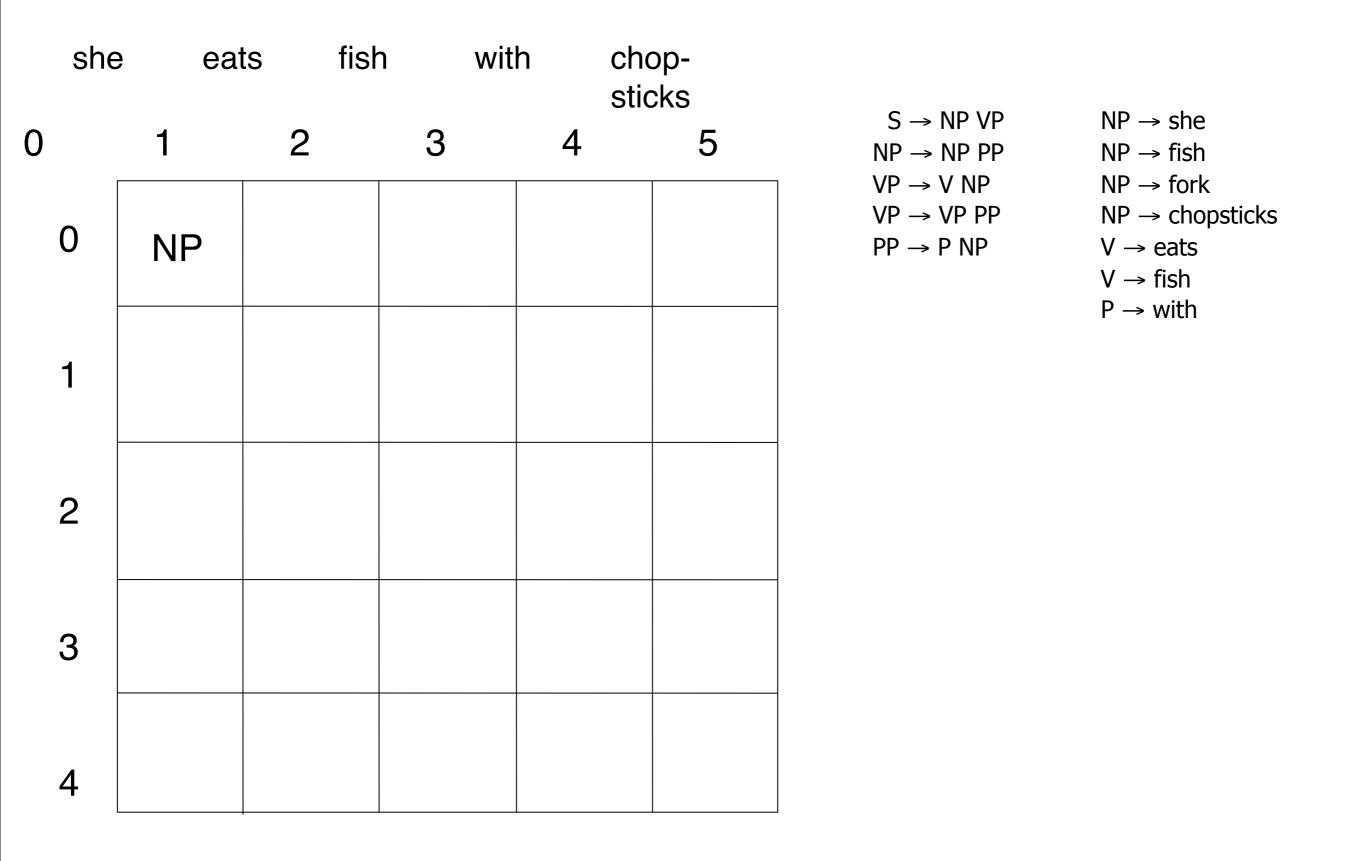
Lecture 15: Context-Free Grammars and the CKY algorithm

Intro to NLP, CS585, Fall 2014 http://people.cs.umass.edu/~brenocon/inlp2014/ Brendan O'Connor

Includes material borrowed from Andrew McCallum, Noah Smith, Dan Klein, Chris Manning, Jurafsky&Martin

Sunday, November 9, 14

Fill in the CYK dynamic programming table to parse the sentence below. In the bottom right corner, draw the two parse trees.



Andrew McCallum, UMass Amherst

Two views of syntax

• Constituents: phrase structure



Parsing: applications

- Language modeling
 - John, who eats cookies, {love, loves} ...
- Machine translation
- Information extraction
- Grammar checking (MS Word!)
- Question answering
- NL interfaces to databases
- Sentiment analysis
- ..



Constituency (phrase structure)

• Phrase structure organizes words into nested constituents.



Constituency (phrase structure)

- Phrase structure organizes words into nested constituents.
- How do we know what is a constituent? (Not that linguists don't argue about some cases.)
 - Distribution: a constituent behaves as a unit that can appear in different places:
 - John talked [to the children] [about drugs].
 - John talked [about drugs] [to the children].
 - *John talked drugs to the children about
 - Substitution/expansion/pro-forms:
 - I sat [on the box/right on top of the box/there].
 - Coordination, regular internal structure, no intrusion, fragments, semantics, ...

Ambiguity in parsing

- Syntactic ambiguity is widespread in language.
 - Attachment ambiguity
 - we ate sushi with chopsticks
 - I shot an elephant in my pajamas
 - Modifier scope
 - southern food store
 - etc.

Context-Free Grammars

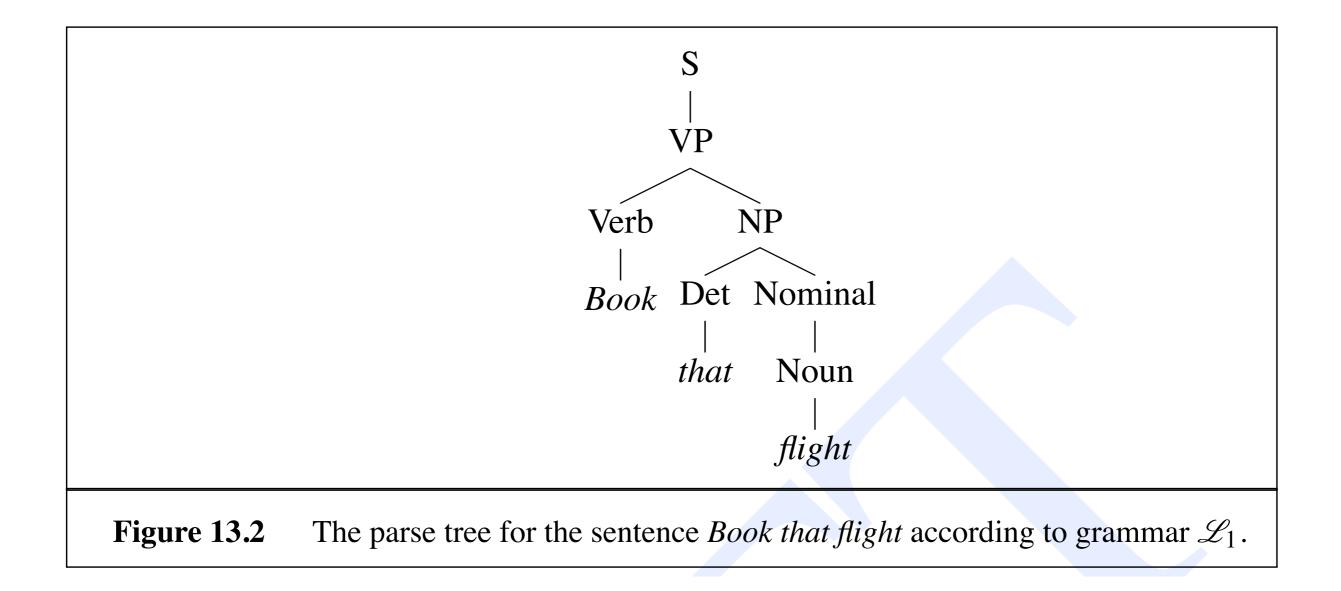
- A generative formalism for constituency structures and text.
 - Generative view: produces a constit. tree and words in sentence.
 - Parsing view: given the words, what parse(s) could have generated it?
- Both boolean and probabilistic versions

Grammar (Production rules)

Lexicon

 $S \rightarrow NP VP$ $Det \rightarrow that \mid this \mid a$ *Noun* \rightarrow *book* | *flight* | *meal* | *money* $S \rightarrow Aux NP VP$ $S \rightarrow VP$ *Verb* \rightarrow *book* | *include* | *prefer* $NP \rightarrow Pronoun$ *Pronoun* \rightarrow *I* | *she* | *me* $NP \rightarrow Proper-Noun$ *Proper-Noun* \rightarrow *Houston* | *TWA* $NP \rightarrow Det Nominal$ $Aux \rightarrow does$ *Preposition* \rightarrow *from* | *to* | *on* | *near* | *through* Nominal \rightarrow Noun *Nominal* \rightarrow *Nominal Noun* Nominal \rightarrow Nominal PP $VP \rightarrow Verb$ $VP \rightarrow Verb NP$ $VP \rightarrow Verb NP PP$ $VP \rightarrow Verb PP$ $VP \rightarrow VP PP$ $PP \rightarrow Preposition NP$

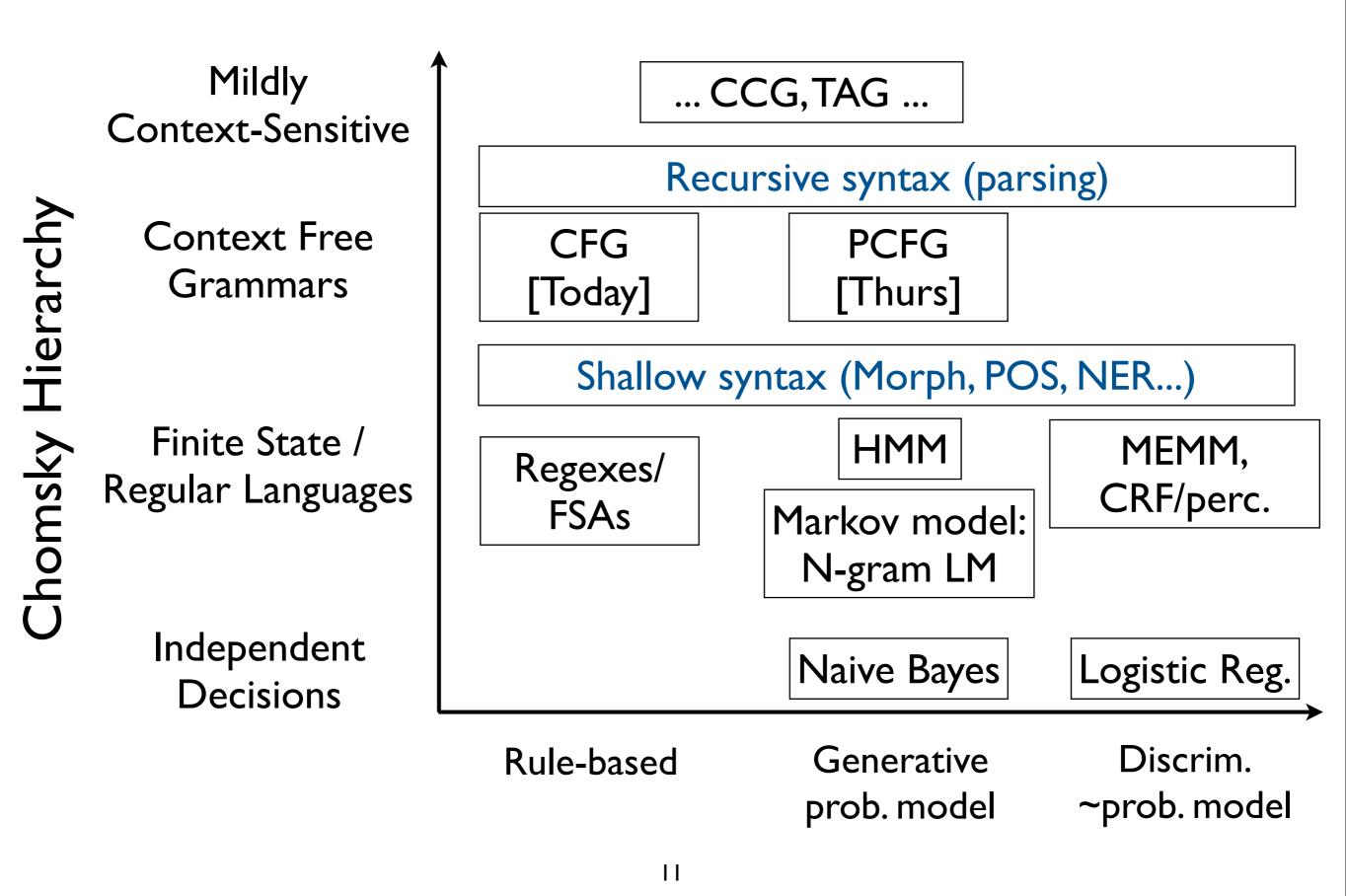
Figure 13.1 The \mathcal{L}_1 miniature English grammar and lexicon.



