Syntax: Context-Free Grammars

LING 571 — Deep Processing Techniques for NLP

Oct 4, 2021

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Announcements

- Thanks for participation on Canvas!
- No readme for HW1 (but there will be for other assignments); free points
- 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
- Tokenizing with punctuation; `nltk.word_tokenize`

```
>>> import nltk
>>> nltk.word_tokenize("Hello darkness, my old friend.")
['Hello', 'darkness', ',', 'my', 'old', 'friend', '.']
```

- Condor: we will use for grading, so you should test with it (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

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- 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?

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It is **the Supreme Court of** that made the ruling	✗

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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 $A \rightarrow \alpha$
    - Where *A* is a non-terminal and $\alpha \in (\Sigma \cup N)^*$
  - A **start** symbol $S \in N$

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  - One non-terminal on LHS and any seq. of terminals and non-terminals on RHS

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    - *Det* → ‘the’

Grammar Rules			Examples
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Jurafsky & Martin, Speech and Language Processing, p.390

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PP	$\longrightarrow$	*Preposition NP*	from + Los Angeles

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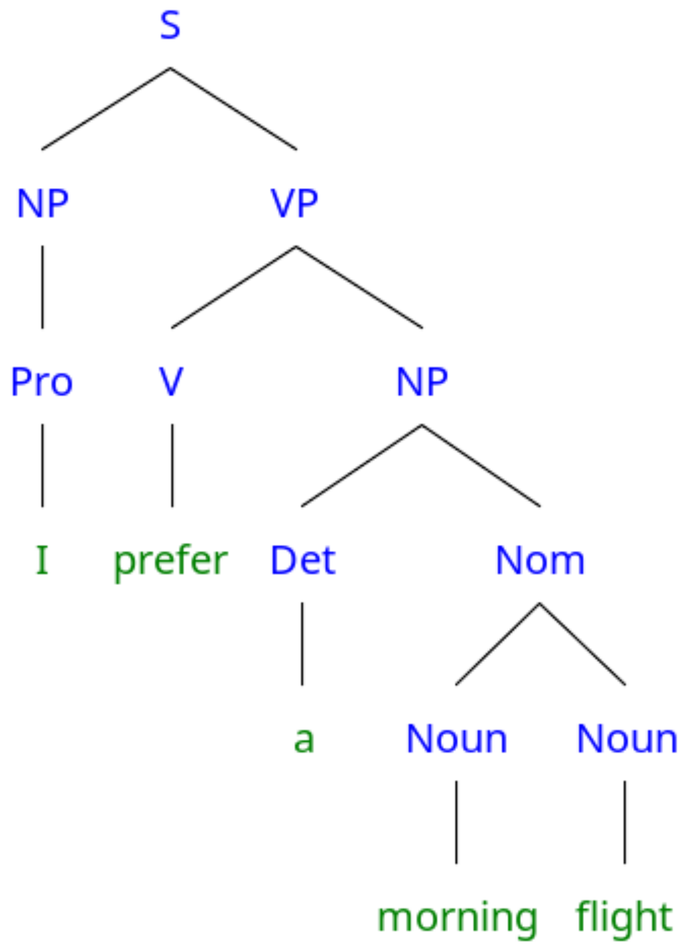
Parse Tree



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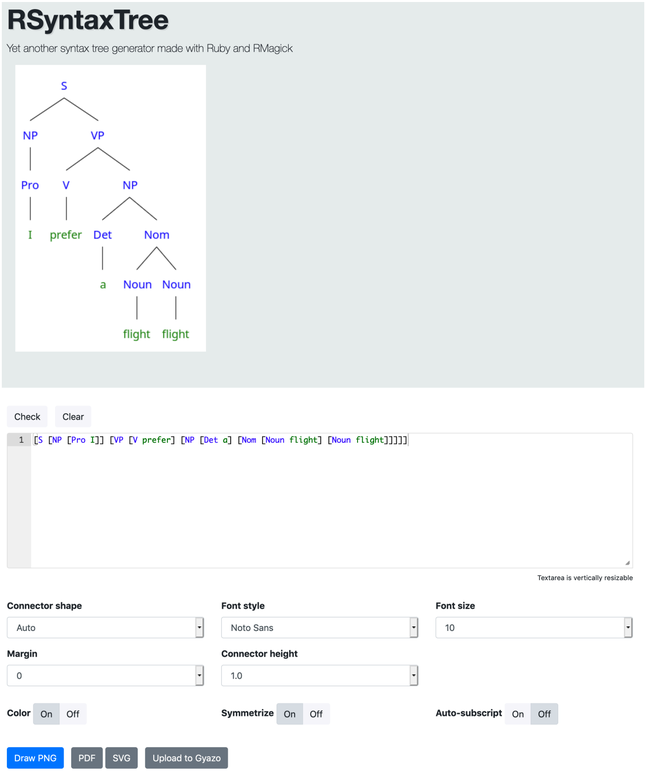
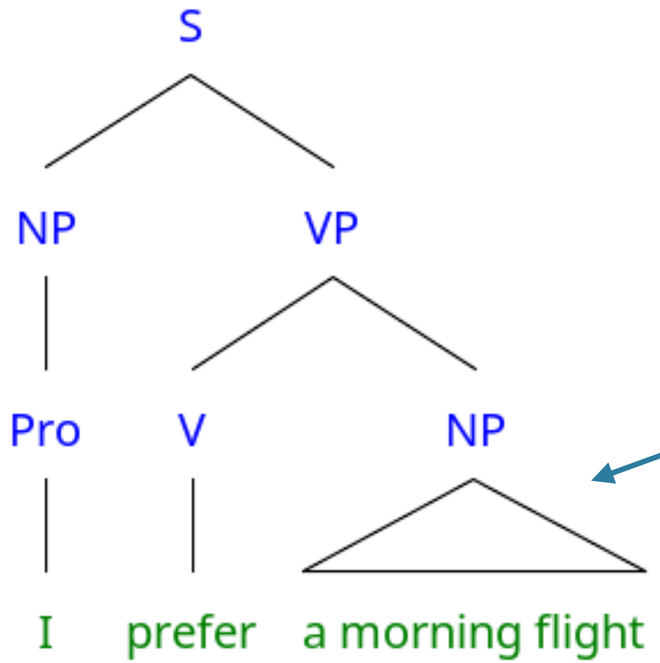
- **Wh-non-subject question**: $S \rightarrow Wh\text{-}NP\ Aux\ NP\ VP$
  - (Wh-NP What flights) (Aux do) (NP you) (VP have from Seattle to Orlando?)

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

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- 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’*

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  - **"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

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

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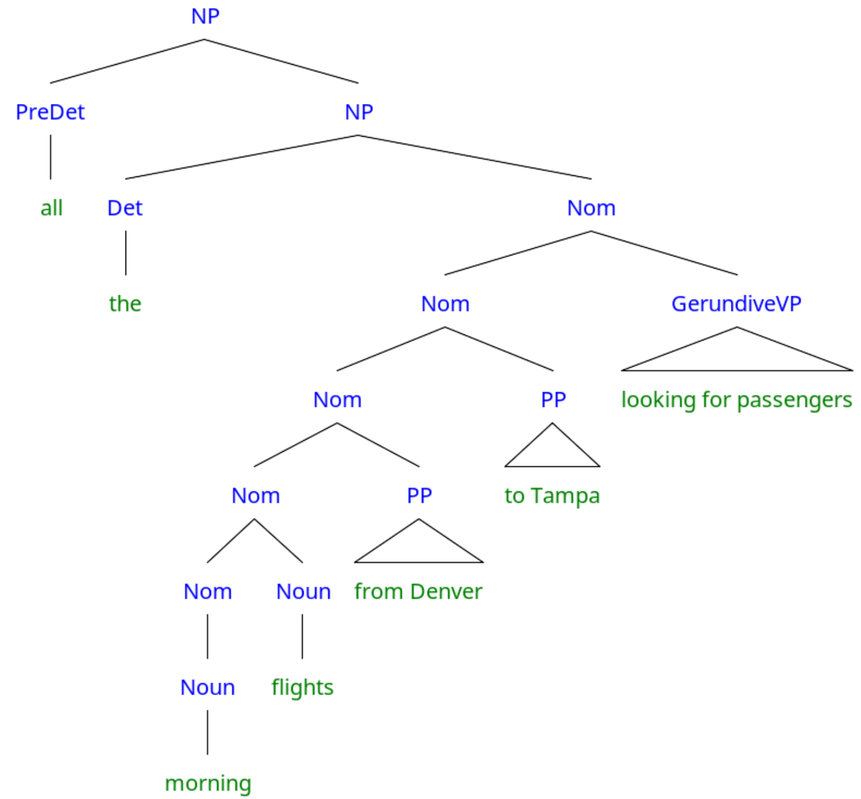
  - **one** flight
  - **the first** route
  - **the last** flight **from Chicago**

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:

$$
\begin{array}{lll}
VP & \longrightarrow & Verb \\
 & | & Verb\ NP \\
 & | & Verb\ NP\ NP
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  - *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***

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- This is problematic for semantic reasons, which we'll cover later.

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$VP \rightarrow Verb\ \boldsymbol{VP}$	want to arrange three flights

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  - Is this a good solution?
    - No, explosive increase in number of rules
    - Similar problem with agreement (NN↔ADJ↔PRON↔VB)

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  - 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!

h/t to Amandalynne Paullada

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- Possible Interpretations:

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

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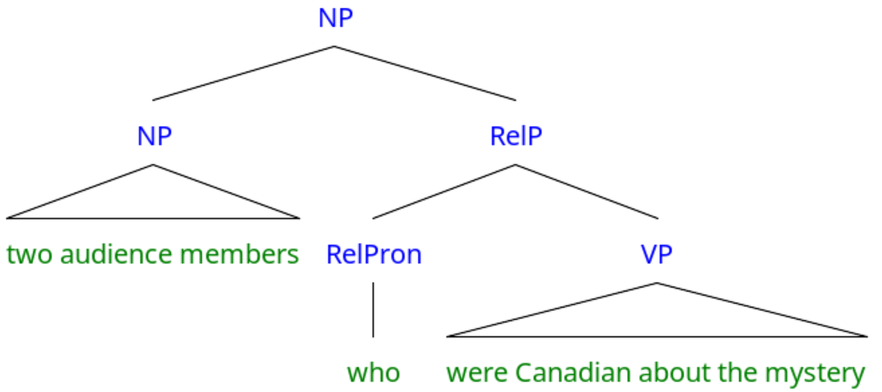
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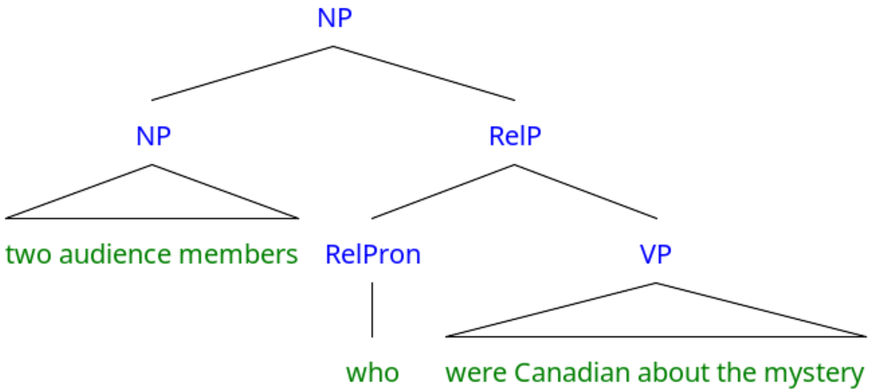
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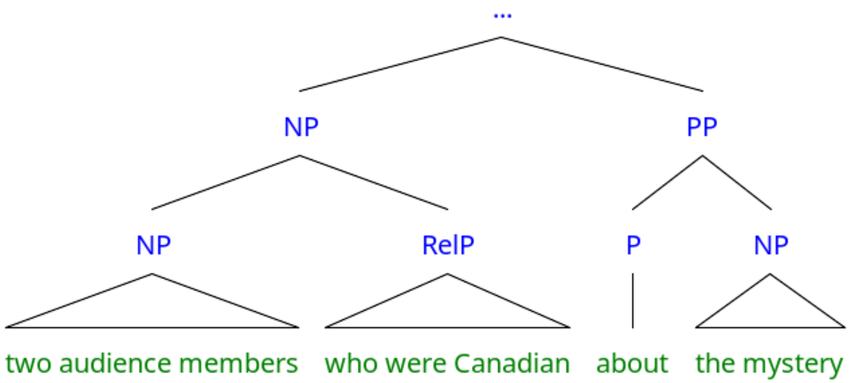
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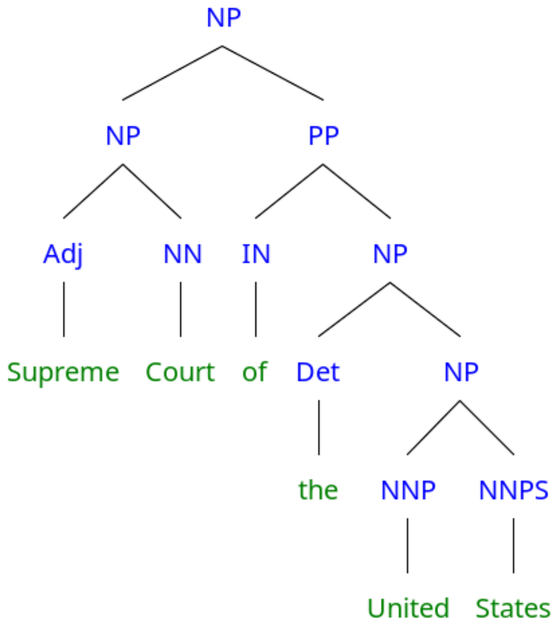

