Chapter 3 Grammar and Parsing

Parsing Technique

Contents

- Parsing with CFGs

  - Top-down

  - Bottom-up

  - Ambiguity

  - Left Recursion

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Parsing with CFG

Parsing

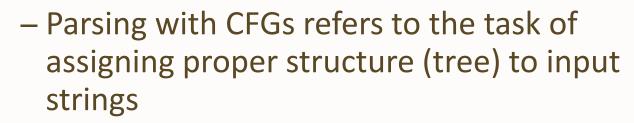- Parsing with CFGs refers to the task of assigning proper structure (tree) to input strings

- Proper here means a tree that covers all and only the elements of the input and has an S at the top

- It doesn't actually mean that the system can select the correct tree from among all the possible trees
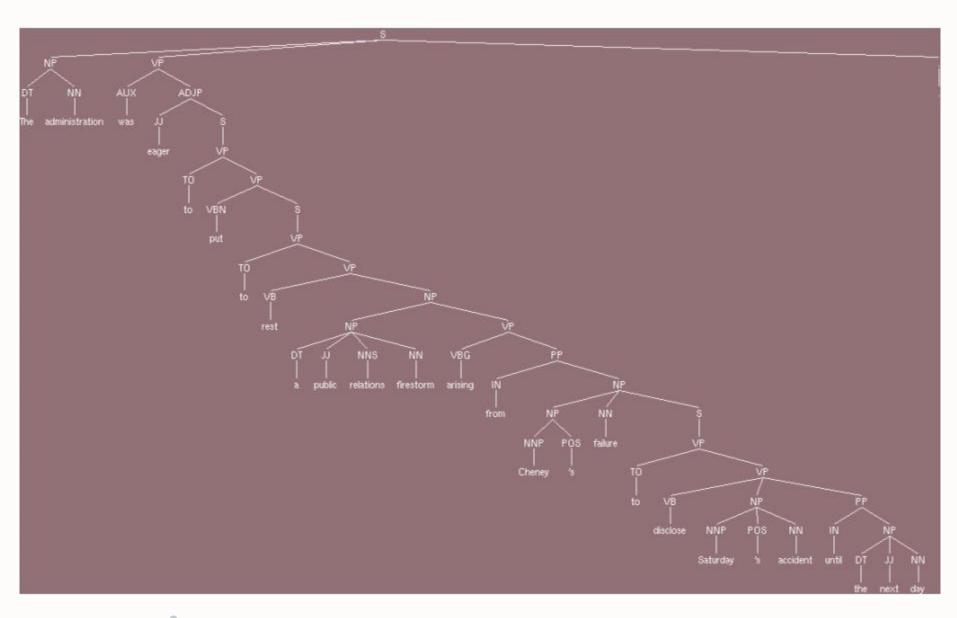
Parsing

– As with everything of interest, parsing involves a search which involves the making of choices

– Parser search through the space of all possible parse trees to find the correct parse tree for a sentence

– We'll start with some basic methods before moving on to the one or two that you need to know

4/30/2023

S
NP VP
DT NN AUX ADJP
The administration was JJ S
eager VP
TO VP
to VBN S
put VP
TO VP
to VB NP
rest NP VP
DT JJ NNS NN VBG PP
a public relations firestorm arising IN NP
from NP NN S
NNP POS failure VP
Cheney 's TO VP
to VB NP PP
disclose NNP POS NN IN NP
Saturday 's accident until DT JJ NN
the next day

