Chart Parsing

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Parsing

Parsing with a CFG is the task of assigning a correct tree (or derivation) to a string given some grammar.

A correct tree is:

- consistent with the grammar, and
- the leaves of the tree cover all and only the words in the input.

There may be a very large number of correct trees for any given input . . .

Problems that arise

- Left Recursion
- Ambiguity
- Inefficiencies due to backtracking

Common substructures

- Despite ambiguity and backtracking there are commons substructures to be taken advantage of.
- Consider parsing the following NP:

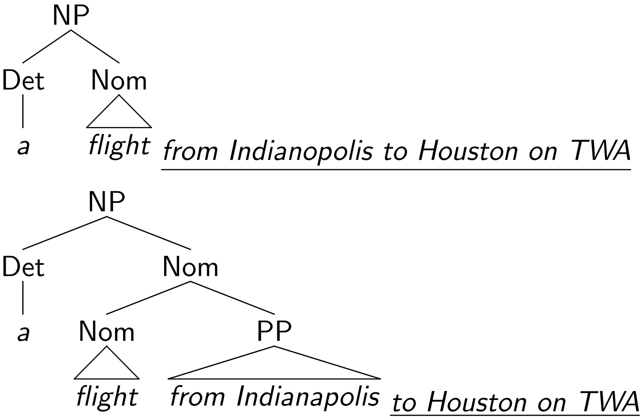
  a flight from Indianapolis to Houston on TWA

  with the following rules:

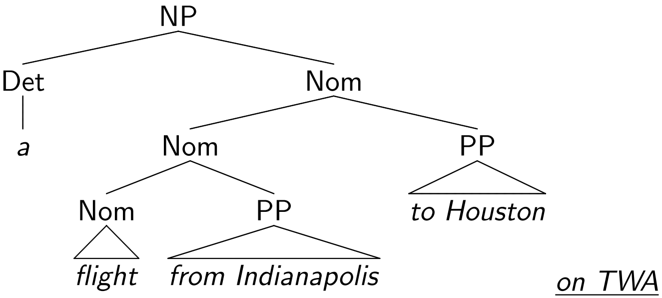
  $NP \longrightarrow Det \quad Nom$
  $Nom \longrightarrow Nom \quad PP$

- What happens with a top-down parser?

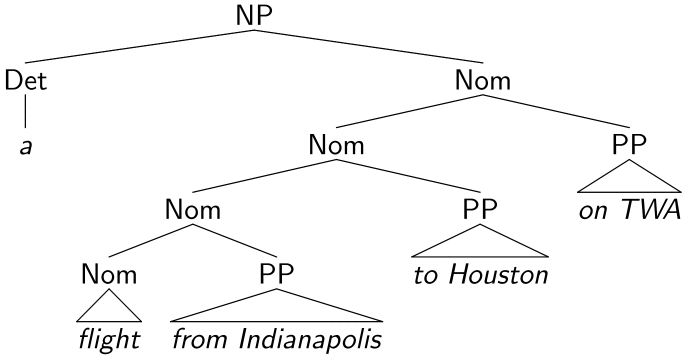
Backtracking



Backtracking, cont



Backtracking, cont



Dynamic Programming

Our current algorithm builds valid trees, discards them during backtracking, then rebuilds them.

- the subtree for *a flight* was derived 4 times.

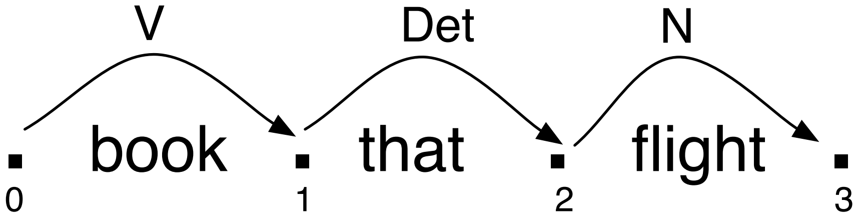
Dynamic programming is one answer to problems that have sub-problems that get solved again and again
We'll consider an algorithm that fills a table with solutions to subproblems that:

- does a parallel top-down search with bottom-up filtering
- does not do repeated work
- solves the left-recursion problem

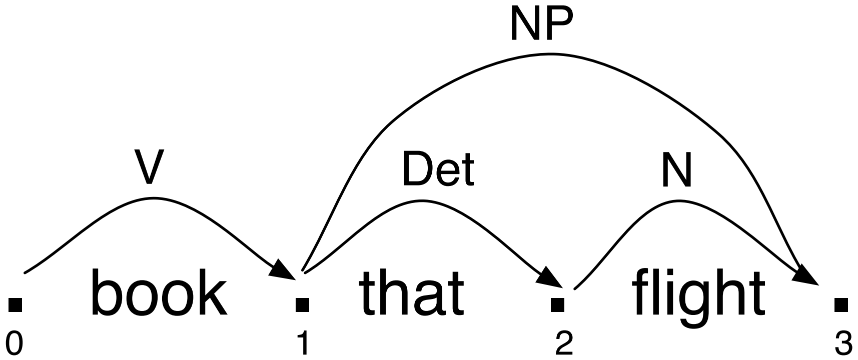
Dynamic Programming and Parsing

- Systematically fill in tables of solutions to subproblems.
- When complete, the table contains all possible solutions to all of the subproblems needed to solve the whole problem
- For parsing:
  - the table stores subtrees for constituents.
  - Solves reparsing inefficiencies, because subtrees are not reparsed but looked up.
  - Solves ambiguity explosions, because the table *implicitly* stores all parses.
  - Each subtree is represented only once and shared by all parses that need it.