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- Built semi-automatically
  - Automatically parsed, manually corrected

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  - Brown Univ. Standard Corp. of Present-Day Am. Eng.
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  - Xinhua, Sinoarma (newswire)
- Arabic
  - Newswire, Broadcast News + Conversation, Web Text…

Other Treebanks

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

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  - Grammatical function (subject, topic, etc)
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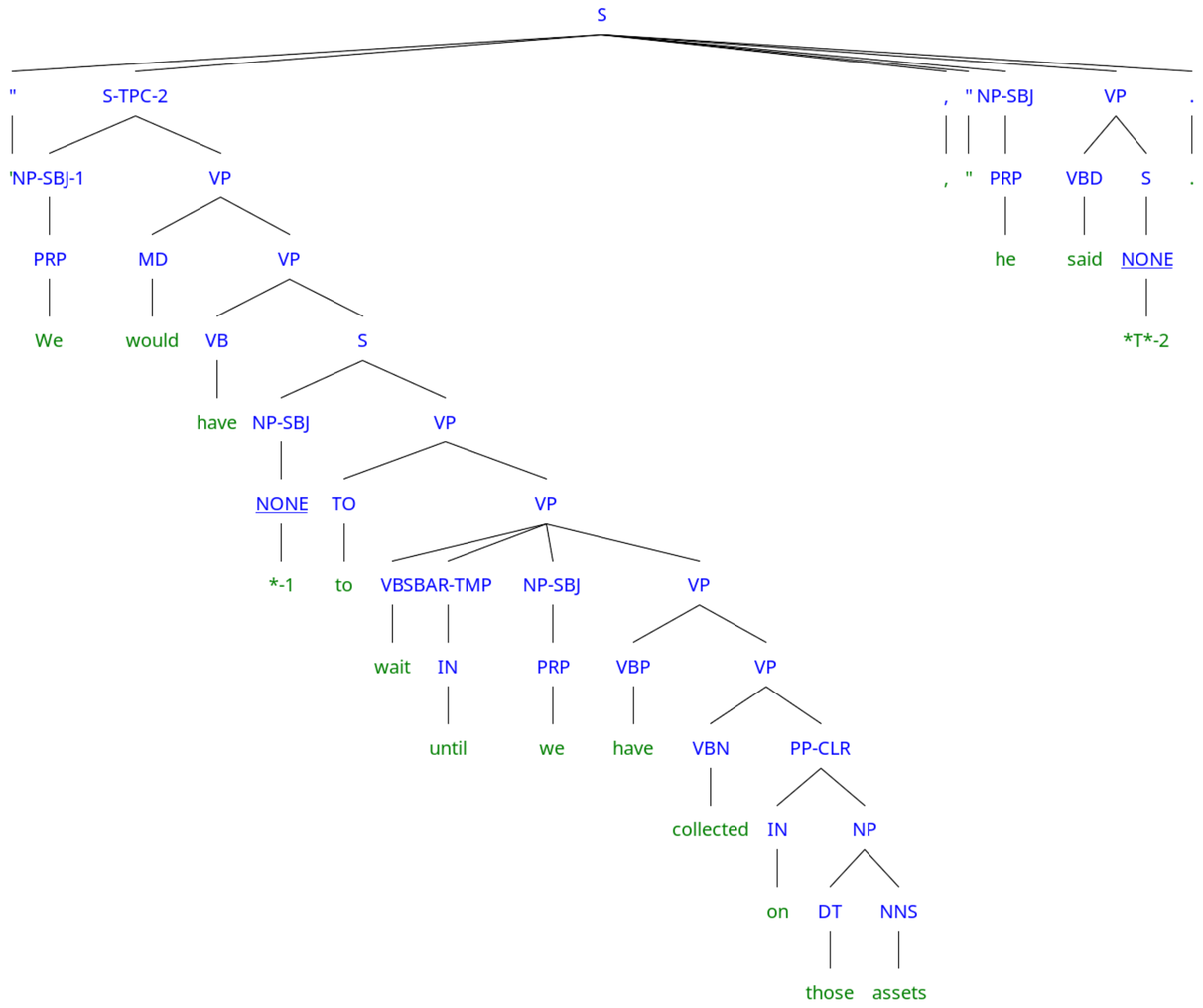
- Implicitly constitute grammar of language
  - Can read off rewrite rules from bracketing
  - Not only presence of rules, but frequency counts
  - Will be crucial in building statistical parsers

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!!

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  - 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!

Roadmap

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

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  - 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).

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  - ** 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

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Parsing as Search

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- 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

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- Path cost:
  - …ignored for now.

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  - Start symbol of CFG
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  - Full parse tree: covering all of, and only the input, rooted at S

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  - Keep expanding nonterminals until they reach words
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  - Consider all parses that expand a single nonterminal…
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- Other alternatives, if have associated path costs.

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  - Must start with the start symbol
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- 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
$S \rightarrow NP\ VP$	$Det \rightarrow that \mid this \mid a$
$S \rightarrow Aux\ NP\ VP$	$Noun \rightarrow book \mid flight \mid meal \mid money$
$S \rightarrow VP$	$Verb \rightarrow book \mid include \mid prefer$

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

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$NP \rightarrow Proper\text{-}Noun$	$Proper\text{-}Noun \rightarrow Houston \mid NWA$
$NP \rightarrow Det\ Nominal$	$Aux \rightarrow does$
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$VP \rightarrow Verb$	

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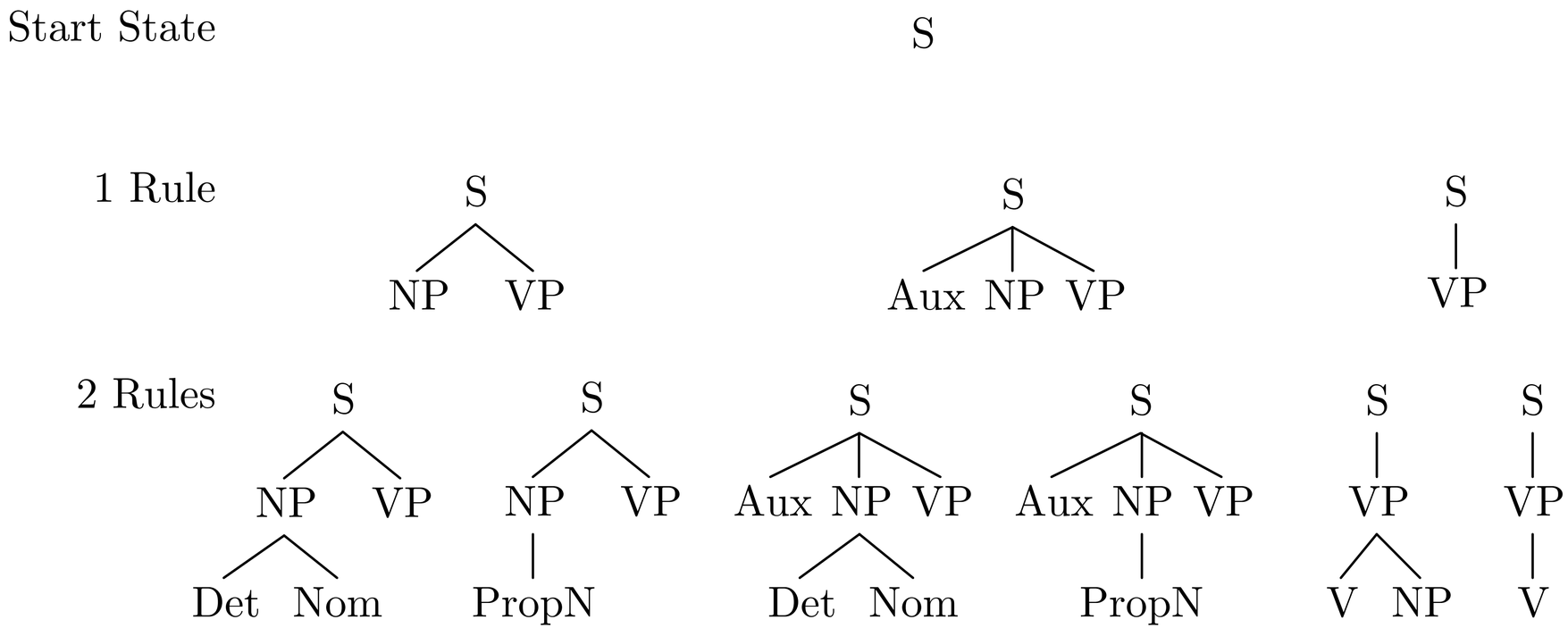
  - e.g. $NP \rightarrow Det\ Nominal;\ VP \rightarrow V\ NP$
- Terminate when all leaves are terminals

Depth-First Search



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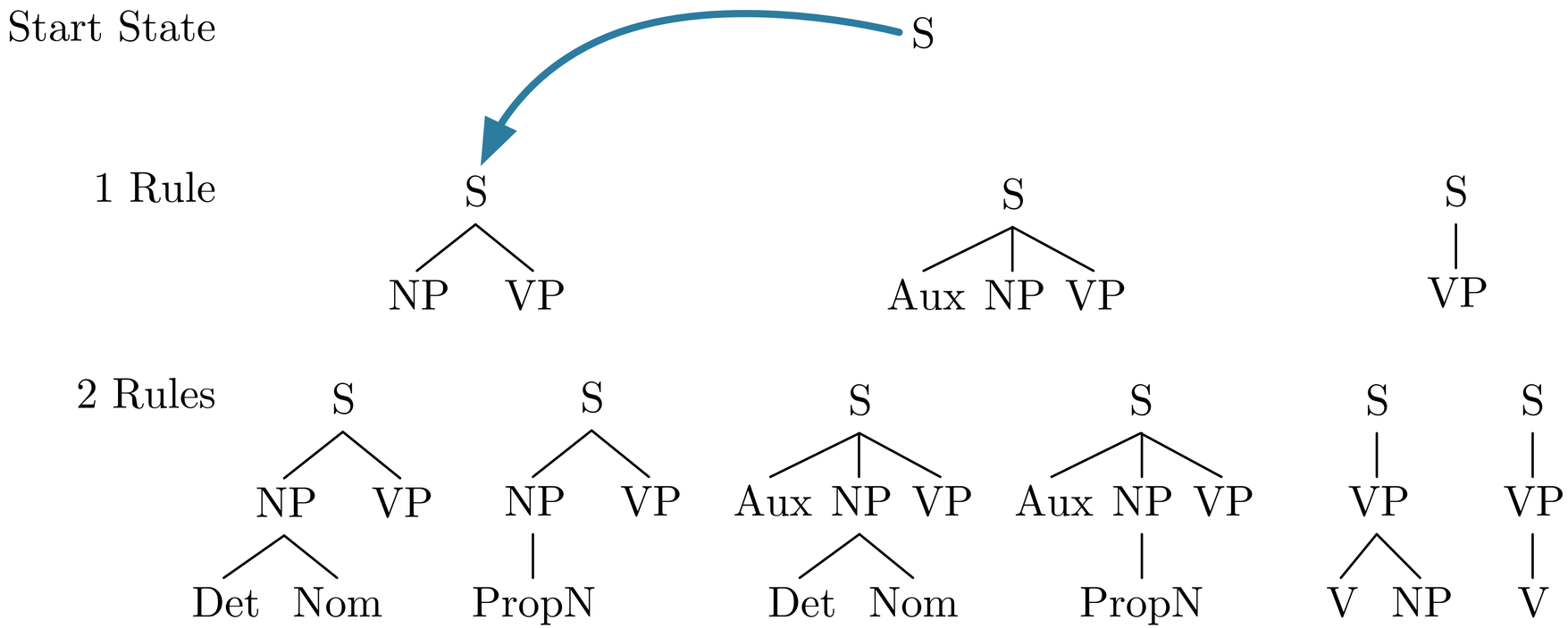

