Syntax:
Context-Free Grammars

LING 571 — Deep Processing Techniques for NLP

Oct 5, 2020

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Announcements

- Please use Canvas for discussions! There really are no stupid questions :)
- Output format:
  - Try to copy *exactly*; your hw1 script run with the toy data should produce output that exactly matches toy_output.txt
  - Single space after the colon
  - Truncate decimals to 3 places
- Python versions: use full paths to binaries; see `ls /opt | grep python`
- File paths will be given as full paths, so your script should accept those
- Condor: we will use for grading, so if you want to test, that's a good idea (and will be necessary in the future)

Roadmap

- **Constituency**
- Context-free grammars (CFGs)
- English Grammar Rules
- Grammars — Revisiting our Motivation
- Treebanks
- Speech and Text
- Parsing

Constituency

- Some examples of noun phrases (NPs):

Harry the Horse	a high-class spot such as Mindy's
the Broadway coppers	the reason he comes into the Hot Box
they	three parties from Brooklyn

- How do we know that these are constituents?
  - We can perform constituent tests

Constituent Tests

- Many types of tests for constituency *(see Sag, Wasow, Bender (2003), pp. 29-33)*
- One type (for English) is **clefting**
  - It is ______ that ______
  - Is the resulting sentence valid English?

It is **the Supreme Court** that made the ruling	✔
It is **the Supreme Court of the United States** that made the ruling	✔
It is **they** that made the ruling	✔
It is **the Supreme Court of** that made the ruling	✗

Constituent Tests

- Another popular one: **coordination.**
  - Only constituents *of the same type* can be coordinated.
  - … ______ CONJ ______ …

Shane and all of the students	✔
three players and the coach’s brother	✔
The friends drank wine and laughed at the show together.	✔
The friends drank wine and all of the students together.	✗

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Representation: Context-free Grammars

- CFGs: 4-tuple
  - A set of **terminal** symbols: Σ
    - (think: words)
  - A set of **nonterminal** symbols: N
    - *(Think: phrase categories)*
  - A set of **productions** P:
    - of the form $\boldsymbol{A} \rightarrow \alpha$
    - Where A is a non-terminal and $\alpha \in (\Sigma \cup N)^*$
  - A **start** symbol $S \in N$

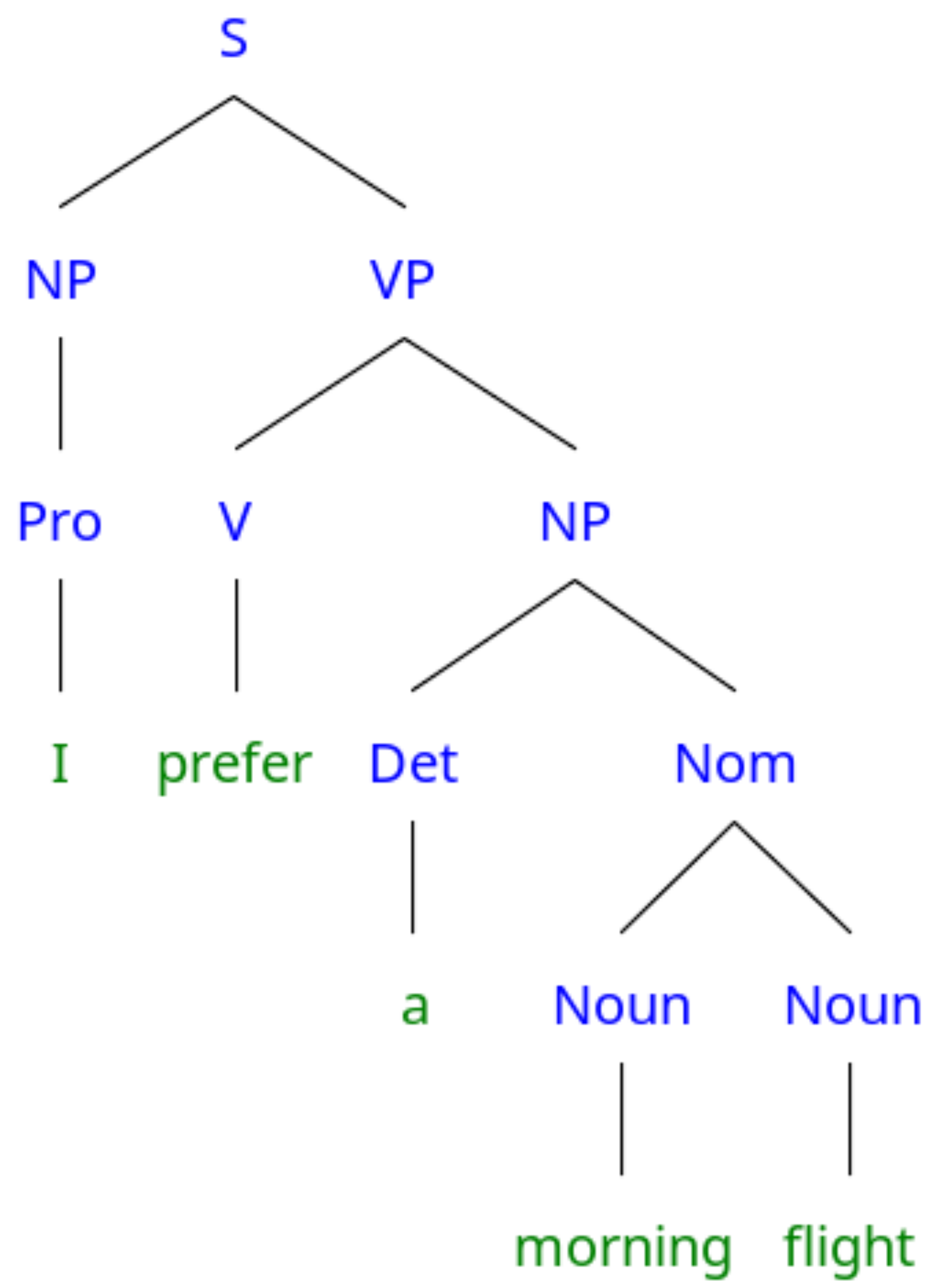
CFG Components

- Productions:
  - One non-terminal on LHS and any seq. of terminals and non-terminals on RHS
    - *S* → *NP VP*
    - *VP* → *V NP PP* | *V NP*
    - *Nominal* → *Noun* | *Nominal Noun*
    - *Noun* → ‘dog’ | ‘cat’ | ‘rat’
    - *Det* → ‘the’

Grammar Rules			Examples
S	⟶	*NP VP*	I + want a morning flight
NP	⟶	*Pronoun*	I
	|	*Proper-Noun*	Los Angeles
	|	*Det Nominal*	a + flight
Nominal	⟶	*Nominal Noun*	morning + flight
	|	*Noun*	flights
VP	⟶	*Verb*	do
	|	*Verb NP*	want + a flight
	|	*Verb NP PP*	leave + Boston + in the morning
	|	*Verb PP*	leaving + on Thursday
PP	⟶	*Preposition NP*	from + Los Angeles

