

# CKY Parsing

LING 571 — Deep Processing Techniques for NLP

October 8, 2018

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*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:
    - siʔaɬ ['siʔa:ɬ]
- Duwamish — Dx<sup>w</sup>dəwʔabš [dx<sup>w</sup>dəwʔabʃ]



# 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
  - **?uǰ<sup>w</sup>** ti                      **sbiaw**  
**goes** that-which           **is-a-coyote**  
"The/a coyote goes"
  - **sbiaw**                      ti                      **?uǰ<sup>w</sup>**  
**is-a-coyote** that-which **goes**  
"The one who goes is a coyote" via [Beck, 2013](#)
- (Translation distinction provided for clarity — semantically equivalent)

# Indigenous Peoples' Day

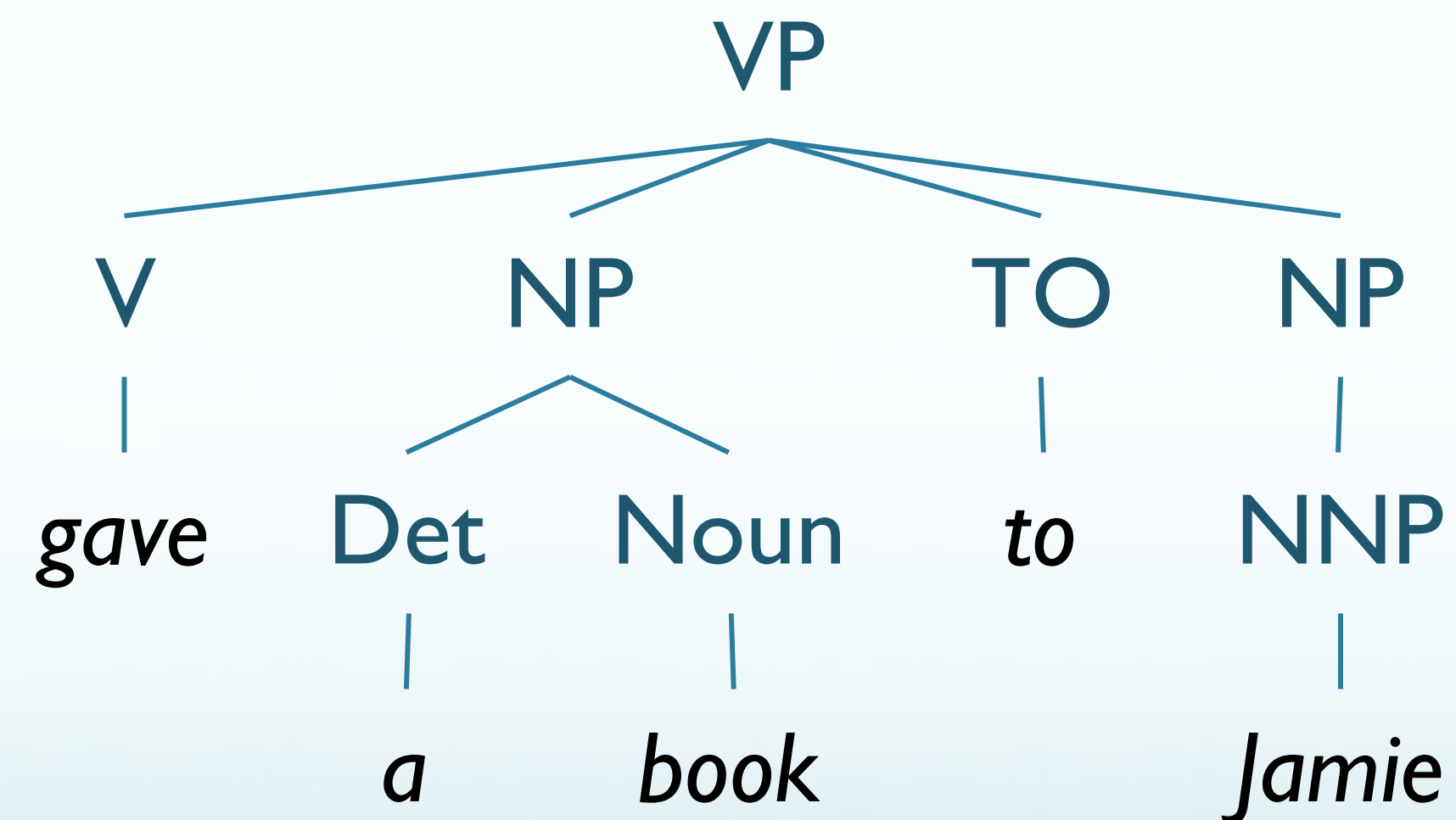
- UW American Indian Studies Courses
- (Sometimes including language courses, e.g. Southern Lushootseed)



# Variation in CNF: Binarization

Original Rule

$VP \rightarrow V NP TO NP$





# Variation in CNF: Binarization

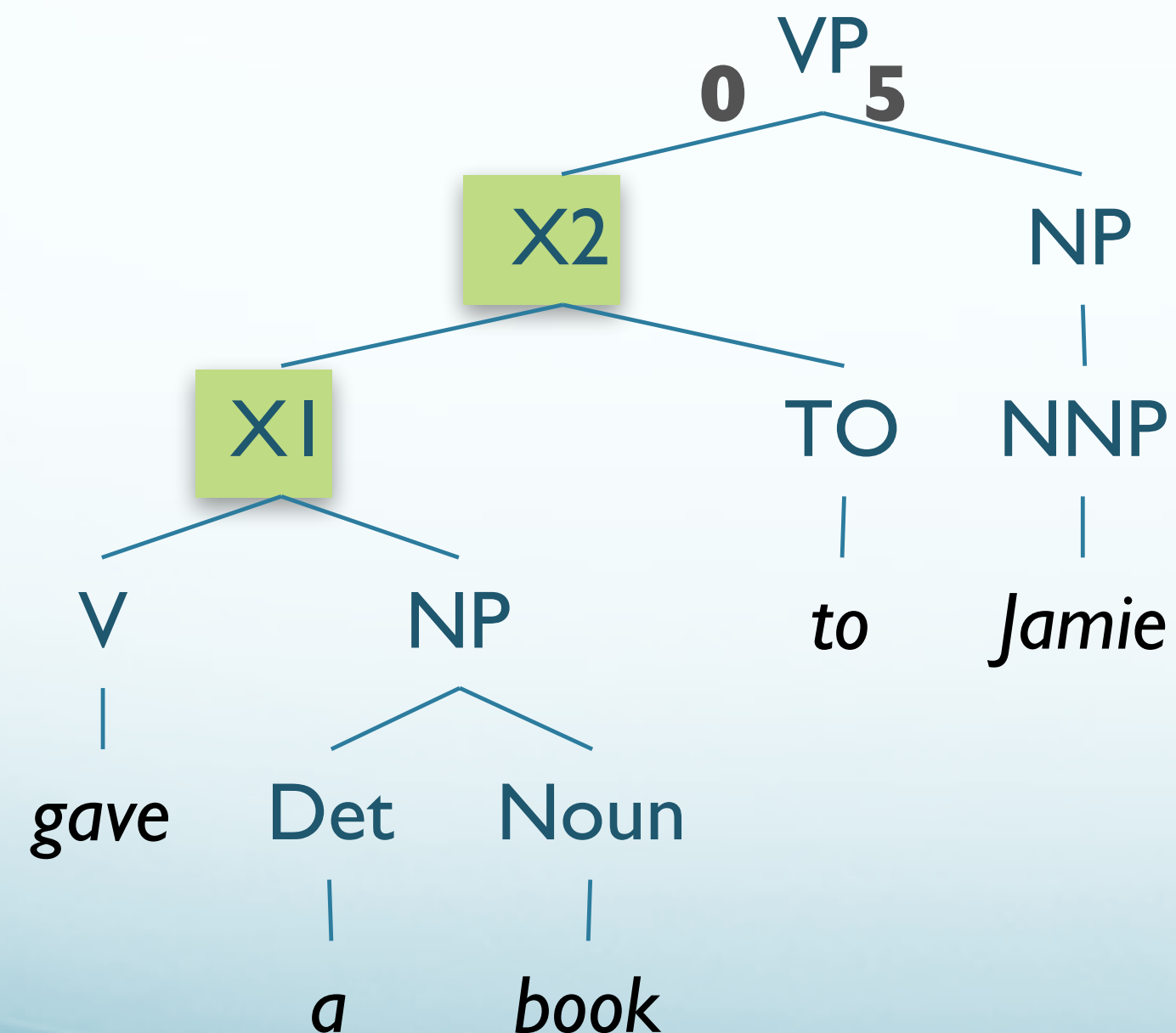
## Original Rule

$VP \rightarrow V NP TO NP$

## Left to Right Reduction

$VP \rightarrow X1 TO NP$        $X1 \rightarrow V NP$

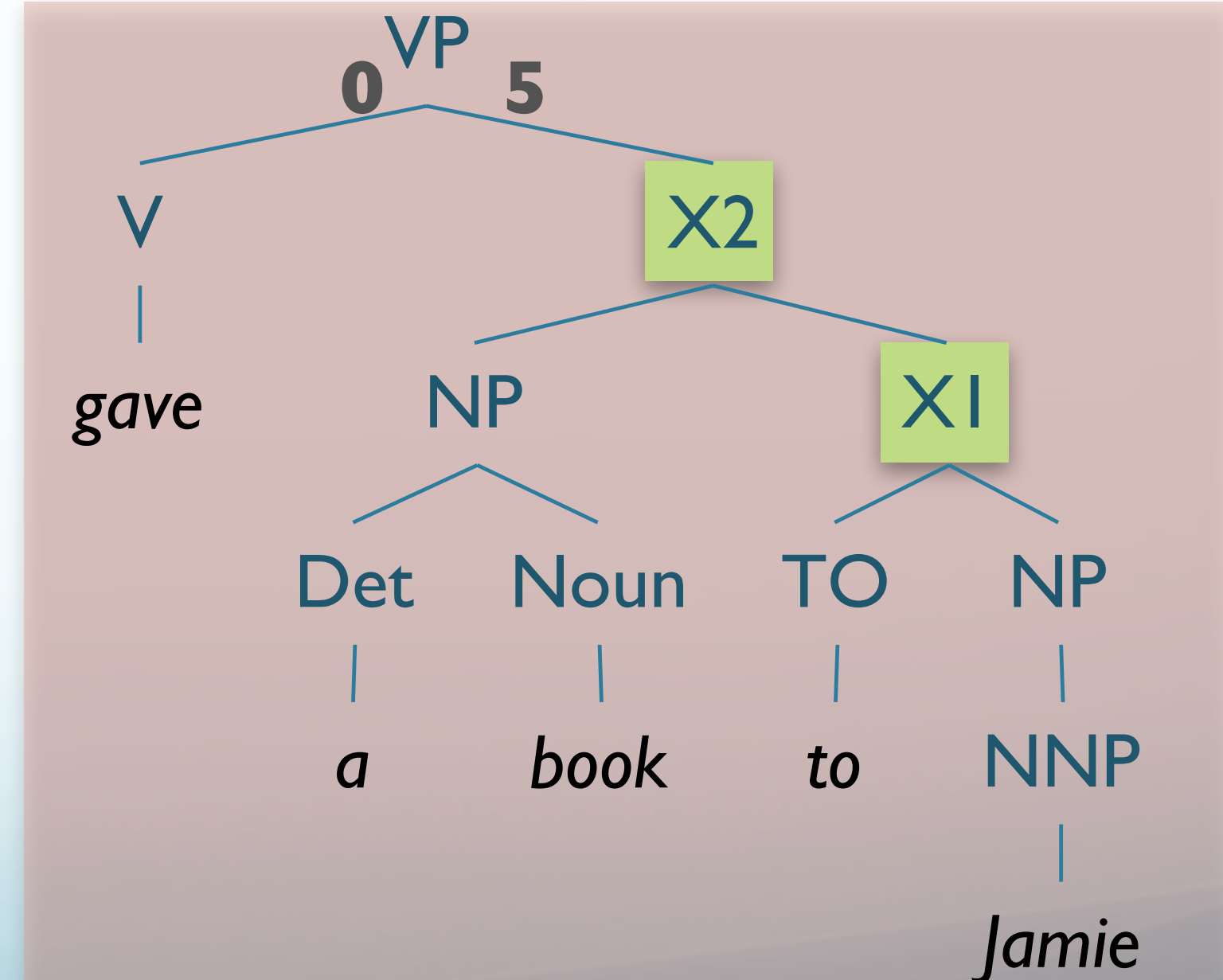
$VP \rightarrow X2 NP$        $X2 \rightarrow X1 TO$



## Right to Left Reduction

$VP \rightarrow V NP X1$        $X1 \rightarrow TO NP$

$VP \rightarrow V X2$        $X2 \rightarrow NP X1$



# Roadmap

- CKY Parsing Algorithm
  - Dynamic programming structure
  - Algorithm and example
  - Analysis & Discussion
- Probabilistic CFGs
  - Motivation: Ambiguity
  - Augmenting CFGs with probabilities

# CKY

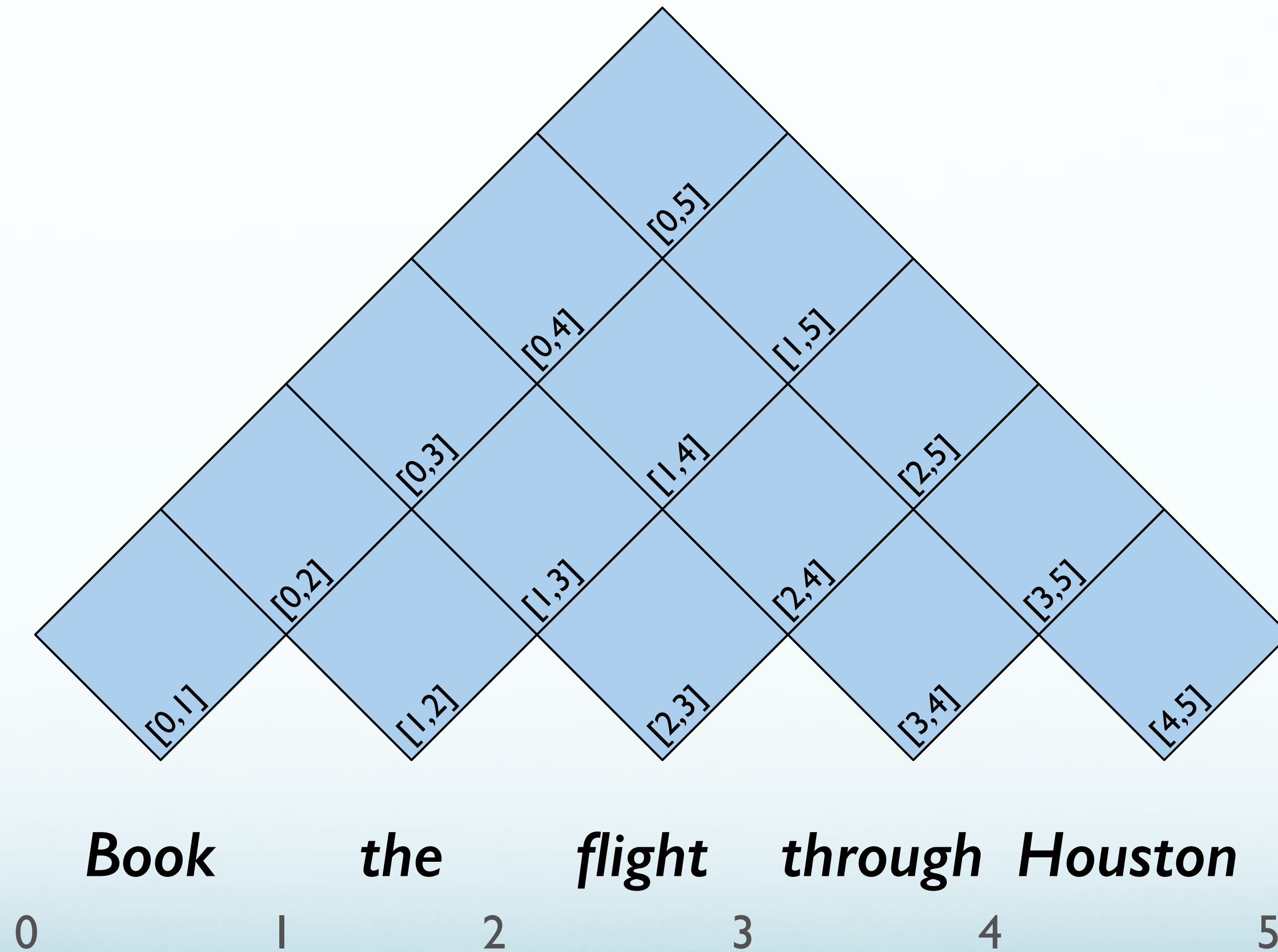
- Given an input string  $S$  of length  $n$
- Build table  $(n + 1) \times (n + 1)$ 
  - Indexes correspond to inter-word positions
  - $_0$  Book  $_1$  that  $_2$  flight  $_3$
- Each cell  $[i, j]$  contains SETS  $\{ \}$  of non-terminals with derivations spanning  $i, j$ 
  - $[j - 1, j]$  contains pre-terminals
  - if  $[0, n]$  contains the start symbol, the sentence is **accepted**

# CKY Matrix

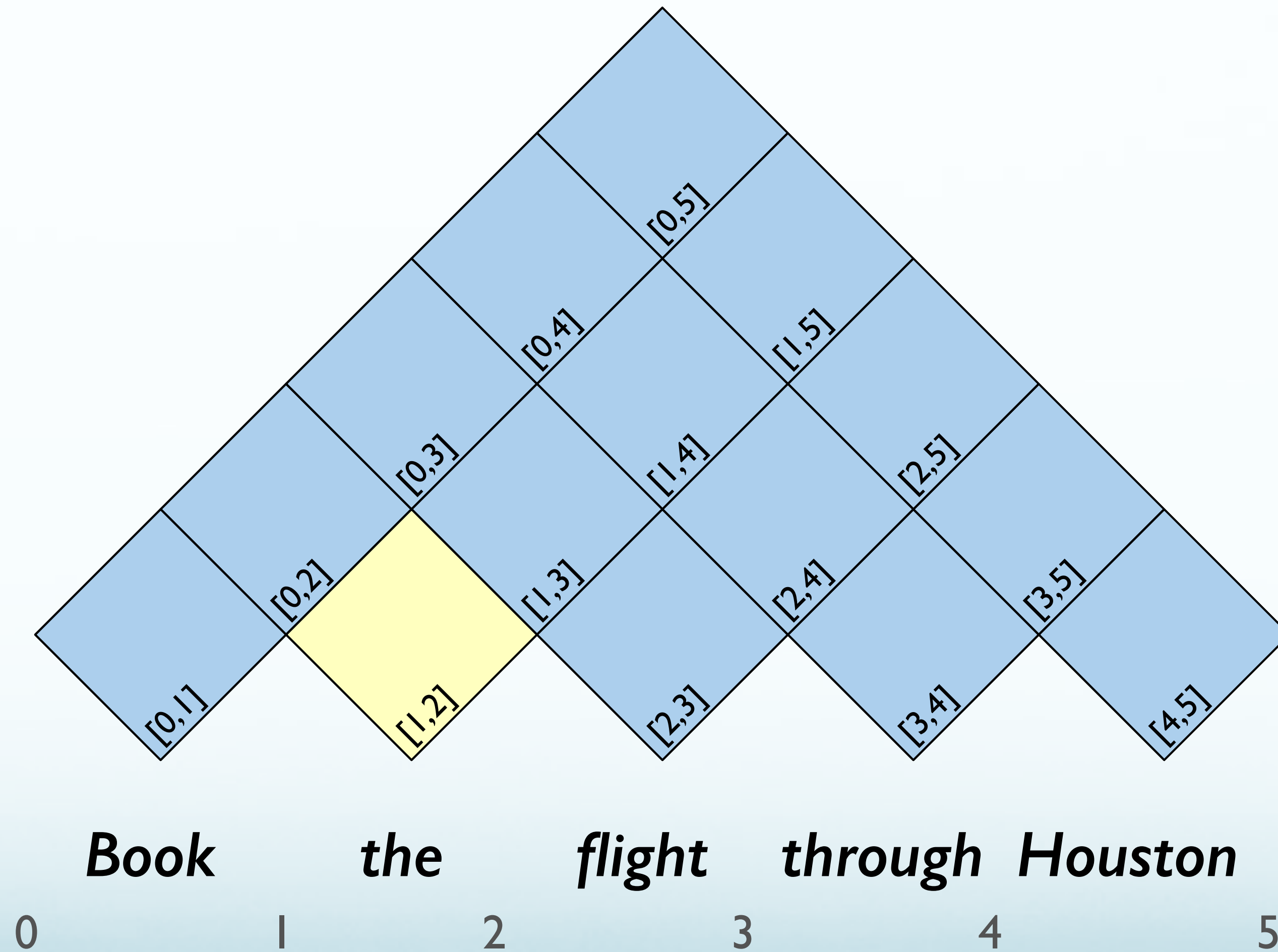
<i>Book</i>	<i>the</i>	<i>flight</i>	<i>through</i>	<i>Houston</i>
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]
	[1,2]	[1,3]	[1,4]	[1,5]
		[2,3]	[2,4]	[2,5]
			[3,4]	[3,5]
				[4,5]



