MG Parsing as a Model of Effort in Online RC Processing

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CPL 2025

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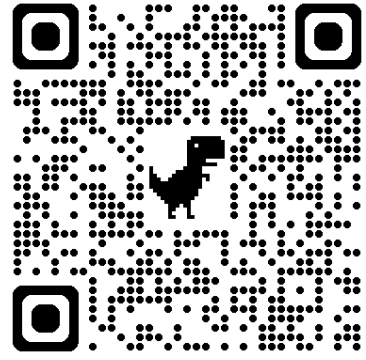

One Big Question

Which aspects of grammar influence sentence processing?

(Demberg & Keller 2008; Brennan et al., 2016; Stanojevic et al., 2023)

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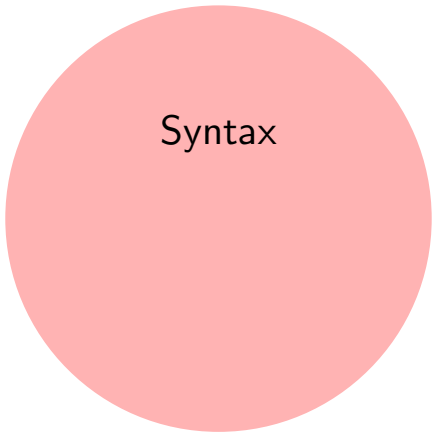

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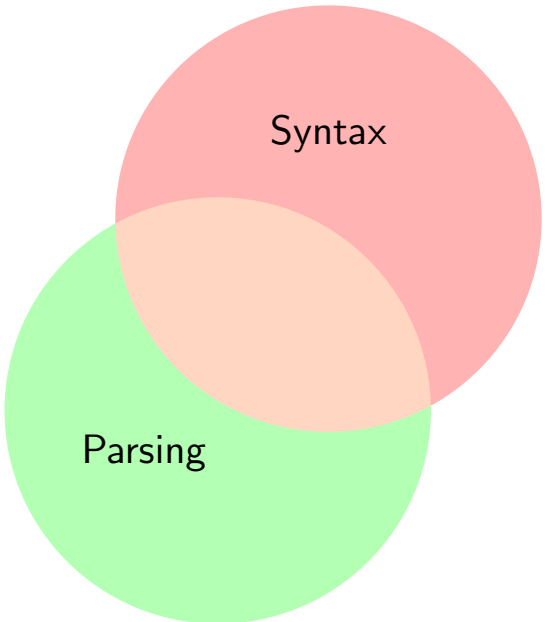

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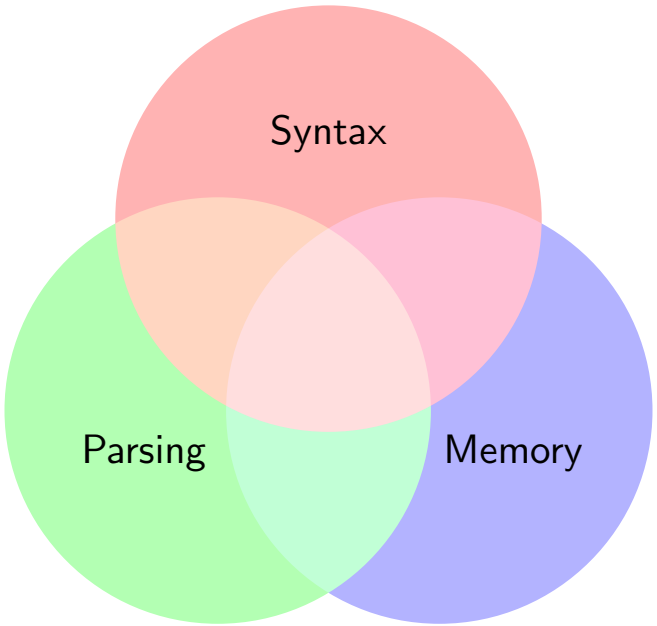

1. Does (MG) structure building predict behavioral results?
2. How do structure building/memory metrics fare wrt expectation based ones?

(Demberg & Keller 2008; Brennan et al., 2016; Stanojevic et al., 2023)

Forward to the Past

(How much) does grammatical structure matter in sentence processing?

> *A realistic grammar should [...] contribute to the explanation of linguistic behavior and to our larger understanding of the human faculty of language.*
>
> *(Bresnan 1978: pg. 58)*

Derivational Theory of Complexity (Miller and Chomsky, 1963)

- Processing complexity ∼ length of a derivation
  (Fodor & Garrett 1967; Berwick & Weinberg 1983)
- Essentially: there is a **cost** to mental computations.

- What does the syntactic derivation look like?
- What is costly? And why?

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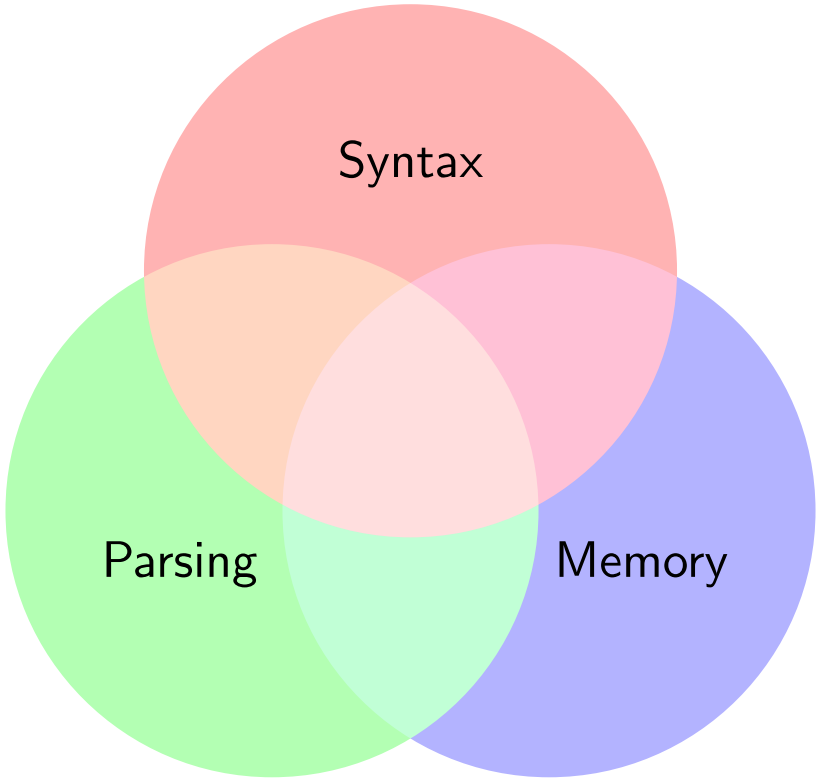

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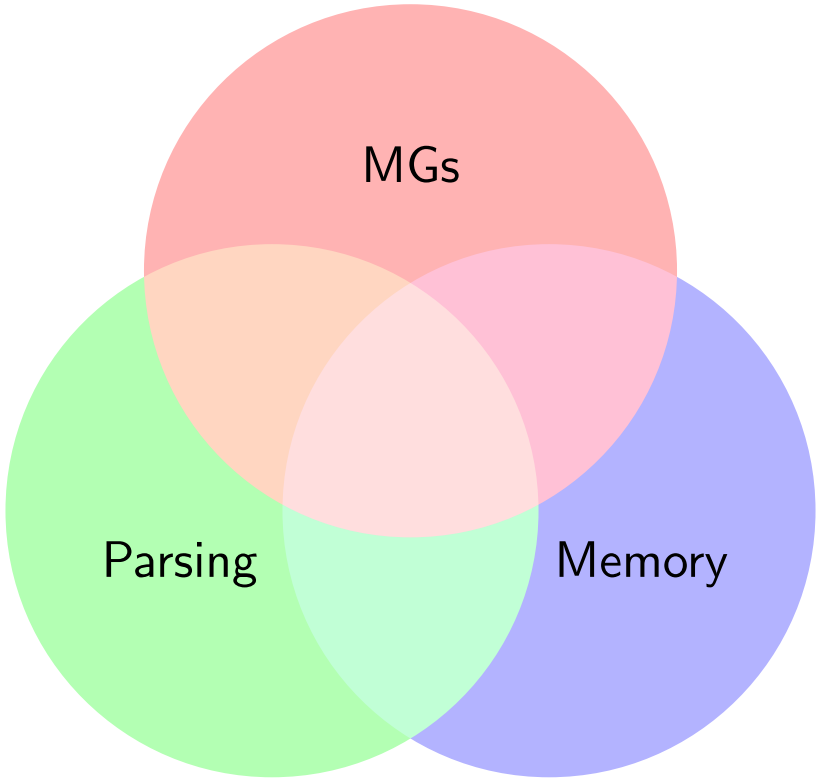

