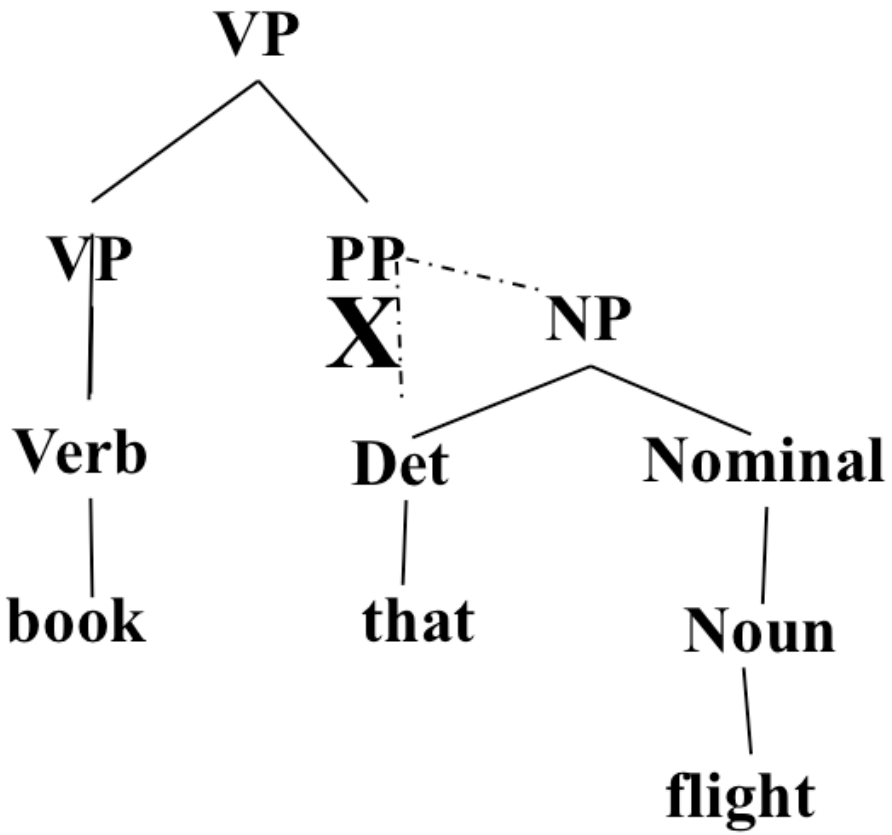

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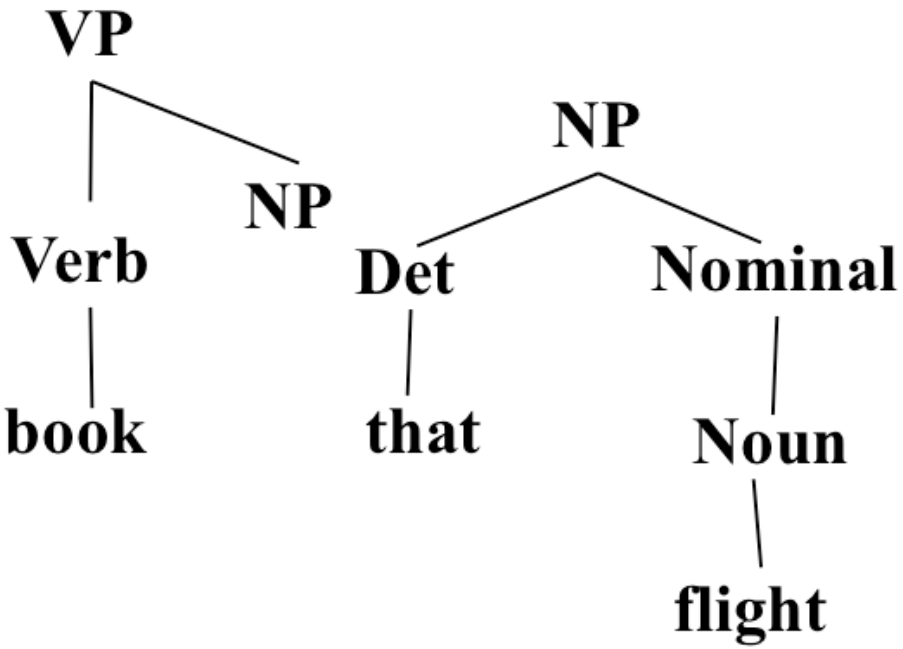

