Syntax: Context-Free Grammars

LING 571 — Deep Processing Techniques for NLP
Oct 1, 2018
Ryan Georgi

Announcements

- Don't worry about Canvas renaming your files with -1, -2, etc.
- **HW #1** Due Tonight, 11:00PM

Commandline Arguments in Bash & Python

- When we say "don't hardcode," two solutions:
  - `sys.argv` or `argparse` in Python *(links go to tutorials)*
  - `$1`, `$2`, or `$@` in bash

- Helpful commands: obtaining the directory containing a script:
  - `dirname $0` [bash]
  - `os.path.dirname(__file__)` [python]

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 ✗

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Representation: Context-free Grammars

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

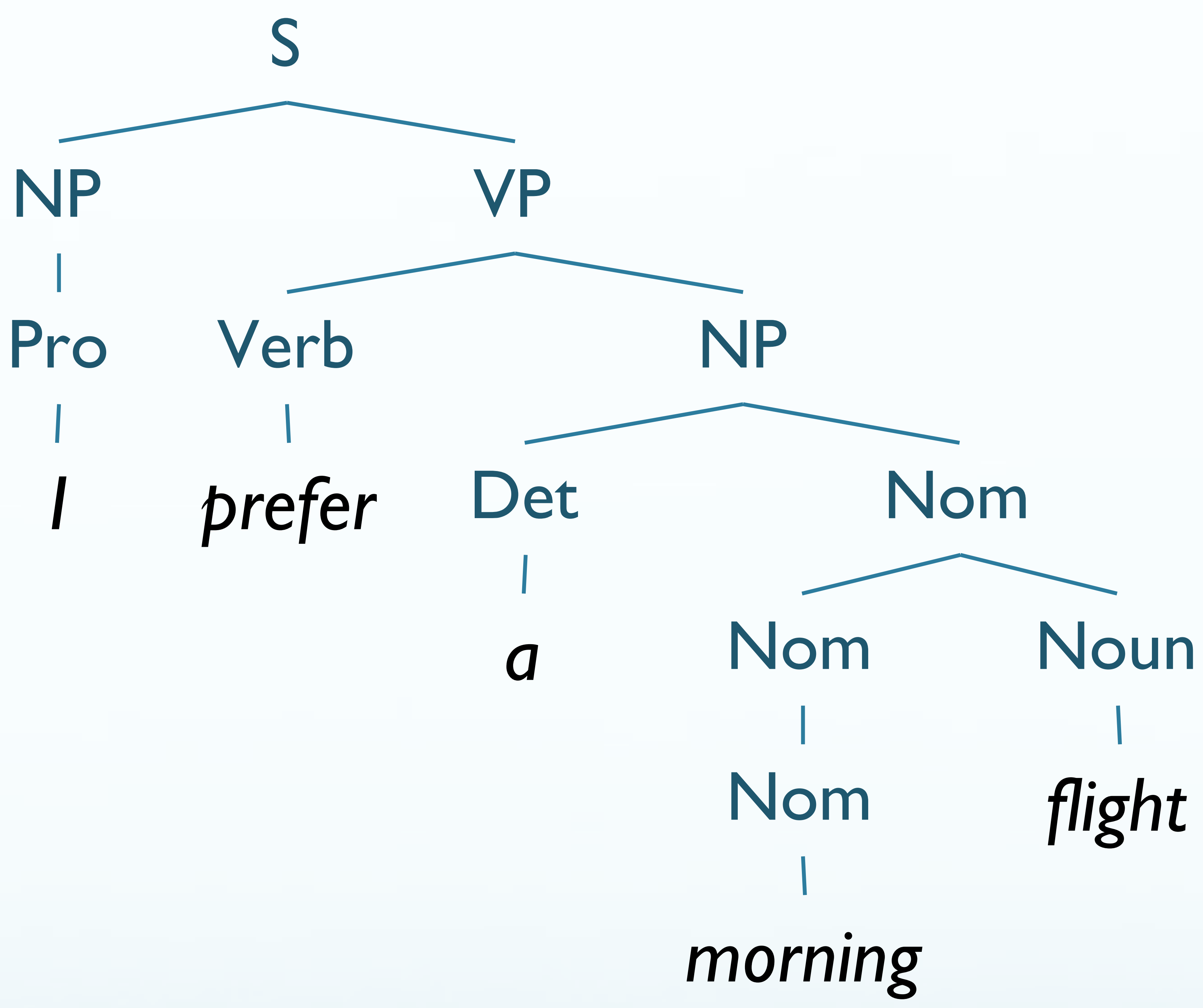
CFG Components

- Productions:
  - One non-terminal on LHS and any number 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
PP	→	*Preposition NP*	from + Los Angeles

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

Parse Tree


S
NP
VP
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I
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Noun
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flight
morning

Some English Grammar

- Sentences: Full sentence or clause; a complete thought
- **Declarative**: $S \rightarrow \boldsymbol{NP}\ \boldsymbol{VP}$
  - [I $_{\mathrm{NP}}$] [want a flight from SeaTac to Denver. $_{\mathrm{VP}}$]
- **Imperative**: $S \rightarrow \boldsymbol{VP}$
  - [Show me the cheapest flight from New York to Los Angeles. $_{\mathrm{VP}}$]
- **Yes-no Question**: $S \rightarrow \boldsymbol{Aux}\ \boldsymbol{NP}\ \boldsymbol{VP}$
  - [Can $_{\mathrm{Aux}}$] [you $_{\mathrm{NP}}$] [give me the nonstop flights to Boston? $_{\mathrm{VP}}$]
- **Wh-subject question**: $S \rightarrow \boldsymbol{Wh\text{-}NP}\ \boldsymbol{VP}$
  - [Which flights $_{\mathrm{Wh\text{-}NP}}$] [arrive in Pittsburgh before 10pm? $_{\mathrm{VP}}$]
- **Wh-non-subject question**: $S \rightarrow \boldsymbol{Wh\text{-}NP}\ \boldsymbol{Aux}\ \boldsymbol{NP}\ \boldsymbol{VP}$
  - [What flights $_{\mathrm{Wh\text{-}NP}}$] [do $_{\mathrm{Aux}}$] [you $_{\mathrm{NP}}$] [have from Seattle to Orlando? $_{\mathrm{VP}}$]

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
those flights

the flights
any flights

this flight
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

- $Det \rightarrow DT$
  - *'the', 'this', 'a', 'those'*
- $Det \rightarrow$ ***NP*** **'s**
  - "United's flight": $[[\textbf{United}\ _{\text{NP}}]\ \textbf{'s}\ _{\text{Det}}]$ flight
  - "Chicago's airport": $[[\textbf{Chicago}\ _{\text{NP}}]\ \textbf{'s}\ _{\text{Det}}]$ airport

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', 'dinner', 'airport', 'Chicago Midway'*

