

CKY Parsing

LING 571 — Deep Processing Techniques for NLP

October 12, 2020

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Announcements

- HW1: grades posted
 - In general, we will aim for Monday release of grades.
- Some notes:
 - Make sure dir structure of your submission is correct [generally, no nested directories]
 - Run `check_hwX.sh` before submitting!
 - Pay careful attention to format of output files; make sure there's exact match on toy examples
 - patas/dryas, etc: will regrade HW1 if that was an issue
 - Use full paths for python binaries to be safe

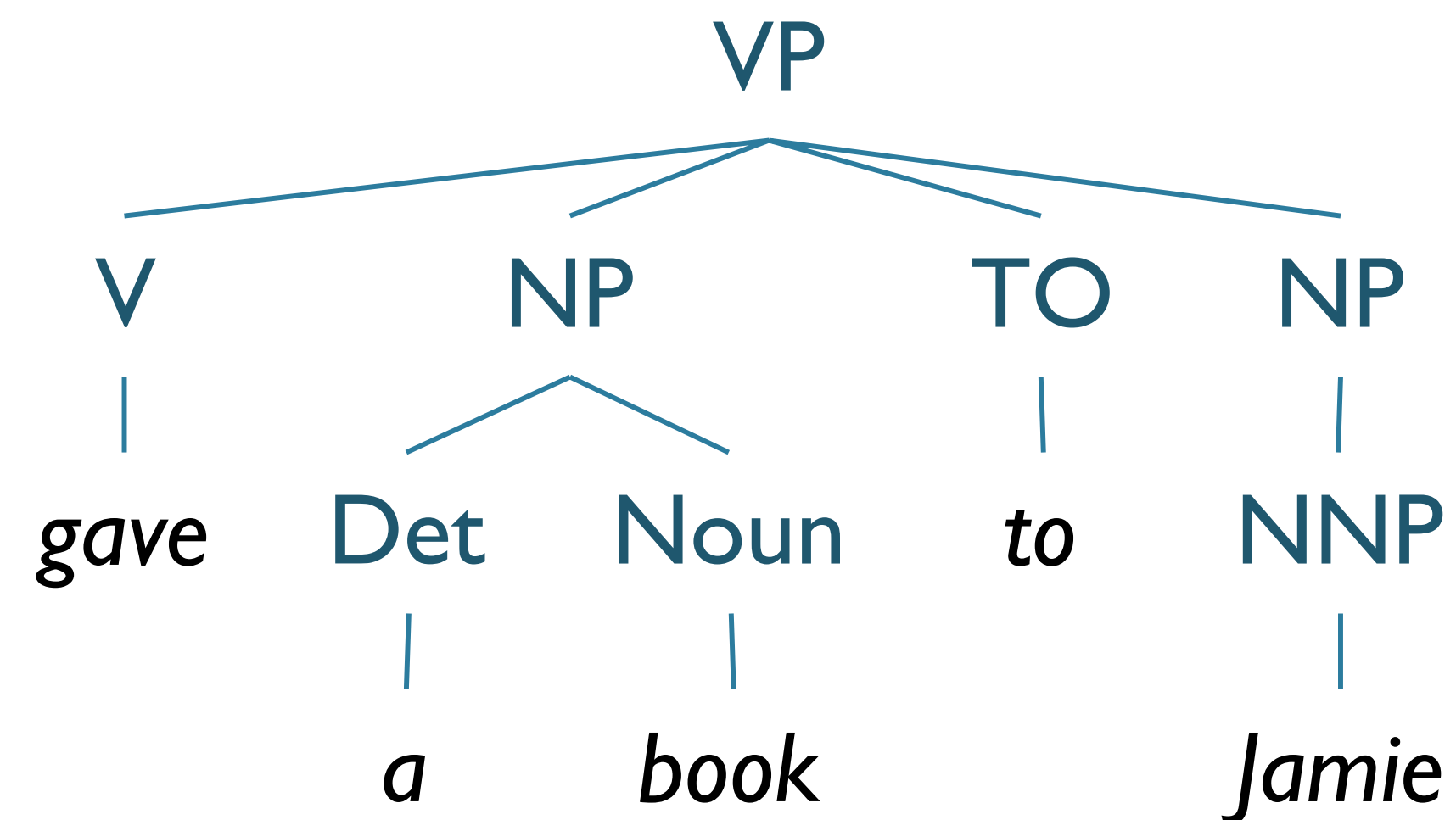
Announcements: HW #2

- Due Wednesday, 11:00pm Pacific
- Grammar output format:
 - Terminals quoted (single or double)
 - One production per line
- *Optionally*, RHS alternates with vertical bar/pipe character: |
 - Start symbol is first nonterminal encountered in file

Variation in CNF: Binarization

Original Rule

$VP \rightarrow V NP TO NP$



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Left to Right Reduction

$VP \rightarrow X1 TO NP$

$X1 \rightarrow V NP$

$VP \rightarrow X2 NP$

$X2 \rightarrow X1 TO$

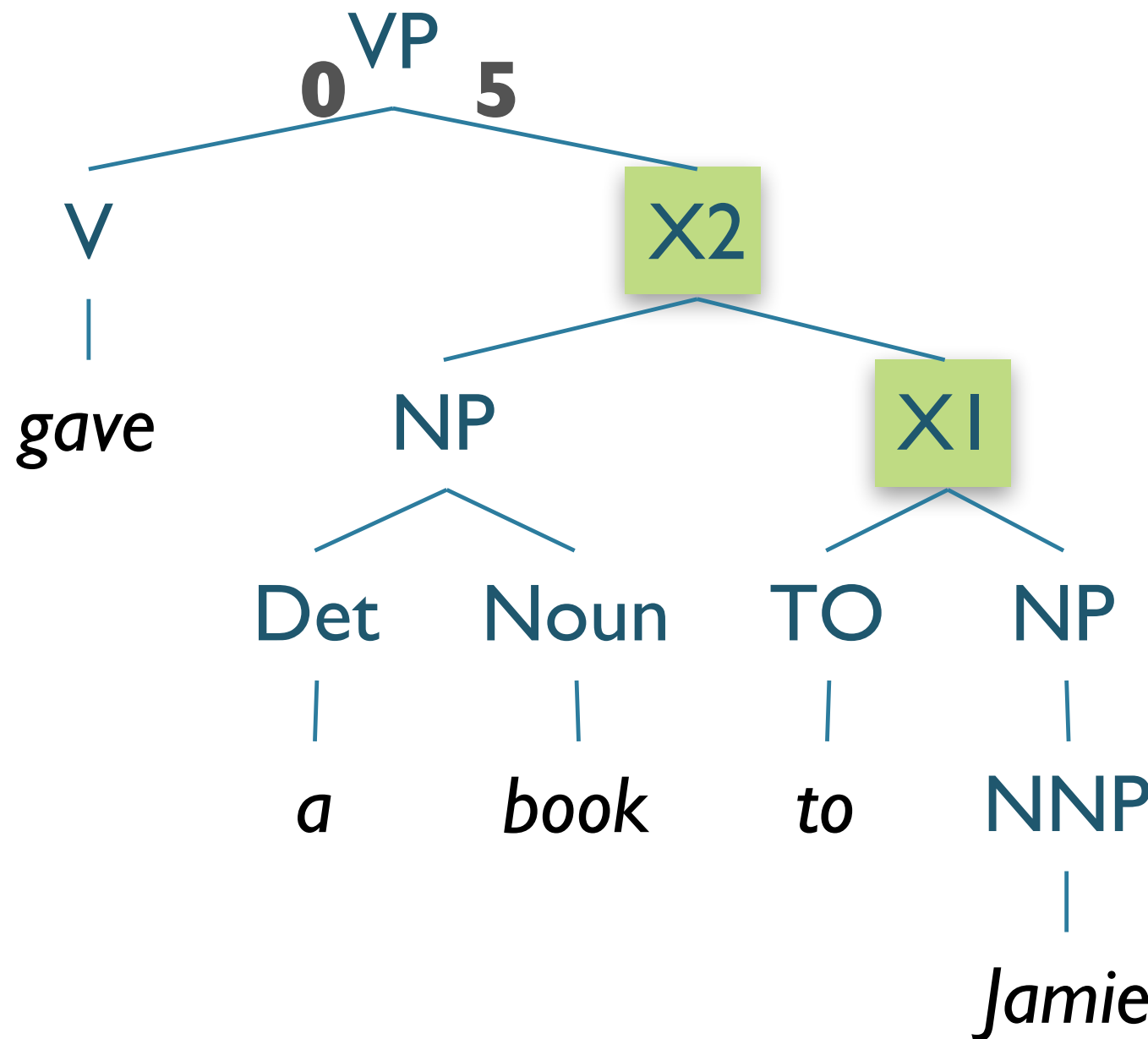
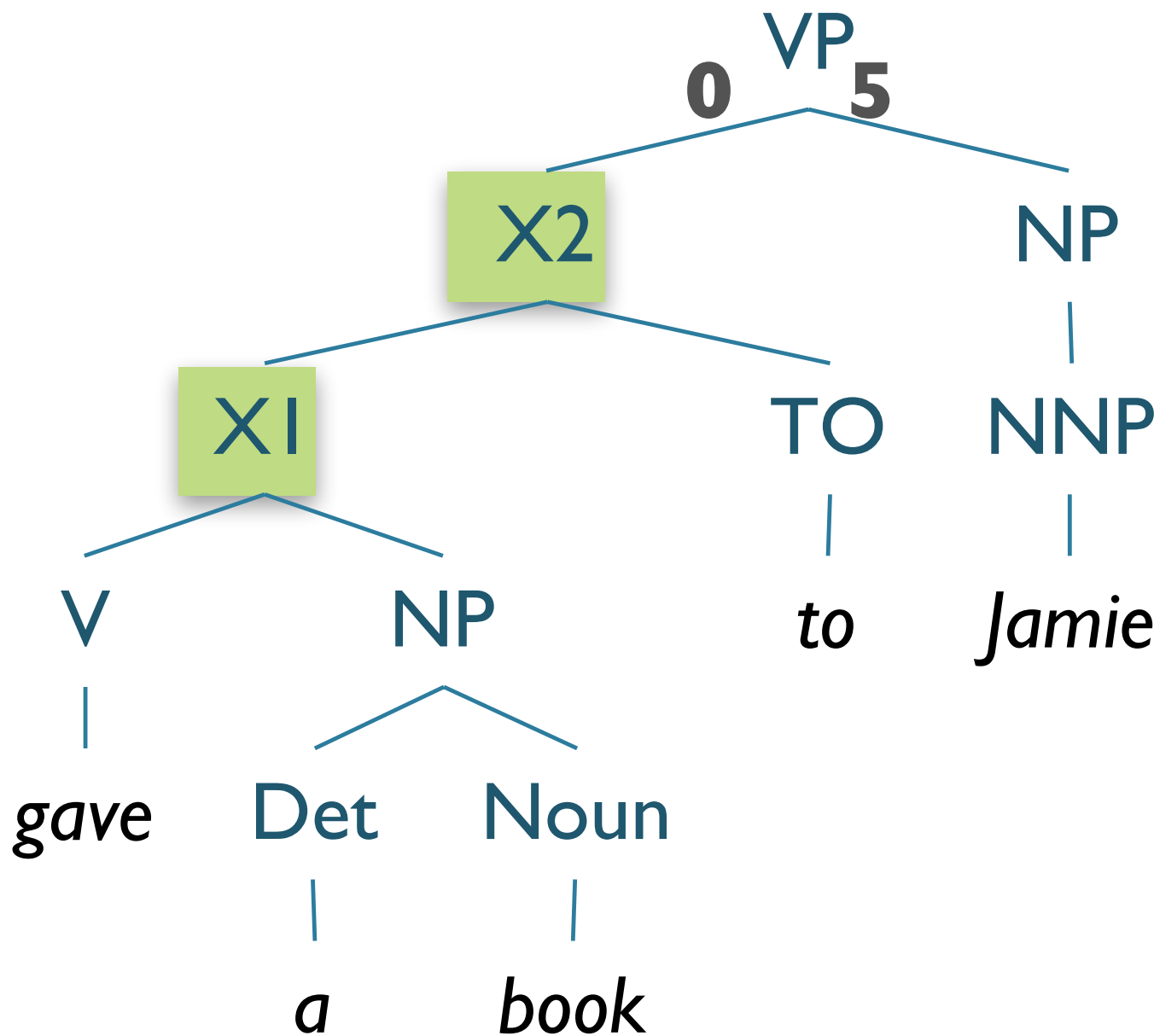
Right to Left Reduction

$VP \rightarrow V NP X1$

$X1 \rightarrow TO NP$

$VP \rightarrow V X2$

$X2 \rightarrow NP X1$



Indigenous Peoples' Day

- Seattle/Sealth/Si'ahl



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- For those of you taking 550:
 - The Lushootseed spelling [IPA] of Chief Seattle/Sealth/Si'ahl:
 - siʔat̚ ['siʔaːt̚]



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- Duwamish — Dx^wdəwʔabš̌ [dx^wdəwʔabʃ]



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- IPA resources:
 - 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

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 - Many interesting phenomena in non-Indo-European languages
- Lushootseed exhibits debatable distinction between verbs and nouns [link to Glottolog page for more references]
 - | | | |
|------------------------|-------------------|--------------------|
| ?uǰ^w | ti | sbiaw |
| goes | that-which | is-a-coyote |
| "The/a coyote goes" | | |
 - | | | |
|--------------------------------|-------------------|------------------------|
| sbiaw | ti | ?uǰ^w |
| is-a-coyote | that-which | goes |
| "The one who goes is a coyote" | | |
- (Translation distinction provided for clarity — semantically equivalent)

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via [Beck, 2013](#)
 - (Translation distinction provided for clarity — semantically equivalent)
- Lillooet Salish quantification has repercussions for e.g. English ([Matthewson 2001](#))

Indigenous Peoples' Day

- UW American Indian Studies Courses
 - (Sometimes including language courses, e.g. Southern Lushootseed)
- Lushootseed resources: <https://tulaliplushootseed.com/>

Roadmap

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

CKY

- Given an input string S of length n

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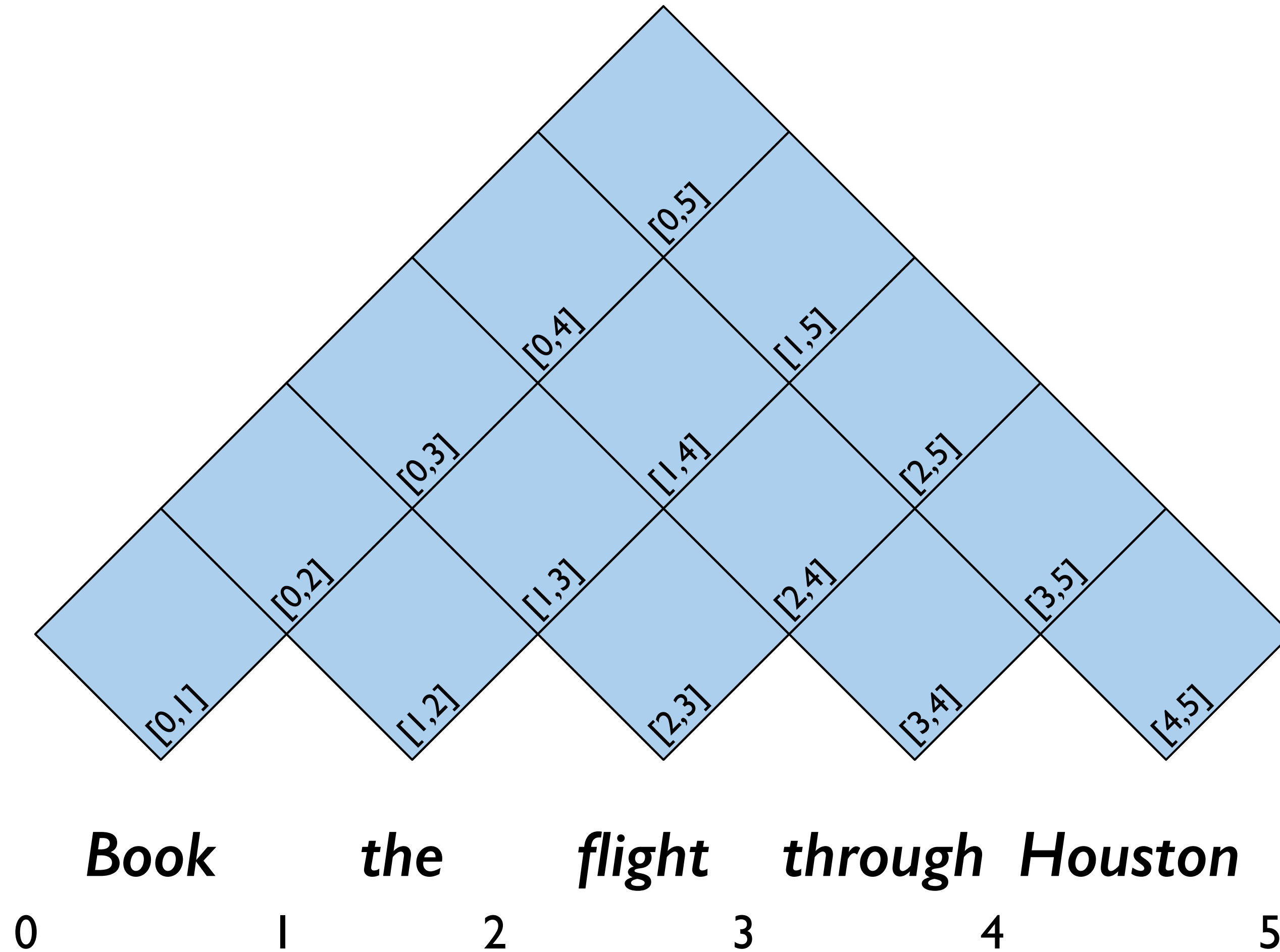
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- Each cell $[i, j]$ contains SETS $\{ \}$ of non-terminals with derivations spanning i, j
 - $[j - 1, j]$ contains pre-terminals
 - if $[0, n]$ contains the start symbol, the sentence is ***accepted***

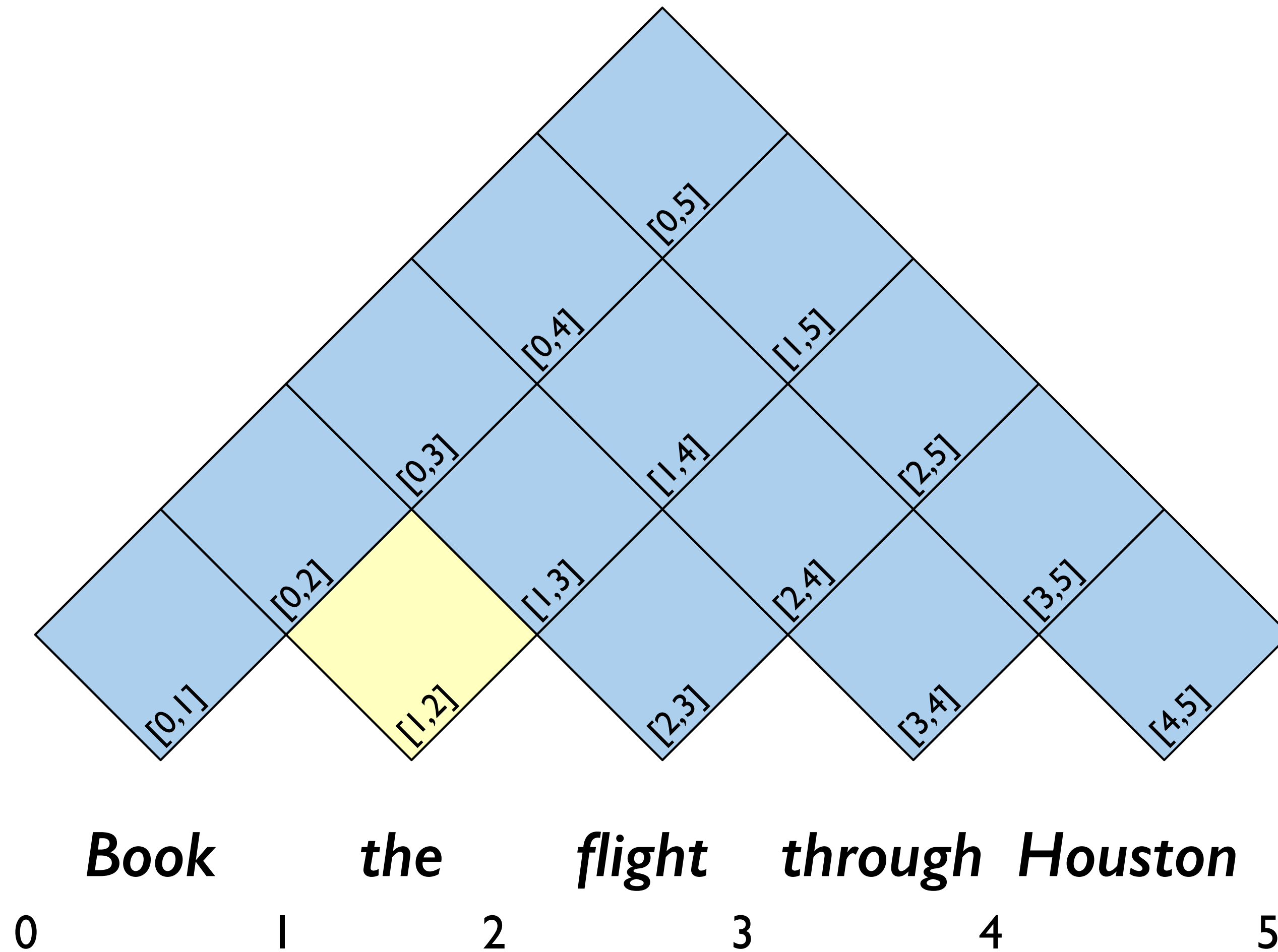
CKY Matrix

<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]

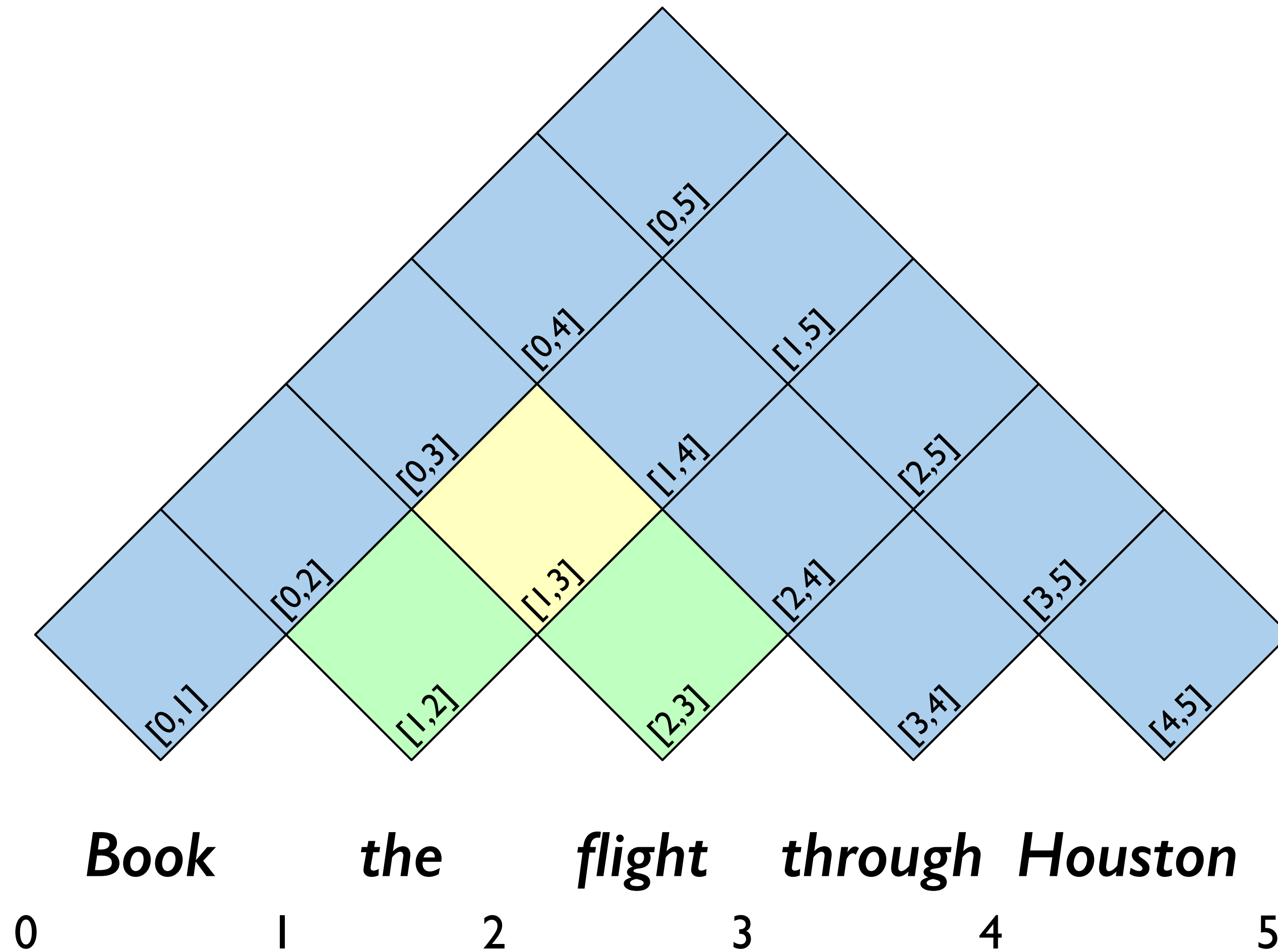
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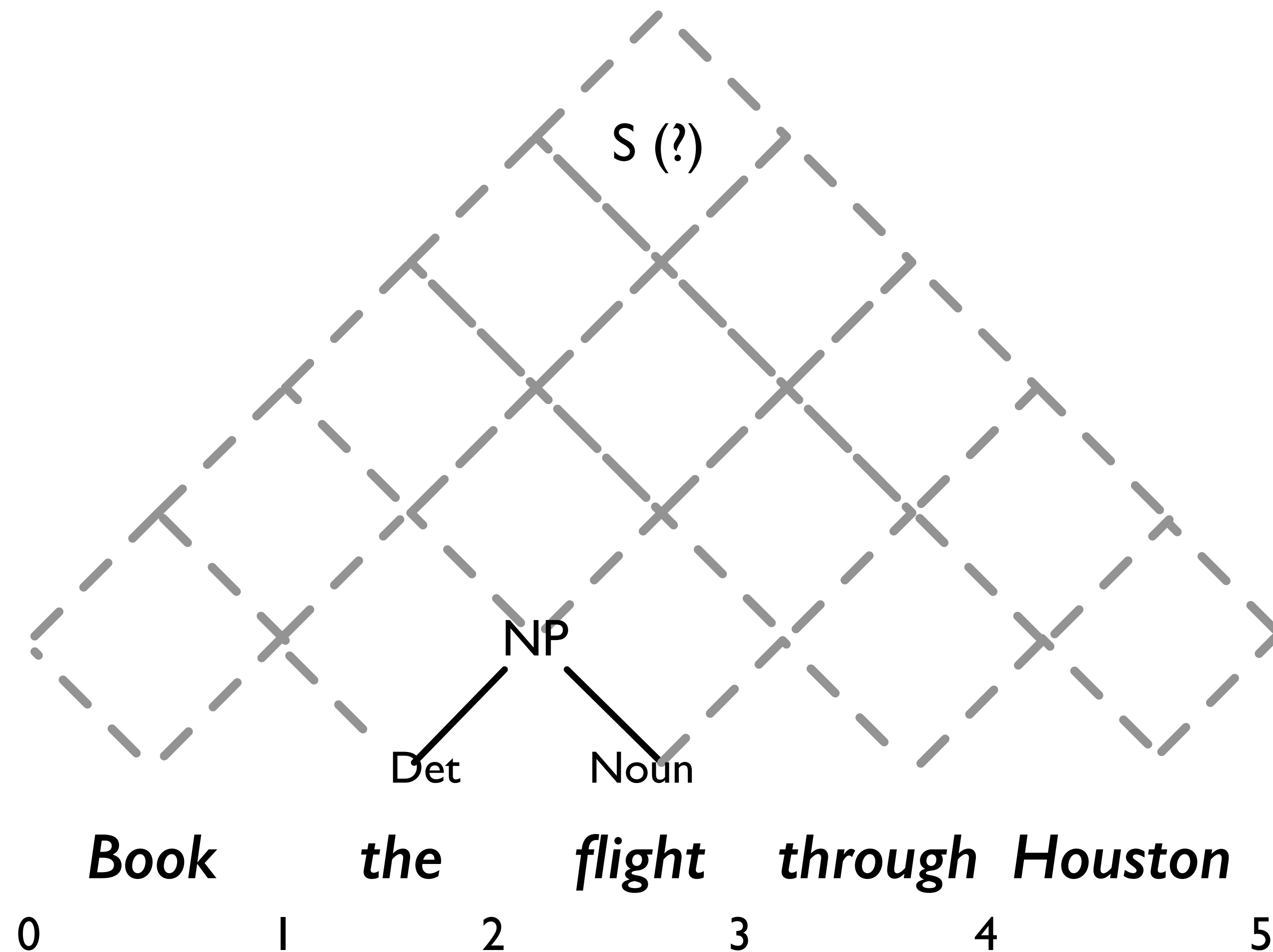
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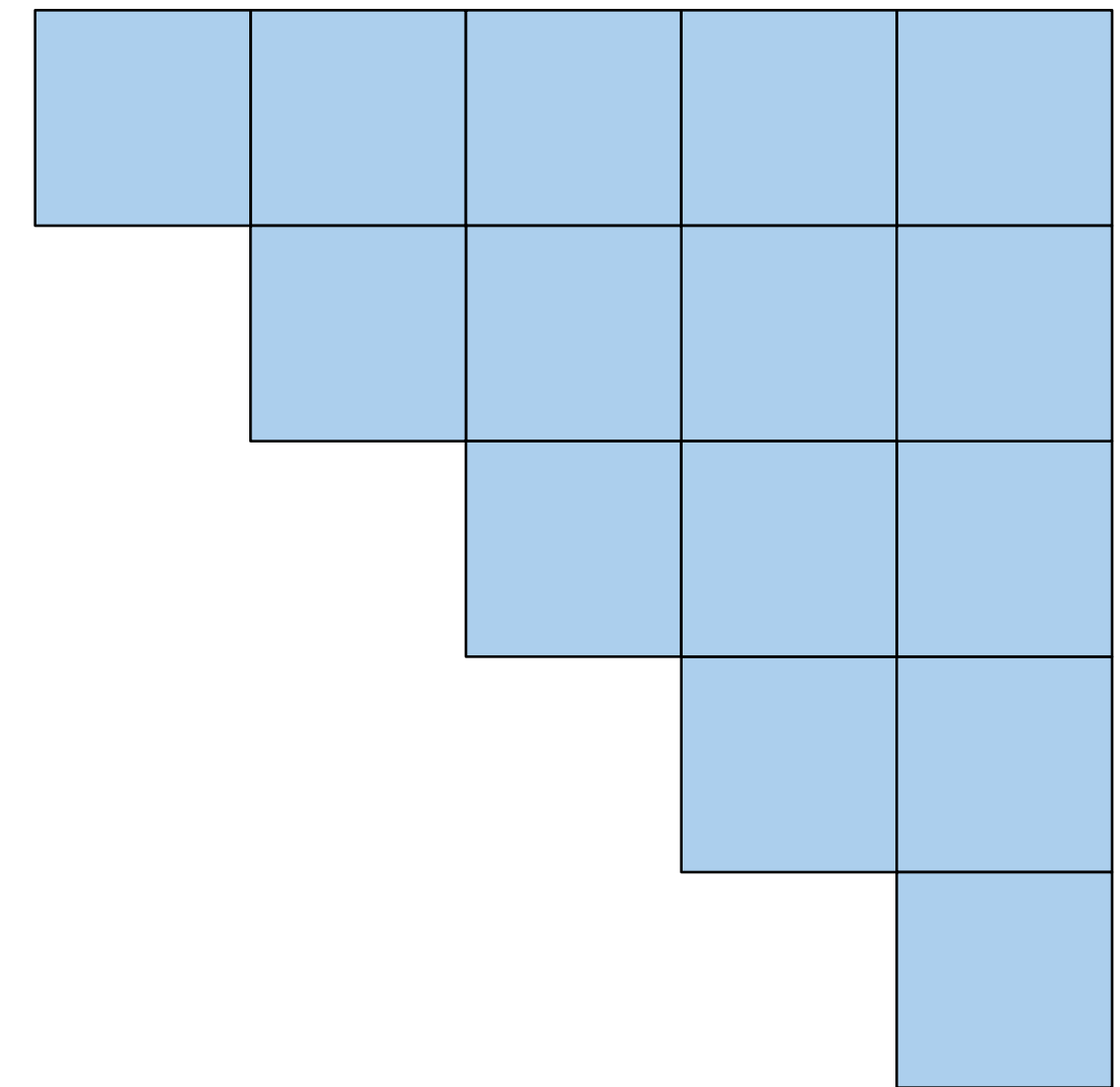


