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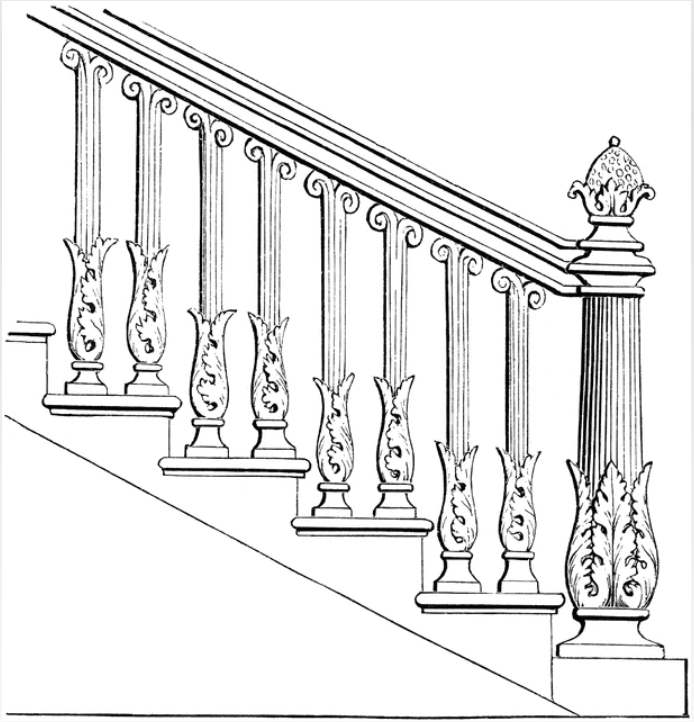
From Balustrades to Pierre Vinken:

Looking for Syntax in Transformer Self-Attentions

Charles University, Prague
Faculty of Mathematics and Physics
Institute of Formal and Applied Linguistics

BlackboxNLP Workshop, Firenze, 1 August 2019

From balustrades to Pierre Vinken



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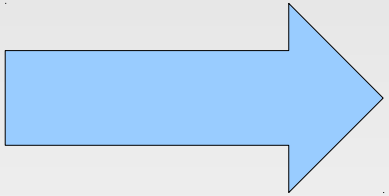
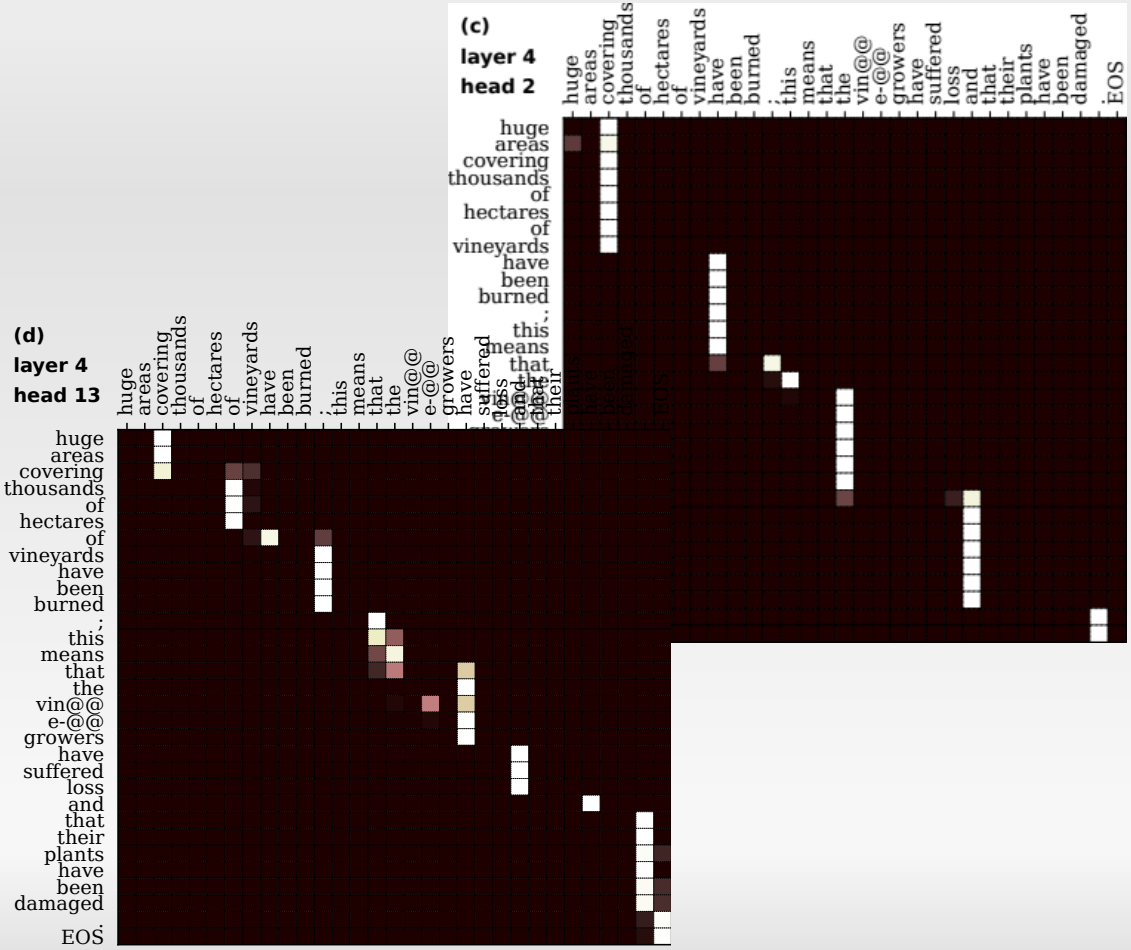
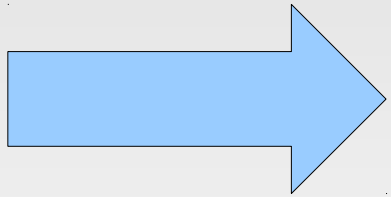
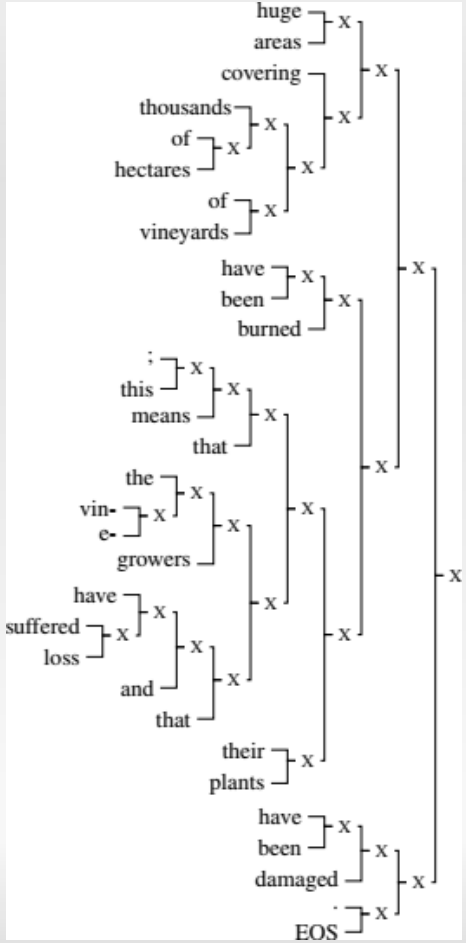


