CKY Parsing

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

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COMPUTATIONAL LINGUISTICS

Start recording!

Misc. & Announcements

HW #2

- Due tonight, 11:00pm Pacific

- Grammar output format:

1. Terminals quoted (single or double)

2. One production per line
   - *Optionally*, RHS alternates with vertical bar/pipe character: |

3. Start symbol is first nonterminal encountered in file

Indigenous Peoples' Day

- Seattle/Sealth

- For those of you taking 550:
  - The Lushootseed spelling [IPA] of Chief Seattle/Sealth:
    - siʔaɫ [ˈsiʔaːɫ]

- Duwamish — Dxʷdəwʔabš [dxʷdɐwʔabʃ]

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

  - **ʔux̌ʷ**   ti   **sbiaw**
    goes that-which   **is-a-coyote**
    "The/a coyote goes"

  - **sbiaw**   ti   **ʔux̌ʷ**
    is-a-coyote that-which **goes**
    "The one who goes is a coyote"   *via Beck, 2013*

  - (Translation distinction provided for clarity — semantically equivalent)

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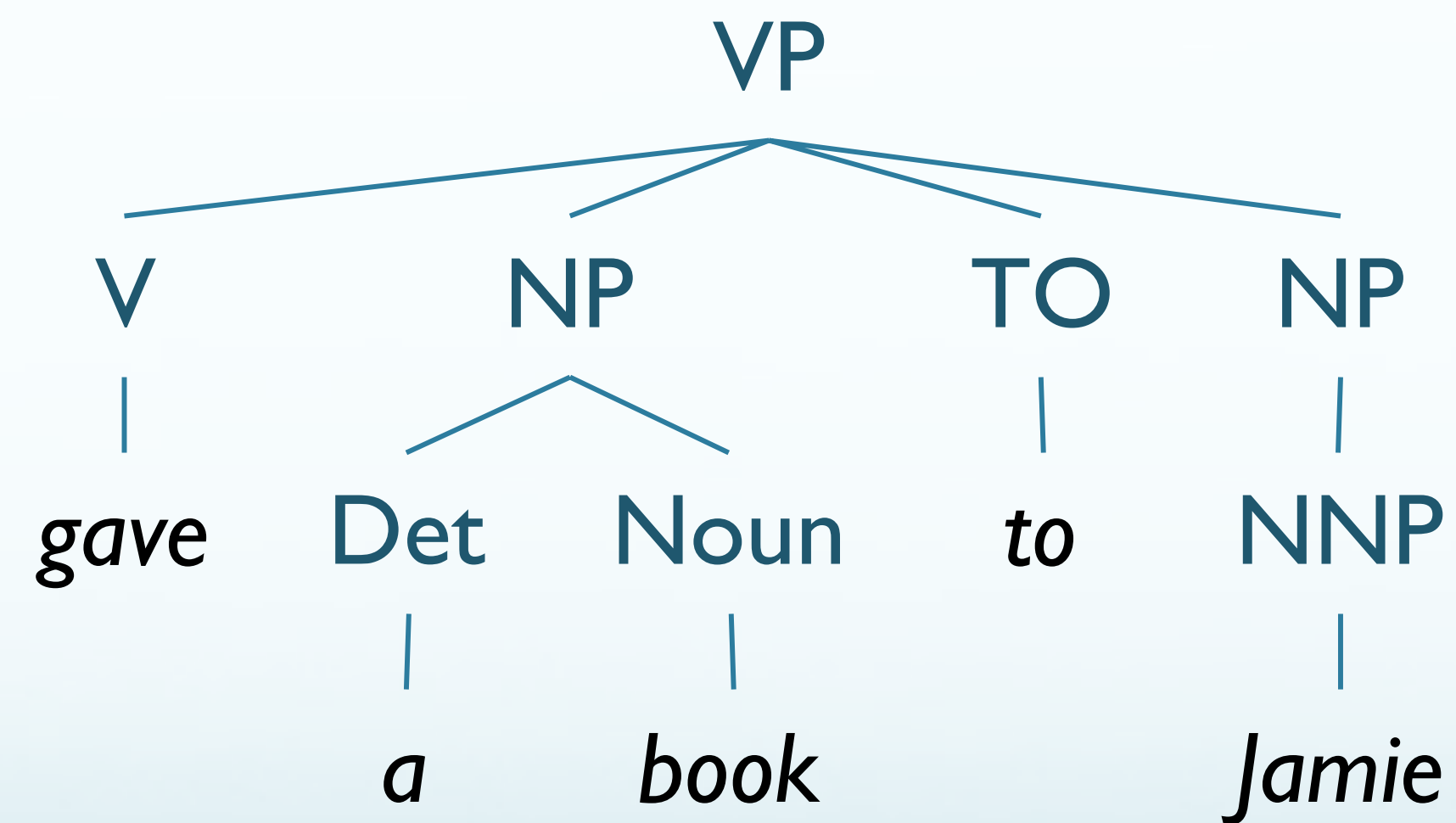COMPUTATIONAL LINGUISTICS

Indigenous Peoples' Day

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

Variation in CNF: Binarization

Original Rule

$VP \rightarrow V\ NP\ TO\ NP$
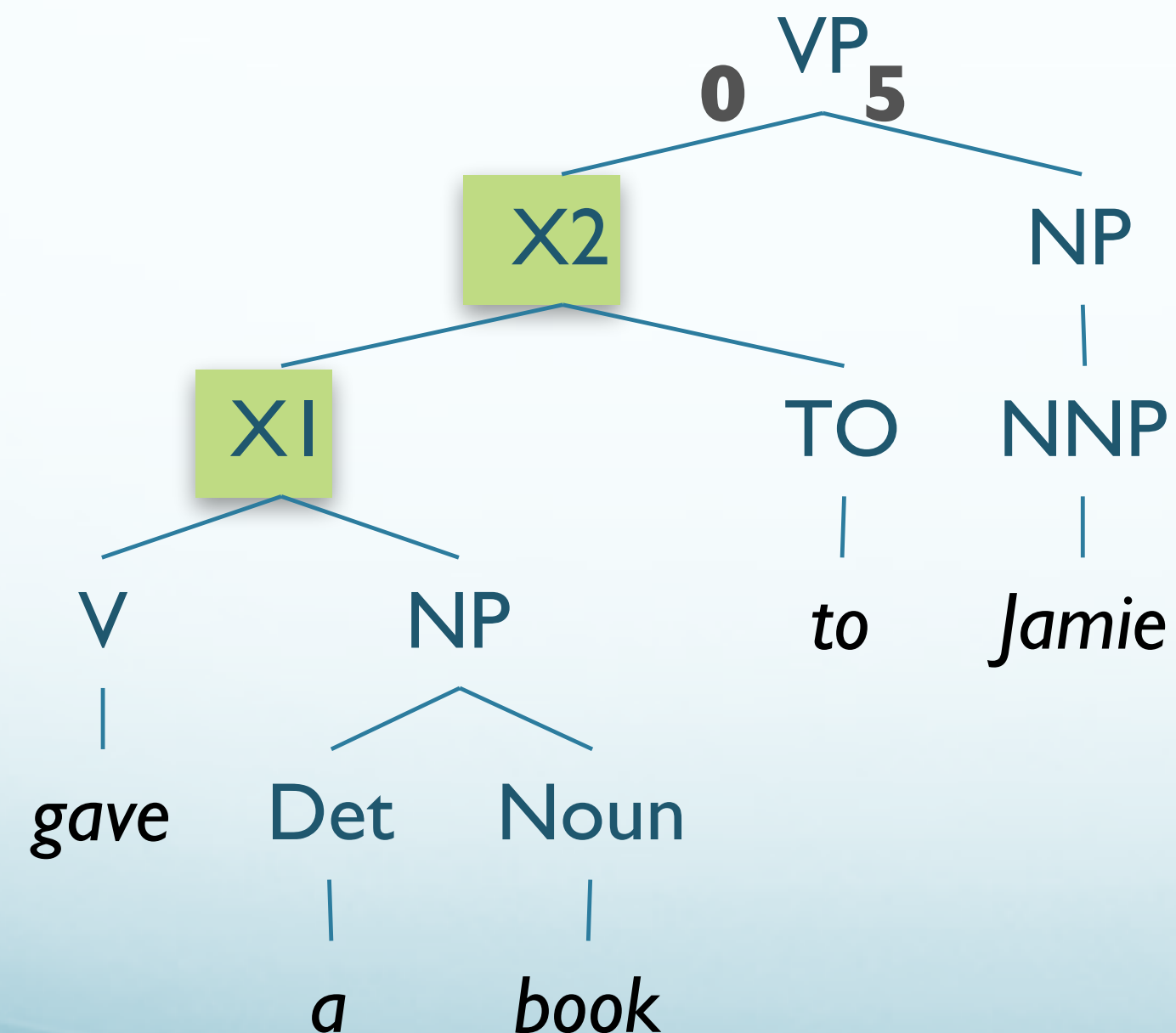
Variation in CNF: Binarization

Original Rule
$VP \rightarrow$ V NP TO NP

Left to Right Reduction		Right to Left Reduction	
$VP \rightarrow$ X1 TO NP	$X1 \rightarrow V\ NP$	$VP \rightarrow$ V NP X1	$X1 \rightarrow TO\ NP$
$VP \rightarrow$ X2 NP	$X2 \rightarrow X1\ TO$	$VP \rightarrow$ V X2	$X2 \rightarrow NP\ X1$
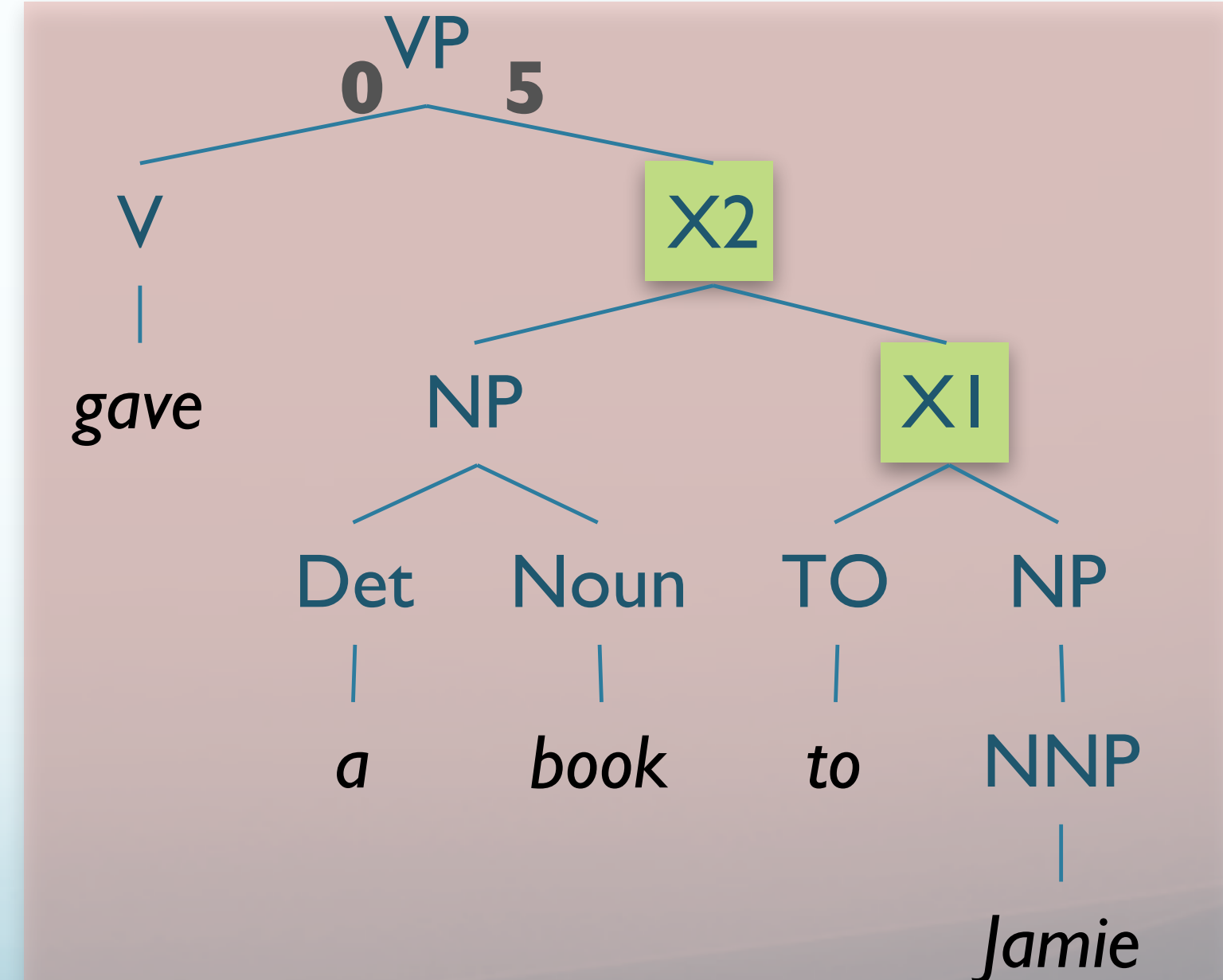
Roadmap

- CKY Parsing Algorithm

  - Dynamic programming structure

  - Algorithm and example

  - Analysis & Discussion

- Probabilistic CFGs

  - Motivation: Ambiguity

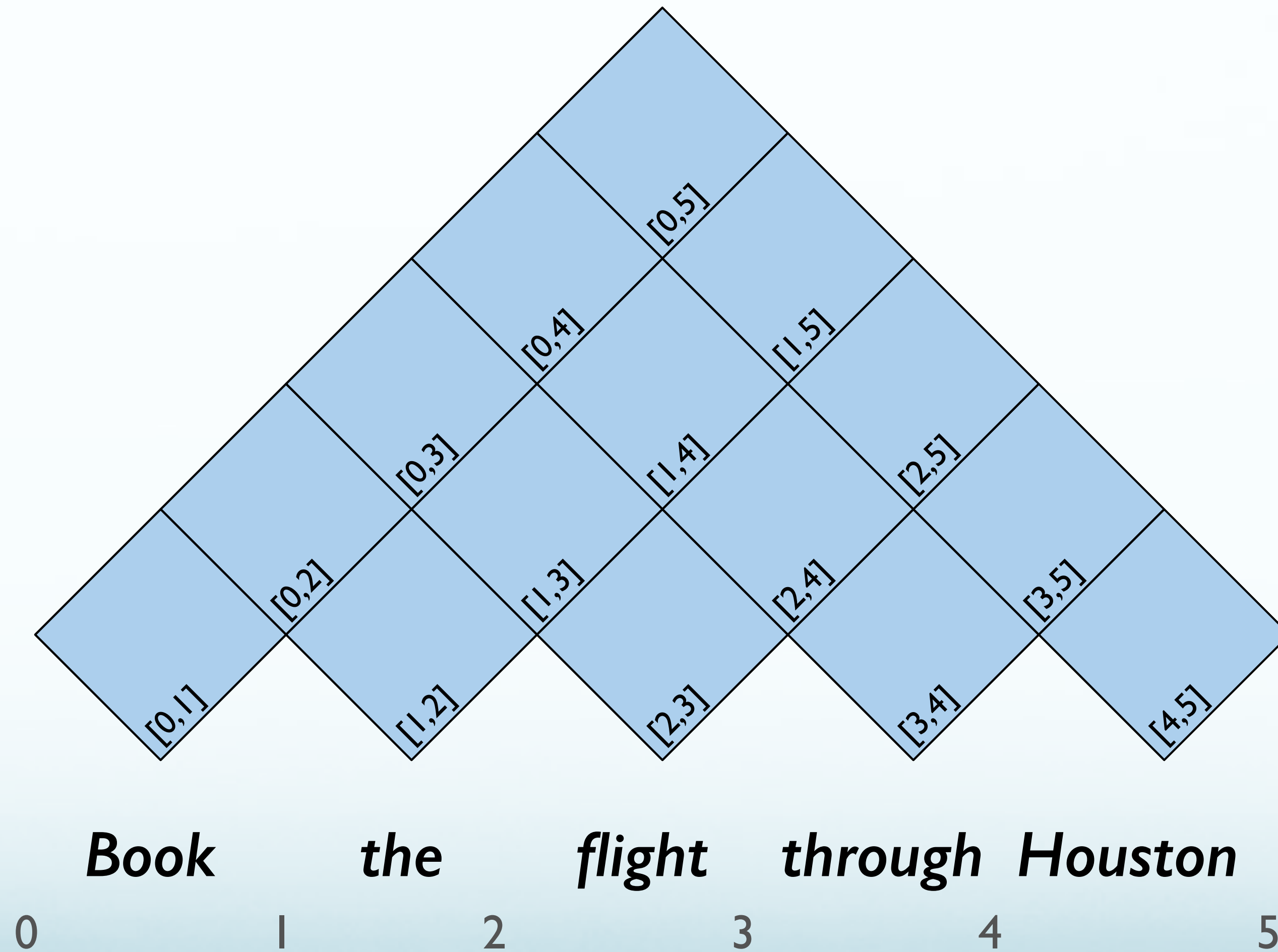 - Augmenting CFGs with probabilities

CKY

- Given an input string S of length n

- Build table $(n + 1) \times (n + 1)$

  - Indexes correspond to inter-word positions

  - $_0$ Book $_1$ that $_2$ flight $_3$

- 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*

CKY Matrix

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]

CKY Matrix

Book   the   flight   through   Houston

0   1   2   3   4   5

CKY Matrix

Book   the   flight   through   Houston

0   1   2   3   4   5

CKY Matrix

S (?)

