Natural Language Processing

Lecture 5: Introduction to Syntax and Formal Languages.

11/8/2020

COMS W4705
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Sentences:
the good, the bad, and the ugly

- Some good sentences:
  - *the boy likes a girl*
  - *the small girl likes a big girl*
  - *a very small nice boy sees a very nice boy*
- Some bad sentences:
  - *the boy the girl likes*
  - *small boy likes nice girl*
- Ugly word salad: *very like nice the girl boy*

Syntax as an Interface

- Syntax can be seen as the interface between morphology (structure of words) and semantics.

- Why treat syntax separately from semantics?

  - Can judge if a sentence is grammatical or not, even if it doesn’t make sense semantically.

    Colorless green ideas sleep furiously.

    **Sleep ideas furiously colorless green.*

Key Concepts of Syntax

- Constituency and Recursion.
- Dependency.
- Grammatical Relations.
- Subcategorization.
- Long-distance dependencies.

Constituents

- A constituent is a group of words that behave as a single unit (within a hierarchical structure).

- Noun-Phrase examples:

  - [they], [the woman], [three parties from Brooklyn],
    [a high-class spot such as Mindy's], [the horse raced past the barn]

  - Noun phrases can appear before verbs (among other things) and they must be complete:

    - **from **arrive**…*
      the **is ….*
      spot **sat….*

Constituency Tests

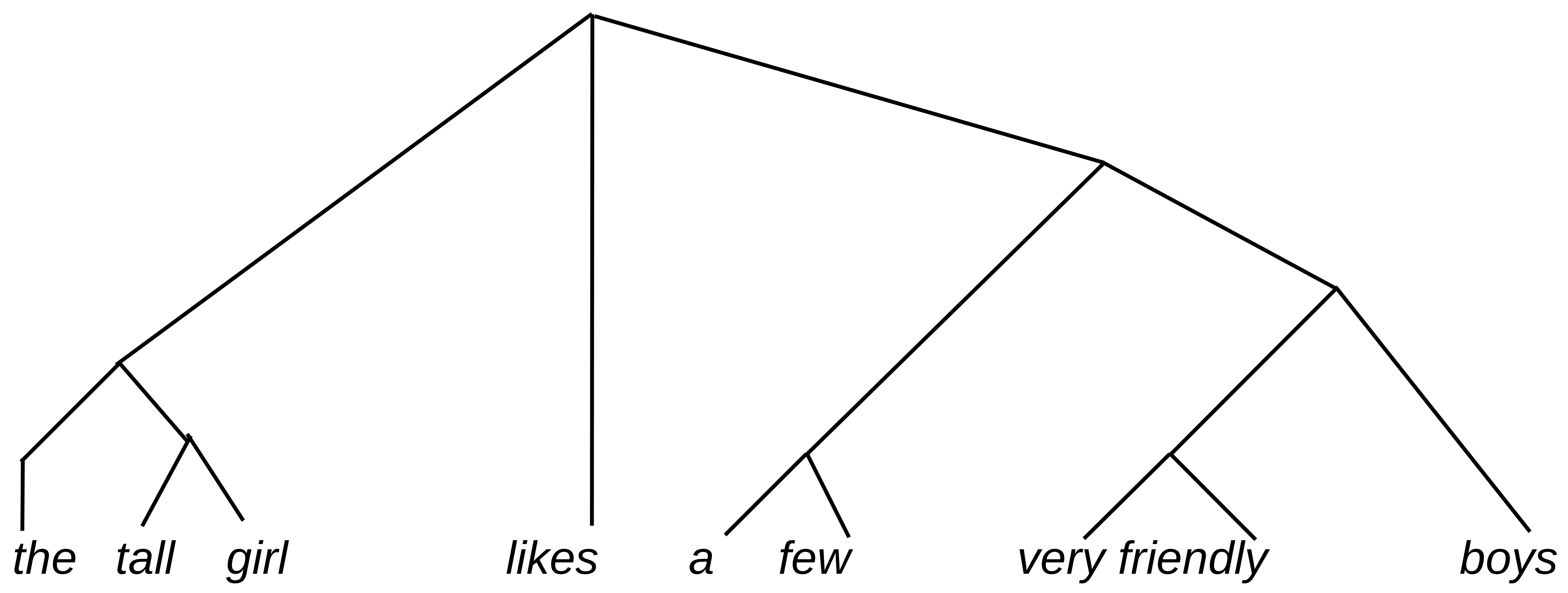
- ***On September seventeenth**, I’d like to fly to New York.*
- *I’d like to fly to New York **on September seventeenth.***
- *I’d like to fly **on September seventeenth** to New York.*
- ***On** *I’d like to fly to New York* **September seventeeth**.
- ***On September** *I’d like to fly* **seventeenth** *to New York.*

More Constituency Tests

- There is a great number of constituency tests. They typically involve moving constituents around or replacing them.
- Topicalization:
  - *I won't eat* ***that pizza*** ***That pizza****, I won't eat* *****pizza*** *I won't eat that*
- Pro-form Substitution:
  - *I don't know* ***the man who sent flowers.*** *I don't know* ***him.***
    ****I*** *don't know* ***him*** *flowers.*
- Wh-question test.
  - ***Where*** *would you like to fly on September seventeeth?*
  - ***When*** *would you like to fly to New York?*

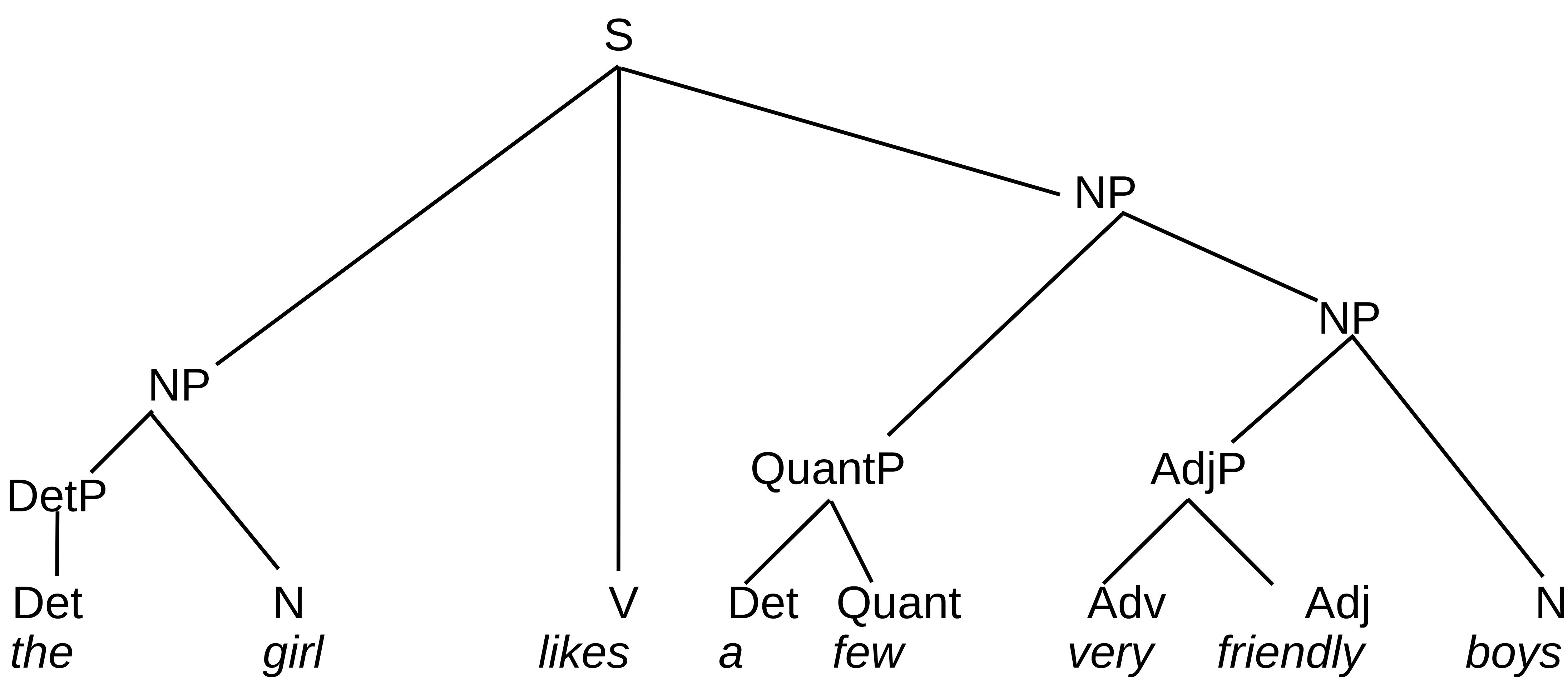
Sentence Structure as Trees

- [the tall girl likes a few very friendly boys]
- [[the tall girl] likes [a few very friendly boys]]
- [[the] tall girl] likes [[a few] [very friendly] boys]]



