

# CKY Parsing

LING 571 — Deep Processing Techniques for NLP  
Shane Steinert-Threlkeld

# Announcements

- HW1 grades posted
- Reference code in hw1/ref on dropbox
  - Will try to give reference implementations for many assignments (not all, where it is less applicable)
  - Please do not distribute them!
- `check_hwX.sh`:
  - Unzips tar.gz file and checks its contents against submit-file-list
  - Best practice to do this before submitting!

# Indigenous Peoples' Day

- Seattle/Sealth/Si'ahl



# Indigenous Peoples' Day

- Seattle/Sealth/Si'ahl
- The Lushootseed spelling [IPA] of Chief Seattle/Sealth/Si'ahl:
  - siʔaɫ ['siʔaɫ]
  - ɫ : voiceless alveolar lateral fricative



# Indigenous Peoples' Day

- Seattle/Sealth/Si'ahl
- The Lushootseed spelling [IPA] of Chief Seattle/Sealth/Si'ahl:
  - siʔaʔ [ˈsiʔaːɸ]
  - ɸ : voiceless alveolar lateral fricative
- Duwamish — Dx<sup>w</sup>dəwʔabš [dx<sup>w</sup>dəwʔabʃ]



# Indigenous Peoples' Day

- Seattle/Sealth/Si'ahl
- The Lushootseed spelling [IPA] of Chief Seattle/Sealth/Si'ahl:
  - siʔaɫ ['siʔaɫ]
  - ɫ : voiceless alveolar lateral fricative
- Duwamish — Dx<sup>w</sup>dəwʔabš [dx<sup>w</sup>dəwʔabʃ]
- Vi Hilbert (Skagit elder) recording:
  - Source, with more Lushootseed: <https://historylink.org/File/8156>



# Indigenous Peoples' Day

- Seattle/Sealth/Si'ahl
- The Lushootseed spelling [IPA] of Chief Seattle/Sealth/Si'ahl:
  - siʔaɫ ['siʔaɫ]
  - ɫ : voiceless alveolar lateral fricative
- Duwamish — Dx<sup>w</sup>dəwʔabš [dx<sup>w</sup>dəwʔabʃ]
- Vi Hilbert (Skagit elder) recording:
  - Source, with more Lushootseed: <https://historylink.org/File/8156>



# Indigenous Peoples' Day

- Seattle/Sealth/Si'ahl
- The Lushootseed spelling [IPA] of Chief Seattle/Sealth/Si'ahl:
  - siʔaɫ ['siʔaɫ]
  - ɫ : voiceless alveolar lateral fricative
- Duwamish — Dx<sup>w</sup>dəwʔabš [dx<sup>w</sup>dəwʔabʃ]
- Vi Hilbert (Skagit elder) recording:
  - Source, with more Lushootseed: <https://historylink.org/File/8156>
- IPA resources:
  - [https://en.wikipedia.org/wiki/International\\_Phonetic\\_Alphabet](https://en.wikipedia.org/wiki/International_Phonetic_Alphabet)
  - <http://web.mit.edu/6.mitx/www/24.900%20IPA/IPAapp.html>



# Indigenous Peoples' Day

- Studying non-English languages gives more holistic insight for NLP tasks
  - Many interesting phenomena in non-Indo-European languages

# Indigenous Peoples' Day

- Studying non-English languages gives more holistic insight for NLP tasks
  - Many interesting phenomena in non-Indo-European languages
- Important that our technologies work for all languages of the world

# Indigenous Peoples' Day

- Studying non-English languages gives more holistic insight for NLP tasks
  - Many interesting phenomena in non-Indo-European languages
  - Important that our technologies work for all languages of the world
- Lushootseed exhibits debatable distinction between verbs and nouns [link to Glottolog page for more references]
  - **?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"
  - (Translation distinction provided for clarity — semantically equivalent)

# Indigenous Peoples' Day

- Studying non-English languages gives more holistic insight for NLP tasks
  - Many interesting phenomena in non-Indo-European languages
  - Important that our technologies work for all languages of the world
  - Lushootseed exhibits debatable distinction between verbs and nouns [link to Glottolog page for more references]
    - **?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"
- (Translation distinction provided for clarity — semantically equivalent)
- Lillooet Salish quantification has repercussions for e.g. English (Matthewson 2001)

via Beck, 2013



# Can you name any other languages indigenous to the Americas?

Total Results: 0

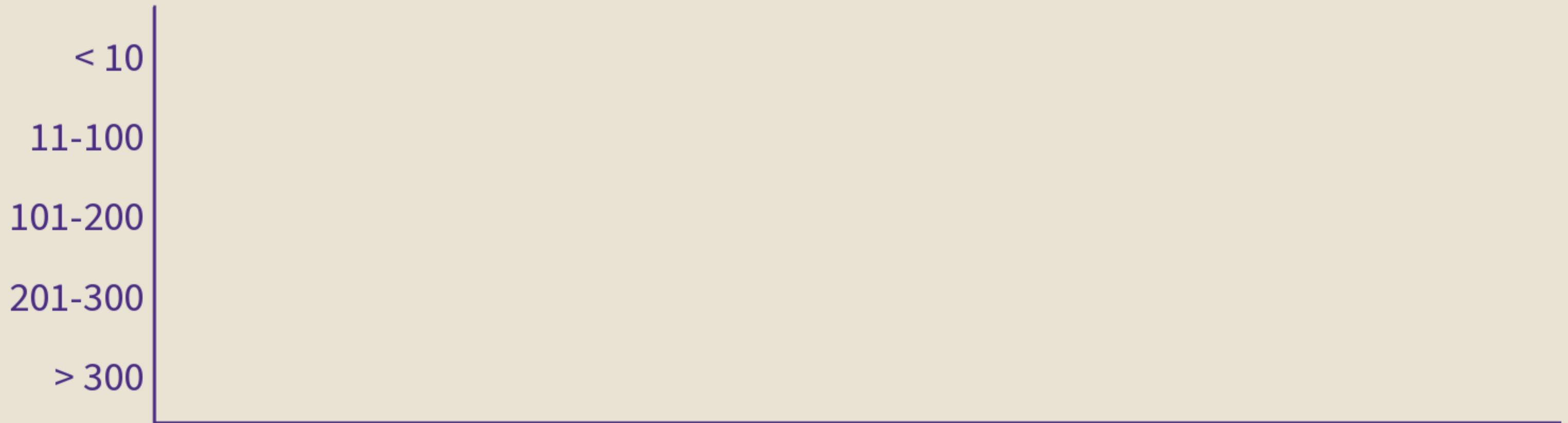
Powered by  **Poll Everywhere**

Start the presentation to see live content. For screen share software, share the entire screen. Get help at [pollev.com/app](https://pollev.com/app)

🌐 When poll is active, respond at [pollev.com/shanest](https://pollev.com/shanest)

📱 Text **SHANEST** to **22333** once to join

# W How many indigenous languages do you think there are in the US today?



Total Results: 0

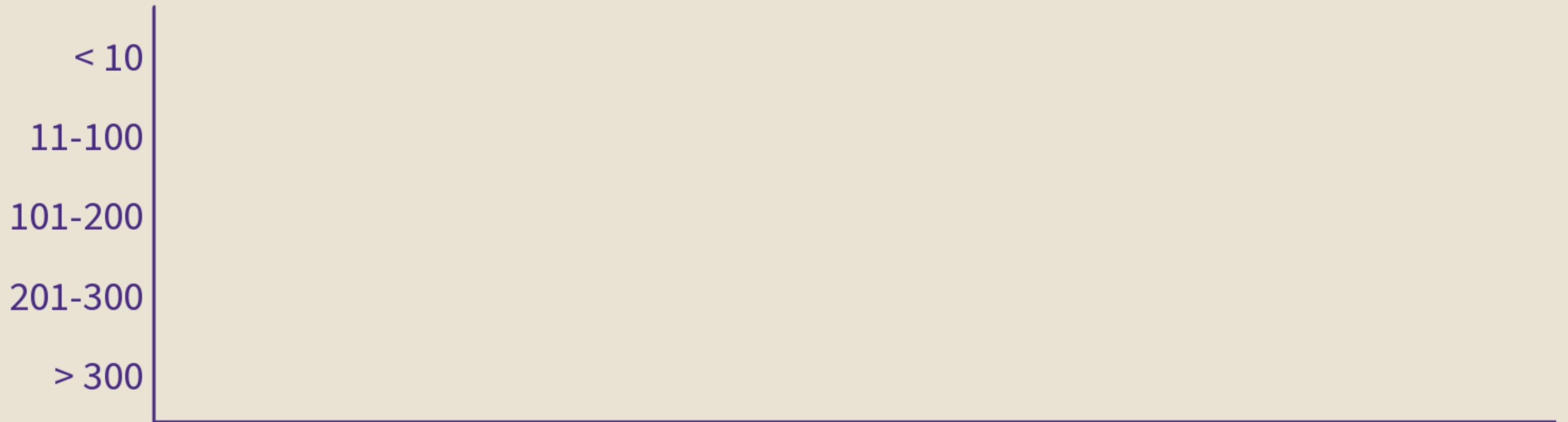
Powered by  **Poll Everywhere**

Start the presentation to see live content. For screen share software, share the entire screen. Get help at [pollev.com/app](https://pollev.com/app)

When poll is active, respond at [pollev.com/shanest](https://pollev.com/shanest)

Text **SHANEST** to **22333** once to join

# W How many languages do you think were spoken in the now-US at the time Europeans arrived?



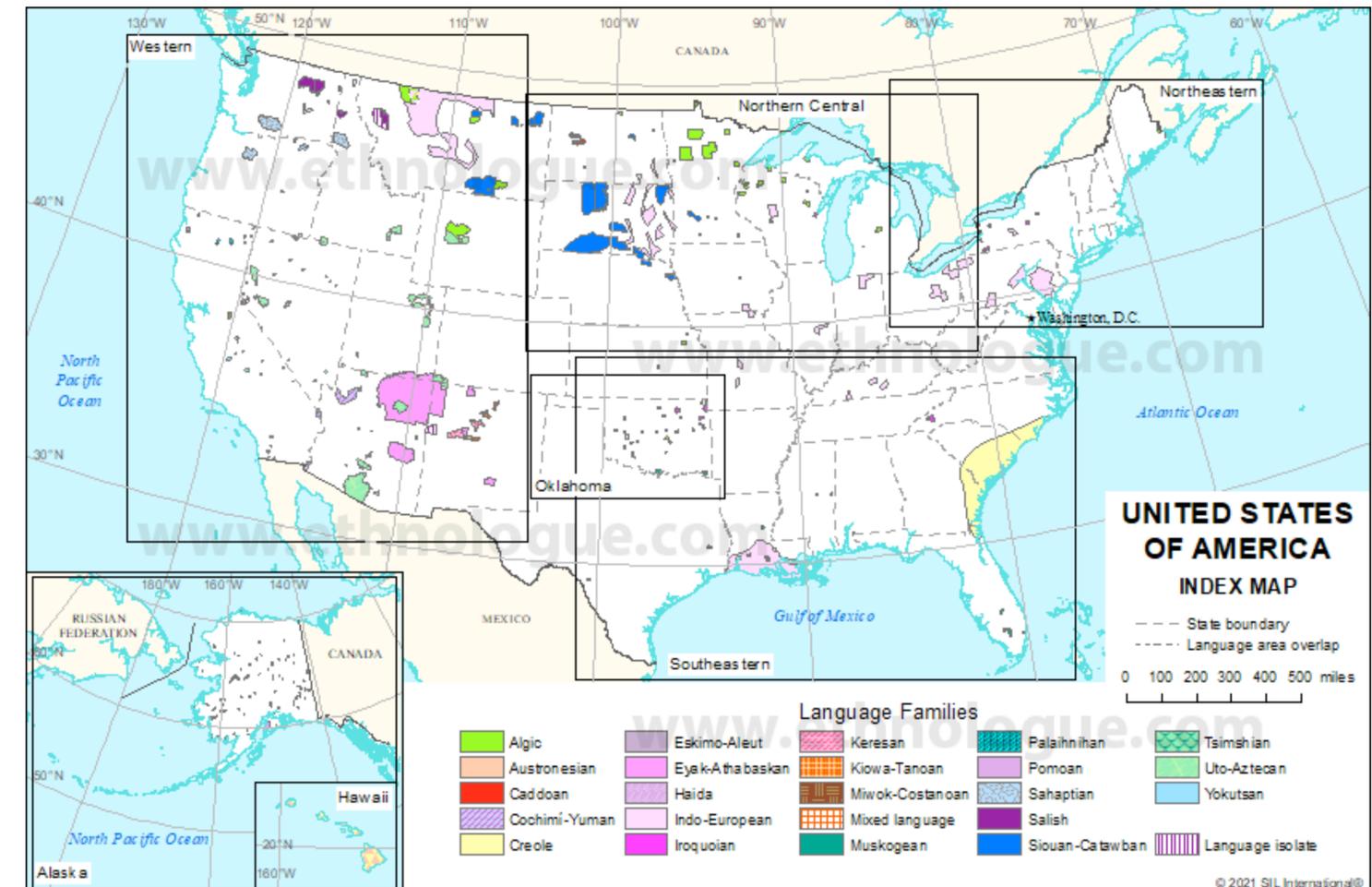
Total Results: 0

Powered by  **Poll Everywhere**

Start the presentation to see live content. For screen share software, share the entire screen. Get help at [pollev.com/app](https://pollev.com/app)

# Languages in the U.S.

- Current estimate (Ethnologue): 238
  - 226 living, 12 extinct
  - 195 indigenous
- Navajo: ~170,000 speakers
  - Not in U.S. top 25 by pop size
- Many, many endangered; increased need for revitalization efforts



[https://www.ethnologue.com/map/US\\_x\\_](https://www.ethnologue.com/map/US_x_)

# Indigenous Peoples' Day: Resources

- UW American Indian Studies Courses
  - (Sometimes including language courses, e.g. Southern Lushootseed, Salish)
- Lushootseed resources: <https://tulaliplushootseed.com/>
- Computational Methods in the Study of Endangered Languages: <https://computel-workshop.org/>
- AmericasNLP: <http://turing.iimas.unam.mx/americasnlp/index.html>
  - 2021: <https://aclanthology.org/volumes/2021.americasnlp-1/>
  - 2022 shared task: <https://github.com/AmericasNLP/americasnlp2022>

# Roadmap

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

# CKY

- Given an input string  $S$  of length  $n$

# CKY

- Given an input string  $S$  of length  $n$
- Build table  $(n + 1) \times (n + 1)$

# 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  $_3$

# 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  $i, j$

# 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

# 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

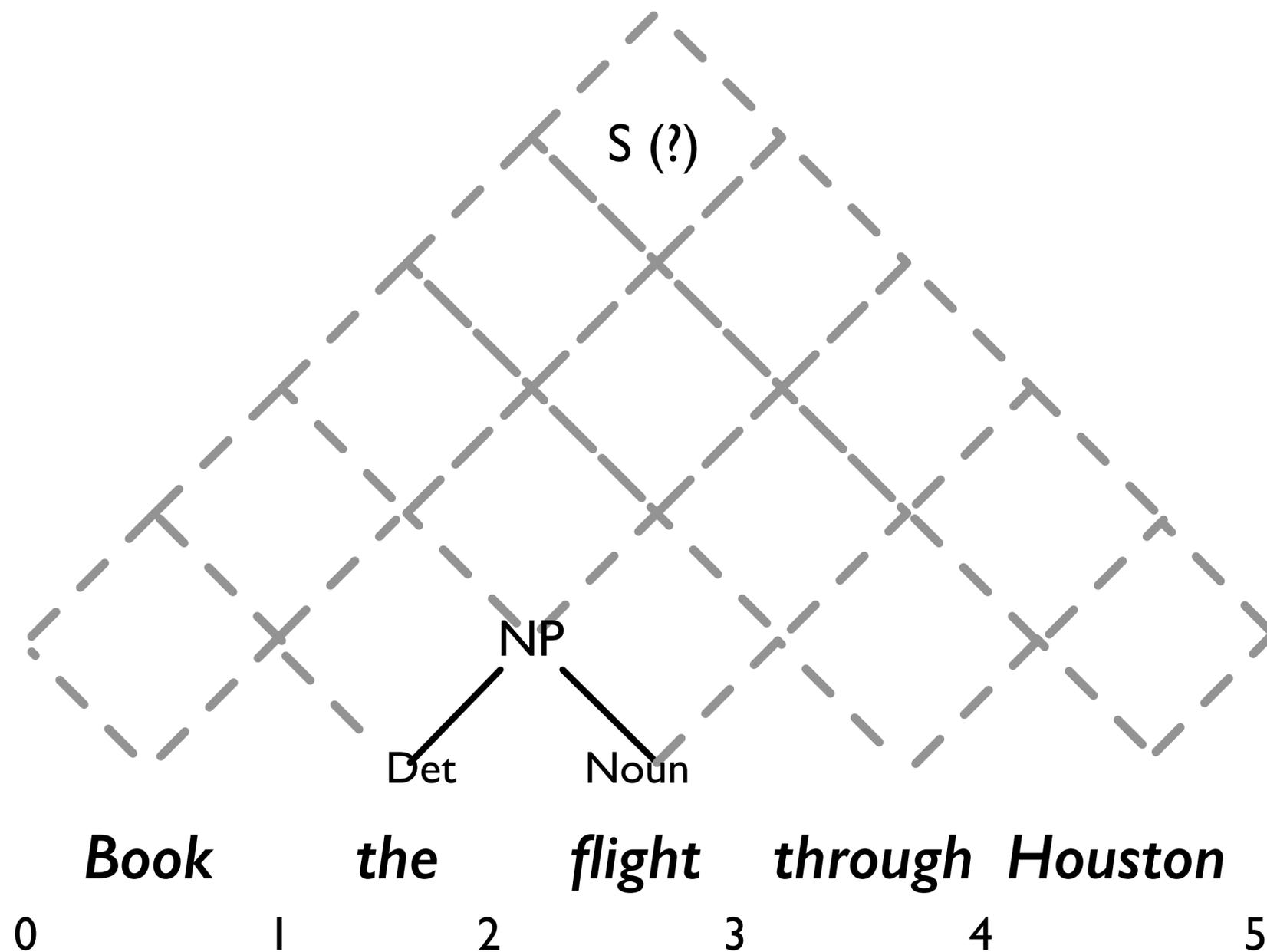
<i>Book</i>	<i>the</i>	<i>flight</i>	<i>through</i>	<i>Houston</i>
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]
	[1,2]	[1,3]	[1,4]	[1,5]
		[2,3]	[2,4]	[2,5]
			[3,4]	[3,5]
				[4,5]







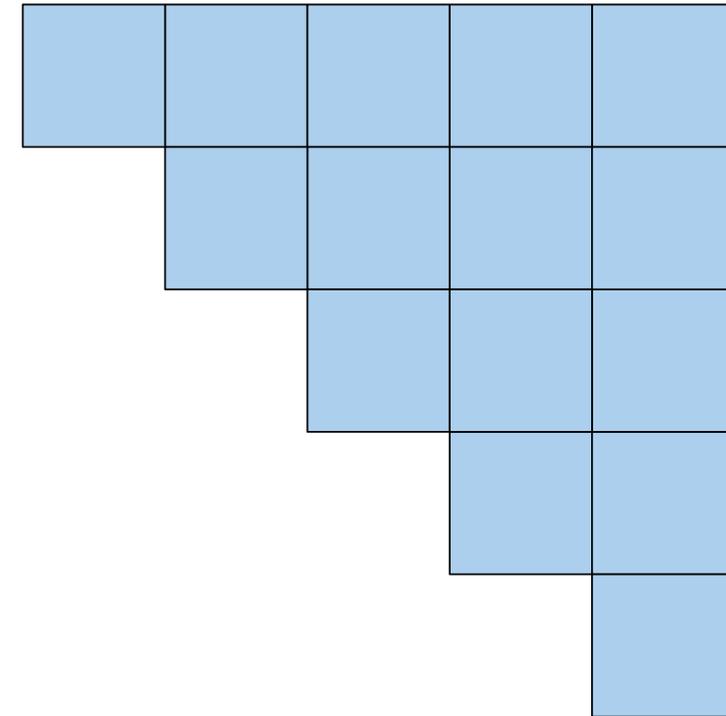
# CKY Matrix



# Dynamic Programming in CKY

- Key idea:
  - for  $i < k < j$
  - ...and a parse spanning substring  $[ i, j ]$
  - There is a  $k$  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  $[ i, k ]$  and  $C$  in  $[ k, j ]$  for some  $i < k < j$
  - CNF forces this for all  $j > i + 1$

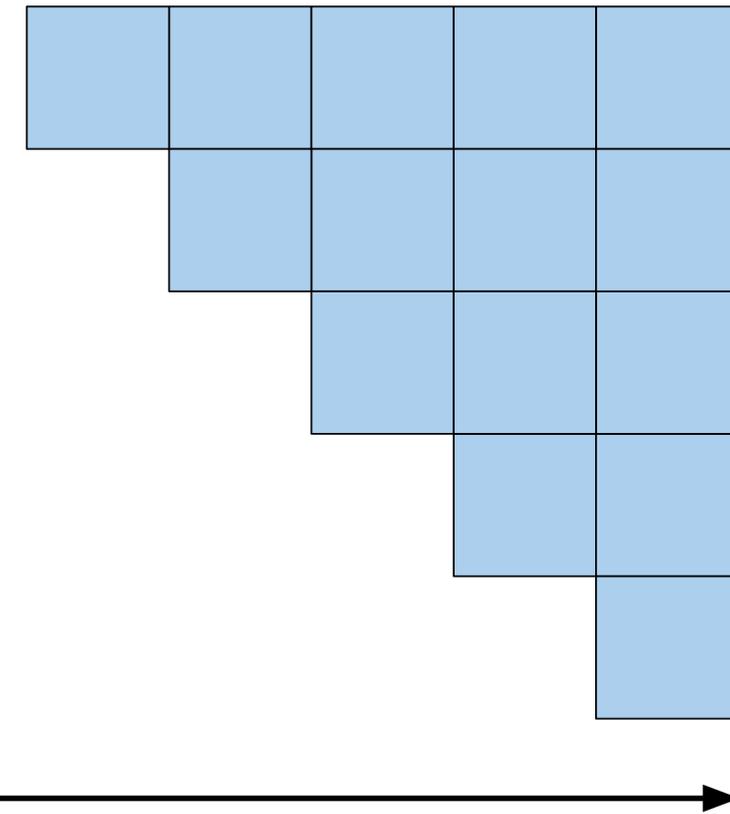
# CKY



- Table fills:

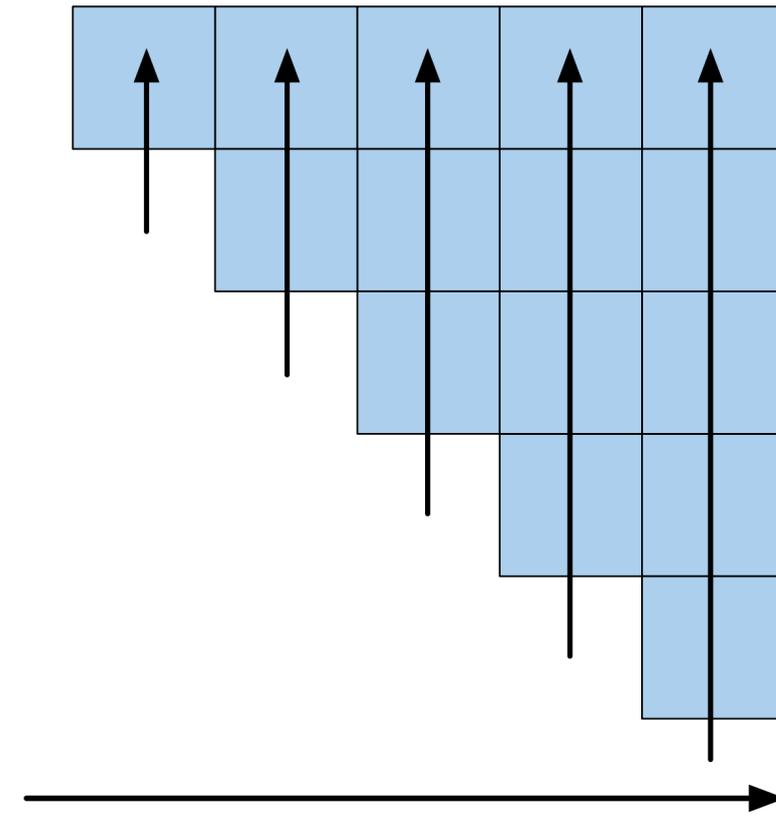
# CKY

- Table fills:
  - Column-by-column, left-to-right



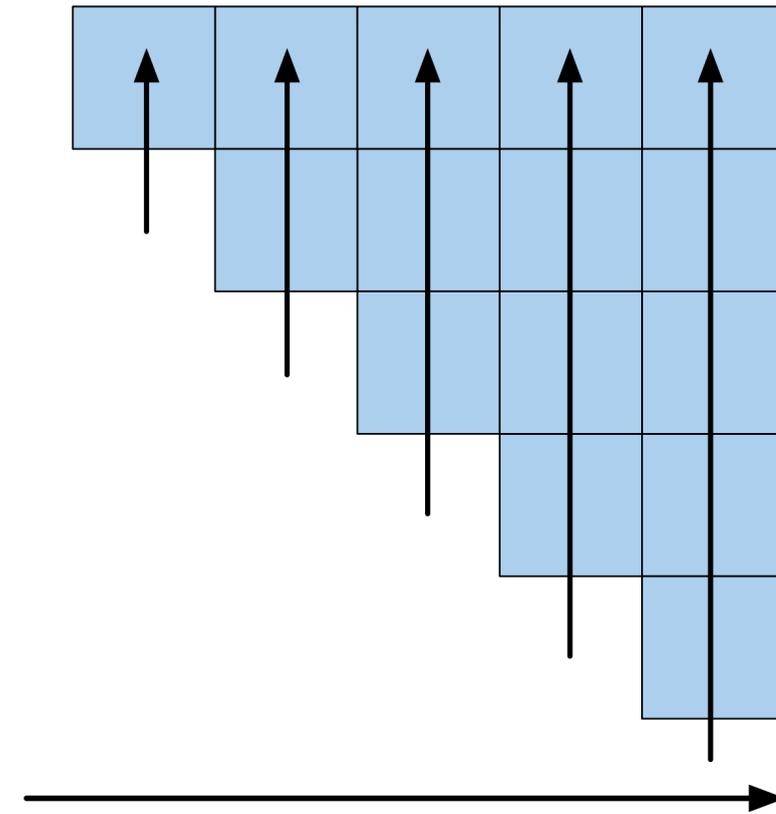
# CKY

- Table fills:
  - Column-by-column, left-to-right
  - bottom-to-top



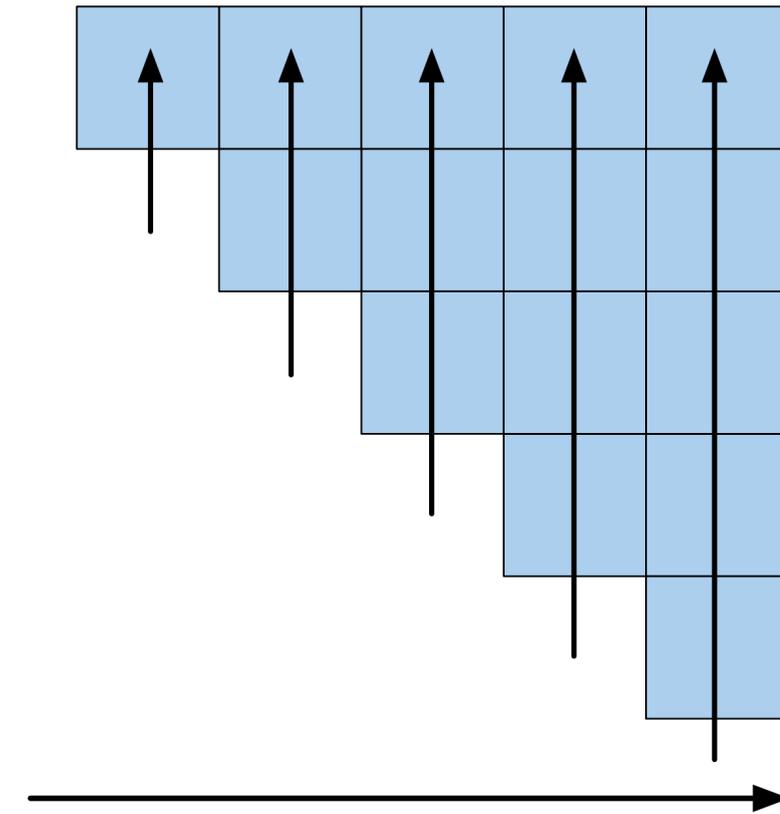
# CKY

- Table fills:
  - Column-by-column, left-to-right
  - bottom-to-top
- Why?