Grammar

S → NP VP
S → Aux NP VP
S → VP
NP → Pronoun
NP → Proper-Noun
NP → Det Nominal
Nominal → Noun
Nominal → Nominal Noun
Nominal → Nominal PP
VP → Verb
VP → Verb NP
VP → VP PP
PP → Prep NP

Lexicon

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

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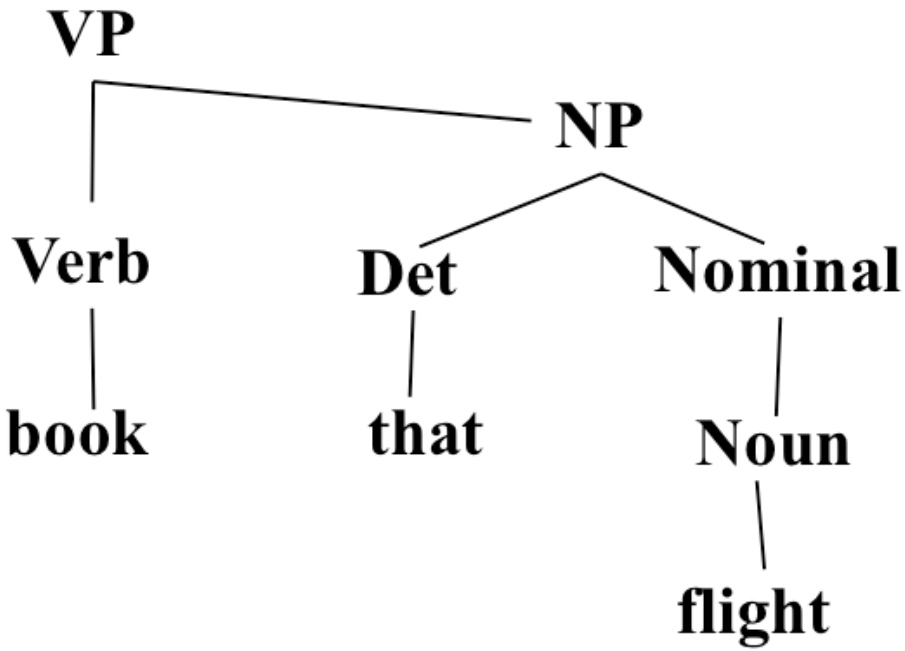

