

CKY Parsing

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

Announcements

- HW1 grades coming soon
- 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!
- HW2: only need the three operations we discussed on the slides
 - NB: order of application matters!

Type Hinting in Python

Type Hinting in Python

- Supported in ≥ 3.6

```
from nltk.grammar import Production
```

```
def fix_hybrid_production(hybrid_prod: Production) -> list[Production]:  
    ...
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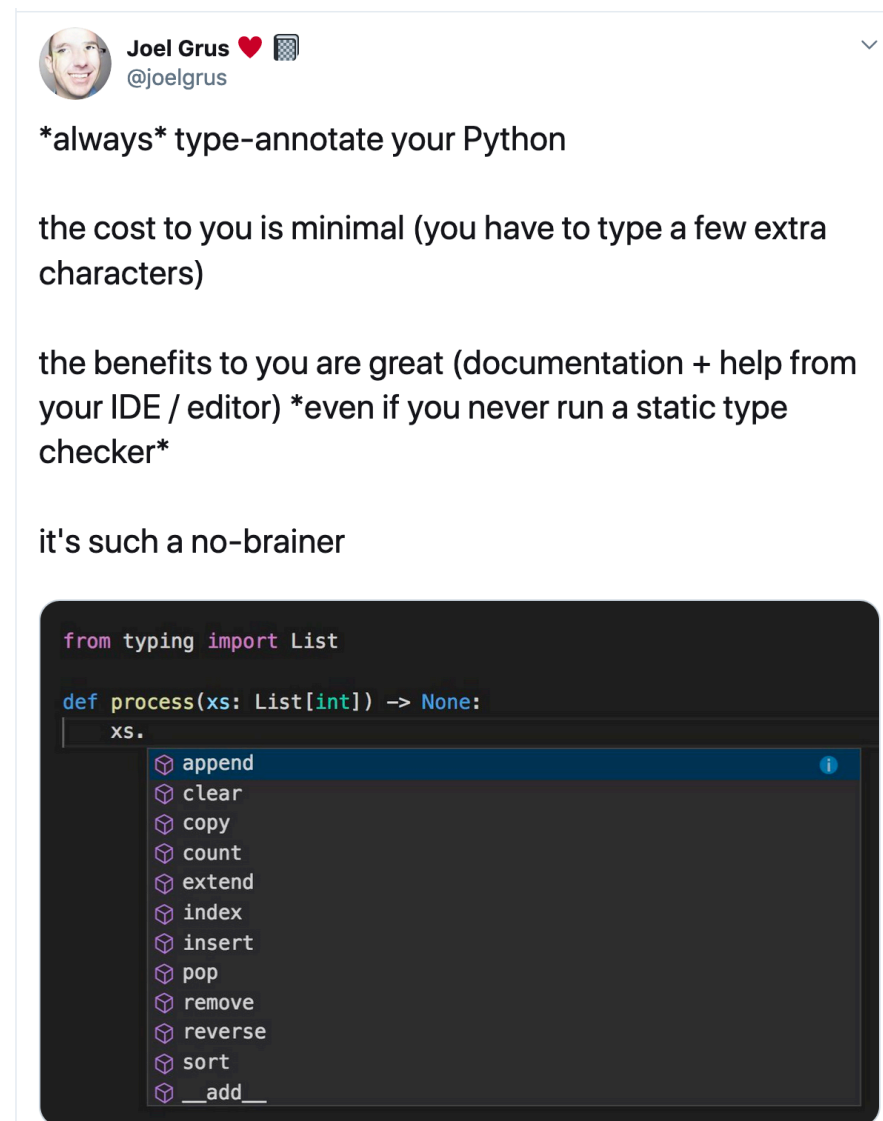
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- https://mypy.readthedocs.io/en/stable/cheat_sheet_py3.html
- <https://peps.python.org/pep-0483/>
- Tools for your editor:
 - [Mypy](#)
 - [Pylint](#): a great default to use!



Roadmap

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

CKY Parsing

- (Relatively) efficient parsing algorithm
- Based on tabulating substring parses to avoid repeat work
- Approach:
 - Use CNF Grammar
 - Build an $(n + 1) \times (n + 1)$ matrix to store subtrees
 - Upper triangular portion
 - Incrementally build parse spanning whole input string

CKY

- Given an input string S of length n

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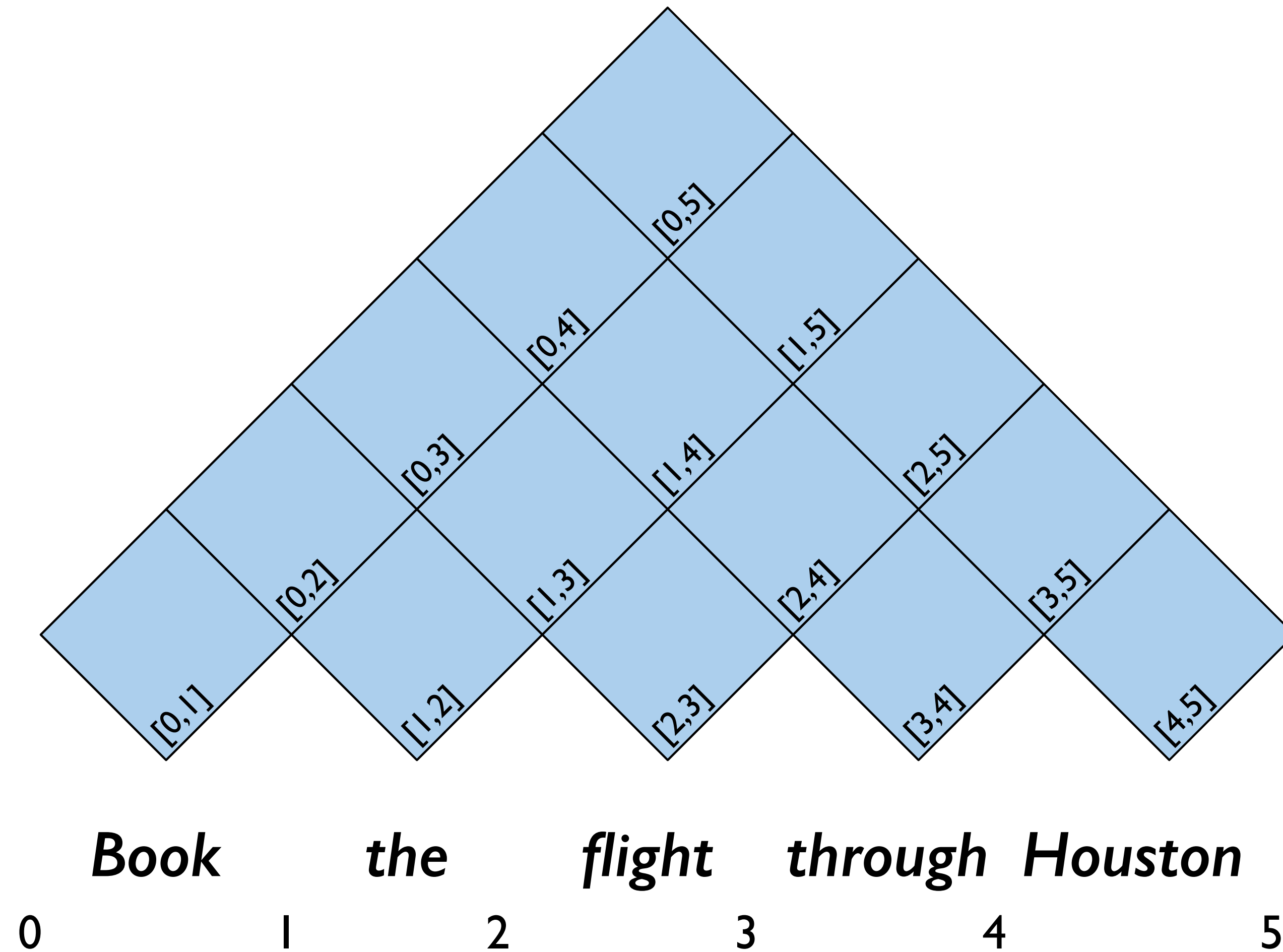
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 - $[j - 1, j]$ contains pre-terminals
 - if $[0, n]$ contains the start symbol, the sentence is ***accepted***

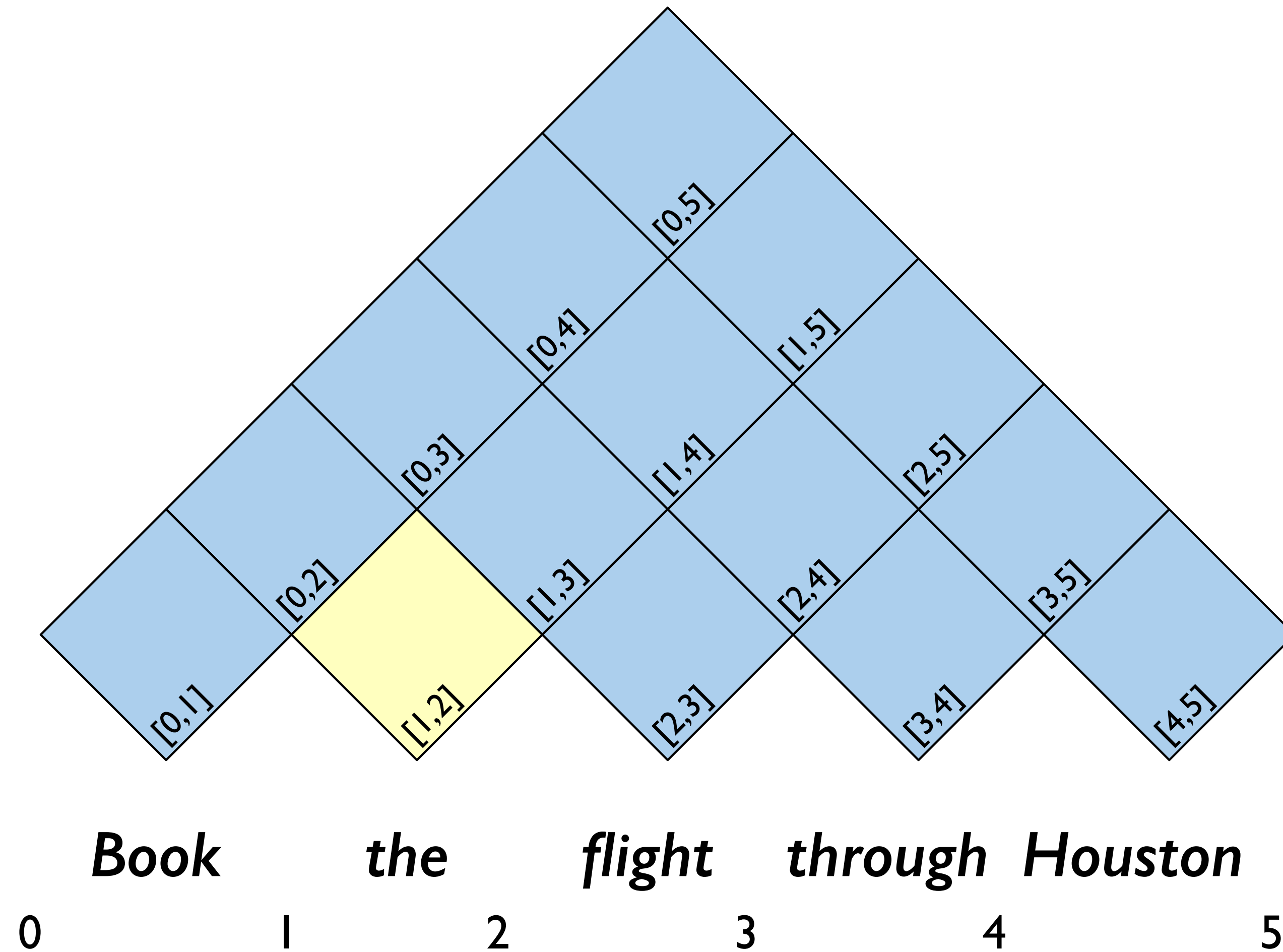
CKY Matrix

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

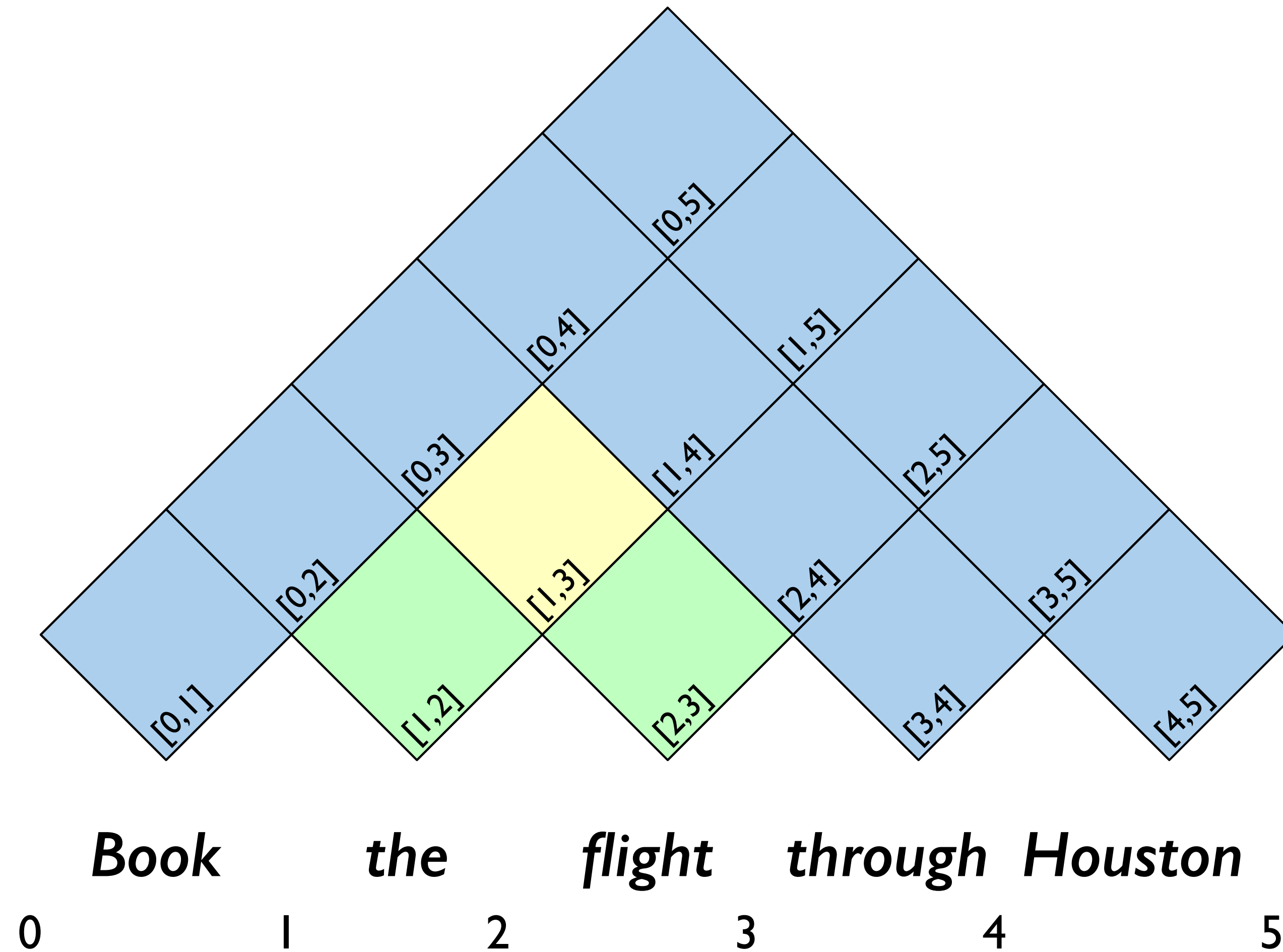
CKY Matrix



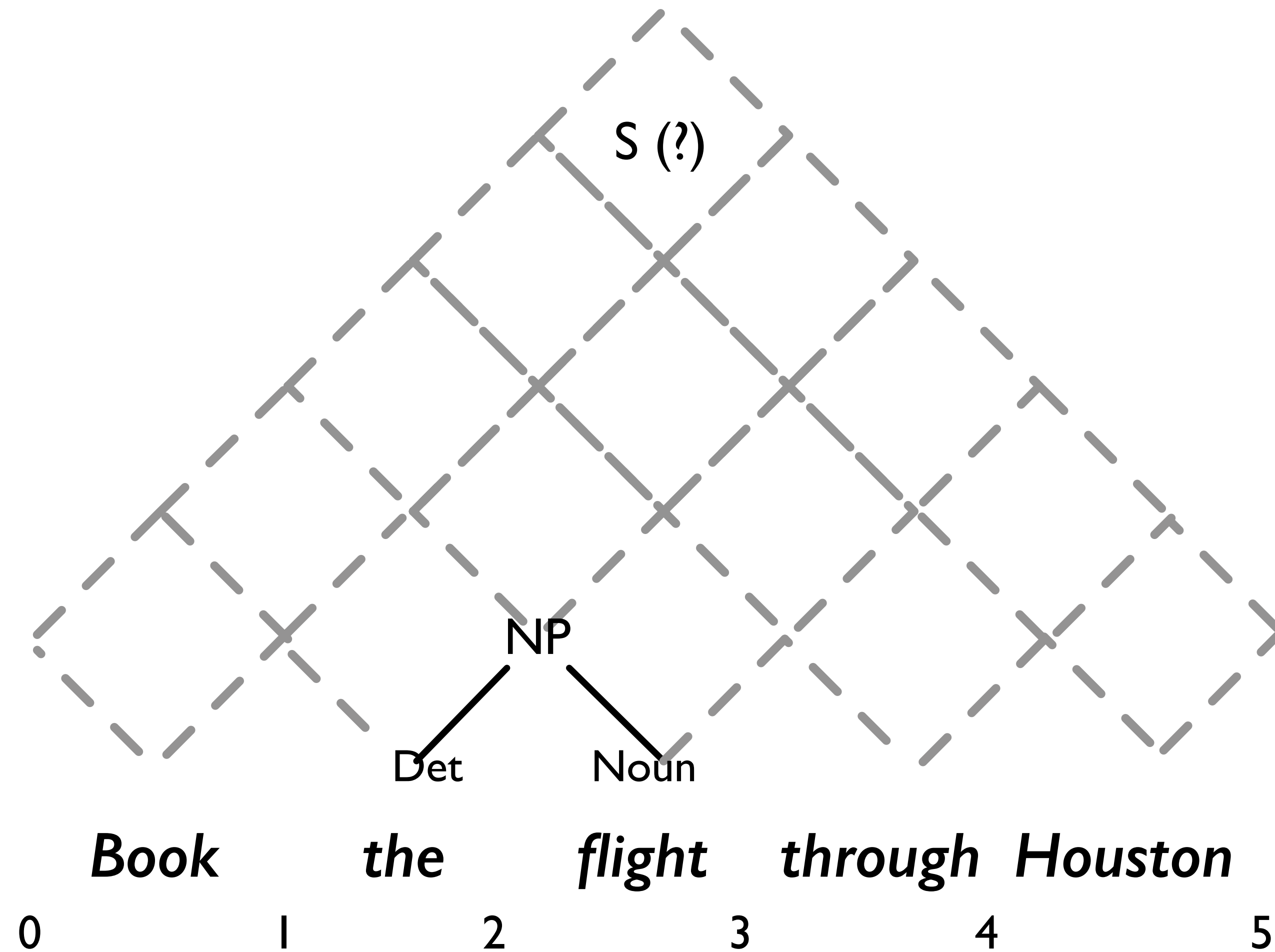
CKY Matrix



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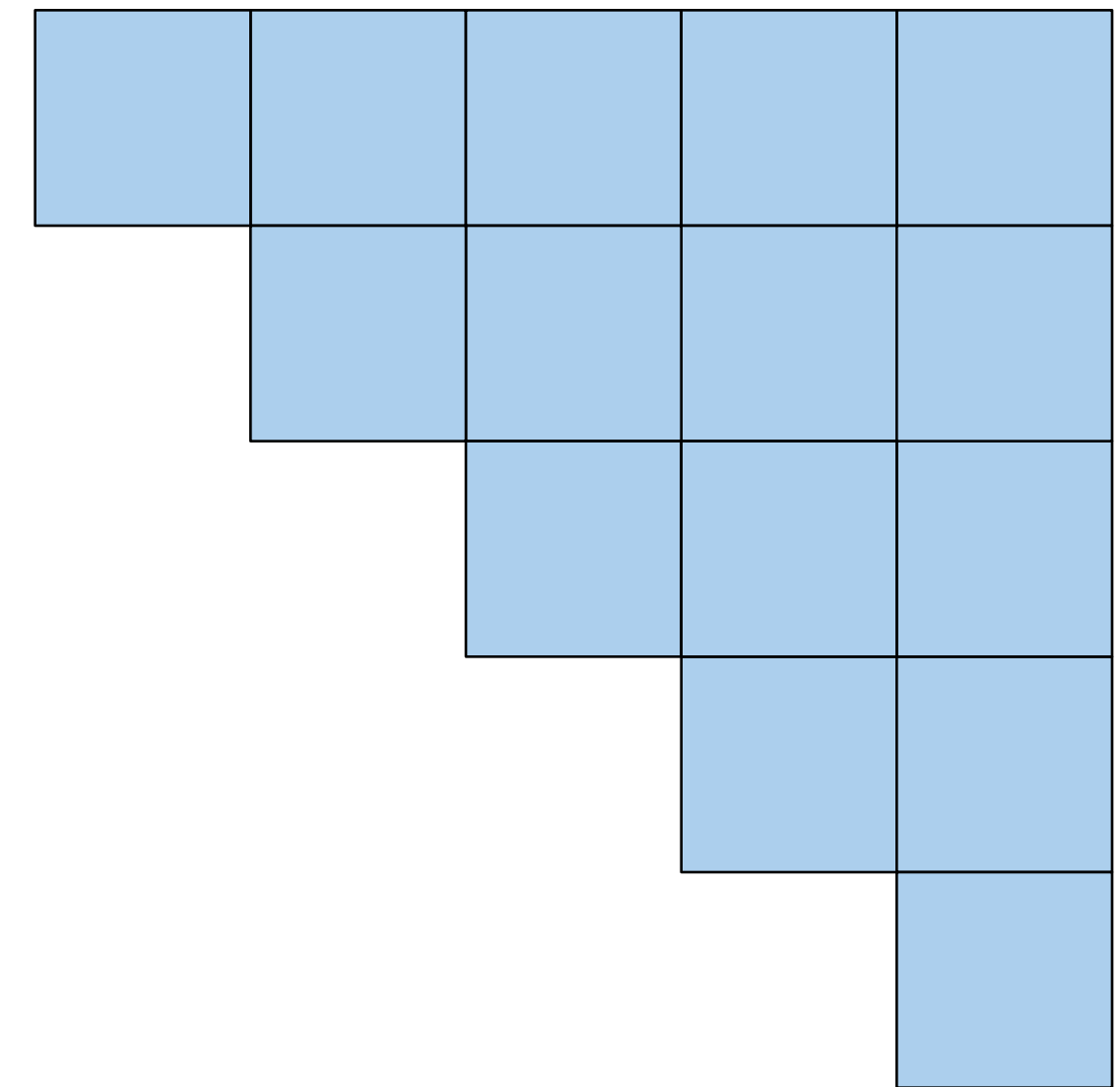
CKY Matrix



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 $j > i + 1$

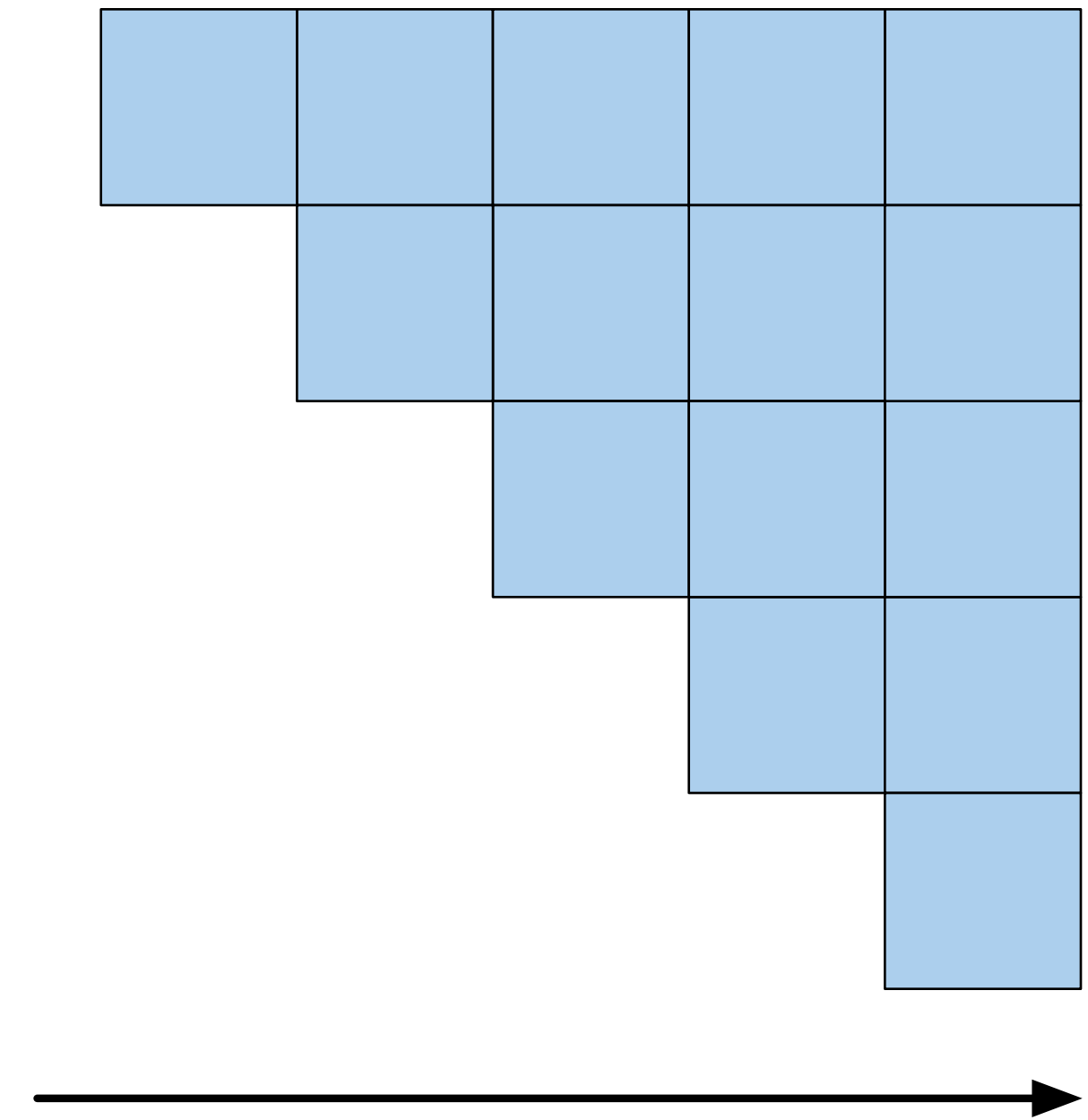
CKY



- Table fills:

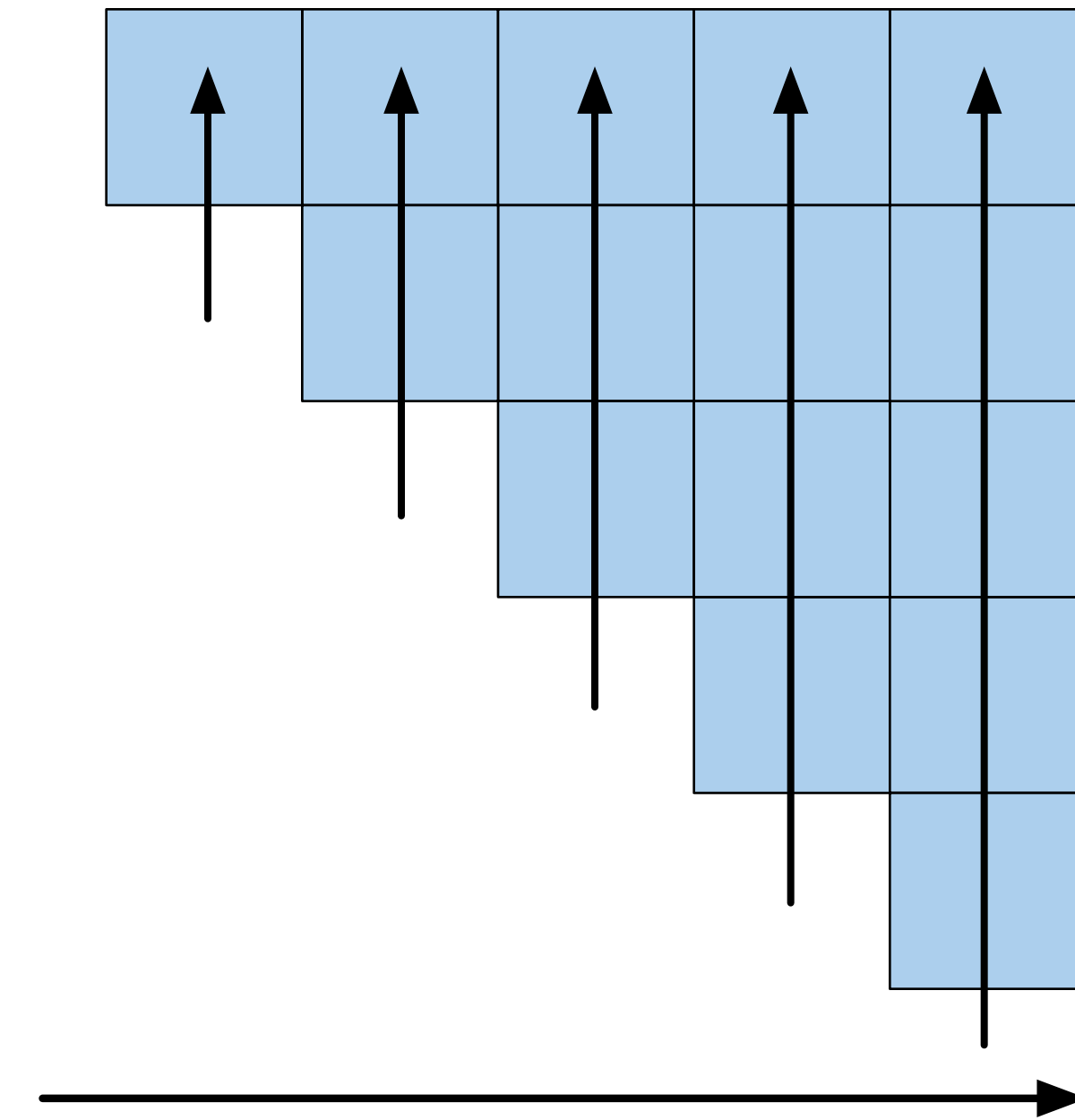
CKY

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



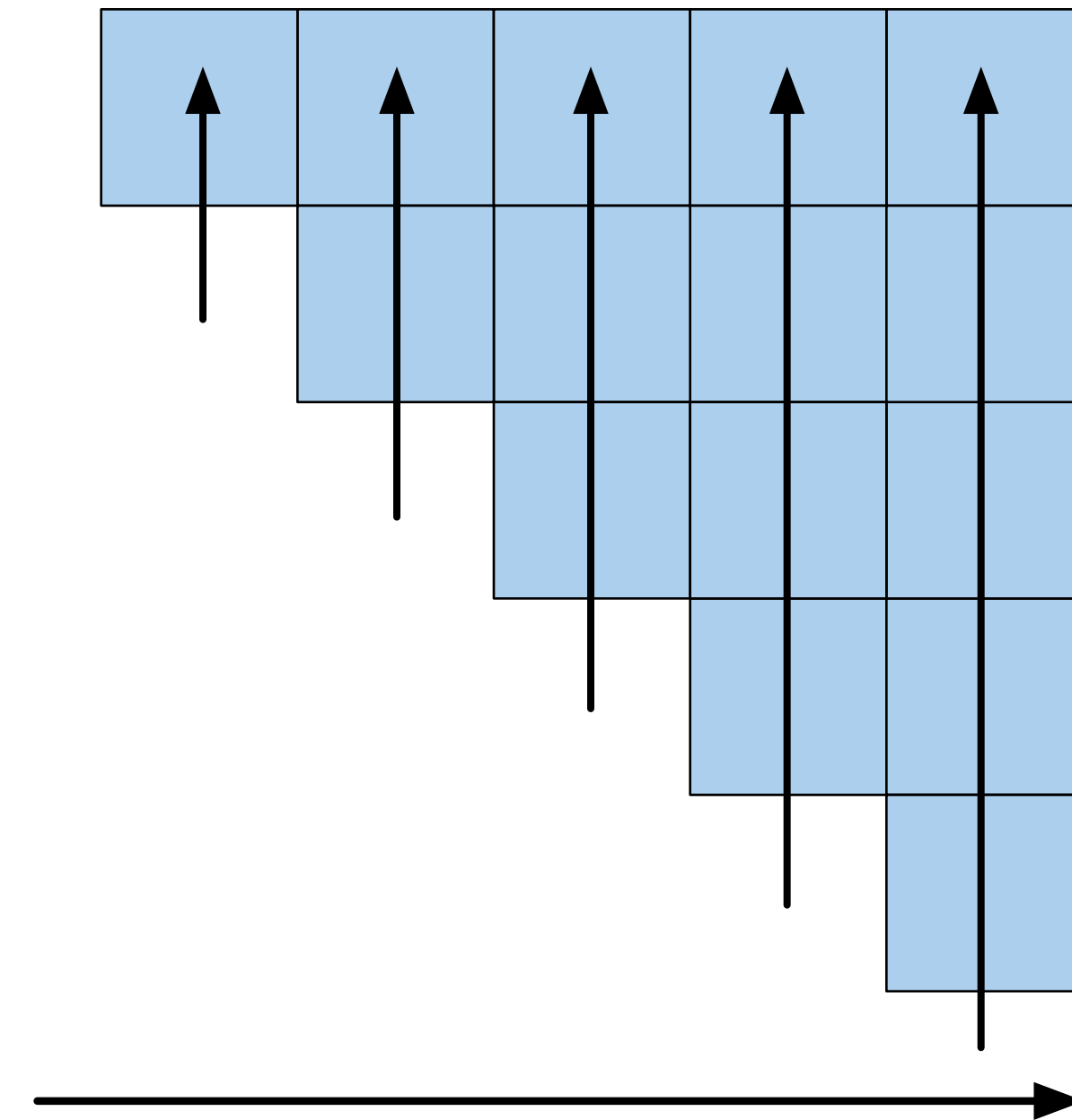
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- Table fills:
 - Column-by-column, left-to-right
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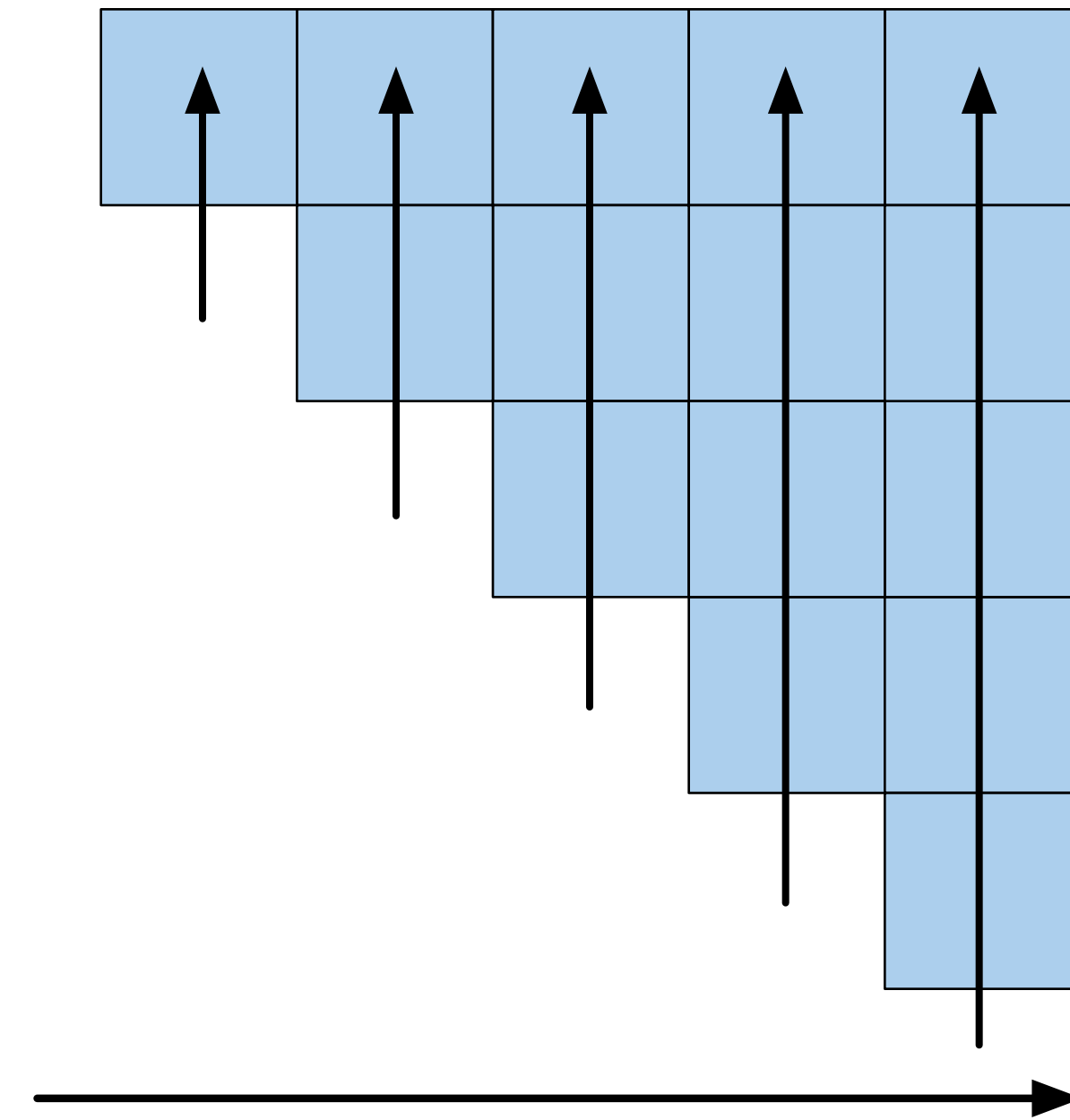
CKY

- Table fills:
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- Why?