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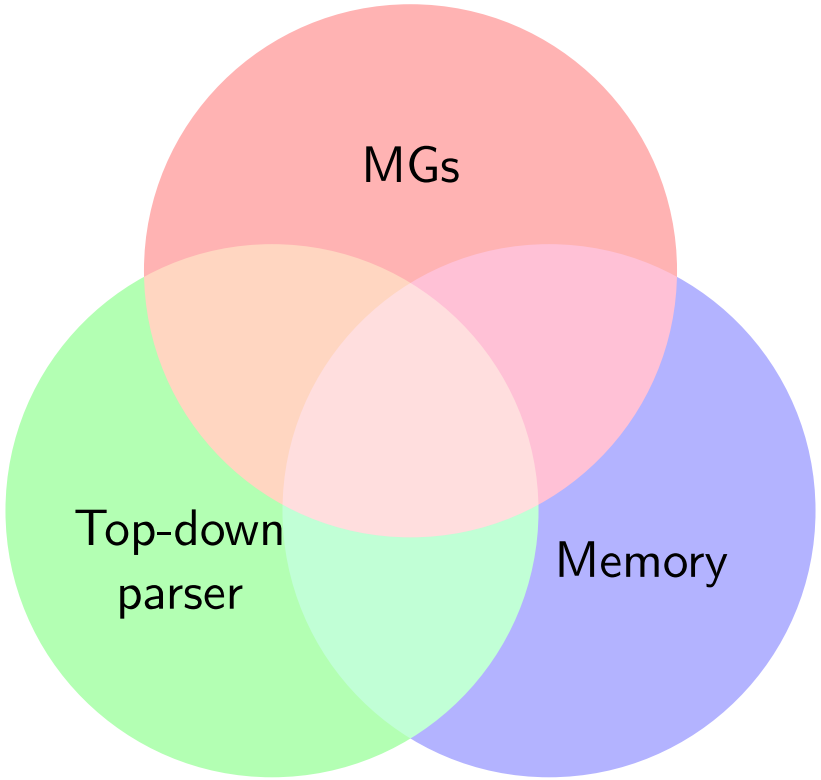

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2. A theory of how structures are built → top-down parser

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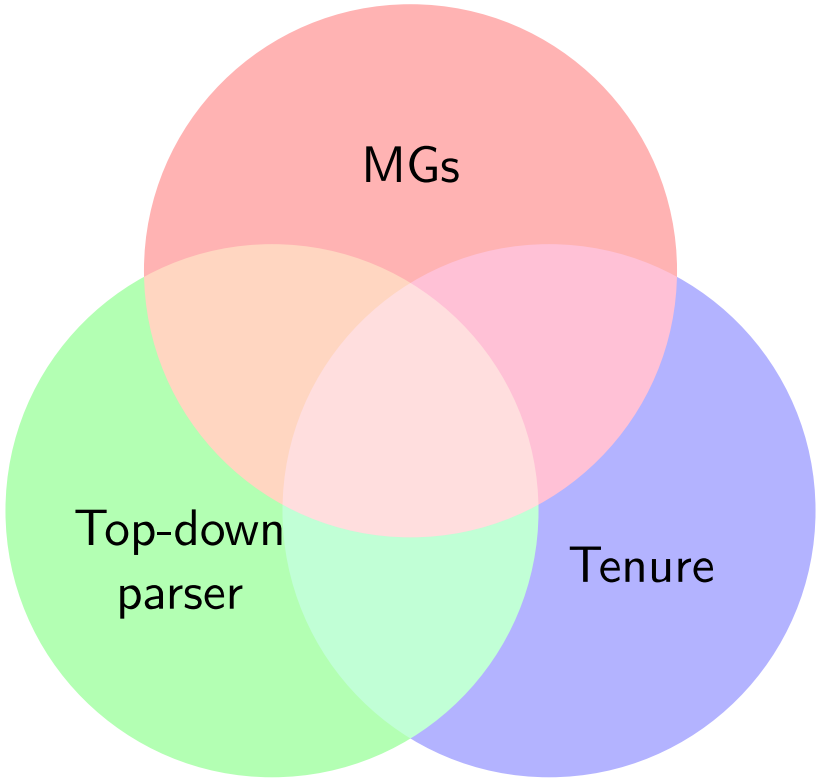

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2. A theory of how structures are built → top-down parser
3. A psychologically grounded linking theory → tenure

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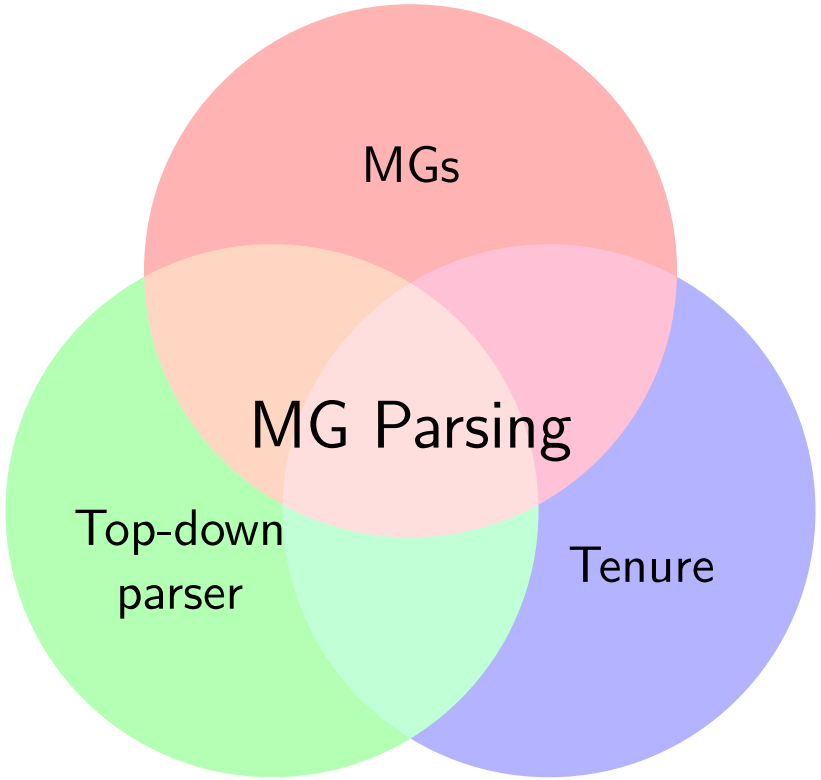

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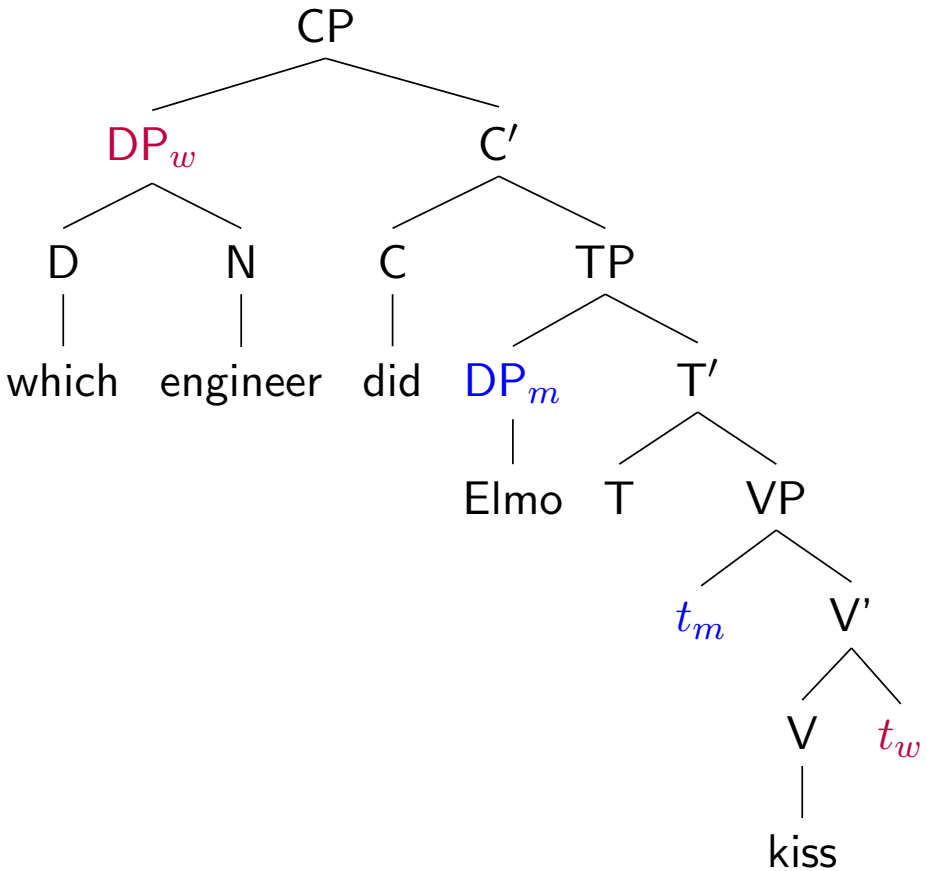
Outline

