Syntax and formal grammars

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What is syntax?

- **Syntax** is the branch of linguistics that studies the **structural properties of sentences**
  - It does not study the structural properties of **wordforms**, which are by definition the **atoms of syntax**
  - It does not directly study the consequence of the semantic properties of word(form)s, but it studies how such properties are dealt with in syntax
  - Syntax is heavily **language-dependent**
  - Syntax is heavily "**lexicalised**"

Syntax and NLP

- In NLP, **syntax** is at the crossroads between:
  - **syntax** *per se*, i.e. the branch of linguistic that studies syntax:
    what structures do we need to represent?
    - introspection
    - corpus studies
    - psycholinguistics / neurolinguistics
  - **formal grammars**, a branch of theoretical computer science:
    what formal devices do we need to represent such structures?
  - **language resources:**
    - syntactically annotated corpora, a.k.a. **treebanks**:
      can we build collections of sentences annotated with syntactic structures?
    - **syntactic lexicons**:
      can we describe the syntactic properties of wordforms/lexemes?

Parsing

- To build the syntactic structure of a sentence = to **parse** the sentence
- If syntactic structures are represented in the form of a tree, the syntactic structure of a sentence = its **parse tree**
- Producing the parse of a sentence = **parsing**
- "Parsing" can be used in more complex terms (e.g. semantic parsing)
  - By default, parsing = syntactic parsing
- A computer program for parsing is called a **parser**

- **Parsing** is a key step towards the computational exploitation of a sentence or a text. Most NLP tasks rely on or benefit from parsing, although it is not always easy to do so.

- **Parsing will be the topic of the next class** (and of today's assignment)

Syntactic structures

Structures in trees

- **Grammatical** sentences:
  - *the boy likes a girl*
  - *the small girl likes the big girl*
  - *a very small nice boy sees a very nice boy*
- **Ungrammatical** sentences:
  - **the boy the girl*
  - **small boy likes nice girl*
- Can we find a way of distinguishing the two kinds of sequences?
- Can we identify similarities among grammatical subsequences?

A first version of constituent structure

- Underlying idea: sequences of words belonging together form **constituents**
- Grammatical sentences:
  - *(the) boy (likes a girl)*
  - *(the small) girl (likes the big girl)*
  - *(a very small nice) boy (sees a very nice boy)*
- Ungrammatical sentences:
  - **(the) boy (the girl)*
  - **(small) boy (likes nice girl)*

A second version of constituent structure

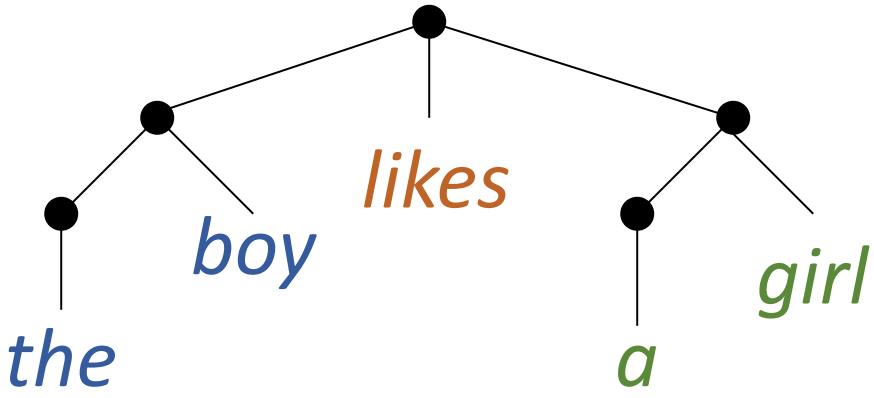
- Underlying idea: sequences of words belonging together form **constituents**
- Grammatical sentences:
  - *(the boy) likes (a girl)*
  - *(the small girl) likes (the big girl)*
  - *(a very small nice boy) sees (a very nice boy)*
- Ungrammatical sentences:
  - **(the boy) (the girl)*
  - **(small boy) likes (nice girl)*
- Intuition: this version is better because it uses fewer types of constituents (blue and green are of same type)

More stuctures

- Underlying idea: sequences of words belonging together form **constituents**, in a **hierarchical** way
- Grammatical sentences:
  - *((the) boy) likes ((a) girl)*
  - *((the) (small) girl) likes ((the) (big) girl)*
  - *((a) ((very) small) (nice) boy) sees ((a) ((very) nice) boy)*
- Ungrammatical sentences:
  - **((the) boy) ((the) girl)*
  - **((small) boy) likes ((nice) girl)*

Constituency trees: a first attempt

- *((the) boy) likes ((a) girl)*



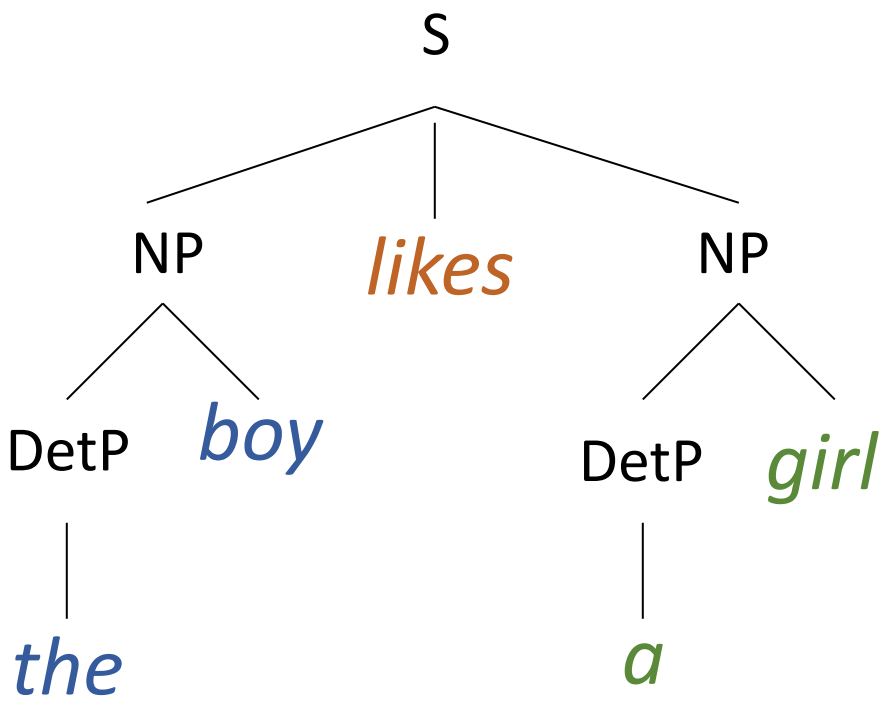
How do we label the nodes?

- *(((the) boy) likes ((a) girl))*

- Build constituents so each one has exactly one non-bracketed word, called its **head**
- Cluster constituents and word(form)s in a consistent way: words within the same cluster should head similar constituents
  - Wordform cluster = its **syntactic category**, or **part-of-speech (PoS)**
    - e.g. N(oun), V(erb), ADV(erb), ADJ(ective), DET(erminer), PREP(osition)…
  - Constituent type = XP(hrase), where X = PoS of its head
    - e.g. NP = noun phrase, AdjP = adjectival phrase…

Constituency trees: a first attempt

- *((the/DET) boy/N) likes/V ((a/DET) girl/N)*

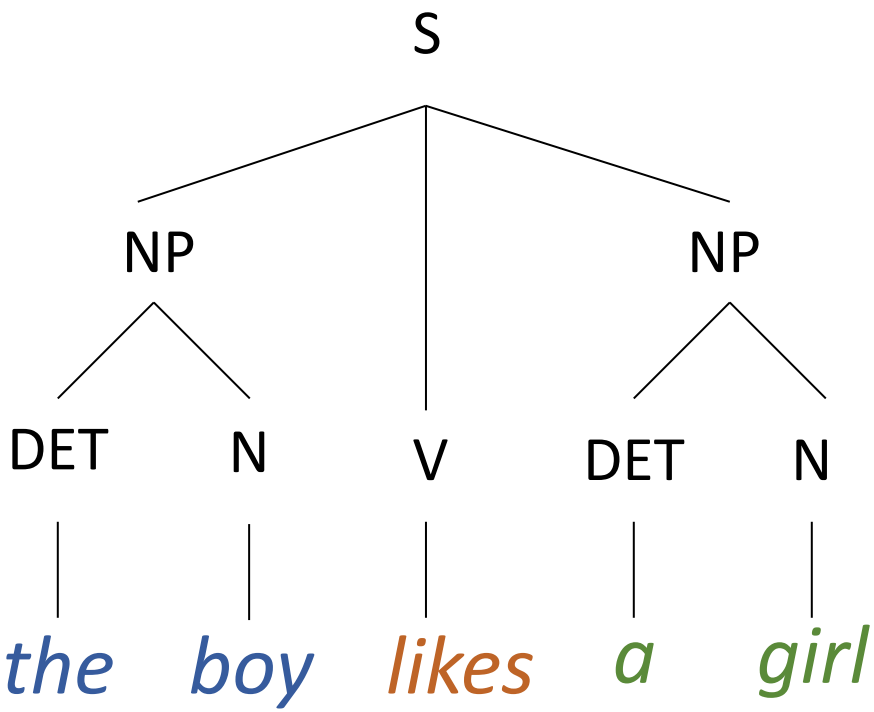


Constituency trees

- The “1 non-bracketed wordform per constituent” constraint is not applicable in practice
- The perfect symmetry between PoS and constituent types is a linguistic decision, not shared by everyone
  - We do not want to limit ourselves to one particular type of linguistic theory regarding syntax.
- It is useful and therefore common practice to insert **PoS as immediate ancestors of leaf nodes** (i.e. wordforms)
- We temporarily lose the notion of constituent head
  - It will come back in a few slides

Constituency trees: a second attempt

- *(S (NP (DET the) (N boy)) (V likes) (NP (DET a) (N girl)))*



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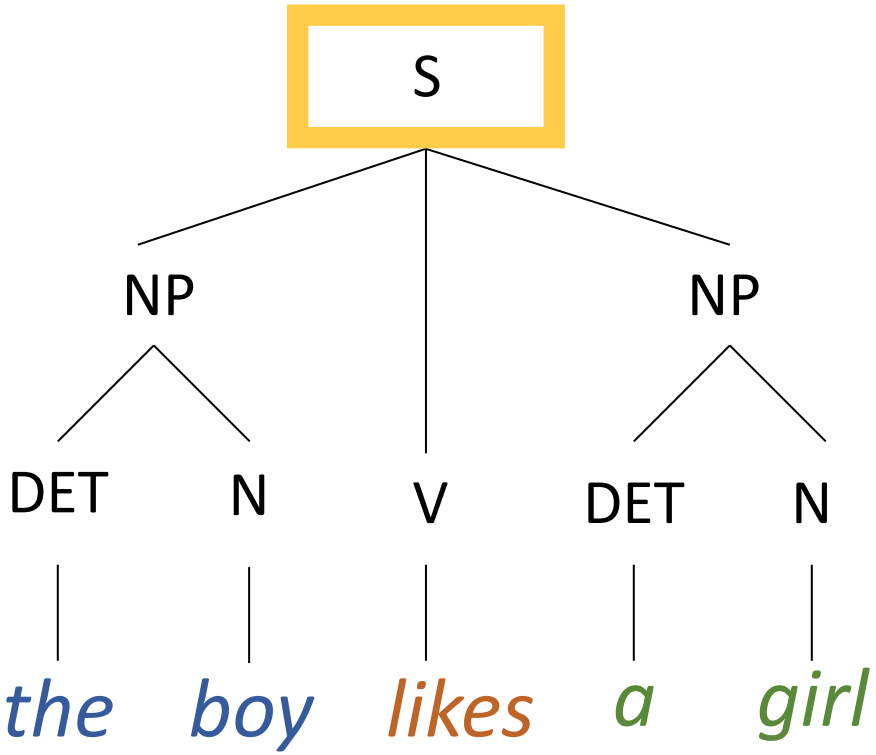
Root of the tree



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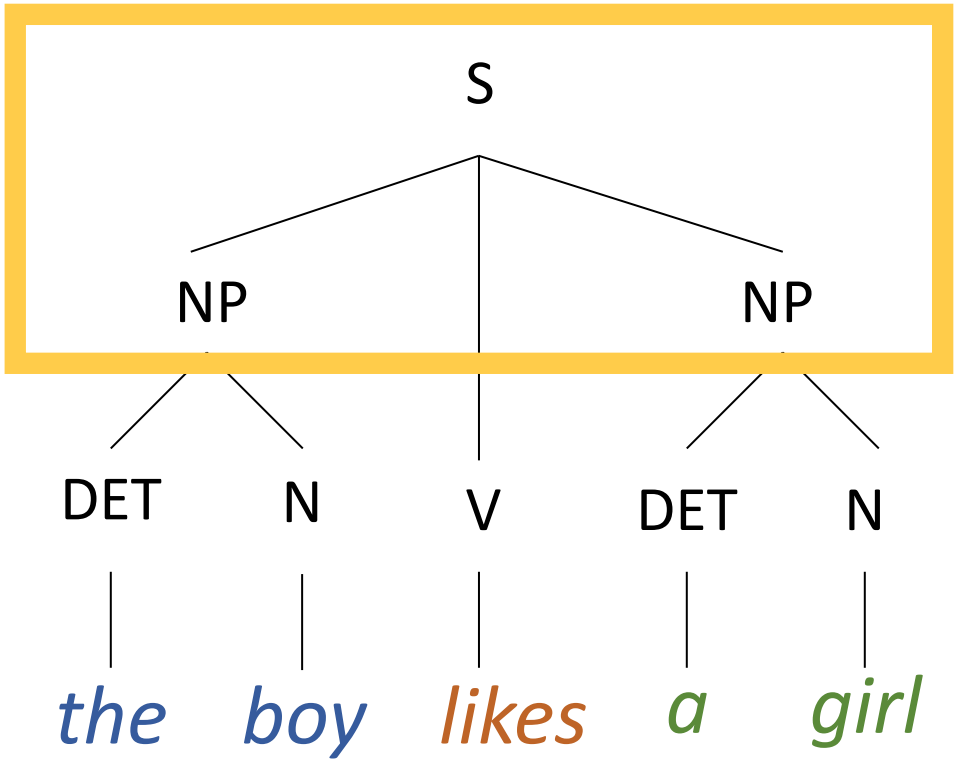
Non-terminal symbols



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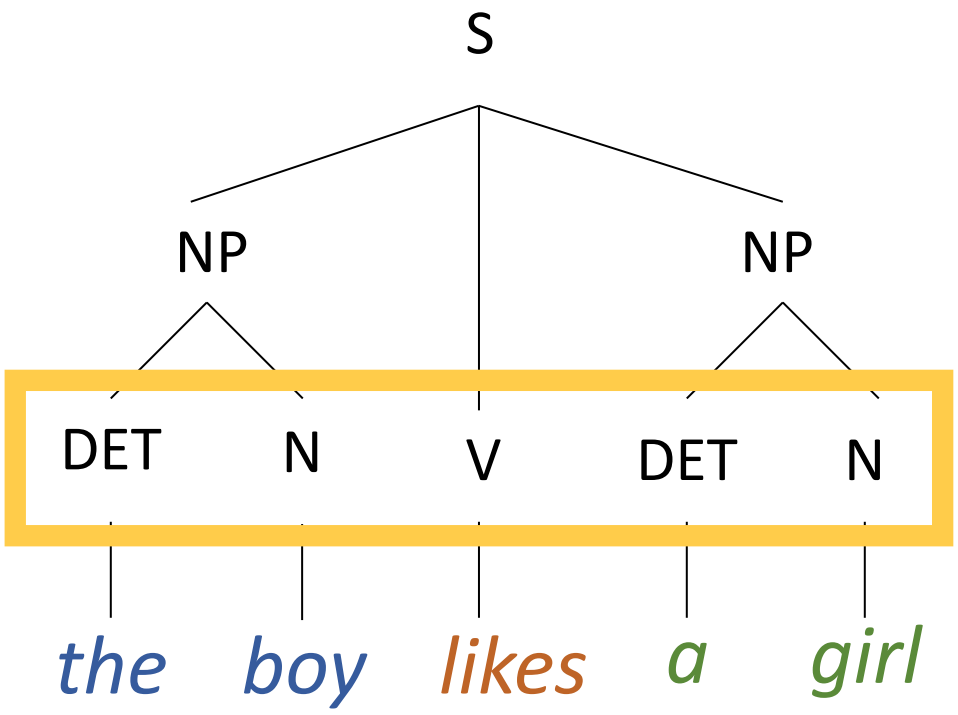

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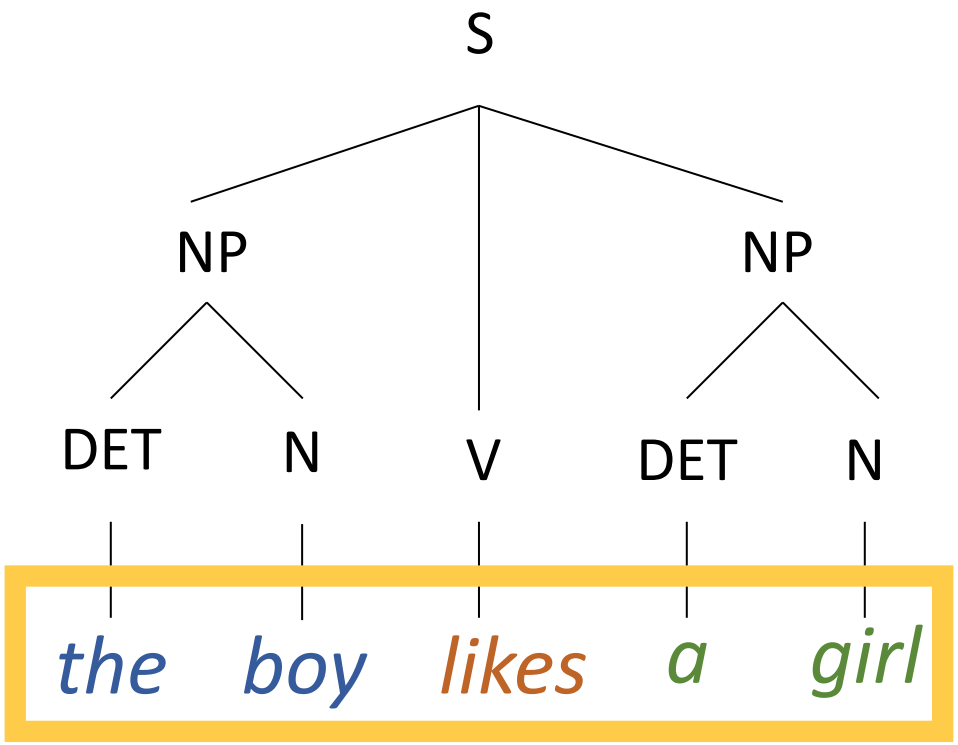
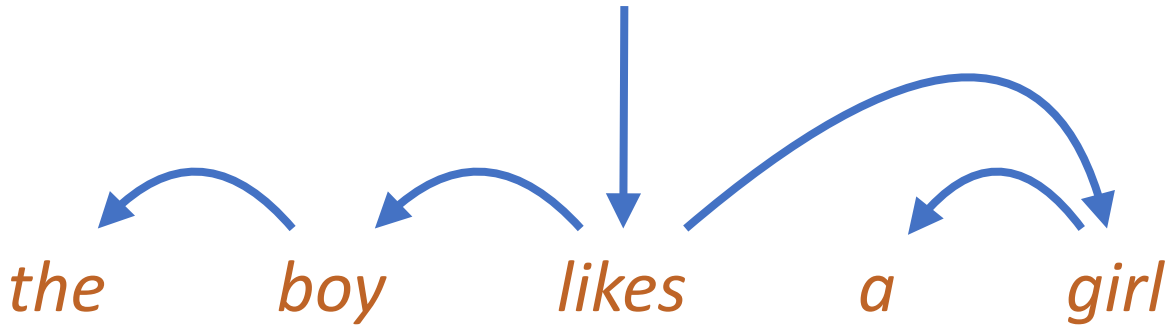
Lexical anchors



Dependencies

- Underlying idea: each word is **governed** by another word, except for the "main" word of the sentence
- A link between a word and its governor is a **dependency**



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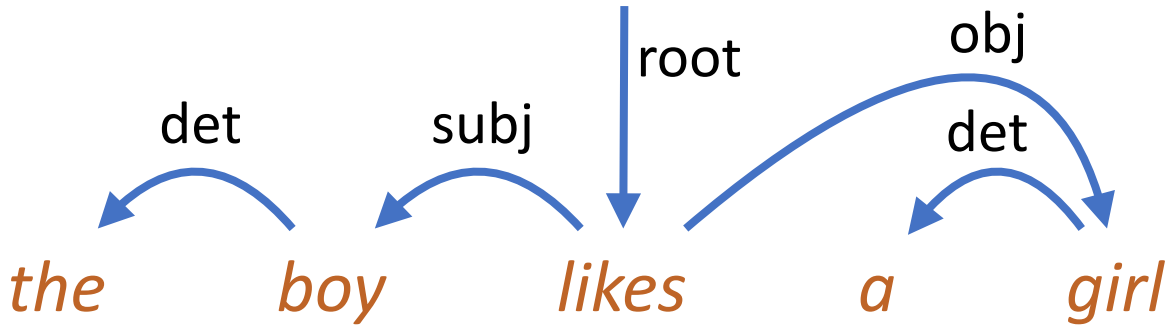
- Such links can be **labelled** with dependency types



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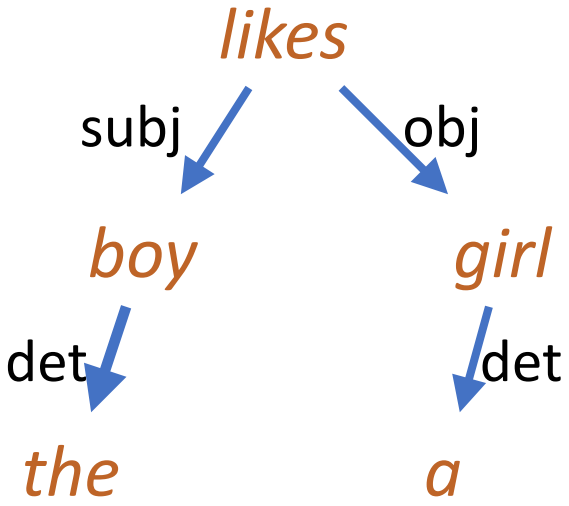
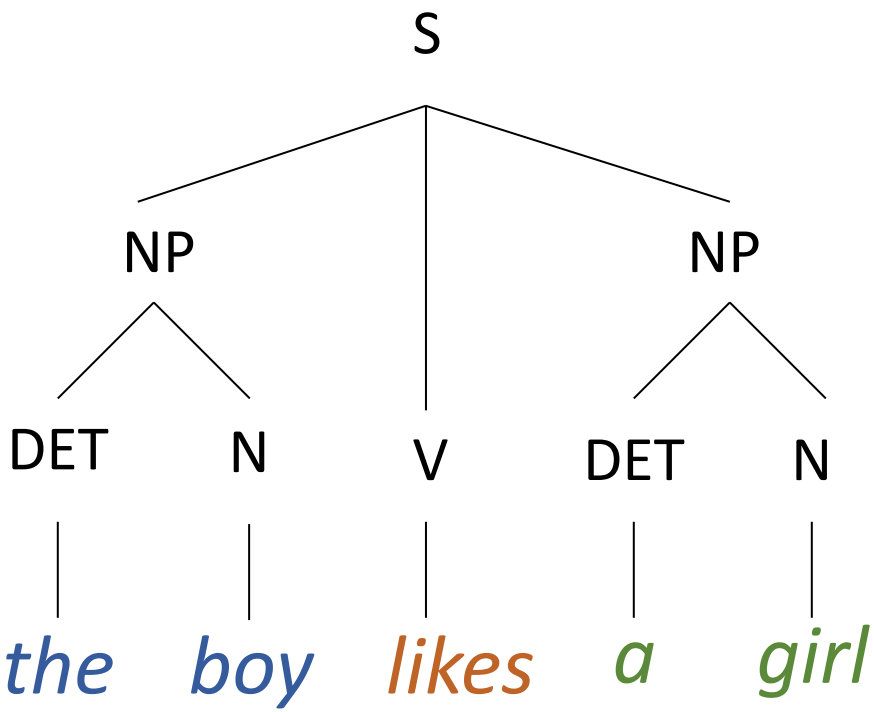


Dependencies vs. constituents

- A dependency tree provides all the information needed to create the **structure** of the constituency tree
  - But information is missing for labelling internal nodes (i.e. to know non-terminal symbols)
- A constituency tree is not enough to re-create the dependency tree
  - We need to know the **head** of each constituent
  - We have abandoned the “1 non-bracketed wordform per constituent” approximation => we need a way to know the head of each constituent

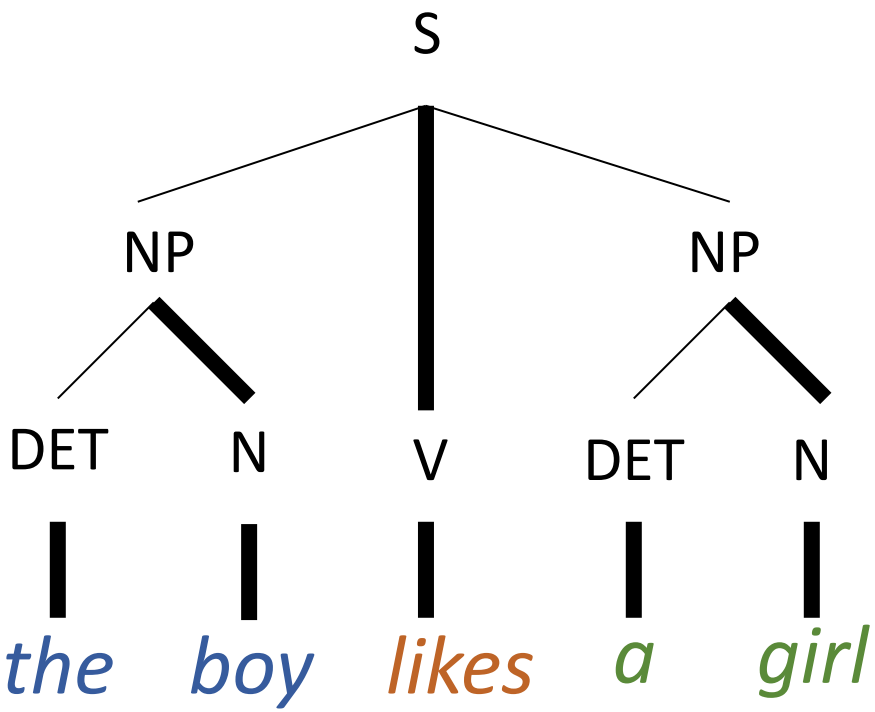
Constituency trees: specifying heads

- *(S (NP (DET the) (N boy)) (V likes) (NP (DET a) (N girl)))*



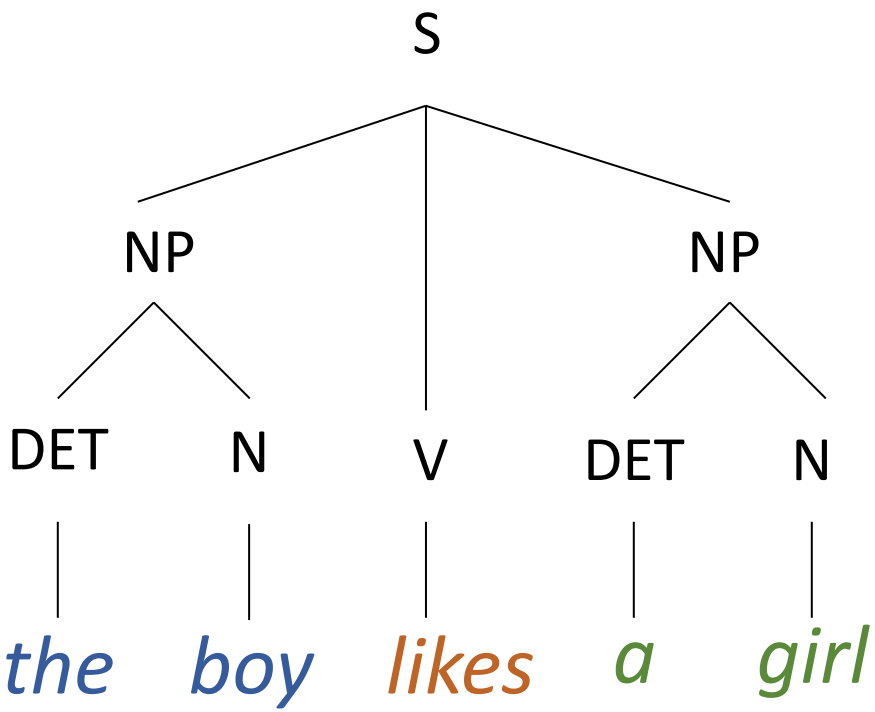
Constituency trees: specifying heads

- Explicit specification



Constituency trees: specifying heads

- Head percolation table



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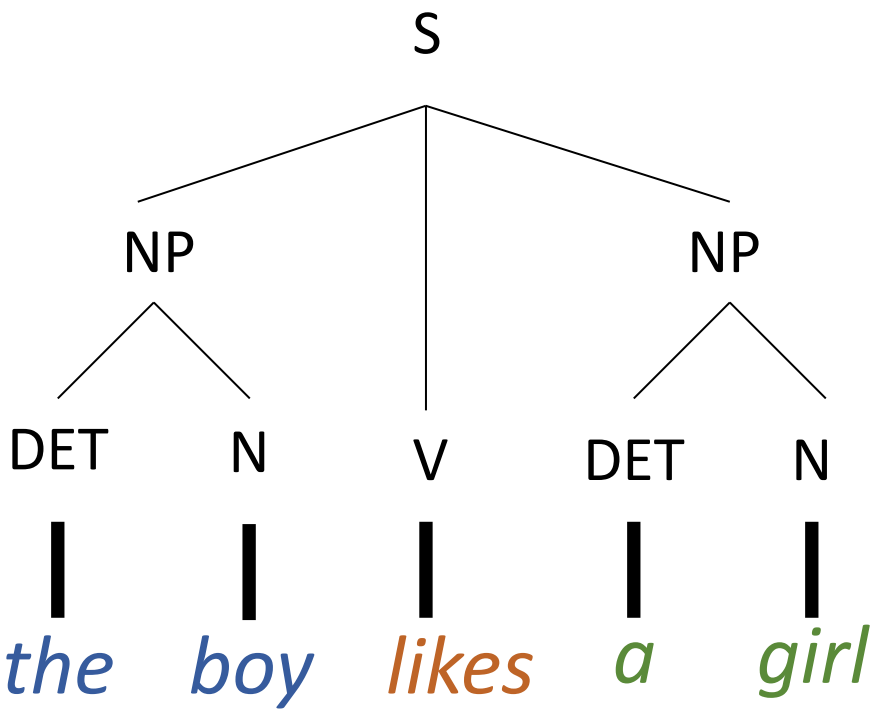

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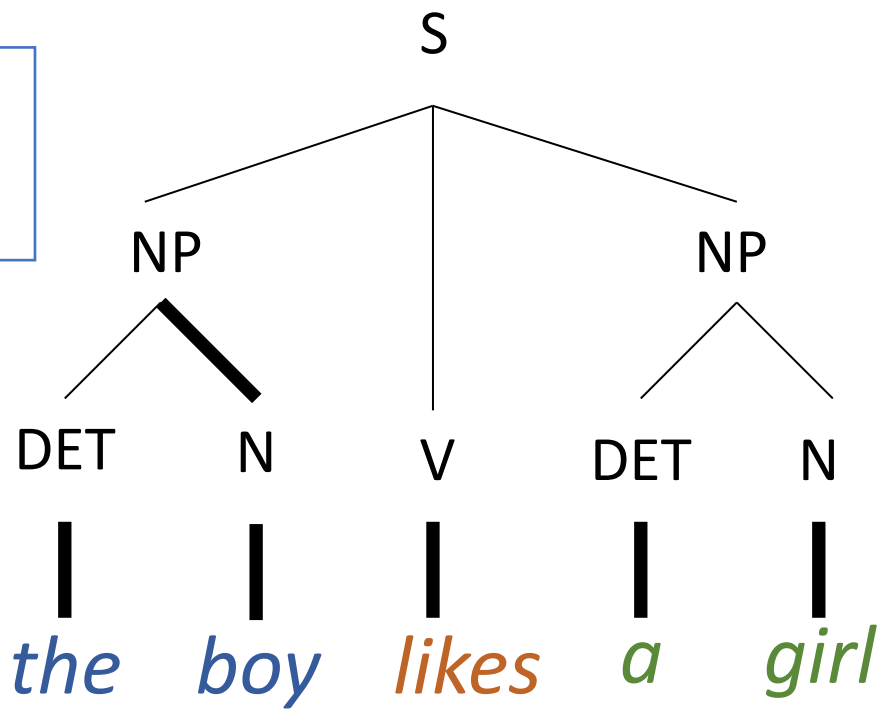

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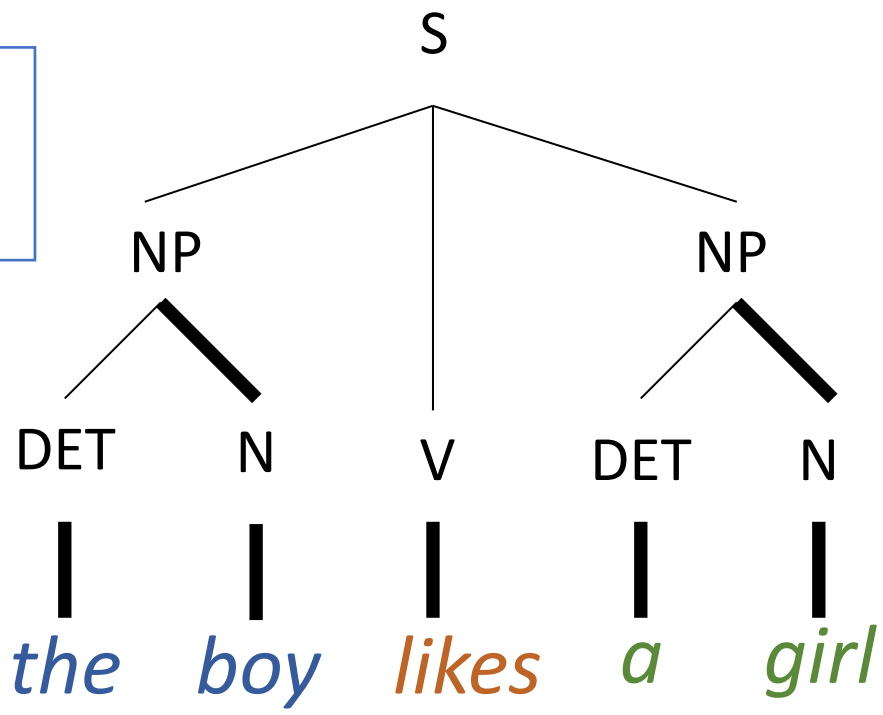

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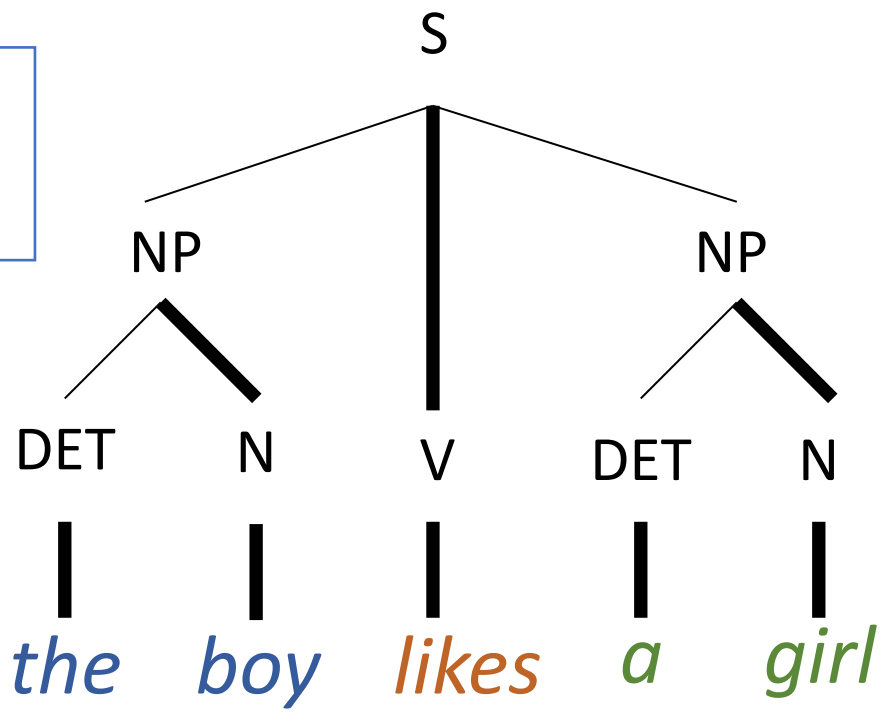
S (… **V*** …)



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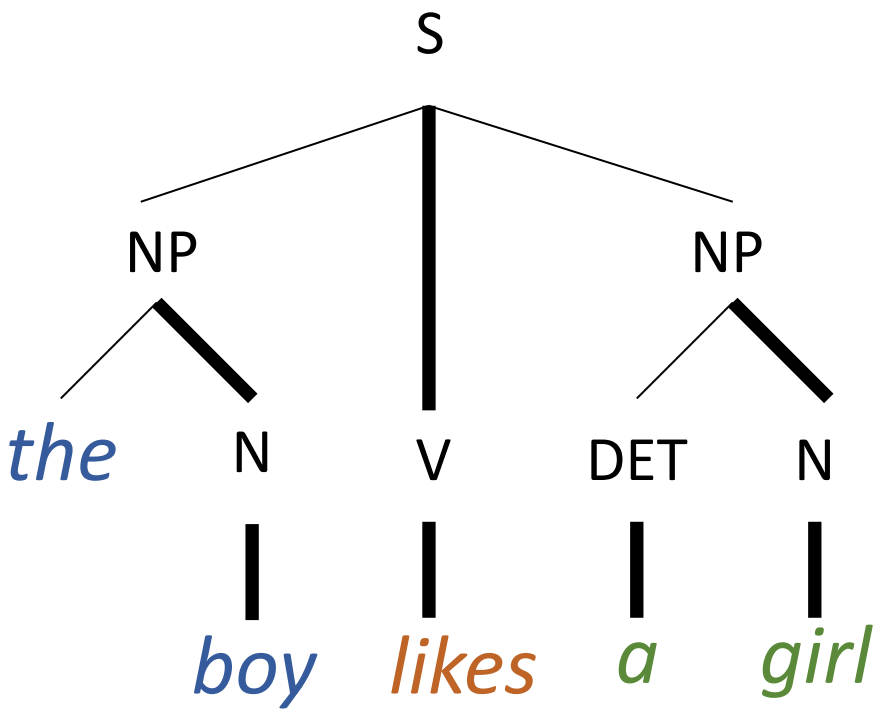

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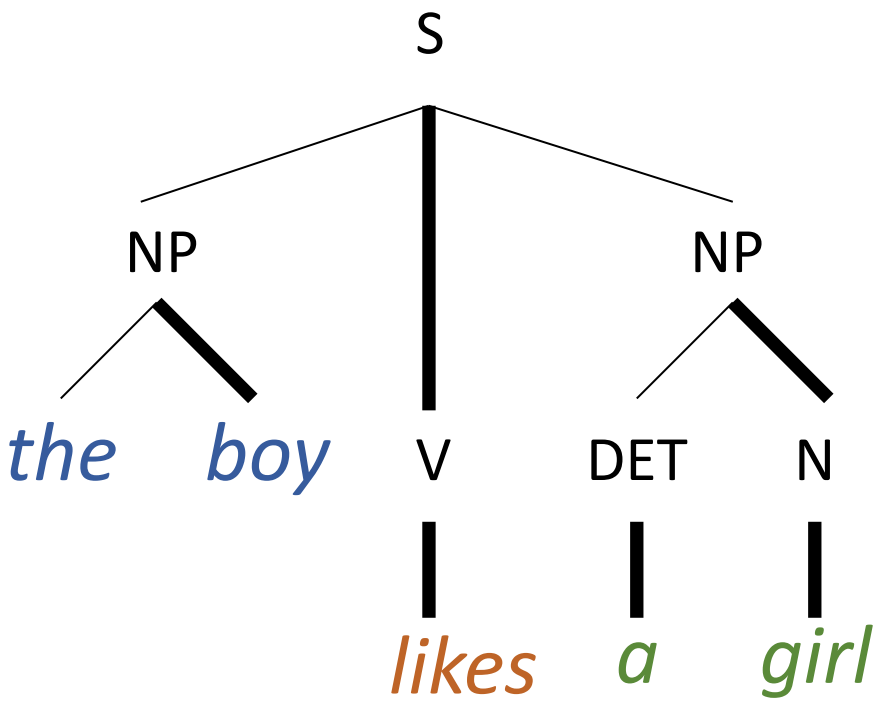

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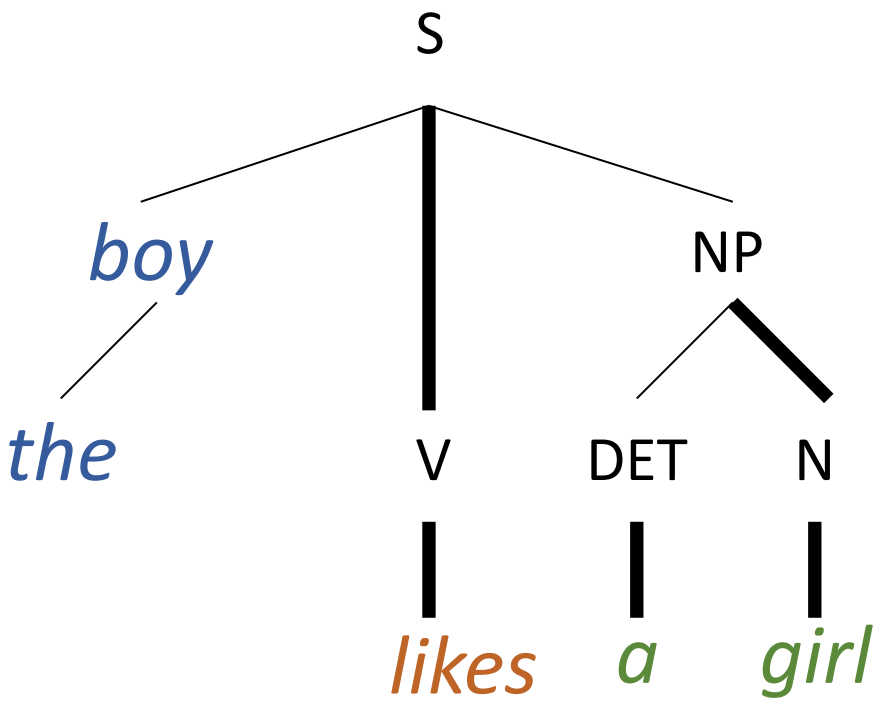

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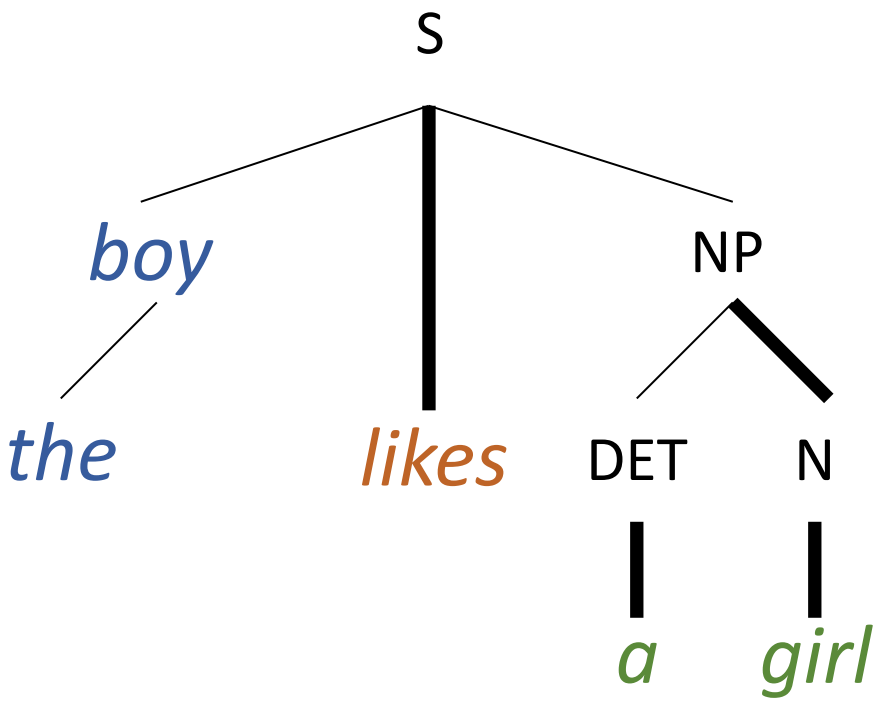