[0,5]

[0,4]   [1,5]

[0,3]   [1,4]   [2,5]

[0,2]   [1,3]   [2,4]   [3,5]

NP

[0,1]   [1,2]   [2,3]   [3,4]   [4,5]

Det   Noun

Book   the   flight   through   Houston

0   1   2   3   4   5

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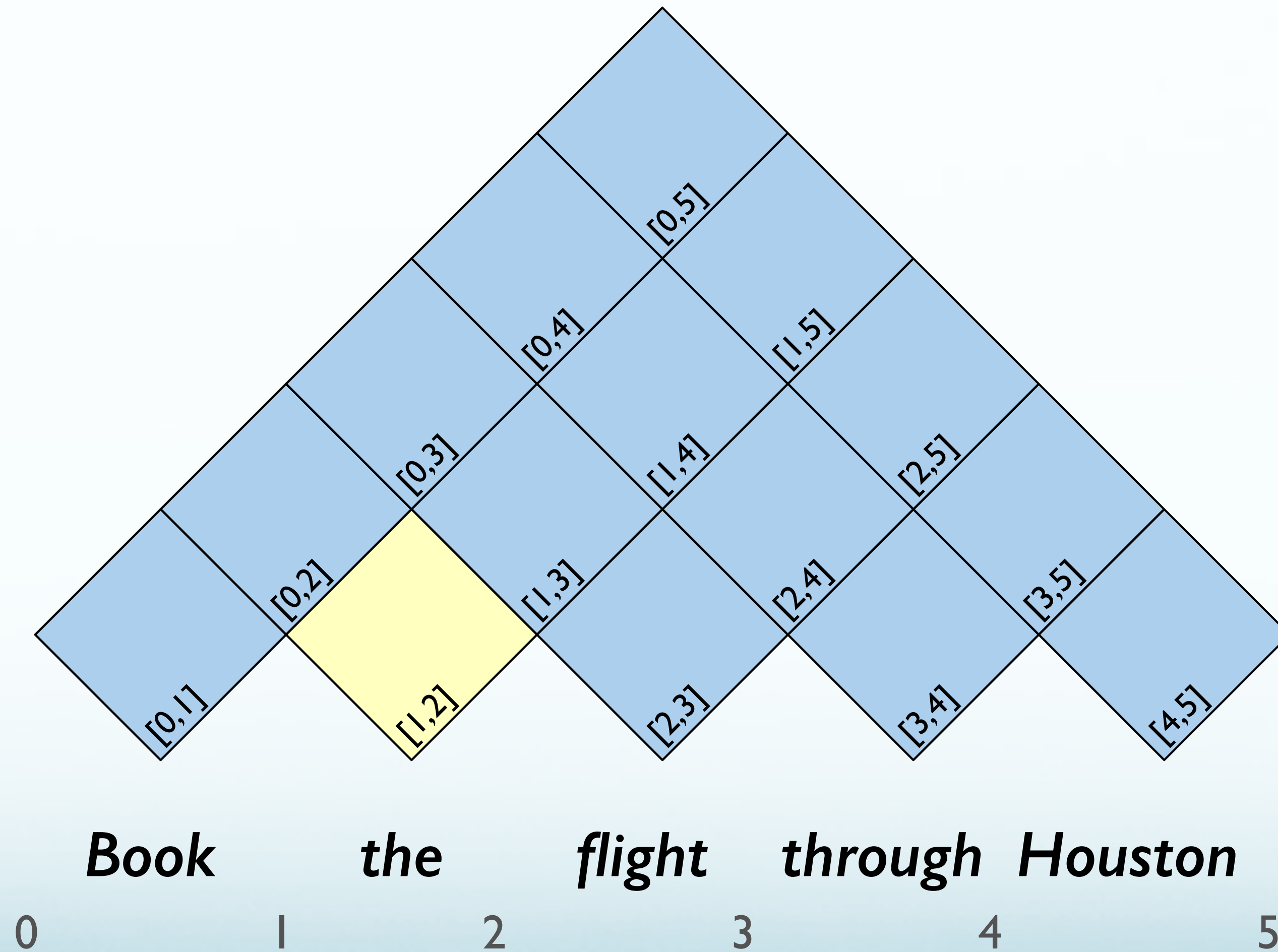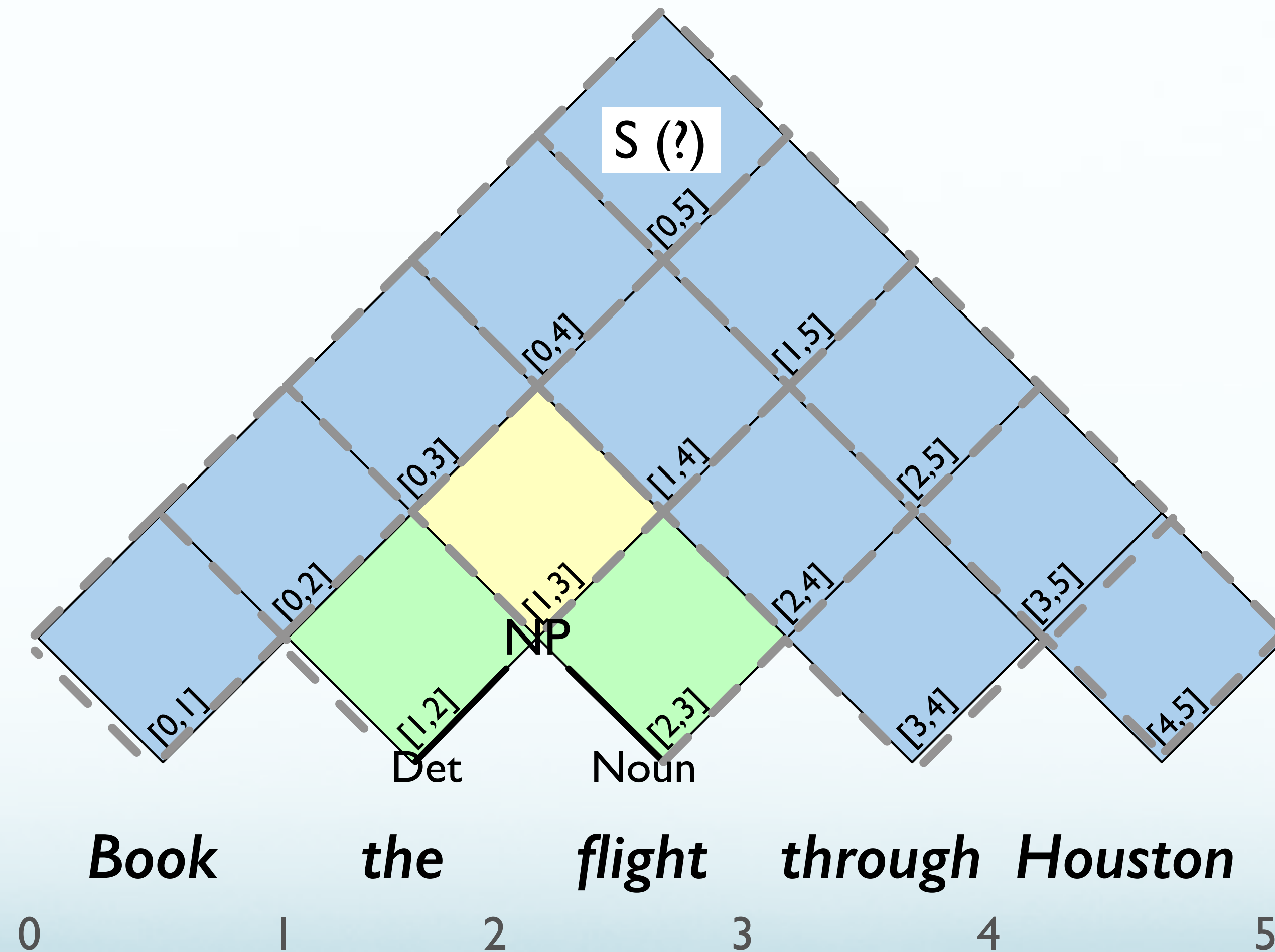
Dynamic Programming in CKY

- Key idea:

  - for $i < k < j$

  - …and a parse spanning substring $[\ i,\ j\ ]$

  - $\exists k$ such that there are parses spanning $[\ i,\ k\ ]$ and $[\ k,\ j\ ]$

  - We can construct parses for whole sentences by building from these partial parses

- So to have a rule $A \rightarrow B\ C$ in $[\ i,\ j\ ]$

  - Must have B in $[\ i,\ j\ ]$ and C in $[\ k,\ j\ ]$ for some $i < k < j$

  - CNF forces this for all $j > i + 1$

CKY

- 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 $i < k < j$
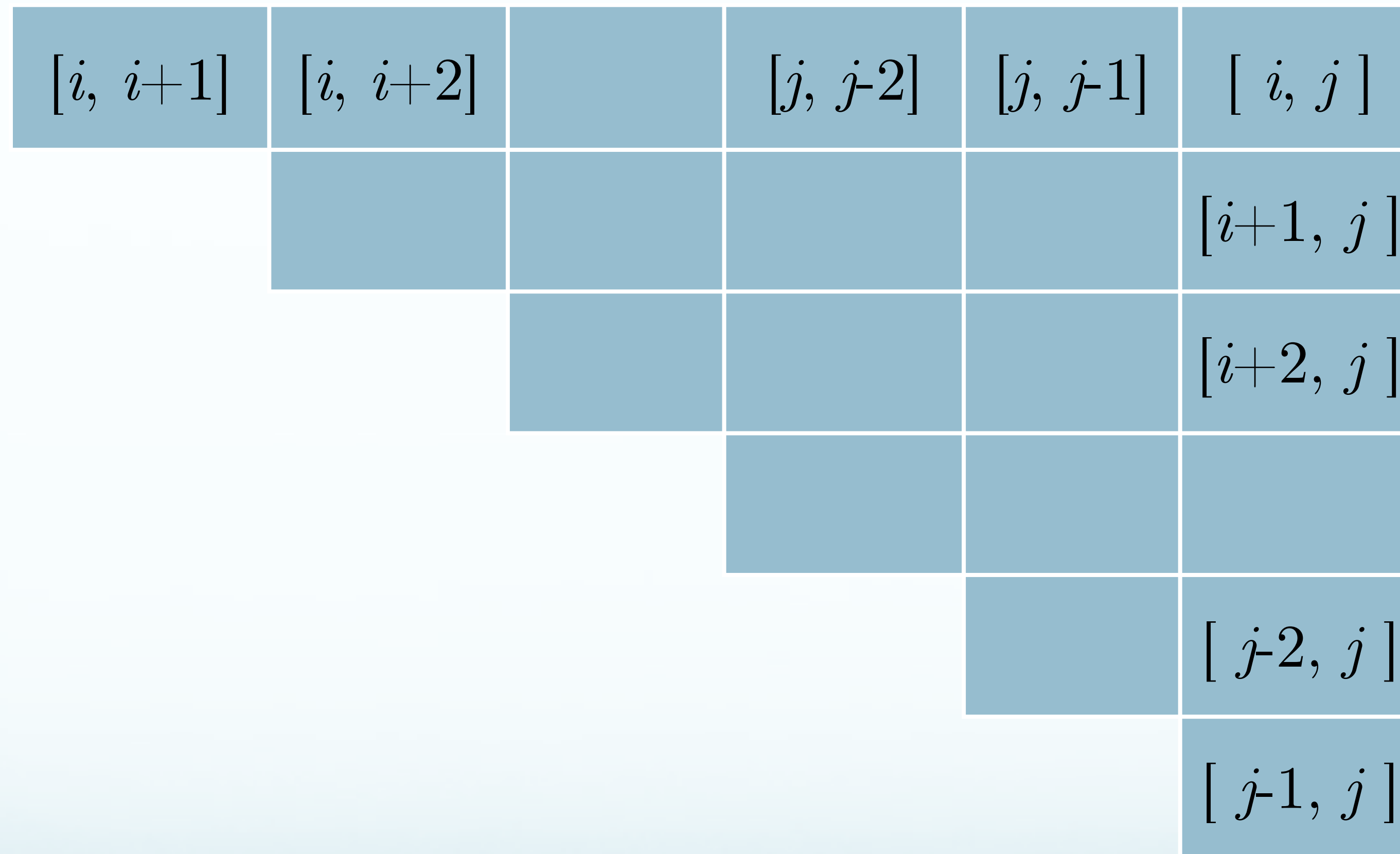- Allows online sentence analysis
  - Works across input string as it arrives
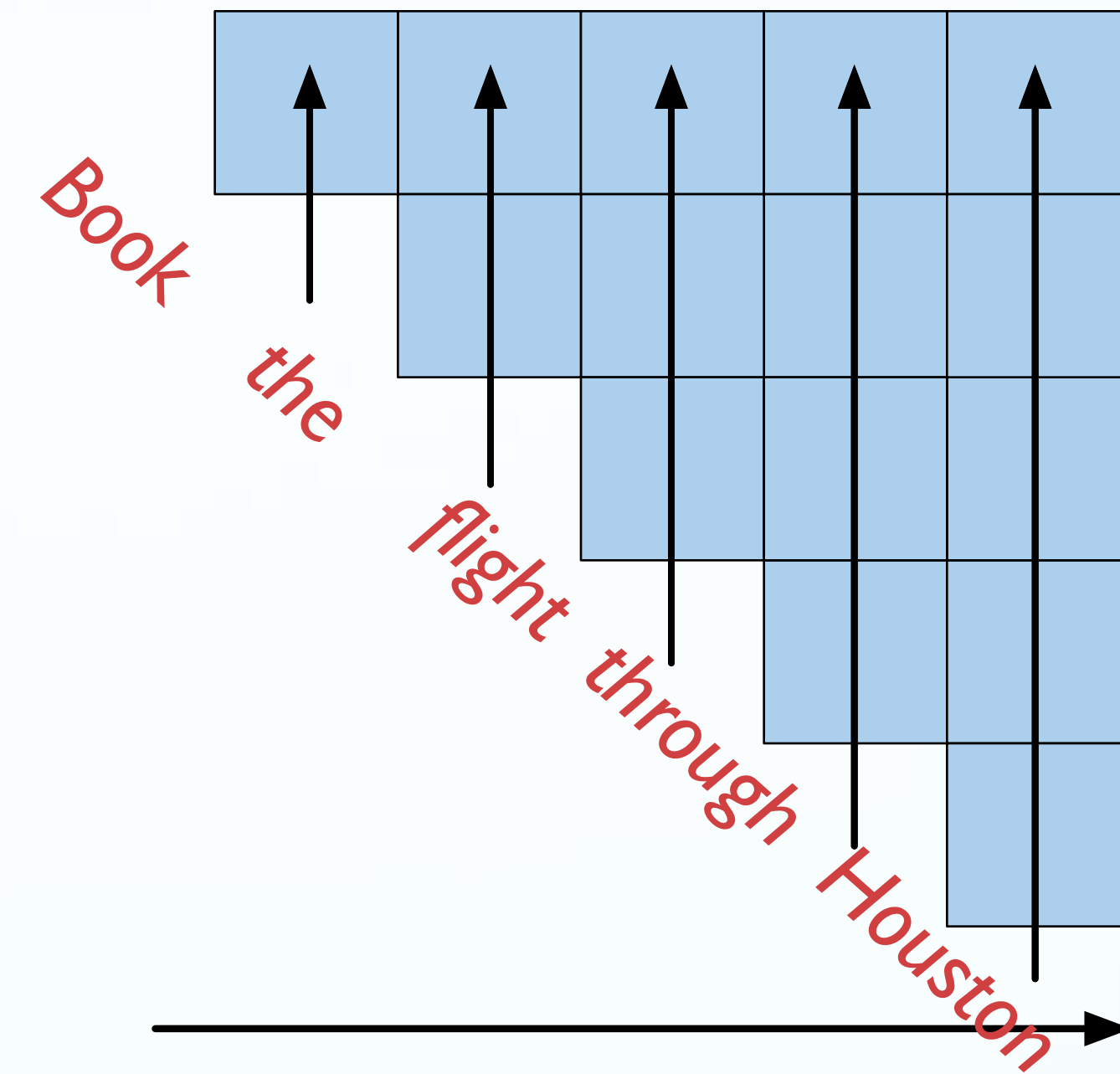
CKY Algorithm

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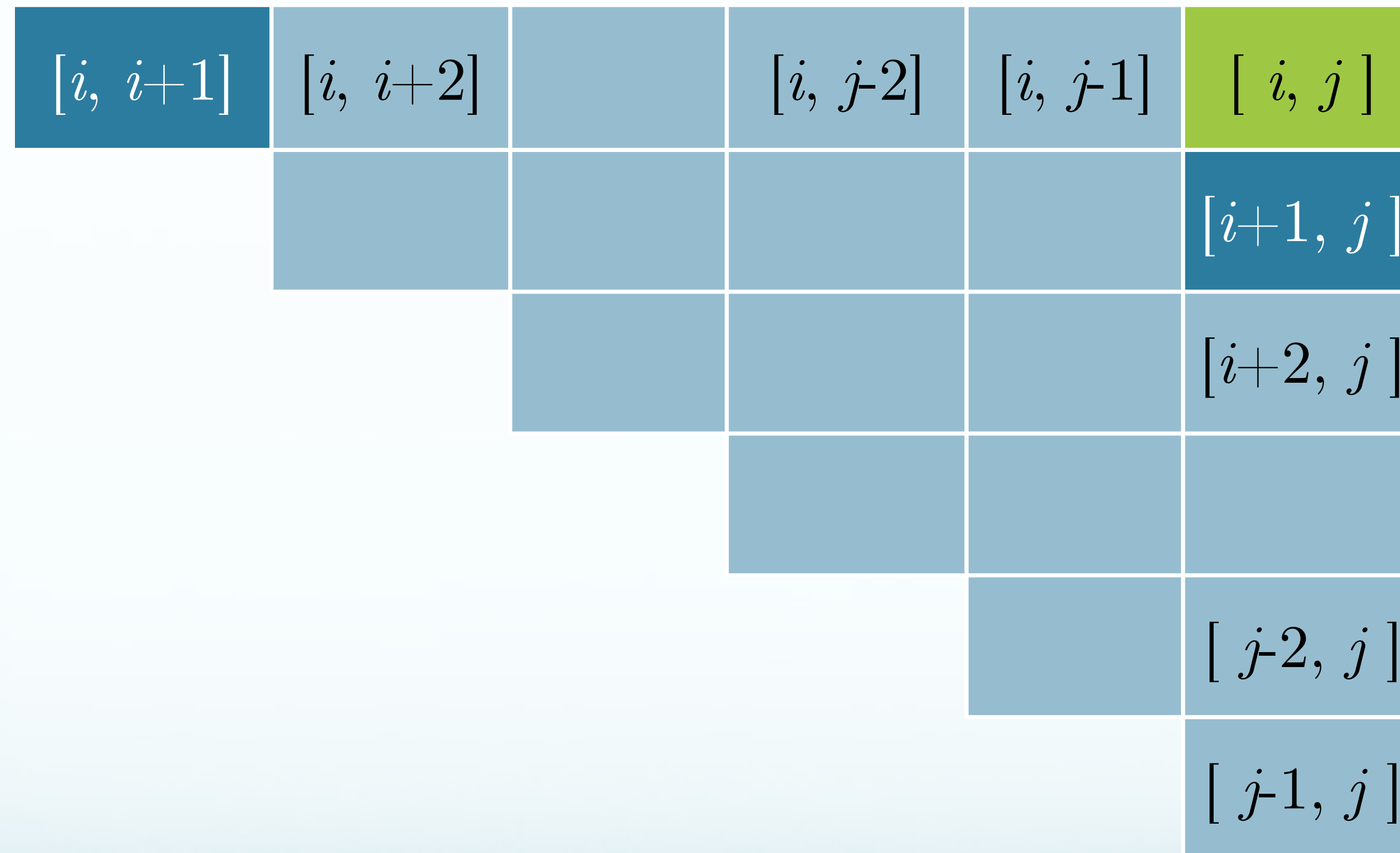 $B \in table[\,i,\,k\,],$
          $C \in table[\,k,\,j\,]\}$

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

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Filling Cell [i, j]

For cell [i, j], find rule spanning cells [i, k] and [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]

Filling Cell [i, j]

$[i,\ i{+}1]$	$[i,\ i{+}2]$		$[i,\ j{-}2]$	$[i,\ j{-}1]$	$[\ i,\ j\ ]$
					$[i{+}1,\ j\ ]$
					$[i{+}2,\ j\ ]$
					$[\ j{-}2,\ j\ ]$
					$[\ j{-}1,\ j\ ]$

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

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Filling Cell [i, j]

$[i,\ i{+}1]$	$[i,\ i{+}2]$		$[i,\ j{-}2]$	$[i,\ j{-}1]$	$[\ i,\ j\ ]$
					$[i{+}1,\ j\ ]$
					$[i{+}2,\ j\ ]$
					$[\ j{-}2,\ j\ ]$
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$[i,\ i{+}1]$	$[i,\ i{+}2]$		$[i,\ j{-}2]$	$[i,\ j{-}1]$	$[\ i,\ j\ ]$
					$[i{+}1,\ j\ ]$
					$[i{+}2,\ j\ ]$
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$[i,\ i{+}1]$	$[i,\ i{+}2]$		$[i,\ j{-}2]$	$[i,\ j{-}1]$	$[\ i,\ j\ ]$
					$[i{+}1,\ j\ ]$
					$[i{+}2,\ j\ ]$
				$[\ j{-}2,\ j\ ]$	
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For cell $[\ i,\ j\ ]$, find rule spanning cells $[i,\ k\ ]$ and $[\ k,\ j\ ]$ where $i < k < j$

Filling Cell [i, j]

$[i,\ i{+}1]$	$[i,\ i{+}2]$		$[i,\ j{-}2]$	$[i,\ j{-}1]$	$[\ i,\ j\ ]$
					$[i{+}1,\ j\ ]$
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For cell $[\ i,\ j\ ]$, find rule spanning cells $[\ i,\ k\ ]$ and $[\ k,\ j\ ]$ where $i < k < j$

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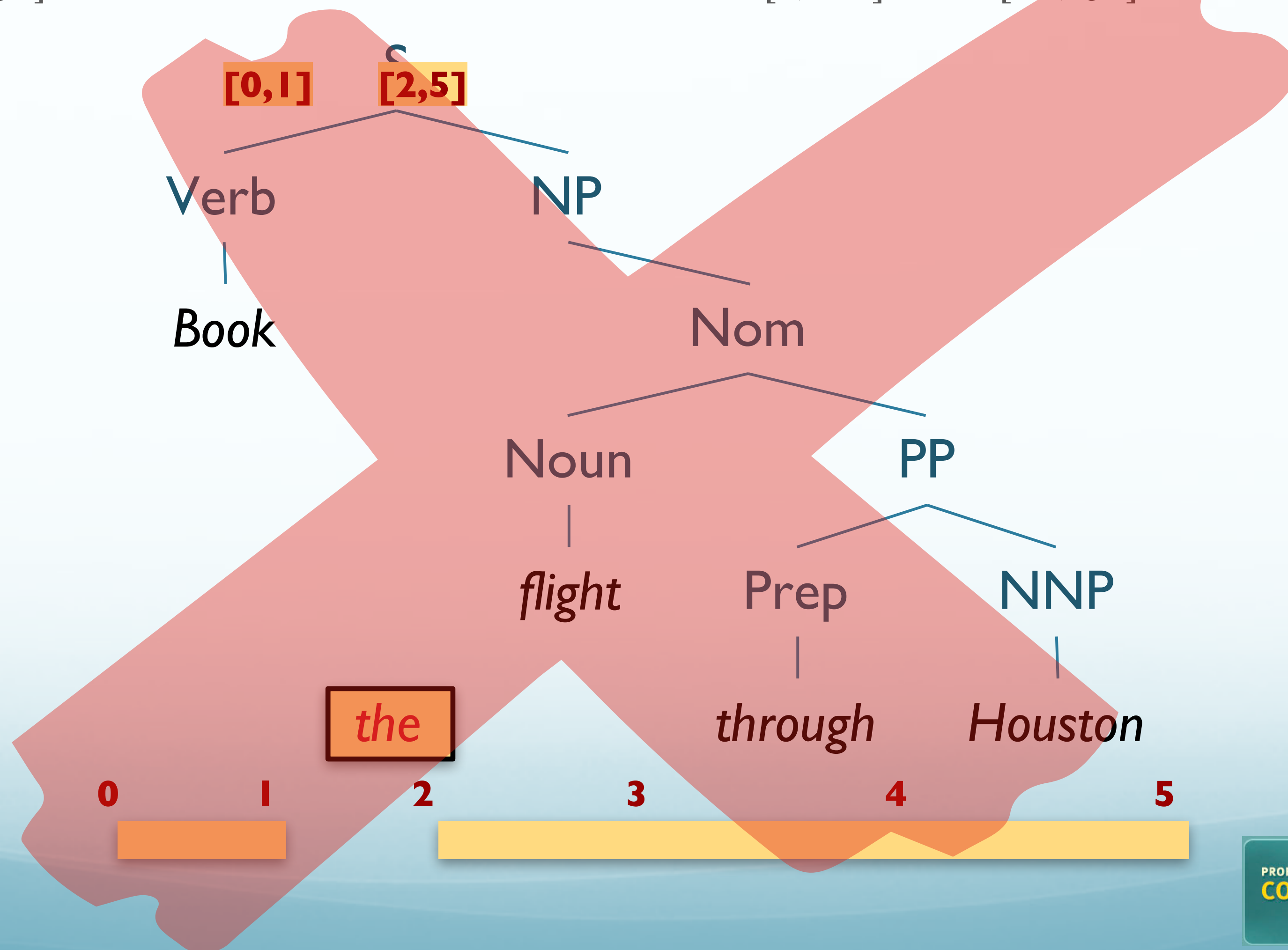COMPUTATIONAL LINGUISTICS

Why fill cells this way?