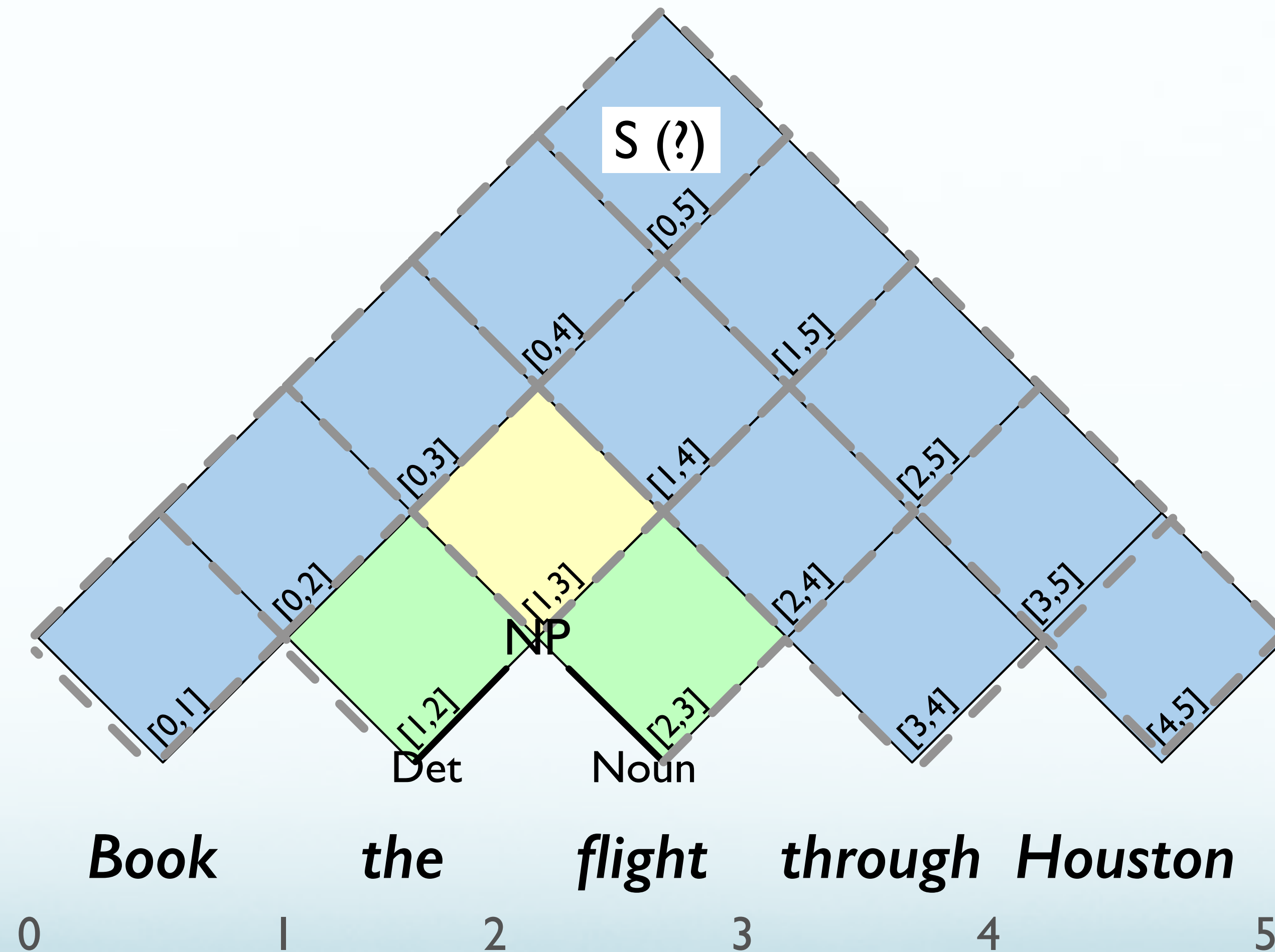
# CKY Matrix



# CKY Matrix



# CKY Matrix



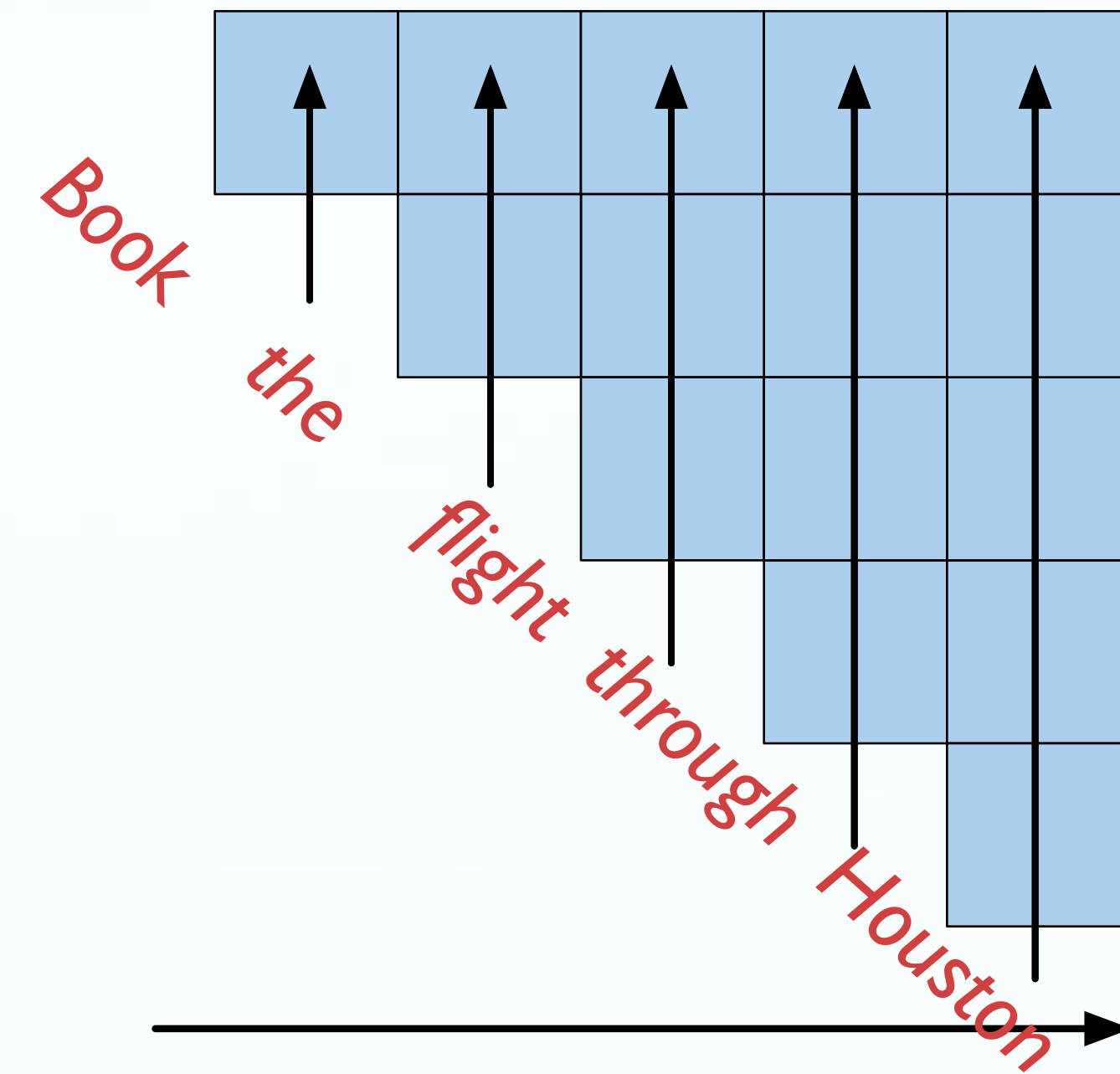
# Dynamic Programming in CKY

- 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

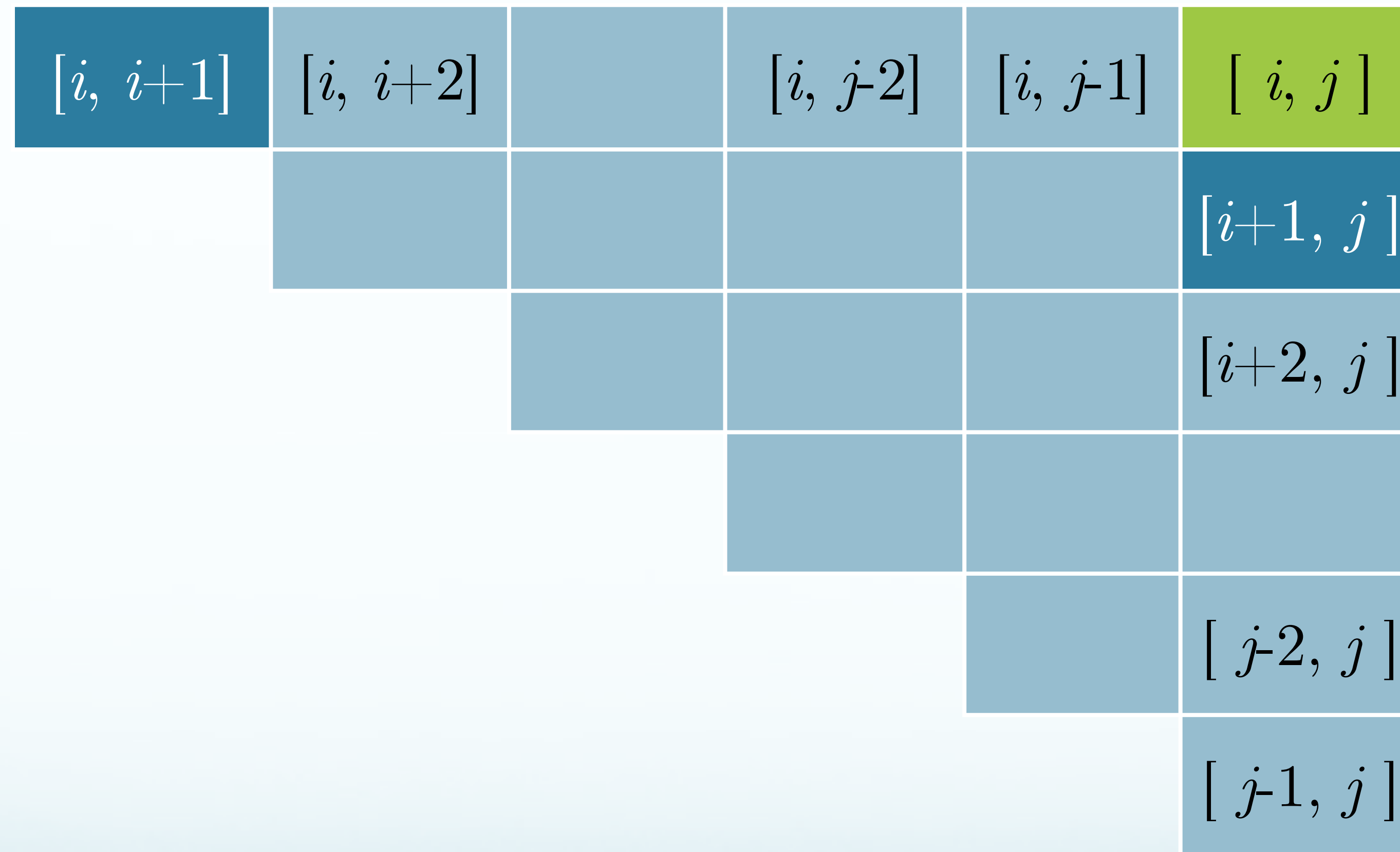


# CKY Algorithm

```
function CKY-PARSE(words, grammar) returns table
for j ← from 1 to LENGTH(words) do
  table[ j - 1, j ] ← { A | A → words[ j ] ∈ grammar }
  for i ← from j - 2 downto 0 do
    for k ← i + 1 to j - 1 do
      table[ i, j ] ← table[ i, j ] ∪
        { A | A → BC ∈ grammar
          B ∈ table[ i, k ],
          C ∈ table[ k, j ] }
```

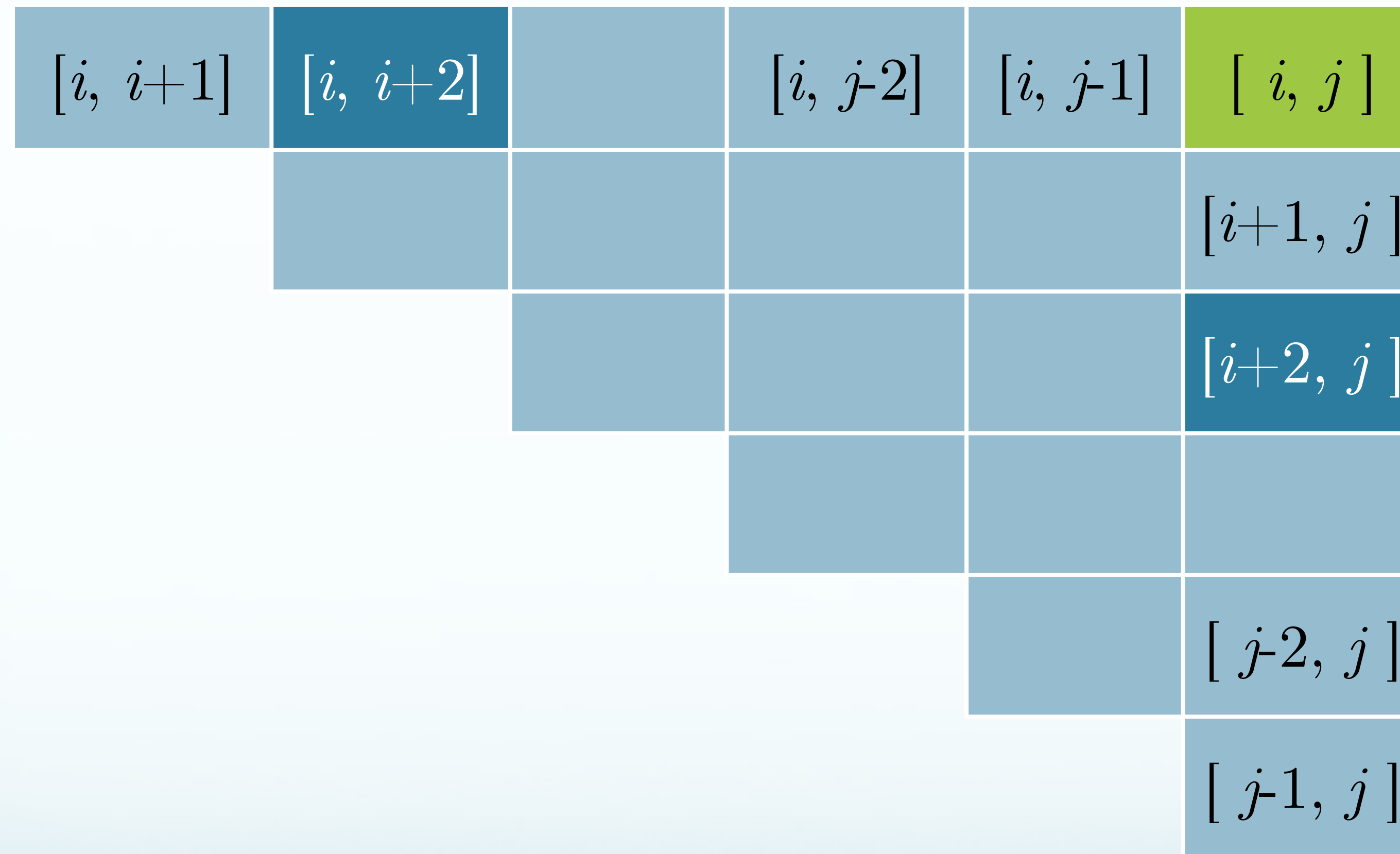
- Left-to-right, bottom-to-top
- Sliding *k* as the pivot for child nodes
- Filling the cell with set of applicable rules

# Filling Cell $[i, j]$



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

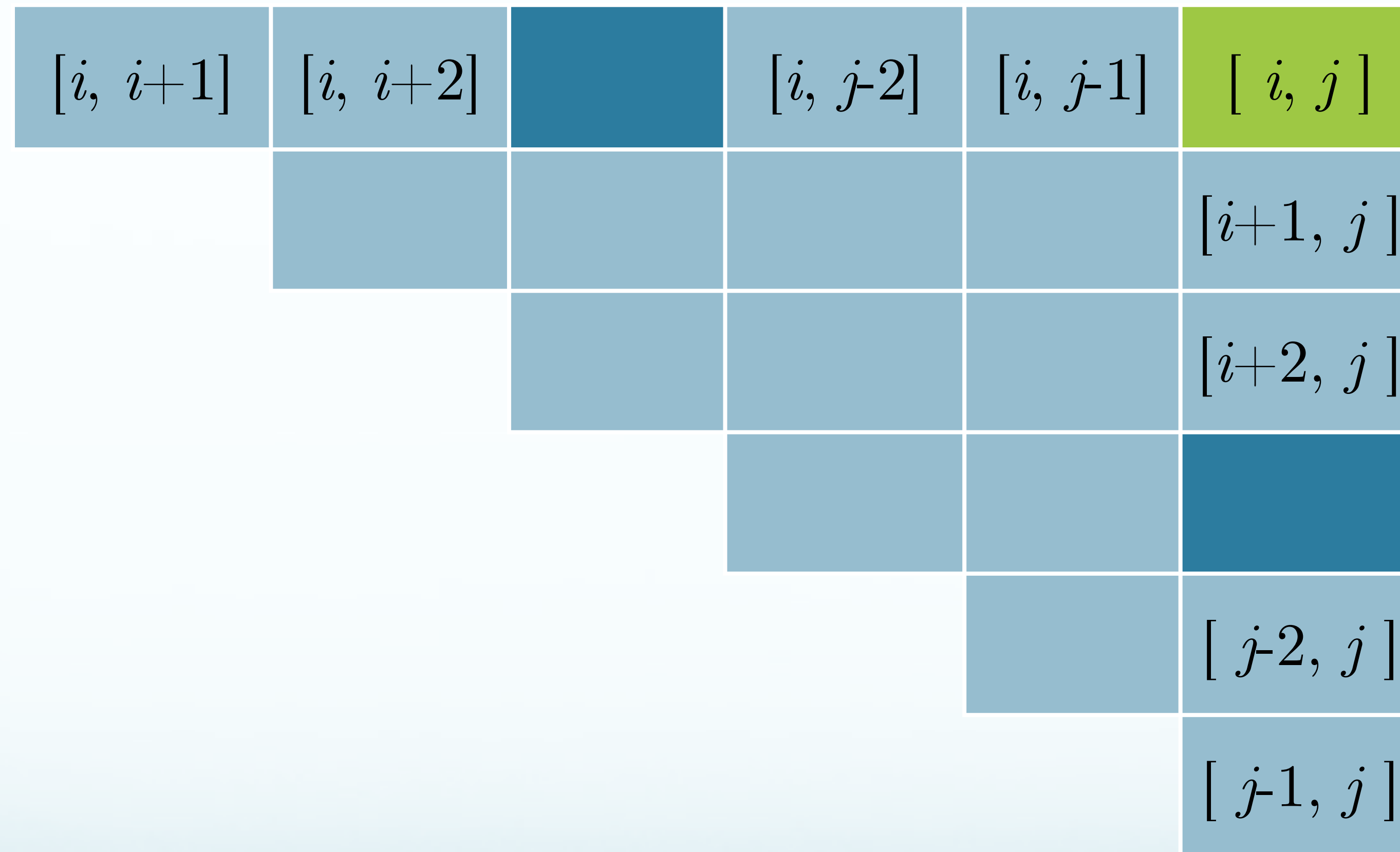
# Filling Cell [i, j]