For Now

– Assume…

  – You have all the words already in some buffer

  – The input isn't POS tagged

  – We won't worry about morphological analysis

  – All the words are known

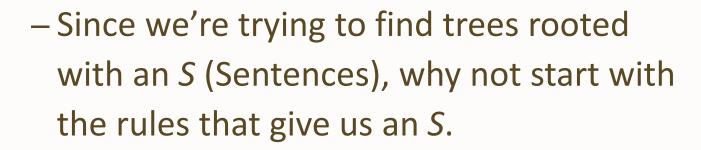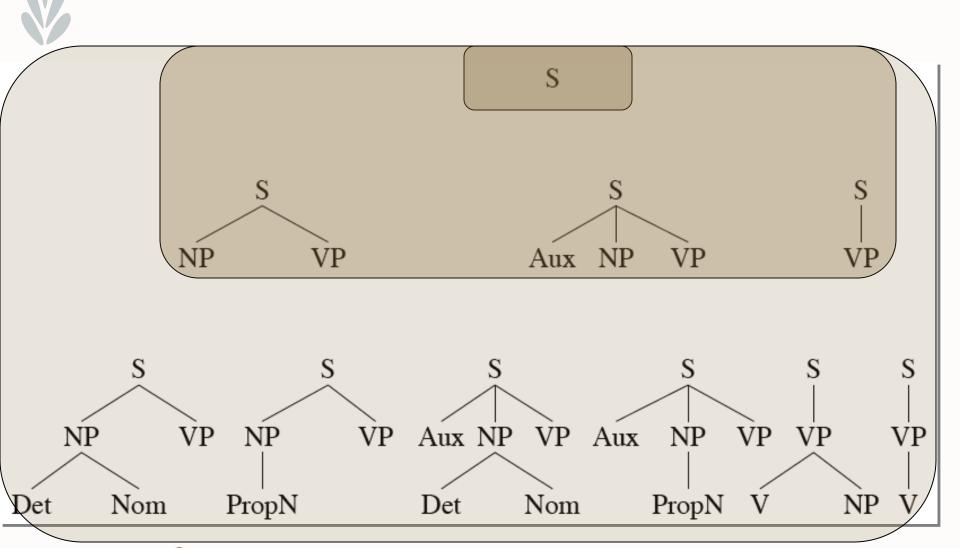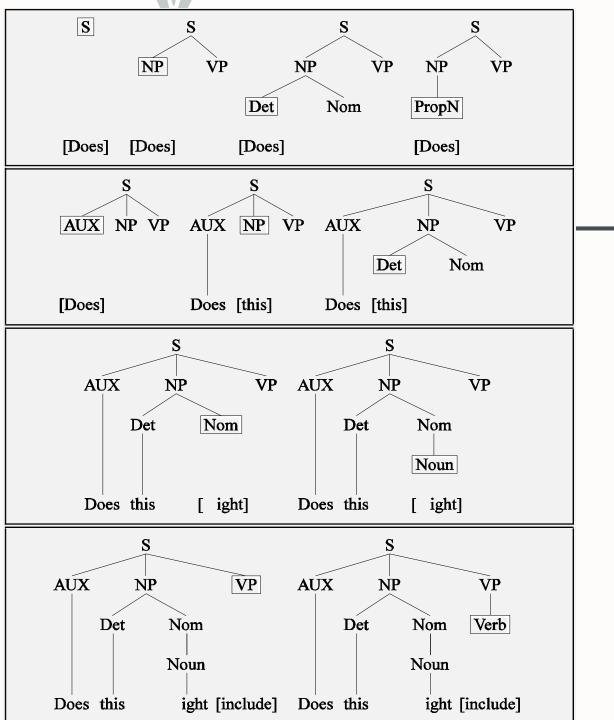 – These are all problematic in various ways, and would have to be addressed in real applications.

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Top Down Parsing

Top-Down Search

– Since we're trying to find trees rooted with an *S* (Sentences), why not start with the rules that give us an *S*.

– Then we can work our way down from there to the words.

Top Down Space

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Derivation top down, left-to-right, depth first

"Does this flight include a meal"

Bottom Up Parsing
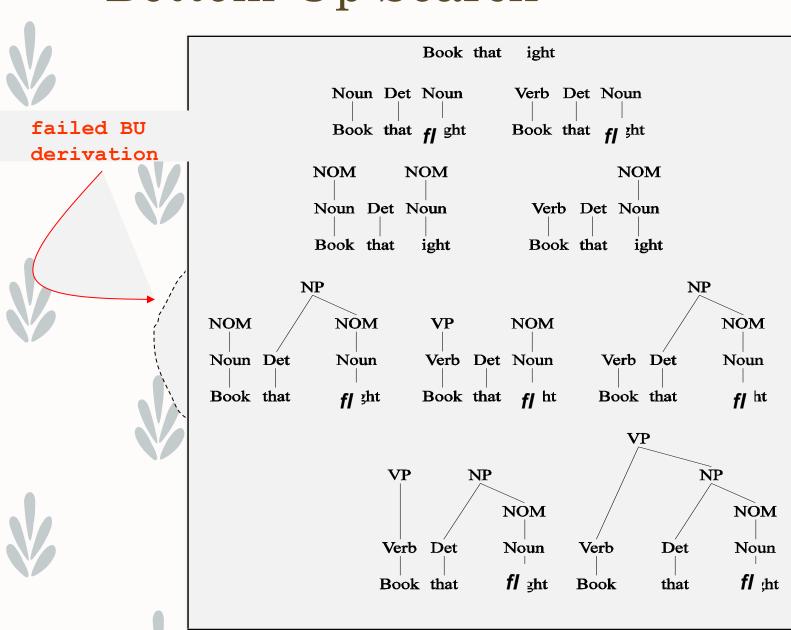
Bottom-Up Parsing

- Of course, we also want trees that cover the input words. So we might also start with trees that link up with the words in the right way.

- Then work your way up from there to larger and larger trees.
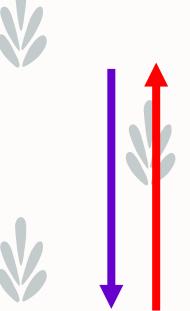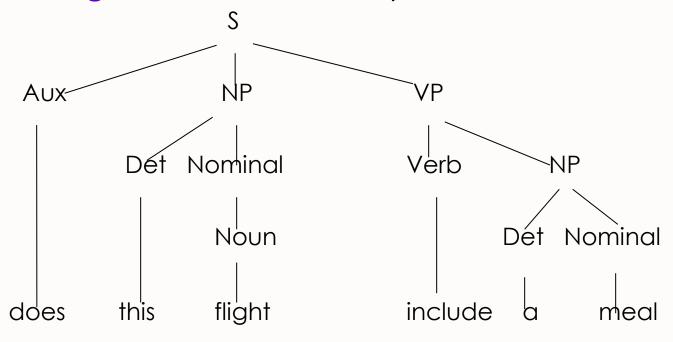
Bottom-Up Search

