PARSING

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CS159 – Fall 2020

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Admin

Assignment 3

Quiz #1

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Parsing

Parsing is the field of NLP interested in automatically determining the syntactic structure of a sentence

parsing can also be thought of as determining what sentences are "valid" English sentences

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Parsing

We have a grammar, determine the possible parse tree(s)

Let's start with parsing with a CFG (no probabilities)

S → NP VP
NP → PRP
NP → N PP
VP → V NP
VP → V NP PP
PP → IN N
PRP → I
V → eat
N → sushi
N → tuna
IN → with

I eat sushi with tuna

approaches?
algorithms?

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Parsing

Top-down parsing
- ends up doing a lot of repeated work
- doesn't take into account the words in the sentence until the end!

Bottom-up parsing
- constrain based on the words
- avoids repeated work (dynamic programming)
- doesn't take into account the high-level structure until the end!
- CKY parser

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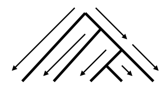
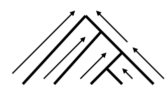
Parsing

Top-down parsing
- start at the top (usually S) and apply rules
- matching left-hand sides and replacing with right-hand sides



Bottom-up parsing
- start at the bottom (i.e. words) and build the parse tree up from there
- matching right-hand sides and replacing with left-hand sides



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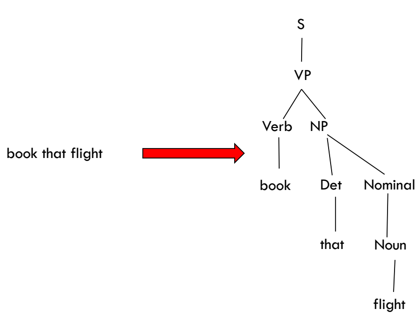
Parsing Example



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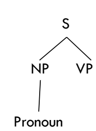
Top Down Parsing



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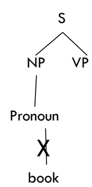
Top Down Parsing



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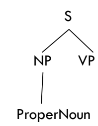
Top Down Parsing



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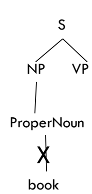
Top Down Parsing



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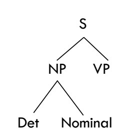
Top Down Parsing



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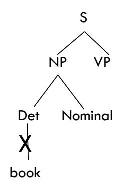
Top Down Parsing



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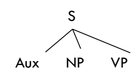
Top Down Parsing



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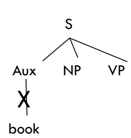
Top Down Parsing



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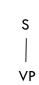
Top Down Parsing



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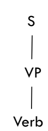
Top Down Parsing



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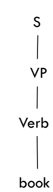
Top Down Parsing



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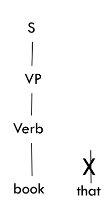
Top Down Parsing



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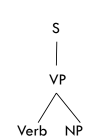
Top Down Parsing



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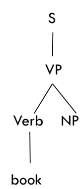
Top Down Parsing



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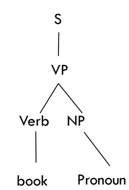
Top Down Parsing



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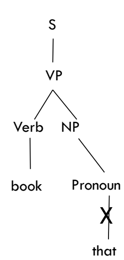
Top Down Parsing



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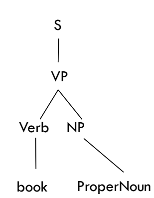
Top Down Parsing



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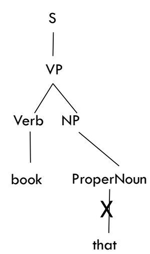
Top Down Parsing



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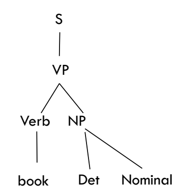
Top Down Parsing



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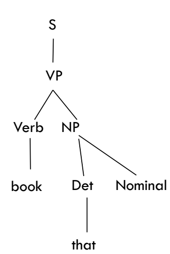
Top Down Parsing



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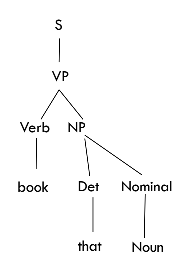
Top Down Parsing



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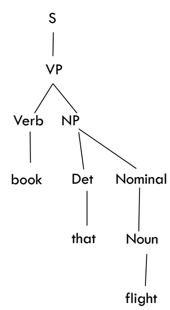
Top Down Parsing



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Bottom Up Parsing

book that flight

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Bottom Up Parsing

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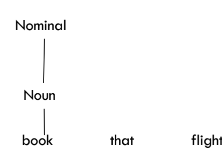
Bottom Up Parsing



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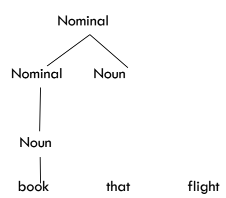
Bottom Up Parsing