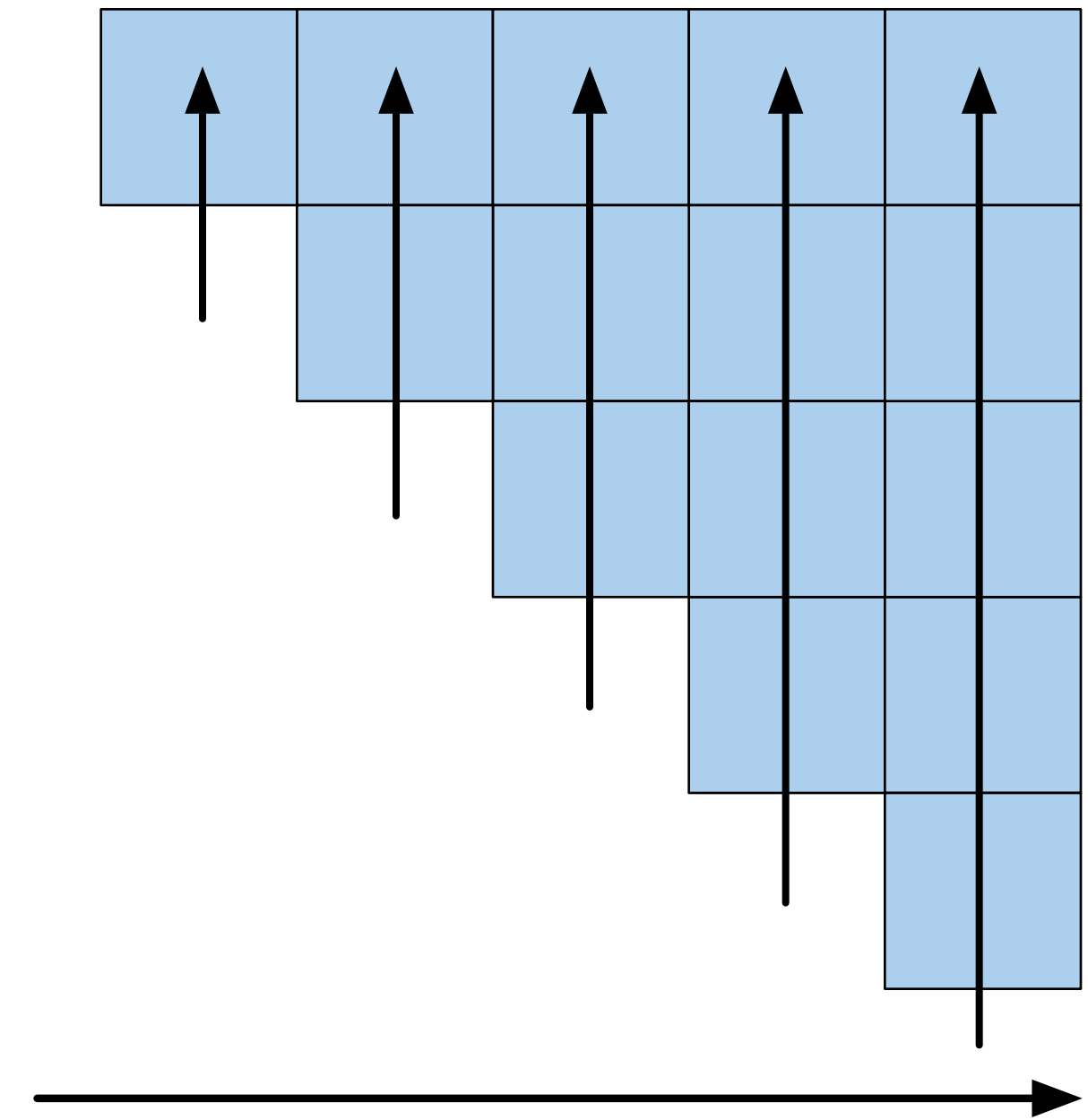
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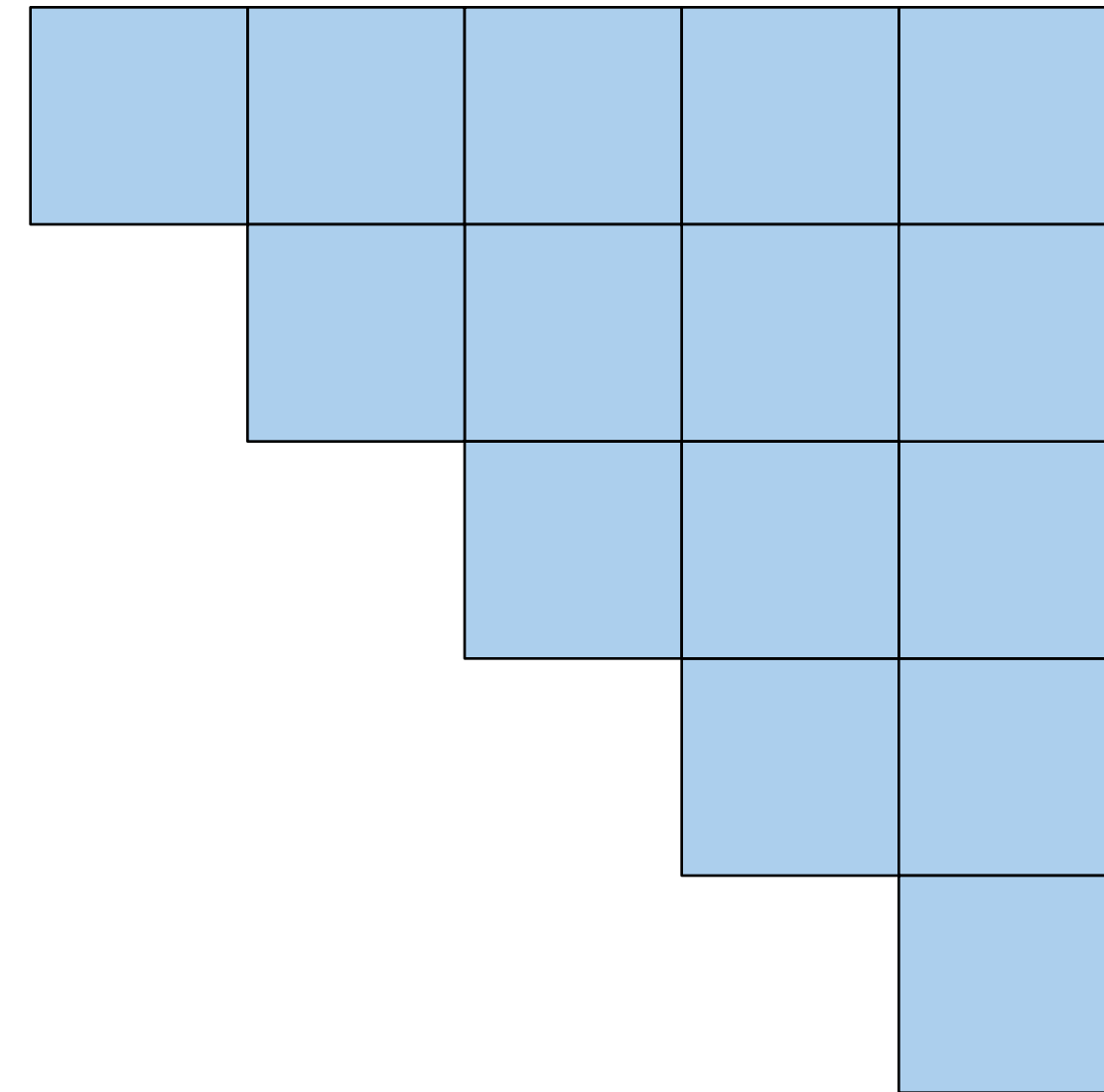


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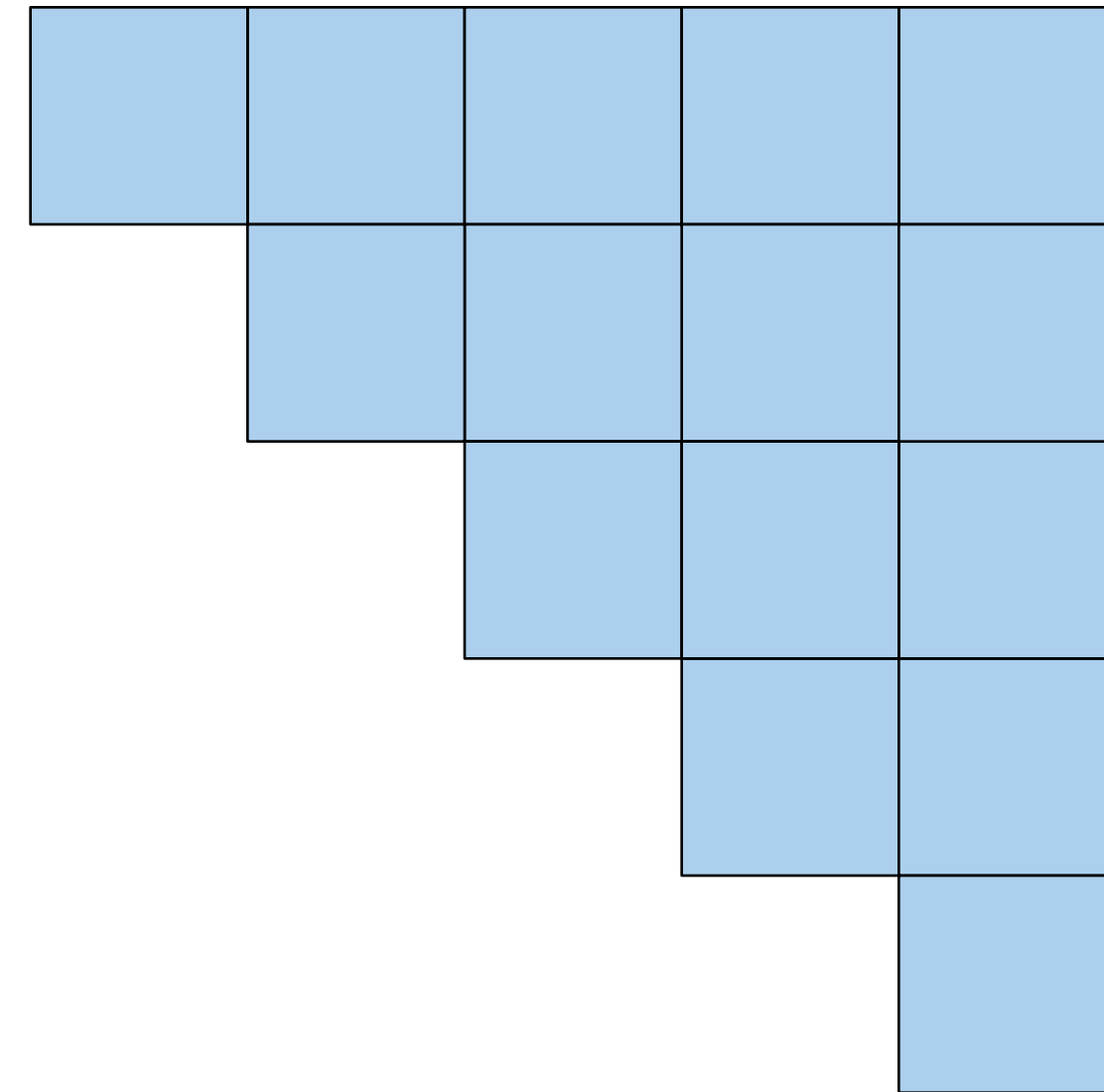


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 - Allows online sentence analysis

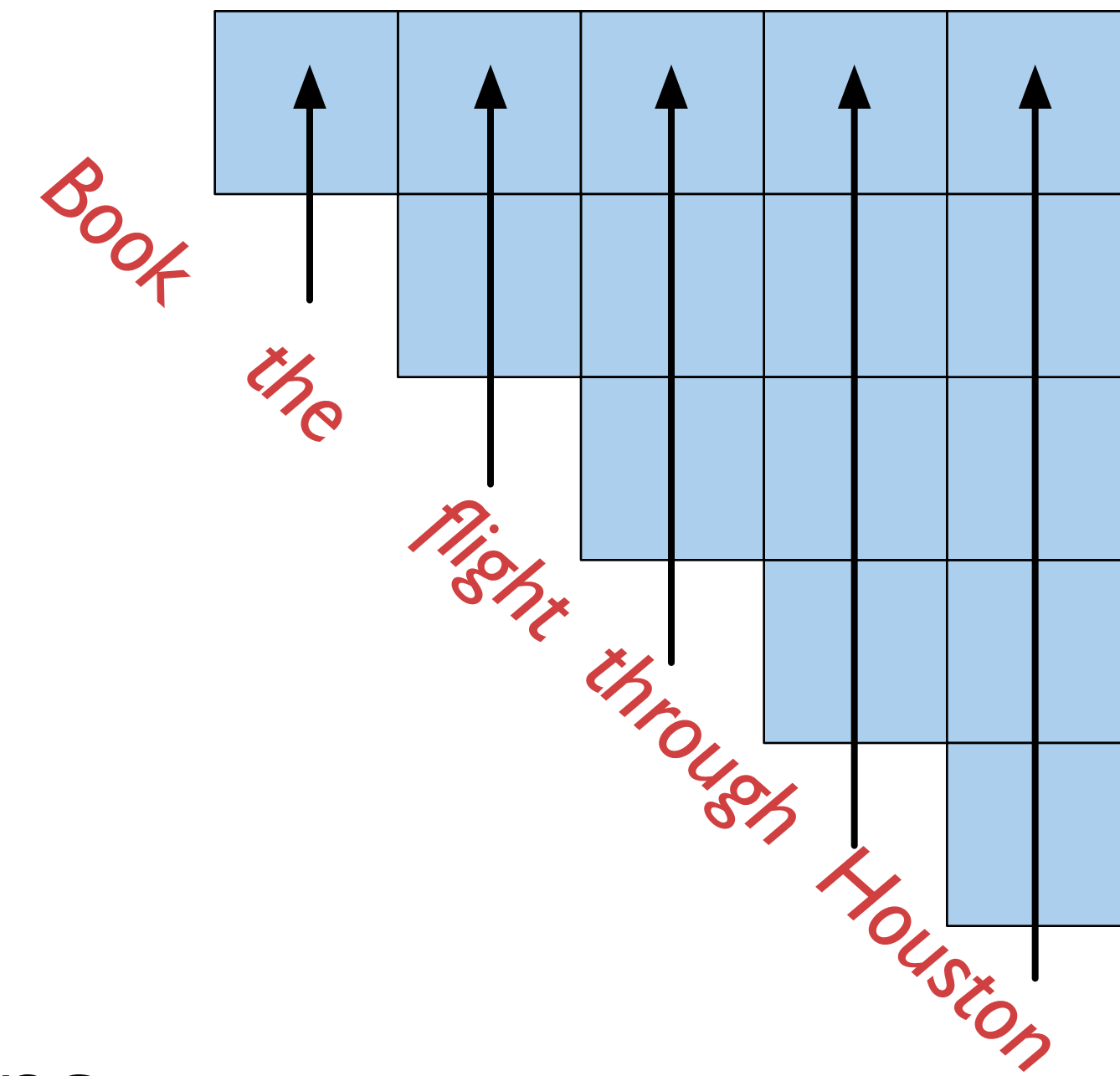
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 - Works across input string as it arrives

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CKY Algorithm

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

Sliding k as the pivot for child nodes

CKY Algorithm

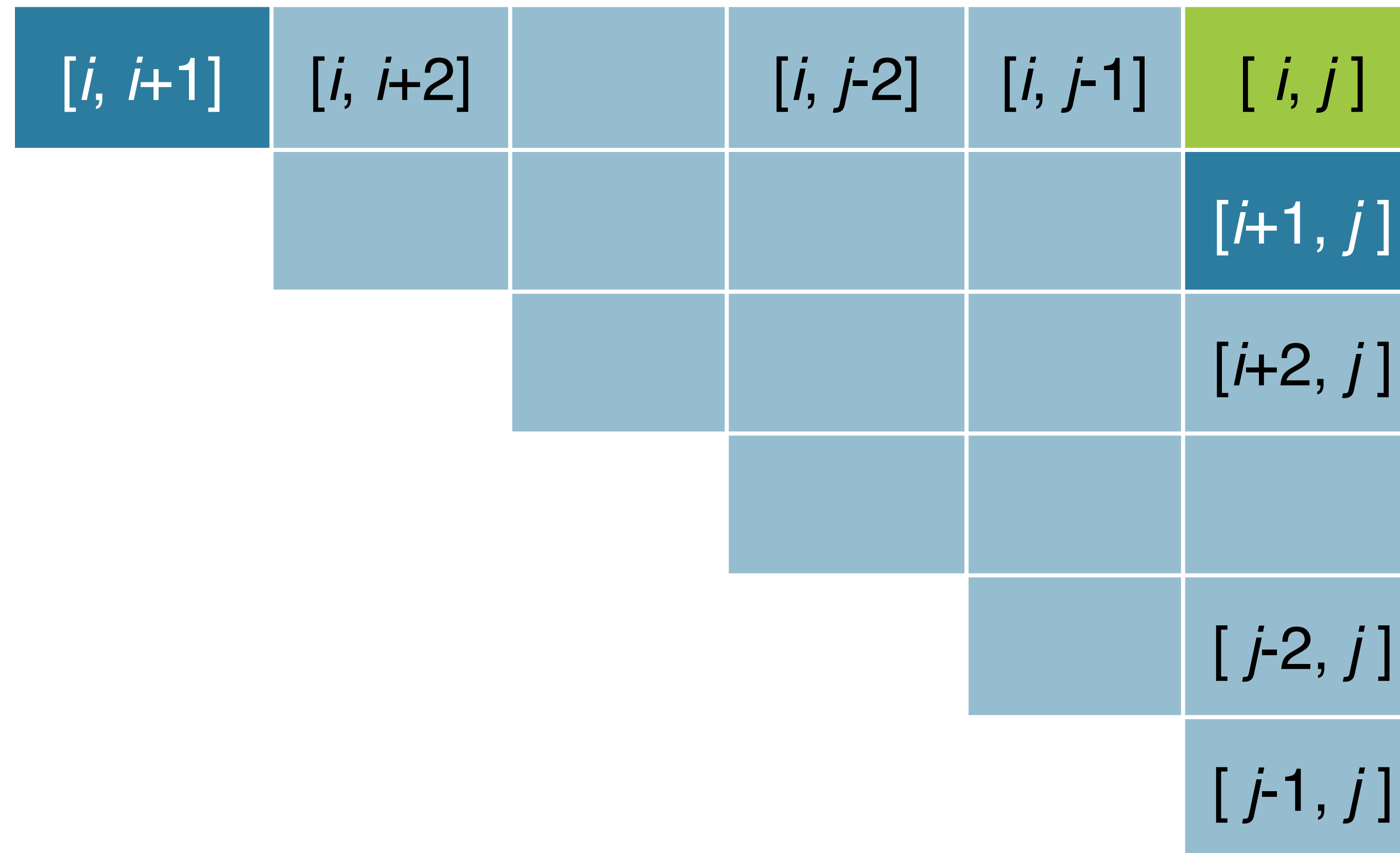
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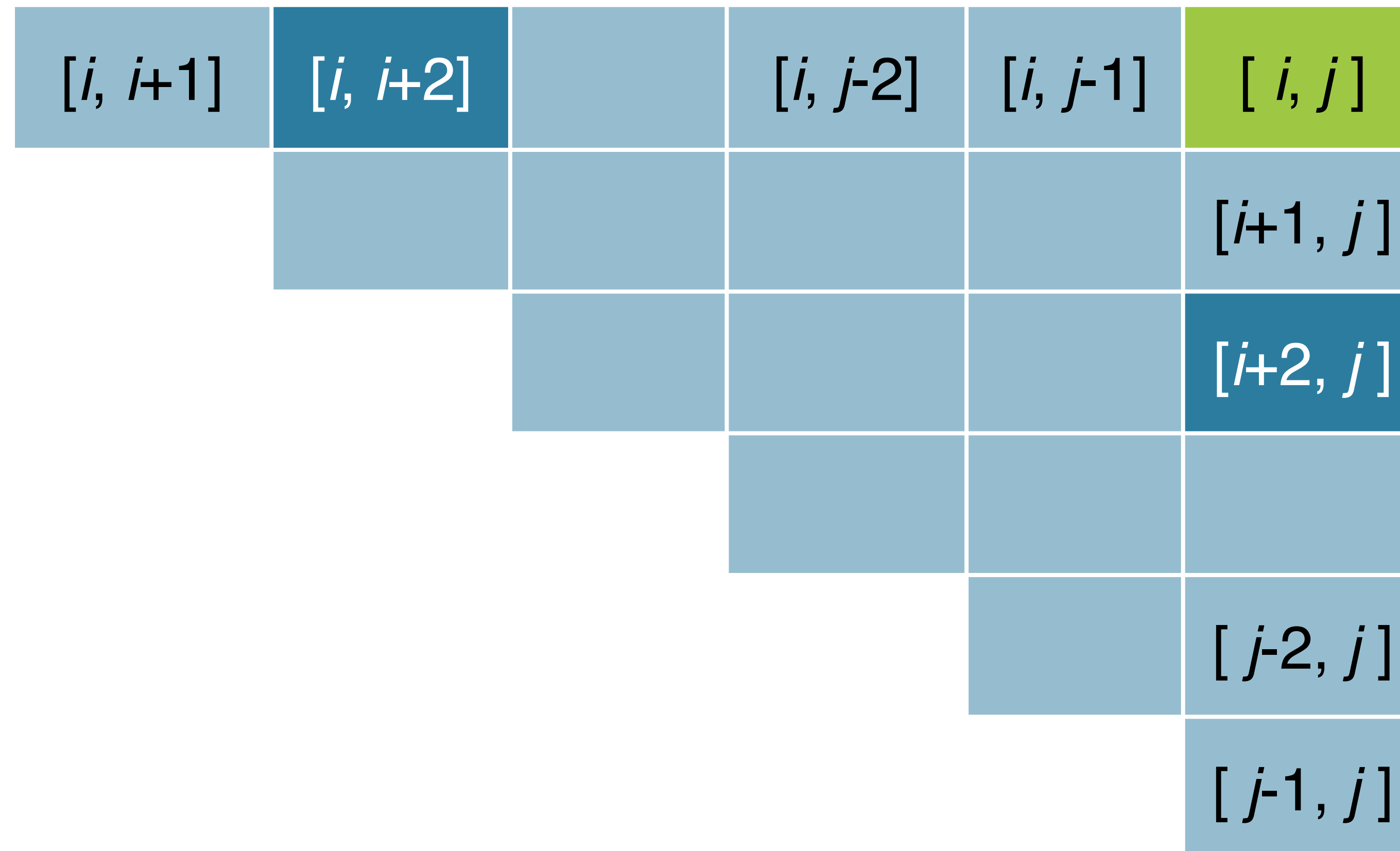
Filling the cell with set of applicable rules

Filling Cell $[i, j]$



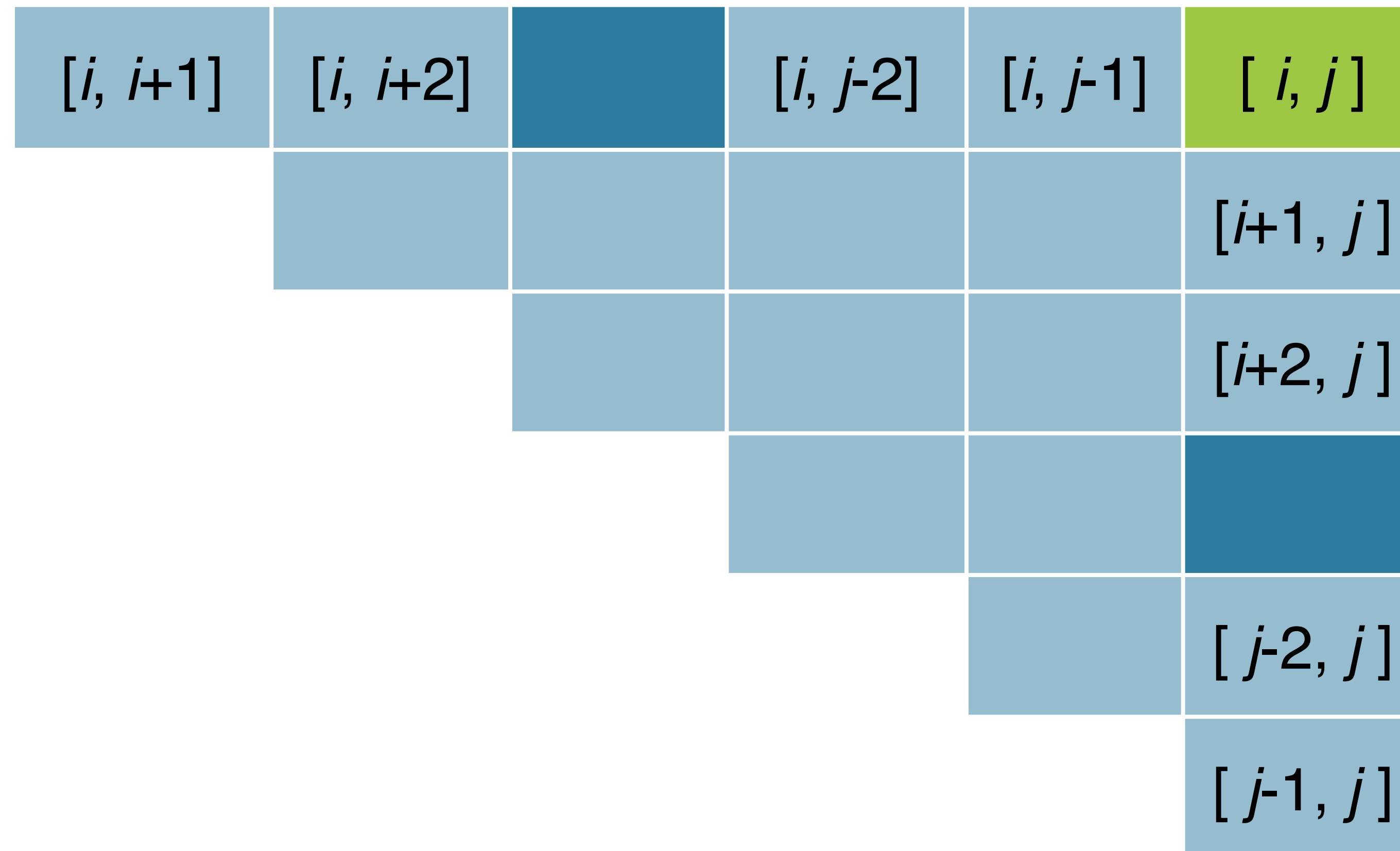
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Filling Cell $[i, j]$



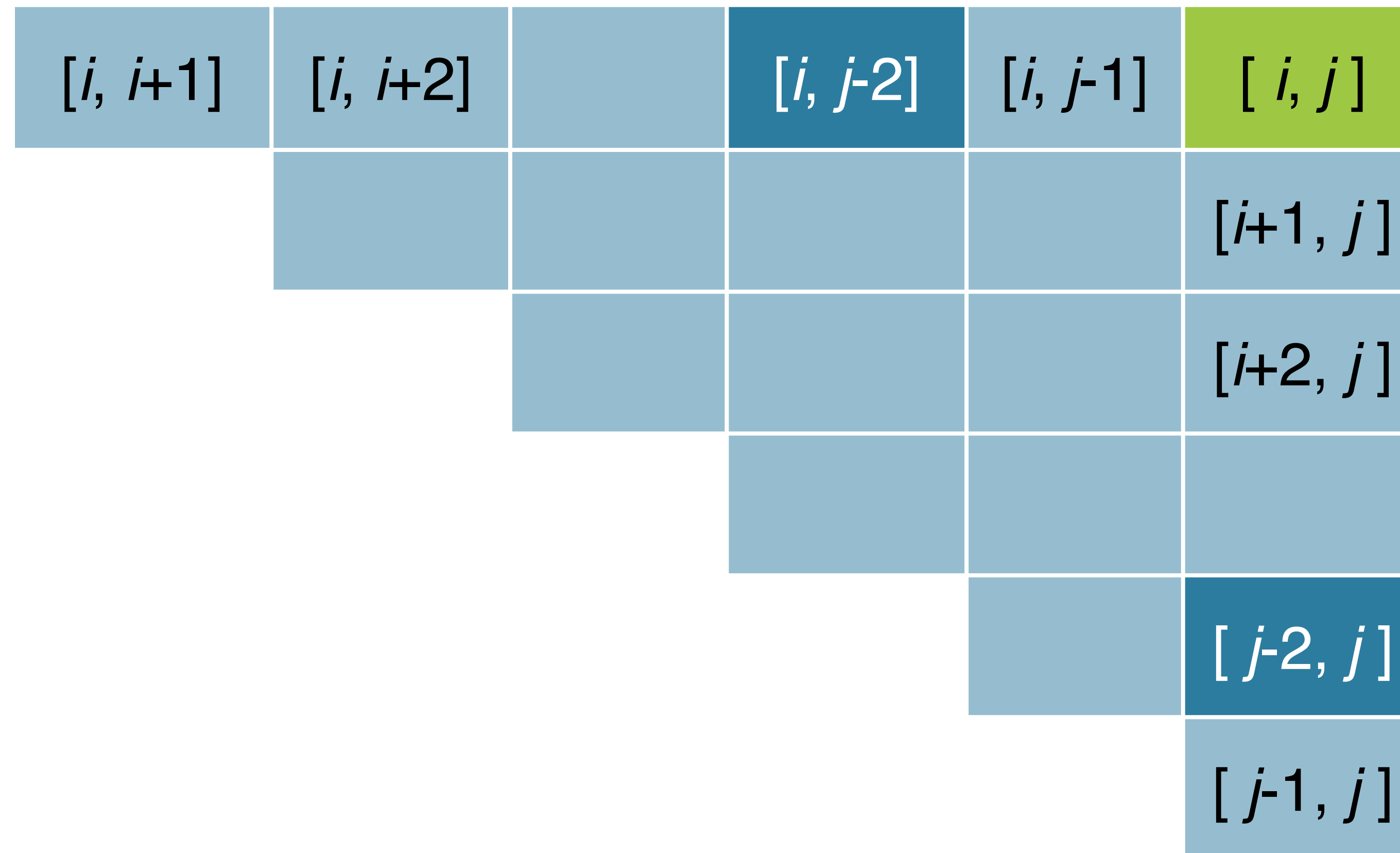
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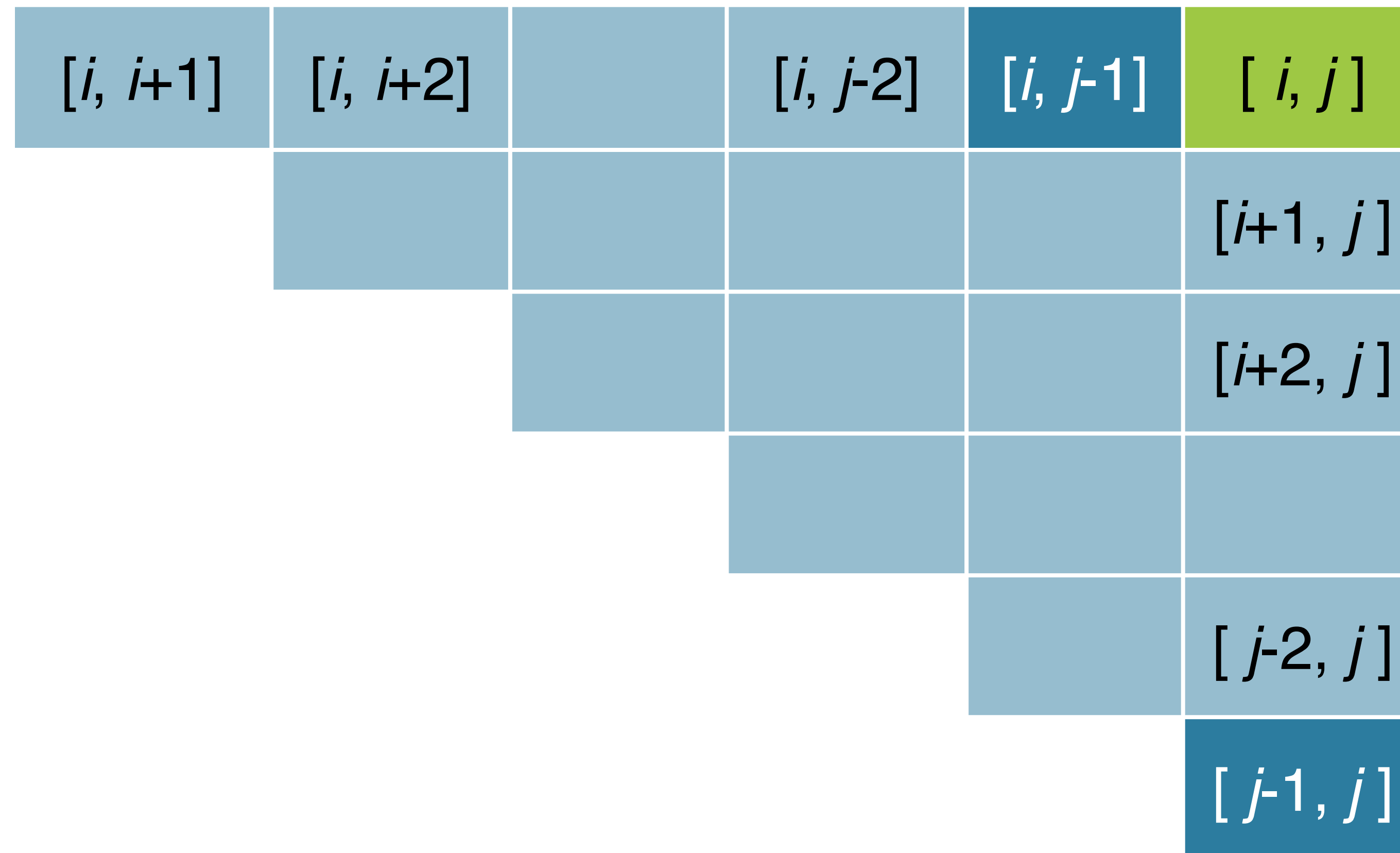
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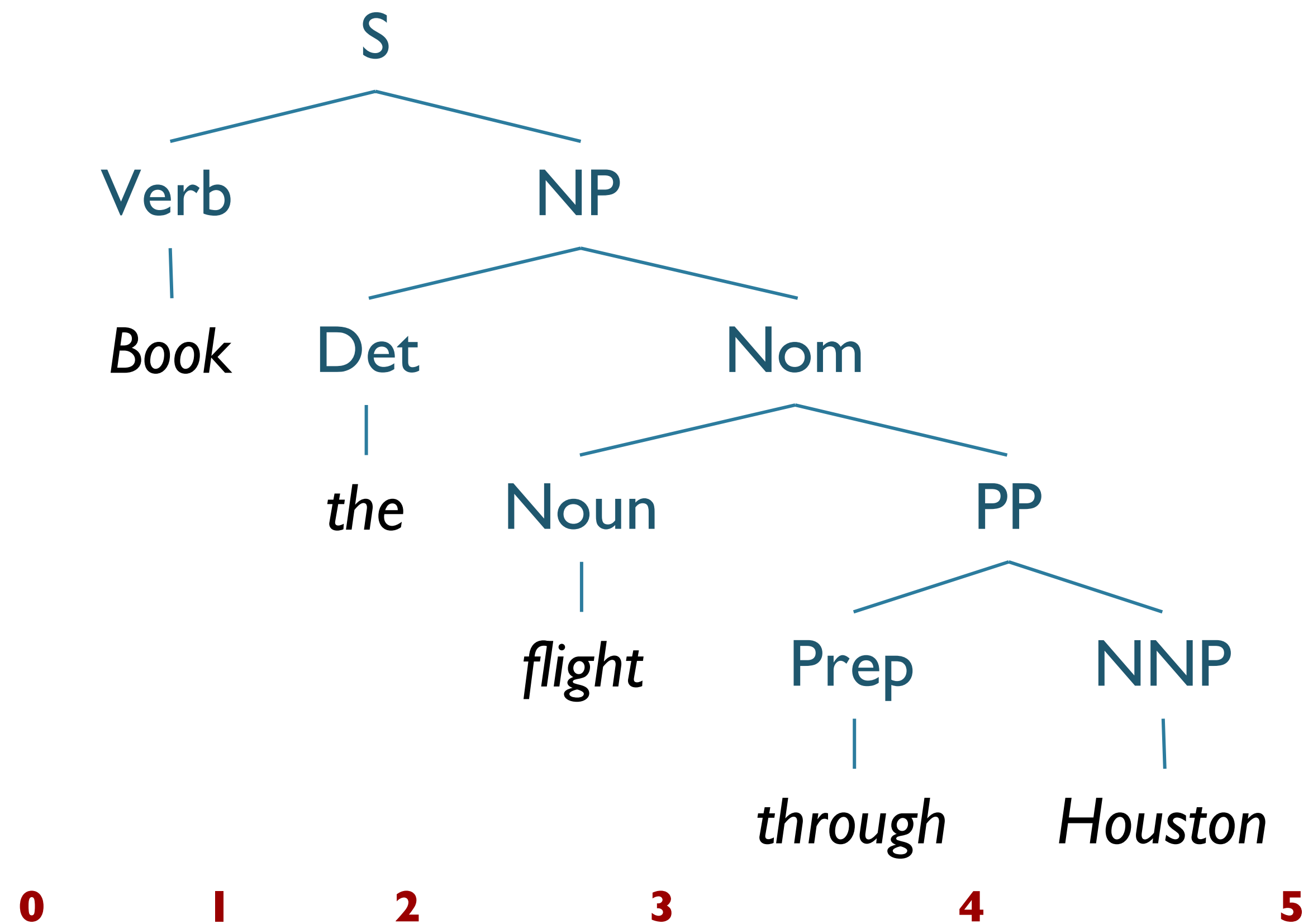
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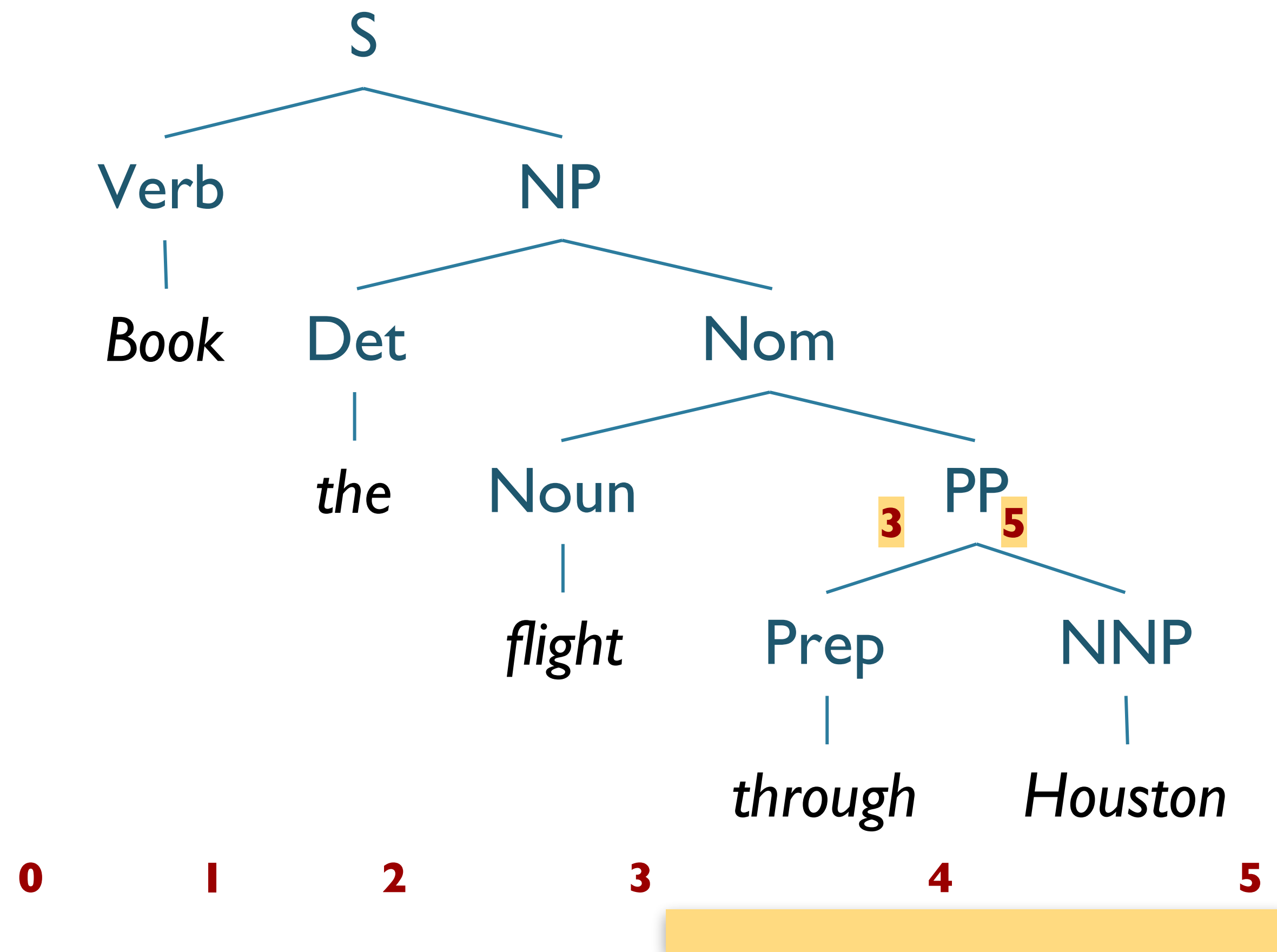
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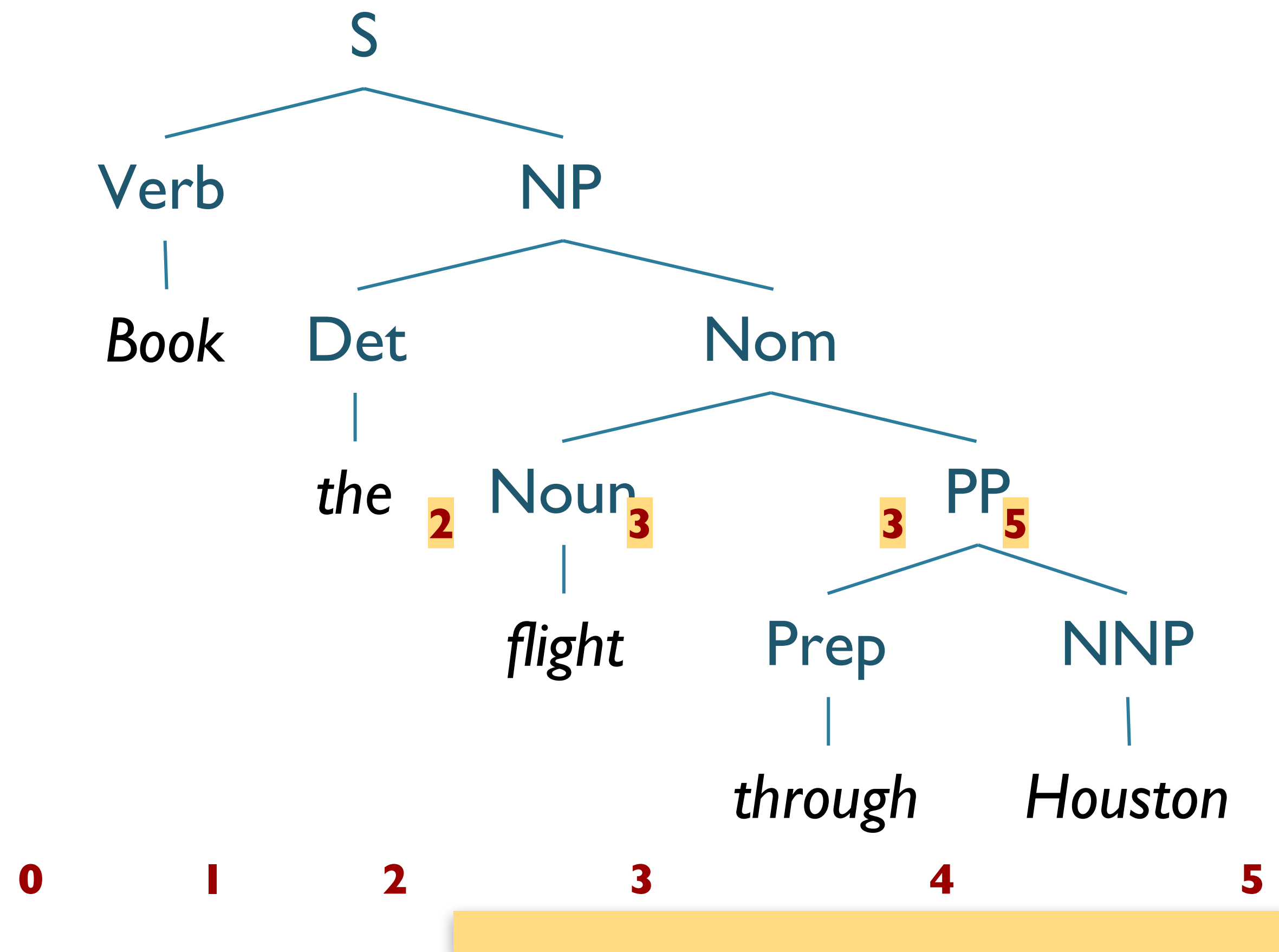
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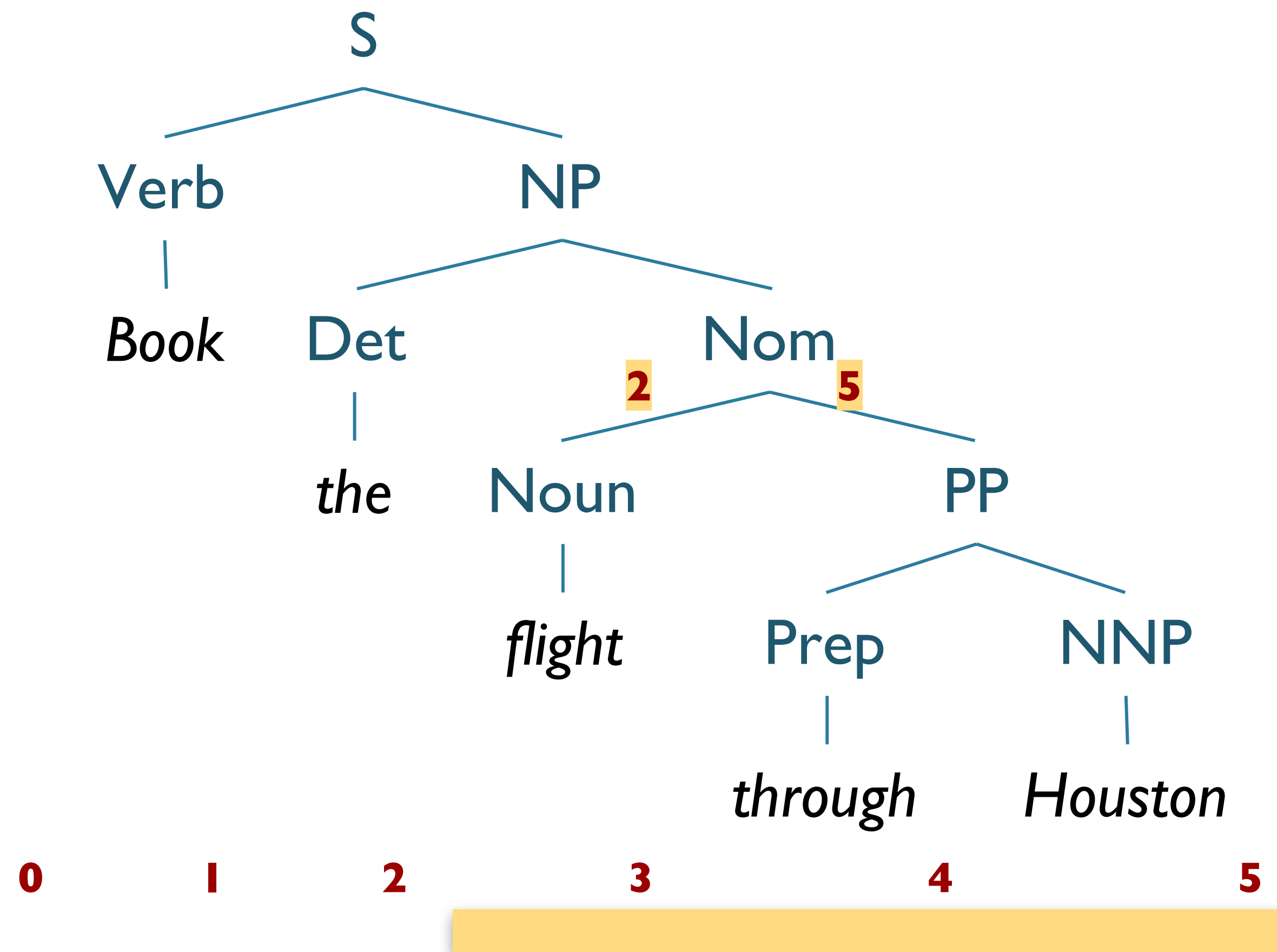
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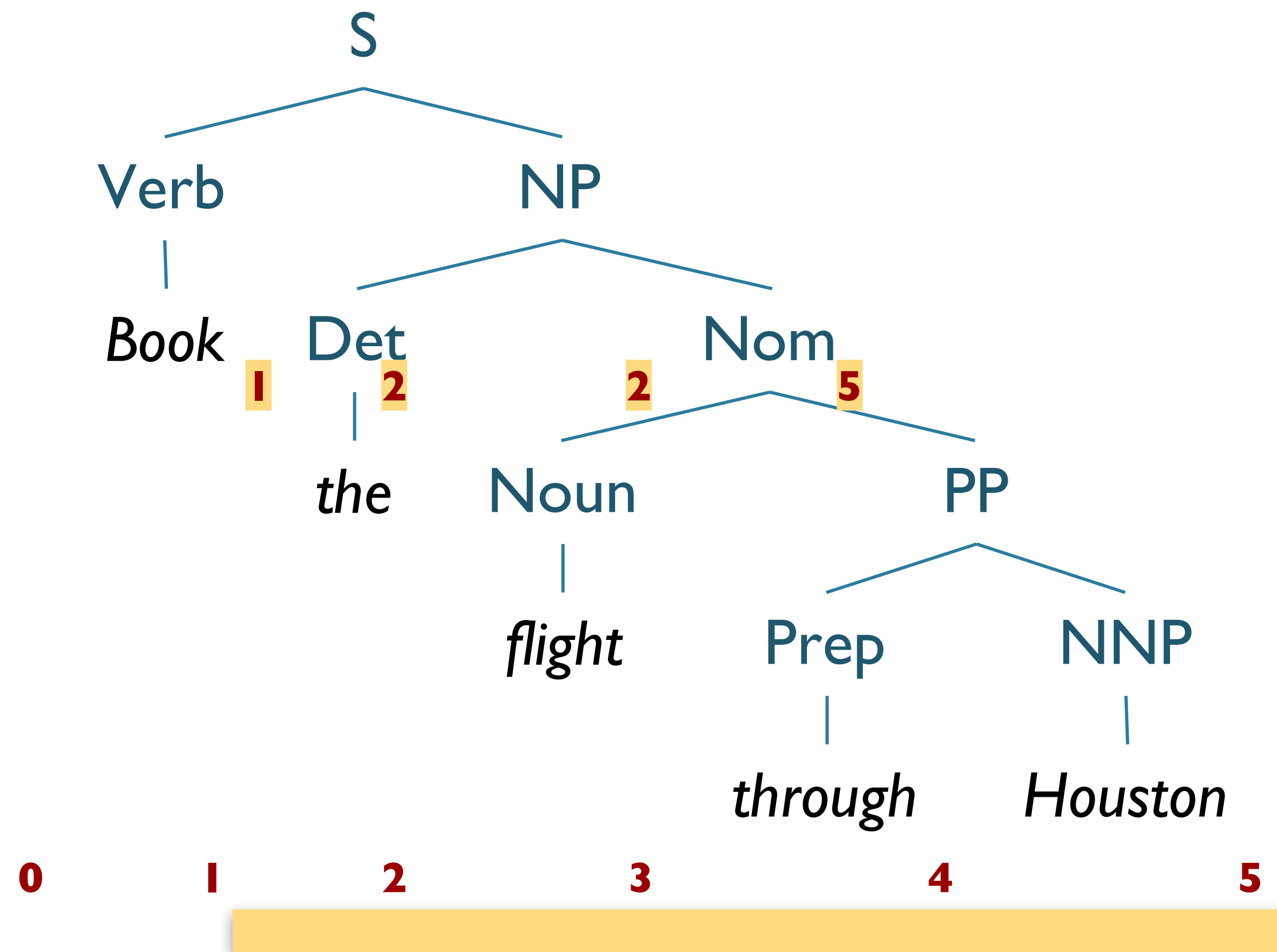
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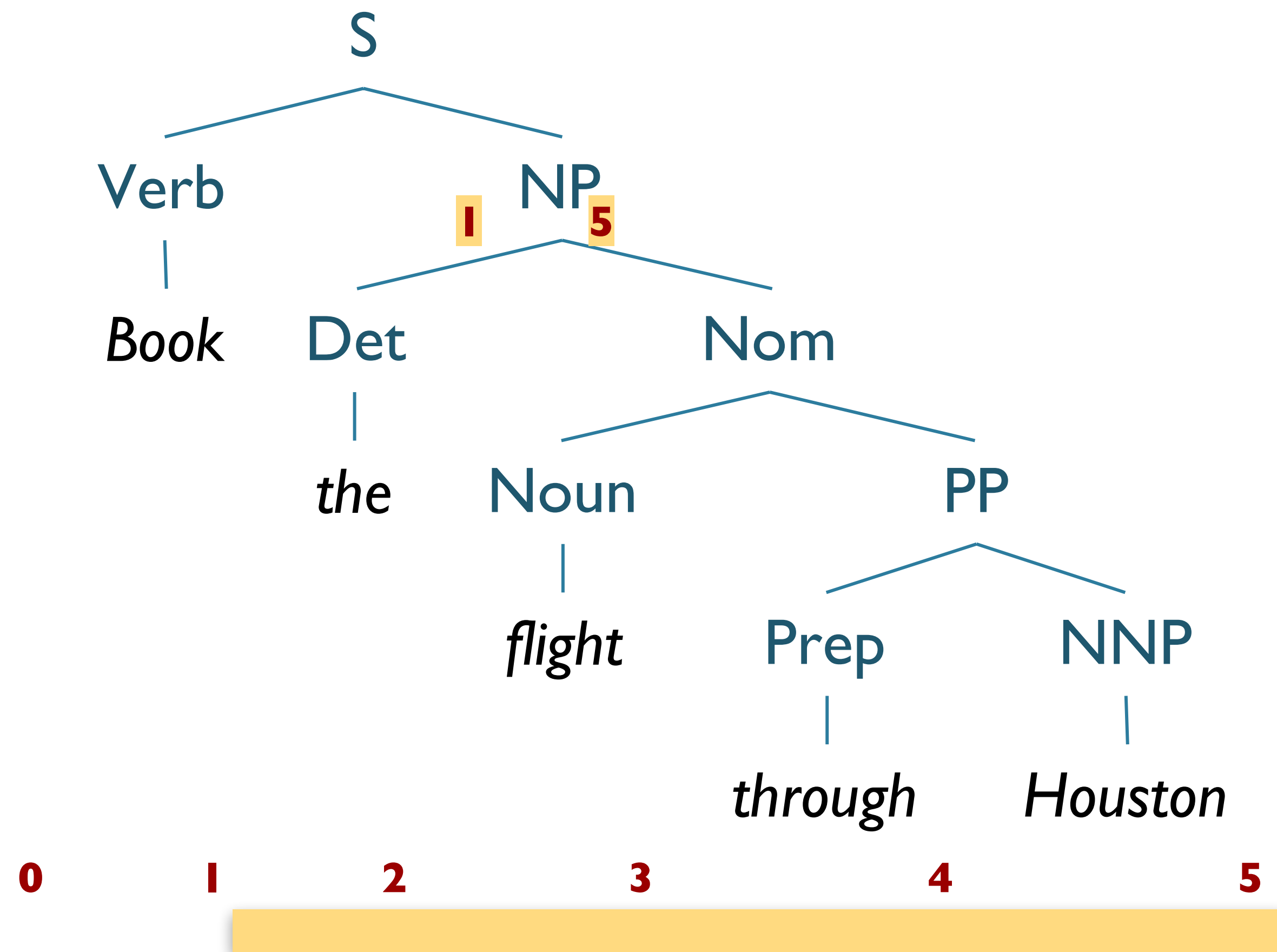
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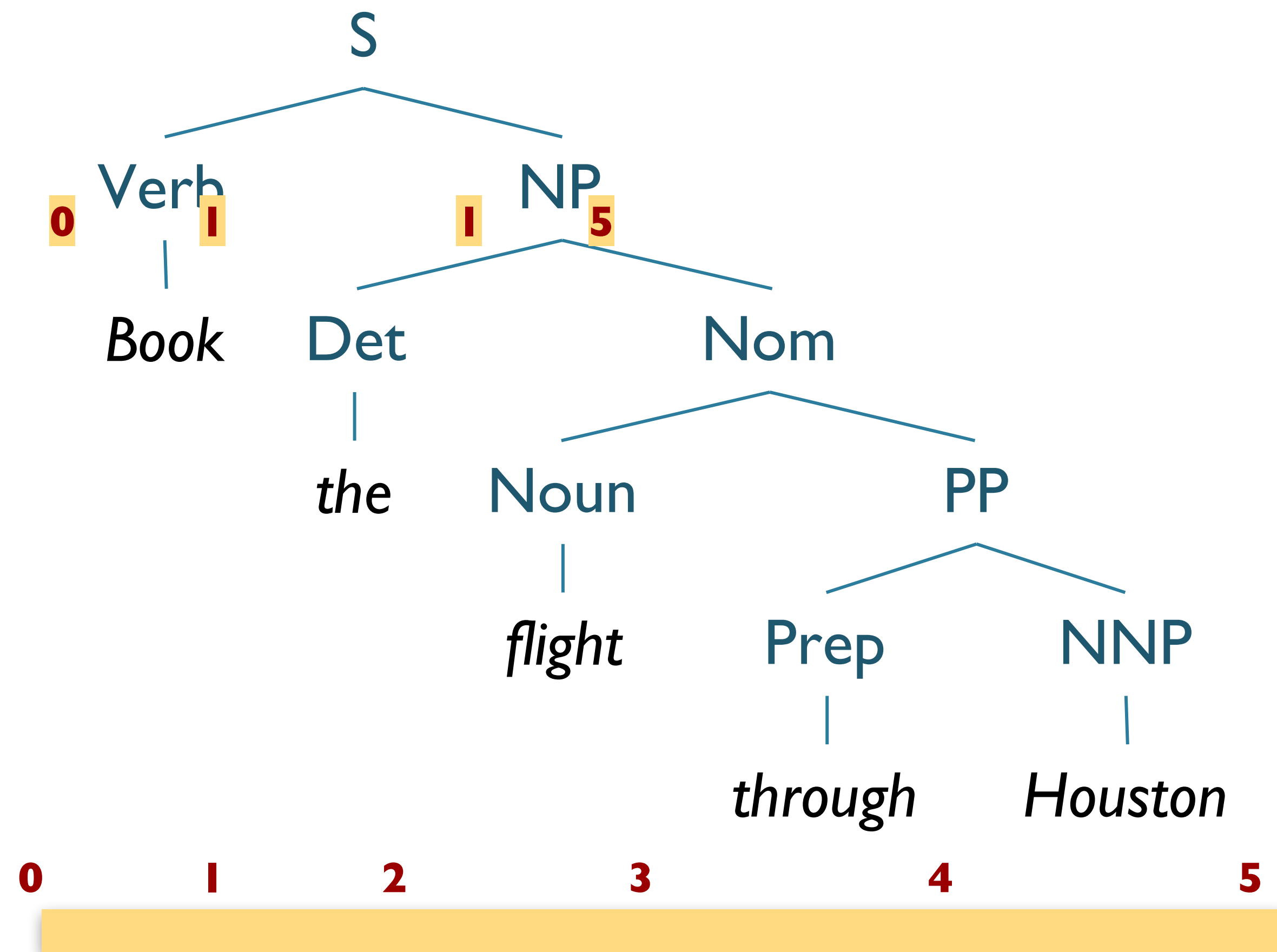
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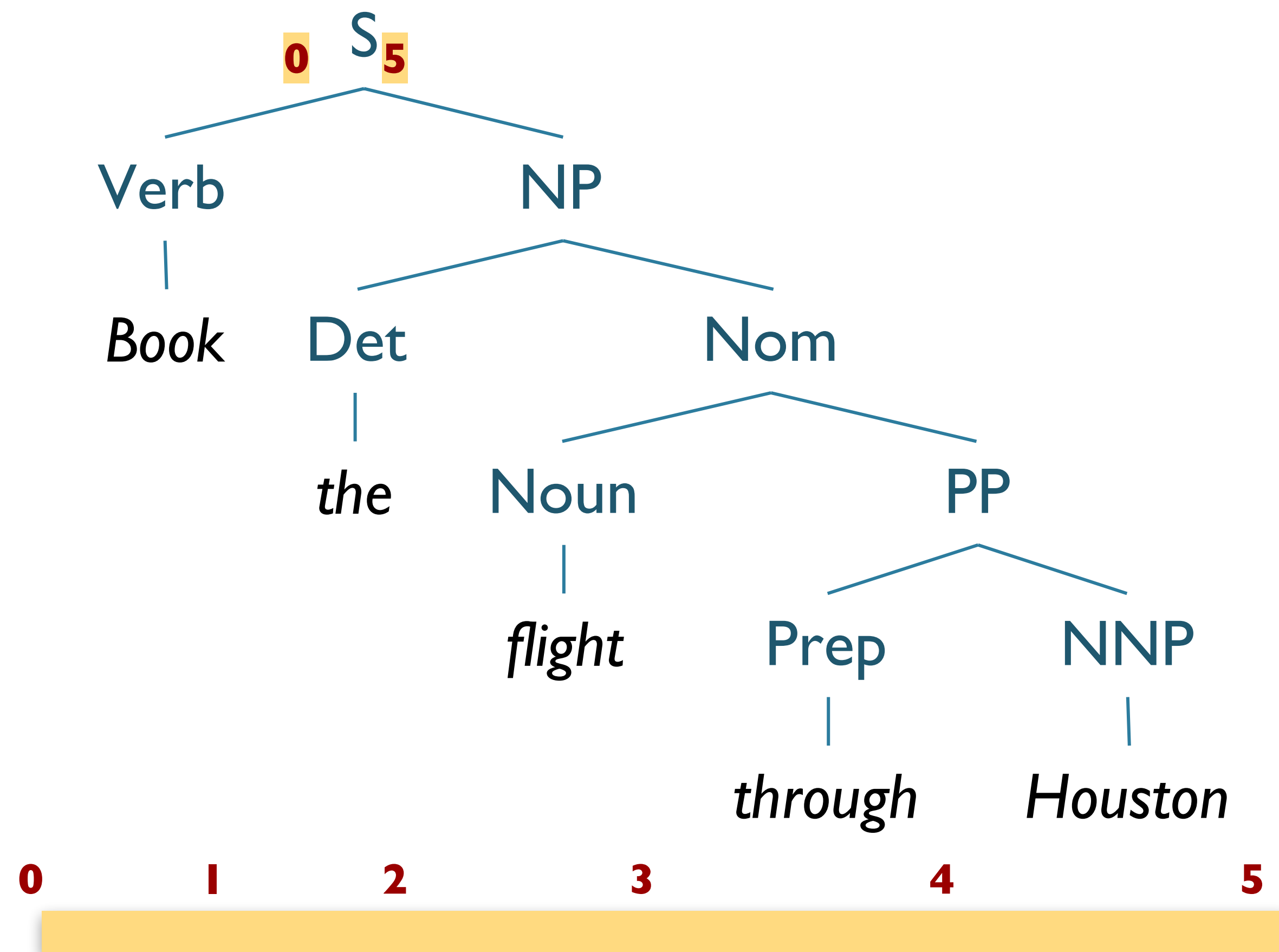
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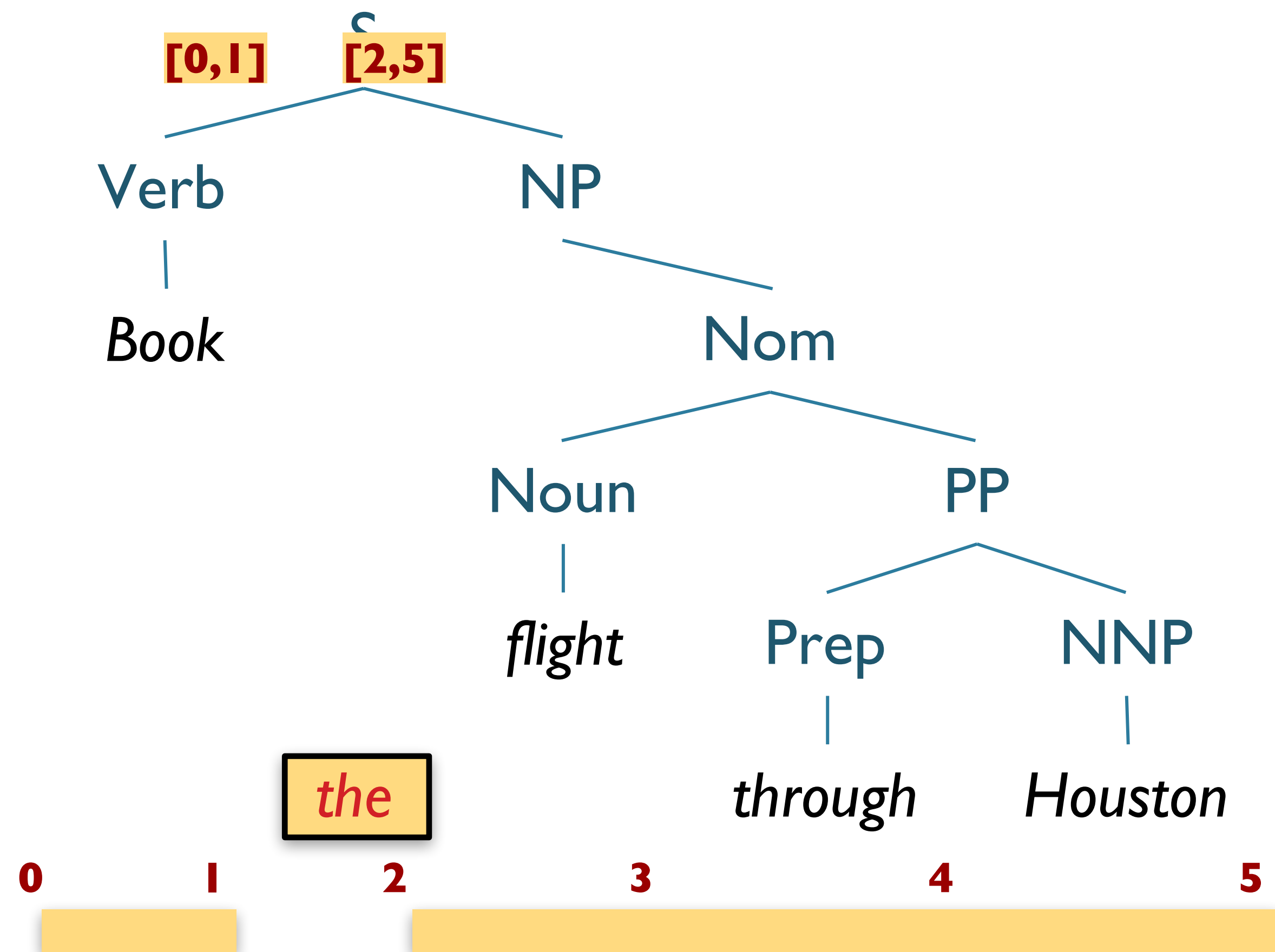