Jurafsky & Martin, Speech and Language Processing, p.390

Parse Tree

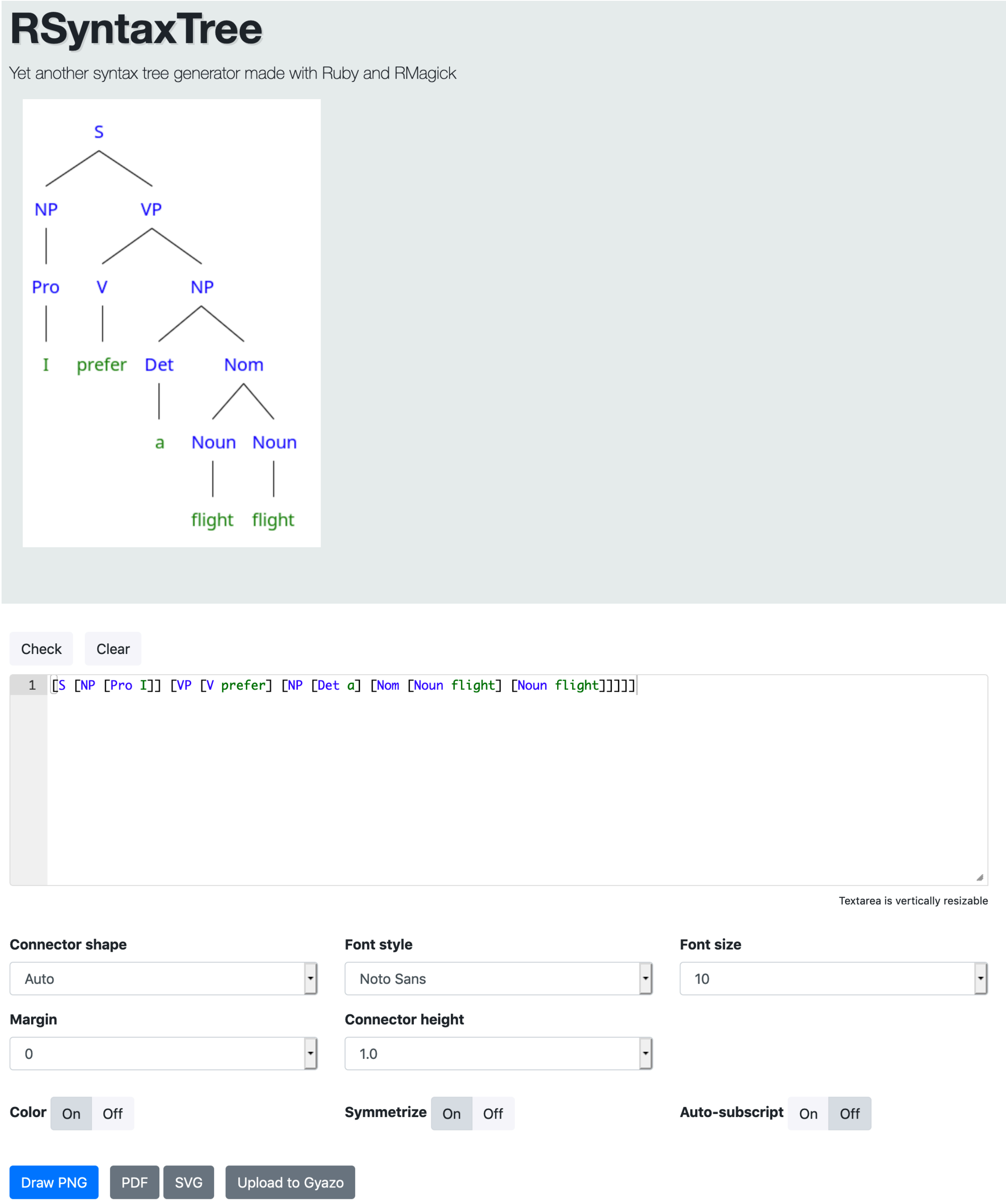


Some English Grammar

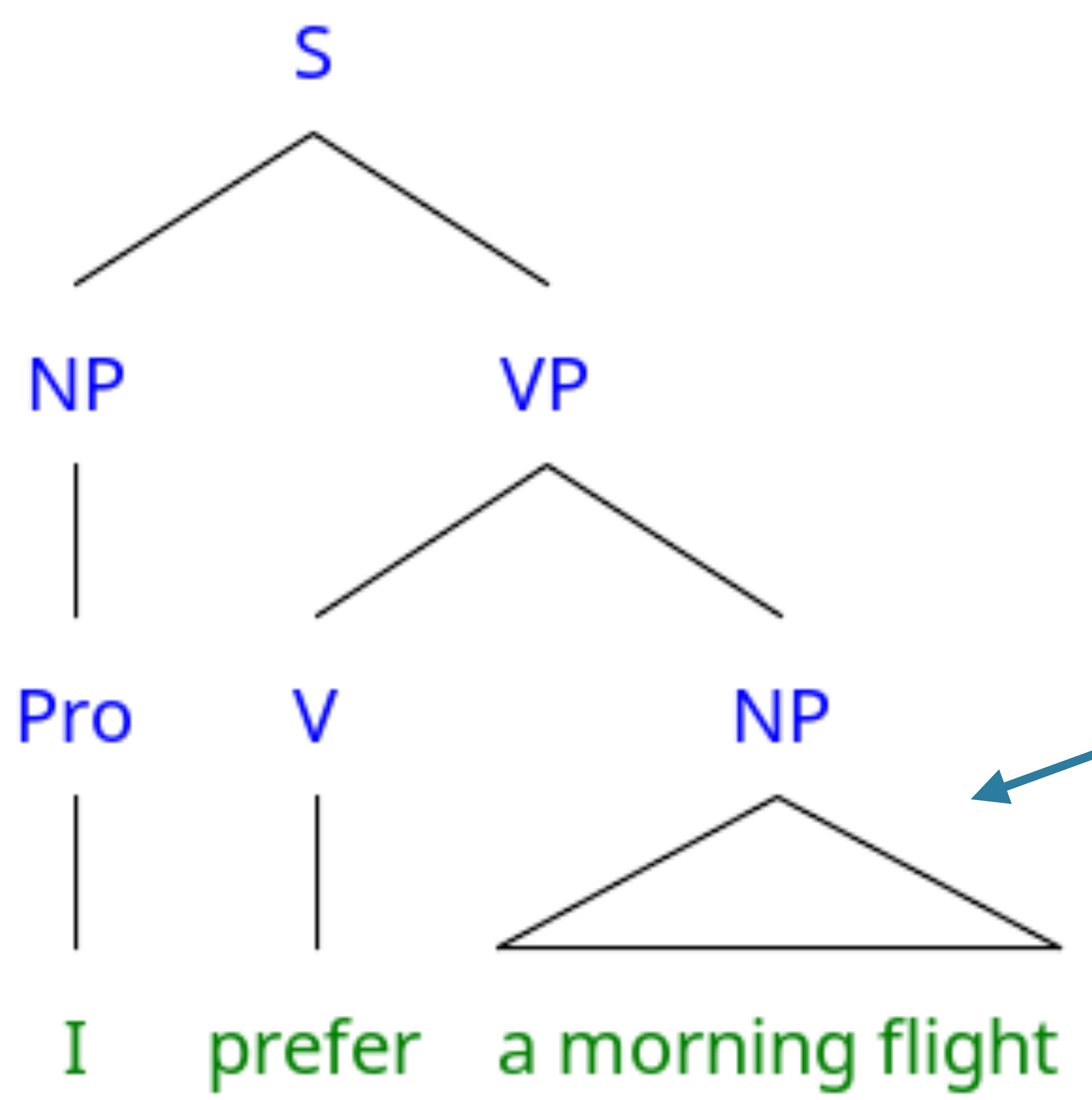
- Sentences: Full sentence or clause; a complete thought
- **Declarative**: ***S*** → ***NP VP***
  - (S (NP I) (VP want a flight from SeaTac to Amsterdam))
- **Imperative**: ***S*** → ***VP***
  - (VP Show me the cheapest flight from New York to Los Angeles.)
- **Yes-no Question**: ***S*** → ***Aux NP VP***
  - (Aux Can) (NP you) (NP give me the nonstop flights to Boston?)
- **Wh-subject question**: ***S*** → ***Wh-NP VP***
  - (Wh-NP Which flights) (VP arrive in Pittsburgh before 10pm?)
- **Wh-non-subject question**: ***S*** → ***Wh-NP Aux NP VP***
  - (Wh-NP What flights) (Aux do) (NP you) (VP have from Seattle to Orlando?)