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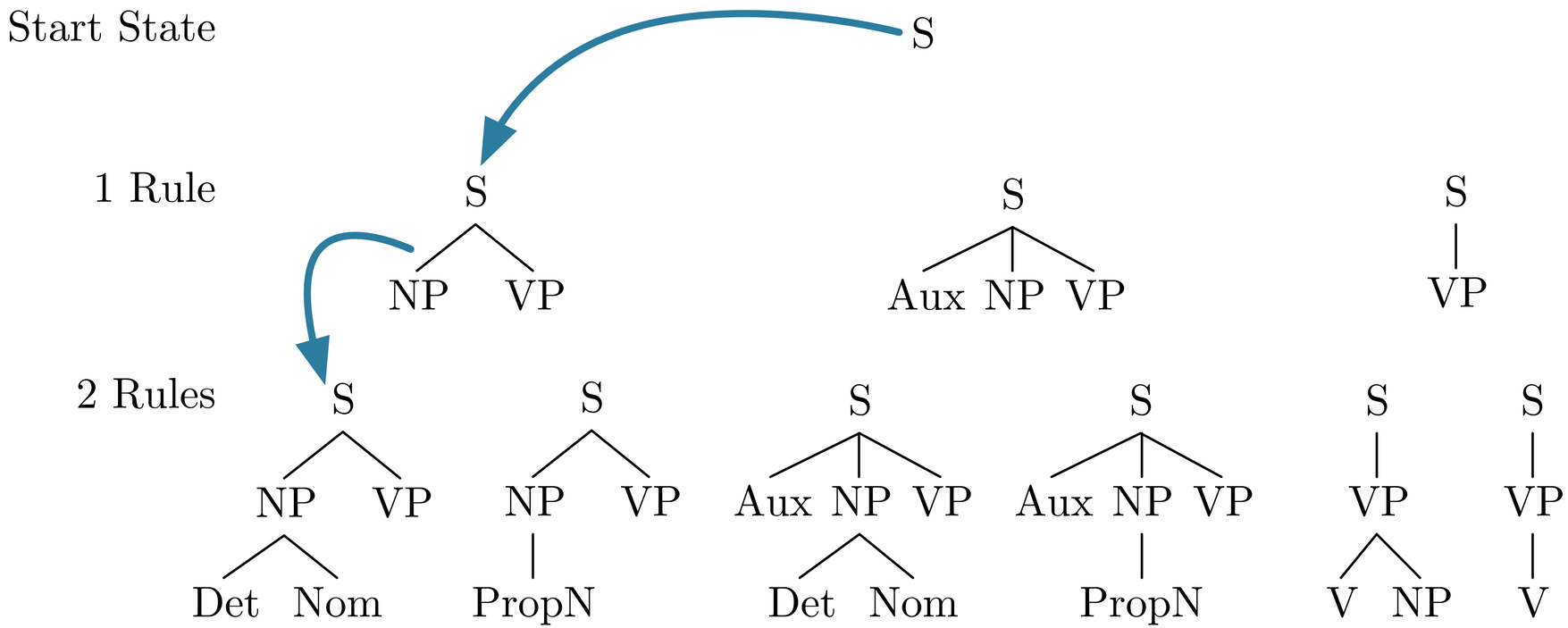

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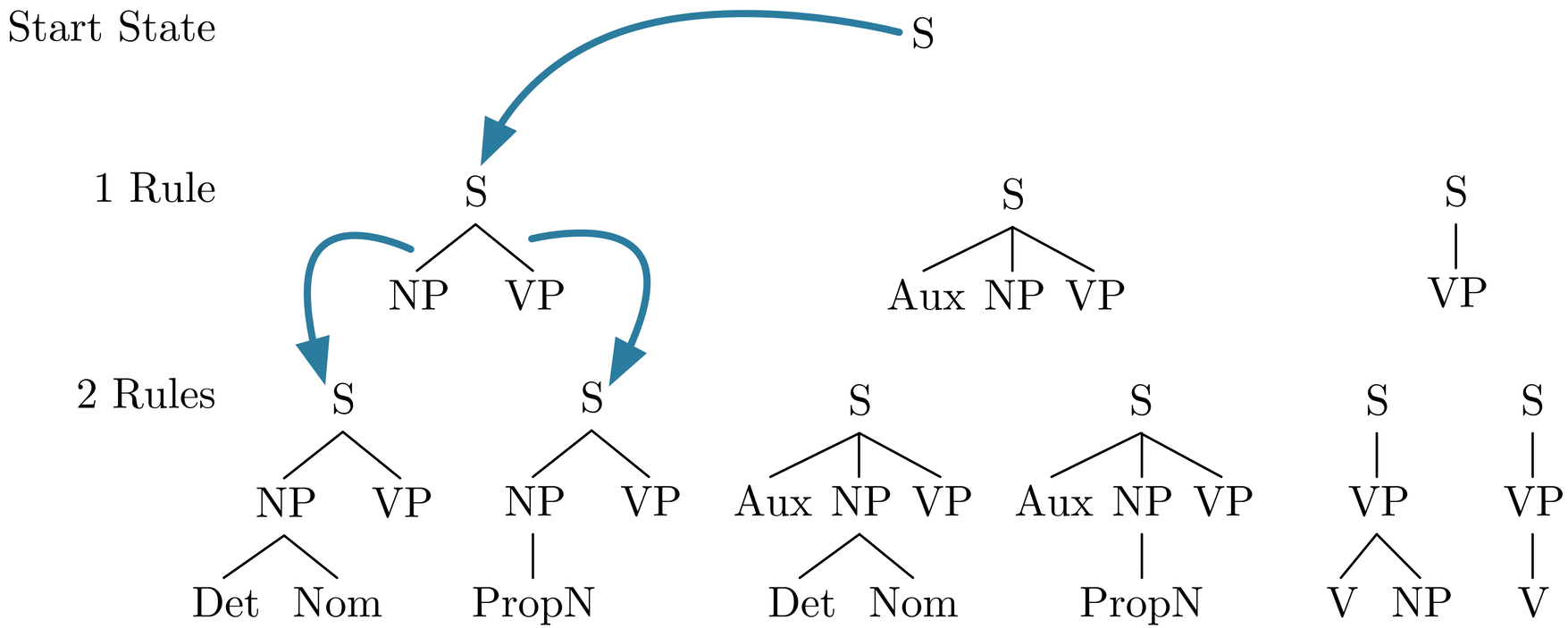

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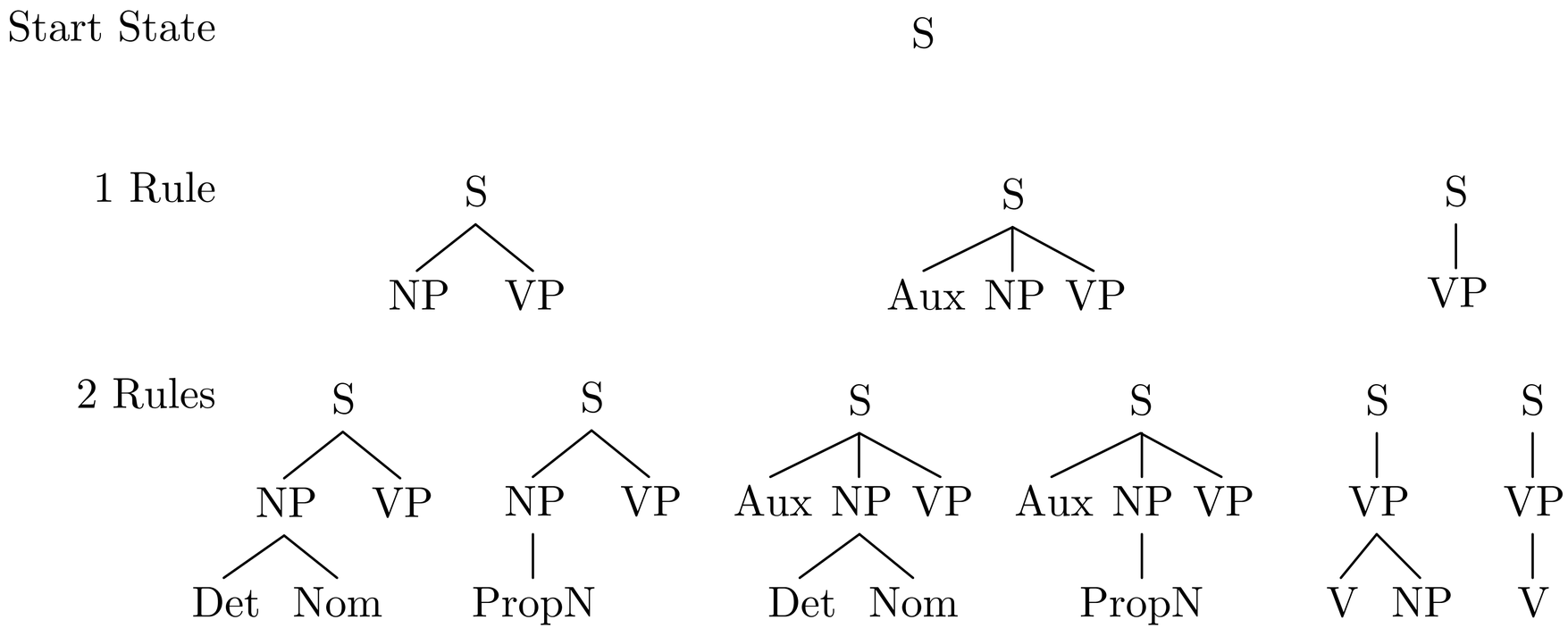

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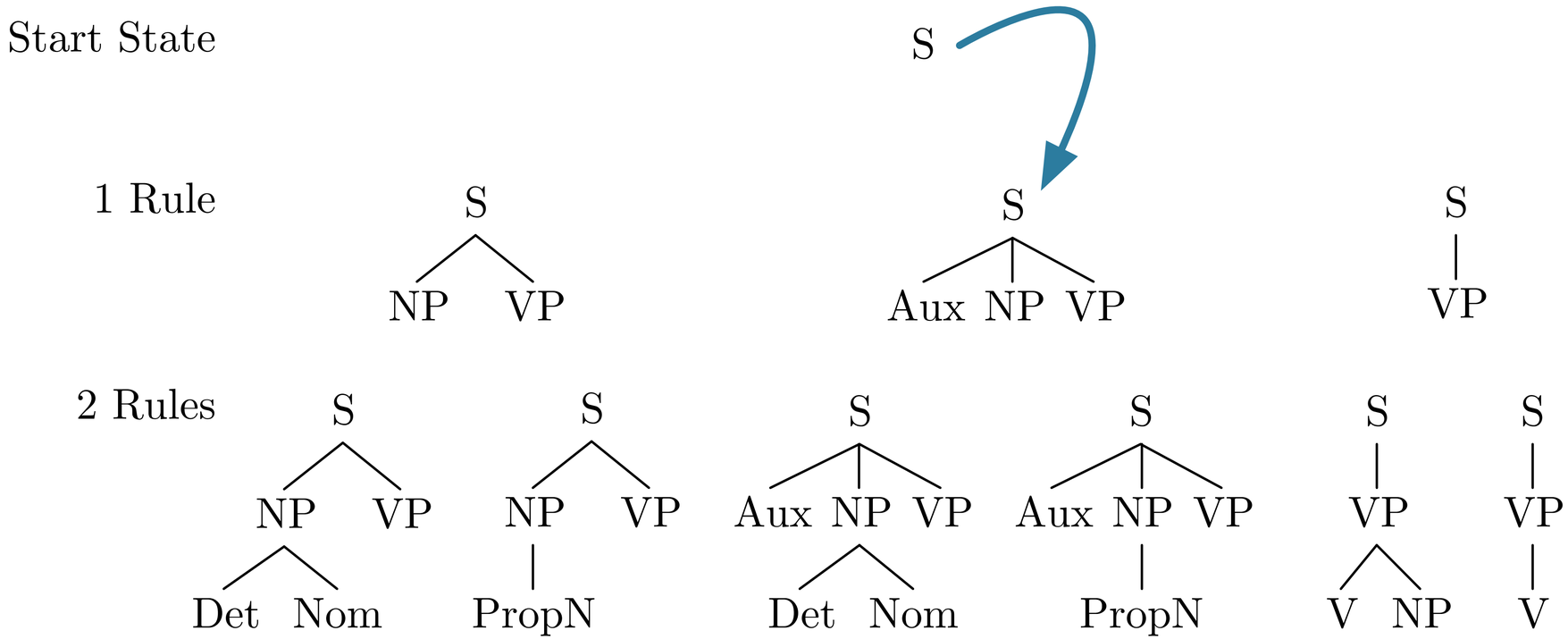