1 Parsing Minimalist Grammars

2 A Case Study: SRC vs ORC

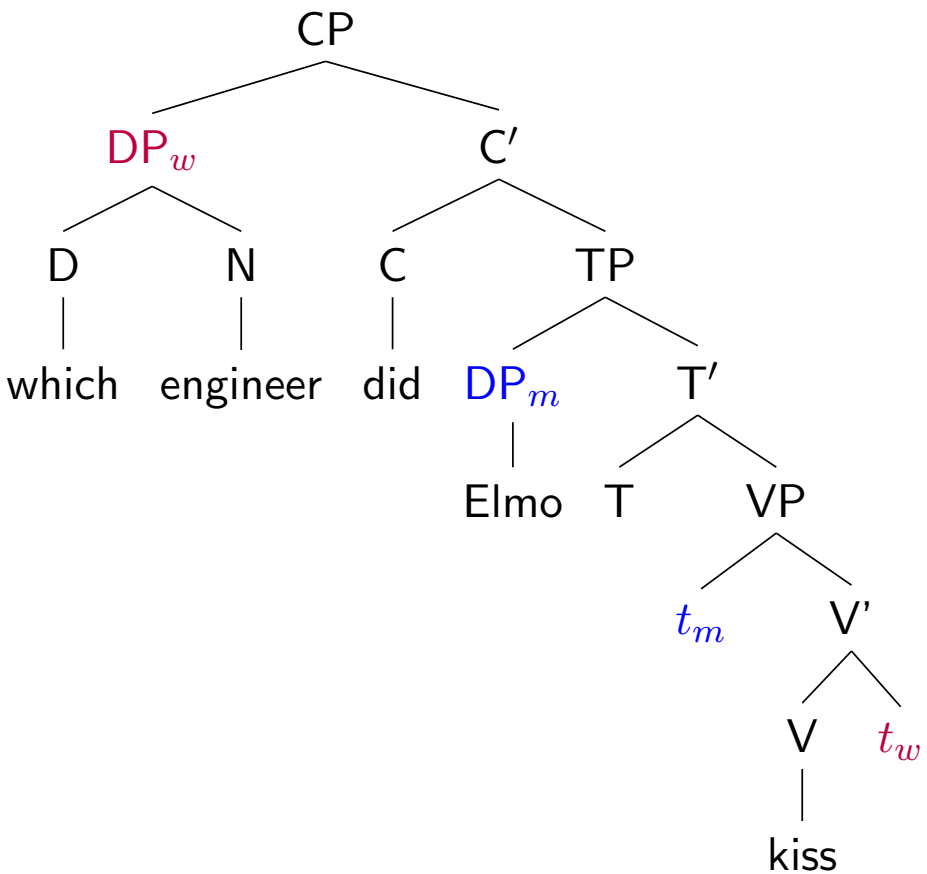
3 Results

Minimalist Grammars (MGs) & Derivation Trees



Phrase Structure Tree

Minimalist Grammars (MGs) & Derivation Trees



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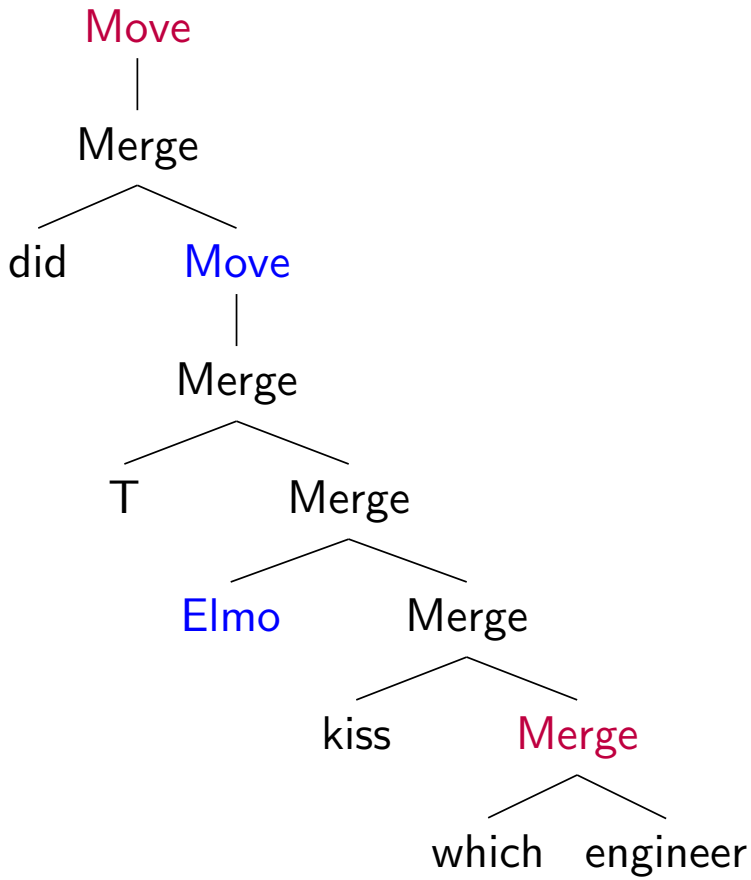
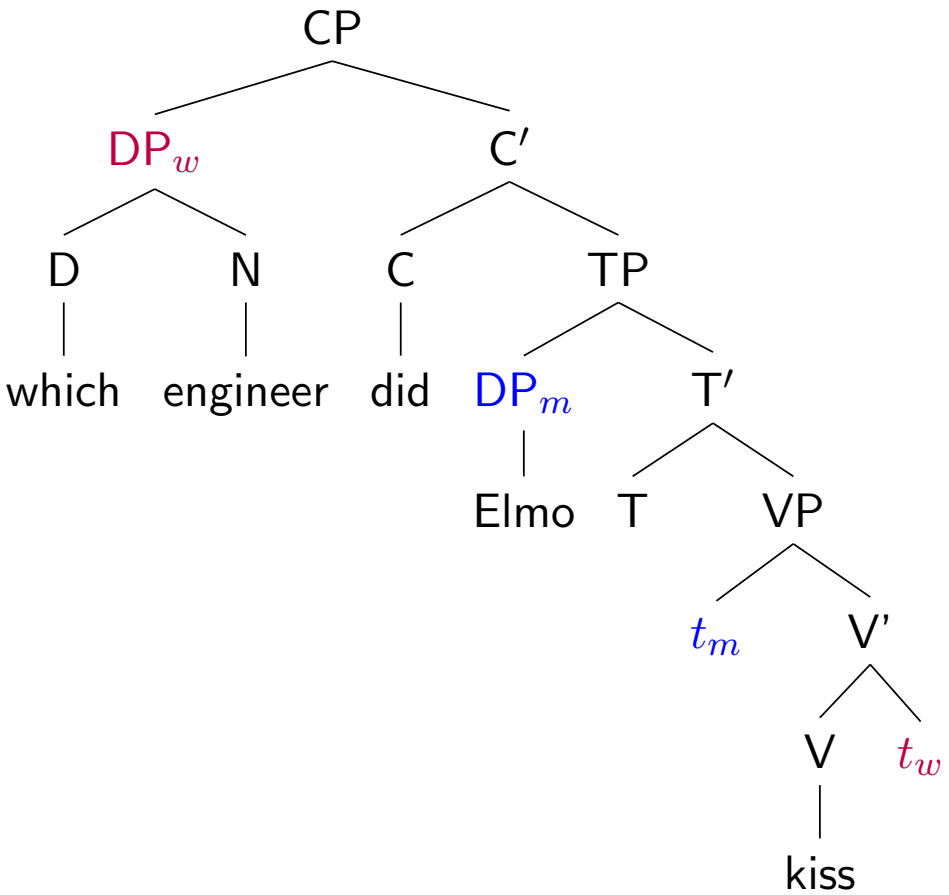


Derivation Tree

MG Syntax: Derivation Trees



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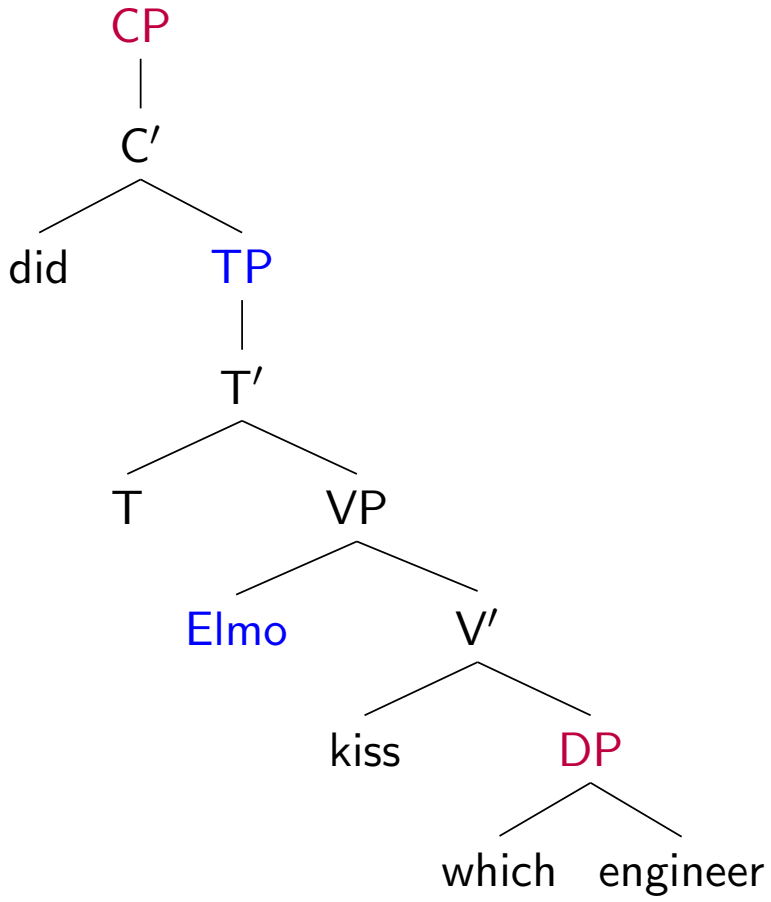

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The Intuition: Top-Down MG Parsing

Who does Salem mock?