Context-Free Grammars

- Unlike programming language grammars: Massive ambiguity!
- Unlike finite state grammars: Potentially infinite recursion

Computation/Statistics in NLP (in this course)



Approaches to CFG parsing

- Top-down and Bottom-up search
- Shift-reduce: left-to-right
- [Today]
 Dynamic programming: CKY algorithm Exact search!
- Probabilistic/weighted variants of each of these:
 Find the best parse (e.g. most probable)

Binarized rules

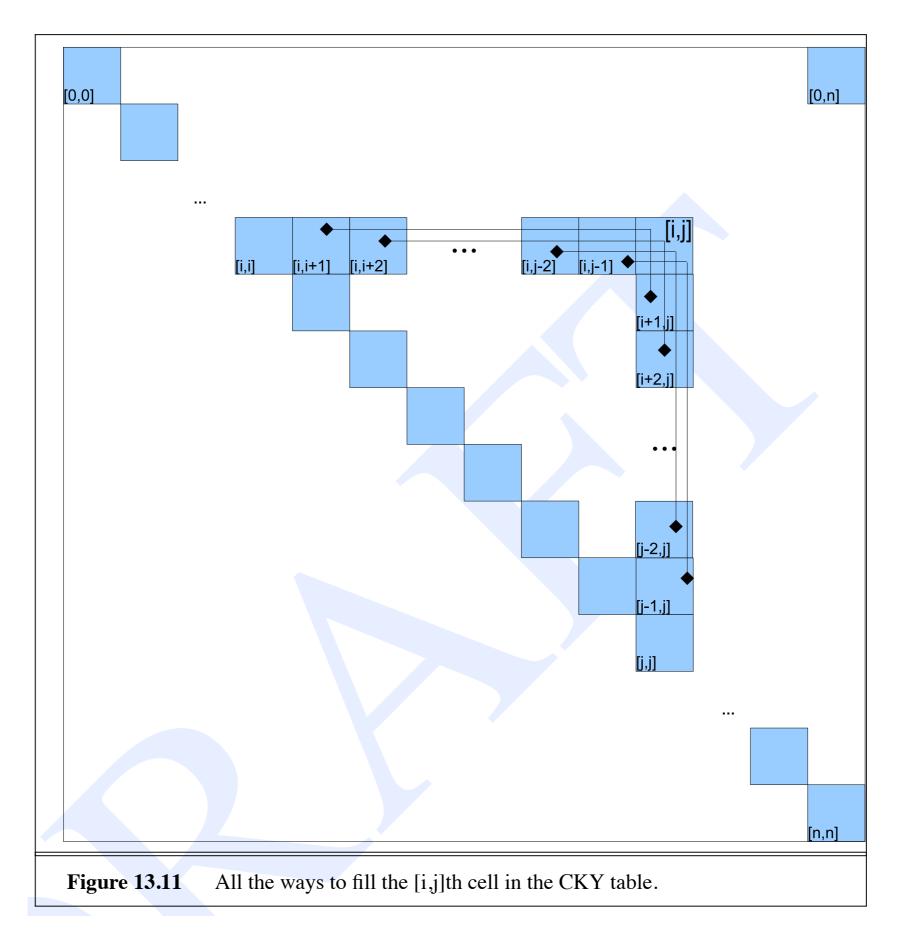
Necessary for CKY algorithm Can convert to equivalent binarized grammar

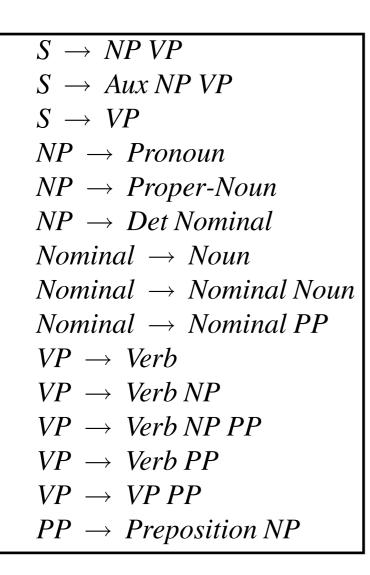
$$S \rightarrow NP VP$$
$$S \rightarrow Aux NP VP$$

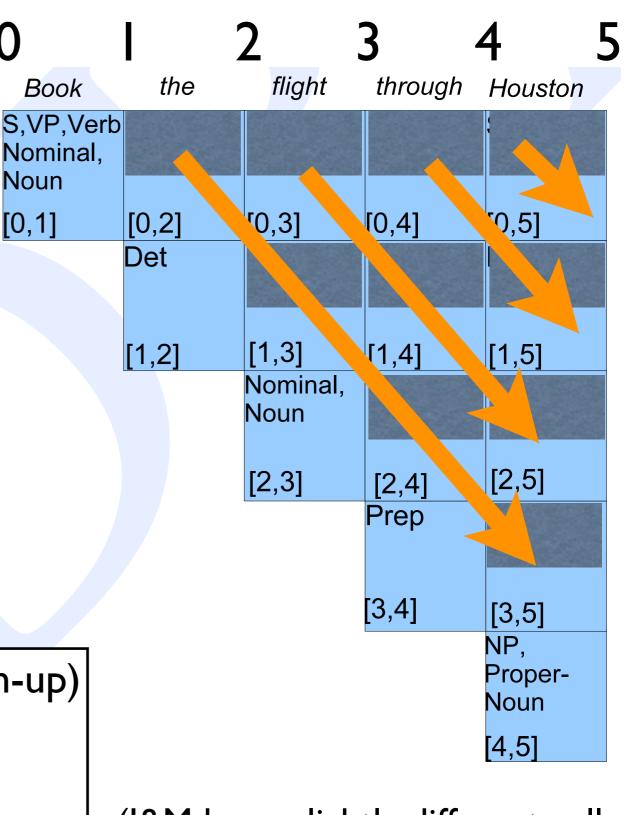
 $\begin{vmatrix} S &\to NP \ VP \\ S &\to X1 \ VP \\ X1 &\to Aux \ NP \end{vmatrix}$

- Fill in all length-1 spans with possible nonterminals.
- Go bottom-up: progressively fill each cell with possible states, based on possible combinations below.
- If the top cell [0,5] can expand from ROOT, then accept!
- To get one of possible parses: trace backpointers
- Dynamic programming: what's below the cell does not matter

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







For cell [i,j] (loop through them bottom-up) For possible splitpoint k=(i+1)..(j-1): For every B in [i,k] and C in [k,j], If exists rule A -> B C, <u>add</u> A to cell [i,j]

$S \rightarrow NP VP$
$S \rightarrow Aux NP VP$
$S \rightarrow VP$
$NP \rightarrow Pronoun$
$NP \rightarrow Proper-Noun$
$NP \rightarrow Det Nominal$
Nominal \rightarrow Noun
Nominal \rightarrow Nominal Noun
Nominal \rightarrow Nominal PP
$VP \rightarrow Verb$
$VP \rightarrow Verb NP$
$VP \rightarrow Verb NP PP$
$VP \rightarrow Verb PP$
$VP \rightarrow VP PP$
$PP \rightarrow Preposition NP$

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Book	the	flight	through	Houston	
S,VP,Ve Nominal Noun	the second se				
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
	Det				
	[1,2]	[1,3]	[1,4]	[1,5]	
		Nominal, Noun			
		[2,3]	[2,4]	[2,5]	
			Prep		
			[3,4]	[3,5]	
n-up)				NP, Proper- Noun	
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For cell [i,j] (loop through them bottom-up) For possible splitpoint k=(i+1)..(j-1): For every B in [i,k] and C in [k,j], If exists rule A -> B C, <u>add</u> A to cell [i,j]

$S \rightarrow NP VP$
$S \rightarrow Aux NP VP$
$S \rightarrow VP$
$NP \rightarrow Pronoun$
$NP \rightarrow Proper-Noun$
$NP \rightarrow Det Nominal$
Nominal \rightarrow Noun
Nominal \rightarrow Nominal Noun
Nominal \rightarrow Nominal PP
$VP \rightarrow Verb$
$VP \rightarrow Verb NP$
$VP \rightarrow Verb NP PP$
$VP \rightarrow Verb PP$
$VP \rightarrow VP PP$
$PP \rightarrow Preposition NP$

0	1	2	3	4 5	5
Book	the	flight	through	Houston	
S,VP,Ver Nominal, Noun	b				
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
	Det				
	[1,2]	[1,3]	[1,4]	[1,5]	
		Nominal, Noun			
		[2,3]	[2,4]	[2,5]	
			Prep		
			[3,4]	[3,5]	
n-up)				NP, Proper- Noun	
				[4,5]	
	(I&M ha	s a sligh	tly diffe	rent cell	

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$S \rightarrow NP VP$
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$S \rightarrow VP$
$NP \rightarrow Pronoun$
$NP \rightarrow Proper-Noun$
$NP \rightarrow Det Nominal$
Nominal \rightarrow Noun
Nominal \rightarrow Nominal Noun
Nominal \rightarrow Nominal PP
$VP \rightarrow Verb$
$VP \rightarrow Verb NP$
$VP \rightarrow Verb NP PP$
$VP \rightarrow Verb PP$
$VP \rightarrow VP PP$
$PP \rightarrow Preposition NP$

0	I	2	3	4 5	-
Book	the	flight	through	Houston	
S,VP,Ve Nominal Noun					
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
	Det	NP			
	[1,2]	[1,3]	[1,4]	[1,5]	
		Nominal, Noun			
		[2,3]	[2,4]	[2,5]	
			Prep		
			[3,4]	[3,5]	
n-up)				NP, Proper- Noun	
				[4,5]	1
	(]& M h	as a sligh	tly diffe	rent cell	

ordering. Both OK.)