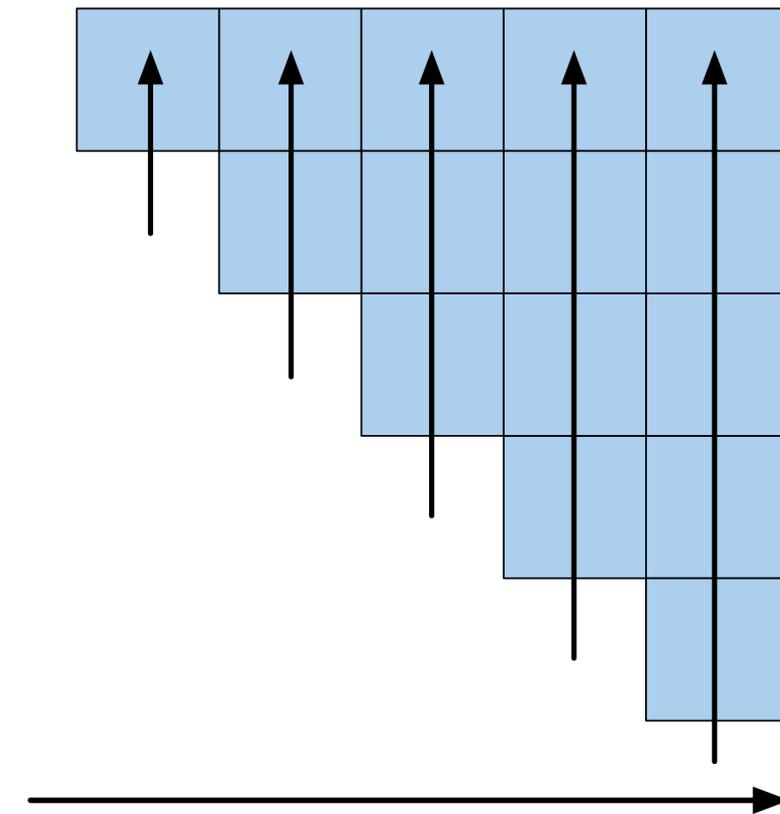


# CKY

- Table fills:
  - Column-by-column, left-to-right
  - bottom-to-top
- Why?
  - To fill each cell, must have access to all sub-spans

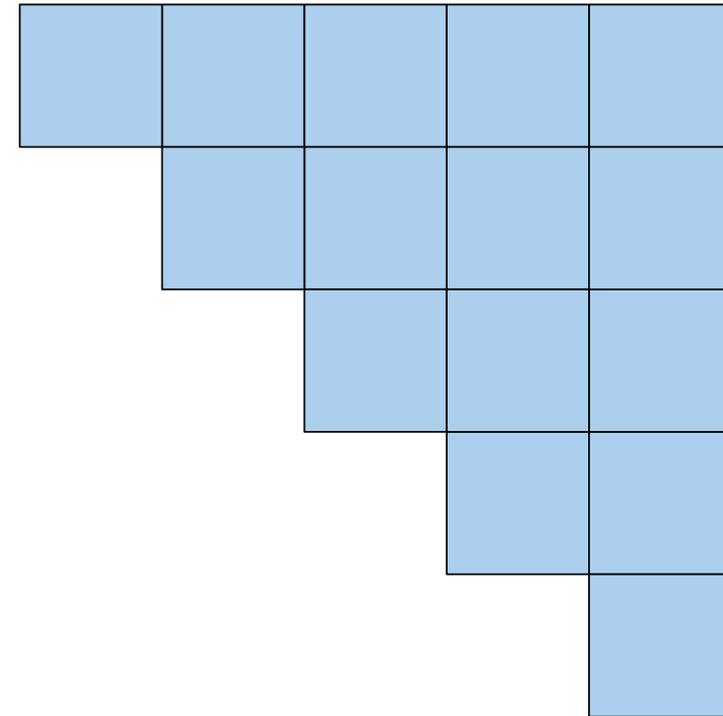


# CKY



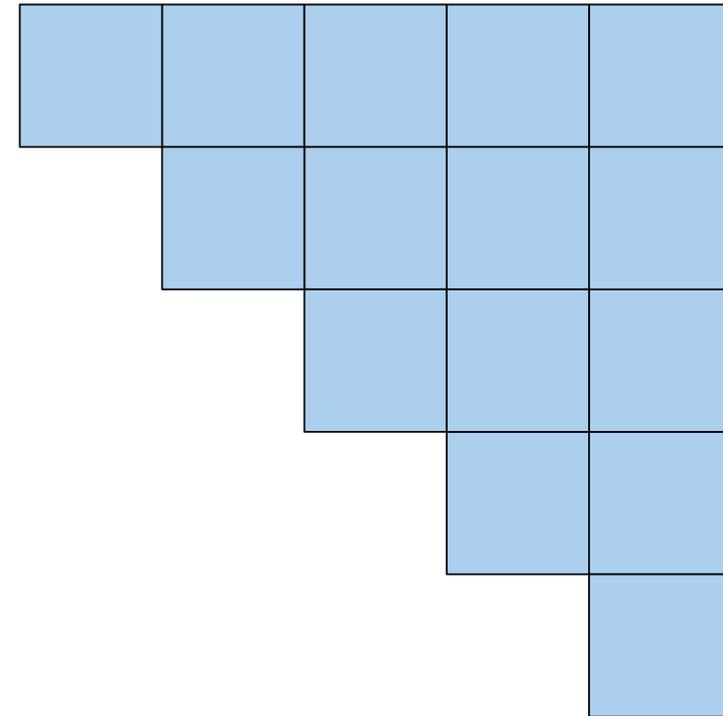
- Table fills:
  - Column-by-column, left-to-right
  - bottom-to-top
- Why?
  - To fill each cell, must have access to all sub-spans
    - For cell  $[ i, j ]$ , must be able to access all cells  $[ i, k ]$  and  $[ k, j ]$  where  $i < k < j$

# CKY



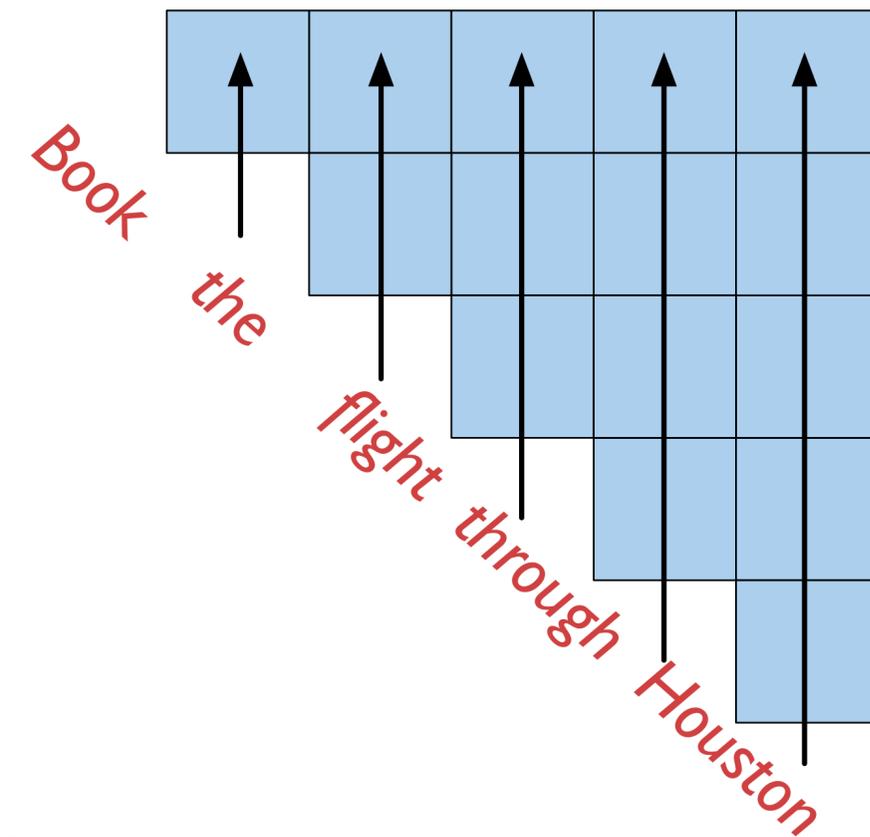
- Table fills:
  - Column-by-column, left-to-right
  - bottom-to-top
- Why?
  - To fill each cell, must have access to all sub-spans
    - For cell  $[ i, j ]$ , must be able to access all cells  $[ i, k ]$  and  $[ k, j ]$  where  $i < k < j$
  - Allows online sentence analysis

# 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



- 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 ] }
```

# 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

# 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

# CKY Algorithm

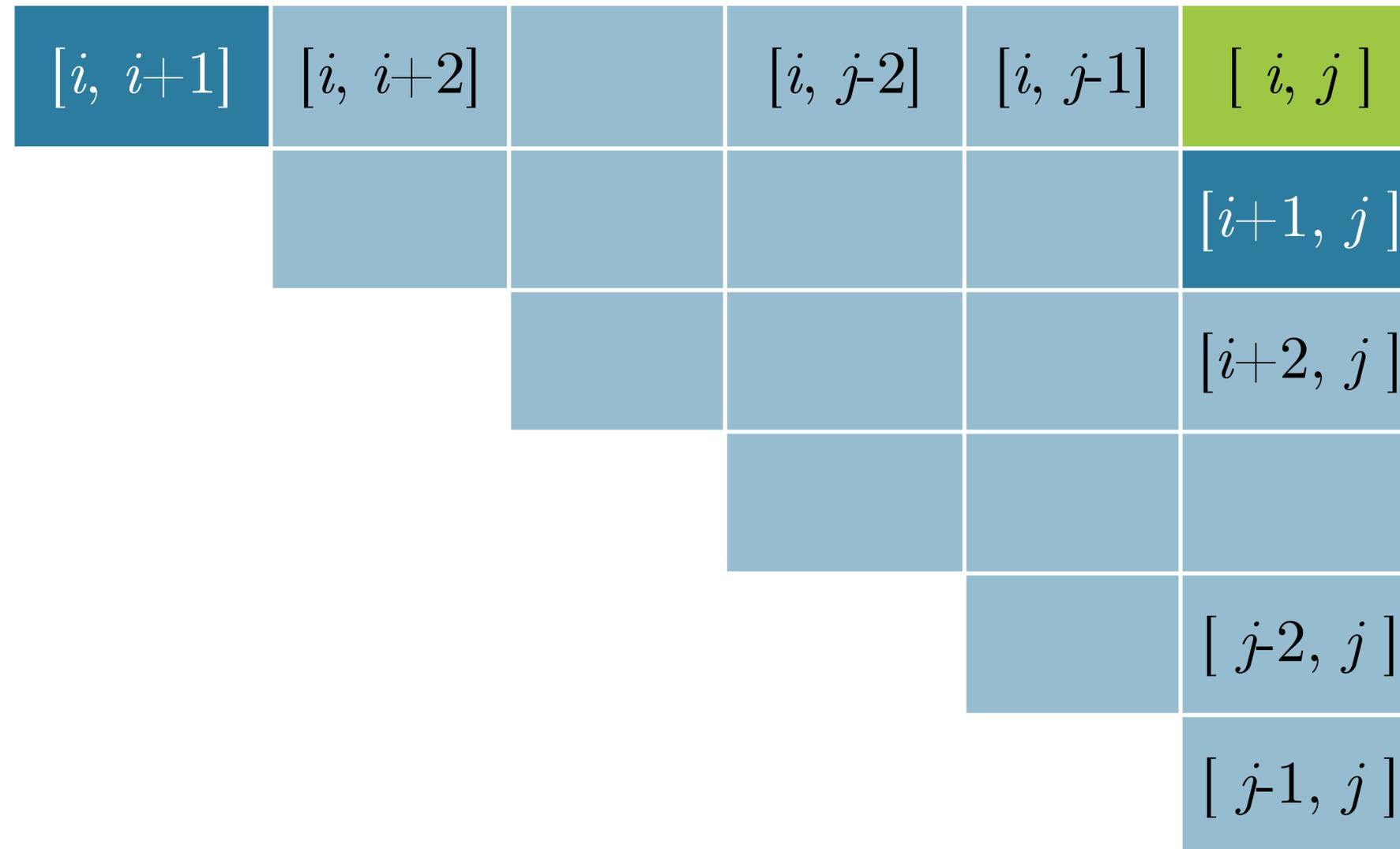
```
function CKY-PARSE(words, grammar) returns table
for j ← from 1 to LENGTH(words) do
  table[j - 1, j] ← { A | A → words[j] ∈ grammar }
  for i ← from j - 2 downto 0 do
    for k ← i + 1 to j - 1 do
      table[i, j] ← table[i, j] ∪
        { A | A → BC ∈ grammar
          B ∈ table[i, k ],
     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

Left-to-right, bottom-to-top

Sliding *k* as the pivot for child nodes

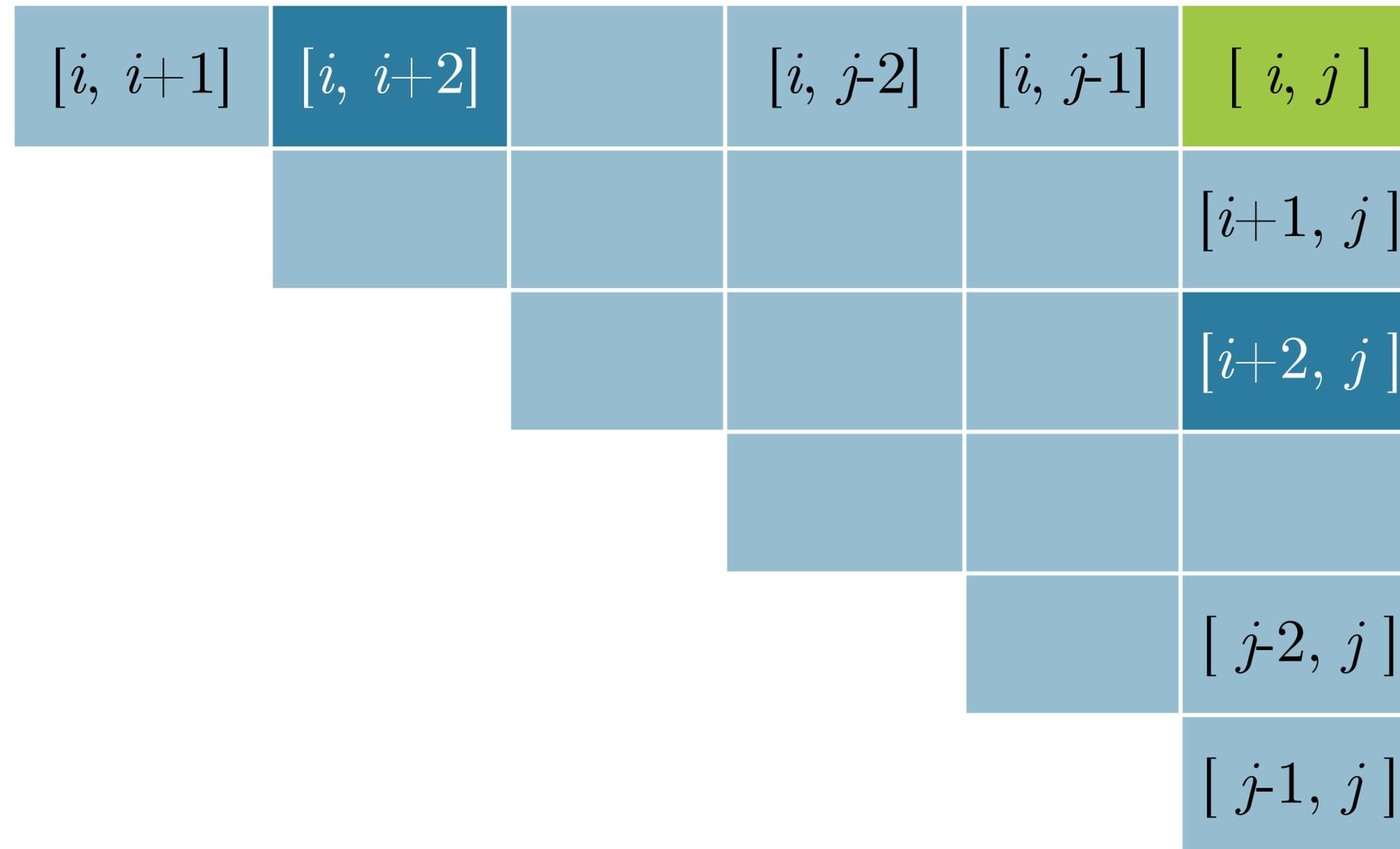
Filling the cell with set of applicable rules

# Filling Cell $[i, j]$



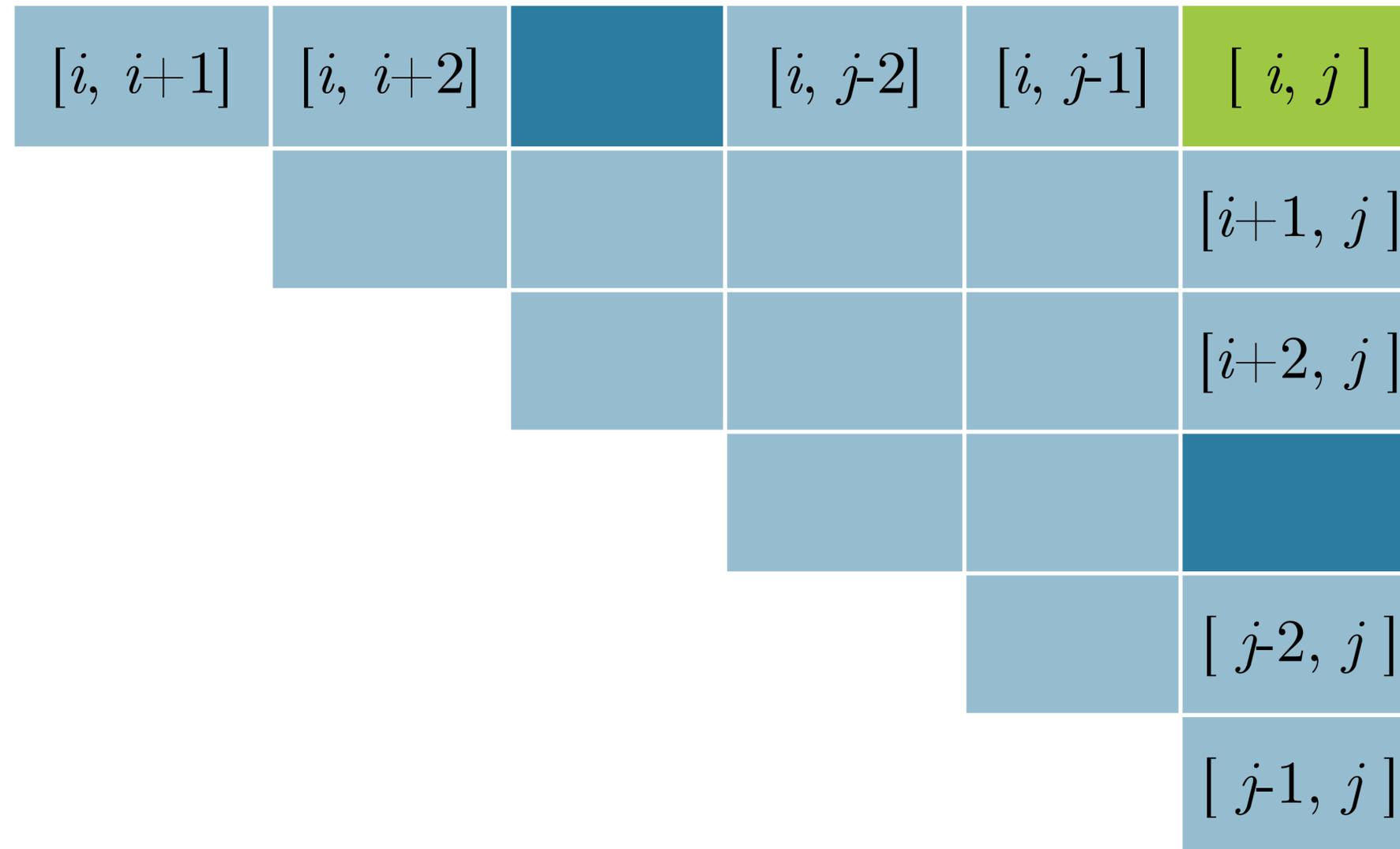
For cell  $[i, j]$ , find rule spanning cells  $[i, k]$  and  $[k, j]$  where  $i < k < j$

# Filling Cell $[i, j]$



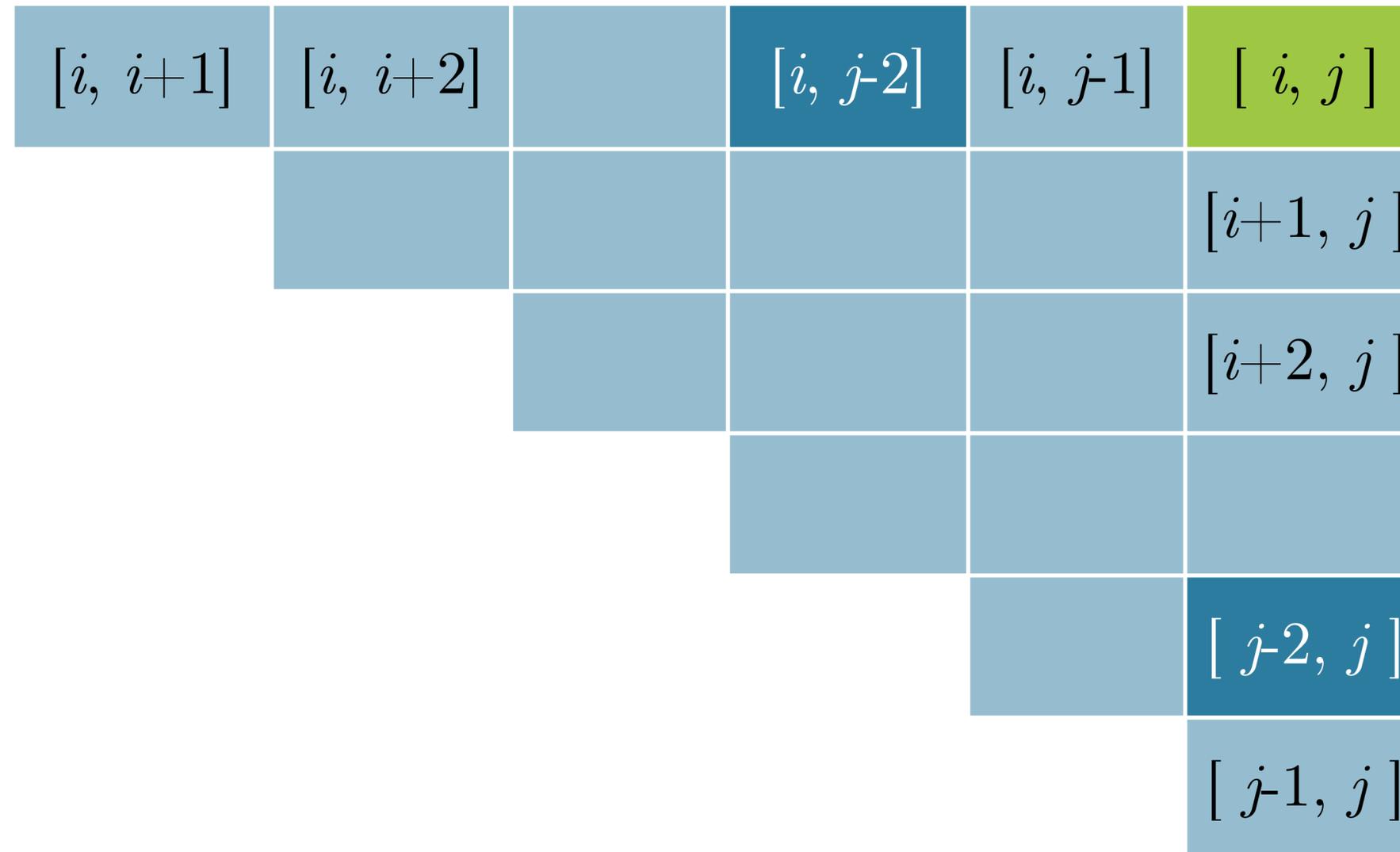
For cell  $[i, j]$ , find rule spanning cells  $[i, k]$  and  $[k, j]$  where  $i < k < j$

# Filling Cell $[i, j]$



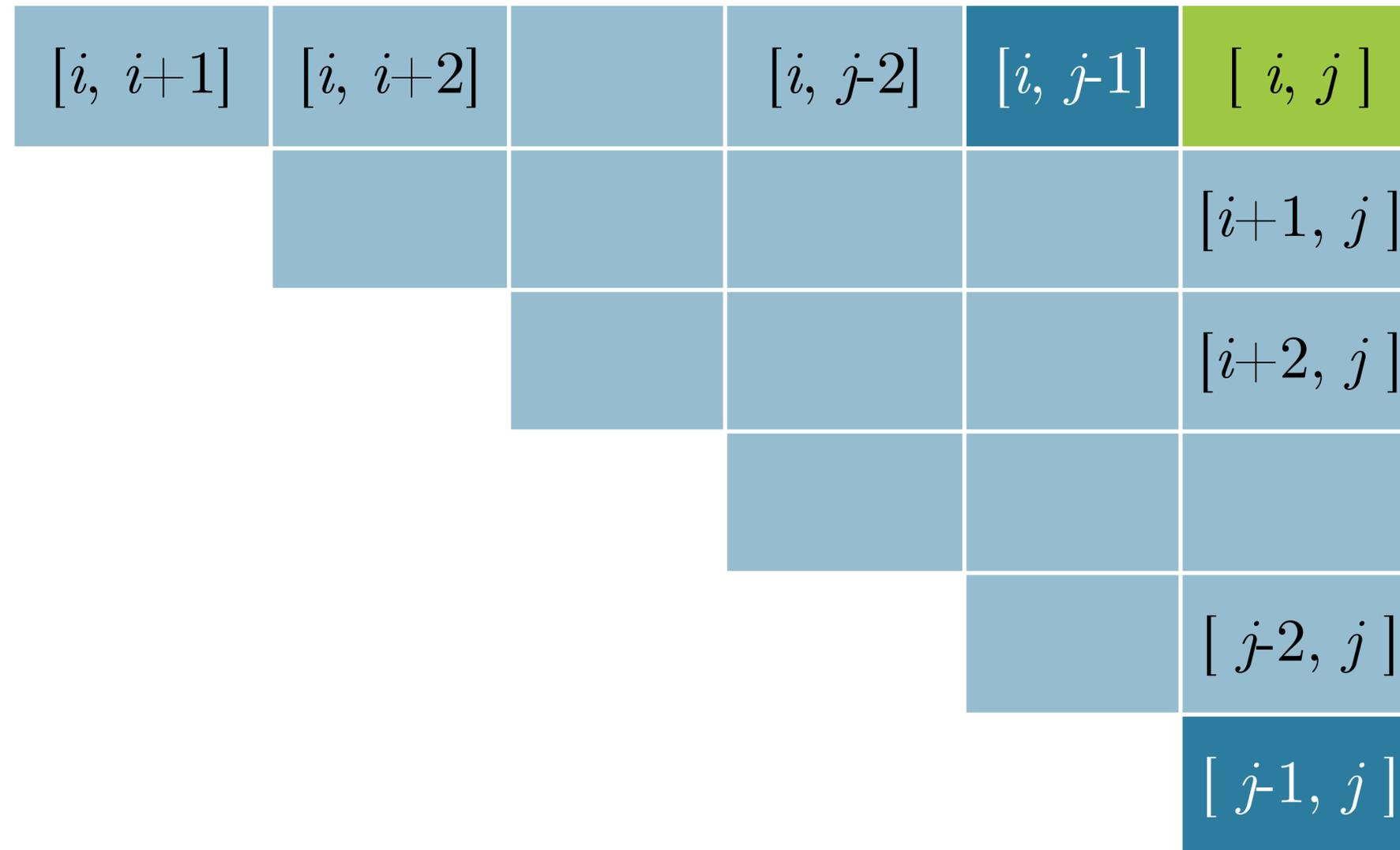
For cell  $[i, j]$ , find rule spanning cells  $[i, k]$  and  $[k, j]$  where  $i < k < j$

# Filling Cell $[i, j]$



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

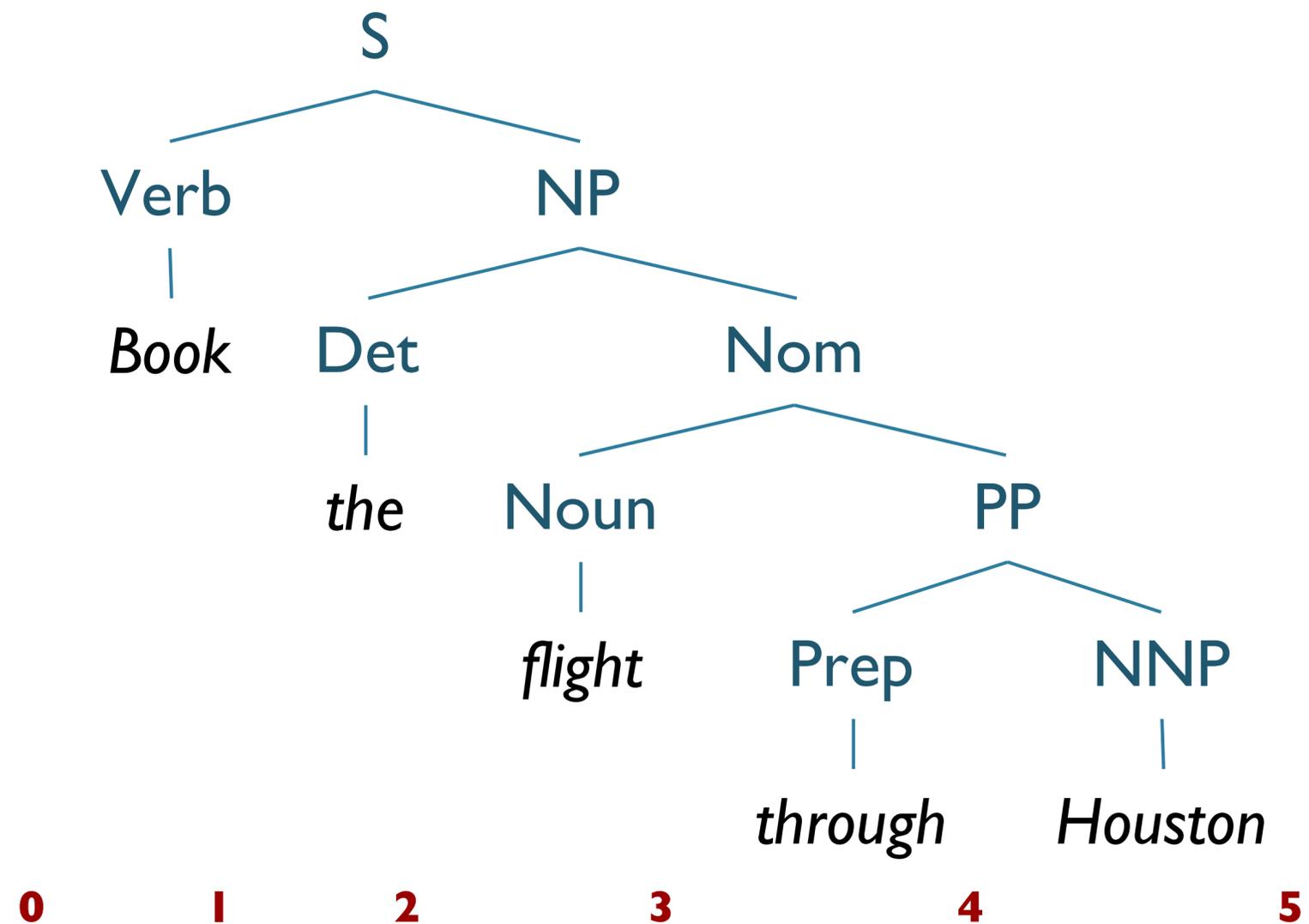
# Filling Cell $[i, j]$



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

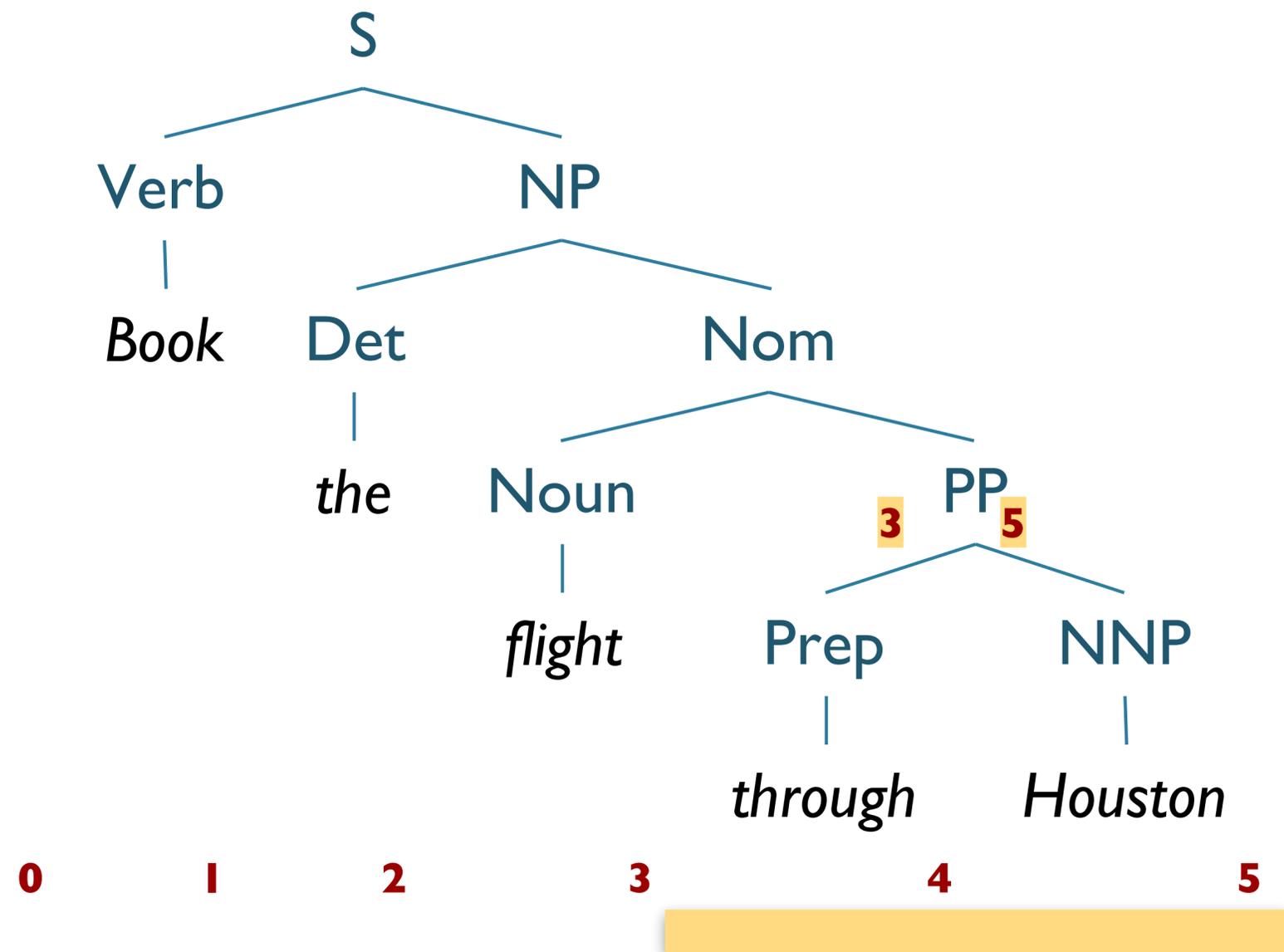
# Why fill cells this way?