Constituent Labels

- Choose constituents so each one has one non-bracketed word: the **head.**
- Category of Constituent: XP, where X is the part-of-speech of the head
  NP, VP, AdjP, AdvP, DetP



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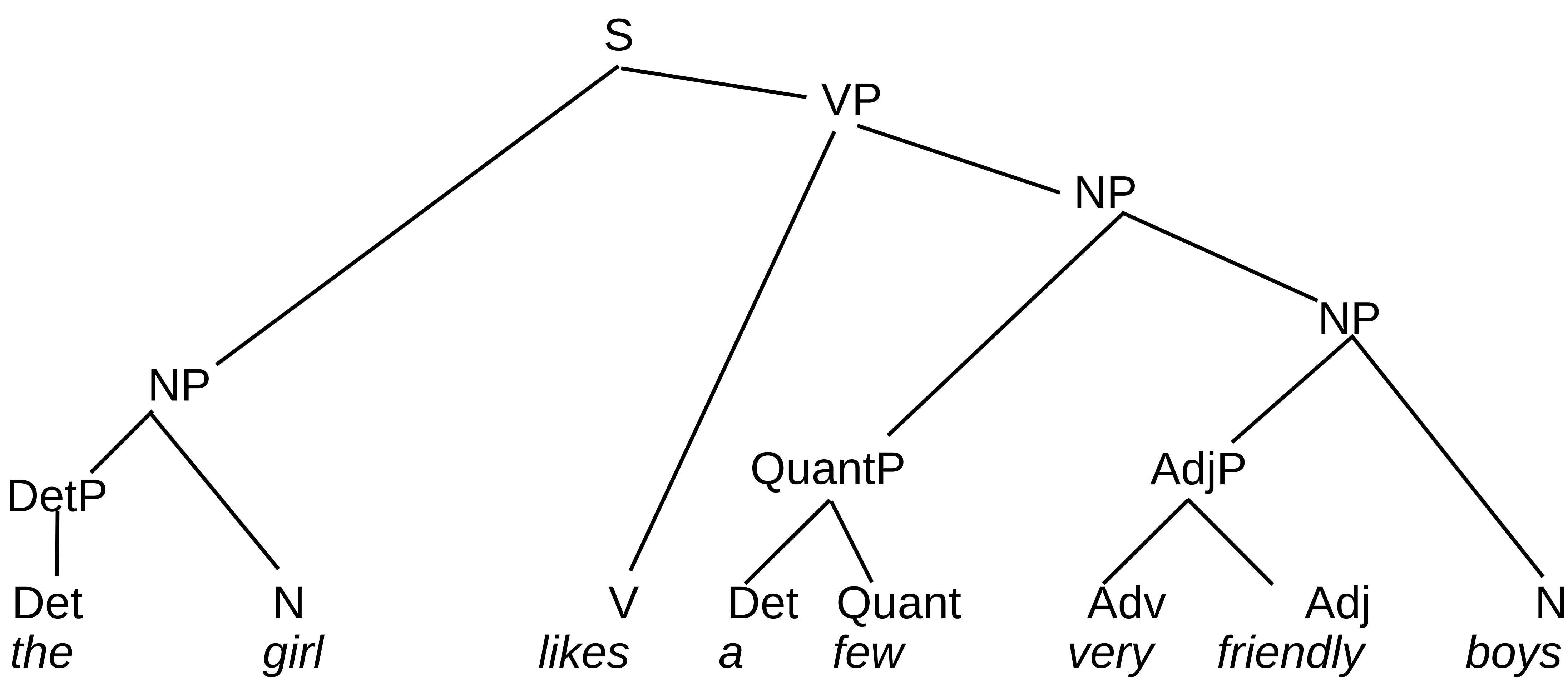

Review: Constituency

The students easily completed the difficult NLP homework.

Which constituents can you identify? What tests could you use?

Recursion in Language

- One of the most important attributes of Natural Languages is that they are **recursive.**

  - *He made pie*
    [with apples [from the orchard [near the farm [in …]]]]

  - *[The mouse [the cat [the dog chased]] ate] died.*

- There are infinitely many sentences in a language, but in predictable structures.

- How do we model the set of sentences in a language and their structure?

Context Free Grammars (CFG)

S → NP VP	V → saw
VP → V NP	P → with
VP → VP PP	D → the
PP → P NP	N → cat
NP → D N	N → tail
NP → NP PP	N → student

S

Context Free Grammars (CFG)

S → NP VP
VP → V NP
VP → VP PP
PP → P NP
NP → D N
NP → NP PP

V → saw
P → with
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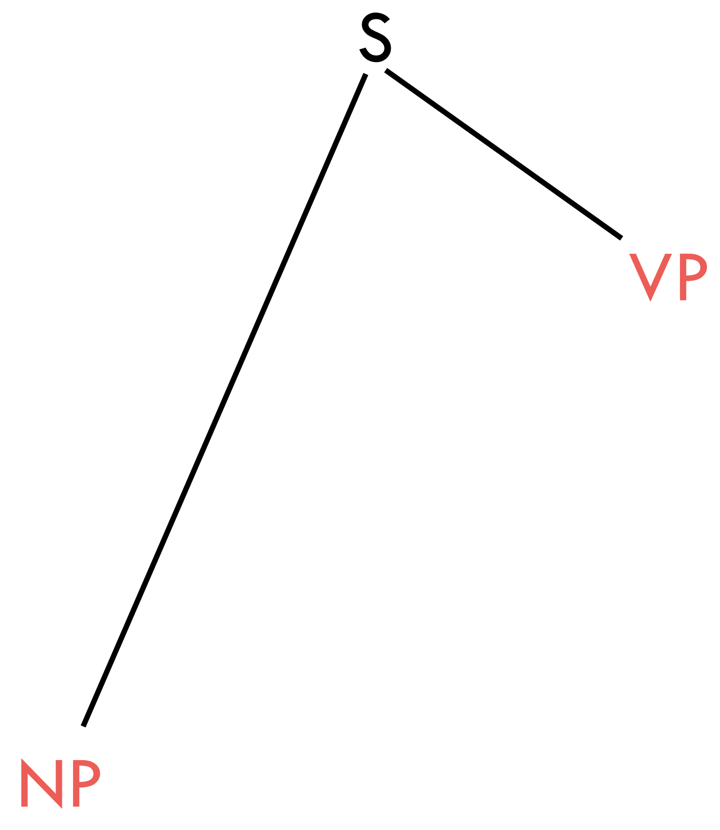
N → cat
N → tail
N → student



Context Free Grammars (CFG)