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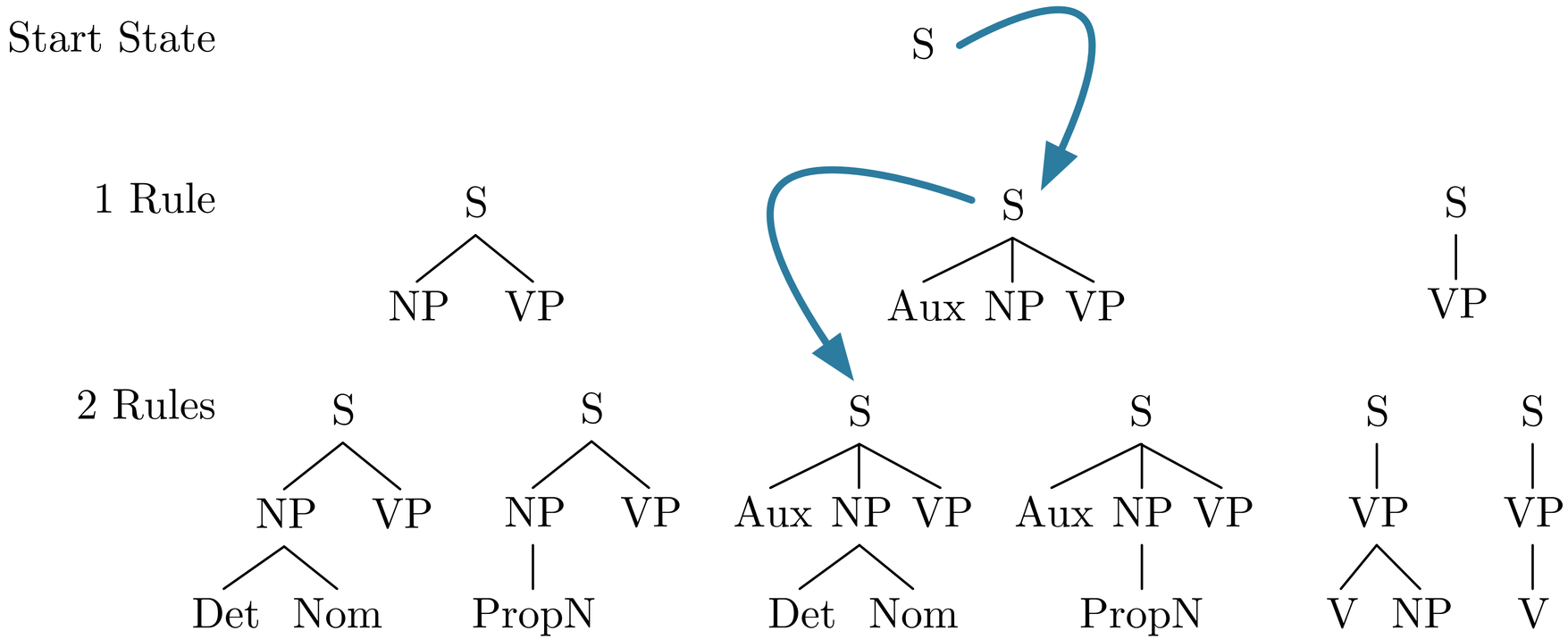

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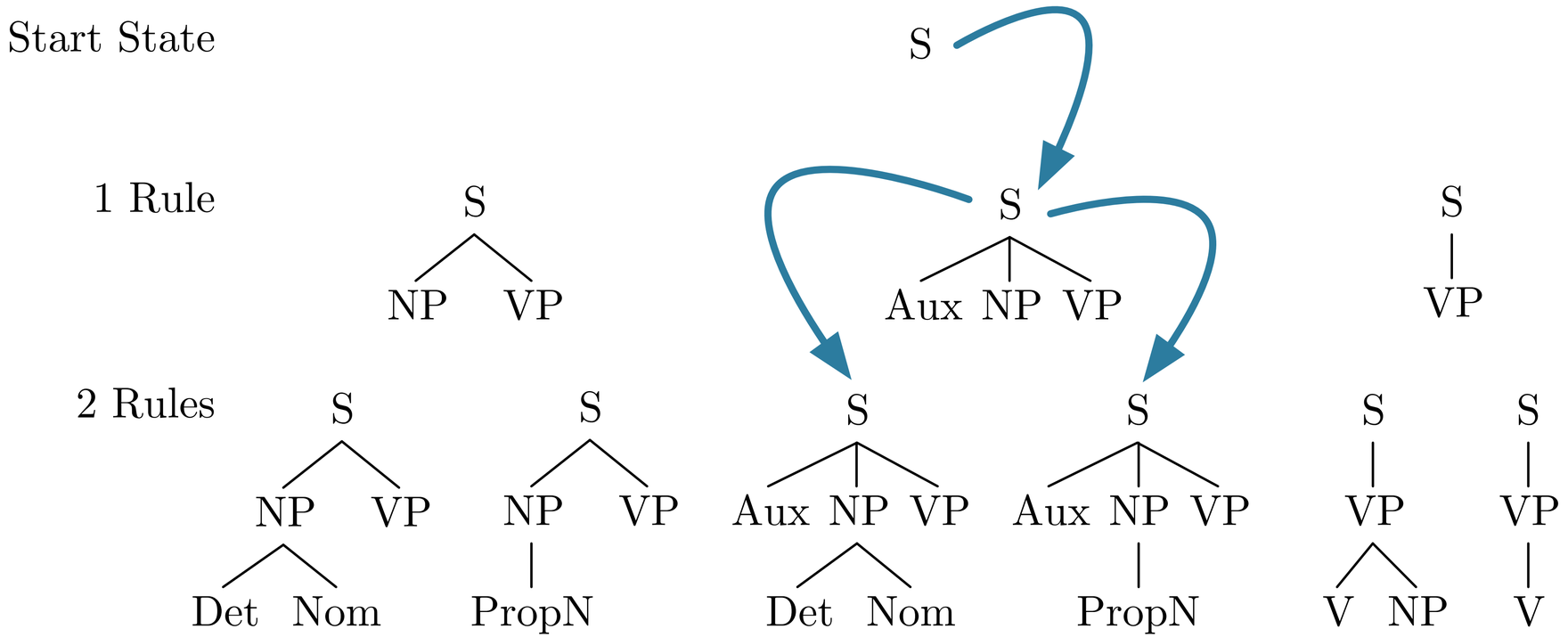

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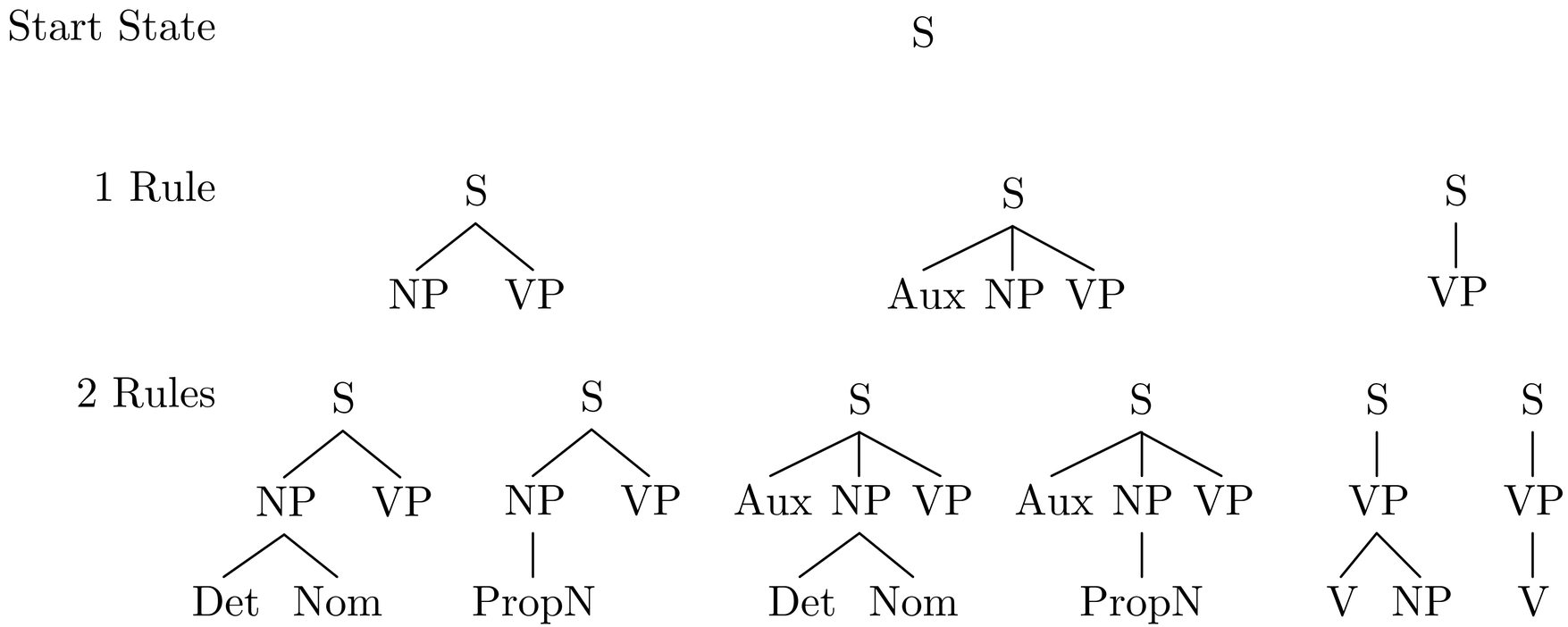

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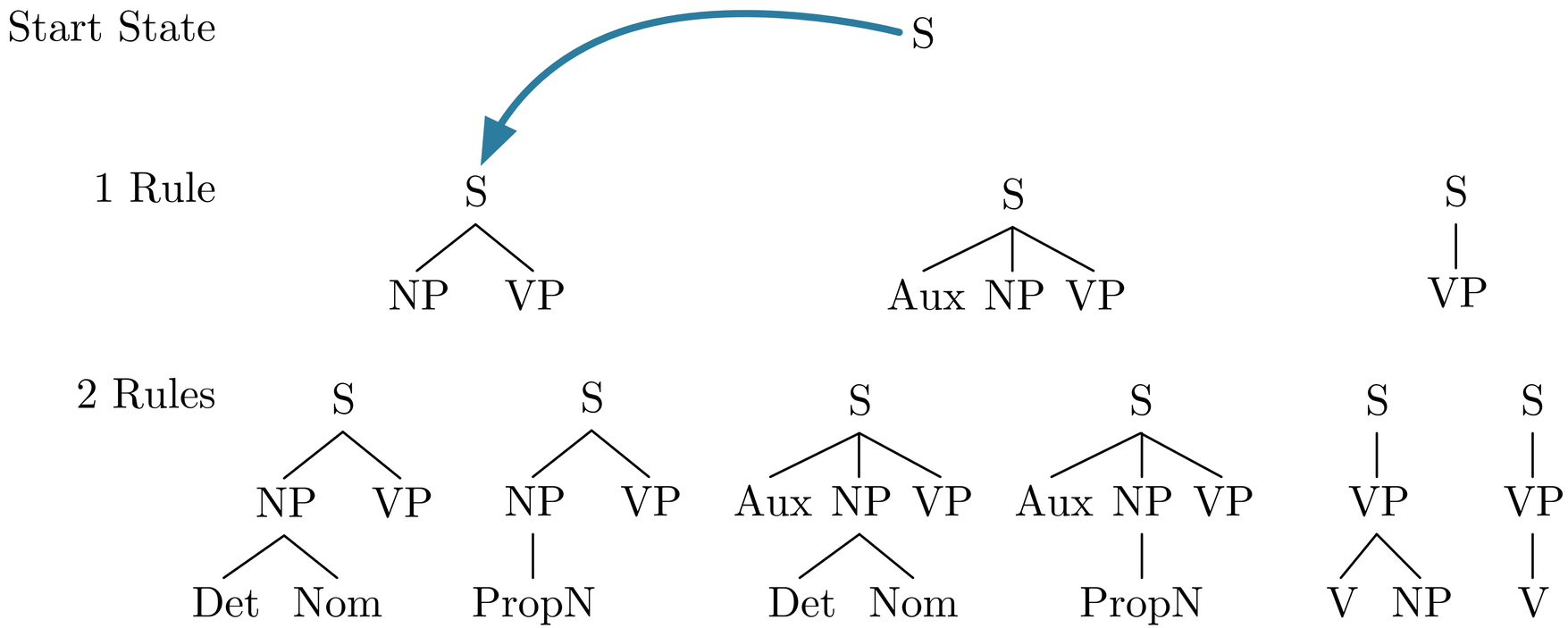