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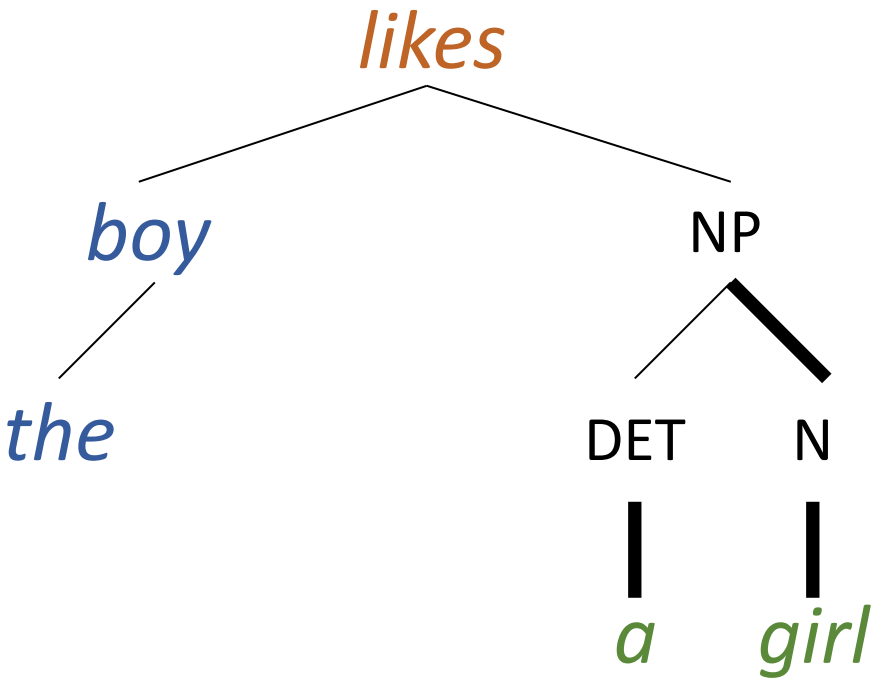

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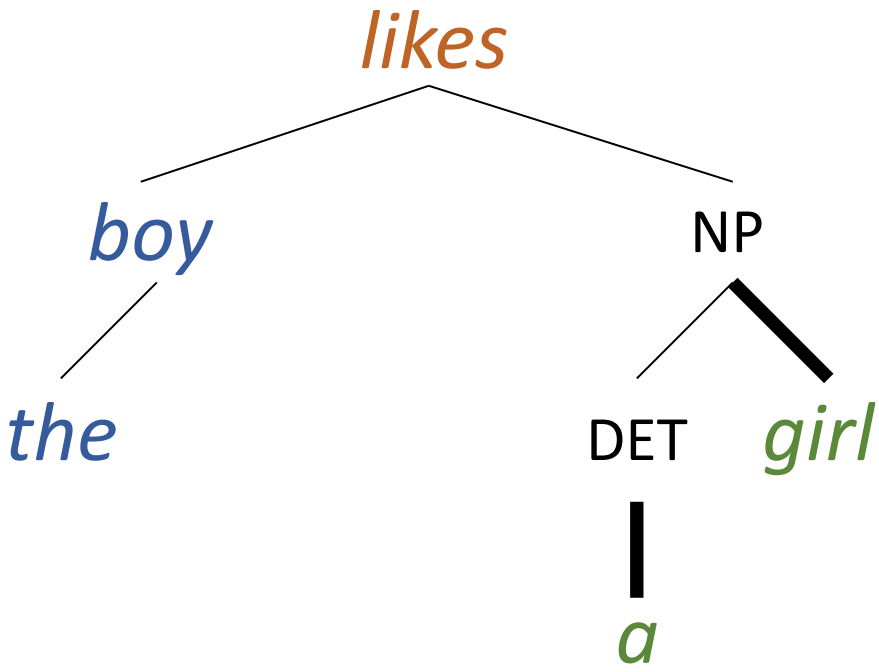
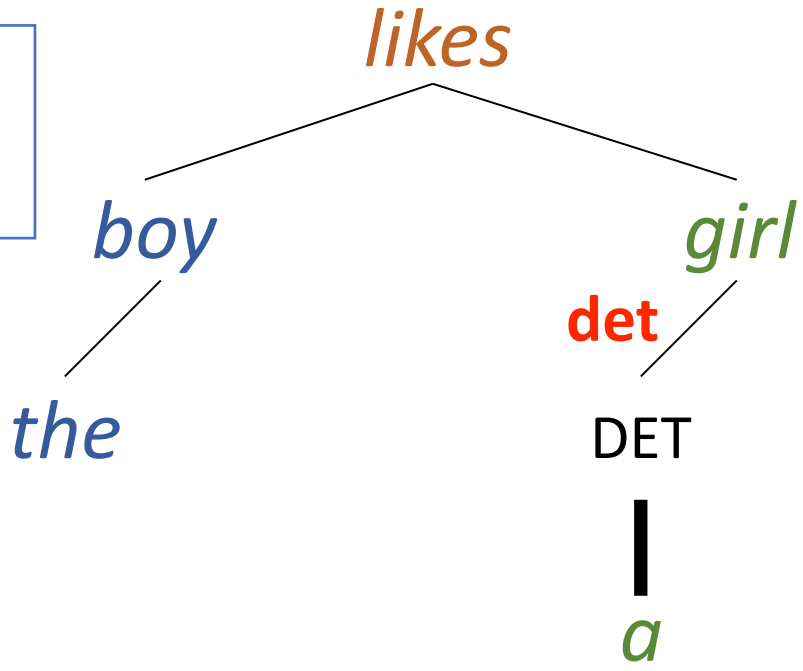


Constituency trees: specifying heads

- Head percolation table, which can include dependency type information

NP (DET$^{\text{det}}$ **N**)



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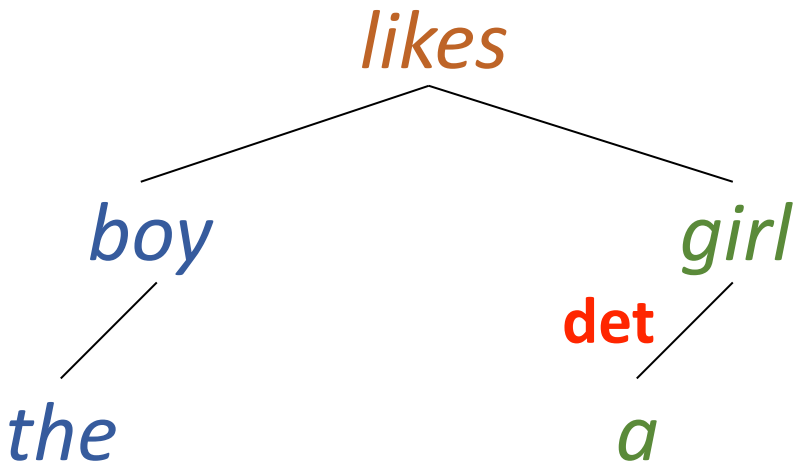

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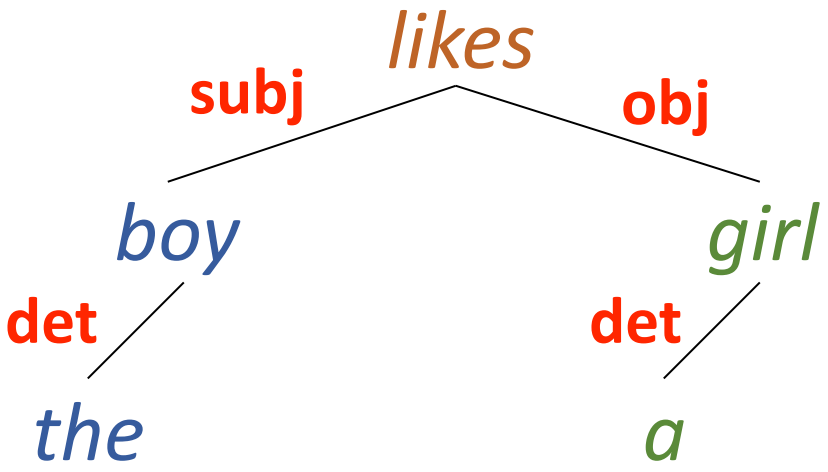
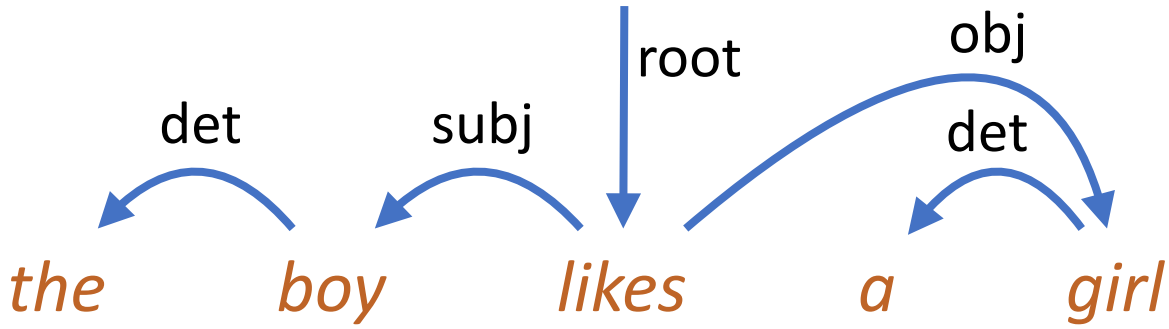


Key observation

- **Dependency structures** look like semantic structures
  - They are more useful for downstream applications
  - They tend to be more and more used, especially over the last ~10 years
- **Constituency structures** are still very important, especially for configurational languages such as English (and to a lesser extent French)
- The two types of structures capture **different aspects** of the syntactic structure of a sentence

Non-projective dependencies

- **Projective case:**



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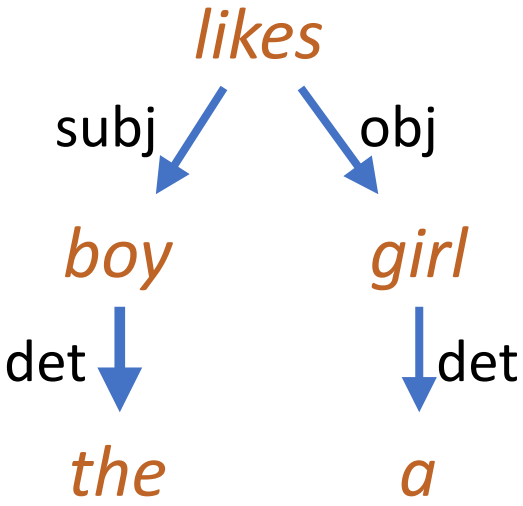

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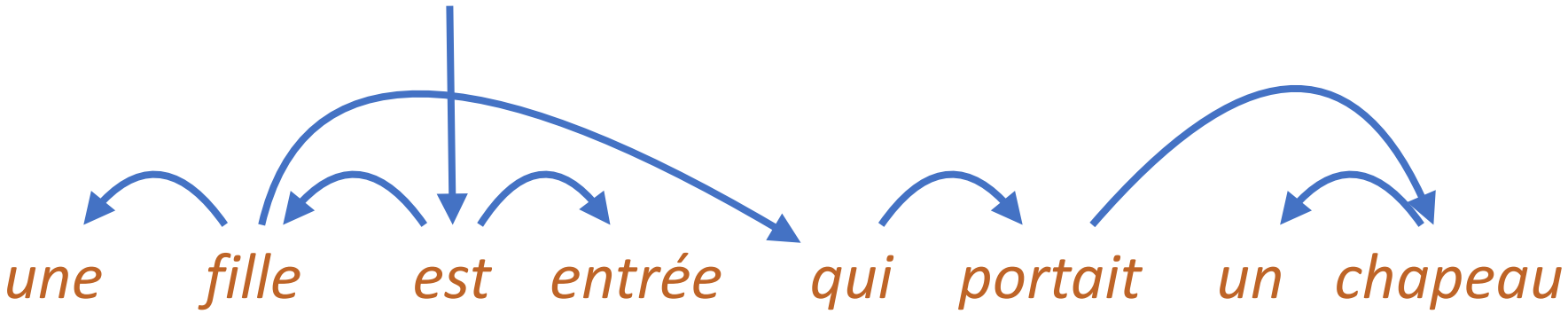

‘A girl entered, who was wearing a hat’

Non-projective dependencies

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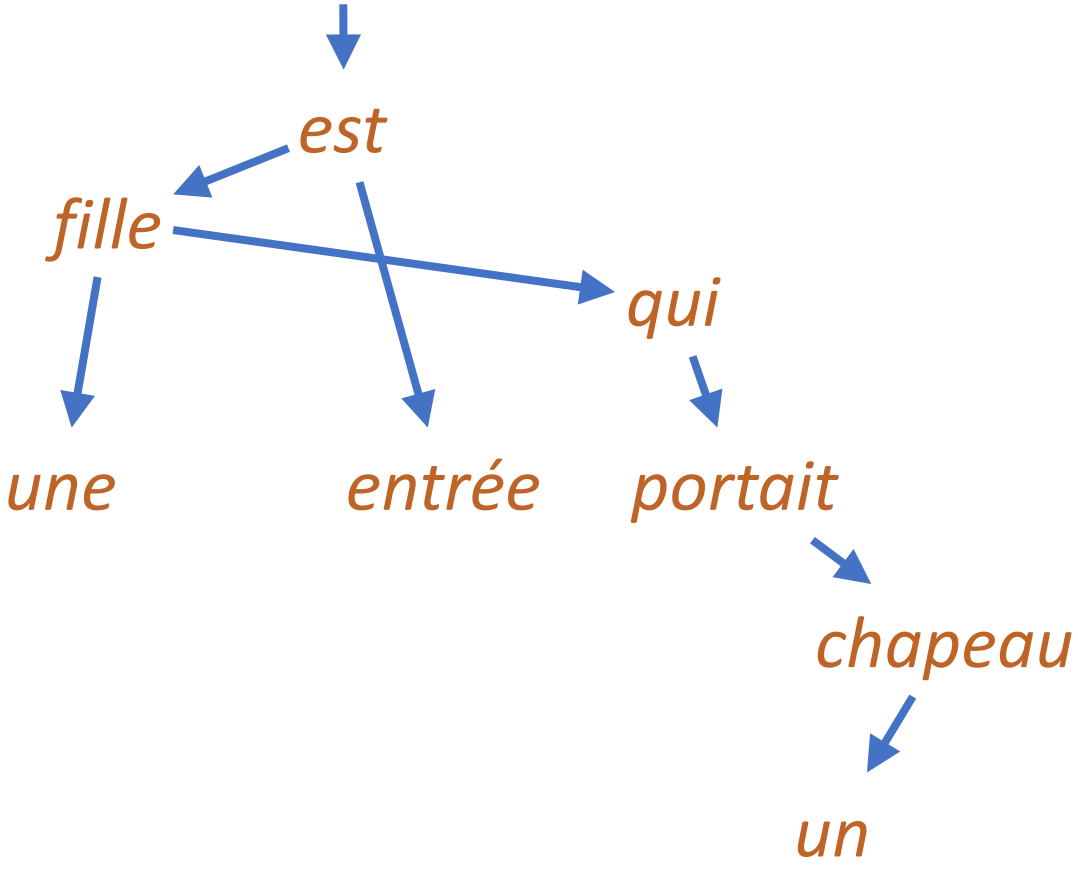
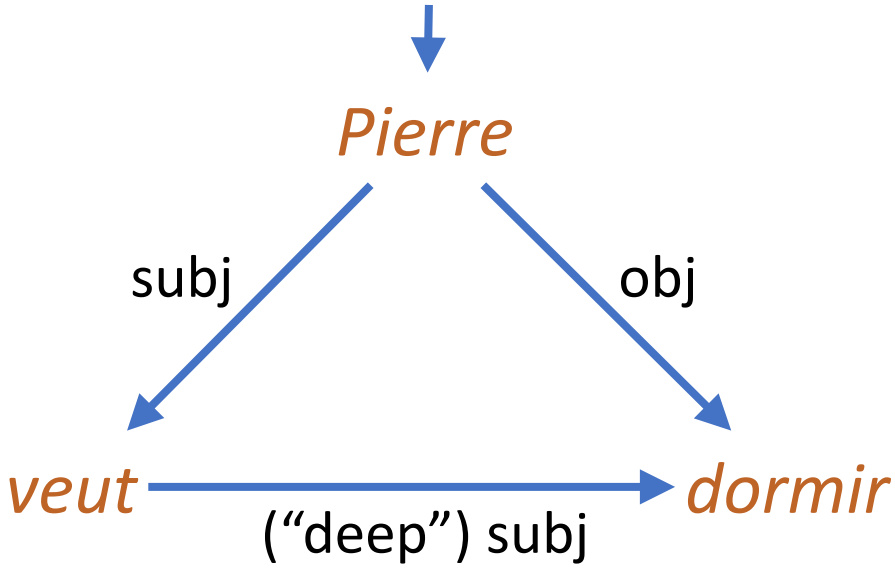


Control, raising and attribution

- **Non-tree case:**



‘Peter wants to sleep’

Overall objective

- Ideally, we would like to be able to **simultaneously** generate for each sentence both:
  - a constituency structure,
  - a semantic-ish dependency-like structure
- We will limit ourselves to **projective, tree-like** structures
- We will start with constituents

Formal grammars

Language

- **Language** = an set of words over an alphabet *T*, called the vocabulary
- In other words, a language is a subset of T^*
  E.g. {*a*, *ab*, *aa*, *aaa*, *aab*,….}
  - Finite or infinite
  - T^* is infinite yet countable (enumerable)
  - The number of languages defined over T^* (i.e. how many subsets, i.e. the size of powerset of T^*) is non-enumerable
- Note: in NLP, we tend to replace “word” (element of the language) with “sentence”, and “character” (element of *T*) with “word”
- More examples:

  $L_1 = \{a, b\}$

  $L_2 = \{a, b, \varepsilon\}$

  $L_3 = \{a^n b^n \mid n \in \mathbb{N}\}$

  $L_4 = \{ww^{-1} \mid w \in T\}$, where w^{-1} is the mirror image of w

Grammar

A grammar G is defined as a quadruple

$$G = (V, T, S, P)$$

where

V is a finite set of objects called **variables**, or **non-terminal symbols**,

T is a finite set of objects called **terminal symbols**,

$S \in V$ is a special symbol called the **start** variable,

P is a finite set of **productions**, or **rewriting rules**

Grammar: an example

$$G = (\{S\}, \{a, b\}, S, P),$$

with P given by

$$S \to aSb,$$
$$S \to \varepsilon .$$

Then

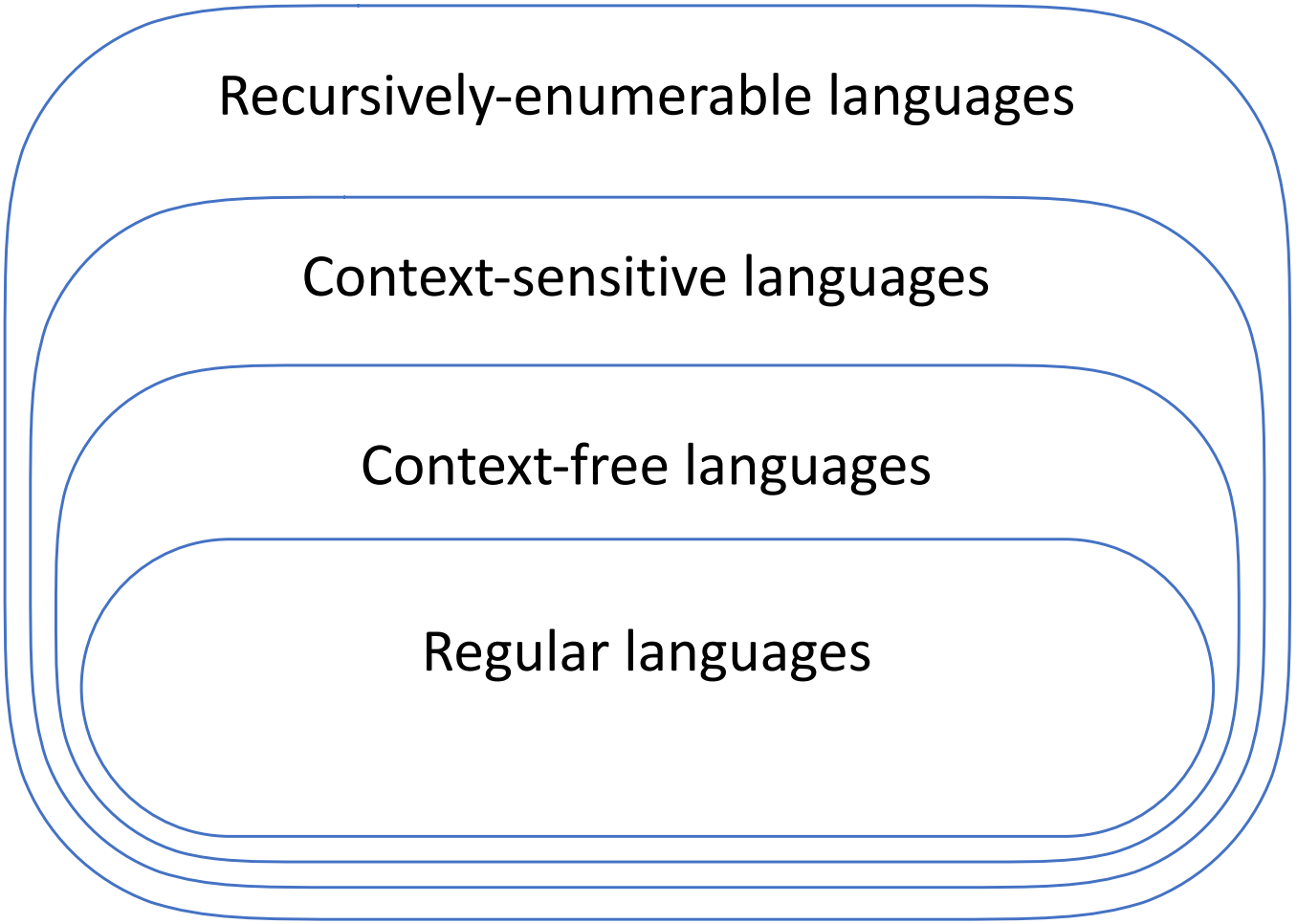
$$S \Rightarrow aSb \Rightarrow aaSbb \Rightarrow aabb,$$

so we can write

$$S \overset{*}{\Rightarrow} aabb.$$

The string *aabb* is a sentence in the language generated by G, while *aaSbb* is a sentential form.

Chomsky hierarchy



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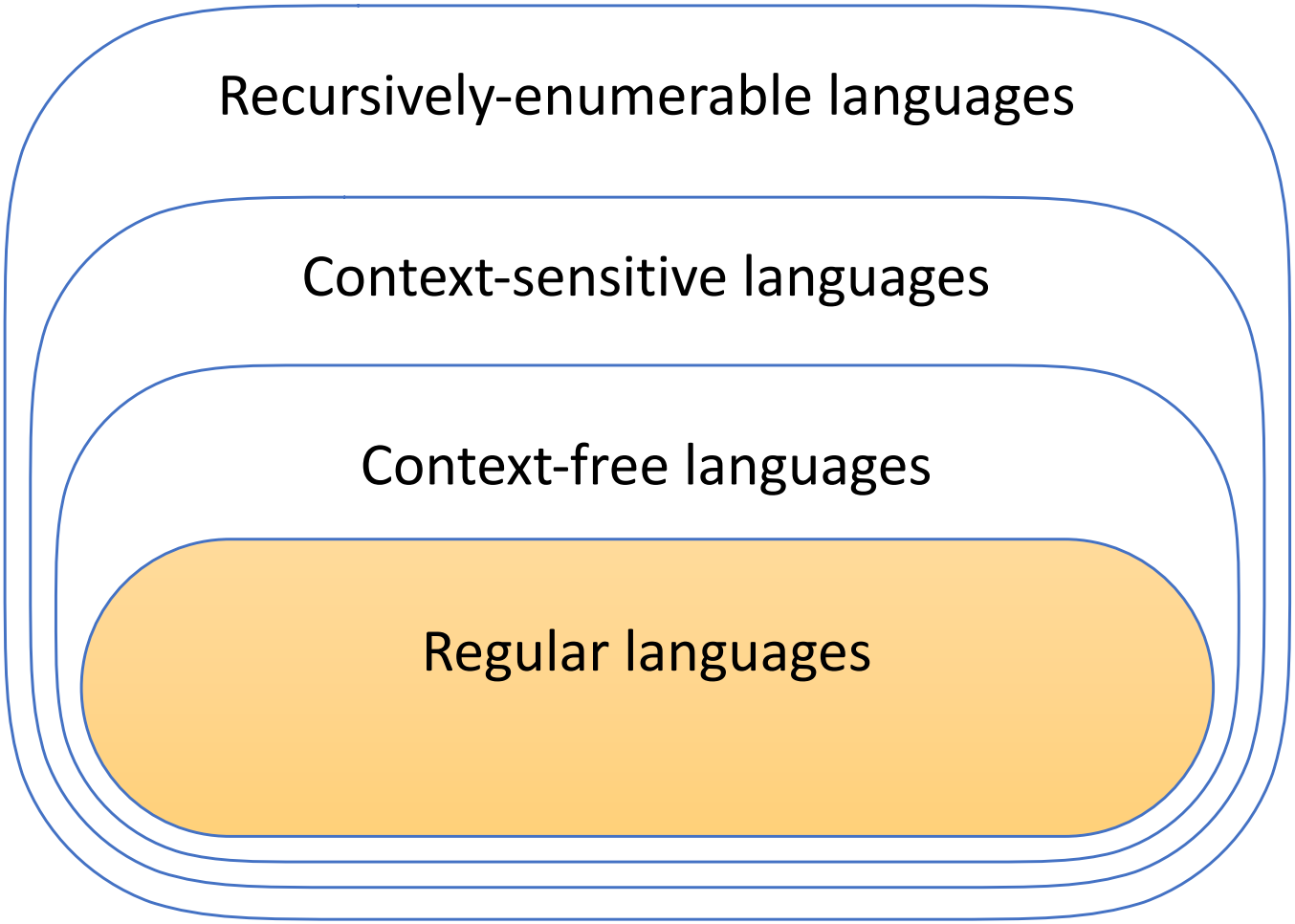
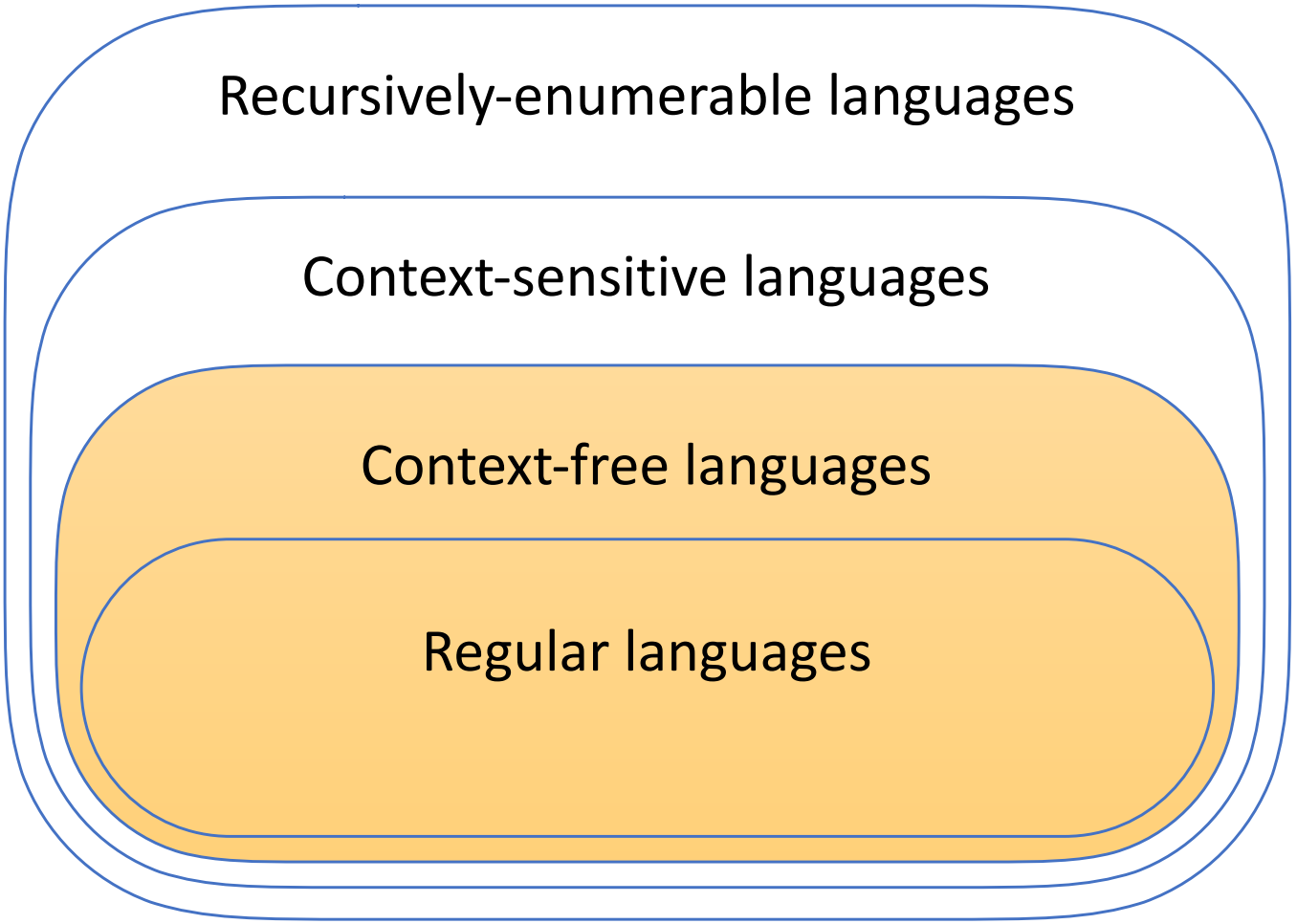


Allowed rewriting rule forms:
- B -> a
- B -> aC
- B -> ε

OR
- B -> a
- B -> Ca
- B -> ε

Complexity:
O(*n*)

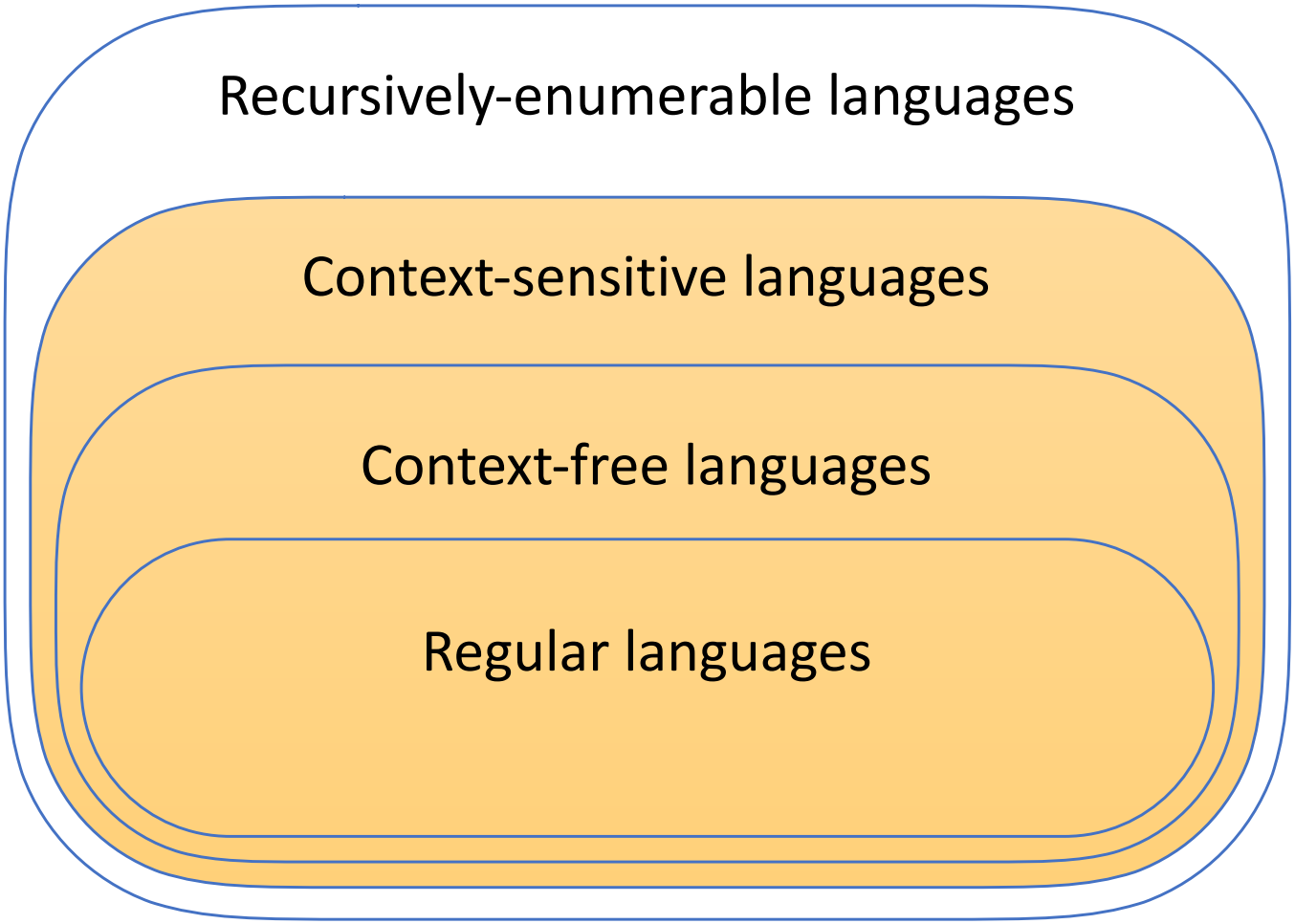
Chomsky hierarchy



Allowed rewriting rule forms:
- B -> γ
where γ is zero, one or more terminal and/or non-terminal symbols

Complexity:
O(n^3)

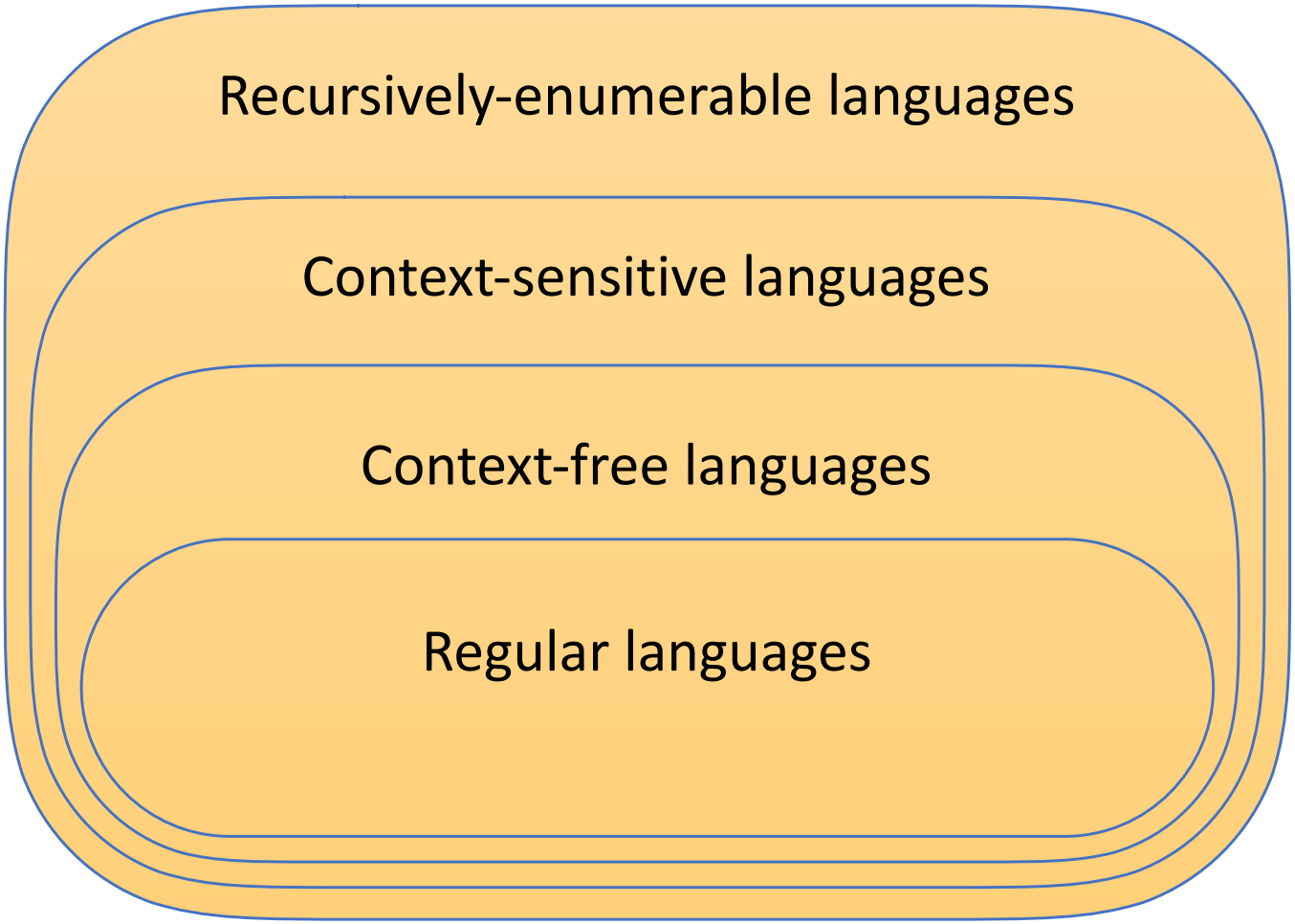
Chomsky hierarchy



Allowed rewriting rule forms:
- αBβ -> αγβ where α, β and γ are zero, one or more terminal and/or non-terminal symbols

Complexity:
NP-complete

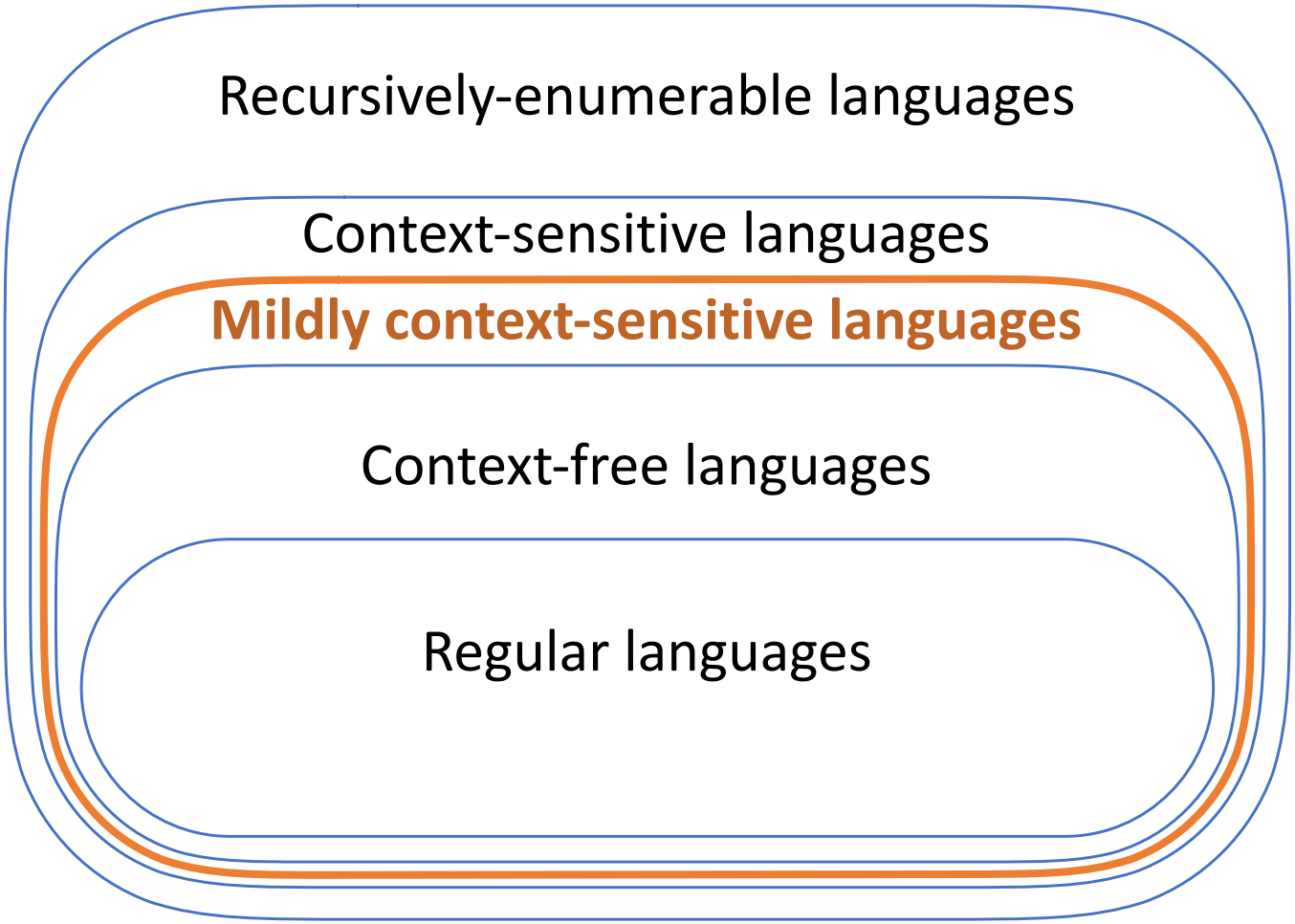
Chomsky hierarchy



Allowed rewriting rule forms:
- $\alpha \rightarrow \beta$
where α and β are the same as before

Complexity:
Undecidable (=halting problem for Turing machines)

Chomsky hierarchy



Context-free grammars

Context-free grammars (CFGs)

- (Note to French speakers: context-free grammars, grammaires hors-contexte, grammaires non-contextuelles, grammaires algébriques)

Context-free grammars (CFGs)

- From now on, terminals (PoS) are lowercase, non-terminals are uppercase, and the left-hand side of the first rule of a grammar is its axiom
- Example grammar:

1	S ⟶ NP VP
2	VP ⟶ v adv NP
3	NP ⟶ np
4	NP ⟶ det N
5	N ⟶ nc PP
6	PP ⟶ p nc
7	np ⟶ ‘Pierre’
8	v ⟶ ‘mange’
9	adv ⟶ ‘souvent’
10	det ⟶ ‘des’
10	nc ⟶ ‘pommes’
11	v ⟶ ‘pommes’
12	p ⟶ ‘de’
13	nc ⟶ ‘terre’

Lexicon

- As discussed above, words are associated with a PoS
- In the trees we saw earlier, PoS were terminals (there are too many words, using words as terminals would not be practical)
- We extract rules number 7+ from the grammar and store them in the form of a **lexicon**

1	S ⟶ NP VP
2	VP ⟶ v adv NP
3	NP ⟶ np
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5	N ⟶ nc PP
6	PP ⟶ p nc

Pierre	np
mange	v
souvent	adv
des	det
pommes	nc
pommes	v
de	p
terre	nc

First parse

- *Pierre mange souvent des pommes de terre*
  'Peter often eats potatoes'