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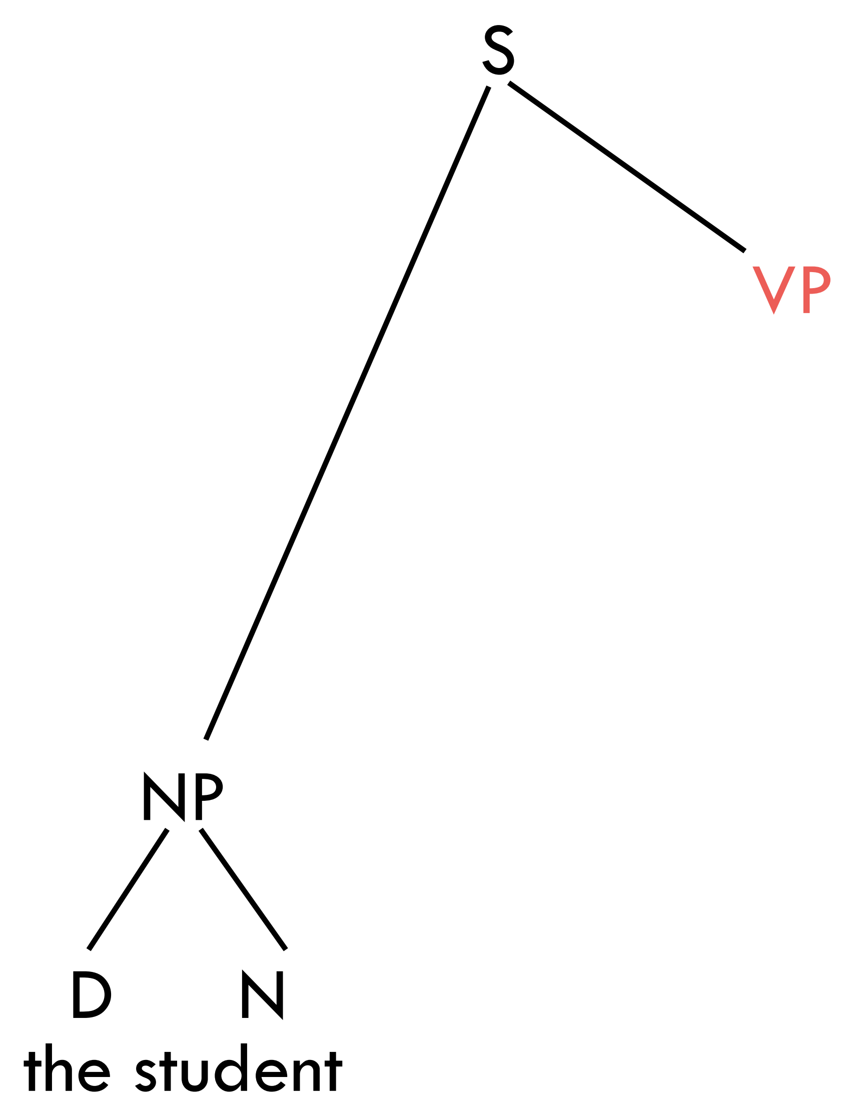
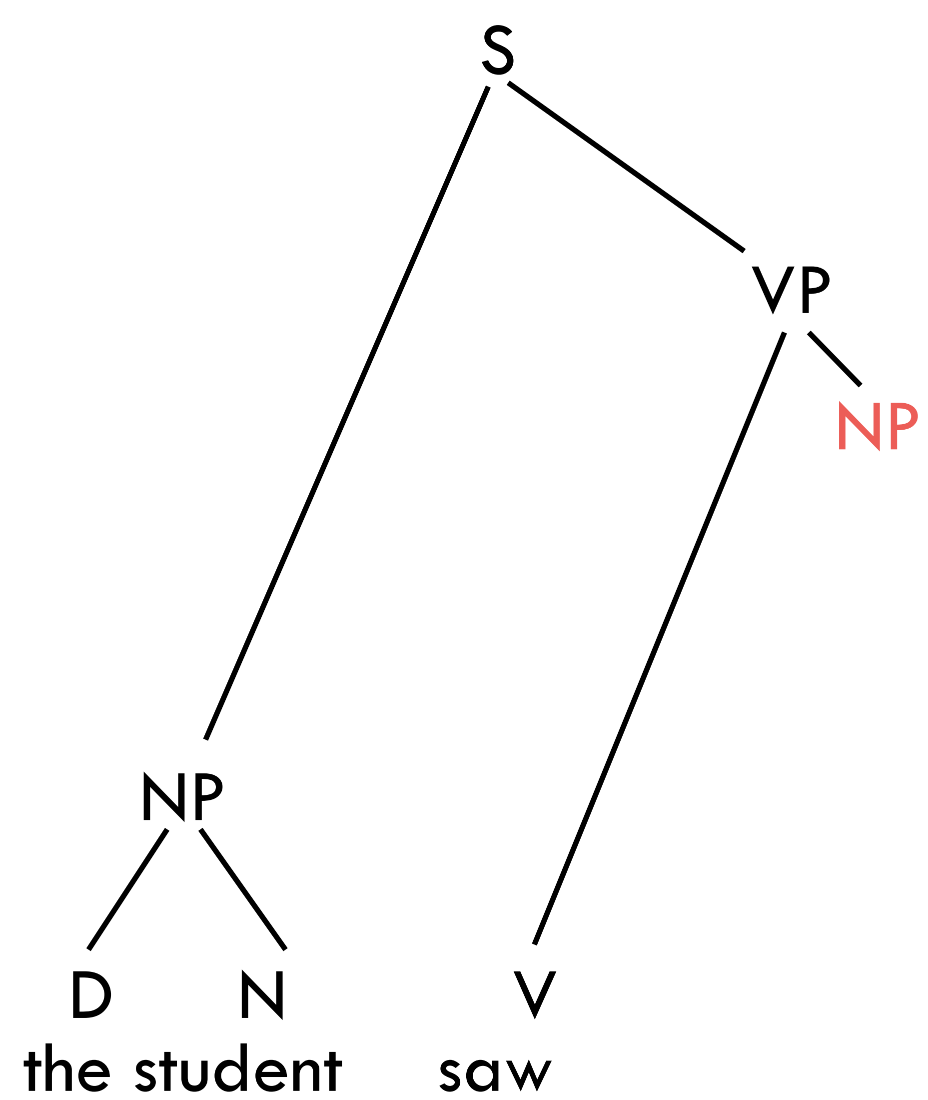


Context Free Grammars (CFG)

S	$\rightarrow$	NP VP	V	$\rightarrow$	saw
VP	$\rightarrow$	V NP	P	$\rightarrow$	with
VP	$\rightarrow$	VP PP	D	$\rightarrow$	the
PP	$\rightarrow$	P NP	N	$\rightarrow$	cat
NP	$\rightarrow$	D N	N	$\rightarrow$	tail
NP	$\rightarrow$	NP PP	N	$\rightarrow$	student



Context Free Grammars (CFG)