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

Why fill cells this way?
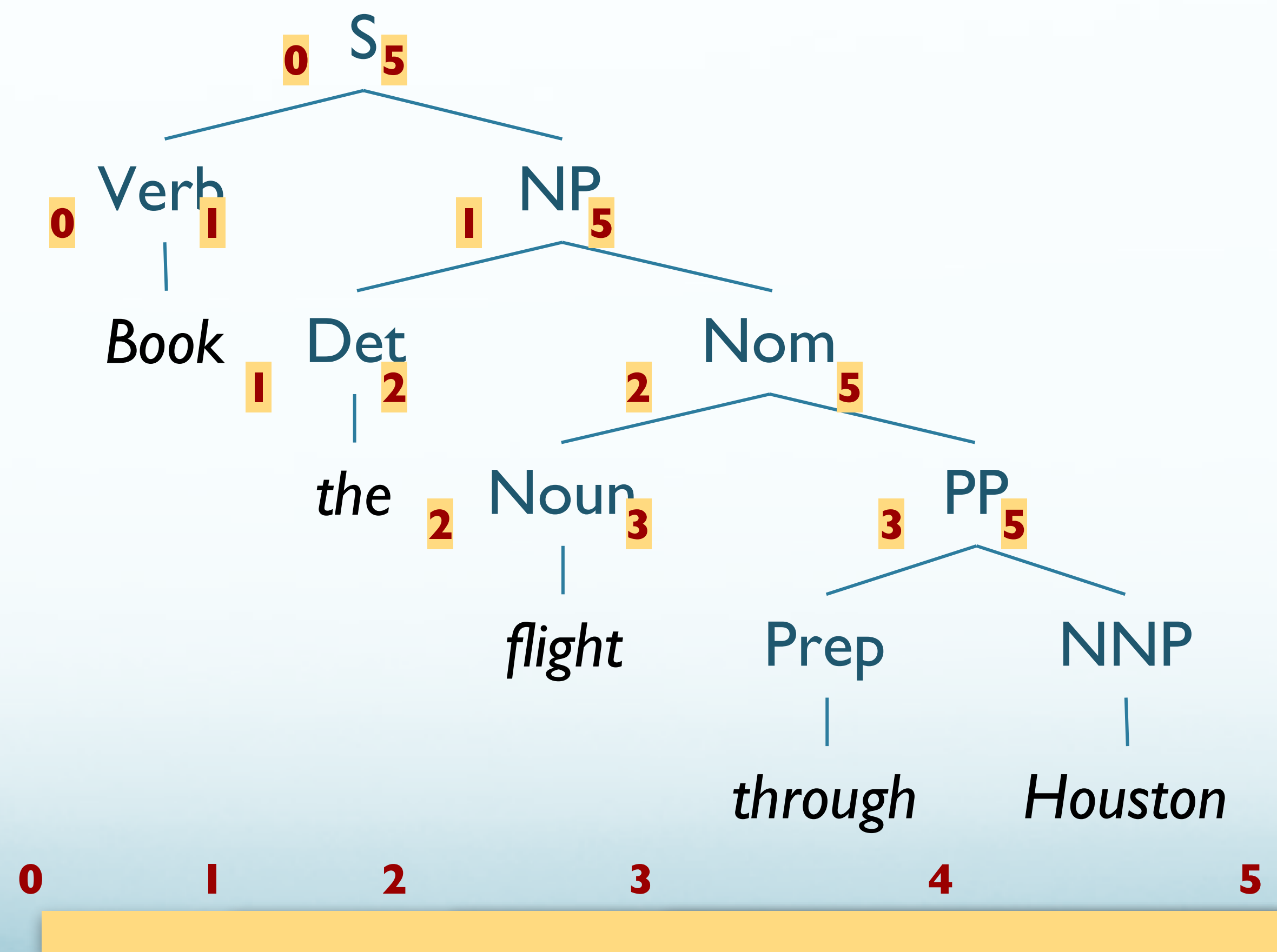
- For cell $[\ i,\ j\ ]$, must be able to access all cells $[\ i,\ k\ ]$ and $[\ k,\ j\ ]$ where $i < k < j$

CKY Parsing Example
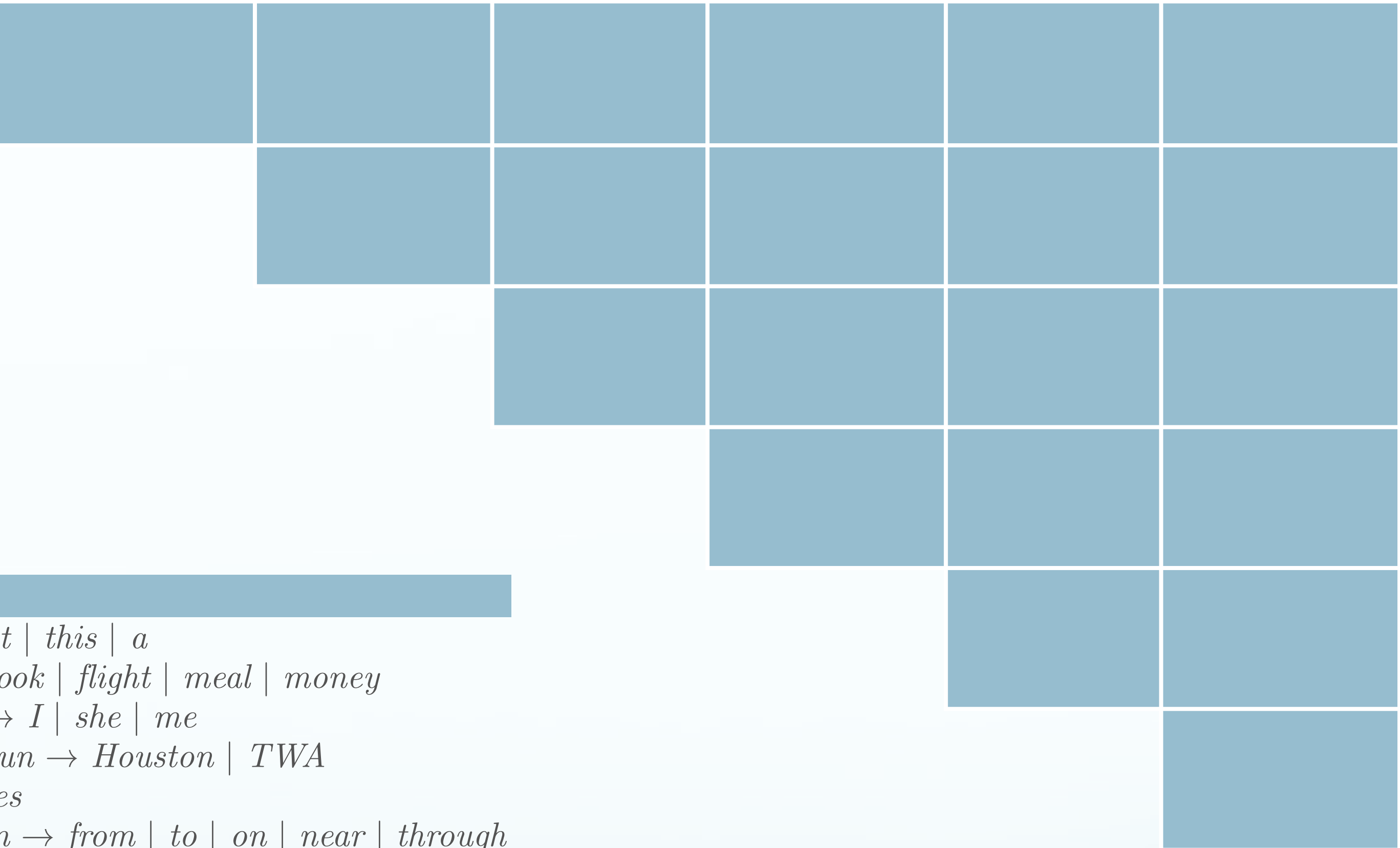
$\mathscr{L}_1$ **Grammar**

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
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$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
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NP

[0,1]

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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NP, Pronoun
[0,1]

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𝓛₁ Grammar

S → NP VP
S → X1 VP
X1 → Aux NP
S → book | include | *prefer*
S → Verb NP
S → X2 PP
S → Verb PP
S → VP PP

NP → I | she | me
NP → TWA | Houston
NP → Det Nominal

Nominal → book | flight | meal | money
Nominal → Nominal Noun
Nominal → Nominal PP

VP → book | include | *prefer*
VP → Verb NP
VP → X2 PP
X2 → Verb NP
VP → Verb PP
VP → VP PP

PP → Preposition NP

Lexicon

Det → that | this | a
Noun → book | flight | meal | money
Pronoun → I | she | me
Proper-Noun → Houston | TWA
Aux → does
Preposition → from | to | on | near | through
Verb → book | include | *prefer*

NP, Pronoun [0,1]					
	Verb, VP, S [1,2]				

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NP, NP, Pronoun [0,1]	Pronoun [0,2]				
	Verb, VP, S [1,2]				

I   prefer   a   flight   on   TWA
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NP, NP, Pronoun [0,1]	NP, Pronoun [0,2]				
	Verb, VP, S [1,2]				

I   prefer   a   flight   on   TWA

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NP, NP, Pronoun [0,1]	[0,2]				
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$VP \to X2\ PP$
$X2 \to Verb\ NP$
$VP \to Verb\ PP$
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$PP \to Preposition\ NP$

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NP, NP, Pronoun [0,1]	[0,2]				
	Verb, VP, S [1,2]				

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ℒ₁ Grammar

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$Aux \rightarrow does$
$Preposition \rightarrow from \mid to \mid on \mid near \mid through$
$Verb \rightarrow book \mid include \mid prefer$

NP, Pronoun [0,1]	S, S [0,2]				
	Verb, VP, S [1,2]				

I prefer a flight on TWA

0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

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NP, NP, Pronoun [0,1]	S, S [0,2]				
	Verb, VP, S [1,2]				

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$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

NP, NP, Pronoun [0,1]	S, S [0,2]				
	Verb, VP, S [1,2]				

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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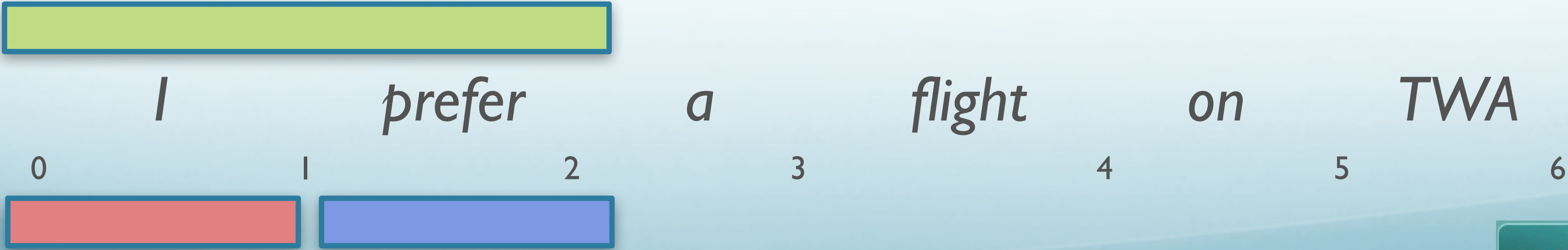- - - - - - - - - - - - - - - - - - - -
$VP \rightarrow book \mid include \mid prefer$
$VP \rightarrow Verb\ NP$
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NP, Pronoun [0,1]	S [0,2]				
	Verb, VP, S [1,2]				
		Det [2,3]			

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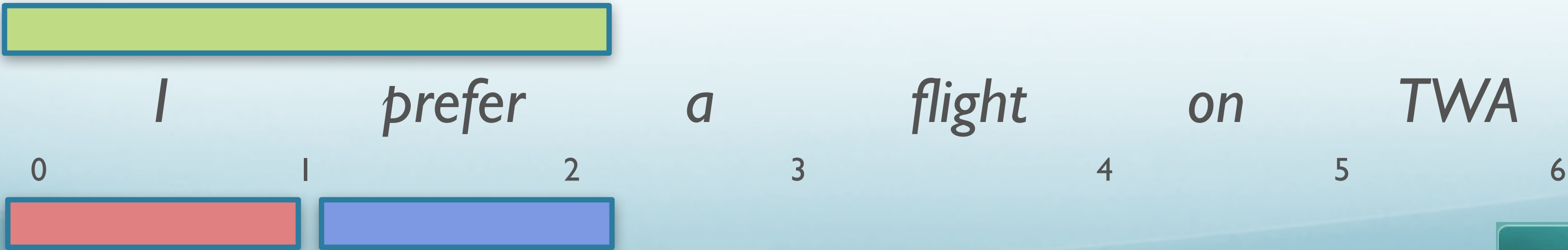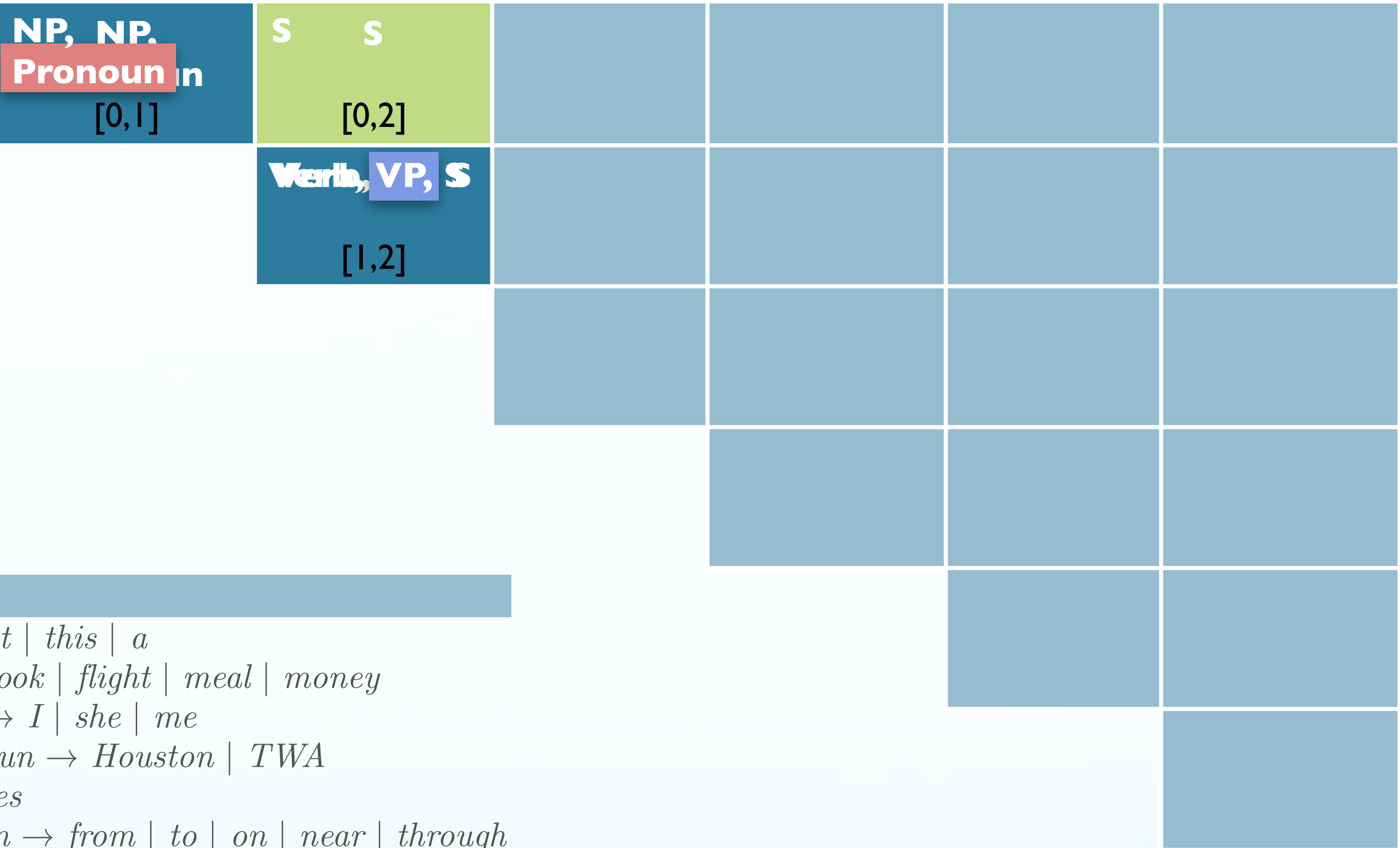$NP \rightarrow Det\ Nominal$

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$VP \rightarrow book \mid include \mid prefer$
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NP, Pronoun [0,1]	S [0,2]				
	Verb, VP, S [1,2]	[1,3]			
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NP, Pronoun [0,1]	S [0,2]				
	Verb, VP, S [1,2]	[1,3]			
		Det Det [2,3]			

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NP, Pronoun [0,1]	S [0,2]				
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		Det Det [2,3]			

I prefer a flight on TWA

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NP, Pronoun [0,1]	S [0,2]				
	Verb, VP, S [1,2]	[1,3]			
		Det Det [2,3]			

I   prefer   a   flight   on   TWA

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NP, Pronoun [0,1]	S [0,2]				
	Verb, VP, S [1,2]	[1,3]			
		Det [2,3]			