Dynamic Programming in CKY

- 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 $j > i + 1$

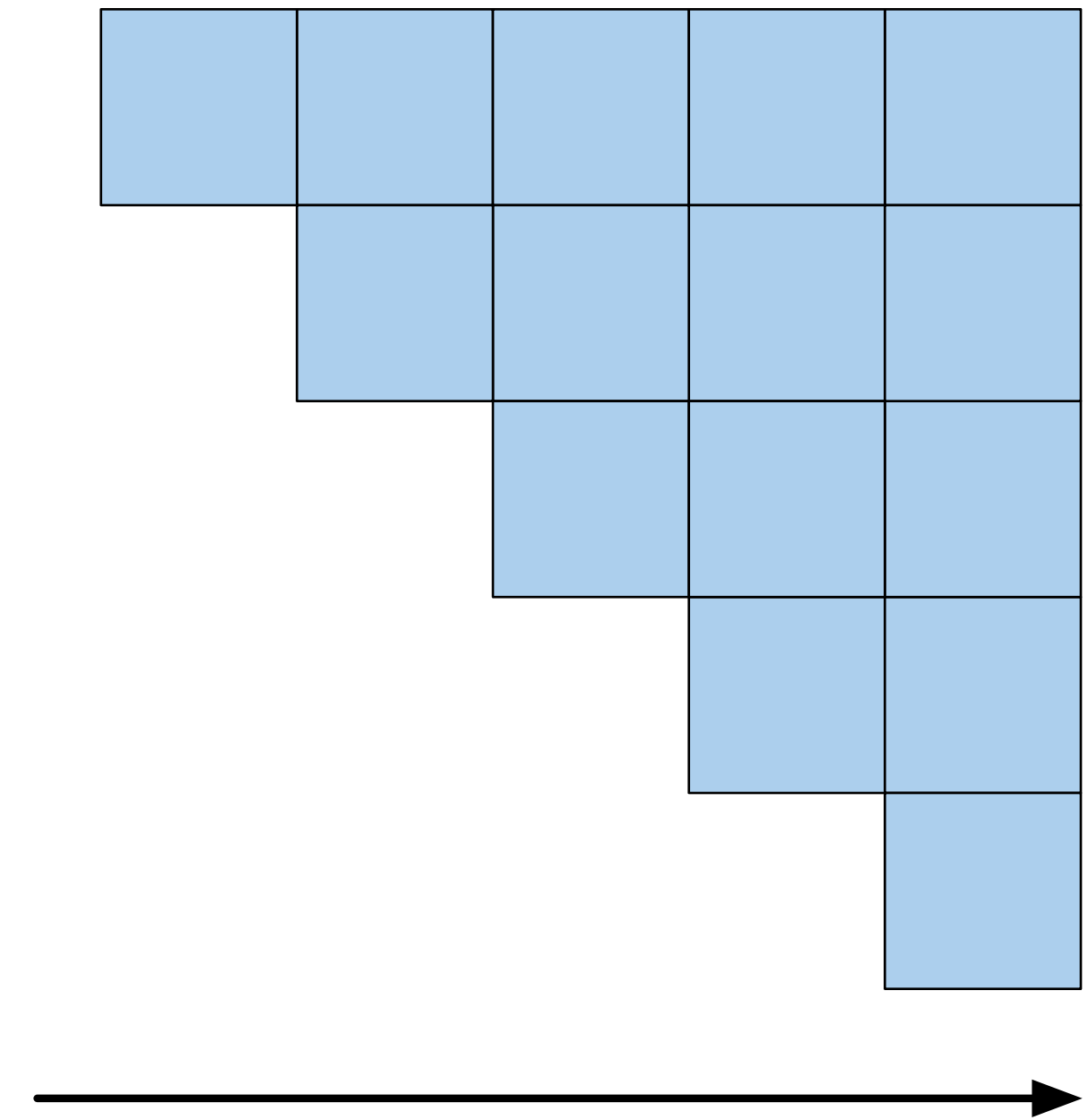
CKY

- Table fills:



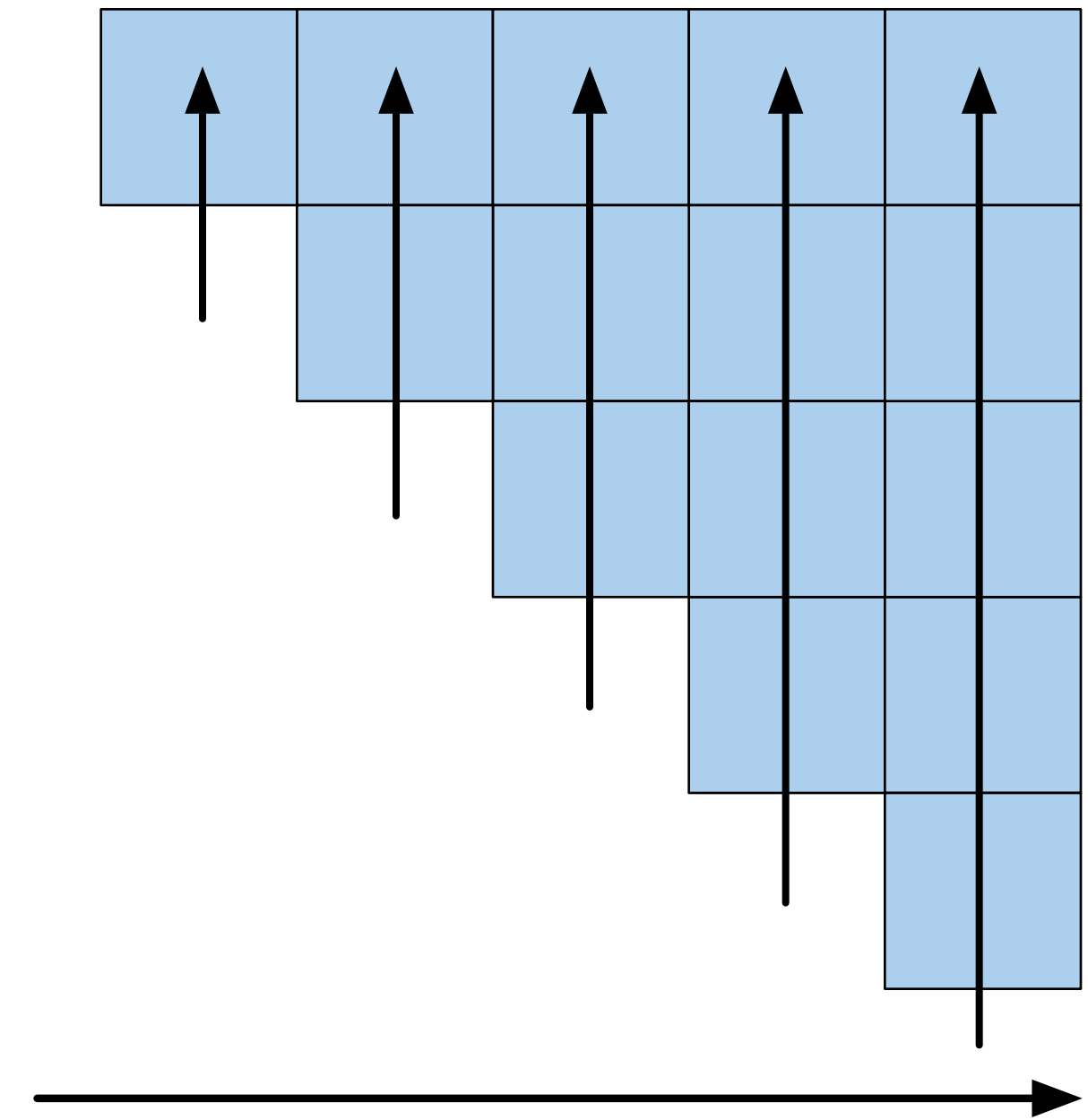
CKY

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



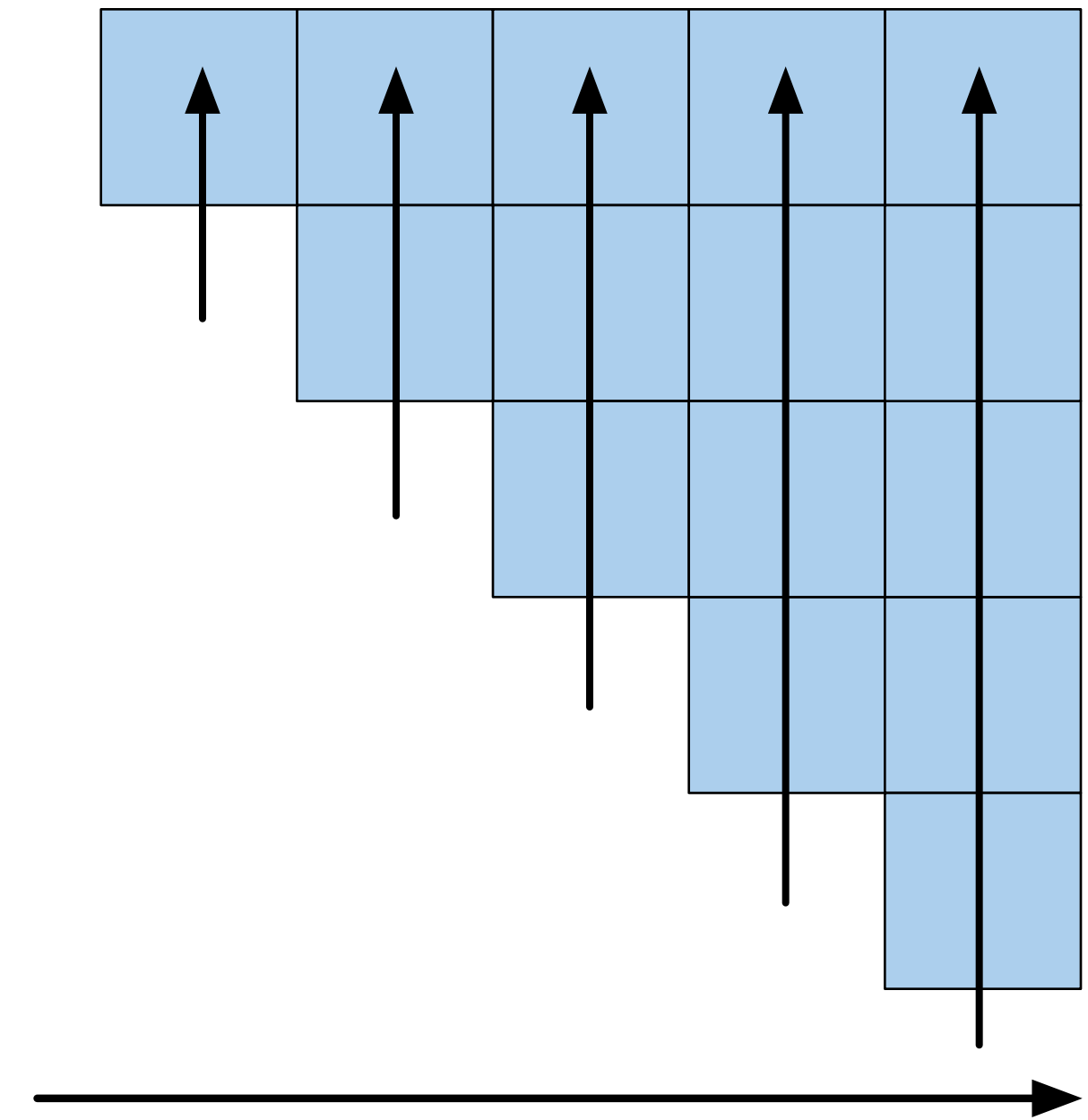
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- Table fills:
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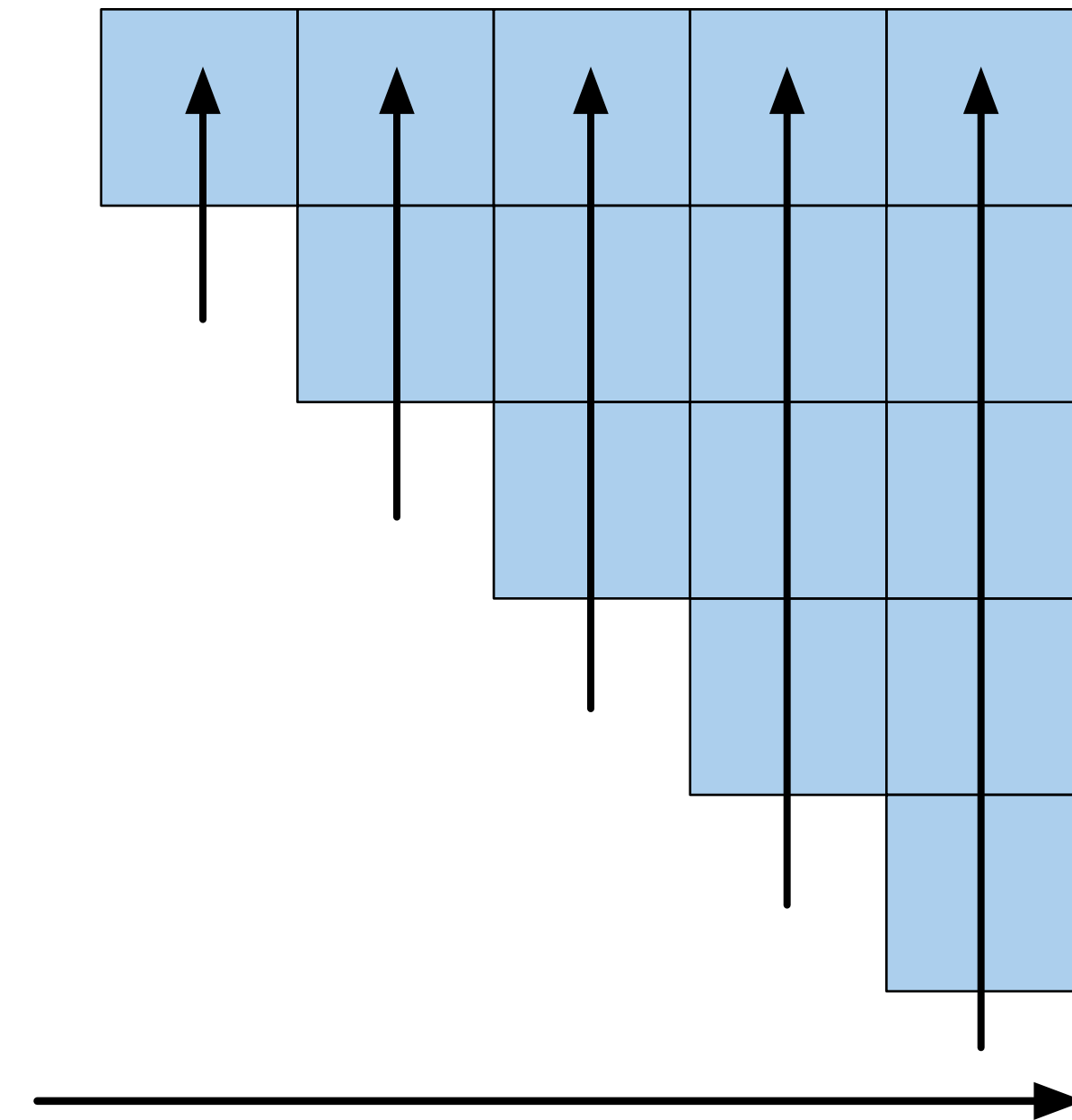
CKY

- Table fills:
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- Why?



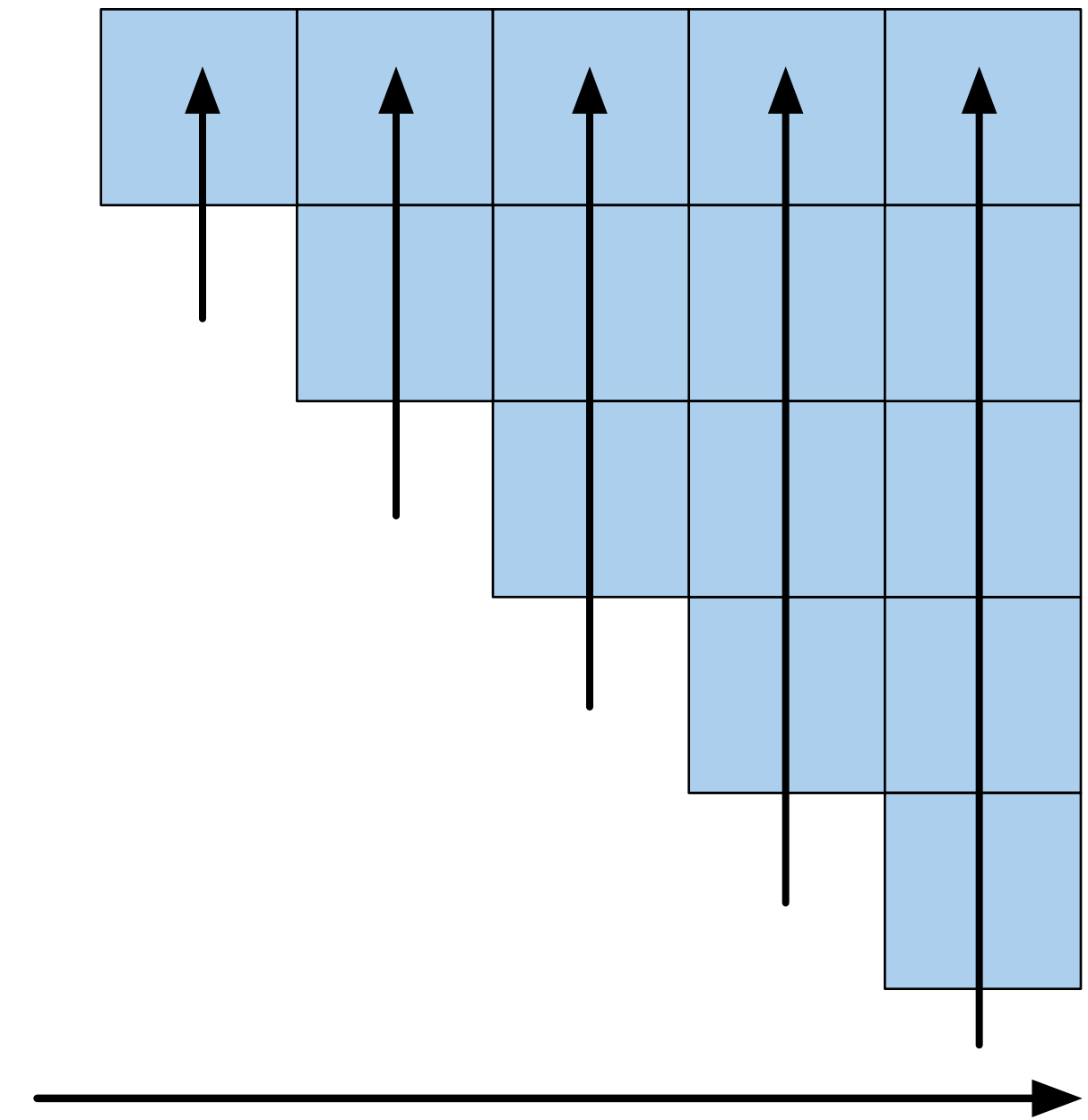
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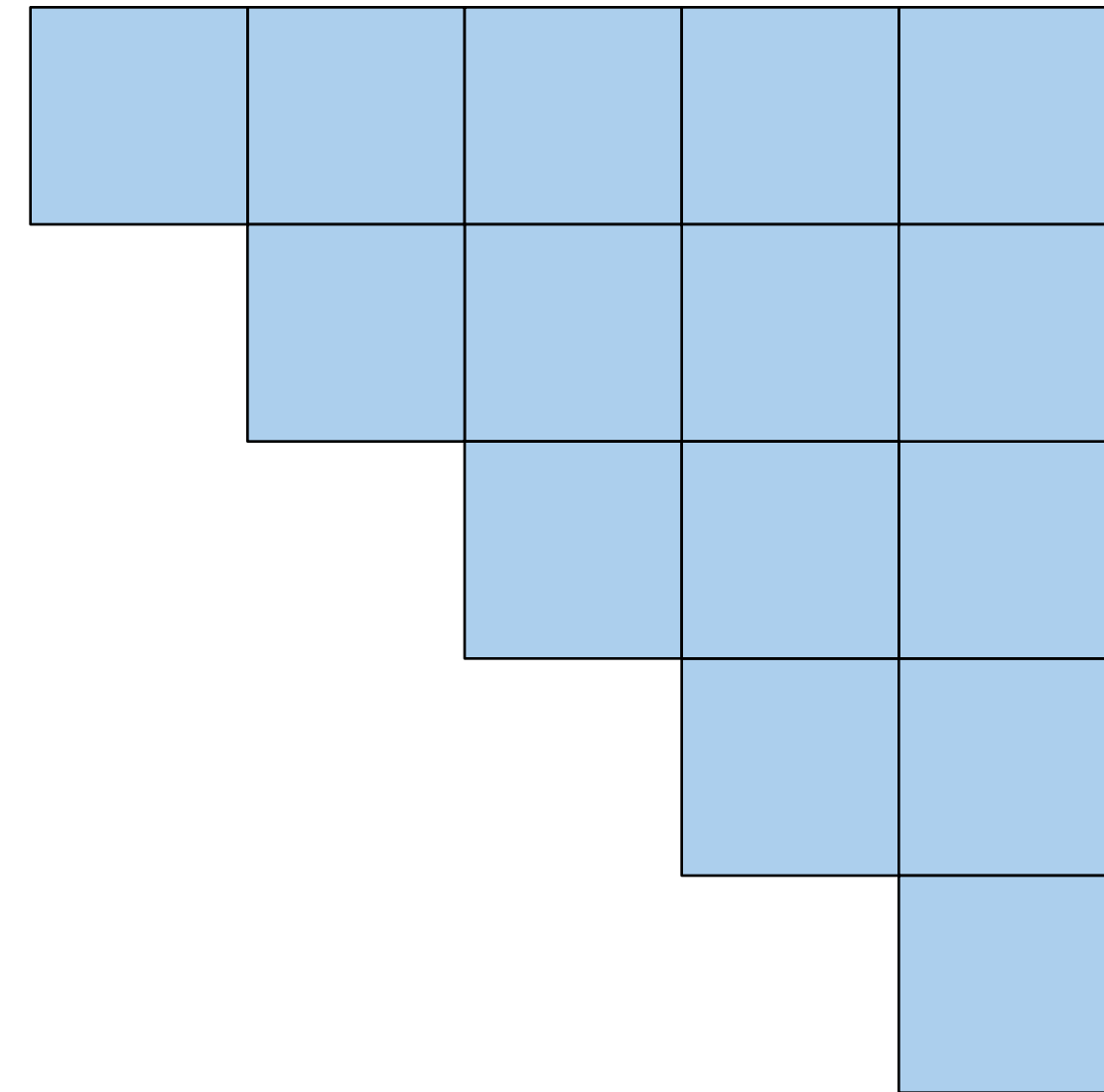


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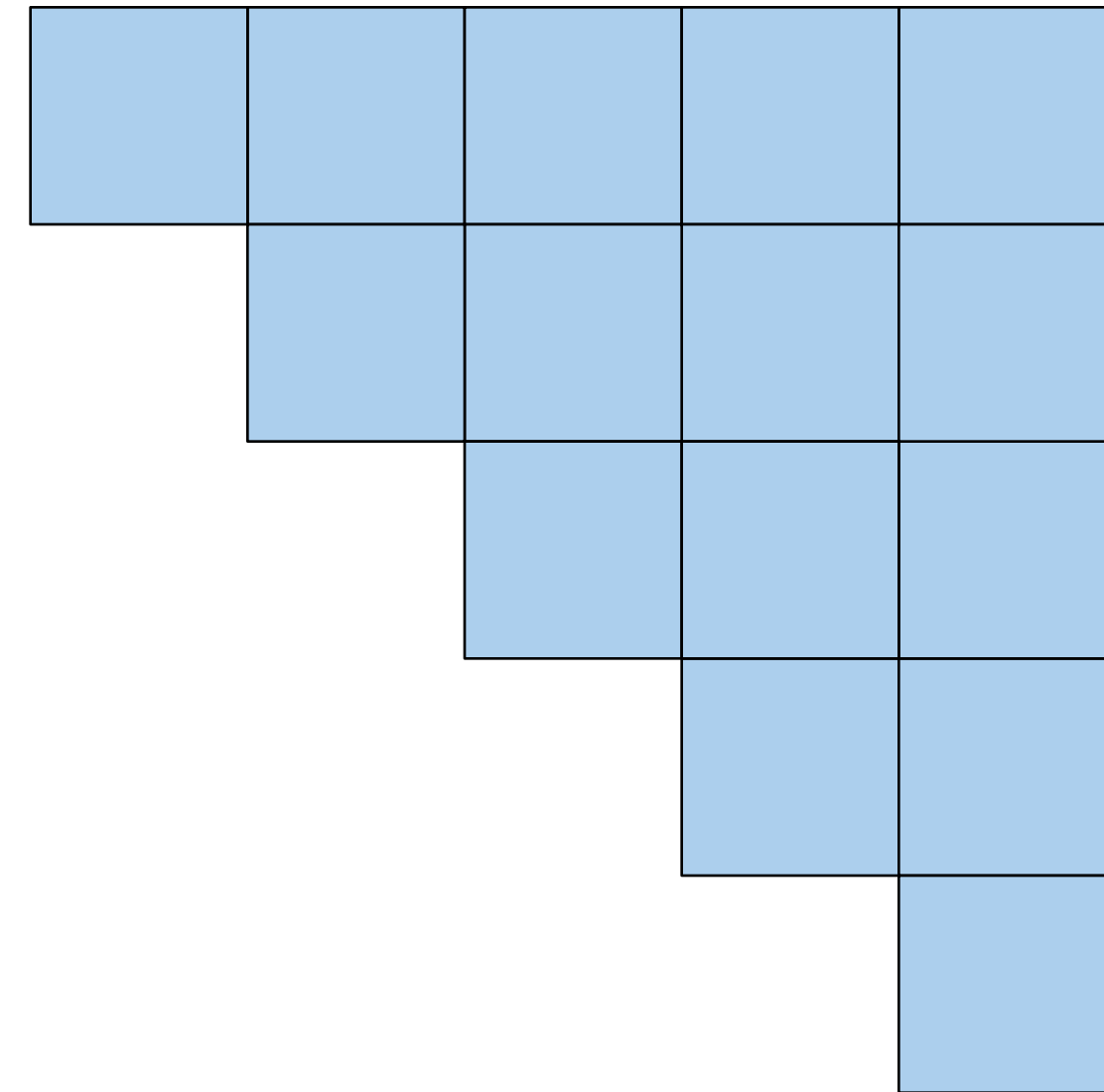


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 - For cell $[i, j]$, must be able to access all cells $[i, k]$ and $[k, j]$ where $i < k < j$
 - Allows online sentence analysis

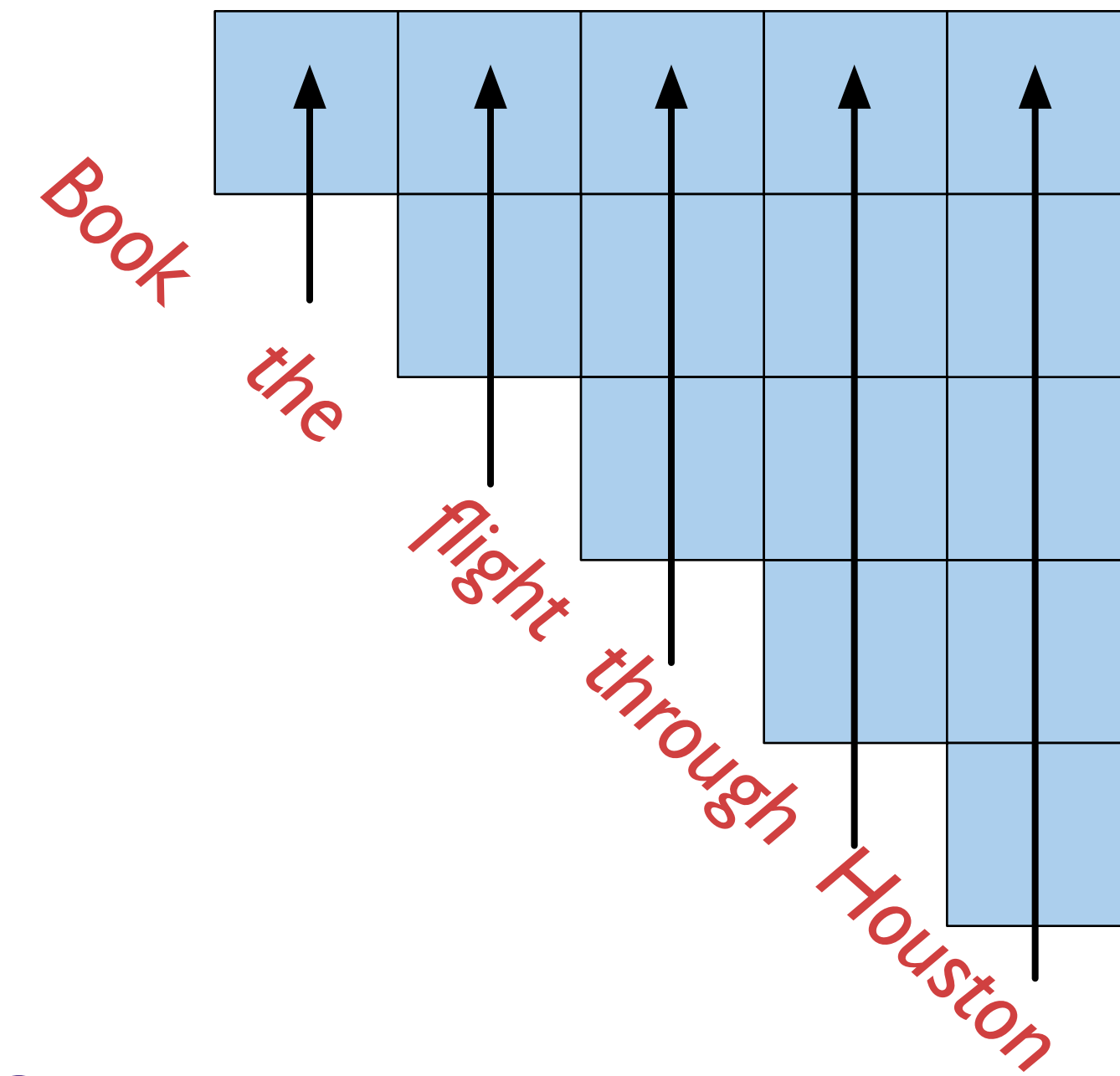
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 - Works across input string as it arrives

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CKY Algorithm

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

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Left-to-right, bottom-to-top

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Left-to-right, bottom-to-top

Sliding k as the pivot for child nodes

CKY Algorithm

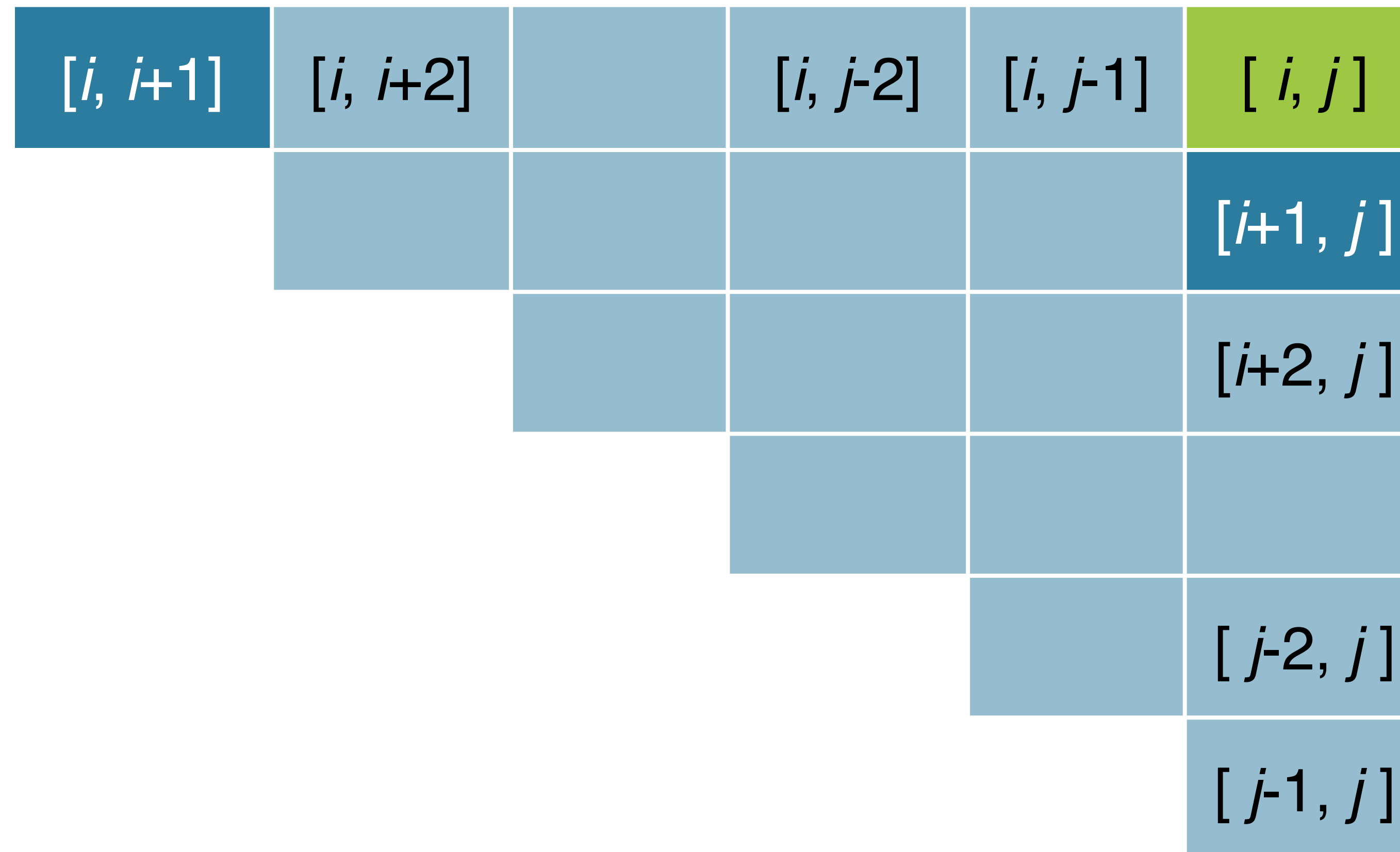
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function CKY-PARSE(words, grammar) returns table
for j ← from 1 to LENGTH(words) do
  table[j - 1, j] ← { A | A → words[j] ∈ grammar }
  for i ← from j - 2 downto 0 do
    for k ← i + 1 to j - 1 do
      table[i, j] ← table[i, j] ∪
        { A | A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