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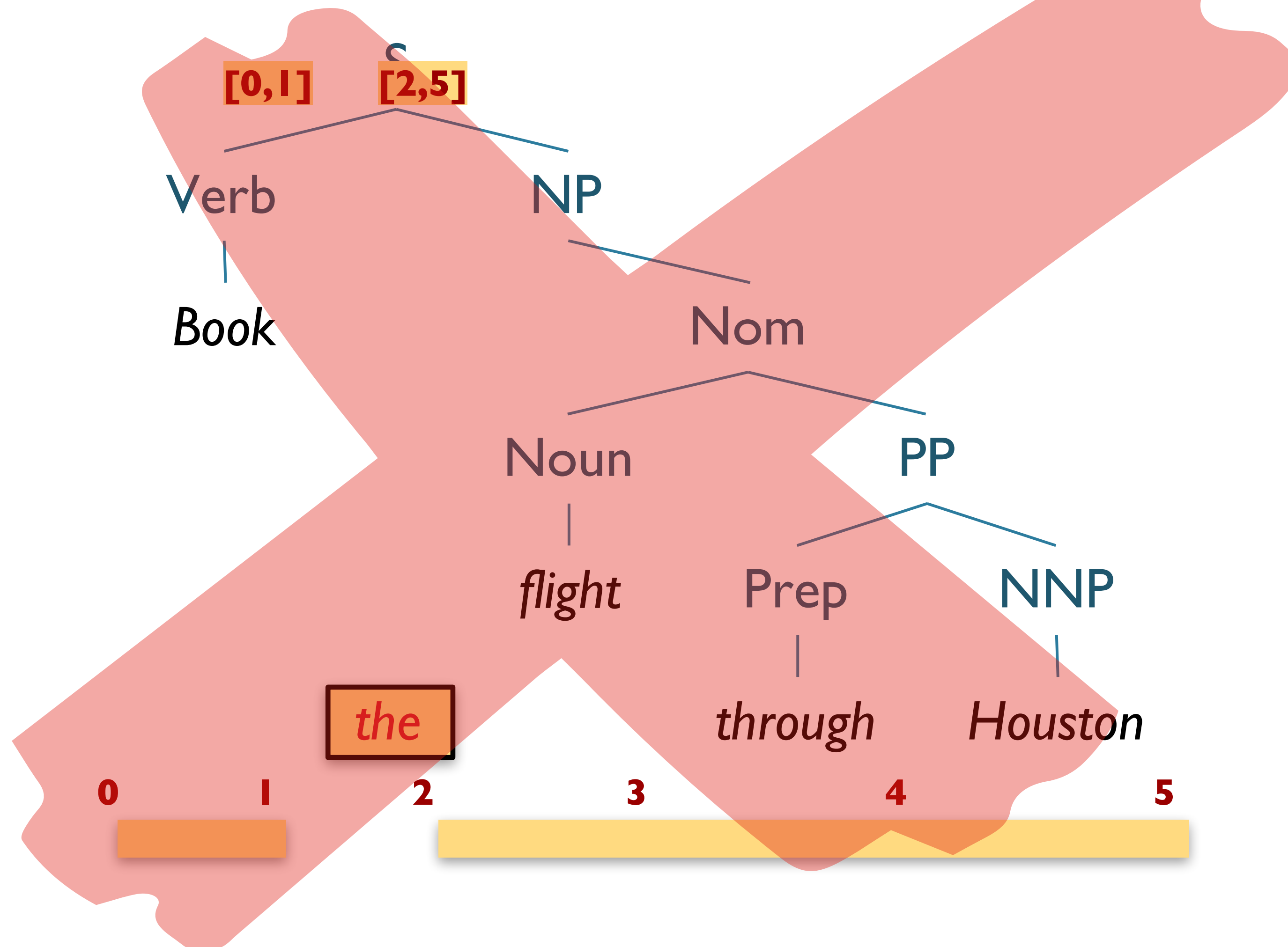
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Would you say CKY is a top-down or a bottom-up parsing algorithm?



Top-down

0

Bottom-up

0

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

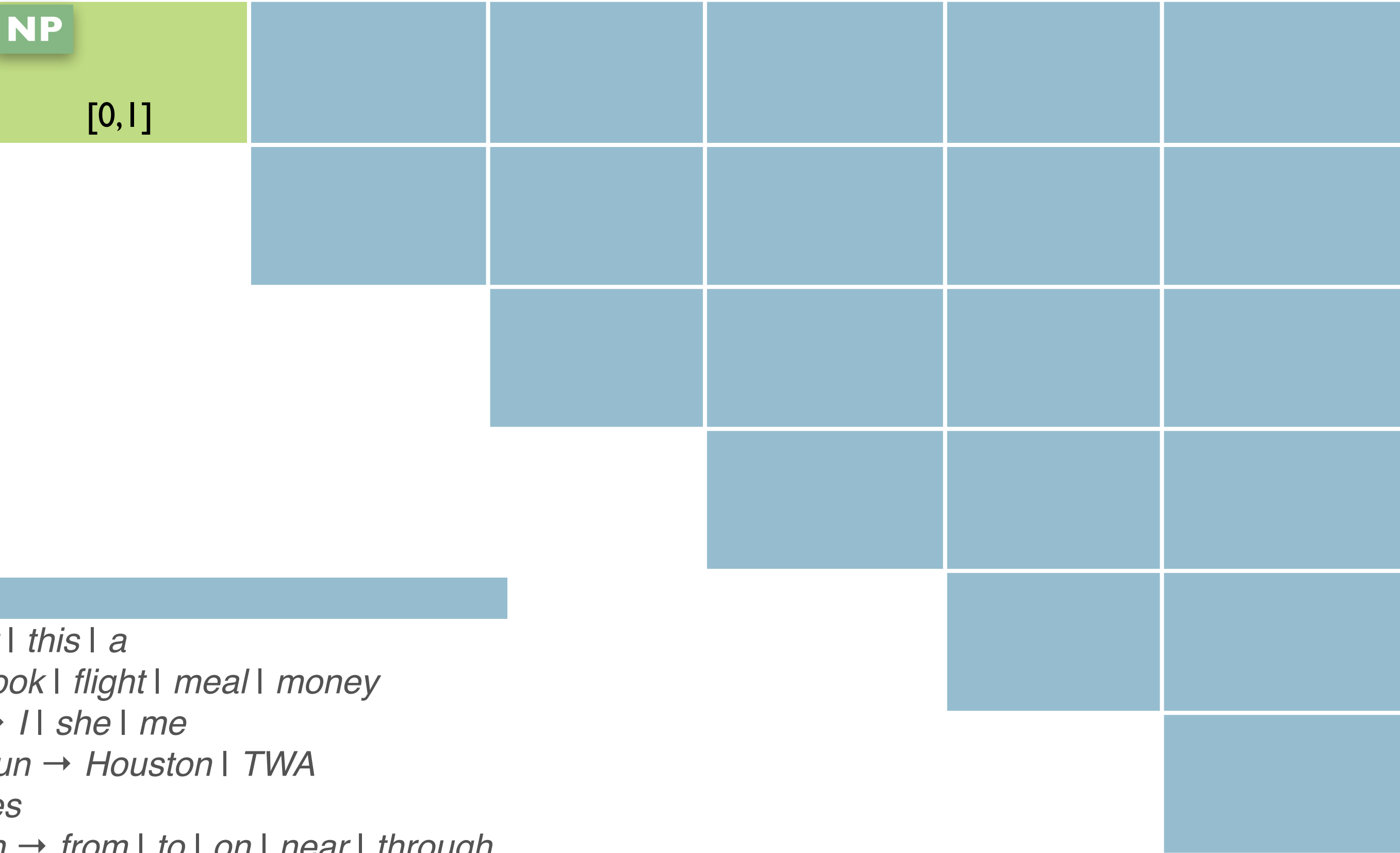
6

I
prefer
a
flight
on
TWA

\mathcal{L}_1 Grammar

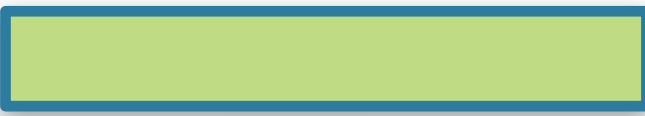
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I

prefer

a

flight

on

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I

01

prefer

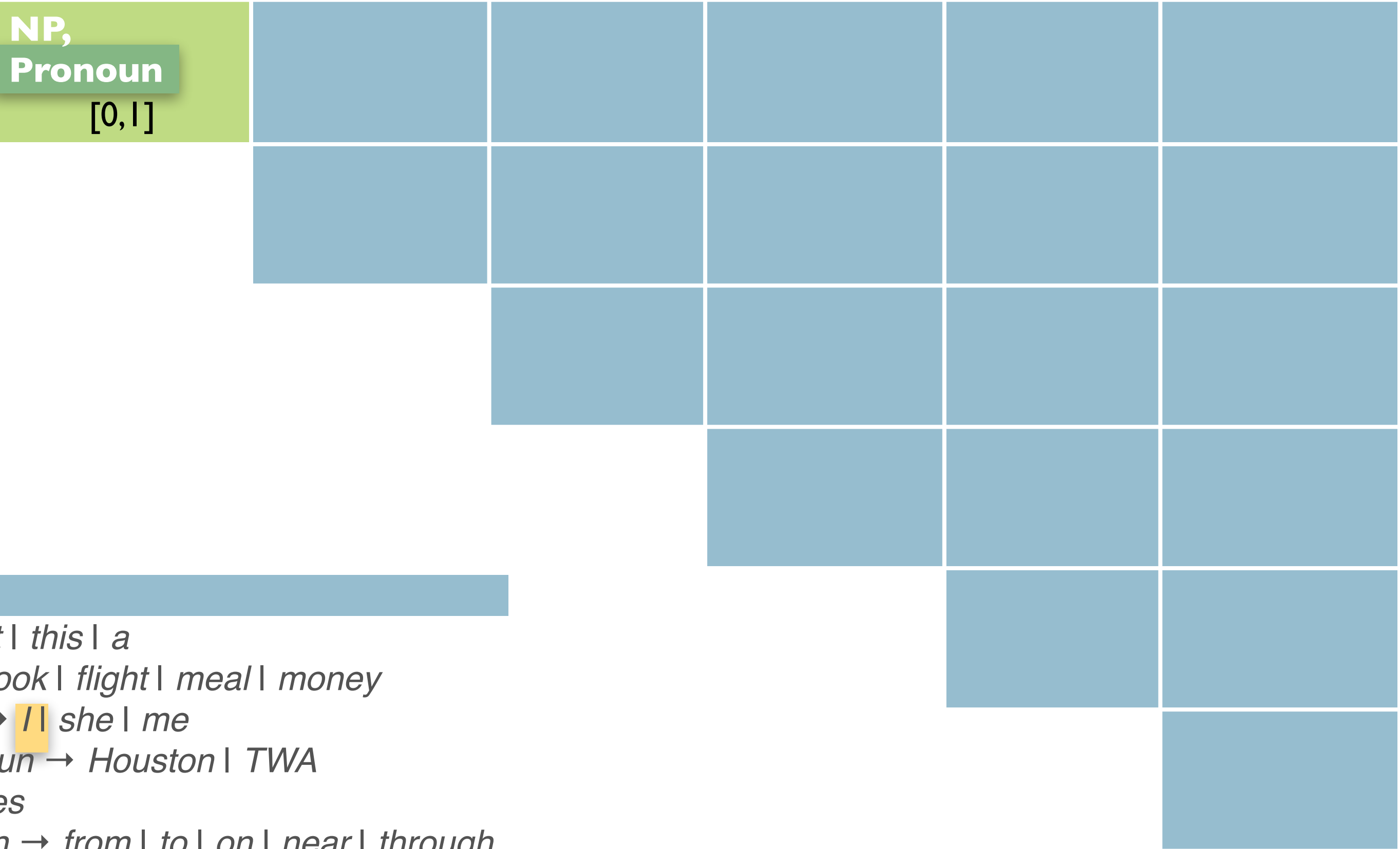
a

flight

on

TWA

23456



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

S → book / include / **prefer**

$S \rightarrow \text{Verb NP}$

$$S \rightarrow X^2 PP$$
$$S \rightarrow \textit{Verb PP}$$
$$S \rightarrow VP PP$$

$NP \rightarrow I / she / me$

NP → TWA / Houston

NP → Det Nominal

Nominal → book / flight / meal / money

Nominal → *Nominal Noun*

Nominal → Nominal PP

VP → book / include / prefer

$VP \rightarrow Verb\ NP$

$$VP \rightarrow X_2 PP$$
$$X_2 \rightarrow \textit{Verb NP}$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP PP$$

PP → *Preposition NP*

NP, Pronoun [0,1]

Verb, VP, S

[1,2]

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*

A

prefer

a

flight

on

TWA

\mathcal{L}_1 Grammar

$$S \rightarrow X1 VP$$

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NP → TWA / Houston

Nominal → *book / flight / meal / money*

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$$VP \rightarrow Verb\ NP$$
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NP, Pronoun [0,1]

$[0,2]$

Verb, VP, S

[1,2]

Lexicon

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

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Verb → *book* | *include* | *prefer*

prefer

flight

TWA

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VP → book I include I prefer

