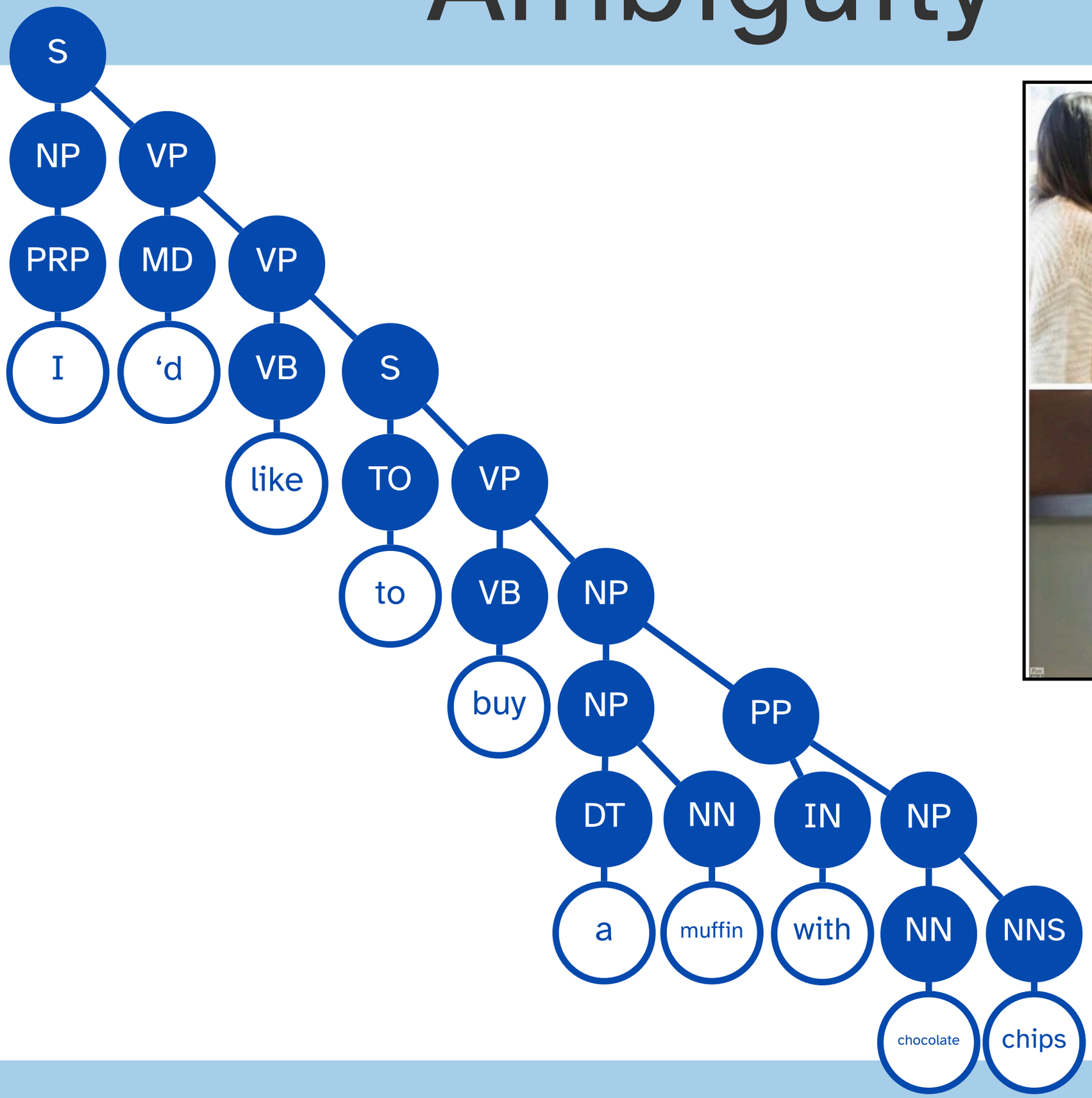
Linguistics: Syntax

EECS 183/283a: Natural Language Processing

Today

- Challenges for language modeling
  - Ambiguity
  - Grammaticality
- Formal languages
- Structures underlying natural language

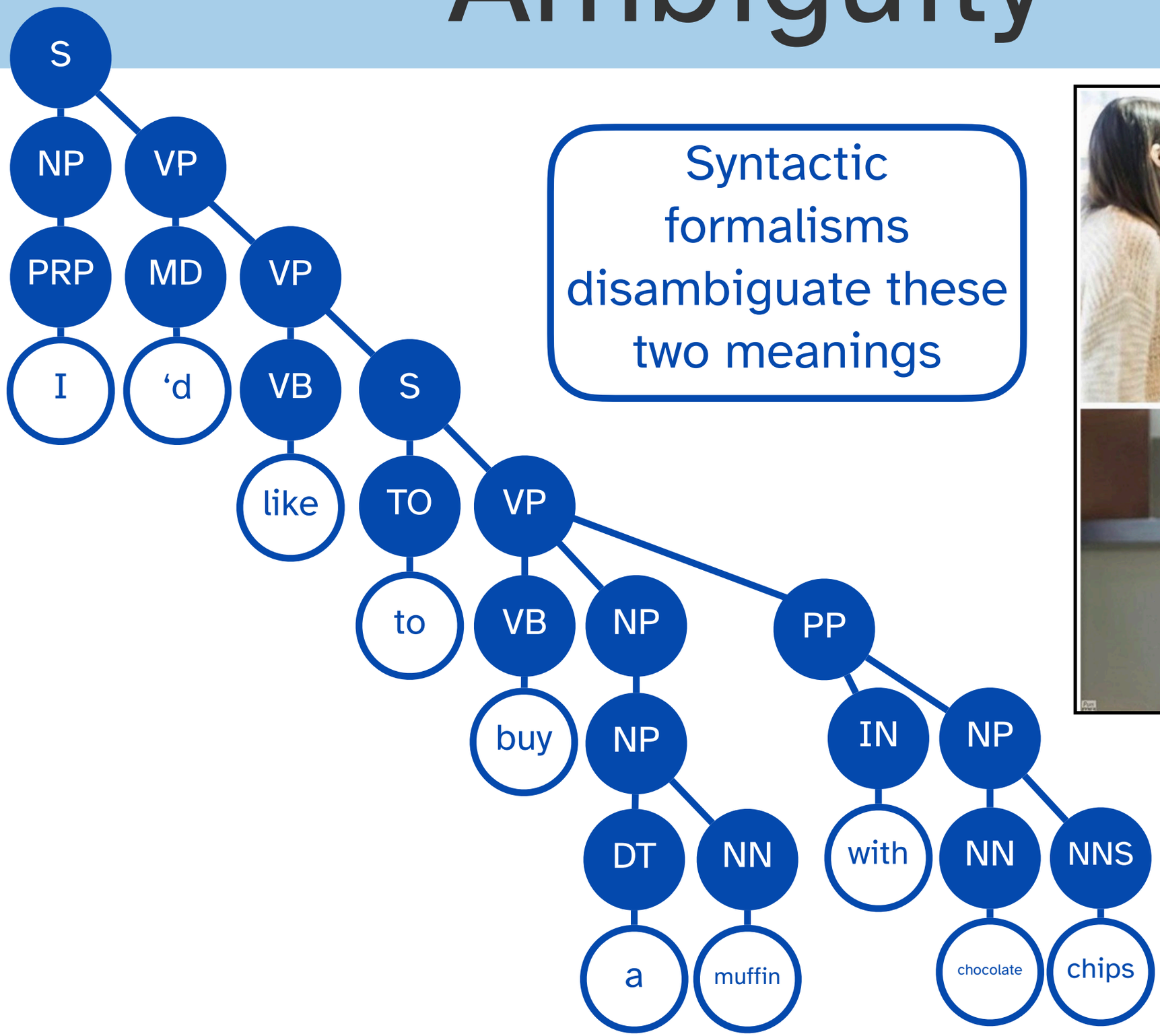
Ambiguity



example from Yoav Artzi

Preview: constituency parsing

Ambiguity



Syntactic formalisms disambiguate these two meanings

example from Yoav Artzi

Preview: constituency parsing

Grammaticality

- Does a sentence sound “right” according to a native speaker?

- Grammaticality judgments are not universal!
  - No such thing as “bad grammar” — disagreements over what feels grammatical or not are due to language variation
  - Grammatical sentences don’t need to be meaningful

Colorless green ideas sleep furiously

Chomsky 1957

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*Colorless green ideas sleep**s** furiously*

Chomsky 1957

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Green colorless *ideas sleep furiously*

Chomsky 1957

Grammaticality

- Why might something sound grammatical or not?
- Our main task: we have some language L, and we want to know whether a new sentence $x \in L$
- Should we represent L as a finite-sized set of possible sentences?
- What about a regular expression?

