A computational Minimalist program for syntax and sentence processing

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A better title (Fodor & Fernandez 2015)

Toward a unified theory of language knowledge and use

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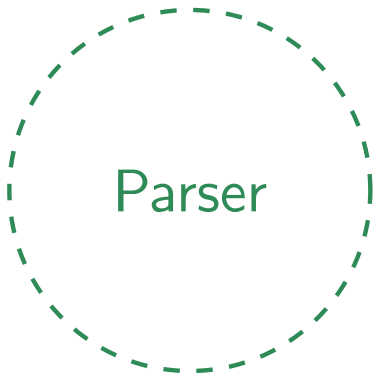

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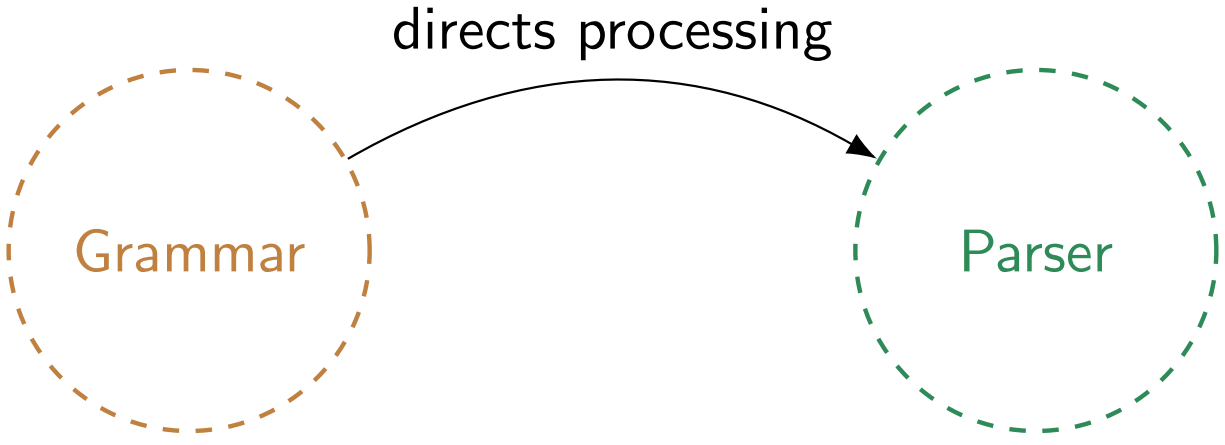

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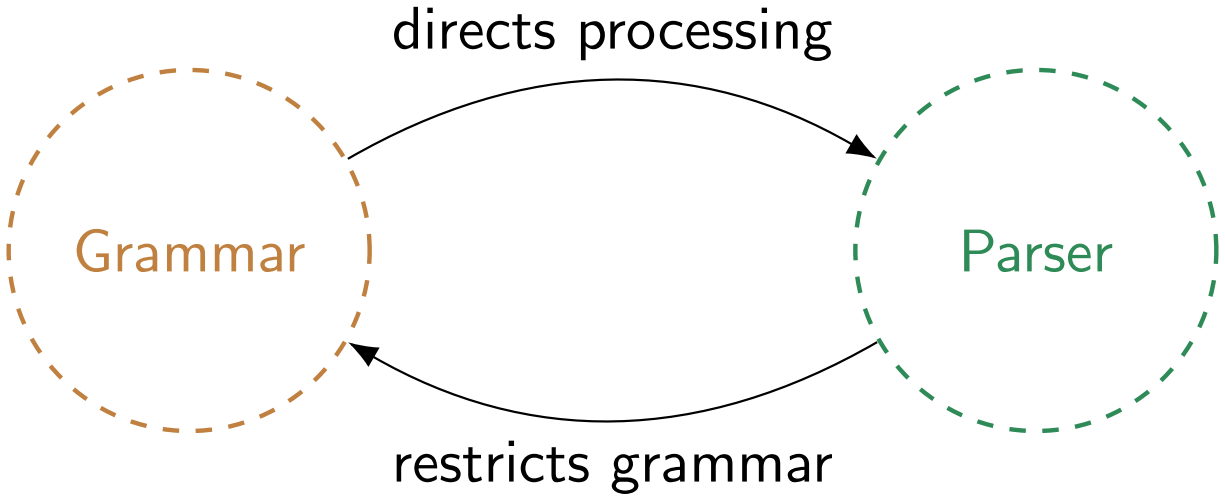
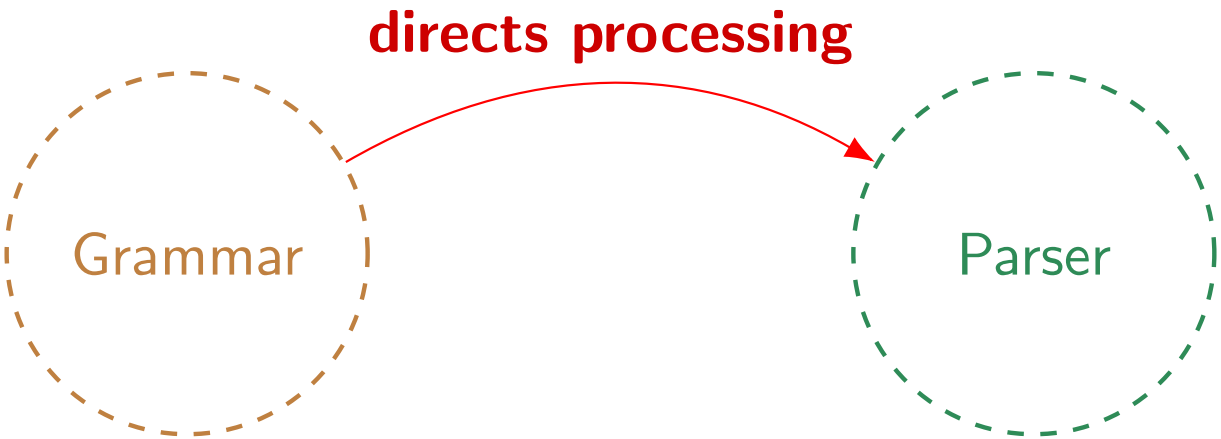


Take-home message

- Computation is the **glue between knowledge and use**.
- Syntactic structure explains many processing differences.
- Processing requirements explain many syntactic constraints.
- Concretely:
  1. **top-down parser for Minimalist grammars**
  2. **head-sensing tree automata**

Outline


directs processing
Grammar
Parser

An overly simplistic approach to processing...

Syntactic processing is influenced by many factors:

- lexical frequency
- structural frequency
- lexical ambiguity
- structural ambiguity
- semantics
- and much more

A much simpler question

How hard is it to build the target structure
if we already know what this structure looks like?

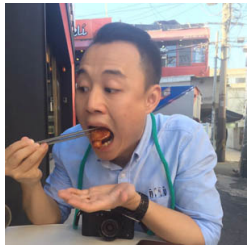
. . . works remarkably well

Structural complexity explains numerous processing preferences

- right-embedding < center-embedding
  (Greg Kobele, John Hale, Sabrina Gerth 2013)
- crossing dependencies < nested dependencies
  (Kobele et al. 2013)
- post-nominal subject RC < post-nominal object RC
  (Graf et al. 2017)
- pre-nominal subject RC < pre-nominal object RC
  (Graf et al. 2017)
- [SC [RC]] < [RC [SC]]
  (Graf et al. 2017)
- processing of stacked RCs in English and Chinese
  (Zhang 2017)

. . . way better than I ever expected

- heavy NP shift preferences
  (Liu 2018)
- attachment preferences in English and Korean
  (Lee 2019)
- structural priming effects
  (De Santo 2020)
- quantifier scope preferences
  (Pasternak and Graf 2020)

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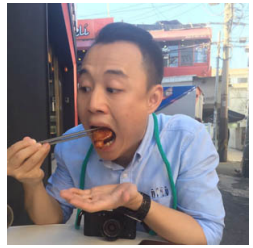
But how does it work?

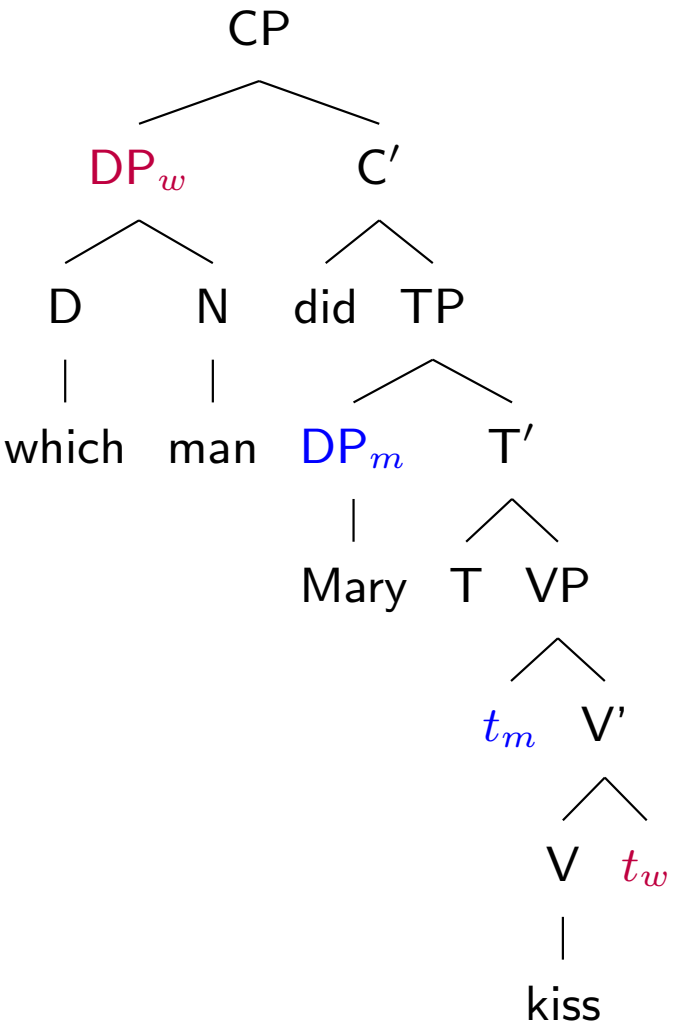


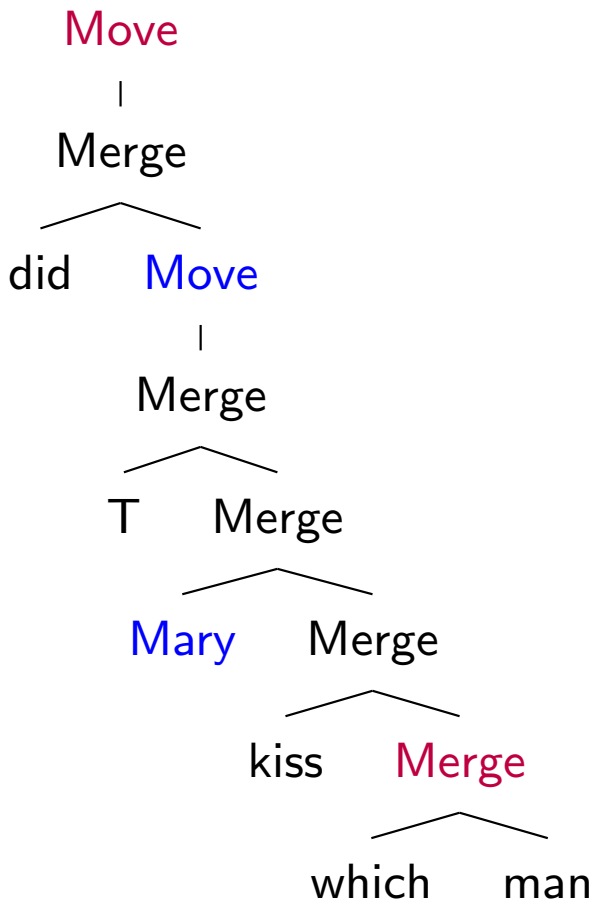

Three components

1. **Syntactic model: MGs** (Stabler 1997, 2011)
   - closely modeled after Minimalist syntax
   - allows us to use sophisticated analyses
2. **Parsing model: Recursive descent**
   - builds trees top-down, left-to-right
   - the main complication is what "left-to-right" means in syntax
3. **Cognitive linking hypothesis: Memory usage**
   - There are many ways to measure memory.
   - We mostly use **MaxTen** (longest time a node stays in memory) and **SumSize** ($\sim$ combined length of movement dependencies)

MGs: Derivation trees, not phrase structure trees

- **MGs**: syntactic structure = derivation tree
- **Advantage**: allows us to use CFG techniques





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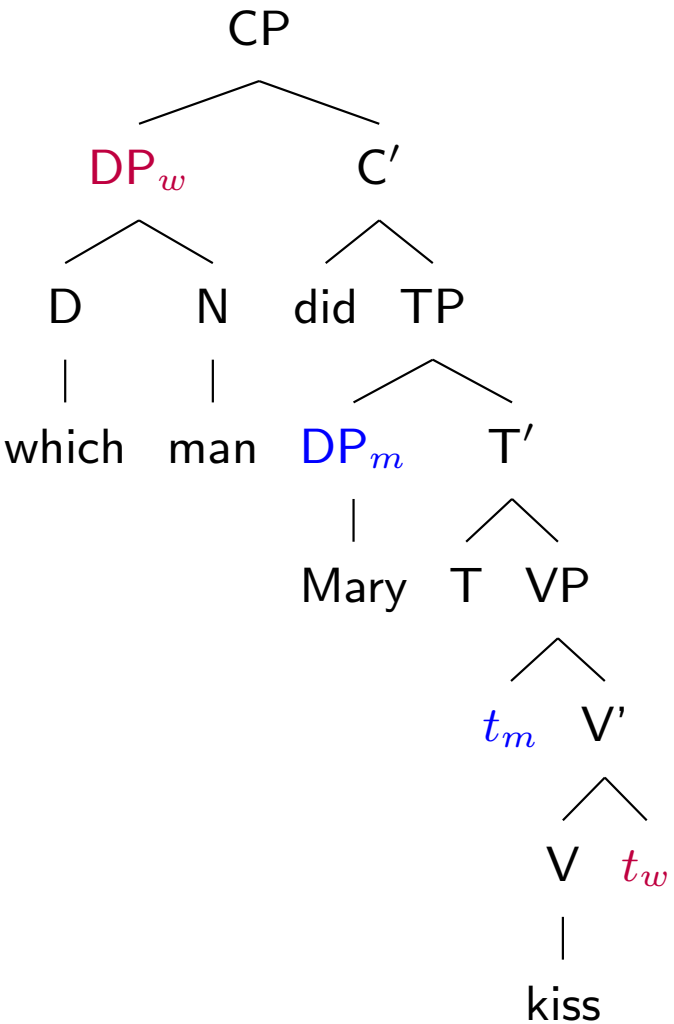
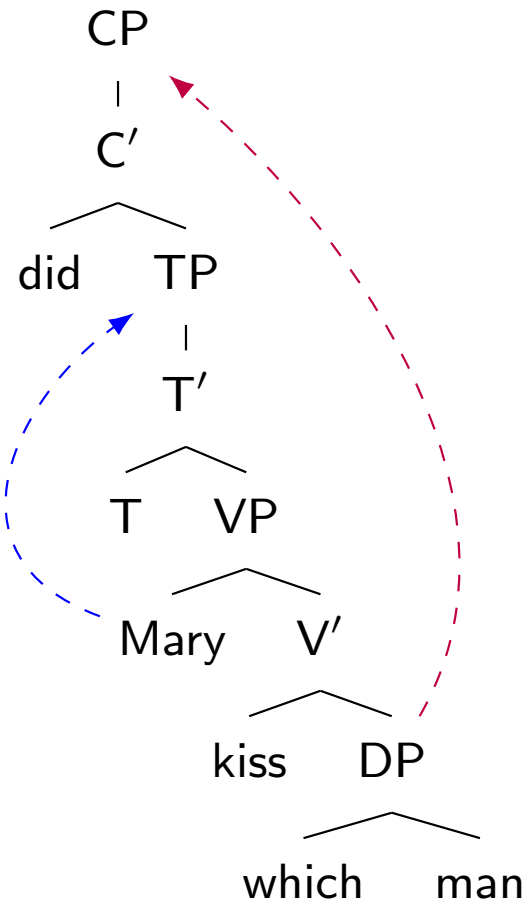
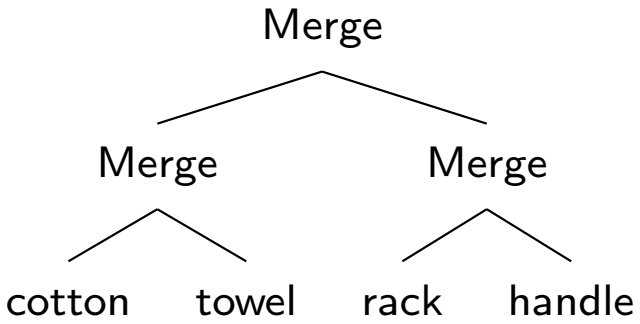




Recursive descent parsing without movement



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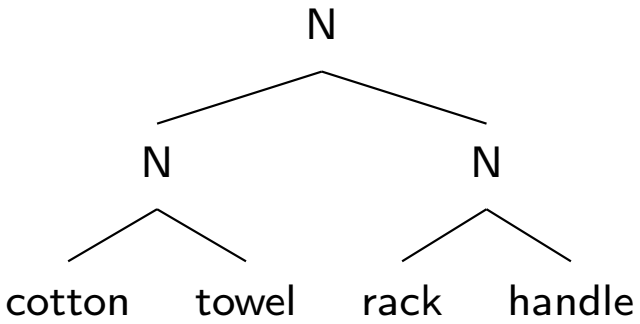

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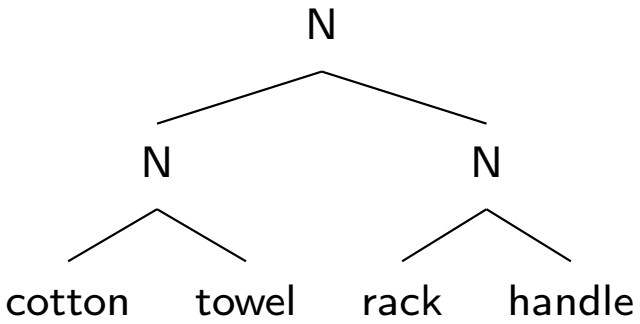

● cotton towel rack handle

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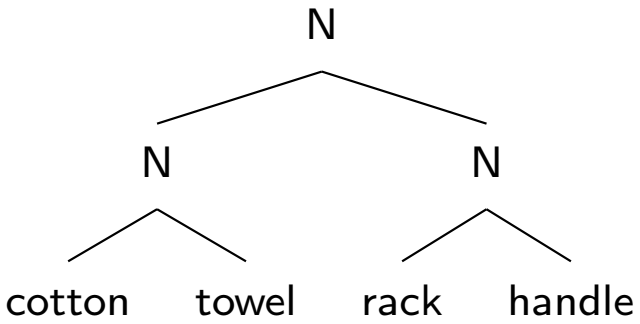

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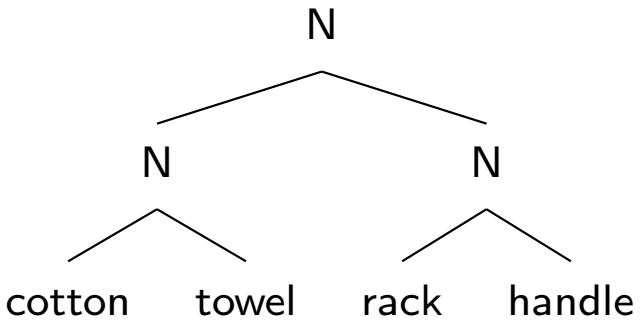

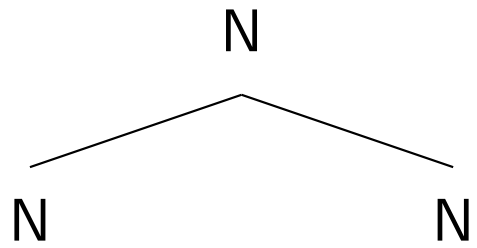

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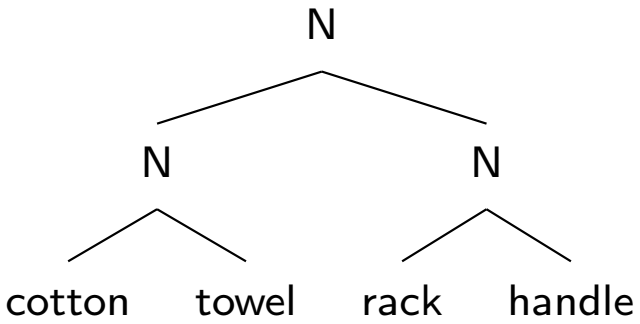

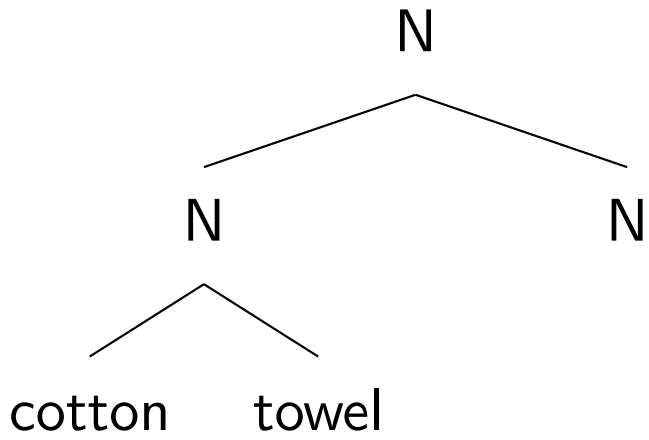

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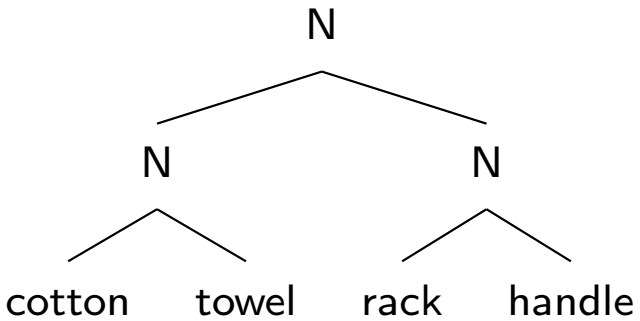

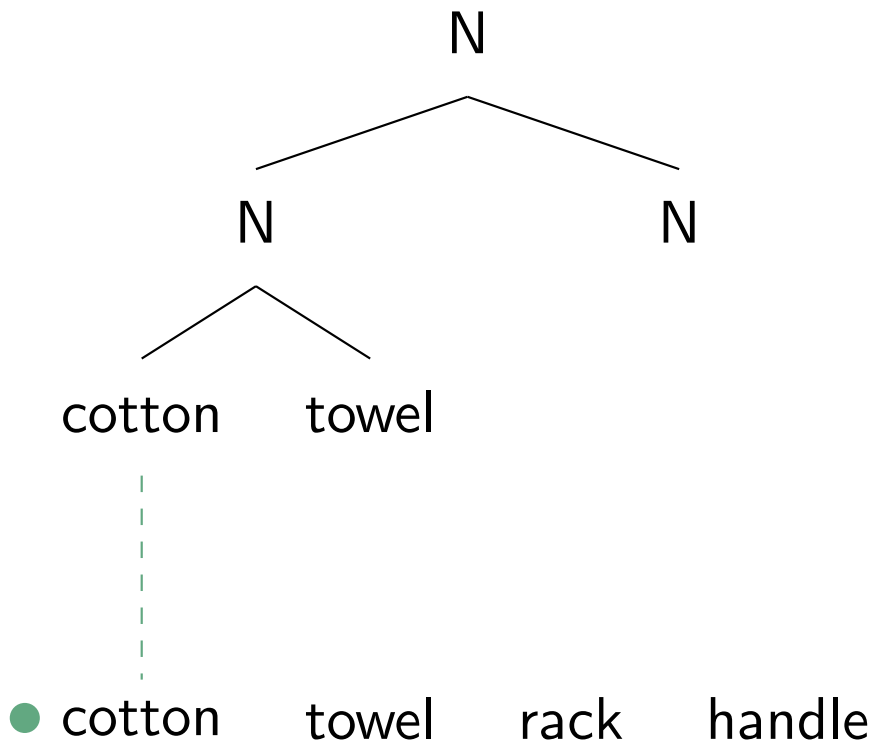

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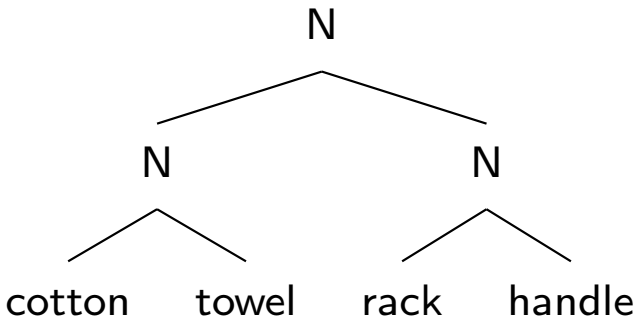

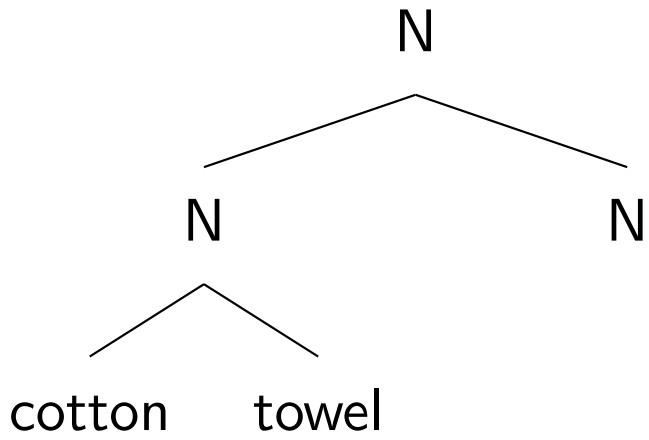

cotton ● towel rack handle

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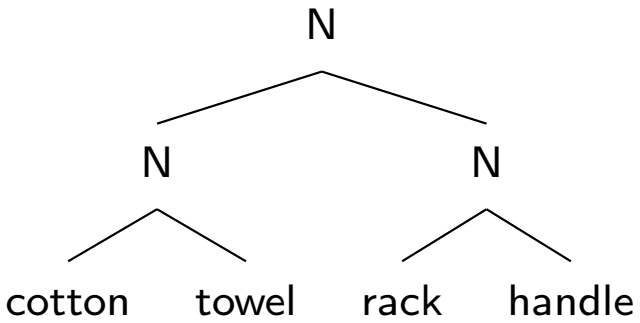

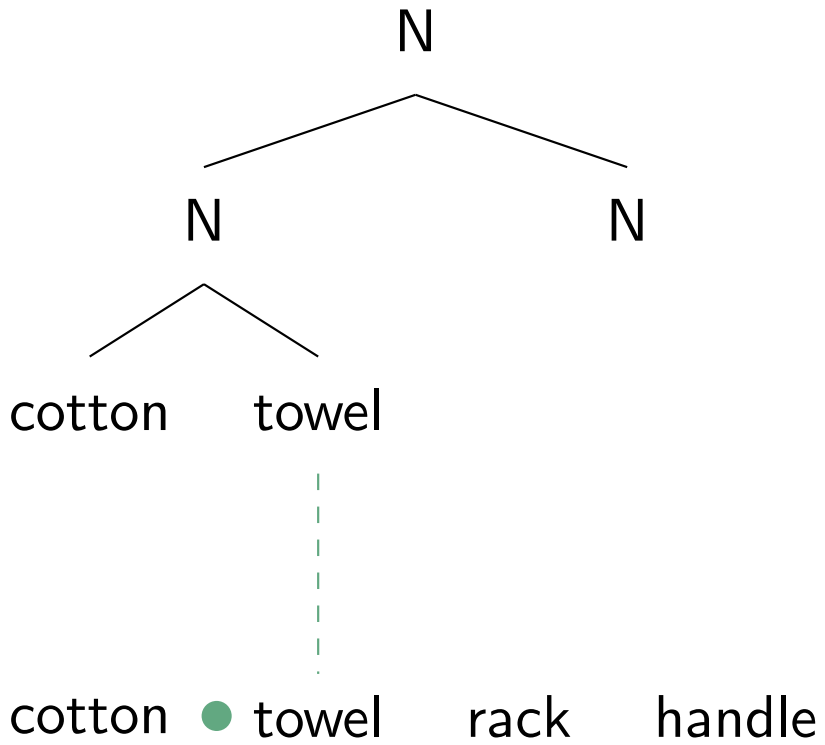

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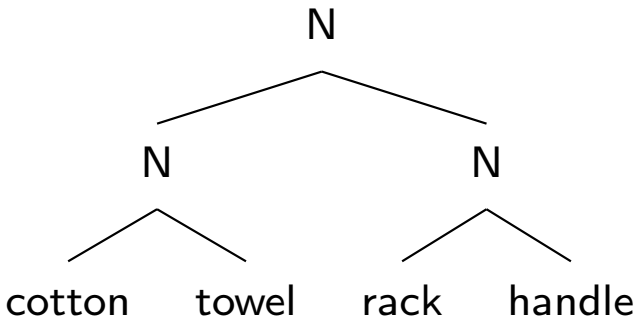

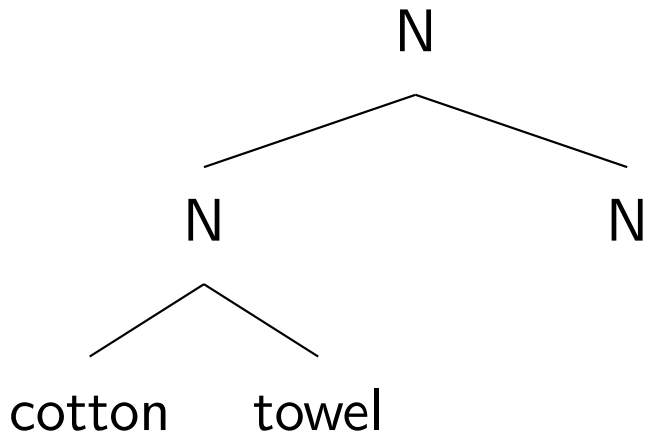

cotton towel • rack handle

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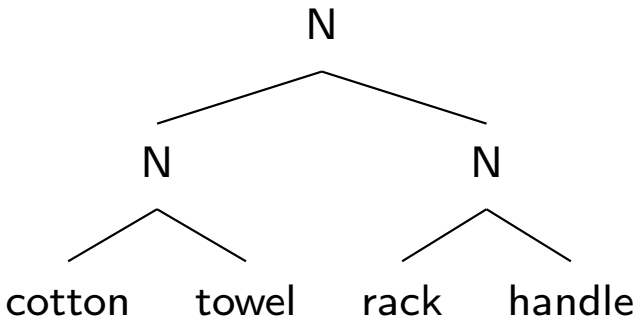

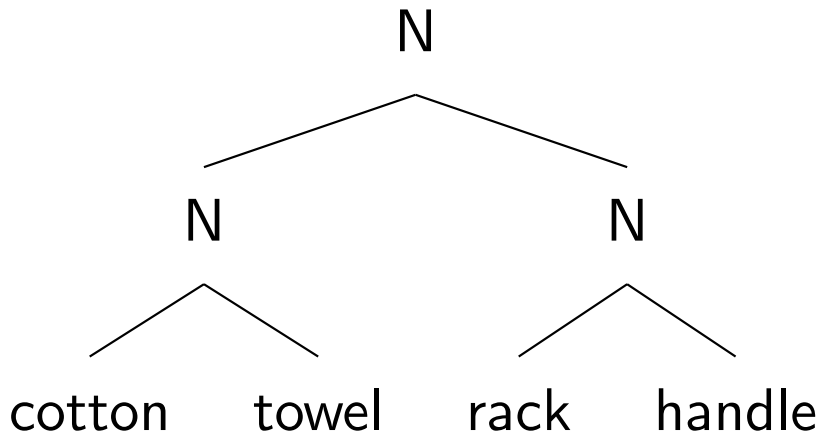

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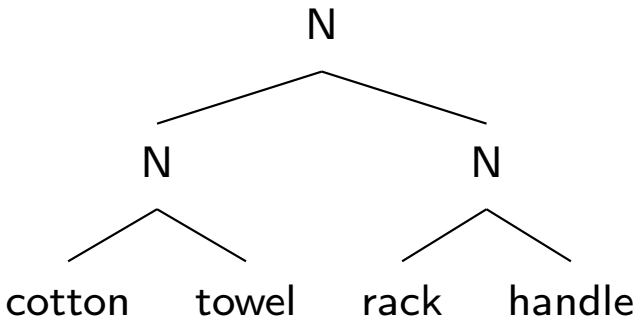

