CKY Parsing

LING 571 — Deep Processing Techniques for NLP
October 8, 2018
Ryan Georgi





Start recording!





Misc. & Announcements





HW #2

- Due tonight, I I:00pm Pacific
- Grammar output format:
 - 1. Terminals quoted (single or double)
 - 2. One production per line
 - Optionally, RHS alternates with vertical bar/pipe character: |
 - 3. Start symbol is first nonterminal encountered in file





Indigenous Peoples' Day

- Seattle/Sealth
- For those of you taking 550:
 - The Lushootseed spelling [IPA] of Chief Seattle/Sealth:
 - si?ał [ˈsi?aːł]
- Duwamish Dx^wdəw?abš [dx^wdew?ab∫]







Indigenous Peoples' Day

- Studying non-English languages gives more holistic insight for NLP tasks
 - Many interesting phenomena in non-Indo-European languages
- Lushootseed exhibits debatable distinction between verbs and nouns
 - ?uxw ti sbiaw
 goes that-which is-a-coyote
 "The/a coyote goes"
 - sbiaw ti ?uxw is-a-coyote that-which goes "The one who goes is a coyote"

via Beck, 2013

(Translation distinction provided for clarity — semantically equivalent)





Indigenous Peoples' Day

- UW American Indian Studies Courses
 - (Sometimes including language courses, e.g. Southern Lushootseed)

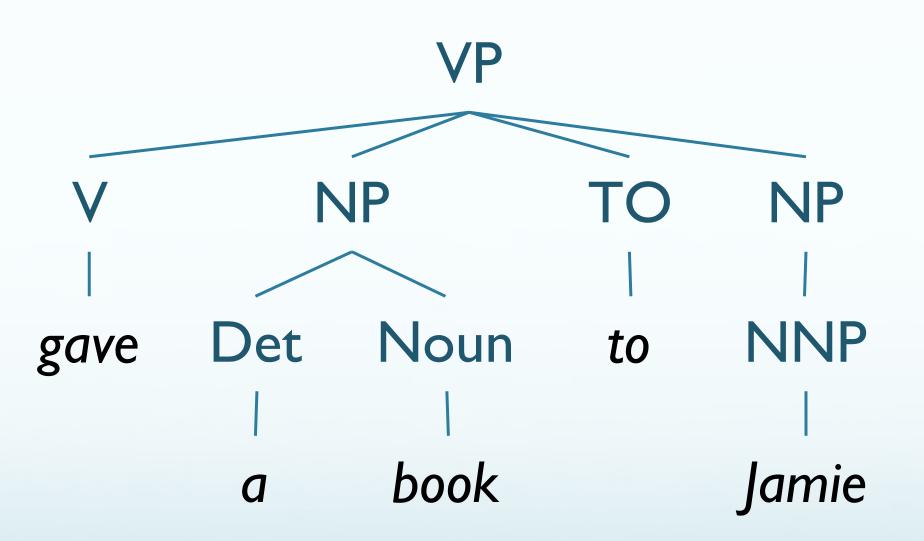




Variation in CNF: Binarization

Original Rule

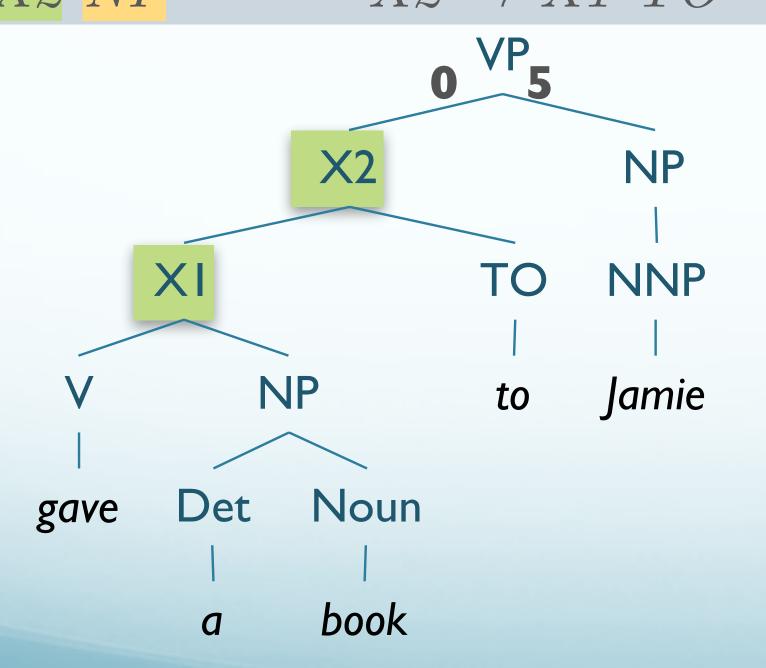
 $VP \rightarrow V NP TO NP$

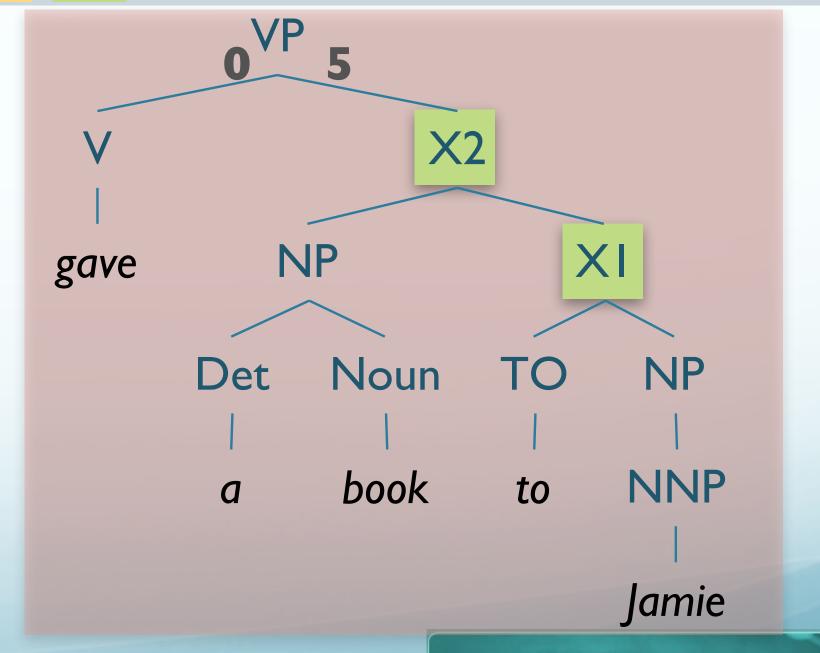






Variation in CNF: Binarization





Roadmap

- CKY Parsing Algorithm
 - Dynamic programming structure
 - Algorithm and example
 - Analysis & Discussion

- Probabilistic CFGs
 - Motivation: Ambiguity
 - Augmenting CFGs with probabilities





CKY

- Given an input string S of length n
- Build table $(n + 1) \times (n + 1)$
 - Indexes correspond to inter-word positions
 - Book | that 2 flight 3
- ullet Each cell [i,j] contains SETS $\{\ \}$ of non-terminals with derivations spanning i,j
 - [j-1, j] contains pre-terminals
 - if [0, n] contains the start symbol, the sentence is **accepted**

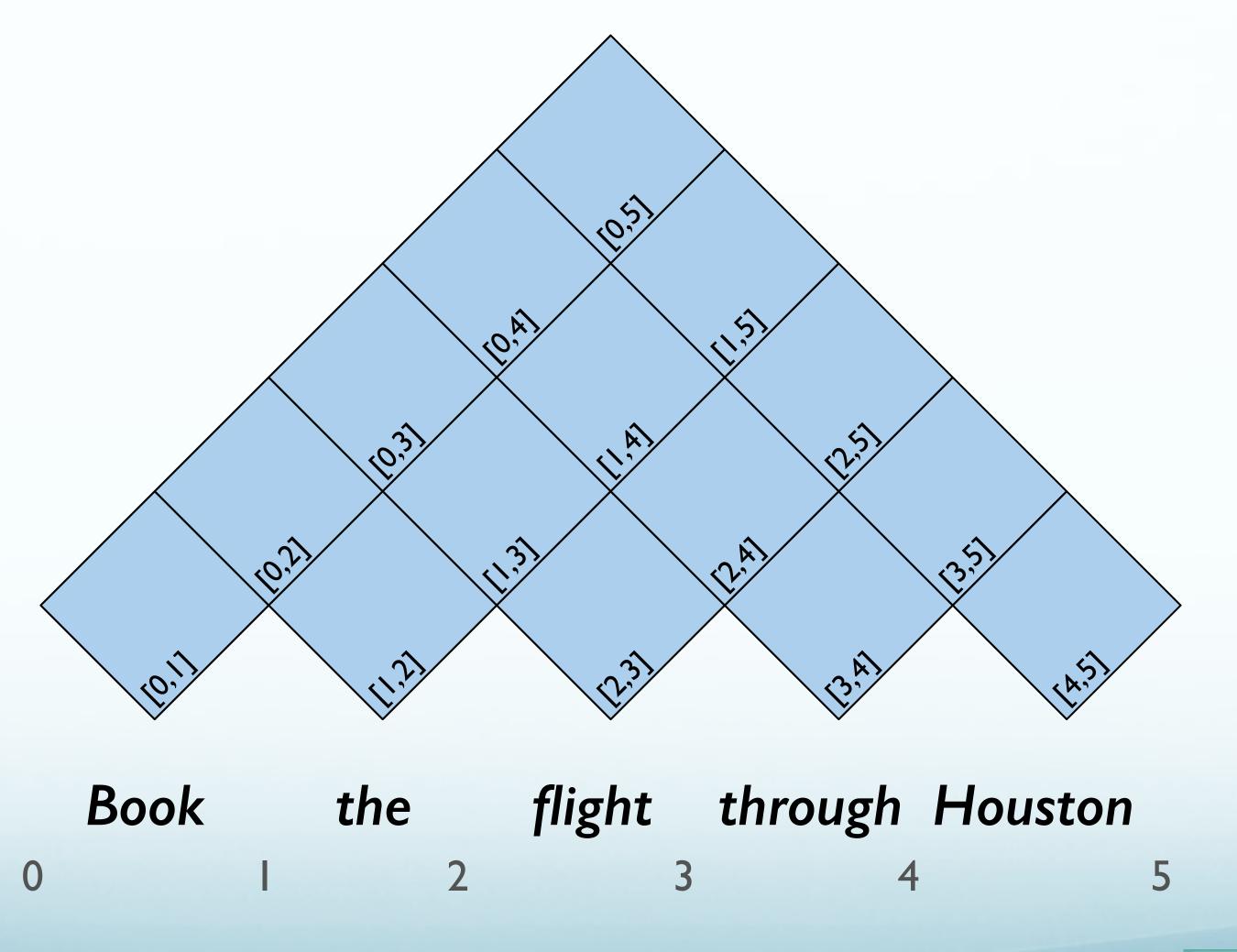




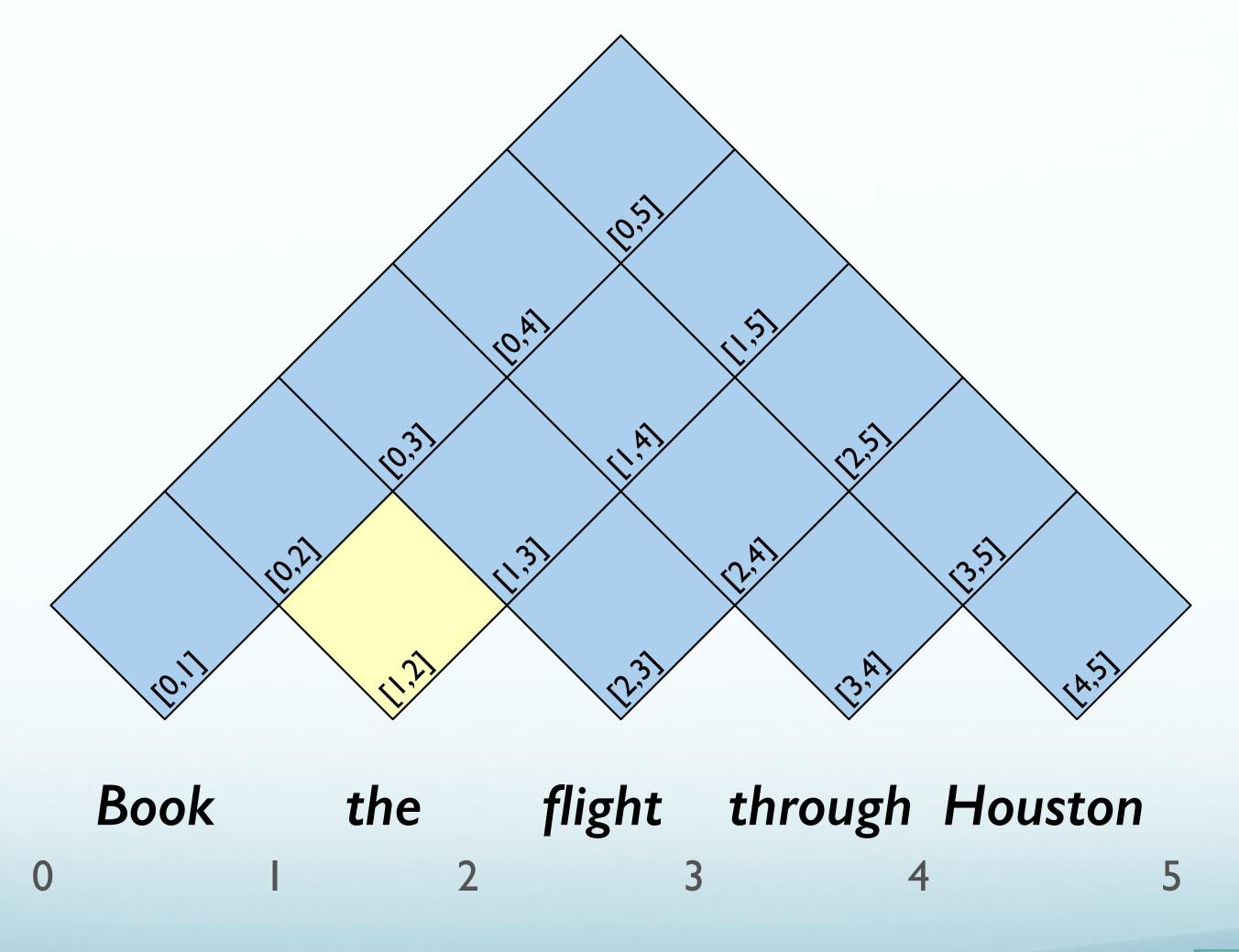
Book	the	flight	through	Houston
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]
	[1,2]	[1,3]	 [1,4]	[1,5]
		[2,3]	[2,4]	[2,5]
			[3,4]	[3,5]
			[
				Γ 4 Ε3
				[4,5]



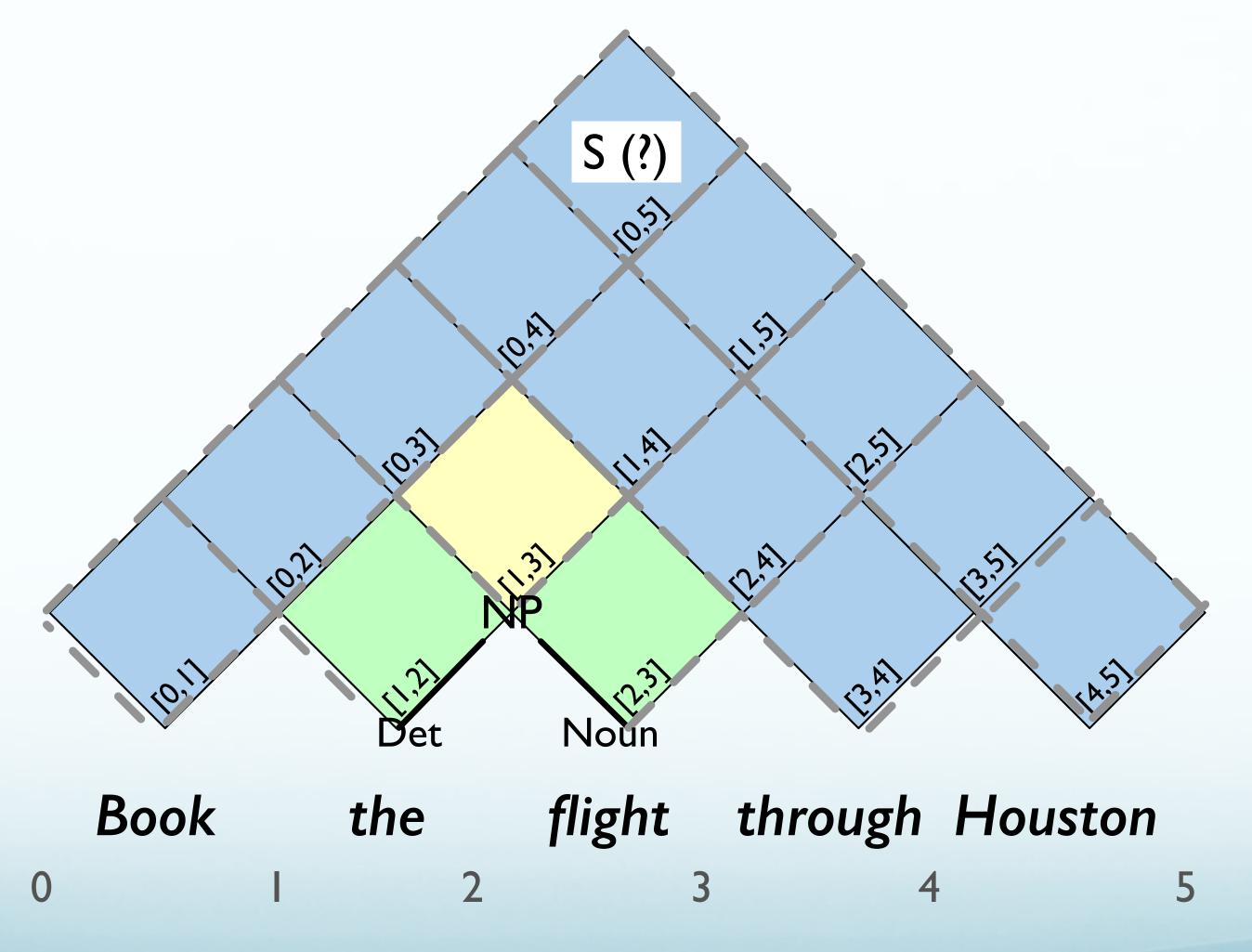
















Dynamic Programming in CKY

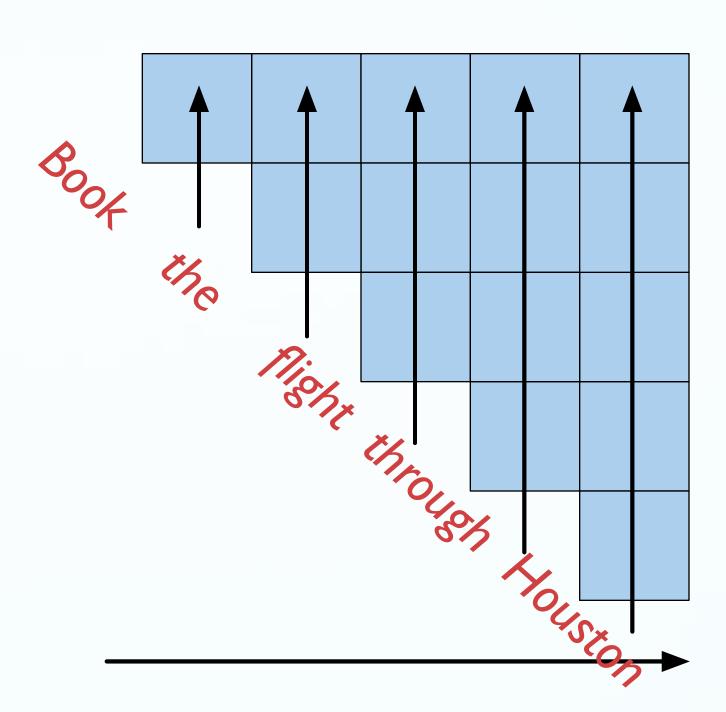
- Key idea:
 - ullet for i < k < j
 - ullet ...and a parse spanning substring [i,j]
 - ullet $\exists k$ such that there are parses spanning [i, k] and [k, j]
 - We can construct parses for whole sentences by building from these partial parses
- ullet So to have a rule $oldsymbol{A} o oldsymbol{B}$ $oldsymbol{C}$ in [~i,~j~]
 - ullet Must have B in $[\ i,j\]$ and C in $[\ k,j\]$ for some i < k < j
 - ullet CNF forces this for all j>i+1







- Table fills:
 - Column-by-column, left-to-right
 - bottom-to-top
- Why?
 - To fill each cell, must have access to all sub-spans
 - For cell [i, j], must be able to access all cells [i, k] and [k, j] where i < k < j
 - Allows online sentence analysis
 - Works across input string as it arrives





CKY Algorithm

```
function CKY-Parse(words, grammar) returns table
for j \leftarrow from 1 to Length(words) do
     table[j-1,j] \leftarrow \{A \mid A \rightarrow words[j] \in grammar\}
        for i \leftarrow \text{from } j-2 \text{ downto } 0 \text{ do}
            for k \leftarrow i + 1 to j - 1 do
                table[i, j] \leftarrow table[i, j] \cup
                    \{A \mid A \rightarrow BC \in grammar\}
                     B \in table[i, k],
                     C \in table[k, j]
```

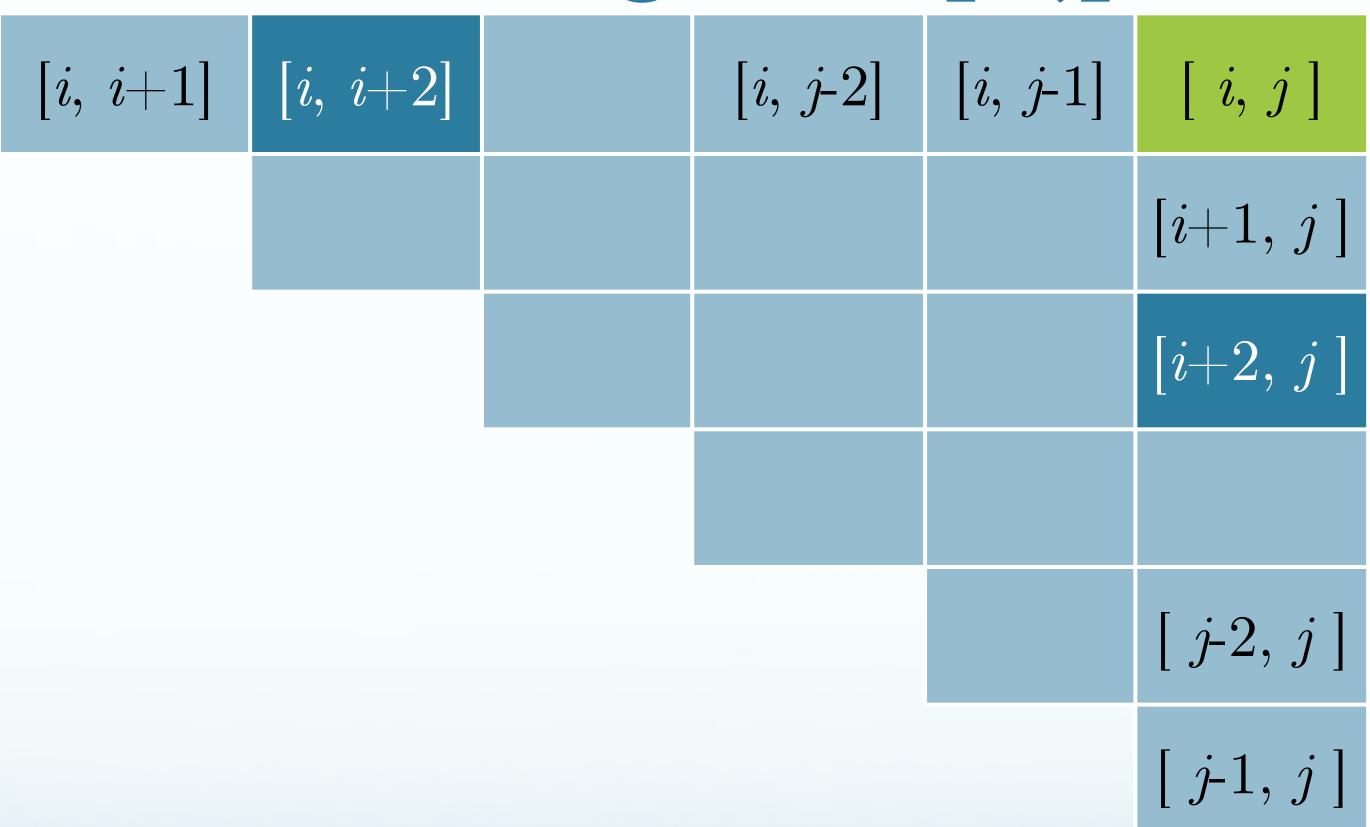
- Left-to-right, bottom-to-top
- Sliding k as the pivot for child nodes
- Filling the cell with set of applicable rules





