Speech and Language Processing

Chapter 11

Syntactic Parsing

Today

- Parsing with CFGs
  - Bottom-up, top-down
  - Ambiguity
  - CKY parsing
  - (Earley)
  - Shallow

Parsing

- Parsing with CFGs refers to the task of assigning proper trees 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
- We'll start with some basic (meaning bad) methods before moving on to the one that you need to know

For Now

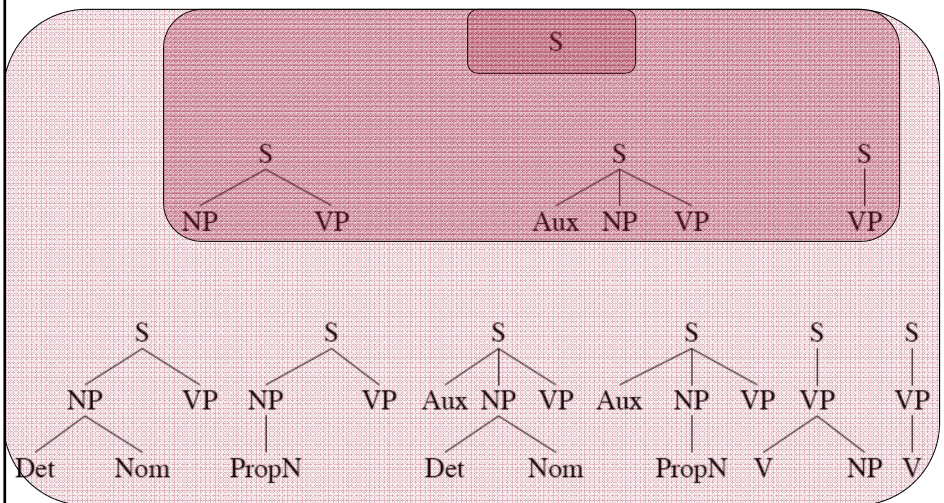
- Assume...
  - You have all the words already in some buffer
  - The input isn't POS tagged
  - We won't worry about morphological analysis
  - All the words are known

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

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



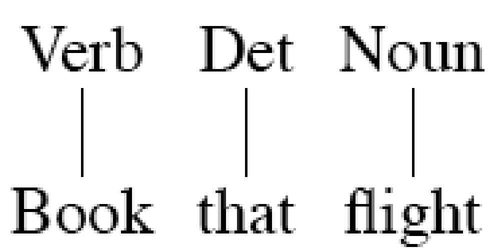
Bottom-Up Parsing

- 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.