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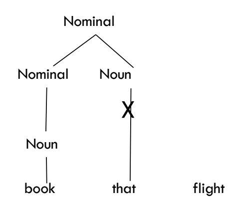
Bottom Up Parsing



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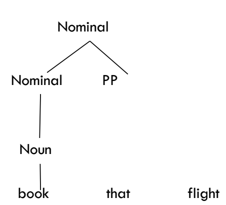
Bottom Up Parsing



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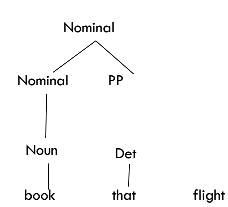
Bottom Up Parsing



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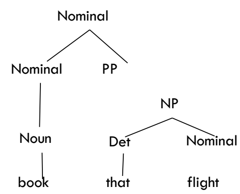
Bottom Up Parsing



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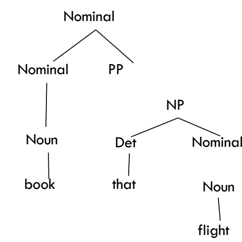
Bottom Up Parsing



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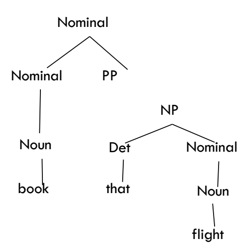
Bottom Up Parsing



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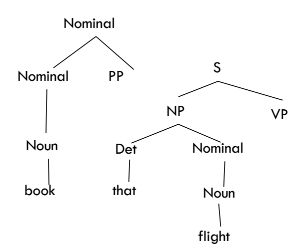
Bottom Up Parsing



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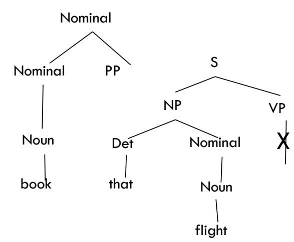
Bottom Up Parsing



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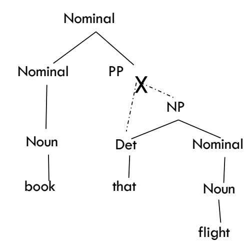
Bottom Up Parsing



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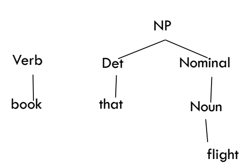
Bottom Up Parsing



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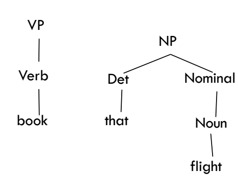
Bottom Up Parsing



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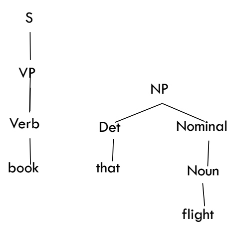
Bottom Up Parsing



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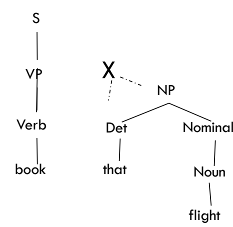
Bottom Up Parsing



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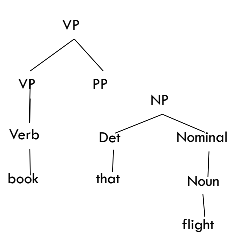
Bottom Up Parsing



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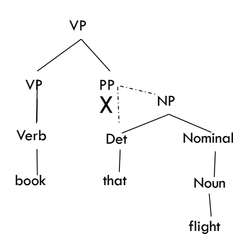
Bottom Up Parsing



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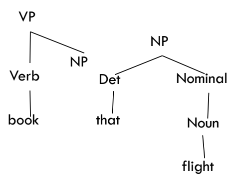
Bottom Up Parsing



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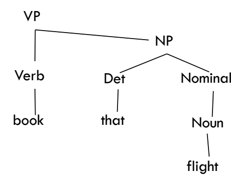
Bottom Up Parsing



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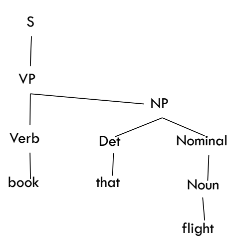
Bottom Up Parsing



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Parsing

Pros/Cons?

- Top-down:
  - Only examines parses that could be valid parses (i.e. with an S on top)
  - Doesn't take into account the actual words!
- Bottom-up:
  - Only examines structures that have the actual words as the leaves
  - Examines sub-parses that may NOT result in a valid parse!

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Why is parsing hard?

Actual grammars are large

Lots of ambiguity!

- Most sentences have many parses
- Some sentences have a lot of parses
- Even for sentences that are not ambiguous, there is often ambiguity for subtrees (i.e. multiple ways to parse a phrase)

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Why is parsing hard?

I saw the man on the hill with the telescope

What are some interpretations?