Visualizing Parse Trees

- ```
  >>> tree = nltk.tree.Tree.fromstring("(S (NP (Pro I)) (VP (V prefer) (NP (Det a) (Nom (Noun flight) (Noun flight)))))")
  >>> tree.draw()
  ```
- Web apps: https://yohasebe.com/rsyntaxtree/
- LaTeX: qtree (/ tikz-qtree) package


  ```

Partial Parses



When internal structure
doesn't matter
for whatever reason

The Noun Phrase

- Noun phrase constituents can take a range of different forms:

Harry the Horse	a magazine
water	twenty-three alligators
Ram’s homework	the last page of Ram’s homework’s

- We’ll examine a few ways these differ

The Determiner

- Determiners provide referential information about an NP
- Often position the NP within the current discourse

a stop	the flights	this flight
those flights	any flights	some flights

- Can more explicitly introduce an entity as part of the specifier

United's flight
United's pilot's union
Denver's mayor's mother's canceled flight

The Determiner

- *Det → DT*
  - *'the', 'this', 'a', 'those'*
- *Det → **NP*** **'s**
  - **"United's flight": (Det (NP United) 's)**
  - **"the professor's favorite brewery": (Det (NP (Det the) (NP professor)) 's)**

The Nominal

- Nominals contain pre- and post-head noun modifiers
  - Occurs after the determiner (in English)
- Can exist as just a bare noun:
  - *Nominal* → *Noun*
    - PTB POS: `NN, NNS, NNP, NNPS`
    - *'flight', 'dinners', 'Chicago Midway', 'UW Libraries'*

Pre-nominal modifiers *("Postdeterminers")*

- Occur before the head noun in a nominal
- Can be any combination of:
  - Cardinal numbers (e.g. *one*, *fifteen*)
  - Ordinal numbers (e.g. *first*, *thirty-second*)
  - Quantifiers (e.g. *some*, *a few*)
  - Adjective phrases (e.g. *longest*, *non-stop*)

Postmodifiers

- Occur after the head noun
- In English, most common are: (*a flight…*)
  - Prepositional phrase (e.g. … *from Cleveland*)
  - non-finite clause (e.g. … *arriving after eleven a.m.*)
  - relative clause (e.g. … *that serves breakfast*)

Combining Everything

- *NP → (Det) Nom*
- *Nom → (Card) (Ord) (Quant) (AP) Nom*
- *Nom → Nom PP*

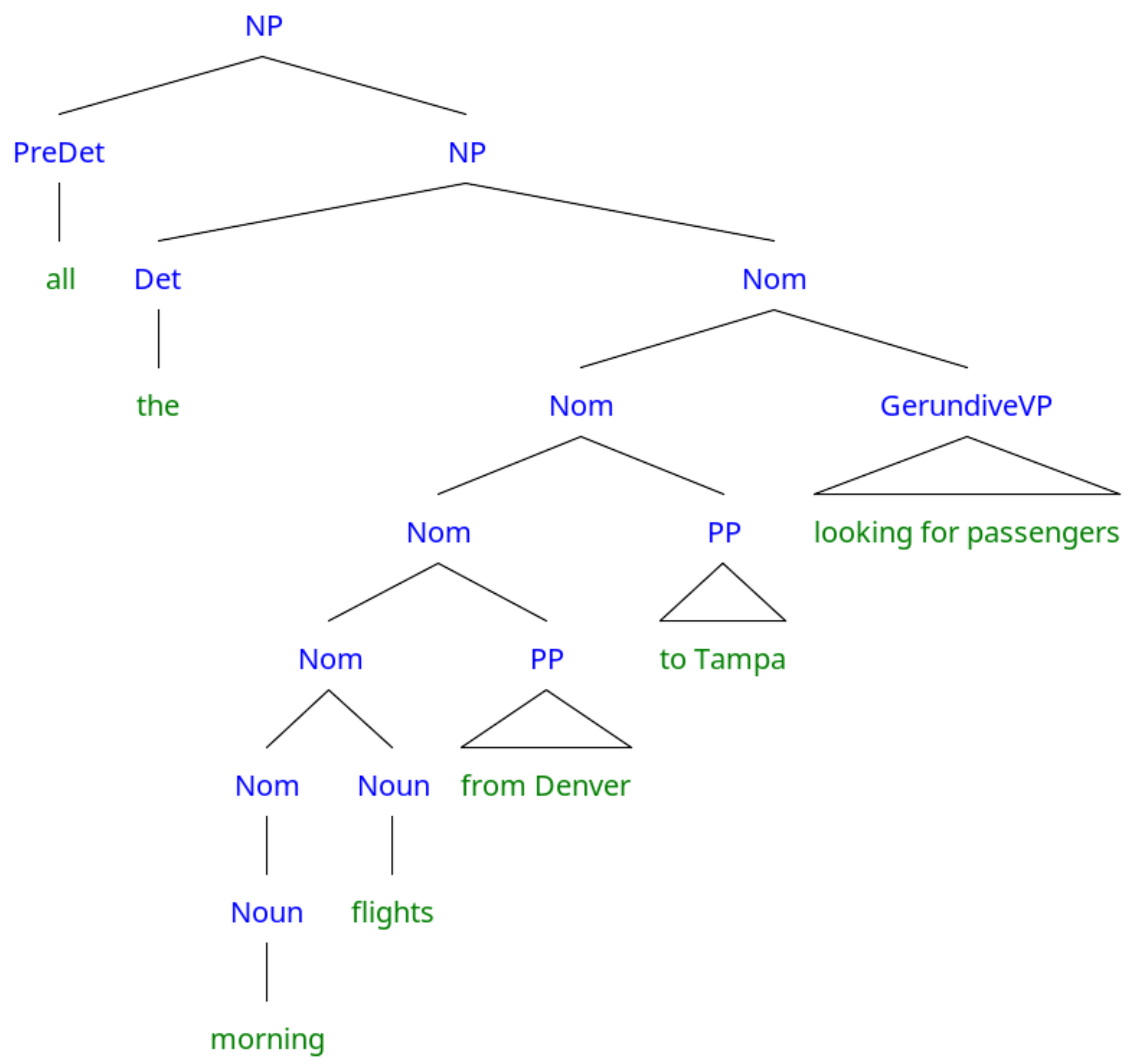
- The least expensive fare
- one flight
- the first route
- the last flight from Chicago

