Syntax:
Context-Free Grammars

LING 571 — Deep Processing Techniques for NLP
Oct 4, 2021
Shane Steinert-Threlkeld

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

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

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    - $S \rightarrow NP\ VP$
    - $VP \rightarrow V\ NP\ PP \mid V\ NP$

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    - *Det* → ‘the’

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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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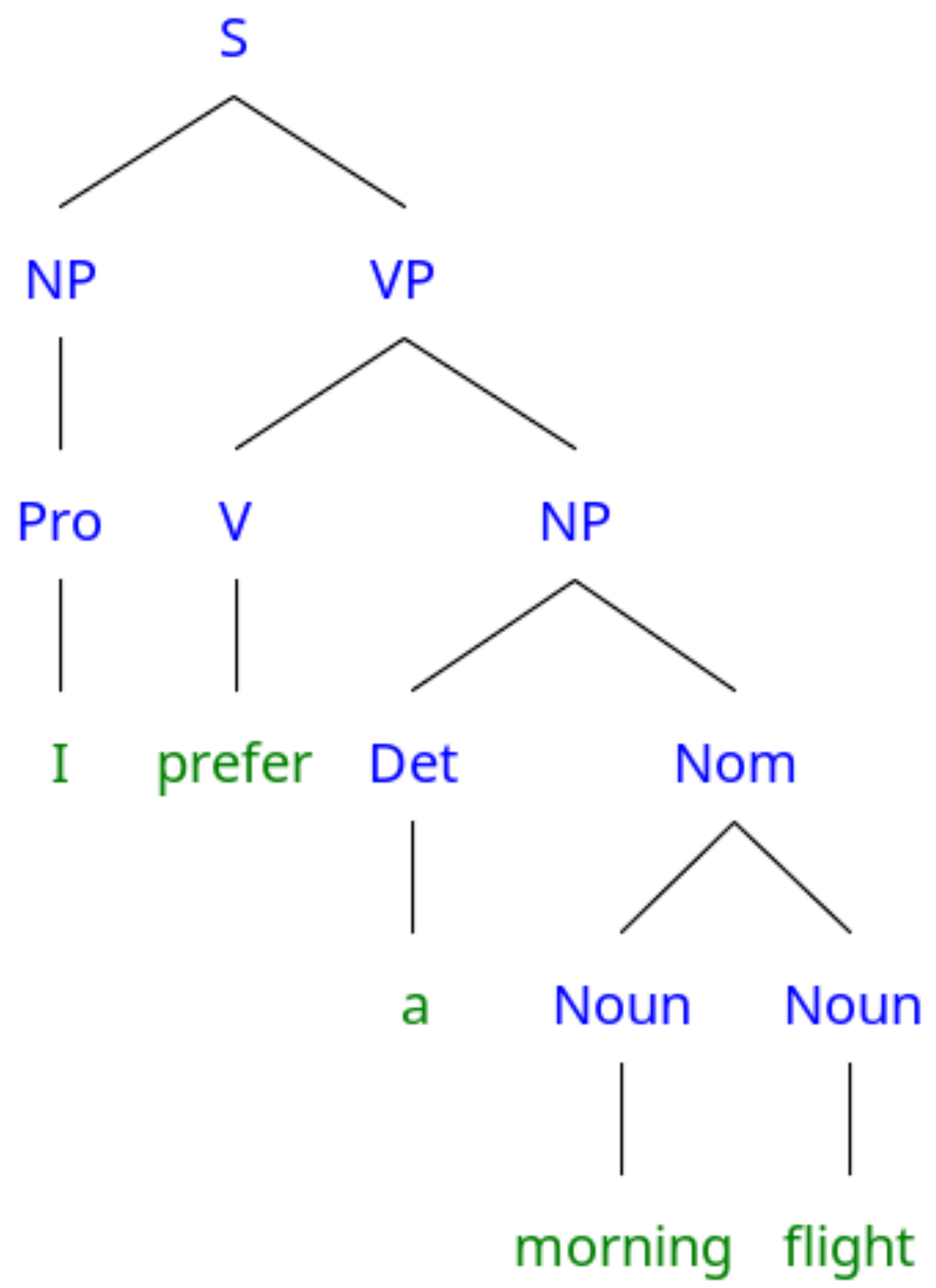
Parse Tree



Some English Grammar

- Sentences: Full sentence or clause; a complete thought
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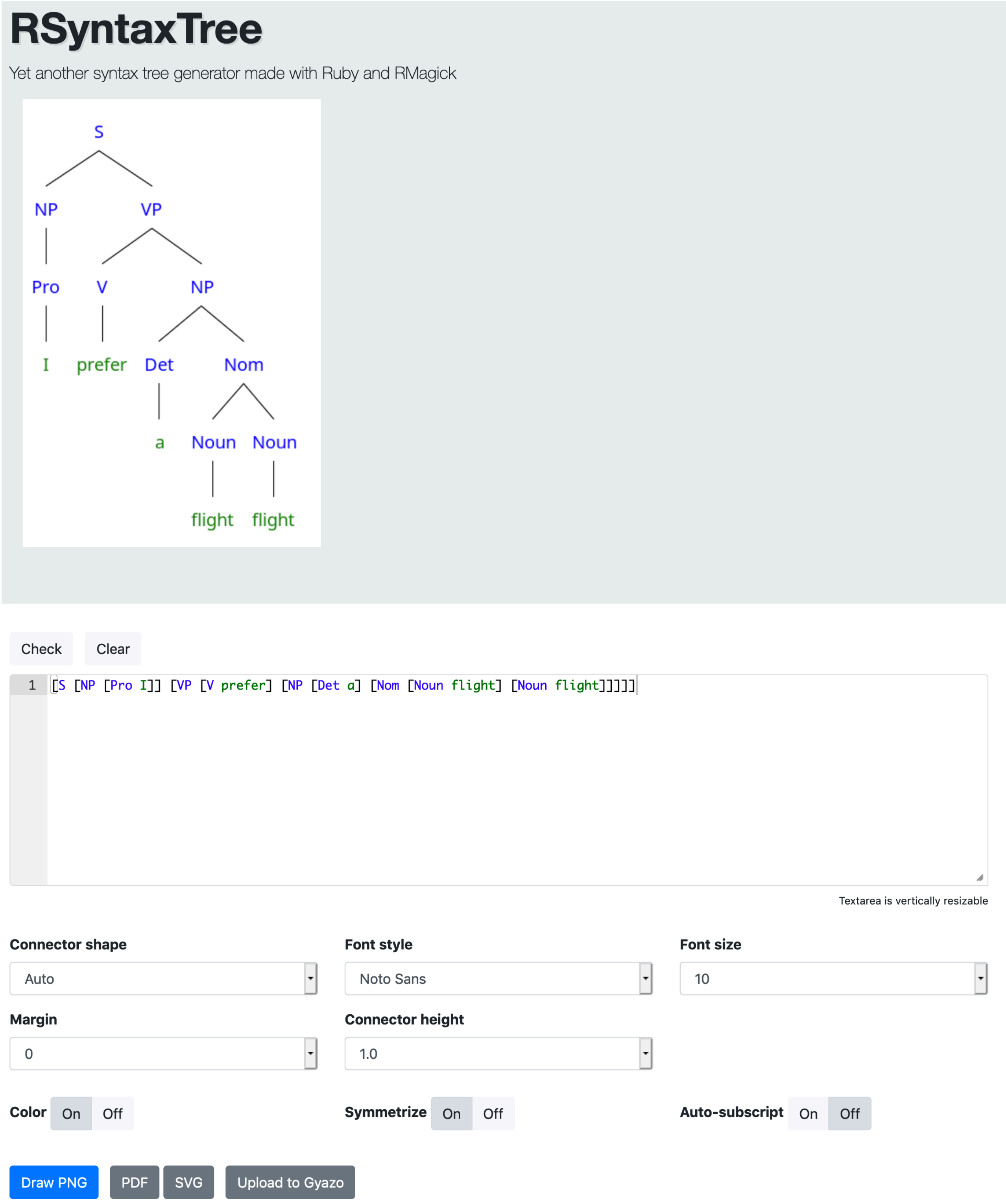
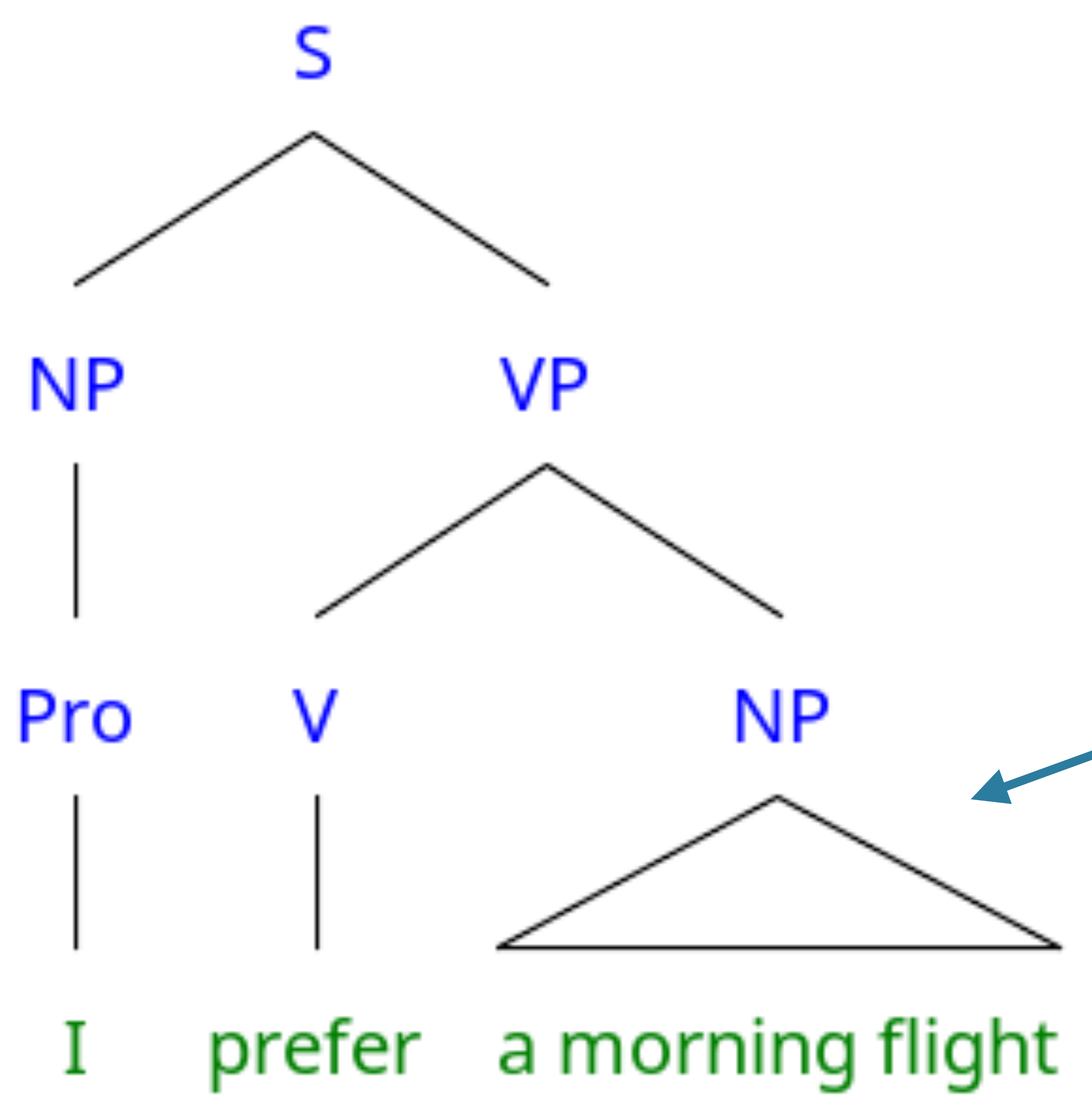
- **Wh-non-subject question**: $S \rightarrow Wh\text{-}NP\ Aux\ NP\ VP$
  - (Wh-NP What flights) (Aux do) (NP you) (VP have from Seattle to Orlando?)

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

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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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  - **"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*

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- ***NP* → *(Det) Nom***
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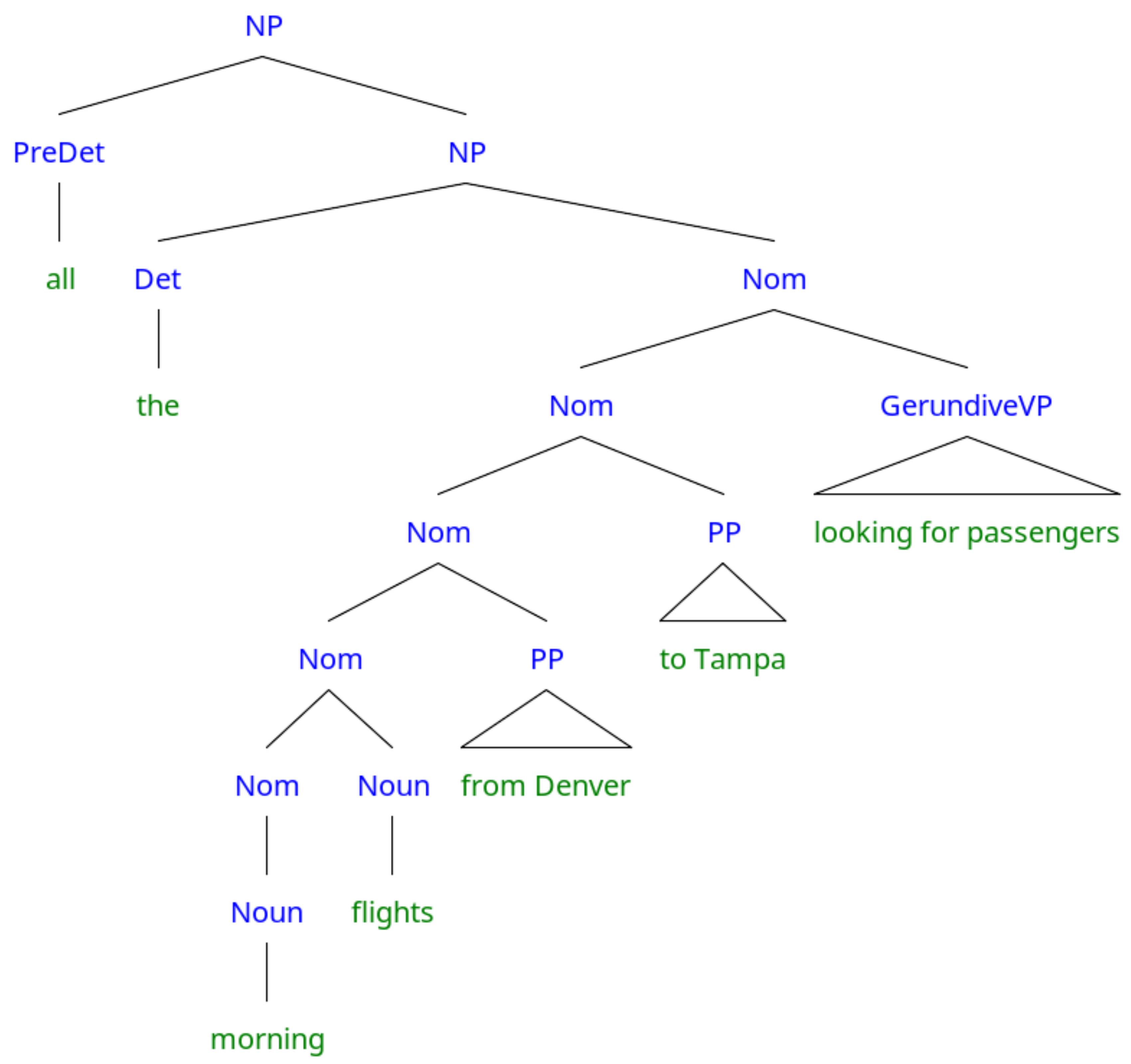
  - The least expensive fare
  - one flight
  - the first route
  - the last flight from Chicago

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"*



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- With this grammar:

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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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$VP \rightarrow Verb\ VP$	want to arrange three flights