by Jan Hein van Dierendonck

Transformer self-attentions → syntactic trees







Observation

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- Common pattern in Transformer NMT self-attention heads

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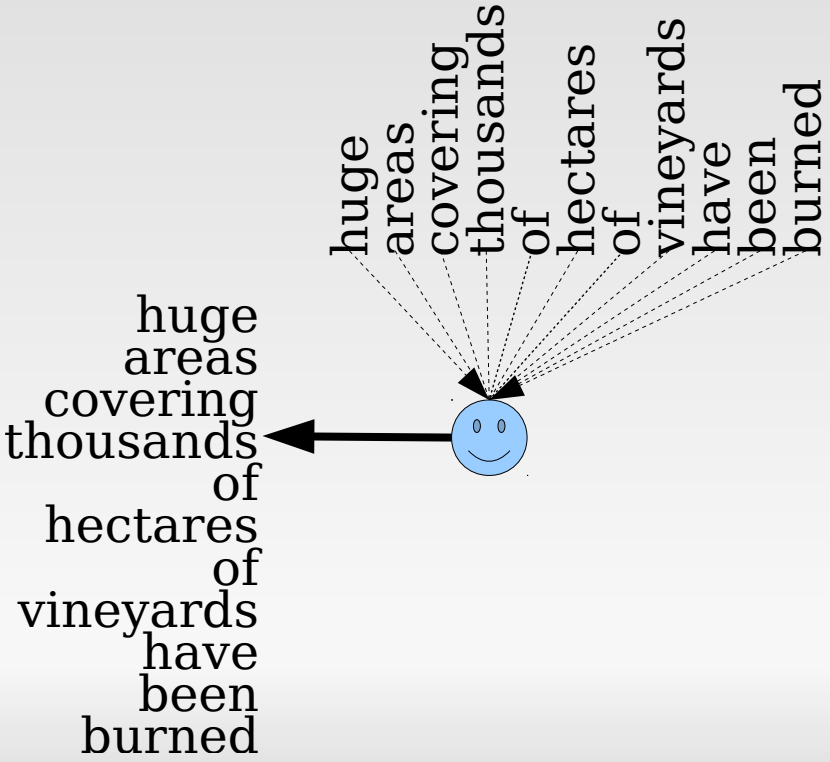