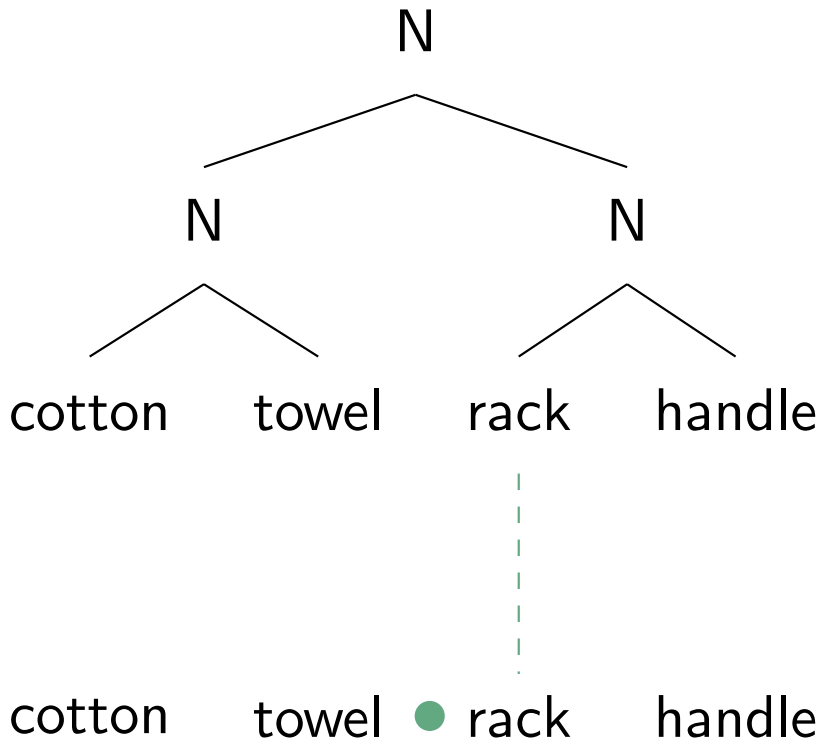

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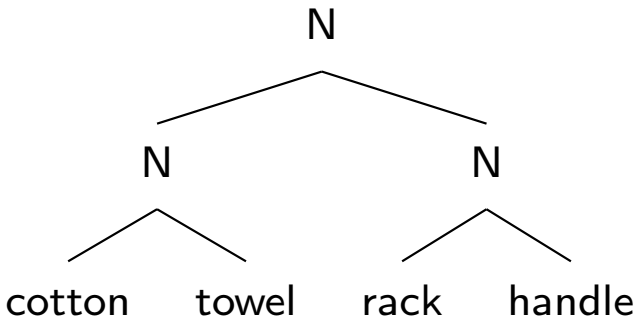

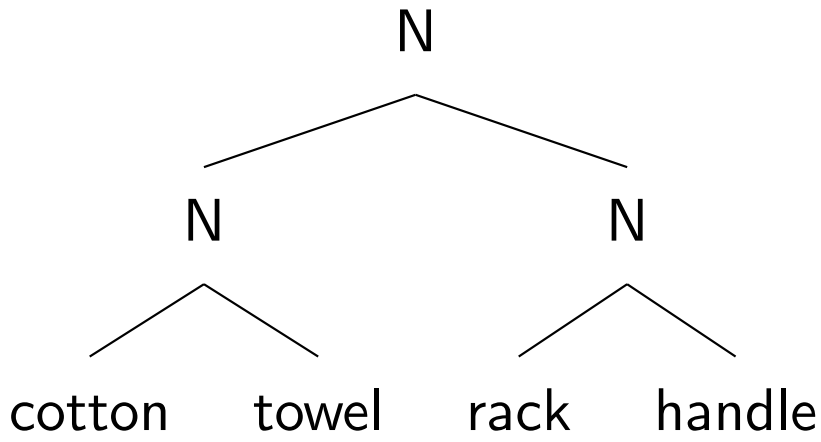

cotton towel rack ● handle

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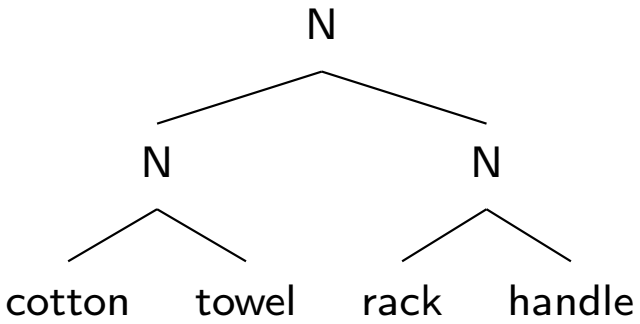

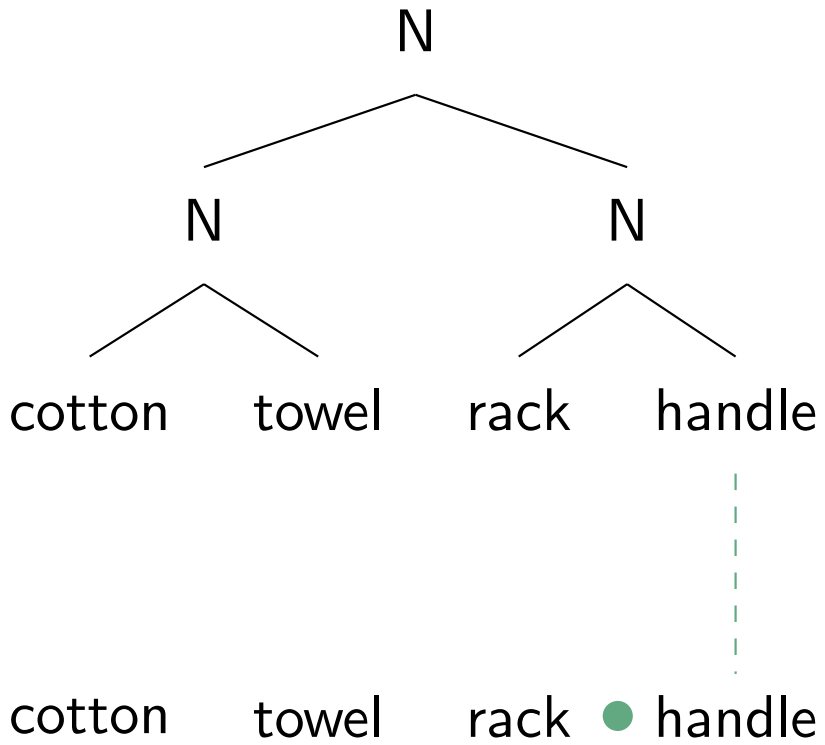

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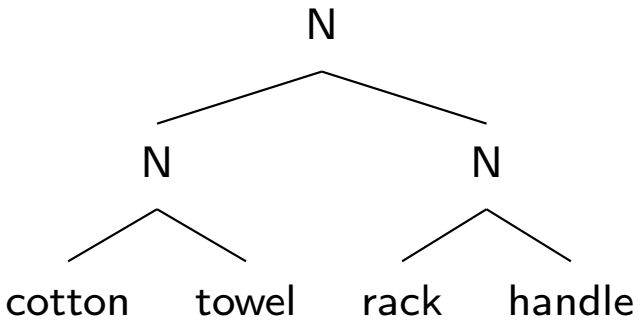

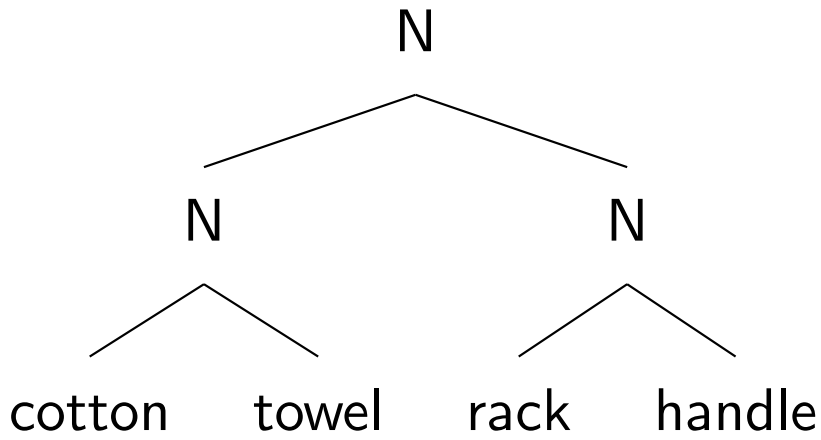

cotton towel rack handle

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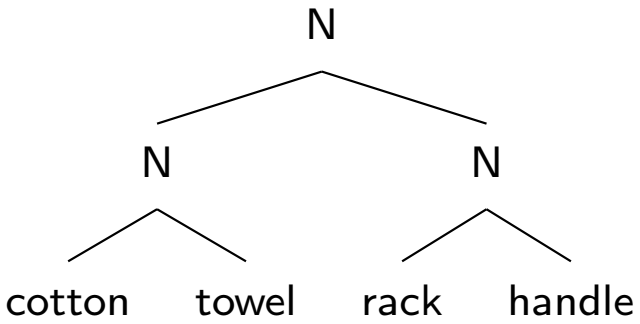

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- cotton towel rack handle

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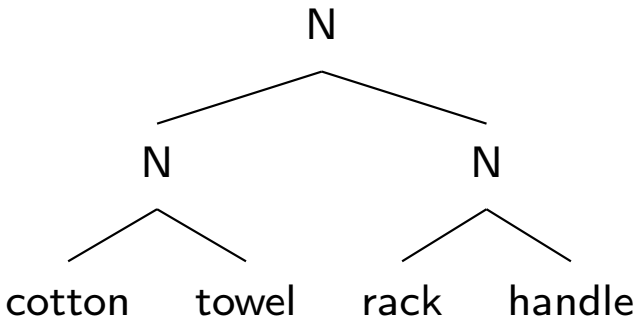

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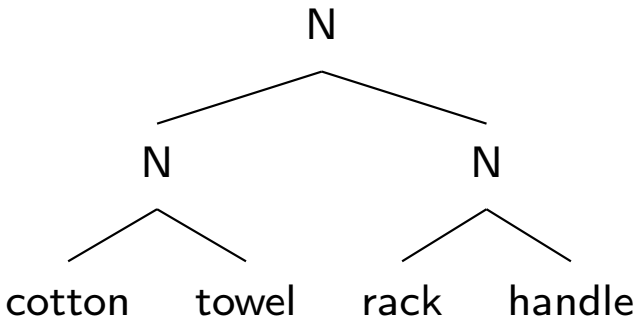

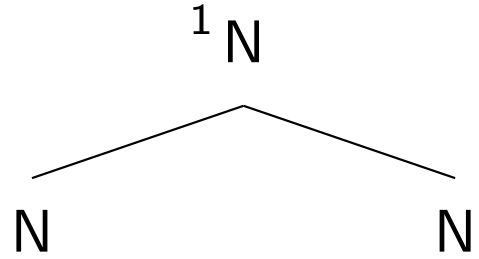

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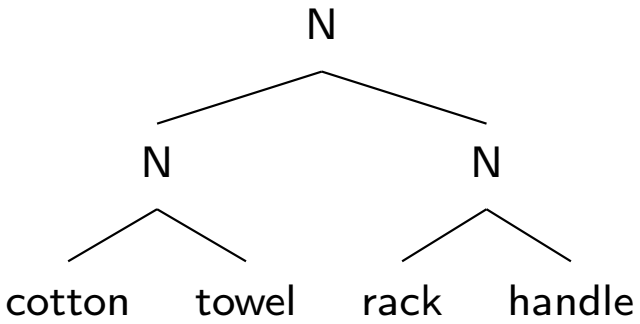

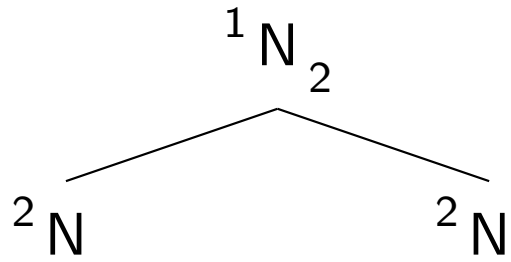

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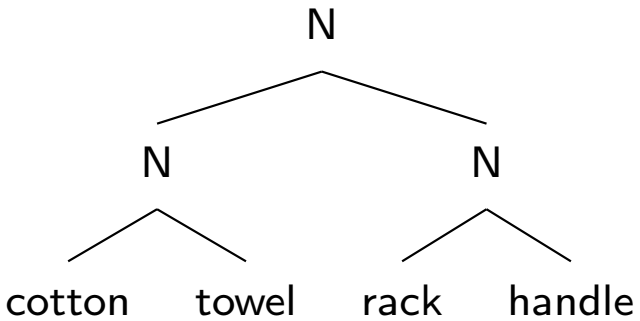
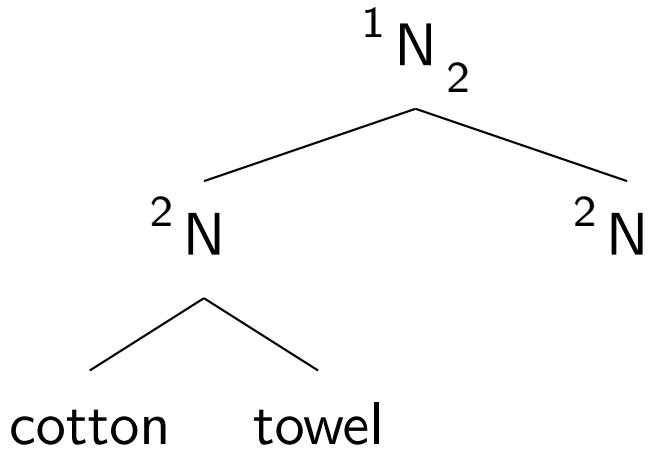
Recursive descent parsing without movement





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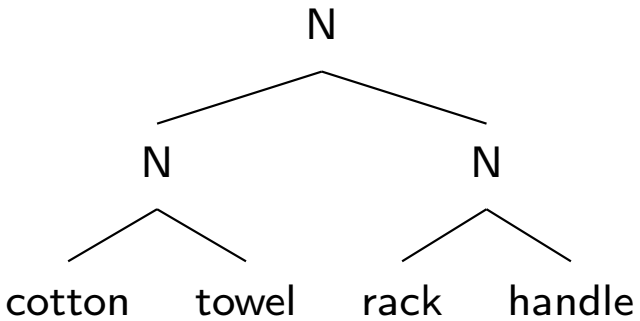

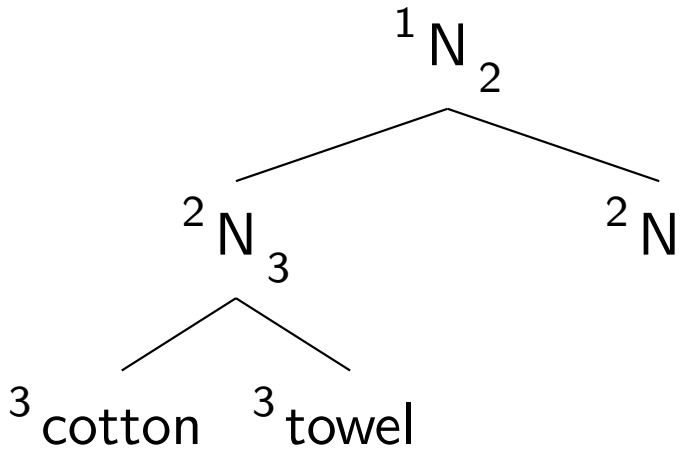

● cotton towel rack handle

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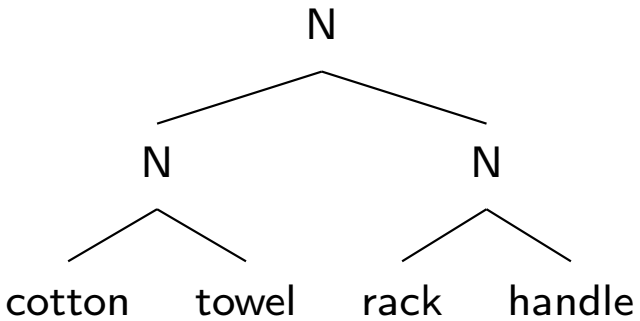

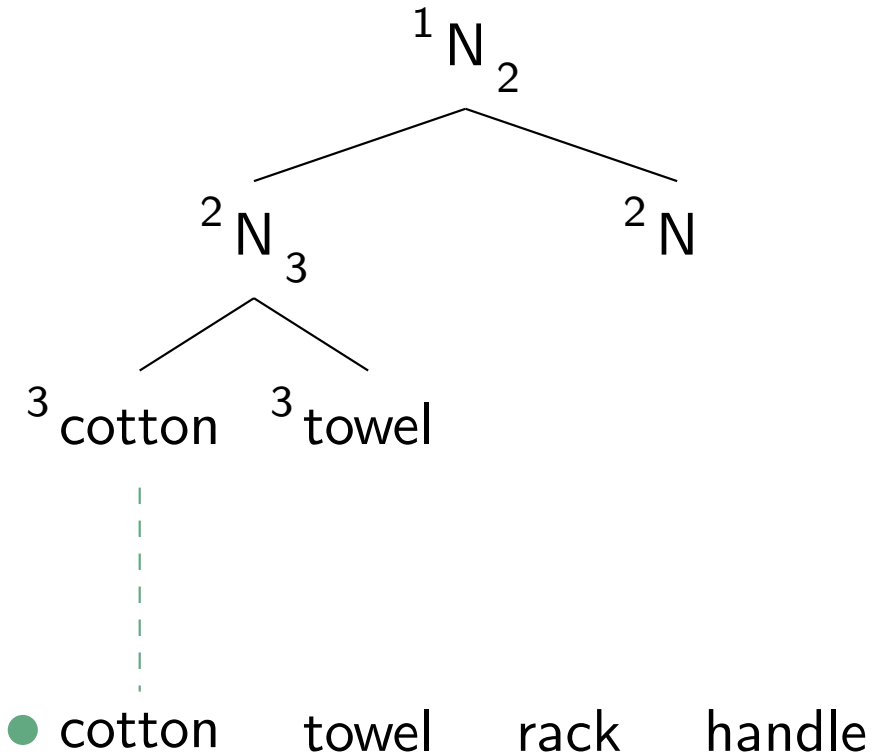

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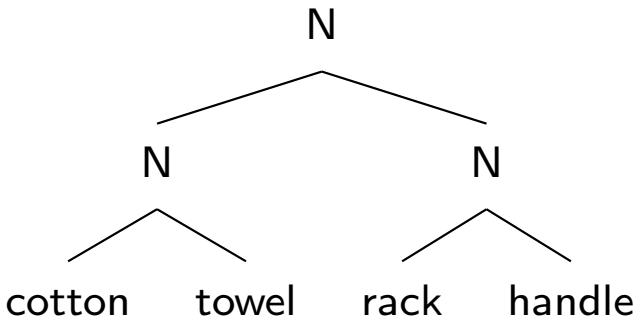

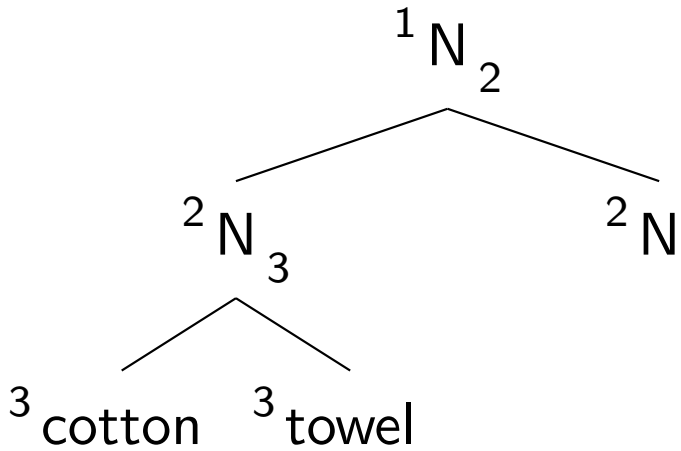

cotton ● towel rack handle

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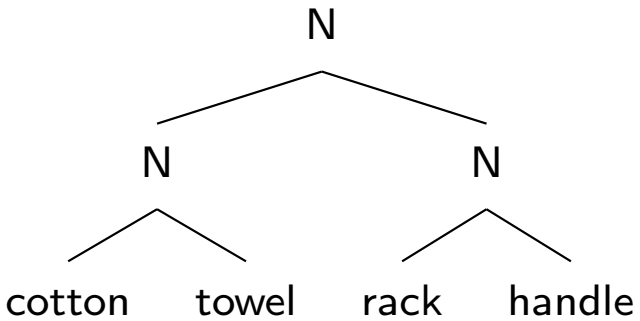

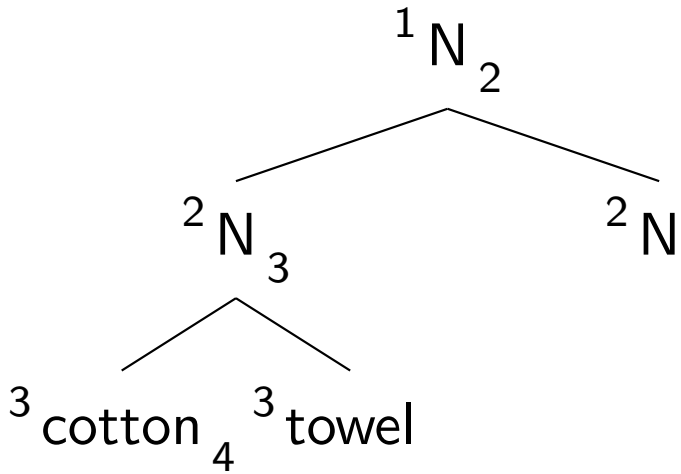

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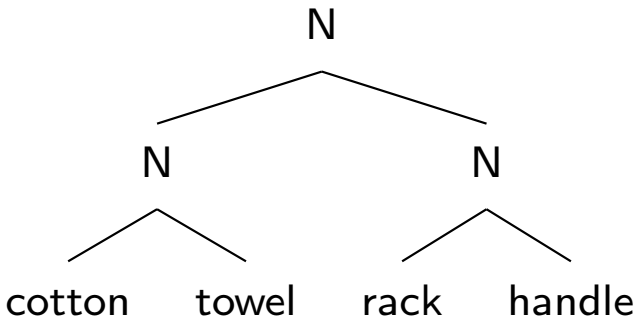
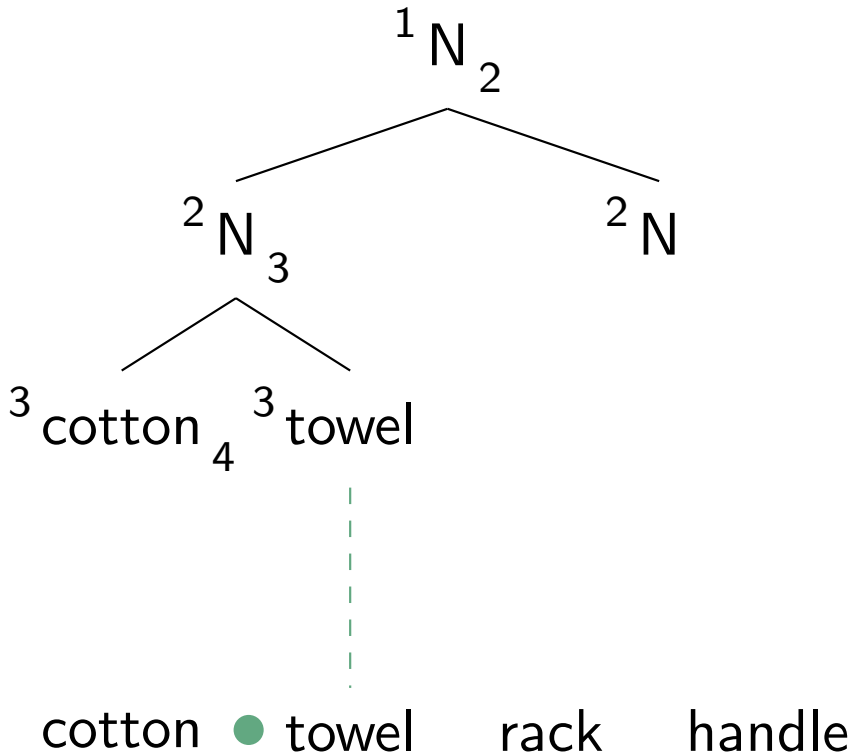
Recursive descent parsing without movement





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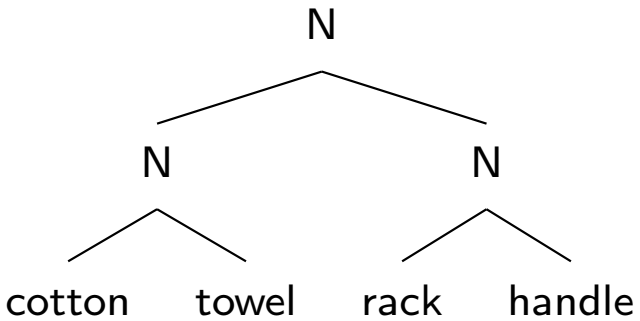
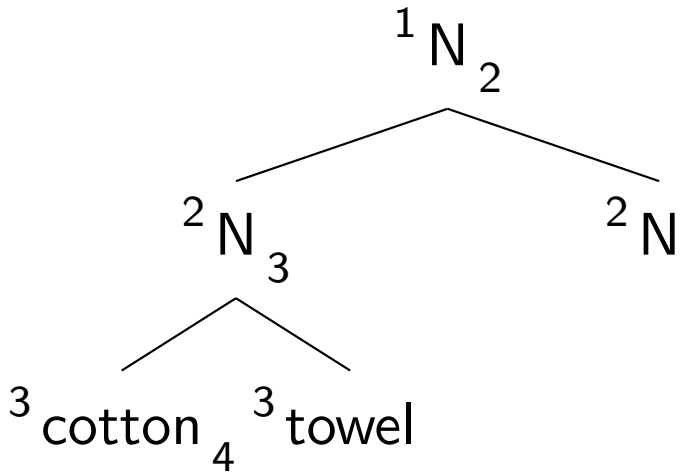
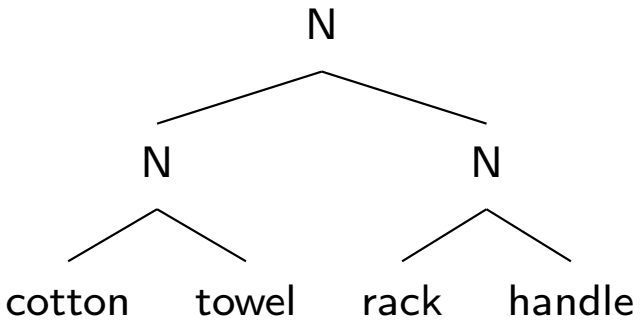
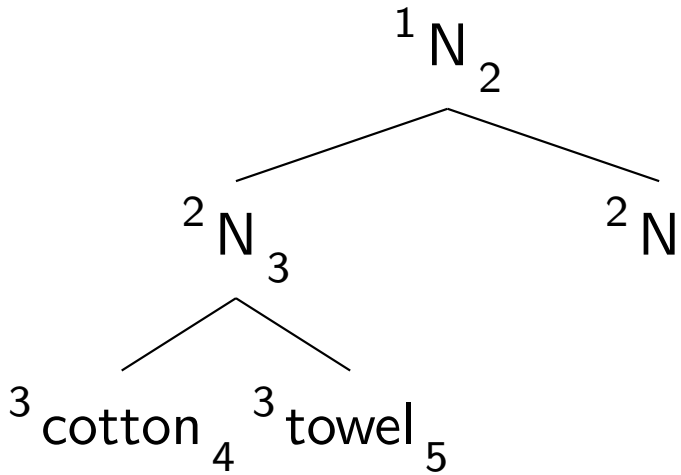




cotton towel ● rack handle

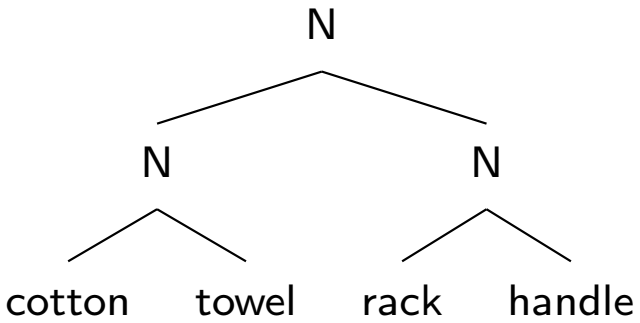
Recursive descent parsing without movement

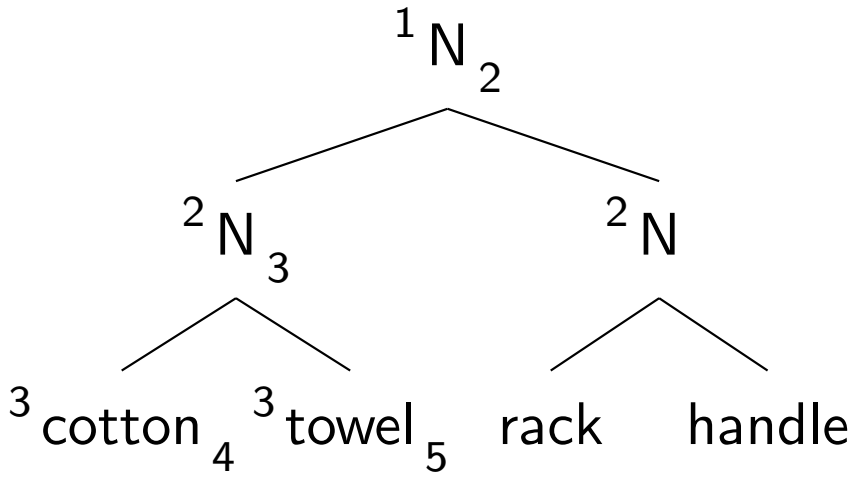




cotton towel rack handle

Recursive descent parsing without movement





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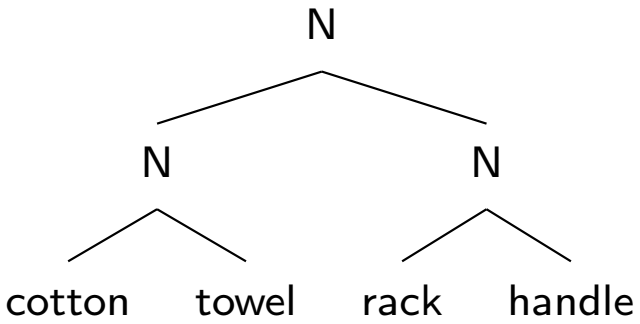

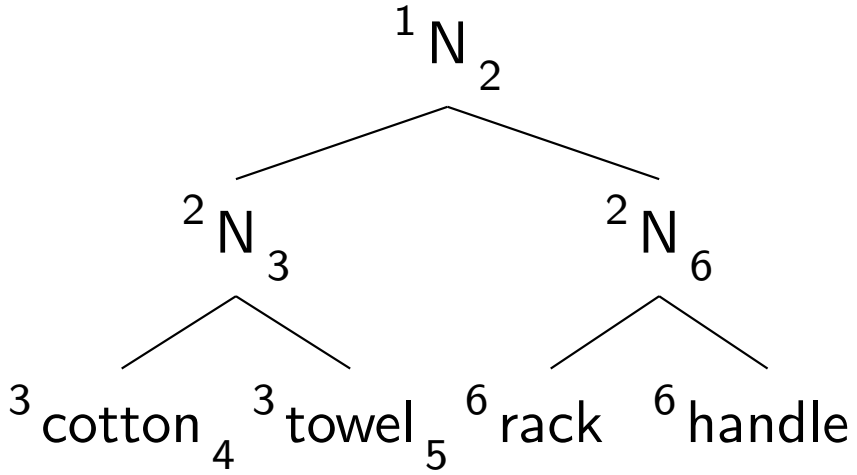

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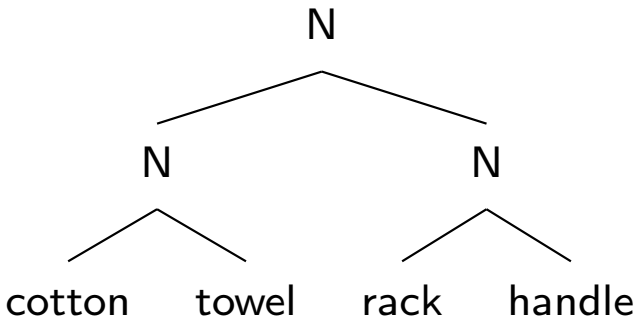