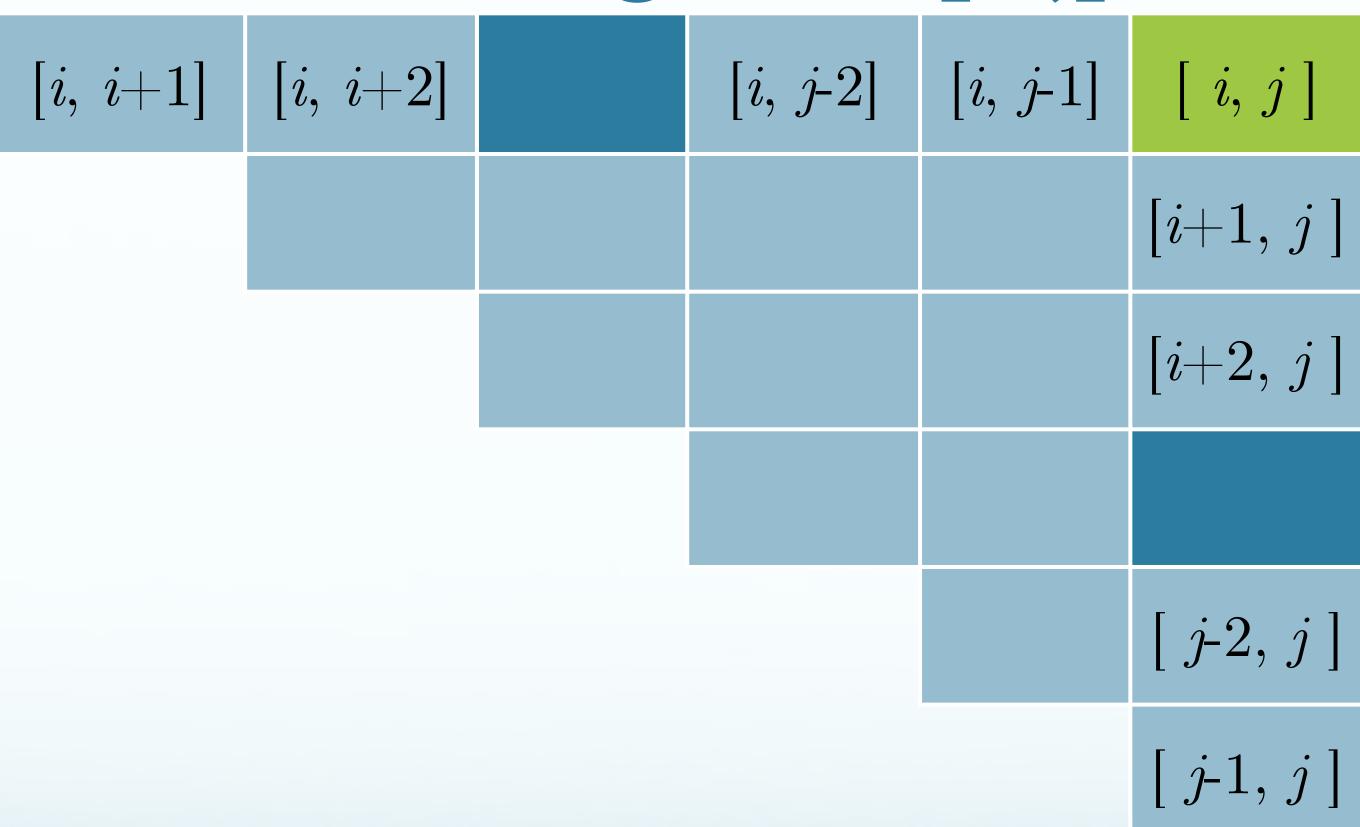






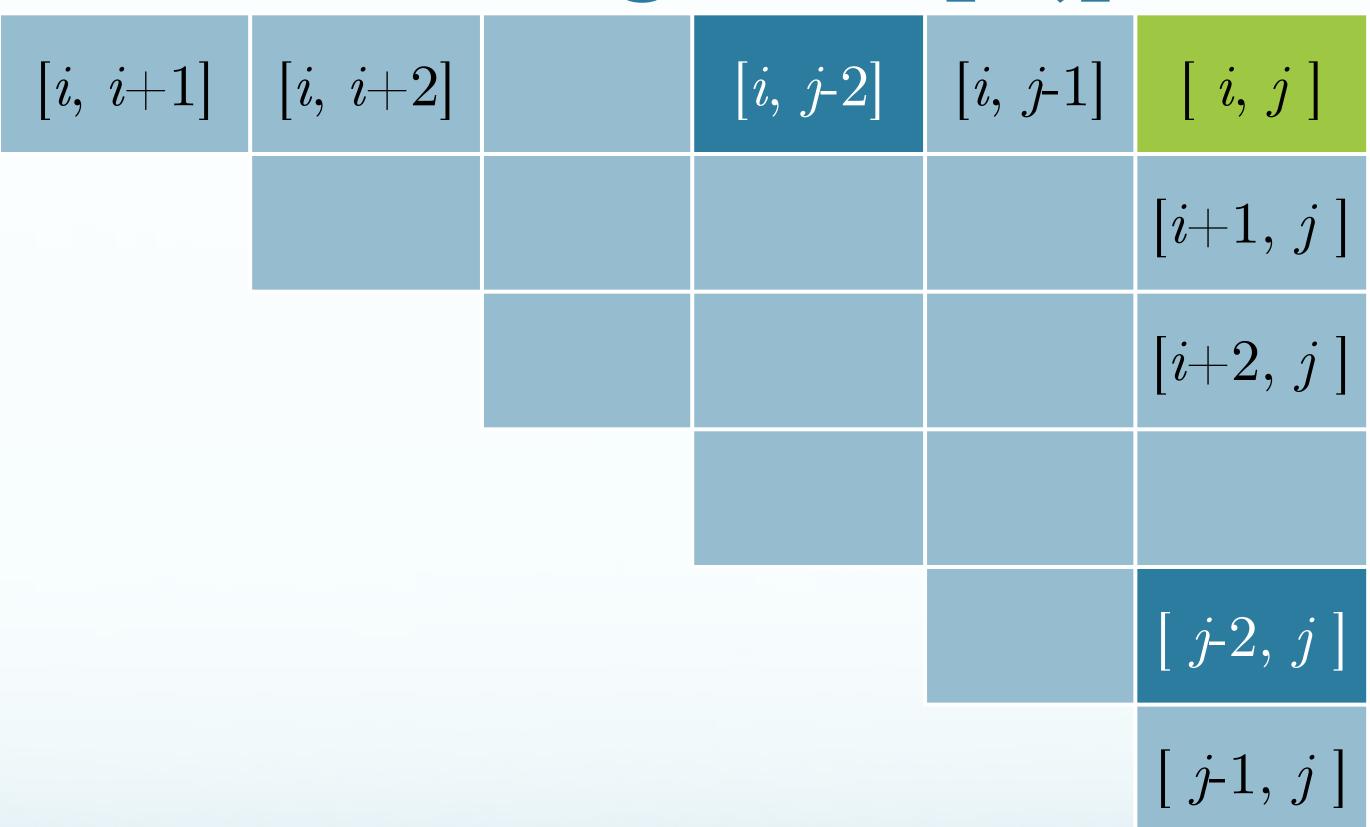














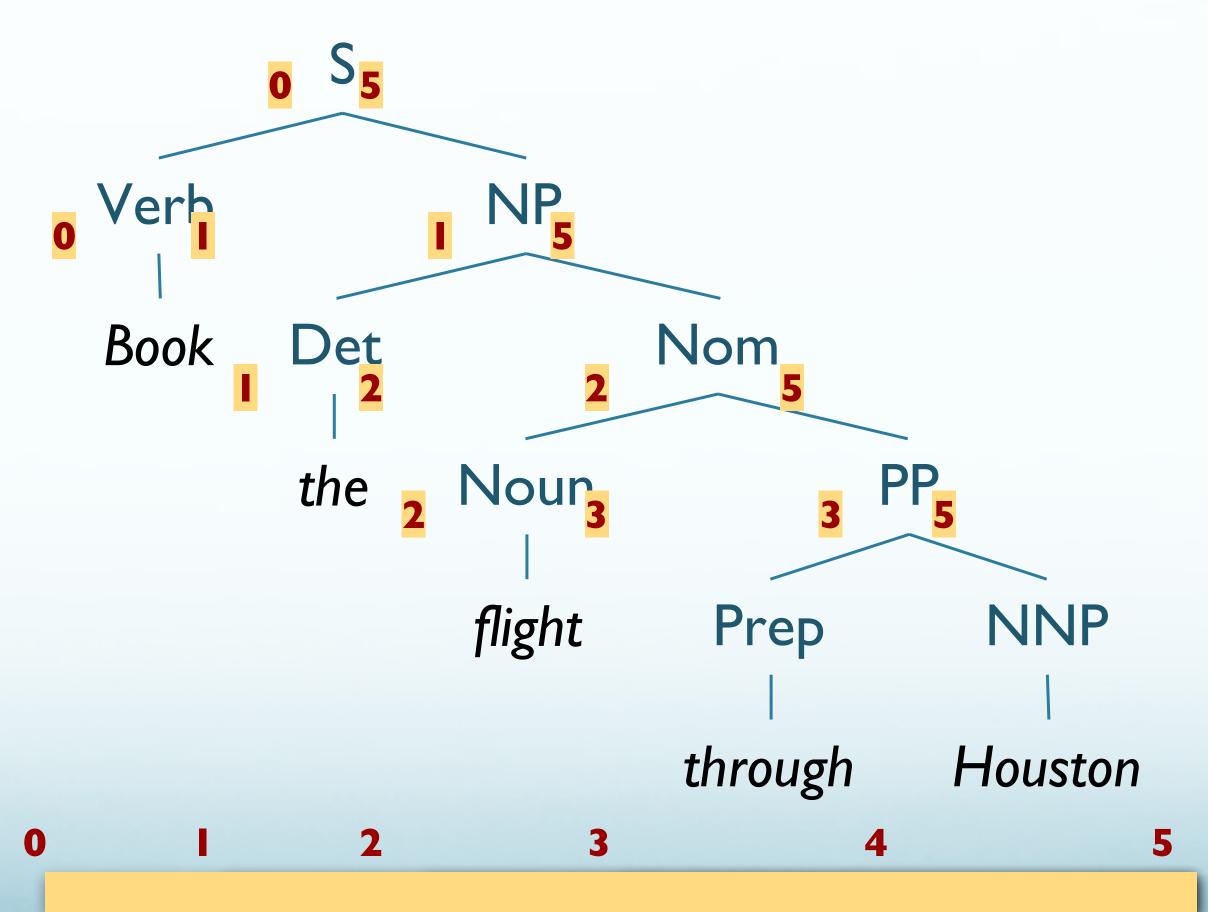






Why fill cells this way?

• For cell [i, j], must be able to access all cells [i, k] and [k, j] where i < k < j

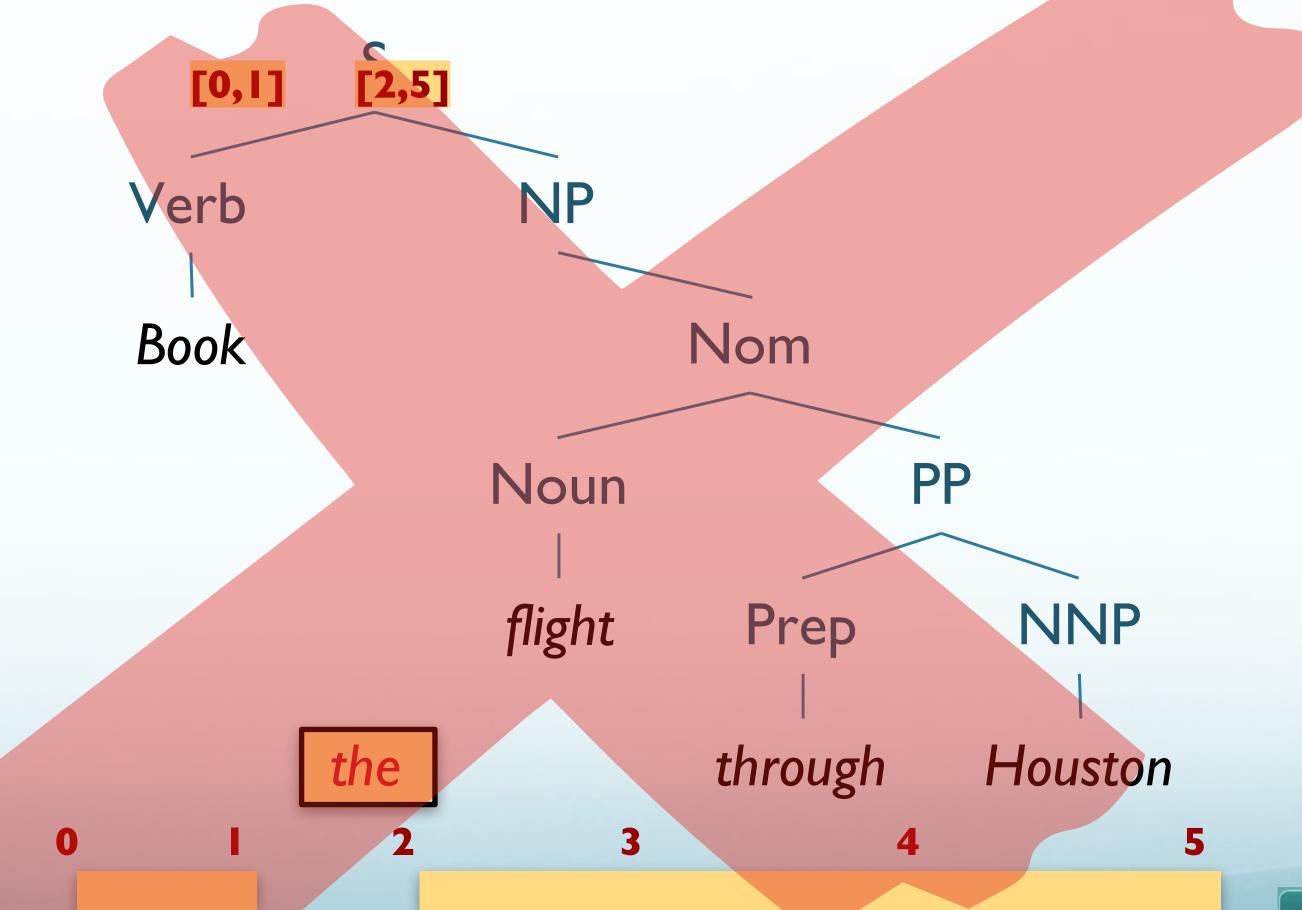




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Why fill cells this way?

• For cell [i, j], must be able to access all cells [i, k] and [k, j] where i < k < j





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CKY Parsing Example



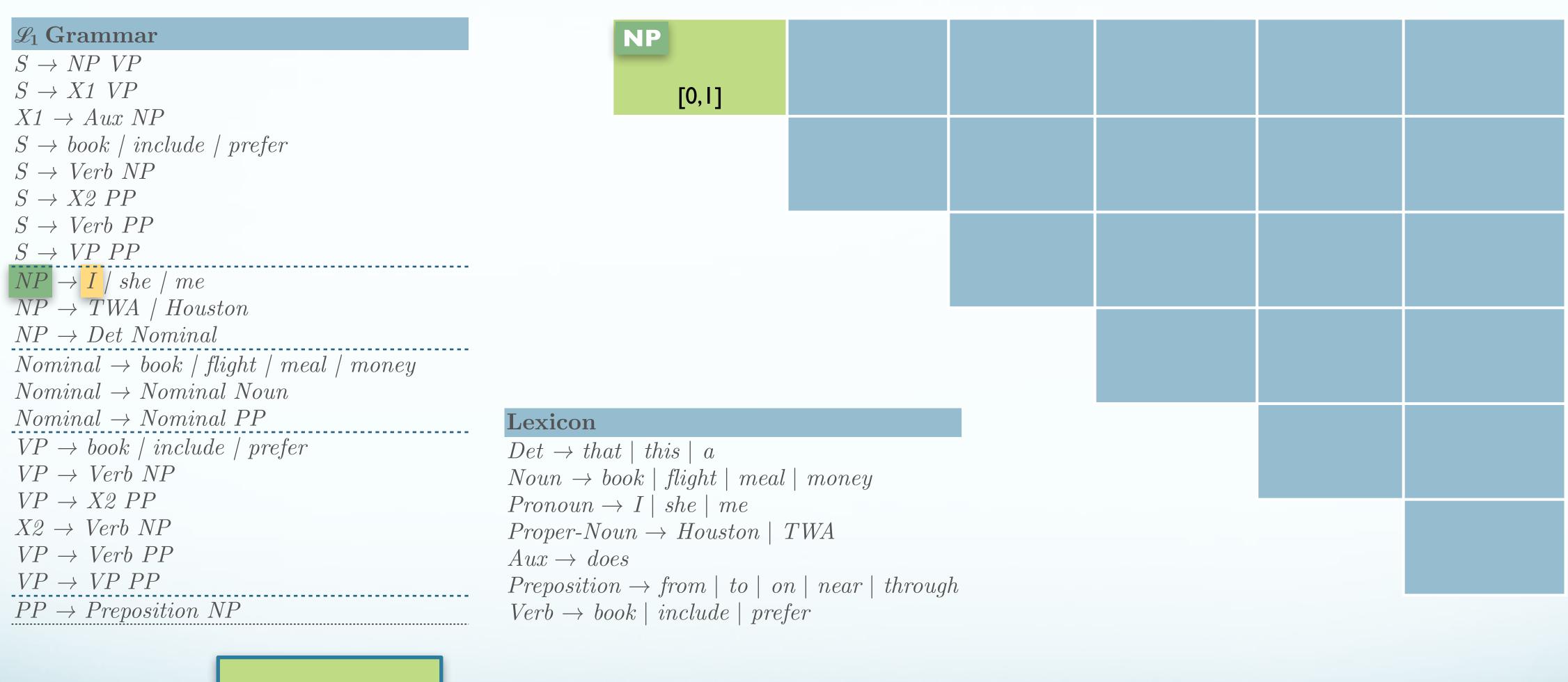


\mathscr{L}_1 Grammar			
$S \to NP VP$			
$S \to X1 VP$			
$X1 \rightarrow Aux NP$			
$S \rightarrow book / include / prefer$			
$S \rightarrow Verb NP$			
$S \to X2 PP$			
$S \rightarrow Verb PP$			
$S \to VP PP$			
$NP \rightarrow I / she / me$			
$NP \rightarrow TWA / Houston$			
$NP \rightarrow Det \ Nominal$			
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$			
$Nominal \rightarrow Nominal \ Noun$			
$Nominal \rightarrow Nominal PP$	Lexicon		
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$		
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid meal \mid money$		
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$		
$X2 \rightarrow Verb NP$	$Proper-Noun \stackrel{\cdot}{ o} Houston \mid TWA$		
$VP \rightarrow Verb PP$	$Aux \rightarrow does$		
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid on \mid near \mid through$		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid prefer$		

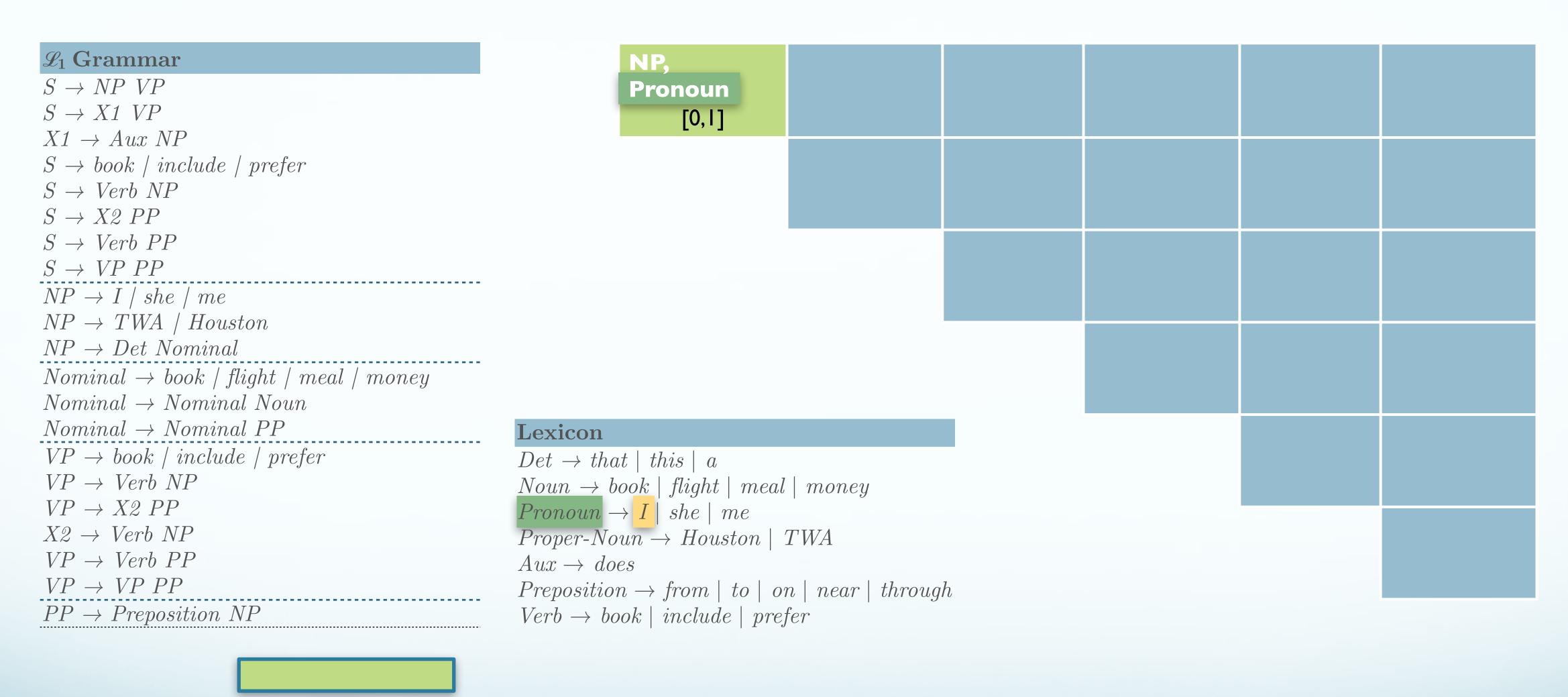
I prefer a flight on TWA of the second of th