For cell [i,j] (loop through them bottom-up) For possible splitpoint k=(i+1)..(j-1): For every B in [i,k] and C in [k,j], If exists rule A -> B C, <u>add</u> A to cell [i,j]

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$S \rightarrow NP VP$ $S \rightarrow Aux NP VP$ $S \rightarrow VP$ $NP \rightarrow Pronoun$ $NP \rightarrow Proper-Noun$ $NP \rightarrow Det Nominal$ $Nominal \rightarrow Noun$ $Nominal \rightarrow Nominal Noun$ $Nominal \rightarrow Nominal PP$ $VP \rightarrow Verb$ $VP \rightarrow Verb NP$ $VP \rightarrow Verb NP$ $VP \rightarrow Verb NP PP$ $VP \rightarrow Verb PP$ $VP \rightarrow VP PP$ $PP \rightarrow Preposition NP$	
$S \rightarrow VP$ $NP \rightarrow Pronoun$ $NP \rightarrow Proper-Noun$ $NP \rightarrow Det Nominal$ $Nominal \rightarrow Noun$ $Nominal \rightarrow Nominal Noun$ $Nominal \rightarrow Nominal PP$ $VP \rightarrow Verb$ $VP \rightarrow Verb NP$ $VP \rightarrow Verb NP$ $VP \rightarrow Verb NP PP$ $VP \rightarrow Verb PP$ $VP \rightarrow Verb PP$	$S \rightarrow NP VP$
$NP \rightarrow Pronoun$ $NP \rightarrow Proper-Noun$ $NP \rightarrow Det Nominal$ $Nominal \rightarrow Noun$ $Nominal \rightarrow Nominal Noun$ $Nominal \rightarrow Nominal PP$ $VP \rightarrow Verb$ $VP \rightarrow Verb NP$ $VP \rightarrow Verb NP$ $VP \rightarrow Verb NP PP$ $VP \rightarrow Verb PP$ $VP \rightarrow VP PP$	$S \rightarrow Aux NP VP$
$NP \rightarrow Proper-Noun$ $NP \rightarrow Det Nominal$ $Nominal \rightarrow Noun$ $Nominal \rightarrow Nominal Noun$ $Nominal \rightarrow Nominal PP$ $VP \rightarrow Verb$ $VP \rightarrow Verb NP$ $VP \rightarrow Verb NP PP$ $VP \rightarrow Verb PP$ $VP \rightarrow Verb PP$ $VP \rightarrow VP PP$	$S \rightarrow VP$
$NP \rightarrow Det Nominal$ $Nominal \rightarrow Noun$ $Nominal \rightarrow Nominal Noun$ $Nominal \rightarrow Nominal PP$ $VP \rightarrow Verb$ $VP \rightarrow Verb NP$ $VP \rightarrow Verb NP PP$ $VP \rightarrow Verb PP$ $VP \rightarrow VP PP$	$NP \rightarrow Pronoun$
$Nominal \rightarrow Noun$ $Nominal \rightarrow Nominal Noun$ $Nominal \rightarrow Nominal Noun$ $Nominal \rightarrow Nominal PP$ $VP \rightarrow Verb$ $VP \rightarrow Verb NP$ $VP \rightarrow Verb NP PP$ $VP \rightarrow Verb PP$ $VP \rightarrow VP PP$	$NP \rightarrow Proper-Noun$
$\begin{array}{l} \textit{Nominal} \rightarrow \textit{Nominal Noun} \\ \textit{Nominal} \rightarrow \textit{Nominal Noun} \\ \textit{Nominal} \rightarrow \textit{Nominal PP} \\ \textit{VP} \rightarrow \textit{Verb} \\ \textit{VP} \rightarrow \textit{Verb} \\ \textit{VP} \rightarrow \textit{Verb} \\ \textit{NP} \\ \textit{VP} \rightarrow \textit{Verb} \\ \textit{NP} \\ \textit{VP} \rightarrow \textit{Verb} \\ \textit{PP} \\ \textit{VP} \rightarrow \textit{Verb} \\ \textit{PP} \\ \textit{VP} \rightarrow \textit{VP} \\ \textit{PP} \end{array}$	$NP \rightarrow Det Nominal$
$\begin{array}{l} \textit{Nominal} \rightarrow \textit{Nominal PP} \\ \textit{VP} \rightarrow \textit{Verb} \\ \textit{VP} \rightarrow \textit{Verb NP} \\ \textit{VP} \rightarrow \textit{Verb NP PP} \\ \textit{VP} \rightarrow \textit{Verb PP} \\ \textit{VP} \rightarrow \textit{VP PP} \end{array}$	Nominal \rightarrow Noun
$VP \rightarrow Verb$ $VP \rightarrow Verb NP$ $VP \rightarrow Verb NP PP$ $VP \rightarrow Verb PP$ $VP \rightarrow VP PP$	Nominal \rightarrow Nominal Noun
$VP \rightarrow Verb NP$ $VP \rightarrow Verb NP PP$ $VP \rightarrow Verb PP$ $VP \rightarrow VP PP$	Nominal \rightarrow Nominal PP
$VP \rightarrow Verb NP PP$ $VP \rightarrow Verb PP$ $VP \rightarrow VP PP$	$VP \rightarrow Verb$
$VP \rightarrow Verb PP$ $VP \rightarrow VP PP$	$VP \rightarrow Verb NP$
$VP \rightarrow VP PP$	$VP \rightarrow Verb NP PP$
	$VP \rightarrow Verb PP$
$PP \rightarrow Preposition NP$	$VP \rightarrow VP PP$
	$PP \rightarrow Preposition NP$

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Book	the	flight	through	Houston	
S,VP,Ve Nominal Noun					
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
	Det	NP			
	[1,2]	[1,3]	[1,4]	[1,5]	
		Nominal, Noun			
		[2,3]	[2,4]	[2,5]	
			Prep		
			[3,4]	[3,5]	
n-up)				NP, Proper- Noun	
				[4,5]	
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For cell [i,j] (loop through them bottom-up) For possible splitpoint k=(i+1)..(j-1): For every B in [i,k] and C in [k,j], If exists rule A -> B C, <u>add</u> A to cell [i,j]

$S \rightarrow NP VP$
$S \rightarrow Aux NP VP$
$S \rightarrow VP$
$NP \rightarrow Pronoun$
$NP \rightarrow Proper-Noun$
$NP \rightarrow Det Nominal$
Nominal \rightarrow Noun
Nominal \rightarrow Nominal Noun
Nominal \rightarrow Nominal PP
$VP \rightarrow Verb$
$VP \rightarrow Verb NP$
$VP \rightarrow Verb NP PP$
$VP \rightarrow Verb PP$
$VP \rightarrow VP PP$
$PP \rightarrow Preposition NP$

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Book	the	flight	through	Houston
S,VP,Verb Nominal, Noun				
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]
	Det	NP		
	[1,2]	[1,3]	[1,4]	[1,5]
		Nominal, Noun		
		[2,3]	[2,4]	[2,5]
			Prep	PP
			[3,4]	[3,5]
n-up)				NP, Proper- Noun
				[4,5]
	(J&M ha	s a sligh [,]	tly diffe	rent cell

ordering. Both OK.)

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$S \rightarrow NP VP$
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$S \rightarrow VP$
$NP \rightarrow Pronoun$
$NP \rightarrow Proper-Noun$
$NP \rightarrow Det Nominal$
Nominal \rightarrow Noun
Nominal \rightarrow Nominal Noun
Nominal \rightarrow Nominal PP
$VP \rightarrow Verb$
$VP \rightarrow Verb NP$
$VP \rightarrow Verb NP PP$
$VP \rightarrow Verb PP$
$VP \rightarrow VP PP$
$PP \rightarrow Preposition NP$

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S,VP,Ve Nomina Noun		S,VP,X2			
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
	Det	NP			
	[1,2]	[1,3]	[1,4]	[1,5]	
		Nominal, Noun			
		[2,3]	[2,4]	[2,5]	
			Prep	PP	
			[3,4]	[3,5]	
n-up)				NP, Proper- Noun	
				[4,5]	
	(]&M h	as a sligh	tly diffe	rent cell	

ordering. Both OK.)

For cell [i,j] (loop through them bottom-up) For possible splitpoint k=(i+1)..(j-1): For every B in [i,k] and C in [k,j], If exists rule A -> B C, <u>add</u> A to cell [i,j]

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$S \rightarrow VP$
$NP \rightarrow Pronoun$
$NP \rightarrow Proper-Noun$
$NP \rightarrow Det Nominal$
Nominal \rightarrow Noun
Nominal \rightarrow Nominal Noun
Nominal \rightarrow Nominal PP
$VP \rightarrow Verb$
$VP \rightarrow Verb NP$
$VP \rightarrow Verb NP PP$
$VP \rightarrow Verb PP$
$VP \rightarrow VP PP$
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Book	the	flight	through	Houston
S,VP,Verl Nominal, Noun	D	S,VP,X2		
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]
	Det	NP		
	[1,2]	[1,3]	[1,4]	[1,5]
		Nominal, Noun		
		[2,3]	[2,4]	[2,5]
			Prep	PP
			[3,4]	[3,5]
n-up)				NP, Proper- Noun
				[4,5]
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ordering. Both OK.)

For cell [i,j] (loop through them bottom-up) For possible splitpoint k=(i+1)..(j-1): For every B in [i,k] and C in [k,j], If exists rule A -> B C, <u>add</u> A to cell [i,j]

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$NP \rightarrow Pronoun$
$NP \rightarrow Proper-Noun$
$NP \rightarrow Det Nominal$
Nominal \rightarrow Noun
Nominal \rightarrow Nominal Noun
Nominal \rightarrow Nominal PP
$VP \rightarrow Verb$
$VP \rightarrow Verb NP$
$VP \rightarrow Verb NP PP$
$VP \rightarrow Verb PP$
$VP \rightarrow VP PP$
$PP \rightarrow Preposition NP$

0	1	2	3	4 5
Book	the	flight	through	Houston
S,VP,Vert Nominal, Noun	D	S,VP,X2		
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]
	Det	NP		
	[1,2]	[1,3]	[1,4]	[1,5]
		Nominal, Noun		Nominal
		[2,3]	[2,4]	[2,5]
			Prep	PP
			[3,4]	[3,5]
n-up)				NP, Proper- Noun
				[4,5]
	(I&M ha	s a sligh	tly diffe	rent cell

For cell [i,j] (loop through them bottom-up) For possible splitpoint k=(i+1)..(j-1): For every B in [i,k] and C in [k,j], If exists rule A -> B C, <u>add</u> A to cell [i,j]

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$S \rightarrow Aux NP VP$
$S \rightarrow VP$
$NP \rightarrow Pronoun$
$NP \rightarrow Proper-Noun$
$NP \rightarrow Det Nominal$
Nominal \rightarrow Noun
Nominal \rightarrow Nominal Noun
Nominal \rightarrow Nominal PP
$VP \rightarrow Verb$
$VP \rightarrow Verb NP$
$VP \rightarrow Verb NP PP$
$VP \rightarrow Verb PP$
$VP \rightarrow VP PP$
$PP \rightarrow Preposition NP$

0	I	2	3	4 5	-
Book	the	flight	through	Houston	
S,VP,Ve Nomina Noun		S,VP,X2			
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
	Det	NP			
	[1,2]	[1,3]	[1,4]	[1,5]	
		Nominal, Noun		Nominal	
		[2,3]	[2,4]	[2,5]	
			Prep	PP	
			[3,4]	[3,5]	
n-up)				NP, Proper- Noun	
				[4,5]	1
	(J&M h	as a sligh	tly diffe	rent cell	

ordering. Both OK.)

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Nominal \rightarrow Noun
Nominal \rightarrow Nominal Noun
Nominal \rightarrow Nominal PP
$VP \rightarrow Verb$
$VP \rightarrow Verb NP$
$VP \rightarrow Verb NP PP$
$VP \rightarrow Verb PP$
$VP \rightarrow VP PP$
$PP \rightarrow Preposition NP$

0		2	3	4 5	5
Book	the	flight	through	Houston	
S,VP,Verb Nominal, Noun		S,VP,X2			
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
	Det	NP		NP	
	[1,2]	[1,3]	[1,4]	[1,5]	
		Nominal, Noun		Nominal	
		[2,3]	[2,4]	[2,5]	
			Prep	PP	
			[3,4]	[3,5]	
n-up)				NP, Proper- Noun	
				[4,5]	
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For cell [i,j] (loop through them bottom-up) For possible splitpoint k=(i+1)..(j-1): For every B in [i,k] and C in [k,j], If exists rule A -> B C, <u>add</u> A to cell [i,j]