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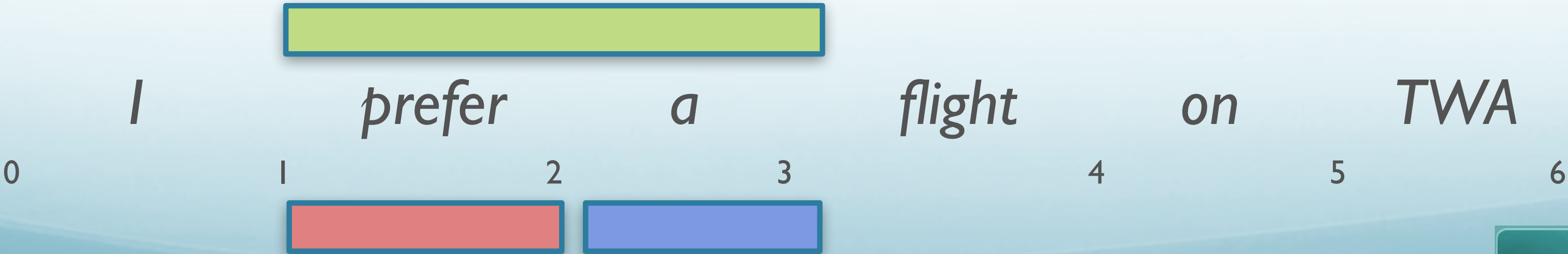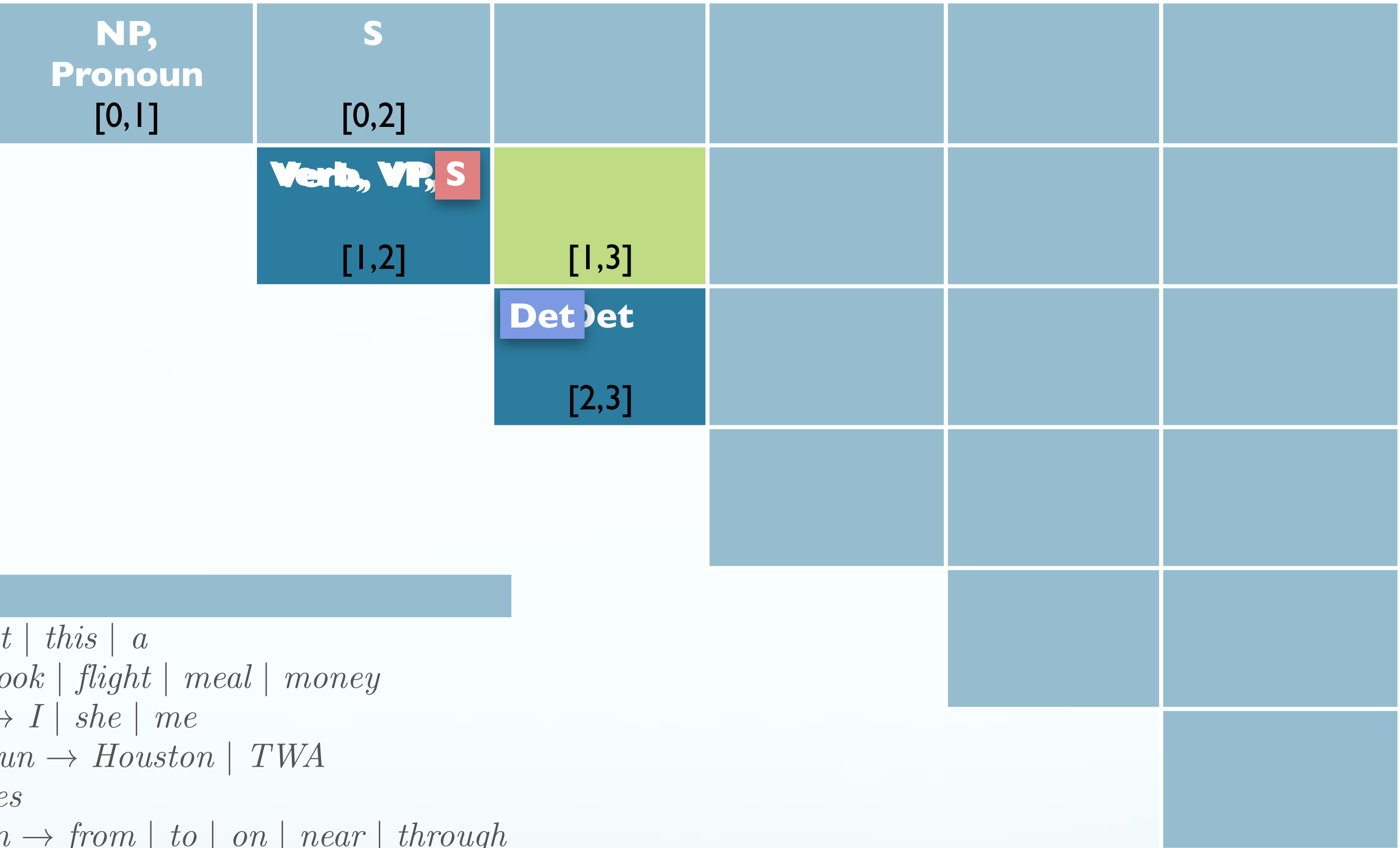$NP \rightarrow Det\ Nominal$
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$VP \rightarrow book\ |\ include\ |\ prefer$
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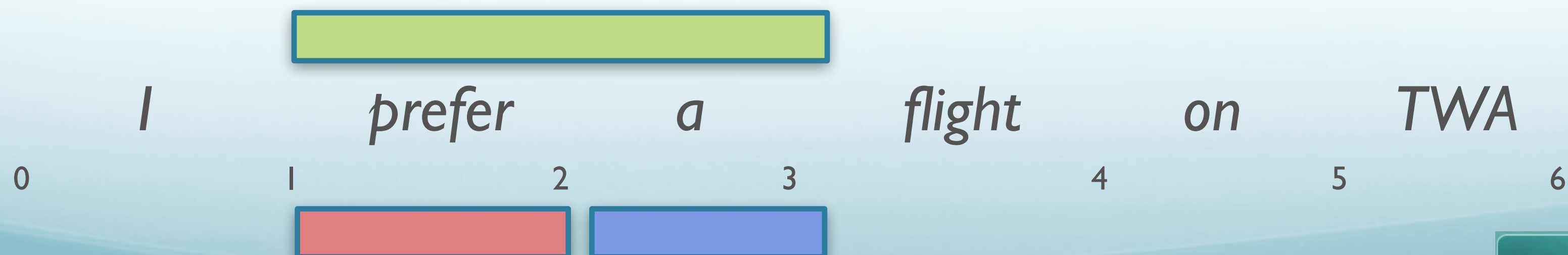
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NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]			
		Det [2,3]			

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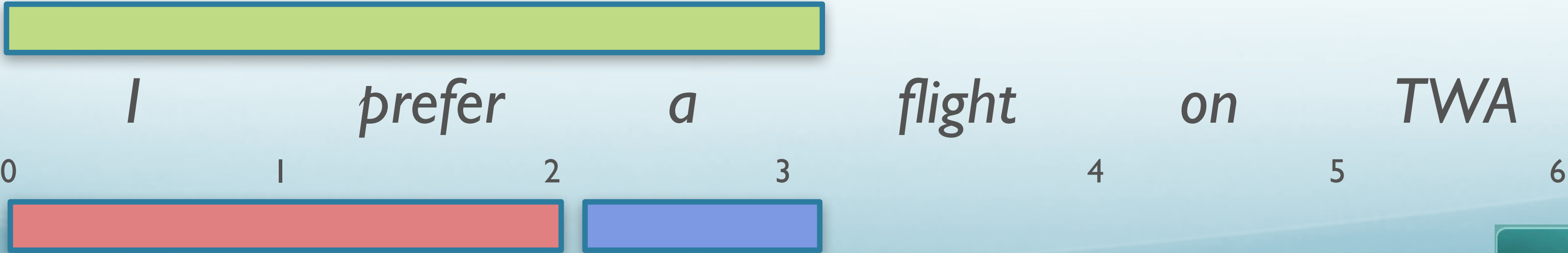- -
$VP \rightarrow book \mid include \mid prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
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	Verb, VP, S [1,2]	[1,3]			
		Det Det [2,3]			

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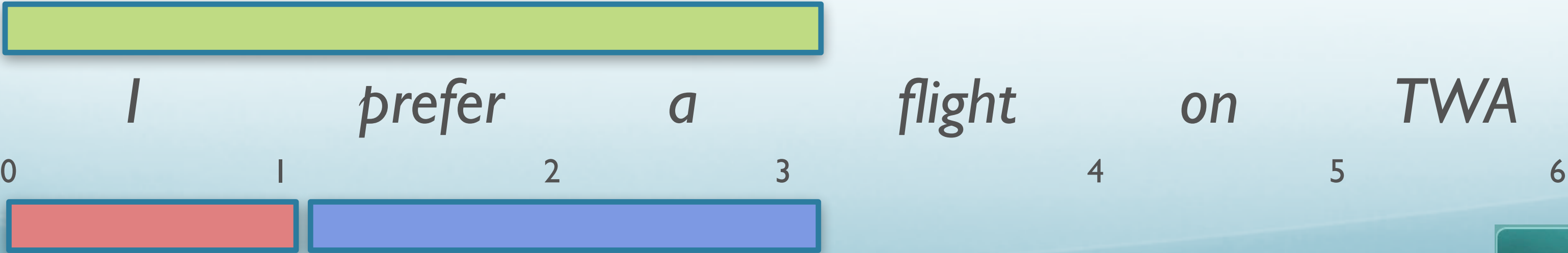$Nominal \rightarrow Nominal\ PP$

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NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]			
		Det [2,3]			
			Noun, Nom [3,4]		

I   prefer   a   flight   on   TWA

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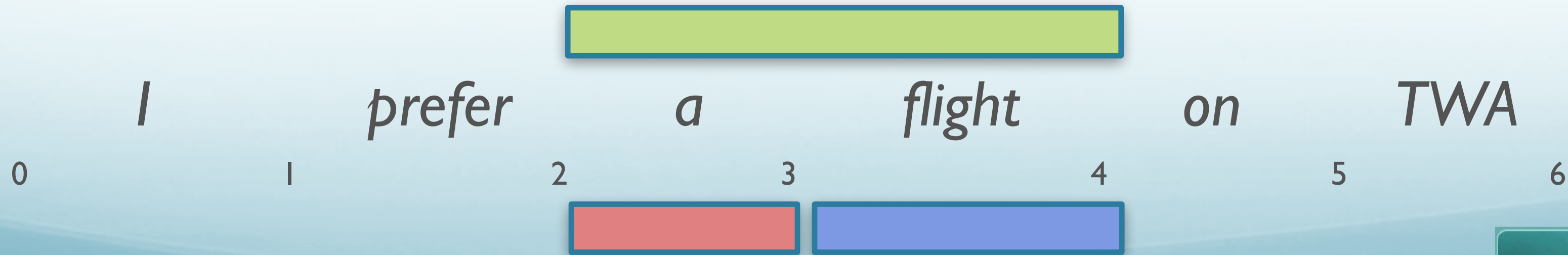$Nominal \rightarrow Nominal\ PP$
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NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]			
		Det [2,3]	[2,4]		
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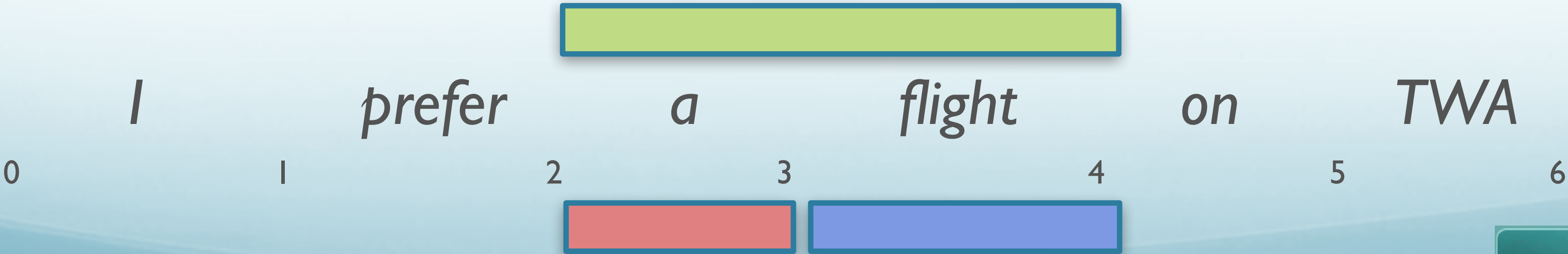$Nominal \rightarrow Nominal\ Noun$
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NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]			
		Det [2,3]	[2,4]		
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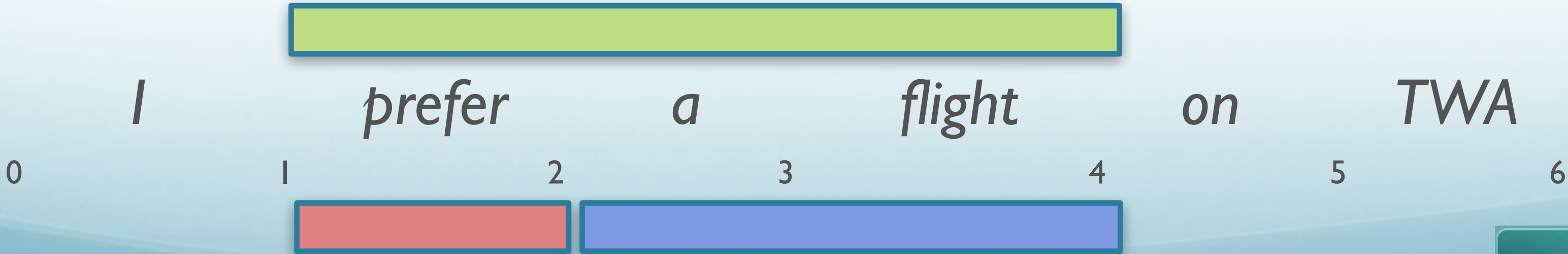$Nominal \rightarrow Nominal\ Noun$
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NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]			
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I prefer a flight on TWA

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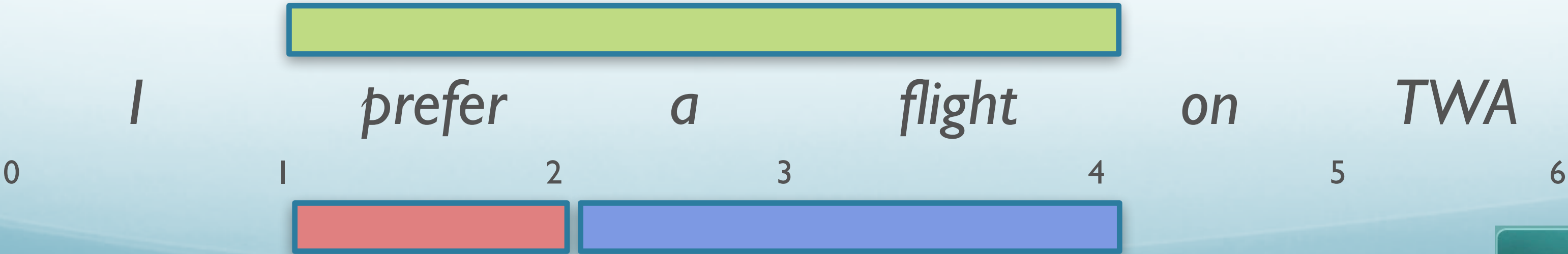$Nominal \rightarrow Nominal\ PP$

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NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]	[1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I prefer a flight on TWA

0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
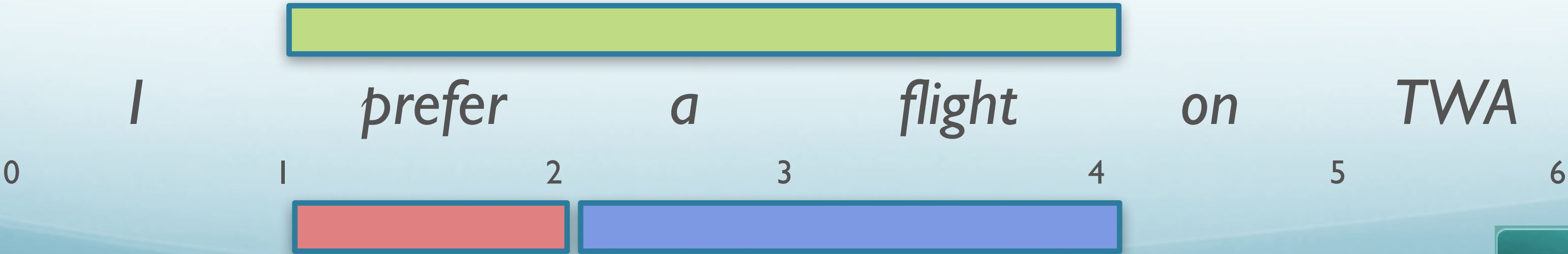- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

NP, Pronoun	S				
[0,1]	[0,2]	[0,3]			
	Verb, VP, S		VP		
	[1,2]	[1,3]	[1,4]		
		Det	NP		
		[2,3]	[2,4]		
			Noun, Nom		
			[3,4]		

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
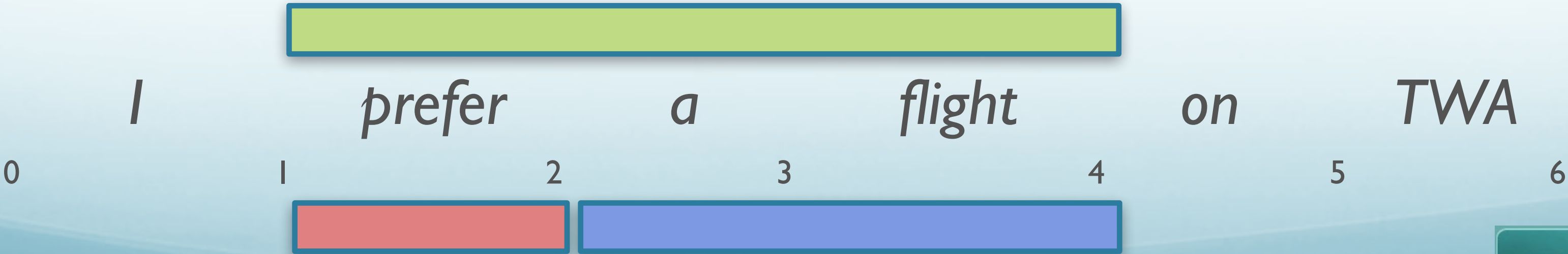- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
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$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]	VP, X2 [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \to NP\ VP$
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$NP \to I\ |\ she\ |\ me$
$NP \to TWA\ |\ Houston$
$NP \to Det\ Nominal$
$Nominal \to book\ |\ flight\ |\ meal\ |\ money$
$Nominal \to Nominal\ Noun$
$Nominal \to Nominal\ PP$
$VP \to book\ |\ include\ |\ prefer$
$VP \to Verb\ NP$
$VP \to X2\ PP$
$X2 \to Verb\ NP$
$VP \to Verb\ PP$
$VP \to VP\ PP$
$PP \to Preposition\ NP$

Lexicon

$Det \to that\ |\ this\ |\ a$
$Noun \to book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \to I\ |\ she\ |\ me$
$Proper\text{-}Noun \to Houston\ |\ TWA$
$Aux \to does$
$Preposition \to from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \to book\ |\ include\ |\ prefer$

NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I prefer a flight on TWA

0 1 2 3 4 5 6

PROFESSIONAL MASTER'S IN COMPUTATIONAL LINGUISTICS

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𝓛₁ Grammar

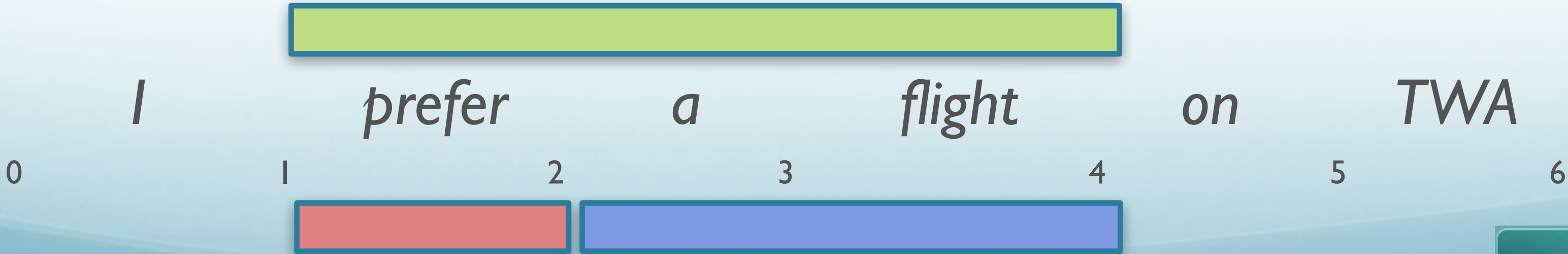$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
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- -
$NP \rightarrow I\ |\ she\ |\ me$
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$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
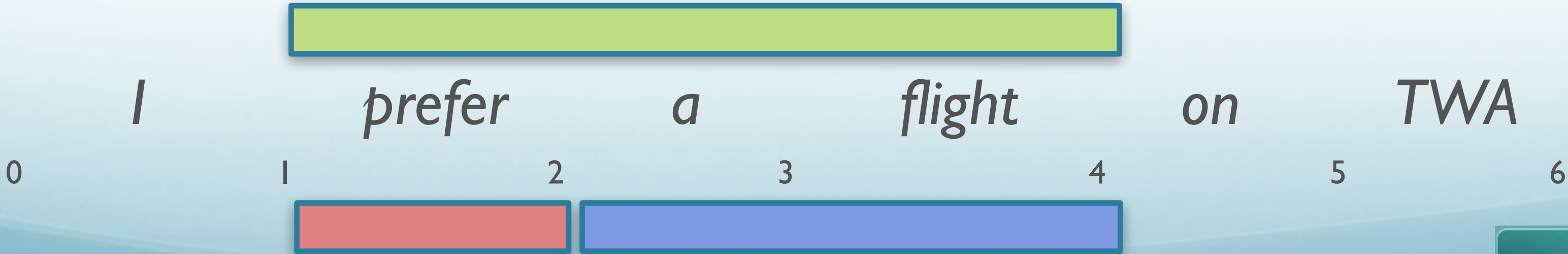- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
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$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
	Det [2,3]	NP [2,4]			
		Noun, Nom [3,4]			