S $\rightarrow$ NP VP	V $\rightarrow$ saw
VP $\rightarrow$ V NP	P $\rightarrow$ with
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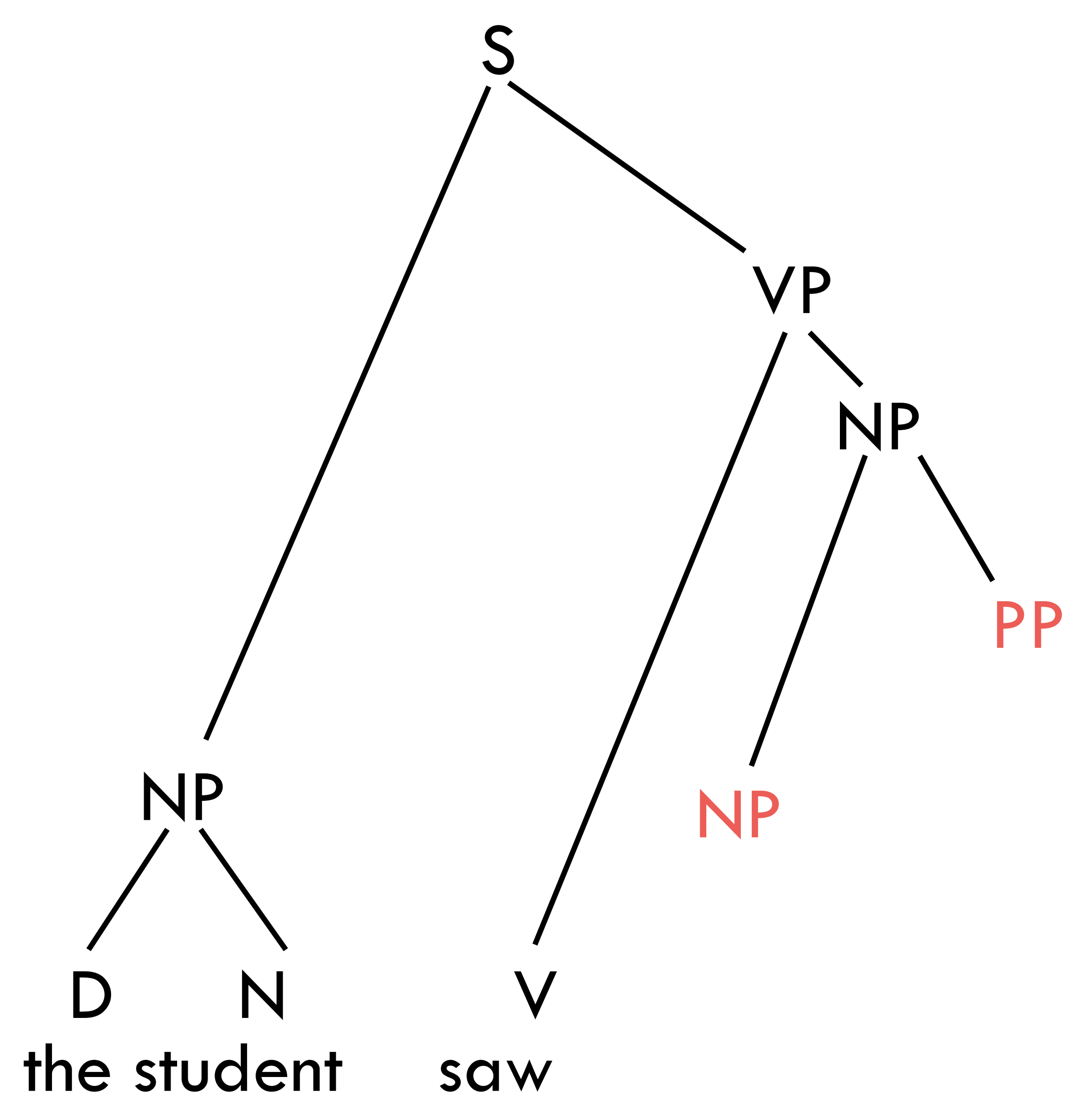
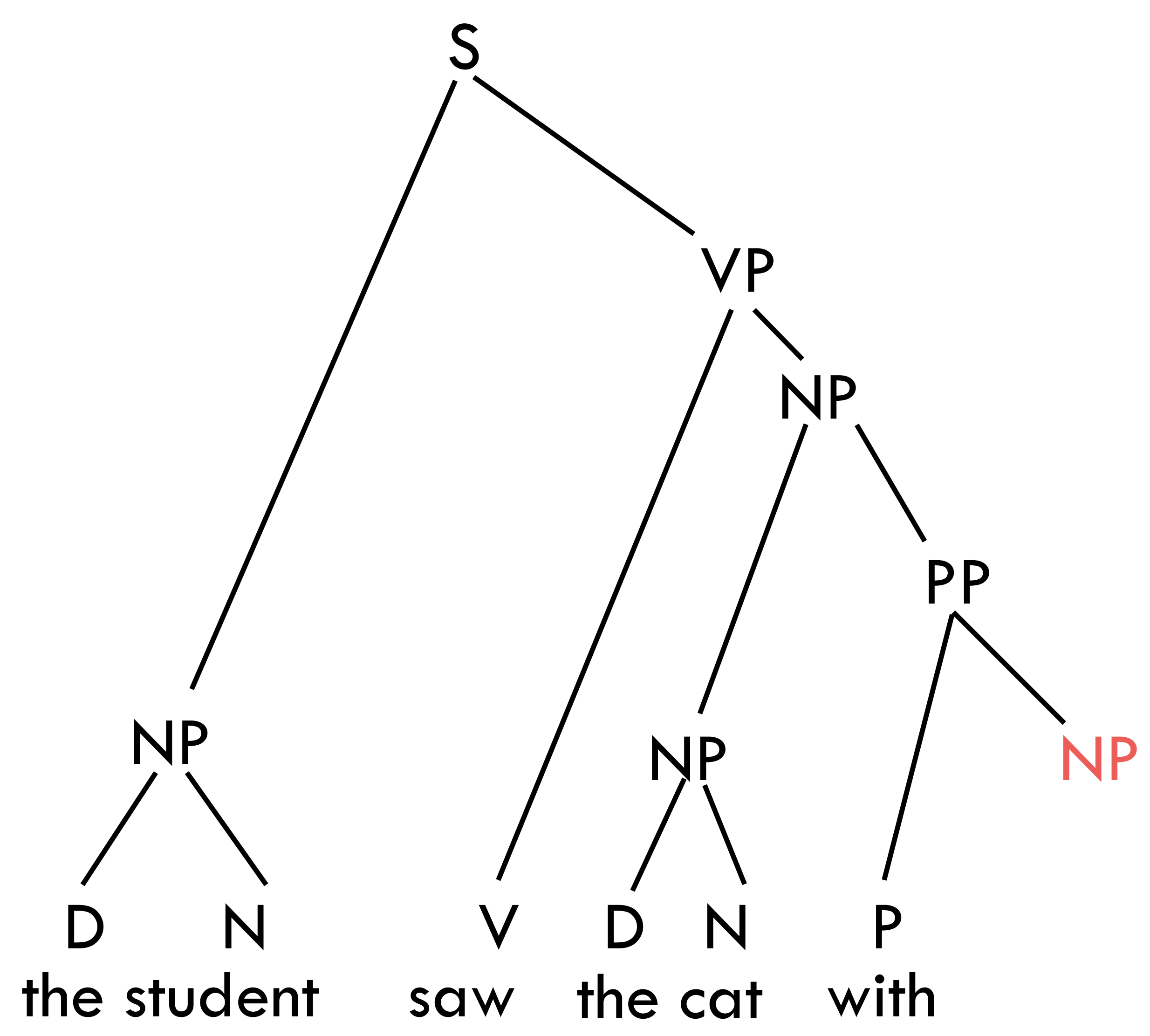


Context Free Grammars (CFG)

$S \rightarrow NP\ VP$
$VP \rightarrow V\ \ NP$
$VP \rightarrow VP\ PP$
$PP \rightarrow P\ NP$
$NP \rightarrow D\ N$
$NP \rightarrow NP\ PP$

$V \rightarrow$ saw
$P \rightarrow$ with
$D \rightarrow$ the
$N \rightarrow$ cat
$N \rightarrow$ tail
$N \rightarrow$ student



Context Free Grammars (CFG)

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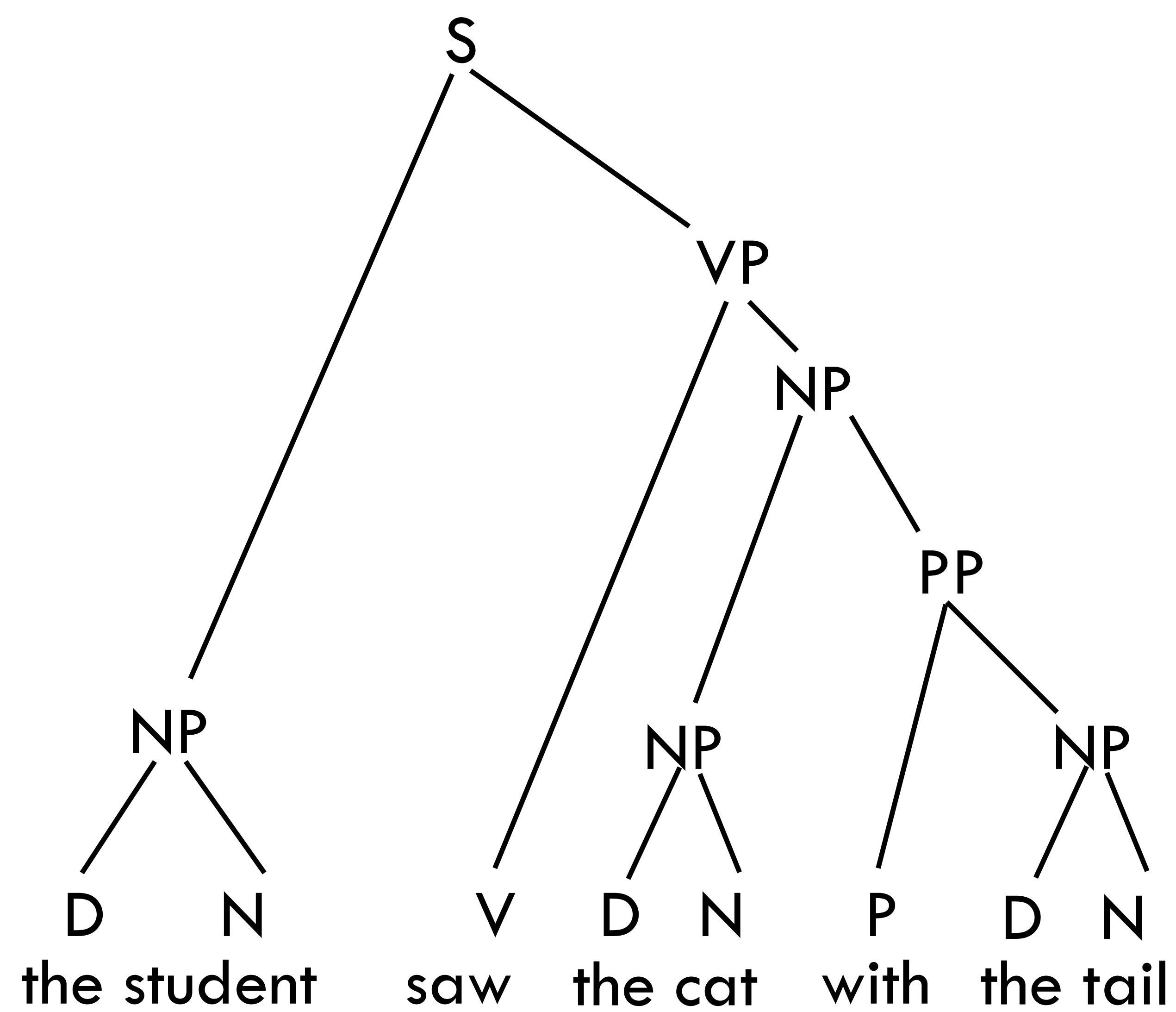


Context Free Grammars

- A context free grammar is defined by:
  - Set of **terminal symbols** Σ.
  - Set of **non-terminal symbols** N.
  - A **start symbol** $S \in N$.
  - Set R of **productions** of the form $A \rightarrow \beta$, where A $\in$ N and $\beta \in (\Sigma \cup N)^*$, *i.e.* β is a string of terminals and non-terminals.