Top-Down VS. Bottom-Up

Top-Down VS. Bottom-Up

Bottom-up – from word-nodes to sentence-symbol
Top-down Parsing – from sentence-symbol to words

```
                        S
          ┌─────────────┼─────────────┐
         Aux           NP             VP
          │         ┌───┴───┐      ┌───┴───┐
          │        Det   Nominal  Verb     NP
          │         │       │      │     ┌──┴───┐
          │         │      Noun    │    Det  Nominal
          │         │       │      │     │       │
        does      this    flight include  a     meal
```

Top-Down VS. Bottom-Up

- Top-down
  - Only searches for trees that can be answers
  - But suggests trees that are not consistent with the words
  - Guarantees that tree starts with S as root
  - Does not guarantee that tree will match input words

- Bottom-up
  - Only forms trees consistent with the words
  - Suggest trees that make no sense globally
  - Guarantees that tree matches input words
  - Does not guarantee that parse tree will lead to S as a root

- Combine the advantages of the two by doing a search constrained from both sides (top and bottom)
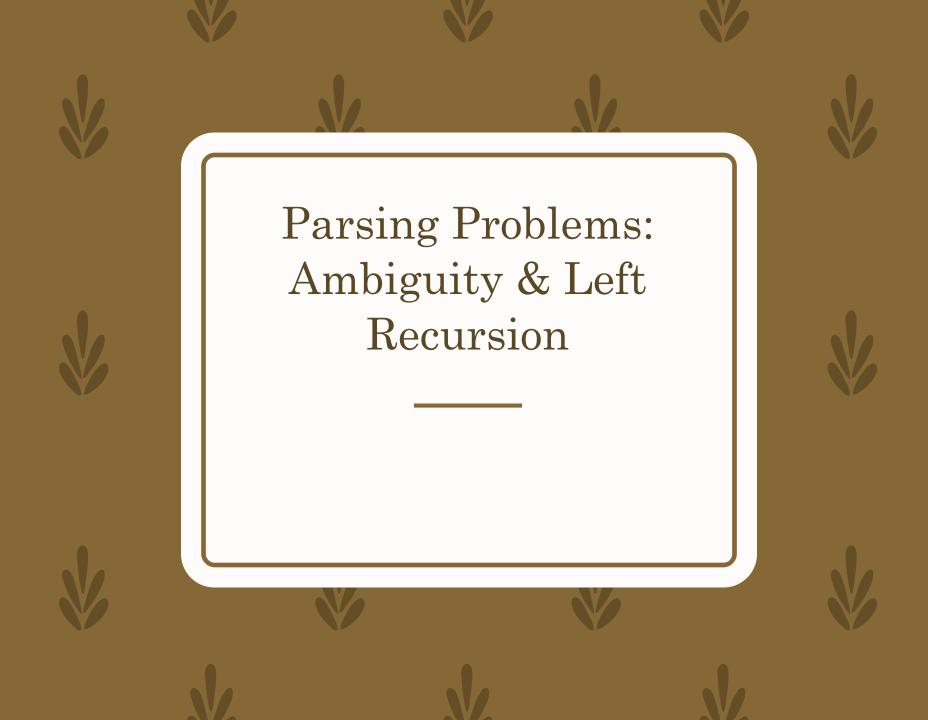
Control

– Of course, in both cases we left out how to keep track of the search space and how to make choices

  – Which node to try to expand next

  – Which grammar rule to use to expand a node

– One approach is called backtracking.

  – Make a choice, if it works out then fine

  – If not then back up and make a different choice

Parsing Problems: Ambiguity & Left Recursion

Problems

– Even with the best filtering, backtracking methods are doomed because of two inter-related problems

- – Ambiguity

- – Left Recursion

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Ambiguity
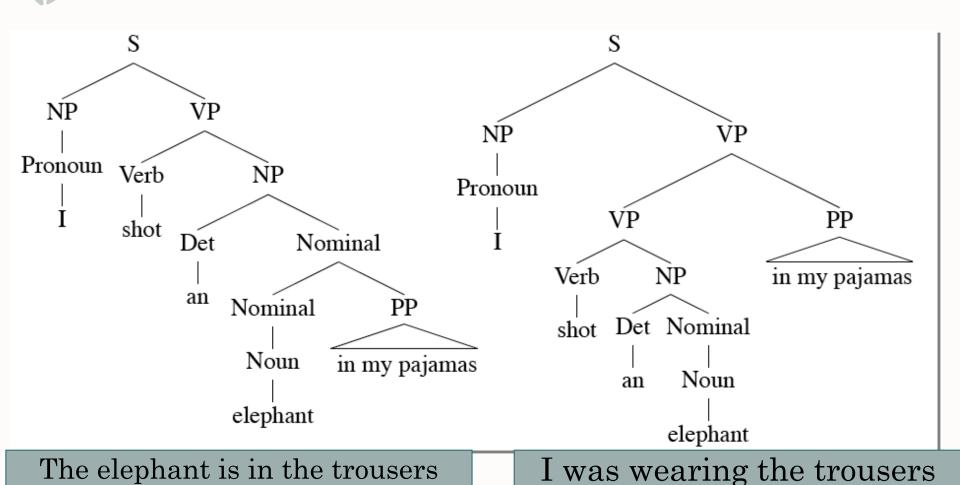

The elephant is in the trousers

I was wearing the trousers

Left Recursion

- No matter what kind of search (top-down or bottom-up or mixed) that we choose.