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
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- - -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- - -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
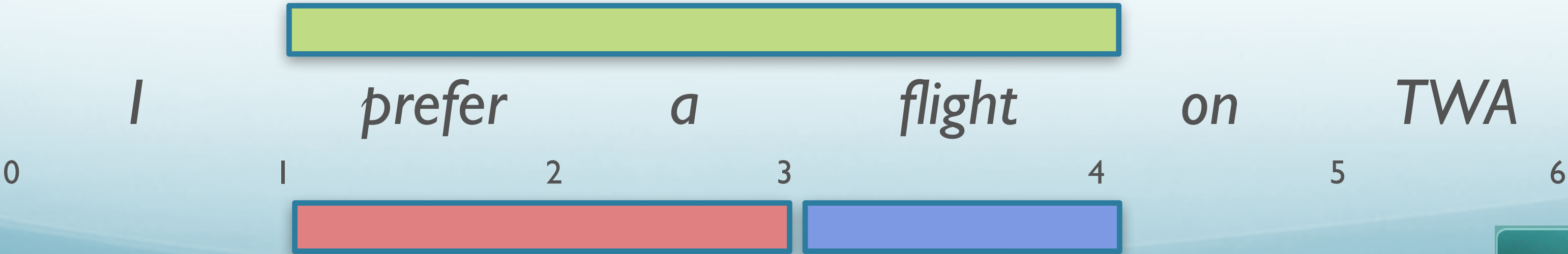$Nominal \rightarrow Nominal\ PP$
- - -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- - -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
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$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
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$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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PROFESSIONAL MASTER'S IN COMPUTATIONAL LINGUISTICS

$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
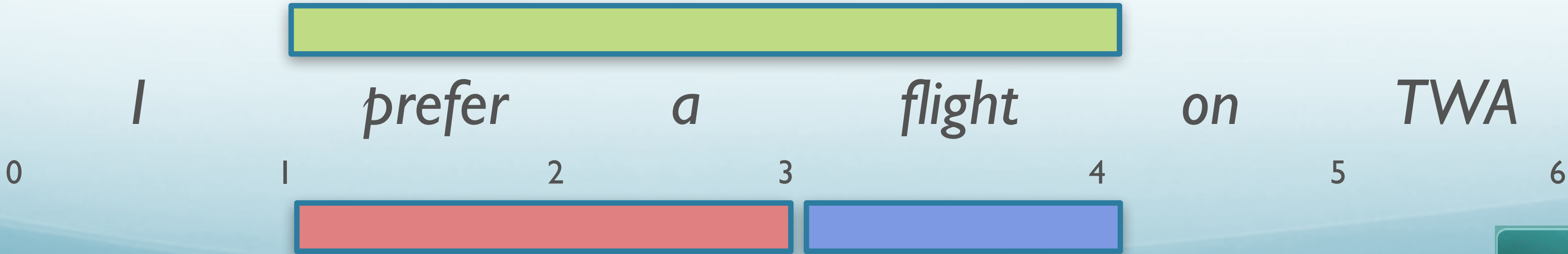$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
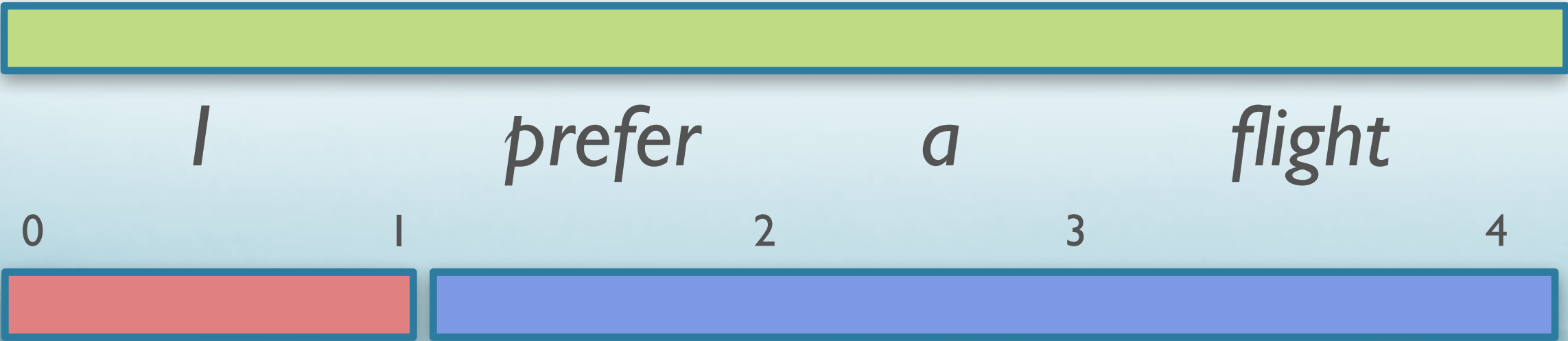- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
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$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
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NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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PROFESSIONAL MASTER'S IN COMPUTATIONAL LINGUISTICS

ℒ₁ Grammar

S → NP VP
S → X1 VP
X1 → Aux NP
S → book | include | prefer
S → Verb NP
S → X2 PP
S → Verb PP
S → VP PP

NP → I | she | me
NP → TWA | Houston
NP → Det Nominal

Nominal → book | flight | meal | money
Nominal → Nominal Noun
Nominal → Nominal PP

VP → book | include | prefer
VP → Verb NP
VP → X2 PP
X2 → Verb NP
VP → Verb PP
VP → VP PP

PP → Preposition NP

Lexicon

Det → that | this | a
Noun → book | flight | meal | money
Pronoun → I | she | me
Proper-Noun → Houston | TWA
Aux → does
Preposition → from | to | on | near | through
Verb → book | include | prefer

NP, Pronoun [0,1]	S [0,2]	[0,3]	[0,4]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	
		Det [2,3]	NP [2,4]	
			Noun, Nom [3,4]	

I   prefer   a   flight   on   TWA

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$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$

$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$

$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
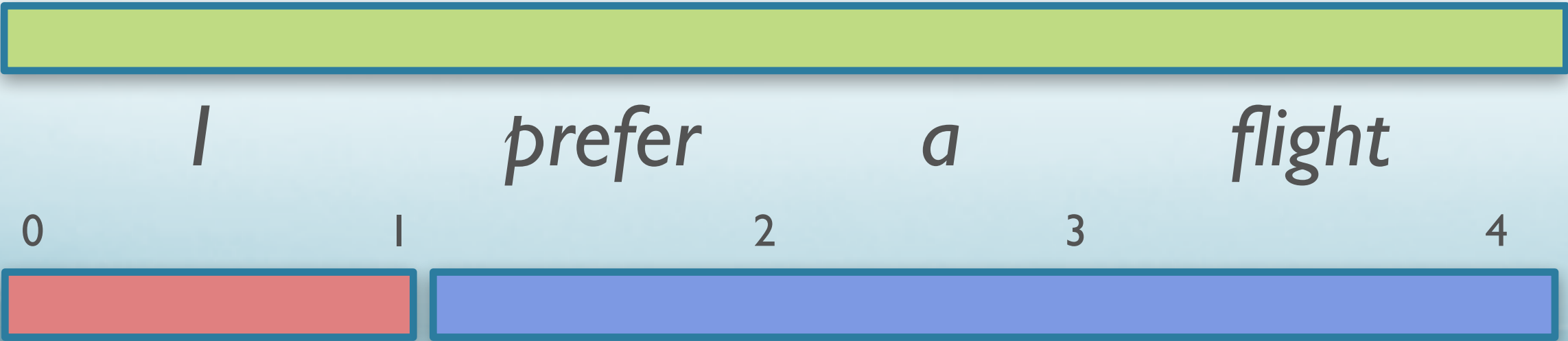$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]		
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
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$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
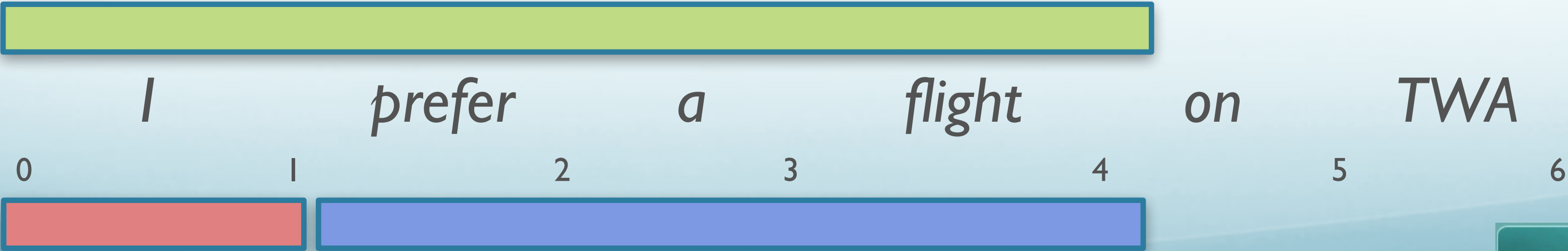$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
$PP \rightarrow Preposition\ NP$

Lexicon

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$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]		
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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PROFESSIONAL MASTER'S IN COMPUTATIONAL LINGUISTICS

𝓛₁ Grammar

S → NP VP
S → X1 VP
X1 → Aux NP
S → book | include | prefer
S → Verb NP
S → X2 PP
S → Verb PP
S → VP PP
NP → I | she | me
NP → TWA | Houston
NP → Det Nominal
Nominal → book | flight | meal | money
Nominal → Nominal Noun
Nominal → Nominal PP
VP → book | include | prefer
VP → Verb NP
VP → X2 PP
X2 → Verb NP
VP → Verb PP
VP → VP PP
PP → Preposition NP

Lexicon

Det → that | this | a
Noun → book | flight | meal | money
Pronoun → I | she | me
Proper-Noun → Houston | TWA
Aux → does
Preposition → from | to | on | near | through
Verb → book | include | prefer

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]		
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I   prefer   a   flight   on   TWA
0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \to NP\ VP$
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$X1 \to Aux\ NP$
$S \to book\ |\ include\ |\ prefer$
$S \to Verb\ NP$
$S \to X2\ PP$
$S \to Verb\ PP$
$S \to VP\ PP$
- - - - - - - - - - - - - - - - - - - -
$NP \to I\ |\ she\ |\ me$
$NP \to TWA\ |\ Houston$
$NP \to Det\ Nominal$
- - - - - - - - - - - - - - - - - - - -
$Nominal \to book\ |\ flight\ |\ meal\ |\ money$
$Nominal \to Nominal\ Noun$
$Nominal \to Nominal\ PP$
- - - - - - - - - - - - - - - - - - - -
$VP \to book\ |\ include\ |\ prefer$
$VP \to Verb\ NP$
$VP \to X2\ PP$
$X2 \to Verb\ NP$
$VP \to Verb\ PP$
$VP \to VP\ PP$
- - - - - - - - - - - - - - - - - - - -
$PP \to Preposition\ NP$

Lexicon

$Det \to that\ |\ this\ |\ a$
$Noun \to book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \to I\ |\ she\ |\ me$
$Proper\text{-}Noun \to Houston\ |\ TWA$
$Aux \to does$
$Preposition \to from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \to book\ |\ include\ |\ prefer$

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]		
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book \mid include \mid prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$

$NP \rightarrow I \mid she \mid me$
$NP \rightarrow TWA \mid Houston$
$NP \rightarrow Det\ Nominal$

$Nominal \rightarrow book \mid flight \mid meal \mid money$
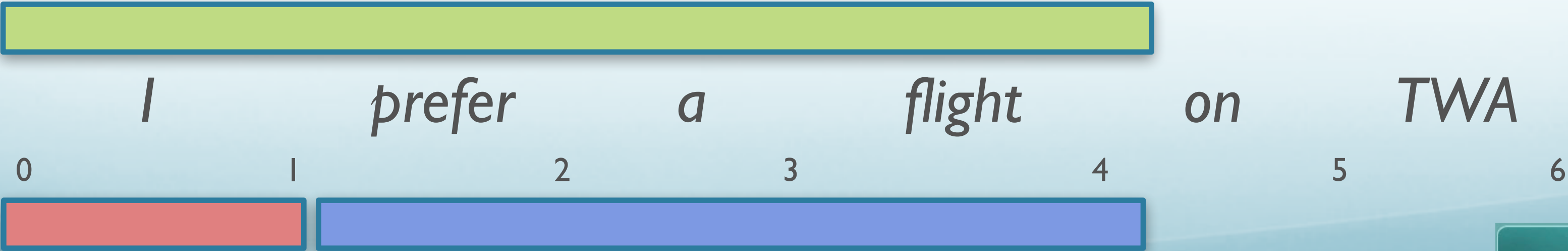$Nominal \rightarrow Nominal\ Noun$
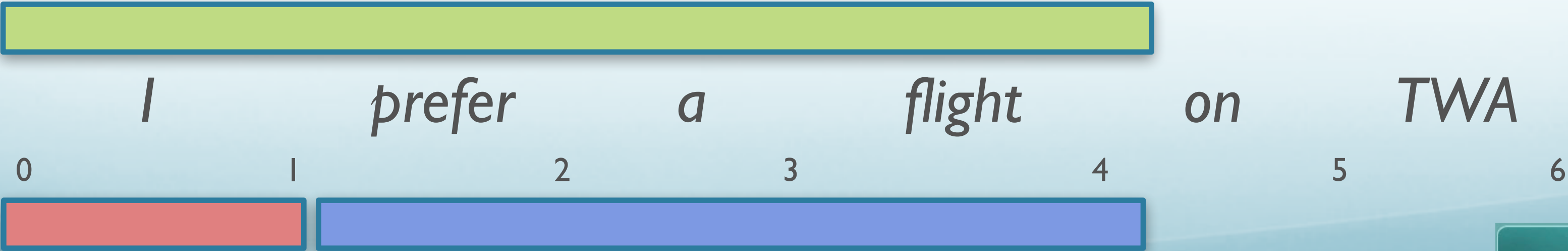$Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book \mid include \mid prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that \mid this \mid a$
$Noun \rightarrow book \mid flight \mid meal \mid money$
$Pronoun \rightarrow I \mid she \mid me$
$Proper\text{-}Noun \rightarrow Houston \mid TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from \mid to \mid on \mid near \mid through$
$Verb \rightarrow book \mid include \mid prefer$

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]		
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
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$NP \rightarrow TWA \mid Houston$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow book \mid flight \mid meal \mid money$
$Nominal \rightarrow Nominal\ Noun$
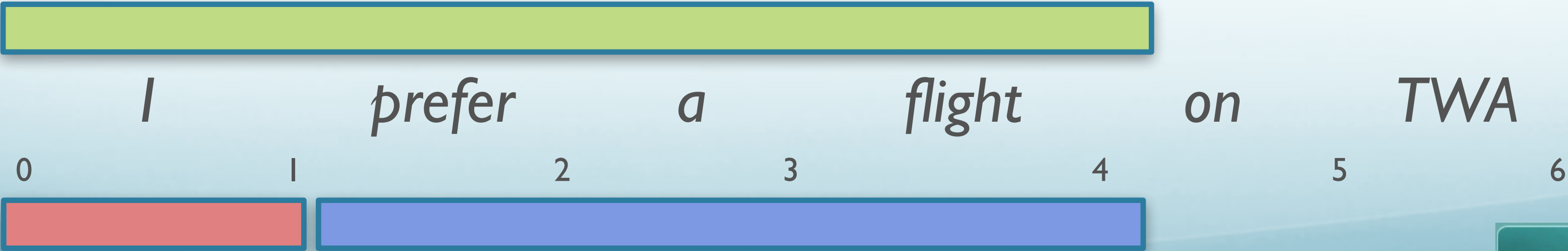$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow book \mid include \mid prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
$PP \rightarrow Preposition\ NP$

Lexicon

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$Aux \rightarrow does$
$Preposition \rightarrow from \mid to \mid on \mid near \mid through$
$Verb \rightarrow book \mid include \mid prefer$

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]		
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I   prefer   a   flight   on   TWA
0   1   2   3   4   5   6

66

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
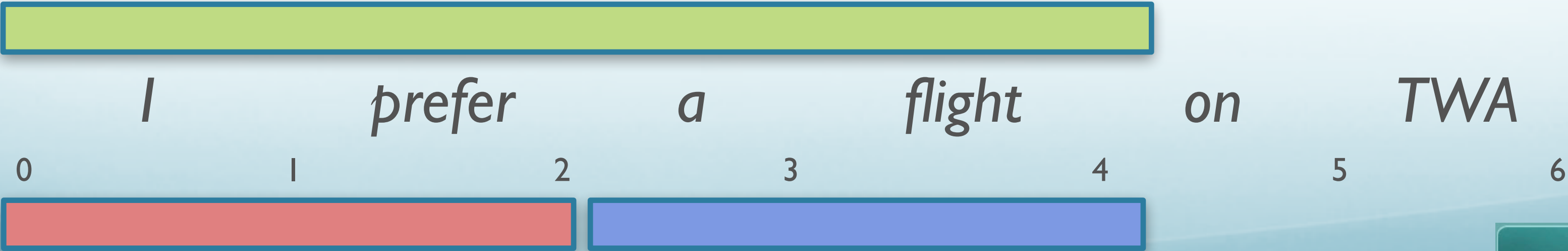- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]		
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I	prefer	a	flight	on	TWA
0	1	2	3	4	5	6

$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
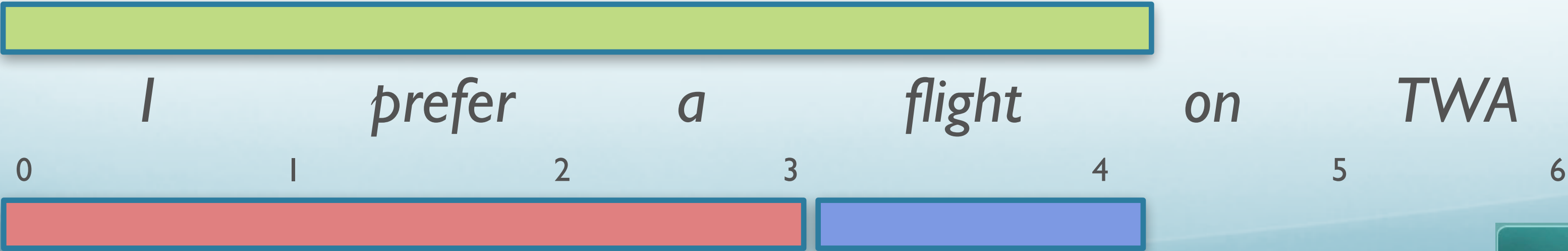$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]		
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- - - - - - - - - - - - - - - - - - - -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- - - - - - - - - - - - - - - - - - - -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
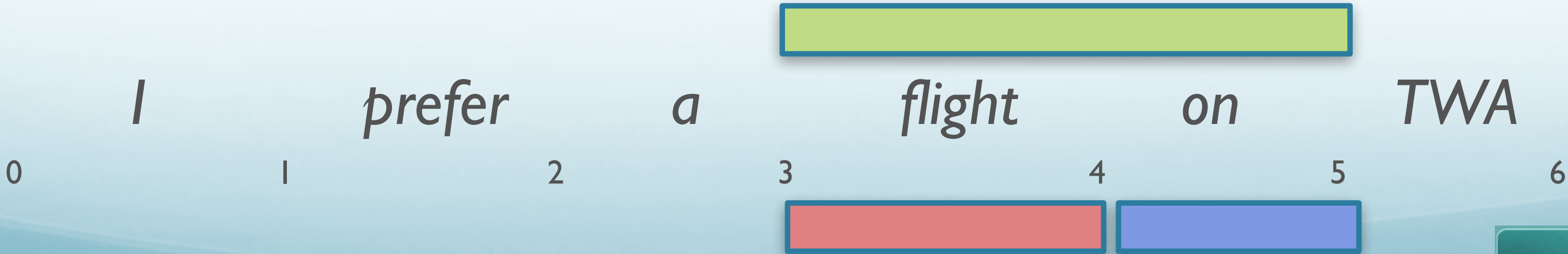- - - - - - - - - - - - - - - - - - - -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- - - - - - - - - - - - - - - - - - - -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$