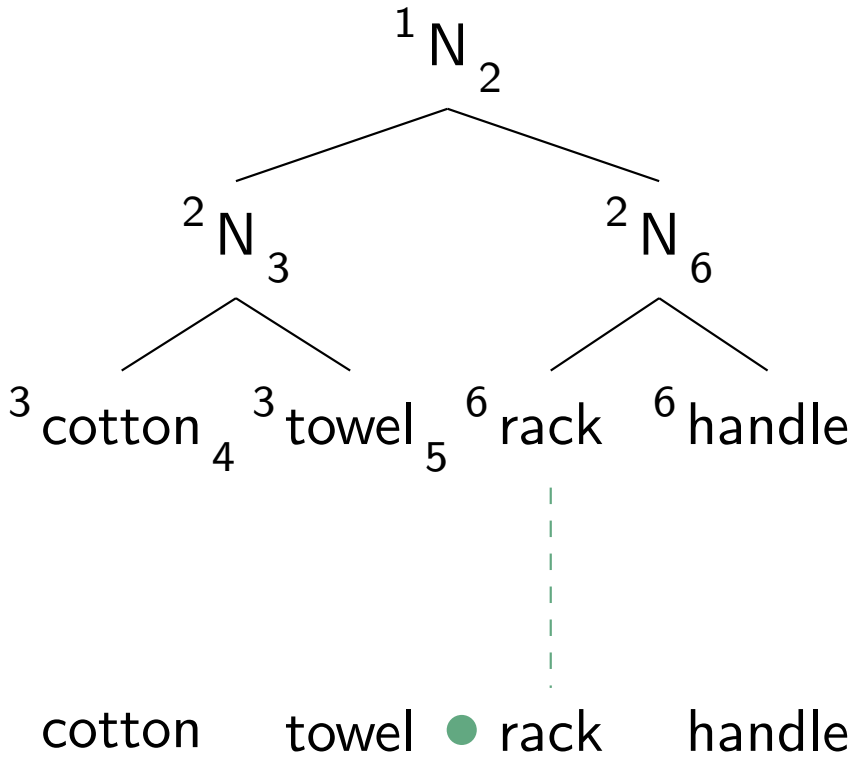

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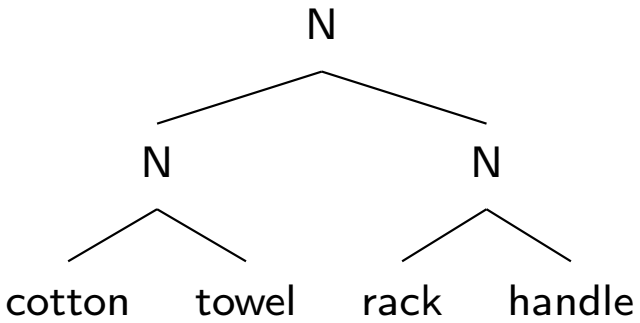
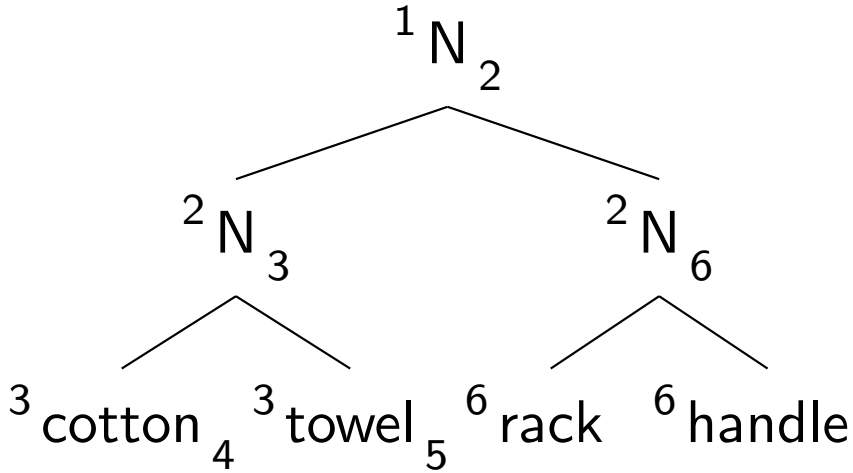
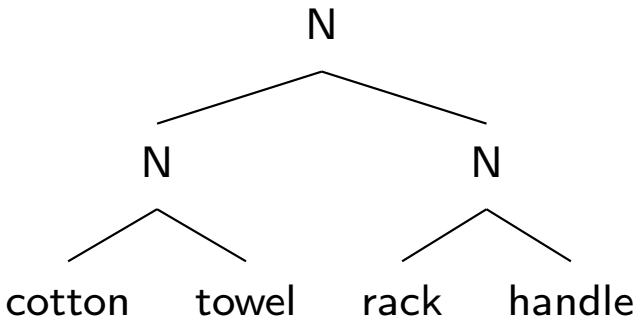
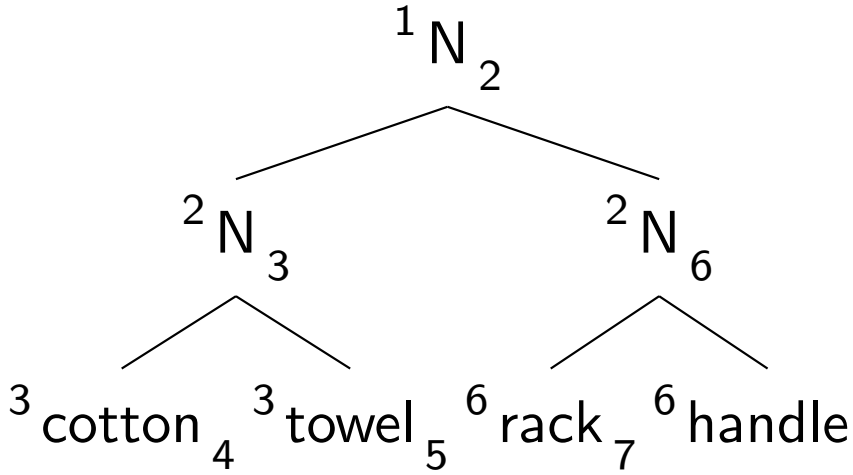




cotton towel rack handle

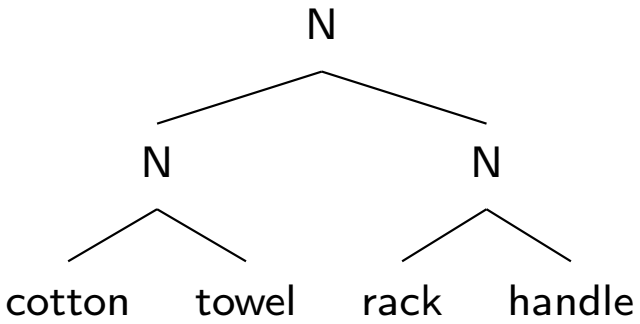
Recursive descent parsing without movement

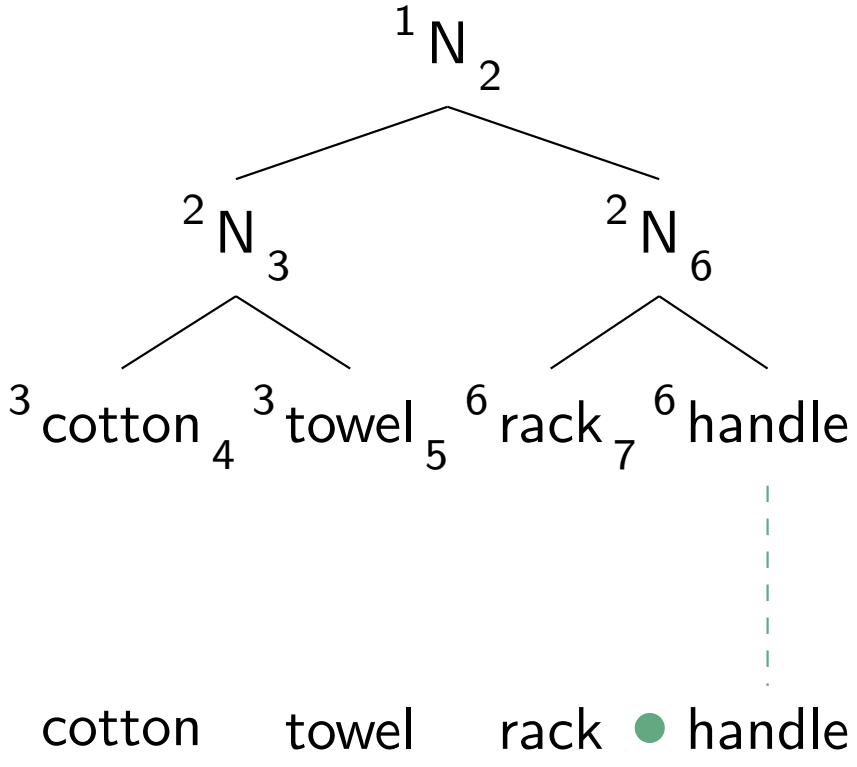




cotton towel rack handle

Recursive descent parsing without movement





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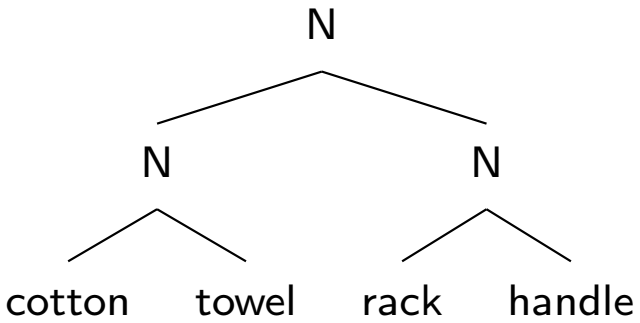
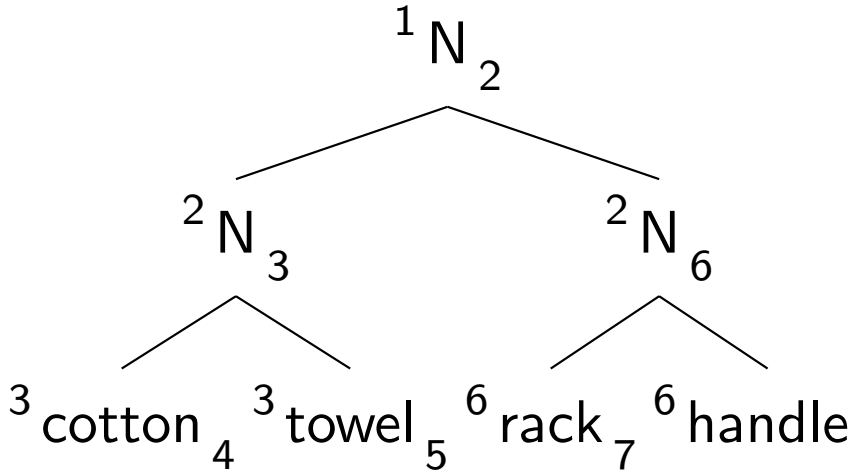
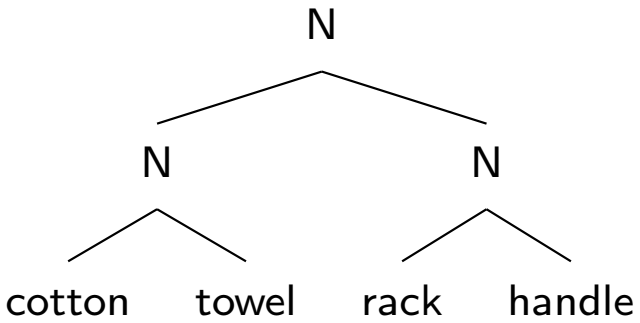
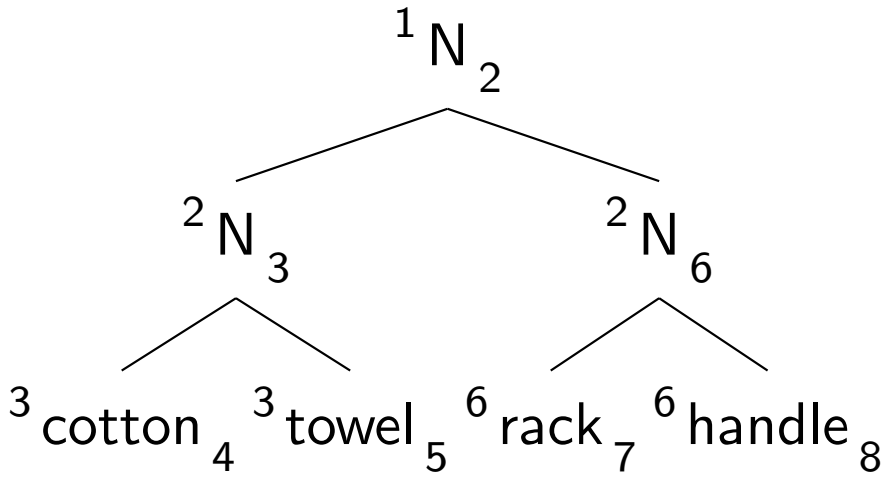




cotton towel rack handle

Recursive descent parsing without movement





cotton towel rack handle

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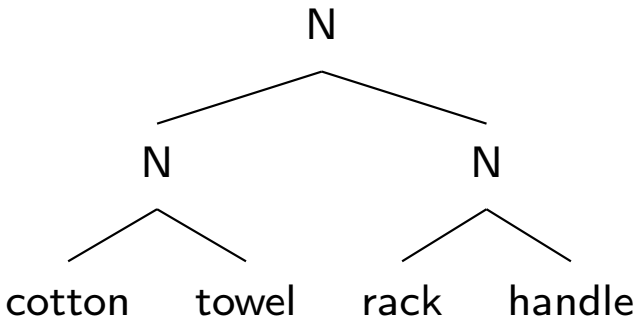

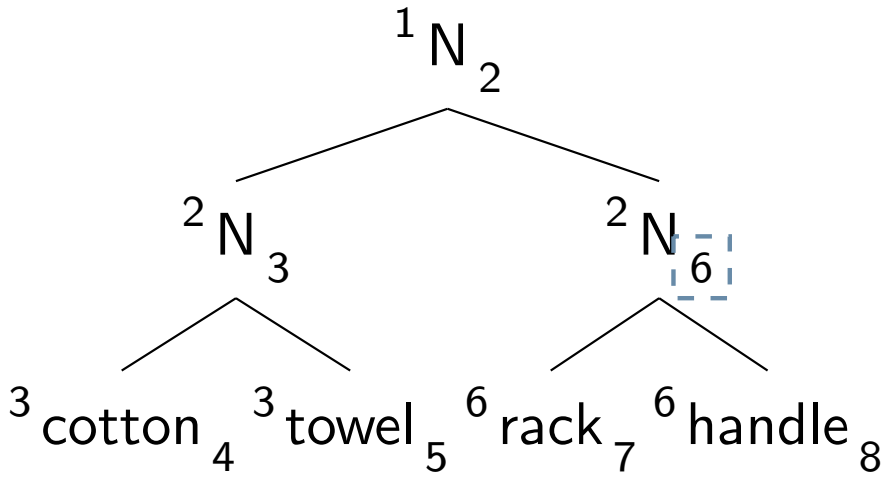

cotton towel rack handle

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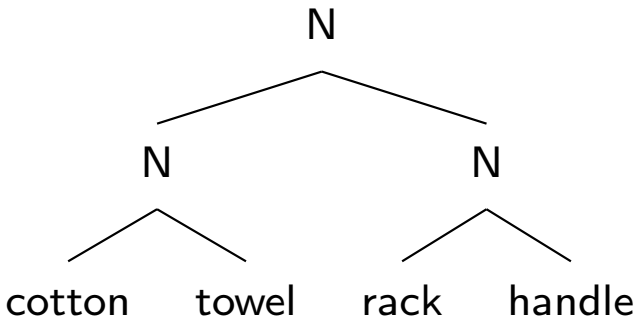
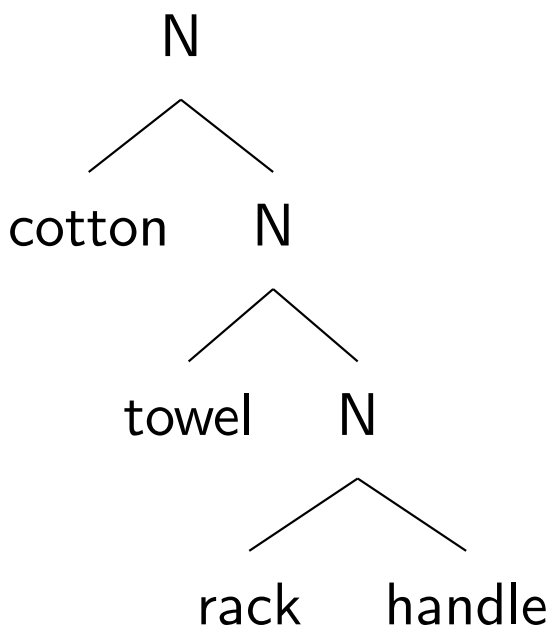
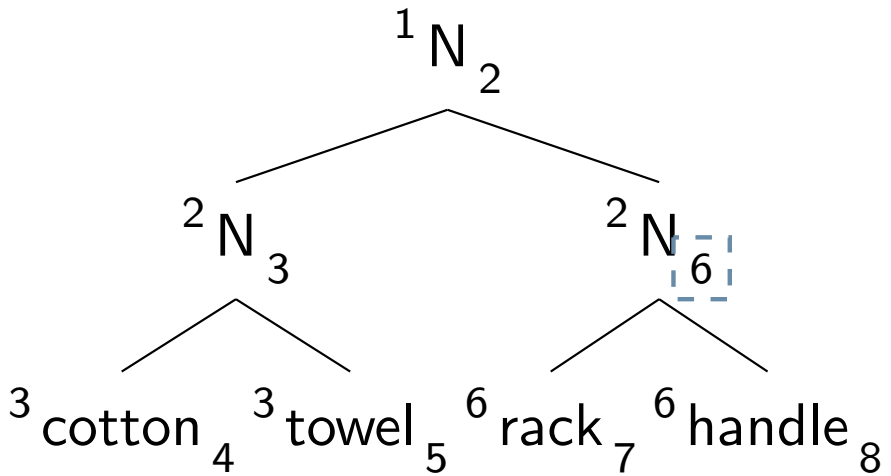
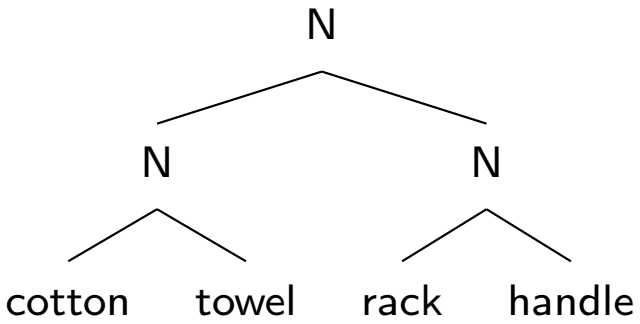


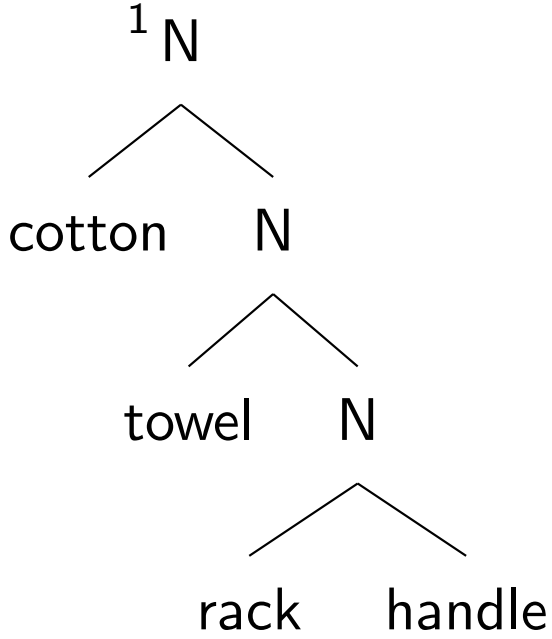


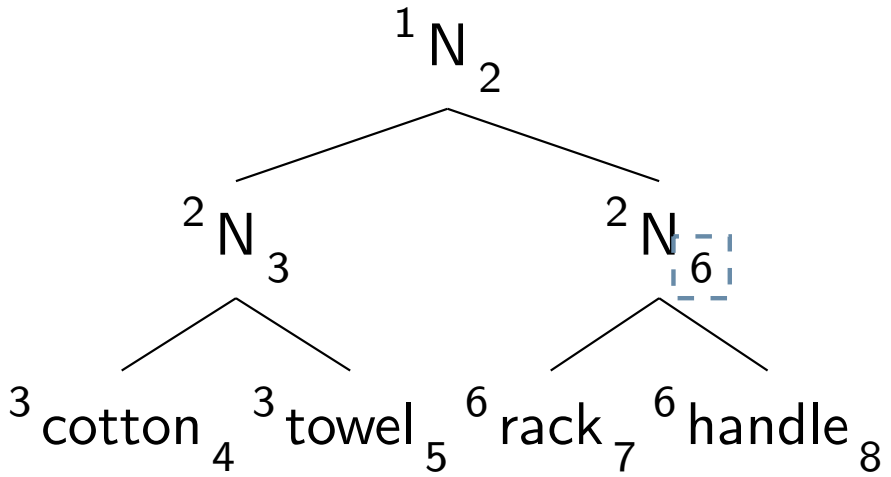


cotton towel rack handle

Recursive descent parsing without movement







cotton towel rack handle

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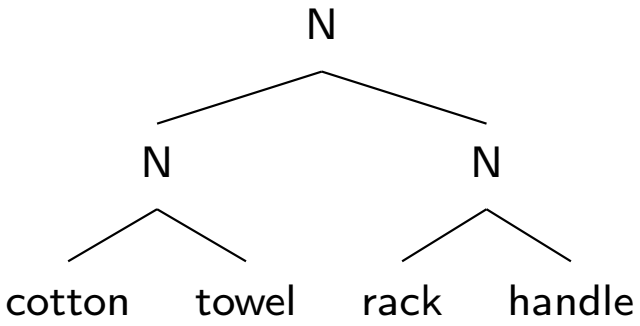

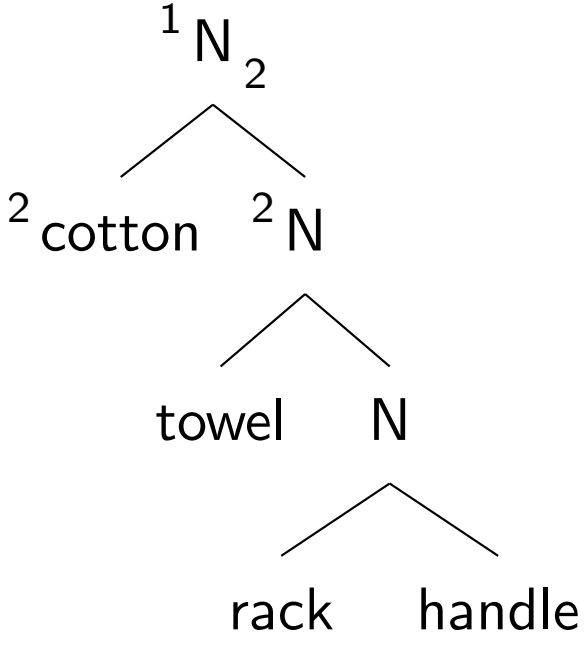

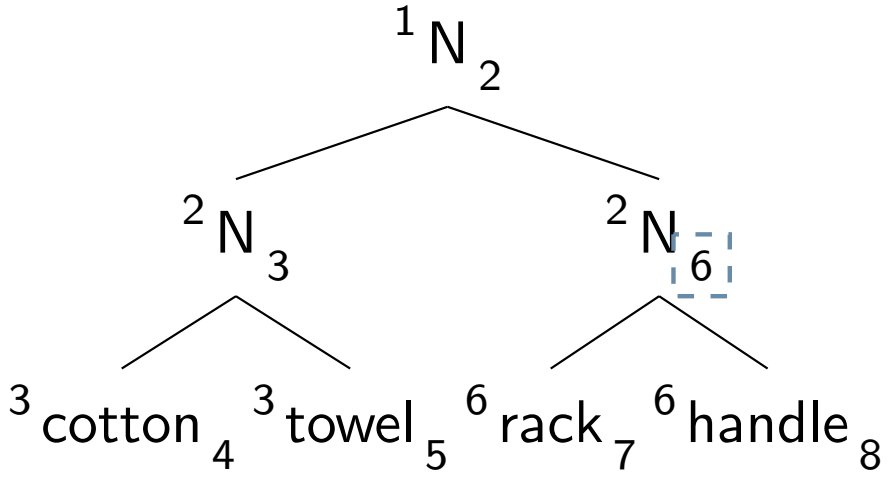

cotton towel rack handle

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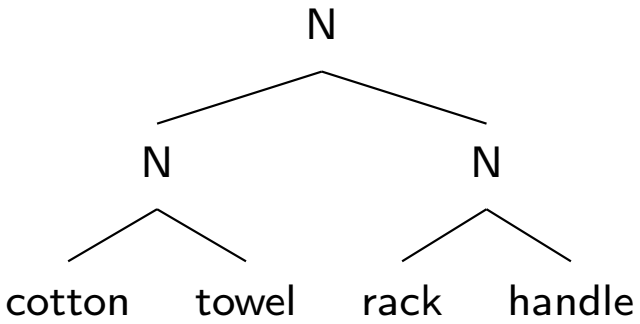

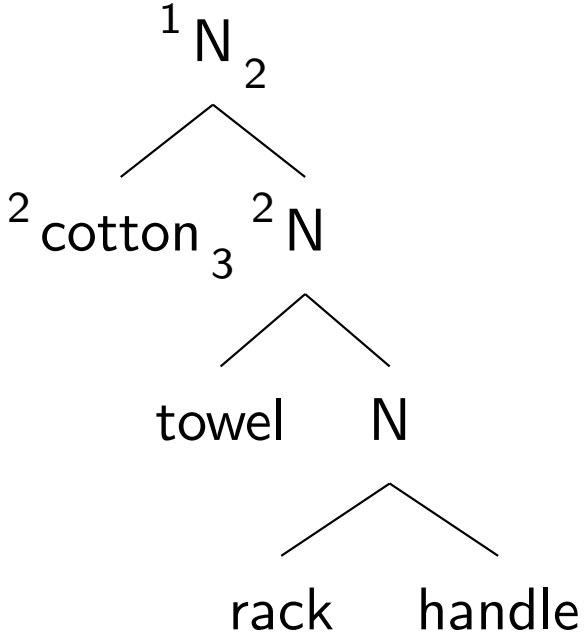

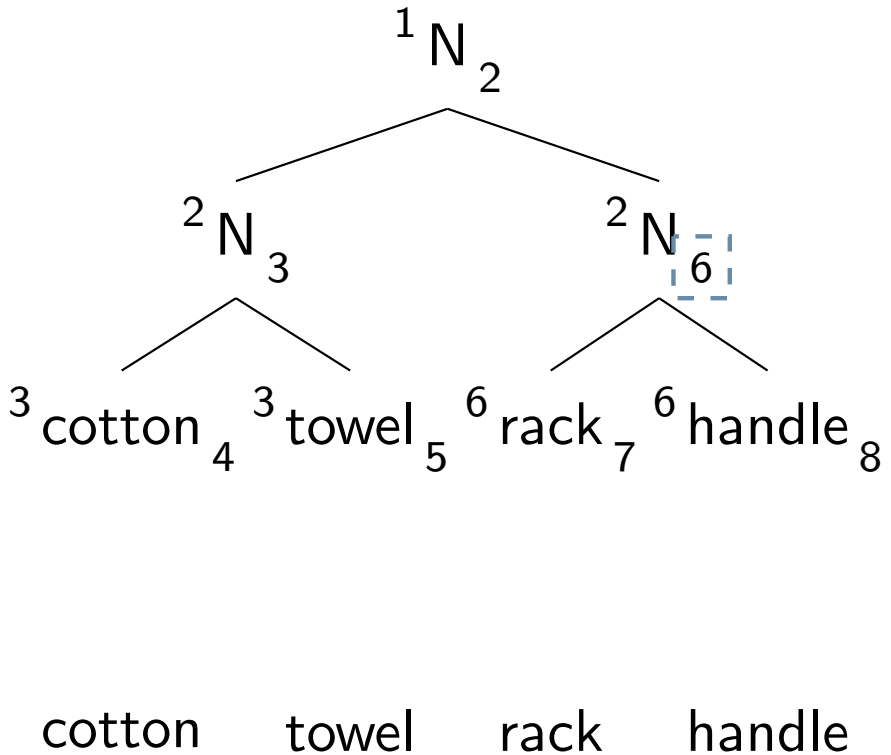

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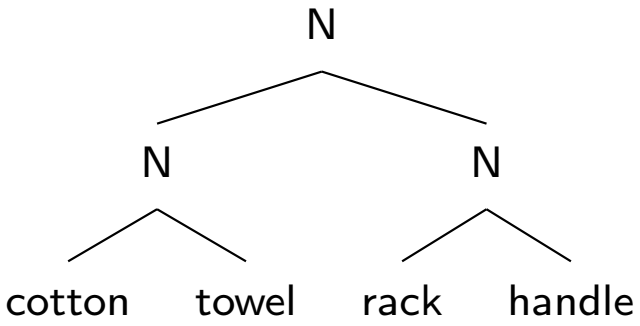

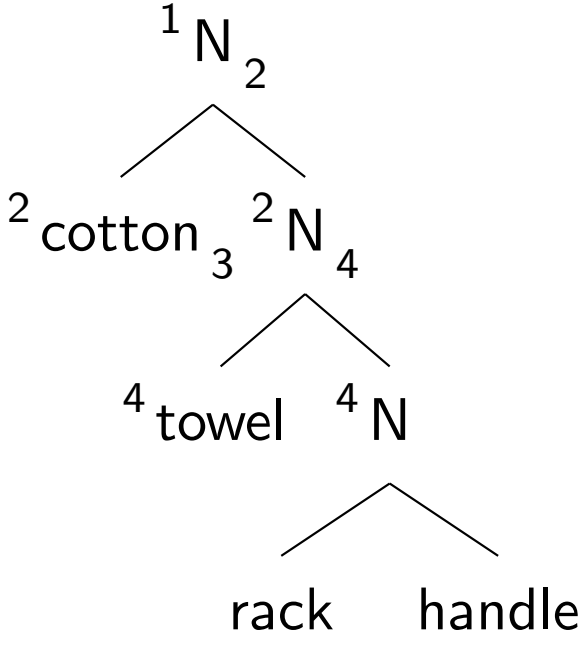

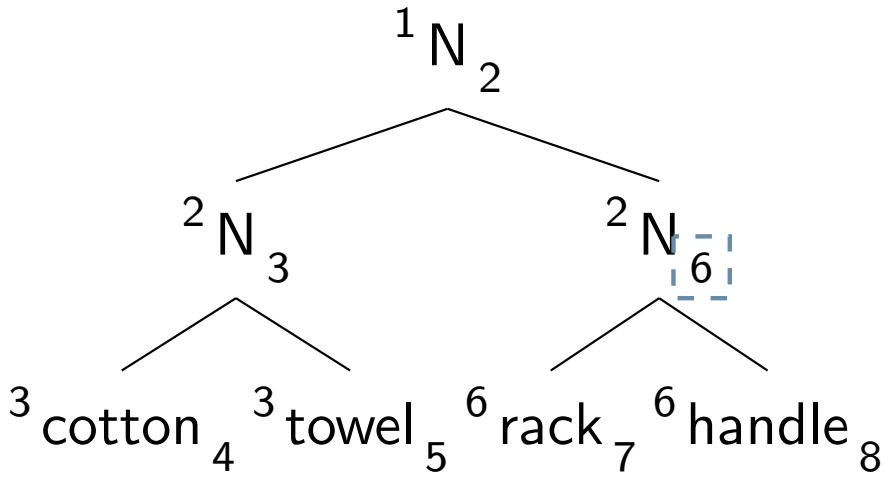

cotton towel rack handle

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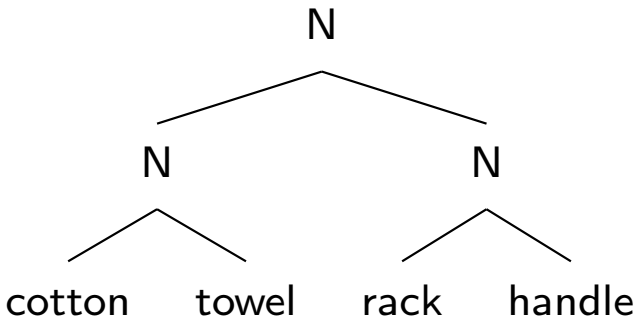
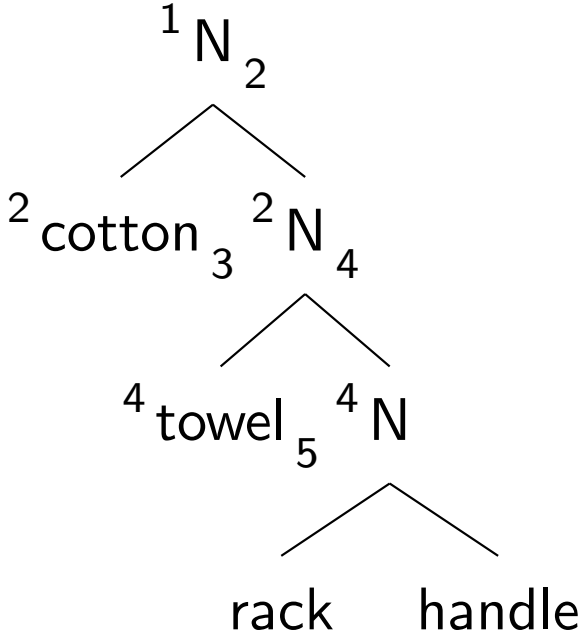
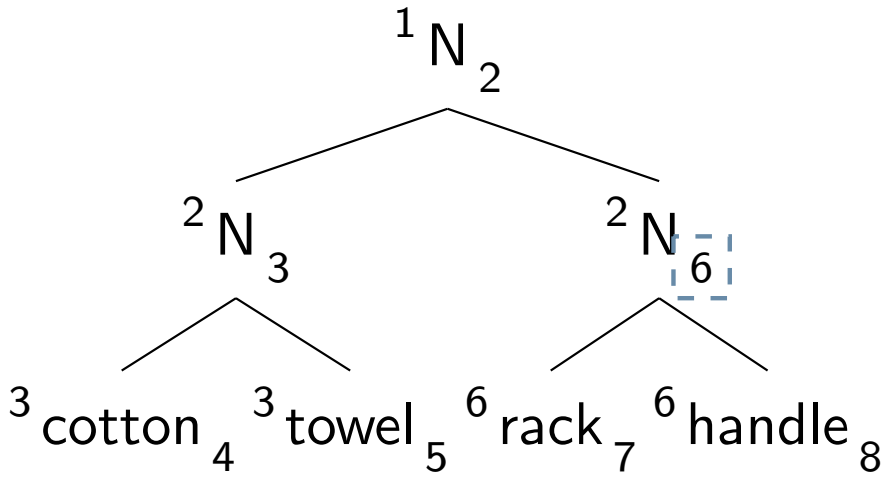
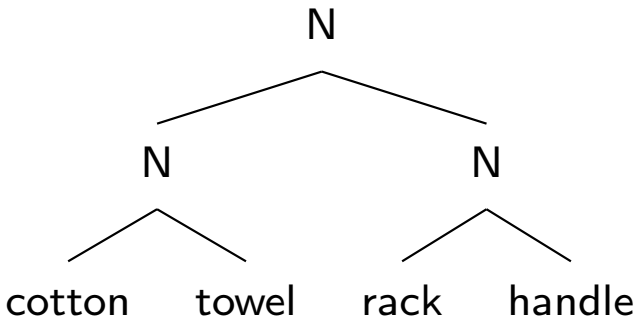


