# Syntax: Context-Free Grammars

LING 571 — Deep Processing Techniques for NLP

Shane Steinert-Threlkeld

# Announcements

- 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
  - Your parse trees **can** be a single line, unlike the toy output file
- File paths will be given as full paths, so your script should accept those
- readme.(txt|pdf): not strictly required for this assignment, but feel free to include one explaining any thought processes in your code, issues you overcame, etc

# Roadmap

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

# Constituency

- Some examples of noun phrases (NPs):

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| 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 _____
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ambiguity!

# What are some constituents in: "The students are currently responding to a PollEverywhere about constituency in natural language."?

0

Nobody has responded yet.

Hang tight! Responses are coming in.

Title logo

# What are some non-constituents in: "The students are currently responding to a PollEverywhere about constituency in natural language."?

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# Roadmap

- Constituency
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- English Grammar Rules
- Grammars — Revisiting our Motivation
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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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    - $VP \rightarrow V\ NP\ PP \mid V\ NP$

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    - *Noun* → ‘dog’ | ‘cat’ | ‘rat’
    - *Det* → ‘the’

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

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| *PP* | → | *Preposition NP* | from + Los Angeles |

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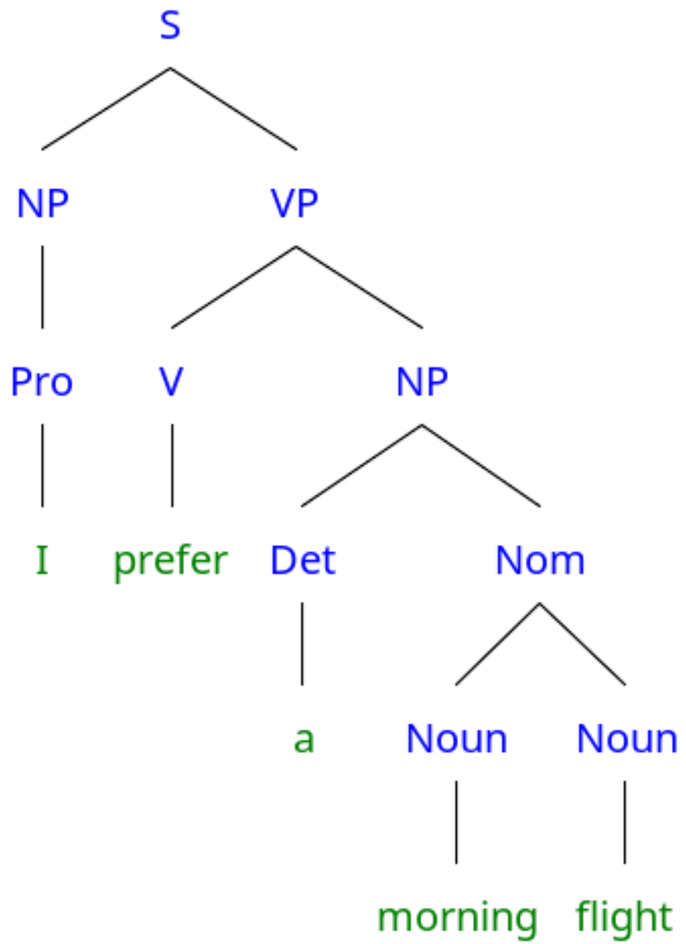
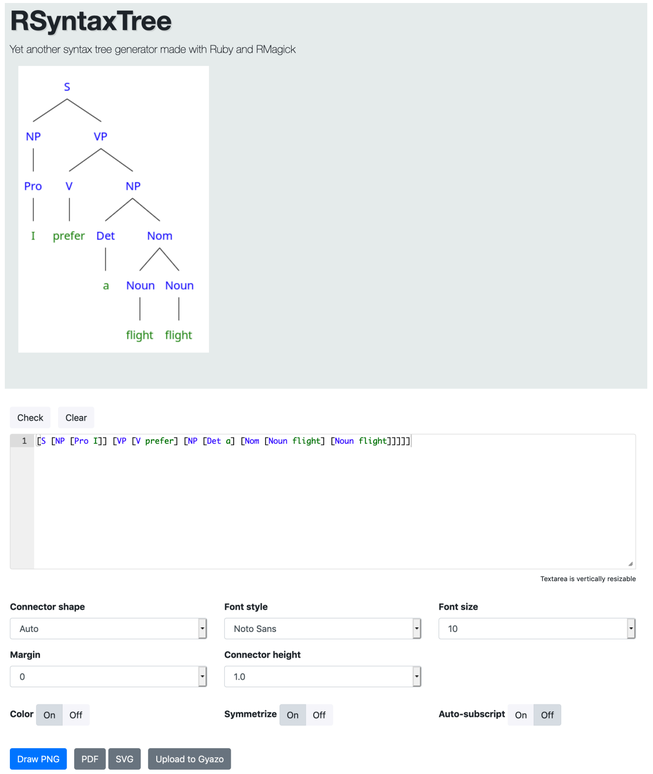
# Parse Tree

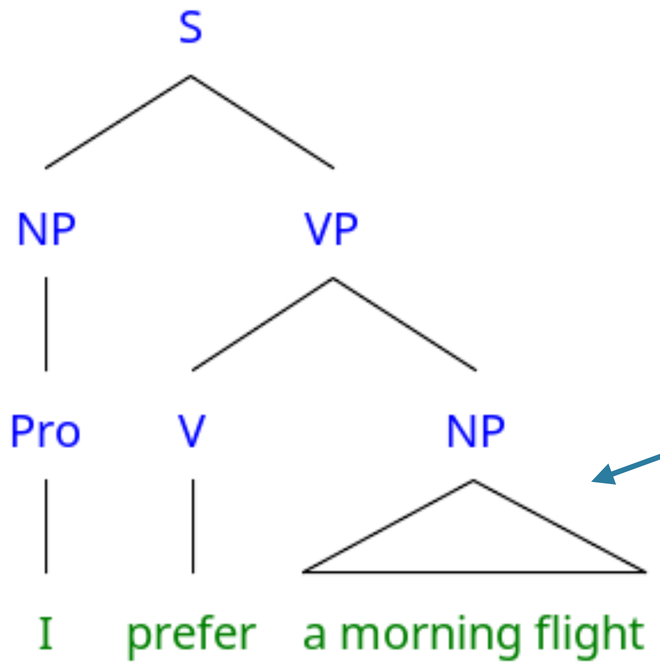


# Visualizing Parse Trees

- `>>> 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

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

# 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

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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***
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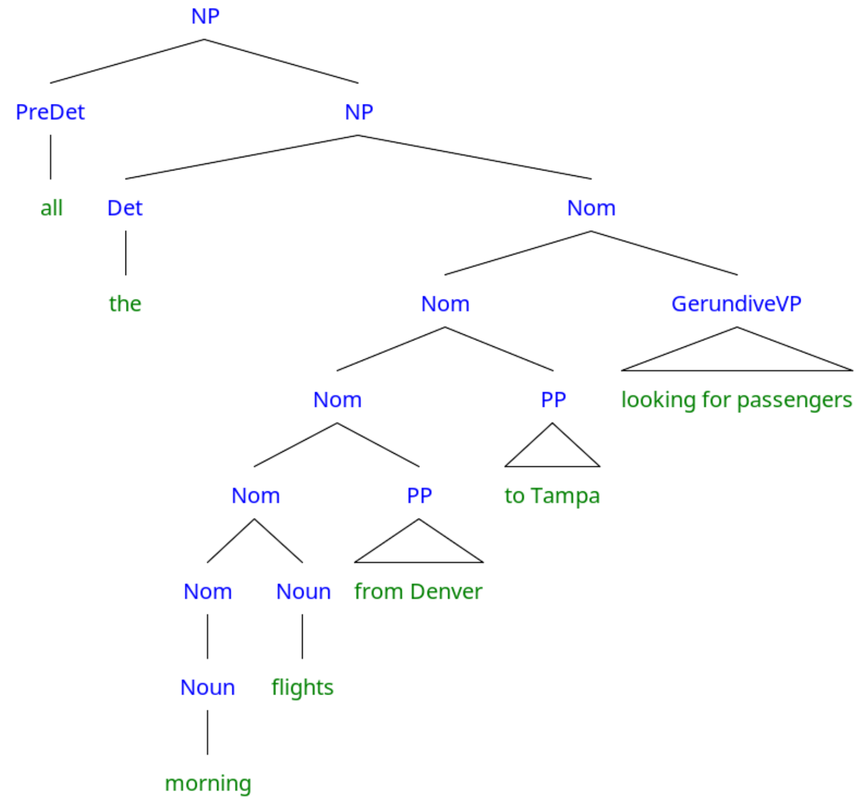
- **(Bonus: within the AP: *adjective ordering preferences* [Scontras et al '19])**
  - **e.g. The big red mug > the red big mug**

# 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:

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- 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*

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

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| *VP* → *Verb* ***S*** | think I want that flight |
| *VP* → *Verb* ***VP*** | want to arrange three flights |

# CFGs and Subcategorization

- Issues?
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  - 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)

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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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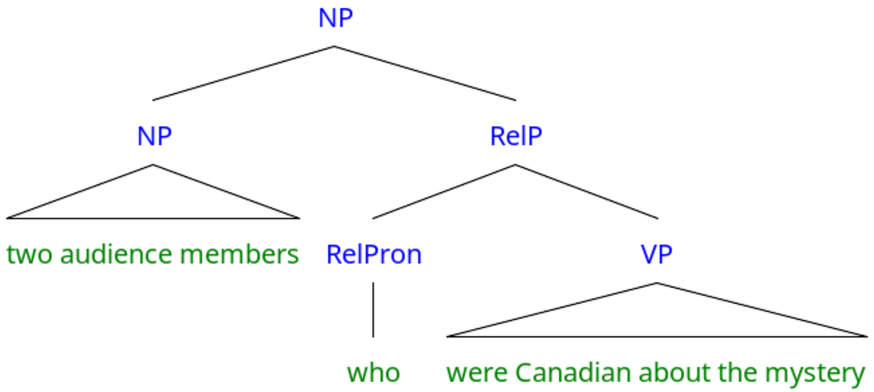
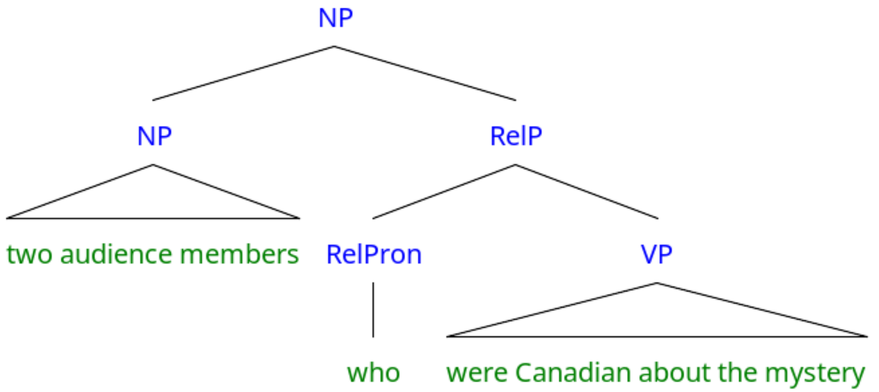
- Possible Interpretations:

  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
NP
RelP
two audience members
RelPron
VP
who
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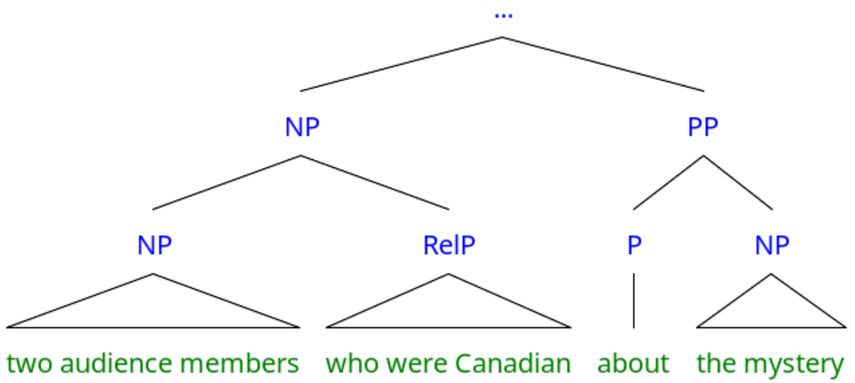
...
NP
PP
NP
RelP
P
NP
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who were Canadian
about
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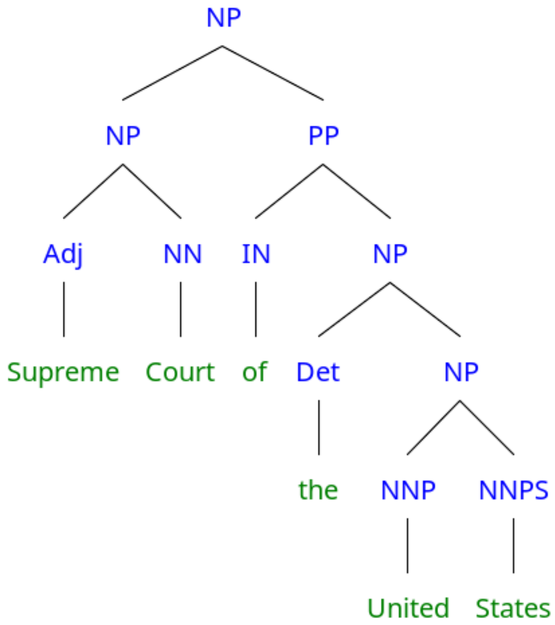