$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$

$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
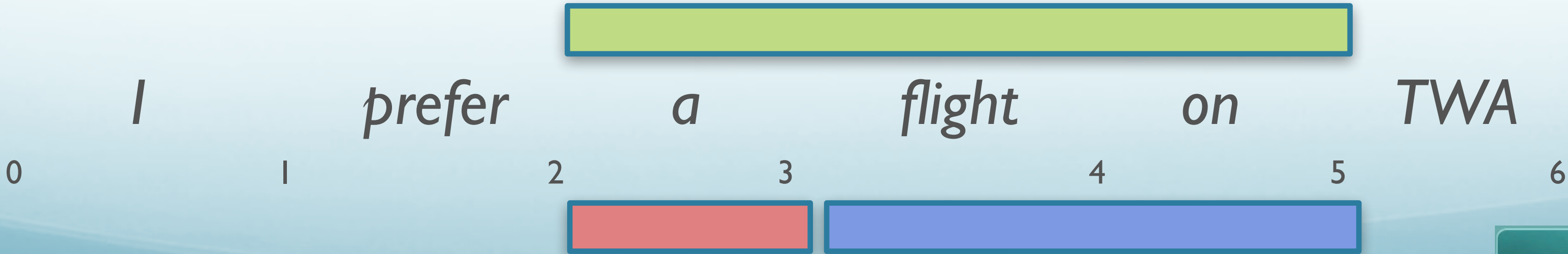$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \to NP\ VP$
$S \to X1\ VP$
$X1 \to Aux\ NP$
$S \to book\ |\ include\ |\ prefer$
$S \to Verb\ NP$
$S \to X2\ PP$
$S \to Verb\ PP$
$S \to VP\ PP$
$NP \to I\ |\ she\ |\ me$
$NP \to TWA\ |\ Houston$
$NP \to Det\ Nominal$
$Nominal \to book\ |\ flight\ |\ meal\ |\ money$
$Nominal \to Nominal\ Noun$
$Nominal \to Nominal\ PP$
$VP \to book\ |\ include\ |\ prefer$
$VP \to Verb\ NP$
$VP \to X2\ PP$
$X2 \to Verb\ NP$
$VP \to Verb\ PP$
$VP \to VP\ PP$
$PP \to Preposition\ NP$

Lexicon

$Det \to that\ |\ this\ |\ a$
$Noun \to book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \to I\ |\ she\ |\ me$
$Proper\text{-}Noun \to Houston\ |\ TWA$
$Aux \to does$
$Preposition \to from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \to book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
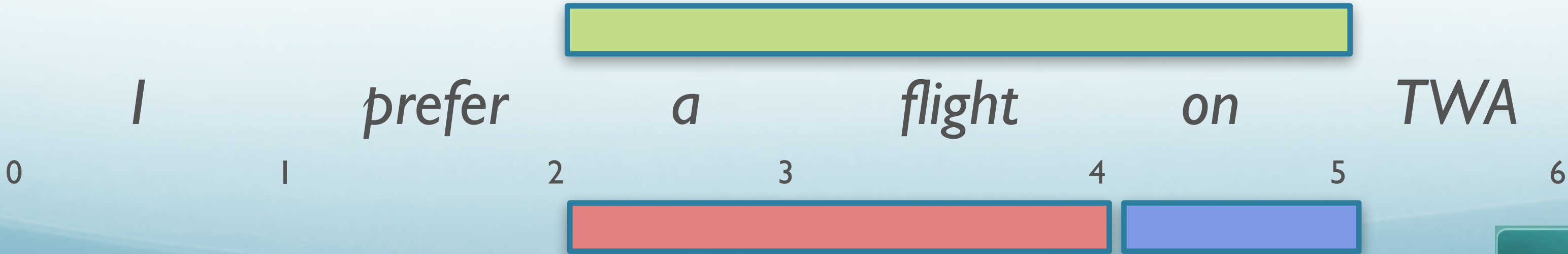$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I — prefer — a — flight — on — TWA

0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book \mid include \mid prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I \mid she \mid me$
$NP \rightarrow TWA \mid Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book \mid flight \mid meal \mid money$
$Nominal \rightarrow Nominal\ Noun$
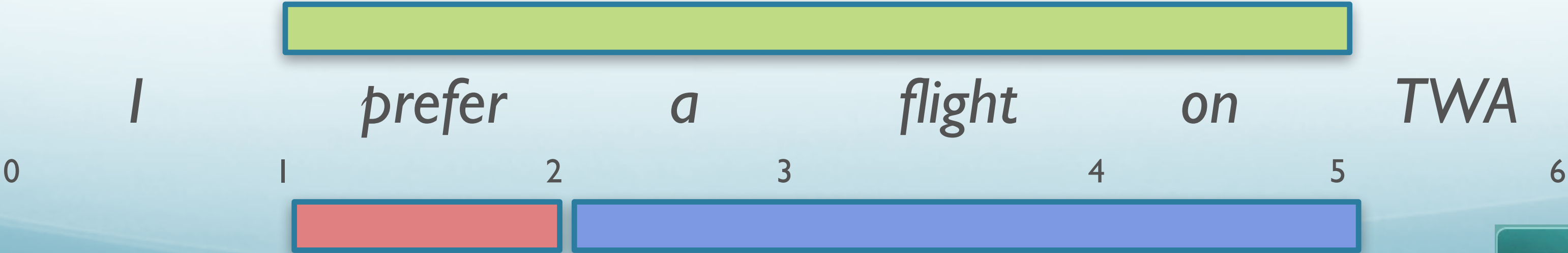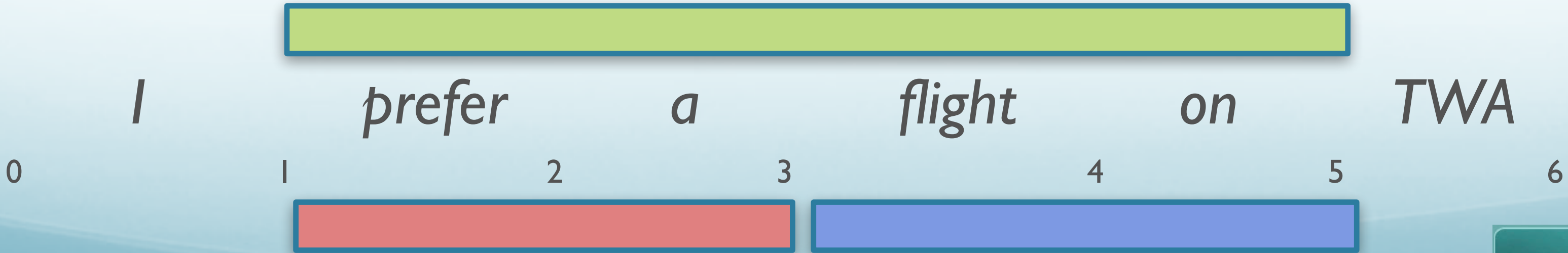$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow book \mid include \mid prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that \mid this \mid a$
$Noun \rightarrow book \mid flight \mid meal \mid money$
$Pronoun \rightarrow I \mid she \mid me$
$Proper\text{-}Noun \rightarrow Houston \mid TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from \mid to \mid on \mid near \mid through$
$Verb \rightarrow book \mid include \mid prefer$

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

I prefer a flight on TWA

0   1   2   3   4   5   6

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PROFESSIONAL MASTER'S IN COMPUTATIONAL LINGUISTICS

𝓛₁ Grammar

S → NP VP
S → X1 VP
X1 → Aux NP
S → book | include | prefer
S → Verb NP
S → X2 PP
S → Verb PP
S → VP PP

NP → I | she | me
NP → TWA | Houston
NP → Det Nominal

Nominal → book | flight | meal | money
Nominal → Nominal Noun
Nominal → Nominal PP

VP → book | include | prefer
VP → Verb NP
VP → X2 PP
X2 → Verb NP
VP → Verb PP
VP → VP PP

PP → Preposition NP

Lexicon

Det → that | this | a
Noun → book | flight | meal | money
Pronoun → I | she | me
Proper-Noun → Houston | TWA
Aux → does
Preposition → from | to | on | near | through
Verb → book | include | prefer

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- - - - - - - - - - - - - - - - - - - -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- - - - - - - - - - - - - - - - - - - -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
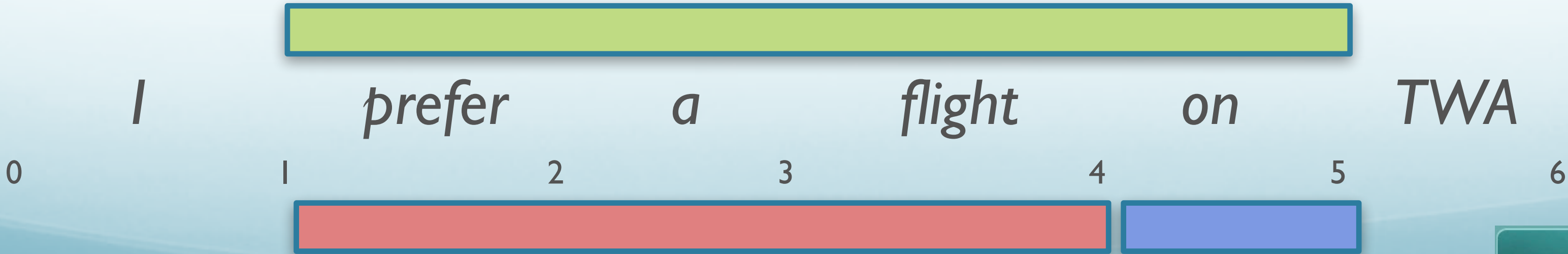- - - - - - - - - - - - - - - - - - - -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- - - - - - - - - - - - - - - - - - - -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
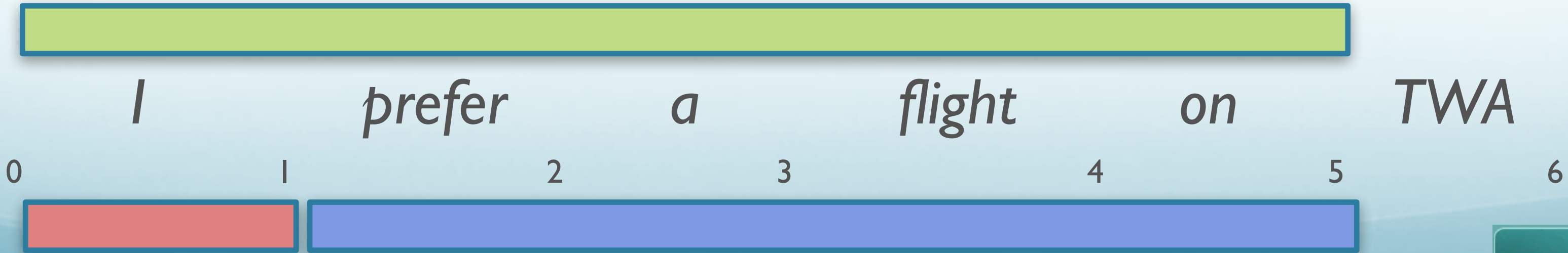- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   *prefer*   *a*   *flight*   *on*   TWA

0   1   2   3   4   5   6

PROFESSIONAL MASTER'S IN COMPUTATIONAL LINGUISTICS

$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
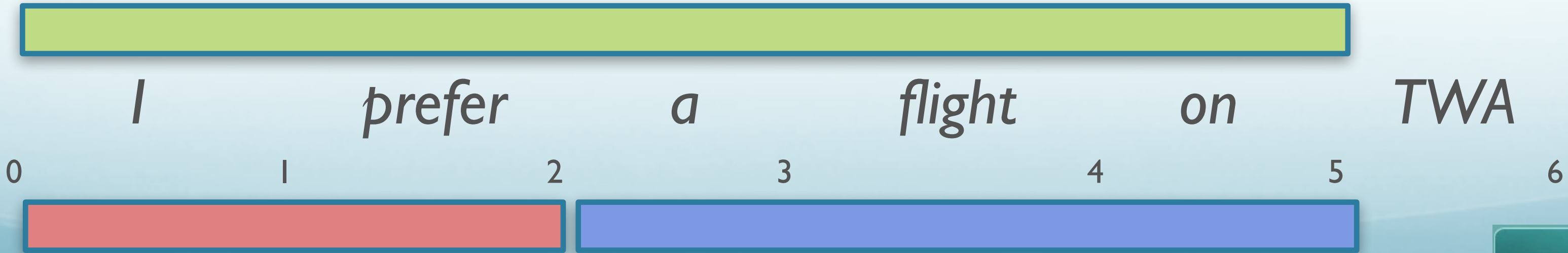$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I prefer a flight on TWA

0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
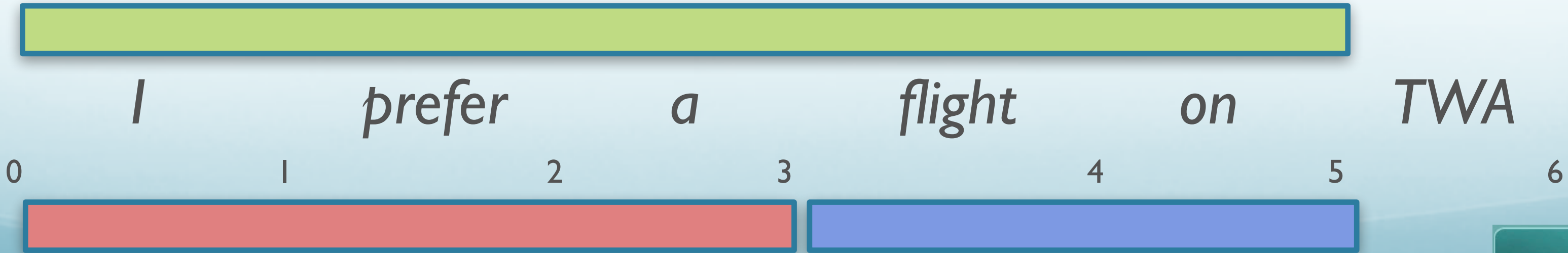- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
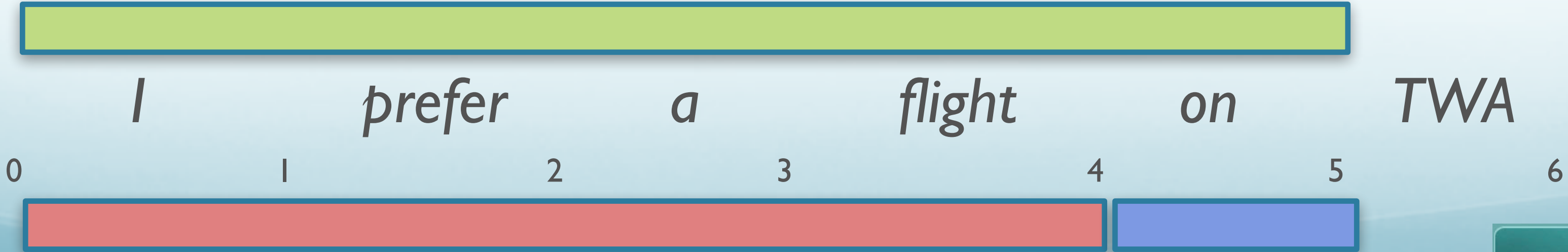- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
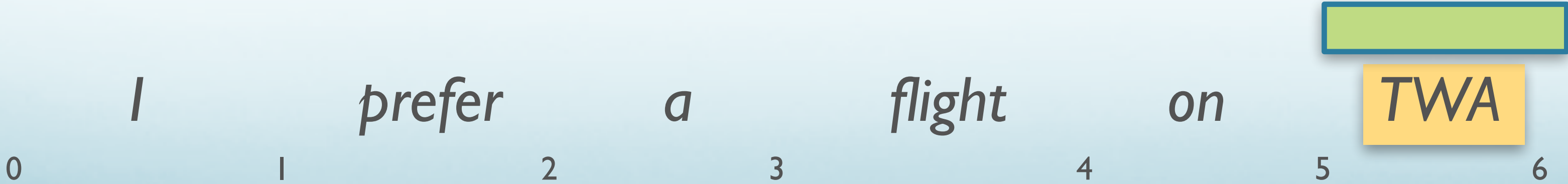$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I prefer a flight on TWA
0   1   2   3   4   5   6

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$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book \mid include \mid prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I \mid she \mid me$
$NP \rightarrow TWA \mid Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book \mid flight \mid meal \mid money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
- -
$VP \rightarrow book \mid include \mid prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that \mid this \mid a$
$Noun \rightarrow book \mid flight \mid meal \mid money$
$Pronoun \rightarrow I \mid she \mid me$
$Proper\text{-}Noun \rightarrow Houston \mid TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from \mid to \mid on \mid near \mid through$
$Verb \rightarrow book \mid include \mid prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

UNIVERSITY OF WASHINGTON

PROFESSIONAL MASTER'S IN COMPUTATIONAL LINGUISTICS

$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

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$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- - -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- - -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
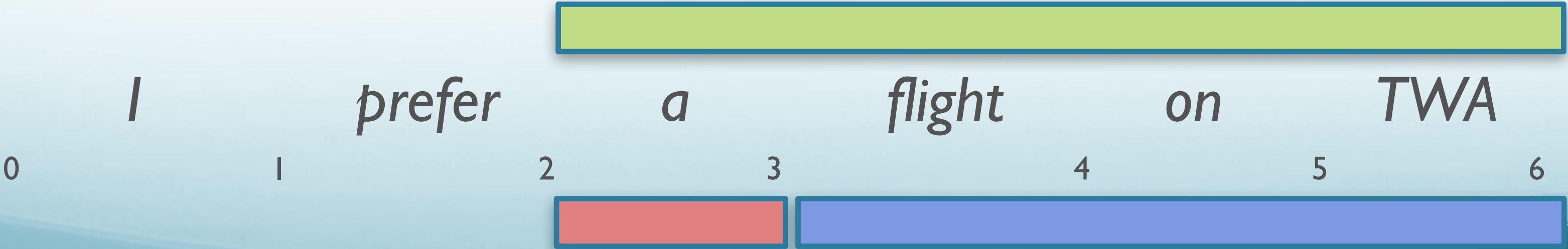$Nominal \rightarrow Nominal\ PP$
- - -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- - -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

ℒ₁ Grammar

S → NP VP
S → X1 VP
X1 → Aux NP
S → book | include | prefer
S → Verb NP
S → X2 PP
S → Verb PP
S → VP PP
- -
NP → I | she | me
NP → TWA | Houston
NP → Det Nominal
- -
Nominal → book | flight | meal | money
Nominal → Nominal Noun
Nominal → Nominal PP
- -
VP → book | include | prefer
VP → Verb NP
VP → X2 PP
X2 → Verb NP
VP → Verb PP
VP → VP PP
- -
PP → Preposition NP

Lexicon

Det → that | this | a
Noun → book | flight | meal | money
Pronoun → I | she | me
Proper-Noun → Houston | TWA
Aux → does
Preposition → from | to | on | near | through
Verb → book | include | prefer

Chart

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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PROFESSIONAL MASTER'S IN COMPUTATIONAL LINGUISTICS

𝓛₁ Grammar

$S \to NP\ VP$
$S \to X1\ VP$
$X1 \to Aux\ NP$
$S \to book \mid include \mid prefer$
$S \to Verb\ NP$
$S \to X2\ PP$
$S \to Verb\ PP$
$S \to VP\ PP$

$NP \to I \mid she \mid me$
$NP \to TWA \mid Houston$
$NP \to Det\ Nominal$

$Nominal \to book \mid flight \mid meal \mid money$
$Nominal \to Nominal\ Noun$
$Nominal \to Nominal\ PP$