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    - 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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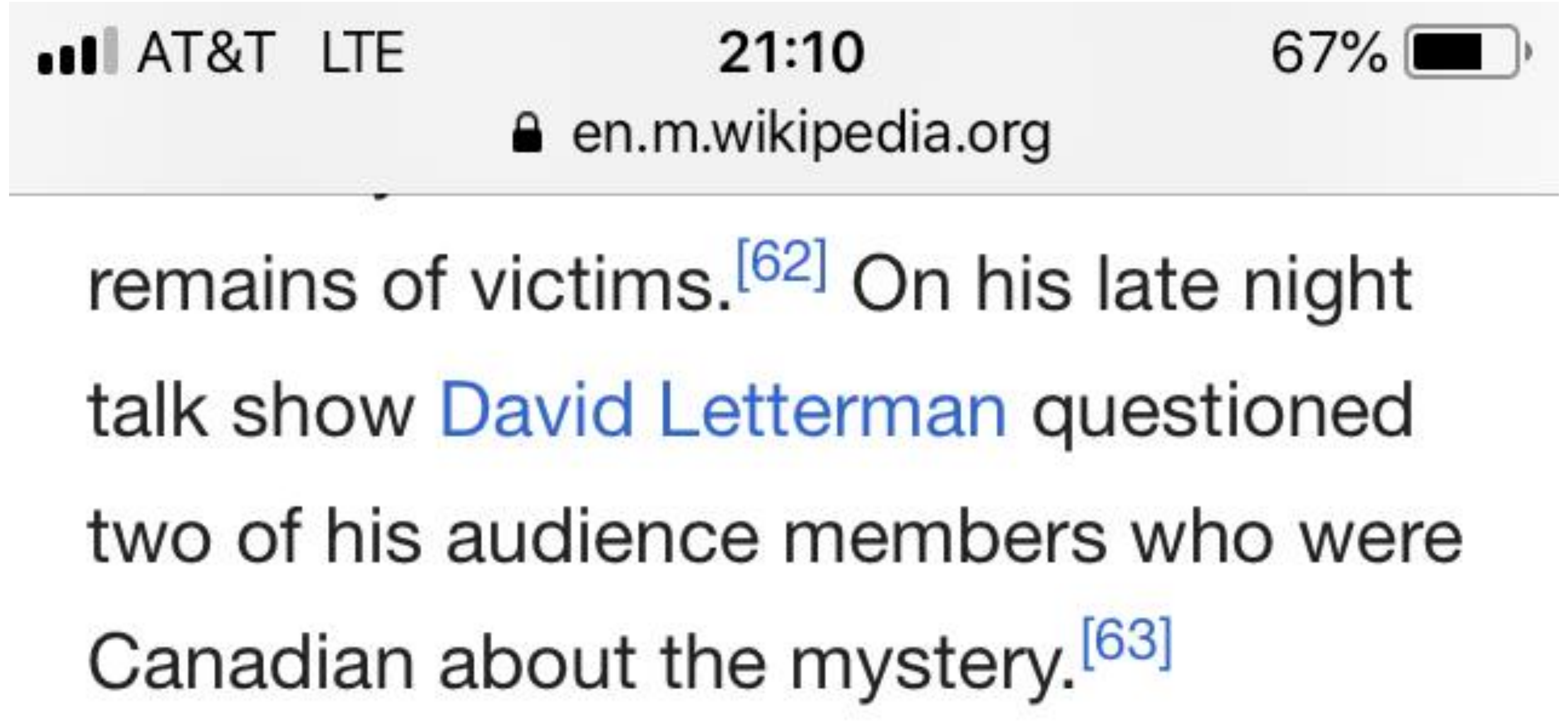
Grammars… So What?

- 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!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h/t to Amandalynne Paullada

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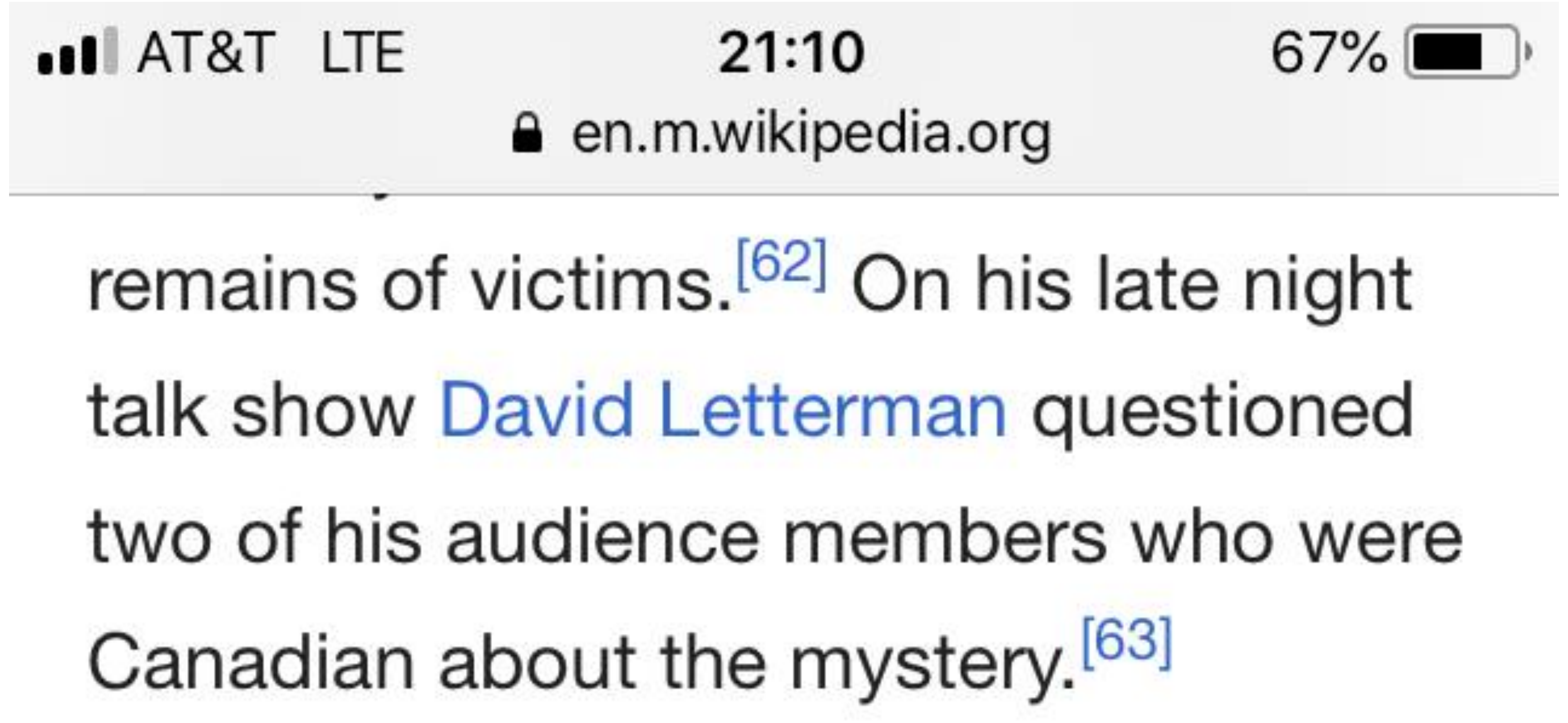

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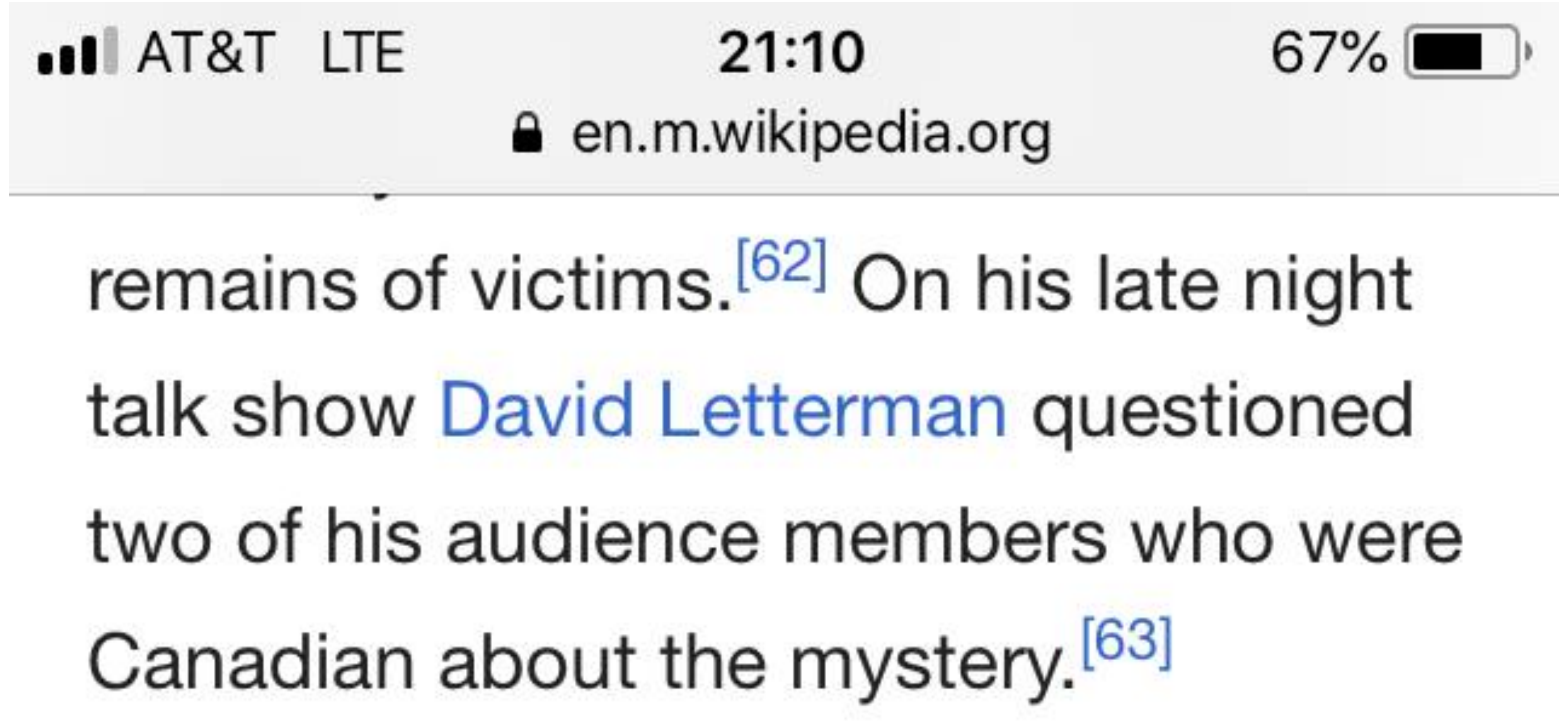