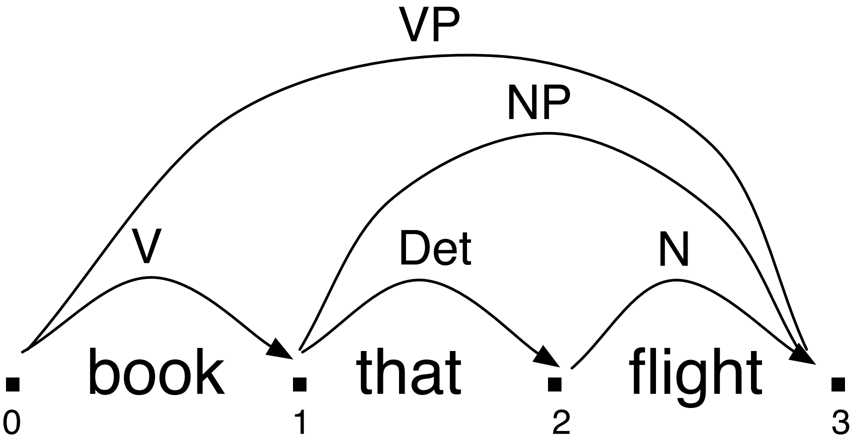
Lexical Edges



Nonterminal Edges: NP

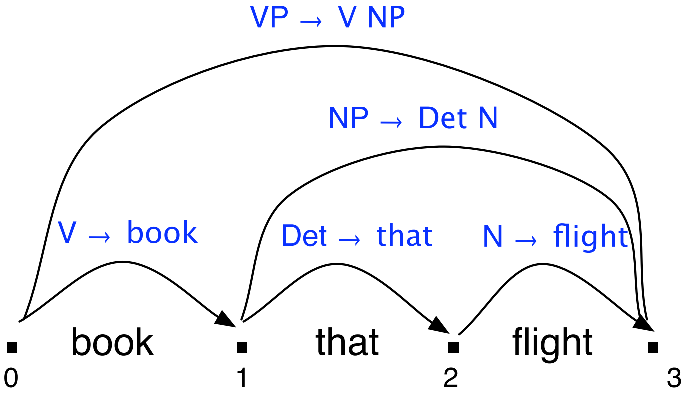


Nonterminal Edges: VP



Nonterminal Edges: Rules

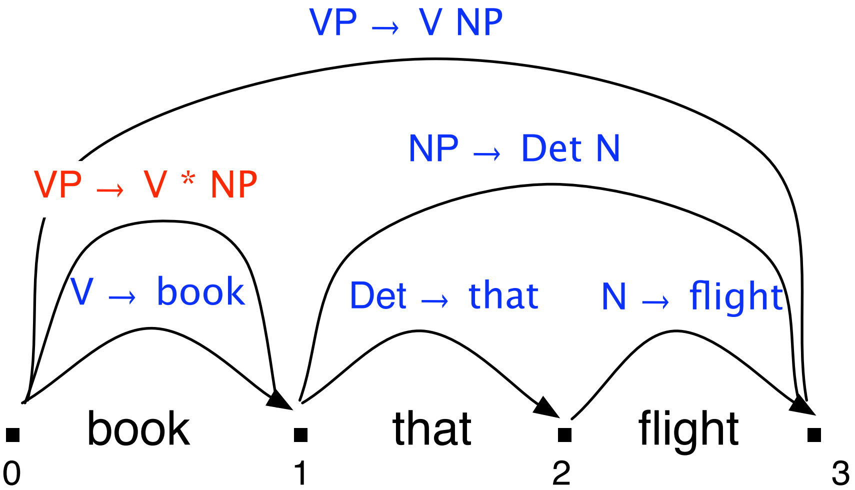
- Useful to label arcs with rules rather than categories:



Incomplete Edges

- Recall that the parser can make predictions on the basis of rules:
  - I'm trying to expand an VP, and I've found a V so I'll start looking for an NP.
- Record incomplete constituents with dotted rules:
  - Dot on the RHS of a rule shows what wevé found already: VP $\rightarrow$ V $\bullet$ NP
  - We can use this as a label for an incomplete constituent.

Incomplete Edges, cont.



Dynamic Programming and Parsing

The Earley algorithm:

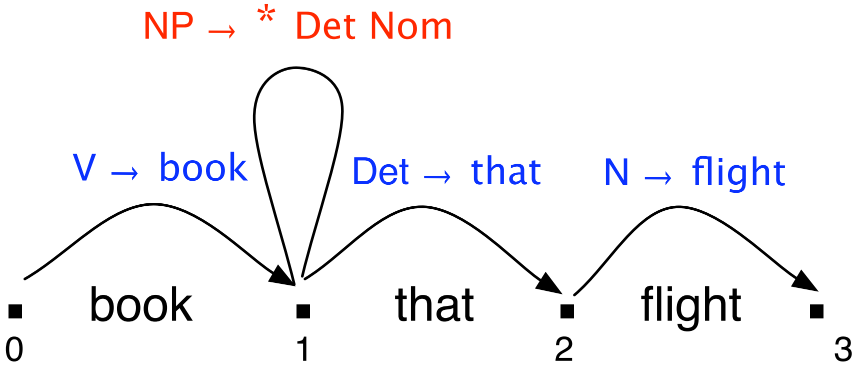
- fills a table (the chart) in a single left-to-right pass over the input.
- The chart will be size $N + 1$, where N is the number of words in the input.
- Chart entries are associated with the gaps between the words — like slice indexing in Python.
- For each word position in the sentence, the chart contains a set of edges representing the partial parse trees generated so far.
- So Chart[0] is the set of edges representing the parse before looking at a word.

States

- J&M call the chart entries states.
- The chart entries represent three distinct kinds of things:
  - completed constituents;
  - in-progress constituents; and
  - predicted constituents
- The three kinds of states correspond to different dot locations in dotted rules:

Completed: $\text{VP} \rightarrow \text{V} \quad \text{NP} \bullet$
In-progress: $\text{NP} \rightarrow \text{Det} \bullet \quad \text{Nom}$
Predicted: $\text{S} \rightarrow \bullet \quad \text{VP}$