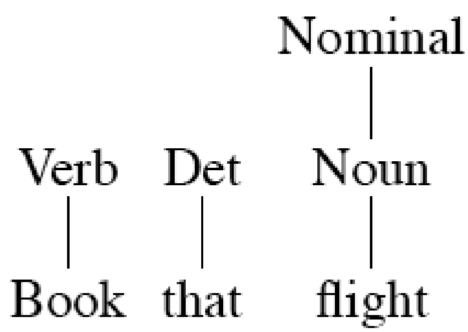
Bottom-Up Search

Book that flight

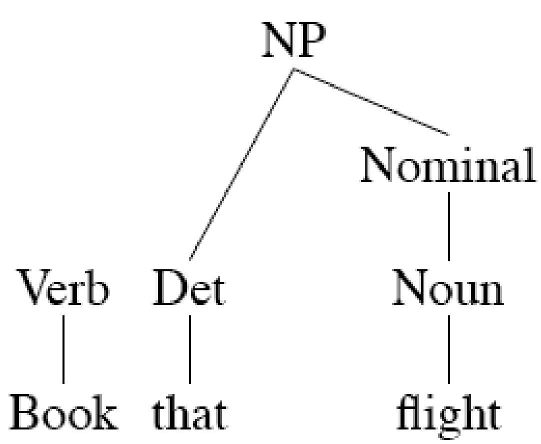
Bottom-Up Search



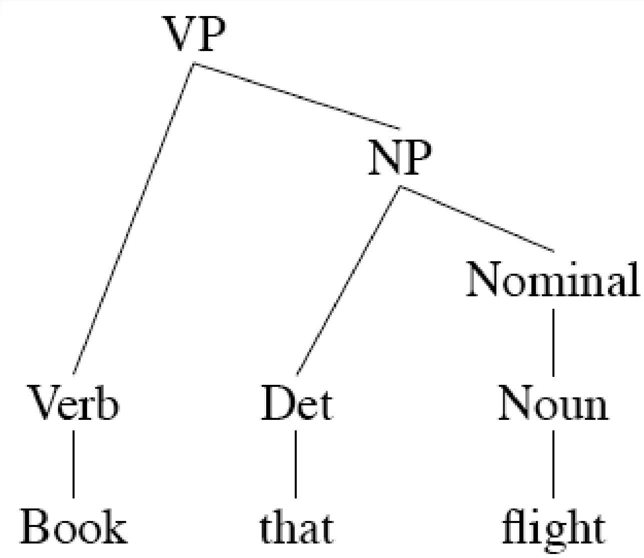
Bottom-Up Search



Bottom-Up Search



Bottom-Up Search



"The old dog the footsteps of the young."

S → NP VP	VP → V
S → Aux NP VP	*VP -> V PP*
S -> VP	*PP -> Prep NP*
NP → Det Nom	N → old | dog | footsteps | young
NP →PropN	V → dog | eat | sleep | bark | meow
Nom -> Adj N	Aux → does | can
Nom → N	Prep →from | to | on | of
Nom → N Nom	PropN → Fido | Felix
Nom → Nom PP	Det → that | this | a | the
VP → V NP	Adj -> old | happy| young

Top-Down and Bottom-Up

- Top-down
  - Only searches for trees that can be answers (i.e. S's)
  - But also suggests trees that are not consistent with any of the words
- Bottom-up
  - Only forms trees consistent with the words
  - But suggests trees that make no sense globally

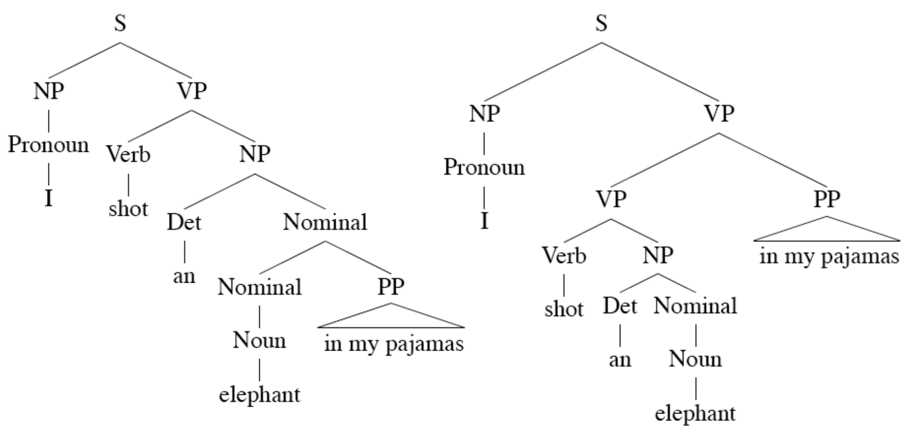
Control

- 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

Problems

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

Ambiguity



Example types of ambiguity

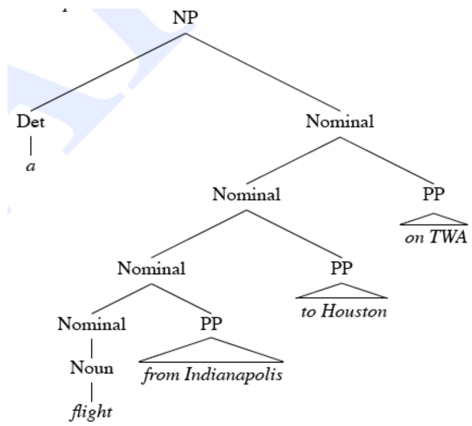
- POS
- Attachment
  - PP
  - Coordination (*old dogs and cats*)

Shared Sub-Problems

- 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.