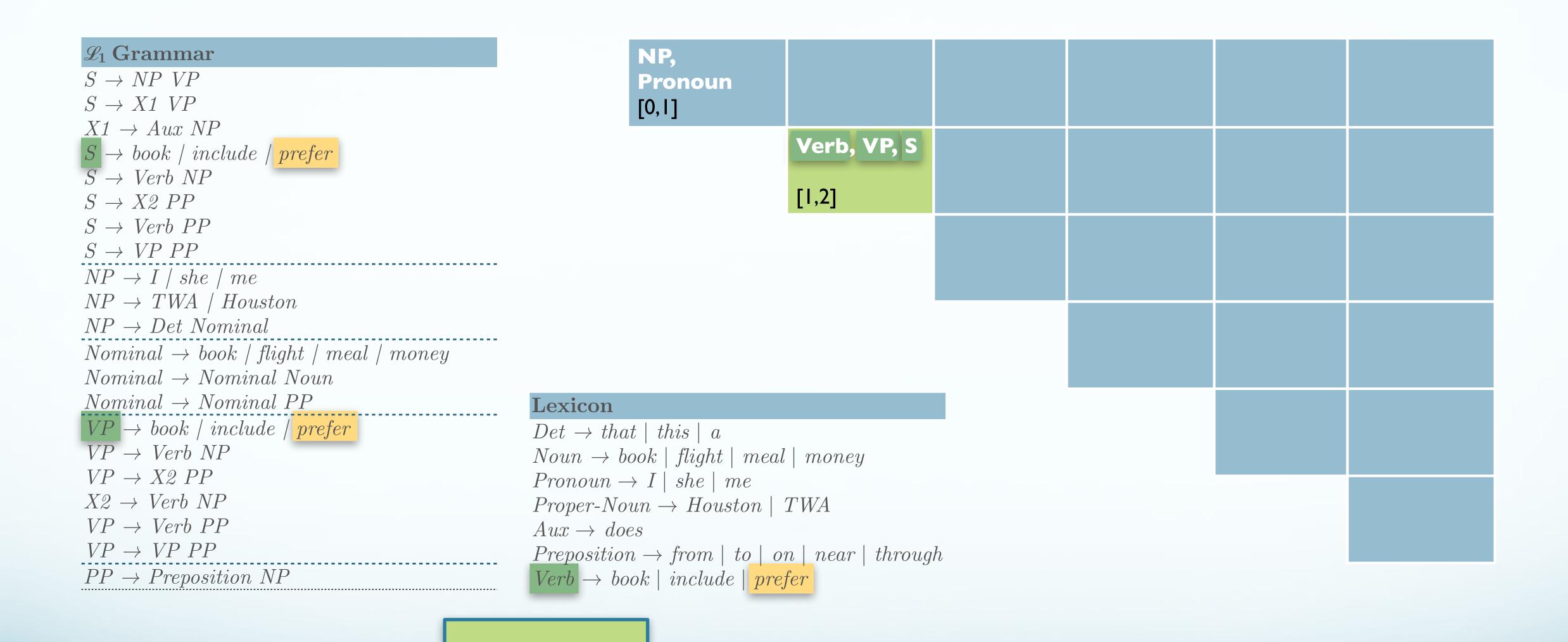








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flight

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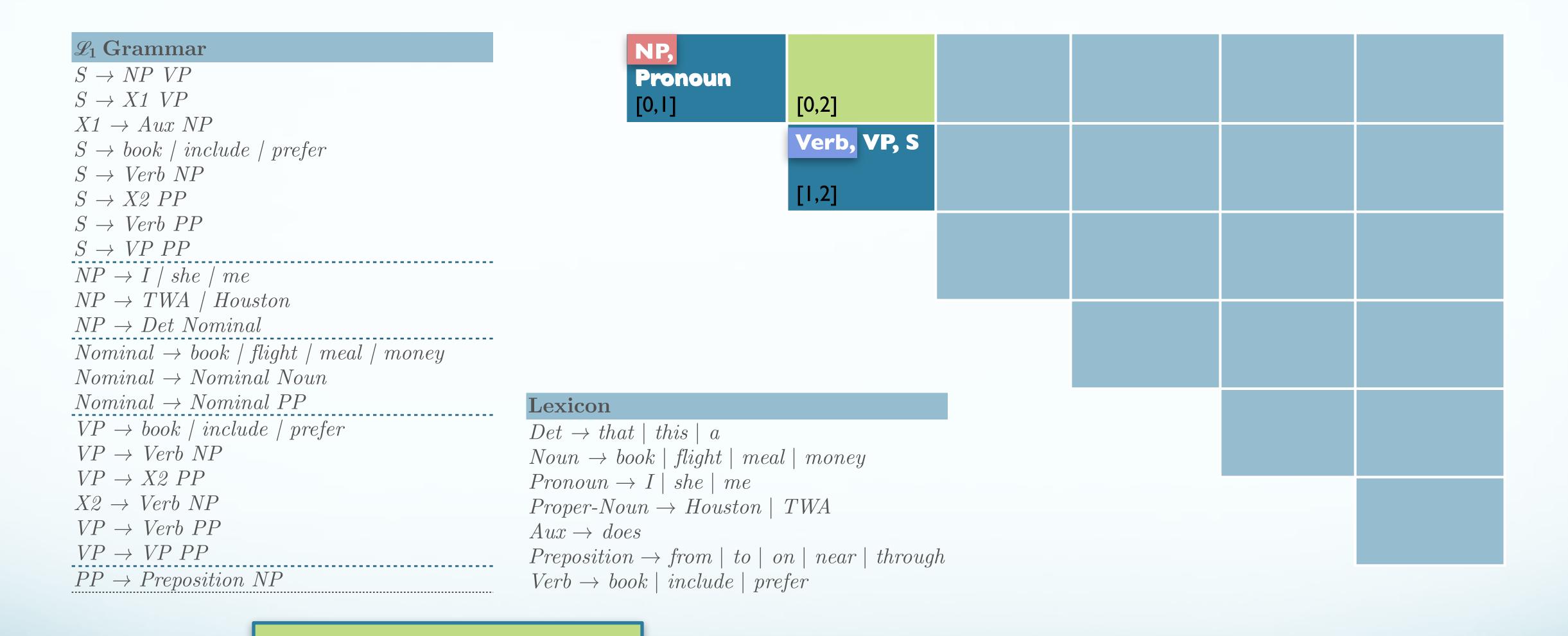


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on

 \mathcal{L}_1 Grammar NP, $S \rightarrow NP VP$ Pronoun $S \rightarrow X1 VP$ [0,1][0,2] $X1 \rightarrow Aux NP$ Verb, VP, S $S \rightarrow book / include / prefer$ $S \rightarrow Verb NP$ [1,2] $S \rightarrow X2 PP$ $S \rightarrow Verb PP$ $S \rightarrow VP PP$ $NP \rightarrow I / she / me$ $NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det\ Nominal$ $Nominal \rightarrow book / flight / meal / money$ $Nominal \rightarrow Nominal Noun$ $Nominal \rightarrow Nominal PP$ Lexicon $VP \rightarrow book / include / prefer$ $Det \rightarrow that \mid this \mid a$ $VP \rightarrow Verb NP$ $Noun \rightarrow book \mid flight \mid meal \mid money$ $VP \rightarrow X2 PP$ $Pronoun \rightarrow I \mid she \mid me$ $X2 \rightarrow Verb NP$ $Proper-Noun \rightarrow Houston \mid TWA$ $VP \rightarrow Verb PP$ $Aux \rightarrow does$ $VP \rightarrow VP PP$ $Preposition \rightarrow from \mid to \mid on \mid near \mid through$ $PP \rightarrow Preposition NP$ $Verb \rightarrow book \mid include \mid prefer$

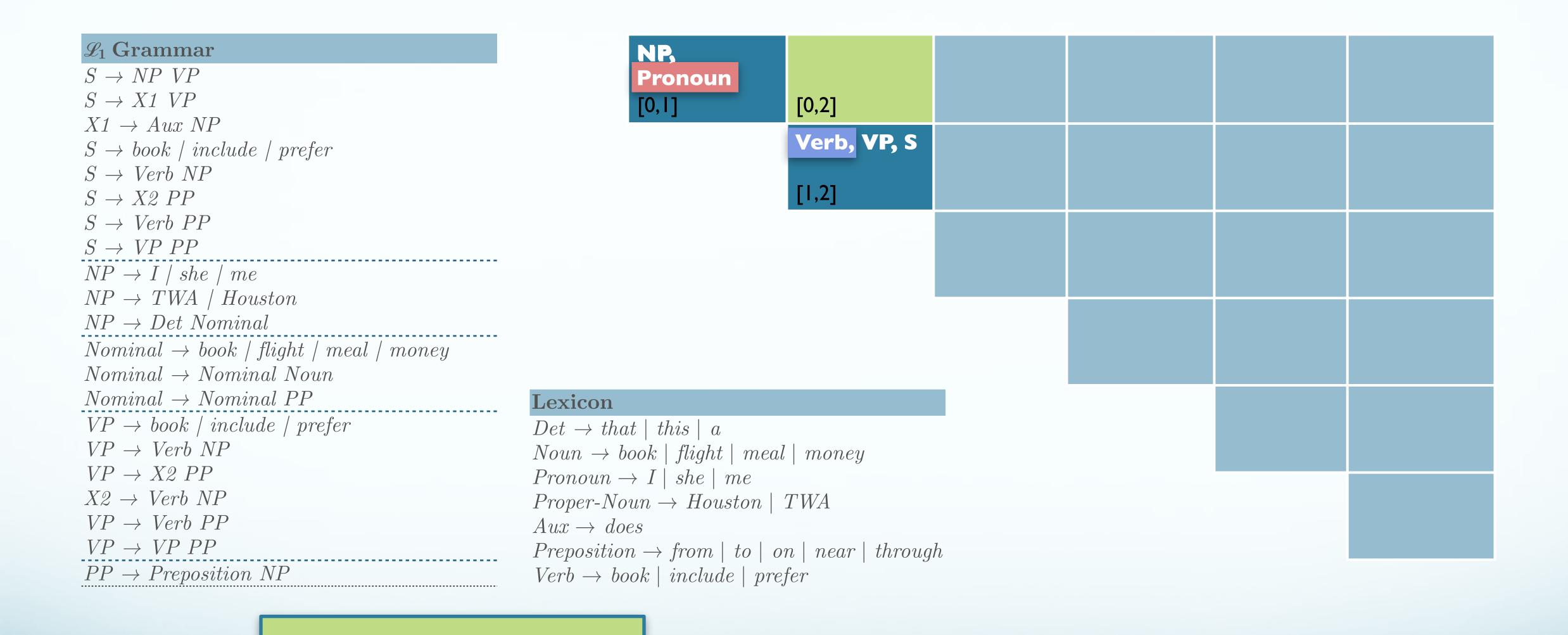






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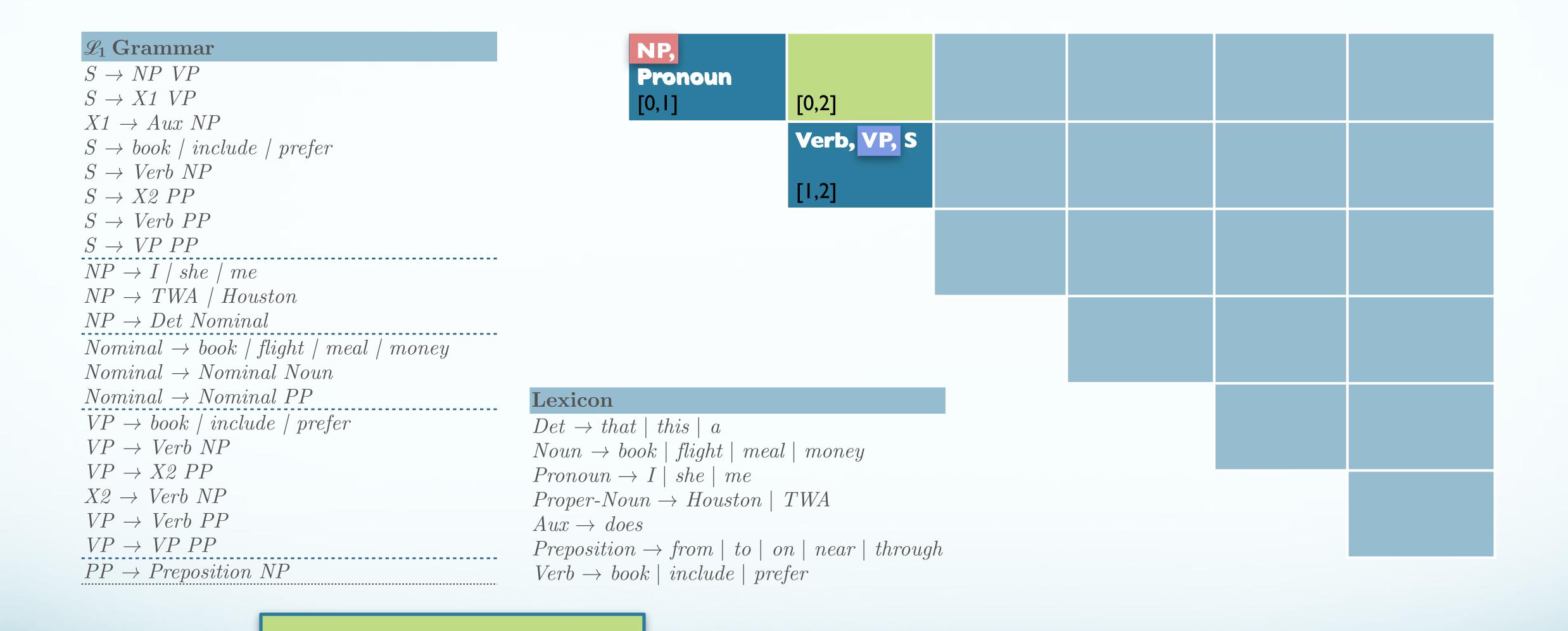
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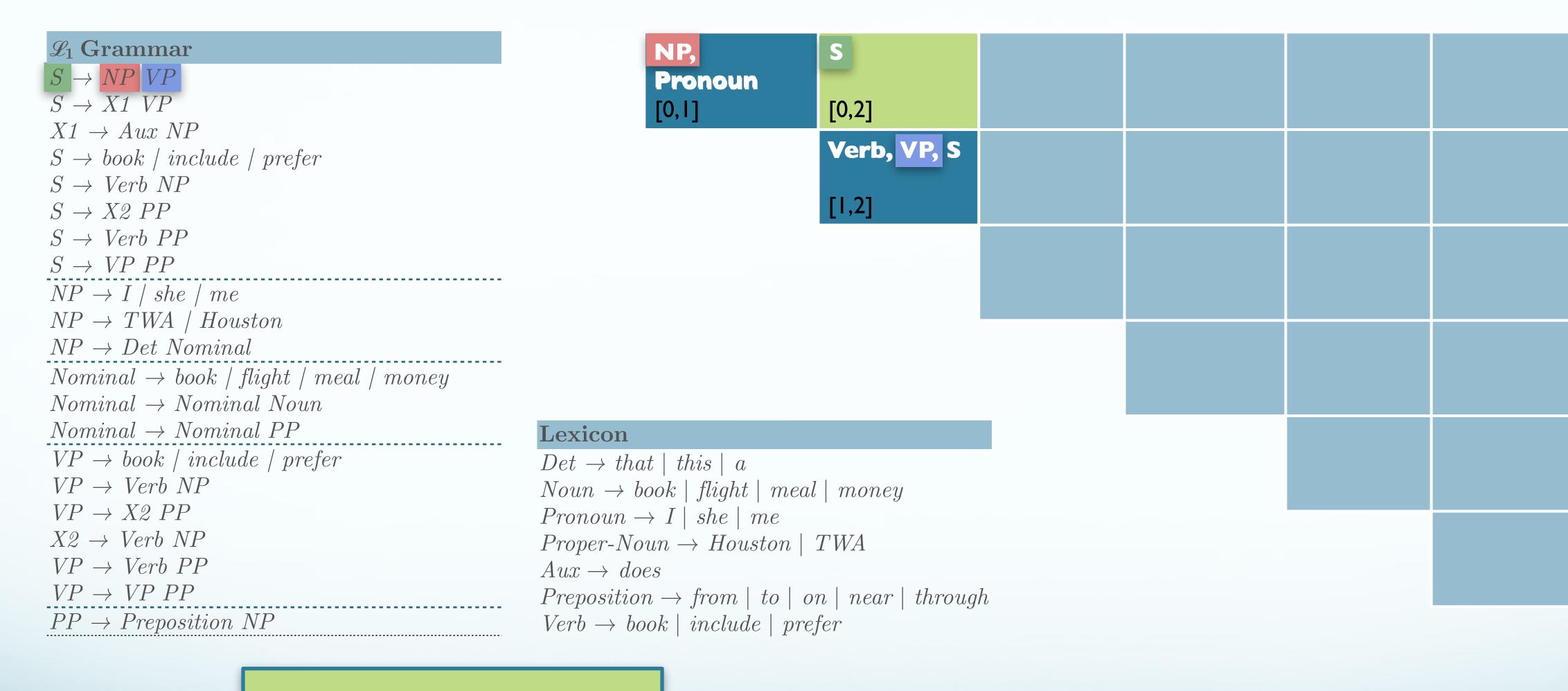
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\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$ $Y_1 \to A_{MR} \ NP$	NP, Pronoun [0,1] [0,2]
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$ $S \rightarrow Verb \ NP$ $S \rightarrow X2 \ PP$	Verb, VP, S [1,2]
$S \rightarrow Verb \ PP$ $S \rightarrow VP \ PP$ $NP \rightarrow I \ \ she \ \ me$ $NP \rightarrow TWA \ \ Houston$	
$NP \rightarrow Det\ Nominal$ $Nominal \rightarrow book\ /\ flight\ /\ meal\ /\ money$ $Nominal \rightarrow Nominal\ Noun$	
$Nominal \rightarrow Nominal PP$ $VP \rightarrow book \mid include \mid prefer$ $VP \rightarrow Verb NP$ $VP \rightarrow X2 PP$	Lexicon $Det \rightarrow that \mid this \mid a$ $Noun \rightarrow book \mid flight \mid meal \mid money$ $Pronoun \rightarrow I \mid she \mid me$
$X2 \rightarrow Verb \ NP$ $VP \rightarrow Verb \ PP$ $VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$Proper-Noun ightarrow Houston \mid TWA$ $Aux ightarrow does$ $Preposition ightarrow from \mid to \mid on \mid near \mid through$ $Verb ightarrow book \mid include \mid prefer$



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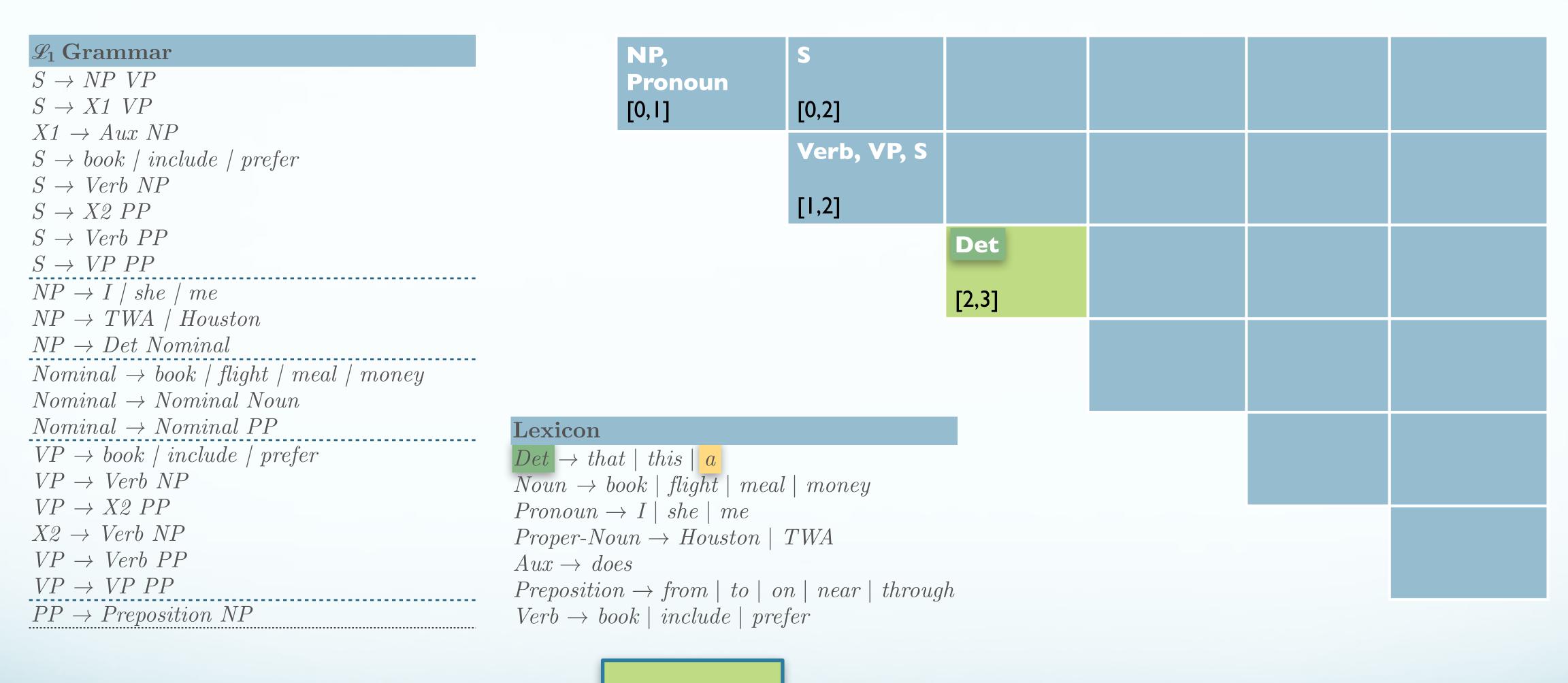
\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1] [0,2]	
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ \ include \ \ prefer$ $S \rightarrow Verb \ NP$	Verb, VP, S	
$S \rightarrow X2 \ PP$ $S \rightarrow Verb \ PP$ $S \rightarrow VP \ PP$		
$NP \rightarrow I \mid she \mid me$ $NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$		
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$ $Nominal \rightarrow Nominal \ Noun$		
$Nominal \rightarrow Nominal PP$ $VP \rightarrow book \mid include \mid prefer$ $VP \rightarrow Verb NP$ $VP \rightarrow VQ PP$	Lexicon $Det \rightarrow that \mid this \mid a$ $Noun \rightarrow book \mid flight \mid meal \mid money$	
$VP \rightarrow X2 \ PP$ $X2 \rightarrow Verb \ NP$ $VP \rightarrow Verb \ PP$	$Pronoun ightarrow I \mid she \mid me$ $Proper-Noun ightarrow Houston \mid TWA$ $Aux ightarrow does$	
$VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$Preposition ightarrow from \mid to \mid on \mid near \mid through$ $Verb ightarrow book \mid include \mid prefer$	