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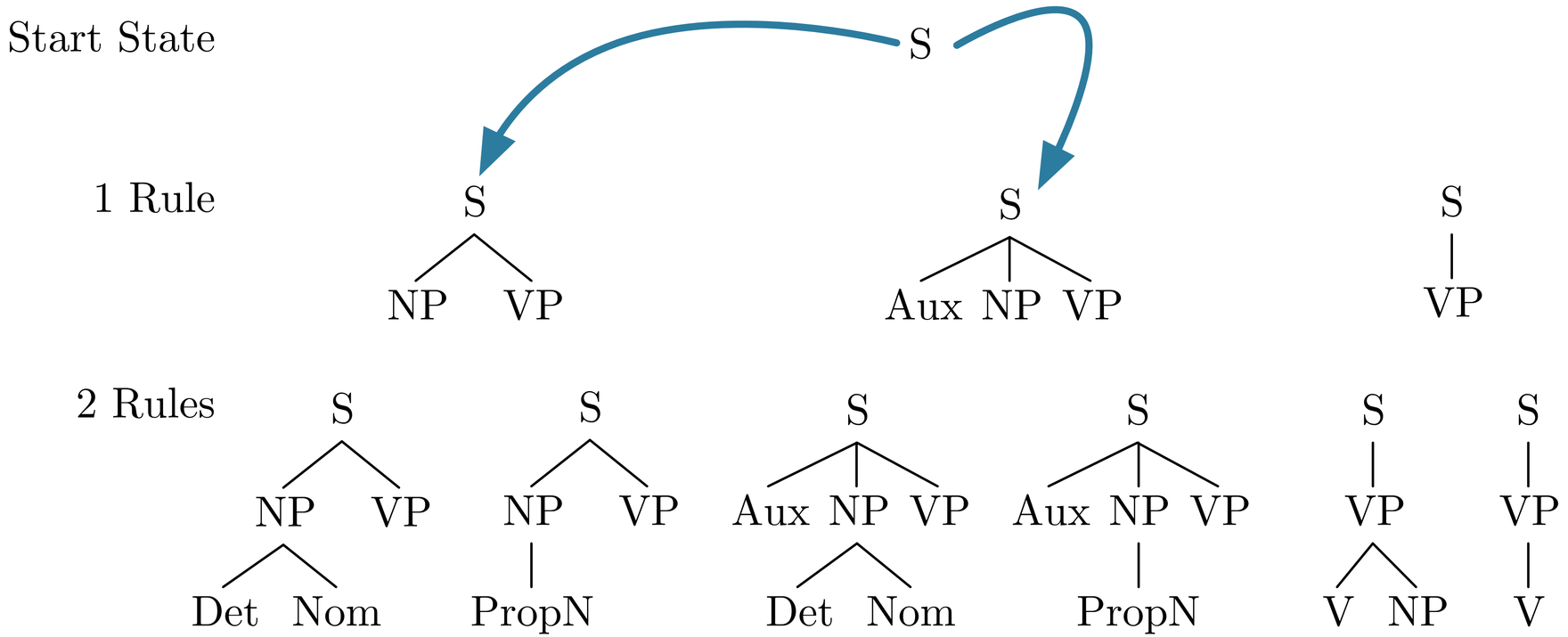

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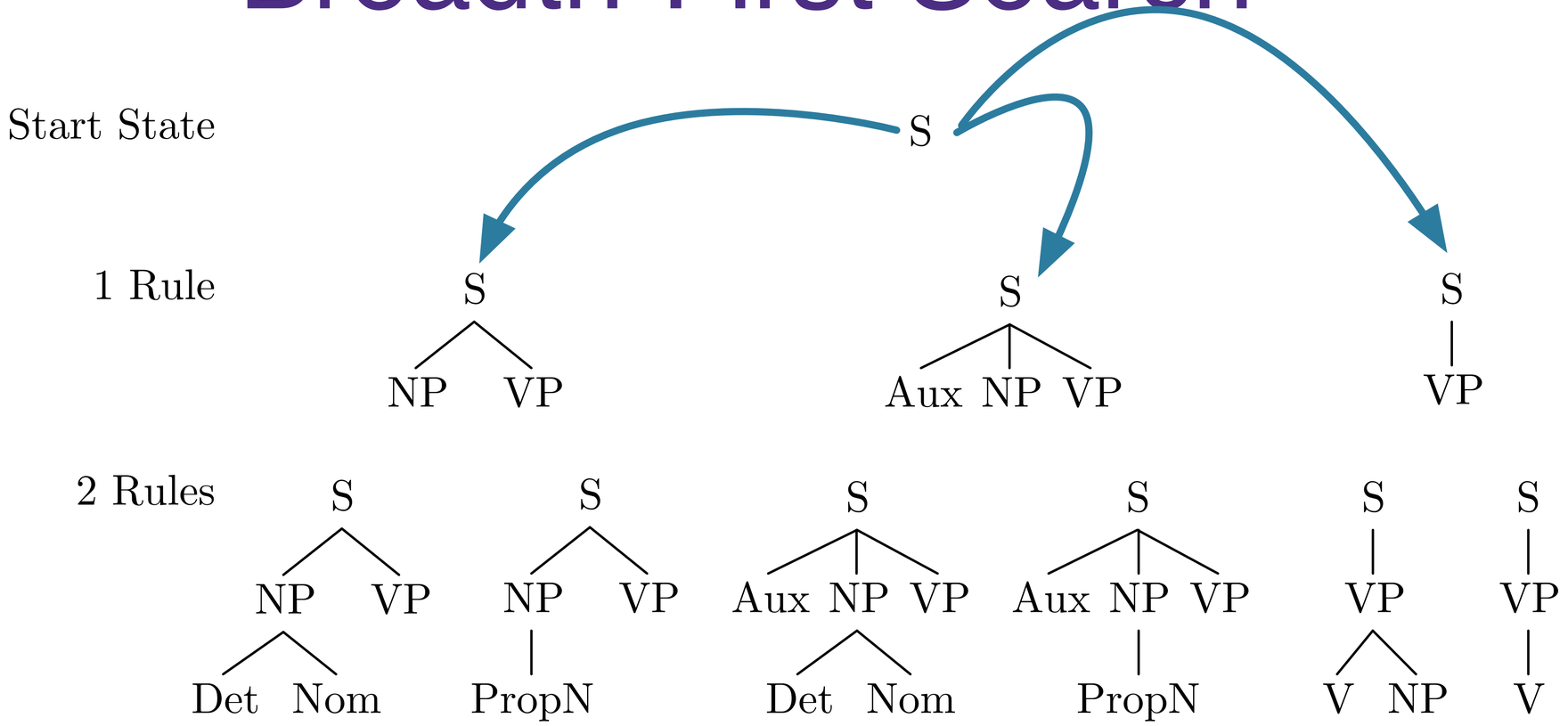

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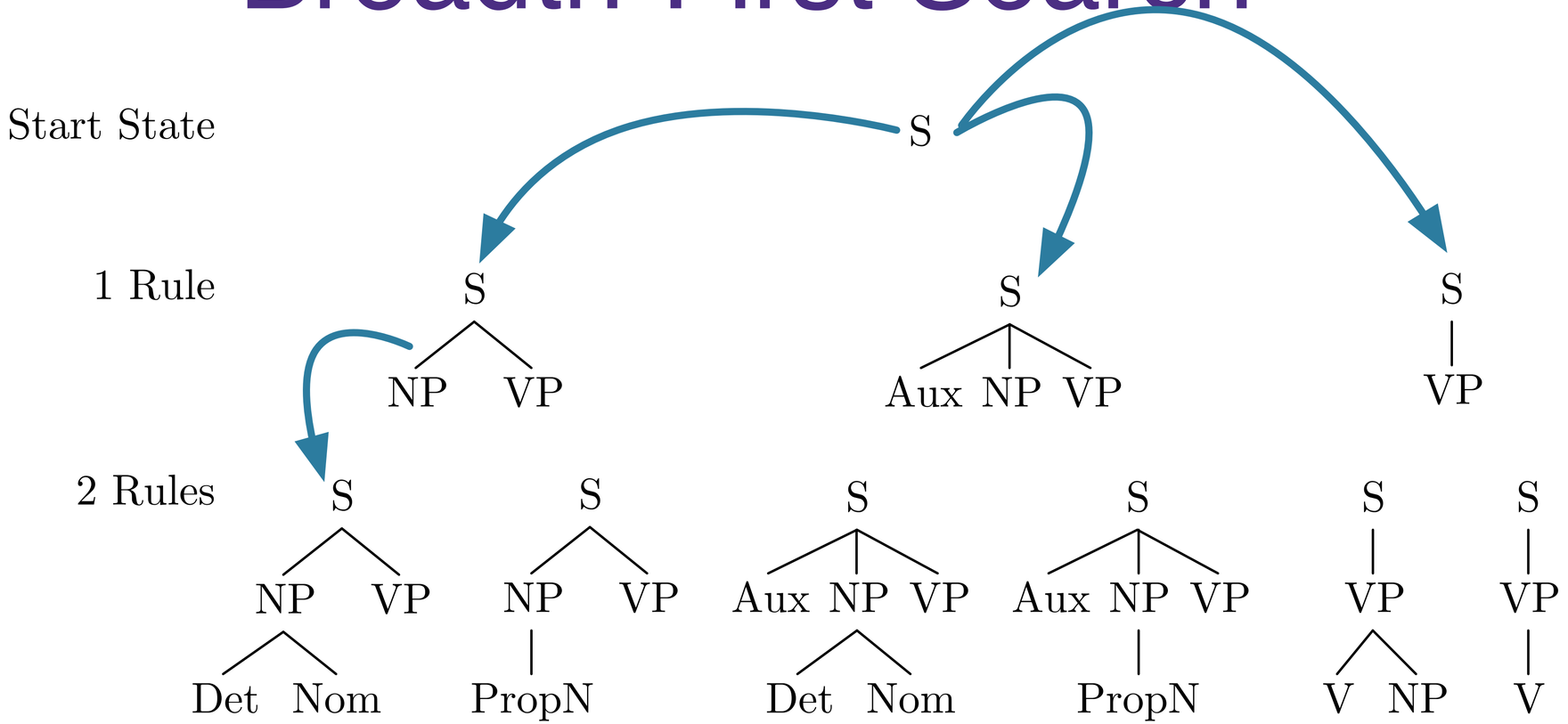

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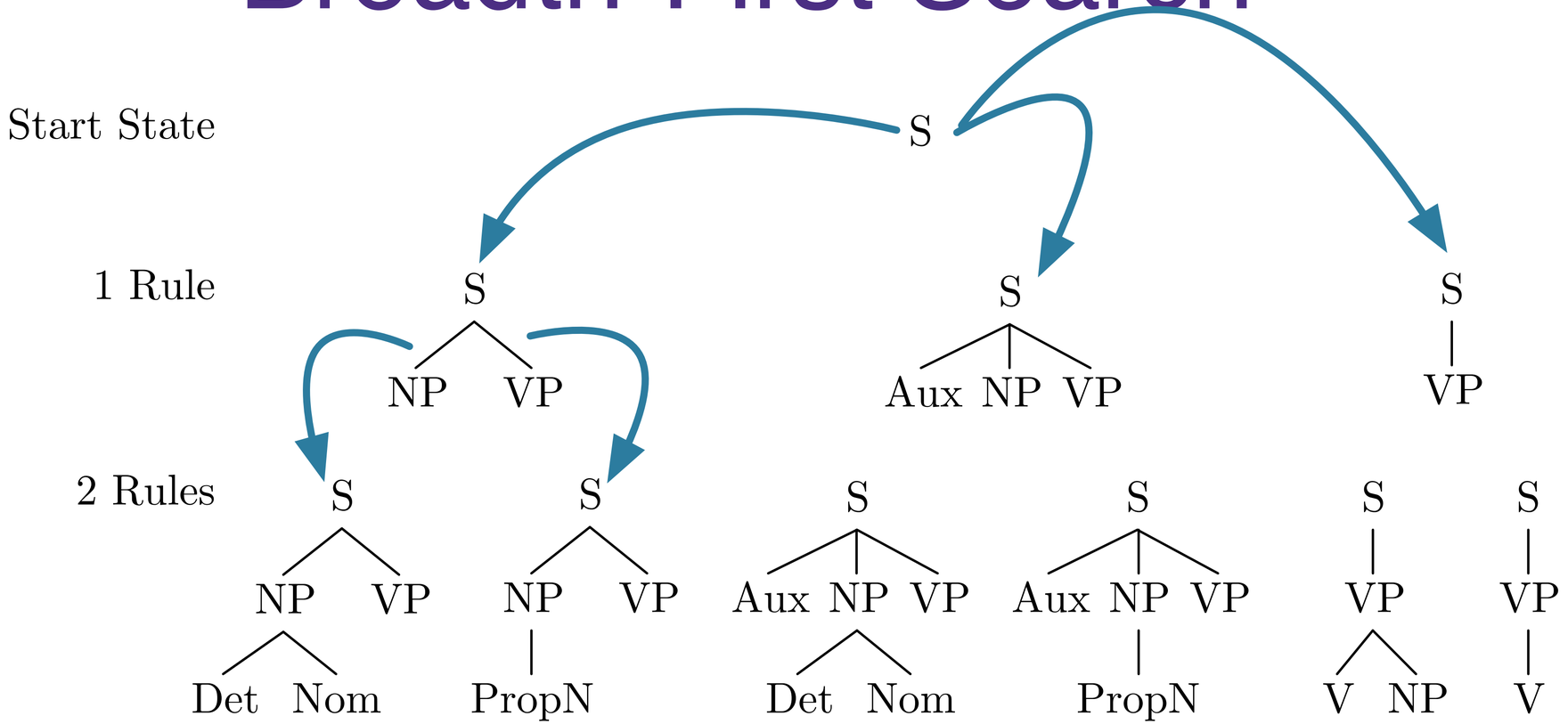