    - We don't want to redo work we've already done.

    - Unfortunately, naïve backtracking will lead to duplicated work.

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Left Recursion

Problems with left-recursive rules like NP $\rightarrow$ NP PP: don't know how many times recursion is needed

Pure Bottom-up or Top-down Parsing is inefficient because it generates and explores too many structures which in the end turn out to be invalid (several grammar rules applicable $\rightarrow$ 'interim' ambiguity).

Combine top-down and bottom-up approach:
Start with sentence; use rules top-down (look-ahead); read input; try to find shortest path from input to highest unparsed constituent (from left to right).

Some Solutions to Parsing Problems

- AMBIGUITY: SOLUTIONS
  - Use a PROBABILISTIC GRAMMAR
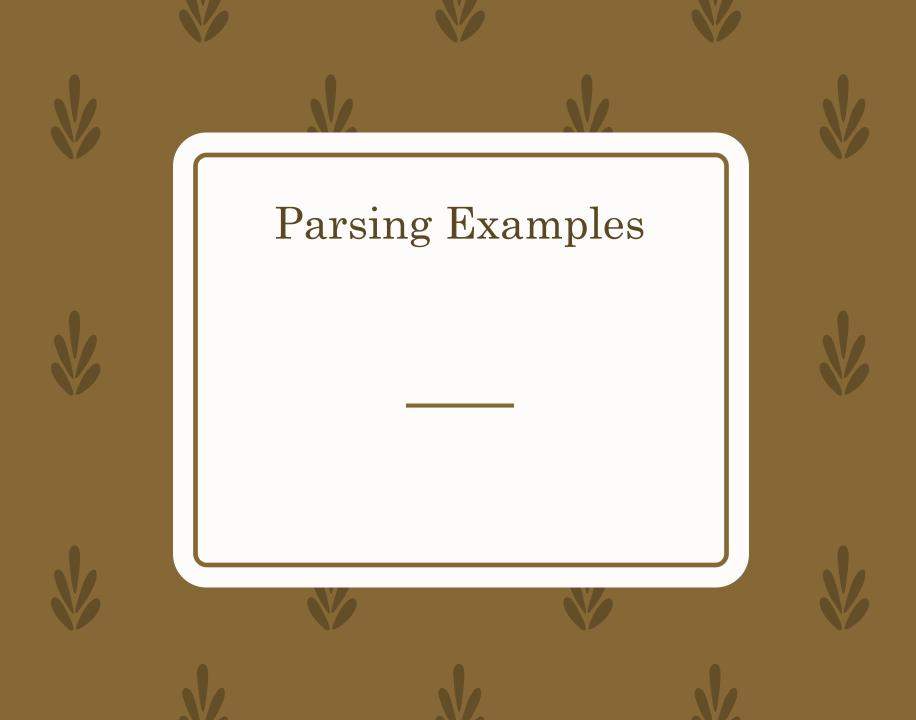 - Use semantics

- LEFT RECURSION: SOLUTIONS
  - Use LEFT CORNER PARSING
    - *A hybrid of top-down and bottom-up parsing*
    - *Strategy: don't consider any expansion unless the current input can serve as the LEFT-CORNER of that expansion*
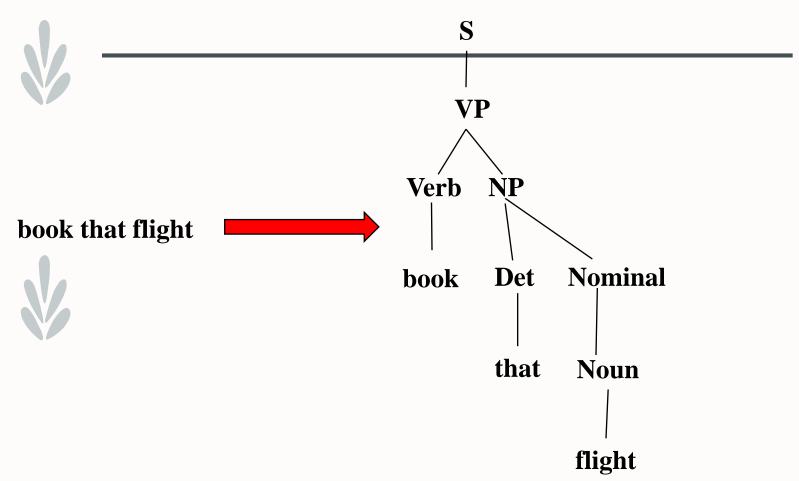
Parsing Examples

Parsing Example

S

──

VP

book that flight ⟶

Verb   NP

book   Det   Nominal

that   Noun

flight

Top Down Parsing

S
NP   VP
Pronoun

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

S

NP   VP

Pronoun

X

book

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

S
├── NP
│   └── ProperNoun
└── VP
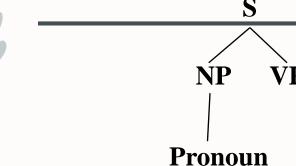
Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

```
                    S
                   / \
                 NP   VP

             ProperNoun

                 X
                 |
               book
```

