CS395-T
Topics in Natural Language Processing

LECTURE 4

Sanda Harabagiu
Department of Computer Sciences
University of Texas at Austin
Tu, Th 11AM-12:20 PM
sanda@cs.utexas.edu
http://www.cs.utexas.edu/users/sanda/cs395T.html
http://www.engr.smu.edu/~sanda/cs395T.html

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Using a depth-First Strategy For Parsing

- Depth-first search expands the search space incrementally by systematically exploring one state at a time
- Which state is chosen for expansion ?
  - The most recently generated one
- What happens when this search arrives at a tree that is not consistent with the input ?
  - The search continues by returning to the most recently generated, yet unexplored tree

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Example Grammar

S → NP VP	Det → that | this | a
S → Aux NP VP	Noun → book | flight | meal | money
S → VP	Verb → book | include | prefer
NP → Det Nominal	Aux → does
Nominal → Noun	
Nominal → Noun Nominal	Prep → from | to | on
NP → Proper-Noun	Proper-Noun → Houston | TWA
VP → Verb	
VP → Verb NP	Nominal → Nominal PP

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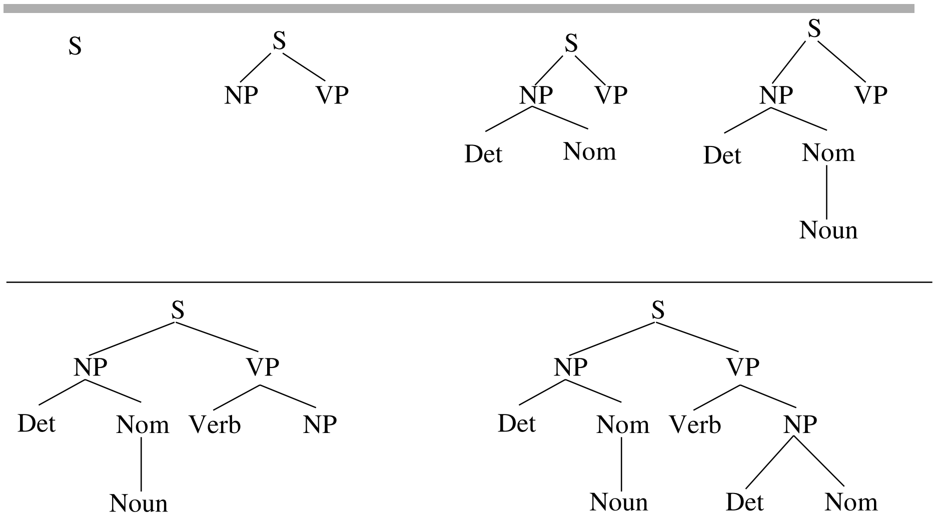
A Top-Down Depth-First Derivation



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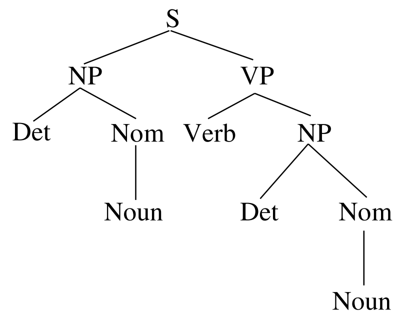
A Top-Down Depth-First Derivation