Language of a CFG

- Given a CFG $G=(N, \Sigma, R, S)$:
  - Given a string $\alpha A \gamma$, where $A \in N$, we can derive $\alpha\beta\gamma$ if there is a production $A \rightarrow \beta \in R$.
  - $\alpha \Rightarrow \beta$ means that G can derive β from α in a single step.
  - $\alpha \Rightarrow^* \beta$ means that G can derive β from α in a finite number of steps.
  - The **language of *G*** is defined as the set of all terminal strings that can be derived from the start symbol.

$$L(G) = \{\beta \in \Sigma^*, \text{ s.t. } S \Rightarrow^* \beta\}$$

Derivations and Derived Strings

- CFG is a string rewriting formalism, so the **derived objects** are strings.

- A derivation is a sequence of rewriting steps.

- CFGs are **context free:** applicability of a rule depends only on the nonterminal symbol, not on its context.

  - Therefore, the order in which multiple non-terminals in a partially derived string are replaced does not matter.
    We can represent identical derivations in a **derivation tree.**

  - The derivation tree implies a parse tree.

Recursion in CFGs

S $\rightarrow$ NP VP
VP $\rightarrow$ V NP
VP $\rightarrow$ VP PP
PP $\rightarrow$ P NP
NP $\rightarrow$ D N
NP $\rightarrow$ NP PP

V $\rightarrow$ saw
P $\rightarrow$ with
D $\rightarrow$ the
N $\rightarrow$ cat
N $\rightarrow$ tail
N $\rightarrow$ student

Parse Tree:

NP

Derived String:

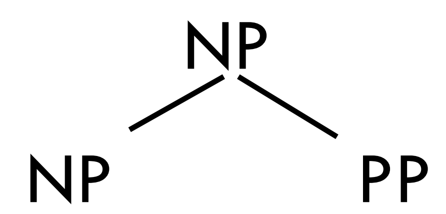
NP

Recursion in CFGs

S $\rightarrow$ NP VP
VP $\rightarrow$ V NP
VP $\rightarrow$ VP PP
PP $\rightarrow$ P NP
NP $\rightarrow$ D N
NP $\rightarrow$ NP PP

V $\rightarrow$ saw
P $\rightarrow$ with
D $\rightarrow$ the
N $\rightarrow$ cat
N $\rightarrow$ tail
N $\rightarrow$ student

Parse Tree:



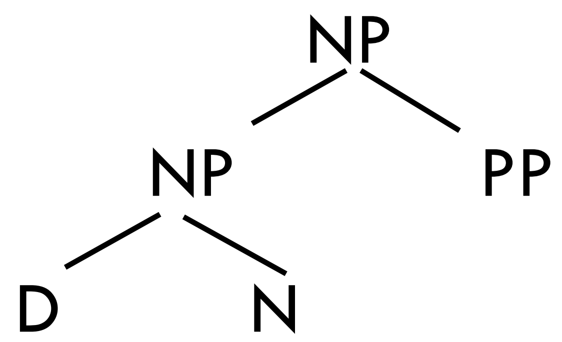
Derived String:

NP PP

Recursion in CFGs

S	→	NP VP	V	→	saw
VP	→	V NP	P	→	with
VP	→	VP PP	D	→	the
PP	→	P NP	N	→	cat
NP	→	D N	N	→	tail
NP	→	NP PP	N	→	student

Parse Tree:



Derived String:

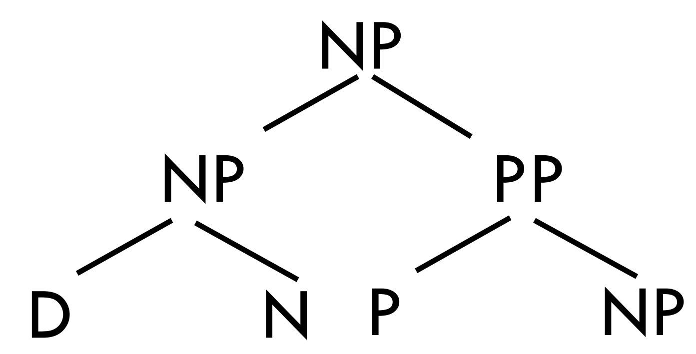
the student PP

Recursion in CFGs

S → NP VP
VP → V NP
VP → VP PP
PP → P NP
NP → D N
NP → NP PP

V → saw
P → with
D → the
N → cat
N → tail
N → student

Parse Tree:



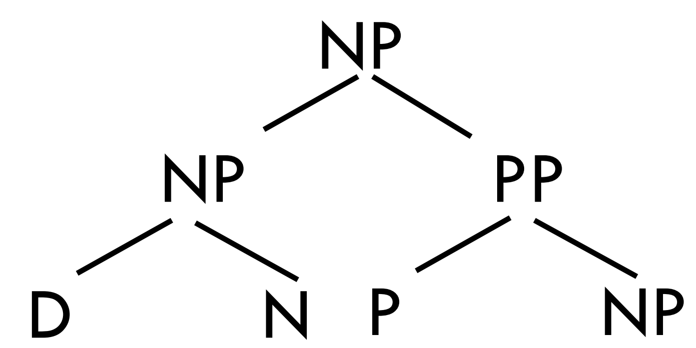
Derived String:

the student P NP

Recursion in CFGs

S → NP VP	V → saw
VP → V NP	P → with
VP → VP PP	D → the
PP → P NP	N → cat
NP → D N	N → tail
NP → NP PP	N → student

Parse Tree:



Derived String:

the student with NP

Recursion in CFGs

S → NP VP
VP → V NP
VP → VP PP
PP → P NP
NP → D N
NP → NP PP

V → saw
P → with
D → the
N → cat
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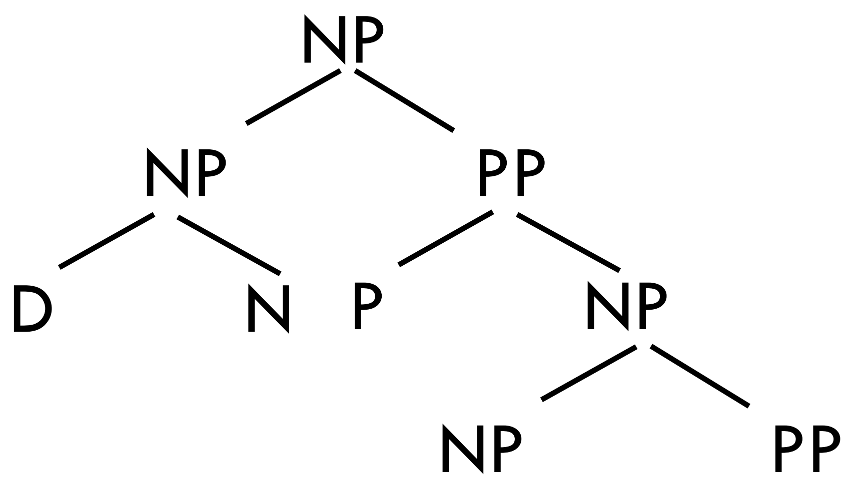
Parse Tree:



Derived String:

the student with NP PP

Recursion in CFGs

S → NP VP
VP → V NP
VP → VP PP
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NP → D N
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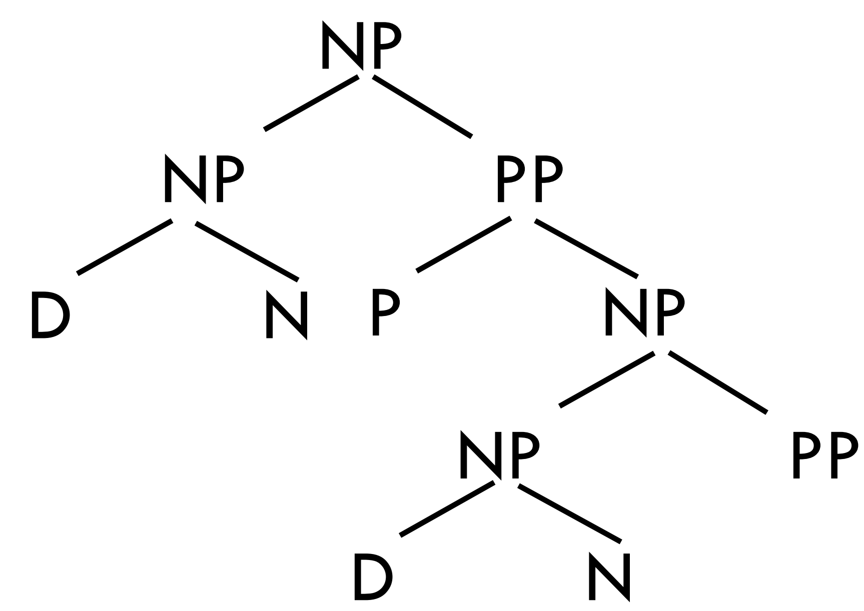
Parse Tree:



Derived String:

the student with the cat PP

Recursion in CFGs

S $\rightarrow$ NP VP
VP $\rightarrow$ V NP
VP $\rightarrow$ VP PP
PP $\rightarrow$ P NP
NP $\rightarrow$ D N
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V $\rightarrow$ saw
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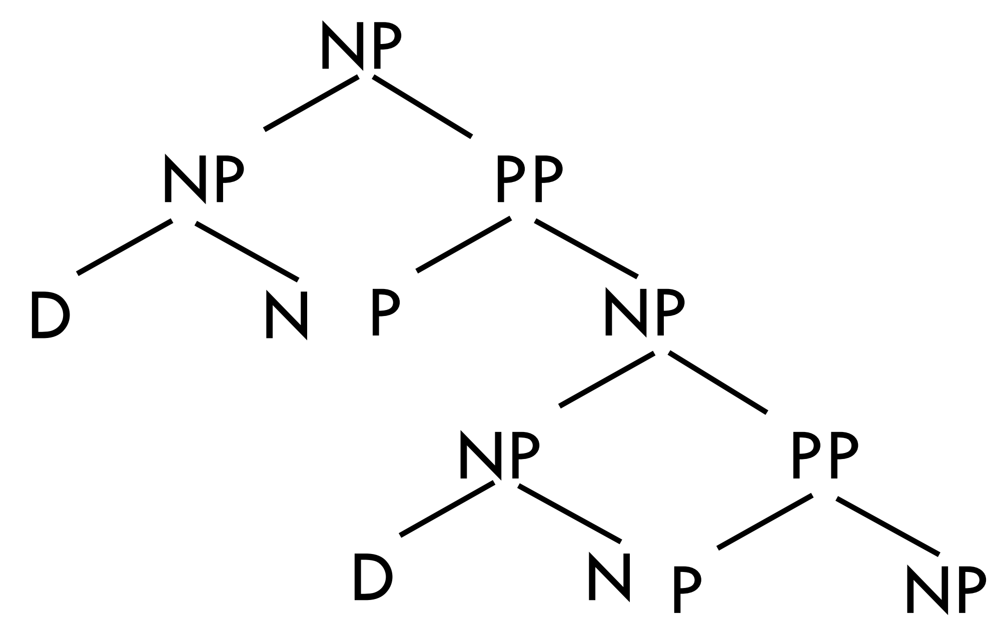
Parse Tree:



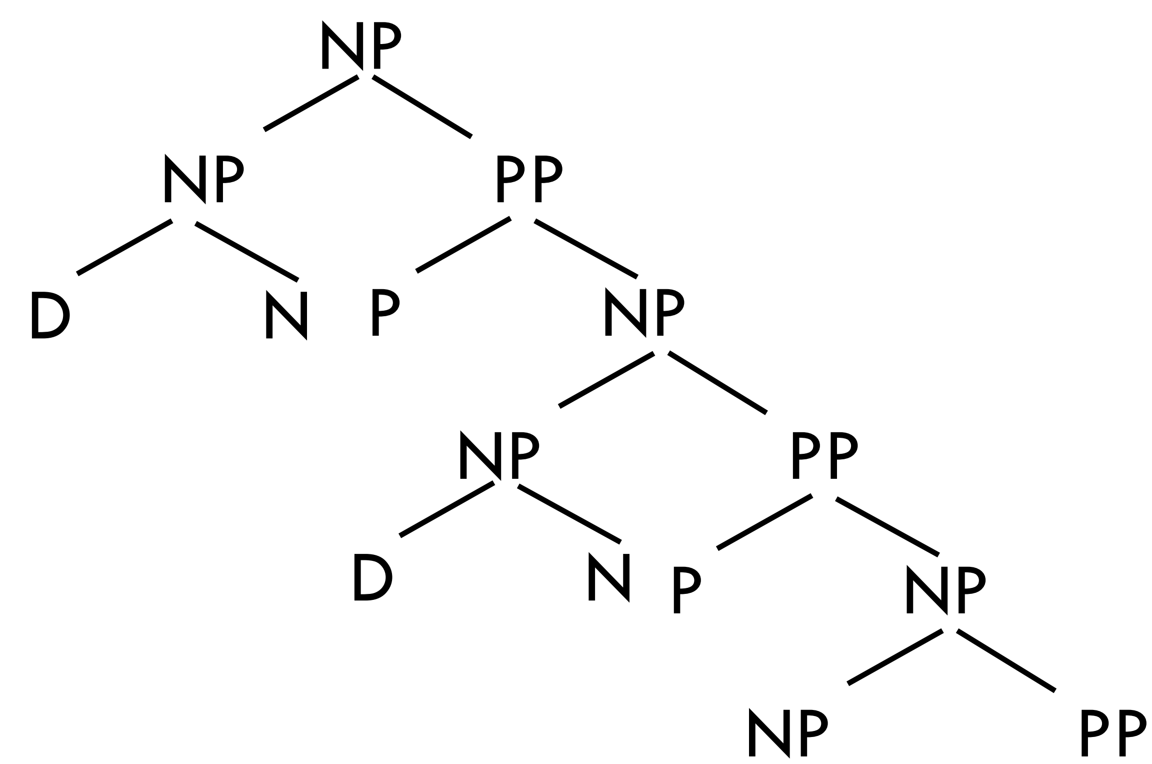
Derived String:

the student with the cat with NP

Recursion in CFGs

S $\rightarrow$ NP VP	V $\rightarrow$ saw
VP $\rightarrow$ V NP	P $\rightarrow$ with
VP $\rightarrow$ VP PP	D $\rightarrow$ the
PP $\rightarrow$ P NP	N $\rightarrow$ cat
NP $\rightarrow$ D N	N $\rightarrow$ tail
NP $\rightarrow$ NP PP	N $\rightarrow$ student

Parse Tree:



Derived String:

the student with the cat with NP PP

Recursion in CFGs

S $\rightarrow$ NP VP
VP $\rightarrow$ V NP
VP $\rightarrow$ VP PP
PP $\rightarrow$ P NP
NP $\rightarrow$ D N
NP $\rightarrow$ NP PP

V $\rightarrow$ saw
P $\rightarrow$ with
D $\rightarrow$ the
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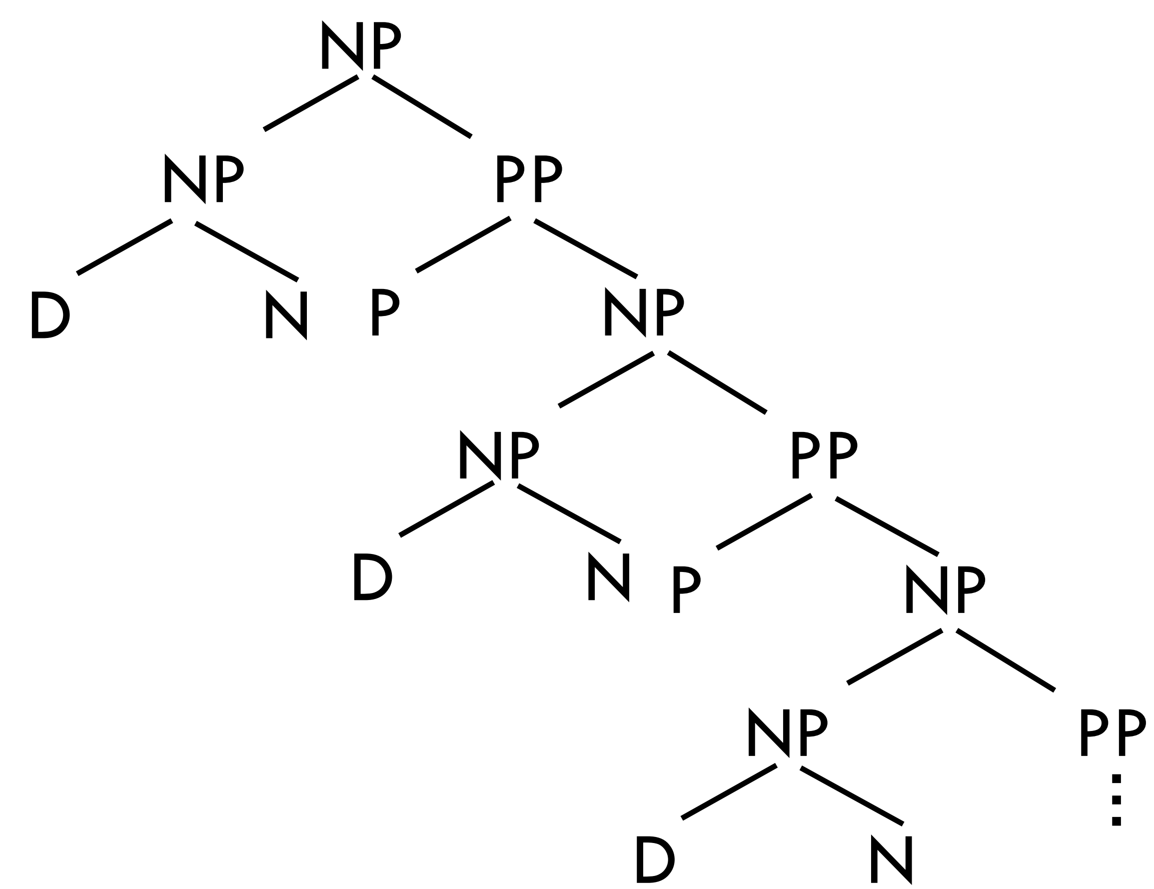
Parse Tree:



Derived String:

the student with the cat with the tail PP

Recursion in CFGs

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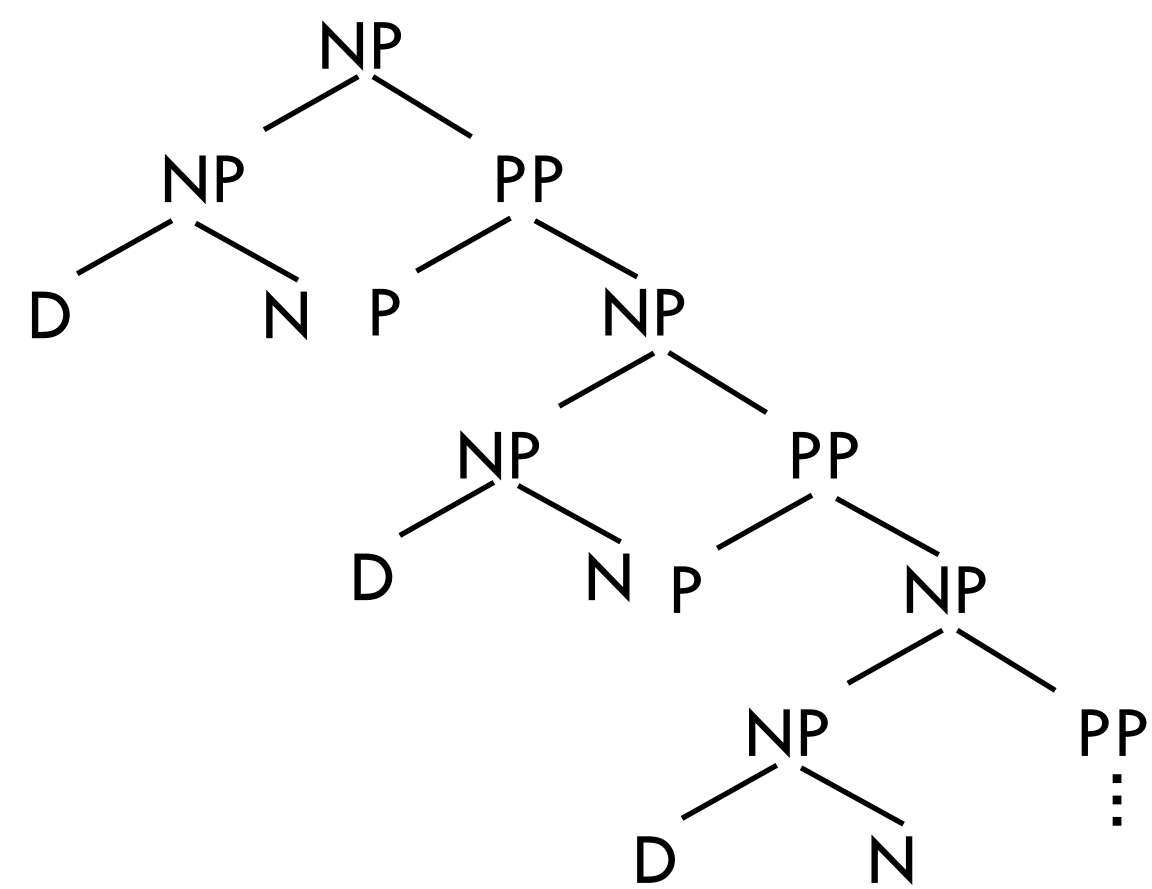
Parse Tree:



Derived String:

the student with the cat with the tail PP

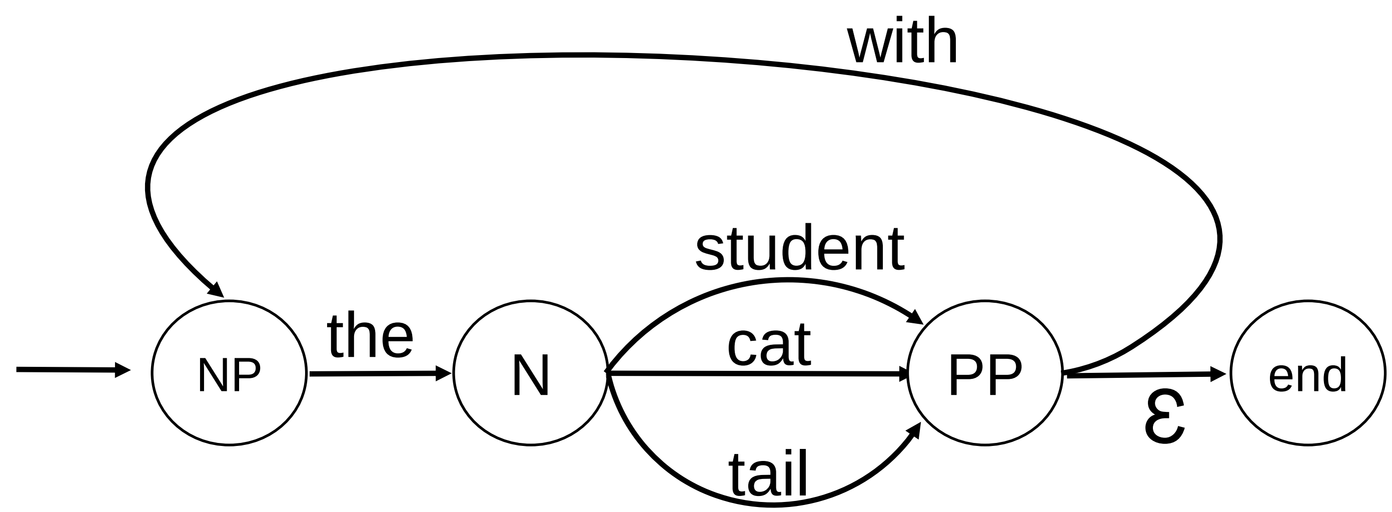
Regular Grammars

- A regular grammar is defined by:
  - Set of **terminal symbols** Σ.
  - Set of **non-terminal symbols** N.
  - A **start symbol** $S \in N$.
  - Set R of **productions** of the form $A \to aB$, or $A \to a$ where $A,B \in N$ and $a \in \Sigma$.