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# Roadmap

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

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- All sentences annotated syntactically with a parse
- Built semi-automatically
  - Automatically parsed, manually corrected

# Penn Treebank

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  - Switchboard (conversational speech)
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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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- 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) ))
   (. .)
)
```

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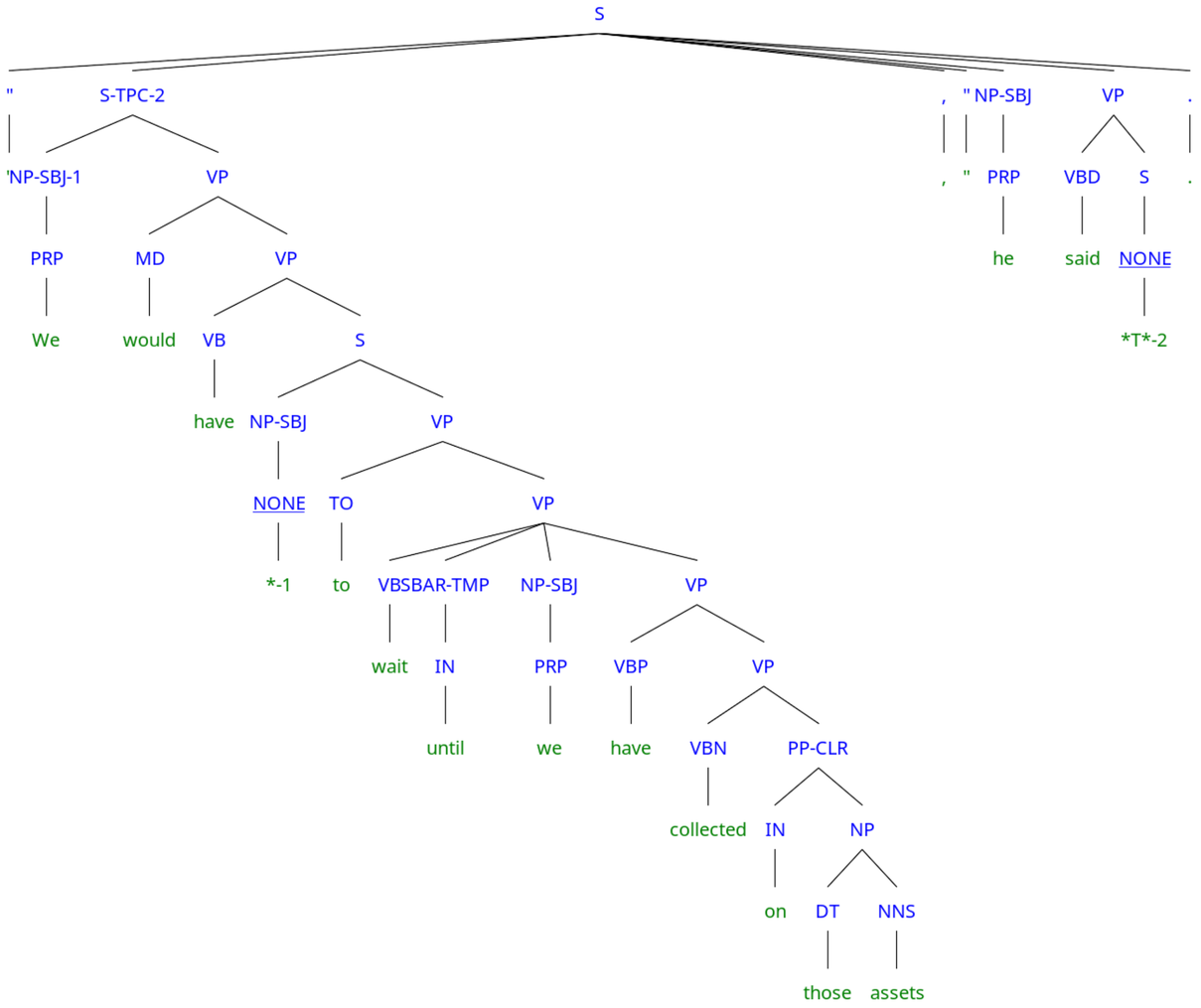

# Treebanks & Corpora on Patas

```
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/live/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!

# Roadmap

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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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- 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

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- 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

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  - …ignored for now.

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- Depth First
  - 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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- 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 \| this \| a* |
| *S → Aux NP VP* | *Noun → book \| flight \| meal \| money* |
| *S → VP* | *Verb → book \| include \| prefer* |

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

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- Terminate when all leaves are terminals

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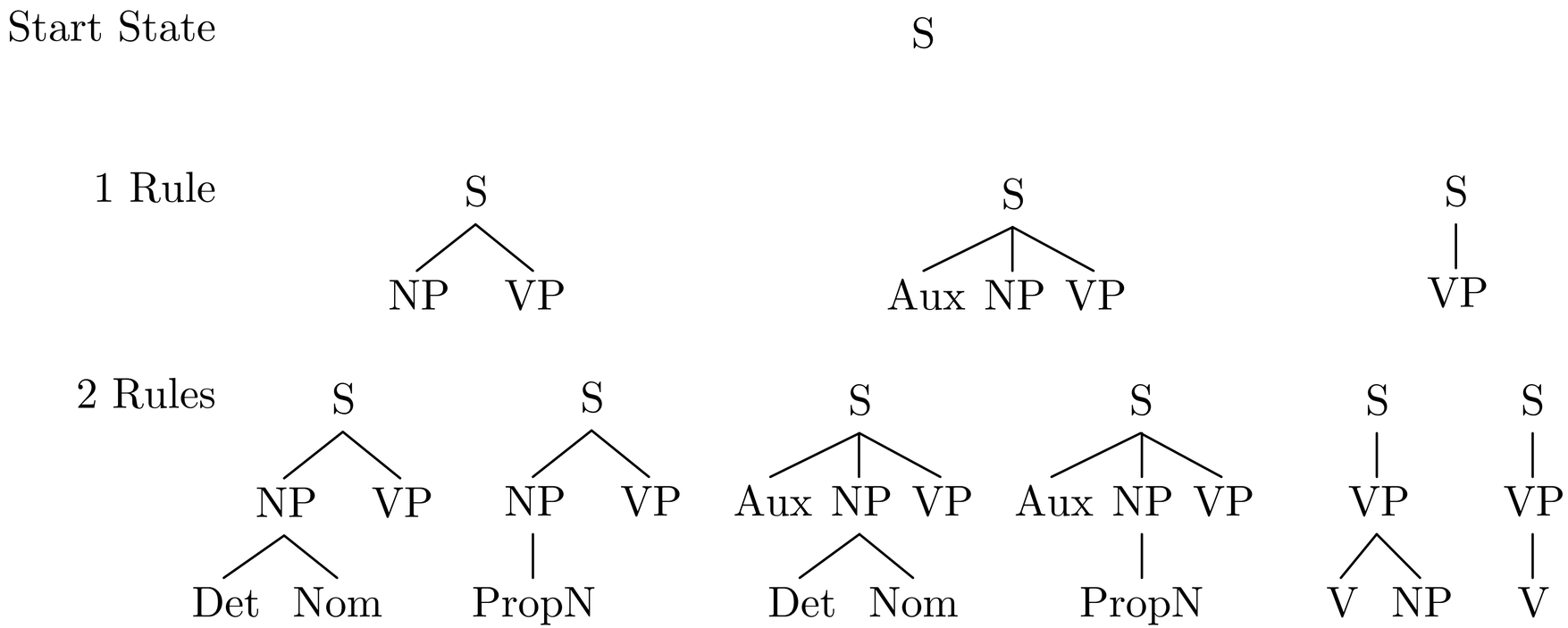

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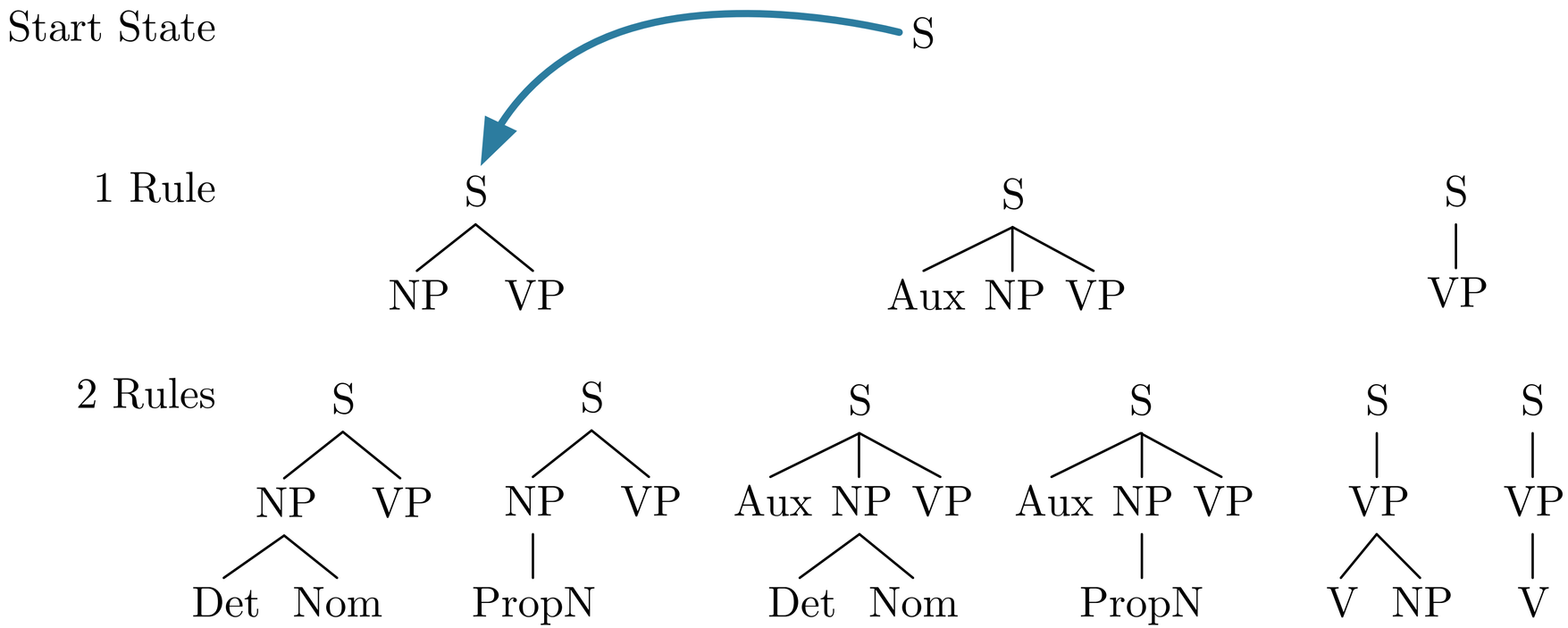