$$VP \rightarrow Verb\ NP$$
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PP → *Preposition NP*

NP,
Pronoun
[0,1]

$[0,2]$

Verb, VP, S

[1,2]

Verb, VP, S

[1,2]

Lexicon

Det → *that* | *this* | *a*

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

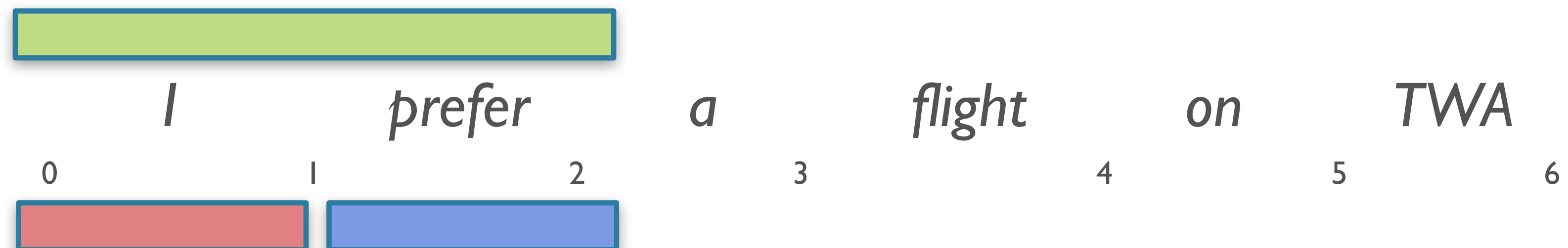
Pronoun → I | she | me

Proper-Noun → *Houston* | *TWA*

Aux → *does*

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

Verb → *book* | *include* | *prefer*



\mathcal{L}_1 Grammar

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

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

$$S \rightarrow \textit{Verb NP}$$
$$S \rightarrow X^2 PP$$
$$S \rightarrow Verb PP$$
$$S \rightarrow VP PP$$

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

NP → TWA / Houston

$NP \rightarrow Det\ Nominal$

Nominal → *book* / *flight* / *meal* / *money*

Nominal → *Nominal Noun*

Nominal \rightarrow *Nominal PP*

VP → *book I include I prefer*

$$VP \rightarrow Verb\ NP$$
$$VP \rightarrow X_2 PP$$
$$X_2 \rightarrow \textit{Verb NP}$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP PP$$

PP → *Preposition NP*

NP,
Pronoun
[0,1]

NP,
Pronoun
[0,1]

$[0,2]$

Verb, VP, S

[1,2]

Verb, VP, S

[1,2]

Lexicon

Det → *that* | *this* | *a*

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Aux → *does*

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

Verb → *book* | *include* | *prefer*

A diagram of a 3-point Likert scale. At the top, a long green horizontal bar represents the statement "I prefer". Below this bar, the word "I" is positioned above the number "0" and the word "prefer" is positioned above the number "2". The scale is represented by two horizontal bars at the bottom: a red bar on the left, corresponding to the "0" anchor, and a blue bar on the right, corresponding to the "2" anchor. The number "1" is positioned between the two bottom bars, indicating the midpoint.