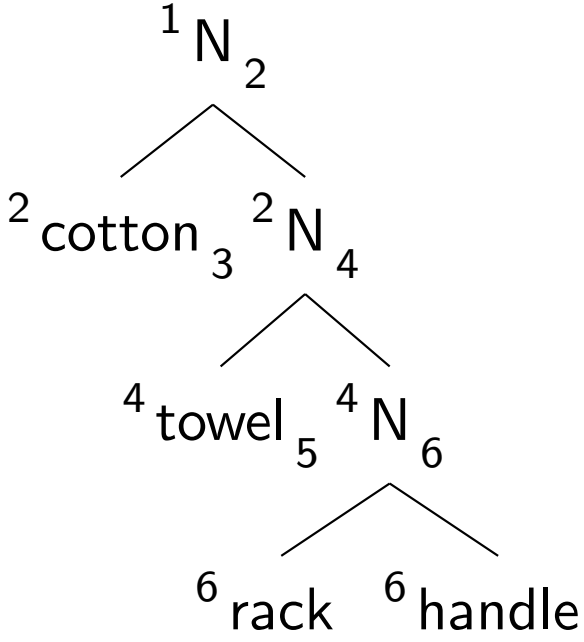


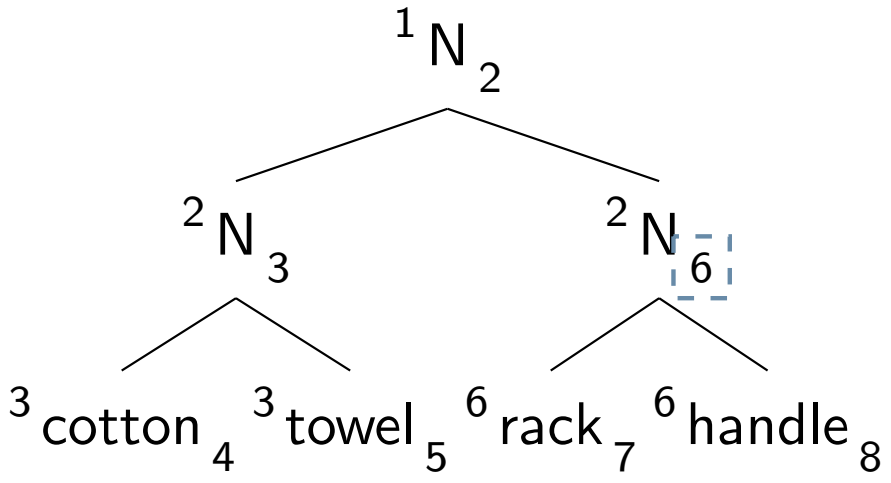


cotton towel rack handle

Recursive descent parsing without movement

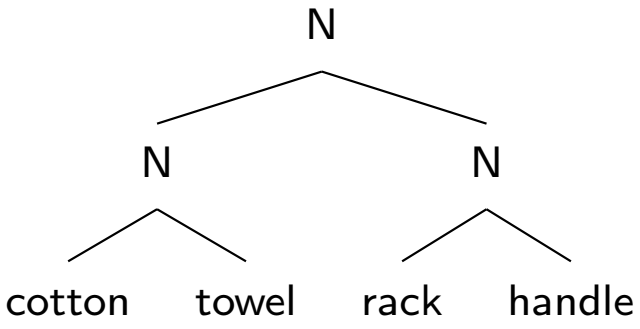


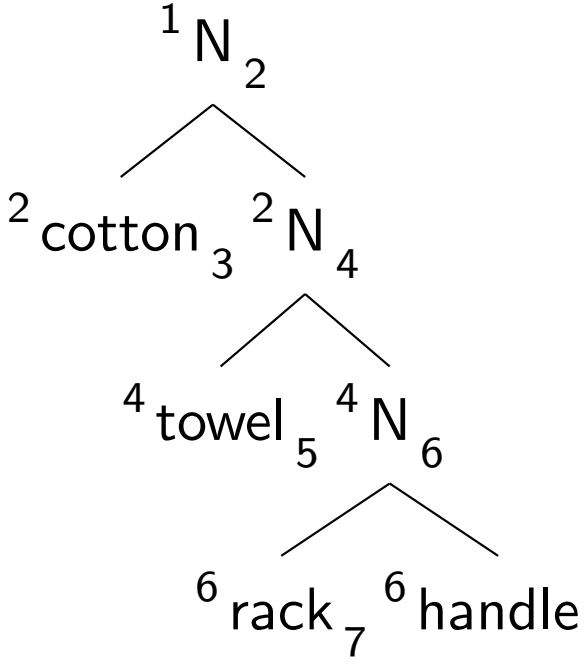


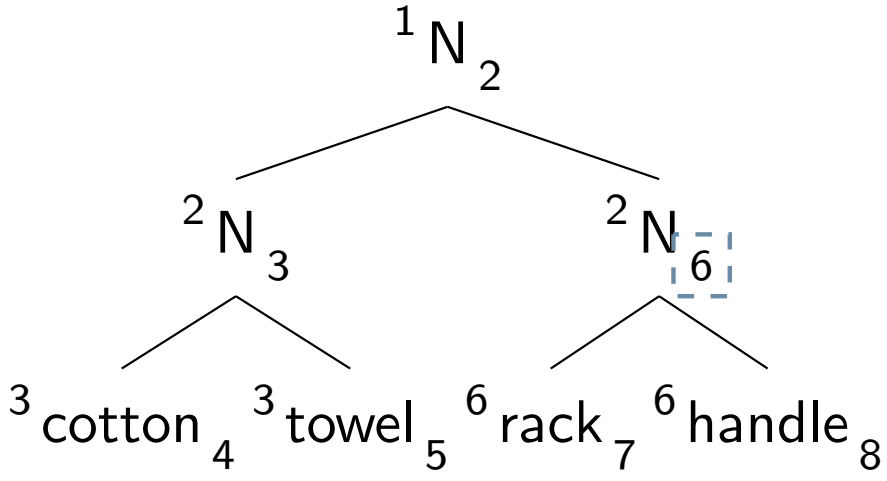


cotton towel rack handle

Recursive descent parsing without movement

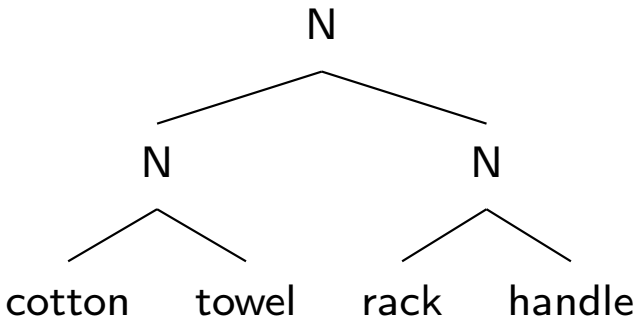


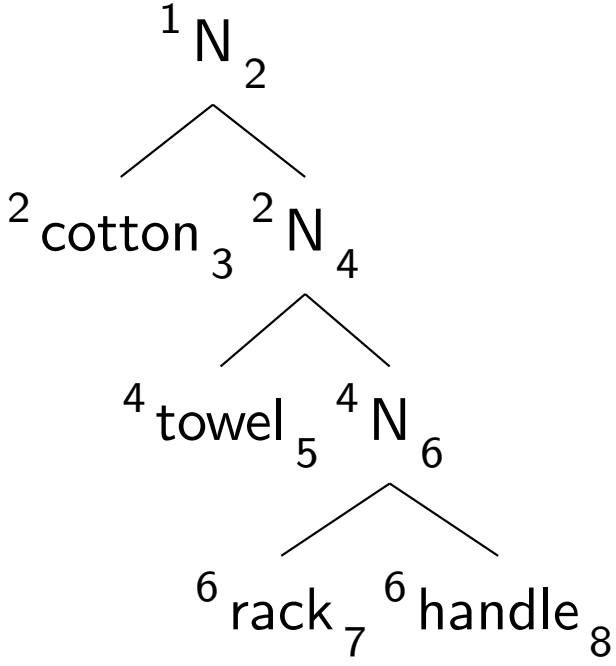


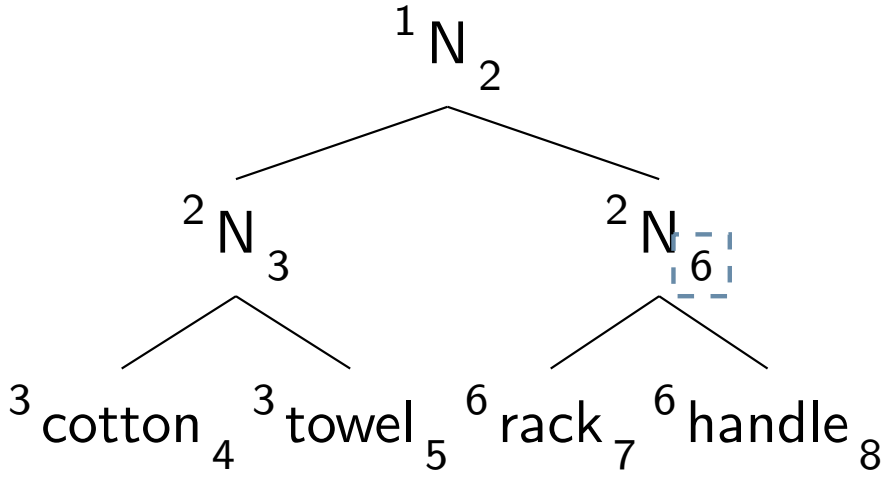


cotton towel rack handle

Recursive descent parsing without movement

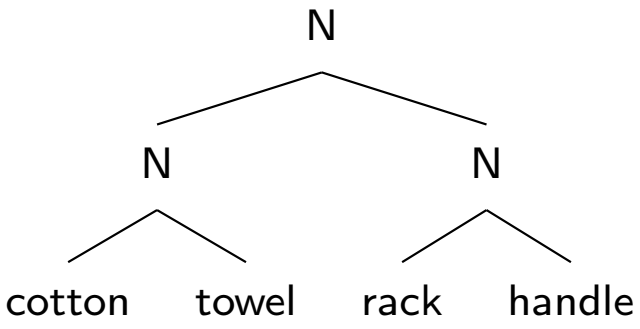


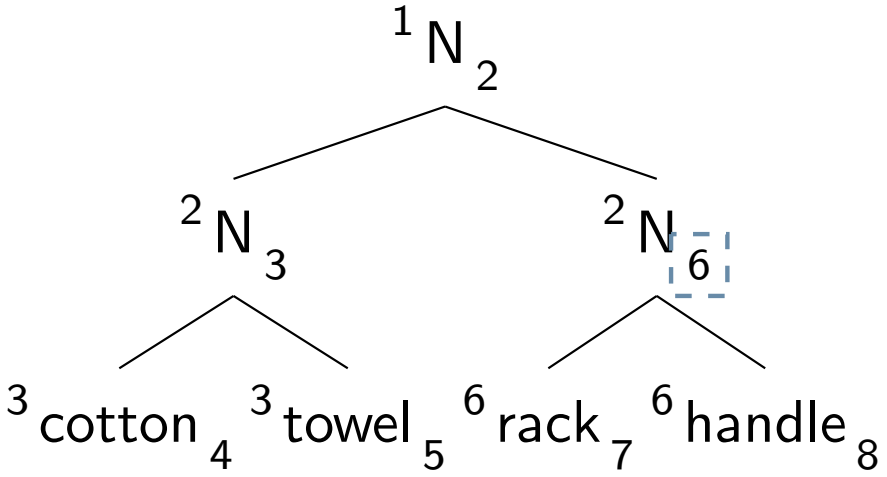


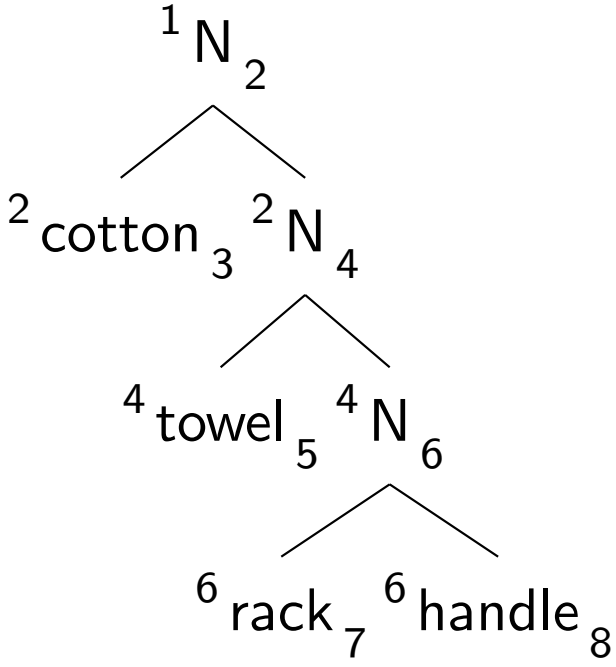


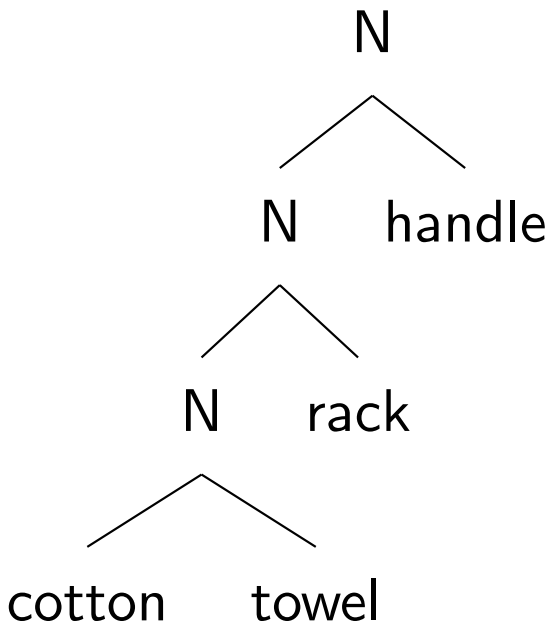
cotton towel rack handle

Recursive descent parsing without movement

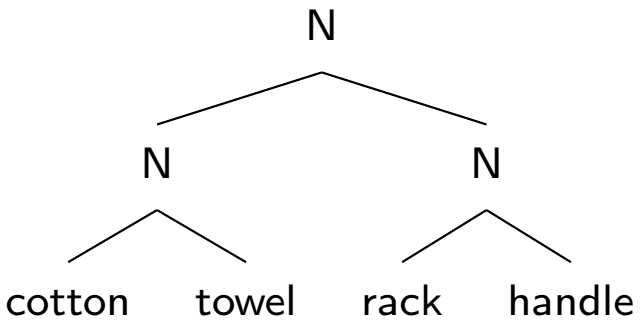


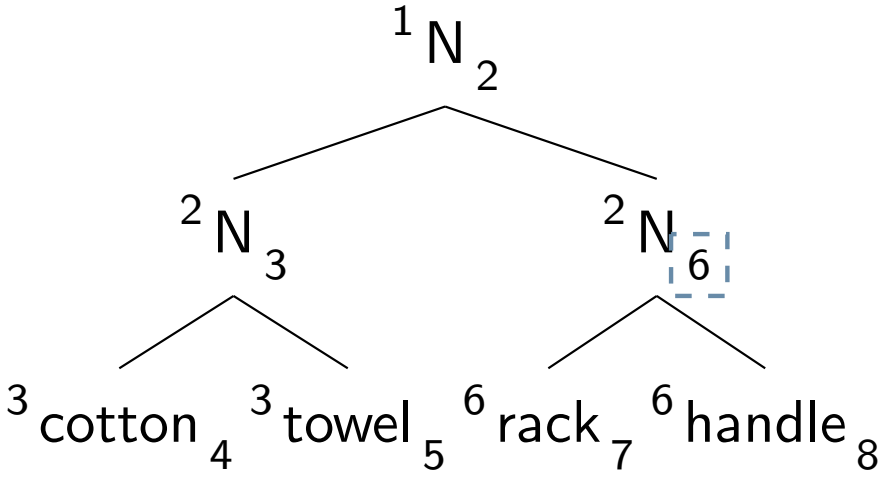


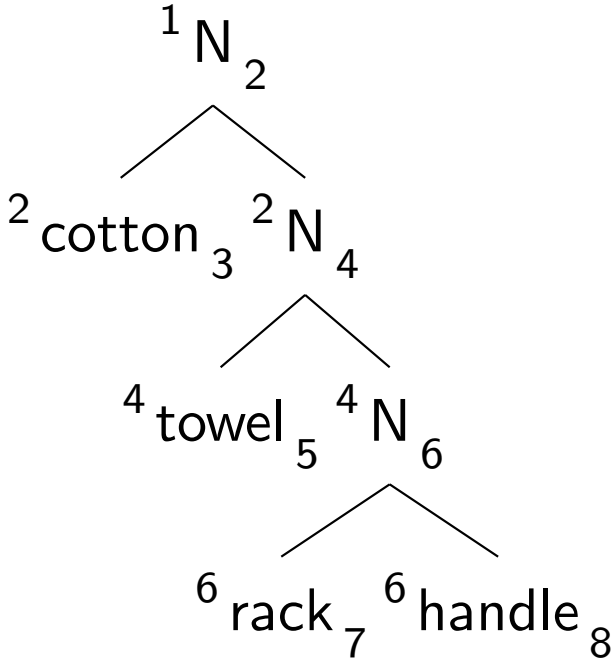


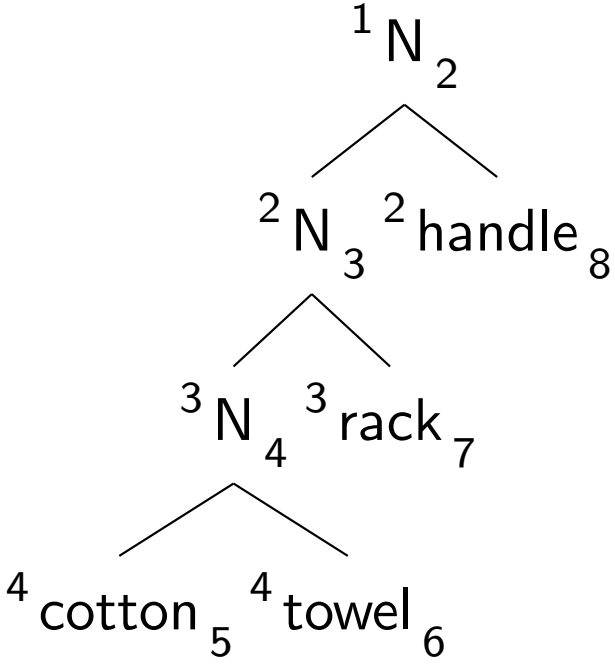


Recursive descent parsing without movement

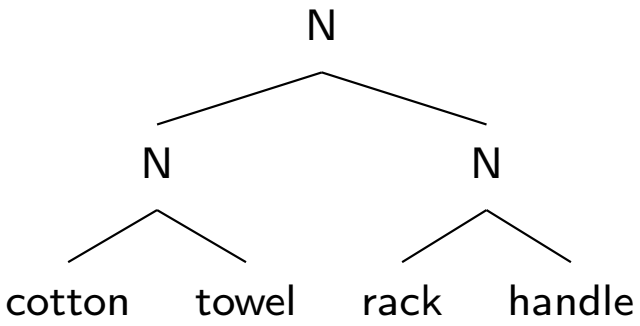


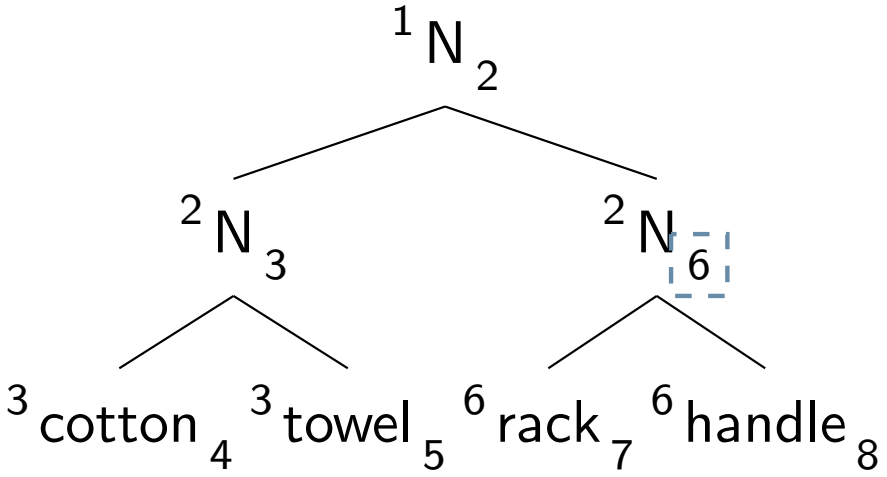


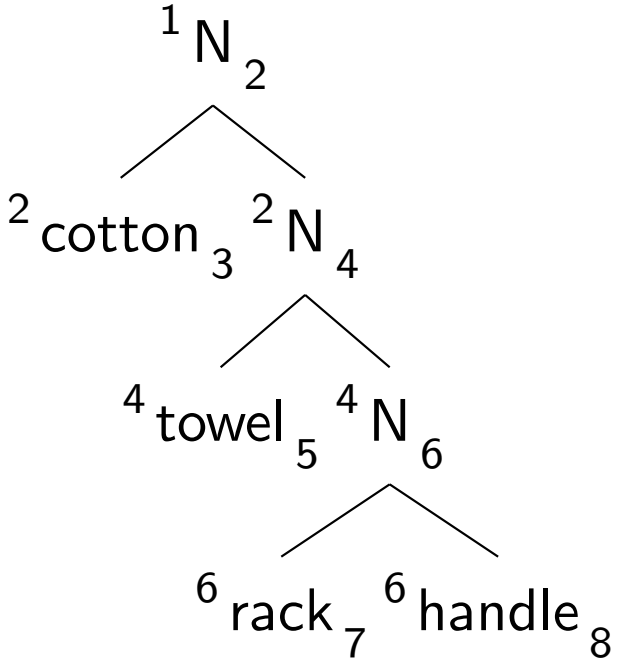


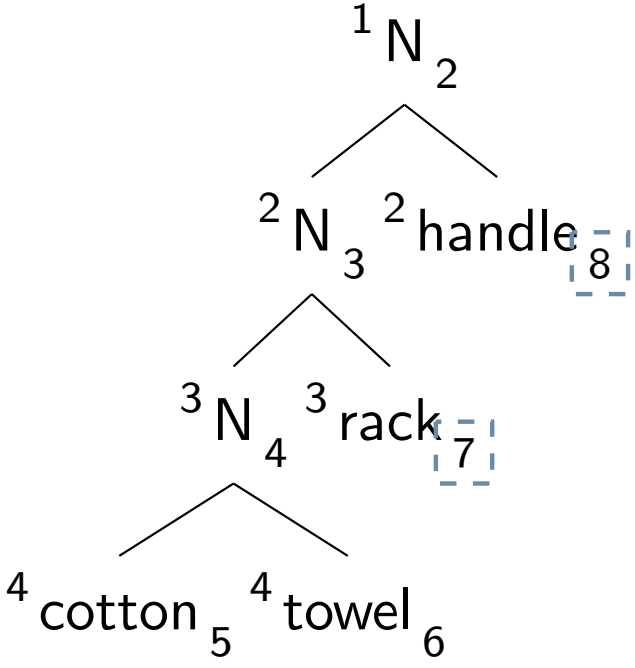


Recursive descent parsing without movement









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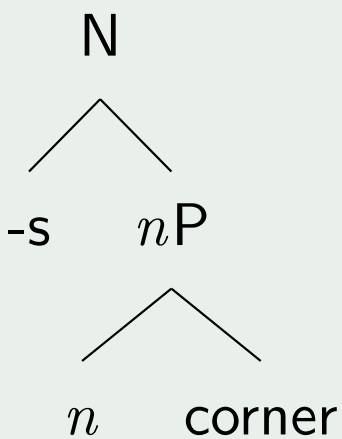

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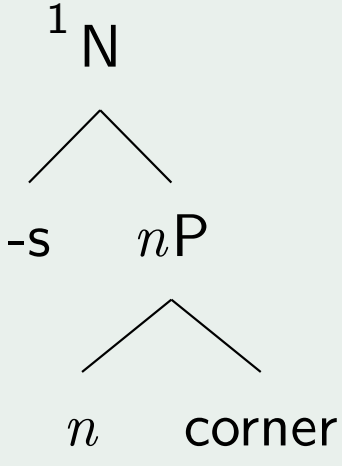

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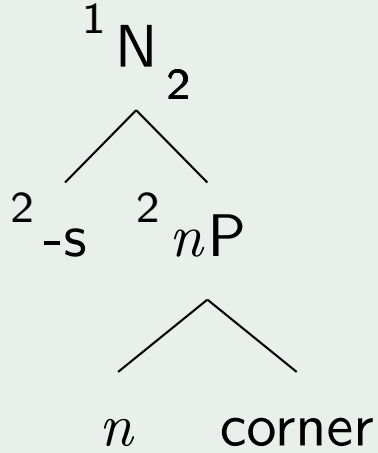

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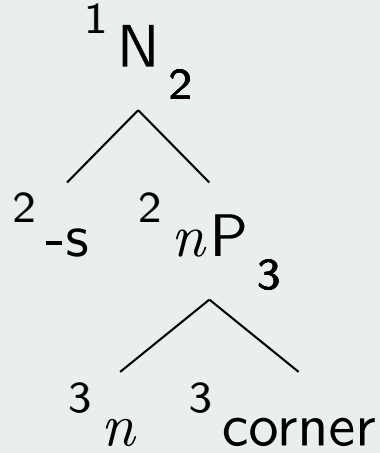

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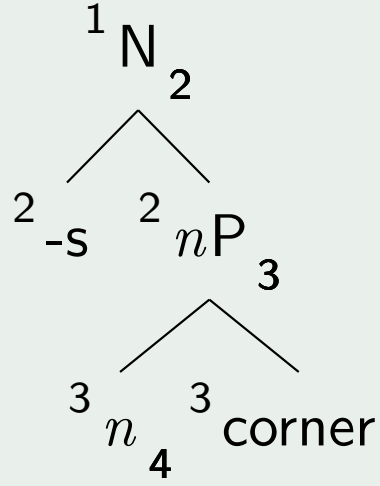

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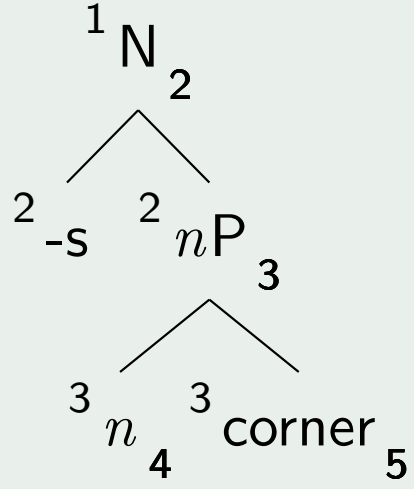

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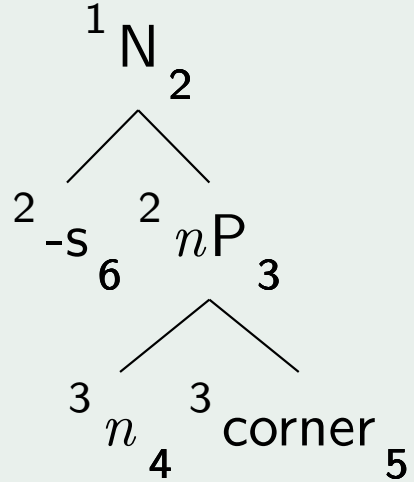

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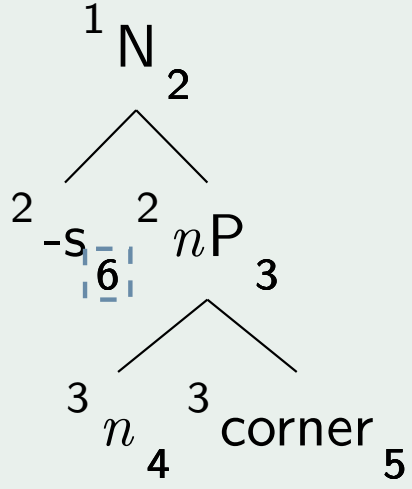

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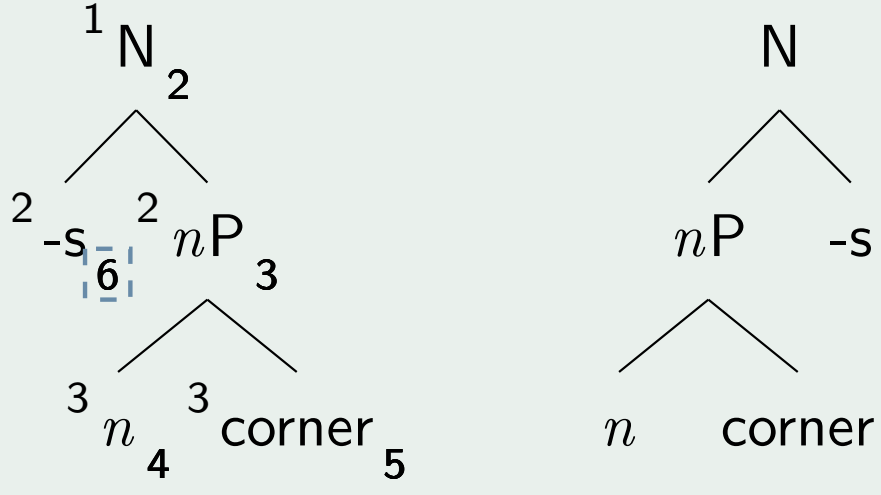

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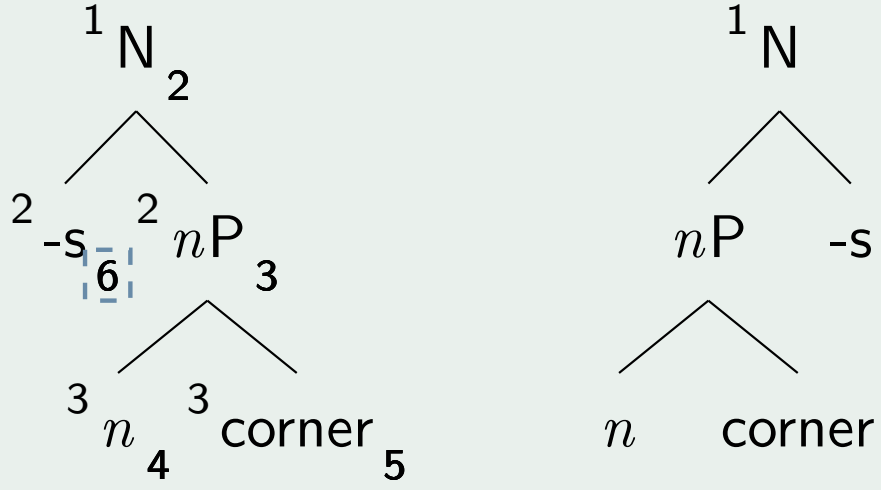

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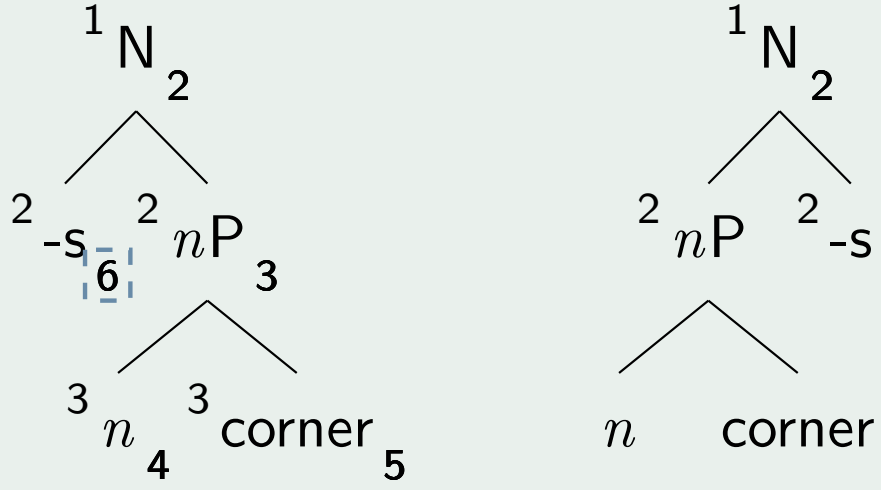