\mathscr{L}_1 Grammar	NP,
$S \to NP \ VP$ $S \to X1 \ VP$	Pronoun
$X1 \rightarrow Aux NP$	
$S \rightarrow book / include / prefer$	Verb, VP, S
$S \rightarrow Verb NP$	
$S \to X2 PP$	
$S \rightarrow Verb PP$	
$S \rightarrow VP PP$	
$NP \rightarrow I / she / me$	
$NP \rightarrow TWA / Houston$	
$NP \rightarrow Det\ Nominal$	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$ $Nominal \rightarrow Nominal \ Noun$	
$Nominal \rightarrow Nominal \ PP$	Lexicon
$VP \rightarrow book \ / \ include \ / \ prefer$	$Det ightarrow that \mid this \mid a$
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid meal \mid money$
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$
$X2 \rightarrow Verb NP$	$Proper-Noun ightarrow Houston \mid TWA$
$VP \rightarrow Verb PP$	$Aux \rightarrow does$
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid on \mid near \mid through$
$PP \rightarrow Preposition NP$	$Verb ightarrow book \mid include \mid prefer$

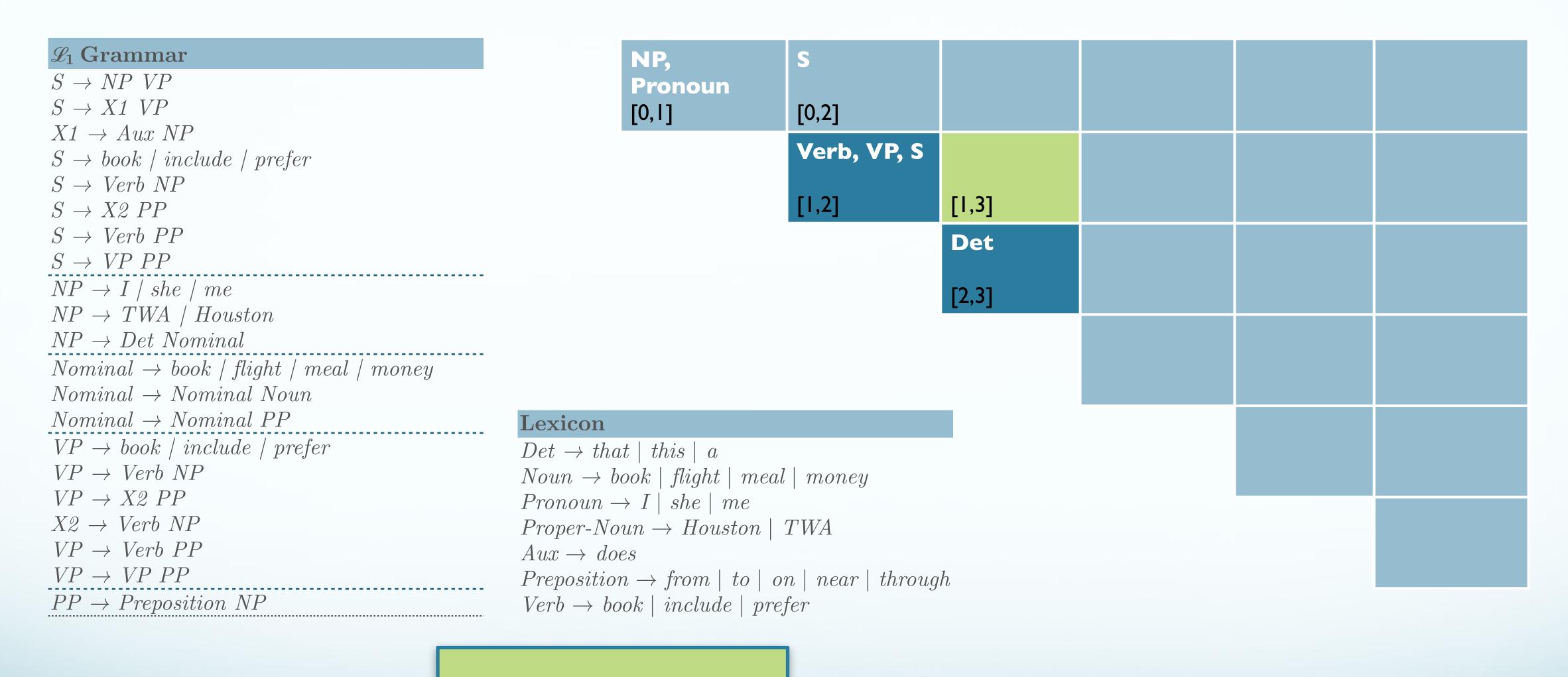


flight TWA on



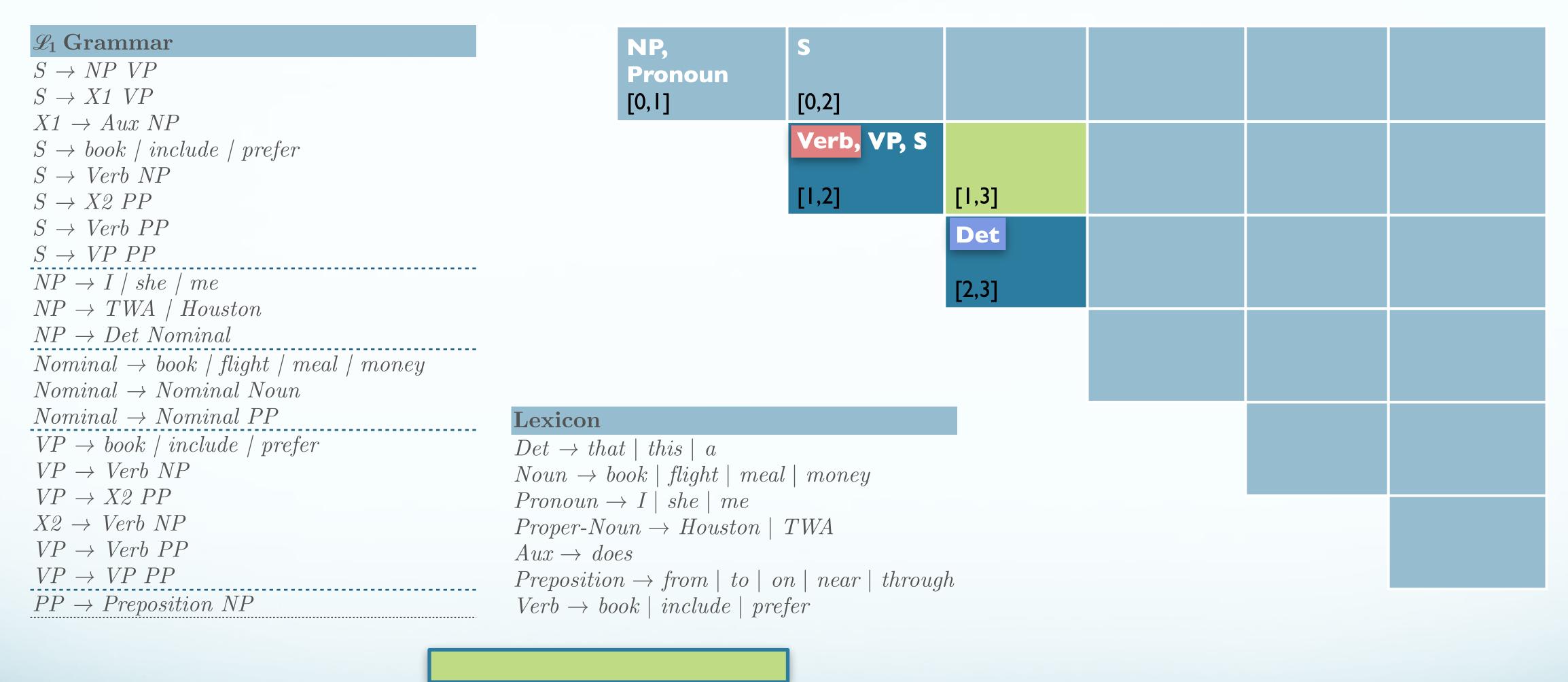


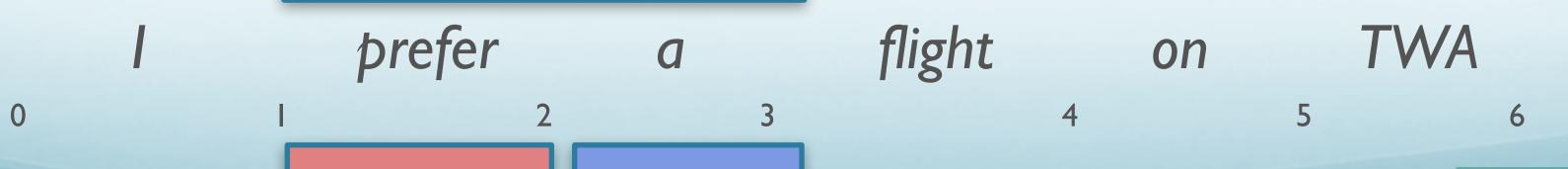




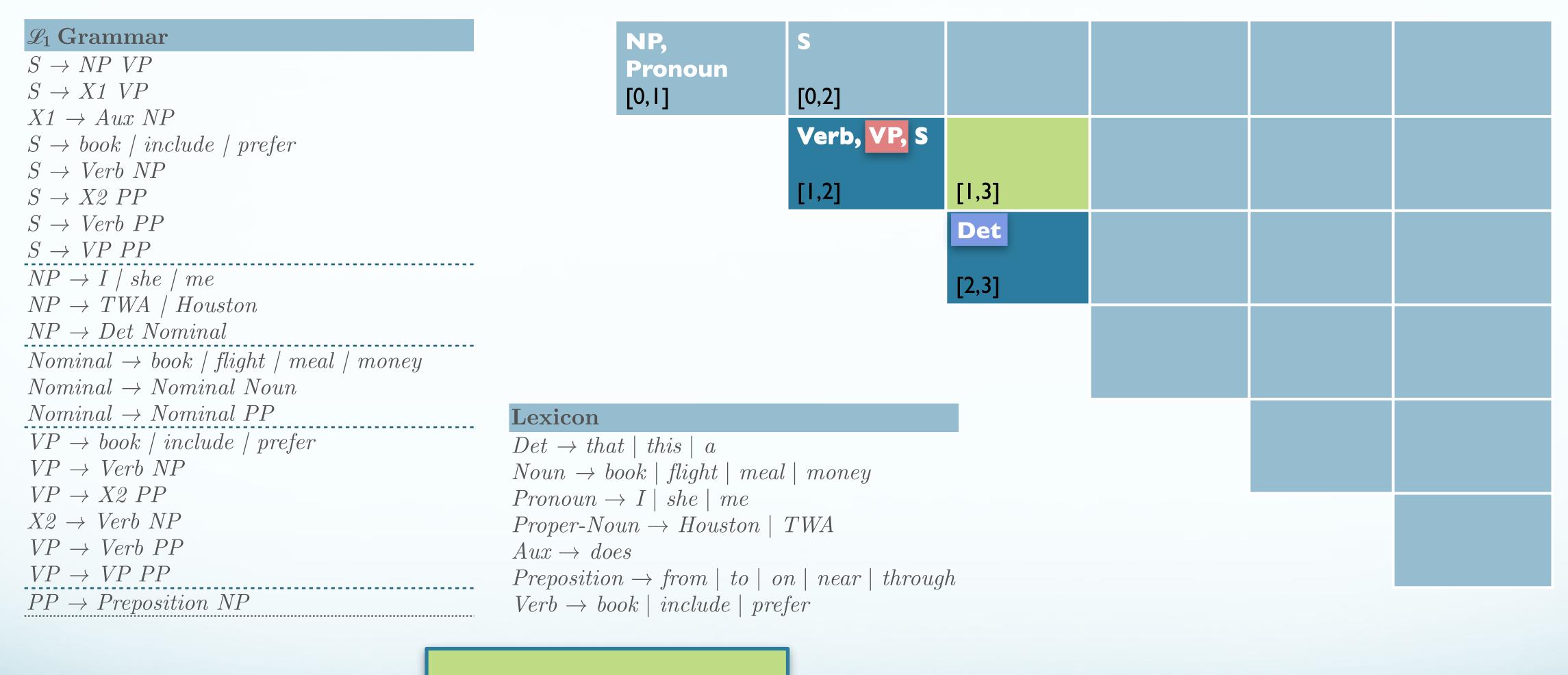


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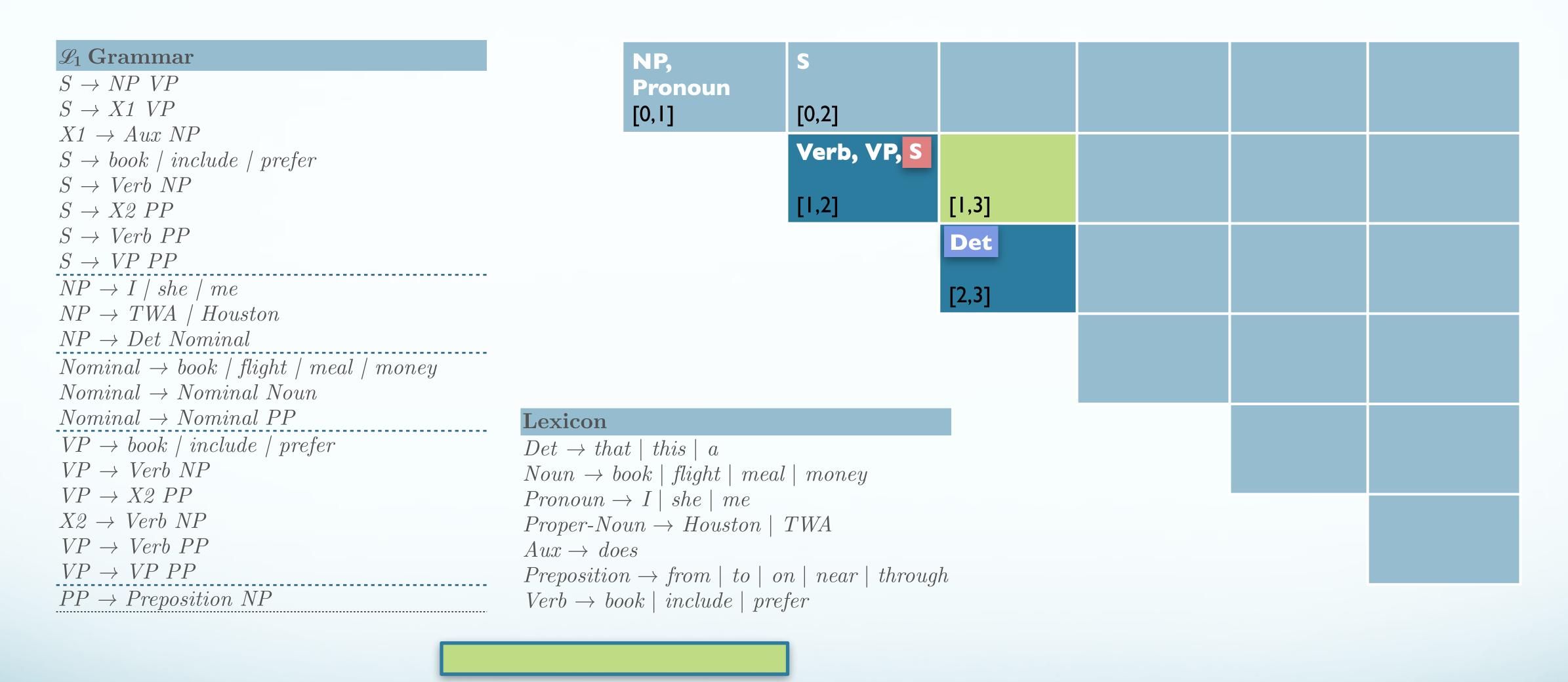






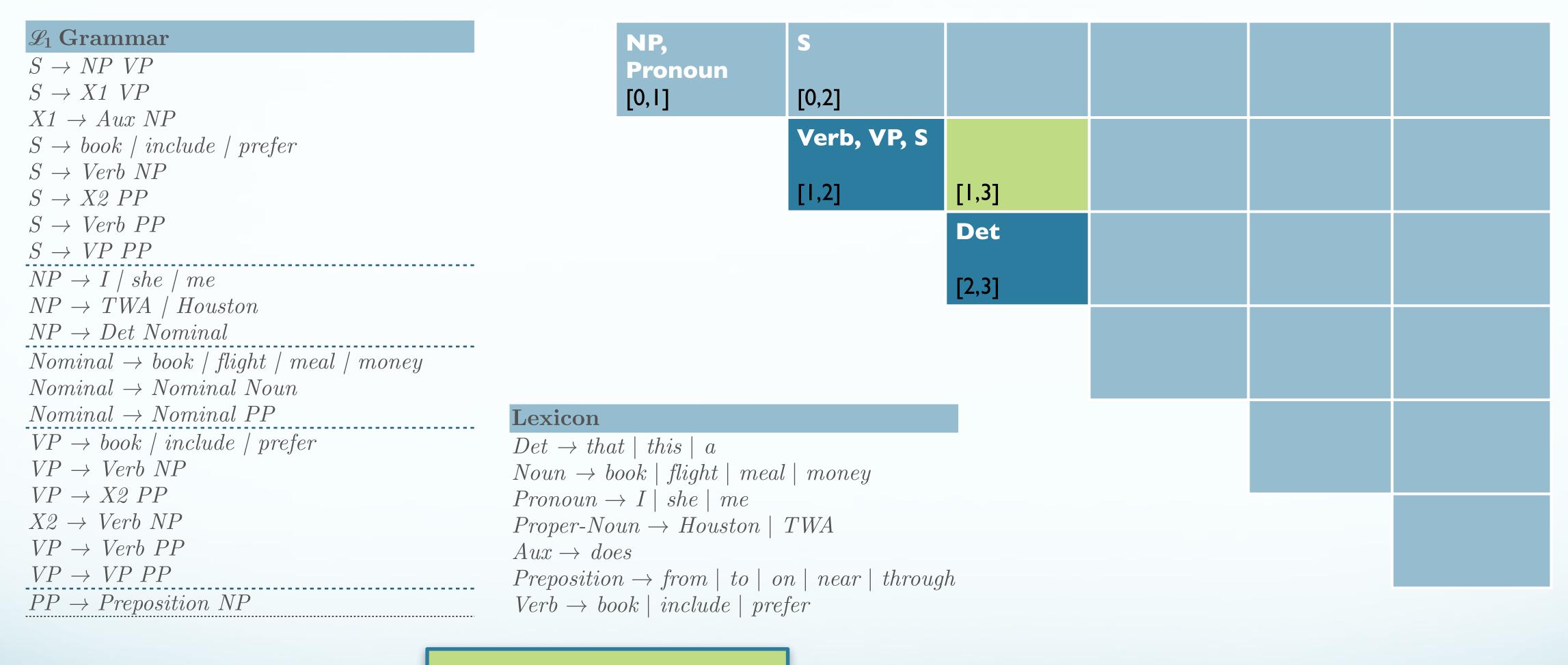








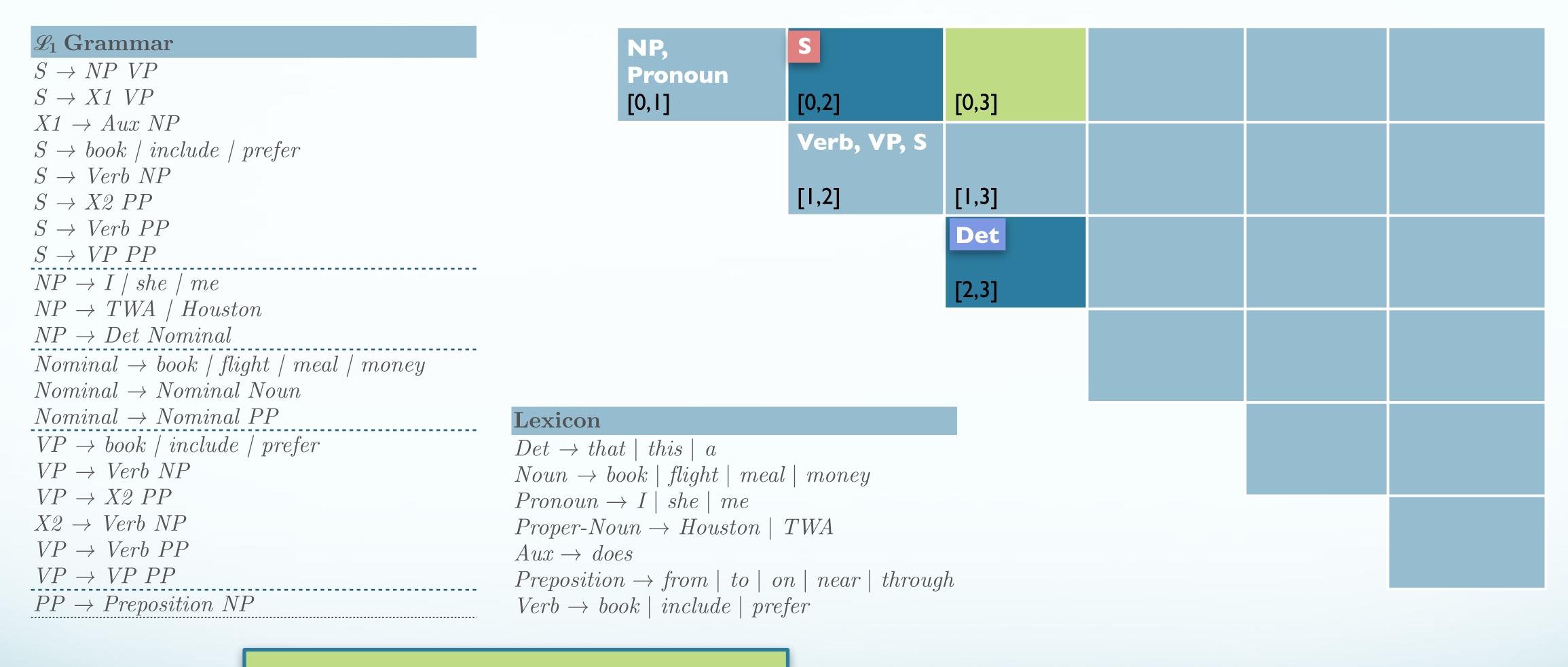


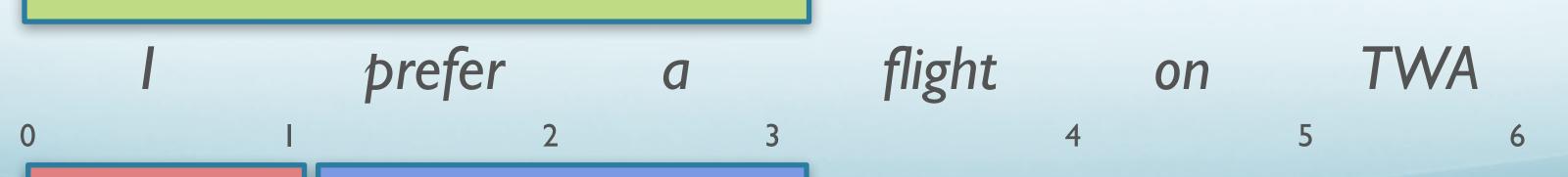




\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ \ include \ \ prefer$ $S \rightarrow Verb \ NP$		Verb, VP, S			
$S \to X2 PP$		[1,2]	[1,3]		
$S \rightarrow Verb \ PP$ $S \rightarrow VP \ PP$			Det		
$NP \rightarrow I \mid she \mid me$ $NP \rightarrow TWA \mid Houston$			[2,3]		
$NP \rightarrow Det Nominal$					
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$ $Nominal \rightarrow Nominal \ Noun$					
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book \mid include \mid prefer$ $VP \rightarrow Verb \mid NP$	$Det \rightarrow that \mid this \mid a$ $Noun \rightarrow book \mid flight \mid mo$	eal money			
$VP \rightarrow X2 \ PP$ $X2 \rightarrow Verb \ NP$	$Pronoun \rightarrow I \mid she \mid me$ $Proper-Noun \rightarrow Houston$	TWA			
$VP \rightarrow Verb \ PP$ $VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$Aux \rightarrow does$ $Preposition \rightarrow from \mid to \mid$ $Verb \rightarrow book \mid include \mid p$	'	gh		