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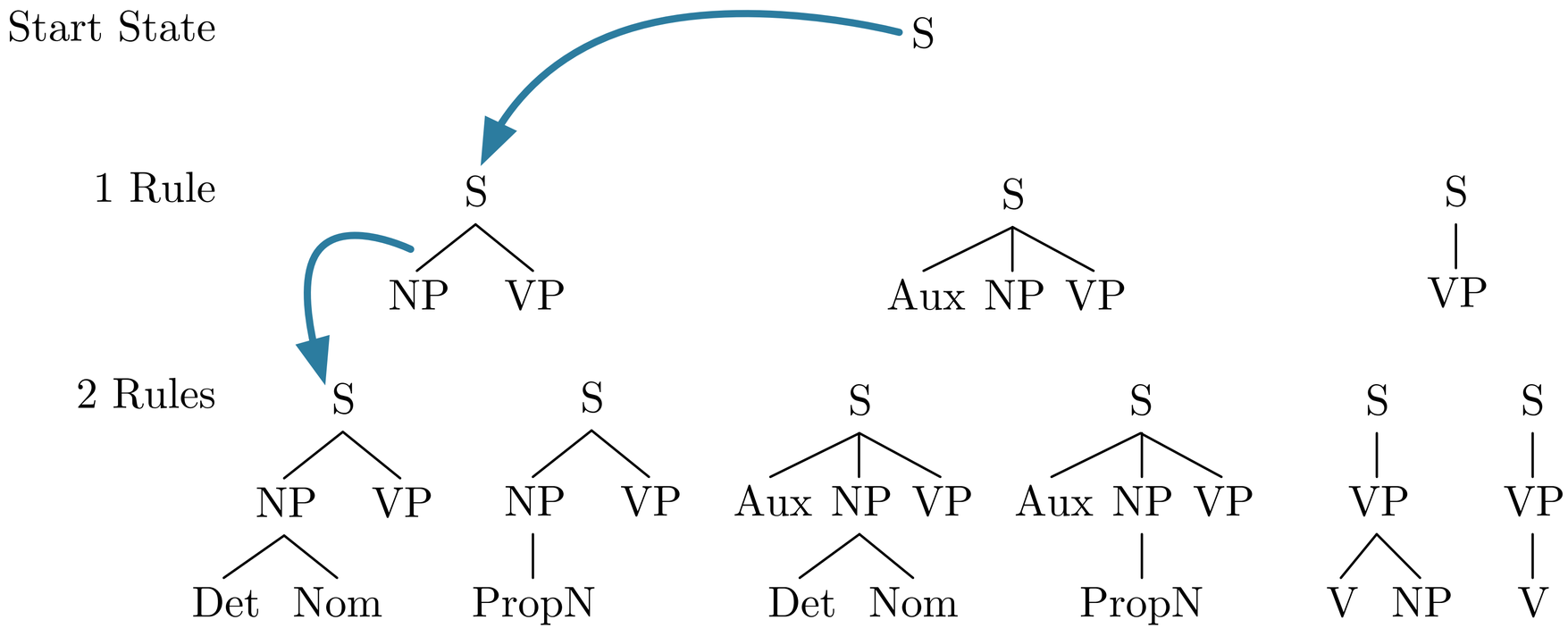

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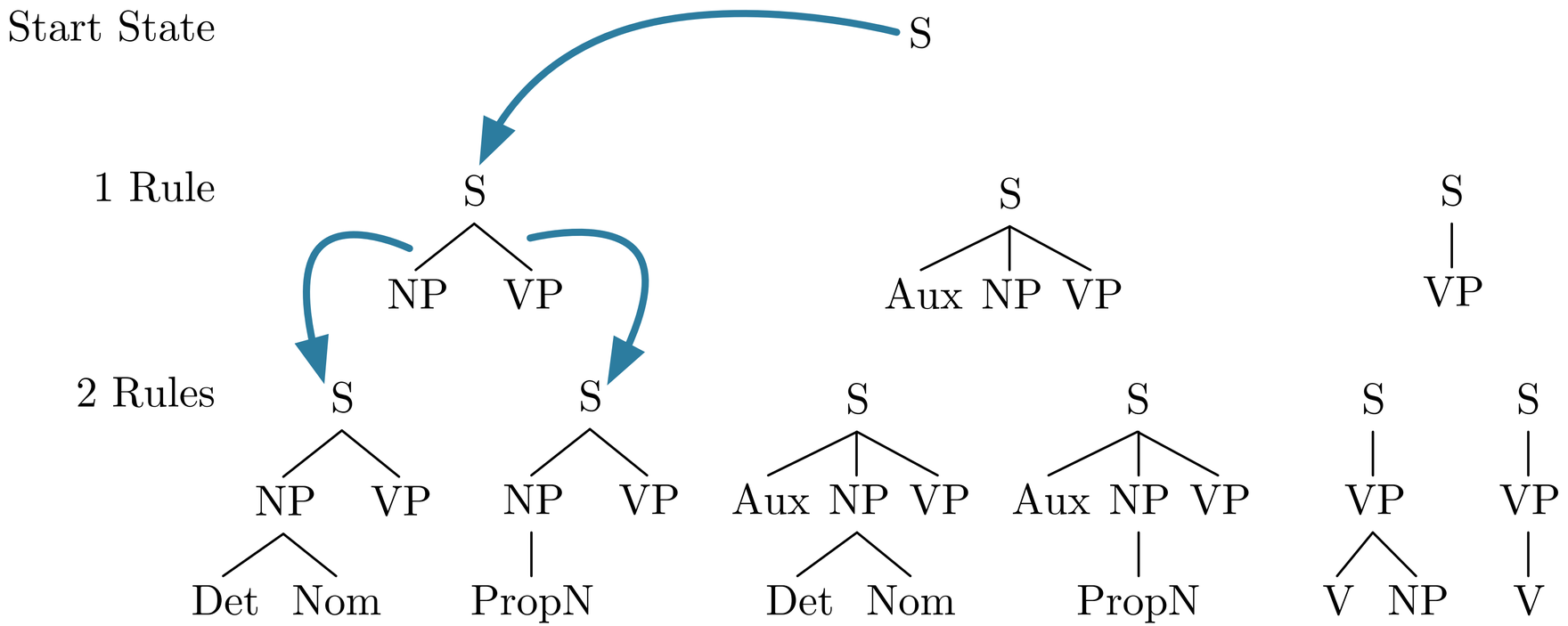

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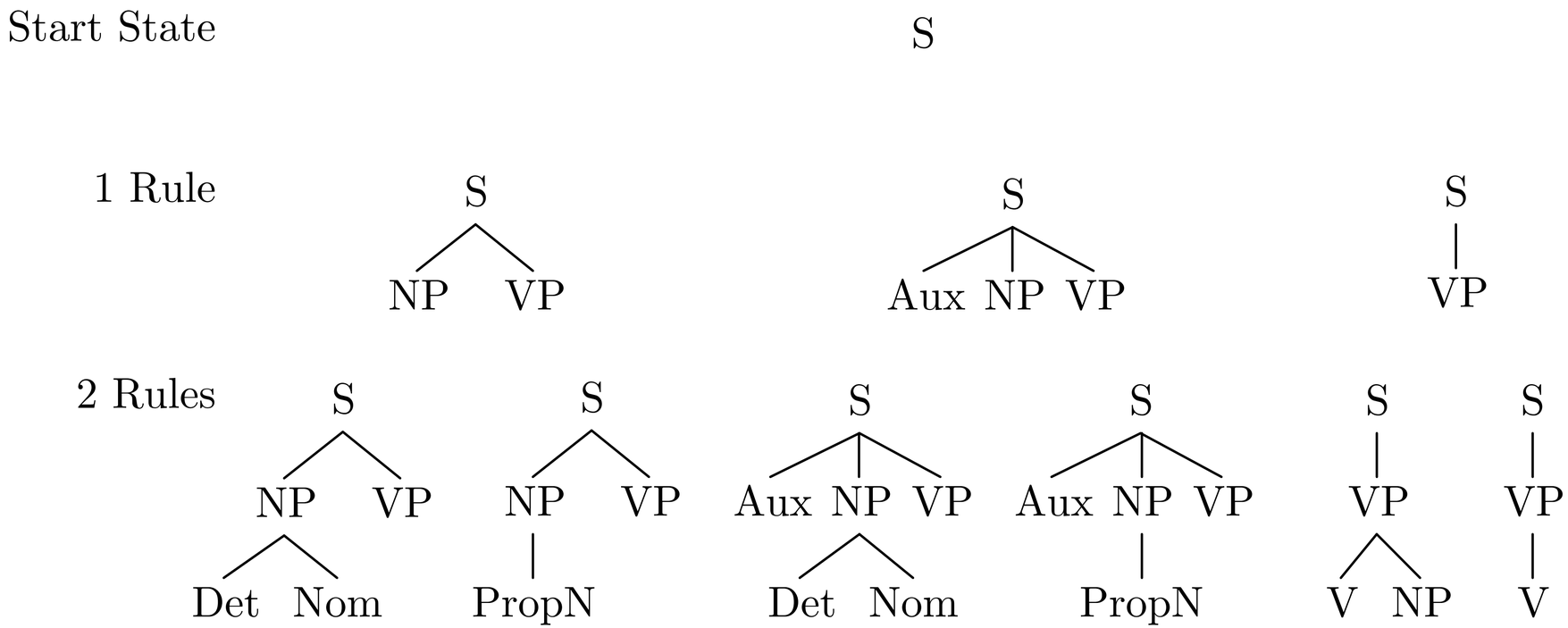

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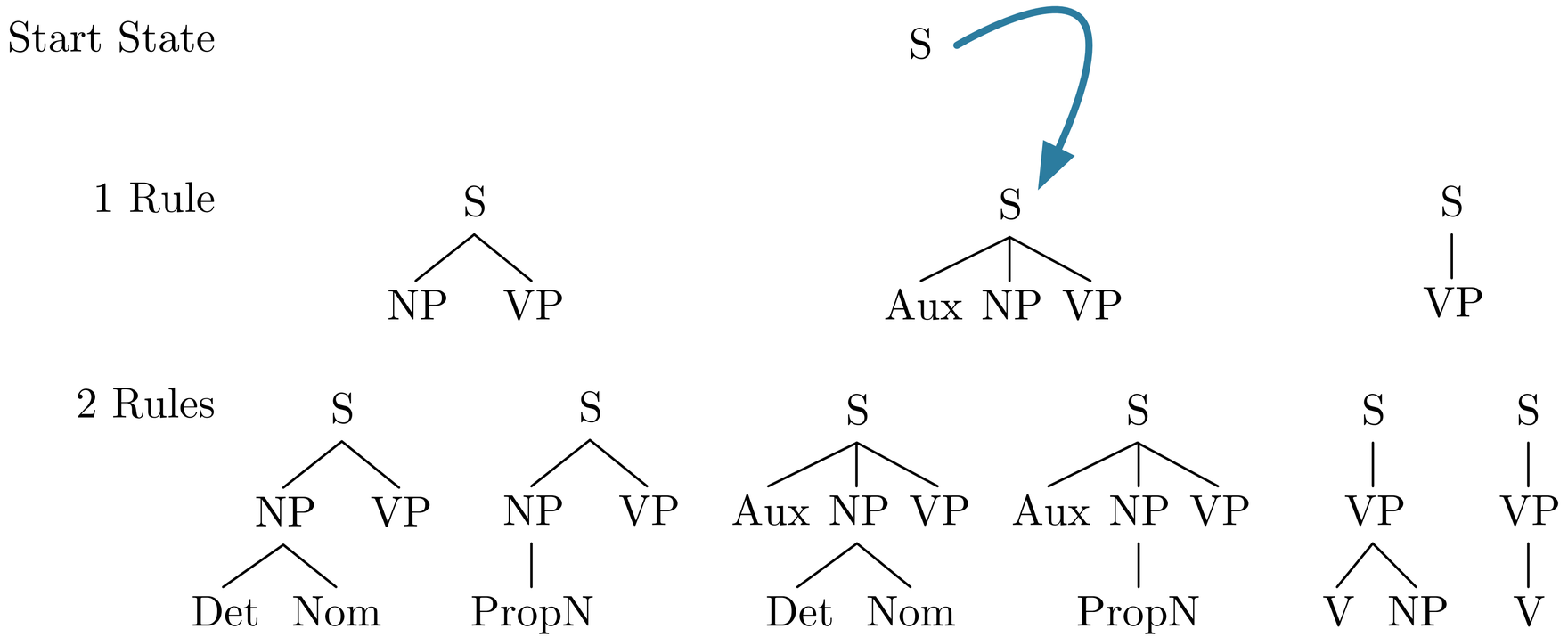