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
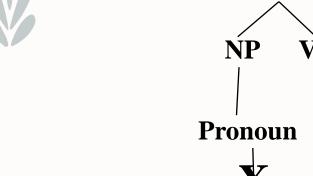NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

S
```
        S
       / \
      NP  VP
     /  \
   Det  Nominal
```

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
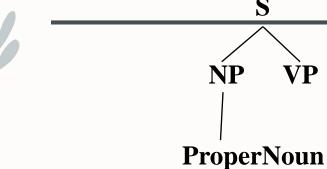NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

S

NP   VP

Det   Nominal

X

book

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
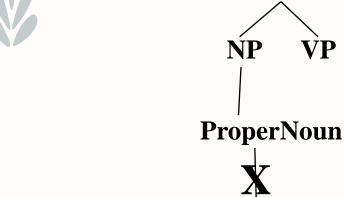NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

```
                        S
                      / | \
                   Aux  NP  VP
```
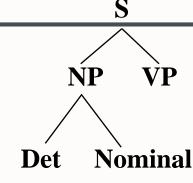
Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

```
                    S
        _____|_____
       |           |        |
      Aux          NP       VP
       |
       X
       |
      book
```
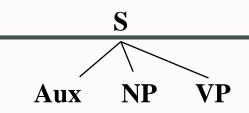
Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
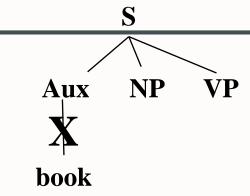VP -> Verb NP

Top Down Parsing

S
|
VP

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

```
                    S
  ─────────────────────────────────────────
                    │
                    VP
                    │
                   Verb
```

S->NP VP

S-> AUX NP VP

S-> VP

NP -> Pronoun

NP -> Proper Noun

NP -> Det Nom

Nom -> Noun

VP -> Verb

VP -> Verb NP

Top Down Parsing

```
                          S
  ─────────────────────────────────────────────
                          │
                          VP
                          │
                          Verb
                          │
                          book
```
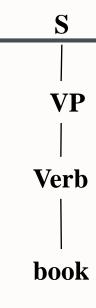
S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
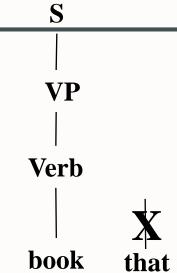NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

```
                    S
                    |
                    VP
                    |
                    Verb
                    |                 X
                   book             that
```

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

```
                    S
                    |
                   VP
                  /  \
               Verb   NP
```

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

S
_____

        VP

  Verb   NP

  book

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
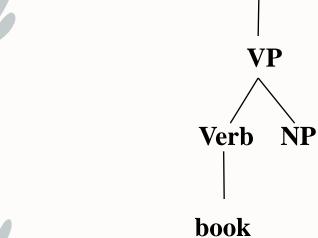VP -> Verb NP

Top Down Parsing

```
                        S
─────────────────────────────────────────
                        │
                       VP
                      /  \
                 Verb     NP
                   │        \
                 book      Pronoun
```

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
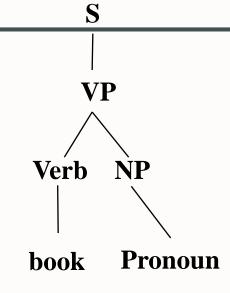NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

S
_____

VP

Verb   NP

book   Pronoun

X

that

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
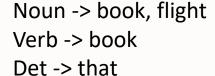VP -> Verb NP

Top Down Parsing

```
                    S
_____|_____

                    VP

              Verb     NP

              book    ProperNoun
```
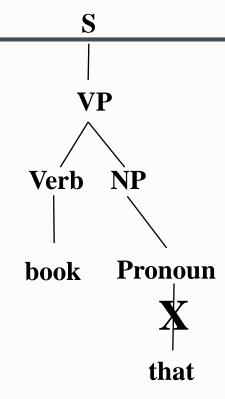
Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

```
              S
              |
             VP
            /  \
        Verb    NP
         |        \
        book    ProperNoun
                  X
                  |
                 that
```

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
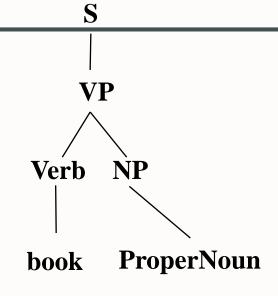NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

S
|
VP
/ \
Verb NP
| / \
book Det Nominal
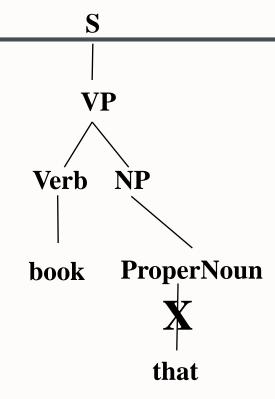
Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

S
|
VP
/   \
Verb   NP
| /   \
book Det   Nominal
|
that

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
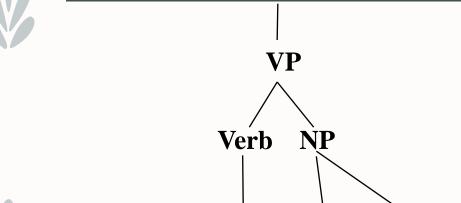NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

