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



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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)

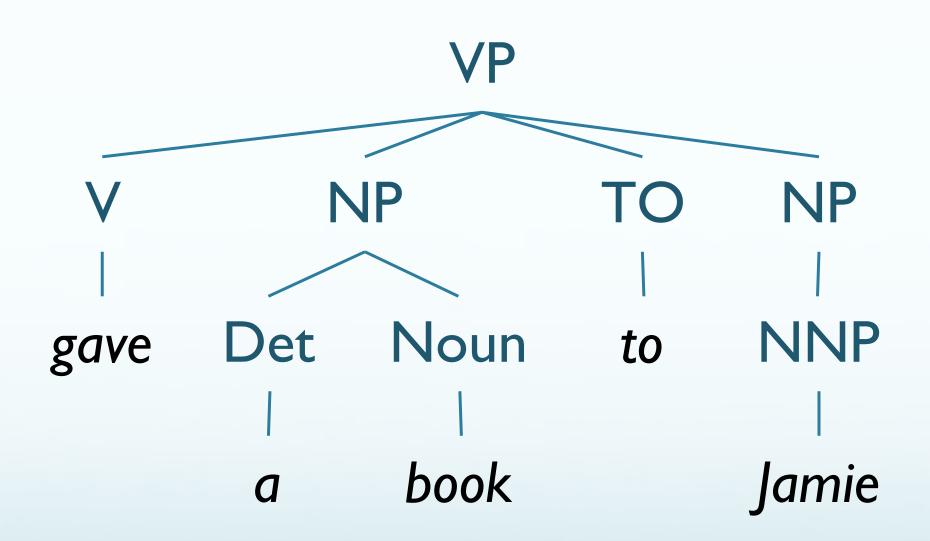




Variation in CNF: Binarization

Original Rule

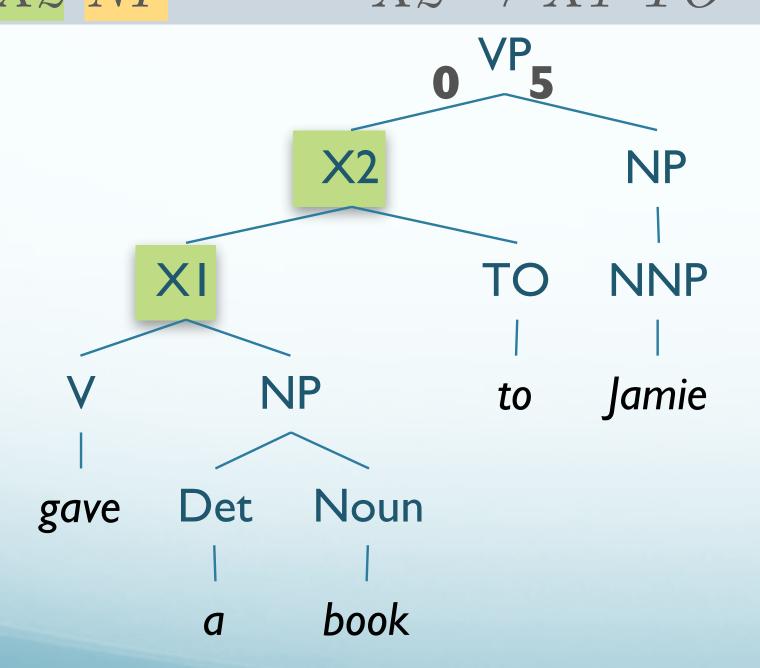
 $VP \rightarrow V NP TO NP$

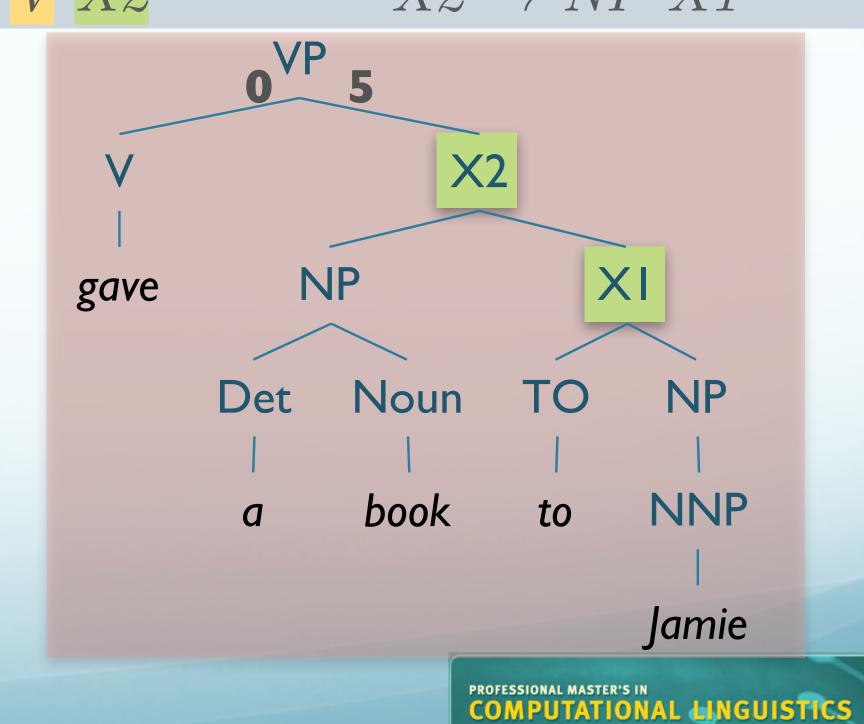






Variation in CNF: Binarization







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**

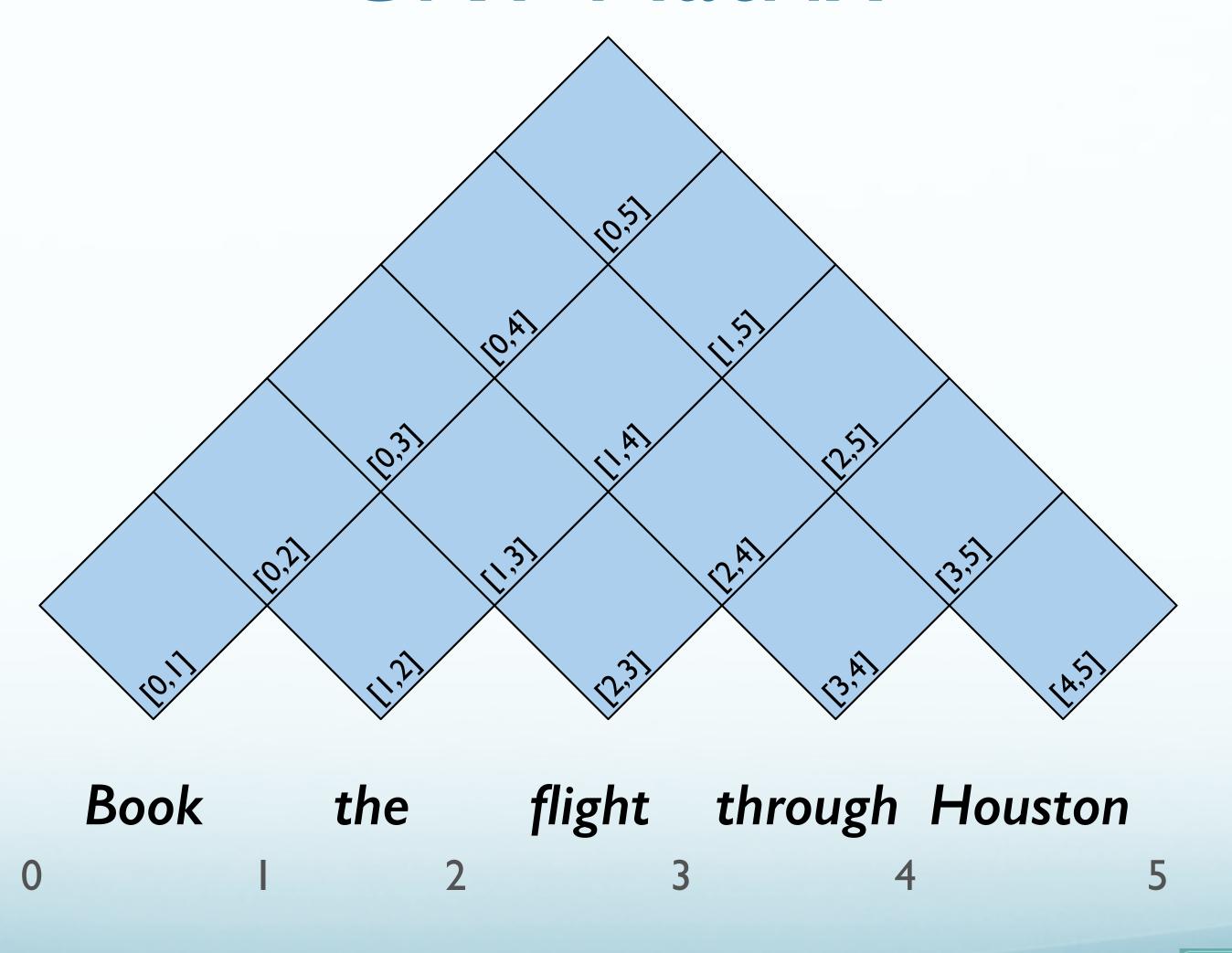




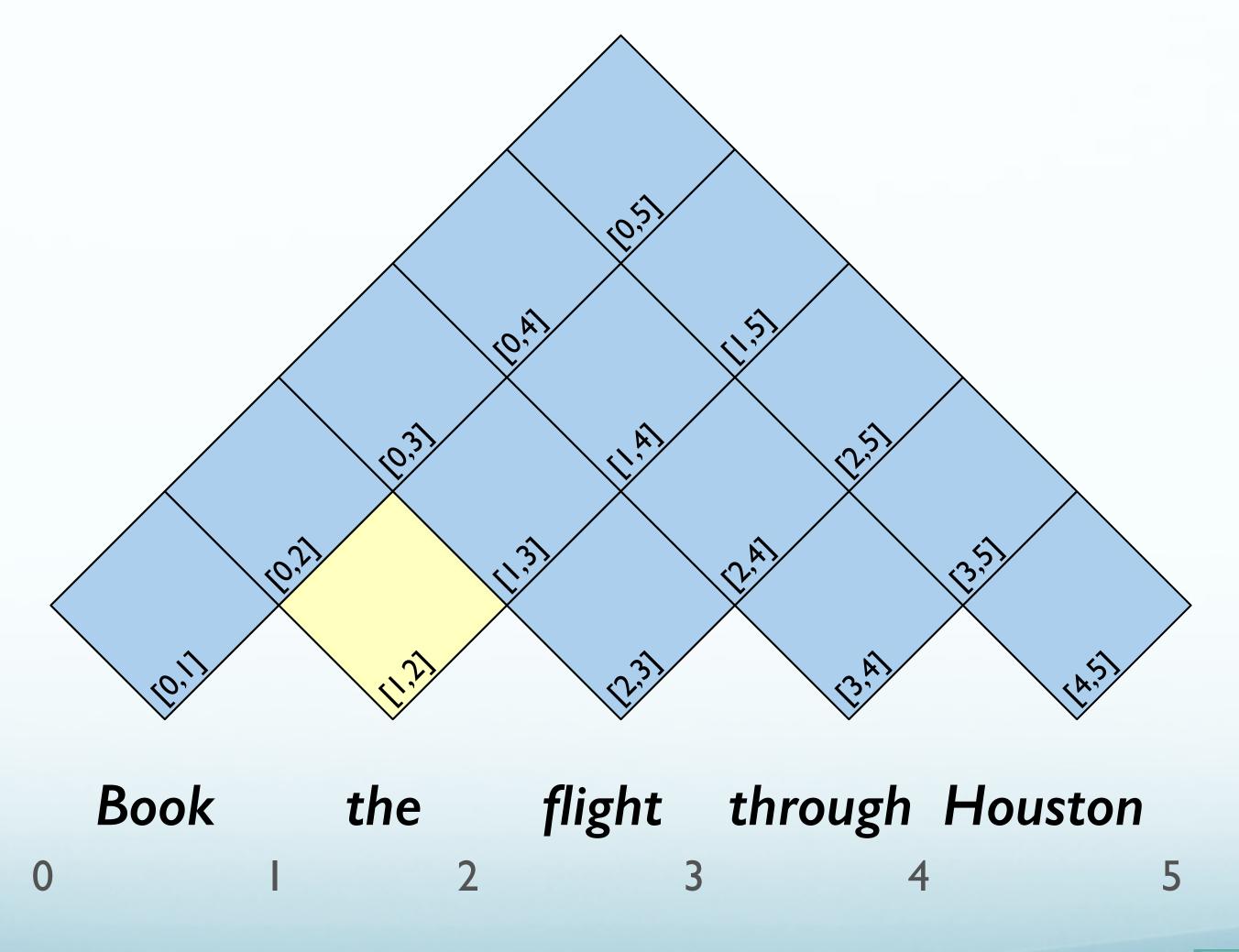
Book	the	flight	through	Houston
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]
	[1,2]	[1,3]	 [1,4]	[1,5]
		[2,3]	[2,4]	[2,5]
			[3,4]	[3,5]
			[
				[4 5]
				[4,5]



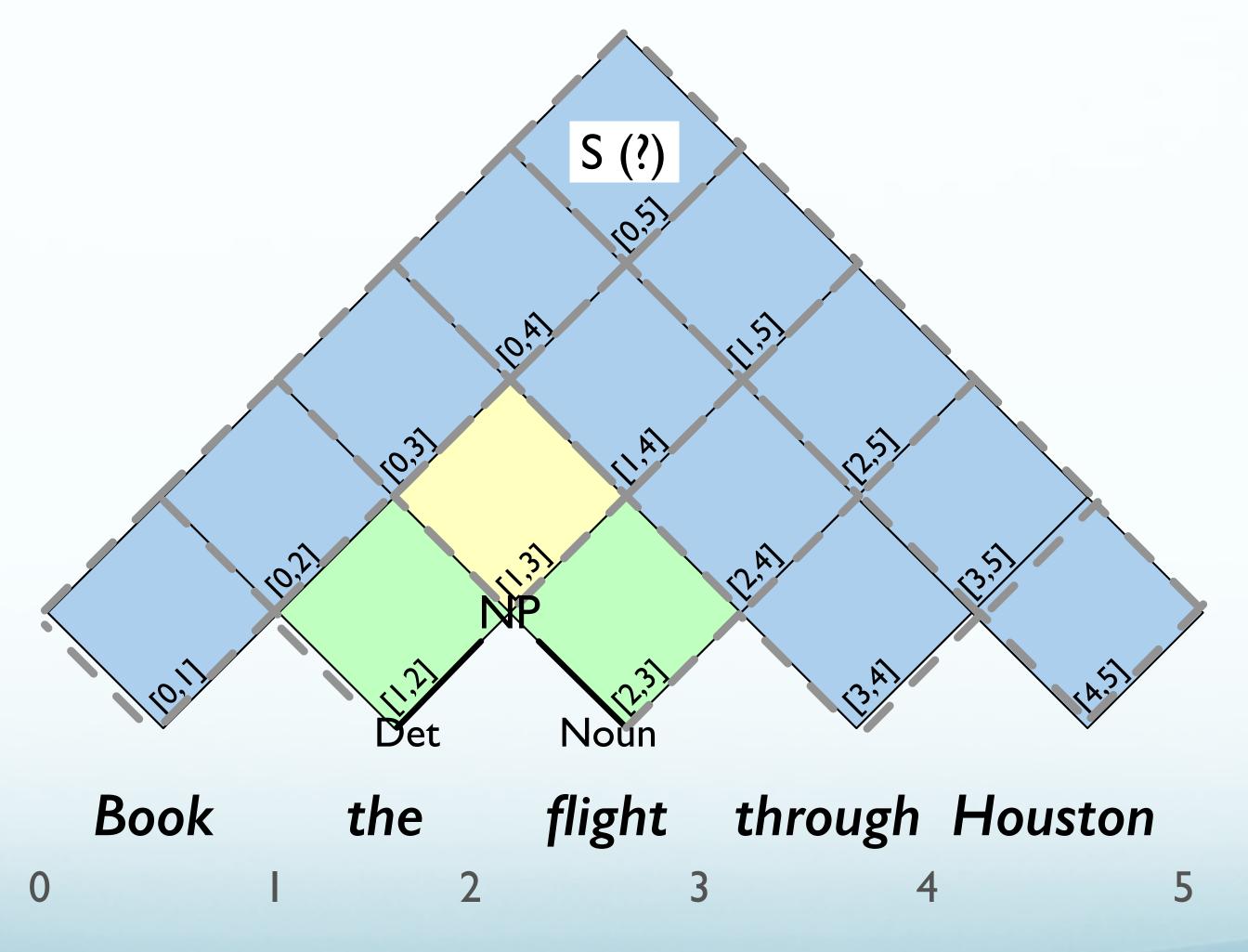
















Dynamic Programming in CKY

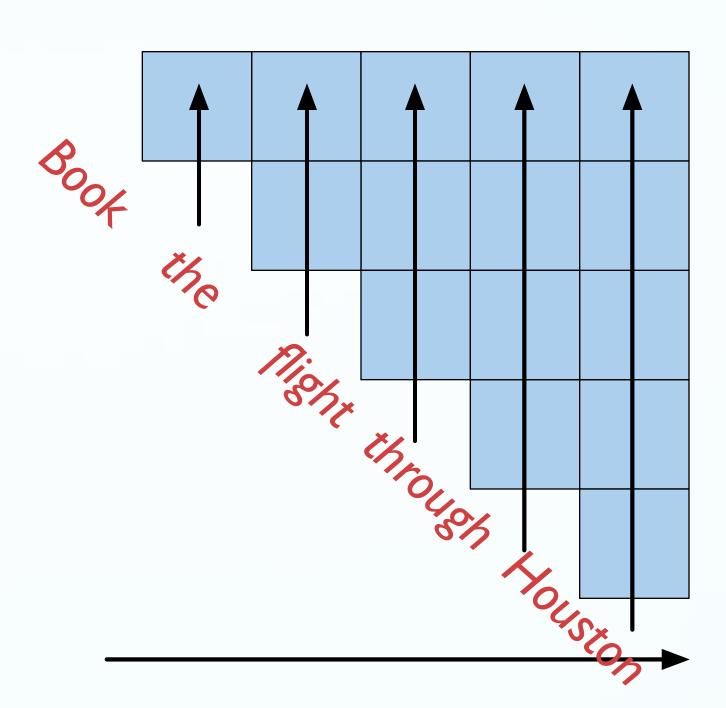
- Key idea:
 - ullet for i < k < j
 - ullet ...and a parse spanning substring [i,j]
 - ullet $\exists k$ such that there are parses spanning [i, k] and [k, j]
 - We can construct parses for whole sentences by building from these partial parses
- ullet So to have a rule $oldsymbol{A} o oldsymbol{B}$ $oldsymbol{C}$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



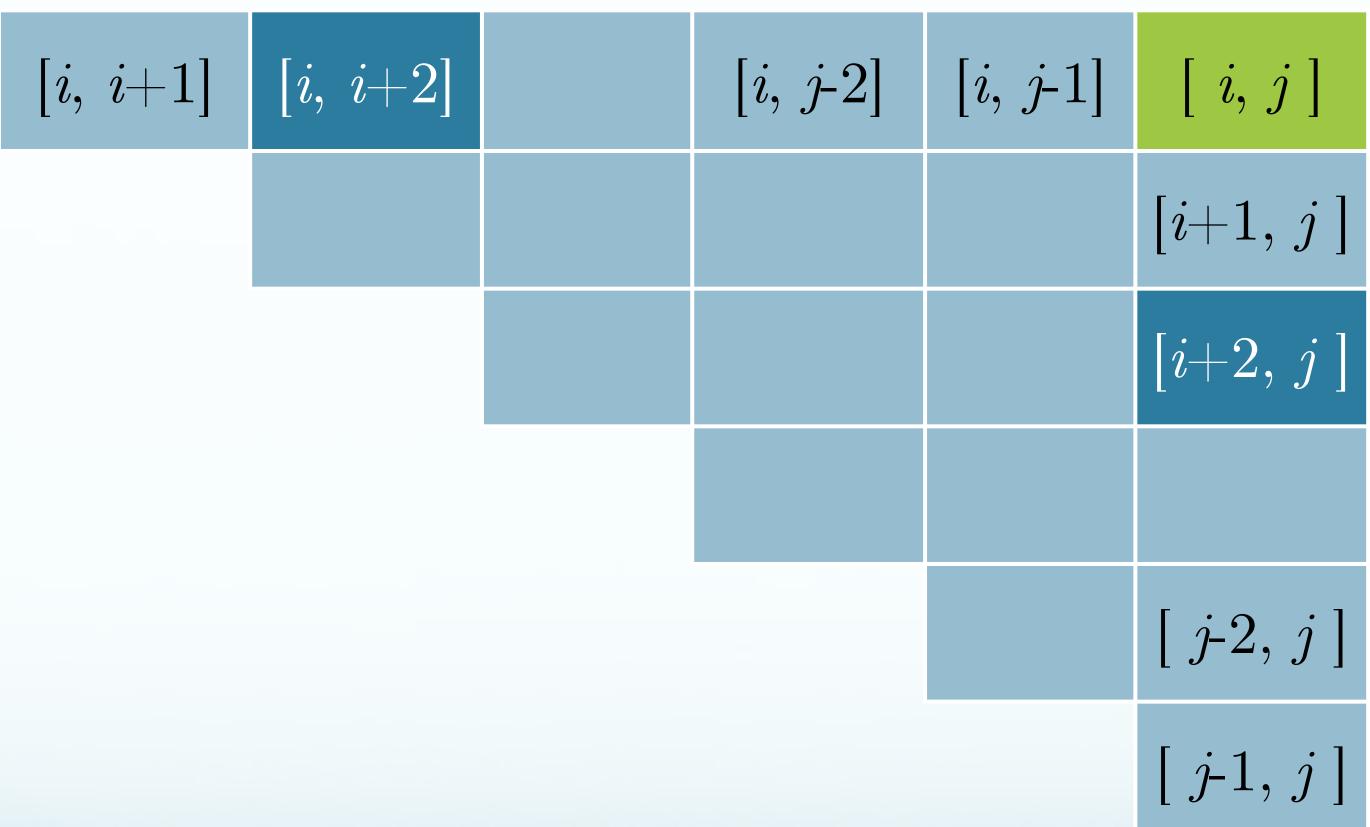


For cell [i,j], find rule spanning cells $[i\!\!\!-\!\!\!k]$ and $[i\!\!\!k,j]$ where i< k< j

