

CKY Parsing

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

Announcements

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

Indigenous Peoples' Day

- Seattle/Sealth/Si'ahl



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- The Lushootseed spelling [IPA] of Chief Seattle/Sealth/Si'ahl:
 - siʔat [siʔa:t]
 - t̪ : voiceless alveolar lateral fricative



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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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- Lushootseed exhibits debatable distinction between verbs and nouns [link to Glottolog page for more references]
 - **?učw** **ti** **sbiaw**
goes **that-which** **is-a-coyote**
“The/a coyote goes”
 - **sbiaw** **ti** **?učw**
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“The one who goes is a coyote”
 - (Translation distinction provided for clarity — semantically equivalent)

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“The one who goes is a coyote”
 - (Translation distinction provided for clarity — semantically equivalent)
- Lillooet Salish quantification has repercussions for e.g. English (Matthewson 2001)

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

Total Results: 0

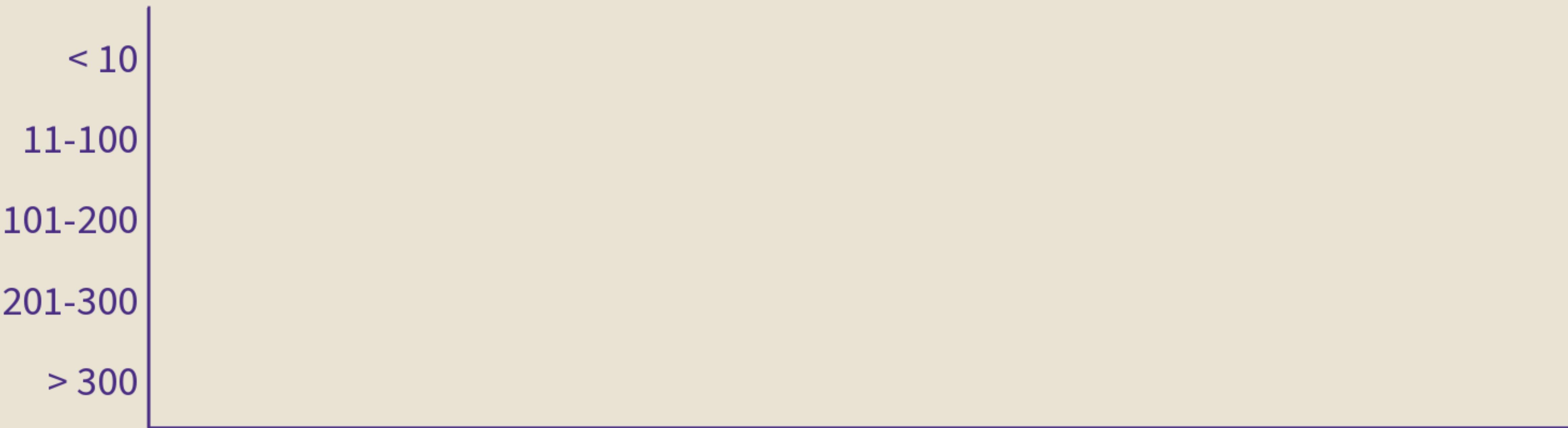
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SMS Text **SHANEST** to **22333** once to join

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



Total Results: 0

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



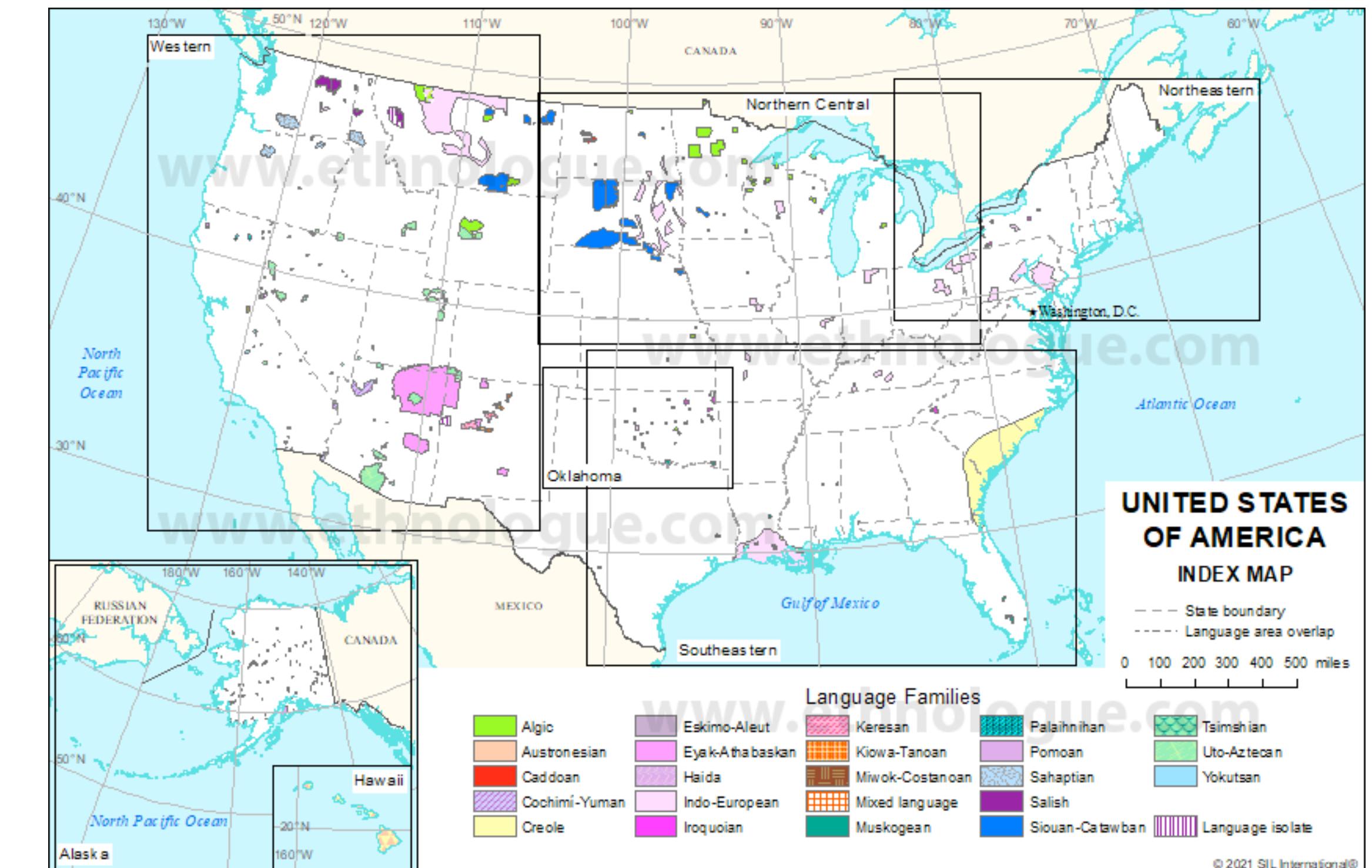
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Languages in the U.S.

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



https://www.ethnologue.com/map/US_x

Indigenous Peoples' Day: Resources

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

Roadmap

- CKY Parsing Algorithm

- Dynamic programming structure

- Algorithm and example

- Analysis & Discussion

- Next time: Probabilistic CFGs

- Motivation: Ambiguity

- Augmenting CFGs with probabilities

CKY

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CKY

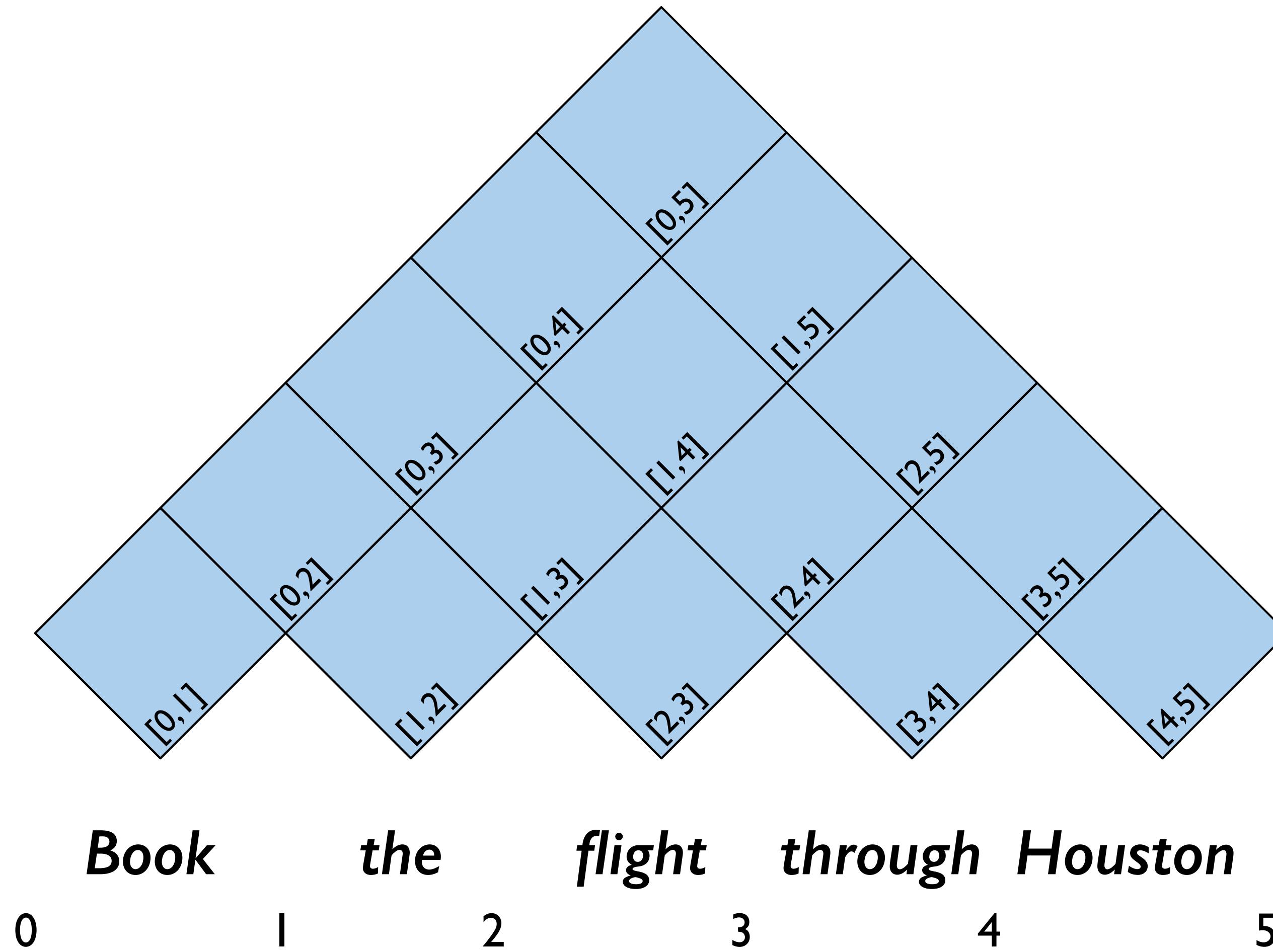
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 - $[j - 1, j]$ contains pre-terminals
 - if $[0, n]$ contains the start symbol, the sentence is **accepted**

CKY Matrix

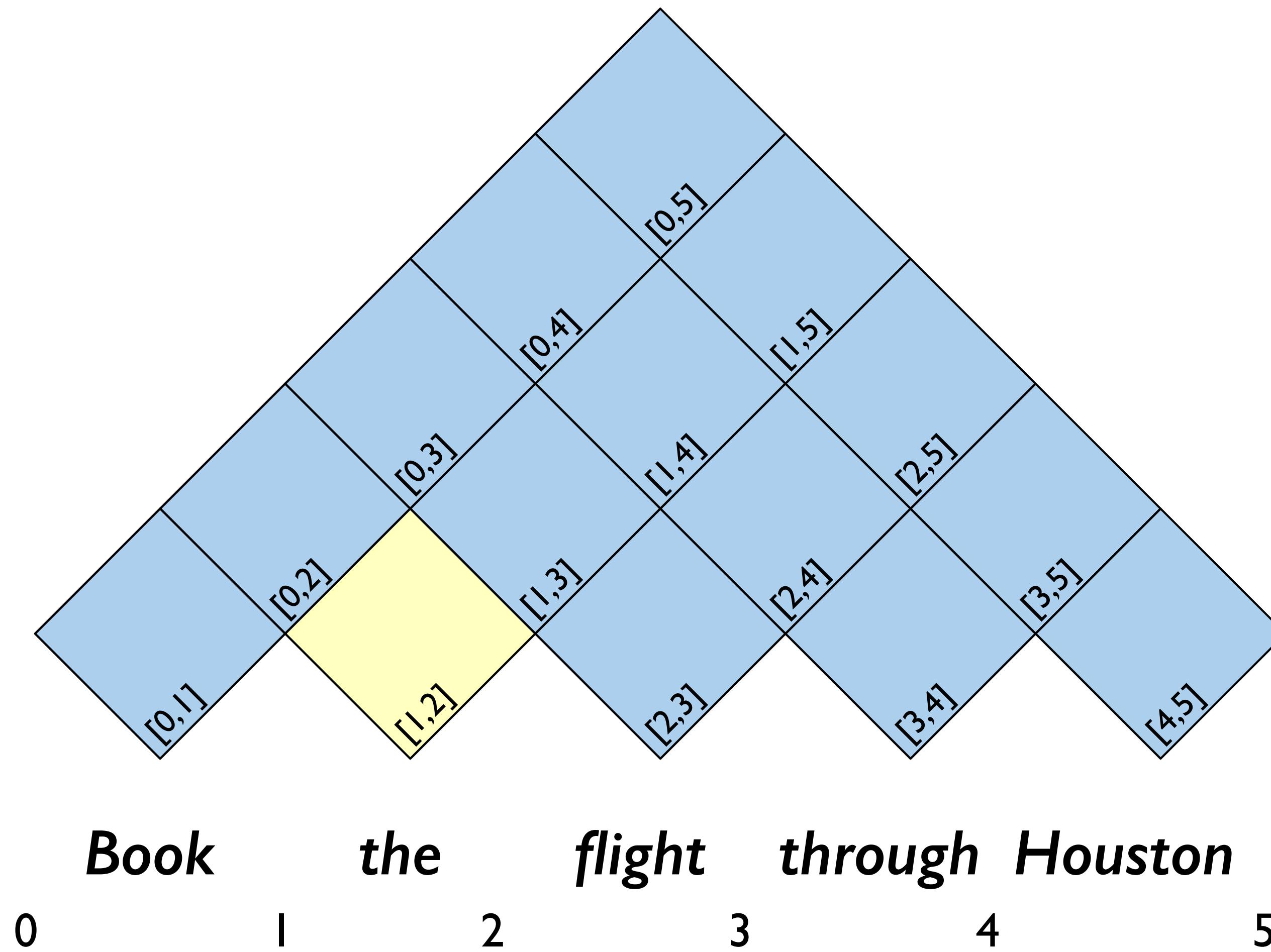
Book the flight through Houston

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

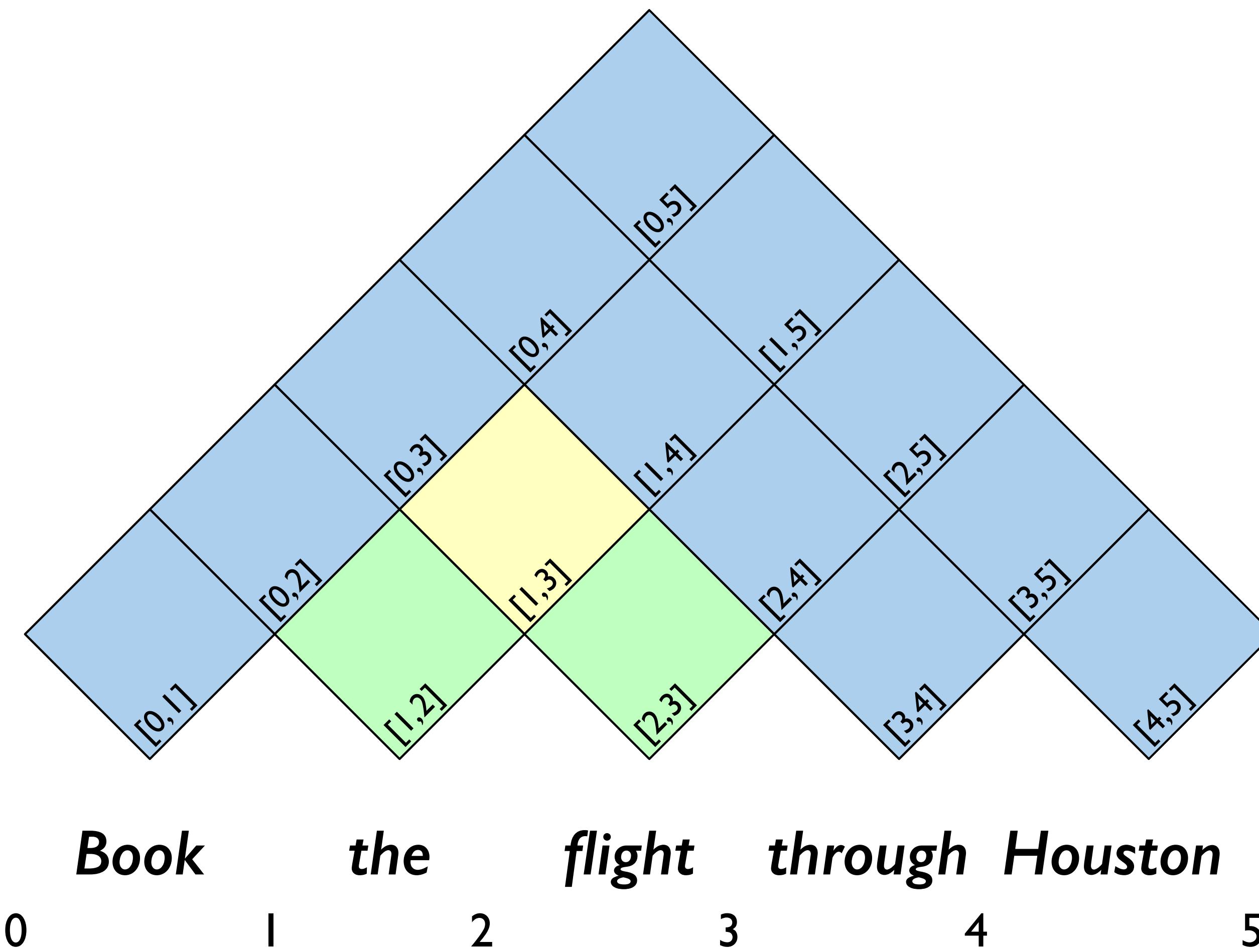
CKY Matrix



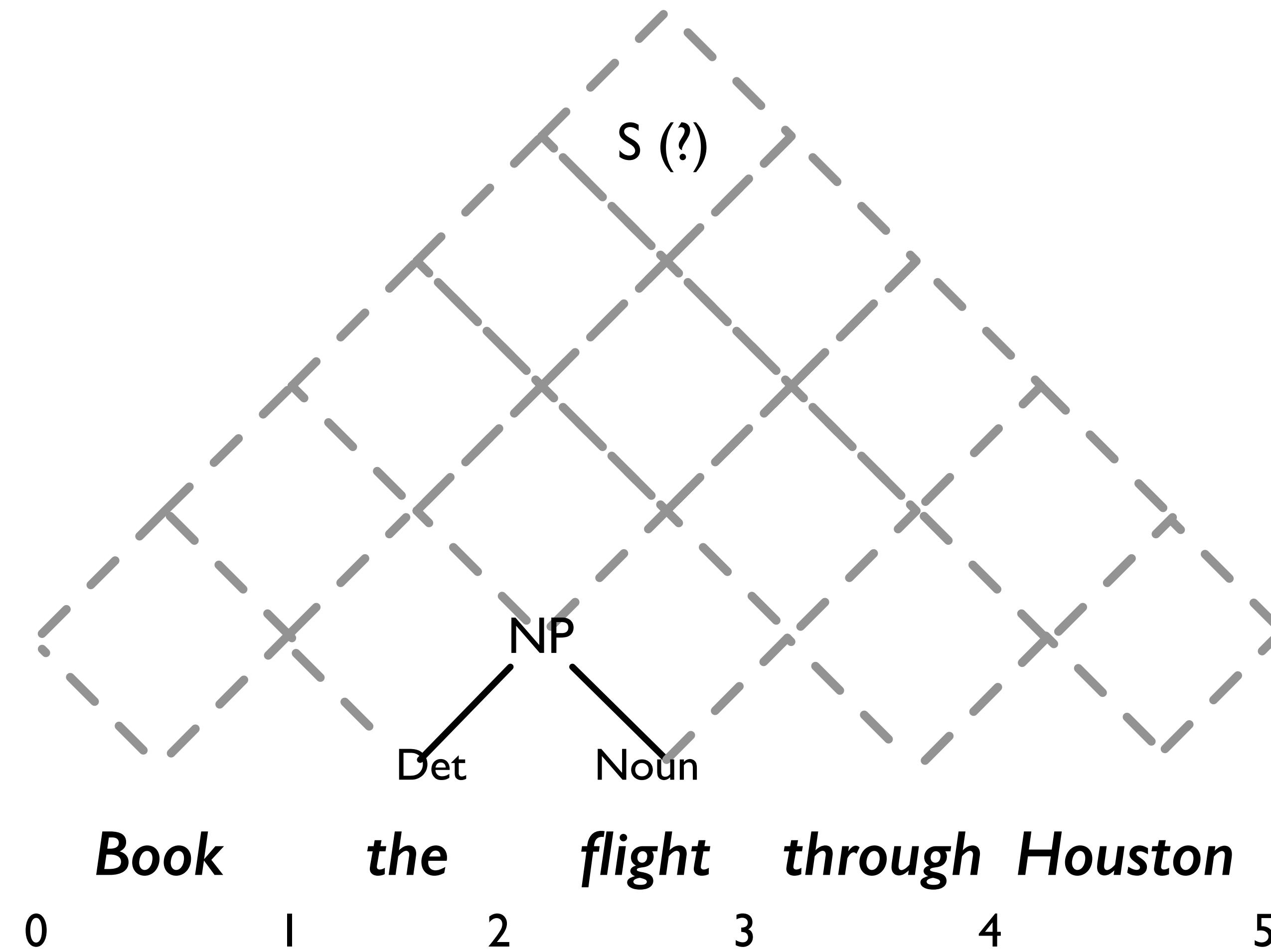
CKY Matrix



CKY Matrix



CKY Matrix



Dynamic Programming in CKY

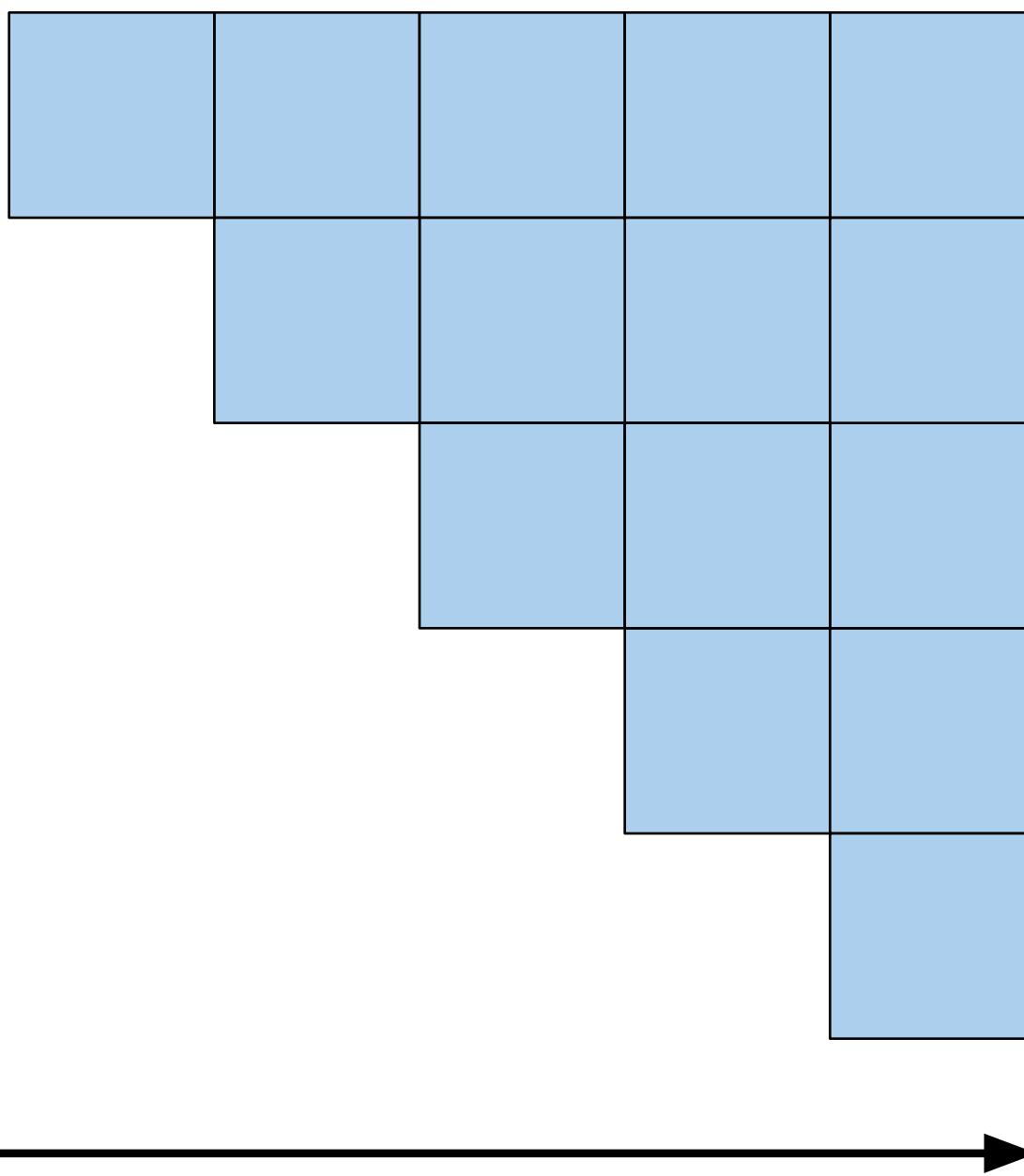
- Key idea:
 - for $i < k < j$
 - ...and a parse spanning substring $[i, j]$
 - There is a k such that there are parses spanning $[i, k]$ and $[k, j]$
 - We can construct parses for whole sentences by building from these partial parses
- So to have a rule $A \rightarrow B \ C$ in $[i, j]$
 - Must have B in $[i, k]$ and C in $[k, j]$ for some $i < k < j$
 - CNF forces this for all $j > i + 1$

CKY

- Table fills:

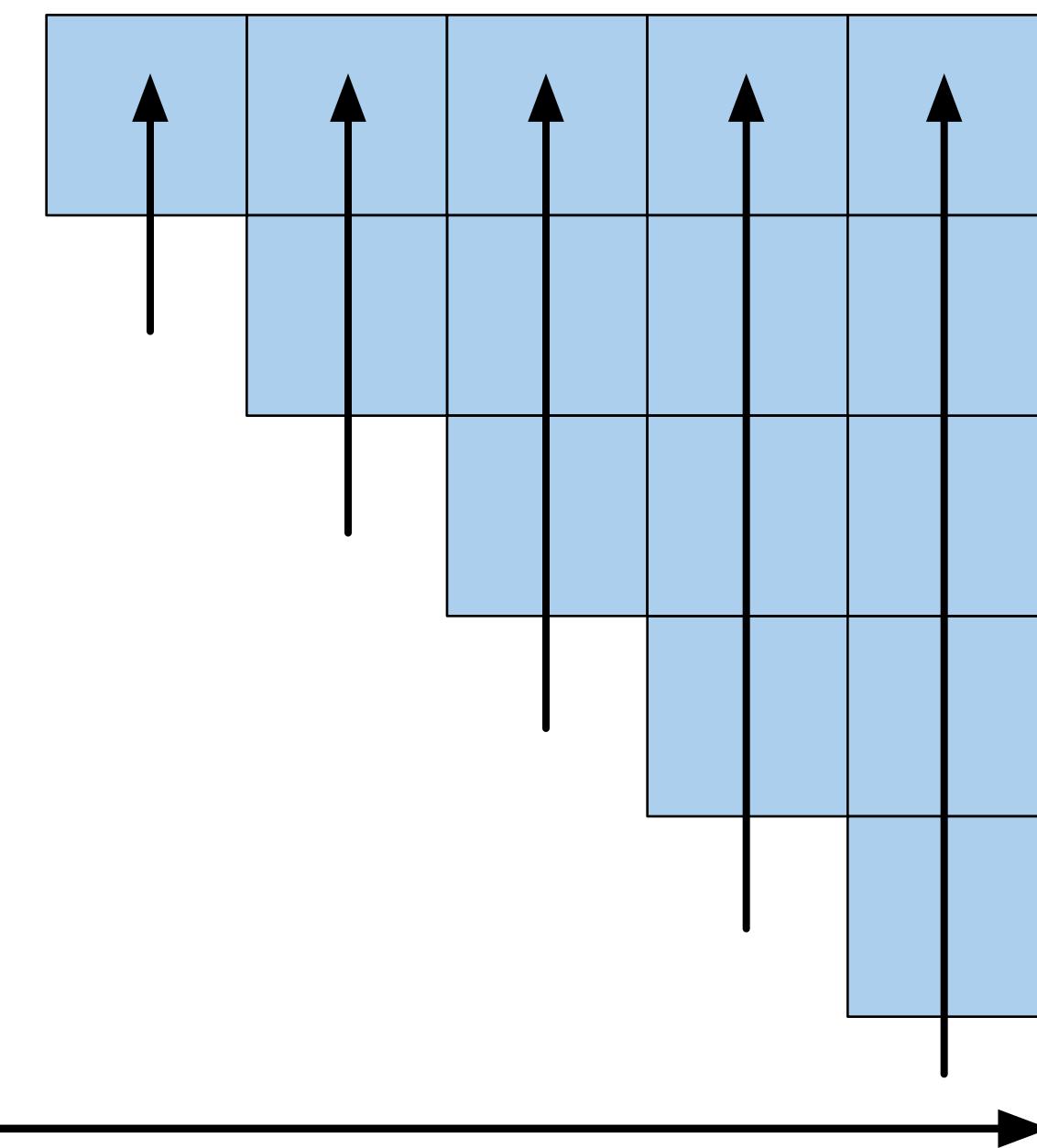
CKY

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



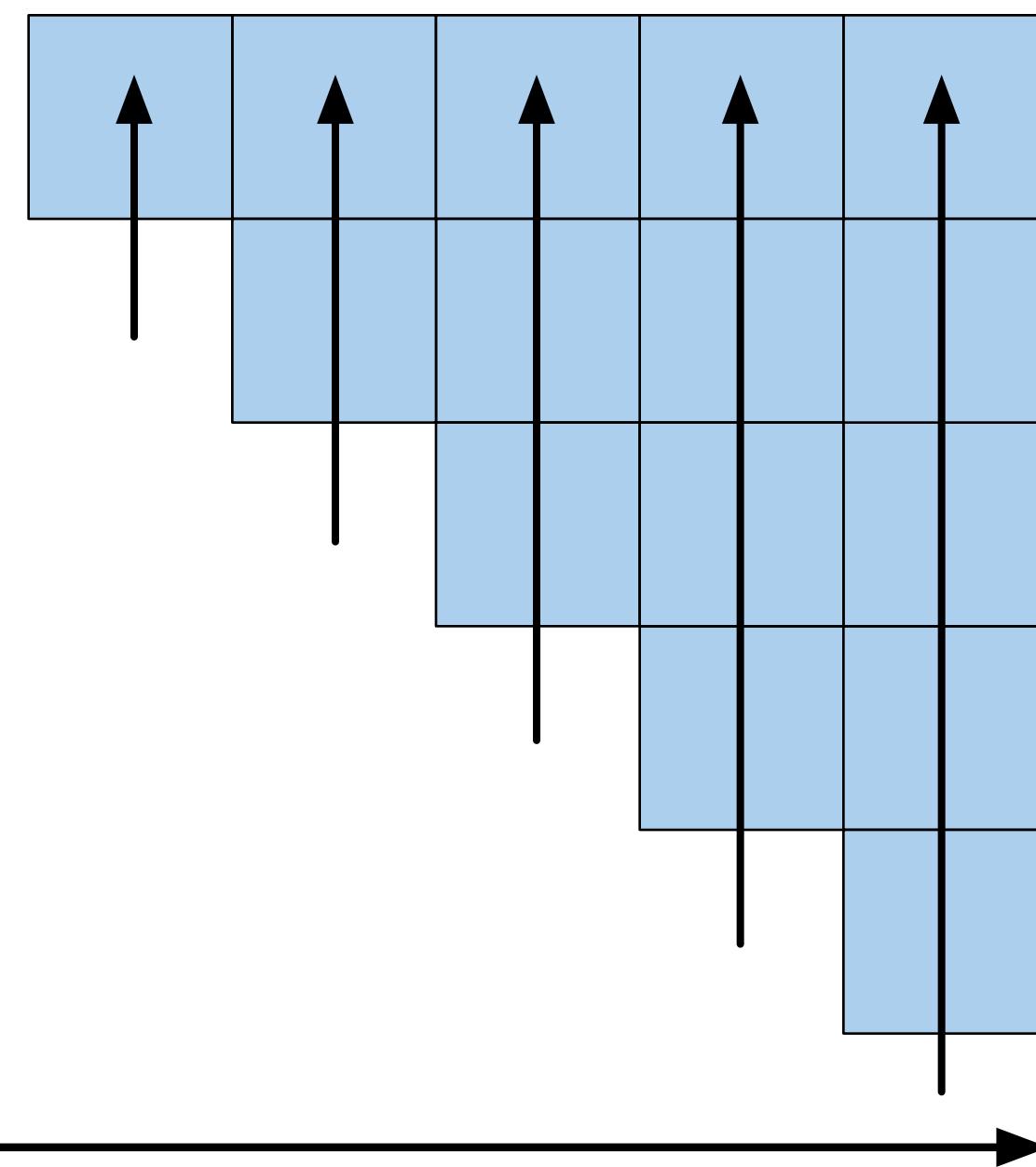
CKY

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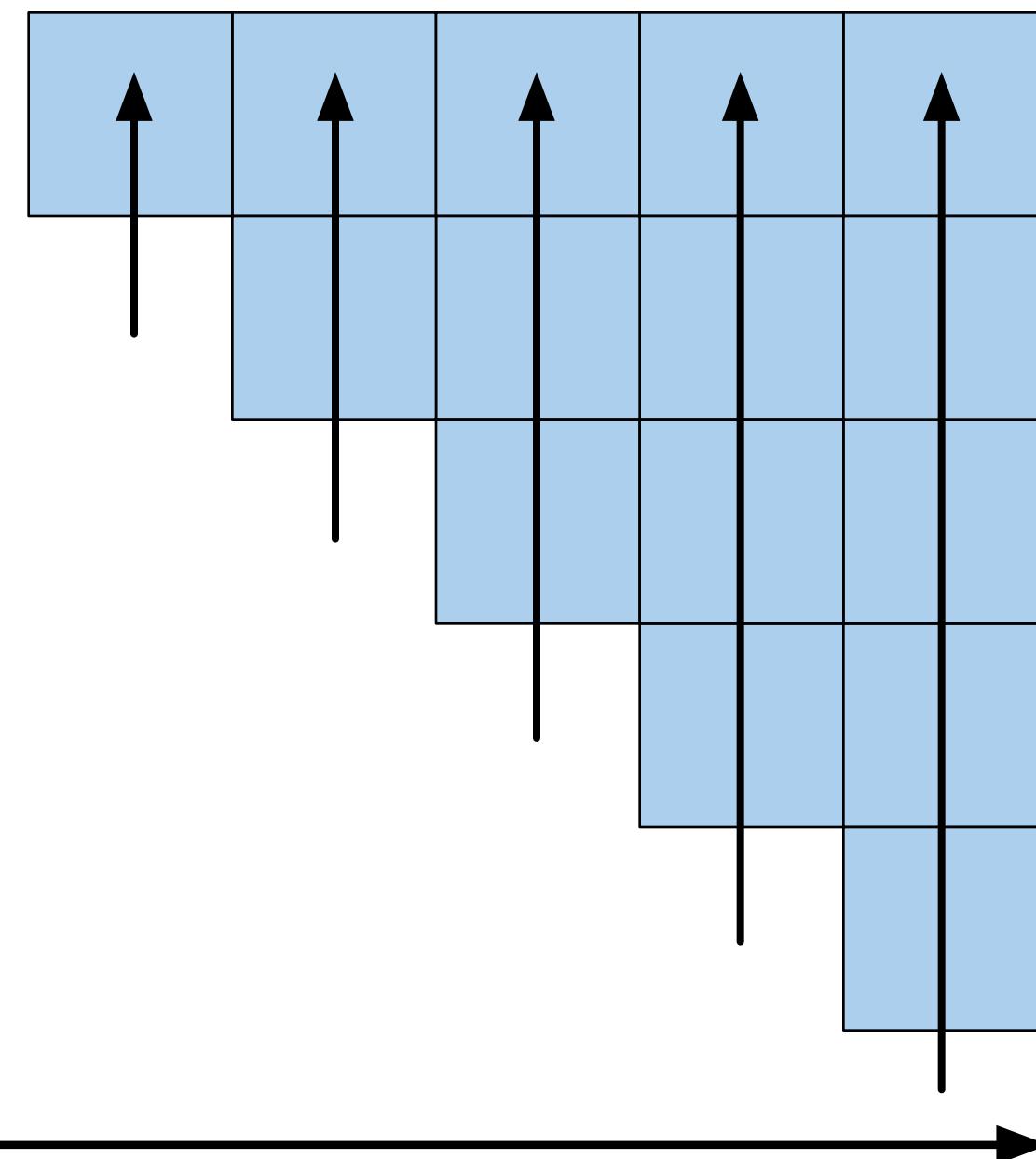
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- Why?



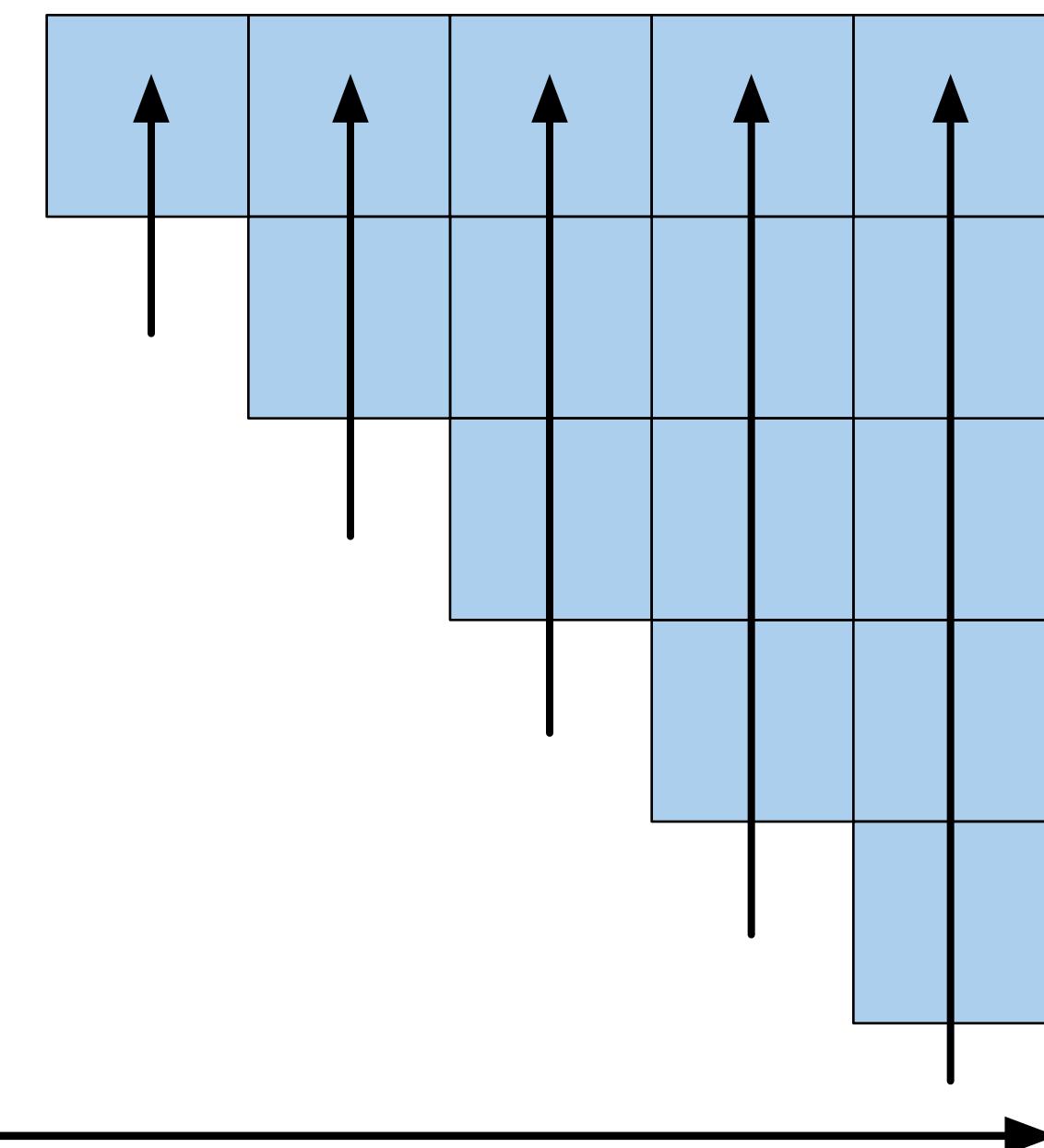
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 - To fill each cell, must have access to all sub-spans

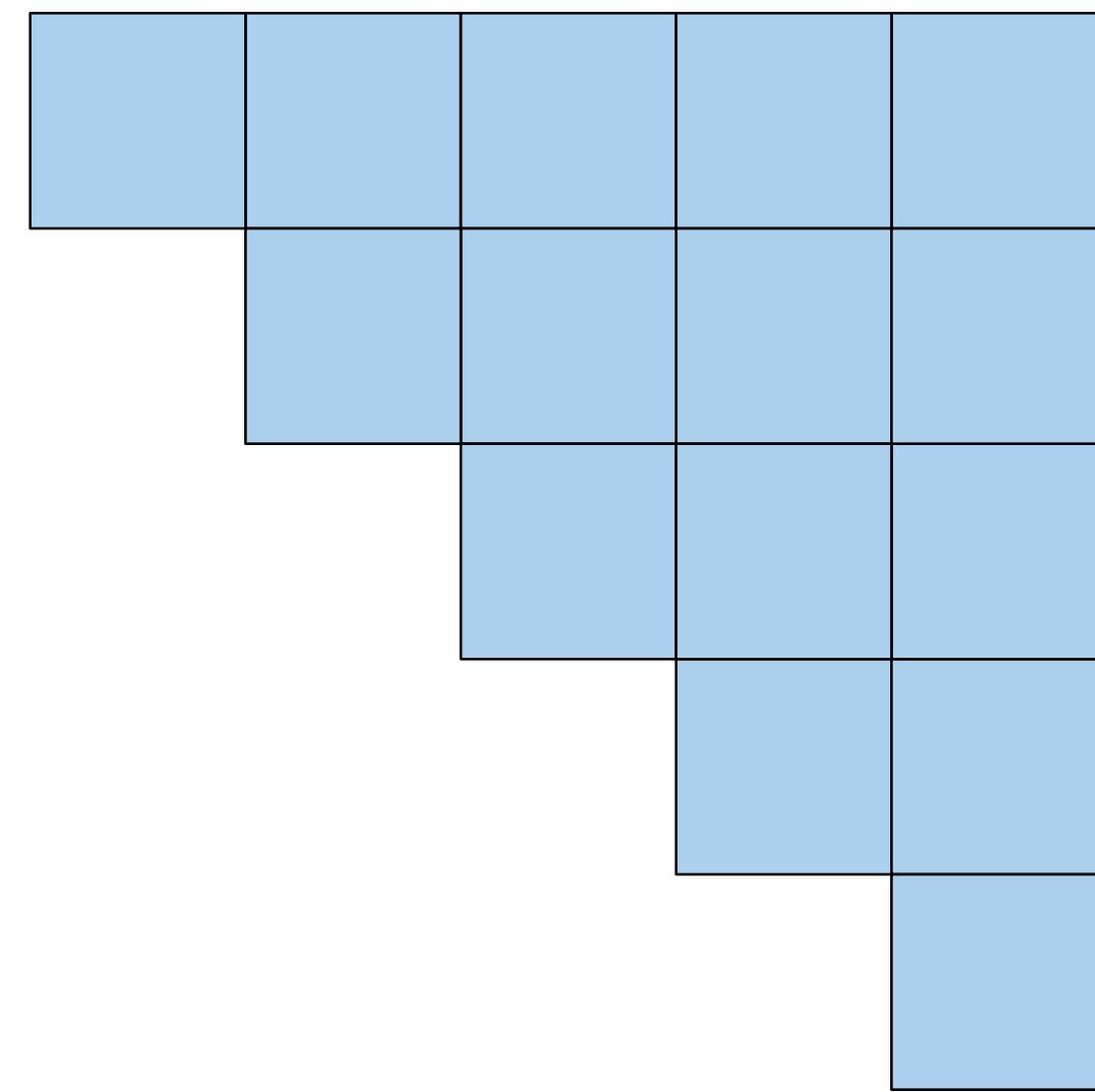


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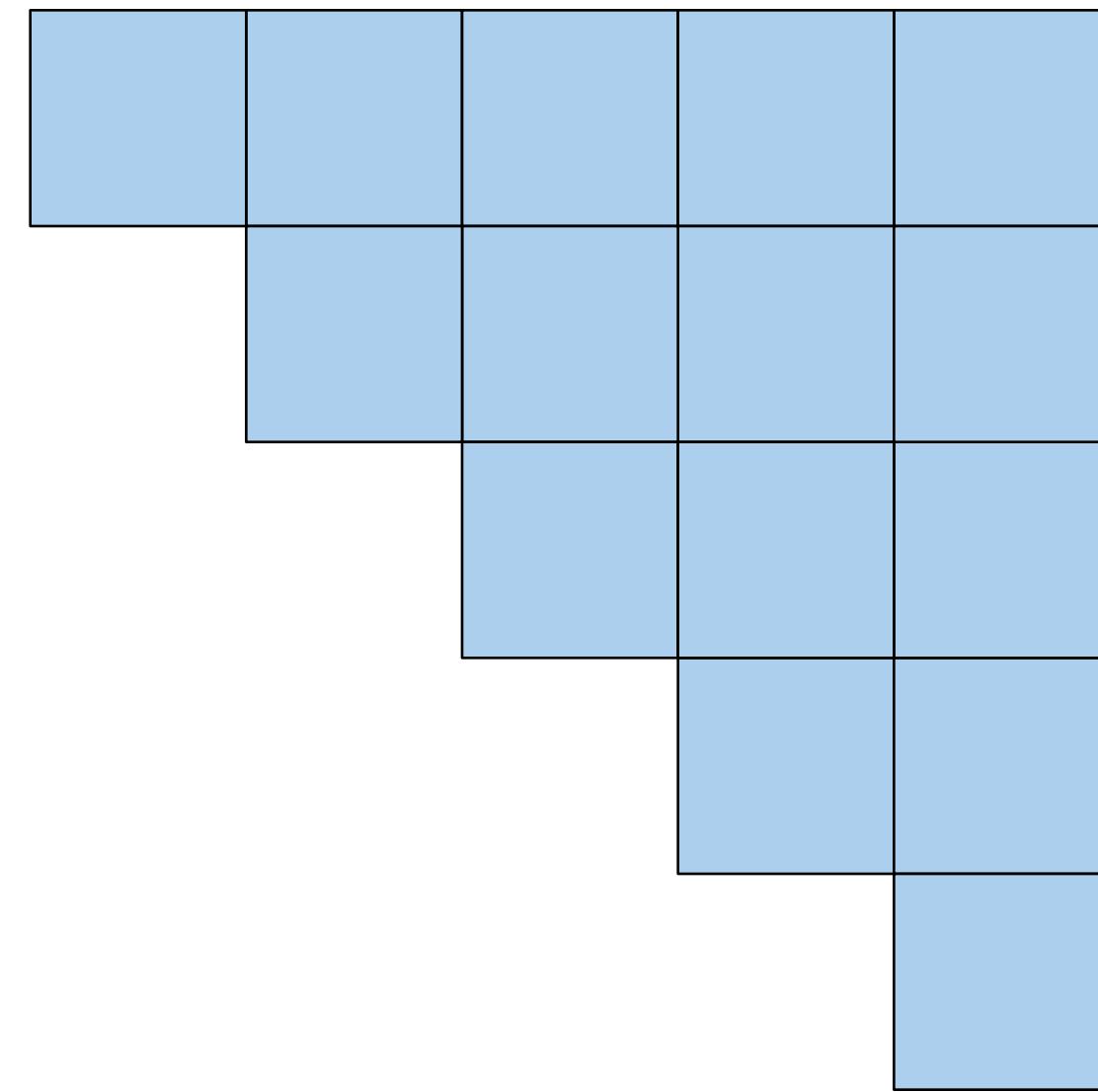


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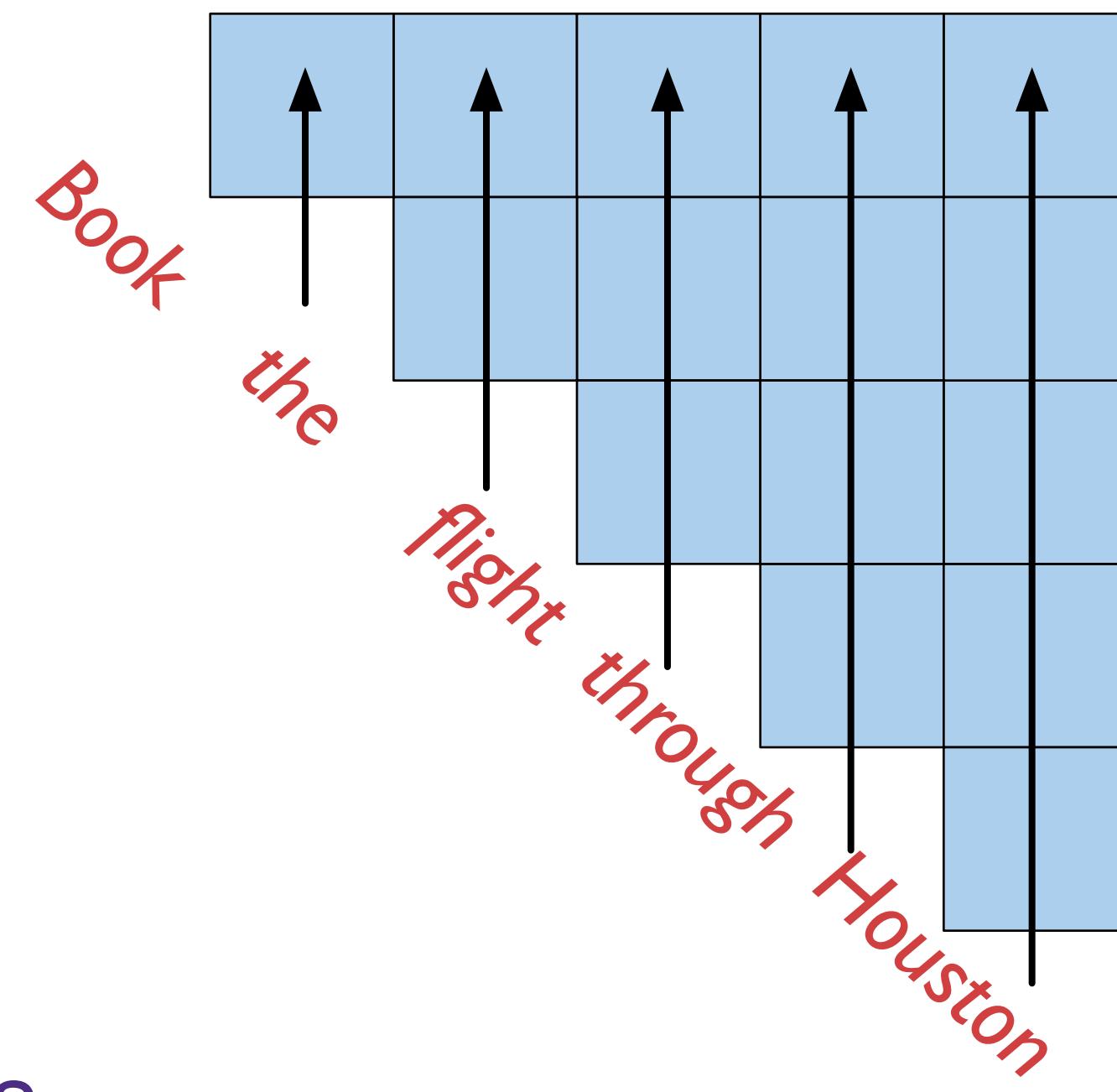
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function CKY-PARSE(words, grammar) returns table
for j  $\leftarrow$  from 1 to LENGTH(words) do
  table[ j - 1, j ]  $\leftarrow$  { A | A  $\rightarrow$  words[ j ]  $\in$  grammar }
  for i  $\leftarrow$  from j - 2 downto 0 do
    for k  $\leftarrow$  i + 1 to j - 1 do
      table[ i, j ]  $\leftarrow$  table[ i, j ]  $\cup$ 
      { A | A  $\rightarrow$  BC  $\in$  grammar
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Left-to-right, bottom-to-top
Sliding k as the pivot for child nodes