S
|
VP
/ \
Verb   NP
| / \
book Det   Nominal
| |
that   Noun

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
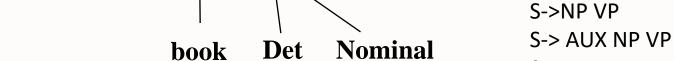NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Top Down Parsing

```
                    S
 ───────────────────────────────────────
                    │
                    VP
                   ╱ ╲
               Verb    NP
                 │    ╱  ╲
               book  Det  Nominal
                      │      │
                     that   Noun
                             │
                           flight
```
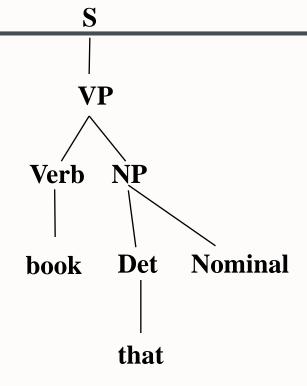
Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Bottom Up Parsing

book   **that**   **flight**

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
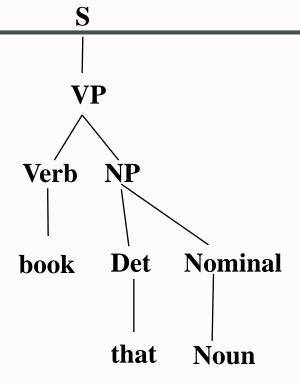NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
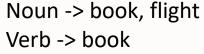VP -> Verb NP

Bottom Up Parsing

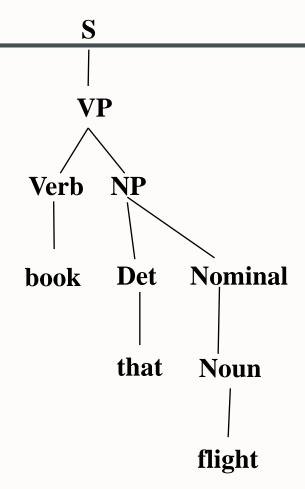Noun -> book, flight
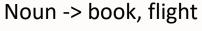Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Noun
|
book   **that**   **flight**

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

Nominal
|
Noun
|
book   **that**   **flight**

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

Nominal

Nominal   **Noun**

Noun

book   **that**   **flight**

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

Nominal
    Nominal   Noun
               X
      Noun
      book   that   flight

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

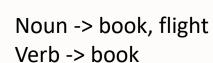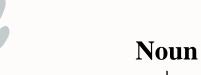# Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

Nominal

Nominal　　**PP**

Noun

book　　　**that**　　　**flight**

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

```
              Nominal
             /       \
        Nominal       PP
           |
         Noun          Det
           |            |
         book          that         flight
```

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
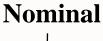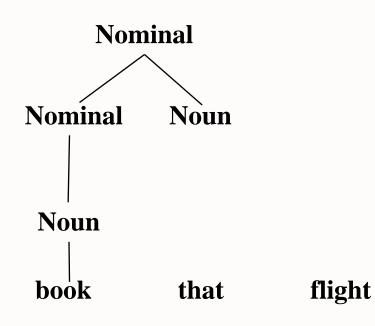NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

```
                    Nominal
                   /       \
            Nominal         PP
               |                        NP
             Noun                     /      \
               |                   Det        Nominal
             book                   |            |
                                   that        flight
```

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
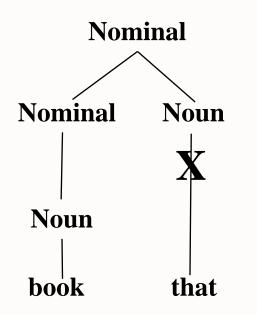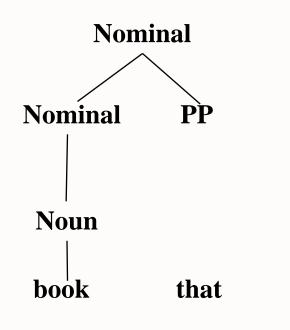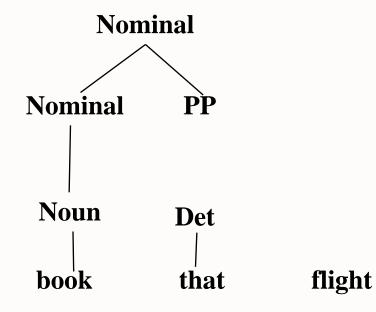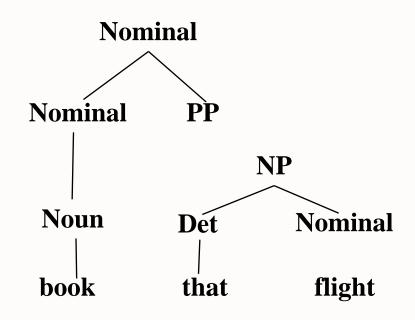NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Nominal
  Nominal   PP
    Noun   NP
                Det   Nominal
    book   that   Noun