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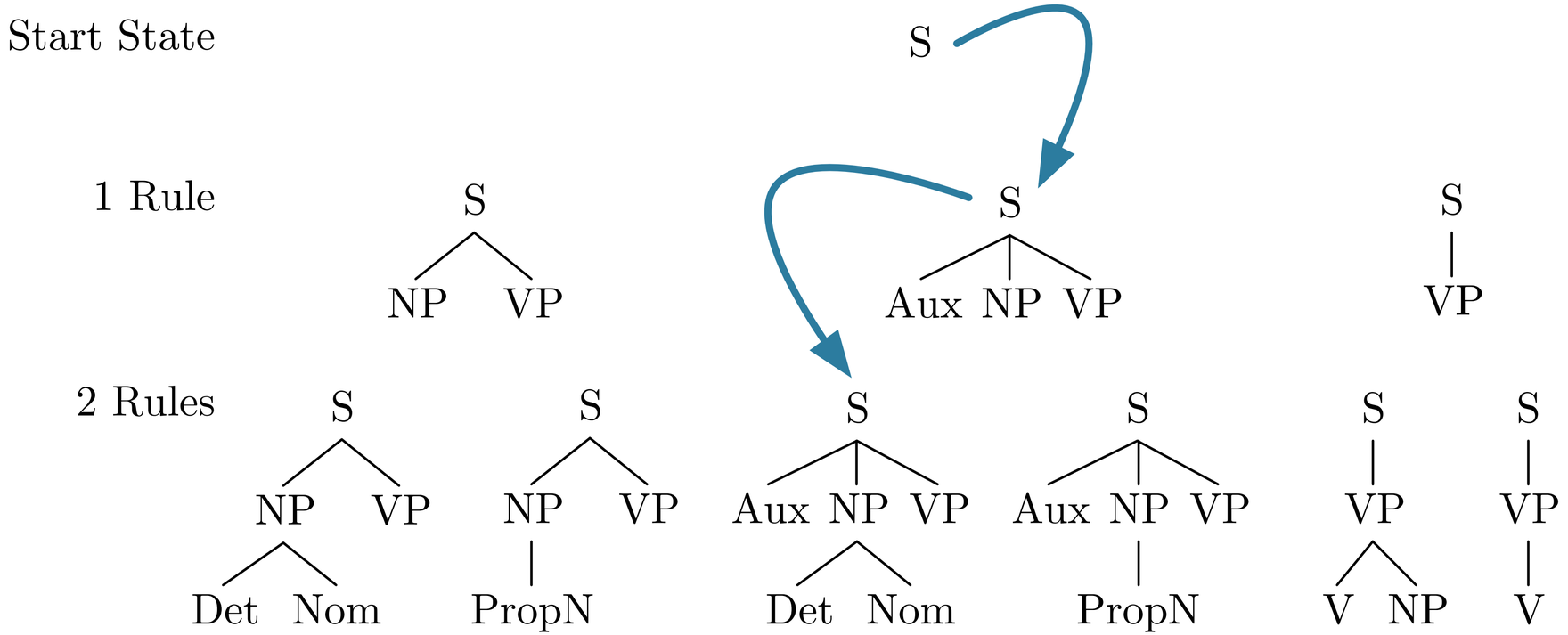

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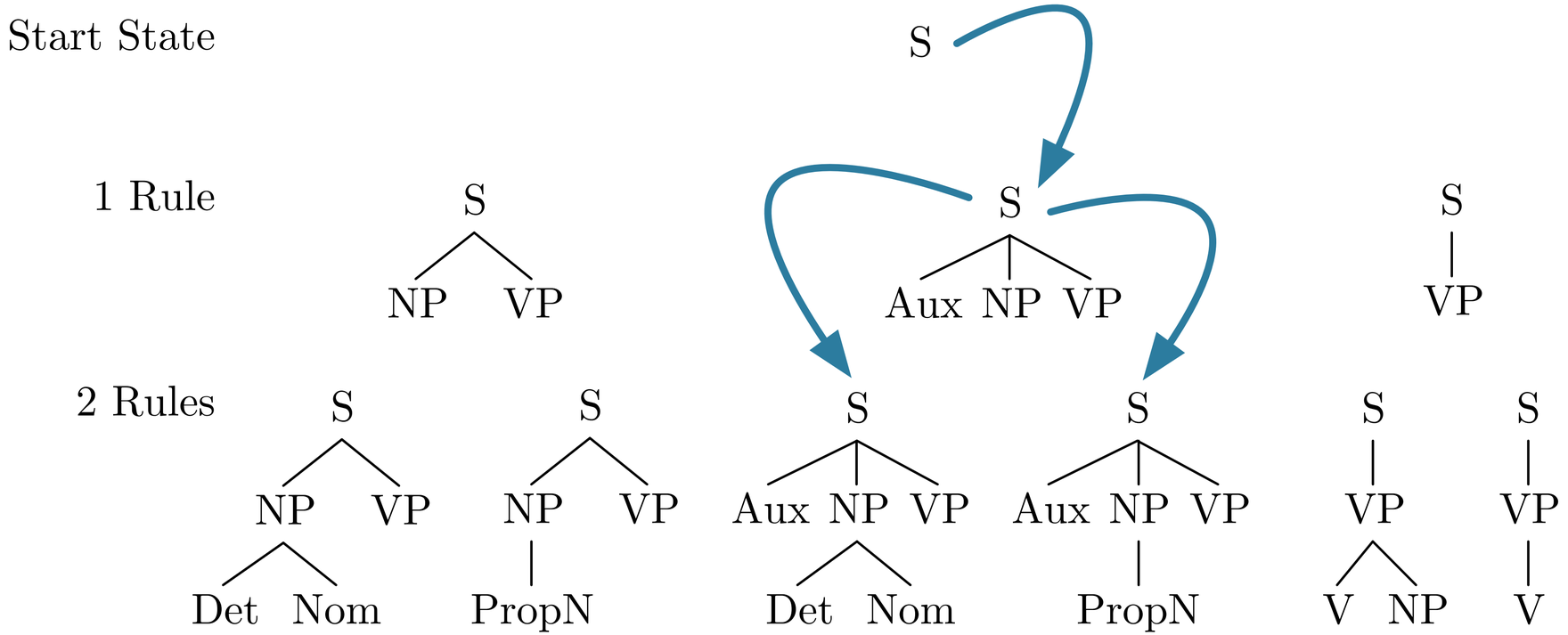

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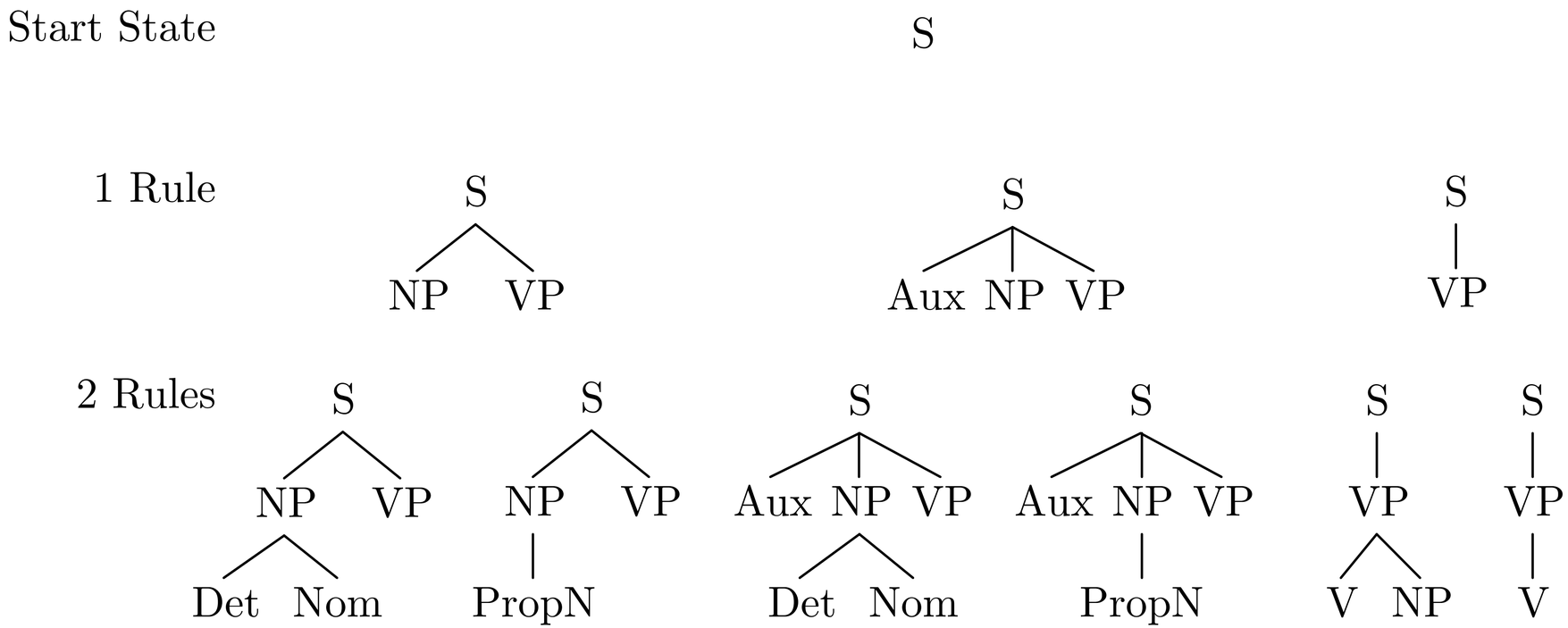

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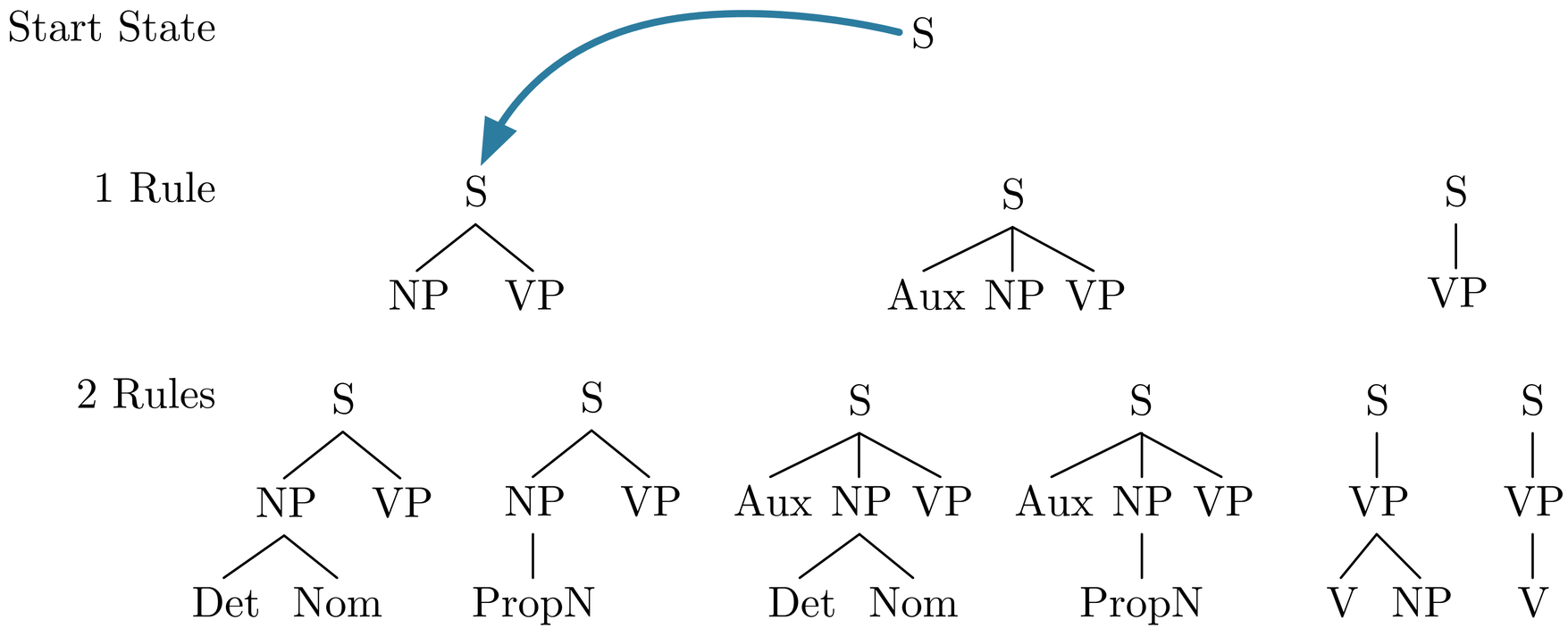