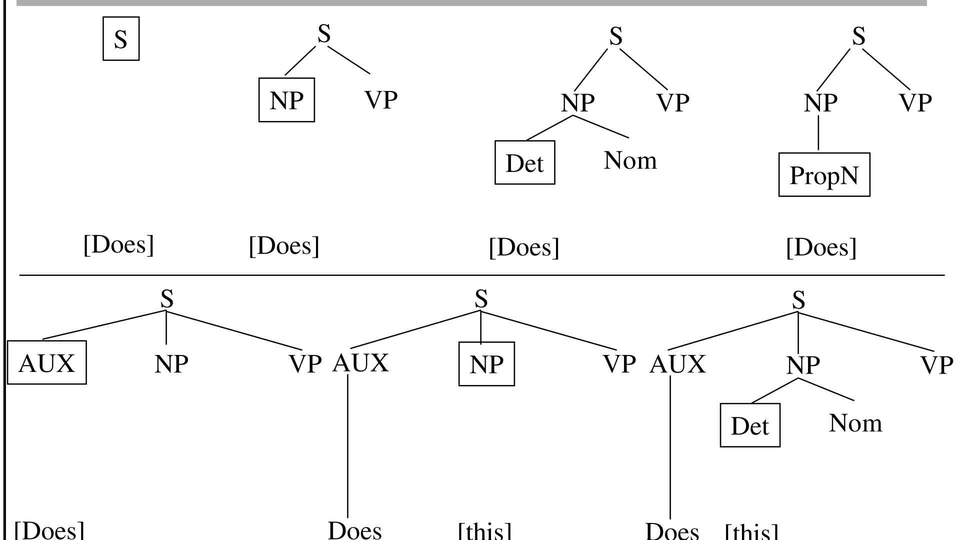
Parsing With an Agenda

- Search states = (partial tree, pointer to the next word in the sentence)
- Agenda = list of search states

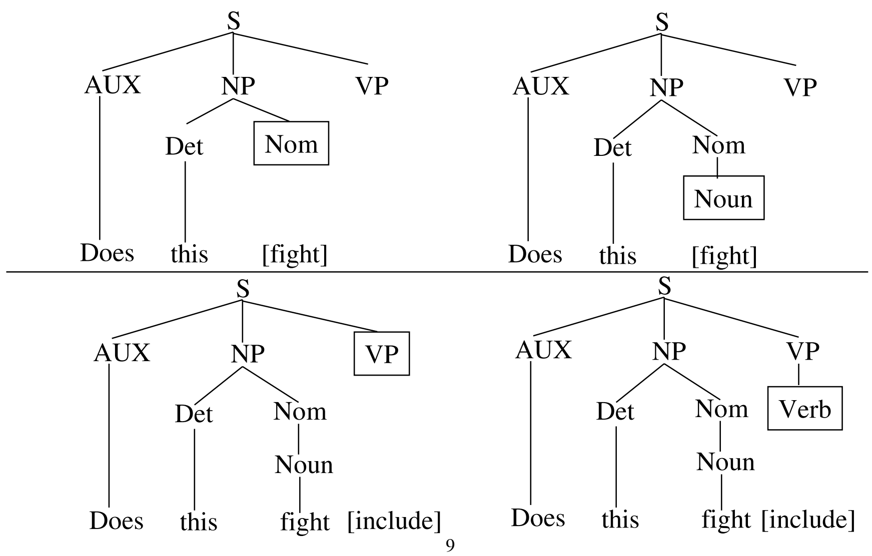
A Top-Down, Depth-First Left-to-Right Parser

function TOP-DOWN-PARSE(input, grammar) **returns** a parse tree
agenda ← *(Initial S tree, Beginning of input)*
Current-search-state ← POP(*agenda*)
loop
  if SUCCESSFUL-PARSE?(*current-search-state*) **then**
    return TREE(*current-search-state*)
  else
    if CAT(NODE-TO-EXPAND(*current-search-state*)) is a POS **then**
      if CAT(node-to-expand) ⊂ POS(CURRENT-INPUT(*current-search-state*)) **then**
        PUSH(APPLY-LEXICAL-RULE(*current-search-state*),*agent*)
      else return reject
    else PUSH(APPLY-RULES(*current-search-state,grammar*),*agenda*)
  if agenda is empty **then return** reject
  else *current-search-state* ← NEXT(*agenda*)
end

A Top-Down Depth-First Derivation



Continue Derivation



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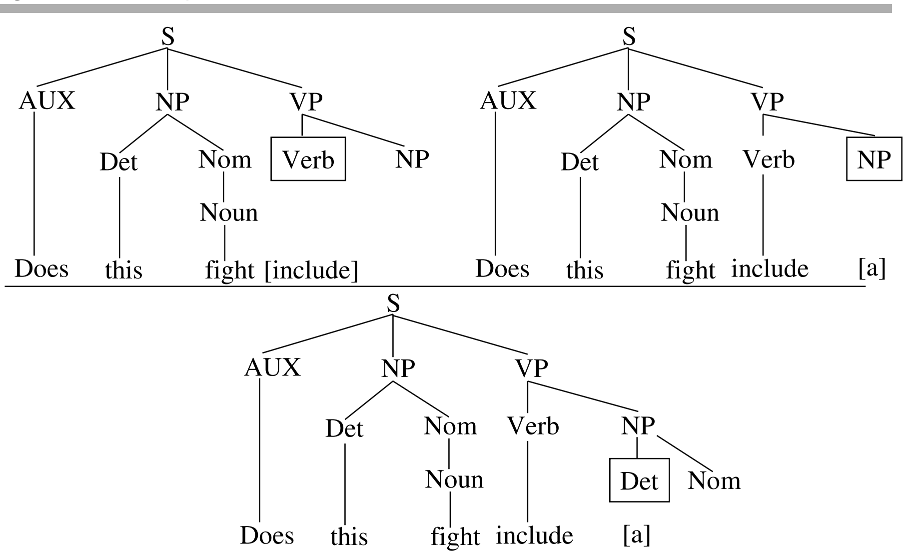
A Top-Down, Depth-First Left-to-Right Parser CONTINUED