Sliding *k* as the pivot for child nodes

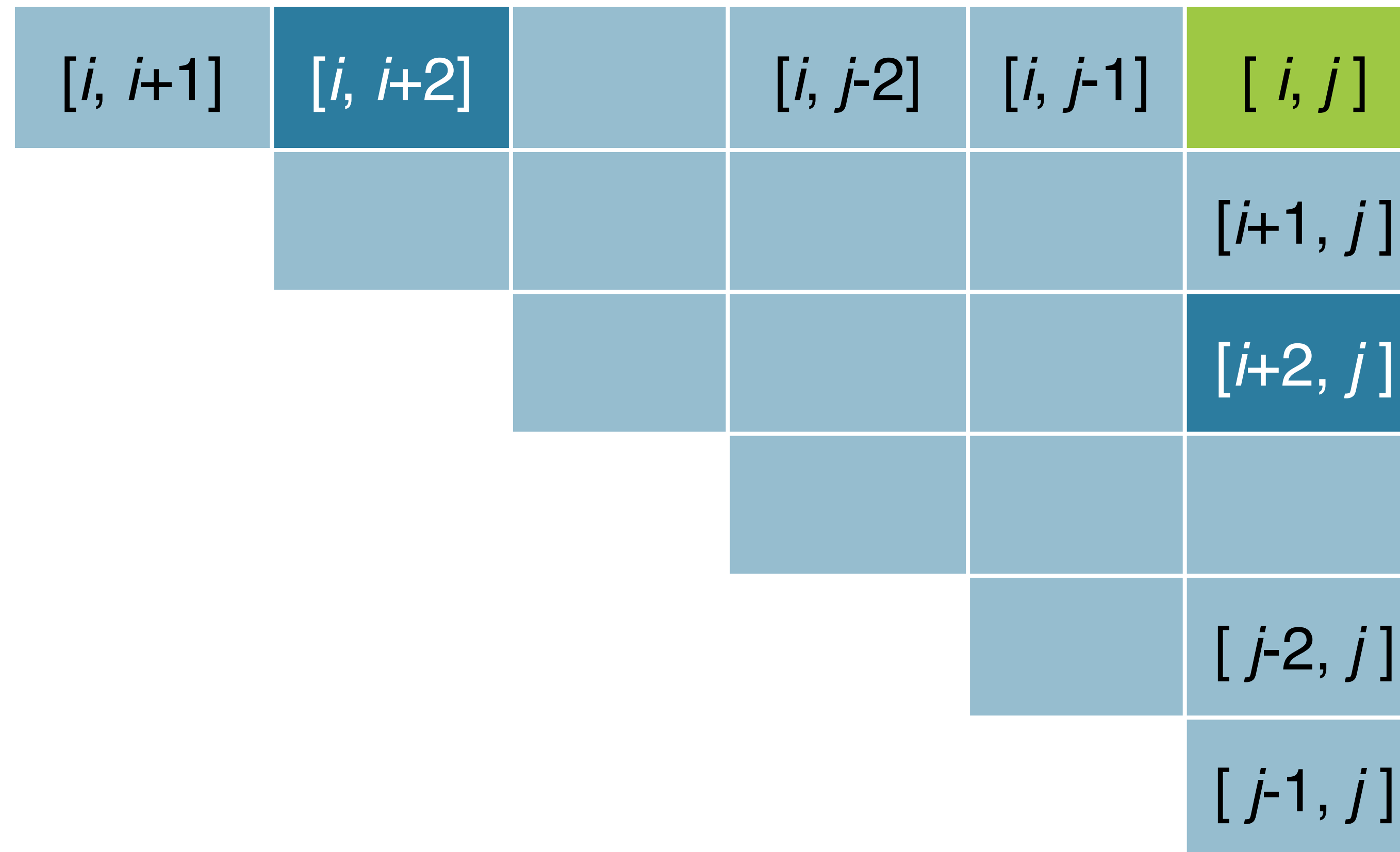
Filling the cell with set of applicable rules

Filling Cell $[i, j]$



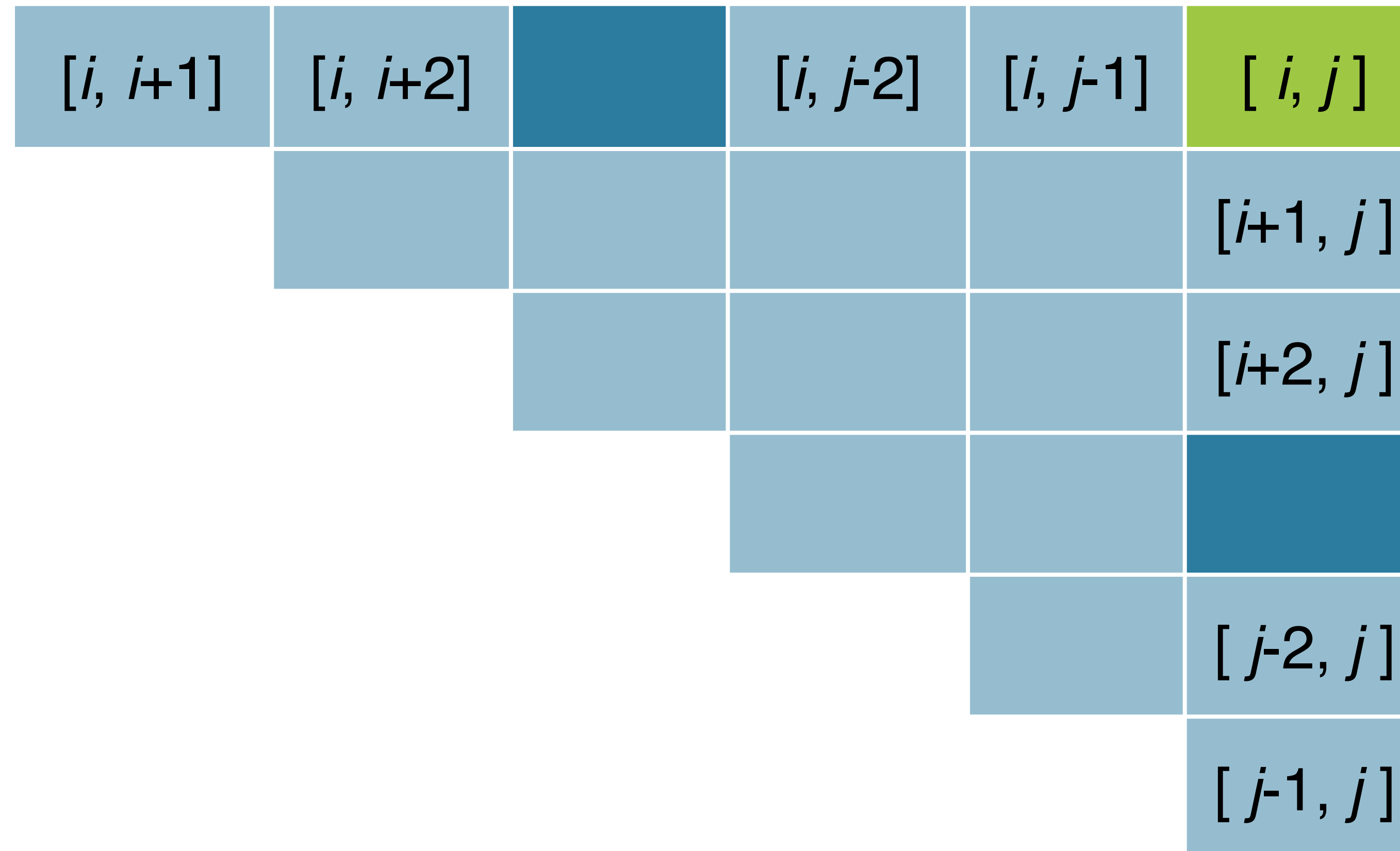
For cell $[i, j]$, find rule spanning cells $[i, k]$ and $[k, j]$ where $i < k < j$

Filling Cell $[i, j]$



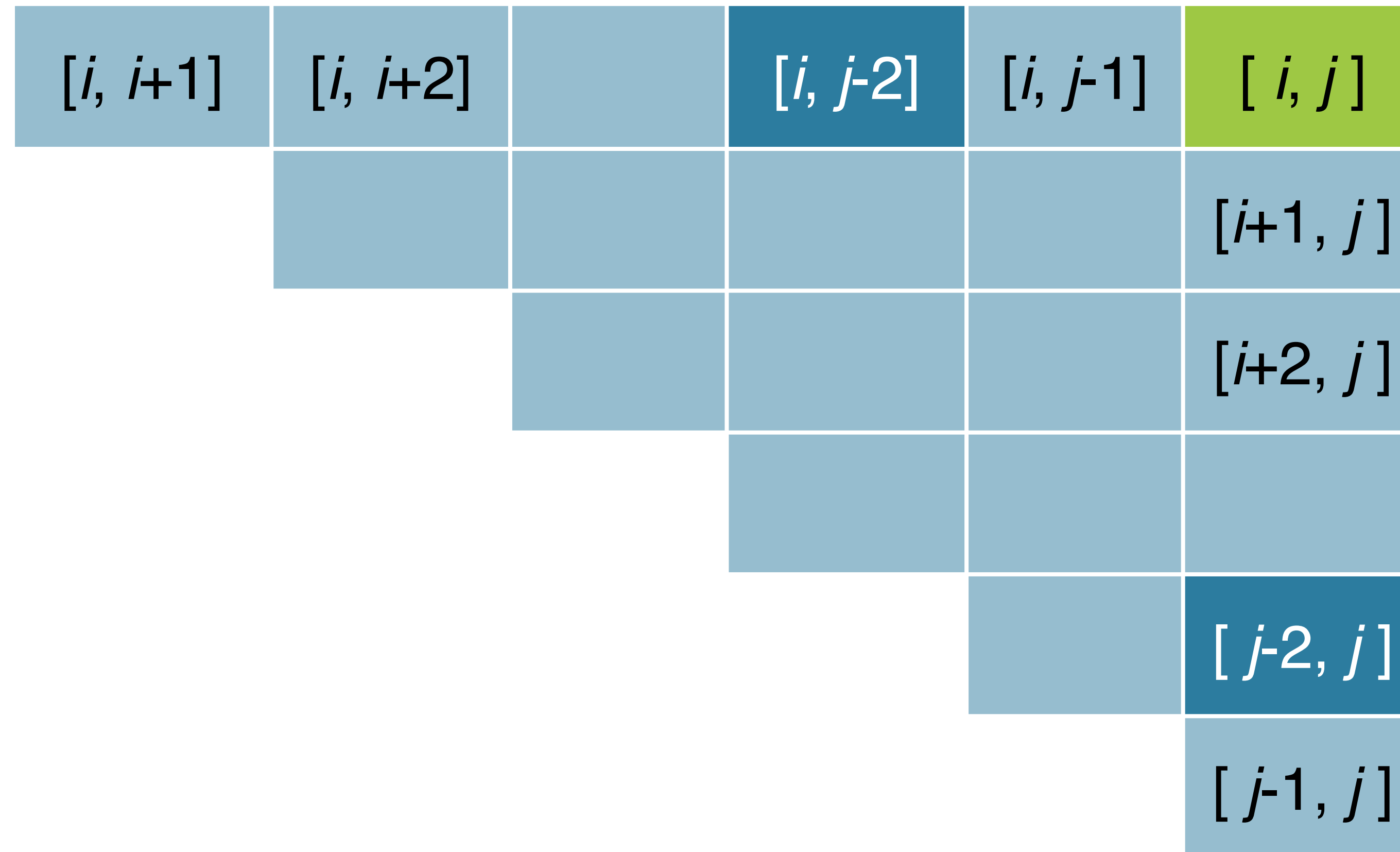
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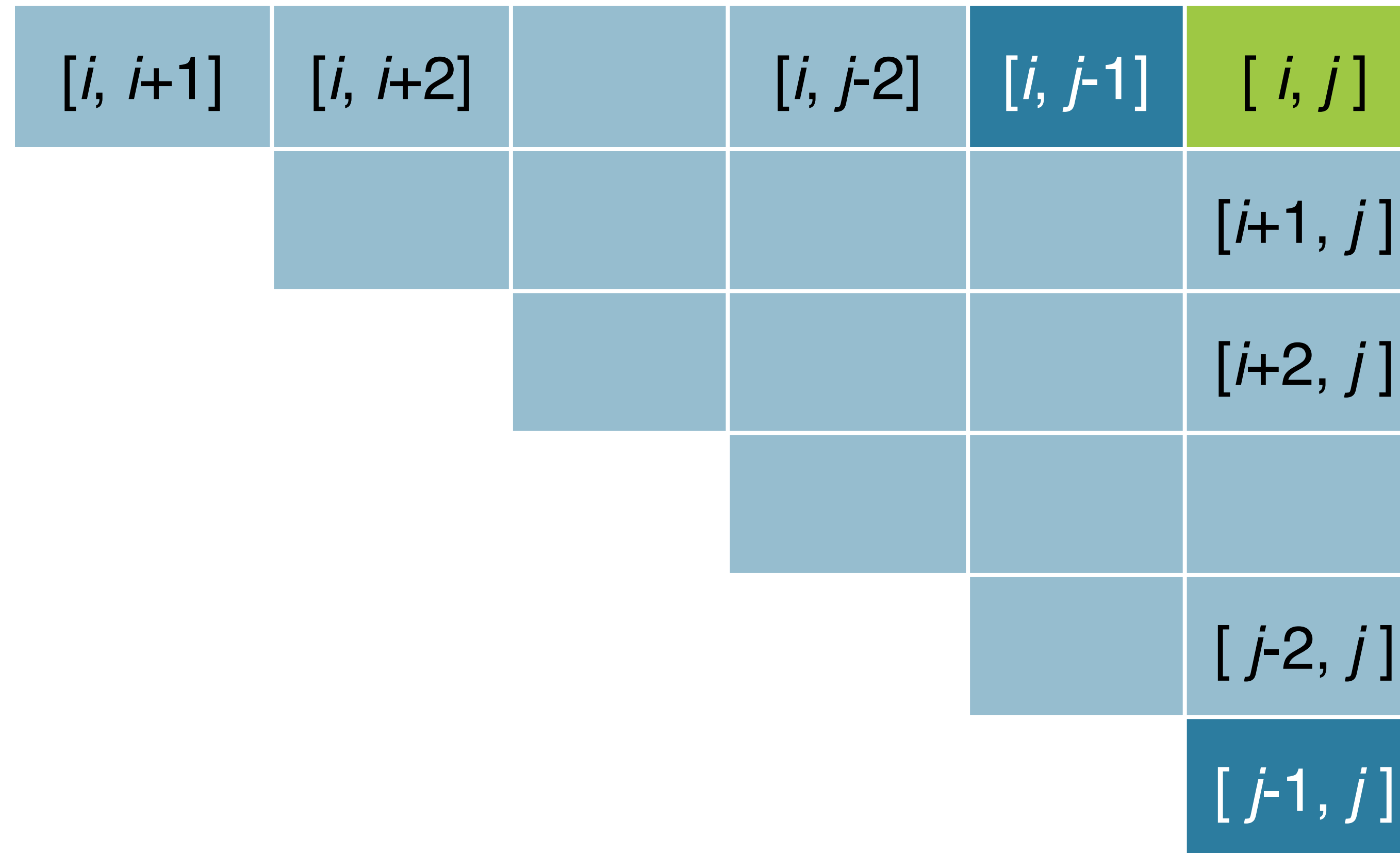
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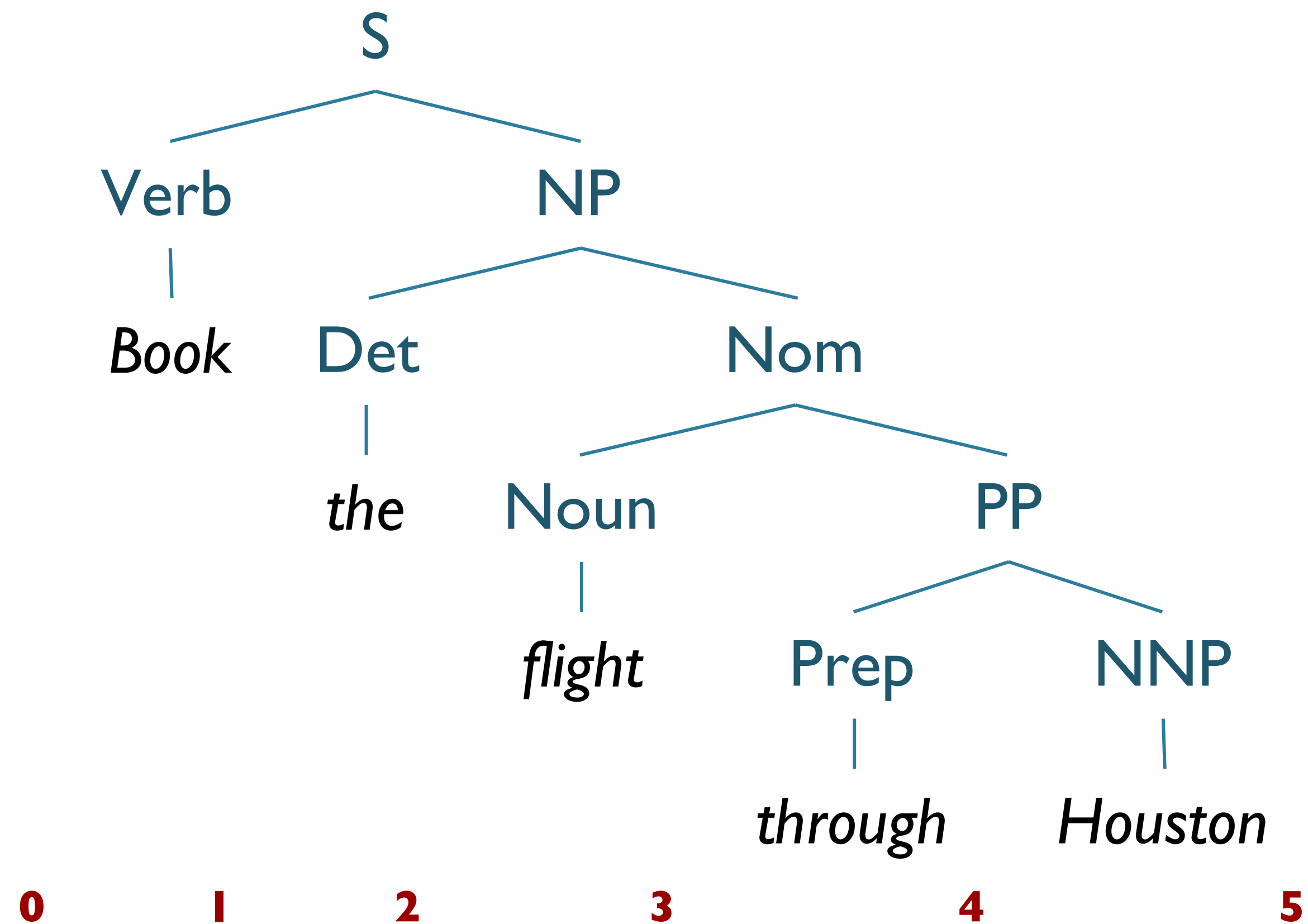
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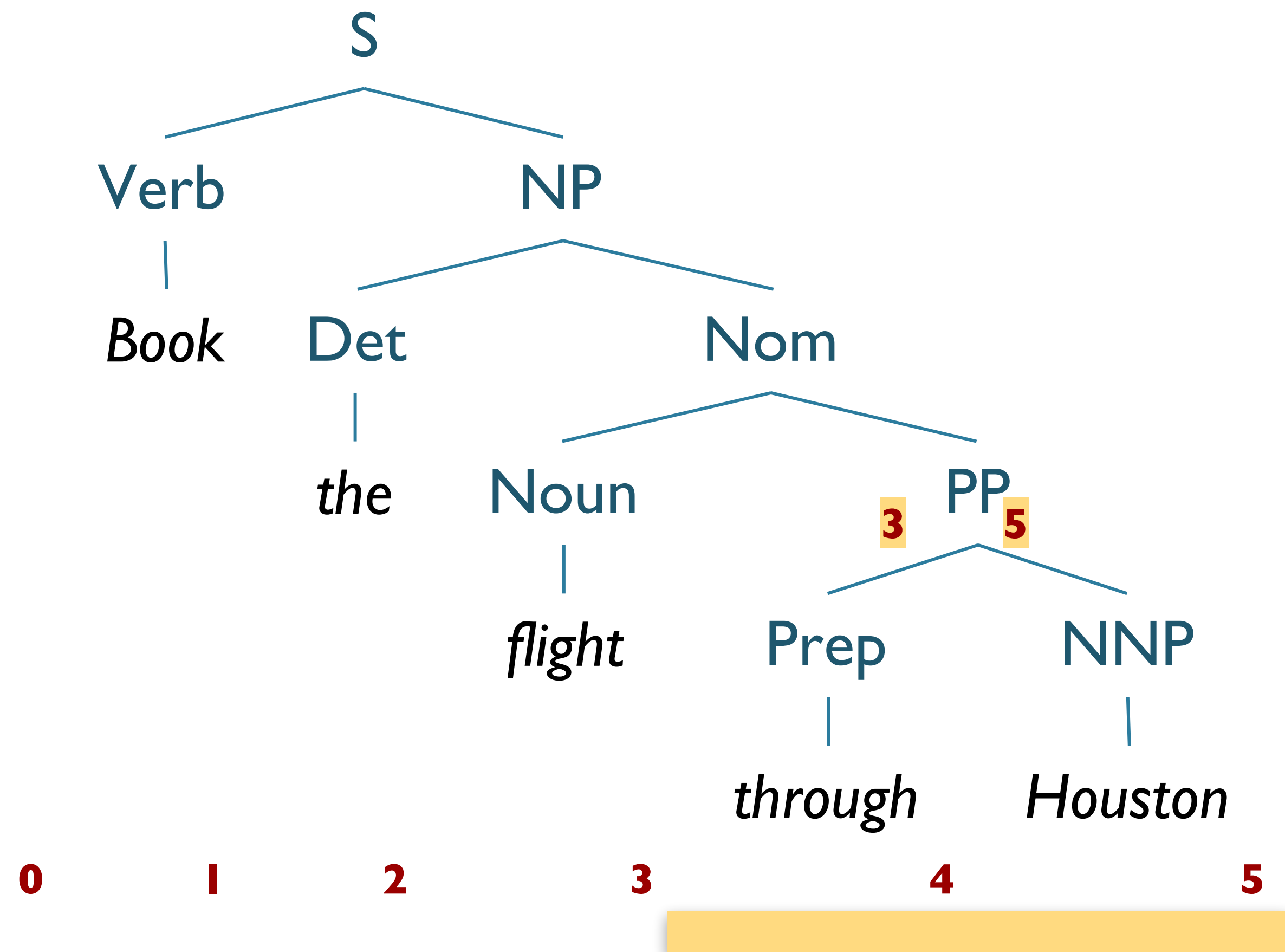
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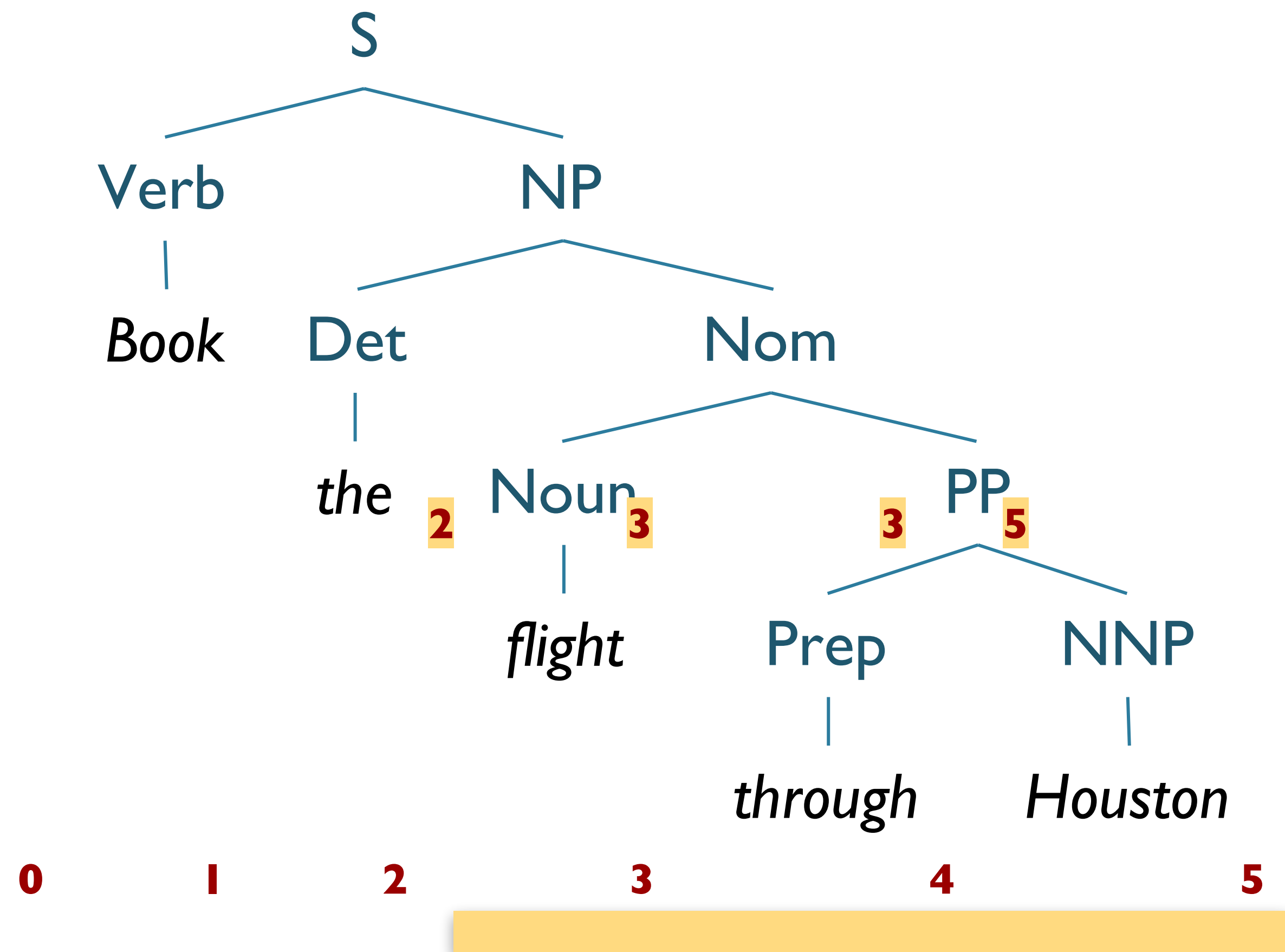
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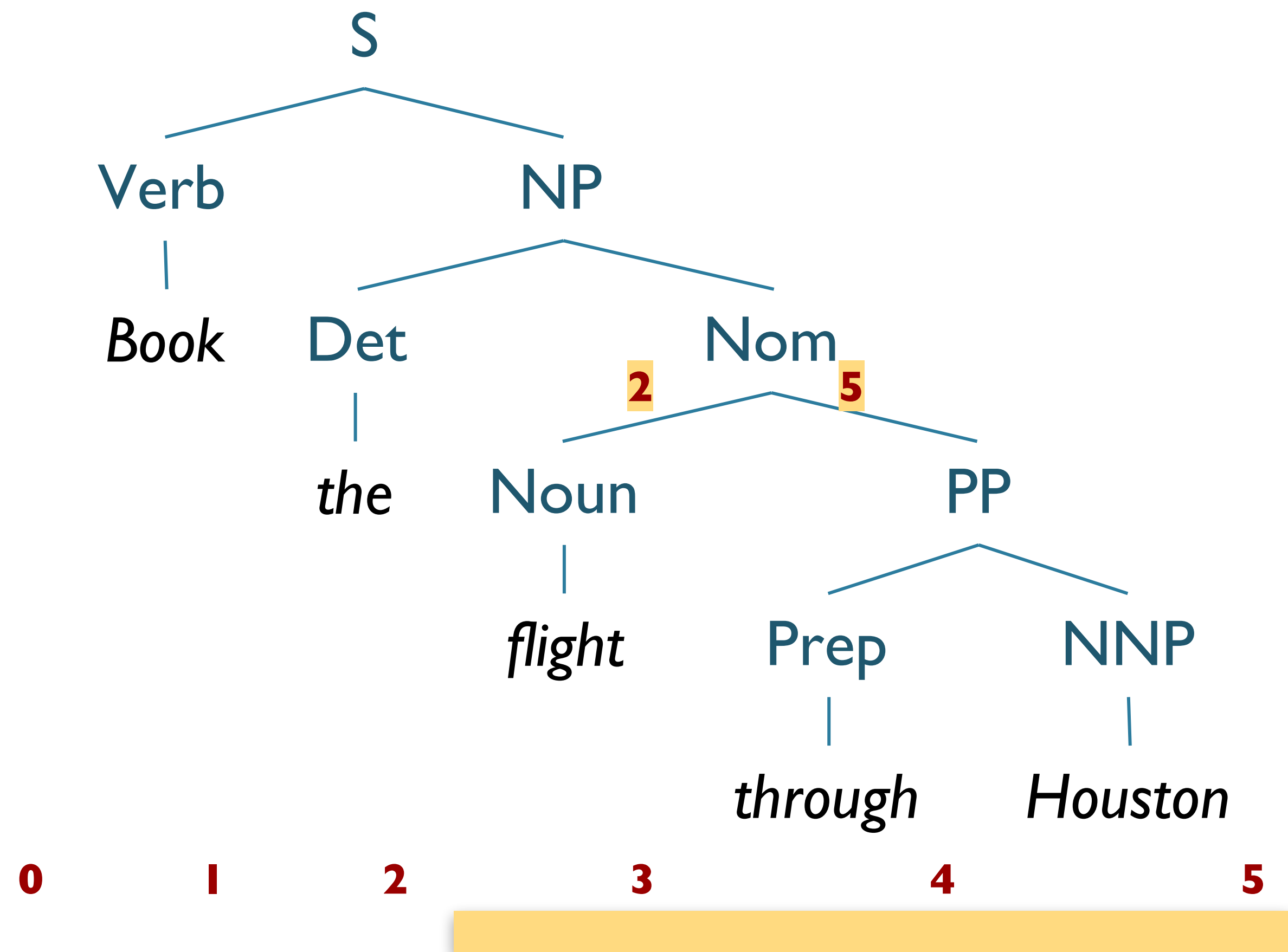
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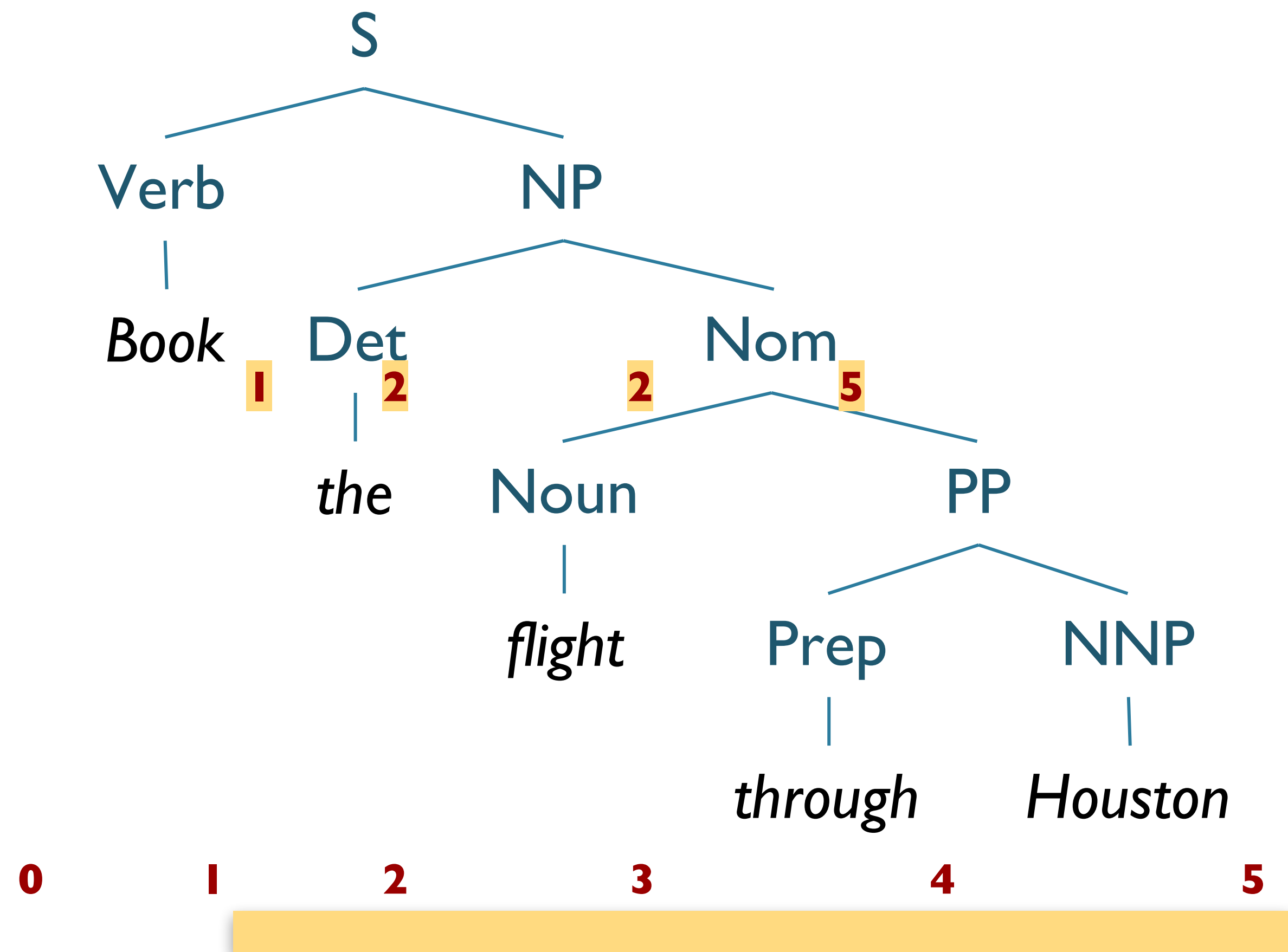
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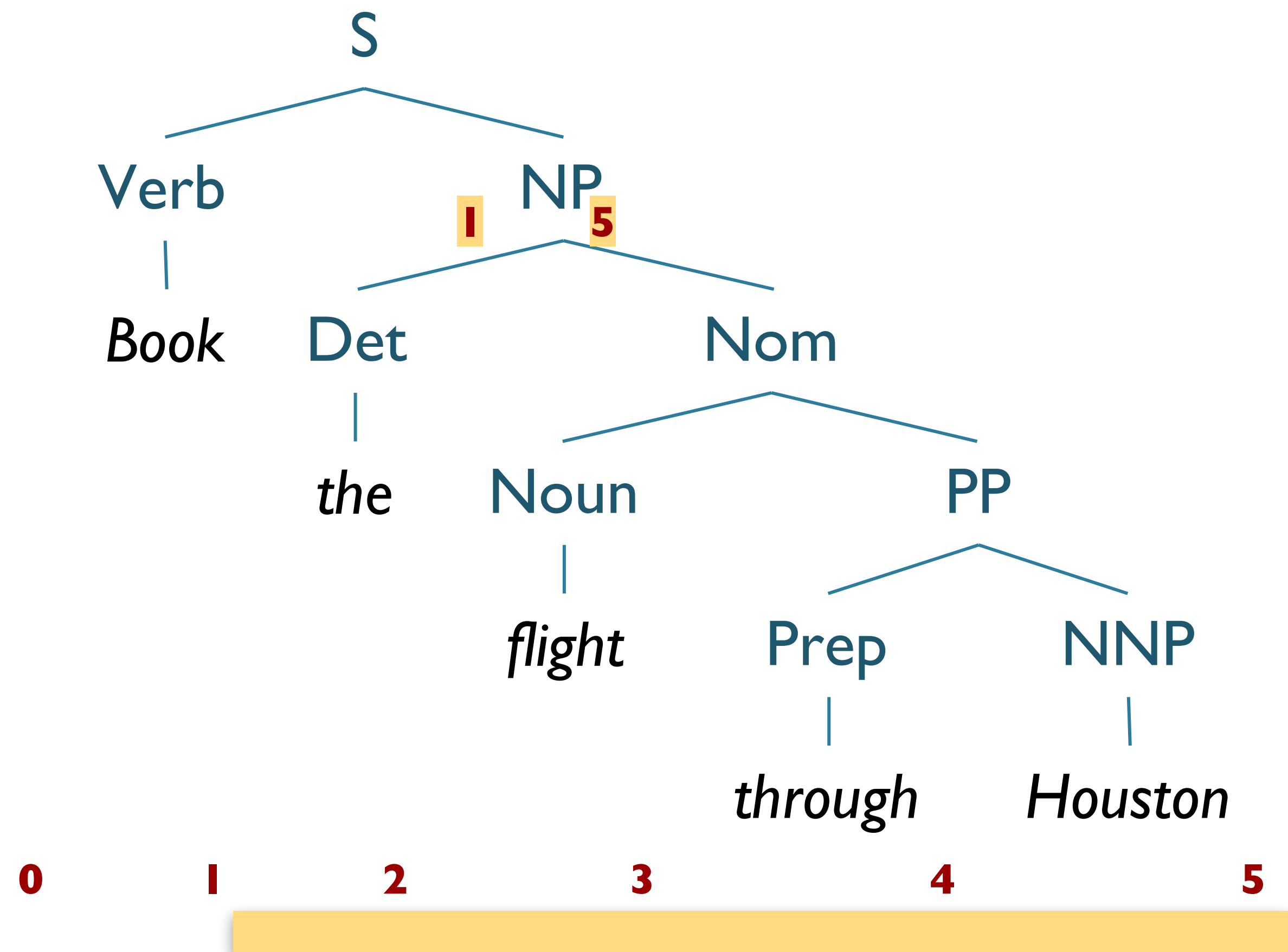
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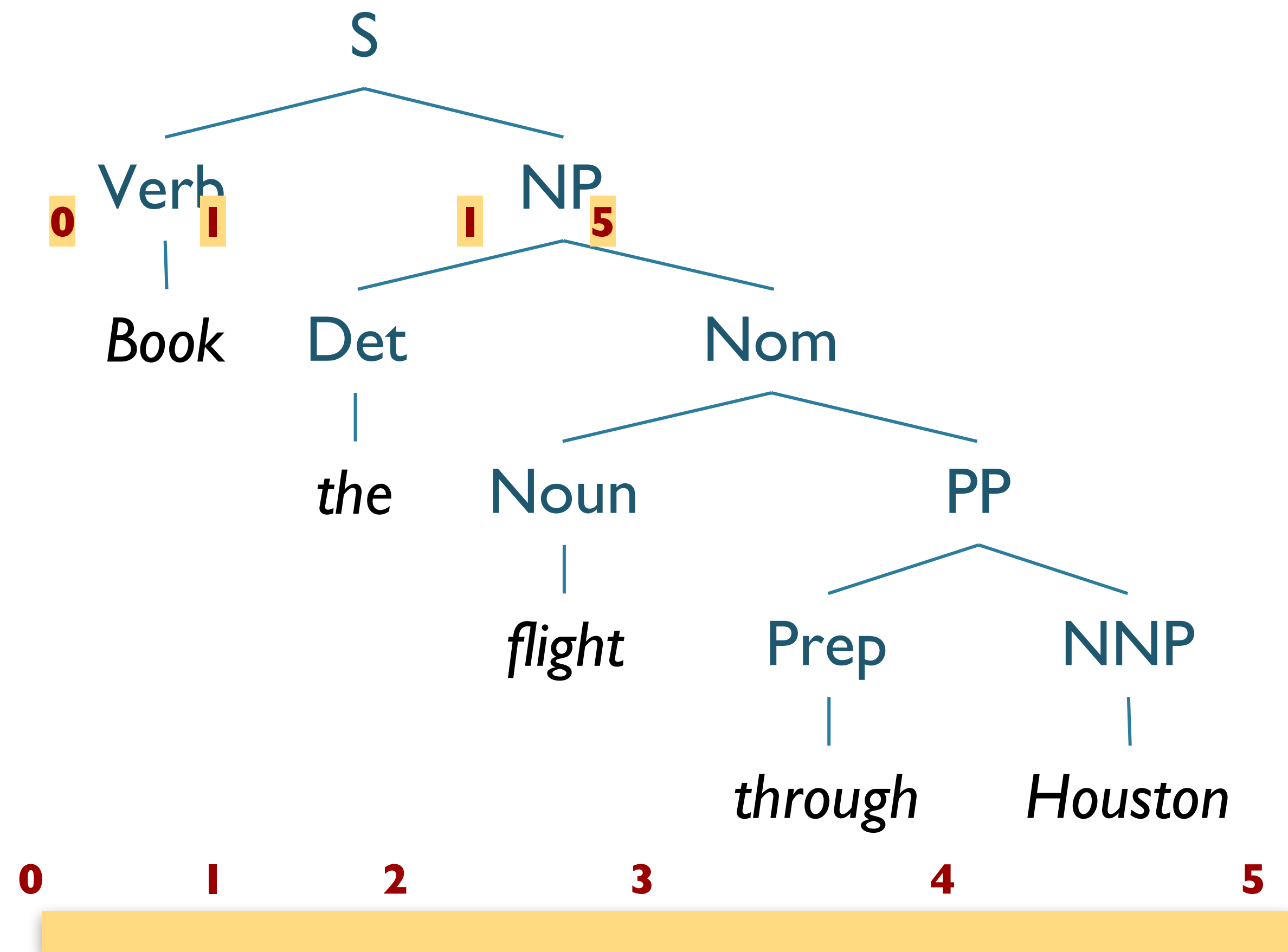
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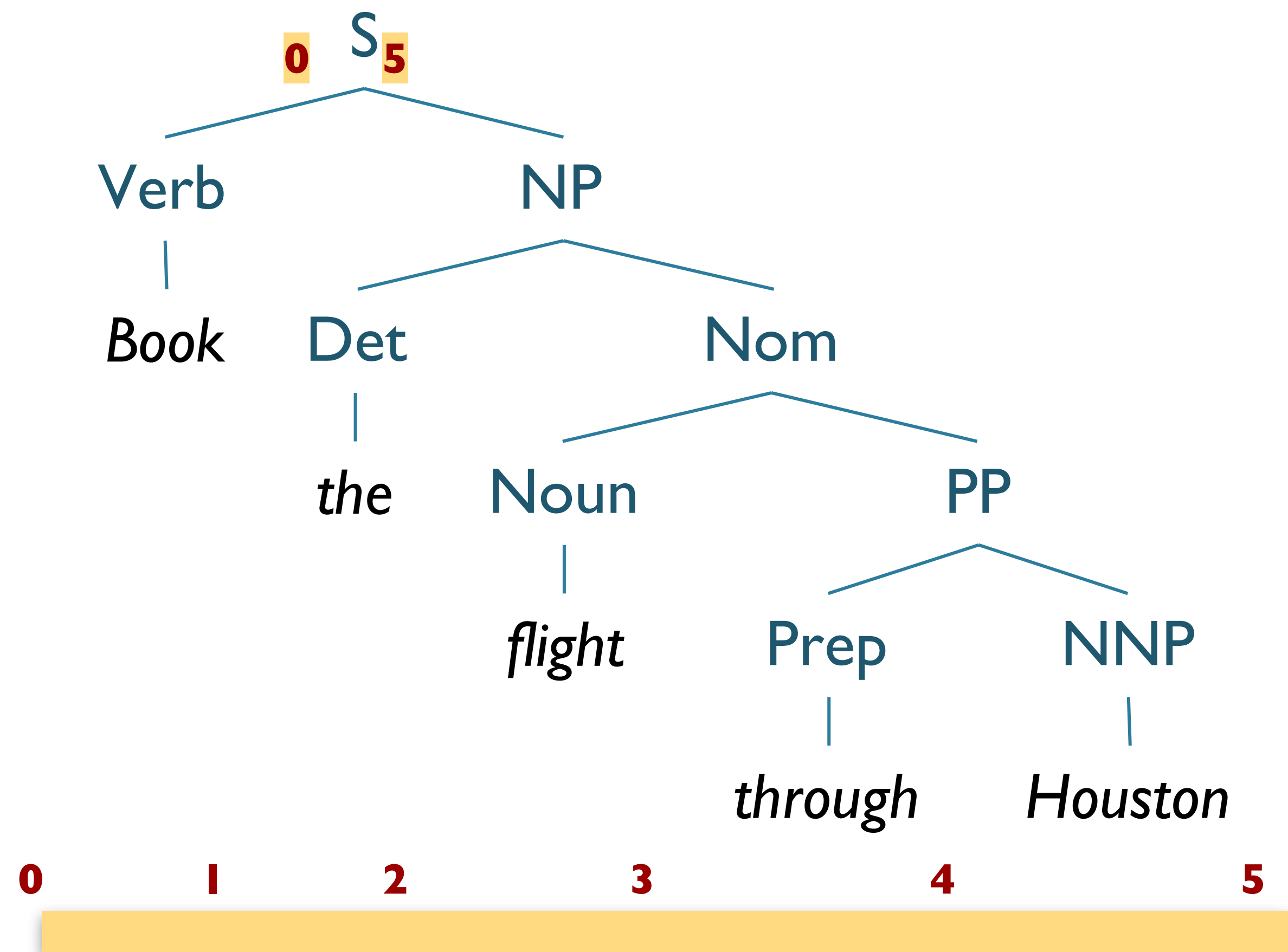
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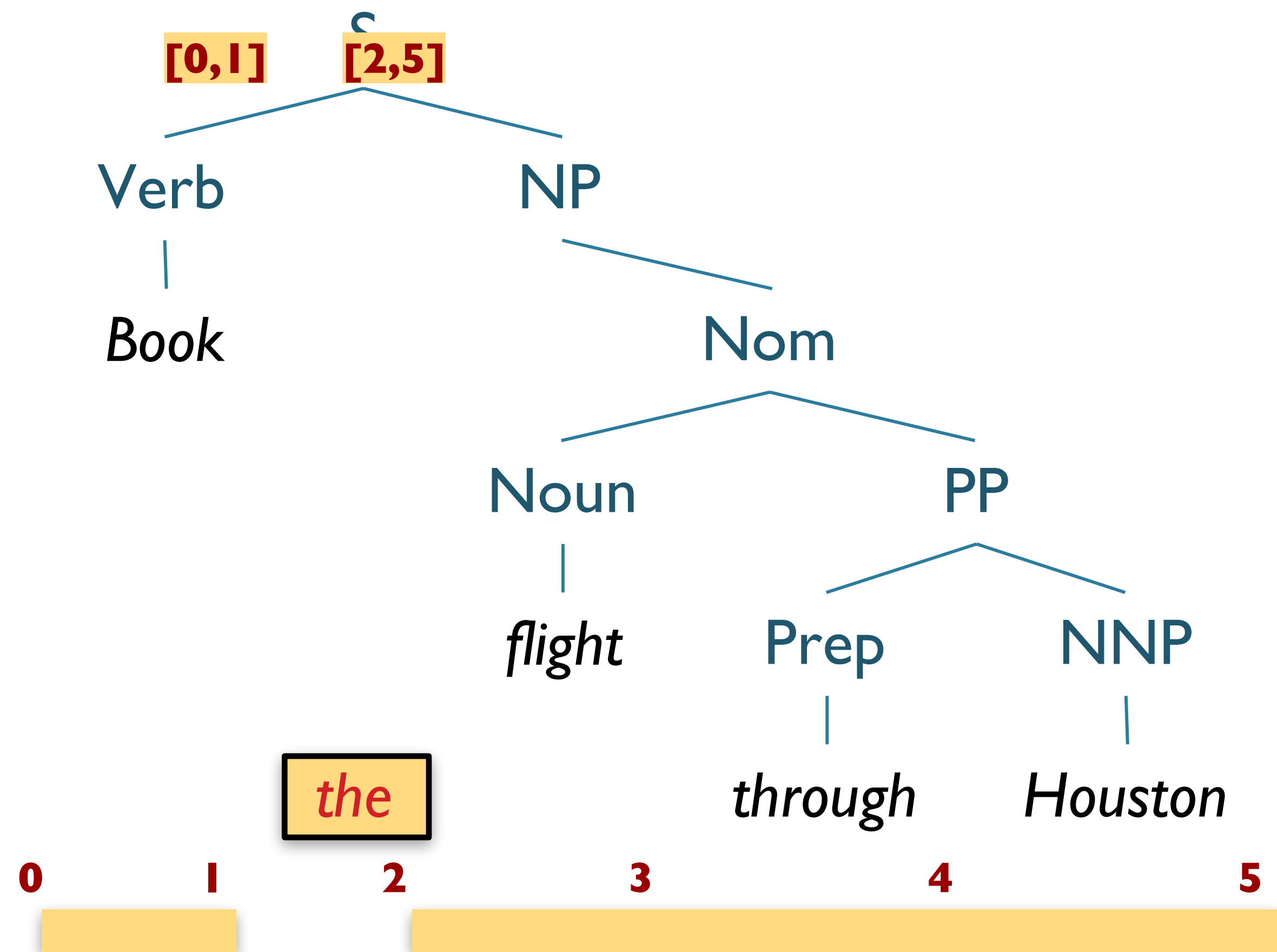
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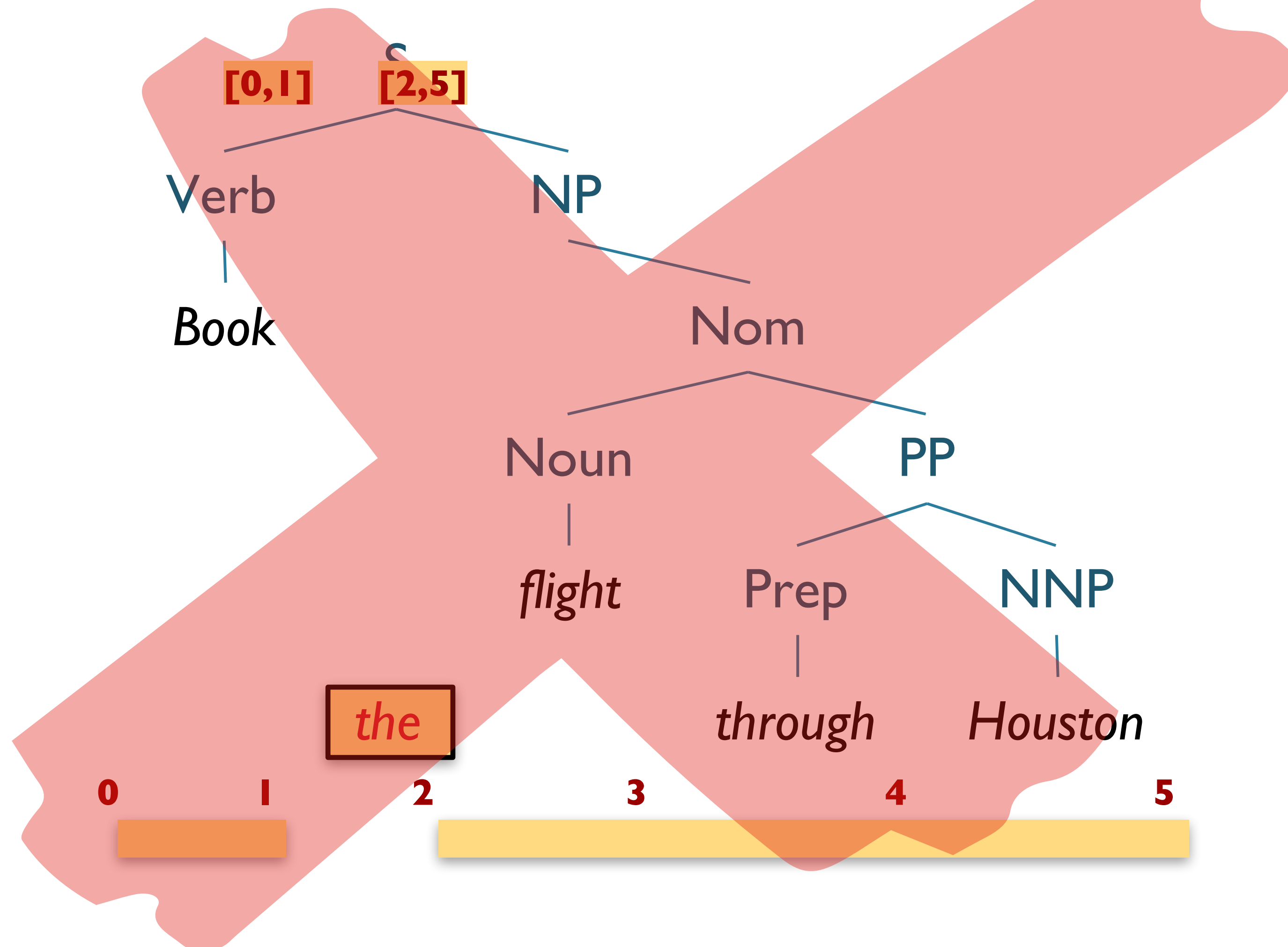
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CKY Parsing Example