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*

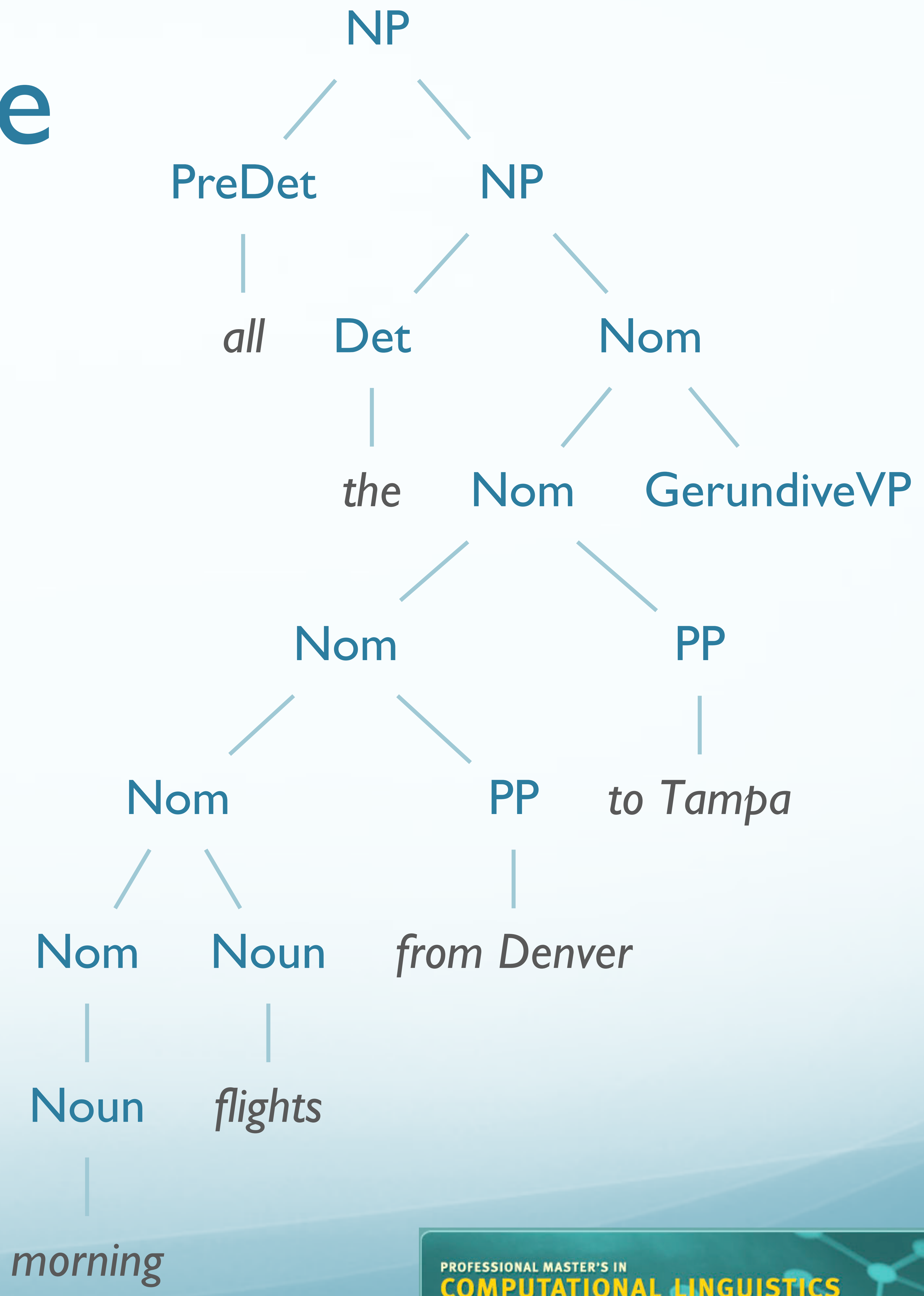
- **The least expensive** fare
- **one** flight
- **the first** route
- **the last** flight **from Chicago**

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"*



Verb Phrases and Subcategorization

- With this grammar:

$$\begin{array}{lcl} VP & \longrightarrow & Verb \\ & | & Verb\ NP \\ & | & Verb\ NP\ NP \end{array}$$

- This grammar licenses the following ***correctly***:
  - The teacher handed the student a book
- And the following ***incorrectly:***
  - *The teacher handed the student
  - *The teacher handed a book
  - *The teacher handed

Verb Phrases and Subcategorization

- With this grammar:

$$\begin{array}{lcc} VP & \longrightarrow & Verb \\ & | & Verb\ NP \\ & | & Verb\ NP\ NP \end{array}$$

- It also licenses
  - *****<span></span>*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

$VP \rightarrow Verb\ \emptyset$	disappear
$VP \rightarrow Verb\ \boldsymbol{NP}$	book a flight
$VP \rightarrow Verb\ \boldsymbol{PP}\ \boldsymbol{PP}$	fly from Chicago to Seattle
$VP \rightarrow Verb\ \boldsymbol{S}$	think I want that flight
$VP \rightarrow Verb\ \boldsymbol{VP}$	want to arrange three flights

CFGs and Subcategorization

- Issues?
  - "I prefer United has a flight." ($\rightarrow$ S)
  - "I prefer a window seat." ($\rightarrow$ NP)
- How can we solve this problem?
  - Create explicit subclasses of verb
    - $Verb\text{-}with\text{-}NP \rightarrow \ldots$
    - $Verb\text{-}with\text{-}S\text{-}complement \rightarrow \ldots$
  - 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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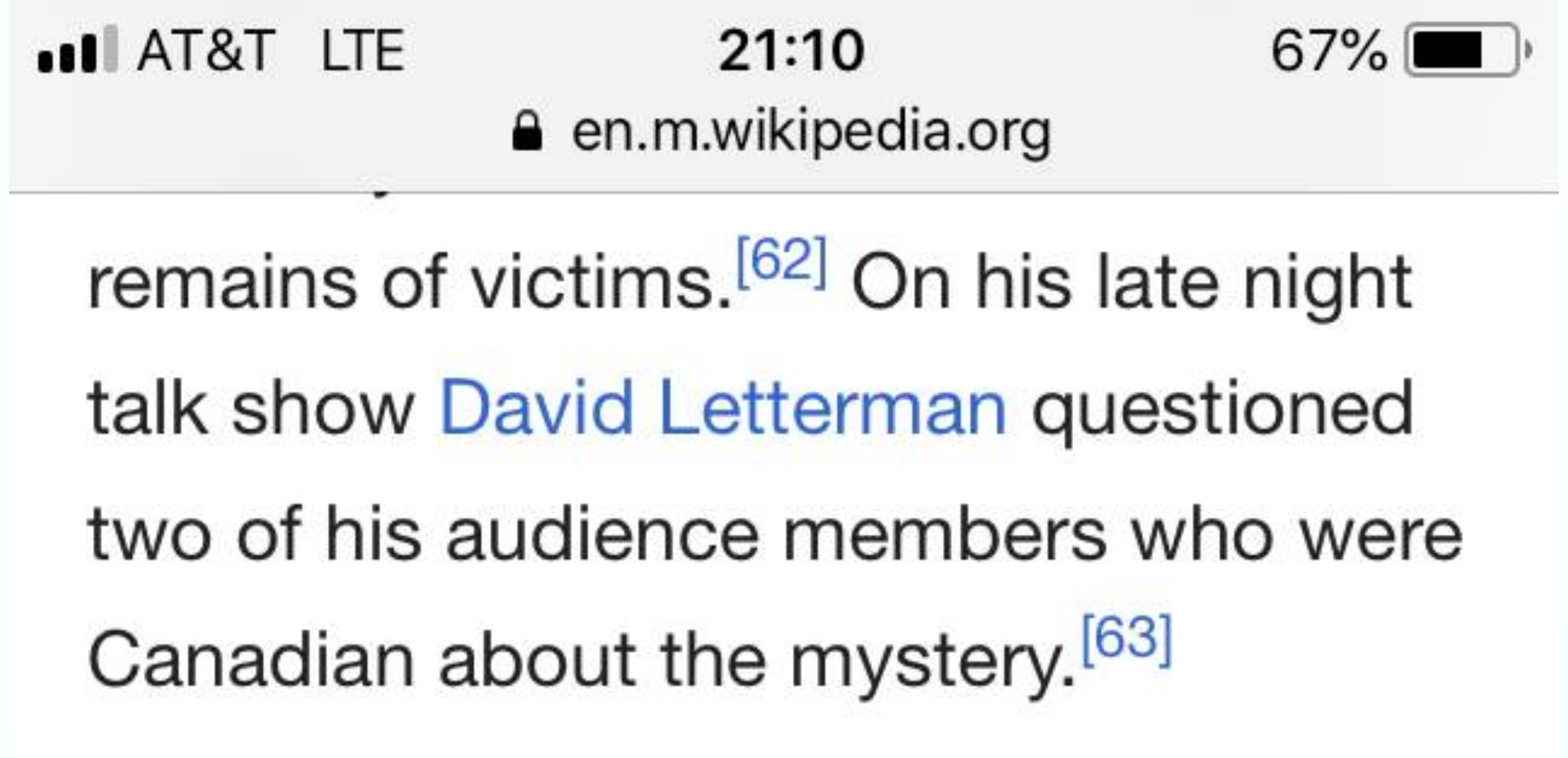
Grammars… So What?