Shared Sub-Problems

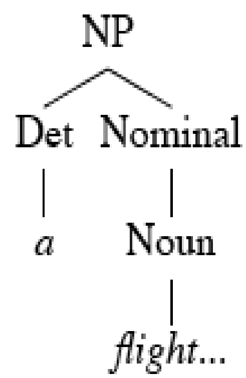
- Consider
  - A flight from Indianapolis to Houston on TWA



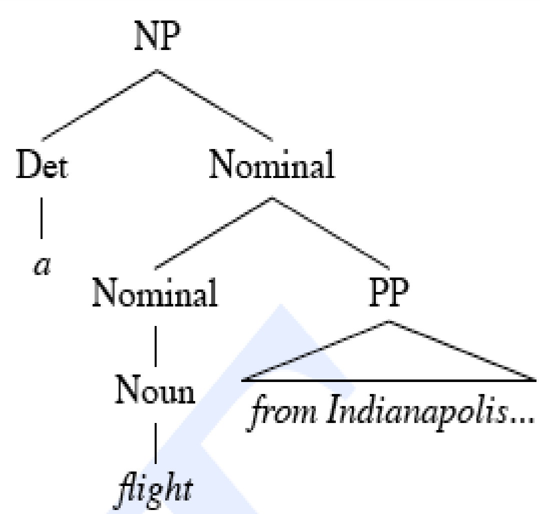
Shared Sub-Problems

- Assume a top-down parse making choices among the various Nominal rules.
- In particular, between these two
  - Nominal -> Noun
  - Nominal -> Nominal PP
- Statically choosing the rules in this order leads to the following bad results...