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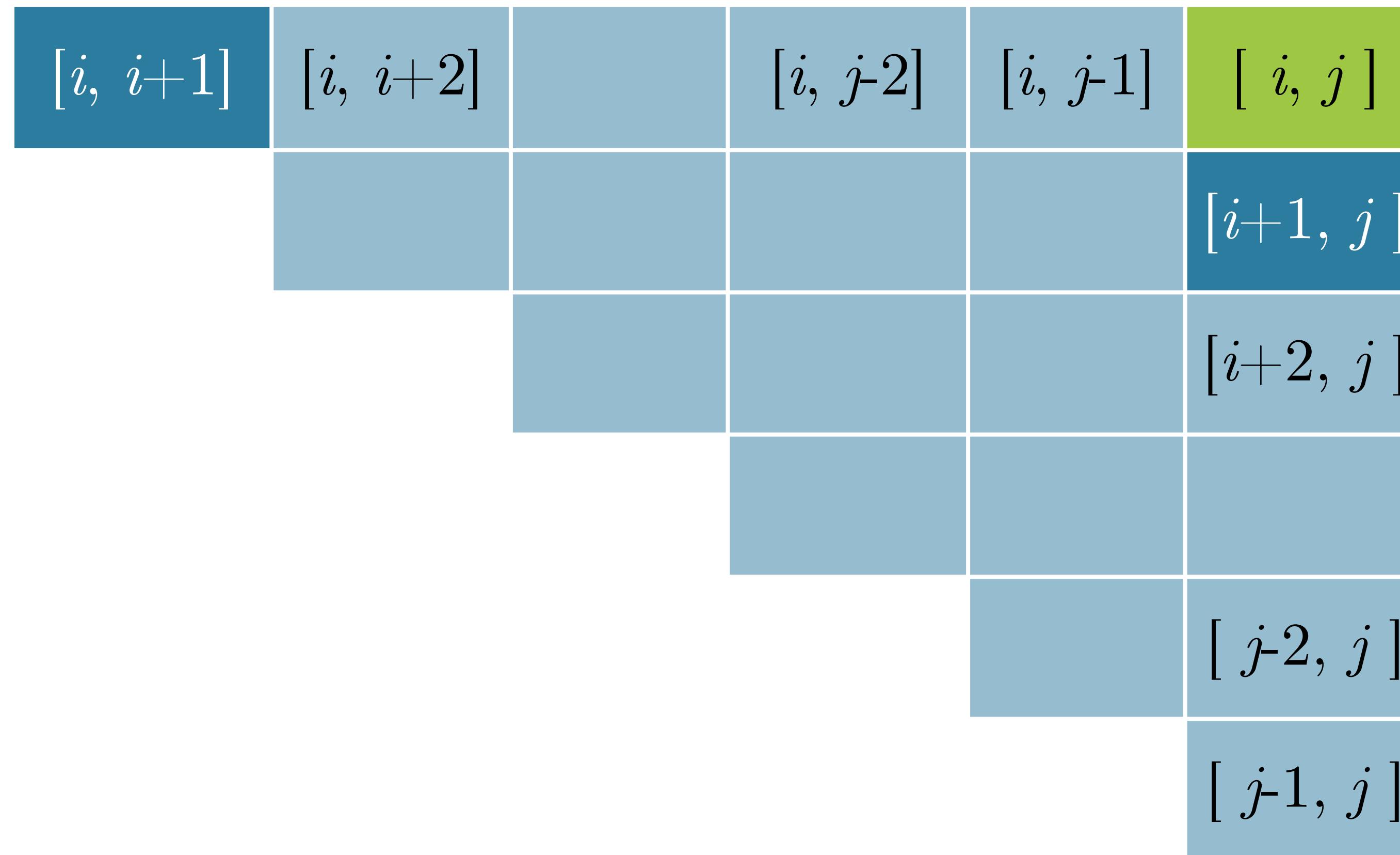
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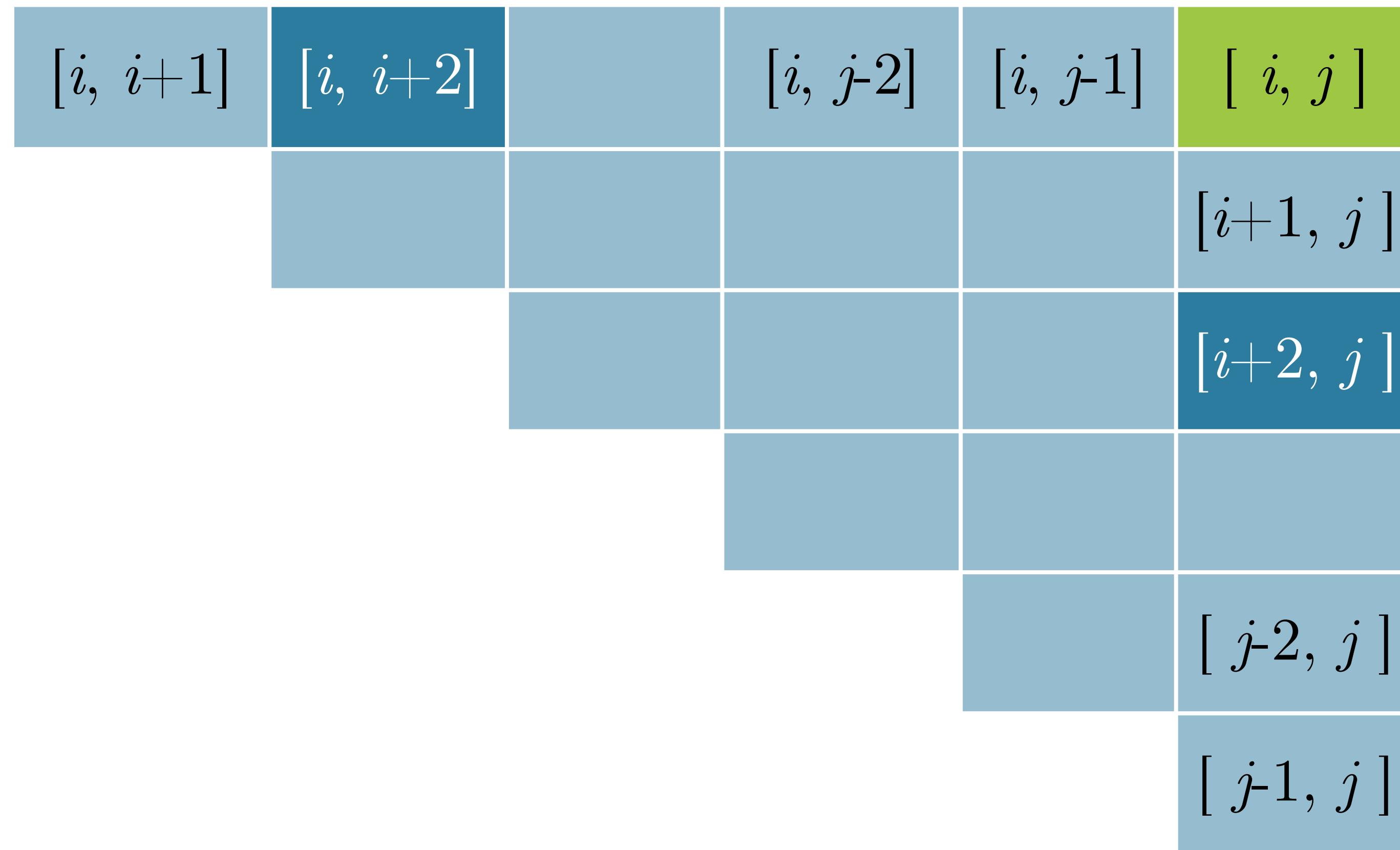
Filling the cell with set of applicable rules

Filling Cell $[i, j]$



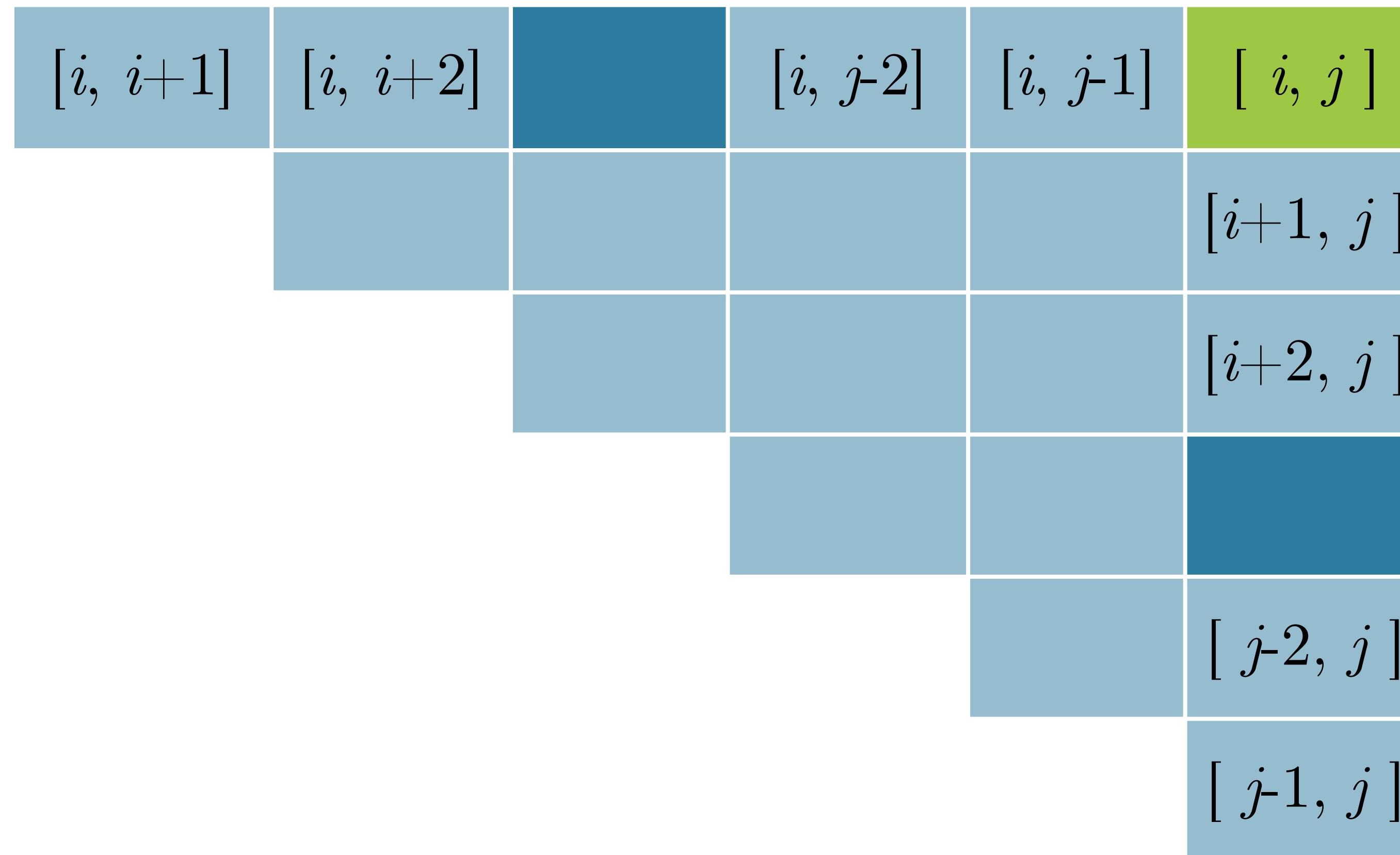
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Filling Cell $[i, j]$