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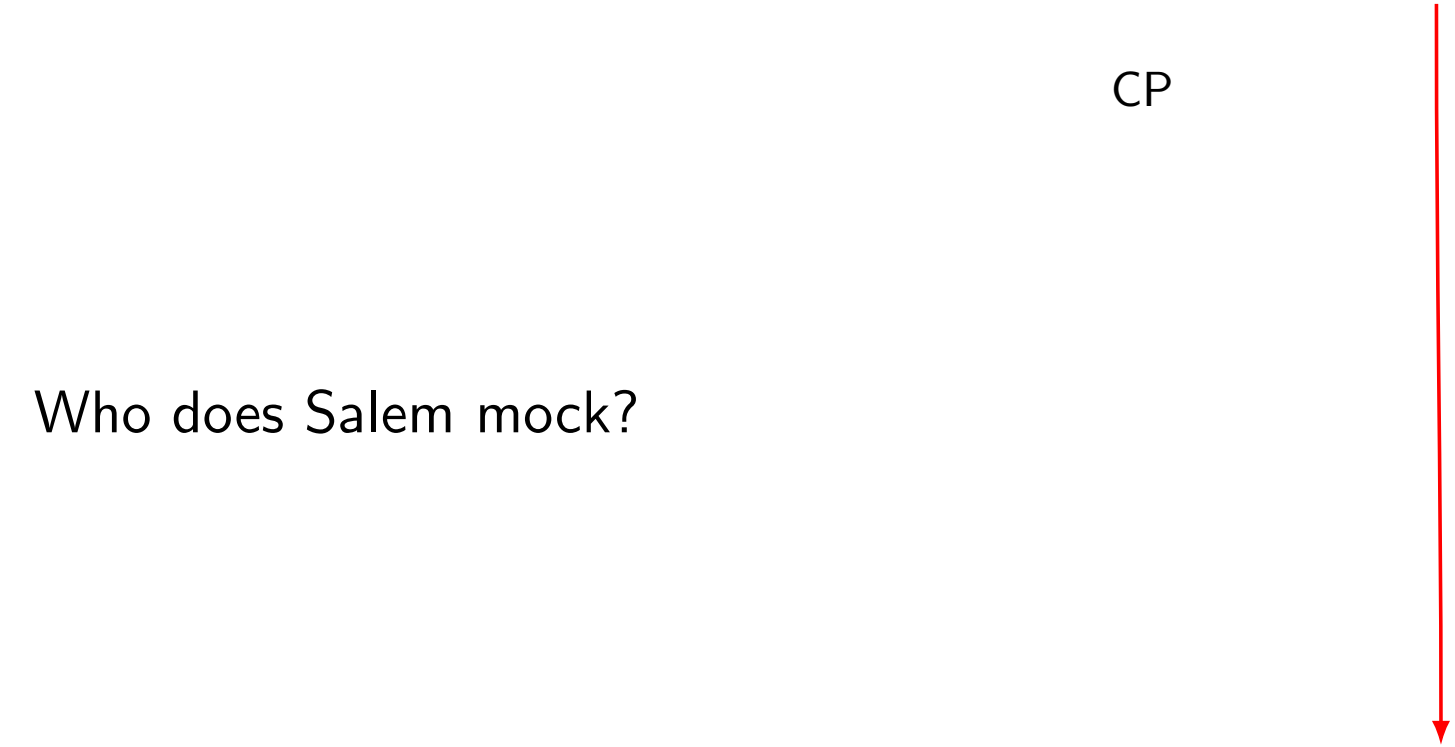

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- Takes elements in an out of memory
- Complexity of the structure $\approx$ how much memory is used!

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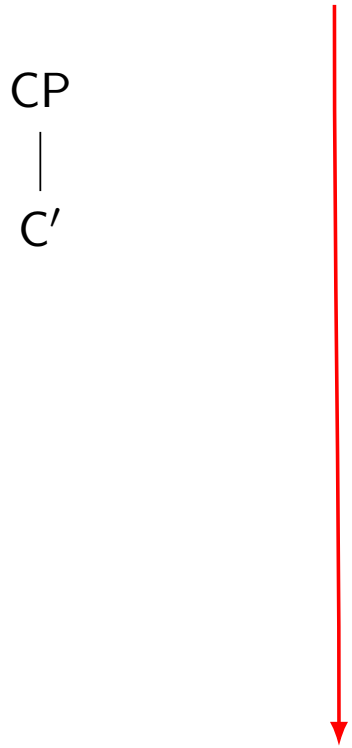

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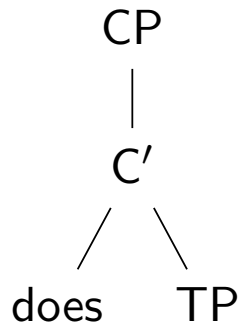

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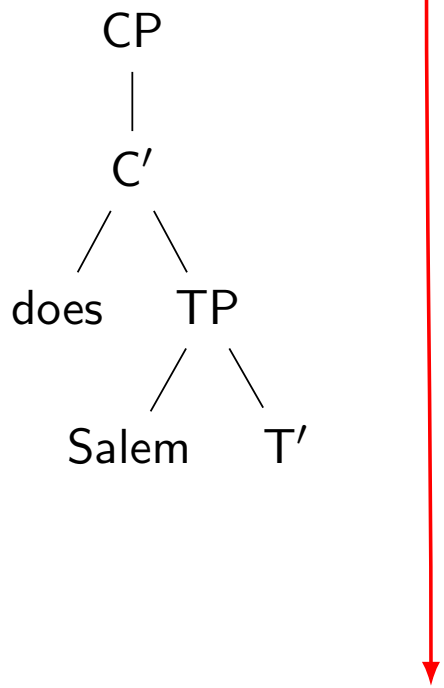

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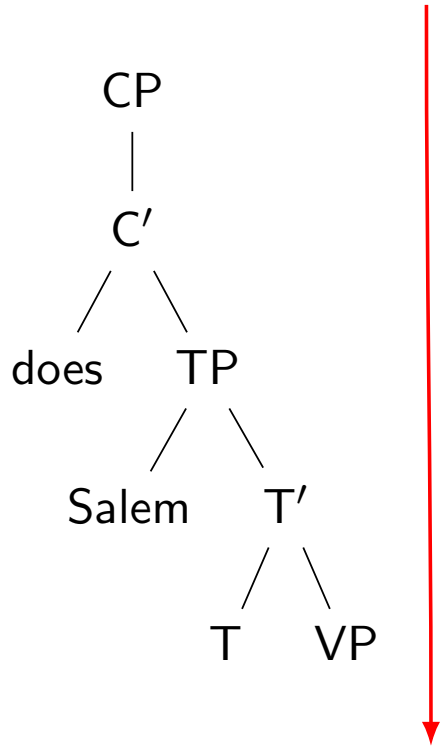

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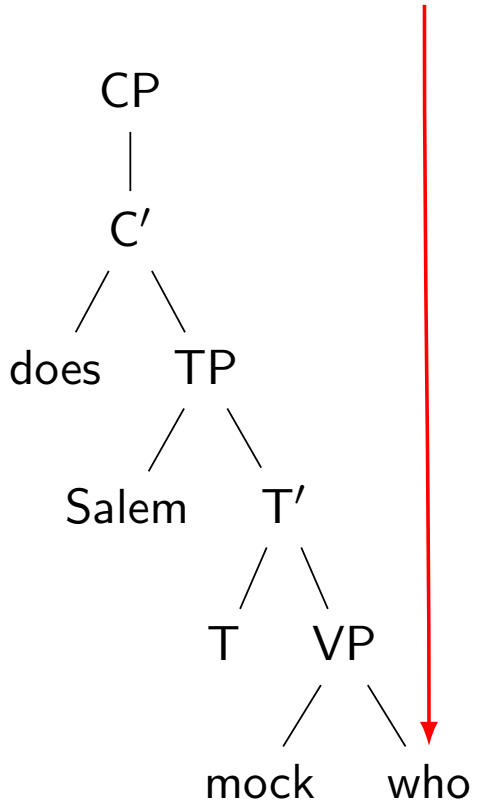

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Incremental Top-Down Parsing

Technical details!