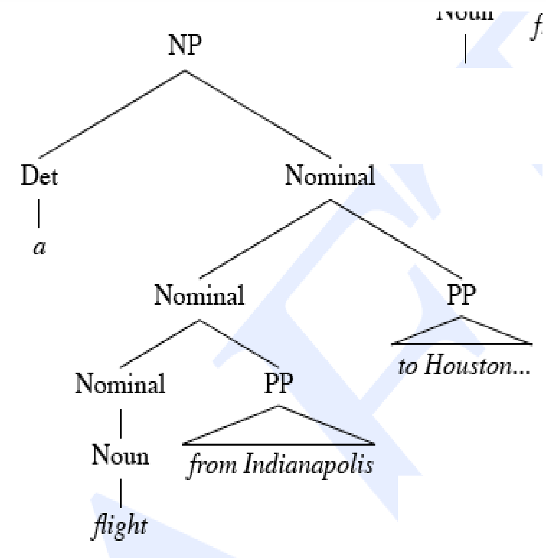
Shared Sub-Problems



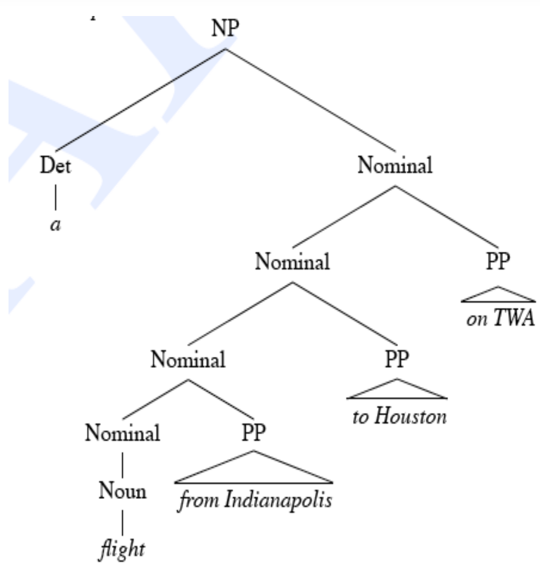
Shared Sub-Problems



Shared Sub-Problems



Shared Sub-Problems



Dynamic Programming

- DP search methods fill tables with partial results and thereby
  - Avoid doing avoidable repeated work
  - Solve exponential problems in polynomial time
  - Efficiently store ambiguous structures with shared sub-parts.
- Two approaches roughly correspond to bottom-up and top-down approaches.
  - CKY
  - Earley

CKY Parsing

- First we'll limit our grammar to epsilon-free, binary rules (more later)
- Consider the rule $A \rightarrow BC$
  - If there is an A somewhere in the input then there must be a B followed by a C in the input.
  - If the A spans from i to j in the input then there must be some k st. $i<k<j$
    - Ie. The B splits from the C someplace.

Problem

- What if your grammar isn't binary?
  - As in the case of the TreeBank grammar?
- Convert it to binary... any arbitrary CFG can be rewritten into Chomsky-Normal Form automatically.
- What does this mean?
  - The resulting grammar accepts (and rejects) the same set of strings as the original grammar.
  - But the resulting derivations (trees) are different.

Problem

- More specifically, we want our rules to be of the form

  $A \rightarrow B\ C$

  Or

  $A \rightarrow w$

  That is, rules can expand to either 2 non-terminals or to a single terminal.

Binarization Intuition

- Eliminate chains of unit productions.
- Introduce new intermediate non-terminals into the grammar that distribute rules with length > 2 over several rules.
  - So... *S → A B C turns into*

  S → X C and

  X → A B

  Where X is a symbol that doesn't occur anywhere else in the the grammar.

Sample L1 Grammar

Grammar	Lexicon
S → NP VP	*Det → that* | *this* | *a*
S → Aux NP VP	*Noun → book* | *flight* | *meal* | *money*
S → VP	*Verb → book* | *include* | *prefer*
NP → Pronoun	*Pronoun → I* | *she* | *me*
NP → Proper-Noun	*Proper-Noun → Houston* | *NWA*
NP → Det Nominal	*Aux → does*
Nominal → Noun	*Preposition → from* | *to* | *on* | *near* | *through*
Nominal → Nominal Noun	
Nominal → Nominal PP	
VP → Verb	
VP → Verb NP	
VP → Verb NP PP	
VP → Verb PP	
VP → VP PP	
PP → Preposition NP	

CNF Conversion

$\mathscr{L}_1$ Grammar	$\mathscr{L}_1$ in CNF
$S \rightarrow NP\ VP$	$S \rightarrow NP\ VP$
$S \rightarrow Aux\ NP\ VP$	$S \rightarrow X1\ VP$
	$X1 \rightarrow Aux\ NP$
$S \rightarrow VP$	$S \rightarrow book \mid include \mid prefer$
	$S \rightarrow Verb\ NP$
	$S \rightarrow X2\ PP$
	$S \rightarrow Verb\ PP$
	$S \rightarrow VP\ PP$
$NP \rightarrow Pronoun$	$NP \rightarrow I \mid she \mid me$
$NP \rightarrow Proper\text{-}Noun$	$NP \rightarrow TWA \mid Houston$
$NP \rightarrow Det\ Nominal$	$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow Noun$	$Nominal \rightarrow book \mid flight \mid meal \mid money$
$Nominal \rightarrow Nominal\ Noun$	$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$	$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow Verb$	$VP \rightarrow book \mid include \mid prefer$
$VP \rightarrow Verb\ NP$	$VP \rightarrow Verb\ NP$
$VP \rightarrow Verb\ NP\ PP$	$VP \rightarrow X2\ PP$
	$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$	$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$	$VP \rightarrow VP\ PP$
$PP \rightarrow Preposition\ NP$	$PP \rightarrow Preposition\ NP$

CKY

- So let's build a table so that an A spanning from i to j in the input is placed in cell [i,j] in the table.
- So a non-terminal spanning an entire string will sit in cell [0, n]
  - Hopefully an *S*
- If we build the table bottom-up, we'll know that the parts of the A must go from i to k and from k to j, for some k.