1 S ⟶ NP VP
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Pierre mange souvent des pommes de terre

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np *v* *adv* *det* *nc* *p* *nc*

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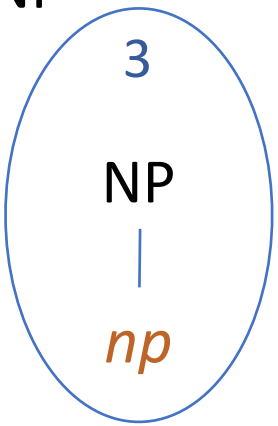

v *adv* *det* *nc* *p* *nc*

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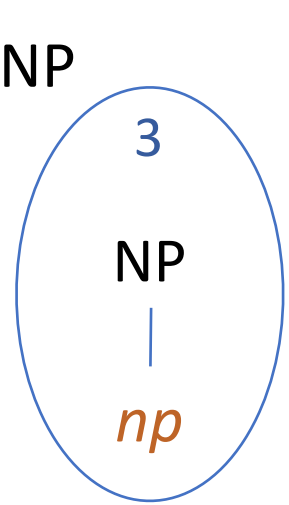
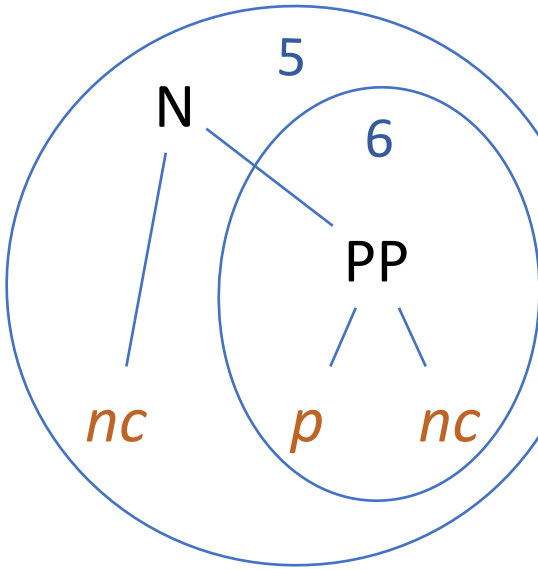


v *adv* *det*



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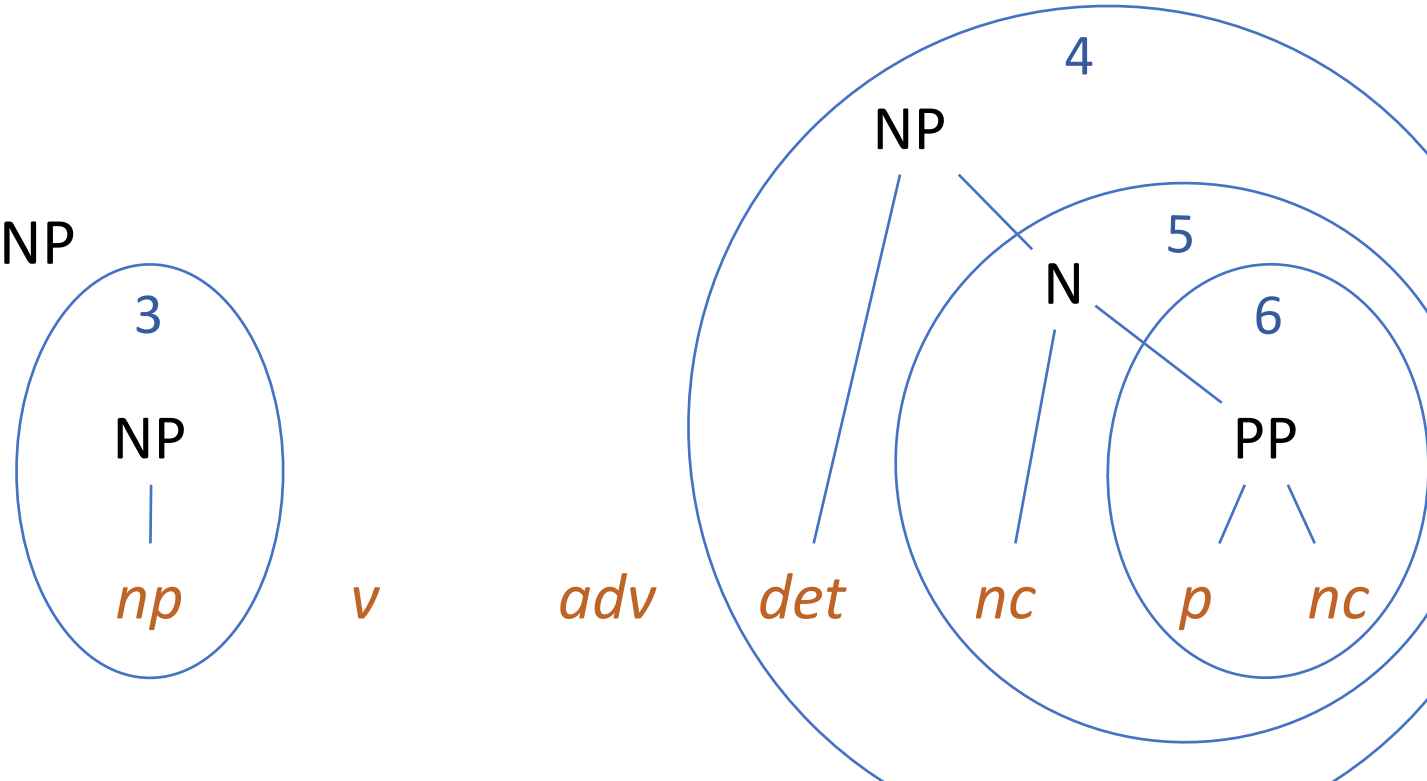

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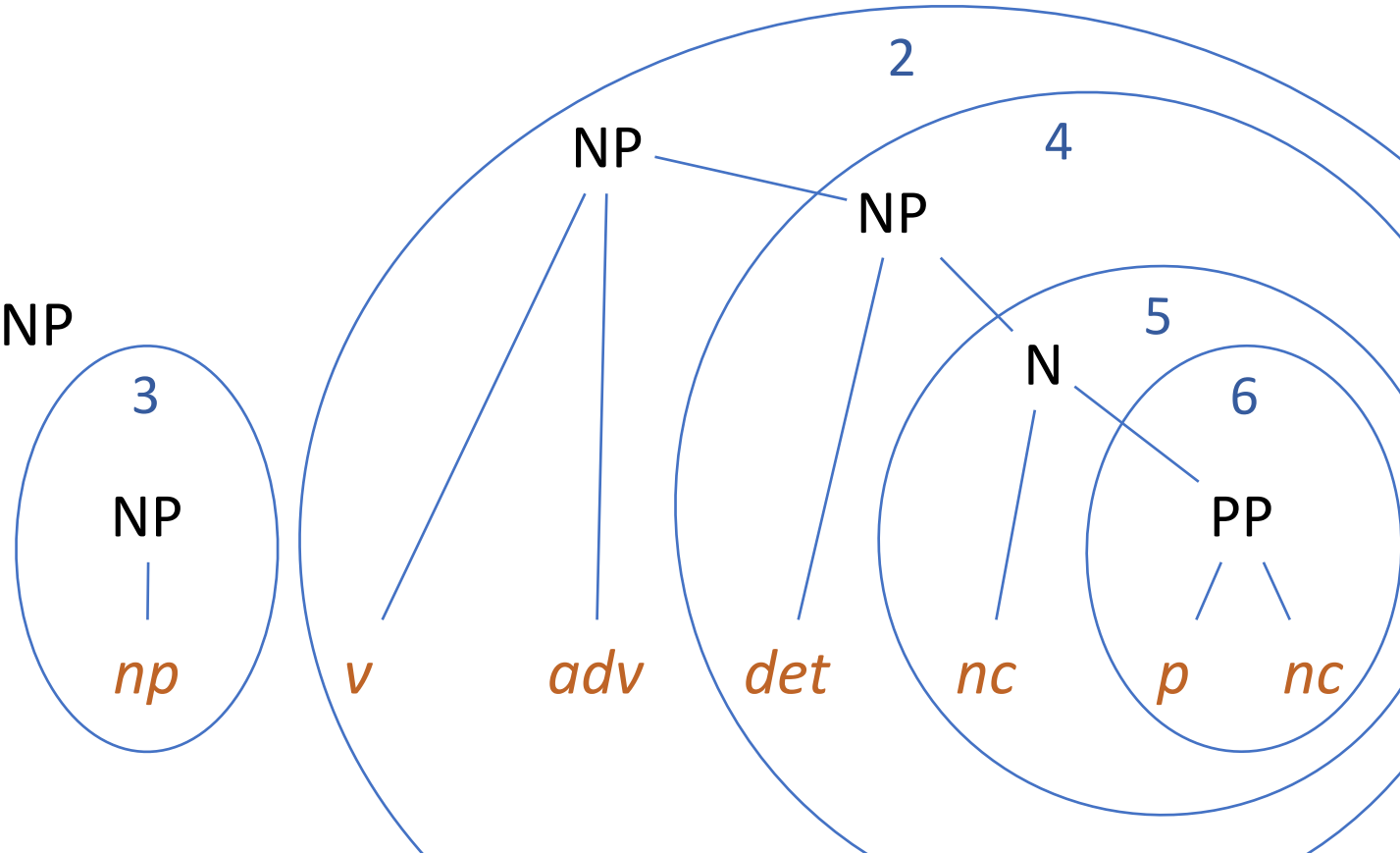

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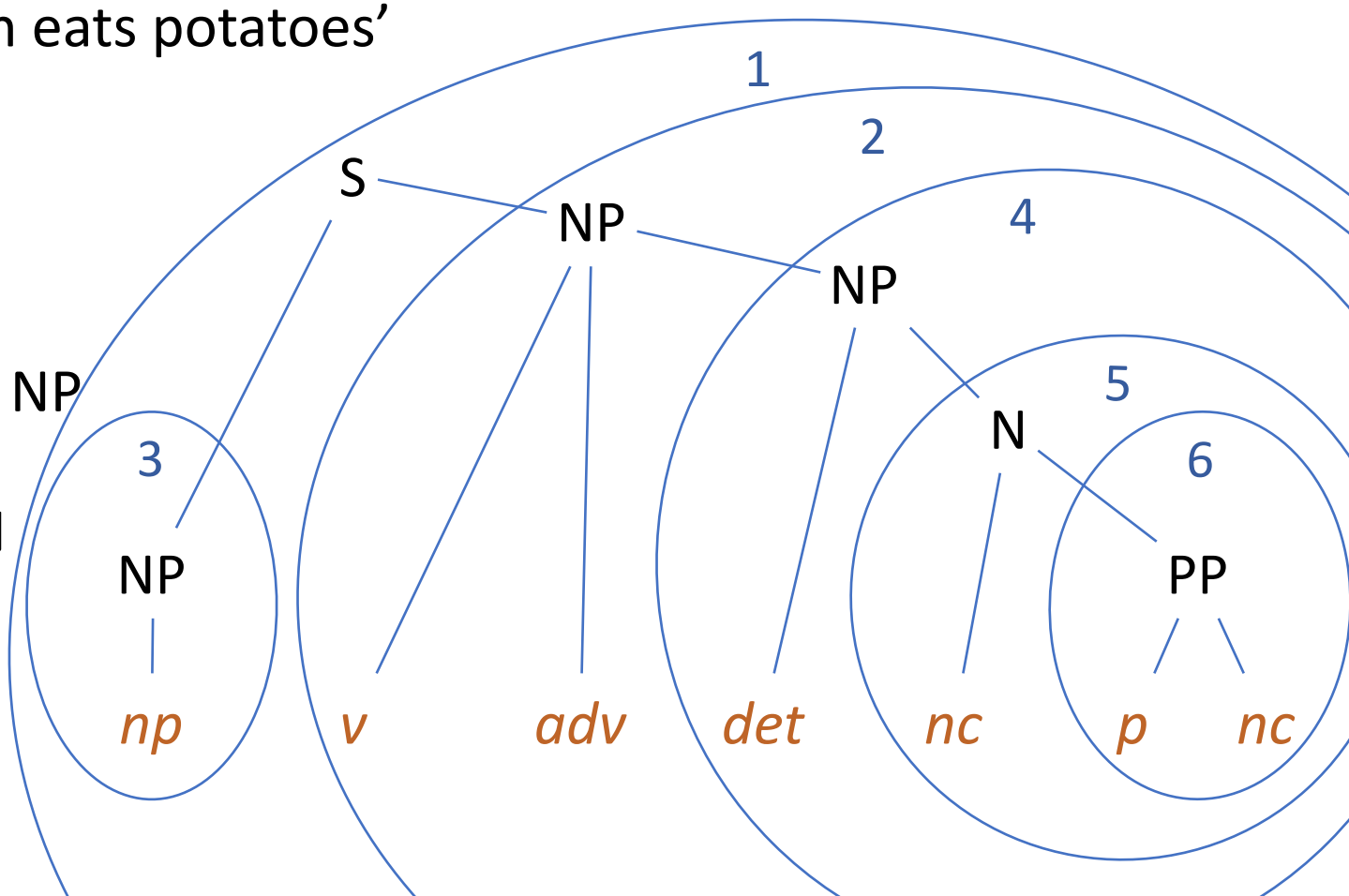
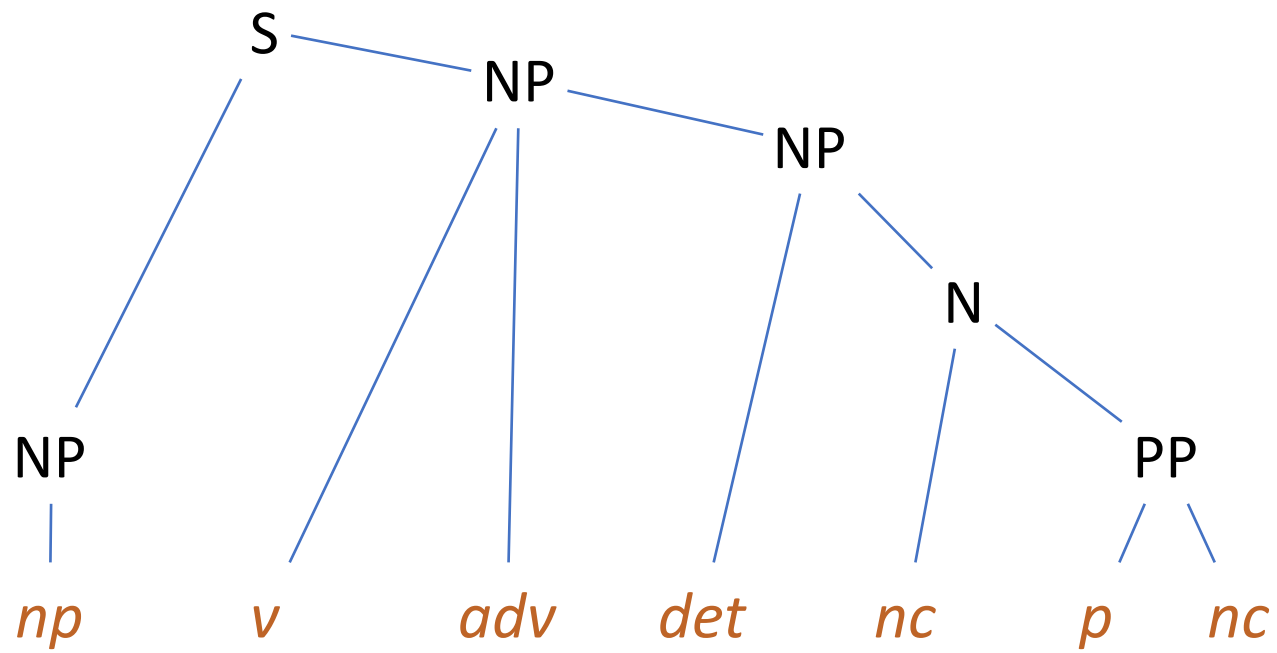


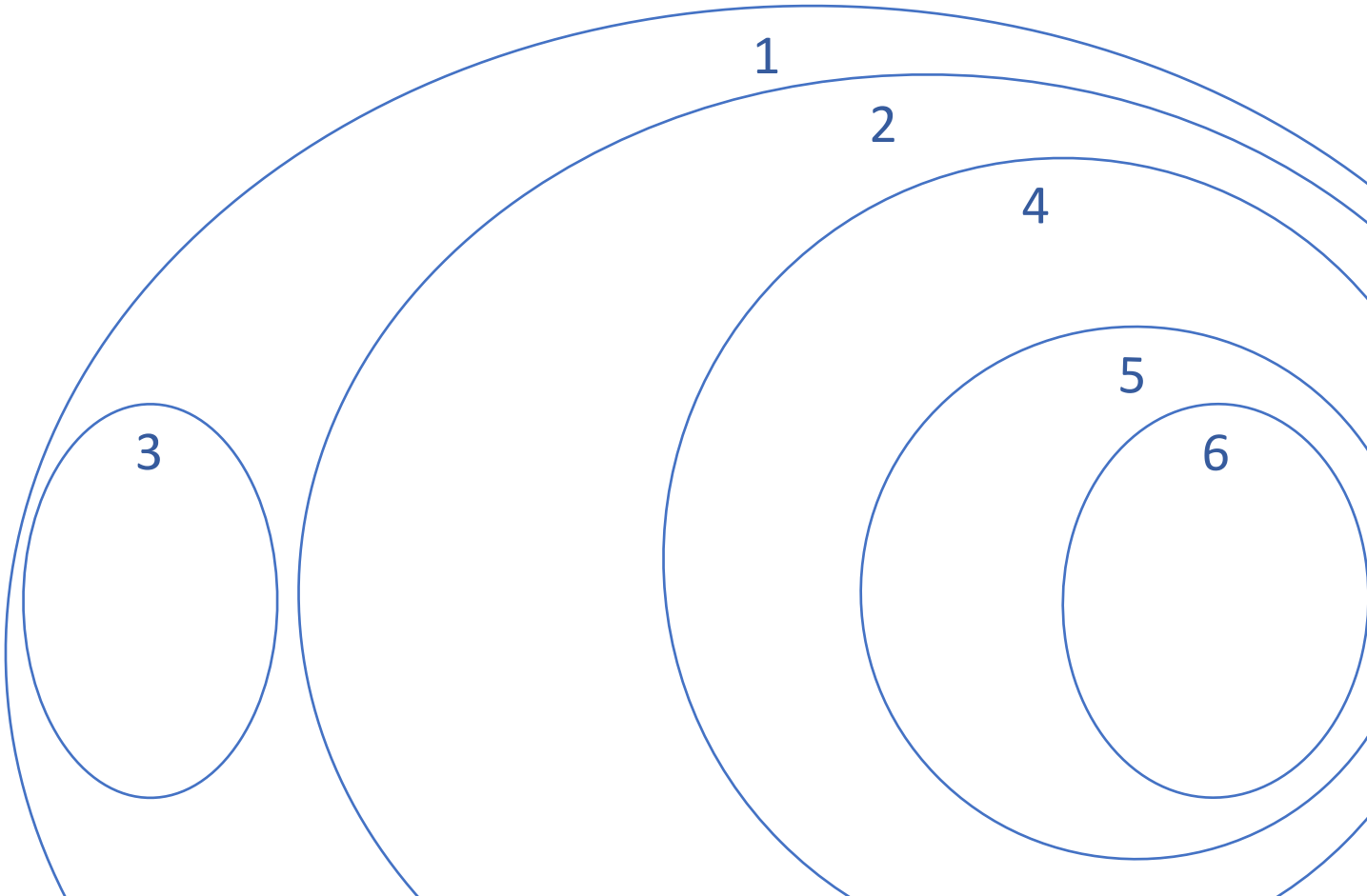
The derived tree

- **Derived tree** = outcome of the parse derivation process



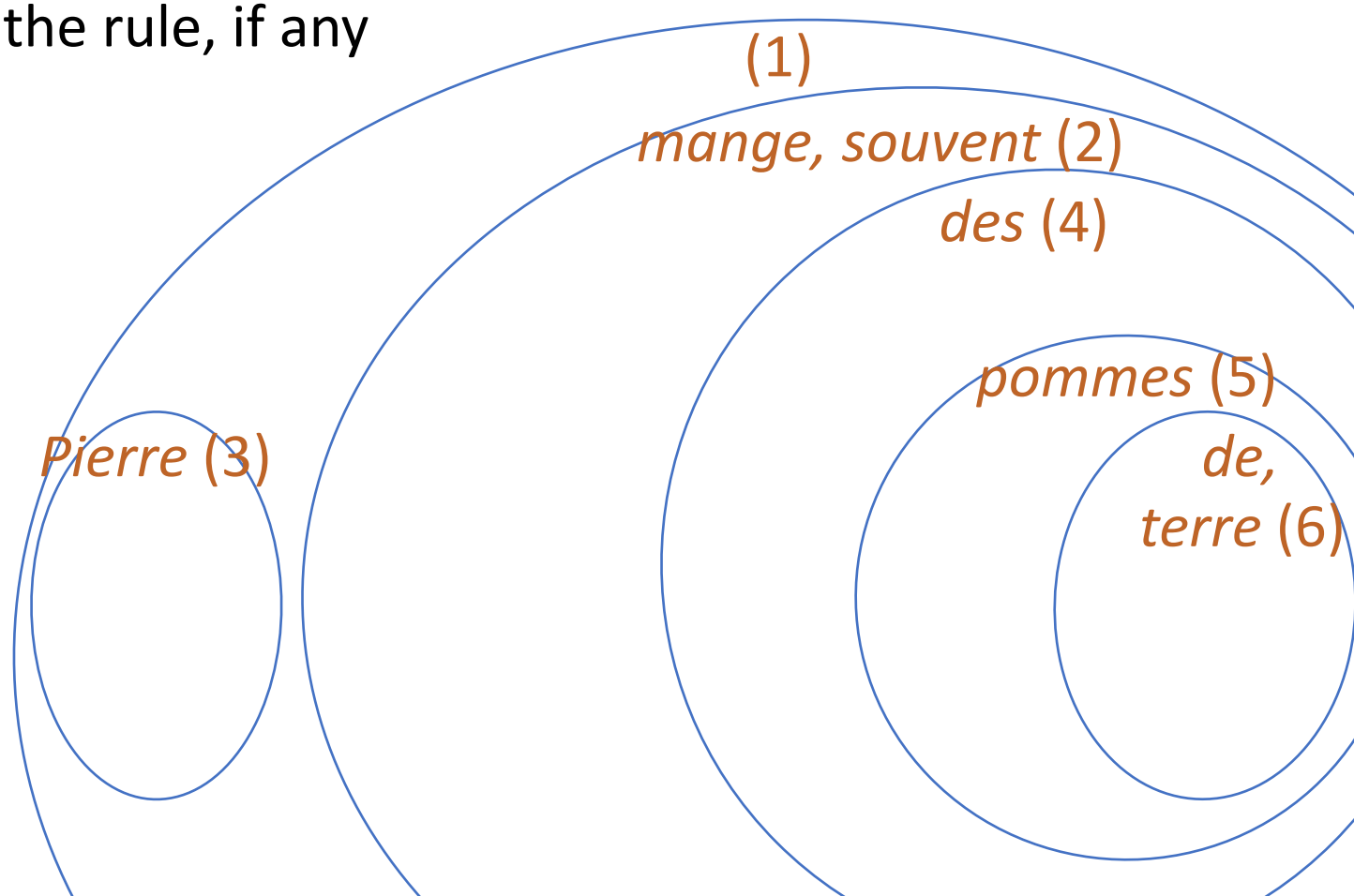
The derivation tree

- **Derivation tree = history of the derivation**



The derivation tree

- Replacing rules by the words correPPonding to terminal symbols in the rule, if any



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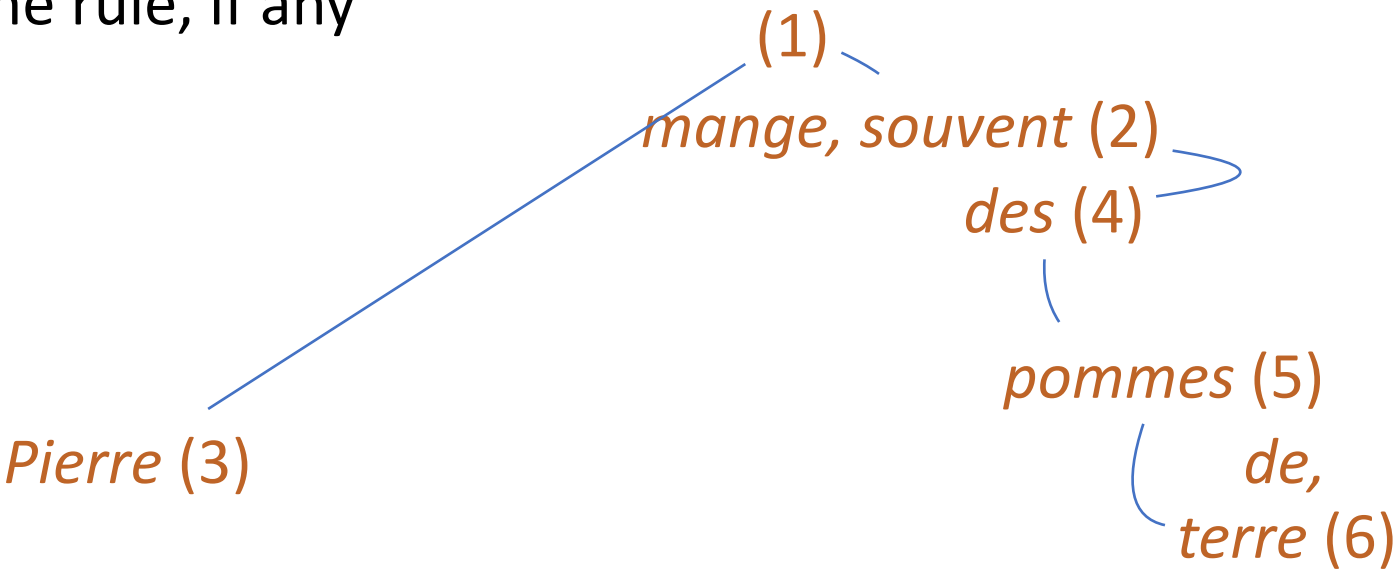

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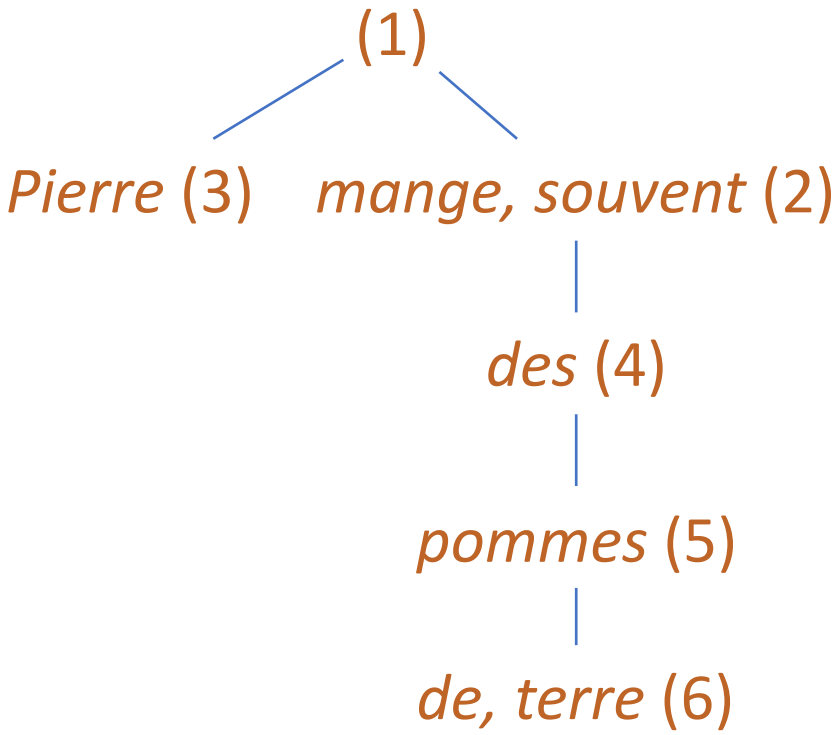
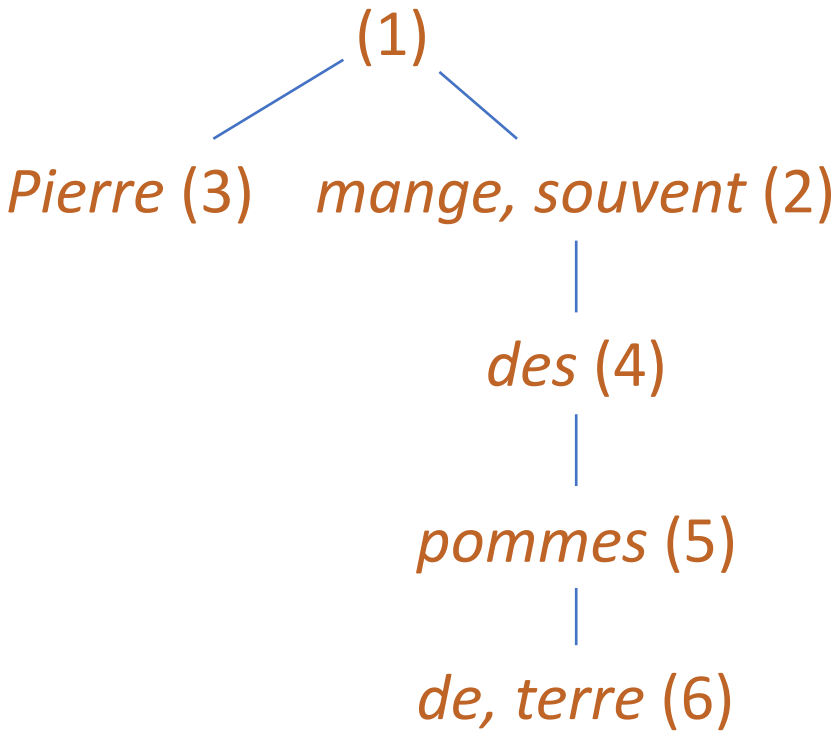


The derived tree

- The derived tree provides us with a second structure
- What would it require for this structure to be closer to a semantic structure (~ a dependency tree)?



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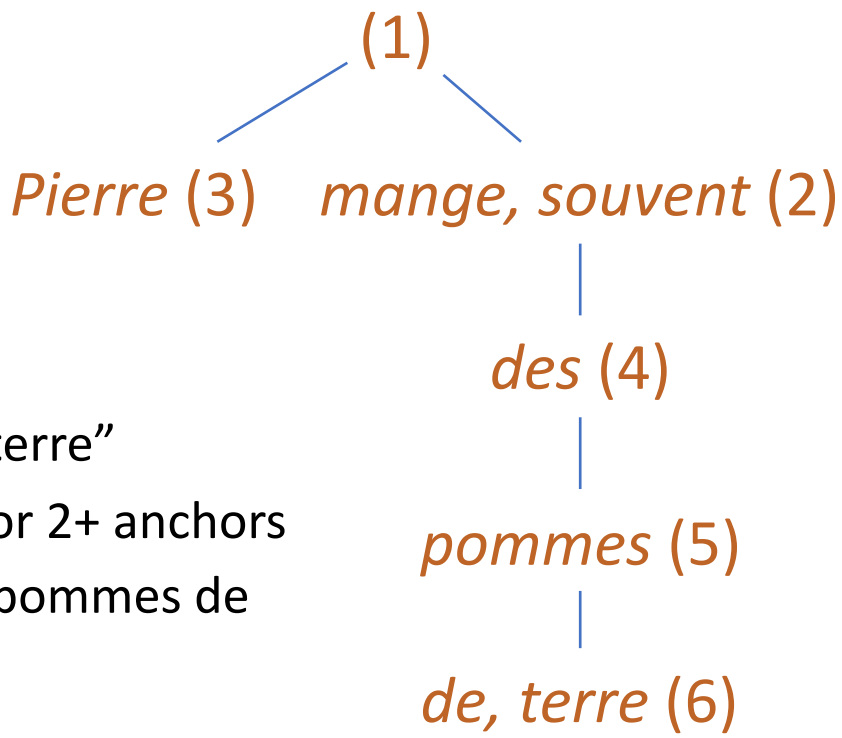

- Problems:
  - “pommes de terre”
  - nodes with 0 or 2+ anchors
  - “des” above ”pommes de terre”

Tree Substitution Grammars

Context-free grammars (CFGs)

- We replace rewriting rules by equivalent "**elementary trees**"

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2 VP ⟶ v adv NP
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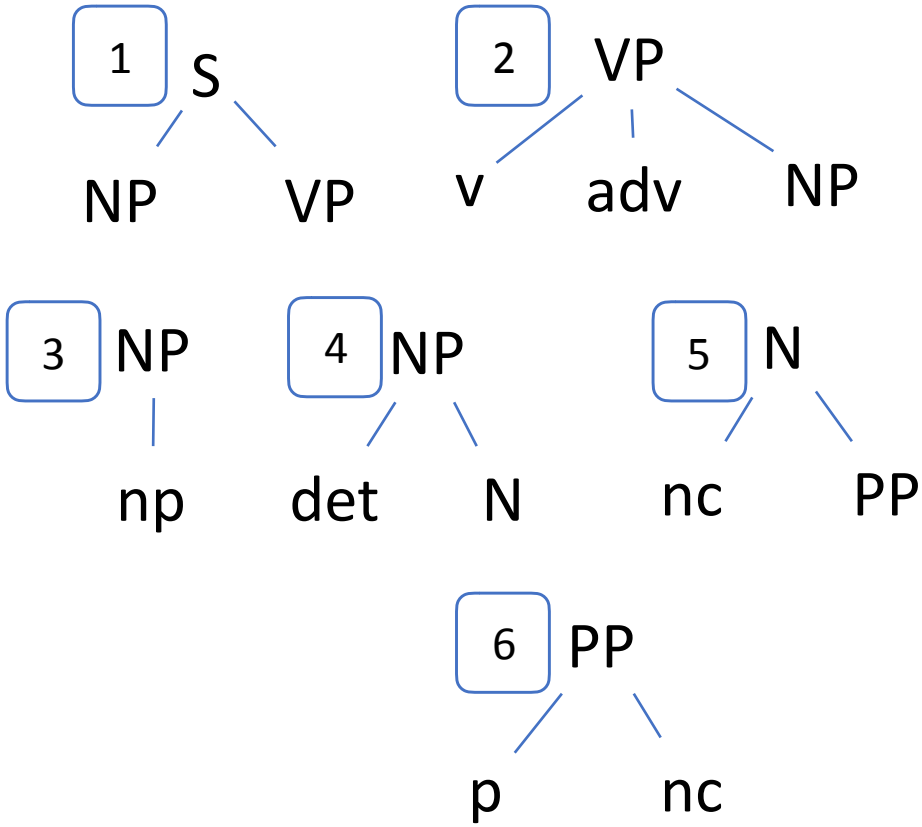

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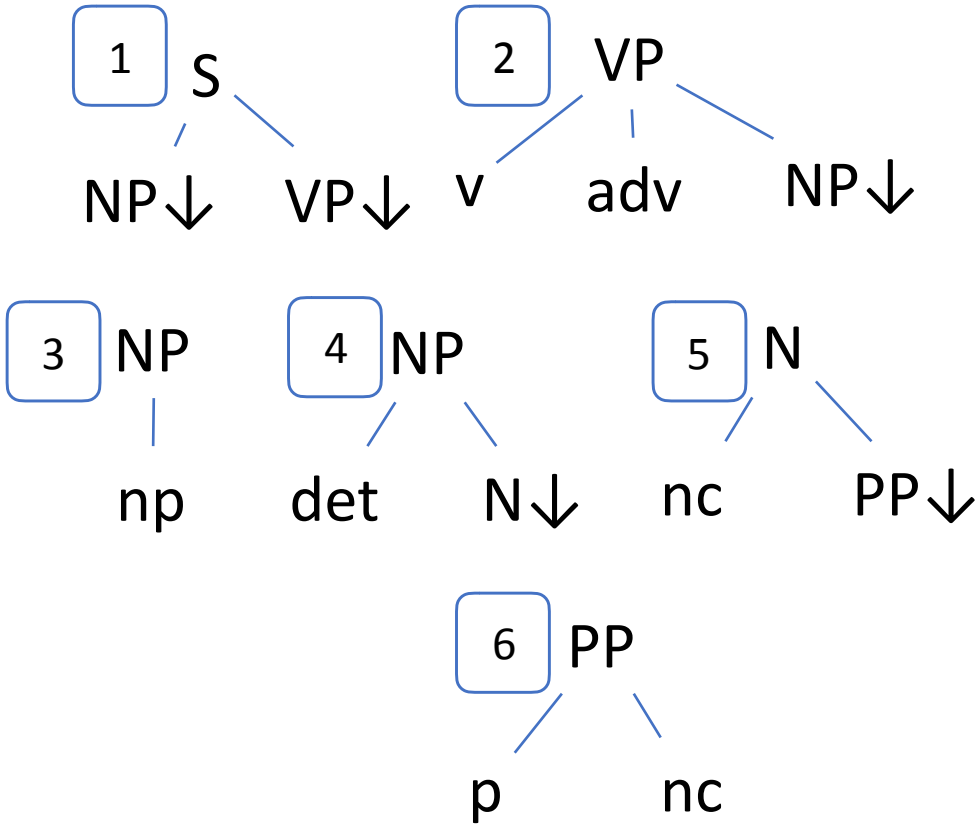
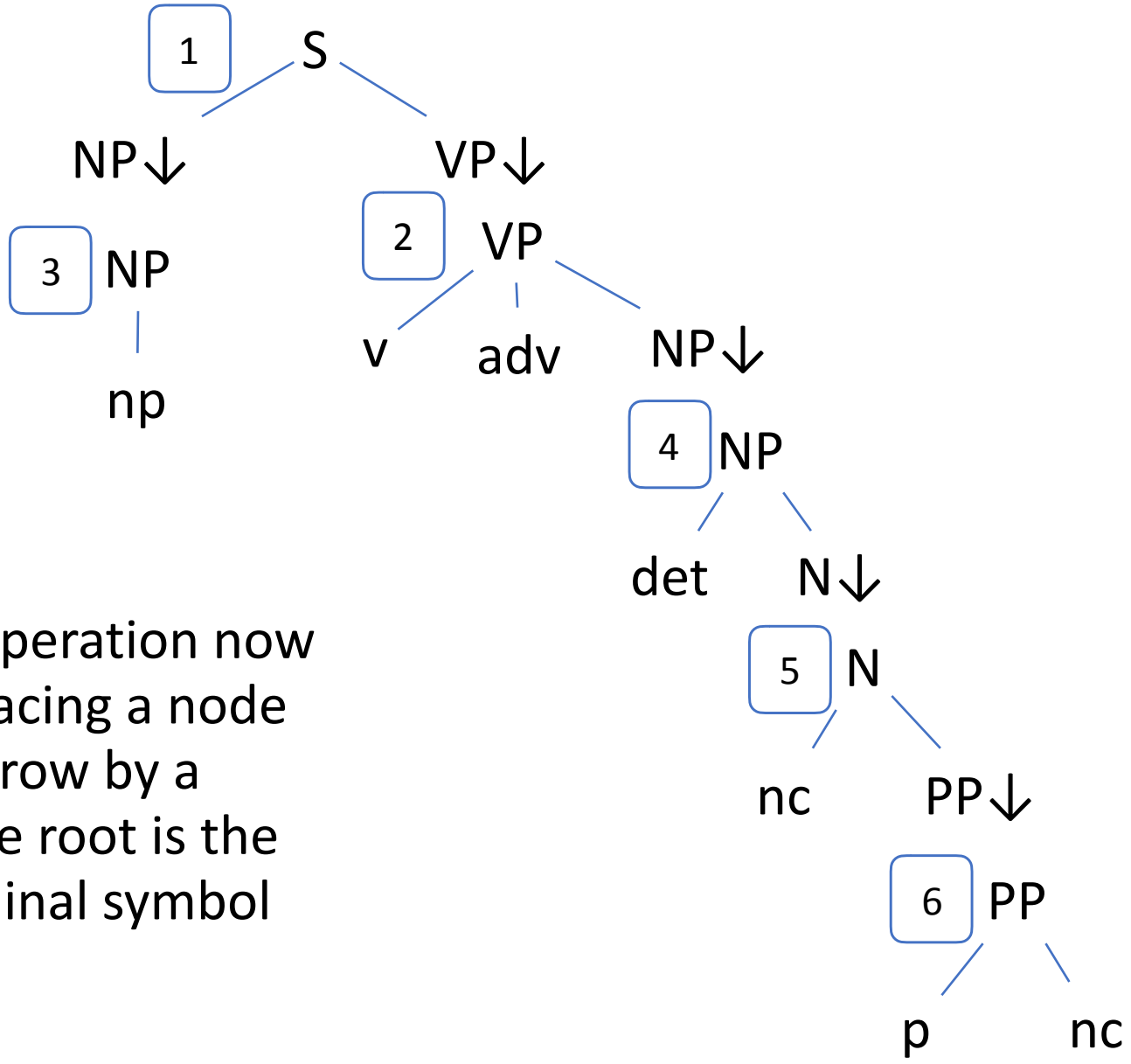
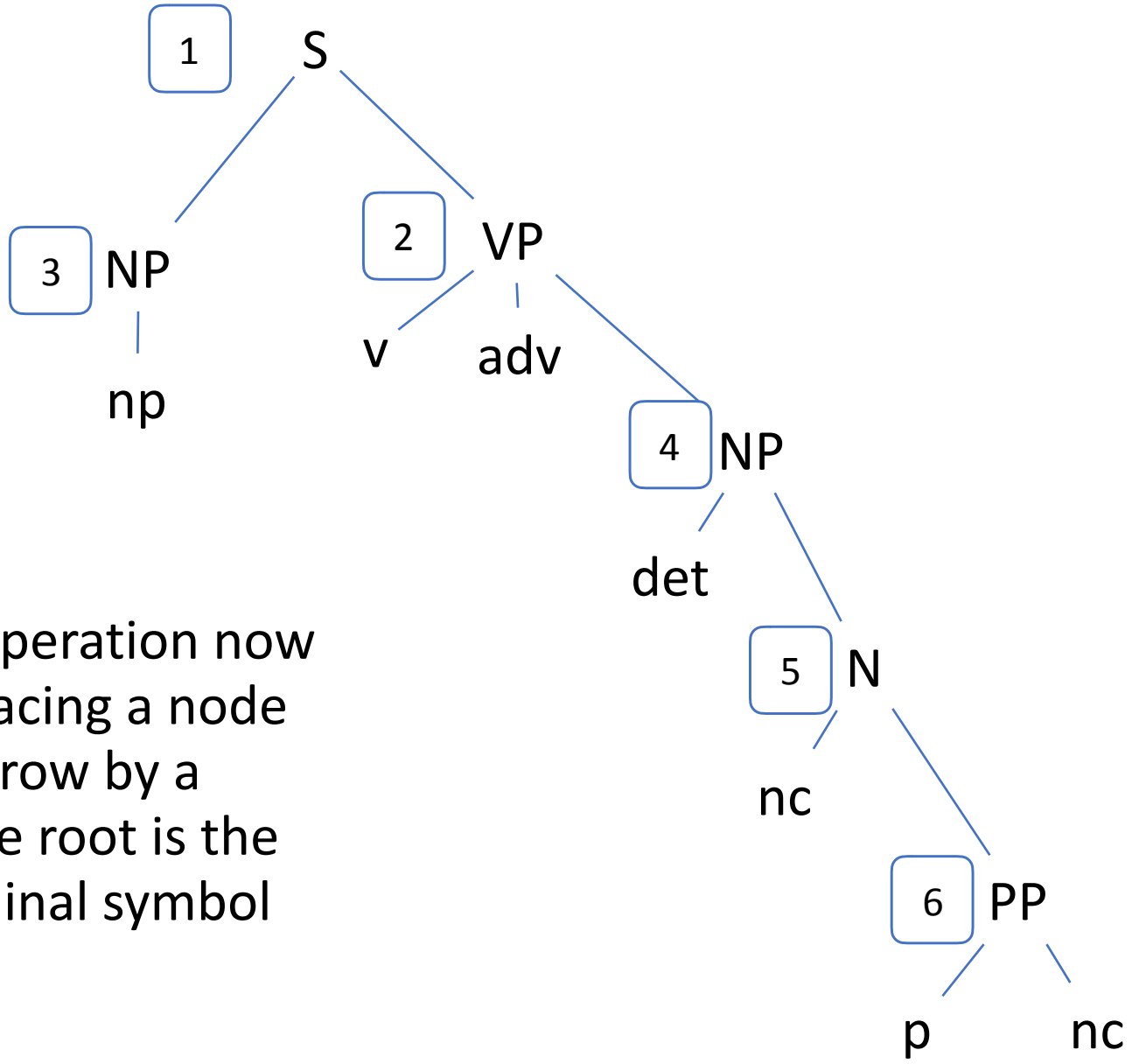