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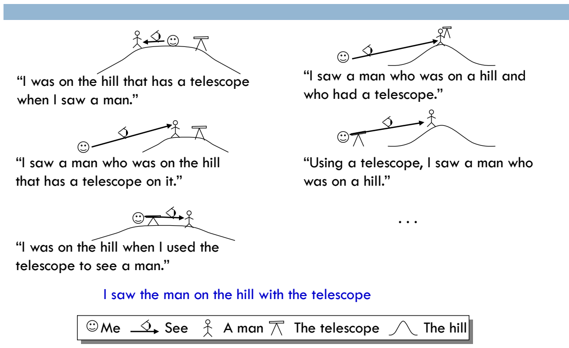
Structural Ambiguity Can Give Exponential Parses



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Dynamic Programming Parsing

To avoid extensive repeated work you must cache intermediate results, specifically found constituents

Caching (memoizing) is critical to obtaining a polynomial time parsing algorithm for CFGs

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.

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Dynamic Programming Parsing Methods

CKY (Cocke-Kasami-Younger) algorithm based on bottom-up parsing and requires first normalizing the grammar.

Earley parser is based on top-down parsing and does not require normalizing grammar but is more complex.

These both fall under the general category of **chart parsers** which retain completed constituents in a chart

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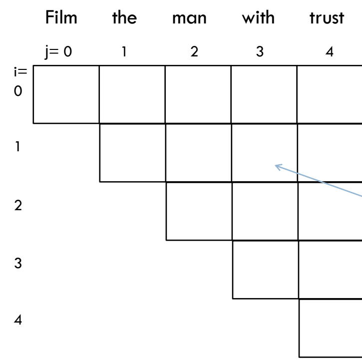
CKY parser: the chart



Cell[*i*,*j*] contains all constituents covering words *i* through *j*

what does this cell represent?

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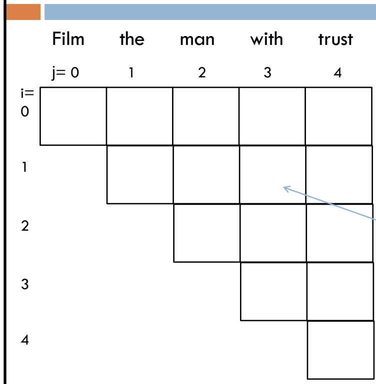
CKY parser: the chart



Cell[*i*,*j*] contains all constituents covering words *i* through *j*

all constituents spanning 1-3 or "the man with"

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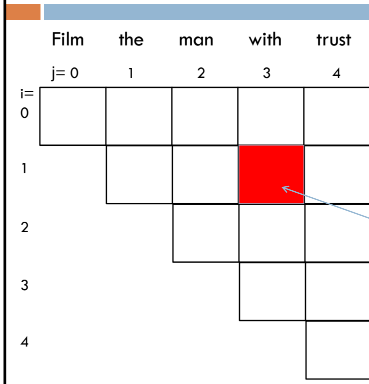
CKY parser: the chart



Cell[*i*,*j*] contains all constituents covering words *i* through *j*

how could we figure this out?

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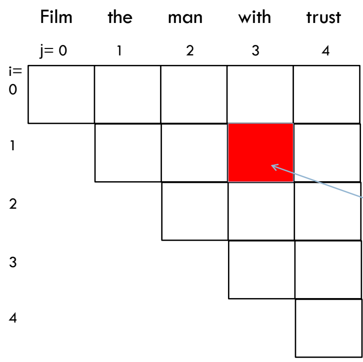
CKY parser: the chart



Cell[*i*,*j*] contains all constituents covering words *i* through *j*

Key: rules are binary and only have two constituents on the right hand side

VP -> VB NP
NP -> DT NN

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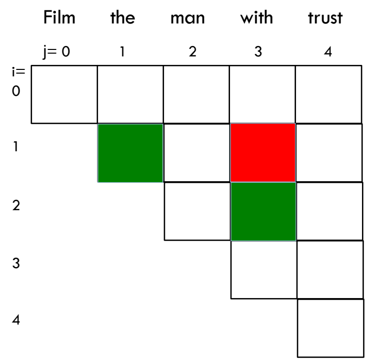
CKY parser: the chart



Cell[*i*,*j*] contains all constituents covering words *i* through *j*

See if we can make a new constituent combining any for “the” with any for “man with”

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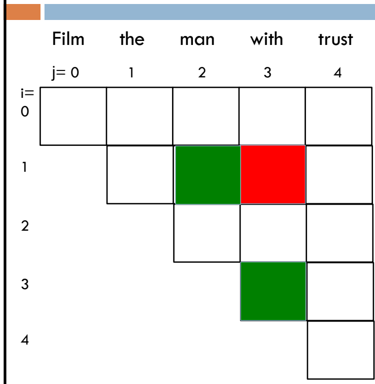
CKY parser: the chart



Cell[*i*,*j*] contains all constituents covering words *i* through *j*

See if we can make a new constituent combining any for “the man” with any for “with”

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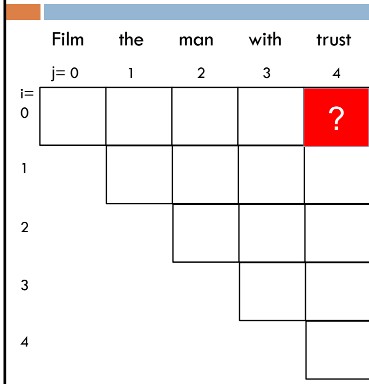
CKY parser: the chart



Cell[*i*,*j*] contains all constituents covering words *i* through *j*

What combinations do we need to consider when trying to put constituents here?