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



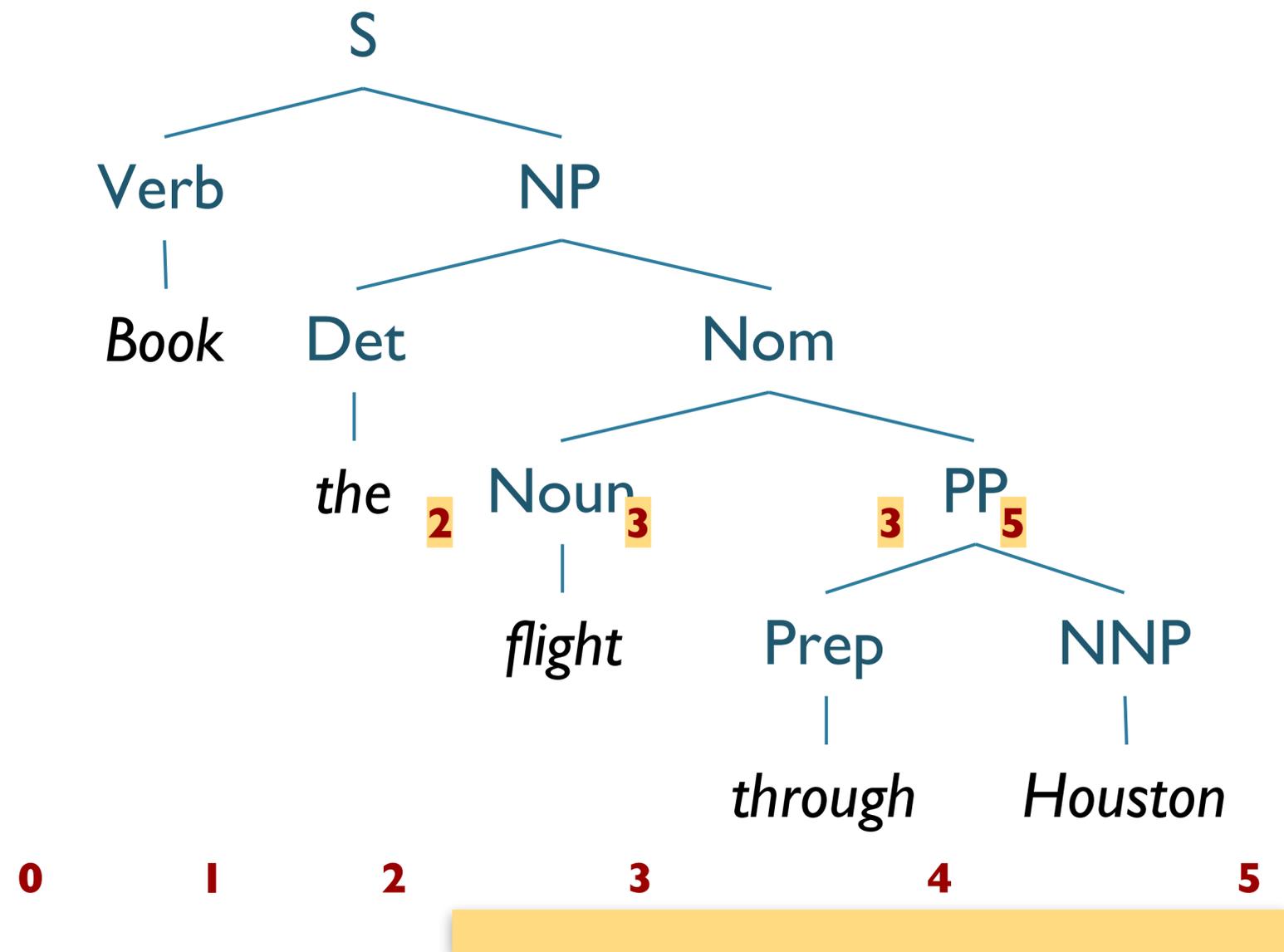
# Why fill cells this way?

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



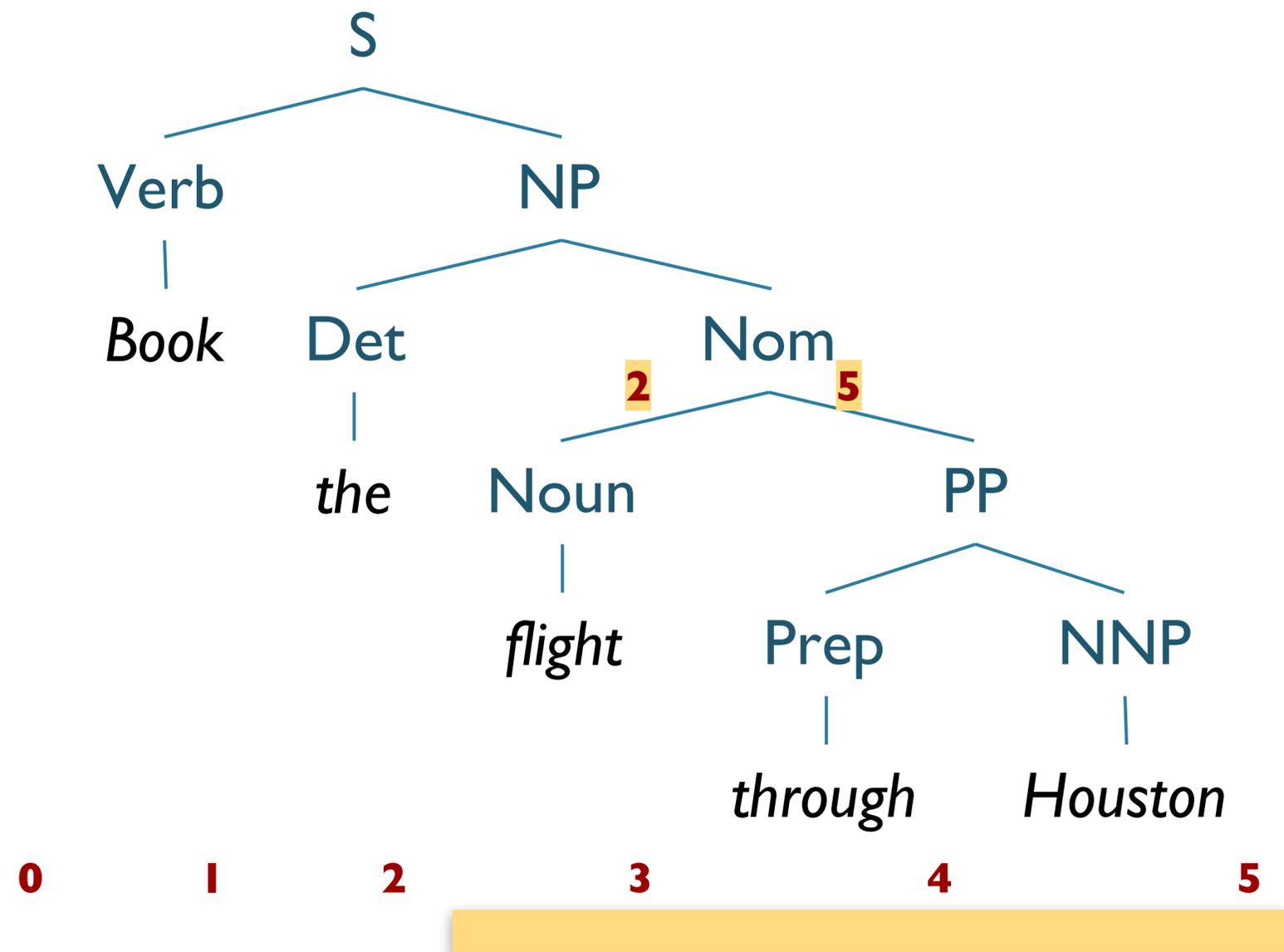
# Why fill cells this way?

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



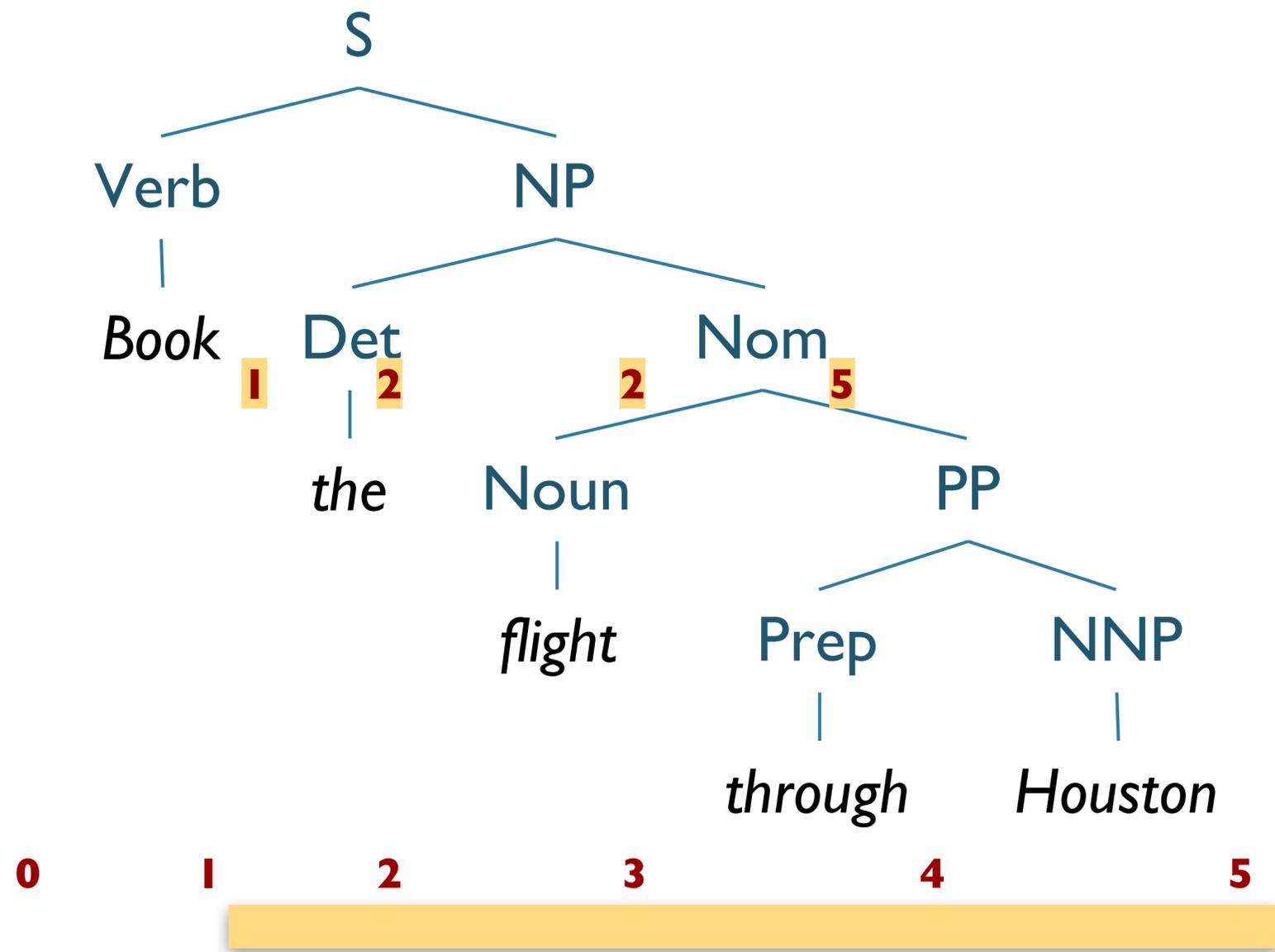
# Why fill cells this way?

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



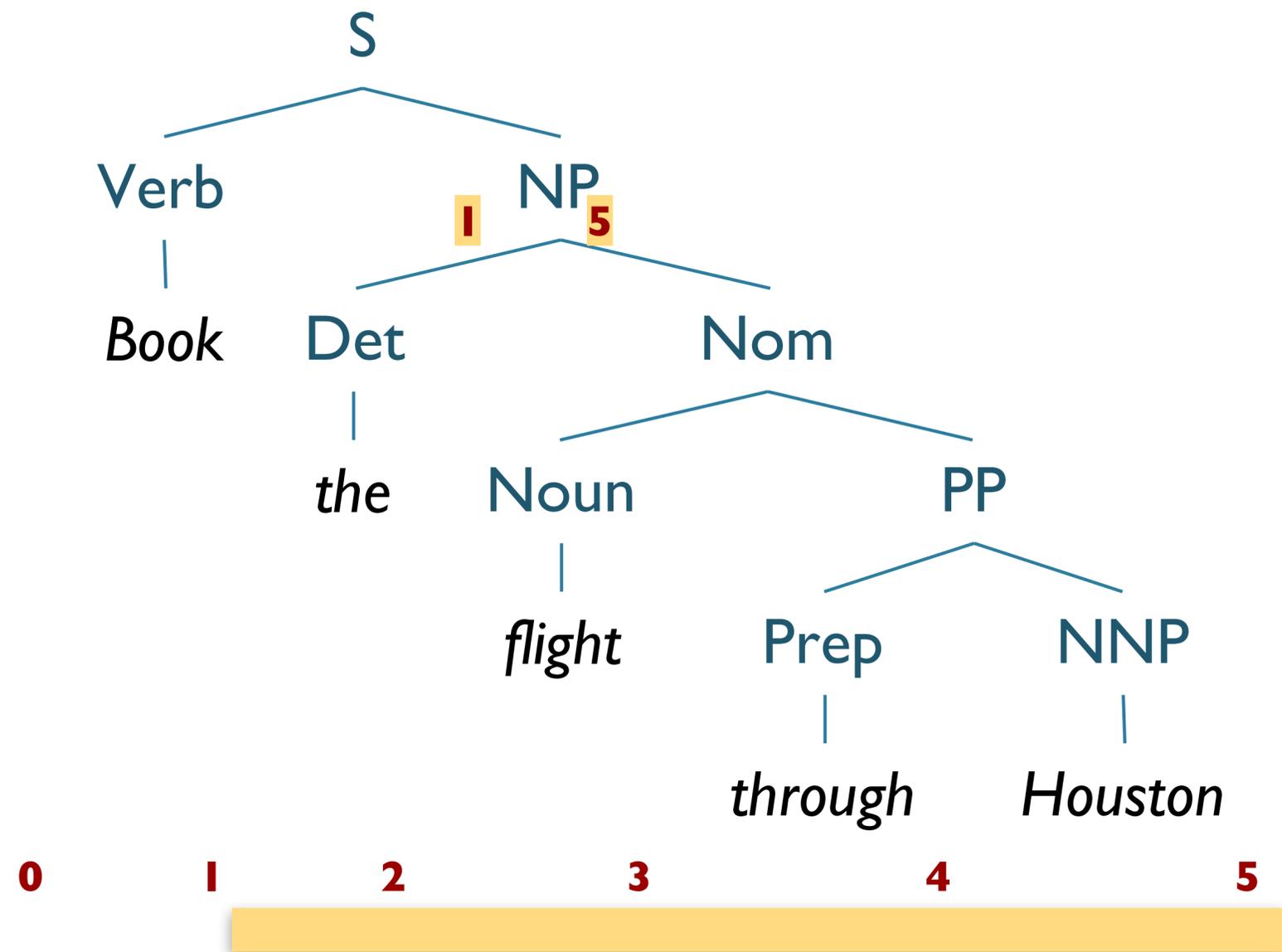
# Why fill cells this way?

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



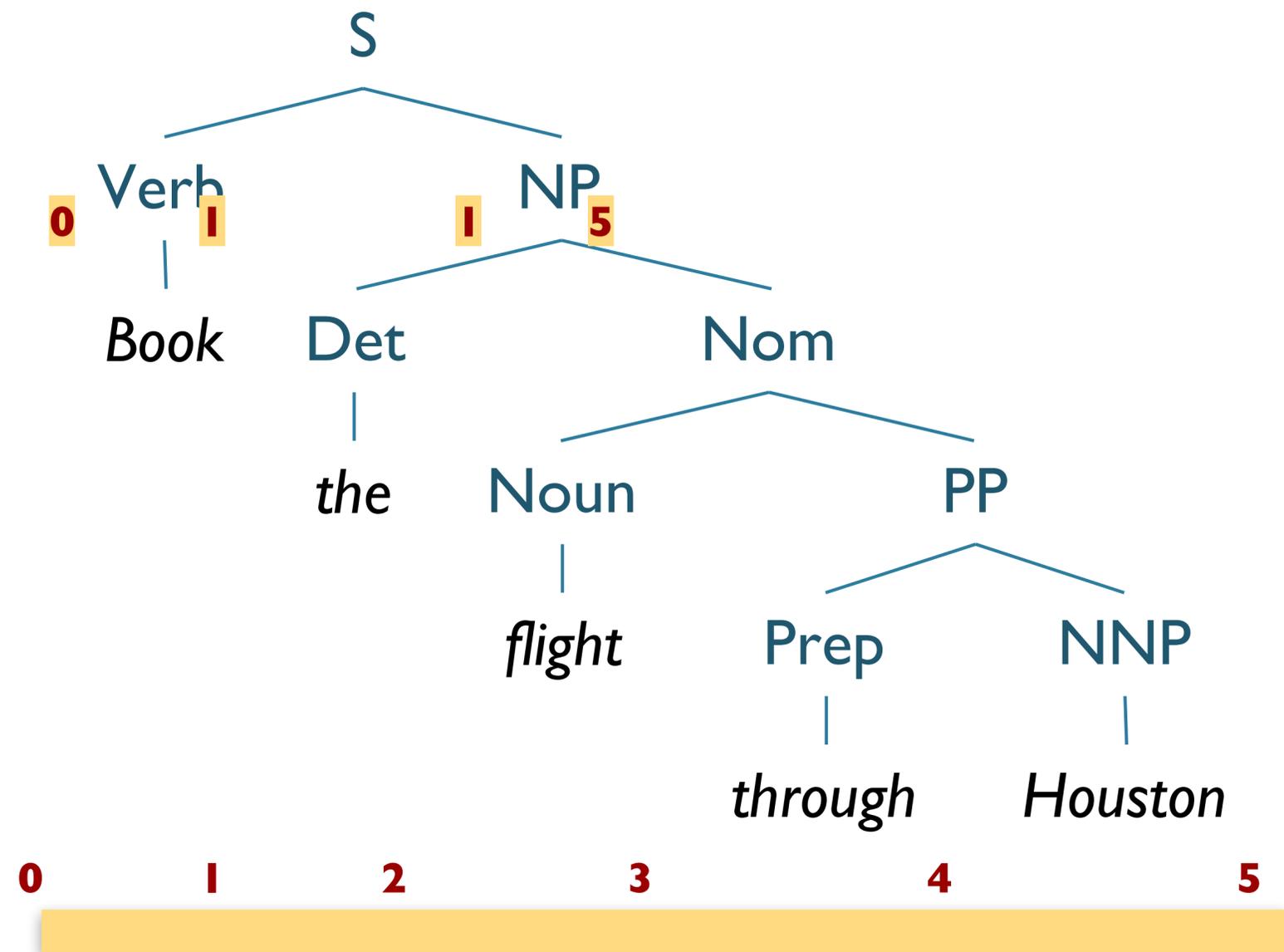
# Why fill cells this way?

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



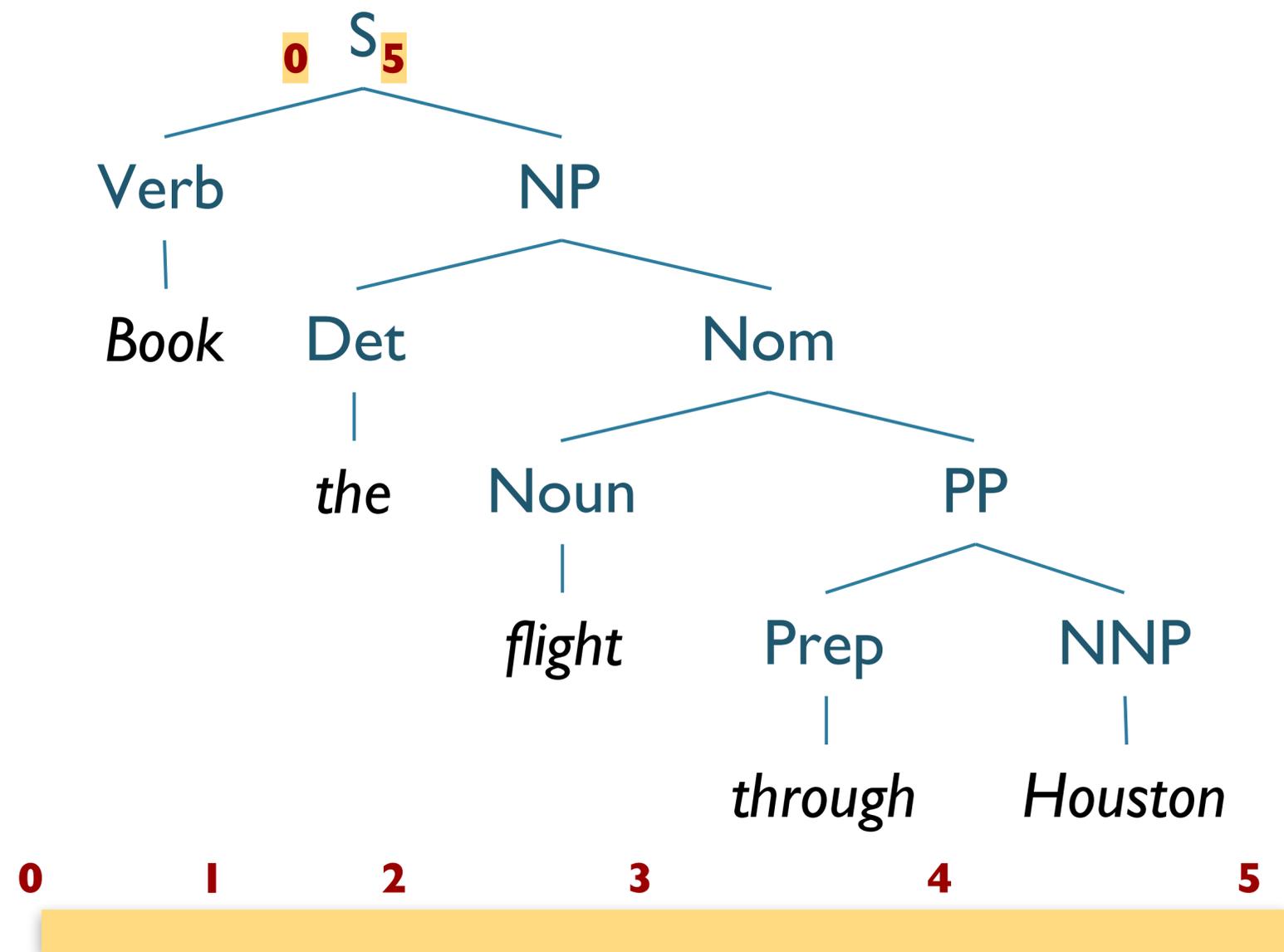
# Why fill cells this way?

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



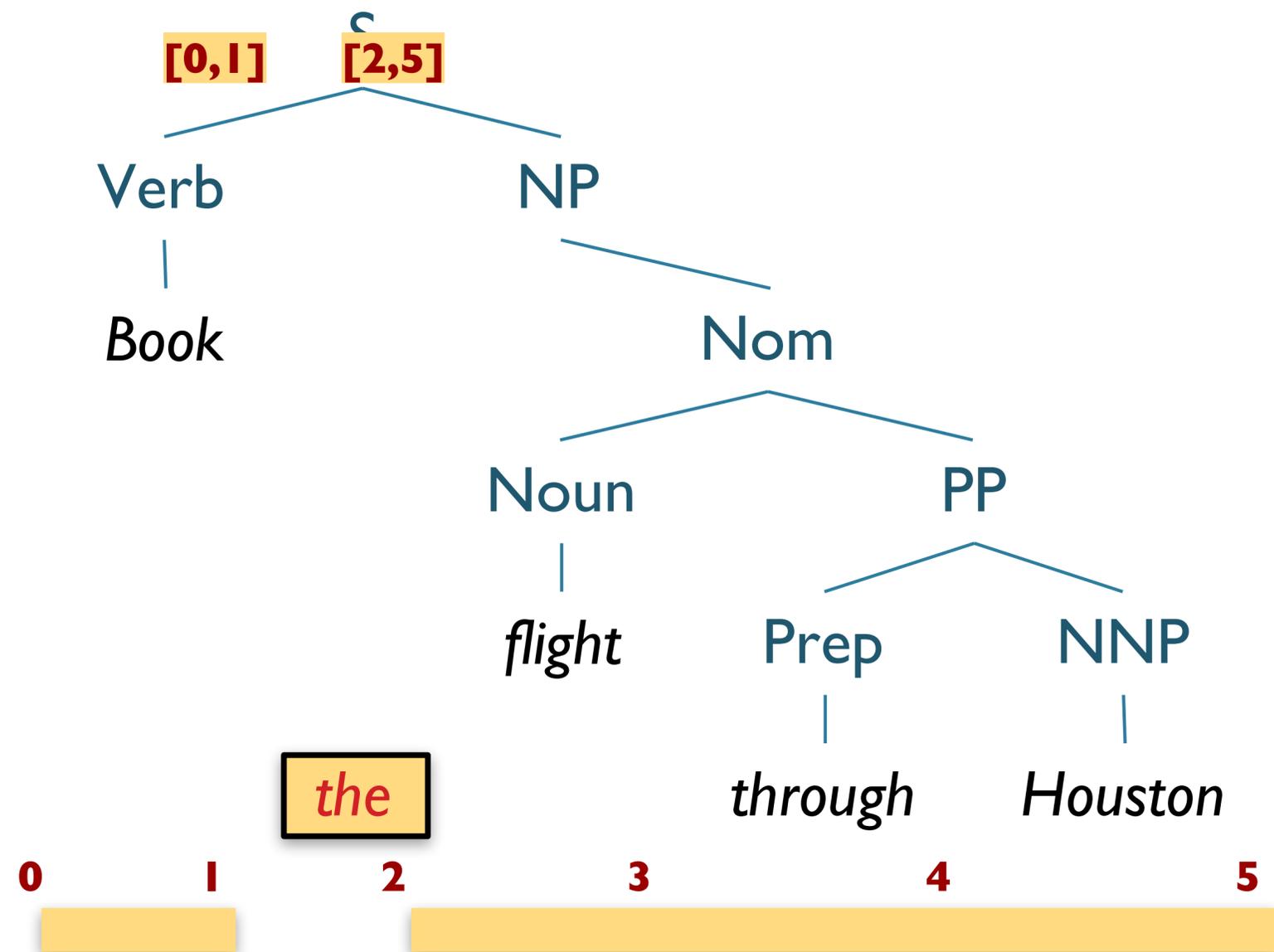
# Why fill cells this way?

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



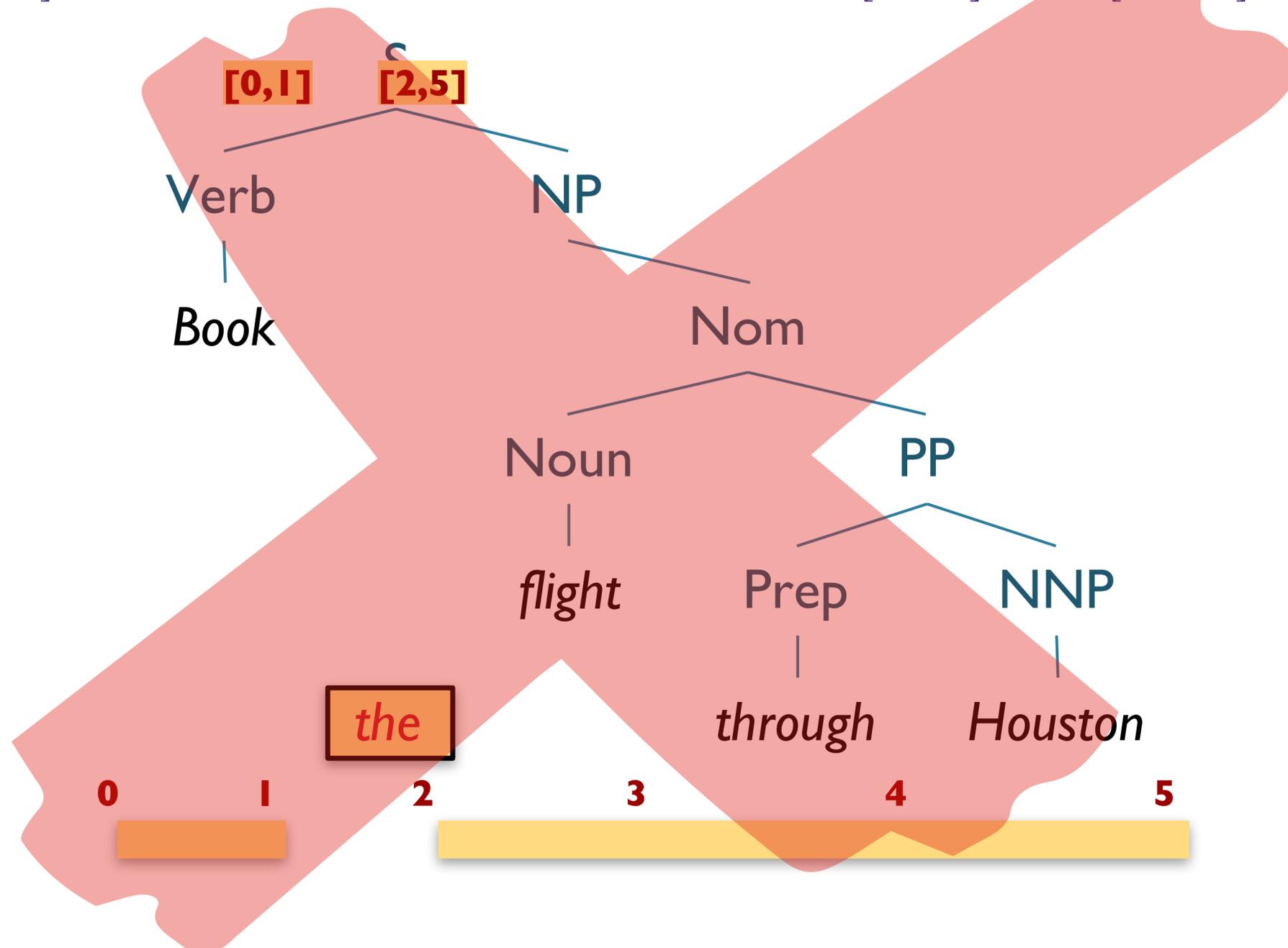
# Why fill cells this way?