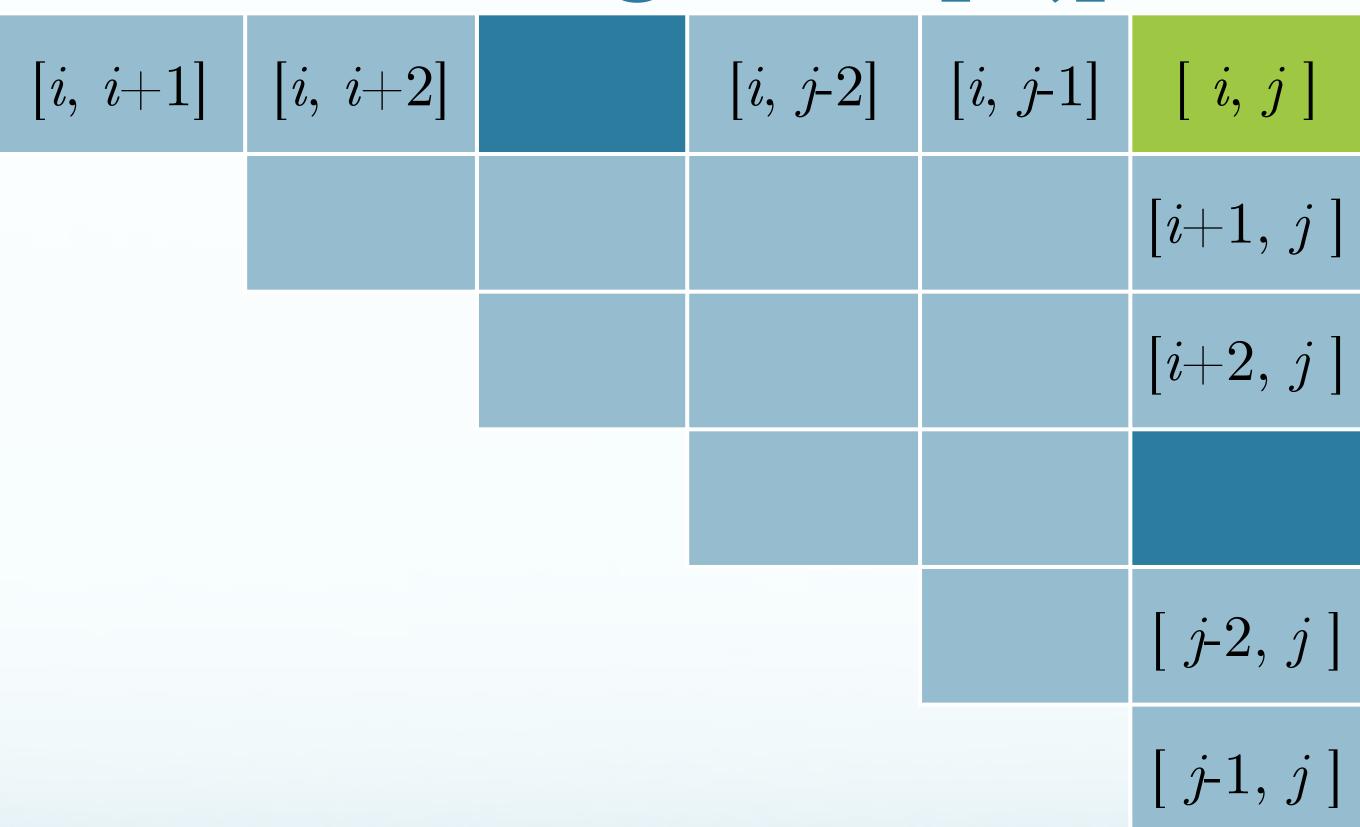
[i, i+1]	[i, i+2]	[j, j-2]	[j, j-1]	[i,j]
				[i+1,j]
				[i+2,j]
				[j-2, j]
				[j-1, j]





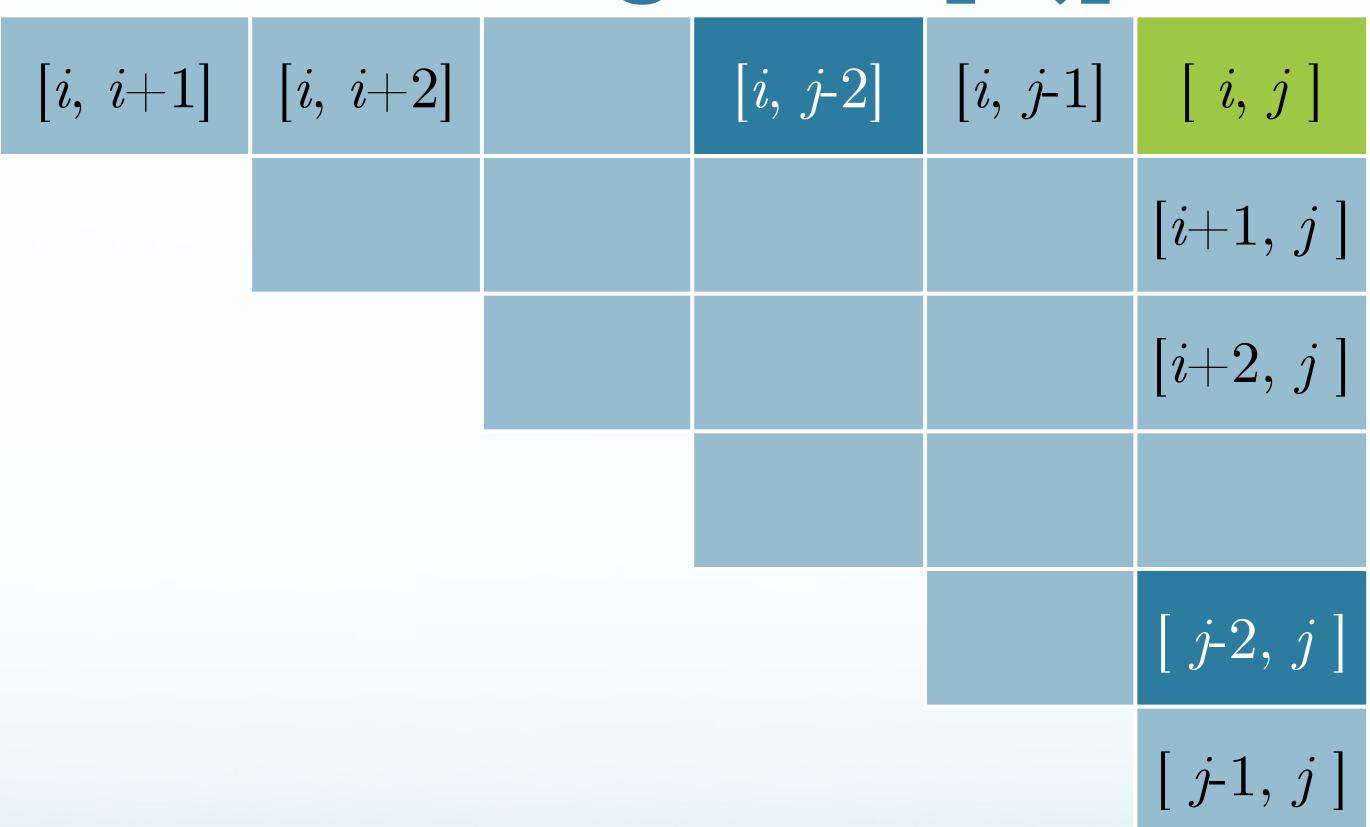
















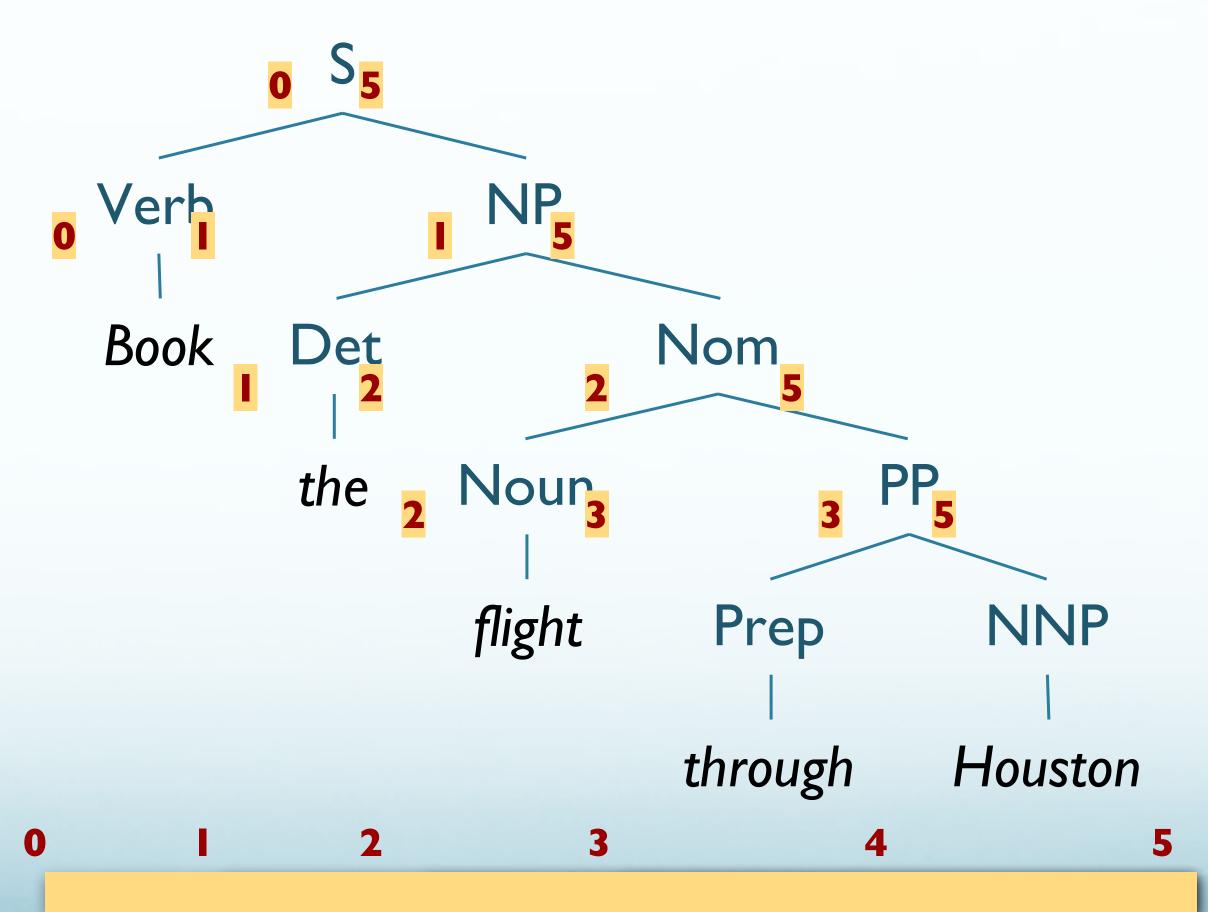
$[i,\ i+1]$	$[i,\ i+2]$	[i, j-2]	[i, j-1]	[i,j]
				$[i\!\!+\!\!1,j]$
				[i+2,j]
				[j-2, j]
				[j-1, j]





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

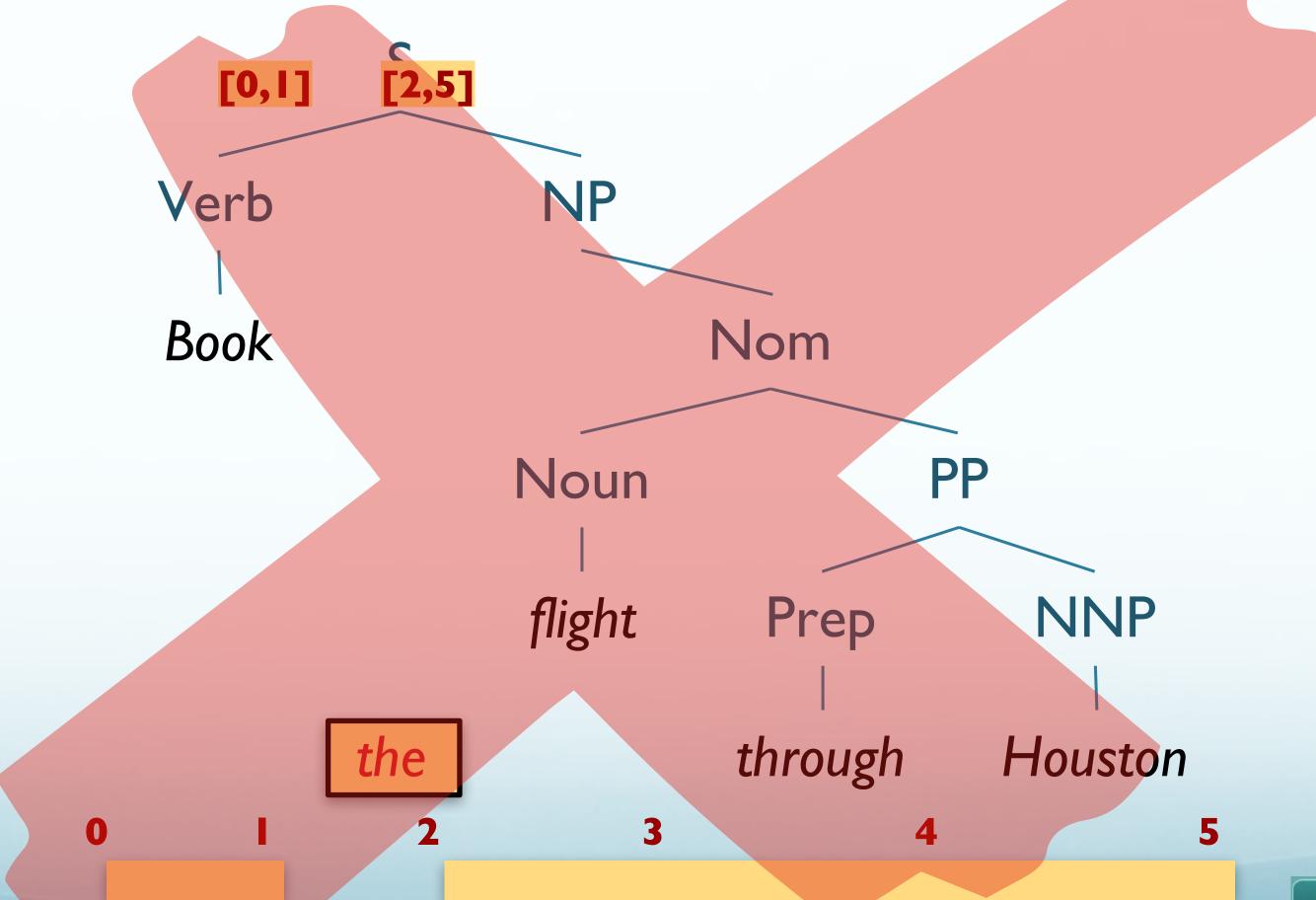




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Why fill cells this way?

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





40

CKY Parsing Example





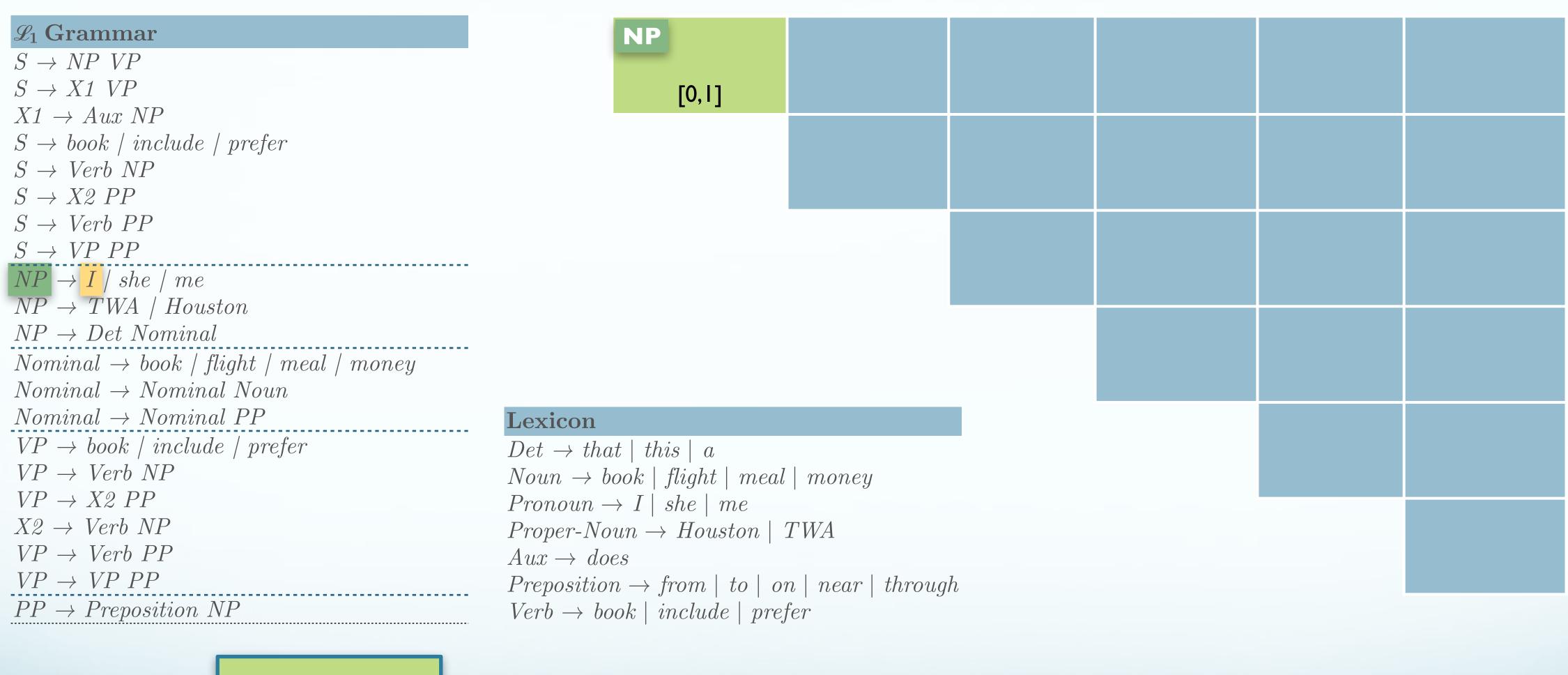
\mathscr{L}_1 Grammar			
$S \to NP VP$			
$S \rightarrow X1 VP$			
$X1 \rightarrow Aux NP$			
$S \rightarrow book / include / prefer$			
$S \rightarrow Verb NP$			
$S \to X2 PP$			
$S \rightarrow Verb PP$			
$S \to VP PP$			
$NP \rightarrow I / she / me$			
$NP \rightarrow TWA \mid Houston$			
$NP \rightarrow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