- The rewriting operation now consists in replacing a node with a down-arrow by a (sub)tree whose root is the same non-terminal symbol



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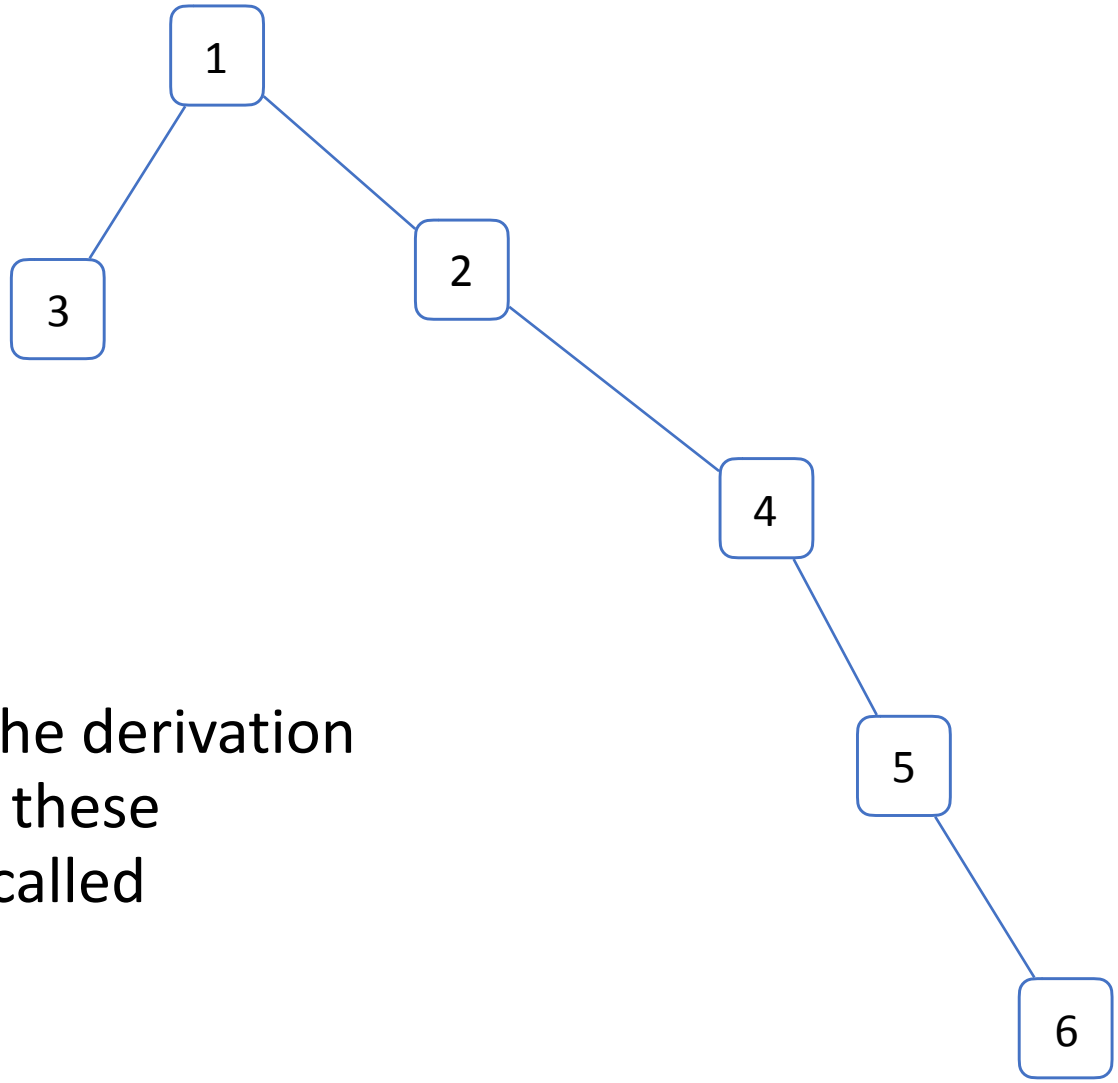
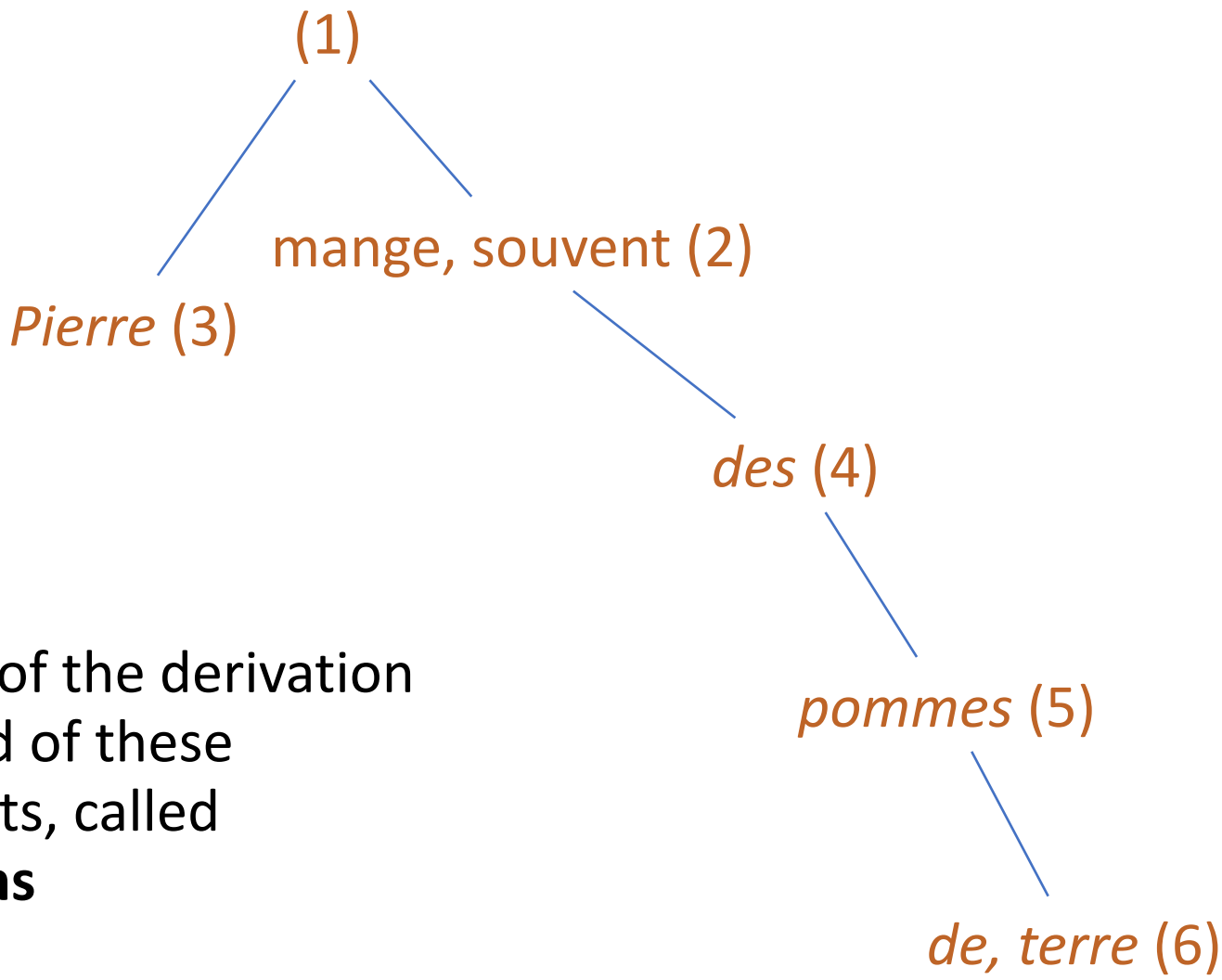


- The history of the derivation is the record of these replacements, called **substitutions**



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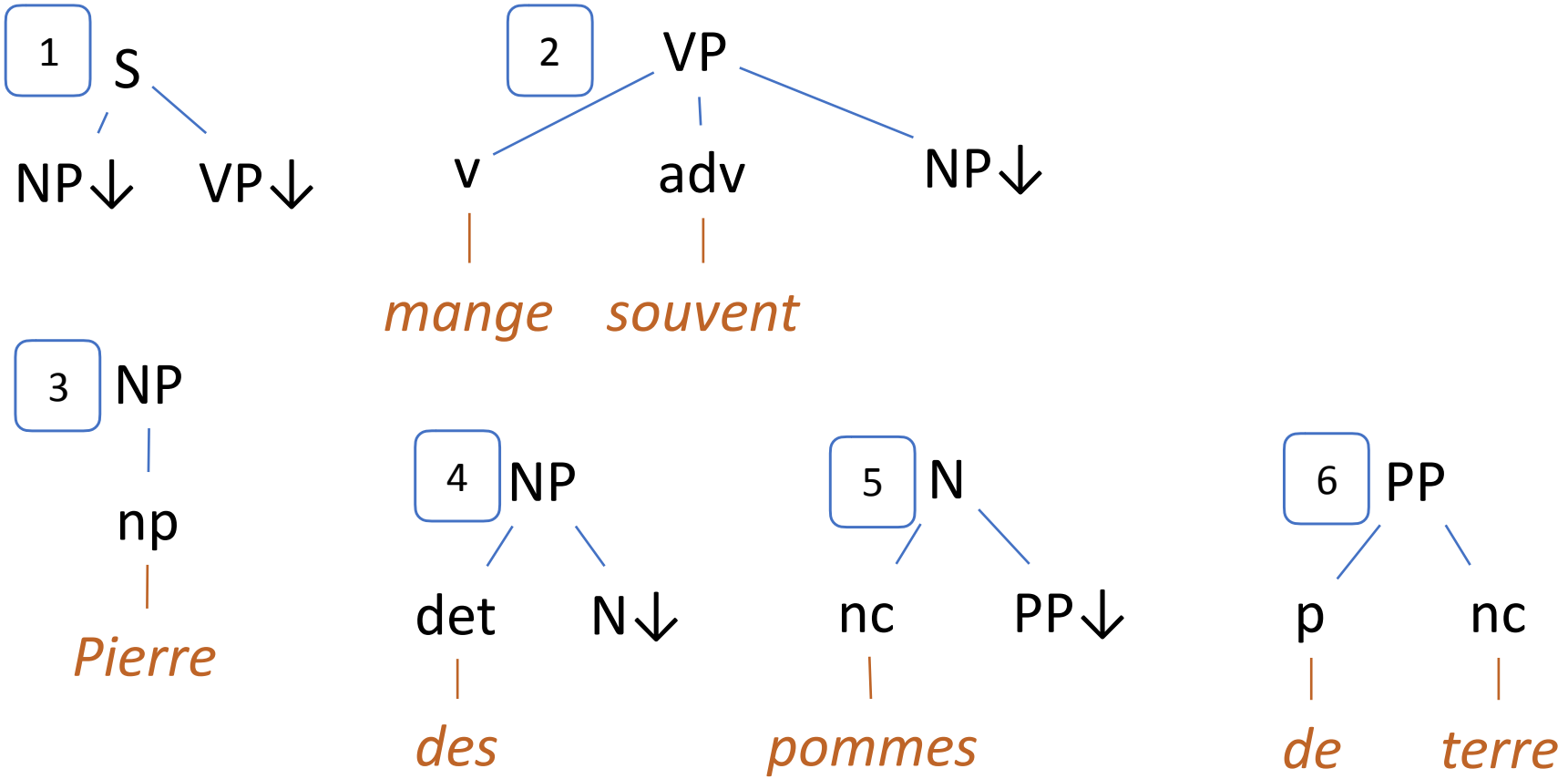
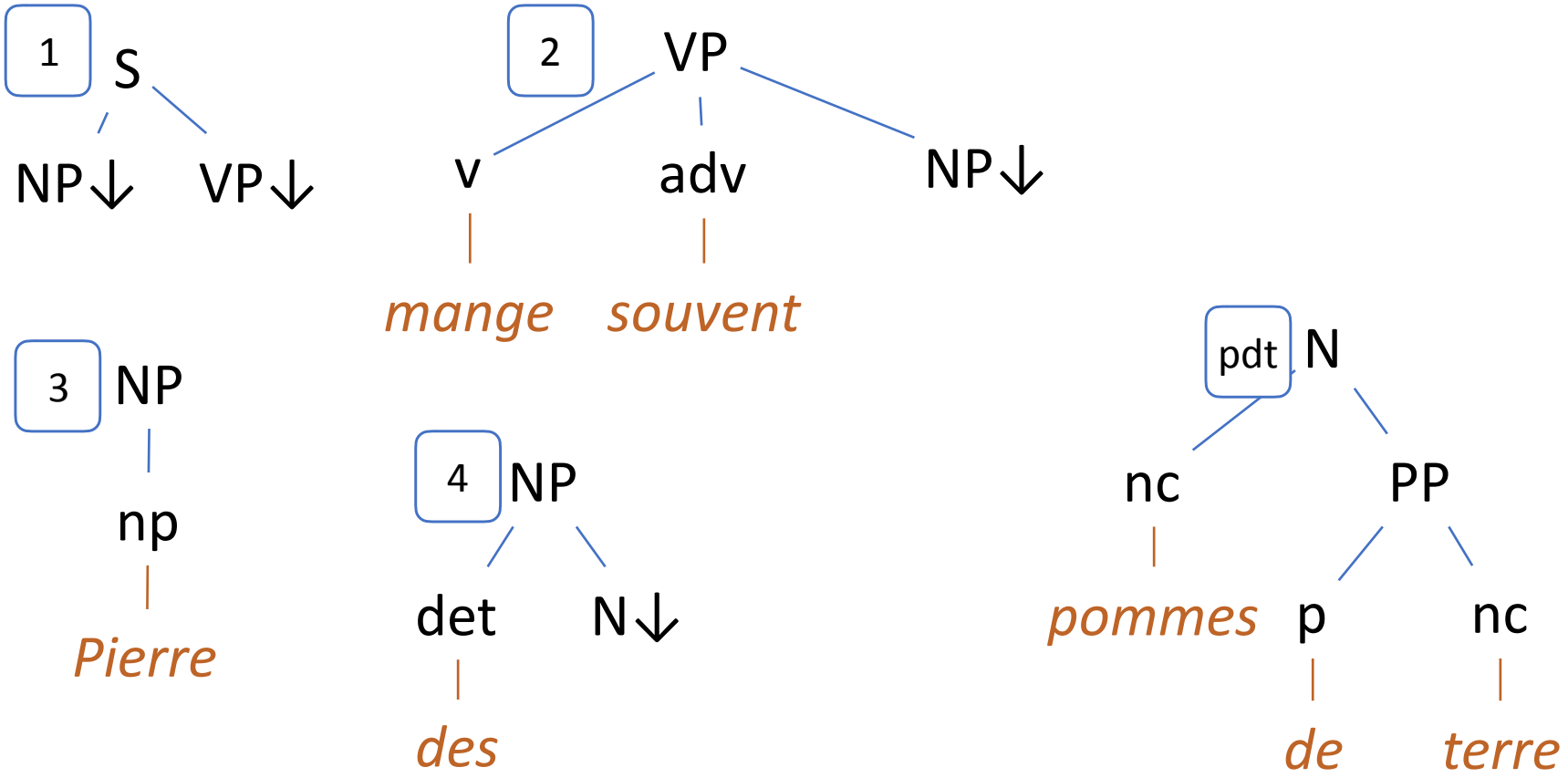
Tree substitution grammars

- Let us reintroduce the lexicon (i.e. anchoring)

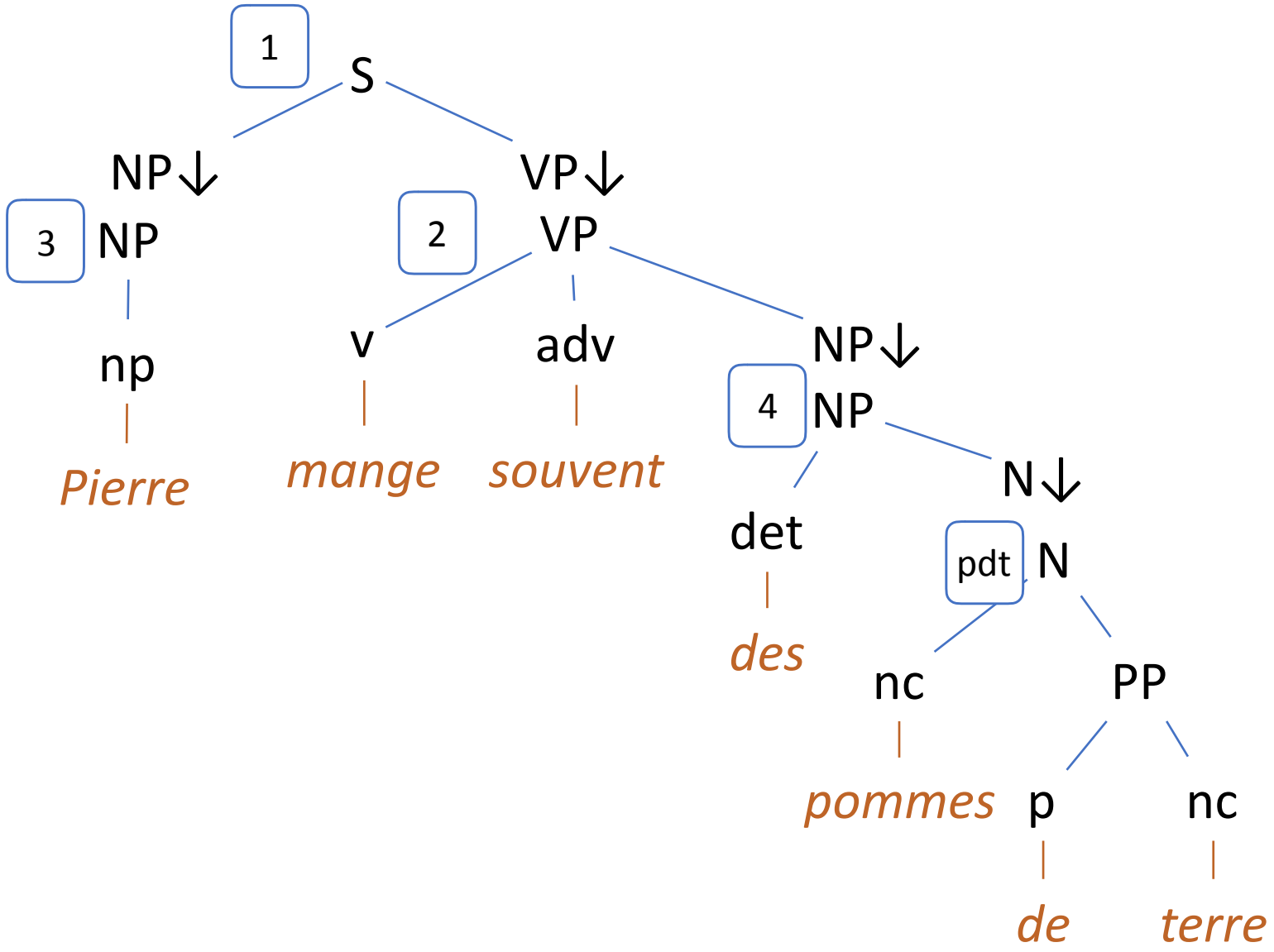


Tree substitution grammars

- There is no reason to stick to 2-level elementary trees



Solving the compound word problem



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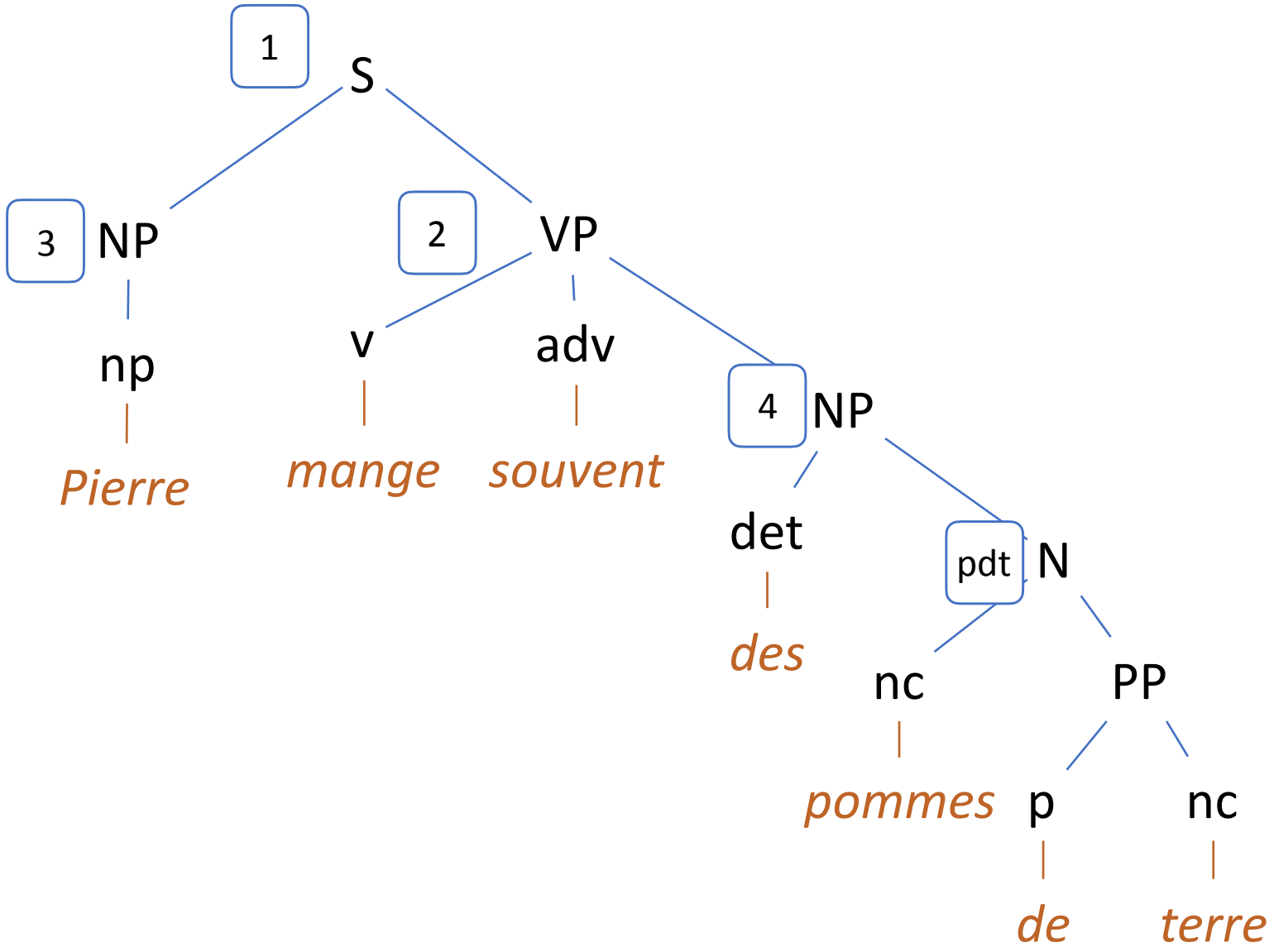

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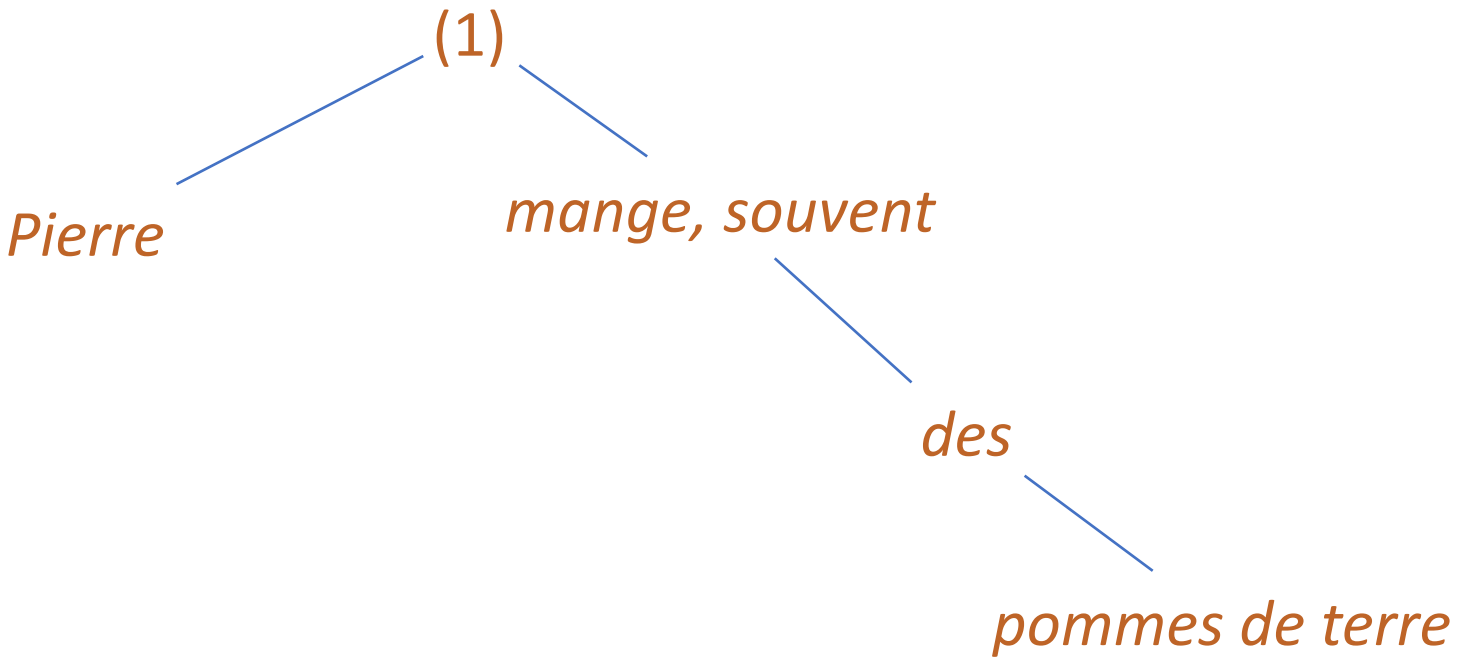
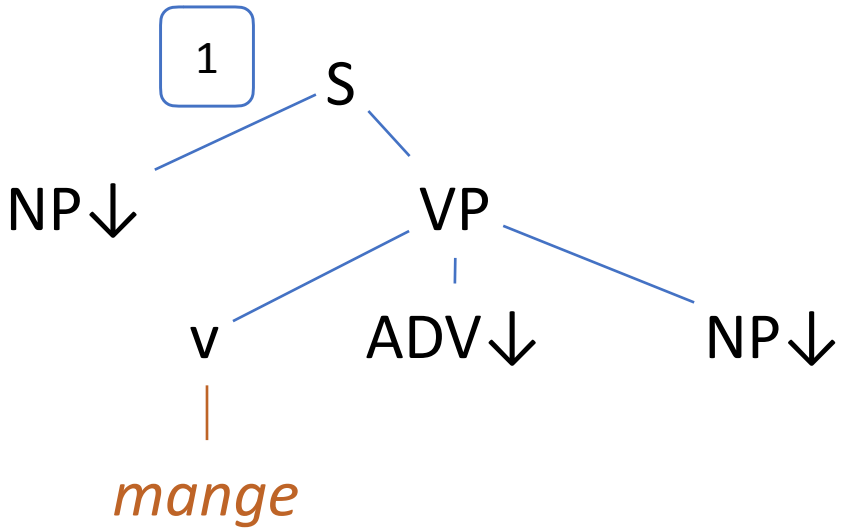


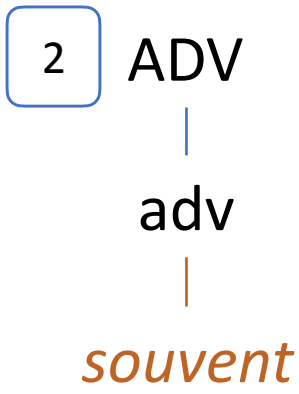
Lexicalisation

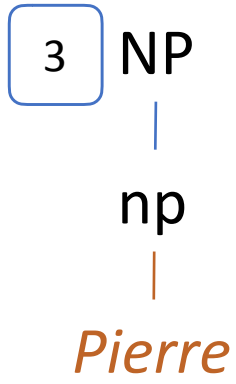
Lexicalisation

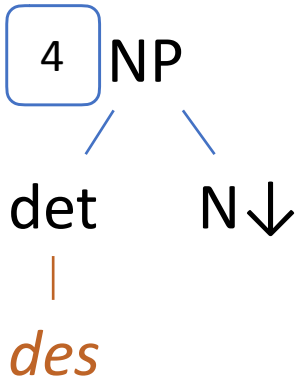
- In order to avoid non-anchored nodes, we can ensure that every elementary tree has **at least one terminal symbol**
- Moreover, we can ensure that every tree has **anchors that constitute a semantic word**
- We will once again take advantage of the fact that TSGs do not bound the depth of elementary trees (contrary to CFGs)

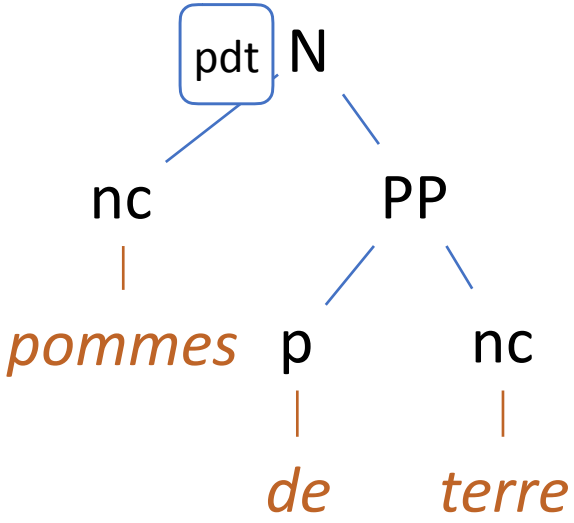
Lexicalised tree substitution grammar











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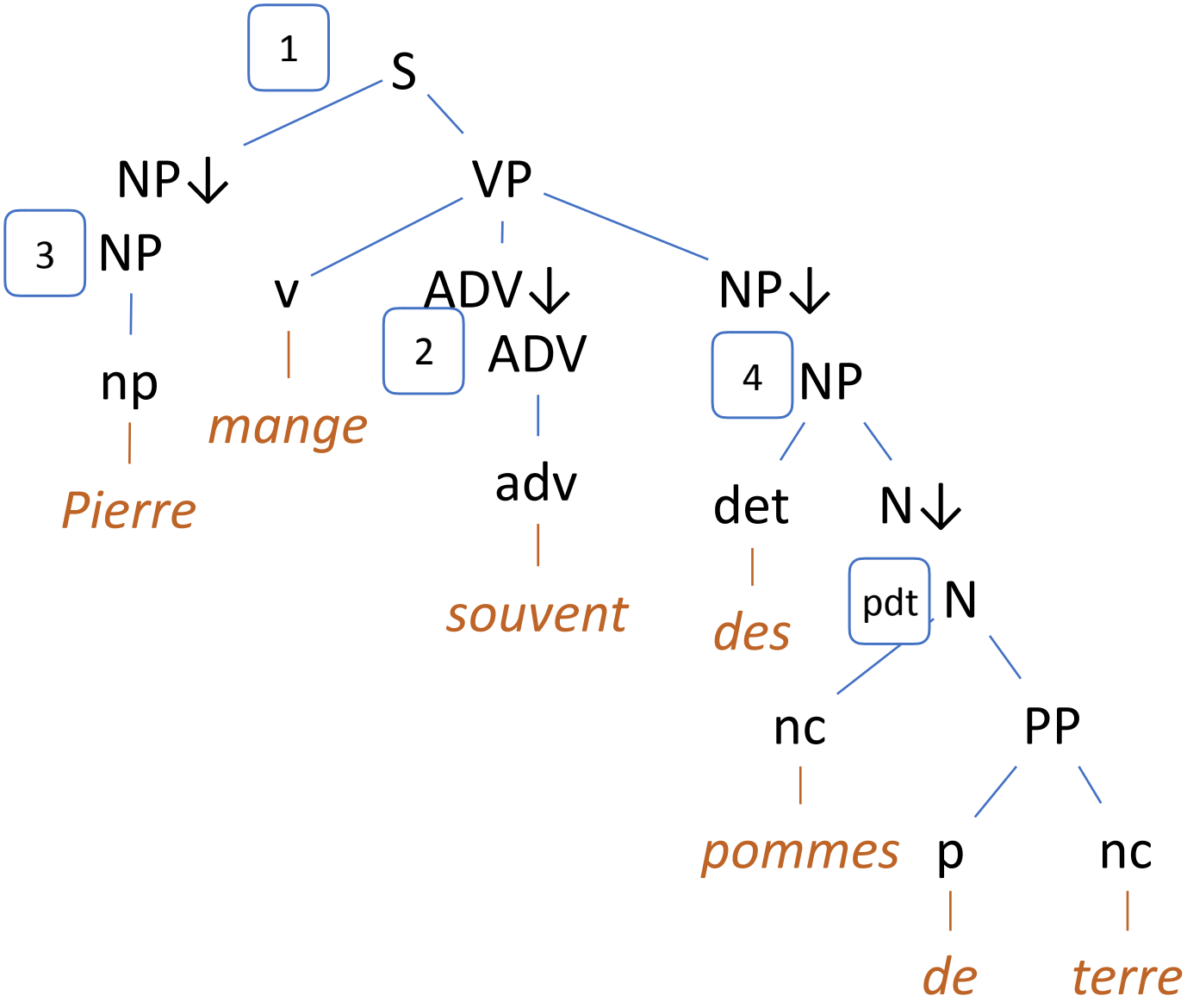

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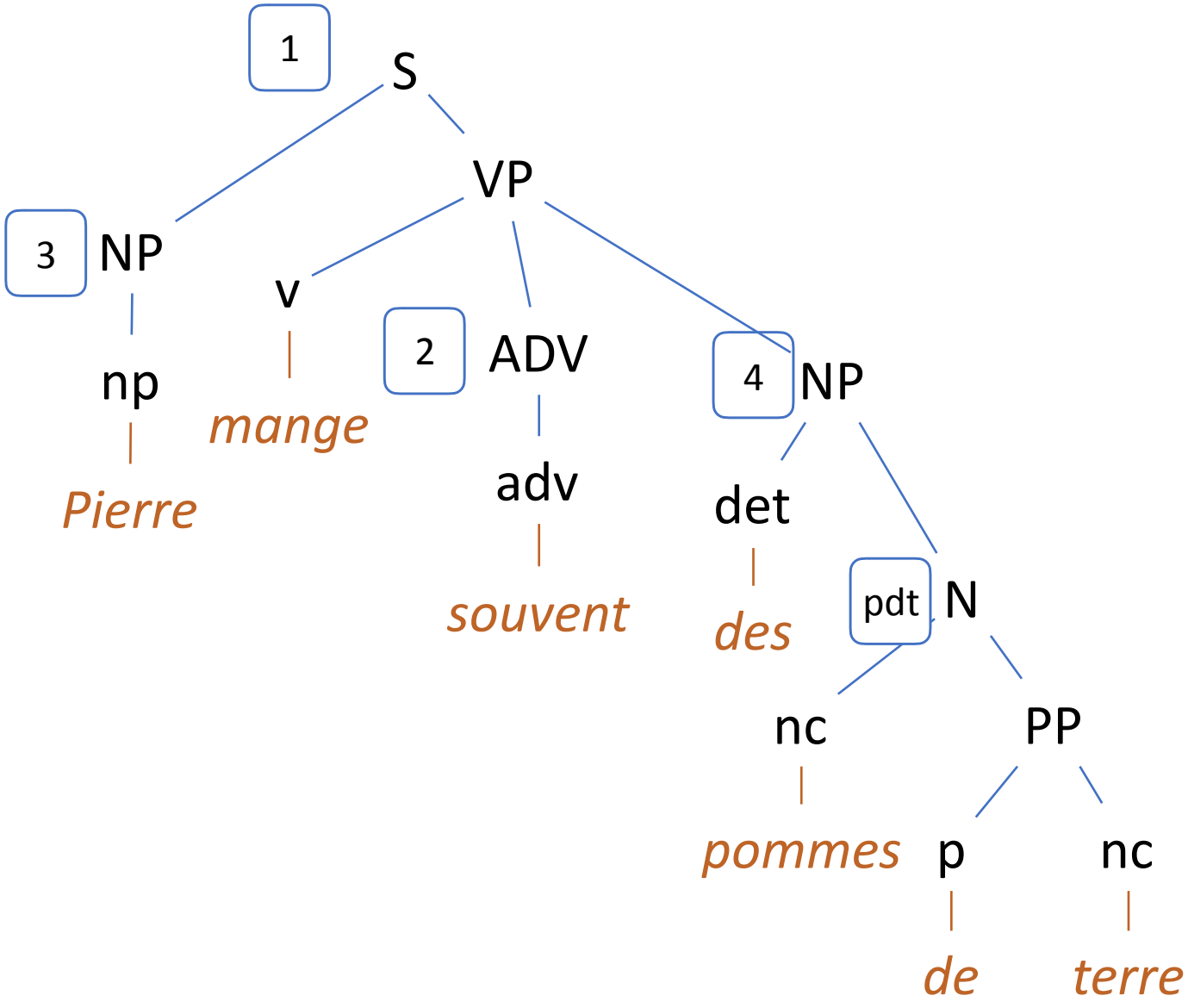

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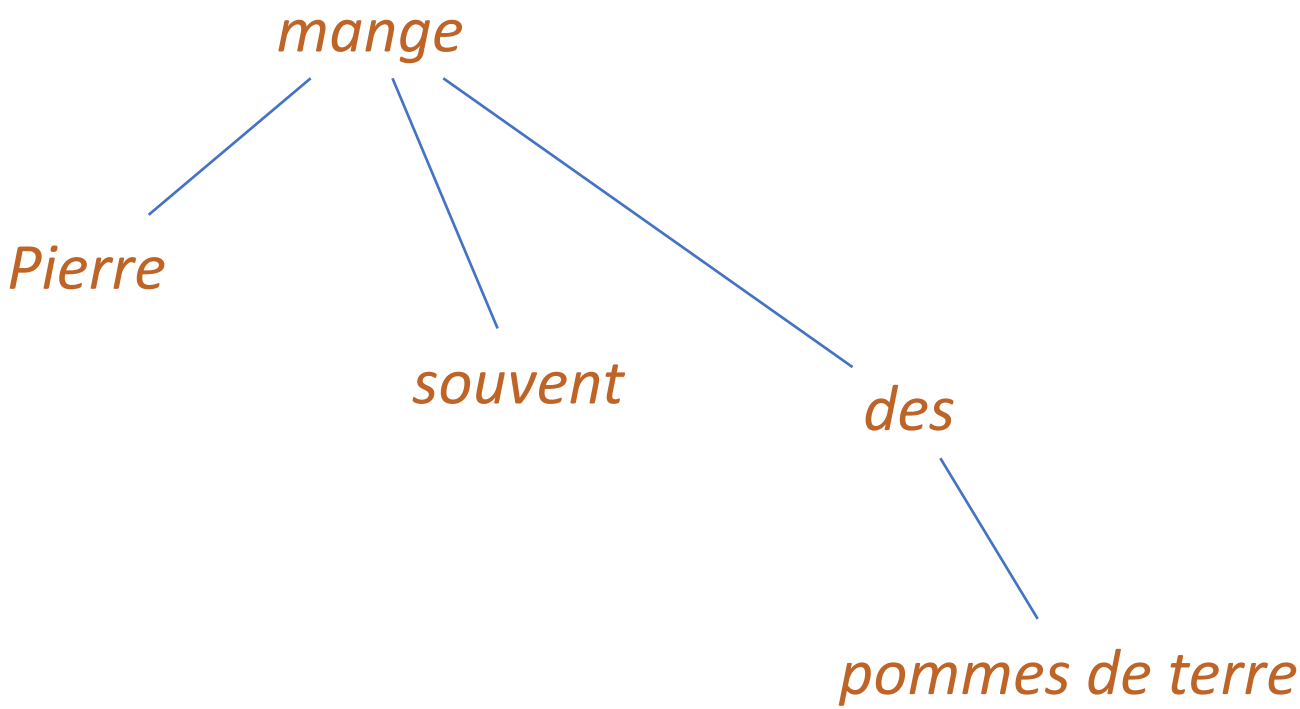
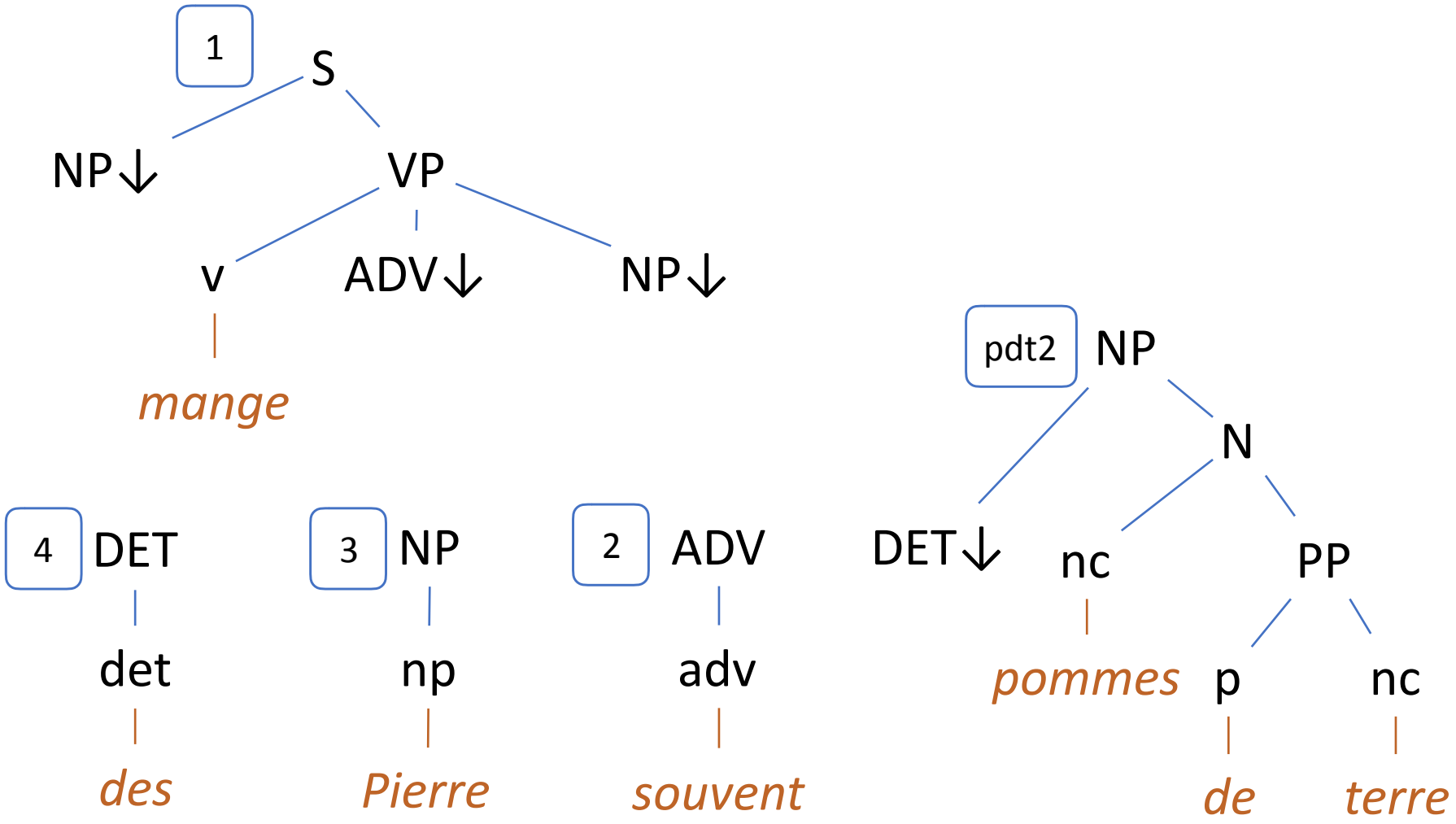