Before the Noun Phrase

- “Predeterminers” can “scope” noun phrases
  - e.g. *‘all,’*
  - *“all the morning flights from Denver to Tampa”*

A Complex Example

- *“all the morning flights from Denver to Tampa looking for passengers”*



Verb Phrases and Subcategorization

- With this grammar:

VP	$\longrightarrow$	*Verb*
	|	*Verb NP*
	|	*Verb NP NP*

- This grammar licenses the following ***correctly***:
  - *The teacher handed the student a book*
- And the following ***incorrectly*** (i.e. the grammar "overgenerates"):
  - **The teacher handed the student*
  - **The teacher handed a book*
  - **The teacher handed*

Verb Phrases and Subcategorization

- With this grammar:

VP	$\longrightarrow$	*Verb*
	|	*Verb NP*
	|	*Verb NP NP*

- It also licenses
  - **The teacher handed a book the student*
- This is problematic for semantic reasons, which we'll cover later.

Verb Phrase and Subcategorization

- Verb phrases include a verb and ***optionally other constituents***
- Subcategorization frame
  - what constituent arguments the verb requires

VP → *Verb Ø*	disappear
VP → *Verb* ***NP***	book a flight
VP → *Verb* ***PP PP***	fly from Chicago to Seattle
VP → *Verb* ***S***	think I want that flight
VP → *Verb* ***VP***	want to arrange three flights

CFGs and Subcategorization

- Issues?
  - “I prefer United has a flight.” (→ ***S***)
  - “I prefer a window seat.” (→ ***NP***)
- How can we solve this problem?
  - Create explicit subclasses of verb
    - *Verb-with-NP* → …
    - *Verb-with-S-complement* → …
  - Is this a good solution?
    - No, explosive increase in number of rules
    - Similar problem with agreement (NN↔ADJ↔PRON↔VB)

CFGs and Subcategorization

- Better solution:
  - *Feature structures:*
    - Further nested information
    - a.k.a → *Deeper* analysis!
  - Will get to this toward end of the month

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Grammars… So What?

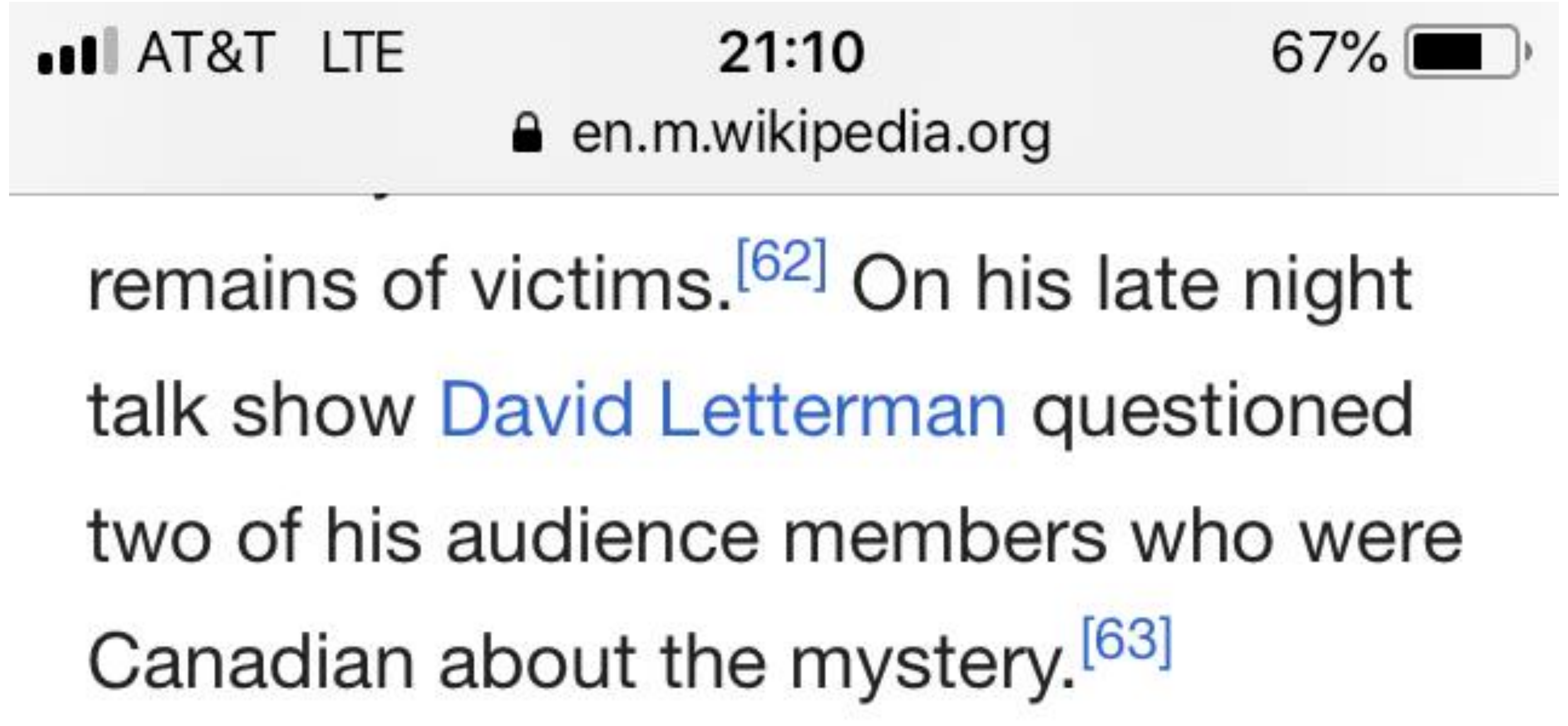
- Grammars propose a formal way to make distinctions in syntax
- Distinctions in syntax can help us get a hold on distinctions in meaning

Syntax to the Rescue!

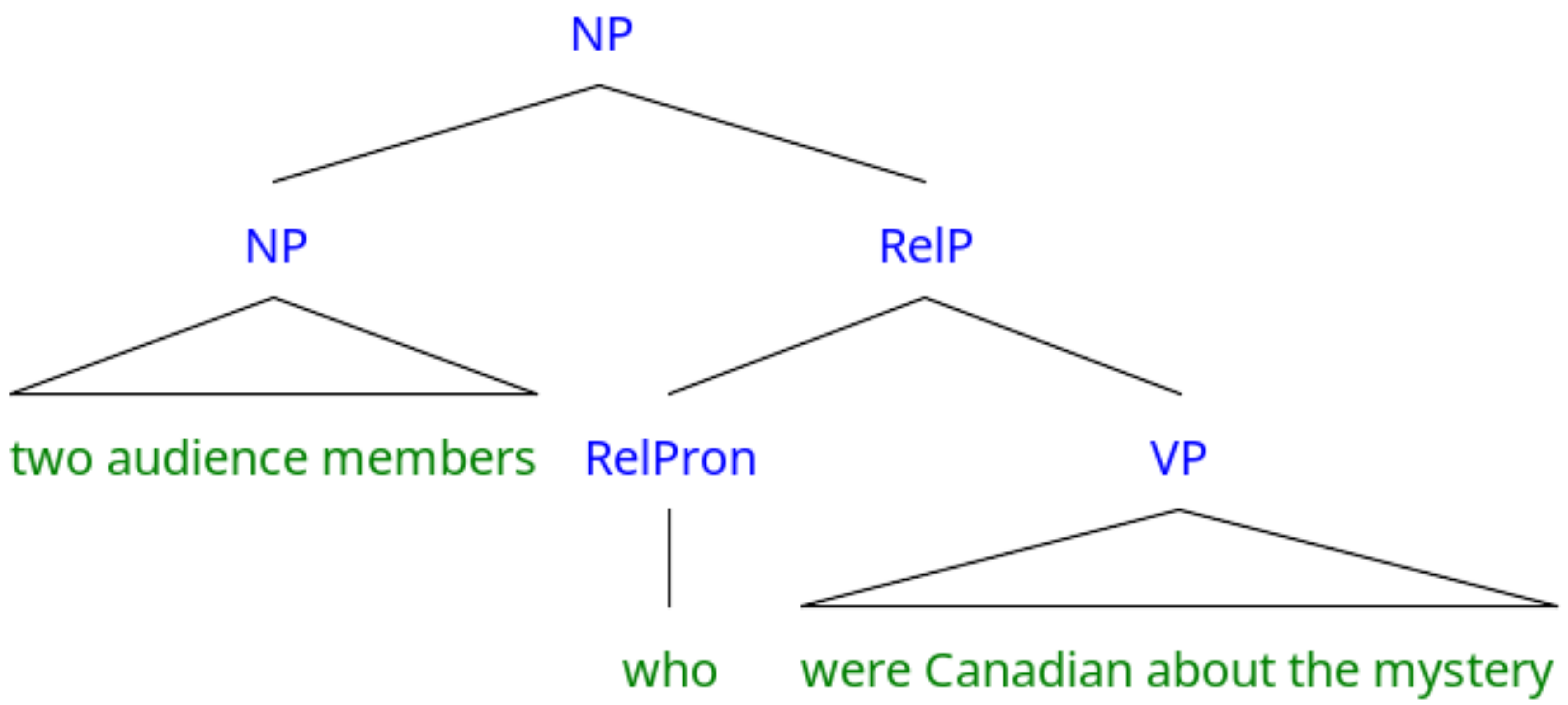