- 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  $i < k < j$



🌐 When poll is active, respond at [pollev.com/shanest](https://pollev.com/shanest)

📱 Text **SHANEST** to **22333** once to join

# W Would you say CKY is a top-down or a bottom-up parsing algorithm?

Top-down

Bottom-up

Total Results: 0

Powered by  **Poll Everywhere**

Start the presentation to see live content. For screen share software, share the entire screen. Get help at [pollev.com/app](https://pollev.com/app)

# CKY Parsing Example

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

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

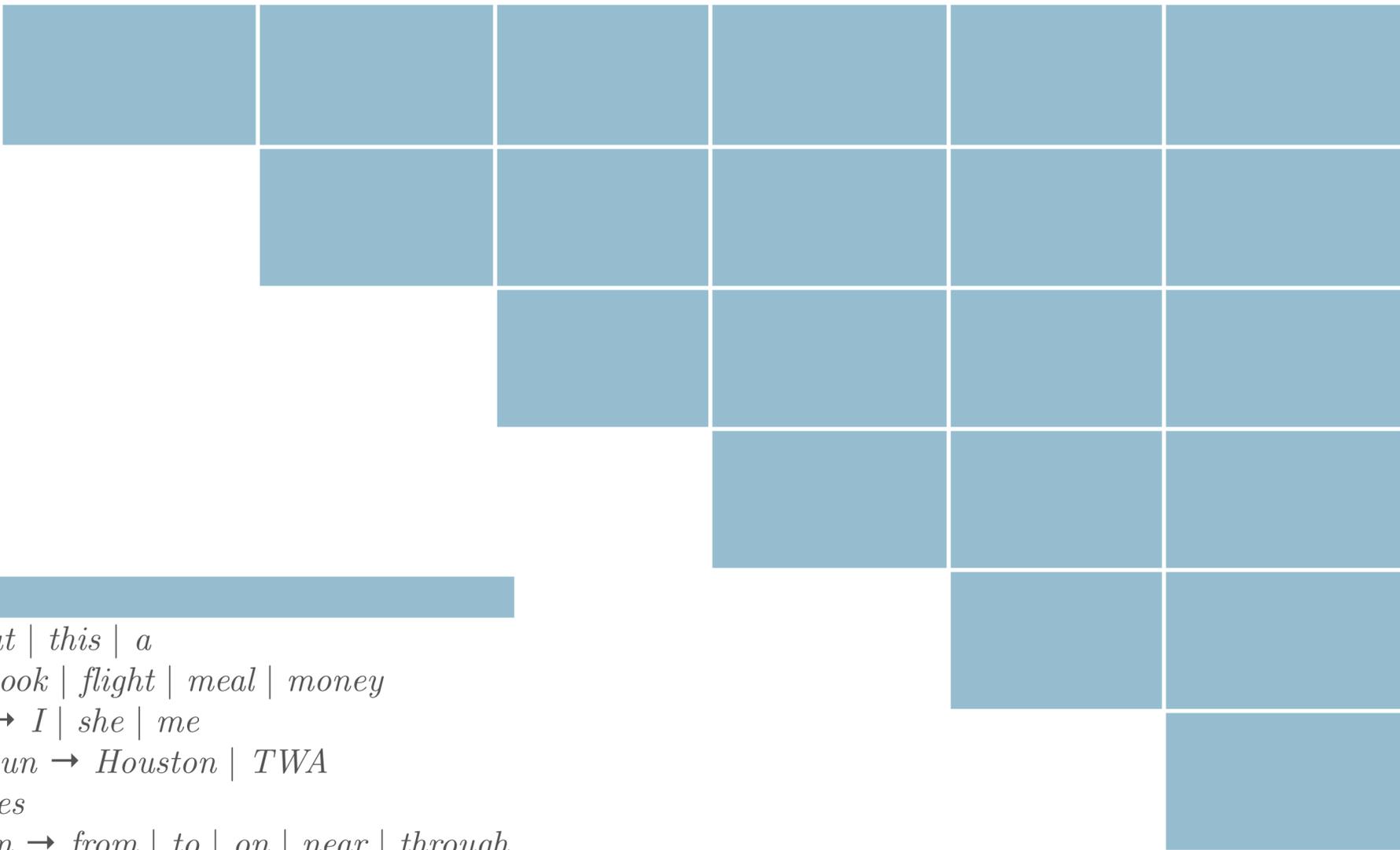
- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

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

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

**Lexicon**

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



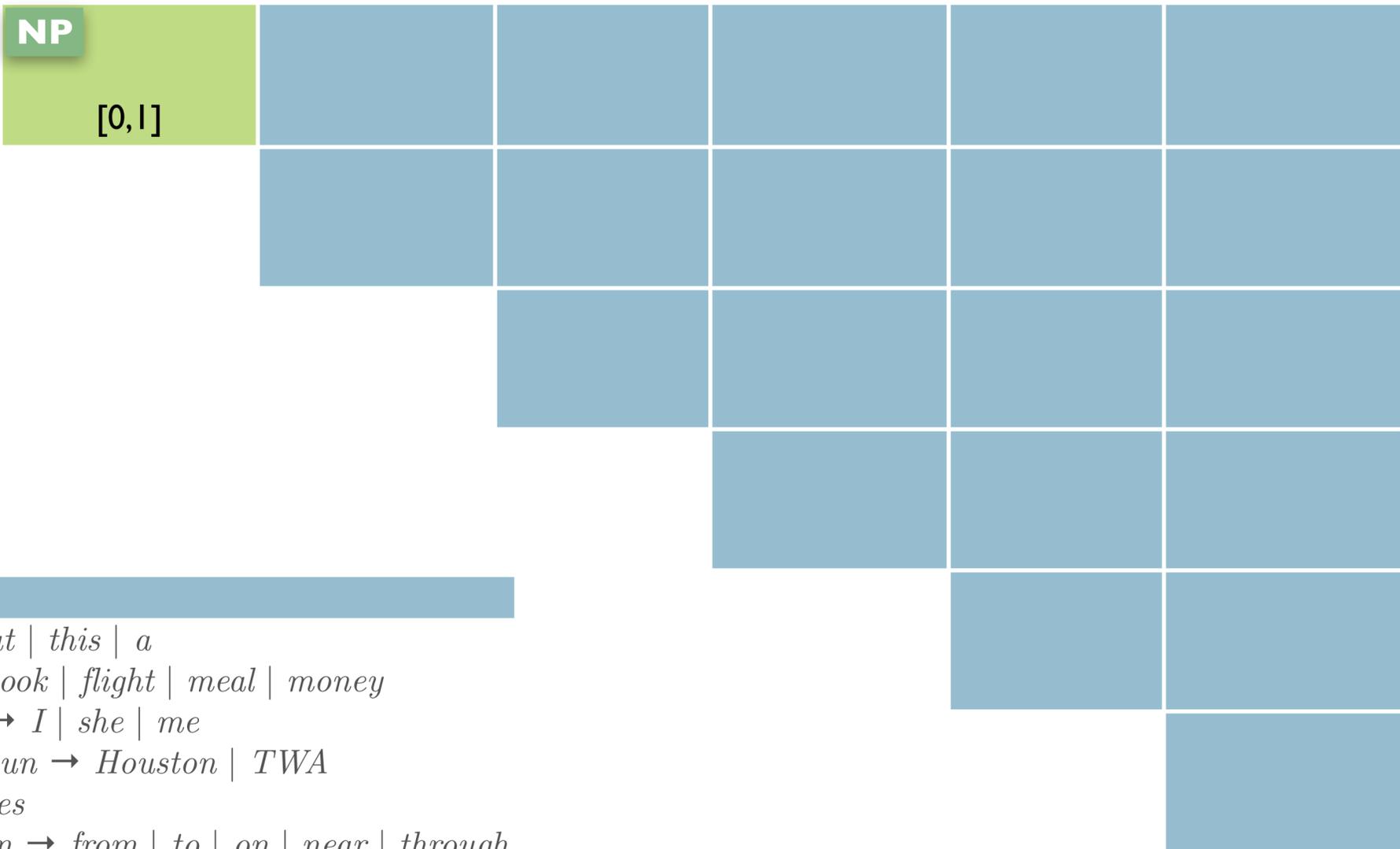
0                    1                    2                    3                    4                    5                    6

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

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

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

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



**Lexicon**

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



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

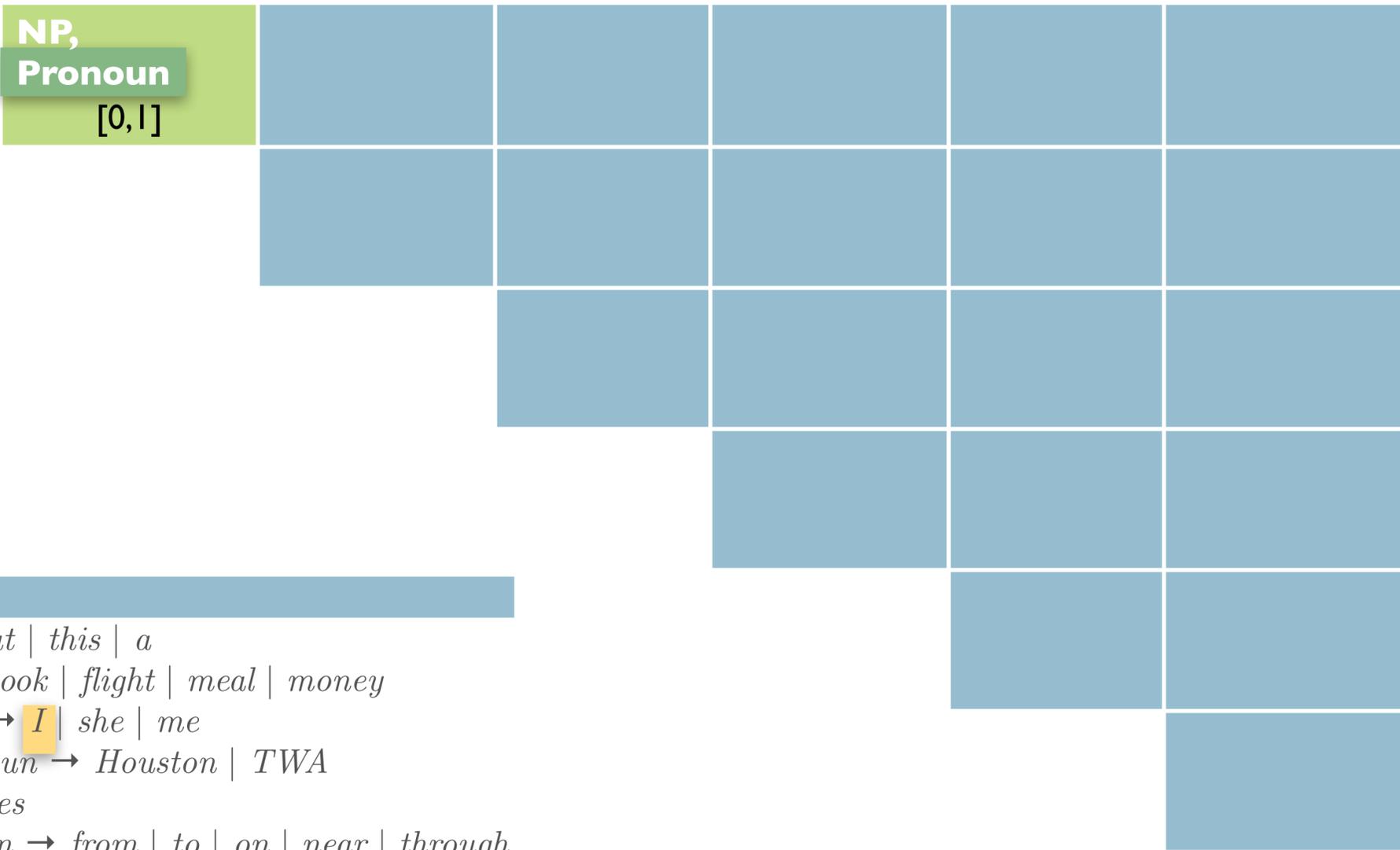
- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

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

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

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

- 
- $PP \rightarrow Preposition NP$



**Lexicon**

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



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

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

---

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

---

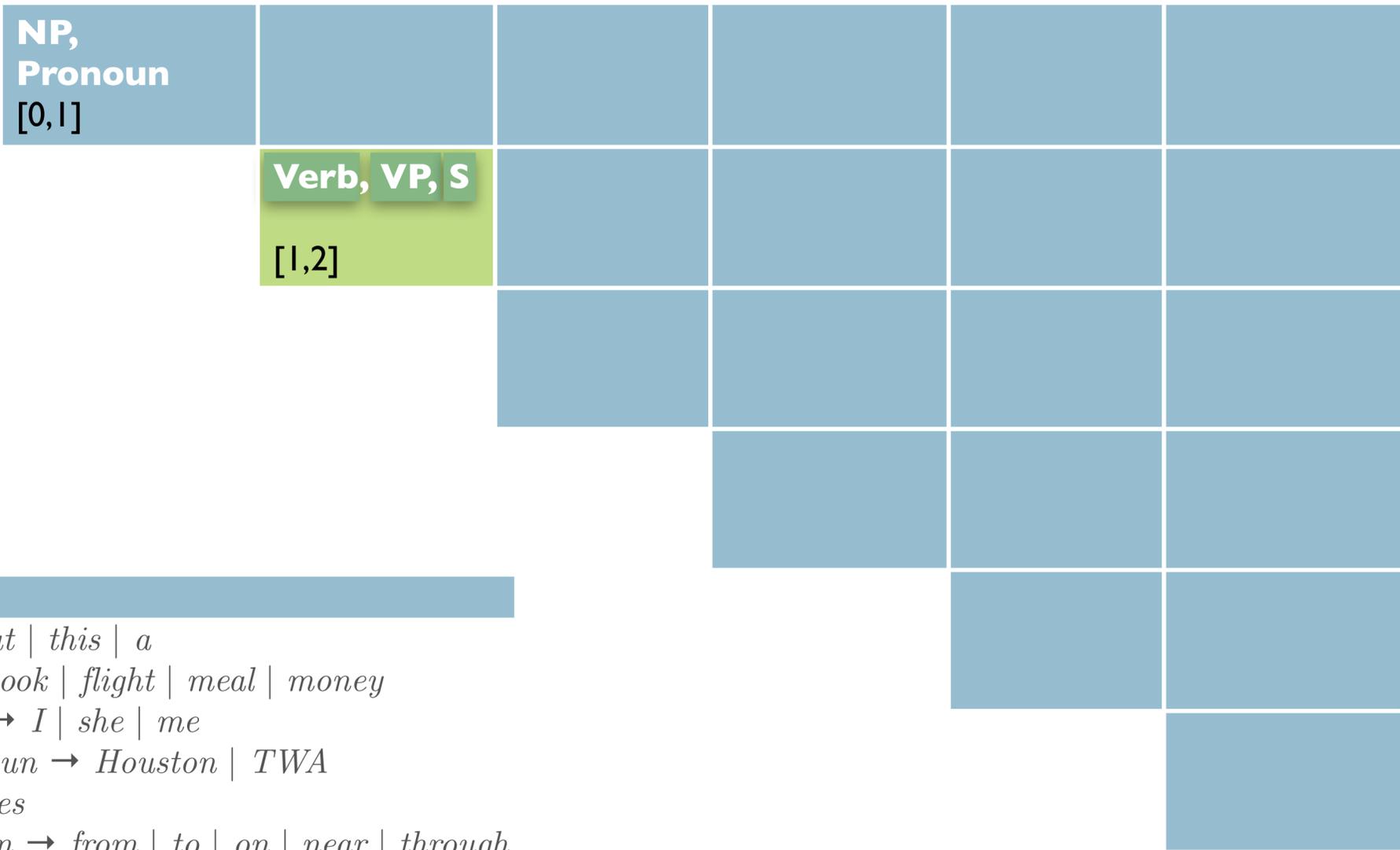
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

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

---

- $PP \rightarrow Preposition NP$



**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**  $\rightarrow book \mid include \mid prefer$



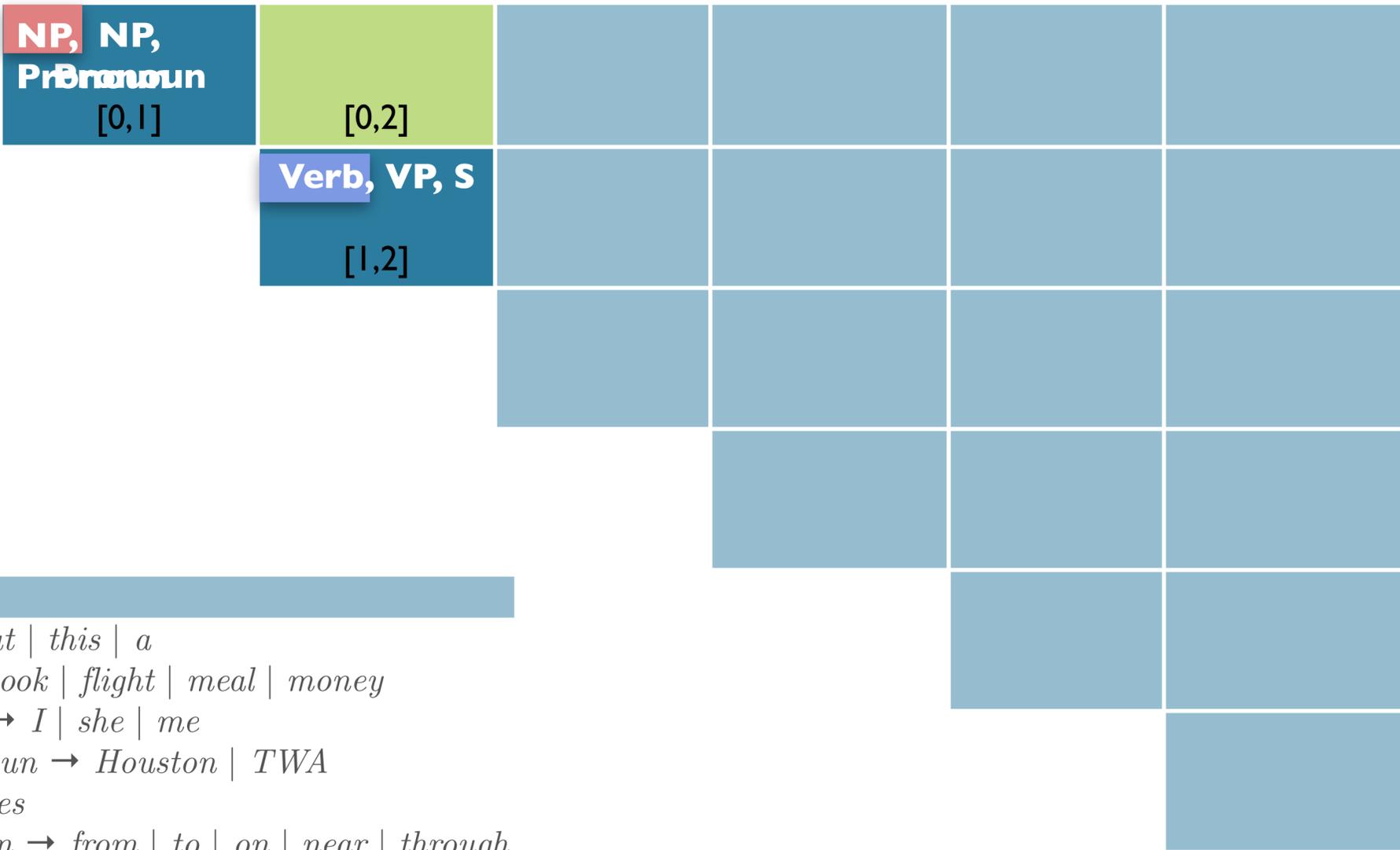


**$\mathcal{L}_1$  Grammar**

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

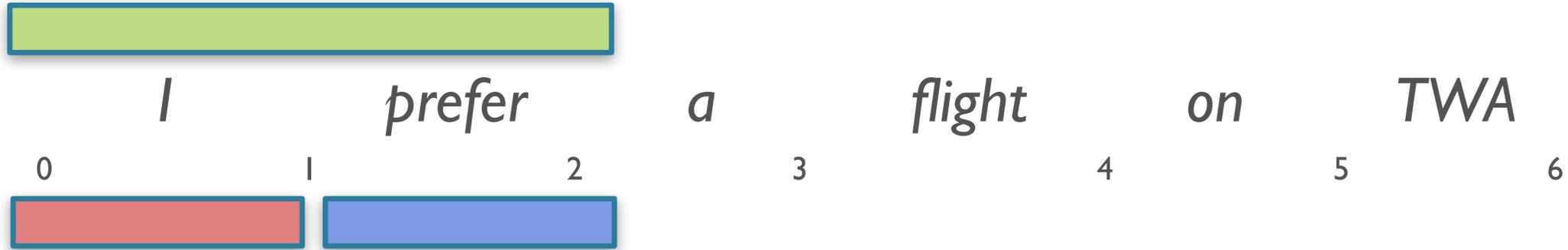
- 
- $NP \rightarrow I \mid she \mid me$
  - $NP \rightarrow TWA \mid Houston$
  - $NP \rightarrow Det Nominal$
- 
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
  - $Nominal \rightarrow Nominal Noun$
  - $Nominal \rightarrow Nominal PP$

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



**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*  $\rightarrow book \mid include \mid prefer$



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

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

---

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

---

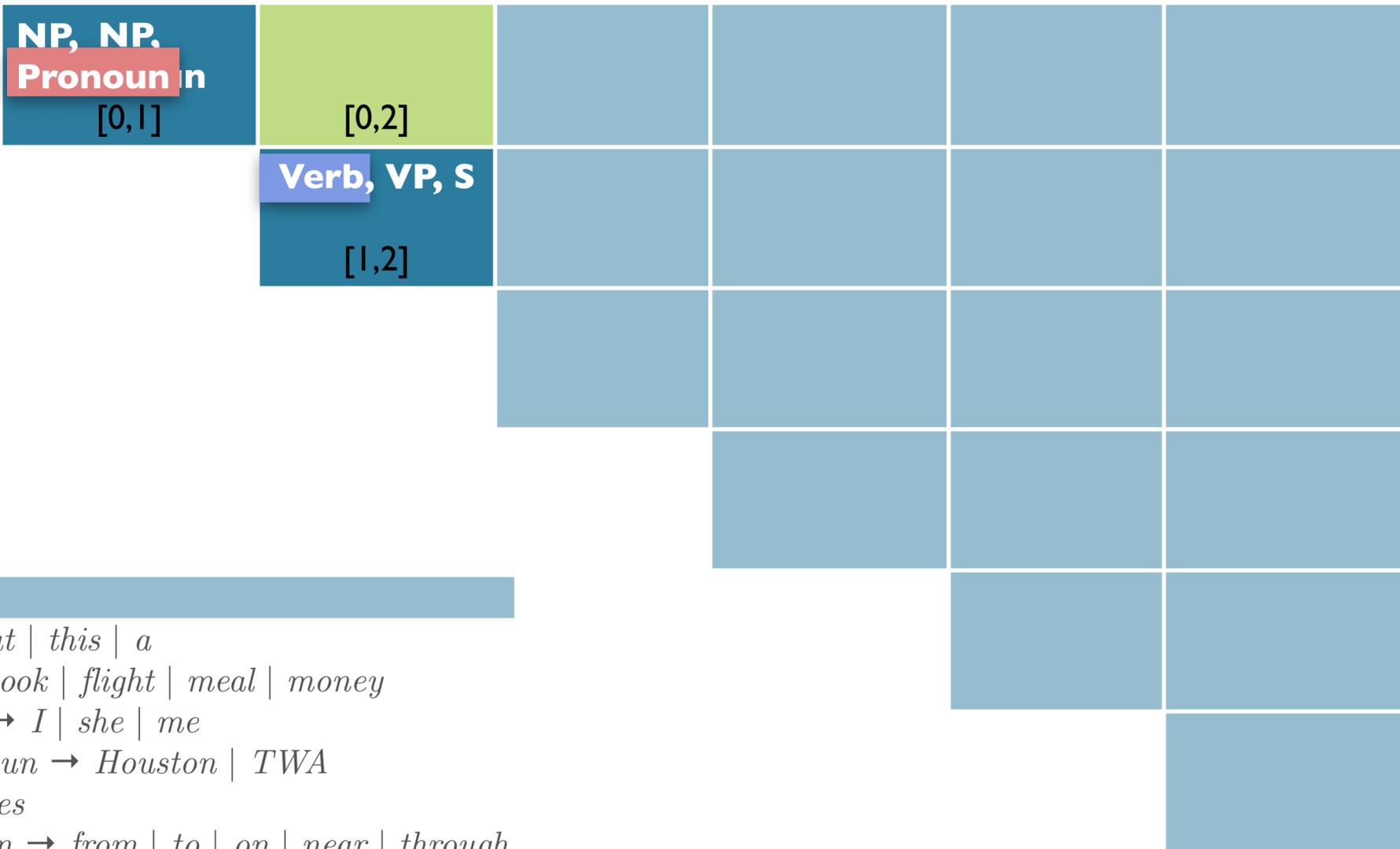
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

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

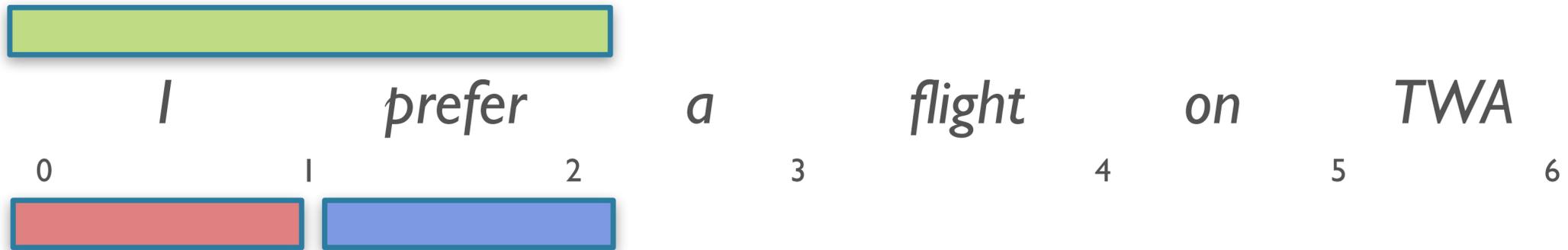
---

- $PP \rightarrow Preposition NP$



**Lexicon**

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



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

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

---

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

---

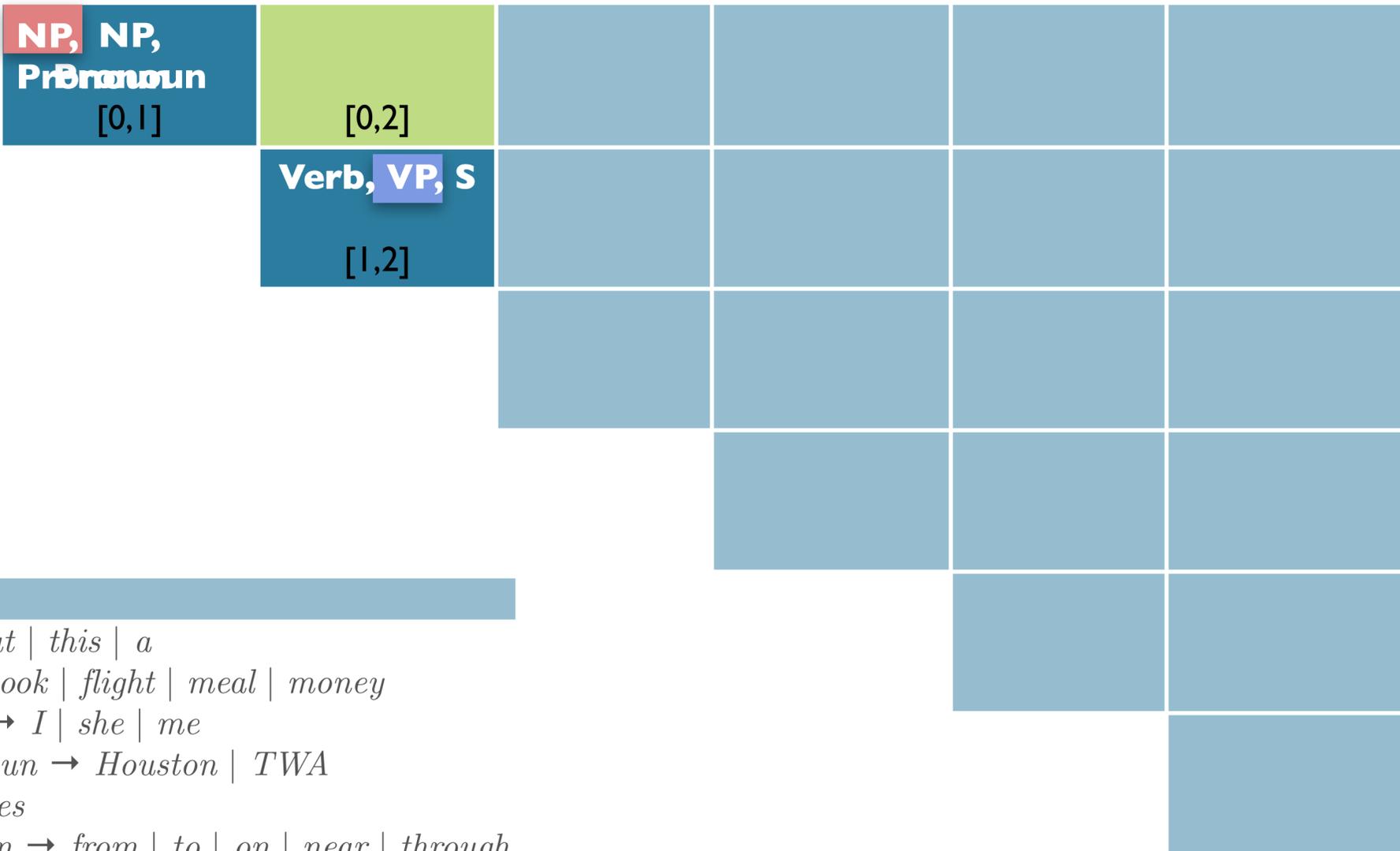
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