                        flight

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

```
              Nominal
             /       \
        Nominal      PP
           |              NP
           |            /     \
         Noun        Det    Nominal
           |           |        |
         book        that     Noun
                               |
                             flight
```

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

```
            Nominal
           /      \
     Nominal      PP            S
        |                      / \
      Noun           NP          VP
        |           /   \
      book        Det   Nominal
                   |       |
                  that    Noun
                           |
                         flight
```

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
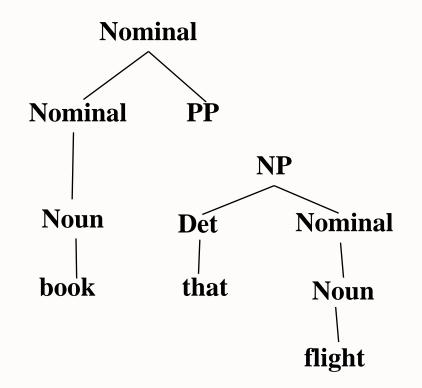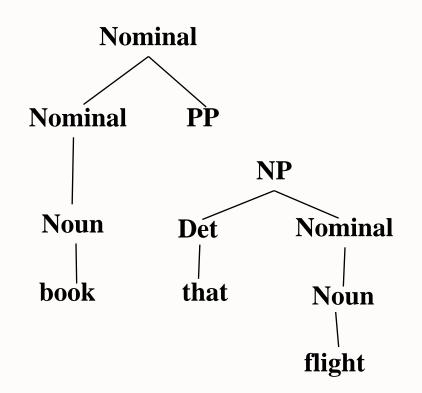NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

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Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

Nominal

Nominal   **PP**   **S**

                        NP   **VP** S->NP VP
                                          S-> AUX NP VP
                                          S-> VP
Noun   **Det**   **Nominal**   **X** NP -> Pronoun
                                          NP -> Proper Noun
                                          NP -> Det Nom
book   **that**   **Noun**   Nom -> Noun
                                          VP -> Verb
                         flight   VP -> Verb NP

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
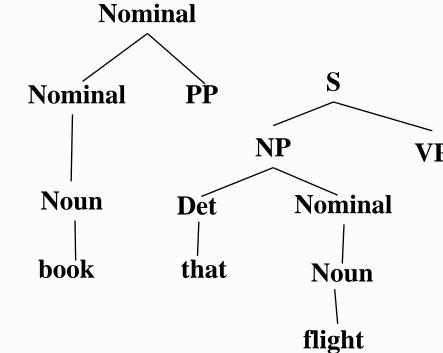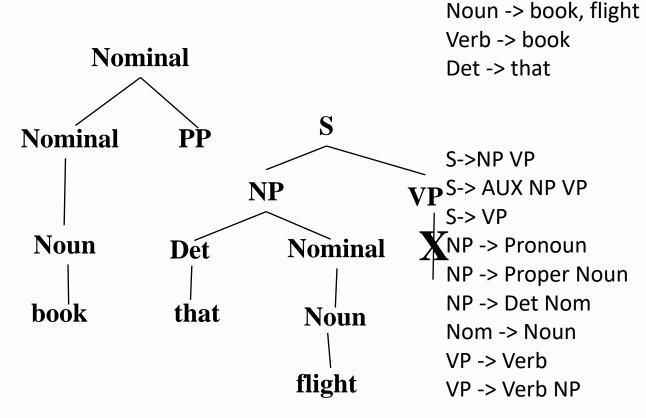NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Bottom Up Parsing


```
                Nominal

        Nominal       PP
                        X
                          NP
          Noun      Det       Nominal

          book      that        Noun

                                flight
```

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
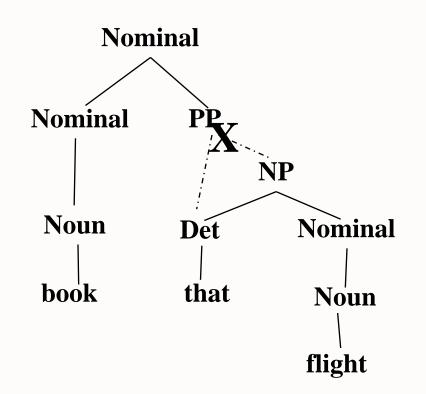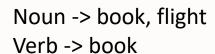NP -> Proper Noun
NP -> Det Nom
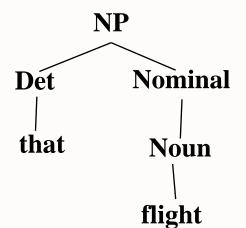Nom -> Noun
VP -> Verb
VP -> Verb NP

Verb
|
book

NP
Det   **Nominal**
| |
that   **Noun**
            |
            flight

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

```
      VP                           NP
      |                          /    \
    Verb                      Det      Nominal
      |                        |          |
    book                     that        Noun
                                          |
                                        flight
```

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
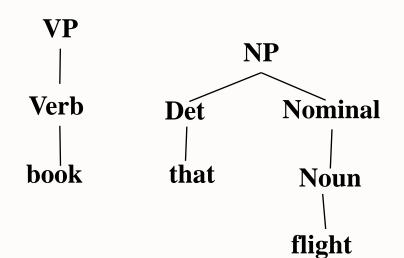NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP
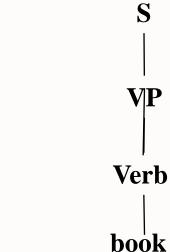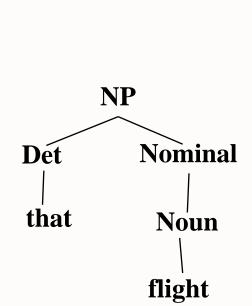
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Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