- Possible Interpretations:

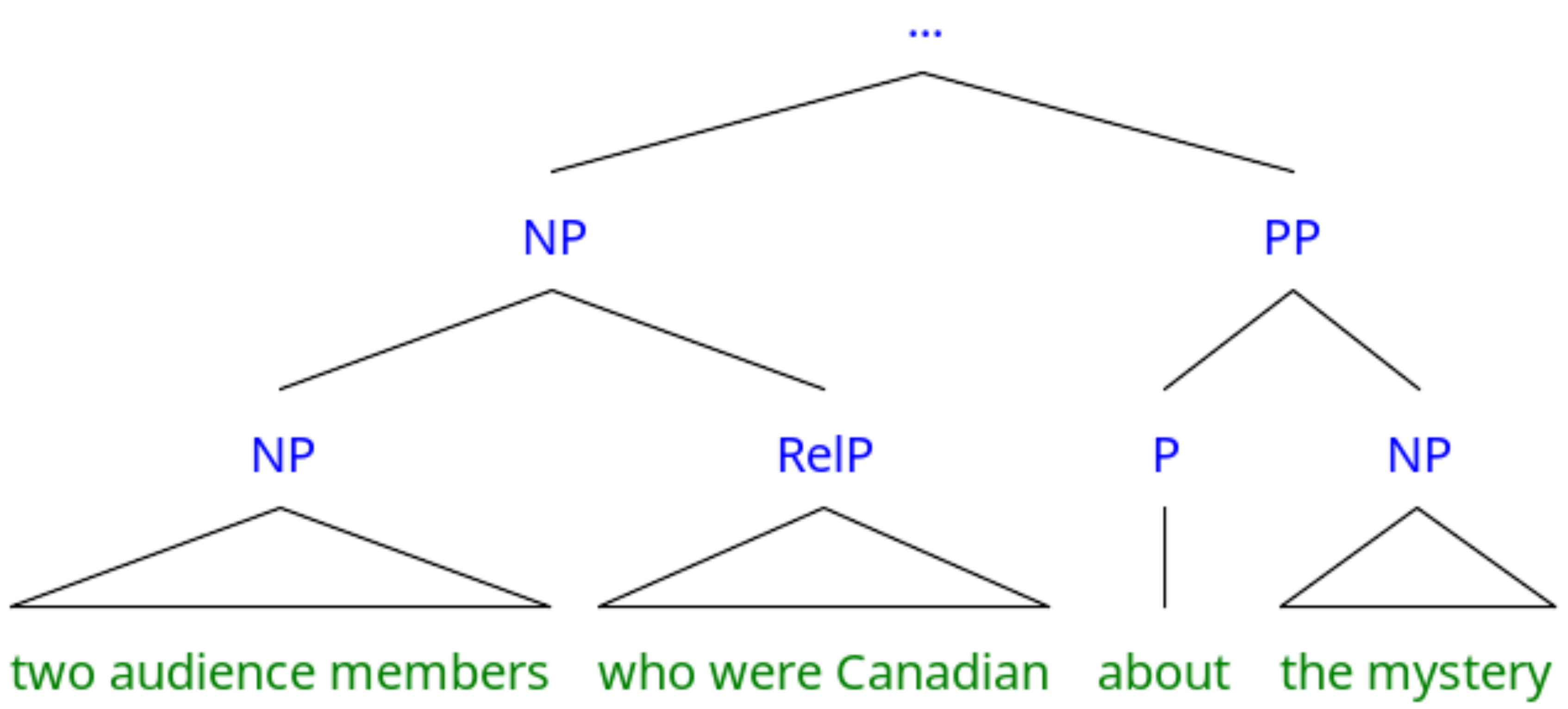
  Two audience members, when questioned, behaved Canadian-ly

  Two audience members, who happened to be Canadian Citizens, were questioned



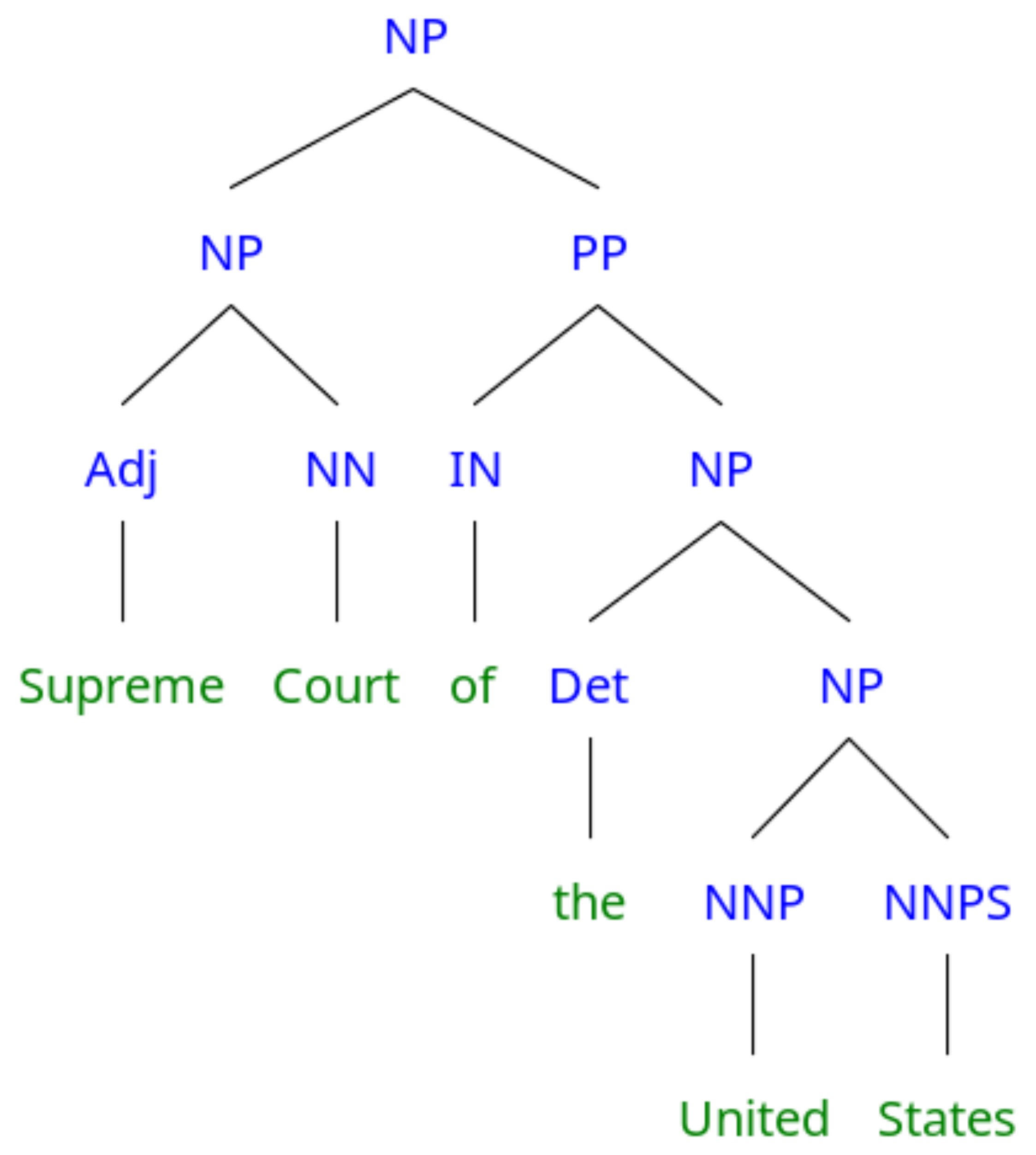
h/t to Amandalynne Paullada


NP
NP
RelP
two audience members
RelPron
VP
who
were Canadian about the mystery


...
NP
PP
NP
RelP
P
NP
two audience members
who were Canadian
about
the mystery

Grammars Promote Deeper Analysis

- Shallow techniques useful, but limited
  - “Supreme Court of the United States”
  - `ADJ NN IN DET NNP NNPS`
  - What does this tell us about the fragment?
- vs.



Grammars Promote Deeper Analysis

- Meaning implicit in this analysis tree:
  - "*The United States*" is an entity
  - The court is specific to the US
- Inferable from this tree:
  - "*The United States*" is an entity that can possess (grammatically) other institutions

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Treebanks

- Instead of writing out grammars by hand, could we learn them from data?
- Large corpus of sentences
- All sentences annotated syntactically with a parse
- Built semi-automatically
  - Automatically parsed, manually corrected

Penn Treebank

- A well-established and large treebank
- English:
  - Brown Univ. Standard Corp. of Present-Day Am. Eng.
  - Switchboard (conversational speech)
  - ATIS (human-computer dialog, Airline bookings)
  - Wall Street Journal
- Chinese:
  - Xinhua, Sinoarma (newswire)
- Arabic
  - Newswire, Broadcast News + Conversation, Web Text…

Other Treebanks

- DeepBank (HPSG)
- Prague Dependency Treebank (Czech: Morphologically rich)
- Universal Dependency Treebank (60 languages, reduced POS tags)
- CCGBank (Penn, but with CCG annotations)

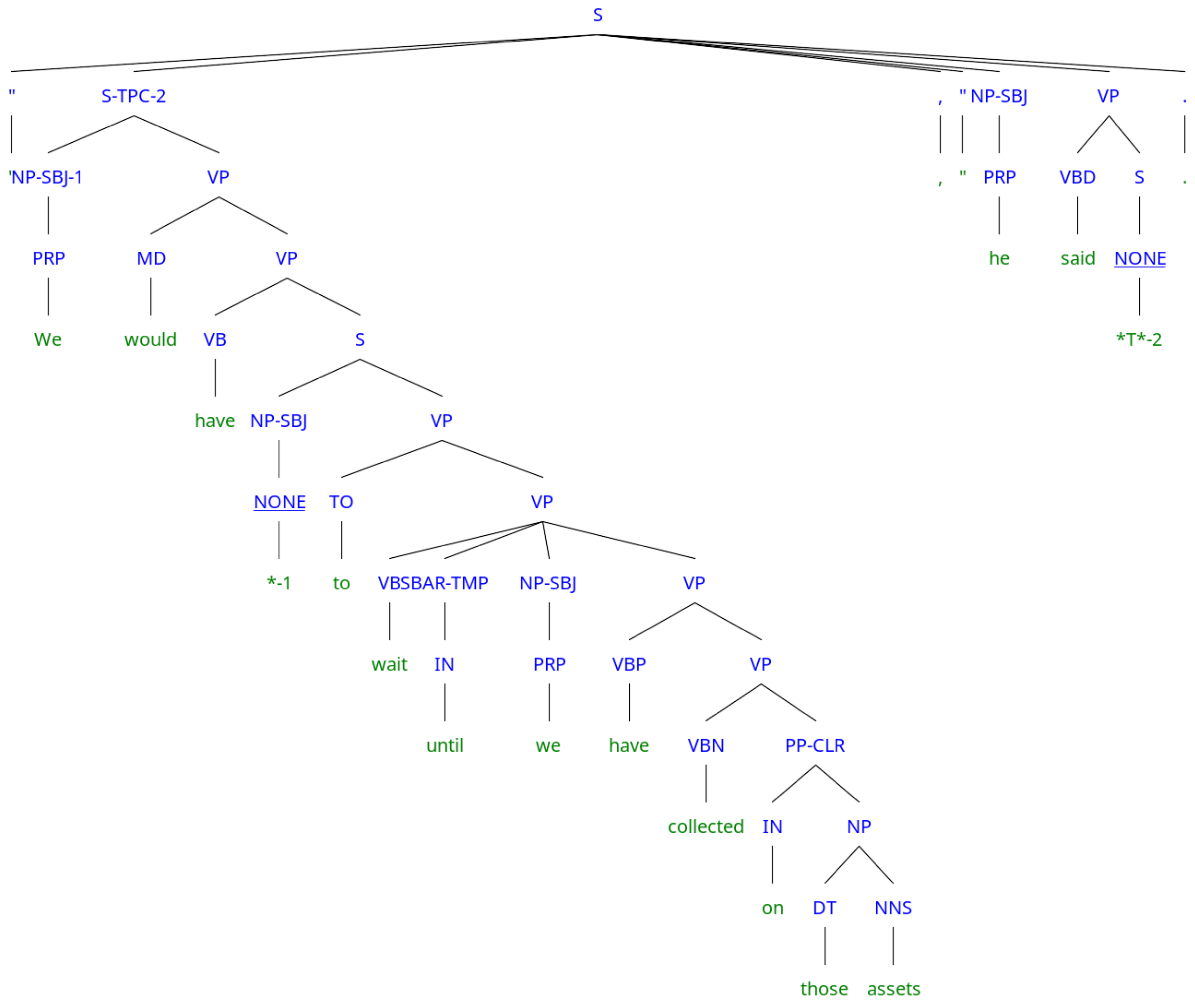
Treebanks

- Include wealth of language information
  - Traces (for movement analyses)
  - Grammatical function (subject, topic, etc)
  - Semantic function (temporal, location)
- Implicitly constitute grammar of language
  - Can read off rewrite rules from bracketing
  - Not only presence of rules, but frequency counts
  - Will be crucial in building statistical parsers

Treebank WSJ Example

