PCFGs:
Parsing & Evaluation

LING 571 — Deep Processing Techniques for NLP
October 14, 2020
Shane Steinert-Threlkeld

Roadmap

- CKY + back-pointers
- PCFGs
- PCFG Parsing (PCKY)
- Inducing a PCFG
- Evaluation
- [Earley parsing]
- HW3 + collaboration

CKY Parsing: Backpointers

Backpointers

- Instead of list of possible nonterminals for that node, each cell should have:
  - Nonterminal for the node
  - Pointer to left and right children cells
    - Either direct pointer to cell, or indices

For example:

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

CKY *Parser*

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

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

$VP \rightarrow VP\ PP$

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bp_1 = BackPointer()
bp_1.l_child = [VP, (1,4)]
bp_1.r_child = [PP, (4,6)]
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	VP [1,6]
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			Noun, Nom [3,4]	[3,5]	Nom [3,6]
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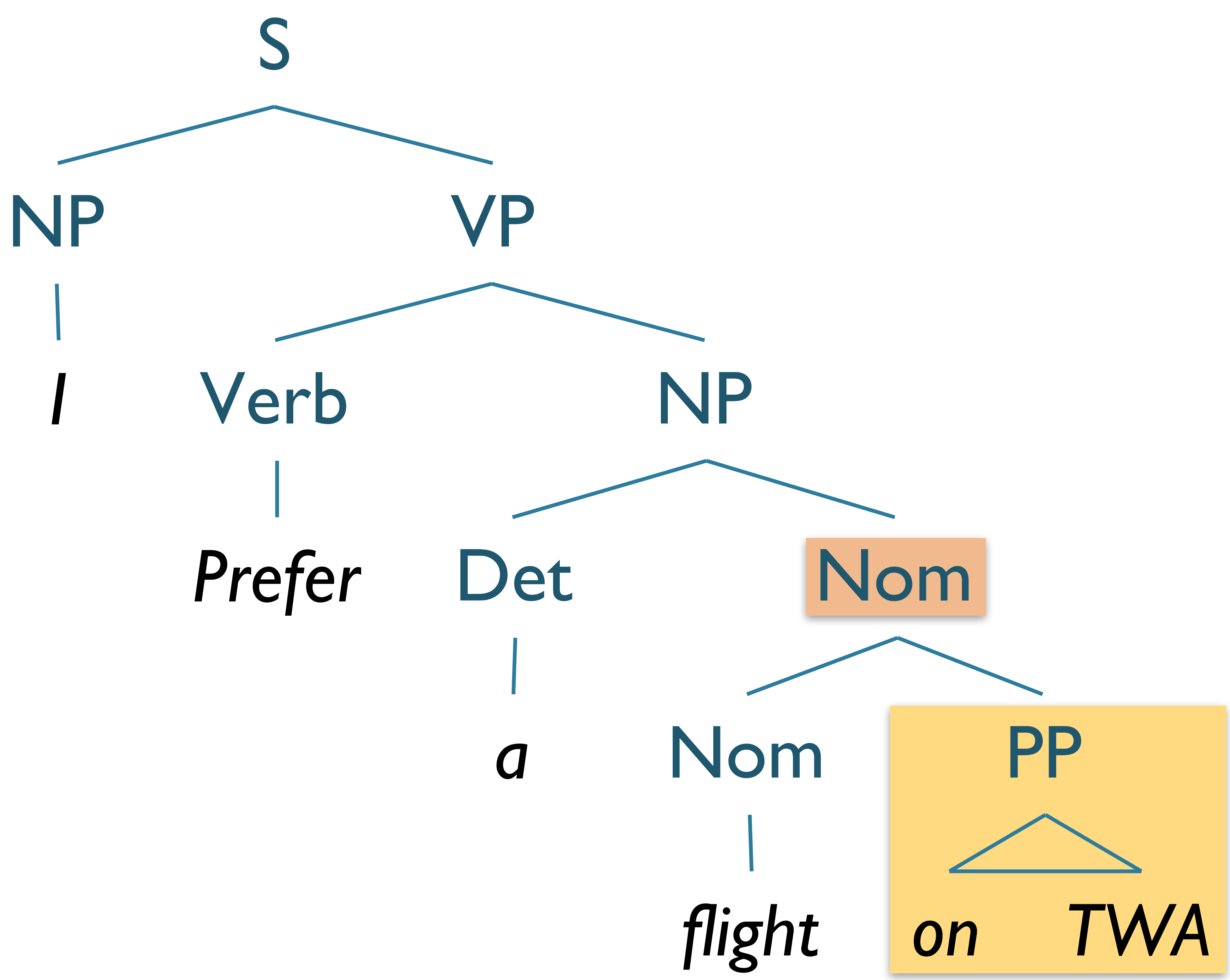
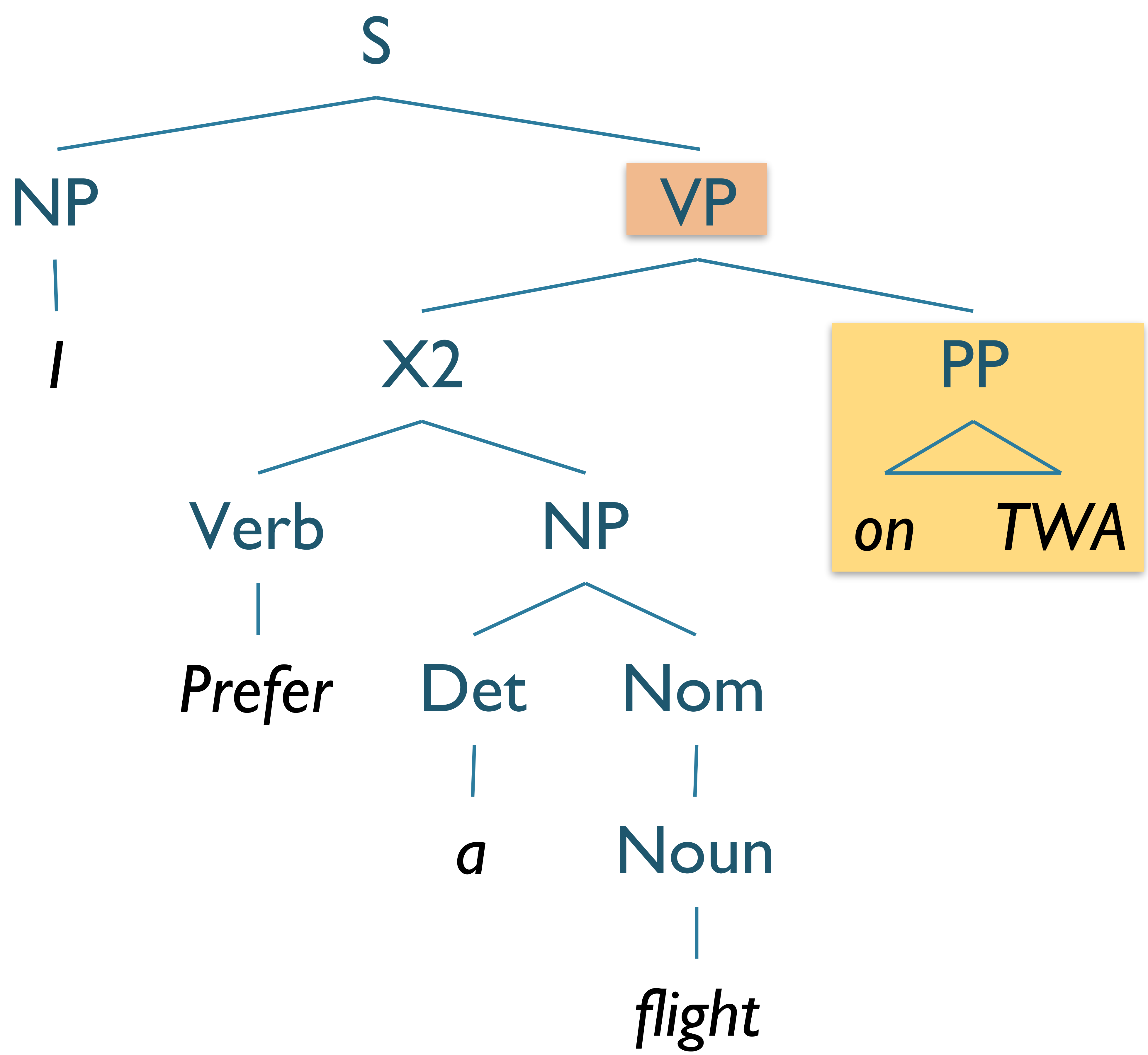
Resulting Parses





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

CKY + Back-pointers Example

```
cky_table[0,6][S] = {(NP, (0,1),
                      VP, (1,6))}
```

NP, Pronoun [0,1]	**S** [0,2]	[0,3]	**S** [0,4]	[0,5]	**S** [0,6]
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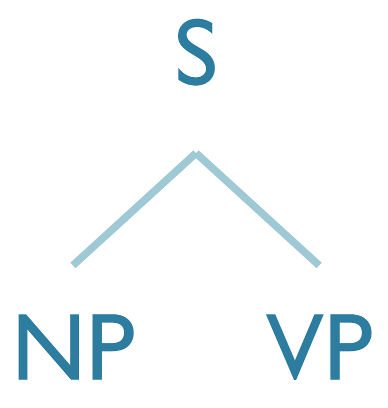

I prefer a flight on TWA

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cky_table[0,6][S] = {(NP, (0,1),
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```

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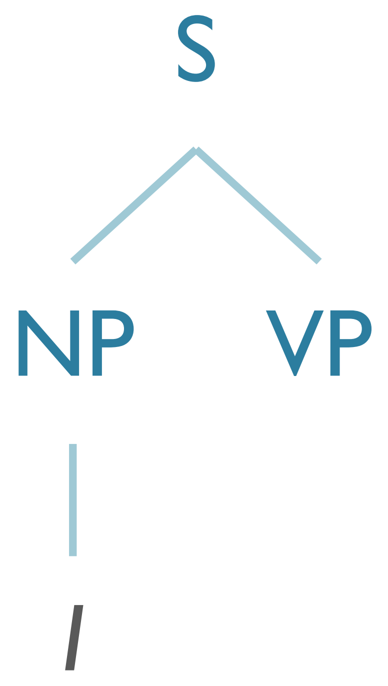

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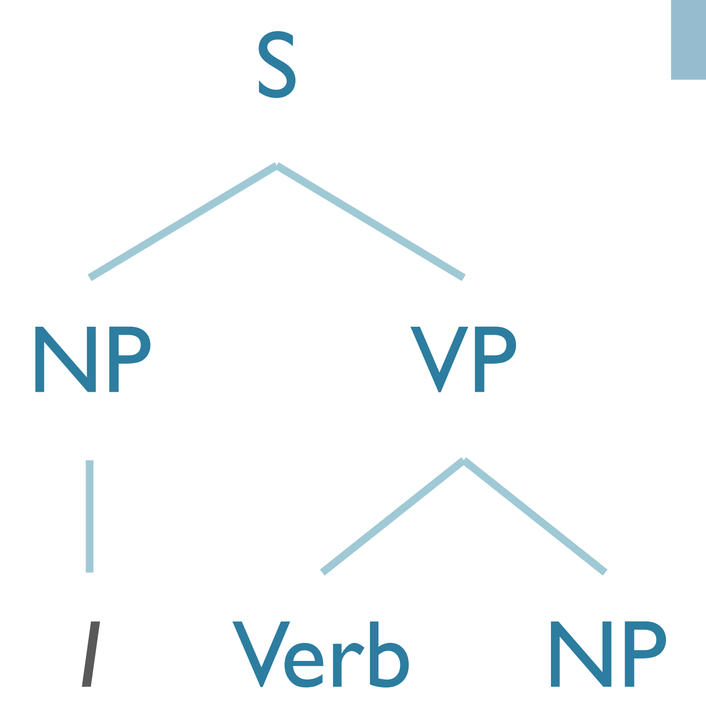

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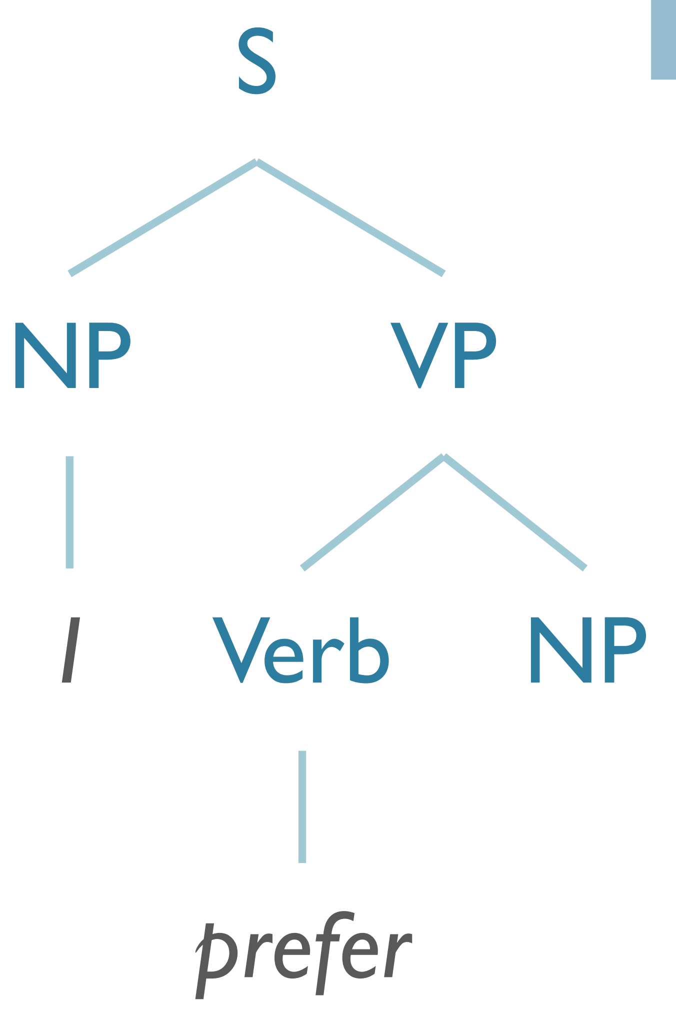

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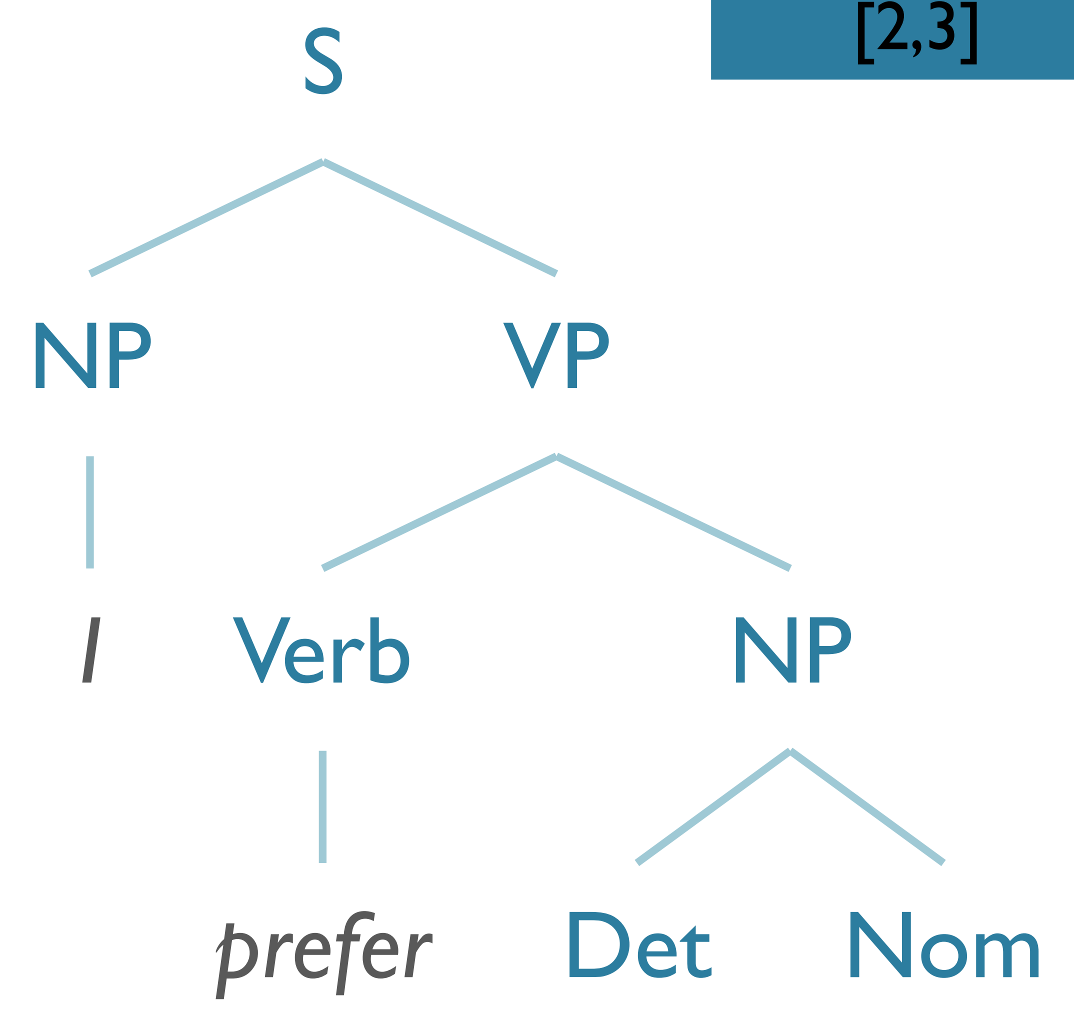

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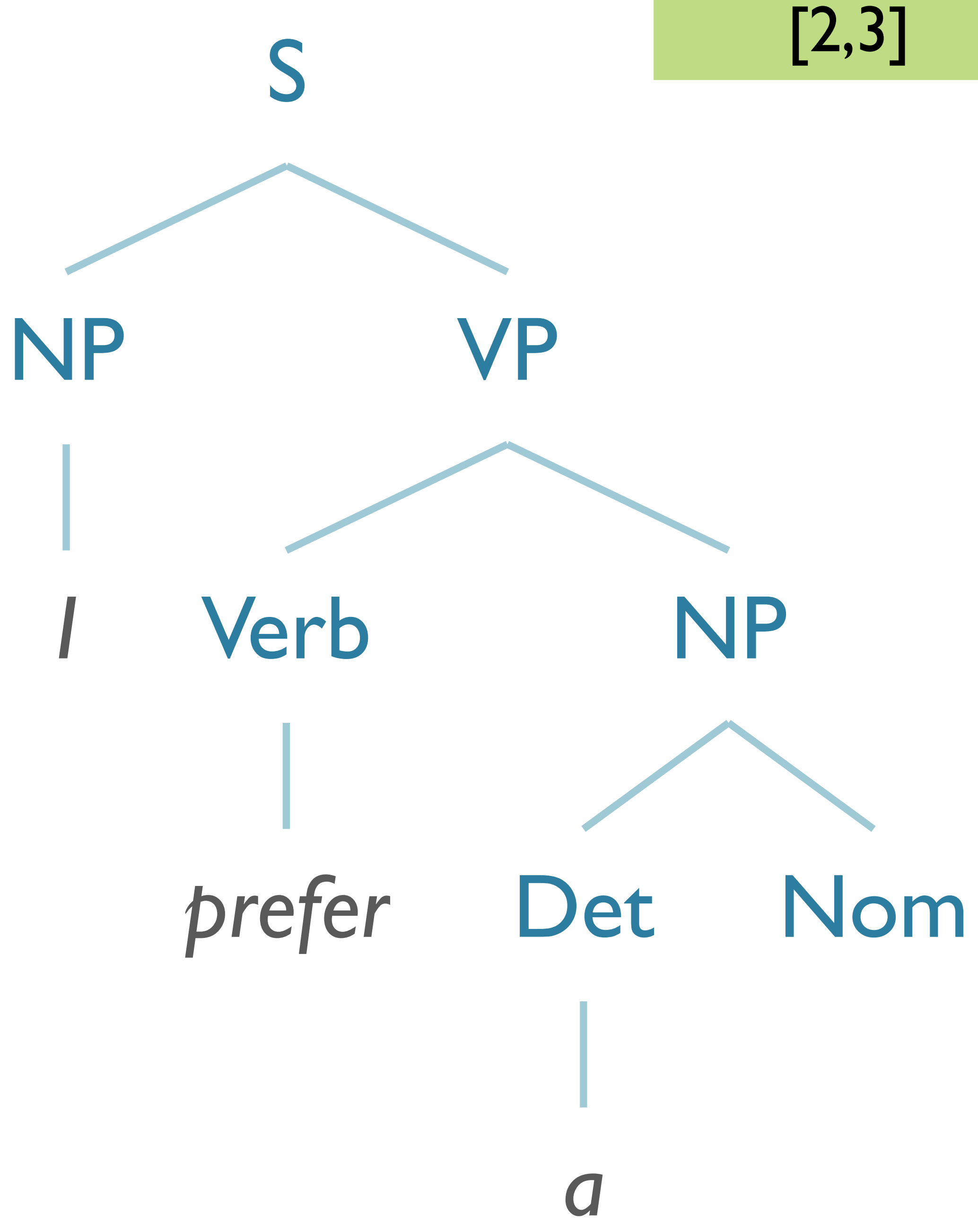

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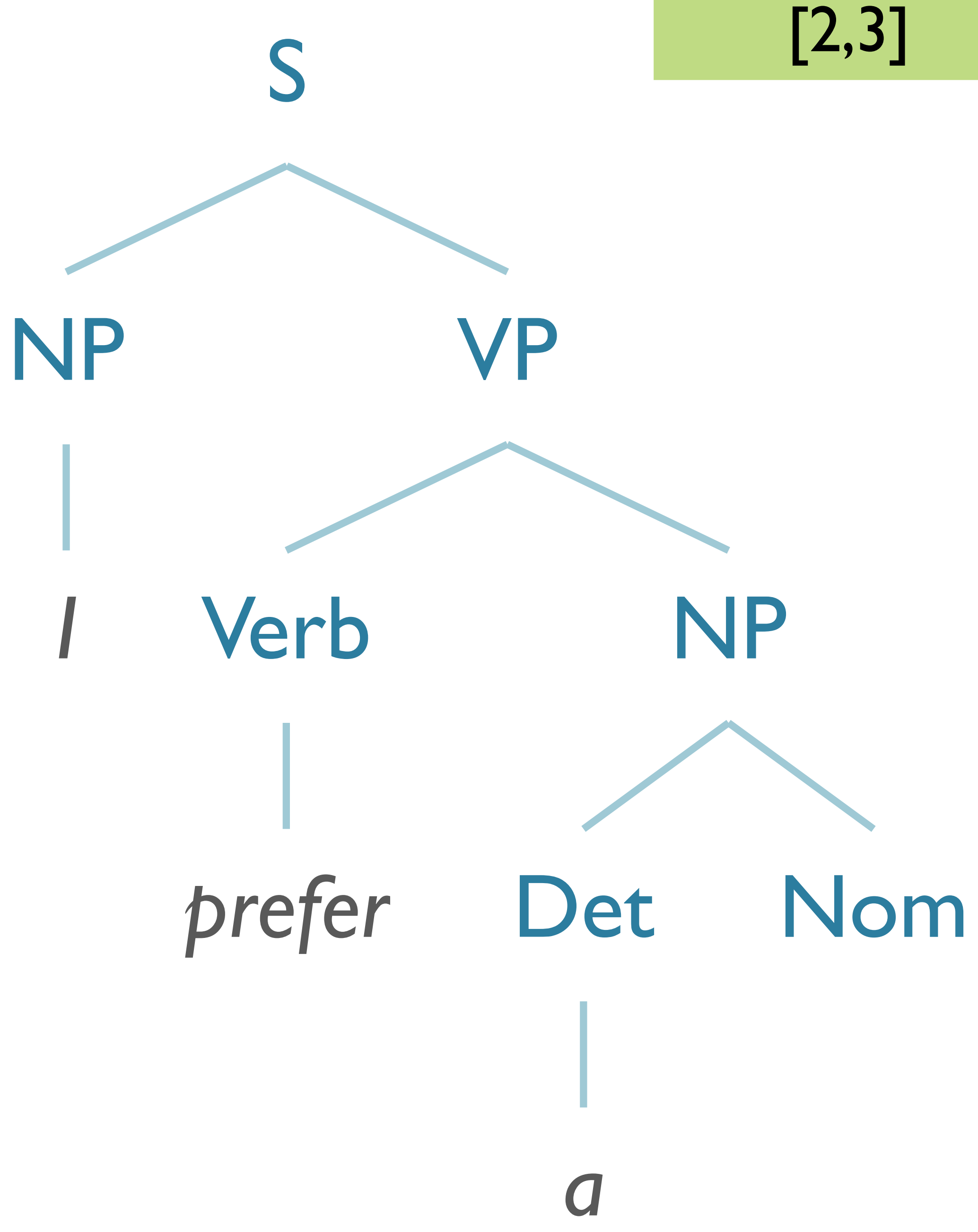

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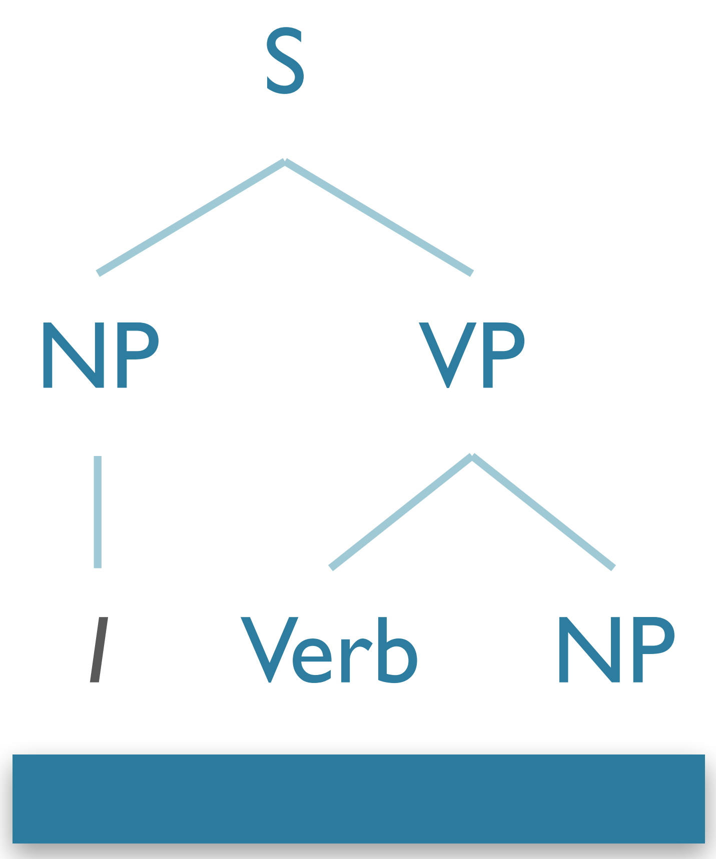

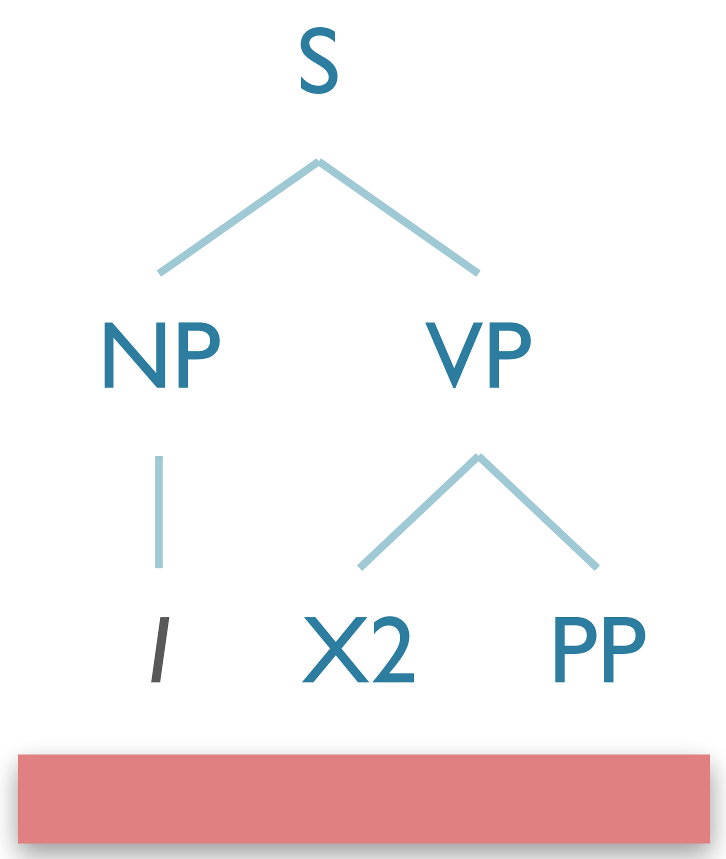

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Probabilistic Context-Free Grammars

Probabilistic Context-free Grammars: Roadmap

Motivation: Ambiguity

Approach:

- Definition
- Disambiguation
- Parsing
- Evaluation
- Enhancements

Motivation

What about ambiguity?