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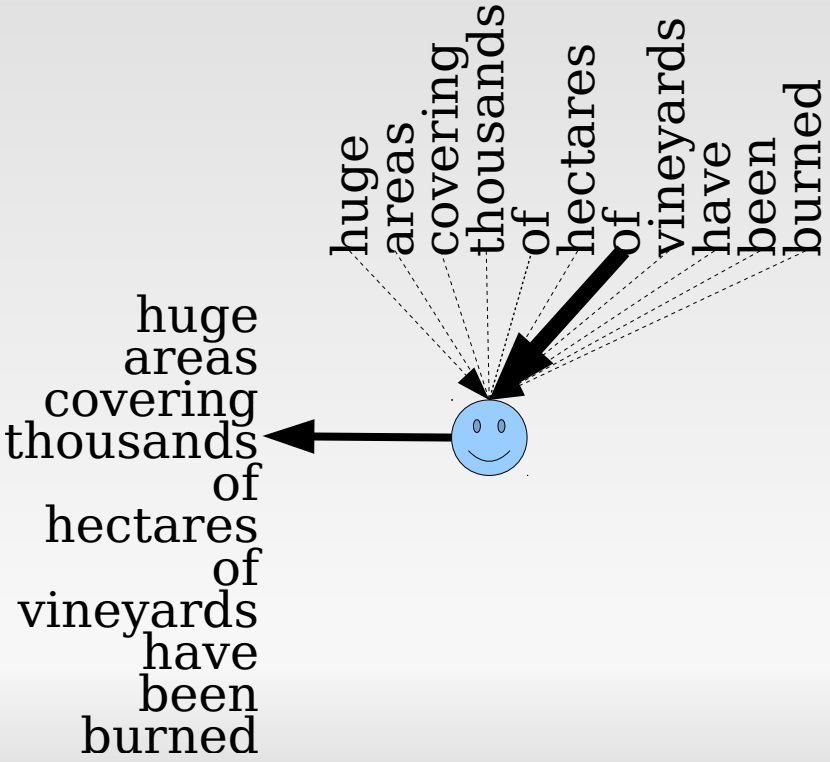

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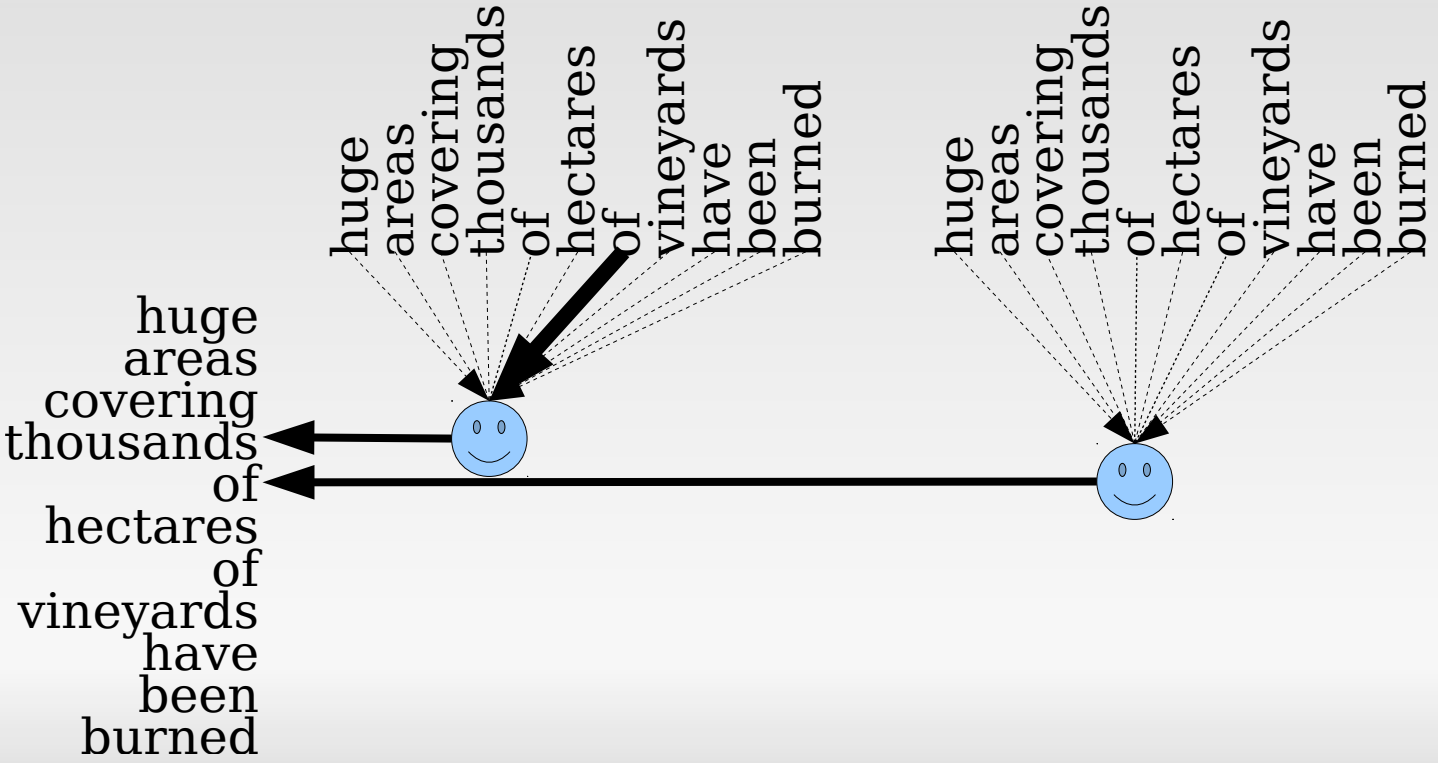