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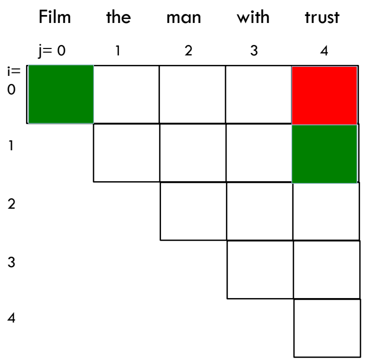
CKY parser: the chart



Cell[*i*,*j*] contains all constituents covering words *i* through *j*

See if we can make a new constituent combining any for "Film" with any for "the man with trust"

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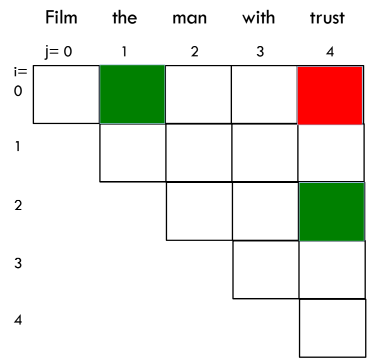
CKY parser: the chart



Cell[*i*,*j*] contains all constituents covering words *i* through *j*

See if we can make a new constituent combining any for "Film the" with any for "man with trust"

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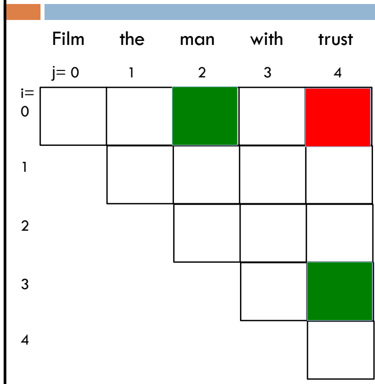
CKY parser: the chart



Cell[*i*,*j*] contains all constituents covering words *i* through *j*

See if we can make a new constituent combining any for "Film the man" with any for "with trust"

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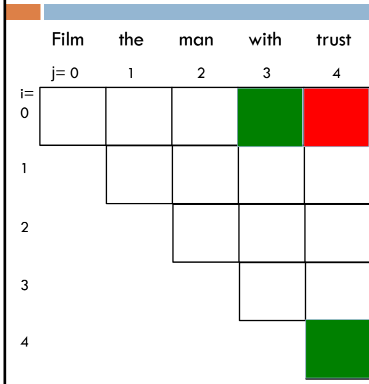
CKY parser: the chart



Cell[*i*,*j*] contains all constituents covering words *i* through *j*

See if we can make a new constituent combining any for "Film the man with" with any for "trust"

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CKY parser: the chart

	Film	the	man	with	trust
	j= 0	1	2	3	4
i= 0					
1					
2					
3					
4					

Cell[*i*,*j*] contains all constituents covering words *i* through *j*

What if our rules weren't binary?

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CKY parser: the chart

	Film	the	man	with	trust
	j= 0	1	2	3	4
i= 0					
1					
2					
3					
4					

Cell[*i*,*j*] contains all constituents covering words *i* through *j*

See if we can make a new constituent combining any for "Film" with any for "the man" with any for "with trust"

70

CKY parser: the chart

	Film	the	man	with	trust
	j= 0	1	2	3	4
i= 0					
1					
2					
3					
4					

Cell[*i*,*j*] contains all constituents covering words *i* through *j*

What order should we fill the entries in the chart?

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CKY parser: the chart

	Film	the	man	with	trust
	j= 0	1	2	3	4
i= 0					
1					
2					
3					
4					

Cell[*i*,*j*] contains all constituents covering words *i* through *j*

Our dependencies are left and down

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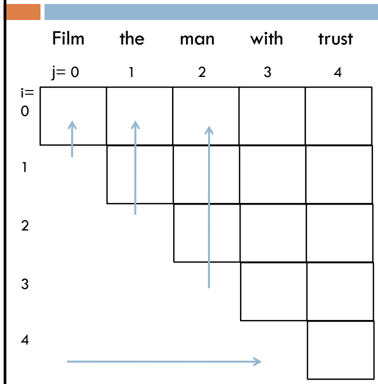
CKY parser: the chart