A diagram of a 3-point Likert scale. At the top, a long green horizontal bar represents the statement "I prefer". Below this bar, the word "I" is positioned above the number "0" and the word "prefer" is positioned above the number "2". The scale is represented by two horizontal bars at the bottom: a red bar on the left, corresponding to the "0" anchor, and a blue bar on the right, corresponding to the "2" anchor. The number "1" is positioned between the two bottom bars, indicating the midpoint of the scale.

A diagram illustrating a 3-point Likert scale for the statement "I prefer". The scale is represented by a horizontal bar divided into three segments, labeled 0, 1, and 2 from left to right. The first segment (0) is red, the second segment (1) is blue, and the third segment (2) is green. The statement "I prefer" is written in the center of the scale.

A diagram illustrating a 3-point Likert scale for the statement "I prefer". The scale is represented by a horizontal bar divided into three segments, labeled 0, 1, and 2 from left to right. The first segment (0) is red, the second segment (1) is blue, and the third segment (2) is green. The statement "I prefer" is written in the center of the scale.

A diagram illustrating a 3-point Likert scale for the statement "I prefer". The scale is represented by a horizontal bar divided into three segments, labeled 0, 1, and 2 from left to right. The first segment (0) is red, the second segment (1) is blue, and the third segment (2) is green. The statement "I prefer" is written in the center of the scale.

A diagram illustrating a 3-point Likert scale for the statement "I prefer". The scale is represented by a horizontal bar divided into three segments, labeled 0, 1, and 2 from left to right. The first segment (0) is red, the second segment (1) is blue, and the third segment (2) is green. The statement "I prefer" is written in the center of the scale.

\mathcal{L}_1 Grammar

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

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

$$S \rightarrow \textit{Verb NP}$$
$$S \rightarrow X^2 PP$$
$$S \rightarrow Verb PP$$
$$S \rightarrow VP PP$$

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

NP → TWA / Houston

NP → *Det Nominal*

Nominal → *book / flight / meal / money*

Nominal → *Nominal Noun*

Nominal \rightarrow *Nominal PP*

VP → book I include I prefer

$$VP \rightarrow Verb\ NP$$
$$VP \rightarrow X_2 PP$$
$$X_2 \rightarrow \textit{Verb NP}$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP PP$$

PP → *Preposition NP*

NP, Pronoun [0,1]

$[0,2]$

Verb, VP, S

[1,2]

Lexicon

Det → *that* | *this* | *a*

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

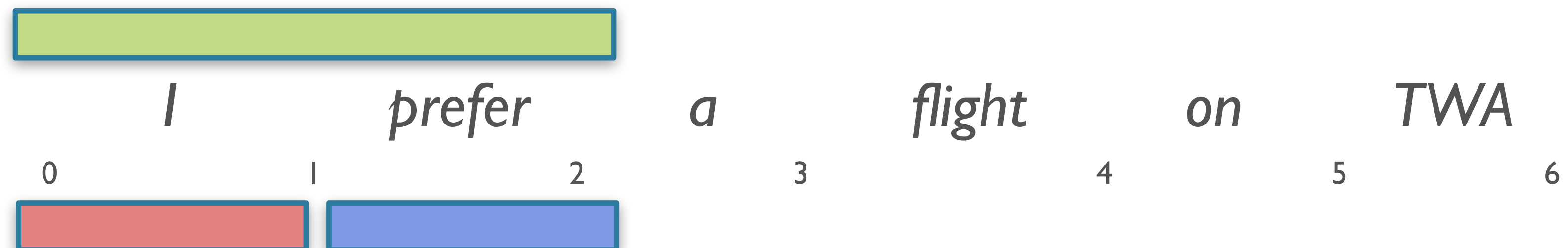
Pronoun → I | she | me

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Aux → *does*

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

Verb → *book* | *include* | *prefer*



\mathcal{L}_1 Grammar

$S \rightarrow NP VP$

$$S \rightarrow X1 VP$$
$$X1 \rightarrow Aux\ Ni$$

$S \rightarrow \textit{book} \mid \textit{include} \mid \textit{prefer}$

$$S \rightarrow \textit{Verb NP}$$
$$S \rightarrow X^2 PP$$
$$S \rightarrow \textit{Verb PF}$$
$$S \rightarrow VP PP$$

$NP \rightarrow I / she / me$

NP → TWA / Houston

NP → *Det Nominal*

Nominal → *book / flight / meal / money*

Nominal → *Nominal Noun*

Nominal → *Nominal PP*

VP → *book* / *include* / *prefer*

$$VP \rightarrow Verb\ NP$$
$$VP \rightarrow X_2 PP$$
$$X_2 \rightarrow \textit{Verb NP}$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP PP$$

PP → *Preposition NP*

NP, Pronoun [0,1]

S

[0,2]

Verb, VP, S

[1,2]

Lexicon

Det → *that* | *this* | *a*

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

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Aux → *does*

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

Verb → *book* | *include* | *prefer*

1

prefer

a

flight

on

TWA

0

1

2

3

4

5

6

\mathcal{L}_1 Grammar

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

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

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

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

NP → TWA / Houston

NP → *Det Nominal*

Nominal → *book* / *flight* / *meal* / *money*

Nominal → *Nominal Noun*

Nominal → *Nominal PP*

VP → book / include / prefer

$$VP \rightarrow Verb\ NP$$
$$VP \rightarrow X_2 PP$$
$$X_2 \rightarrow \textit{Verb NP}$$

$VP \rightarrow Verb PP$

$$VP \rightarrow VP PP$$

PP → *Preposition NP*

Lexicon

Det → *that* | *this* | *a*

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

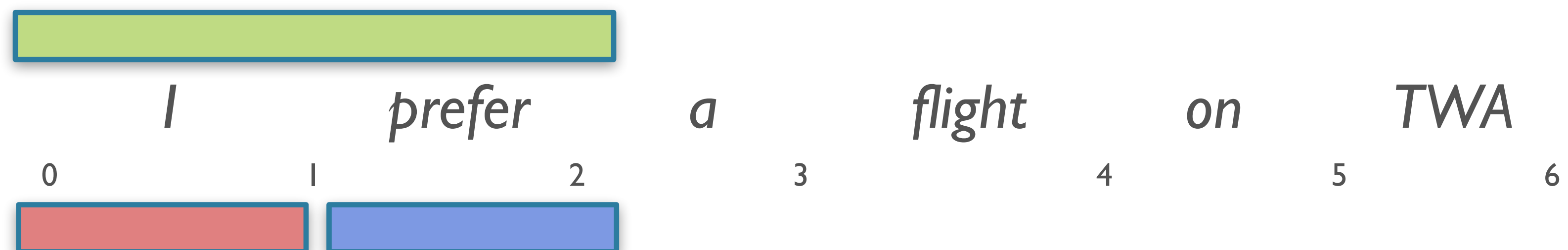
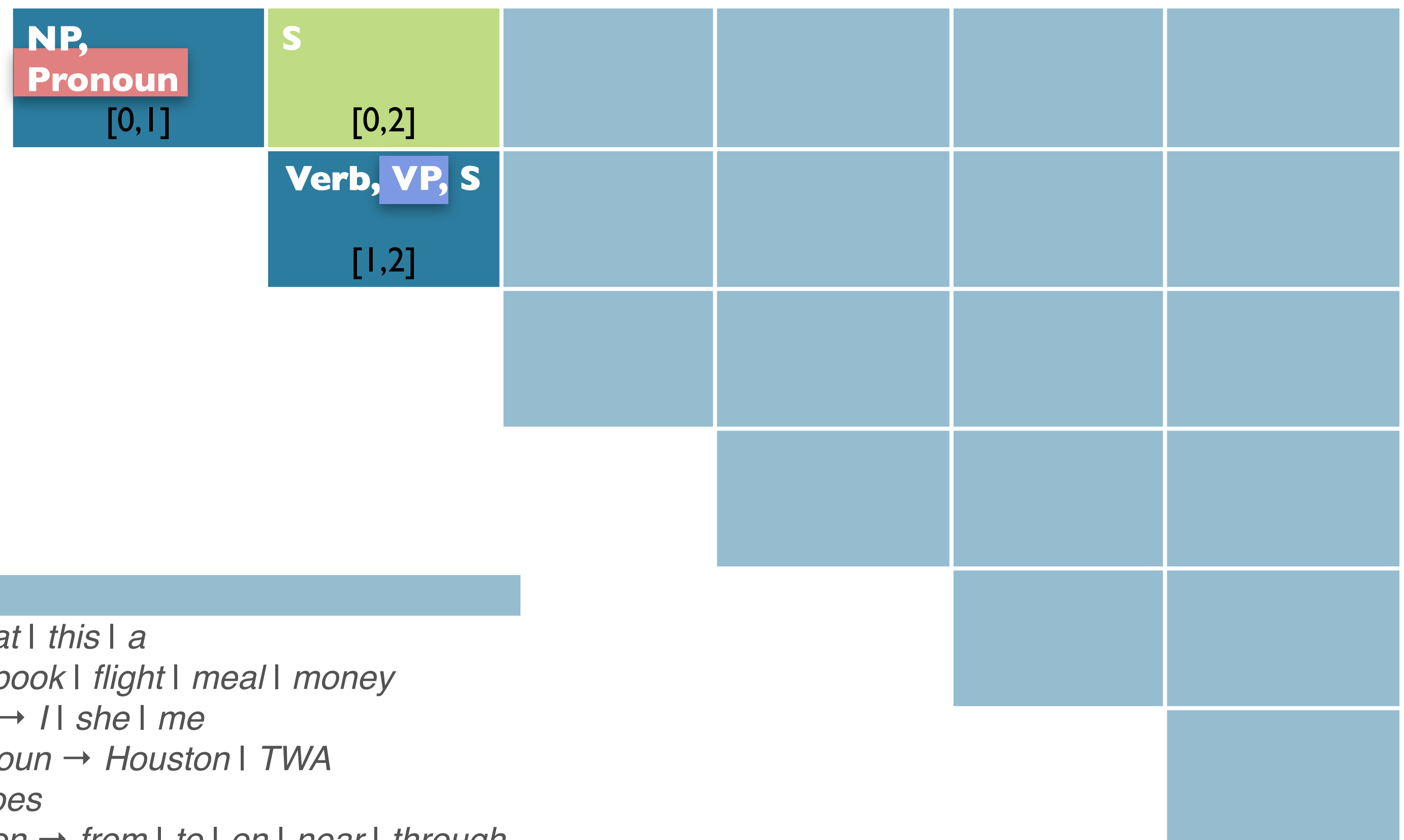
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\mathcal{L}_1 Grammar

$$S \rightarrow NP VP$$
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$$S \rightarrow VP PP$$

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

NP → TWA / Houston

NP → *Det Nominal*

Nominal → *book / flight / meal / money*

Nominal → *Nominal Noun*

Nominal \rightarrow *Nominal PP*

VP → book I include I prefer

$$VP \rightarrow Verb\ NP$$
$$VP \rightarrow X_2 PP$$
$$X_2 \rightarrow \textit{Verb NP}$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP PP$$

PP → *Preposition NP*

NP,
Pronoun
[0,1]

S

[0,2]

Verb, VP, S

[1,2]

Lexicon

Det → *that* | *this* | *a*

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

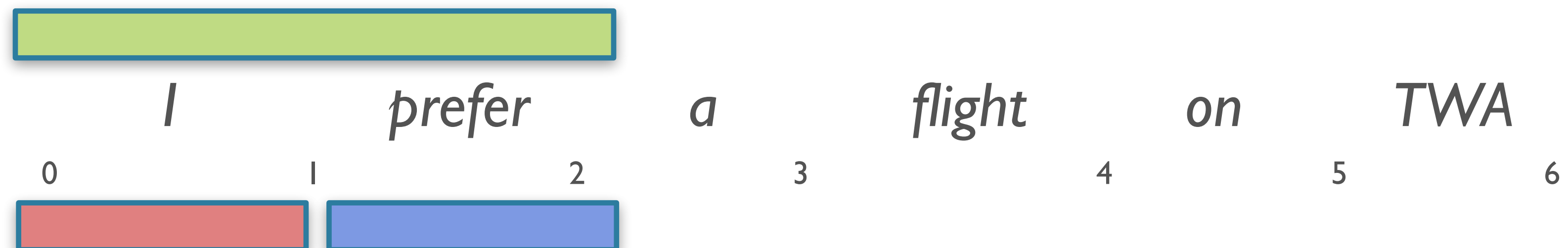
Pronoun → I | she | me

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\mathcal{L}_1 Grammar

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

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

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

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

$PP \rightarrow Preposition NP$

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 $\rightarrow book \mid include \mid prefer$

Diagram illustrating the sentence "I prefer a flight on TWA" with indices 0 to 6. The word "a" is highlighted in a yellow box at index 2.5, and a green box highlights the word "a" at index 2.

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\mathcal{L}_1 Grammar

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

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

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

$NP \rightarrow I / she / me$

NP → TWA / Houston

NP → *Det Nominal*

Nominal → *book* / *flight* / *meal* / *money*

Nominal → *Nominal Noun*

Nominal \rightarrow *Nominal PP*

VP → book / include / prefer

$VP \rightarrow Verb\ NP$

$$VP \rightarrow X^2 PP$$
$$X_2 \rightarrow \textit{Verb NP}$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP PP$$

PP → *Preposition NP*

.....

Lexicon

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

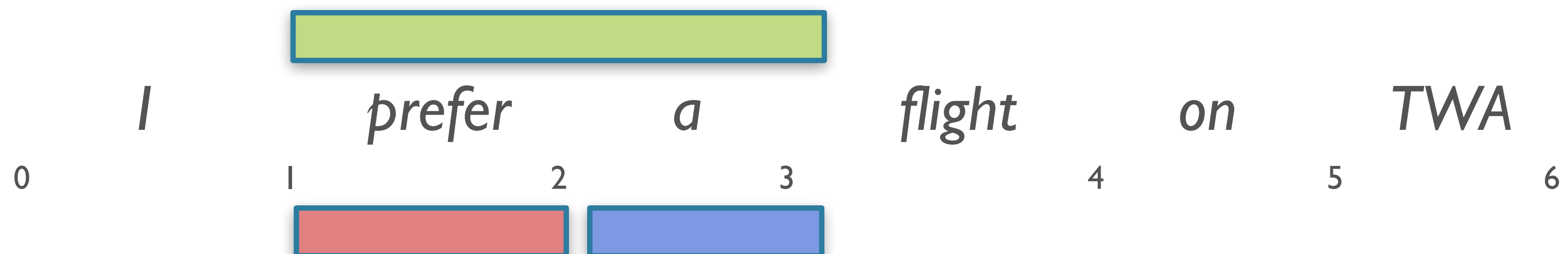
Pronoun → I | she | me

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Aux → *does*

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

Verb \rightarrow book | include | prefer



\mathcal{L}_1 Grammar

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

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

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

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

NP → TWA / Houston

NP → *Det Nominal*

Nominal → *book* / *flight* / *meal* / *money*

Nominal → *Nominal Noun*

Nominal → *Nominal PP*

VP → book / include / prefer

$VP \rightarrow Verb\ NP$

$$VP \rightarrow X_2 PP$$
$$X_2 \rightarrow \textit{Verb NP}$$

$VP \rightarrow Verb PP$

$$VP \rightarrow VP PP$$

PP → *Preposition NP*

Lexicon

Det → *that* | *this* | *a*

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

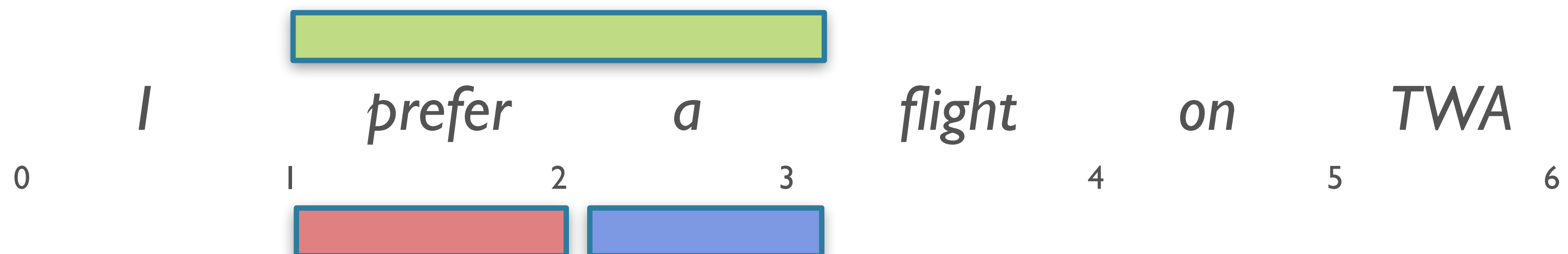
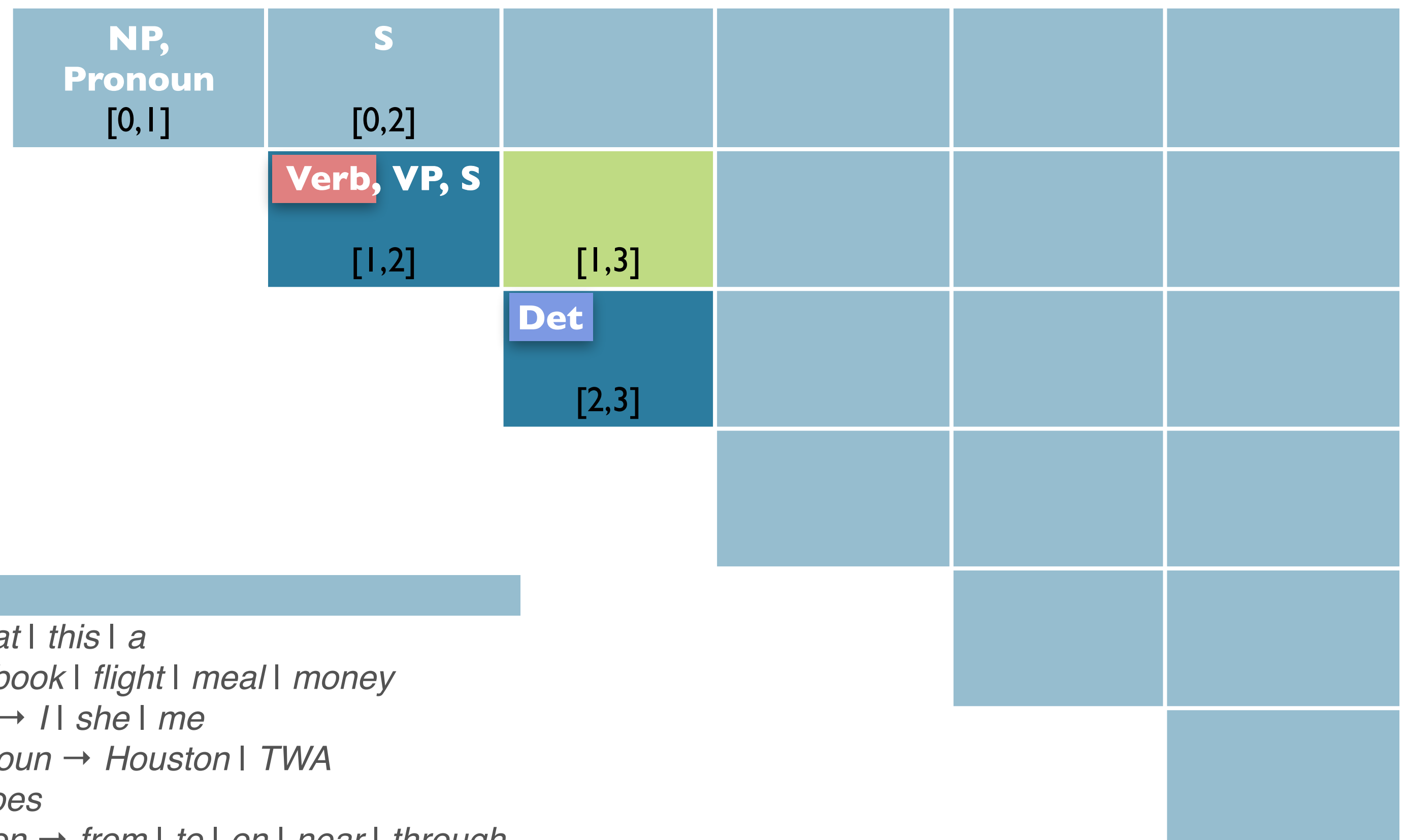
Pronoun → I | she | me

Proper-Noun → *Houston* | *TWA*

Aux → *does*

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

Verb → *book* | *include* | *prefer*



\mathcal{L}_1 Grammar

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

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

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

$NP \rightarrow I / she / me$

NP → TWA / Houston

NP → *Det Nominal*

Nominal → *book* / *flight* / *meal* / *money*

Nominal → *Nominal Noun*

Nominal → *Nominal PP*

VP → book / include / prefer

$VP \rightarrow Verb\ NP$

$$VP \rightarrow X^2 PP$$
$$X_2 \rightarrow \textit{Verb NP}$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP PP$$

PP → *Preposition NP*

Lexicon

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

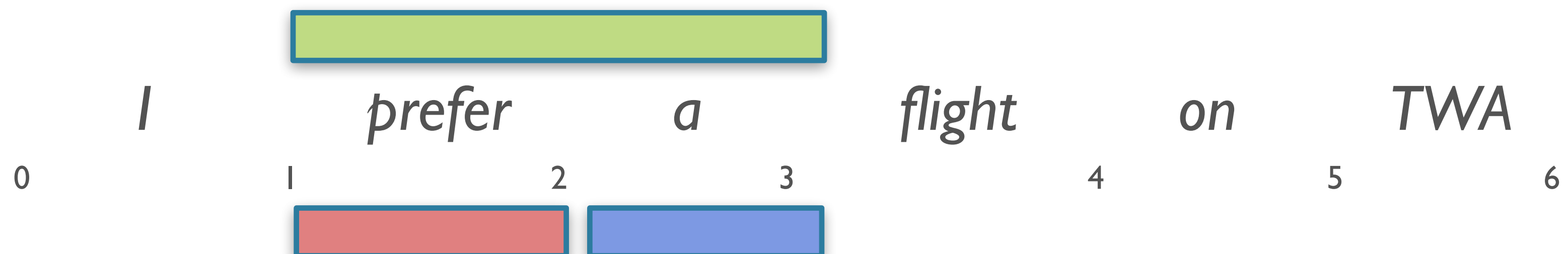
Pronoun → I | she | me

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Aux → *does*

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

Verb \rightarrow book | include | prefer



\mathcal{L}_1 Grammar

$$S \rightarrow X1 VP$$

$S \rightarrow \textit{book} \mid \textit{include} \mid \textit{prefer}$

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

NP → TWA / Houston

Nominal → *book / flight / meal / money*

Nominal → *Nominal PP*

$$VP \rightarrow Verb\ NP$$
$$X_2 \rightarrow \textit{Verb NP}$$
$$VP \rightarrow VP PP$$

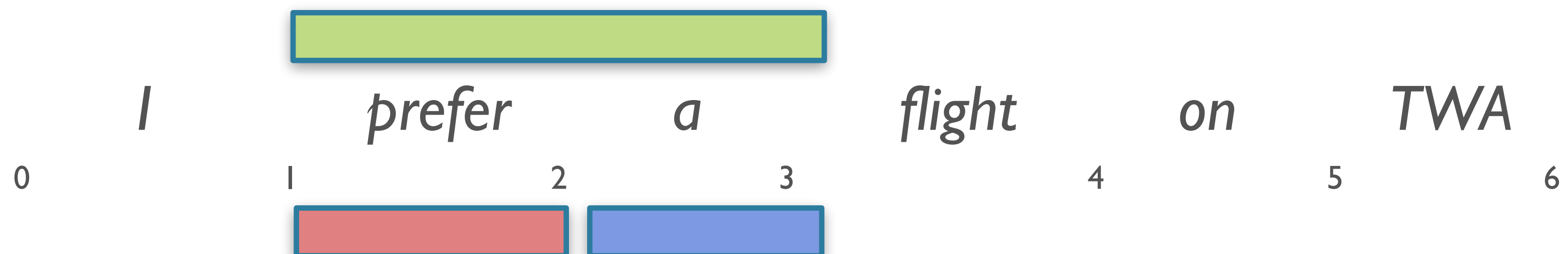
Lexicon

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Proper-Noun → *Houston* | *TWA*

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

Verb → *book* | *include* | *prefer*



\mathcal{L}_1 Grammar

$$S \rightarrow X1 VP$$

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

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

NP → TWA / Houston

Nominal → *book / flight / meal / money*

Nominal → *Nominal PP*

$$VP \rightarrow \textit{Verb NP}$$
$$X_2 \rightarrow \textit{Verb NP}$$
$$VP \rightarrow VP PP$$

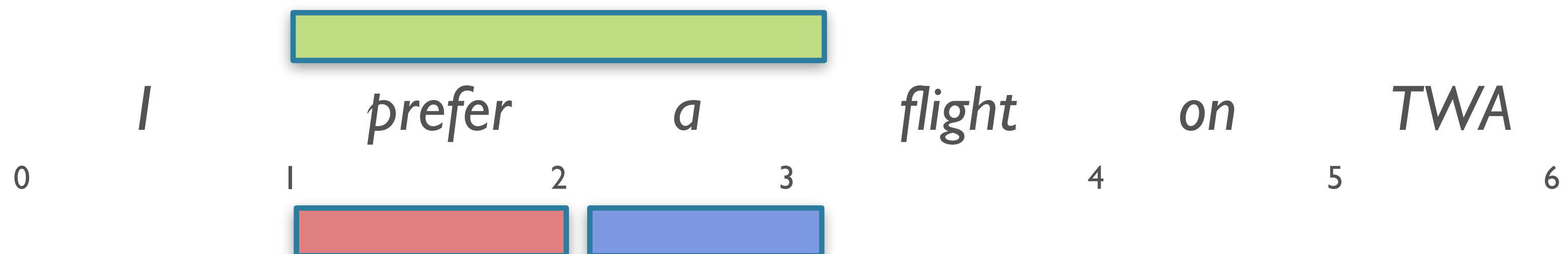
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Preposition → *from* | *to* | *on* | *near* | *through*

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\mathcal{L}_1 Grammar

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

$S \rightarrow \textit{book} \mid \textit{include} \mid \textit{prefer}$

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

$NP \rightarrow I / she / me$

NP → TWA / Houston

NP → *Det Nominal*

Nominal → *book* / *flight* / *meal* / *money*

Nominal → *Nominal Noun*

Nominal → Nominal PP

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

$$VP \rightarrow Verb NP$$
$$VP \rightarrow X_2 PP$$
$$X_2 \rightarrow \textit{Verb NP}$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP PP$$

PP → *Preposition NP*

Lexicon

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

Pronoun → I | she | me

Proper-Noun → *Houston* | *TWA*

Aux → *does*

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

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

A diagram illustrating a 3D vector space. The axes are labeled i , $prefer$, and a . The axes are represented by colored bars: a green bar for i , a red bar for $prefer$, and a blue bar for a . The axes are labeled with 0, 1, 2, and 3.