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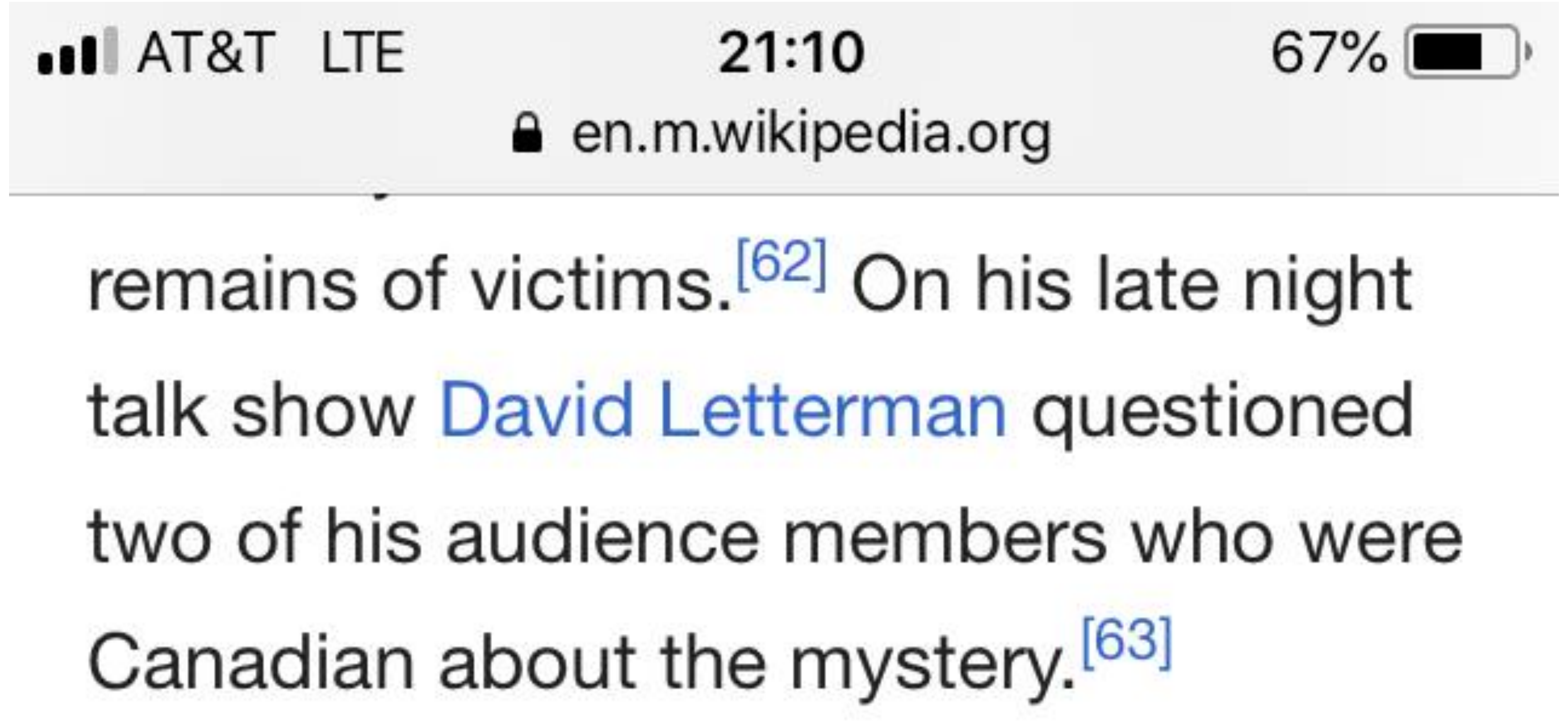
  Two audience members, who happened to be Canadian Citizens, were questioned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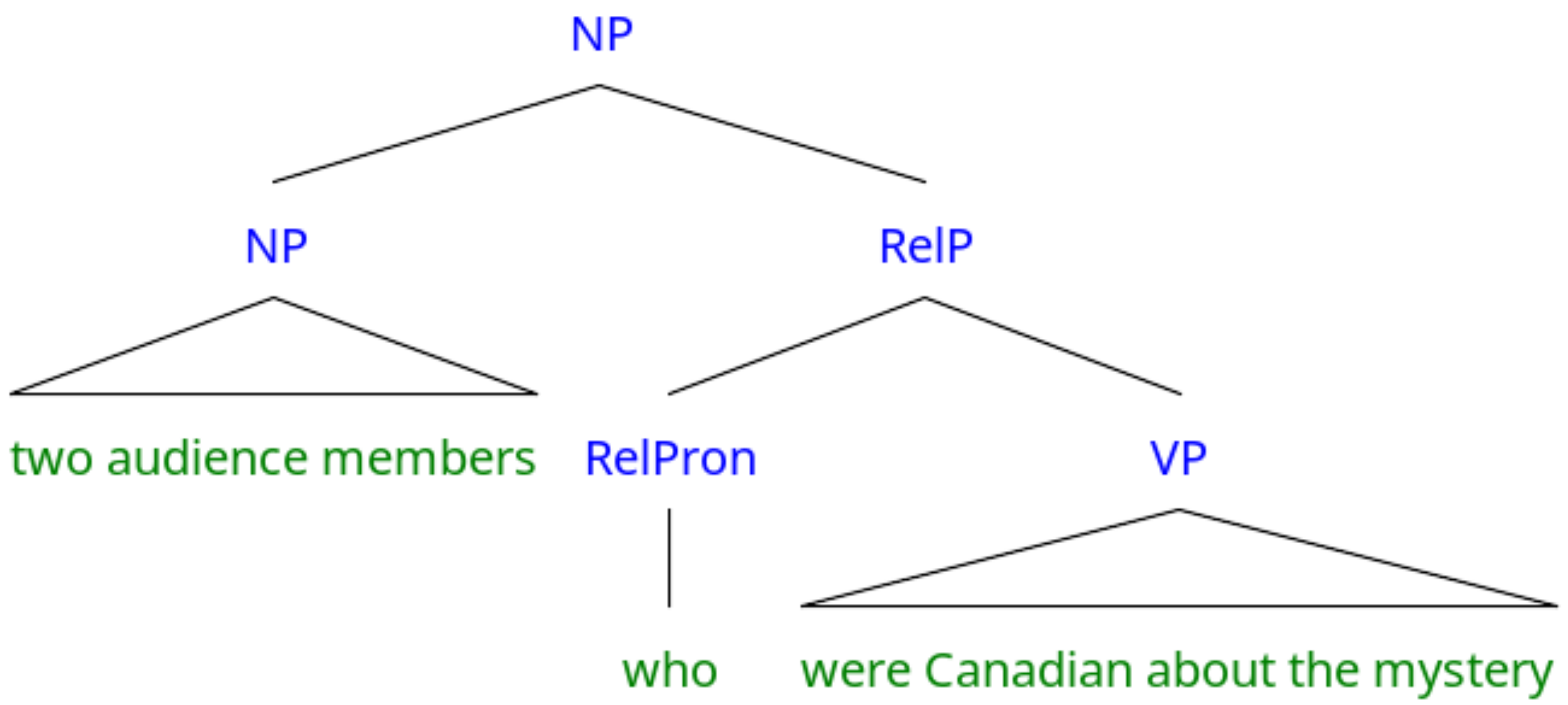
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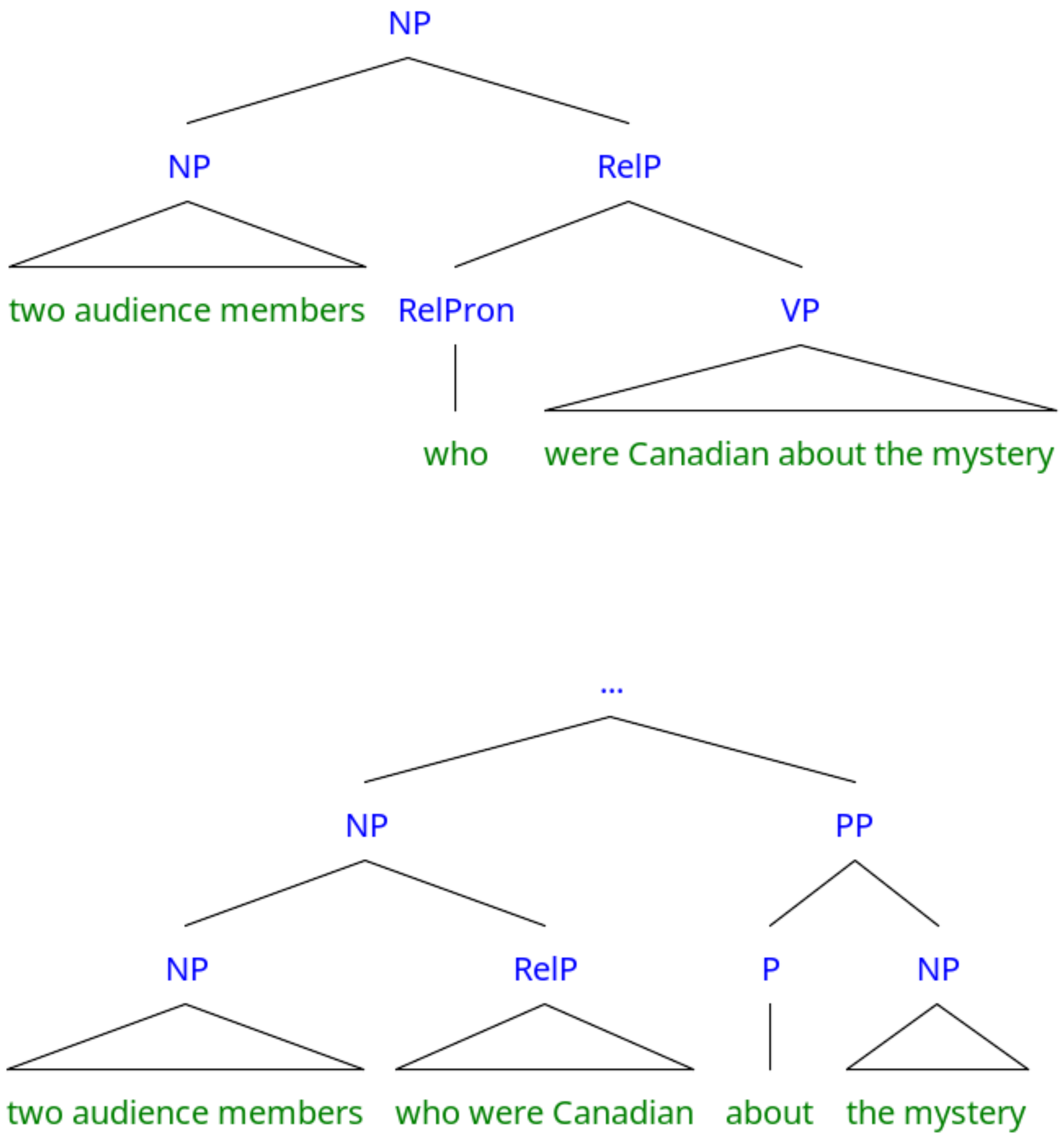
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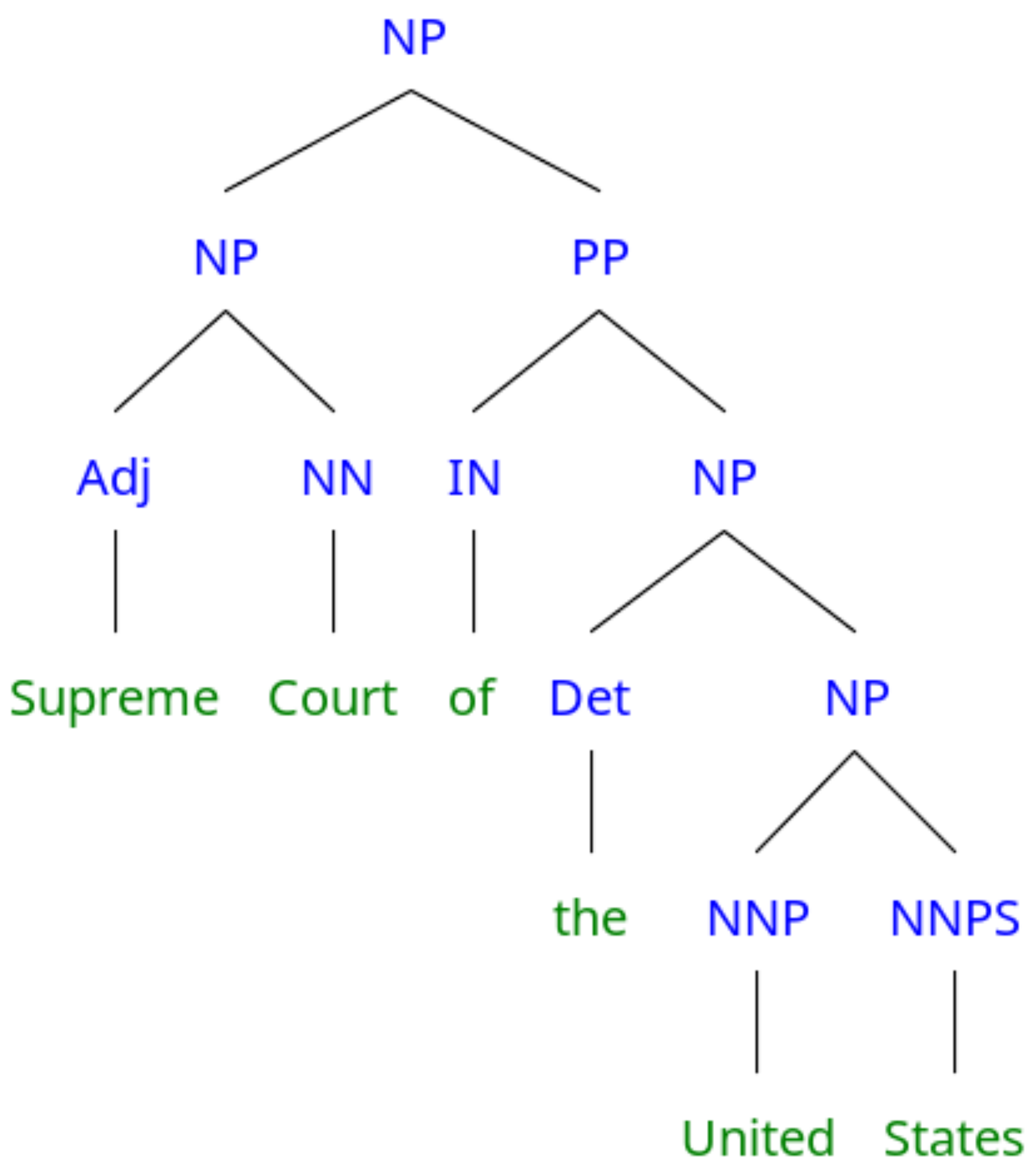

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  - The court is specific to the US
- Inferable from this tree:
  - "*The United States*" is an entity that can possess (grammatically) other institutions

Roadmap

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

Treebanks

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- Built semi-automatically
  - Automatically parsed, manually corrected

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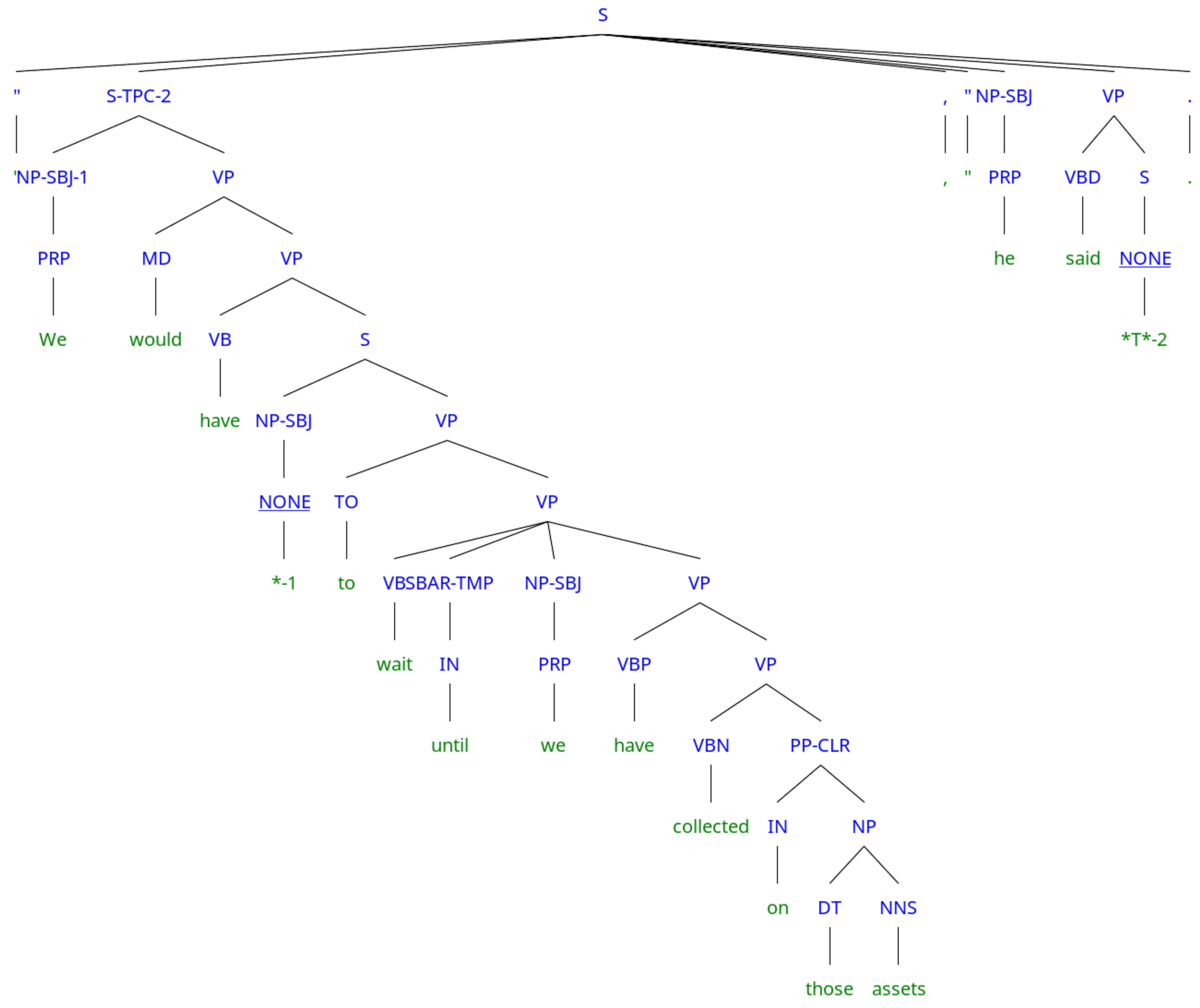
- Implicitly constitute grammar of language
  - Can read off rewrite rules from bracketing
  - Not only presence of rules, but frequency counts
  - Will be crucial in building statistical parsers

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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- 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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  - 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

- Syntactic parsing searches through possible trees to find one or more trees that derive input

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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  - 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

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

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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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$VP \rightarrow Verb$	

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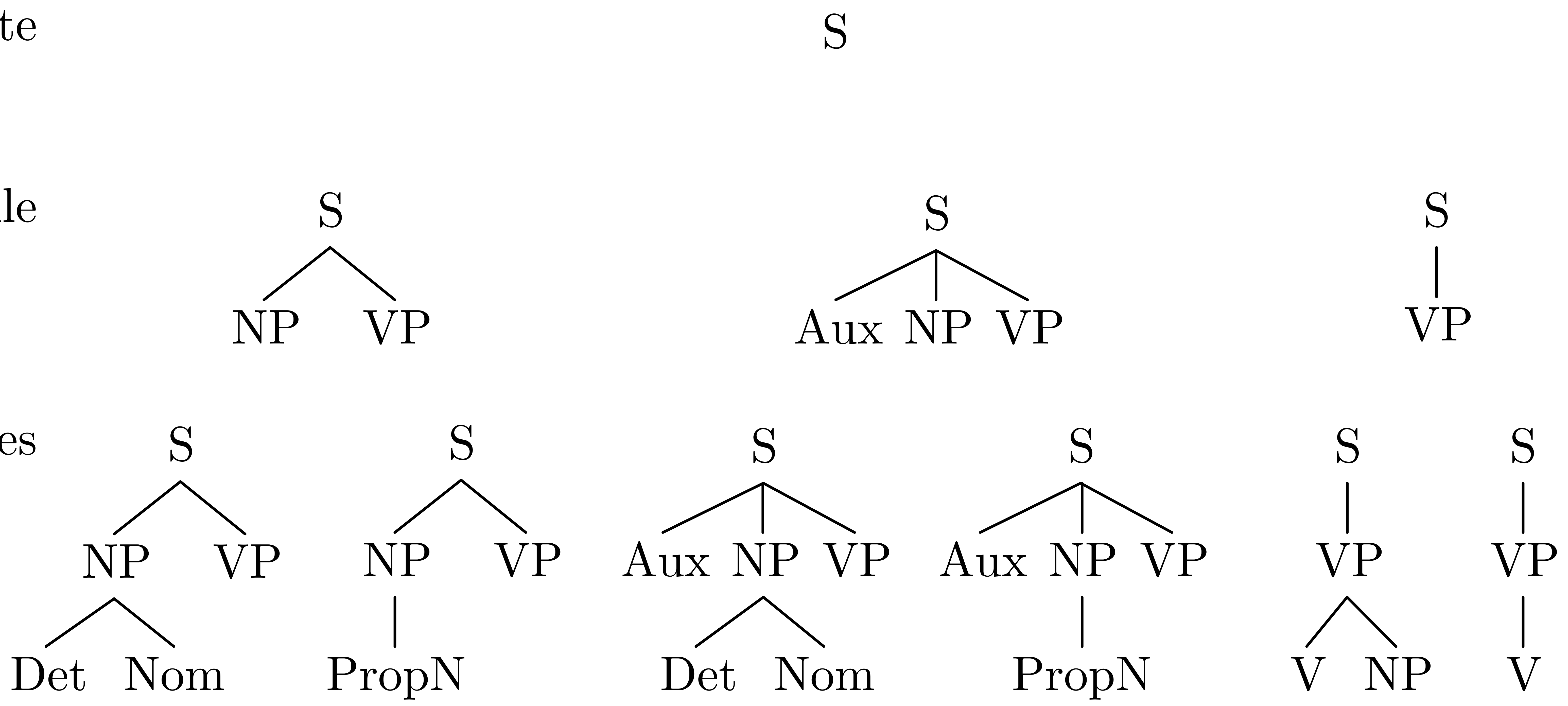
  - e.g. $NP \rightarrow Det\ Nominal;\ VP \rightarrow V\ NP$
- Terminate when all leaves are terminals