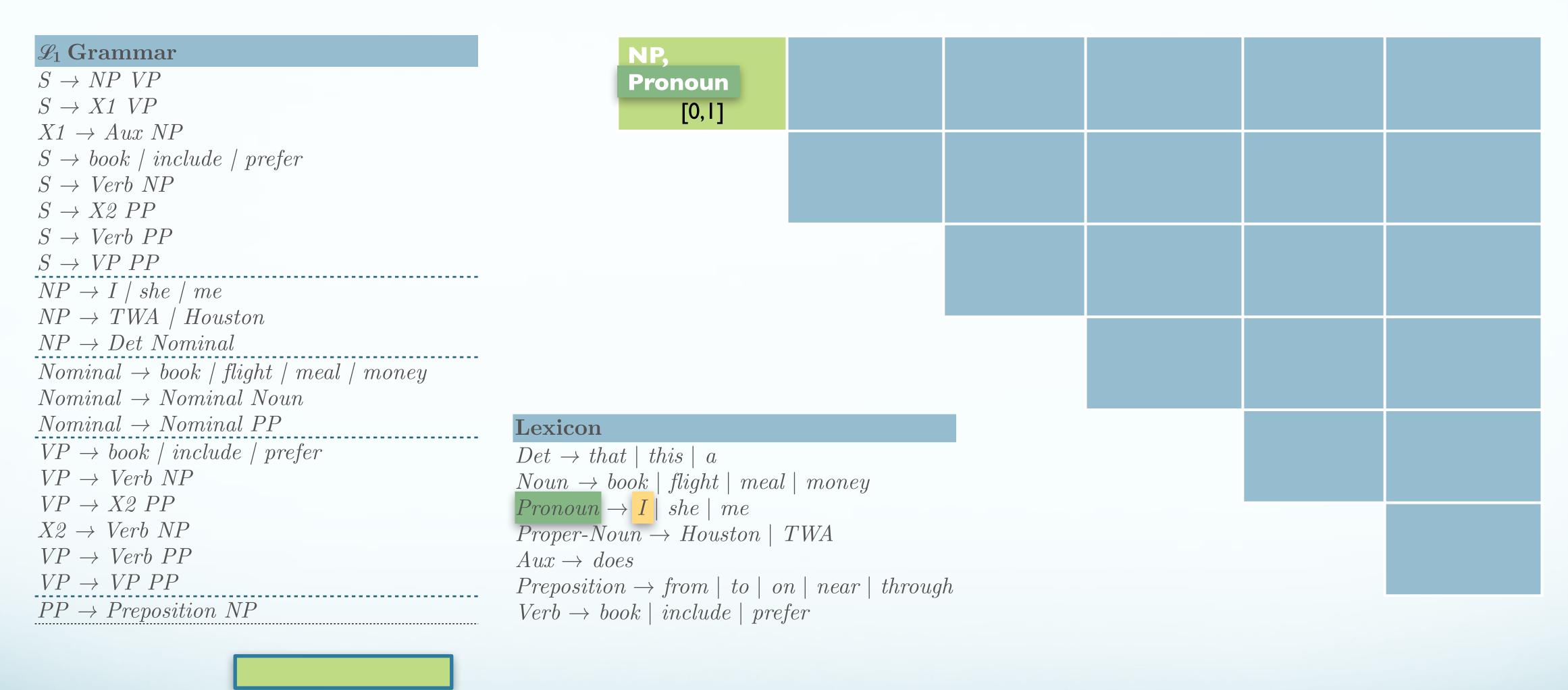
O 1 2 3 4 5 6



28

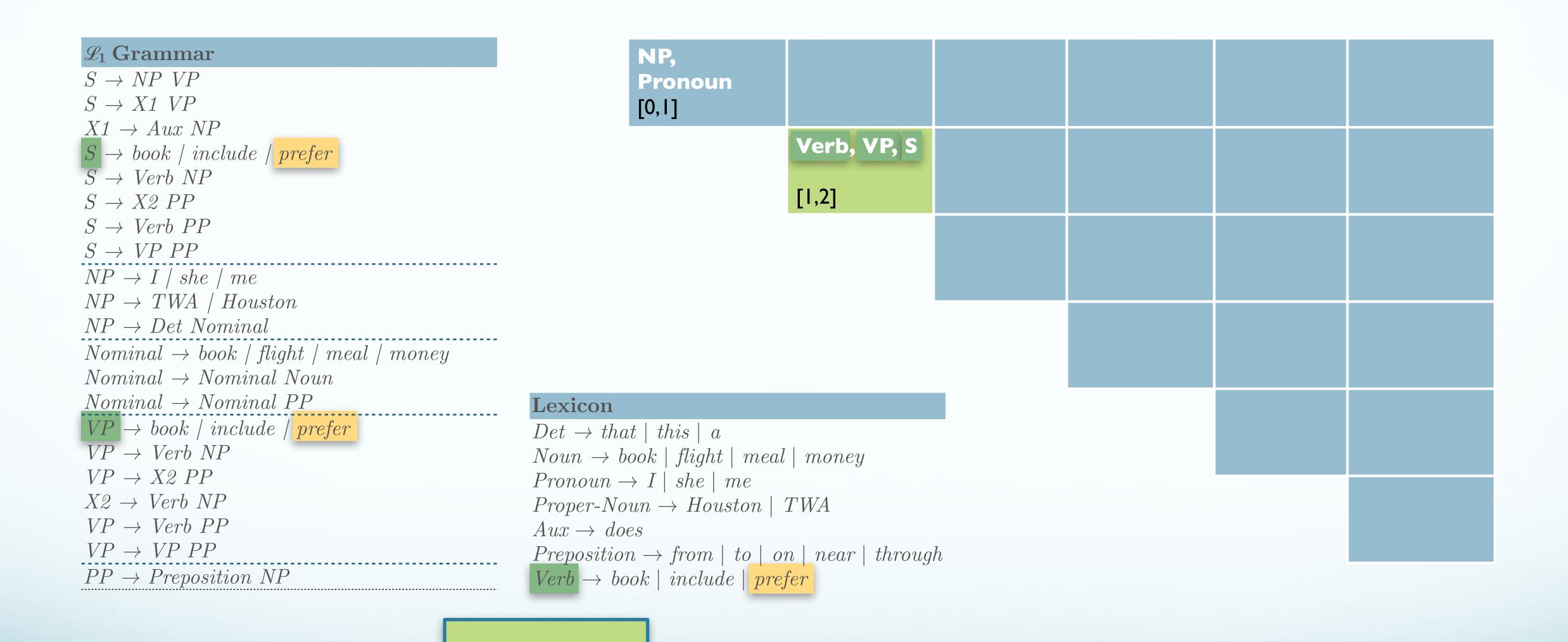












flight

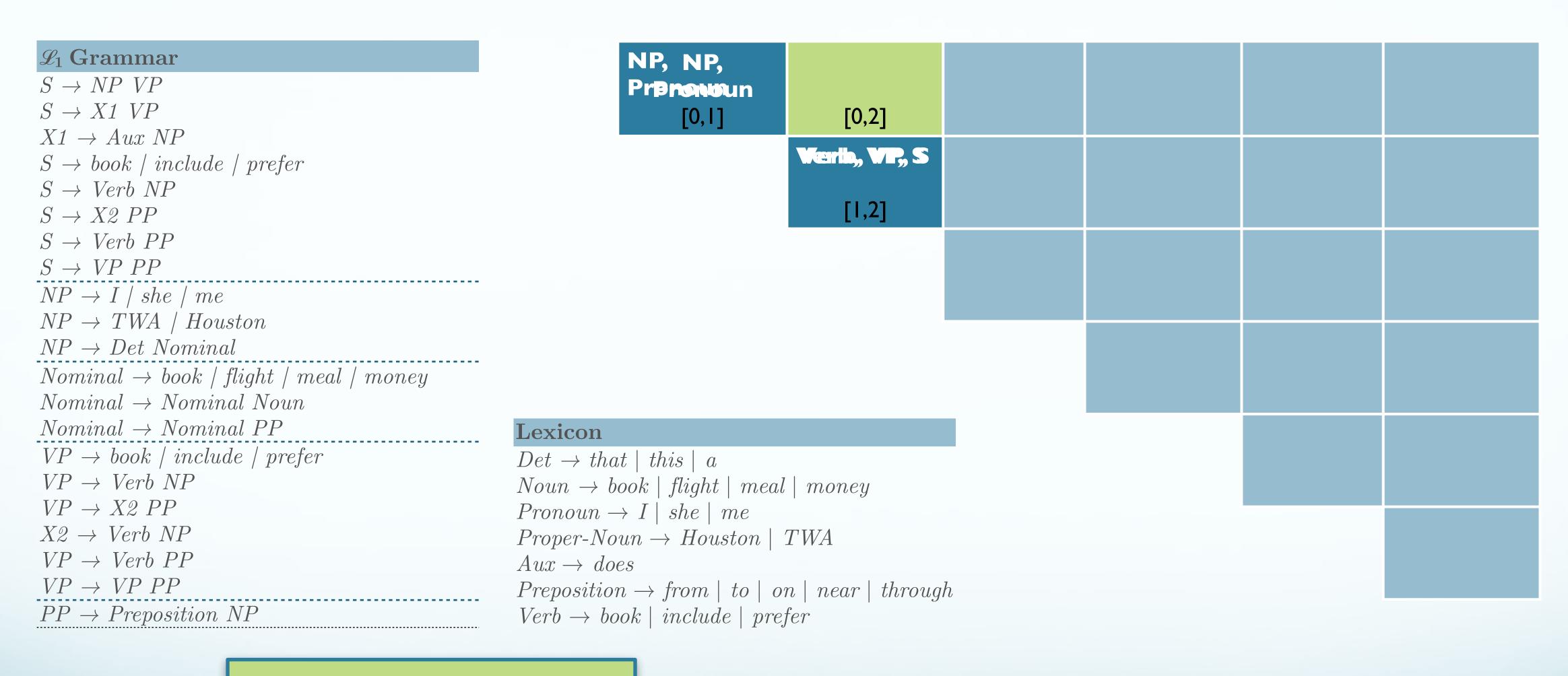
prefer





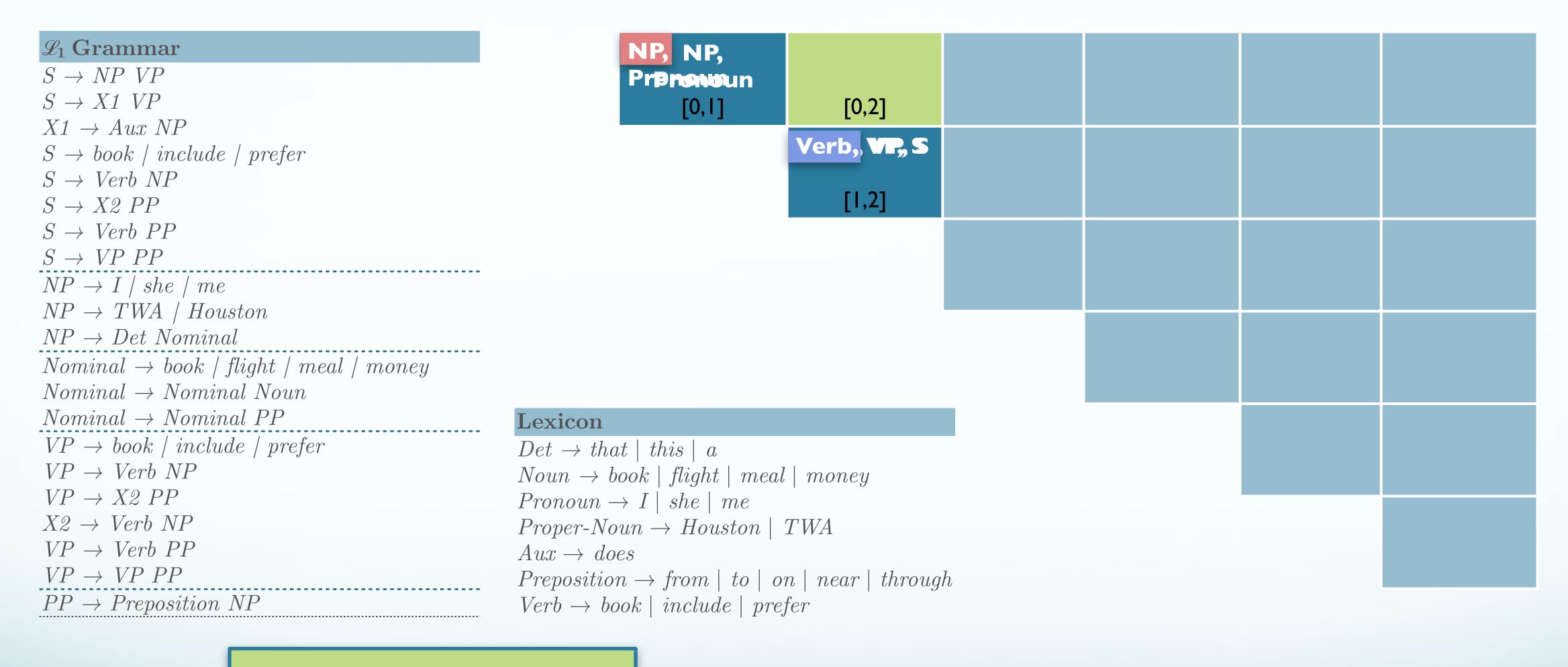
TWA

on





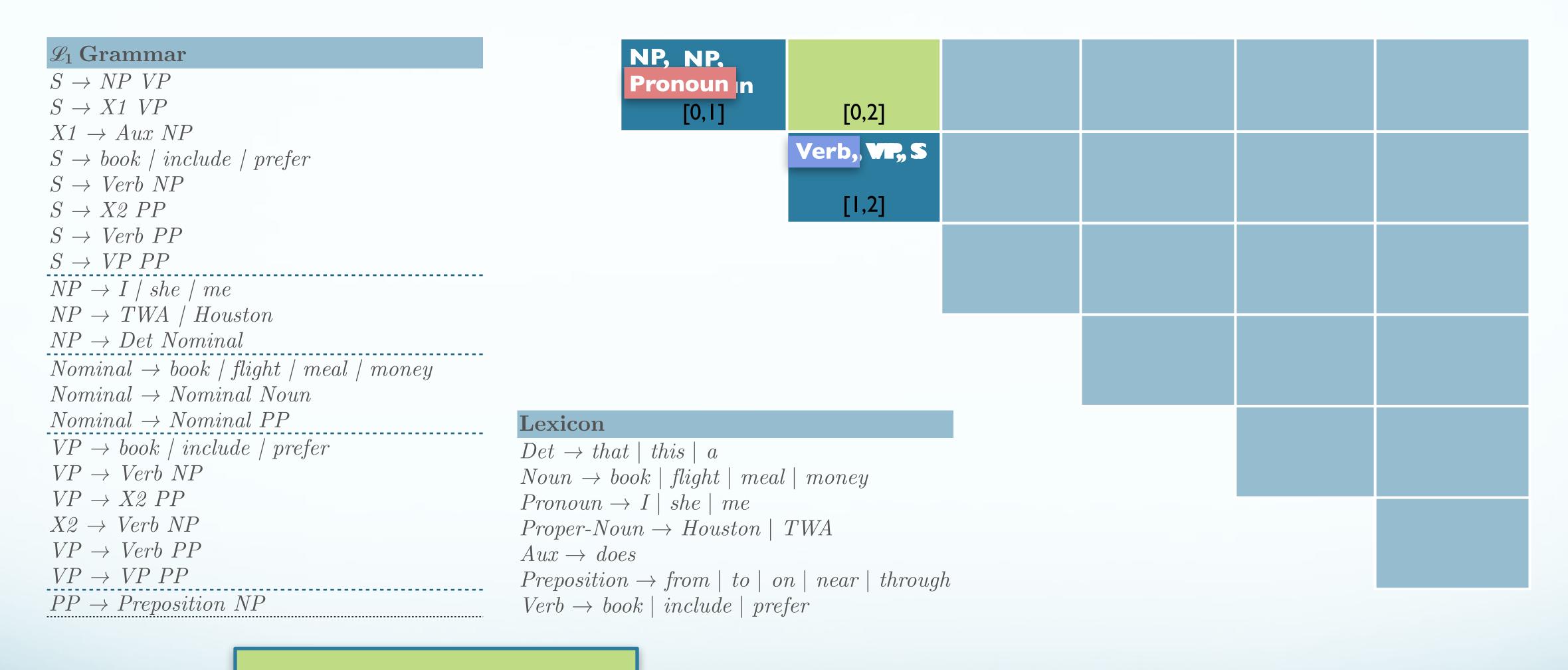




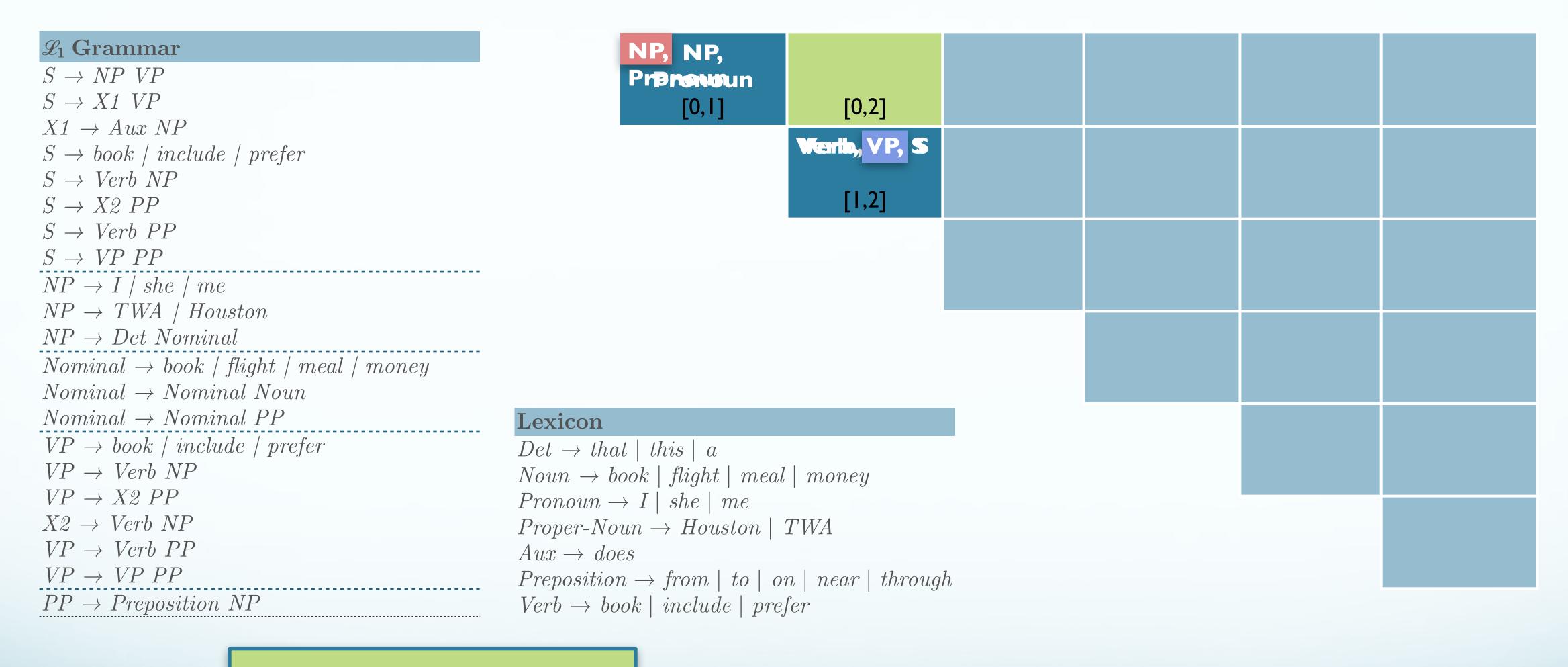


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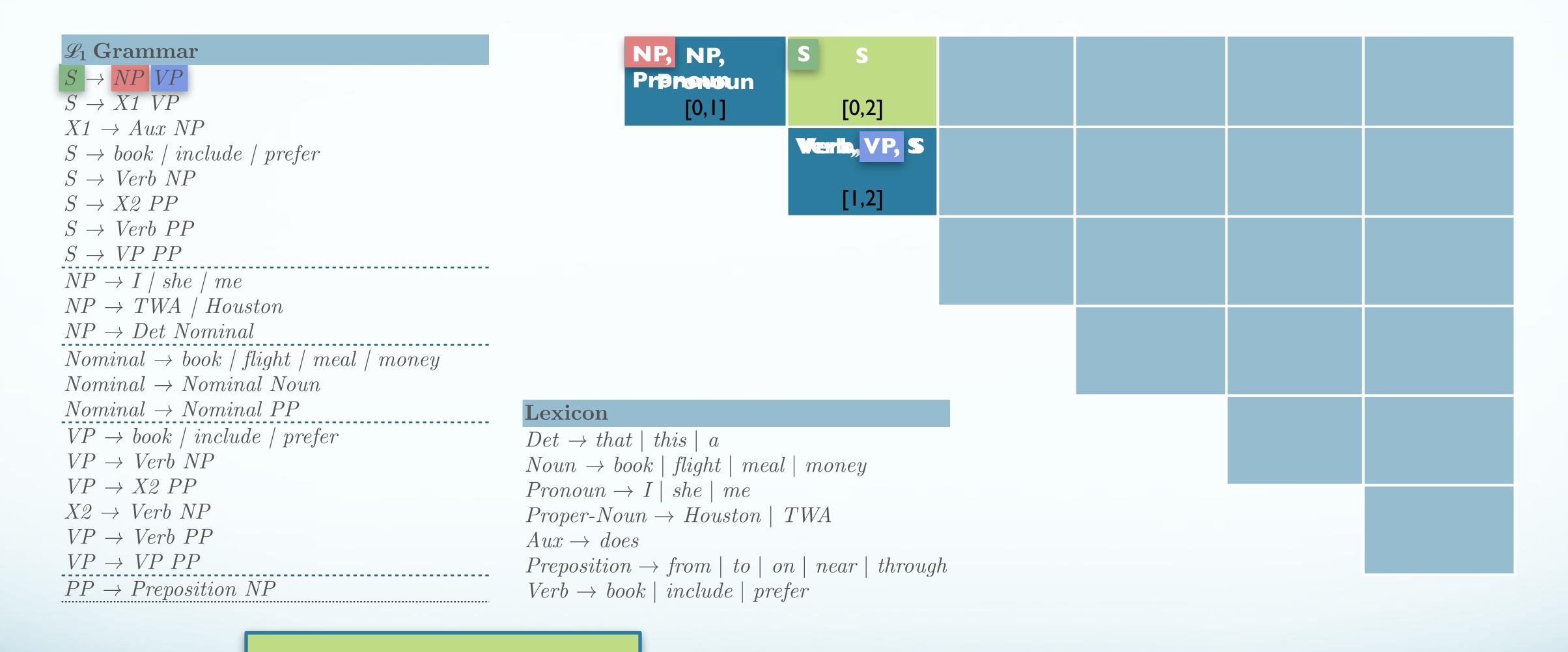