- String-driven recursive descent parser (Stabler 2013)

- • Who • does • Salem • T • mock

step 1 CP is conjectured
step 2 CP expands to C′
step 3 C′ expands to does and TP
step 4 TP expands to Salem and T′
step 5 T′ expands to T and VP
step 6 VP expands to mock and who
step 7 who is found
step 8 does is found
step 9 Salem is found
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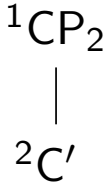

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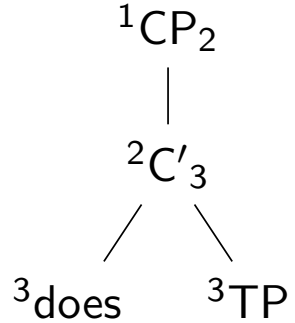

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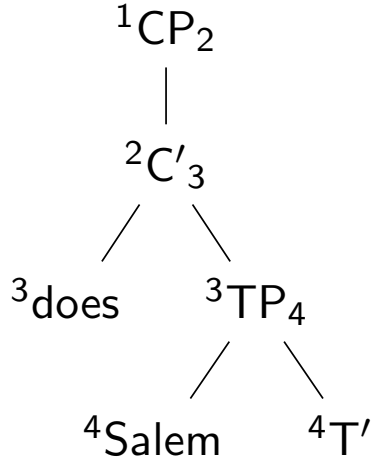

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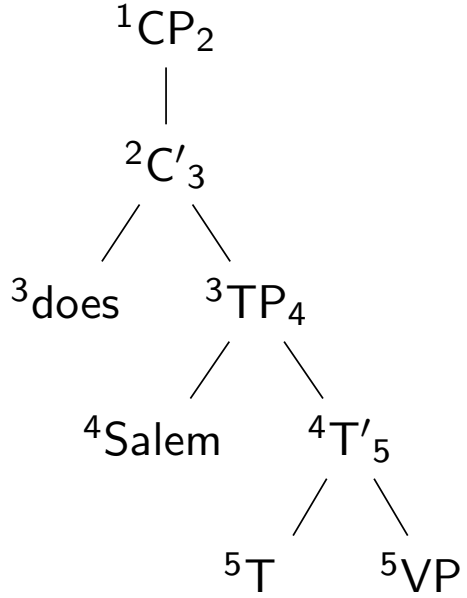

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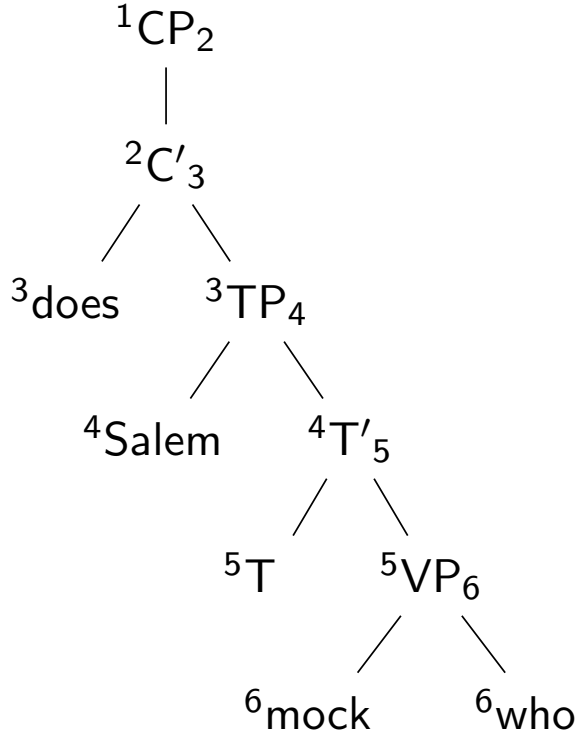

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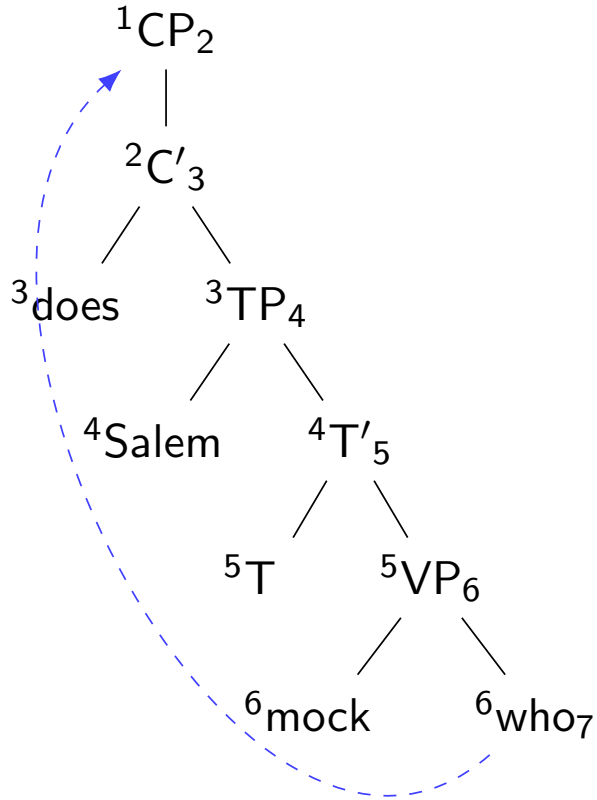

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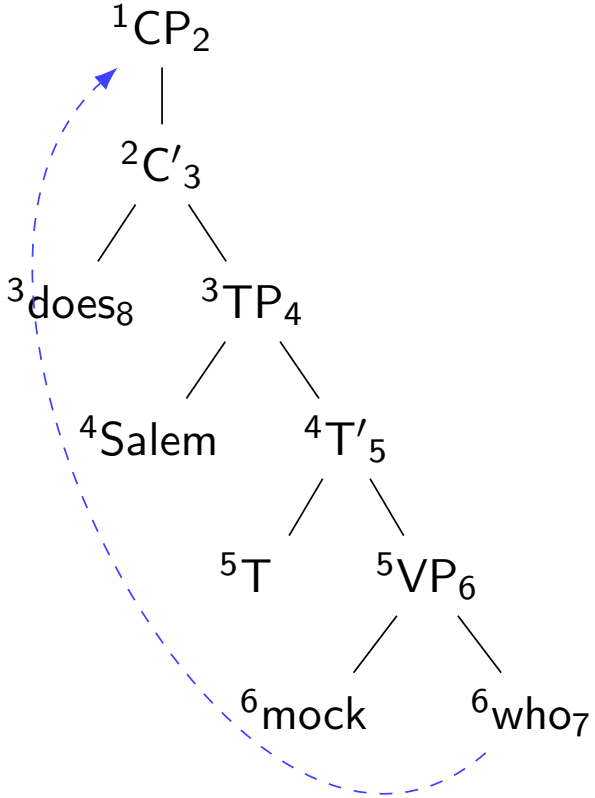

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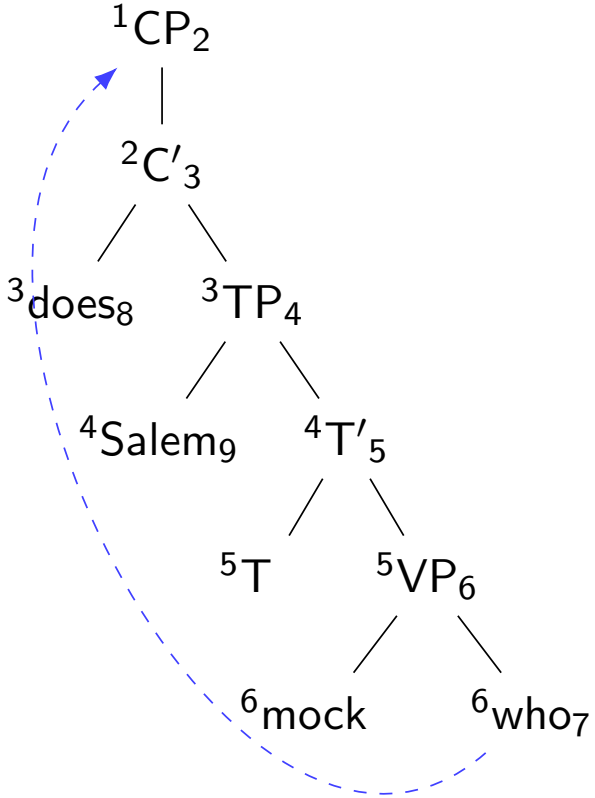

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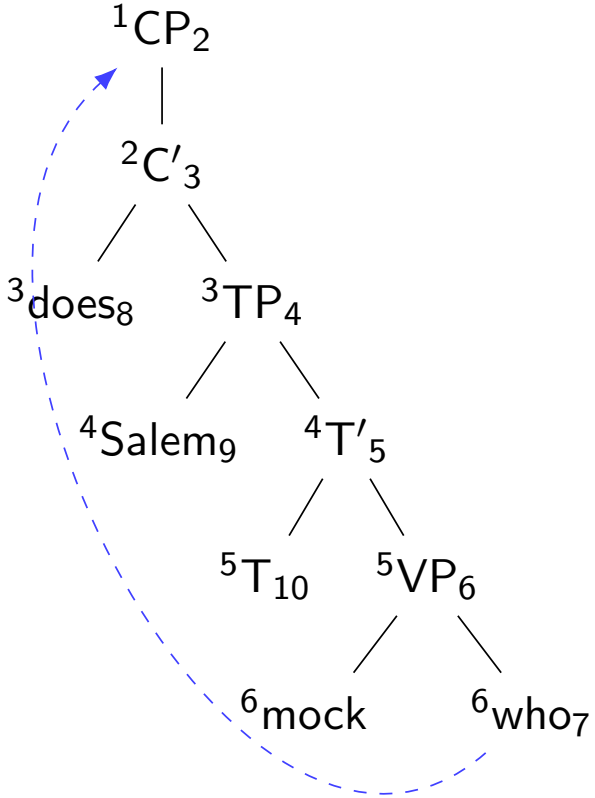