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

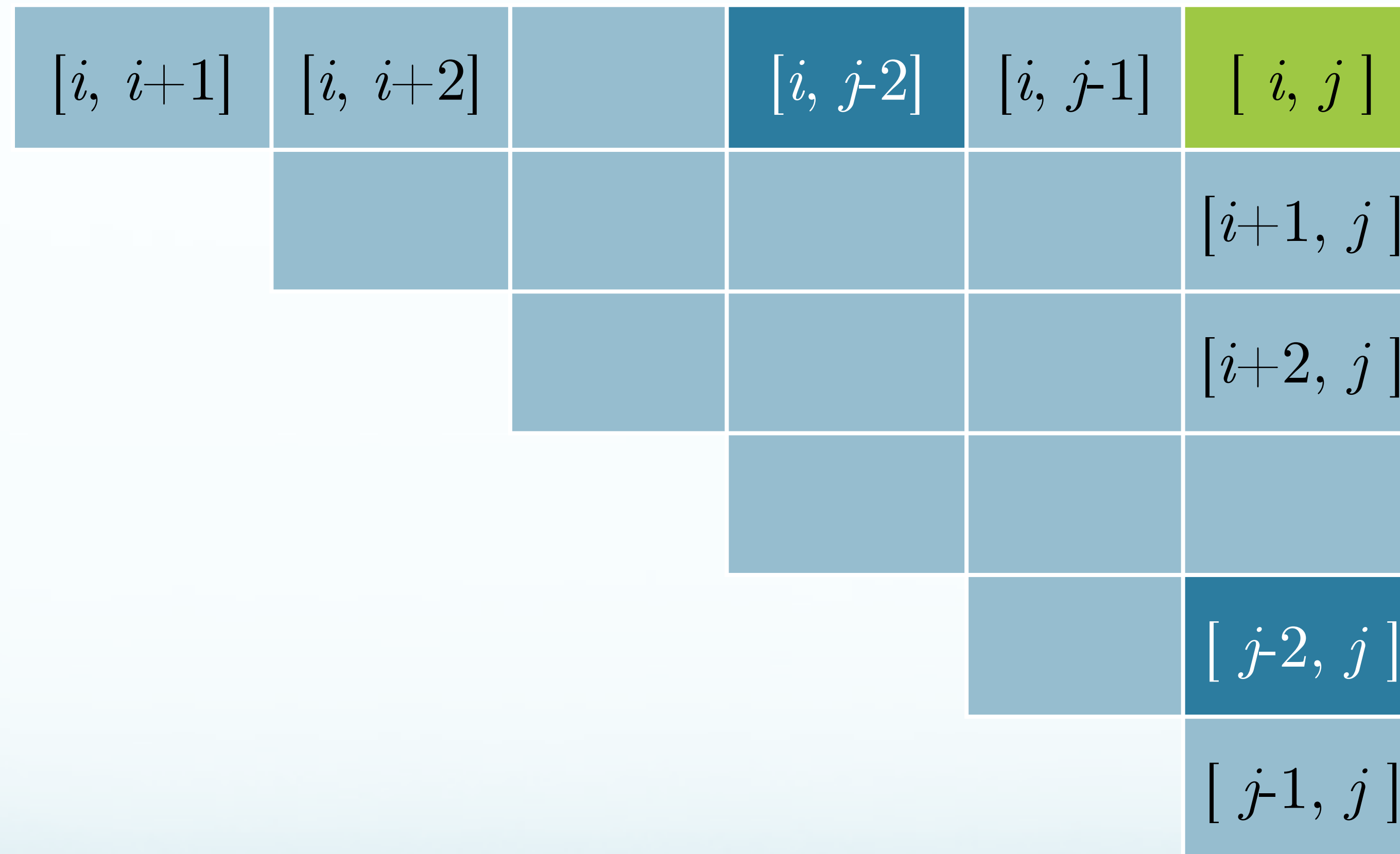


# Filling Cell $[i, j]$



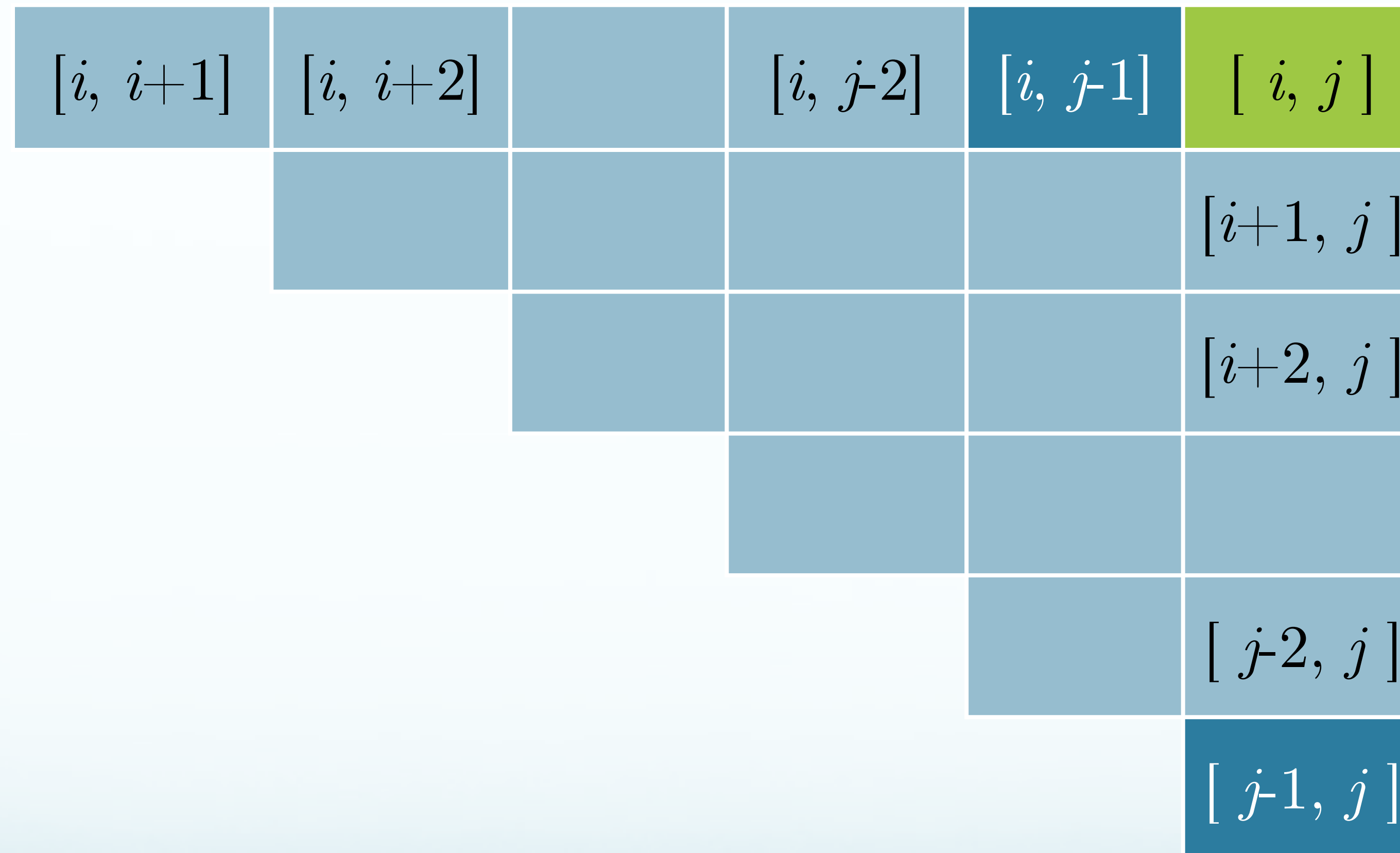
For cell  $[i, j]$ , find rule spanning cells  $[i, k]$  and  $[k, j]$  where  $i < k < j$

# Filling Cell $[i, j]$



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

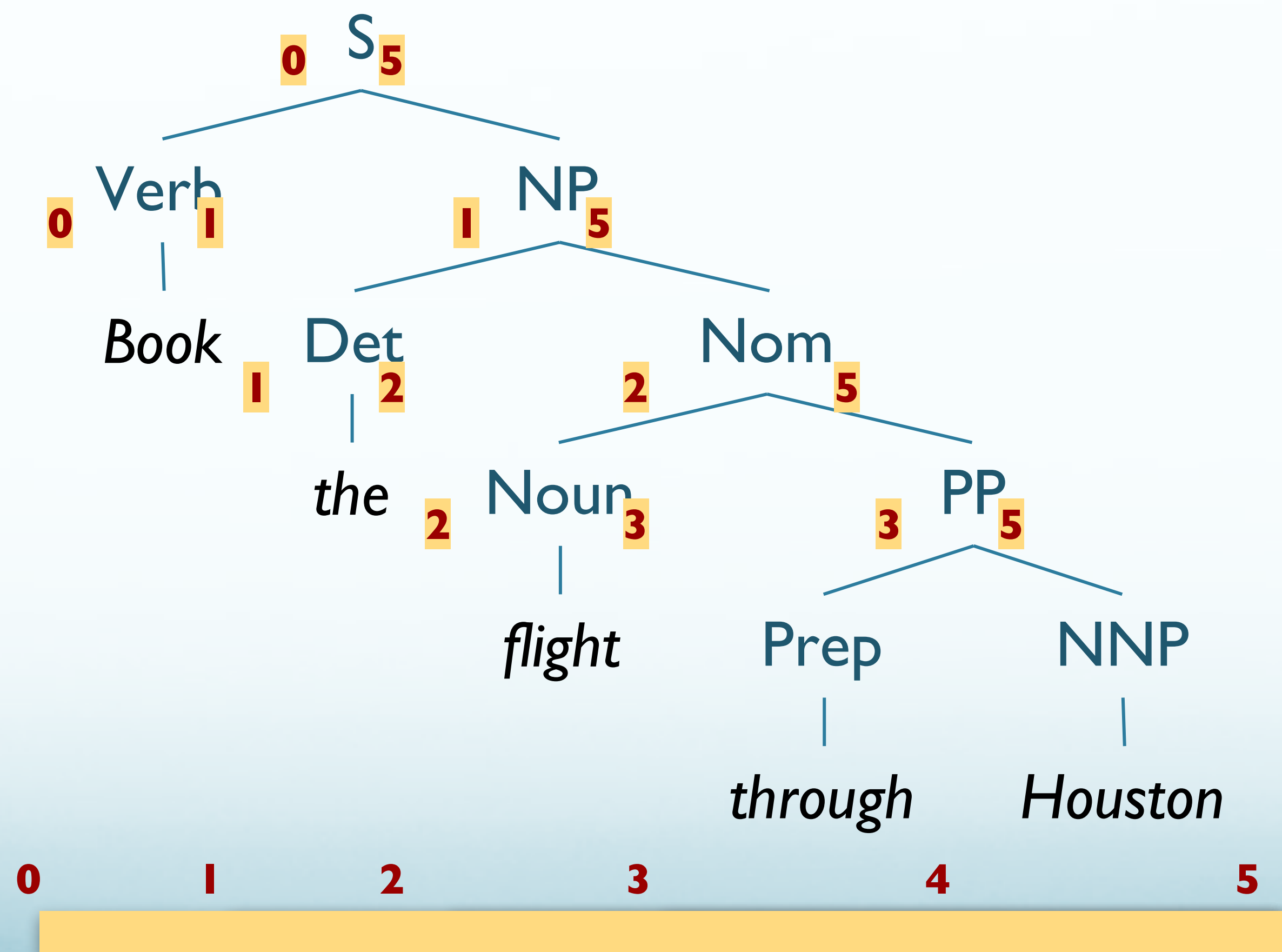
# Filling Cell $[i, j]$



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

# Why fill cells this way?

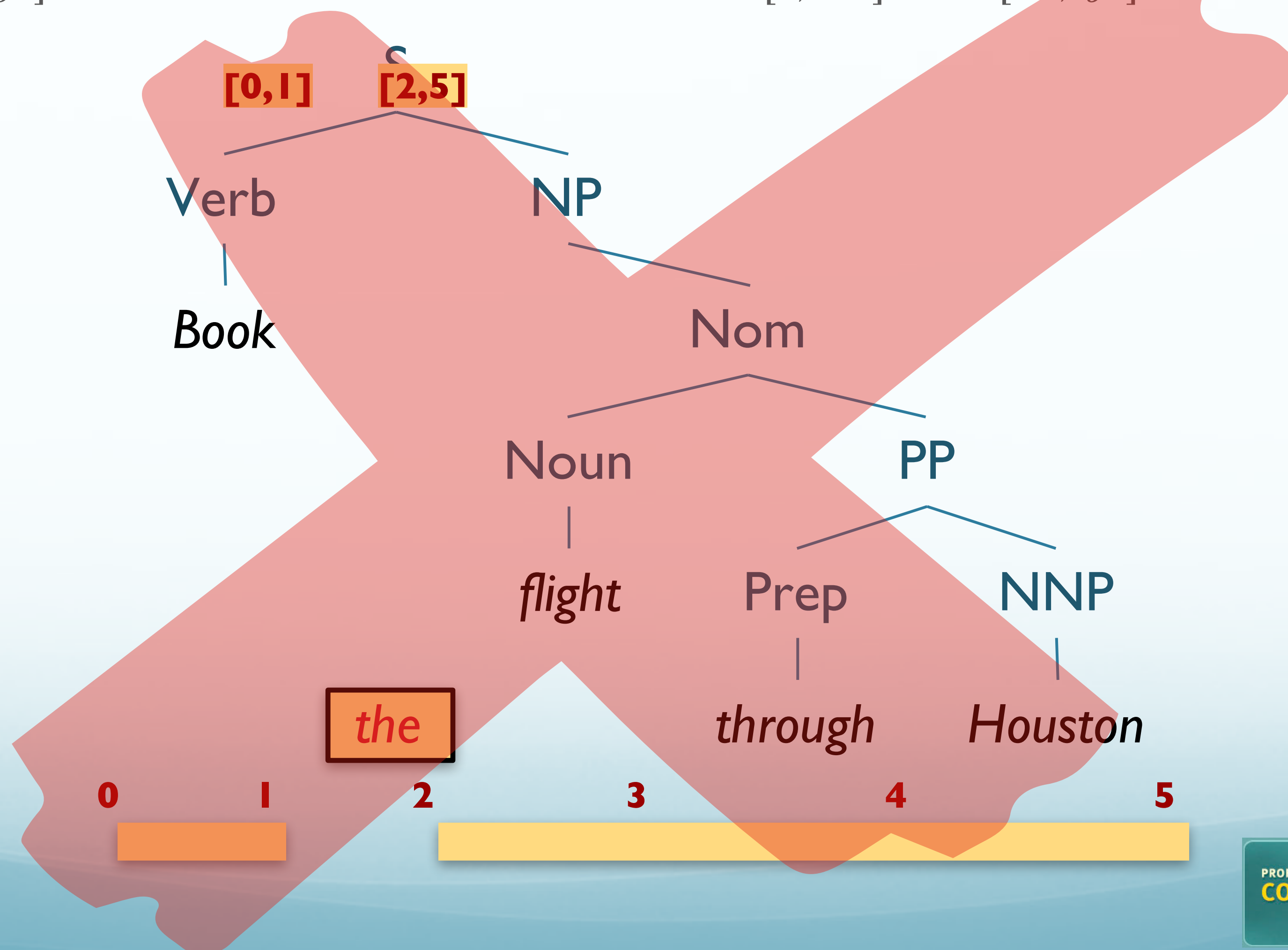
- For cell  $[i, j]$ , must be able to access all cells  $[i, k]$  and  $[k, j]$  where  $i < k < j$





# 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

**$\mathcal{L}_1$  Grammar**

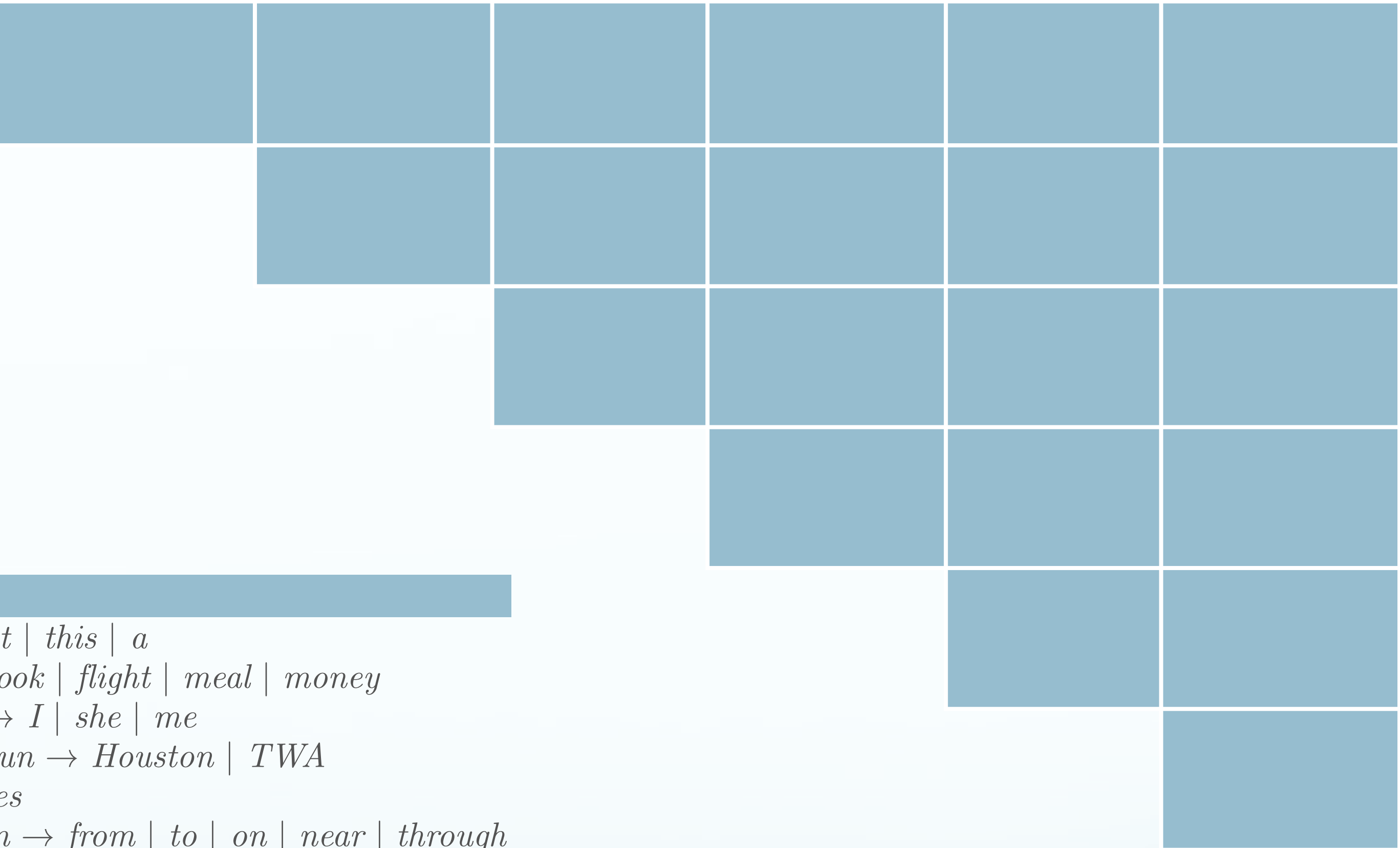
$S \rightarrow NP\ VP$   
 $S \rightarrow X1\ VP$   
 $X1 \rightarrow Aux\ NP$   
 $S \rightarrow book\ /\ include\ /\ prefer$   
 $S \rightarrow Verb\ NP$   
 $S \rightarrow X2\ PP$   
 $S \rightarrow Verb\ PP$   
 $S \rightarrow VP\ PP$

$NP \rightarrow I\ /\ she\ /\ me$   
 $NP \rightarrow TWA\ /\ Houston$   
 $NP \rightarrow Det\ Nominal$   
 $Nominal \rightarrow book\ /\ flight\ /\ meal\ /\ money$   
 $Nominal \rightarrow Nominal\ Noun$   
 $Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$   
 $PP \rightarrow Preposition\ NP$

**Lexicon**

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



0                      1                      2                      3                      4                      5                      6

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

$\mathcal{L}_1$  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

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-Noun  $\rightarrow$  Houston | TWA

Aux  $\rightarrow$  does

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

Verb  $\rightarrow$  book | include | prefer





## $\mathcal{L}_1$ Grammar

$$S \rightarrow NP VP$$
$$S \rightarrow X1 \text{ VP}$$
$$X1 \rightarrow Aux NP$$

$S \rightarrow book / include / prefer$

$$S \rightarrow Verb\ NP$$
$$S \rightarrow X2 PP$$
$$S \rightarrow Verb PP$$
$$S \rightarrow VP \ PP$$
$$NP \rightarrow I \mid she \mid me$$

*NP → TWA / Houston*

$$NP \rightarrow Det \textit{ Nominal}$$

*Nominal*  $\rightarrow$  *book* / *flight* / *meal* / *money*

*Nominal*  $\rightarrow$  *Nominal Noun*

*Nominal*  $\rightarrow$  *Nominal PP*

$VP \rightarrow book / include / prefer$

$$VP \rightarrow Verb\ NP$$
$$VP \rightarrow X^2 PP$$
$$X2 \rightarrow Verb\ NP$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP \ PP$$

$PP \rightarrow Preposition\ NP$

**NP,  
Pronoun**  
[0,1]

## Lexicon

$$Det \rightarrow that \mid this \mid a$$

Noun → book | flight | meal | money

*Pronoun*  $\rightarrow$  *I* | *she* | *me*

*Proper-Noun*  $\rightarrow$  *Houston* | *TWA*

*Aux*  $\rightarrow$  *does*

*Preposition* → *from* | *to* | *on* | *near* | *through*

*Verb*  $\rightarrow$  *book* | *include* | *prefer*



*prefer*

*a*

*flight*

*on*

**TWA**

## $\mathcal{L}_1$ Grammar

$$S \rightarrow NP VP$$

$S \rightarrow X1 \text{ VP}$

$X1 \rightarrow Aux NP$

$S \rightarrow \text{book} / \text{include} / \text{prefer}$

$$S \rightarrow Verb\ NP$$
$$S \rightarrow X2 PP$$
$$S \rightarrow Verb PP$$

$NR \rightarrow I / ch_2 / m_2$

$NP \Rightarrow I / she / me$   
 $NP \Rightarrow TWA / Houston$

$$NP \Rightarrow Det\ Nominal$$

*Nominal*  $\rightarrow$  *book* / *flight* / *meal* / *money*

*Nominal* → *Nominal Noun*

### Nominal $\rightarrow$ Nominal PP

$VP \rightarrow book / include / prefer$

$$VP \rightarrow Verb\ NP$$
$$VP \rightarrow X^2 PP$$
$$X2 \rightarrow Verb\ NP$$
$$VP \rightarrow Verb PP$$

$VP \rightarrow VP PP$

---

$PP \rightarrow \text{Preposition } NP$

---

100%

# NP, Pronoun [0,1]

**Verb, VP, S**

[1,2]

\_\_\_\_\_

## Lexicon

*Det* → *that* | *this* | *a*

*Noun*  $\rightarrow$  *book* | *flight* | *meal* | *money*

*Pronoun*  $\rightarrow$  *I* | *she* | *me*

*Proper-Noun*  $\rightarrow$  *Houston* | *TWA*

*Aux*  $\rightarrow$  *does*  
*Proposition*  $\rightarrow$  *from* | *to* | *on* | *near* | *through*

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

verb / noun | include | prefer

0

1

2

3

4

5

6

30

## $\mathcal{L}_1$ Grammar

$$S \rightarrow NP VP$$
$$S \rightarrow X1 \text{ VP}$$
$$X1 \rightarrow Aux NP$$

$S \rightarrow book / include / prefer$

$$S \rightarrow Verb\ NP$$
$$S \rightarrow X2 PP$$
$$S \rightarrow Verb PP$$
$$S \rightarrow VP \ PP$$
$$NP \rightarrow I \mid she \mid me$$

*NP → TWA / Houston*

$$NP \rightarrow Det \textit{ Nominal}$$

*Nominal*  $\rightarrow$  *book* / *flight* / *meal* / *money*

*Nominal*  $\rightarrow$  *Nominal Noun*

*Nominal*  $\rightarrow$  *Nominal PP*

$VP \rightarrow book / include / prefer$

$$VP \rightarrow Verb\ NP$$
$$VP \rightarrow X^2 PP$$
$$X2 \rightarrow Verb\ NP$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP \ PP$$

$PP \rightarrow \textit{Preposition NP}$

# NP, Pronoun [0, I]

$[0,2]$

**Verb, VP, S**

[1,2]

## Lexicon

$$Det \rightarrow that \mid this \mid a$$

*Noun*  $\rightarrow$  *book* | *flight* | *meal* | *money*

*Pronoun*  $\rightarrow$  *I* | *she* | *me*

*Proper-Noun*  $\rightarrow$  *Houston* | *TWA*

*Aux* → *does*

*Preposition* → *from* | *to* | *on* | *near* | *through*

*Verb*  $\rightarrow$  *book* | *include* | *prefer*

1

prefer

0 1 2

1

prefer

0 1 2

A horizontal bar chart with a green bar extending from 0 to 1 on a scale from 0 to 2. The word "prefer" is written next to the bar.