Current algorithm can ***represent*** it

…can’t resolve it.

Probabilistic Parsing

- Provides strategy for solving disambiguation problem
  - Compute the probability of all analyses
  - Select the most probable

- Employed in language modeling for speech recognition
  - N-gram grammars predict words, constrain search
  - Also, constrain generation, translation

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S	a designated **start symbol**

PCFGs

- Augment each production with probability that LHS will be expanded as RHS
  - $P(A \rightarrow \beta)$
  - $P(A \rightarrow \beta | A)$
  - $P(\beta | A)$
  - $P(RHS \mid LHS)$
- NB: the first is often used; but the latter are what's really meant.

PCFGs

- Sum over all possible expansions is 1

$$\sum_{\beta} P(A \rightarrow \beta) = 1$$

- A PCFG is ***consistent*** if sum of probabilities of all sentences in language is 1
  - Recursive rules often yield inconsistent grammars *(Booth & Thompson, 1973)*

Example PCFG: Augmented $\mathscr{L}_1$

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

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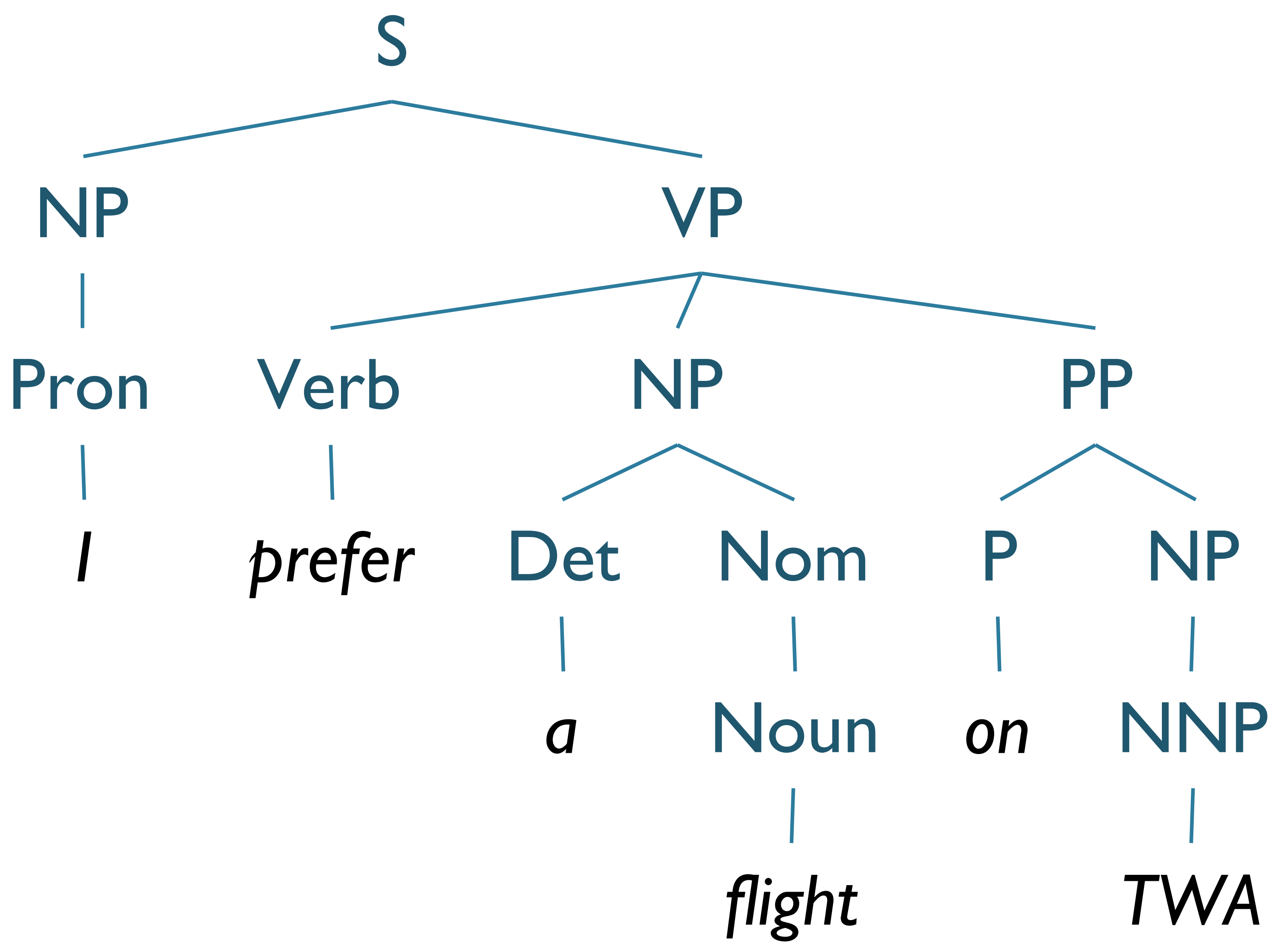
Disambiguation

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

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

$$P(T, S) = P(T)P(S \mid T) = P(T)$$



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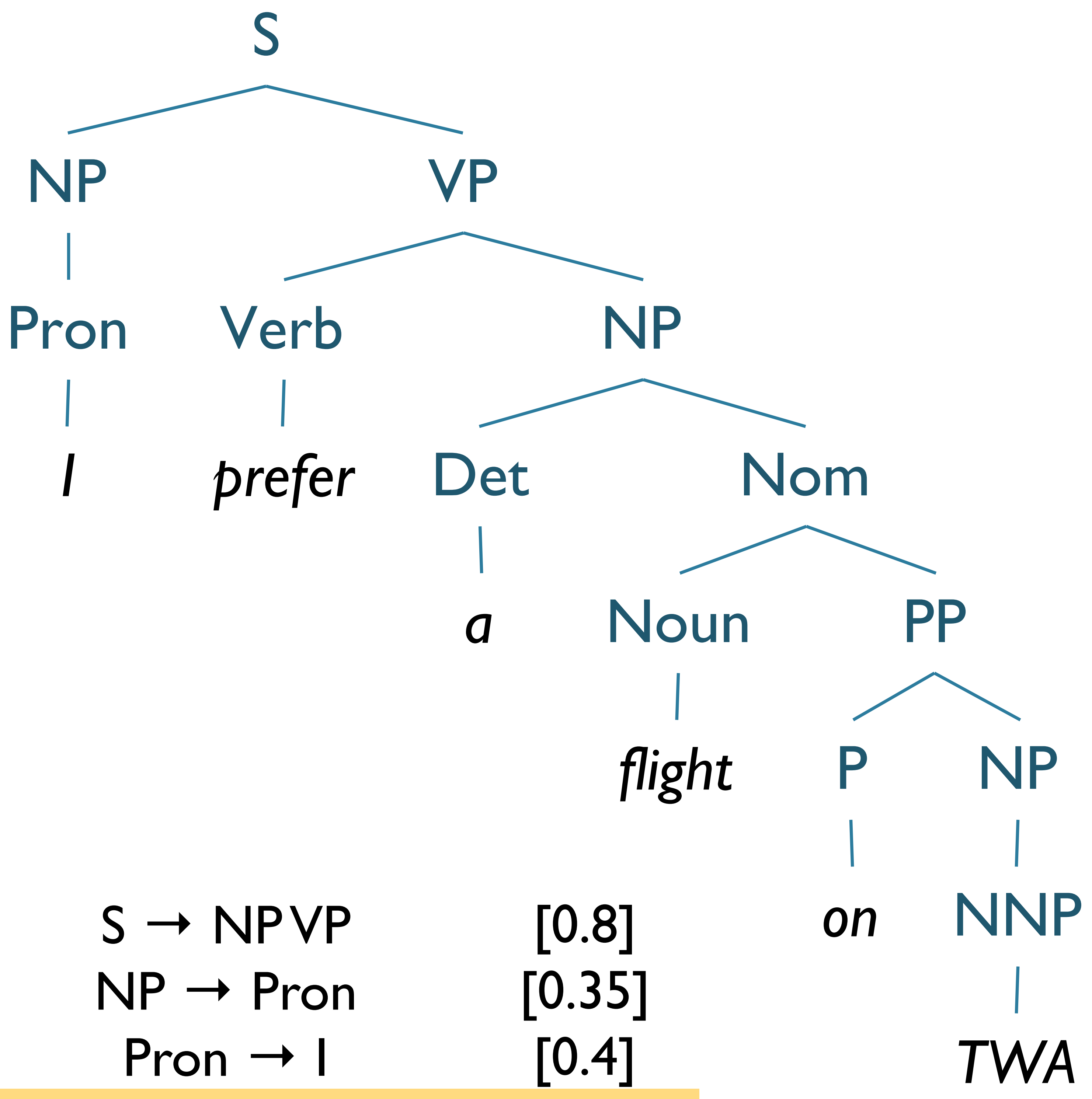
NNP → NWA	[0.4]



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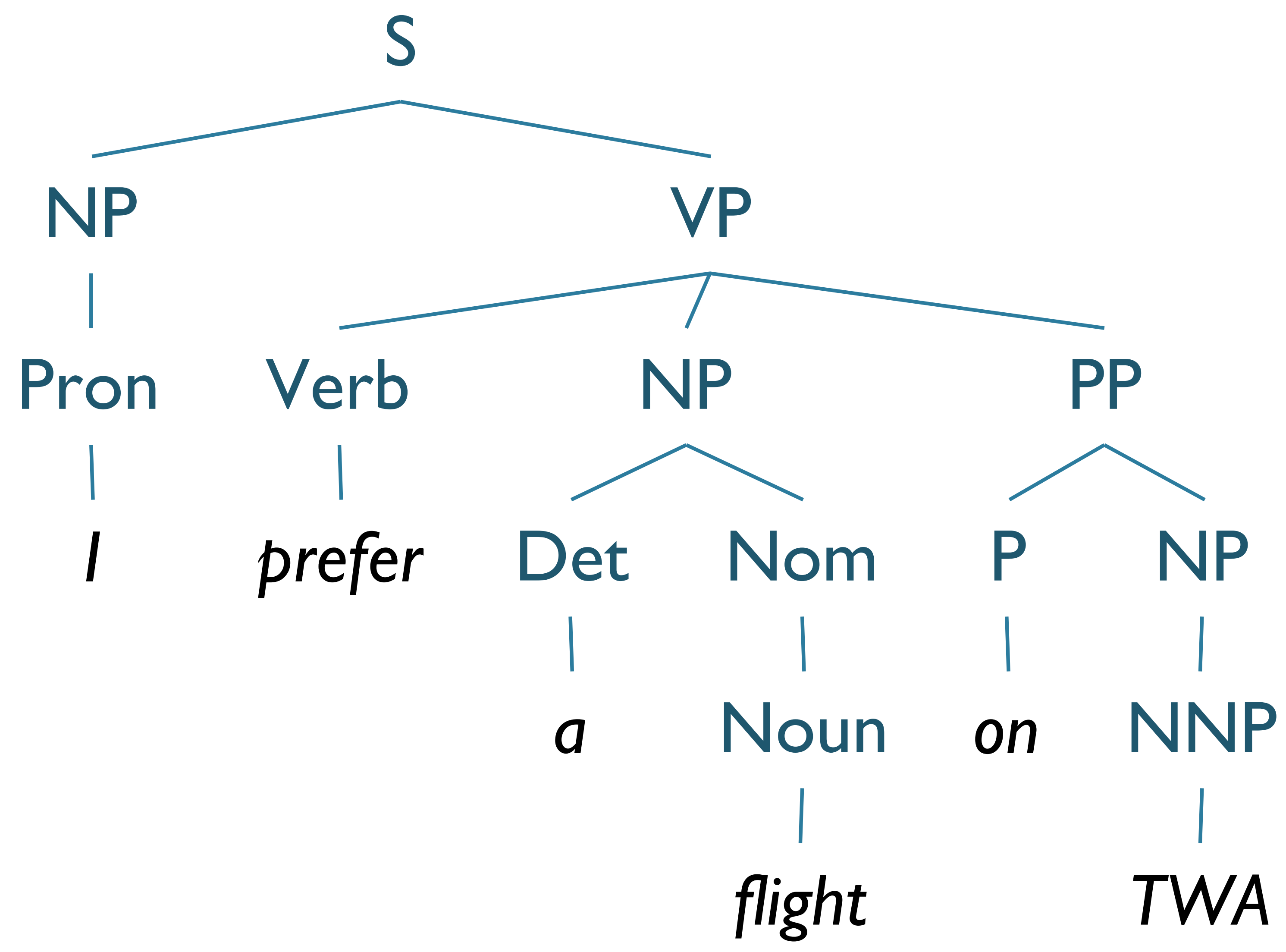

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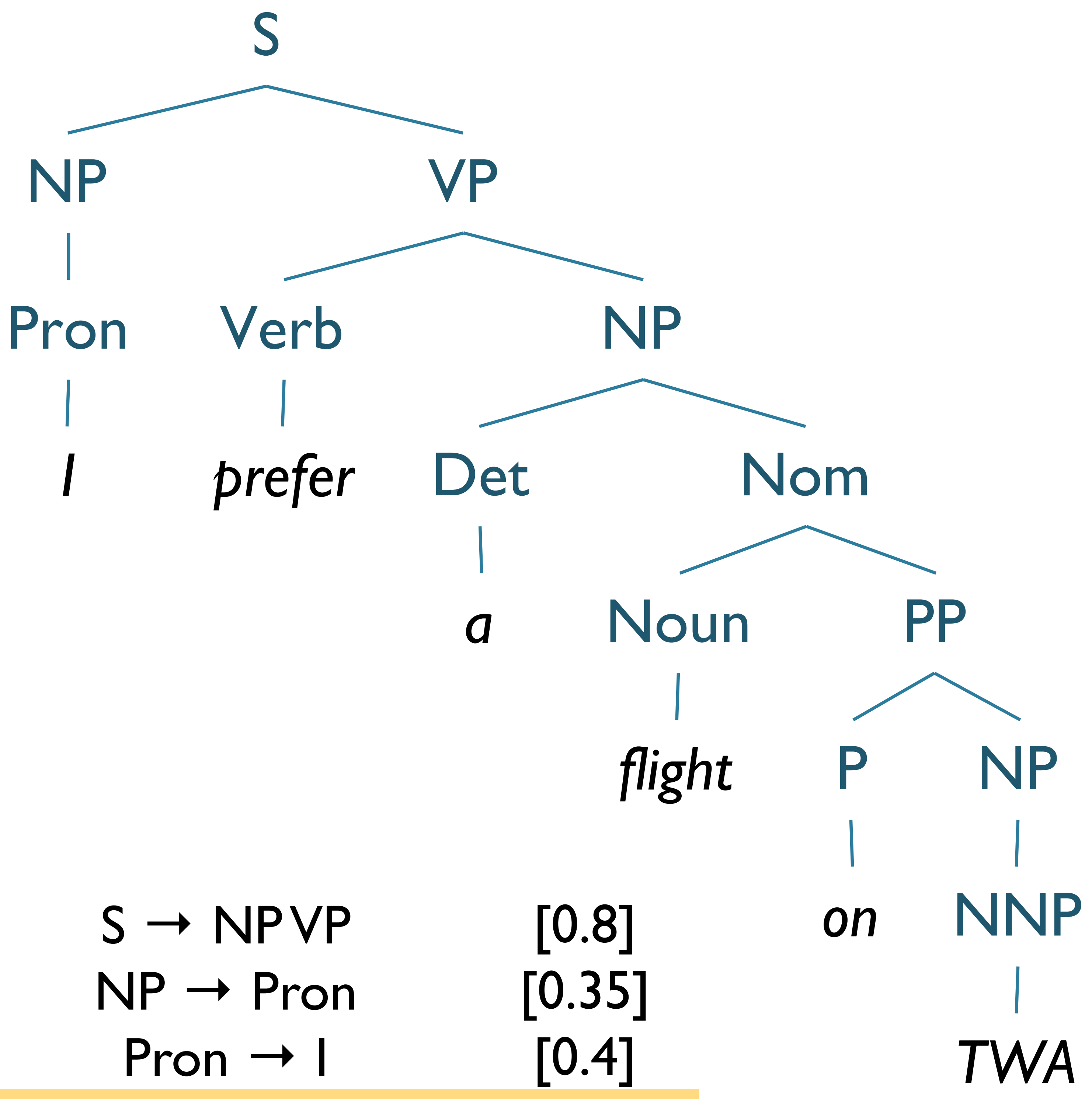
~1.452×10^{-6}



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NP → NNP	[0.3]
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~1.452×10^{-7}

Parsing Problem for PCFGs

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

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

- String of words S is $yield$ of parse tree
- Select the tree $\hat{T}$ that maximizes the probability of the parse

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- To model a whole sentence with *n-grams* either:
  - Must use 10+-grams… too sparse
  - Approximate using conditioning on limited context: $P(w_i \mid w_{i-1}) = \dfrac{P(w_{i-1}, w_i)}{P(w_{i-1})}$
- PCFGs are able to give probability of entire string without as bad sparsity

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- To model a whole sentence with *n-grams* either:
    - Must use 10+-grams… too sparse
    - Approximate using conditioning on limited context: $P(w_i \mid w_{i-1}) = \dfrac{P(w_{i-1}, w_i)}{P(w_{i-1})}$
- PCFGs are able to give probability of entire string without as bad sparsity
- Model probability of *syntactically valid* sentences

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- PCFGs are able to give probability of entire string without as bad sparsity
- Model probability of *syntactically valid* sentences
  - Not just probability of sequence of words

PCFGs: Parsing

Probabilistic CKY (PCKY)

- Like regular CKY
  - Assumes grammar in Chomsky Normal Form (CNF)
    - $A \rightarrow B\ C$
    - $A \rightarrow \mathrm{w}$
  - Represent input with indices b/t words:
    - $_0$ Book $_1$ that $_2$ flight $_3$ through $_4$ Houston $_5$

Probabilistic CKY (PCKY)

- For input string length n and non-terminals V
  - Cell [i, j, A] in (n+1) × (n+1) × V matrix
  - Contains probability that A spans $[i, j]$

PCKY Algorithm

function PROBABILISTIC-CKY-PARSE(*words*, *grammar*) **returns** most probable parse and its probability

for j ← **from** 1 to LENGTH(*words*) **do**

for all $\{ A \mid A \rightarrow words[j] \in grammar \}$

$table[j{-}1, j, A] \leftarrow P(A \rightarrow words[j])$

for i ← **from** $j{-}2$ **downto** 0 **do**

for $k \leftarrow i + 1$ **to** $j{-}1$ **do**

for all $\{ A \mid A \rightarrow B\ C \in grammar,$

and $table[i, k, B] > 0$ **and** $table[k, j, C] > 0 \}$

if $(table[i, j, A] < P(A \rightarrow BC) \times table[i, k, B] \times table[k, j, C])$ **then**

$table[i, j, A] \leftarrow P(A \rightarrow BC) \times table[i, k, B] \times table[k, j, C]$

$back[i, j, A] \leftarrow \{ k, B, C \}$

return BUILD_TREE(*back*[1, LENGTH(*words*), *S*]), *table*[1,LENGTH(*words*), *S*]