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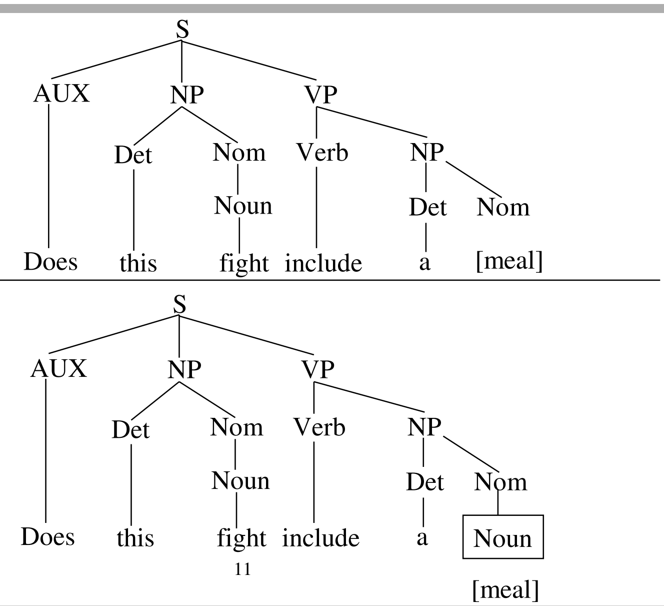
A Top-Down, Depth-First Left-to-Right Parser CONTINUED



Adding Bottom-up Filtering

Observations:

1) The parser expands non-terminal symbols along the edge of the parse tree, down to the word at the bottom left edge of the tree.
2) When the word is incorporated in a tree, the input pointer moves on, the parser will expand the next left-most non-terminal symbol down to the new left-corner word.

Conclusion: the input word serves as the first word in the derivation of the unexpanded node that the parser is currently processing.

Lesson learned

- The parser should not consider any grammar rule if the current input cannot serve as the first word along the left edge of some derivation from this rule.
- Left-corner of the tree: - first word + left edge of the derivation

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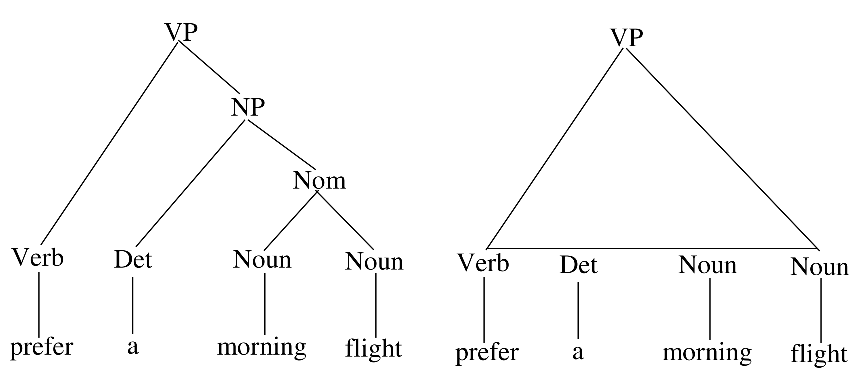
Illustration of the left-corner notion



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Formal Definition

- B is a left corner of A if:

$$A \overset{*}{\Rightarrow} B\alpha$$

- **Example**: *Does this flight include a meal?*

S → NP VP

S → Aux NP VP → the only rule for which <u>*does*</u> may serve as a left-corner

S → VP

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Practical Information

- Compile all information needed to efficiently implement such a filter in a table that lists all the valid left-corner categories for each non-terminal of the grammar.