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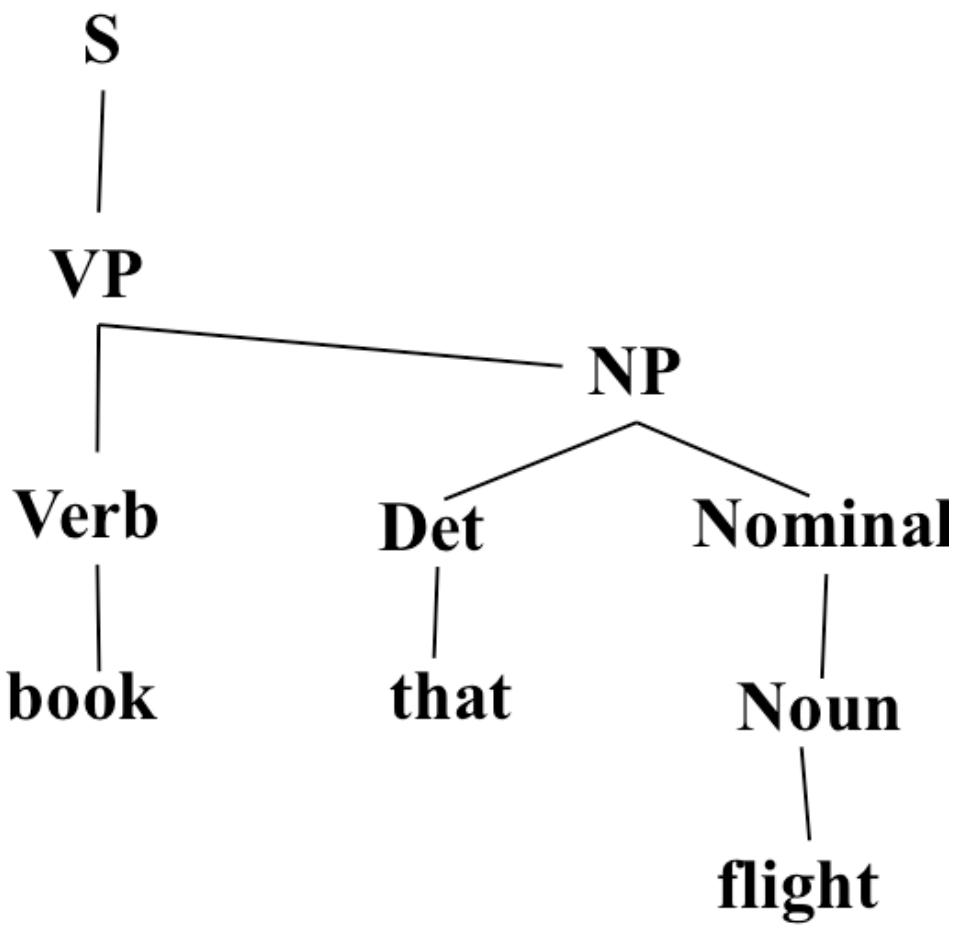

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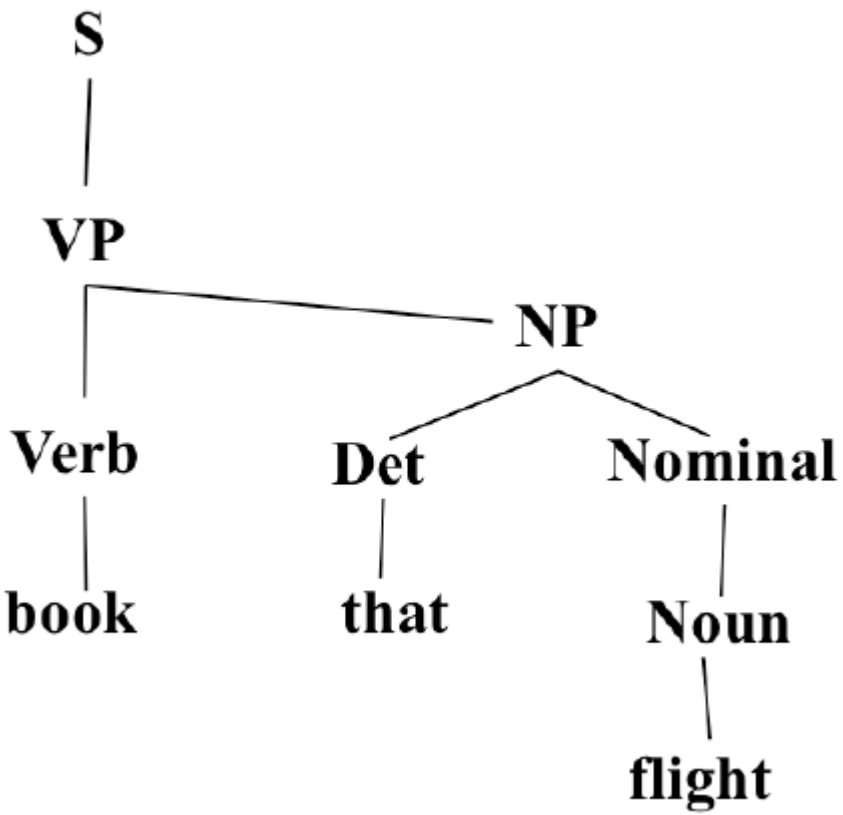


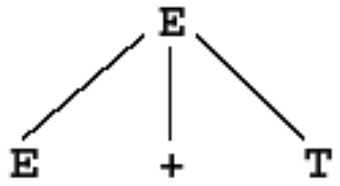
Top-Down vs. Bottom-Up

- Top down never explores options that will not lead to a full parse, but can explore many options that never connect to the actual sentence.
- Bottom up never explores options that do not connect to the actual sentence but can explore options that can never lead to a full parse.
- Relative amounts of wasted search depend on how much the grammar branches in each direction.