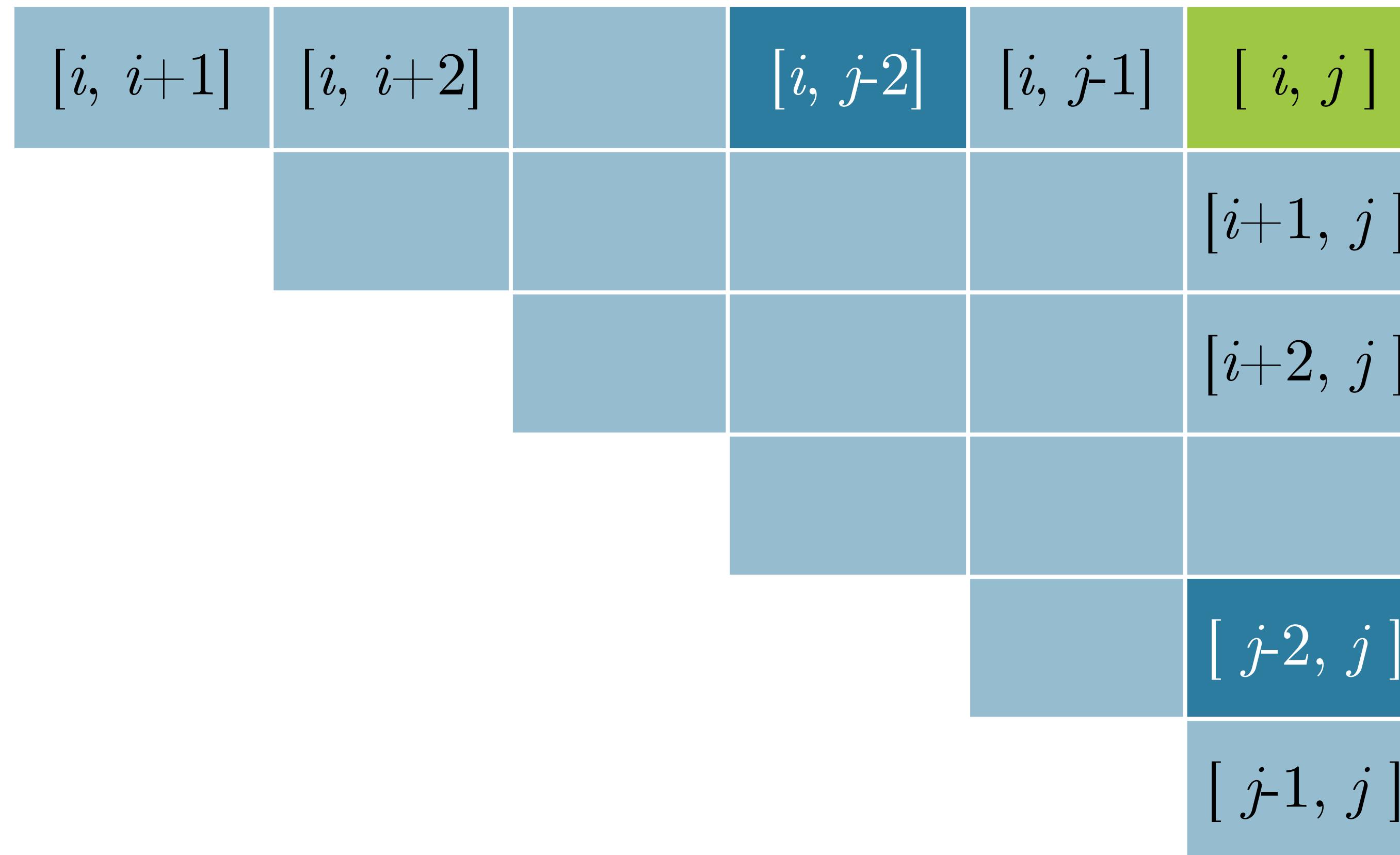
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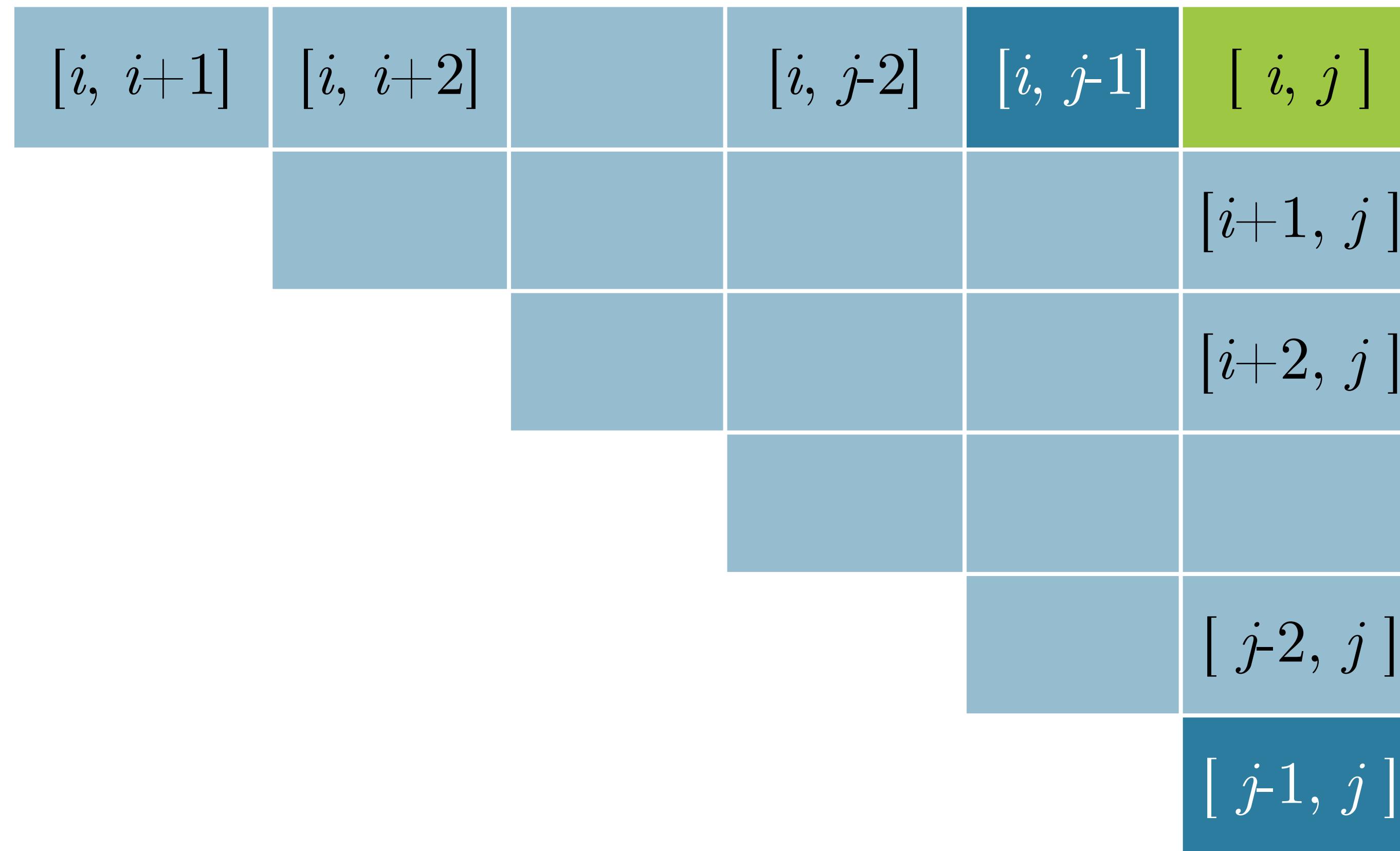
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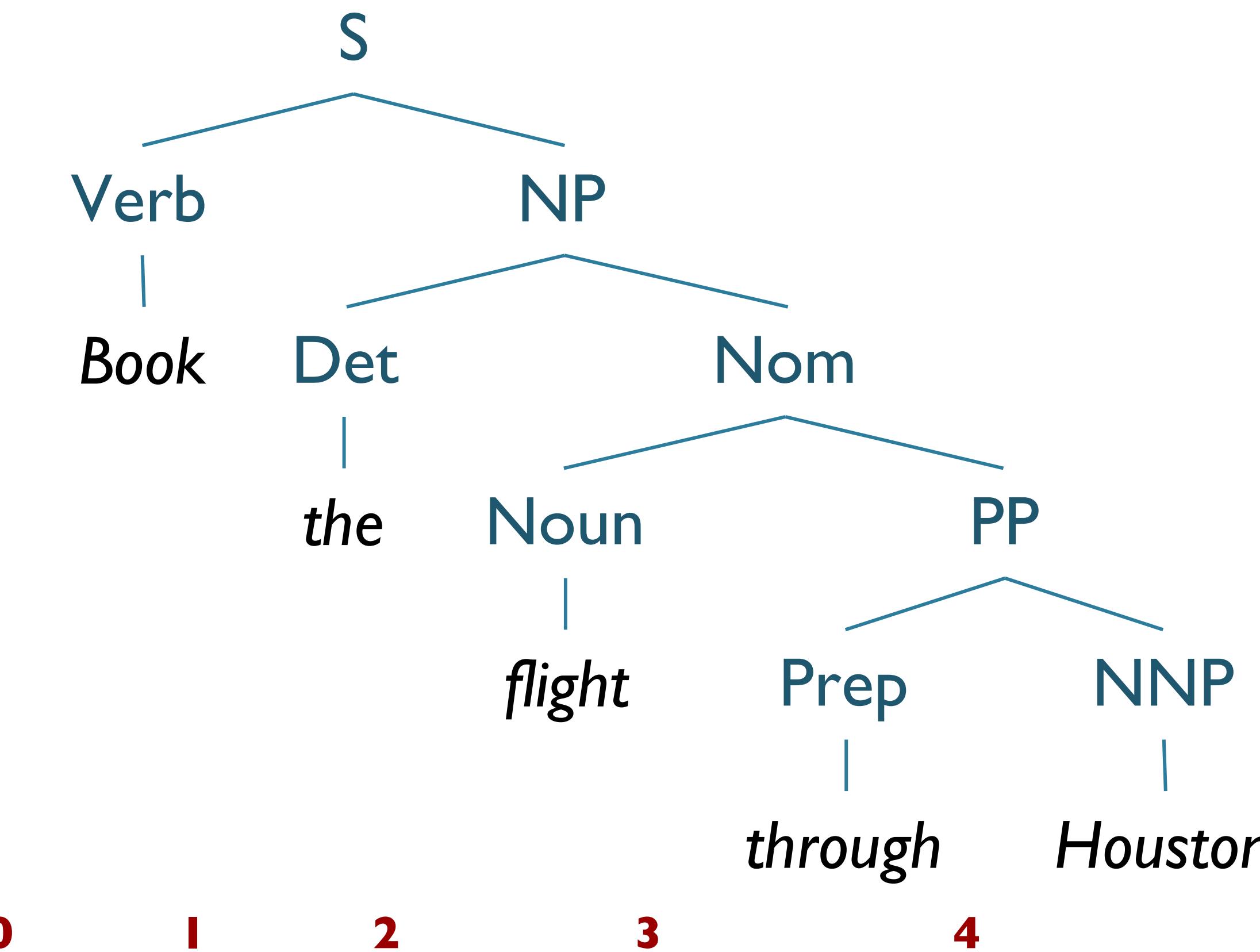
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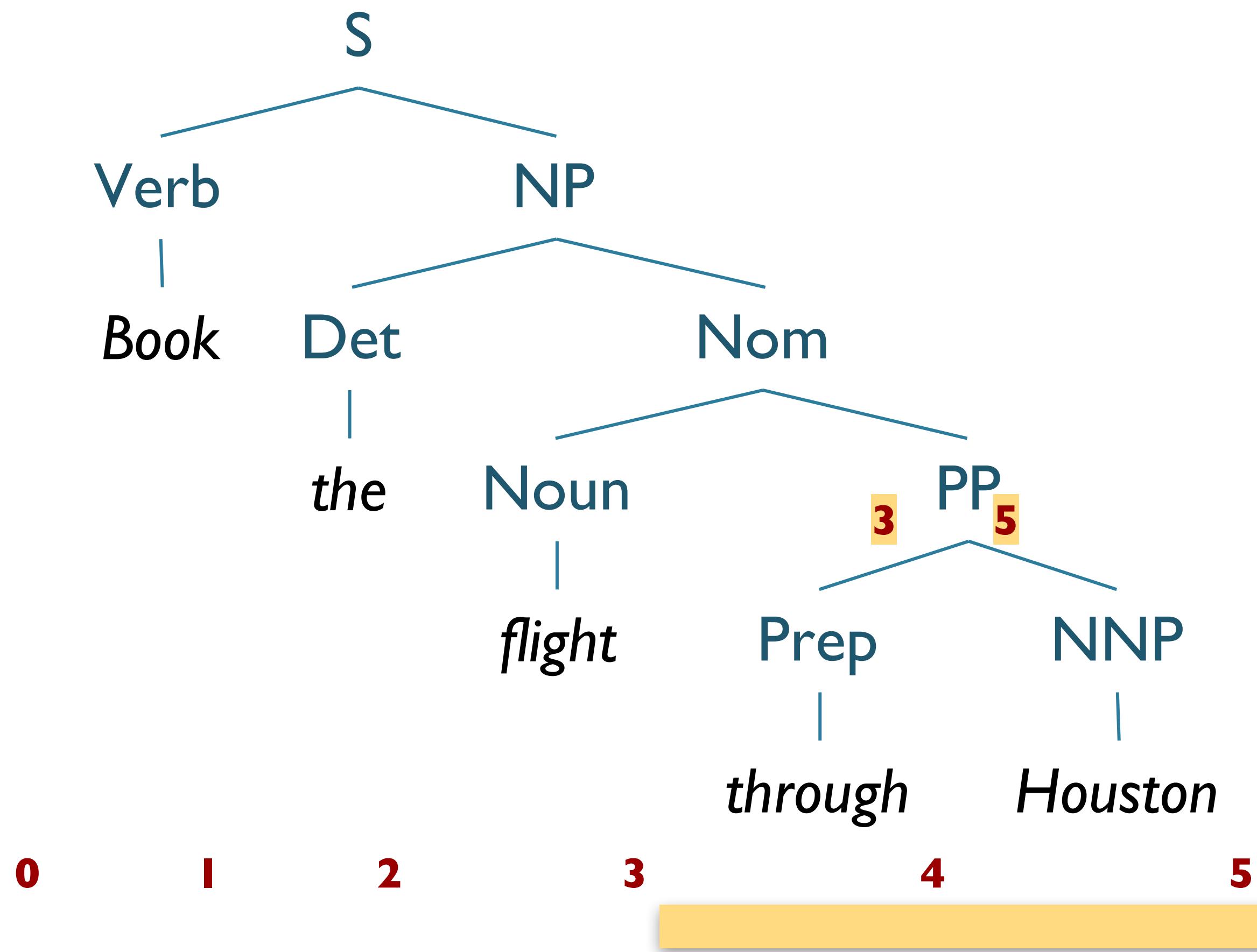
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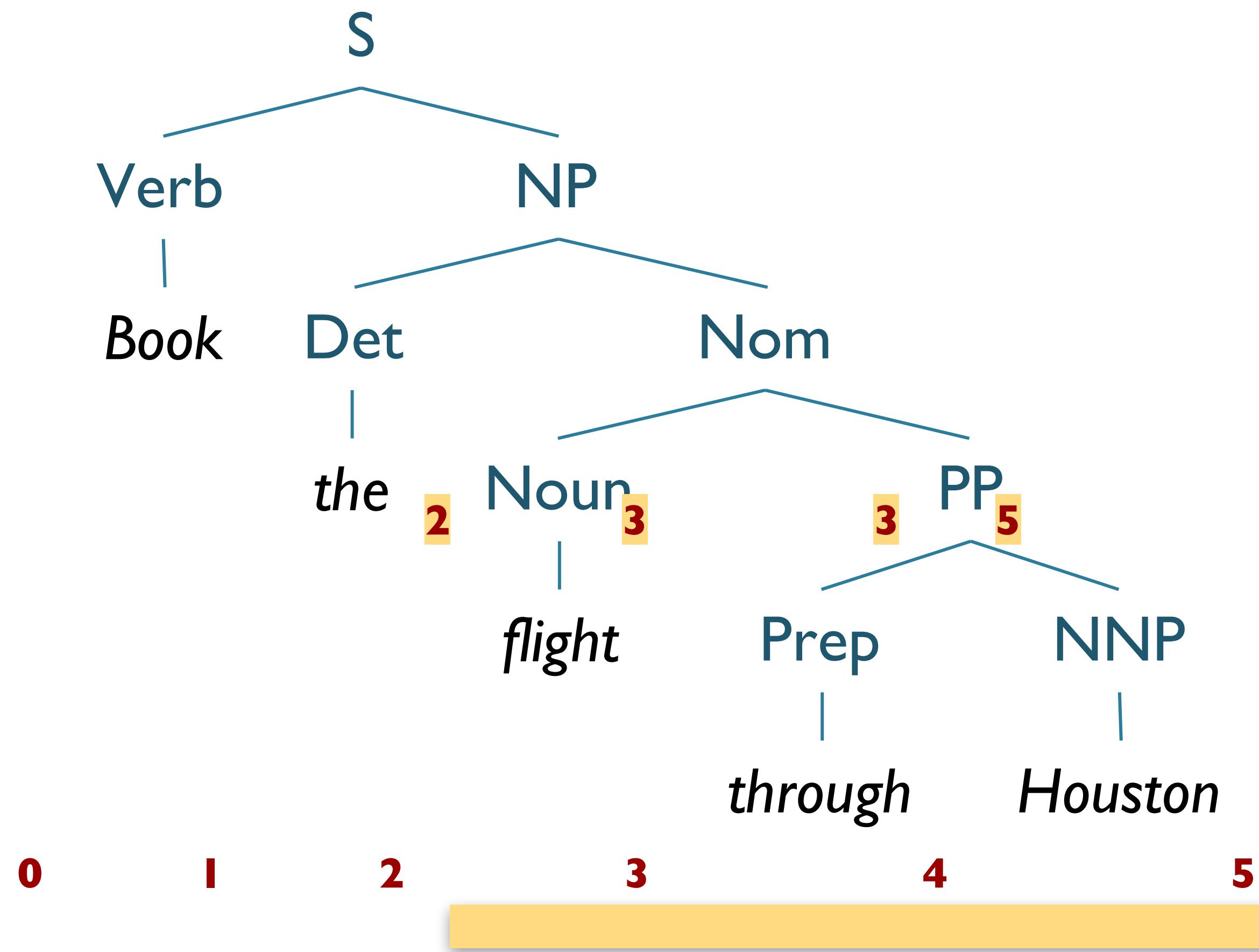
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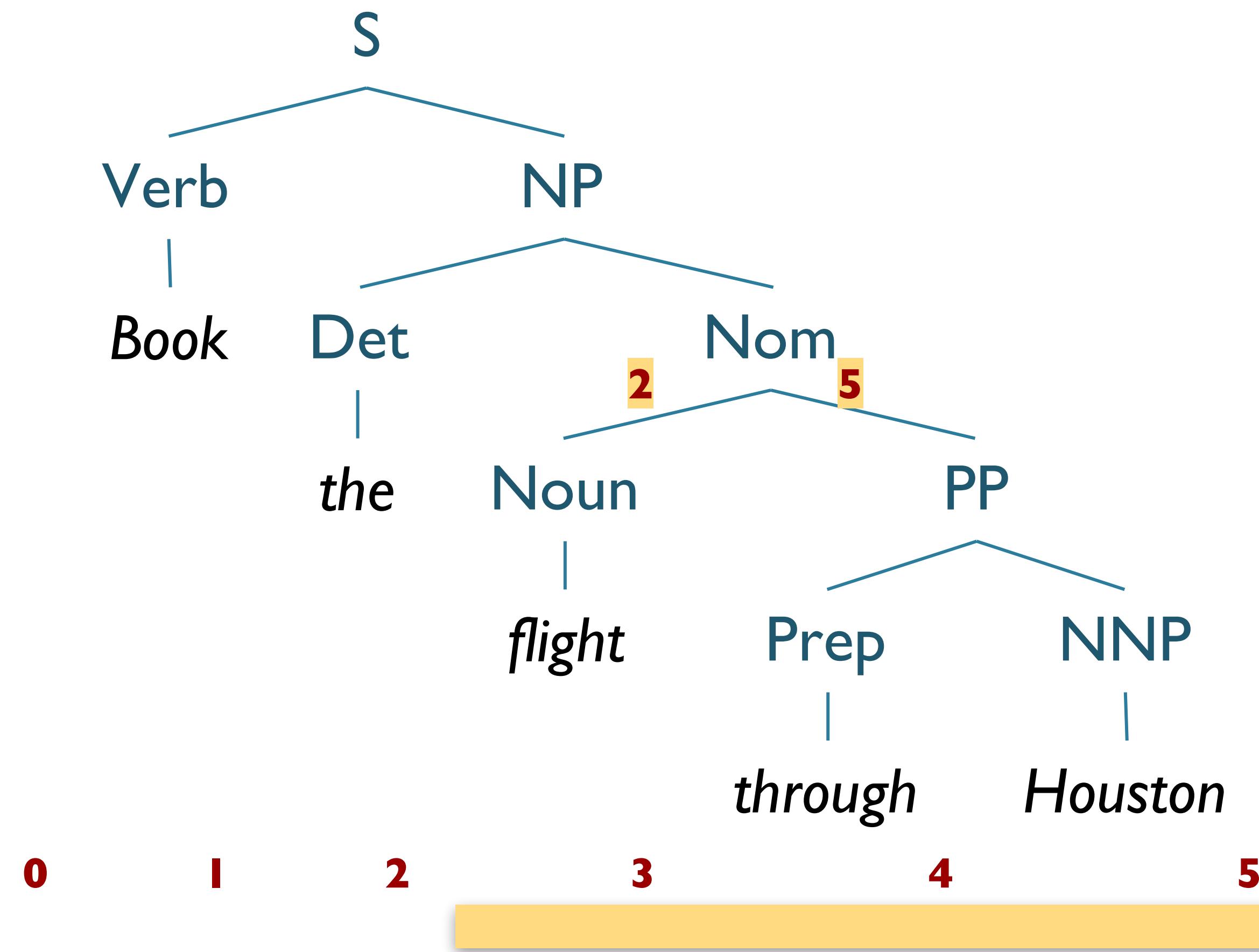
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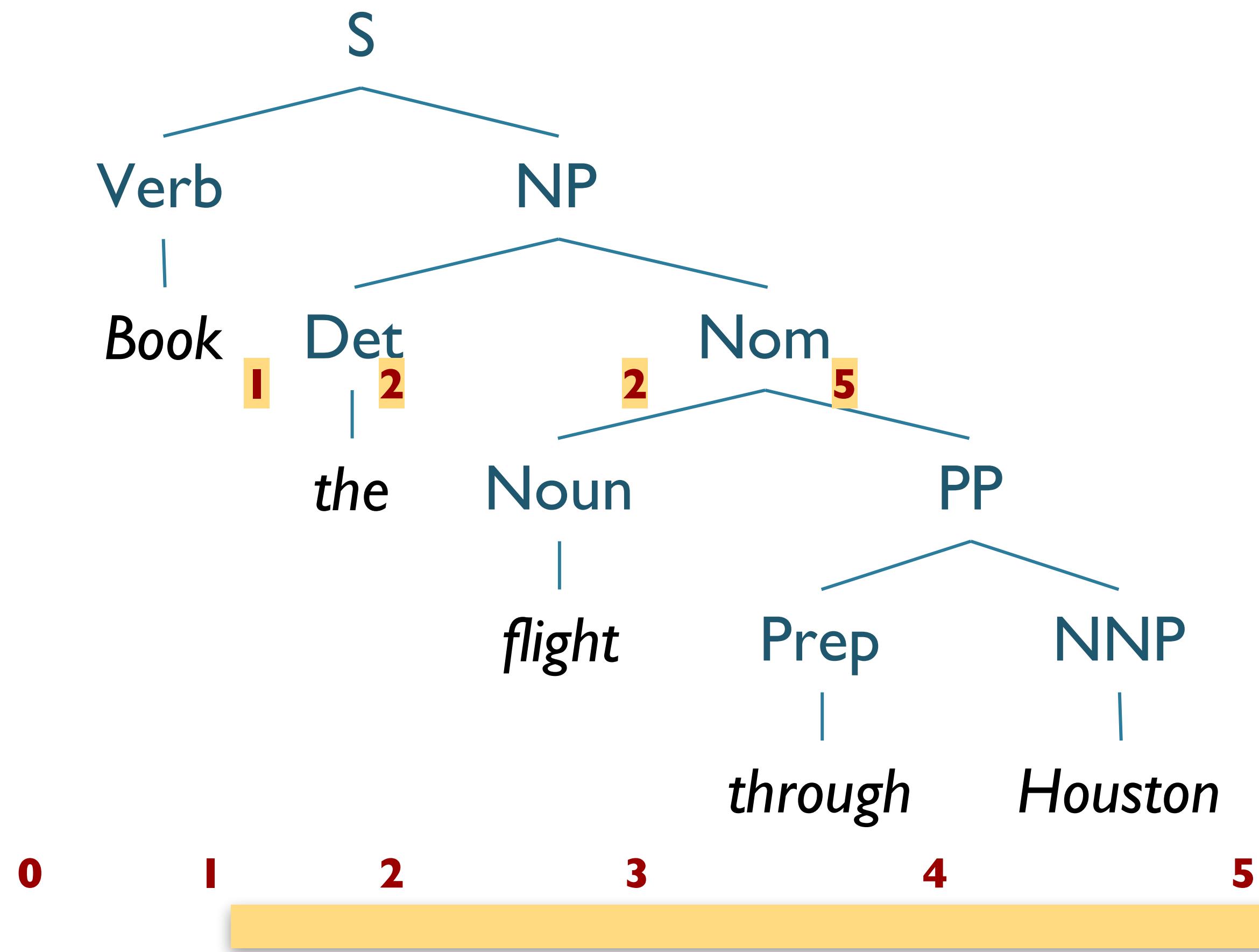
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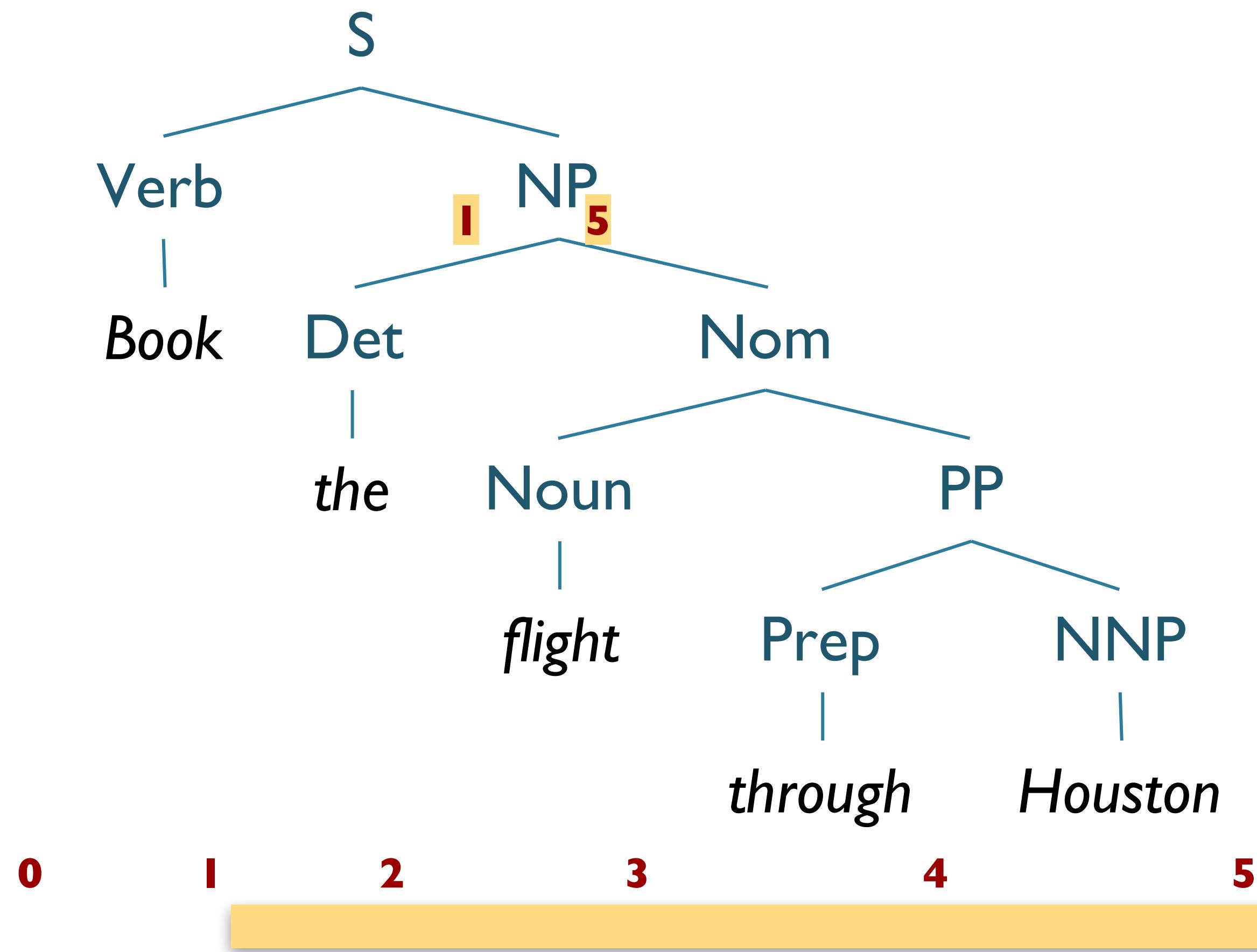
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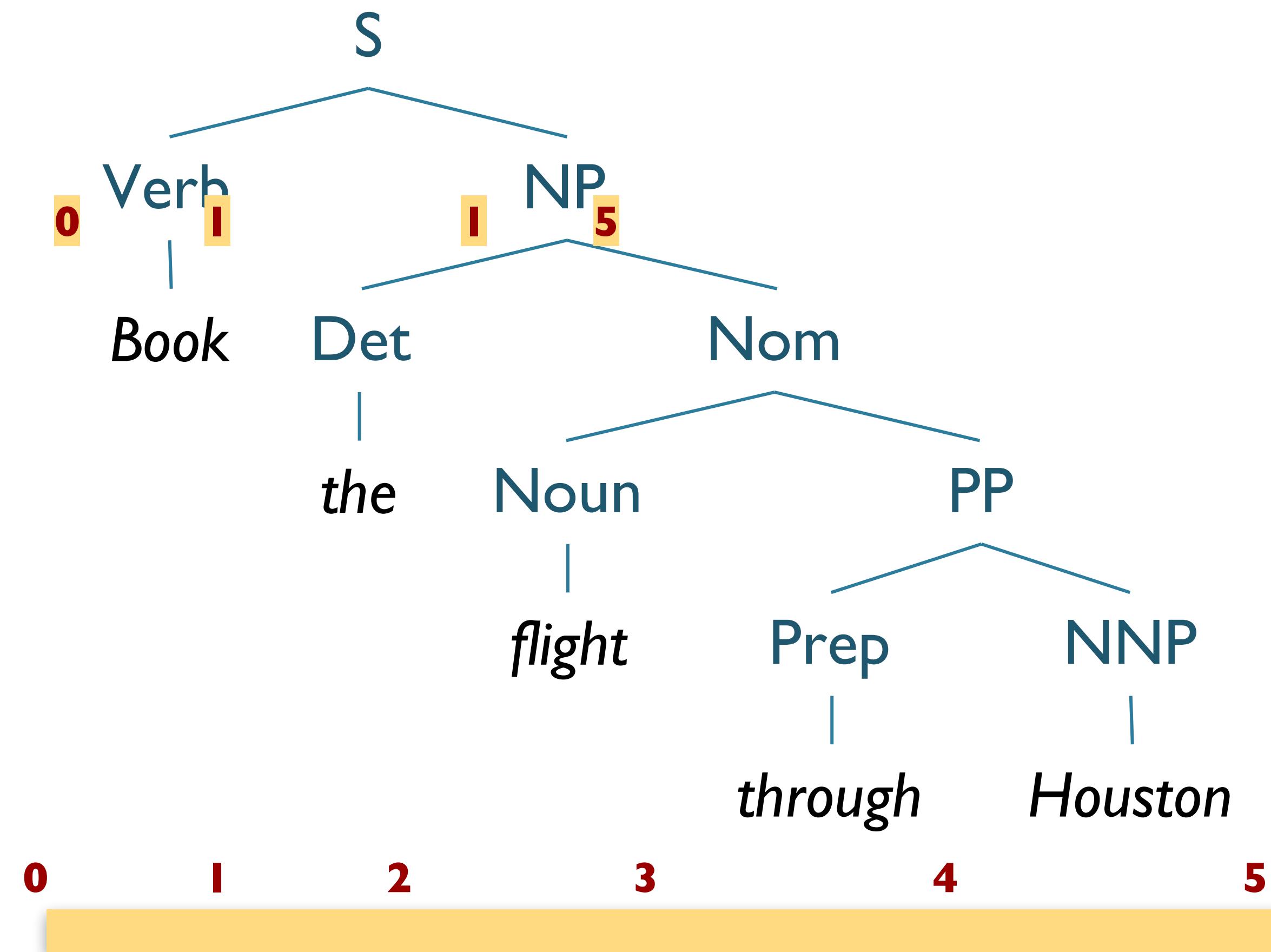
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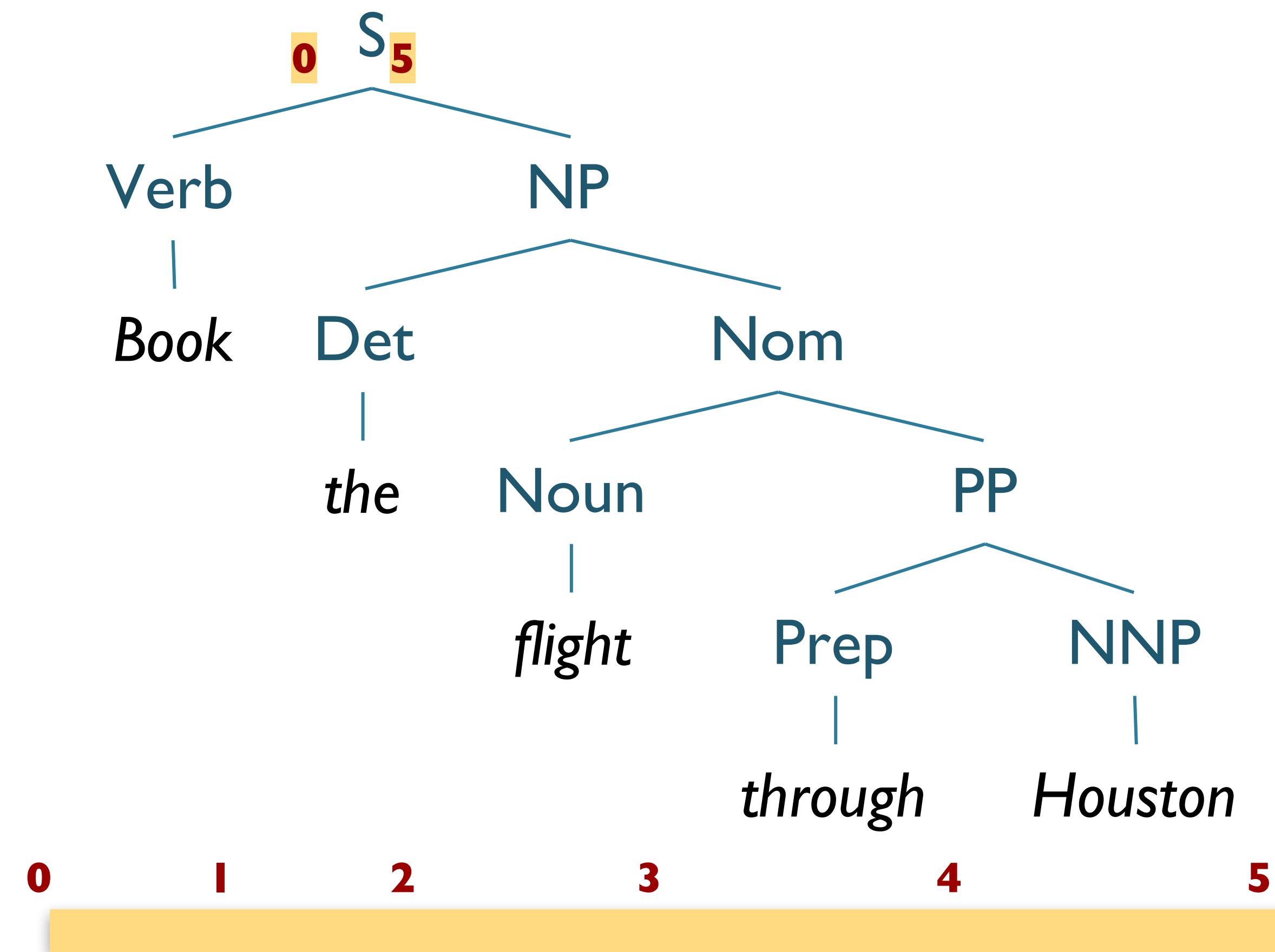
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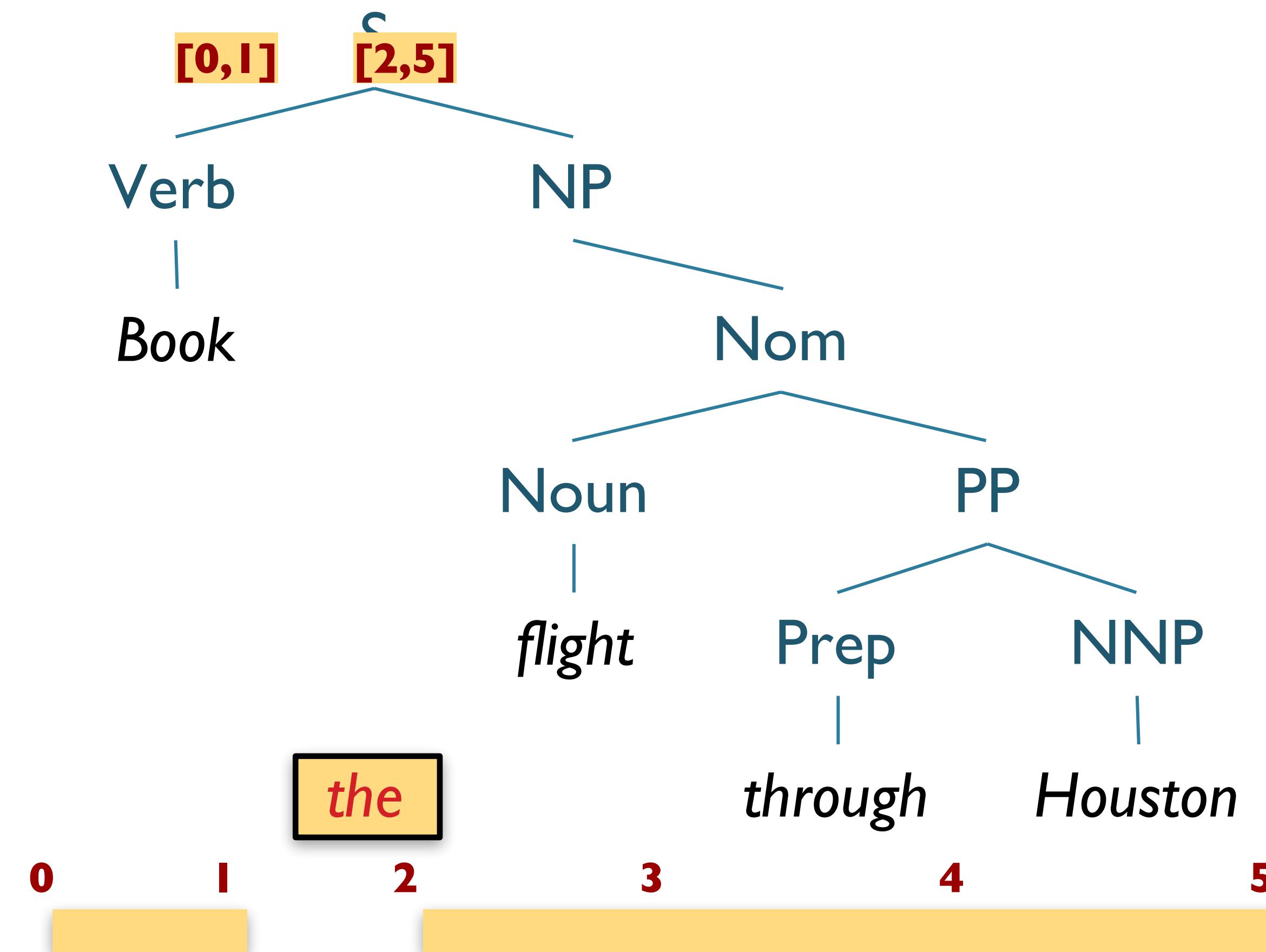
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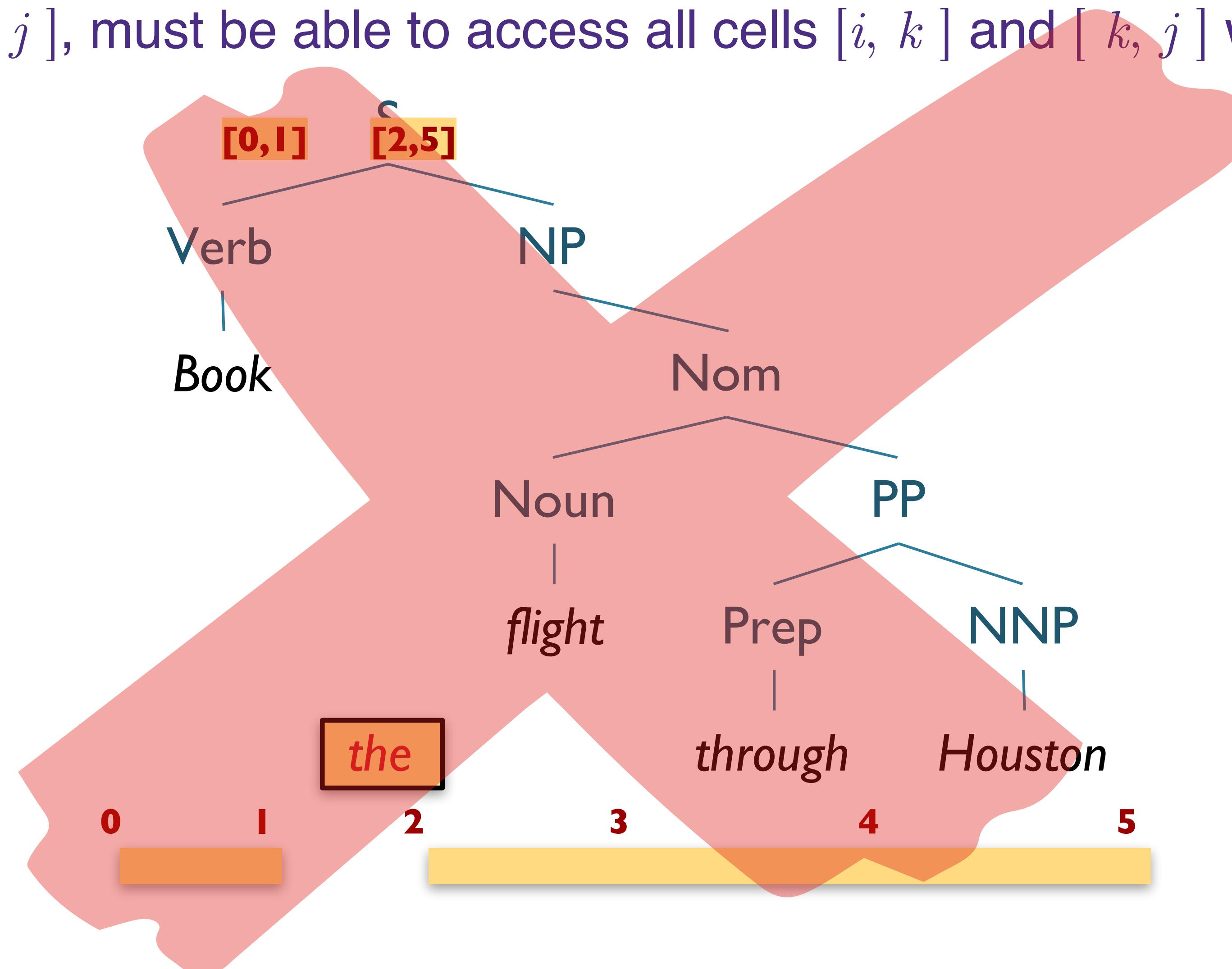
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🌐 When poll is active, respond at **pollev.com/shanest**