Depth-First Search

Start State

1 Rule

2 Rules



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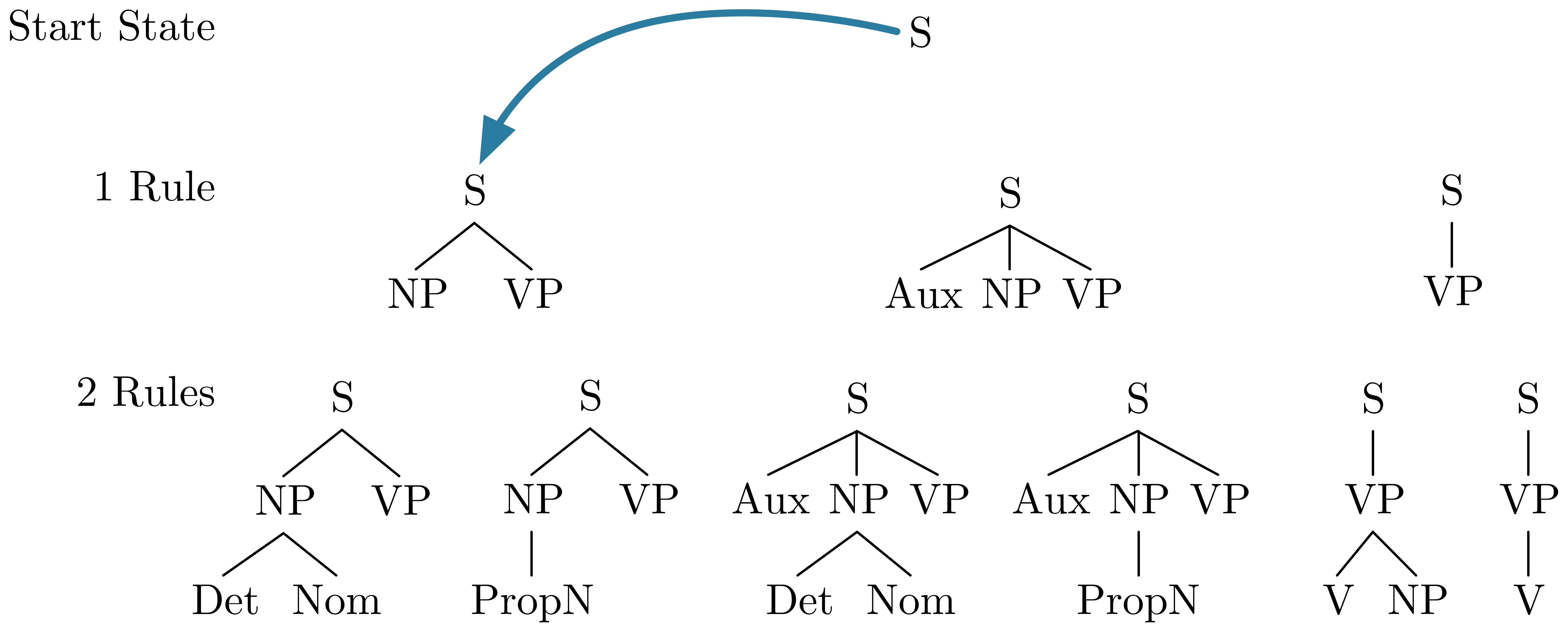

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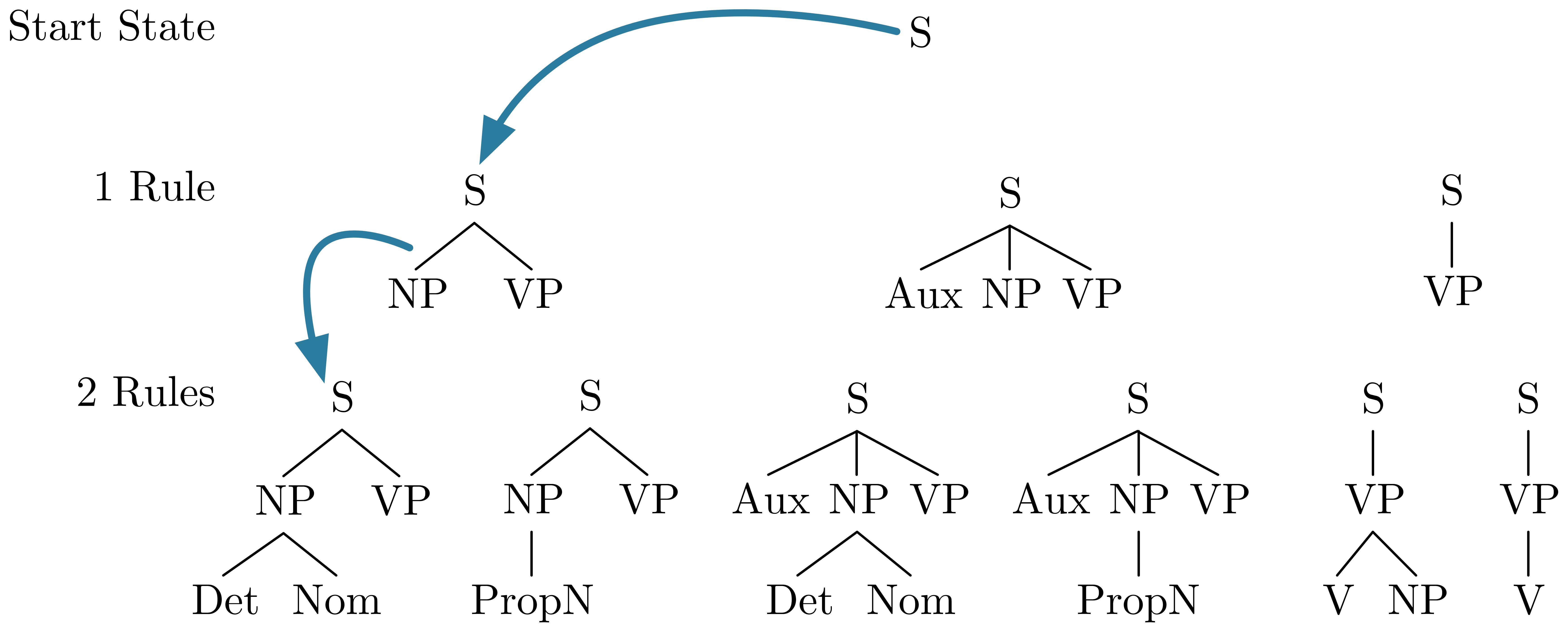

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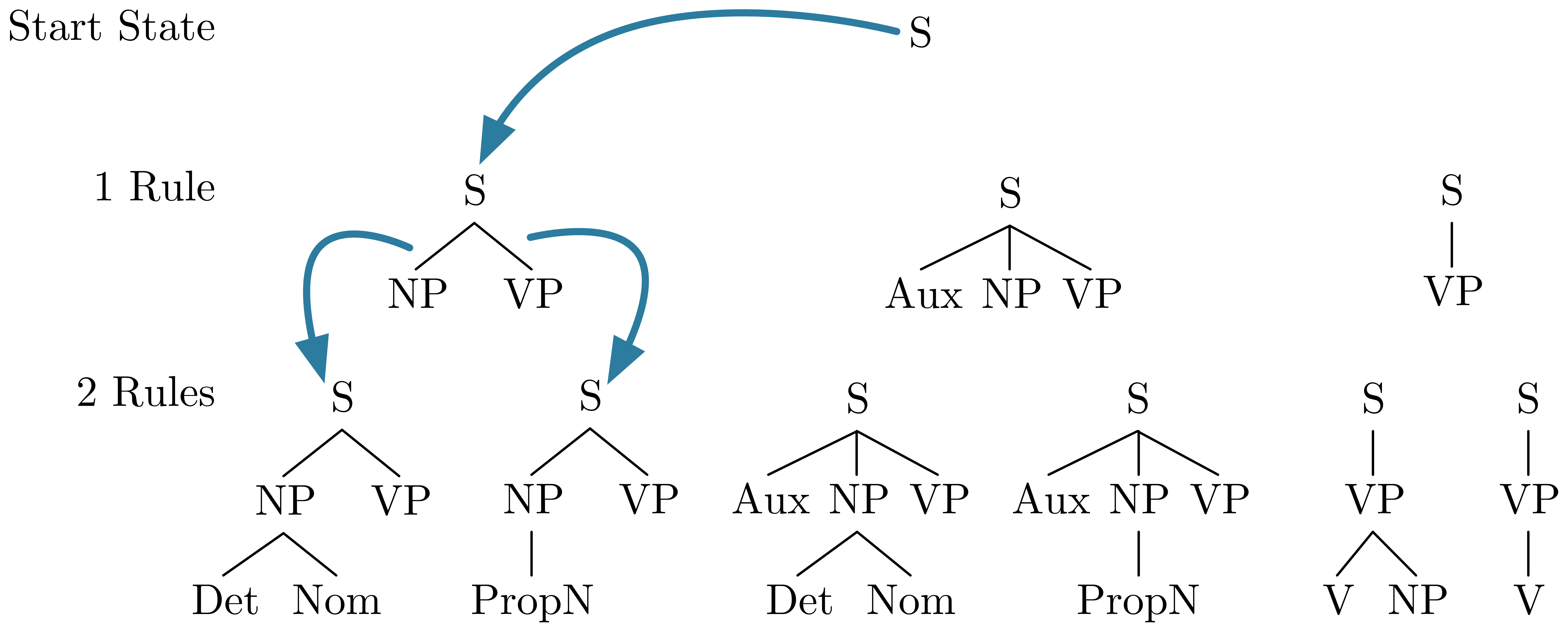

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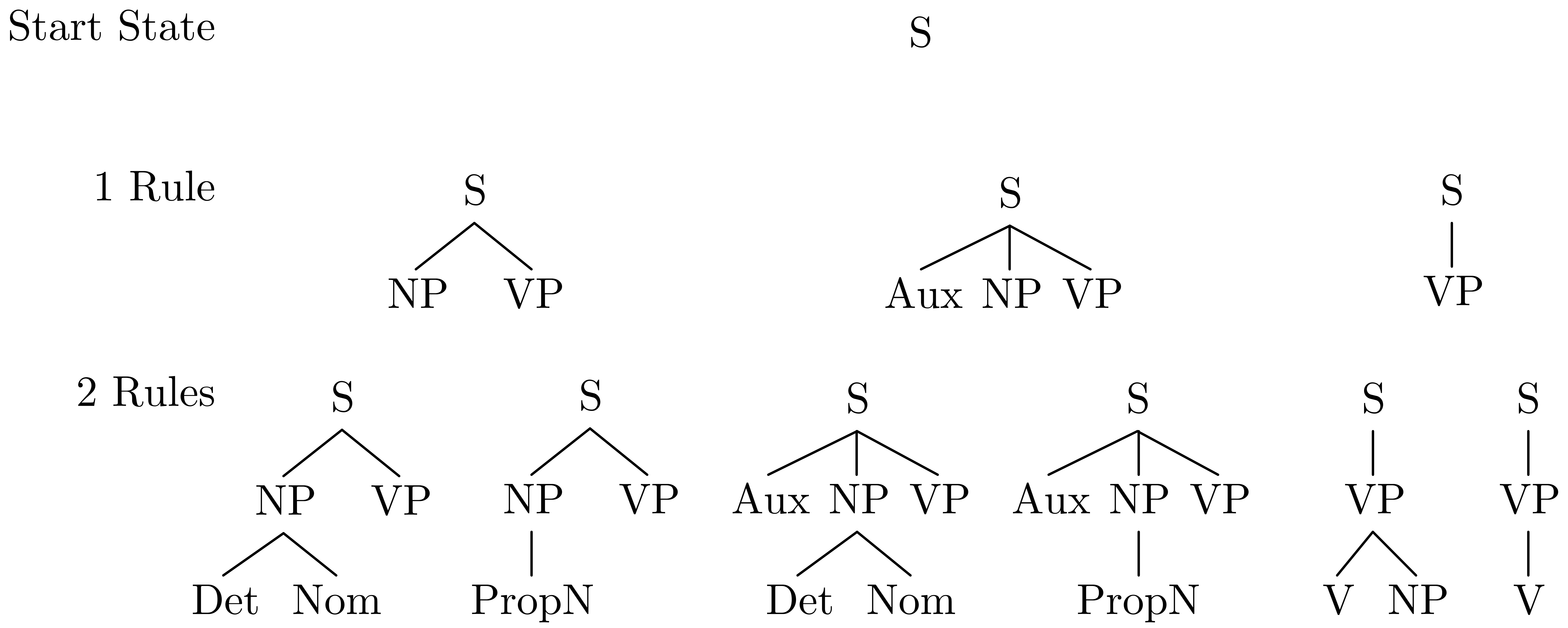

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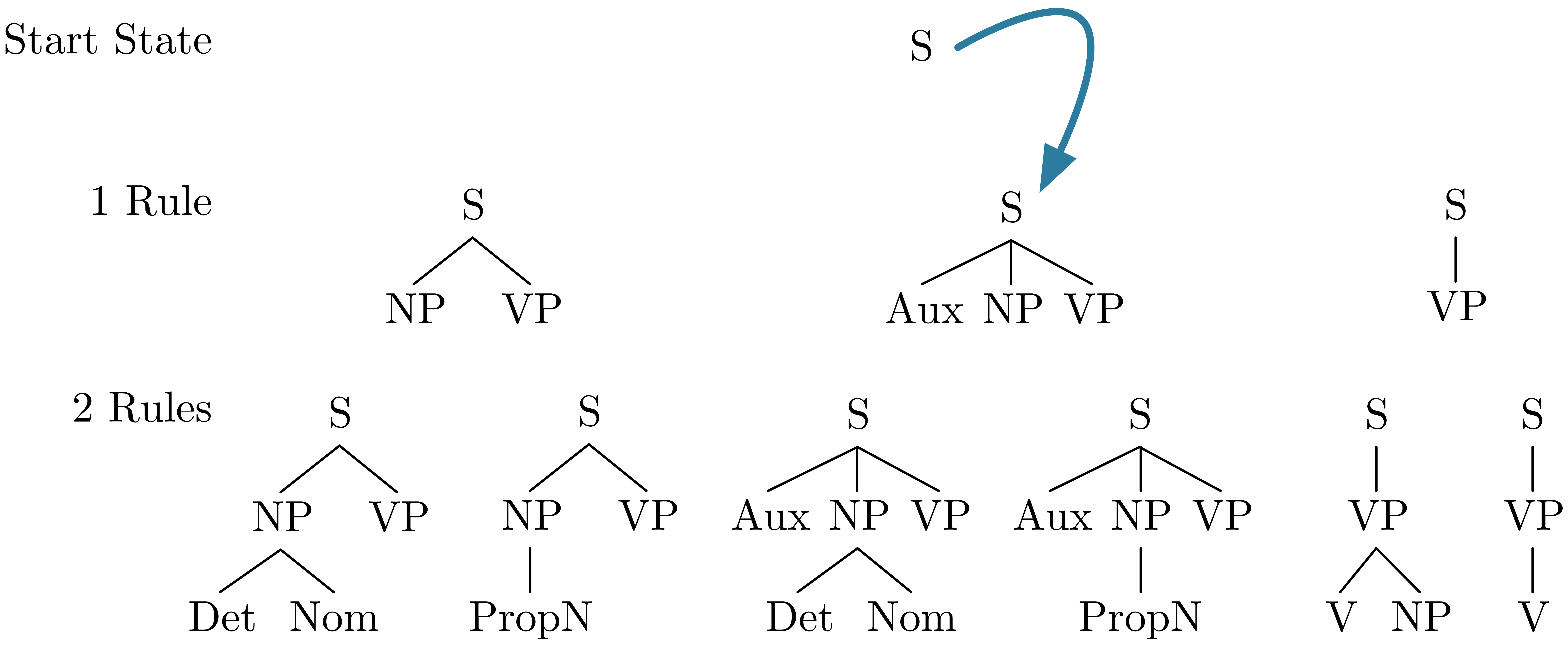

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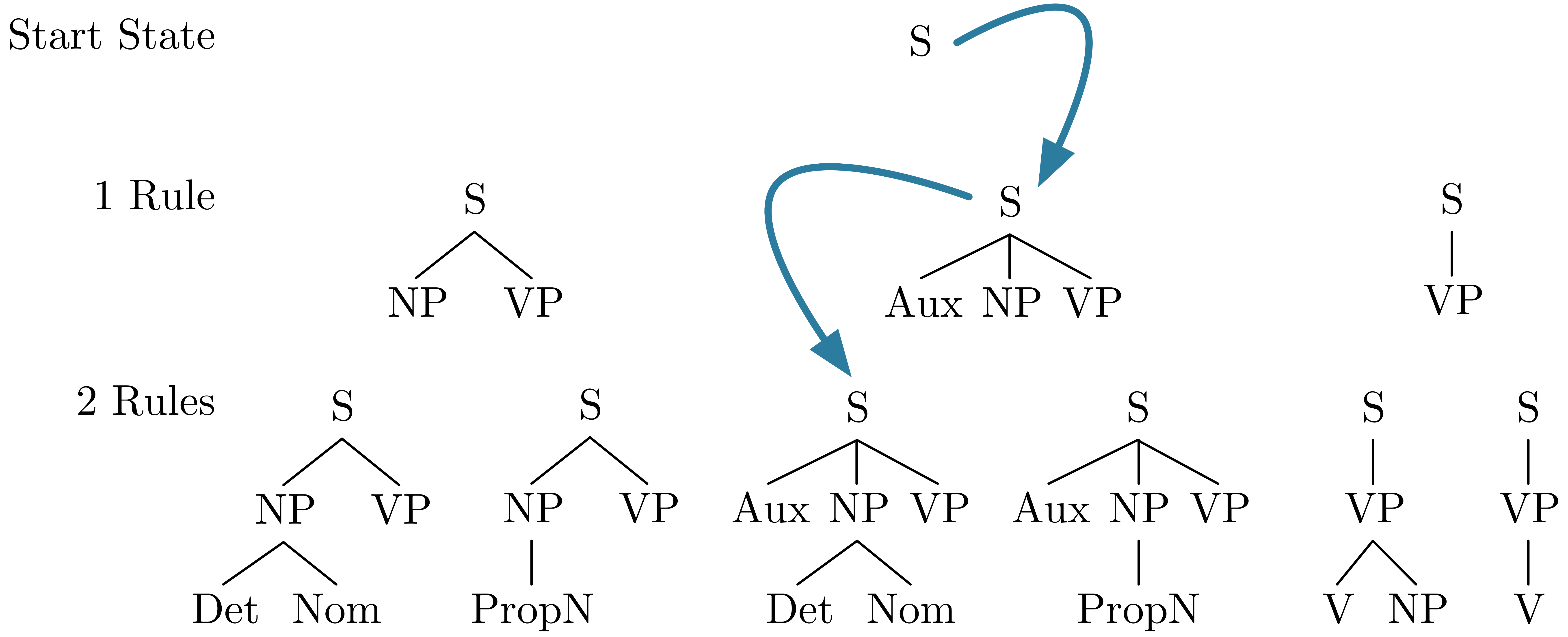