Cell[*i*,*j*] contains all constituents covering words *i* through *j*

From bottom to top, left to right

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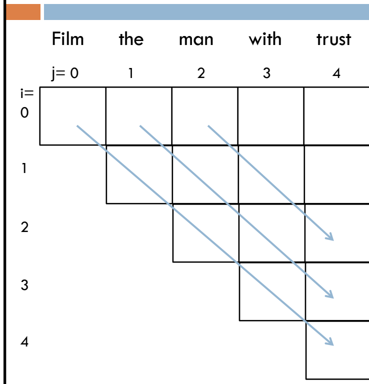
CKY parser: the chart



Cell[*i*,*j*] contains all constituents covering words *i* through *j*

Top-left along the diagonals moving to the right

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CKY parser: unary rules

S -> VP
VP -> VB NP
VP -> VP2 PP
VP2 -> VB NP
NP -> DT NN
NP -> NN
NP -> NP PP
PP -> IN NP
DT -> the
IN -> with
VB -> film
VB -> trust
NN -> man
NN -> film
NN -> trust

Often, we will leave unary rules rather than converting to CNF

Do these complicate the algorithm?

Must check whenever we add a constituent to see if any unary rules apply

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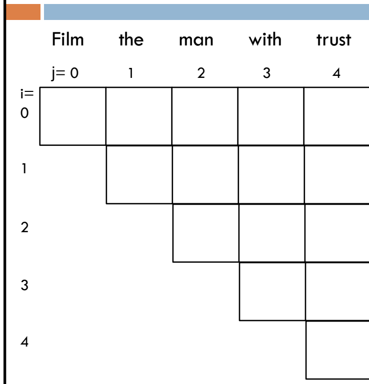
CKY parser: the chart



S → VP
VP → VB NP
VP → VP2 PP
VP2 → VB NP
NP → DT NN
NP → NN
NP → NP PP
PP → IN NP
DT → the
IN → with
VB → film
VB → man
VB → trust
NN → man
NN → film
NN → trust

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CKY parser: the chart

	Film	the	man	with	trust
	j= 0	1	2	3	4
i= 0	NN NP VB				
1		DT			
2			VB NN NP		
3				IN	
4					VB NN NP

S → VP
VP → VB NP
VP → VP2 PP
VP2 → VB NP
NP → DT NN
NP → NN
NP → NP PP
PP → IN NP
DT → the
IN → with
VB → film
VB → man
VB → trust
NN → man
NN → film
NN → trust

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CKY parser: the chart

	Film	the	man	with	trust
	j= 0	1	2	3	4
i= 0	NN NP VB	—			
1		DT	NP		
2			VB NN NP	—	
3				IN	PP
4					VB NN NP

S → VP
VP → VB NP
VP → VP2 PP
VP2 → VB NP
NP → DT NN
NP → NN
NP → NP PP
PP → IN NP
DT → the
IN → with
VB → film
VB → man
VB → trust
NN → man
NN → film
NN → trust

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CKY parser: the chart

	Film	the	man	with	trust
	j= 0	1	2	3	4
i= 0	NN NP VB	—	VP2 VP S		
1		DT	NP	—	
2			VB NN NP	—	NP
3				IN	PP
4					VB NN NP

S → VP
VP → VB NP
VP → VP2 PP
VP2 → VB NP
NP → DT NN
NP → NN
NP → NP PP
PP → IN NP
DT → the
IN → with
VB → film
VB → man
VB → trust
NN → man
NN → film
NN → trust

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CKY parser: the chart

	Film	the	man	with	trust
	j= 0	1	2	3	4
i= 0	NN NP VB	—	VP2 VP S	—	
1		DT	NP	—	NP
2			VB NN NP	—	NP
3				IN	PP
4					VB NN NP

S → VP
VP → VB NP
VP → VP2 PP
VP2 → VB NP
NP → DT NN
NP → NN
NP → NP PP
PP → IN NP
DT → the
IN → with
VB → film
VB → man
VB → trust
NN → man
NN → film
NN → trust

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CKY parser: the chart

	Film	the	man	with	trust
	j= 0	1	2	3	4
i= 0	NN NP VB	—	VP2 VP S	—	S VP VP2
1		DT	NP	—	NP
2			VB NN NP	—	NP
3				IN	PP
4					VB NN NP

S → VP
VP → VB NP
VP → VP2 PP
VP2 → VB NP
NP → DT NN
NP → NN
NP → NP PP
PP → IN NP
DT → the
IN → with
VB → film
VB → man
VB → trust
NN → man
NN → film
NN → trust

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CKY: some things to talk about

After we fill in the chart, how do we know if there is a parse?