CKY

- Meaning that for a rule like $A \rightarrow B\ C$ we should look for a B in [i,k] and a C in [k,j].
- In other words, if we think there might be an A spanning i,j in the input… AND

  $A \rightarrow B\ C$ is a rule in the grammar THEN
- There must be a B in [i,k] and a C in [k,j] for some $i<k<j$

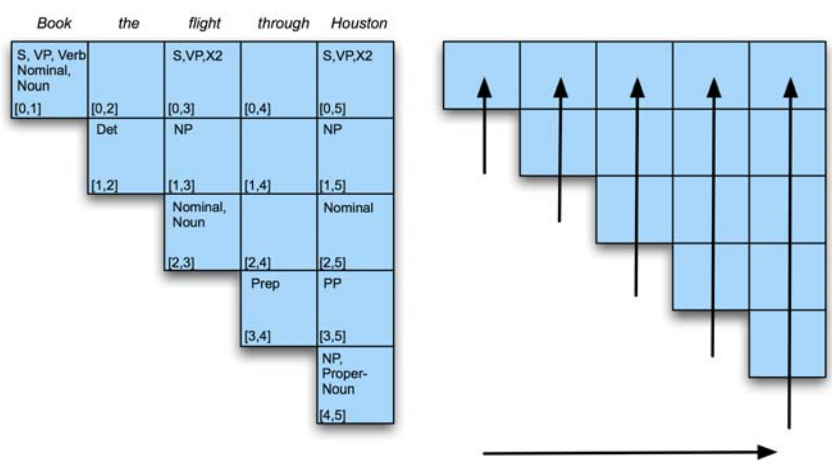
CKY

- So to fill the table loop over the cell[i,j] values in some systematic way
  - What constraint should we put on that systematic search?
  - For each cell, loop over the appropriate k values to search for things to add.

Note

- We arranged the loops to fill the table a column at a time, from left to right, bottom to top.
  - This assures us that whenever we're filling a cell, the parts needed to fill it are already in the table (to the left and below)
  - It's somewhat natural in that it processes the input a left to right a word at a time
    - Known as online

Example



CKY Parser

	Book j= 1	the 2	flight 3	through 4	Houston 5
i= 0					
1					
2					
3					
4					

Cell[*i,j*] contains all constituents (non-terminals) covering words *i* +1 through *j*

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CKY Parser

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun	None			
	Det	NP		
		Nominal, Noun		

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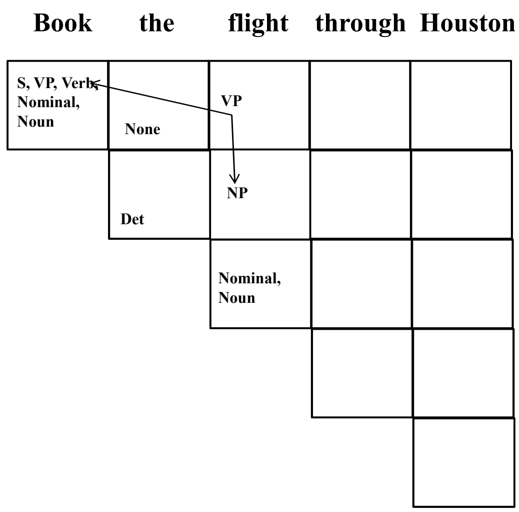
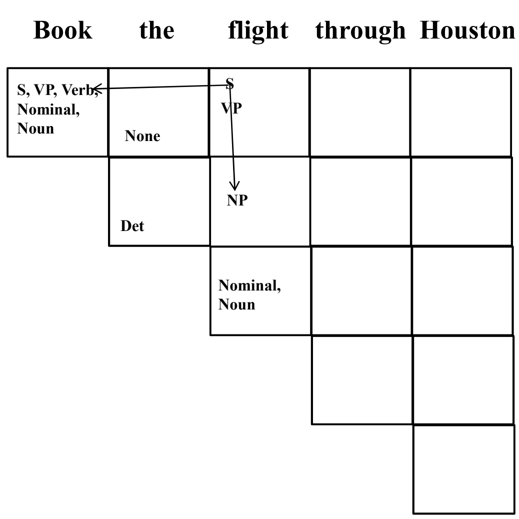
CKY Parser