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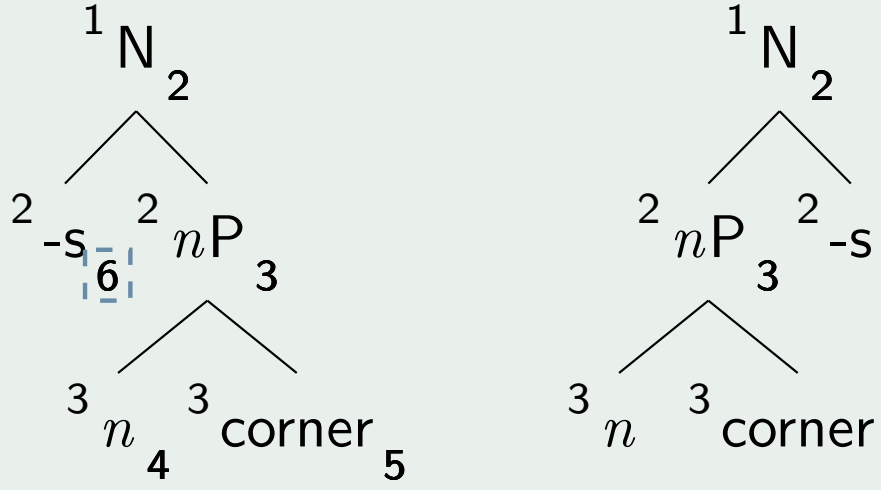

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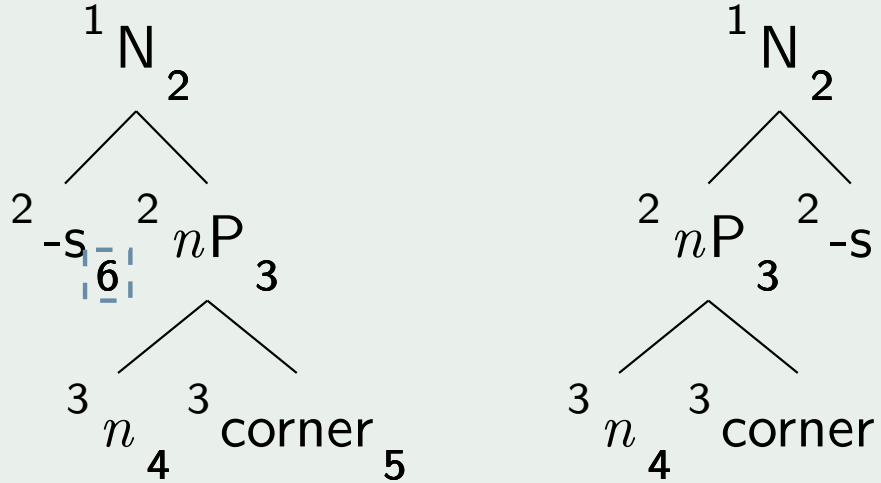

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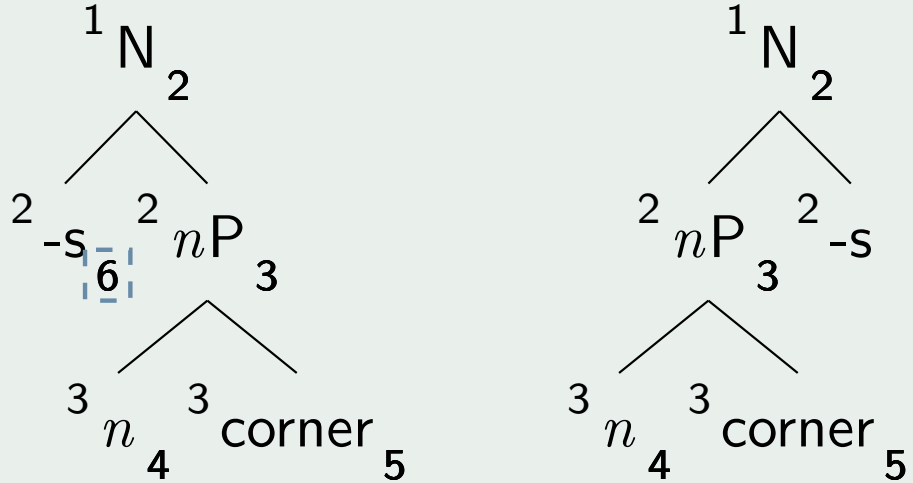

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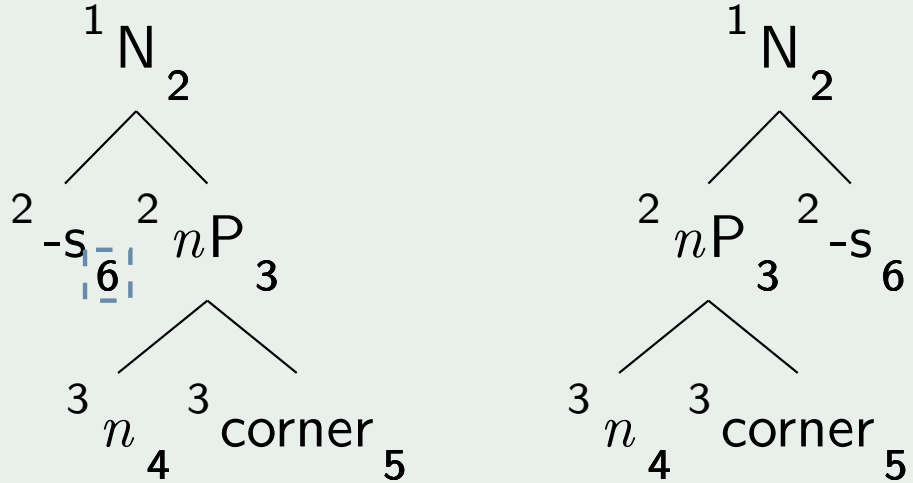

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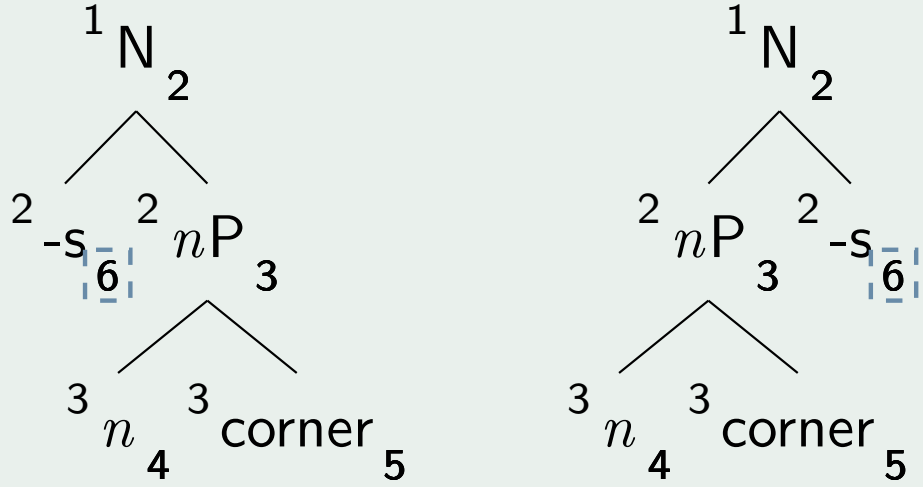

Handling movement

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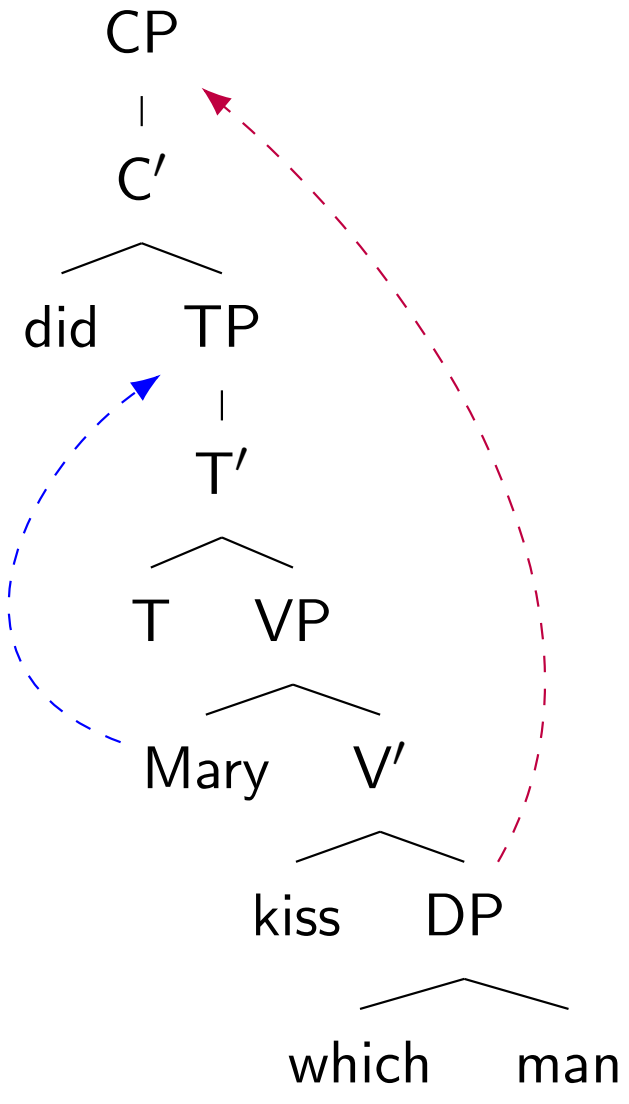

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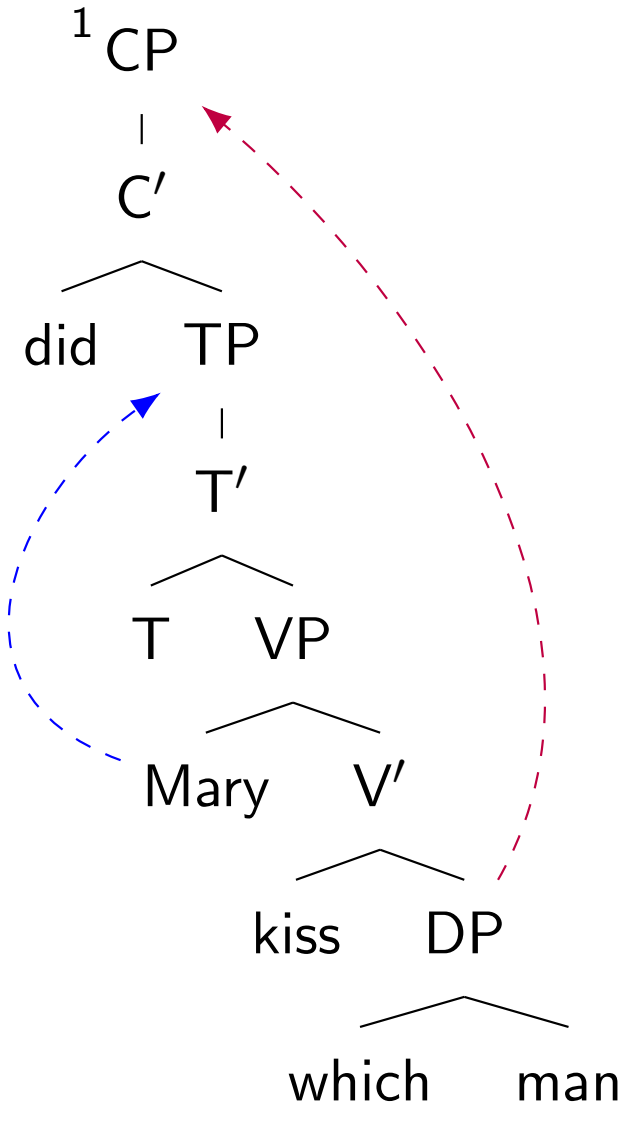

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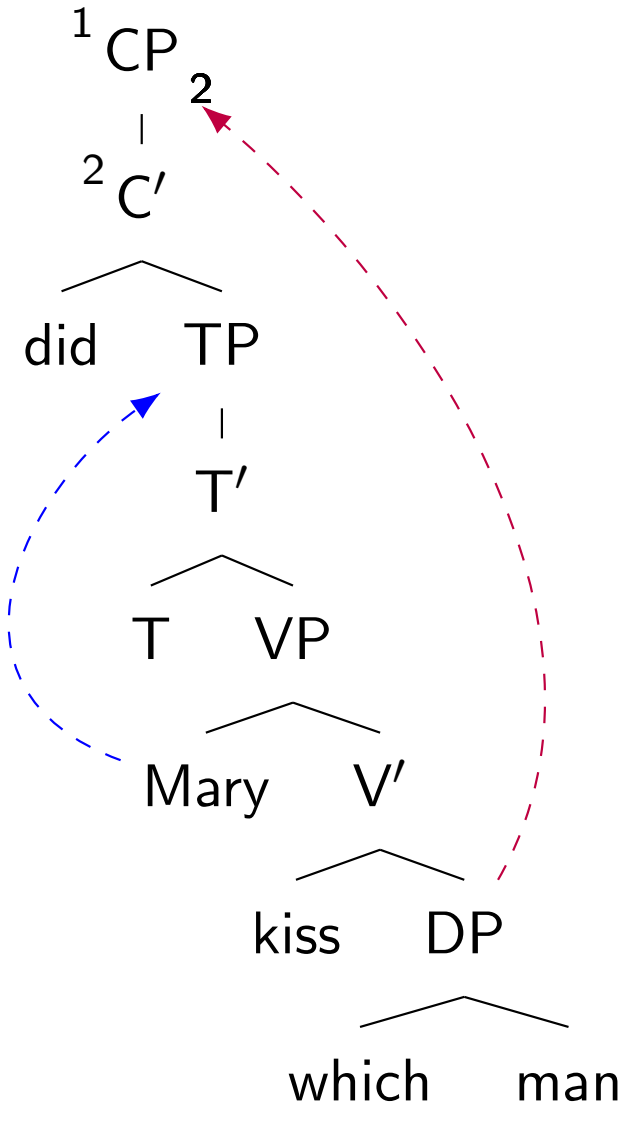

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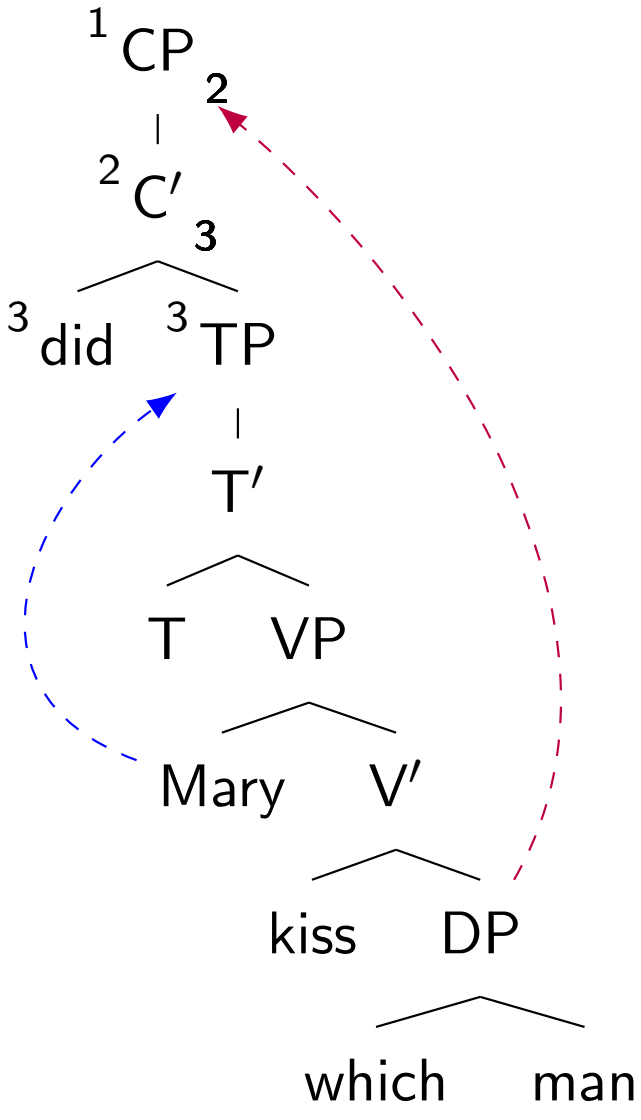

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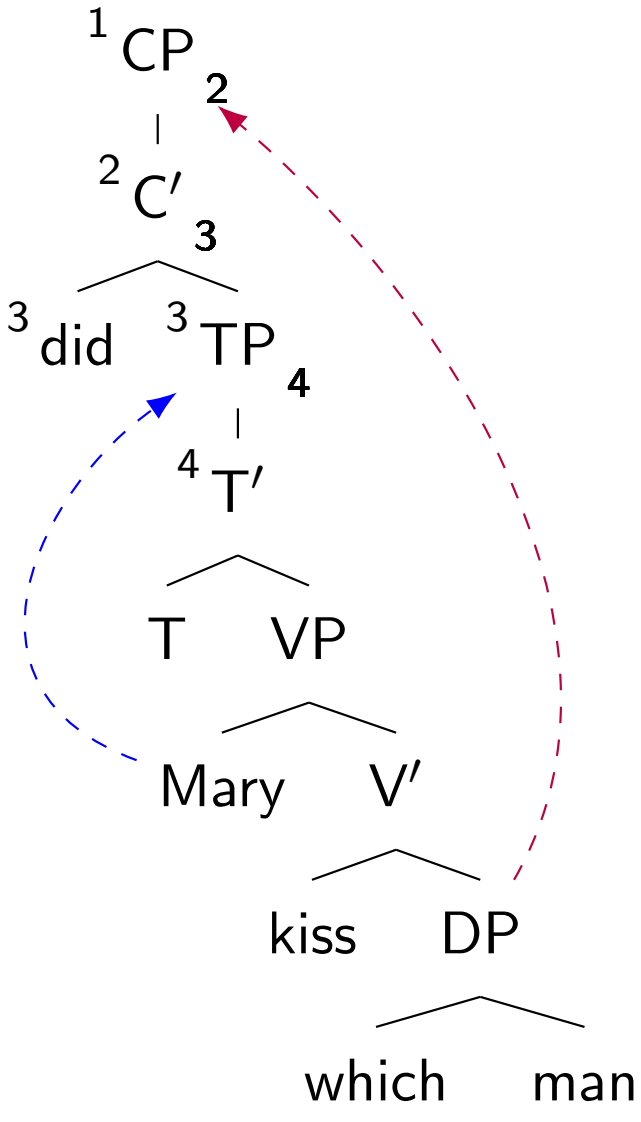

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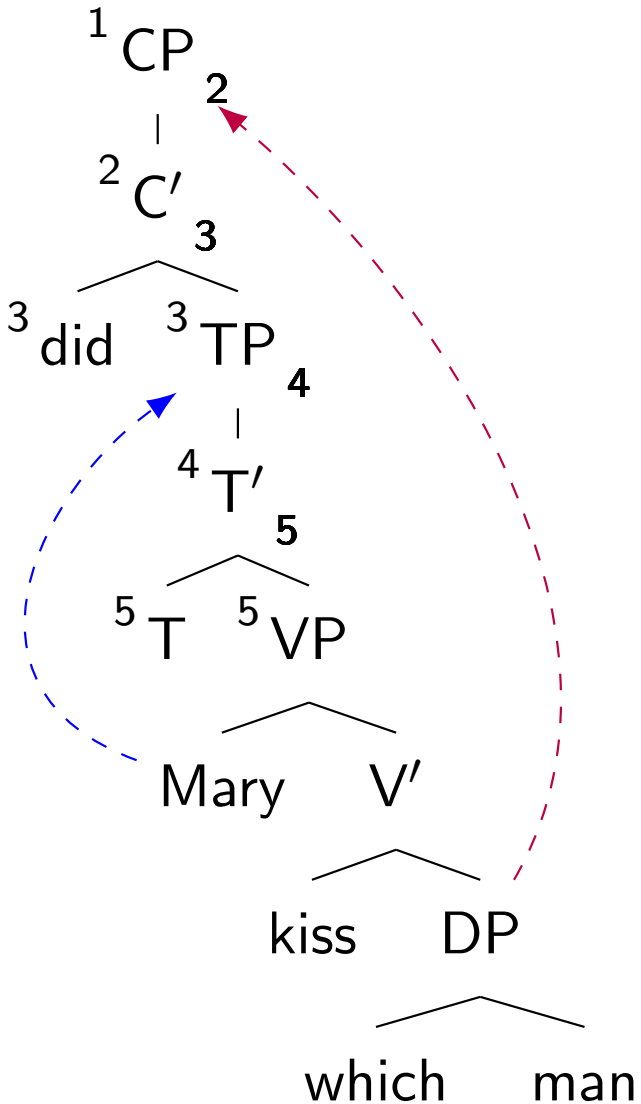

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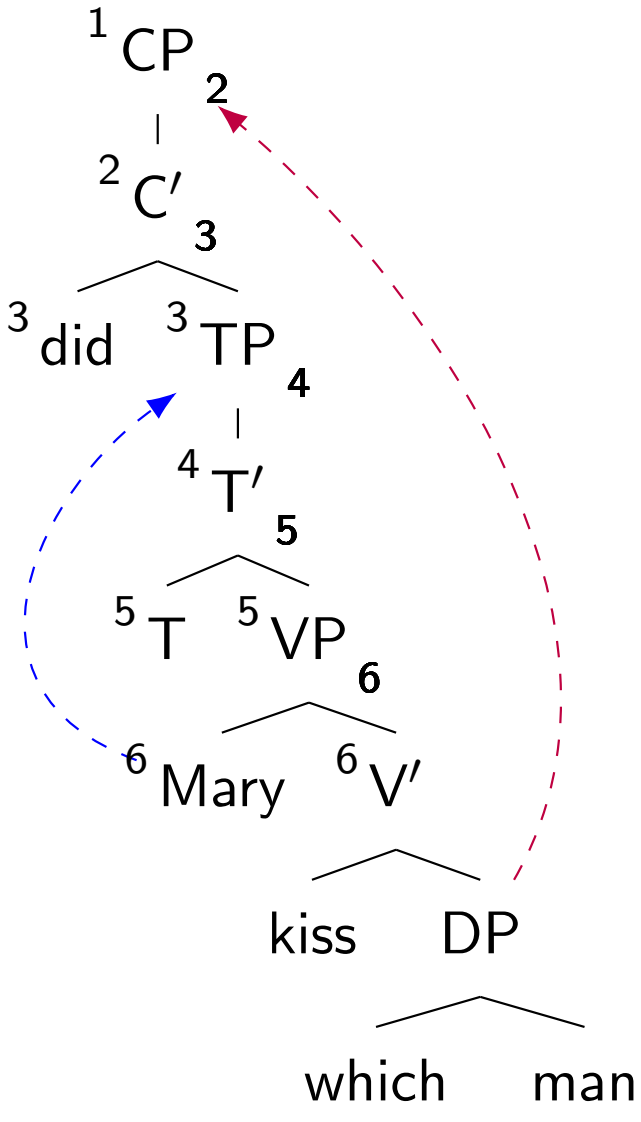

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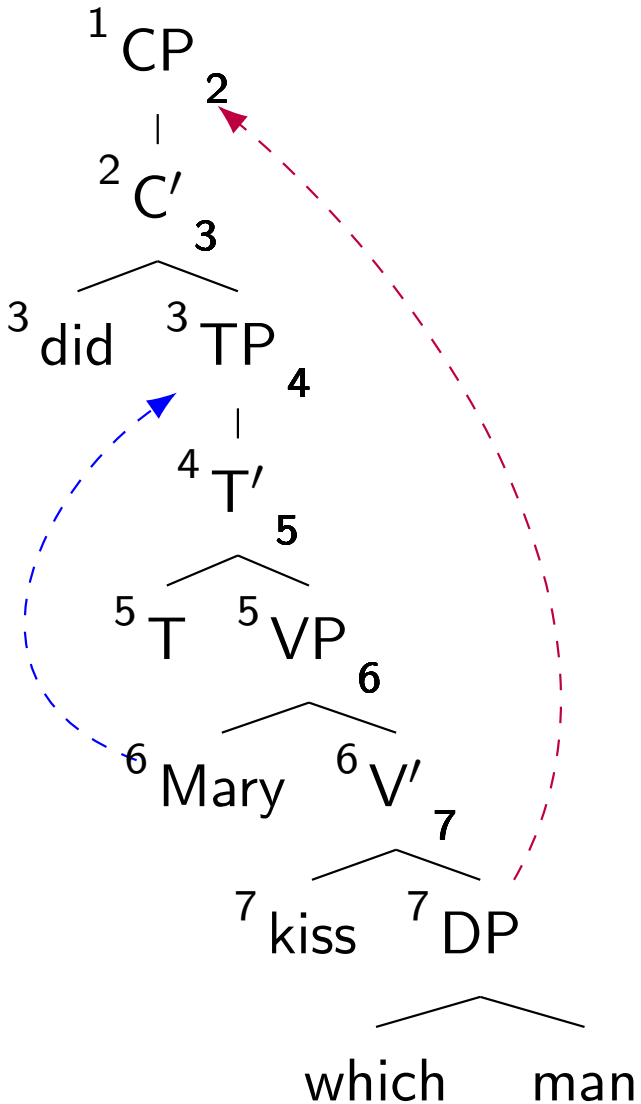

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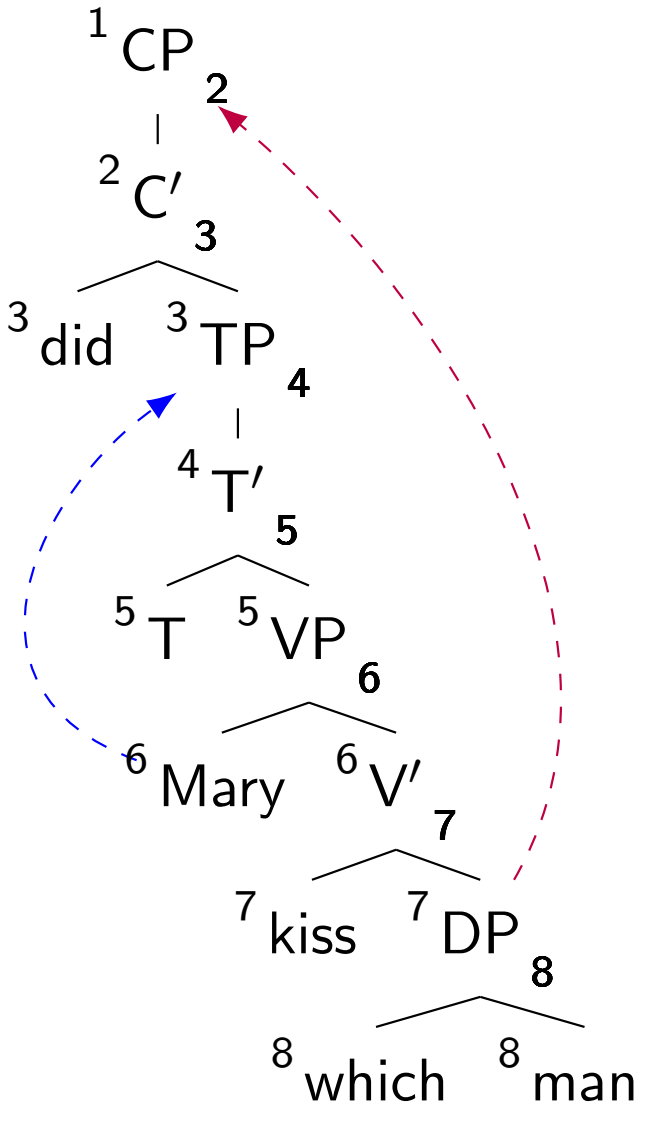

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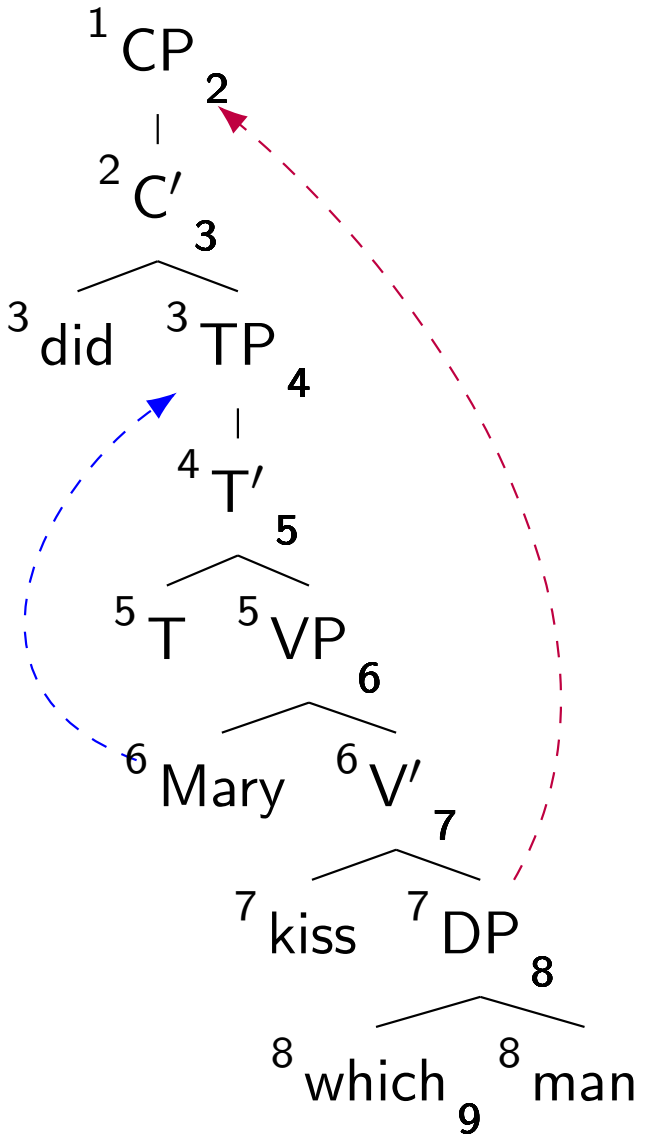

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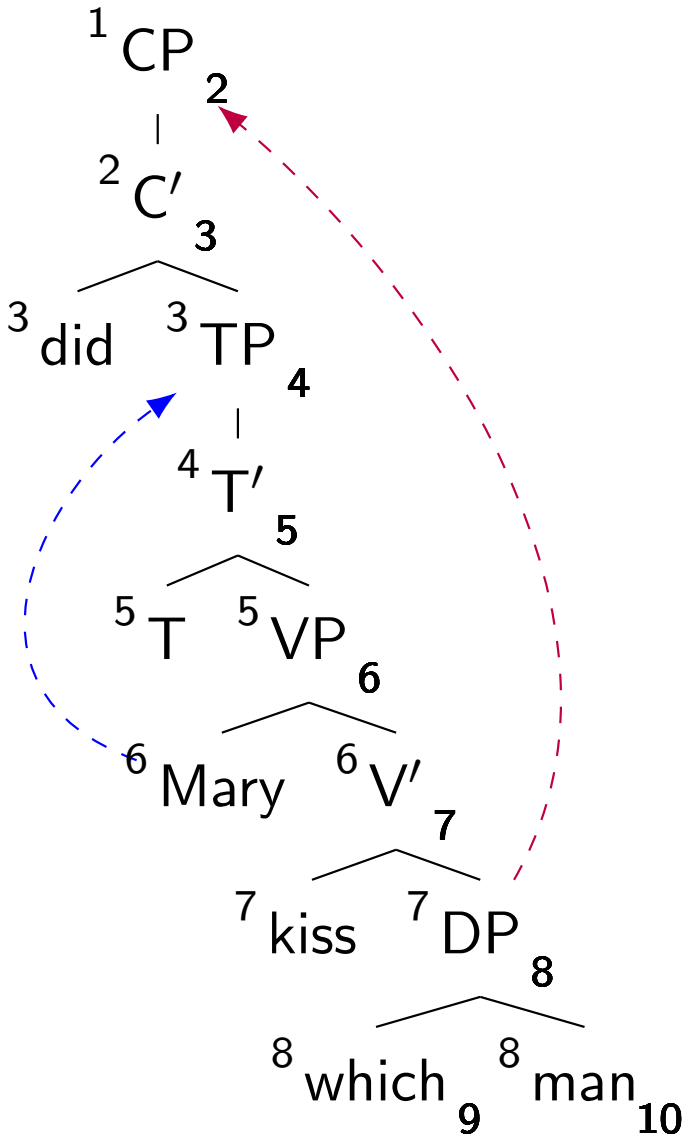

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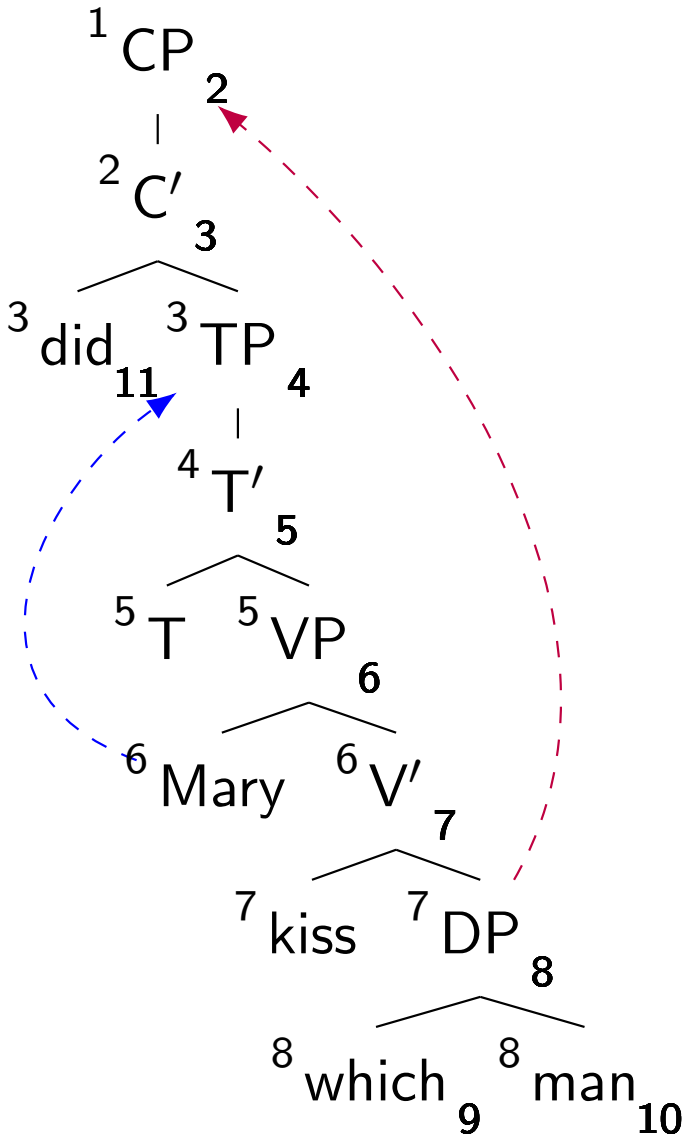