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

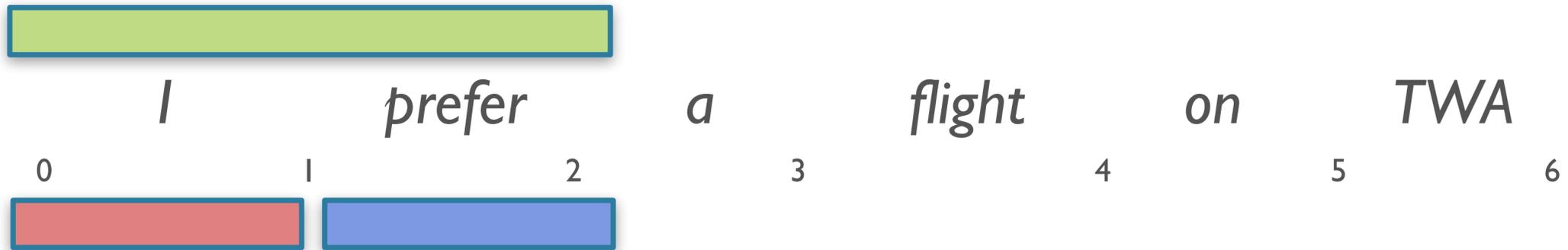
---

- $PP \rightarrow Preposition NP$



**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*  $\rightarrow book \mid include \mid prefer$



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

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

---

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

---

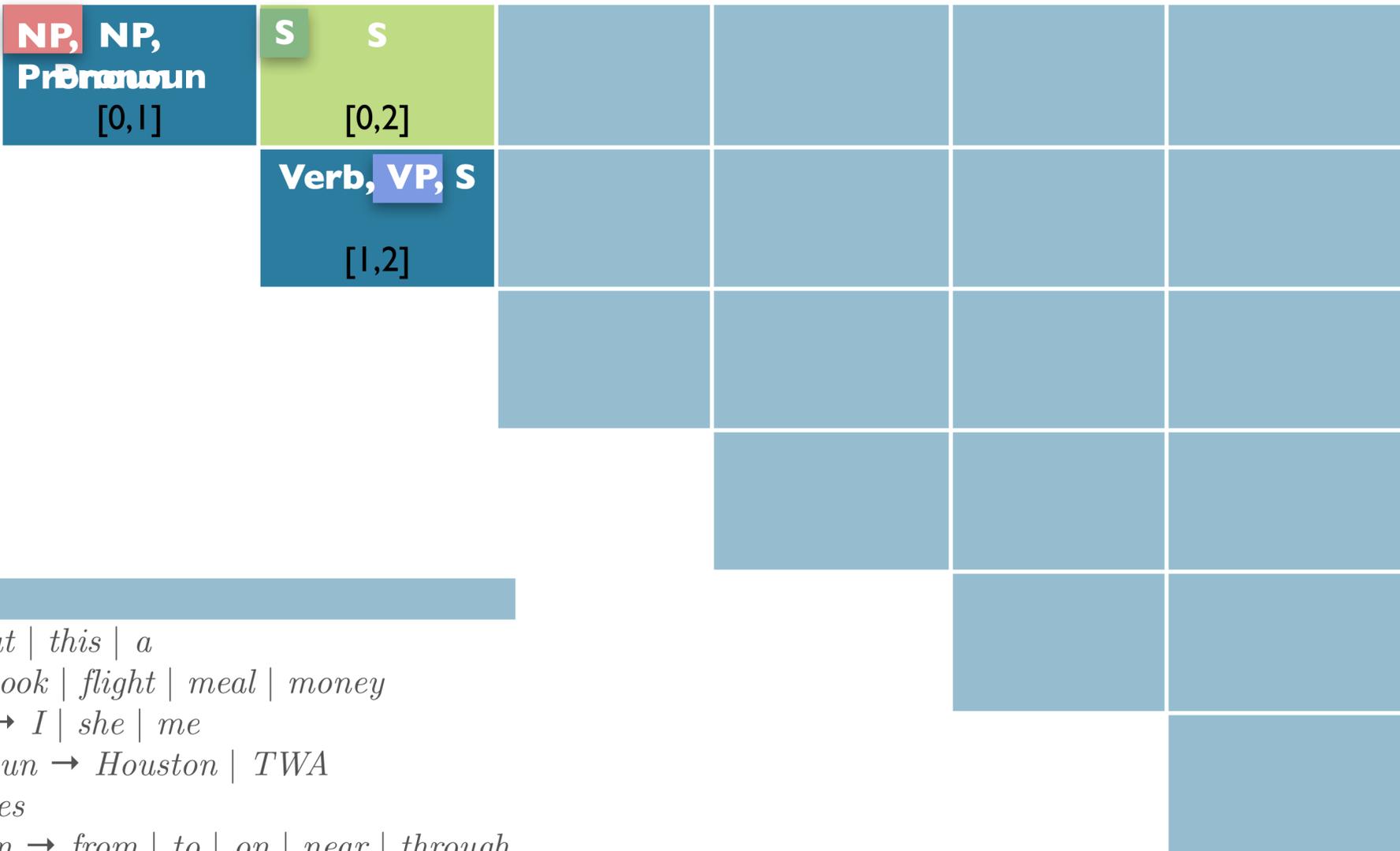
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

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

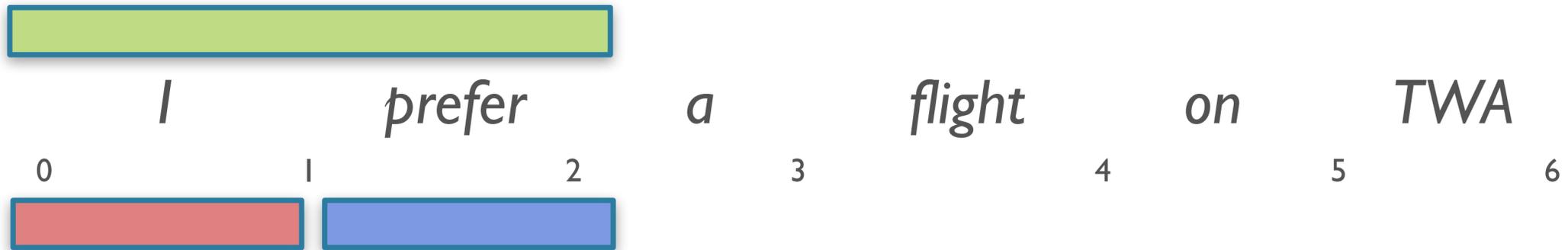
---

- $PP \rightarrow Preposition NP$



**Lexicon**

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



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

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

---

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

---

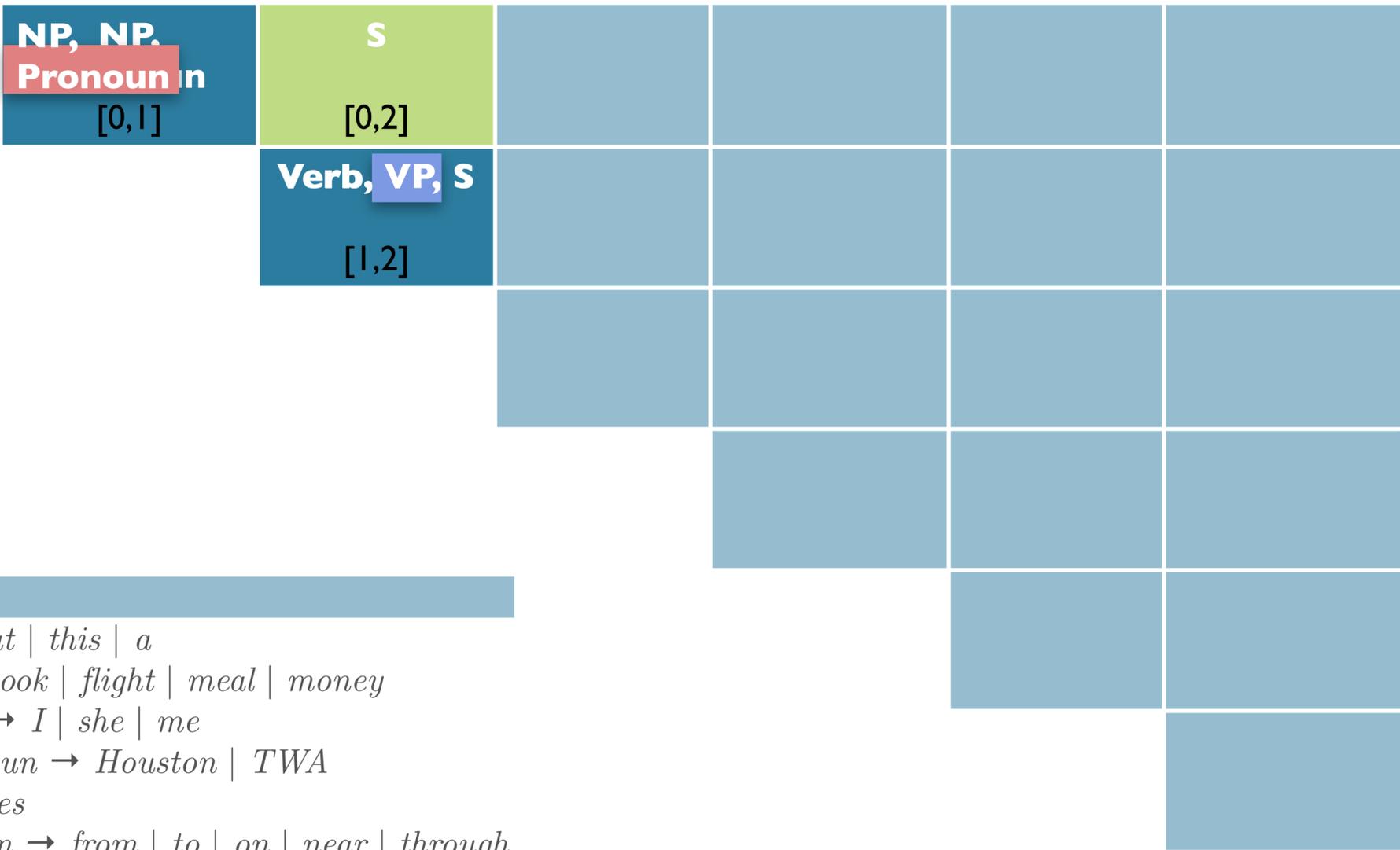
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

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

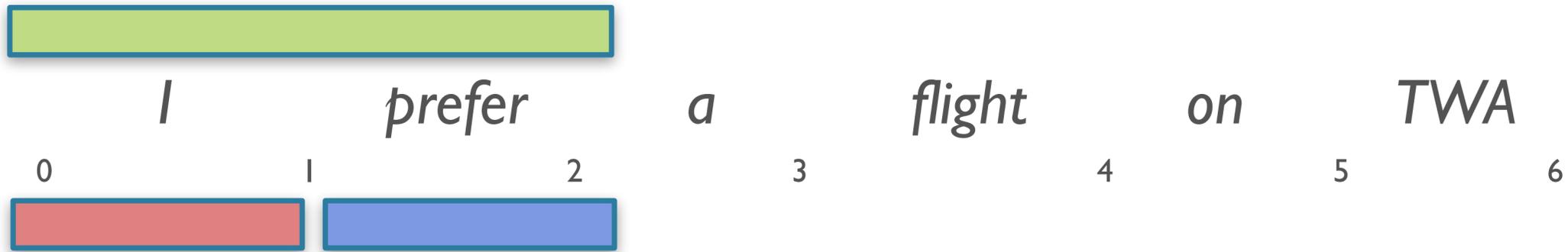
---

- $PP \rightarrow Preposition NP$



**Lexicon**

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



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

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

---

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

---

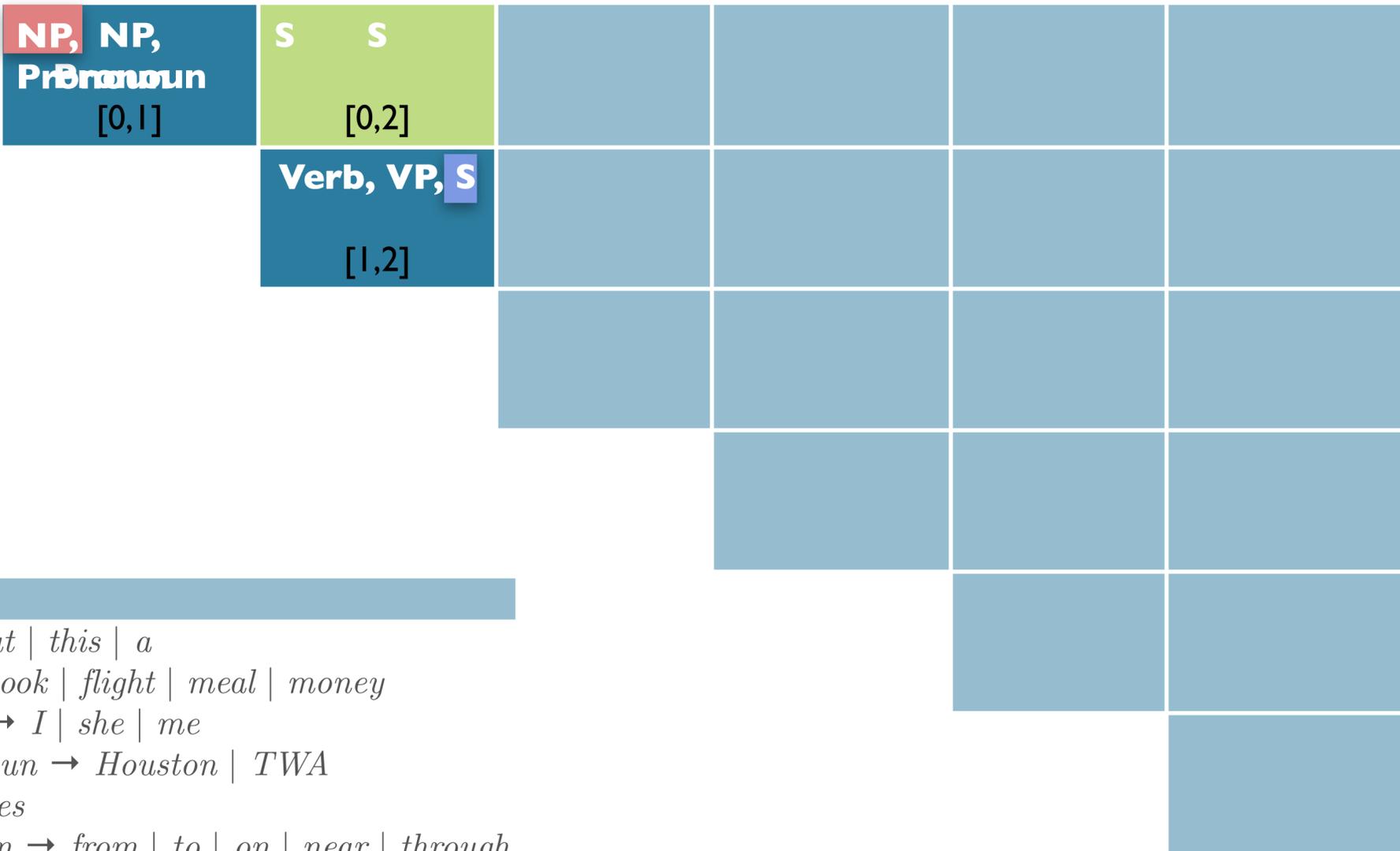
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

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

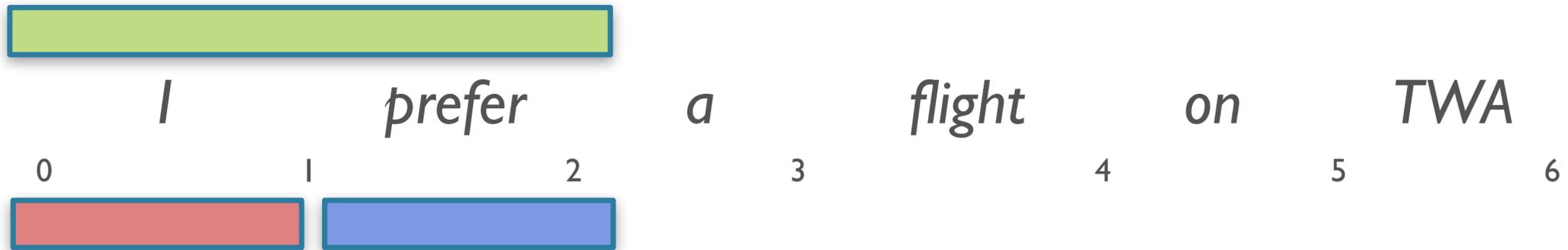
---

- $PP \rightarrow Preposition NP$



**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*  $\rightarrow book \mid include \mid prefer$



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

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

---

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

---

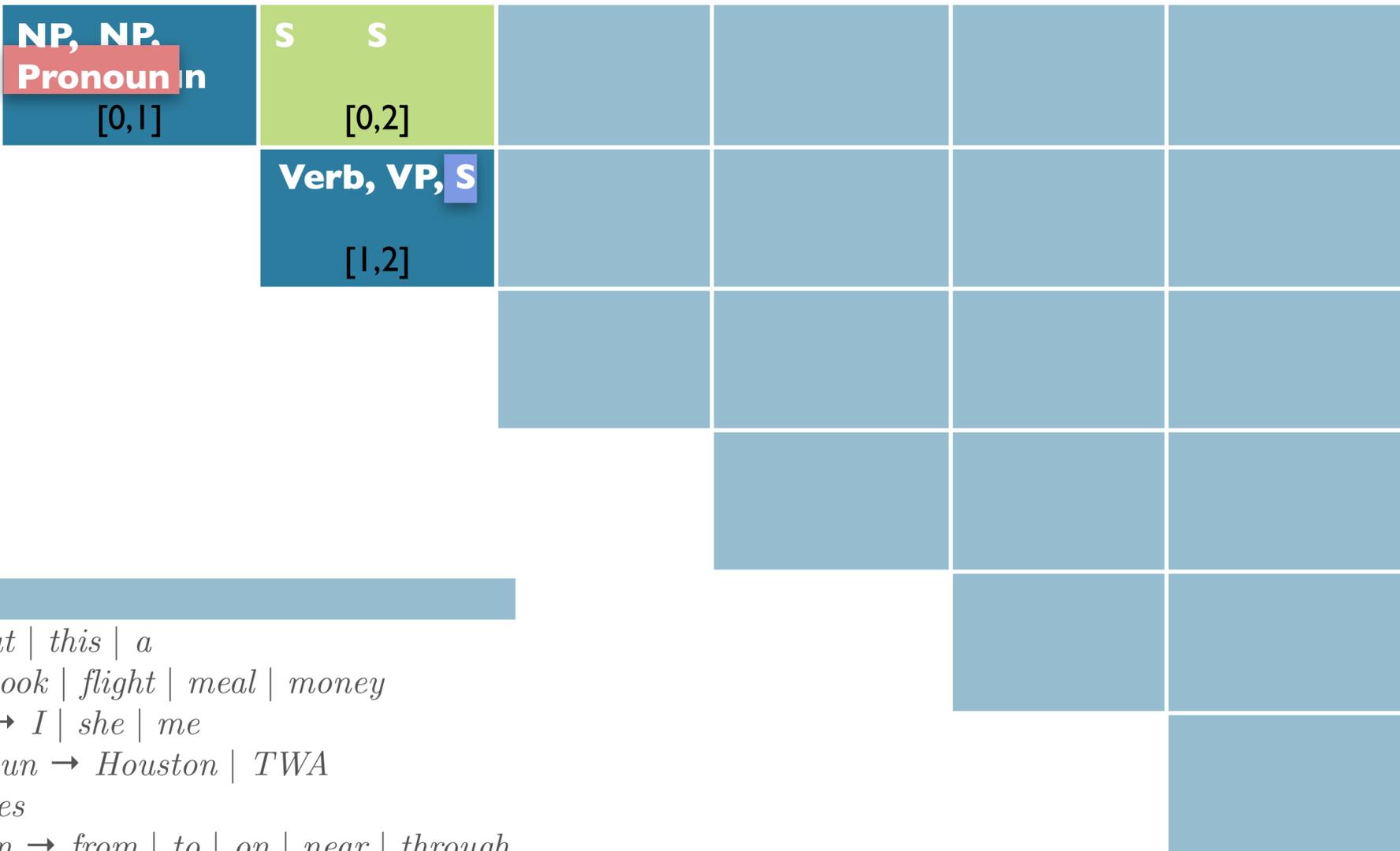
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

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

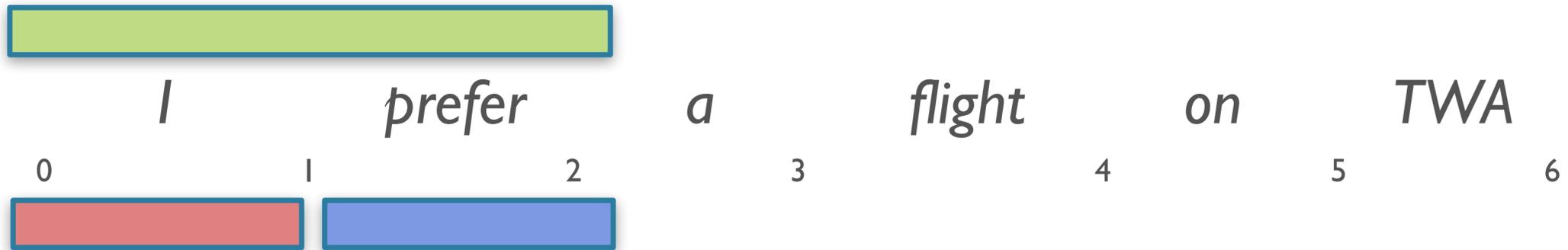
---

- $PP \rightarrow Preposition NP$



**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*  $\rightarrow book \mid include \mid prefer$



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

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

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

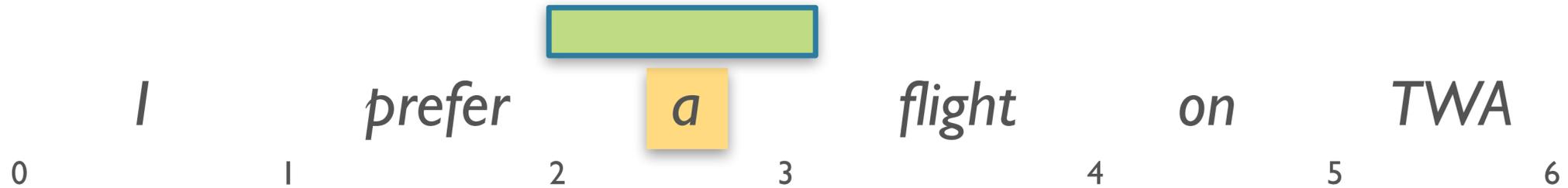
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

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

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

**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**  $\rightarrow book \mid include \mid prefer$



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

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

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

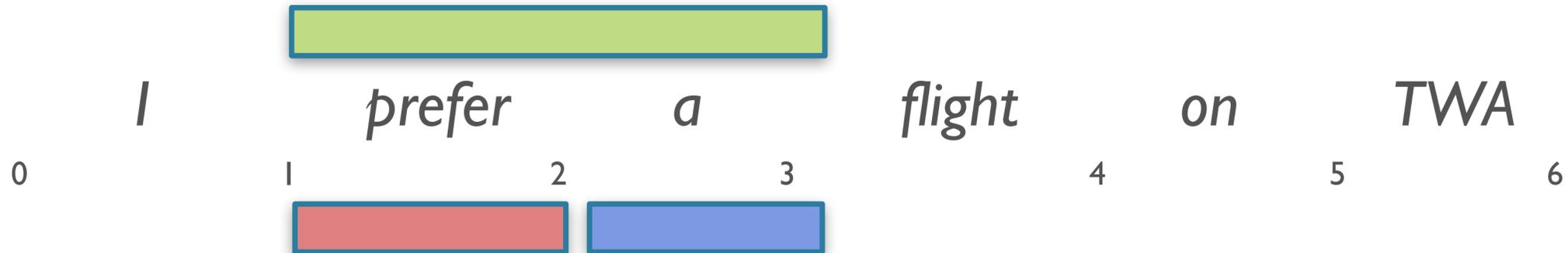
- 
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
  - $Nominal \rightarrow Nominal Noun$
  - $Nominal \rightarrow Nominal PP$

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

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

**Lexicon**

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



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

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

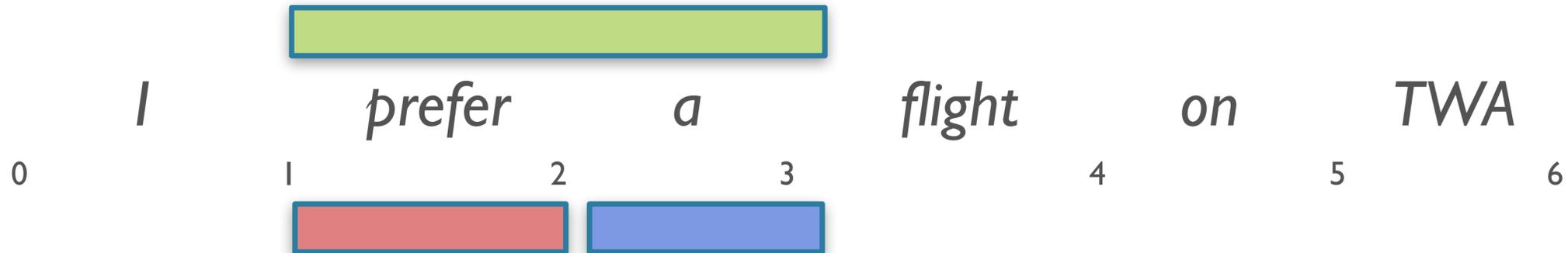
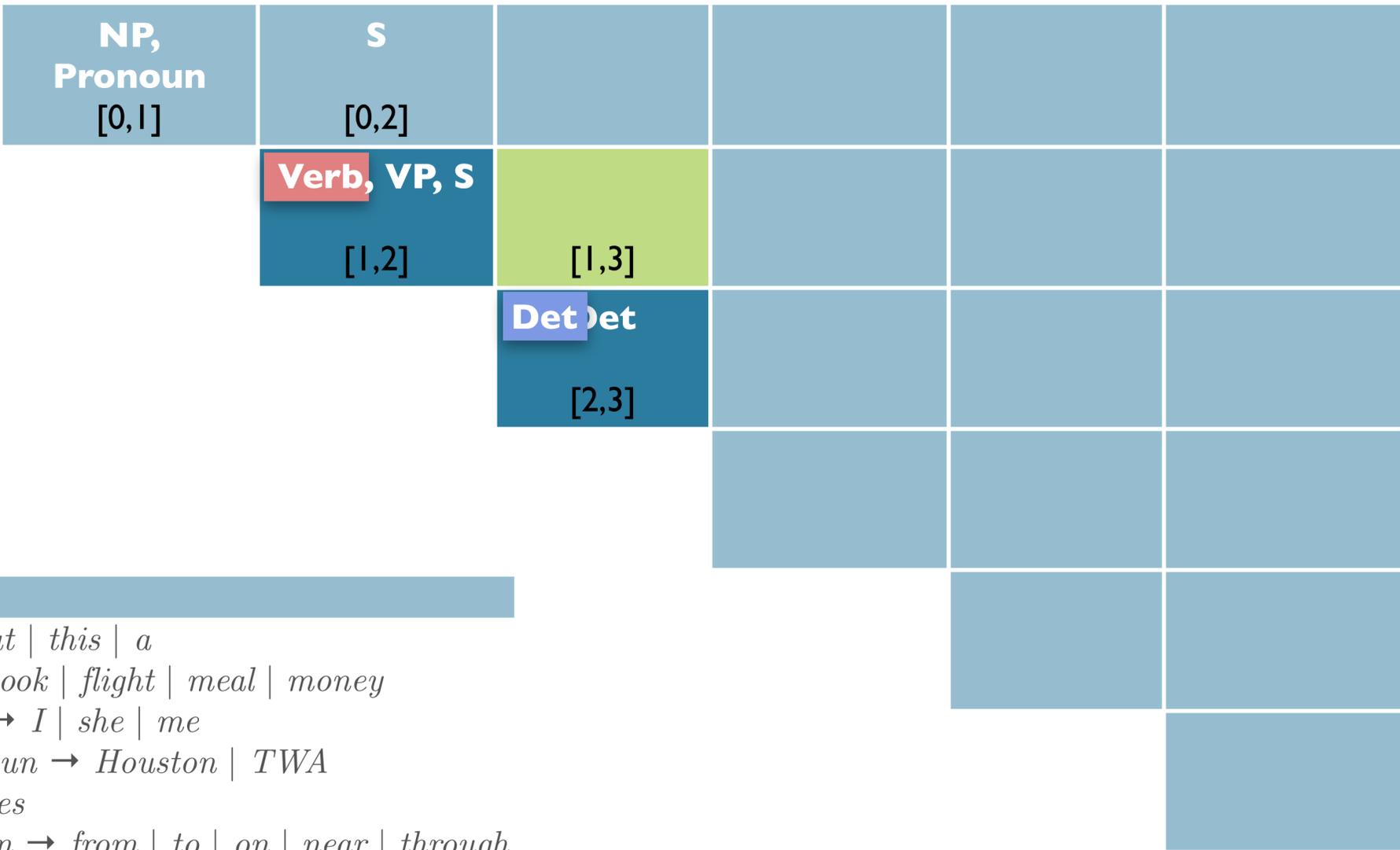
- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

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

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

**Lexicon**

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



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

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

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

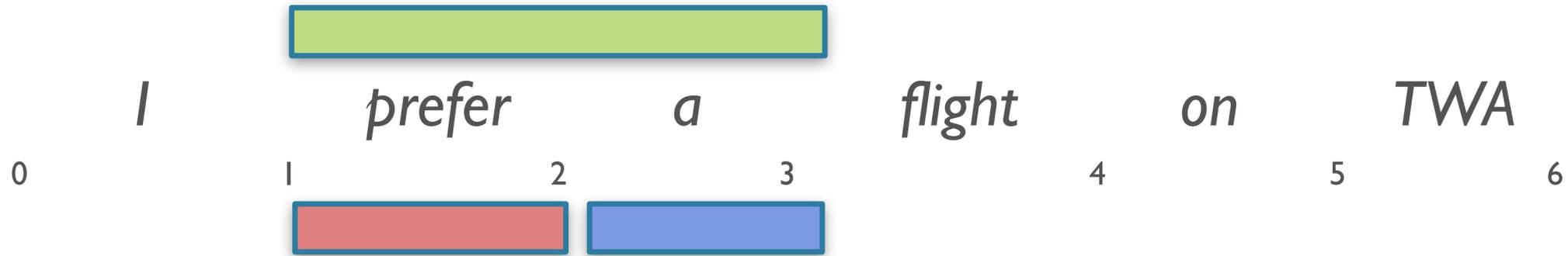
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