S

VP

Verb

book

NP

Det   Nominal

that   Noun

flight

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

```
      S
      |
      VP        X
      |          \·._
     Verb          \   NP
      |          Det   Nominal
    book         |       |
                that    Noun
                         |
                       flight
```

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
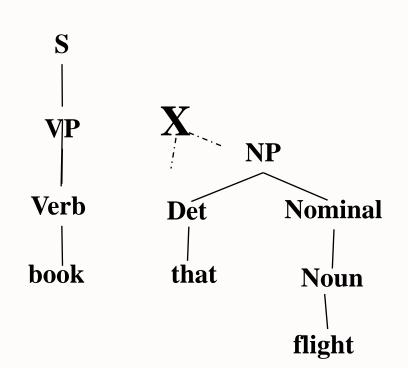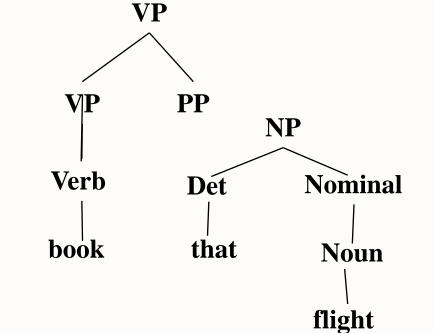NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

```
                    VP
                  /    \
                VP      PP
                |              NP
              Verb          /    \
                |         Det    Nominal
              book        |         |
                        that      Noun
                                    |
                                  flight
```

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

```
                    VP
                  /    \
               VP       PP
               |       X'·.___
             Verb     /       NP
              |      Det      /  \
            book     |    Nominal
                    that      |
                            Noun
                              |
                           flight
```

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
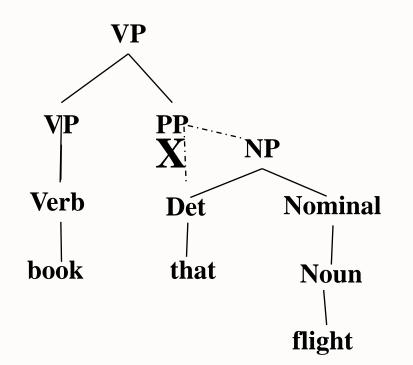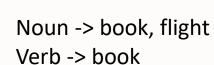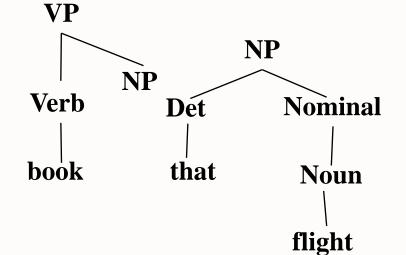NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

VP
  Verb
    book
  NP

NP
  Det
    that
  Nominal
    Noun
      flight

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

```
         VP
        /    \
       /      NP
      /      /    \
   Verb    Det   Nominal
    |       |       |
   book    that    Noun
                    |
                  flight
```
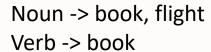
S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
NP -> Proper Noun
NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Bottom Up Parsing

Noun -> book, flight
Verb -> book
Det -> that

```
        S
        |
        VP
       /  \
      /     \
   Verb      NP
    |        /  \
   book    Det   Nominal
           |       |
          that    Noun
                   |
                 flight
```

S->NP VP
S-> AUX NP VP
S-> VP
NP -> Pronoun
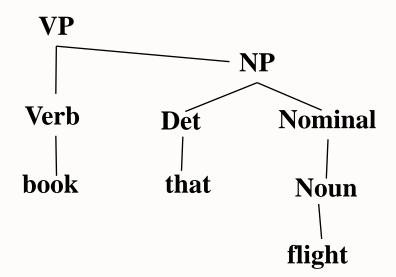NP -> Proper Noun
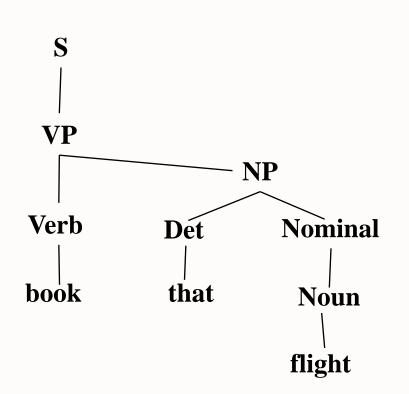NP -> Det Nom
Nom -> Noun
VP -> Verb
VP -> Verb NP

Exercises

———

Exercise

1. Using Top Down Parsing draw the parse tree for the following sentence:

a)   *John hit the ball.*

b) *A flight from Indianapolis to Houston on TWA*

Exercise

NP->NP PP
PP-> P NP

2. Using Bottom Up Parsing draw the parse tree for the following sentence:

a) *John hit the ball*

b) *A flight from Indianapolis to Houston on TWA*