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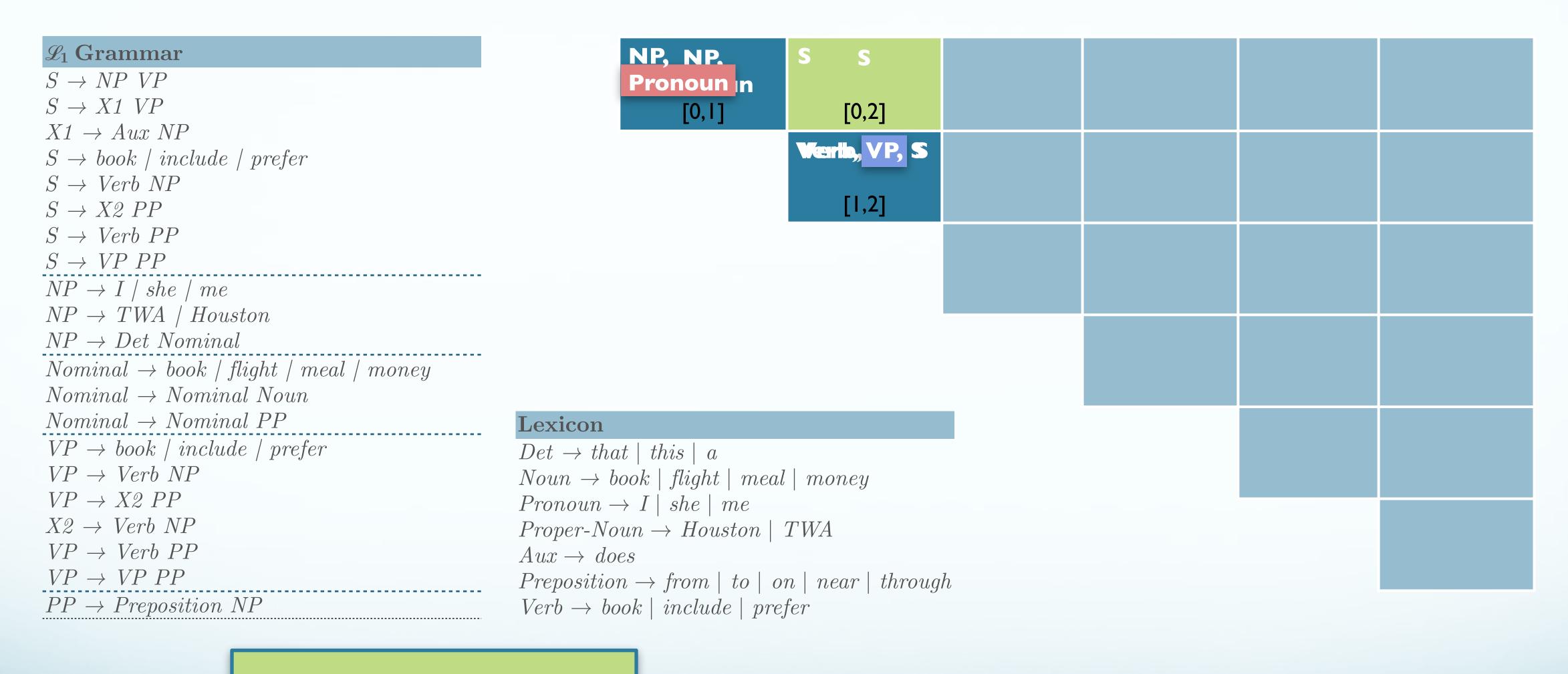




flight on TW/

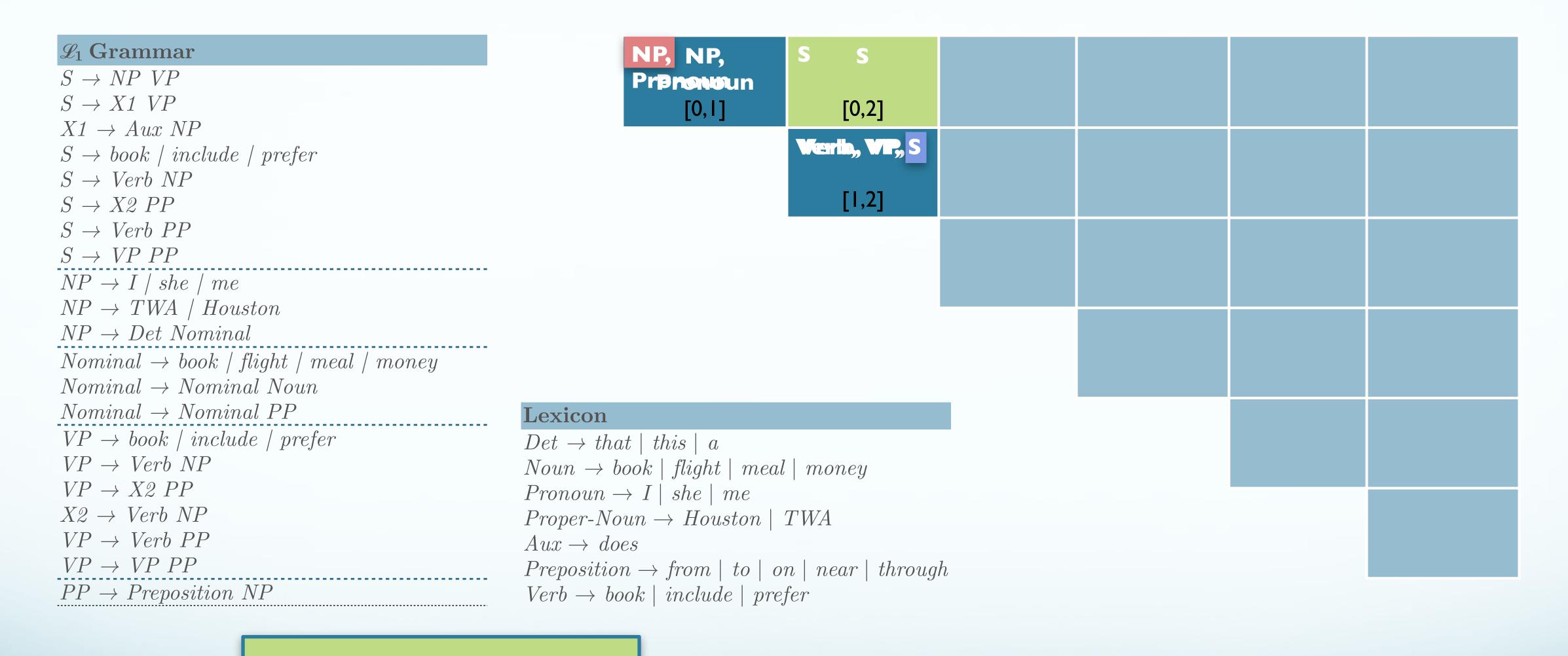
5 6

3



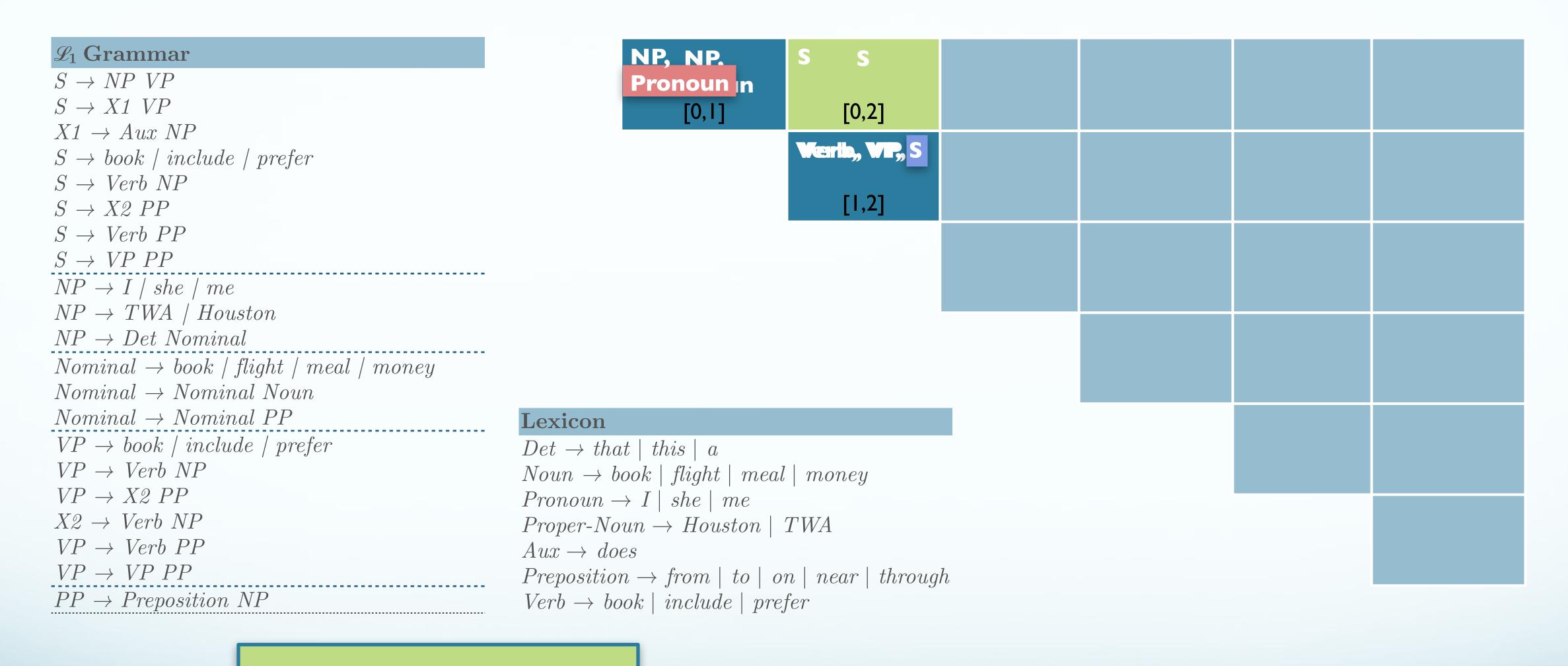




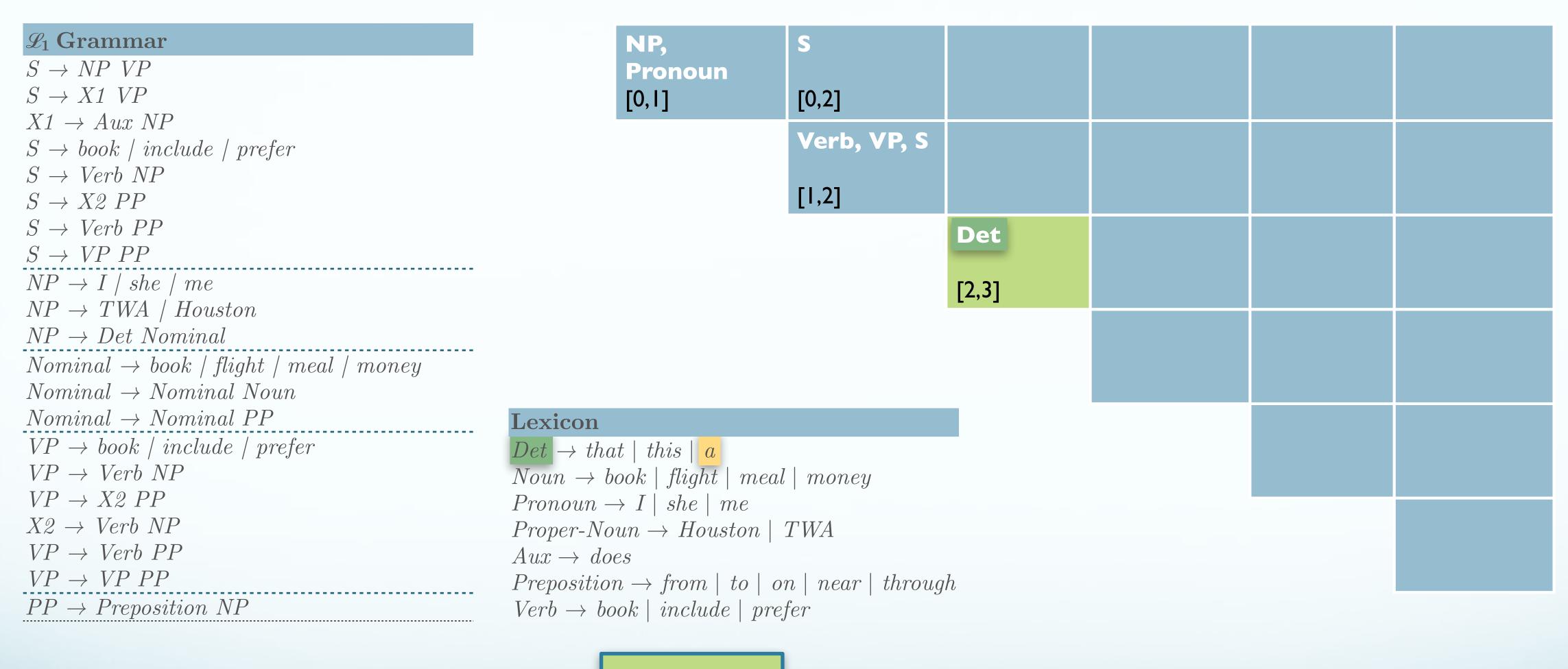




prefer







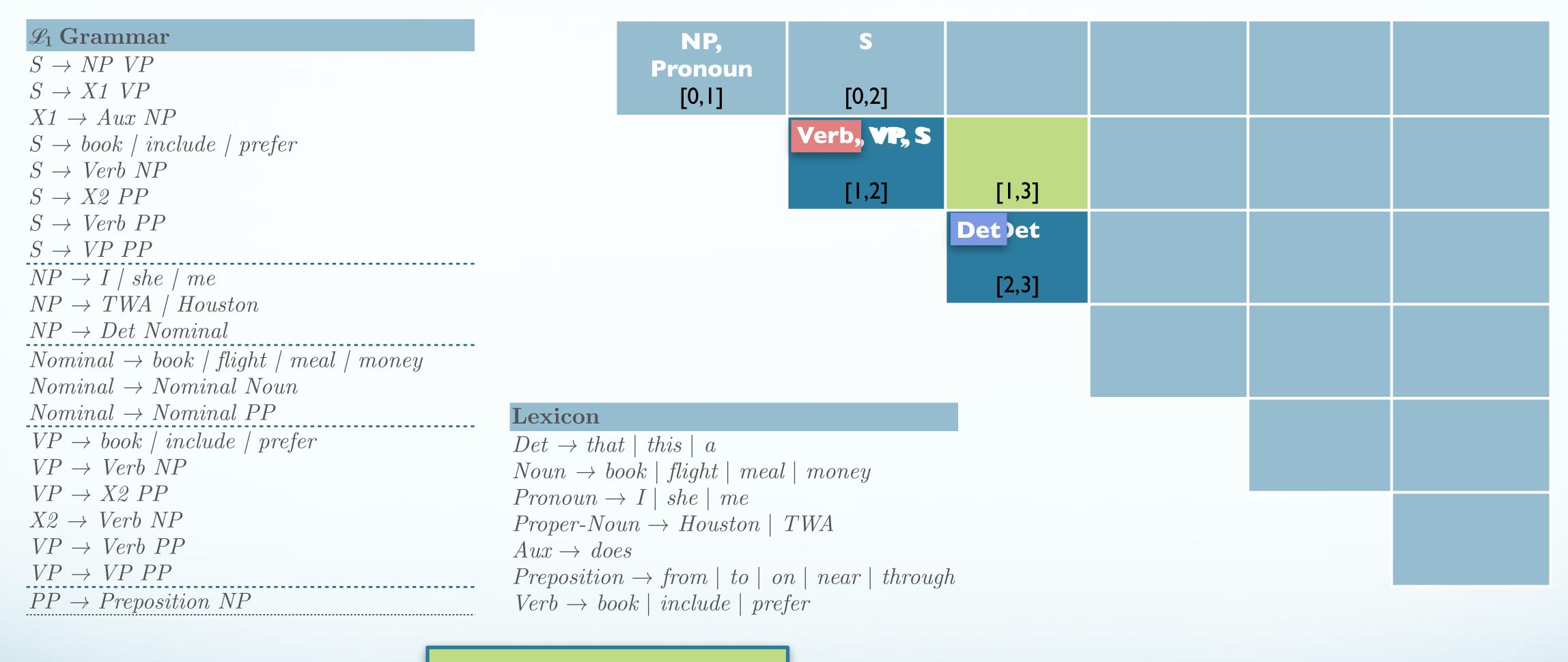




$\mathcal{L}_{1} \mathbf{Grammar}$ $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun	S [0.21			
$X1 \rightarrow Aux NP$ $S \rightarrow book / include / prefer$	[0,1]	[0,2] Verb, VP, S			
$S \rightarrow Verb \ NP$ $S \rightarrow X2 \ PP$		[1,2]	[1,3]		
$S \rightarrow Verb PP$ $S \rightarrow VP PP$	_		Det		
$NP \rightarrow I \mid she \mid me$ $NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$			[2,3]		
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$ $Nominal \rightarrow Nominal \ Noun$	-				
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book \mid include \mid prefer$ $VP \rightarrow Verb \mid NP$	$Det \rightarrow that \mid this \mid a$	1 200 0 20 0 21			
$VP \rightarrow X2 PP$	$Noun ightarrow book \mid flight \mid meal$ $Pronoun ightarrow I \mid she \mid me$	g money			
$X2 \rightarrow Verb NP$	$Proper-Noun ightarrow Houston \mid$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	_ ,,,,,,,			
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid o$	$n \mid near \mid through$	h		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$				