PCKY Algorithm

```
function PROBABILISTIC-CKY-PARSE(words, grammar) returns most probable parse and its probability
for j ← from 1 to LENGTH(words) do
 for all { A | A → words[j] ∈ grammar }
      table[ j–1, j, A ] ← P(A → words[j])
 for i ← from j–2 downto 0 do
  for k ← i + 1 to j–1 do
  for all { A | A → B C ∈ grammar,
        and table[i, k, B] > 0 and table[ k, j, C ] > 0 }
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```

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PCKY Grammar Segment

$S \rightarrow NP\ VP$	[0.80]		$Det \rightarrow$ the	[0.40]
$NP \rightarrow Det\ N$	[0.30]		$Det \rightarrow$ a	[0.40]
$VP \rightarrow V\ NP$	[0.20]		$V \rightarrow$ includes	[0.05]
			$N \rightarrow$ meal	[0.01]
			$N \rightarrow$ flight	[0.02]

PCKY Matrix

$S \rightarrow NP\ VP$ [0.80]
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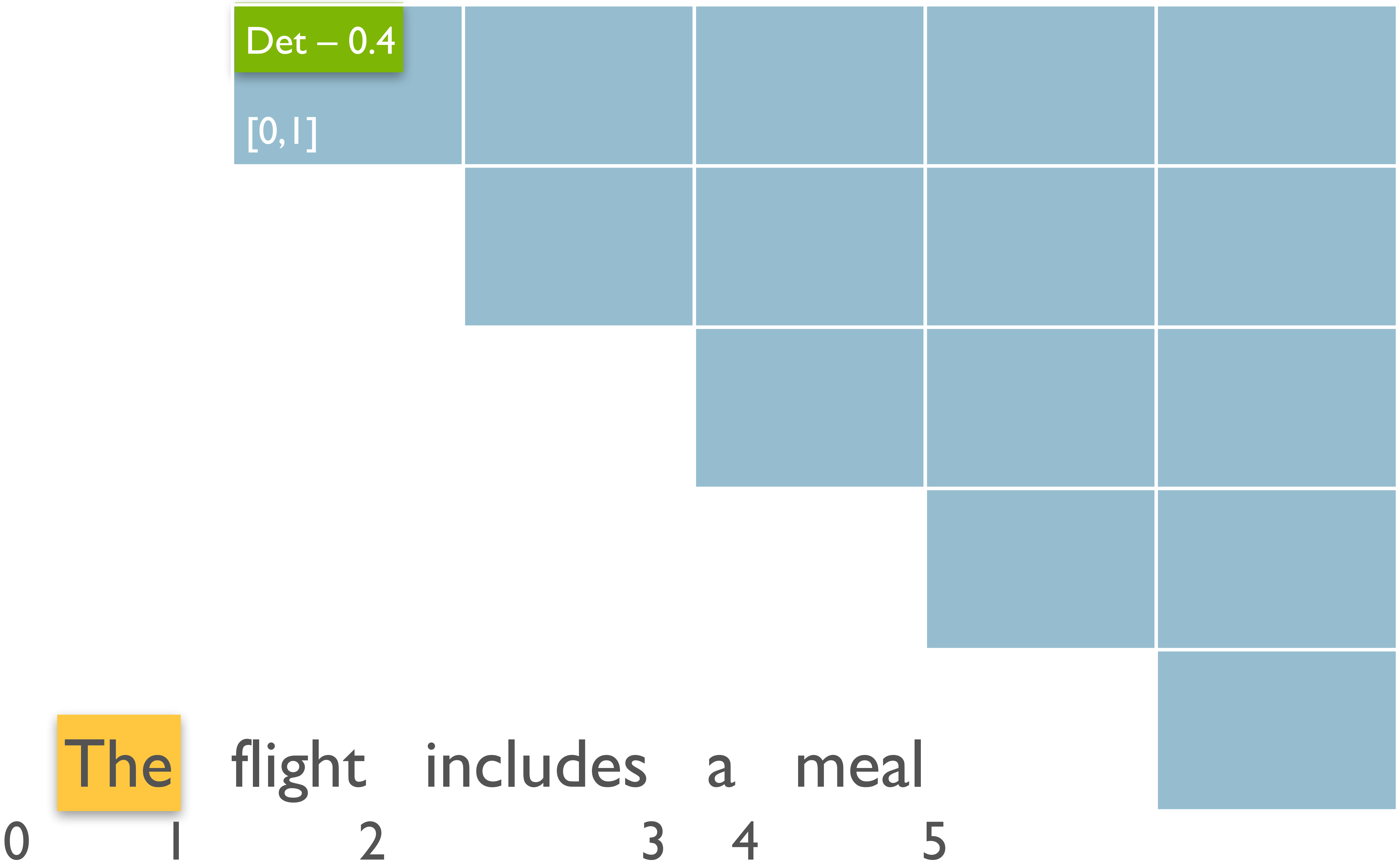

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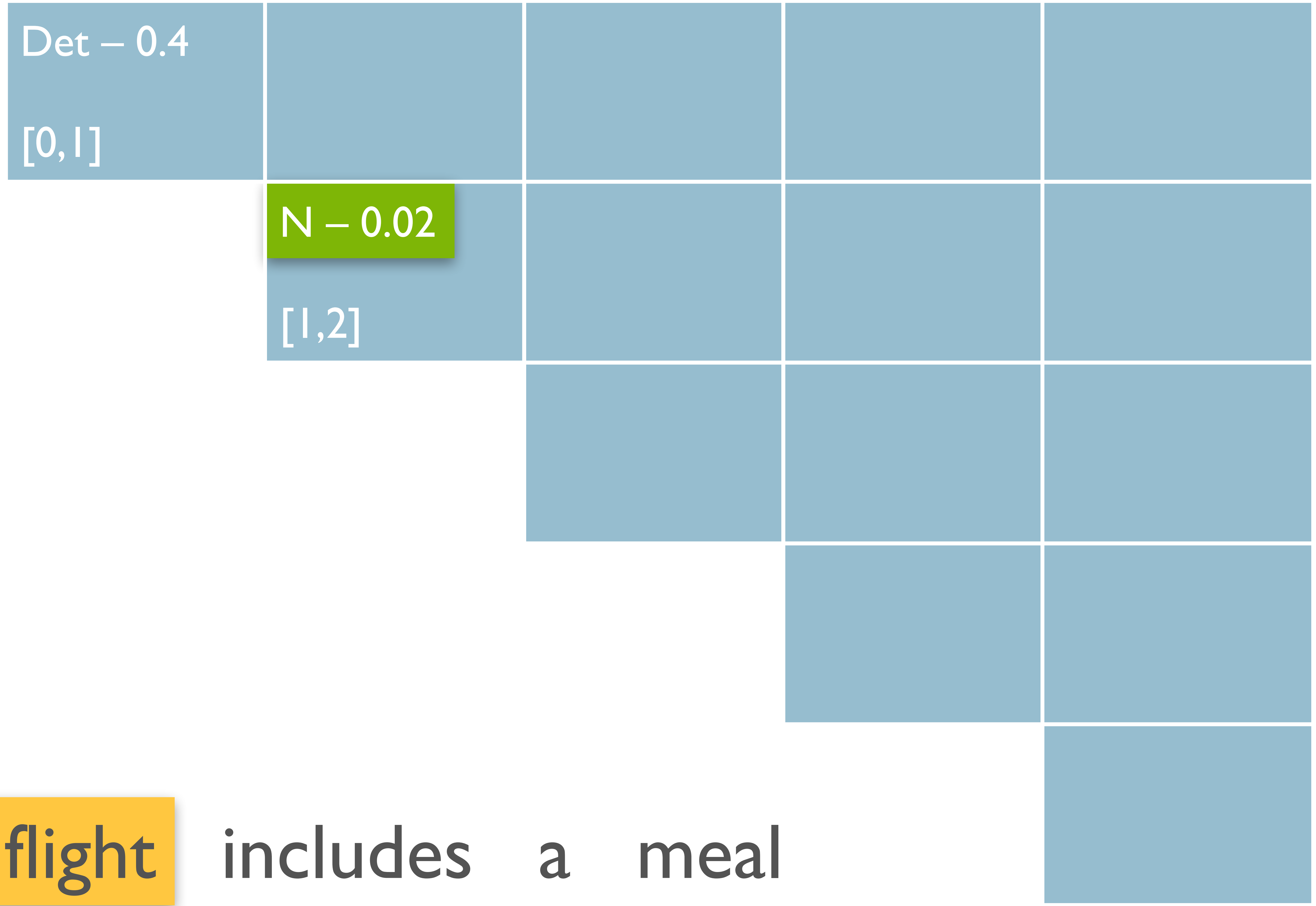

The flight includes a meal

0 1 2 3 4 5

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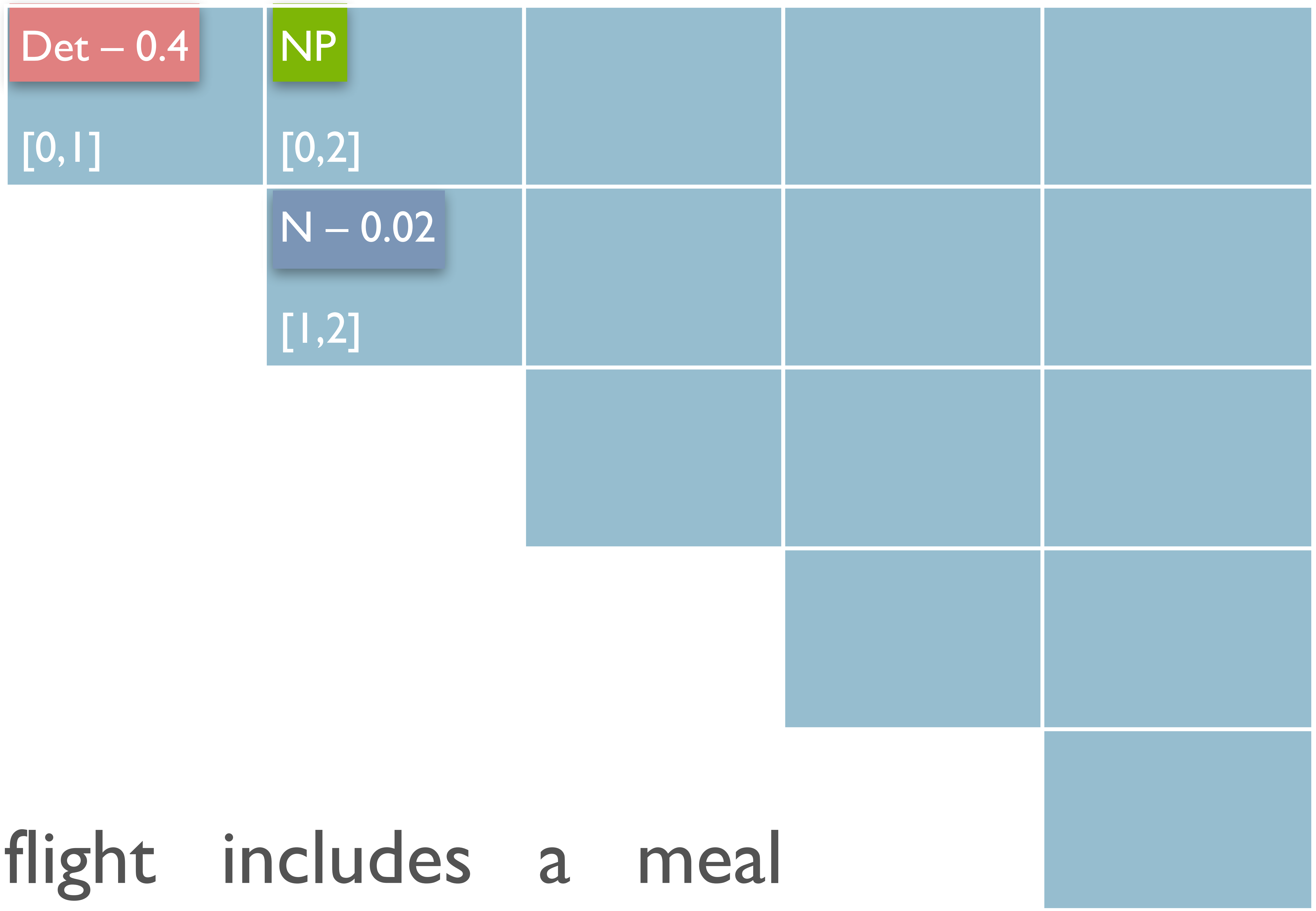

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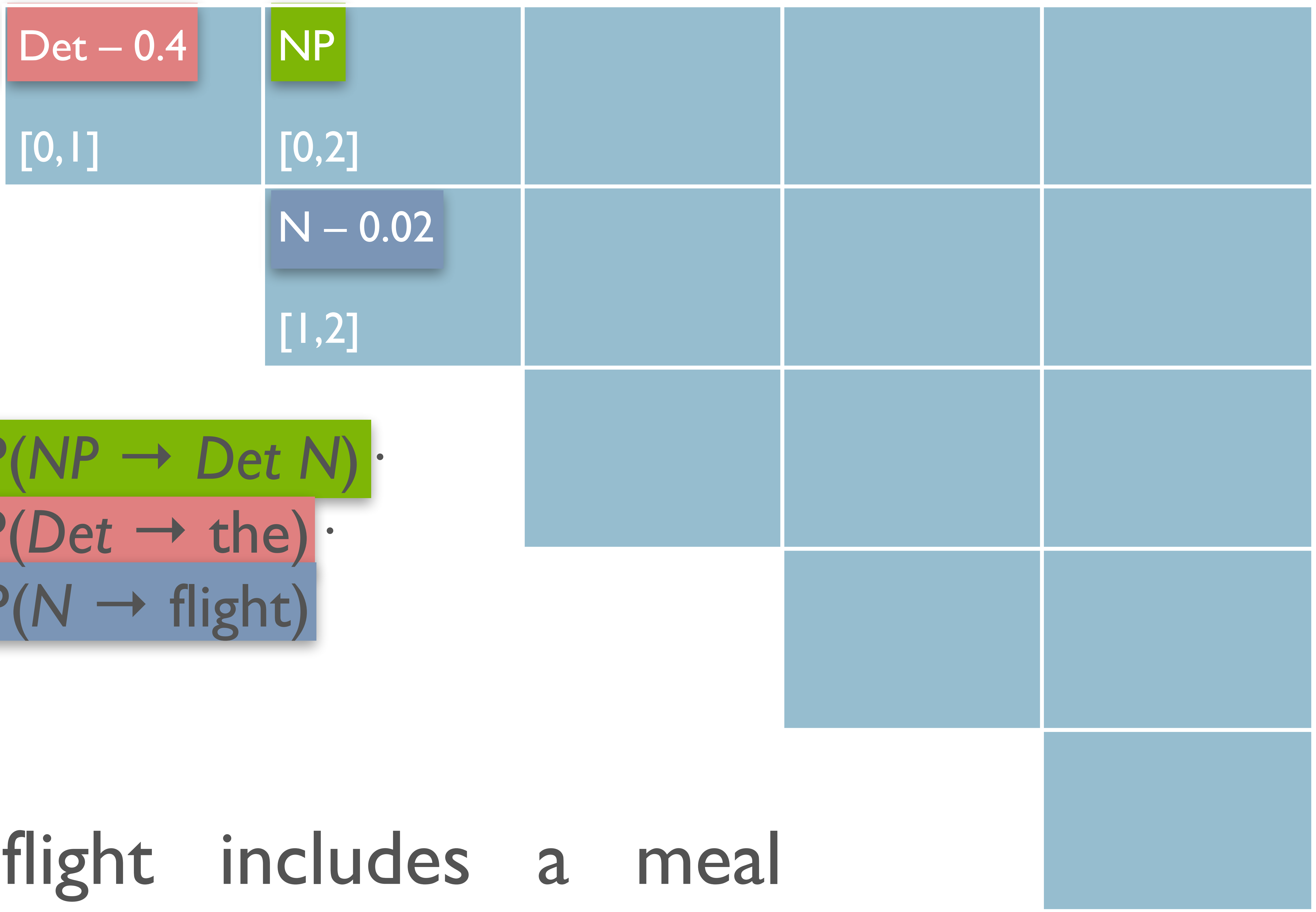

$$P = P(NP \rightarrow Det\ N) \cdot P(Det \rightarrow \text{the}) \cdot P(N \rightarrow \text{flight})$$

The flight includes a meal

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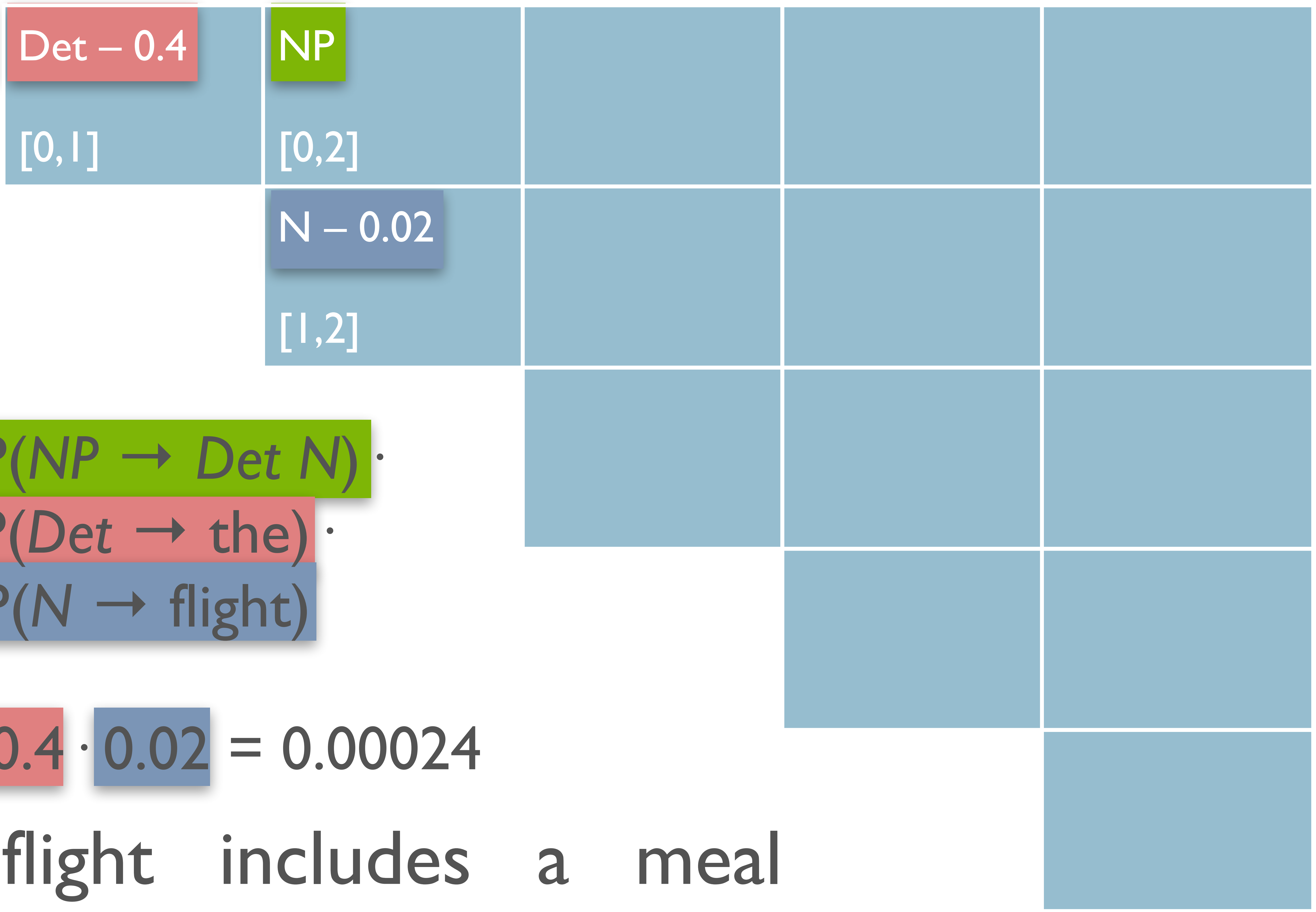

$P = P(NP \rightarrow Det\ N) \cdot P(Det \rightarrow \text{the}) \cdot P(N \rightarrow \text{flight})$

$P = 0.3 \cdot 0.4 \cdot 0.02 = 0.00024$

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Det – 0.4

[0,1]

NP – 0.0024

[0,2]

N – 0.02

[1,2]

$$P = P(NP \rightarrow Det\ N) \cdot P(Det \rightarrow a) \cdot P(N \rightarrow flight)$$

$$P = 0.3 \cdot 0.4 \cdot 0.02 = 0.00024$$

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Det – 0.4 [0,1]	NP – 0.0024 [0,2]	[0,3]	[0,4]	S – 2.304×10^{-8} [0,5]