Regular Expressions

- Recall: (simplified) English syllable structure (C3)V(C4), with two types of sounds:
  - Consonants C: {p,b,t,d,k,g,m,n,ŋ,f,v,θ,ð,s,z,ʃ,ʒ,h,ɹ,l,j,w}
  - Vowels V: {i,u,ɛ,æ,ɪ,ɑ,ə,ʊ,ɔ,aɪ,oʊ,eɪ}
    - Allows us to generate “unattested” but still “accepted” syllables: θɹaɪm, skɹoʊp, fɹɪŋk
- Can syntax also be described with regular expressions?
  - How about {DET}{ADJ}*{NOUN}?

the agreement *an ill proposal* *a tiresome merciful teacher*

Regular Expressions

The cat that thinks the cow thinks
the rabbits hid are wrong. ✗

The rabbits hid.
DT N VB

Regex:

DT N VB

The cow thinks the rabbits hid.
DT N VB DT N VB (DT N VB)*

The cat that thinks the cow thinks the rabbits hid is wrong.
DT N IN VB DT N VB DT N VB VB JJ

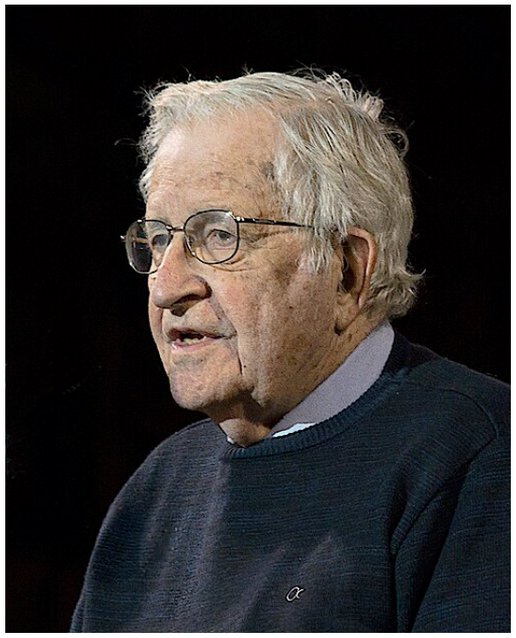
DT N IN (DT N VB)* VB JJ?

Is there another formalism that tells us whether
a string is “accepted” in a language or not?

Context-Free Grammars

- CFGs offer arbitrary expressivity through recursive structure

- You might have seen these before in programming languages classes — basically, most programming languages are CFGs



Σ, Wikpiedia

- CFGs were actually first described formally by Noam Chomsky (b. 1928), but the recursive structure of natural language was described by many linguists, including Pāṇini (~1-5th century BCE)

Context-Free Grammars

- Set of nonterminal symbols
- Set of terminal symbols (wordtypes)
- Set of production rules defining how nonterminal symbols could be expressed via the composition of other nonterminal and terminal symbols

Nonterminal symbols

DT N VB JJ IN

S NP VP SBAR

Terminal symbols (vocabulary)

are, cat, cow, hid, is, rabbits, that, the, thinks, wrong, ...

Production rules

DT → {*the, a, an, ...*}

N → {*cat, cow, rabbits, dogs, ...*}

VB → {*hid, is, thinks, was, are, ...*}

JJ → {*wrong, right, blue, red, ...*}

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NP → {DT N, NP IN VP}

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The cat that thinks the cow thinks the rabbits hid is wrong.
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Context-Free Grammars

The cat	that	thinks	the cow	thinks	the rabbits	hid	is	wrong.
DT N	IN	VB	DT N	VB	DT N	VB	VB	JJ
NP			**NP**		**NP**			

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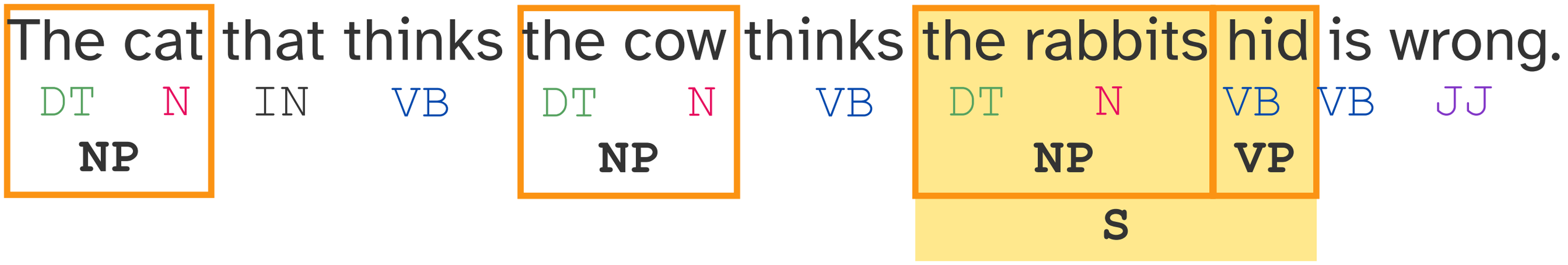

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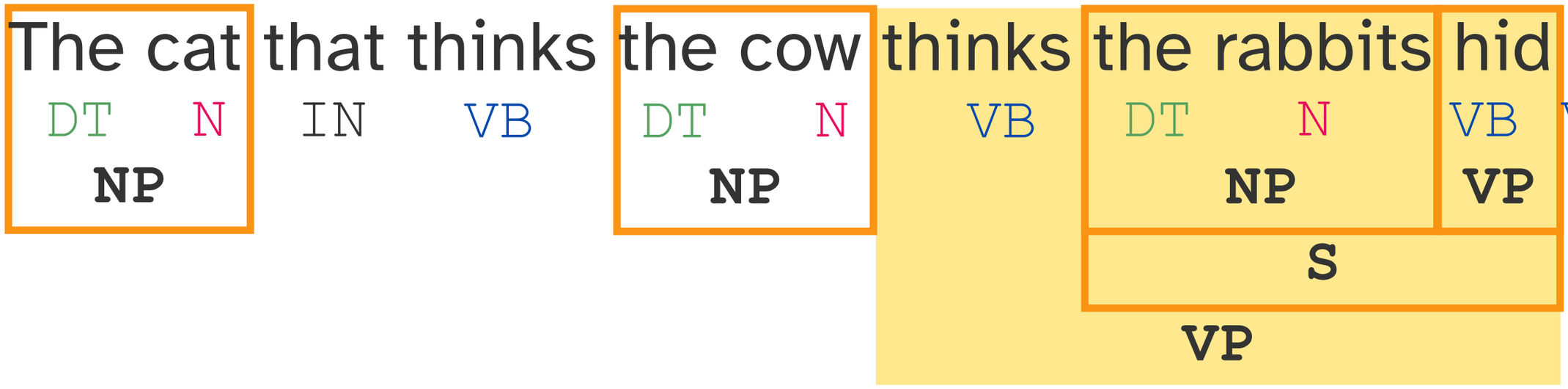

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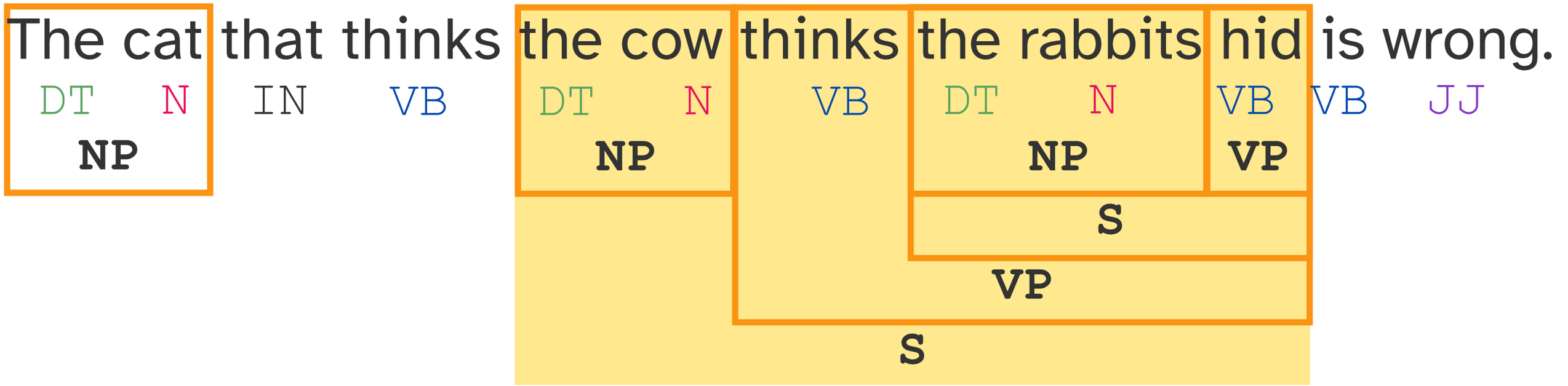