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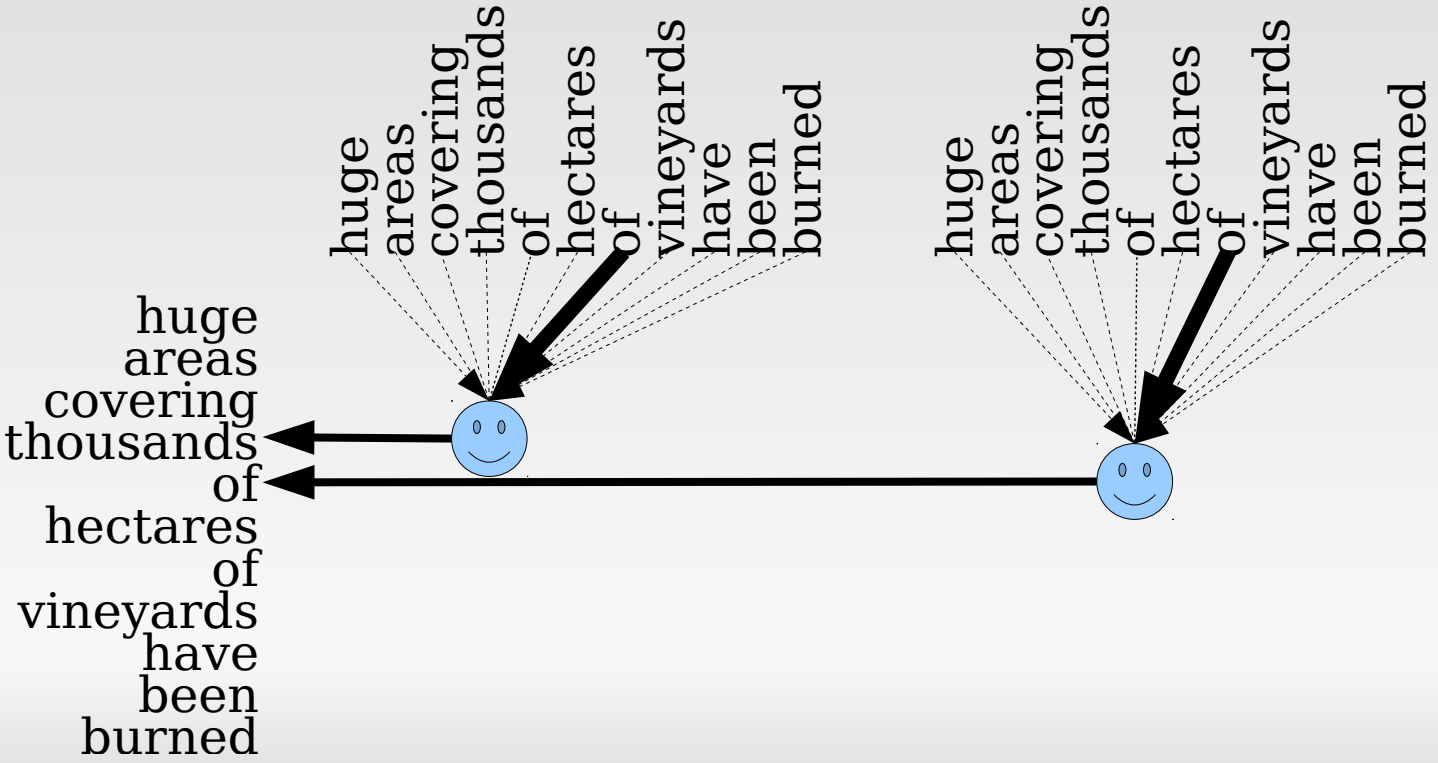

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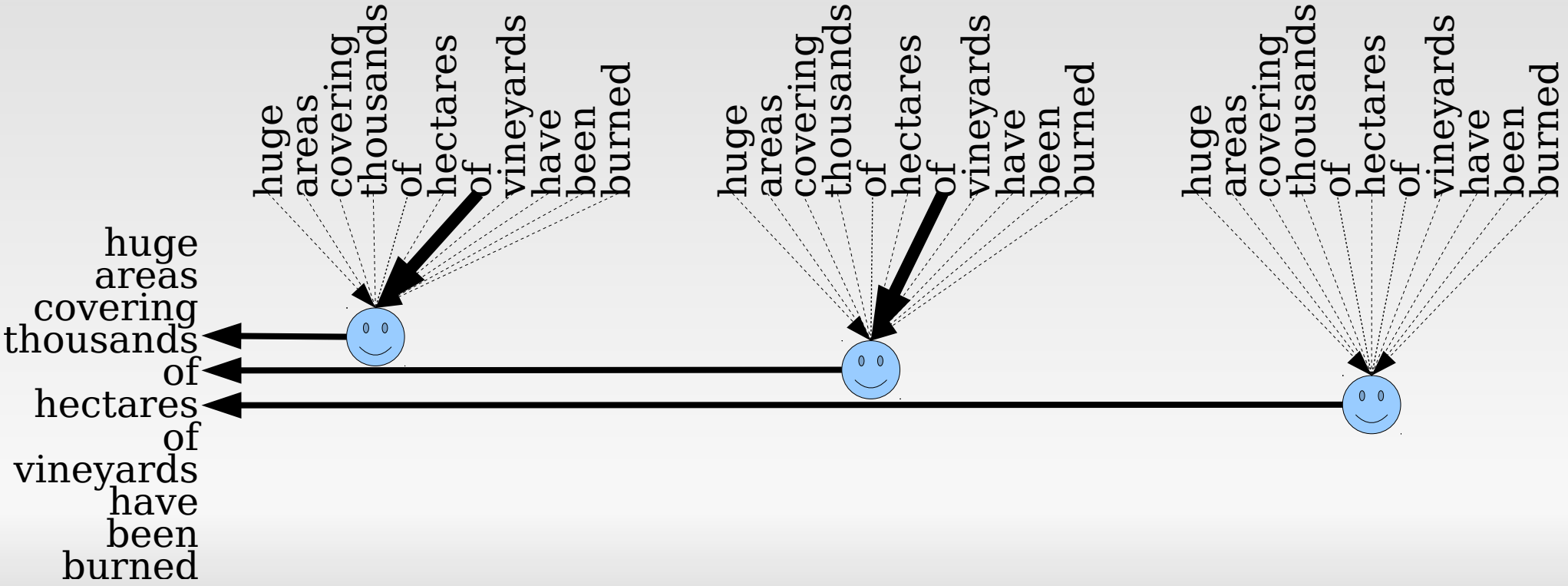