Illustration

$$
\begin{array}{lcl}
E & \rightarrow & E + T \mid T \\
T & \rightarrow & T * F \mid F \\
F & \rightarrow & (E) \mid \texttt{id}
\end{array}
$$

The parse tree:



Leftmost derivation:

$$\underline{E} \Rightarrow \underline{E} + T$$

Illustration

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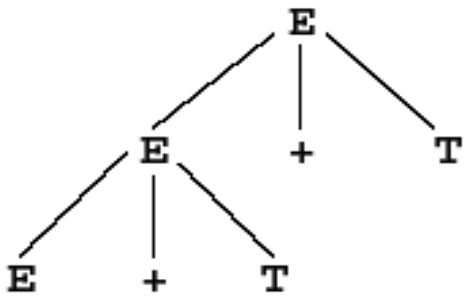

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\underline{E} & \Rightarrow & \underline{E} + T \\
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Illustration

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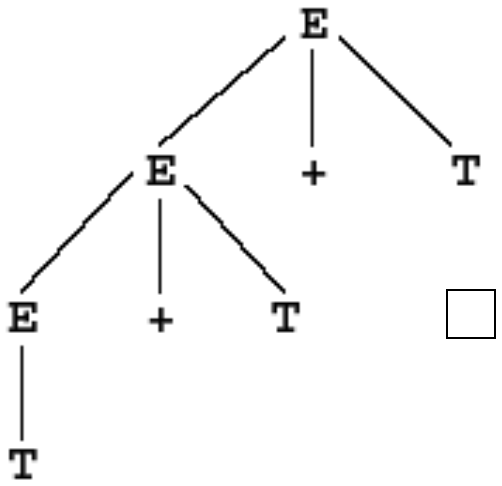

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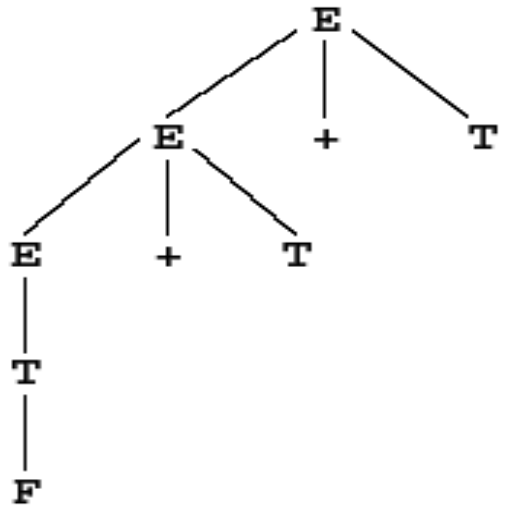

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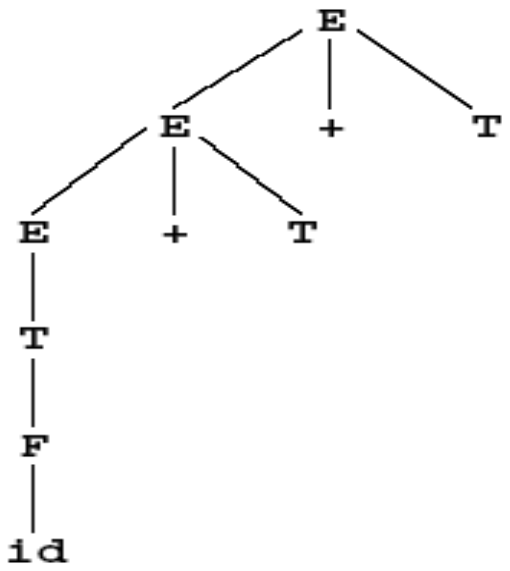
 & \Rightarrow & \underline{T} + T + T \\
 & \Rightarrow & \underline{F} + T + T
\end{array}
$$