	N – 0.02 [1,2]	[1,3]	[1,4]	[1,5]
		V – 0.05 [2,3]	[2,4]	VP – 1.2×10^{-5} [2,5]
			Det – 0.4 [3,4]	NP – 0.0012 [3,5]
				N – 0.01 [4,5]

The flight includes a meal

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Inducing a PCFG

Learning Probabilities

- Simplest way:
  - Use treebank of parsed sentences

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$$P(\alpha \rightarrow \beta \mid \alpha) = \frac{Count(\alpha \rightarrow \beta)}{\sum_\gamma Count(\alpha \rightarrow \gamma)} = \frac{Count(\alpha \rightarrow \beta)}{Count(\alpha)}$$

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$$P(\alpha \rightarrow \beta \mid \alpha) = \frac{Count(\alpha \rightarrow \beta)}{\sum_\gamma Count(\alpha \rightarrow \gamma)} = \frac{Count(\alpha \rightarrow \beta)}{Count(\alpha)}$$

- Alternative: Learn probabilities by re-estimating
  - (Later)

Probabilistic Parser Development Paradigm

	Train	Dev	Test
Size	Large (eg. WSJ 2–21, 39,830 sentences)	Small (e.g. WSJ 22)	Small/Med (e.g. WSJ, 23, 2,416 sentences)
Usage	Estimate rule probabilities	Tuning/Verification, Check for Overfit	Held Out, Final Evaluation

Parser Evaluation

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- How can we tell how good the parser is?
- How can we tell how good a parse is?
  - Maximally strict: identical to ‘gold standard’
  - Partial credit:
    - Constituents in output match those in reference
      - Same start point, end point, non-terminal symbol

Parseval

- How can we compute parse score from constituents?
- Multiple Measures:

$$\text{Labeled Recall (LR)} = \frac{\text{\# of }\textbf{correct}\text{ constituents in }\textbf{hypothetical}\text{ parse}}{\text{\# of }\textbf{total}\text{ constituents in }\textbf{reference}\text{ parse}}$$

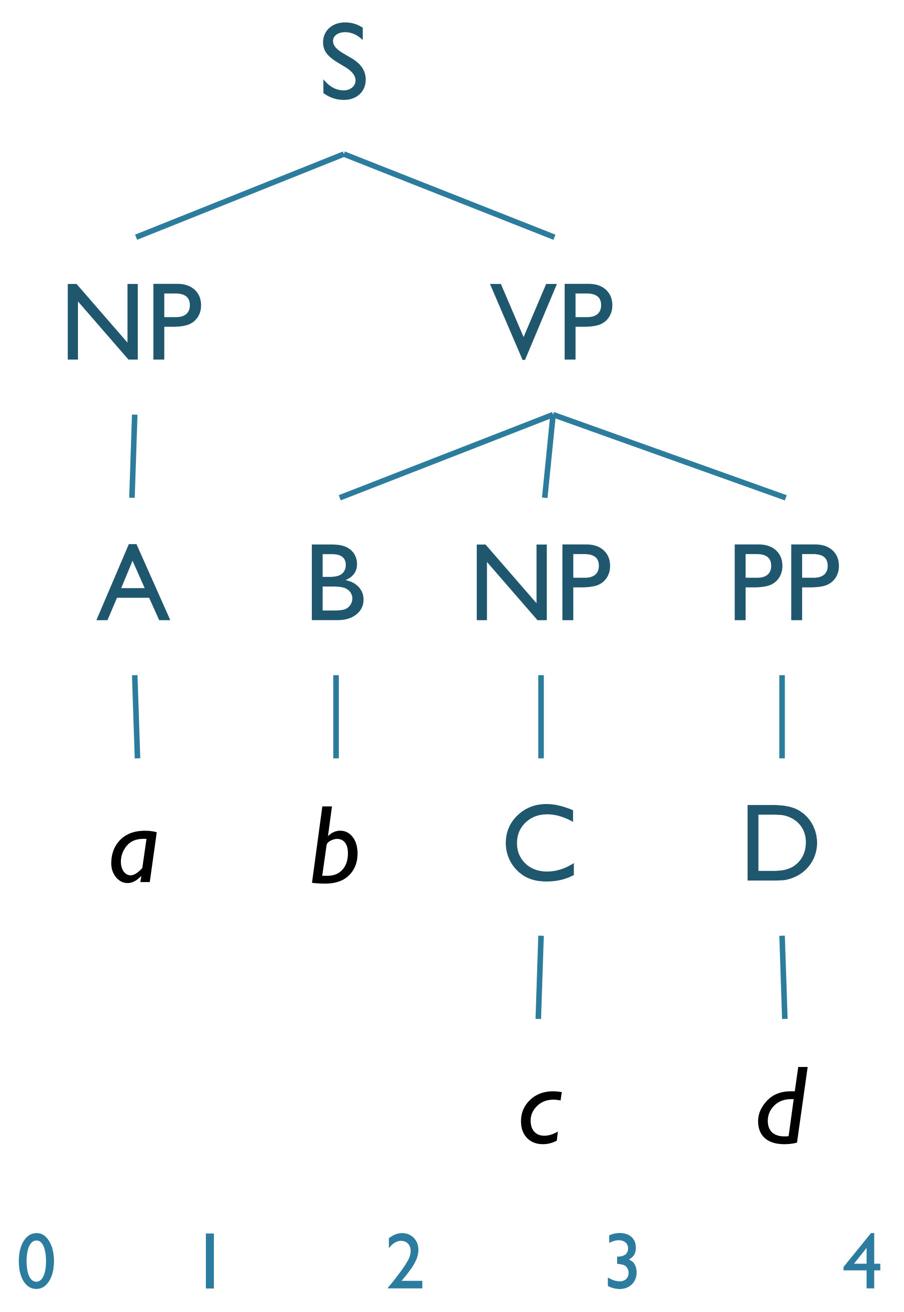
$$\text{Labeled Precision (LP)} = \frac{\text{\# of }\textbf{correct}\text{ constituents in }\textbf{hypothetical}\text{ parse}}{\text{\# of }\textbf{total}\text{ consituents in }\textbf{hypothetical}\text{ parse}}$$