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

at | this | a
book | flight | meal | money
→ I | she | me
oun → Houston | TWA
oes
on → from | to | on | near | through

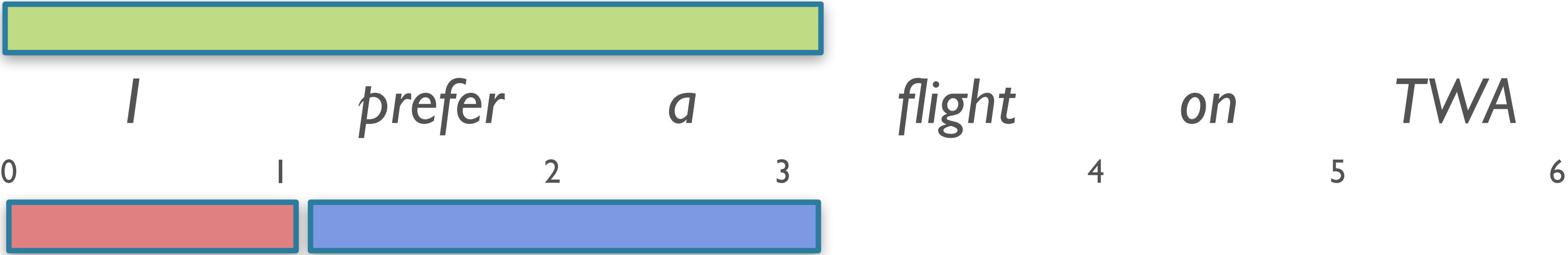
\mathcal{L}_1 Grammar

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

Lexicon

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

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



\mathcal{L}_1 Grammar

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

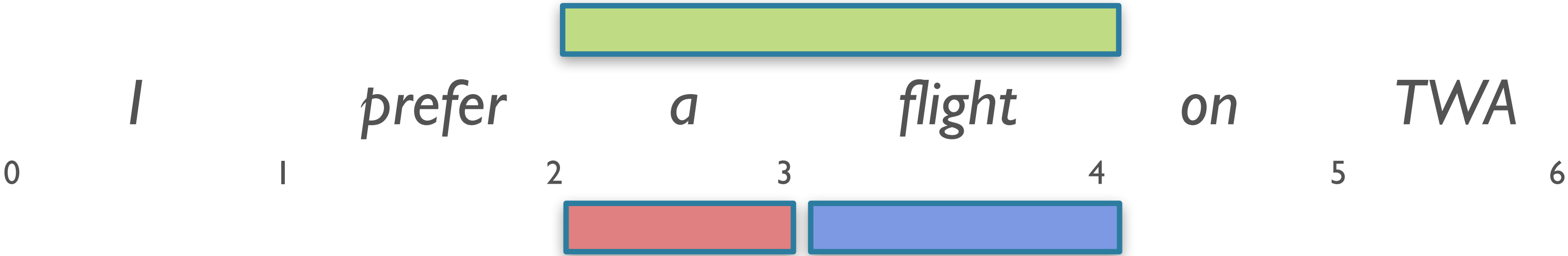
$NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$

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

Lexicon

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

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



\mathcal{L}_1 Grammar

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

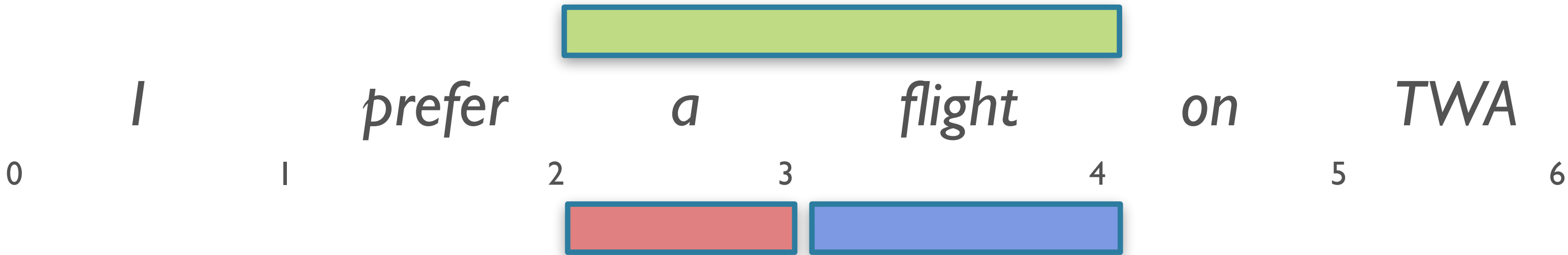
$NP \rightarrow I\ I\ she\ I\ me$
 $NP \rightarrow TWA\ I\ Houston$
 $NP \rightarrow Det\ Nominal$
 $Nominal \rightarrow book\ I\ flight\ I\ meal\ I\ money$
 $Nominal \rightarrow Nominal\ Noun$
 $Nominal \rightarrow Nominal\ PP$

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

Lexicon

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

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



\mathcal{L}_1 Grammar

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

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

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

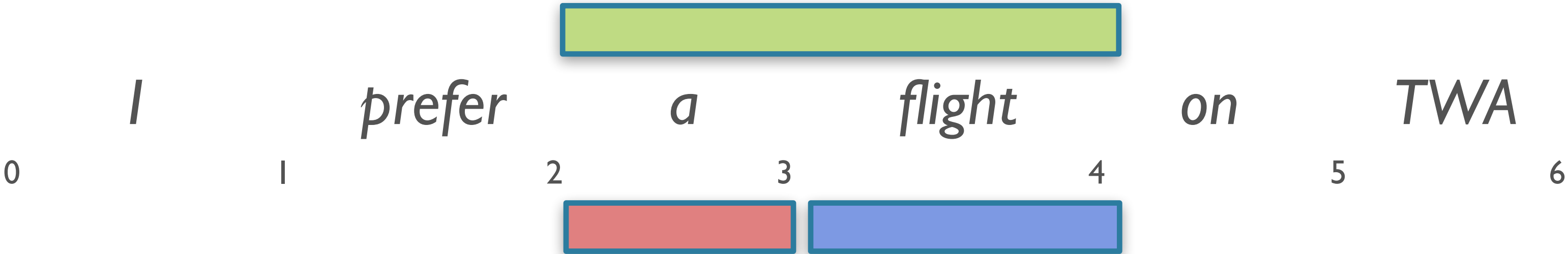
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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

Lexicon

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



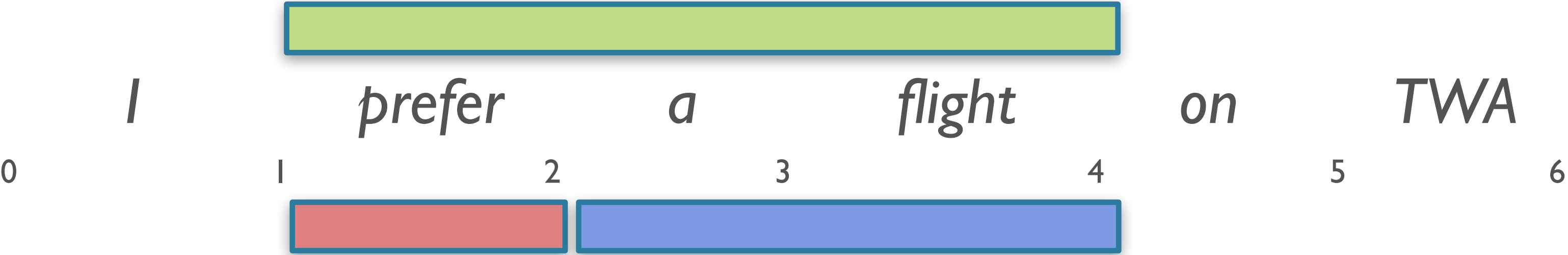
\mathcal{L}_1 Grammar

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

Lexicon

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

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



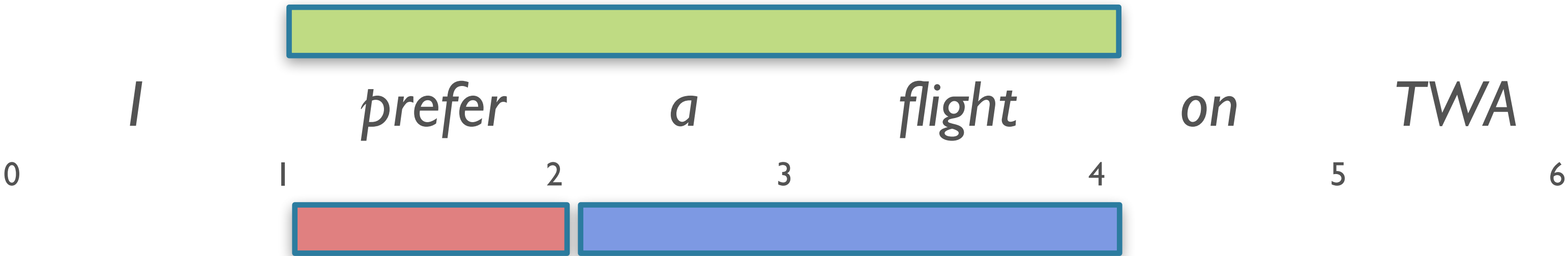
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- $S \rightarrow Verb PP$
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-
- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$
-
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$
-
- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$
-
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NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]	VP [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		



\mathcal{L}_1 Grammar

$S \rightarrow NP VP$

$S \rightarrow X1 VP$

$X1 \rightarrow Aux NP$

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

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

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

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$NP \rightarrow Det Nominal$

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$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

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

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$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

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

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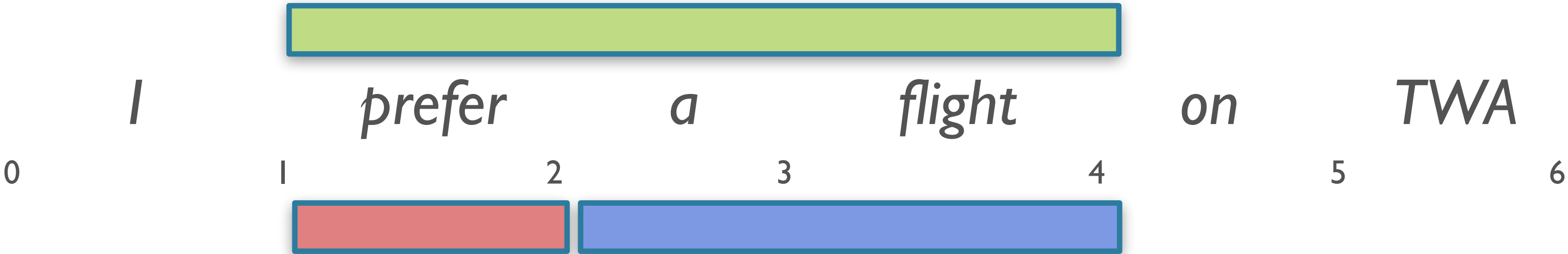
$Proper-Noun \rightarrow Houston \mid TWA$

$Aux \rightarrow does$

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

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

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



\mathcal{L}_1 Grammar

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

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

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

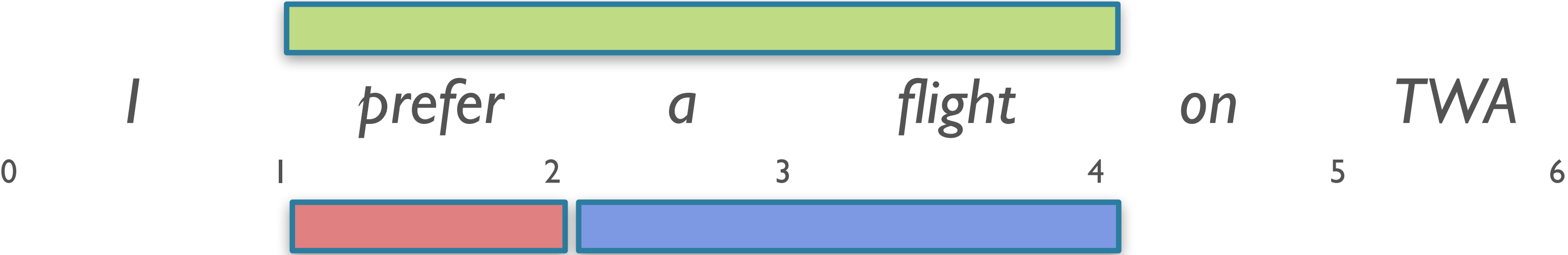
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

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



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 $NP \rightarrow Det Nominal$

$Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
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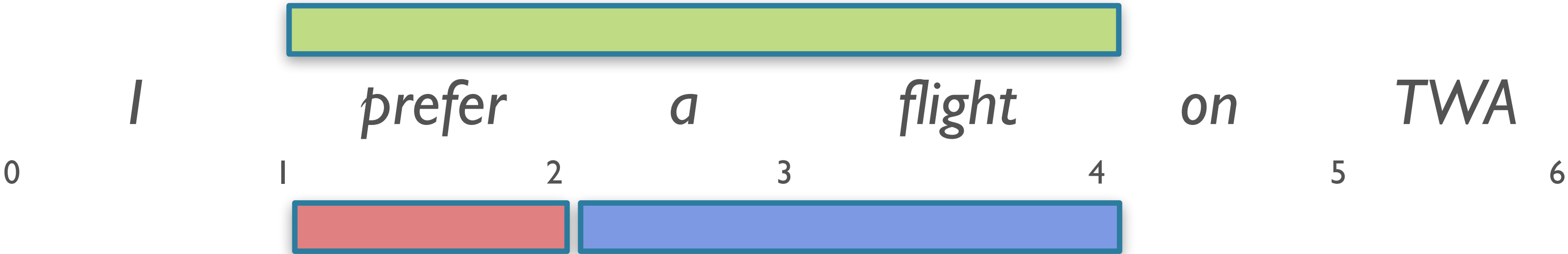
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

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



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

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

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

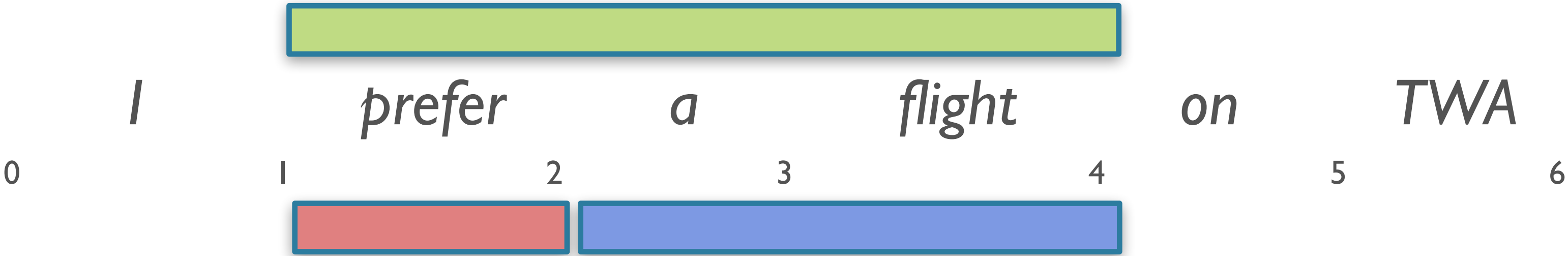
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

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



\mathcal{L}_1 Grammar

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

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

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

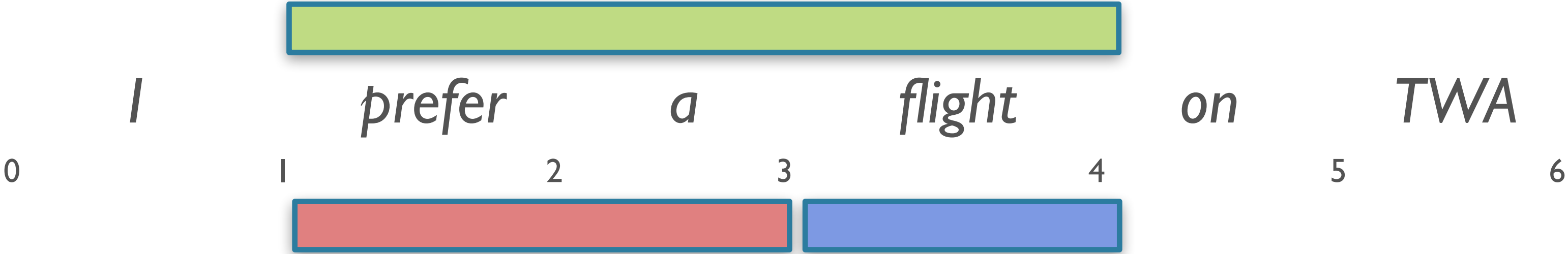
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

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



\mathcal{L}_1 Grammar

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

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

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

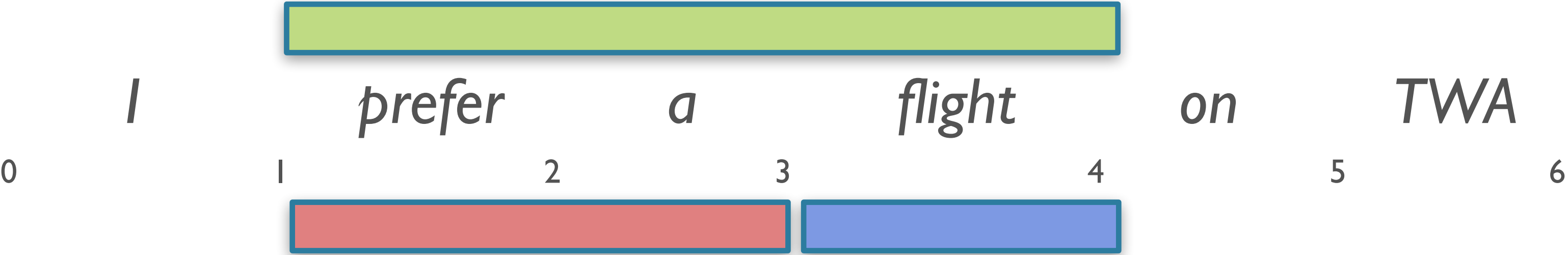
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ I\ this\ I\ a$
 $Noun \rightarrow book\ I\ flight\ I\ meal\ I\ money$
 $Pronoun \rightarrow I\ I\ she\ I\ me$
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NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		



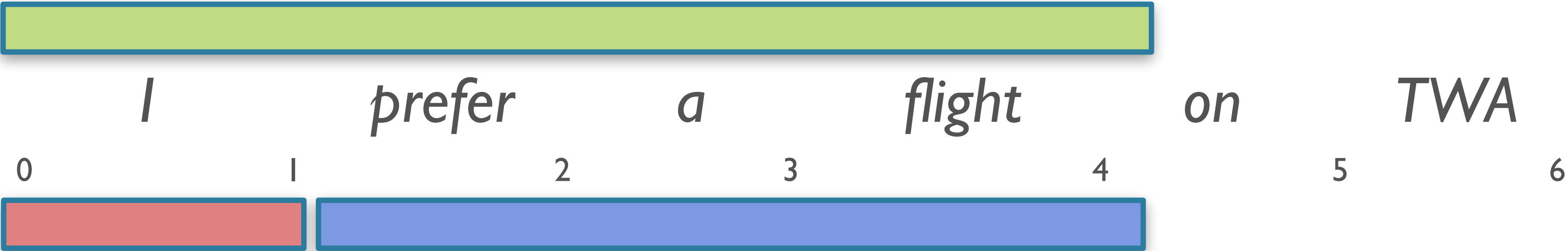
\mathcal{L}_1 Grammar

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-
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
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- $Nominal \rightarrow Nominal PP$
-
- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$
-
- $PP \rightarrow Preposition NP$

Lexicon

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



\mathcal{L}_1 Grammar

S

→

NP

VP

S → X1 VP

X1 → Aux NP

S → book I include I prefer

S → Verb NP

S → X2 PP

S → Verb PP

S → VP PP

NP → I I she I me

NP → TWA I Houston

NP → Det Nominal

Nominal → book I flight I meal I money

Nominal → Nominal Noun

Nominal → Nominal PP

VP → book I include I prefer

VP → Verb NP

VP → X2 PP

X2 → Verb NP

VP → Verb PP

VP → VP PP

PP → Preposition NP

Lexicon

Det → that | this | a

Noun → book | flight | meal | money

Pronoun → I | she | me

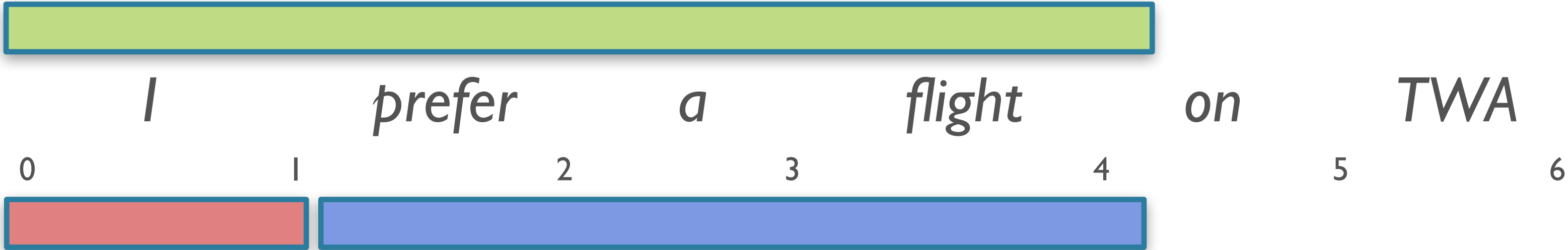
Proper-Noun → Houston | TWA

Aux → does

Preposition → from | to | on | near | through

Verb → book | include | prefer

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



\mathcal{L}_1 Grammar

$S \rightarrow NP VP$

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$X1 \rightarrow Aux NP$

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

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

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

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

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$VP \rightarrow Verb NP$

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$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

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Lexicon

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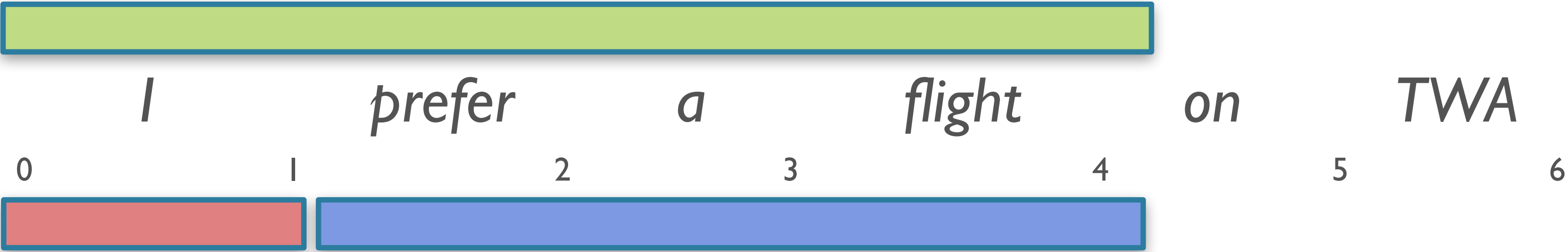
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$Aux \rightarrow does$

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

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

\mathcal{L}_1 Grammar

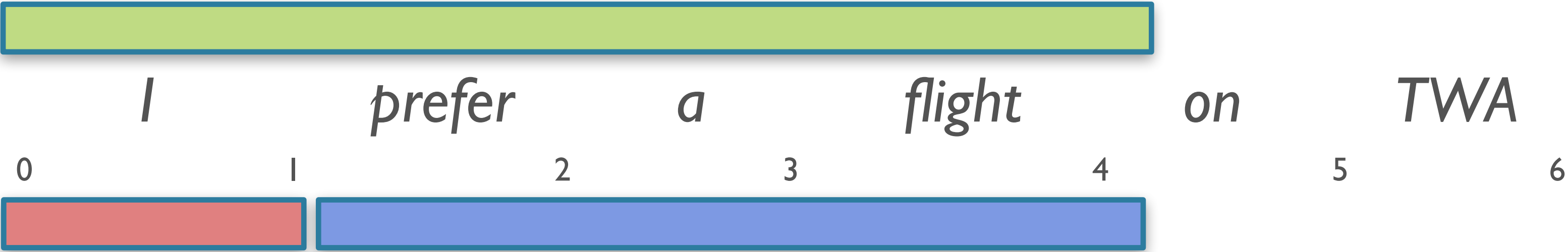