Illustration

$$
\begin{array}{lcl}
E & \longrightarrow & E + T \mid T \\
T & \longrightarrow & T * F \mid F \\
F & \longrightarrow & (E) \mid \texttt{id}
\end{array}
$$

The parse tree:



Leftmost derivation:

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\underline{E} & \Rightarrow & \underline{E} + T \\
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 & \Rightarrow & \underline{T} + T + T \\
 & \Rightarrow & \underline{F} + T + T \\
 & \Rightarrow & id + \underline{T} + T
\end{array}
$$

Illustration

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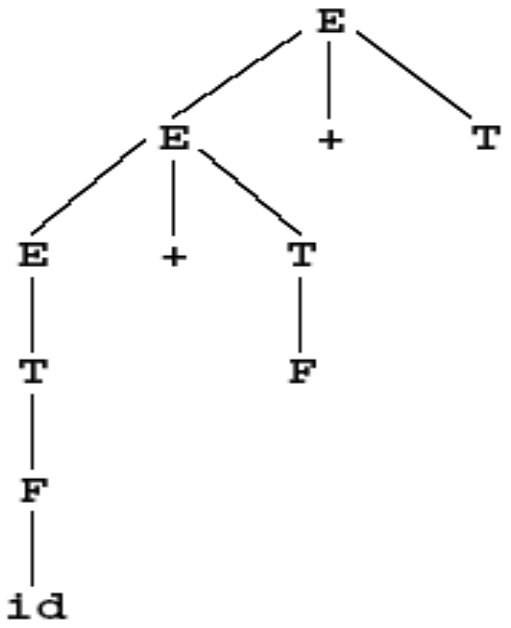

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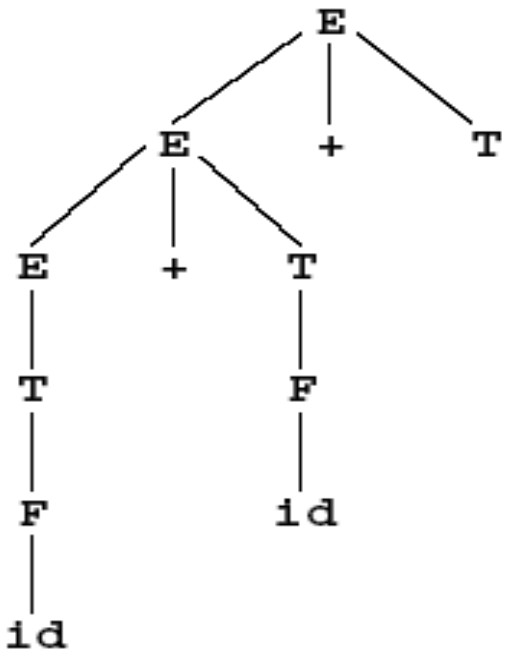

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&\Rightarrow id + id + \underline{T}
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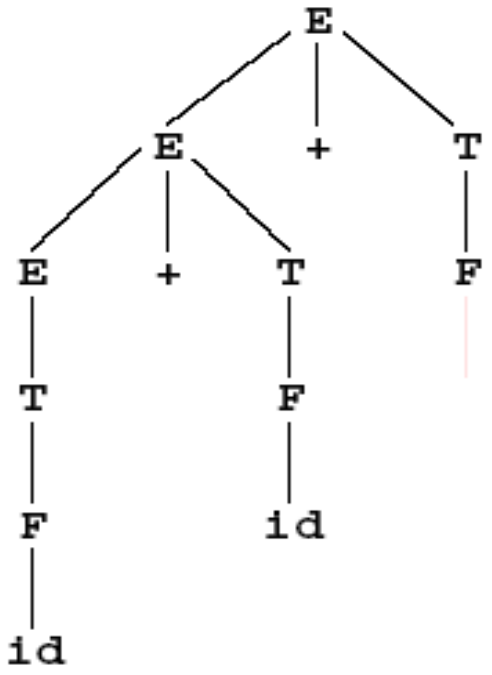