CKY Parser



CKY Parser

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun	None	S VP, X2		
	Det	NP		
		Nominal, Noun		

CKY Parser

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun	None	S VP	None	
	Det	NP	None	
		Nominal, Noun	None	
			Prep	

CKY Parser

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun	None	S VP	None	
	Det	NP	None	
		Nominal, Noun	None	
			Prep	PP
				NP ProperNoun

CKY Parser

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun	None	S VP	None	
	Det	NP	None	
		Nominal, Noun	None	Nominal
			Prep	PP
				NP ProperNoun

CKY Parser

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun	None	S VP	None	
	Det	NP	None	NP
		Nominal, Noun	None	Nominal
			Prep	PP
				NP ProperNoun

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CKY Parser

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun	None	S VP	None	VP
	Det	NP	None	NP
		Nominal, Noun	None	Nominal
			Prep	PP
				NP ProperNoun

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CKY Parser

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun	None	S VP	None	S VP
	Det	NP	None	NP
		Nominal, Noun	None	Nominal
			Prep	PP
				NP ProperNoun

CKY Parser

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun	None	S VP	None	VP S VP
	Det	NP	None	NP
		Nominal, Noun	None	Nominal
			Prep	PP
				NP ProperNoun

CKY Parser

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun	None	S VP	None	S VP S VP
	Det	NP	None	NP
		Nominal, Noun	None	Nominal
			Prep	PP
				NP ProperNoun

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CKY Parser

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun	None	S VP	None	S VP S X2 VP S
	Det	NP	None	NP
		Nominal, Noun	None	Nominal
			Prep	PP
				NP ProperNoun

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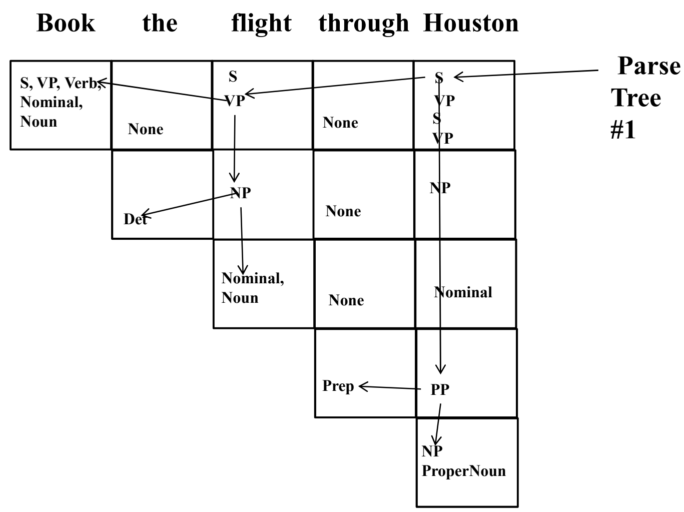
CKY Parser