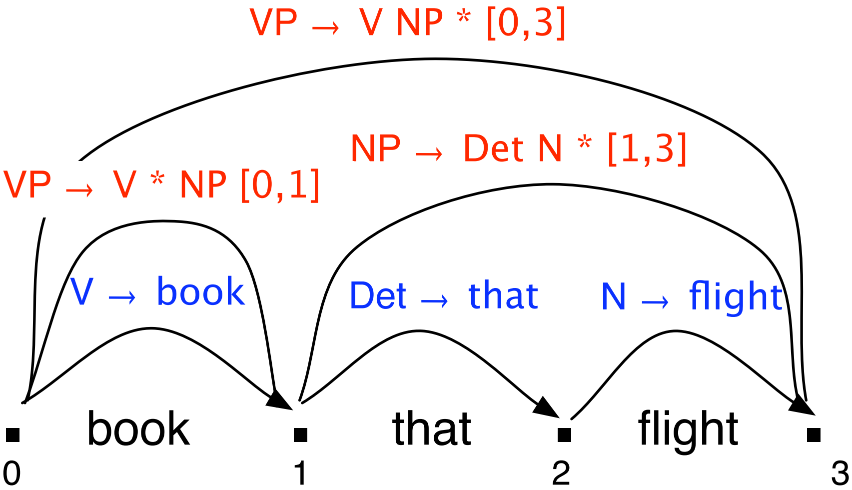
Incomplete NP Edge: Self-loop



States, cont.

- Given dotted rules like those we've just seen, we need to record:
  - where the represented constituent is in the input, and
  - what its parts are.
- So we add a pair of coordinates $[x, y]$ to the state:
  - $A \rightarrow \alpha,\ [x, y]$
  - x indicates the position in input where the state begins
  - y indicates position of dot

Example with coordinates



States, cont.

Example states in parsing *Book that flight*:

1. S $\rightarrow$ • VP, [0,0]
   - First 0 indicates that the constituent begins at the start of the input.
   - Second 0 indicates that the dot also begins at start of input, and thus indicates a top-down prediction.
2. NP $\rightarrow$ Det • Nom, [1,2]
   - the NP begins at position 1
   - the dot is at position 2
   - Det has been successfully *completed*
   - Nom is predicted next

States, cont.

1. VP $\rightarrow$ V NP $\bullet$, [0,3]
    - VP is completed
    - no further predictions from this rule
    - a successful parse that spans the entire input

Success

The final answer is found by looking at the last column of the table. In particular, for an input of *N* words, if we find the following kind of state in the chart then we've succeeded:

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

Parsing

Parsing is sweeping through the chart creating the three kinds of states as we go. States are never removed, and we never backtrack.

- New *predicted* states are based on existing table entries (predicted, or in-progress) that predict a certain constituent at that spot.
- New *in-progress* states are created by updating older states to reflect the fact that previously expected completed constituents have been located.
- New *completed* states are created when the dot in an in-progress state moves to the end.

More Specifically

1. Predict all the states you can.
2. Read an input.
   - See what predictions you can match.
   - Extend matched states, add new predictions.
   - Go to next state (goto 2)
3. At the end, see if $state[N+1]$ contains a complete S.

Earley Algorithm

The Earley algorithm has three main functions that do all the work:

- **Predictor:** Adds predictions into the chart
- **Completer:** Moves the dot to the right when new constituents are found
- **Scanner:** Reads the input words and enters states representing those words into the chart

Predictor

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

- Intuition: new states represent top-down expectations.
- Applied when a state has a non-terminal to the right of a dot that is not a part-of-speech.
- Generates one new state for each alternative expansion of the non-terminal in the grammar.
- Adds states to the same chart entry as generating state.

Completer

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

- Intuition: parser has discovered a constituent, so must find and advance states that were looking for this grammatical category at this position in input.
- Applied when dot has reached right end of rule.
- New states are generated by copying old state and advancing dot over expected category.
- Adds new states to same chart entry as generating state.

Scanner

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

- New states for predicted part-of-speech.
- Applicable when part-of-speech is to the right of a dot.
- Adds states to next chart entry.

Note: Earley parser uses top-down predictions to help disambiguate part-of-speech ambiguities. Only those parts-of-speech of a word that are predicted by some state will find their way into the chart.