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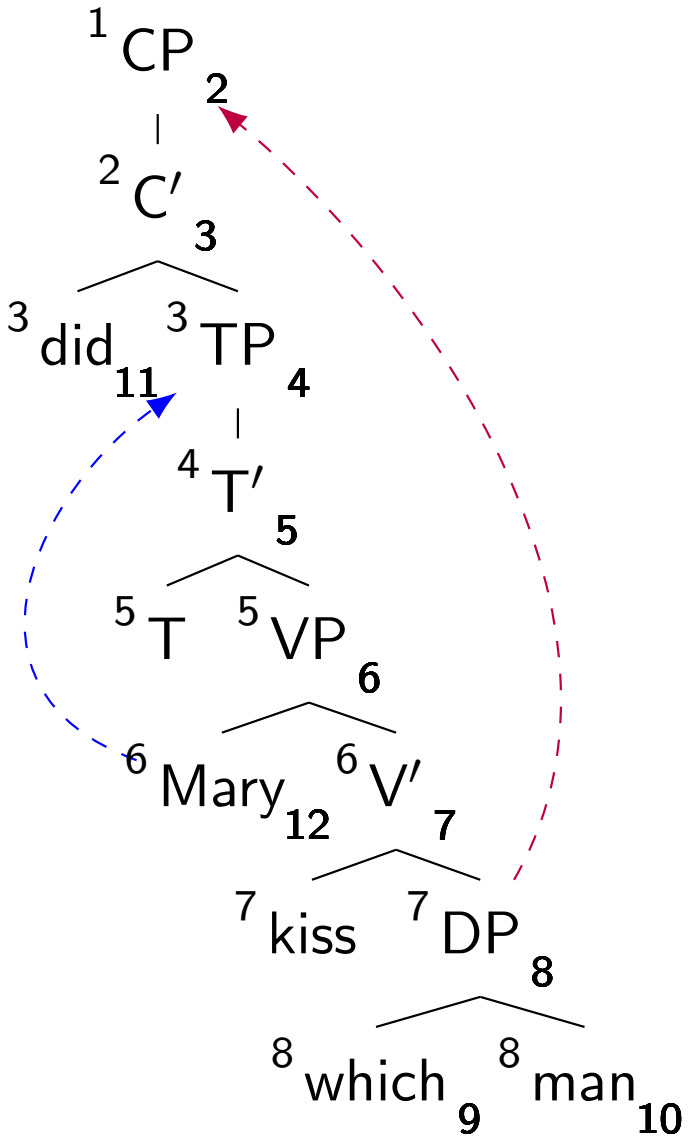

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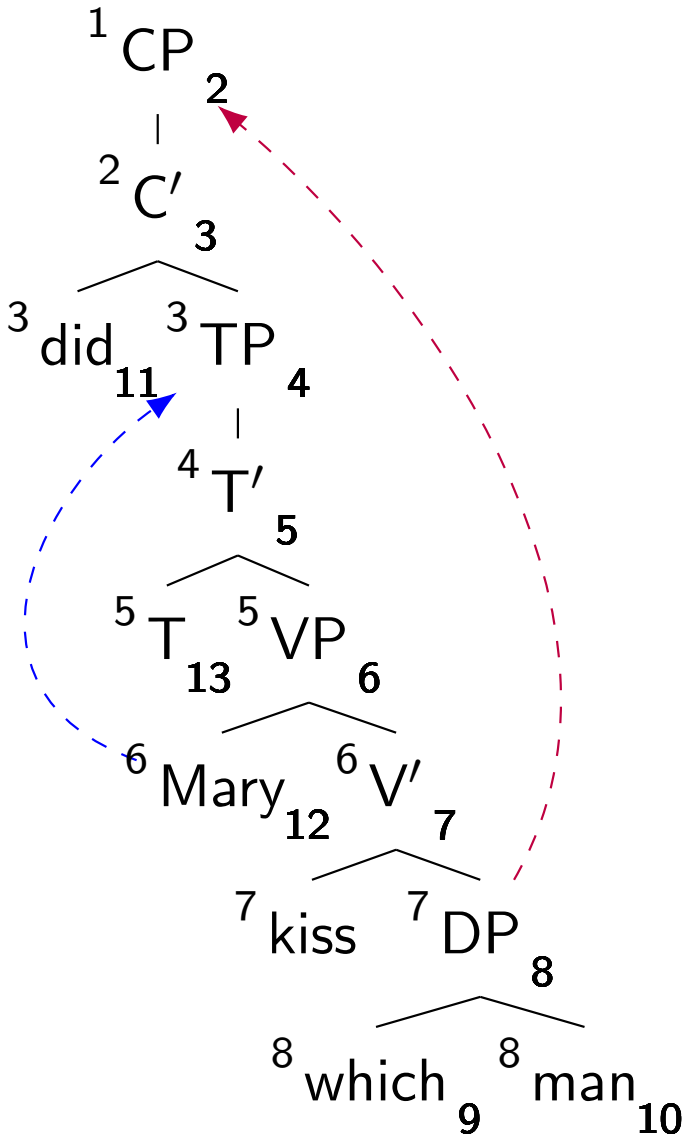

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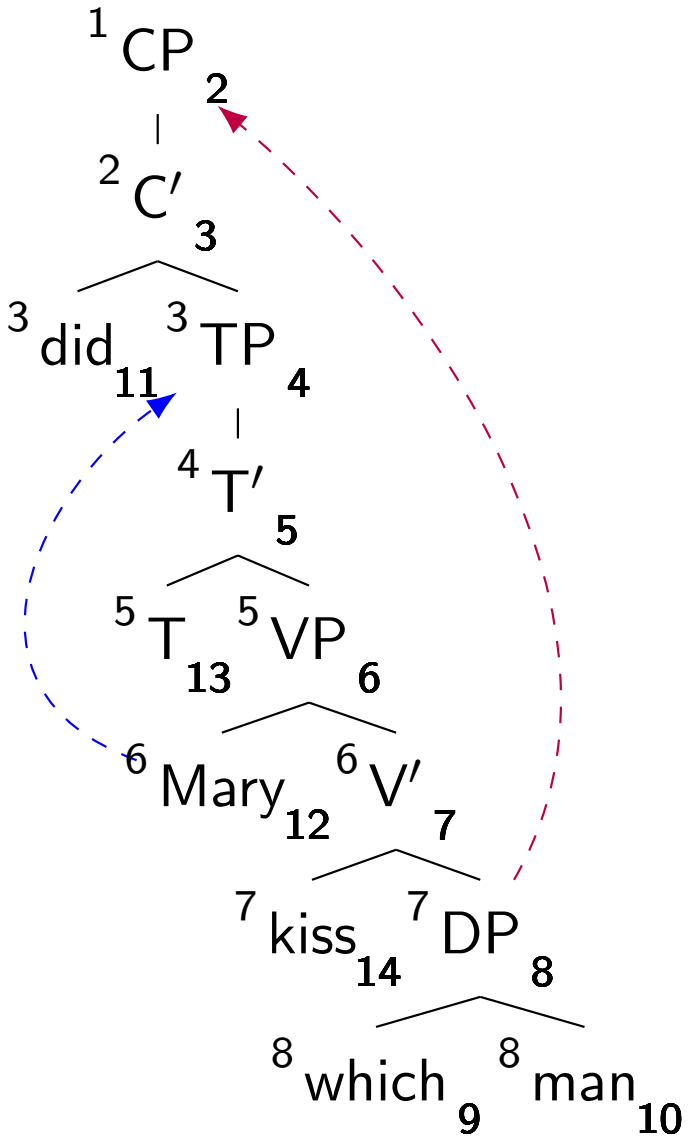

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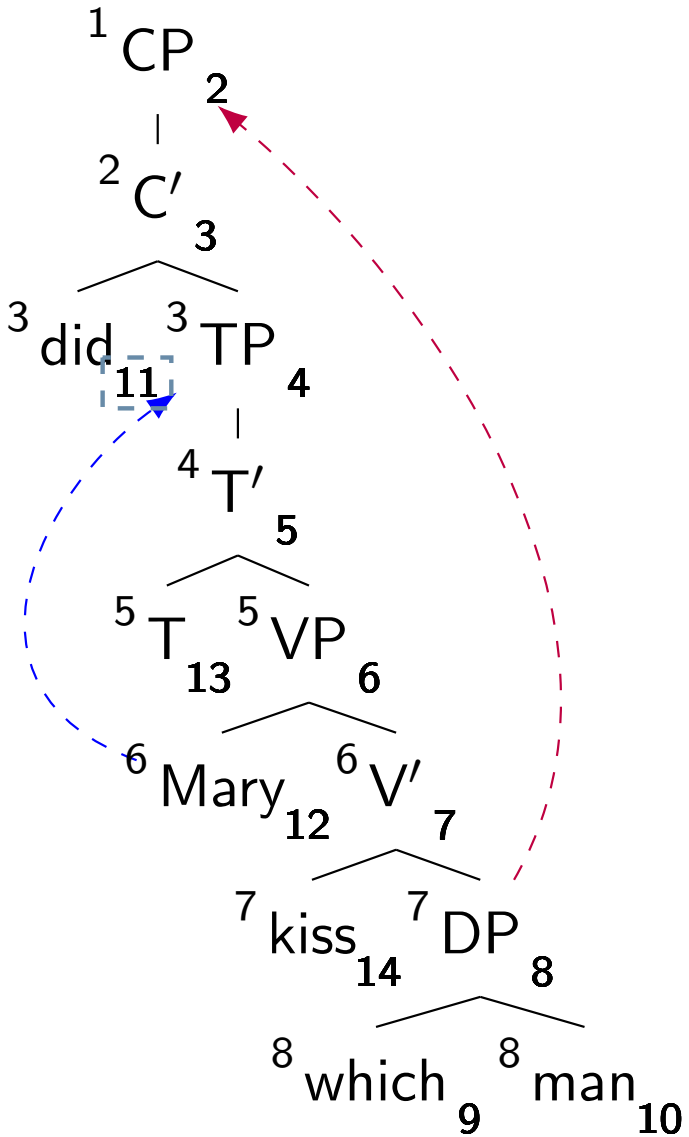

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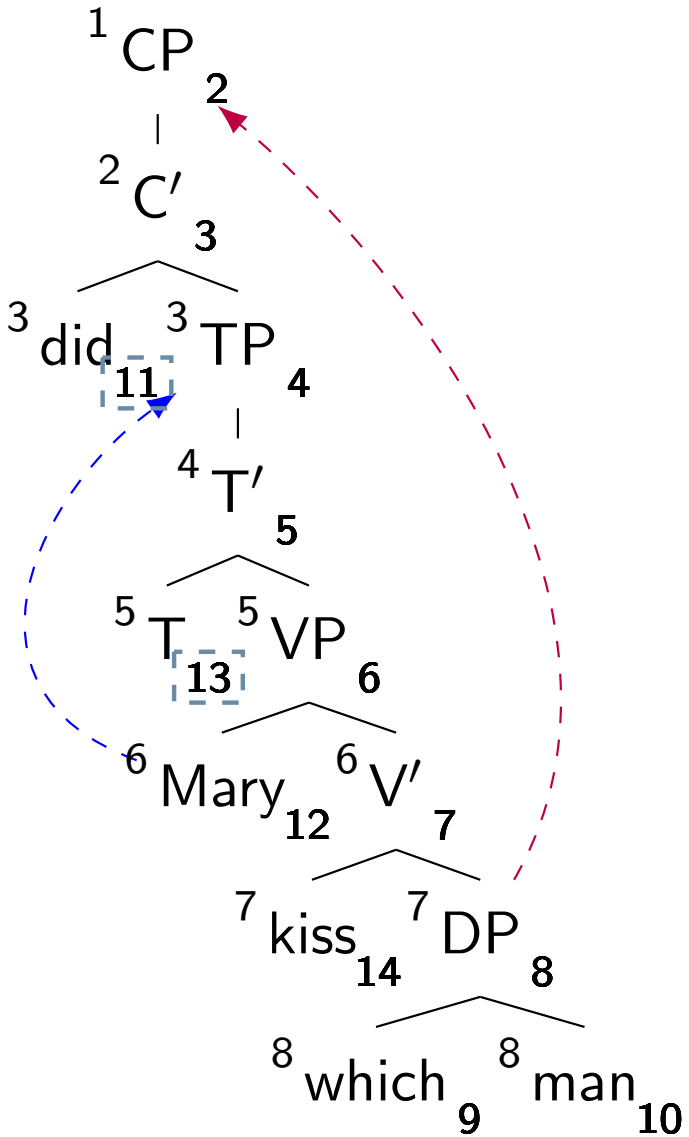

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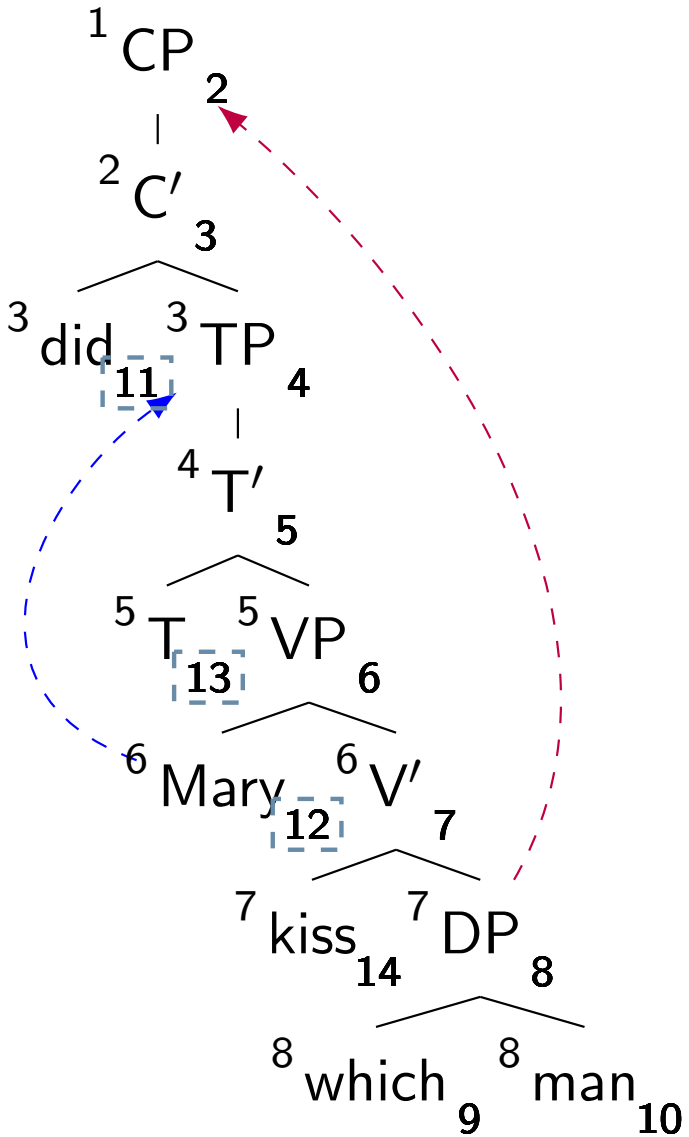

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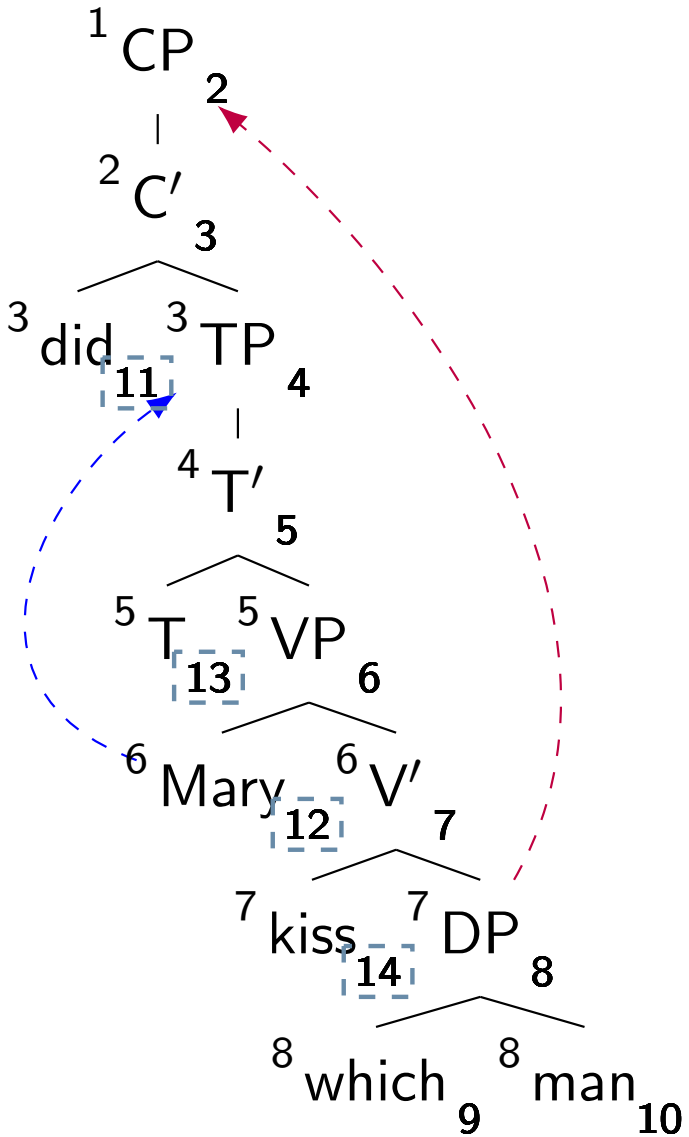

General methodology

1. Pick a processing contrast observed in the literature
2. Pick Minimalist analysis from literature
   (often multiple competing options, then we try all)
3. Construct MG derivation trees according to analysis.
4. Annotate derivation trees.
5. Compute memory usage metrics:

Tenure	|node's index − node's oudex|
MaxTen	largest tenure in derivation
Size	|mover's index − outdex of mover's landing site|
SumSize	sum of size values

6. Preferred structure should have lower values

SRC $<$ ORC: The basics

- SRCs are processed faster than ORCs in languages with post-nominal RCs:
  English, French, German, ...
  (Mecklinger et al. 1995; Gibson 2000; Gordon et al. 2006)

(1) **SRC $<$ ORC in English**

a. The reporter$_i$ [$_{\text{RC}}$ who t_i attacked the senator] admitted the error.

b. The reporter$_i$ [$_{\text{RC}}$ who the senator attacked t_i] admitted the error.

- This can be explained in terms of string distance between the head noun and the gap.

SRC < ORC: The challenge

- The SRC-advantage also holds with pre-nominal RCs: Japanese, Korean, Chinese
  (Gibson and Wu 2013; Miyamoto and Nakamura 2013)

(2) **SRC < ORC in Japanese**

a. [$_{\text{RC}}$ t_i giin-ga hinanshita] kisha$_i$-ga
senator-ACC attacked reporter-NOM
ayamari-o mitometa
error-ACC admitted

b. [$_{\text{RC}}$ giin-ga t_i hinanshita] kisha$_i$-ga
senator-NOM attacked reporter-NOM
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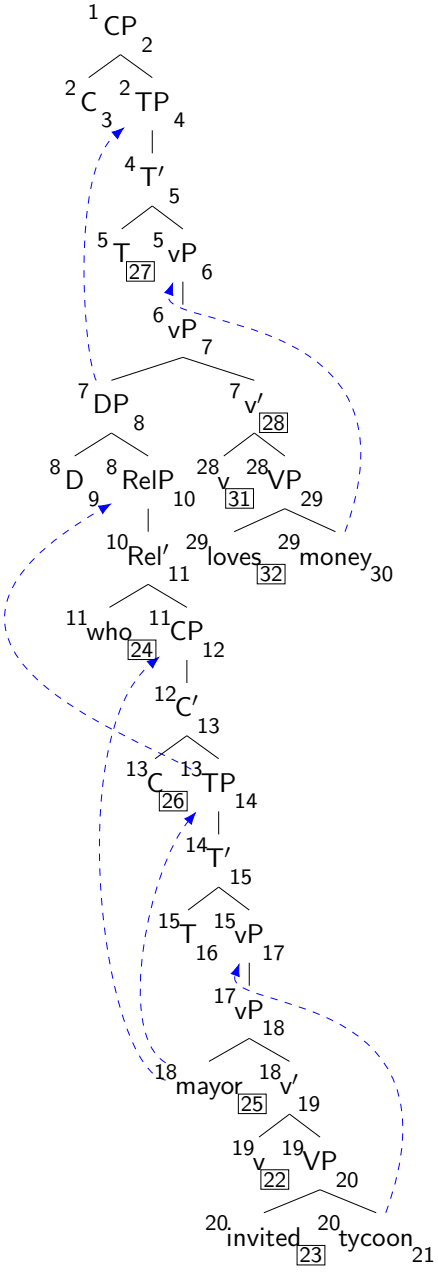
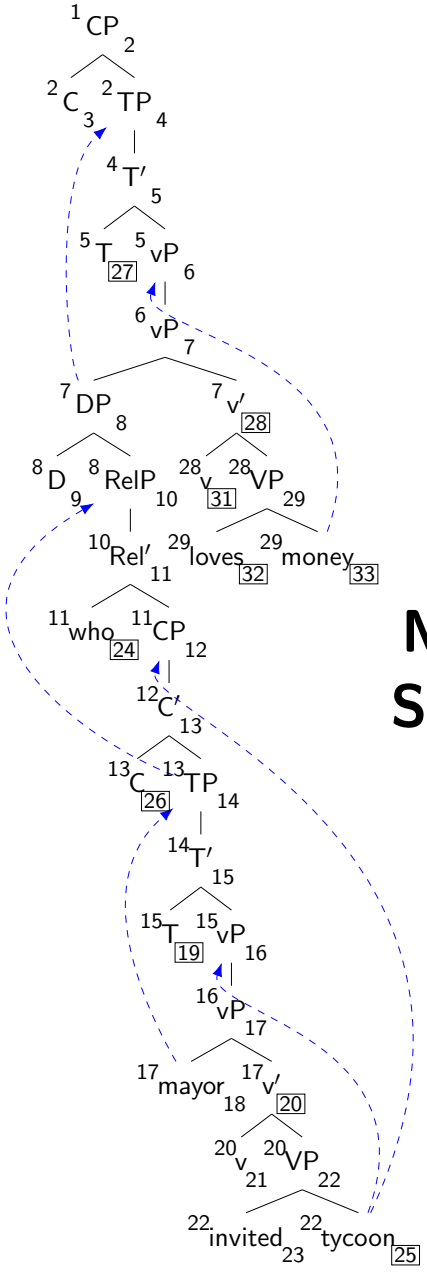
- String distance fails here.
- But a structural account succeeds.





	SRC	ORC
MaxTen	22	22
SumSize	38	42

Taking stock

- The MG processing model ties use to knowledge:
  processing complexity $\equiv$ structural complexity
- The linking hypothesis is maximally simple:
  1. top-down parsing
  2. simple memory usage metrics
- Every syntactic analysis is also a processing model.
- Doing syntax $\equiv$ doing psycholinguistics

For future reference: Two recent entry points

Cyclic scope and processing difficulty in a Minimalist parser*

Robert Pasternak
Leibniz-Center for General Linguistics (ZAS)
mail@robertpasternak.com

Thomas Graf
Stony Brook University
mail@thomasgraf.net

Structure and Memory:

A Computational Model of Storage, Gradience, and Priming

by

Aniello De Santo

Doctor of Philosophy

in

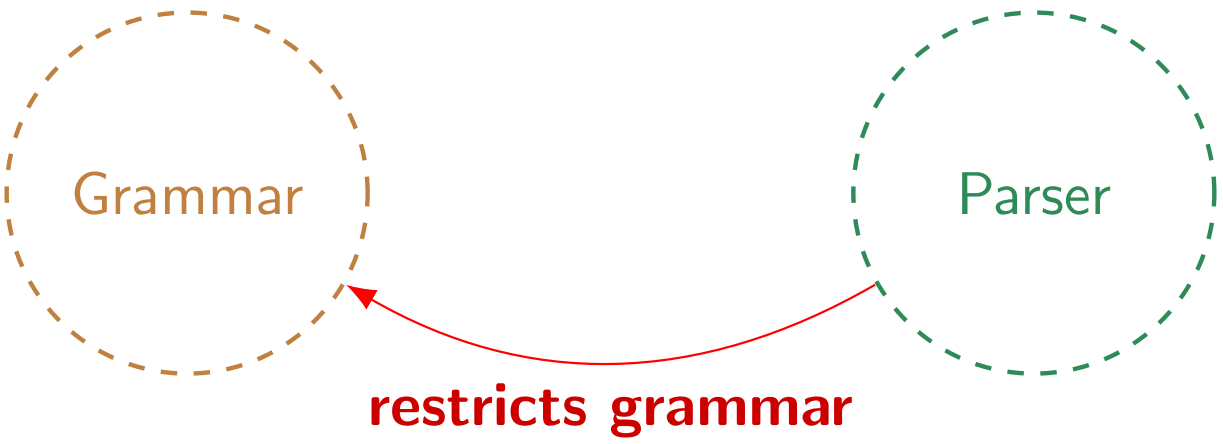
Linguistics

Stony Brook University

2020

aniellodesanto.github.io

The mid-talk turn-around



Third-factor considerations

- Minimalist assumption: syntax limited by external factors (Chomsky 2005)
- If the parser is indeed top-down,
  syntax should be easy to parse top-down.
- But what does "easy" mean?

Roadmap to a definition of "easy"

1. Syntactic computation as **tree automata**
2. Identify an efficient class of top-down tree automata

Syntactic computation as automata

- Syntactic computations can be encoded as **tree automata**. (cf. Morawietz and Cornell 1999; Kobele et al. 2007)
- Each node in the tree is assigned a **state**.
- The tree is well-formed iff the state assignment is valid.
- For top-down efficiency, we want tree automata that are:

finite-state the set of available states is finite

deterministic when deciding what state to assign to a node n, there is only one option

- But this limits what is computable!

limited automaton $\equiv$ limited syntactic computation

Standard deterministic tree automata are too weak

- Deterministic top-down tree automata are myopic.
- They can't even handle c-selection.
- What state is assigned to a node n depends only on
  1. the state of the mother of n, and
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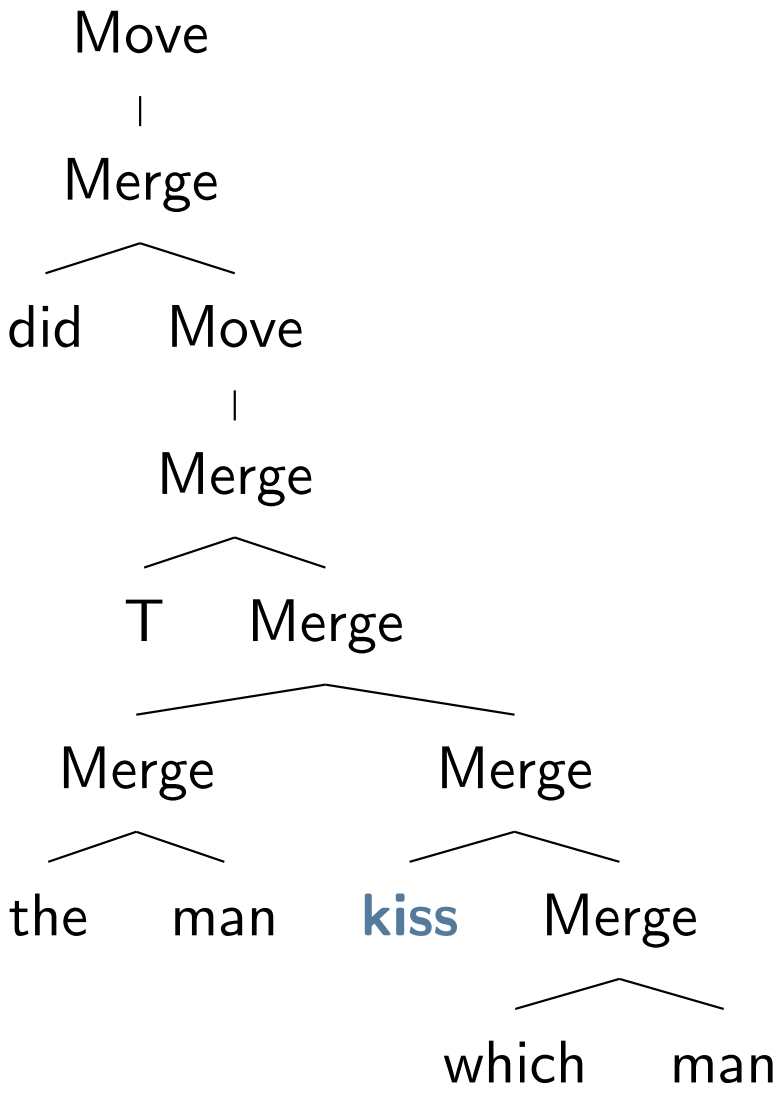
- **Corollary:** state of n depends only on ancestors of n
- We can visualize this as the **s[yntactic]-horizon** of n.