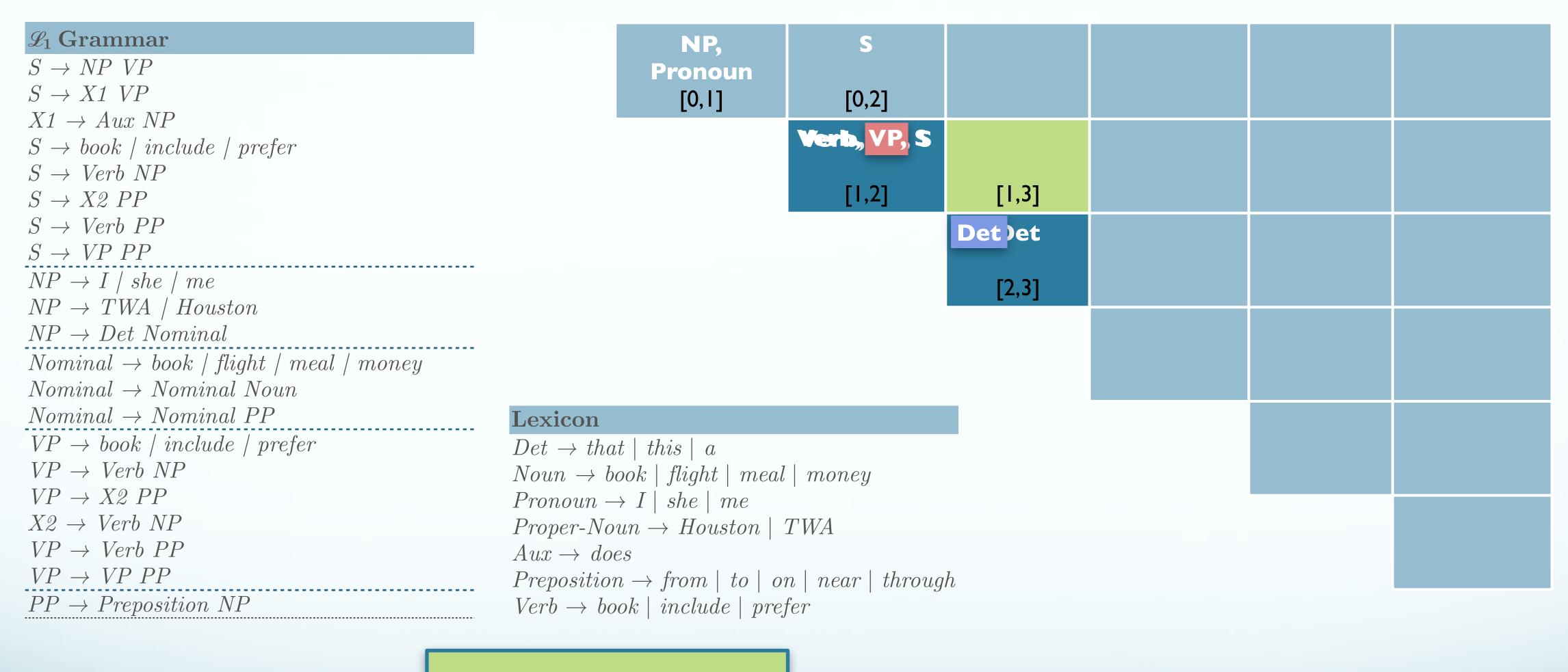


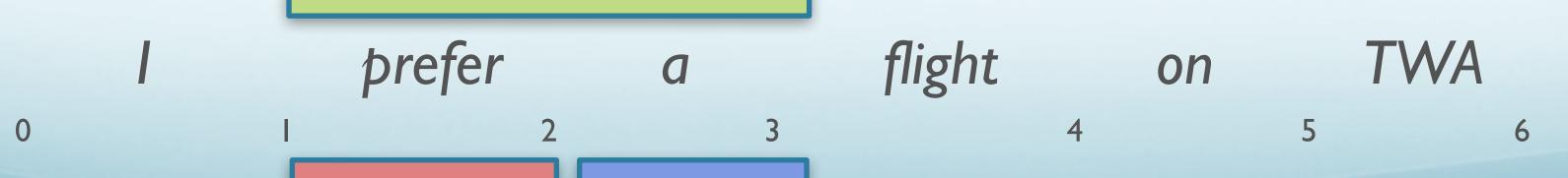
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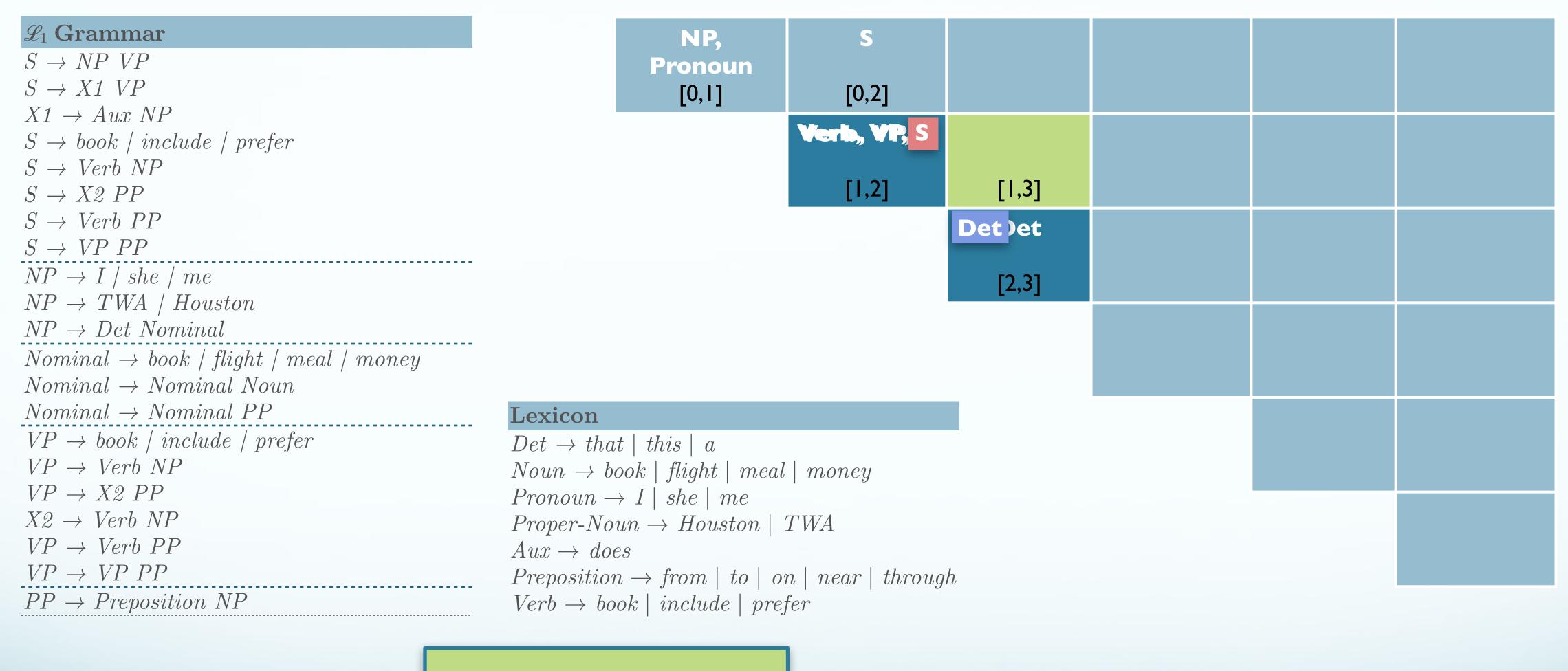


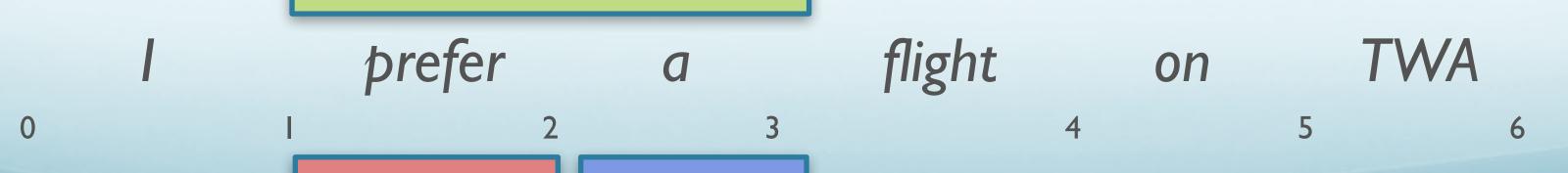














\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$		NP, Pronoun [0,1]	S [0,2]			
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ \ include \ \ prefer$ $S \rightarrow Verb \ NP$			Verb, VP, S			
$S \to X2 PP$			[1,2]	[1,3]		
$S \rightarrow Verb PP$ $S \rightarrow VP PP$				Det		
$NP \rightarrow I \mid she \mid me$ $NP \rightarrow TWA \mid Houston$	-			[2,3]		
$NP \rightarrow Det\ Nominal$	-					
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$ $Nominal \rightarrow Nominal \ Noun$						
$Nominal \rightarrow Nominal PP$	Lexicon					
$VP \rightarrow book / include / prefer$	$Det \rightarrow tha$	$t \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow b$	$ook \mid flight \mid meal$	$l \mid money$			
$VP \rightarrow X2 PP$	Pronoun -	$\rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	Proper-No	$un \rightarrow Houston \mid$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow doc$	cs				
$VP \rightarrow VP PP$	_ Preposition	$n \rightarrow from \mid to \mid o$	$n \mid near \mid through$	h		
$PP \rightarrow Preposition NP$	$Verb \rightarrow bo$	ok include pre	fer			



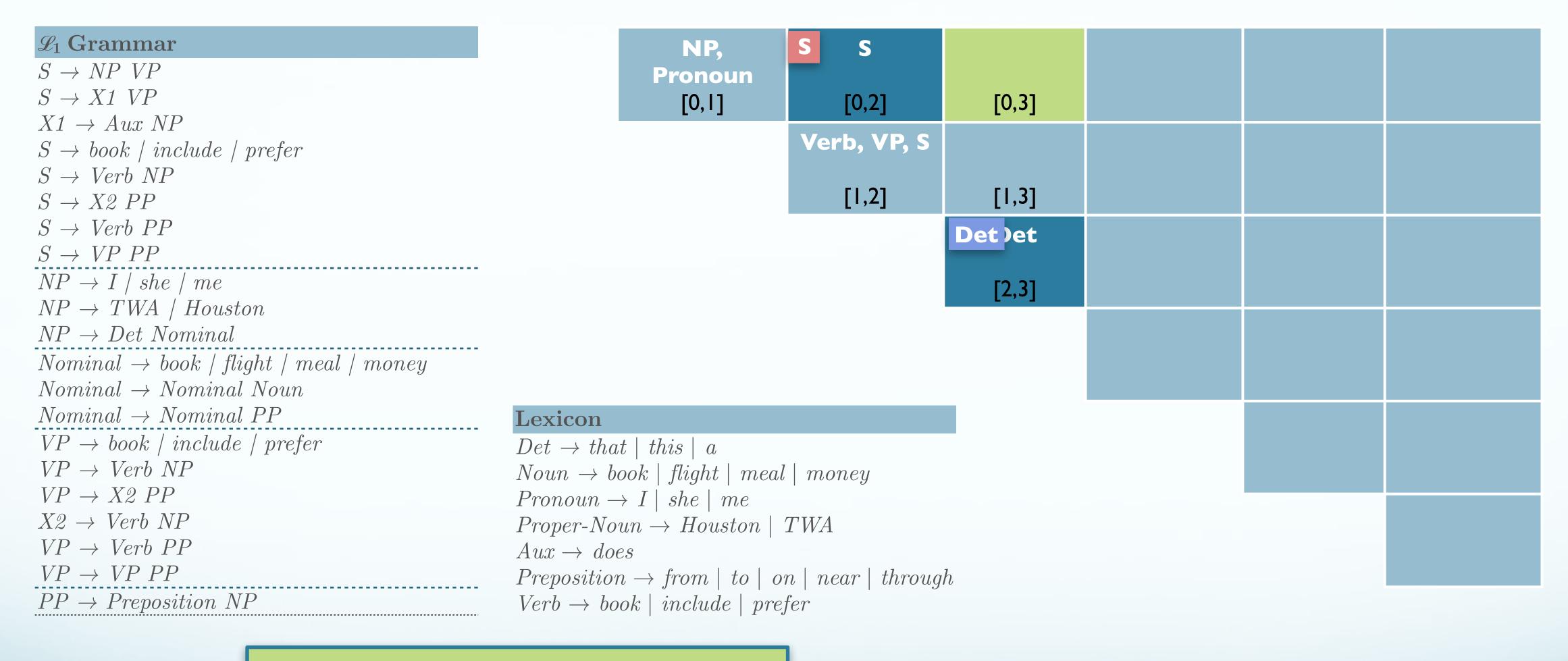
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\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	S [0,2]	[0,3]		
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$ $S \rightarrow Verb \ NP$		Verb, VP, S			
$S \to X2 PP$		[1,2]	[1,3]		
$S \to Verb \ PP$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

I prefer a flight on TWA of the second of th

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\mathcal{L}_1 Grammar $S \to NP \ VP$	NP,	S			
$S \rightarrow NP VP$ $S \rightarrow X1 VP$	Pronoun	FO 01	FO 23		
	[0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux NP$		Verb, VP, S			
$S \rightarrow book / include / prefer$		vens, vi, s			
$S \rightarrow Verb NP$		ΓI 21	[] 2]		
$S \to X2 PP$		[1,2]	[1,3]		
$S \rightarrow Verb PP$			Det		
$S \rightarrow VP PP$					
$NP \rightarrow I / she / me$			[2,3]		
$NP \rightarrow TWA \mid Houston$			L / J	Name Name	
$NP \rightarrow Det\ Nominal$				Noun, Nom	
$Nominal \rightarrow book / flight / meal / money$				FD 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 flight mea$	$al \mid moneu$			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	_ ,,,,,			
$VP \rightarrow VP PP$	$Preposition ightarrow from \mid to \mid c$	$nn \mid near \mid through$	ah.		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$,,,		
11 / 1 / CPOSSOSO TO 111	reio room miciaac pro				

flight



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\mathcal{L}_1 Grammar $S \to NP \ VP$	NP, Pronoun	S			
$S \to X1 VP$	[0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux NP$		Verb, VP, S			
$S \rightarrow book / include / prefer$		verb, vr, 5			
$S \rightarrow Verb NP$		[] 2]	LI 31		
$S \rightarrow X2 PP$		[1,2]	[1,3]		
$S \rightarrow Verb PP$ $S \rightarrow VP PP$			Det		
$NP \rightarrow I \mid she \mid me$				4-	
$NP \rightarrow T / She / Me$ $NP \rightarrow TWA / Houston$			[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				
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid me$	eal 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 throug	gh		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid p$	refer			

flight



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

flight



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NP, Pronoun [0,1]	[0,2]	[0,3]		
	[1,2]	Det	NP	
		[2,3]	[2,4]	
Lexicon			[-, .]	
$Noun \rightarrow book \mid flight \mid m$	eal money			
$Proper-Noun \rightarrow Houston$	e TWA			
$Preposition \rightarrow from \mid to$	•	ugh		

flight



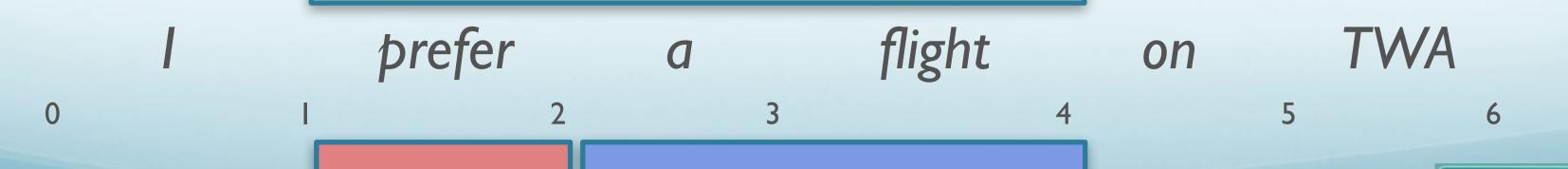
\mathscr{L}_1 Grammar	NP,	S			
$S \rightarrow NP VP$	Pronoun				
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux NP$	[0,1]		[0,5]		
$S \rightarrow book \ / \ include \ / \ prefer$		Verb, VP, S			
$S \rightarrow Verb NP$					
$S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$			Det		
$NP \rightarrow I / she / me$			ro 21	Γ2 4 1	
$NP \rightarrow TWA / Houston$			[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				
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid me$	$al \mid money$			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid$	$on \mid near \mid through$	vh		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid properties $	1			
		€			



\mathscr{L}_1 Grammar	NP,	S			
$S \to NP \ VP$ $S \to X1 \ VP$	Pronoun [0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$		Verb, VP, S		VP	
$S \rightarrow Verb NP$			[] 2]	ΓΙ <i>Δ</i> Ί	
$S \to X2 \ PP$ $S \to Verb \ PP$		[1,2]	[1,3] Det	[1,4] NP	
$S \rightarrow VP \ PP$ $NP \rightarrow I \ / \ she \ / \ me$					
$NP \rightarrow T / She / me$ $NP \rightarrow TWA / Houston$			[2,3]	[2,4]	
$NP \rightarrow Det\ Nominal$ $Nominal \rightarrow book\ /\ flight\ /\ meal\ /\ money$				Noun, Nom	
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$ $VP \rightarrow book / include / prefer$	Lexicon $Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$ $VP \rightarrow X2 PP$	$Noun \rightarrow book \mid flight \mid me$	$al \mid money$			
$VP \rightarrow X2 PP$ $X2 \rightarrow Verb NP$	$Pronoun ightarrow I \mid she \mid me$ $Proper-Noun ightarrow Houston$	l TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	'	7		
$VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$Preposition ightarrow from \mid to \mid$ $Verb ightarrow book \mid include \mid pri$, ,	gh.		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pr$	refer	_		



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



\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]		[0,5]		
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S	
S ightarrow Verb NP					
$S \rightarrow book / include / prefer$ $S \rightarrow Verb NP$ $S \rightarrow X2 PP$		[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]	
$NP \rightarrow TWA / Houston$			[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				
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$al \mid moneu$			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$	9			
$X2 \rightarrow Verb NP$	Proper-Noun Houston	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid$	$on \mid near \mid through$	ah		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pr$				
		v			



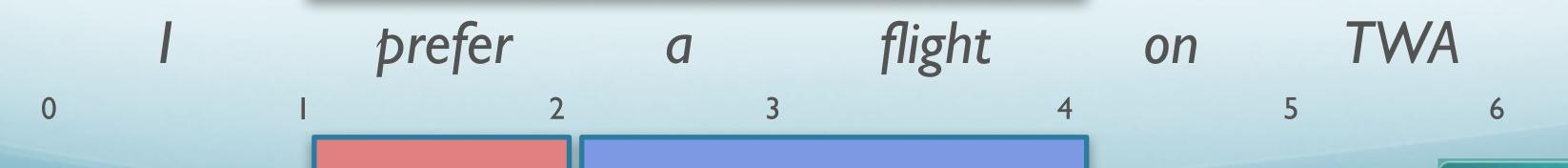


\mathscr{L}_1 Grammar	NP,	S			
$S \to NP VP$	Pronoun				
$S \to X1 VP$	[0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux NP$					
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S	
$S \rightarrow Verb NP$					
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$					
$NP \rightarrow I / she / me$			[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			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid$	$on \mid near \mid through$	ah		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pr$				
zz, zrepostotoro zvz	pr				



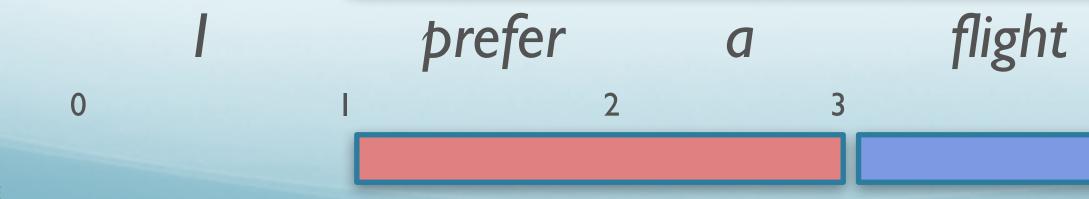


\mathscr{L}_1 Grammar	NP,				
$S \rightarrow NP VP$	Pronoun				
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]		
$X1 \rightarrow Aux NP$	L = / - J				
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S	
$S \rightarrow Verb NP$					
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det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





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



TWA 6

on

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

flight



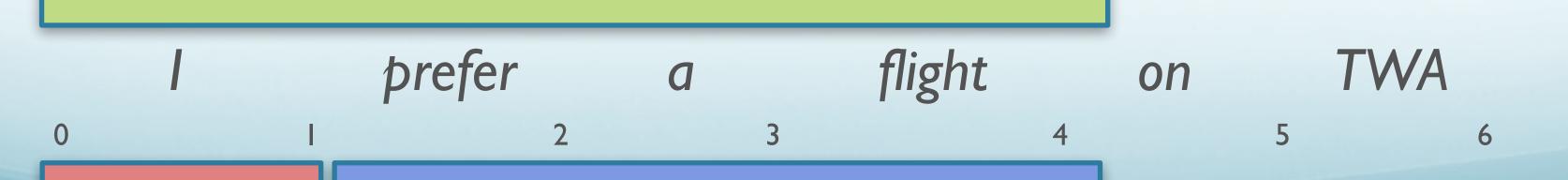
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TWA

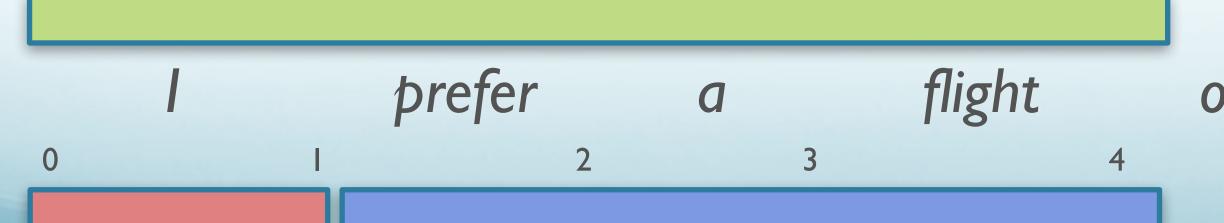
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NP,	S			
	ΓO 21	[O 3]	ΓΩ 4 1	
	Verb, VP, S		VP, X2, S	
	F1 07	F1 27	F1 43	
	[1,2]	[1,3]	[1,4]	
		Det	NP	
		[2,3]	[2,4]	
			Noun Nom	
			idodii, idoiii	
			Γ3 4 1	
T		_	[3, 1]	
· · · · · · · · · · · · · · · · · · ·	7			
	$al \mid money$			
•	TTIX/A			
	I VVA			
	on near through	ah		
		J1 0		
	Pronoun [0,1] Lexicon $Det o that \mid this \mid a$ $Noun o book \mid flight \mid me$ $Pronoun o I \mid she \mid me$ $Proper-Noun o Houston$ $Aux o does$ $Preposition o from \mid to \mid$		Pronoun [0,1] [0,2] [0,3]	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 Det \rightarrow that this a Noun \rightarrow book flight meal money Pronoun \rightarrow I she me Proper-Noun \rightarrow Houston TWA Aux \rightarrow does Preposition \rightarrow from to on near through



\mathscr{L}_1 Grammar	NP,	S
$S \rightarrow NP VP$	Pronoun	
$S \rightarrow X1 VP$	[0,1]	[0,2
$X1 \rightarrow Aux NP$		_
$S \rightarrow book / include / prefer$		Ve
$S \rightarrow Verb NP$		
$S \to X2 PP$		[1,2
$S \rightarrow Verb PP$		
$S \rightarrow VP PP$		
$NP ightarrow I \ / \ she \ / \ me$		
$NP \rightarrow TWA / Houston$		
$NP \rightarrow Det Nominal$		
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$		
$Nominal \rightarrow Nominal \ Noun$		
$Nominal \rightarrow Nominal PP$	Lexicon	
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$	
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid meal \mid$	$\mid m \mid$
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$	110
$X2 \rightarrow Verb NP$	$Proper-Noun ightarrow Houston \mid T$	7 I IZZ
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	V V 1
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid on$	$ \gamma$
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid prefe$	'
1 1 / 1 / Oposition 1 1 1	vero / ooon memae preje)

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]	
on				
that this a				
$\rightarrow book \mid flight \mid meal$	$\mid money$			
$un \rightarrow I \mid she \mid me$				
e -Noun \rightarrow Houston 1	TWA			
does				
$ition \rightarrow from \mid to \mid or$	$n \mid near \mid throug$	h		