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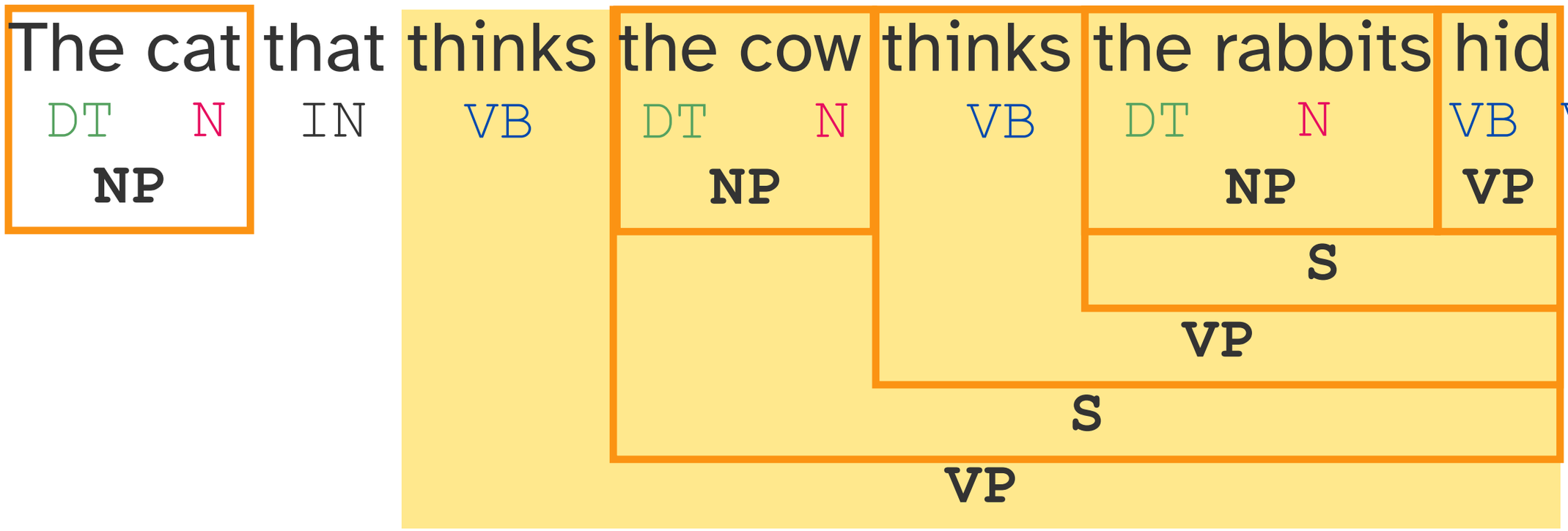

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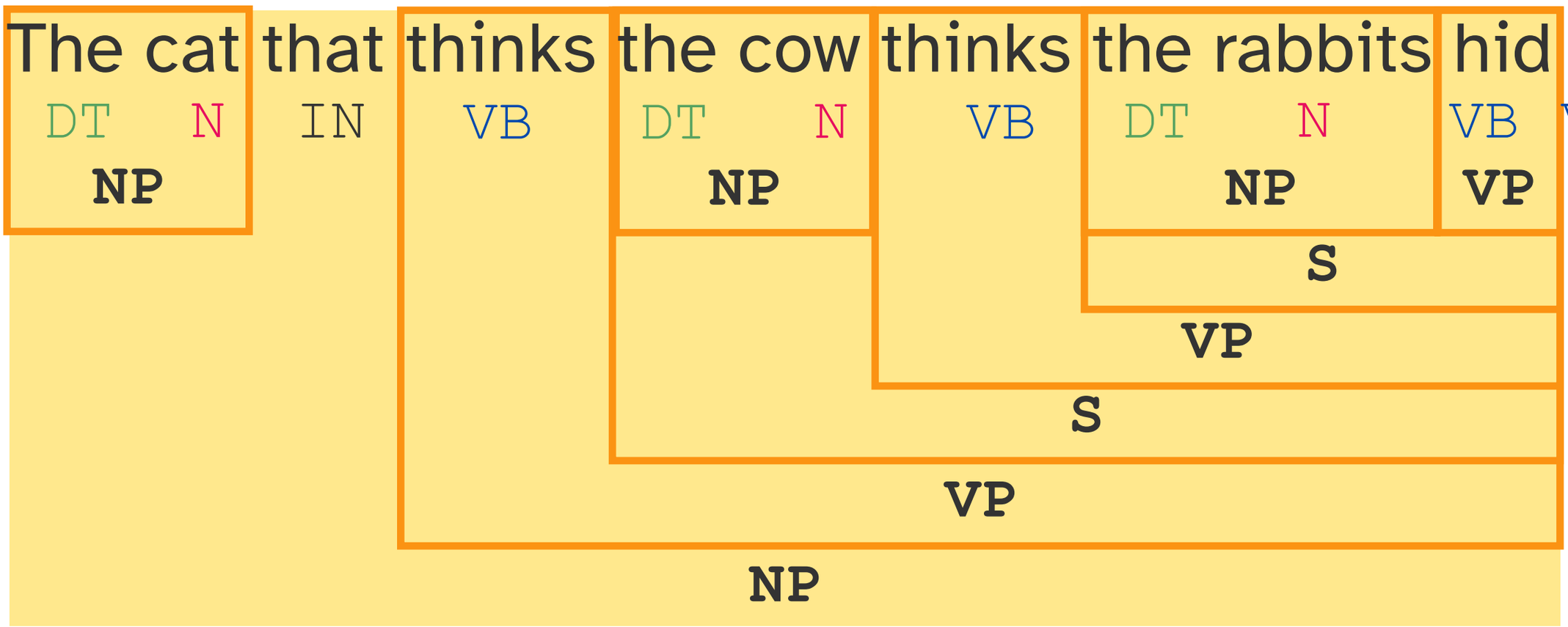

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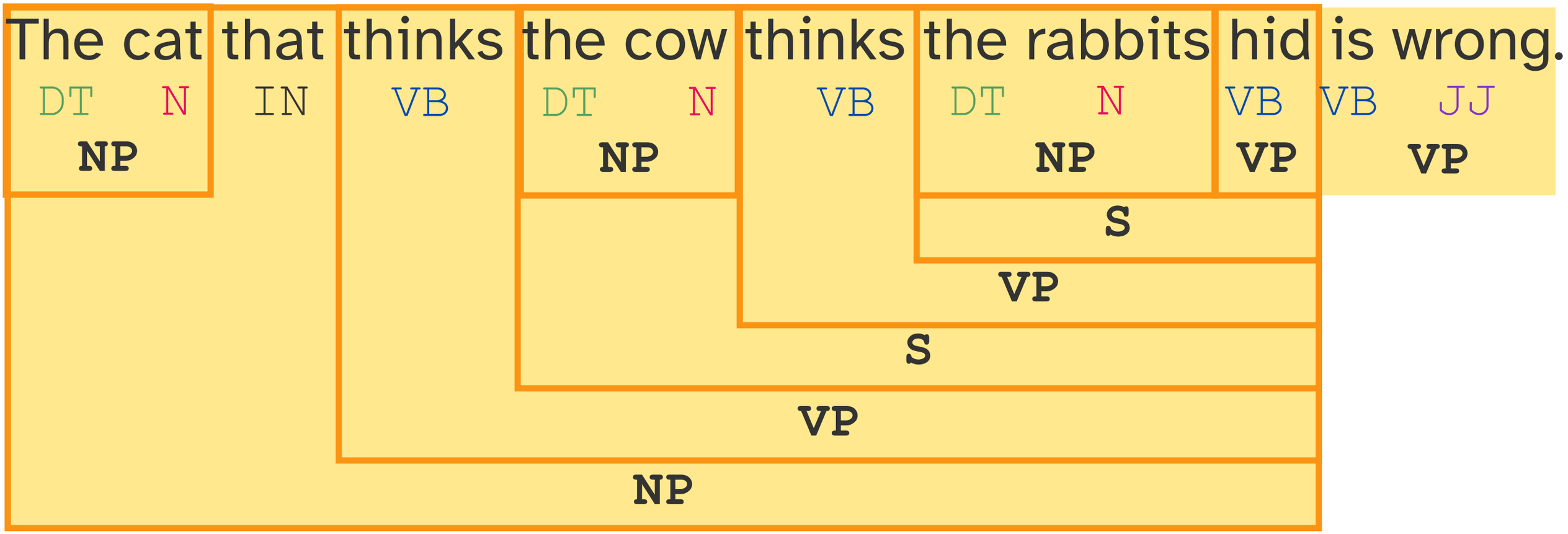