Parseval

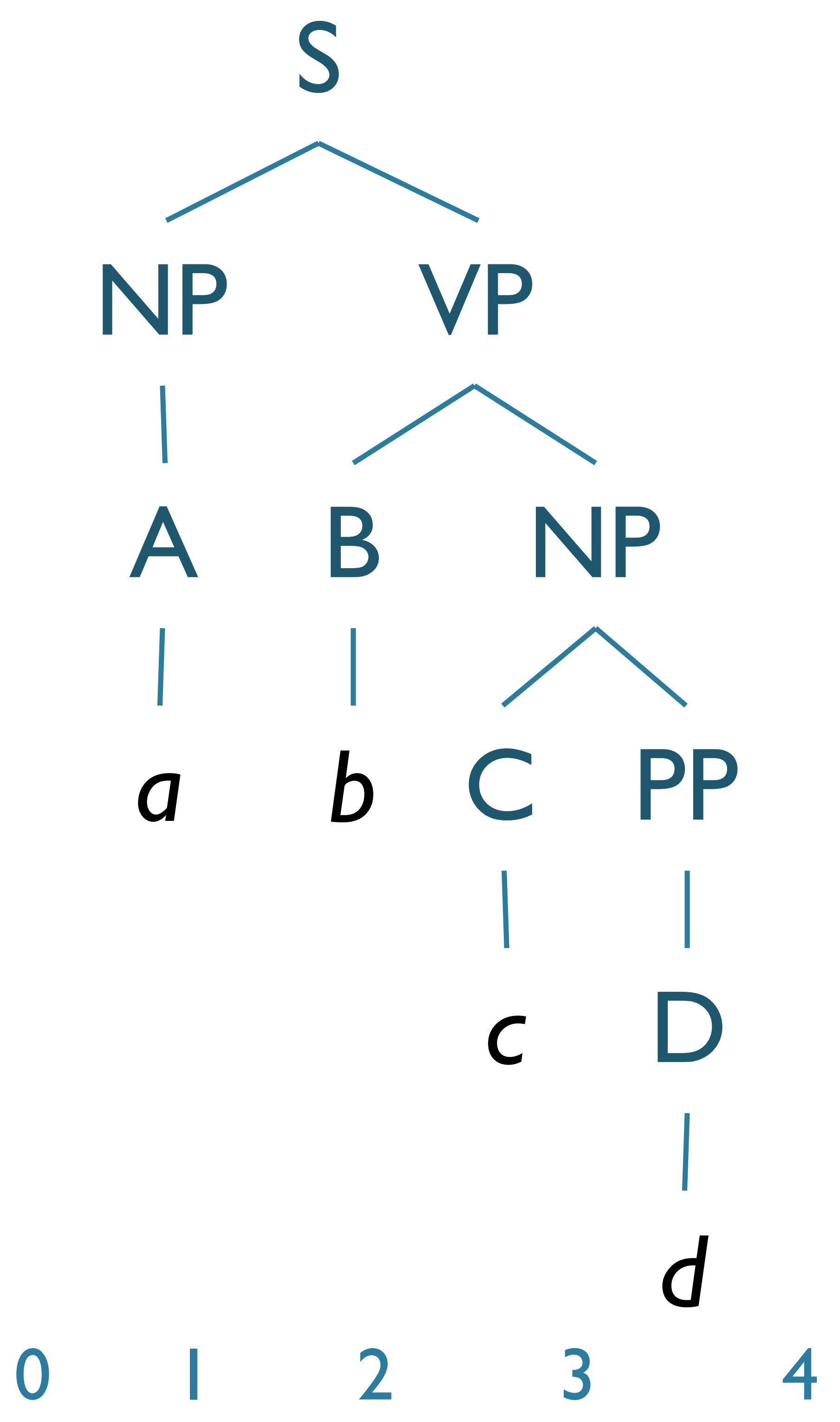
- **F-measure:**
  - Combines precision and recall
  - Let $\beta \in \mathbb{R}$, $\beta > 0$ that adjusts *P* vs. *R* s.t. $\beta \propto \frac{R}{P}$
  - F_β -measure is then: $$F_\beta = (1+\beta^2) \cdot \frac{P \cdot R}{\beta^2 \cdot P + R}$$
  - With F1-measure as $$F_1 = \frac{2PR}{P+R}$$

Evaluation: Example

Reference



Hypothesis



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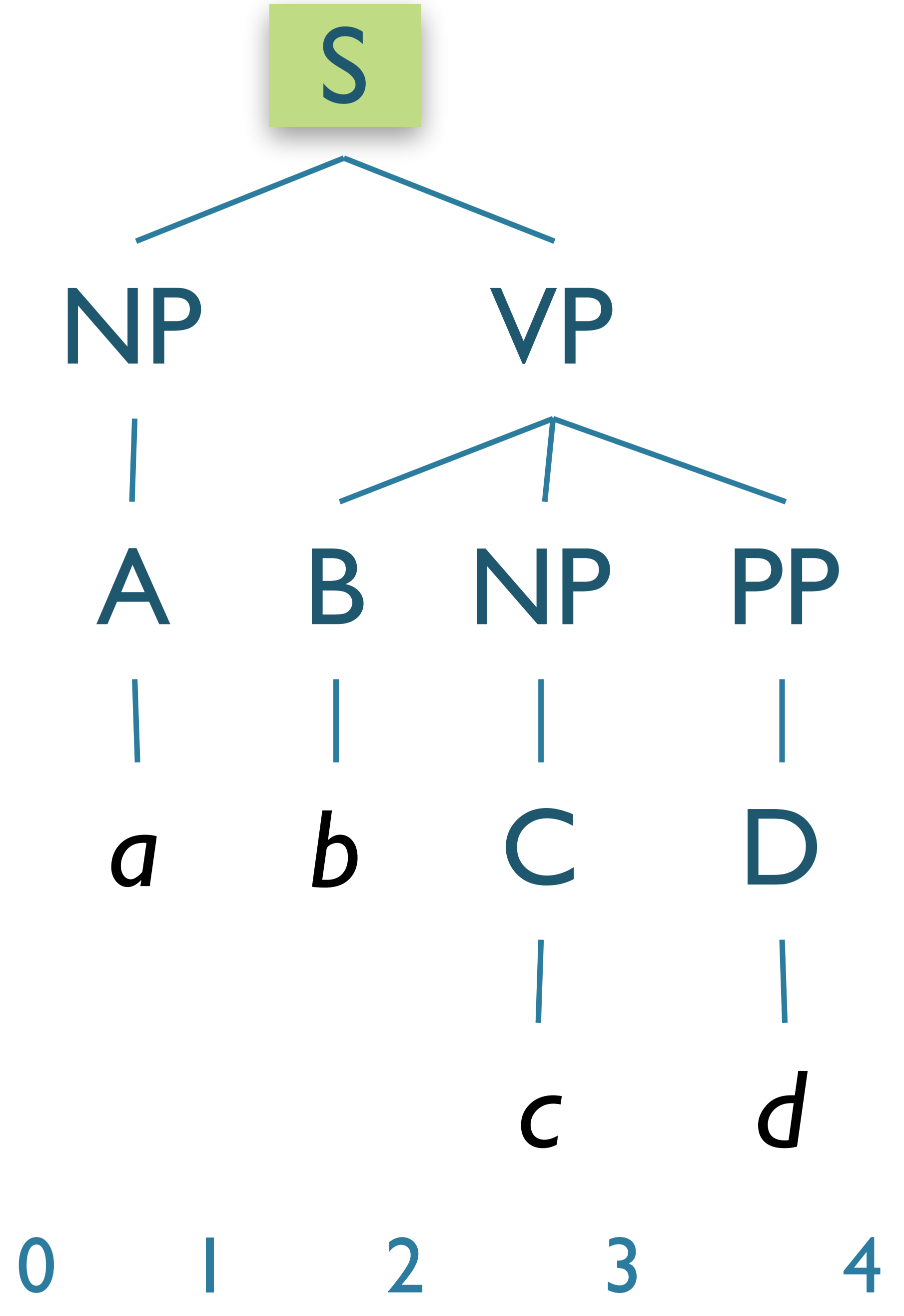
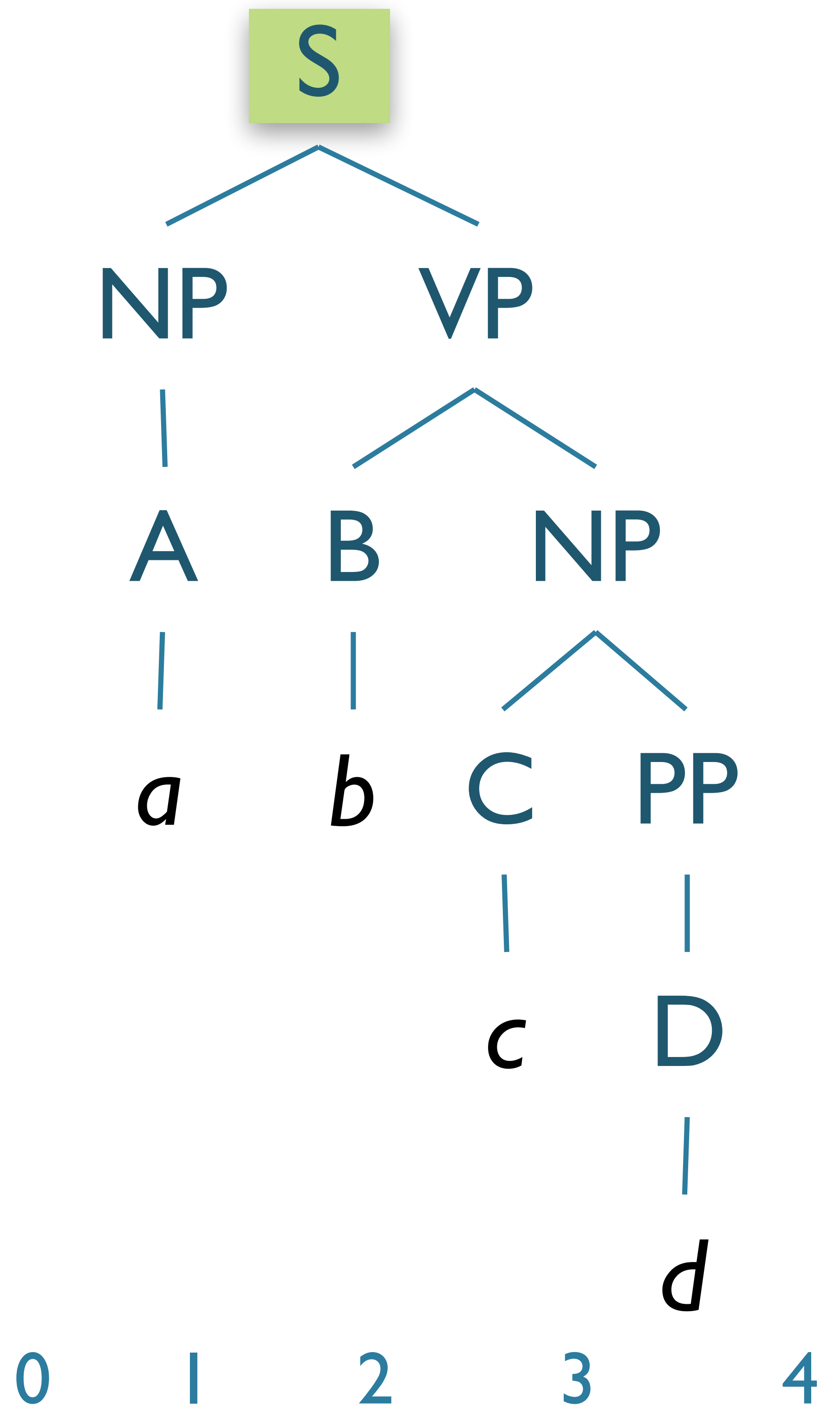


S(0,4)

Hypothesis



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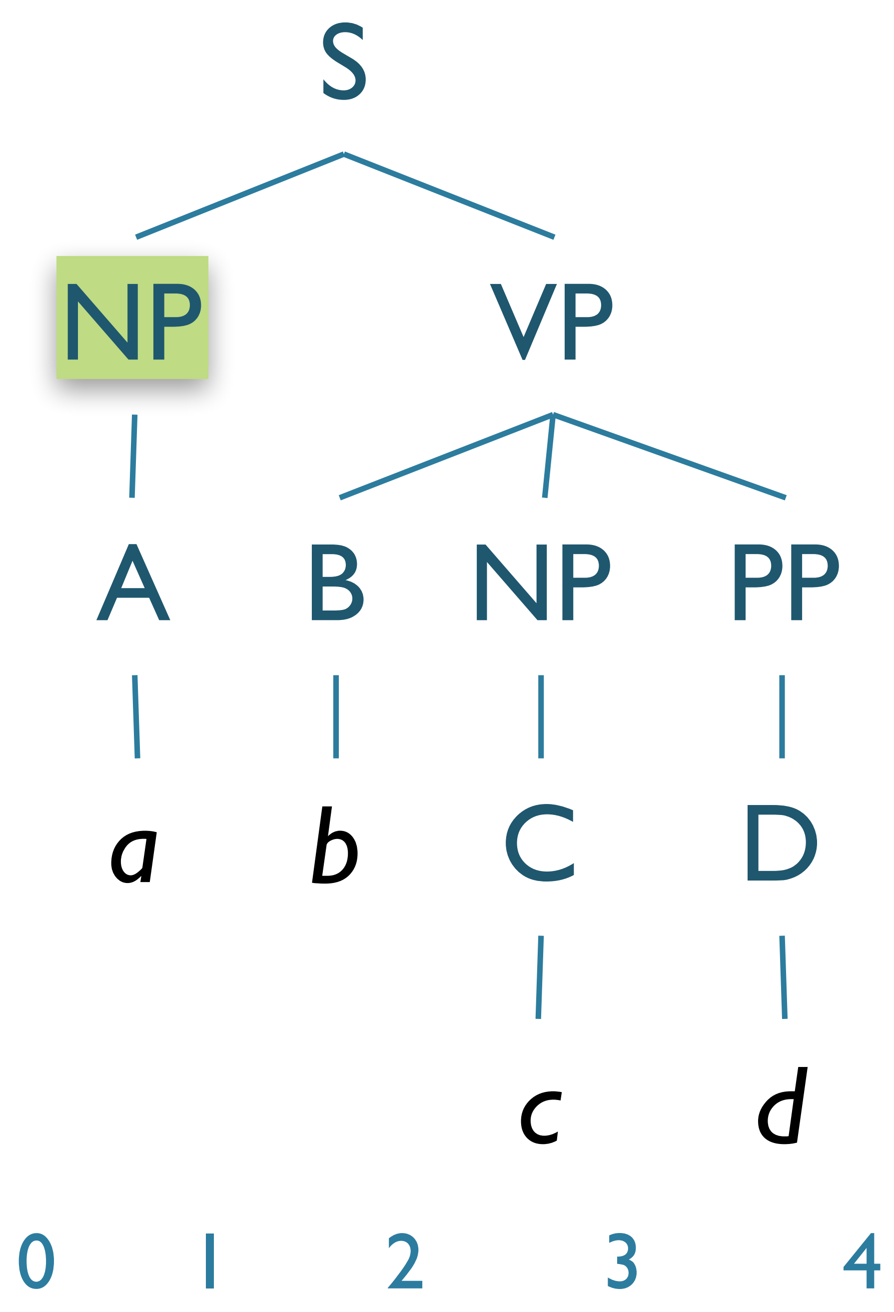
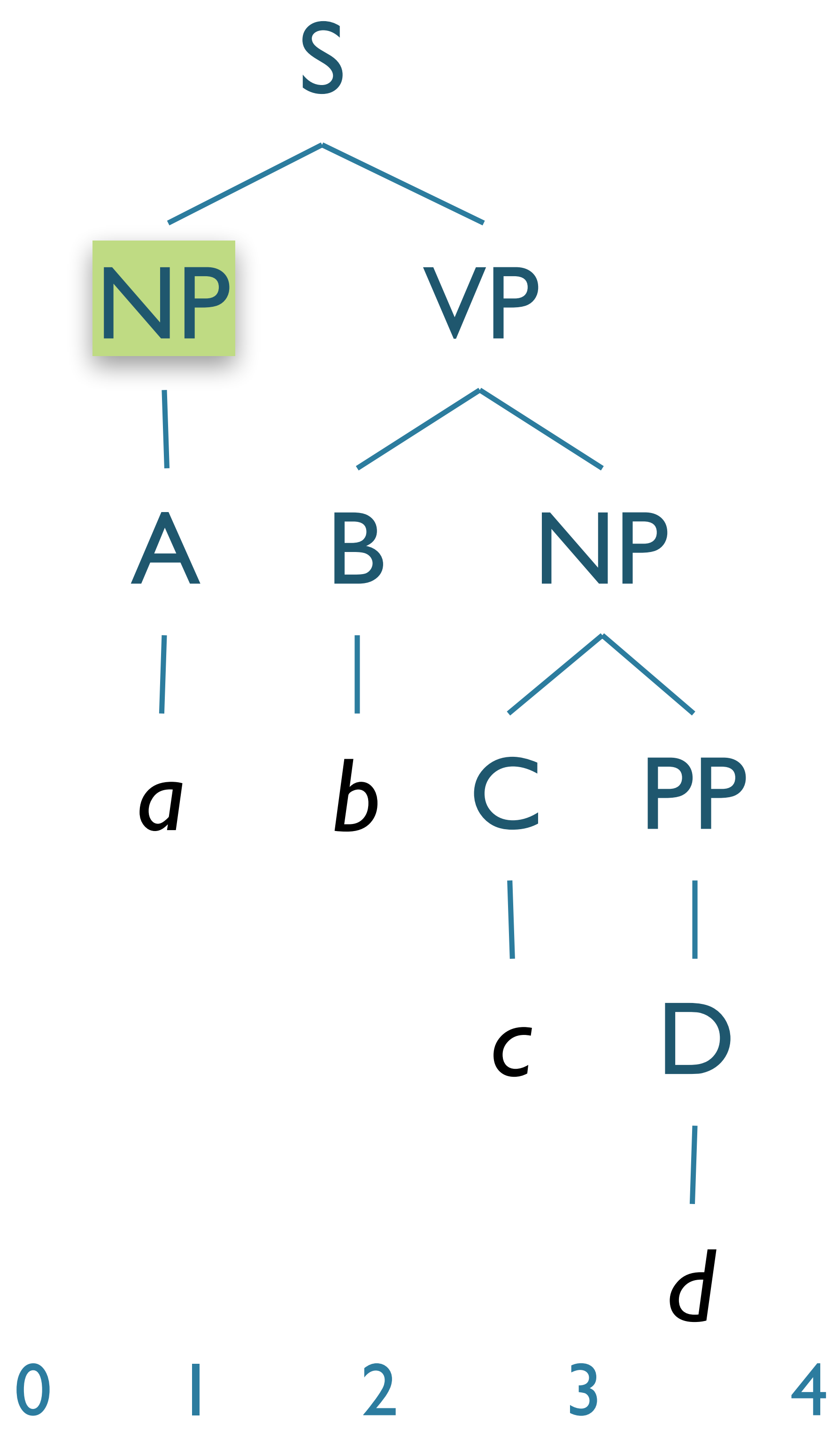


S(0,4)
NP(0,1)

Hypothesis



S(0,4)
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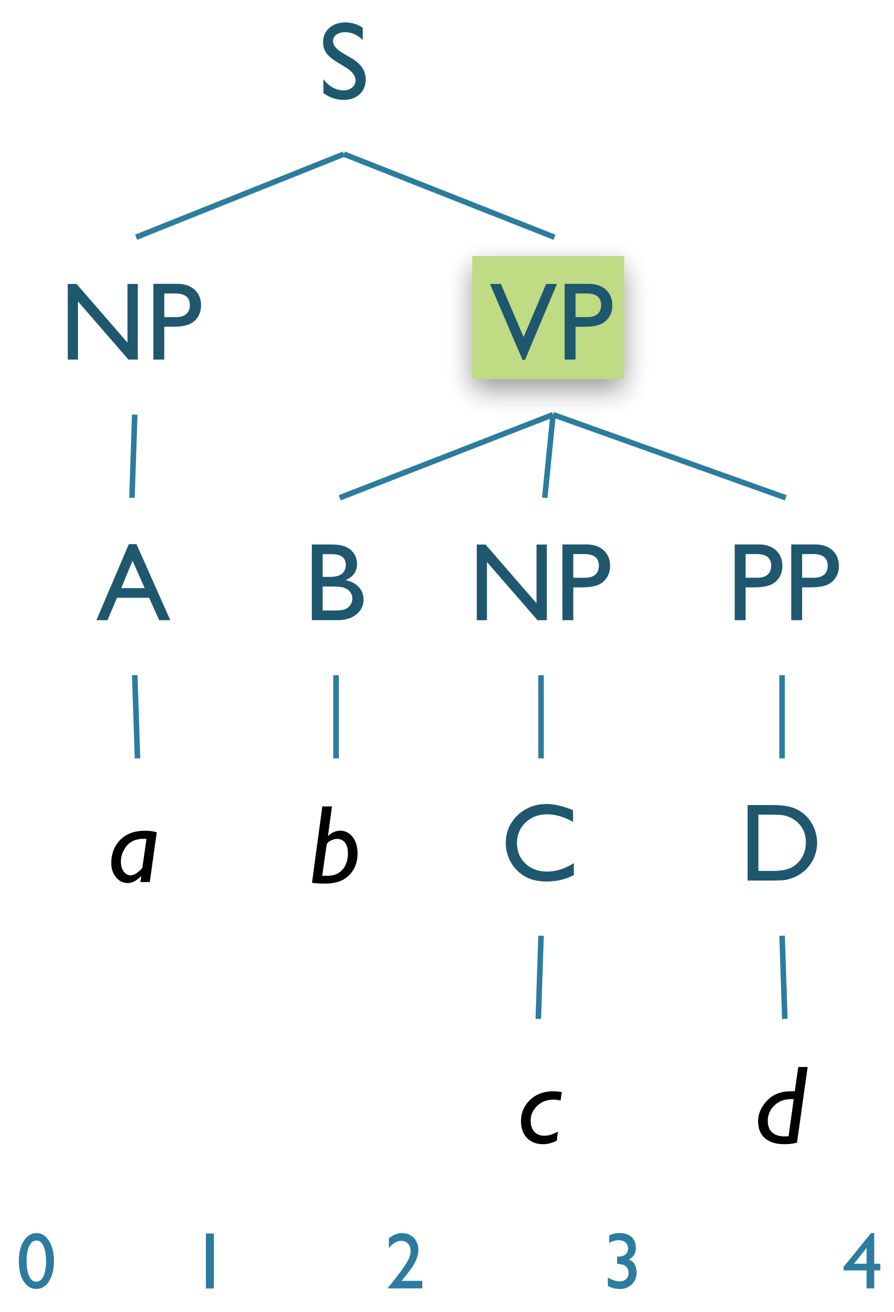
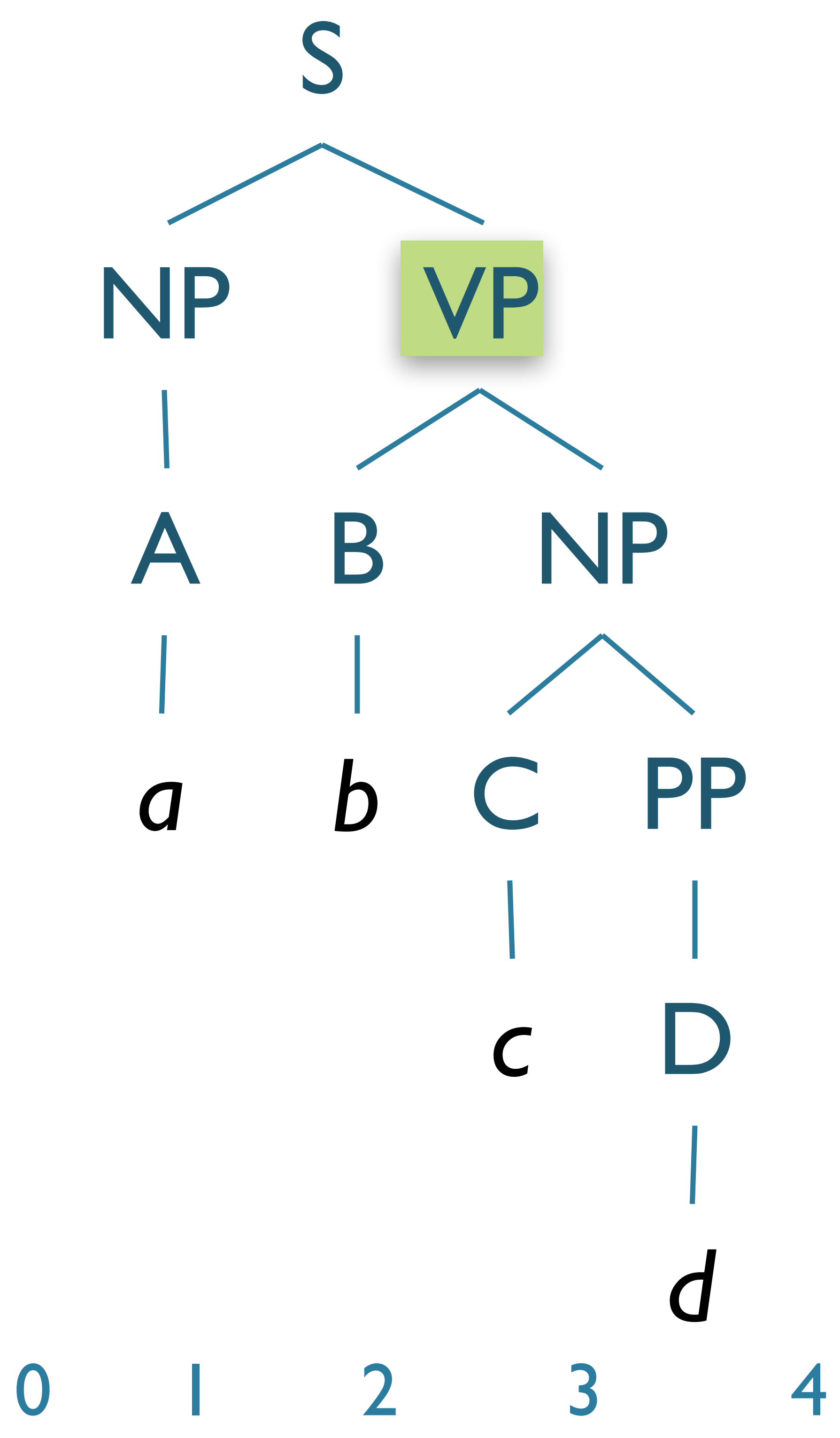


S(0,4)
NP(0,1)
VP(1,4)

Hypothesis



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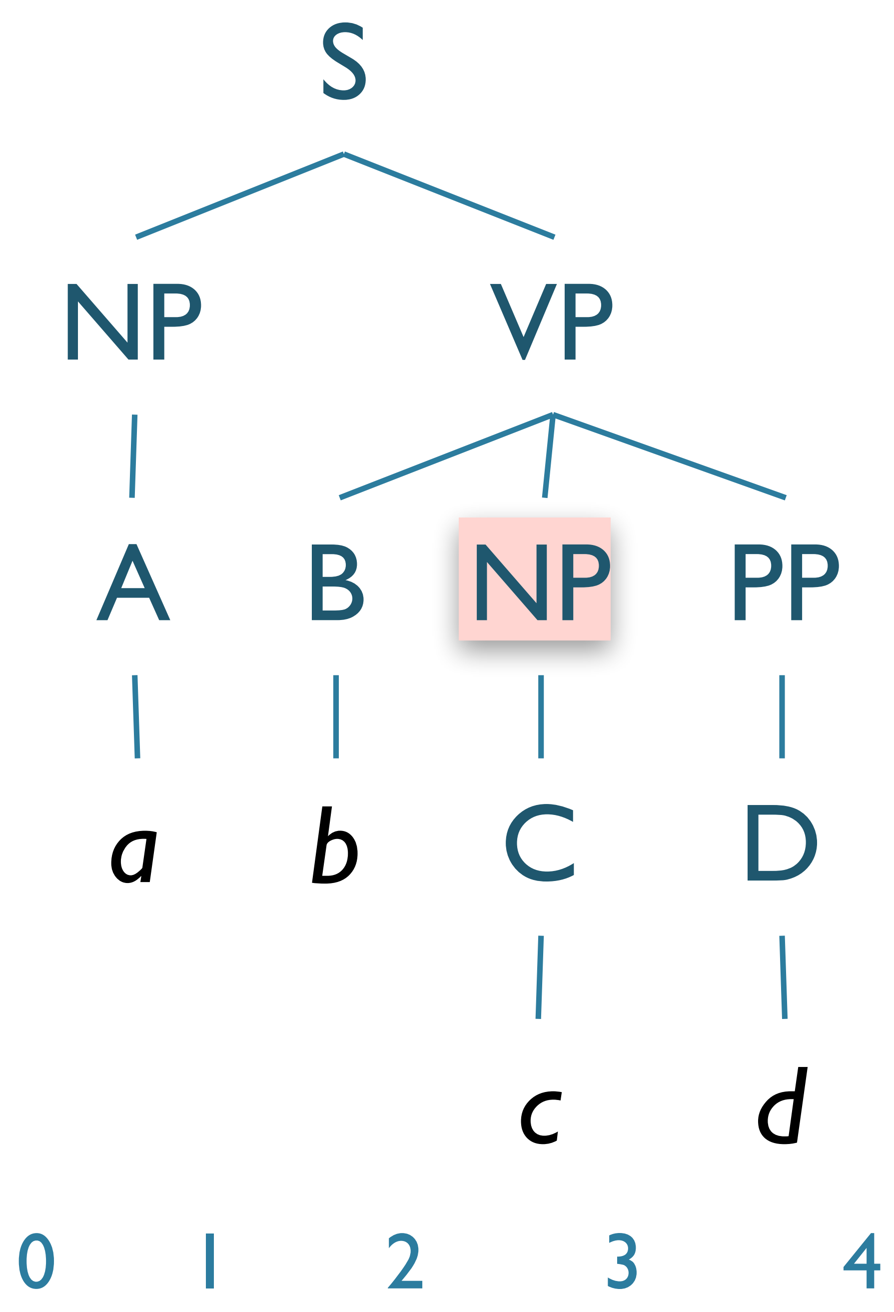
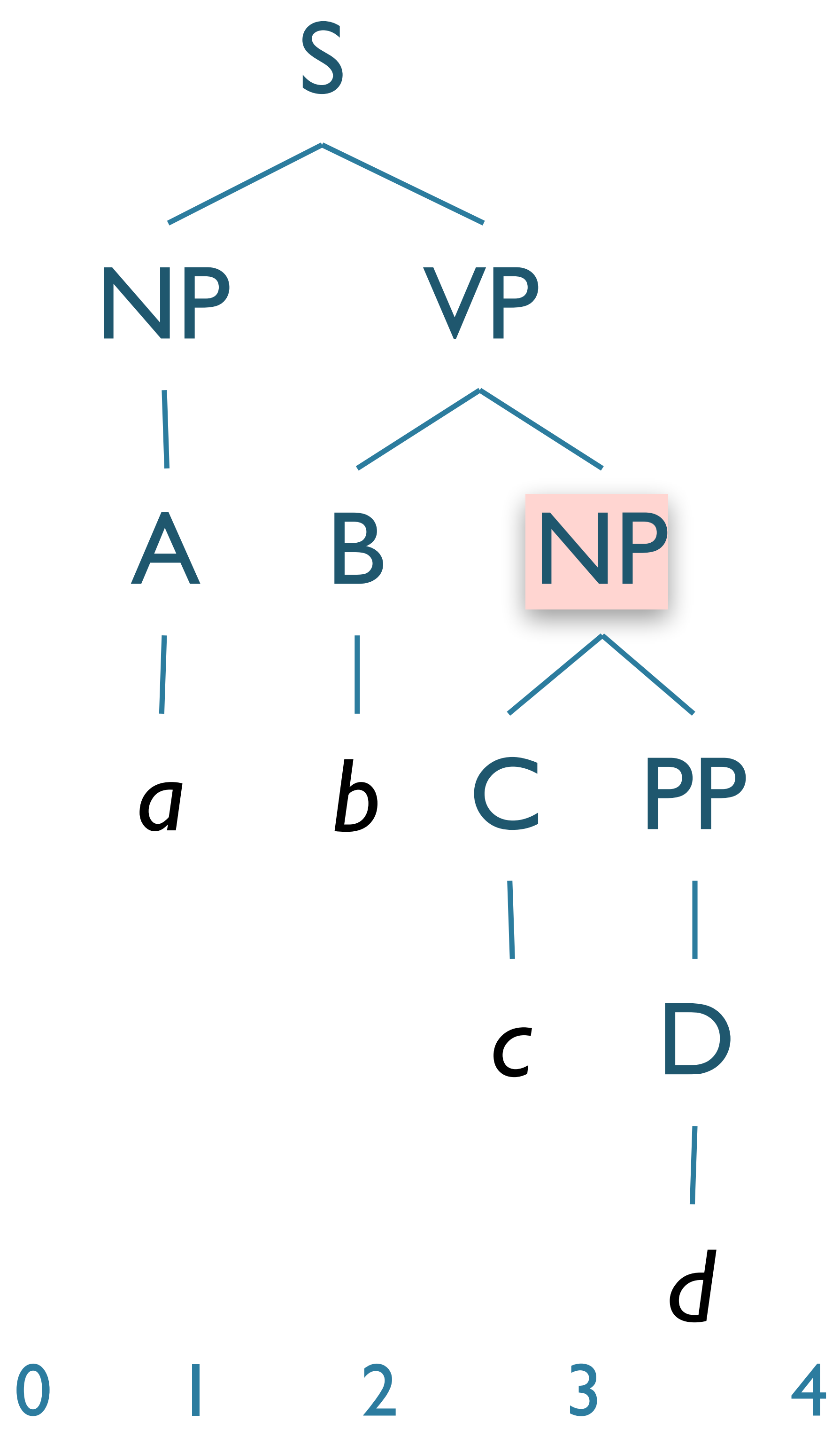


S(0,4)
NP(0,1)
VP(1,4)
NP(2,3)

Hypothesis



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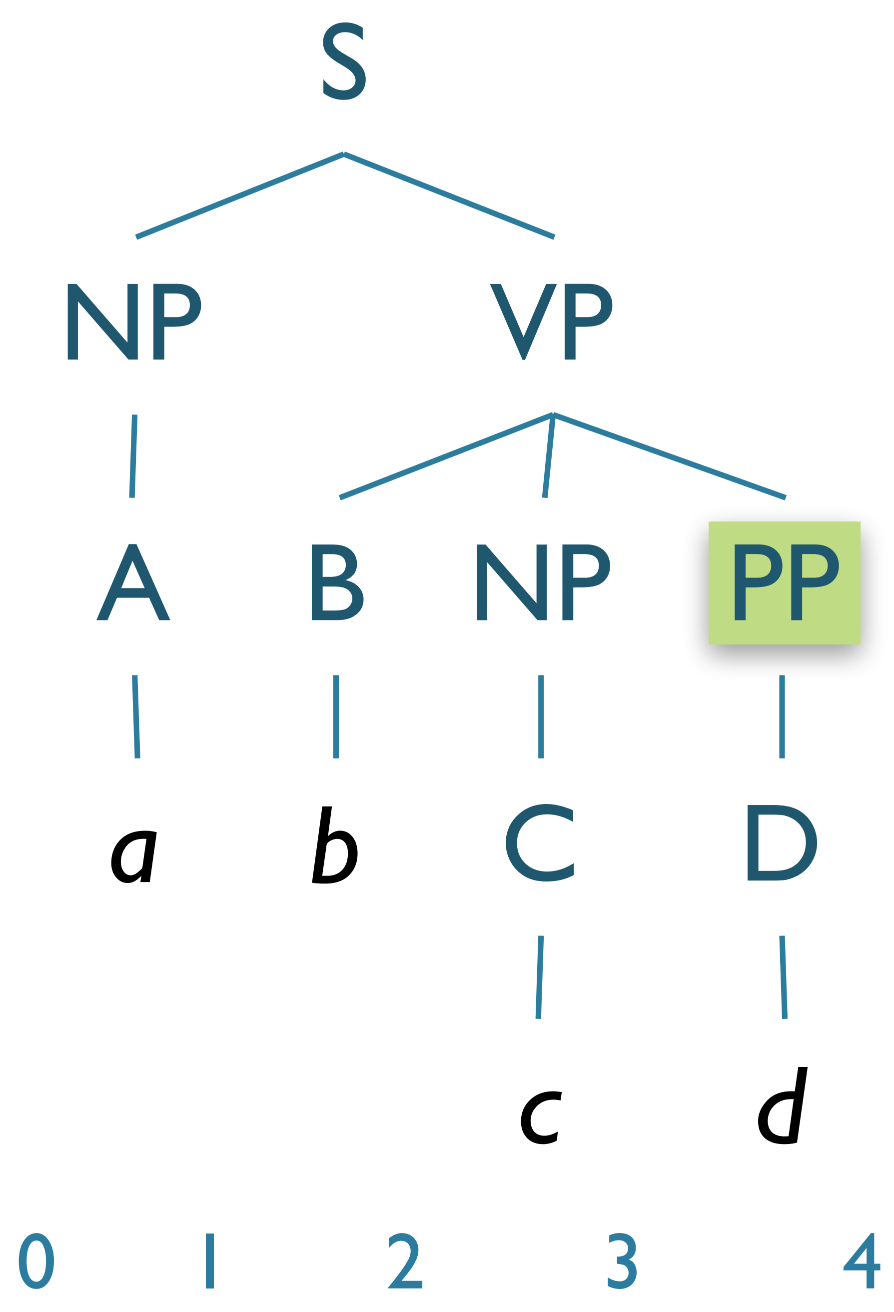

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PP(3,4)

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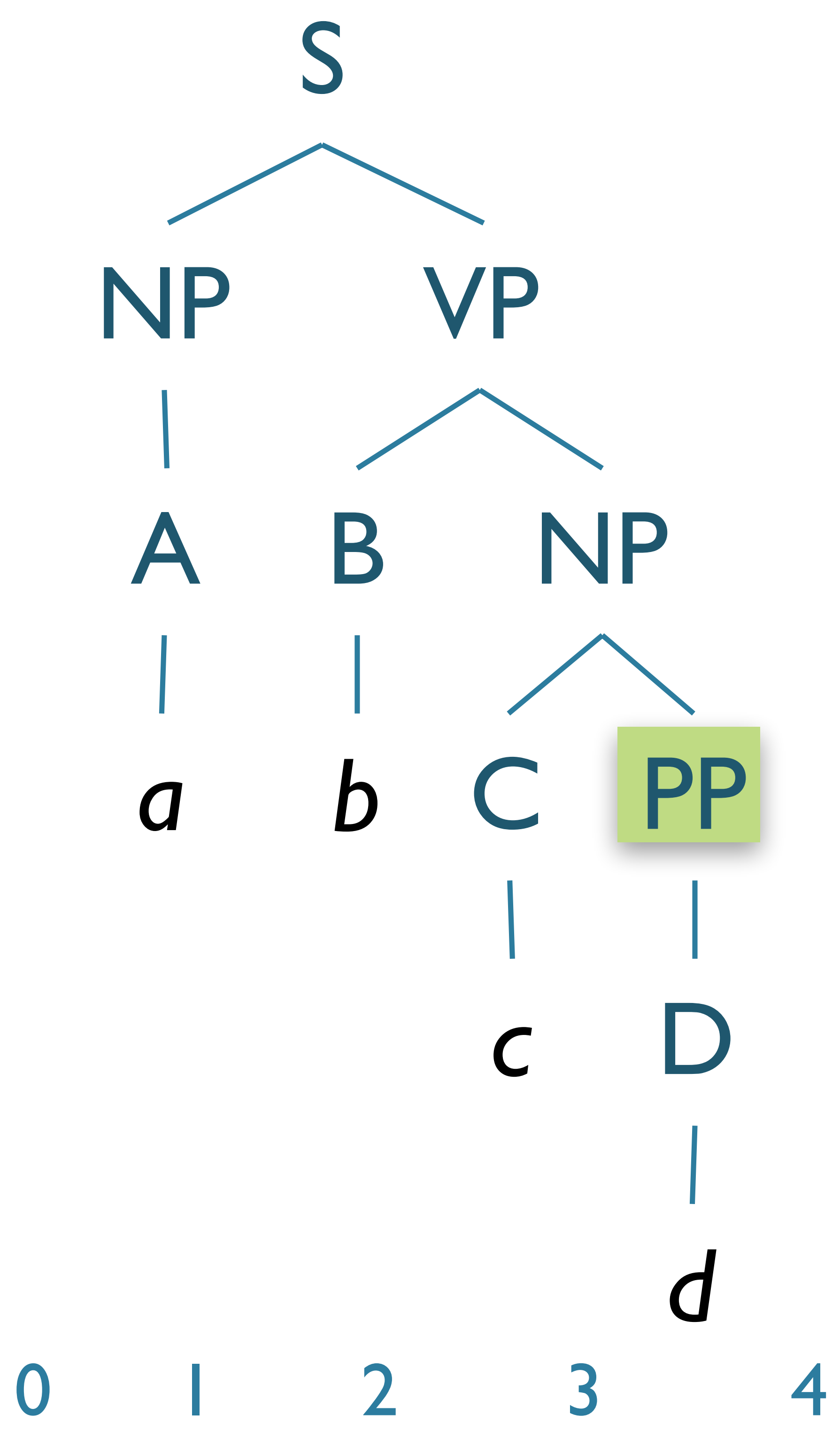

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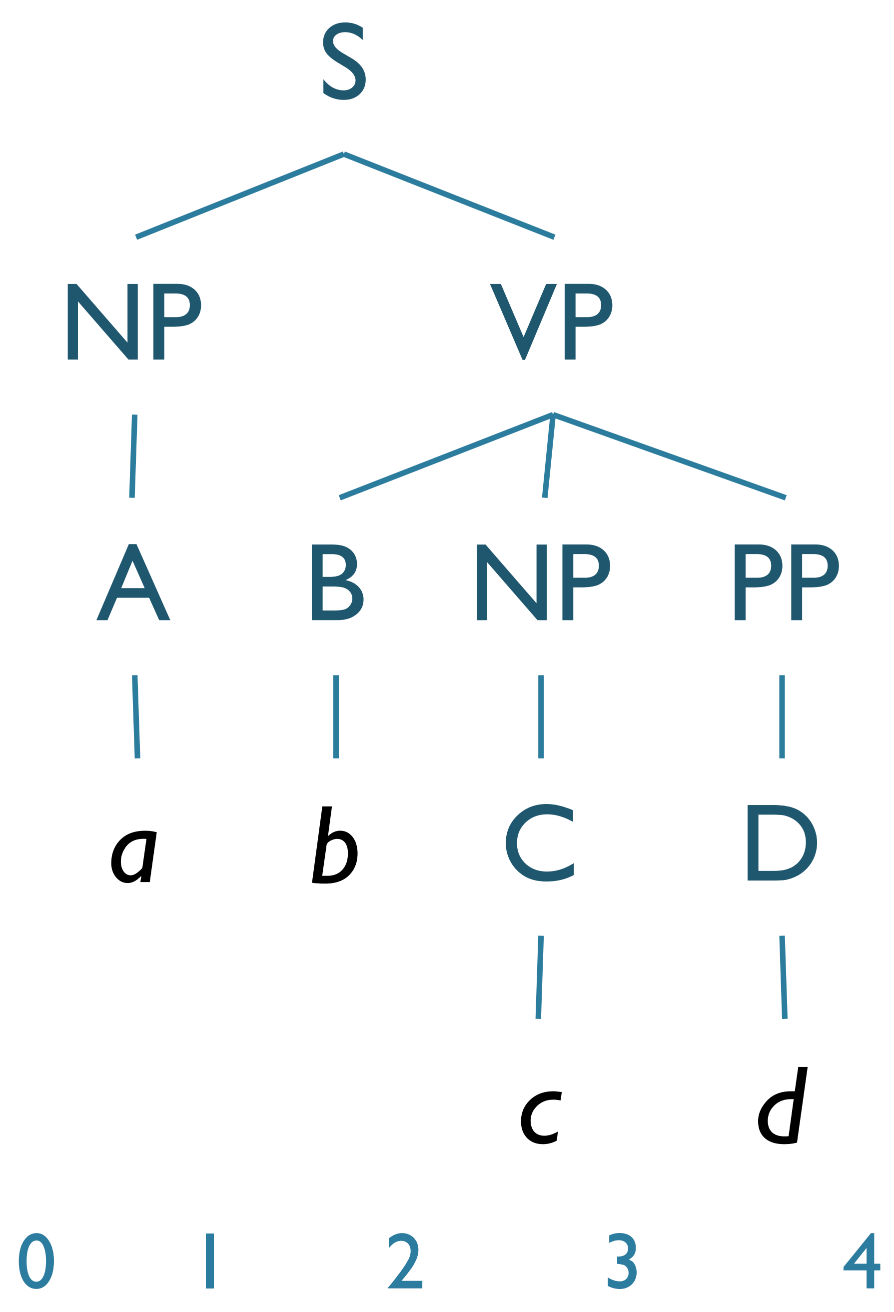

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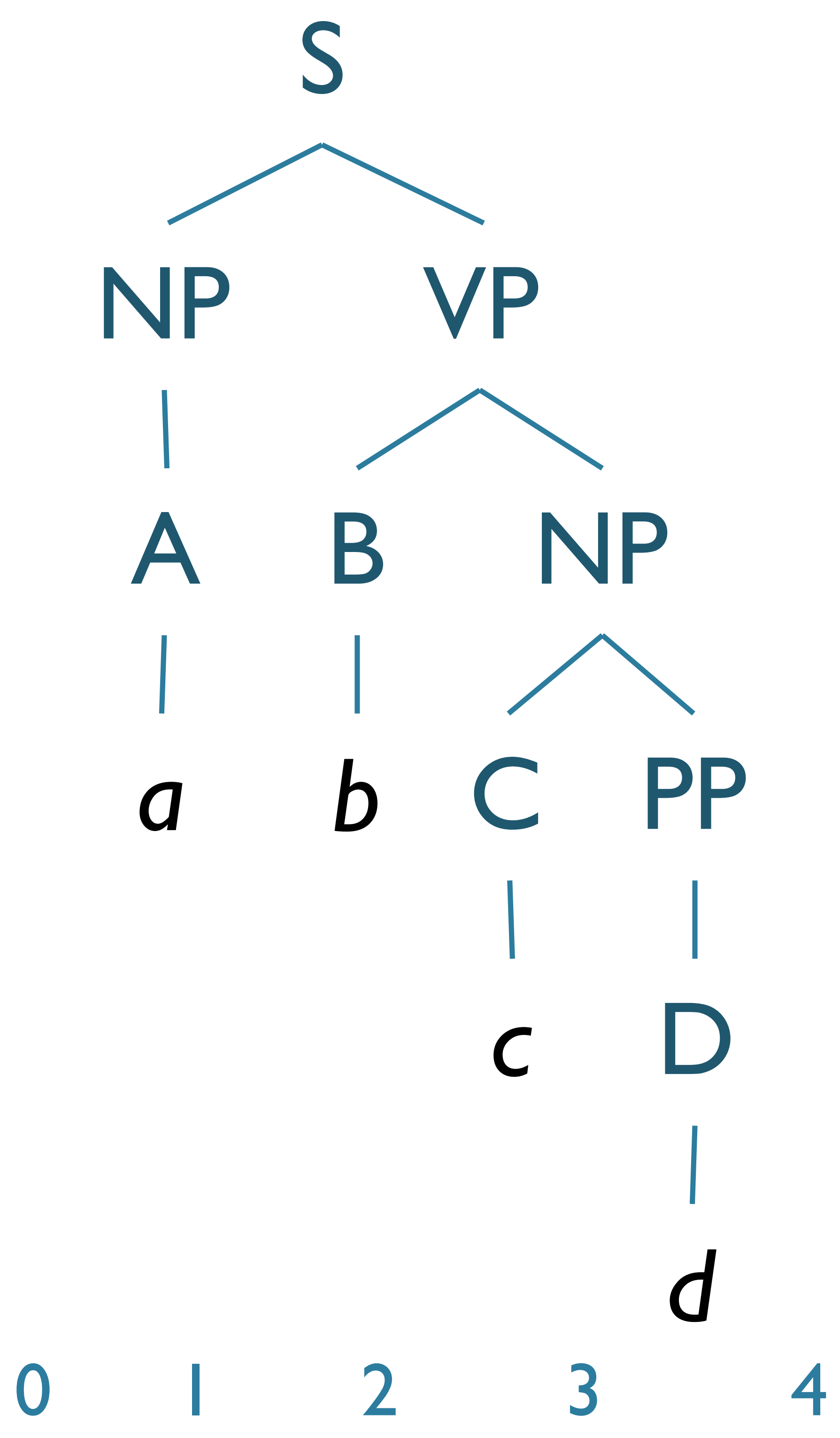

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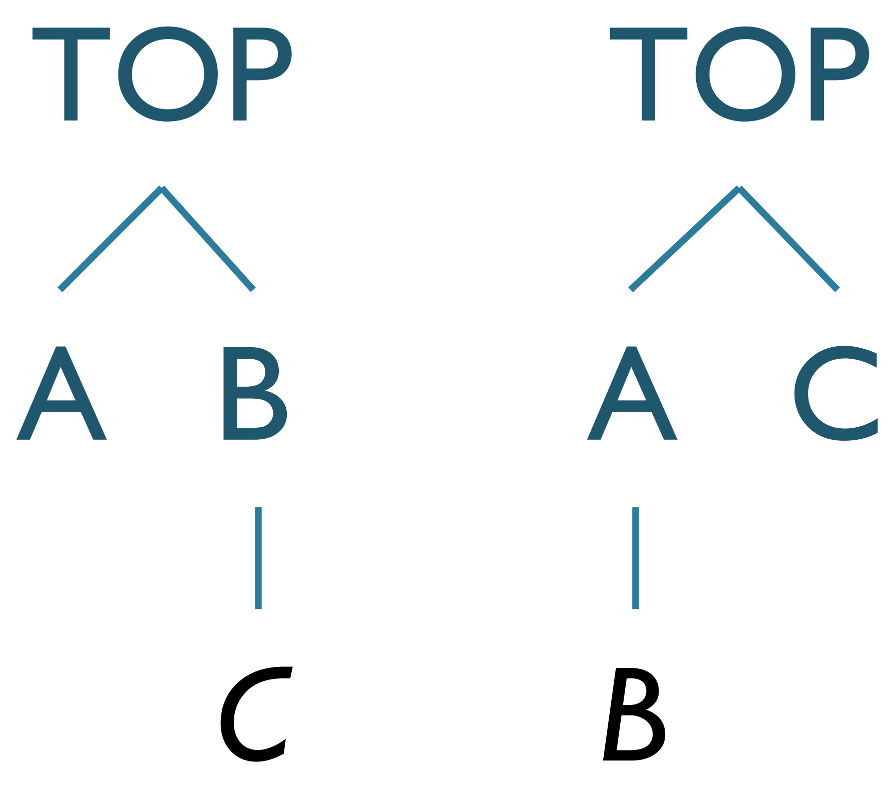
LP: 4/5
LR: 4/5
F_1: 4/5

Parser Evaluation

- Crossing Brackets:
  - # of constituents where produced parse has bracketings that overlap for the siblings:
  - ((A B) C) — { (0,2), (2,3) }
    and hyp. has
    (A (B C)) — { (0,1), (1, 3) }