A horizontal bar chart with a green bar extending from 0 to 1 on a scale from 0 to 2. The word "prefer" is written next to the bar.

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$\mathcal{L}_1$  Grammar

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

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

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

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

$PP \rightarrow Preposition\ NP$

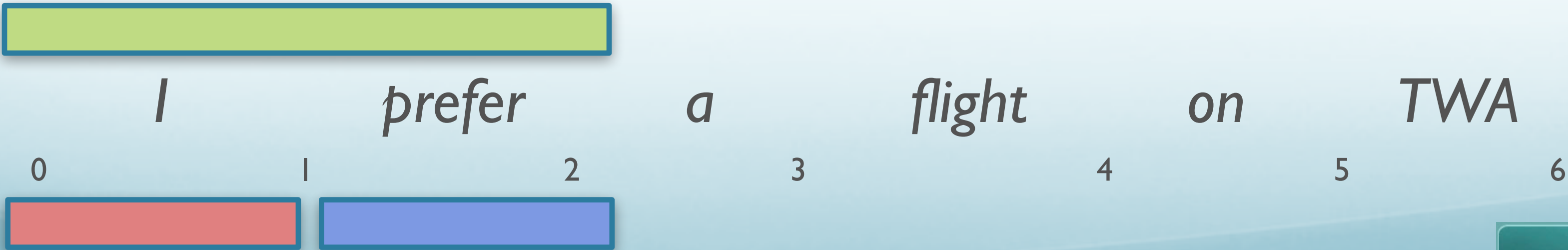
NP, Pronoun  
[0,1]

[0,2]

Verb, VP, S  
[1,2]

Lexicon

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







## $\mathcal{L}_1$ Grammar

$$S \rightarrow NP VP$$
$$S \rightarrow X1 \text{ VP}$$
$$X1 \rightarrow Aux NP$$

$S \rightarrow book / include / prefer$

$$S \rightarrow Verb\ NP$$
$$S \rightarrow X^2 PP$$
$$S \rightarrow Verb PP$$
$$S \rightarrow VP \ PP$$

$NP \rightarrow I \mid she \mid me$

*NP* → *TWA* / *Houston*

$$NP \rightarrow Det \textit{ Nominal}$$

*Nominal*  $\rightarrow$  *book* / *flight* / *meal* / *money*

*Nominal*  $\rightarrow$  *Nominal Noun*

*Nominal*  $\rightarrow$  *Nominal PP*

$VP \rightarrow book / include / prefer$

$$VP \rightarrow Verb\ NP$$
$$VP \rightarrow X^2 PP$$
$$X2 \rightarrow Verb\ NP$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP PP$$

---

$PP \rightarrow \textit{Preposition NP}$

**NP,**  
**Pronoun**  
[0,1]

**S**

**[0,2]**

**Verb, VP, S**

**[1,2]**

## Lexicon

*Det*  $\rightarrow$  *that* | *this* | *a*

*Noun*  $\rightarrow$  *book* | *flight* | *meal* | *money*

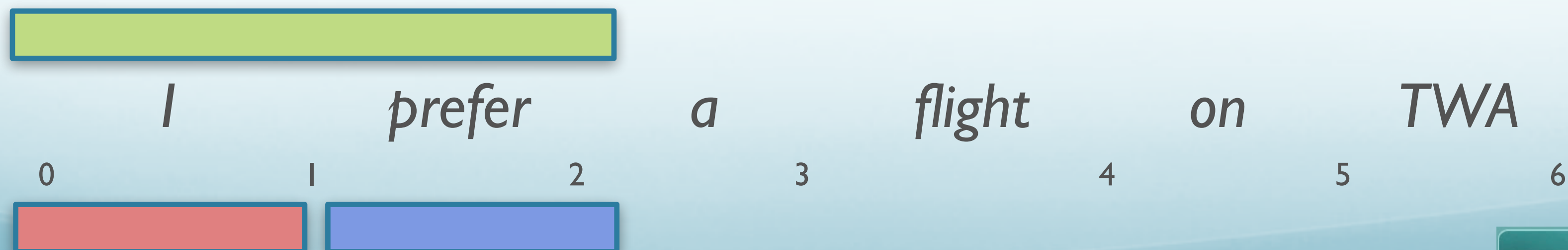
*Pronoun*  $\rightarrow$  *I* | *she* | *me*

*Proper-Noun*  $\rightarrow$  *Houston* | *TWA*

*Aux*  $\rightarrow$  *does*

*Preposition* → *from* | *to* | *on* | *near* | *through*

*Verb*  $\rightarrow$  *book* | *include* | *prefer*









## $\mathcal{L}_1$ Grammar

---


$$S \rightarrow NP VP$$
$$S \rightarrow X1 \quad VP$$
$$X1 \rightarrow Aux NP$$

$S \rightarrow book / include / prefer$

$$S \rightarrow Verb\ NP$$
$$S \rightarrow X2 PP$$
$$S \rightarrow Verb PP$$
$$S \rightarrow VP \ PP$$

$NP \rightarrow I \mid she \mid me$

*NP → TWA / Houston*

$$NP \rightarrow Det \textit{ Nominal}$$

*Nominal*  $\rightarrow$  *book* / *flight* / *meal* / *money*

*Nominal*  $\rightarrow$  *Nominal Noun*

*Nominal*  $\rightarrow$  *Nominal PP*

$VP \rightarrow book / include / prefer$

$$VP \rightarrow Verb\ NP$$
$$VP \rightarrow X^2 PP$$
$$X2 \rightarrow Verb\ NP$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP \ PP$$

---

$PP \rightarrow \textit{Preposition NP}$

# NP, Pronoun [0, 1]

**S**

**[0,2]**

[0,2]

**Verb, VP, S**

**[1,2]**

[1,2]

**Det**

**[2,3]**

[2,3]

## Lexicon

*Det* → *that* | *this* | *a*

*Noun* → *book* | *flight* | *meal* | *money*

$$\textit{Pronoun} \rightarrow I \mid she \mid me$$

*Proper-Noun*  $\rightarrow$  *Houston* | *TWA*

*Aux*  $\rightarrow$  *does*

*Preposition* → *from* | *to* | *on* | *near* | *through*

*Verb*  $\rightarrow$  *book* | *include* | *prefer*

1

*prefer*

a

*flight*

*on*

**TWA**



## $\mathcal{L}_1$ Grammar

---


$$S \rightarrow NP \ VP$$
$$S \rightarrow X1 \quad VP$$
$$X1 \rightarrow Aux NP$$

$S \rightarrow book / include / prefer$

$$S \rightarrow Verb\ NP$$
$$S \rightarrow X2 PP$$
$$S \rightarrow Verb PP$$
$$S \rightarrow VP \ PP$$

$NP \rightarrow I \mid she \mid me$

*NP → TWA / Houston*

$$NP \rightarrow Det \textit{ Nominal}$$

*Nominal*  $\rightarrow$  *book* / *flight* / *meal* / *money*

*Nominal*  $\rightarrow$  *Nominal Noun*

*Nominal*  $\rightarrow$  *Nominal PP*

$VP \rightarrow book / include / prefer$

$$VP \rightarrow Verb\ NP$$
$$VP \rightarrow X_2 PP$$
$$X2 \rightarrow Verb\ NP$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP PP$$

---

$PP \rightarrow Preposition\ NP$

# NP, Pronoun [0,1]

**S**

**[0,2]**

[0,2]

**Verb, VP, S**

[1,2]

[1,2]

[1,3]

**Det**  
[2,3]

[2,3]

## Lexicon

$$Det \rightarrow that \mid this \mid a$$

*Noun*  $\rightarrow$  *book* | *flight* | *meal* | *money*

$$Pronoun \rightarrow I \mid she \mid me$$

*Proper-Noun*  $\rightarrow$  *Houston* | *TWA*

*Aux*  $\rightarrow$  *does*

*Preposition* → *from* | *to* | *on* | *near* | *through*

*Verb*  $\rightarrow$  *book* | *include* | *prefer*

I prefer a

*prefer*      *a*

$a$

*flight*

*on*

TWA



## $\mathcal{L}_1$ Grammar

---

$S \rightarrow NP VP$

$$S \rightarrow X1 \quad VP$$
$$X1 \rightarrow Aux NP$$

$S \rightarrow book / include / prefer$

$$S \rightarrow Verb\ NP$$
$$S \rightarrow X2 PP$$
$$S \rightarrow Verb PP$$
$$S \rightarrow VP \ PP$$

---

$NP \rightarrow I \mid she \mid me$

*NP → TWA / Houston*

$$NP \rightarrow Det \textit{ Nominal}$$

*Nominal*  $\rightarrow$  *book* / *flight* / *meal* / *money*

*Nominal*  $\rightarrow$  *Nominal Noun*

*Nominal*  $\rightarrow$  *Nominal PP*

$VP \rightarrow book / include / prefer$

$$VP \rightarrow Verb\ NP$$
$$VP \rightarrow X^2 PP$$
$$X2 \rightarrow Verb\ NP$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP PP$$

---

*PP*  $\rightarrow$  *Preposition NP*

## NP, Pronoun [0,1]

**S**

**[0,2]**

[0,2]

**Verb, VP, S**

[1,2]

[1,2]

[1,3]

**Det**

[2,3]

[2,3]

## Lexicon

$$Det \rightarrow that \mid this \mid a$$

*Noun*  $\rightarrow$  *book* | *flight* | *meal* | *money*

$$\textit{Pronoun} \rightarrow I \mid she \mid me$$

*Proper-Noun*  $\rightarrow$  *Houston* | *TWA*

*Aux* → *does*

*Preposition* → *from* | *to* | *on* | *near* | *through*

*Verb*  $\rightarrow$  *book* | *include* | *prefer*

A horizontal Likert scale with four points labeled 0, 1, 2, and 3. The item 'I prefer a' is centered above the scale. A green bar is positioned above the scale, spanning from point 1 to point 3. Below the scale, there are two colored bars: a red bar from point 1 to point 2, and a blue bar from point 2 to point 3.

A horizontal Likert scale with four points labeled 0, 1, 2, and 3. The item 'I prefer a' is centered above the scale. A green bar is positioned above the scale, spanning from point 1 to point 3. Below the scale, there are two colored bars: a red bar from point 1 to point 2, and a blue bar from point 2 to point 3.

A horizontal Likert scale with four points labeled 0, 1, 2, and 3. The item 'I prefer a' is centered above the scale. A green bar is positioned above the scale, spanning from point 1 to point 3. Below the scale, there are two colored bars: a red bar from point 1 to point 2, and a blue bar from point 2 to point 3.

A horizontal Likert scale with four points labeled 0, 1, 2, and 3. The item 'I prefer a' is centered above the scale. A green bar is positioned above the scale, spanning from point 1 to point 3. Below the scale, there are two colored bars: a red bar from point 1 to point 2, and a blue bar from point 2 to point 3.

A horizontal Likert scale with four points labeled 0, 1, 2, and 3. The item 'I prefer a' is centered above the scale. A green bar is positioned above the scale, spanning from point 1 to point 3. Below the scale, there are two colored bars: a red bar from point 1 to point 2, and a blue bar from point 2 to point 3.

A horizontal Likert scale with four points labeled 0, 1, 2, and 3. The item 'I prefer a' is centered above the scale. A green bar is positioned above the scale, spanning from point 1 to point 3. Below the scale, there are two colored bars: a red bar from point 1 to point 2, and a blue bar from point 2 to point 3.

---

$PP \rightarrow \textit{Preposition NP}$

*Verb*  $\rightarrow$  *book* | *include* | *prefer*

TWA

6





$\mathcal{L}_1$  Grammar

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

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

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

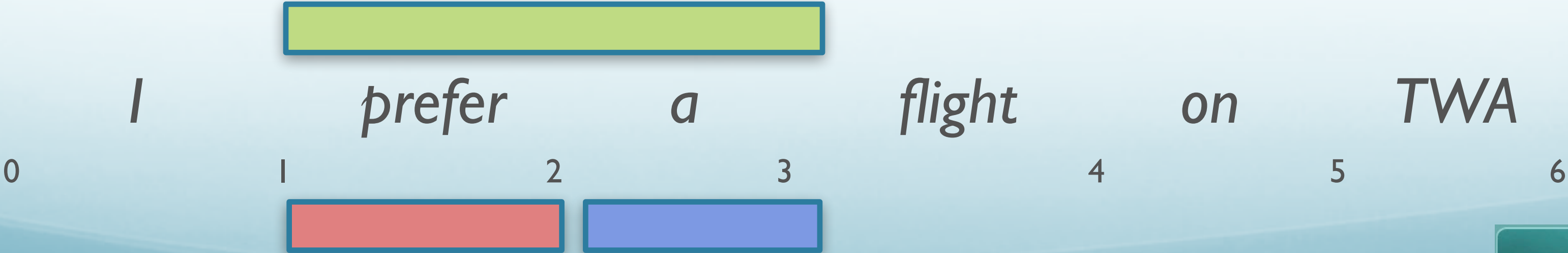
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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





$\mathcal{L}_1$  Grammar

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

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

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

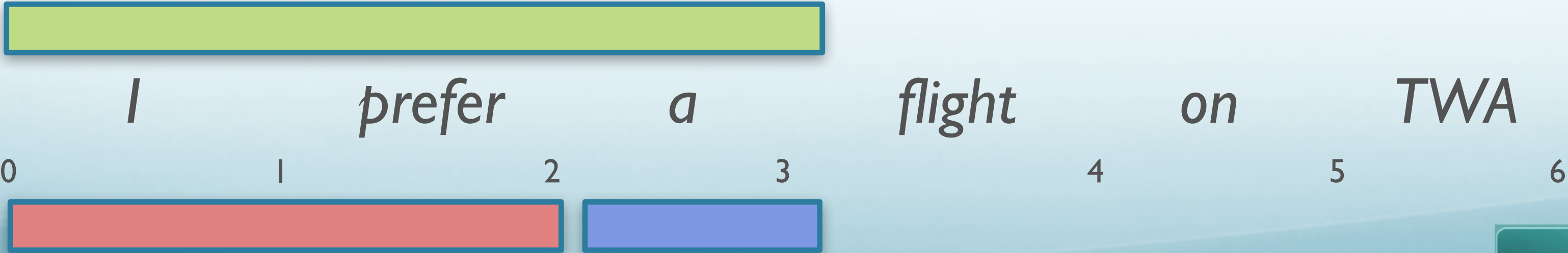
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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



$\mathcal{L}_1$  Grammar

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

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

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

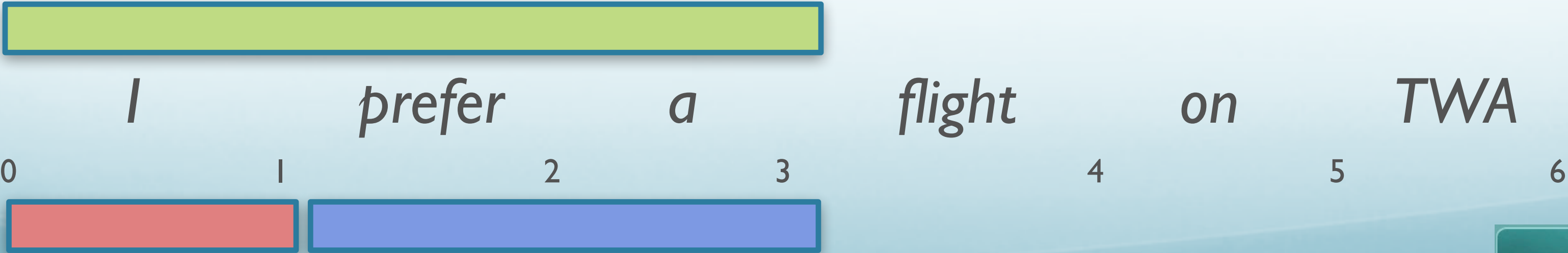
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

NP, Pronoun [0,1]	<div>S</div> <div>[0,2]</div>	<div></div> <div>[0,3]</div>			
	<div>Verb, VP, S</div> <div>[1,2]</div>				
		<div>Det</div> <div>[2,3]</div>			



$\mathcal{L}_1$  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

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

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

I

prefer

a

flight

on

TWA

0

1

2

3

4

5

6



$\mathcal{L}_1$  Grammar

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

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

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

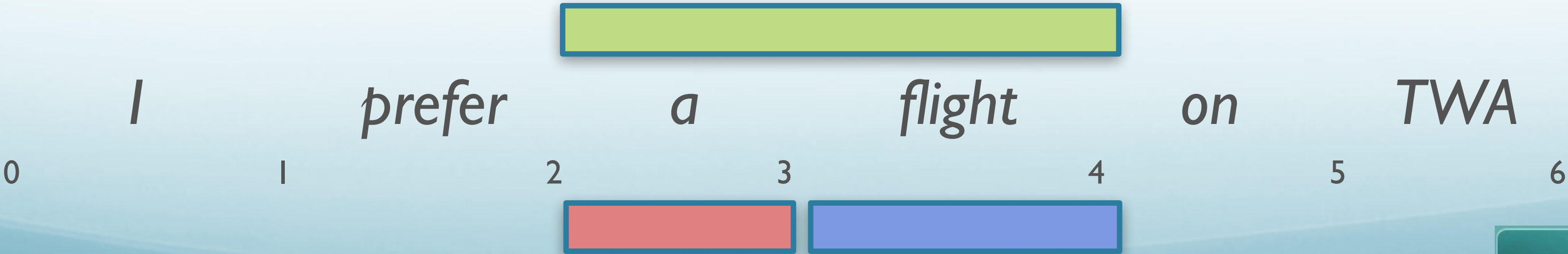
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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







$\mathcal{L}_1$  Grammar

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

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

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

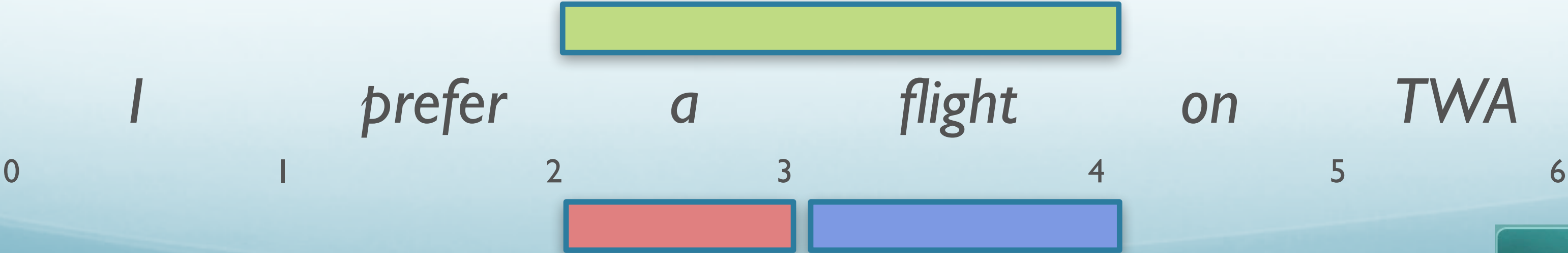
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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]		

Lexicon

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



$\mathcal{L}_1$  Grammar

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

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

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

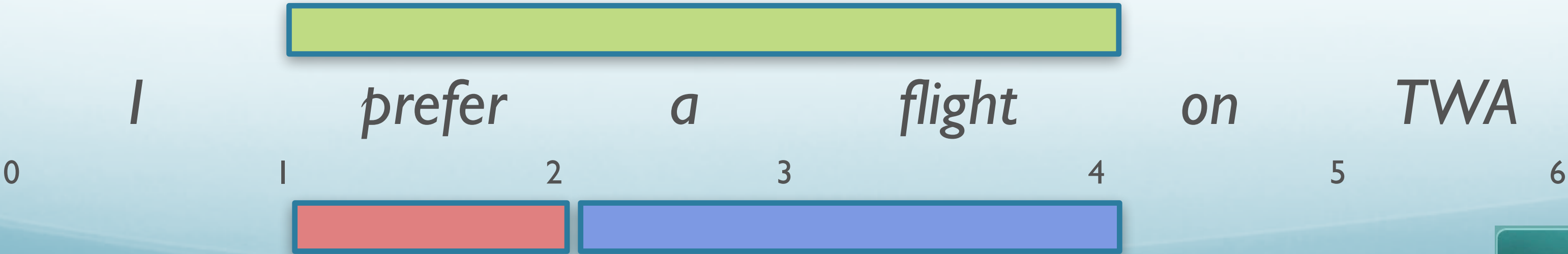
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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