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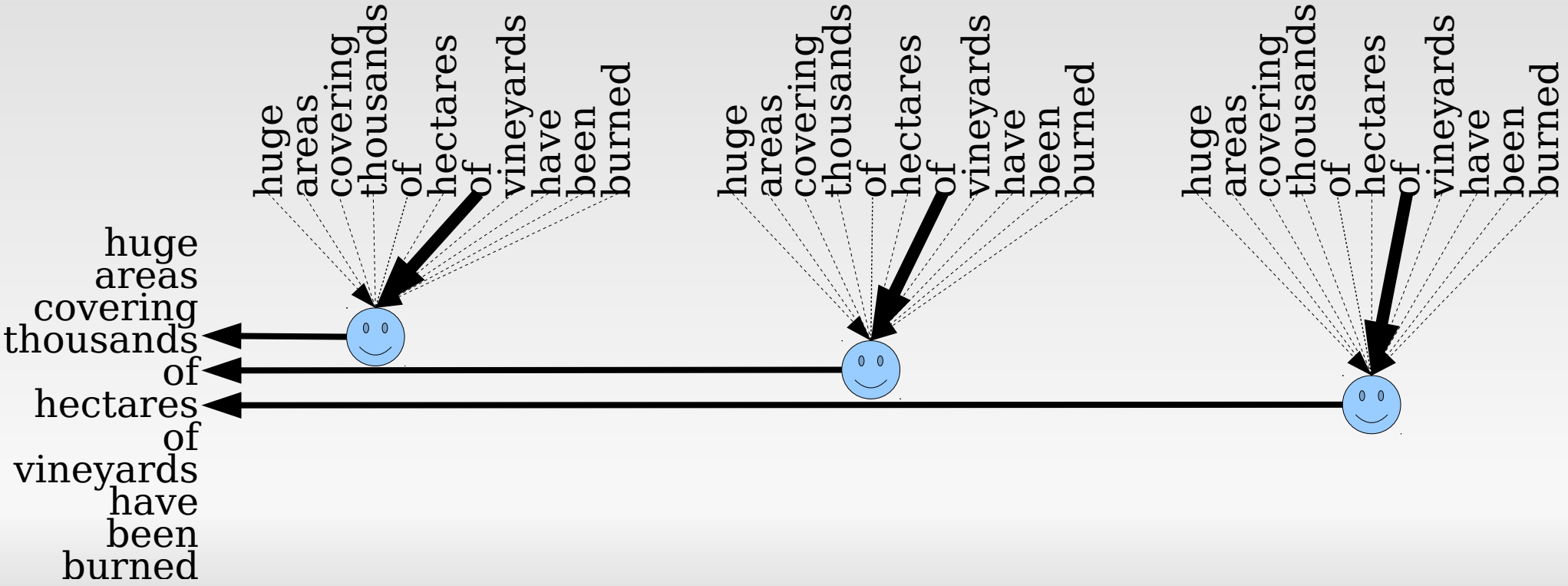

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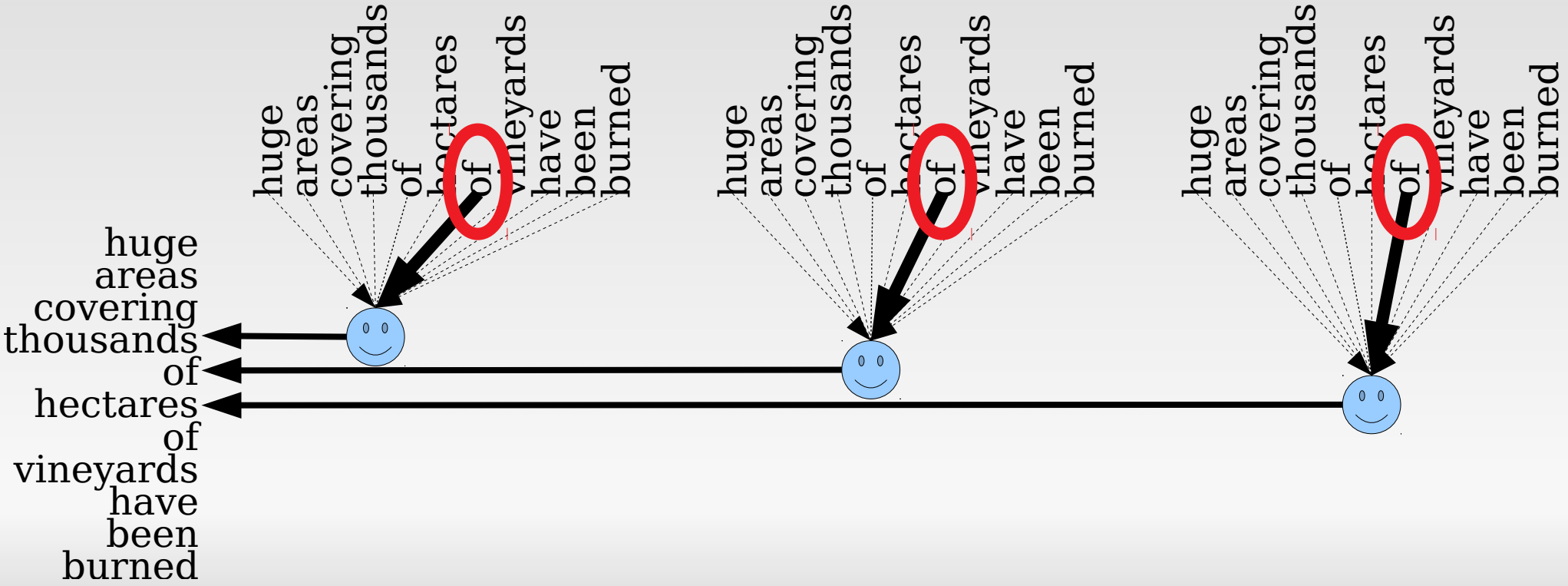