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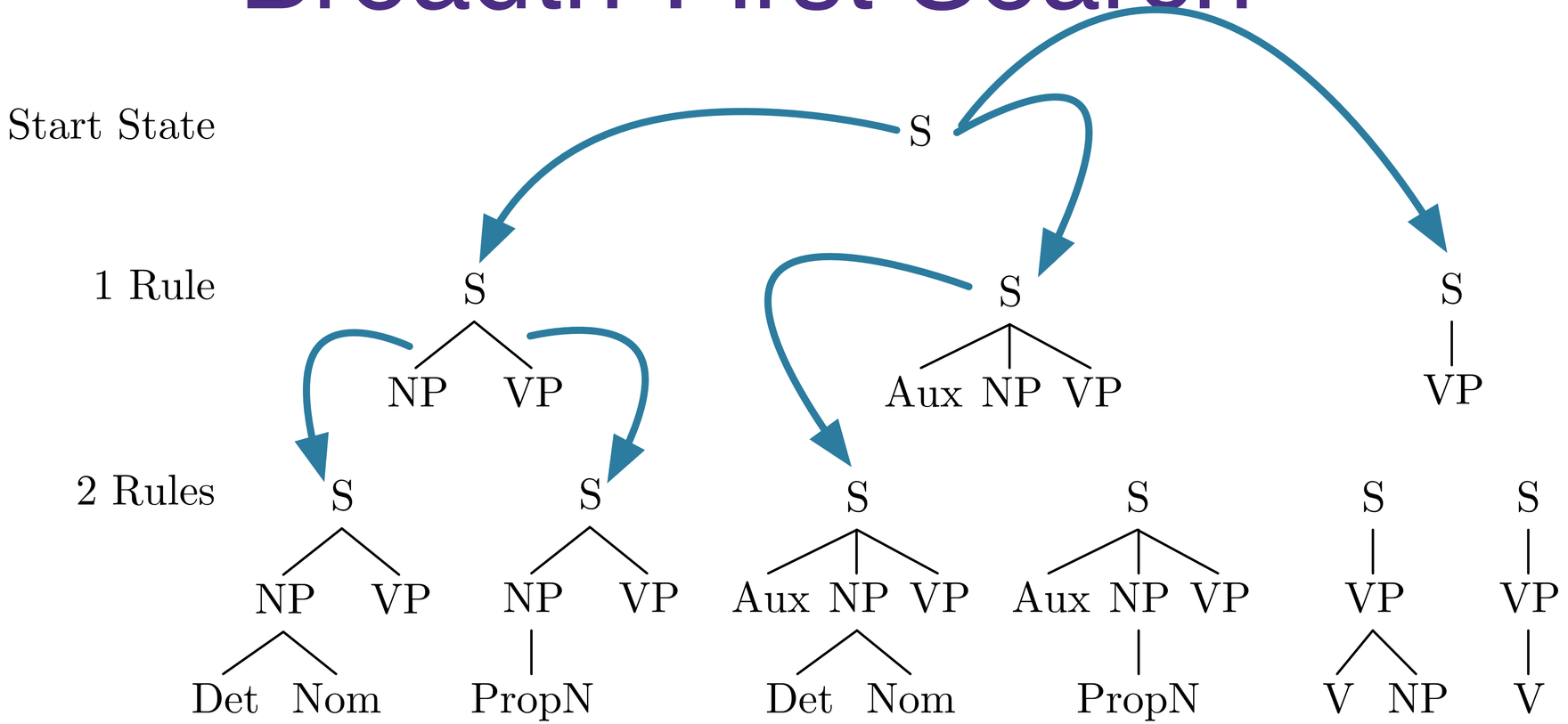

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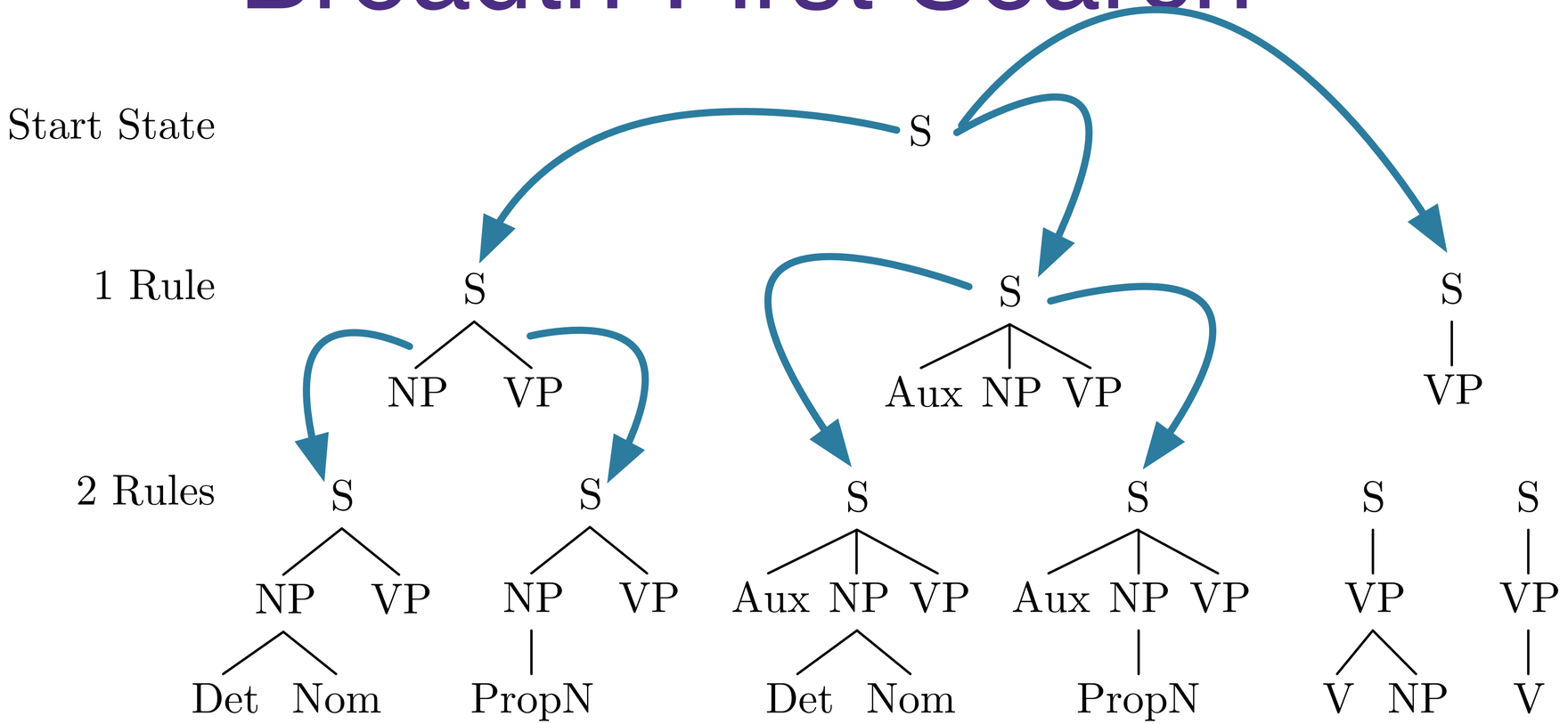

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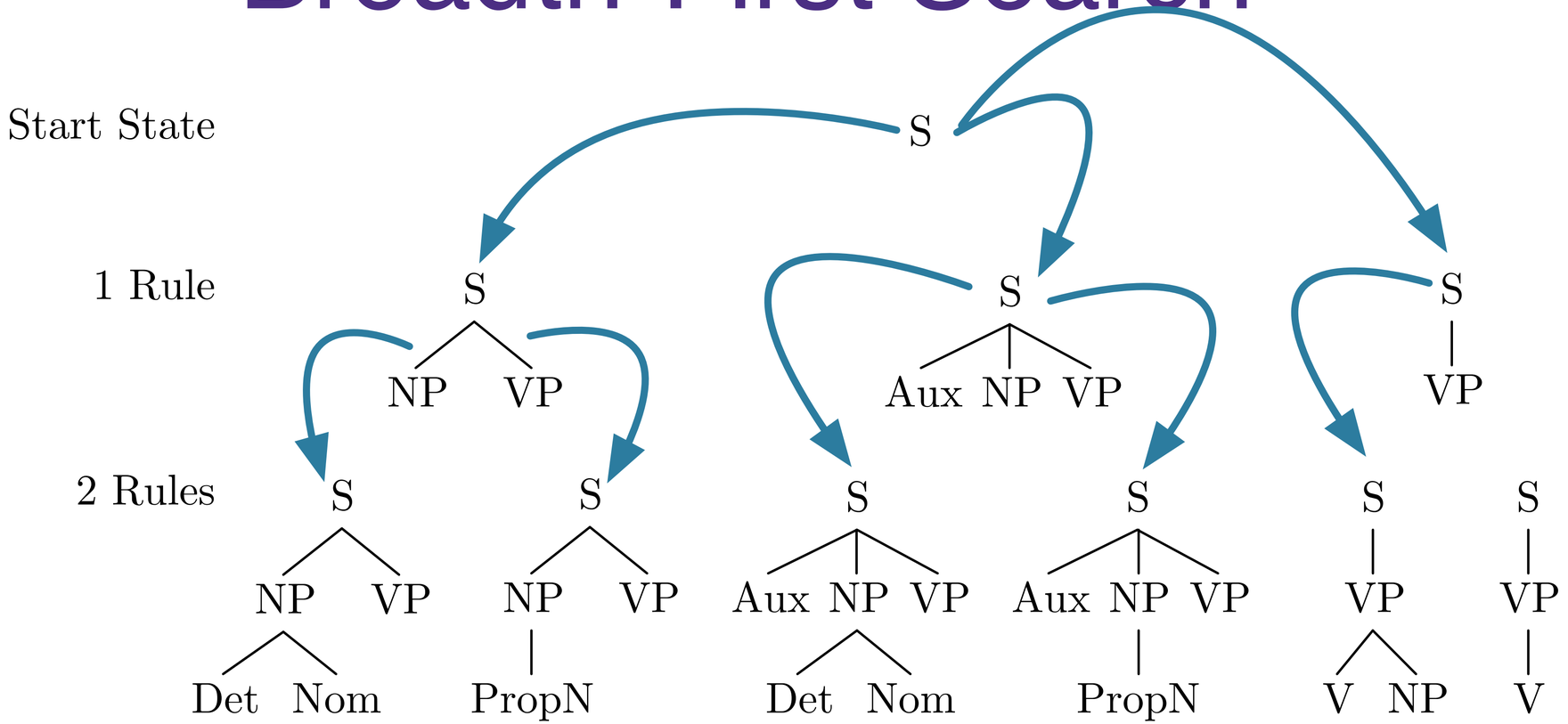