\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

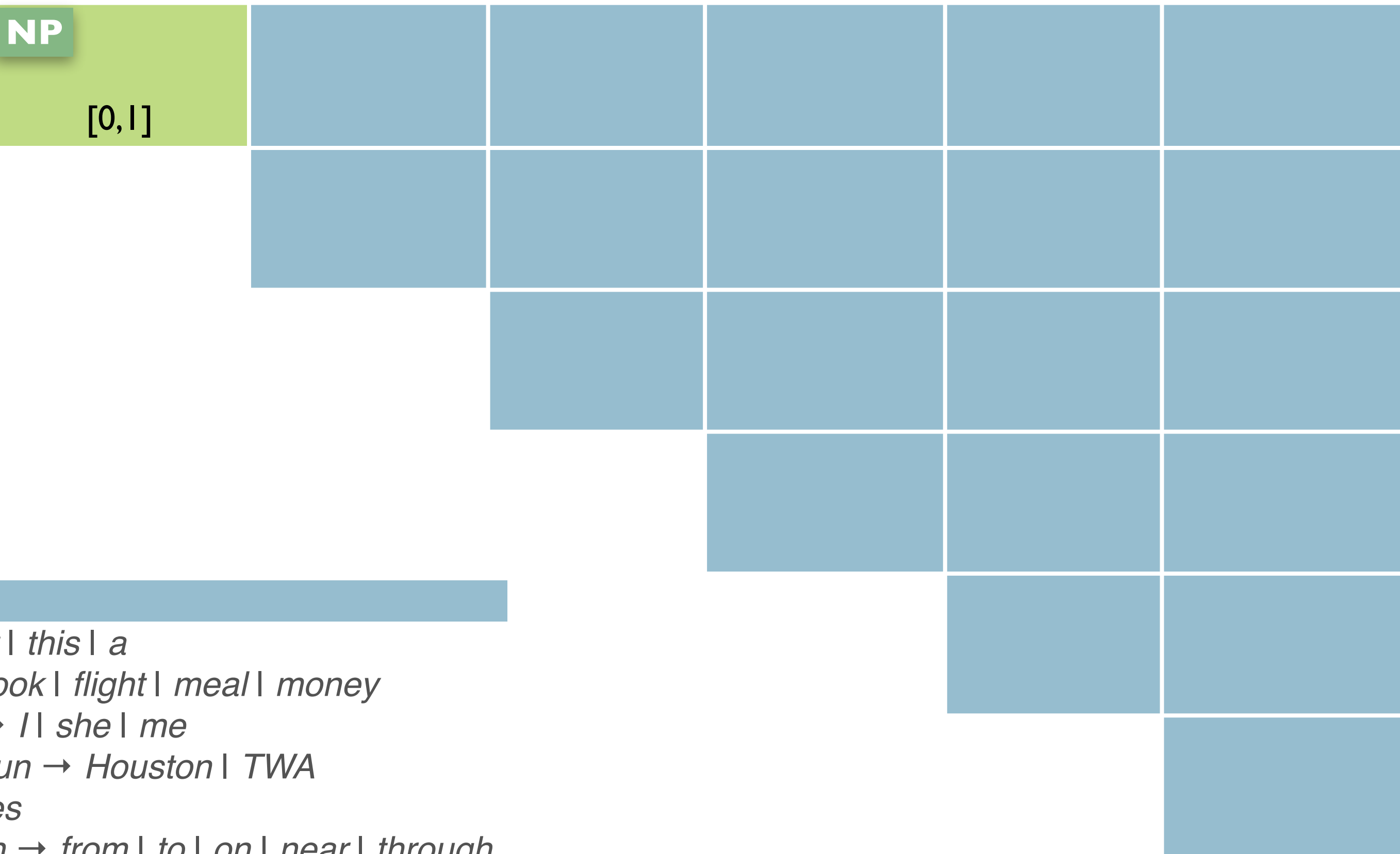
on

TWA

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



L_1 Grammar

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

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

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

$NP \rightarrow I / she / me$

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]

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*

1

prefer

a

flight

on

TWA

L_1 Grammar

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

S → *book / include / prefer*

$S \rightarrow \text{Verb NP}$

$$S \rightarrow X_2 PP$$
$$S \rightarrow Verb PP$$
$$S \rightarrow VP PP$$

$NP \rightarrow I / she / me$

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*

NP, Pronoun [0,1]

Verb, VP, S

[1,2]

[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*

/

prefer

a

flight

on

TWA

L_1 Grammar

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

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

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

$NP \rightarrow I / she / me$

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*

**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*

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L_1 Grammar

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

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

$NP \rightarrow I / she / me$

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*

NP, NP,
Präposition
[0,1]

$[0,2]$

Verb, VP, S

[1,2]

Verb, VP, S

[1,2]

Lexicon

Det → *that* | *this* | *a*

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

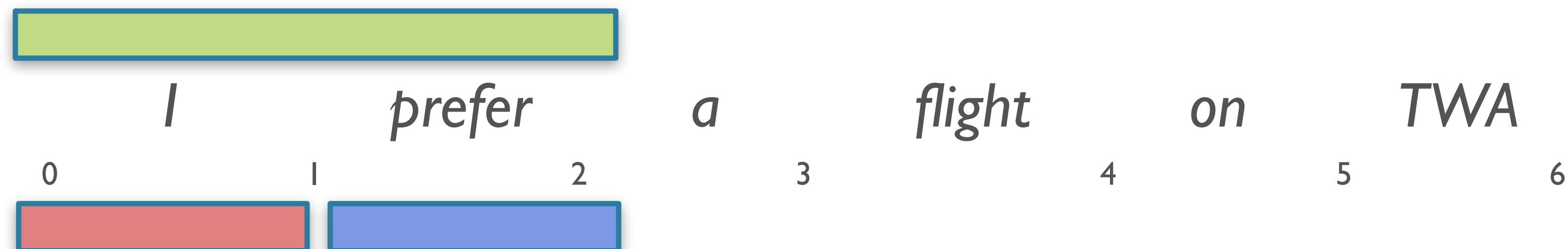
Pronoun → I | she | me

Proper-Noun → *Houston* | *TWA*

Aux → *does*

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

Verb → *book* | *include* | *prefer*



\mathcal{L}_1 Grammar

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

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

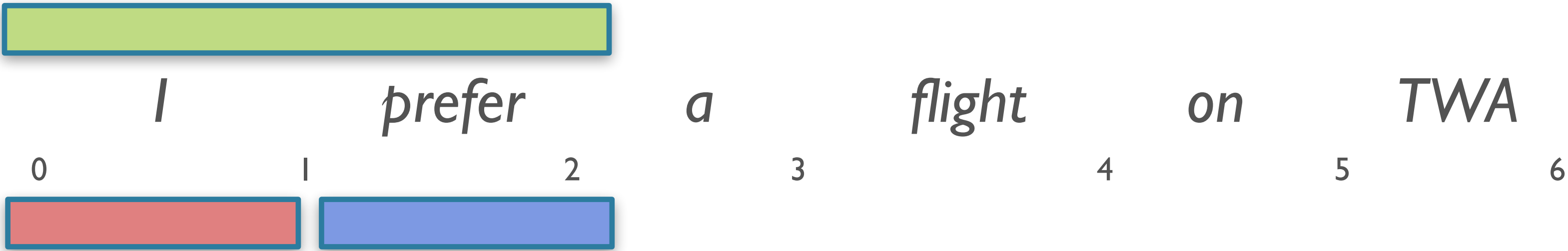
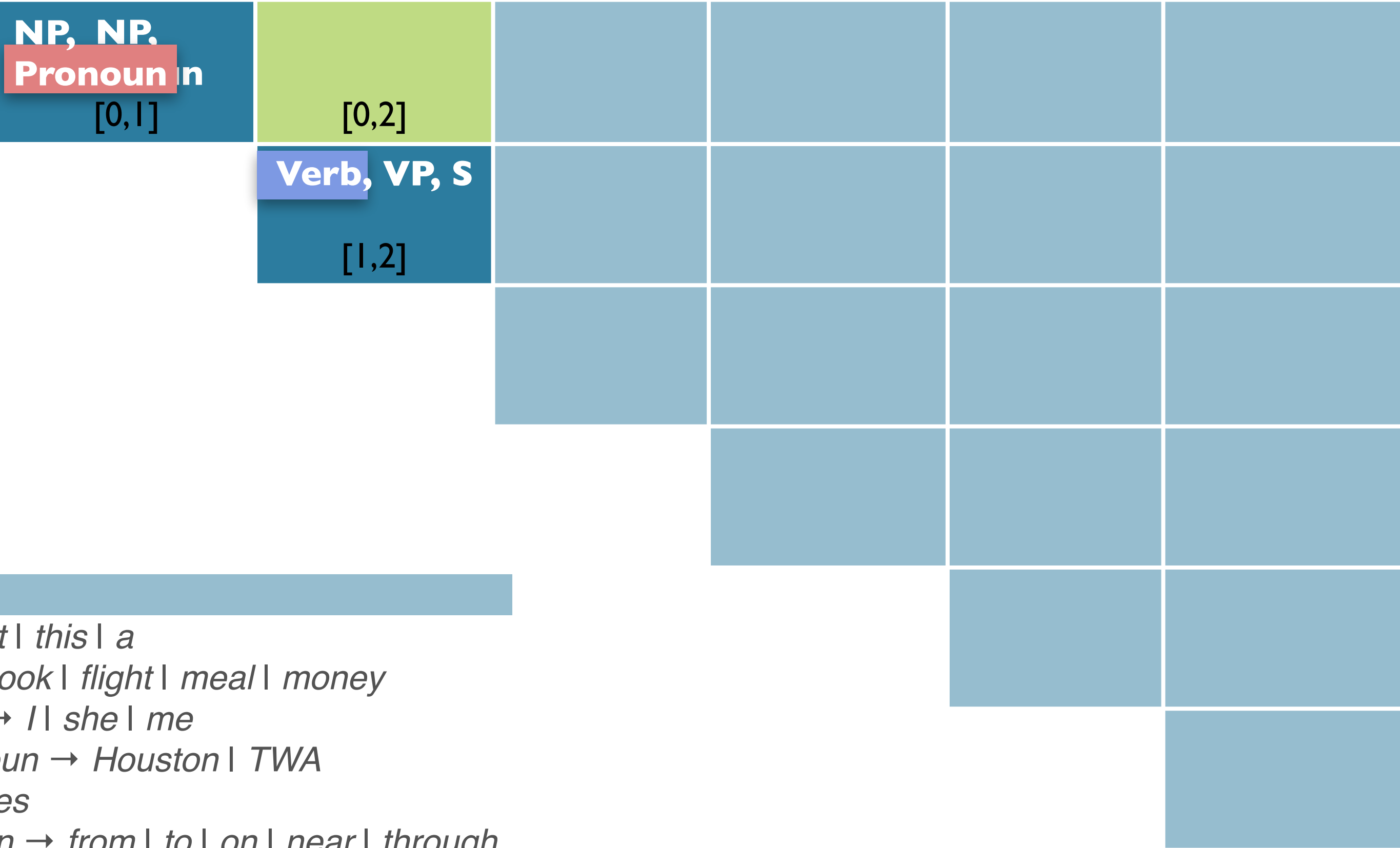
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$