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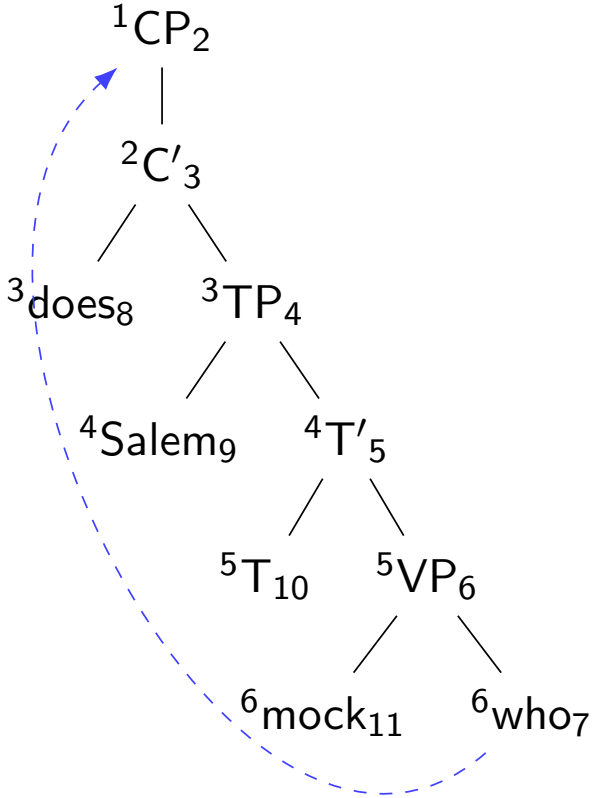

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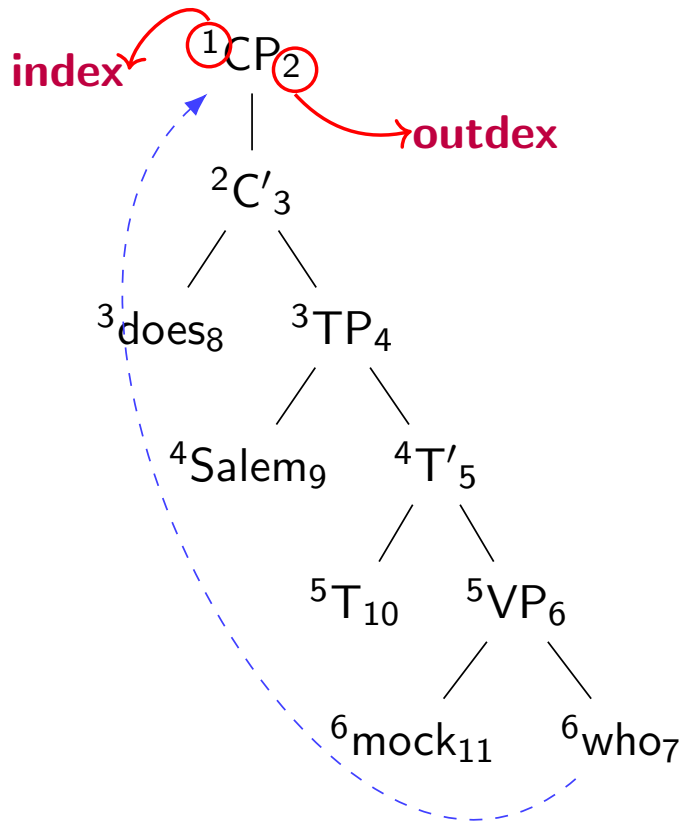

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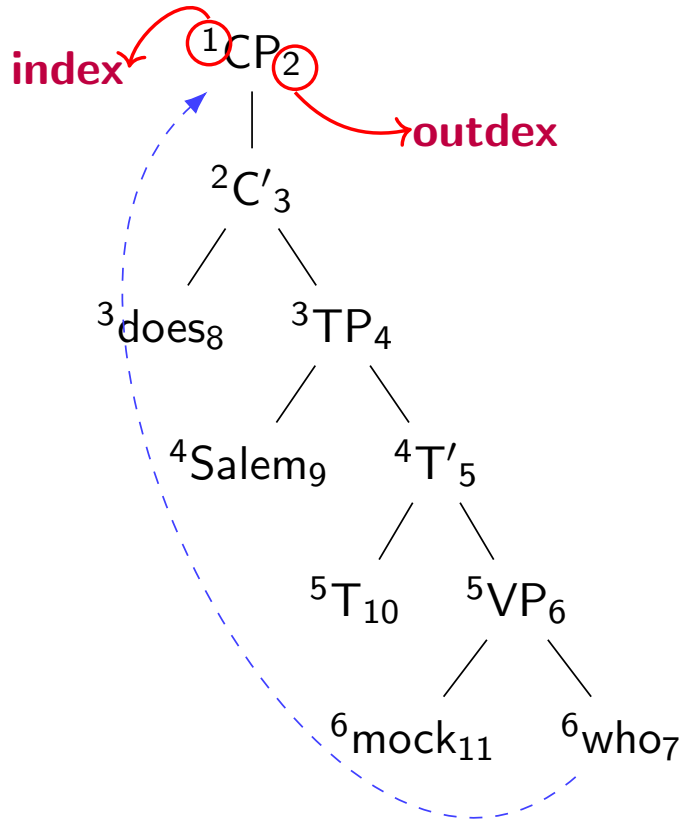


Index and Outdex are our connection to memory!

Measuring Memory Usage

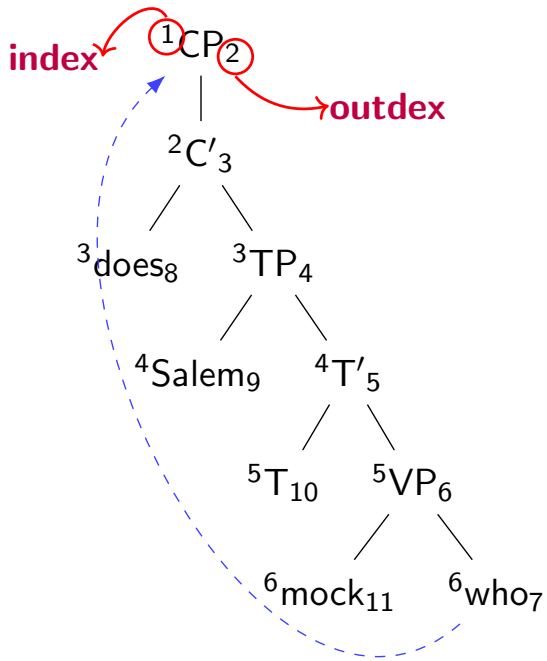
- **Memory usage**:
  (Kobele et al. 2012; Gibson, 1998)

Tenure How long a node is kept in memory

	Who	does	Salem	mock
Tenure	1	5	5	5

- Formalized into offline complexity metrics
  (Graf et a. 2017; De Santo 2020, 2021; a.o.)

MaxT $max(\{\text{tenure-of}(n)|n \text{ a node of the tree}\})$



Measuring Memory Usage

- **Memory usage**:
  (Kobele et al. 2012; Gibson, 1998)

Tenure How long a node is kept in memory

	Who	does	Salem	mock
Tenure	1	5	5	5

- Formalized into **offline complexity metrics**
  (Graf et a. 2017; De Santo 2020, 2021; a.o.)

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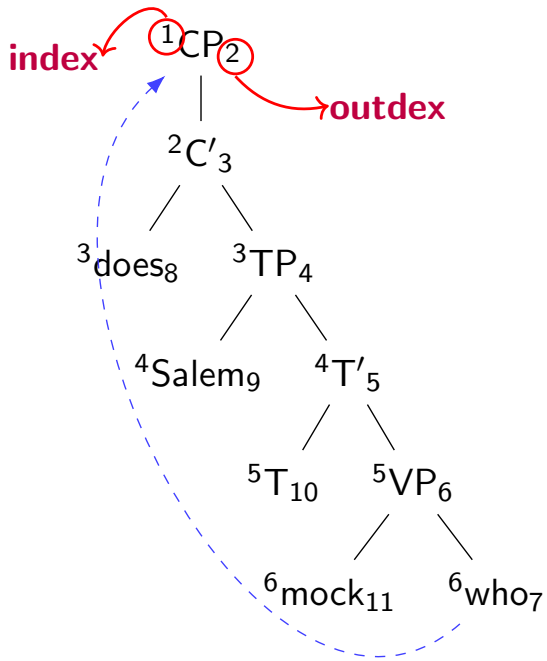

Processing Asymmetries All the Way Down

A variety of offline processing insights!

Across Many Constructions

- Right > center embedding (Kobele et al. 2012)
- Crossing > nested dependencies (Kobele et al. 2012)
- SRC > ORC
  (Graf et al. 2017; De Santo 2020; Fiorini, Chang, De Santo 2023)
- Priming/Stacked RCs (De Santo 2020, 2022)
- Postverbal subjects
  (De Santo 2019, 2021; Del Valle & De Santo 2023)
- Persian attachment ambiguities (De Santo & Shafiei 2019)
- RC attachment preferences
  (De Santo & Lee 2022; Lee & De Santo 2023)

Across Languages

- English, German, Italian, French, Spanish
- Korean, Japanese, Mandarin Chinese
- Basque, Persian, ...

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A Case Study: English SRC vs ORC

(1) The horse that has chased the lions **SRC**

(2) The horse that the lions have chased **ORC**

SRC > ORC

- Well-attested cross-linguistically (Lau & Tanaka 2021)
- ... with some possible exceptions (Mandarin?)