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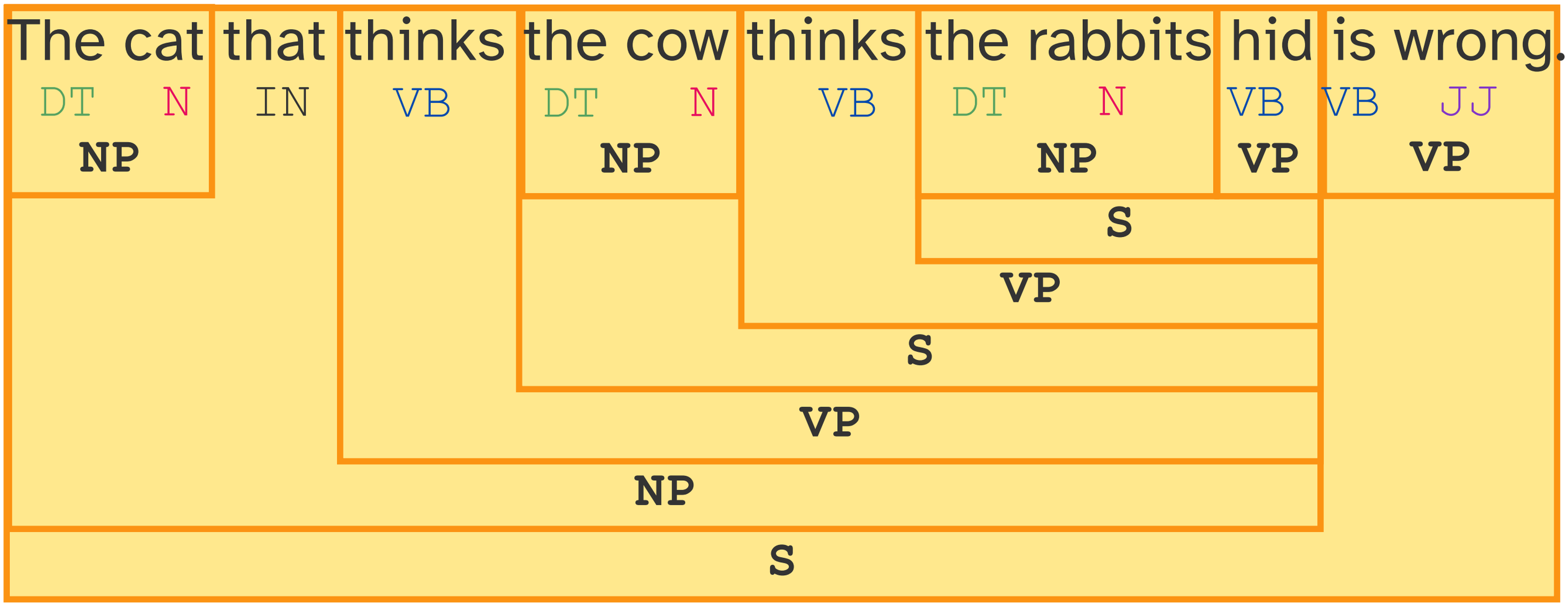

NP is singular, so its corresponding VP should be too

Nonterminal symbols

DT N VB JJ IN

S NP VP

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Generating from a Grammar

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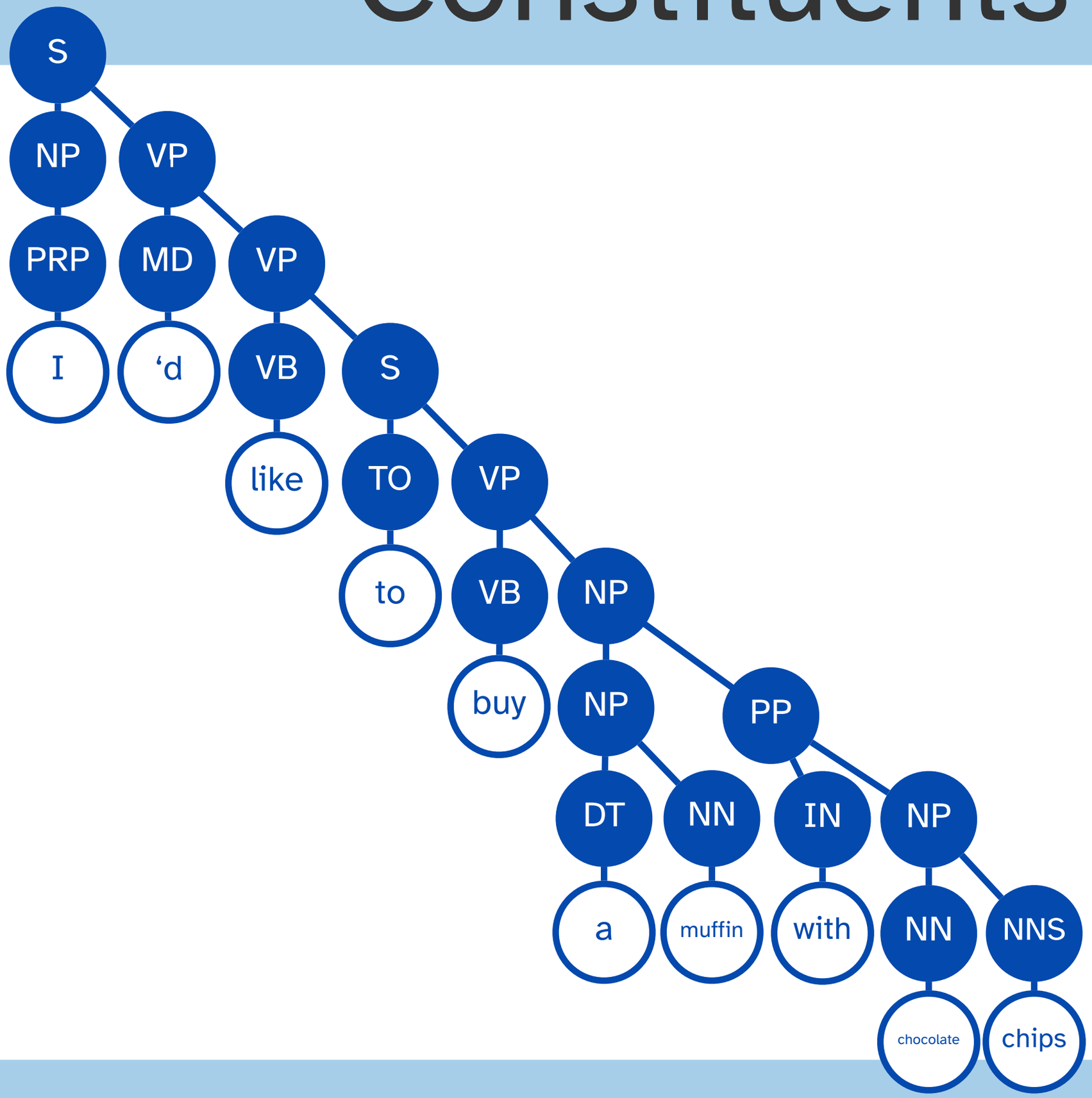
Constituents