$\mathcal{L}_1$  Grammar

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

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

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

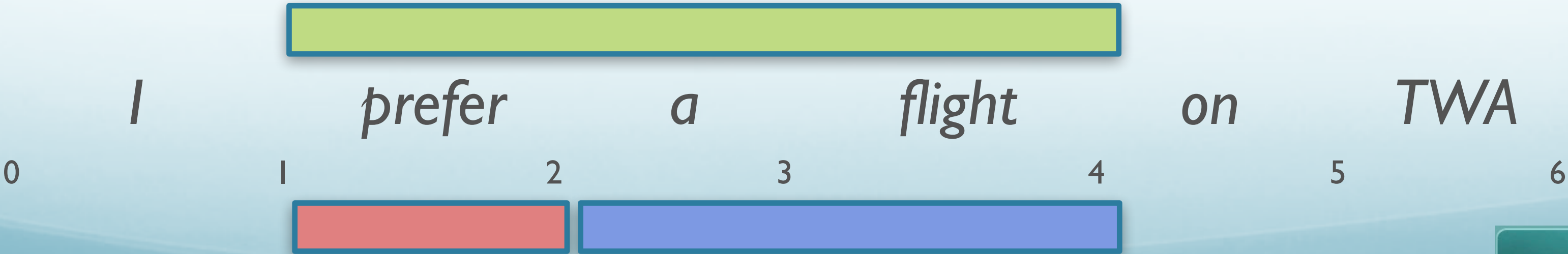
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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





$\mathcal{L}_1$  Grammar

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

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

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

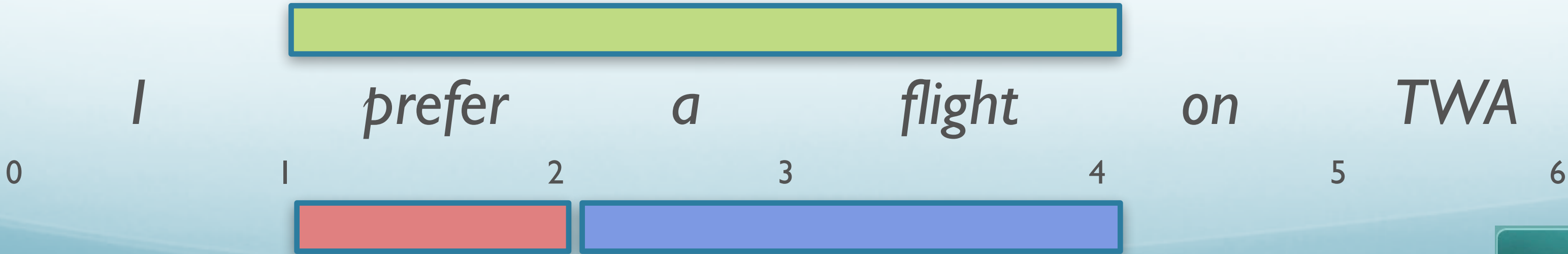
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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



$\mathcal{L}_1$  Grammar

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

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

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

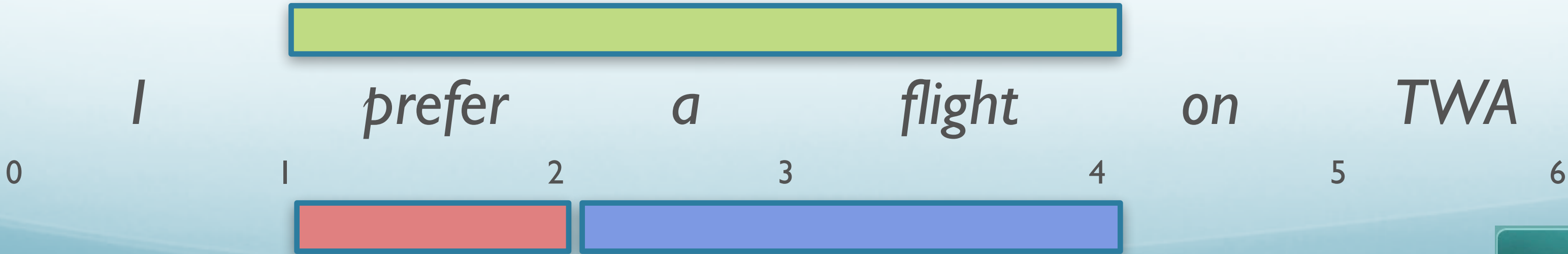
$VP \rightarrow book / include / prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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



$\mathcal{L}_1$  Grammar

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

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

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

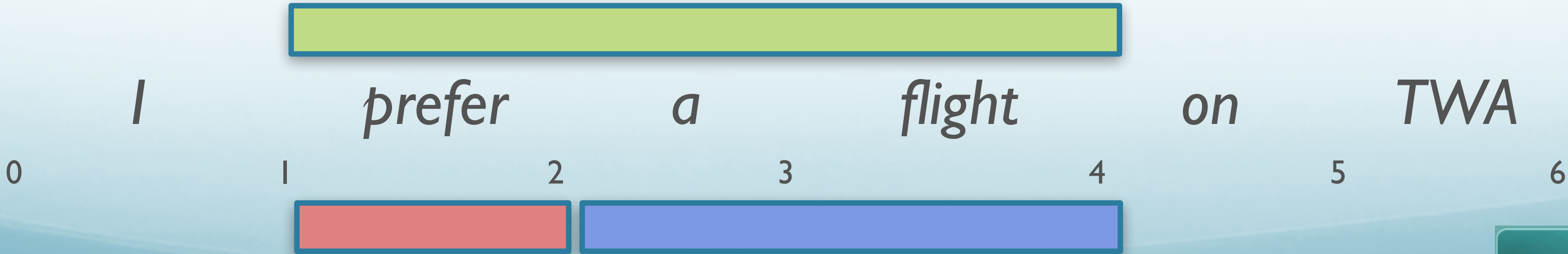
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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





$\mathcal{L}_1$  Grammar

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

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

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

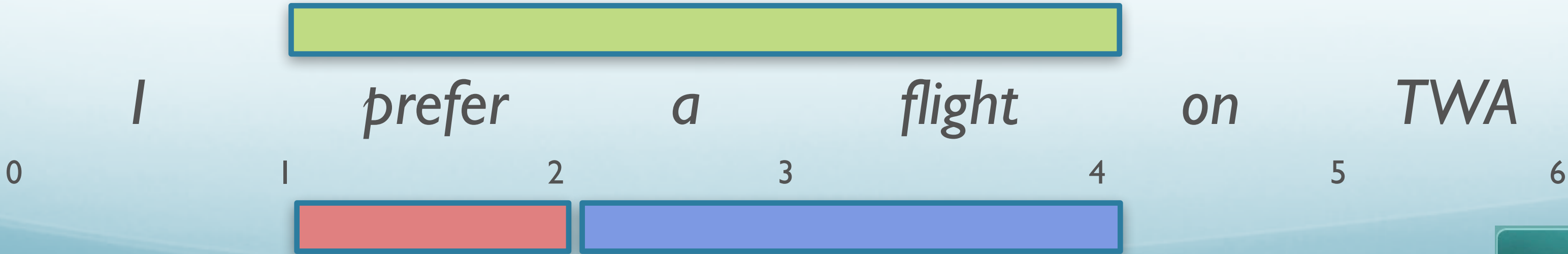
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]		





$\mathcal{L}_1$  Grammar

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

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

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

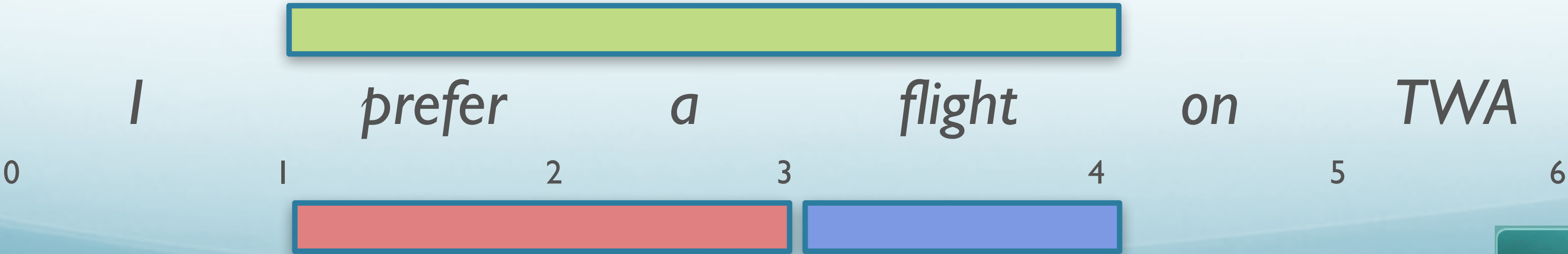
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]		



$\mathcal{L}_1$  Grammar

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

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

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

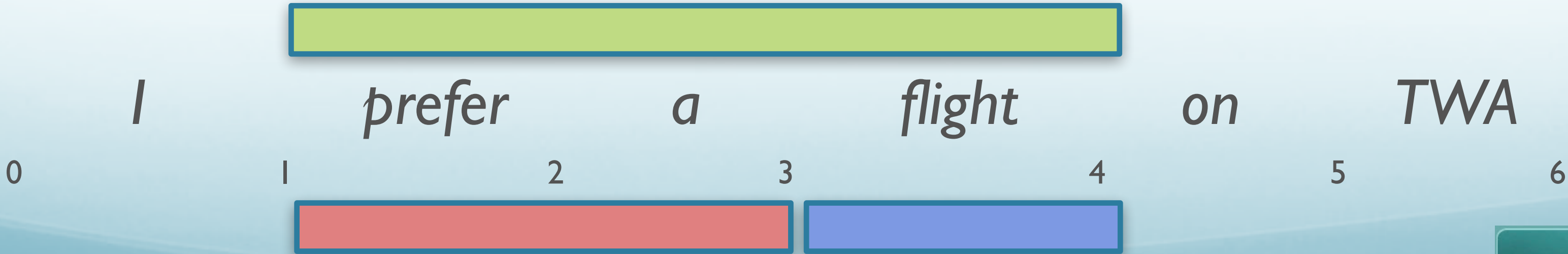
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]		



$\mathcal{L}_1$  Grammar

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

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

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

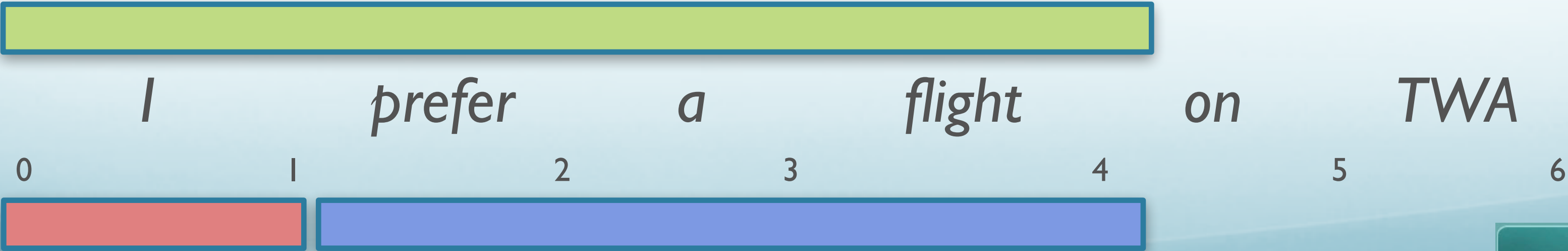
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

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





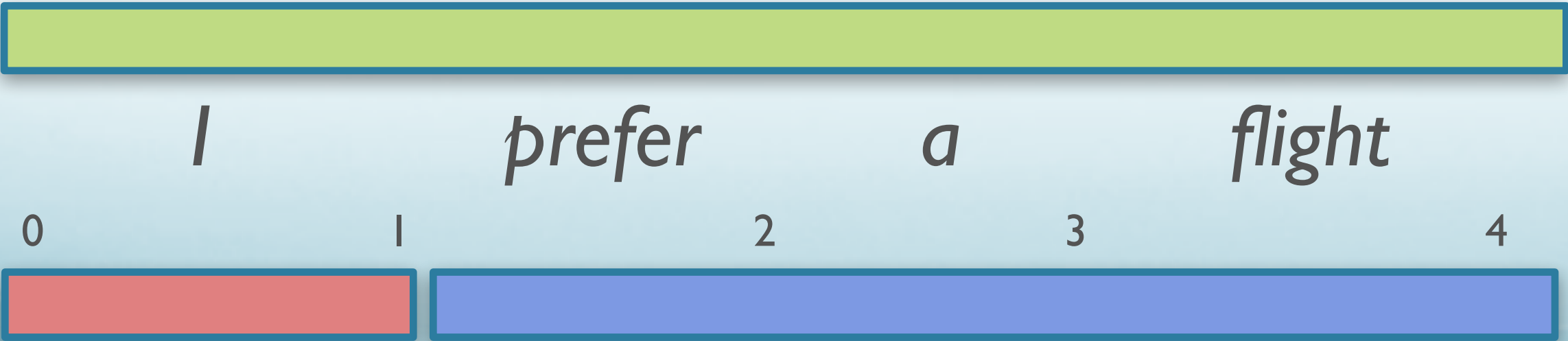
$\mathcal{L}_1$  Grammar

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

Lexicon

$Det \rightarrow that \mid this \mid a$   
 $Noun \rightarrow book \mid flight \mid meal \mid money$   
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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]		





$\mathcal{L}_1$  Grammar

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

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

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

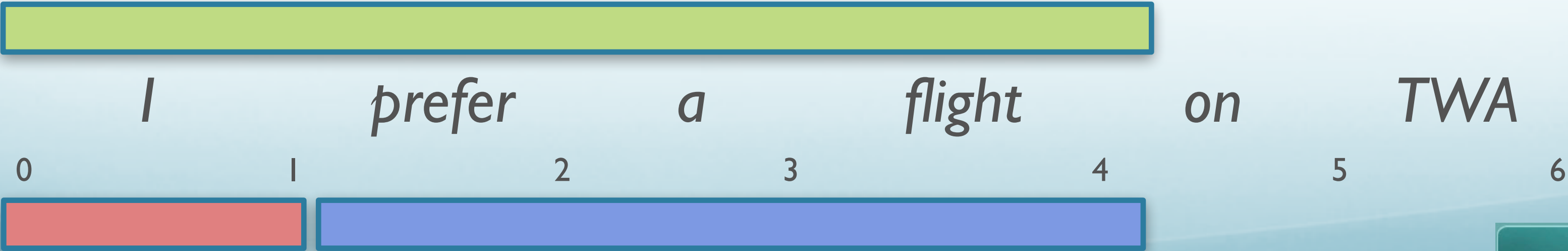
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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 $Noun \rightarrow book\ /\ flight\ /\ meal\ /\ money$   
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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]		



$\mathcal{L}_1$  Grammar

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

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

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

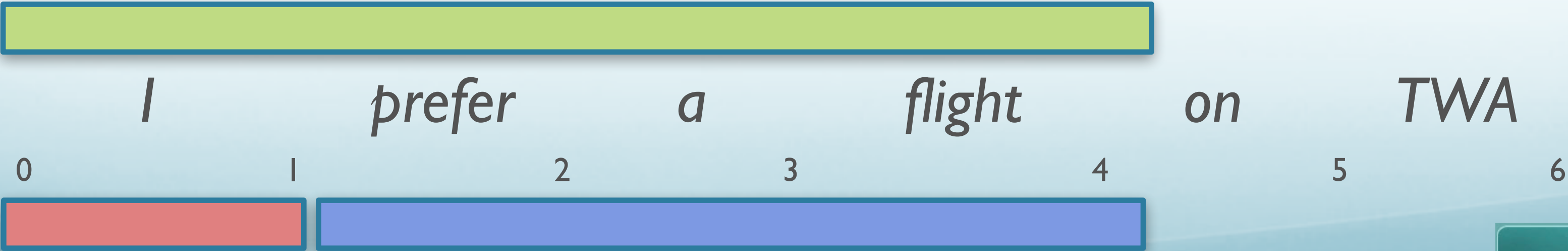
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

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Lexicon

$Det \rightarrow that\ /\ this\ /\ a$   
 $Noun \rightarrow book\ /\ flight\ /\ meal\ /\ money$   
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 $Proper-Noun \rightarrow Houston\ /\ TWA$   
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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]		



$\mathcal{L}_1$  Grammar

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

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

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

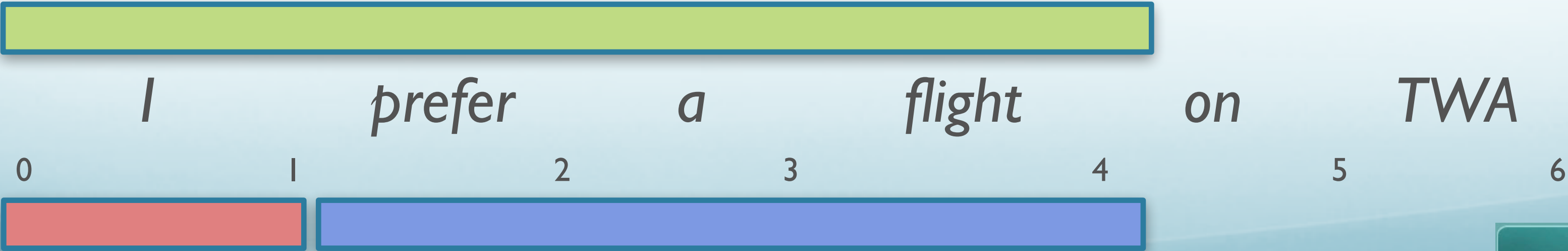
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]		





$\mathcal{L}_1$  Grammar

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

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

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

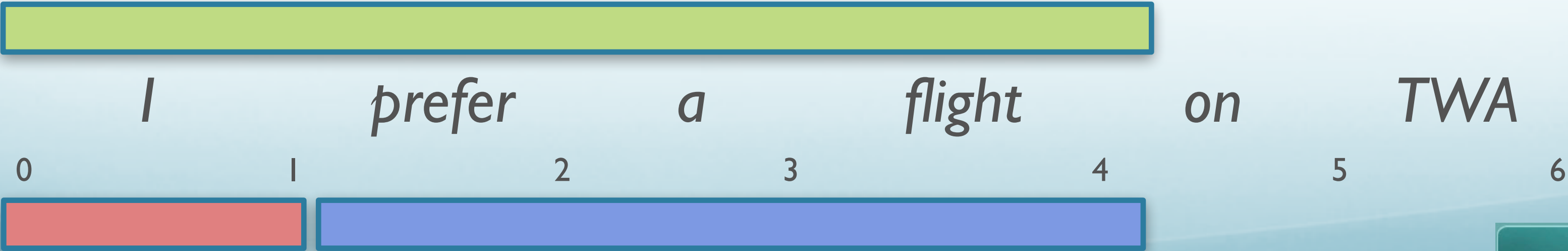
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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





$\mathcal{L}_1$  Grammar

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

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

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

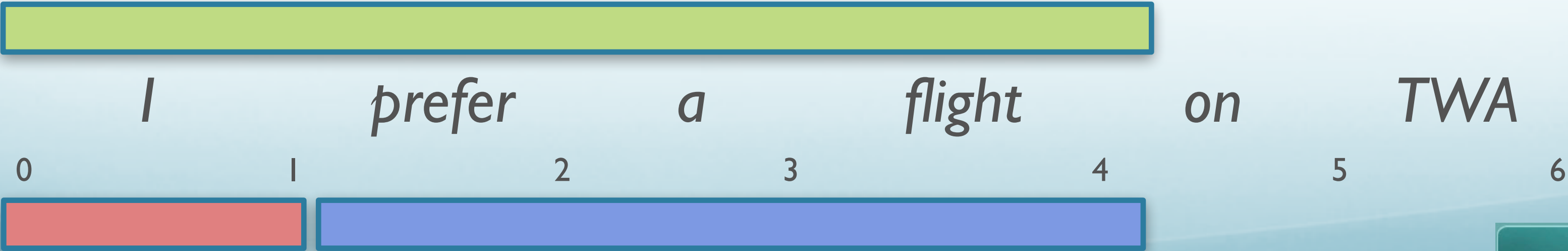
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]		



$\mathcal{L}_1$  Grammar

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

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

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

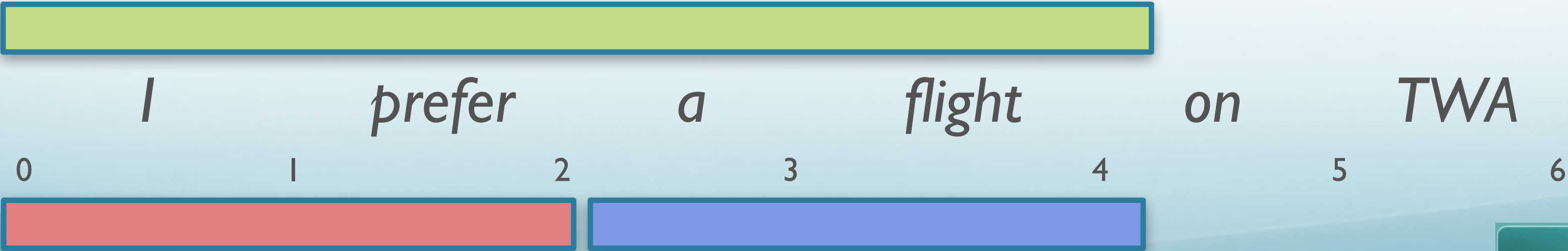
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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