```
(S ('' '')
   (S-TPC-2
   (NP-SBJ-1 (PRP We))
   (VP (MD would)
     (VP (VB have)
         (S
           (NP-SBJ (-NONE- *-1))
           (VP (TO to)
                (VP (VB wait)
                     (SBAR-TMP (IN until))
                     (NP-SBJ (PRP we))
                     (VP (VBP have)
                       (VP (VBN collected)
                         (PP-CLR (IN on)
                            (NP (DT those) (NNS assets)))))))))))
   (, ,) ('' '')
   (NP-SBJ (PRP he))
   (VP (VBD said)
     (S (-NONE- *T*-2) ))
   (. .)
)
```

Treebank WSJ Example



Treebanks & Corpora on Patas

```
patas$ ls /corpora
birkbeck                    grammars          opt
coconut                     HathiTrust        private
Communicator2000_Emotion    ICAME             proj-gutenberg
ComParE                     ICSI              reuters
Conll                       JRC-Acquis.3.0    scope
delph-in                    LDC               tc-wikipedia
DUC                         LEAP              TREC
ELRA                        lemur             treebanks
enron_email_dataset         levow             UIC
europarl                    mdsd-2.0          UWCL
europarl-old                med-data          UWCSE
framenet                    nltk
freebase                    OANC
```

Treebanks & Corpora on Patas

- Many large corpora from LDC, such as the Penn Treebank v3:
  - `/corpora/LDC/LDC99T42/`
  - Find the full LDC corpora catalog online: catalog.ldc.upenn.edu
- Web search interface: https://cldb.ling.washington.edu/livesearch-corpus-form.php
- Many corpus samples in NLTK
  - `/corpora/nltk/nltk-data`
- **NOTE:** do not move corpora, either *within* or *off of* patas!!

Treebank Issues

- Large, expensive to produce
- Complex
  - Agreement among annotators can be an issue
- Labeling implicitly captures bias in theory
  - Penn Treebank is “bushy,” long productions
- Enormous numbers of rules
  - **4,500** rules in PTB for VP alone
  - 1M rule tokens; 17,500 distinct types — and counting!

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- Parsing

Spoken vs. Written

- Can we just use models for written language directly?
- **NO!**
- Challenges of spoken language:
  - Disfluency
    - *Can I um uh can I g– get a flight to Boston on the fifteenth?*
  - Short, fragmentary
    - *Uh one way*
    - Only 37% of Switchboard utterances > 2 words
  - More pronouns, ellipsis
    - *That one*

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Computational Parsing

- Given a grammar, how can we derive the analysis of an input sentence?
  - Parsing as search
  - CKY parsing
- Given a body of (annotated) text, how can we derive the grammar rules of a language, and employ them in automatic parsing?