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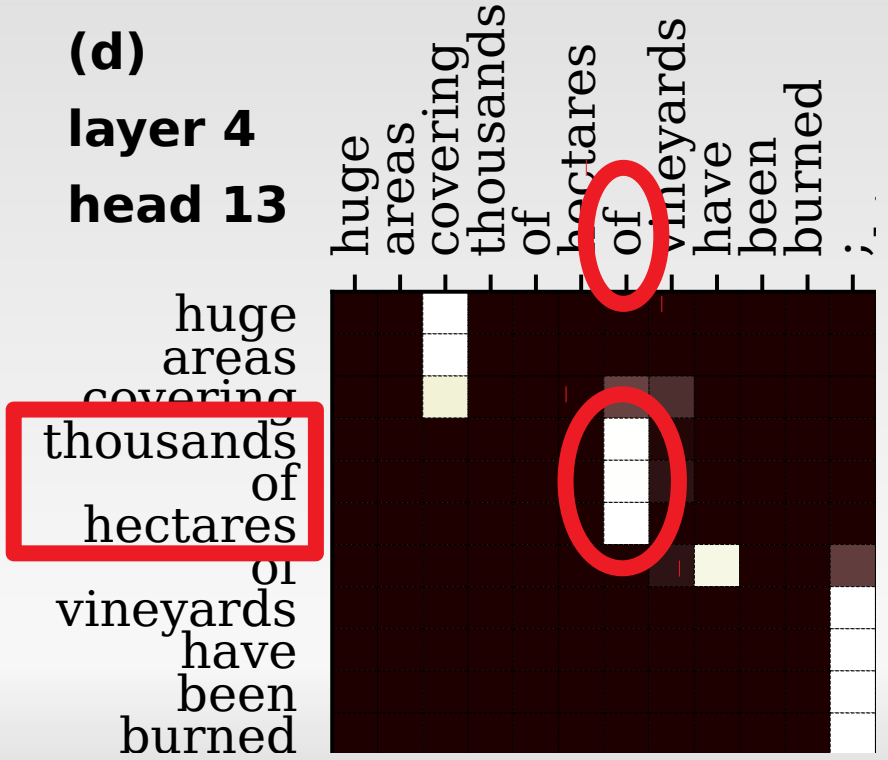

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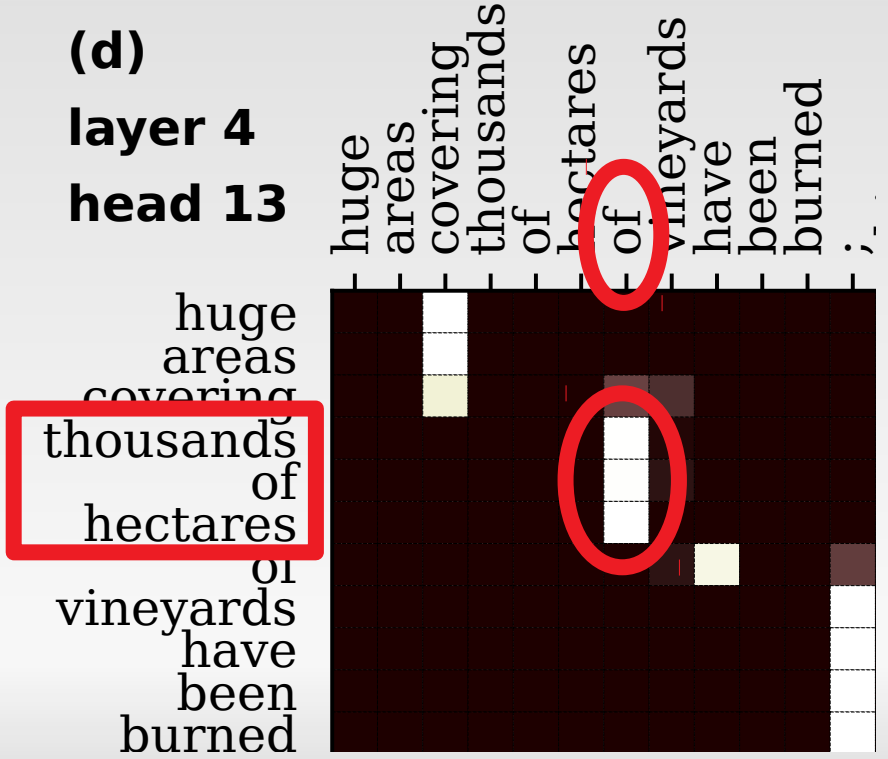
- Common pattern in Transformer NMT self-attention heads
  - “balusters”