$\mathcal{L}_1$  Grammar

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

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

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

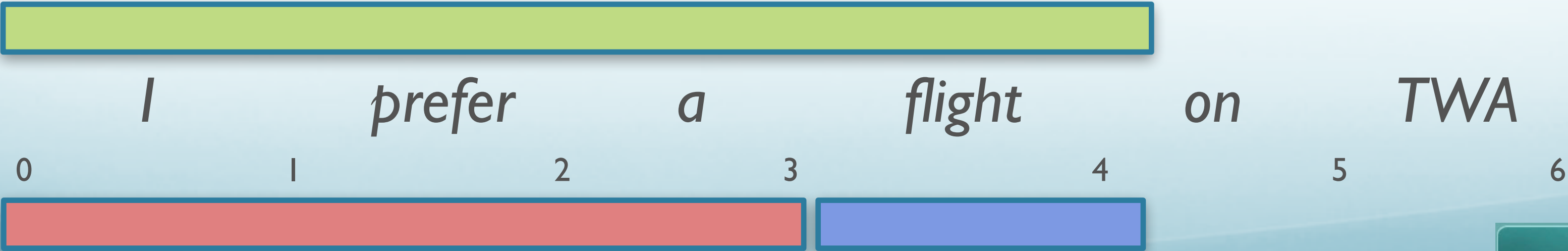
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]		





$\mathcal{L}_1$  Grammar

$S \rightarrow NP\ VP$

$S \rightarrow X1\ VP$

$X1 \rightarrow Aux\ NP$

$S \rightarrow book \mid include \mid prefer$

$S \rightarrow Verb\ NP$

$S \rightarrow X2\ PP$

$S \rightarrow Verb\ PP$

$S \rightarrow VP\ PP$

$NP \rightarrow I \mid she \mid me$

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det\ Nominal$

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

$Nominal \rightarrow Nominal\ Noun$

$Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book \mid include \mid prefer$

$VP \rightarrow Verb\ NP$

$VP \rightarrow X2\ PP$

$X2 \rightarrow Verb\ NP$

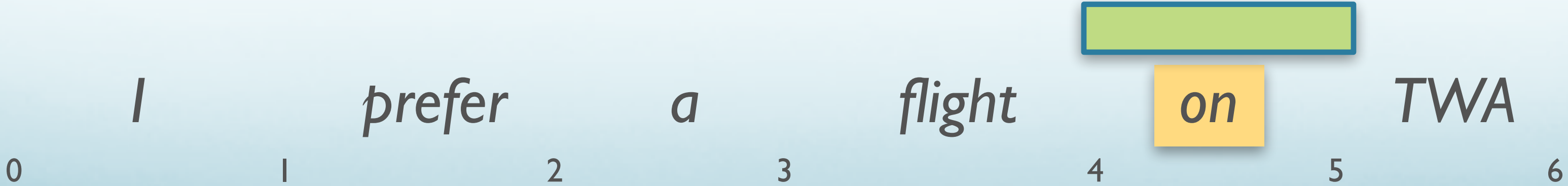
$VP \rightarrow Verb\ PP$

$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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

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]	





$\mathcal{L}_1$  Grammar

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

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

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

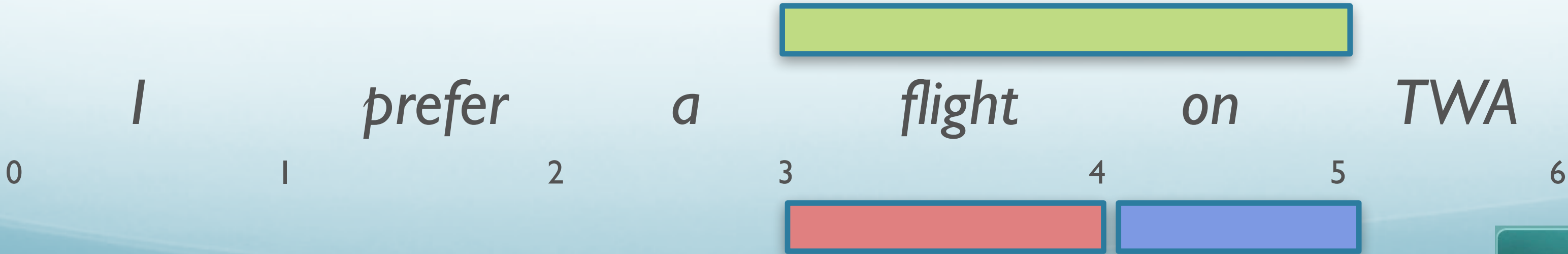
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ /\ this\ /\ a$   
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 $Pronoun \rightarrow I\ /\ she\ /\ me$   
 $Proper-Noun \rightarrow Houston\ /\ TWA$   
 $Aux \rightarrow does$   
 $Preposition \rightarrow from\ /\ to\ /\ on\ /\ near\ /\ through$   
 $Verb \rightarrow book\ /\ include\ /\ prefer$

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]	



$\mathcal{L}_1$  Grammar

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

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

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

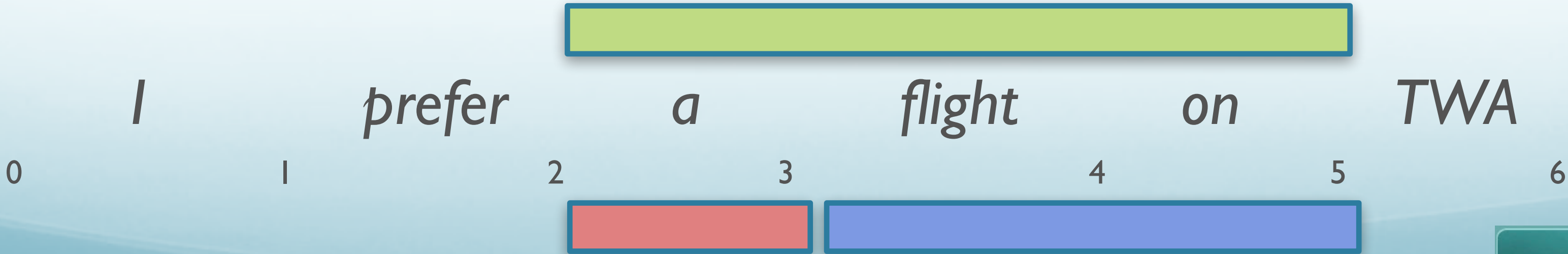
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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$Det \rightarrow that\ /\ this\ /\ a$   
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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]		
	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]	



$\mathcal{L}_1$  Grammar

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

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

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

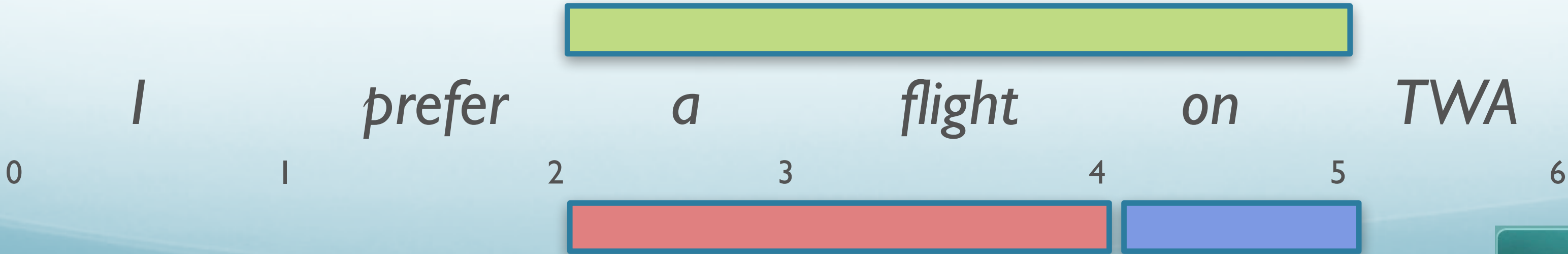
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]	





$\mathcal{L}_1$  Grammar

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

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

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

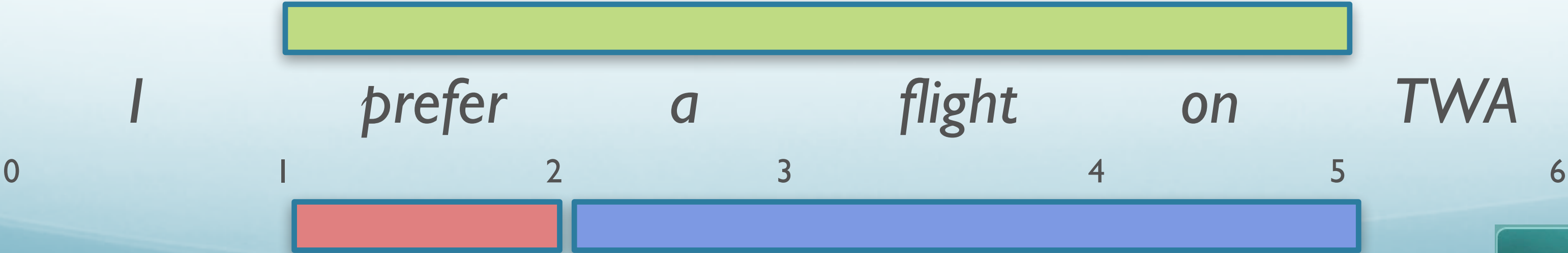
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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





$\mathcal{L}_1$  Grammar

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

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

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

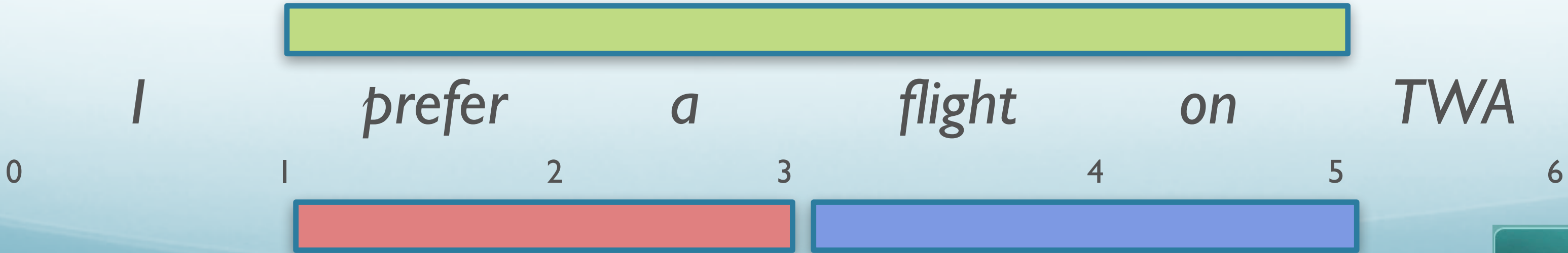
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]		
			Noun, Nom [3,4]	[3,5]	
				Prep [4,5]	



$\mathcal{L}_1$  Grammar

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

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

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

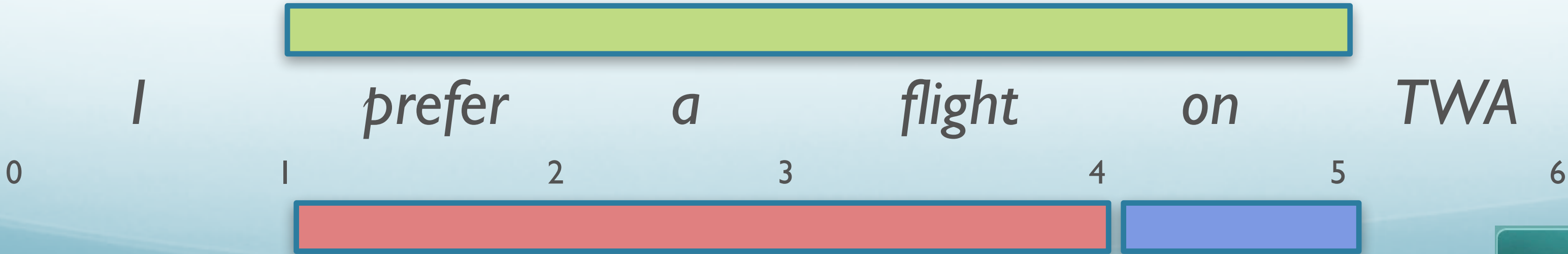
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]	



$\mathcal{L}_1$  Grammar

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

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

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

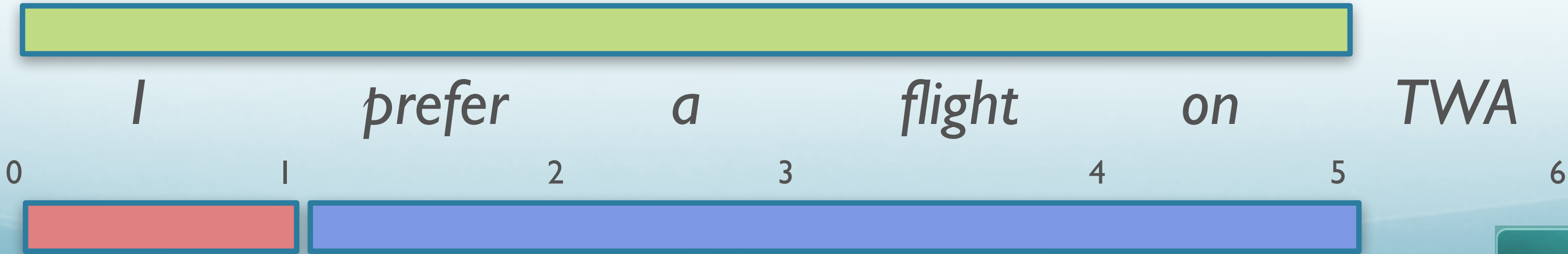
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]	





$\mathcal{L}_1$  Grammar

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

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

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

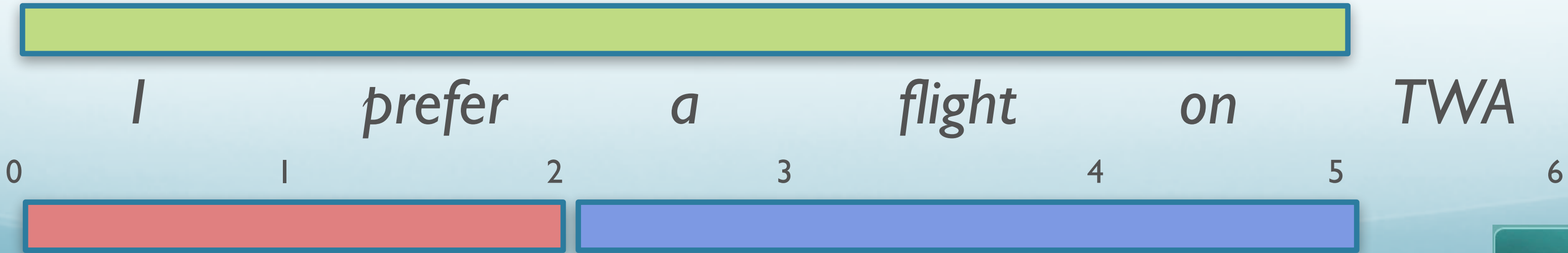
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]	





$\mathcal{L}_1$  Grammar

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

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

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

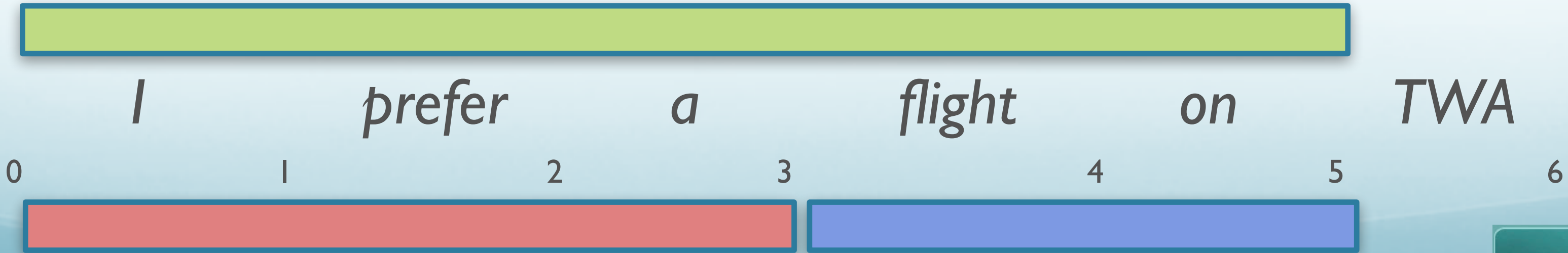
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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



$\mathcal{L}_1$  Grammar

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

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

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

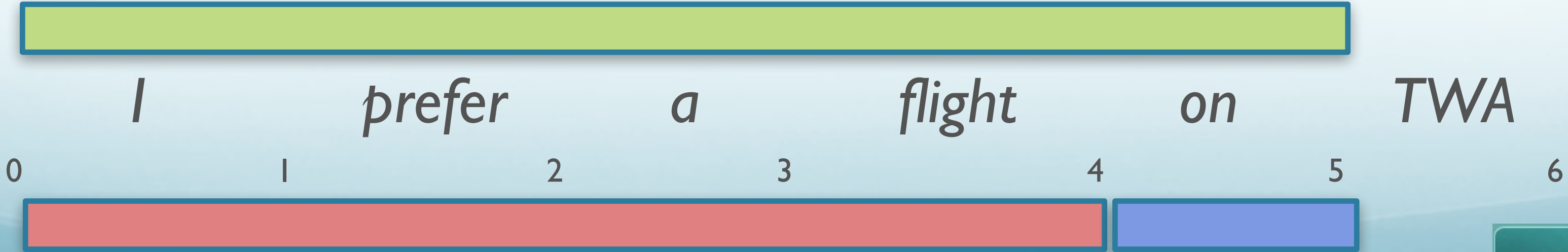
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]	

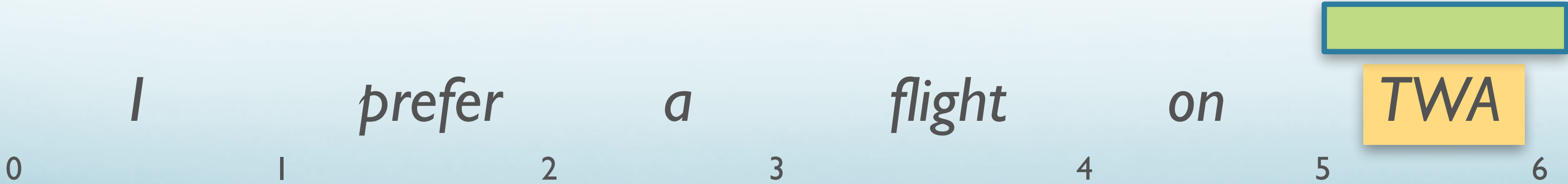


$\mathcal{L}_1$ Grammar	
$S \rightarrow NP\ VP$	
$S \rightarrow X1\ VP$	
$X1 \rightarrow Aux\ NP$	
$S \rightarrow book\ /\ include\ /\ prefer$	
$S \rightarrow Verb\ NP$	
$S \rightarrow X2\ PP$	
$S \rightarrow Verb\ PP$	
$S \rightarrow VP\ PP$	
<hr/>	
$NP \rightarrow I\ /\ she\ /\ me$	
$NP \rightarrow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

**Lexicon**

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

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]





$\mathcal{L}_1$ 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	
$Det \rightarrow that\ /\ this\ /\ a$	
$Noun \rightarrow book\ /\ flight\ /\ meal\ /\ money$	
$Pronoun \rightarrow I\ /\ she\ /\ me$	
$Proper-Noun \rightarrow Houston\ /\ TWA$	
$Aux \rightarrow does$	
$Preposition \rightarrow from\ /\ to\ /\ on\ /\ near\ /\ through$	
$Verb \rightarrow book\ /\ include\ /\ prefer$	

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]





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

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

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]



$\mathcal{L}_1$  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
$Det \rightarrow that \mid this \mid a$
$Noun \rightarrow book \mid flight \mid meal \mid money$
$Pronoun \rightarrow I \mid she \mid me$
$Proper-Noun \rightarrow Houston \mid TWA$
$Aux \rightarrow does$
$Preposition \rightarrow from \mid to \mid on \mid near \mid through$
$Verb \rightarrow book \mid include \mid prefer$

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]



$\mathcal{L}_1$  Grammar

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

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

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

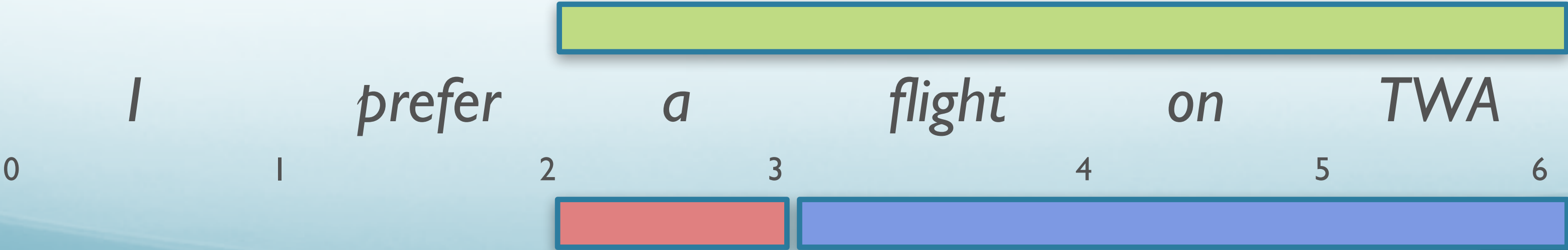
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]





$\mathcal{L}_1$  Grammar

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

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

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

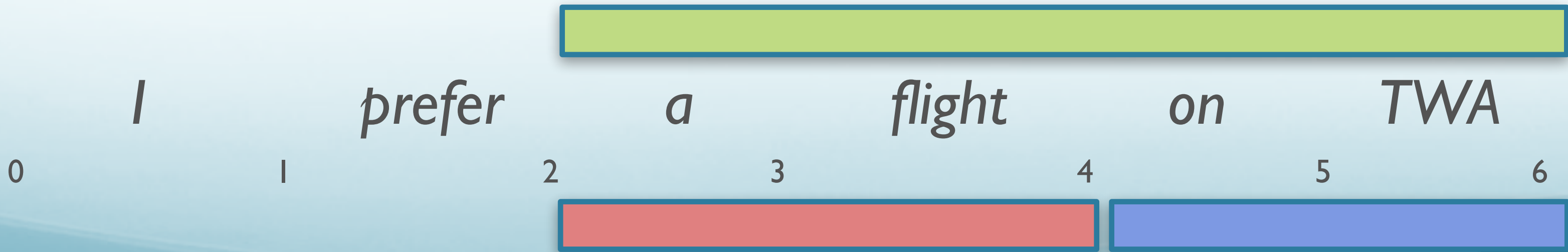
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]