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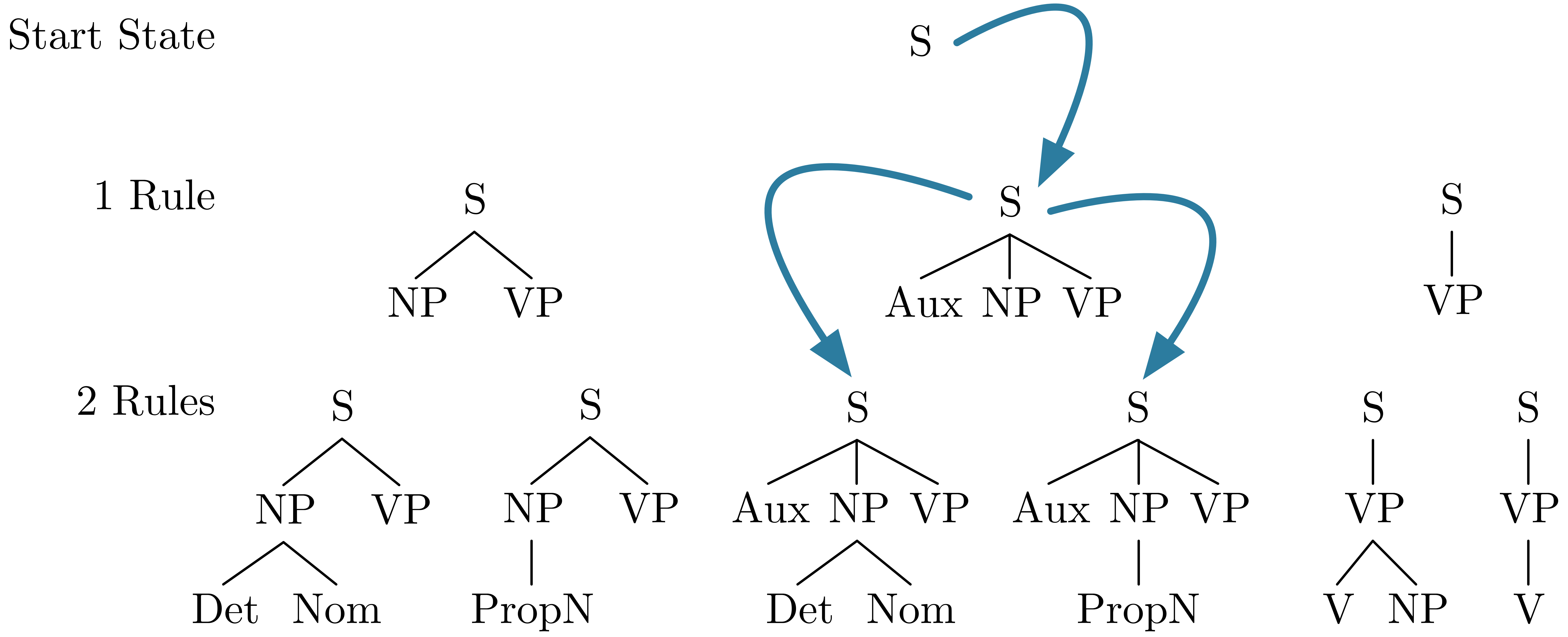

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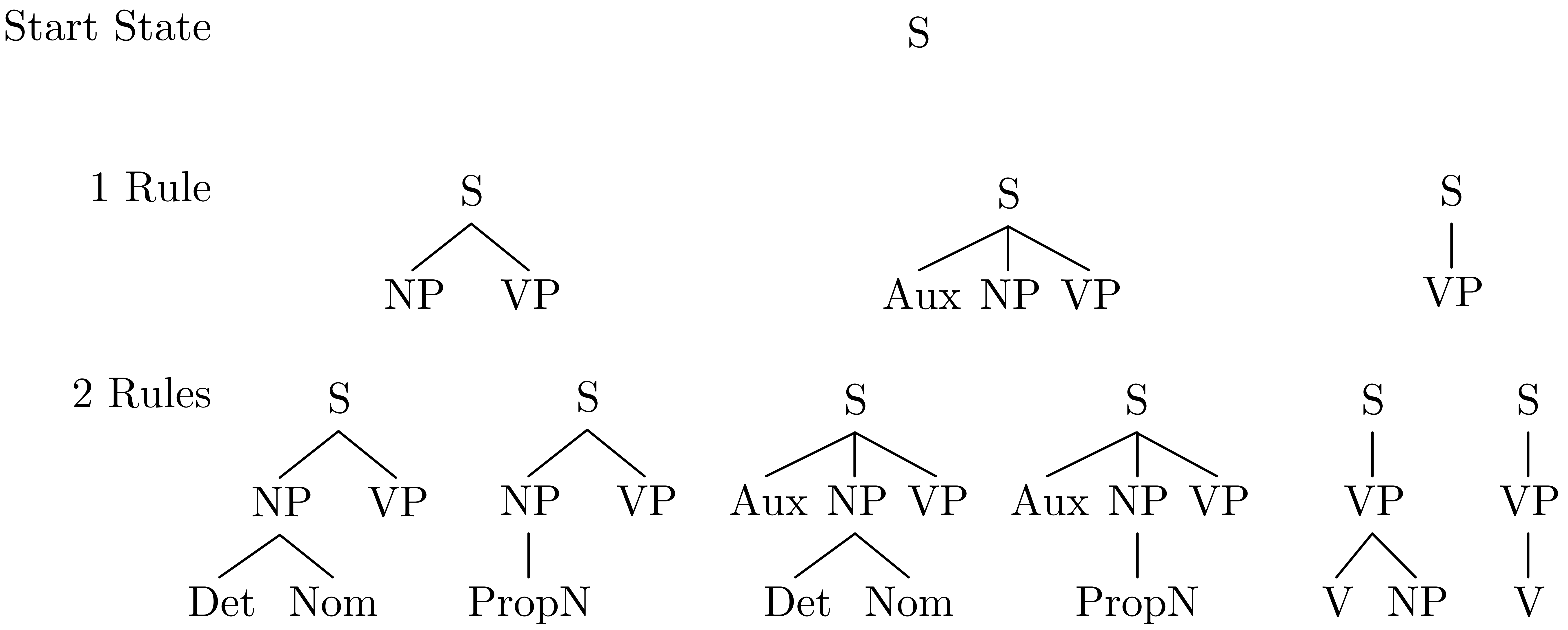

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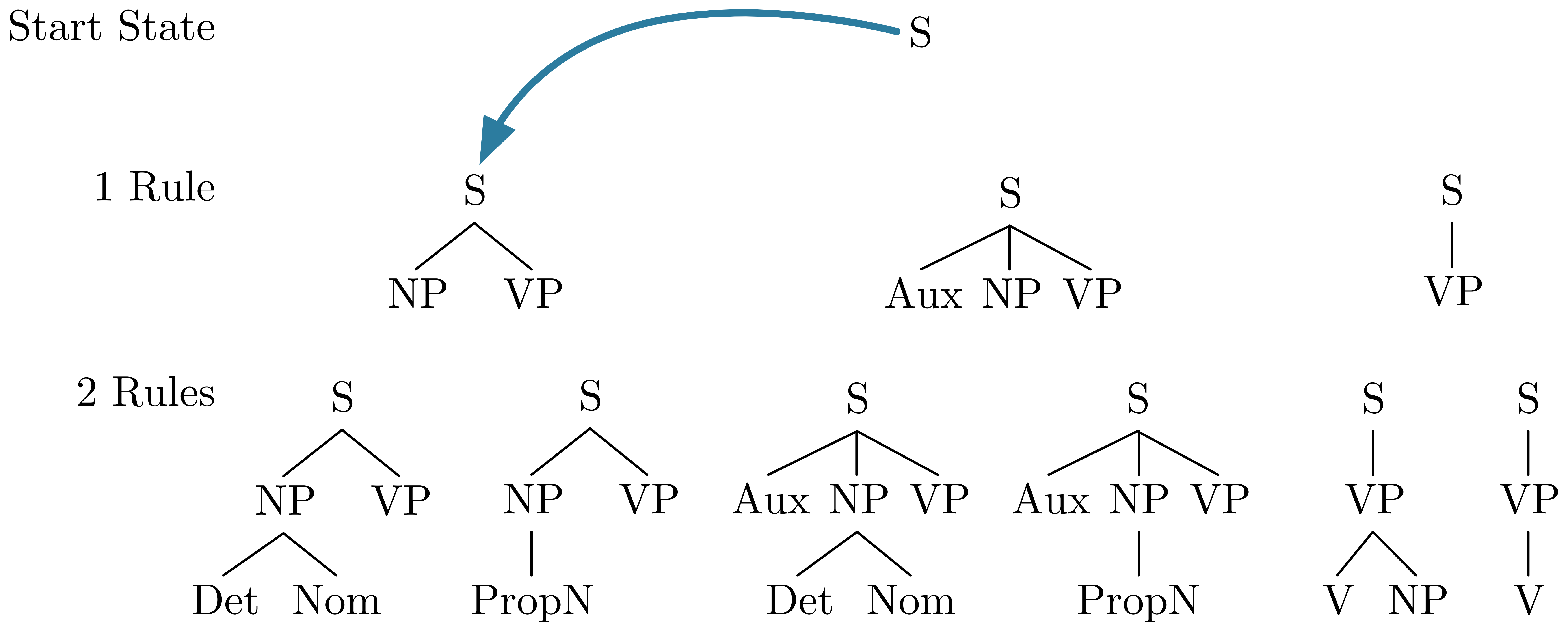

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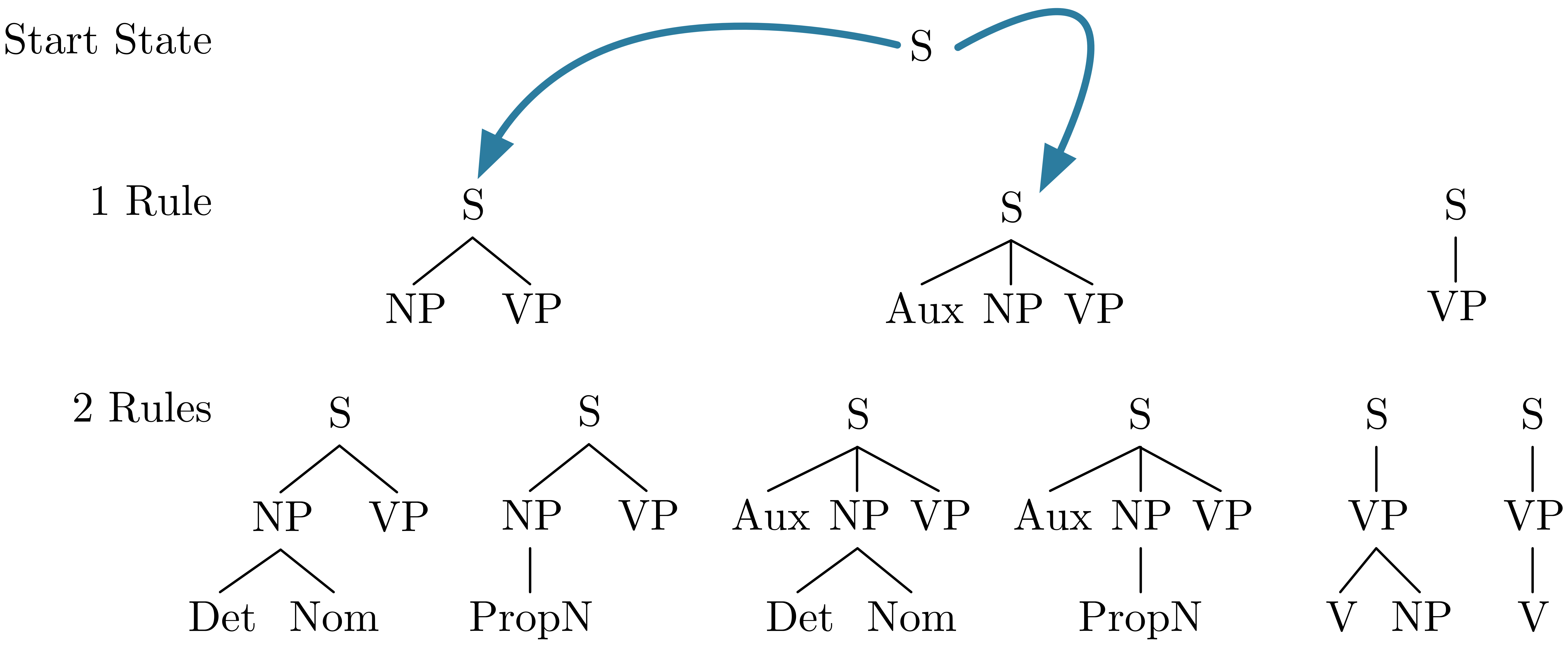

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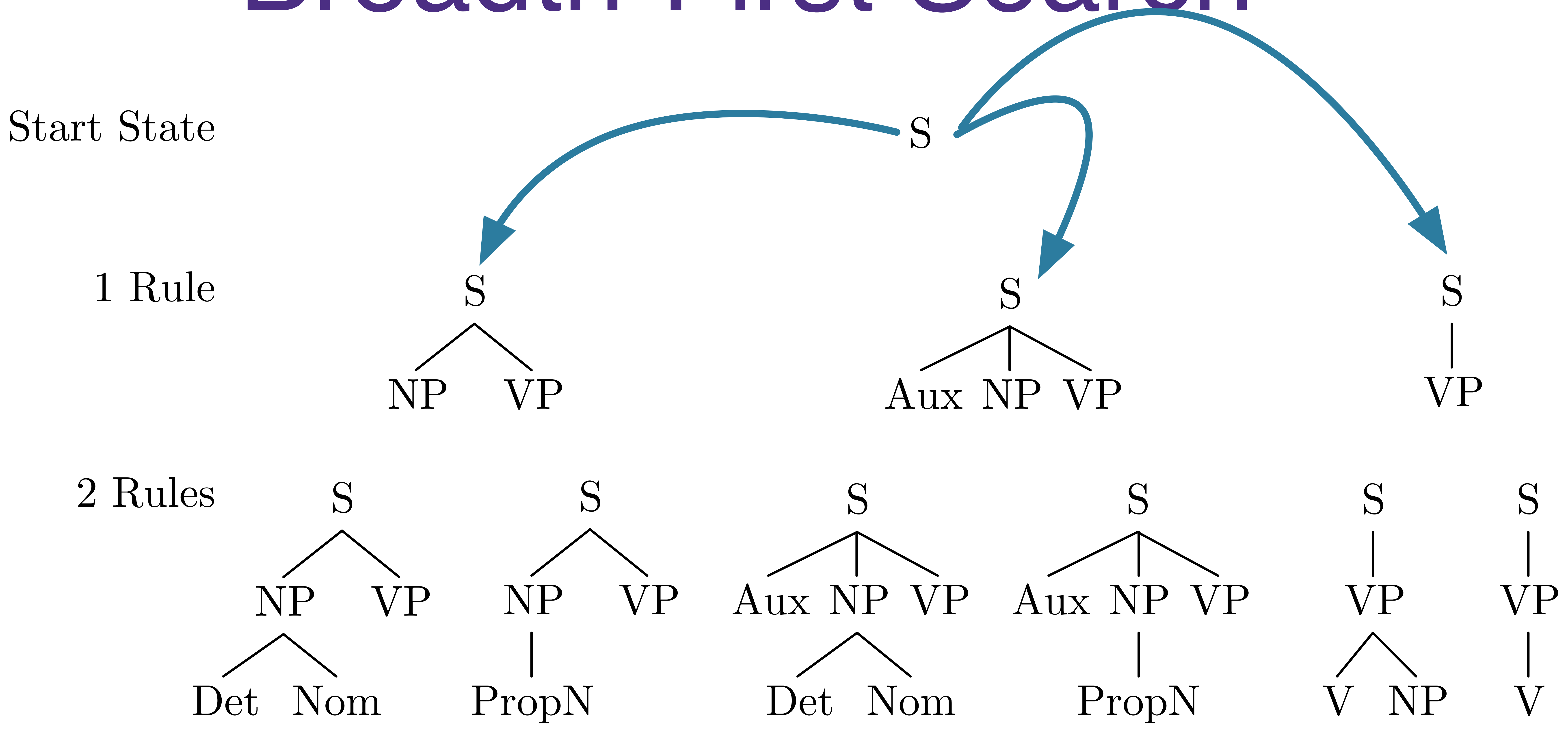