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

Top-down

Bottom-up

Total Results: 0

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CKY Parsing Example

\mathcal{L}_1 Grammar

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

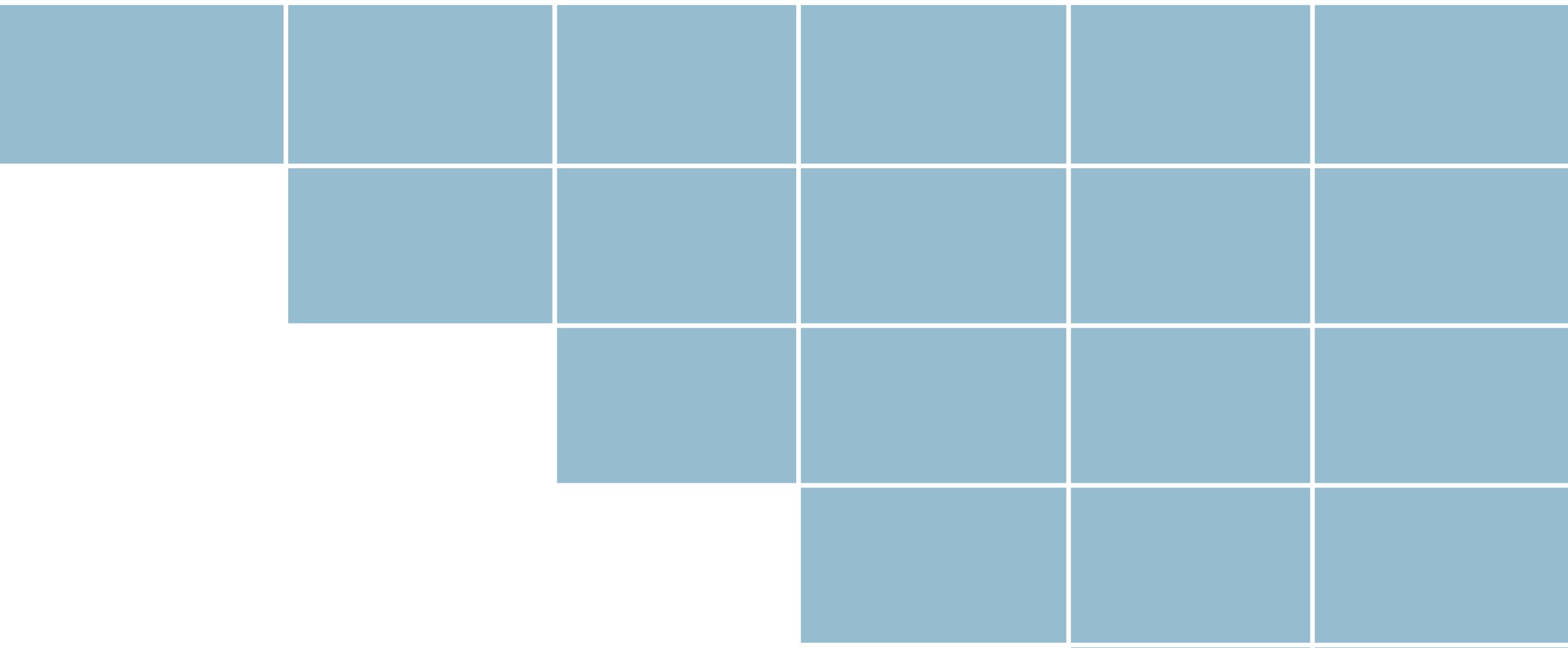
$S \rightarrow Verb\ NP$
 $S \rightarrow X2\ PP$
 $S \rightarrow Verb\ PP$
 $S \rightarrow VP\ PP$

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

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

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

$PP \rightarrow Preposition\ NP$



Lexicon

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

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

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$VP \rightarrow X2\ PP$

$X2 \rightarrow Verb\ NP$

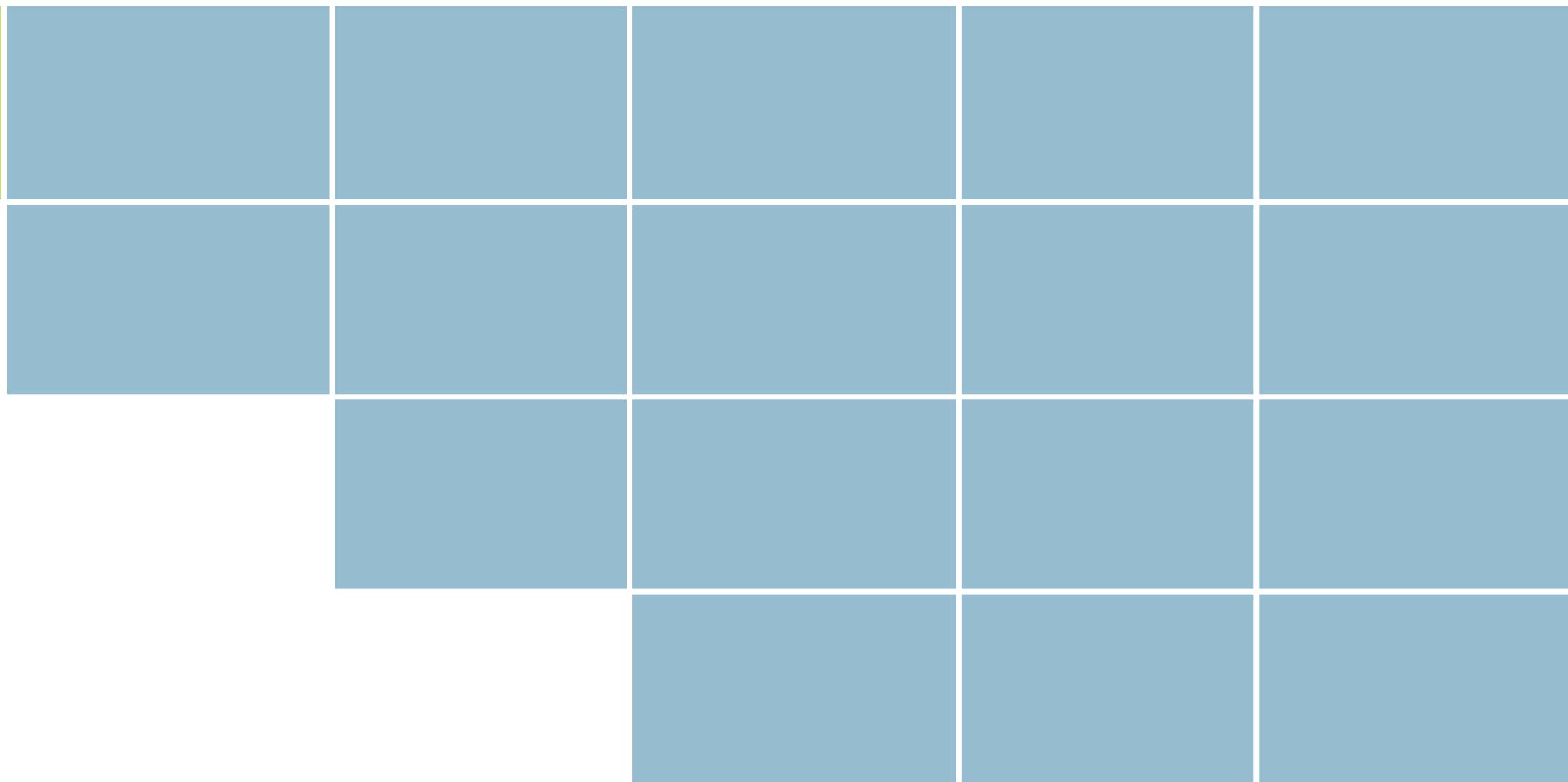
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$PP \rightarrow Preposition\ NP$

NP

[0, 1]



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



\mathcal{L}_1 Grammar

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

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

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

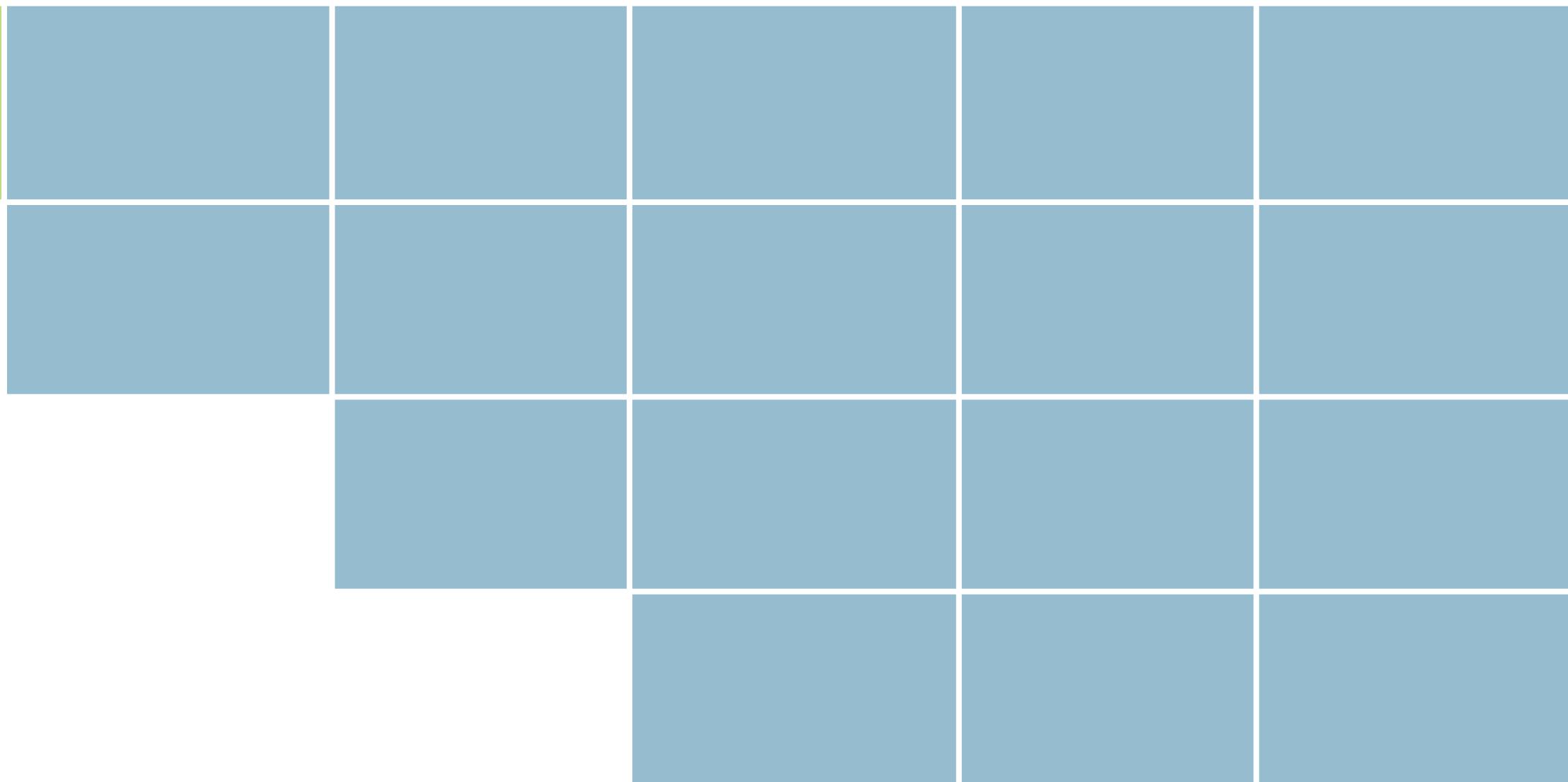
$Nominal \rightarrow book\ / flight\ / meal\ / money$
 $Nominal \rightarrow Nominal\ Noun$
 $Nominal \rightarrow Nominal\ PP$

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

$PP \rightarrow Preposition\ NP$

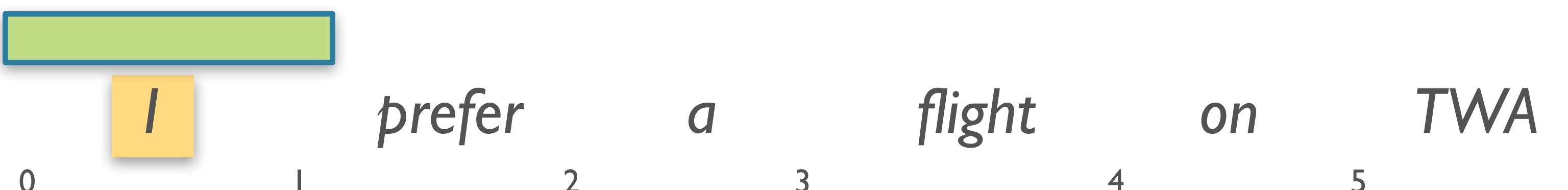
**NP,
Pronoun**

[0,1]



Lexicon

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



\mathcal{L}_1 Grammar

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

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

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

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

$Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

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

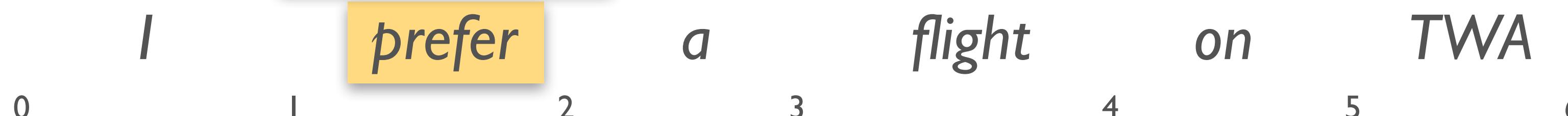
$PP \rightarrow Preposition NP$

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

Verb, VP, S
[1,2]

Lexicon

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



\mathcal{L}_1 Grammar

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

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

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

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

[0,2]

Verb, VP, S
[1,2]

Lexicon

$Det \rightarrow that | this | a$

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

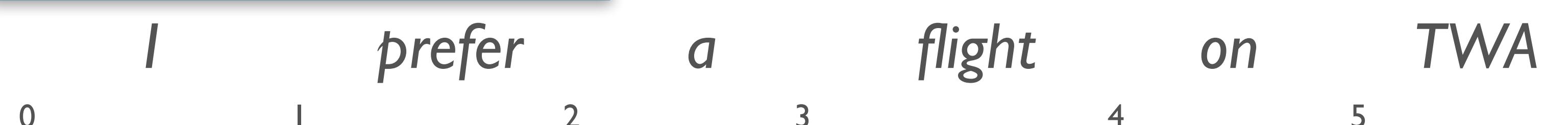
$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$



\mathcal{L}_1 Grammar

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

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

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

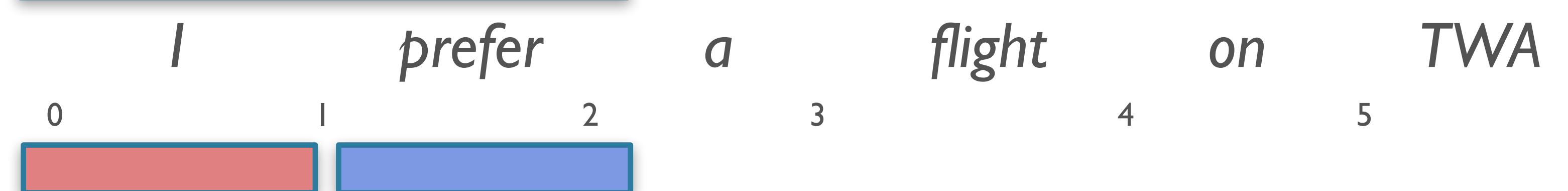
$PP \rightarrow Preposition NP$

**NP, NP,
ProNoun**
[0,1]

Verb, VP, S
[1,2]

Lexicon

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



\mathcal{L}_1 Grammar

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

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

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

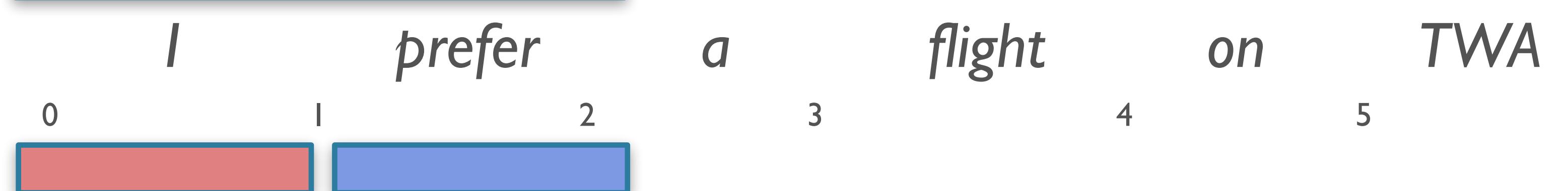
$PP \rightarrow Preposition\ NP$

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

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

Lexicon

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

$S \rightarrow NP\ VP$
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 $S \rightarrow book\ / include\ / prefer$

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

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

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

$Nominal \rightarrow Nominal\ Noun$
 $Nominal \rightarrow Nominal\ PP$

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

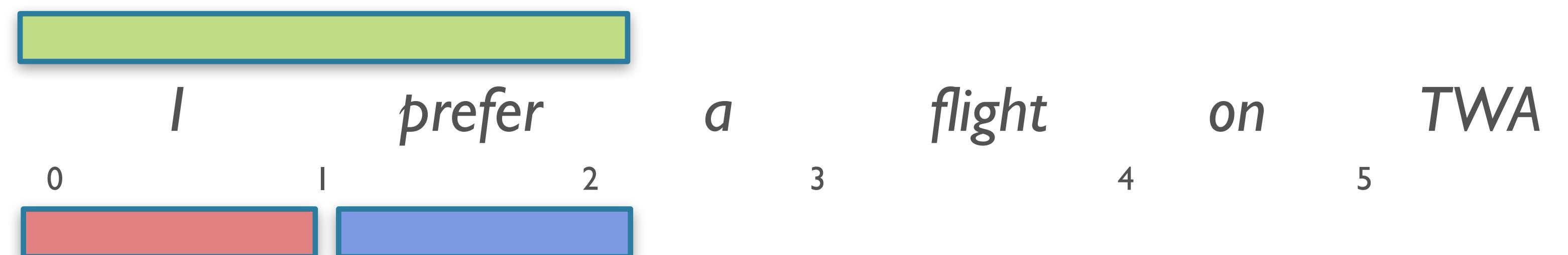
$PP \rightarrow Preposition\ NP$

**NP, NP,
ProNoun**
 $[0,1]$

Verb, VP, S
 $[1,2]$

Lexicon

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



\mathcal{L}_1 Grammar

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

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

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

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

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

$PP \rightarrow Preposition NP$

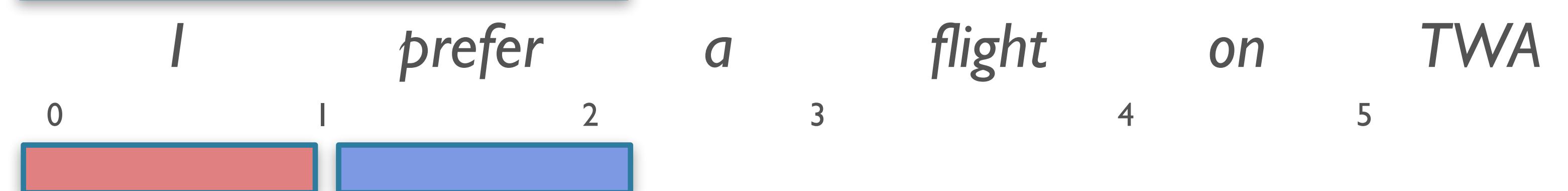
NP, NP, Pronoun
 $[0,1]$

S S

Verb, VP, S
 $[1,2]$

Lexicon

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



\mathcal{L}_1 Grammar

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

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

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

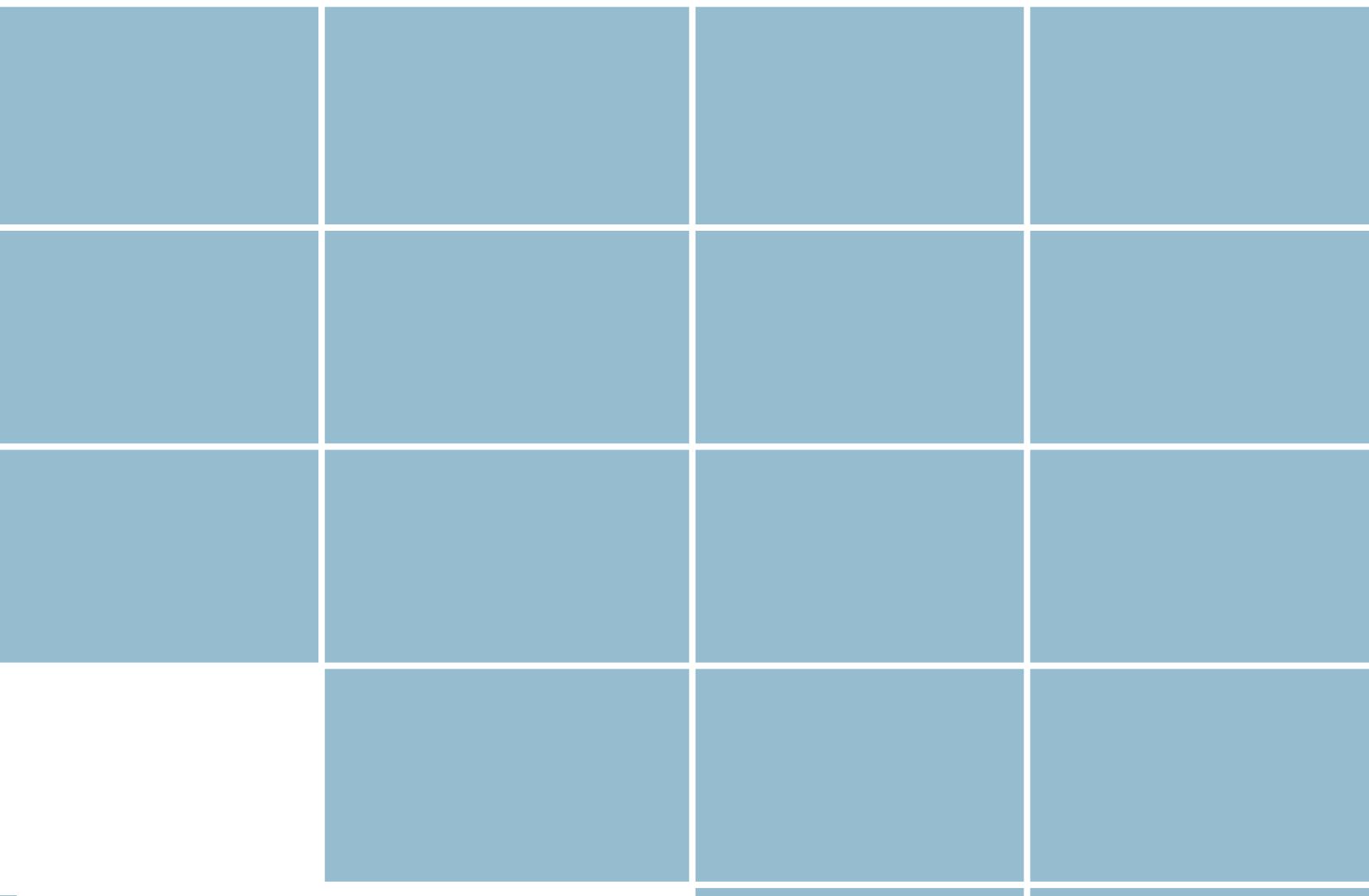
$Nominal \rightarrow book\ / flight\ / meal\ / money$
 $Nominal \rightarrow Nominal\ Noun$
 $Nominal \rightarrow Nominal\ PP$

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

$PP \rightarrow Preposition\ NP$

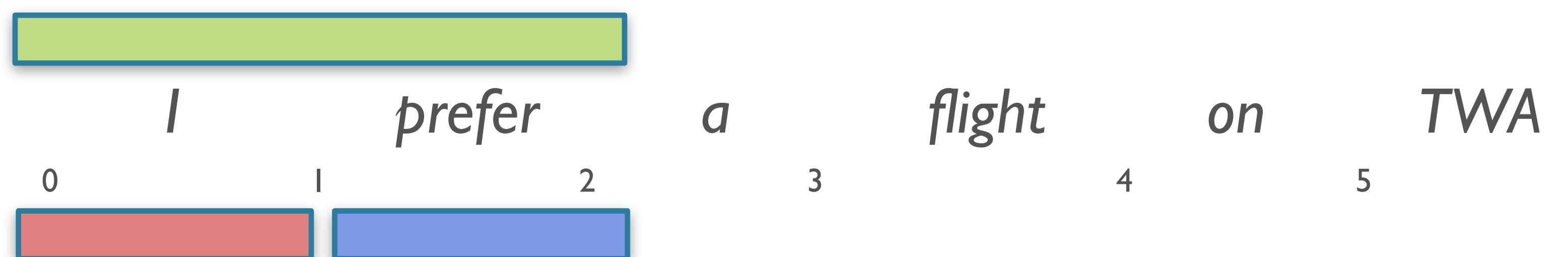
**NP, NP,
Pronoun**
In [0,1]

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



Lexicon

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



\mathcal{L}_1 Grammar

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

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

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

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

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

$PP \rightarrow Preposition NP$

**NP, NP,
ProNoun**
 $[0,1]$

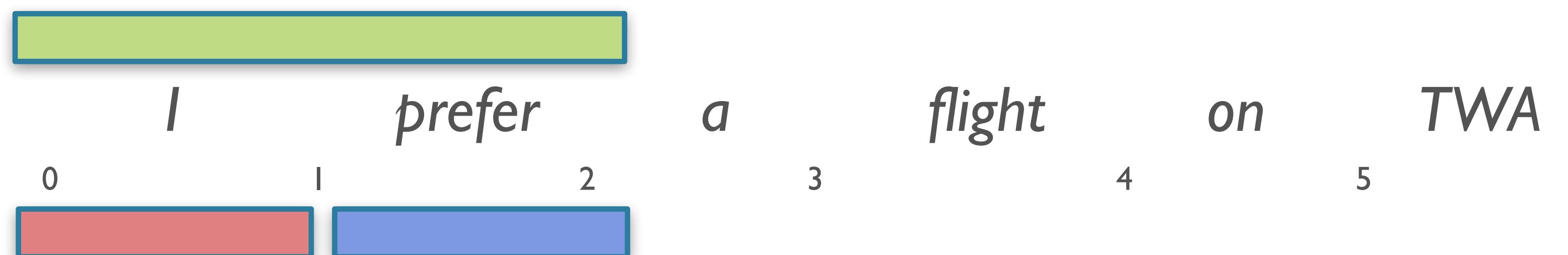
S S

$[0,2]$

Verb, VP, S
 $[1,2]$

Lexicon

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



\mathcal{L}_1 Grammar

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

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

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

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

$Nominal \rightarrow Nominal\ Noun$
 $Nominal \rightarrow Nominal\ PP$

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

$PP \rightarrow Preposition\ NP$

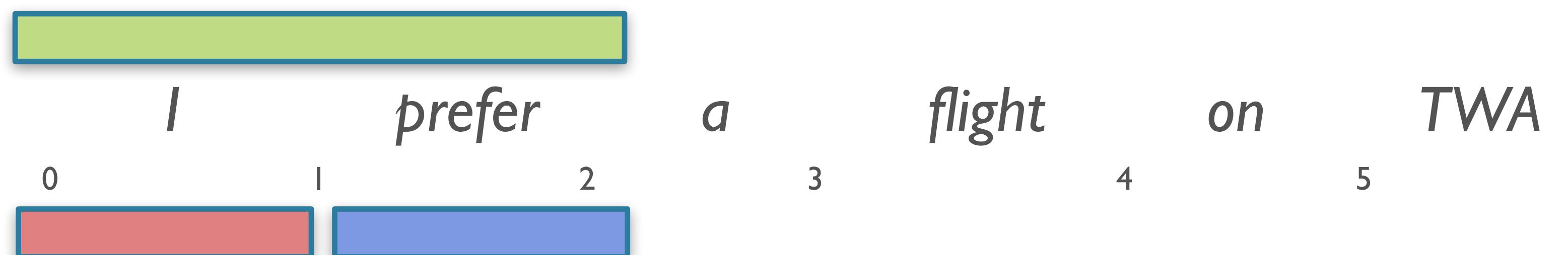
**NP, NP,
Pronoun**
[0,1]