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Illustration

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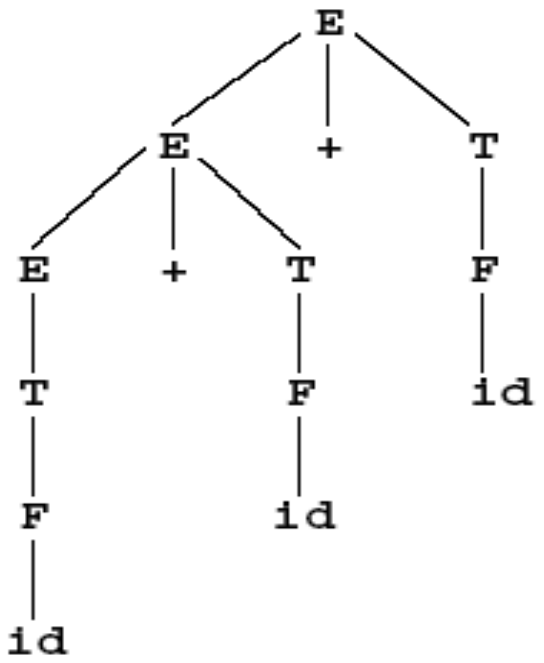

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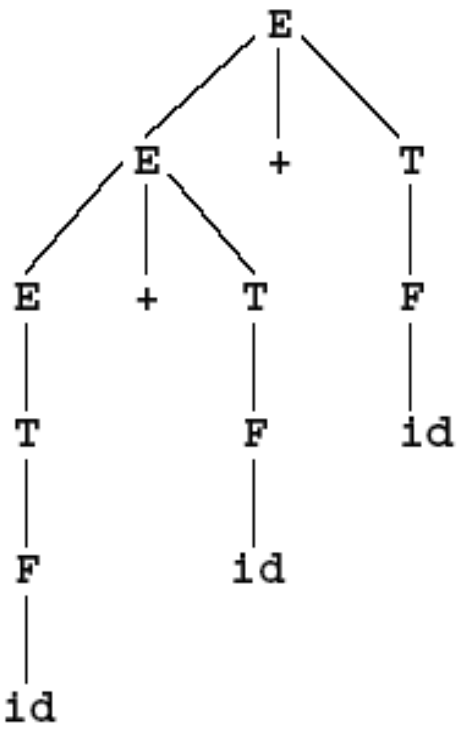

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&\Rightarrow id + id + \underline{T} \\
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Rightmost derivation:

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\begin{aligned}
\underline{E} &\Rightarrow E + \underline{T} \\
&\Rightarrow E + \underline{F} \\
&\Rightarrow \underline{E} + id \\
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&\Rightarrow \underline{F} + id + id \\
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$$

Dynamic Programming Parsing

Dynamic Programming Parsing

- To avoid extensive repeated work, must cache intermediate results, i.e.completed phrases.
- Dynamic programming algorithms based on both top-down and bottom-up search can achieve $O(n^3)$ recognition time where n is the length of the input string.

Dynamic Programming Parsing Methods

1. CKY (Cocke-Kasami-Younger) algorithm: bottom-up, requires normalizing the grammar
2. Chart Parsers - retain completed phrases in a chart and can combine top-down and bottom-up searches.
3. Arc Eager Parsers
4. Classifier Based Parsers

CKY Algorithm

- Grammar must be converted to Chomsky normal form (CNF) in which all productions must have:
  - Either, exactly two non-terminals on the RHS
  - Or, 1 terminal symbol on the RHS
- Parse bottom-up storing phrases formed from all substrings in a triangular table (chart)

Converting to CNF

Original Grammar

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Noun → book | flight | meal | money
Verb → book | include | prefer
Proper-Noun → Houston | NWA

Aux → is, am

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