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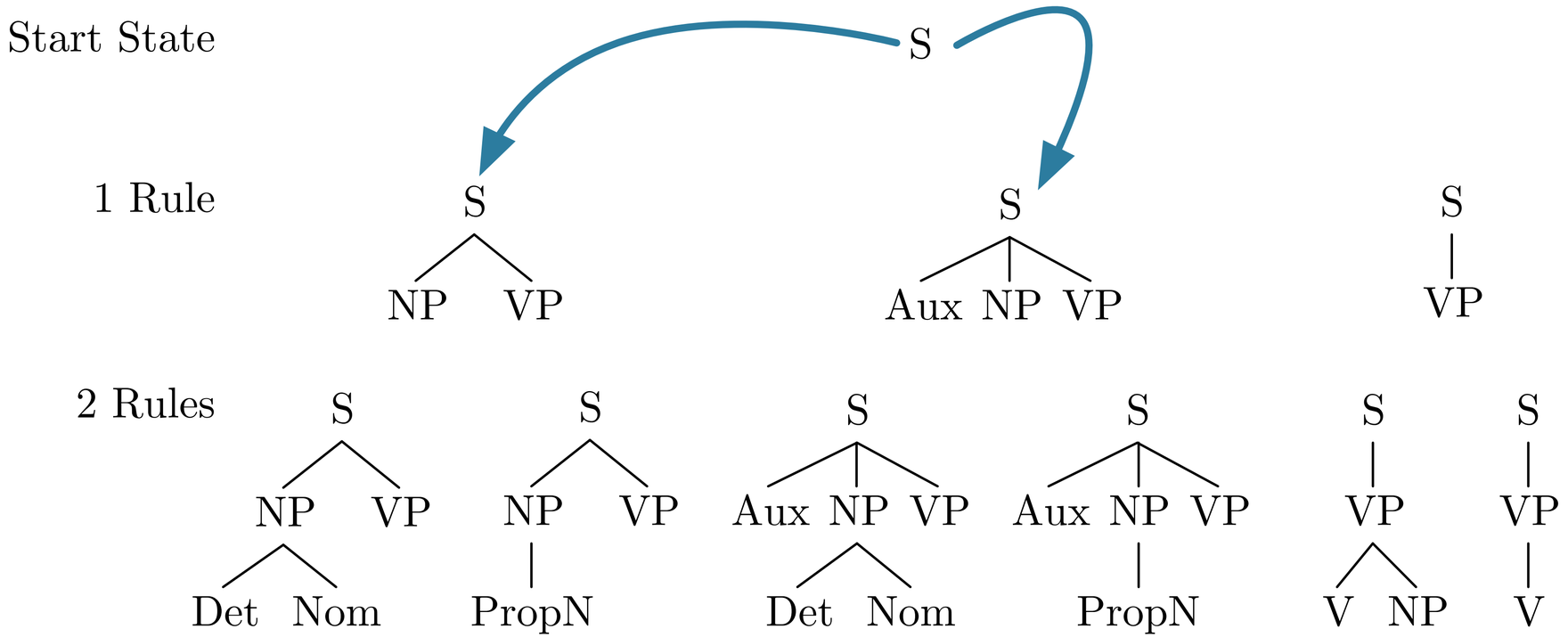

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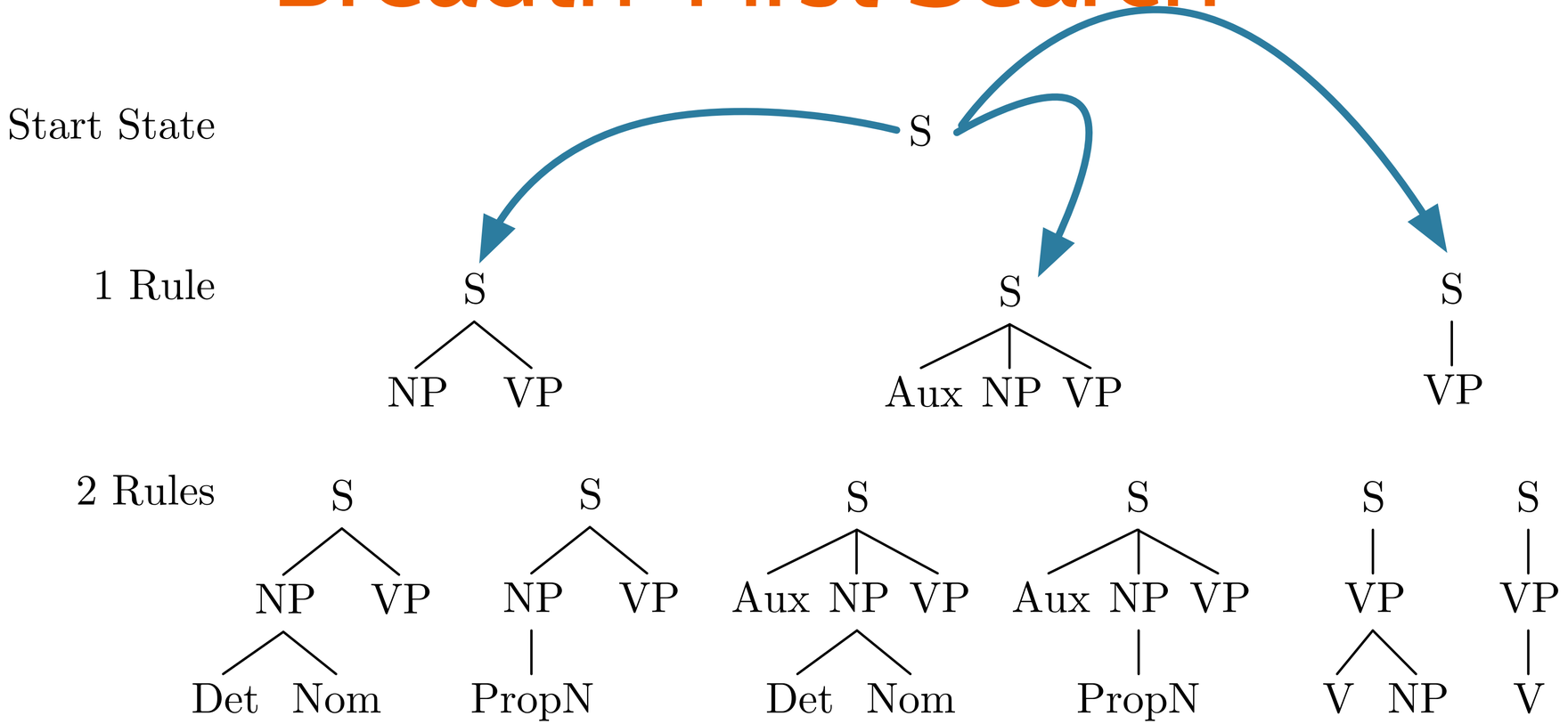

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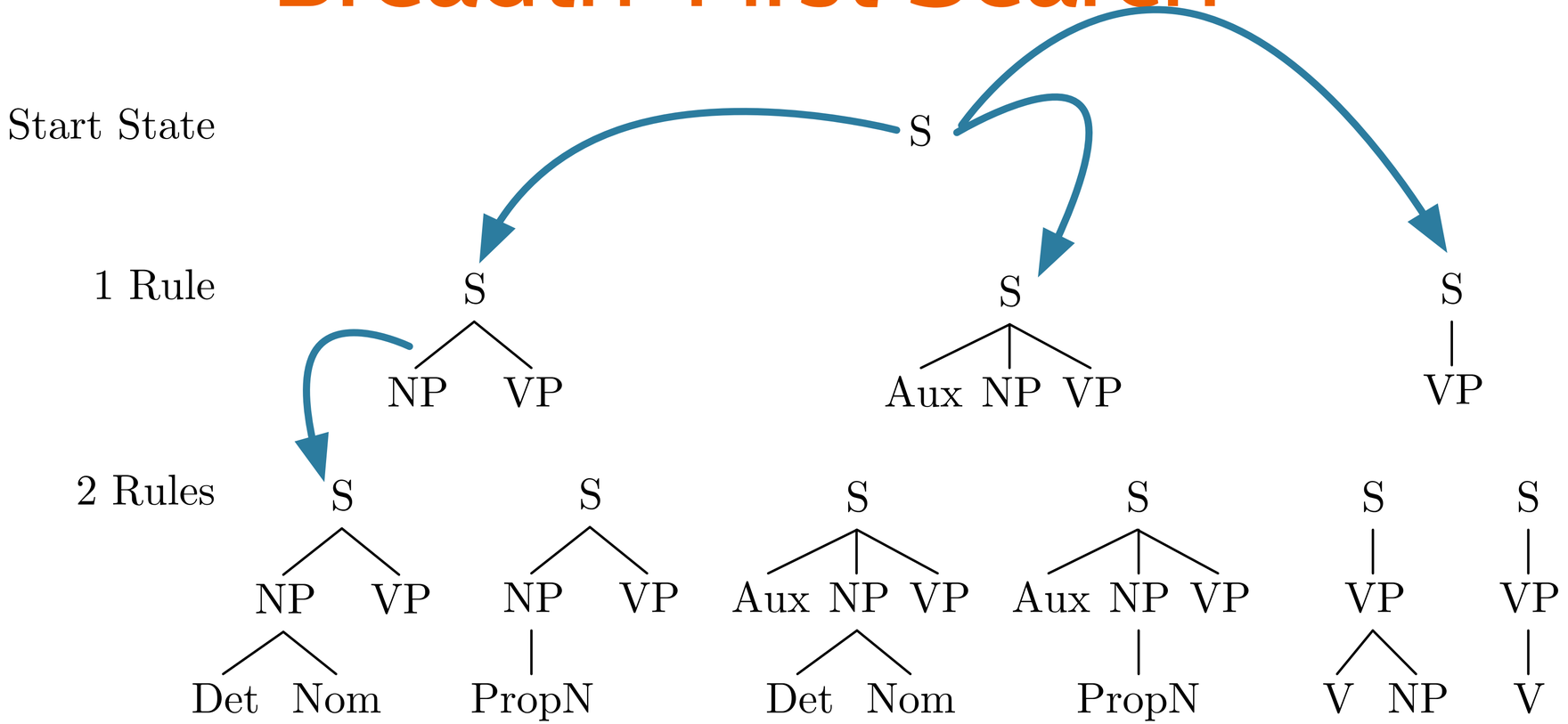

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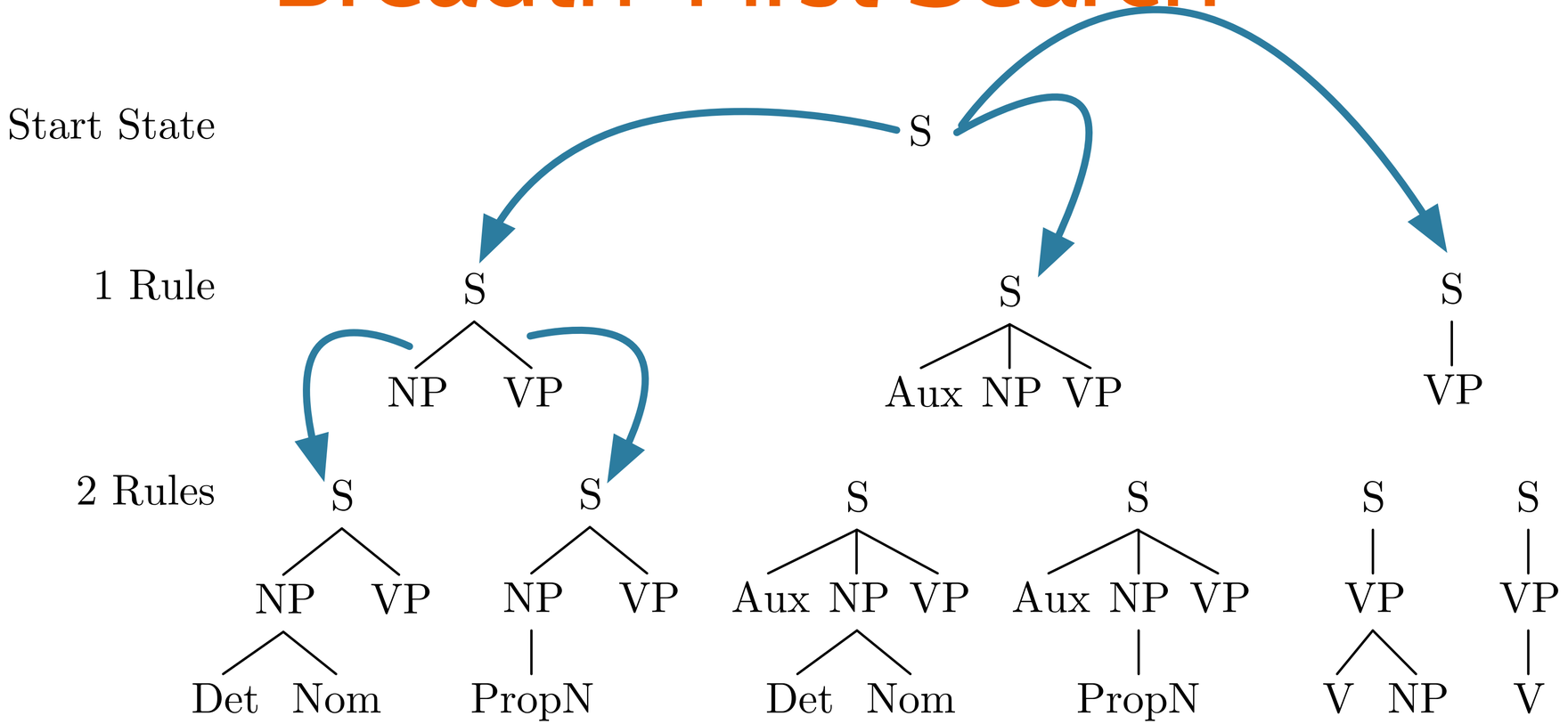