  - Treebanks & PCFGs

What is Parsing?

- CFG parsing is the task of assigning trees to input strings
  - For any input ***A*** and grammar ***G***
    - …assign ≥0 parse trees ***T*** that represent its syntactic structure, and…
    - Cover all and only the elements of ***A***
    - Have, as root, the start symbol ***S*** of ***G***
    - …do not necessarily pick one single (or correct) analysis
- Subtask: Recognition
  - Given input ***A***, ***G*** – is ***A*** in language defined by ***G*** or not?

Motivation

- Is this sentence in the language — i.e. is it “grammatical?”
  - ** I prefer United has the earliest flight.*
  - FSAs accept regular languages defined by finite-state automata.
  - Parsers accept languages defined by CFG (equiv. pushdown automata).
- What is the syntactic structure of this sentence?
  - *What airline has the cheapest flight?*
  - *What airport does Southwest fly from near Boston?*
  - Syntactic parse provides framework for semantic analysis
    - What is the subject? Direct object?

Parsing as Search

- Syntactic parsing searches through possible trees to find one or more trees that derive input
- Formally, search problems are defined by:
  - Start state ***S***
  - Goal state ***G*** (with a test)
  - Set of actions that transition from one state to another
    - "Successor function"
  - A path cost function

Parsing as Search: One Model

- Start State ***S***: Start Symbol
- Goal test:
  - Does the parse tree cover all of, and only, the input?
- Successor function:
  - Expand a nonterminal using a production where nonterminal is the LHS of the production
- Path cost:
  - …ignored for now.

Parsing as Search: One Model

- Node:
  - Partial solution to search problem (partial parse)
- Search start node (initial state):
  - Input string
  - Start symbol of CFG
- Goal node:
  - Full parse tree: covering all of, and only the input, rooted at ***S***

Search Algorithms

- Depth First
  - Keep expanding nonterminals until they reach words
  - If no more expansions available, back up
- Breadth First
  - Consider all parses that expand a single nonterminal…
  - …then all with two expanded, etc…
- Other alternatives, if have associated path costs.

Parse Search Strategies

- Two constraints on parsing:
  - Must start with the start symbol
  - Must cover exactly the input string
- Correspond to main parsing search strategies
  - Top-down search (Goal-directed)
  - Bottom-up search (Data-driven search)

A Grammar

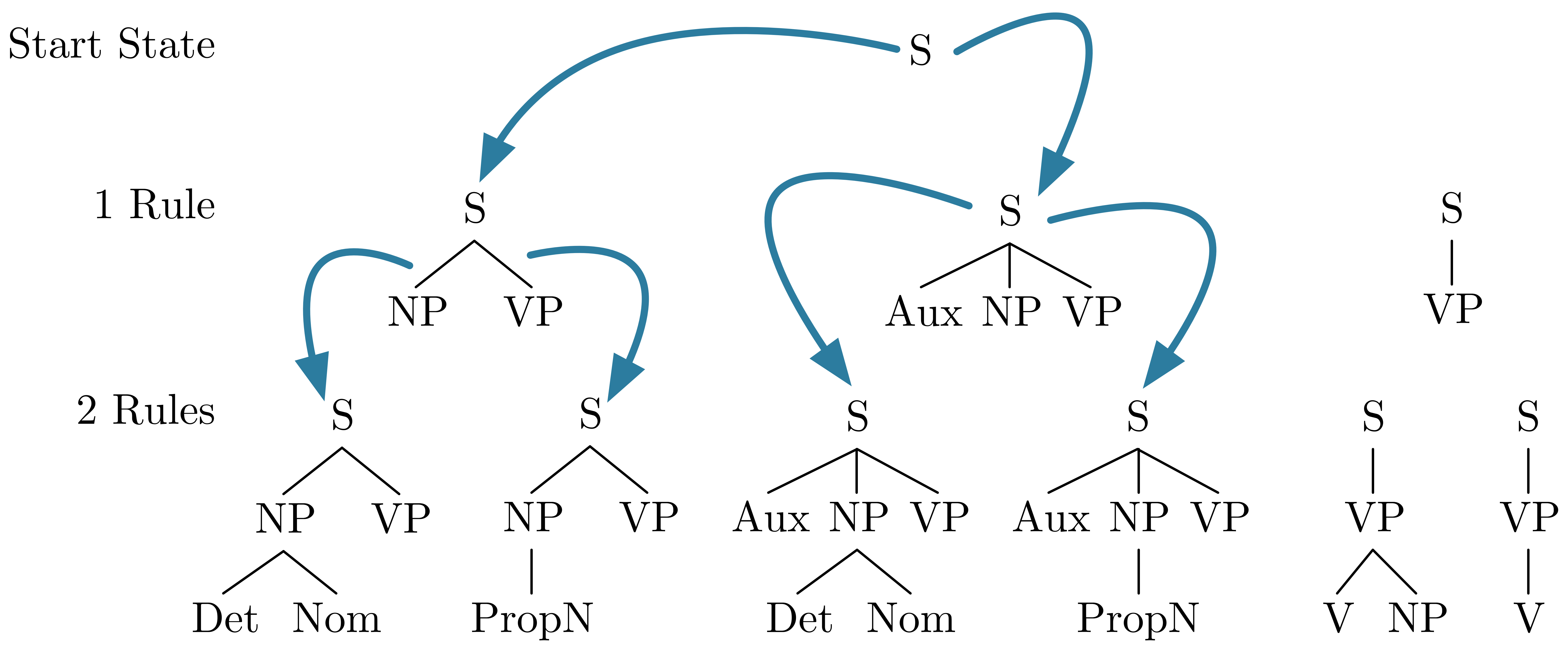
Grammar	Lexicon
S → NP VP	*Det → that ǀ this ǀ a*
S → Aux NP VP	*Noun → book ǀ flight ǀ meal ǀ money*
S → VP	*Verb → book ǀ include ǀ prefer*
NP → Pronoun	*Pronoun → I ǀ she ǀ me*
NP → Proper-Noun	*Proper-Noun → Houston ǀ NWA*