\mathscr{L}_1 Grammar	NP,	S			
$S \rightarrow NP \ VP$	Pronoun				
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux NP$					
$S \rightarrow book / include / prefer$		Verb, VP, S			
$S \rightarrow Verb NP$		г . Э1	FI 21		
$S \rightarrow X2 PP$		[1,2]	[1,3]		
$S \rightarrow Verb PP$			Det		
$S \rightarrow VP PP$					
$NP \rightarrow I \mid she \mid me$ $NP \rightarrow TWA \mid Houston$			[2,3]		
$NP \rightarrow Det\ Nominal$				Noun, Nom	
$Nominal \rightarrow book / flight / meal / money$					
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book \ / \ include \ / \ prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$d \mid money$			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston \mid$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid c$		gh		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$	efer			

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\mathscr{L}_1 Grammar	NP,	S			
$S \rightarrow NP VP$	Pronoun				
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux NP$ $S \rightarrow book / implied of marting$		Verb, VP, S			
$S \rightarrow book \mid include \mid prefer$ $S \rightarrow Verb NP$					
$S \rightarrow X2 PP$		[1,2]	[1,3]		
$S \rightarrow Verb PP$			Det		
$S \rightarrow VP PP$					
$NP \rightarrow I / she / me$			[2,3]	[2,4]	
$NP \rightarrow TWA \mid Houston$					
$NP \rightarrow Det\ Nominal$				Noun, Nom	
$Nominal \rightarrow book / flight / meal / money$				[3,4]	
$Nominal \rightarrow Nominal \ Noun$ $Nominal \rightarrow Nominal \ PP$	T				
$VP \rightarrow book / include / prefer$	Lexicon Detailed this lea				
$VP \rightarrow Verb NP$	$Det \rightarrow that \mid this \mid a$ $Noun \rightarrow book \mid flight \mid mea$	ıl moneu			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid d$	on near throug	gh		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$	efer			
			_		

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\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$ $S \rightarrow Verb \ NP$		Verb, VP, S			
$S \rightarrow X2 \ PP$ $S \rightarrow Verb \ PP$ $S \rightarrow VP \ PP$		[1,2]	[1,3] Det		
$NP \rightarrow I \mid she \mid me$ $NP \rightarrow TWA \mid Houston$			[2,3]	[2,4] Noun, Nom	
$NP \rightarrow Det\ Nominal$ $Nominal \rightarrow book\ /\ flight\ /\ meal\ /\ money$ $Nominal \rightarrow Nominal\ Noun$	-			[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid model$	$eal \mid money$			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid$	on near through	gh		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid p$	refer			



$\begin{array}{c} \mathscr{L}_{1} \ \mathbf{Grammar} \\ S \to NP \ VP \\ S \to X1 \ VP \end{array}$	NP, Pronoun [0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$		Verb, VP, S			
$S \rightarrow Verb \ NP$ $S \rightarrow X2 \ PP$		[1,2]	[1,3]		
$S \rightarrow Verb \ PP$ $S \rightarrow VP \ PP$			Det	NP	
$egin{aligned} & ext{VP} ightarrow I \mid she \mid me \ & ext{VP} ightarrow TWA \mid Houston \end{aligned}$			[2,3]	[2,4]	
$egin{aligned} egin{aligned} egin{aligned\\ egin{aligned} egi$	_			Noun, Nom	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$ $Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book \mid include \mid prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid m$	$neal \mid money$			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	$n \mid TWA$			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	1 . 7	7		
$VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$\begin{array}{c} Preposition \rightarrow from \mid to \\ Verb \rightarrow book \mid include \mid \end{array}$	·	ugh		
	$verv o vook \mid include \mid j$	prejer			

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\mathscr{L}_1 Grammar	NP,	S			
$S \to NP VP$	Pronoun				
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux NP$	L = 9 - 1				
$S \rightarrow book / include / prefer$		Verb, VP, S			
$S \rightarrow Verb NP$					
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$			Dec		
$NP \rightarrow I / she / me$			[2,3]	[2,4]	
$NP \rightarrow TWA / Houston$			[2,5]		
$NP \rightarrow Det \ Nominal$				Noun, Nom	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$					
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow Verb NP$		$al \mid moneu$			
$VP \rightarrow X2 PP$					
$X2 \rightarrow Verb NP$		TWA			
$VP \rightarrow Verb PP$	- 1				
$VP \rightarrow VP PP$		$on \mid near \mid through$	ah		
$PP \rightarrow Preposition NP$					
$Nominal ightarrow Nominal PP$ $VP ightarrow book \mid include \mid prefer$ $VP ightarrow Verb NP$ $VP ightarrow X2 PP$ $X2 ightarrow Verb NP$ $VP ightarrow Verb PP$ $VP ightarrow VP PP$	Lexicon $Det ightharpoonup that this a$ $Noun ightharpoonup book flight mea$ $Pronoun ightharpoonup I she me$ $Proper-Noun ightharpoonup Houston $ $Aux ightharpoonup does$ $Preposition ightharpoonup from to $ $Verb ightharpoonup book include proper-Nounup from $	TWA $on \mid near \mid throug$	ηh		

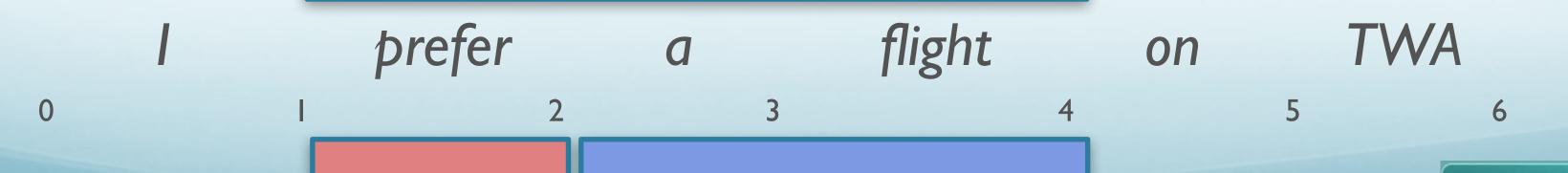


PROFESSIONAL MASTER'S IN
COMPUTATIONAL LINGUISTICS

\mathcal{L}_1 Grammar $S \to NP \ VP$	NP, Pronoun	S			
$S \to X1 \ VP$ $X1 \to Aux \ NP$	[0,1]	[0,2]	[0,3]		
$S \rightarrow book / include / prefer$		Verb, VP, S		VP	
$S \rightarrow Verb \ NP$ $S \rightarrow X2 \ PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP \ PP$ $NP \rightarrow I \ \ she \ \ me$	-		[2,3]	[2,4]	
$NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$				Noun, Nom	
$Nominal \rightarrow book \mid flight \mid meal \mid money \ Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book / include / prefer$ $VP \rightarrow Verb NP$ $VP \rightarrow X2 PP$	$Det ightarrow that \mid this \mid a$ $Noun ightarrow book \mid flight \mid m$ $Pronoun ightarrow I \mid she \mid me$	eal money			
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA			
$VP \rightarrow Verb \ PP$ $VP \rightarrow VP \ PP$	$Aux \rightarrow does$ $Preposition \rightarrow from \mid to \mid$	on near throug	gh		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid p$	orefer			

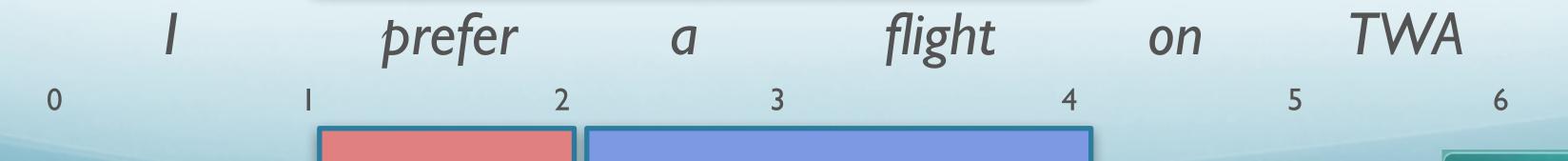


\mathscr{L}_1 Grammar	NP,	S			
$S \to NP VP$	Pronoun				
$S \to X1 VP$	[0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2	
$S \rightarrow book / include / prefer$		verb, vi, s		VI, AZ	
$S \rightarrow Verb \ NP$ $S \rightarrow X2 \ PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow A \gtrsim TT$ $S \rightarrow Verb PP$		L·,-J			
$S \rightarrow VP PP$			Det	NP	
$NP \rightarrow I / she / me$			ro 21	Γ Ω 41	
$NP \rightarrow TWA / Houston$			[2,3]	[2,4]	
$NP \rightarrow Det Nominal$				Noun, Nom	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$					
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$al \mid money$			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid$		h		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pr$	refer			

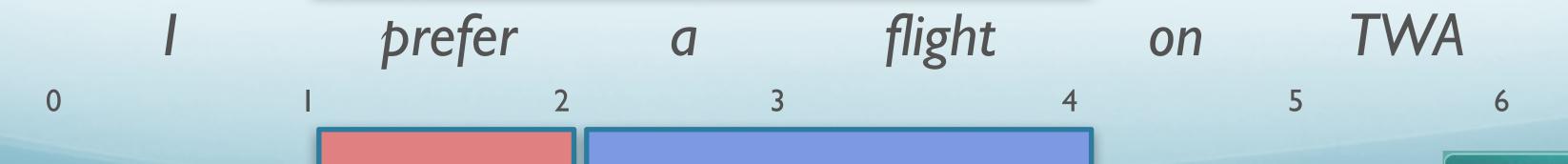




\mathscr{L}_1 Grammar	NP,	S			
$S \rightarrow NP VP$	Pronoun				
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux NP$	[-,.]		[0,0]		
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S	
$S ightarrow Verb NP \ S ightarrow X2 PP$					
$S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$					
$NP \rightarrow I / she / me$			[2,3]	[2,4]	
$NP \rightarrow TWA / Houston$			[2,5]		
$NP \rightarrow Det Nominal$				Noun, Nom	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$					
$Nominal \rightarrow Nominal Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid me$	$al \mid money$			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	Proper-Noun Houston	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	I			
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid$	$on \mid near \mid through$	h		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pr$				
		U			

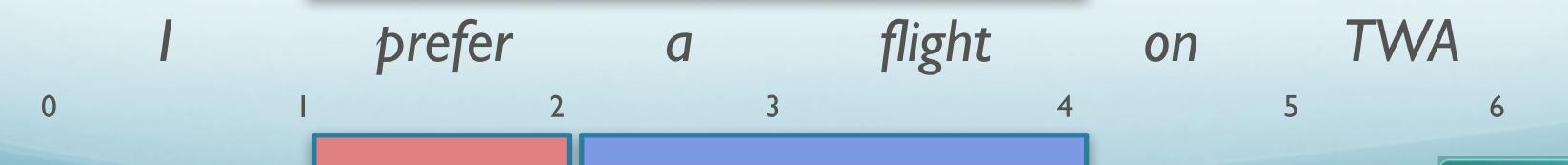


\mathscr{L}_1 Grammar	NP,	S			
$S \rightarrow NP VP$	Pronoun				
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux NP$	[0,1]		[0,0]		
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S	
$S \rightarrow Verb NP$					
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$			Всс		
$NP \rightarrow I / she / me$			[2,3]	[2,4]	
$NP \rightarrow TWA / Houston$			[2,5]		
$NP \rightarrow Det Nominal$				Noun, Nom	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$					
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid me$	$al \mid money$			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	I			
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid$	on near through	ah		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pro$	1			
		·			



PROFESSIONAL MASTER'S IN
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\mathscr{L}_1 Grammar	NP,	S			
$S \to NP VP$	Pronoun				
$S \to X1 VP$	[0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux NP$	L°, · J				
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S	
$S \rightarrow Verb NP$					
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$					
$NP \rightarrow I / she / me$			[2,3]	[2,4]	
$NP \rightarrow TWA / Houston$			[2,5]		
$NP \rightarrow Det\ Nominal$				Noun, Nom	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$					
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$al \mid money$			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid d$	$on \mid near \mid throug$	h		
$PP \rightarrow Preposition NP$					
	$Verb \rightarrow book \mid include \mid pre$		10		





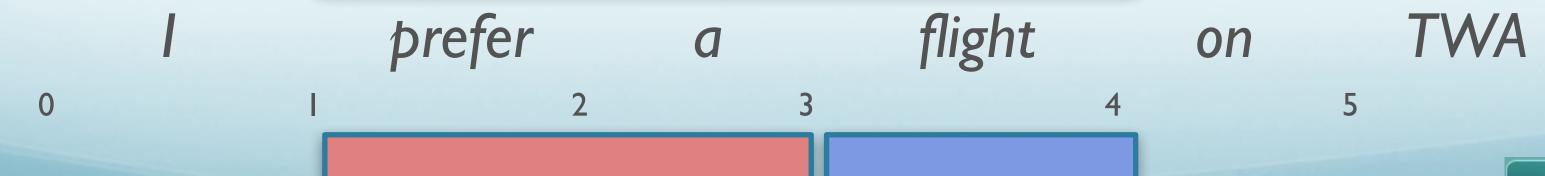
$\mathcal{L}_{1} \mathbf{Grammar}$ $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	S [0,2]	[0,3]		
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$ $S \rightarrow Verb \ NP$		Verb, VP, S		VP, X2, S	
$S \to X2 \ PP$ $S \to Verb \ PP$		[1,2]	[1,3] Det	[1,4] NP	
$S \rightarrow VP \ PP$ $NP \rightarrow I \ \ she \ \ me$			[2,3]	[2,4]	
$NP ightarrow TWA \mid Houston$ $NP ightarrow Det \ Nominal$ $Nominal \rightarrow book \mid flight \mid mond \mid mond \mid$				Noun, Nom	
$Nominal \rightarrow book \mid flight \mid meal \mid money \ Nominal \rightarrow Nominal \ Noun \ Nominal \rightarrow Nominal \ PP$	T arriages			[3,4]	
$VP \rightarrow book \mid include \mid prefer$ $VP \rightarrow Verb \mid NP$ $VP \rightarrow X2 \mid PP$	Lexicon $Det \rightarrow that \mid this \mid a$ $Noun \rightarrow book \mid flight \mid meas$ $Pronoun \rightarrow I \mid she \mid me$	l money			
$X2 \rightarrow Verb \ NP$ $VP \rightarrow Verb \ PP$ $VP \rightarrow VP \ PP$	$Proper-Noun ightarrow Houston \mid$ $Aux ightarrow does$ $Preposition ightarrow from \mid to \mid o$		h		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$				



prefer

flight

$\mathcal{L}_{1} \mathbf{Grammar}$ $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	S [0,2]	[0,3]		
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$ $S \rightarrow Verb \ NP$		Verb, VP, S		VP, X2, S	
$S \to X2 \ PP$ $S \to Verb \ PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Vero TT$ $S \rightarrow VP PP$			Det	NP	
$NP \rightarrow I \mid she \mid me$ $NP \rightarrow TWA \mid Houston$			[2,3]	[2,4]	
$NP \rightarrow Det\ Nominal$				Noun, Nom	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$ $Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book \mid include \mid prefer$ $VP \rightarrow Verb \mid NP$	$Det \rightarrow that \mid this \mid a$ $Noun \rightarrow book \mid flight \mid meab$	l moneu			
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$				
$X2 \rightarrow Verb \ NP$ $VP \rightarrow Verb \ PP$	$Proper-Noun ightarrow Houston \mid Aux ightarrow does$	TWA			
$VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$Preposition ightarrow from \mid to \mid o$ $Verb ightarrow book \mid include \mid pre$		h		

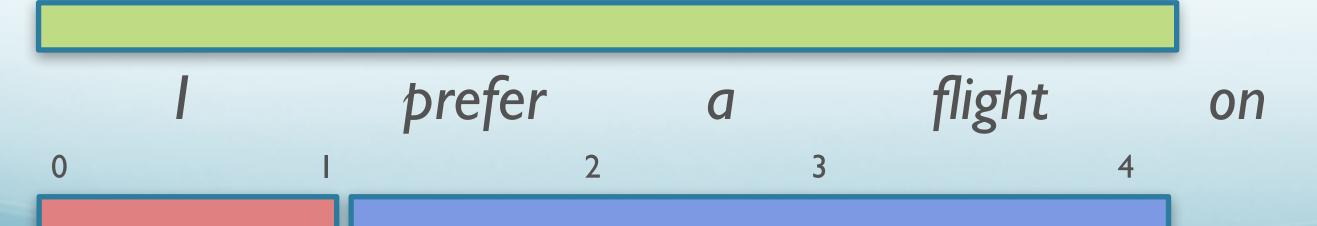


\mathscr{L}_1 Grammar	NP,	S			
$S \rightarrow NP VP$	Pronoun				
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	
$X1 \rightarrow Aux NP$		Words WD C		VD V2 C	
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S	
$S \rightarrow Verb NP$					
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$					
$NP \rightarrow I / she / me$			[2,3]	[2,4]	
$NP \rightarrow TWA / Houston$			[2,5]		
$NP \rightarrow Det\ Nominal$				Noun, Nom	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$					
$Nominal \rightarrow Nominal Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$ul \mid moneu$			
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$	<i>y</i> <i>y</i>			
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	_ ,,			
$VP \rightarrow VP PP$	$Preposition ightarrow from \mid to \mid c$	$on \mid near \mid through$	ah		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pro$	1	<i>)</i>		



\mathscr{L}_1 Grammar	
$S \rightarrow NP VP$	
$S \rightarrow X1 VP$	
$X1 \rightarrow Aux NP$	
$S \rightarrow book / include / prefer$	
$S \rightarrow Verb NP$	
$S \to X2 PP$	
$S \rightarrow Verb PP$	
$S \rightarrow VP PP$	
$NP ightarrow I \ / \ she \ / \ me$	
$NP \rightarrow TWA / Houston$	
$NP \rightarrow Det\ Nominal$	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$	
$Nominal \rightarrow Nominal \ Noun$	
$Nominal \rightarrow Nominal PP$	Lexico
$VP \rightarrow book \ / \ include \ / \ prefer$	$Det \rightarrow t$
$VP \rightarrow Verb NP$	Noun -
$VP \rightarrow X2 PP$	Pronour
$X2 \rightarrow Verb NP$	Proper-
$VP \rightarrow Verb PP$	$Aux \rightarrow$
$VP \rightarrow VP PP$	Preposit
$PP \rightarrow Preposition NP$	$Verb \rightarrow$

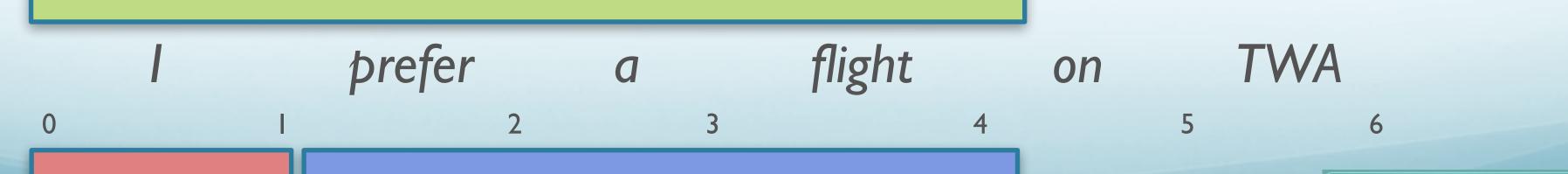
NP, Pronoun	S		S	
[0,1]	[0,2]	[0,3]	[0,4]	
	Verb, VP, S		VP , X2, S	
	[1,2]	[1,3]	[1,4]	
		Det	NP	
		[2,3]	[2,4]	
			Noun, Nom	
			[3,4]	
con				
	$\mid money$			
$egin{aligned} oun ightarrow I \mid she \mid me \ er ext{er-Noun} ightarrow Houston} \mid T \end{aligned}$	TWA			
ightarrow does	_ , , , , ,			
$psition ightarrow from \mid to \mid on \ ightarrow book \mid include \mid pref$	· ·	h		



TWA



\mathscr{L}_1 Grammar	NP,	S		S	
$S \to NP VP$	Pronoun				
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S	
$S \rightarrow book / include / prefer$		verb, vi, s		VI , XZ , S	
$S \rightarrow Verb NP$		г г ээ	FI 21	ΓΙ / 1	
$S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S o VP \ PP$	_				
$VP \rightarrow I / she / me$			[2,3]	[2,4]	
$VP \rightarrow TWA \mid Houston$					1 1
$VP \rightarrow Det\ Nominal$	-			Noun, Nom	
$Vominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 47	
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book \ / \ include \ / \ prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid m$	eal money			
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \stackrel{\cdot}{ ightarrow} Houston$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	l			
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid$	$on \mid near \mid through$	qh		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid p$				



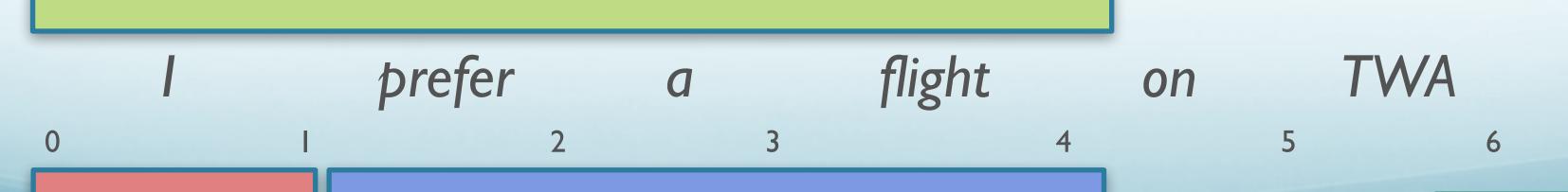


\mathscr{L}_1 Grammar	NP,	S		S	
$S \to NP VP$	Pronoun				
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S	
$S \rightarrow book / include / prefer$		verb, vi, s		, , , , , , , , , , , , , , , , , , ,	
$S \rightarrow Verb NP$		ГI 21	[1 3]	ΓΙ Δ Ί	
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$					
$VP \rightarrow I / she / me$			[2,3]	[2,4]	
$NP \rightarrow TWA / Houston$				Noun, Nom	
$VP \rightarrow Det\ Nominal$	·-			Noun, Nom	
$Vominal \rightarrow book / flight / meal / money$				F2 41	
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Vominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book \ / \ include \ / \ prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid m$	eal money			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \stackrel{'}{ ightarrow} Houston$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	ı			
$VP \rightarrow VP PP$	$Preposition o from \mid to \mid$	$on \mid near \mid through$	qh		
$PP \rightarrow Preposition NP$	$Verb ightarrow book \mid include \mid p$				