- **Example:**

Category	Left Corners
S	Det, Proper-Noun, Aux, Verb
NP	Det, Proper-Noun
Nominal	Noun
VP	Verb

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3 More problems with the parser

- Left Recursive
- Ambiguity
- Inefficient reparsing of subtrees

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Left recursion

Problem of depth-first search

- if infinite search space ➡ it may dive down an infinitely deeper path and never return to visit unexpanded states.

The problem exists when

- *left recursive grammars* are used

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Left-recursive grammars

Formally: a grammar is left-recursive if it contains a non-terminal category that has a derivation that contains itself anywhere along its leftmost branch.

$$A \overset{*}{\Rightarrow} \alpha A \beta$$

and

$$\alpha \overset{*}{\Rightarrow} \varepsilon$$

Example:

- Possessives: *(Atlanta's airport)*

$$\left\{\begin{array}{l} NP \rightarrow Det\ Nominal \\ Det \rightarrow NP\text{'s} \end{array}\right.$$

rules that induce left-recursion

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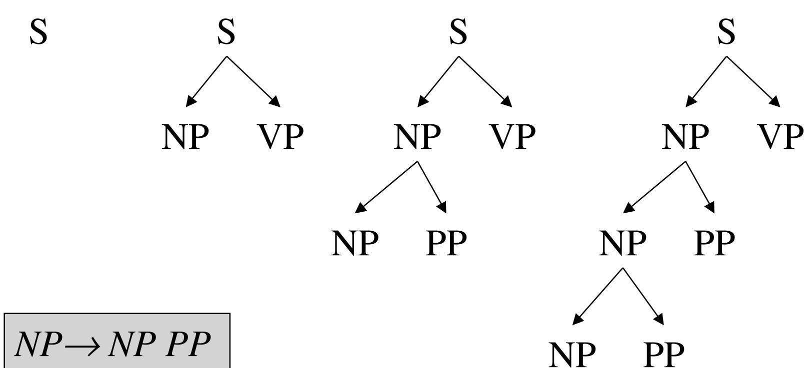
More obvious case of left-recursion



NP→ NP PP
VP→ VP PP
S→ S and S

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2 solutions

1) Rewrite the grammar

2) Explicitly managing the depth of the search during parsing

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How should we rewrite rules ?

Example :

$A \rightarrow A\ \beta \mid \alpha$

Rewrite :

$\left.\begin{array}{l} A \rightarrow \alpha\ A' \\ A' \rightarrow \beta\ A' \mid \varepsilon \end{array}\right\} \Rightarrow$ changes the left recursion to right recursion.

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Ambiguity

- Lexical ambiguity ⇒ POS taggers
- Structural ambiguity ⇒ Parsing problems

3 forms
- attachment ambiguity
- coordination ambiguity
- noun-phrase bracketing ambiguity

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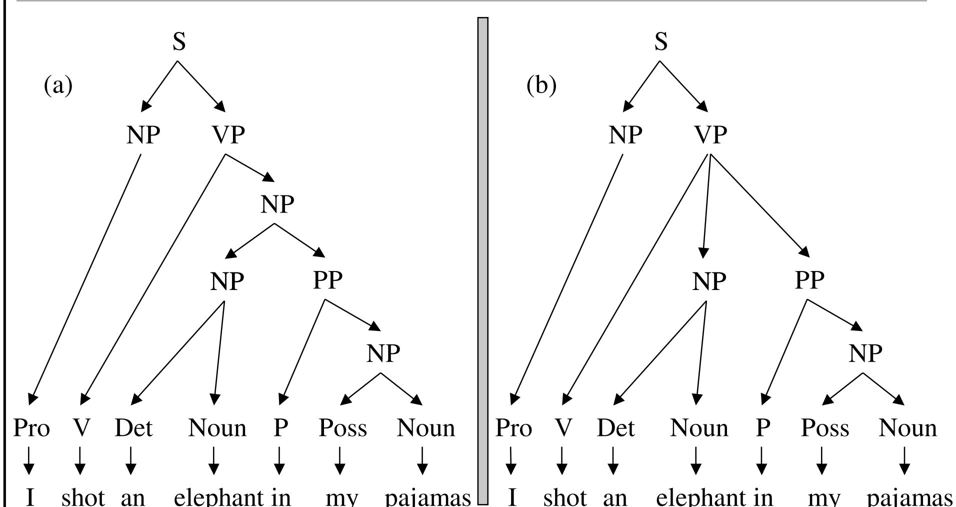
Attachment ambiguity