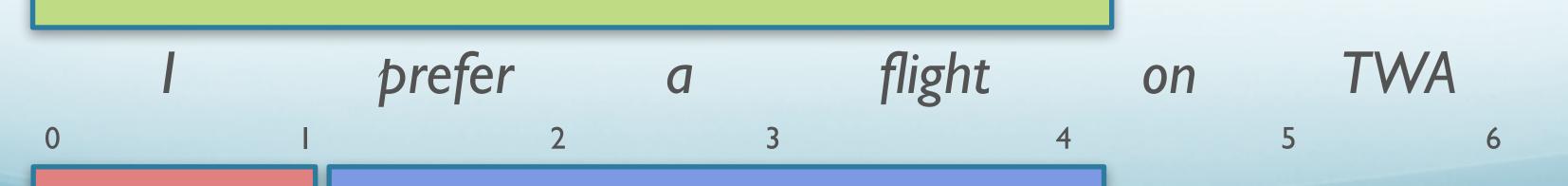


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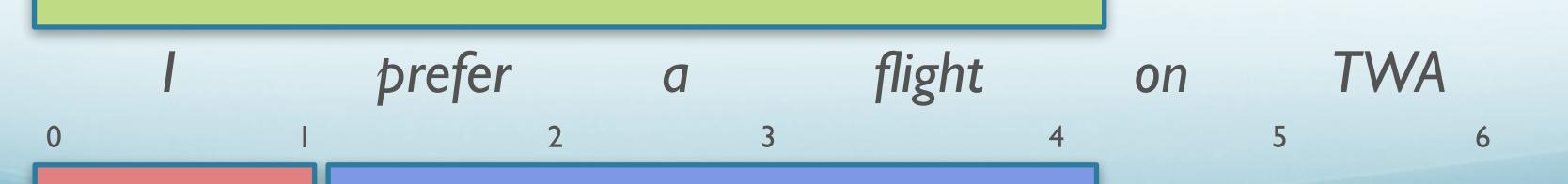


\mathscr{L}_1 Grammar	NP,	S		S	
$S \to NP VP$	Pronoun				
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S	
$S \rightarrow book / include / prefer$		verb, vi, 5		11,222, 5	
$V \rightarrow Verb NP$		ГI 21	[] 31	ΓΙ Δ Ί	
$X \to X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$					
NP ightarrow I / she / me			[2,3]	[2,4]	
$NP \rightarrow TWA \mid Houston$					
$NP \rightarrow Det\ Nominal$. -			Noun, Nom	
$Vominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 41	
$Vominal \rightarrow Nominal \ Noun$				[3,4]	
$Vominal \rightarrow Nominal PP$	Lexicon				
VP ightarrow book / include / prefer	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid m$	eal money			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \stackrel{\cdot}{ ightarrow} Houston$	$n \mid TWA$			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	ı			
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to$	on near through	gh		
$PP \rightarrow Preposition NP$	$Verb ightarrow book \mid include \mid g$)		

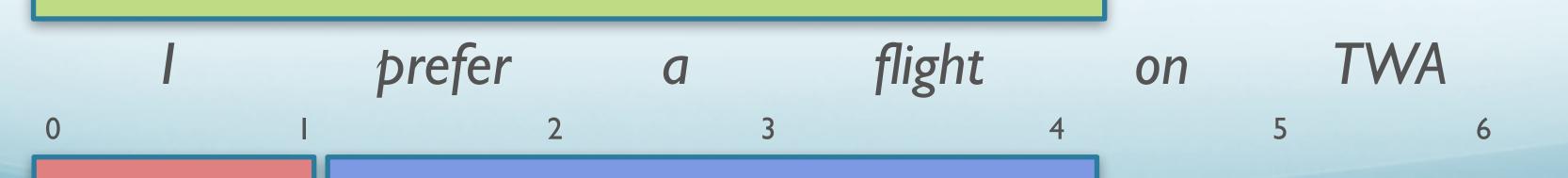


WASHINGTON

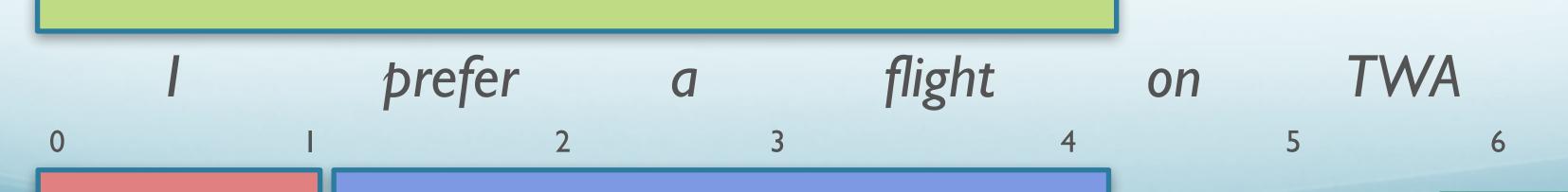
\mathscr{L}_1 Grammar	NP,	S		S	
$S \to NP VP$	Pronoun				
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S	
$S \rightarrow book / include / prefer$		verb, vi, s		VI, 222, 5	
$V \rightarrow Verb NP$		ГI 21	[] 21	ΓΙ <i>Δ</i> Ί	
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$	_				
NP ightarrow I / she / me			[2,3]	[2,4]	
$VP \rightarrow TWA \mid Houston$					
$NP \rightarrow Det\ Nominal$	_			Noun, Nom	
$Vominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				FO 43	
$Vominal \rightarrow Nominal \ Noun$				[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			
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \stackrel{\cdot}{ ightarrow} Houston$	$I \mid TWA$			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to$	$\mid on \mid near \mid through$	qh		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid p$	' '	,		



\mathscr{L}_1 Grammar	NP,			S	
$S \to NP VP$	Pronoun				
$S \to X1 VP$	[0,1]	,2]	[0,3]	[0,4]	
$X1 \rightarrow Aux NP$		orb VD C		VD V2 C	
$S \rightarrow book / include / prefer$		erb, VP, S		VP, X2, S	
$S \rightarrow Verb NP$		21	FL 27	F1 47	
$S \to X2 PP$	Li	,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \to VP PP$	_				
$NP \rightarrow I / she / me$			[2,3]	[2,4]	
$NP \rightarrow TWA / Houston$			L / J		
$NP \rightarrow Det\ Nominal$	_			Noun, Nom	
$Nominal \rightarrow book / flight / meal / money$				F2 41	
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid meal \mid r$	noney			
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston \mid TW$	VA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid on \mid$	near throug	h		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid prefer$				



\mathscr{L}_1 Grammar	NP,	S		S	
$S \to NP VP$	Pronoun				
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S	
$S \rightarrow book / include / prefer$		verb, vr, s		VP, AZ, S	
$S \rightarrow Verb NP$		[]]	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	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 43	
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$ul \mid money$			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	$Preposition o from \mid to \mid c$	$on \mid near \mid through$	gh		
$PP \rightarrow Preposition NP$	$Verb ightarrow book \mid include \mid pre$	1 1			

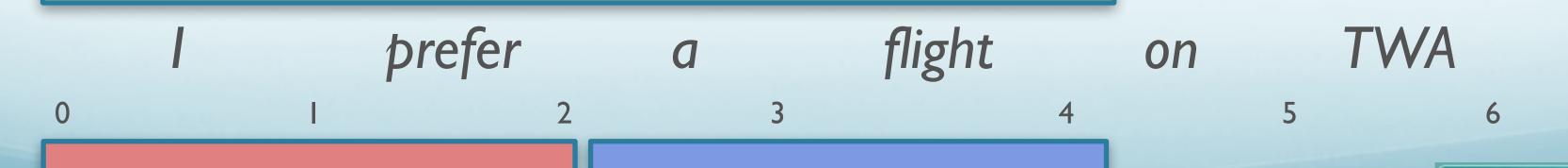


\mathscr{L}_1 Grammar	NP,	S		S	
$S \to NP VP$	Pronoun				
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S	
$S \rightarrow book / include / prefer$		verb, vr, s		VP, AZ, S	
$S \rightarrow Verb NP$		FL 23	F1 27	F1 47	
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	
$S \rightarrow Verb PP$			Det	NP	
$S \rightarrow VP PP$	_				
$VP \rightarrow I / she / me$			[2,3]	[2,4]	
$VP \rightarrow TWA \mid Houston$			L / J		
$NP \rightarrow Det\ Nominal$	_			Noun, Nom	
$Vominal \rightarrow book / flight / meal / money$				F2 47	
$Nominal \rightarrow Nominal \ Noun$				[3,4]	
$Nominal \rightarrow Nominal PP$	Lexicon				
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$al \mid money$			
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA			
$VP \rightarrow Verb PP$	$Aux \rightarrow does$				
$VP \rightarrow VP PP$	Preposition \rightarrow from to c	$on \mid near \mid through$	gh		
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pro$	1 1			





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



\mathcal{L}_1 Grammar $S \to NP \ VP$	NP, Pronoun	S		S		
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]		
$X1 \rightarrow Aux NP$ $S \rightarrow book / implied o / profess$		Verb, VP, S		VP, X2, S		
$S \rightarrow book \mid include \mid prefer$ $S \rightarrow Verb NP$						
$S \rightarrow X2 PP$		[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		
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$	•					
$Nominal \rightarrow Nominal \ Noun$				[3,4]		
$Nominal \rightarrow Nominal PP$	Lexicon					
$VP \rightarrow book \mid include \mid prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mean$	$l \mid money$				
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$					
$X2 \rightarrow Verb NP$	$Proper-Noun ightarrow Houston \mid TWA$					
$VP \rightarrow Verb PP$	$Aux \rightarrow does$		_			
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid o$	1	h			
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$	ter				

flight



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

	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	
$Det \rightarrow the$	$at \mid this \mid a$					
	$pook \mid flight \mid meal$	$\mid money$			[4,5]	
	$\rightarrow I \mid she \mid me$					
_	$oun \rightarrow Houston \mid $	TWA				
$Aux \rightarrow do$	_		7.			
	$egin{array}{c c} n ightarrow from to egin{array}{c c} ot \ ook include present \ \end{array}$		n			
VC10 -7 00	on momme pre					



\mathscr{L}_1 Grammar	NP,	S		S		
$S \to NP VP$	Pronoun					
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]		
$X1 \rightarrow Aux NP$						
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		
$S \rightarrow Verb NP$		FL 21	FL 21	ΓΙ 4 1		
$S \rightarrow X2 PP$		[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]		
$NP \rightarrow TWA / Houston$				Noun, Nom		
$NP \rightarrow Det\ Nominal$				Roun, Rom		
$Nominal \rightarrow book / flight / meal / money$				Γ2 <i>Δ</i> 1	[3,5]	
$Nominal \rightarrow Nominal \ Noun$				[3,4]		
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$	- 1				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid meal \mid money$				[4,5]	
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$					
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston \mid TWA$					
$VP \rightarrow Verb PP$ $VD \rightarrow VD DD$	$Aux \rightarrow does$	1	7			
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid o$		ıh			
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$	<i>fer</i>				



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prefer

\mathscr{L}_1 Grammar	NP,	S		S		
$S \rightarrow NP VP$	Pronoun					
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]		
$X1 \rightarrow Aux NP$	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		
$S \to VP PP$						
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	
$NP \rightarrow TWA / Houston$						
$NP \rightarrow Det\ Nominal$				Noun, Nom		
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				 4-		
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	
$VP \rightarrow book \ / \ include \ / \ prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid meal \mid money$				[4,5]	
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$		L -7~]			
$X2 \rightarrow Verb NP$	$Proper-Noun ightarrow Houston \mid TWA$					
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid o$	$n \mid near \mid throug$	h			
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$					

prefer



\mathscr{L}_1 Grammar $S \to NP \ VP$	NP,	S		S		
$S \to X1 VP$	Pronoun [0,1]	[0,2]	[0,3]	[0,4]		
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$		Verb, VP, S		VP, X2, S		
$S \rightarrow Verb NP$ $S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]		
$S \rightarrow Verb PP$		L - / — J	Det	NP		
$S \rightarrow VP \ PP$ $NP \rightarrow I \ \ she \ \ me$			רט טו	Γ 2 4 1	[O []	
$NP \rightarrow TWA / Houston$			[2,3]	[2,4] Noun, Nom	[2,5]	
$NP \rightarrow Det\ Nominal$ $Nominal \rightarrow book\ /\ flight\ /\ meal\ /\ money$				idouii, idoiii		
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	
	Lexicon				Prep	
$VP \rightarrow Verb NP$	$Det ightarrow that \mid this \mid a$ $Noun ightarrow book \mid flight \mid mea$	$nl \mid money$			[4,5]	
	$Pronoun ightarrow I \mid she \mid me$ $Proper-Noun ightarrow Houston \mid TWA$					
$VP \rightarrow Verb PP$	$Aux \rightarrow does$		7			
$VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$Preposition ightarrow from \mid to \mid r$ $Verb ightarrow book \mid include \mid pr$		ın			

prefer

flight



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TWA

on

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



TWA 6

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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]	[1,5]	
$S \rightarrow Verb \ PP$ $S \rightarrow VP \ PP$ $NP \rightarrow I \ \ she \ \ me$			Det	NP		
$NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$			[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	
$VP ightarrow book \ / \ include \ / \ prefer$ $VP ightarrow Verb \ NP$ $VP ightarrow X2 \ PP$ $X2 ightarrow Verb \ NP$ $VP ightarrow Verb \ PP$ $VP ightarrow VP \ PP$ $PP ightarrow Preposition \ NP$	$Det ightarrow that \mid this \mid a$ $Noun ightarrow book \mid flight \mid meal$ $Pronoun ightarrow I \mid she \mid me$ $Proper-Noun ightarrow Houston \mid$ $Aux ightarrow does$ $Preposition ightarrow from \mid to \mid o$ $Verb ightarrow book \mid include \mid pre$	TWA $n \mid near \mid throug$	h		[4,5]	



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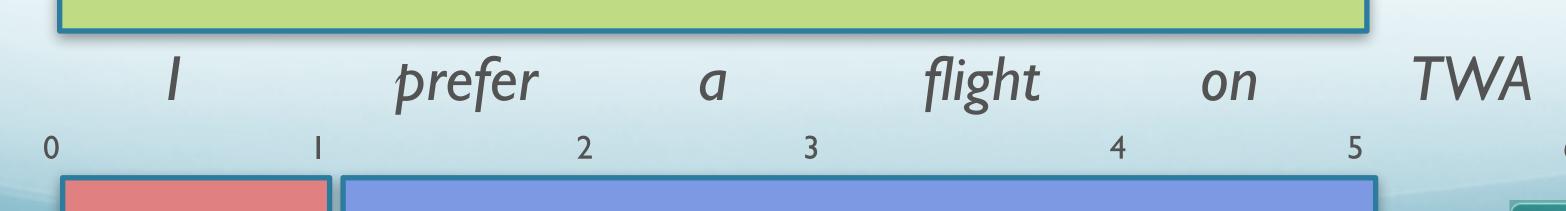
$\mathcal{L}_{1} \mathbf{Grammar}$ $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]		
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ \ include \ \ prefer$ $S \rightarrow Verb \ NP$ $S \rightarrow X2 \ PP$		Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
$S \rightarrow Verb \ PP$ $S \rightarrow VP \ PP$			Det	NP		
$NP \rightarrow I \mid she \mid me$ $NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$			[2,3]	[2,4] Noun, Nom	[2,5]	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$ $Nominal \rightarrow Nominal \ Noun$ $Nominal \rightarrow Nominal \ PP$	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]	



TWA 6 75

on

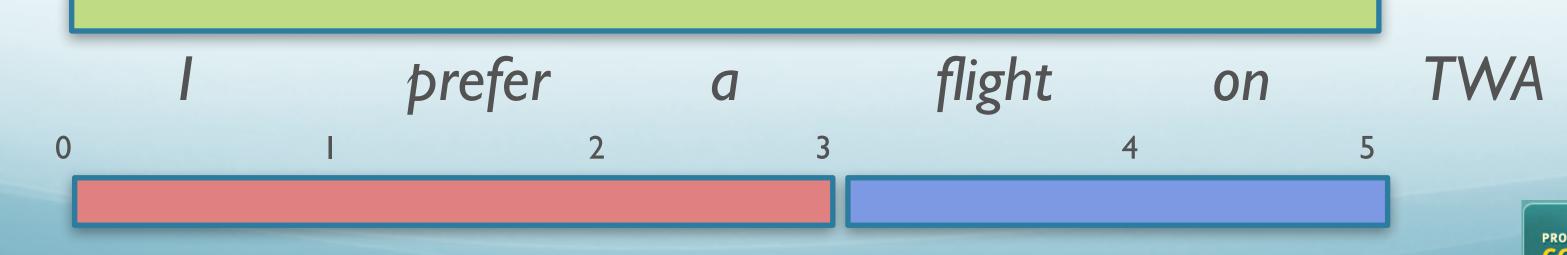
\mathscr{L}_1 Grammar	NP,	S		S		
$S \rightarrow NP VP$	Pronoun					
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$						
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		
$S \rightarrow Verb NP$						
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow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



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



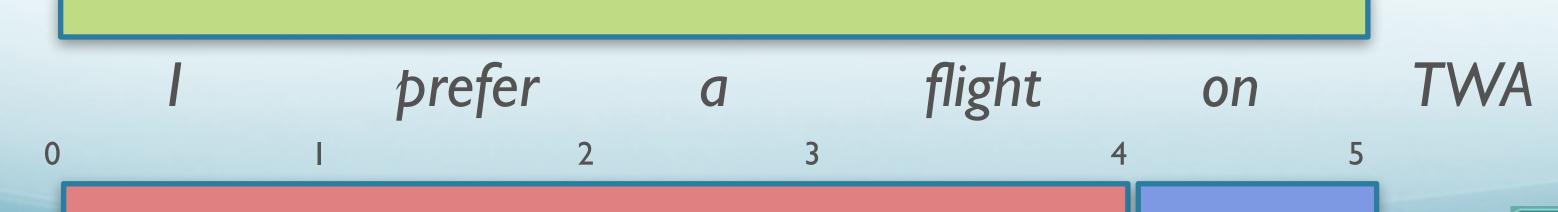
\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ \ include \ \ prefer$ $S \rightarrow Verb \ NP$		Verb, VP, S		VP, X2, S		
$S \to X2 \ PP$ $S \to Verb \ PP$		[1,2]	[1,3] Det	[1,4] NP	[1,5]	
$S o VP \ PP$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



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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]	
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$ $S \rightarrow Verb \ NP$		Verb, VP, S		VP, X2, S		
$S \rightarrow Vero NP$ $S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow Verb PP$ $S \rightarrow VP PP$			Det	NP		
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	
$NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$				Noun, Nom		
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$ $Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	
$VP \rightarrow book \mid include \mid prefer$ $VP \rightarrow Verb \mid NP$ $VP \rightarrow X2 \mid PP$	$Det ightarrow that \mid this \mid a$ $Noun ightarrow book \mid flight \mid mea$	$l \mid money$			[4,5]	
$X2 \rightarrow Verb \ NP$ $VP \rightarrow Verb \ PP$	$Pronoun \rightarrow I \mid she \mid me$ $Proper-Noun \rightarrow Houston \mid Aux \rightarrow does$	TWA				
$VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$Preposition ightarrow from \mid to \mid c$ $Verb ightarrow book \mid include \mid pre$		gh			



\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	[0,5]	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		
$NP \rightarrow I / she / me$ $NP \rightarrow TWA / Houston$ $NP \rightarrow Det Nominal$			[2,3]	[2,4] Noun, Nom	[2,5]	
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$ $Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	
$Nominal \rightarrow Nominal \ PP$ $VP \rightarrow book \ / \ include \ / \ prefer$	$\begin{array}{c} \textbf{Lexicon} \\ Det \rightarrow that \mid this \mid a \end{array}$				Prep	
$VP \rightarrow Verb \ NP$ $VP \rightarrow X2 \ PP$	$Noun ightharpoonup book \mid flight \mid meal \mid money$ [4,5] $Pronoun ightharpoonup I \mid she \mid me$					NINID NID
$X2 \rightarrow Verb \ NP$ $VP \rightarrow Verb \ PP$	$\begin{array}{c} Proper-Noun \rightarrow Houston \mid TWA \\ Aux \rightarrow does \end{array}$					NNP, NP
$VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$Preposition \rightarrow from \mid to \mid o$ $Verb \rightarrow book \mid include \mid pre$		[5,6]			

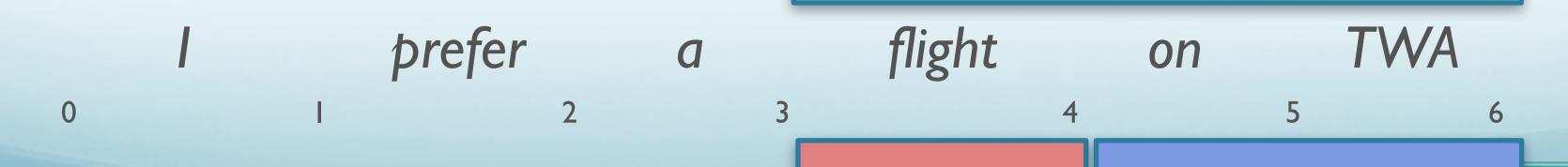




\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun	S [0 2]	Γ Λ 21	S [0 4]	Γ Λ 51	
$X1 \rightarrow Aux NP$	[0,1]	[0,2] Verb, VP, S	[0,3]	[0,4] VP, X2, S	[0,5]	
$S \rightarrow book \mid include \mid prefer$ $S \rightarrow Verb NP$		verb, vr, s				
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow Verb PP$ $S \rightarrow VP PP$			Det	NP		
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	
$NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$				Noun, Nom		
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$ $Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	
	Lexicon				Prep	PP
	$Det \rightarrow that \mid this \mid a$	1 m om on			F4 F1	F4 47
	$Noun \rightarrow book \mid flight \mid mea$ $Pronoun \rightarrow I \mid she \mid me$	t money			[4,5]	[4,6]
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston \mid$	TWA				NNP, NP
$VP \rightarrow Verb \ PP$ $VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$Aux \rightarrow does$ $Preposition \rightarrow from \mid to \mid c$ $Verb \rightarrow book \mid include \mid pre$	1	vh			[5,6]