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 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$

$NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
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 $VP \rightarrow book \mid include \mid prefer$
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 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]		
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		



\mathcal{L}_1 Grammar

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

$S \rightarrow \textit{book} \mid \textit{include} \mid \textit{prefer}$

$$S \rightarrow Verb NP$$
$$S \rightarrow X^2 PP$$
$$S \rightarrow \textit{Verb PP}$$
$$S \rightarrow VP PP$$

$NP \rightarrow I / she / me$

NP → TWA / Houston

NP → *Det Nominal*

Nominal → *book / flight / meal / money*

Nominal → *Nominal Noun*

Nominal → Nominal PP

VP → *book* / *include* / *prefer*

$$VP \rightarrow Verb NP$$
$$VP \rightarrow X_2 PP$$
$$X_2 \rightarrow \textit{Verb NP}$$
$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP PP$$

PP → *Preposition NP*

NP,
Pronoun
[0,1]

S

[0,2]

[0,2]

Verb, VP, S

[1,2]

[1,2]

S
[0,4]

[0,4]

VP, X2, S
[1,4]

[1,4]

NP

[2,4]

[2,4]

Noun, Nom

[3,4]

[3,4]

Lexicon

Det → *that* | *this* | *a*

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

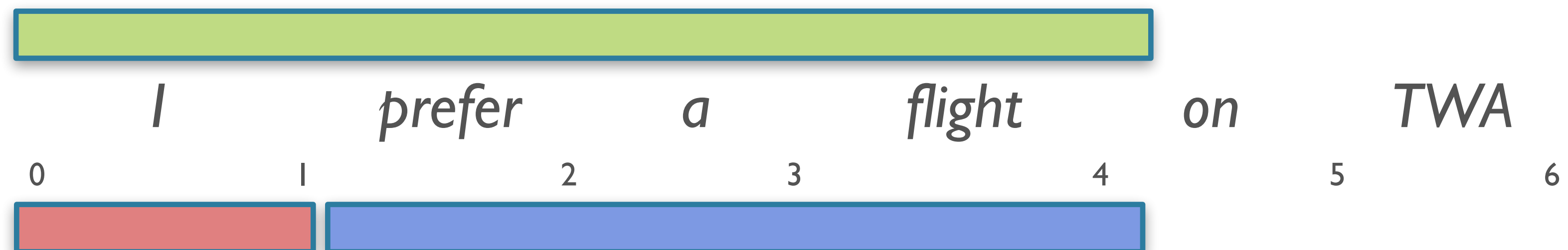
Pronoun → I | she | me

Proper-Noun → *Houston* | *TWA*

Aux → *does*

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

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$X2 \rightarrow Verb NP$

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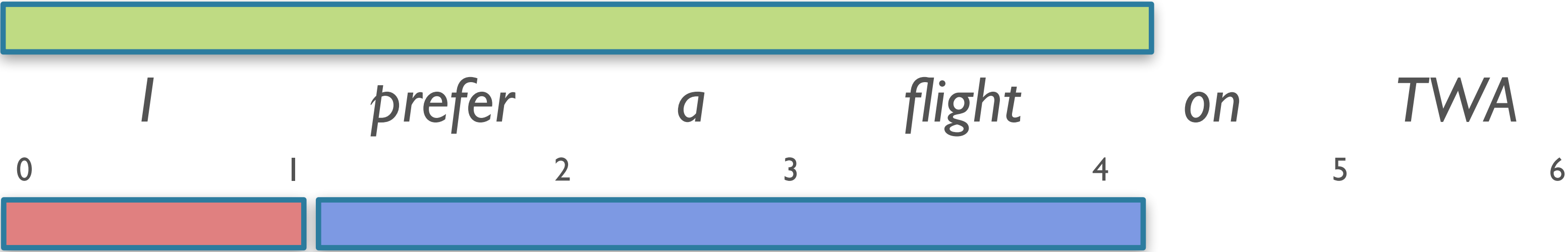
$Pronoun \rightarrow I \mid she \mid me$

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$Aux \rightarrow does$

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

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

\mathcal{L}_1 Grammar

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

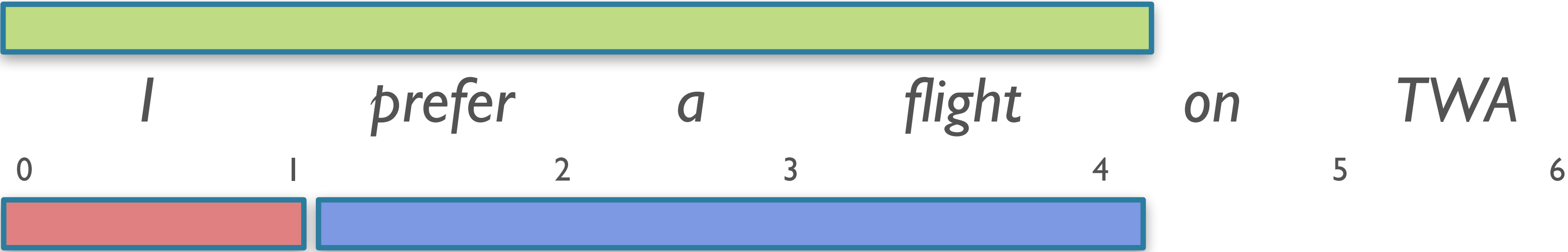
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$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
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 $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
 $Verb \rightarrow book \mid include \mid prefer$

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



\mathcal{L}_1 Grammar

$S \rightarrow NP VP$

$S \rightarrow X1 VP$

$X1 \rightarrow Aux NP$

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

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

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

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

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

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

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

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

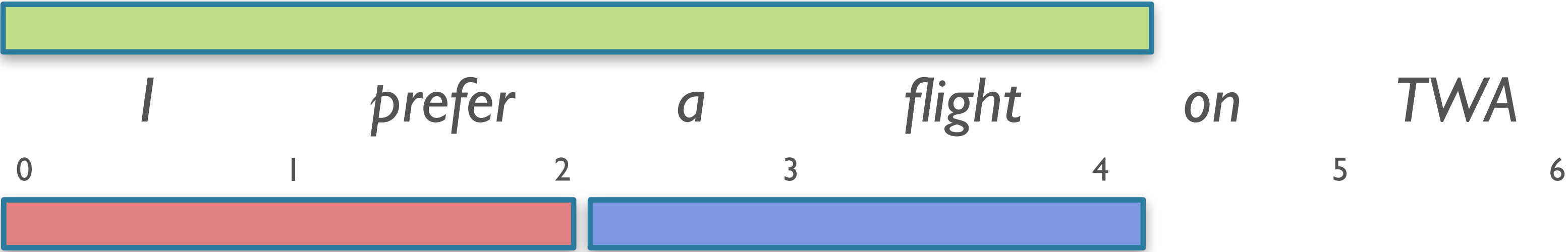
$Pronoun \rightarrow I \mid she \mid me$

$Proper-Noun \rightarrow Houston \mid TWA$

$Aux \rightarrow does$

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

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



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

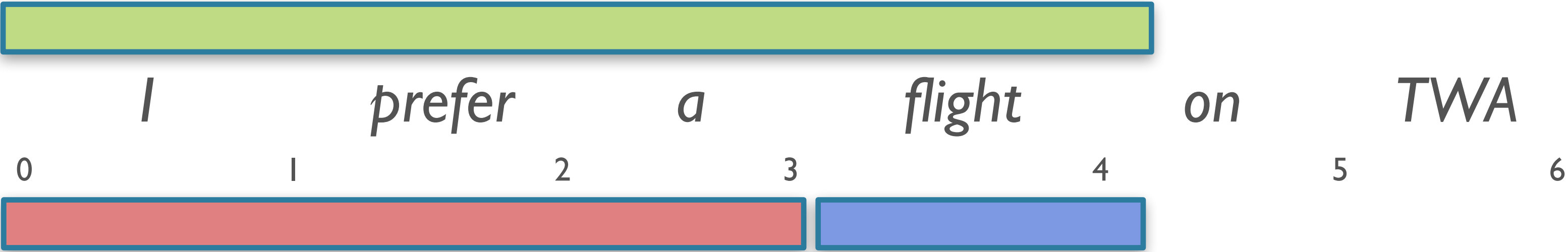
\mathcal{L}_1 Grammar

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

Lexicon

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

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



\mathcal{L}_1 Grammar

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

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

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

$PP \rightarrow Preposition NP$

Lexicon

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

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



\mathcal{L}_1 Grammar

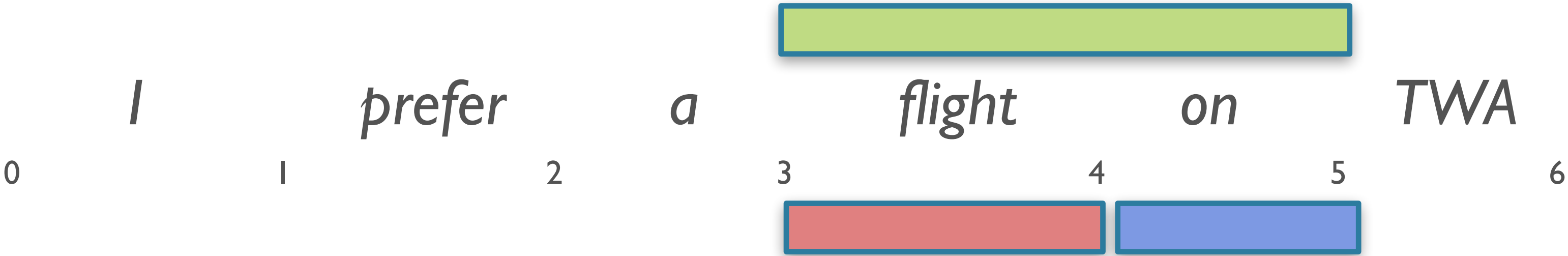
$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$

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

Lexicon

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



\mathcal{L}_1 Grammar

$S \rightarrow NP VP$

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$X1 \rightarrow Aux NP$

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$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

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

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

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$Nominal \rightarrow Nominal PP$

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

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

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

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

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

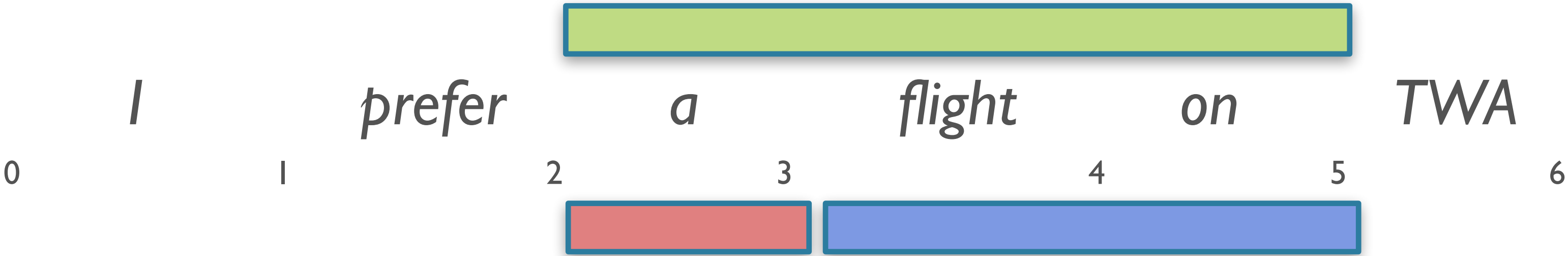
$Proper-Noun \rightarrow Houston \mid TWA$

$Aux \rightarrow does$

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

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

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



\mathcal{L}_1 Grammar

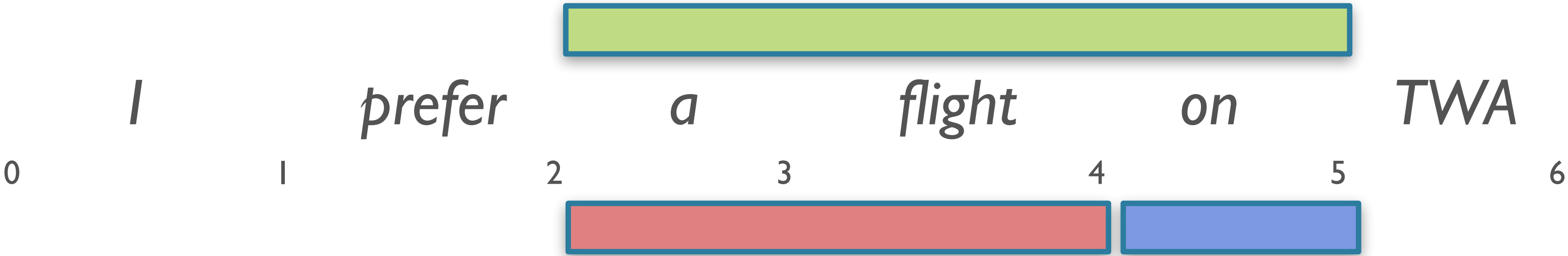
$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$

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

Lexicon

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

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



\mathcal{L}_1 Grammar

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

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

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

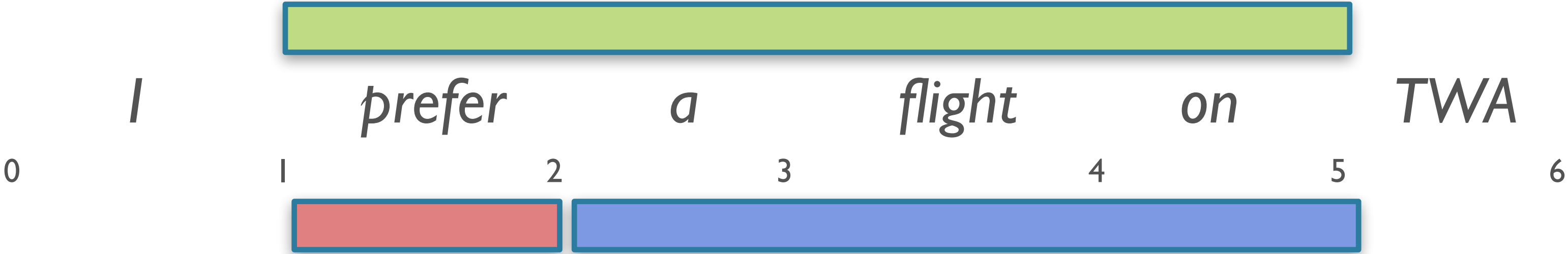
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

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

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



\mathcal{L}_1 Grammar

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

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

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

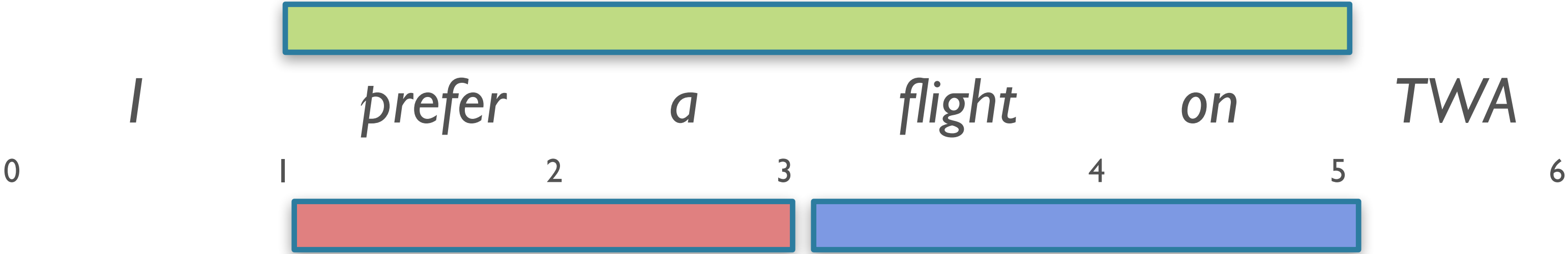
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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



\mathcal{L}_1 Grammar

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

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

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

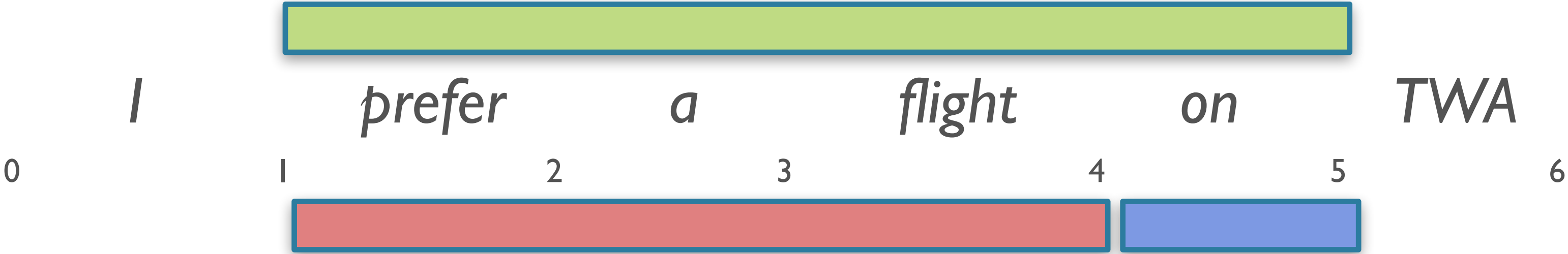
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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



\mathcal{L}_1 Grammar

$S \rightarrow NP VP$

$S \rightarrow X1 VP$

$X1 \rightarrow Aux NP$

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

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

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

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

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

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

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

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

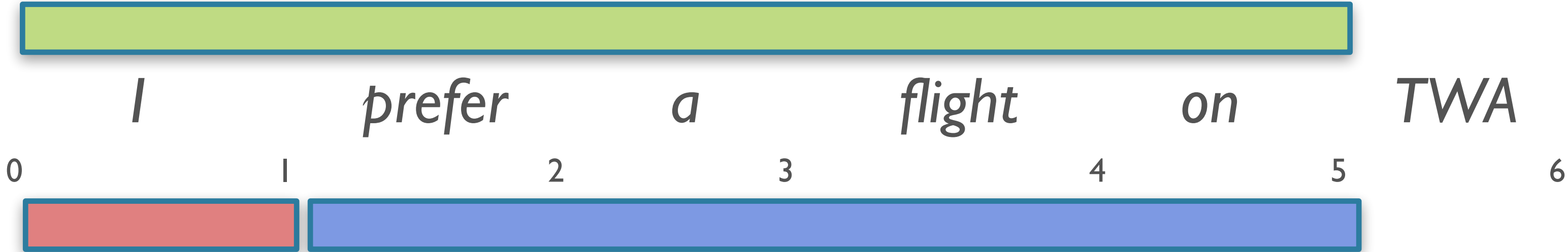
$Pronoun \rightarrow I \mid she \mid me$

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$Aux \rightarrow does$

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

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



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

\mathcal{L}_1 Grammar

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

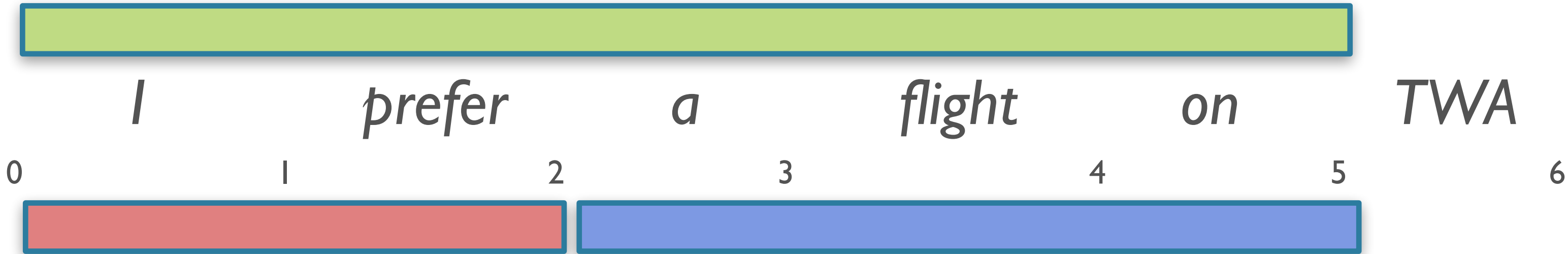
$NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$