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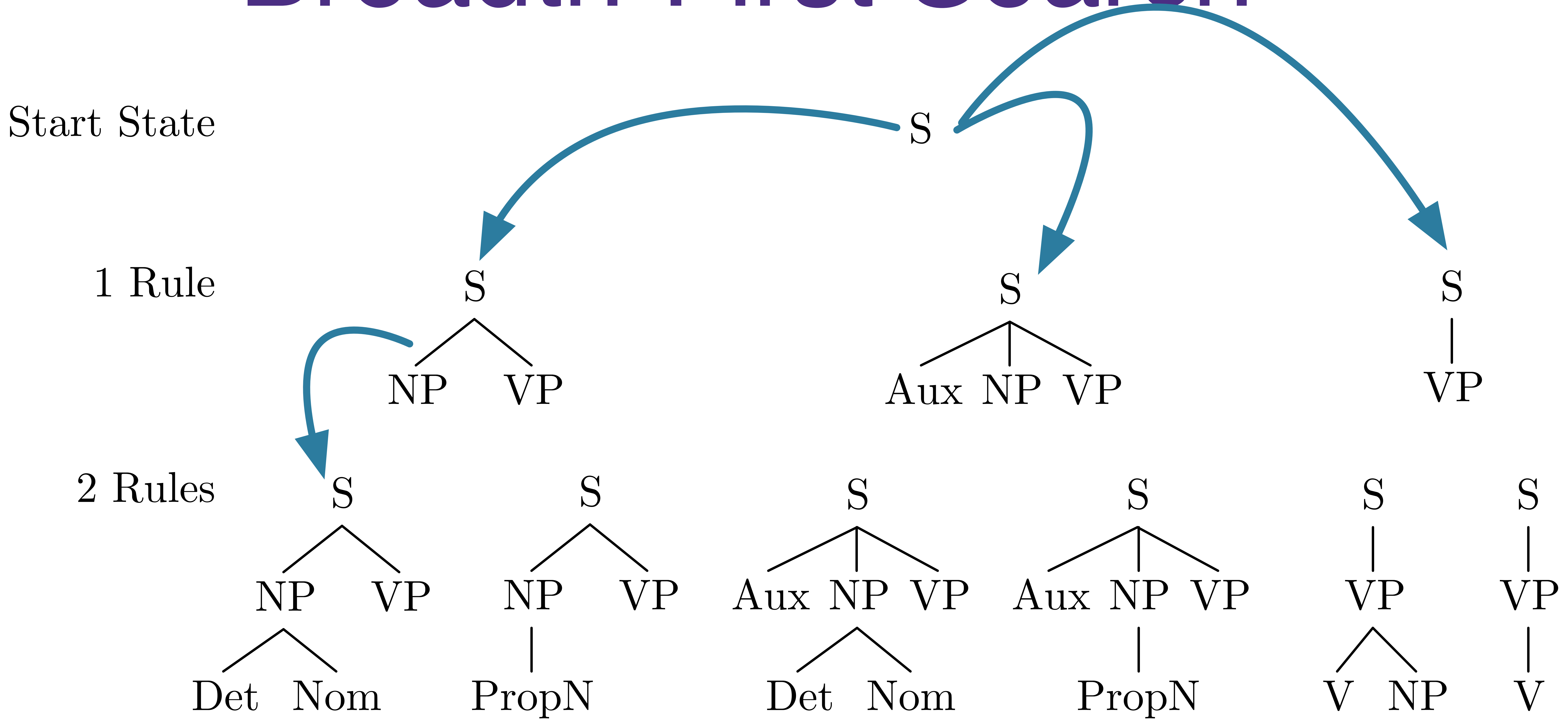

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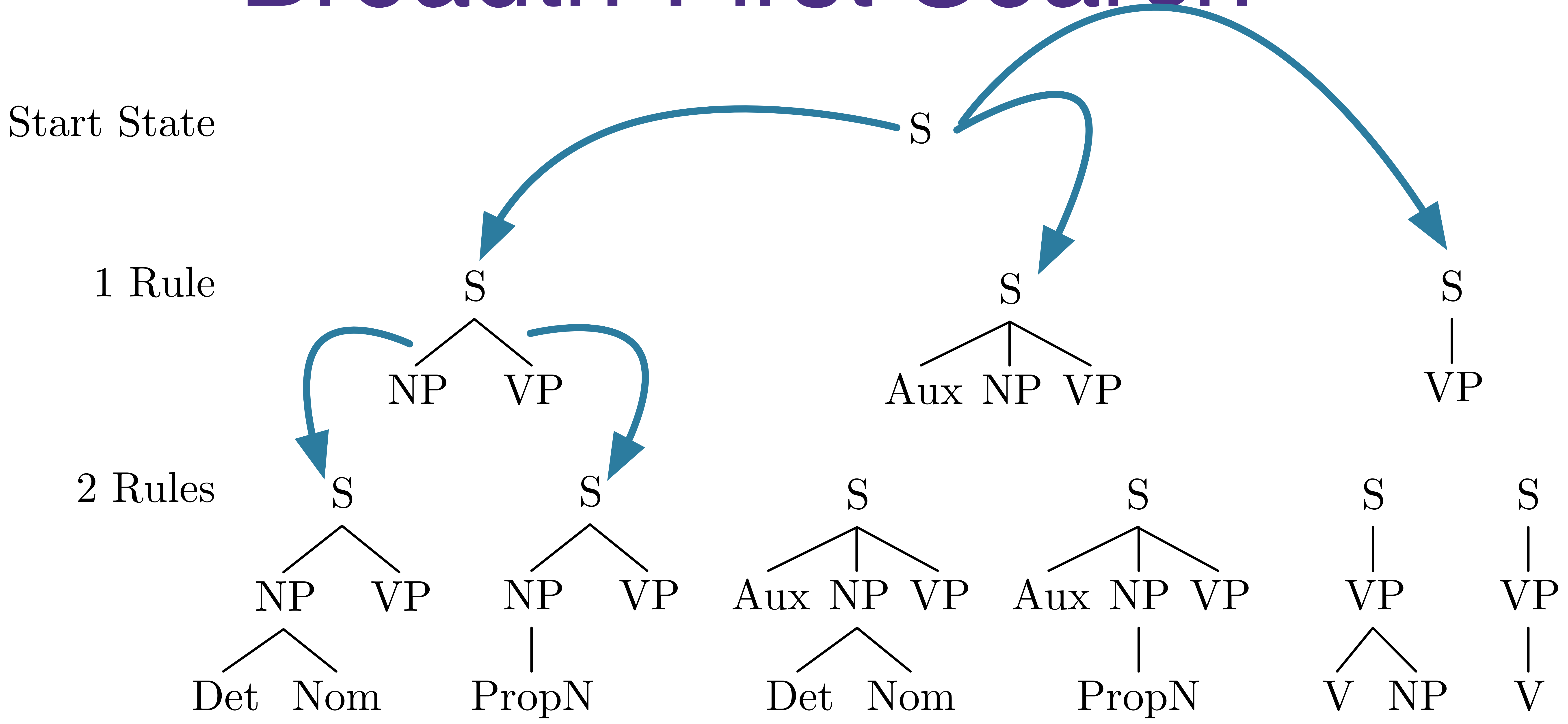

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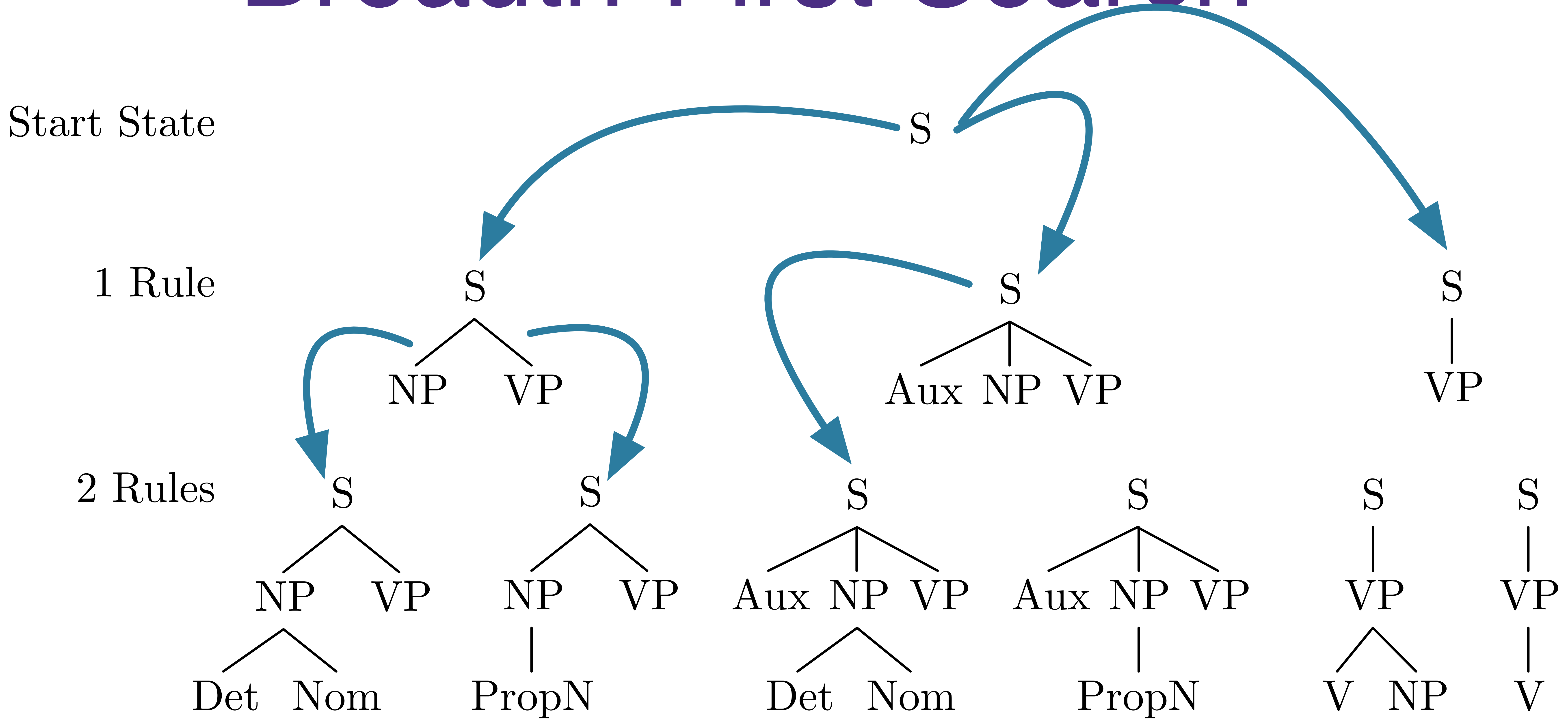

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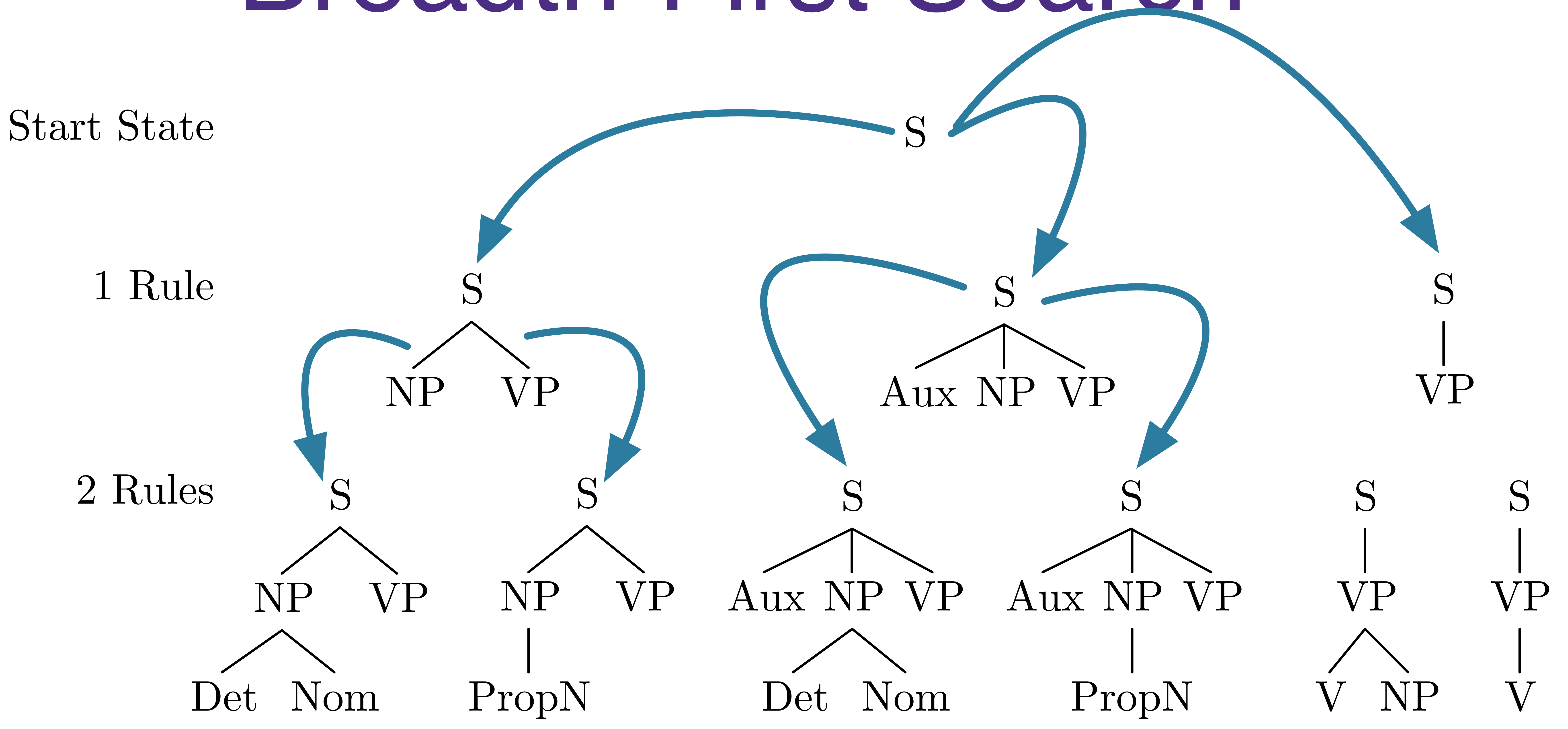