Possible Accounts?

- Working-memory
  (Warren & Gibson 2008; Lewis & Vasishth, 2005; a.o.)
  ⇒ BUT: Nakamura & Miyamoto 2(013) Cf. Graf et al (2017)
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Modeling Assumptions

Data

- SAP Benchmark (Huang et al. 2024)
  - self-paced reading
  - 2000 participants
  - SRC/ORC RTs
  - 24 RC sets

Reminder: Model Details

- Parsing strategy
  ⇒ Top-down parser
- Linking Hypothesis
  ⇒ Processing Cost :: (word-by-word) Tenure

Degrees of freedom: Syntactic analyses

- RC constructions → (Kayne 1994)

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$$RT \sim WordPosition(i) + logfreq(i) * length(i)$$
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Results: Best Fitting Model

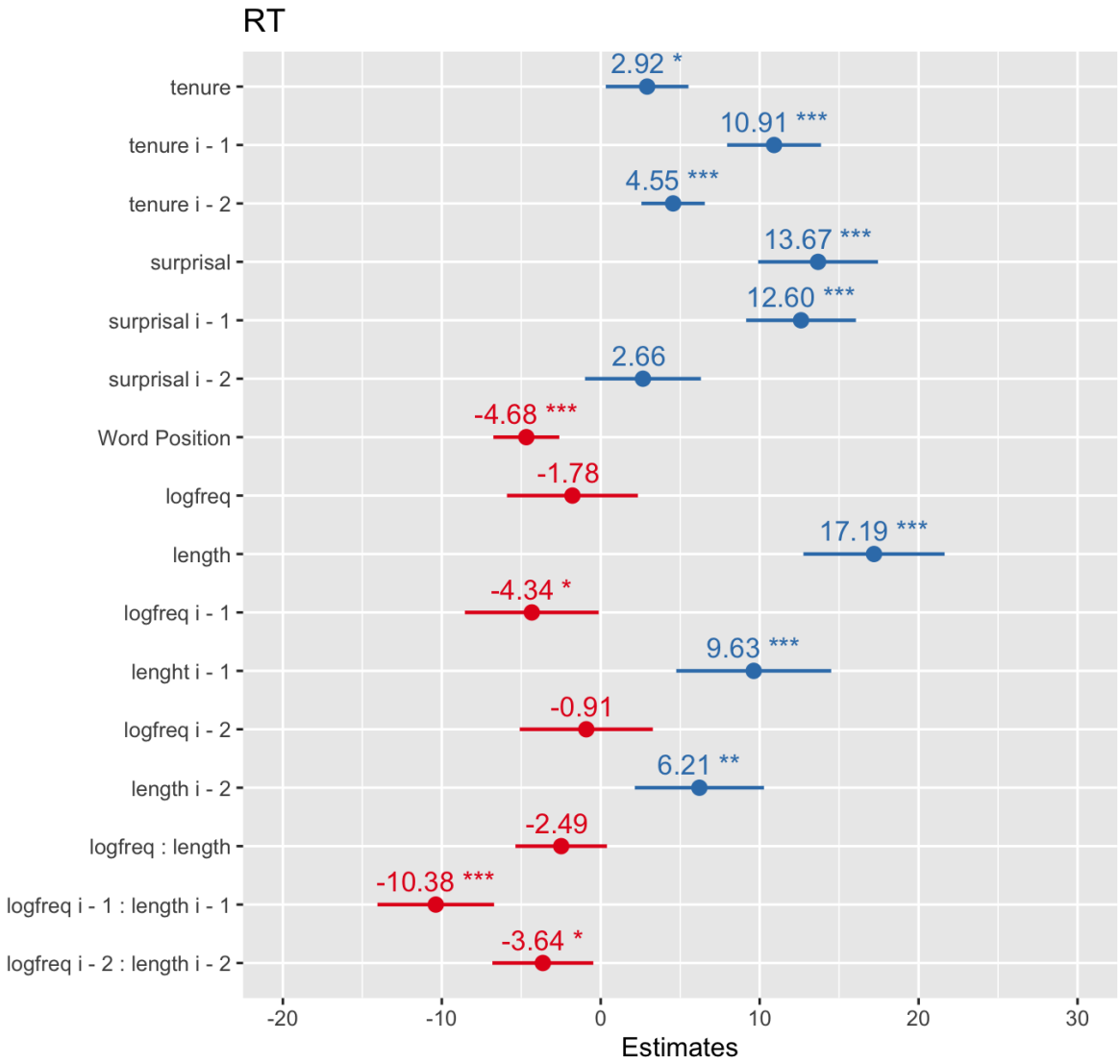

Figure: Estimates of coefficients for GTP Surprisal + Tenure.

Conclusion

TL;DR

MG-based Tenure is a good predictor of RTs.

- Support for MGs + Tenure beyond offline measures!
- Bridge generative syntax/sentence processing!
- Next: cross-linguistic online data, Tenure and empty heads...

The tip of the iceberg!

- Structure- vs. expectation-based predictors!
  (Futrell et al., 2020; Chen and Hale, 2021; Oh et al., 2022; Arehalli et al., 2022; Kajikawa et al. 2024)
- Deeper exploration of computational linking theories
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- And much more!

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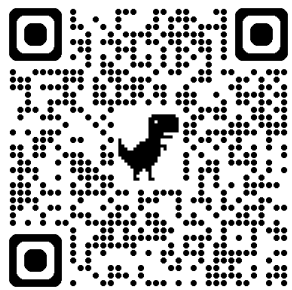


Appendix

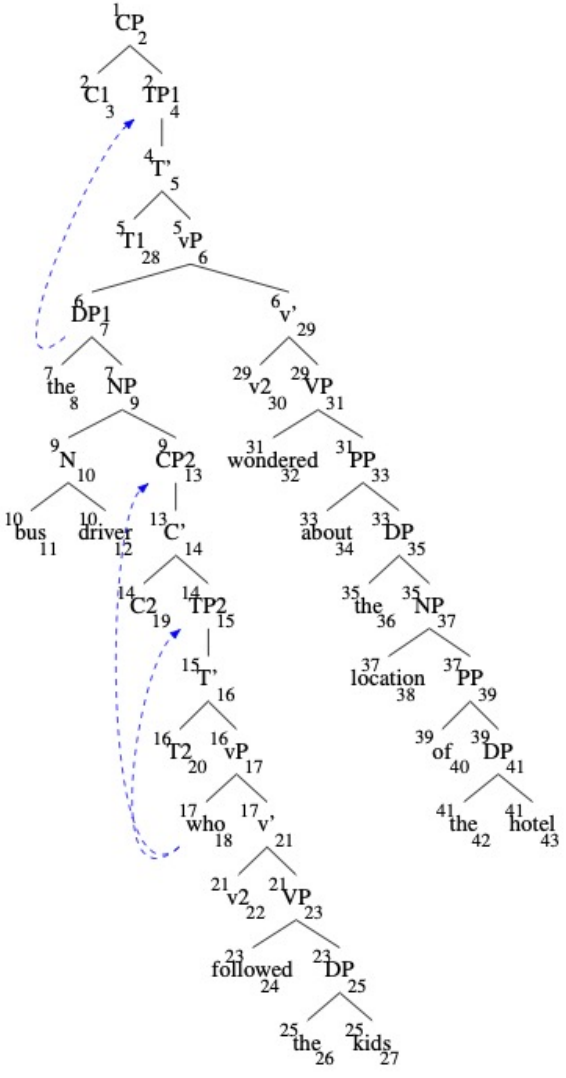
Computation and Theory Building

[...] this is a confusion of two quite separate issues, **simulation and explanation**. *[...] What we are* **really** *interested in [...] is explanation — in developing models that help us* **understand how it is that people behave** *that way, not merely demonstrating that we can build an artifact that behaves similarly.*

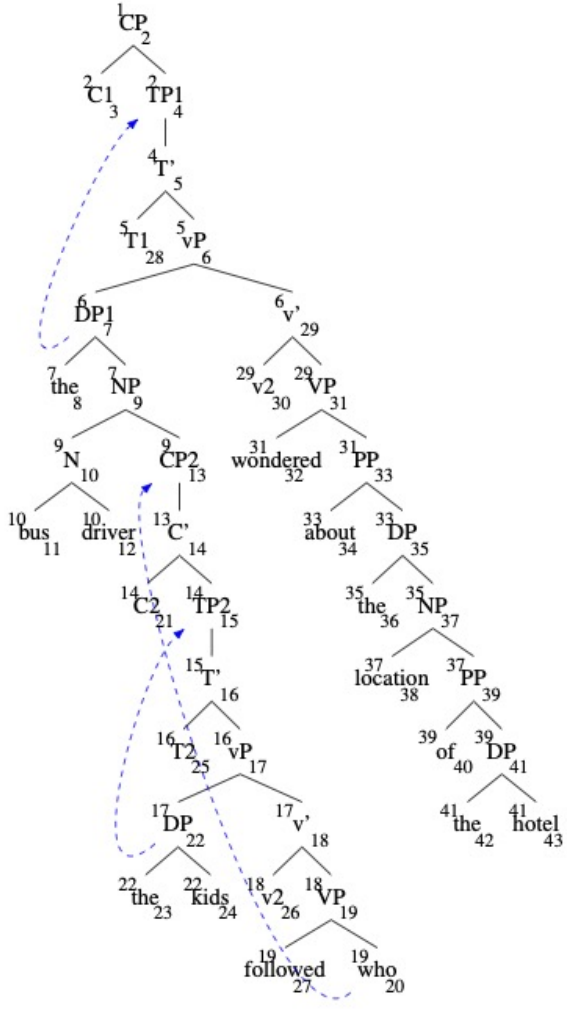
(Kaplan, 1995)

Interpretability for the win!