Finite State Automata

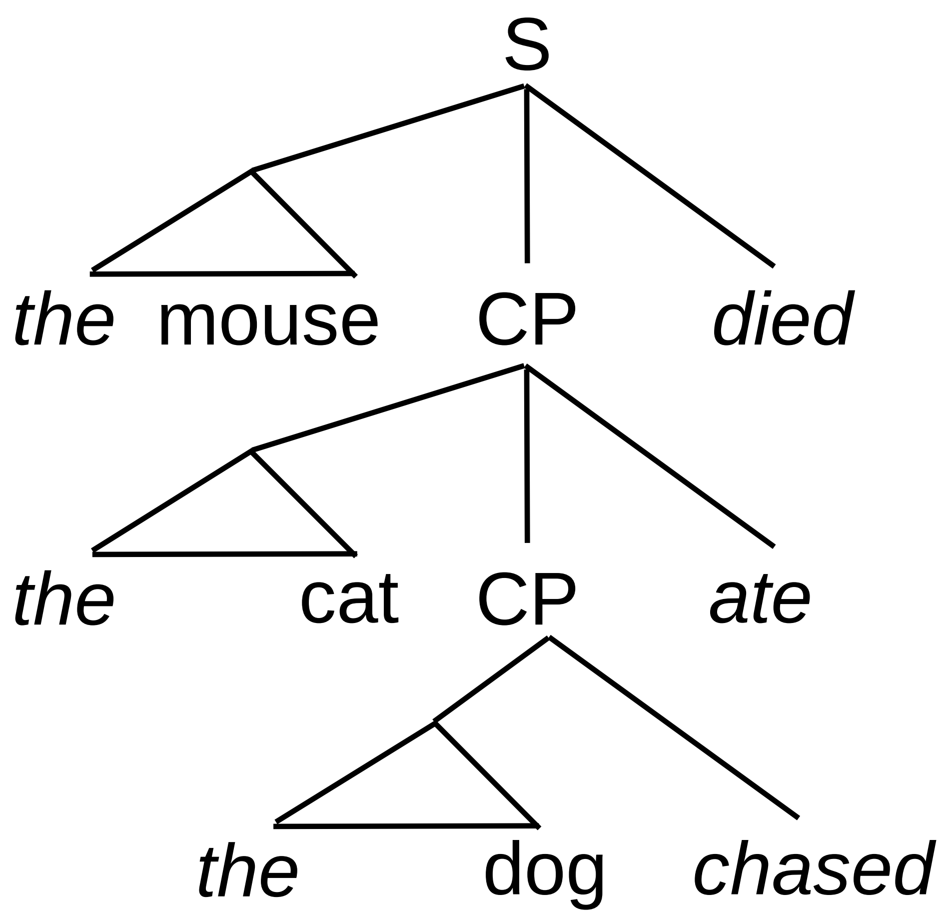
- Regular grammars can be implemented as finite state automata.

NP $\rightarrow$ the N
N $\rightarrow$ student PP
N $\rightarrow$ cat PP
N $\rightarrow$ tail PP
PP $\rightarrow$ with NP
PP $\rightarrow$ ε



- The set of all regular languages is strictly smaller than the set of context-free languages.

Center Embeddings



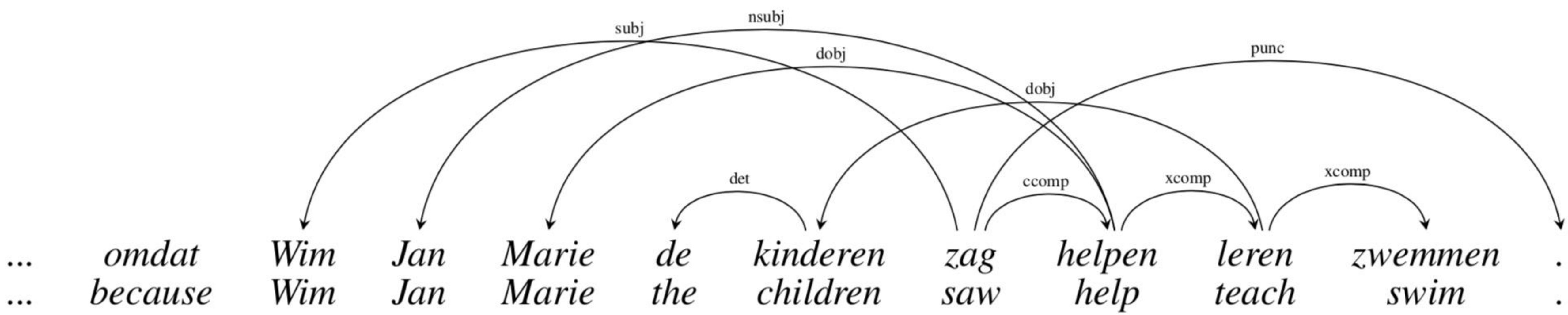
- Problem: Regular grammars cannot capture long-distance dependencies.

- This example follows the pattern $\mathbf{a^n b^n}$.
  Can show that is language is not regular (using the “pumping lemma”).

Linguistically, this is not a perfect analysis.

Is Natural Language Context Free?

- Probably not. An example from Dutch:



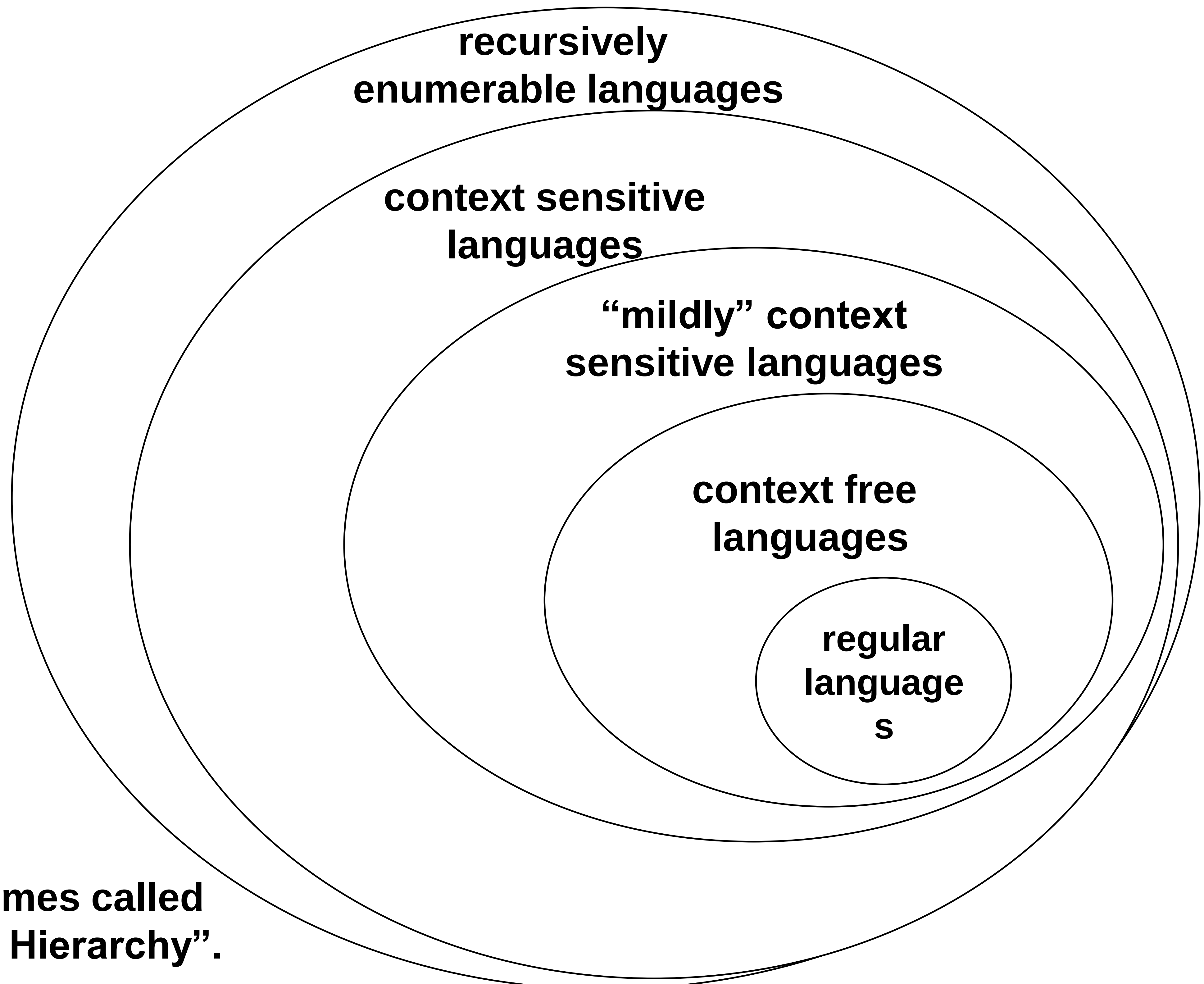
"…because Wim saw Jan help Marie teach the children to swim"

- Context Free Grammars cannot describe crossing dependencies. For example, it can be shown that

$$\mathbf{a^n b^m c^n d^m}$$

is not a context free language.

Complexity Classes



This is sometimes called the "Chomsky Hierarchy".

Formal Grammar and Parsing

- Formal Grammars are used in linguistics, NLP, programming languages.
- We want to build a compact model that describes a complete language.
- Need efficient algorithms to determine if a sentence is in the language or not **(recognition problem)**.
- We also want to recover the structure imposed by the grammar (**parsing problem**).

Acknowledgments

- Some slides by Kathy McKeown and Owen Rambow.