\mathscr{L}_1 Grammar	NP,	S		S	
$S \to NP VP$	Pronoun				
$S \rightarrow X1 \ VP$	[0,1]	[0,2]	[0,3]	[0,4]	
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S	
$S \rightarrow book / include / prefer$		verb, vr, s		VI , A 2, 3	
$S \rightarrow Verb NP$		ГI 21	ΓI 21	ΓI ⊿ 1	
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$	_				
$VP \rightarrow I / she / me$			[2,3]	[2,4]	
$VP \rightarrow TWA \mid Houston$					
$VP \rightarrow Det\ Nominal$	_			Noun, Nom	
$Vominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 41	
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book \ / \ include \ / \ prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$al \mid money$			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	Preposition \rightarrow from to	on near through	gh		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pr$				



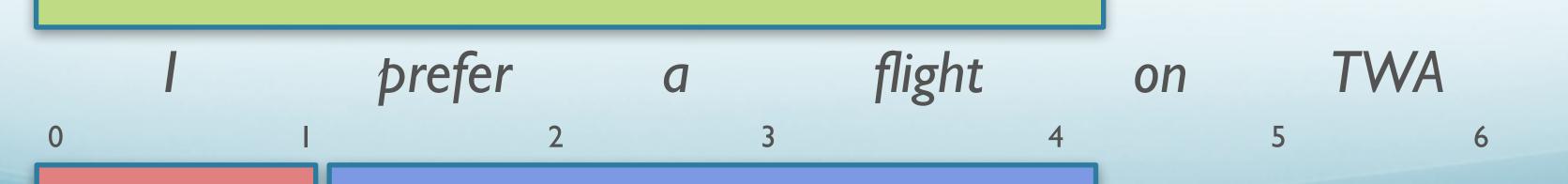


\mathscr{L}_1 Grammar	NP,	S		S	
$S \to NP VP$	Pronoun				
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S	
$S \rightarrow book / include / prefer$		verb, vr, s		VP, AZ, S	
$S \rightarrow Verb NP$		г . Ээ	EL 21	F1 47	
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$	_				
$VP \rightarrow I / she / me$			[2,3]	[2,4]	
$VP \rightarrow TWA \mid Houston$			L / J		
$VP \rightarrow Det\ Nominal$	_			Noun, Nom	
$Vominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 47	
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book \ / \ include \ / \ prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$al \mid money$			
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	$Preposition ightarrow from \mid to \mid e$	$on \mid near \mid through$	gh		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pro$	1 1			





\mathscr{L}_1 Grammar	NP,	S		S	
$S \rightarrow NP VP$	Pronoun				
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S	
$S \rightarrow book / include / prefer$		verb, vr, s			
$S \rightarrow Verb NP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow X2 PP$		[',4]	[1,5]		
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$	-				
$NP \rightarrow I / she / me$			[2,3]	[2,4]	
$VP \rightarrow TWA / Houston$				Noun, Nom	
$VP \rightarrow Det\ Nominal$	_			idouii, idoiii	
$Vominal \rightarrow book / flight / meal / money$				Γ 2 Λ 1	
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid me$	eal money			
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	Proper-Noun Houston	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	ı			
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid$	$on \mid near \mid throw$	gh		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid p$	'			



$\begin{array}{c} \mathscr{L}_{1} \ \mathbf{Grammar} \\ S \to NP \ VP \\ S \to X1 \ VP \end{array}$	NP, Pronoun	S [0 2]	ΓΛ 21	S [0 4]	
$X1 \rightarrow Aux NP$	[0,1]	[0,2]	[0,3]	[0,4]	
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S	
$S \rightarrow Verb NP$		F1 07	F1 27	F1 43	
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$					
$NP \rightarrow I / she / me$			[2,3]	[2,4]	
$NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$				Noun, Nom	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$					
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
Nominal o Nominal PP Lexicon	า				
	$that \mid this \mid a$				
	$\rightarrow book \mid flight \mid mea$	$l \mid money$			
	$n \rightarrow I \mid she \mid me$				
±	$Noun \rightarrow Houston \mid$	TWA			
$VP \rightarrow Verb PP$ $Aux \rightarrow$					
	$tion \rightarrow from \mid to \mid o$		ηh		
$PP \rightarrow Preposition NP$ $Verb \rightarrow$	book include pre	efer			

prefer a

flight



PROFESSIONAL MASTER'S IN COMPUTATIONAL LINGUISTICS

TWA

on

\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$ $S \rightarrow Verb \ NP$ $S \rightarrow X2 \ PP$		Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	
$S \rightarrow Verb \ PP$ $S \rightarrow VP \ PP$		[·,—]	Det	NP	
$NP \rightarrow I \mid she \mid me$ $NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$			[2,3]	[2,4] Noun, Nom	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$ $Nominal \rightarrow Nominal \ Noun$ $Nominal \rightarrow Nominal \ PP$	Lexicon			[3,4]	
$VP \rightarrow book \mid include \mid prefer$ $VP \rightarrow Verb \mid NP$ $VP \rightarrow X2 \mid PP$	$Det \rightarrow that \mid this \mid a$ $Noun \rightarrow book \mid flight \mid meal$ $Pronoun \rightarrow I \mid she \mid me$	money			
$X2 \rightarrow Verb \ NP$ $VP \rightarrow Verb \ PP$ $VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$Proper-Noun ightarrow Houston \mid$ $Aux ightarrow does$ $Preposition ightarrow from \mid to \mid o$ $Verb ightarrow book \mid include \mid pre$	$n \mid near \mid throug$	ah		

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flight



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

	NP,	S		S		
	Pronoun					
	[0,1]	[0,2]	[0,3]	[0,4]		
		Verb, VP, S		VP, X2, S		
		[1,2]	[1,3]	[1,4]		
			Det	NP		
			[2,3]	[2,4]		
				Noun, Nom		
				[3,4]		
Lexicon					Prep	
$Det \rightarrow the$	$at \mid this \mid a$				_	
	$book \mid flight \mid meal$	money			[4,5]	
	$ ightarrow I \mid she \mid me$					
Proper-No	$oun \rightarrow Houston \mid$	TWA				
$Aux \rightarrow dc$	_					
	$on \rightarrow from \mid to \mid o$		h			
Wamb b	ook include nro	$f_{\alpha\alpha}$				



 $Verb \rightarrow book \mid include \mid prefer$



\mathscr{L}_1 Grammar	NP,	S		S		
$S \to NP VP$	Pronoun					
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]		
$X1 \rightarrow Aux NP$						
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		
$S \rightarrow Verb NP$		FL 27	EL 23	F1 43		
$S \to X2 PP$		[1,2]	[1,3]	[1,4]		
$S \rightarrow Verb PP$			Det	NP		
$S \rightarrow VP PP$						
$NP \rightarrow I / she / me$			[2,3]	[2,4]		
$NP \rightarrow TWA / Houston$						
$NP \rightarrow Det\ Nominal$				Noun, Nom		
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				FO 47	F2 F3	
$Nominal \rightarrow Nominal \ Noun$			_	[3,4]	[3,5]	
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$l \mid money$			[4,5]	
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$					
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston \mid$	TWA				
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid c$	$on \mid near \mid throug$	h			
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$					

prefer



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\mathscr{L}_1 Grammar	ND	S		C		
$S \rightarrow NP \ VP$	NP,					
$S \rightarrow X1 \ VP$	Pronoun	ro 21	ro 21	Γ Λ 41		
$X1 \rightarrow Aux NP$	[0,1]	[0,2]	[0,3]	[0,4]		
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		
$S \rightarrow bbbk / thetade / prejer$ $S \rightarrow Verb NP$						
$S \rightarrow Vero NI$ $S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]		
$S \rightarrow Az II$ $S \rightarrow Verb PP$		L · /—]				
$S \rightarrow Vero TT$ $S \rightarrow VP PP$			Det	NP		
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	
$NP \rightarrow TWA / Houston$				Noun, Nom		
$NP \rightarrow Det\ Nominal$						
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				r> / 1	[2 E]	
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	
Nominal o Nominal PP	xicon				Prep	
$VP \rightarrow book / include / prefer$	$at \rightarrow that \mid this \mid a$					
	$bun \rightarrow book \mid flight \mid meab$	$l \mid money$			[4,5]	
	$onoun \rightarrow I \mid she \mid me$				[.,•]	
TTO TT 1 3TD	$oper$ -Noun \rightarrow Houston	TWA				
	$dx \rightarrow does$	_ ,,				
	$eposition ightarrow from \mid to \mid o$	$n \mid near \mid through$	ıh.			
	$rb ightarrow book \mid include \mid pre$	·				
	, o , ooon moodade pro	<i>J</i>				



\mathscr{L}_1 Grammar	NP,	S		S		
$S \rightarrow NP VP$	Pronoun					
$S \rightarrow X1 \ VP$	[0,1]	[0,2]	[0,3]	[0,4]		
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S		
$S \rightarrow book \mid include \mid prefer$ $S \rightarrow Verb NP$						
$S \rightarrow Vero NF$ $S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]		
$S \rightarrow Verb PP$		L / J				
$S \rightarrow VP PP$			Det	NP		
$NP \rightarrow I / she / me$			[2 2]	[2,4]	r2 51	
$NP \rightarrow TWA / Houston$			[2,3]		[2,5]	
$NP \rightarrow Det Nominal$				Noun, Nom		
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				4-		
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	
$VP \rightarrow book \ / \ include \ / \ prefer$	$Det \rightarrow that \mid this \mid a$				•	
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid me$	$al \mid money$			[4,5]	
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				L / J	
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA				
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid$	on near through	gh			
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pr$	refer				

flight

prefer



PROFESSIONAL MASTER'S IN
COMPUTATIONAL LINGUISTICS

TWA

on

\mathscr{L}_1 Grammar	NP,	S		S		
$S \rightarrow NP VP$	Pronoun					
$S \rightarrow X1 \ VP$	[0,1]	[0,2]	[0,3]	[0,4]		
$X1 \rightarrow Aux NP$		Verb, VP, S		VP V2 C		
$S \rightarrow book / include / prefer$		verb, vr, s		VP, X2, S		
$S \rightarrow Verb NP$		F1 07	EL 27	F1 47	F1 F3	
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow Verb PP$			Det	NP		
$S \rightarrow VP PP$						
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	
$NP \rightarrow TWA / Houston$			[2,0]		[2,3]	
$NP \rightarrow Det\ Nominal$				Noun, Nom		
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				FO 47		
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$l \mid money$			[4,5]	
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				[.,•]	
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA				
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid c$	$n \mid near \mid through$	h			
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$					



TWA

72

\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]		
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ \ include \ \ prefer$ $S \rightarrow Verb \ NP$ $S \rightarrow X2 \ PP$		Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
$S \rightarrow Verb \ PP$ $S \rightarrow VP \ PP$			Det	NP		
$NP \rightarrow I \mid she \mid me$ $NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$			[2,3]	Noun, Nom	[2,5]	
$Nominal \rightarrow book \mid flight \mid meal \mid money \ Nominal \rightarrow Nominal \ Noun \ Nominal \rightarrow Nominal \ PP$	Lexicon			[3,4]	[3,5] Prep	
$VP ightarrow book \mid include \mid prefer$ $VP ightarrow Verb \ NP$ $VP ightarrow X2 \ PP$ $X2 ightarrow Verb \ NP$ $VP ightarrow Verb \ PP$ $VP ightarrow VP \ PP$ $PP ightarrow Preposition \ NP$	$Det ightarrow that \mid this \mid a$ $Noun ightarrow book \mid flight \mid meal$ $Pronoun ightarrow I \mid she \mid me$ $Proper-Noun ightarrow Houston \mid$ $Aux ightarrow does$ $Preposition ightarrow from \mid to \mid o$ $Verb ightarrow book \mid include \mid pre$	TWA $n \mid near \mid throug$	h		[4,5]	



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\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]		
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ \ include \ \ prefer$ $S \rightarrow Verb \ NP$ $S \rightarrow X2 \ PP$		Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
$S \rightarrow Verb \ PP$ $S \rightarrow VP \ PP$		L · ,—]	Det	NP		
$NP \rightarrow I \mid she \mid me$ $NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$			[2,3]	Noun, Nom	[2,5]	
$Nominal \rightarrow book \mid flight \mid meal \mid money \ Nominal \rightarrow Nominal \mid Noun \ Nominal \rightarrow Nominal \mid PP$	Lexicon			[3,4]	[3,5] Prep	
$VP ightarrow book \ \ include \ \ prefer$ $VP ightarrow Verb \ NP$ $VP ightarrow X2 \ PP$ $X2 ightarrow Verb \ NP$ $VP ightarrow Verb \ PP$ $VP ightarrow VP \ PP$ $PP ightarrow Preposition \ NP$	$Det ightarrow that \mid this \mid a$ $Noun ightarrow book \mid flight \mid meal$ $Pronoun ightarrow I \mid she \mid me$ $Proper-Noun ightarrow Houston \mid$ $Aux ightarrow does$ $Preposition ightarrow from \mid to \mid o$ $Verb ightarrow book \mid include \mid pre$	TWA $n \mid near \mid throug$	h		[4,5]	

flight

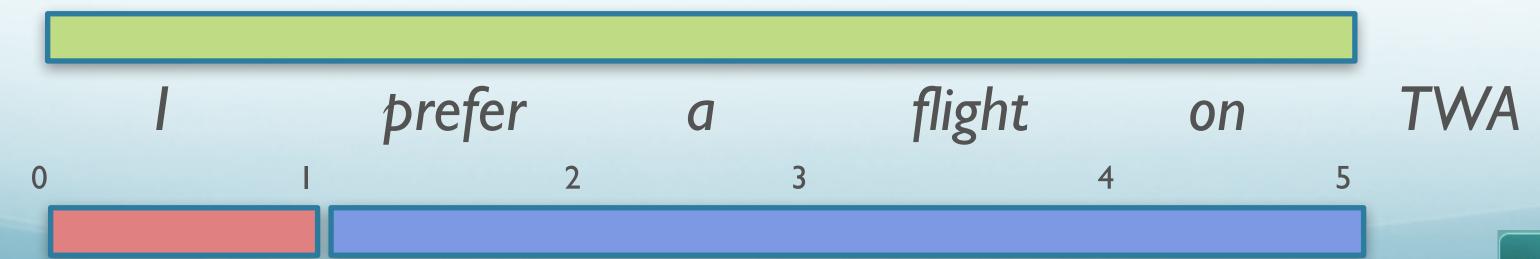
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TWA

\mathscr{L}_1 Grammar	NP,	S		S		
$S \to NP VP$	Pronoun					
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$					E / 3	
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		
$S \rightarrow Verb NP$						
$S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow Verb PP$			Det	NP		
$S \rightarrow VP PP$			Det			
$NP \rightarrow I / she / me$			ra 21	ro 41	ro r1	
$NP \rightarrow TWA / Houston$			[2,3]	[2,4]	[2,5]	
$NP \rightarrow Det\ Nominal$				Noun, Nom		
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$						
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	
	-			L / J		
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$l \mid money$			[4,5]	
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				L / J	
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA				
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition ightarrow from \mid to \mid c$	$n \mid near \mid through$	h			
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$	· ·				
		€.				



WASHINGTON

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\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$ $S \rightarrow Verb \ NP$	L~, · J	Verb, VP, S		VP, X2, S		
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow Verb \ PP$ $S \rightarrow VP \ PP$			Det	NP		
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	
$NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$				Noun, Nom		
$Nominal \rightarrow book \mid flight \mid meal \mid money \ Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	
$VP \rightarrow book \mid include \mid prefer$ $VP \rightarrow Verb \mid NP$ $VP \rightarrow X2 \mid PP$	$Det ightarrow that \mid this \mid a$ $Noun ightarrow book \mid flight \mid meab$ $Pronoun ightarrow I \mid she \mid me$	$l \mid money$			[4,5]	
$X2 \rightarrow Verb NP$ $VP \rightarrow Verb PP$	$Proper-Noun \rightarrow 1 \mid she \mid me$ $Proper-Noun \rightarrow Houston \mid Aux \rightarrow does$	TWA				
$VP \rightarrow VP PP$ $PP \rightarrow Preposition NP$	$Preposition ightarrow from \mid to \mid o$ $Verb ightarrow book \mid include \mid pre$	1	ah			

flight



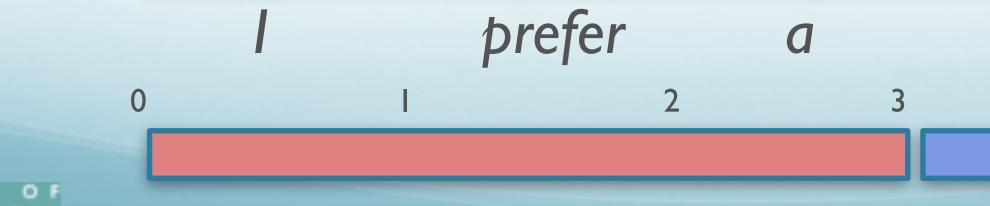
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TWA

\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$	L~,·J	Verb, VP, S		VP, X2, S		
$S \rightarrow Verb \ NP$ $S \rightarrow X2 \ PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow Verb \ PP$ $S \rightarrow VP \ PP$			Det	NP		
$NP \rightarrow I / she / me$ $NP \rightarrow TWA / Houston$			[2,3]	[2,4] Noun, Nom	[2,5]	
$NP \rightarrow Det\ Nominal$ $Nominal \rightarrow book\ /\ flight\ /\ meal\ /\ money$					F2 F1	
$Nominal \rightarrow Nominal \ Noun$ $Nominal \rightarrow Nominal \ PP$	Lexicon			[3,4]	[3,5] Prep	
$VP \rightarrow book \mid include \mid prefer$ $VP \rightarrow Verb \mid NP$ $VP \rightarrow X2 \mid PP$	$Det ightarrow that \mid this \mid a$ $Noun ightarrow book \mid flight \mid mea$ $Pronoun ightarrow I \mid she \mid me$	$l \mid money$			[4,5]	
$X2 \rightarrow Verb \ NP$ $VP \rightarrow Verb \ PP$ $VD \rightarrow VD \ DP$	$Proper-Noun \rightarrow Houston \mid Aux \rightarrow does$		7			
$VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$Preposition \rightarrow from \mid to \mid o$ $Verb \rightarrow book \mid include \mid pre$		ηh			

flight



TWA

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6



\mathscr{L}_1 Grammar	ND	<u> </u>		S		
$S \rightarrow NP \ VP$	NP,	S		3		
$S \rightarrow NI VI$ $S \rightarrow X1 VP$	Pronoun	ro 21	ΓΛ 21	FO 41	ro F1	
$X1 \rightarrow Aux NP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		
$S \rightarrow Verb NP$						
$S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow Verb PP$		L / J				
$S \rightarrow VP PP$			Det	NP		
$NP \rightarrow I / she / me$			ro 01	FO 47	FO F1	
$NP \rightarrow TWA / Houston$			[2,3]	[2,4]	[2,5]	
$NP \rightarrow Det\ Nominal$				Noun, Nom		
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$						
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$		_			
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$al \mid moneu$			[4,5]	
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$					
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA				
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid$	$on \mid near \mid through$	gh			
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pr$	1				
		U				

prefer a

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TWA

$\mathcal{L}_{1} \mathbf{Grammar}$ $S \to NP \ VP$ $S \to X1 \ VP$ $Y1 \to Aum \ NP$	NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ \ include \ \ prefer$ $S \rightarrow Verb \ NP$ $S \rightarrow X2 \ PP$		Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
$S \rightarrow Verb \ PP$ $S \rightarrow VP \ PP$ $NP \rightarrow I \ \ she \ \ me$			Det [2,3]	NP [2,4]	[2,5]	
$NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$ $Nominal \rightarrow book \mid flight \mid meal \mid money$				Noun, Nom [3,4]	[3,5]	
$Nominal \rightarrow Nominal \ Noun$ $Nominal \rightarrow Nominal \ PP$ $VP \rightarrow book \ / \ include \ / \ prefer$ $VP \rightarrow Verb \ NP$	Lexicon $Det \rightarrow that \mid this \mid a$ $Noun \rightarrow book \mid flight \mid meal$! money			Prep [4,5]	
$VP \rightarrow X2 \ PP$ $X2 \rightarrow Verb \ NP$ $VP \rightarrow Verb \ PP$ $VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$egin{aligned} Pronoun & ightarrow I \mid she \mid me \ Proper-Noun & ightarrow Houston \mid \ Aux & ightarrow does \ Preposition & ightarrow from \mid to \mid o \ Verb & ightarrow book \mid include \mid pre \end{aligned}$	$n \mid near \mid throug$	h			NNP, NP [5,6]



$\mathcal{L}_{1} \mathbf{Grammar}$ $S \to NP \ VP$ $S \to V1 \ VD$	NP, Pronoun	S 50.01	FO 27	S	FO F3	
$S \to X1 \ VP$ $X1 \to Aux \ NP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		
$S \rightarrow Verb NP$						
$S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow Verb PP$			Det	NP		
$S \to VP PP$						
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	
$NP \rightarrow TWA \mid Houston$			L / J			
$NP \rightarrow Det\ Nominal$				Noun, Nom		
$Nominal \rightarrow book / flight / meal / money$				[2 4]	[2 E]	
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	
	Lexicon				Prep	PP
	$Det \rightarrow that \mid this \mid a$					_
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid med$	$nl \mid money$			[4,5]	[4,6]
	$Pronoun \rightarrow I \mid she \mid me$					NNP, NP
	$Proper-Noun \rightarrow Houston \mid$	TWA				MINIT, INIT
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					Γ 5 6 1
	$Preposition \rightarrow from \mid to \mid c$		ηh			[5,6]
PP ightarrow Preposition NP	$Verb \rightarrow book \mid include \mid pr$	efer				



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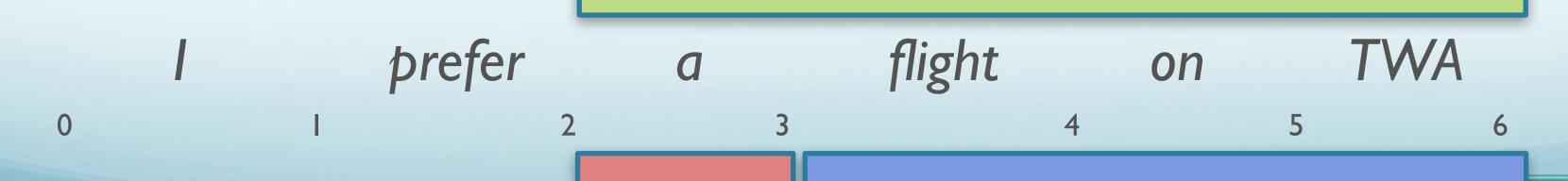
\mathscr{L}_1 Grammar	NP,	S		S		
$S \rightarrow NP \ VP$	Pronoun					
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$					L / 1	
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		
$S \rightarrow Verb NP$		F1 03	F1 27	F1 47	F1 F3	
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow Verb PP$			Det	NP		
$S \to VP PP$						
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	
$NP \rightarrow TWA / Houston$				Noun, Nom		Nom
$NP \rightarrow Det\ Nominal$				Noull, Noill		Nom
$Nominal \rightarrow book / flight / meal / money$				[3,4]	F2 51	r2 41
$Nominal \rightarrow Nominal Noun$			_	[5,7]	[3,5]	[3,6]
Nominal ightarrow Nominal PP	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid meal$	$l \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$					NNP, NP
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston \mid$	TWA				, , , , , ,
$VP \rightarrow Verb PP$ $VD \rightarrow VD DD$	$Aux \rightarrow does$	17	7			[5,6]
$VP \rightarrow VP PP$ $DD \rightarrow Dromo \ oition \ ND$	$Preposition \rightarrow from \mid to \mid o$	· ·	$^{\prime}h$			[-,-]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$	<i>fer</i>				