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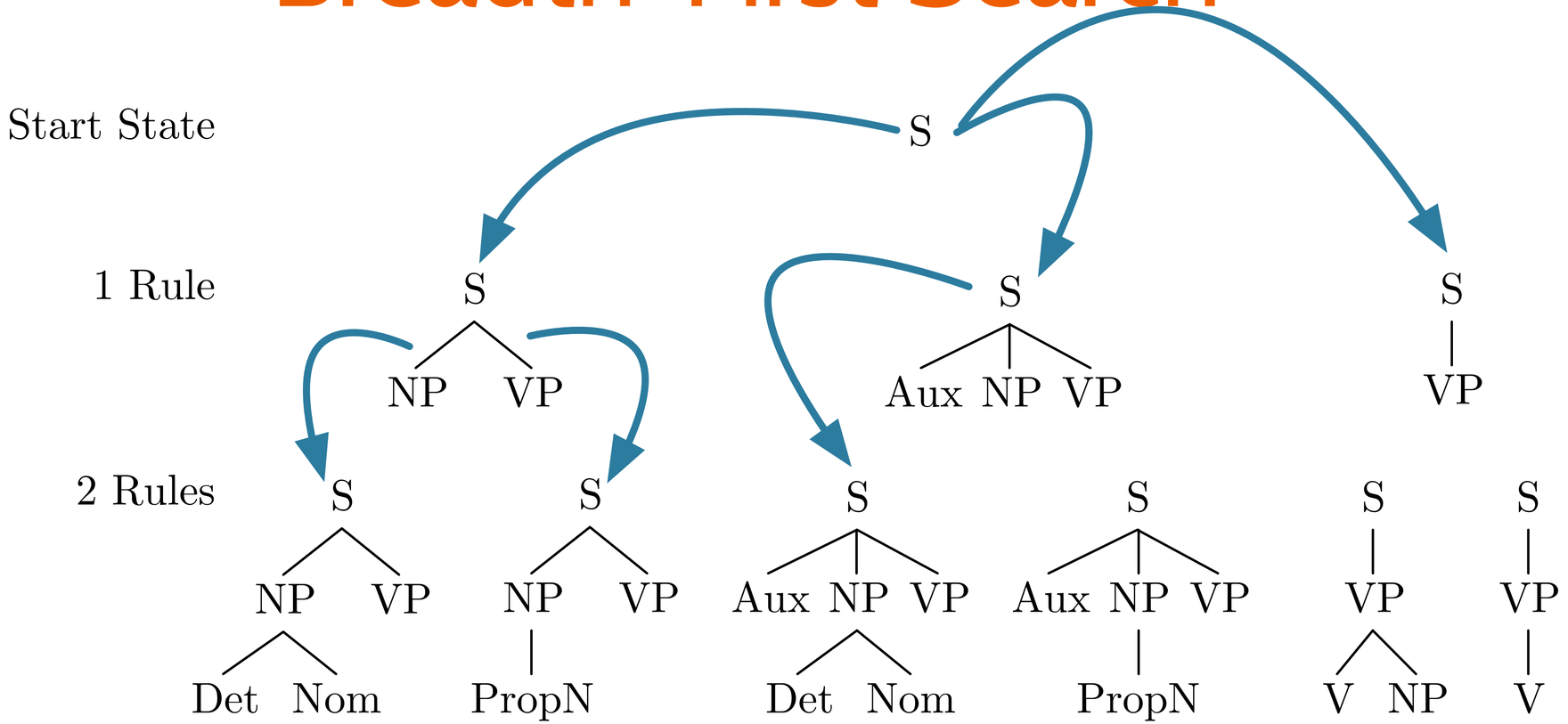

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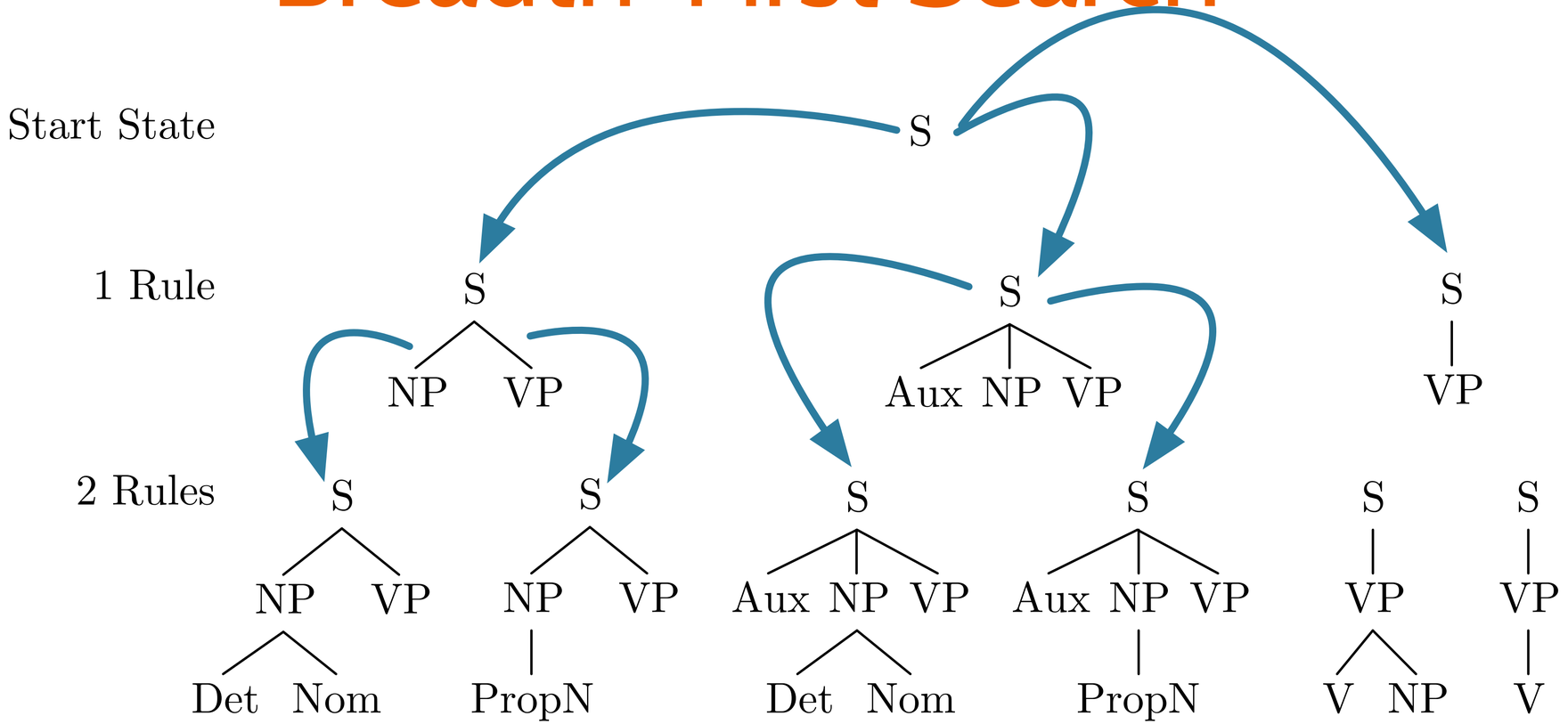

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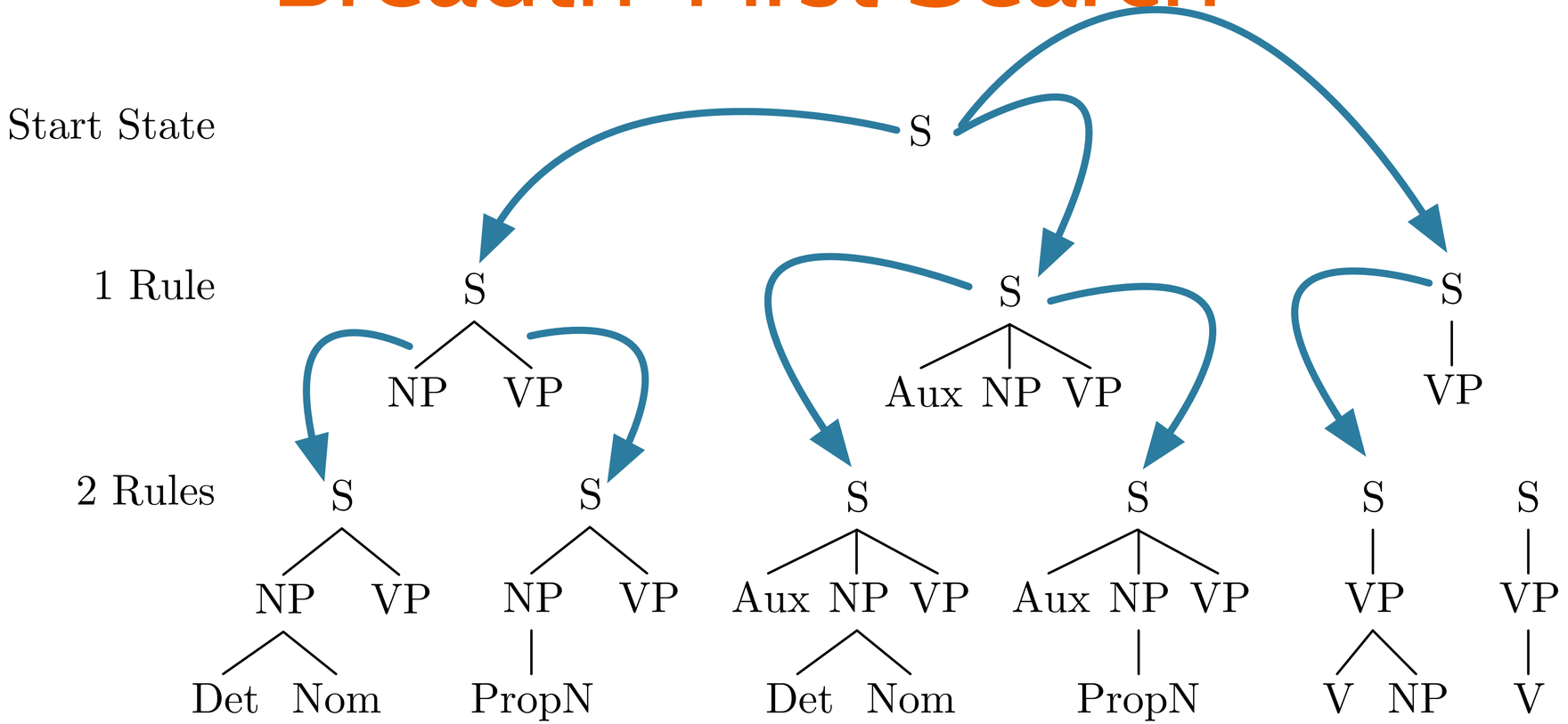

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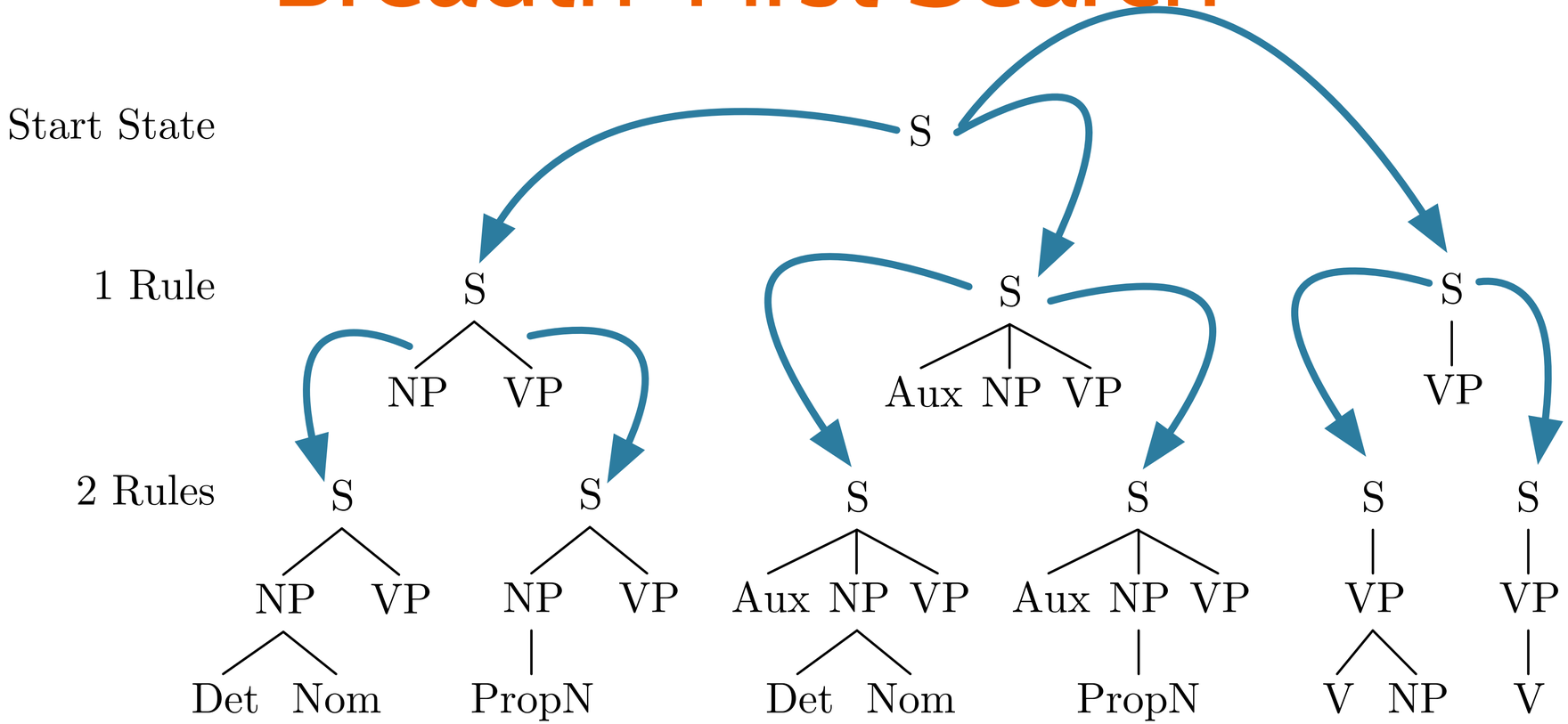