$VP \to book \mid include \mid prefer$
$VP \to Verb\ NP$
$VP \to X2\ PP$
$X2 \to Verb\ NP$
$VP \to Verb\ PP$
$VP \to VP\ PP$

$PP \to Preposition\ NP$

Lexicon

$Det \to that \mid this \mid a$
$Noun \to book \mid flight \mid meal \mid money$
$Pronoun \to I \mid she \mid me$
$Proper\text{-}Noun \to Houston \mid TWA$
$Aux \to does$
$Preposition \to from \mid to \mid on \mid near \mid through$
$Verb \to book \mid include \mid prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- - - - - - - - - - - - - - - - - - - -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- - - - - - - - - - - - - - - - - - - -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
- - - - - - - - - - - - - - - - - - - -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- - - - - - - - - - - - - - - - - - - -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
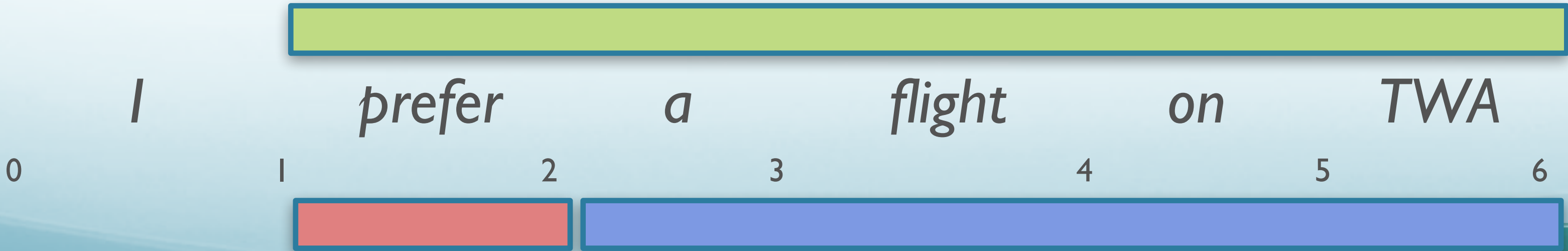- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

[0,5]
VP [1,6]
NP [2,6]
Nom [3,6]
PP [4,6]
NNP, NP [5,6]

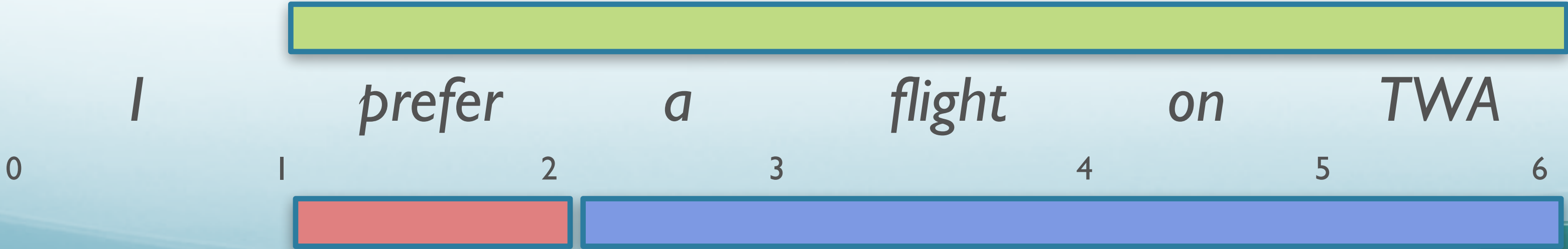I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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𝓛₁ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

	I	prefer	a	flight	on	TWA	
0		1		2	3		4	5	6

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
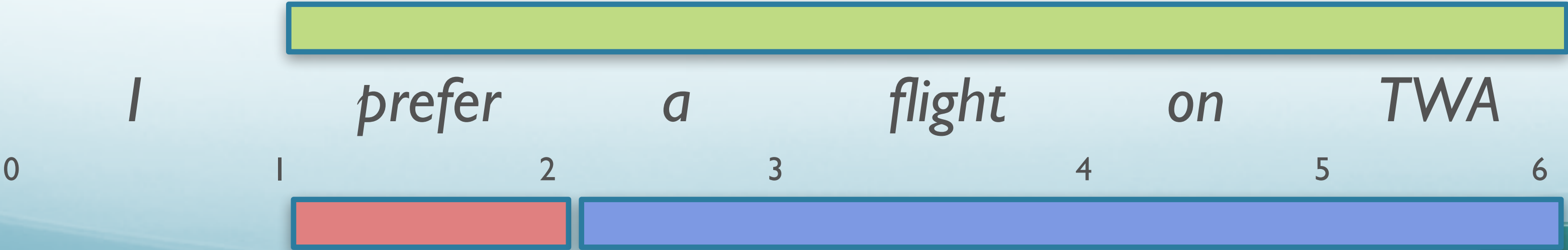$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
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$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA
0   1   2   3   4   5   6

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$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
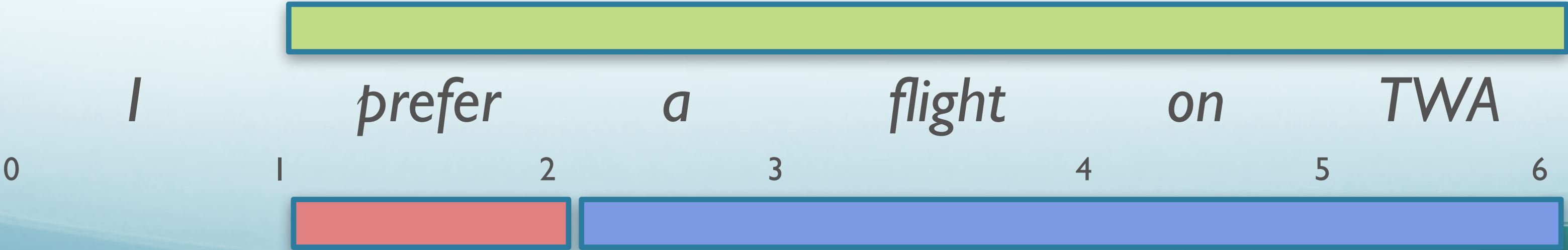$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
$PP \rightarrow Preposition\ NP$

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$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA
0   1   2   3   4   5   6

91

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
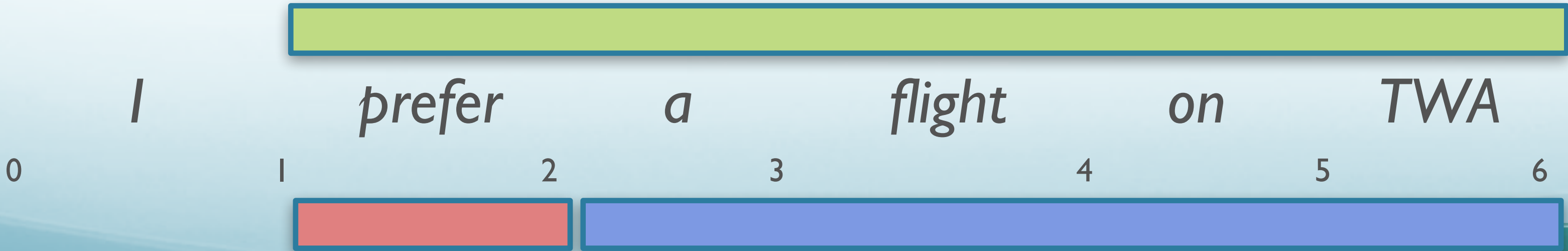$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$

$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$

$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
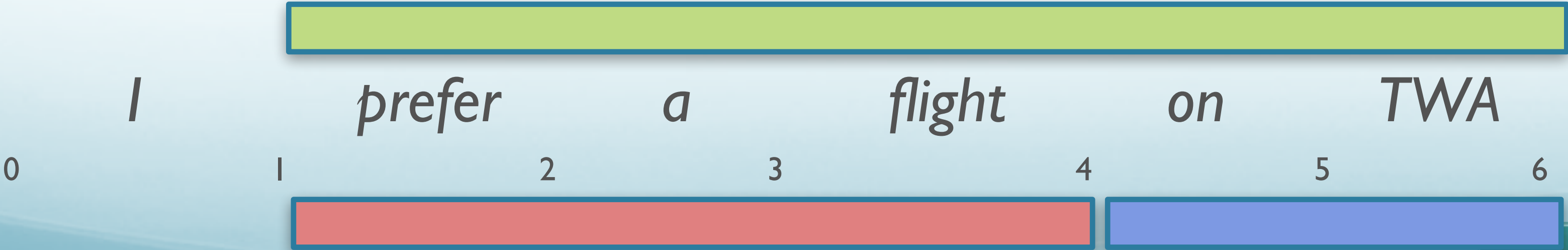$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

| VP, X2, S [1,6] |
| NP [2,6] |
| Nom [3,6] |
| PP [4,6] |
| NNP, NP [5,6] |

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0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book \mid include \mid prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$

$NP \rightarrow I \mid she \mid me$
$NP \rightarrow TWA \mid Houston$
$NP \rightarrow Det\ Nominal$

$Nominal \rightarrow book \mid flight \mid meal \mid money$
$Nominal \rightarrow Nominal\ Noun$
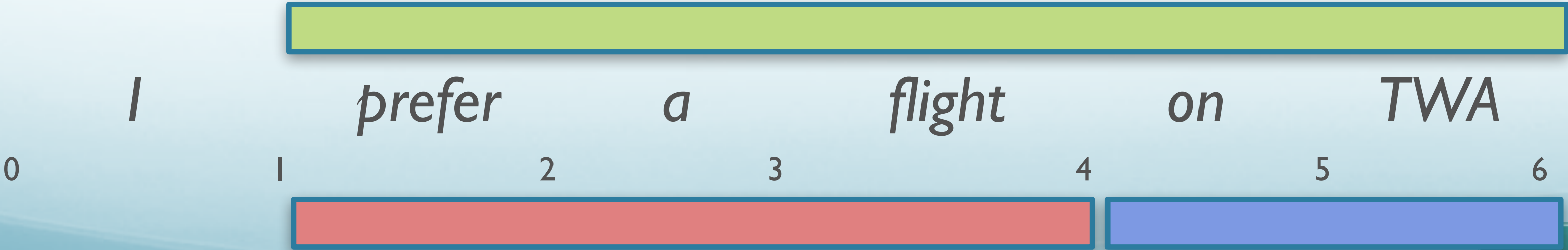$Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book \mid include \mid prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that \mid this \mid a$
$Noun \rightarrow book \mid flight \mid meal \mid money$
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$Aux \rightarrow does$
$Preposition \rightarrow from \mid to \mid on \mid near \mid through$
$Verb \rightarrow book \mid include \mid prefer$

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

VP, X2, S [1,6]
NP [2,6]
Nom [3,6]
PP [4,6]
NNP, NP [5,6]

I   prefer   a   flight   on   TWA
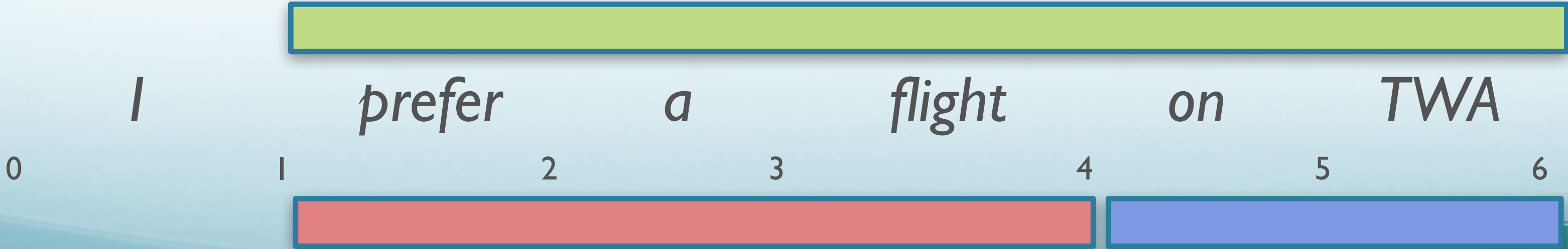
0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book \mid include \mid prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- - - - - - - - - - - -
$NP \rightarrow I \mid she \mid me$
$NP \rightarrow TWA \mid Houston$
$NP \rightarrow Det\ Nominal$
- - - - - - - - - - - -
$Nominal \rightarrow book \mid flight \mid meal \mid money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
- - - - - - - - - - - -
$VP \rightarrow book \mid include \mid prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- - - - - - - - - - - -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that \mid this \mid a$
$Noun \rightarrow book \mid flight \mid meal \mid money$
$Pronoun \rightarrow I \mid she \mid me$
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$Aux \rightarrow does$
$Preposition \rightarrow from \mid to \mid on \mid near \mid through$
$Verb \rightarrow book \mid include \mid prefer$

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

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$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
$PP \rightarrow Preposition\ NP$

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$Det \rightarrow that\ |\ this\ |\ a$
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$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

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$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
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$S \rightarrow Verb\ PP$
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- -
$NP \rightarrow I\ |\ she\ |\ me$
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$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

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$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

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$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
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$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
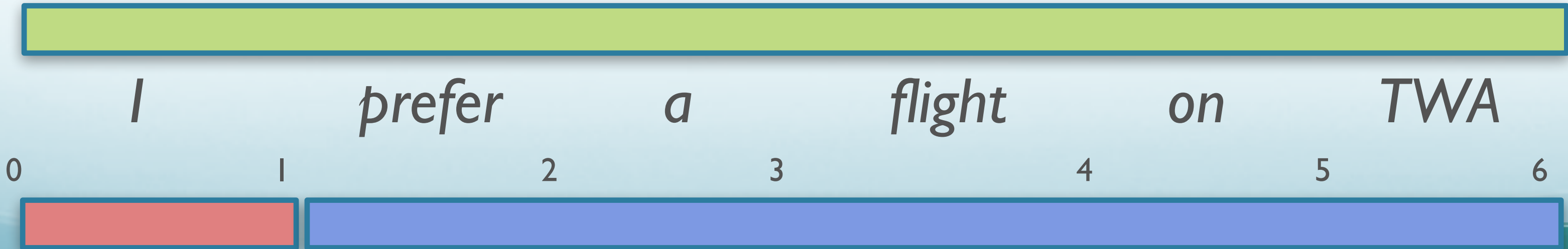$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
$PP \rightarrow Preposition\ NP$

Lexicon

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$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

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$X1 \rightarrow Aux\ NP$
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$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
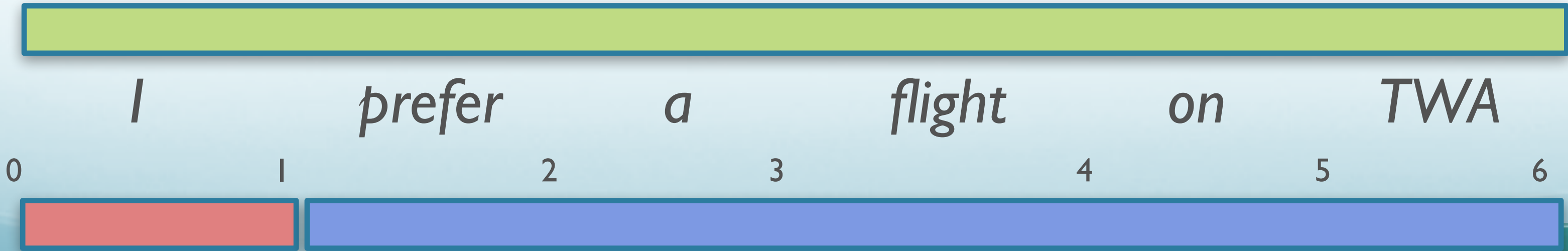$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

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$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
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$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
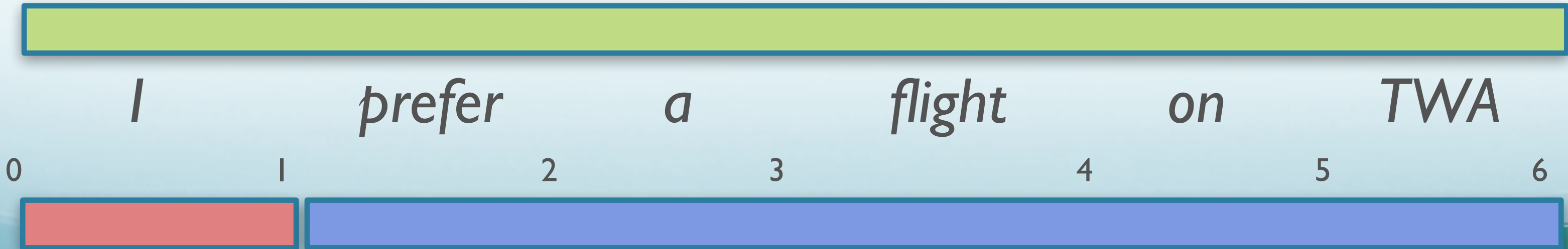- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

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$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathscr{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
$Proper\text{-}Noun \rightarrow Houston\ |\ TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I prefer a flight on TWA

0   1   2   3   4   5   6

$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
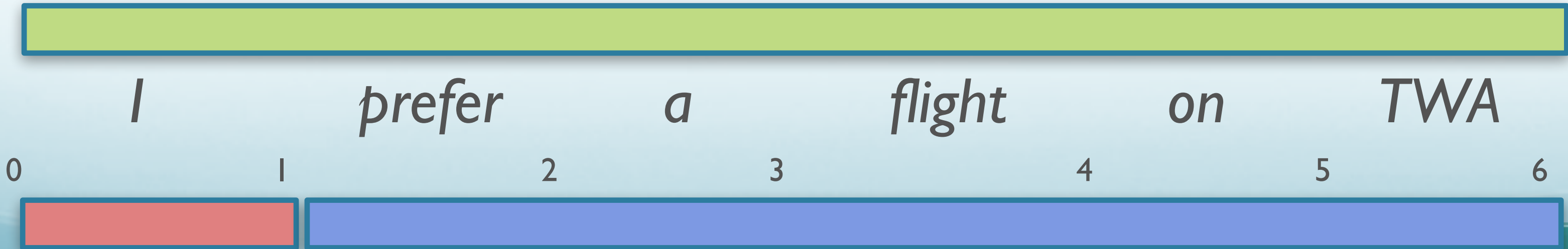$Nominal \rightarrow Nominal\ PP$
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
$PP \rightarrow Preposition\ NP$

Lexicon

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$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book \mid include \mid prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I \mid she \mid me$
$NP \rightarrow TWA \mid Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book \mid flight \mid meal \mid money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
- -
$VP \rightarrow book \mid include \mid prefer$
$VP \rightarrow Verb\ NP$
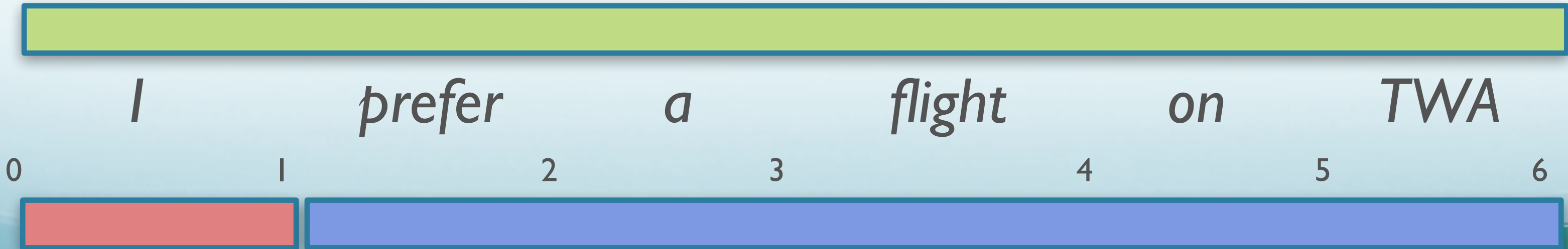$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

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$Pronoun \rightarrow I \mid she \mid me$
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$Aux \rightarrow does$
$Preposition \rightarrow from \mid to \mid on \mid near \mid through$
$Verb \rightarrow book \mid include \mid prefer$