\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$		Verb, VP, S		VP, X2, S		
$S \rightarrow Verb \ NP$ $S \rightarrow X2 \ PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \to Verb PP$ $S \to VP PP$			Det	NP		
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	
$NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$				Noun, Nom		Nom
Nominal $\rightarrow book \ / \ flight \ / \ meal \ / \ money$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal \ Noun$ $Nominal \rightarrow Nominal \ PP$	Lexicon				Prep	PP
$VP \rightarrow book \mid include \mid prefer$ $VP \rightarrow Verb \mid NP$	$Det \rightarrow that \mid this \mid a$ $Noun \rightarrow book \mid flight \mid meab$	$l \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 \ PP$ $X2 \rightarrow Verb \ NP$	$Pronoun ightarrow I \mid she \mid me$ $Proper-Noun ightarrow Houston \mid$	TWA				NNP, NP
$VP \rightarrow Verb \ PP$ $VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$Aux ightarrow does$ $Preposition ightarrow from \mid to \mid o$ $Verb ightarrow book \mid include \mid pre$	$n \mid near \mid throug$	vh			[5,6]



\mathscr{L}_1 Grammar	NP,	S		S		
$S \to NP \ VP$ $S \to X1 \ VP$	Pronoun [0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$ $S \rightarrow book \mid include \mid prefer$		Verb, VP, S		VP, X2, S		
$S \rightarrow Verb \ NP$ $S \rightarrow X2 \ PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow Verb PP$ $S \rightarrow VP PP$			Det	NP		NP
$NP \rightarrow I \mid she \mid me$ $NP \rightarrow TWA \mid Houston$			[2,3]	[2,4]	[2,5]	[2,6]
$NP ightarrow Det \ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \mid flight \mid meal \mid money \ Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
	Lexicon				Prep	PP
$VP \rightarrow Verb NP$	$Det \rightarrow that \mid this \mid a$ $Noun \rightarrow book \mid flight \mid mea$	$l \mid money$			[4,5]	[4,6]
$X2 \rightarrow Verb NP$	$Pronoun \rightarrow I \mid she \mid me$ $Proper-Noun \rightarrow Houston \mid$	TWA				NNP, NP
TID TID DD	$Aux \rightarrow does$ $Preposition \rightarrow from \mid to \mid c$	$n \mid near \mid throug$	h			[5,6]
	$Verb \rightarrow book \mid include \mid pre$	· · · · · · · · · · · · · · · · · · ·				



$\mathcal{L}_{1} \mathbf{Grammar}$ $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$		Verb, VP, S		VP, X2, S		
$S \rightarrow Verb NP$ $S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow Verb PP$		L · /	Det	NP	Life	NP
$S \rightarrow VP PP$						
$NP ightarrow I \mid she \mid me$ $NP ightarrow TWA \mid Houston$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow Det\ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book / flight / meal / money$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal \ Noun \ Nominal \rightarrow Nominal \ PP$	T •					
$VP \rightarrow book \ / \ include \ / \ prefer$	Lexicon Detailed this lea				Prep	PP
$VP \rightarrow Verb NP$	$Det \rightarrow that \mid this \mid a$ $Noun \rightarrow book \mid flight \mid mean$	$l \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$	l			[.,-]	
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston \mid$	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	1 . 7	1			[5,6]
$VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$Preposition ightarrow from \mid to \mid o$ $Verb ightarrow book \mid include \mid preg$		rh			

prefer a

flight



PROFESSIONAL MASTER'S IN
COMPUTATIONAL LINGUISTICS

TWA

$\mathcal{L}_{1} \mathbf{Grammar}$ $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$		Verb, VP, S		VP, X2, S		
$S \rightarrow Verb NP$		ΓI 21	ΓΙ 2 1	ΓΙ Δ Ί	[
$S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow Verb PP$ $S \rightarrow VP PP$			Det	NP		NP
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$						
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book \ / \ include \ / \ prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mean$	$l \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				L / J	
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston \mid$	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					FF / 1
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid o$	1	h			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$	fer				

prefer a

flight



PROFESSIONAL MASTER'S IN
COMPUTATIONAL LINGUISTICS

TWA

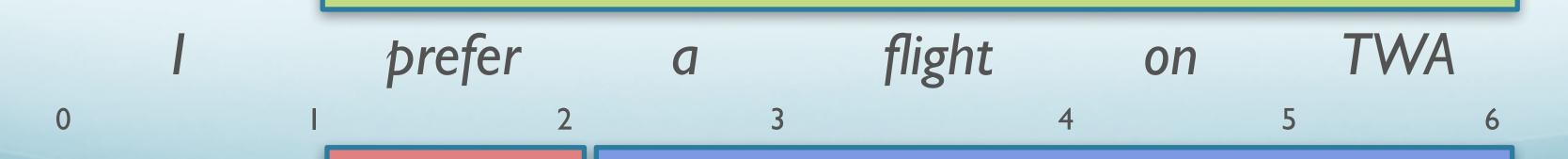
\mathscr{L}_1 Grammar
$S \rightarrow NP \ VP$
$S \rightarrow X1 \ VP$
$X1 \rightarrow Aux NP$
$S \rightarrow book / include / prefer$
$S \rightarrow Verb NP$
$S \rightarrow X2 PP$
$S \rightarrow Verb PP$
$S \rightarrow VP PP$
$NP \rightarrow I / she / me$
$NP \rightarrow TWA / Houston$
$NP \rightarrow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

	NP,	S		S		
	Pronoun					
	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
		Verb, VP, S		VP, X2, S		
		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
			Det	NP		NP
			[2,3]	[2,4]	[2,5]	[2,6]
				Noun, Nom		Nom
				[3,4]	[3,5]	[3,6]
Lexicon					Prep	PP
$Det \rightarrow tha$	at this a					
	$look \mid flight \mid meal$	$\mid money$			[4,5]	[4,6]
	$\rightarrow I \mid she \mid me$					NNP, NP
-	$un \rightarrow Houston \mid$	TWA				
$Aux \rightarrow do$			-			[5,6]
Preposition	$n o from \mid to \mid o$	$n \mid near \mid throug$	h			[5,6]

prefer flight TWA on

 $Verb \rightarrow book \mid include \mid prefer$

\mathscr{L}_1 Grammar	NP,	S		S		
$S \to NP VP$	Pronoun					
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$						VD
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		VP
$S \rightarrow Verb NP$		F1 07	EL 33	F1 43	F1 F3	F1 /7
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \to VP PP$	_					_
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA \mid Houston$			L / J			
$NP \rightarrow Det\ Nominal$	_			Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 47	F2 F3	F2 43
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
VP ightarrow Verb NP	$Noun \rightarrow book \mid flight \mid mea$	$ul \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$				L / J	
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					FF 43
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid d$	on near throug	h			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pro$					



\mathscr{L}_1 Grammar	NP,	S		S		
$S \to NP VP$	Pronoun					
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$					L . , .]	
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		VP, X2
$S \rightarrow Verb NP$						
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \rightarrow VP PP$						
$NP \rightarrow I / she / me$	·-		[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA / Houston$			[2,5]		[2,5]	
$NP \rightarrow Det \ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$	· -					
$Nominal \rightarrow Nominal Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid me$	$al \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				[.,•]	
$X2 \rightarrow Verb NP$	Proper-Noun Houston	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition o from \mid to \mid$	$on \mid near \mid through$	ah			[5,6]
$PP \rightarrow Preposition NP$	$Verb ightarrow book \mid include \mid pr$,			

I prefer a flight on TWA 5 6

\mathscr{L}_1 Grammar	NP,	S		S		
$S \rightarrow NP VP$	Pronoun					
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$						VP V2 C
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		VP, X2, S
$egin{array}{cccccccccccccccccccccccccccccccccccc$		F1 27	EL 23	F1 47	F1 F3	EL /3
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \to VP PP$						_
NP ightarrow I / she / me			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA \mid Houston$			L / J			
$NP \rightarrow Det\ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				FO. 47	F0 F7	FO 47
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book \ / \ include \ / \ prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$al \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$				[.,-]	
$X2 \rightarrow Verb NP$	Proper-Noun Houston	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition o from \mid to \mid c$	$on \mid near \mid through$	vh			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$					

prefer a flight on TWA

2 3 4 5 6

\mathscr{L}_1 Grammar	NP,	S		S		
$S \rightarrow NP VP$	Pronoun					
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$						VP V2 C
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		VP, X2, S
$S \rightarrow Verb NP$		F1 07	F1 07	F1 47	F. F.	F1 43
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \to VP PP$	_					_
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA \mid Houston$			L / J			
$NP \rightarrow Det\ Nominal$	_			Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 47	FO F7	FO 43
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid m$	eal money			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				L ., • J	
$X2 \rightarrow Verb NP$	$Proper-Noun \stackrel{\cdot}{ ightarrow} Houston$	$I \mid TWA$				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	1				
$VP \rightarrow VP PP$	$Preposition ightarrow from \mid to \mid$	on near through	gh			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid p$					

I prefer a flight on TWA or 1 2 3 4 5 6



\mathscr{L}_1 Grammar	NP,	S		S		
$S \to NP VP$	Pronoun					
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$						MD MO C
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		VP, X2, S
$S \rightarrow Verb NP$						^-
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \to VP PP$						_
$NP ightarrow I \ / \ she \ / \ me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA / Houston$			[_,0]			
$NP \rightarrow Det\ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$						
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book \ / \ include \ / \ prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$al \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$				[·,•]	
$X2 \rightarrow Verb NP$	Proper-Noun Houston	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition ightarrow from \mid to \mid c$	$on \mid near \mid through$	gh			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$	1				

I prefer a flight on TWA on 1 2 3 4 5 6



\mathscr{L}_1 Grammar
$S \rightarrow NP VP$
$S \rightarrow X1 VP$
$X1 \rightarrow Aux NP$
$S \rightarrow book / include / prefer$
$S \rightarrow Verb NP$
$S \rightarrow X2 PP$
$S \rightarrow Verb PP$
$S \rightarrow VP PP$
$NP \rightarrow I / she / me$
$NP \rightarrow TWA / Houston$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$
$Nominal \rightarrow Nominal \ Noun$
$Nominal \rightarrow Nominal PP$
$VP \rightarrow book / include / prefer$
$VP \rightarrow Verb NP$
$VP \rightarrow X2 PP$
$X2 \rightarrow Verb NP$
$VP \rightarrow Verb PP$
$VP \rightarrow VP PP$
$PP \rightarrow Preposition NP$
$TI \rightarrow I I C \mu O S U U O U I V I$

	NP, Pronoun	S		S		
	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
		Verb, VP, S		VP, X2, S		VP, X2, S
		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
			Det	NP		NP
			[2,3]	[2,4]	[2,5]	[2,6]
				Noun, Nom		Nom
				[3,4]	[3,5]	[3,6]
Lexicon					Prep	PP
$Det \rightarrow tha$	at this a					
$Noun \rightarrow b$	$pook \mid flight \mid meal$	$\mid money$			[4,5]	[4,6]
$Pronoun \rightarrow I \mid she \mid me$						NNP, NP
-	$oun \rightarrow Houston \mid 1$	TWA				
$Aux \rightarrow do$		1	1			[5,6]
Preposition	$n \rightarrow from \mid to \mid or$	$n \mid near \mid throug$	n			[-,-]

I prefer a flight on TWA of the second of th

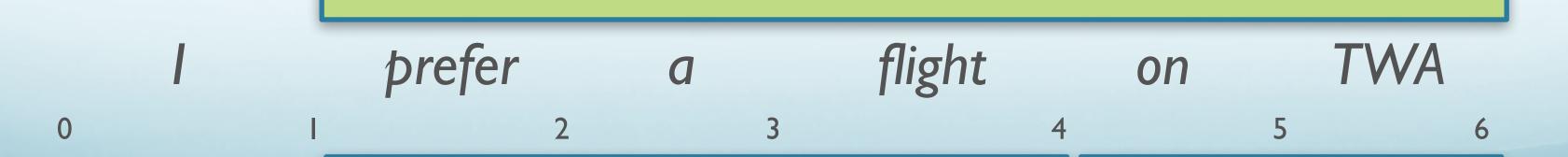
 $Verb \rightarrow book \mid include \mid prefer$



\mathscr{L}_1 Grammar	NP,	S		S		
$S \to NP VP$	Pronoun					
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$						V/D V/O O
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		VP, X2, S
$S \rightarrow Verb NP$						
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \to VP PP$						
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA / Houston$			[_,-]		[_,_,	
$NP \rightarrow Det\ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$	-					
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					_
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid me$	eal money			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$				[., ~]	
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	1				
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid$	on near throug	ah			[5,6]
$PP \rightarrow Preposition NP$	$Verb ightarrow book \mid include \mid pro$					

flight prefer TWA a on

\mathscr{L}_1 Grammar	NP,	S		S	
$S \rightarrow NP \ VP$	Pronoun				
$S \rightarrow X1 \ VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]
$X1 \rightarrow Aux NP$			[0,5]		[0,5]
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S	
$S \rightarrow Verb'NP$					
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]
$S \rightarrow \underline{Verb} PP$			Det	NP	
$S \rightarrow VP PP$					
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]
$NP \rightarrow TWA / Houston$			[2,5]		[2,5]
$NP \rightarrow Det\ Nominal$				Noun, Nom	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$					
$Nominal \rightarrow Nominal Noun$				[3,4]	[3,5]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$al \mid money$			[4,5]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				L .,• J
$X2 \rightarrow Verb NP$	Proper-Noun Houston	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid c$	$on \mid near \mid through$	gh		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$				



VP, X2, S

[1,6]

NP

[2,6]

Nom

[3,6]

[4,6]

[5,6]

NNP, NP

\mathscr{L}_1 Grammar	NP,	S		S		
$S \rightarrow NP VP$	Pronoun					
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$						VD V0 6
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		VP, X2, S
$S \rightarrow Verb NP$						
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \rightarrow VP PP$			Dec			
$NP \rightarrow I / she / me$	•		[O 0]	ro 41	[2 []	[O 4]
$NP \rightarrow TWA / Houston$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow Det\ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$	-					
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
	T •			L / J		
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$al \mid money$			[4,5]	[4,6]
VP ightarrow X2 PP	$Pronoun \rightarrow I \mid she \mid me$					
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston \mid$	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid$	$on \mid near \mid through$	ηh			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pr$					

I prefer a flight on TWA or 1 2 3 4 5 6

\mathscr{L}_1 Grammar	ND	C		C
$S \rightarrow NP \ VP$	NP,	S		S
$S \rightarrow X1 \ VP$	Pronoun [0,1]	[0,2]	[0,3]	[0
$X1 \rightarrow Aux NP$			[0,5]	_
$S \rightarrow book / include / prefer$		Verb, VP, S		V
$S \rightarrow Verb NP$				
$S \to X2 PP$		[1,2]	[1,3]	[1
$S \rightarrow Verb PP$			Det	N
$S \to VP PP$				
$NP \rightarrow I / she / me$			[2,3]	[2
$NP \rightarrow TWA / Houston$			[2,5]	_
$NP \rightarrow Det \ Nominal$				N
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$	-			
$Nominal \rightarrow Nominal Noun$				[3
$Nominal \rightarrow Nominal PP$	Lexicon			
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$			
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$l \mid money$		
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$			
$X2 \rightarrow Verb NP$	Proper-Noun Houston	TWA		
$VP \rightarrow Verb PP$	$Aux \rightarrow does$			
$VP \rightarrow VP PP$	$Preposition o from \mid to \mid c$	on near throug	h	
$PP \rightarrow Preposition NP$	$Verb ightarrow book \mid include \mid pre$	1		

	NP,	S		S		
	Pronoun					
	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
		Verb, VP, S		VP, X2, S		VP, X2, S
		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
			Det	NP		NP
			[2,3]	[2,4]	[2,5]	[2,6]
				Noun, Nom		Nom
				[3,4]	[3,5]	[3,6]
on					Prep	PP
	$t \mid this \mid a$					
	$pok \mid flight \mid meal$	money			[4,5]	[4,6]
	$ ightarrow I \mid she \mid me \ un ightarrow Houston \mid She angle$	TIMA				NNP, NP
$\rightarrow doe$	'	I VV A				
	$n o from \mid to \mid or$	$n \mid near \mid through$	h			[5,6]

prefer flight TWA



\mathscr{L}_1 Grammar
$S \rightarrow NP VP$
$S \rightarrow X1 VP$
$X1 \rightarrow Aux NP$
$S \rightarrow book / include / prefer$
$S \rightarrow Verb NP$
$S \to X2 PP$
$S \rightarrow Verb PP$
$S \rightarrow VP PP$
$NP ightarrow I \ / \ she \ / \ me$
$NP \rightarrow TWA / Houston$
$NP \rightarrow Det \ Nominal$
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$
$Nominal \rightarrow Nominal \ Noun$
$Nominal \rightarrow Nominal PP$
$VP \rightarrow book / include / prefer$
$VP \rightarrow Verb NP$
$VP \rightarrow X2 PP$
$X2 \rightarrow Verb NP$
$VP \rightarrow Verb PP$
$VP \rightarrow VP PP$
$PP \rightarrow Preposition NP$

	NP,	S		S		
	Pronoun					
	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
		Verb, VP, S		VP, X2, S		VP, X2, S
		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
			Det	NP		NP
			[2,3]	[2,4]	[2,5]	[2,6]
				Noun, Nom		Nom
				[3,4]	[3,5]	[3,6]
Lexicon					Prep	PP
$Det \rightarrow tha$	$at \mid this \mid a$					
	$ook \mid flight \mid meal$	$\mid money$			[4,5]	[4,6]
	$\rightarrow I \mid she \mid me$					NNP, NP
_	$un \rightarrow Houston \mid S$	TWA				
$Aux \rightarrow do$			_			Γ 5
Preposition	$n o from \mid to \mid or$	$n \mid near \mid through$	h			[5,6]

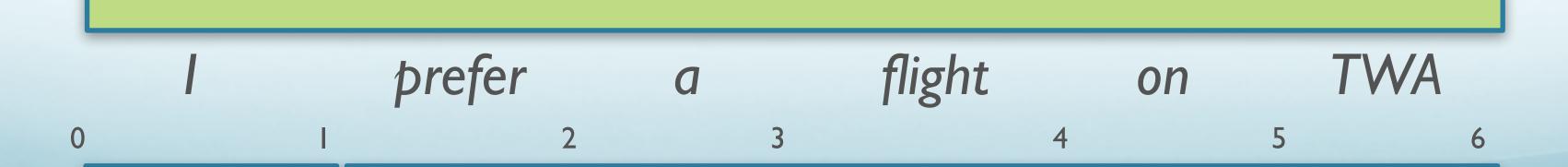
prefer flight TWA on

 $Preposition \rightarrow from \mid to \mid on \mid near \mid through$

 $Verb \rightarrow book \mid include \mid prefer$



\mathscr{L}_1 Grammar $S \to NP \ VP$	NP, Pronoun	S		S		
$S \to X1 VP$		[0,2]	[0,3]	[0,4]	[0,5]	[0,6]
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S		VP, X2, S
$S \rightarrow book / include / prefer$		verb, vr, s		VP, AZ, 5		VP, AZ, S
$S \rightarrow Verb NP$		[]]	[]]	F1 47	C1 C3	F1 /1
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \to VP PP$						
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA \mid Houston$			L / J		L / J	
$NP \rightarrow Det\ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 43	F2 F3	F2 43
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				•	
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid meal$	$l \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				L 1,0 J	
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid o$	$n \mid near \mid throug$	h			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$					



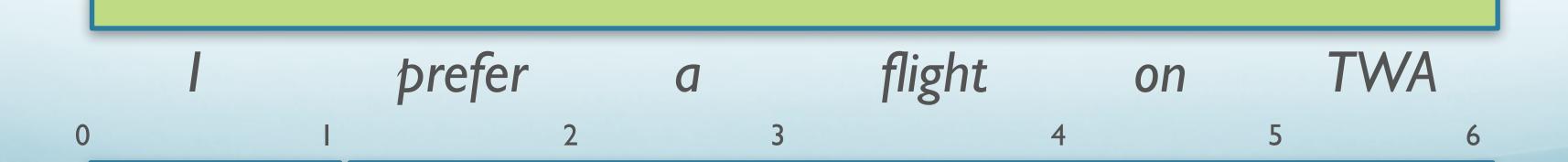


\mathscr{L}_1 Grammar	NP,	S		S		S
$S \rightarrow NP VP$ $S \rightarrow X1 VP$	Pronoun					_
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	[0,6]
$X1 \rightarrow Aux NP$						
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		VP, X2, S
$S \rightarrow Verb NP$			F.1. 0.7	F1 47	F. F.	F1 49
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \rightarrow VP PP$						
NP ightarrow I / she / me			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA / Houston$			L—, • J			
$NP \rightarrow Det\ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$						
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid meal$	$l \mid moneu$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				[.,•]	
$X2 \rightarrow Verb NP$	Proper-Noun Houston	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid o$	$n \mid near \mid through$	ηh			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$	1				
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$	ter				

I prefer a flight on TWA
o 1 2 3 4 5 6



\mathscr{L}_1 Grammar	NP,	S		S		S
$S \rightarrow NP VP$	Pronoun					
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	[0,6]
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S		VP, X2, S
$S \rightarrow book / include / prefer$		verb, vr, s		VF, AZ, 3		VP, AZ, S
$S \rightarrow Verb NP$		F1 03	EL 33	F1 43	F1 F3	F1 /3
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \rightarrow VP PP$						
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA / Houston$			[2,5]			
$NP \rightarrow Det\ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				FO 47	FO F7	FD 47
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid meal$	$l \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				L / J	
$X2 \rightarrow Verb NP$	Proper-Noun Houston	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid o$	$n \mid near \mid through$	h			[5,6]
$PP \rightarrow Preposition NP$	$Verb ightarrow book \mid include \mid pre$					



\mathscr{L}_1 Grammar	NP,	S		S		S
$S \rightarrow NP VP$	Pronoun					
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	[0,6]
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S		VP, X2, S
$S \rightarrow book / include / prefer$		verb, vr, s		VP, AZ, 3		VP, AZ, S
$S \rightarrow Verb NP$		EL 03	F1 33	F1 43	F1 F3	F1 /3
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \rightarrow VP PP$						
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA / Houston$			[2,5]			
$NP \rightarrow Det\ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 47	F2 F3	F2 43
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid meat$	$l \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				L / J	
$X2 \rightarrow Verb NP$	Proper-Noun Houston	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid o$	$n \mid near \mid through$	h			[5,6]
$PP \rightarrow Preposition NP$	$Verb ightarrow book \mid include \mid pre$					