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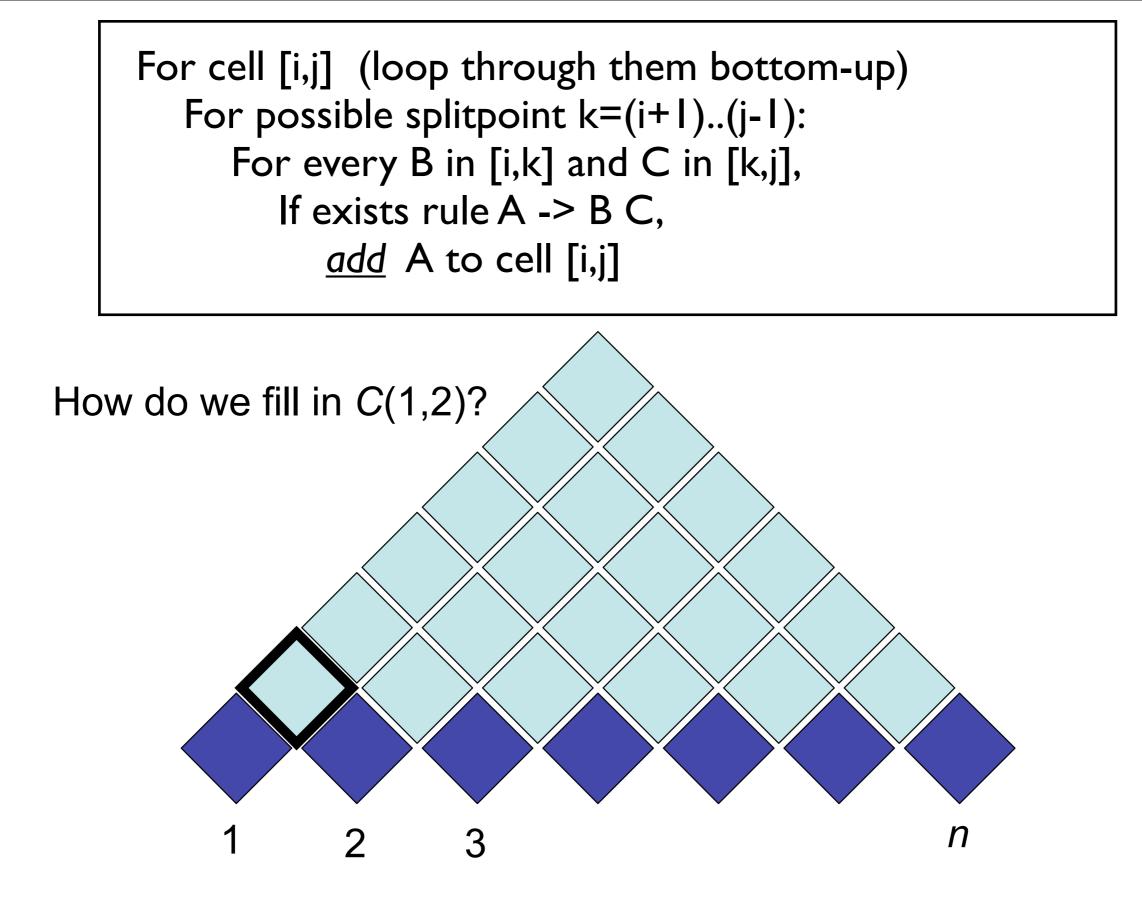
0	I	2	3	4 5
Book	the	flight	through	Houston
S,VP,Ve Nominal, Noun		S,VP,X2		S, VP
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]
	Det	NP		NP
	[1,2]	[1,3]	[1,4]	[1,5]
		Nominal, Noun		Nominal
		[2,3]	[2,4]	[2,5]
			Prep	PP
			[3,4]	[3,5]
n-up)				NP, Proper- Noun
				[4,5]
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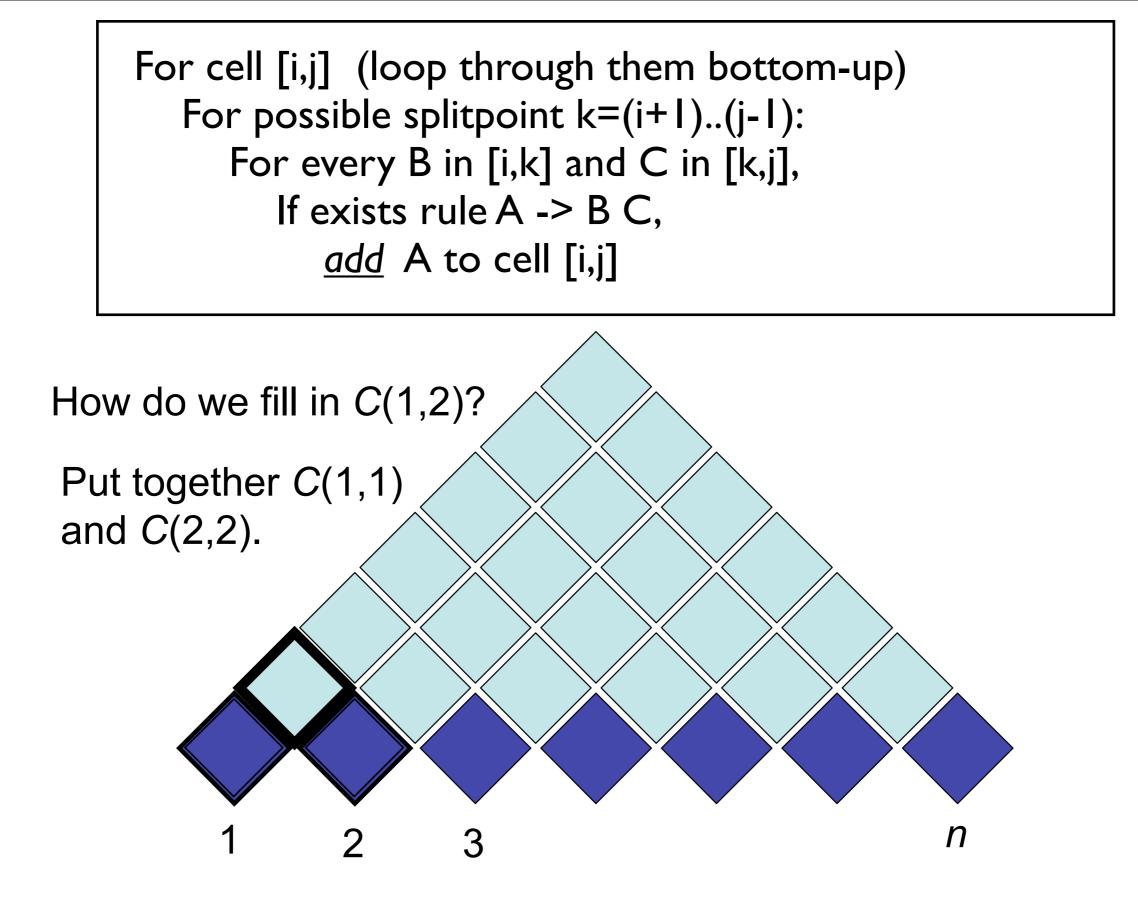
For cell [i,j] (loop through them bottom-up) For possible splitpoint k=(i+1)..(j-1): For every B in [i,k] and C in [k,j], If exists rule A -> B C, <u>add</u> A to cell [i,j]

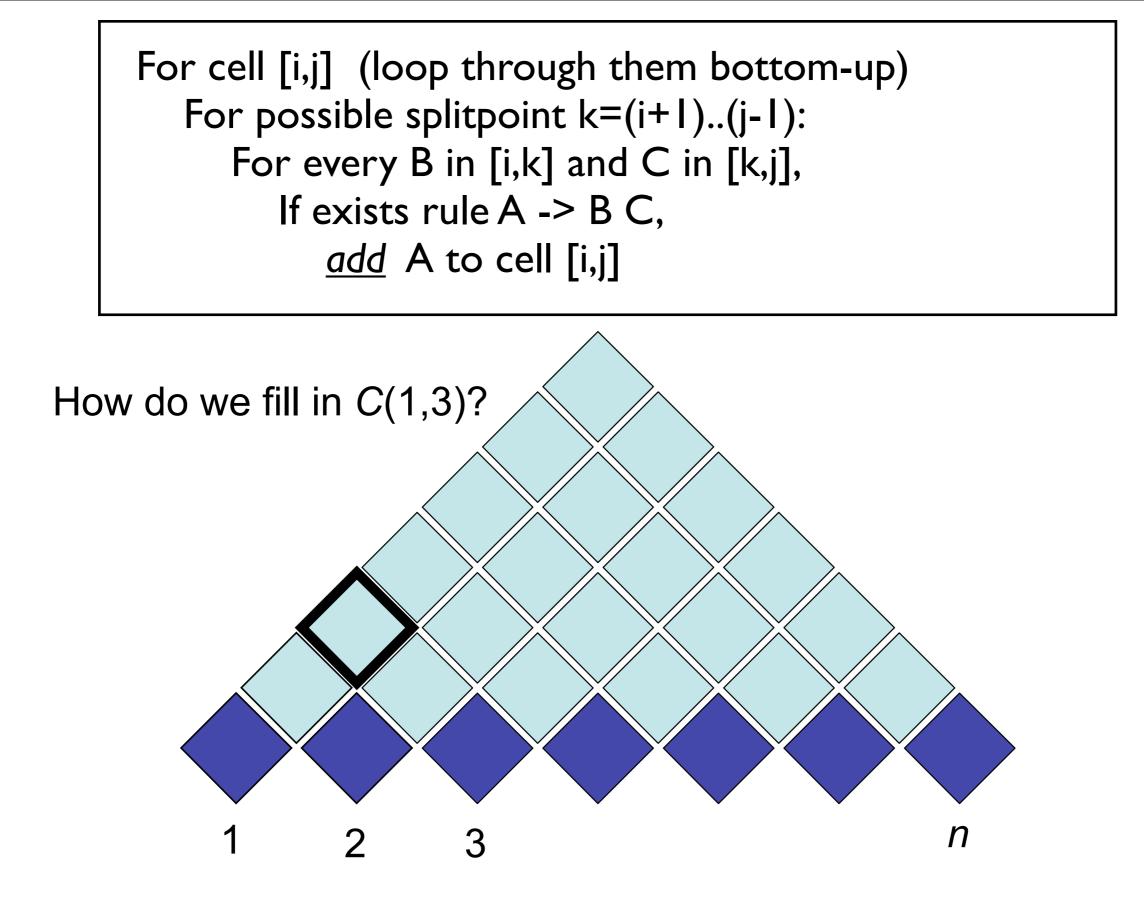
$S \rightarrow NP VP$
$S \rightarrow Aux NP VP$
$S \rightarrow VP$
$NP \rightarrow Pronoun$
$NP \rightarrow Proper-Noun$
$NP \rightarrow Det Nominal$
Nominal \rightarrow Noun
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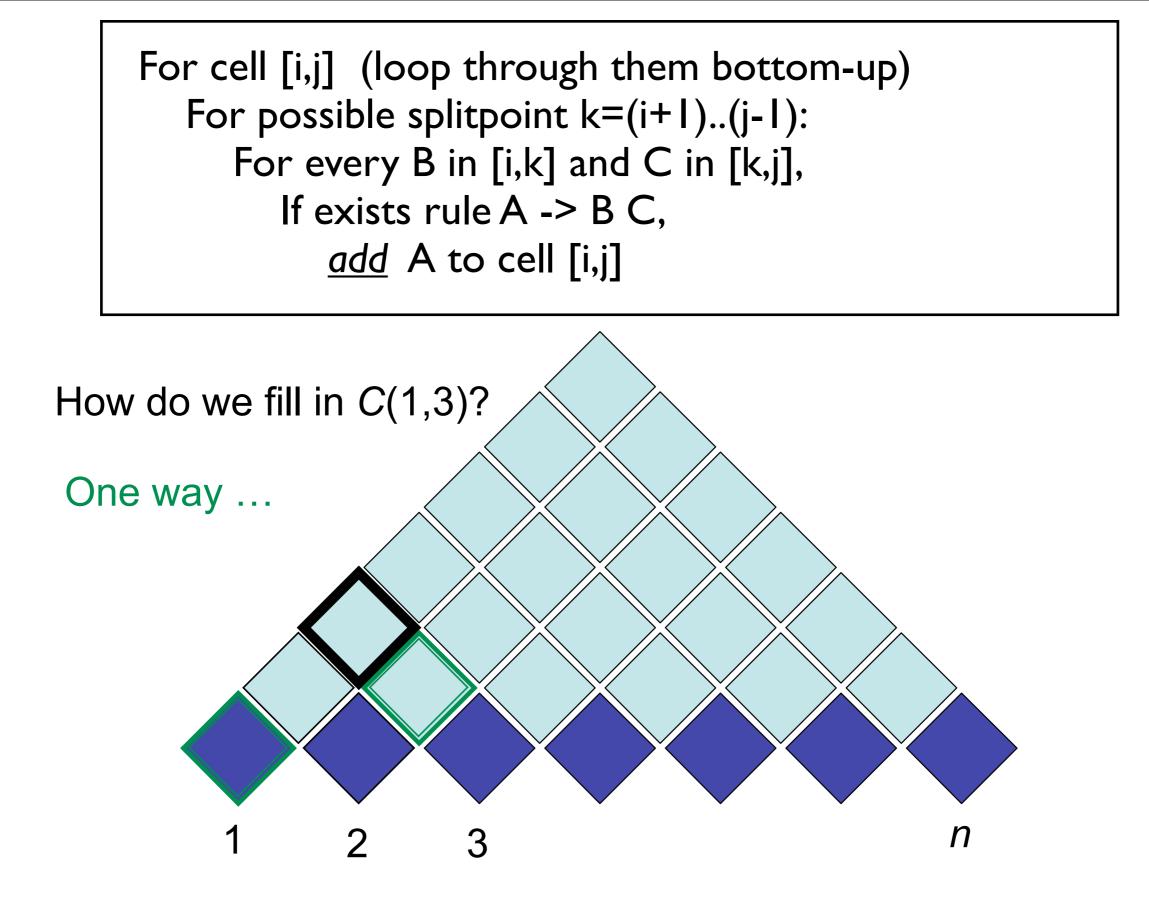
0	I	2	3	4 5
Book	the	flight	through	Houston
S,VP,Ve Nominal, Noun		S,VP,X2		S, VP
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]
	Det	NP		NP
	[1,2]	[1,3]	[1,4]	[1,5]
		Nominal, Noun		Nominal
		[2,3]	[2,4]	[2,5]
			Prep	PP
			[3,4]	[3,5]
n-up)				NP, Proper- Noun
				[4,5]
	(J&M has a slightly different cell			