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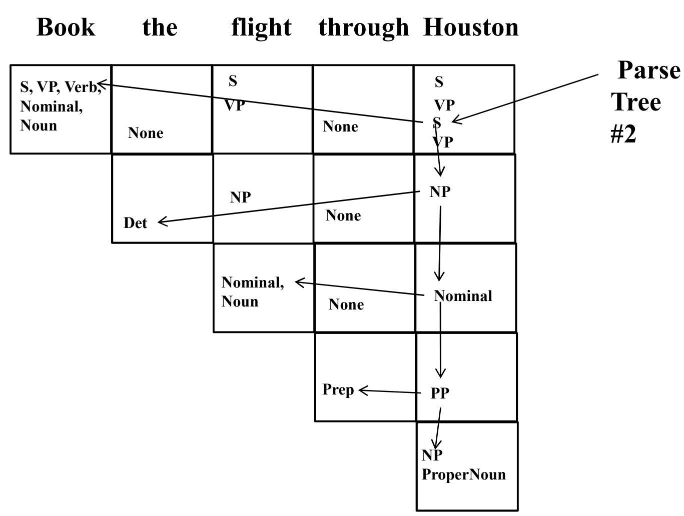
CKY Parser



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Example

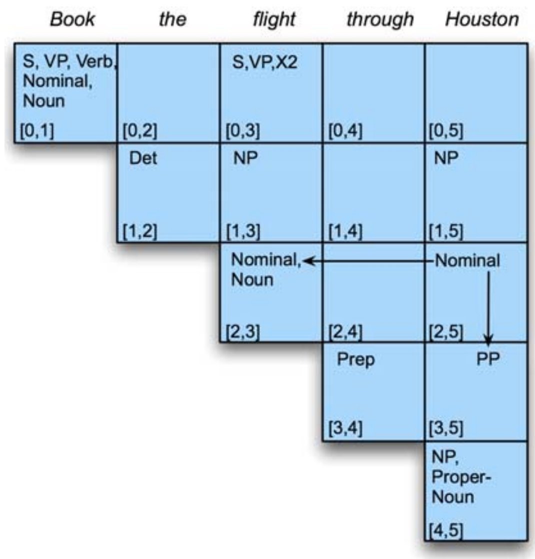
Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun [0,1]	[0,2]	S,VP,X2 [0,3]	[0,4]	[0,5]
	Det [1,2]	NP [1,3]	[1,4]	[1,5]
		Nominal, Noun [2,3]	[2,4]	Nominal [2,5]
			Prep [3,4]	[3,5]
				NP, Proper-Noun [4,5]

Filling column 5

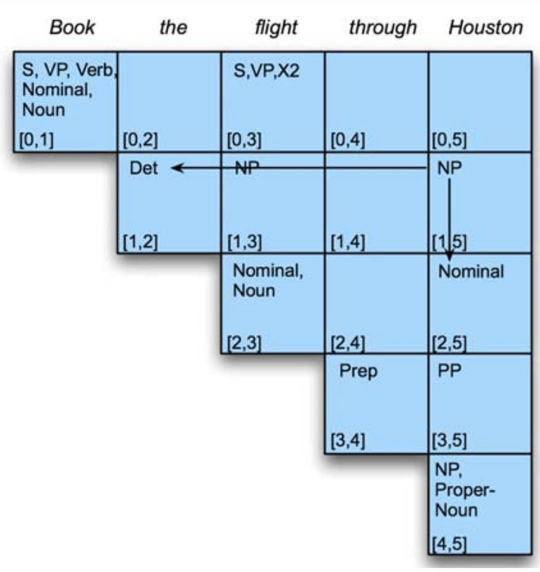
Example

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun [0,1]	[0,2]	S,VP,X2 [0,3]	[0,4]	[0,5]
	Det [1,2]	NP [1,3]	[1,4]	NP [1,5]
		Nominal, Noun [2,3]	[2,4]	[2,5]
			Prep [3,4]	PP [3,5]
				NP, Proper-Noun [4,5]