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

**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>Verb, VP, S</b> [1,2]				
		<b>Det Det</b> [1,3]			
			<b>Det Det</b> [2,3]		



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

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

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

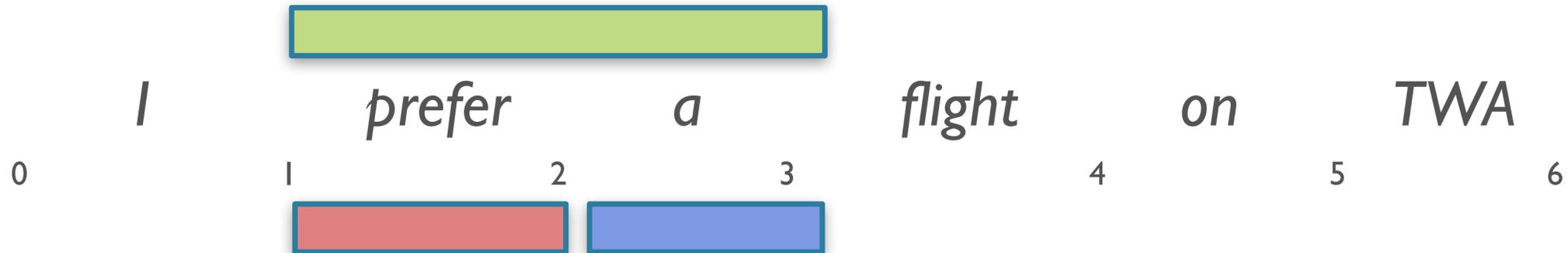
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

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

**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>Verb, VP, S</b> [1,2]				
		<b>Det Det</b> [1,3]			
			<b>Det Det</b> [2,3]		



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

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

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

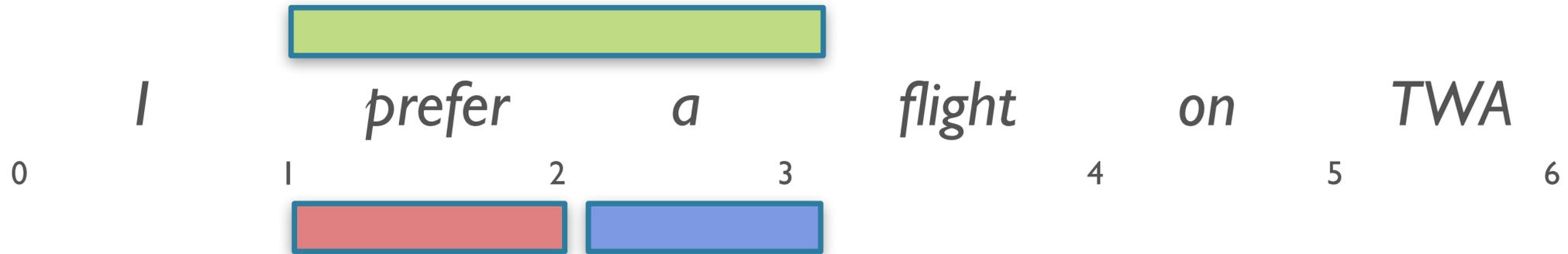
- 
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
  - $Nominal \rightarrow Nominal Noun$
  - $Nominal \rightarrow Nominal PP$

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

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

**Lexicon**

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



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

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

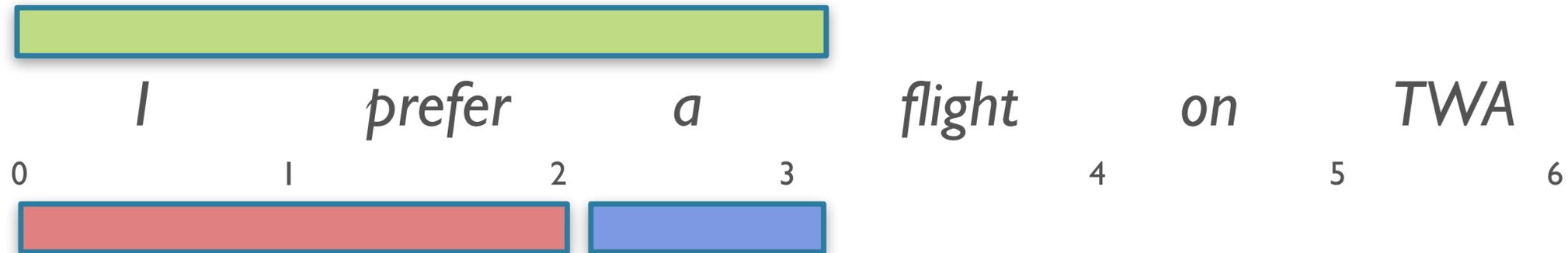
$NP \rightarrow I \mid she \mid me$   
 $NP \rightarrow TWA \mid Houston$   
 $NP \rightarrow Det Nominal$   
 $Nominal \rightarrow book \mid flight \mid meal \mid money$   
 $Nominal \rightarrow Nominal Noun$   
 $Nominal \rightarrow Nominal PP$

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

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

**Lexicon**

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



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

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

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

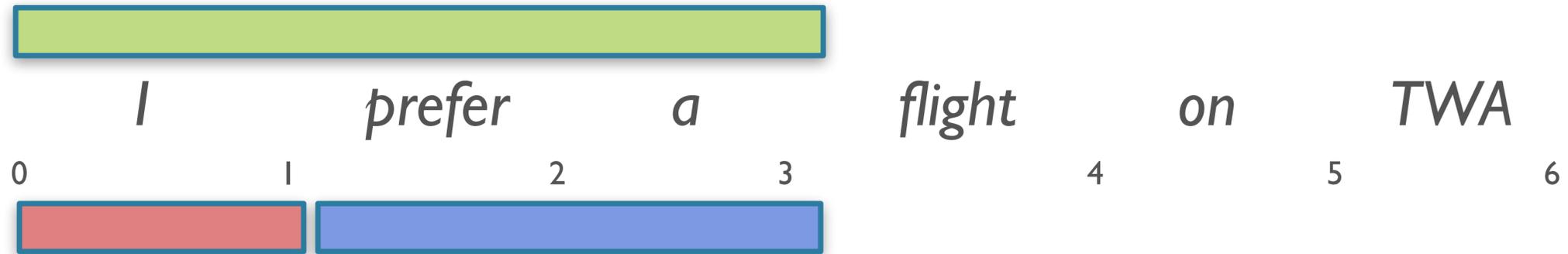
$Nominal \rightarrow book \mid flight \mid meal \mid money$   
 $Nominal \rightarrow Nominal Noun$   
 $Nominal \rightarrow Nominal PP$

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

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

**Lexicon**

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



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

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

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

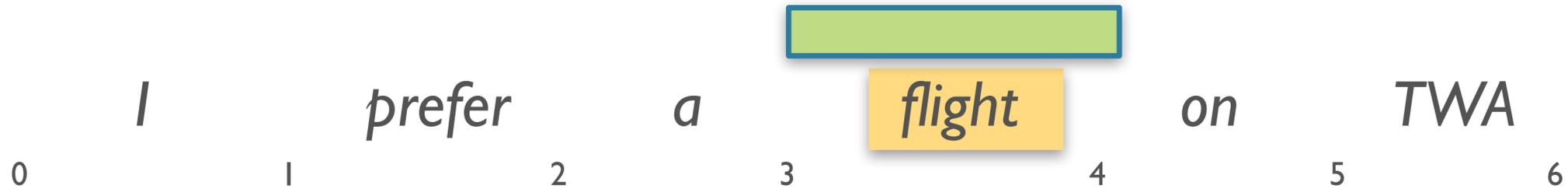
**Nominal**  $\rightarrow book \mid flight \mid meal \mid money$   
 $Nominal \rightarrow Nominal Noun$   
 $Nominal \rightarrow Nominal PP$

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

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

**Lexicon**

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



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

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

---

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

---

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

---

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

---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

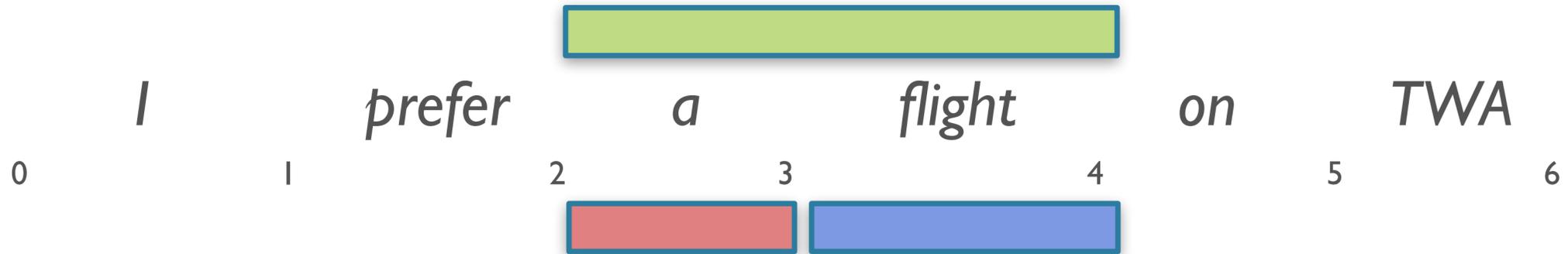
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

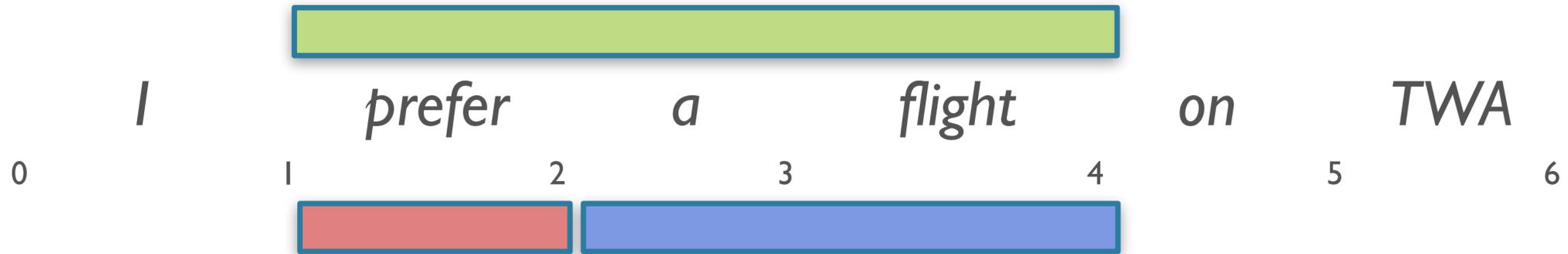
---

- $PP \rightarrow Preposition NP$

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

**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*  $\rightarrow book \mid include \mid prefer$



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

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

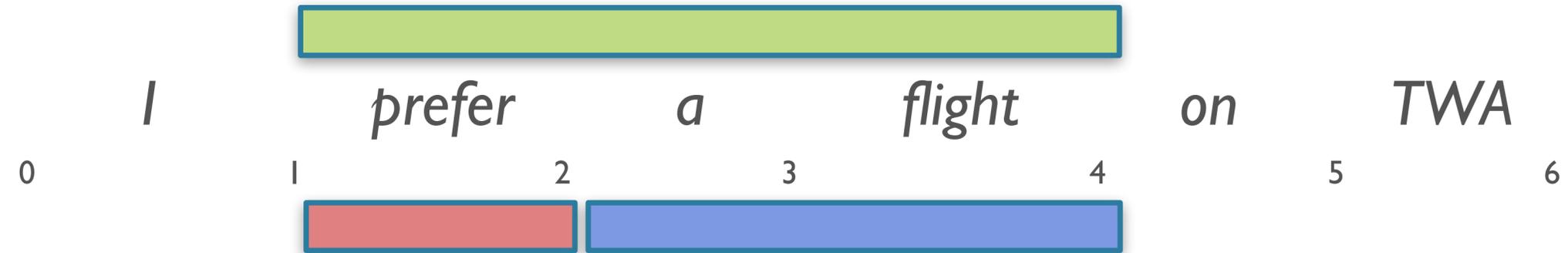
- 
- $NP \rightarrow I \mid she \mid me$
  - $NP \rightarrow TWA \mid Houston$
  - $NP \rightarrow Det Nominal$
- 
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
  - $Nominal \rightarrow Nominal Noun$
  - $Nominal \rightarrow Nominal PP$

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

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

**Lexicon**

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



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

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

---

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

---

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

---

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

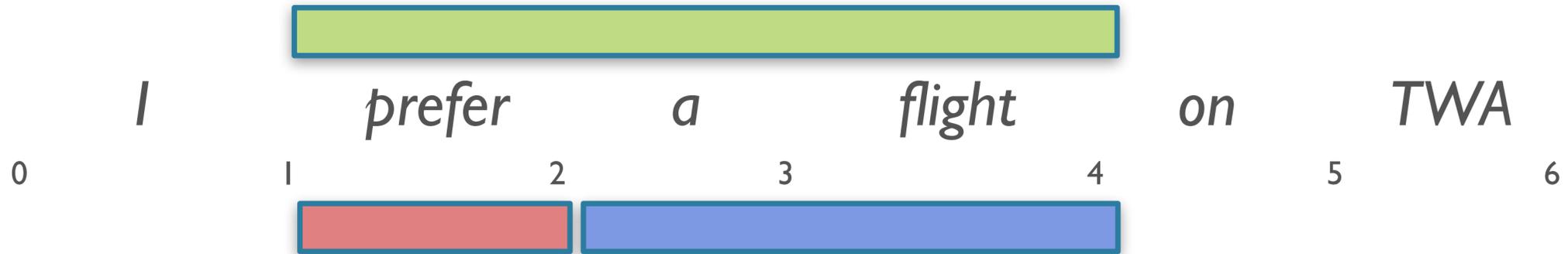
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

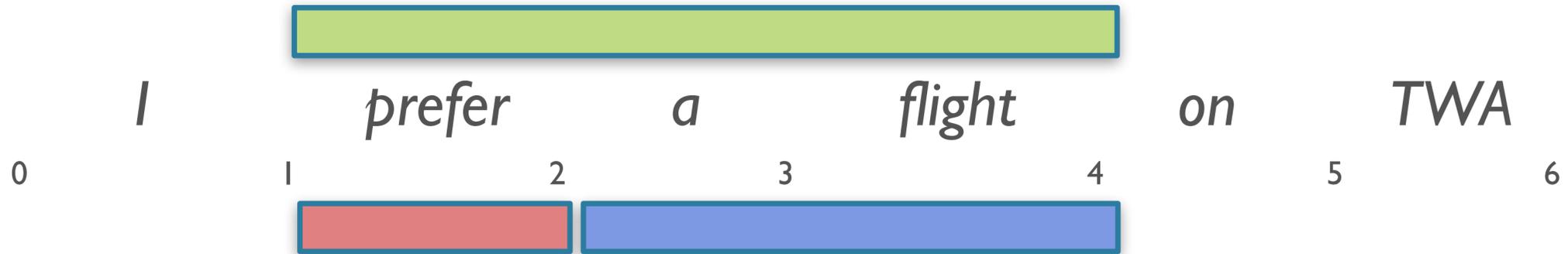
---

- $PP \rightarrow Preposition NP$

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

**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**

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

---

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

---

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

---

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

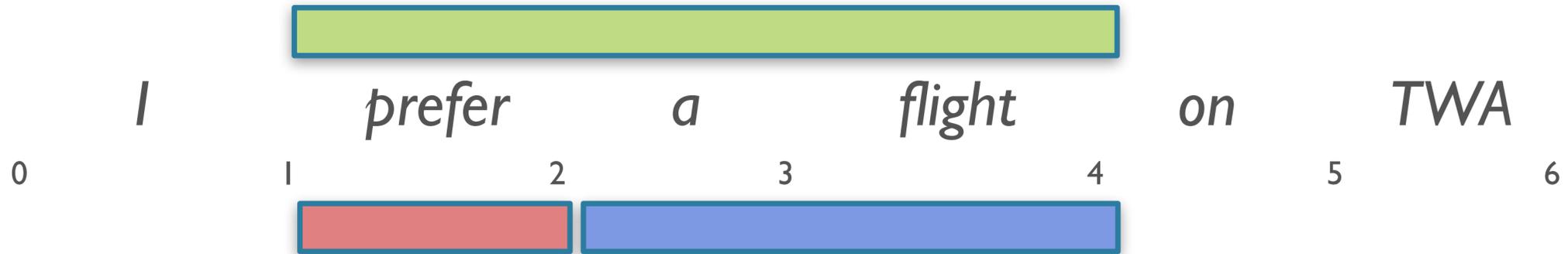
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

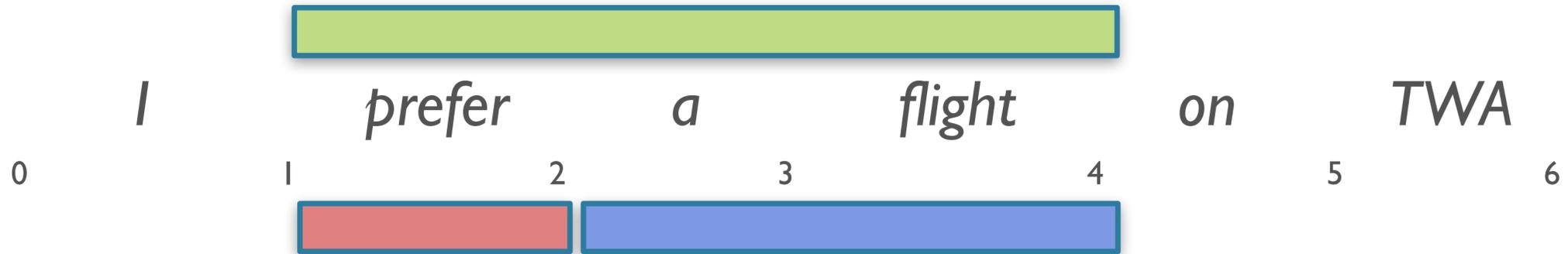
---

- $PP \rightarrow Preposition NP$

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

**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*  $\rightarrow book \mid include \mid prefer$



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

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

---

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

---

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

---

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

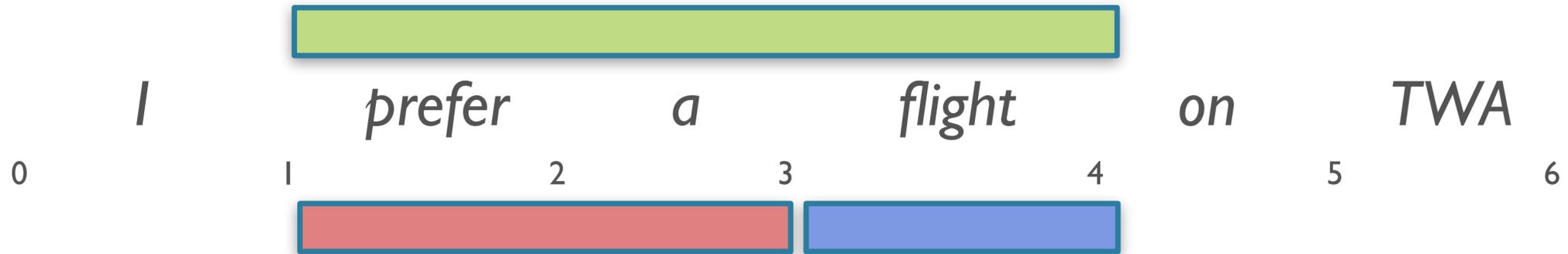
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

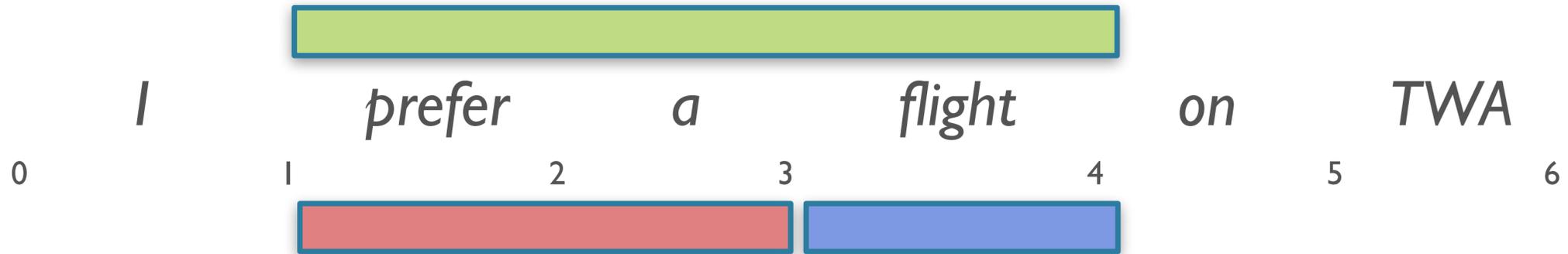
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

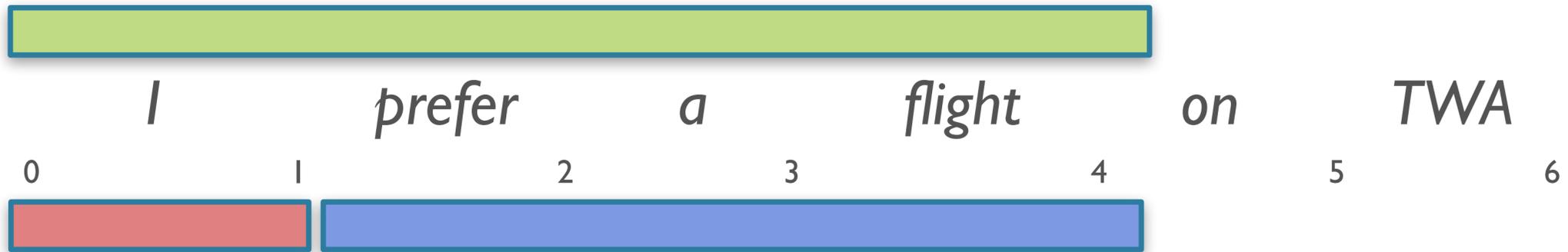
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



$\mathcal{L}_1$  Grammar

$S \rightarrow NP VP$

$S \rightarrow X1 VP$

$X1 \rightarrow Aux NP$

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

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

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

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

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

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

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

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

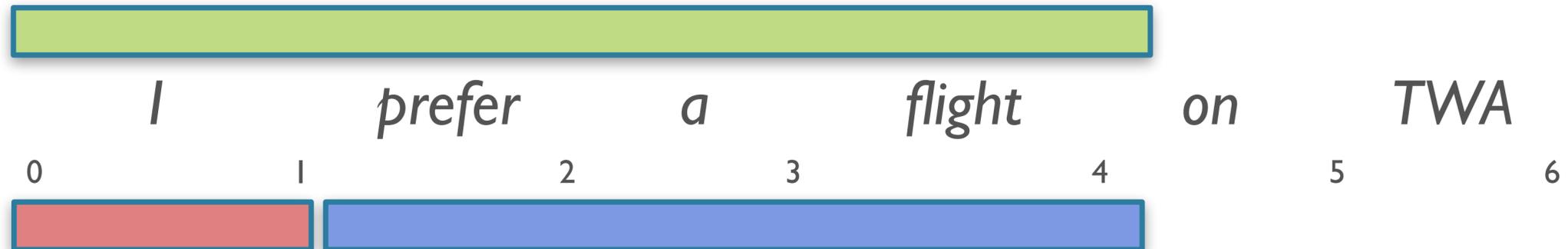
*Pronoun*  $\rightarrow I \mid she \mid me$

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

*Aux*  $\rightarrow does$

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

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



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

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

---

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

---

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

---

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

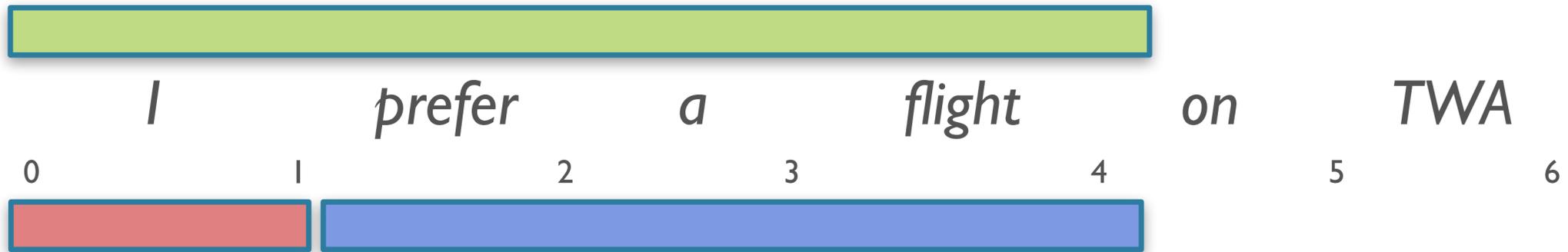
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

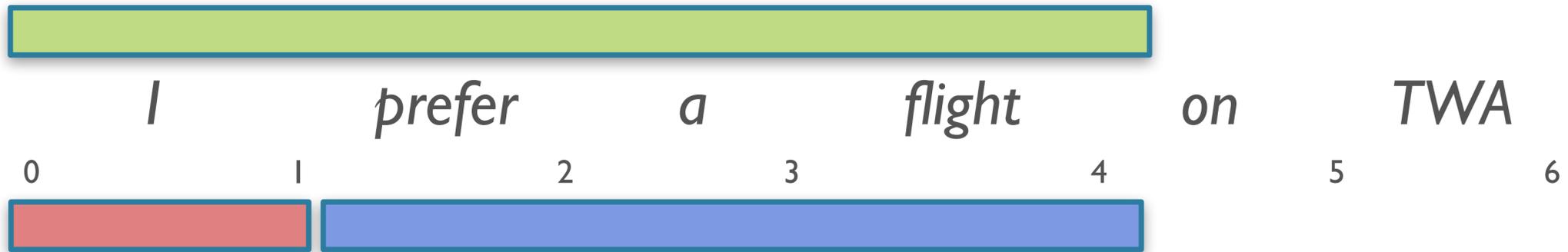
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

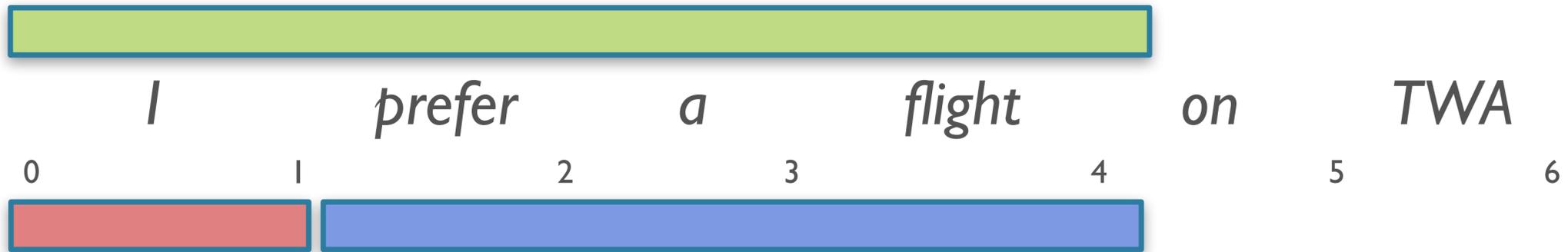
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

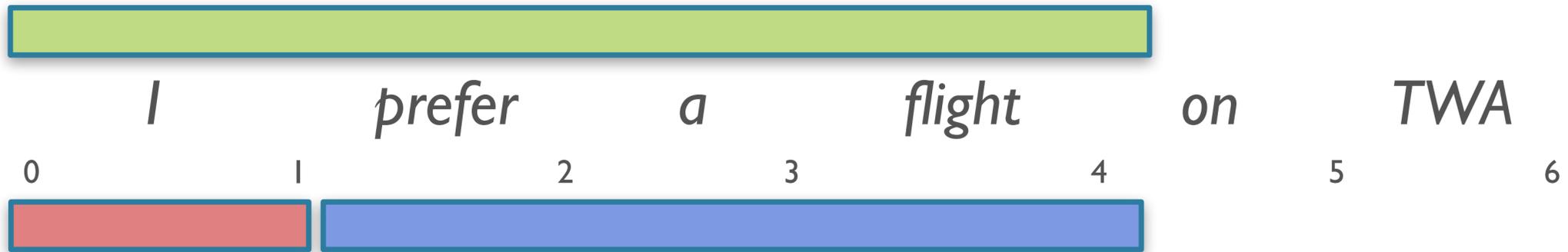
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

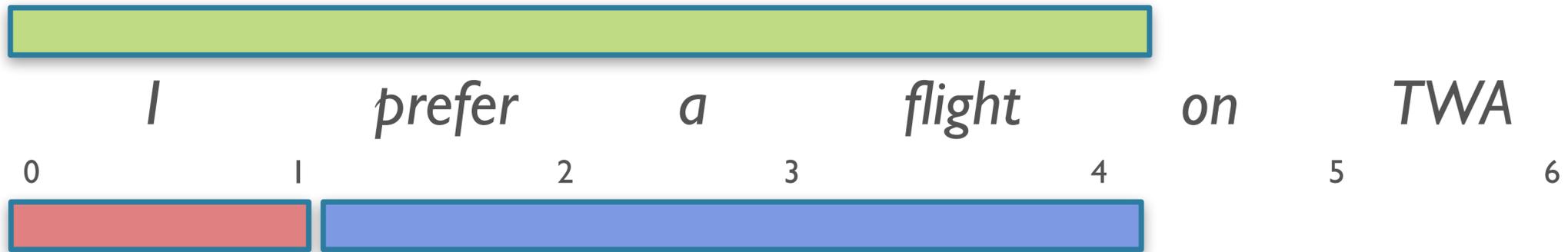
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

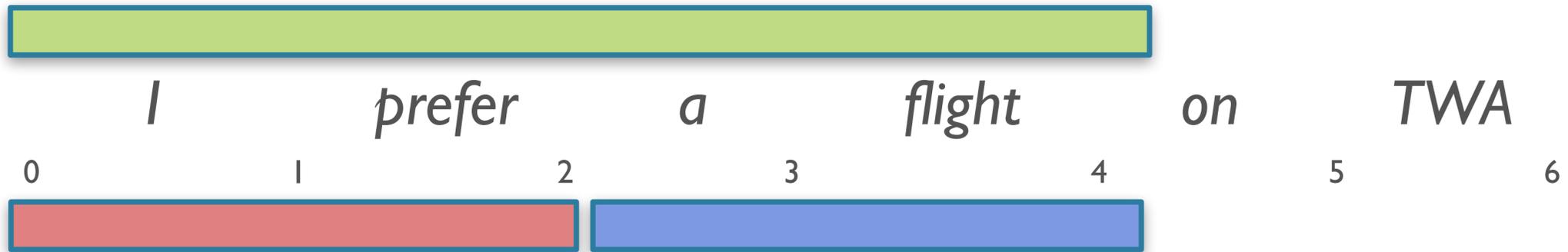
---

- $PP \rightarrow Preposition NP$

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]		