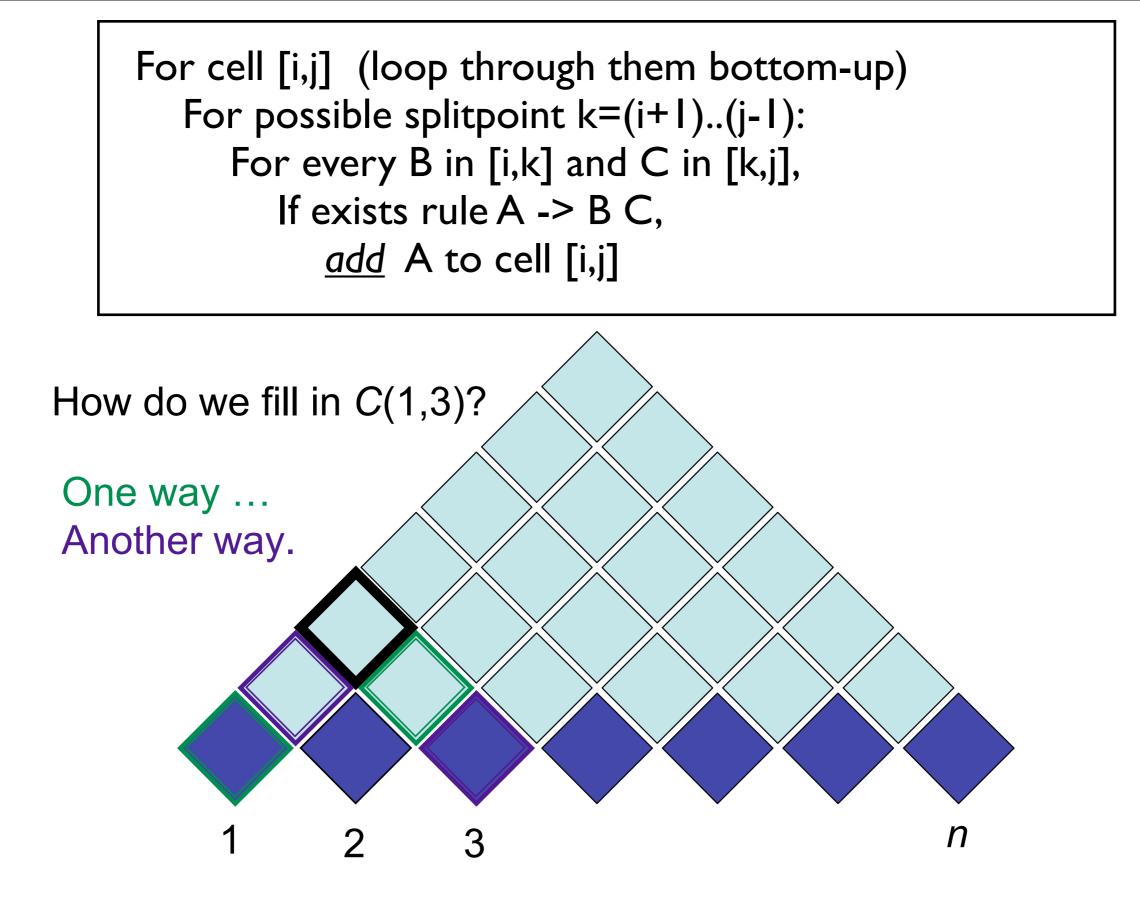
For cell [i,j] (loop through them bottom-up) For possible splitpoint k=(i+1)..(j-1): For every B in [i,k] and C in [k,j], If exists rule A -> B C, <u>add</u> A to cell [i,j]