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- Common pattern in Transformer NMT self-attention heads
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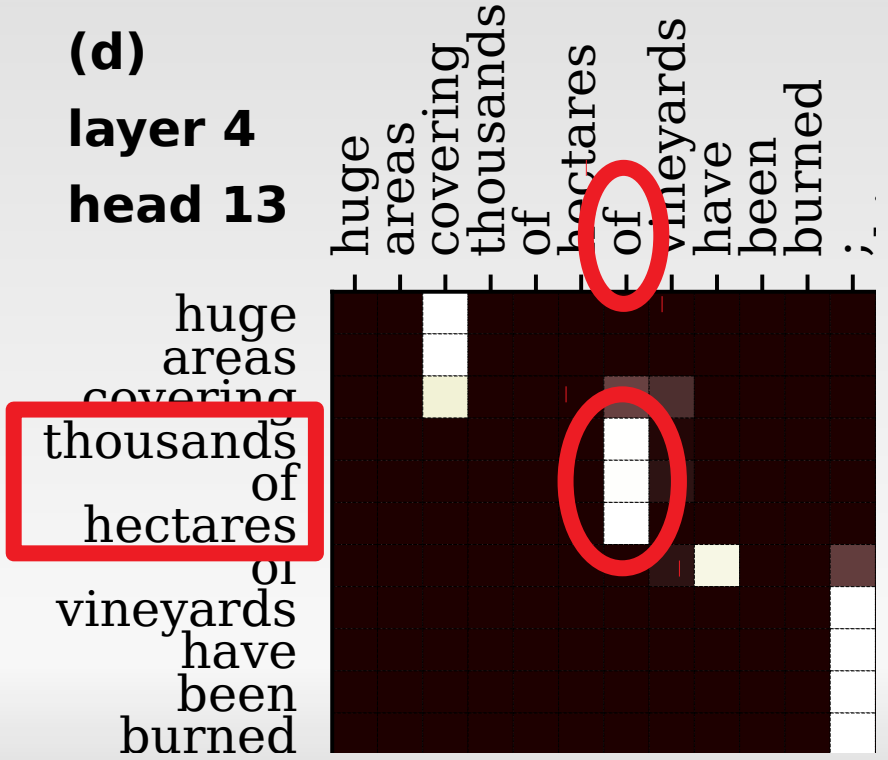
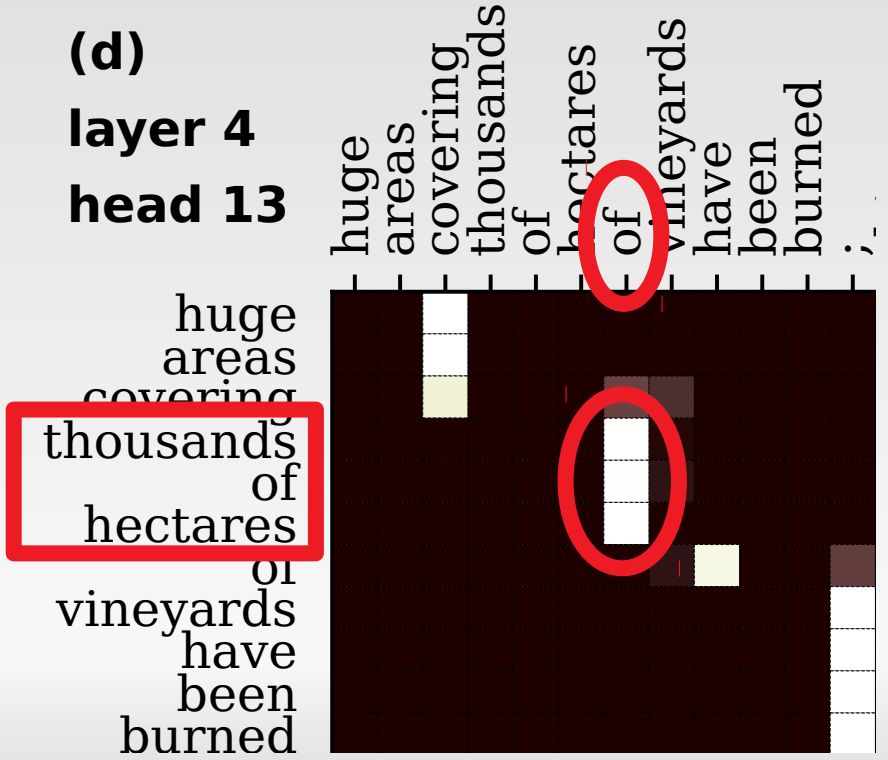
- Resemble syntactic phrases



Observation

- Common pattern in Transformer NMT self-attention heads
  - “balusters”
- Resemble syntactic phrases
  - To what extent?
    → That’s our research question!