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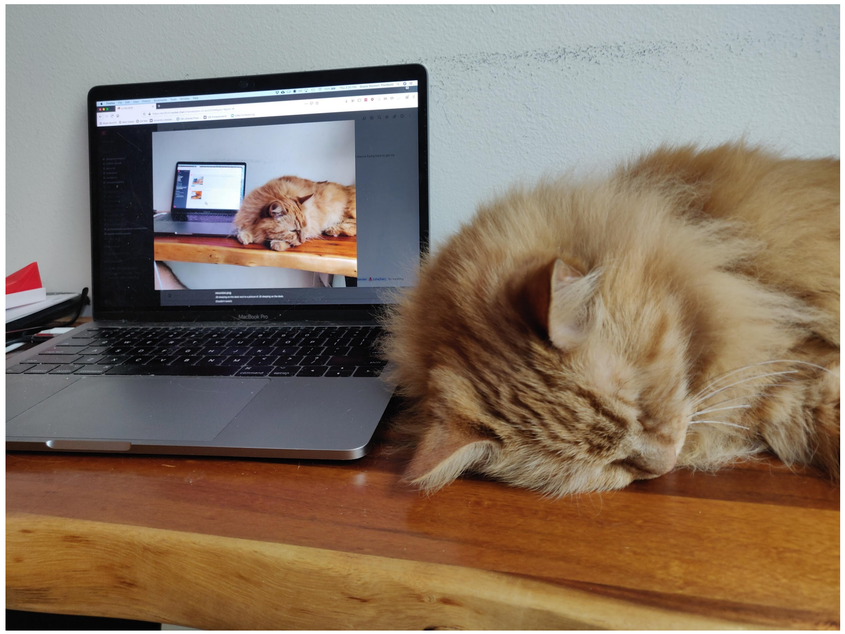
- Cons:
  - Produces trees that may not match input
  - May not terminate in presence of recursive rules
  - May re-derive subtrees as part of search



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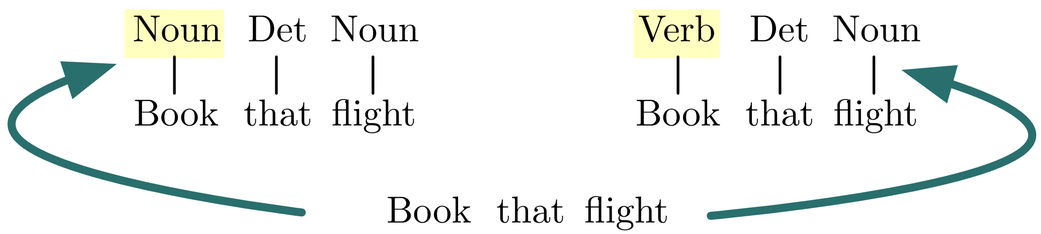
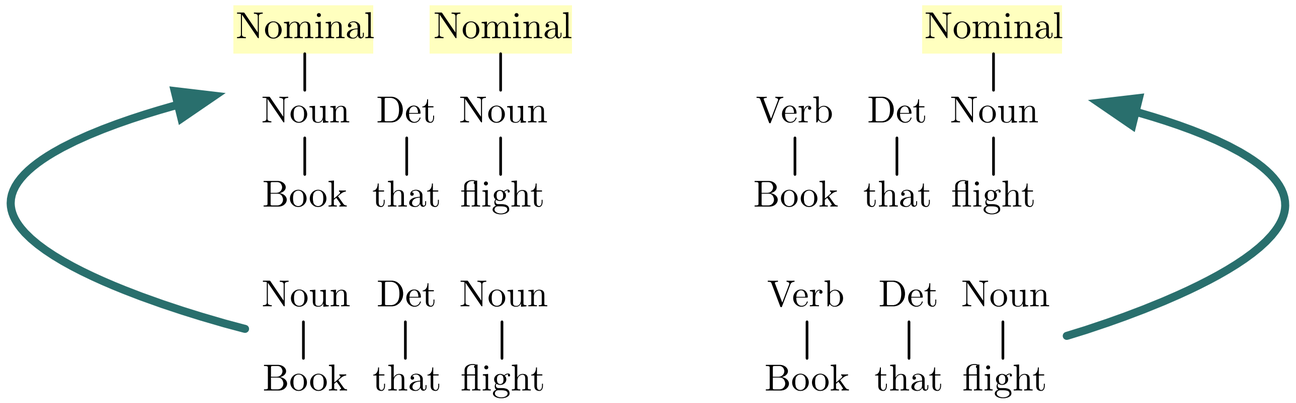
- Stop when spanned by S, or no more rules apply

Book that flight


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


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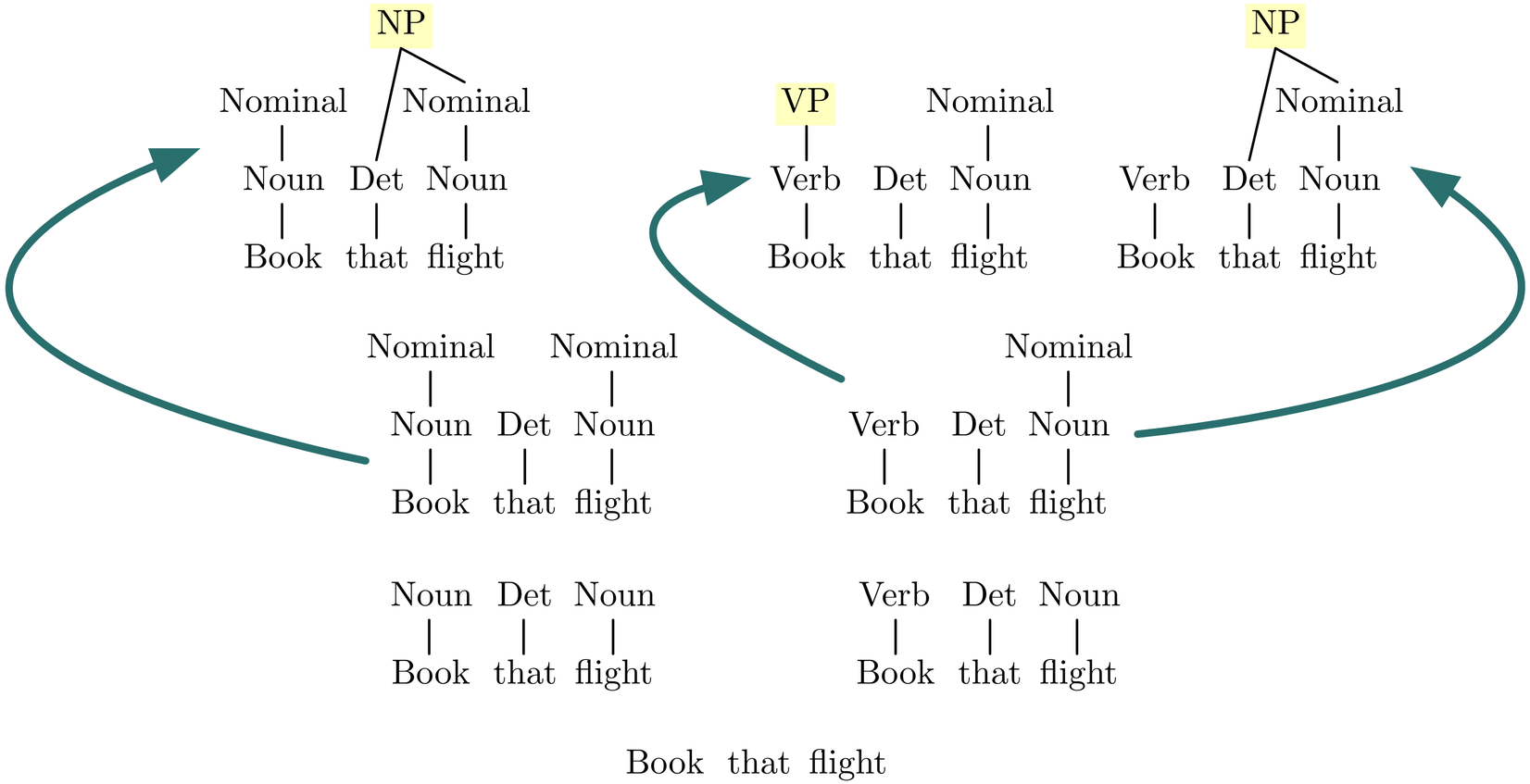
Book that flight
Book that flight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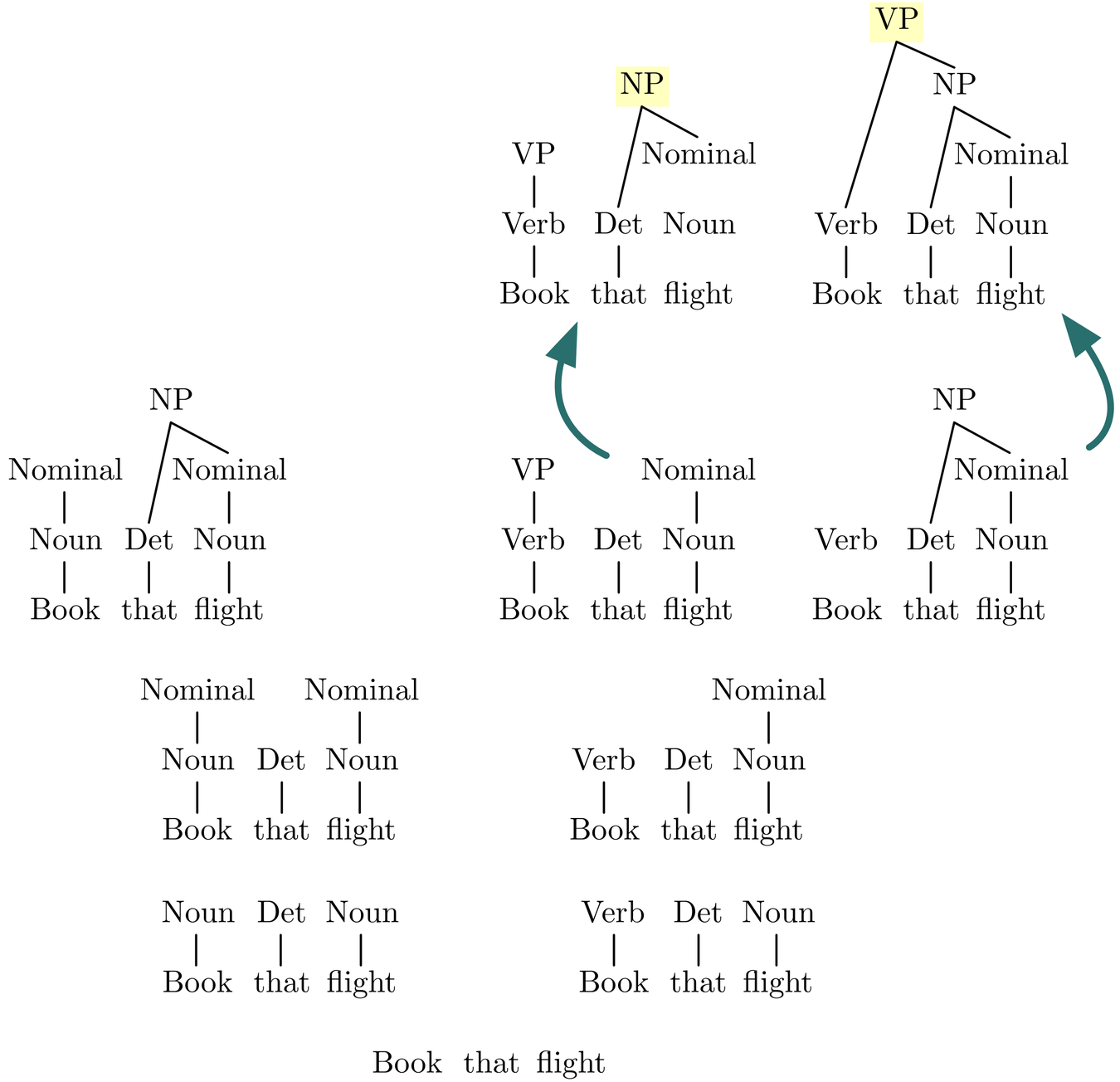
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# Pros and Cons of Bottom-Up Search