- If there is an **S** in the upper right corner

What if we want an actual tree/parse?

	j= 0	1	2	3	4
i= 0	NN VB	—	VB2 VP S	—	S VP
1		DT	NP	—	NP
2			VB NN NP	—	NP
3				IN	PP
4					VB NN NP

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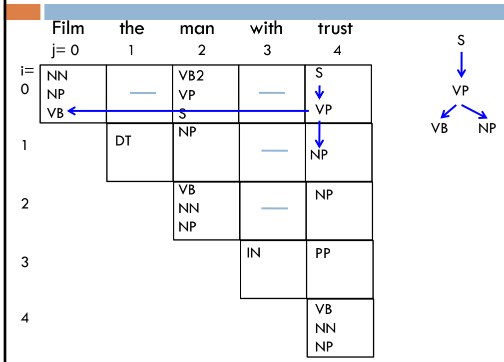
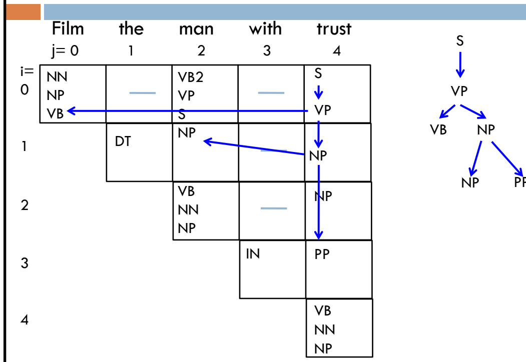
CKY: retrieving the parse



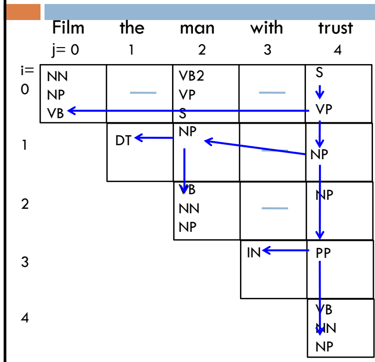
83

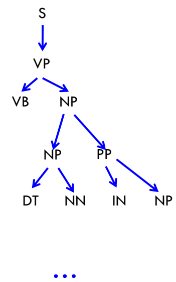
CKY: retrieving the parse



84

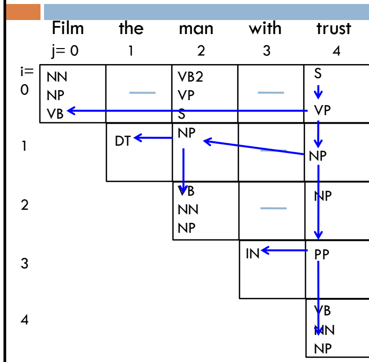
CKY: retrieving the parse





85

CKY: retrieving the parse



Where do these arrows/references come from?

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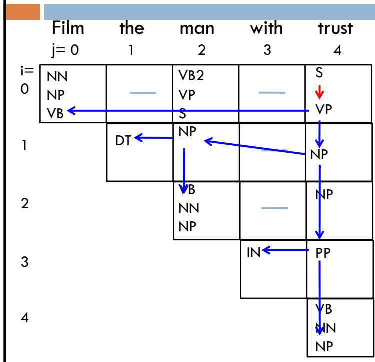
CKY: retrieving the parse



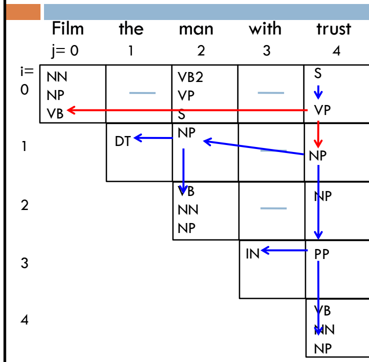
S → VP

To add a constituent in a cell, we're applying a rule

The references represent the smaller constituents we used to build this constituent

87

CKY: retrieving the parse



VP → VB NP

To add a constituent in a cell, we're applying a rule

The references represent the smaller constituents we used to build this constituent

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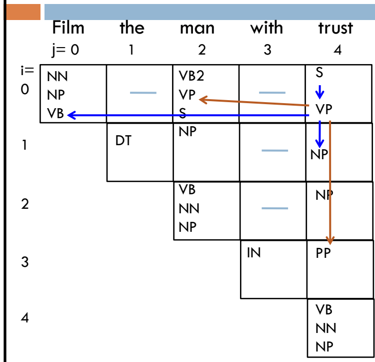
CKY: retrieving the parse



What about ambiguous parses?

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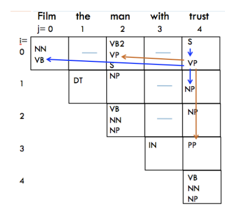
CKY: retrieving the parse



We can store multiple derivations of each constituent

This representation is called a "parse forest"

It is often convenient to leave it in this form, rather than enumerate all possible parses. Why?

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CKY: some things to think about

CNF

S → VP
VP → VB NP
VP → VP2 PP
VP2 → VB NP
NP → DT NN
NP → NN
…

We get a CNF parse tree

Actual grammar

S → VP
VP → VB NP
VP → VB NP PP
NP → DT NN
NP → NN
…

but want one for the actual grammar

Ideas?