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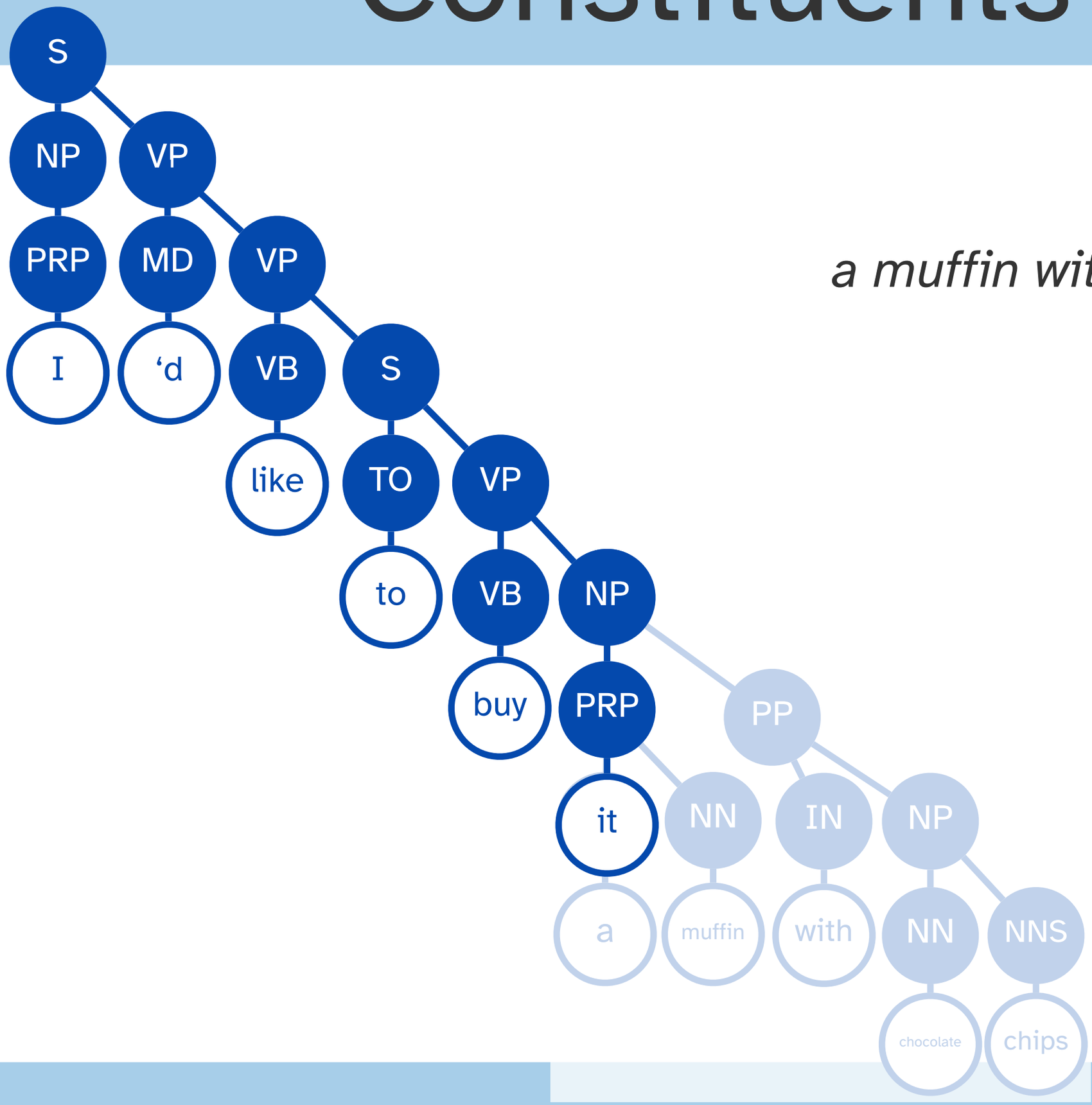
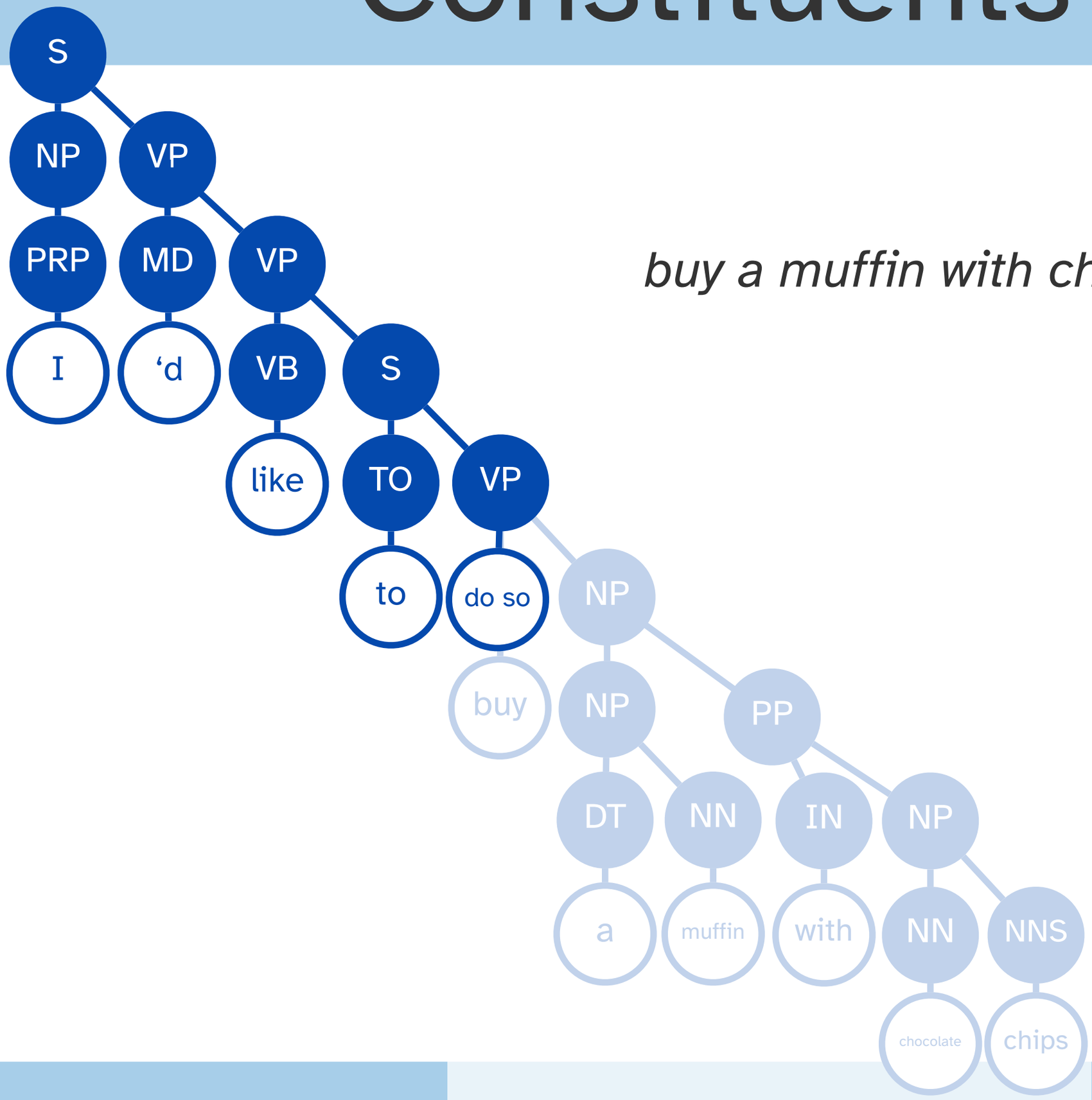


Substitution:

NP → NP PP **or** PRP

a muffin with chocolate chips → *it*

Constituents

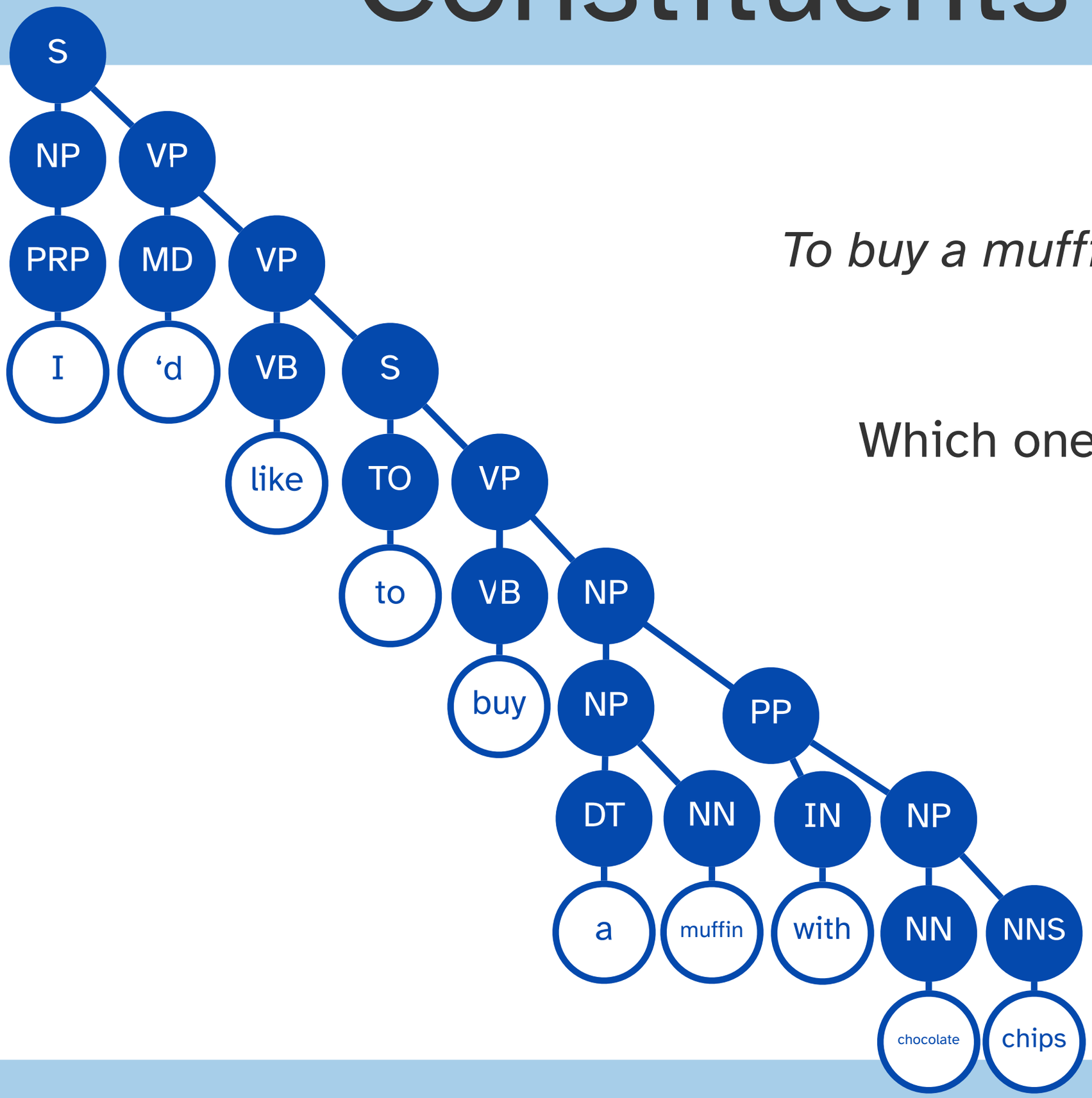


Substitution:

VP → *do so*

buy a muffin with chocolate chips → *do so*

Constituents

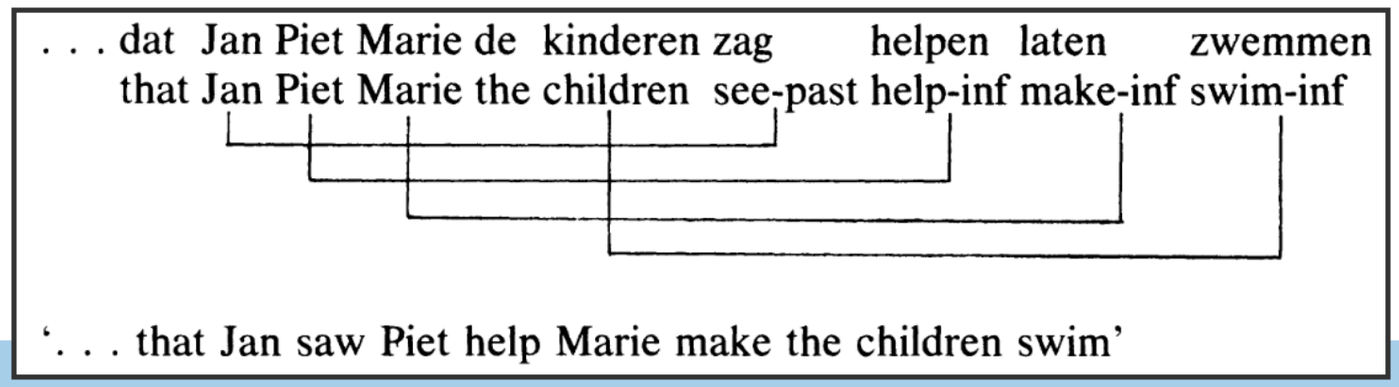


Answer ellipsis:
What would I like?
To buy a muffin with chocolate chips

Which one would you like to buy?
With chocolate chips

Constituents

- CFG is often called phrase structure or constituency grammar
- Each production rule describes a **constituent**
- Constituent constructions are independent of one another (this is why the grammar is context-free)
- Augmenting a CFG with agreement (e.g., distinguishing plural vs. singular NPs and plural vs. singular VPs plural) means it is no longer context-free
- Also, some languages aren't even context-free, not even considering agreement:



Kaplan et al. 1982

Probabilistic CFG

Production rules

augmented with probabilities

DT → {*the*, *a*, *an*, …} 0.5 0.2 0.2

N → {*cat*, *cow*, *rabbits*, *dogs*, …} 0.02 0.01 0.01 0.02

VB → {*hid*, *is*, *thinks*, *was*, *are*, …} 0.01 0.5 0.05 0.3 0.2

JJ → {*wrong*, *right*, *blue*, *red*, …} 0.05 0.1 0.05 0.05

IN → {*that*, *in*, *of*, *because*, …} 0.4 0.3 0.2 0.05

NP → {DT N, NP IN VP, …} 0.8 0.1

VP → {VB, VB JJ, VB S, …} 0.3 0.2 0.1

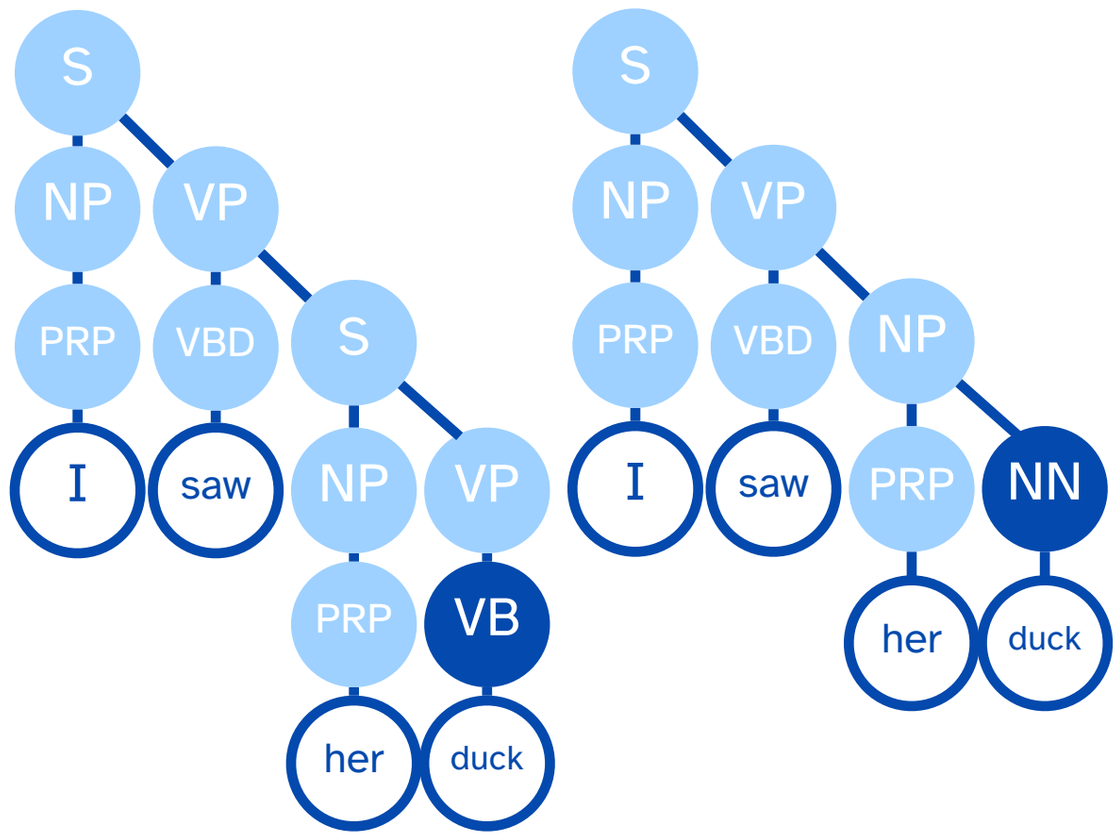
S → {NP VP, VP, …} 0.7 0.05

$$p(\text{rule}|\text{nonterminal})$$

learn from data

syntactic parsing: given a PCFG, which rule applications generated our sentence?

Why is this hard?



Combinatory Categorial Grammar (CCG)

- Another way of representing a constituency grammar: bottom-up

- Elements of a CCG:
  - Lexical items (wordtypes)
  - Each paired with a syntactic type (≈ nonterminal or composition thereof)

$\text{the} : NP/N$	$\text{dog} : N$	$\text{John} : NP$	$\text{bit} : (S\backslash NP)/NP$
If a Noun appears to the right, then it creates a Noun Phrase	Noun	Noun Phrase	If a Noun Phrase appears to the right, then it creates an element with the type S \ NP
NP → DT N DT → *the*	N → *dog*	NP → PRO PRO → *John*	If an NP appears to the left of that element, it creates a Sentence

Example from Wikipedia

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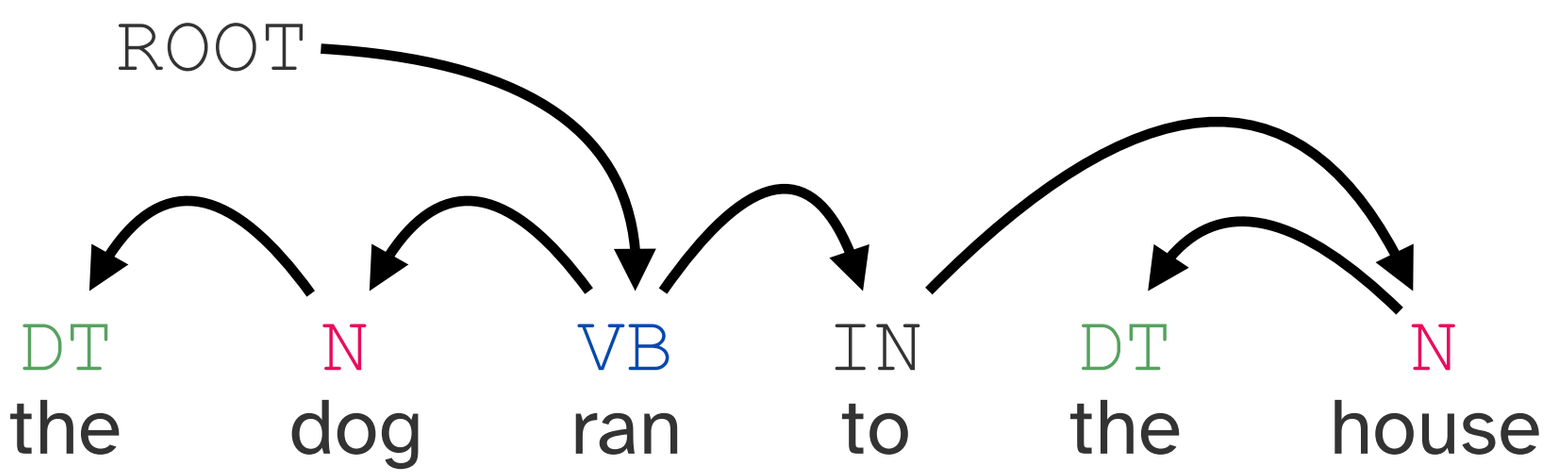
the : NP/N	dog : N	John : NP	bit : $(S\backslash NP)/NP$
the	dog	bit	John