Lexicalisation

- Slight improvement: a new non-terminal to get the determiner *below* its nouns

Lexicalisation



Tree adjunction grammars

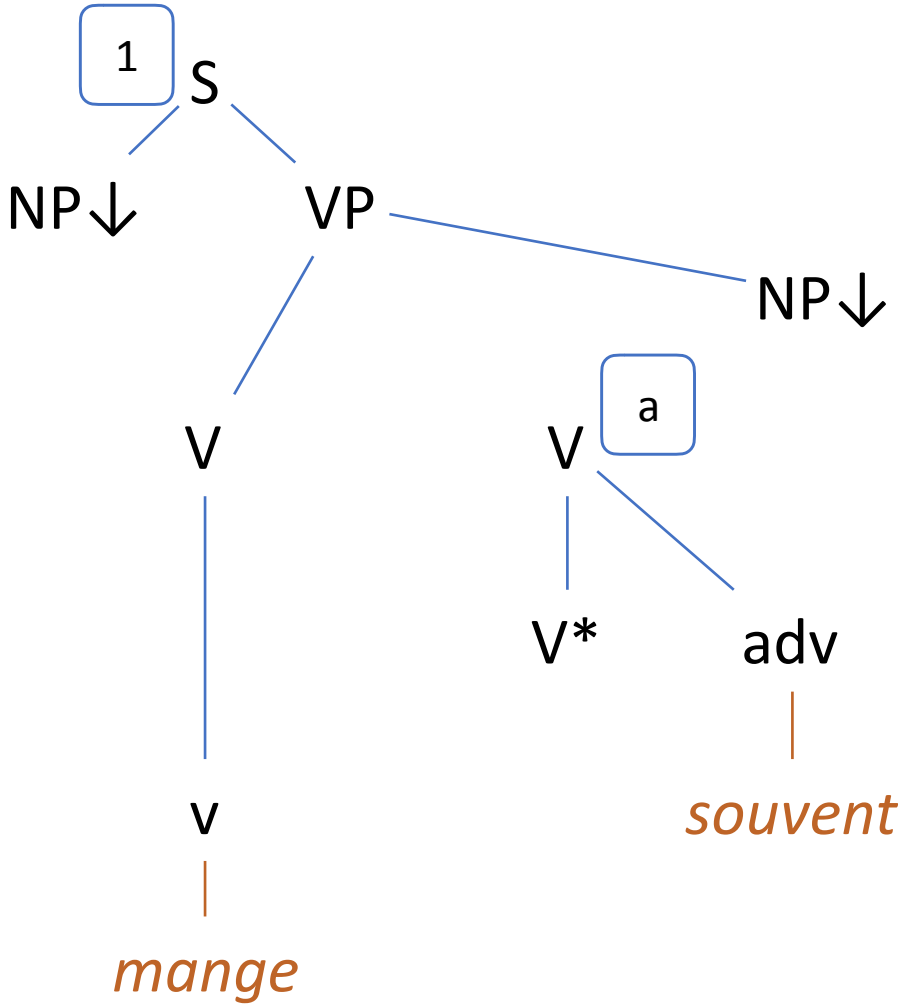
Arguments and modifiers

- In syntax, two major categories of dependencies are distinguished: **arguments and modifiers**
  - The presence or absence and the properties of an argument are determined by its governor
  - A modifier is a self-standing phrase that modifies its governor
- Generally, a direct object is an argument, whereas a cicumstancial complement (e.g. expressing a location) is a modifier
  - In our example, *souvent* ‘often’ is a modifier of *mange* ‘eat’, whereas *Pierre* and *des pommes de terre* ‘potatoes’ are arguments of *mange*

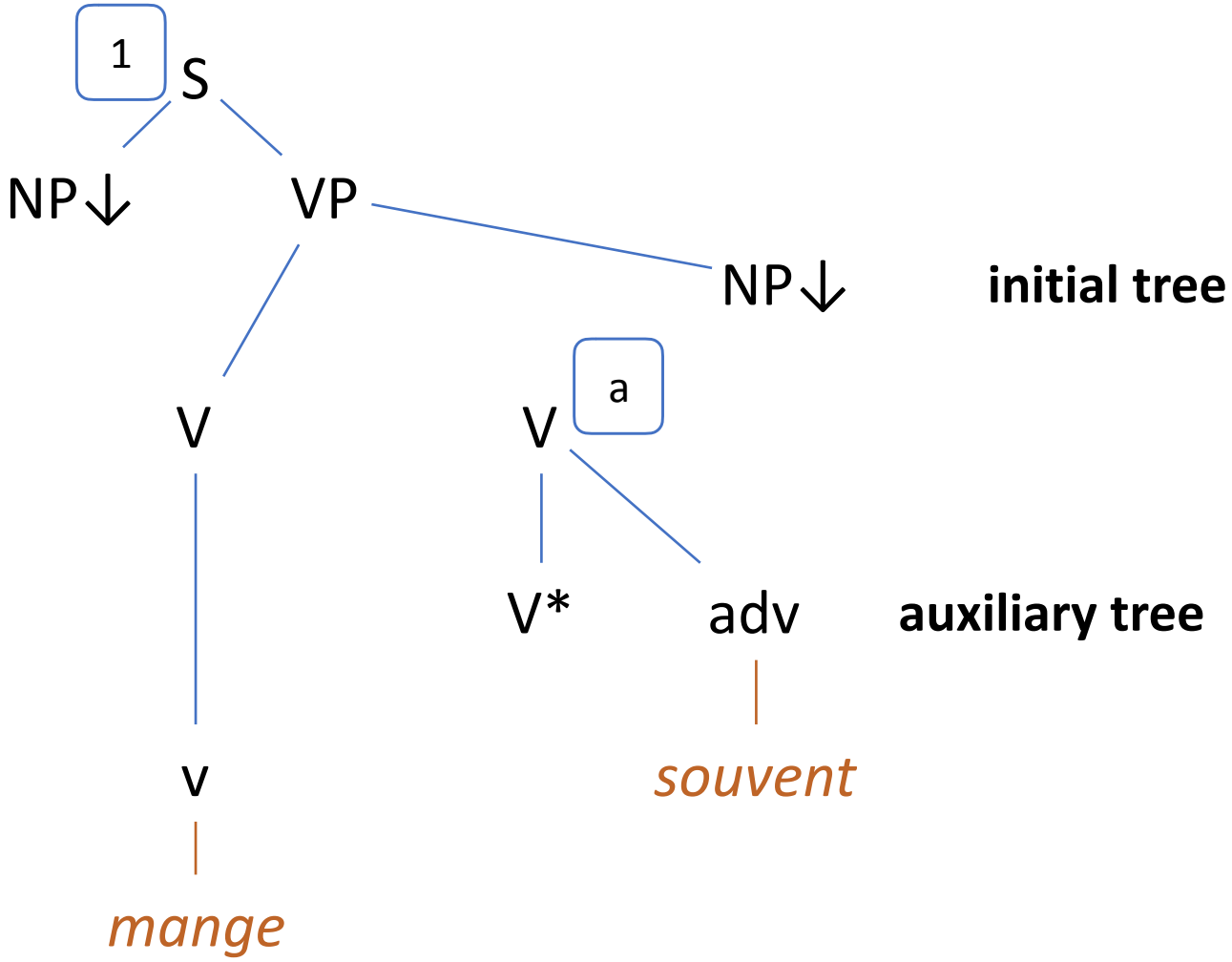
Arguments and modifiers

- Ideally, we would need a way to distinguish arguments and modifiers
  - We would like **arguments** to be “requested” in the elementary tree of the governor => **substitution nodes**
  - We would like a mechanism for modifiers to actually “attach” by themselves to their governor, which would work as a host
- It would be a more elegant way to solve our “determiner” issue
- We will define a new operation, on top of substitution, thus defining Tree Adjoining Grammars (TAGs)
  - LTAGs when they are lexicalised

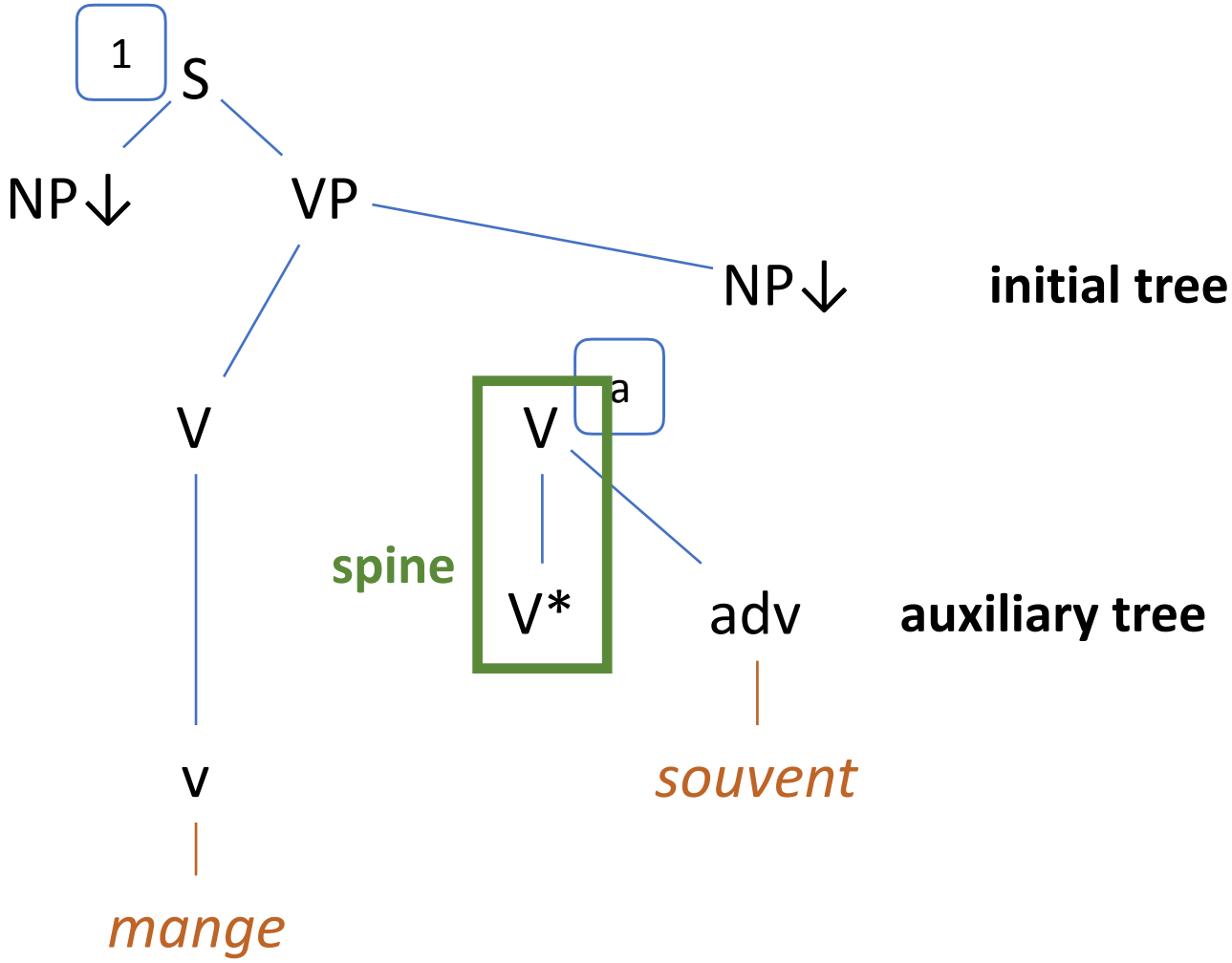
The adjunction operation



The adjunction operation



The adjunction operation



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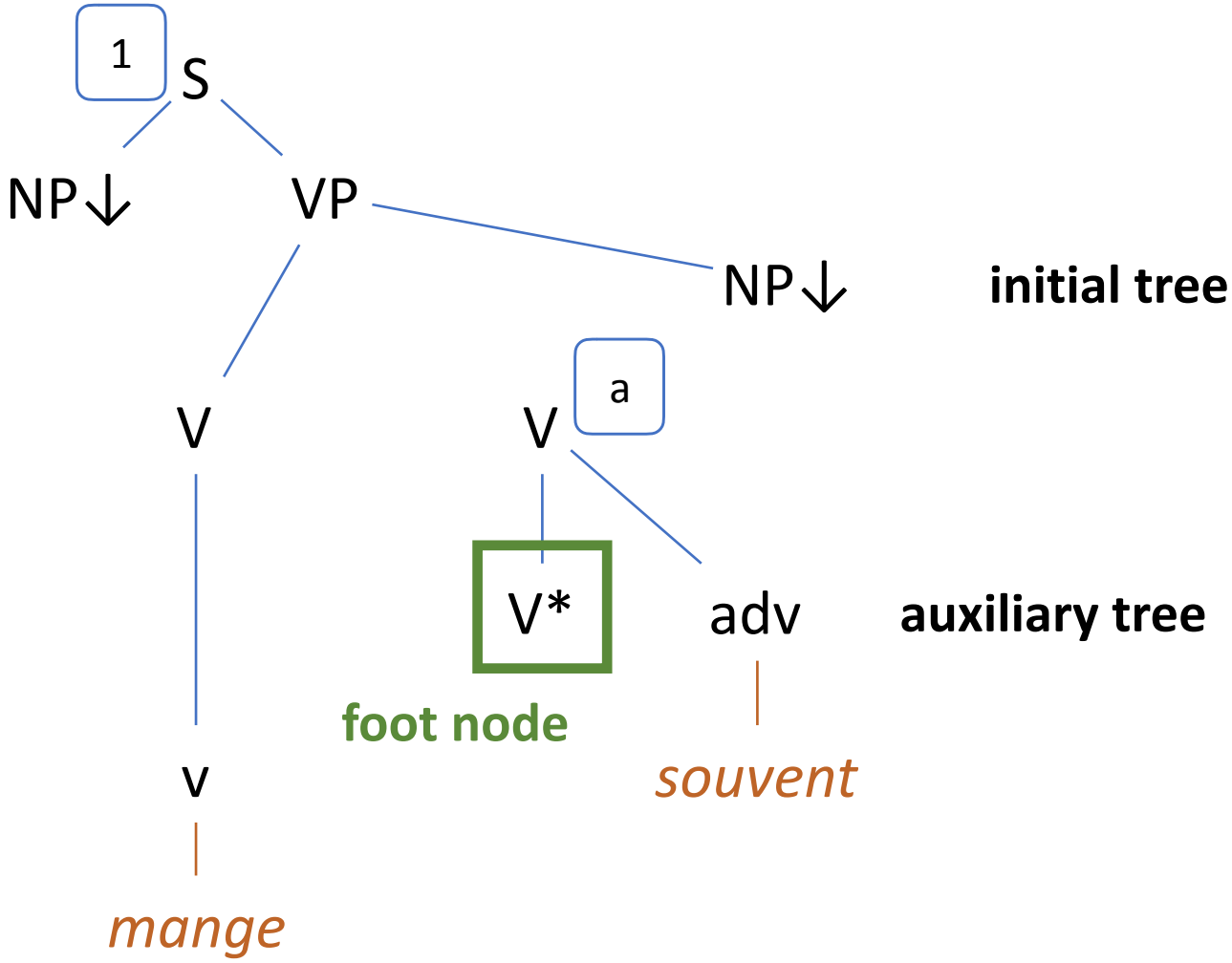

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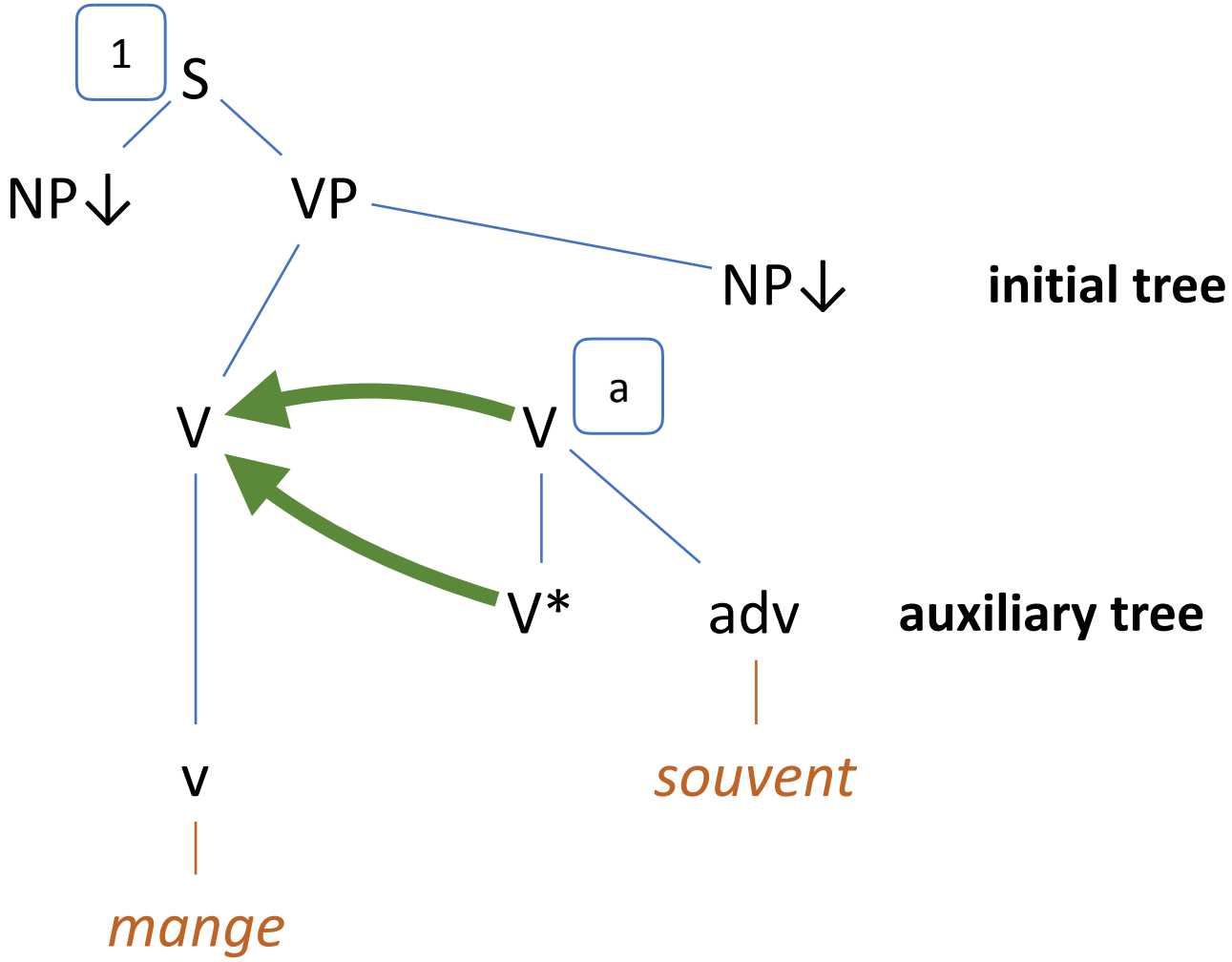

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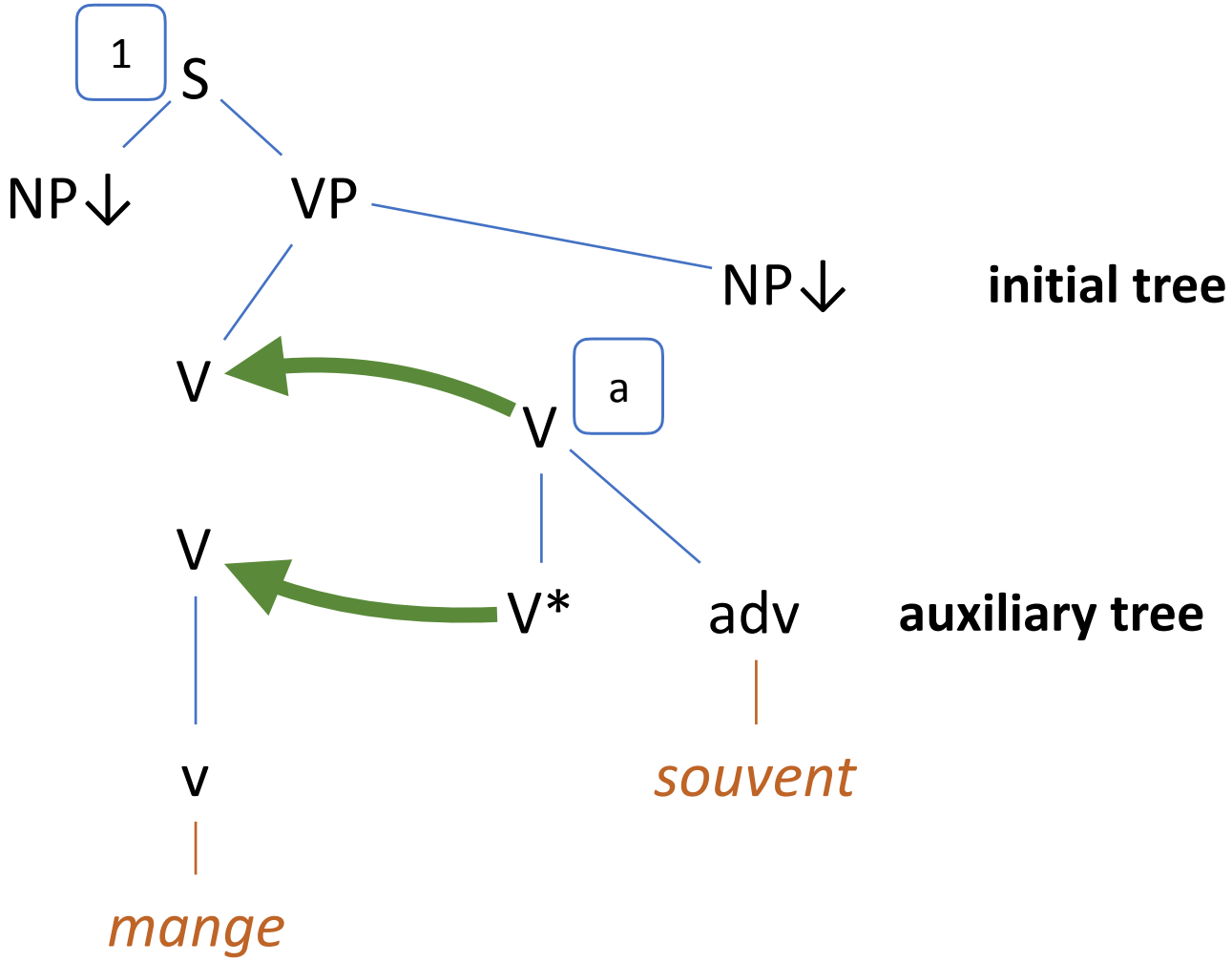

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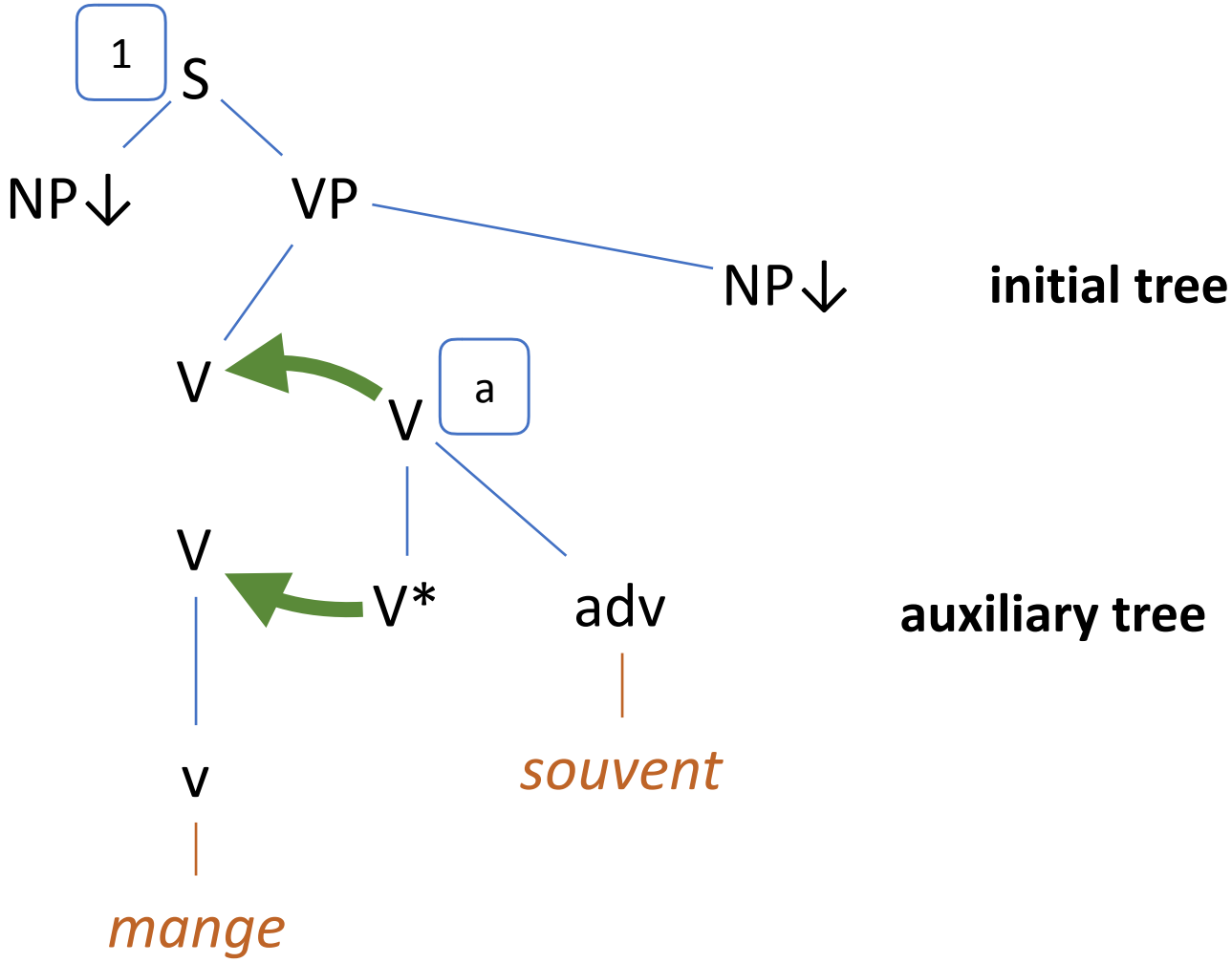

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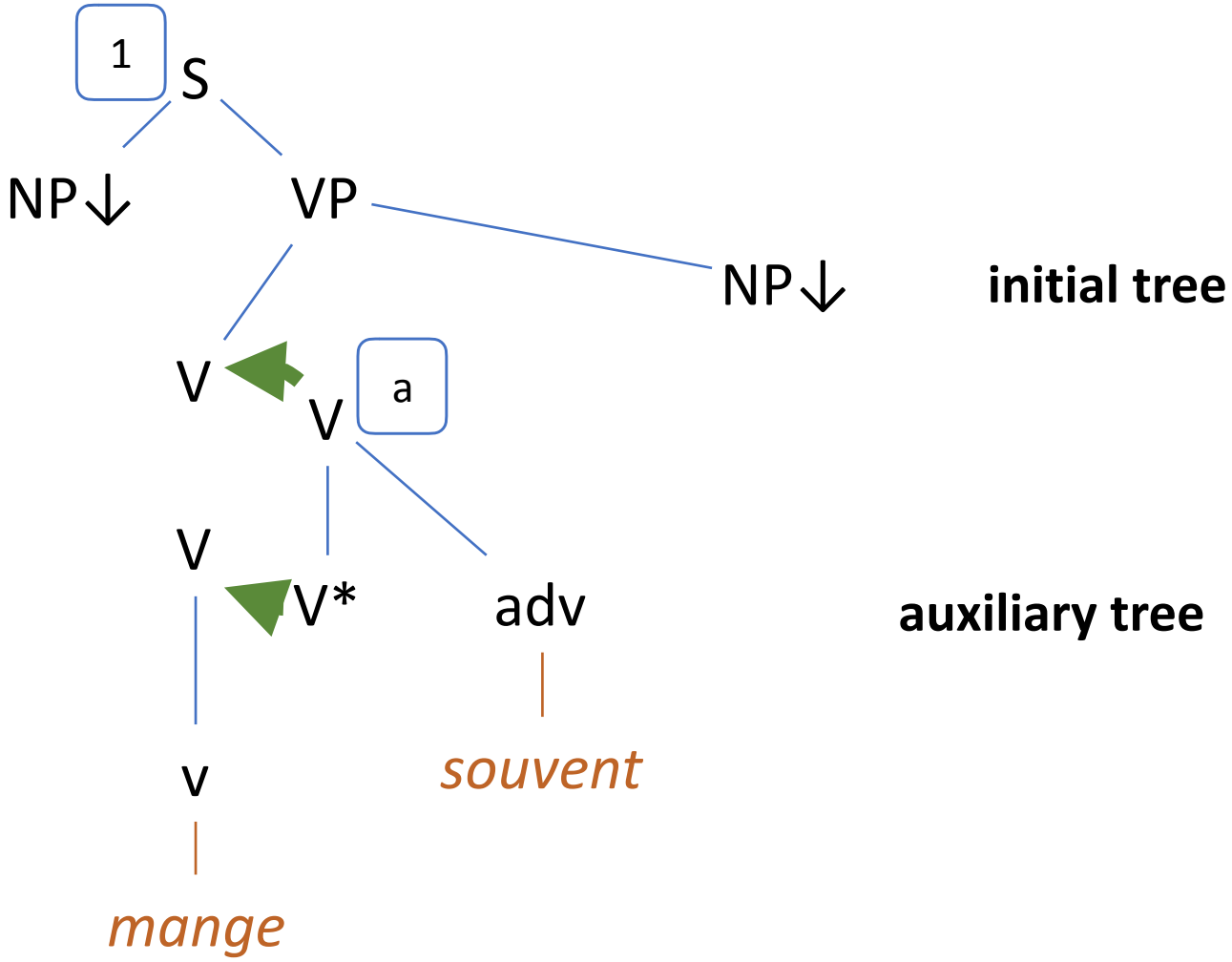

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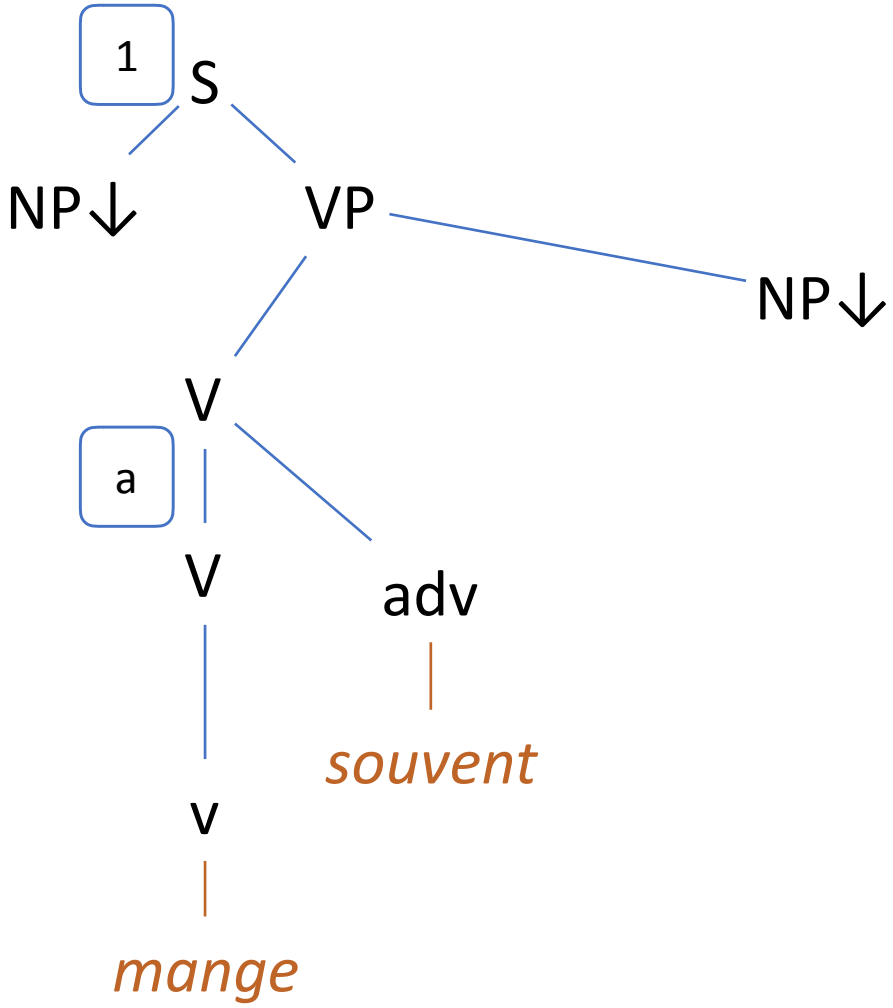

The adjunction operation

- In the derivation tree, we must now represent 2 distinct operations:
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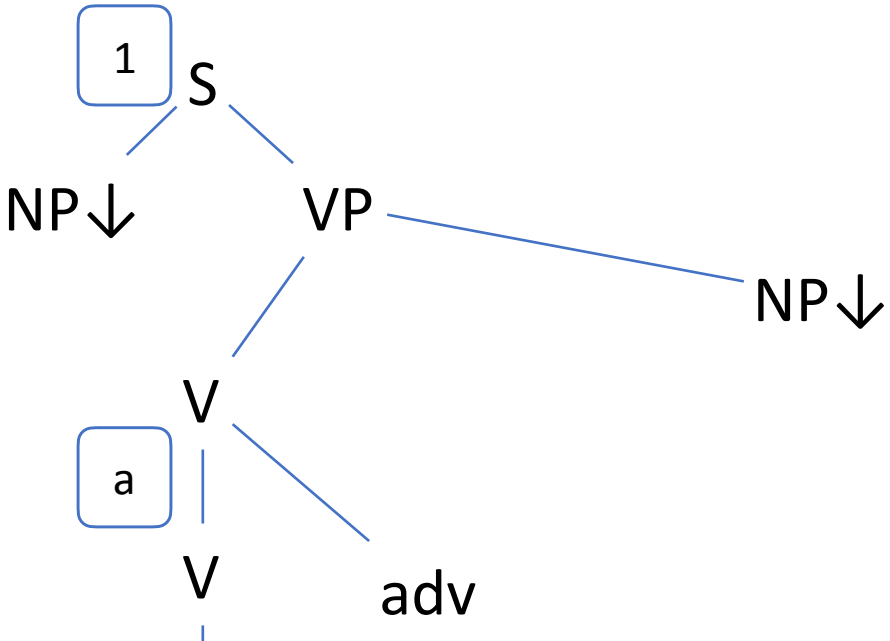

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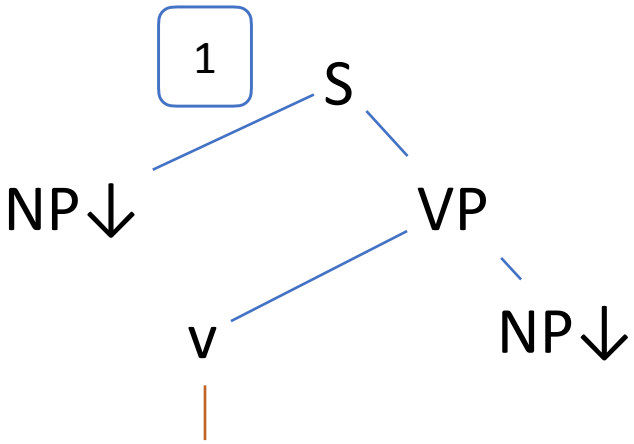
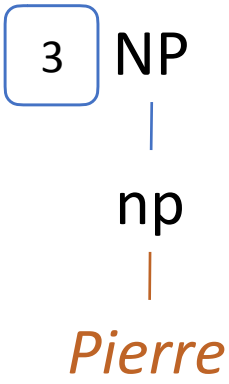
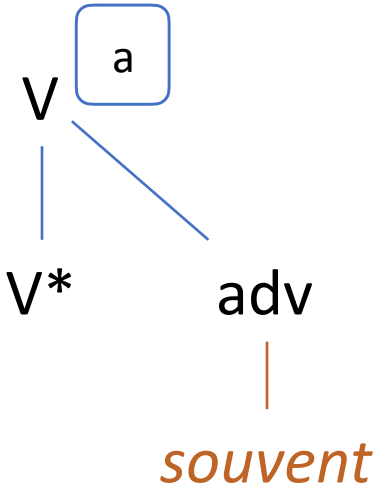
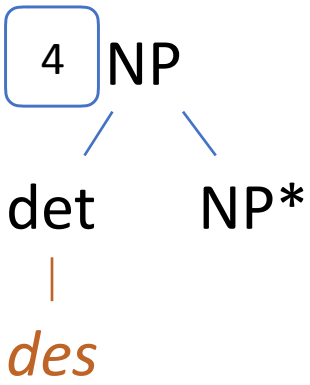
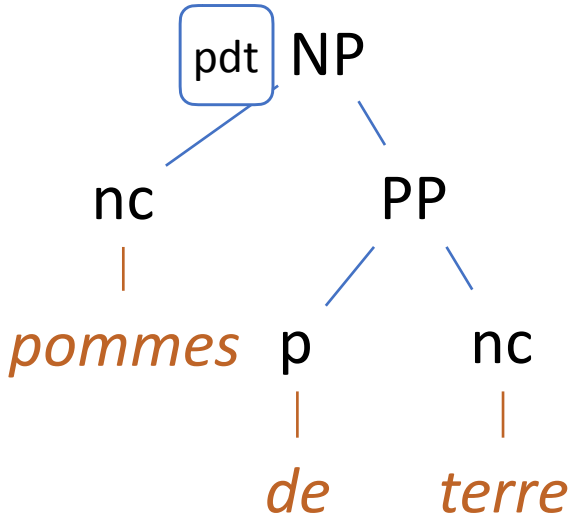




Derivation tree







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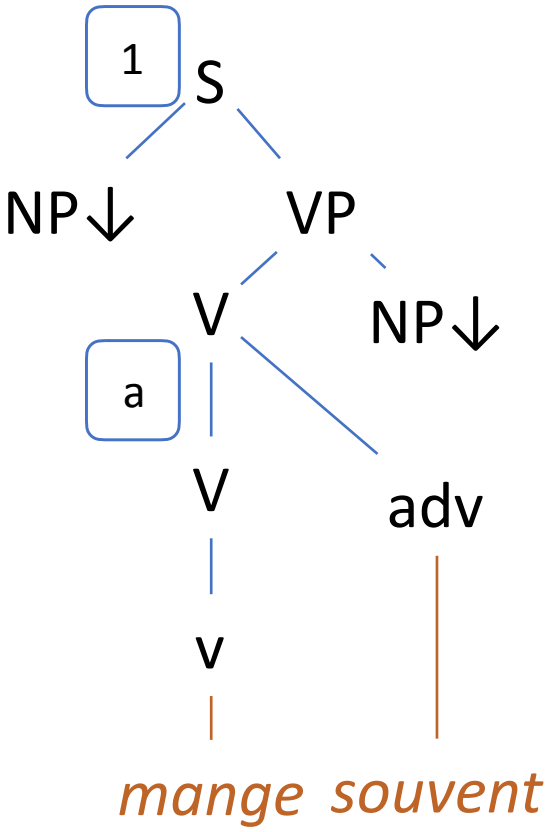

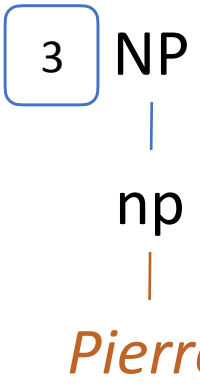

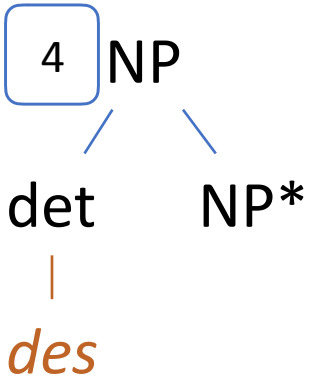

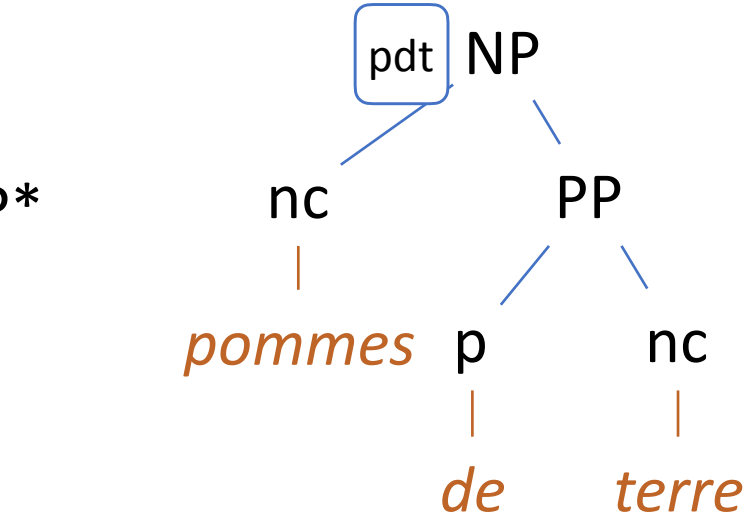

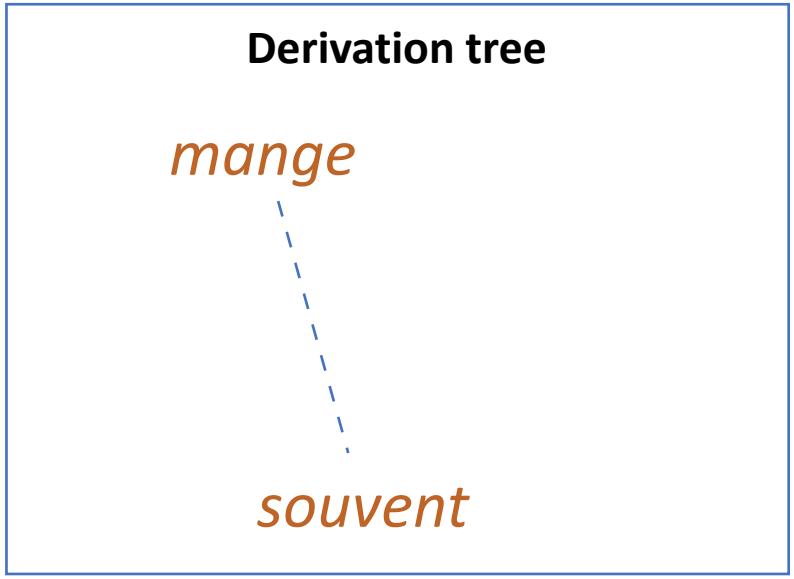

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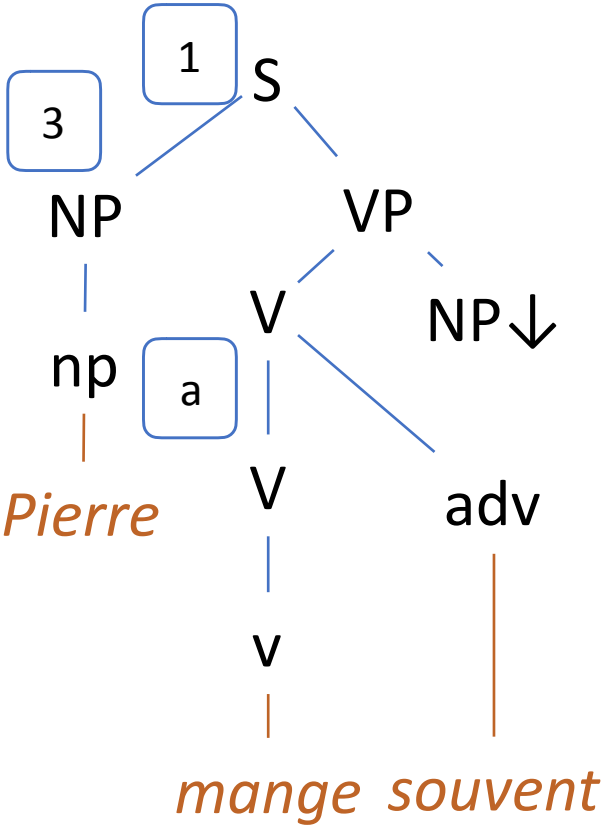