```
/* crossing is counted based on the brackets */
/* in test rather than gold file (by Mike)   */
for(j=0;j<bn2;j++){
  for(i=0;i<bn1;i++){
    if(bracket1[i].result != 5 &&
       bracket2[j].result != 5 &&
       ((bracket1[i].start < bracket2[j].start &&
         bracket1[i].end   > bracket2[j].start &&
         bracket1[i].end   < bracket2[j].end) ||
        (bracket1[i].start > bracket2[j].start &&
         bracket1[i].start < bracket2[j].end &&
         bracket1[i].end   > bracket2[j].end))){
```

from evalb.c

State-of-the-Art Parsing

- Parsers trained/tested on Wall Street Journal PTB
  - LR: 90%+;
  - LP: 90%+;
  - Crossing brackets: 1%

- Standard implementation of Parseval:
  - **`evalb`**

Evaluation Issues

- Only evaluating constituency
- There are other grammar formalisms:
  - LFG (Constraint-based)
  - Dependency Structure
- **Extrinsic** evaluation
  - How well does getting the correct parse match the semantics, etc?

Earley Parsing

Earley vs. CKY

- CKY doesn't capture full original structure
  - Can back-convert binarization, terminal conversion
  - Unit non-terminals require change in CKY

Earley vs. CKY

- CKY doesn't capture full original structure
  - Can back-convert binarization, terminal conversion
  - Unit non-terminals require change in CKY
- Earley algorithm
  - Supports parsing efficiently with arbitrary grammars
  - Top-down search
  - Dynamic programming
    - Tabulated partial solutions
  - Some bottom-up constraints

Earley Algorithm

- Another dynamic programming solution
  - Partial parses stored in “chart”
  - Compactly encodes ambiguity
  - $O(N^3)$
- Chart entries contain:
  - Subtree for a single grammar rule
  - Progress in completing subtree
  - Position of subtree w.r.t. input

Earley Algorithm

- First, left-to-right pass fills out a chart with *N+1* states
  - Chart entries — sit between words in the input string
  - Keep track of states of the parse at those positions
  - For each word position, chart contains set of states representing all partial parse trees generate so far
    - e.g. `chart[0]` contains all partial parse trees generated at the beginning of sentence

Chart Entries

- Three types of constituents:
  - Predicted constituents
  - In-progress constituents
  - Completed constituents

Parse Progress

- Represented by Dotted Rules
  - Position of • indicates type of constituent
- $_0$ Book $_1$ that $_2$ flight $_3$
  - $S \rightarrow \bullet\ VP$ [0,0] (predicted)
  - $NP \rightarrow Det \bullet Nom$ [1,2] (in progress)
  - $VP \rightarrow V\ NP \bullet$ [0,3] (completed)
- [x,y] tells us what portion of the input is spanned so far by rule
- Each state s_i: <*dotted rule*>, [<*back pointer*>, <*current position*>]

$_0$ Book $_1$ that $_2$ flight $_3$

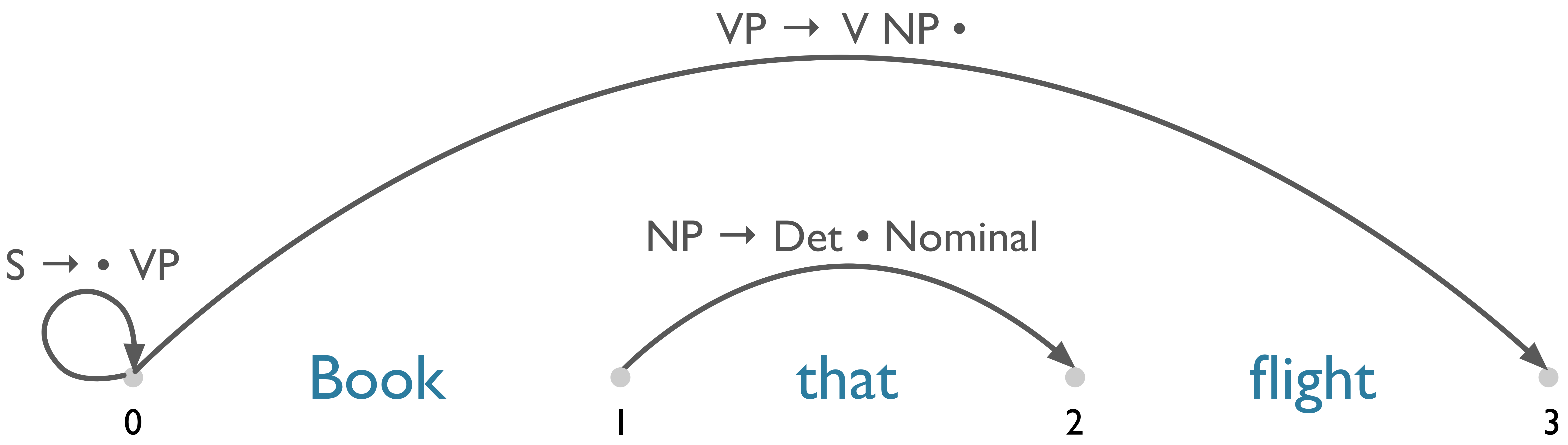
- $S \rightarrow VP$, [0,0]
  - First 0 means S constituent begins at the start of input
  - Second 0 means the dot is here too
  - So, this is a top-down prediction

$_0$ Book $_1$ that $_2$ flight $_3$

- *S* → *VP*, [0,0]
  - First 0 means S constituent begins at the start of input
  - Second 0 means the dot is here too
  - So, this is a top-down prediction
- *NP* → *Det* • *Nom*, [1,2]
  - the NP begins at position 1
  - the dot is at position 2
  - so, Det has been successfully parsed
  - Nom predicted next

$_0$ Book $_1$ that $_2$ flight $_3$ (continued)

- *V* → *V NP* • [0,3]
  - Successful VP parse of entire input



Successful Parse

- Final answer found by looking at last entry in chart
- If entry resembles $S \rightarrow \alpha \bullet [0,N]$ then input parsed successfully
- Chart will also contain record of all possible parses of input string, given the grammar

Parsing Procedure for the Earley Algorithm

- Move through each set of states in order, applying one of three operations:
  - **predictor**: add predictions to the chart
  - **scanner**: read input and add corresponding state to chart
  - **completer**: move dot to right when new constituent found
- Results (new states) added to current or next set of states in chart
- No backtracking and no states removed: keep complete history of parse

Earley Algorithm

function EARLEY-PARSE(*words*, *grammar*) **returns** *chart*
  ENQUEUE(($\gamma \longrightarrow \bullet$ S, [0,0]), *chart*[*0*])
  for $i \longleftarrow$ from 0 to LENGTH(*words*) **do**