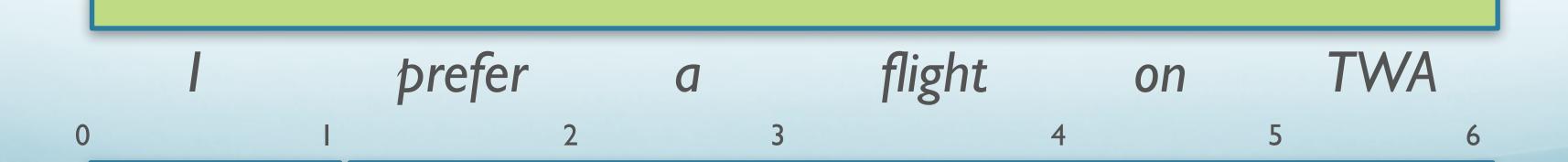


\mathcal{L}_1 Grammar $S \to NP \ VP$	NP,	S		S		S
$S \to X1 VP$	Pronoun [0,1]	[0,2]	[0,3]	[0,4]	[0,5]	[0,6]
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$		Verb, VP, S		VP, X2, S		VP, X2, S
$S \rightarrow Verb NP$ $S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \rightarrow VP \ PP$ $NP \rightarrow I \ \ she \ \ me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA / Houston$ $NP \rightarrow Det Nominal$			[2,5]	Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$						F2 /1
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$al \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				L / J	
$X2 \rightarrow Verb NP$	Proper-Noun Houston	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition ightarrow from \mid to \mid c$	$on \mid near \mid through$	ah			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$					





\mathscr{L}_1 Grammar	NP,	S		S		S
$S \rightarrow NP VP$	Pronoun					
$S \rightarrow X1 \ VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	[0,6]
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S		VP, X2, S
$S \rightarrow book / include / prefer$		vers, vi, s		, , , , , ,		VI, 202, S
$S \rightarrow Verb NP$		EL 21	ГI 21	ΓΙ / 1	F1 E1	ΓΙ ζ Ί
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \to VP PP$						
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA \mid Houston$					L/- J	
$NP \rightarrow Det\ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				 4-		4T
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mean$	$l \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				L ., -]	
$X2 \rightarrow Verb NP$	Proper-Noun Houston	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid o$	$n \mid near \mid through$	h			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$					



Current CKY Algorithm

- Limitations:
- Only stores non-terminals in cell
 - Not rules or cells corresponding to RHS
 - Stores SETS of non-terminals
 - Multiple rules with same LHS collide
- Currently only acceptance/recognition





CKY Parser

- Pair each nonterminal with backpointer to cells from which it was derived
- Last step: construct trees from backpointers in [0, n]





NP,	S		S		
Pronoun [0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
	Verb, VP, S		VP, X2, S		VP
	[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
		Det	NP		NP
		[2,3]	[2,4]	[2,5]	[2,6]
			Noun, Nom		Nom
			[3,4]	[3,5]	[3,6]
				Prep	PP
				[4,5]	[4,6]
					NNP, NP
					[5,6]







NP, Pronoun [0,1]

[0,2] Verb, VP, S

[1,2]

[0,3]

[1,3]

Det

[2,3]

[0,4] VP, X2, S

S

NP

[3,4]

[1,4] [1,5]

NP

VP

[1,6]

[2,6]

[3,6]

PP

[4,6]

Nom

[2,4] [2,5]

Noun, Nom

[3,5]

[0,5]

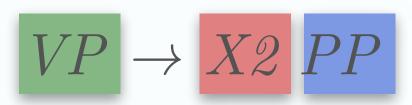
Prep

[4,5]

NNP, NP

[5,6]

bp_	_1 =	BackPo	oir	nter()	
bp_	_1.1_	child	=	[VP,	(1,4)]
bp_	_1.r_	child	=	[PP,	(4,6)]



NP,
Pronoun
[0,1]

[1,2]

[1,3]

Det

[2,3]

[1,4]

NP

[3,4]

NNP, NP

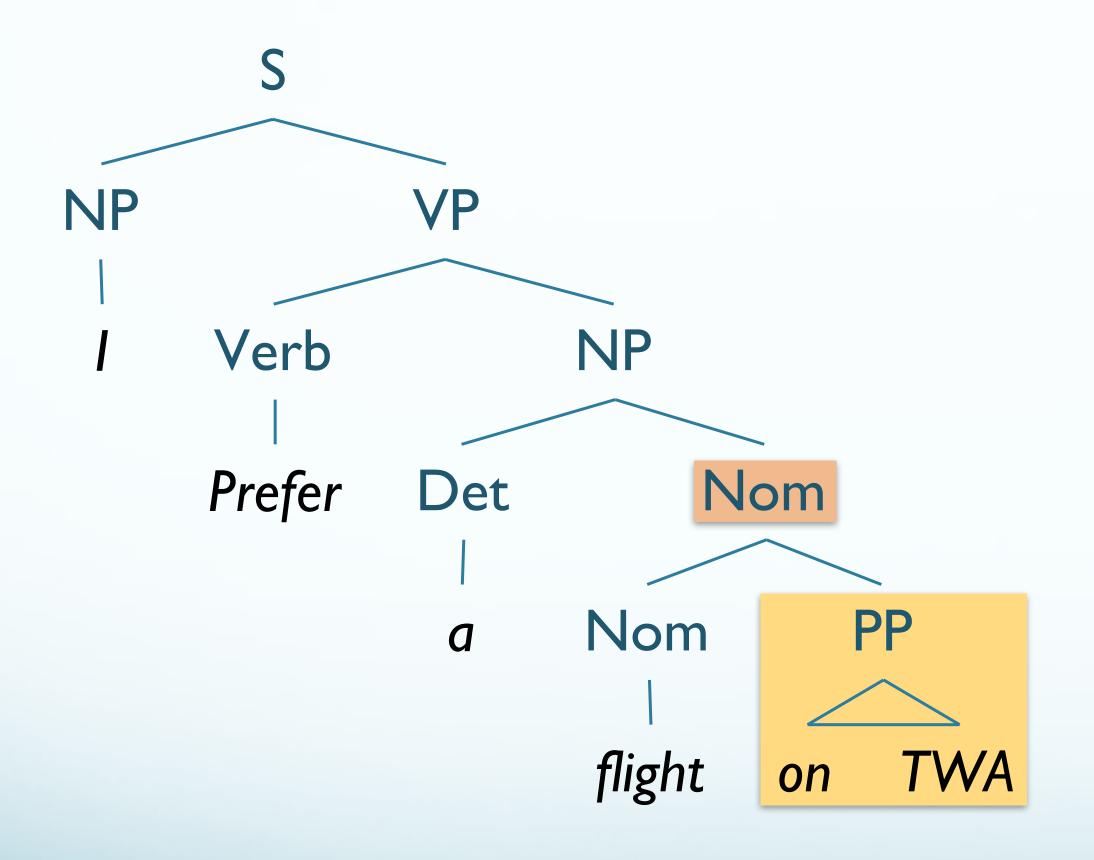
[5,6]

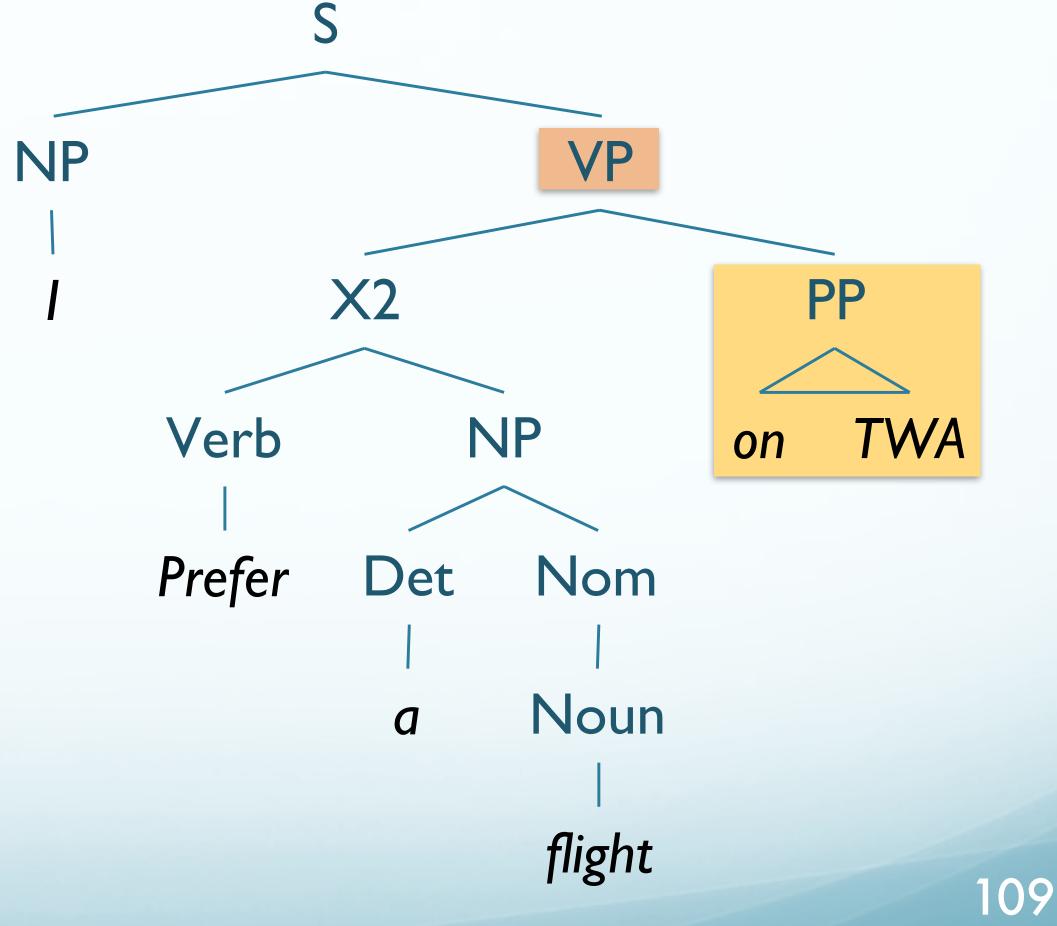
bp_2 = BackI	BackPointer()					
bp_2.1_child	d =	[X2,	(1,4)]			
bp_2.r_child	d =	[PP,	(4,6)]			

WASHINGTON



Resulting Parses









CKY Discussion

- Running time:
 - ullet $O(n^3)$ where n is the length of the input string
 - Inner loop grows as square of # of non-terminals
- Expressiveness:
 - As implemented, requires CNF
 - Weak equivalence to original grammar
 - Doesn't capture full original structure
 - Back-conversion?
 - Can do binarization, terminal conversion
 - Unit productions requires change in CKY





Parsing: PCFGs

Ling 571
Deep Processing Techniques for NLP
January 18, 2017





Probabilistic Context-free Grammars: Roadmap

- Motivation: Ambiguity
- Approach:
 - Definition
 - Disambiguation
 - Parsing
 - Evaluation
 - Enhancements





Motivation

What about ambiguity?

• Current algorithm can represent it

...can't resolve it.





Probabilistic Parsing

- Provides strategy for solving disambiguation problem
 - Compute the probability of all analyses
 - Select the most probable

- Employed in language modeling for speech recognition
 - N-gram grammars predict words, constrain search
 - Also, constrain generation, translation





PCFGs: Formal Definition

N	a set of non-terminal symbols (or variables)		
\sum	a set of terminal symbols (disjoint from N)		
R	a set of rules of productions, each of the form $A ooldsymbol{\beta}[p]$, where A is a non-terminal where A is a non-terminal, $oldsymbol{\beta}$ is a string of symbols from the infinite set of strings $(\Sigma\cup N)*$ and p is a number between 0 and 1 expressing $P(oldsymbol{\beta} A)$		
S	a designated start symbol		



PCFGs

- Augment each production with probability that LHS will be expanded as RHS
 - $P(A \rightarrow \beta)$
 - $P(A \rightarrow \beta | A)$
 - \bullet $P(RHS \mid LHS)$





PCFGs

• Sum over all possible expansions is 1

$$\sum_{\beta} P(A \to \beta) = 1$$

- A PCFG is consistent if sum of probabilities of all sentences in language is 1
 - Recursive rules often yield inconsistent grammars (Booth & Thompson, 1973)





Example PCFG: Augmented \mathcal{L}_1

Grammar		Lexicon
$S \rightarrow NP VP$	[.80]	$Det \rightarrow that [.10] \mid a [.30] \mid the [.60]$
$S \rightarrow Aux NP VP$	[.15]	$Noun \rightarrow book [.10] \mid flight [.30] \mid meal [.15] \mid money [0.5]$
$S \rightarrow VP$	[.05]	$\mid flights \; [0.40] \mid dinner \; [.10]$
$NP \rightarrow Pronoun$	[.35]	$Verb \rightarrow book [.30] \mid include [.30] \mid prefer [.40]$
NP ightarrow Proper-Noun	[.30]	$Pronoun \rightarrow I [.40] \mid she [.05] \mid me [.15] \mid you [.40]$
$NP \rightarrow Det\ Nominal$	[.20]	$Proper-Noun \rightarrow Houston [.60] \mid NWA [.40]$
$NP \rightarrow Nominal$	[.15]	$Aux \rightarrow does [.60] \mid can [.40]$
$Nominal \rightarrow Noun$	[.75]	$Preposition \rightarrow from \ [.30] \mid to \ [.30] \mid on \ [.20] \mid near \ [.15]$
$Nominal \rightarrow Nominal\ Noun$	[.20]	$\mid through \; [.05]$
$Nominal \rightarrow Nominal \ PP$	[.05]	
$VP \rightarrow Verb$	[.35]	
$VP \rightarrow Verb NP$	[.20]	
$VP \rightarrow Verb NP PP$	[.10]	
$VP \rightarrow Verb PP$	[.15]	
$VP \rightarrow Verb NP NP$	[.05]	
$VP \rightarrow VP PP$	[.15]	
$PP \rightarrow Preposition NP$	[1.0]	





Example PCFG: Augmented \mathcal{L}_1

Grammar		Lexicon
$S \rightarrow NP VP$	[.80]	$Det \rightarrow that [.10] \mid a [.30] \mid the [.60]$
$S \rightarrow Aux NP VP$	[.15]	$Noun \rightarrow book [.10] \mid flight [.30] \mid meal [.15] \mid money [0.5]$
$S \rightarrow VP$	[.05]	$\mid flights \; [0.40] \mid dinner \; [.10]$
$NP \rightarrow Pronoun$	[.35]	$Verb \rightarrow book [.30] \mid include [.30] \mid prefer [.40]$
NP o Proper-Noun	[.30]	$Pronoun \rightarrow I [.40] \mid she [.05] \mid me [.15] \mid you [.40]$
$NP \rightarrow Det\ Nominal$	[.20]	$Proper-Noun \rightarrow Houston [.60] \mid NWA [.40]$
$NP \rightarrow Nominal$	[.15]	$Aux \rightarrow does [.60] \mid can [.40]$
$Nominal \rightarrow Noun$	[.75]	$Preposition \rightarrow from \ [.30] \mid to \ [.30] \mid on \ [.20] \mid near \ [.15]$
$Nominal \rightarrow Nominal\ Noun$	[.20]	$\mid through \; [.05]$
$Nominal \rightarrow Nominal \ PP$	[.05]	
$VP \rightarrow Verb$	[.35]	
$VP ightarrow Verb \ NP$	[.20]	
$VP \rightarrow Verb NP PP$	[.10]	
$VP \rightarrow Verb PP$	[.15]	
$VP \rightarrow Verb NP NP$	[.05]	
$VP \rightarrow VP PP$	[.15]	
$PP \rightarrow Preposition NP$	[1.0]	





Disambiguation

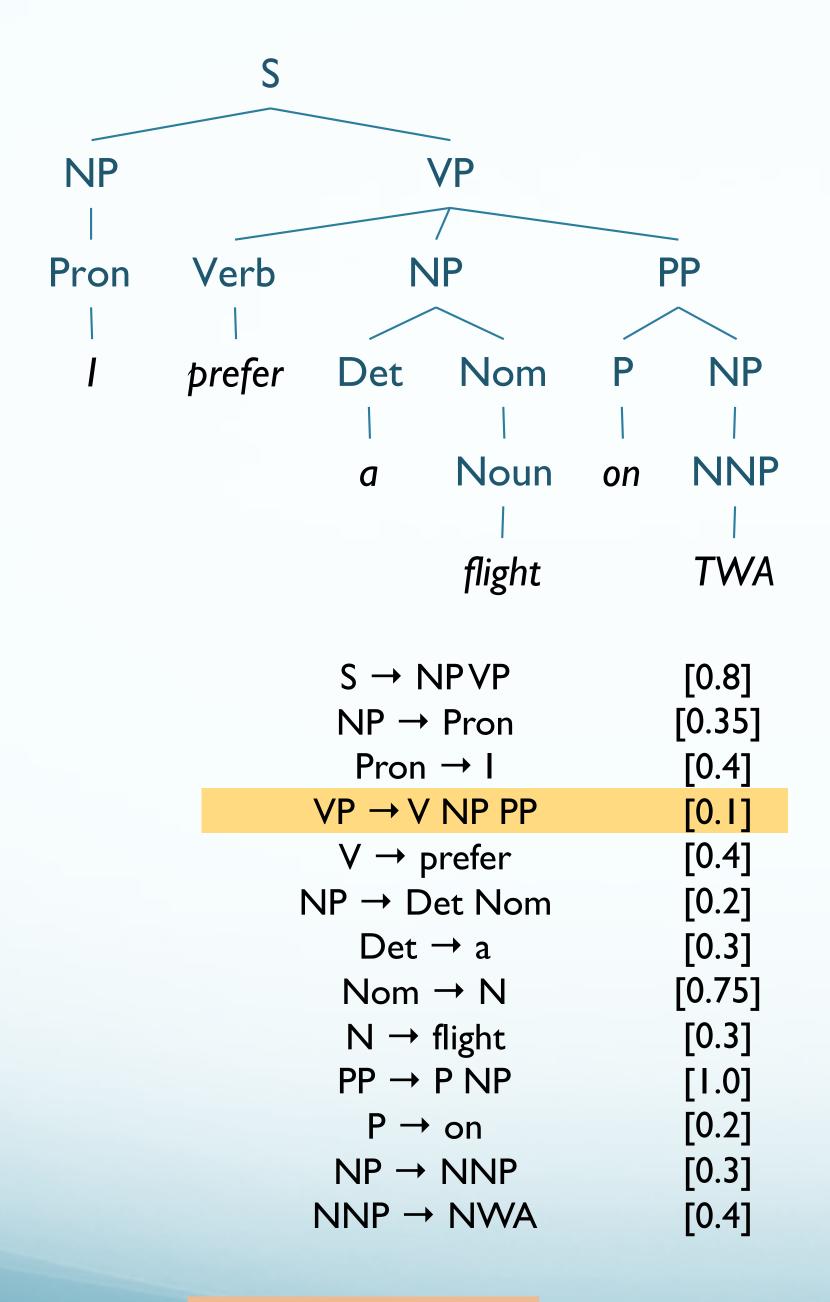
- ullet A PCFG assigns probability to each parse tree T for input S
- ullet Probability of T: product of all rules used to derive T

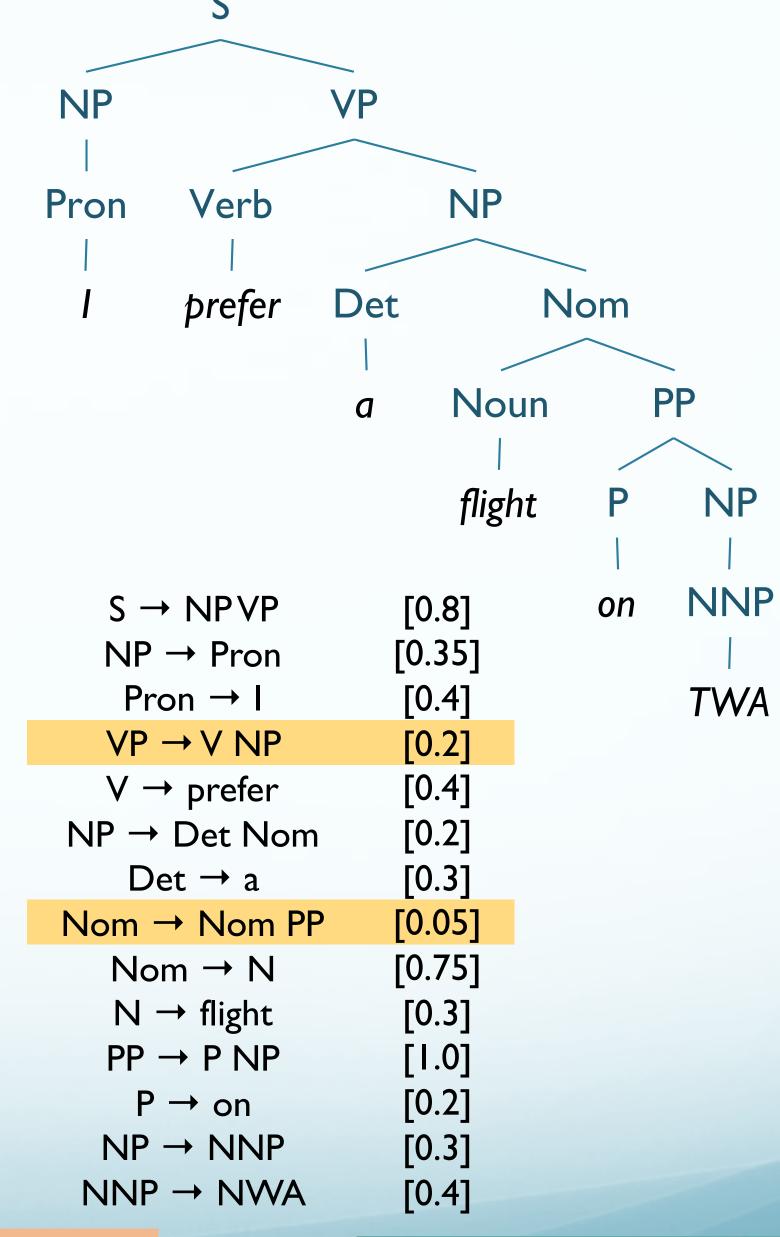
$$P(T,S) = \prod_{i=1}^{n} P(RHS_i | LHS_i)$$

$$P(T,S) = P(T)P(S \mid T) = P(T)$$









 $\sim 1.452 \times 10^{-7}$

PROFESSIONAL MASTER'S IN COMPUTATIONAL LINGUISTICS

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Parsing Problem for PCFGs

• Select T such that (s.t.)

$$\hat{T}(S) = \underset{Ts.t.S=yield(T)}{\operatorname{argmax}} P(T)$$

- String of words S is yield of parse tree
- ullet Select the tree \hat{T} that maximizes the probability of the parse





Unit Testing





Unit Testing

- Strategy of testing individual pieces of code in isolation
- Helps ensure:
 - Basic functionality in isolation
 - Complex functionality when individual components are combined





Unit Testing in Python

- Many good tutorials on the web [here's one]
- In a nutshell:





Unit Testing in Python

"nose" is a test running framework that will detect all test_* method functions python3 -m nose hw2.py

```
AssertionError: Items in the first set but not the second:

A -> B _X0_
_X0_ -> C D

Items in the second set but not the first:

A -> B C

Ran 12 tests in 0.040s

FAILED (failures=1)
```





Unit Testing

- Good practice:
 - Save input that crashes your program for a unit test





HW #3





CKY Parsing: Goals

- Complete implementation of CKY parser
- Implement dynamic programming approach
- Incorporate/follow backpointers to recover parse





Implementation

- Build full parser
- Can use any language, per course policies
- You may use existing data structures for rules, trees
 - e.g. NLTK has nice tree data structure
 - CKY algorithm must be your own
- Dynamic programming table filling crucial!
- Will use smaller grammar (similar to HW #1)
- Back to ATIS for HW #4





Notes

- Teams:
 - You may work in teams of two on this assignment
- Test grammar
 - Pre-converted to CNF
 - Start symbol: TOP
 - Parse should span input and be rooted at: TOP