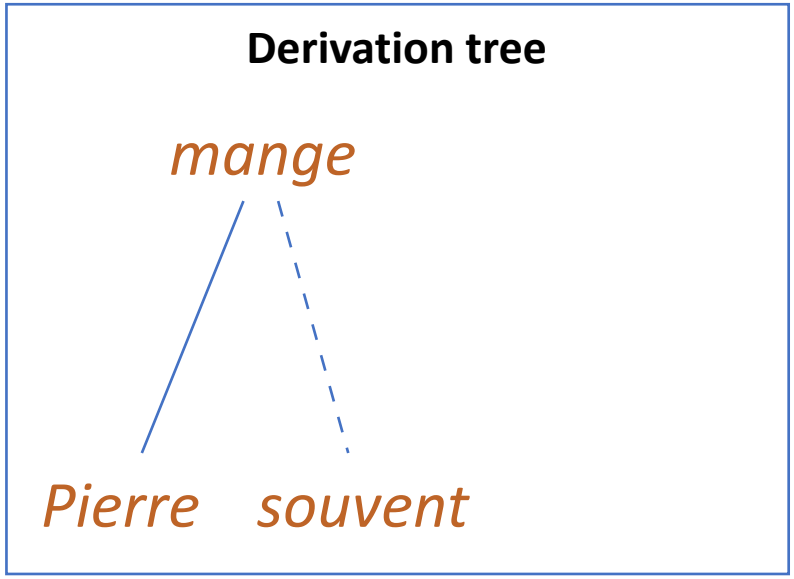

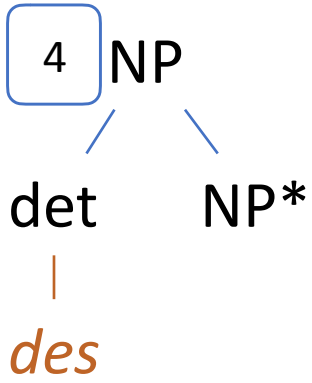

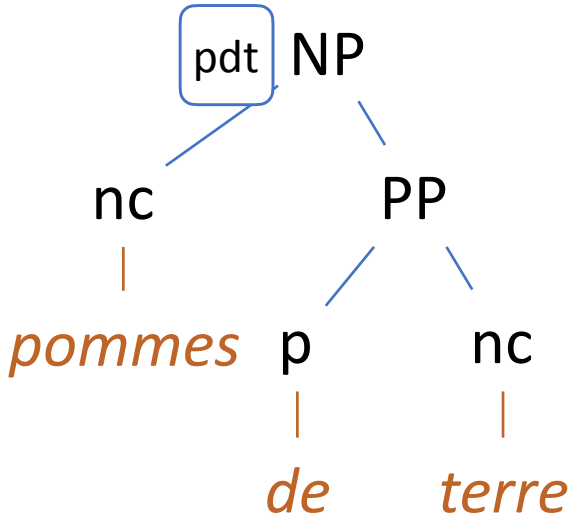

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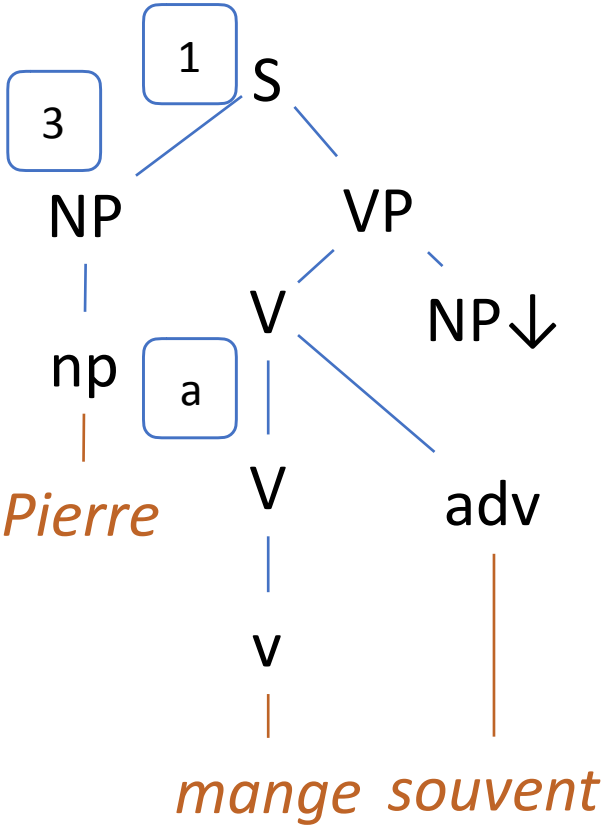

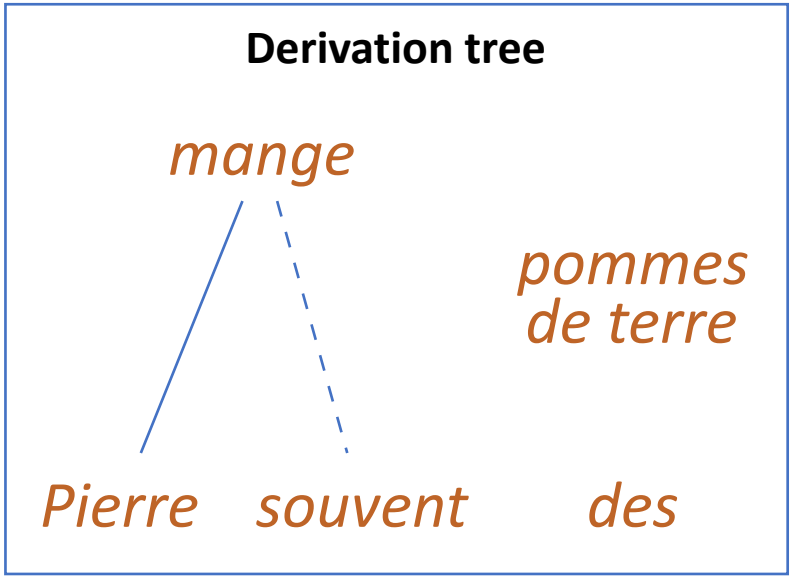

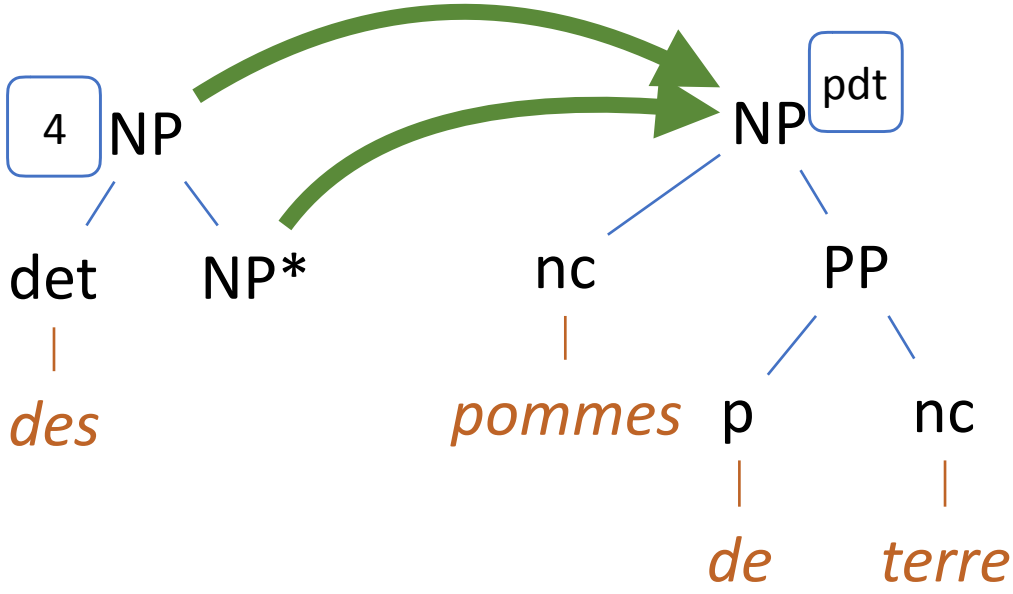

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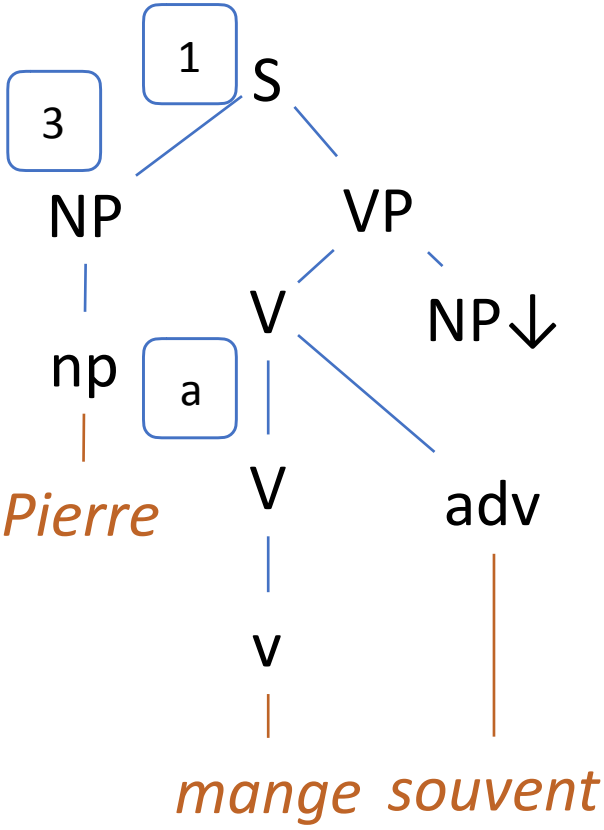

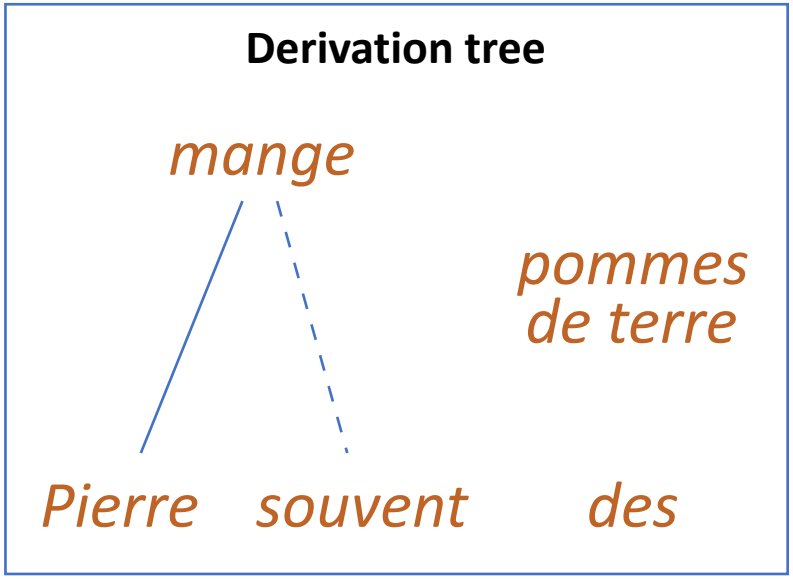

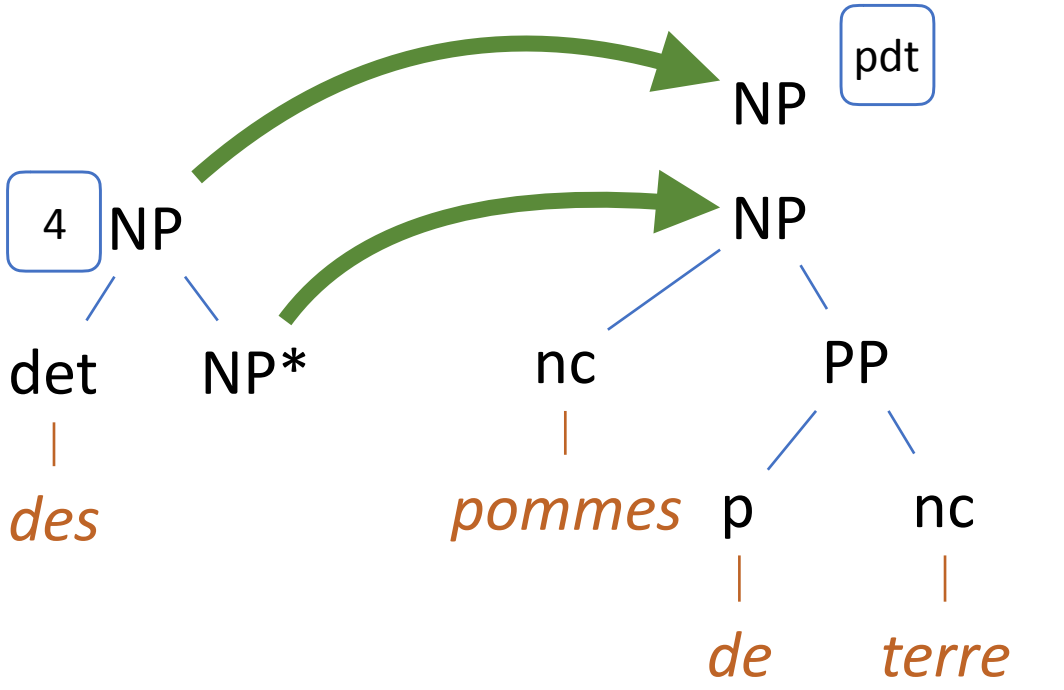

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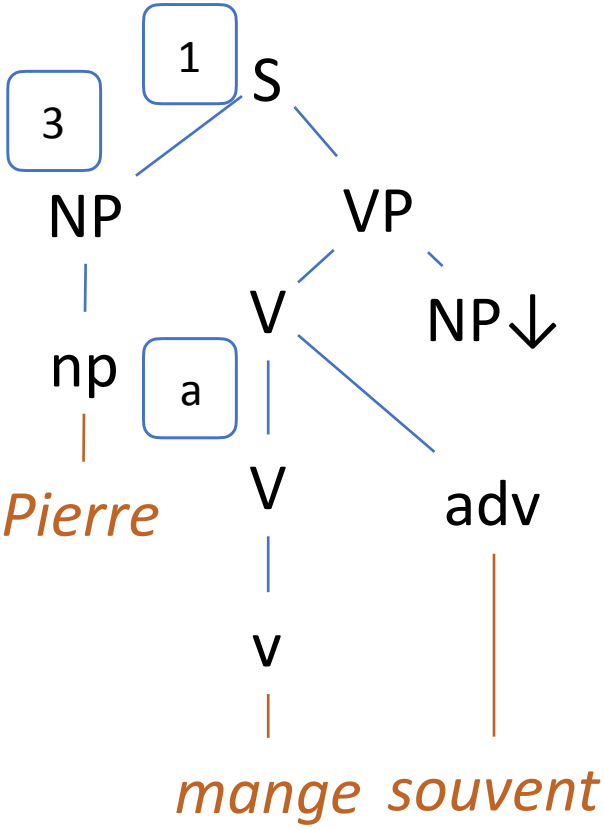

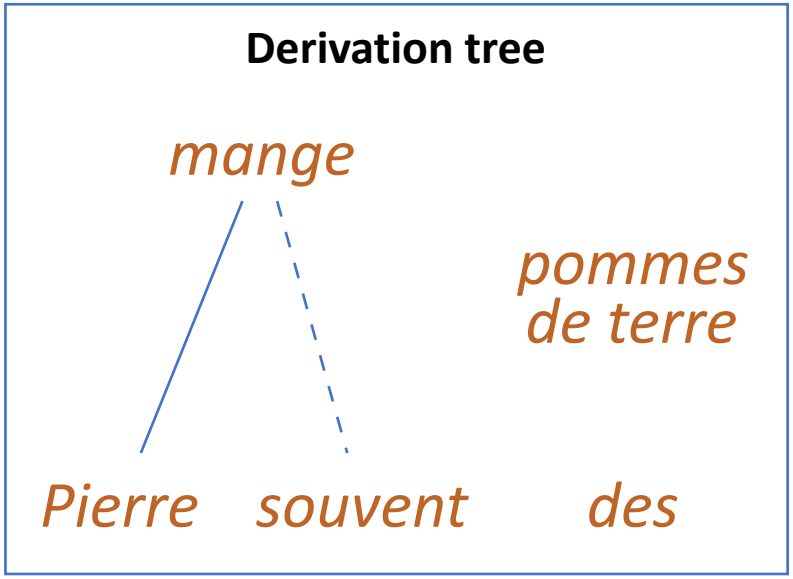

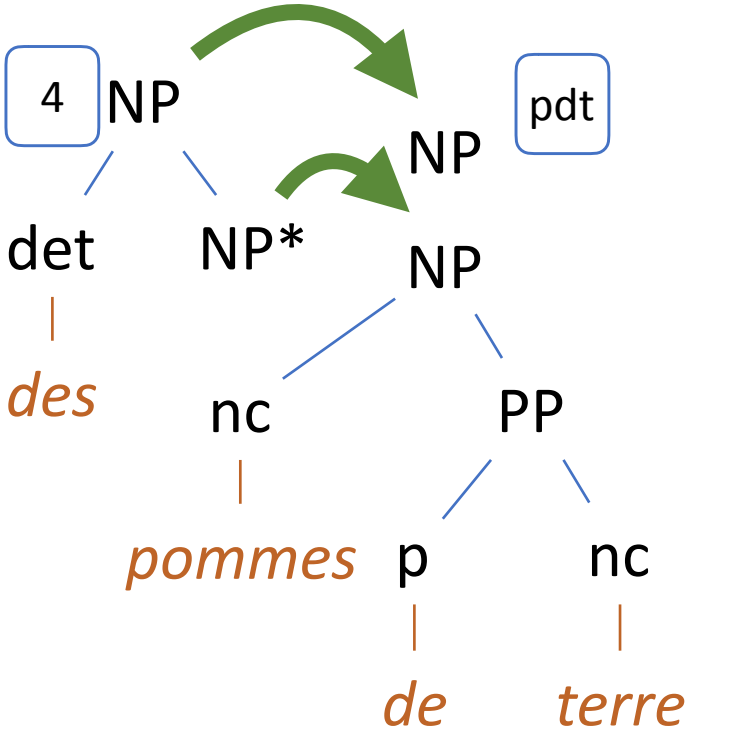

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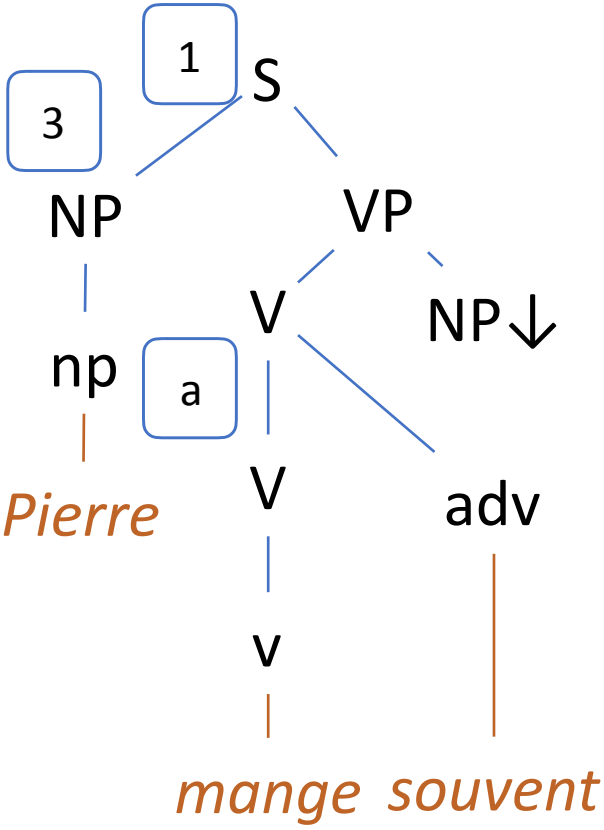

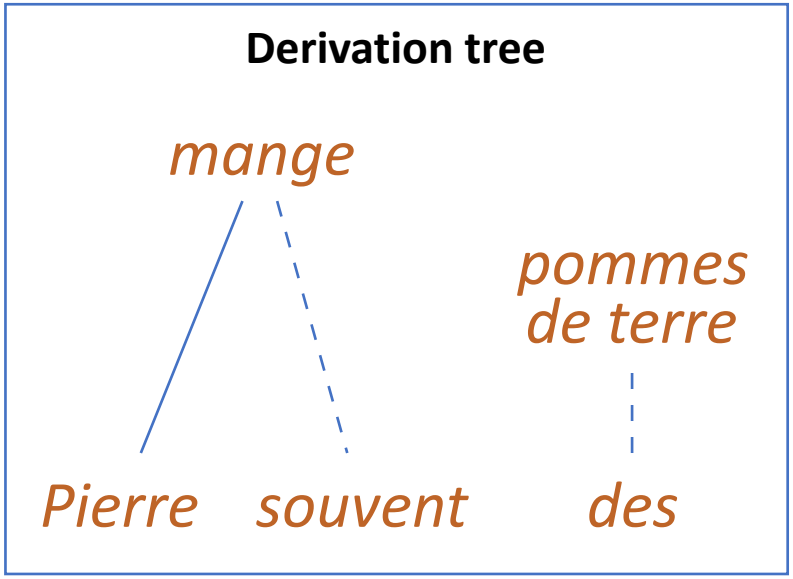

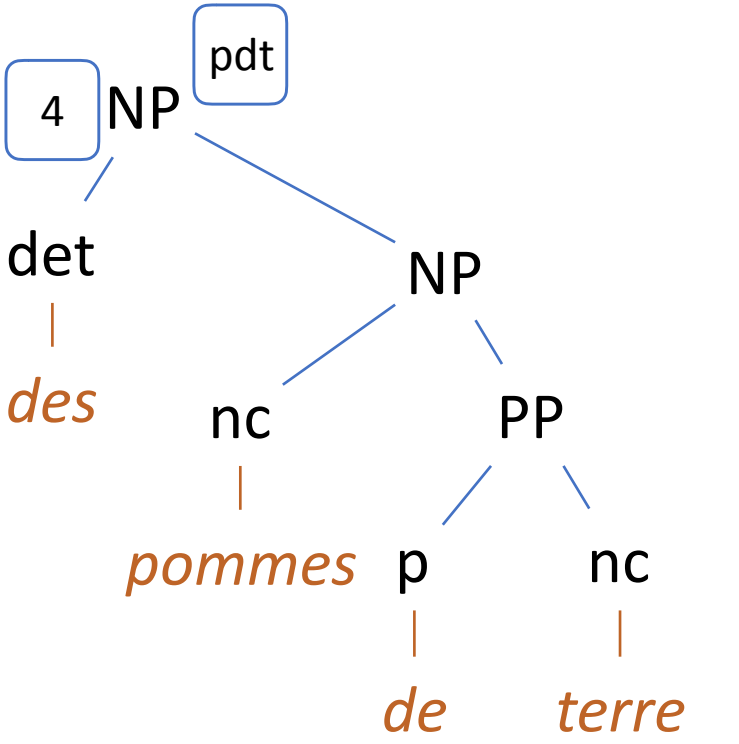

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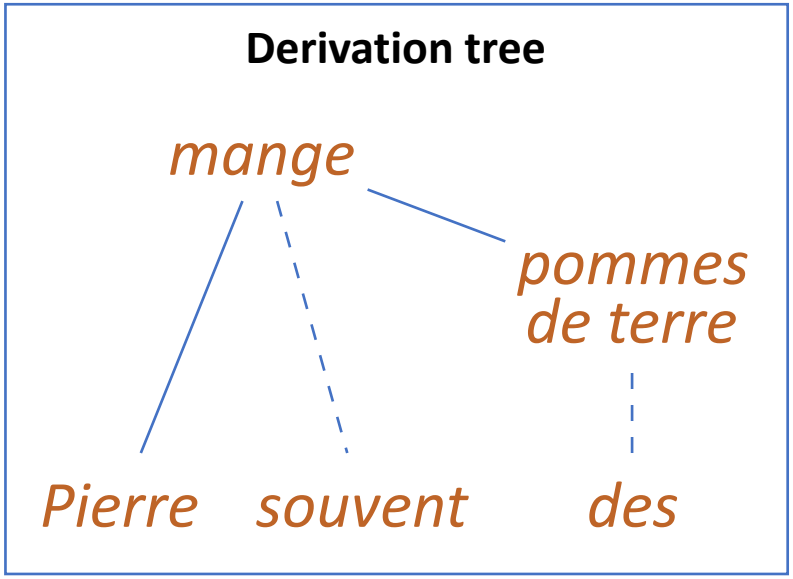

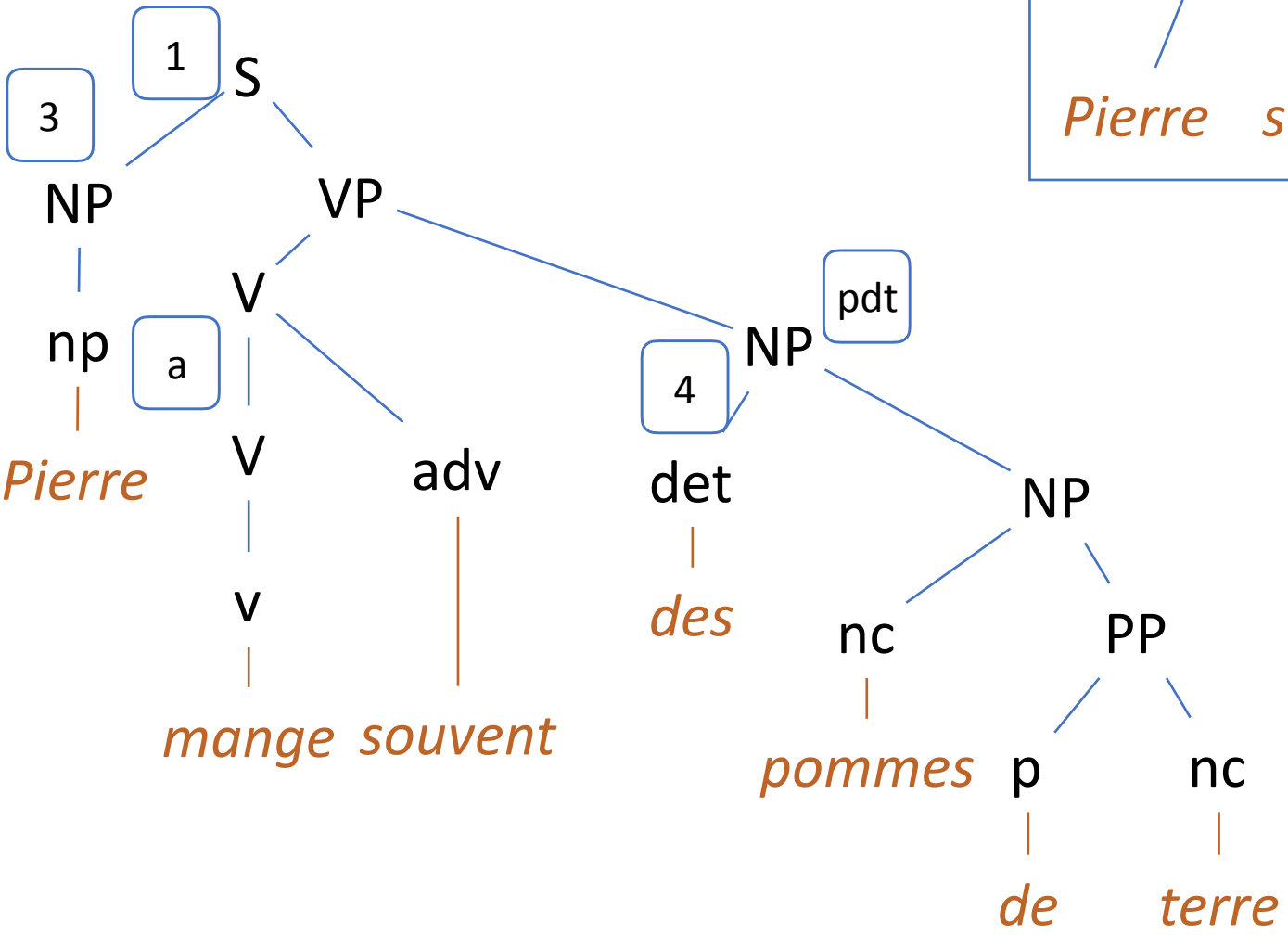

Wrapping trees

- There are no restrictions for auxiliary trees to have their spine one one side or the other of the tree
- TAGs allow **wrapping trees**

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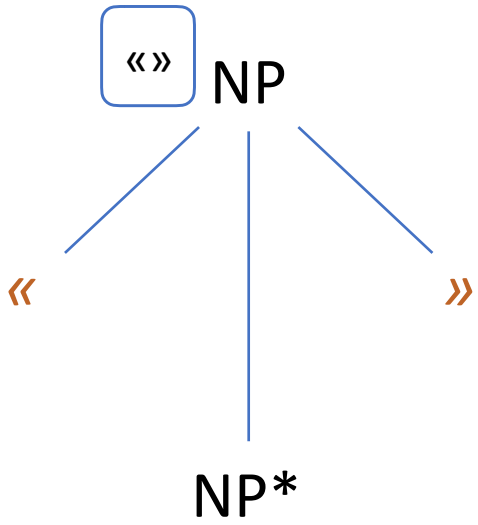

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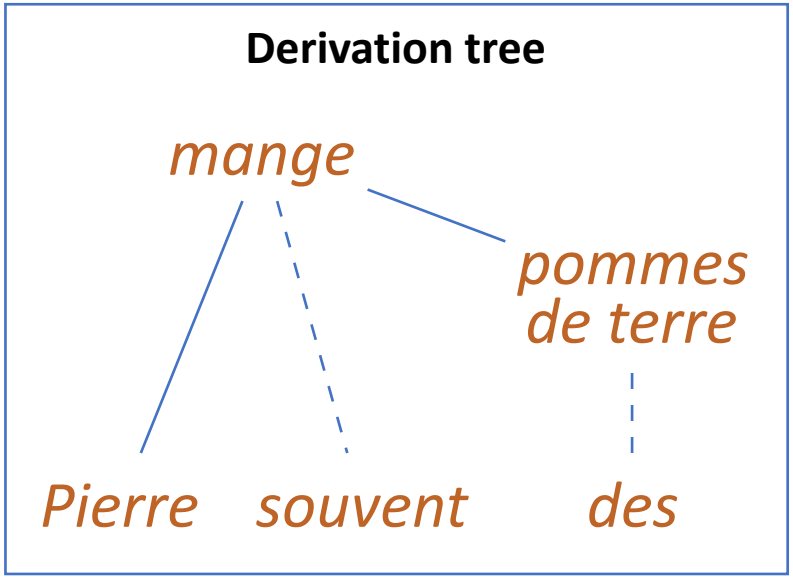

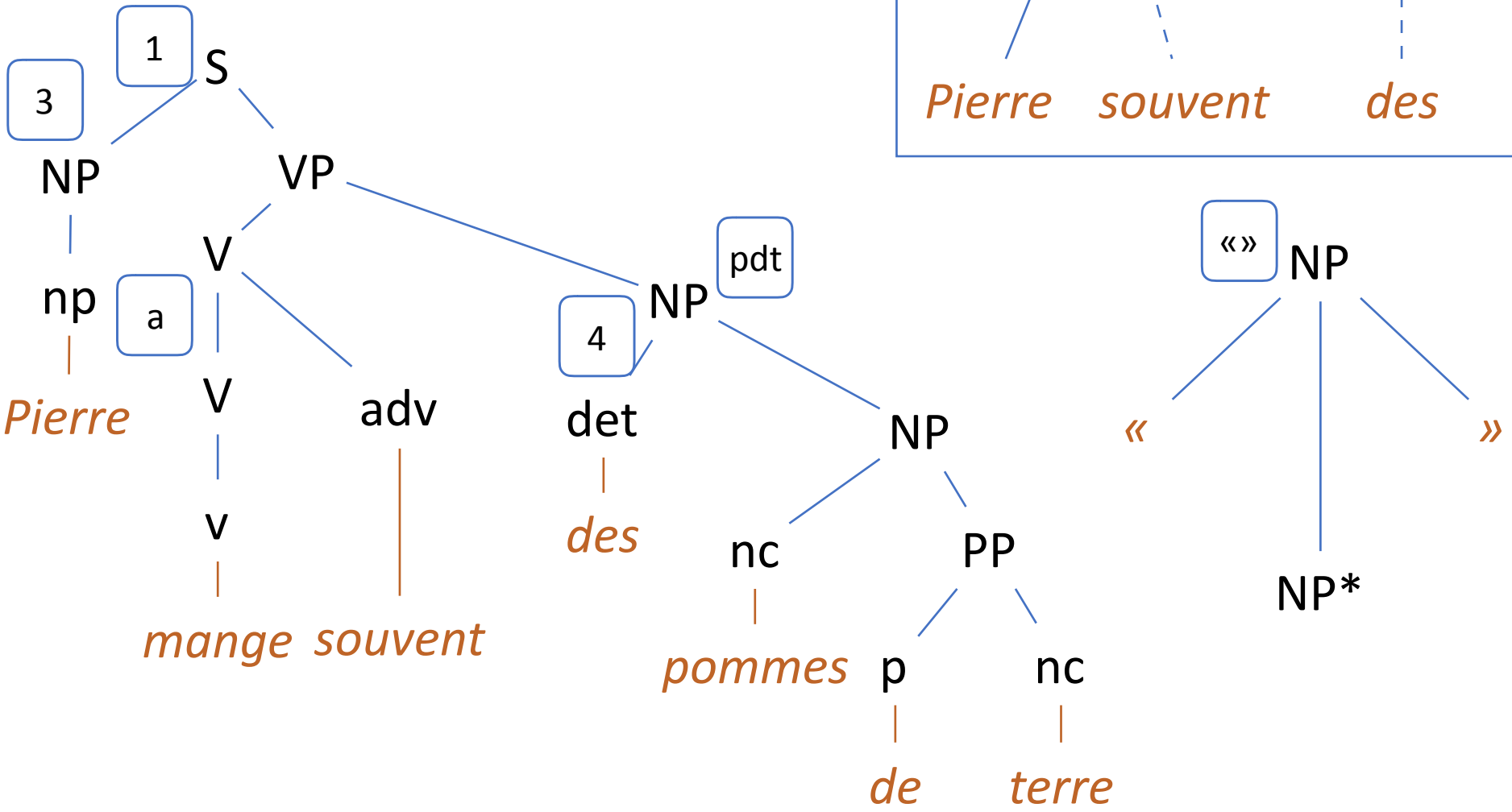

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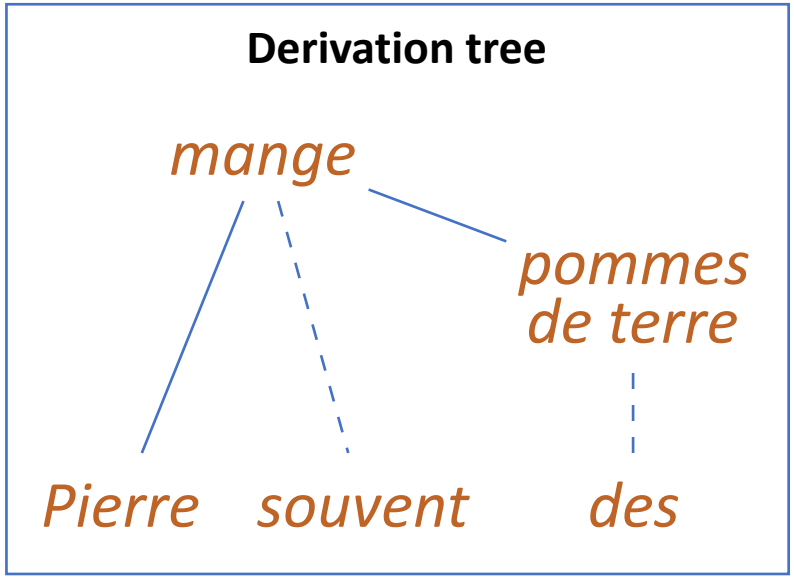

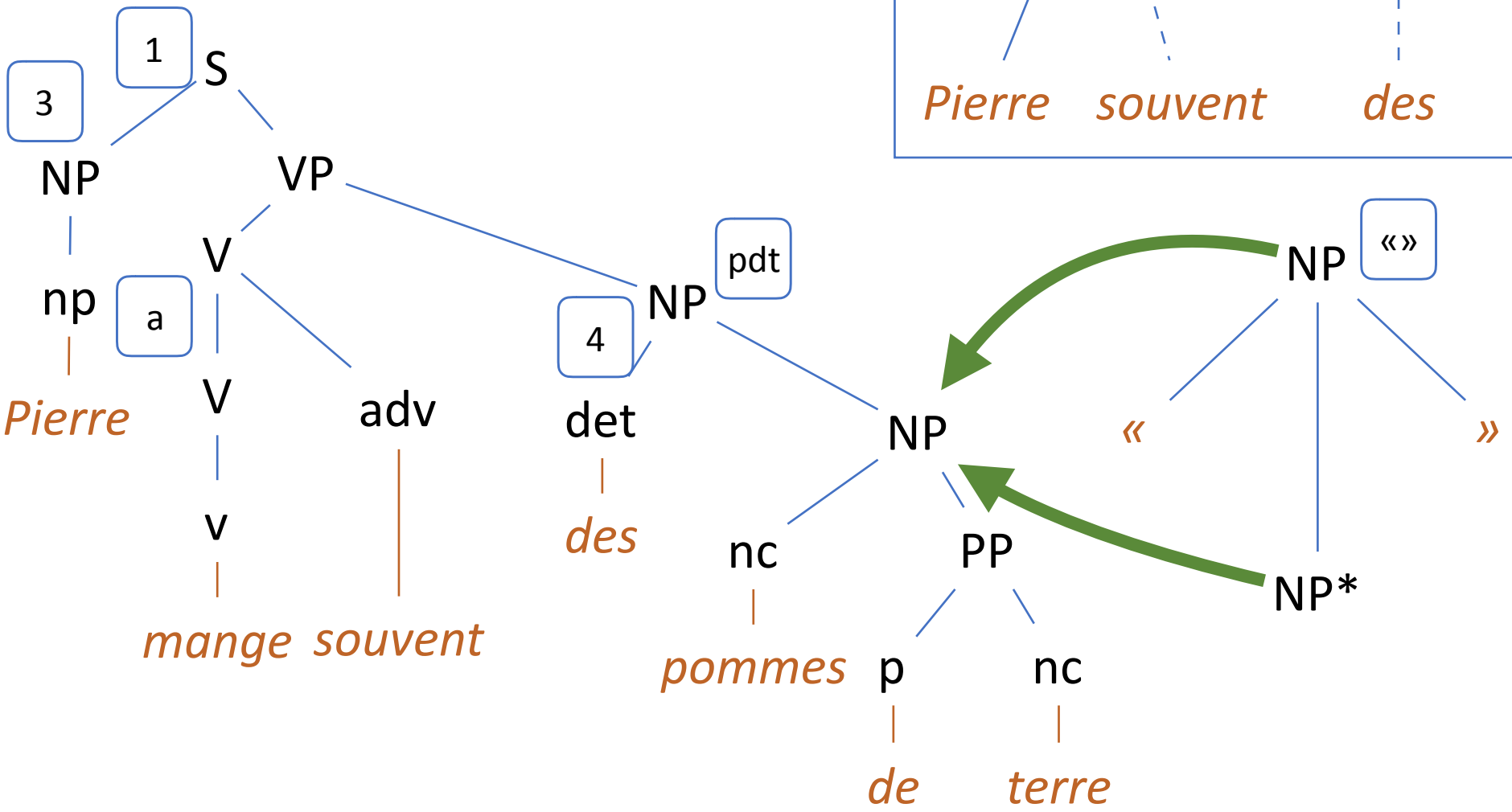

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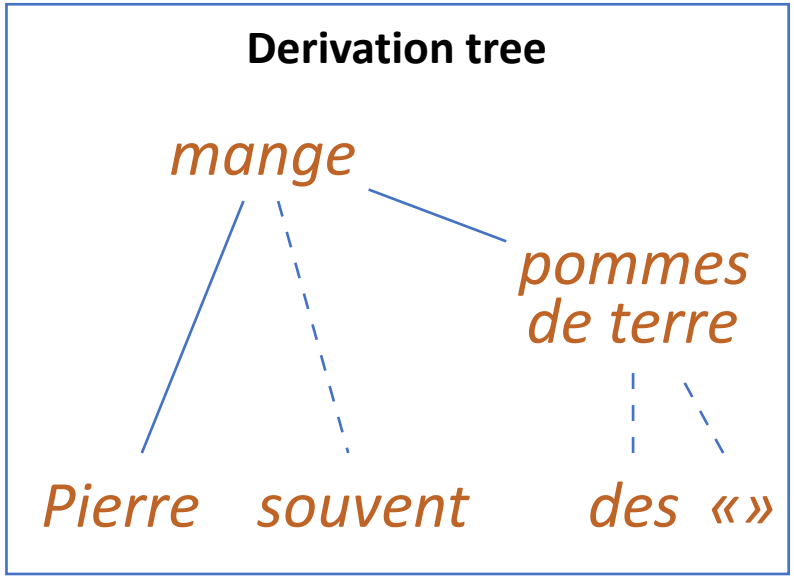
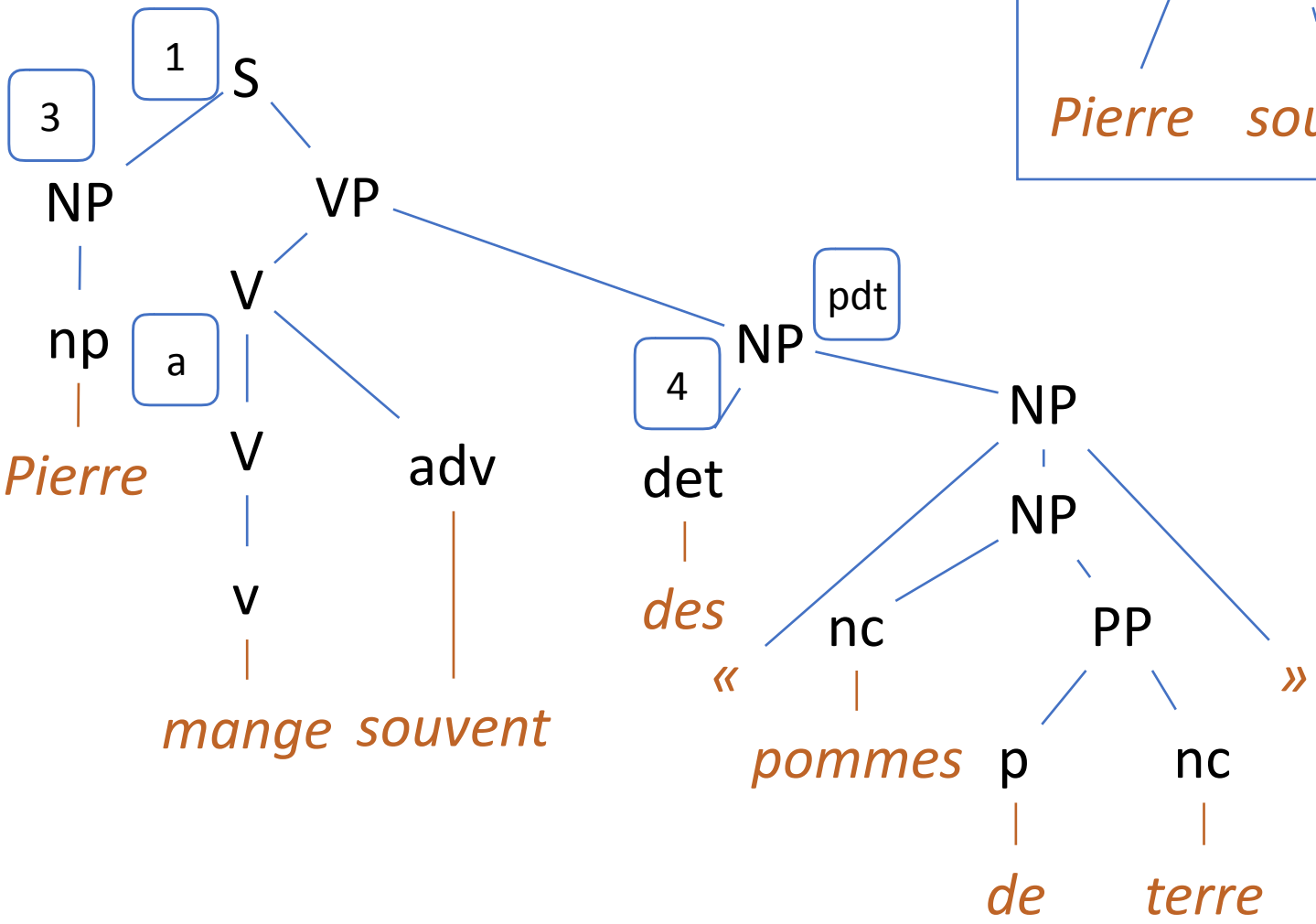




Online question 1

How do (non necessarily lexicalised) CFGs and TAGs compare in terms of expressive power? Let us consider the following languages: $\{a^n b^n\}$, $\{a^n b^n c^n\}$, $\{a^n b^n c^n d^n\}$. For each of the two formalisms, for which of these three languages is it possible to write a grammar?