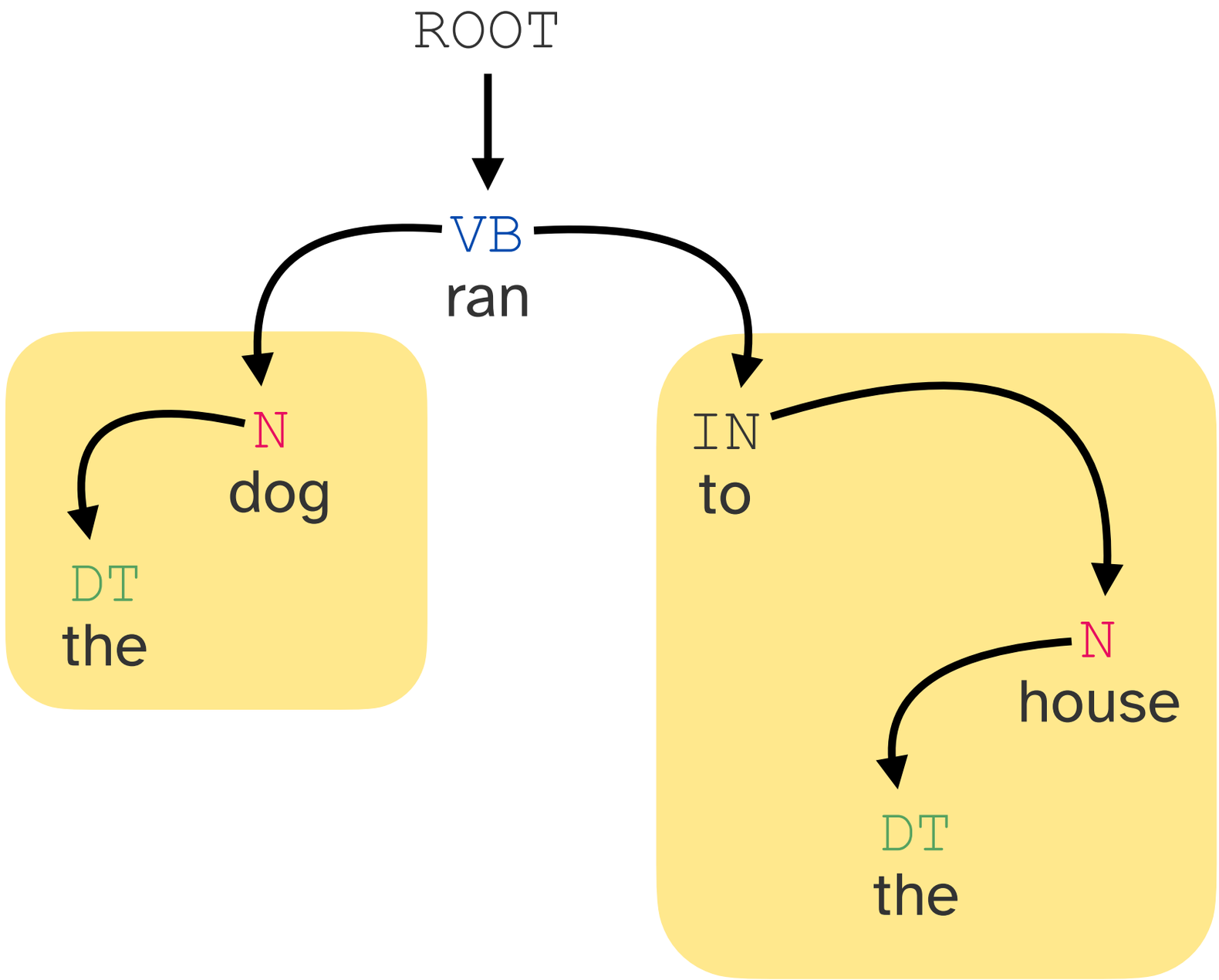
Example from Wikipedia

Dependency Grammar

- A dependency grammar includes:
  - Terminal symbols (wordtypes)
  - Parts of speech
  - Some constraints on which parts of speech can be attached to other parts of speech



Dependency Grammar



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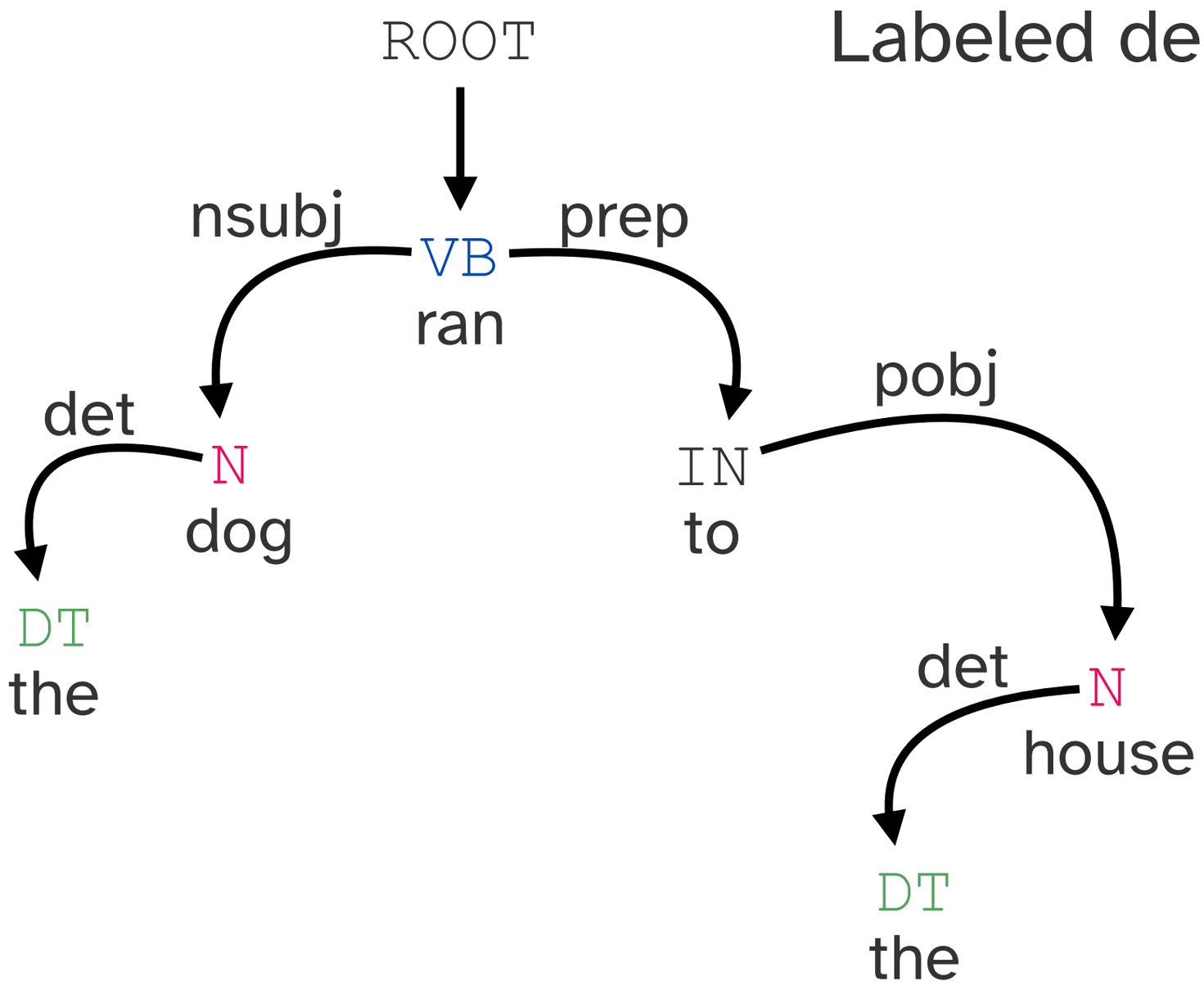
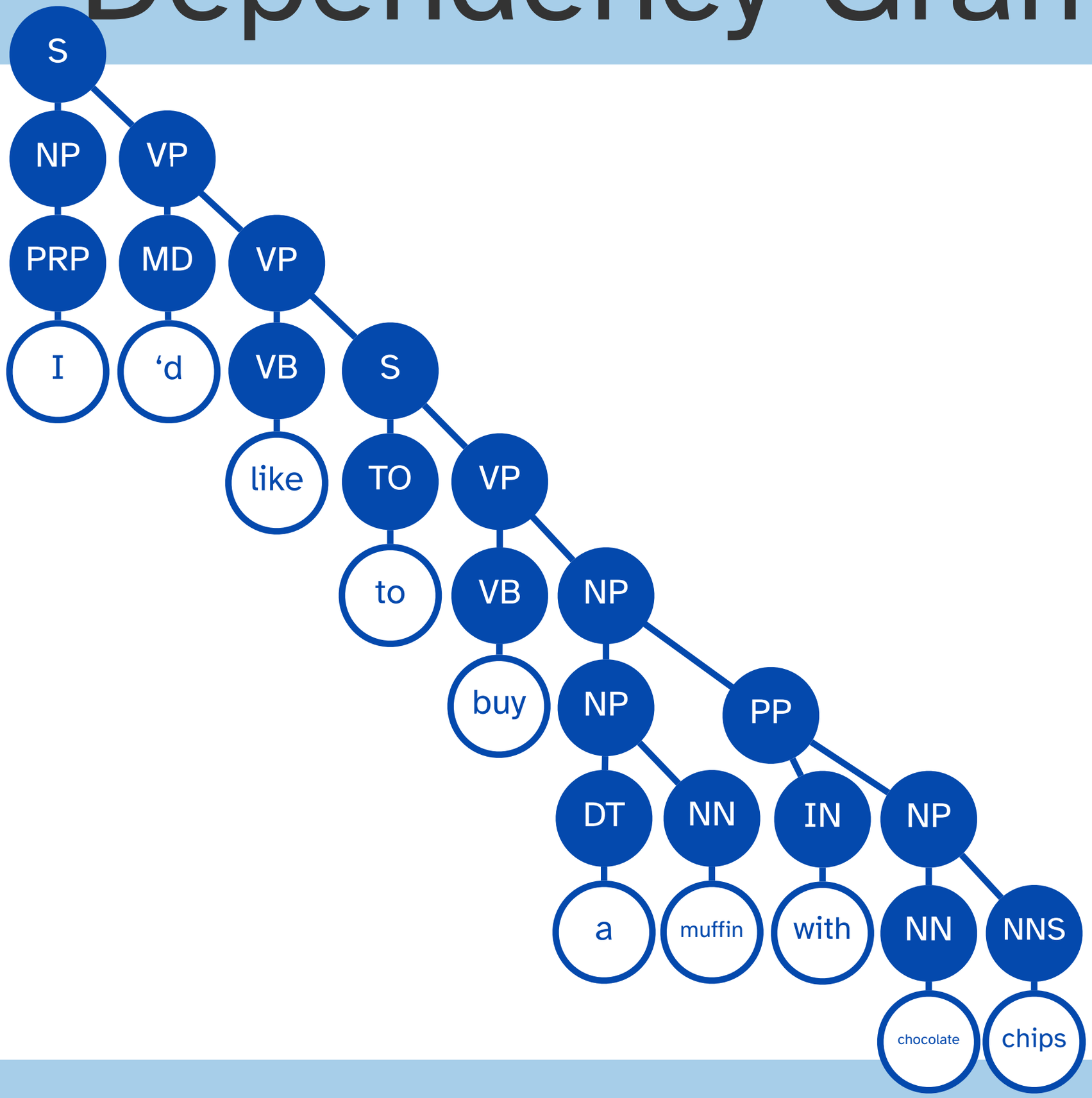