    for each *state* **in** *chart*[*i*] **do**
      if INCOMPLETE?(*state*) **and**
          NEXT-CAT(*state*) is **not** a part of speech **then**
        PREDICTOR(*state*)
      elseif INCOMPLETE?(*state*) **and**
          NEXT-CAT(*state*) is a part of speech **then**
        SCANNER(*state*)
      else
        COMPLETER(*state*)
      end
    end
  return(*chart*)

Earley Algorithm

procedure PREDICTOR($(A \rightarrow \alpha \bullet B\ \beta\ ,\ [i,j])$)
  for each (B → γ) **in** GRAMMAR-RULES-FOR($B, grammar$) **do**
    ENQUEUE($(B \rightarrow \bullet\ \gamma,\ [j,j]),\ chart[j]$)
  end

procedure SCANNER($(A \rightarrow \alpha \bullet B\ \beta, [i,j])$)
  if B ⊂ PARTS-OF-SPEECH($word[j]$) **then**
    ENQUEUE((B → $word[j] \bullet,\ [j,j+1]),\ chart[j+1]$)

procedure COMPLETER($(B \rightarrow \gamma \bullet,\ [j,k])$)
  for each $(\boldsymbol{A \rightarrow \alpha \bullet B\ \beta,\ [i,j]})$ **in** $\boldsymbol{chart[j]}$ **do**
    ENQUEUE($(A \rightarrow \alpha\ B \bullet\ \beta,\ [i,k]),\ chart[k]$)
  end

3 Main Subroutines of Earley

- Predictor
  - Adds predictions into the chart
- Scanner
  - Reads the input words and enters states representing those words into the chart
- Completer
  - Moves the dot to the right when new constituents are found

Predictor

- Intuition:
  - Create new state for top-down prediction of new phrase
- Applied when non part-of-speech non-terminals are to the right of a dot:
  - *S* → • *VP* [0,0]
- Adds new states to *current* chart
  - One new state for each expansion of the non-terminal in the grammar
    VP → • V [0,0]
    VP → • *V NP* [0,0]

Chart[0]

S0	$\gamma \rightarrow \cdot S$	[0,0]	Dummy start state
S1	$S \rightarrow \cdot NP\ VP$	[0.0]	Predictor
S2	$S \rightarrow \cdot Aux\ NP\ VP$	[0,0]	Predictor
S3	$S \rightarrow \cdot VP$	[0,0]	Predictor
S4	$NP \rightarrow \cdot Pronoun$	[0,0]	Predictor
S5	$NP \rightarrow \cdot Proper\text{-}Noun$	[0,0]	Predictor
S6	$NP \rightarrow \cdot Det\ Nominal$	[0,0]	Predictor
S7	$VP \rightarrow \cdot Verb$	[0,0]	Predictor
S8	$VP \rightarrow \cdot Verb\ NP$	[0,0]	Predictor
S9	$VP \rightarrow \cdot Verb\ NP\ PP$	[0,0]	Predictor
S10	$VP \rightarrow \cdot Verb\ PP$	[0,0]	Predictor
S11	$VP \rightarrow \cdot VP\ PP$	[0,0]	Predictor

Chart[1]

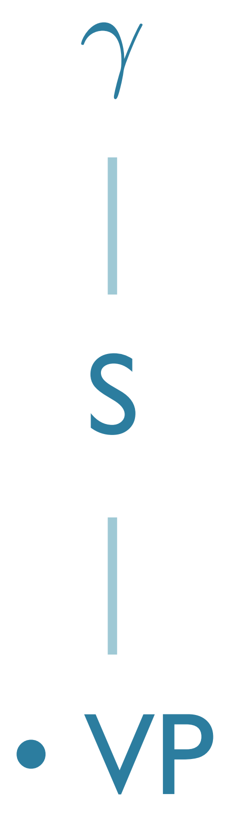
S12	*Verb → book •*	[0,1]	Scanner
S13	*VP → Verb •*	[0,1]	Completer
S14	*VP → Verb • NP*	[0,1]	Completer
S15	*VP → Verb • NP PP*	[0,1]	Completer
S16	*VP → Verb • PP*	[0,1]	Completer
S17	*S → VP •*	[0,1]	Completer
S18	*VP → VP • PP*	[0,1]	Completer
S19	*NP → • Pronoun*	[1,1]	Predictor
S20	*NP → • Proper-Noun*	[1,1]	Predictor
S21	*NP → • Det Nominal*	[1,1]	Predictor
S22	*PP → • Prep NP*	[1,1]	Predictor

Book that flight

S0: $\gamma \rightarrow \bullet\, S$ [0,0]

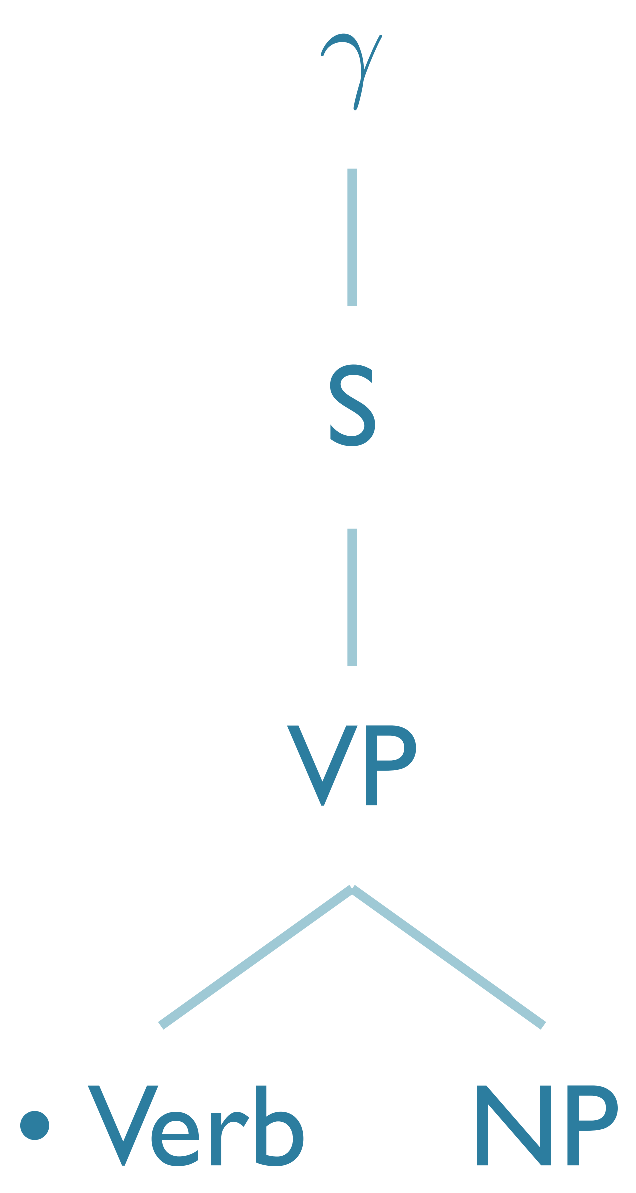
Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow \bullet\ VP$ [0,0]



Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow \bullet\ VP$ [0,0]
S8: $VP \rightarrow \bullet\ Verb\ NP$ [0,0]



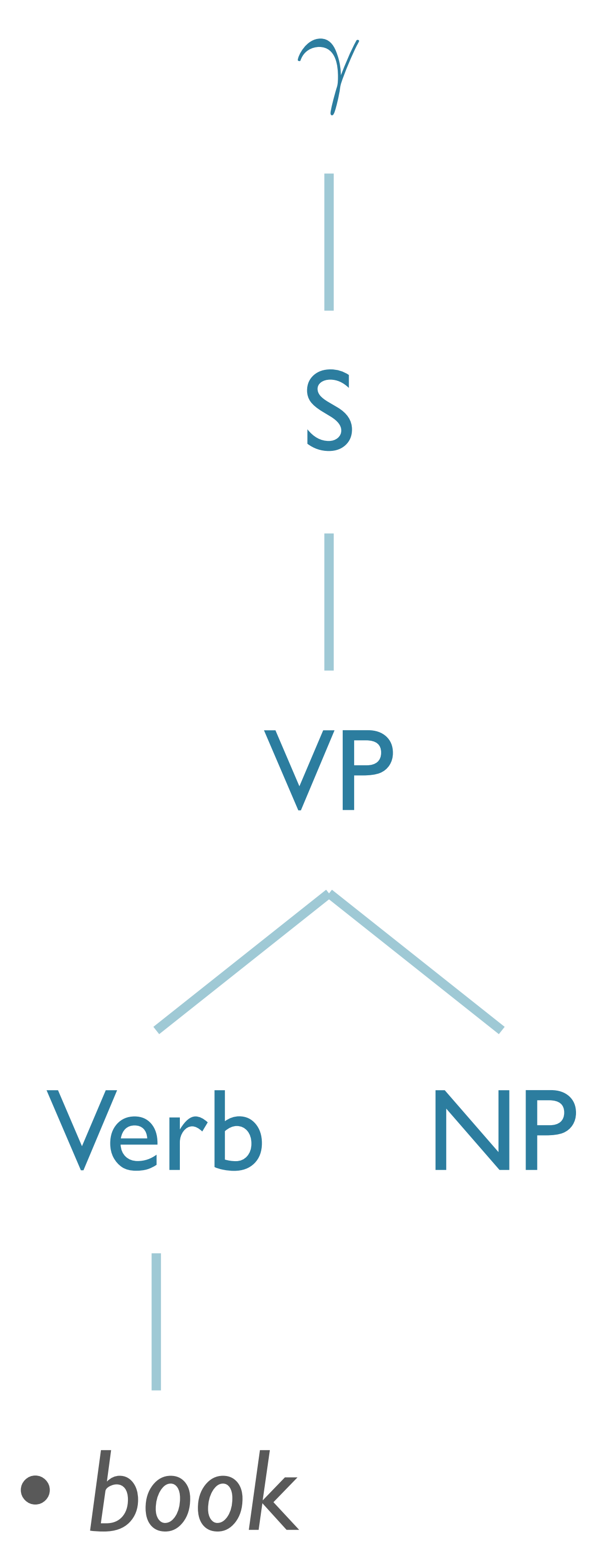
Book that flight

S0: $\gamma \rightarrow \bullet\ S\ [0,0]$

S3: $S \rightarrow \bullet\ VP\ [0,0]$

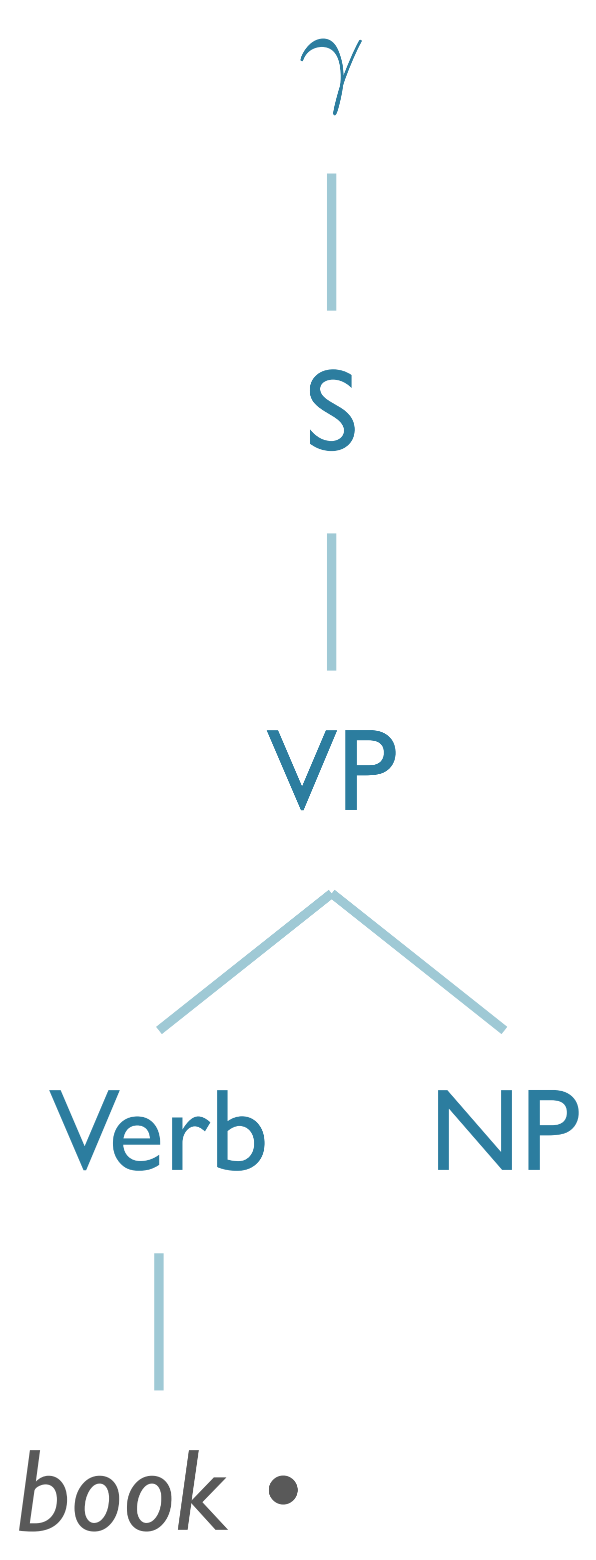
S8: $VP \rightarrow \bullet\ Verb\ NP\ [0,0]$

S12: $Verb \rightarrow \bullet\ book\ [0,0]$



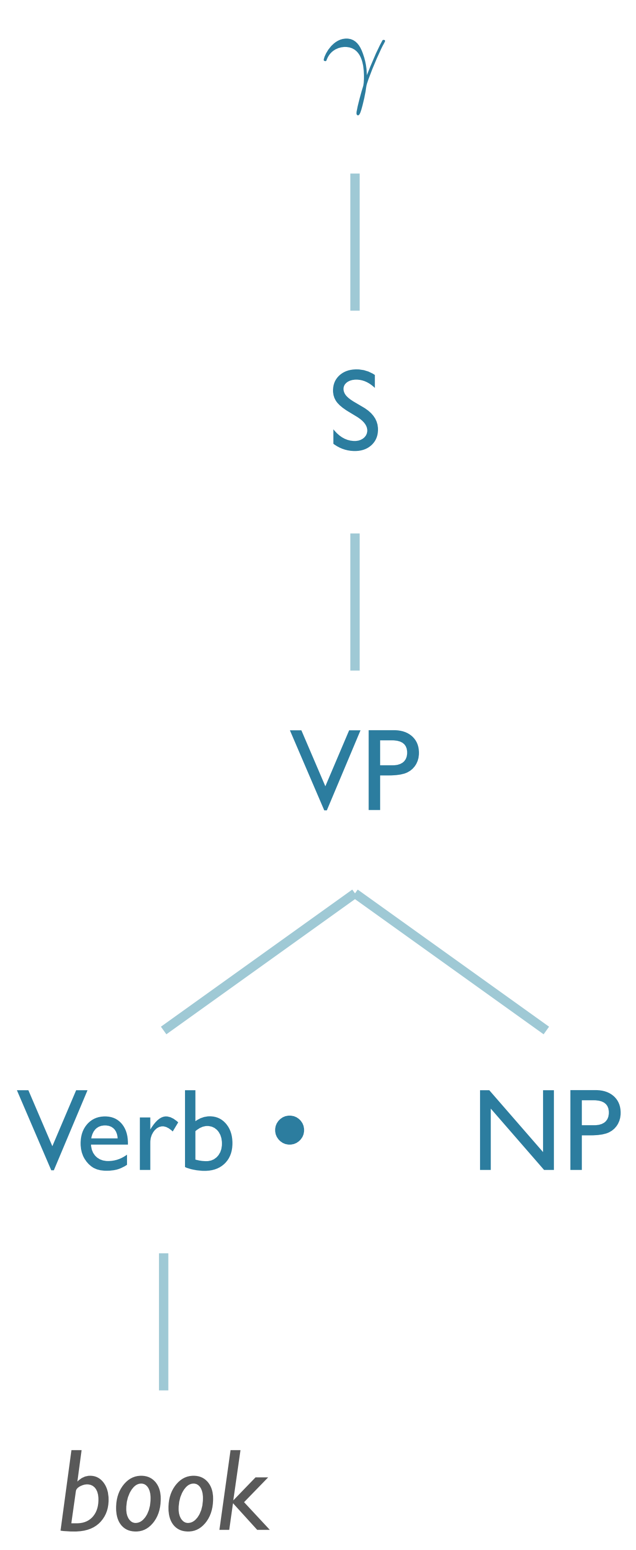
Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow \bullet\ VP$ [0,0]
S8: $VP \rightarrow \bullet\ Verb\ NP$ [0,0]
S12: $Verb \rightarrow book\ \bullet$ [0,1]



Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow \bullet\ VP$ [0,0]
S8: $VP \rightarrow Verb \bullet NP$ [0,1]

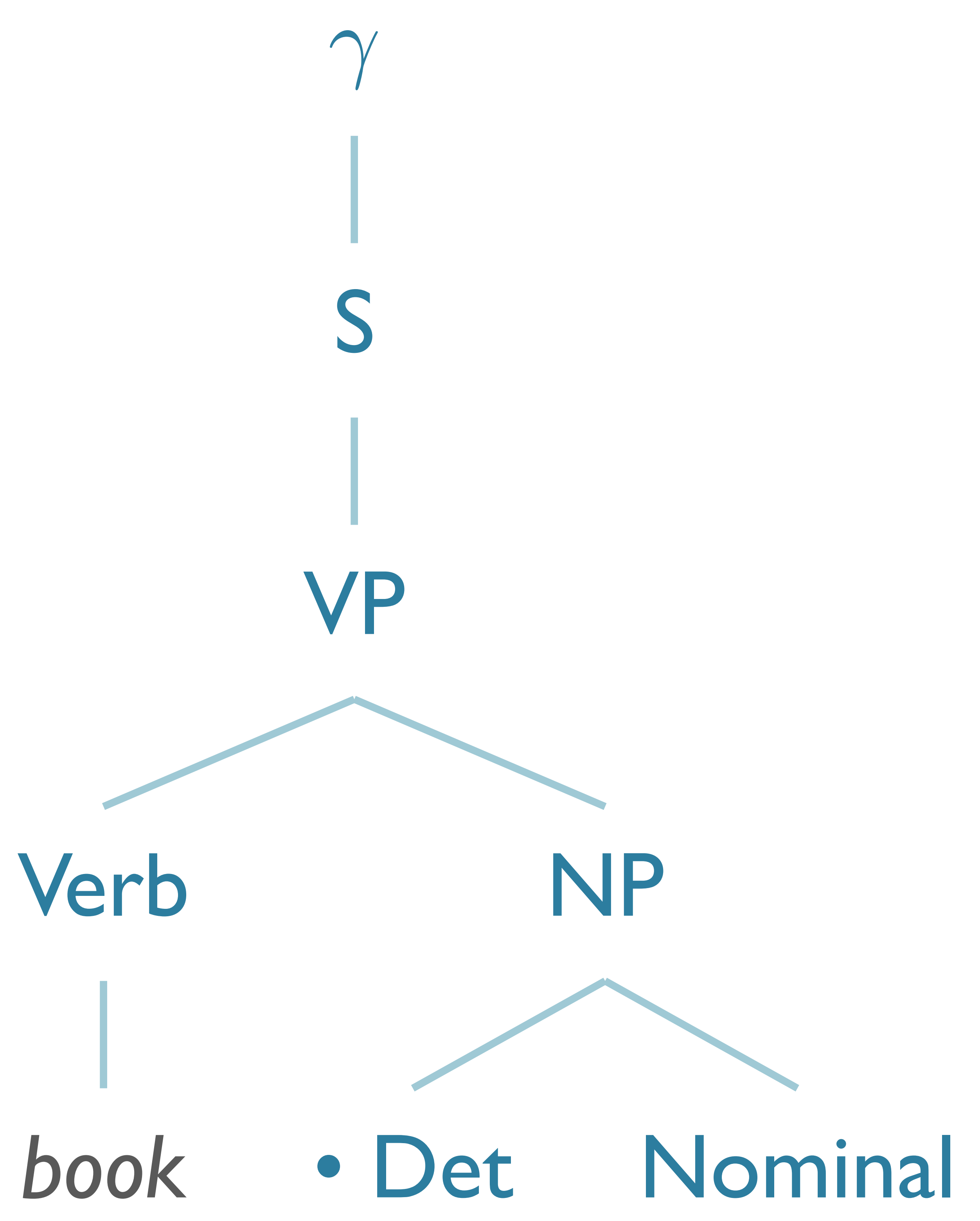


Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow VP \bullet$ [0,1]
S8: $VP \rightarrow Verb \bullet NP$ [0,1]

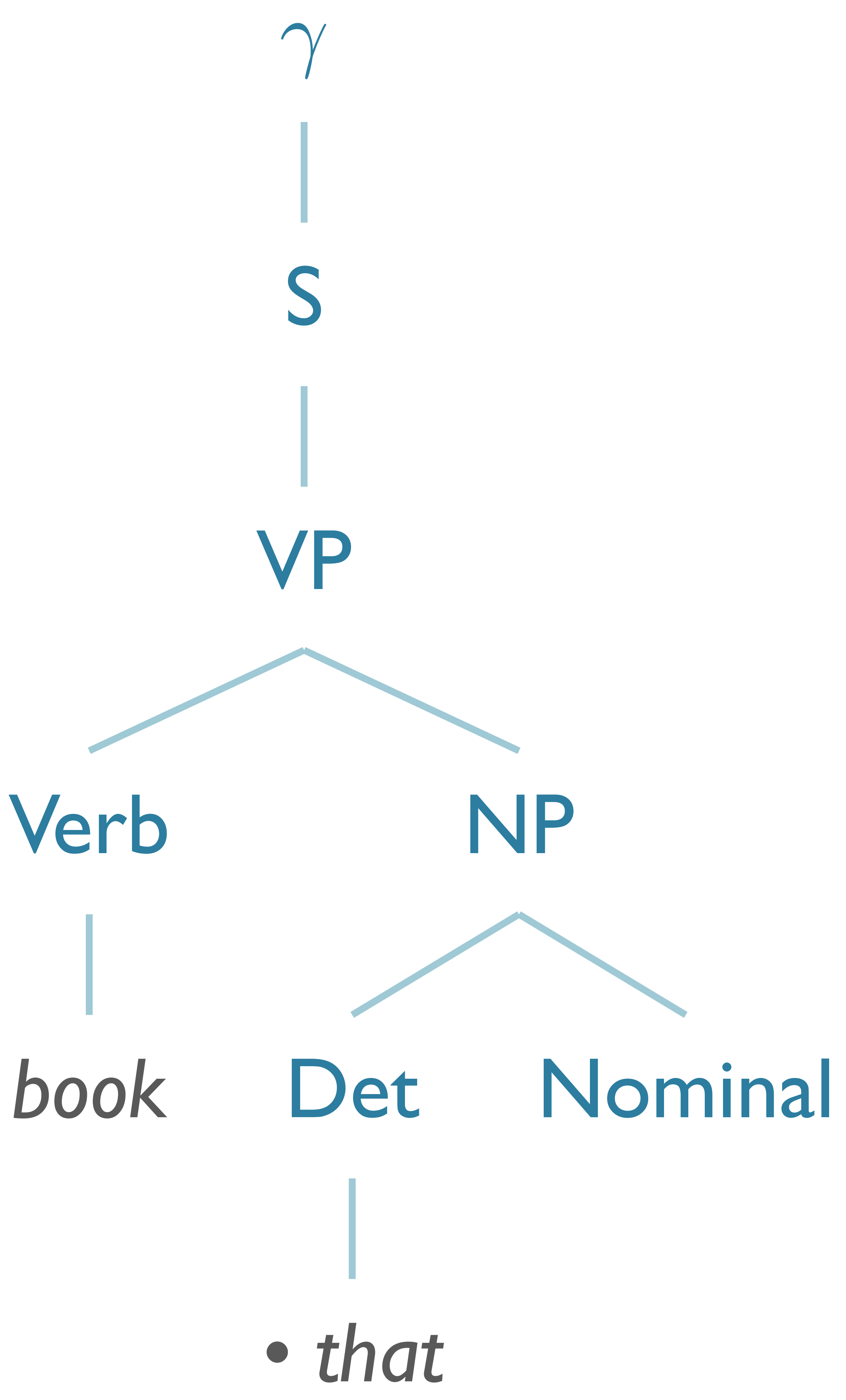
Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow VP \bullet$ [0,1]
S8: $VP \rightarrow Verb \bullet NP$ [0,1]
S21: $NP \rightarrow \bullet\ Det\ Nominal$ [1,1]



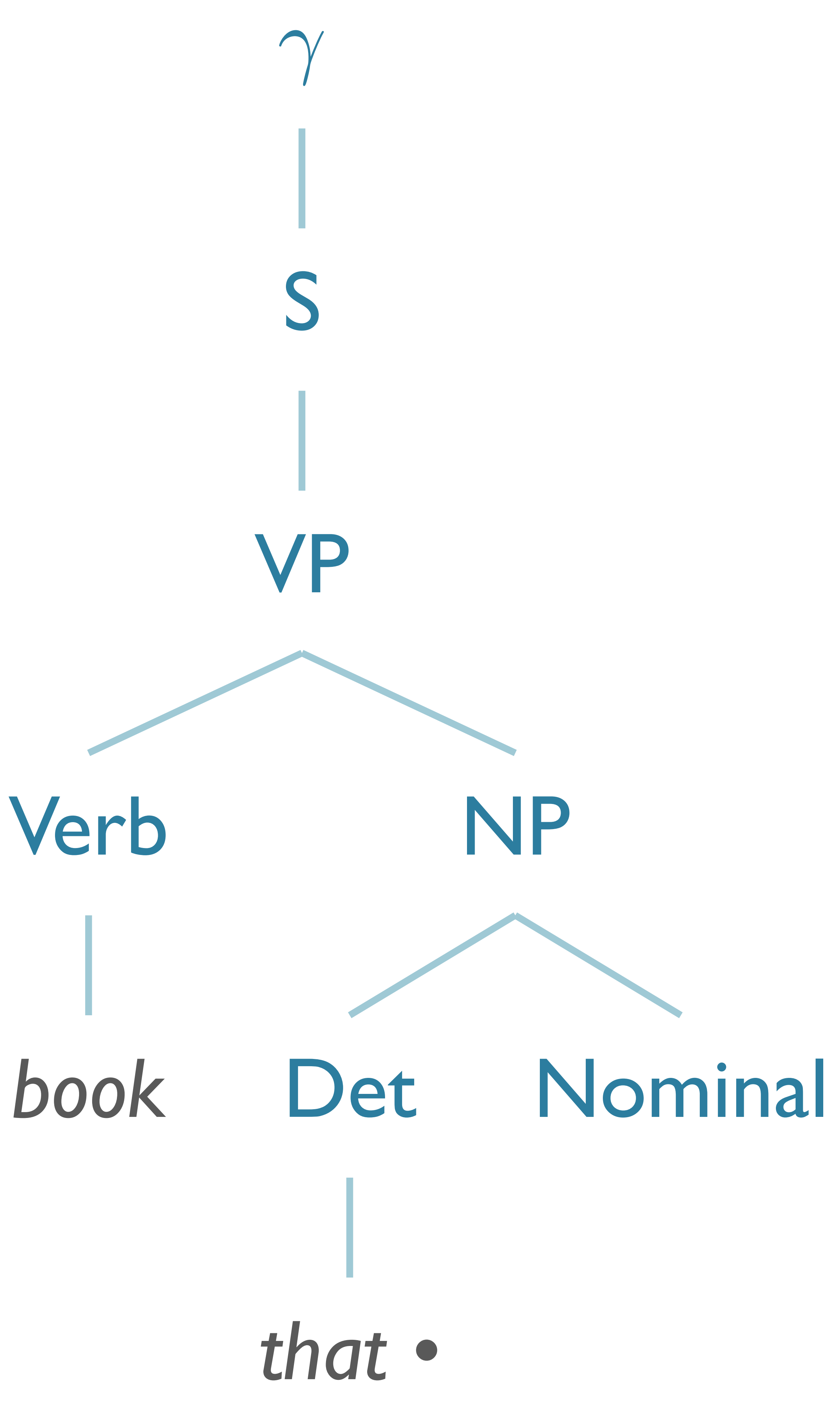
Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow VP \bullet$ [0,1]
S8: $VP \rightarrow Verb \bullet NP$ [0,1]
S21: $NP \rightarrow \bullet\ Det\ Nominal$ [1,1]
S23: $Det \rightarrow \bullet$ *"that"* [1,1]



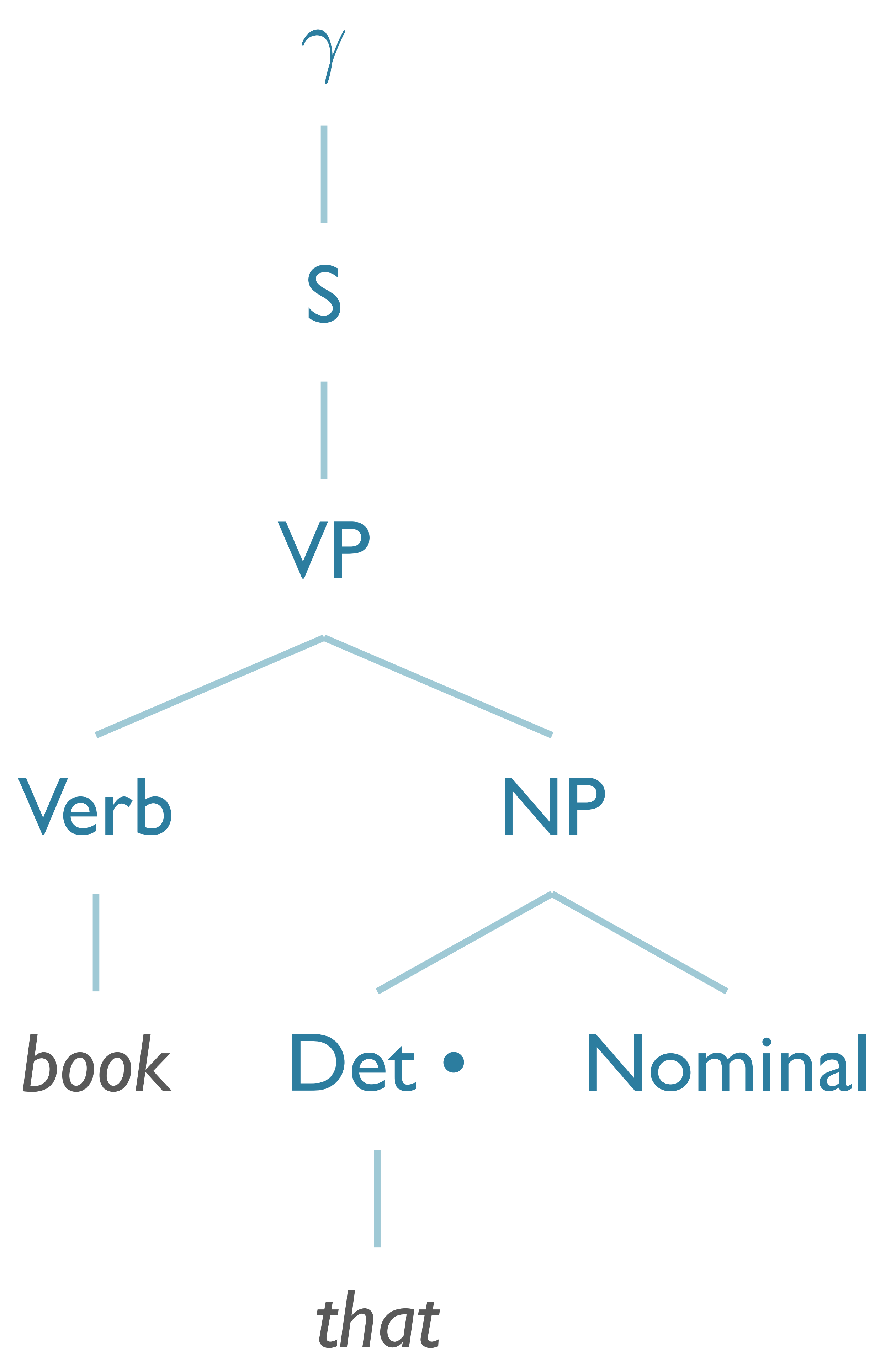
Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow VP \bullet$ [0,1]
S8: $VP \rightarrow Verb \bullet NP$ [0,1]
S21: $NP \rightarrow \bullet\ Det\ Nominal$ [1,1]
S23: $Det \rightarrow$ *"that"* $\bullet$ [1,2]



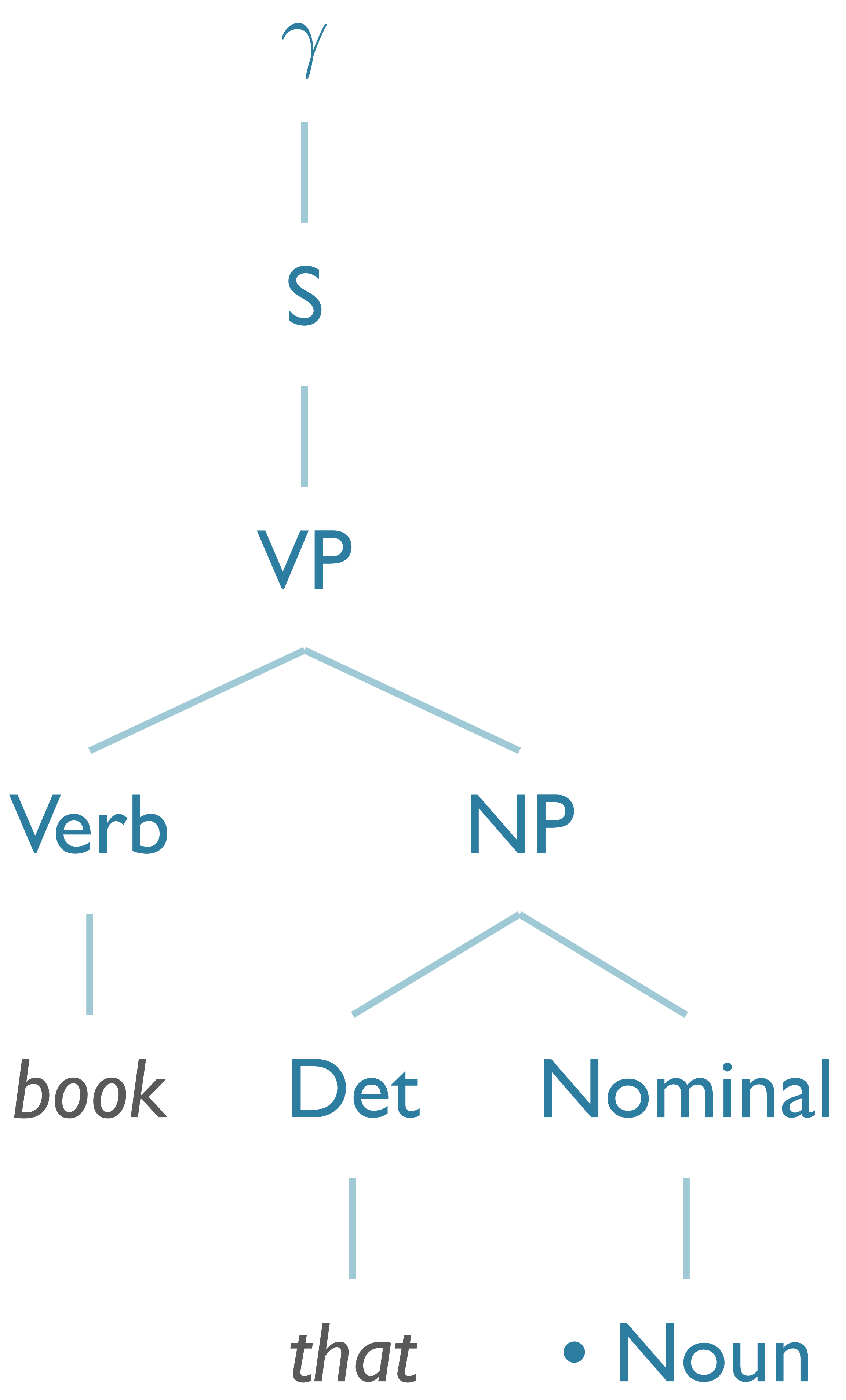
Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow VP \bullet$ [0,1]
S8: $VP \rightarrow Verb \bullet NP$ [0,1]
S21: $NP \rightarrow Det \bullet Nominal$ [1,2]



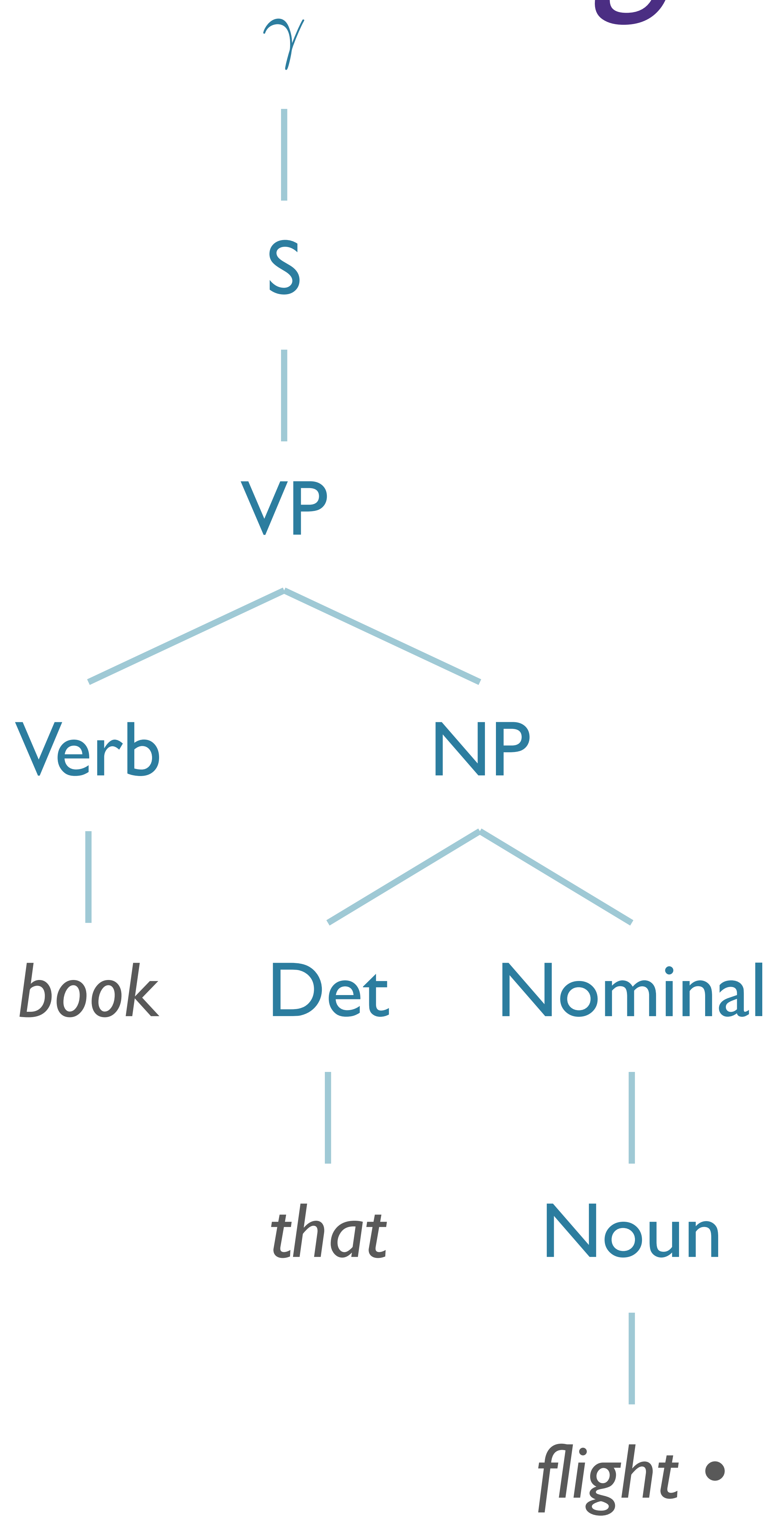
Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow VP \bullet$ [0,1]
S8: $VP \rightarrow Verb \bullet NP$ [0,1]
S21: $NP \rightarrow Det \bullet Nominal$ [1,2]
S25: $Nominal \rightarrow \bullet\ Noun$ [2,2]



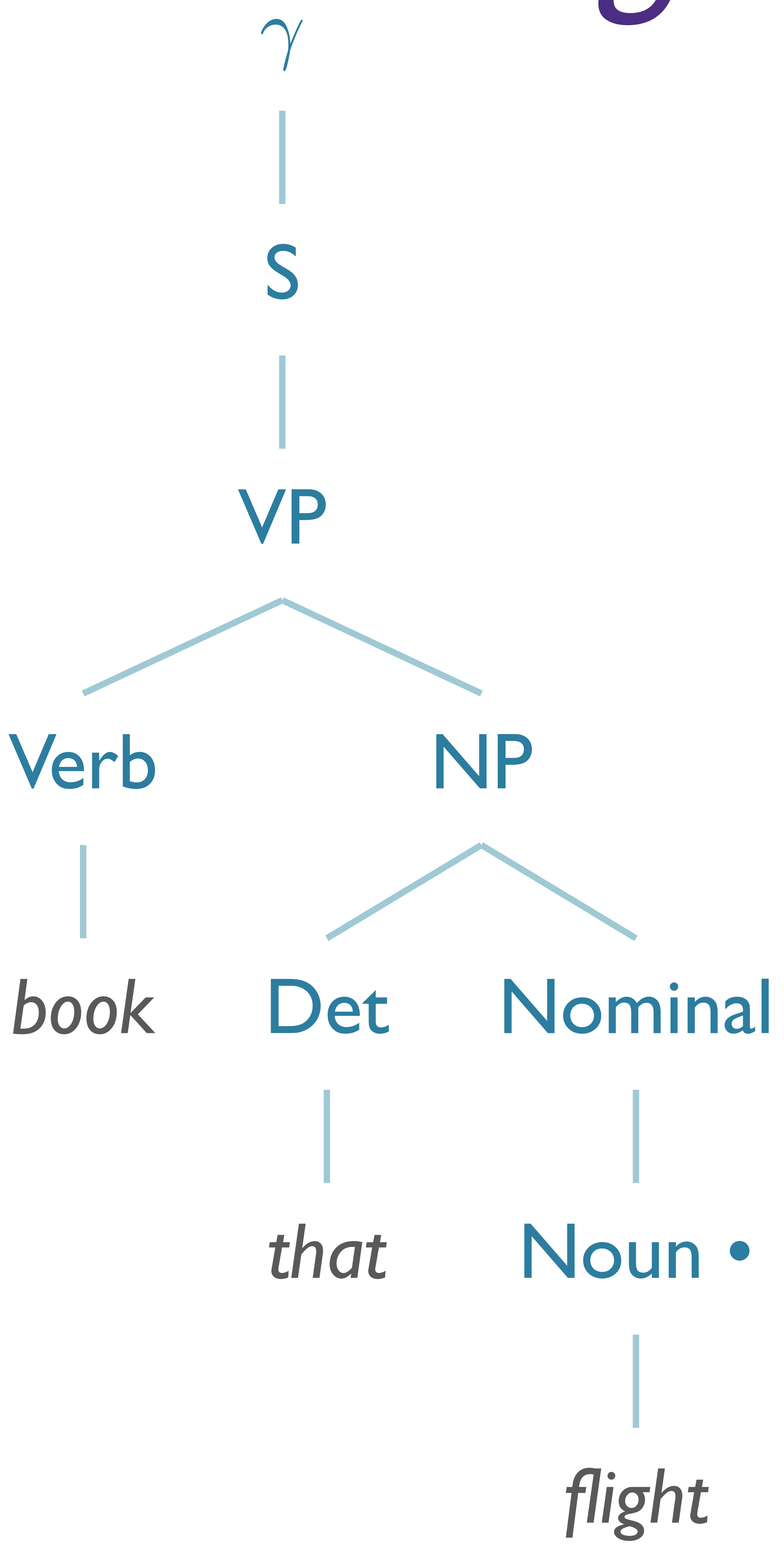
Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow VP \bullet$ [0,1]
S8: $VP \rightarrow Verb \bullet NP$ [0,1]
S21: $NP \rightarrow Det \bullet Nominal$ [1,2]
S25: $Nominal \rightarrow \bullet\ Noun$ [2,2]
S28: $Noun \rightarrow$ *"flight"* $\bullet$ [2,3]



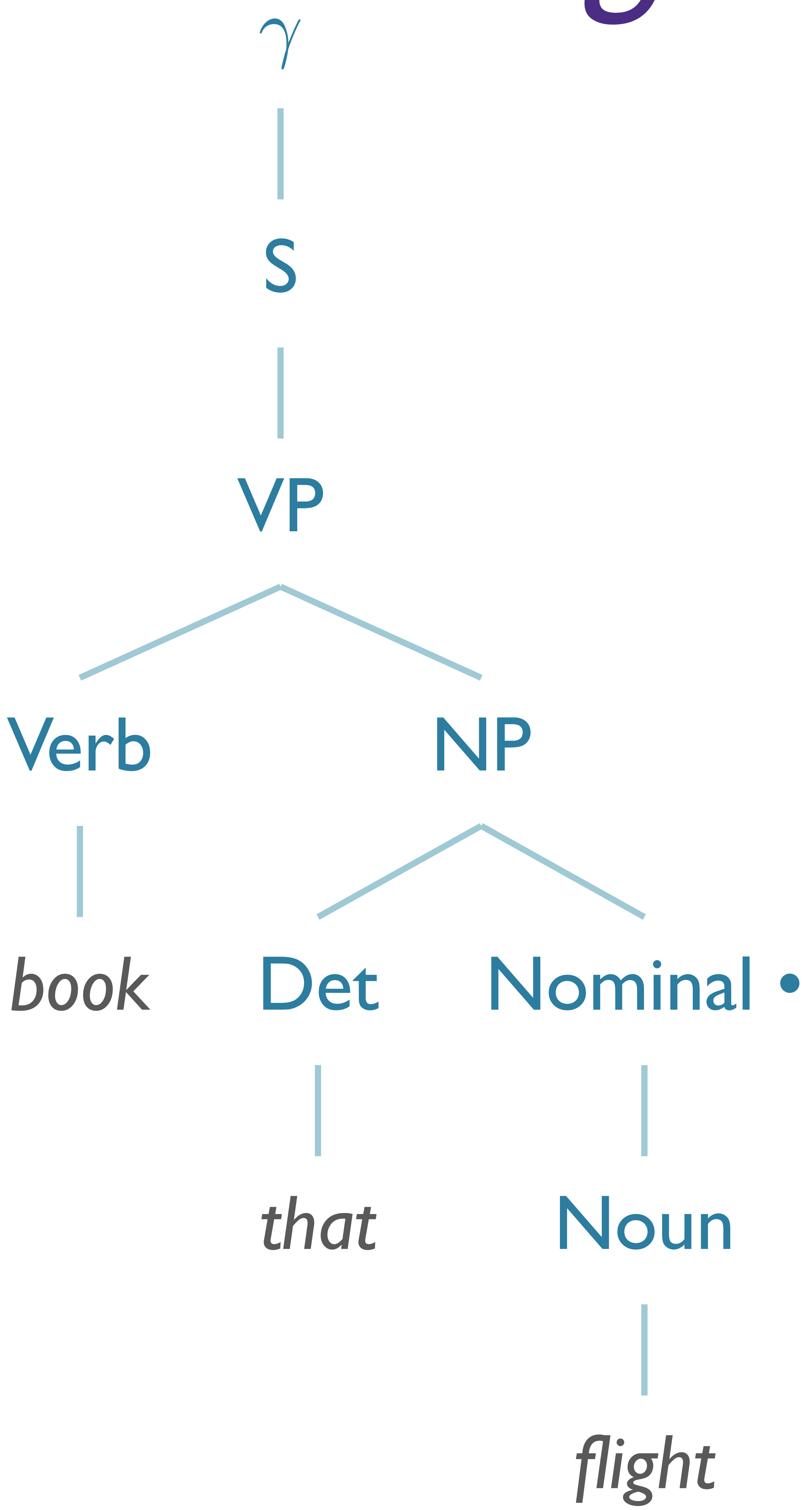
Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow VP \bullet$ [0,1]
S8: $VP \rightarrow Verb \bullet NP$ [0,1]
S21: $NP \rightarrow Det \bullet Nominal$ [1,2]
S25: $Nominal \rightarrow Noun \bullet$ [2,3]



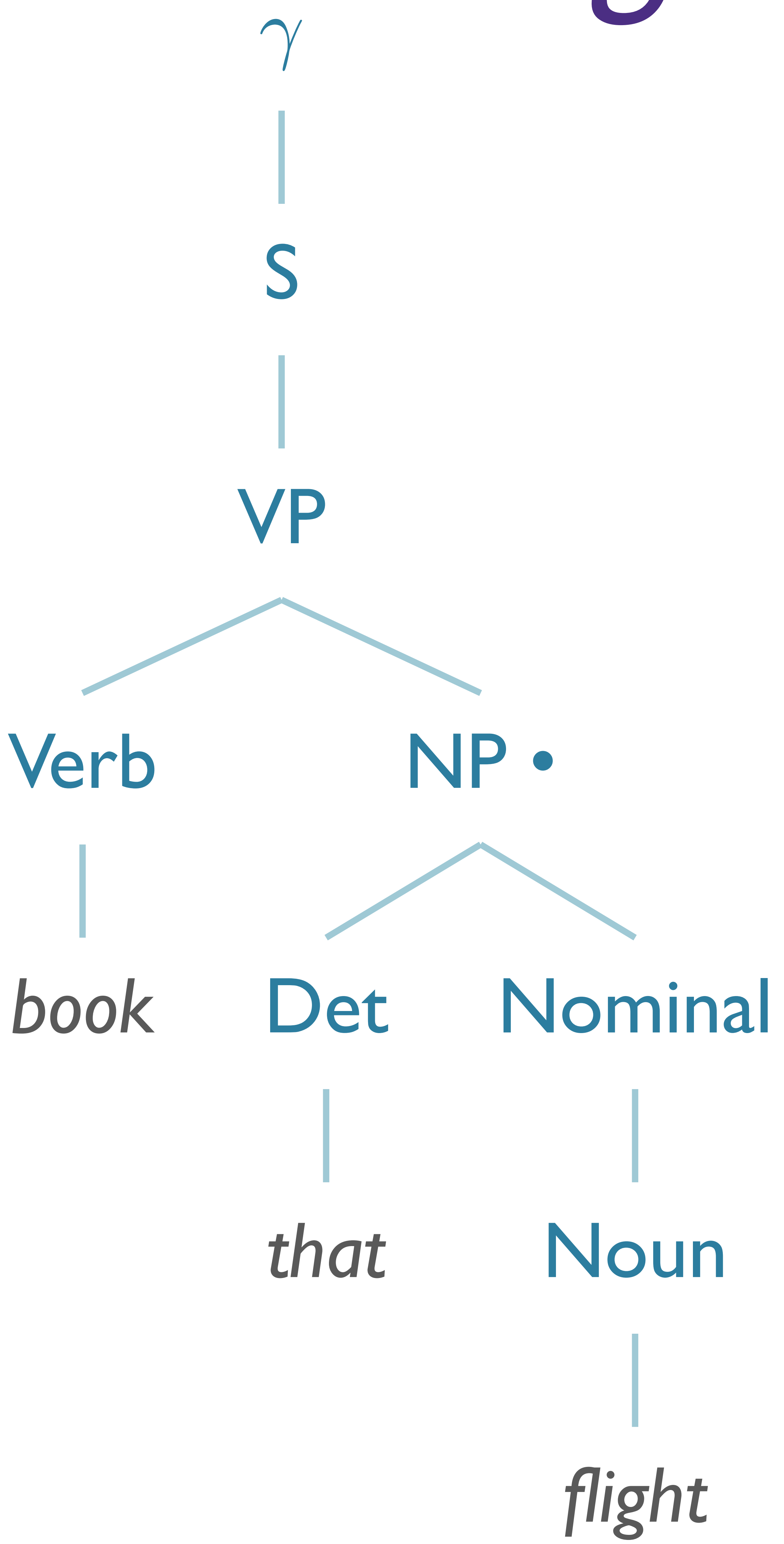
Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow VP \bullet$ [0,1]
S8: $VP \rightarrow Verb \bullet NP$ [0,1]
S21: $NP \rightarrow Det\ Nominal \bullet$ [1,3]



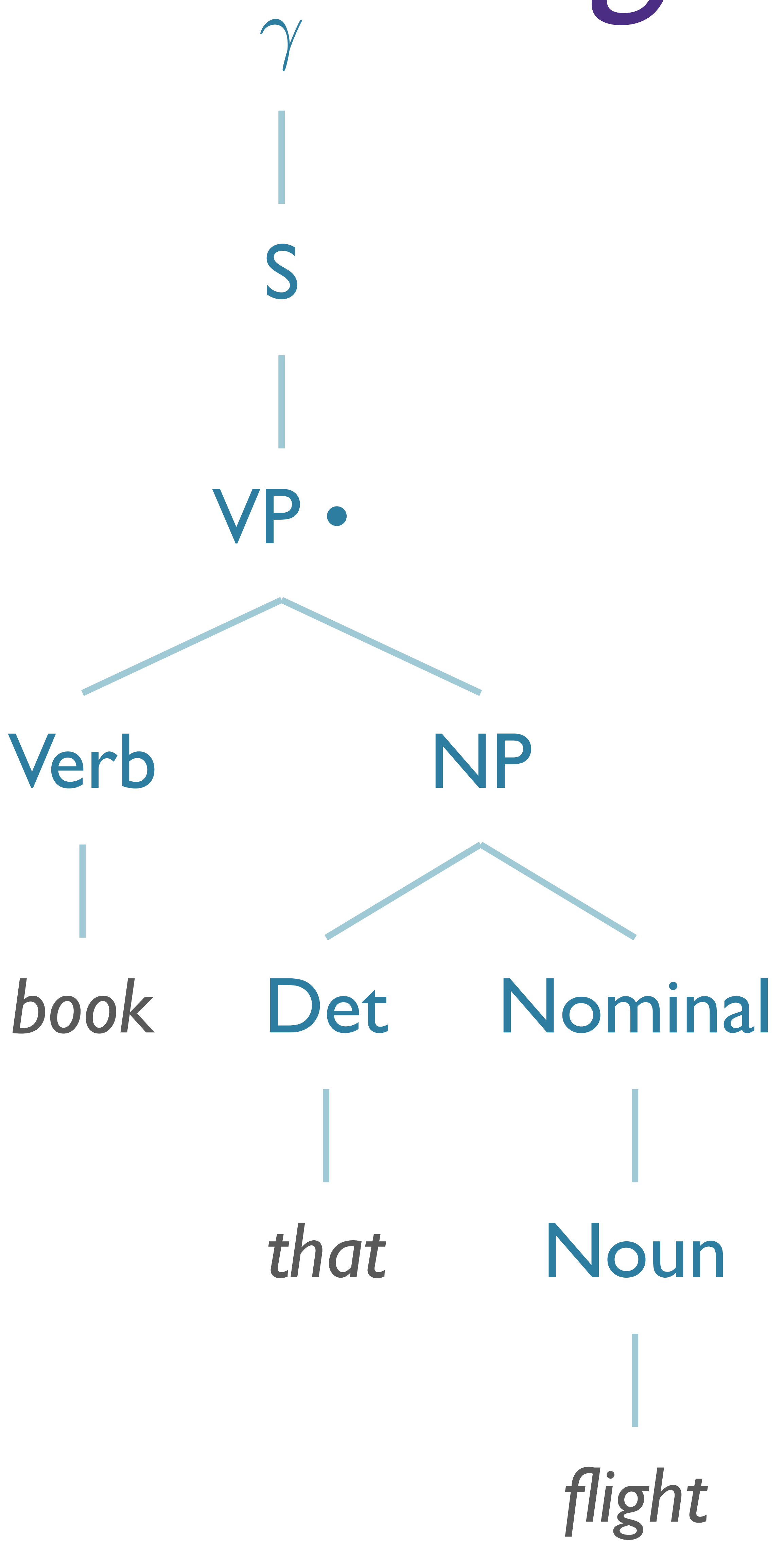
Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow VP \bullet$ [0,1]
S8: $VP \rightarrow Verb\ NP \bullet$ [0,3]



Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S3: $S \rightarrow VP \bullet$ [0,3]

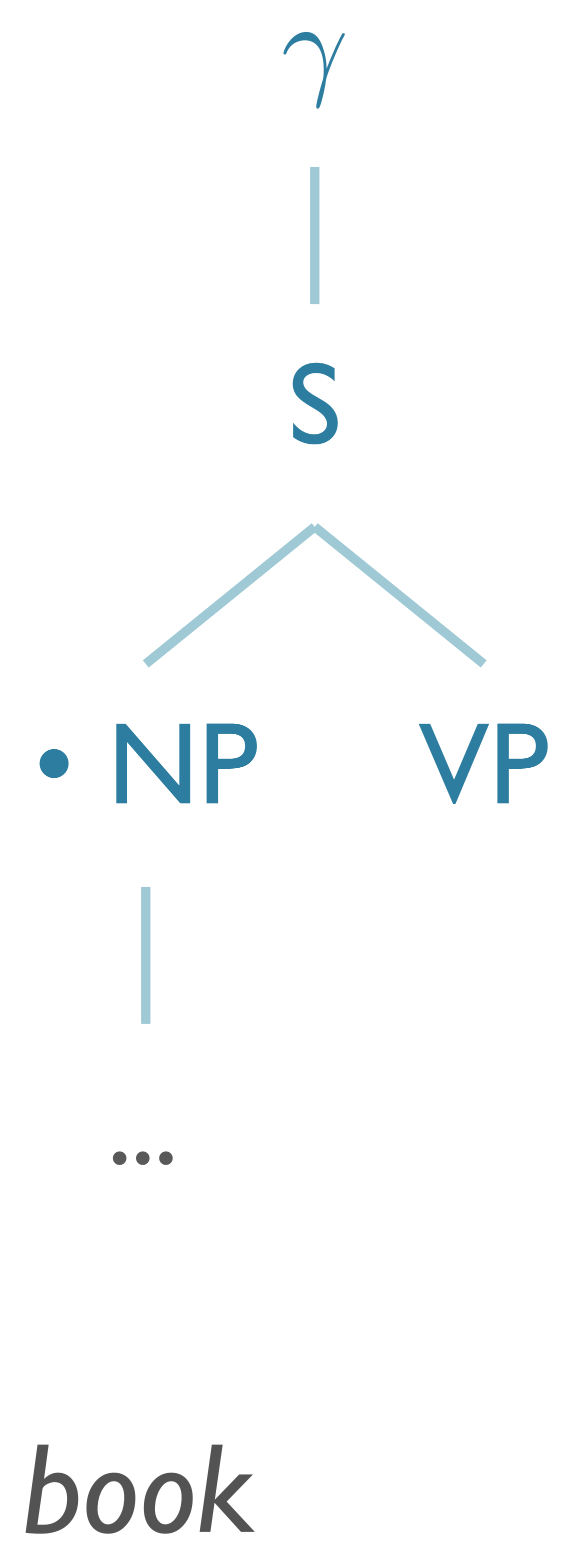


What About Dead Ends?

Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S1: $S \rightarrow \bullet\ NP\ VP$ [0,0]

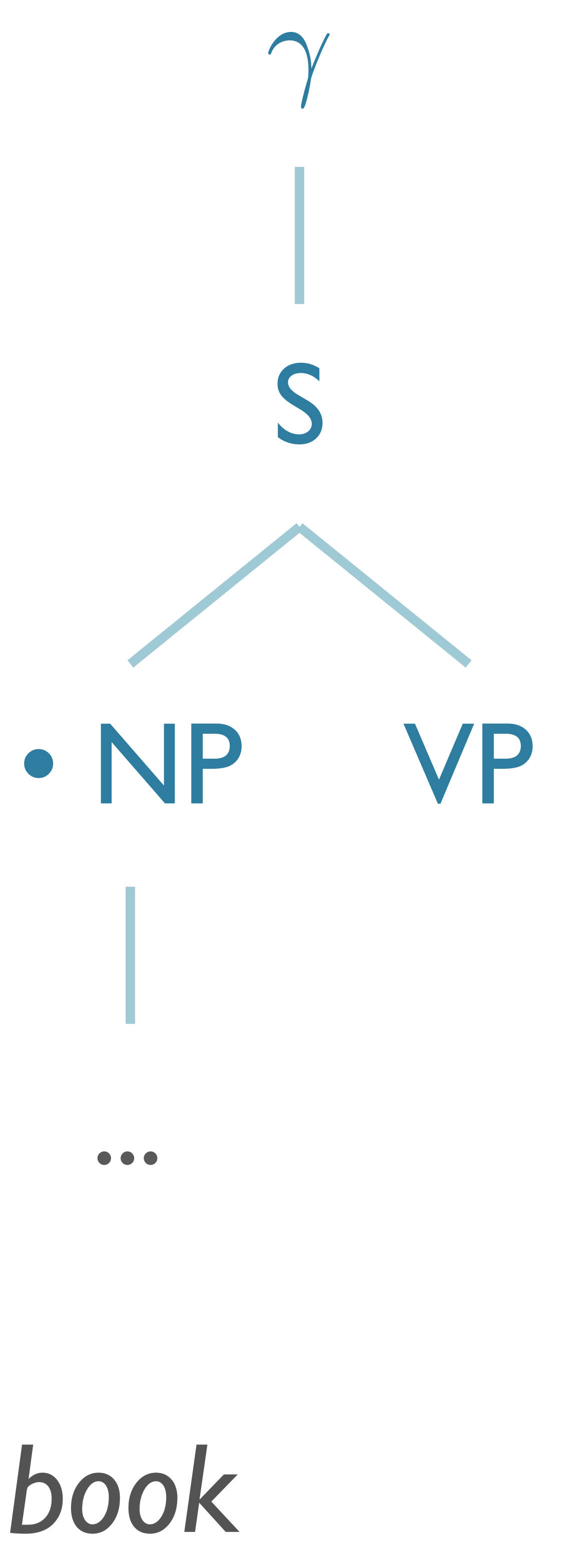
$NP \rightarrow \bullet\ Pronoun$
$NP \rightarrow \bullet\ Proper\text{-}Noun$
$NP \rightarrow \bullet\ Det\ Nominal$



Book that flight

S0: $\gamma \rightarrow \bullet\ S$ [0,0]
S1: $S \rightarrow \bullet\ NP\ VP$ [0,0]

~~$NP \rightarrow \bullet\ Pronoun$~~
~~$NP \rightarrow \bullet\ Proper\text{-}Noun$~~
~~$NP \rightarrow \bullet\ Det\ Nominal$~~



What About Recursion?

What about recursion?

What about recursion?

- We now have a top-down parser in hand. Does it enter infinite loops on rules like S -> S ‘and’ S?

What about recursion?

- We now have a top-down parser in hand. Does it enter infinite loops on rules like S -> S ‘and’ S?
- No!

What about recursion?

- We now have a top-down parser in hand. Does it enter infinite loops on rules like S -> S ‘and’ S?
- No!

HW #3

CKY Parsing: Goals

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

Implementation

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

Implementation

- For CKY Implementation:
  - NLTK's **`CFG.productions()`** method:
    - optional `rhs=` argument *only looks at first token of RHS*

Notes

- Teams:

  You may work in teams of two on this assignment

- Test grammar

  Pre-converted to CNF

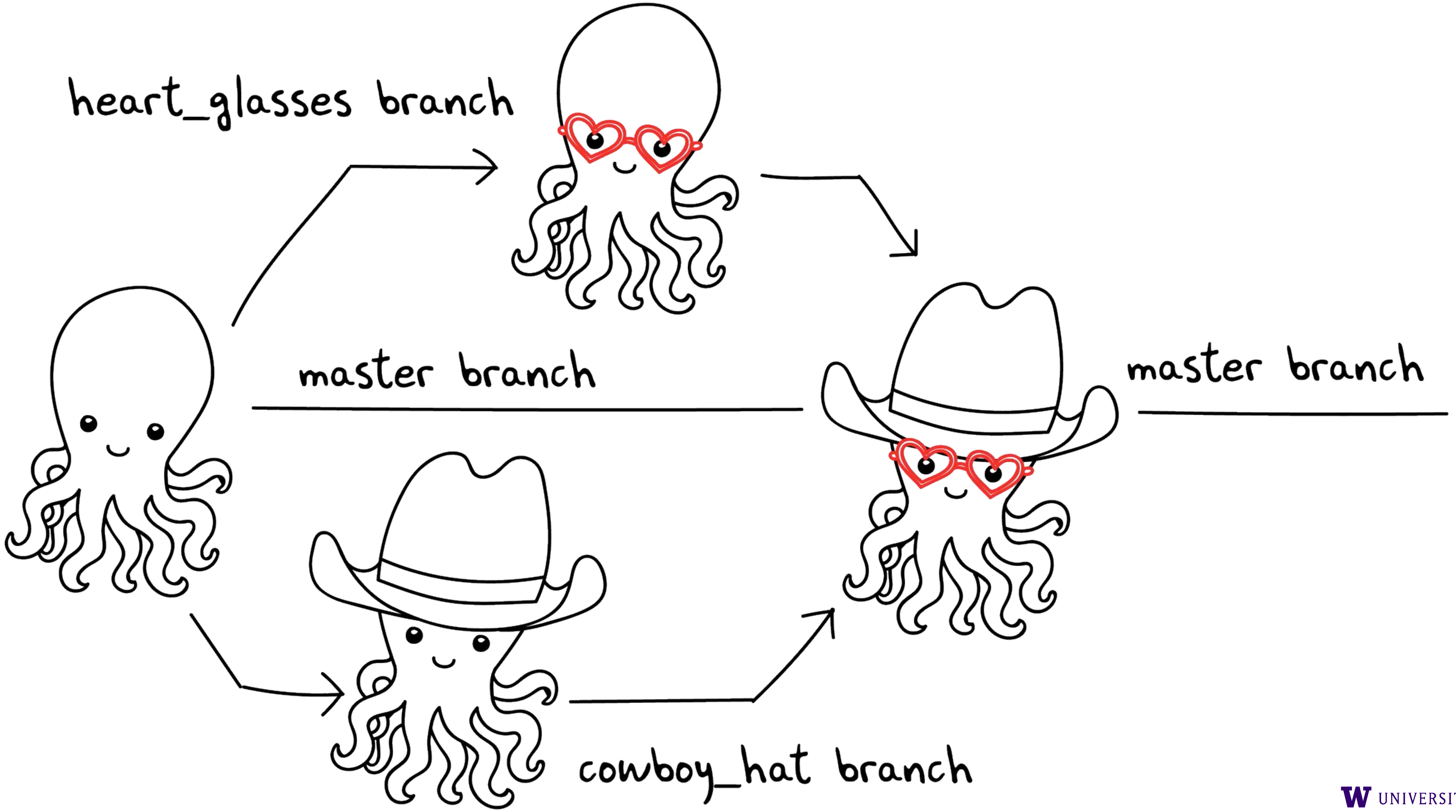
  Start symbol: **TOP**

  Parse should span input and be rooted at: **TOP**

Some Collaboration Basics

Git Branches

- Good for semi-isolating your development code from the shared, reviewed code



Recommended Git Flow

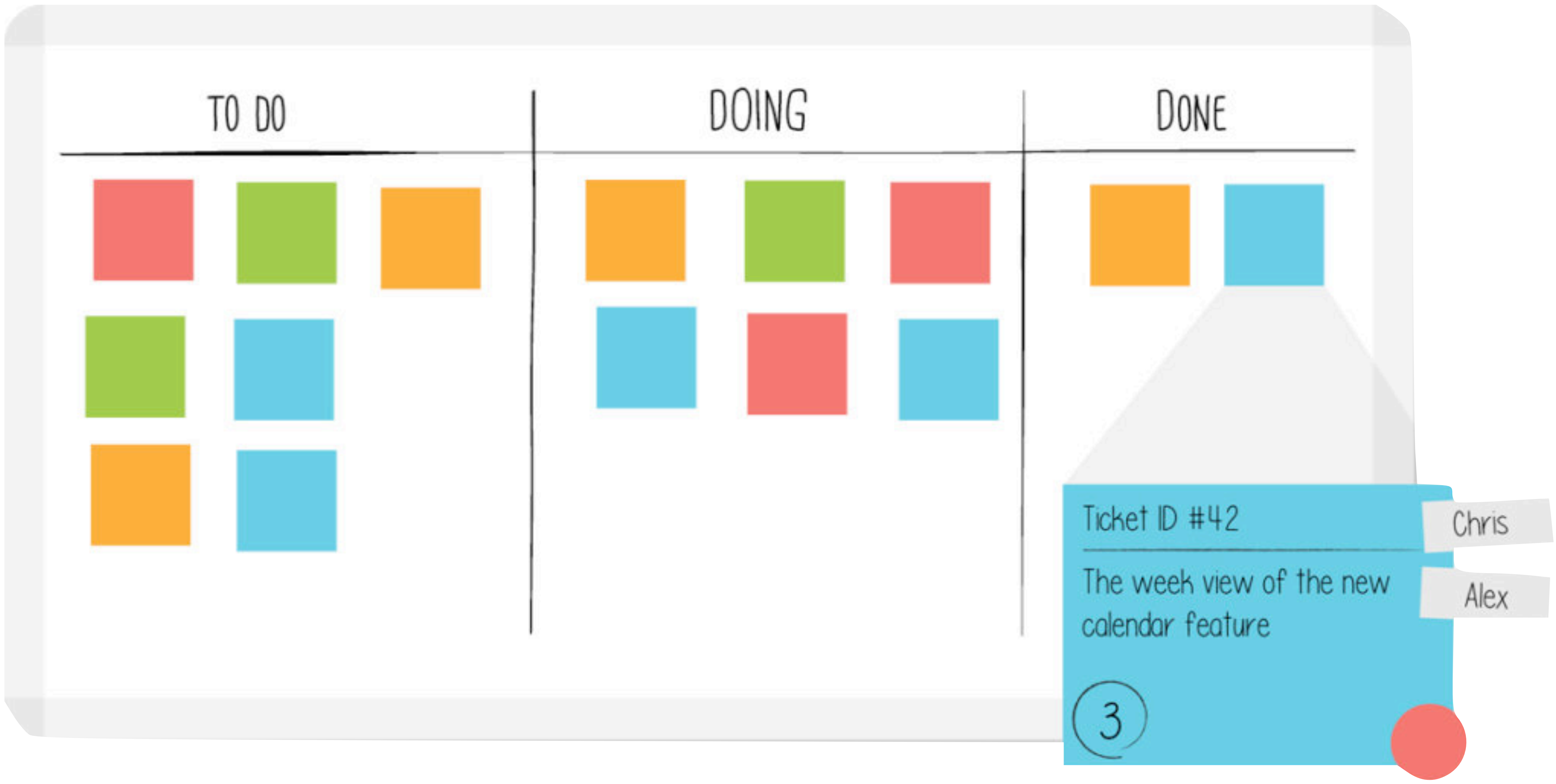
- Initialize a git repository, with a `master` branch
  - (Create initial checkin, if necessary)
- Create a new branch, maybe "`adding_rule_objects`"
- Make regular checkins on your branch (like saving)
- Switch to `master` branch, and "pull"
- Merge your branch to master
- …rinse & repeat
- If using GitHub (or GitLab, etc): **MUST BE PRIVATE REPO!**

Communication: Check-ins

- For check-ins, three main points:
  - What have you been working on?
  - What do you plan to work on next?
  - Is there anything “blocking” you?
- In industry, these brief check-ins among small teams are often done daily

Project Planning: Kanban Boards

- Before you start working:
  - Write out tasks on sticky notes.
  - Place in three columns:
    - To-Do
    - Doing
    - Done
  - As you work, you can move them from column to column
  - Add tasks as new issues come up



- trello.com – has free online implementation of Kanban Boards