1. CFG and TAG: none of them
2. CFG and TAG: $\{a^n b^n\}$
3. CFG and TAG: $\{a^n b^n\}$; TAG only: $\{a^n b^n c^n\}$
4. CFG and TAG: $\{a^n b^n\}$; TAG only: $\{a^n b^n c^n\}$ and $\{a^n b^n c^n d^n\}$
5. CFG and TAG: $\{a^n b^n\}$ and $\{a^n b^n c^n\}$
6. CFG and TAG: $\{a^n b^n\}$ and $\{a^n b^n c^n\}$; TAG only: $\{a^n b^n c^n d^n\}$
7. CFG and TAG: $\{a^n b^n\}$, $\{a^n b^n c^n\}$ and $\{a^n b^n c^n d^n\}$

https://api.socrative.com/rc/KBcrE4

Expressive power of TAGs vs. CFGs

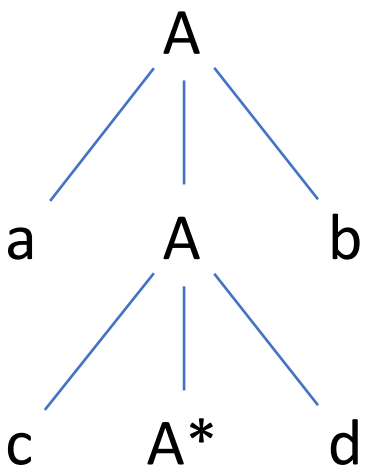
- The following context-free grammar defines $a^n b^n$:

$$S \longrightarrow a\ S\ b$$
$$S \longrightarrow \varepsilon$$

- However, $\{a^n b^n c^n\}$ is not a context-free language
  - Proof: look for “pumping lemma for CFG” on Google

Expressive power of TAGs vs. CFGs

- Wrapping tree give an extra expressive power



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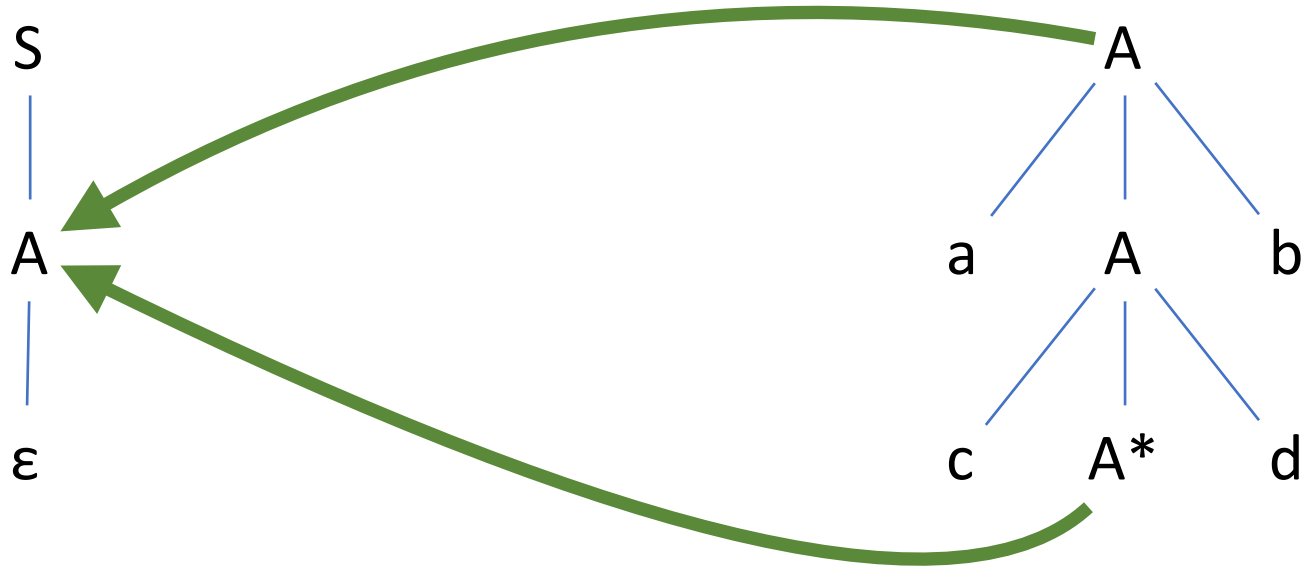

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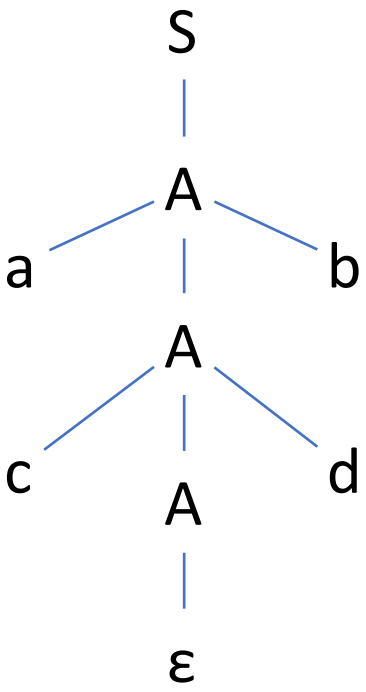
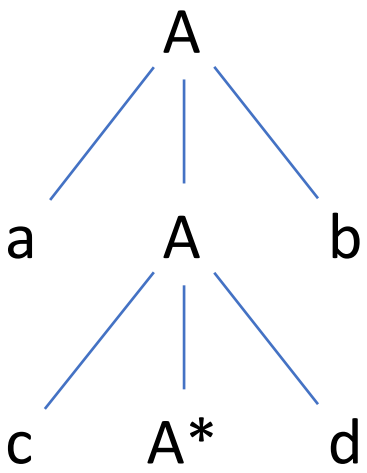
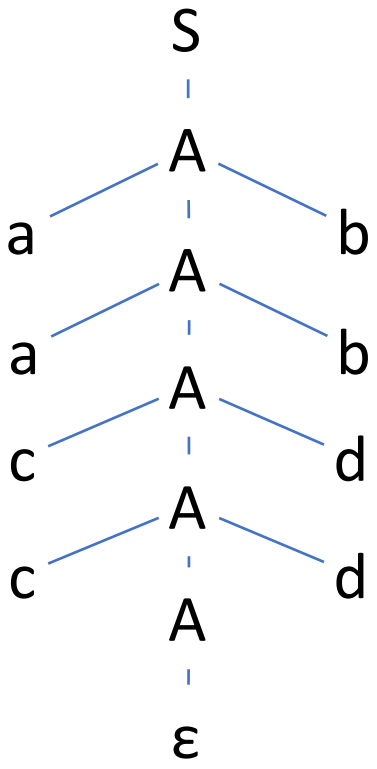
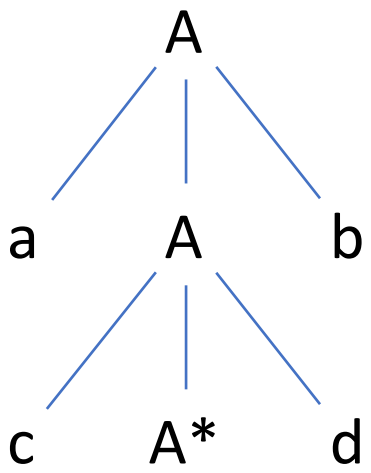




Expressive power of TAGs vs. CFGs

- Wrapping tree give an extra expressive power
  - There are in fact additional details to make this example fully work, but the underlying idea is the right one





Complexity intermezzo

Parsing complexity

- **CFGs and TSDs** are parsable in cubic time, i.e. $\boldsymbol{O(n^3)}$, where *n* is the length of the input sentence
- **TAGs**, in the general case, are parsable in $\boldsymbol{O(n^6)}$
  - Tree Adjoining Languages are closed under union, concatenation, and Kleene-star
- Proofs for these complexities assume binary elementary trees
  - There are trivial ways to turn a non-binary tree into a strictly equivalent binary tree
  - For CFGs, there is an even more restrictive form in which any grammar can be converted, the Chomsky normal form
    - Rules of the form A → BC or A → a or S → ε (S is the axiom)

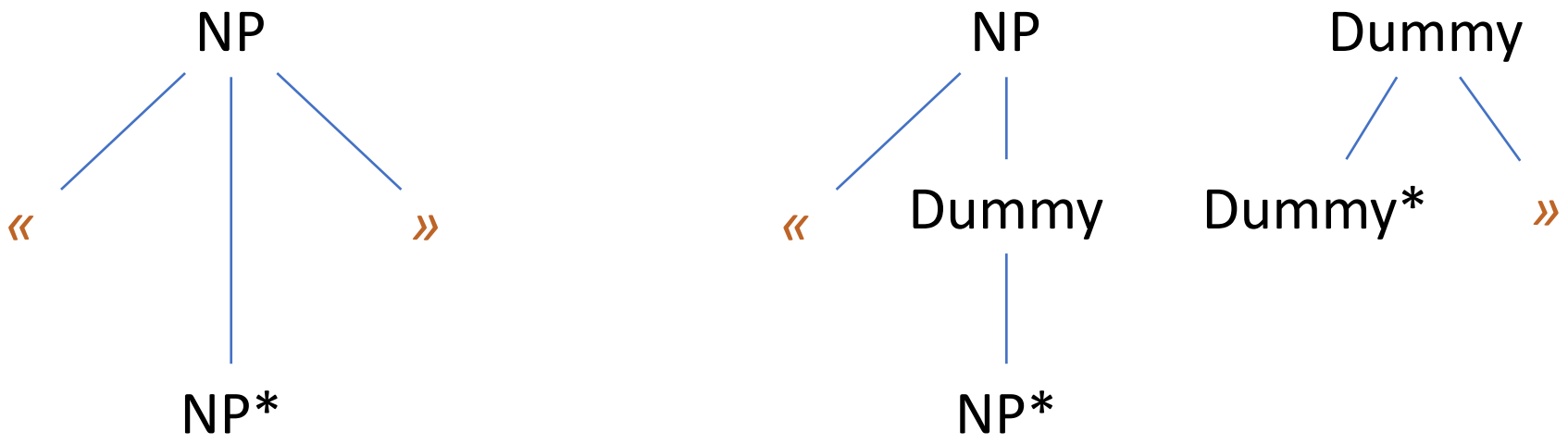
Parsing complexity

- However, the adjunction operation is a useful addition
- Can we keep the adjunction operation without the additional complexity
  - YES: we just need to get rid of wrapping adjunctions
    > Tree Insertion Grammars

Tree insertion grammars

Getting rid of wrapping adjunctions

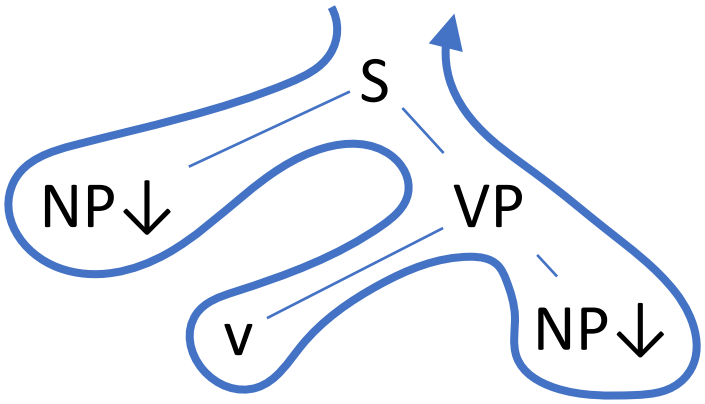
- Underlying intuition:
  - we need to forbid wrapping auxiliary trees
  - we also need to forbid any way to simulate wrapping

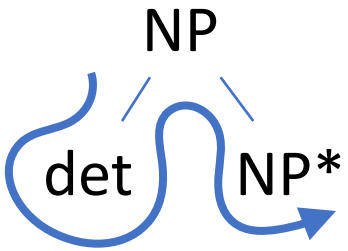


Tree insertion grammars

- A Tree Insertion Grammar (TIG) is a TAG where wrapping adjunction is forbidden
- TIG are parsable in $O(n^3)$!
  - We will prove it by showing how it is possible to convert a TIG into a CFG
  - The underlying intuition is to rewrite each elementary tree in the form of an equivalent CFG rewriting rule
  - using a top-down traversal of the trees

Converting a TIG into a CFG





$S \longrightarrow NP \;\; VP_g \;\; v \;\; NP \;\; VP_d$

$NP_g \longrightarrow det \; NP_g$

TAGs and TIGs in practice?

- In practice, developing a TAG (or a TIG) is a very time-consuming task
- Two major ways out
  - Use a more abstract way to represent grammar rules ("metagrammars") that can generate a TAG (or a TIG)
    - This is how one of the best performing parsers for French was developed (FRMG, de La Clergerie et al.)
  - Extract it from a treebank
    - This allows for integrating probabilities, following the standard way to probabilise CFGs

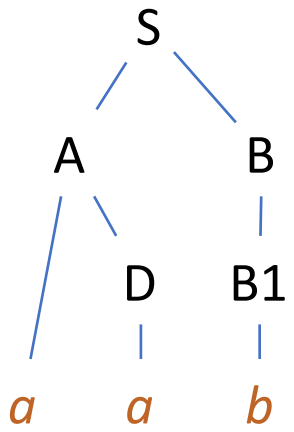
Probabilistic CFGs

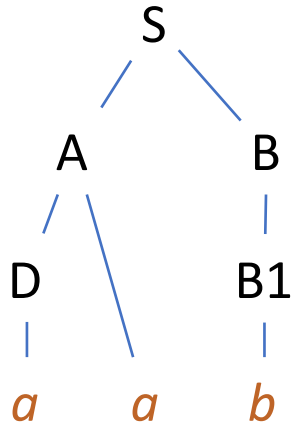
PCFGs

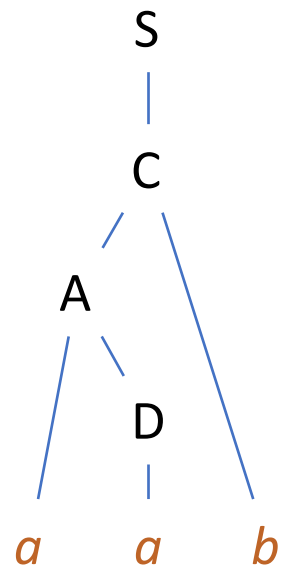
- Probabilistic CFGs (PCFGs) are a direct extension of CFGs
- The probabilisation of a grammatical formalism consists in defining a way to assign a probability to each sentence in the language generated by the grammar
  - Of course, the (often infinite) sum of to probabilities for all sentences in the language must be =1
- CFGs are **non-contextual**
  - A reasonable way to assign a probability distribution over CFGs is to do so in a **non-contextual way**
  - In other words, probabilities will be associated with each rewriting rule
  - The probability of a sentence according to the grammar will be the product of the probabilities of all rewritings in the derivation

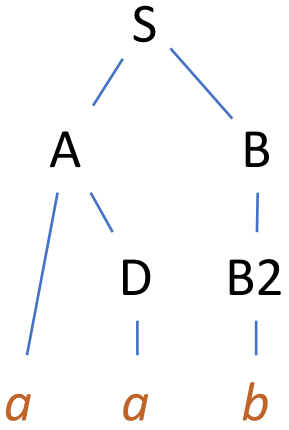
PCFG on an example

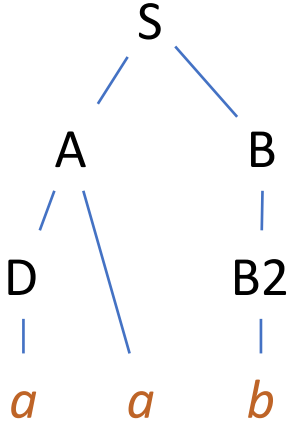
S -> A B	3/4
S -> C	1/4
A -> a D	2/3
A -> D a	1/3
D -> a	1
C -> A b	1
B -> B1	2/3
B -> B2	1/3
B1 -> b	1
B2 -> b	1

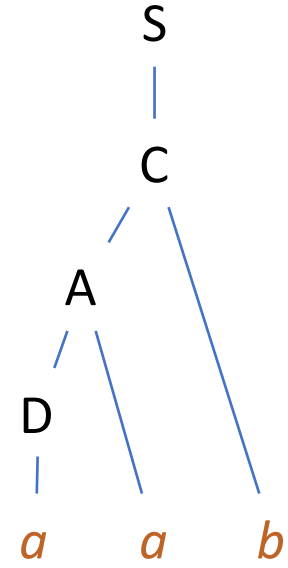








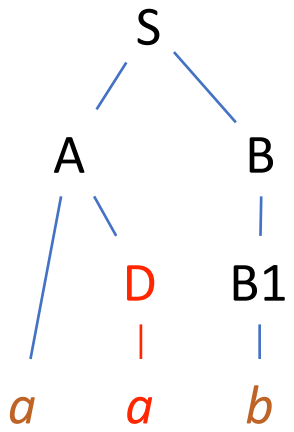


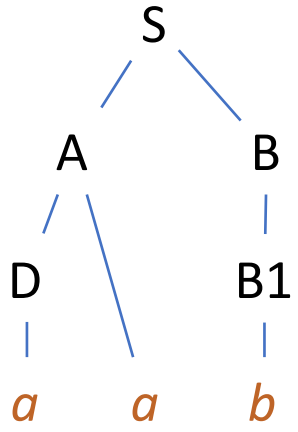


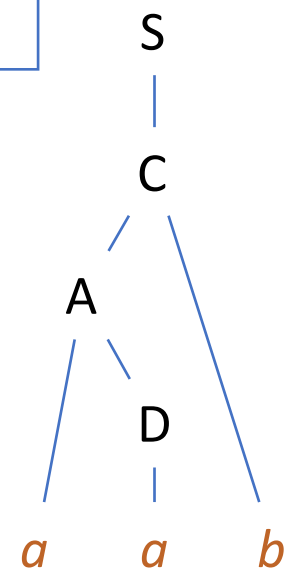
PCFG on an example

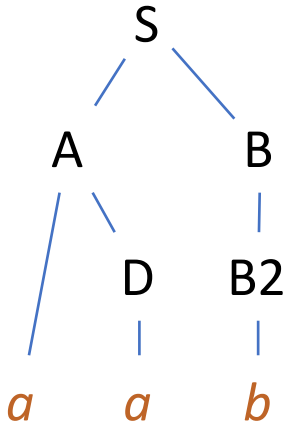
1

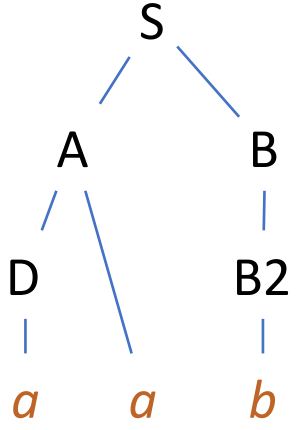
S -> A B	3/4
S -> C	1/4
A -> a D	2/3
A -> D a	1/3
D -> a	1
C -> A b	1
B -> B1	2/3
B -> B2	1/3
B1 -> b	1
B2 -> b	1

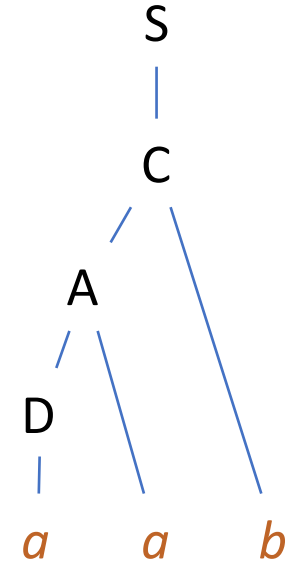








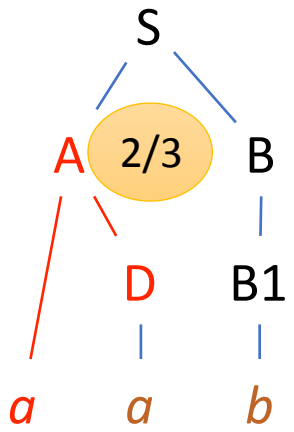


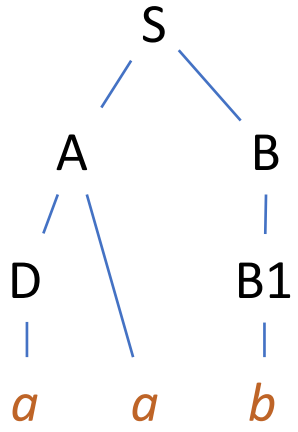


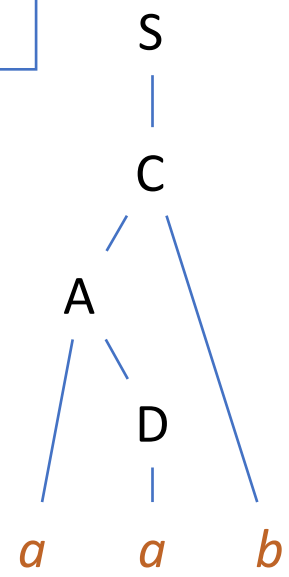
PCFG on an example

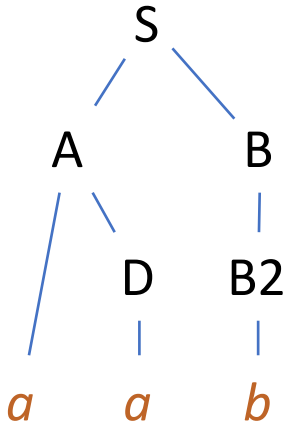
(1*2/3)

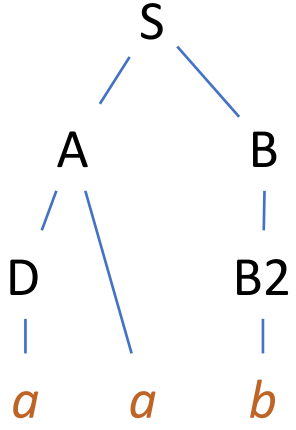
S -> A B	3/4
S -> C	1/4
A -> a D	2/3
A -> D a	1/3
D -> a	1
C -> A b	1
B -> B1	2/3
B -> B2	1/3
B1 -> b	1
B2 -> b	1

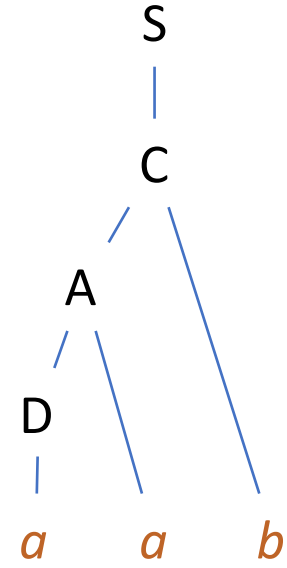








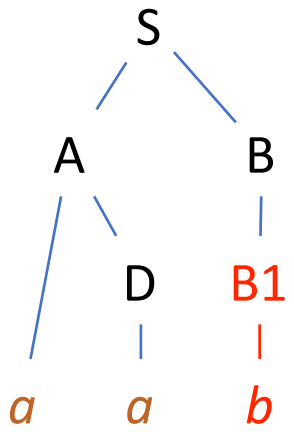


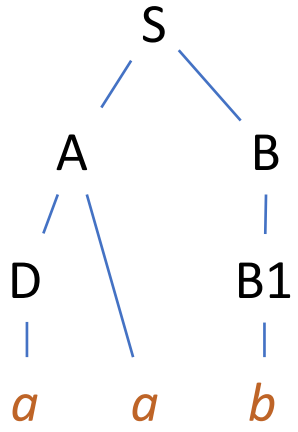


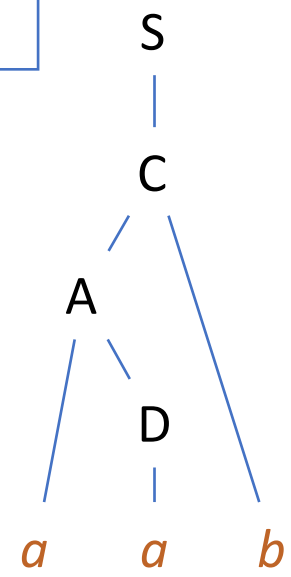
PCFG on an example

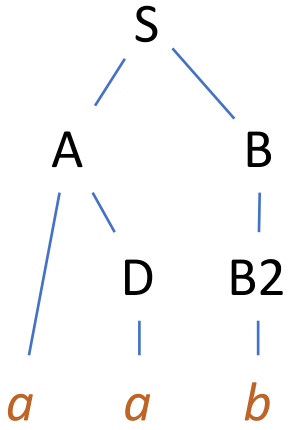
(1*2/3) * (1

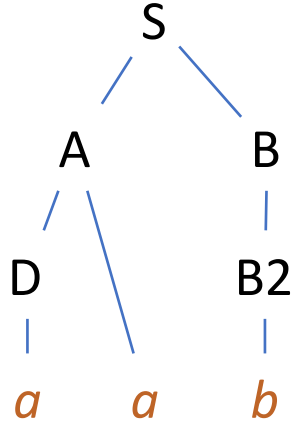
S -> A B	3/4
S -> C	1/4
A -> a D	2/3
A -> D a	1/3
D -> a	1
C -> A b	1
B -> B1	2/3
B -> B2	1/3
B1 -> b	1
B2 -> b	1

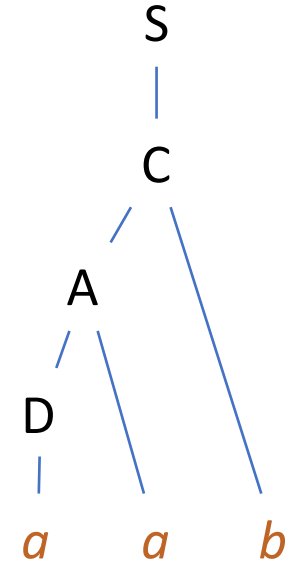








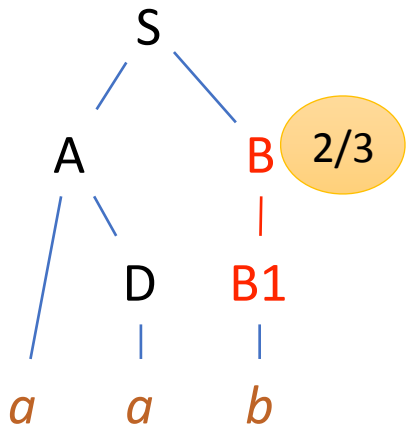


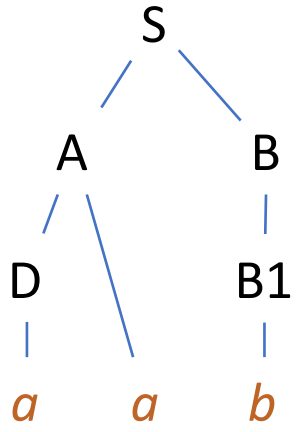


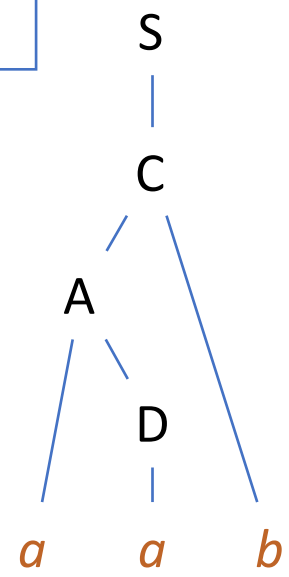
PCFG on an example

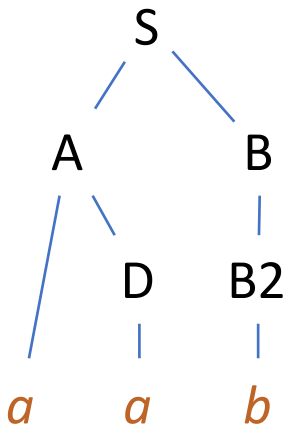
(1*2/3) * (1*2/3)

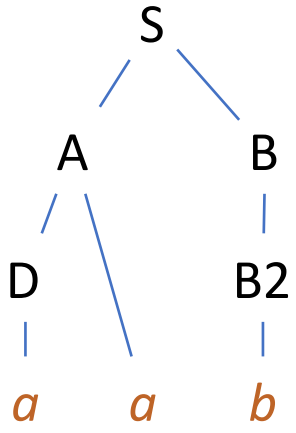
S -> A B	3/4
S -> C	1/4
A -> a D	2/3
A -> D a	1/3
D -> a	1
C -> A b	1
B -> B1	2/3
B -> B2	1/3
B1 -> b	1
B2 -> b	1

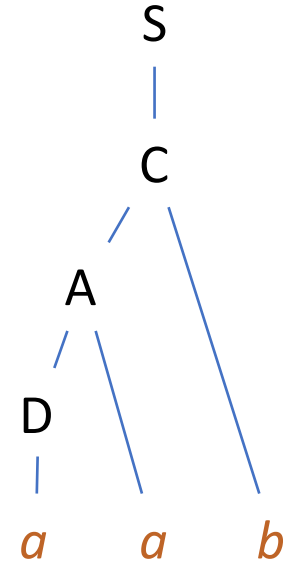








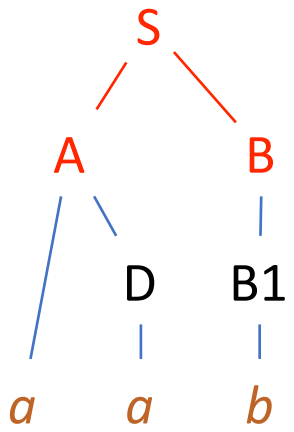


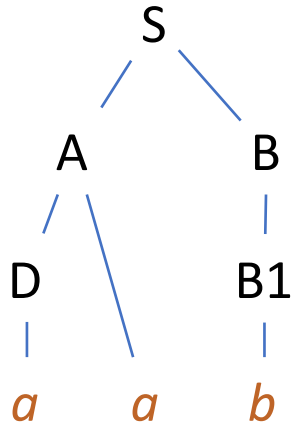


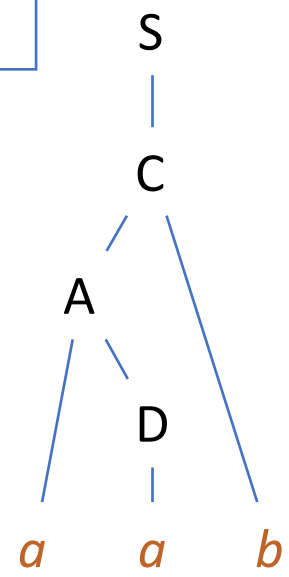
PCFG on an example

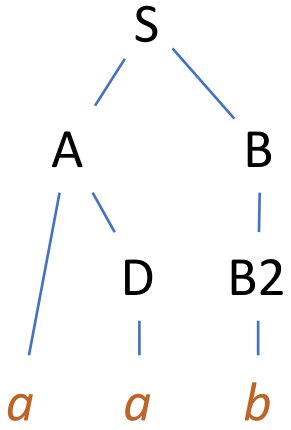
(1*2/3) * (1*2/3) * 3/4

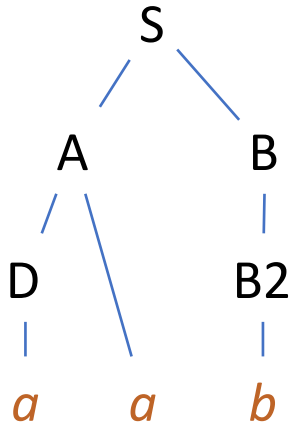
S -> A B	3/4
S -> C	1/4
A -> a D	2/3
A -> D a	1/3
D -> a	1
C -> A b	1
B -> B1	2/3
B -> B2	1/3
B1 -> b	1
B2 -> b	1

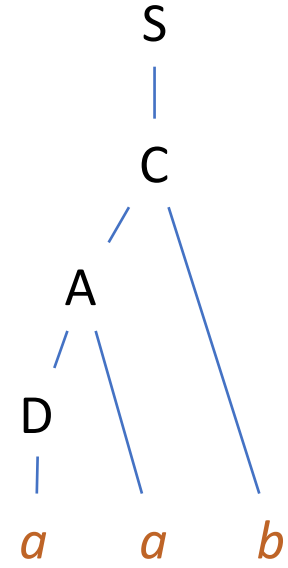








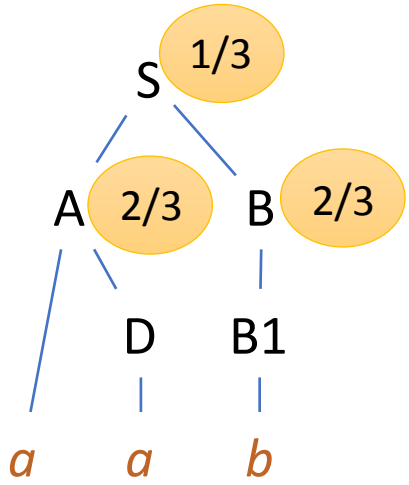


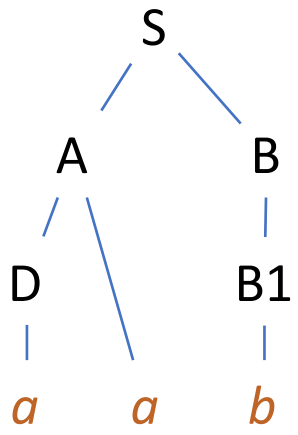


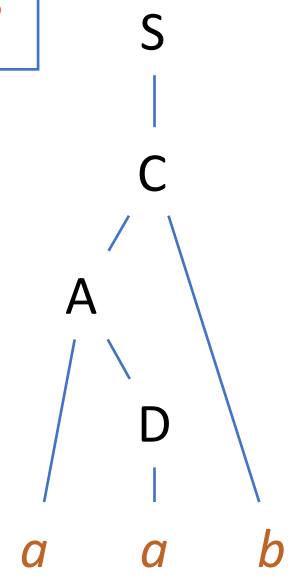
PCFG on an example

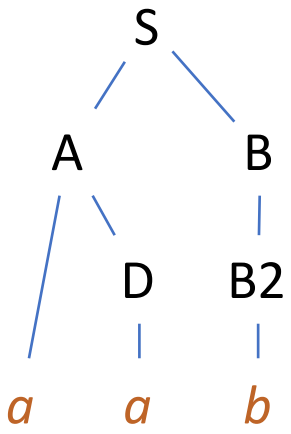
(1*2/3) * (1*2/3) * 3/4 = 1/3

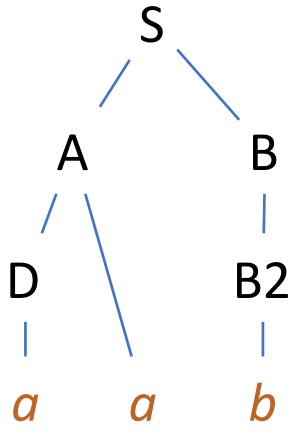
S -> A B	3/4
S -> C	1/4
A -> a D	2/3
A -> D a	1/3
D -> a	1
C -> A b	1
B -> B1	2/3
B -> B2	1/3
B1 -> b	1
B2 -> b	1

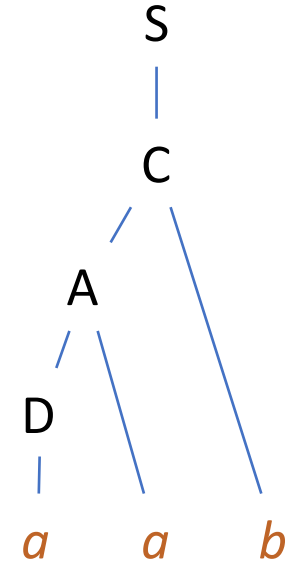






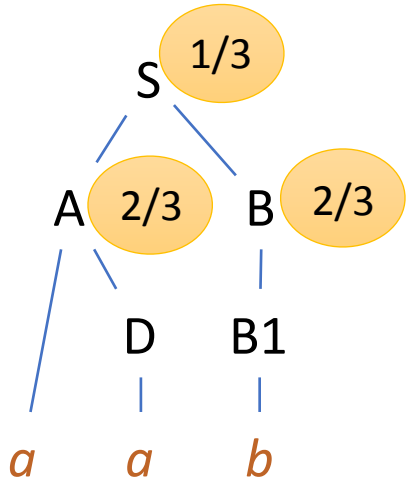


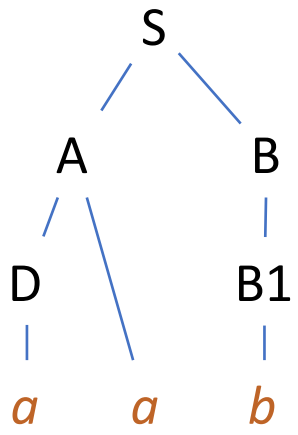


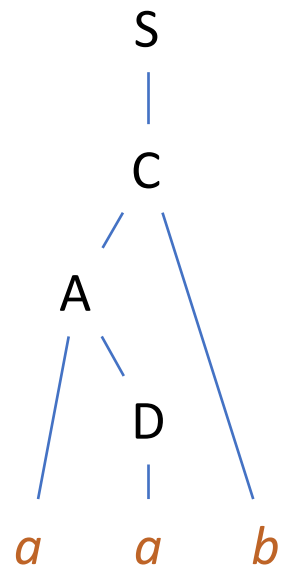


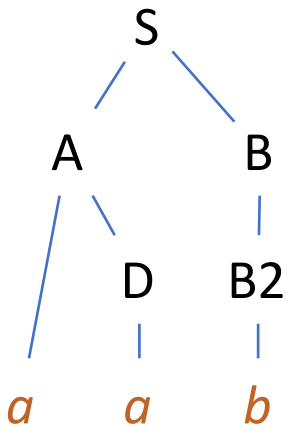
PCFG on an example

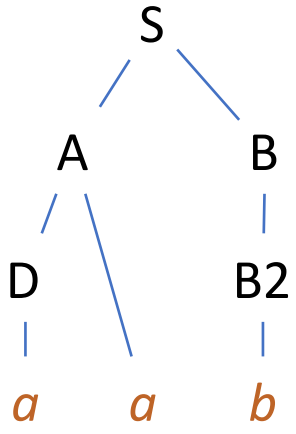
S -> A B	3/4
S -> C	1/4
A -> a D	2/3
A -> D a	1/3
D -> a	1
C -> A b	1
B -> B1	2/3
B -> B2	1/3
B1 -> b	1
B2 -> b	1

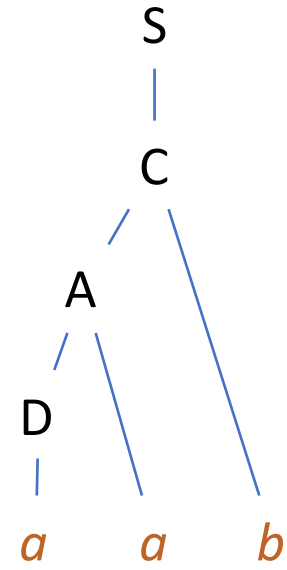






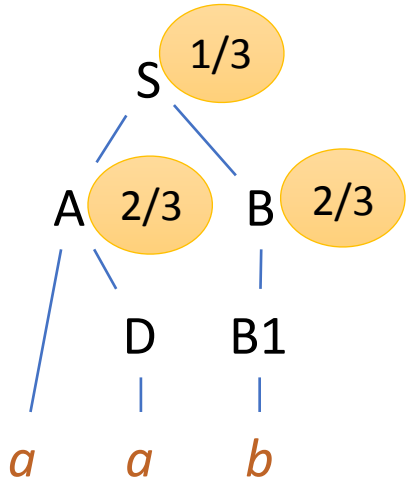


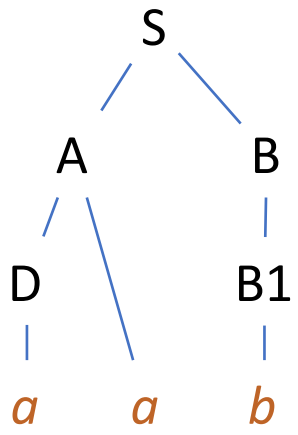


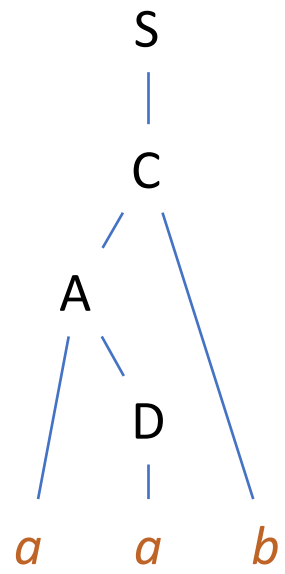


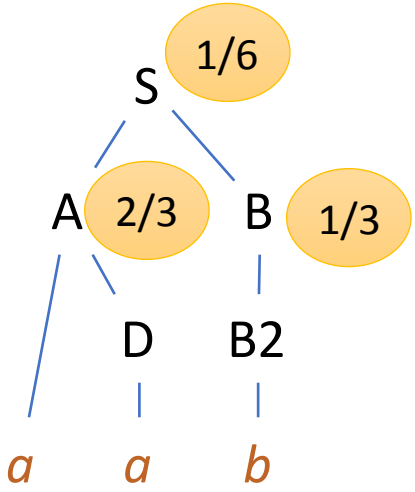
PCFG on an example

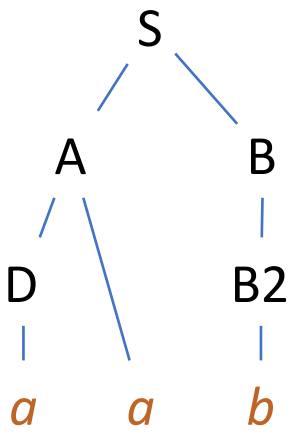
S -> A B	3/4
S -> C	1/4
A -> a D	2/3
A -> D a	1/3
D -> a	1
C -> A b	1
B -> B1	2/3
B -> B2	1/3
B1 -> b	1
B2 -> b	1