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

 $PP \rightarrow Preposition NP$

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

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

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

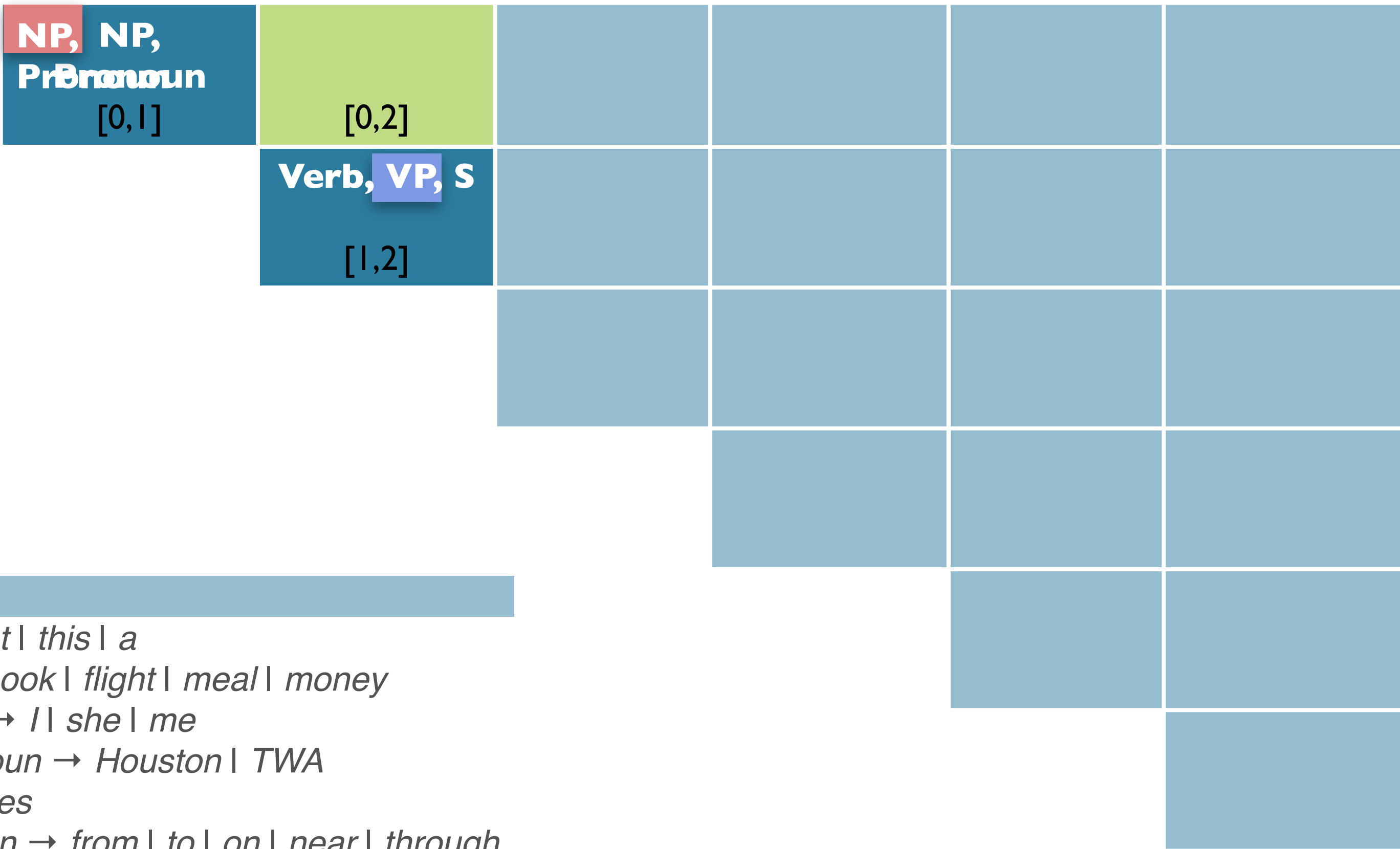
$Pronoun \rightarrow I \mid she \mid me$

$Proper-Noun \rightarrow Houston \mid TWA$

$Aux \rightarrow does$

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

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



\mathcal{L}_1 Grammar

$S \rightarrow NP VP$

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

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

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

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

NP → TWA / Houston

NP → *Det Nominal*

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

Nominal → *Nominal Noun*

Nominal → *Nominal PP*

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

$VP \rightarrow Verb\ NP$

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

$VP \rightarrow Verb PP$

$$VP \rightarrow VP PF$$

PP → *Preposition NP*

NP, NP, Pronoun
[0,1]

S S

[0,2

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*

prefer

flight

TWA

6

\mathcal{L}_1 Grammar

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

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

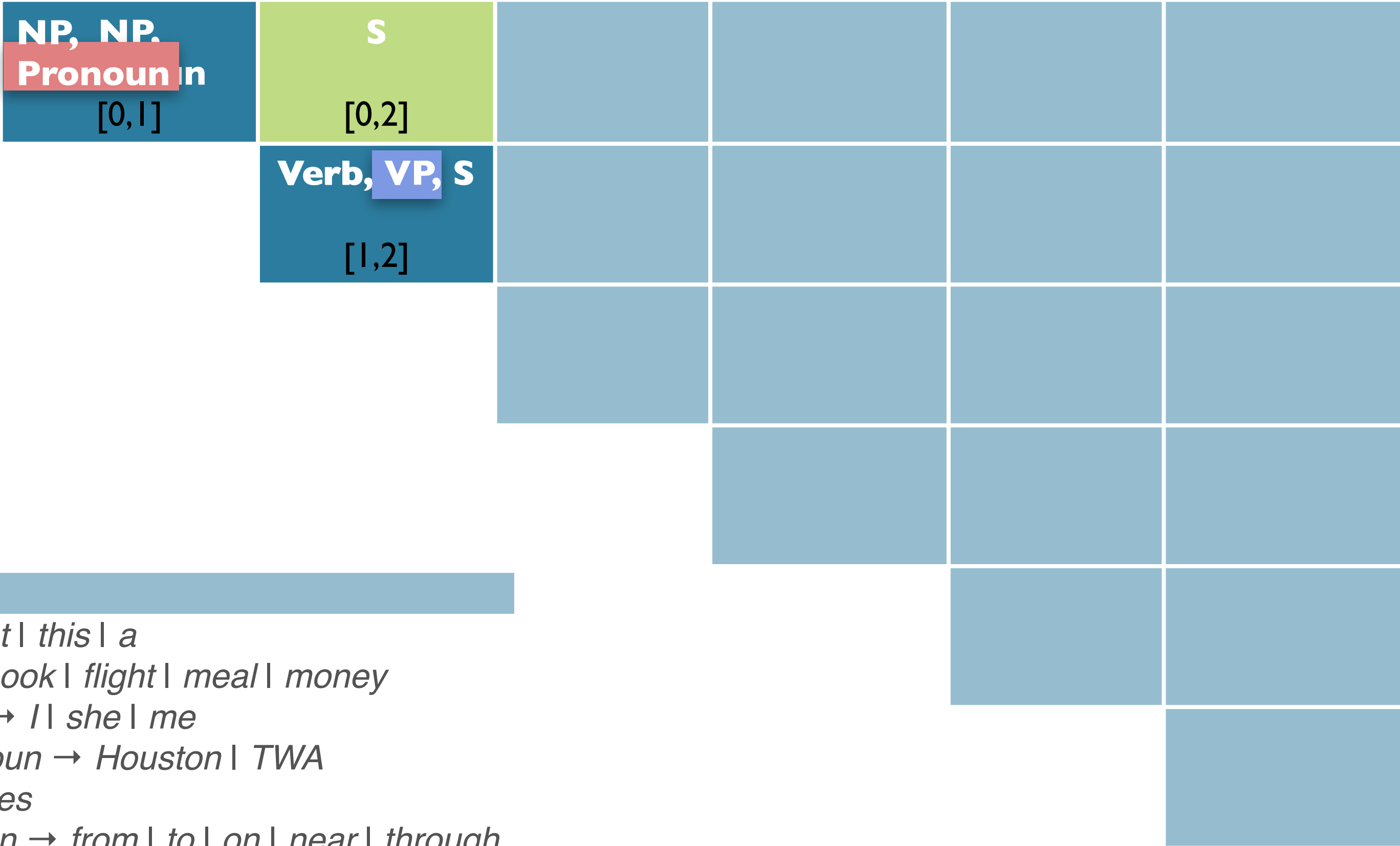
$Nominal \rightarrow book\ I\ flight\ I\ meal\ I\ money$
 $Nominal \rightarrow Nominal\ Noun$
 $Nominal \rightarrow Nominal\ PP$

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

$PP \rightarrow Preposition\ NP$

Lexicon

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



\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

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

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

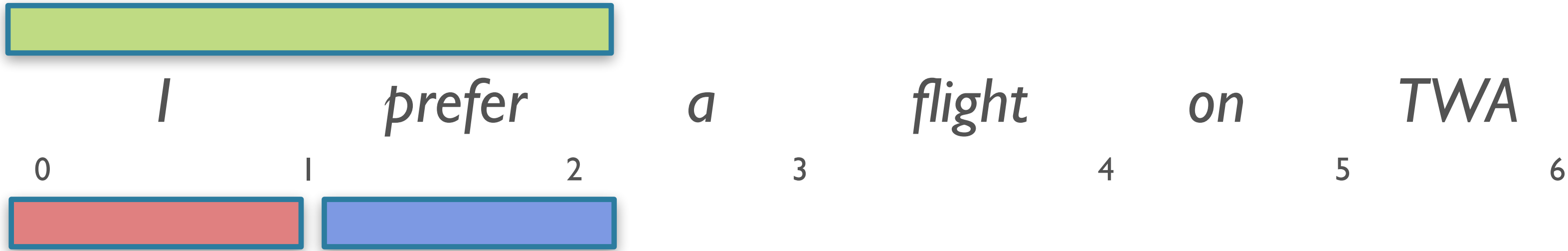
$Pronoun \rightarrow I \mid she \mid me$

$Proper-Noun \rightarrow Houston \mid TWA$

$Aux \rightarrow does$

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

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



\mathcal{L}_1 Grammar

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

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

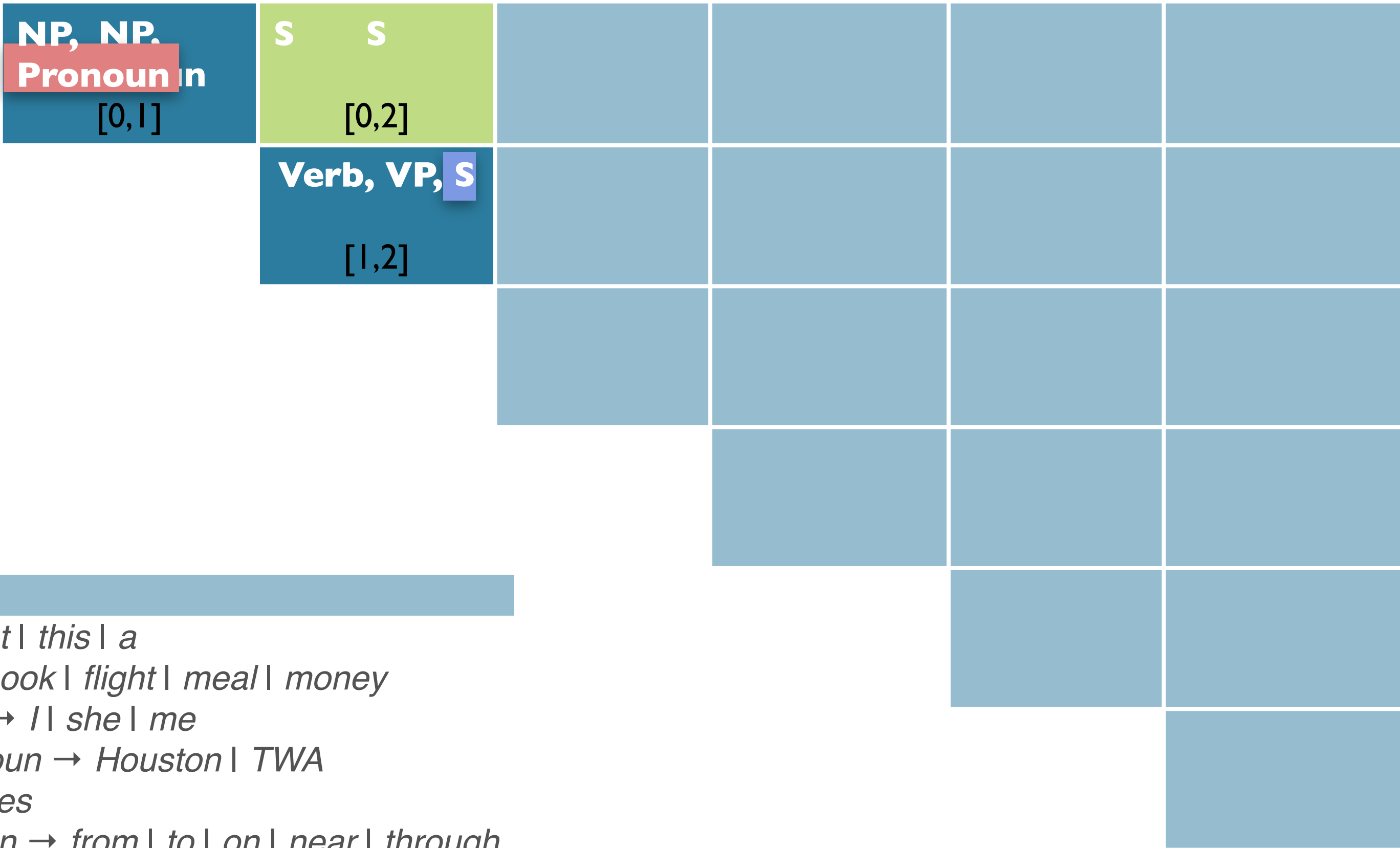
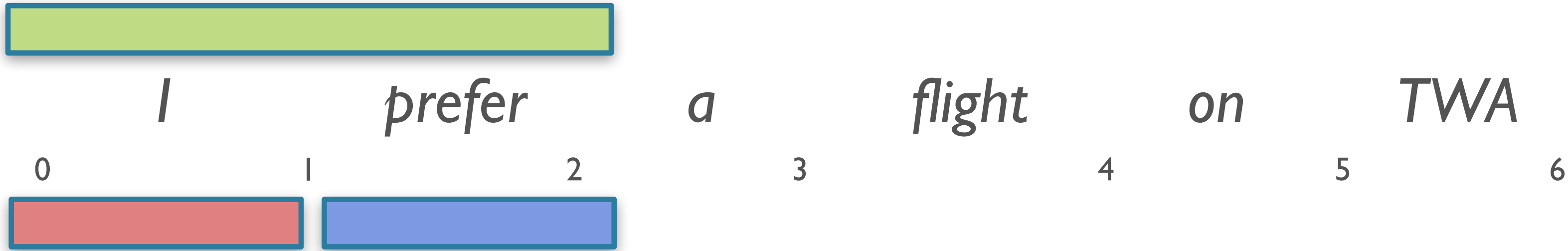
$Nominal \rightarrow book\ |\ flight\ |\ meal\ |\ money$
 $Nominal \rightarrow Nominal\ Noun$
 $Nominal \rightarrow Nominal\ PP$

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

$PP \rightarrow Preposition\ NP$

Lexicon

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



\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

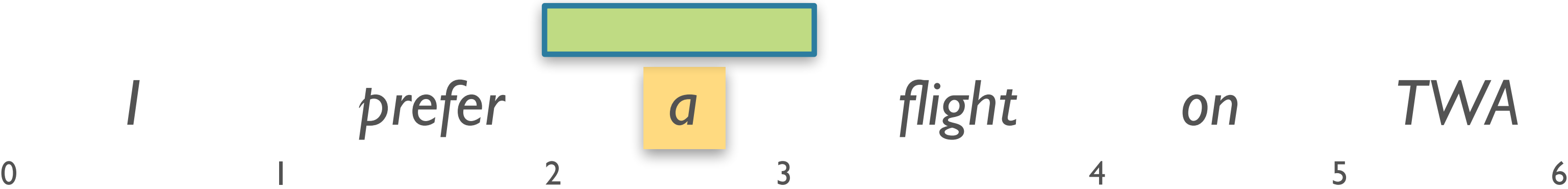
$\rightarrow does$

Preposition

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

Verb

$\rightarrow book \mid include \mid prefer$



L_1 Grammar

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

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

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

$NP \rightarrow I / she / me$

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

Det → *that* | *this* | *a*

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

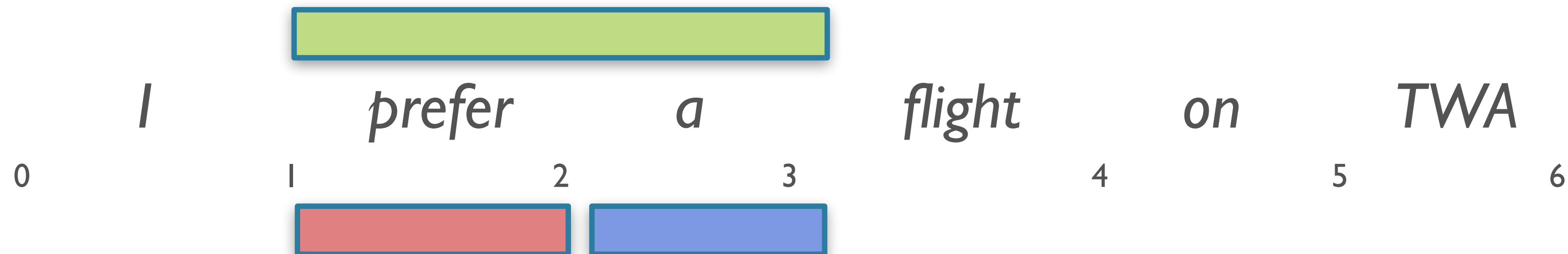
Pronoun → I | she | me

Proper-Noun → *Houston* | *TWA*

Aux → *does*

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

Verb → *book* | *include* | *prefer*



L_1 Grammar

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

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

PP → *Preposition NP*

Lexicon

Det → *that* | *this* | *a*

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

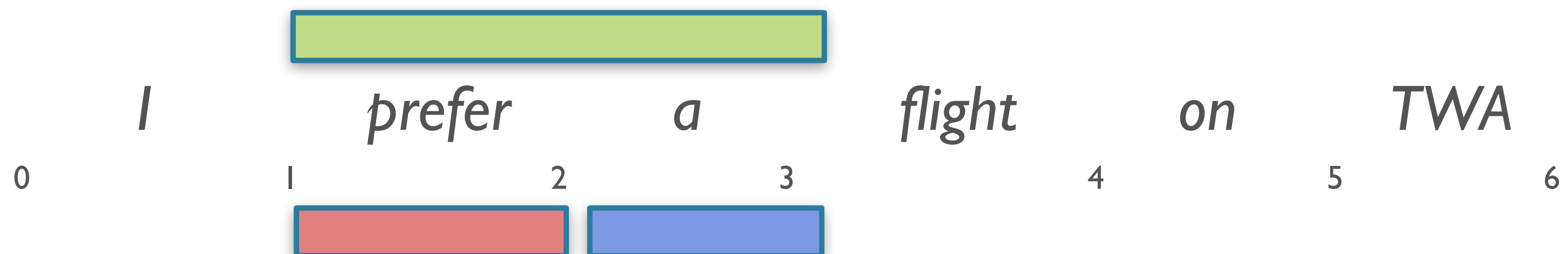
Pronoun → I | she | me

Proper-Noun → *Houston* | *TWA*

Aux → *does*

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

Verb → *book* | *include* | *prefer*



L_1 Grammar

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

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NP → TWA / Houston

NP → *Det Nominal*

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Nominal → *Nominal Noun*

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

PP → *Preposition NP*

Lexicon

Det → *that* | *this* | *a*

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

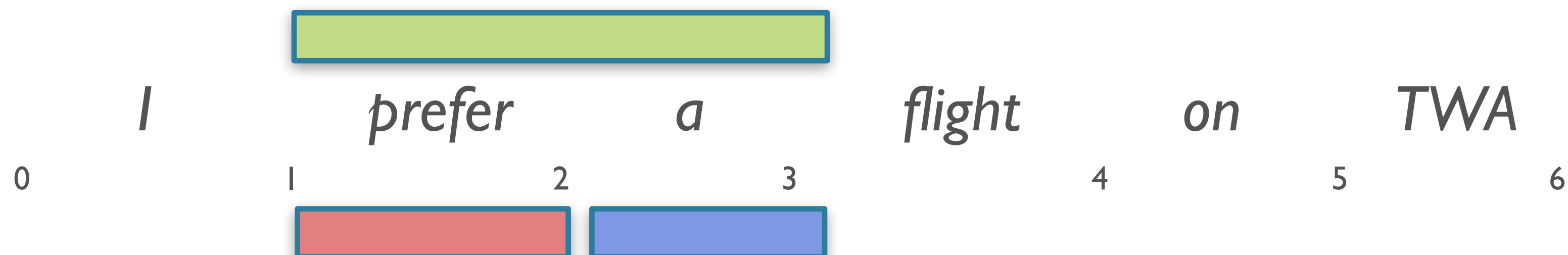
Pronoun → I | she | me

Proper-Noun → *Houston* | *TWA*

Aux → *does*

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

Verb → *book* | *include* | *prefer*



\mathcal{L}_1 Grammar

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

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

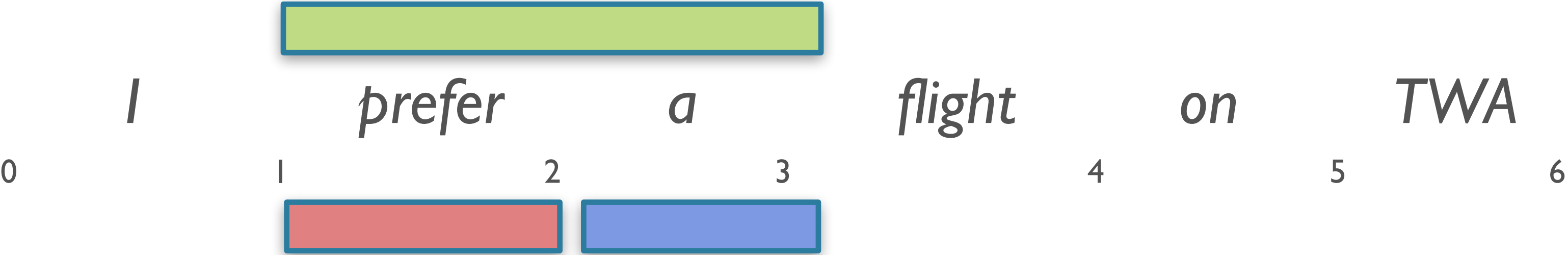
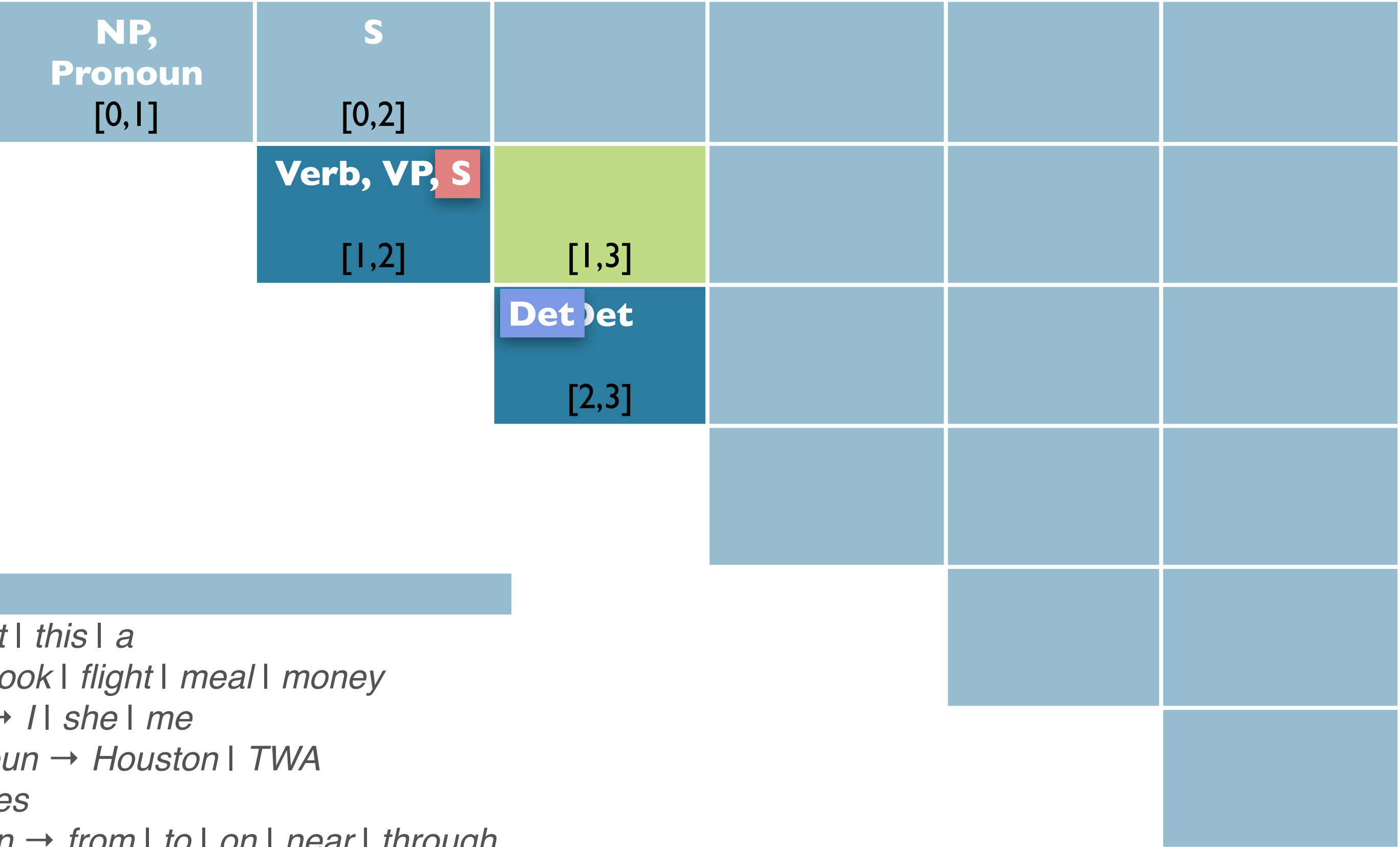
$Nominal \rightarrow book\ I\ flight\ I\ meal\ I\ money$
 $Nominal \rightarrow Nominal\ Noun$
 $Nominal \rightarrow Nominal\ PP$

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

$PP \rightarrow Preposition\ NP$

Lexicon

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



\mathcal{L}_1 Grammar

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

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

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

$NP \rightarrow I / she / me$

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*

Lexicon

Det → *that* | *this* | *a*

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

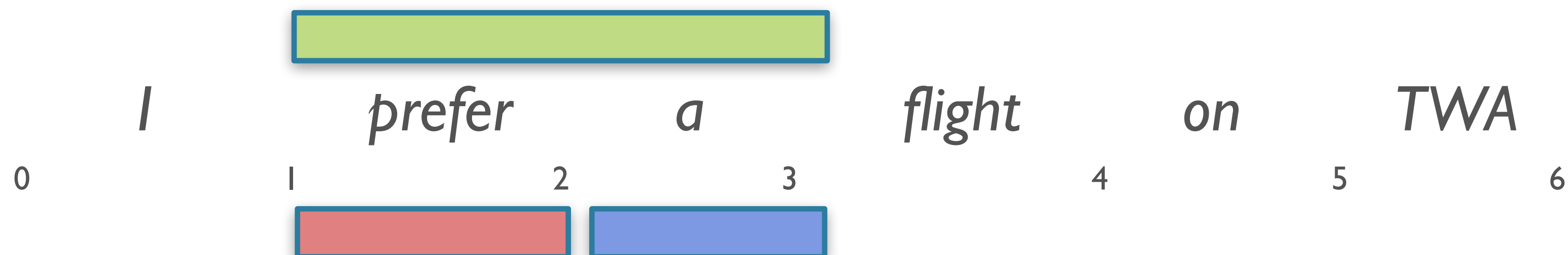
Pronoun → I | she | me

Proper-Noun → *Houston* | *TWA*

Aux → *does*

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

Verb → *book* | *include* | *prefer*



\mathcal{L}_1 Grammar

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

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

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

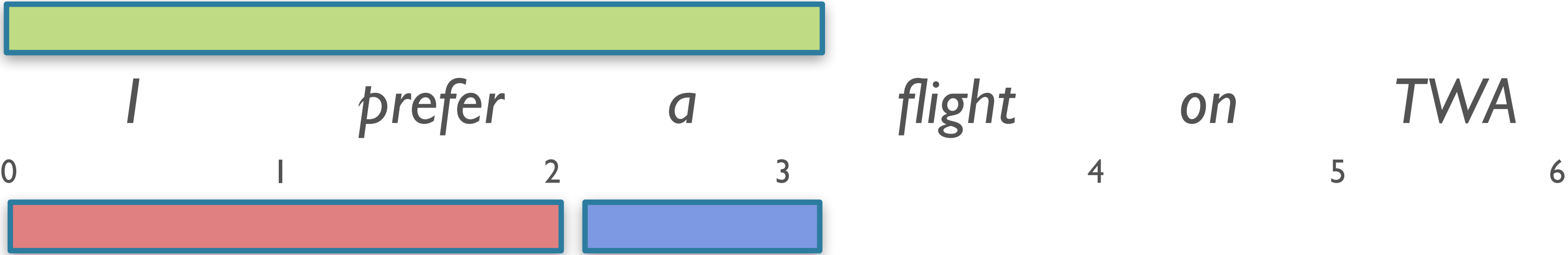
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

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

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

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

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

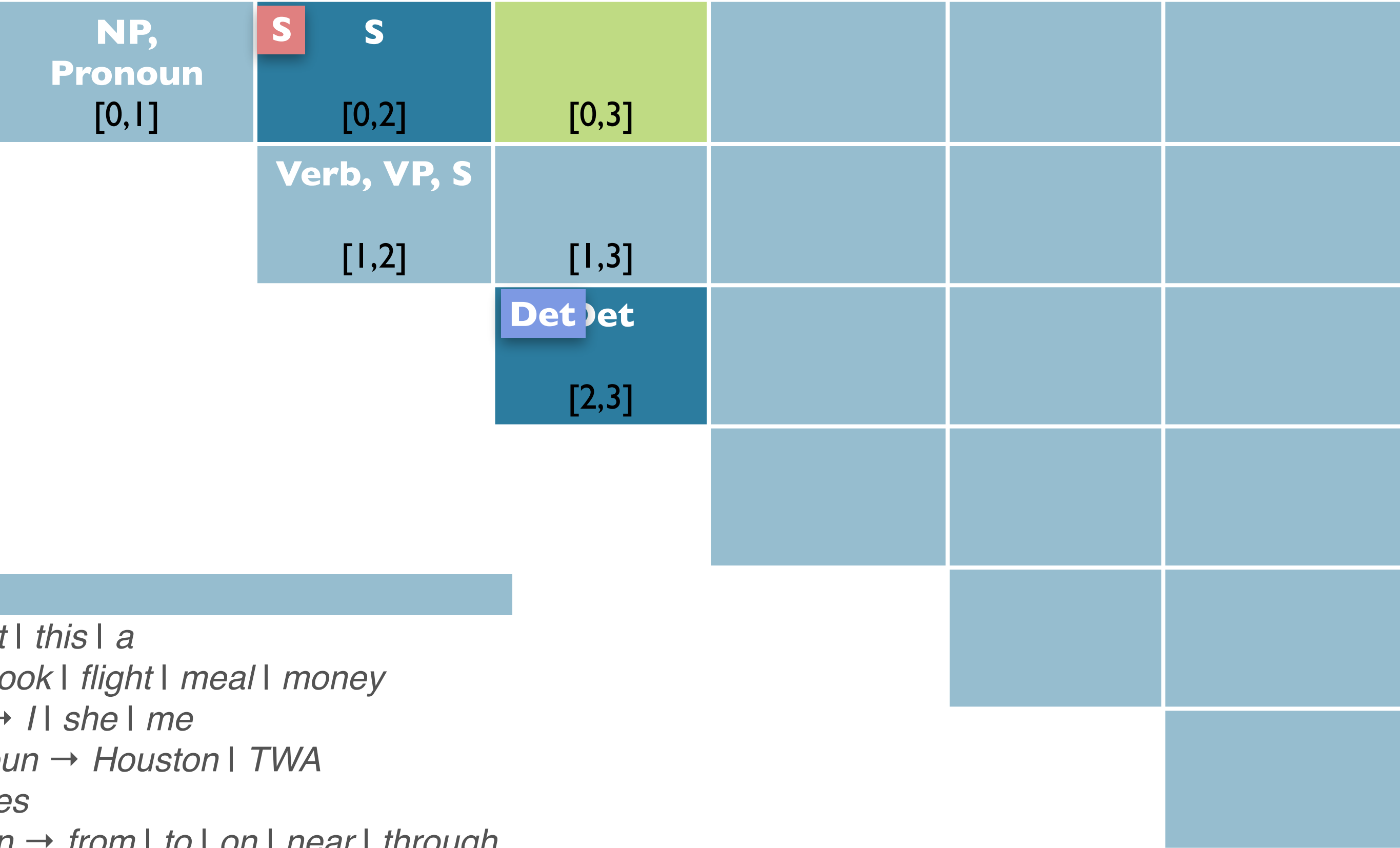
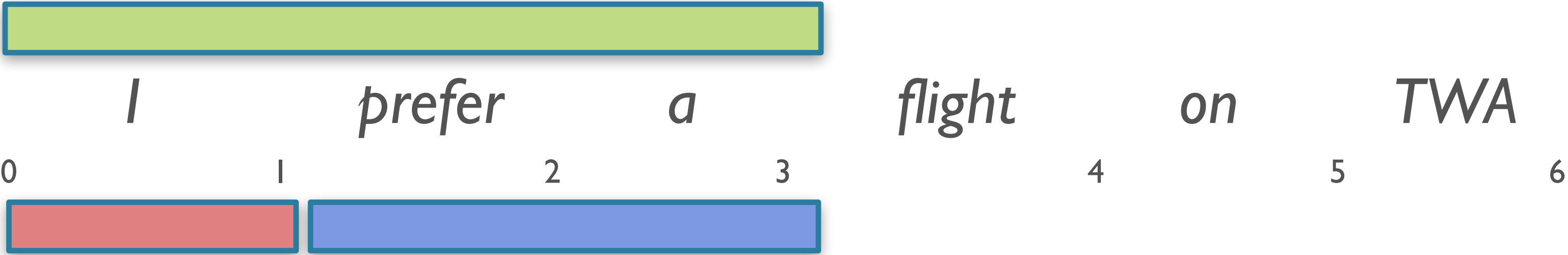
$Pronoun \rightarrow I \mid she \mid me$