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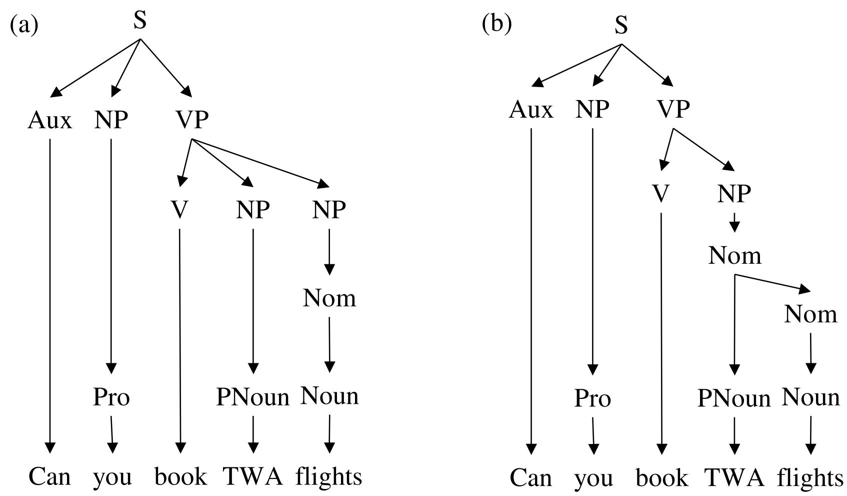
Other examples



Coordination ambiguity

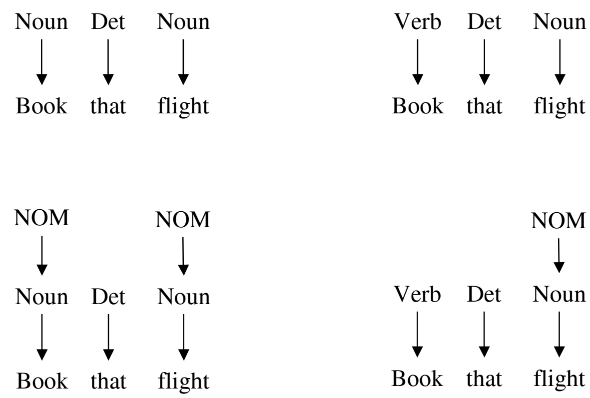
Old men and women

[Old [man and women]]

[Old man] and [women]

Combination of ambiguity

Book that flight



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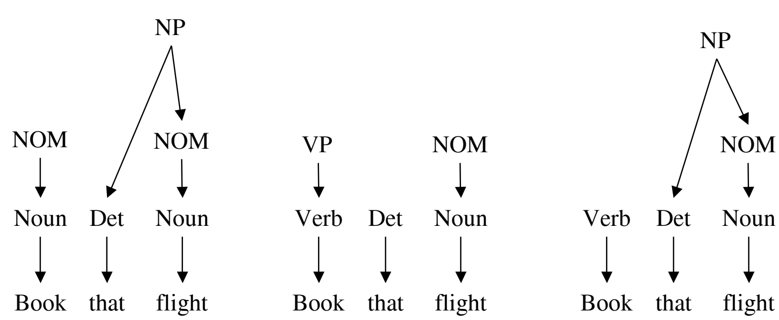
Combination of ambiguity (cont'd)

Book that flight



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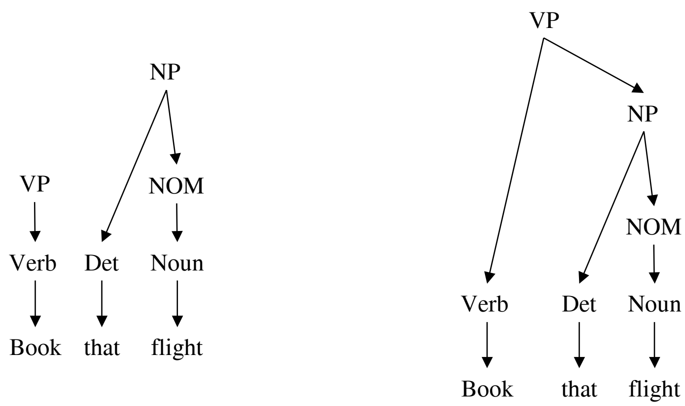
Combination of ambiguity (cont'd)