Standard deterministic tree automata are too weak

- Deterministic top-down tree automata are myopic.
- They can't even handle c-selection.
- What state is assigned to a node n depends only on
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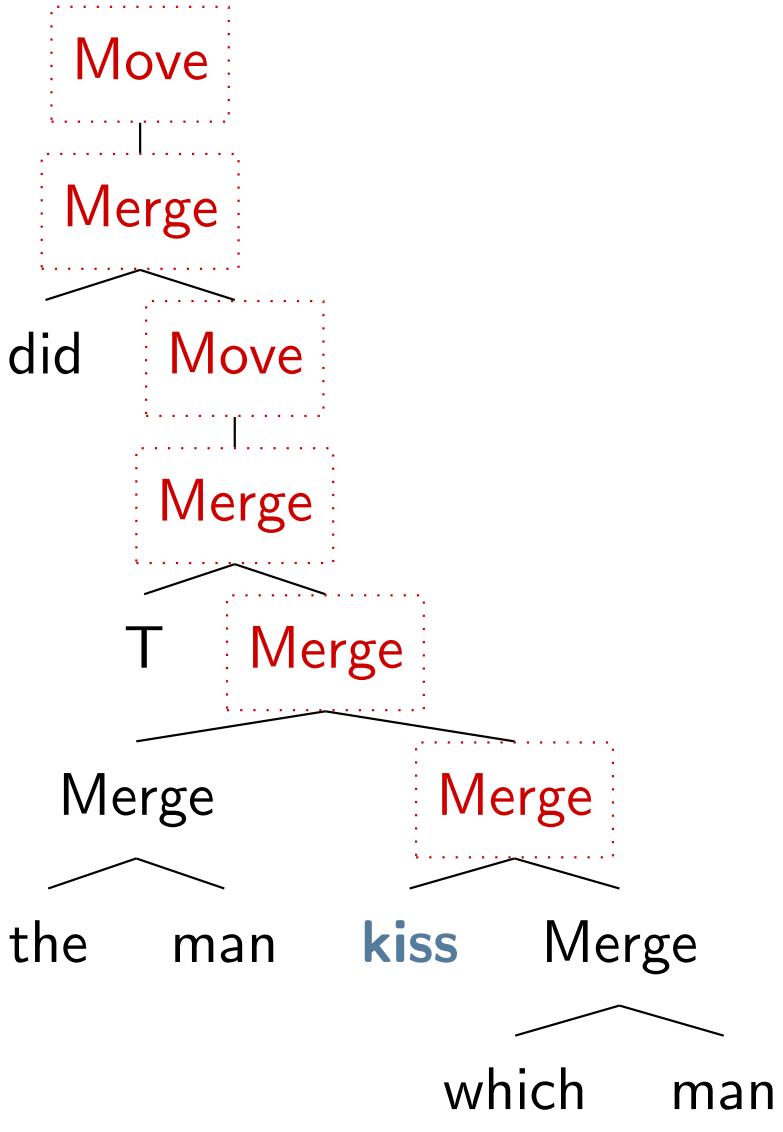

Sensing tree automata (STAs)

- STAs have a more powerful state assignment mechanism.
- What state is assigned to a node n depends only on
  1. the state of the mother of n, and
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  3. the labels of n's siblings, and
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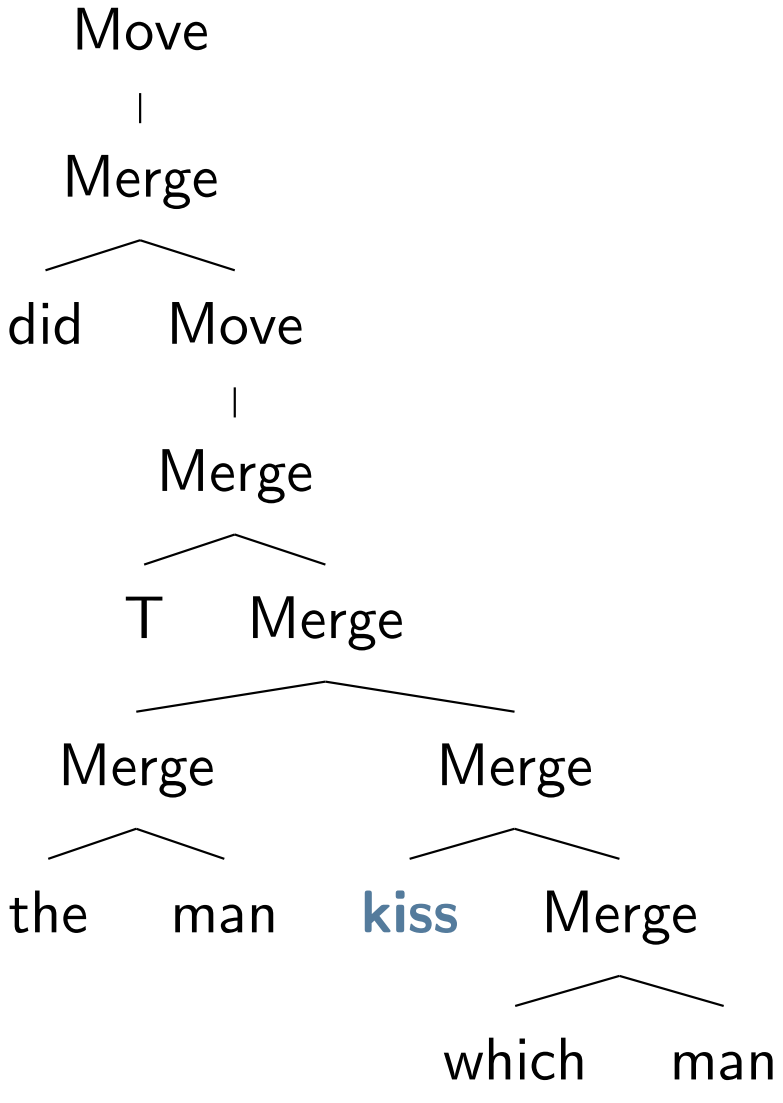
- **Result:** larger s-horizon



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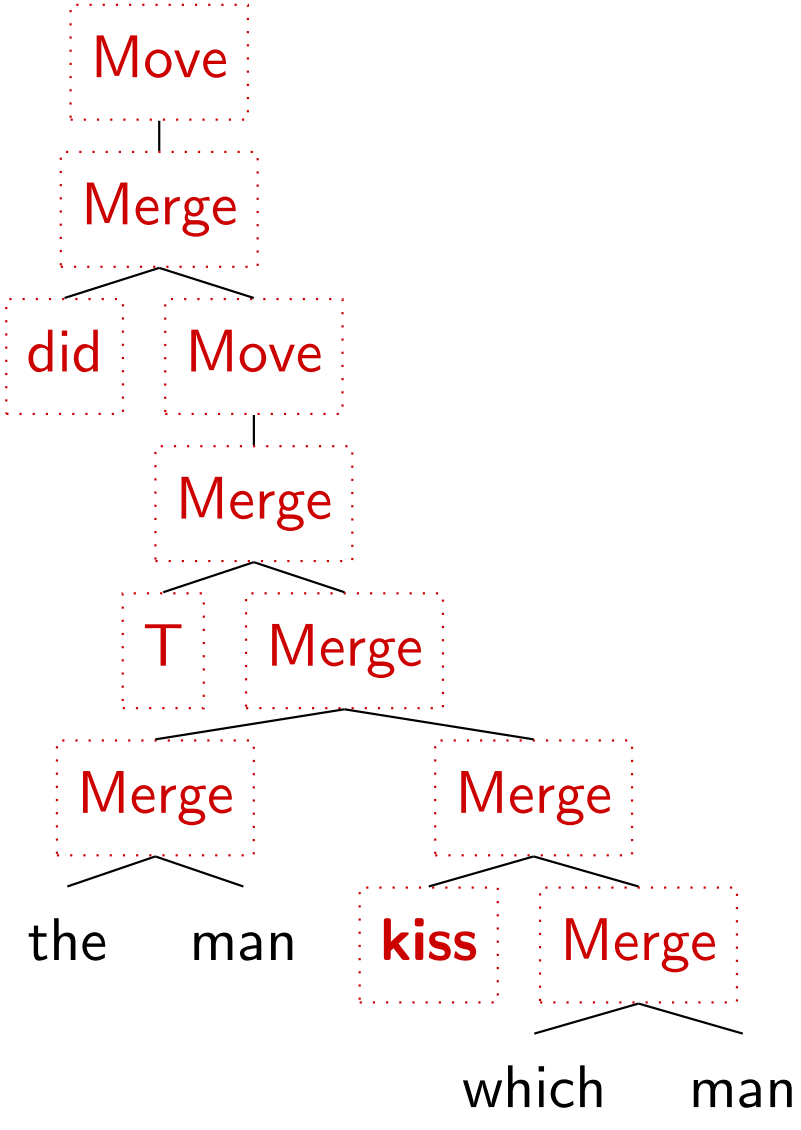


A final tweak: Head-sensing tree automata

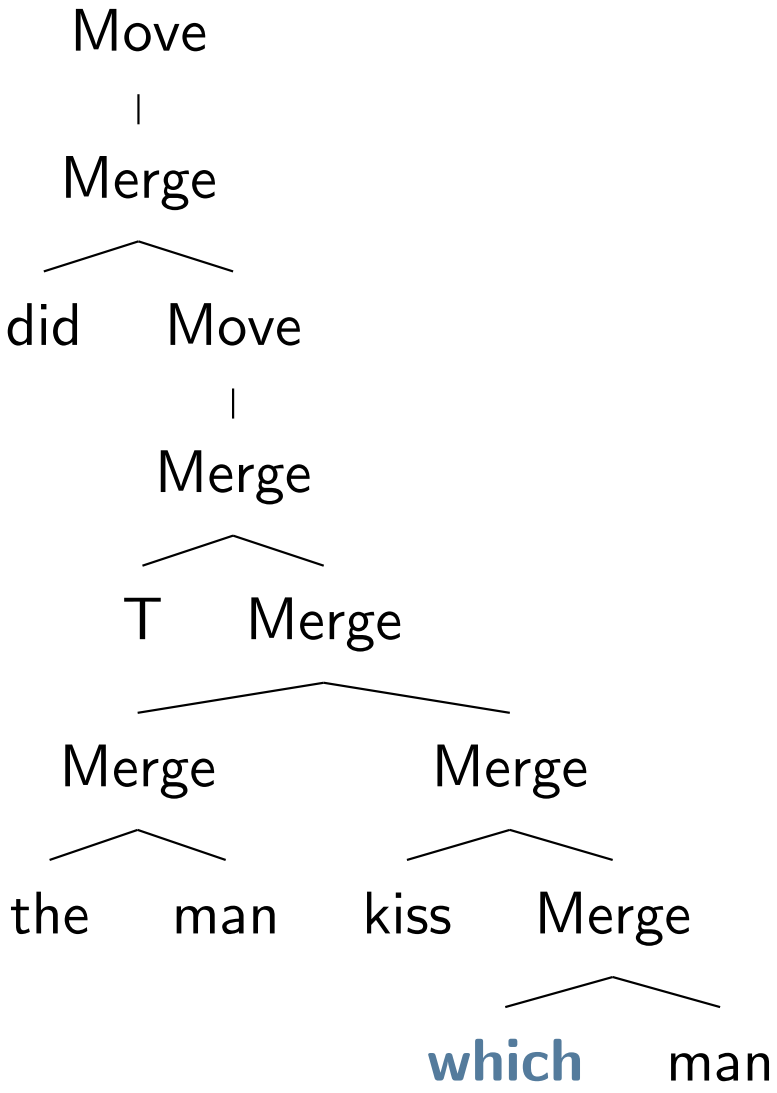
- STAs look promising, almost like c-command.
- But they're stipulative from a Minimalist perspective.
- How can we make STAs linguistically natural?
- Adapt them to Merge: "mother" and "sibling" don't matter, we want **head-argument relations**.

Head-sensing tree automata (HSTAs)

What state is assigned to a head h depends only on

1. the state of the head selecting h, and
2. the label/features of the head selecting h, and
3. the label/features of the head of each co-argument of h, and
4. the label/features of h itself.

Visualizing HSTAs with dependency trees



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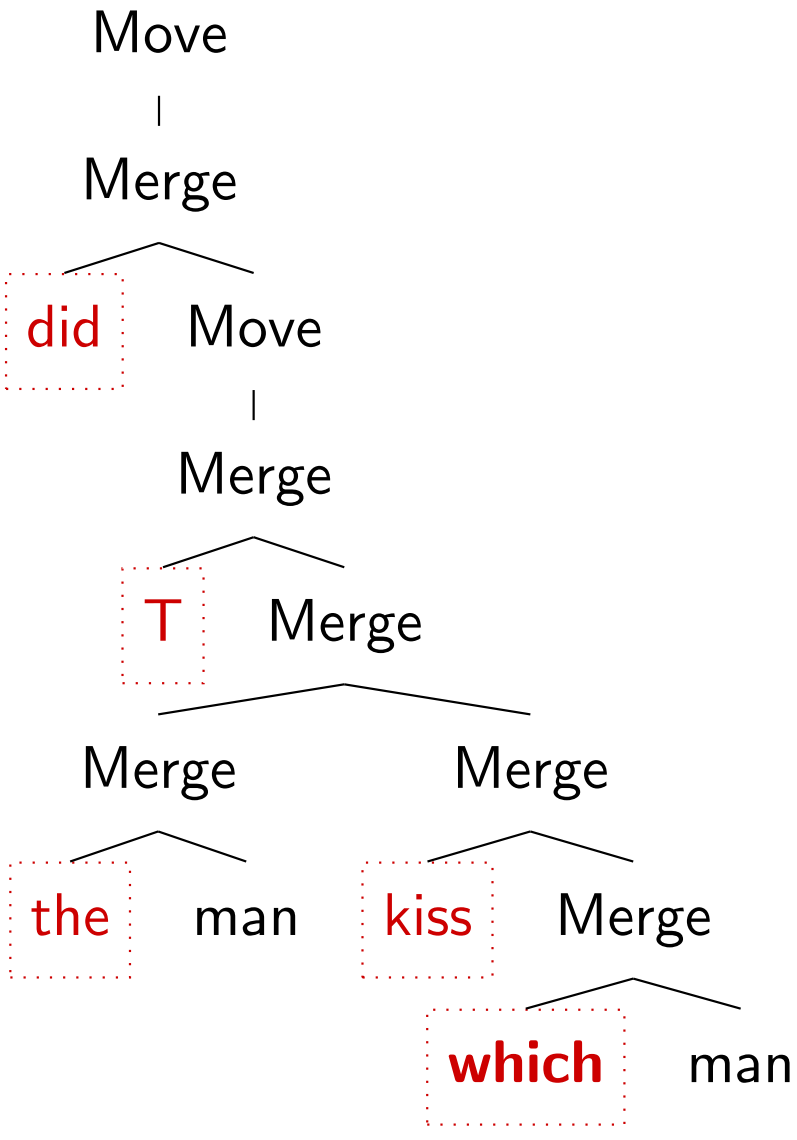

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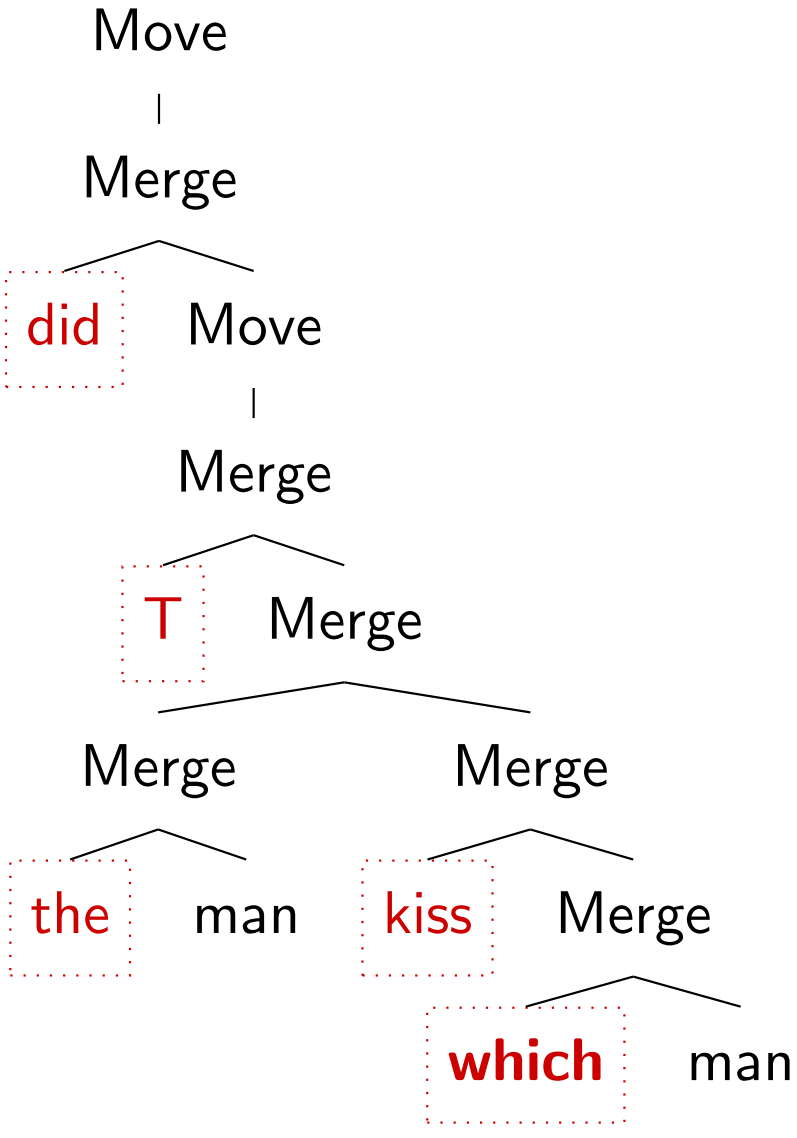

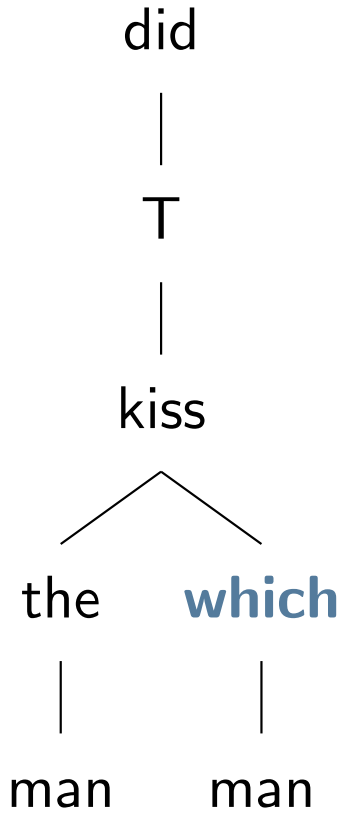

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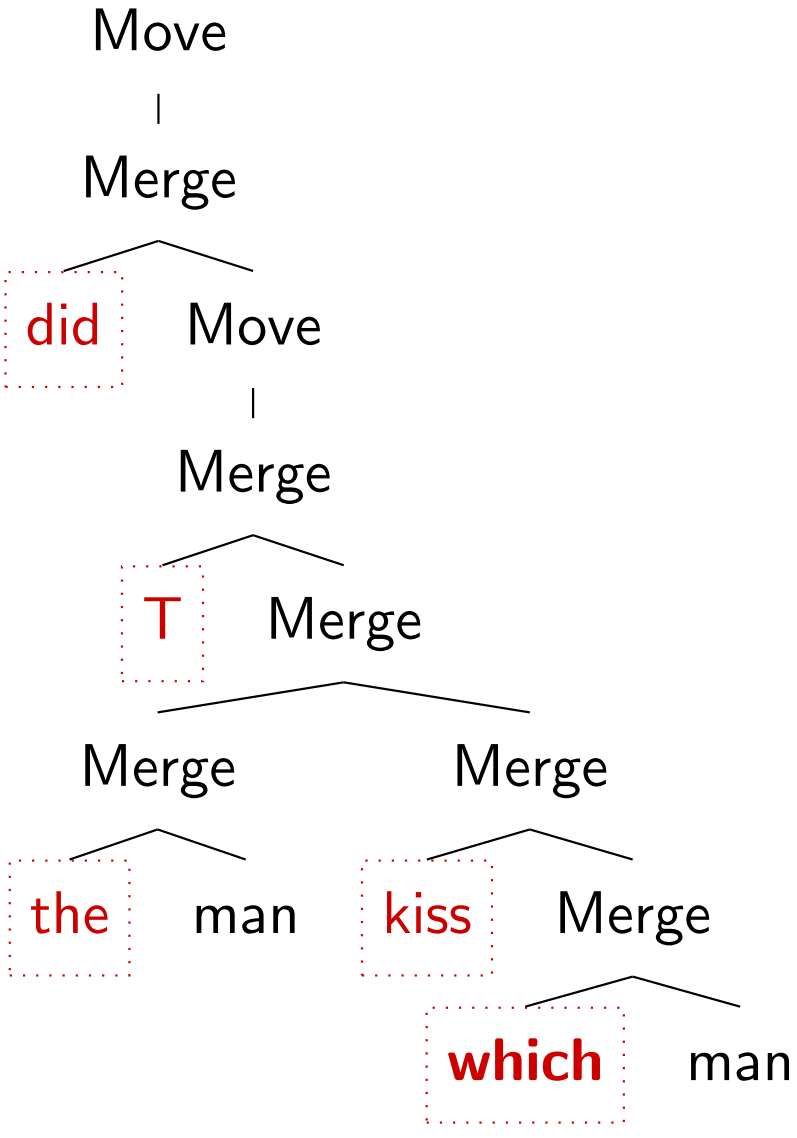
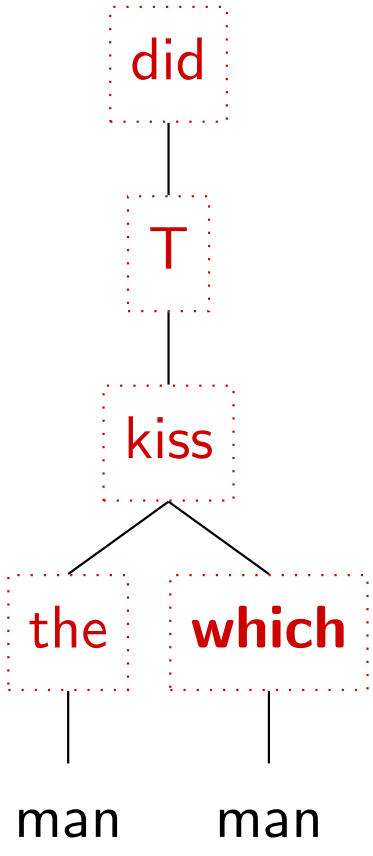
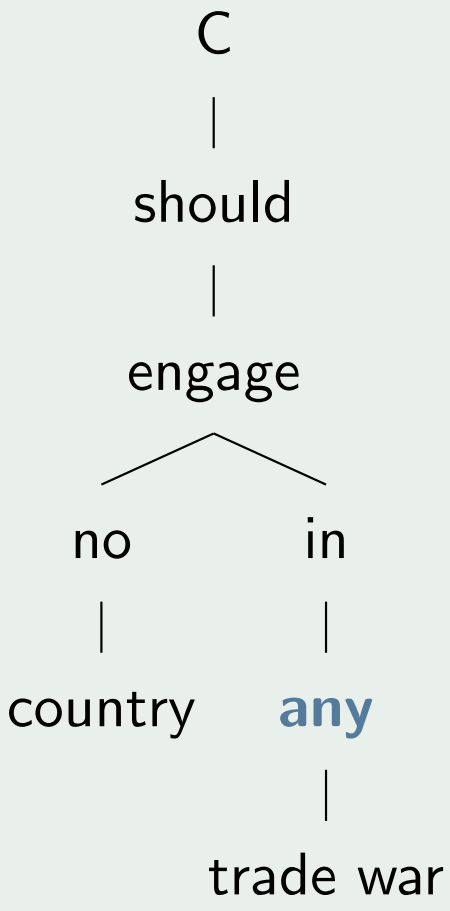




HSTAs for syntactic constraints

- HSTAs can handle almost everything in syntax.
  (Graf and De Santo 2019; Graf and Shafiei 2019)

Example: NPI-licensing upward and downward



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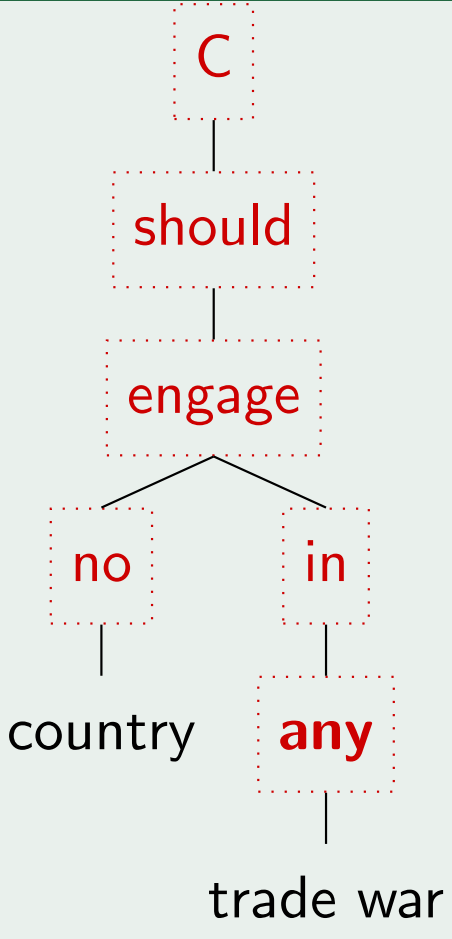

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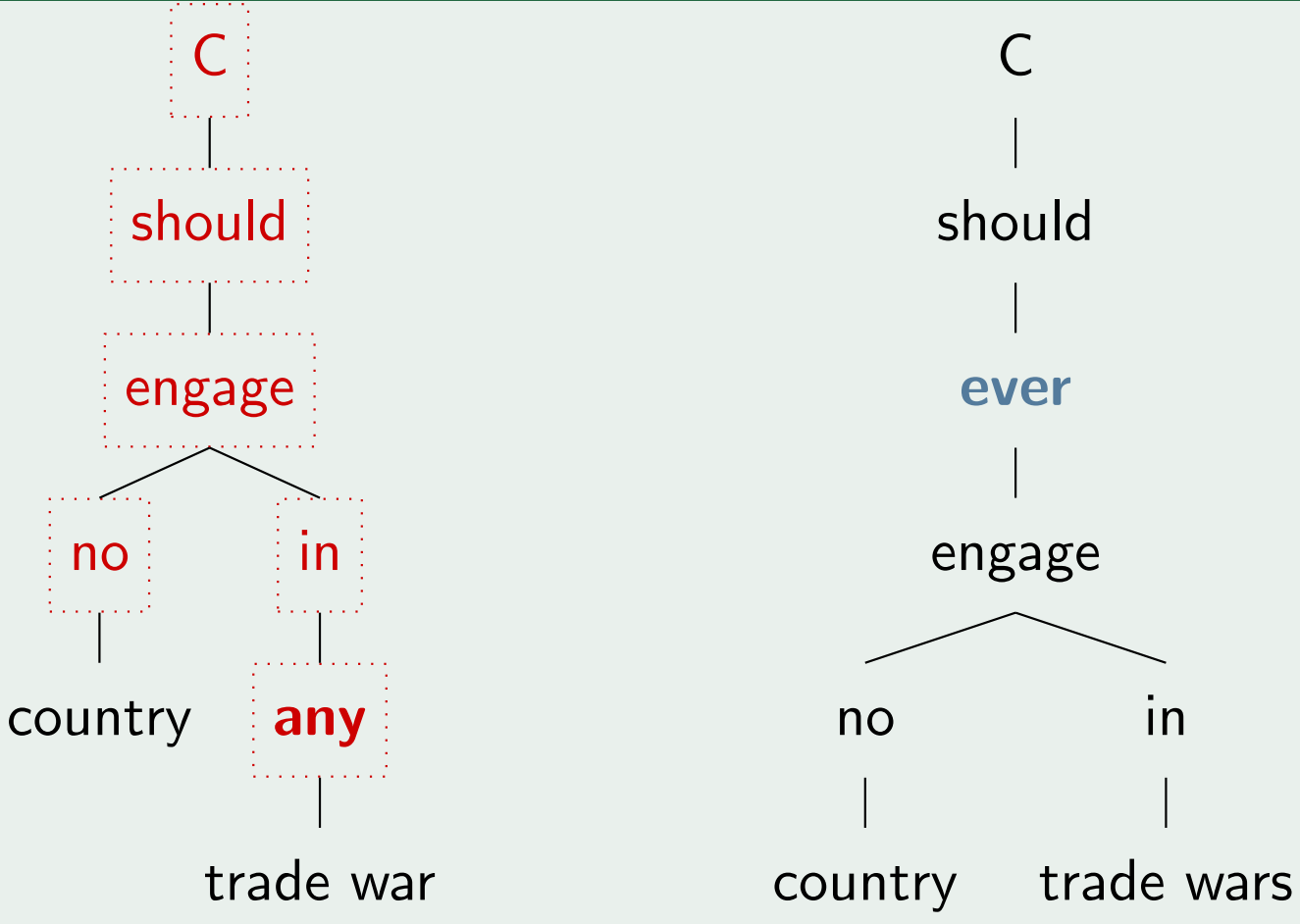

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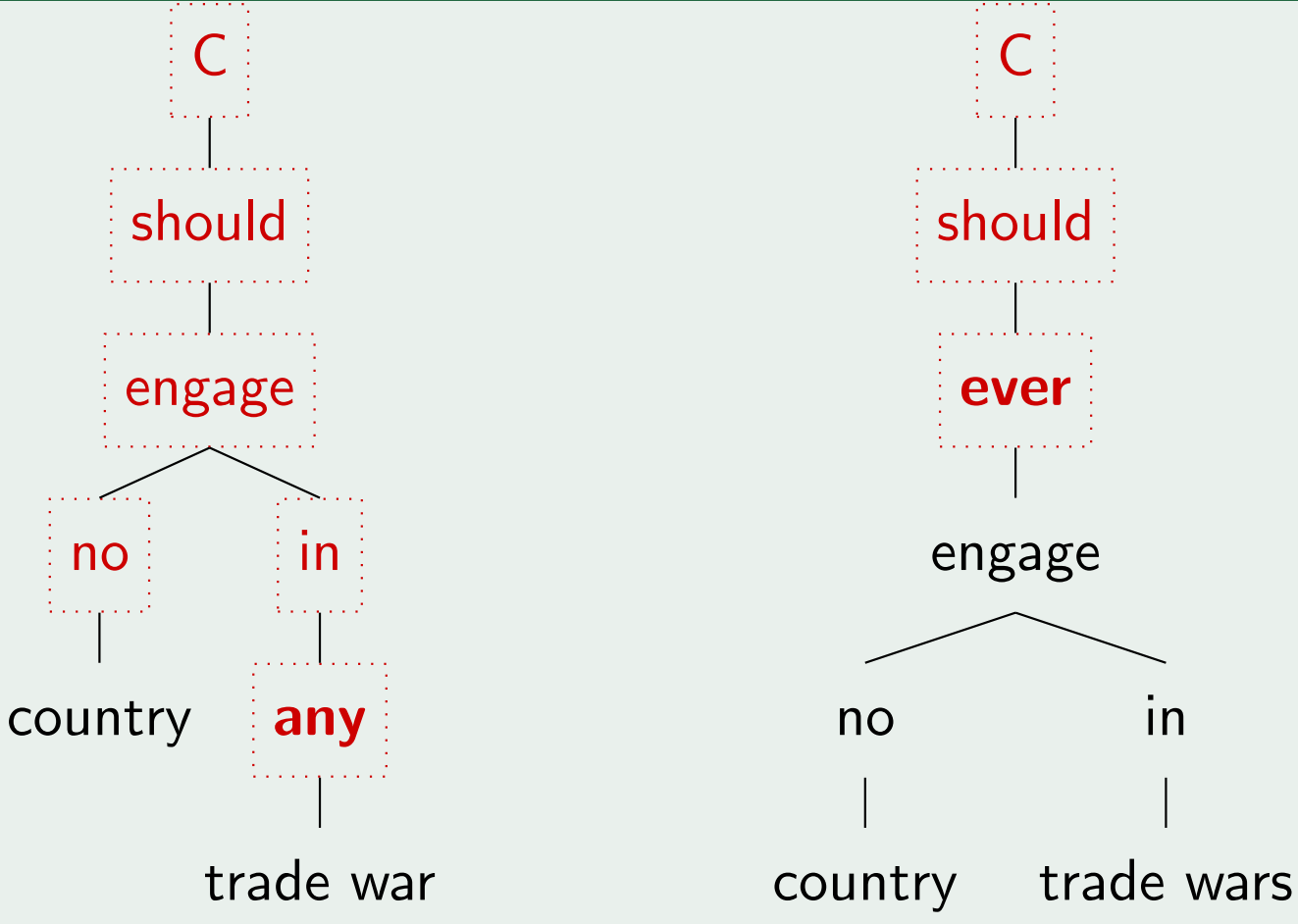

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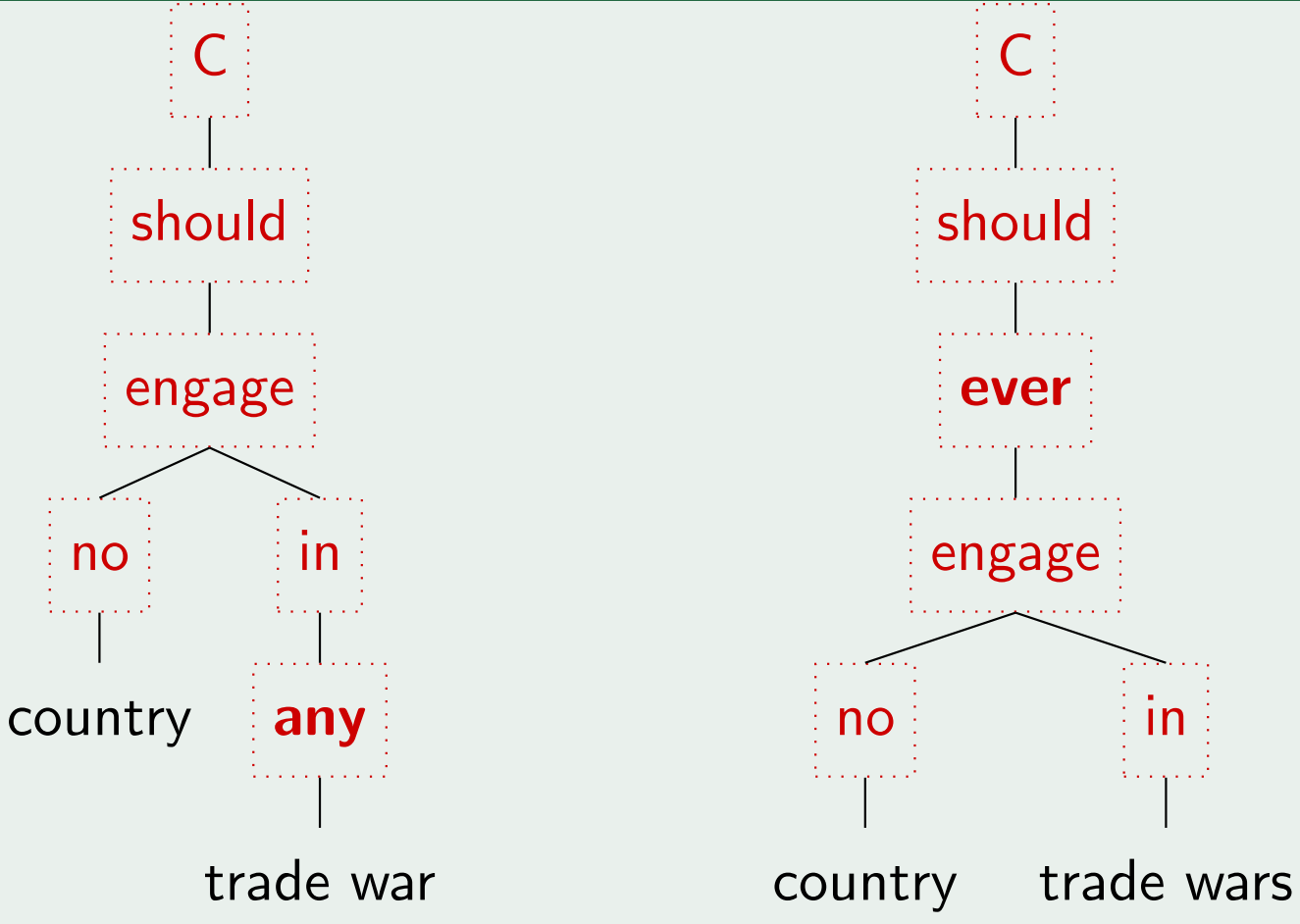
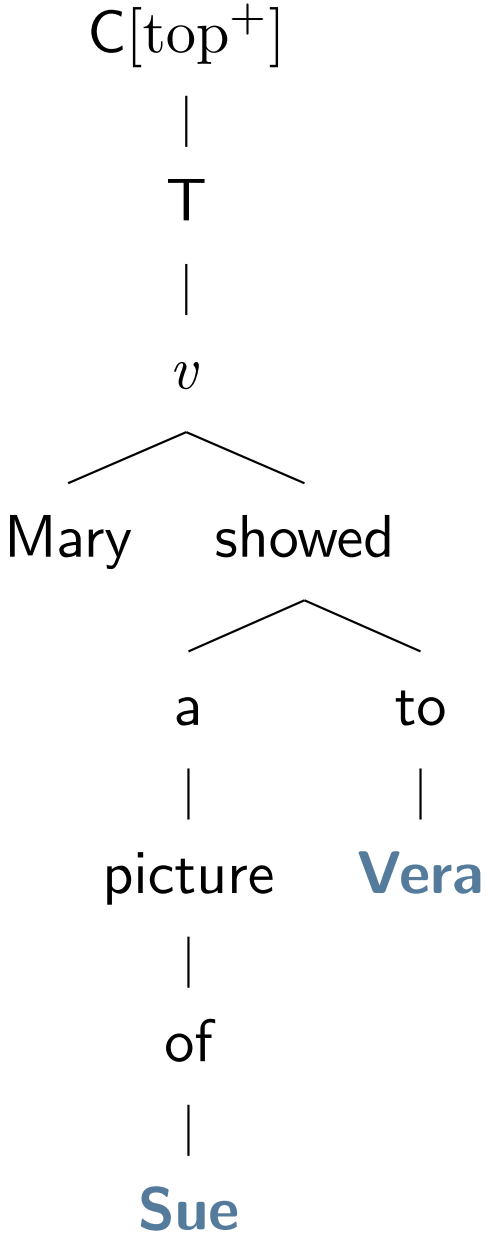


A (welcome) problem with movement

- In MGs, movement is triggered by two matching features:
  - **licensor** feature f^{+} at the target site
  - **licensee** feature f^{-} on the head of the mover
- A licensor feature must not remain unchecked.
- HSTAs fail to enforce this in some cases.