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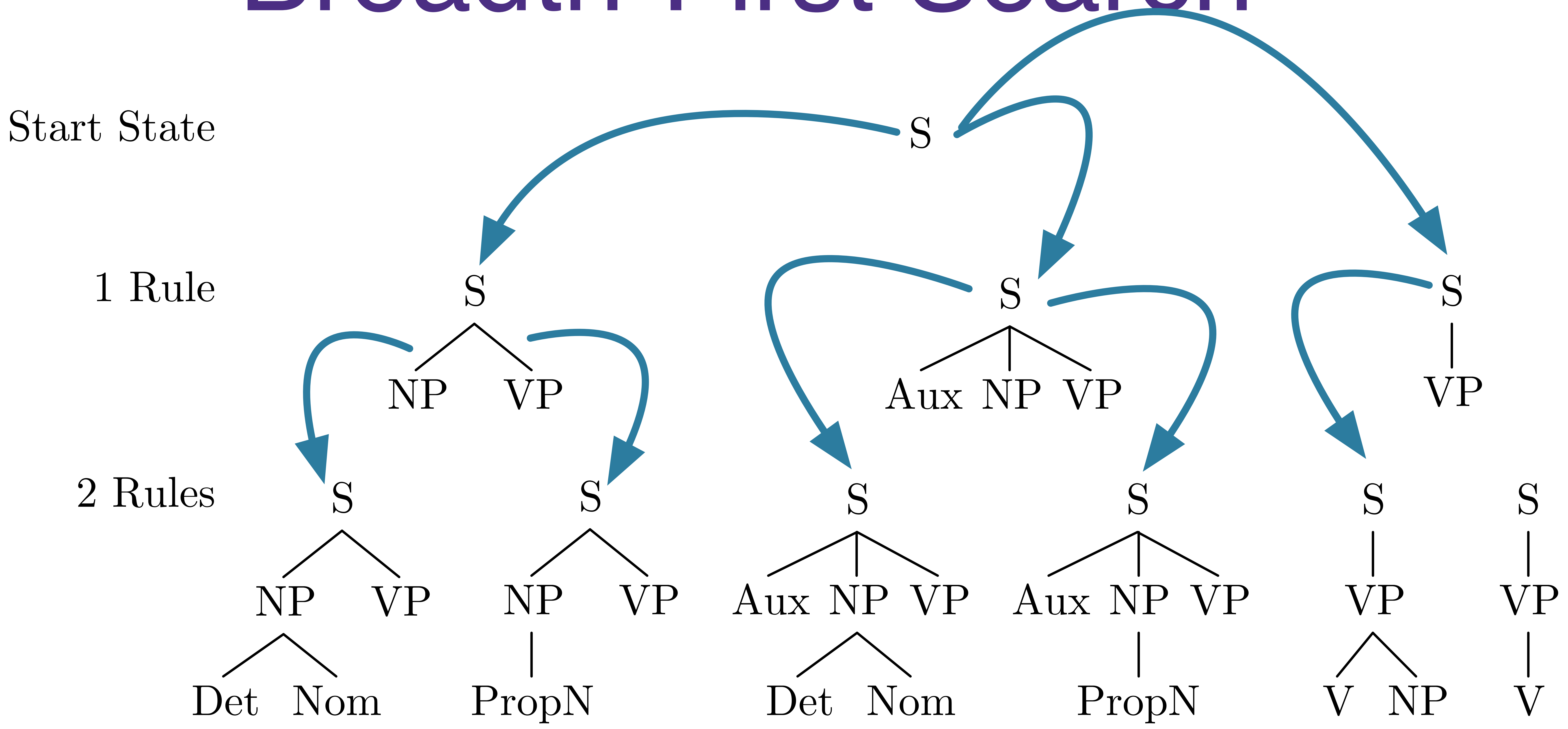

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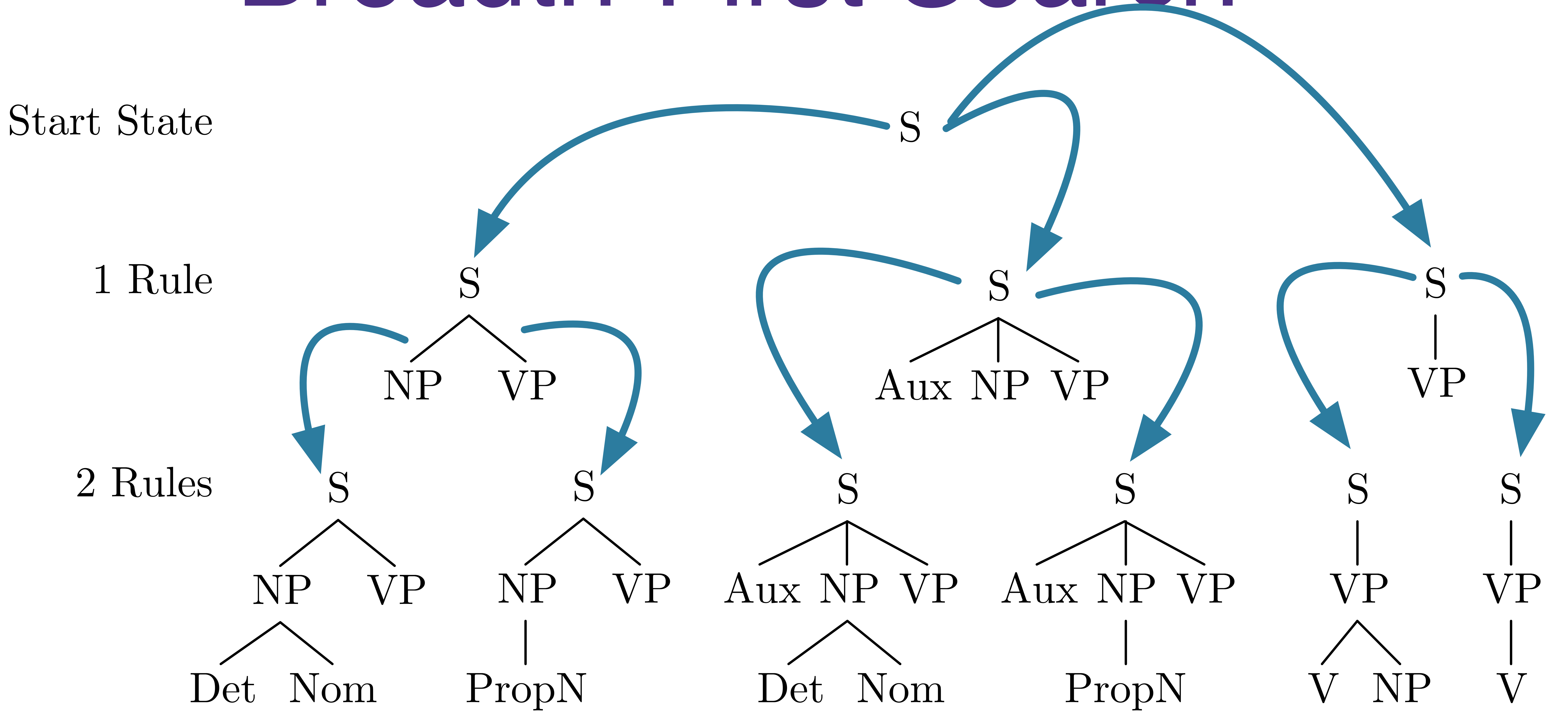

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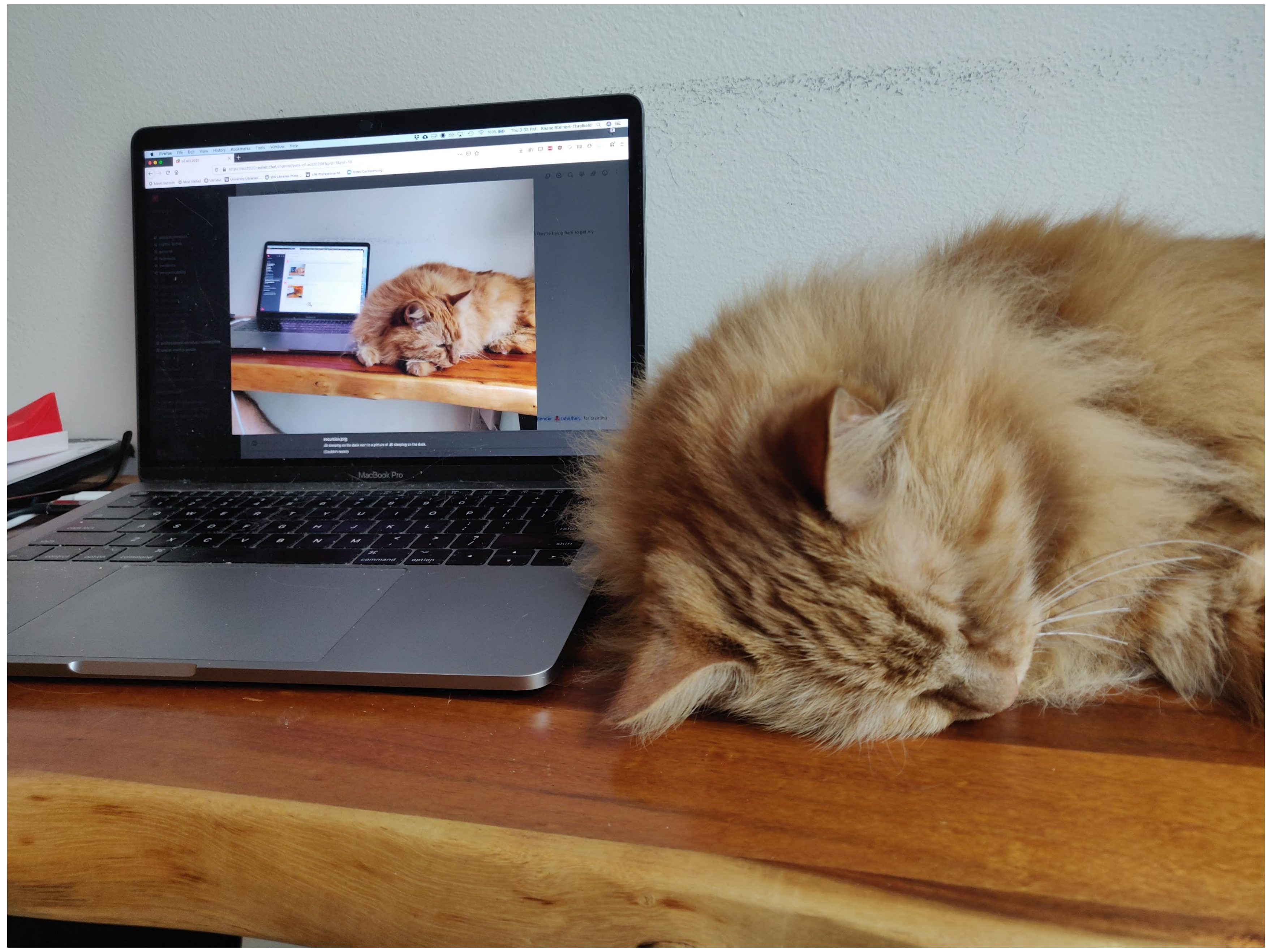

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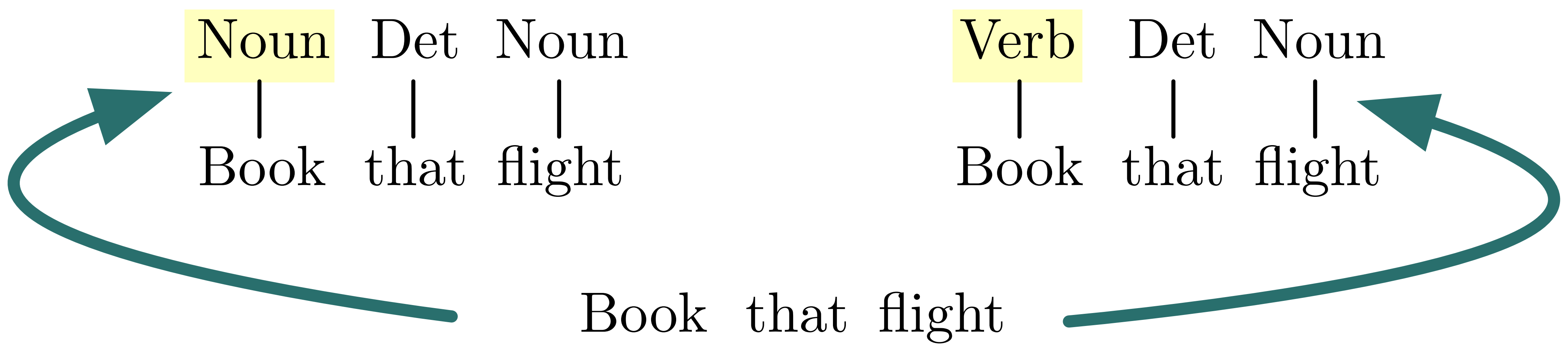
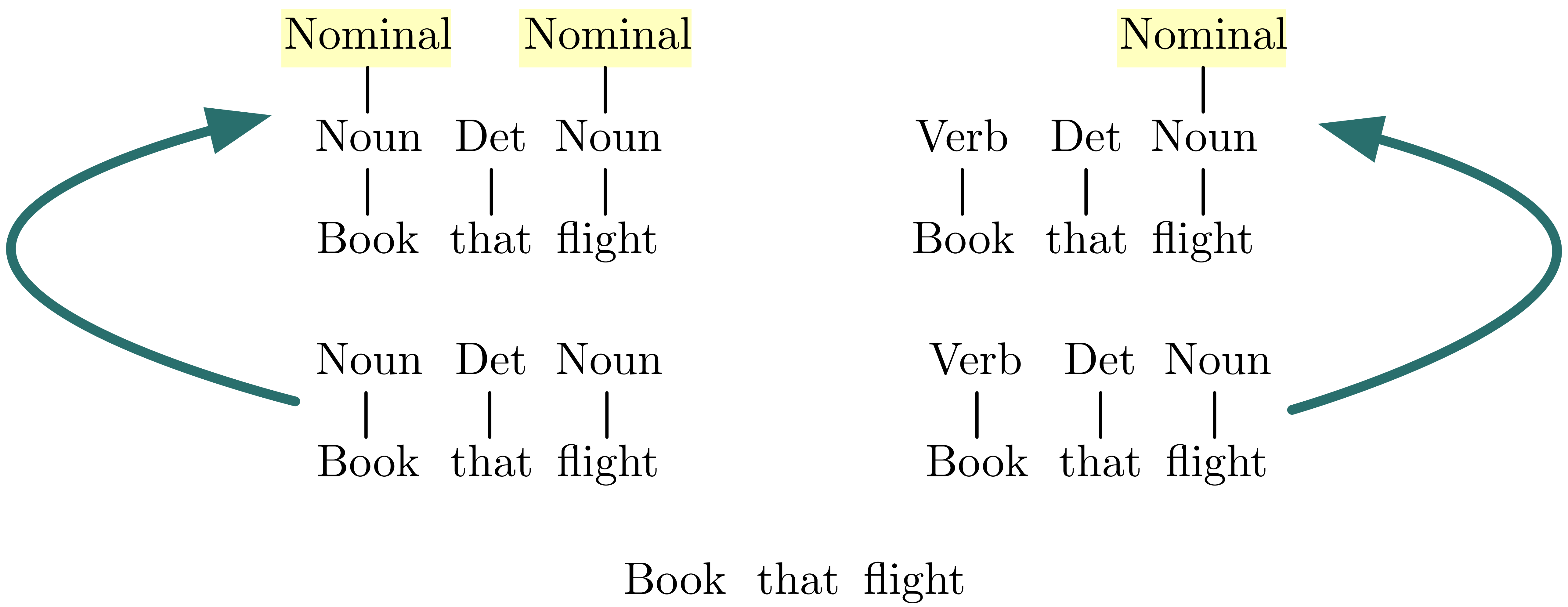
Book that flight


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


Nominal
Nominal
Noun Det Noun
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Book that flight
Nominal
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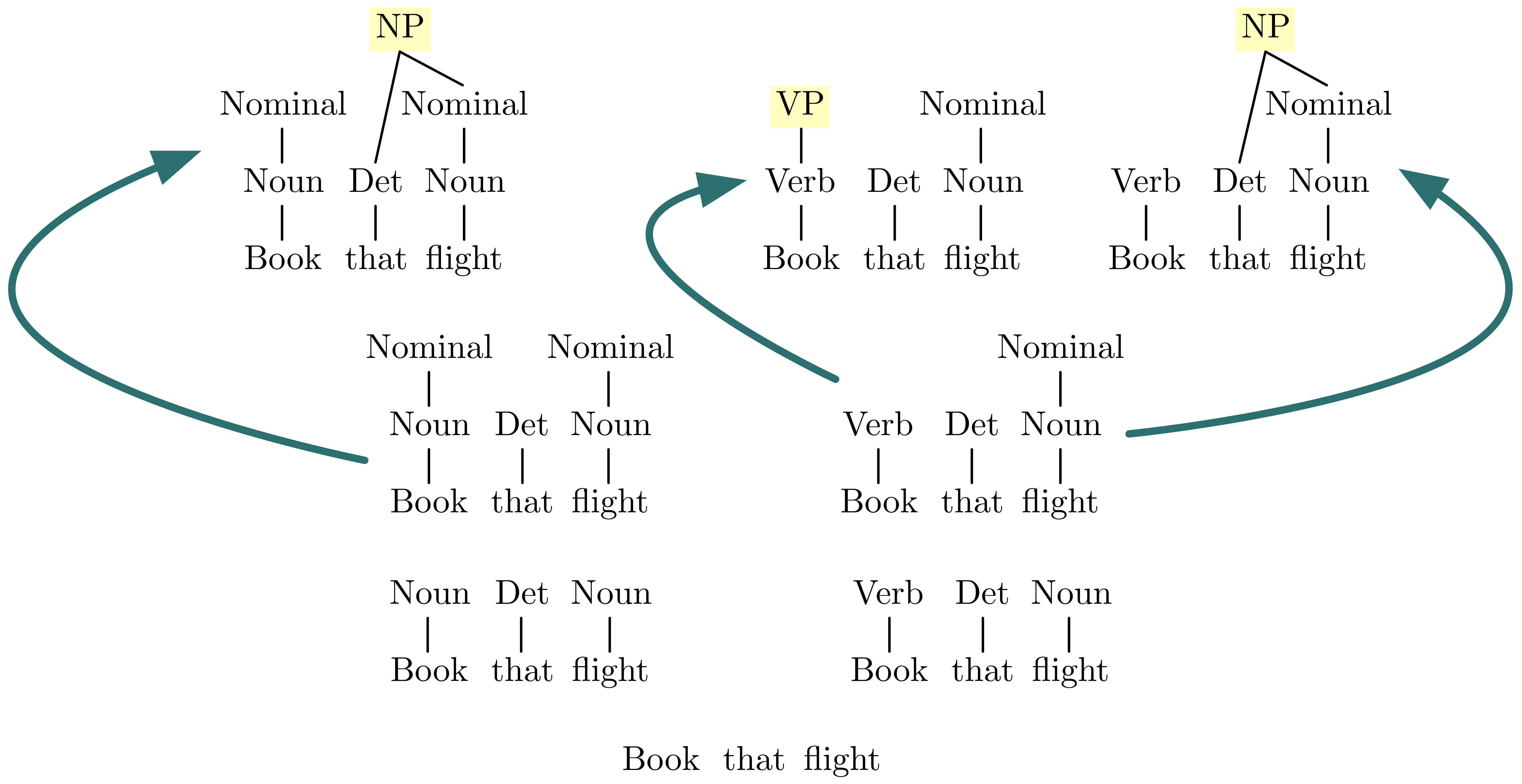
Book that flight
Book that flight