- 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!



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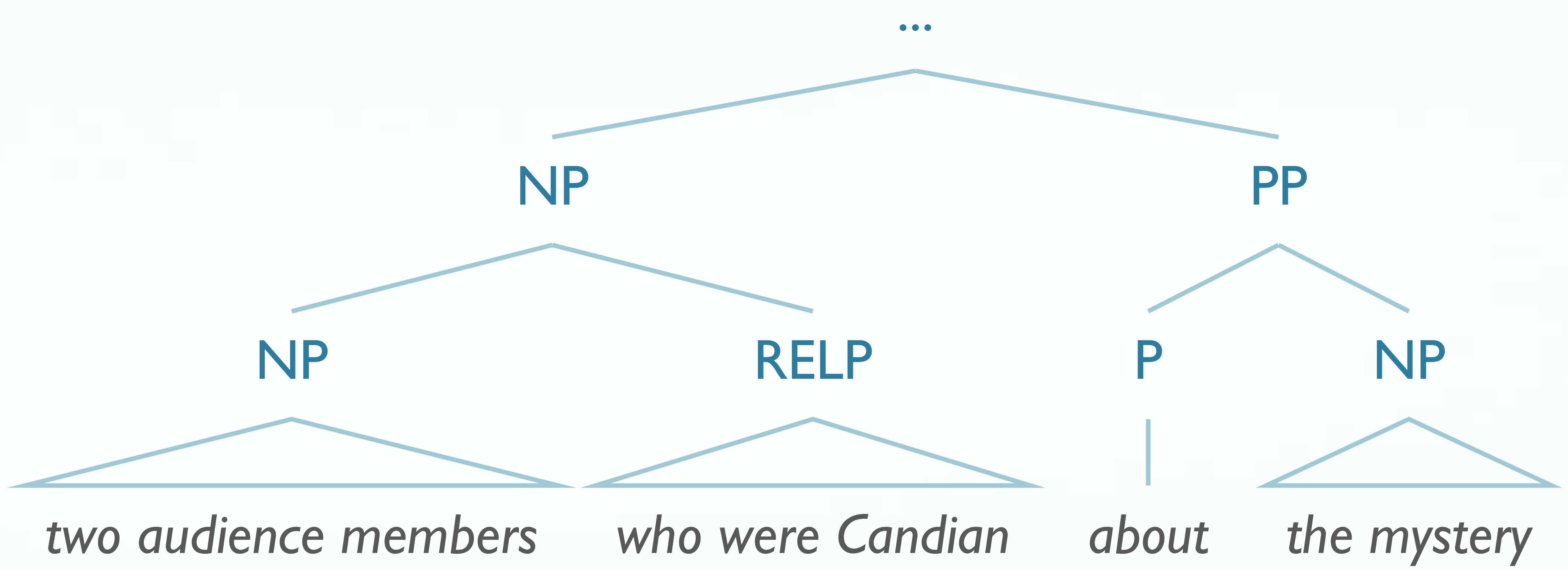
remains of victims.[62] On his late night talk show David Letterman questioned two of his audience members who were Canadian about the mystery.[63]

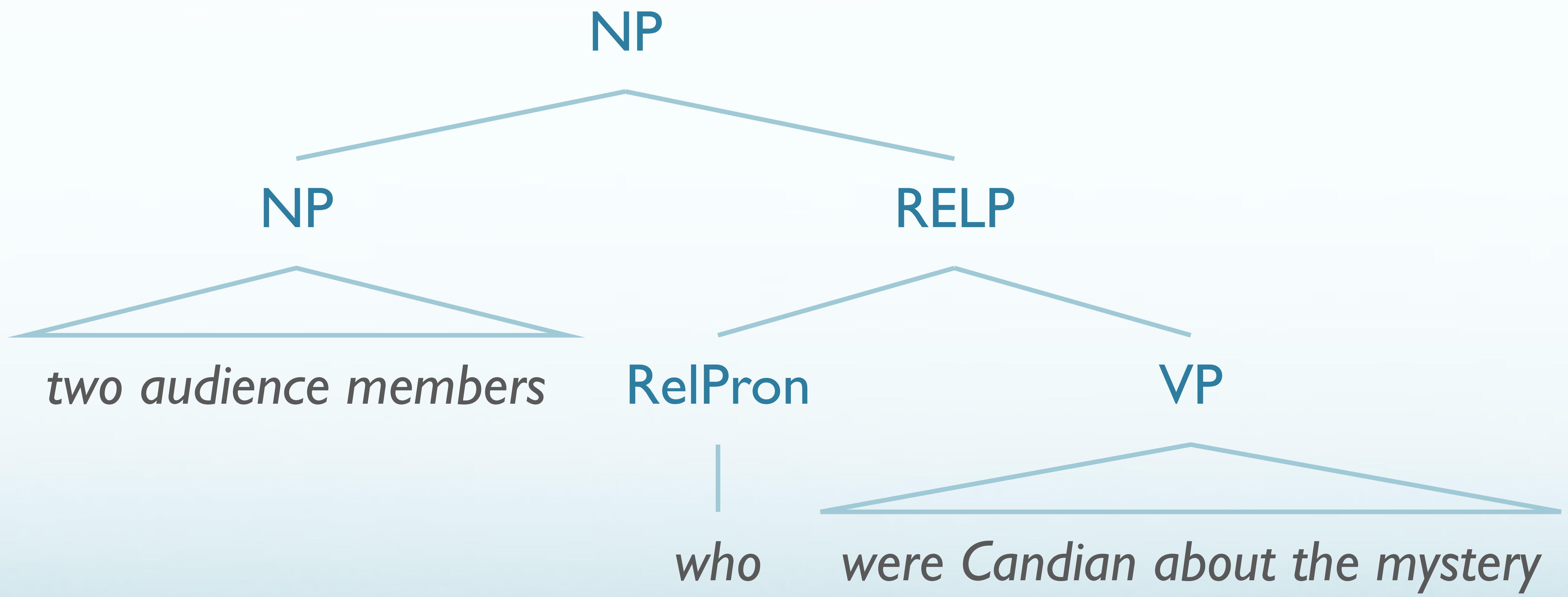
h/t to Amandalynne Paullada

- Possible Interpretations:

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

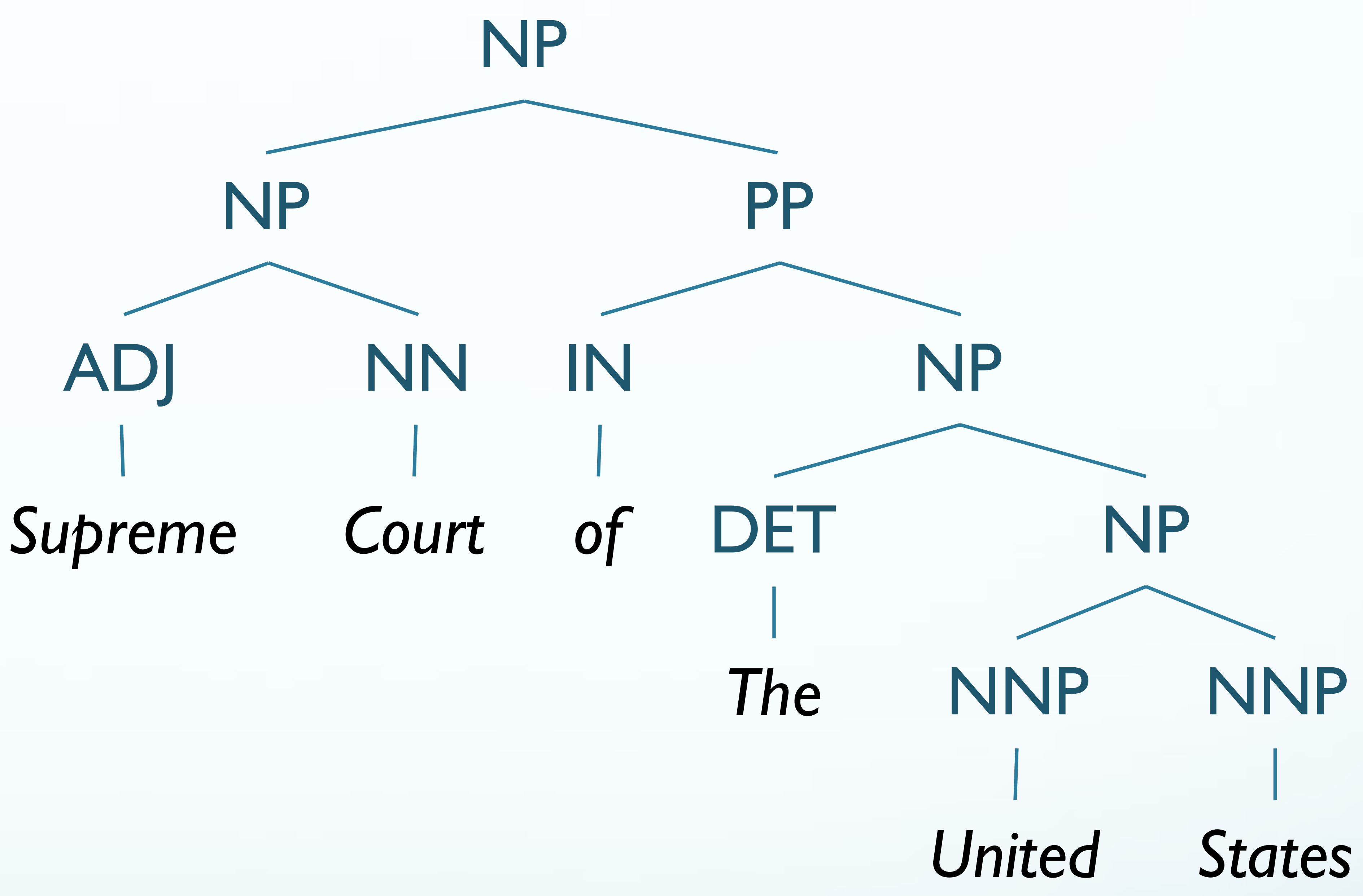
B. Two audience members, when questioned, behaved Canadian-ly


…
NP
PP
NP
RELP
P
NP
two audience members
who were Candian
about
the mystery


NP
NP
RELP
two audience members
RelPron
VP
who
were Candian about the mystery

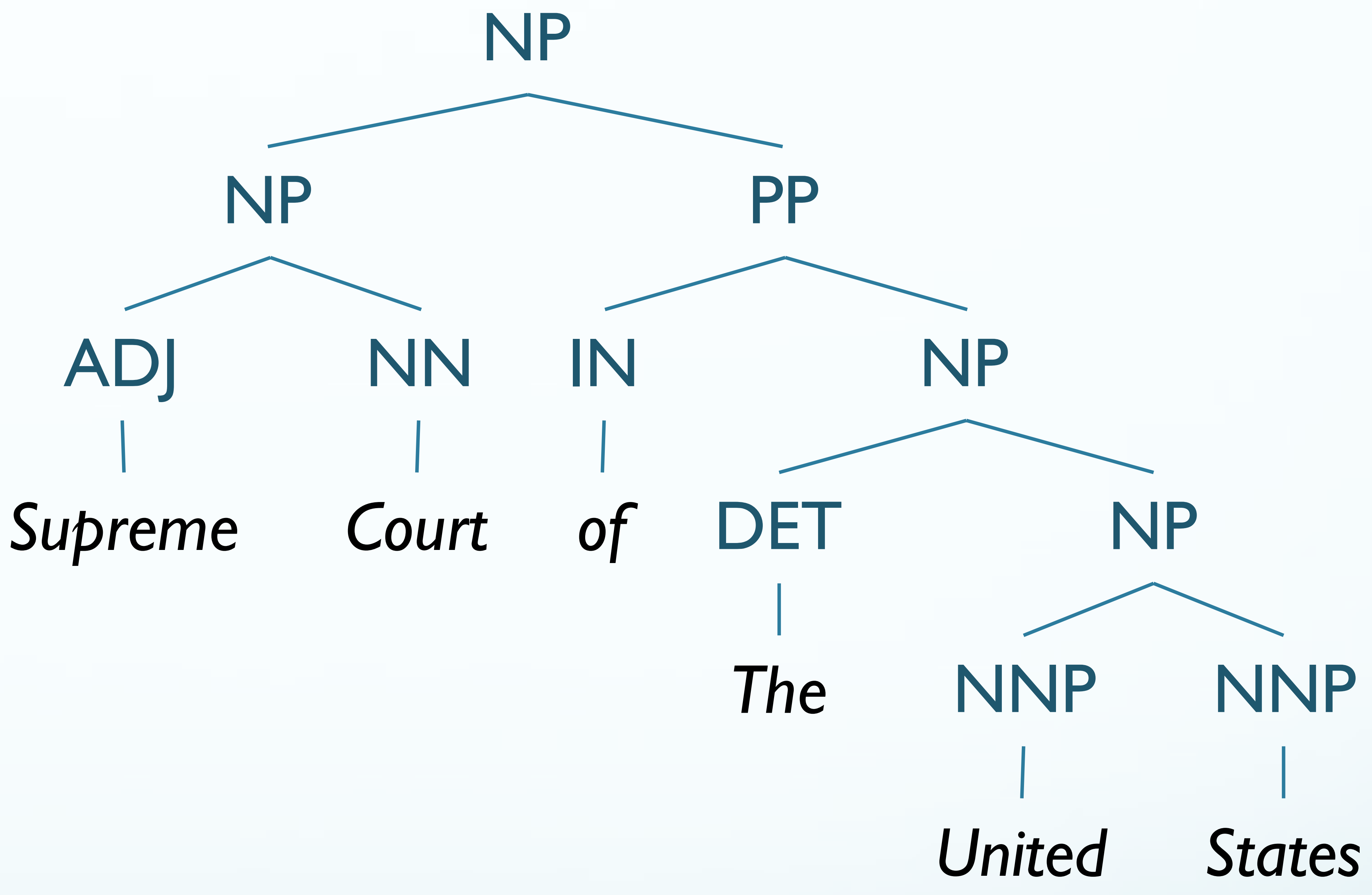
Grammars Promote Deeper Analysis

- Shallow techniques useful, but limited
  - "Supreme Court of the United States"
  - `ADJ NN IN DET NNP NNP`
  - 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: Morphological rich)
- Universal Dependency Treebank (60 languages, reduced POS tags)