$\mathcal{L}_1$  Grammar

$S \rightarrow NP VP$

$S \rightarrow X1 VP$

$X1 \rightarrow Aux NP$

$S \rightarrow book \mid include \mid prefer$

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I \mid she \mid me$

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book \mid include \mid prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

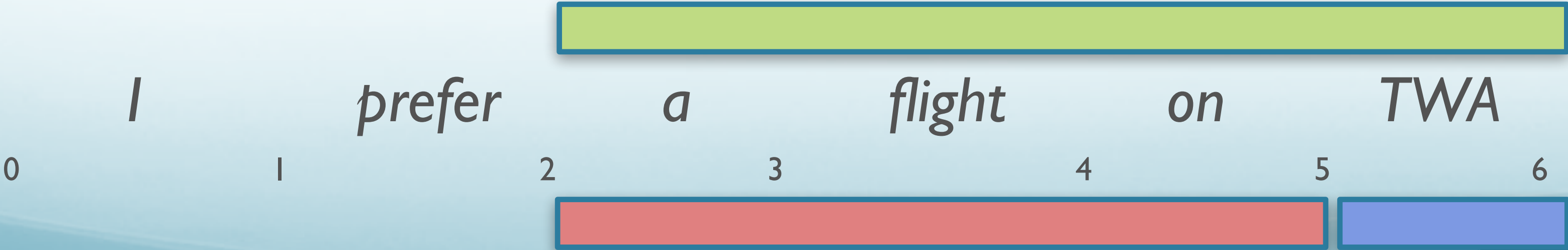
$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

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]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
				Prep [4,5]	PP [4,6]
					NNP, NP [5,6]



$\mathcal{L}_1$  Grammar

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

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

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

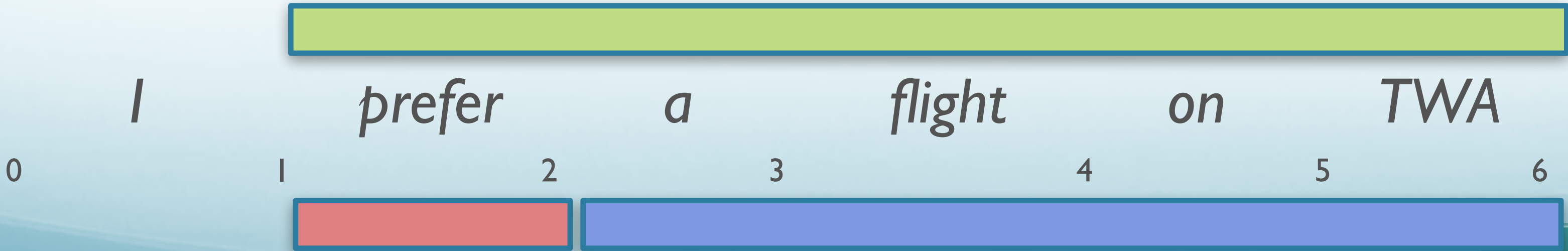
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]



$\mathcal{L}_1$  Grammar

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

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

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

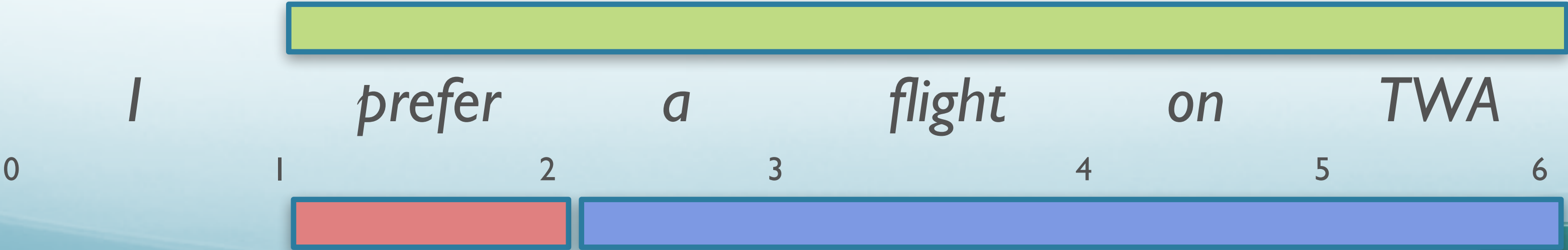
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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 [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]





$\mathcal{L}_1$  Grammar

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

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

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

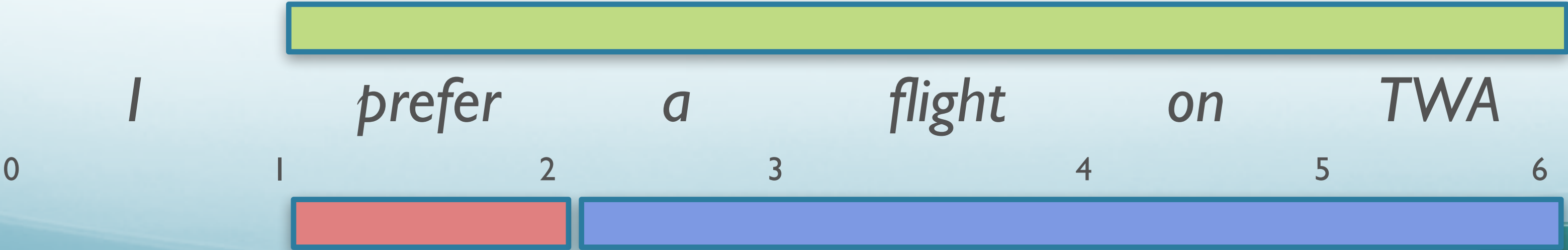
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]



$\mathcal{L}_1$  Grammar

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

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

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

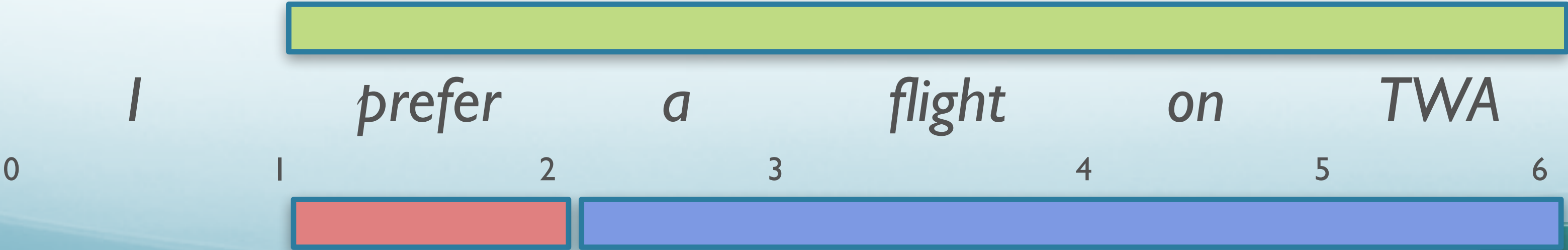
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]



$\mathcal{L}_1$  Grammar

$S \rightarrow NP VP$

$S \rightarrow X1 VP$

$X1 \rightarrow Aux NP$

$S \rightarrow book \mid include \mid prefer$

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I \mid she \mid me$

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book \mid include \mid prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

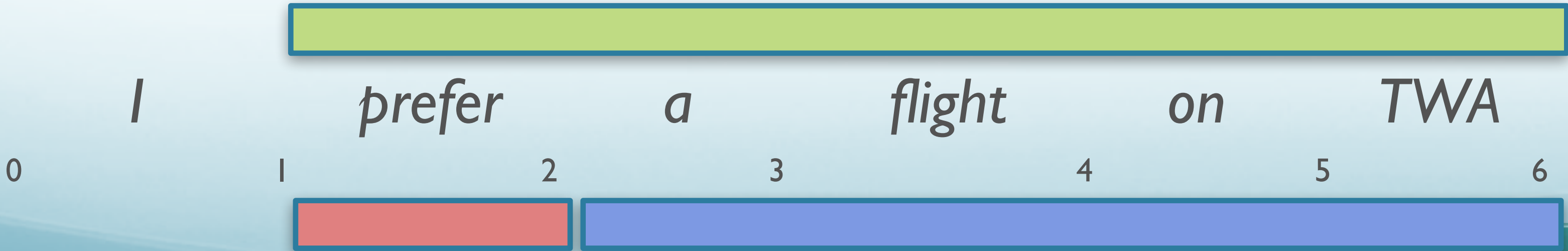
$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

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





$\mathcal{L}_1$  Grammar

$S \rightarrow NP VP$

$S \rightarrow X1 VP$

$X1 \rightarrow Aux NP$

$S \rightarrow book \mid include \mid prefer$

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I \mid she \mid me$

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book \mid include \mid prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

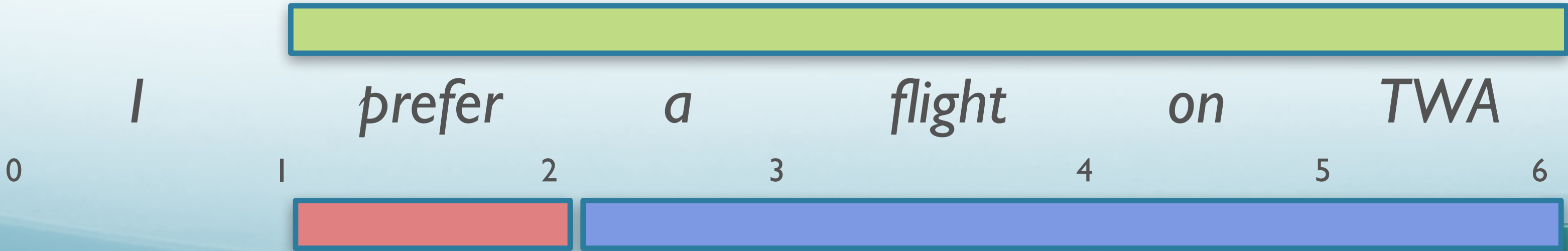
$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

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

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

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



$\mathcal{L}_1$  Grammar

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

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

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

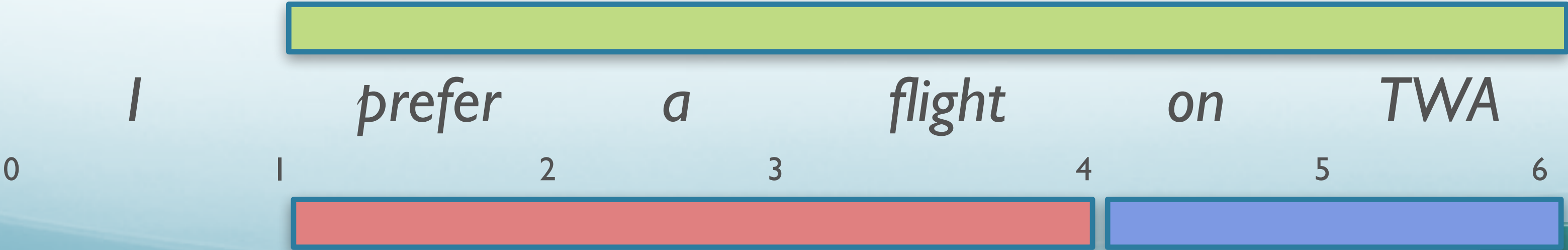
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]



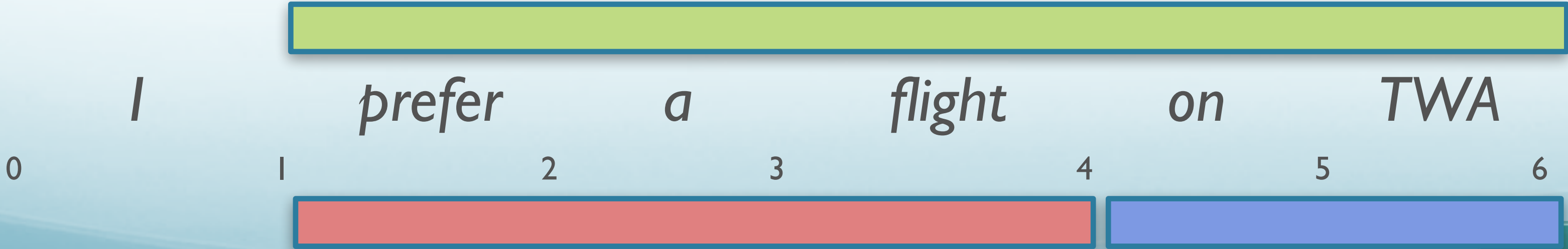


$\mathcal{L}_1$ Grammar	
$S \rightarrow NP\ VP$	
$S \rightarrow X1\ VP$	
$X1 \rightarrow Aux\ NP$	
$S \rightarrow book\ /\ include\ /\ prefer$	
$S \rightarrow Verb\ NP$	
$S \rightarrow X2\ PP$	
$S \rightarrow Verb\ PP$	
$S$	$\rightarrow VP\ PP$
$NP \rightarrow I\ /\ she\ /\ me$	
$NP \rightarrow TWA\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

**Lexicon**

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

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]



$\mathcal{L}_1$  Grammar

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

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

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

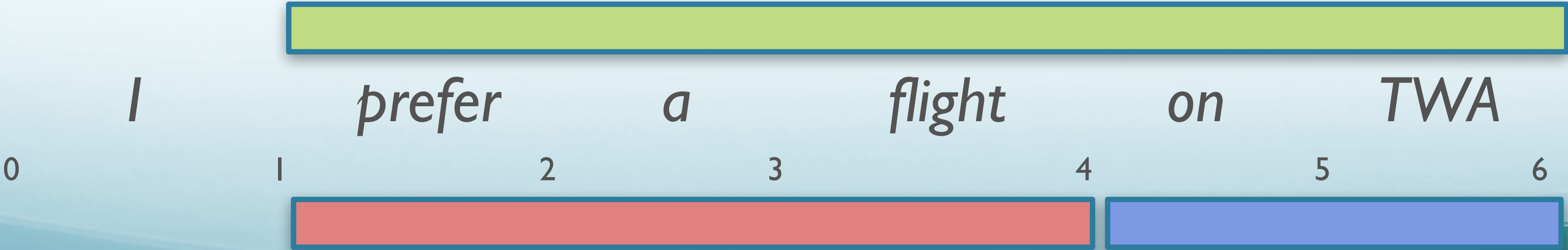
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]



$\mathcal{L}_1$  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**

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

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





$\mathcal{L}_1$  Grammar

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

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

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

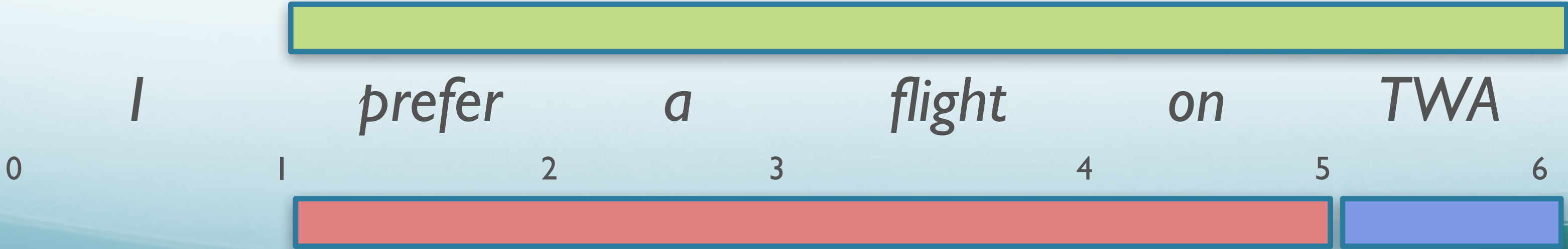
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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]



$\mathcal{L}_1$  Grammar

$S \rightarrow NP\ VP$

$S \rightarrow X1\ VP$

$X1 \rightarrow Aux\ NP$

$S \rightarrow book \mid include \mid prefer$

$S \rightarrow Verb\ NP$

$S \rightarrow X2\ PP$

$S \rightarrow Verb\ PP$

$S \rightarrow VP\ PP$

$NP \rightarrow I \mid she \mid me$

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det\ Nominal$

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

$Nominal \rightarrow Nominal\ Noun$

$Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book \mid include \mid prefer$

$VP \rightarrow Verb\ NP$

$VP \rightarrow X2\ PP$

$X2 \rightarrow Verb\ NP$

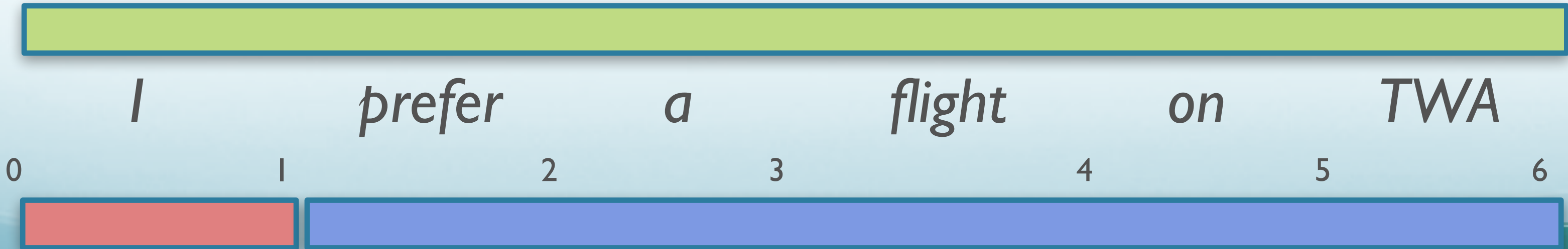
$VP \rightarrow Verb\ PP$

$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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

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]



$\mathcal{L}_1$  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

$Det \rightarrow that \mid this \mid a$

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

$Pronoun \rightarrow I \mid she \mid me$

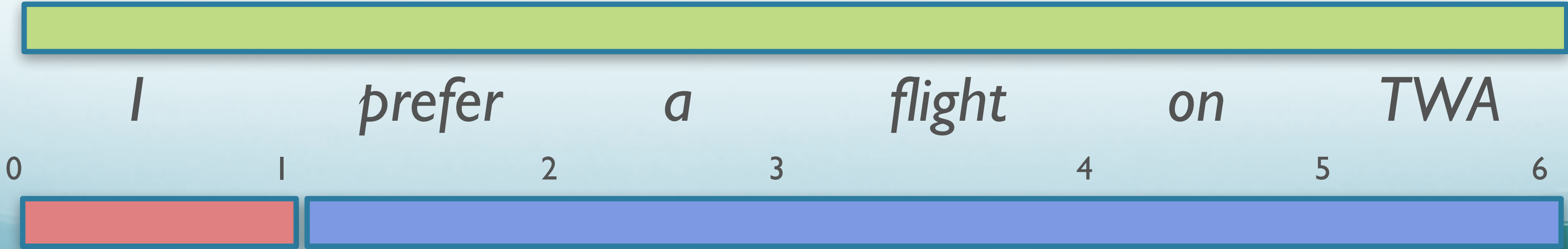
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	S [0,6]
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	VP, X2, S [1,6]
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
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$\mathcal{L}_1$  Grammar

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

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

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

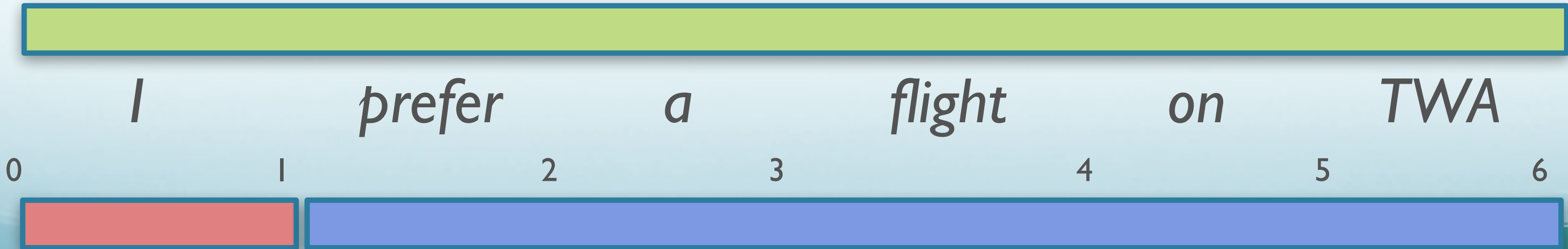
$VP \rightarrow book\ /\ include\ /\ prefer$   
 $VP \rightarrow Verb\ NP$   
 $VP \rightarrow X2\ PP$   
 $X2 \rightarrow Verb\ NP$   
 $VP \rightarrow Verb\ PP$   
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ /\ this\ /\ a$   
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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]		NP [2,6]
			Noun, Nom [3,4]		Nom [3,6]
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$\mathcal{L}_1$  Grammar

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$S \rightarrow book \mid include \mid prefer$

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I \mid she \mid me$

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book \mid include \mid prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