Labeled dependencies

Dependency Grammar



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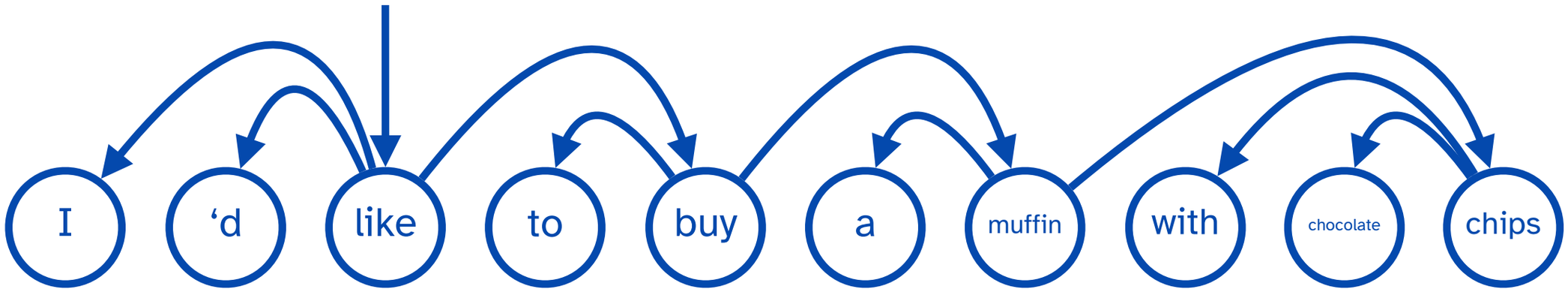

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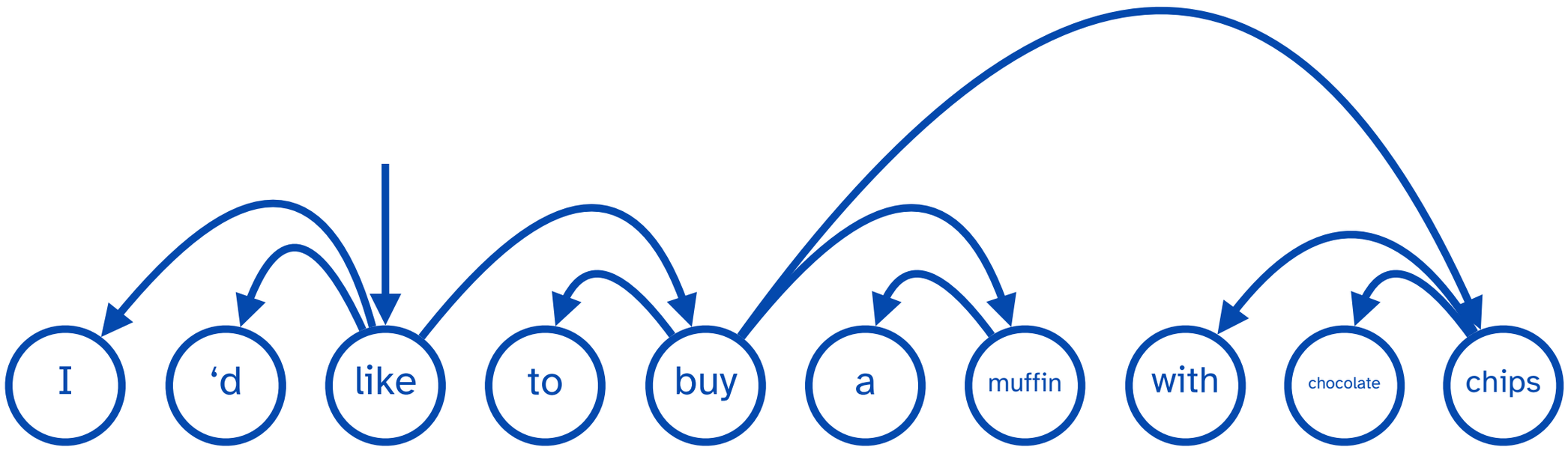


Universal Dependencies

Huge resource of grammar annotations across ~150 languages

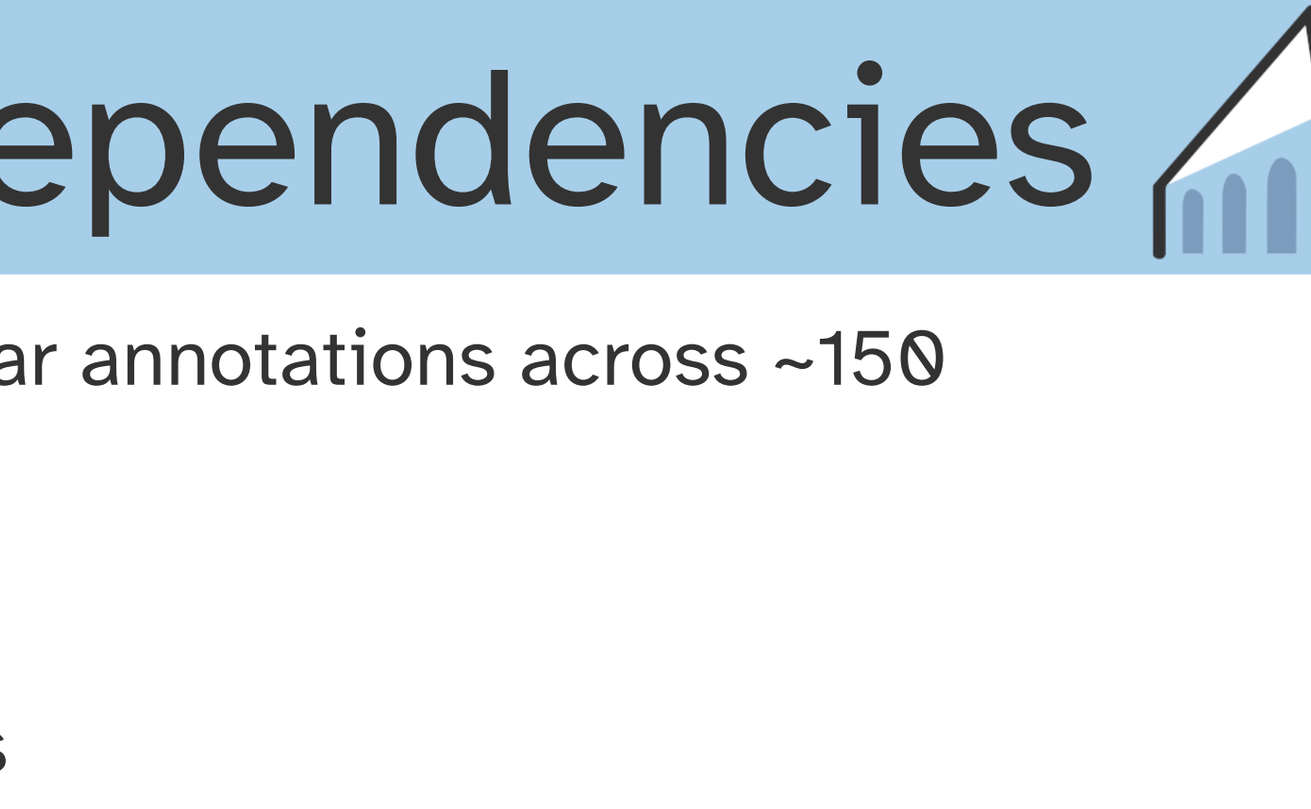
- Parts of speech
- Morphological features
- Syntactic dependency parses

English

Bulgarian

Czech

Swedish



https://universaldependencies.org/