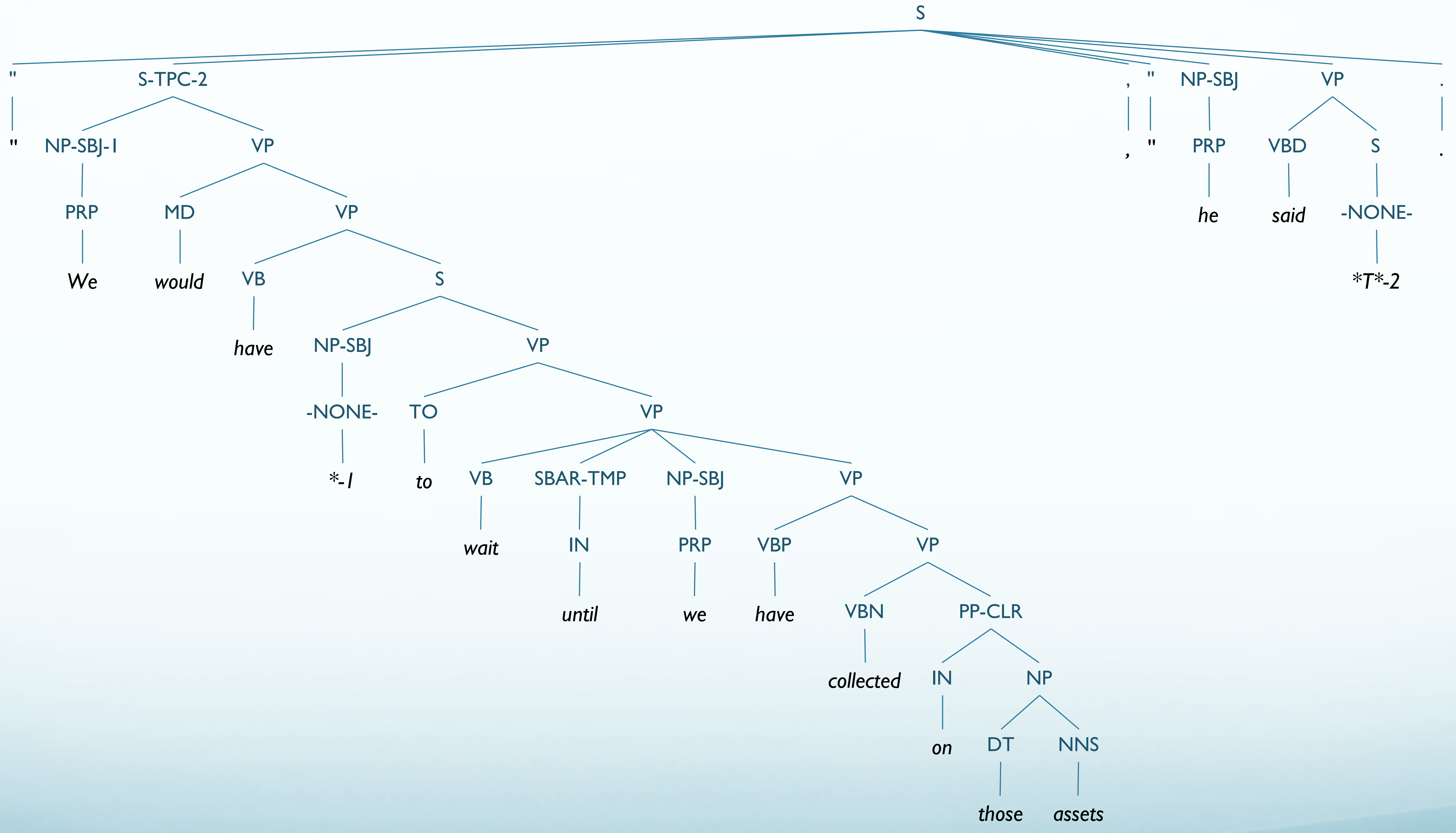
Treebanks

- 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
- Many corpus samples in NLTK
  - `/corpora/nltk/nltk-data`

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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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*

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

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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 automaton.
  - Parsers accept languages defined by CFG.
- 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
  - 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

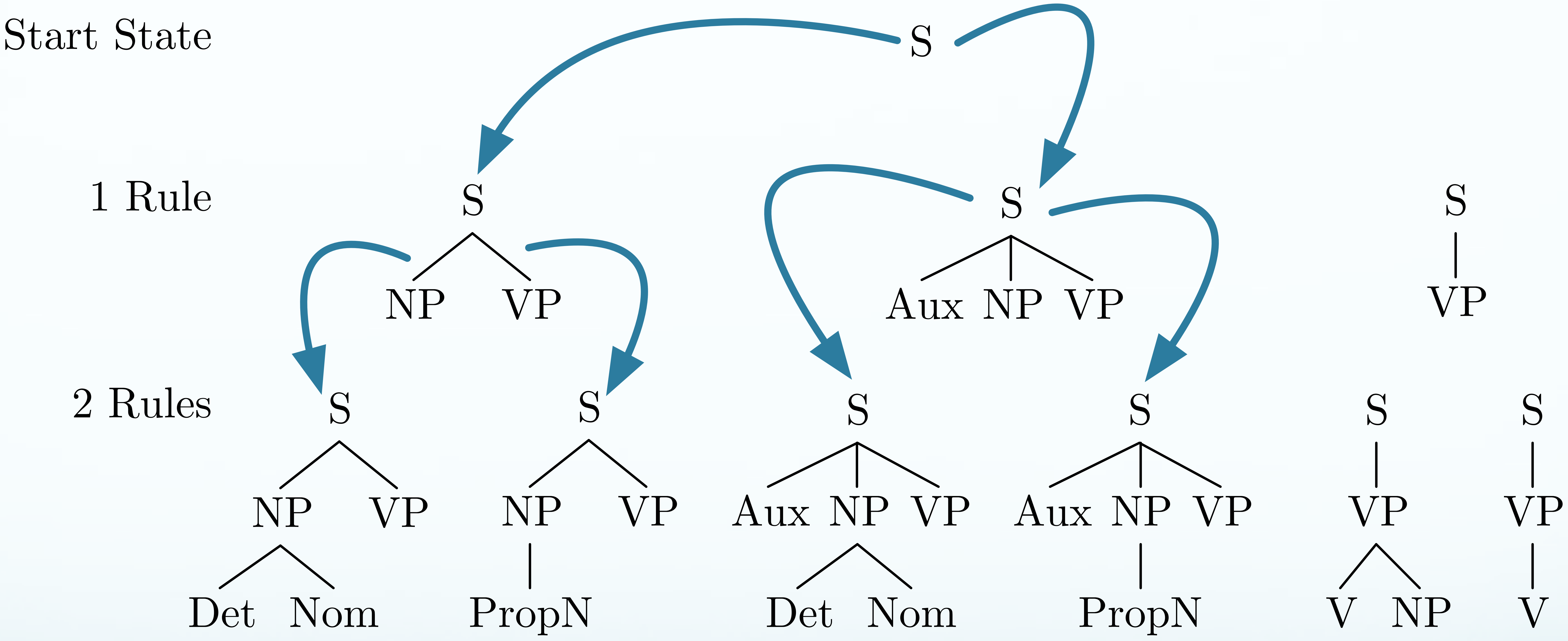
Grammar	Lexicon
$S \rightarrow NP\ VP$	$Det \rightarrow that \mid this \mid a$
$S \rightarrow Aux\ NP\ VP$	$Noun \rightarrow book \mid flight \mid meal \mid money$
$S \rightarrow VP$	$Verb \rightarrow book \mid include \mid prefer$
$NP \rightarrow Pronoun$	$Pronoun \rightarrow I \mid she \mid me$
$NP \rightarrow Proper\text{-}Noun$	$Proper\text{-}Noun \rightarrow Houston \mid NWA$
$NP \rightarrow Det\ Nominal$	$Aux \rightarrow does$
$Nominal \rightarrow Noun$	$Preposition \rightarrow from \mid to \mid on \mid near \mid through$
$Nominal \rightarrow Nominal\ Noun$	
$Nominal \rightarrow Nominal\ PP$	
$VP \rightarrow Verb$	
$VP \rightarrow Verb\ NP$	
$VP \rightarrow Verb\ NP\ PP$	
$VP \rightarrow Verb\ PP$	
$VP \rightarrow VP\ PP$	
$PP \rightarrow Preposition\ NP$	