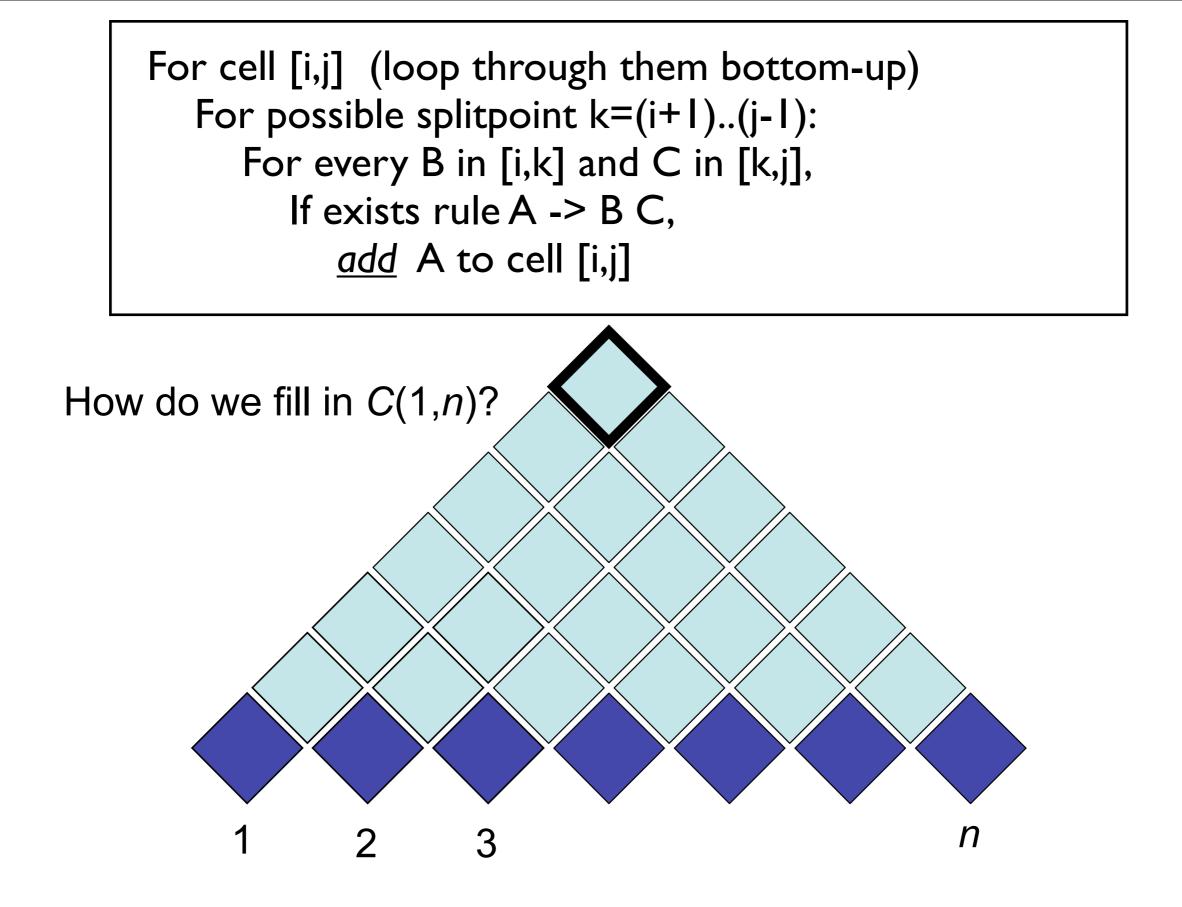


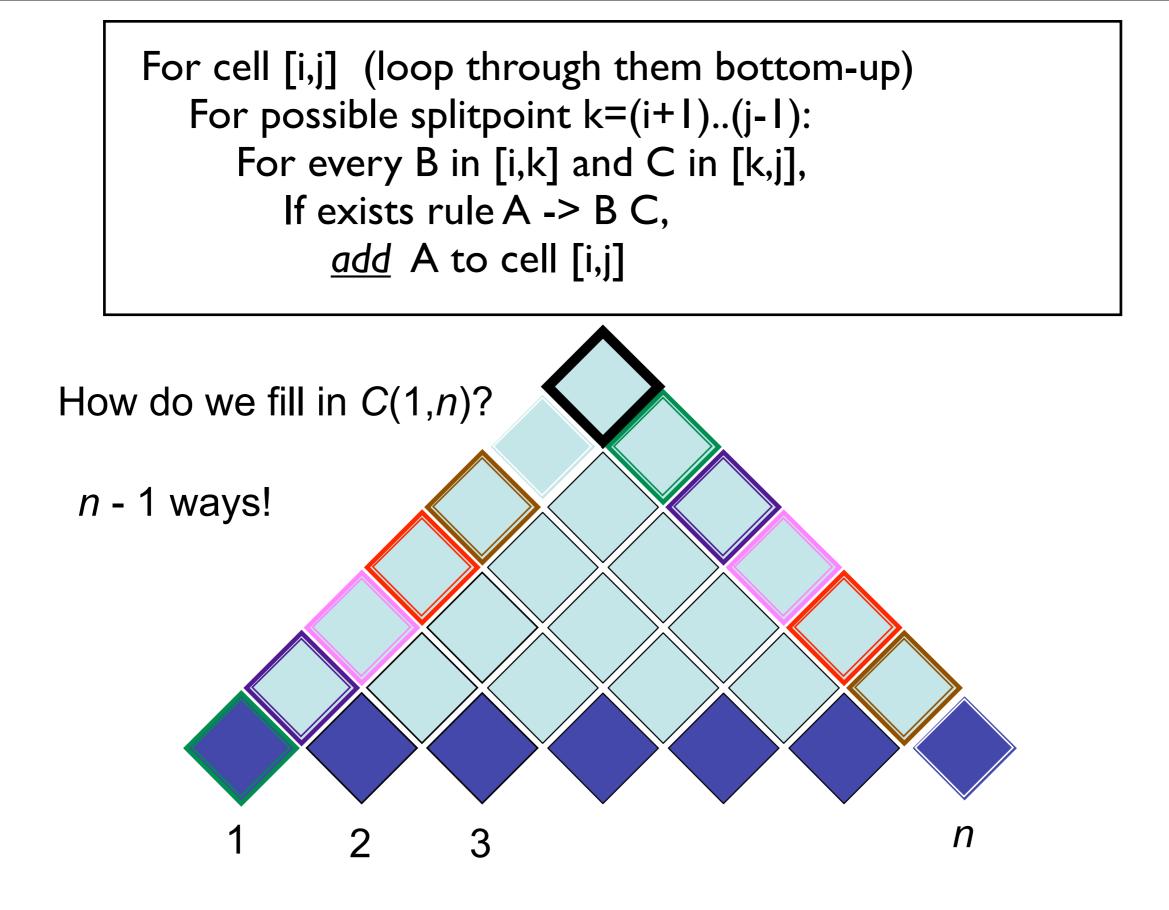


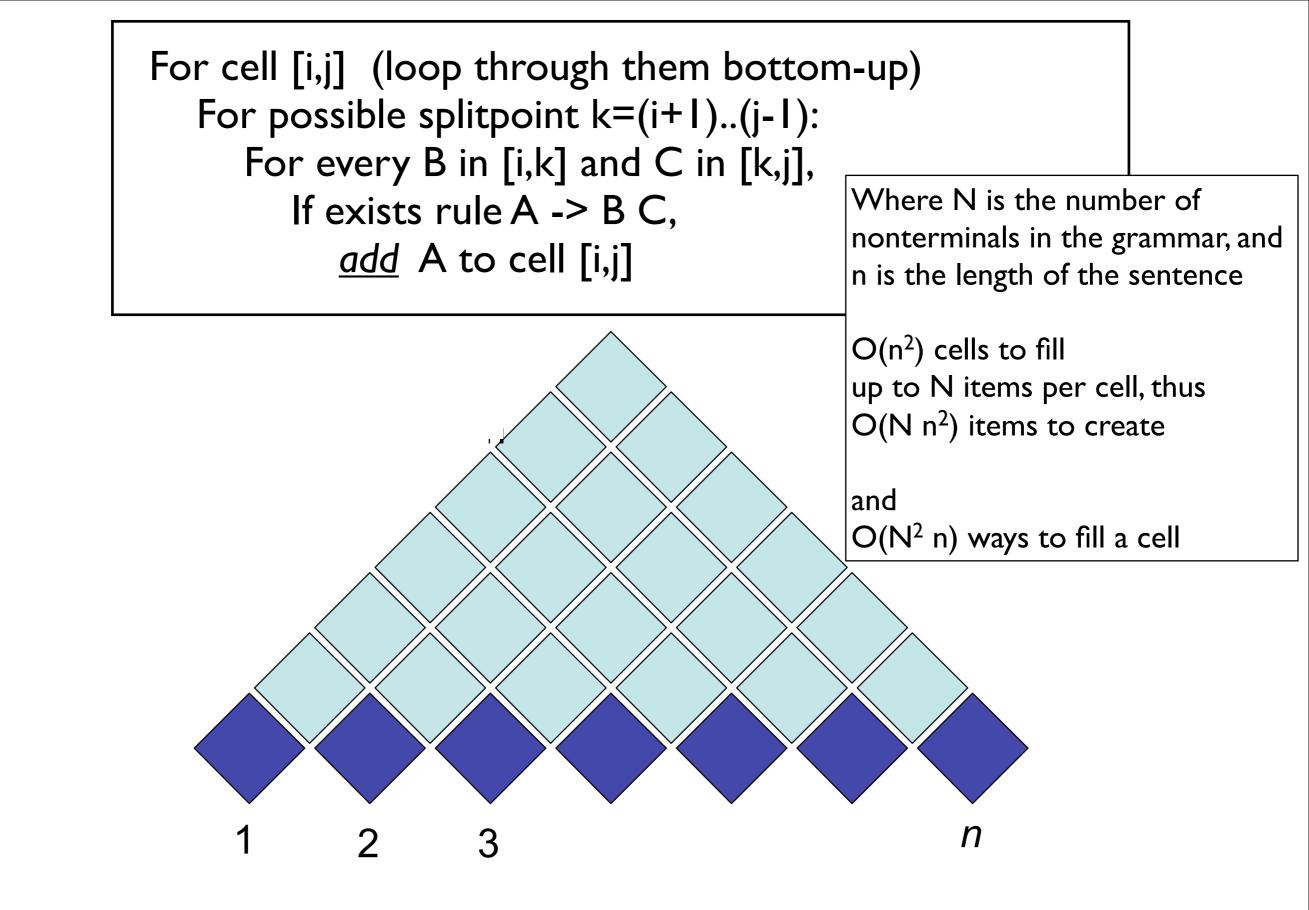






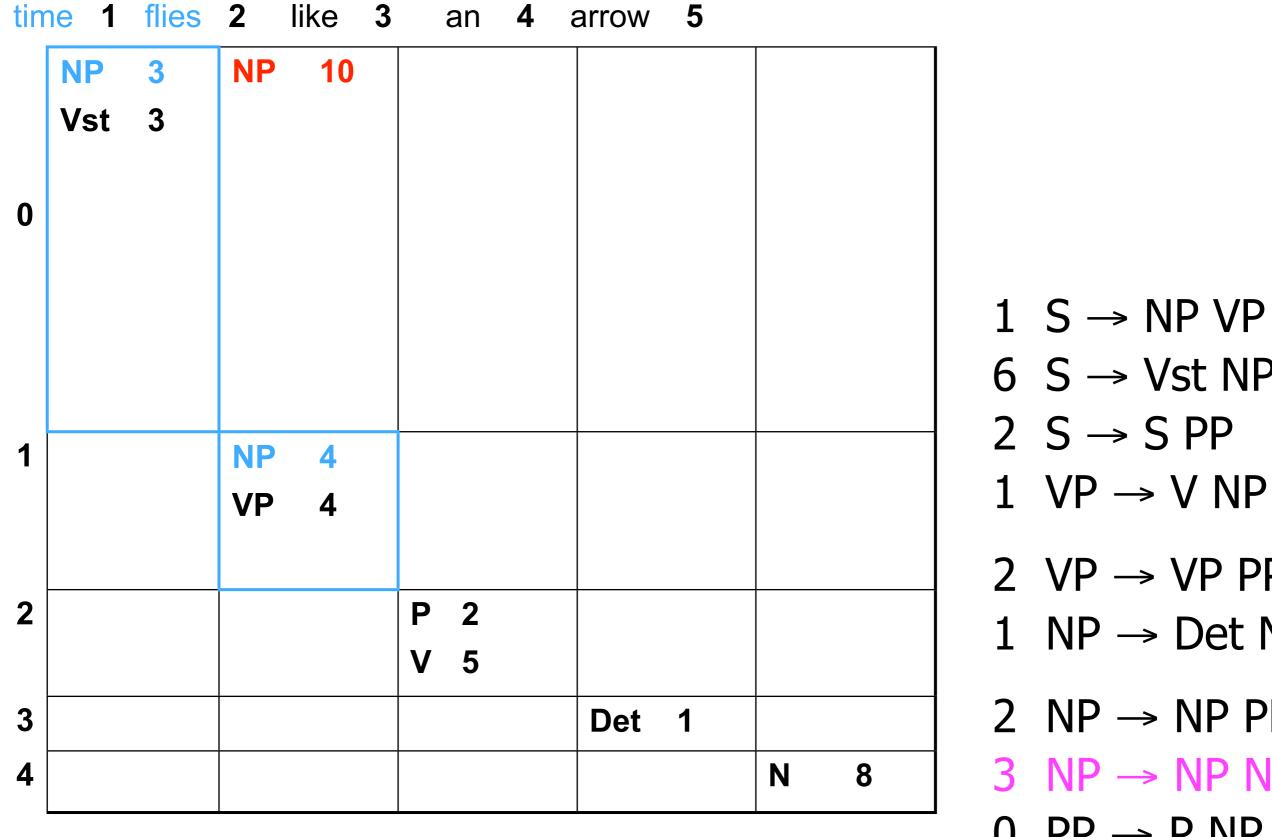






		-			U 1	-	expansi arsing)				$\begin{array}{c} NP \to time \\ Vst \to time \end{array}$
	ne 1	-				-	arrow				$NP \rightarrow flies$
	NP	3									$VP \to flies$
	Vst	3									$P \rightarrow like$
											$V \rightarrow like$
0											$\begin{array}{c} \text{Det} \rightarrow \text{an} \\ \text{N} \rightarrow \text{arrow} \end{array}$
											$1 S \rightarrow NP VP$
											$6 S \rightarrow Vst NP$
1			NP	4							$2 S \rightarrow S PP$
			VP	4							$1 \text{ VP} \rightarrow \text{V NP}$
											$2 \text{ VP} \rightarrow \text{VP PP}$
2					P 2						$1 \text{ NP} \rightarrow \text{Det N}$
					V 5						
3							Det	1			$2 \text{ NP} \rightarrow \text{NP PP}$
4									Ν	8	$3 \text{ NP} \rightarrow \text{NP} \text{ NP}$
			1				<u> </u>				$0 PP \rightarrow P NP$

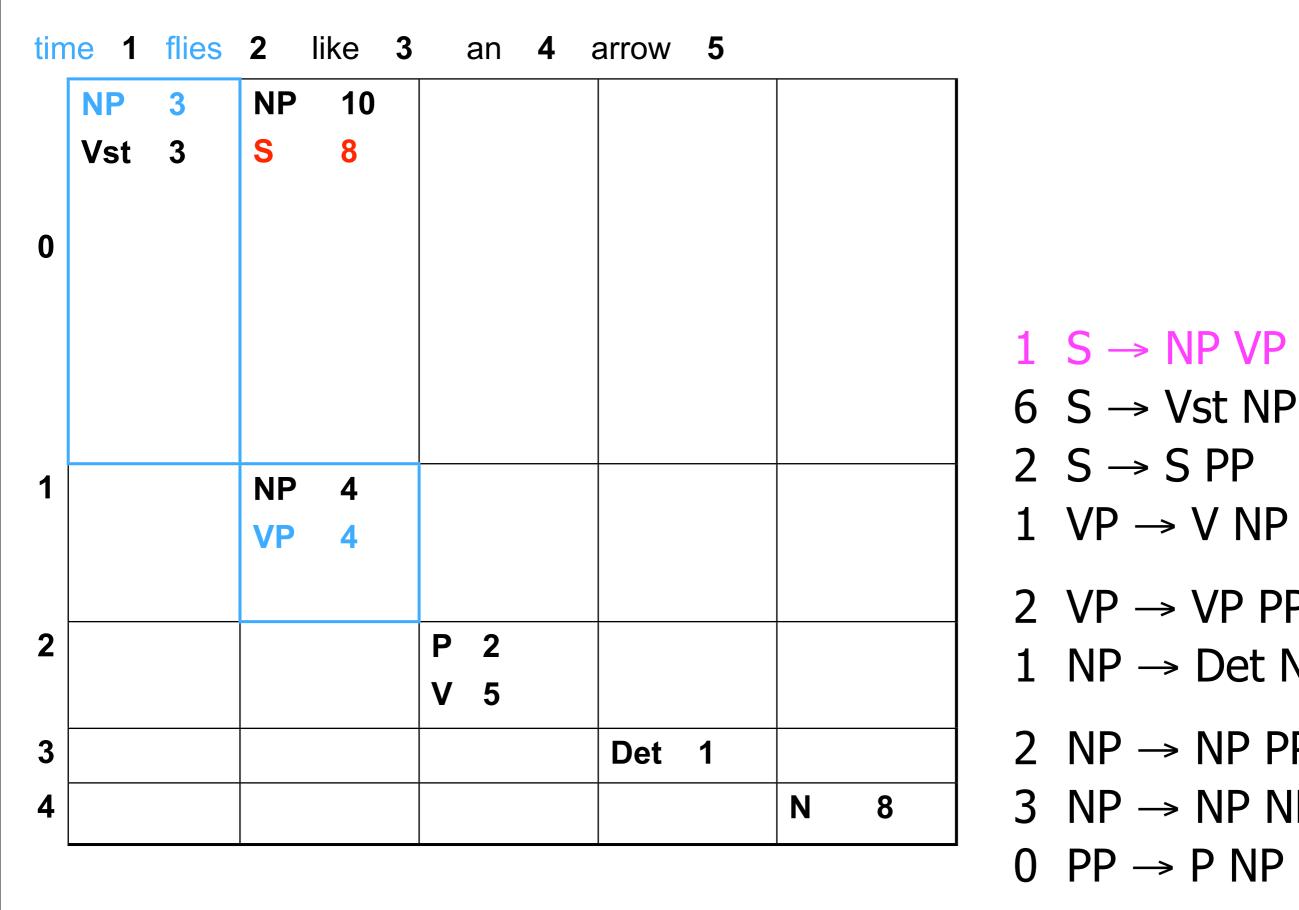
tin	ne 1	flies	2	like	3	ar	ן 4	4	arrow	5			
	NP	3											
	Vst	3											
0													
·													
													$1 S \rightarrow NP VP$
													$6 S \rightarrow Vst NP$
1			NP	4									$-2 S \rightarrow S PP$
•			VP	- 4									1 VP \rightarrow V NP
													$2 VP \rightarrow VP PP$
2						P 2)						$\begin{array}{c c} 2 & V & \searrow V & I \\ 1 & NP & \rightarrow Det N \end{array}$
						V 5	•						
3									Det	1			$2 \text{ NP} \rightarrow \text{NP PP}$
4											N	8	$3 \text{ NP} \rightarrow \text{NP} \text{ NP}$
													$- 0 PP \rightarrow P NP$