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

Lexicon

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

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



\mathcal{L}_1 Grammar

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

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

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

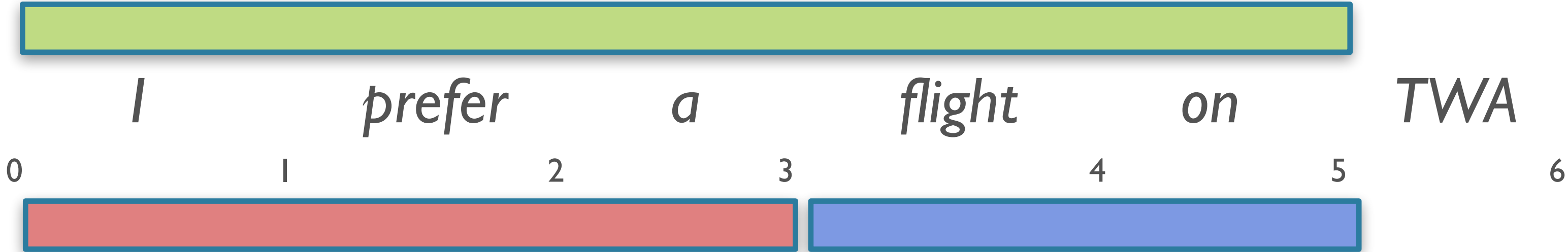
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

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

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



\mathcal{L}_1 Grammar

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

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

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

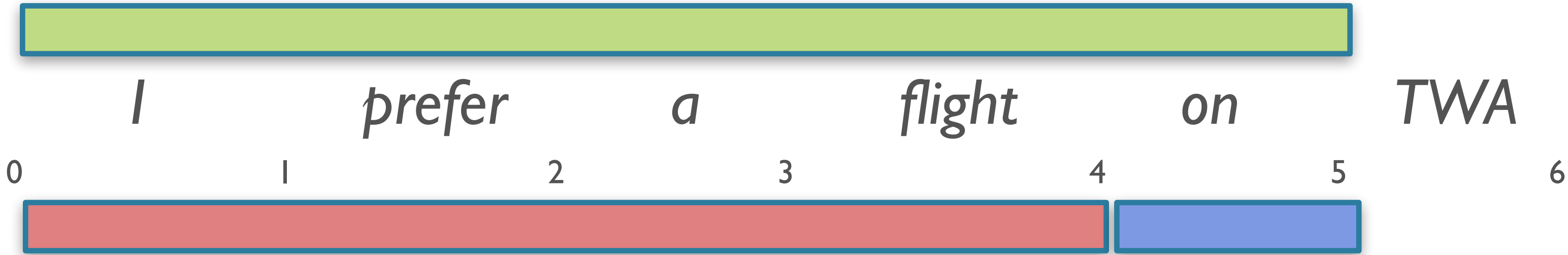
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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



\mathcal{L}_1 Grammar

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

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

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

$NP \rightarrow I / she / me$

NP → TWA / Houston

$NP \rightarrow Det\ Nominal$

Nominal → *book / flight / meal / money*

Nominal → *Nominal Noun*

Nominal → Nominal PP

VP → book / include / prefer

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

$X_2 \rightarrow \text{Verb NP}$

$$VP \rightarrow Verb PP$$
$$VP \rightarrow VP PP$$

PP → *Preposition NP*

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

at | this | a
book | flight | meal | money
→ I | she | me
oun → Houston | TWA
oes
on → from | to | on | near | through

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

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
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$NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$

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

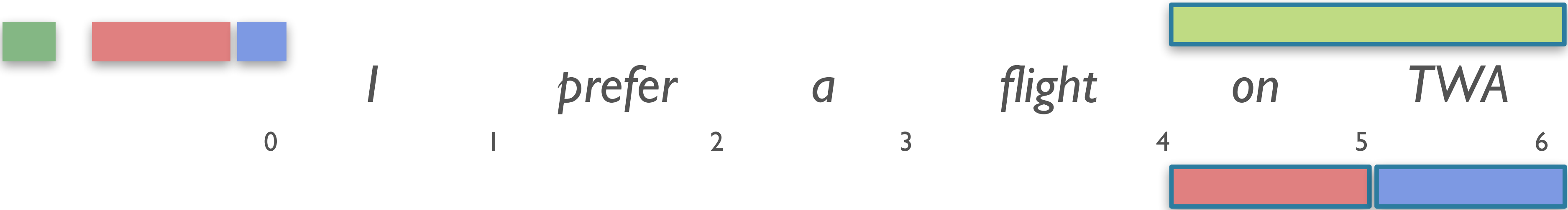
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

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

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



\mathcal{L}_1 Grammar

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

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

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

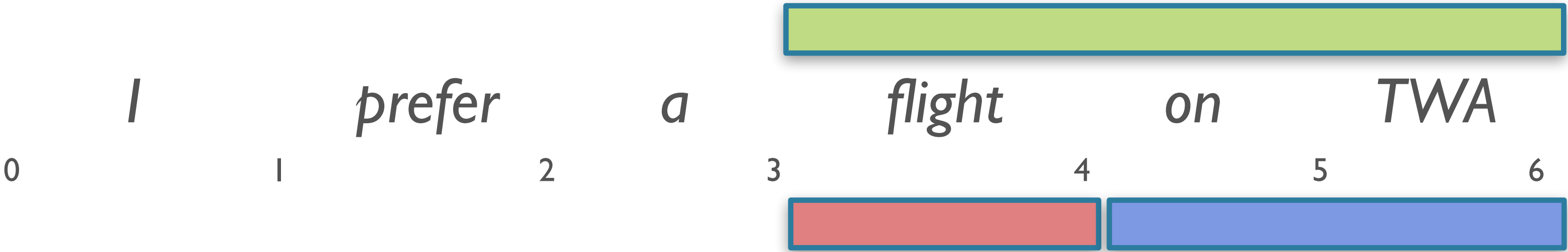
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
		Det [2,3]	NP [2,4]	[2,5]	
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
				Prep [4,5]	PP [4,6]
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\mathcal{L}_1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

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

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

$Nominal \rightarrow book\ I\ flight\ I\ meal\ I\ money$
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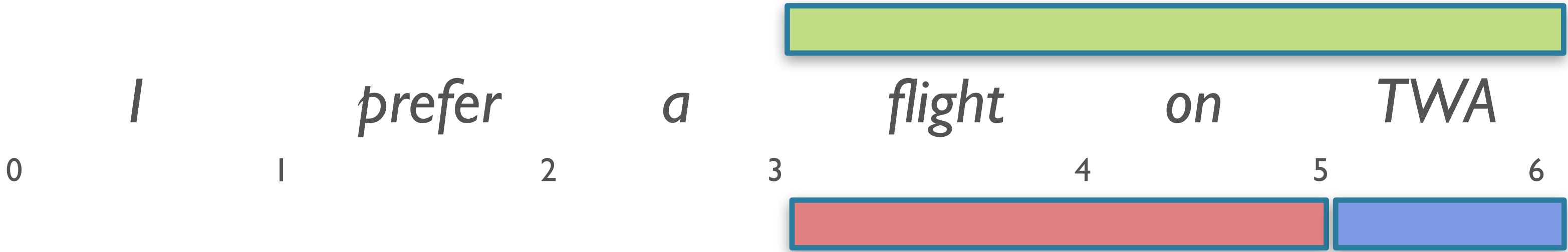
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
		Det [2,3]	NP [2,4]	[2,5]	
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
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 $S \rightarrow VP\ PP$

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

$Nominal \rightarrow book\ I\ flight\ I\ meal\ I\ money$
 $Nominal \rightarrow Nominal\ Noun$
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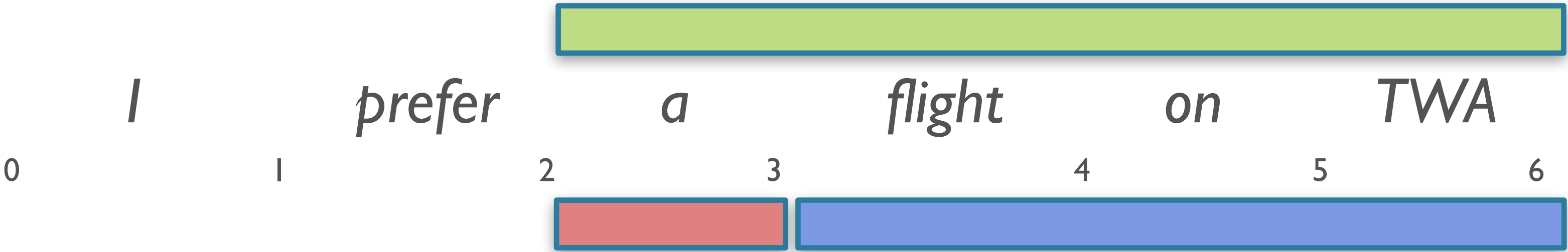
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
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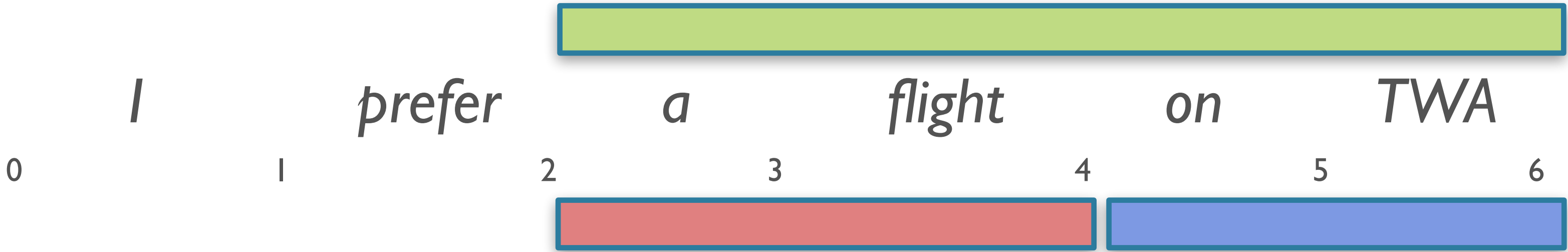
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
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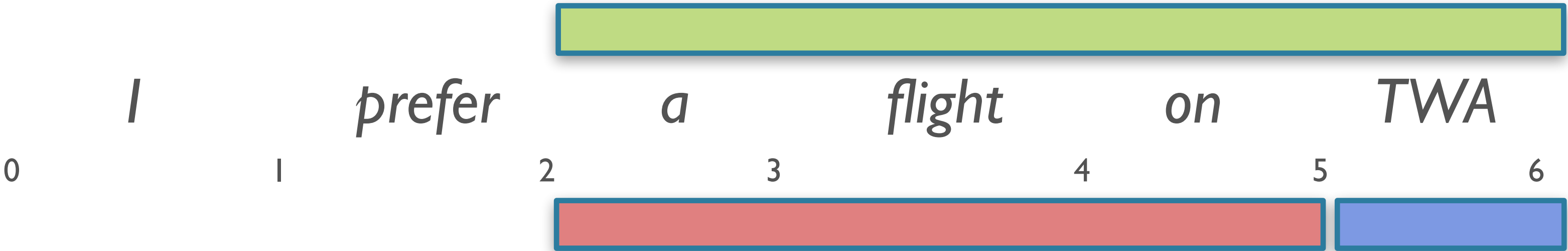
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
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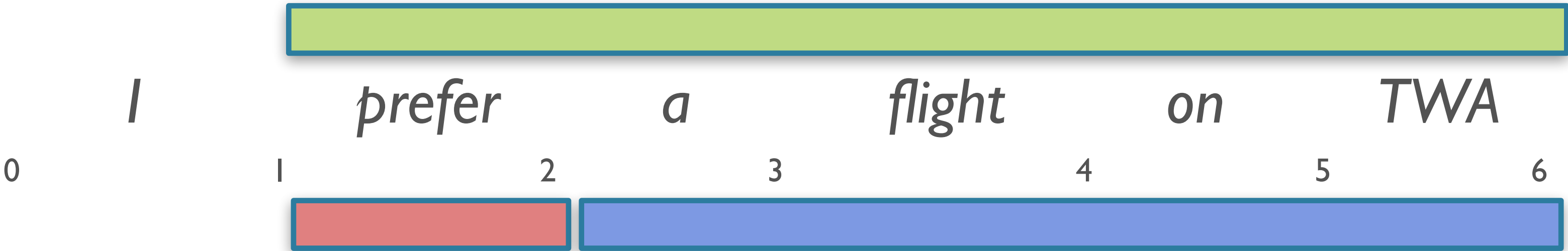
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	[1,6]
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
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VP

Verb

NP

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

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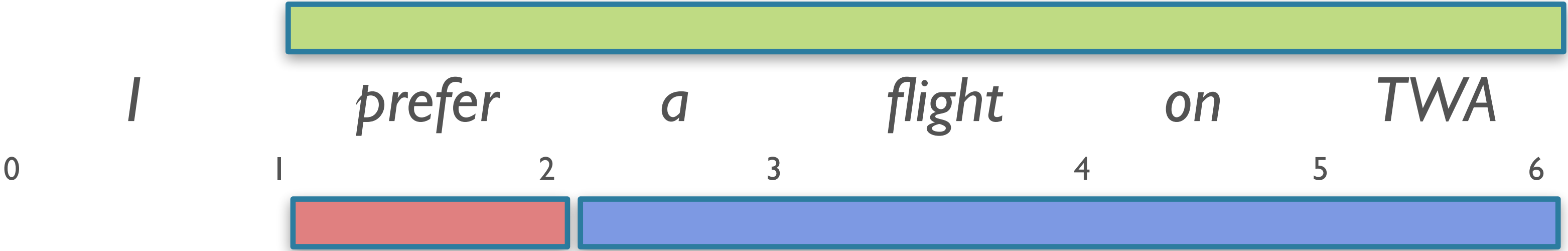
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	VP [1,6]
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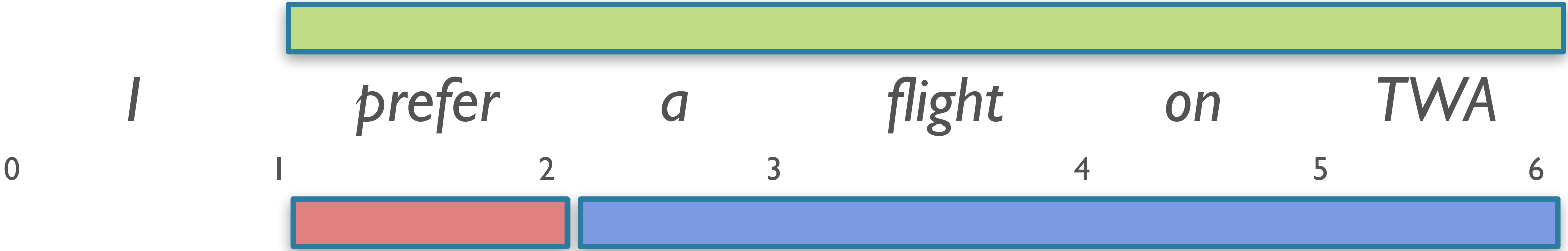
$VP \rightarrow book\ I\ include\ I\ prefer$
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	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	VP, X2 [1,6]
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
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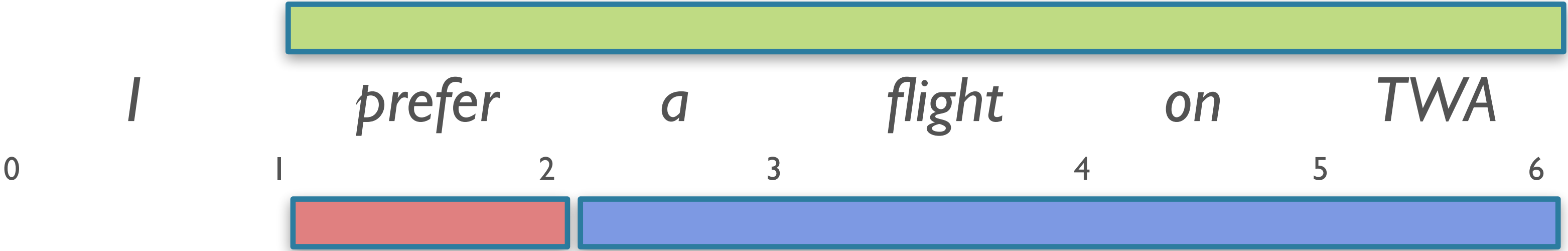
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	Verb, VP, S [1,2]		VP, X2, S [1,4]		VP, X2, S [1,6]
		Det [2,3]	NP [2,4]		NP [2,6]
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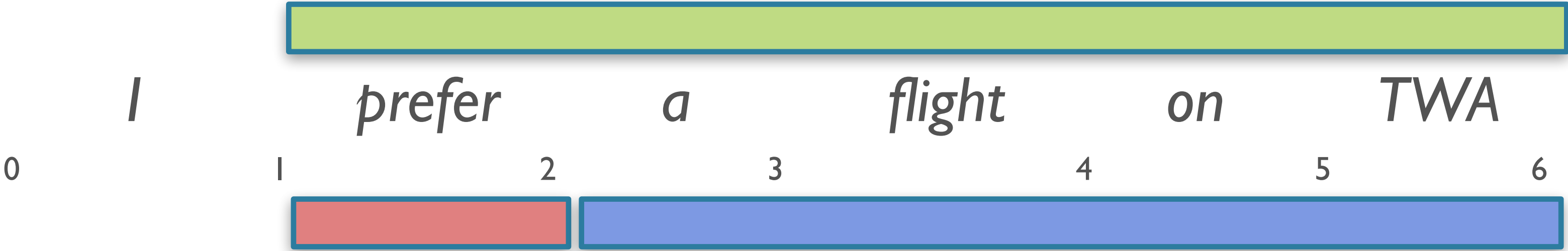
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		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
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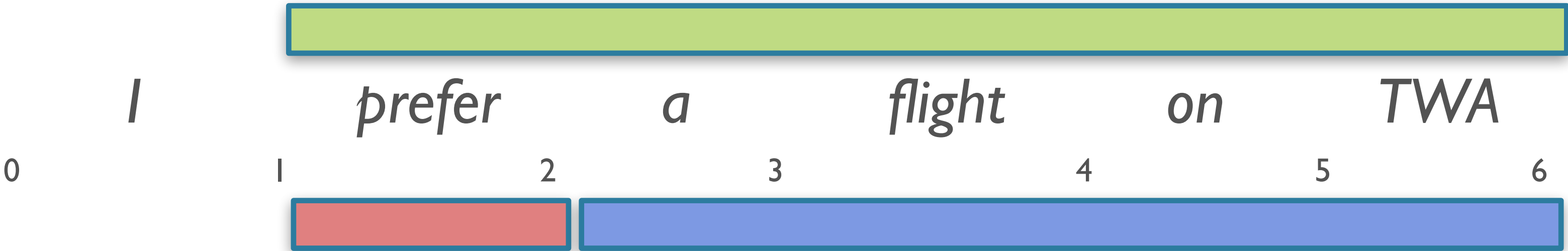
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
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		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
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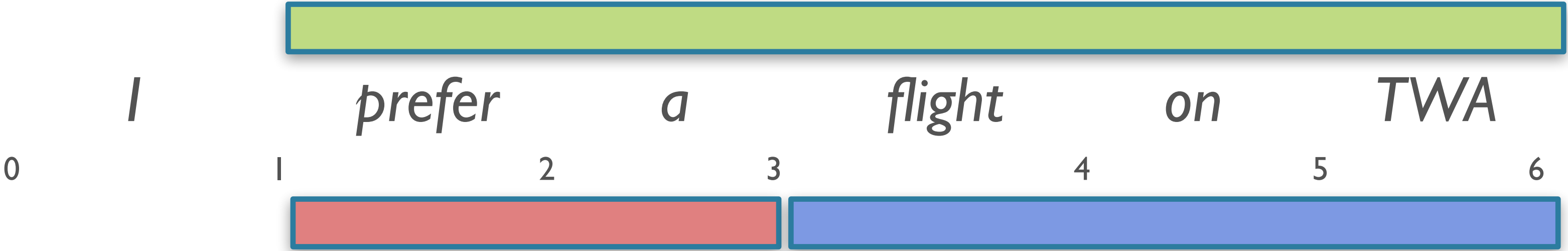
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	VP, X2, S [1,6]
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
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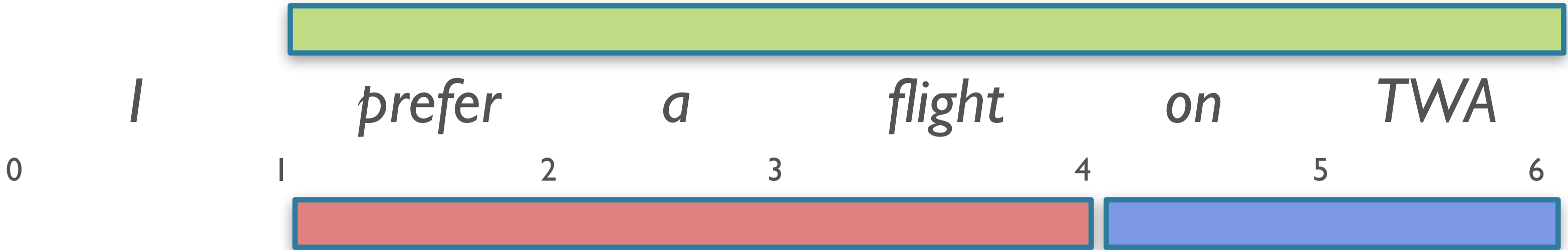
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$S \rightarrow Verb PP$

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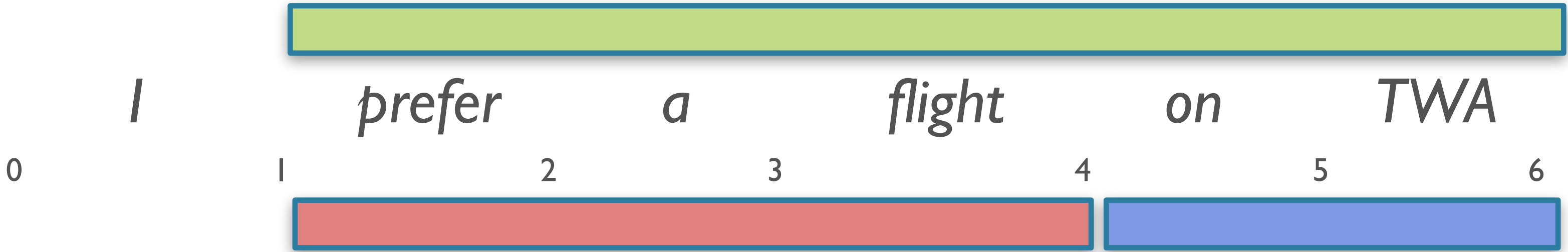
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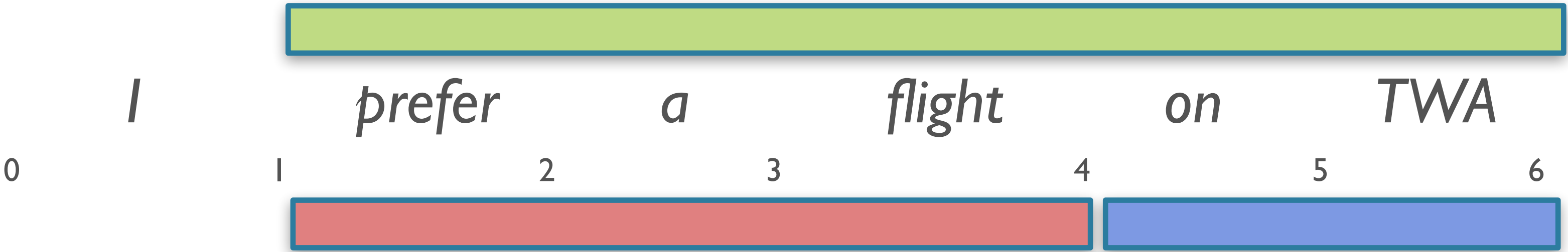
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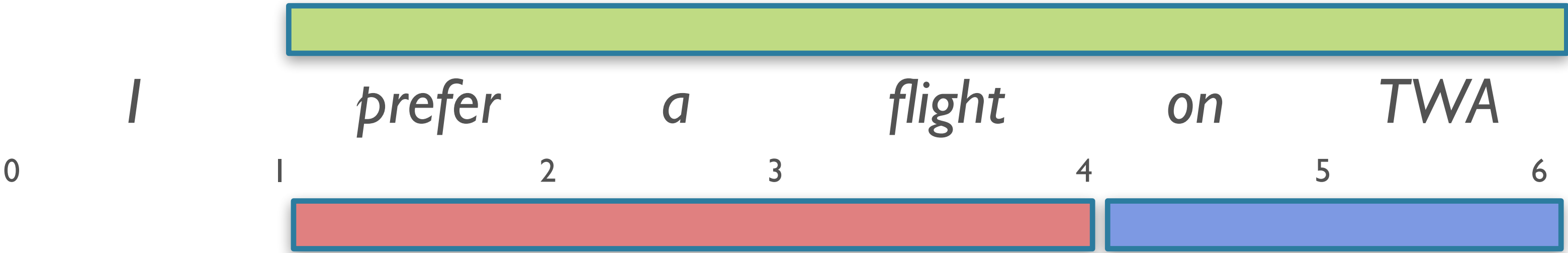
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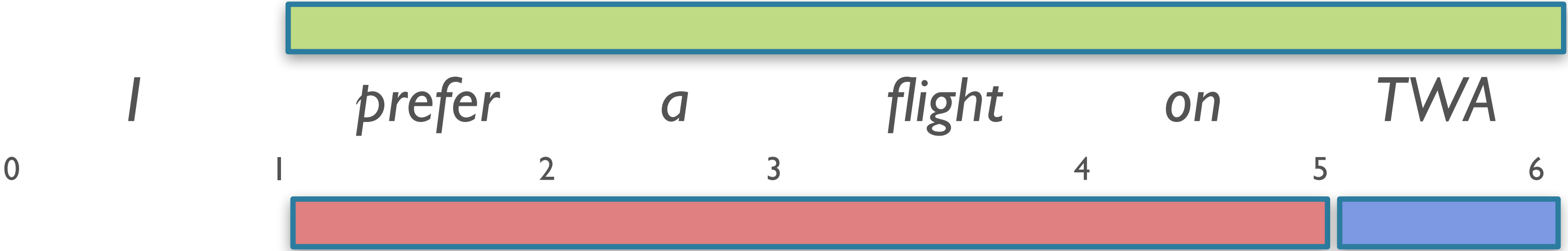
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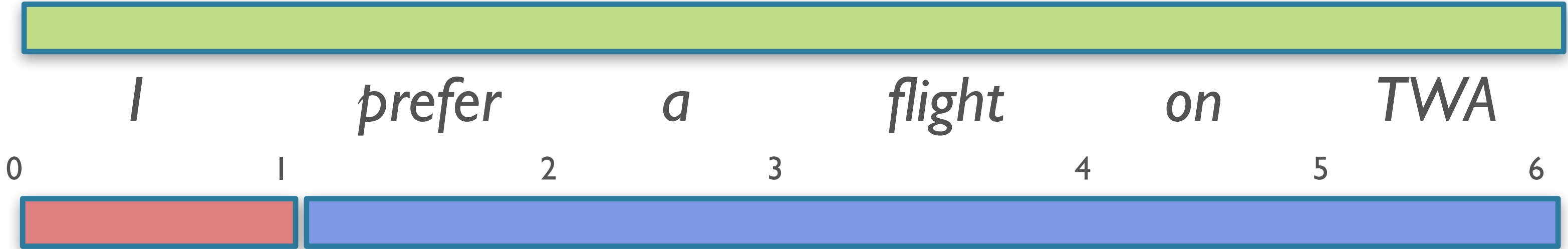
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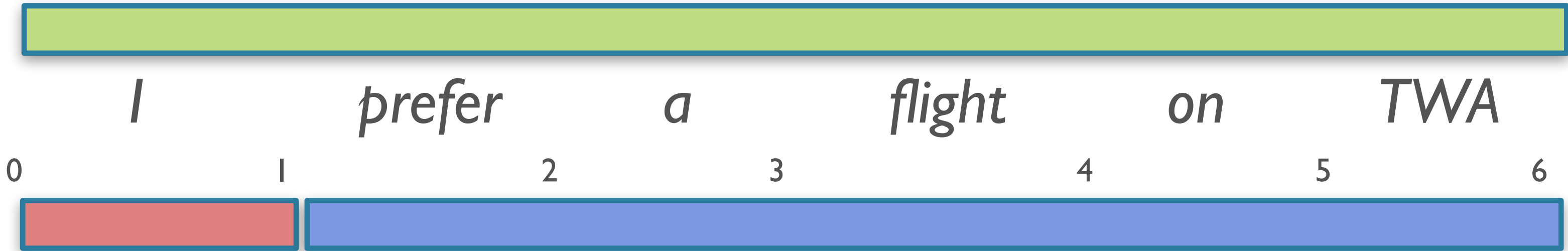
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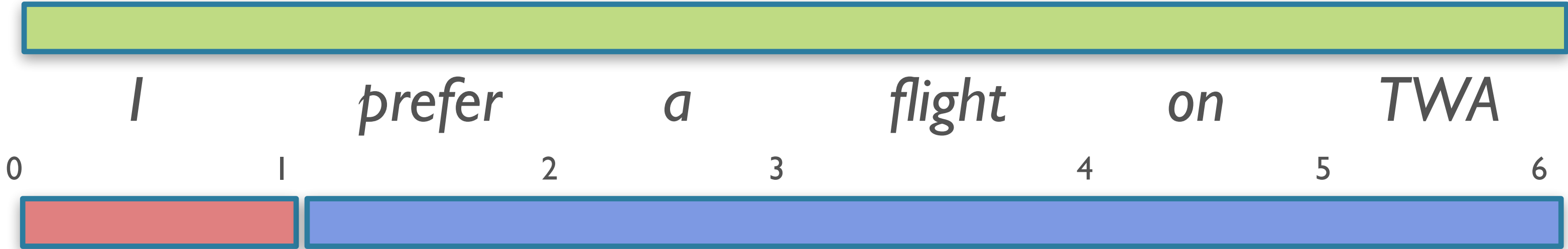
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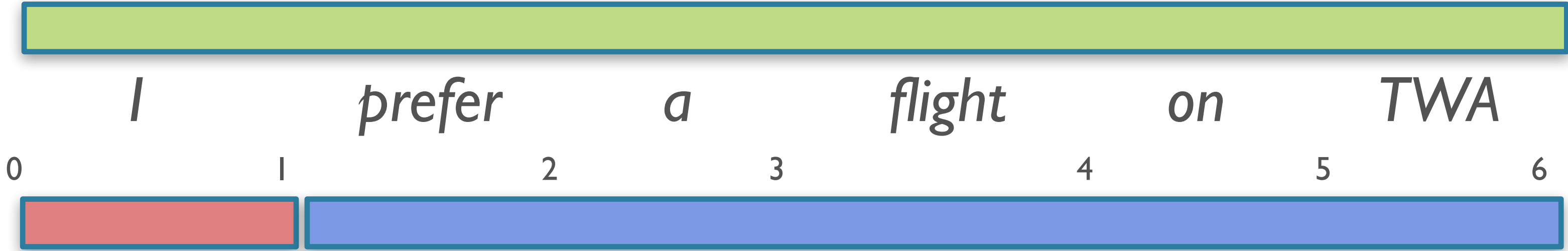
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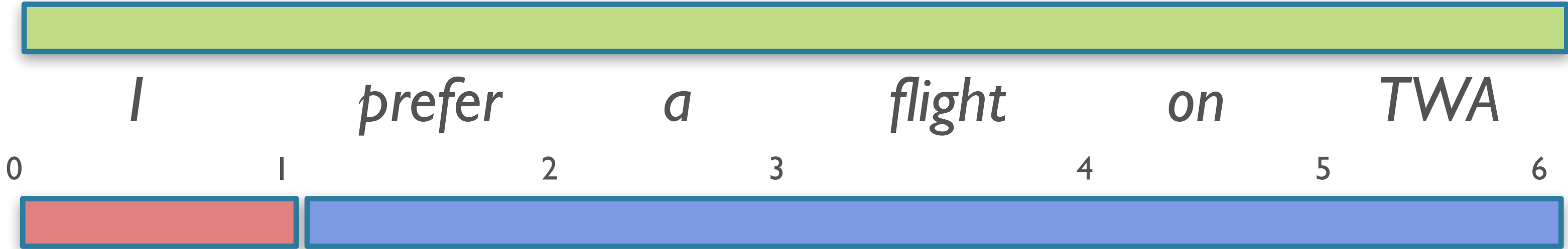
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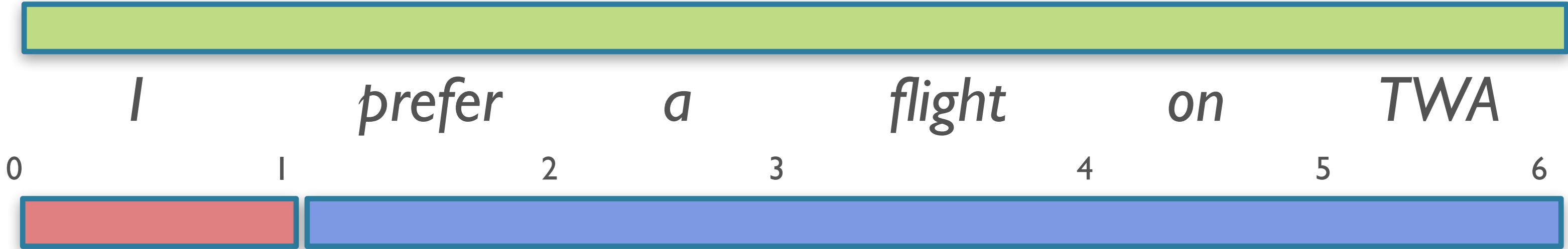
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Current CKY Algorithm

Limitations:

Only stores non-terminals in cell

- Not rules or cells corresponding to RHS

Stores SETS of non-terminals

- Multiple rules with same LHS collide

Currently only ***acceptance/recognition***

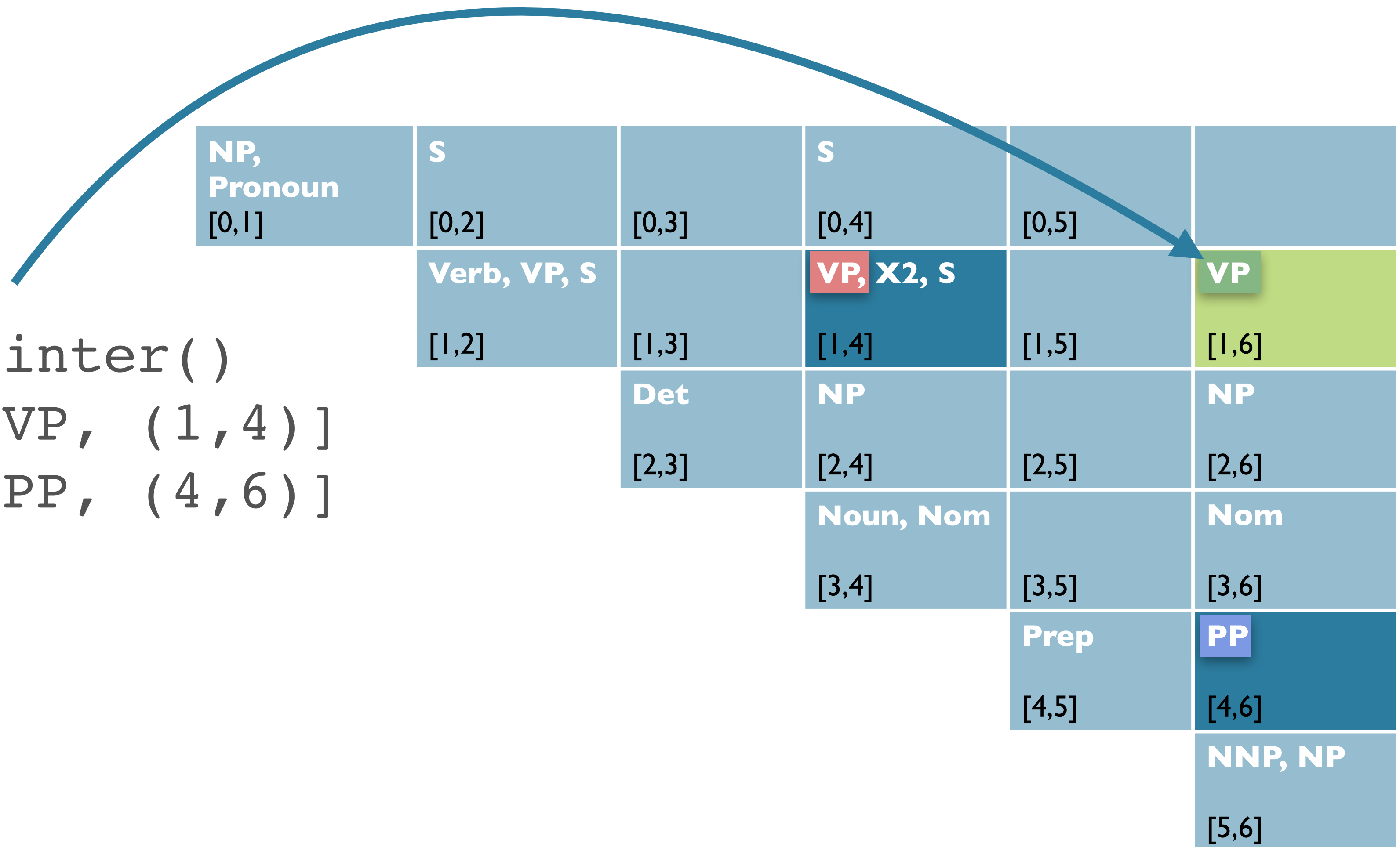
CKY *Parser*

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

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
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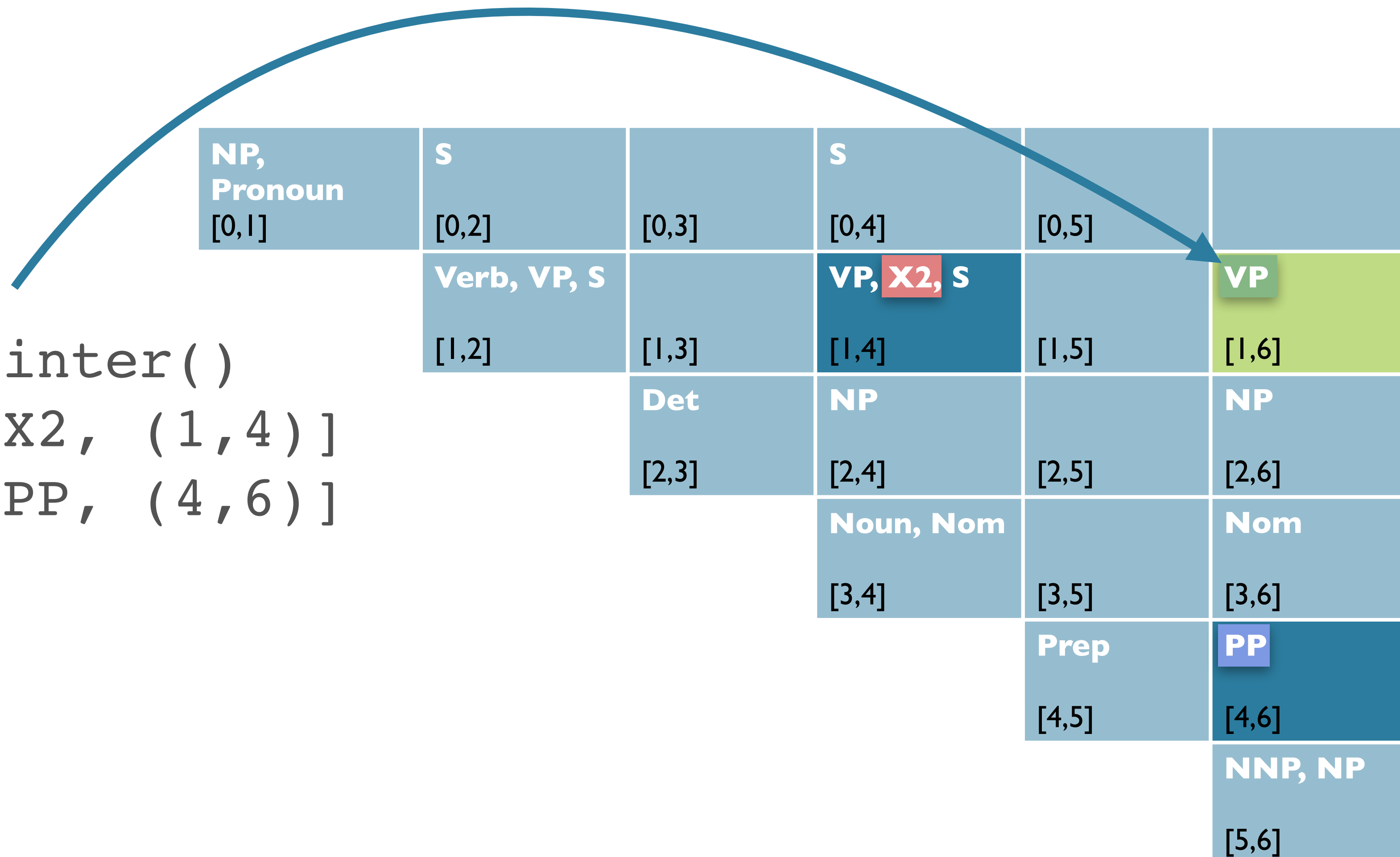
VP → **VP** **PP**

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

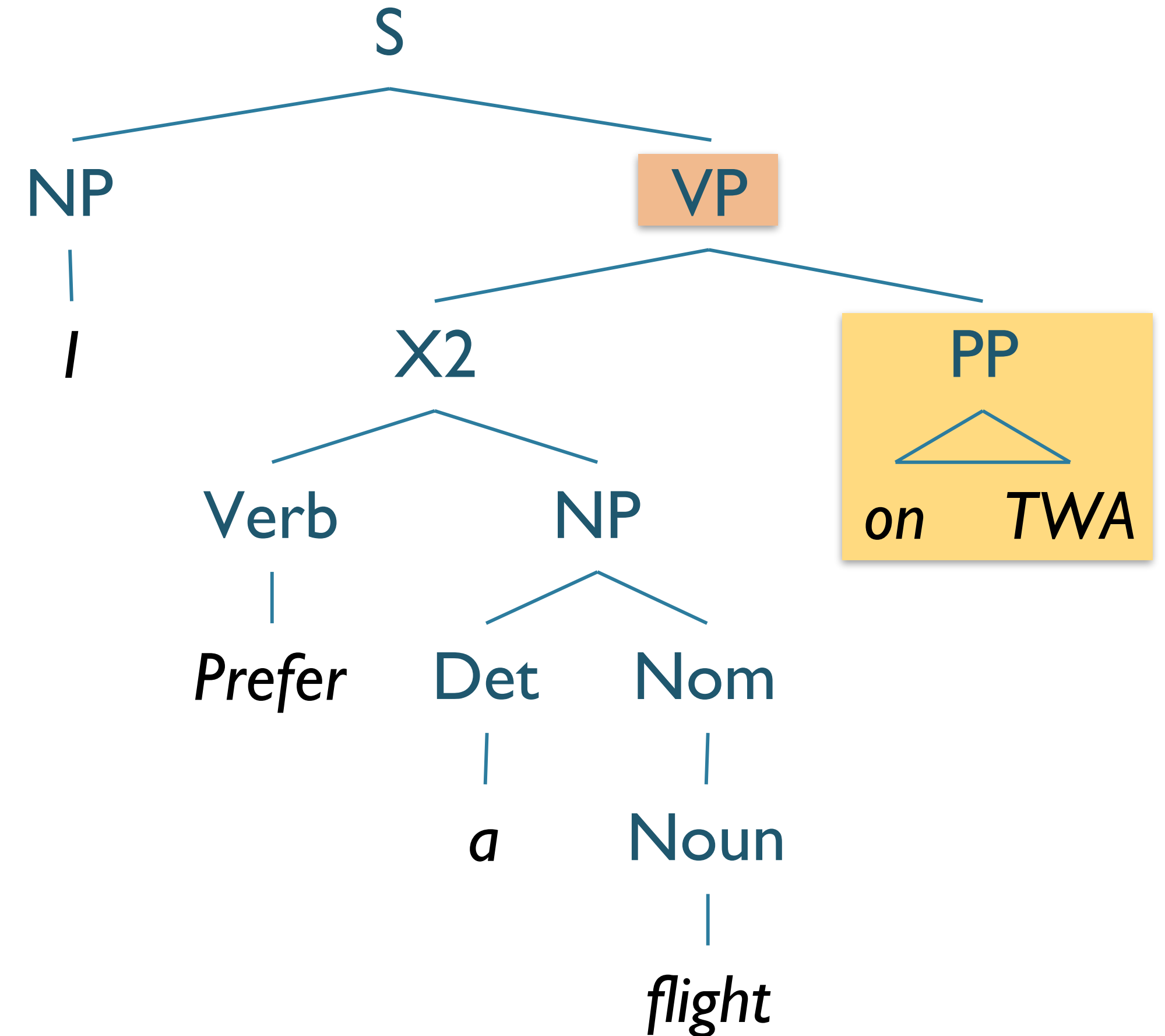
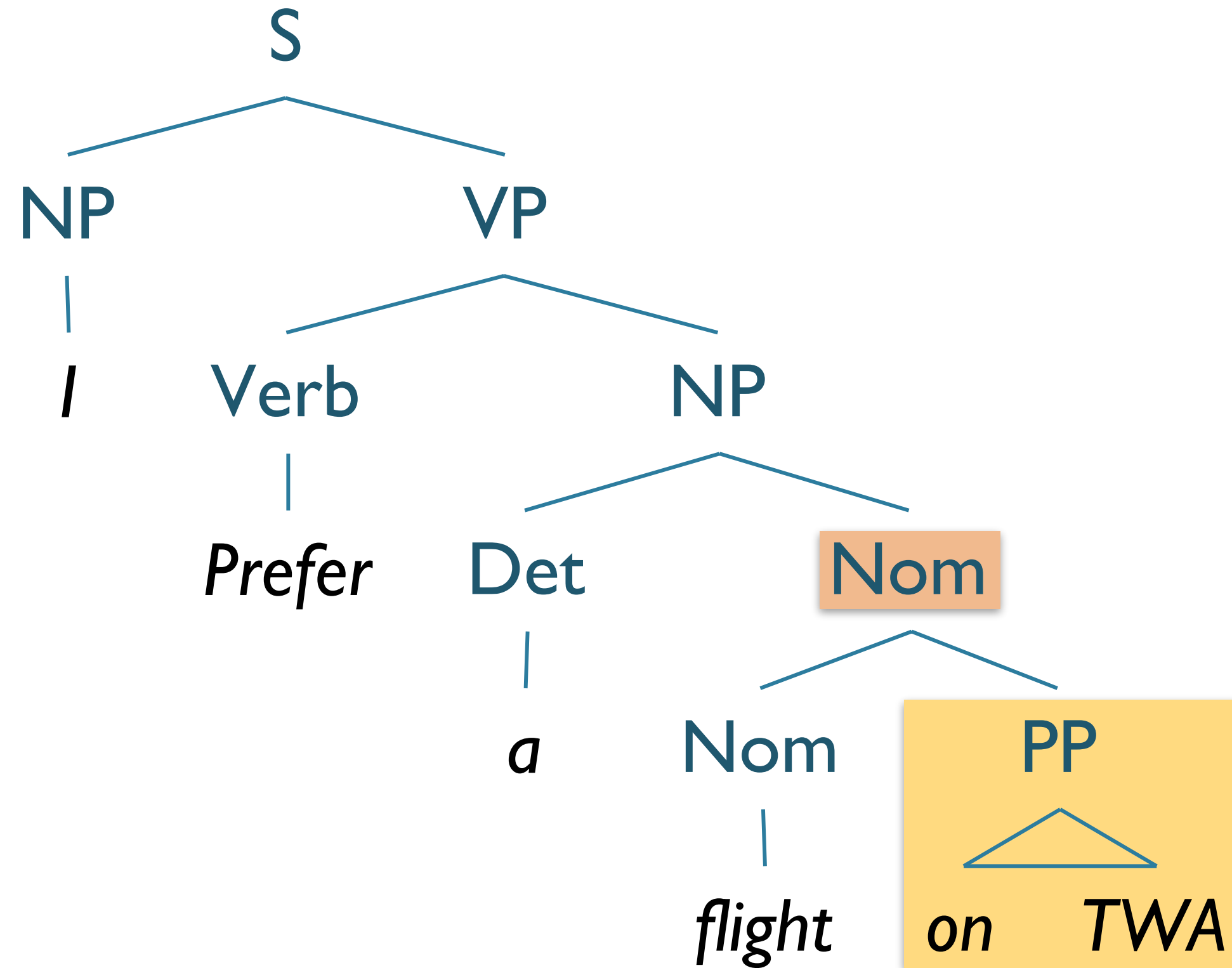


VP → **X2** **PP**

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



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