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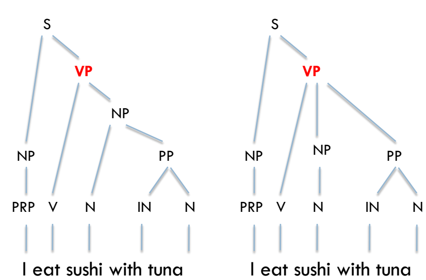
Parsing ambiguity



S → NP VP
NP → PRP
NP → N PP
VP → V NP
VP → V NP PP
PP → IN N
PRP → I
V → eat
N → sushi
N → tuna
IN → with

How can we decide between these?

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A Simple PCFG

Probabilities!

S	→	NP VP	1.0	NP	→	NP PP	0.4
VP	→	V NP	0.7	NP	→	*astronomers*	0.1
VP	→	VP PP	0.3	NP	→	*ears*	0.18
PP	→	P NP	1.0	NP	→	*saw*	0.04
P	→	*with*	1.0	NP	→	*stars*	0.18
V	→	*saw*	1.0	NP	→	*telescope*	0.1

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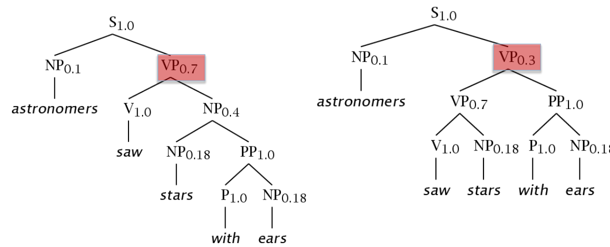

= 1.0 * 0.1 * 0.7 * 1.0 * 0.4 * 0.18 * 1.0 * 1.0 * 0.18
= 0.0009072

= 1.0 * 0.1 * 0.3 * 0.7 * 1.0 * 0.18 * 1.0 * 1.0 * 0.18
= 0.0006804

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Parsing with PCFGs

How does this change our CKY algorithm?

- We need to keep track of the probability of a constituent

How do we calculate the probability of a constituent?

- Product of the PCFG rule times the product of the probabilities of the sub-constituents (right hand sides)
- Building up the product from the bottom-up

What if there are multiple ways of deriving a particular constituent?

- max: pick the most likely derivation of that constituent

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Probabilistic CKY

Include in each cell a probability for each non-terminal

Cell[*i*,*j*] must retain the *most probable* derivation of each constituent (non-terminal) covering words *i* through *j*

When transforming the grammar to CNF, must set production probabilities to preserve the probability of derivations

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Probabilistic Grammar Conversion

Original Grammar		Chomsky Normal Form	
S → NP VP	0.8	S → NP VP	0.8
S → Aux NP VP	0.1	S → X1 VP	0.1
		X1 → Aux NP	1.0
S → VP	0.1	S → book | include | prefer 0.01 0.004 0.006	
		S → Verb NP	0.05
		S → VP PP	0.03
NP → Pronoun	0.2	NP → I | he | she | me 0.1 0.02 0.02 0.06	
NP → Proper-Noun	0.2	NP → Houston | NWA 0.16 .04	
NP → Det Nominal	0.6	NP → Det Nominal	0.6
Nominal → Noun	0.3	Nominal → book | flight | meal | money 0.03 0.15 0.06 0.06	
Nominal → Nominal Noun	0.2	Nominal → Nominal Noun	0.2
Nominal → Nominal PP	0.5	Nominal → Nominal PP	0.5
VP → Verb	0.2	VP → book | include | prefer 0.1 0.04 0.06	
VP → Verb NP	0.5	VP → Verb NP	0.5
VP → VP PP	0.3	VP → VP PP	0.3
PP → Prep NP	1.0	PP → Prep NP	1.0

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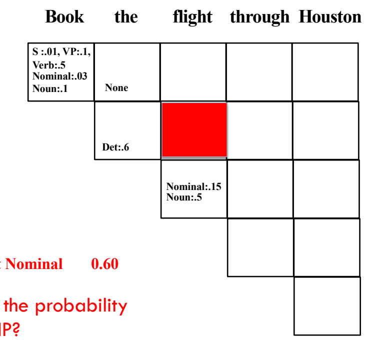
Probabilistic CKY Parser



NP → Det Nominal 0.60

What is the probability of the NP?

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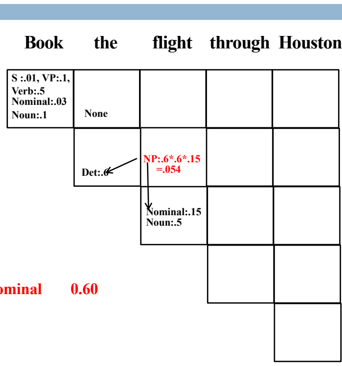
Probabilistic CKY Parser



NP → Det Nominal 0.60

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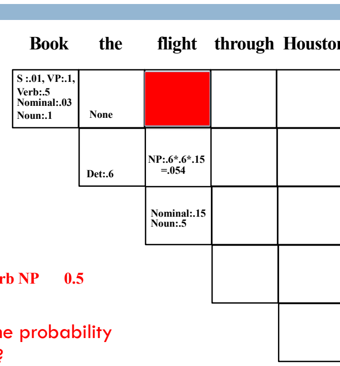
Probabilistic CKY Parser



VP → Verb NP 0.5

What is the probability of the VP?