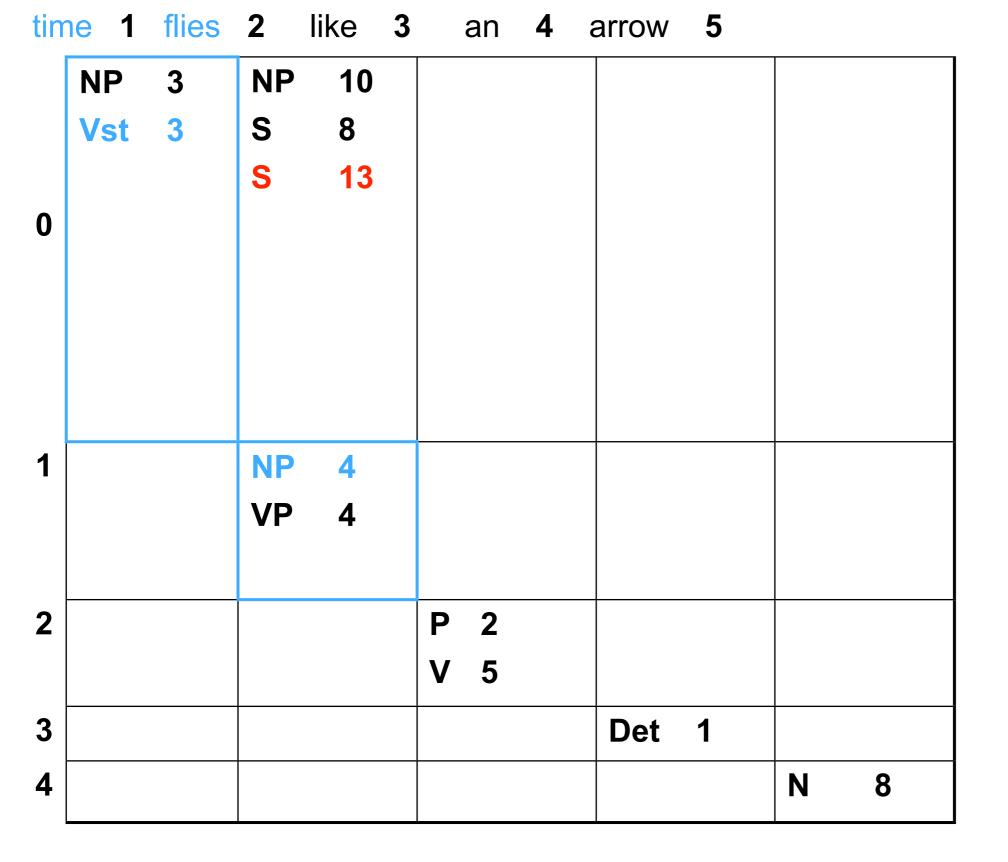
Sunday, November 9, 14

1 NP \rightarrow Det N 2 NP \rightarrow NP PP 3 NP \rightarrow NP NP $0 PP \rightarrow P NP$

- 2 VP \rightarrow VP PP
- 6 S \rightarrow Vst NP 2 S \rightarrow S PP



2 VP \rightarrow VP PP 1 NP \rightarrow Det N 2 NP \rightarrow NP PP 3 NP \rightarrow NP NP $0 PP \rightarrow P NP$



Sunday, November 9, 14

- 2 NP \rightarrow NP PP 3 NP \rightarrow NP NP 0 PP \rightarrow P NP
- 2 VP \rightarrow VP PP 1 NP \rightarrow Det N
- $\begin{array}{ccc} 2 & S \rightarrow S & PP \\ 1 & VP \rightarrow V & NP \end{array}$
- $1 S \rightarrow NP VP$ $6 S \rightarrow Vst NP$

un	ne 1	flies	1		.		an	4		row)	1		
	NP	3	NP	10											
	Vst	3	S	8											
			S	13											
0															
1			NP	4											
			VP	4	-	-									
				-											
•							•								
2)	2		-	-					
					\	/	5								
3									[Det	1				
4													Ν	8	

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time 1 flice 2

- $\begin{array}{ccc} 2 & NP \rightarrow NP & PP \\ 3 & NP \rightarrow NP & NP \\ 0 & PP \rightarrow P & NP \end{array}$
- $\begin{array}{ccc} 2 & VP \rightarrow VP & PP \\ 1 & NP \rightarrow Det & N \end{array}$
- $\begin{array}{ccc} 2 & S \rightarrow S & PP \\ 1 & VP \rightarrow V & NP \end{array}$
- $1 S \rightarrow NP VP$ 6 S \rightarrow Vst NP

	NP	3	NP	10						
	Vst	3	S	8						
			S	13						
			NP	4	_					
			VP	4						
					P	2				
					V	5				
							Det	1	NP	10
•									N	8

time 1 flies 2 like 3 an 4 arrow 5

Sunday, November 9, 14

3 NP \rightarrow NP NP 0 PP \rightarrow P NP

2 NP \rightarrow NP PP

- $\begin{array}{ll} 2 & VP \rightarrow VP \ PP \\ 1 & NP \rightarrow Det \ N \end{array}$
- $\begin{array}{ll} 2 & S \rightarrow S & PP \\ 1 & VP \rightarrow V & NP \end{array}$
- $\begin{array}{l}1 \quad S \rightarrow NP \ VP \\ 6 \quad S \rightarrow Vst \ NP \end{array}$

	NP	3	NP	10						
	Vst	3	S	8						
			S	13						
)										
			NP	4	_					
			VP	4						
2					 Ρ	2	_			
					V	5				
3							 Det	1	NP	10
1									Ν	8

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Sunday, November 9, 14

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- 2 NP \rightarrow NP PP 3 NP \rightarrow NP NP 0 PP \rightarrow P NP
- 2 VP \rightarrow VP PP 1 NP \rightarrow Det N
- $\begin{array}{l} 6 \quad S \rightarrow Vst \ NP \\ 2 \quad S \rightarrow S \ PP \end{array}$

1 VP \rightarrow V NP

1 S \rightarrow NP VP

	1e 1		s 2			an	 arrow	5		
	NP	3	NP	10	—					
	Vst	3	S	8						
			S	13						
			NP	4						
			VP		-		-			
				_						
							_			40
•					Ρ	2	-		PP	12
					V	5				
)							Det	1	NP	10
ļ									Ν	8

2 NP \rightarrow NP PP 3 NP \rightarrow NP NP 0 PP \rightarrow P NP

- $\begin{array}{ccc} 2 & VP \rightarrow VP & PP \\ 1 & NP \rightarrow Det & N \end{array}$
- $\begin{array}{c} \text{S} \rightarrow \text{SPP} \\ 1 \quad \text{VP} \rightarrow \text{VNP} \end{array}$
- $1 S \rightarrow NP VP$ $6 S \rightarrow Vst NP$

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in	ne	1	flies	2	like	3		an	4	arrow	5		
	NF)	3	NP	10		_						
	Vs	t	3	S	8								
				S	13								
0													
1				NP	4								
•				VP	4		—			-			
					T								
2							Ρ	2				PP	12
-							v	5		-		VP	16
3										Det	1	_	10
										Det	1	NP	
4												N	8

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Sunday, November 9, 14

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 $S \rightarrow S PP$ $VP \rightarrow V NP$ $VP \rightarrow VP PP$ $NP \rightarrow Det N$ $NP \rightarrow NP PP$ $NP \rightarrow NP NP$ $PP \rightarrow P NP$

 $\begin{array}{ccc} 1 & S \rightarrow NP & VP \\ 6 & S \rightarrow Vst & NP \end{array}$

	NP	3	NP	10	_					
	Vst	3	S	8						
			S	13						
0										
_										
1			NP	4	-		-			
			VP	4						
2						2	-		PP	12
						5			VP	16
3							Det	1	NP	10
4									Ν	8

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2 NP \rightarrow NP PP 3 NP \rightarrow NP NP 0 PP \rightarrow P NP

- 2 VP \rightarrow VP PP 1 NP \rightarrow Det N
- $\begin{array}{ccc} 6 & S \rightarrow Vst & NP \\ 2 & S \rightarrow S & PP \end{array}$

1 VP \rightarrow V NP

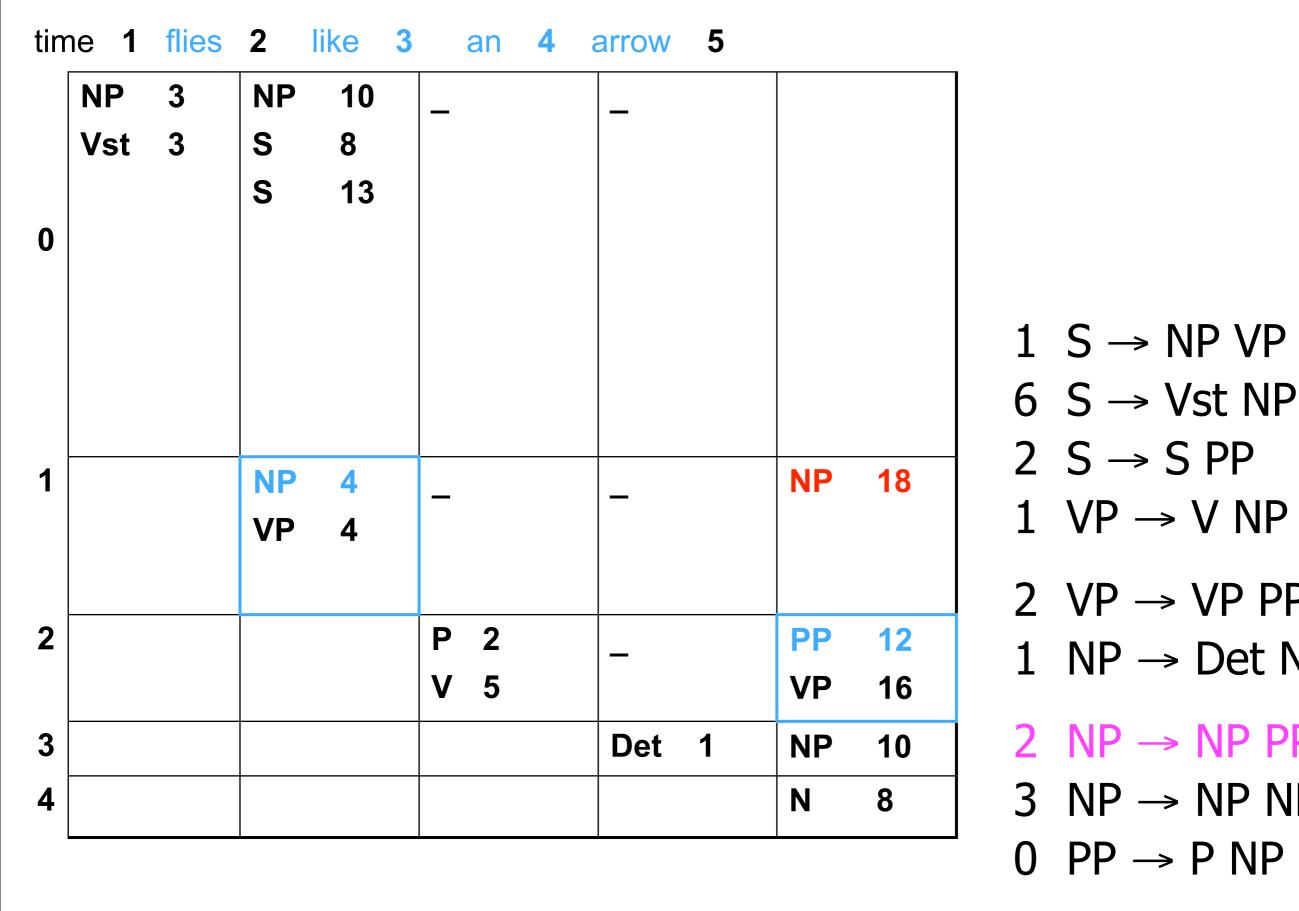
1 S \rightarrow NP VP

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2 VP \rightarrow VP PP 1 NP \rightarrow Det N 2 NP \rightarrow NP PP 3 NP \rightarrow NP NP $0 PP \rightarrow P NP$