Trees


CP 1 2
C1 2 3
TP1 2 4
T' 4 5
T1 5 28
vP 5 6
DP1 6 7
v' 6 29
the 7 8
NP 7 9
v2 29 30
VP 29 31
N 9 10
CP2 9 13
wondered 31 32
PP 31 33
bus 10 11
driver 10 12
C' 13 14
about 33 34
DP 33 35
C2 14 19
TP2 14 15
the 35 36
NP 35 37
T' 15 16
location 37 38
PP 37 39
T2 16 20
vP 16 17
of 39 40
DP 39 41
who 17 18
v' 17 21
the 41 42
hotel 41 43
v2 21 22
VP 21 23
followed 23 24
DP 23 25
the 25 26
kids 25 27

(a)


CP 1 2
C1 2 3
TP1 2 4
T' 4 5
T1 5 28
vP 5 6
DP1 6 7
v' 6 29
the 7 8
NP 7 9
v2 29 30
VP 29 31
N 9 10
CP2 9 13
wondered 31 32
PP 31 33
bus 10 11
driver 10 12
C' 13 14
about 33 34
DP 33 35
C2 14 21
TP2 14 15
the 35 36
NP 35 37
T' 15 16
location 37 38
PP 37 39
T2 16 25
vP 16 17
of 39 40
DP 39 41
DP 17 22
v' 17 18
the 41 42
hotel 41 43
the 22 23
kids 22 24
v2 18 26
VP 18 19
followed 19 27
who 19 20

(b)

Minimalist Grammars (MGs)

We need an explicit model of syntactic structures...

Ed Stabler

- Minimalist grammars (**MGs**): a formalization of Chomskyan syntax
  (Chomsky 1995; Stabler 1997)

Technical details!

- Weakly equivalent to MCFGs
- Essentially: CFGs with a more complicated mapping from trees to strings
- REG tree language!

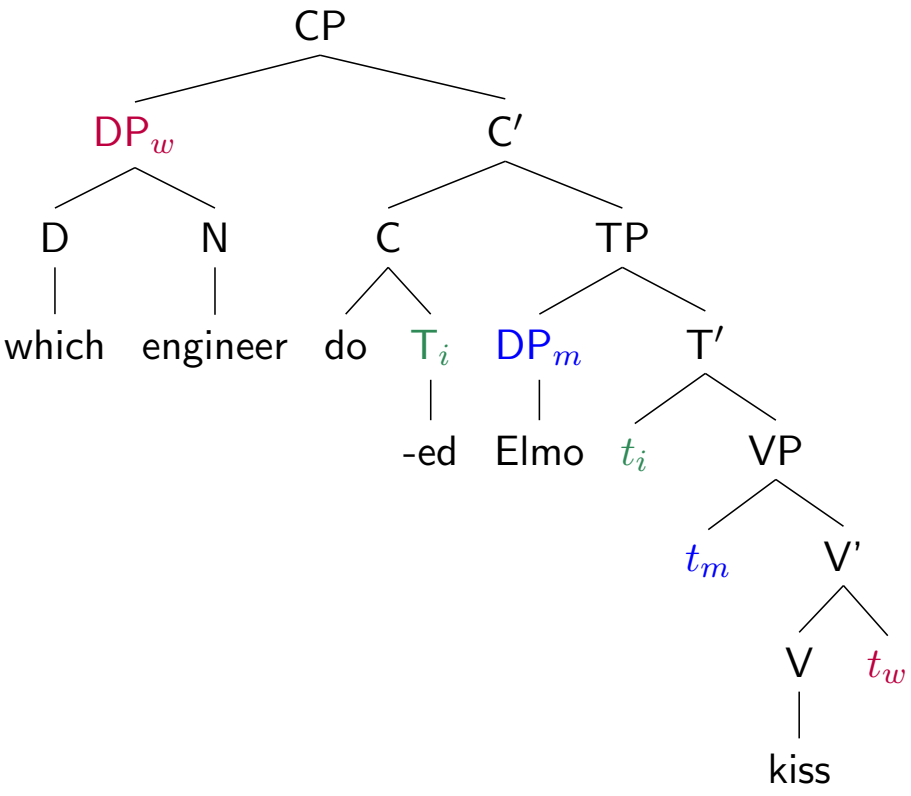
Why MGs?

1. Vast analytical coverage
   - MGs handle virtually all analyses in the generative literature
2. Centrality of derivation trees
   - MGs can be viewed as CFGs with a more complicated mapping from trees to strings
3. Simple parsing algorithms
   - Variant of a recursive descent parser for CFGs
     $\Rightarrow$ cf. TAG (Rambow & Joshi, 1995; Demberg, 2008)

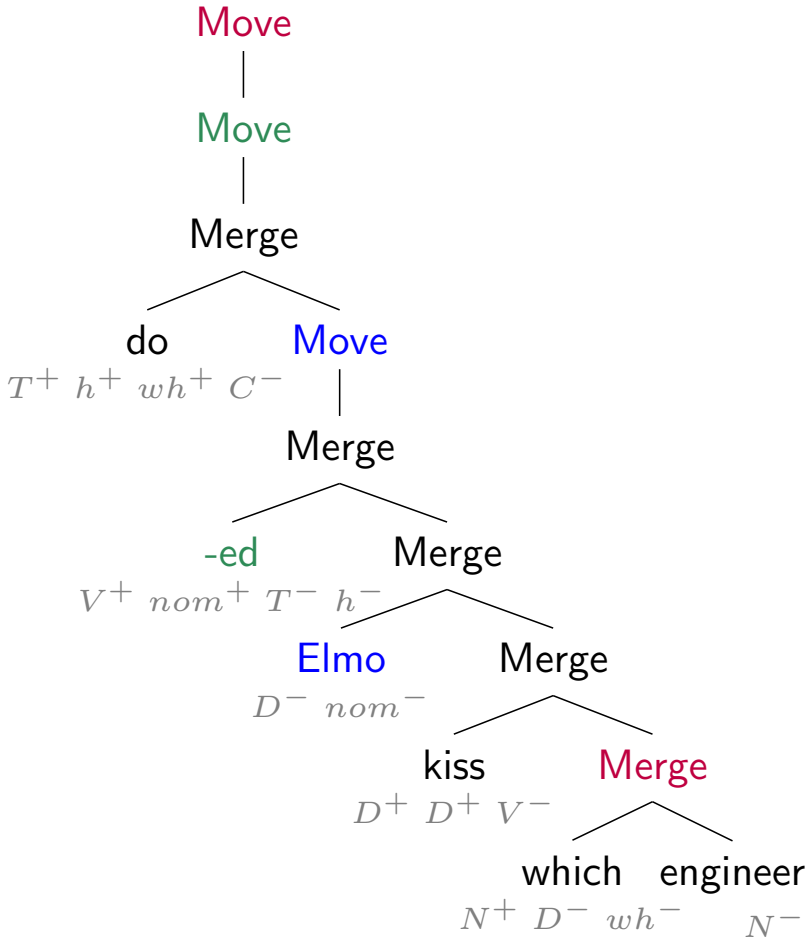
Some Important Properties of MGs

- MGs are weakly equivalent to MCFGs and thus mildly context-sensitive. (Harkema 2001, Michaelis 2001)
- But we can decompose them into two finite-state components: (Michaelis et al. 2001, Kobele et al. 2007, Monnich 2006)
  - a regular language of well-formed derivation trees
  - an MSO-definable mapping from derivations to phrase structure trees
- **Remember:** Every regular tree language can be re-encoded as a CFG (with more fine-grained non-terminal labels). (Thatcher 1967)

Fully Specified Derivation Trees



Phrase Structure Tree



Derivation Tree

Technical Fertility of MGs

MGs can accommodate the full syntactic toolbox:

- sidewards movement (Stabler, 2006; Graf 2013)
- affix hopping (Graf 2012; Graf2013)
- clustering movement (Gartner & Michaelis 2010)
- tucking in (Graf 2013)
- ATB movement (Kobele 2008)
- copy movement (Kobele 2006)
- extraposition (Hunter &Frank 2014)
- Late Merge (Kobele 2010; Graf 2014)
- Agree (Kobele 2011; Graf 2011)
- adjunction (Fowlie 2013; Hunter 2015)
- TAG-style adjunction (Graf 2012)

Why These Metrics?

- These complexity metrics are all related to **storage cost** (cf. Gibson, 1998)
- We could implement alternative ones (cf. Ferrara-Boston, 2012)
  - number of bounding nodes / phases
  - surprisal
  - feature intervention
  - status of discourse referents
  - integration, retrieval, ...
- We want to keep the model **simple** (but not **trivial**):
  - Tenure and Size only refer to the geometry of the derivation
  - they are sensitive the specifics of tree-traversal (cf. node-count; Hale, 2001)

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