$Proper-Noun \rightarrow Houston \mid TWA$

$Aux \rightarrow does$

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

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



\mathcal{L}_1 Grammar
 $S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$

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

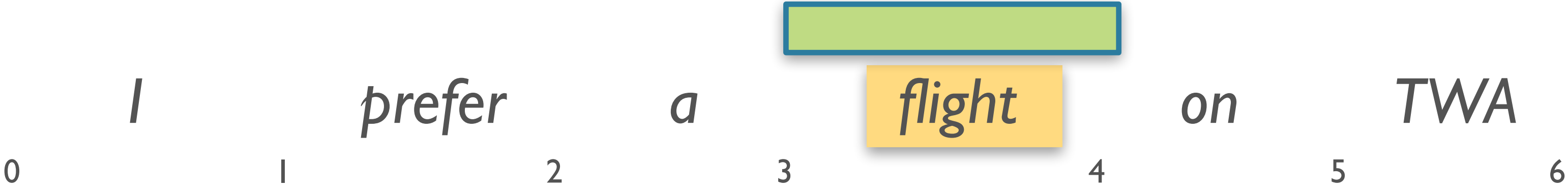
Nominal $\rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$

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

 $PP \rightarrow Preposition NP$

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

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



\mathcal{L}_1 Grammar

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

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

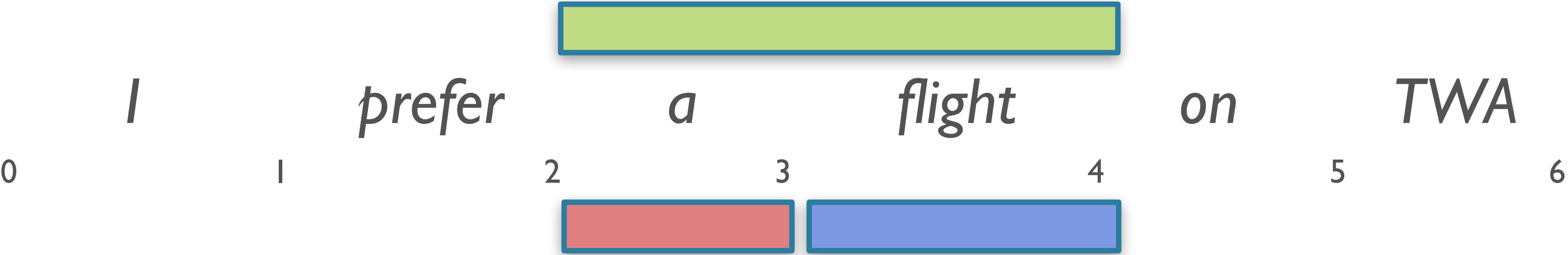
$Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$

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

$PP \rightarrow Preposition NP$

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]		

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

$S \rightarrow NP\ VP$

$S \rightarrow X1\ VP$

$X1 \rightarrow Aux\ NP$

$S \rightarrow book\ I\ include\ I\ prefer$

$S \rightarrow Verb\ NP$

$S \rightarrow X2\ PP$

$S \rightarrow Verb\ PP$

$S \rightarrow VP\ PP$

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

$NP \rightarrow TWA\ I\ Houston$

$NP \rightarrow Det\ Nominal$

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

$Nominal \rightarrow Nominal\ Noun$

$Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book\ I\ include\ I\ prefer$

$VP \rightarrow Verb\ NP$

$VP \rightarrow X2\ PP$

$X2 \rightarrow Verb\ NP$

$VP \rightarrow Verb\ PP$

$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ I\ this\ I\ a$

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

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

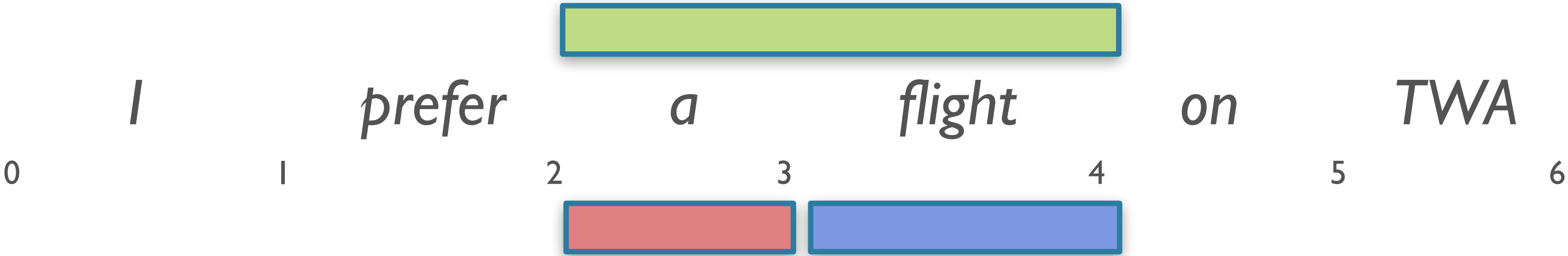
$Proper-Noun \rightarrow Houston\ I\ TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book\ I\ include\ I\ prefer$

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]		



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$S \rightarrow NP VP$

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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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$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

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

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

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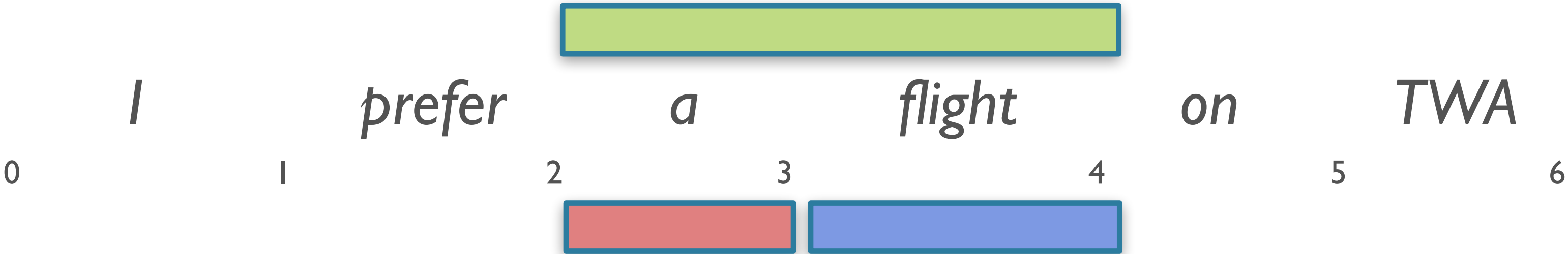
$Proper-Noun \rightarrow Houston \mid TWA$

$Aux \rightarrow does$

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

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



\mathcal{L}_1 Grammar

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

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

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

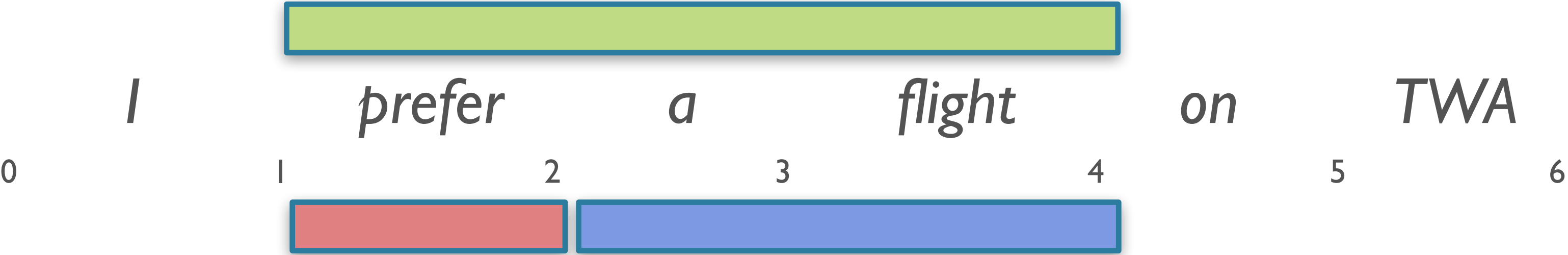
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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



\mathcal{L}_1 Grammar

$S \rightarrow NP\ VP$

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$X1 \rightarrow Aux\ NP$

$S \rightarrow book\ I\ include\ I\ prefer$

$S \rightarrow Verb\ NP$

$S \rightarrow X2\ PP$

$S \rightarrow Verb\ PP$

$S \rightarrow VP\ PP$

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

$NP \rightarrow TWA\ I\ Houston$

$NP \rightarrow Det\ Nominal$

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

$Nominal \rightarrow Nominal\ Noun$

$Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book\ I\ include\ I\ prefer$

VP

Verb

NP

$VP \rightarrow X2\ PP$

$X2 \rightarrow Verb\ NP$

$VP \rightarrow Verb\ PP$

$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

$Det \rightarrow that\ I\ this\ I\ a$

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

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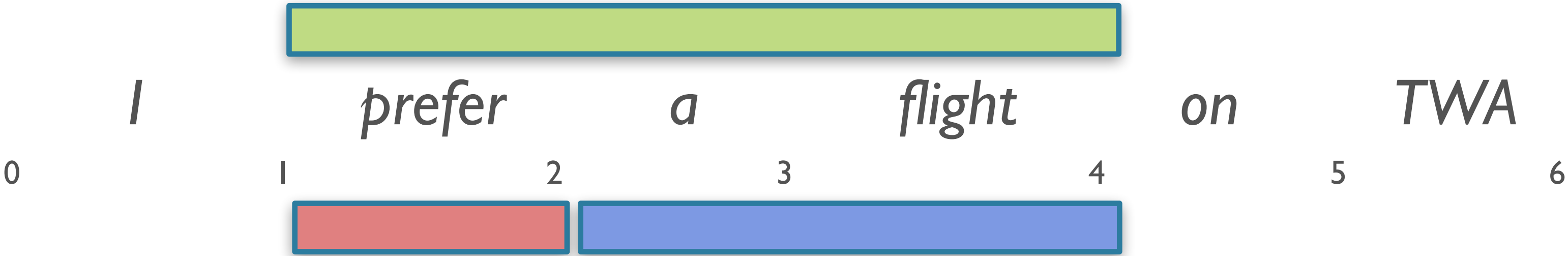
$Proper-Noun \rightarrow Houston\ I\ TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book\ I\ include\ I\ prefer$

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



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$S \rightarrow NP VP$

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$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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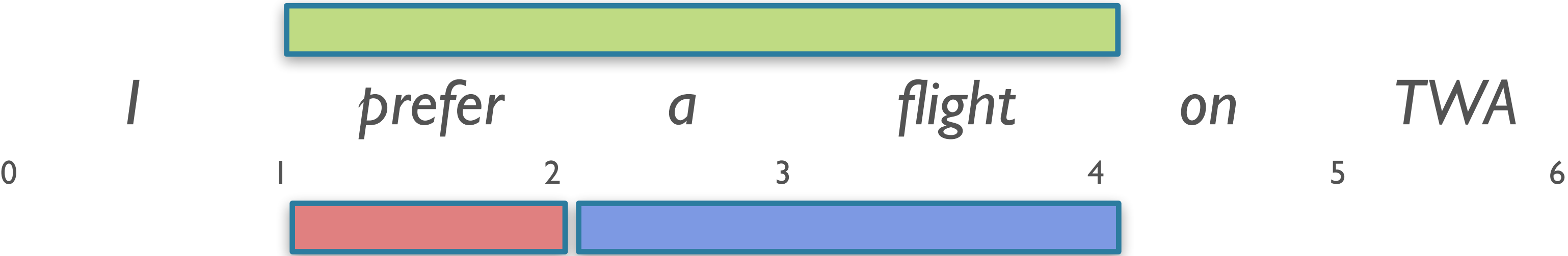
$Proper-Noun \rightarrow Houston \mid TWA$

$Aux \rightarrow does$

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

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

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

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

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 $NP \rightarrow Det Nominal$

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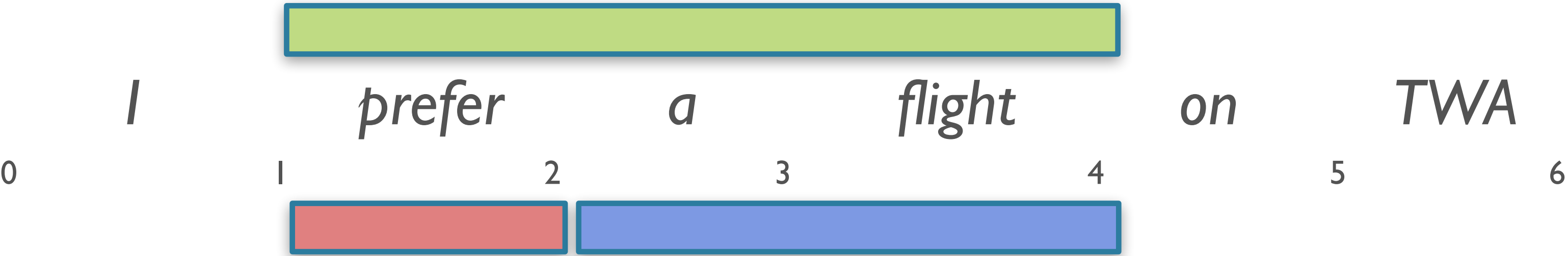
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

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 $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
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NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		



\mathcal{L}_1 Grammar

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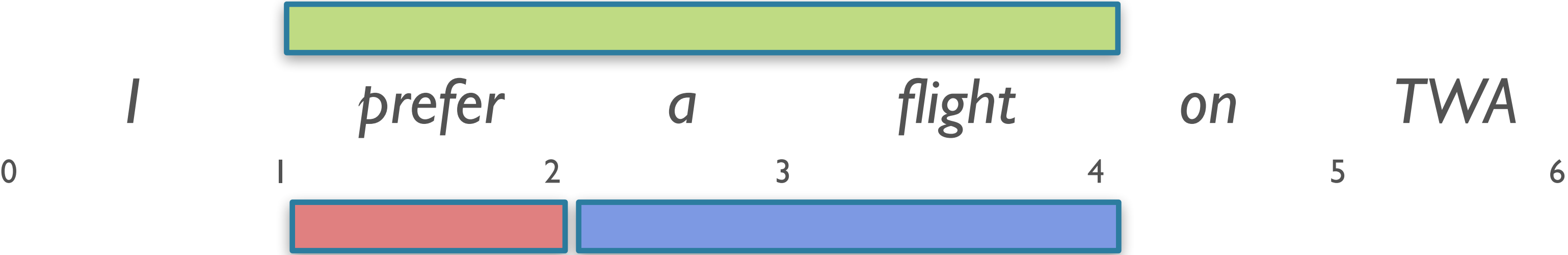
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

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 $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
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NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		



\mathcal{L}_1 Grammar

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

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

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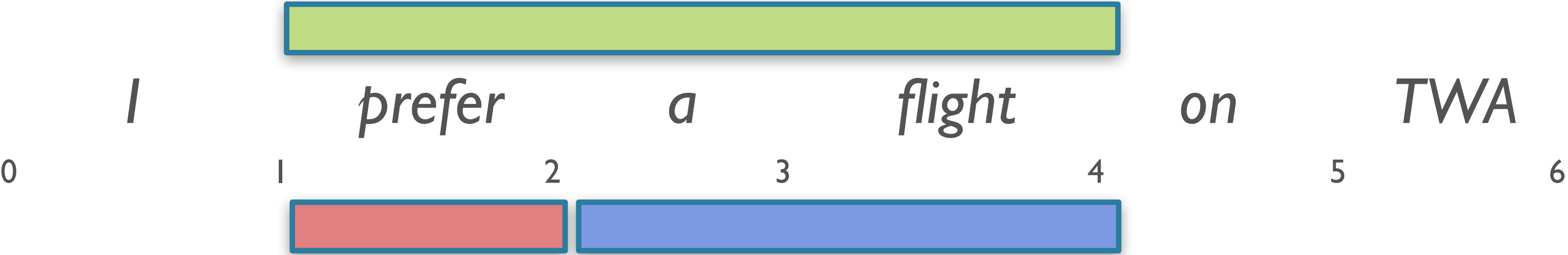
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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 $Preposition \rightarrow from\ I\ to\ I\ on\ I\ near\ I\ through$
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NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		



\mathcal{L}_1 Grammar

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

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

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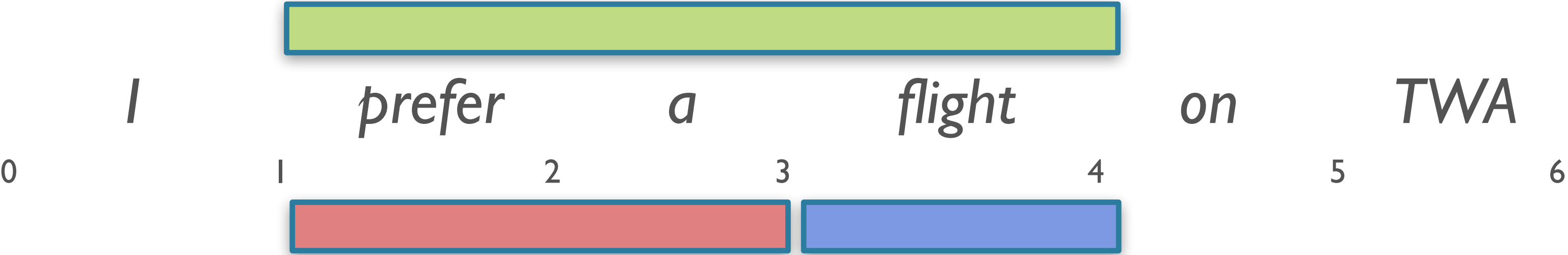
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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

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



\mathcal{L}_1 Grammar

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

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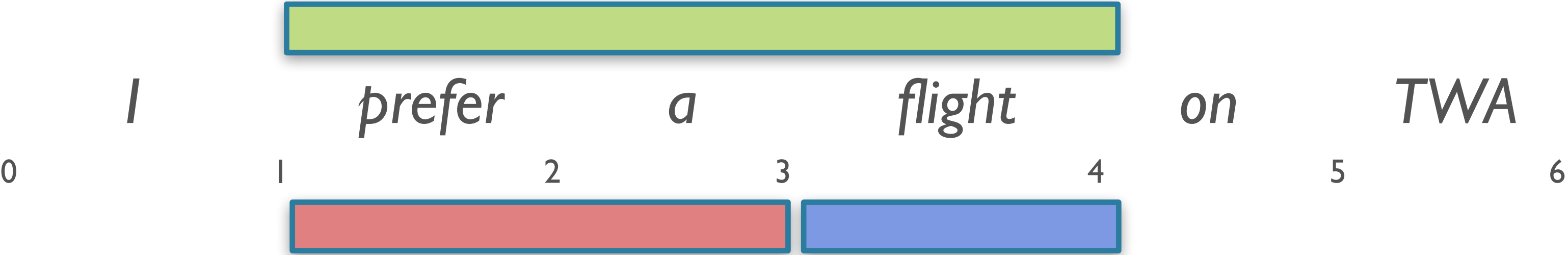
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

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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]		



\mathcal{L}_1 Grammar

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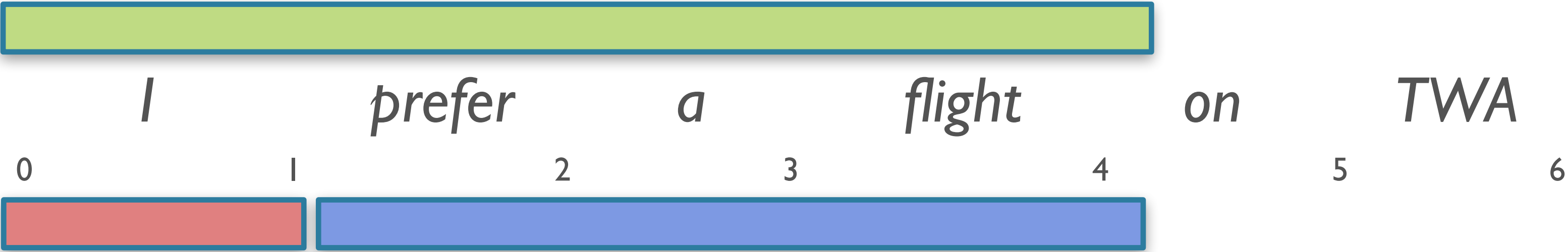
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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 $Noun \rightarrow book\ I\ flight\ I\ meal\ I\ money$
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 $Aux \rightarrow does$
 $Preposition \rightarrow from\ I\ to\ I\ on\ I\ near\ I\ through$
 $Verb \rightarrow book\ I\ include\ I\ prefer$

NP, Pronoun [0,1]	S [0,2]	[0,3]	[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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 $NP \rightarrow Det Nominal$

 $Nominal \rightarrow book \mid flight \mid meal \mid money$
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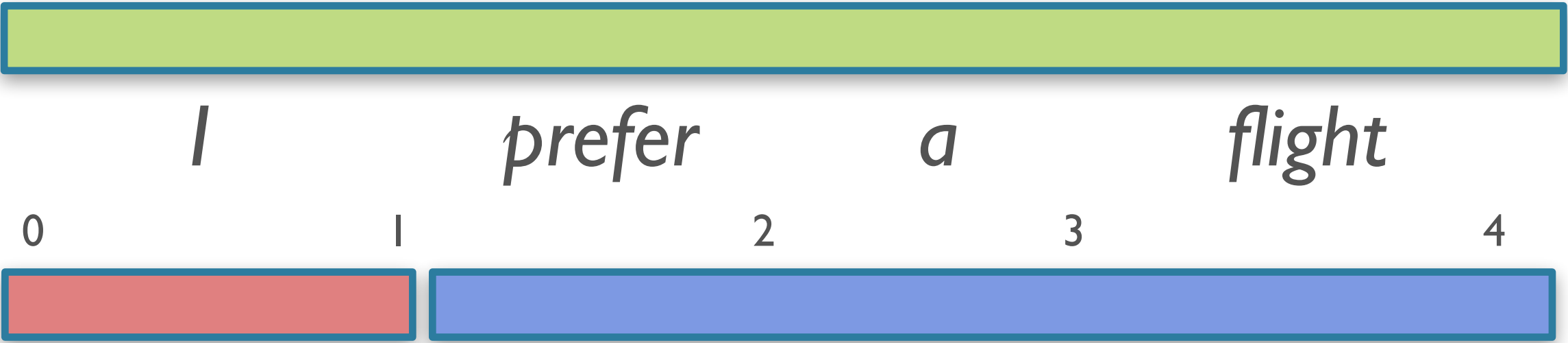
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
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 $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
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NP, Pronoun [0,1]	S [0,2]	[0,3]	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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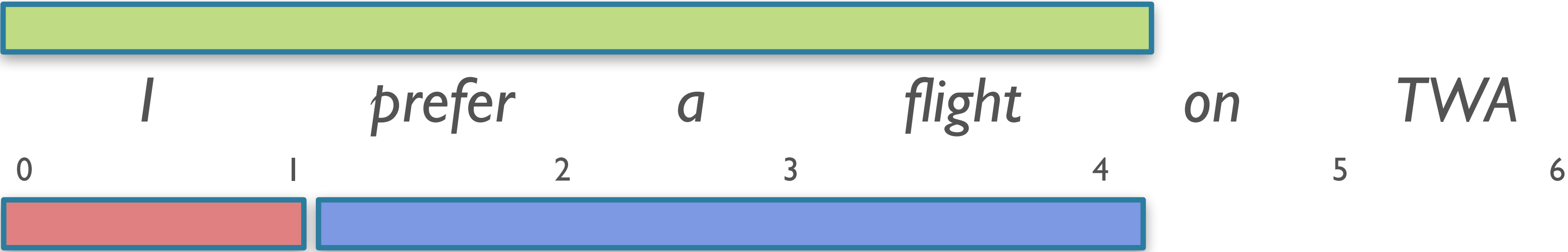
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

Lexicon

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 $Noun \rightarrow book\ I\ flight\ I\ meal\ I\ money$
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 $Aux \rightarrow does$
 $Preposition \rightarrow from\ I\ to\ I\ on\ I\ near\ I\ through$
 $Verb \rightarrow book\ I\ include\ I\ prefer$

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]		



\mathcal{L}_1 Grammar

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
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 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
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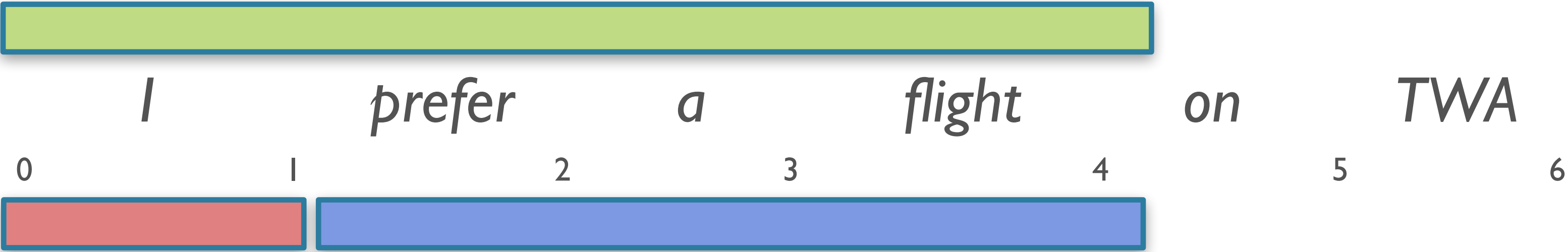
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 $Aux \rightarrow does$
 $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
 $Verb \rightarrow book \mid include \mid prefer$

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

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

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

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

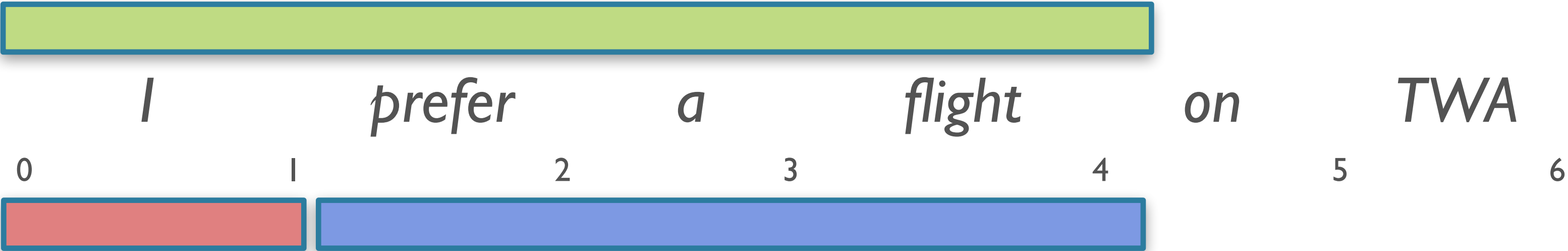
$Proper-Noun \rightarrow Houston \mid TWA$

$Aux \rightarrow does$

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

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

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

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

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

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

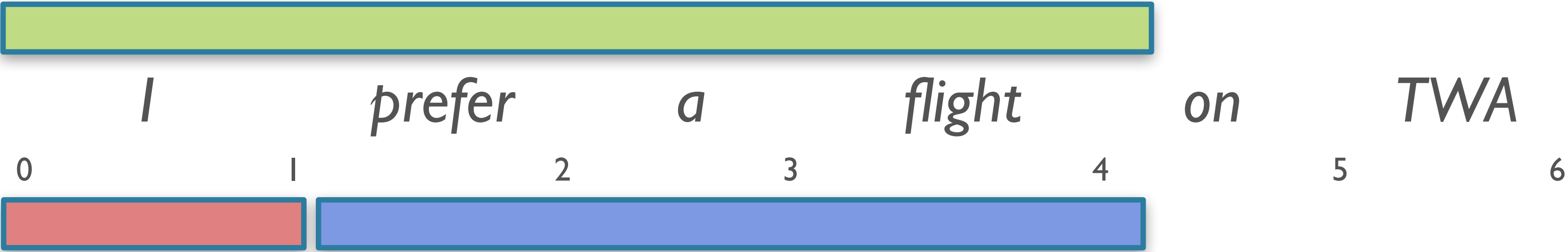
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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]		



\mathcal{L}_1 Grammar

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

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

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

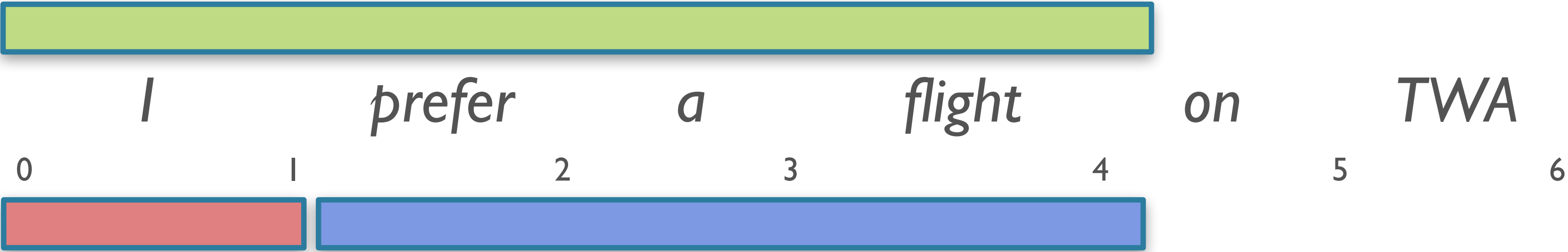
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		



L₁ 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 I this I a*

Noun → *book I flight I meal I money*

Pronoun → *I I she I me*

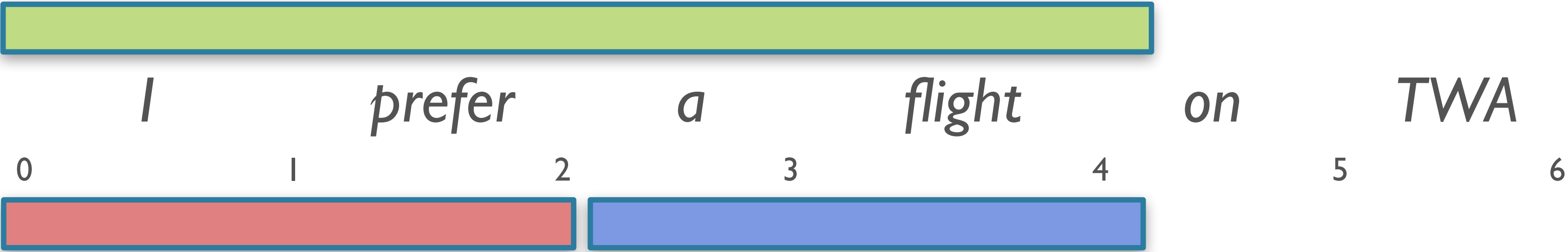
Proper-Noun → *Houston I TWA*

Aux → *does*

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

Verb → *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]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		