Mini grammar and lexicon

S → NP VP | Aux NP VP | VP	Det → *that* | *this* | *a*
NP → Det Nom | PropN	N → *book* | *flight* | *meal*
Nom → Nom PP | N Nom	V → *book* | *include* | *prefer*
PP → P NP	Aux → *does*
VP → V | V NP	P → *from* | *to* | *on*
Nom → N PP | N Nom	PropN → *Houston* | *TWA*

Example: Chart[0] and Chart[1]

Chart[0]

γ	$\rightarrow$	$\bullet$ *S*	[0,0]	Dummy start state
S	$\rightarrow$	$\bullet$ *NP VP*	[0,0]	Predictor
S	$\rightarrow$	$\bullet$ *Aux NP VP*	[0,0]	Predictor
S	$\rightarrow$	$\bullet$ *VP*	[0,0]	Predictor
NP	$\rightarrow$	$\bullet$ *Det NOMINAL*	[0,0]	Predictor
NP	$\rightarrow$	$\bullet$ *Proper-Noun*	[0,0]	Predictor
VP	$\rightarrow$	$\bullet$ *Verb*	[0,0]	Predictor
VP	$\rightarrow$	$\bullet$ *Verb NP*	[0,0]	Predictor

Chart[1]

Verb	$\rightarrow$	*book* $\bullet$	[0,1]	Scanner
VP	$\rightarrow$	*Verb* $\bullet$	[0,1]	Completer
S	$\rightarrow$	*VP* $\bullet$	[0,1]	Completer
VP	$\rightarrow$	*Verb* $\bullet$ *NP*	[0,1]	Completer
NP	$\rightarrow$	$\bullet$ *Det NOMINAL*	[1,1]	Predictor

Example: Chart[1] and Chart[2]

Chart[1]

$Verb \longrightarrow book\ \bullet$	[0,1]	Scanner
$VP \longrightarrow Verb\ \bullet$	[0,1]	Completer
$S \longrightarrow VP\ \bullet$	[0,1]	Completer
$VP \longrightarrow Verb\ \bullet\ NP$	[0,1]	Completer
$NP \longrightarrow \bullet\ Det\ NOMINAL$	[1,1]	Predictor
$NP \longrightarrow \bullet\ Proper - Noun$	[1,1]	Predictor

Chart[2]

$Det \longrightarrow that\ \bullet$	[1,2]	Scanner
$NP \longrightarrow Det \bullet NOMINAL$	[1,2]	Completer
$NOMINAL \longrightarrow \bullet\ Noun$	[2,2]	Predictor
$NOMINAL \longrightarrow \bullet\ Noun\ NOMINAL$	[2,2]	Predictor

Example: Chart[3]

Chart[3]

$Noun \longrightarrow flight \bullet$	[2,3]	Scanner
$NOMINAL \longrightarrow Noun \bullet$	[2,3]	Completer
$NOMINAL \longrightarrow Noun \bullet NOMINAL$	[2,3]	Completer
$NP \longrightarrow Det\ NOMINAL \bullet$	[1,3]	Completer
$VP \longrightarrow Verb\ NP \bullet$	[0,3]	Completer
$S \longrightarrow VP \bullet$	[0,3]	Completer
$NOMINAL \longrightarrow \bullet Noun$	[3,3]	Predictor
$NOMINAL \longrightarrow \bullet Noun\ NOMINAL$	[3,3]	Predictor

Examples: Left Recursion

What about parsing the NP*a flight from Denver to Boston* with the following rules:

$NP \rightarrow NP\ PP$
$NP \rightarrow Det\ Nom$
$NP \rightarrow Proper\text{-}Noun$

- We construct the state (NP $\rightarrow \bullet$ NP PP, [0,0]) and add it to *chart*[0]
- The PREDICTOR function then requires us to find a rule which expands the (non-lexical) category immediately to the right of the dot.
- So let's pick the first rule above, and ENQUEUE the state (NP $\rightarrow \bullet$ NP PP, [0,0]).
- But this is already in the state, so we don't add it again.

Reading

- Read section 10.4 of J&M
- Read the NLTK-Lite Tutorial on Chart Parsing