\mathscr{L}_1 Grammar	NP,	S		S		
$S \rightarrow NP VP$ $C \rightarrow V1 VD$	Pronoun	FO 07	FO 27	FO 43	FO F3	
$S \rightarrow X1 \ VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S		
$S \rightarrow book / include / prefer$, , , , , , , , , , , , , , , , , , ,				
$S \rightarrow Verb NP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \to X2 \ PP$ $S \to Verb \ PP$		[', _]				
			Det	NP		
$S \rightarrow VP PP$						
$NP \rightarrow I / she / me$			[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]
$egin{array}{c} Nominal ightarrow Nominal ightarrow Nominal ightarrow PP \end{array}$	T •					
	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$	7				
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$d \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$ $VO \rightarrow Vocab ND$	$Pronoun \rightarrow I \mid she \mid me$					NNP, NP
$X2 \rightarrow Verb NP$ $VD \rightarrow Verb PD$	$Proper-Noun \rightarrow Houston \mid$	TWA				
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	1 .7	7			[5,6]
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid c$	1	ıh			
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$	efer				

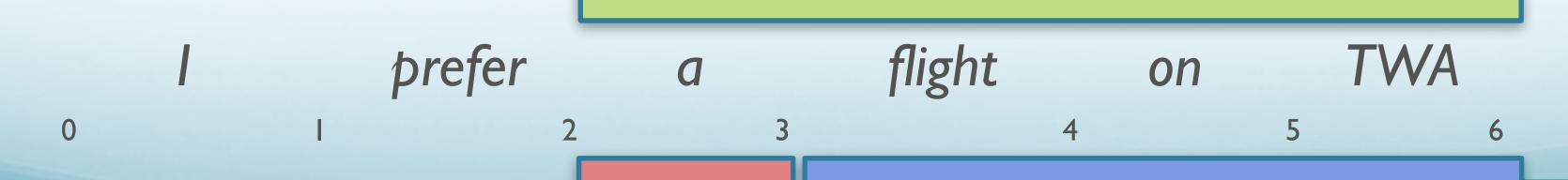


\mathcal{L}_1 Grammar $S \to NP \ VP$ $S \to X1 \ VP$	NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$		Verb, VP, S		VP, X2, S		
$S \rightarrow Verb \ NP$ $S \rightarrow X2 \ PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow Verb PP$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





\mathscr{L}_1 Grammar	NP,	S		S		
$S \to NP \ VP$ $S \to X1 \ VP$	Pronoun	Γ Ω 21	ΓΛ 21	ΓO 4 3	Γ Λ Ε 1	
$X1 \rightarrow Aux NP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		
S o Verb NP						
$S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \rightarrow Verb PP$			Det	NP		NP
$S \rightarrow VP PP$						
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA / Houston$			L_, J			_
$NP ightarrow Det \ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 41	F2 F3	F2
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	xicon				Prep	PP
$VP \rightarrow book / include / prefer$	$at \rightarrow that \mid this \mid a$					
	$oun \rightarrow book \mid flight \mid mea$	$l \mid money$			[4,5]	[4,6]
	$onoun \rightarrow I \mid she \mid me$					NNP, NP
	$oper$ -Noun \rightarrow Houston	TWA				MINF, INF
TID TID DD	$dx \rightarrow does$					Γ 5 6 1
	$eposition \rightarrow from \mid to \mid c$	·	h			[5,6]
$PP \rightarrow Preposition NP$ Ve	$rb \rightarrow book \mid include \mid pre$	efer				





$\mathcal{L}_{1} \mathbf{Grammar}$ $S \to NP \ VP$ $S \to X1 \ VP$	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		
$S \rightarrow Verb NP$		[1,2]	[1,3]	[1,4]	[1,5]	
$S \to X2 \ PP$ $S \to Verb \ PP$		L', _	Det	NP		NP
$S \to VP PP$			Det			
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 ∕ 11	[2 E]	Γ 2
$Nominal \rightarrow Nominal \ Noun$			_	[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$	- 1				
$VP \rightarrow Verb \ NP$ $VP \rightarrow X2 \ PP$	$Noun \rightarrow book \mid flight \mid mean$	$l \mid money$			[4,5]	[4,6]
$XP \rightarrow XZPP$ $X2 \rightarrow Verb NP$	$Pronoun ightarrow I \mid she \mid me$ $Proper-Noun ightarrow Houston \mid$	TMA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$	1 VVA				
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid o$	$n \mid near \mid through$	h			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$					



\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]	
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$ $S \rightarrow Verb \ NP$		Verb, VP, S		VP, X2, S		
$S \to X2 \ PP$ $S \to Verb \ PP$		[1,2]	[1,3] Det	[1,4] NP	[1,5]	NP
$S \rightarrow VP \ PP$ $NP \rightarrow I \ / \ she \ / \ me$					[2 <u>5</u>]	
$NP \rightarrow TWA \mid Houston$ $NP \rightarrow Det \ Nominal$			[2,3]	[2,4] Noun, Nom	[2,5]	[2,6] Nom
$Nominal \rightarrow book \mid flight \mid meal \mid money \ Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$ $VP \rightarrow book \ / \ include \ / \ prefer$	Lexicon $Det \rightarrow that \mid this \mid a$				Prep	PP
$VP \rightarrow Verb \ NP$ $VP \rightarrow X2 \ PP$	$Noun \rightarrow book \mid flight \mid meal$	l money			[4,5]	[4,6]
$X2 \rightarrow Verb NP$	$Pronoun \rightarrow I \mid she \mid me$ $Proper-Noun \rightarrow Houston \mid$	TWA				NNP, NP
$VP \rightarrow Verb \ PP$ $VP \rightarrow VP \ PP$ $PP \rightarrow Preposition \ NP$	$Aux \rightarrow does$ $Preposition \rightarrow from \mid to \mid o$ $Verb \rightarrow book \mid include \mid pre$	1	ηh			[5,6]



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

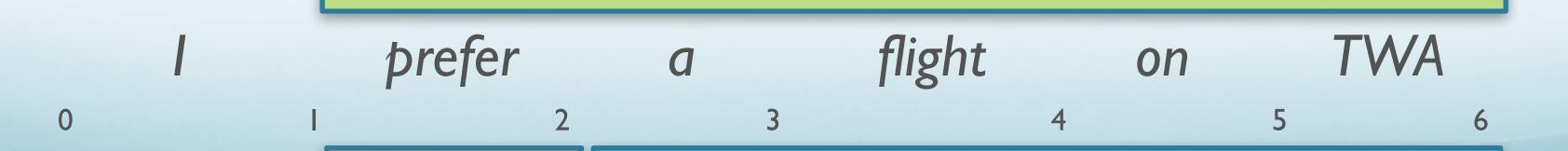
	NP,	S		S		
	Pronoun					
	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
		Verb, VP, S		VP, X2, S		
		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
			Det	NP		NP
			[2,3]	[2,4]	[2,5]	[2,6]
				Noun, Nom		Nom
				[3,4]	[3,5]	[3,6]
Lexicon					Prep	PP
$Det \rightarrow the$	at this a					
$Noun \rightarrow b$	$pook \mid flight \mid meal$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



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

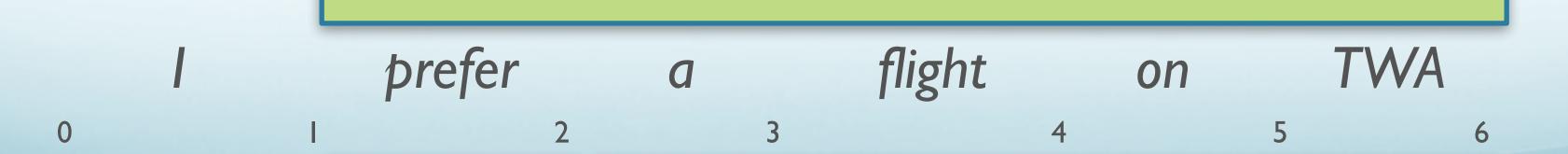
 $Verb \rightarrow book \mid include \mid prefer$

\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]	
$X1 \rightarrow Aux \ NP$ $S \rightarrow book \ / \ include \ / \ prefer$		Verb, VP, S		VP, X2, S		VP
$S \rightarrow Verb NP$		[] O]	F1 27	F1 47	F1 F3	
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \to Verb PP$ $S \to VP PP$			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 ightarrow Verb NP	$Noun \rightarrow book \mid flight \mid mea$	$nl \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$					
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition o from \mid to \mid e$	$on \mid near \mid through$	gh			[5,6]
$PP \rightarrow Preposition NP$	$Verb ightarrow book \mid include \mid pro$					



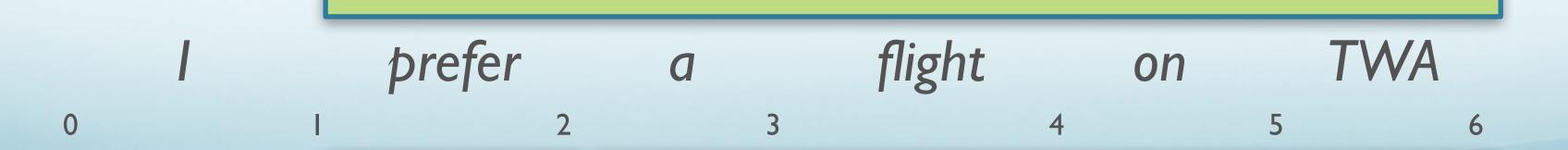


NP,	S		S		
	го.21	[0,3]	ГО.41	[0.5]	
		L / J		L / J	
	Verb, VP, S		VP, X2, S		VP, X2
	[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
		Det	NP		NP
		Г2.31	Г2.41	Γ2.51	[2,6]
		[_,-]			
			Noun, Nom		Nom
			[3,4]	[3,5]	[3,6]
Lexicon				Prep	PP
$Det \rightarrow that \mid this \mid a$					
	eal money			Г 4 .51	[4,6]
1 0 0				[.,•]	
1	$I \mid TWA$				NNP, NP
$Aux \rightarrow does$	'				
$Preposition ightarrow from \mid to \mid$	on near through	gh			[5,6]
_ '	, ,				
	$Det ightarrow that \mid this \mid a$ $Noun ightarrow book \mid flight \mid m$ $Pronoun ightarrow I \mid she \mid me$ $Proper-Noun ightarrow Houston$ $Aux ightarrow does$ $Preposition ightarrow from \mid to$	Pronoun [0,1] [0,2] Verb, VP, S [1,2] Lexicon $Det \rightarrow that \mid this \mid a$ $Noun \rightarrow book \mid flight \mid meal \mid money$ $Pronoun \rightarrow I \mid she \mid me$ $Proper-Noun \rightarrow Houston \mid TWA$ $Aux \rightarrow does$			





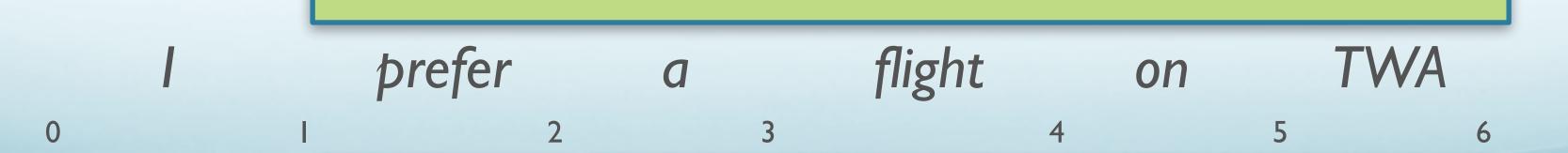
\mathscr{L}_1 Grammar	NP,	S		S		
$S \to NP \ VP$ $S \to X1 \ VP$	Pronoun [0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$	L = 7 - J					VD V2 C
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		VP, X2, S
$\begin{array}{c} S \rightarrow Verb NP \\ S \rightarrow X2 PP \end{array}$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \rightarrow VP PP$			Det			
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA / Houston$			[_,5]		[_,5]	
$NP \rightarrow Det\ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				FD 47		FD 47
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$l \mid money$			[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
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid c$	$on \mid near \mid through$	gh			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$					



\mathscr{L}_1 Grammar S		NP.					
			S		S		
$S \rightarrow NP \ VP$							
$S \to X1 \ VP$ [0,1] [0,3] [0,4] [0,5]		[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$							VD V0 6
$S o book \mid include \mid prefer$			verb, vP,	S	VP, X2, S		VP, X2, S
$S \rightarrow Verb NP$							
$S \to X2 PP$ [1,3] [1,4] [1,5]			[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S o Verb \ PP$				Det	NP		NP
$S \rightarrow VP PP$							
$NP o I \ \ she \ \ me$ [2,4] [2,5] [2,6]				ſ2.31	г 2.4 1	[2.5]	[2,6]
$NP ightarrow TWA \mid Houston$				[_,0]			
$NP o Det \ Nominal$					Noun, No	m	Nom
$Nominal ightarrow book \ / \ flight \ / \ meal \ / \ money$	'						
$Nominal \rightarrow Nominal Noun$ [3,4]					[3,4]	[3,5]	[3,6]
$Nominal \ PP$ Lexicon		Lexicon				Prep	PP
$VP \rightarrow book \mid include \mid prefer$ $Det \rightarrow that \mid this \mid a$							
$VD + V_{res} l_r ND$			meal moneu			г 4 51	[4,6]
$VP \rightarrow X2 \ PP$ $Pronoun \rightarrow I \mid she \mid me$						[1,9]	
$X2 \rightarrow Verb \ NP$ $Proper-Noun \rightarrow Houston \mid TWA$		1					NNP, NP
$VP \rightarrow Verb \ PP$ $Aux \rightarrow does$							
			$to \mid on \mid near \mid thr$	rouah			[5,6]
$PP o Preposition \ NP$ $Verb o book \mid include \mid prefer$							

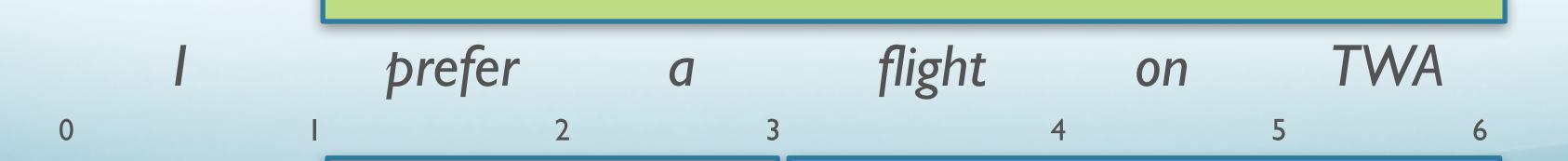
I prefer a flight on TWA 2 3 4 5 6

\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°,.]					
$S \rightarrow book / include / prefer$		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]
$NP \rightarrow TWA / Houston$			[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
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					' '
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid me$	eal moneu			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				[1,5]	[1,0]
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid$	$on \mid near \mid through$	vh			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid p$					



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

	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
$Det \rightarrow the$	at this a					
	$pook \mid flight \mid meal$	money			[4,5]	[4,6]
	$ ightarrow I \mid she \mid me$					NNP, NP
-	$oun \rightarrow Houston \mid$	TWA				
$Aux \rightarrow do$		1 . 7	7			[5,6]
Prepositio	$n \rightarrow from \mid to \mid o$	$n \mid near \mid throug$	h			



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

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



\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 V
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		VP, X
$S \rightarrow Verb NP$		FL 27	F1 27	F1 43	F1 F3	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]
$NP \rightarrow TWA / Houston$						
$NP \rightarrow Det\ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 41	F2 F1	F2 /1
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book \ / \ include \ / \ prefer$	$Det \rightarrow that \mid this \mid a$					_
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid me$	eal money			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				L / J	_
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA				NNP,
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					FF /3
VP ightarrow VP PP	$Preposition \rightarrow from \mid to \mid$	on near throug	gh			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid p$	refer				

1		prefer	а		flight	on		TWA
0	1	2		3	4		5	6

\mathscr{L}_1 Grammar	ND	C		C		
$S \rightarrow NP \ VP$	NP, Pronoun	3		S		
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
$X1 \rightarrow Aux NP$	[0,1]		[0,5]		[0,5]	
$S \rightarrow book / include / prefer$		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
$S \rightarrow VP PP$						
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA / Houston$			L—,~ J		[_,-,-]	
$NP \rightarrow Det\ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 43	F2 F3	F2 41
$Nominal \rightarrow Nominal \ Noun$				[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	
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					FF /3
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid o$	$n \mid near \mid through$	gh			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$	fer				

Prefer a flight on TWA or 1 2 3 4 5 6



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

I prefer a flight on TWA of the second of th



\mathscr{L}_1 Grammar	NP,	S	
$S \to NP VP$	Pronoun		
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0
$X1 \rightarrow Aux NP$	L°, · J		L
$S \rightarrow book / include / prefer$		Verb, VP, S	
$S \rightarrow Verb NP$			
$S \to X2 PP$		[1,2]	[]
$S \rightarrow Verb PP$			D
$S \rightarrow VP PP$			
$NP \rightarrow I / she / me$			[2
$NP \rightarrow TWA / Houston$			L
$NP \rightarrow Det Nominal$			
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$			
$Nominal \rightarrow Nominal Noun$			
$Nominal \rightarrow Nominal PP$	Lexicon		
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$		
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid meat$	$l \mid moneu$	
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$	g	
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA	
$VP \rightarrow Verb PP$	$Aux \rightarrow does$		
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid o$	$n \mid near \mid through$	ih
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$		

	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]
on					Prep	PP
tha	$at \mid this \mid a$					
$\rightarrow b$	$look \mid flight \mid meal$	$\mid money$			[4,5]	[4,6]
	$\rightarrow I \mid she \mid me$					NNP, NP
_	$un o Houston \mid f$	TWA				NINI, INI
$\rightarrow do$						[5 6]
sitio	$n o from \mid to \mid or$	$n \mid near \mid throug$	h			[5,6]

I prefer a flight on TWA 2 3 4 5 6

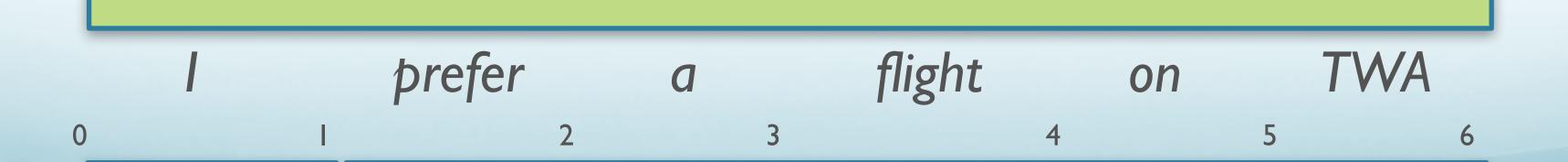
\mathscr{L}_1 Grammar	NP,	S	
$S \to NP VP$	Pronoun		
$S \to X1 VP$	[0,1]	[0,2]	[0,
$X1 \rightarrow Aux NP$			
$S \rightarrow book / include / prefer$		Verb, VP, S	
$S \rightarrow Verb NP$			
$S \to X2 PP$		[1,2]	[1,
$S \rightarrow Verb PP$			D
$S \rightarrow VP PP$			
$NP \rightarrow I / she / me$		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

	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]
icon	, ,7 •				Prep	PP
$n \to b$	$at \mid this \mid a \\ ook \mid flight \mid meal $	money			[4,5]	[4,6]
	$egin{array}{ll} ightarrow I \mid she \mid me \ un ightarrow Houston \mid f \end{array}$	TWA				NNP, NP
$\rightarrow do$	'		h			[5,6]

Prefer a flight on TWA

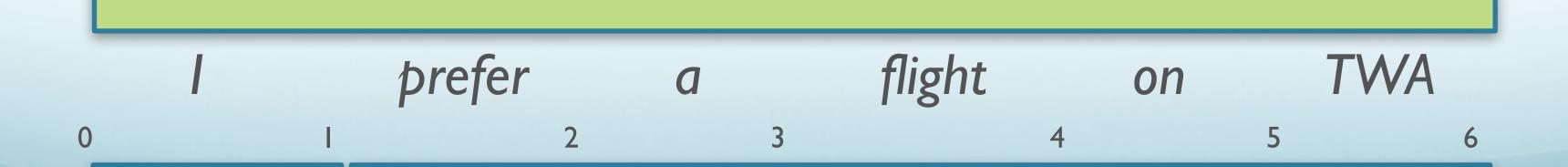
2 3 4 5 6

\mathscr{L}_1 Grammar $S \to NP \ VP$	NP, Pronoun	S		S		
$S \to X1 VP$	[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
$S \rightarrow Verb NP$		FL 27	F1 27	F1 47	F1 F3	F1
$S \to X2 PP$		[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]
$NP \rightarrow TWA / Houston$						Nom
$NP \rightarrow Det\ Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 41	F2 F3	F2 /1
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$l \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$				L .,	
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid c$	$n \mid near \mid through$	vh			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$					