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

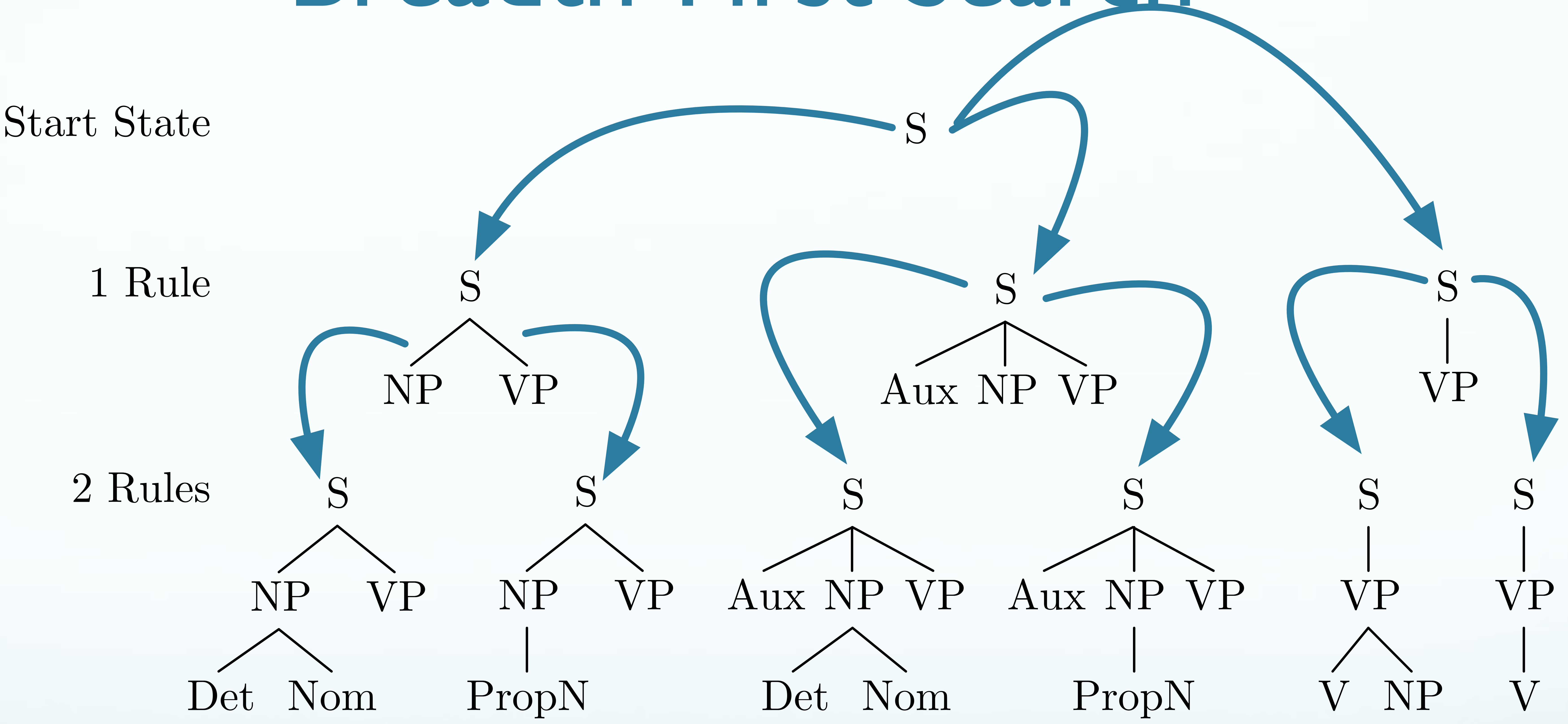
Top-down Search

- 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



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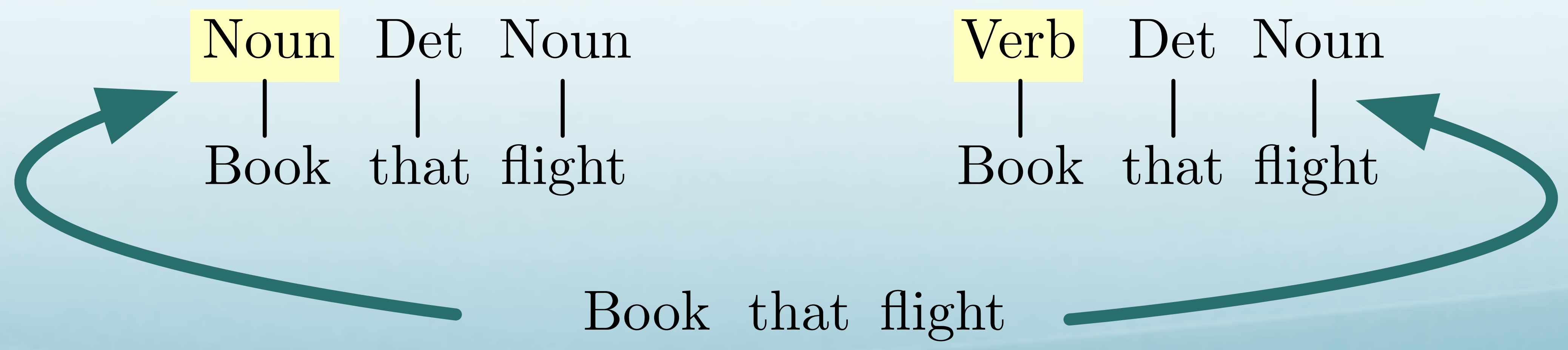
Pros and Cons of Top-down Parsing

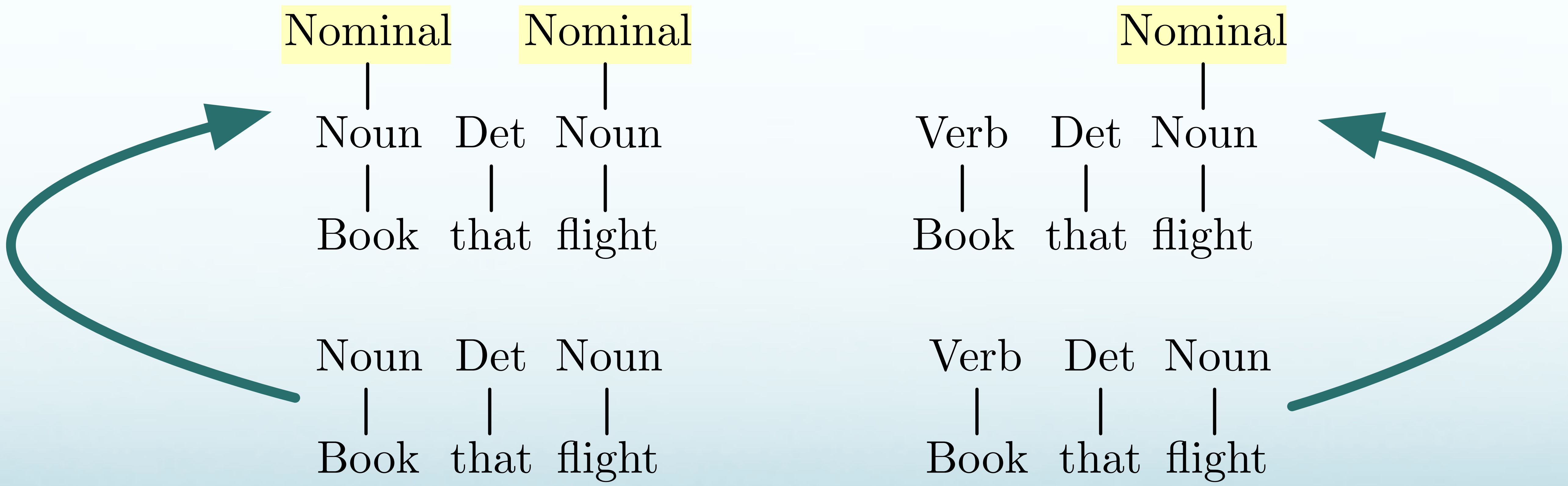
- Pros:
  - Doesn’t explore trees not rooted at S
  - Doesn’t explore subtrees that don’t fit valid trees
- Cons:
  - Produces trees that may not match input
  - May not terminate in presence of recursive rules
  - May rederive subtrees as part of search

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. $N \rightarrow \text{Book};\ \ V \rightarrow \text{Book}$
- 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