Book that flight



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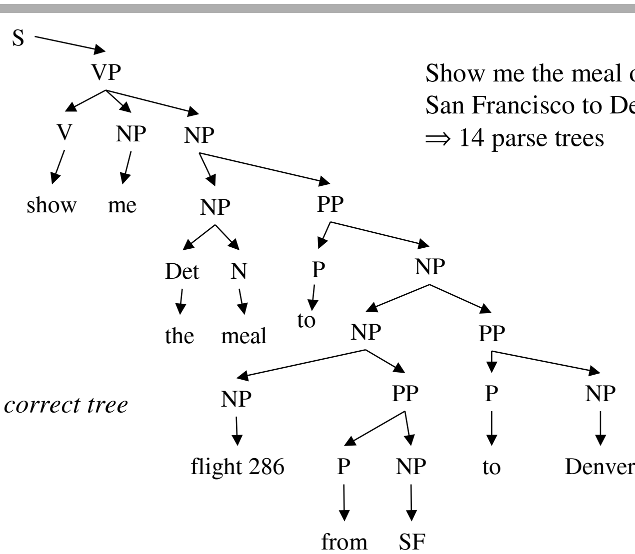
Exponential number of parses



Show me the meal on Flight 286 from San Francisco to Denver

$\Rightarrow$ 14 parse trees

The correct tree

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Exponential growth

$$C(n) = \frac{1}{n+1}\binom{2n}{n}$$ $\rightarrow$ the catalan numbers

Number of PPs	Number of NP Parses
2	2
3	5
4	14
5	132
6	469
7	1430
8	4867

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Repeated parses of subtrees

The parser often builds valid trees for portions of the input, then discards them during bracketing.

$\Rightarrow$ later it finds that it has to rebuild them again.

Example:

the process involved in finding the parse for the NP:

"a flight from Indianapolis to Houston on TWA"

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Repeated parses of subtrees (cont'd)

a flight	4
from Indianapolis	3
to Houston	2
on TWA	1
a flight form Indianapolis	3
a flight form Indianapolis to Houston	2
a flight form Indianapolis to Houston on TWA	1

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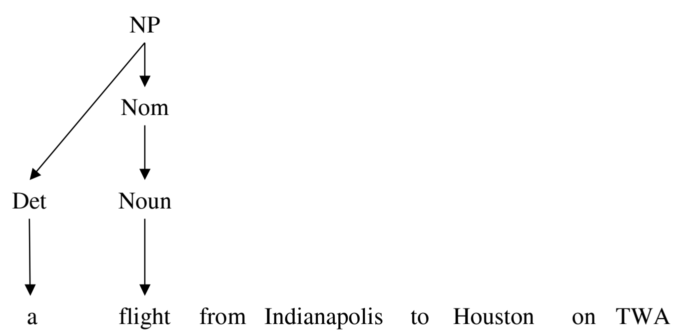
Repeated parses of subtrees (cont'd)



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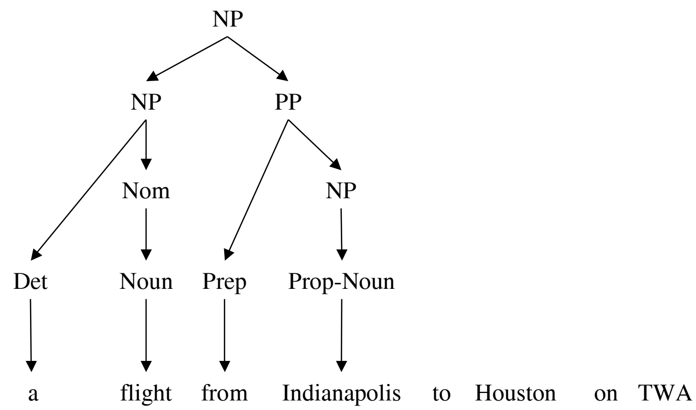
Repeated parses of subtrees (cont'd)