\mathcal{L}_1 Grammar

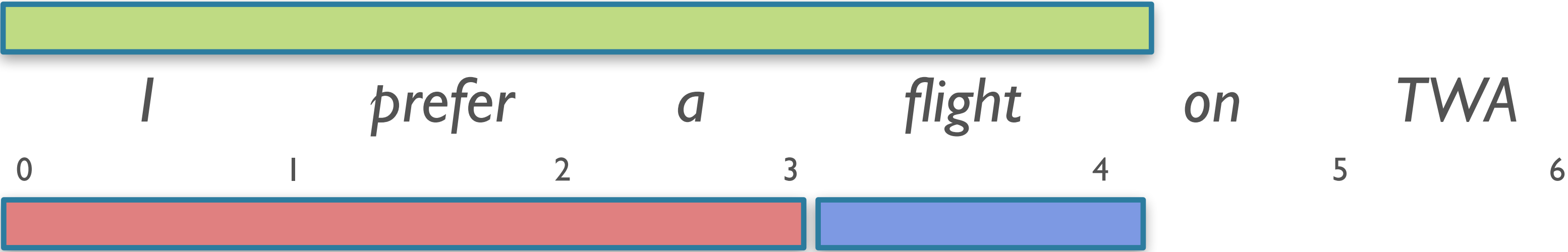
$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$

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

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

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

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

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

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

$PP \rightarrow Preposition\ NP$

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]		
		Det [2,3]	NP [2,4]		
			Noun, Nom [3,4]		
				Prep [4,5]	



\mathcal{L}_1 Grammar

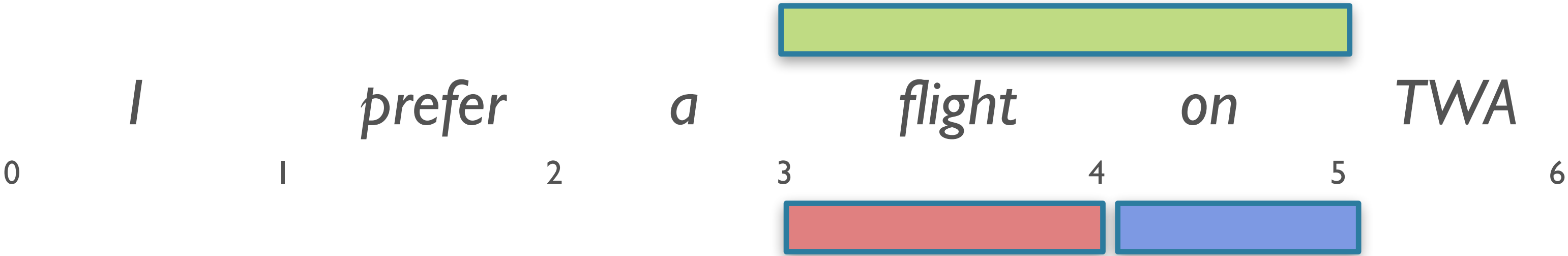
$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$

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

Lexicon

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

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]	[3,5]	
				Prep [4,5]	



\mathcal{L}_1 Grammar

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

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

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

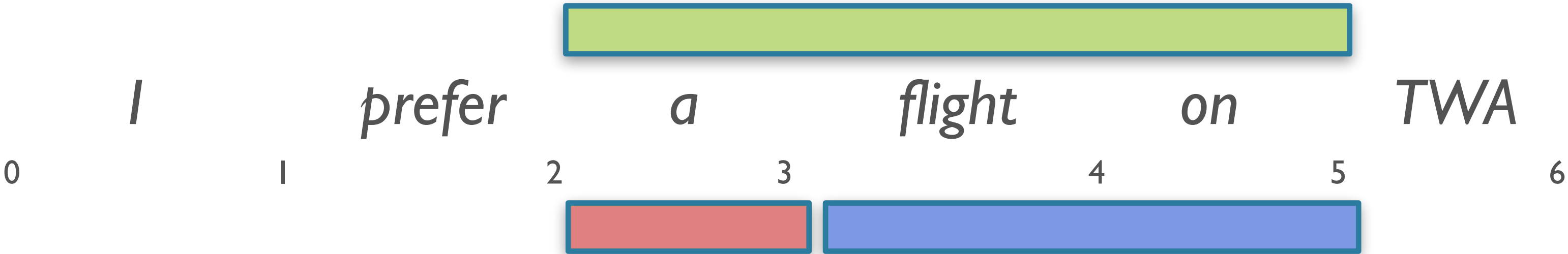
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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]	[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

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

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

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

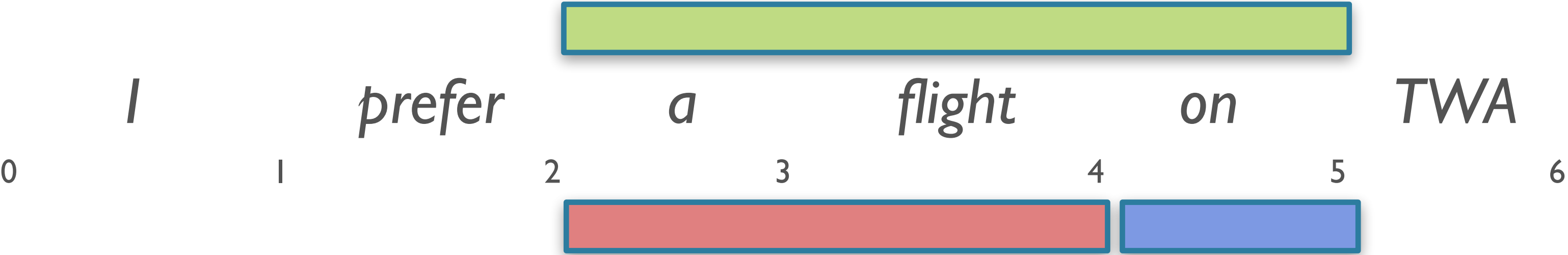
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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]		
		Det [2,3]	NP [2,4]	[2,5]	
			Noun, Nom [3,4]	[3,5]	
				Prep [4,5]	



\mathcal{L}_1 Grammar
 $S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$

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

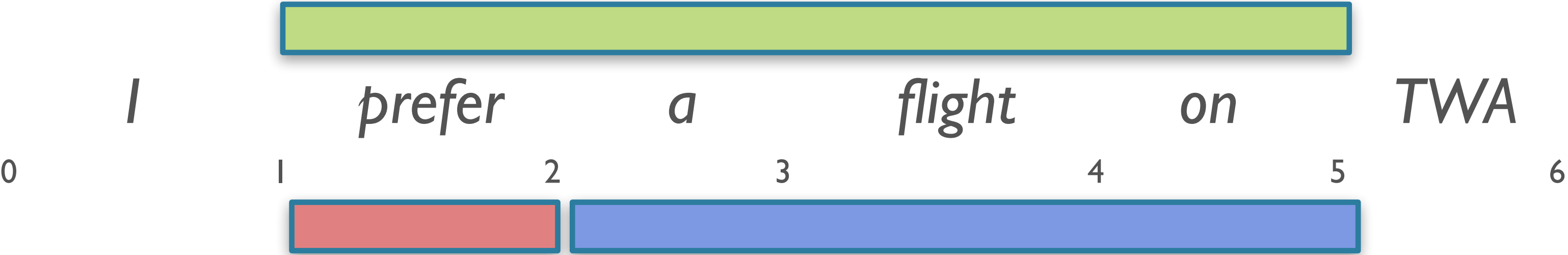
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$

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

 $PP \rightarrow Preposition NP$

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

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

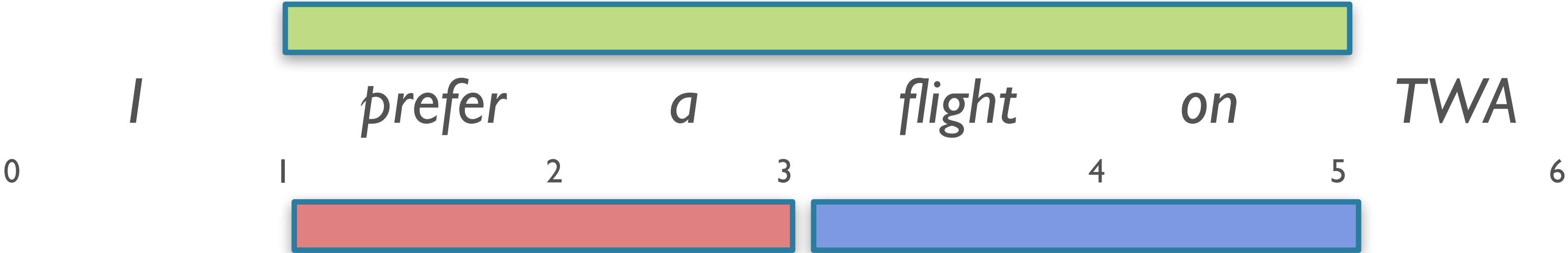
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$

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

 $PP \rightarrow Preposition NP$

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

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

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

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

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

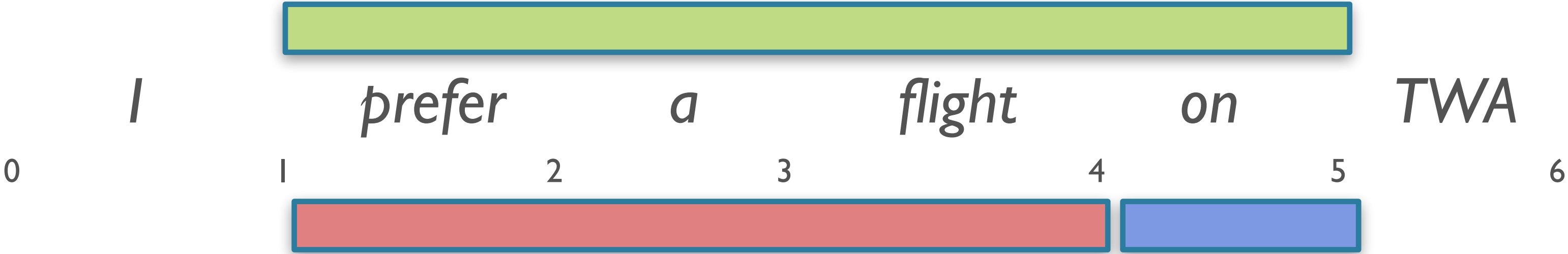
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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]		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

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

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

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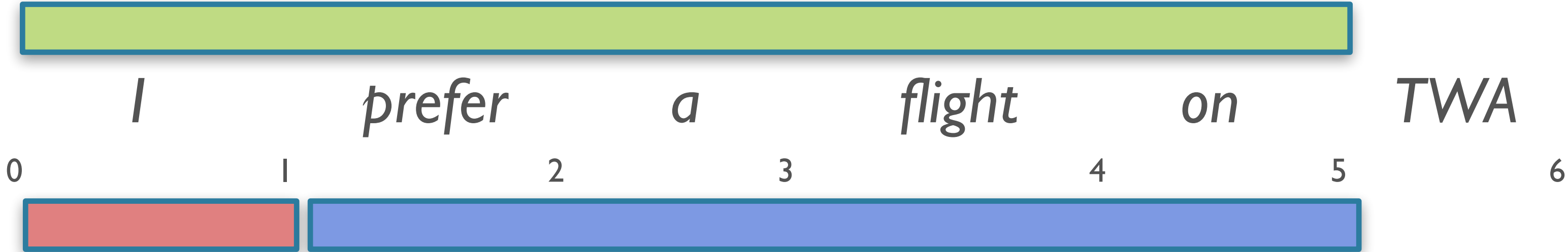
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

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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]	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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 $S \rightarrow book \mid include \mid prefer$
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 $S \rightarrow Verb PP$
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 $NP \rightarrow Det Nominal$

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

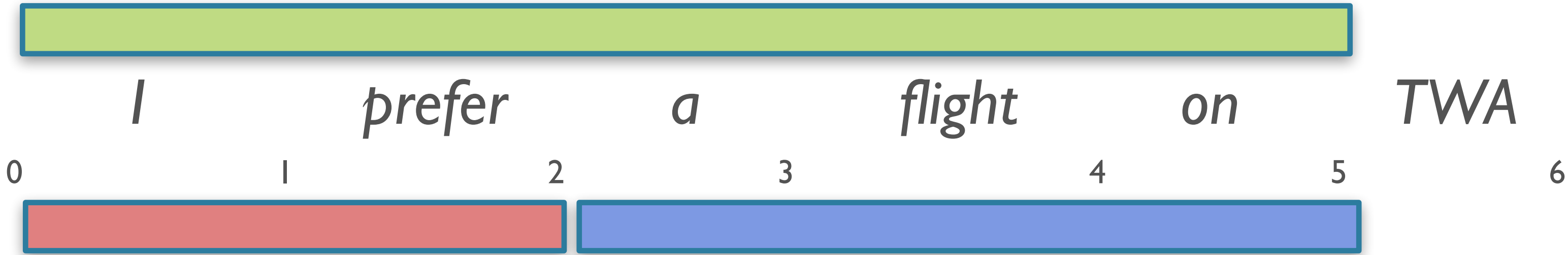
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

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 $Proper-Noun \rightarrow Houston \mid TWA$
 $Aux \rightarrow does$
 $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
 $Verb \rightarrow book \mid include \mid prefer$

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

$S \rightarrow NP VP$
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 $S \rightarrow book \mid include \mid prefer$
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$NP \rightarrow I \mid she \mid me$
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 $NP \rightarrow Det Nominal$

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

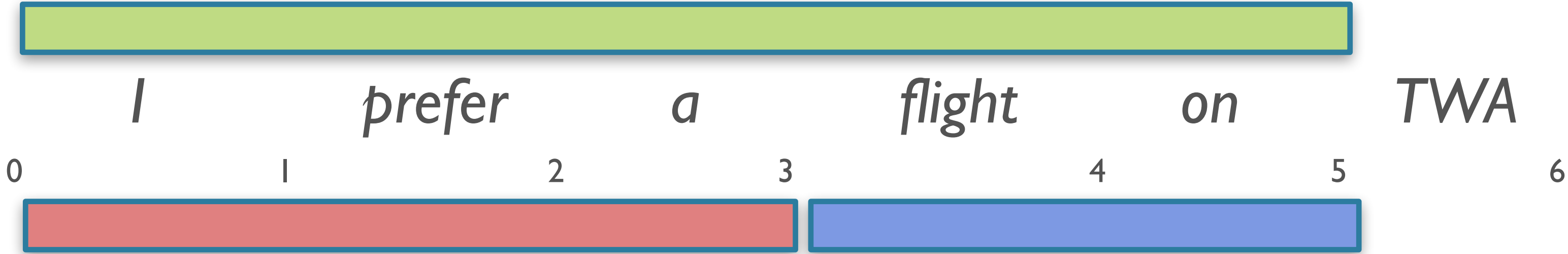
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

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

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

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

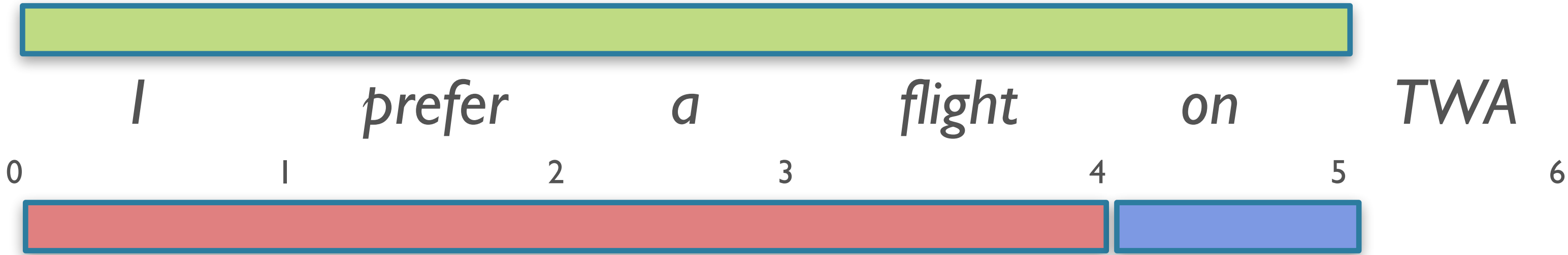
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

$Det \rightarrow that \mid this \mid a$
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[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]	



L₁ 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 I this I a*
Noun → *book I flight I meal I money*
Pronoun → *I I she I me*
Proper-Noun → *Houston I TWA*
Aux → *does*
Preposition → *from I to I on I near I through*
Verb → *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]	
					NNP, NP [5,6]



\mathcal{L}_1 Grammar

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

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

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

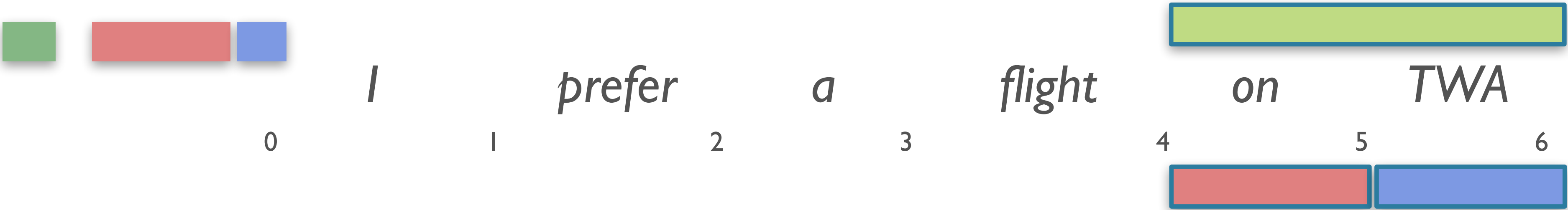
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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 $Verb \rightarrow book\ I\ include\ I\ prefer$

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]	PP [4,6]
					NNP, NP [5,6]



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

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

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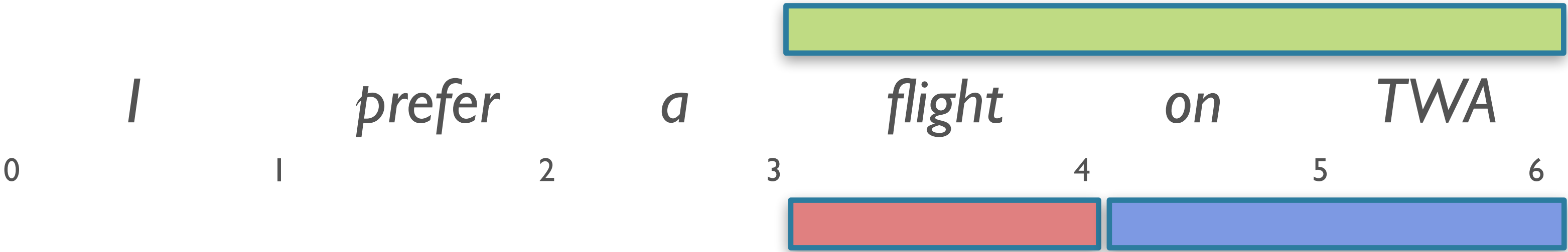
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
	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



\mathcal{L}_1 Grammar

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

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

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

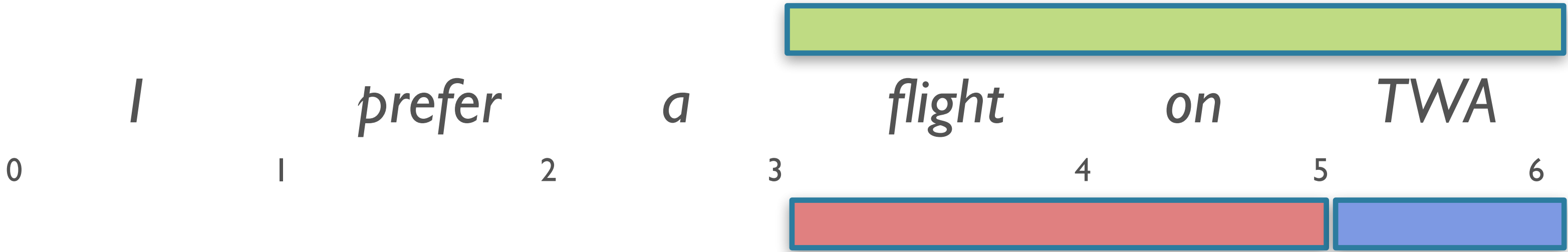
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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]	Nom [3,6]
				Prep [4,5]	PP [4,6]
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\mathcal{L}_1 Grammar

$S \rightarrow NP VP$

$S \rightarrow X1 VP$

$X1 \rightarrow Aux NP$

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

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

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

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

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

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

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Lexicon

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

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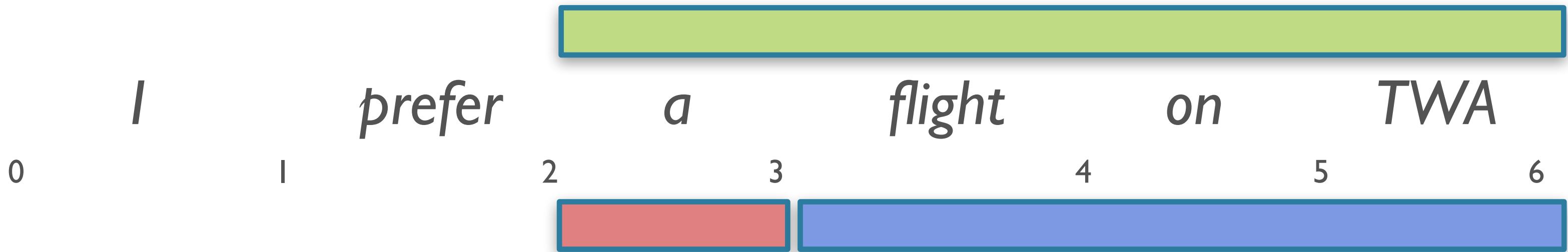
$Proper-Noun \rightarrow Houston \mid TWA$

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



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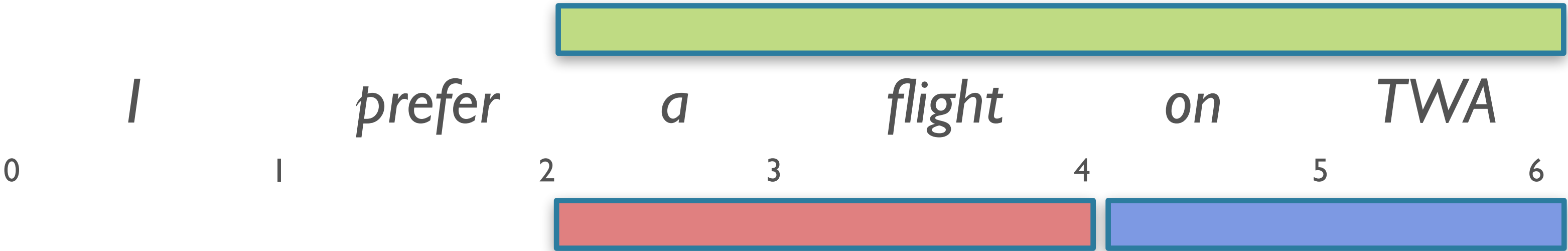
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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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]
				Prep [4,5]	PP [4,6]
					NNP, NP [5,6]



\mathcal{L}_1 Grammar

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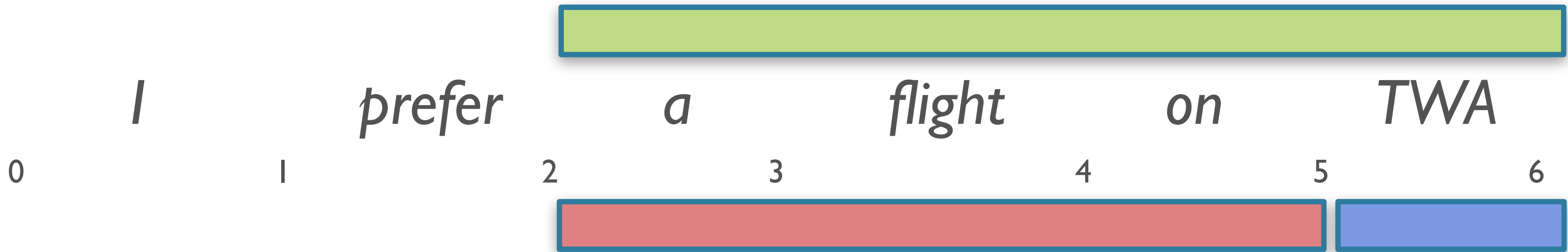
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

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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]
				Prep [4,5]	PP [4,6]
					NNP, NP [5,6]



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

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 $NP \rightarrow Det Nominal$

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

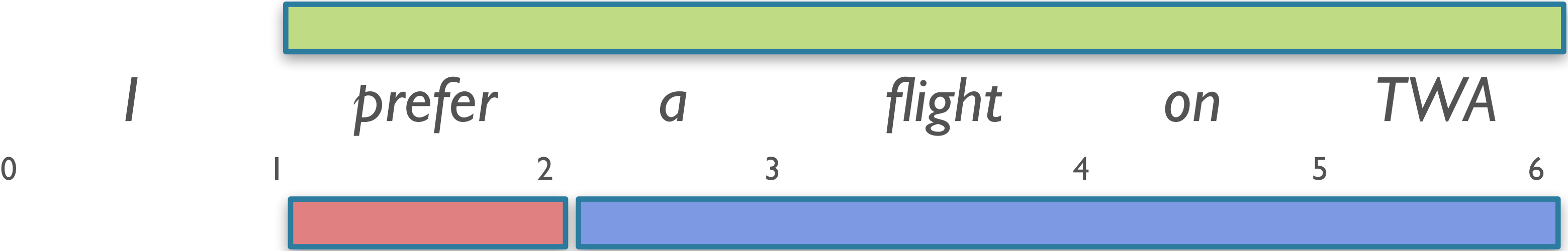
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
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 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]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



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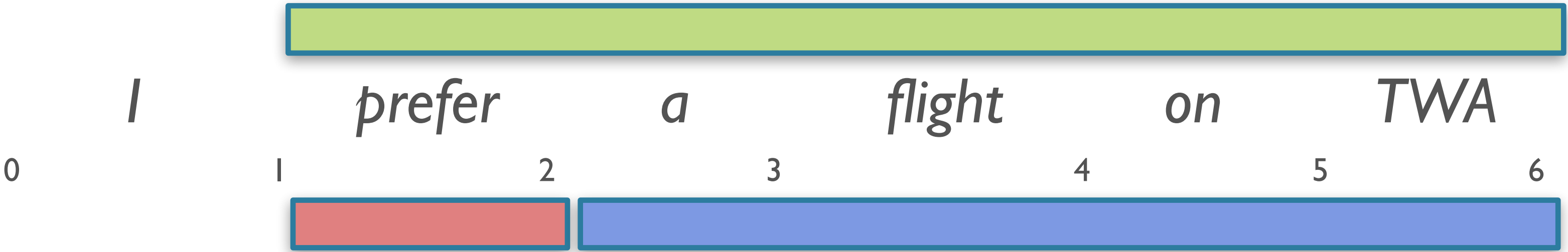
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

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

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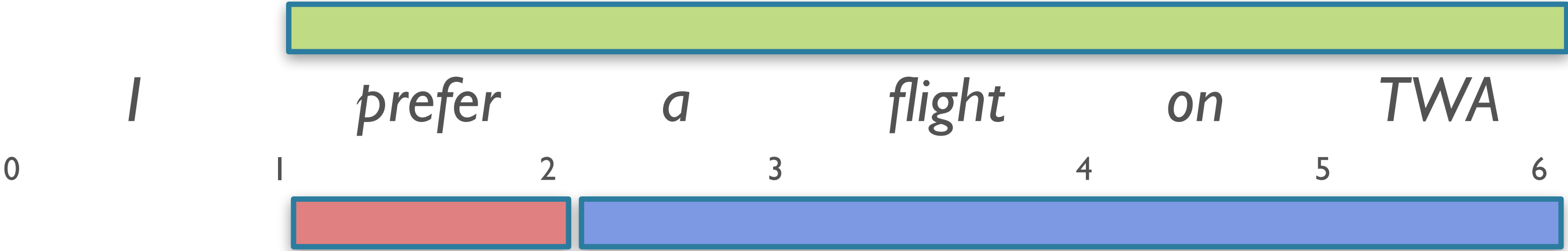
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
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 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

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Pronoun \rightarrow I | she | me
Proper-Noun \rightarrow Houston | TWA
Aux \rightarrow does
Preposition \rightarrow from | to | on | near | through
Verb \rightarrow book | include | prefer

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



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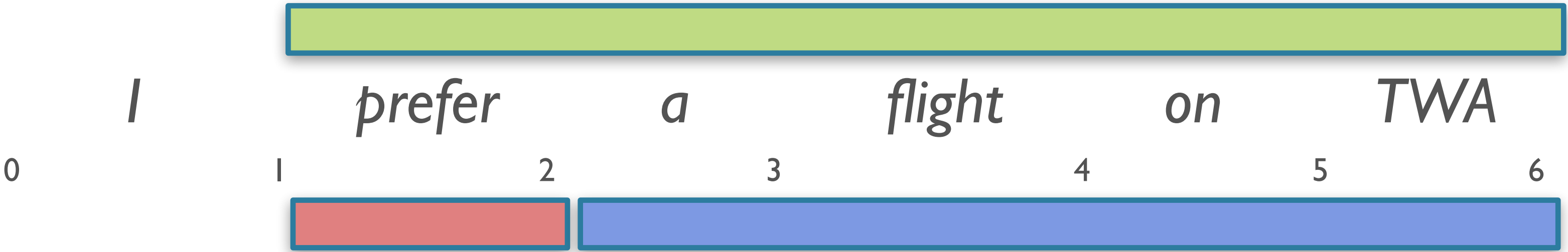
$VP \rightarrow book \mid include \mid prefer$
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NP, Pronoun [0,1]	S [0,2]		S [0,4]		
	Verb, VP, S [1,2]		VP, X2, S [1,4]		VP, X2, S [1,6]
		Det [2,3]	NP [2,4]		NP [2,6]
			Noun, Nom [3,4]		Nom [3,6]
				Prep [4,5]	PP [4,6]
					NNP, NP [5,6]



\mathcal{L}_1 Grammar

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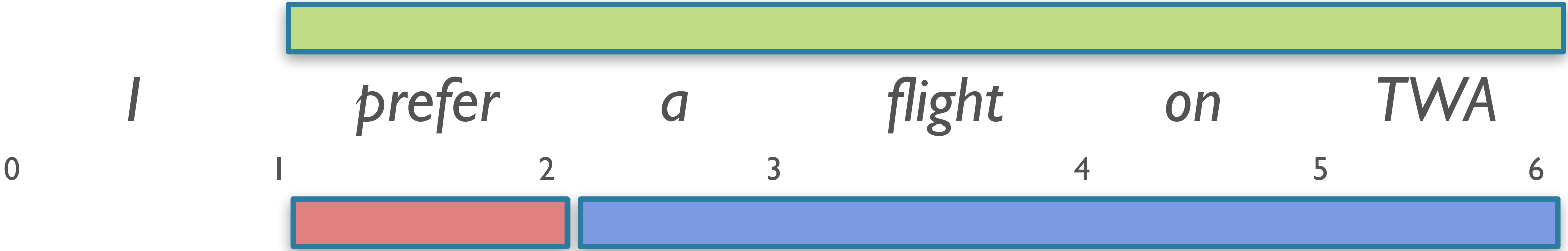
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

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 $Aux \rightarrow does$
 $Preposition \rightarrow from\ I\ to\ I\ on\ I\ near\ I\ through$
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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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 $S \rightarrow VP PP$

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

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

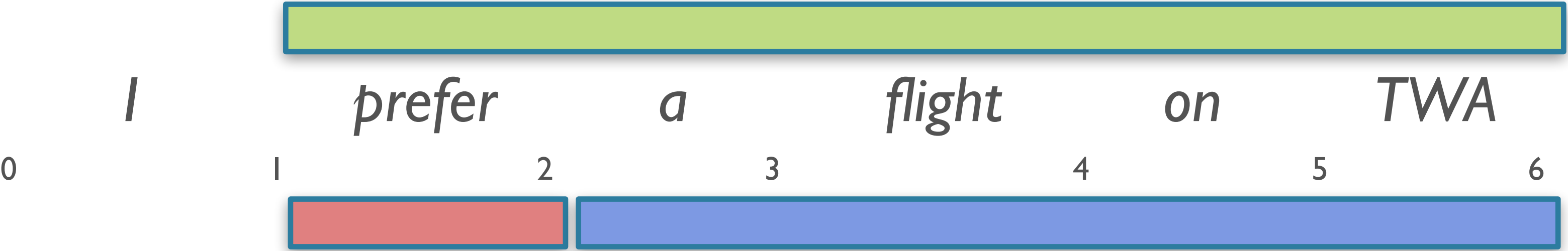
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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



\mathcal{L}_1 Grammar

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

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

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

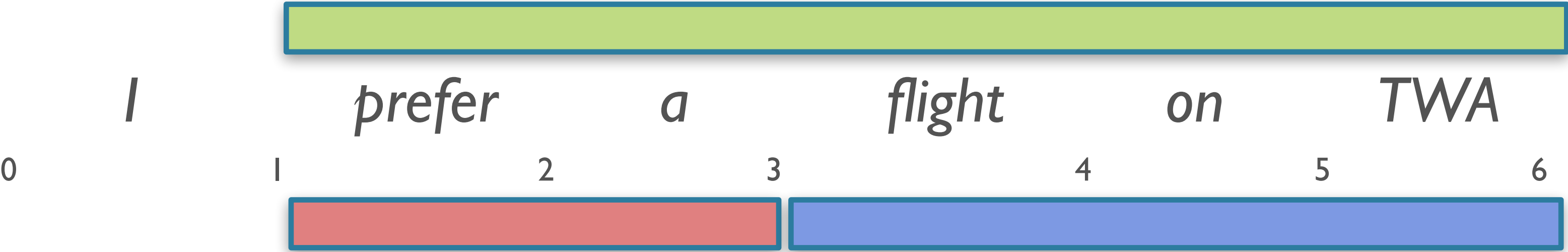
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