**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  $\rightarrow book \mid include \mid prefer$



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

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

---

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

---

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

---

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

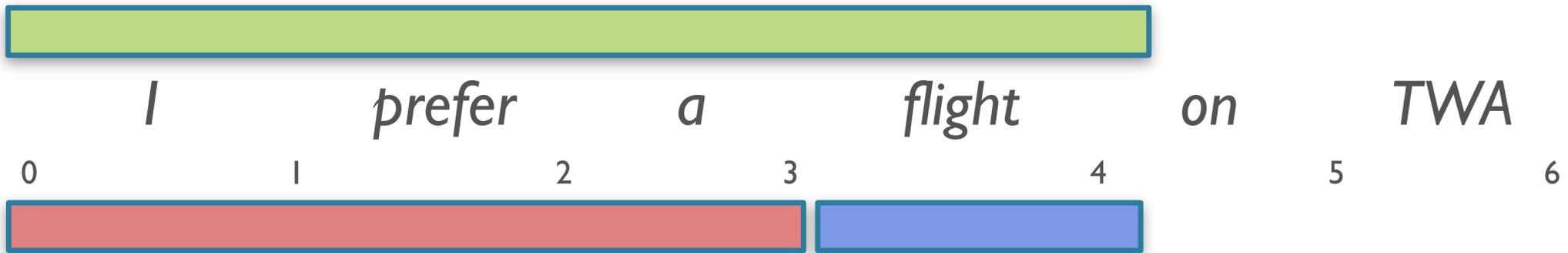
---

- $PP \rightarrow Preposition NP$

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

**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*  $\rightarrow book \mid include \mid prefer$



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

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

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

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

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

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

**Lexicon**

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



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

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

---

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

---

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

---

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

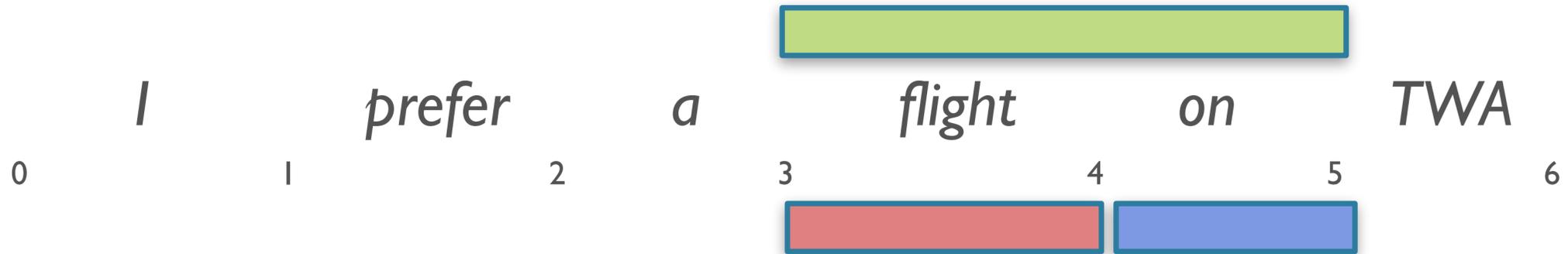
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

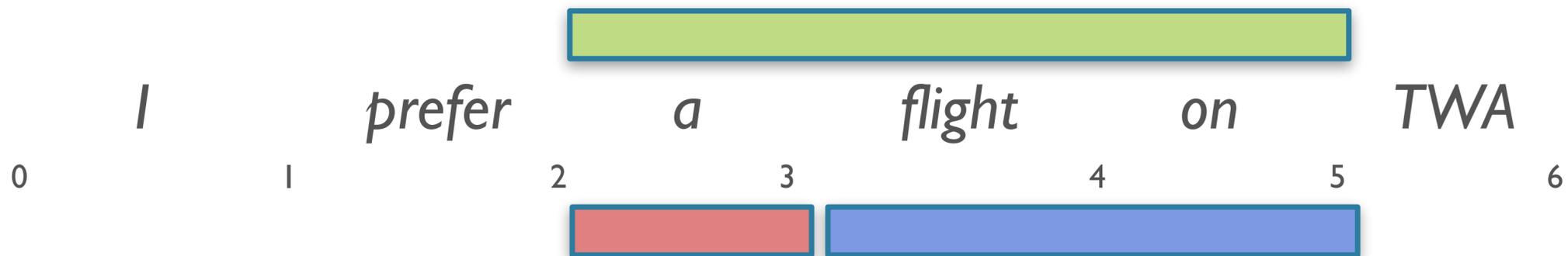
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

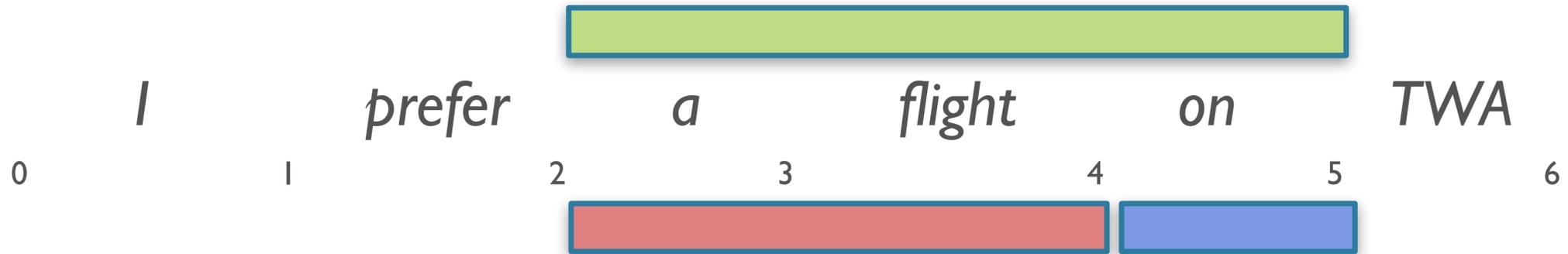
---

- $PP \rightarrow Preposition NP$

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

**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*  $\rightarrow book \mid include \mid prefer$



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

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

---

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

---

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

---

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

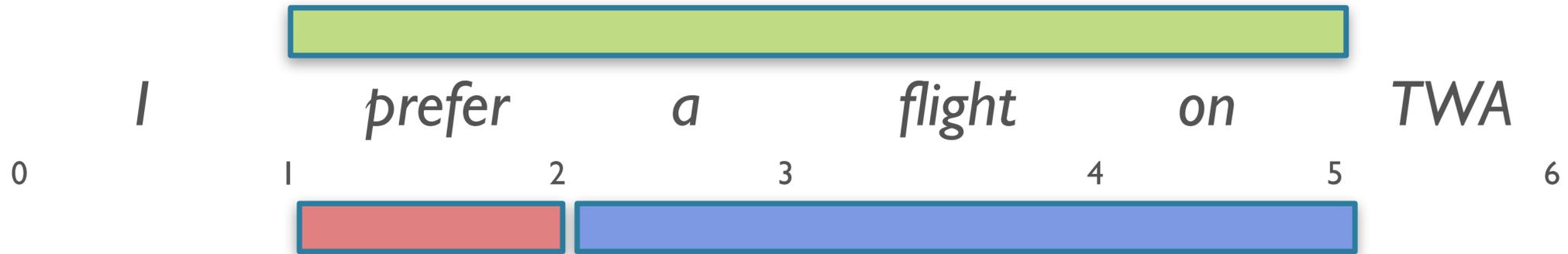
---

- $PP \rightarrow Preposition NP$

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

**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*  $\rightarrow book \mid include \mid prefer$



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

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

---

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

---

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

---

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

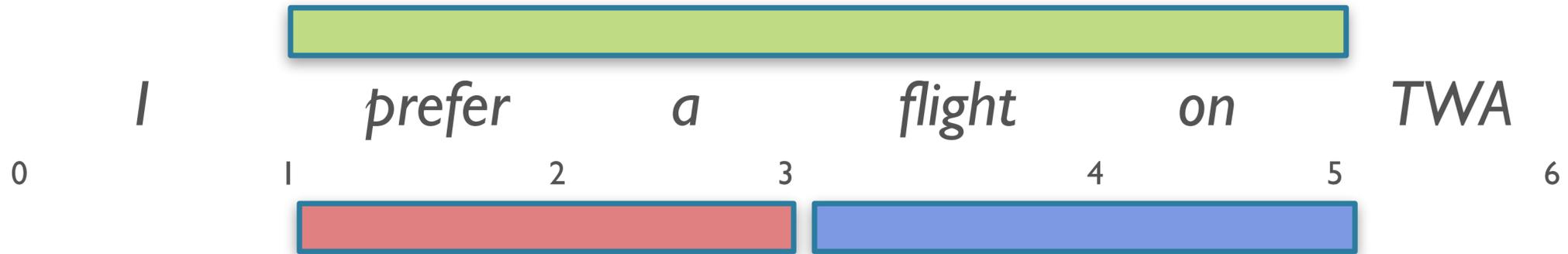
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

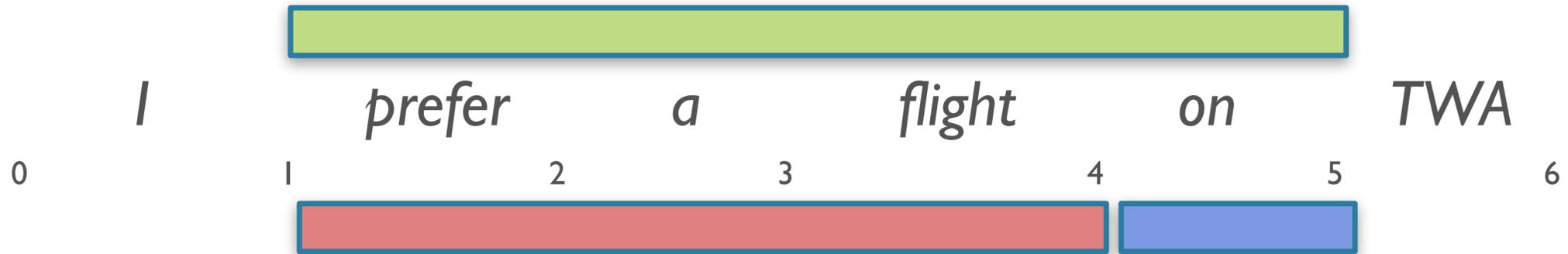
- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

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

**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]		
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
			<b>Noun, Nom</b> [3,4]	[3,5]	
				<b>Prep</b> [4,5]	



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

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

---

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

---

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

---

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

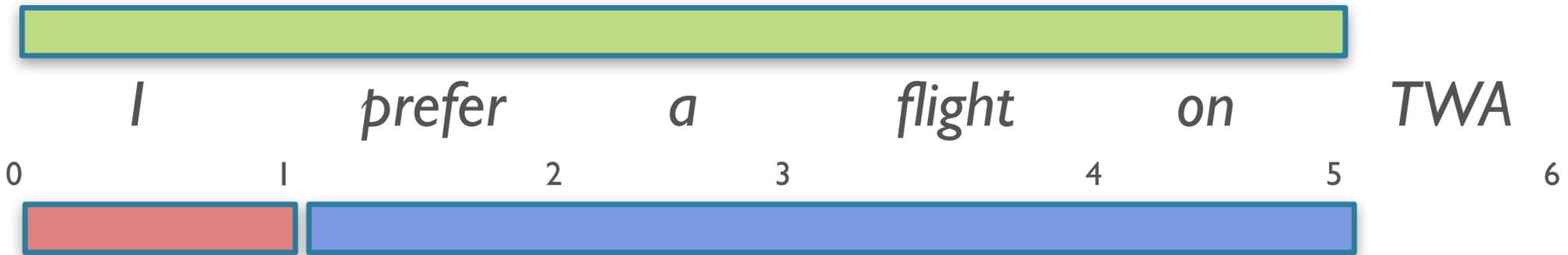
---

- $PP \rightarrow Preposition NP$

<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>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
			<b>Noun, Nom</b> [3,4]	[3,5]	
			<b>Prep</b> [4,5]		

**Lexicon**

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



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

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

---

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

---

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

---

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

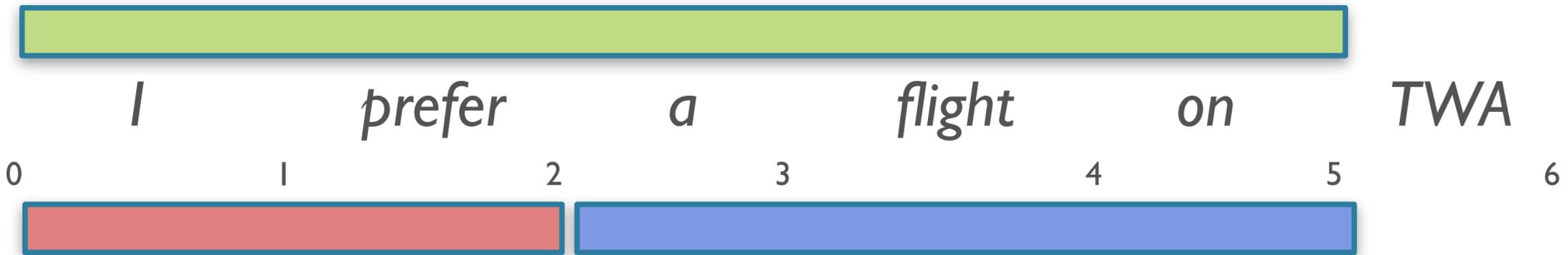
---

- $PP \rightarrow Preposition NP$

<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>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
			<b>Noun, Nom</b> [3,4]	[3,5]	
				<b>Prep</b> [4,5]	

**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*  $\rightarrow book \mid include \mid prefer$



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

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

---

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

---

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

---

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

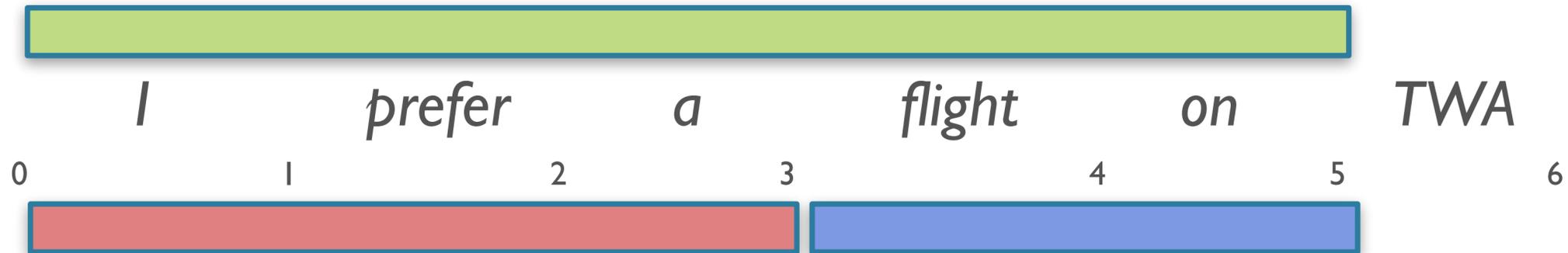
---

- $PP \rightarrow Preposition NP$

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

**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*  $\rightarrow book \mid include \mid prefer$



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

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

---

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

---

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

---

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

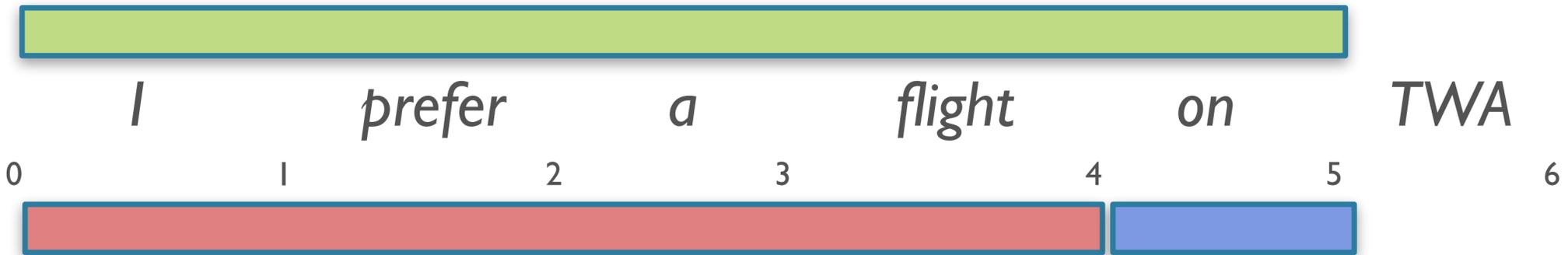
---

- $PP \rightarrow Preposition NP$

<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>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
			<b>Noun, Nom</b> [3,4]	[3,5]	
				<b>Prep</b> [4,5]	

**Lexicon**

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



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

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

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

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

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

<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>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
			<b>Noun, Nom</b> [3,4]	[3,5]	
			<b>Prep</b> [4,5]		
					<b>NNP, NP</b> [5,6]

**Lexicon**

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



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

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

---

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

---

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

---

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

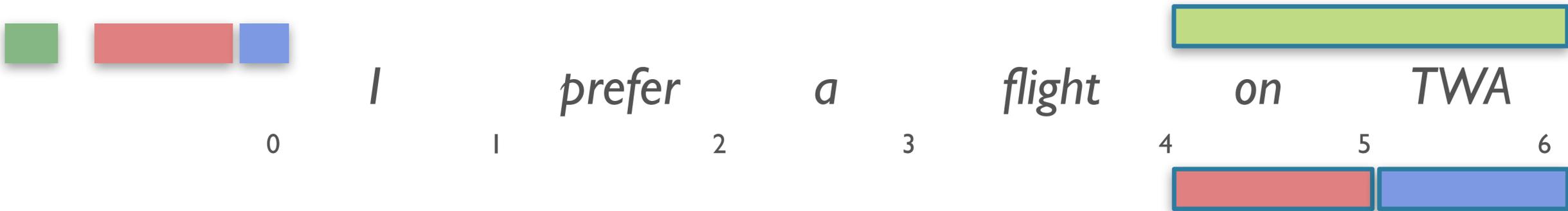
---

- $PP \rightarrow Preposition NP$

<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>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
			<b>Noun, Nom</b> [3,4]	[3,5]	
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
					<b>NNP, NP</b> [5,6]

**Lexicon**

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



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

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

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

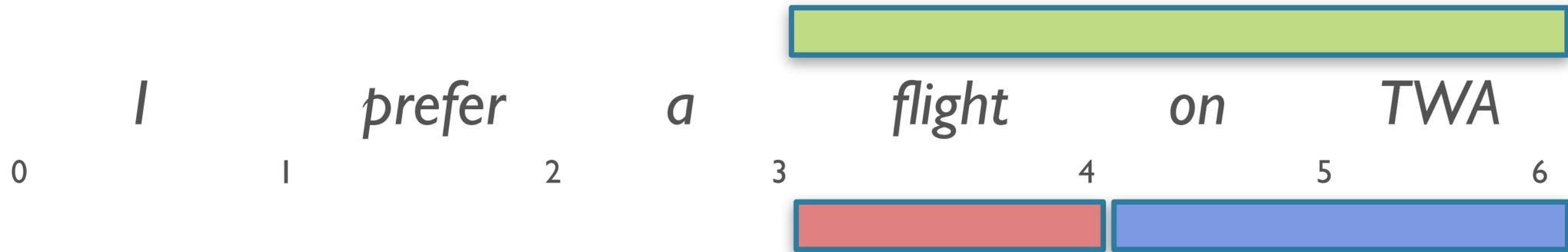
$Nominal \rightarrow Nominal PP$

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

<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>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
			<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]

**Lexicon**

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



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

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

---

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

---

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

---

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

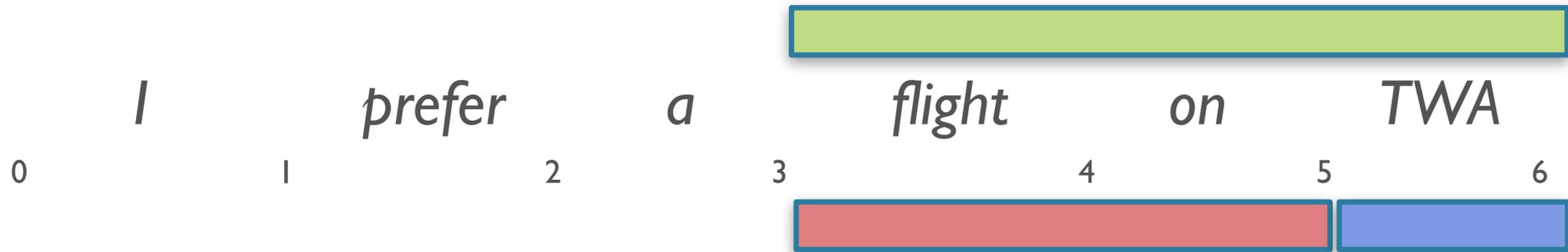
---

- $PP \rightarrow Preposition NP$

<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>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
			<b>Noun, Nom</b> [3,4]	<b>[3,5]</b>	<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
					<b>NNP, NP</b> [5,6]

**Lexicon**

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



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

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

---

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

---

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

---

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

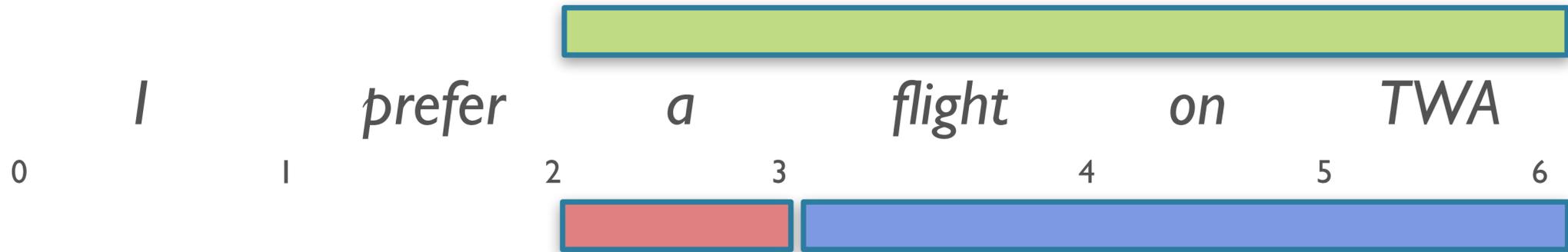
---

- $PP \rightarrow Preposition NP$

<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>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]

**Lexicon**

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



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

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

---

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

---

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

---

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

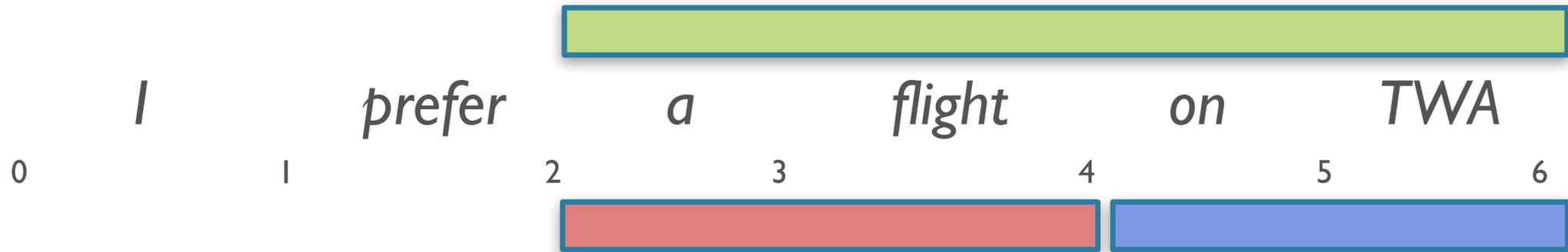
---

- $PP \rightarrow Preposition NP$

<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>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]

**Lexicon**

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



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

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

---

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

---

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

---

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

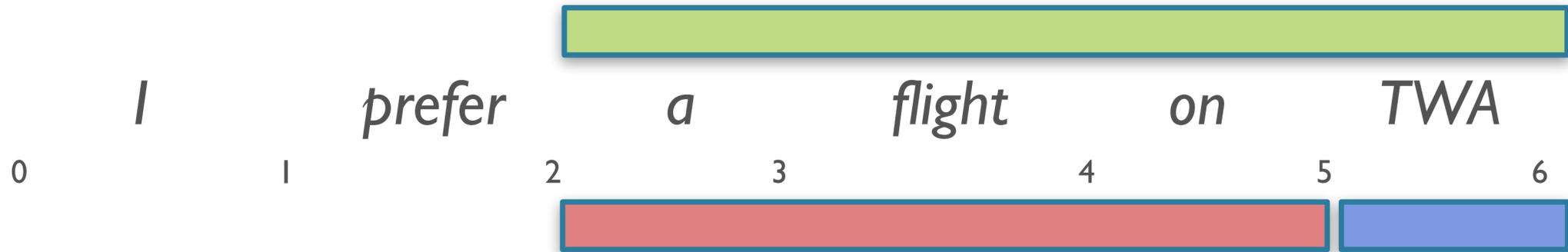
---

- $PP \rightarrow Preposition NP$

<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>Det</b> [2,3]	<b>NP</b> [2,4]	<b>[2,5]</b>	<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]

**Lexicon**

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



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

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

---

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

---

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

---

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

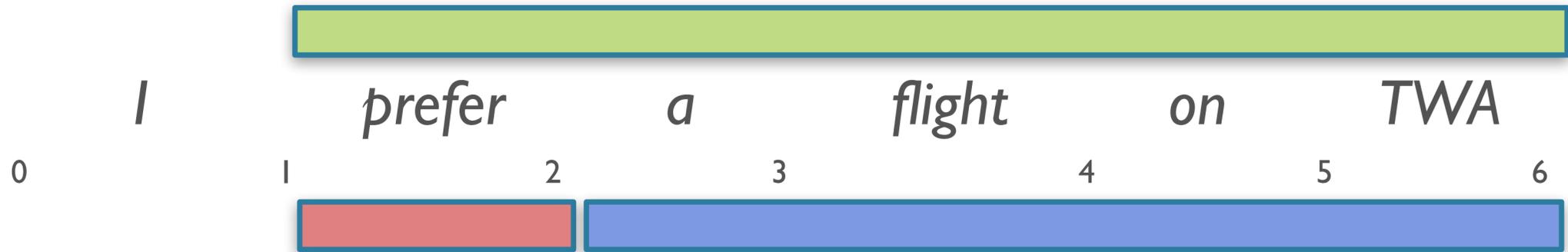
---

- $PP \rightarrow Preposition NP$

<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>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]

**Lexicon**

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



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

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

---

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

---

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

---

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

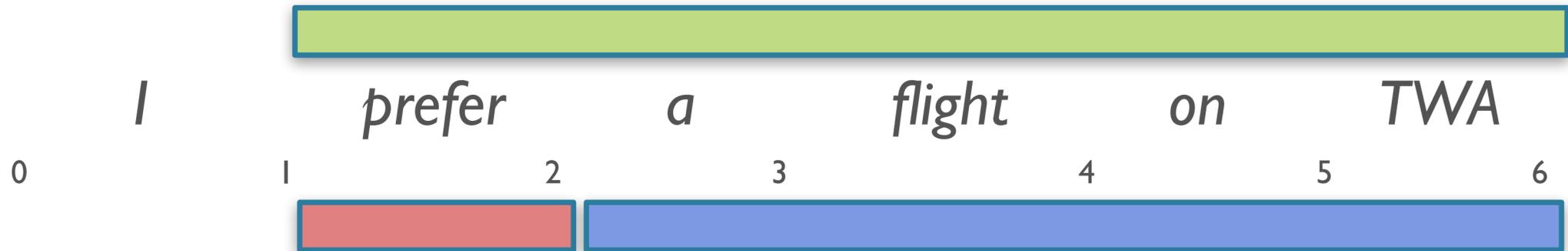
---

- $PP \rightarrow Preposition NP$

<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]		<b>VP, X2, S</b> [1,4]		<b>VP</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]

**Lexicon**

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



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

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

---

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

---

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

---

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

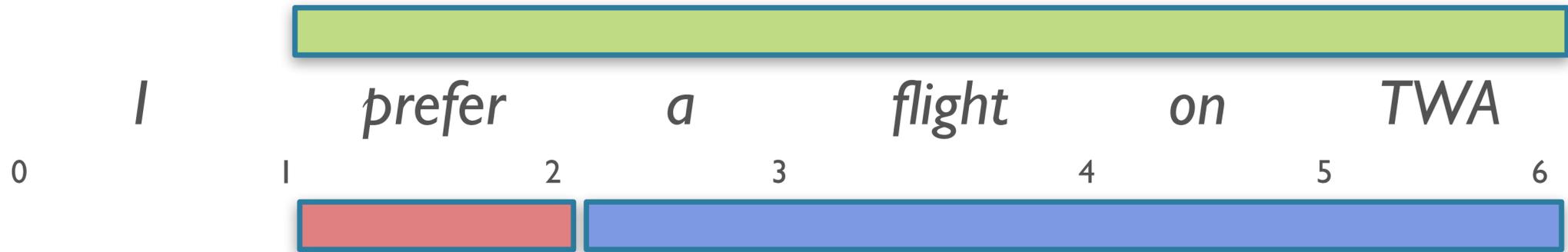
---

- $PP \rightarrow Preposition NP$

<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]		<b>VP, X2, S</b> [1,4]		<b>VP, X2</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]

**Lexicon**

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



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

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

---

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

---

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

---

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

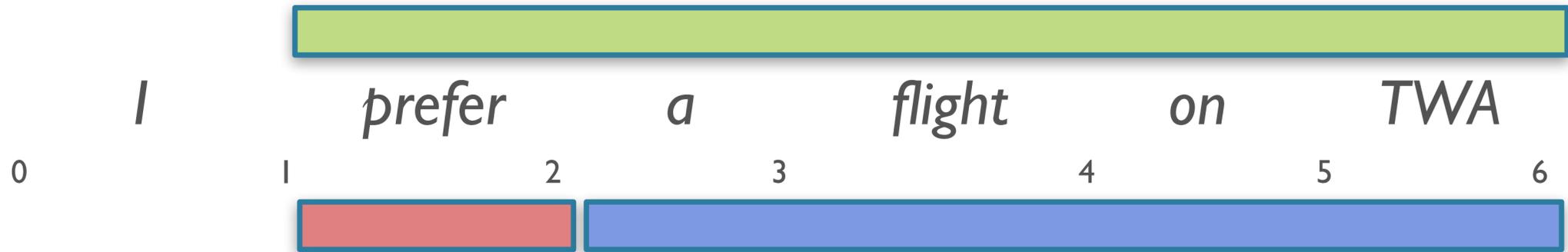
---

- $PP \rightarrow Preposition NP$

<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]		<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]