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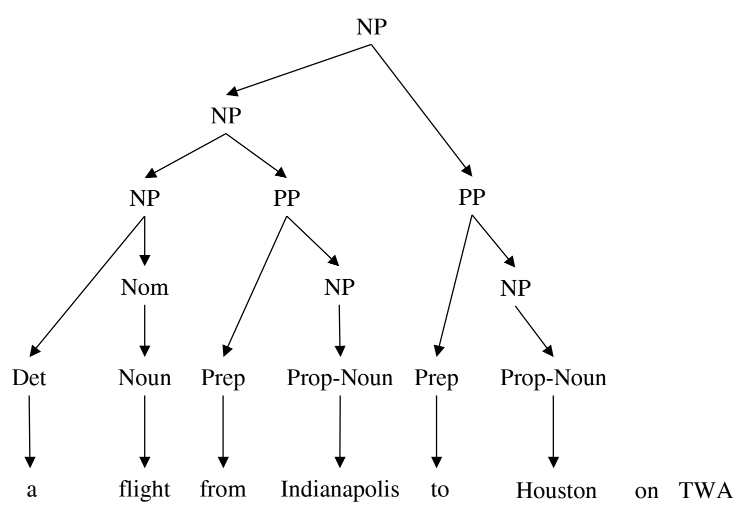
Repeated parses of subtrees (cont'd)



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Repeated parses of subtrees (cont'd)

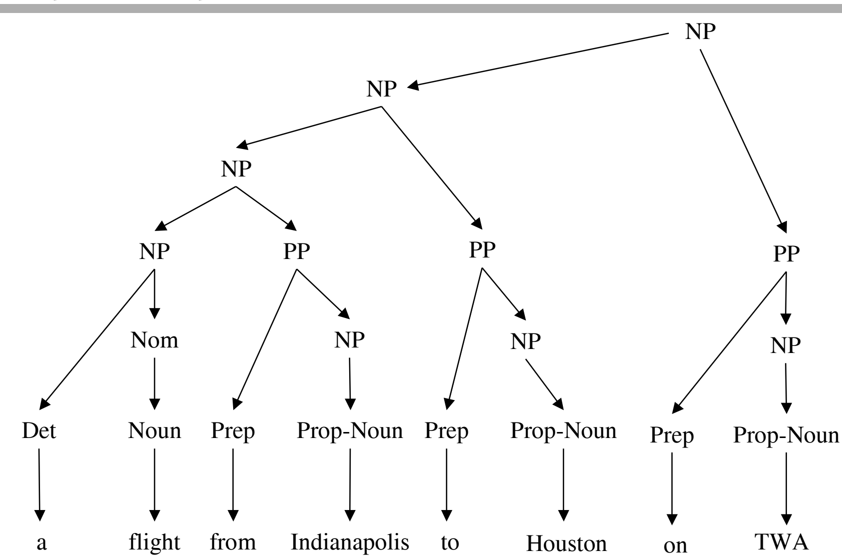

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Chart-Parsing

- Chart ➔ an array that has N+1 entries (the sentence has N words !)
- For each word, the chart contains a list of states representing the partial parse trees that have been generated so far
- **Advantage**: Each possible sub-tree is represented only once, and thus can be shared by all the parses that need it

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The Representation of A State

- 3 kinds of information:
  1) A sub-tree corresponding to a single grammar rule
  2) Information about the **progress** made in completing this sub-tree
  3) The position of the sub-tree with respect to the input

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How Do We Represent Progress ?

- Graphically: use a dot within the right-hand side of a state's grammar rule

  (dotted rule)

- A state position with respect to the input ?
  - 2 numbers [where the state begins]
    [where the dot lies]

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Example

- Sentence: *Book that flight*.
  - State 0   S → • VP, [0,0]
  - State 1   NP → Det • Nominal, [1,2]
  - State 2   VP → V NP • , [0,3]

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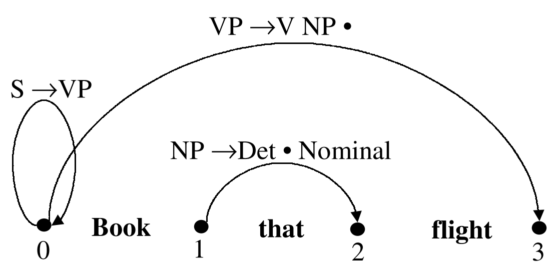
Another Representation



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The Early Parser

- Scan through the N+1 sets of states in the chart in a left → right fashion
  - At each step one of three operators is applied, depending on the state's status
    - Results → addition of new states to the end of either the current or the next set of states in the chart
- Successful parse: the presence of a state

$$S \rightarrow \alpha\bullet, [0,N]$$

in the list of the last chart entry

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What Oprators?

•Predictor	???
•Scanner	???
•Completer	???

- The **Predictor** creates new states representing top-down expectations.
  - applied to any state that has a non-terminal to the right of the dot that is not a PoS category.
- What happenes? ⟹ create a new state for each alternative expansion of that non-terminal provided by the grammar.