S S
[0,2]

Verb, VP, S
[1,2]

Lexicon

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



\mathcal{L}_1 Grammar

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

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

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

$NP \rightarrow Det\ Nominal$

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

$Nominal \rightarrow Nominal\ Noun$

$Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book\ / include\ / prefer$

$VP \rightarrow Verb\ NP$

$VP \rightarrow X2\ PP$

$X2 \rightarrow Verb\ NP$

$VP \rightarrow Verb\ PP$

$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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

S
[0,2]

Verb, VP, S
[1,2]

Det
[2,3]

Lexicon

Det → that | this | a

Noun → book | flight | meal | money

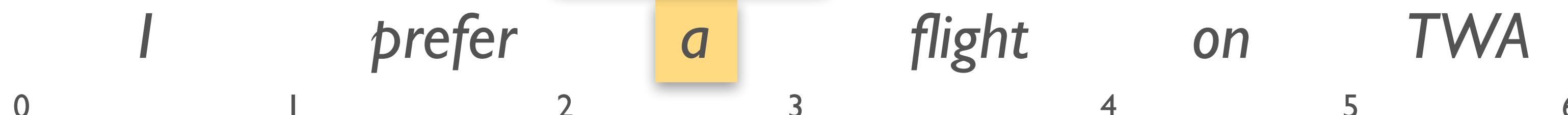
Pronoun → I | she | me

Proper-Noun → Houston | TWA

Aux → does

Preposition → from | to | on | near | through

Verb → book | include | prefer



\mathcal{L}_1 Grammar

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

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

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

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

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

$PP \rightarrow Preposition\ NP$

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

S
 $[0,2]$

Verb, VP, S
 $[1,2]$

Det
 $[1,3]$
 $[2,3]$

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

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

$PP \rightarrow Preposition\ NP$

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

S
 $[0,2]$

Verb, VP, S
 $[1,2]$

Det
 $[1,3]$
Det
 $[2,3]$

Lexicon

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

$S \rightarrow NP\ VP$
 $S \rightarrow X1\ VP$
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 $S \rightarrow book\ / include\ / prefer$

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 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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

S
 $[0,2]$

Verb, VP, S
 $[1,2]$

Det
 $[1,3]$
Det
 $[2,3]$

Lexicon

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 $Noun \rightarrow book\ | flight\ | meal\ | money$
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 $Preposition \rightarrow from\ | to\ | on\ | near\ | through$
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\mathcal{L}_1 Grammar

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

$PP \rightarrow Preposition\ NP$

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

S
[0,2]

Verb, VP, S
[1,2]

Det Det
[1,3]
[2,3]

Lexicon

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 $Preposition \rightarrow from\ | to\ | on\ | near\ | through$
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\mathcal{L}_1 Grammar

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

$PP \rightarrow Preposition\ NP$

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

S
 $[0,2]$

Verb, VP, S
 $[1,2]$

Det
 $[1,3]$
 $[2,3]$

Lexicon

$Det \rightarrow that\ | this\ | a$
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 $Preposition \rightarrow from\ | to\ | on\ | near\ | through$
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\mathcal{L}_1 Grammar

$S \rightarrow NP\ VP$
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 $S \rightarrow X2\ PP$
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$Nominal \rightarrow book\ / flight\ / meal\ / money$

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$Nominal \rightarrow Nominal\ PP$

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$VP \rightarrow X2\ PP$

$X2 \rightarrow Verb\ NP$

$VP \rightarrow Verb\ PP$

$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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

S
[0,2]

[0,3]

Verb, VP, S
[1,2]

[1,3]

Det
[2,3]

Lexicon

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

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

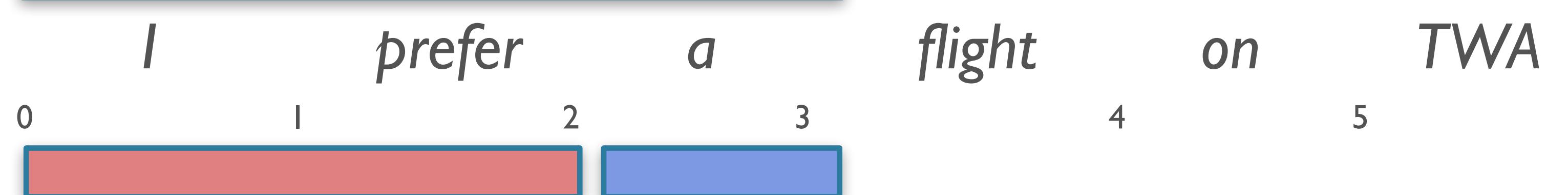
$Pronoun \rightarrow I\ | she\ | me$

$Proper-Noun \rightarrow Houston\ | TWA$

$Aux \rightarrow does$

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

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



\mathcal{L}_1 Grammar

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

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

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

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

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

$PP \rightarrow Preposition\ NP$

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

S
 $[0,2]$

S
 $[0,3]$

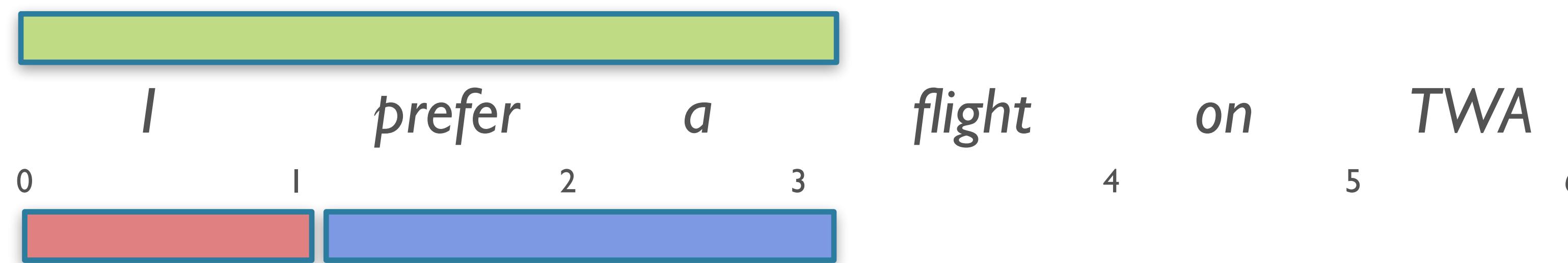
Verb, VP, S
 $[1,2]$

[1,3]

Det
 $[2,3]$

Lexicon

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



\mathcal{L}_1 Grammar

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

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

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

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

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

$PP \rightarrow Preposition\ NP$

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

$[0,2]$

$[0,3]$

Verb, VP, S
 $[1,2]$

$[1,3]$

Det

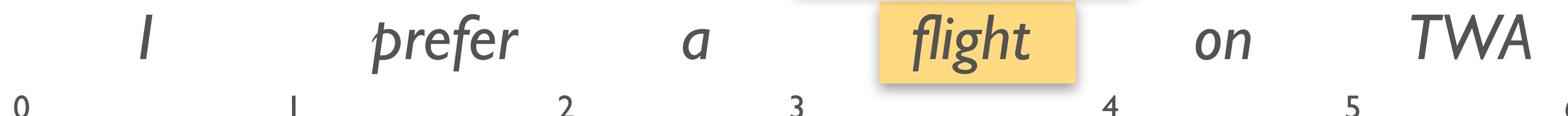
$[2,3]$

Noun, Nom

$[3,4]$

Lexicon

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



\mathcal{L}_1 Grammar

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

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

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

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

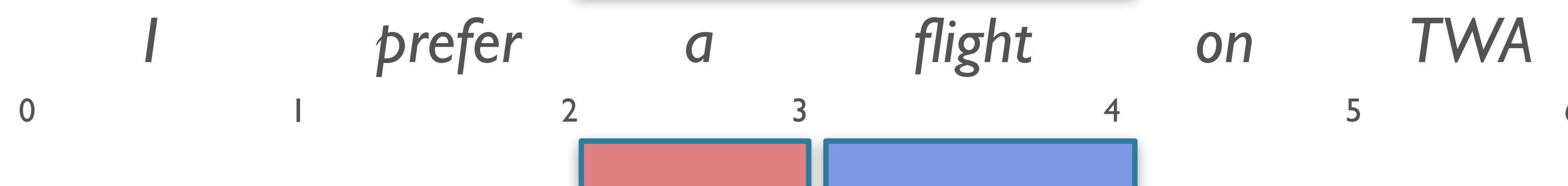
$VP \rightarrow book\ / include\ / prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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

Lexicon

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



\mathcal{L}_1 Grammar

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

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

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

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

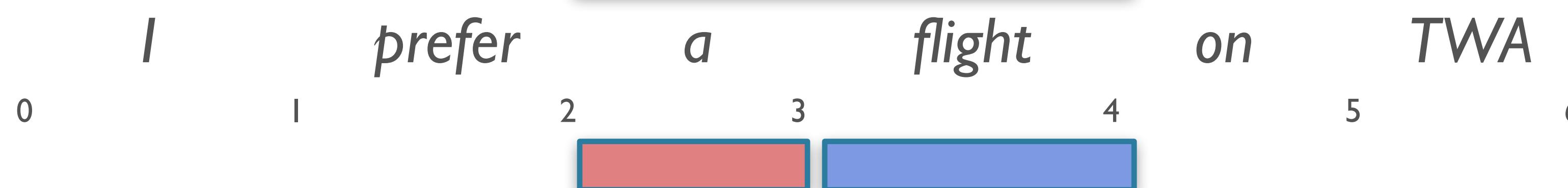
$VP \rightarrow book\ / include\ / prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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

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



\mathcal{L}_1 Grammar

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

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

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

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

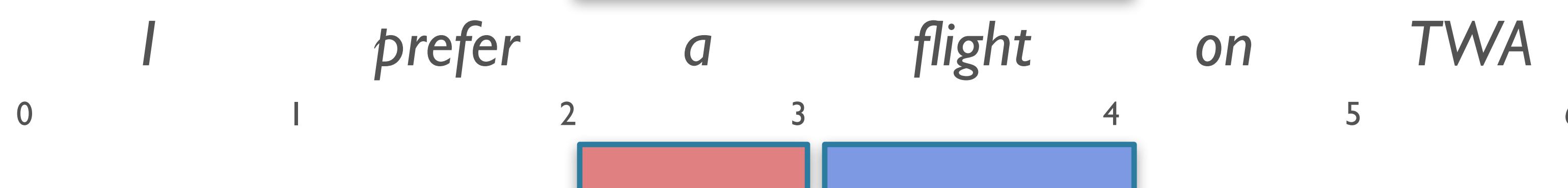
$VP \rightarrow book\ / include\ / prefer$
 $VP \rightarrow Verb\ NP$
 $VP \rightarrow X2\ PP$
 $X2 \rightarrow Verb\ NP$
 $VP \rightarrow Verb\ PP$
 $VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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

Lexicon

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



\mathcal{L}_1 Grammar

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

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

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



\mathcal{L}_1 Grammar

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

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

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

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

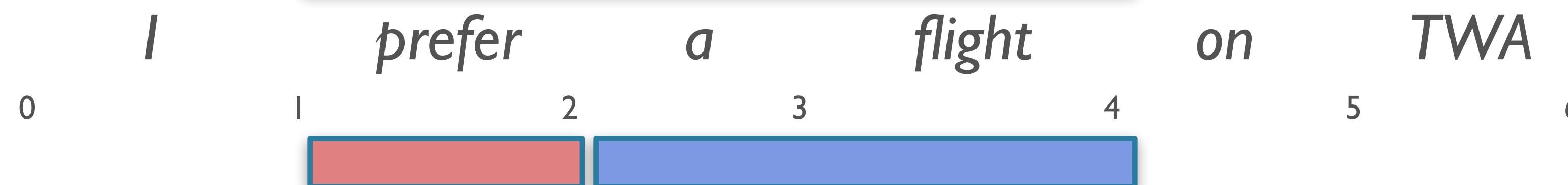
$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

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



\mathcal{L}_1 Grammar

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

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

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

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

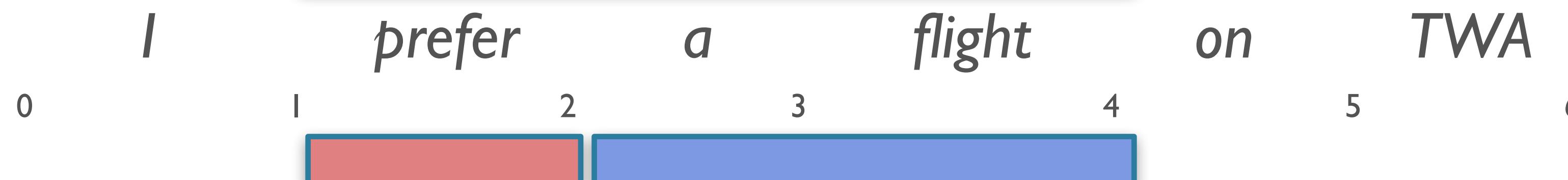
$VP \rightarrow book / include / prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

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



\mathcal{L}_1 Grammar

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

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

$Det \rightarrow that | this | a$

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

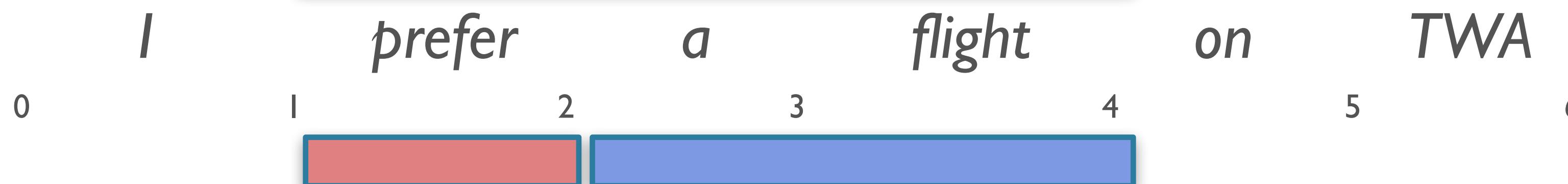
$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$



\mathcal{L}_1 Grammar

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

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

$Det \rightarrow that | this | a$

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

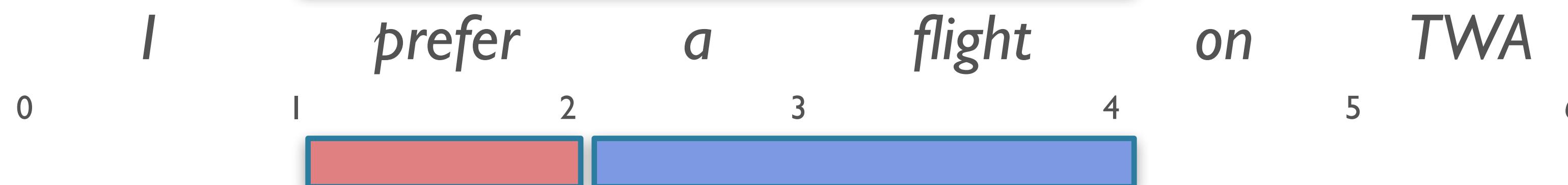
$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$



\mathcal{L}_1 Grammar

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

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

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

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

$Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

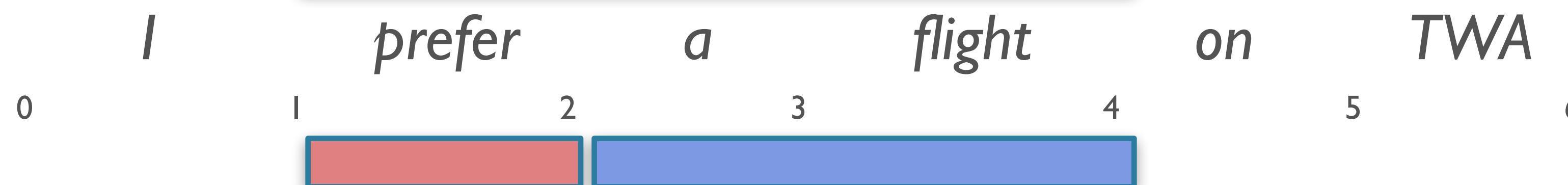
$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

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



\mathcal{L}_1 Grammar

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

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

$Det \rightarrow that | this | a$

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

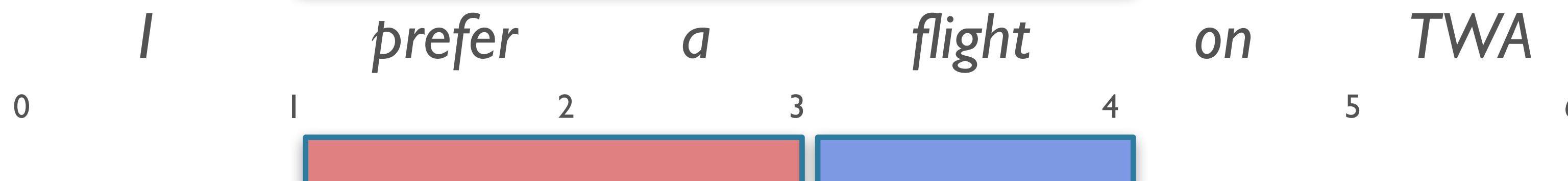
$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$



\mathcal{L}_1 Grammar

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

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

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

$Nominal \rightarrow Nominal\ Noun$

$Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book\ / include\ / prefer$

$VP \rightarrow Verb\ NP$

$VP \rightarrow X2\ PP$

$X2 \rightarrow Verb\ NP$

$VP \rightarrow Verb\ PP$

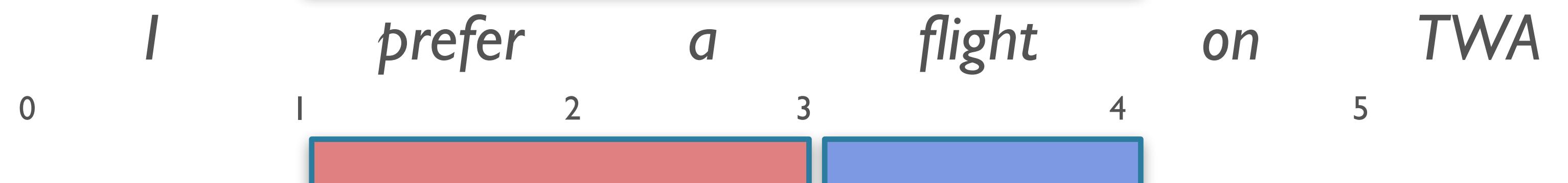
$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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]	

Lexicon

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



\mathcal{L}_1 Grammar

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

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

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

S
[0,2]

Verb, VP, S
[1,2]

Det
[1,3]

NP
[2,3]

Noun, Nom
[2,4]

[3,4]

Lexicon

$Det \rightarrow that | this | a$

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

$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$

I prefer a flight on TWA

0 1 2 3 4 5 6



\mathcal{L}_1 Grammar

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

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

S

[0,2]

S

[0,3]

S

[0,4]

Verb, VP, S

[1,2]

Verb, VP, S

[1,3]

Verb, VP, S

[1,4]

Det

[2,3]

Det

[2,4]

NP

[2,4]

NP

[2,4]

Noun, Nom

[3,4]

Noun, Nom

\mathcal{L}_1 Grammar

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

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

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

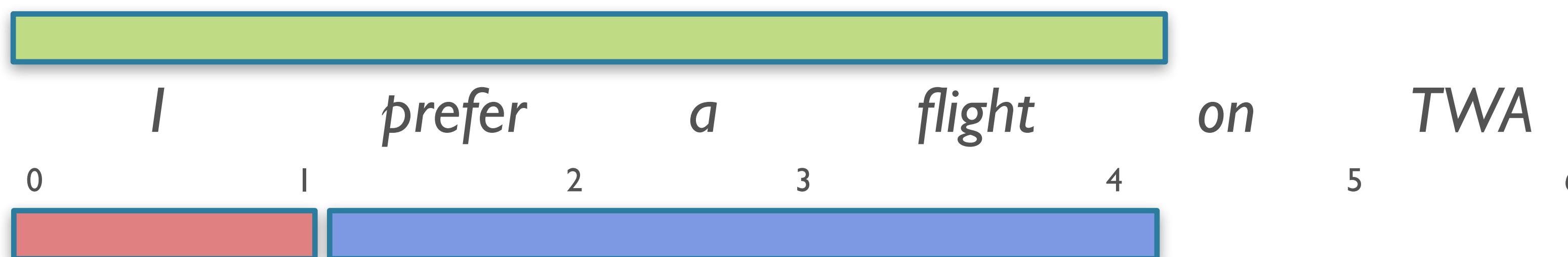
$PP \rightarrow Preposition NP$

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

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

Lexicon

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



\mathcal{L}_1 Grammar

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

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

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

[0,2]

[1,2]

[1,3]

[2,3]

[2,4]

[3,4]

S

[0,3]

[1,3]

[1,4]

[2,4]

[3,4]

S

[0,4]

[1,4]

[2,4]

[3,4]

Verb, VP, S

[1,2]

[1,3]

[1,4]

VP, X2, S

[1,4]

[2,4]

[3,4]

Det

NP

Noun, Nom

Lexicon

$Det \rightarrow that | this | a$

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

$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$



\mathcal{L}_1 Grammar

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

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

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

[0,2]

[0,3]

[0,4]

S
[0,2]

[0,3]

[0,4]

[0,5]

Verb, VP, S
[1,2]

[1,3]

[1,4]

Det
[2,3]

[2,4]

NP
[2,5]

[2,6]

Noun, Nom
[3,4]

[3,5]

[3,6]

[4,5]

[4,6]

[5,6]

Lexicon

$Det \rightarrow that | this | a$

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

$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$

I prefer a flight on TWA

0

1

2

3

4

5

6



\mathcal{L}_1 Grammar

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

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

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

[0,2]

[0,3]

[0,4]

Verb, VP, S
[1,2]

[1,3]

[1,4]

Det
[2,3]

[2,4]

NP

[2,4]

Noun, Nom

[3,4]

Lexicon

$Det \rightarrow that | this | a$

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

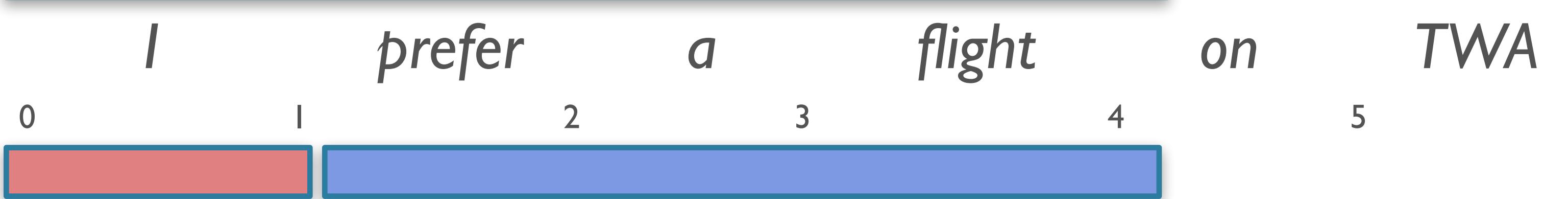
$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$



\mathcal{L}_1 Grammar

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

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

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

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

$PP \rightarrow Preposition NP$

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

S

$[0,2]$

$[0,3]$

S

$[0,4]$

Verb, VP, S

$[1,2]$

$[1,3]$

VP, X2, S

$[1,4]$

Det

$[2,3]$

NP

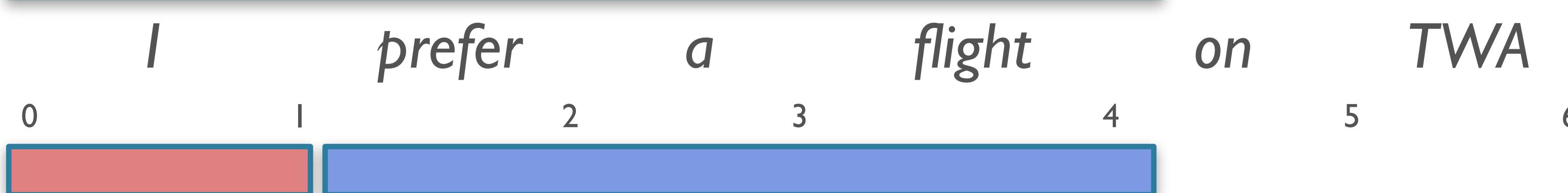
$[2,4]$

Noun, Nom

$[3,4]$

Lexicon

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



\mathcal{L}_1 Grammar

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

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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]		

Lexicon

$Det \rightarrow that | this | a$

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

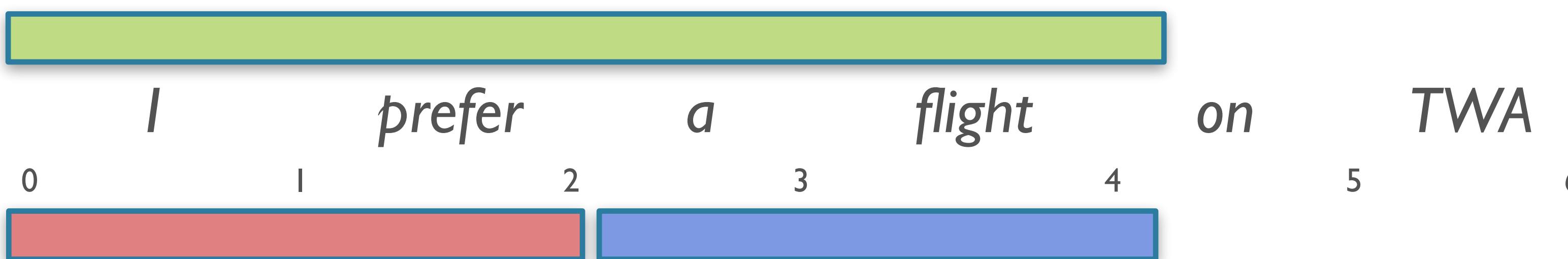
$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$