NP
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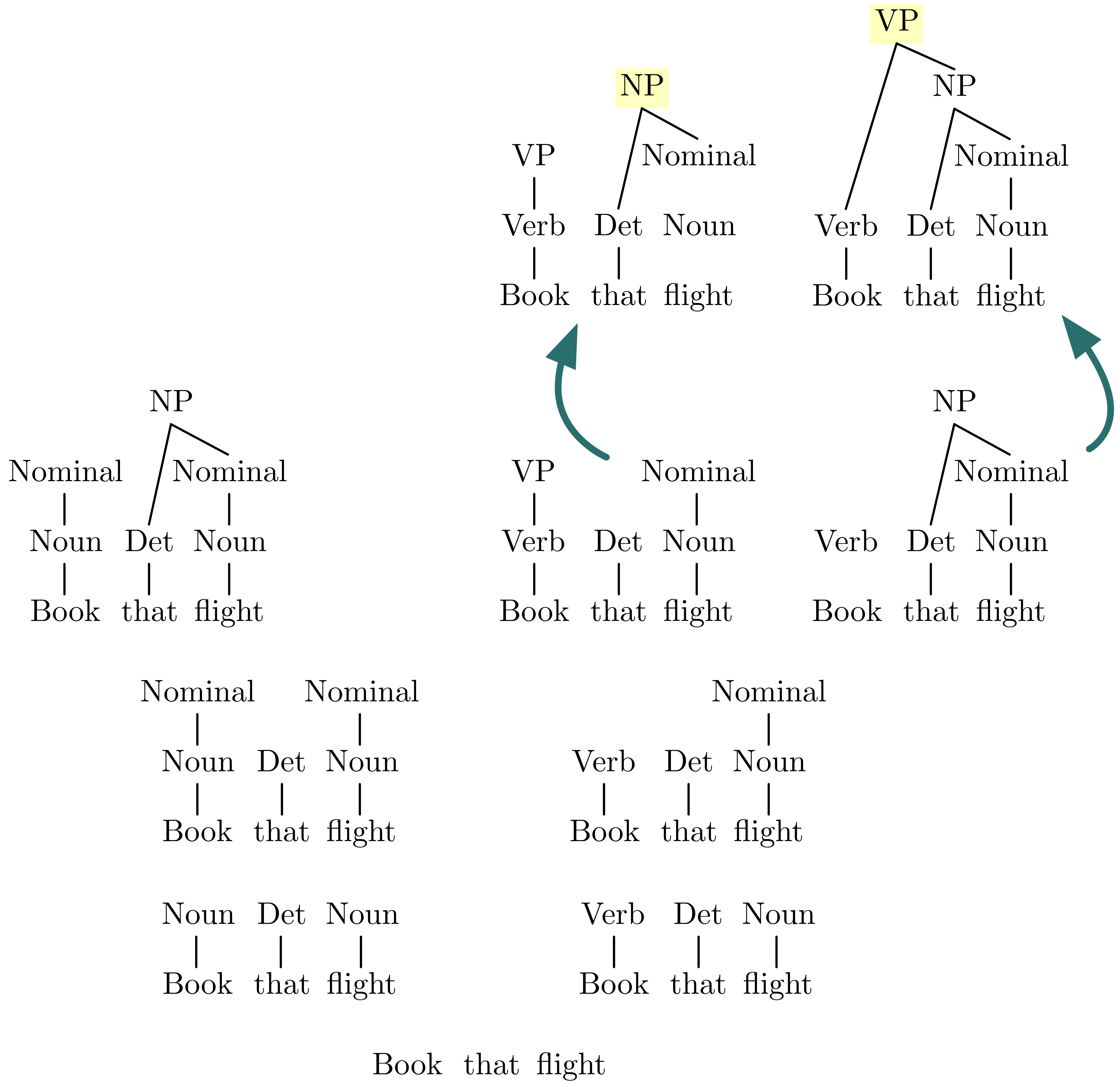
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VP Nominal
Verb Det Noun
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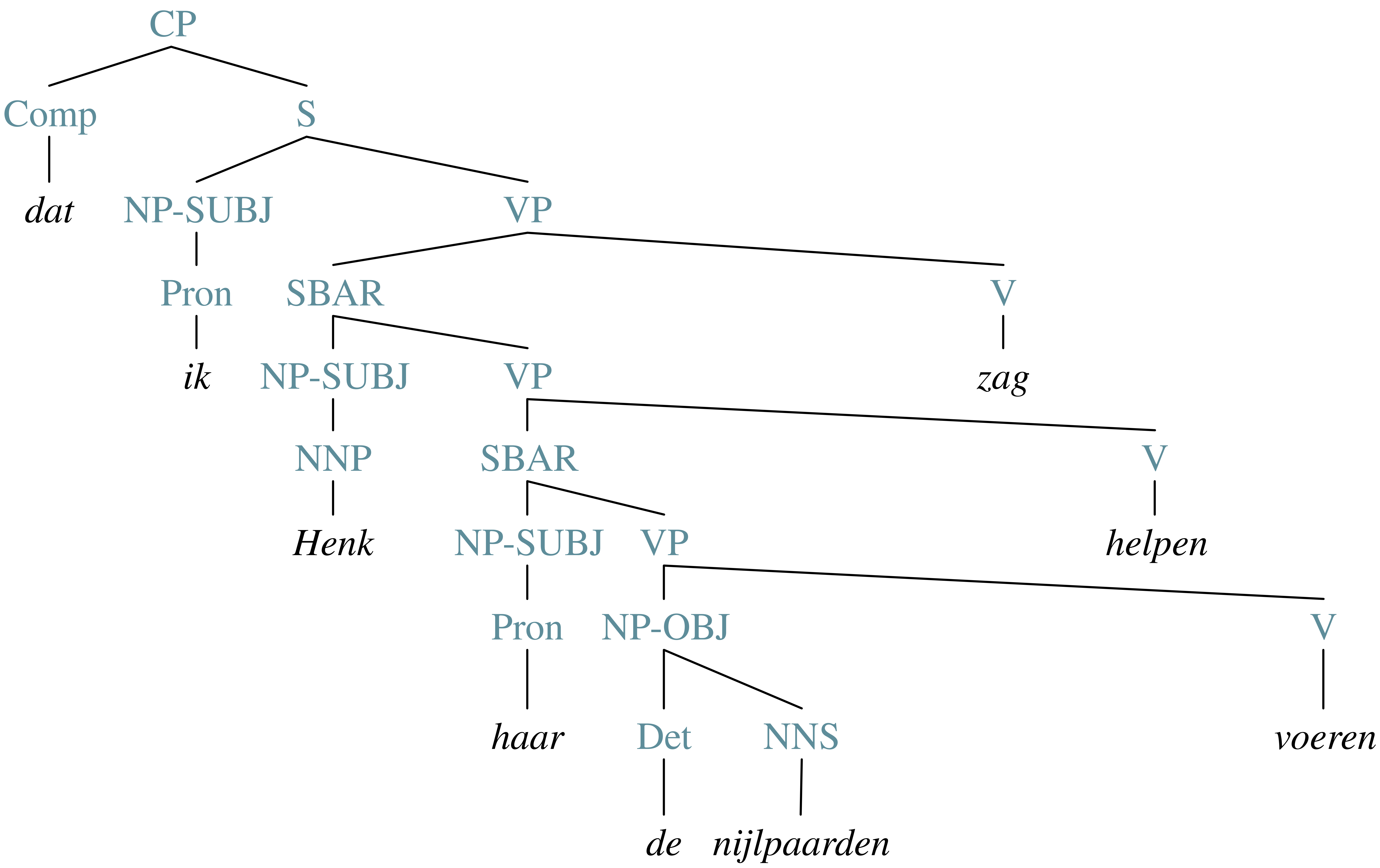
Cross-Serial Dependencies, Revisited

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

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
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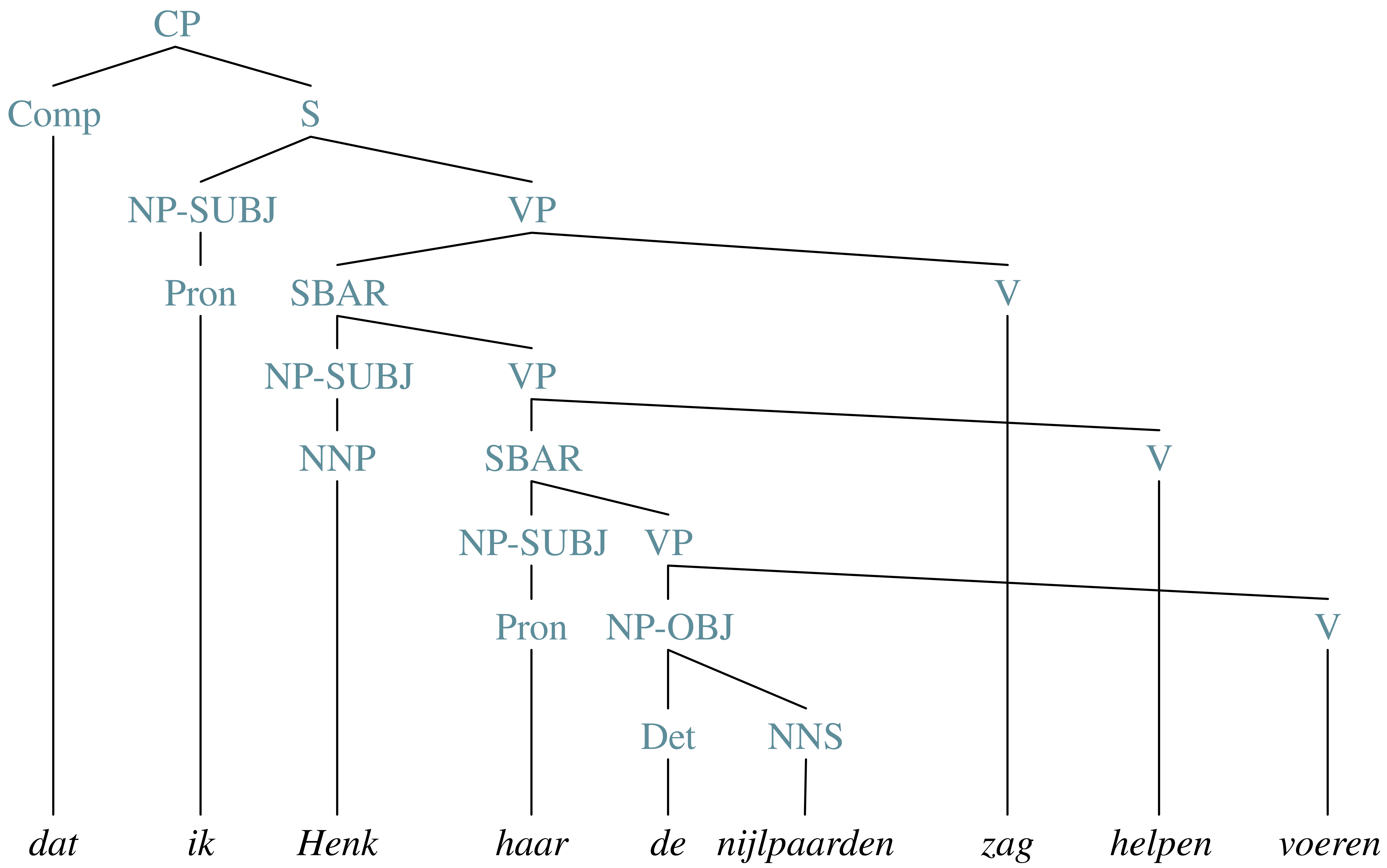
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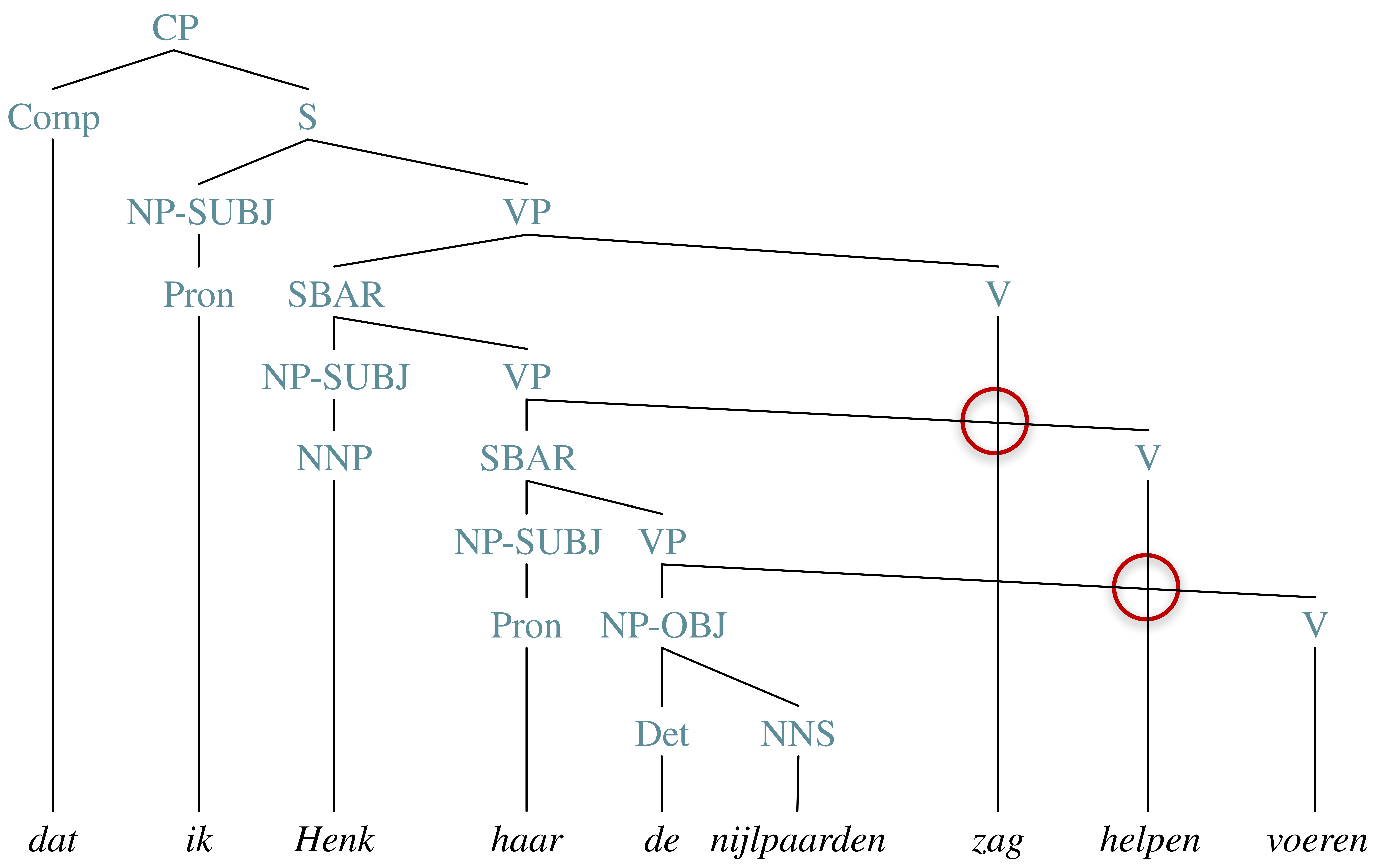
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Next Time

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