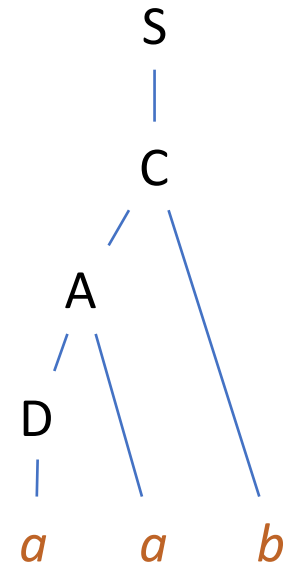






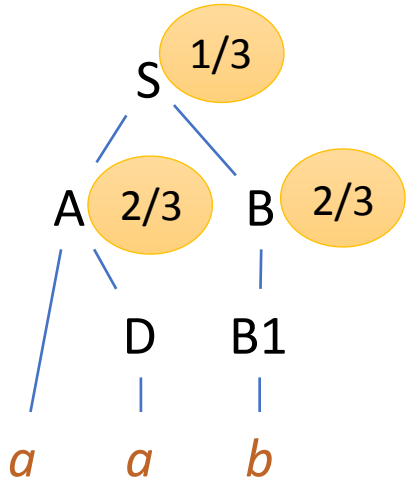


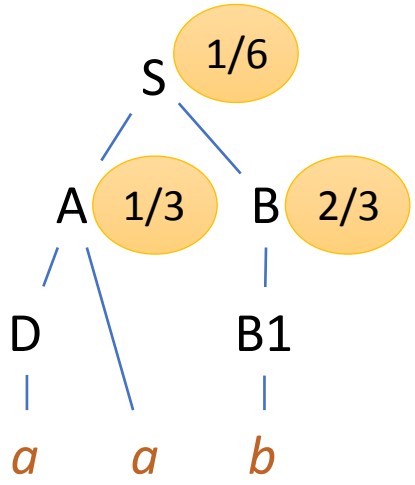


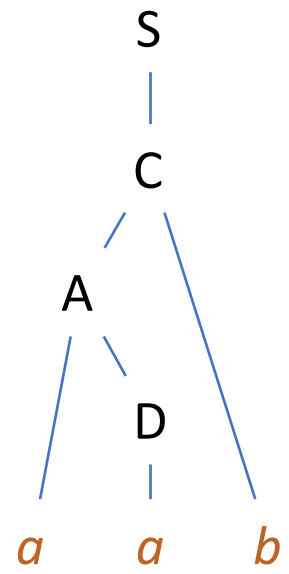


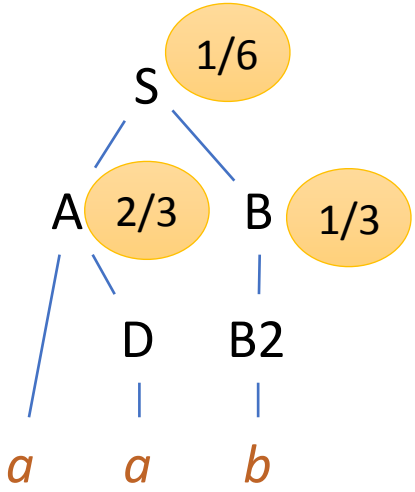
PCFG on an example

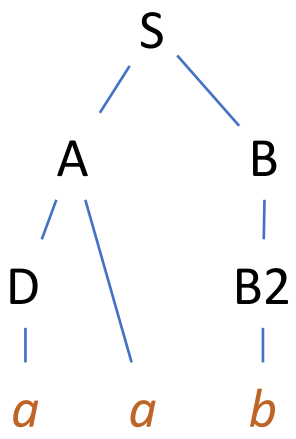
S -> A B	3/4
S -> C	1/4
A -> a D	2/3
A -> D a	1/3
D -> a	1
C -> A b	1
B -> B1	2/3
B -> B2	1/3
B1 -> b	1
B2 -> b	1

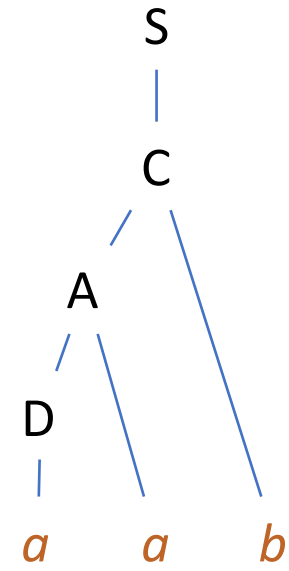






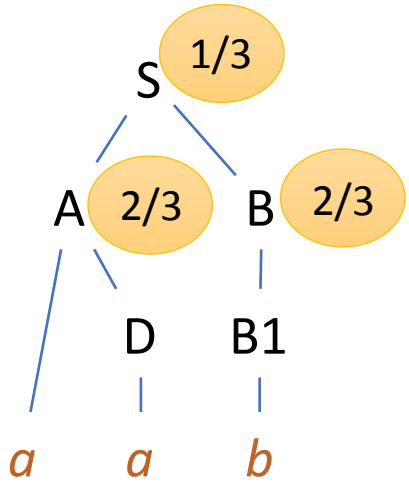


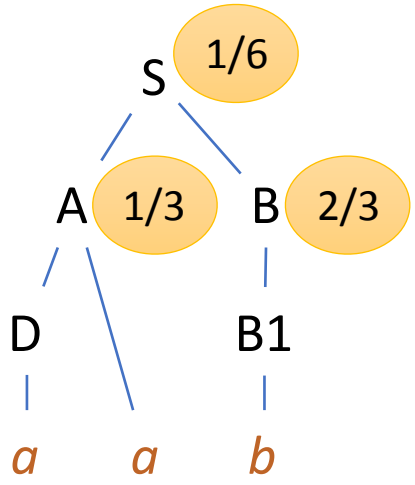


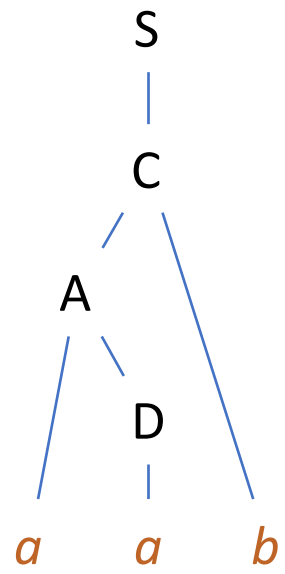


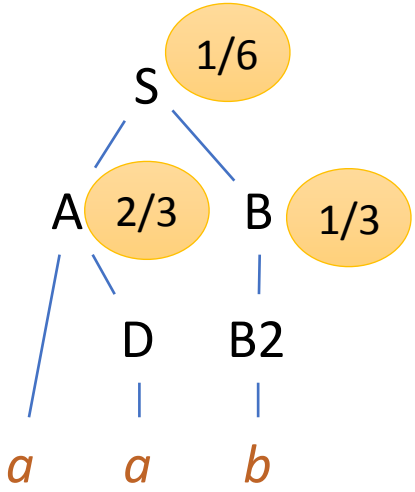
PCFG on an example

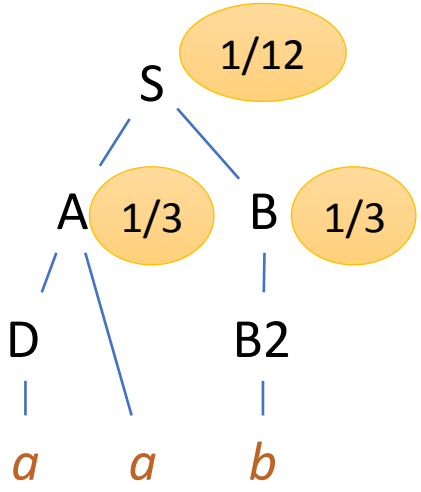
S -> A B	3/4
S -> C	1/4
A -> a D	2/3
A -> D a	1/3
D -> a	1
C -> A b	1
B -> B1	2/3
B -> B2	1/3
B1 -> b	1
B2 -> b	1

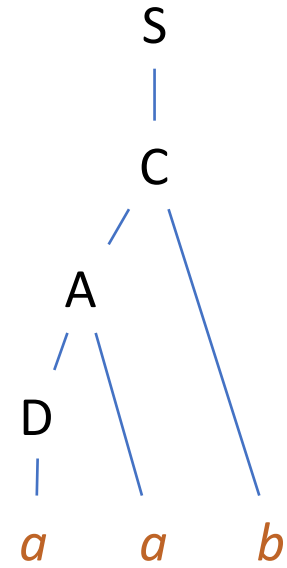






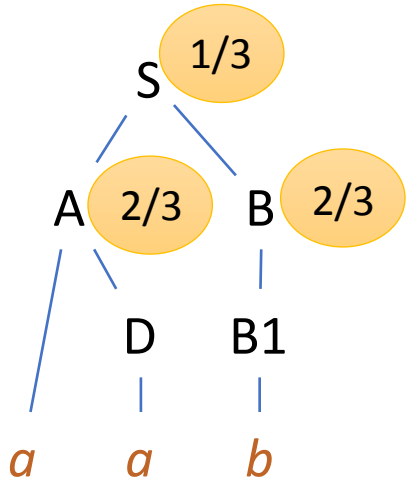


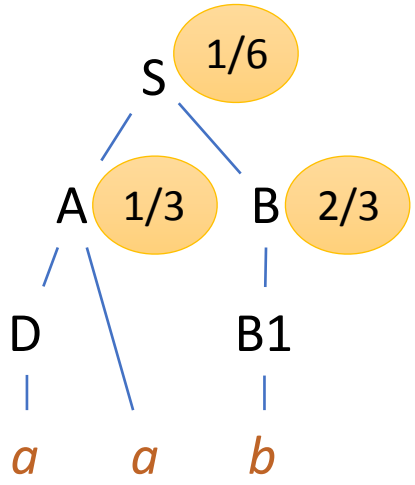


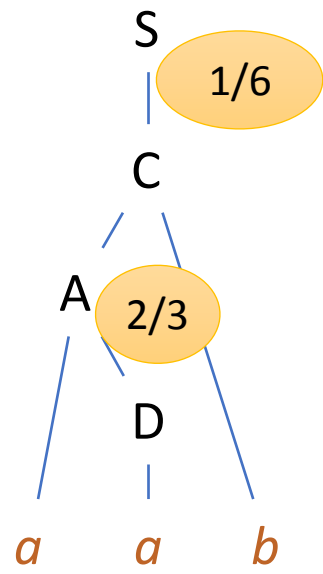


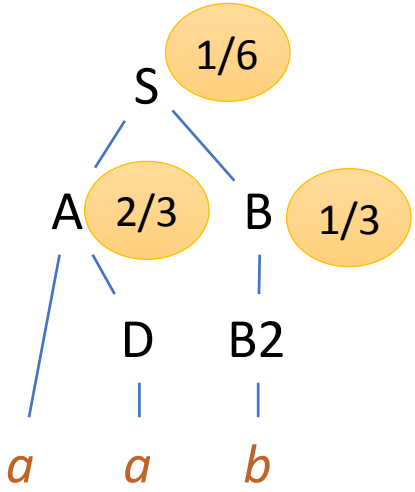
PCFG on an example

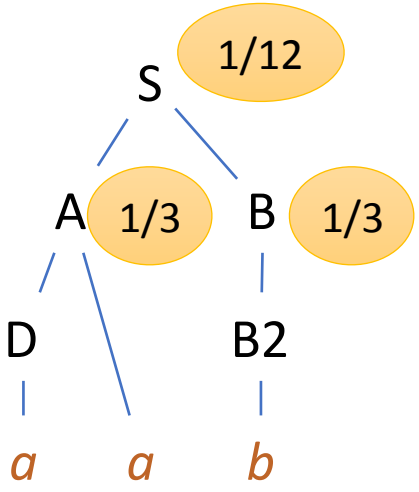
S -> A B	3/4
S -> C	1/4
A -> a D	2/3
A -> D a	1/3
D -> a	1
C -> A b	1
B -> B1	2/3
B -> B2	1/3
B1 -> b	1
B2 -> b	1

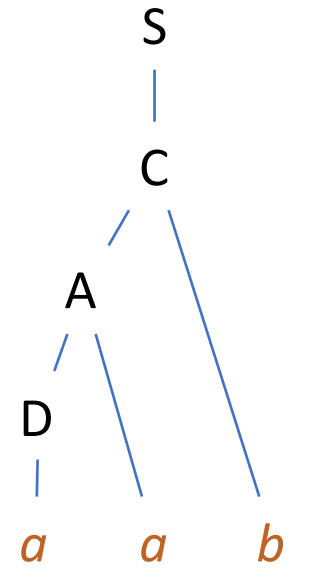






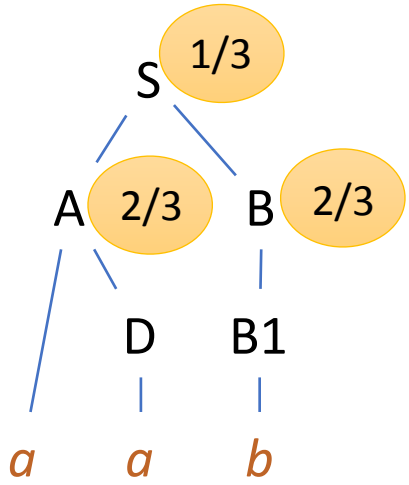


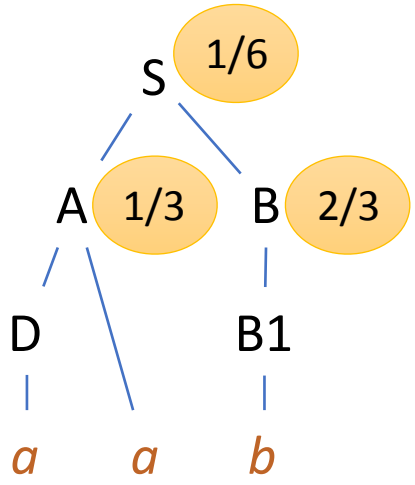


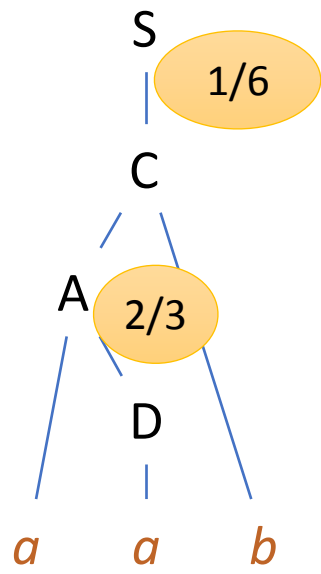


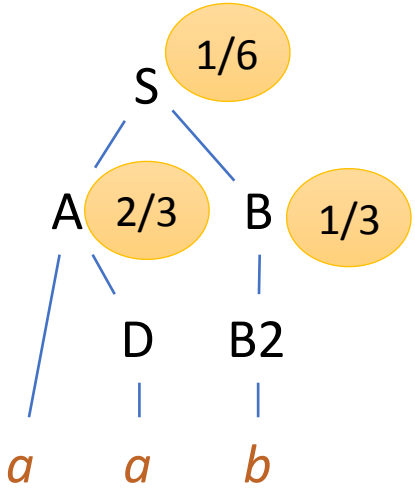
PCFG on an example

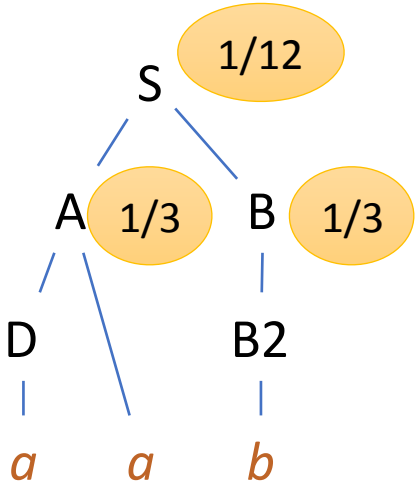
S -> A B	3/4
S -> C	1/4
A -> a D	2/3
A -> D a	1/3
D -> a	1
C -> A b	1
B -> B1	2/3
B -> B2	1/3
B1 -> b	1
B2 -> b	1

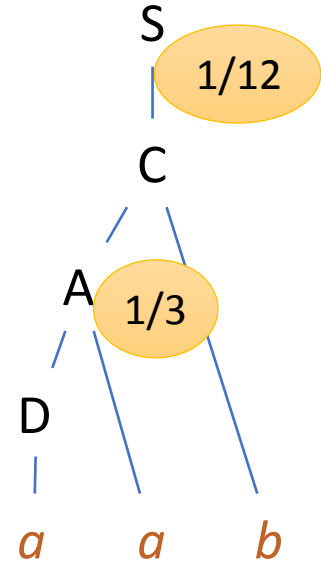








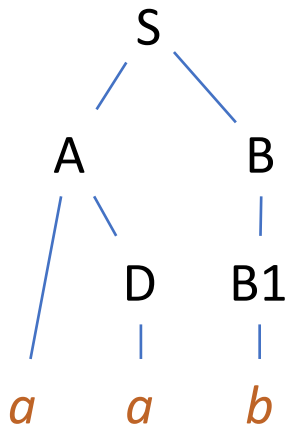


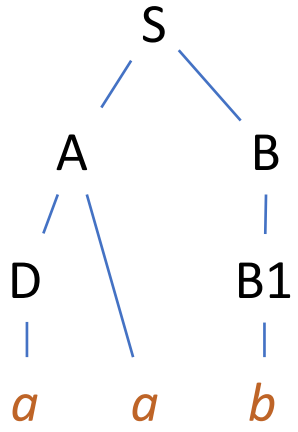


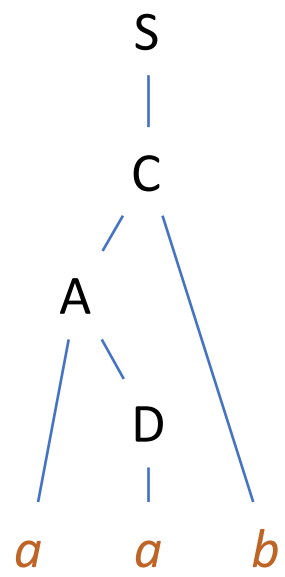
A few words
on shared parse forests

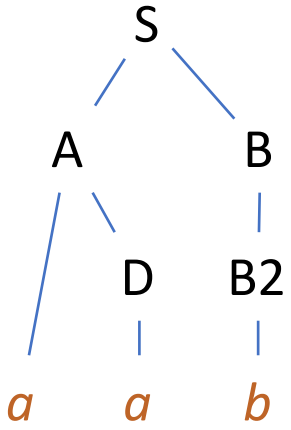
Multiple analyses: not very practical

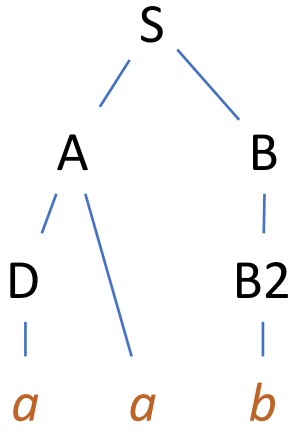
S -> A B
S -> C
A -> a D
A -> D a
D -> a
C -> A b
B -> B1
B -> B2
B1 -> b
B2 -> b

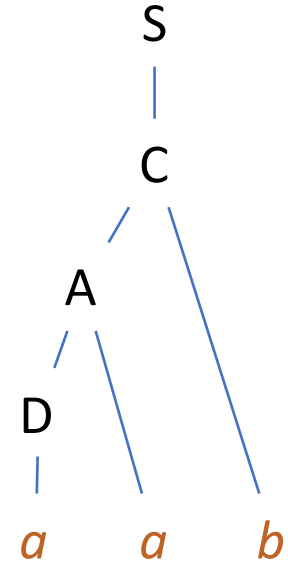






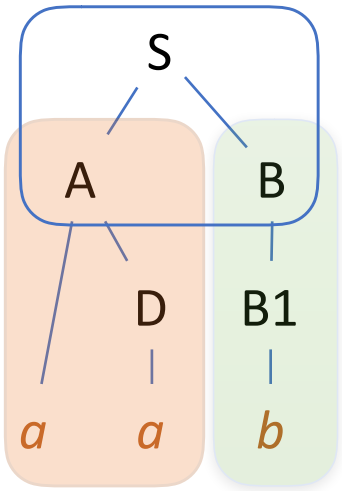


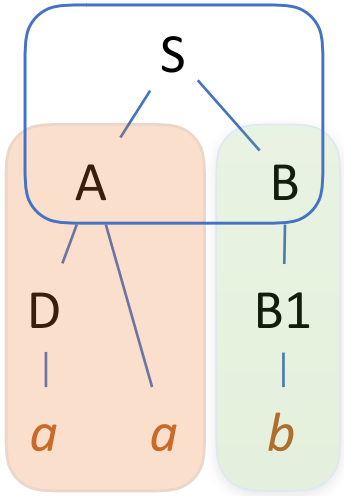


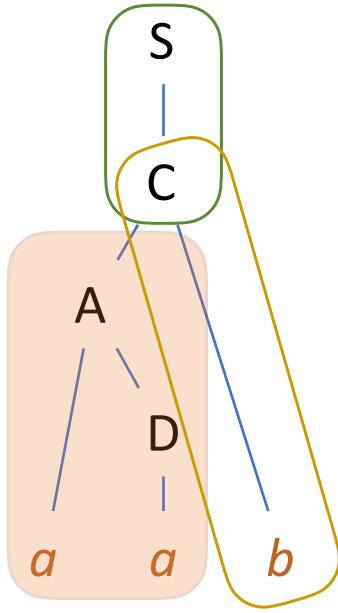


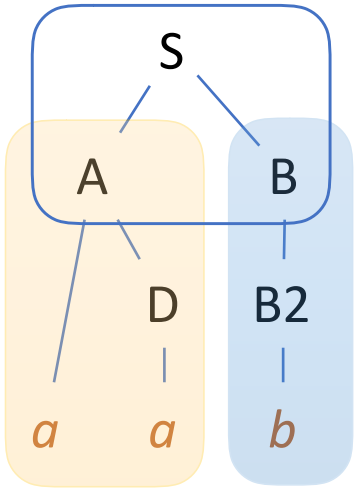
Multiple analyses: a lot of redundancies

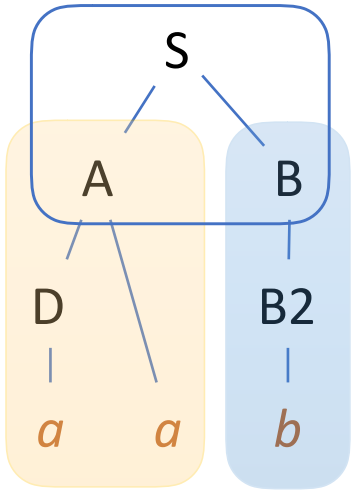
S -> A B
S -> C
A -> a D
A -> D a
D -> a
C -> A b
B -> B1
B -> B2
B1 -> b
B2 -> b

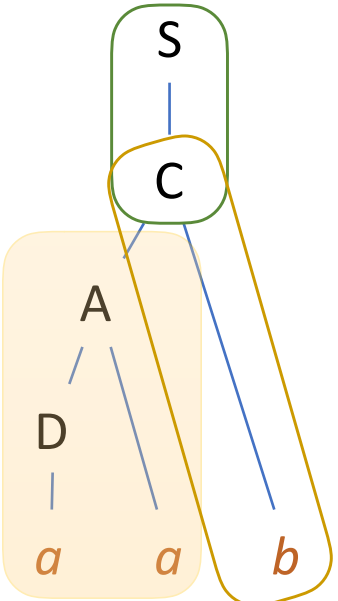






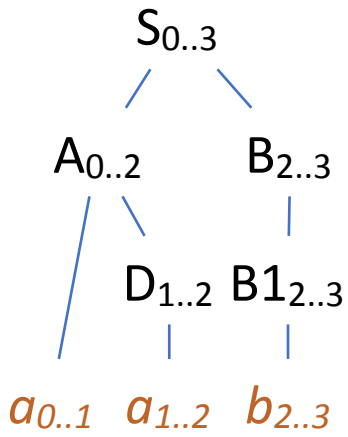


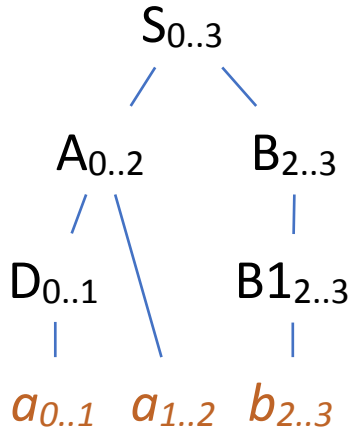


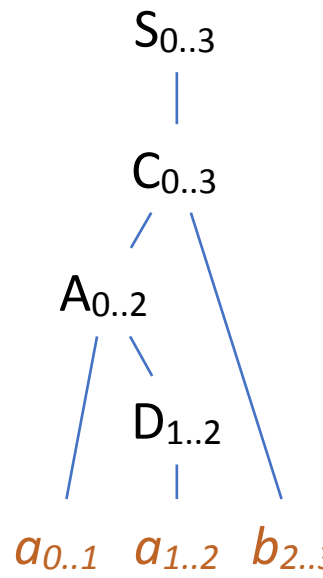


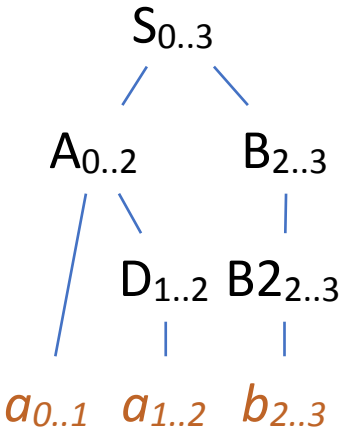
Multiple analyses: instanciation

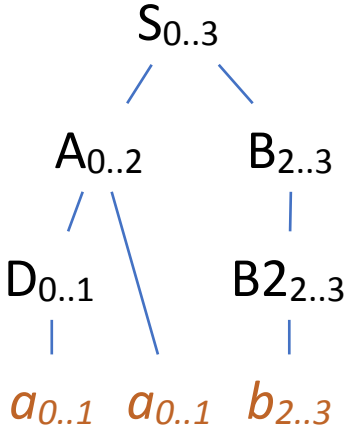
S -> A B
S -> C
A -> a D
A -> D a
D -> a
C -> A b
B -> B1
B -> B2
B1 -> b
B2 -> b

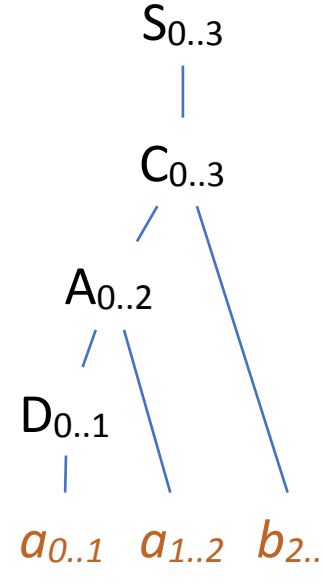






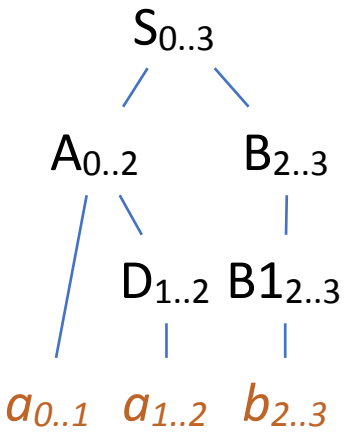






Towards parse forests

- Each parse can be represented as an **instanciated grammar**
  - Rules are instanciated rules of the original grammar
  - One original rule can be used more than once, with different instanciations



$S_{0..3}$ -> $A_{0..2}$ $B_{2..3}$

$A_{0..2}$ -> $a_{0..1}$ $D_{1..2}$

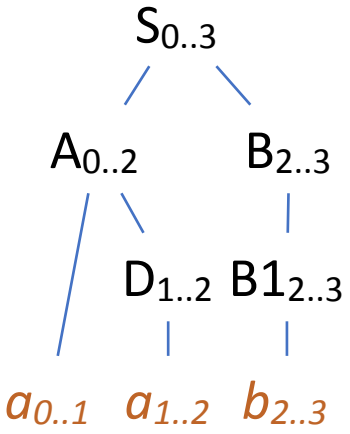
$D_{1..2}$ -> $a_{1..2}$

$B_{2..3}$ -> $B1_{2..3}$

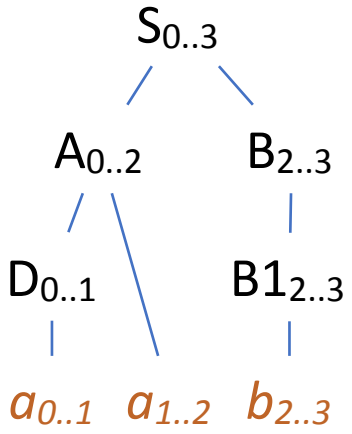
$B1_{2..3}$ -> $b_{2..3}$

Towards parse forests

- All grammars (one for each parse tree) have the same axiom, here $S_{0..3}$
- Whenever there are shared parts, they will appear in the form of repeated (redundant) rules



$S_{0..3}$ -> $A_{0..2}$ $B_{2..3}$
$A_{0..2}$ -> $a_{0..1}$ $D_{1..2}$
$D_{1..2}$ -> $a_{1..2}$
$B_{2..3}$ -> $B1_{2..3}$
$B1_{2..3}$ -> $b_{2..3}$



$S_{0..3}$ -> $A_{0..2}$ $B_{2..3}$
$A_{0..2}$ -> $D_{0..1}$ $a_{1..2}$
$D_{0..1}$ -> $a_{0..1}$
$B_{2..3}$ -> $B1_{2..3}$
$B1_{2..3}$ -> $b_{2..3}$

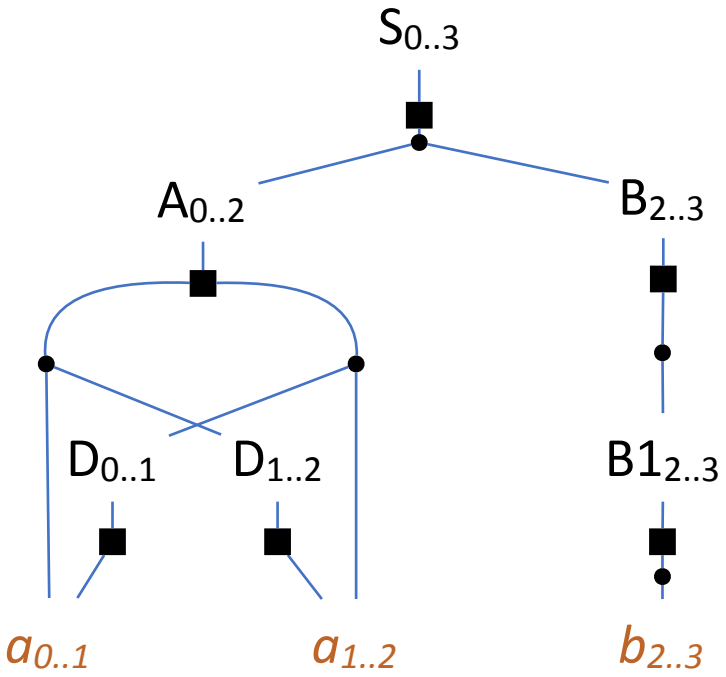
Towards parse forests

- All grammars (one for each parse tree) have the same axiom, here $S_{0..3}$
- Whenever there are shared parts, they will appear in the form of repeated (redundant) rules,
  - which can be merged!

$S_{0..3}$ -> $A_{0..2}$ $B_{2..3}$
$A_{0..2}$ -> $a_{0..1}$ $D_{1..2}$
$D_{1..2}$ -> $a_{1..2}$
$A_{0..2}$ -> $D_{0..1}$ $a_{1..2}$
$D_{0..1}$ -> $a_{0..1}$
$B_{2..3}$ -> $B1_{2..3}$
$B1_{2..3}$ -> $b_{2..3}$

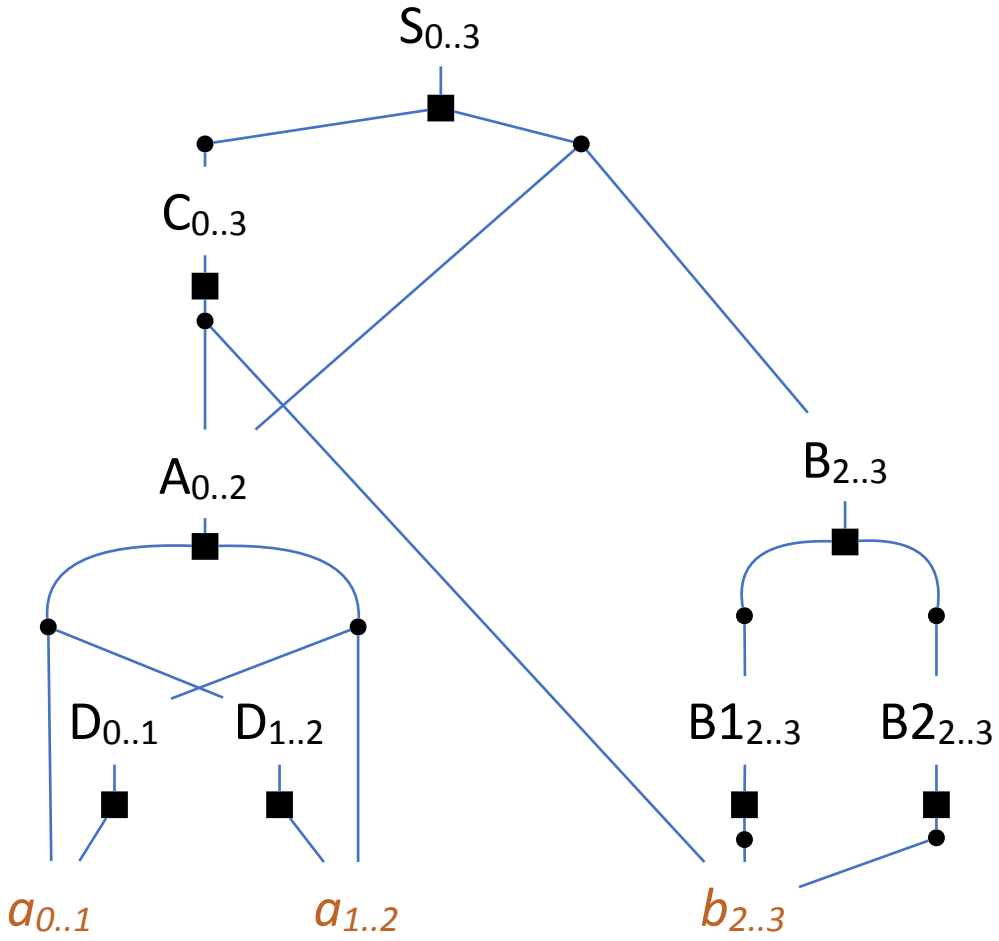
Towards parse forests

- This instanciated grammar defines a language containing the instanciated input string, and allows for two parses for this instanciated string
- We can represent this grammar as an AND-OR graph!



A (shared) parse forest

- We can represent all parses in this way



PCFGs and parse forests

- It is possible to extract the best (or the *n*-best) parse trees from a parse forest without extracting individual trees from the forest
- We do not have enough time for this today
  - For those interested, see Huang & Chiang (2005) "Better *k*-best parsing"
  - The algorithm takes advantage of the non-contextuality of both CFGs and PCFGs
- Parse forests are still a key data structure in parsing
  - But there are different approaches to the parsing problem, e.g. using discriminative algorithms
  - The role of neural networks is different: neural networks learn how to take good decisions; we still need a formal device to map a sequence of decisions into a parse tree

Preparing the pratical assignment:

The CYK algorithm

A membership problem

- The basic Cocke–Younger–Kasami, a.k.a. CYK algorithm, solves a **membership problem**: it is not a parsing algorithm *per se*
  - An implementation of the CYK algorithm is a **recogniser**, not a parser
  - But it can easily be adapted to become a parsing algorithm
- The membership problem is simple: given an CFG and an input string, answer the following question:
  Is the input string in the language defined by the CFG?
- The CFG must be in Chomsky normal form, i.e. all rewriting rules are of one of the following forms:
  - $S \longrightarrow A\ B$
  - $S \longrightarrow a$
  - $S \longrightarrow \varepsilon$
- It is a bottom-up algorithm based on dynamic programming

Basic idea

- Iterative algorithm
- Let $u = x_1x_2\ldots x_n$ be a string to be tested for membership
  - Step 1: For each substring of u of length 1, find the set $\boldsymbol{S}_{i-1,i}$ of non-terminals A with a rule $A \longrightarrow x_i$
  - Step 2: for each substring x_ix_{i+1} of u of length 2 find the set $\boldsymbol{S}_{i-1,i+1}$ of variables A that derives $A \longrightarrow x_ix_{i+1}$
  - …
  - Step n: for the whole string $u = x_1x_2\ldots x_n$, find the set $\boldsymbol{S}_{0,n}$ of variables A that derives $A \longrightarrow x_1x_2\ldots x_n$
  - Iff $\boldsymbol{S}_{0,n}$ contains the axiom S, then u is in the language defined by the grammar.

Diagonal table

$\mathcal{S}_{0,4}$			
$\mathcal{S}_{0,3}$	$\mathcal{S}_{1,4}$		
$\mathcal{S}_{0,2}$	$\mathcal{S}_{1,3}$	$\mathcal{S}_{2,4}$	
$\mathcal{S}_{0,1}$	$\mathcal{S}_{1,2}$	$\mathcal{S}_{2,3}$	$\mathcal{S}_{3,4}$
w_1	w_2	w_3	w_4

CYK on an example

S → AB

A → CC | a | c

B → BC | b

C → CB | BA | c

$S_{0,4}$			
$S_{0,3}$	$S_{1,4}$		
$S_{0,2}$	$S_{1,3}$	$S_{2,4}$	
$S_{0,1}$	$S_{1,2}$	$S_{2,3}$	$S_{3,4}$
c	b	b	a

$S_{0,4}$			
$S_{0,3}$	$S_{1,4}$		
$S_{0,2}$	$S_{1,3}$	$S_{2,4}$	
{A,C}	{B}	{B}	{A}
c	b	b	a

CYK on an example

S → AB

A → CC | a | c

B → BC | b

C → CB | BA | c

$\mathcal{S}_{0,4}$			
$\mathcal{S}_{0,3}$	$\mathcal{S}_{1,4}$		
$\mathcal{S}_{0,2}$	$\mathcal{S}_{1,3}$	$\mathcal{S}_{2,4}$	
$\mathcal{S}_{0,1}$	$\mathcal{S}_{1,2}$	$\mathcal{S}_{2,3}$	$\mathcal{S}_{3,4}$
c	b	b	a

$\mathcal{S}_{0,4}$			
$\mathcal{S}_{0,3}$	$\mathcal{S}_{1,4}$		
{S,C}	$\mathcal{S}_{1,3}$	$\mathcal{S}_{2,4}$	
{A,C}	{B}	{B}	{A}
c	b	b	a

CYK on an example

S → AB

A → CC | a | c

B → BC | b

C → CB | BA | c

$\mathcal{S}_{0,4}$			
$\mathcal{S}_{0,3}$	$\mathcal{S}_{1,4}$		
$\mathcal{S}_{0,2}$	$\mathcal{S}_{1,3}$	$\mathcal{S}_{2,4}$	
$\mathcal{S}_{0,1}$	$\mathcal{S}_{1,2}$	$\mathcal{S}_{2,3}$	$\mathcal{S}_{3,4}$
c	b	b	a

$\mathcal{S}_{0,4}$			
$\mathcal{S}_{0,3}$	$\mathcal{S}_{1,4}$		
{S,C}	∅	$\mathcal{S}_{2,4}$	
{A,C}	{B}	{B}	{A}
c	b	b	a

CYK on an example

S → AB

A → CC | a | c

B → BC | b

C → CB | BA | c

$\mathcal{S}_{0,4}$			
$\mathcal{S}_{0,3}$	$\mathcal{S}_{1,4}$		
$\mathcal{S}_{0,2}$	$\mathcal{S}_{1,3}$	$\mathcal{S}_{2,4}$	
$\mathcal{S}_{0,1}$	$\mathcal{S}_{1,2}$	$\mathcal{S}_{2,3}$	$\mathcal{S}_{3,4}$
c	b	b	a

$\mathcal{S}_{0,4}$			
$\mathcal{S}_{0,3}$	$\mathcal{S}_{1,4}$		
{S,C}	∅	{C}	
{A,C}	{B}	{B}	{A}
c	b	b	a

CYK on an example

S → AB

A → CC | a | c

B → BC | b

C → CB | BA | c

$\mathcal{S}_{0,4}$			
$\mathcal{S}_{0,3}$	$\mathcal{S}_{2,4}$		
$\mathcal{S}_{0,2}$	$\mathcal{S}_{1,3}$	$\mathcal{S}_{2,4}$	
$\mathcal{S}_{0,1}$	$\mathcal{S}_{1,2}$	$\mathcal{S}_{2,3}$	$\mathcal{S}_{3,4}$
c	b	b	a

$\mathcal{S}_{0,4}$			
{C}	$\mathcal{S}_{1,4}$		
{S,C}	∅	{C}	
{A,C}	{B}	{B}	{A}
c	b	b	a

CYK on an example

S → AB

A → CC | a | c

B → BC | b

C → CB | BA | c

$S_{0,4}$			
$S_{0,3}$	$S_{1,4}$		
$S_{0,2}$	$S_{1,3}$	$S_{2,4}$	
$S_{0,1}$	$S_{1,2}$	$S_{2,3}$	$S_{3,4}$
c	b	b	a

$S_{0,4}$			
{C}	{B}		
{S,C}	∅	{C}	
{A,C}	{B}	{B}	{A}
c	b	b	a

CYK on an example

S → AB

A → CC | a | c

B → BC | b

C → CB | BA | c

$S_{0,4}$			
$S_{0,3}$	$S_{1,4}$		
$S_{0,2}$	$S_{1,3}$	$S_{2,4}$	
$S_{0,1}$	$S_{1,2}$	$S_{2,3}$	$S_{3,4}$
c	b	b	a

{S,A,C}			
{C}	{B}		
{S,C}	∅	{C}	
{A,C}	{B}	{B}	{A}
c	b	b	a

CYK on an example

S → AB

A → CC | a | c

B → BC | b

C → CB | BA | c

$\mathcal{S}_{0,4}$			
$\mathcal{S}_{0,3}$	$\mathcal{S}_{1,4}$		
$\mathcal{S}_{0,2}$	$\mathcal{S}_{1,3}$	$\mathcal{S}_{2,4}$	
$\mathcal{S}_{0,1}$	$\mathcal{S}_{1,2}$	$\mathcal{S}_{2,3}$	$\mathcal{S}_{3,4}$
c	b	b	a

{**S**,A,C}			
{C}	{B}		
{S,C}	∅	{C}	
{A,C}	{B}	{B}	{A}
c	b	b	a

=> the string is in the language defined by the CFG

Online question 2

What is the complexity of the CYK algorithm with respect to *n*, the length of the input string?

1. $O(n^3)$
2. $O(n^4)$
3. $O(n^5)$
4. Other

https://api.socrative.com/rc/KBcrE4

Practical assignment 4

Goal

- Develop a **probabilistic parser** using the **CYK algorithm + PCFG model**

- Use the SEQUOIA treebank v6.0 (file in the GitHub, bracketed format):
  - Split it into 3 parts (80% / 10% / 10%)
  - Use the 80% for training (extract CFG rules + learn CFG rule probabilities)
  - Use the first 10% for development purposes (whatever you want to use them for)
  - Use the last 10% for evaluating your parser
  - IMPORTANT: I strongly advice you ignore the functional labels: whenever you find a hyphen in a non-terminal name, ignore it and everything that follows
    E.g.: ((SENT (PP-MOD (P En) (NP (NC 1996))) (PONCT ,) (NP-SUJ (DET la) (NC municipalité)) (VN (V étudie)) (NP-OBJ (DET la) (NC possibilité) (PP (P d') (NP (DET une) (NC construction) (AP (ADJ neuve))))) (PONCT .)))
- You can use any other resource you want (e.g. lexicon for dealing with unknown words)

Assigment devliverable

- An archive containing your code and a short report
- Please respect the instructions given in the assignment description on the GitHub
  - Failure to do so will be penalised

https://github.com/edupoux/MVA_2018_SL/tree/master/TD_%234


That’s all for today!