Nominal Nominal Nominal

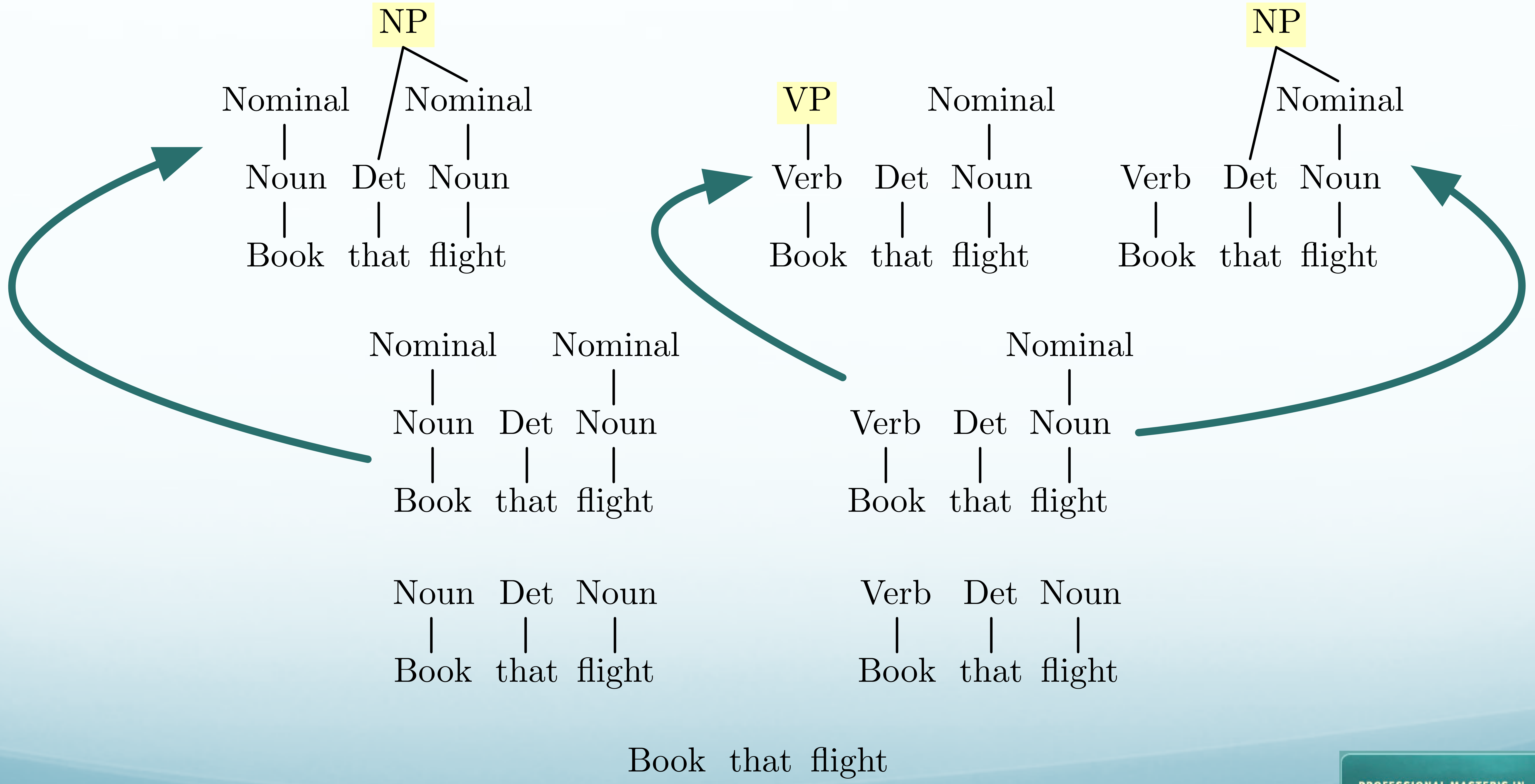
Noun Det Noun Verb Det Noun

Book that flight Book that flight

Noun Det Noun Verb Det Noun

Book that flight Book that flight

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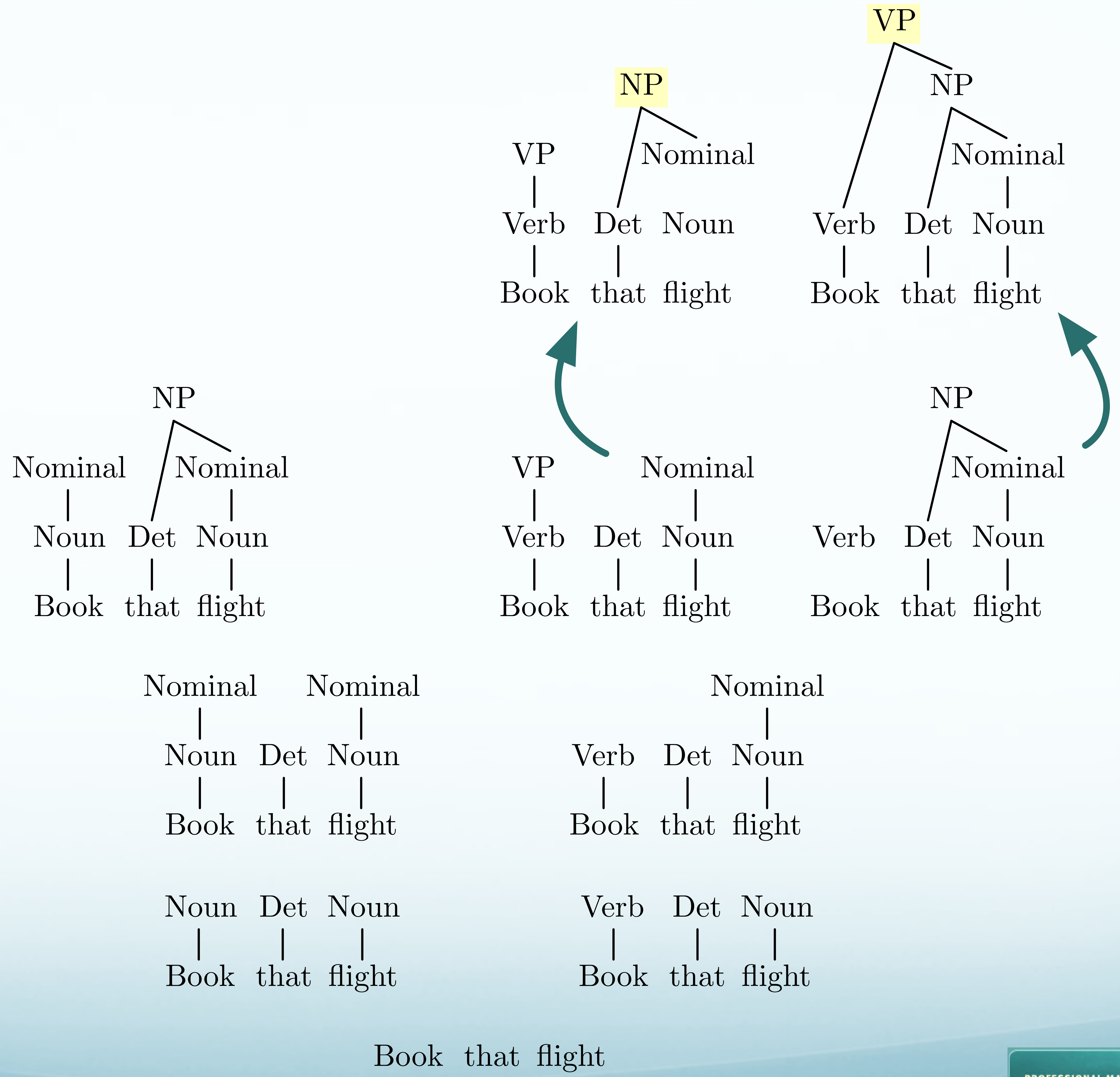
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Book that flight
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Noun Det Noun
Verb Det Noun
Book that flight
Book that flight
Noun Det Noun
Verb Det Noun
Book that flight
Book that flight
Book that flight