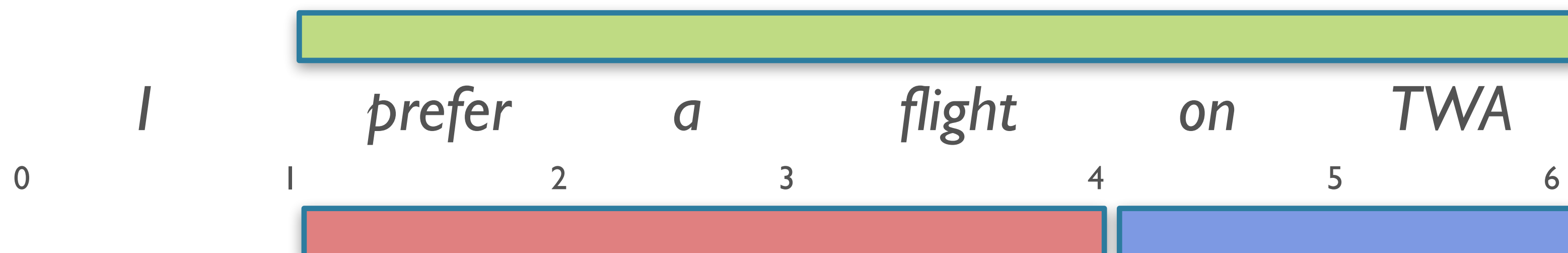
$Det \rightarrow that \mid this \mid a$
 $Noun \rightarrow book \mid flight \mid meal \mid money$
 $Pronoun \rightarrow I \mid she \mid me$
 $Proper-Noun \rightarrow Houston \mid TWA$
 $Aux \rightarrow does$
 $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
 $Verb \rightarrow book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

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



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

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



\mathcal{L}_1 Grammar

$S \rightarrow NP VP$

$S \rightarrow X1 VP$

$X1 \rightarrow Aux NP$

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

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

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

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

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

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

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

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

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

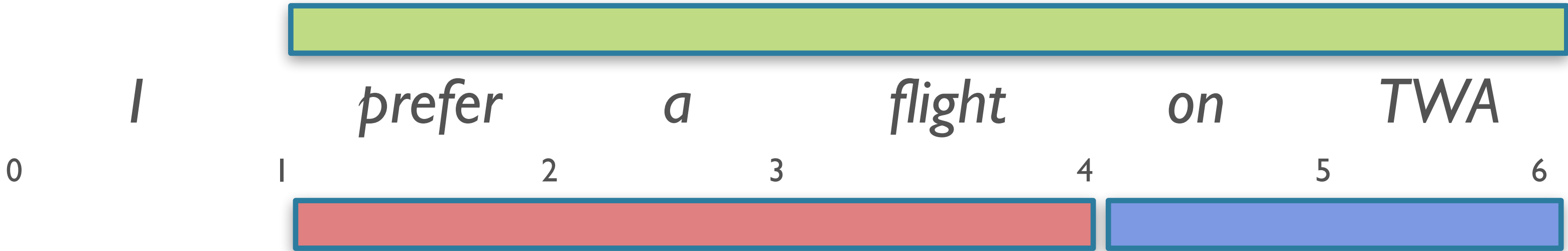
$Proper-Noun \rightarrow Houston \mid TWA$

$Aux \rightarrow does$

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

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

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



\mathcal{L}_1 Grammar

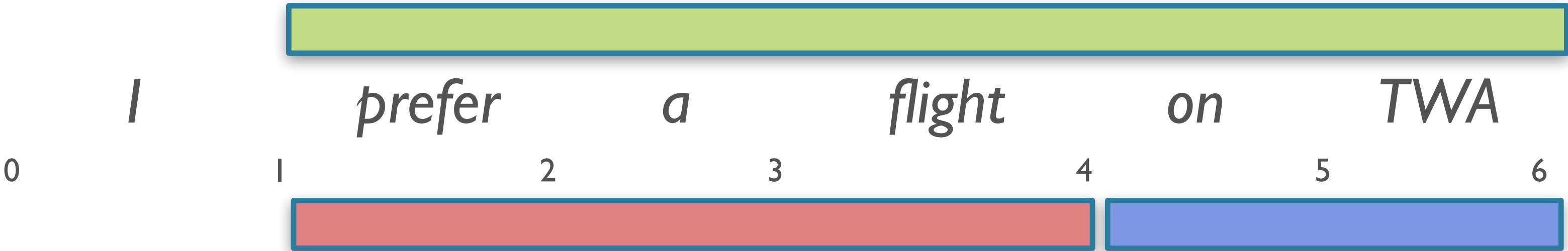
$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$

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

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



\mathcal{L}_1 Grammar

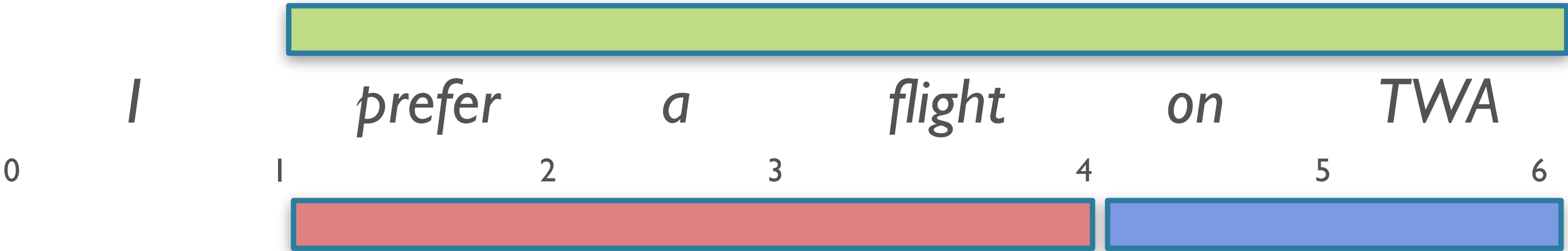
$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$

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

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



\mathcal{L}_1 Grammar

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

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

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

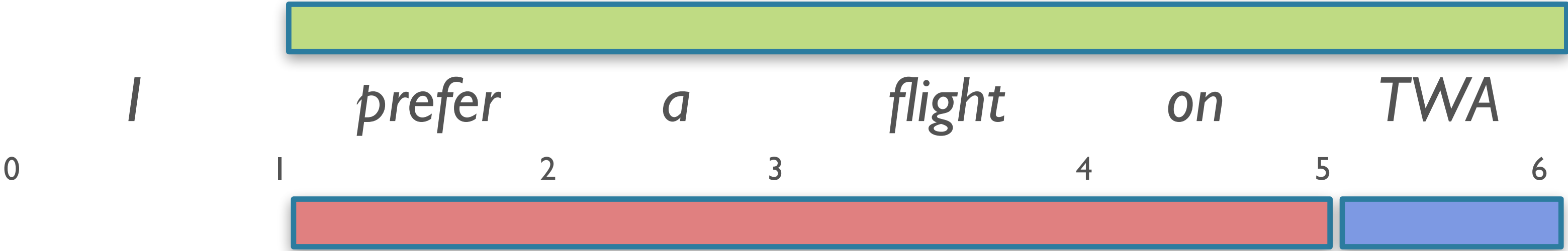
$VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

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



\mathcal{L}_1 Grammar

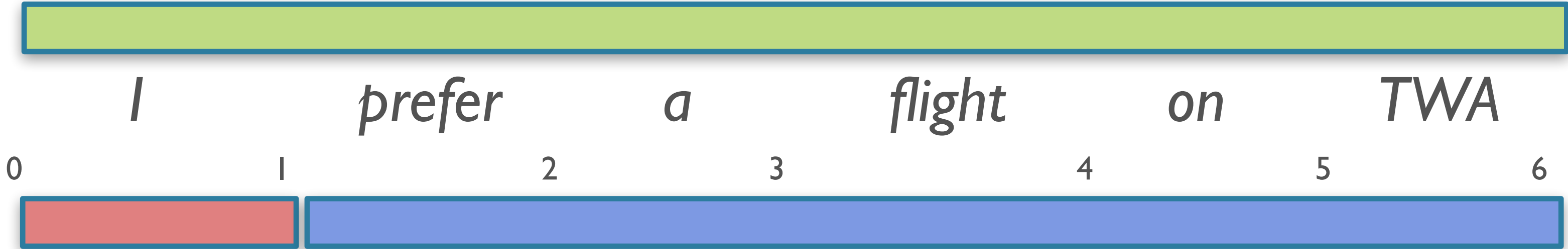
$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$

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

Lexicon

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



\mathcal{L}_1 Grammar

$S \rightarrow NP VP$

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

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

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

$NP \rightarrow I / she / me$

NP → TWA / Houston

$NP \rightarrow Det \text{ Nominal}$

Nominal → book / flight / meal / money

Nominal → *Nominal Noun*

Nominal → *Nominal PP*

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

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

PP → *Preposition NP*

Lexicon

Det → *that* | *this* | *a*

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

Pronoun → I | she | me

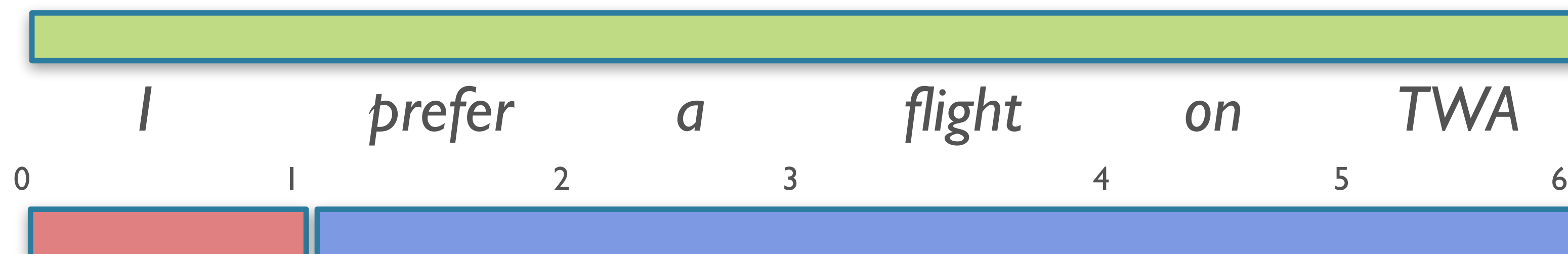
Proper-Noun → *Houston* | *TWA*

Aux → *does*

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

Verb → *book* | *include* | *prefer*

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



\mathcal{L}_1 Grammar

$S \rightarrow NP VP$

$S \rightarrow X1 VP$

$X1 \rightarrow Aux NP$

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

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

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

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

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

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

Lexicon

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

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

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

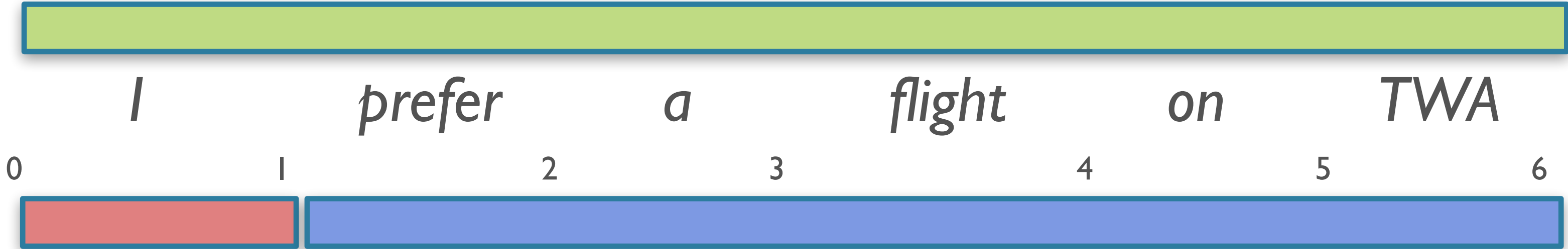
$Proper-Noun \rightarrow Houston \mid TWA$

$Aux \rightarrow does$

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

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

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



\mathcal{L}_1 Grammar

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

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

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

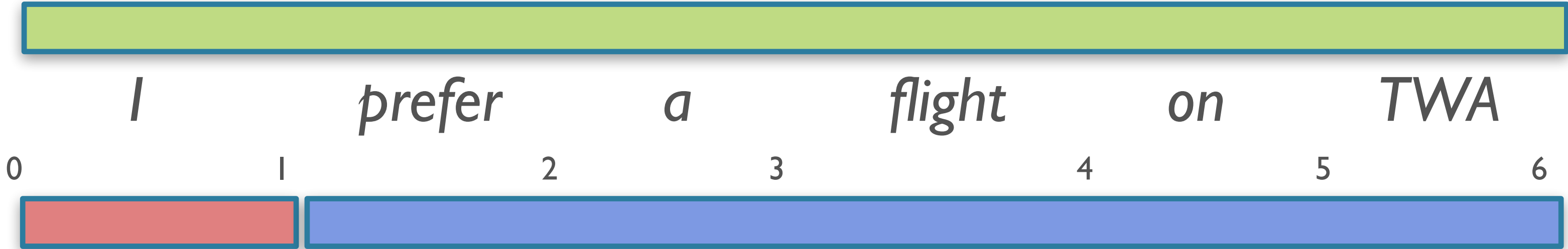
$VP \rightarrow book\ I\ include\ I\ prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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



\mathcal{L}_1 Grammar

$S \rightarrow NP VP$

$S \rightarrow X1 VP$

$X1 \rightarrow Aux NP$

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

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

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

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$NP \rightarrow Det Nominal$

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

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$Nominal \rightarrow Nominal PP$

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

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

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Lexicon

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

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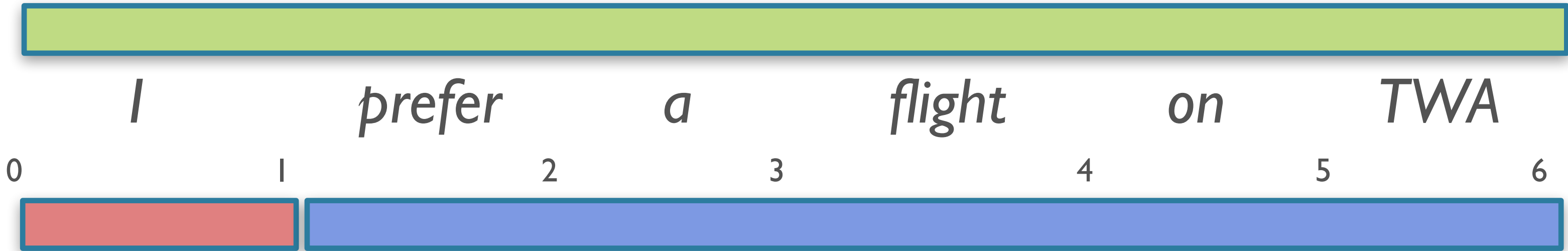
$Proper-Noun \rightarrow Houston \mid TWA$

$Aux \rightarrow does$

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

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

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



\mathcal{L}_1 Grammar

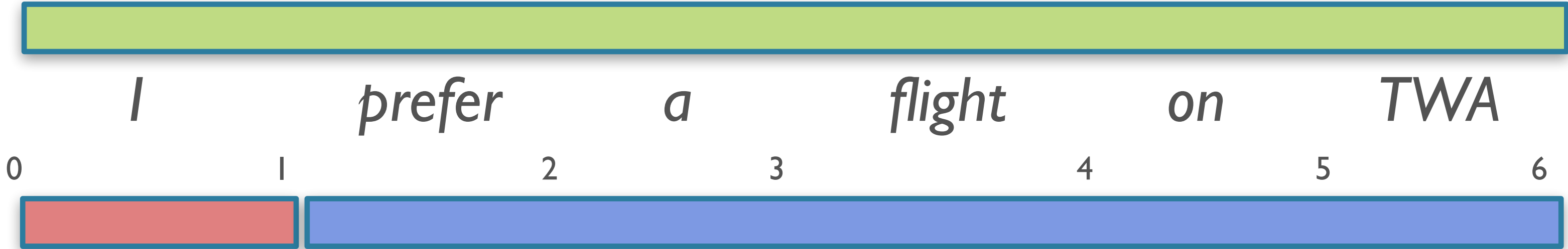
$S \rightarrow NP VP$
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 $S \rightarrow Verb NP$
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 $X2 \rightarrow Verb NP$
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 $Preposition \rightarrow from \mid to \mid on \mid near \mid through$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

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



Current CKY Algorithm

Limitations:

- Only stores non-terminals in cell

 - Not rules or cells corresponding to RHS

- Stores SETS of non-terminals

 - Multiple rules with same LHS collide

Currently only ***acceptance/recognition***

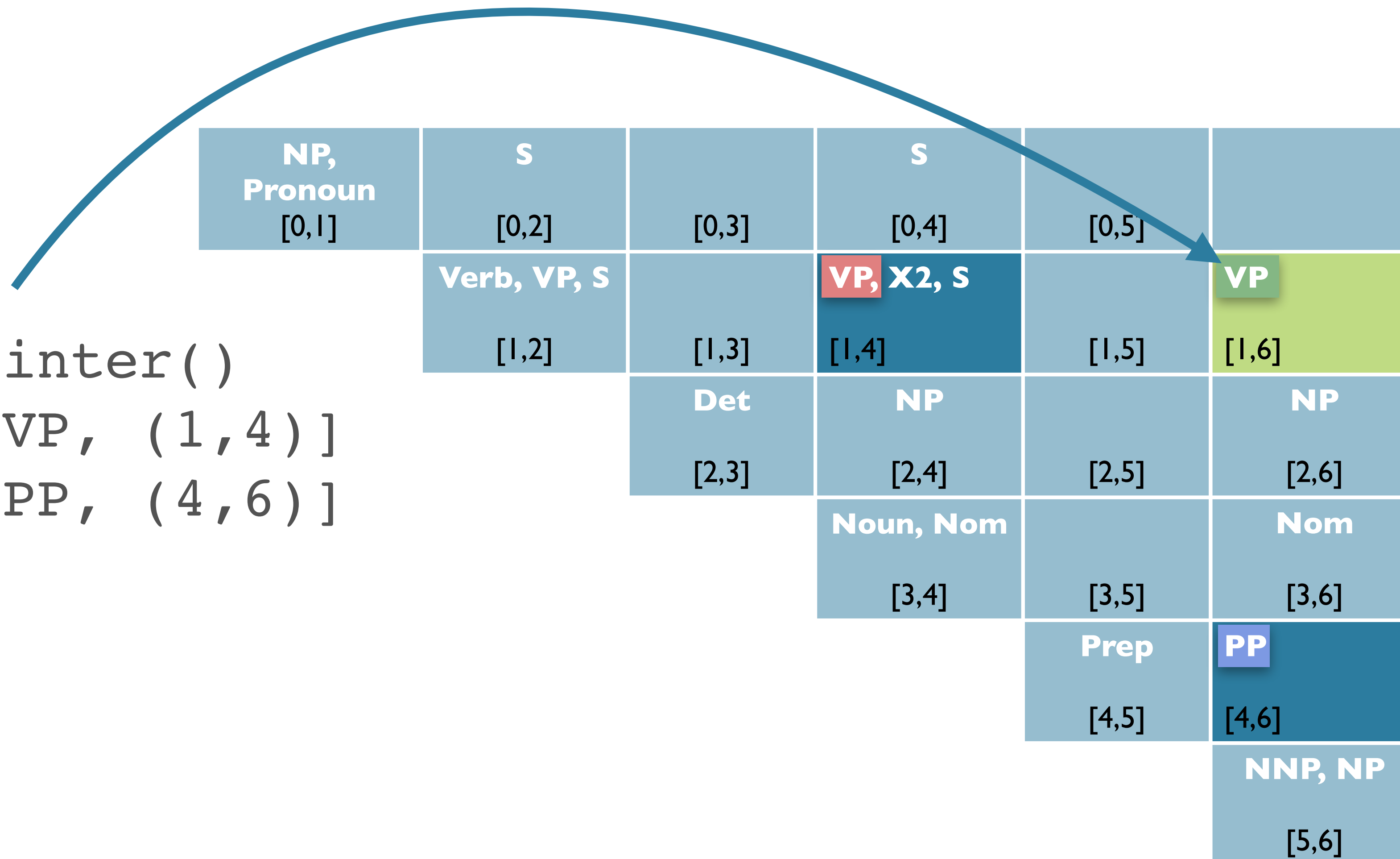
CKY *Parser*

- Pair each nonterminal with 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]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	VP [1,6]
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
				Prep [4,5]	PP [4,6]
					NNP, NP [5,6]

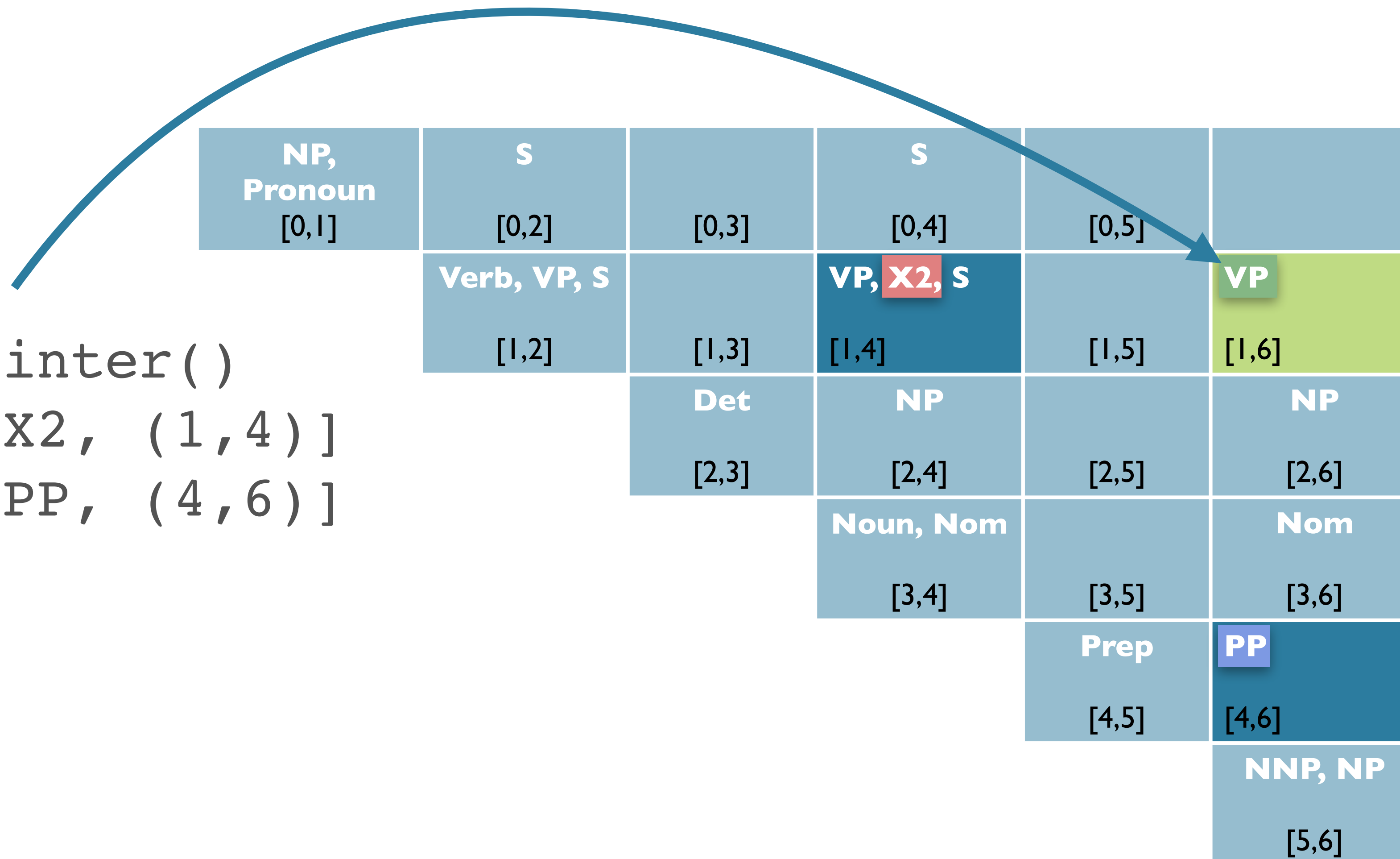
VP → **VP** **PP**

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

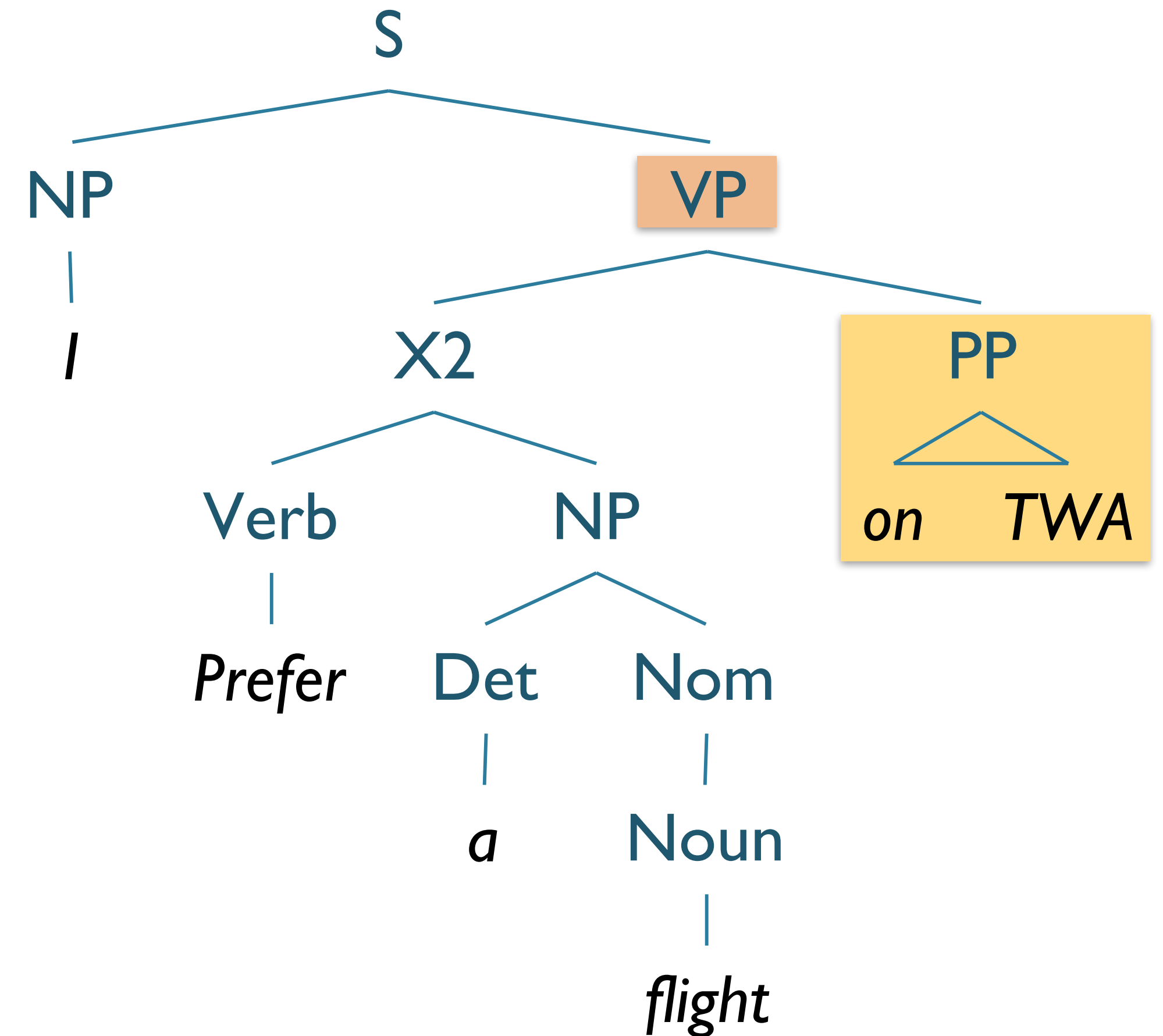
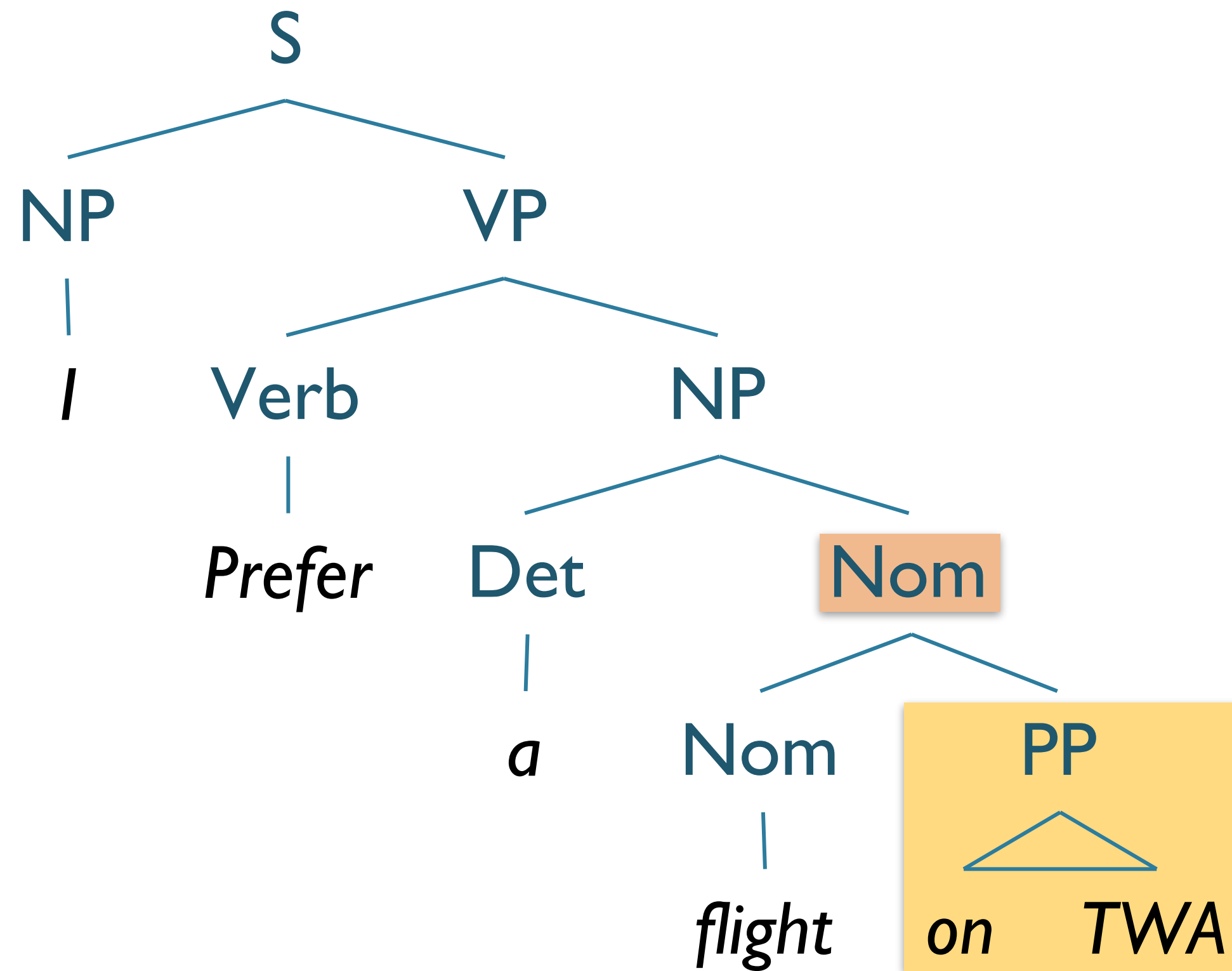


VP → **X2** **PP**

```
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

Unit Testing

Unit Testing

- Strategy of testing individual pieces of code in isolation
- Helps ensure:
 - Basic functionality in isolation
 - Complex functionality when individual components are combined
- In many industry jobs, you can't commit code without unit tests!

Unit Testing in Python

- Many good tutorials on the web [[here's one](#)]
- In a nutshell:

```
from unittest import TestCase
```

```
class longTests(TestCase):
```

```
    def test_three(self):
```

```
        length_3_rule = parse_productions('A -> B C D')
```

```
        target_rules = parse_productions(''A -> B _X0_  
                                         _X0_ -> C D'')
```

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

Unit Testing in Python

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

```
python3 -m nose hw2.py
```

Unit Testing in Python

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

```
python3 -m nose hw2.py
```

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

```
A -> B _X0_
```

```
_X0_ -> C D
```

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

```
A -> B C
```

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

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


Unit Testing

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