- Pros:
  - Will not explore trees that don’t match input
  - Recursive rules less problematic
  - Useful for incremental/fragment parsing

# Pros and Cons of Bottom-Up Search

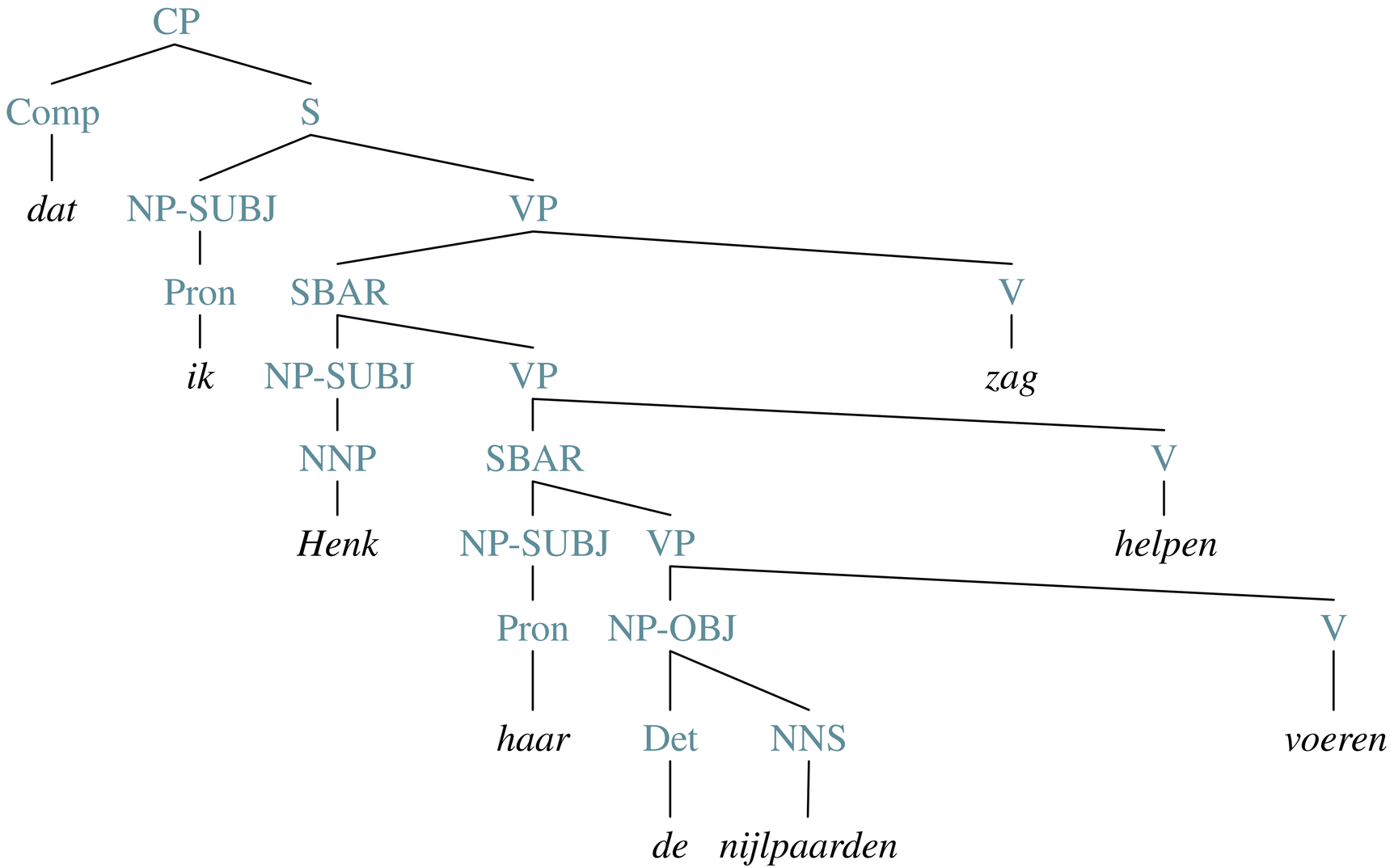
- Pros:
  - Will not explore trees that don’t match input
  - Recursive rules less problematic
  - Useful for incremental/fragment parsing
- Cons:
  - Explore subtrees that will not fit full input

# 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$_3$ |

*A Dutch example from Rentier (1994)*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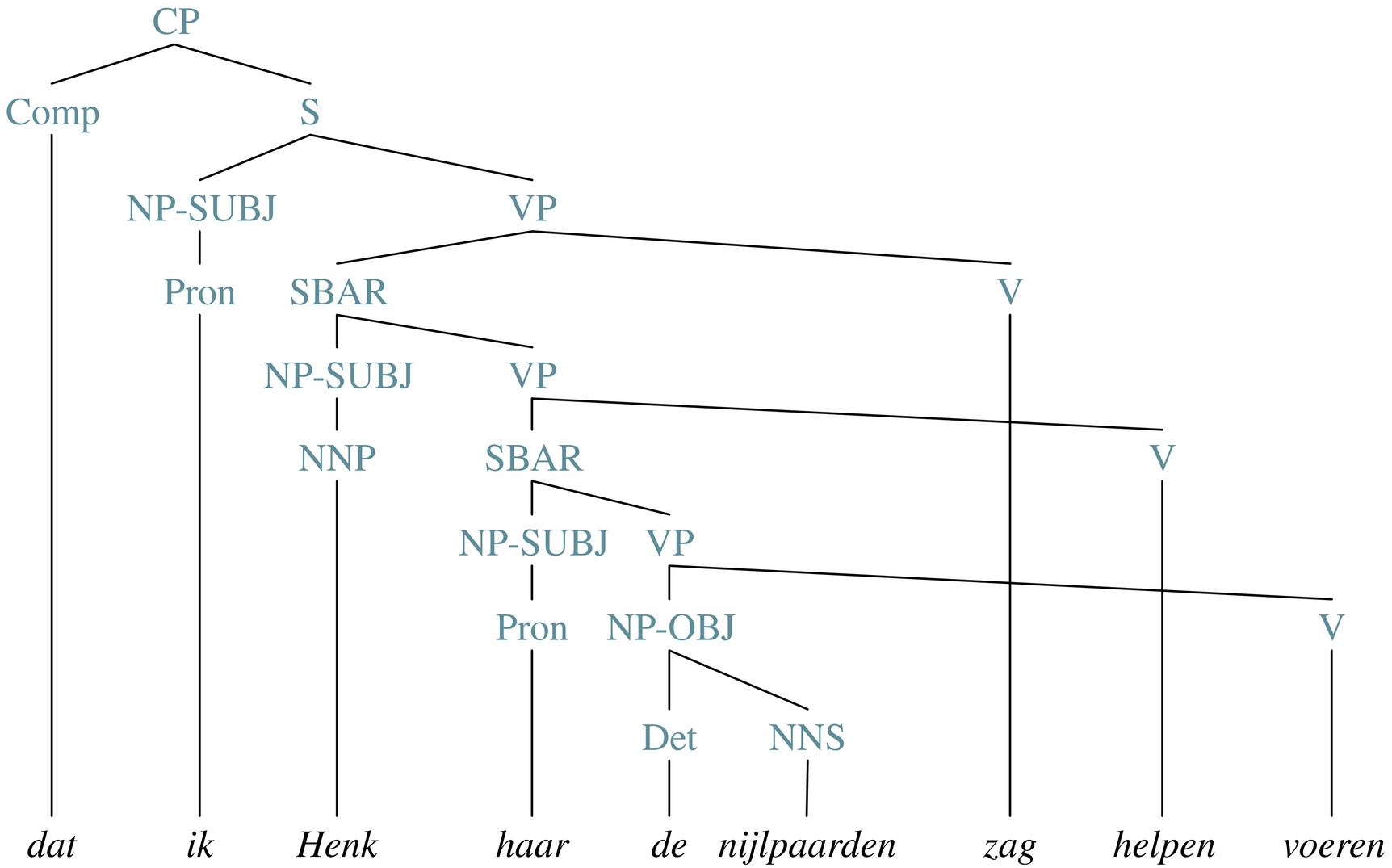
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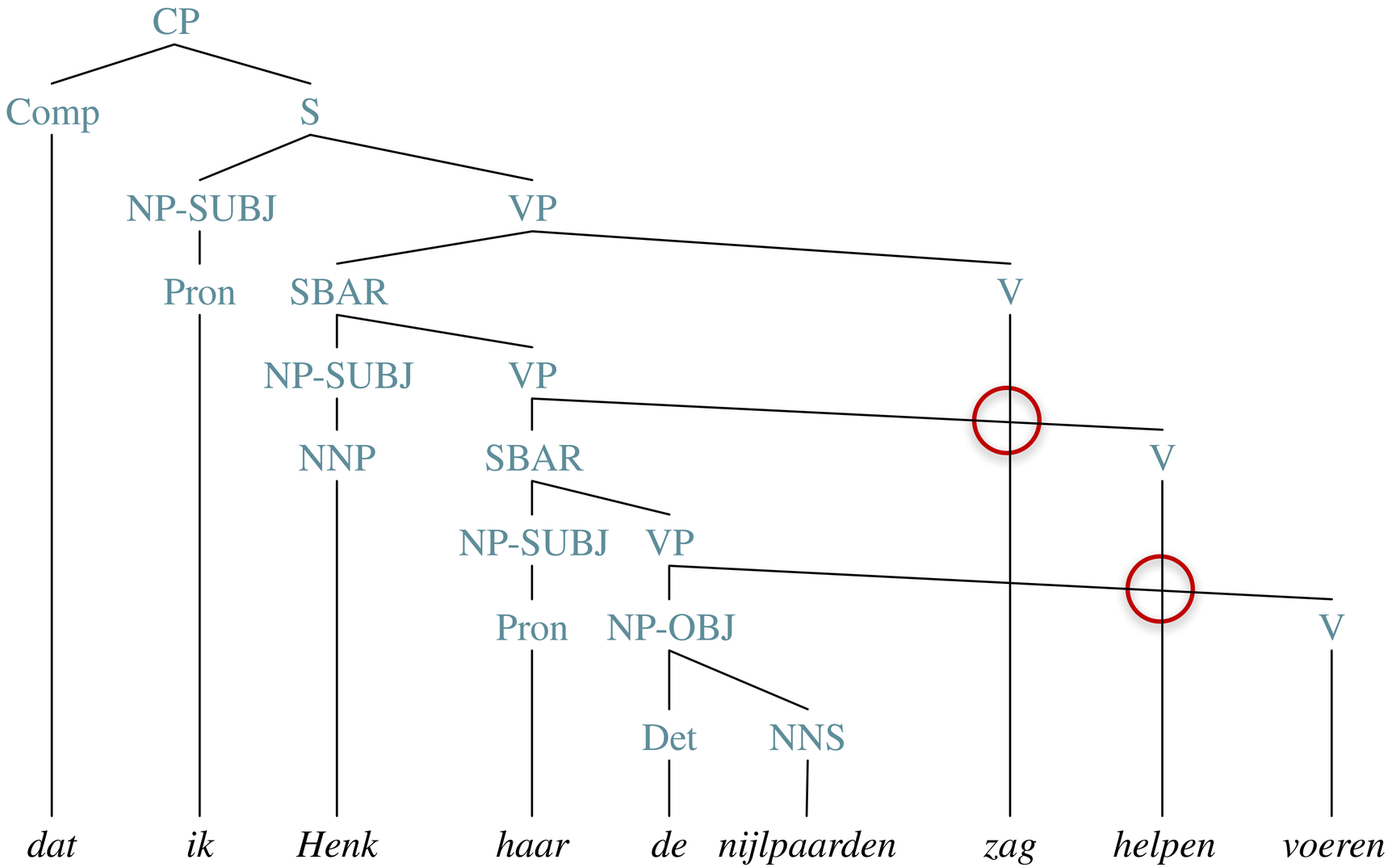
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# Next Time

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