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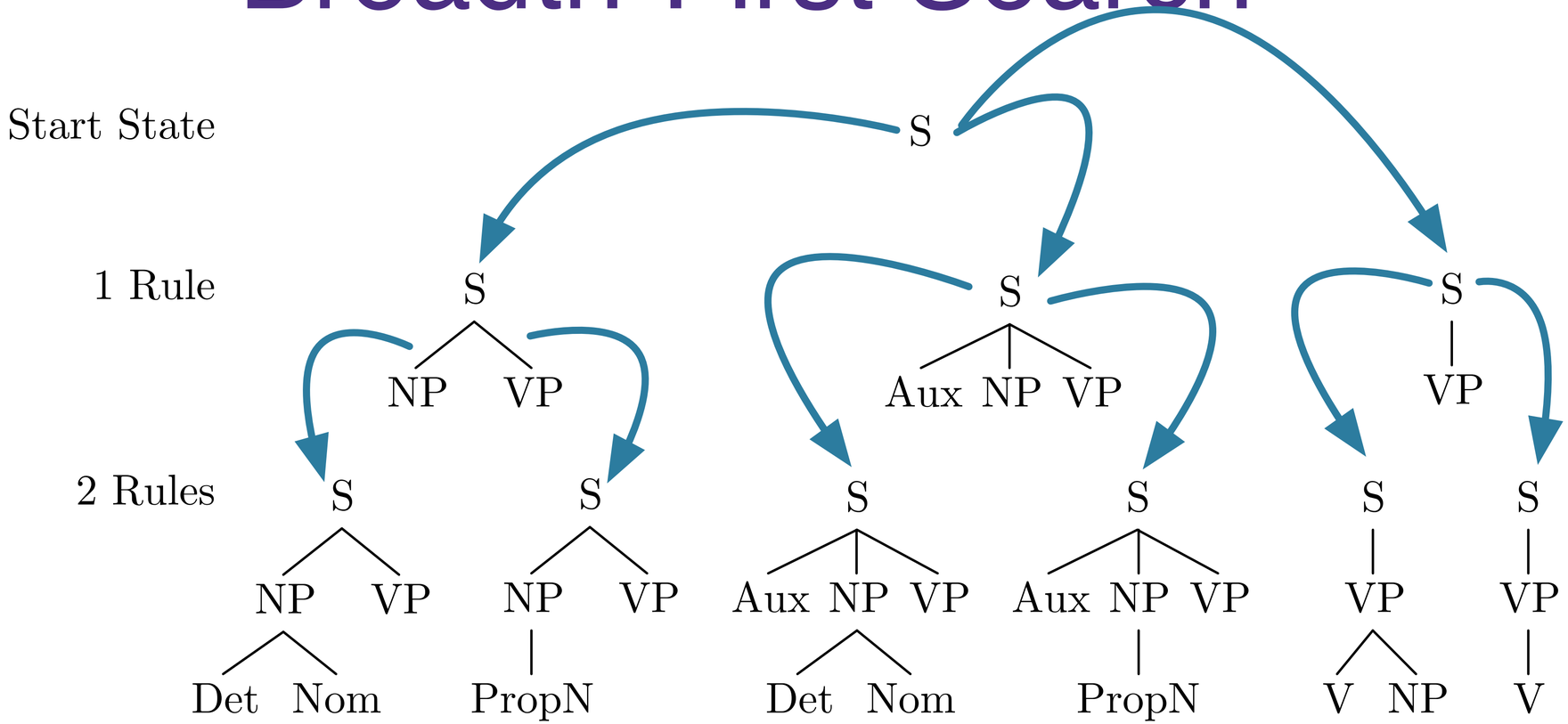

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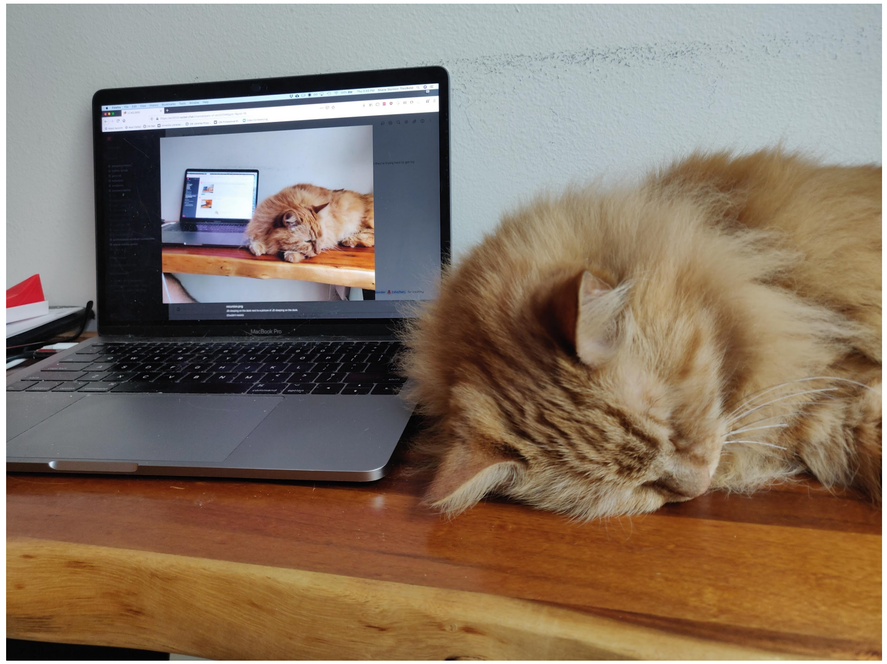

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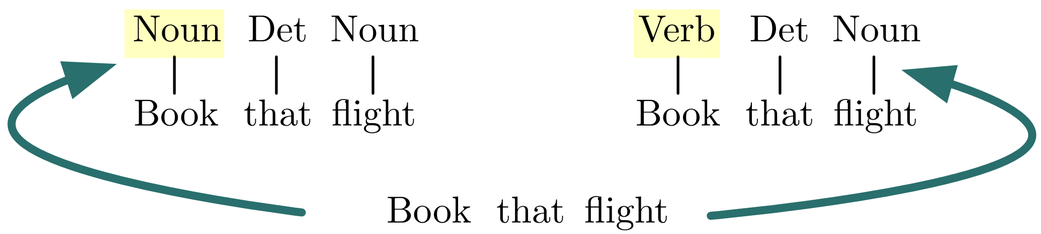
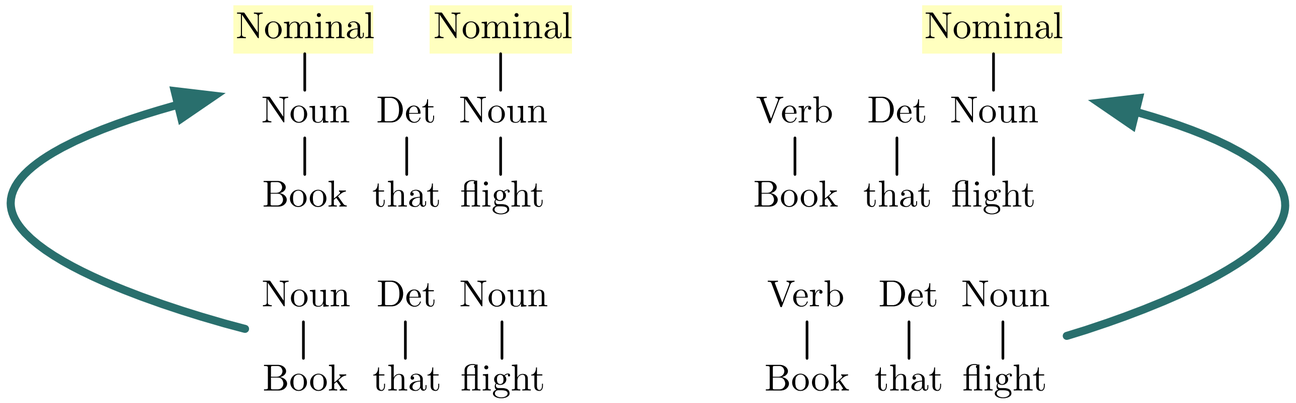
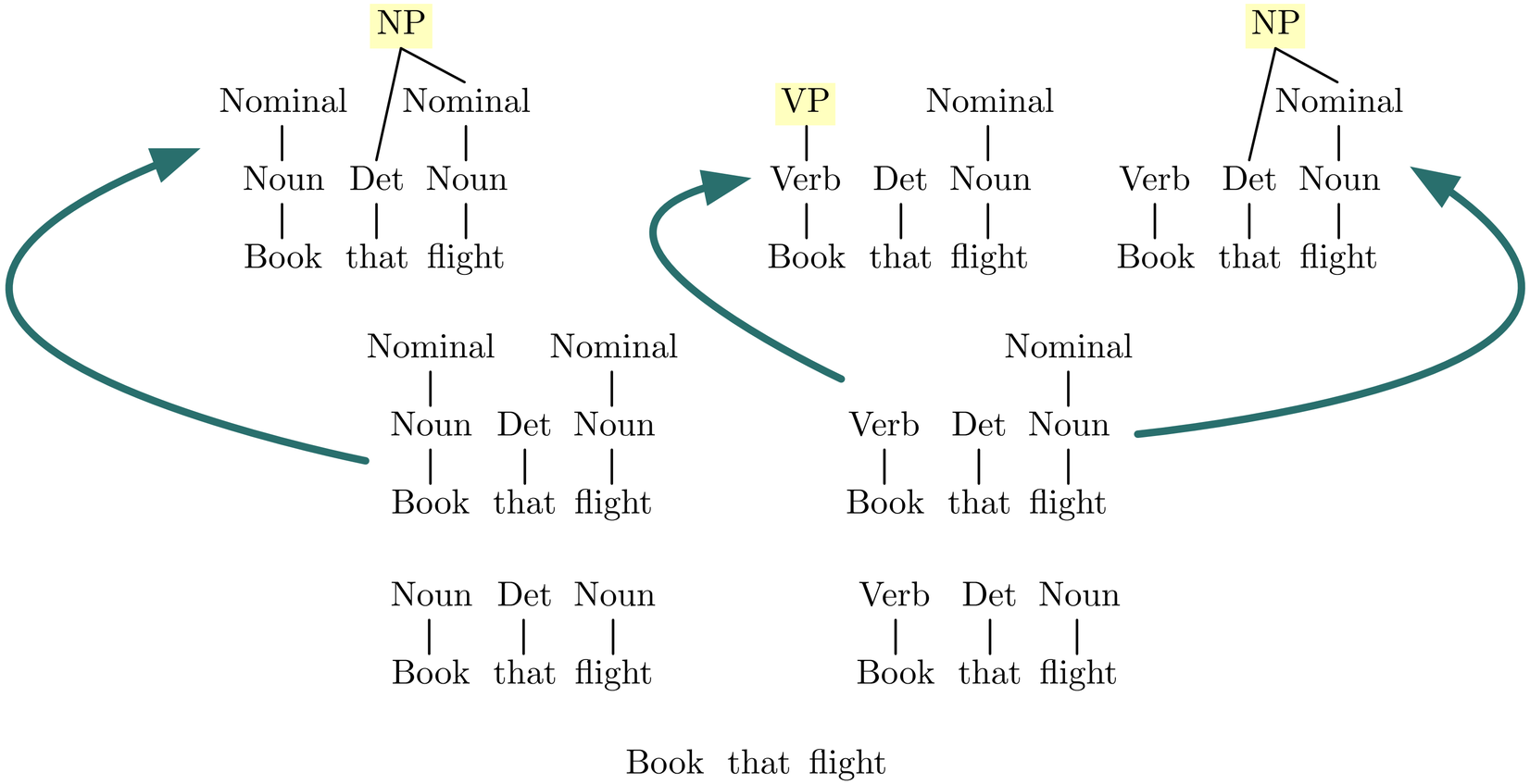
- Stop when spanned by S, or no more rules apply

Book that flight


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



Book that flight


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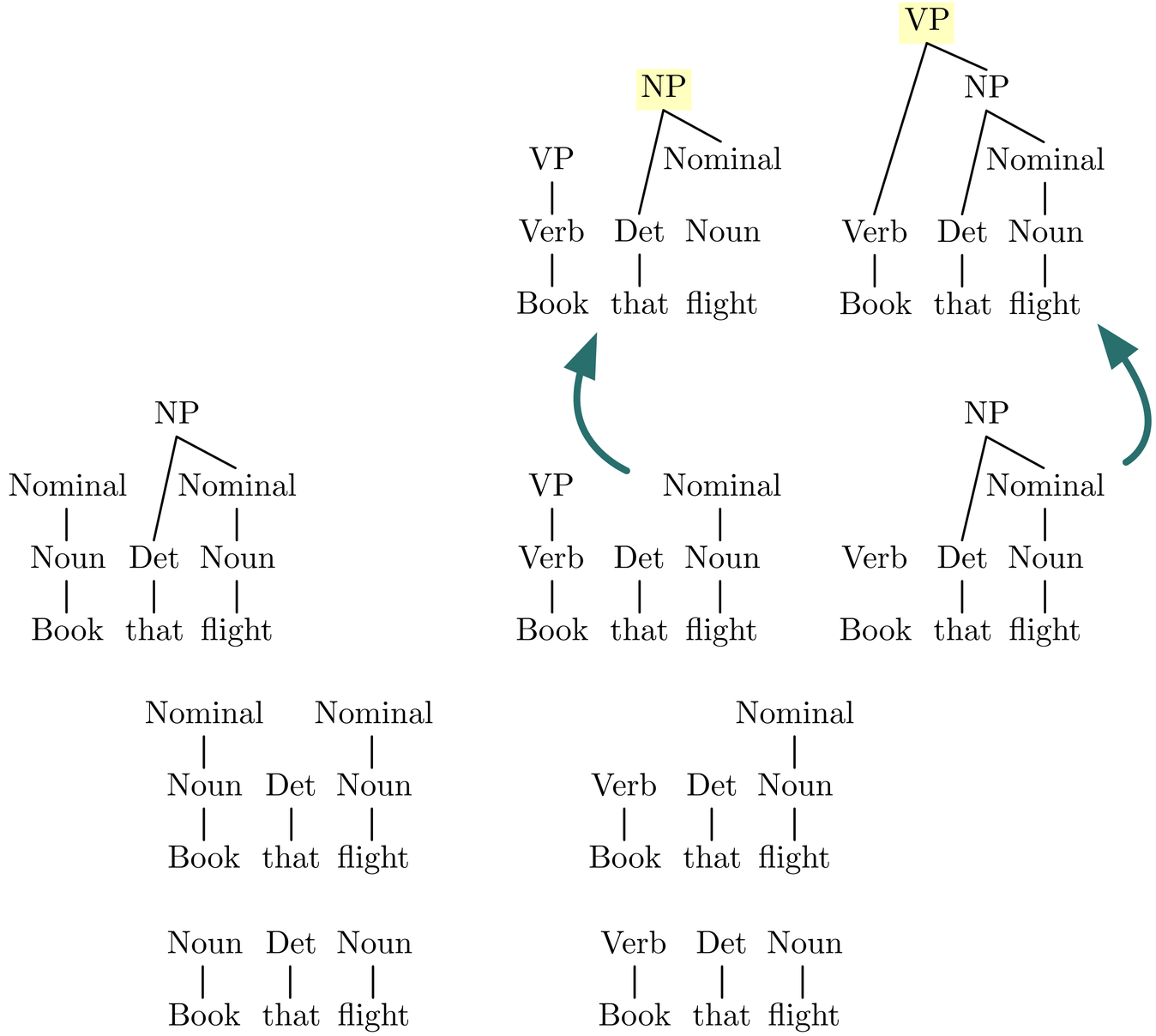
VP
NP
VP
Nominal
Verb
Det
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Book
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NP
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Noun
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that
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Pros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