NP → Det Nominal	*Aux → does*
Nominal → Noun	*Preposition → from ǀ to ǀ on ǀ near ǀ through*
Nominal → Nominal Noun	
Nominal → Nominal PP	
VP → Verb	
VP → Verb NP	
VP → Verb NP PP	
VP → Verb PP	
VP → VP PP	
PP → Preposition NP	

Jurafsky & Martin, Speech and Language Processing, p.390

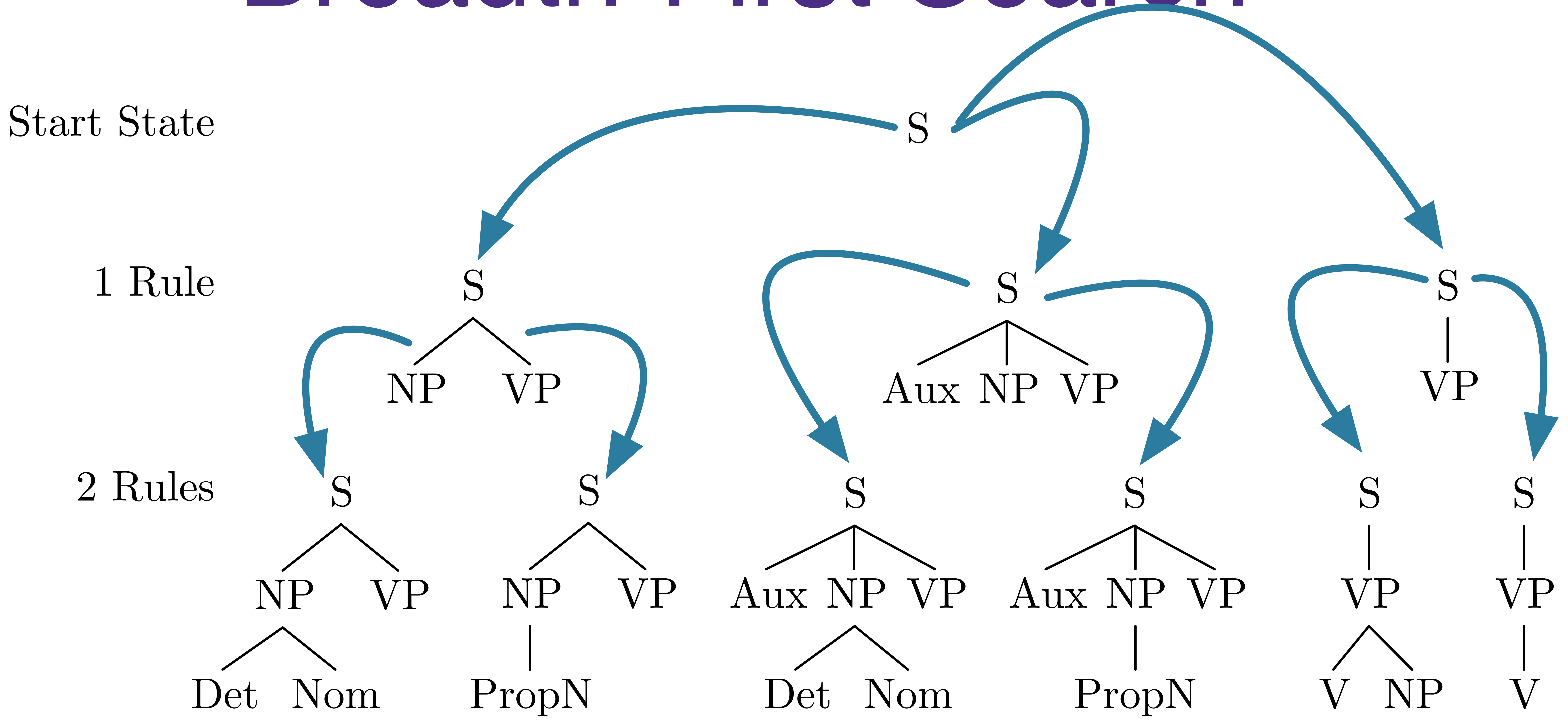
Top-down Search

- All valid parse trees must be rooted with start symbol
- Begin search with productions where S is on LHS
  - e.g. $S \rightarrow NP\ VP$
- Successively expand nonterminals
  - e.g. $NP \rightarrow Det\ Nominal$; $VP \rightarrow V\ NP$
- Terminate when all leaves are terminals

Depth-First Search

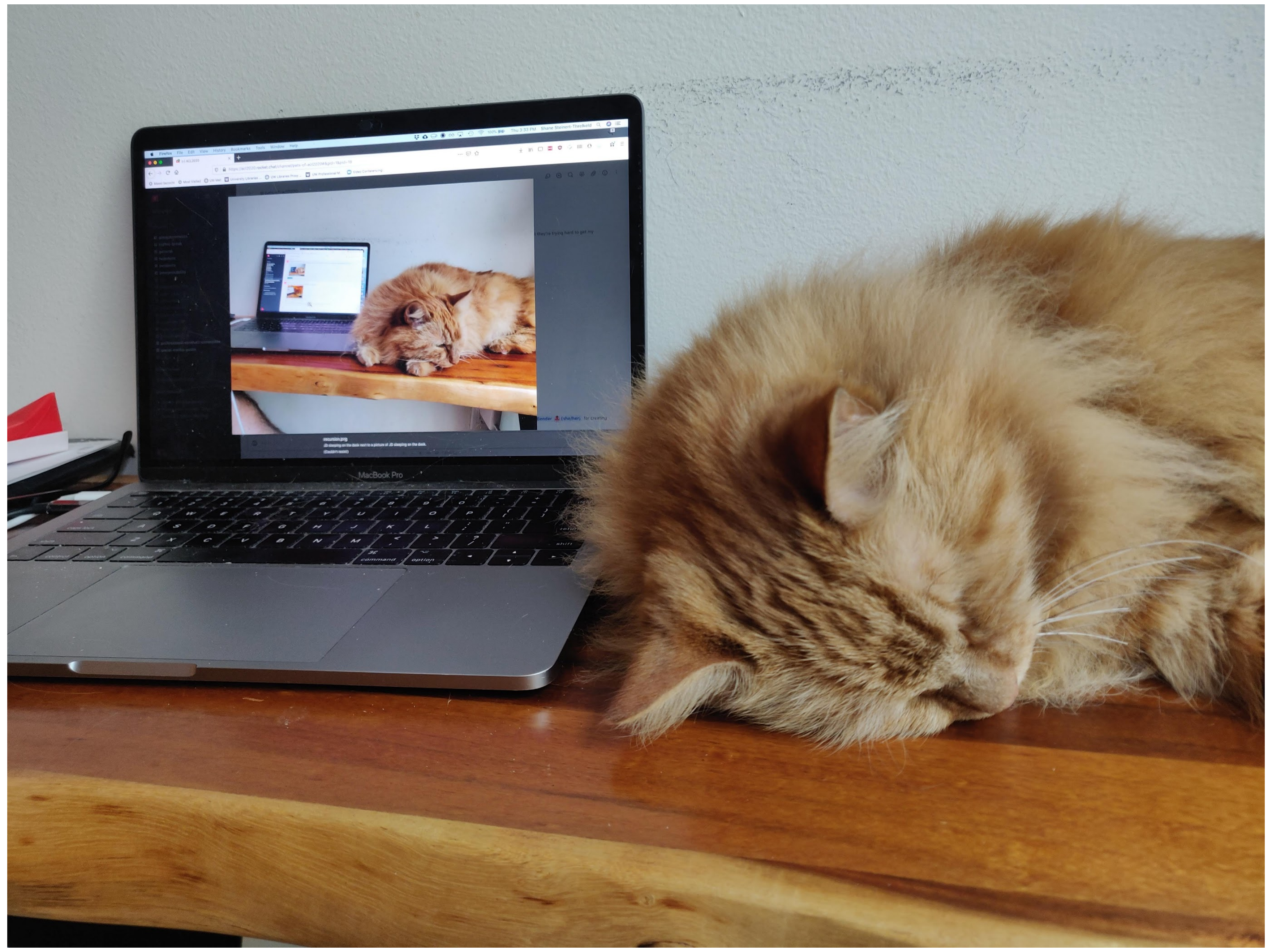


Breadth-First Search



Pros and Cons of Top-down Parsing

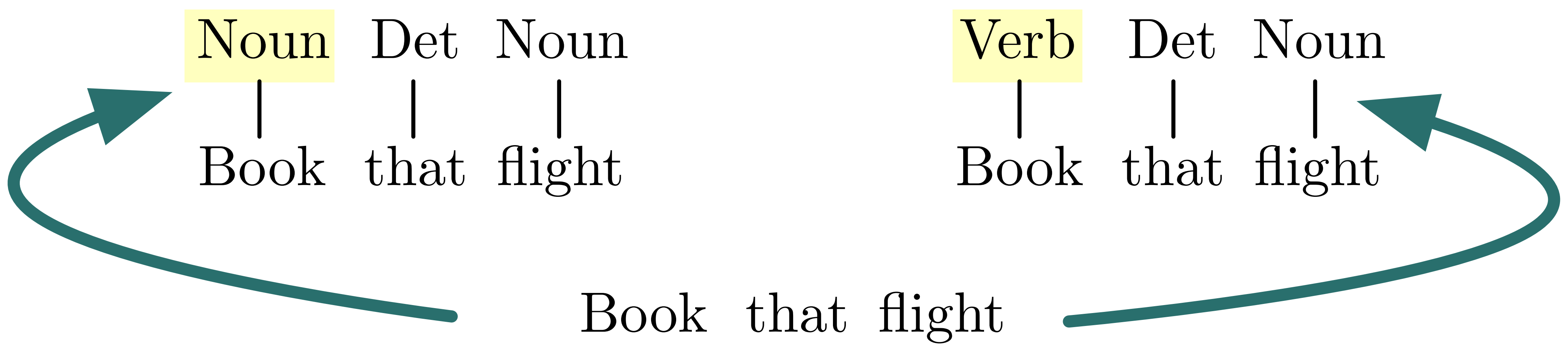
- Pros:
  - Doesn't explore trees not rooted at S
  - Doesn't explore subtrees that don't fit valid trees
- Cons:
  - Produces trees that may not match input
  - May not terminate in presence of recursive rules
  - May re-derive subtrees as part of search

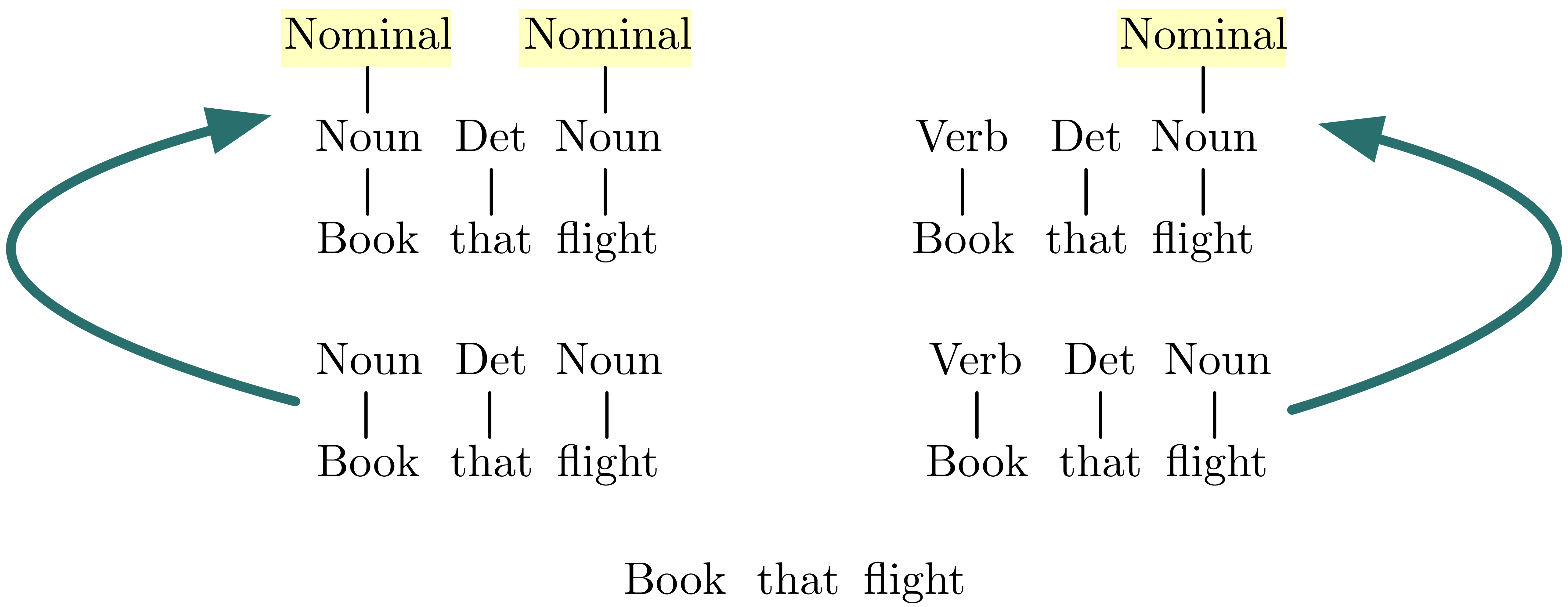


Bottom-Up Parsing

- Try to find all trees that span the input
  - Start with input string
    - Book that flight
- Use all productions with current subtree(s) on RHS
  - e.g. ***N*** → Book; ***V*** → Book
- Stop when spanned by S, or no more rules apply

Book that flight


Noun Det Noun
Book that flight
Verb Det Noun
Book that flight
Book that flight



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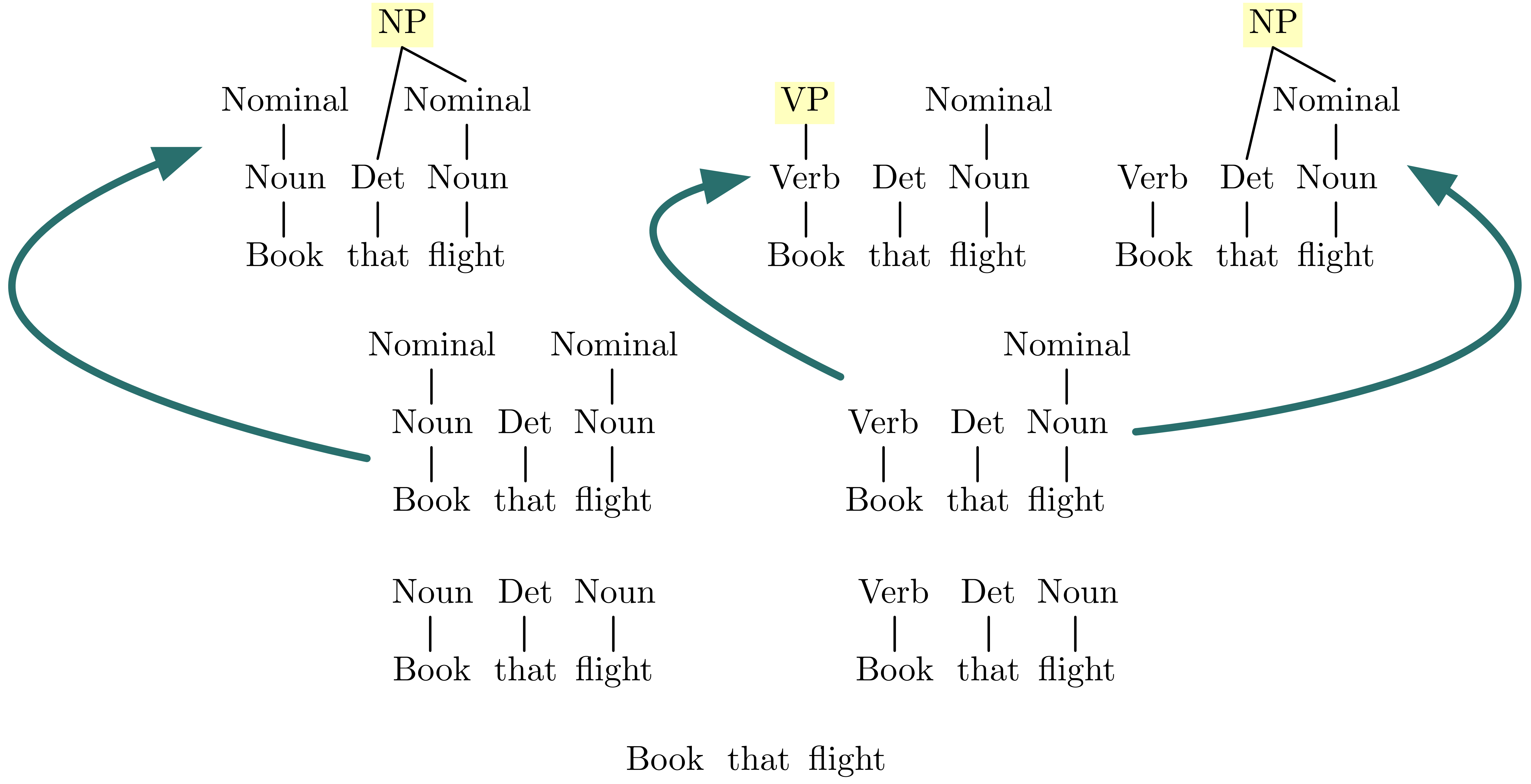
NP
Nominal Nominal
Noun Det Noun
Book that flight
VP Nominal
Verb Det Noun
Book that flight
NP
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Verb Det Noun
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Verb Det Noun
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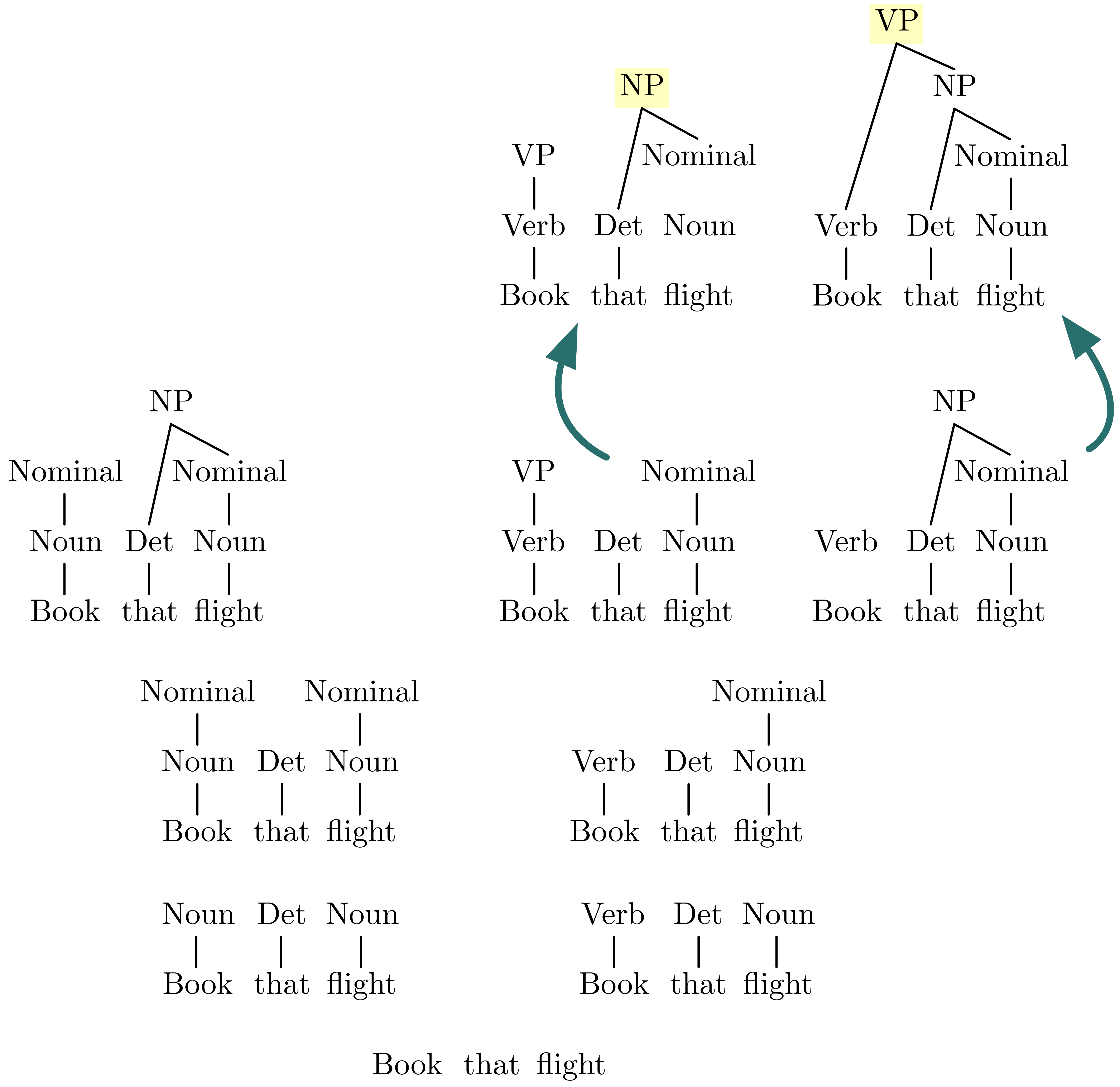
Book that flight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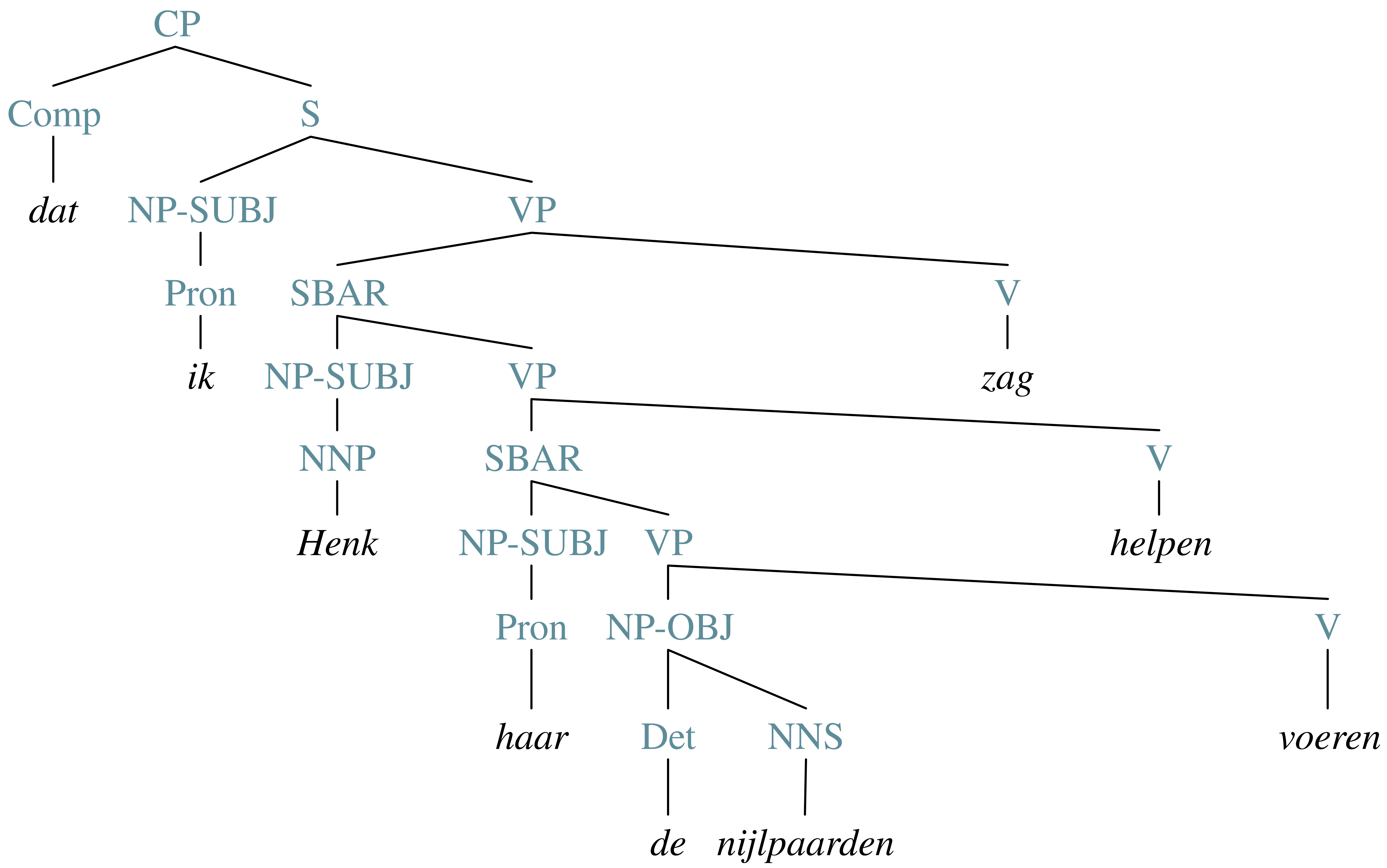
Pros and Cons of Bottom-Up Search

- Pros:
  - Will not explore trees that don’t match input
  - Recursive rules less problematic
  - Useful for incremental/fragment parsing
- Cons:
  - Explore subtrees that will not fit full input

Cross-Serial Dependencies, Revisited

$L' = a^m b^n c^m d^n$

ik_1	$Henk_2$	$haar_3$	$nijlpaarden_3$	zag_1	$helpen_2$	$voeren_3$
I_1	$Henk_2$	her_3	hippos	saw_1	$help_2$	$feed_3$


CP
Comp
S
dat
NP-SUBJ
VP
Pron
SBAR
V
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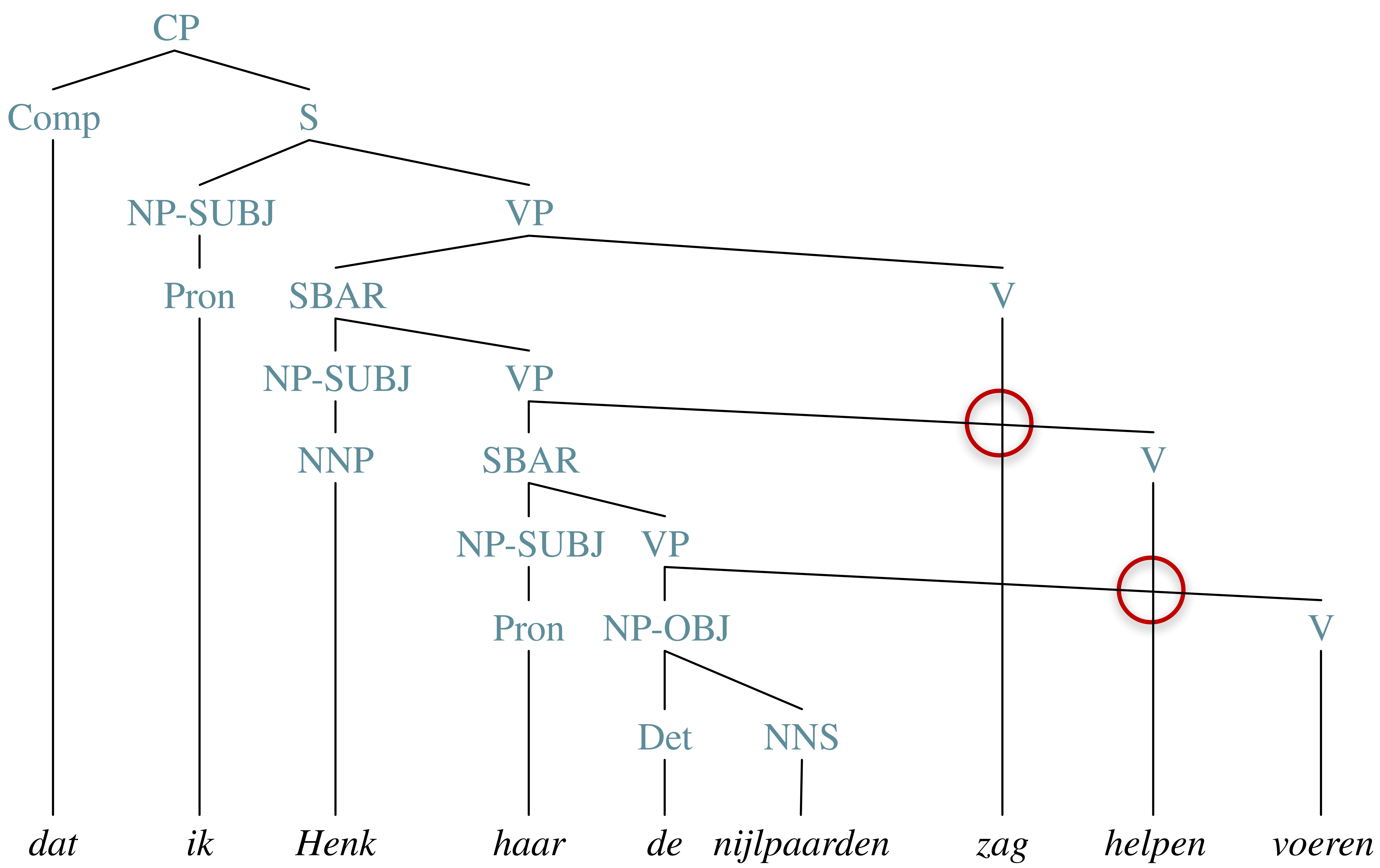
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Next Time

- Beginning to implement CFG parsing algorithms
- Conversion to Chomsky Normal Form
  - Required for CKY algorithm
- HW2 out