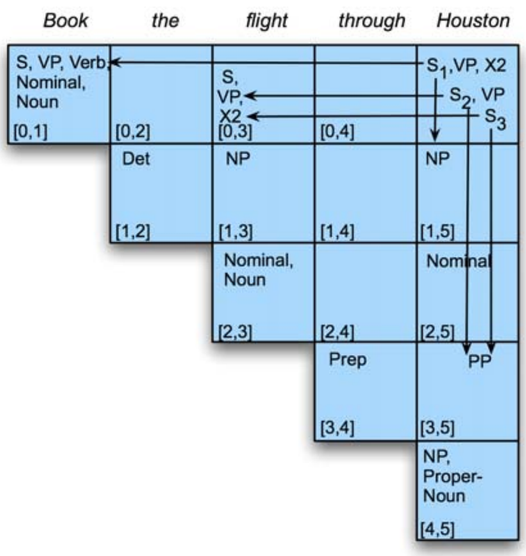
Example



Example



Example



CKY Notes

- Since it's bottom up, CKY populates the table with a lot of phantom constituents.
  - Segments that by themselves are constituents but cannot really occur in the context in which they are being suggested.
  - To avoid this we can switch to a top-down control strategy
  - Or we can add some kind of filtering that blocks constituents where they can not happen in a final analysis.

Earley Parsing

- Allows arbitrary CFGs
- Top-down control
- Fills a table in a single sweep over the input
  - Table is length N+1; N is number of words
  - Table entries represent
    - Completed constituents and their locations
    - In-progress constituents
    - Predicted constituents

Back to Ambiguity

- Did we solve it?

Ambiguity

- No...
  - Both CKY and Earley will result in multiple S structures for the [0,N] table entry.
  - They both efficiently store the sub-parts that are shared between multiple parses.
  - And they obviously avoid re-deriving those sub-parts.
  - But neither can tell us which one is right.

Ambiguity

- In most cases, humans don't notice incidental ambiguity (lexical or syntactic). It is resolved on the fly and never noticed.
  - I ate the spaghetti with chopsticks
  - I ate the spaghetti with meatballs
- We'll try to model that with probabilities.

Shallow or Partial Parsing

- Sometimes we don't need a complete parse tree
  - Information extraction
  - Question answering
- But we would like more than simple POS sequences

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Chunking

- Find major but unembedded constituents like NPs, VPs, AdjPs, PPs
  - Most common task: NP chunking of base NPs
  - [NP I] saw [NP the man] on [NP the hill] with [NP a telescope]
  - No attempt to identify full NPs – no recursion, no post-head words
  - No overlapping constituents
  - E.g., if we add PPs or VPs, they may consist only of their heads, e.g. [PP on]

Approaches: RE Chunking

- Use regexps to identify constituents, e.g.
  - NP → (DT) NN* NN
  - Find longest matching chunk
  - Hand-built rules
  - No recursion but can cascade to approximate true CF parser, aggregating larger and larger constituents

Approaches: Tagging for Chunking

- Require annotated corpus
- Train classifier to classify each element of input in sequence (e.g. IOB Tagging)
  - B (beginning of sequence)
  - I (internal to sequence)
  - O (outside of any sequence)
  - No end-of-chunk coding – it's implicit
  - Easier to detect the beginning than the end

  Book/B_VP that/B_NP flight/I_NP quickly/O

Summary and Limitations

- Sometimes shallow parsing is enough for task
- Performance quite accurate

Distribution of Chunks in CONLL Shared Task

Label	Category	Proportion (%)	Example
NP	Noun Phrase	51	*The most frequently cancelled flight*
VP	Verb Phrase	20	*may not arrive*
PP	Prepositional Phrase	20	*to Houston*
ADVP	Adverbial Phrase	4	*earlier*
SBAR	Subordinate Clause	2	*that*
ADJP	Adjective Phrase	2	*late*

Summing Up

- Parsing as search: what search strategies to use?
  - Top down
  - Bottom up
  - How to combine?
- How to parse as little as possible
  - Dynamic Programming
- Shallow Parsing

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