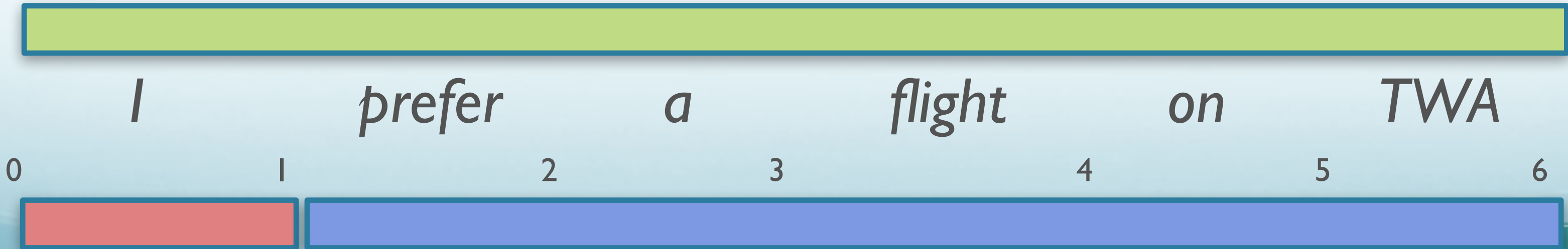
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$VP \rightarrow VP PP$

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Lexicon
$Det \rightarrow that \mid this \mid a$
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NP, Pronoun [0,1]	S [0,2]		S [0,4]		S [0,6]
	Verb, VP, S [1,2]		VP, X2, S [1,4]		VP, X2, S [1,6]
		Det [2,3]	NP [2,4]		NP [2,6]
			Noun, Nom [3,4]		Nom [3,6]
				Prep [4,5]	PP [4,6]
					NNP, NP [5,6]



$\mathcal{L}_1$  Grammar

$S \rightarrow NP VP$

$S \rightarrow X1 VP$

$X1 \rightarrow Aux NP$

$S \rightarrow book \mid include \mid prefer$

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I \mid she \mid me$

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book \mid include \mid prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

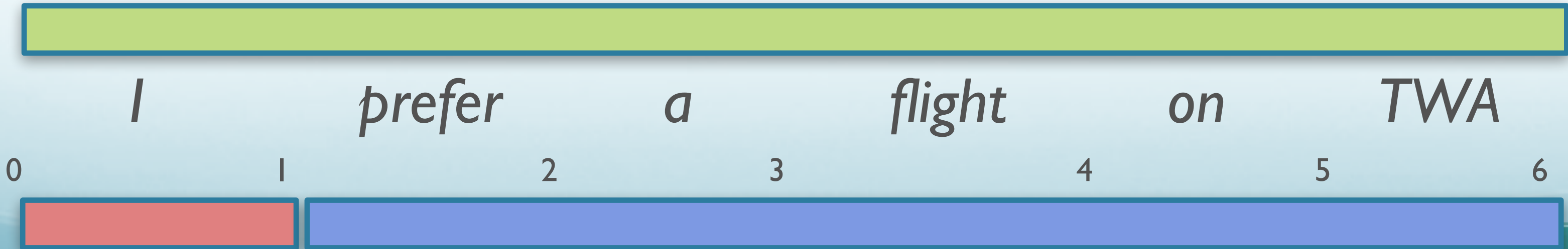
$VP \rightarrow Verb PP$

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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]
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$\mathcal{L}_1$  Grammar

$S \rightarrow NP VP$

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$S \rightarrow book \mid include \mid prefer$

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I \mid she \mid me$

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book \mid include \mid prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

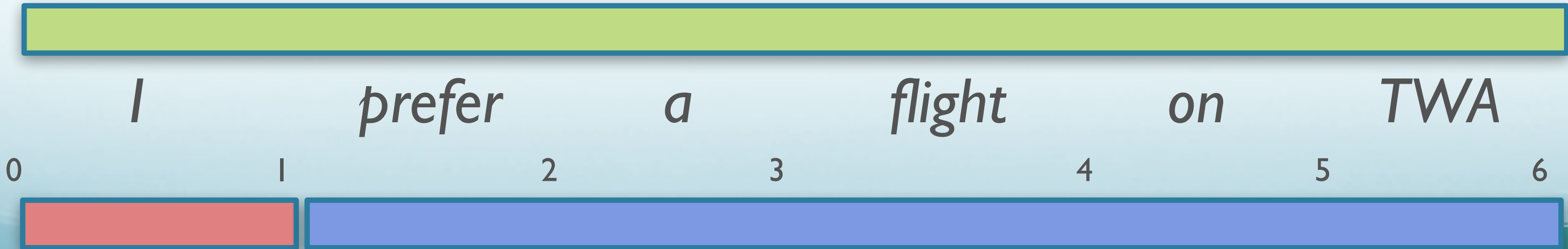
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	S [0,6]
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	VP, X2, S [1,6]
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
				Prep [4,5]	PP [4,6]
					NNP, NP [5,6]



# 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** → **VP** **PP**

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

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

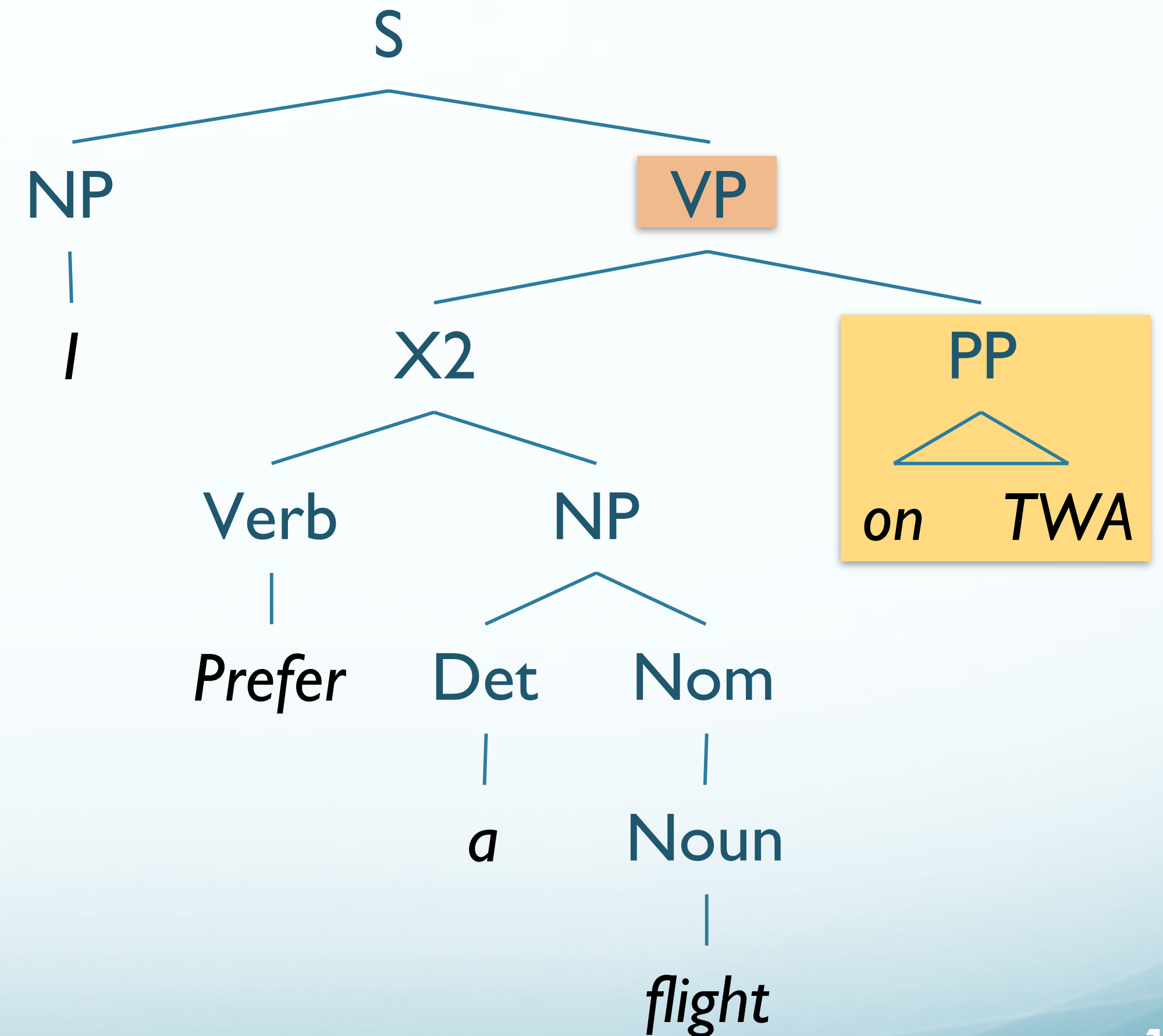
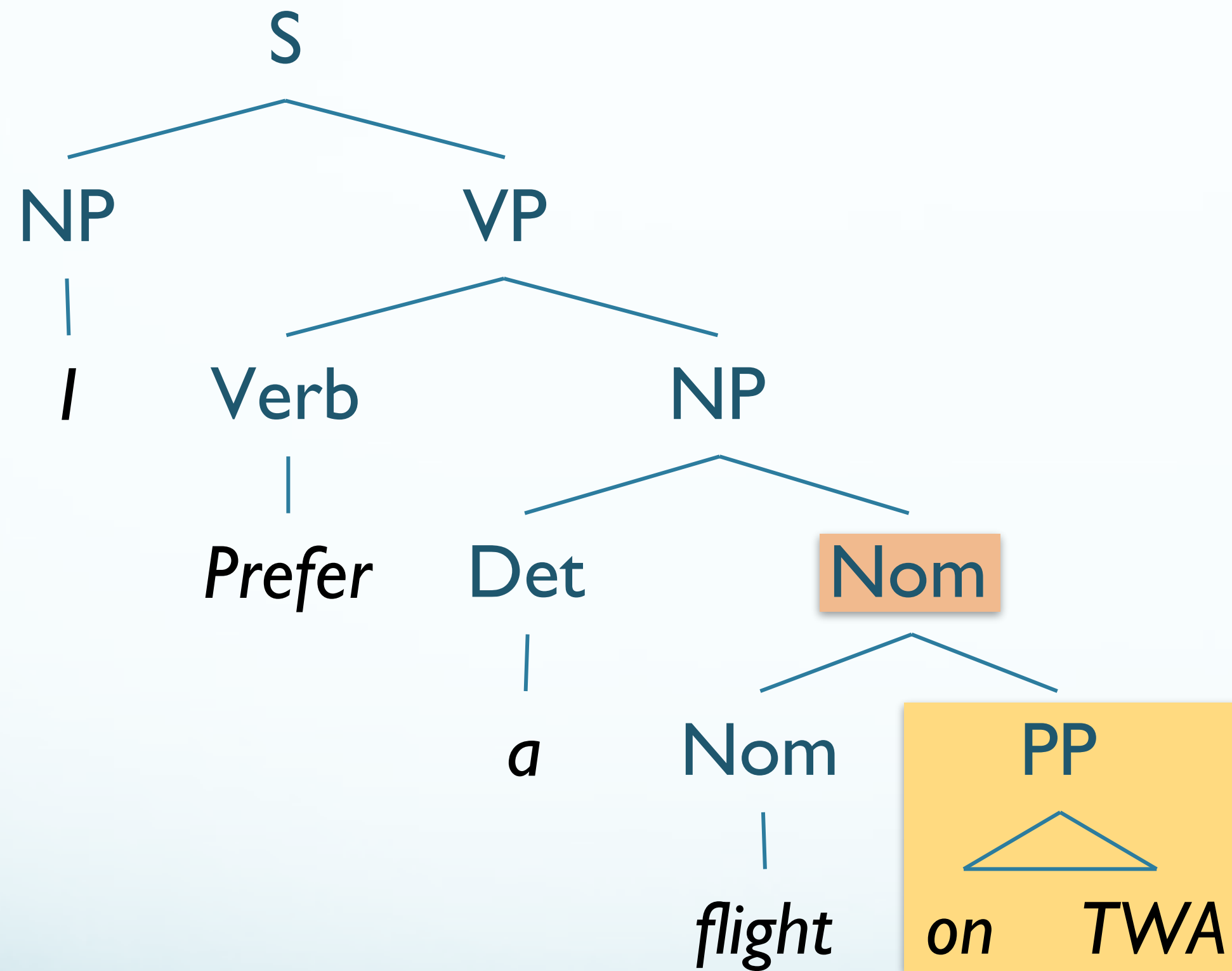
$VP \rightarrow X_2 PP$

```
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]



# 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

# Parsing: PCFGs

Ling 571

Deep Processing Techniques for NLP

January 18, 2017



# Probabilistic Context-free Grammars: Roadmap

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

# Motivation

- What about ambiguity?
- Current algorithm can ***represent*** it
- ...can't resolve it.

# Probabilistic Parsing

- Provides strategy for solving disambiguation problem
  - Compute the probability of all analyses
  - Select the most probable
- Employed in language modeling for speech recognition
  - N-gram grammars predict words, constrain search
  - Also, constrain generation, translation



# PCFGs: Formal Definition

$N$	a set of <b>non-terminal symbols</b> (or <b>variables</b> )
$\Sigma$	a set of <b>terminal symbols</b> (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, $\beta$ is a string of symbols from the infinite set of strings $(\Sigma \cup N)^*$ and $p$ is a number between 0 and 1 expressing $P(\beta A)$
$S$	a designated <b>start symbol</b>

# 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 $\mathcal{L}_1$

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

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

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

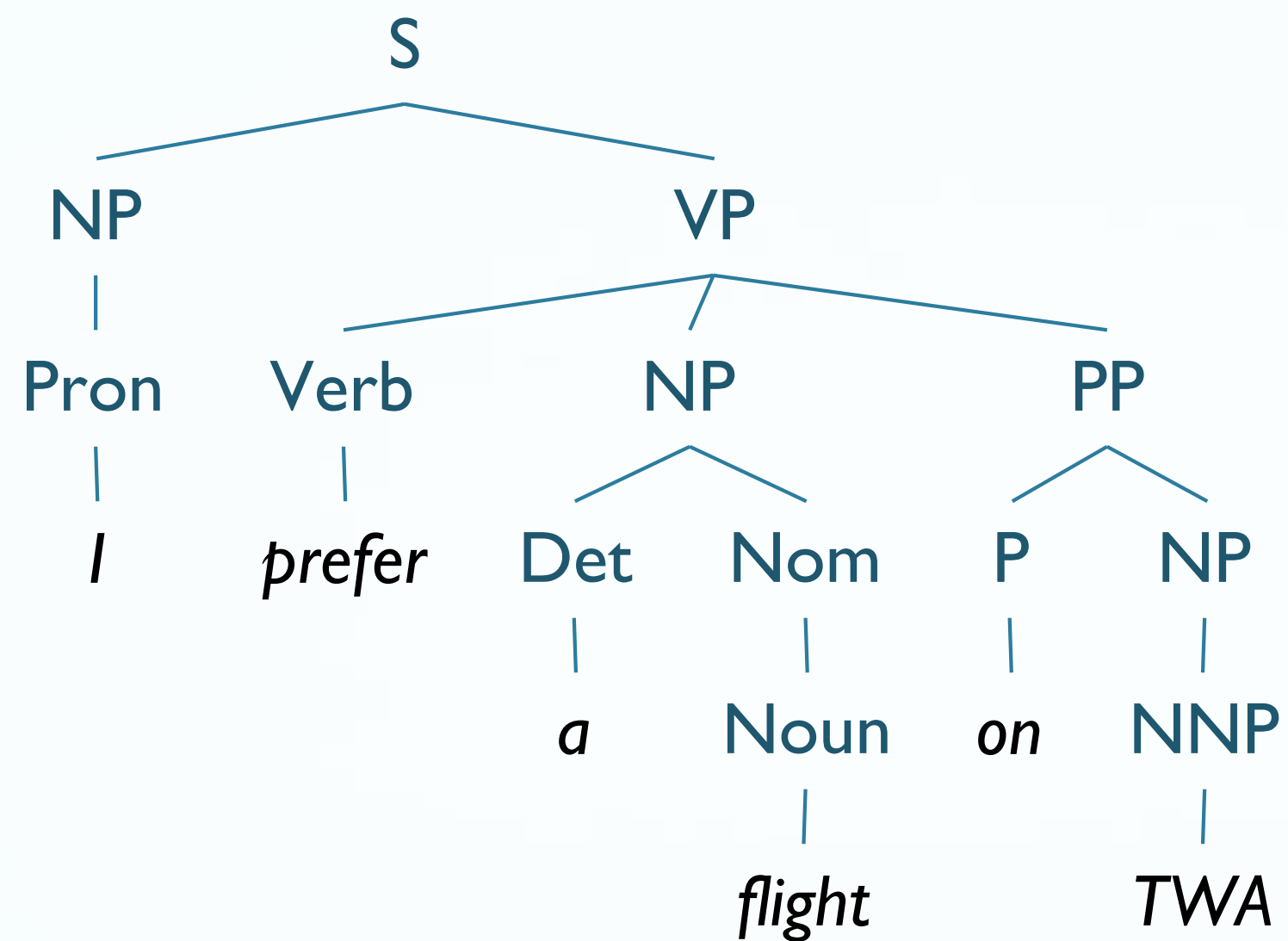
# Disambiguation

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

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

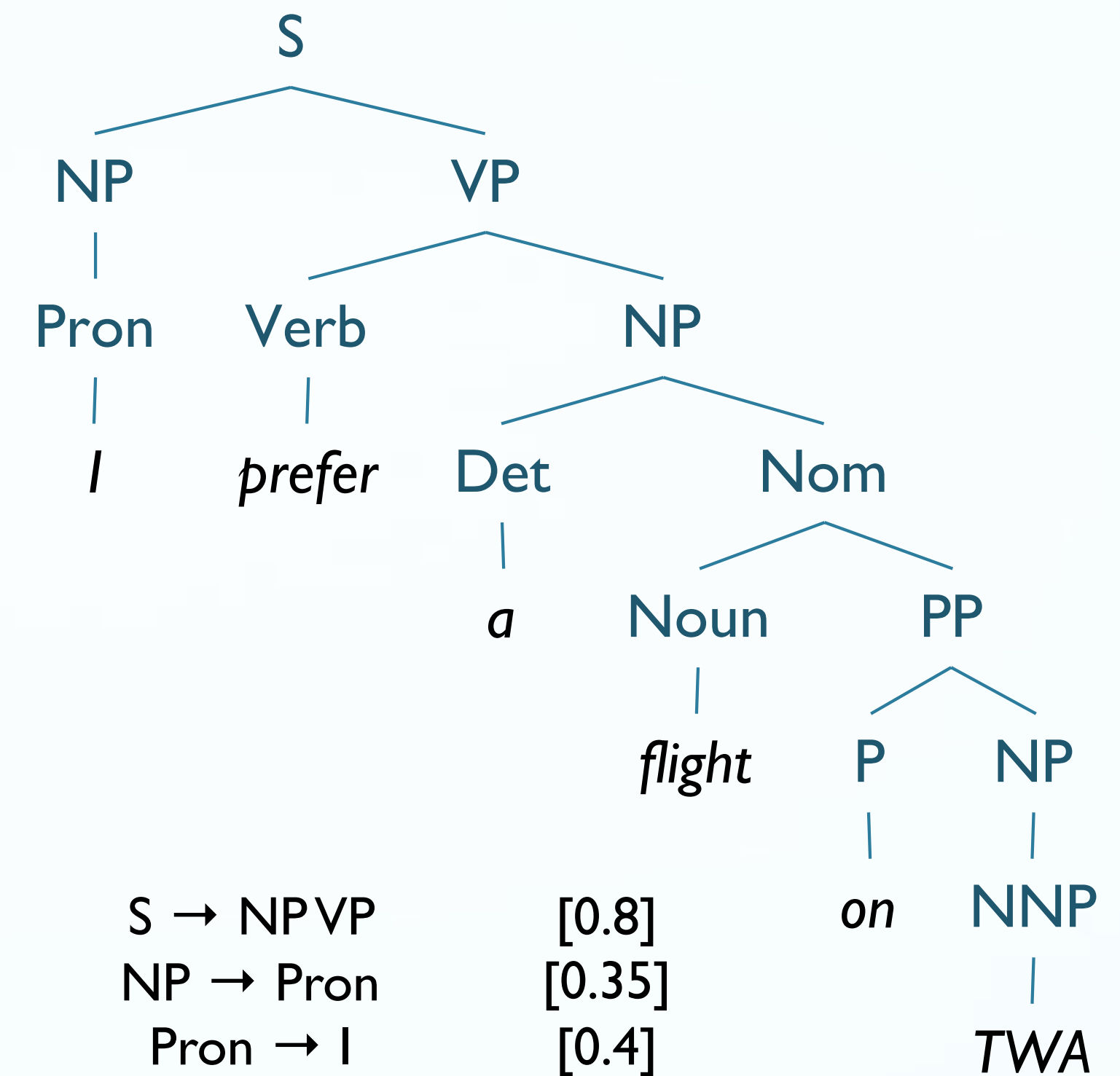
$$P(T, S) = P(T)P(S | T) = P(T)$$





$S \rightarrow NP VP$	[0.8]
$NP \rightarrow Pron$	[0.35]
$Pron \rightarrow I$	[0.4]
$VP \rightarrow V NP PP$	[0.1]
$V \rightarrow prefer$	[0.4]
$NP \rightarrow Det Nom$	[0.2]
$Det \rightarrow a$	[0.3]
$Nom \rightarrow N$	[0.75]
$N \rightarrow flight$	[0.3]
$PP \rightarrow P NP$	[1.0]
$P \rightarrow on$	[0.2]
$NP \rightarrow NNP$	[0.3]
$NNP \rightarrow NWA$	[0.4]

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



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

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

# Parsing Problem for PCFGs

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

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

- 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:

```
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.assertEqual(set(target_rules),  
                          set(fix_long_rules(length_3_rule)))
```

# Unit Testing in Python

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

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

```
A -> B _X0_
```

```
_X0_ -> C D
```

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

```
A -> B C
```

```
-----  
Ran 12 tests in 0.040s
```

```
FAILED (failures=1)
```



# Unit Testing

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

# HW #3

# CKY Parsing: Goals

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

# Implementation

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



# Notes

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