\mathcal{L}_1 Grammar

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

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

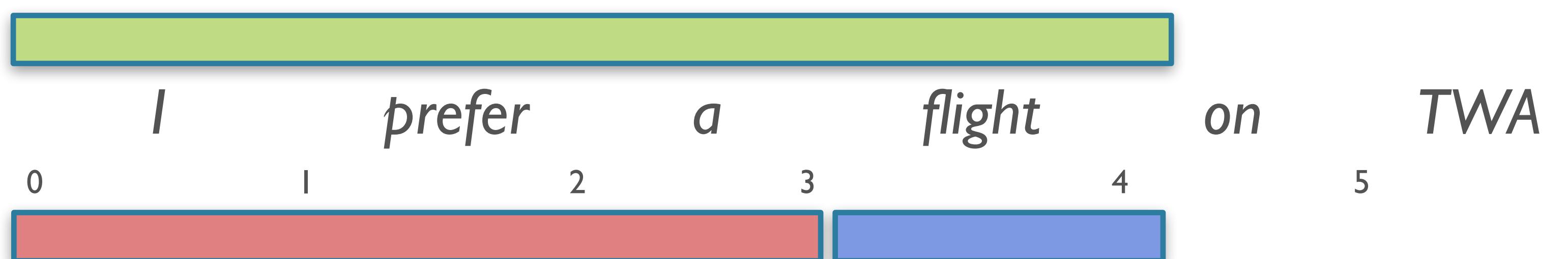
$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

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



\mathcal{L}_1 Grammar

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

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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]	

Lexicon

$Det \rightarrow that | this | a$

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

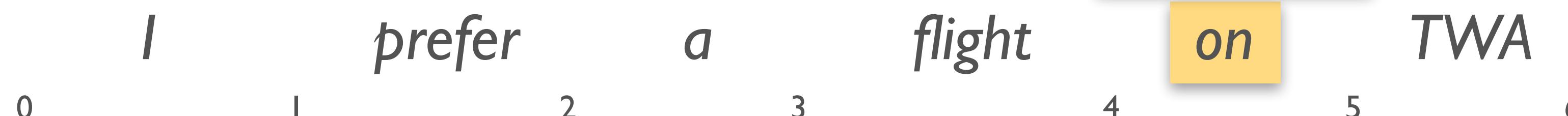
$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$



\mathcal{L}_1 Grammar

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

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

$Det \rightarrow that | this | a$

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

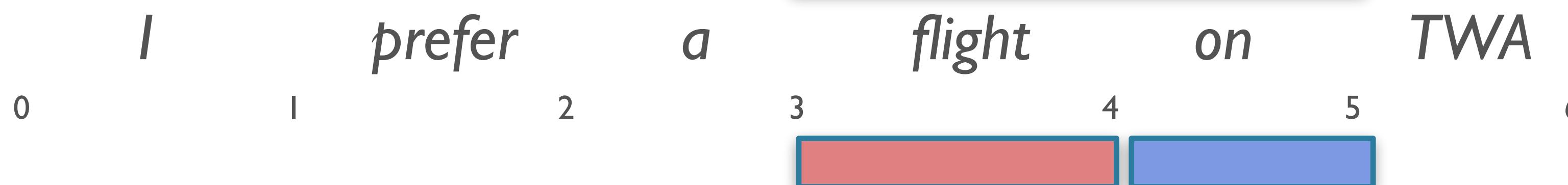
$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$



\mathcal{L}_1 Grammar

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

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

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

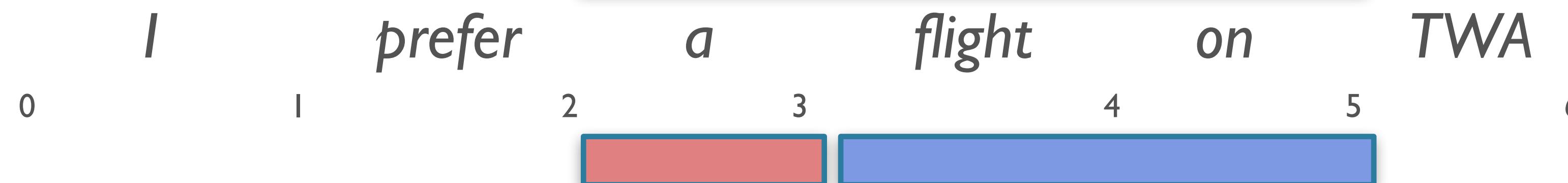
$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

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



\mathcal{L}_1 Grammar

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

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

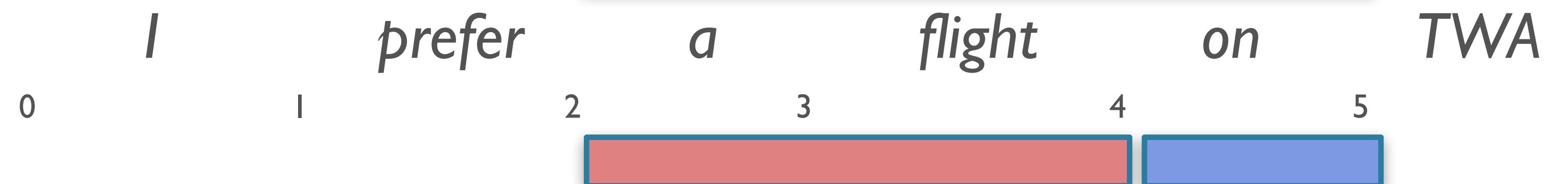
$Nominal \rightarrow book / flight / meal / money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$

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

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

Lexicon

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



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

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

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

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

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

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

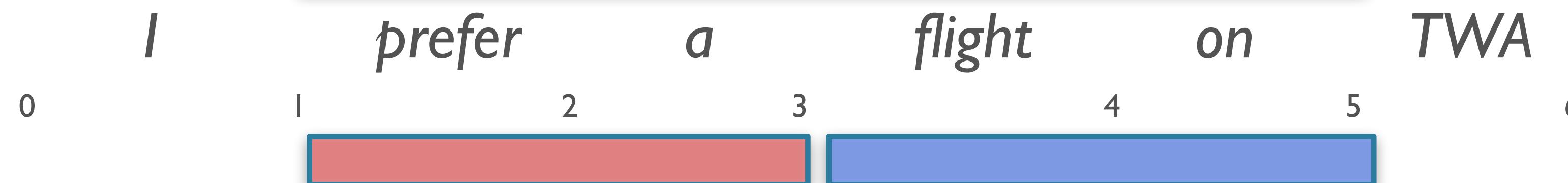
$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

NP, Pronoun [0,1]	S [0,2]		S [0,4]		
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
Det [2,3]		NP [2,4]		[2,5]	
		Noun, Nom [3,4]	[3,5]		
Lexicon			Prep [4,5]		
	<i>Det</i> → <i>that</i> <i>this</i> <i>a</i> <i>Noun</i> → <i>book</i> <i>flight</i> <i>meal</i> <i>money</i> <i>Pronoun</i> → <i>I</i> <i>she</i> <i>me</i> <i>Proper-Noun</i> → <i>Houston</i> <i>TWA</i> <i>Aux</i> → <i>does</i> <i>Preposition</i> → <i>from</i> <i>to</i> <i>on</i> <i>near</i> <i>through</i> <i>Verb</i> → <i>book</i> <i>include</i> <i>prefer</i>				



\mathcal{L}_1 Grammar

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

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

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

$NP \rightarrow TWA\ / Houston$

$NP \rightarrow Det\ Nominal$

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

$Nominal \rightarrow Nominal\ Noun$

$Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book\ / include\ / prefer$

$VP \rightarrow Verb\ NP$

$VP \rightarrow X2\ PP$

$X2 \rightarrow Verb\ NP$

$VP \rightarrow Verb\ PP$

$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

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

Lexicon

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

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

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

$Proper-Noun \rightarrow Houston\ | TWA$

$Aux \rightarrow does$

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

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



\mathcal{L}_1 Grammar

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

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

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

S
[0,2]

S
[0,3]

S
[0,4]

[0,5]

Verb, VP, S
[1,2]

Verb, VP, S
[1,3]

VP, X2, S
[1,4]

[1,5]

Det
[2,3]

NP
[2,4]

Noun, Nom
[2,5]

[3,4]

[3,5]

Prep
[4,5]

Lexicon

$Det \rightarrow that | this | a$

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

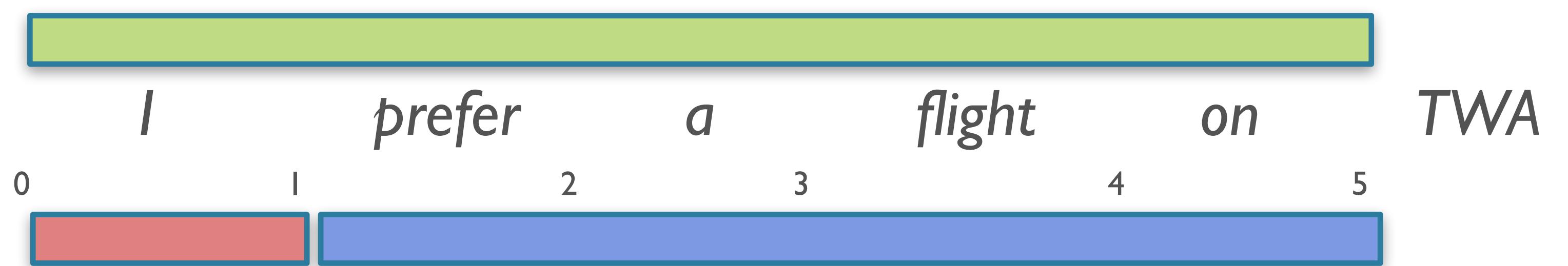
$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$



\mathcal{L}_1 Grammar

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

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

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

S
[0,2]

Verb, VP, S
[1,2]

Det
[2,3]

NP
[2,4]

Noun, Nom
[3,4]

Prep
[4,5]

Lexicon

$Det \rightarrow that | this | a$

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

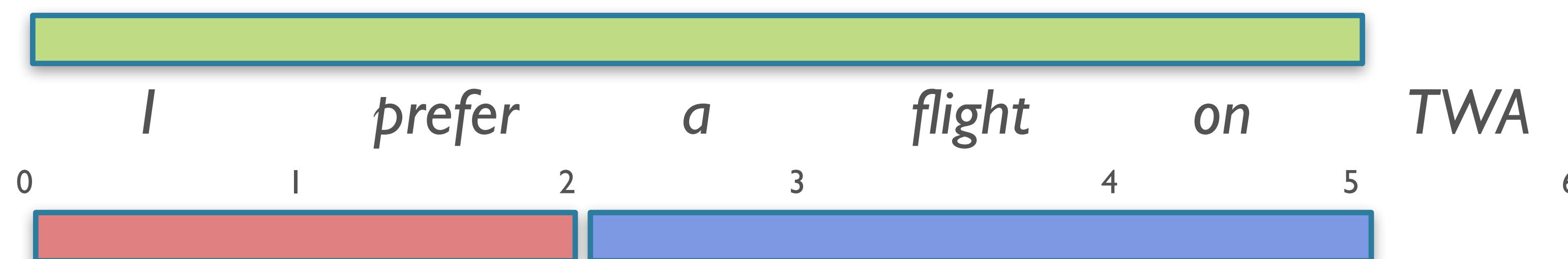
$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$



\mathcal{L}_1 Grammar

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

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

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

$Det \rightarrow that | this | a$

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

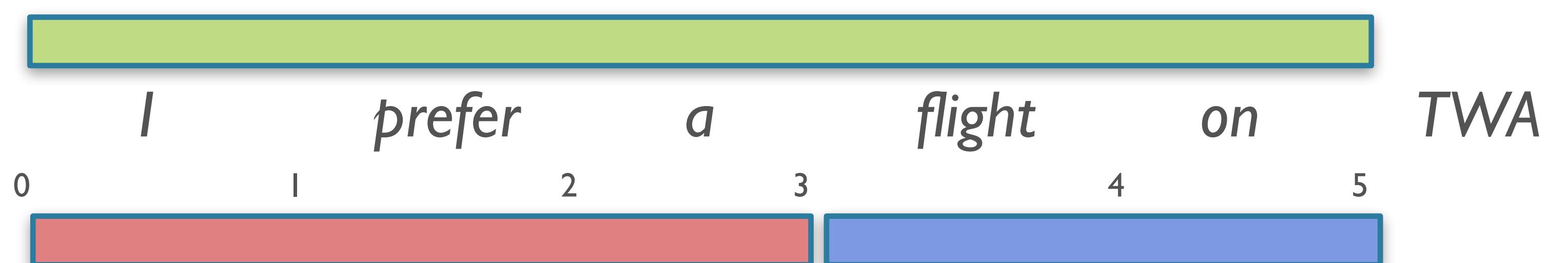
$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$



\mathcal{L}_1 Grammar

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

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

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

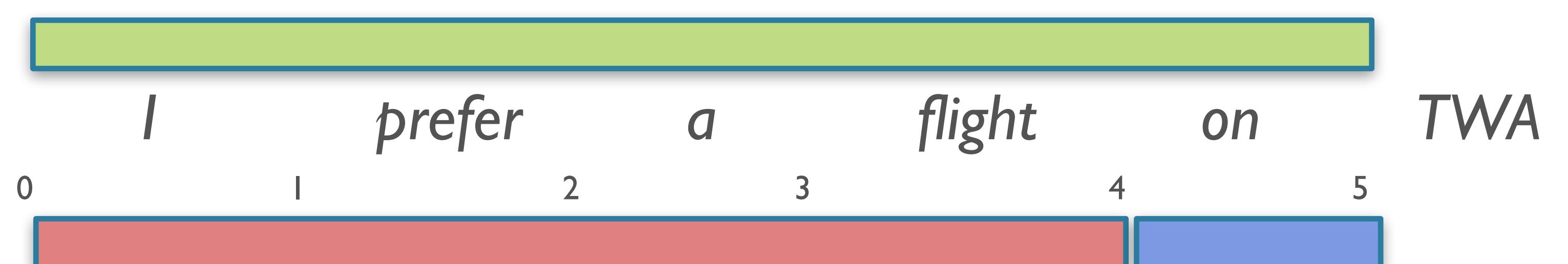
$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

$Det \rightarrow that | this | a$
 $Noun \rightarrow book | flight | meal | money$
 $Pronoun \rightarrow I | she | me$
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 $Aux \rightarrow does$
 $Preposition \rightarrow from | to | on | near | through$
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\mathcal{L}_1 Grammar

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

$S \rightarrow VP PP$

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

NP, Pronoun [0,1]	S [0,2]		S [0,4]		
	Verb, VP, S [1,2]		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]

Lexicon

$Det \rightarrow that | this | a$

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

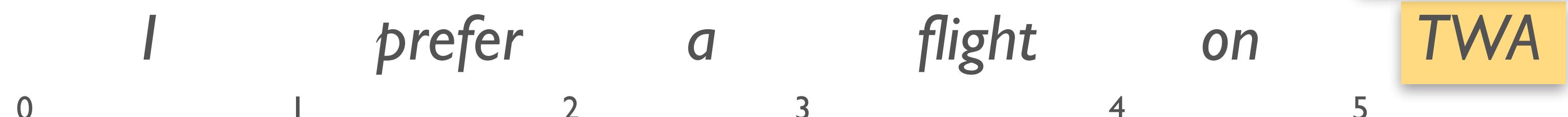
$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$



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$S \rightarrow NP VP$
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 $S \rightarrow Verb PP$
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$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$



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Lexicon

$Det \rightarrow that | this | a$

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

$Pronoun \rightarrow I | she | me$

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$Aux \rightarrow does$

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$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

$Det \rightarrow that | this | a$

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

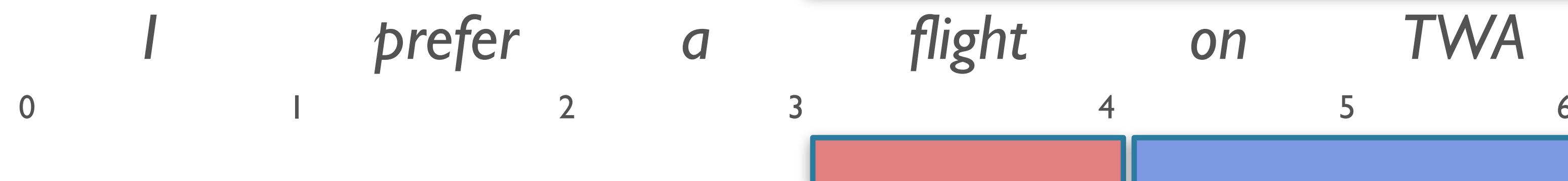
$Pronoun \rightarrow I | she | me$

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$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

$Det \rightarrow that | this | a$

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

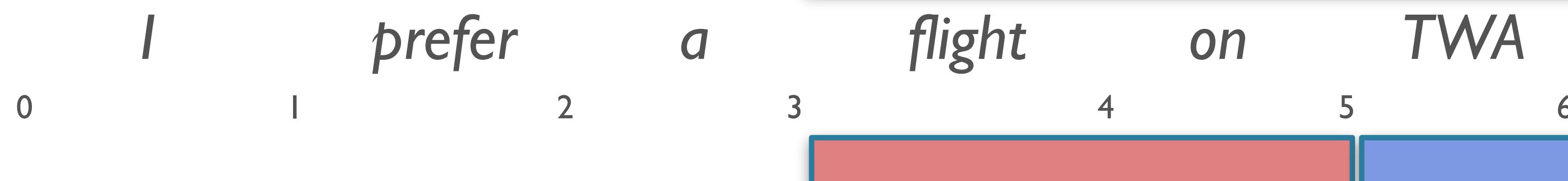
$Pronoun \rightarrow I | she | me$

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 $S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

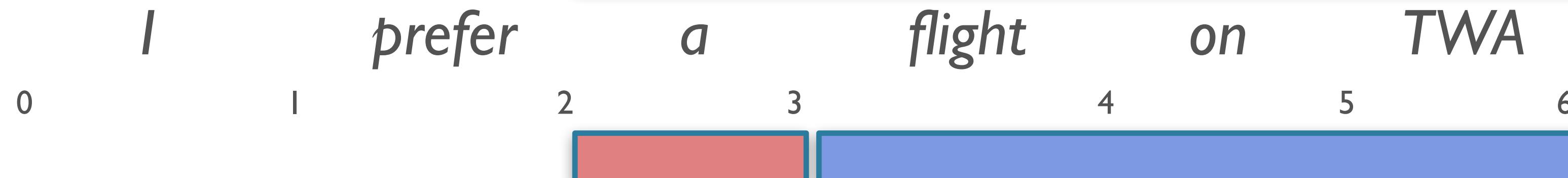
$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

NP, Pronoun [0,1]	S [0,2]		S [0,4]		
	Verb, VP, S [1,2]		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]
Lexicon					
$Det \rightarrow that this a$ $Noun \rightarrow book flight meal money$ $Pronoun \rightarrow I she me$ $Proper-Noun \rightarrow Houston TWA$ $Aux \rightarrow does$ $Preposition \rightarrow from to on near through$ $Verb \rightarrow book include prefer$					



\mathcal{L}_1 Grammar

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

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

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

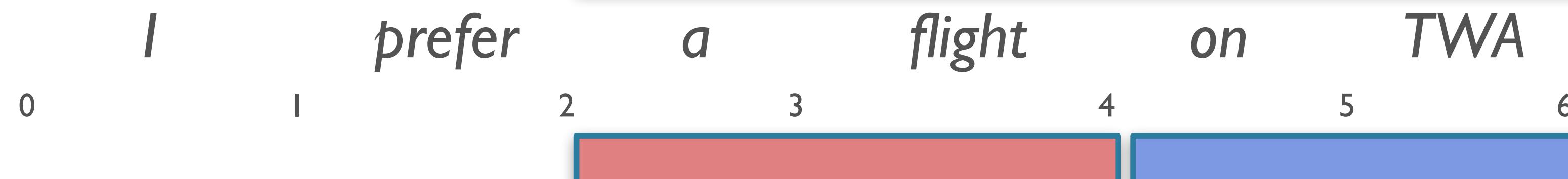
$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

$S \rightarrow NP\ VP$
 $S \rightarrow X1\ VP$
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 $S \rightarrow Verb\ NP$
 $S \rightarrow X2\ PP$

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

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

$NP \rightarrow TWA\ / Houston$

$NP \rightarrow Det\ Nominal$

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

$Nominal \rightarrow Nominal\ Noun$

$Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book\ / include\ / prefer$

$VP \rightarrow Verb\ NP$

$VP \rightarrow X2\ PP$

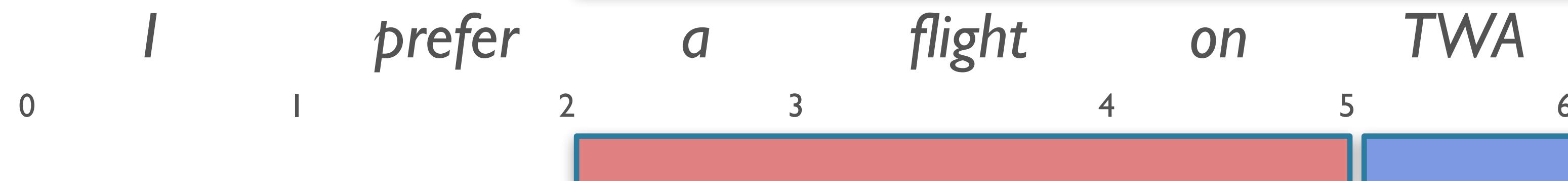
$X2 \rightarrow Verb\ NP$

$VP \rightarrow Verb\ PP$

$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

NP, Pronoun [0,1]	S [0,2]		S [0,4]		
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
	Det [2,3]		NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
				Prep [4,5]	PP [4,6]
					NNP, NP [5,6]
Lexicon					
$Det \rightarrow that\ this\ a$ $Noun \rightarrow book\ flight\ meal\ money$ $Pronoun \rightarrow I\ she\ me$ $Proper-Noun \rightarrow Houston\ TWA$ $Aux \rightarrow does$ $Preposition \rightarrow from\ to\ on\ near\ through$ $Verb \rightarrow book\ include\ prefer$					



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$S \rightarrow NP VP$
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$NP \rightarrow Det Nominal$

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$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

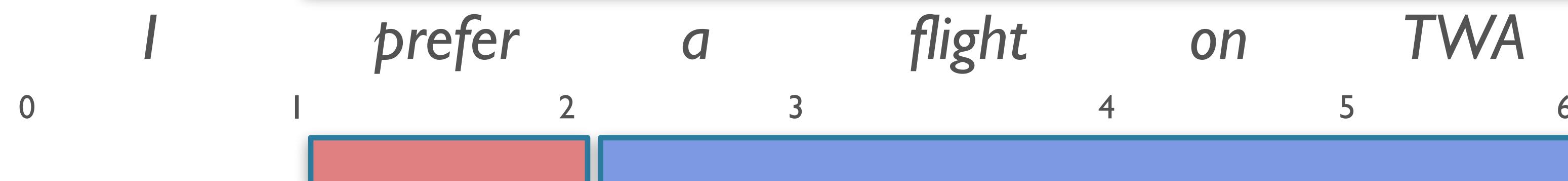
$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

$Det \rightarrow that | this | a$
 $Noun \rightarrow book | flight | meal | money$
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 $Preposition \rightarrow from | to | on | near | through$
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\mathcal{L}_1 Grammar

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$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

$Det \rightarrow that | this | a$

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

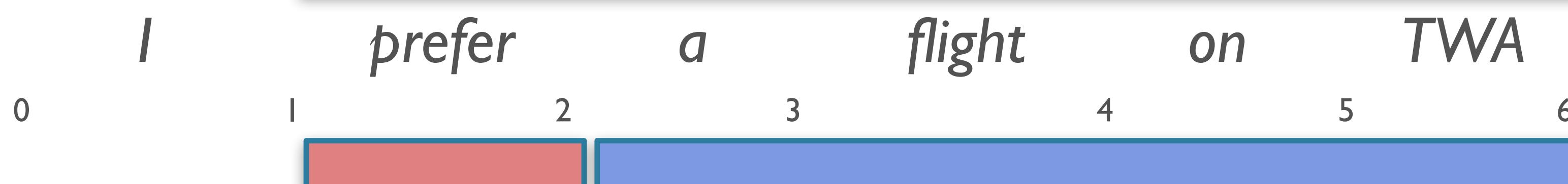
$Pronoun \rightarrow I | she | me$

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$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

Lexicon

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

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

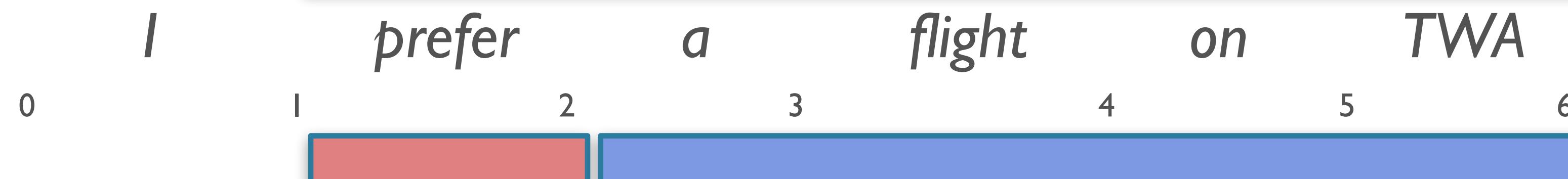
$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

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$NP \rightarrow Det Nominal$

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$Nominal \rightarrow Nominal Noun$

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$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

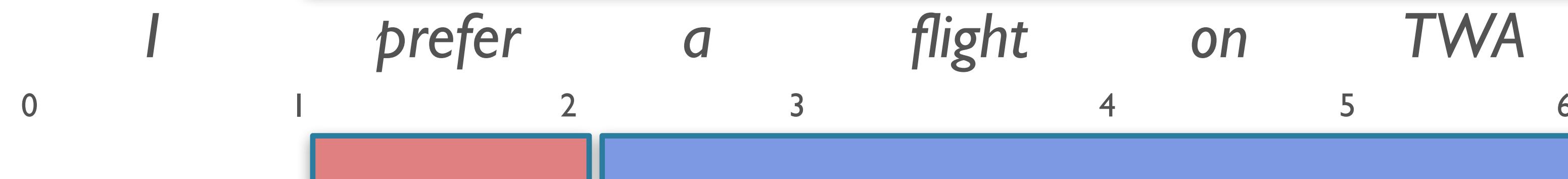
$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]		VP, X2, S [1,3]		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]

Lexicon

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$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

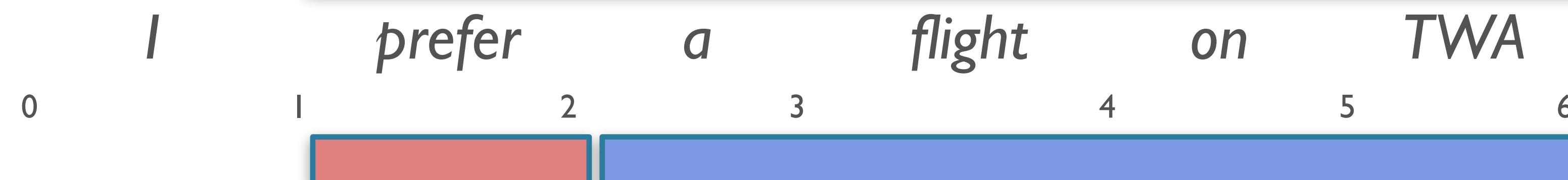
$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	VP, X2, S [1,6]
Verb, VP, S [1,2]	Det [1,3]	VP, X2, S [1,4]	NP [1,5]	NP [2,6]	NP [2,6]
	Det [2,3]	NP [2,4]	Noun, Nom [3,4]	NP [3,5]	Nom [3,6]
Lexicon				Prep [4,5]	PP [4,6]
$Det \rightarrow that this a$ $Noun \rightarrow book flight meal money$ $Pronoun \rightarrow I she me$ $Proper-Noun \rightarrow Houston TWA$ $Aux \rightarrow does$ $Preposition \rightarrow from to on near through$ $Verb \rightarrow book include prefer$					