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

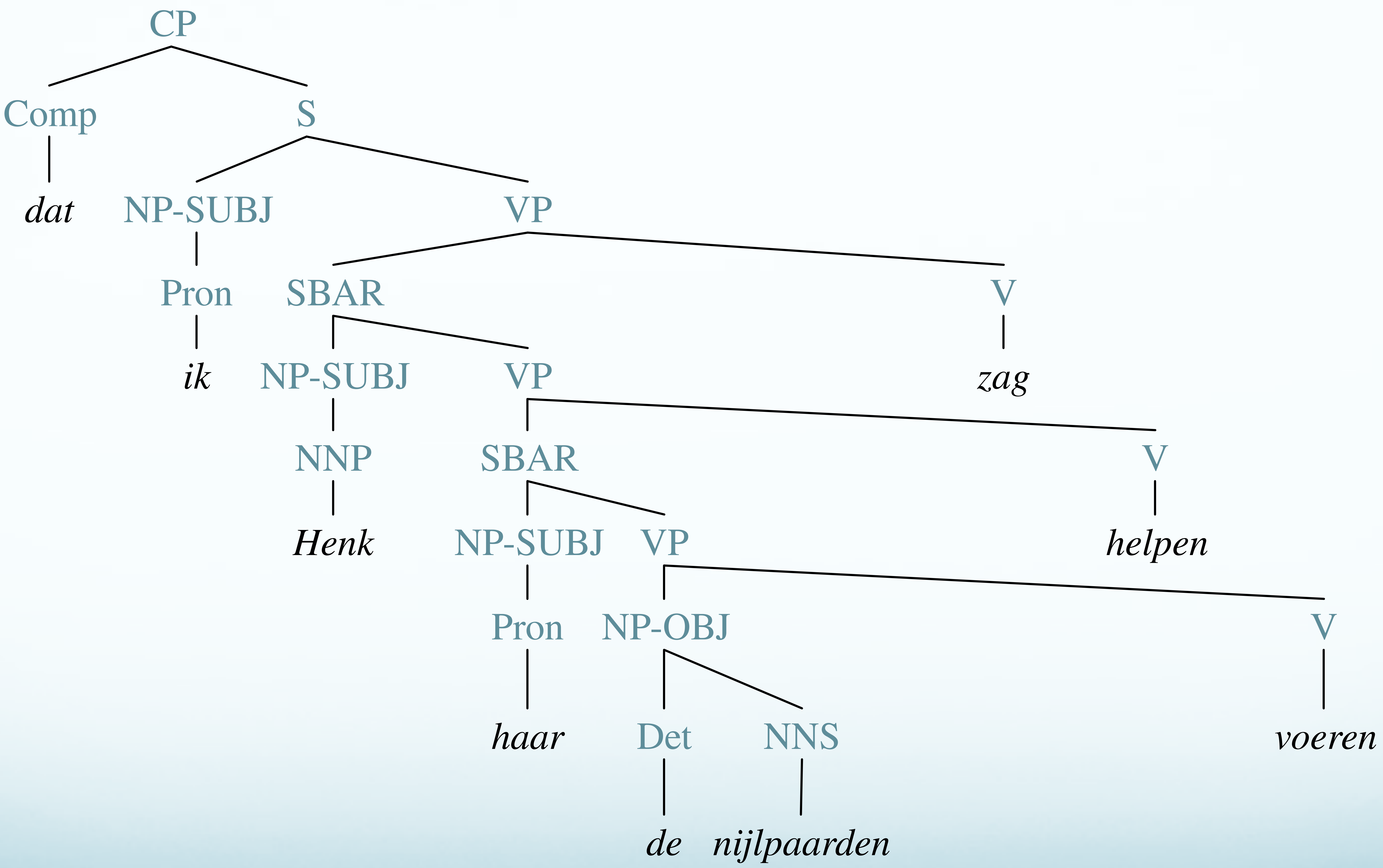
Cross-Serial Dependencies, Revisited

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

dat	ik$_1$	Henk$_2$	haar$_3$	de	nijlpaarden$_3$	zag$_1$	helpen$_2$	voeren$_3$
that	I$_1$	Henk$_2$	her$_3$	the	hippos	saw$_1$	help$_2$	feed$_3$

"…that I saw Henk help her feed the hippos"

A Dutch example from Rentier (1994)


CP
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NP-SUBJ
VP
Pron
SBAR
V
ik
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VP
zag
NNP
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Pron
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haar
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voeren
de
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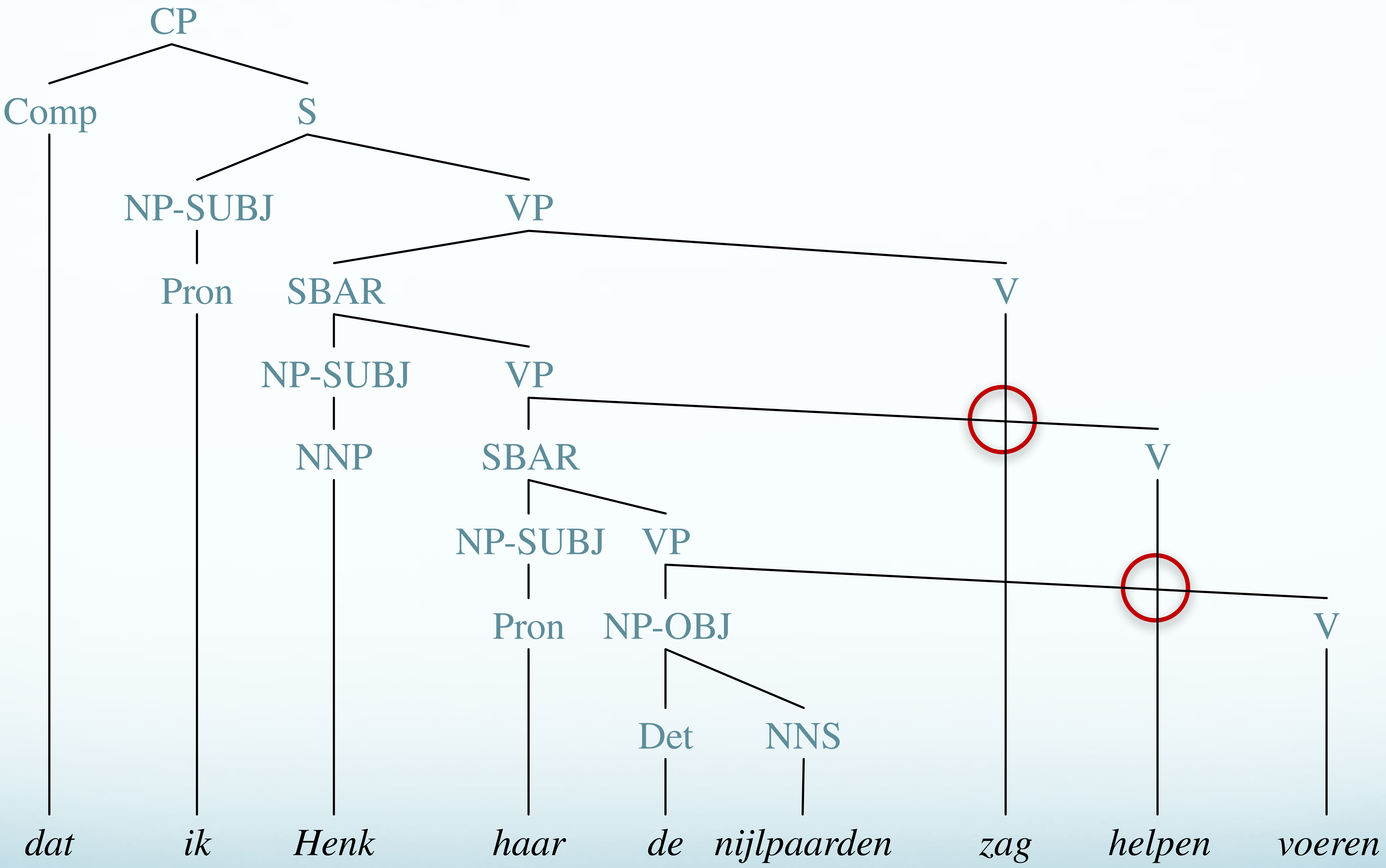
CP
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VP
Pron
NP-OBJ
V
Det
NNS
dat
ik
Henk
haar
de
nijlpaarden
zag
helpen
voeren