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Probabilistic CKY Parser

Book	the	flight	through	Houston
S :.01, VP:.1, Verb:.5 Nominal:.03 Noun:.1	None	VP:.5*.5*.054 =.0135		
	Det:.6	NP:.6*.6*.15 =.054		
		Nominal:.15 Noun:.5		

VP → Verb NP 0.5

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Probabilistic CKY Parser

Book	the	flight	through	Houston
S :.01, VP:.1, Verb:.5 Nominal:.03 Noun:.1	None	S:.05*.5*.054 =.00135 VP:.5*.5*.054 =.0135		
	Det:.6	NP:.6*.6*.15 =.054		
		Nominal:.15 Noun:.5		

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Probabilistic CKY Parser

Book	the	flight	through	Houston
S :.01, VP:.1, Verb:.5 Nominal:.03 Noun:.1	None	S:.05*.5*.054 =.00135 VP:.5*.5*.054 =.0135	None	
	Det:.6	NP:.6*.6*.15 =.054	None	
		Nominal:.15 Noun:.5	None	
			Prep:.2	

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Probabilistic CKY Parser

Book	the	flight	through	Houston
S :.01, VP:.1, Verb:.5 Nominal:.03 Noun:.1	None	S:.05*.5*.054 =.00135 VP:.5*.5*.054 =.0135	None	
	Det:.6	NP:.6*.6*.15 =.054	None	
		Nominal:.15 Noun:.5	None	
			Prep:.2	PP:1.0*.2*.16 =.032
				NP:.16 PropNoun:.8

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Probabilistic CKY Parser

Book	the	flight	through	Houston
S :.01, VP:.1, Verb:.5 Nominal:.03 Noun:.1	None	S:.05*.5*.054 =.00135 VP:.5*.5*.054 =.0135	None	
	Det:.6	NP:.6*.6*.15 =.054	None	
		Nominal:.15 Noun:.5	None	Nominal: .5*.15*.032 =.0024
			Prep:.2	PP:1.0*.2*.16 =.032
				NP:.16 PropNoun:.8

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Probabilistic CKY Parser

Book	the	flight	through	Houston
S :.01, VP:.1, Verb:.5 Nominal:.03 Noun:.1	None	S:.05*.5*.054 =.00135 VP:.5*.5*.054 =.0135	None	
	Det:.6	NP:.6*.6*.15 =.054	None	NP:.6*.6* .0024 =.000864
		Nominal:.15 Noun:.5	None	Nominal: .5*.15*.032 =.0024
			Prep:.2	PP:1.0*.2*.16 =.032
				NP:.16 PropNoun:.8

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Probabilistic CKY Parser

Book	the	flight	through	Houston
S :.01, VP:.1, Verb:.5 Nominal:.03 Noun:.1	None	S:.05*.5*.054 =.00135 VP:.5*.5*.054 =.0135	None	
	Det:.6	NP:.6*.6*.15 =.054	None	NP:.6*.6* .0024 =.000864
		Nominal:.15 Noun:.5	None	Nominal: .5*.15*.032 =.0024
			Prep:.2	PP:1.0*.2*.16 =.032
				NP:.16 PropNoun:.8

S:.05*.5* .000864 =.0000216

S:.03*.0135* .032 =.00001296

Which parse do we pick?

S → VP PP 0.03

S → Verb NP 0.05

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Probabilistic CKY Parser

Book	the	flight	through	Houston
S :.01, VP:.1, Verb:.5 Nominal:.03 Noun:.1	None	S:.05*.5*.054 =.00135 VP:.5*.5*.054 =.0135	None	S:.0000216
	Det:.6	NP:.6*.6*.15 =.054	None	NP:.6*.6* .0024 =.000864
		Nominal:.15 Noun:.5	None	Nominal: .5*.15*.032 =.0024
			Prep:.2	PP:1.0*.2*.16 =.032
				NP:.16 PropNoun:.8

Pick most probable parse, i.e. take max to combine probabilities of multiple derivations of each constituent in each cell

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Generic PCFG Limitations

PCFGs do not rely on specific words or concepts, only general structural disambiguation is possible (e.g. prefer to attach PPs to Nominals)

- Generic PCFGs cannot resolve syntactic ambiguities that require semantics to resolve, e.g. “ate with”: fork vs. meatballs

Smoothing/dealing with out of vocabulary

MLE estimates are not always the best

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