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$Nominal \rightarrow Nominal Noun$

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$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

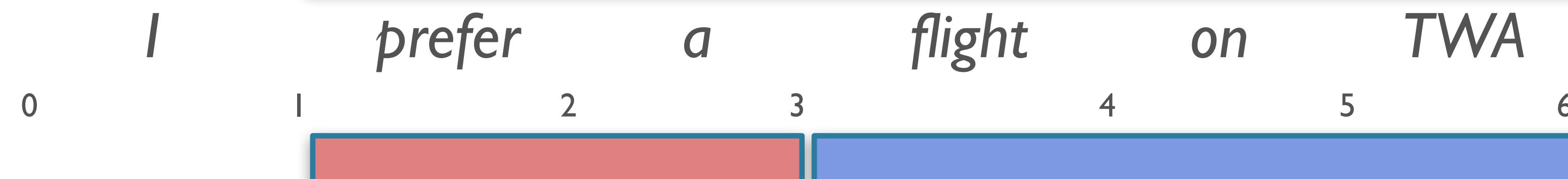
$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

NP, Pronoun [0,1]	S [0,2]		S [0,3]		S [0,4]		[0,5]	
		Verb, VP, S [1,2]		Verb, VP, S [1,3]		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 [3,5]	PP [4,6]
								NNP, NP [5,6]

Lexicon

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



\mathcal{L}_1 Grammar

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

$S \rightarrow Verb\ PP$

$S \rightarrow VP\ PP$

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

$NP \rightarrow TWA\ / Houston$

$NP \rightarrow Det\ Nominal$

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

$Nominal \rightarrow Nominal\ Noun$

$Nominal \rightarrow Nominal\ PP$

$VP \rightarrow book\ / include\ / prefer$

$VP \rightarrow Verb\ NP$

$VP \rightarrow X2\ PP$

$X2 \rightarrow Verb\ NP$

$VP \rightarrow Verb\ PP$

$VP \rightarrow VP\ PP$

$PP \rightarrow Preposition\ NP$

NP, Pronoun [0,1]	S [0,2]		S [0,3]		S [0,4]		[0,5]	
		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]

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$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

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$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

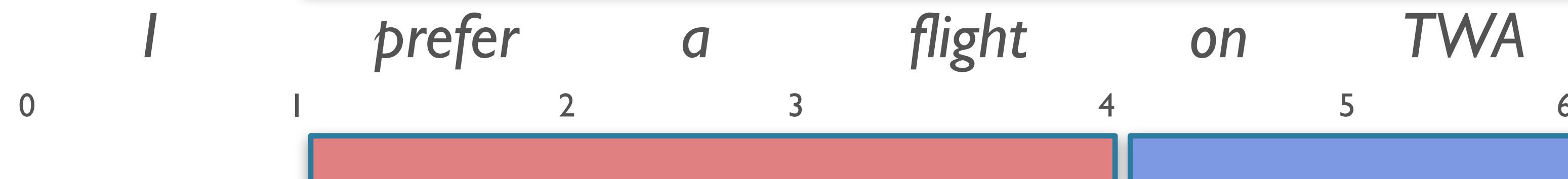
$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

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$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

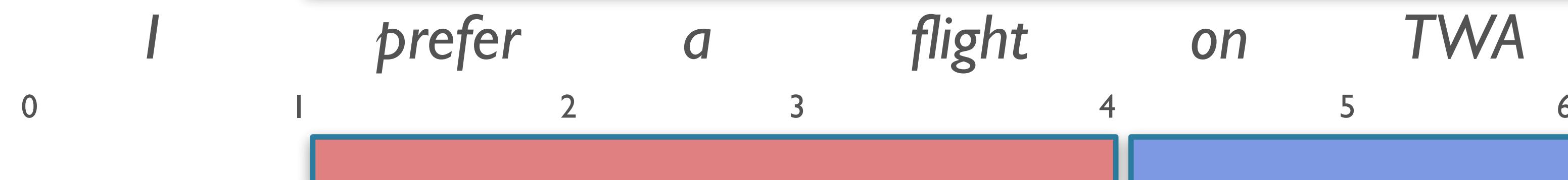
$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

NP, Pronoun [0,1]	S [0,2]		S [0,3]		S [0,4]		[0,5]	
		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]
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$VP \rightarrow Verb PP$

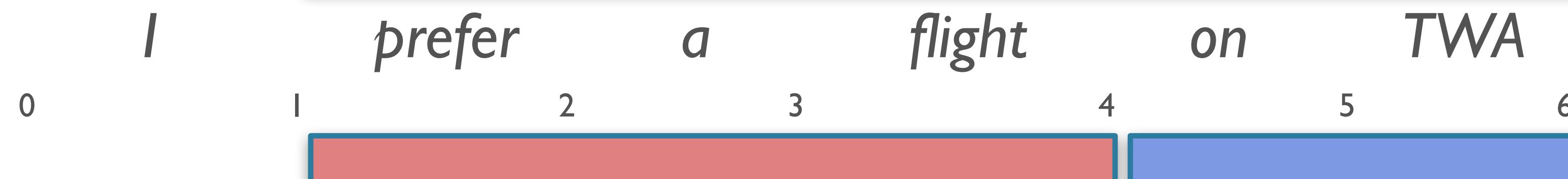
$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

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$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

NP, Pronoun [0,1]	S [0,2]		S [0,3]		S [0,4]		[0,5]	
		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]

Lexicon

$Det \rightarrow that | this | a$

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

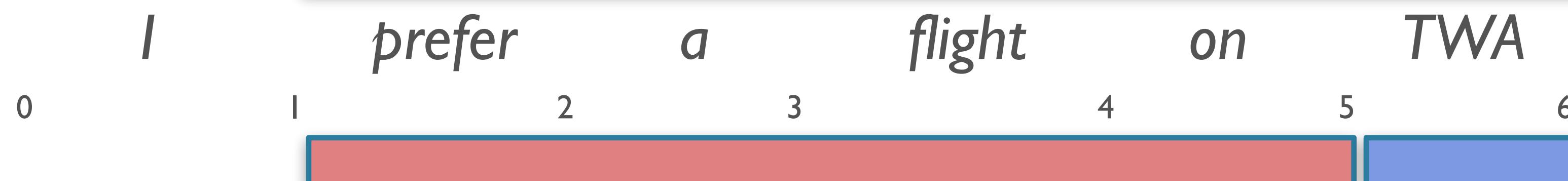
$Pronoun \rightarrow I | she | me$

$Proper-Noun \rightarrow Houston | TWA$

$Aux \rightarrow does$

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

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

$NP \rightarrow I / she / me$

$NP \rightarrow TWA / Houston$

$NP \rightarrow Det Nominal$

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

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book / include / prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

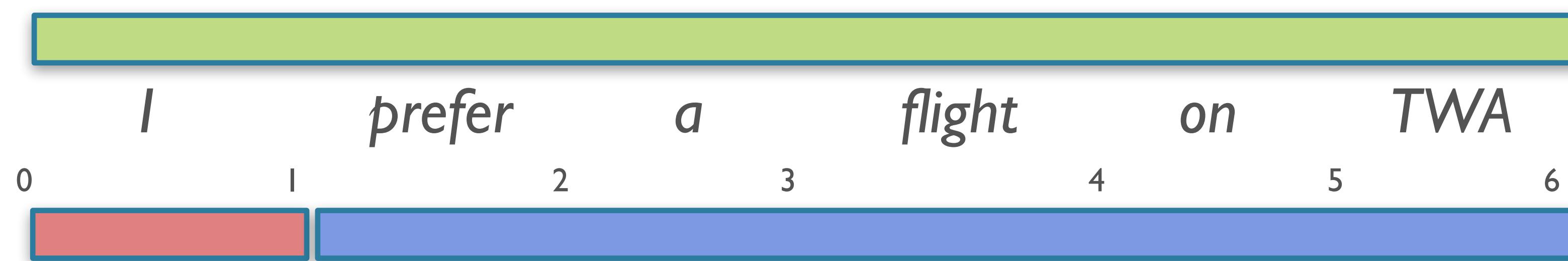
$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

NP, Pronoun [0,1]	S [0,2]		S [0,3]		S [0,4]		[0,5]	[0,6]
	Verb, VP, S [1,2]		Verb, VP, S [1,3]		VP, X2, S [1,4]		[1,5]	VP, X2, S [1,6]
		Det [2,3]			NP [2,4]			NP [2,6]
					Noun, Nom [3,4]		[3,5]	Nom [3,6]
						Prep [4,5]		PP [4,6]
								NNP, NP [5,6]
Lexicon								
$Det \rightarrow that this a$ $Noun \rightarrow book flight meal money$ $Pronoun \rightarrow I she me$ $Proper-Noun \rightarrow Houston TWA$ $Aux \rightarrow does$ $Preposition \rightarrow from to on near through$ $Verb \rightarrow book include prefer$								



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$VP \rightarrow X2 PP$

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$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

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

[0,2]

[0,3]

[0,4]

[0,5]

[0,6]

Verb, VP, S

[1,2]

[1,3]

[1,4]

[1,5]

[1,6]

Det

[2,3]

[2,4]

[2,5]

[2,6]

NP

[2,7]

[2,8]

[2,9]

[2,10]

Noun, Nom

[3,4]

[3,5]

[3,6]

Verb

[4,5]

[4,6]

PP

[4,7]

[4,8]

NNP, NP

[4,9]

[4,10]

Prep

[4,11]

[4,12]

NP

[4,13]

[4,14]

PP

[4,15]

[4,16]

NP

[4,17]

[4,18]

PP

[4,19]

[4,20]

NP

[4,21]

[4,22]

PP

[4,23]

[4,24]

NP

[4,25]

[4,26]

PP

[4,27]

[4,28]

NP

[4,29]

[4,30]

PP

[4,31]

[4,32]

NP

[4,33]

[4,34]

PP

[4,35]

[4,36]

NP

[4,37]

[4,38]

PP

[4,39]

[4,40]

NP

[4,41]

[4,42]

PP

[4,43]

[4,44]

NP

[4,45]

[4,46]

PP

[4,47]

[4,48]

NP

[4,49]

[4,50]

PP

[4,51]

[4,52]

NP

[4,53]

[4,54]

PP

[4,55]

[4,56]

NP

[4,57]

[4,58]

PP

[4,59]

[4,60]

NP

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[4,62]

PP

[4,63]

[4,64]

NP

[4,65]

[4,66]

PP

[4,67]

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NP

[4,69]

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PP

[4,71]

[4,72]

NP

[4,73]

[4,74]

PP

[4,75]

[4,76]

NP

[4,77]

[4,78]

PP

[4,79]

[4,80]

NP

[4,81]

[4,82]

PP

[4,83]

[4,84]

NP

[4,85]

[4,86]

PP

[4,87]

[4,88]

NP

[4,89]

[4,90]

PP

[4,91]

[4,92]

NP

[4,93]

[4,94]

PP

[4,95]

[4,96]

NP

[4,97]

[4,98]

PP

[4,99]

[4,100]

NP

[4,101]

[4,102]

PP

[4,103]

\mathcal{L}_1 Grammar

$S \rightarrow NP VP$
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$NP \rightarrow Det Nominal$

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$Nominal \rightarrow Nominal Noun$

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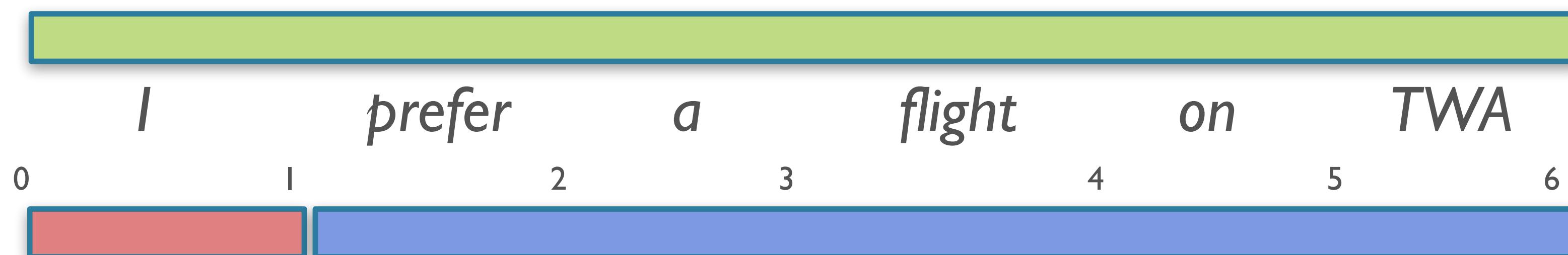
$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	S [0,6]
Verb, VP, S [1,2]	Verb, VP, S [1,3]	VP, X2, S [1,4]	VP, X2, S [1,5]	VP, X2, S [1,6]	VP, X2, S [2,6]
Det [2,3]	Det [2,4]	NP [2,5]	NP [3,4]	NP [3,5]	NP [3,6]
Lexicon		Noun, Nom [3,4]		Prep [4,5]	PP [4,6]
Det → that this a		Nom [3,5]		NNP, NP [5,6]	
Noun → book flight meal money		Proper-Noun [4,6]			
Pronoun → I she me					
Proper-Noun → Houston TWA					
Aux → does					
Preposition → from to on near through					
Verb → book include prefer					



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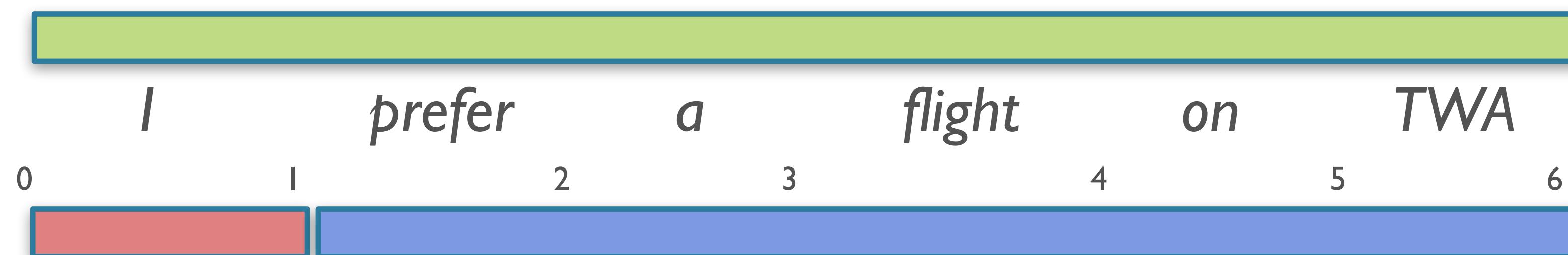
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NP, Pronoun [0,1]	S [0,2]		S [0,3]		S [0,4]		S [0,5]	S [0,6]
		Verb, VP, S [1,2]			VP, X2, S [1,3]			VP, X2, S [1,4]
				Det [2,3]		NP [2,4]		NP [2,5]
						Noun, Nom [3,4]		Nom [3,5]
							Prep [4,5]	PP [4,6]
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$VP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

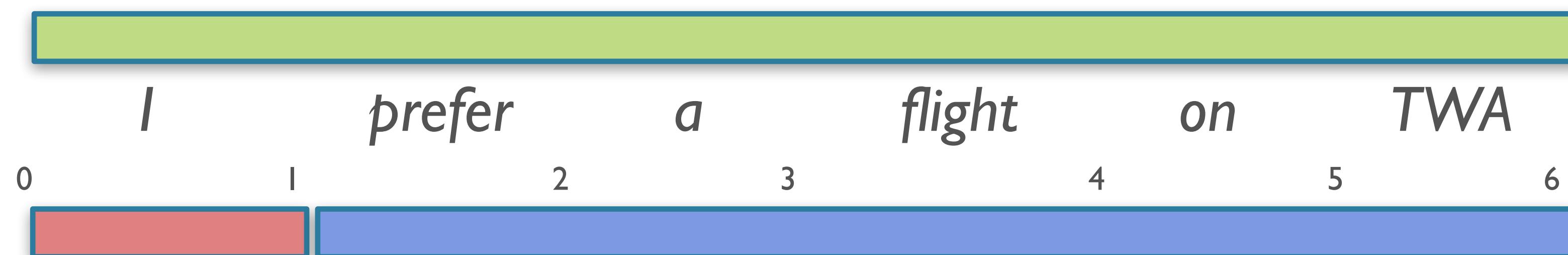
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NP, Pronoun [0,1]	S [0,2]		S [0,3]	S [0,4]		S [0,6]
		Verb, VP, S [1,2]		VP, X2, S [1,4]		VP, X2, S [1,6]
			Det [2,3]	NP [2,4]		NP [2,6]
				Noun, Nom [3,4]		Nom [3,6]
					Prep [4,5]	PP [4,6]
						NNP, NP [5,6]

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NP, Pronoun [0,1]	S [0,2]		S [0,3]	S [0,4]		S [0,6]
	Verb, VP, S [1,2]		Verb, VP, S [1,3]	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]

Lexicon

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

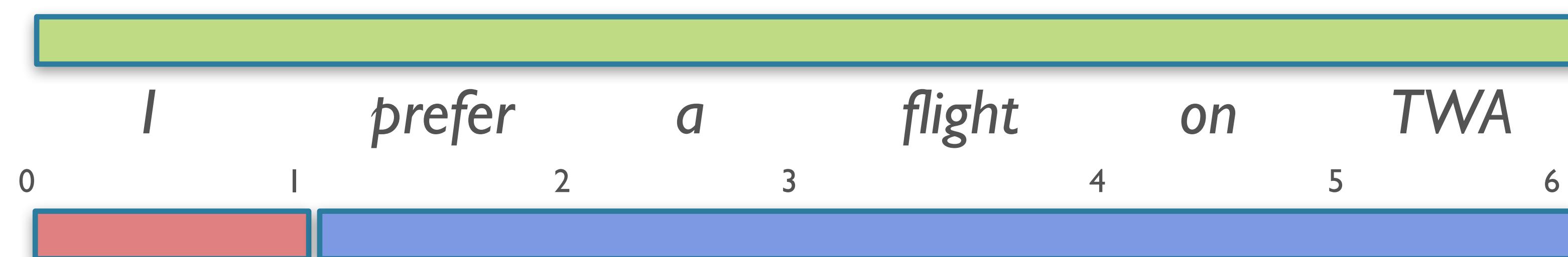
$Pronoun \rightarrow I | she | me$

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$Aux \rightarrow does$

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

$Verb \rightarrow book | include | prefer$



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]		S [0,4]		
	Verb, VP, S [1,2]		VP, X2, S [1,4]		VP [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]

$VP \rightarrow VP \text{ } PP$

$bp_1 = \text{BackPointer}()$
 $bp_1.l_child = [VP, (1, 4)]$
 $bp_1.r_child = [PP, (4, 6)]$

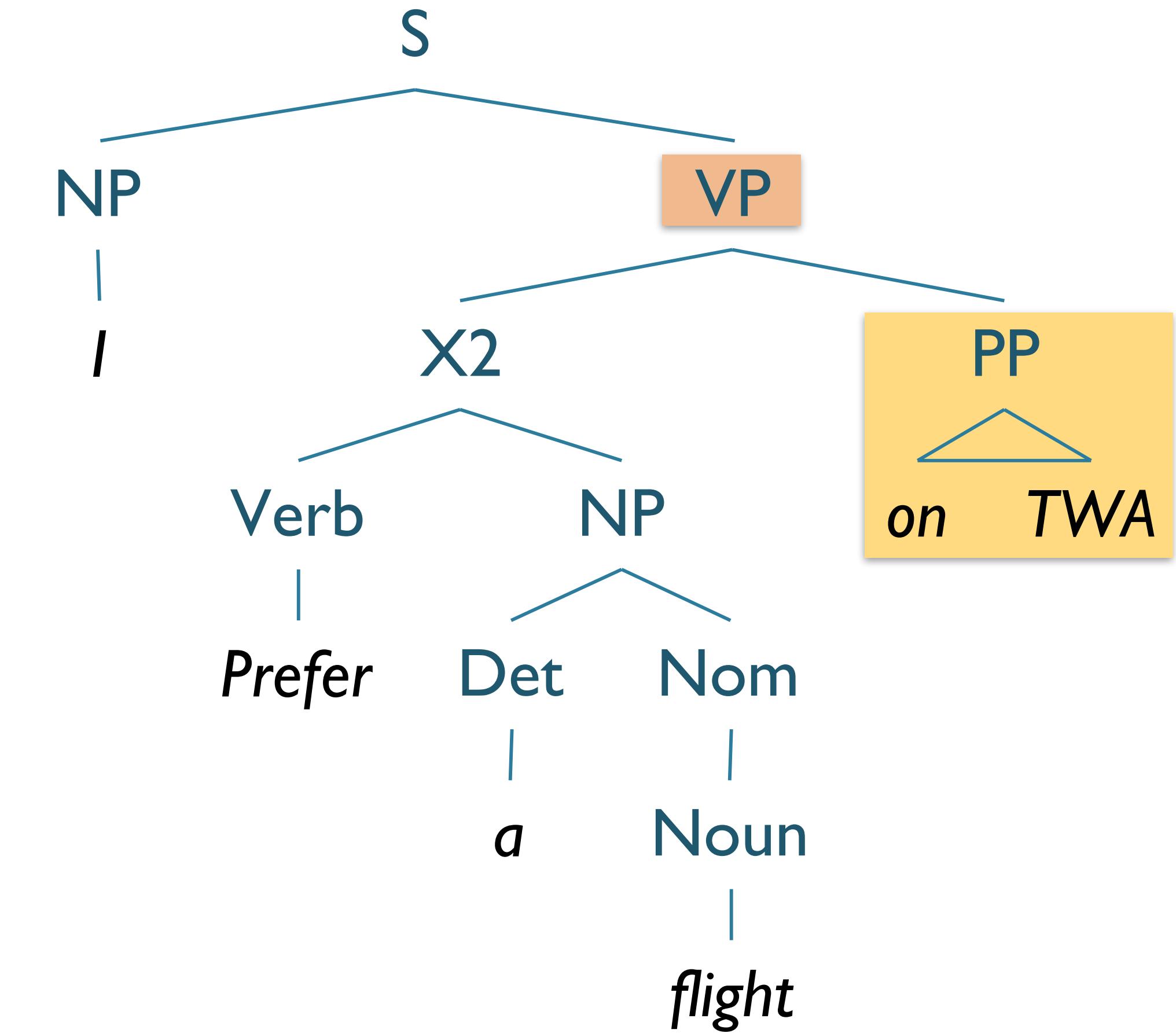
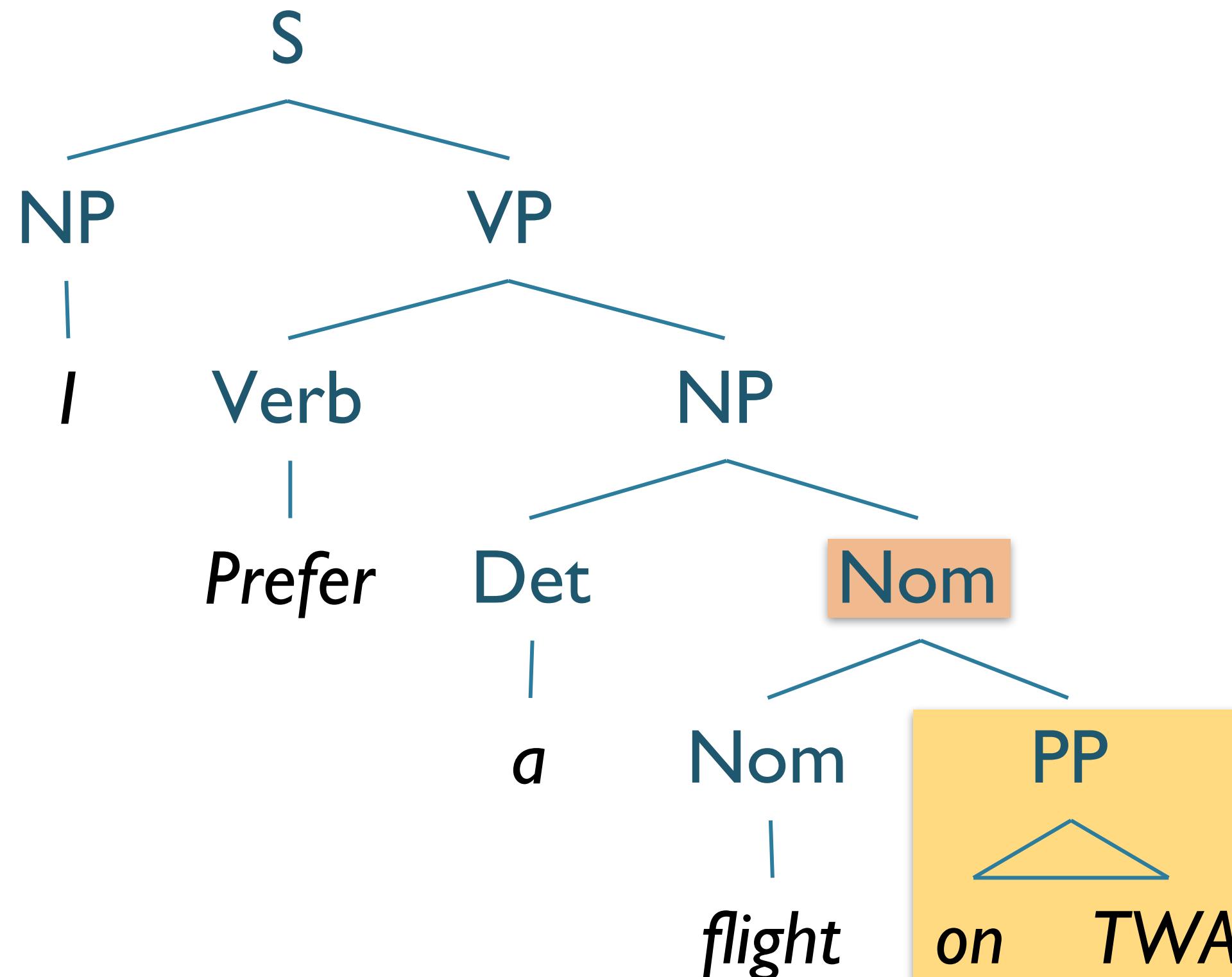
NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	VP
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	VP [1,6]
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
				Prep [4,5]	PP [4,6]
					NNP, NP [5,6]

$VP \rightarrow X2 \text{ } PP$

$bp_2 = \text{BackPointer}()$
 $bp_2.l_child = [X2, (1, 4)]$
 $bp_2.r_child = [PP, (4, 6)]$

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

Resulting Parses



CKY Discussion

Running time:

$O(n^3)$ where n is the length of the input string

Inner loop grows as square of # of non-terminals

Expressiveness:

As implemented, requires CNF

Weak equivalence to original grammar

Doesn't capture full original structure

Back-conversion?

Can do binarization, terminal conversion

Unit productions requires change in CKY