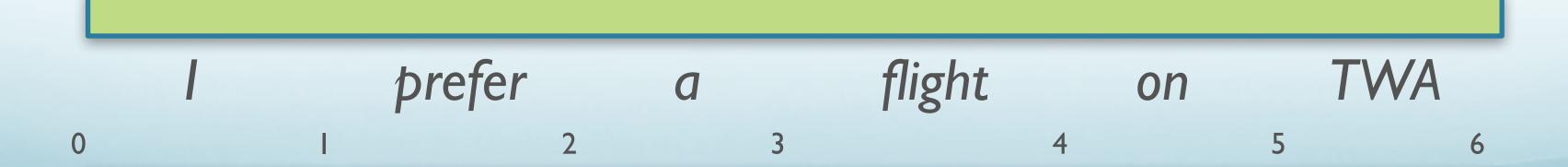
\mathscr{L}_1 Grammar	NP,	S		S		S
$S \rightarrow NP VP$ $S \rightarrow X1 VP$	Pronoun					_
$S \rightarrow X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	[0,6]
$X1 \rightarrow Aux NP$						
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, X2, S		VP, X2, 9
$S \rightarrow Verb NP$		F1 03	EL 33	F1 47	F1 F3	F1 /7
$S \to X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow Verb PP$			Det	NP		NP
$S \rightarrow VP PP$						
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
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				F2 47	F2 F3	F2 /1
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book \ / \ include \ / \ prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$l \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun \rightarrow I \mid she \mid me$				L / J	
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston$	TWA				NNP, NI
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					FF /3
$VP \rightarrow VP PP$	$Preposition \rightarrow from \mid to \mid o$	n near throug	ηh			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$	efer				



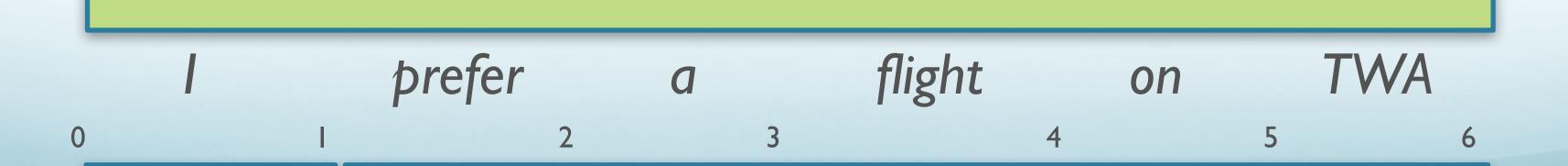
\mathscr{L}_1 Grammar	NP,	S		S		S
$S \rightarrow NP VP$	Pronoun					
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	[0,6]
$X1 \rightarrow Aux NP$		Vorb VD C		VP, X2, S		VP, X2, S
$S \rightarrow book / include / prefer$		Verb, VP, S		VP, AZ, S		V P, AZ, S
$S \rightarrow Verb NP$		F1 07	EL 23	F1 43		F1 /3
$S \to X2 PP$		[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
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				FD 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]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$					



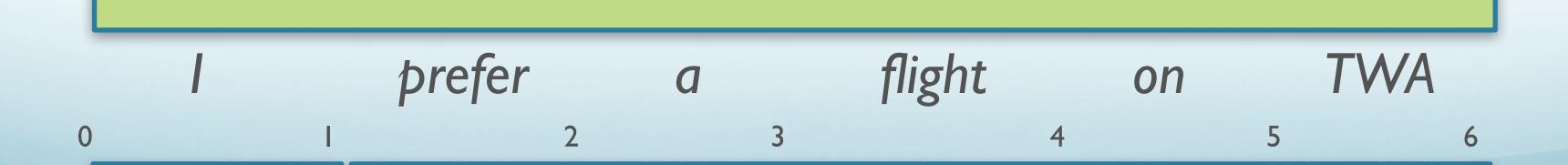
\mathscr{L}_1 Grammar	NP,	S		S		S
$S \rightarrow NP VP$	Pronoun					
$S \to X1 VP$	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	[0,6]
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S		VP, X2, S
$S \rightarrow book / include / prefer$		verb, vr, s		VP, AZ, 3		VP, AZ, 3
$S \rightarrow Verb NP$		EL 03	F1 33	F1 43	F1 F3	F1 43
$S \to X2 PP$		[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]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$					



\mathscr{L}_1 Grammar	NP,	S		S		S
$S \to NP VP$	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		\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \		V F, AZ, S
$S \rightarrow Verb NP$		F1 21	FI 21	ΓΙ <i>Δ</i> 1	F1 E1	Γ1 ∠ 1
$S \to X2 PP$		[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]
$NP \rightarrow TWA / Houston$						
$NP \rightarrow Det\ Nominal$	_			Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				FD 43	F2 F3	F2 /1
$Nominal \rightarrow Nominal \ Noun$				[3,4]	[3,5]	[3,6]
$Nominal \rightarrow Nominal PP$	Lexicon				Prep	PP
$VP \rightarrow book / include / prefer$	$Det \rightarrow that \mid this \mid a$					
$VP \rightarrow Verb NP$	$Noun \rightarrow book \mid flight \mid mea$	$l \mid money$			[4,5]	[4,6]
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$				L -,- J	
$X2 \rightarrow Verb NP$	Proper-Noun Houston	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					
$VP \rightarrow VP PP$	$Preposition ightarrow from \mid to \mid d$	$on \mid near \mid through$	h			[5,6]
$PP \rightarrow Preposition NP$	$Verb ightarrow book \mid include \mid pre$					



\mathscr{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]
$X1 \rightarrow Aux NP$		Verb, VP, S		VP, X2, S		VP, X2, S
$S \rightarrow book \mid include \mid prefer$ $S \rightarrow Verb NP$, , , , , , , , ,		, , , , , , , , ,		
$S \rightarrow Vero NI$ $S \rightarrow X2 PP$		[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
$S \rightarrow N \approx 1.1$ $S \rightarrow Verb PP$					L / L	
$S \rightarrow VP PP$			Det	NP		NP
$NP \rightarrow I / she / me$			[2,3]	[2,4]	[2,5]	[2,6]
$NP \rightarrow TWA / Houston$			[2,5]		[2,3]	
$NP \rightarrow Det Nominal$				Noun, Nom		Nom
$Nominal \rightarrow book \ / \ flight \ / \ meal \ / \ money$				47		 4
$Nominal \rightarrow Nominal \ Noun$				[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]
$VP \rightarrow X2 PP$	$Pronoun ightarrow I \mid she \mid me$				L / J	
$X2 \rightarrow Verb NP$	$Proper-Noun \rightarrow Houston \mid$	TWA				NNP, NP
$VP \rightarrow Verb PP$	$Aux \rightarrow does$					FF (1
$VP \rightarrow VP PP$	$Preposition ightarrow from \mid to \mid d$	$on \mid near \mid through$	gh			[5,6]
$PP \rightarrow Preposition NP$	$Verb \rightarrow book \mid include \mid pre$	efer				



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

	NP,	S		S		S
	Pronoun					
	[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	[0,6]
		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
$Det \rightarrow that \mid this \mid a$						
$Noun \rightarrow book \mid flight \mid meal \mid money$ [4,5]						[4,6]
$Pronoun \rightarrow I \mid she \mid me$						
$Proper-Noun \rightarrow Houston \mid TWA$						NNP, NP
$Aux \rightarrow do$	[5,6]					
Preposition	[5,0]					

	1		prefer	a	flight	on	T	WA
0		1	2		3	4	5	6

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



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, Pronoun	S		S		
[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] [0,3] Verb, VP, S

[2,3]

[0,5] **VP, X2, S**

VP

bp 1 = BackPointer()

 $bp_1.l_child = [VP, (1,4)]$

 $bp_1.r_child = [PP, (4,6)]$

[1,2] [1,6] [1,3] [1,4] [1,5] NP NP Det

[0,4]

[2,4] [2,5] [2,6] Nom Noun, Nom

[3,4] [3,5] [3,6]

> PP Prep

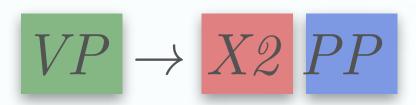
[4,5] [4,6]

NNP, NP

[5,6]







NP,	
Pronoun	
[0,1]	

[2,3]

$$bp_2.l_child = [X2, (1,4)]$$

$$bp_2.r_child = [PP, (4,6)]$$

[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
	Det	NP		NP



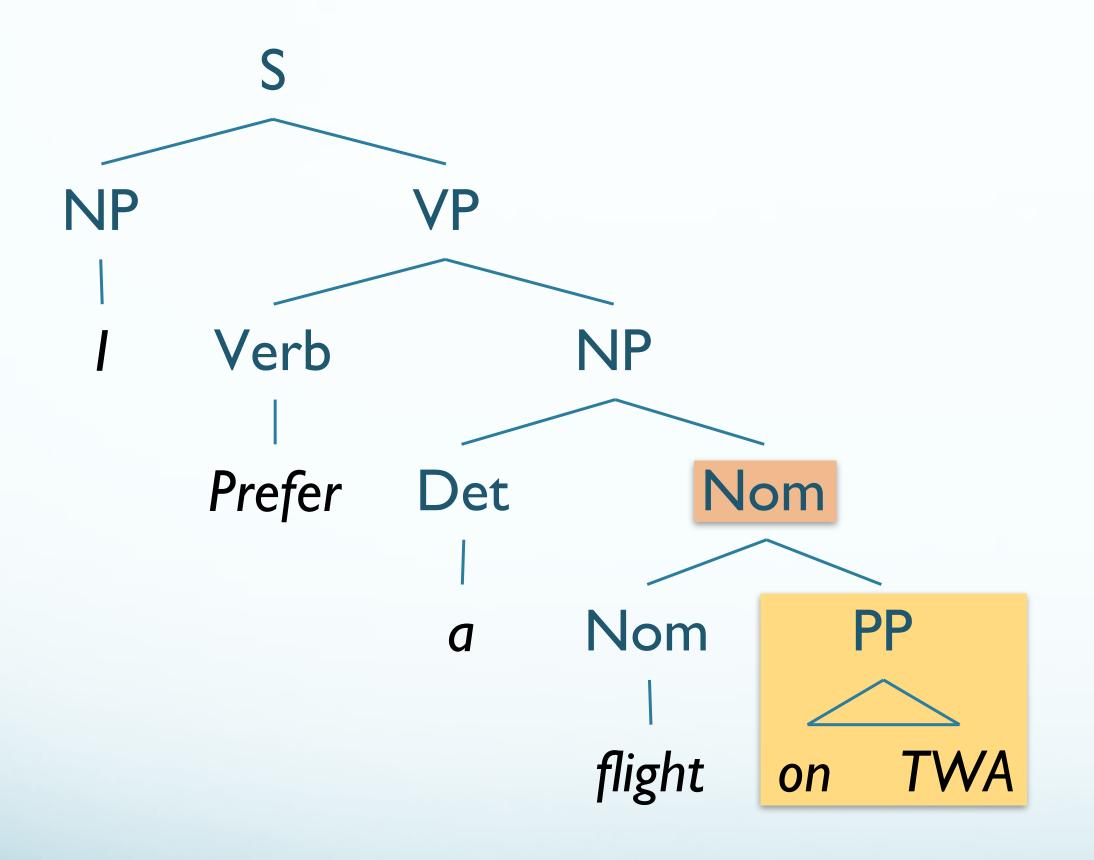
NNP, NP

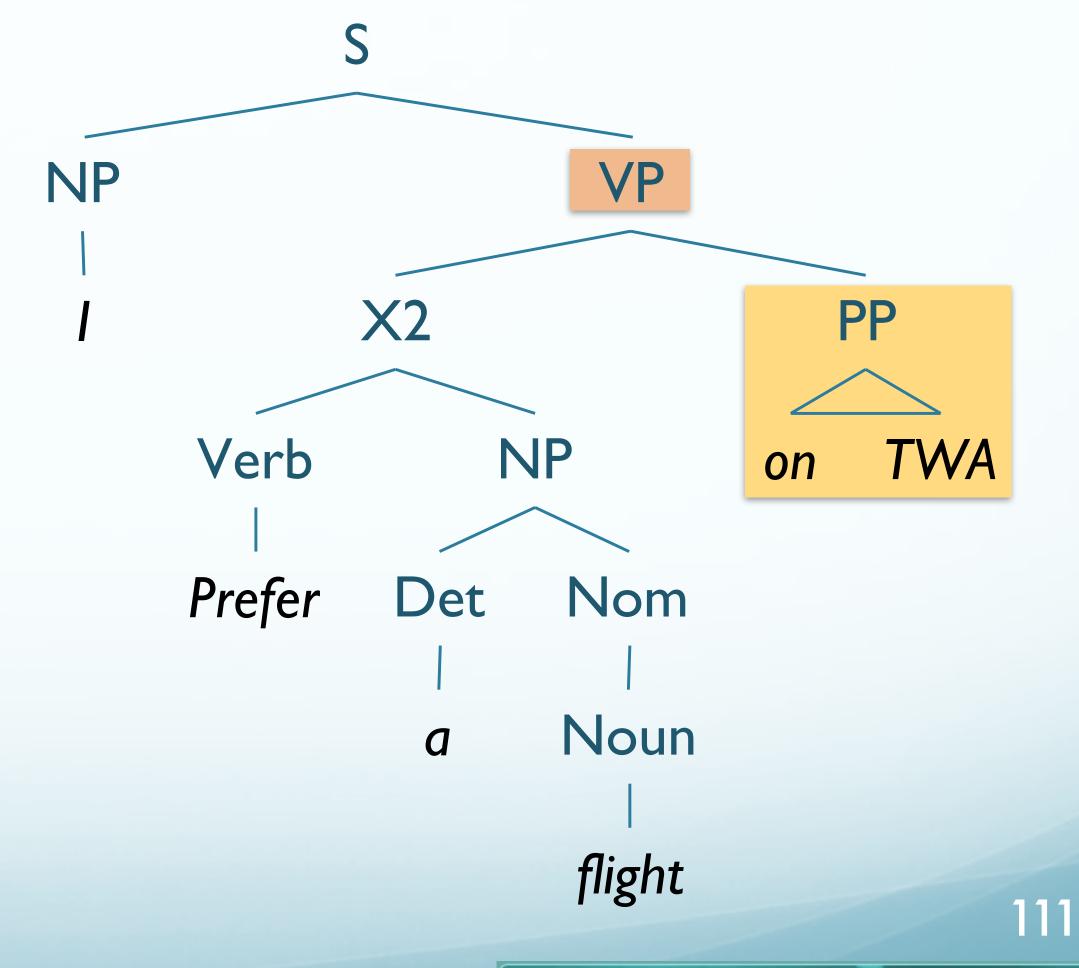
[5,6]





Resulting Parses







PROFESSIONAL MASTER'S IN
COMPUTATIONAL LINGUISTICS

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)		
a set of rules of productions, each of the form $A o m{eta}[p]$, where A is a non-terminal, $m{eta}$ is a string of symbols from the infinite set of strings and p is a number between 0 and 1 expressing $P(m{eta} A)$			
\overline{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]	$Noun \rightarrow book [.10] \mid flight [.30] \mid meal [.15] \mid money [0.5]$
$S \to VP$	[.05]	$\mid flights \; [0.40] \mid dinner \; [.10]$
NP o 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 o 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]	





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 o 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]	





Disambiguation

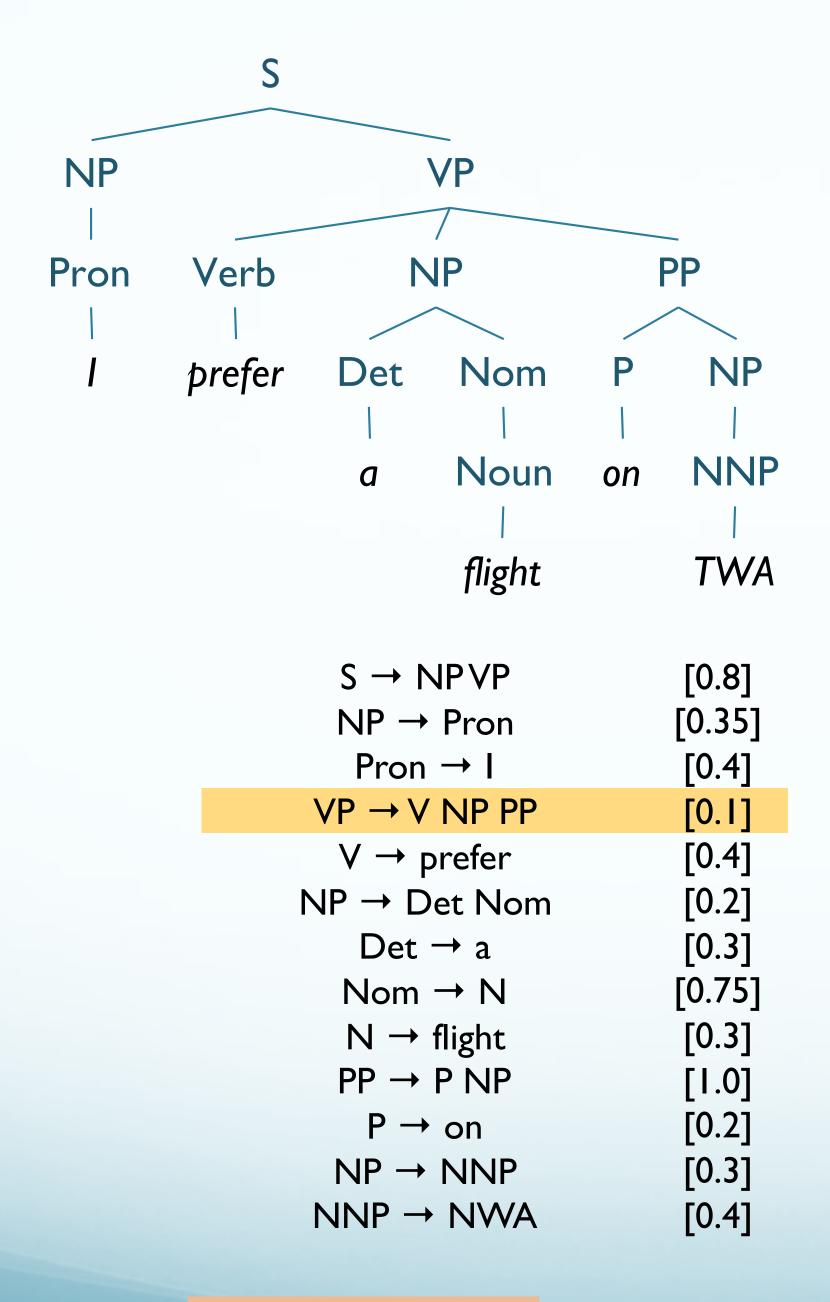
- \bullet A PCFG assigns probability to each parse tree T for input S
- ullet Probability of T: product of all rules used to derive T

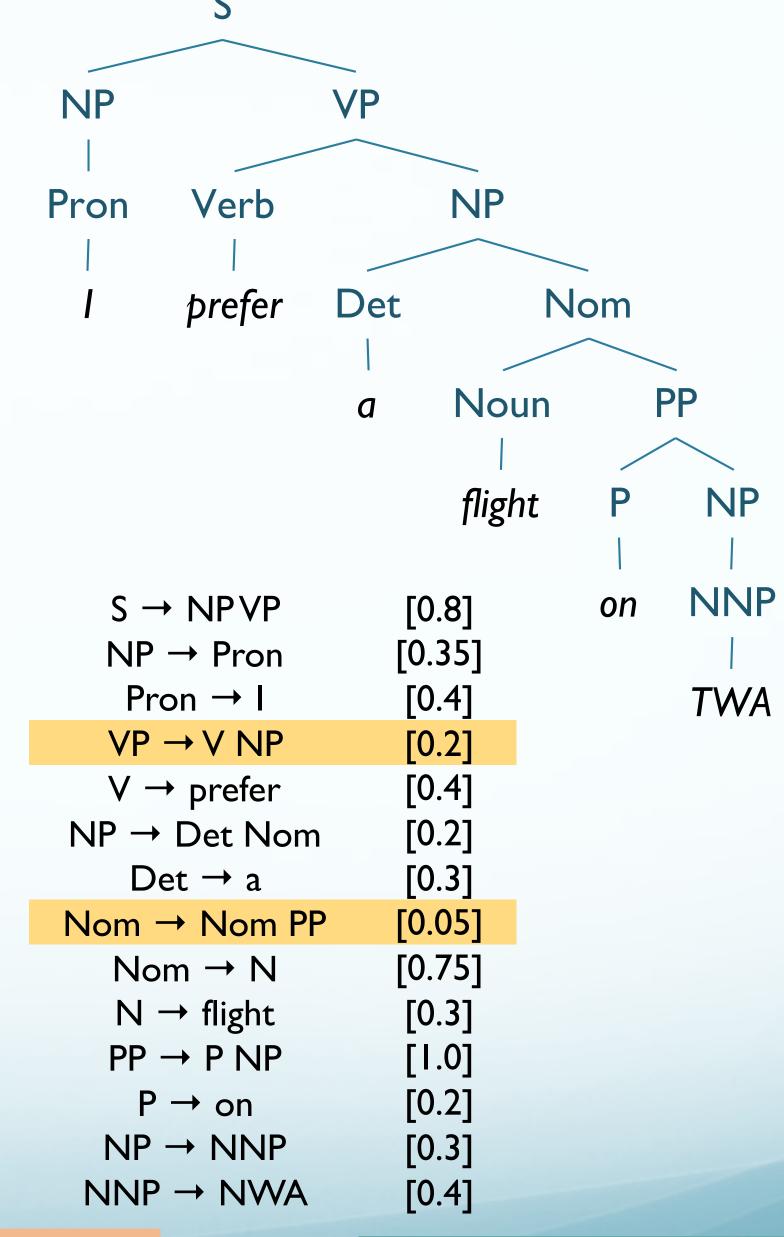
$$P(T,S) = \prod_{i=1}^{n} P(RHS_i | LHS_i)$$

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









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

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





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