ITT	1e 1	flies		пке	3	an	4	arrow	5	-	
	NP	3	NP	10	_			_			
	Vst	3	S	8							
			S	13							
			NP	4	_			_		NP	18
			VP	4						S	21
)					Ρ	2				PP	12
					V	5				VP	16
6								Det	1	NP	10
									-		
ŀ										N	8

time 1 flice 2

Sunday, November 9, 14

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1 VP \rightarrow V NP 2 VP \rightarrow VP PP 1 NP \rightarrow Det N 2 NP \rightarrow NP PP 3 NP \rightarrow NP NP 0 PP \rightarrow P NP

 $1 S \rightarrow NP VP$ 6 S \rightarrow Vst NP

2 S \rightarrow S PP

. 1 1 1	ne 1	flies	1		3	an	4	arrow	5	1	
	NP	3	NP	10	-			_			
	Vst	3	S	8							
			S	13							
1			NP	4	_			_		NP	18
			VP	4						S	21
										VP	18
2					Ρ	2		_		PP	12
					V	5				VP	16
3								Det	1	NP	10
4										N	8

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time 1 flice 2

Sunday, November 9, 14

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1 VP \rightarrow V NP 2 VP \rightarrow VP PP 1 NP \rightarrow Det N 2 NP \rightarrow NP PP 3 NP \rightarrow NP NP 0 PP \rightarrow P NP

 $1 S \rightarrow NP VP$ 6 S \rightarrow Vst NP

2 S \rightarrow S PP

	NP	3	NP	10	_		_			
	Vst	3	S	8						
			S	13						
			NP	4	-		-		NP	18
			VP	4					S	21
									VP	18
					P	2			PP	12
					V	5			VP	16
3							Det	1	NP	10
									N	8

time 1 flips 2

Sunday, November 9, 14

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1 NP \rightarrow Det N 2 NP \rightarrow NP PP 3 NP \rightarrow NP NP 0 PP \rightarrow P NP

- $\begin{array}{c} 1 \quad VP \rightarrow V \quad NP \\ 2 \quad VP \rightarrow VP \quad PP \end{array}$
- 1 S \rightarrow NP VP 6 S \rightarrow Vst NP 2 S \rightarrow S PP

	NP	3	NP	10	_		_		NP	24
	Vst	3	S	8						
			S	13						
)										
1				Λ						10
			NP	4	-		-		NP	18
			VP	4					S	21
									VP	18
2					Р	2	_		PP	12
					V	5			VP	16
3							Det	1	NP	10
			1						N	8

1 S \rightarrow NP VP 6 S \rightarrow Vst NP 2 S \rightarrow S PP 1 VP \rightarrow V NP 2 VP \rightarrow VP PP 1 NP \rightarrow Det N 2 NP \rightarrow NP PP 3 NP \rightarrow NP NP $0 PP \rightarrow P NP$

	NP	3	NP	10	_		_	NP	24
	Vst	3	S	8				S	22
			S	13					
)									
1									10
			NP	4	-		-	NP	18
			VP	4				S	21
								VP	18
2					P	2	_	PP	12
					V	5		VP	16
3							Det 1	NP	10
1								N	8

121

2 S → S PP 1 VP → V NP 2 VP → VP PP 1 NP → Det N 2 NP → NP PP 3 NP → NP NP 0 PP → P NP

1 S \rightarrow NP VP

6 S \rightarrow Vst NP

	NP	3	NP	10	_		_		NP	24
	Vst	3	S	8					S	22
			S	13					S	27
)										
			NP	4	+_		 		NP	18
			VP	4					S	21
									VP	18
)					Ρ	2			PP	12
					V	5			VP	16
3							Det	1	NP	10
									N	8

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1 NP \rightarrow Det N 2 NP \rightarrow NP PP 3 NP \rightarrow NP NP 0 PP \rightarrow P NP

- 2 VP \rightarrow VP PP
- $\begin{array}{ccc} 6 & S \rightarrow Vst & NP \\ 2 & S \rightarrow S & PP \end{array}$

1 VP \rightarrow V NP

 $1 S \rightarrow NP VP$

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	NP	3	NP	10	_		_		NP	24
	Vst	3	S	8					S	22
			S	13					S	27
			NP	4					NP	18
			VP	4	-		-		S	21
				•					VP	18
					P	2			PP	12
•							-			
					V	5			VP	16
)							Det	1	NP	10
þ									N	8

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time 1

Sunday, November 9, 14

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2 VP → VP PP 1 NP → Det N 2 NP → NP PP 3 NP → NP NP 0 PP → P NP

 $1 S \rightarrow NP VP$ $6 S \rightarrow Vst NP$ $2 S \rightarrow S PP$

1 VP \rightarrow V NP

	NP	3	NP	10					NP	24
	Vst	3	S	8					S	22
			S	13					S	27
									NP	24
			NP	4					NP	18
			VP	4					S	21
									VP	18
					Ρ	2			PP	12
					V	5			VP	16
3							Det	1	NP	10
ŀ									N	8

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6 S \rightarrow Vst NP 2 S \rightarrow S PP 1 VP \rightarrow V NP 2 VP \rightarrow VP PP 1 NP \rightarrow Det N 2 NP \rightarrow NP PP 3 NP \rightarrow NP NP 0 PP \rightarrow P NP

1 S \rightarrow NP VP

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	ne 1	flies			3	an	4	arrow	5		
	NP	3	NP	10	_			_		NP	24
	Vst	3	S	8						S	22
			S	13						S	27
)										NP	24
										S	27
			NP	4	_			_		NP	18
			VP	4						S	21
										VP	18
)					Р	2		_		PP	12
					V	5				VP	16
8								Det	1	NP	10
ŀ										Ν	8

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6 S \rightarrow Vst NP 2 S \rightarrow S PP 1 VP \rightarrow V NP 2 VP \rightarrow VP PP 1 NP \rightarrow Det N 2 NP \rightarrow NP PP 3 NP \rightarrow NP NP

1 S \rightarrow NP VP

 $0 PP \rightarrow P NP$

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	ne 1	flies	2	like	3	an	4	arrow	5	-1	
	NP	3	NP	10	_			_		NP	24
	Vst	3	S	8						S	22
			S	13						S	27
)										NP	24
										S	27
										S	22
1			NP VP	4 4						NP S VP	18 21 18
2					P	2				PP	12
					V	5				VP	16
3								Det	1	NP	10
4										N	8

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orrow

time 1

Sunday, November 9, 14

flice 2

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 $VP \rightarrow VP PP$ $NP \rightarrow Det N$ $NP \rightarrow NP PP$ $NP \rightarrow NP NP$ $PP \rightarrow P NP$

 $\begin{array}{l}1 \quad S \rightarrow NP \ VP \\6 \quad S \rightarrow Vst \ NP\end{array}$

1 VP \rightarrow V NP

2 S \rightarrow S PP

	NP	3	NP	10	_	_		NP	24
	Vst	3	S	8				S	22
			S	13				S	27
								NP	24
								S	27
								S	22
								S	27
			NP	4	_			NP	18
			VP	4				S	21
								VP	18
					P 2	_		PP	12
					V 5			VP	16
)						 Det	1	NP	10
•								Ν	8

an

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arrow

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2 VP → VP PP 1 NP → Det N 2 NP → NP PP 3 NP → NP NP 0 PP → P NP

 $6 S \rightarrow Vst NP$ $2 S \rightarrow S PP$

1 VP \rightarrow V NP

 $1 S \rightarrow NP VP$

time 1 flips 2

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Follow backpointers ...

in	ne	1	flies	2	like	3		an	4	arrow	5		
	Ν	Ρ	3	NP	10					_		NP	24
	٧s	st	3	S	8							S	22
				S	13							S	27
0												NP	24
												S	27
												S	22
												S	27
1				NP	4							NP	18
				VP	4							S	21
												VP	18
2							Ρ	2				PP	12
							V	5				VP	16
3										Det	1	NP	10
1												N	8

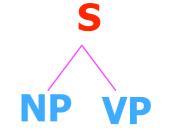
- $0 PP \rightarrow P NP$
- 2 NP \rightarrow NP PP

3 NP \rightarrow NP NP

- 2 VP \rightarrow VP PP 1 NP \rightarrow Det N
- 1 VP \rightarrow V NP
- $2 S \rightarrow S PP$
- $6 S \rightarrow Vst NP$
- $1 S \rightarrow NP VP$

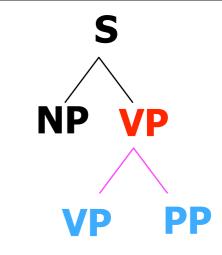
S

im	e 1	flies	2	like	3	6	an	4	arrow	5		
	NP	3	NP	10		_			_		NP	24
	Vst	3	S	8							S	22
			S	13							S	27
0											NP	24
											S	27
											S	22
											S	27
1			NP	4							NP	18
			VP	4							S	21
											VP	18
2					F	2	2		_		PP	12
					\	/	5				VP	16
3									Det	1	NP	10
4 [Ν	8



- 1 S \rightarrow NP VP 6 S \rightarrow Vst NP
- 2 S \rightarrow S PP
- 1 VP \rightarrow V NP
- 2 VP \rightarrow VP PP
- 1 NP \rightarrow Det N
- 2 NP \rightarrow NP PP
- 3 NP \rightarrow NP NP

tim	ne	1	flies	2	like	3		an	4	arrow	5		
	Ν	Ρ	3	NP	10		_			_		NP	24
	٧s	st	3	S	8							S	22
				S	13							S	27
0												NP	24
												S	27
												S	22
												S	27
1				NP	4							NP	18
				VP	4							S	21
												VP	18
2							Ρ	2		_		PP	12
							V	5				VP	16
3										Det	1	NP	10
4												N	8



1 S \rightarrow NP VP

- 6 S \rightarrow Vst NP
- 2 S \rightarrow S PP

2 VP \rightarrow VP PP

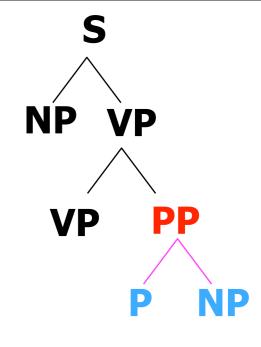
1 NP \rightarrow Det N

- 1 VP \rightarrow V NP

- 2 NP \rightarrow NP PP 3 NP \rightarrow NP NP

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tim	ıe	1	flies	2	like	3		an	4	arrow	5		
	NF		3	NP	10		_			_		NP	24
	Vs	t	3	S	8							S	22
				S	13							S	27
0												NP	24
												S	27
												S	22
												S	27
1				NP	4		_			_		NP	18
				VP	4							S	21
												VP	18
2							Ρ	2		_		PP	12
							V	5				VP	16
3										Det	1	NP	10
4												N	8



 $\begin{array}{l}1 \quad S \rightarrow NP \ VP \\6 \quad S \rightarrow Vst \ NP\end{array}$

 $2 S \rightarrow S PP$

1 VP
$$\rightarrow$$
 V NP

- 2 VP \rightarrow VP PP
- 1 NP \rightarrow Det N
- 2 NP \rightarrow NP PP
- 3 NP \rightarrow NP NP

tin	ne 1	flies	2	like	3		an	4	arrow	5		
	NP	3	NP	10					_		NP	24
	Vst	3	S	8							S	22
			S	13							S	27
0											NP	24
											S	27
											S	22
											S	27
1			NP	4		_			_		NP	18
			VP	4							S	21
											VP	18
2						Ρ	2		_		PP	12
						V	5				VP	16
3									Det	1	NP	10
4											N	8

Det Ν 1 S \rightarrow NP VP 6 S \rightarrow Vst NP 2 S \rightarrow S PP 1 VP \rightarrow V NP 2 VP \rightarrow VP PP 1 NP \rightarrow Det N 2 NP \rightarrow NP PP 3 NP \rightarrow NP NP