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  - Recursive rules less problematic
  - Useful for incremental/fragment parsing

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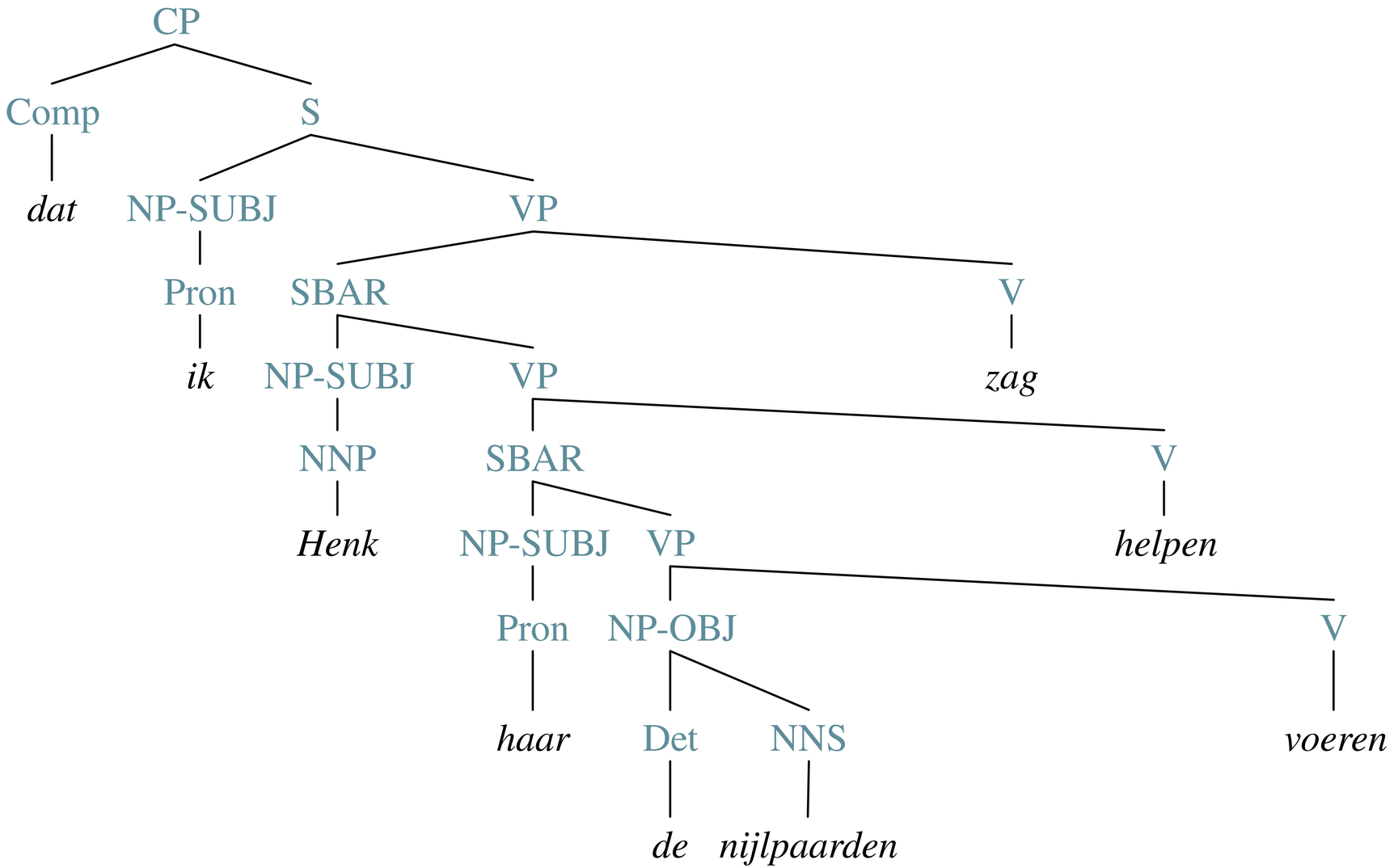
- Cons:
  - Explore subtrees that will not fit full input

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$_3$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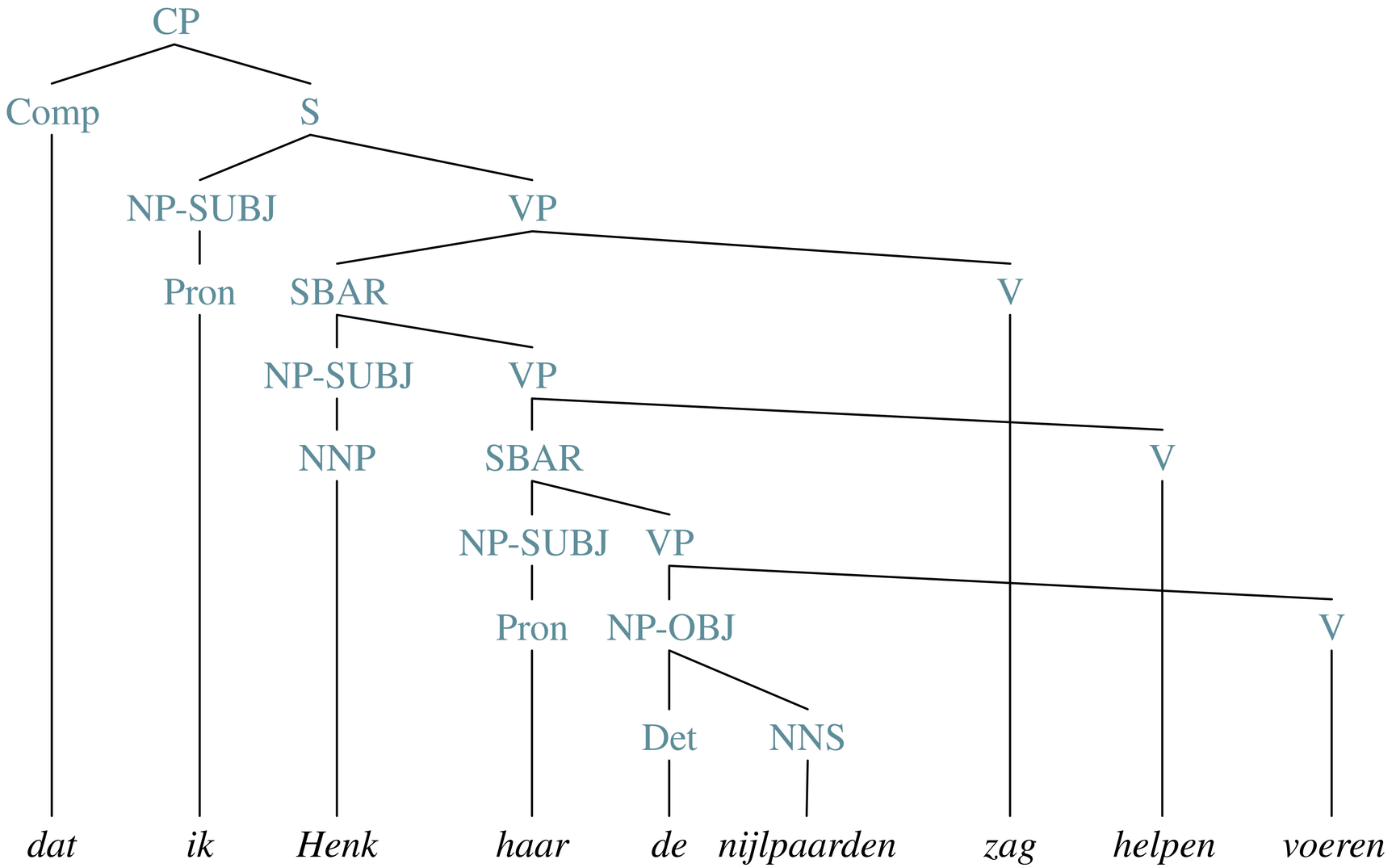
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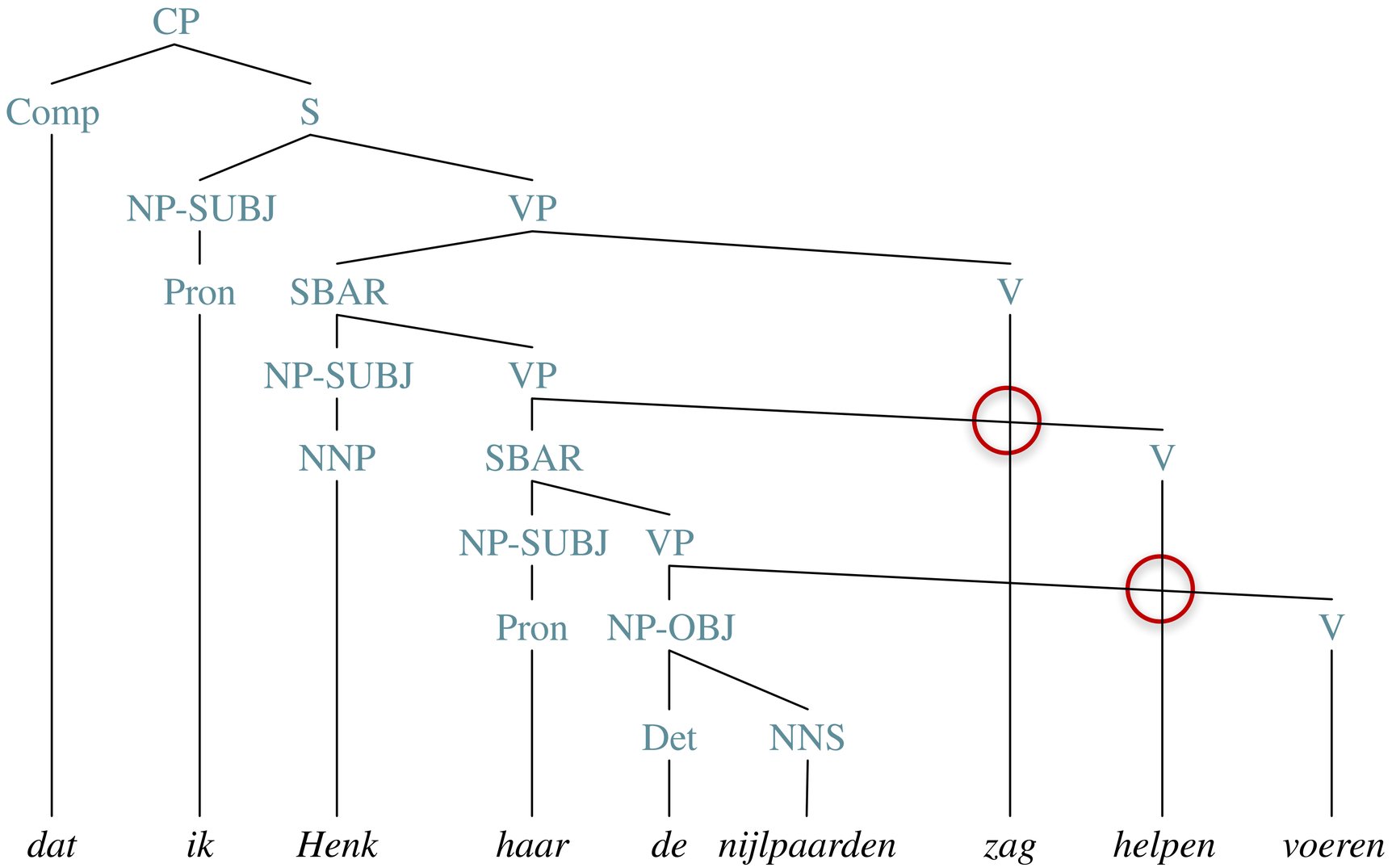
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Next Time

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