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

I	prefer	a	flight	on	TWA
0	1	2	3	4	5	6

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$\mathcal{L}_1$ Grammar

$S \rightarrow NP\ VP$
$S \rightarrow X1\ VP$
$X1 \rightarrow Aux\ NP$
$S \rightarrow book\ |\ include\ |\ prefer$
$S \rightarrow Verb\ NP$
$S \rightarrow X2\ PP$
$S \rightarrow Verb\ PP$
$S \rightarrow VP\ PP$
- -
$NP \rightarrow I\ |\ she\ |\ me$
$NP \rightarrow TWA\ |\ Houston$
$NP \rightarrow Det\ Nominal$
- -
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Nominal \rightarrow Nominal\ Noun$
$Nominal \rightarrow Nominal\ PP$
- -
$VP \rightarrow book\ |\ include\ |\ prefer$
$VP \rightarrow Verb\ NP$
$VP \rightarrow X2\ PP$
$X2 \rightarrow Verb\ NP$
$VP \rightarrow Verb\ PP$
$VP \rightarrow VP\ PP$
- -
$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ |\ this\ |\ a$
$Noun \rightarrow book\ |\ flight\ |\ meal\ |\ money$
$Pronoun \rightarrow I\ |\ she\ |\ me$
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$Aux \rightarrow does$
$Preposition \rightarrow from\ |\ to\ |\ on\ |\ near\ |\ through$
$Verb \rightarrow book\ |\ include\ |\ prefer$

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

I   prefer   a   flight   on   TWA

0   1   2   3   4   5   6

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

$VP \rightarrow VP \; PP$

```
bp_1 = BackPointer()
bp_1.l_child = [VP, (1,4)]
bp_1.r_child = [PP, (4,6)]
```

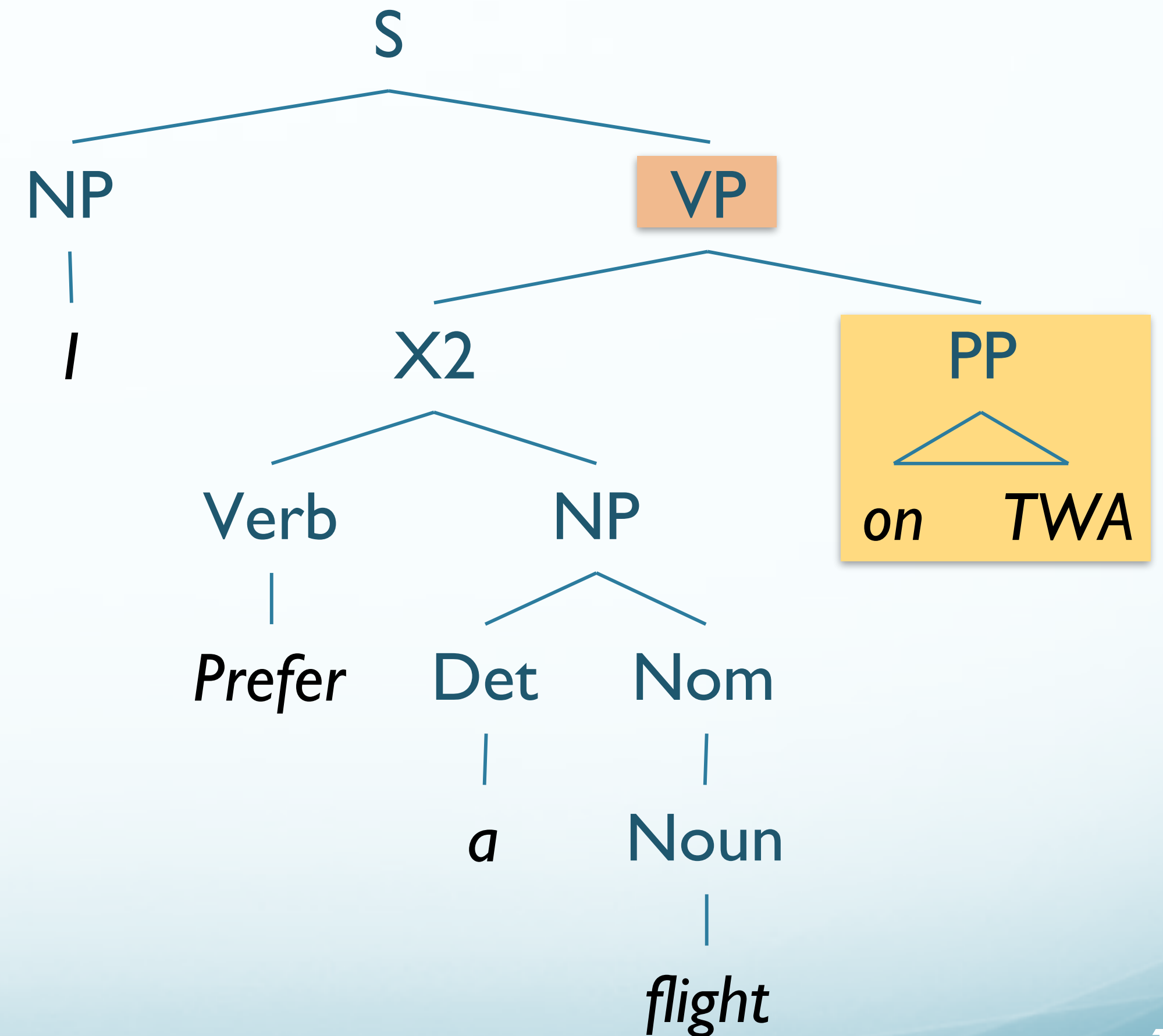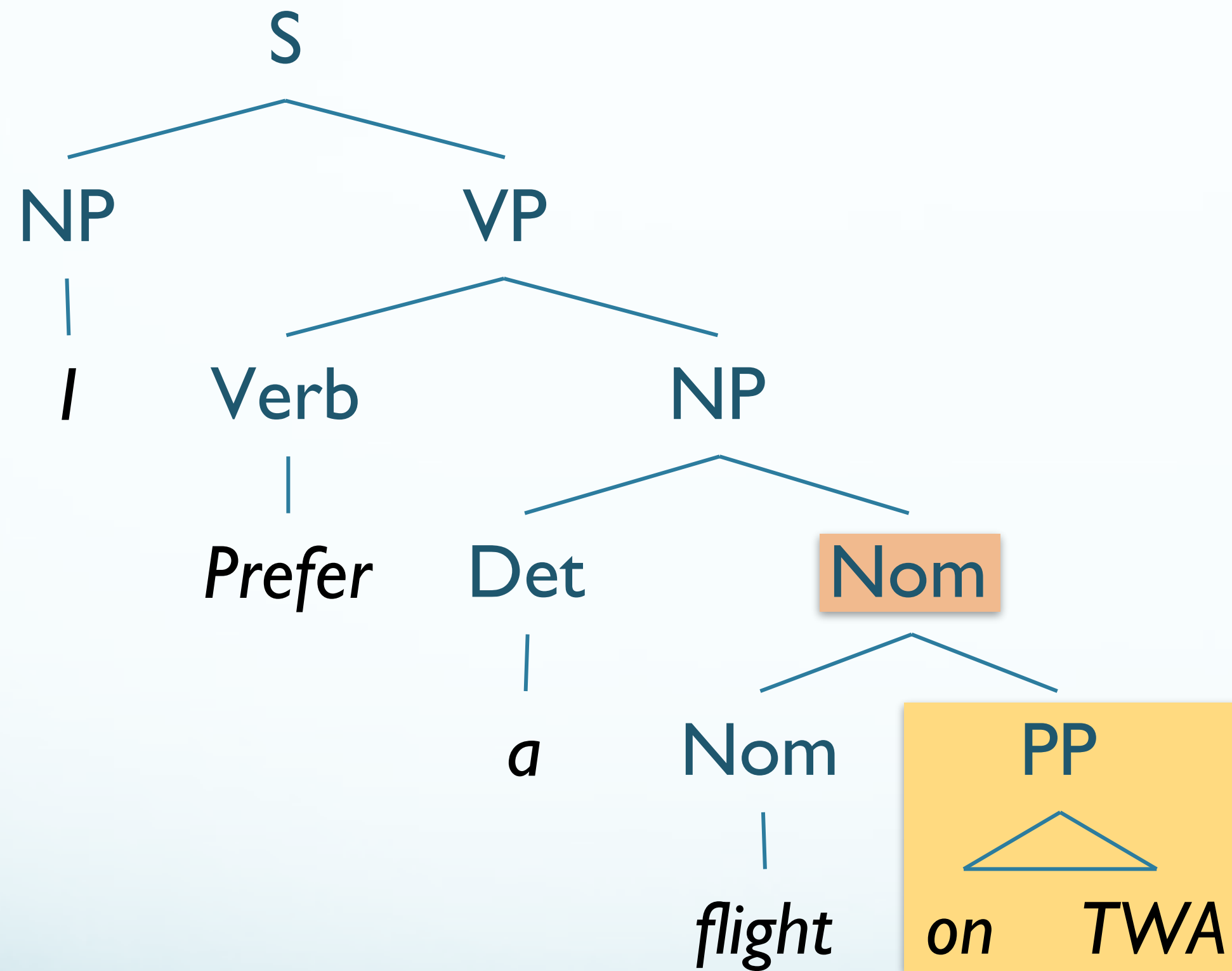| NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	VP [1,6]
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
				Prep [4,5]	PP [4,6]
					NNP, NP [5,6]

$$VP \rightarrow X2\ PP$$

```
bp_2 = BackPointer()
bp_2.l_child = [X2, (1,4)]
bp_2.r_child = [PP, (4,6)]
```

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

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Resulting Parses

CKY Discussion

- Running time:
  - $O(n^3)$ 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

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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

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PCFGs: Formal Definition

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

PCFGs

- Augment each production with probability that LHS will be expanded as RHS

  - $P(A \rightarrow \beta)$

  - $P(A \rightarrow \beta | A)$

  - $P(RHS \mid LHS)$

PCFGs

- Sum over all possible expansions is 1

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

- 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 $\mathscr{L}_1$

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]
$NP \rightarrow Proper\text{-}Noun$	[.30]	$Pronoun \rightarrow I$ [.40] $\mid she$ [.05] $\mid me$ [.15] $\mid you$ [.40]
$NP \rightarrow Det\ Nominal$	[.20]	$Proper\text{-}Noun \rightarrow Houston$ [.60] $\mid NWA$ [.40]
$NP \rightarrow Nominal$	[.15]	$Aux \rightarrow does$ [.60] $\mid can$ [.40]
$Nominal \rightarrow Noun$	[.75]	$Preposition \rightarrow from$ [.30] $\mid to$ [.30] $\mid on$ [.20] $\mid near$ [.15]
$Nominal \rightarrow Nominal\ Noun$	[.20]	$\mid through$ [.05]
$Nominal \rightarrow Nominal\ PP$	[.05]	
$VP \rightarrow Verb$	[.35]	
$VP \rightarrow Verb\ NP$	[.20]	
$VP \rightarrow Verb\ NP\ PP$	[.10]	
$VP \rightarrow Verb\ PP$	[.15]	
$VP \rightarrow Verb\ NP\ NP$	[.05]	
$VP \rightarrow VP\ PP$	[.15]	
$PP \rightarrow Preposition\ NP$	[1.0]	

Example PCFG: Augmented $\mathcal{L}_1$

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

- A PCFG assigns probability to each parse tree T for input S

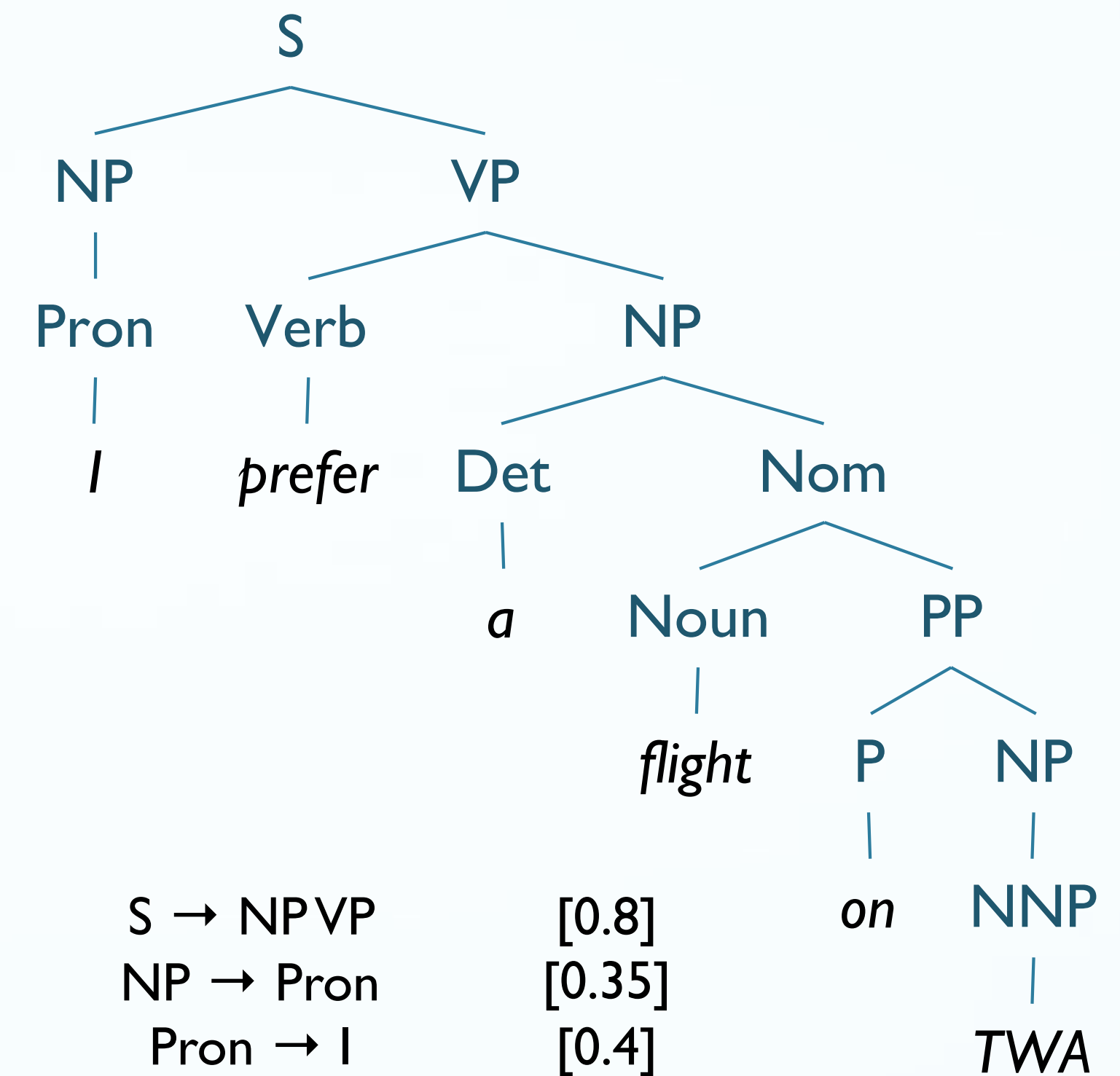- Probability of T: product of all rules used to derive T

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

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

S
NP VP
Pron | I
Verb | prefer
NP
Det | a
Nom
Noun | flight
PP
P | on
NP
NNP | TWA

Left table:
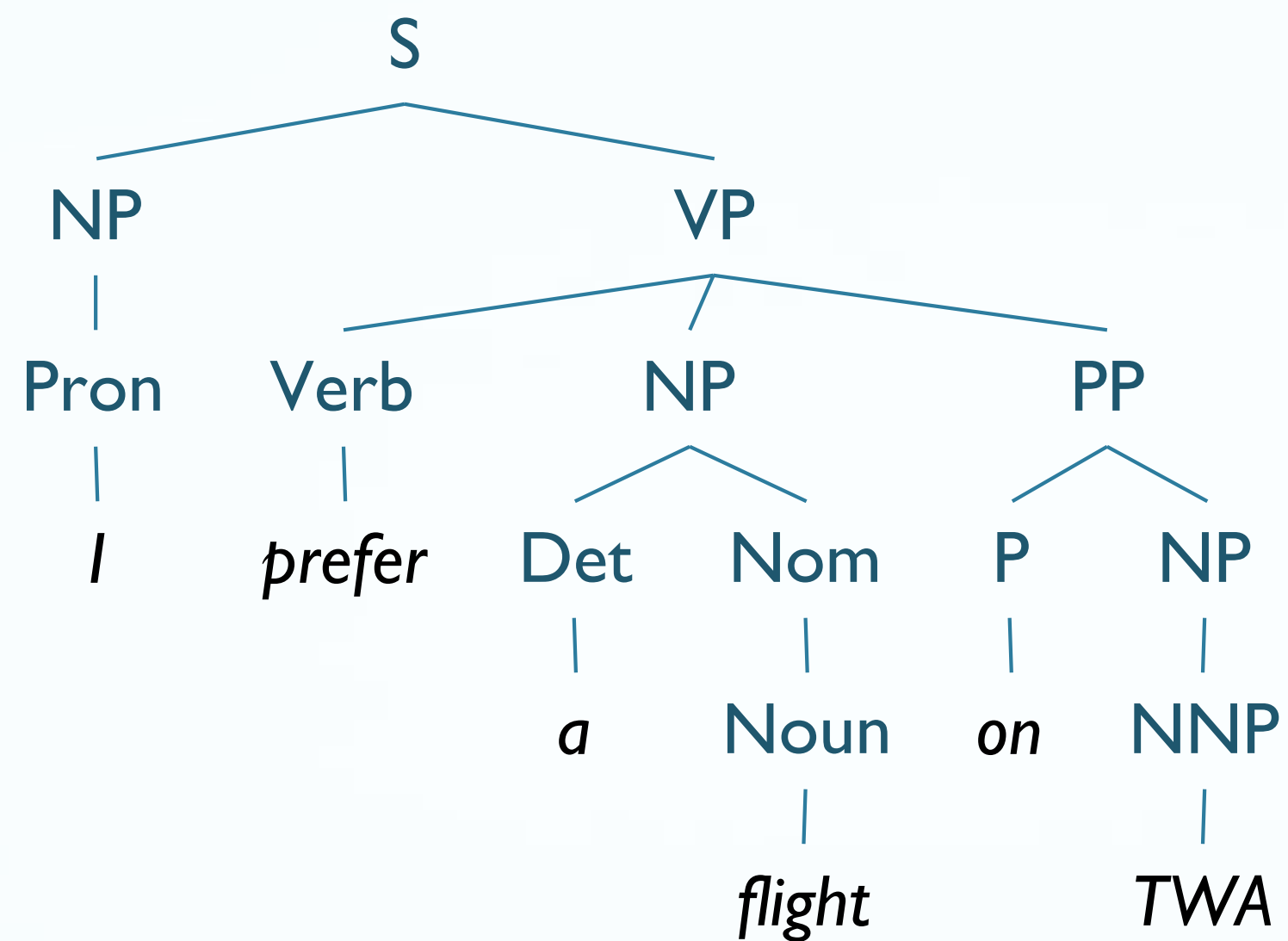
Rule	Prob
S → NP VP	[0.8]
NP → Pron	[0.35]
Pron → I	[0.4]
VP → V NP PP	[0.1]
V → prefer	[0.4]
NP → Det Nom	[0.2]
Det → a	[0.3]
Nom → N	[0.75]
N → flight	[0.3]
PP → P NP	[1.0]
P → on	[0.2]
NP → NNP	[0.3]
NNP → NWA	[0.4]

$\sim 1.452 \times 10^{-6}$

Right tree:

S
NP VP
Pron | I
Verb | prefer
NP
Det | a
Nom
Noun | flight
PP
P | on
NP
NNP | TWA

Right table:

Rule	Prob
S → NP VP	[0.8]
NP → Pron	[0.35]
Pron → I	[0.4]
VP → V NP	[0.2]
V → prefer	[0.4]
NP → Det Nom	[0.2]
Det → a	[0.3]
Nom → Nom PP	[0.05]
Nom → N	[0.75]
N → flight	[0.3]
PP → P NP	[1.0]
P → on	[0.2]
NP → NNP	[0.3]
NNP → NWA	[0.4]

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

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Parsing Problem for PCFGs

- Select T such that *(s.t.)*

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

- String of words S is *yield* of parse tree

- 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:

```python
from unittest import TestCase

class longTests(TestCase):
 def test_three(self):
   length_3_rule = parse_productions('A -> B C D')
   target_rules = parse_productions('''A -> B _X0_
                                        _X0_ -> C D''')
   self.assertSetEqual(set(target_rules),
                     set(fix_long_rules(length_3_rule)))
```

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Unit Testing in Python

- "nose" is a test running framework that will detect all `test_*` method functions

  `python3 -m nose hw2.py`

```
AssertionError: Items in the first set but not the second:
A -> B _X0_
_X0_ -> C D
Items in the second set but not the first:
A -> B C
----------------------------------------------------------------
Ran 12 tests in 0.040s

FAILED (failures=1)
```

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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**