Example: HSTA does not notice missing top^-



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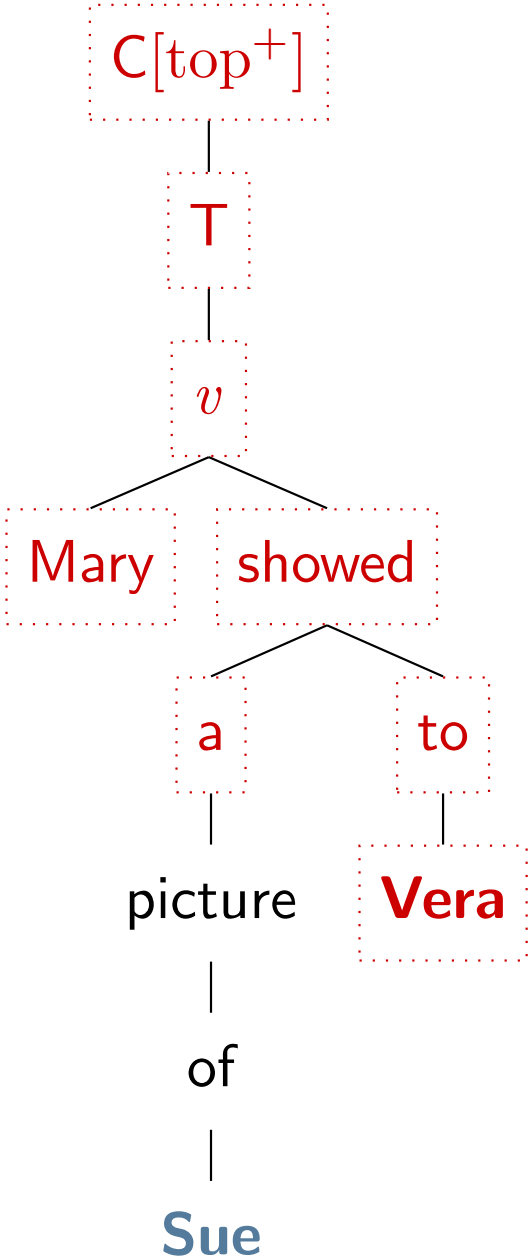

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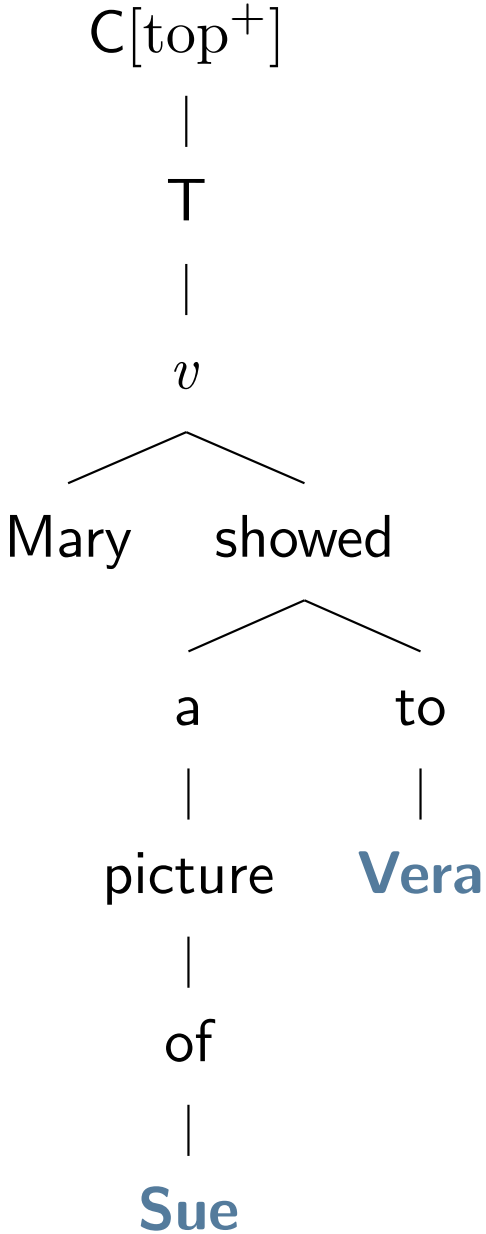

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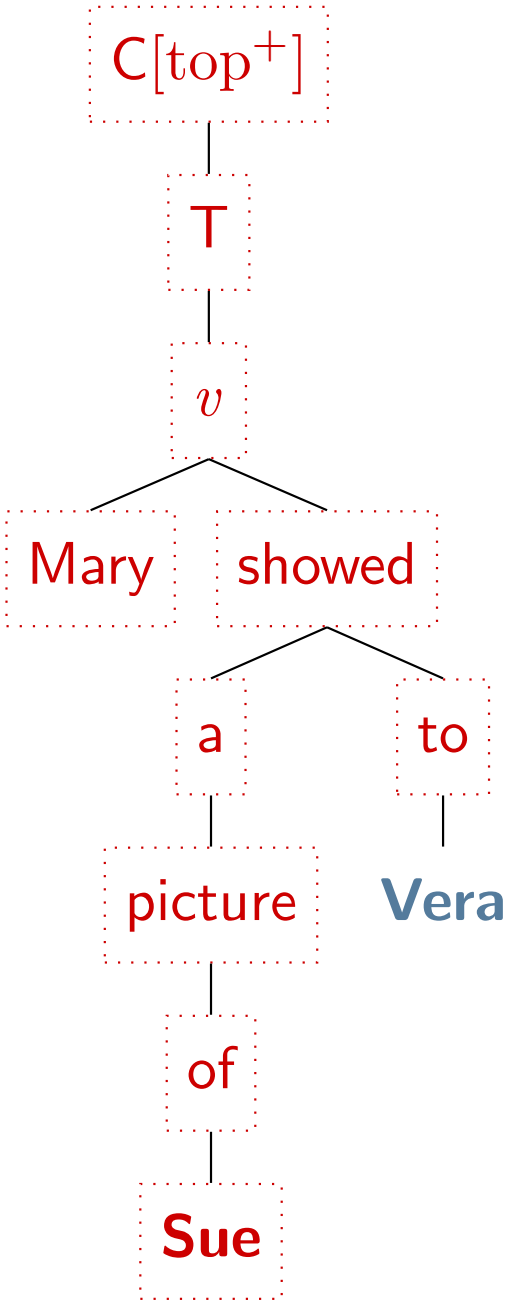

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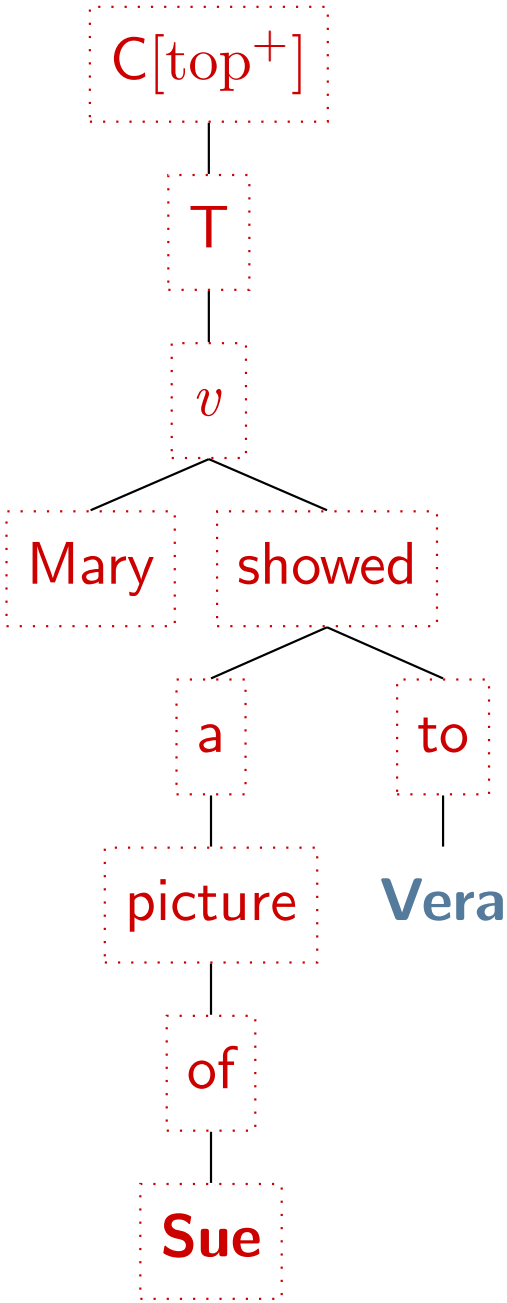

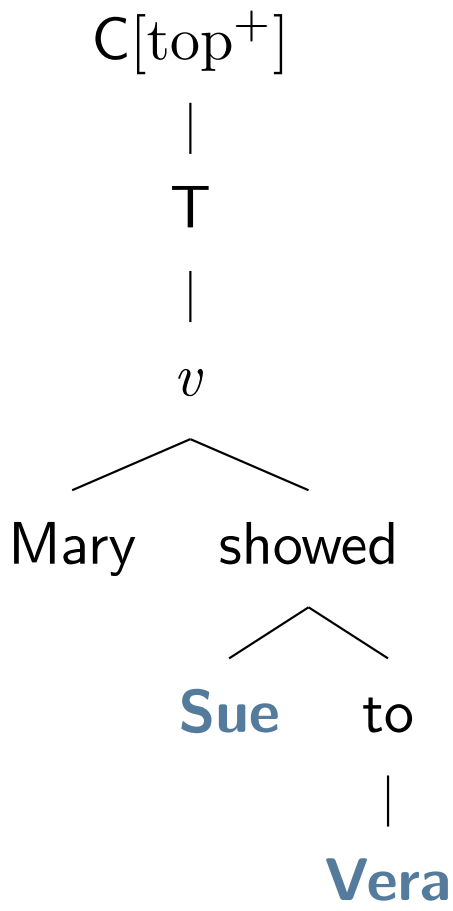

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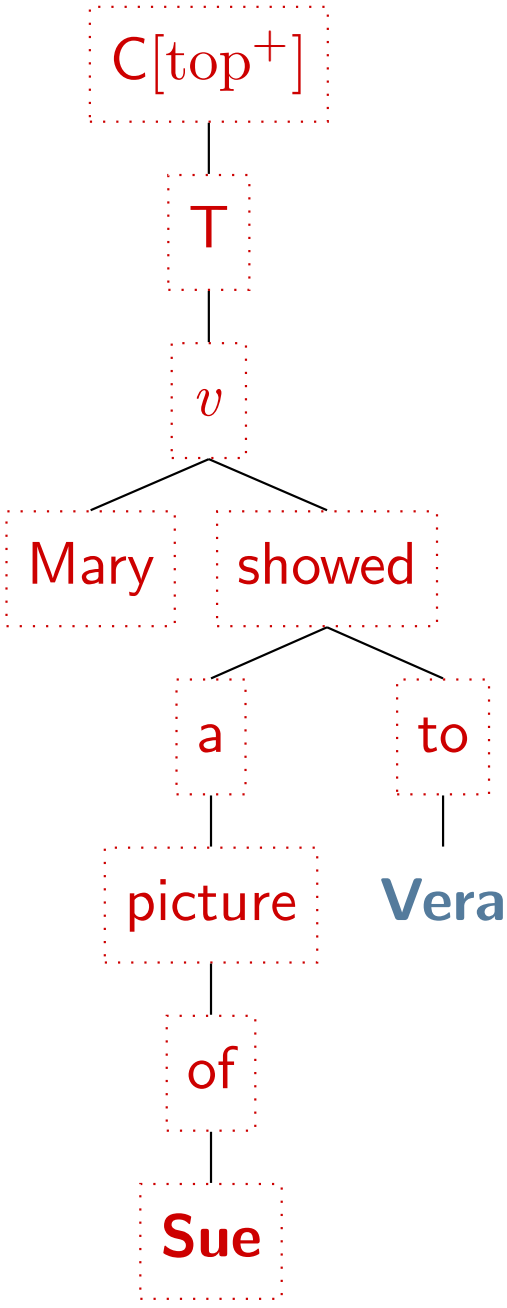

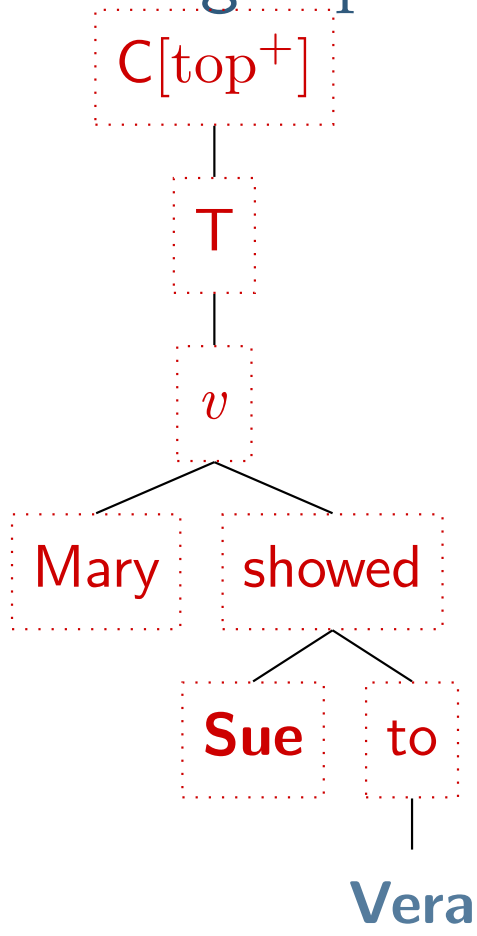

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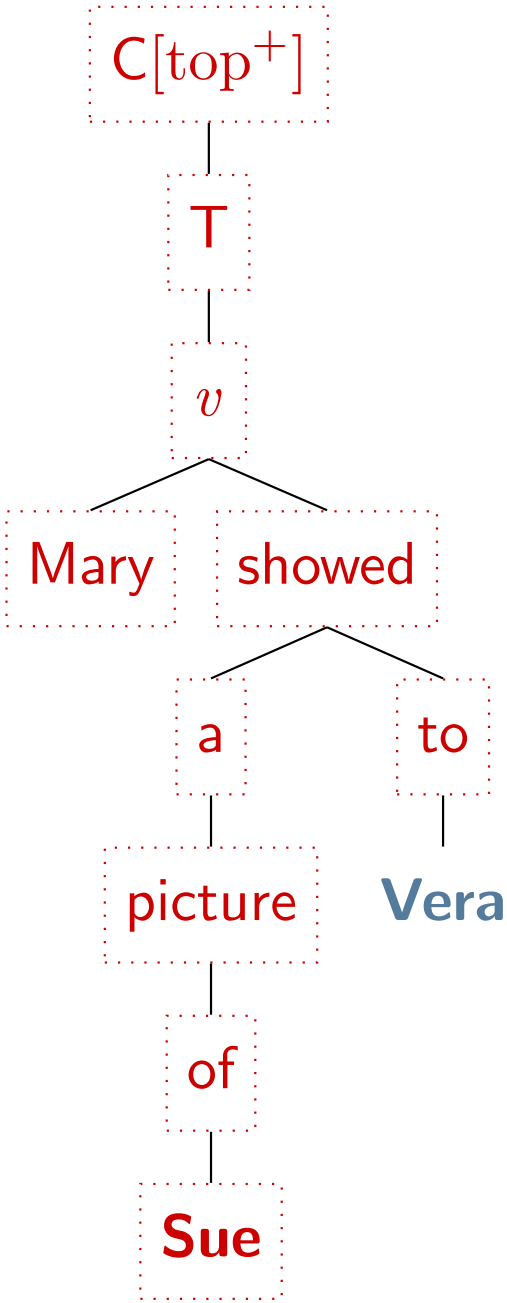

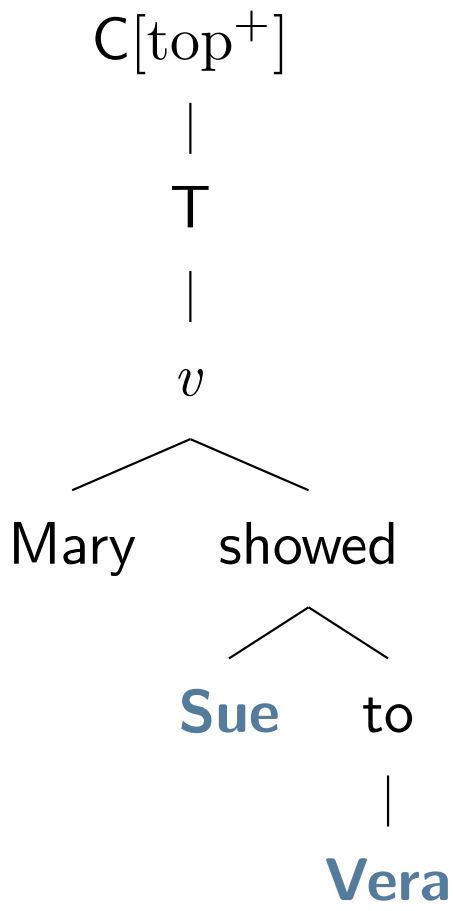

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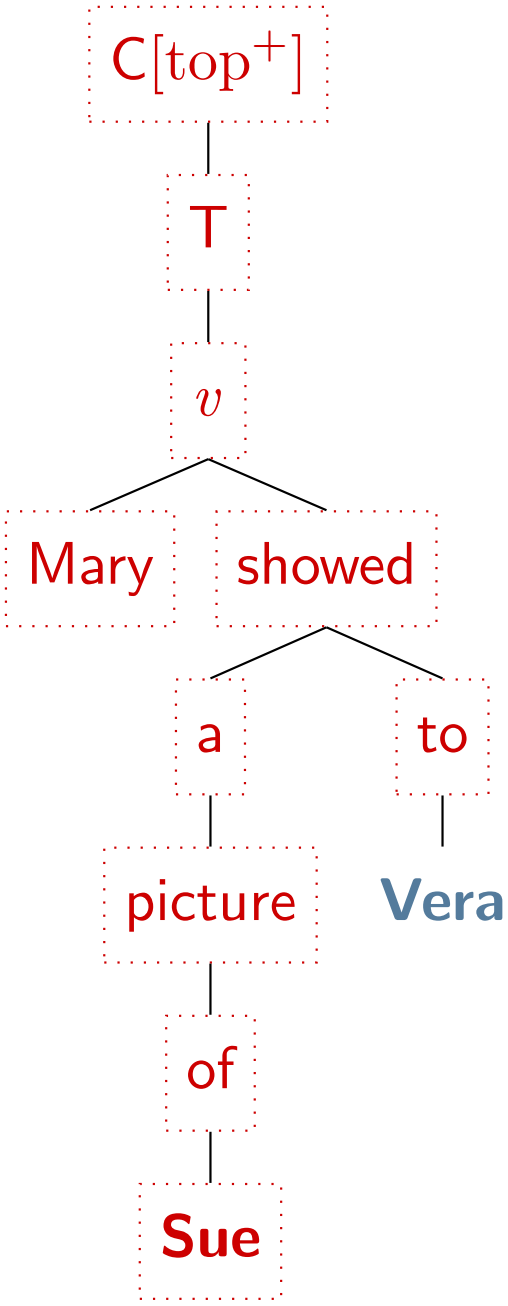
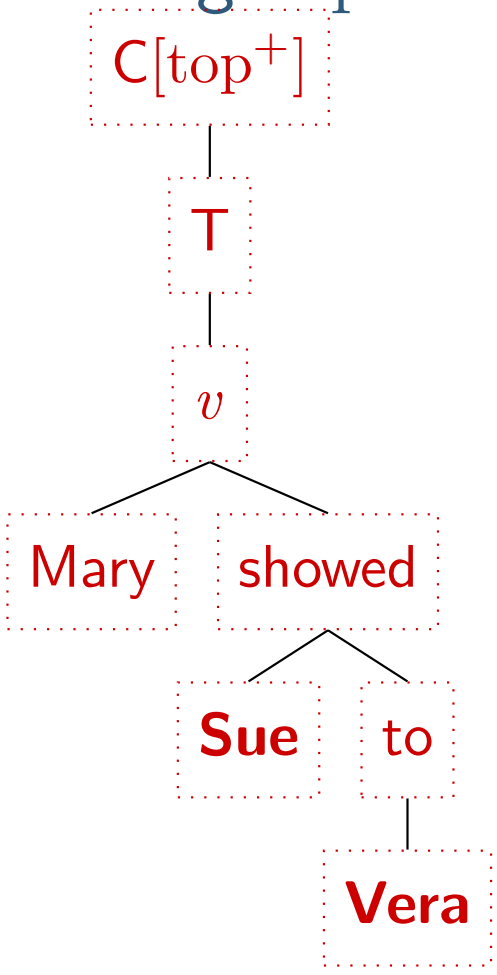




HSTA-movement displays island effects

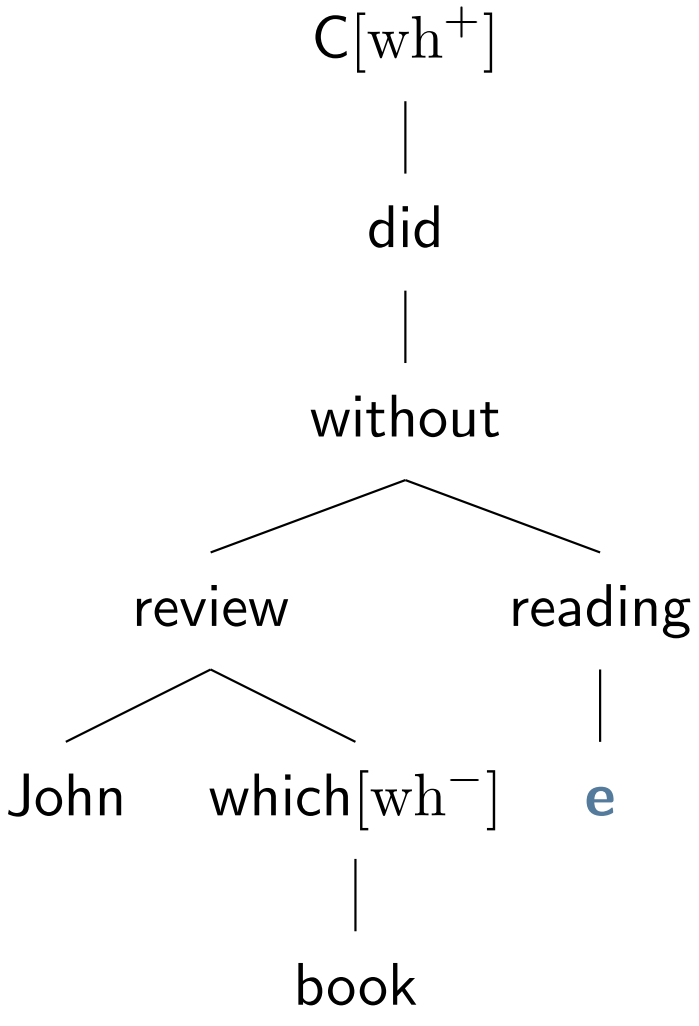
- **Observation**
  If a specifier/adjunct contains a mover, then no node outside the specifier/adjunct has that mover in its s-horizon.
- **Corollary**
  If we want HSTA-computable movement, syntax must obey:
  1. the specifier island constraint
  2. the adjunct island constraint
- Parsing considerations **derive island constraints**.

Interim summary

- **Assumption 1**
  Syntax should allow for efficient top-down parsing.
- **Assumption 2**
  efficient $\equiv$ finite-state & deterministic
- **Definition**
  HSTAs are deterministic top-down finite-state tree automata where state assignment hinges on head-argument relations.
- **Corollary**
  The computational limits of HSTAs derive island constraints.
  These are still syntactic constraints, not processing effects!

HSTAs still allow for parasitic gaps

- HSTAs can still verify PG licensing.
- If a PG's event horizon contains some f^{+} above the adjunct head, but no matching f^{-}, then the PG occurs along a movement path.
- **But:** not all movers license PGs
  $\Rightarrow$ must be inferrable from f^{+}



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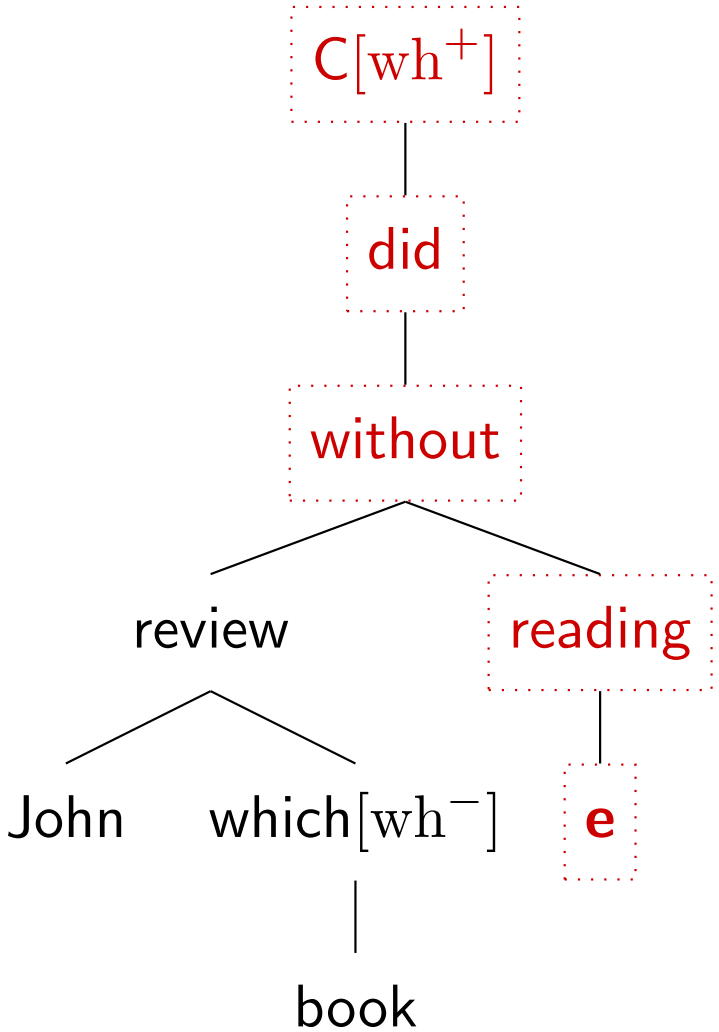
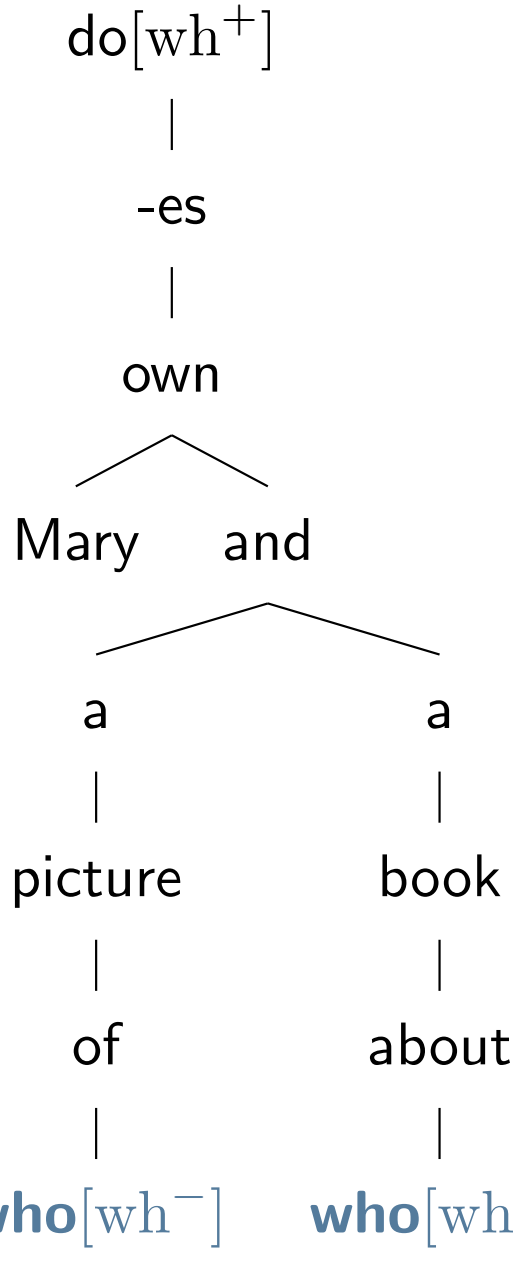


HSTAs allow for across-the-board extraction

- ATB-movement is still possible.
- Since each conjunct has to contain a mover of its own, each conjunct can be considered in isolation.



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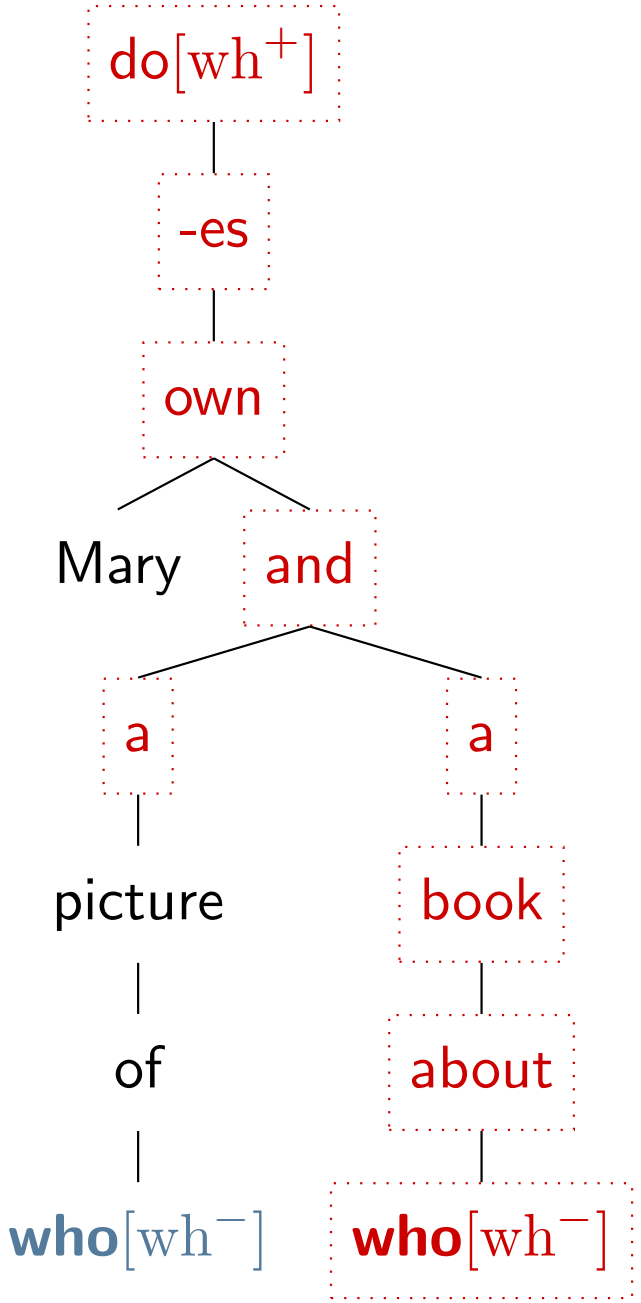

Conclusion

1. **Syntax informs sentence processing**
   A simple linking hypothesis converts syntactic analyses into processing claims.
2. **Parsing informs syntax**
   If syntax must be top-down parser-friendly, syntactic constraints must be limited:
   1. island constraints on movement
   2. primacy of c-command
3. **Open ends**
   - Truswell sentences, left-branch extraction in Japanese, Scandinavian RCs, ...
   - Left-corner parsing

Thanks

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