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Predictor Example

- The state

  S → • VP, [0,0]
- results in states

  VP → • Verb, [0,0]
- and

  VP → • Verb NP, [0,0]

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Scanner

- If a state has a PoS category at the right of the dot!
- The scanner is called to examine the input and incorporate a state corresponding to the predicted PoS in the chart.

Example:

- State 0 VP → • Verb NP, [0,0]

  Book that flight

  verb
- State 1 VP → Verb • NP, [0,1]

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Completer

- Applied to a state if the dot has reached the right end of the rule ⟹ Meaning that the parser has successfully discovered a particular grammatical category over some span of the input.
- **Example:** NP → Det Nominal •, [1,3]

  (looks for states ending at 1, expecting a NP)

➢ finds the state VP → Verb • NP, [0,1]

(created by the scanner)

➢ addition of a new complete state

VP → Verb NP •, [0,3]

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The Early-Parse

function Earley-Parse(*words, grammar*) **returns** *chart*
    Enqueue((γ → • S, [0,0]), *chart[0]*)
    for *i*←**from** 0 **to** Length(*words*) **do**
        for each *state* **in** *chart[i]* **do**
            if Incomplete?(*state*) **and**
              Next-Cat(*state*) is not a part of speech **then**
                Predictor(*state*)
            elseif Incomplete?(*state*) **and**
                Next-Cat(*state*) is a part of speech **then**
                Scanner(*state*)
            else
                Completer(*state*)
        end
    end
    return(*chart*)

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The Early-Parse

procedure Predictor(($A \rightarrow \alpha \bullet B\ \beta$, $[i, j]$))
    for each ($B \rightarrow \gamma$) **in** Grammar-Rules-For(B, *grammar*) **do**
        Enqueue(($B \rightarrow \bullet\ \gamma$, $[j,j]$), *chart[j]*)
    end

procedure Scanner(($A \rightarrow \alpha \bullet B\ \beta$, $[i,j]$))
    if B $\subset$ Parts-of-Speech(*word[j]*) **then**
        Enqueue(($B \rightarrow$ *word[j]*, $[j, j+1]$), *chart[j+1]*)

procedure Completer(($B \rightarrow \gamma \bullet$, $[j,k]$))
    for each ($A \rightarrow \alpha \bullet B\ \beta$, $[i,j]$) **in** *chart[j]* **do**
        Enqueue (($A \rightarrow \alpha\ B \bullet \beta$, $[i,k]$) , *chart[k]*)
    end

procedure Enqueue(*state, chart-entry*)
    if *state* is not already in *chart-entry* **then**
        Push(*state, chart-entry*)
    end

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Chart Content

Chart[0]

$\gamma \rightarrow \bullet\ S$	[0.0]	Dummy start stare
$S \rightarrow \bullet\ NP\ VP$	[0.0]	Predictor
$NP \rightarrow \bullet\ Det\ NOMINAL$	[0.0]	Predictor
$NP \rightarrow \bullet$ *Proper-Noun*	[0.0]	Predictor
$S \rightarrow \bullet\ Aux\ NP\ VP$	[0.0]	Predictor
$S \rightarrow \bullet\ VP$	[0.0]	Predictor
$VP \rightarrow \bullet\ Verb$	[0.0]	Predictor
$VP \rightarrow \bullet\ Verb\ NP$	[0.0]	Predictor

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Chart Content

Chart[1]

Verb → book •	[0,1]	Scanner
VP → Verb •	[0,1]	Completer
S → VP •	[0,1]	Completer
VP → Verb • NP	[0,1]	Completer
NP → • Det NOMINAL	[1,1]	Predictor
NP → • Proper-Noun	[1,1]	Predictor

Chart[2]

Det → that •	[1,2]	Scanner
NP → Det • Nominal	[1,2]	Completer
NOMINAL → • Noun	[2,2]	Predictor
NOMINAL → • Noun Nominal	[2,2]	Predictor

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Chart Content

Chart[3]

Noun → flight •	[2.3]	Scanner
NOMINAL → Noun •	[2.3]	Completer
NOMINAL → Noun • NOMINAL	[2.3]	Completer
NP → Det NOMINAL •	[1.3]	Completer
VP → Verb NP •	[0.3]	Completer
S → VP•	[0.3]	Completer
NOMINAL → • Noun	[3.3]	Predictor
NOMINAL → • Noun NOMINAL	[3.3]	Predictor

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[redacted]