**Lexicon**

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



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

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

---

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

---

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

---

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

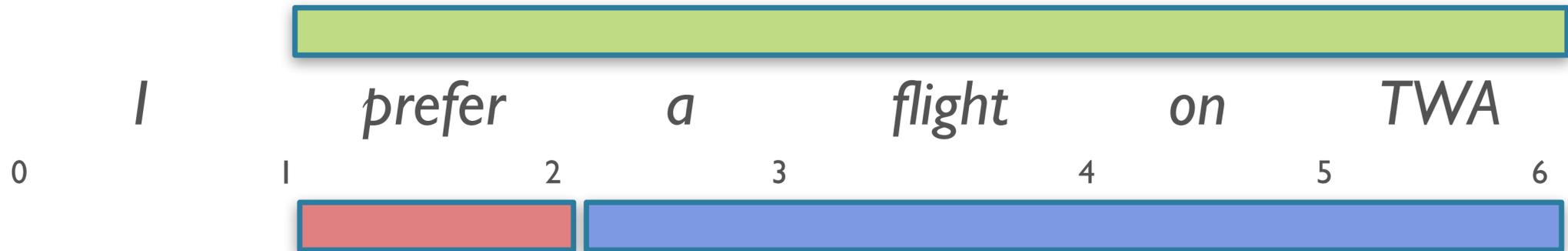
---

- $PP \rightarrow Preposition NP$

<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]		<b>VP, X2, S</b> [1,4]		<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]

**Lexicon**

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



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

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

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

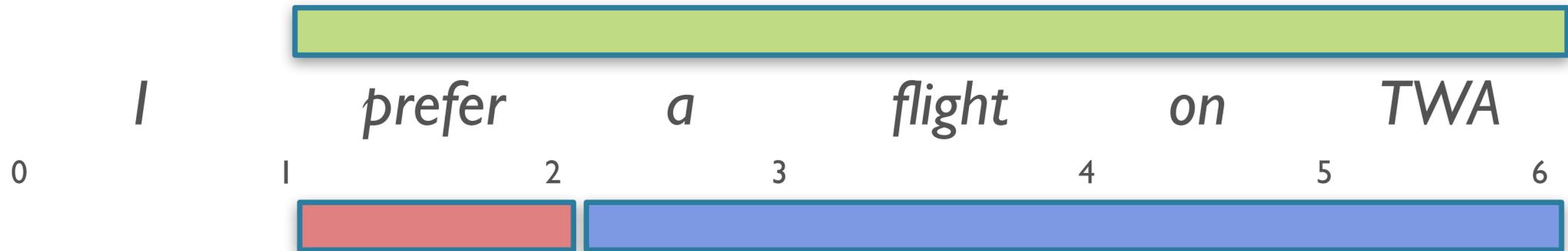
- 
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
  - $Nominal \rightarrow Nominal Noun$
  - $Nominal \rightarrow Nominal PP$

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

**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**

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

---

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

---

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

---

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

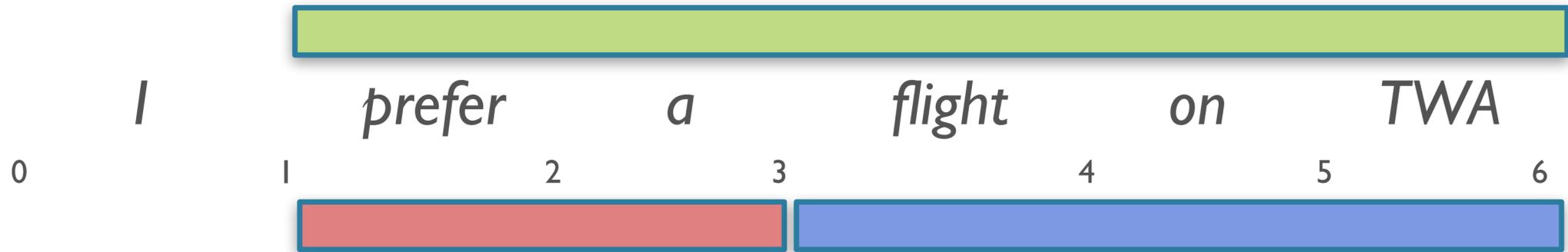
---

- $PP \rightarrow Preposition NP$

<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]	<b>[1,3]</b>	<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]

**Lexicon**

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



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

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

---

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

---

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

---

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

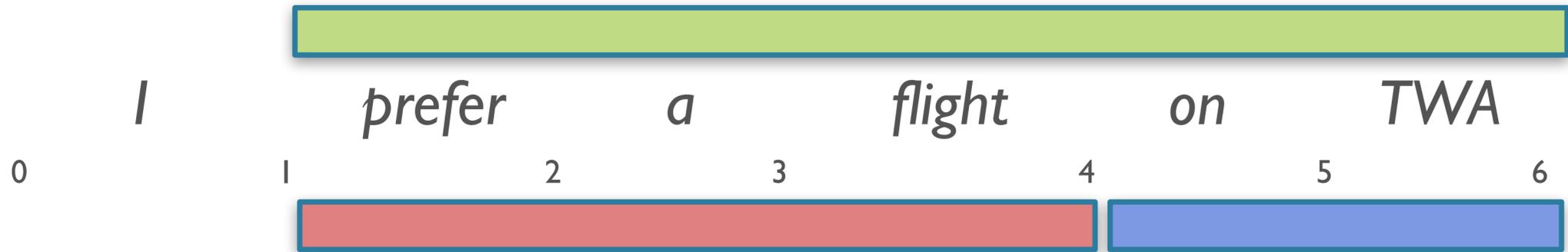
---

- $PP \rightarrow Preposition NP$

<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]

**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*  $\rightarrow book \mid include \mid prefer$



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

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

---

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

---

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

---

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

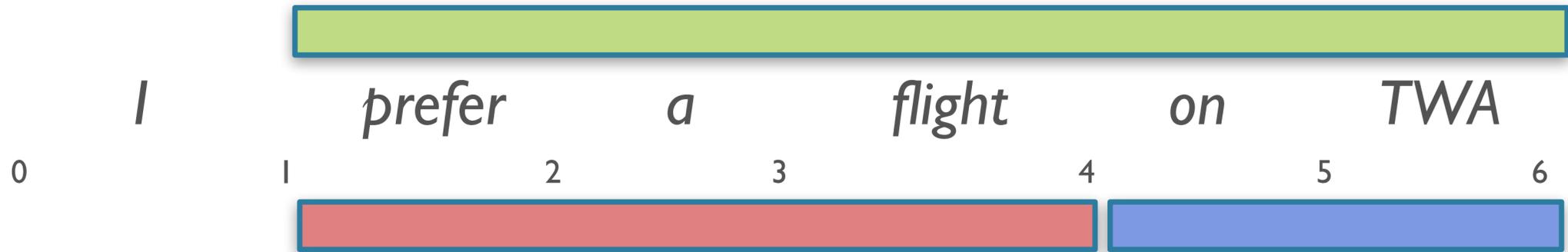
---

- $PP \rightarrow Preposition NP$

<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]

**Lexicon**

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



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

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

---

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

---

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

---

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

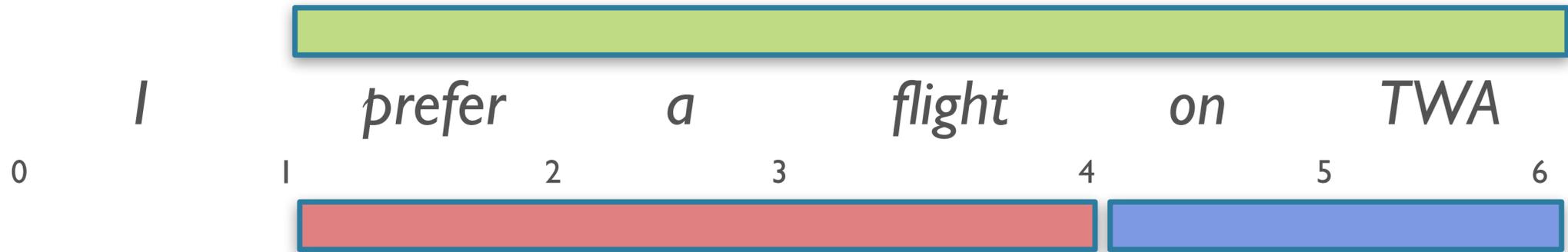
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

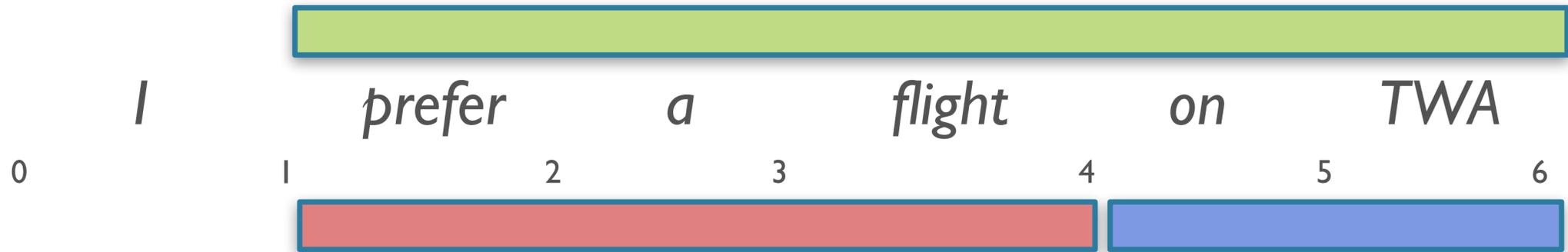
---

- $PP \rightarrow Preposition NP$

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

**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*  $\rightarrow book \mid include \mid prefer$



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

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

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

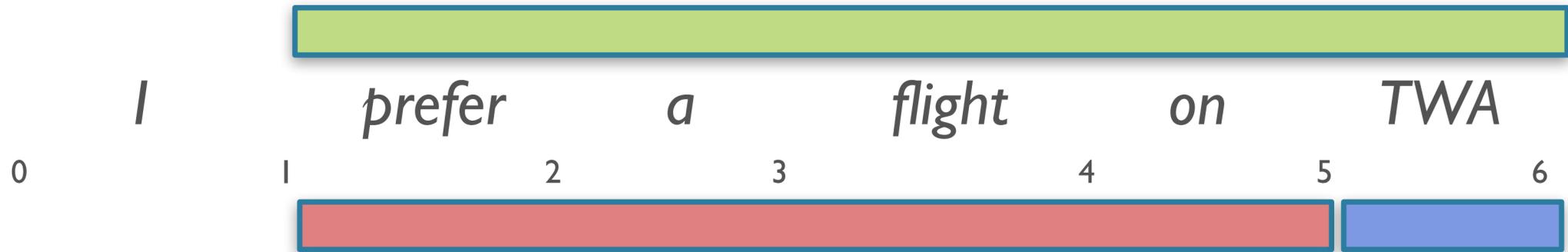
- 
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
  - $Nominal \rightarrow Nominal Noun$
  - $Nominal \rightarrow Nominal PP$

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

**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**

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

---

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

---

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

---

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

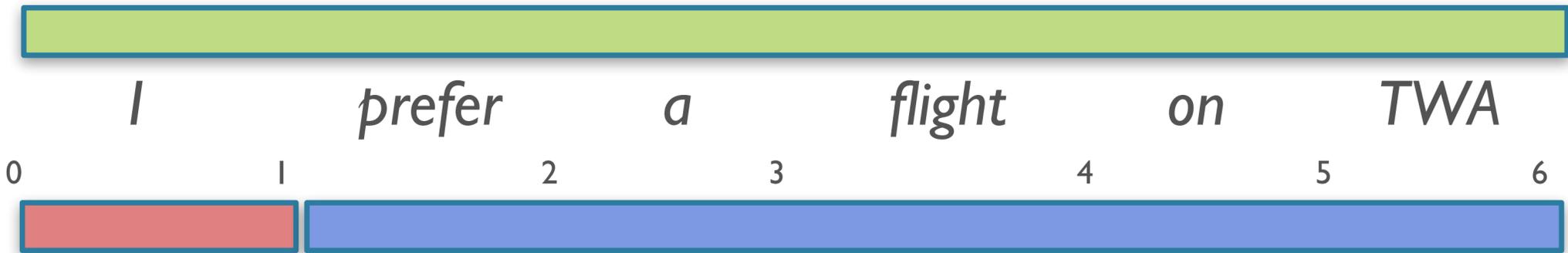
---

- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	[0,6]
	<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]

**Lexicon**

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



$\mathcal{L}_1$  Grammar

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

---

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

---

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

---

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

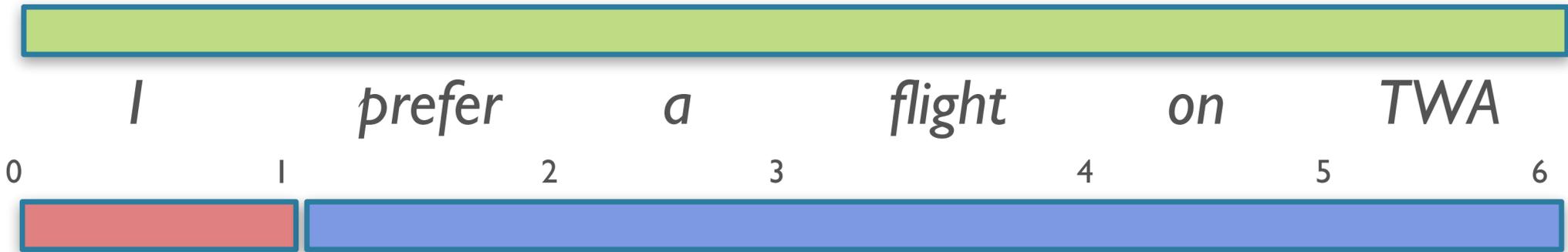
---

- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	<b>S</b> [0,6]
	<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]

Lexicon

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



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

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

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

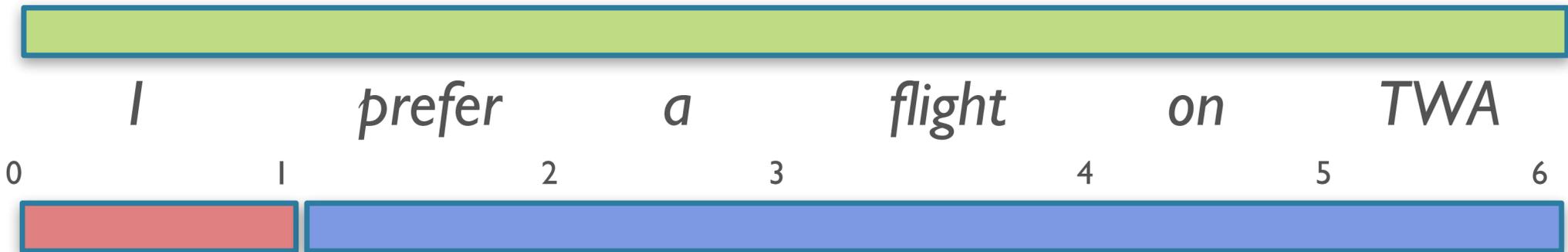
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

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

**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>S</b> [0,6]
	<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**

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

---

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

---

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

---

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

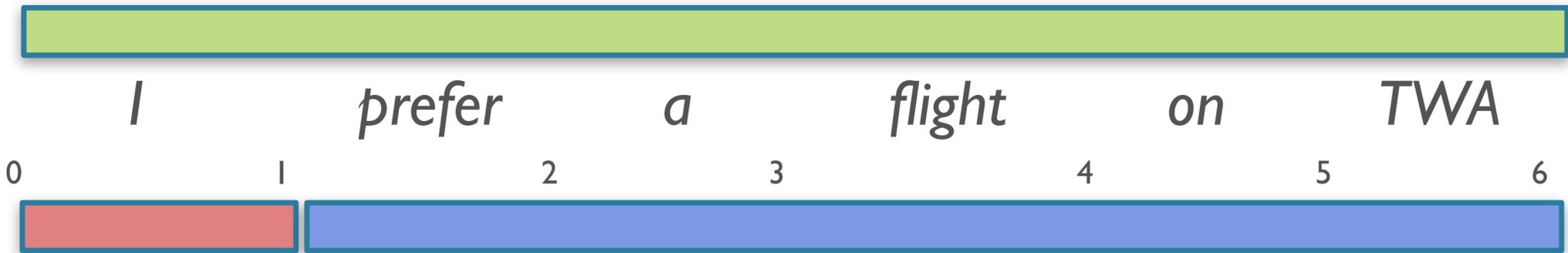
---

- $PP \rightarrow Preposition NP$

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

**Lexicon**

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



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

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

---

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

---

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

---

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

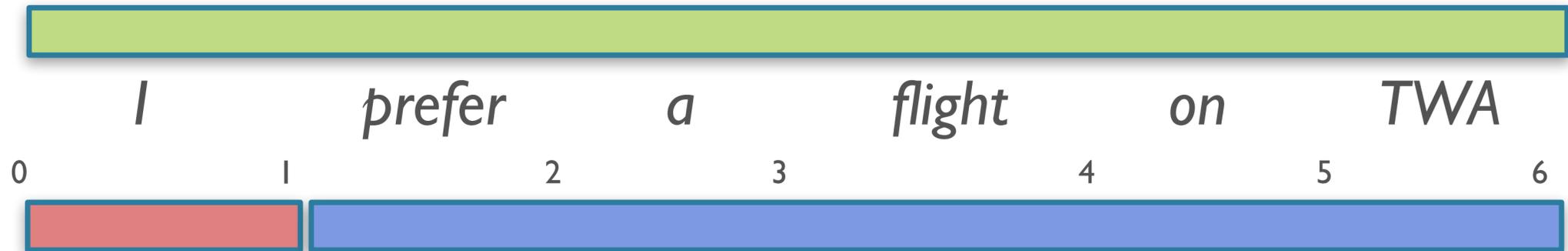
---

- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	<b>S</b> [0,6]
	<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]

**Lexicon**

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



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

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

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

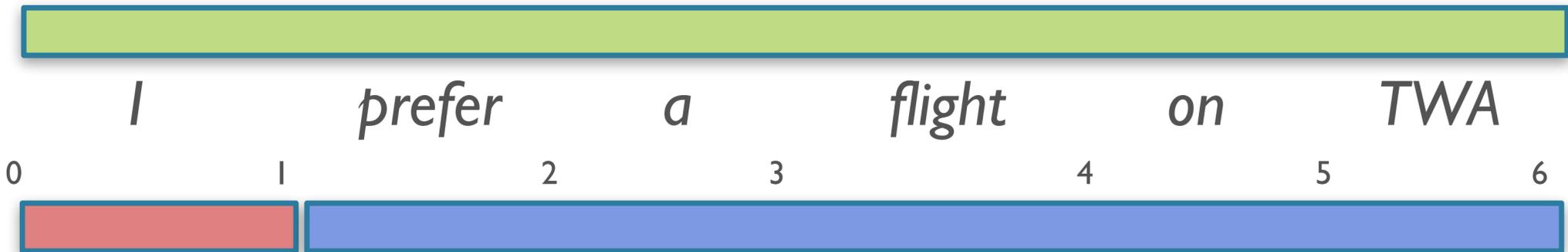
- 
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
  - $Nominal \rightarrow Nominal Noun$
  - $Nominal \rightarrow Nominal PP$

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

**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>S</b> [0,6]
	<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]



# Current CKY Algorithm

Limitations:

Only stores non-terminals in cell

Not rules or cells corresponding to RHS

Stores SETS of non-terminals

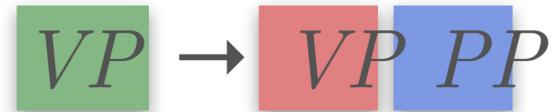
Multiple rules with same LHS collide

Currently only *acceptance/recognition*

# CKY *Parser*

- Pair each nonterminal with back-pointer to cells from which it was derived
- Last step:
  - construct trees from back-pointers in  $[ 0, n ]$

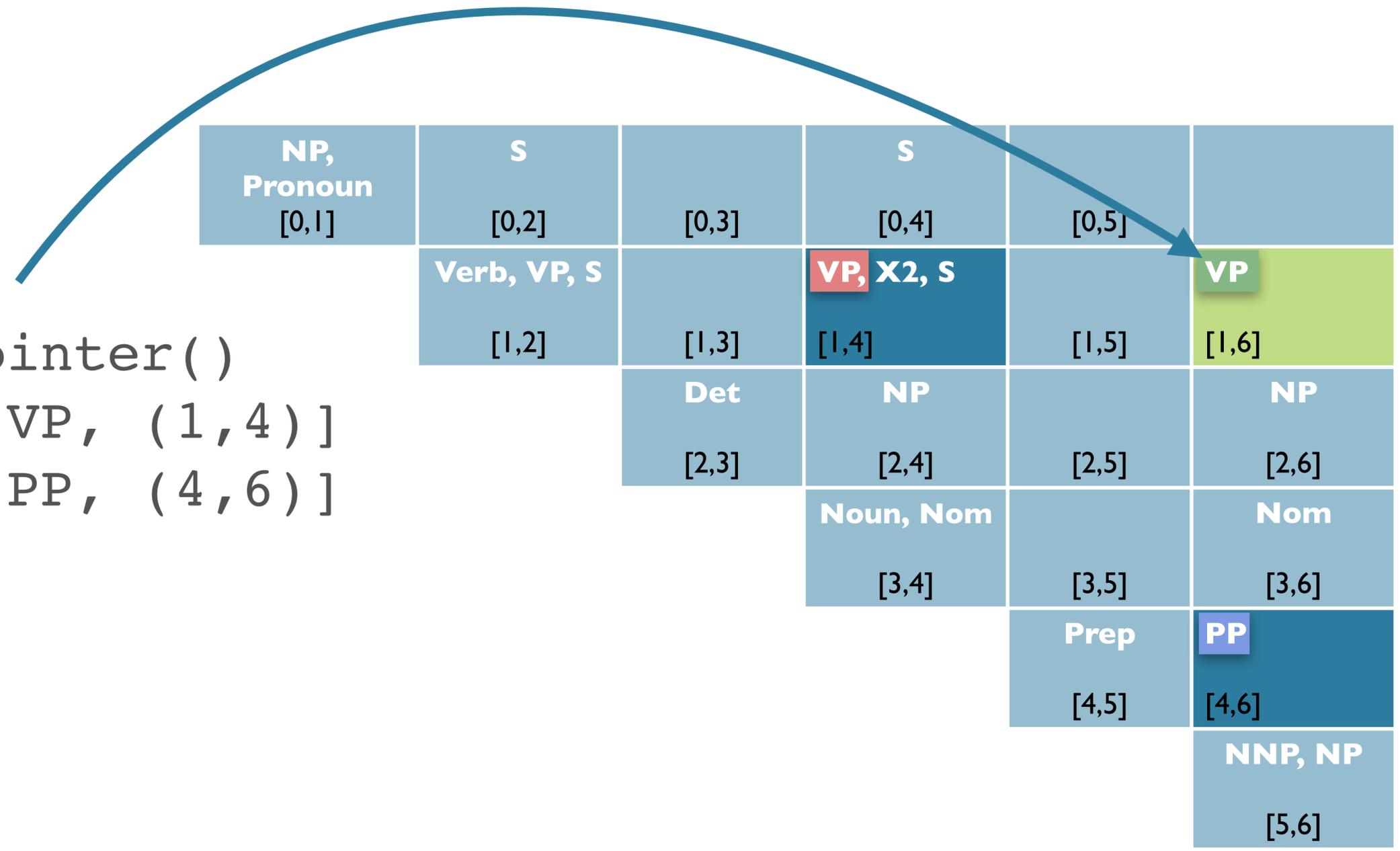
<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	<b>VP</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
					<b>NNP,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

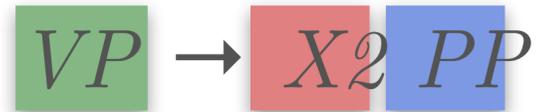


```

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

```





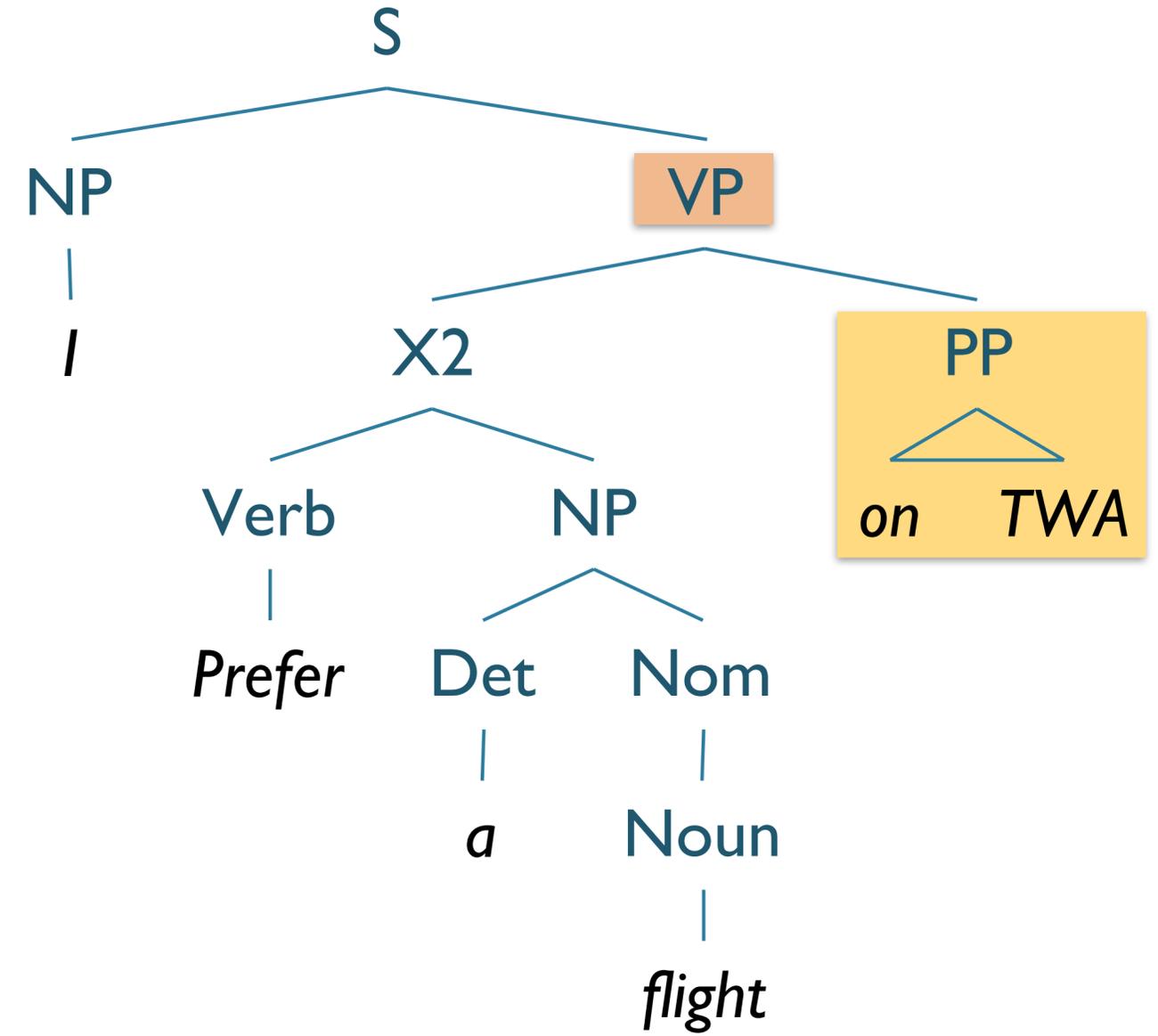
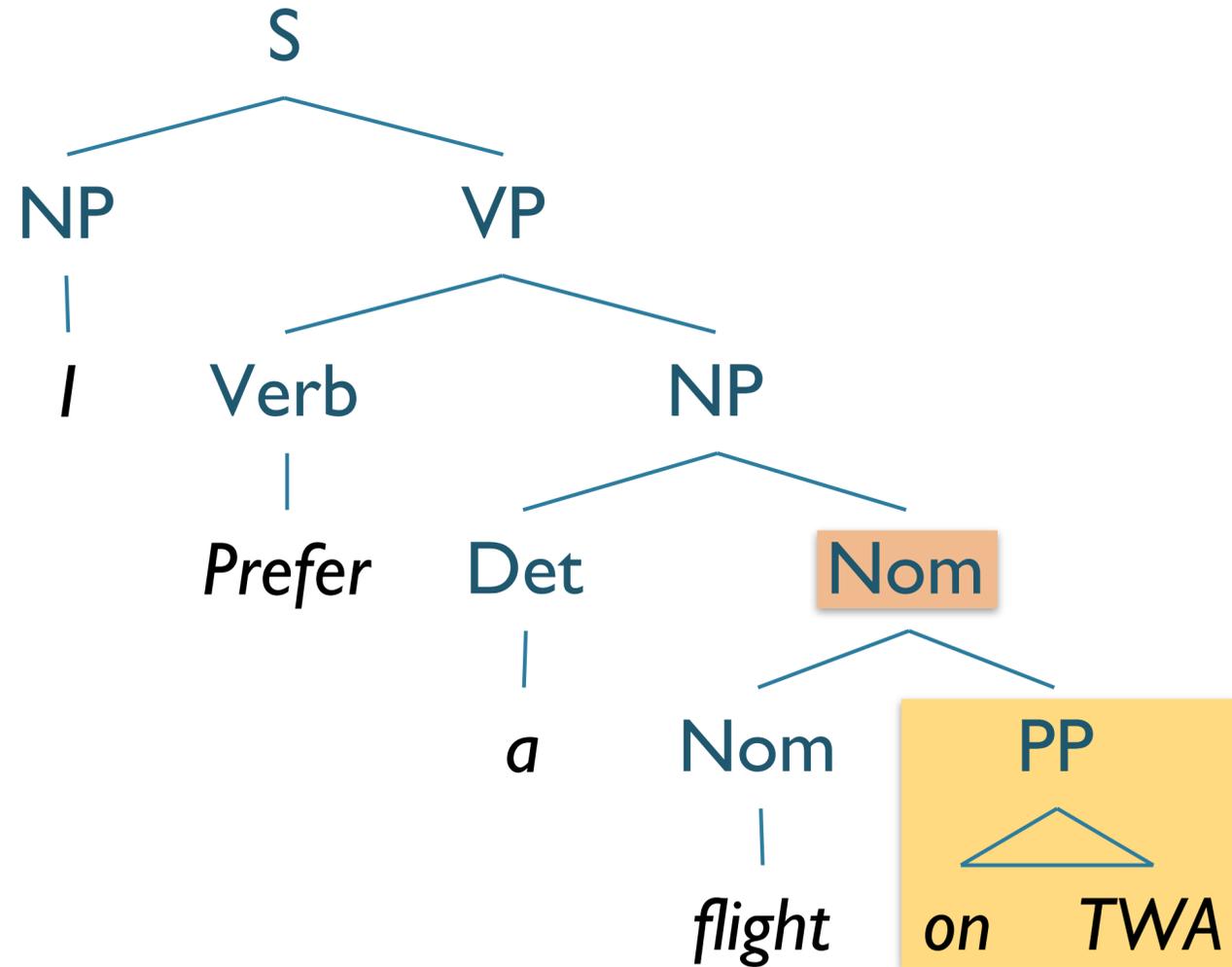
```

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]	<b>VP, X2, S</b> [1,4]	[1,5]	<b>VP</b> [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]	<b>PP</b> [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