Approach

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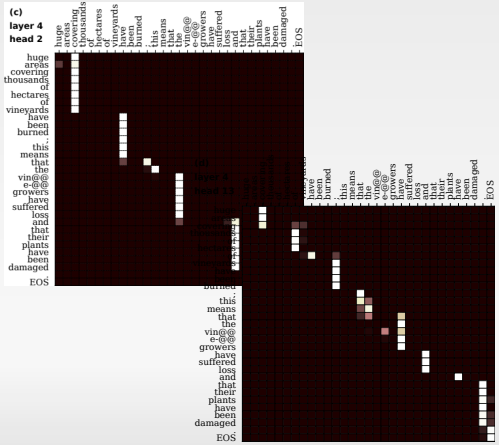
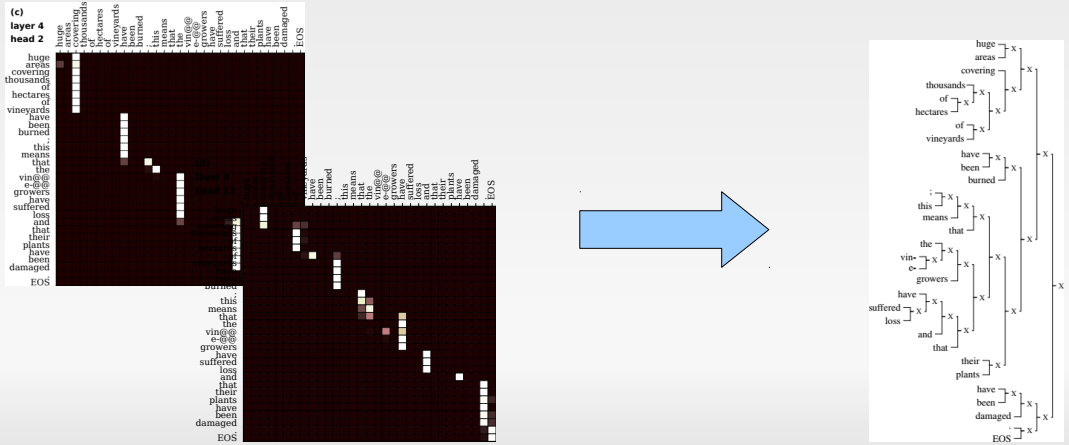
1. Balusters → phrase candidates



Approach

1. Balusters → phrase candidates
2. Phrase candidates → constituency tree
   - Linguistically uninformed algorithm



Approach

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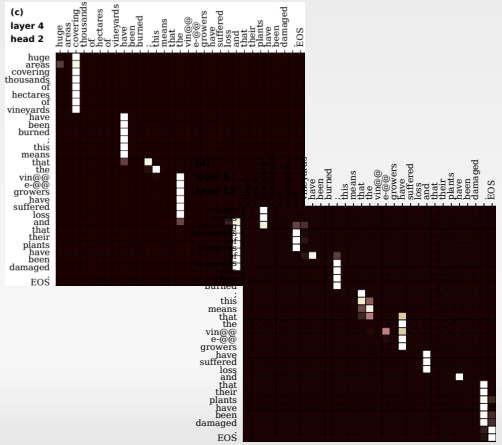
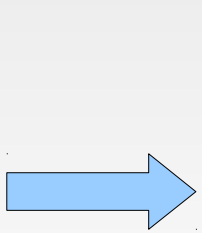
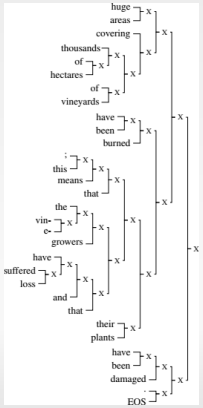
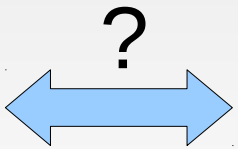
3. Compare to standard syntactic trees



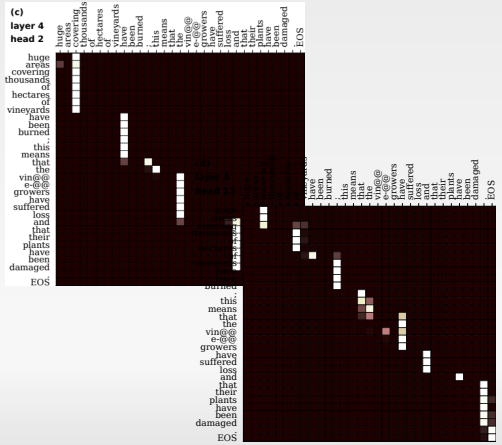


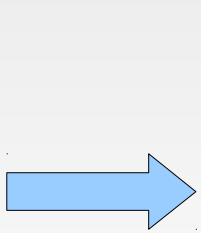


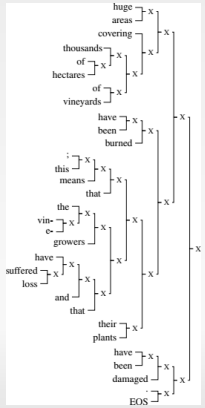


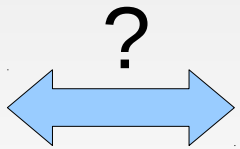
Approach

1. Balusters → phrase candidates
2. Phrase candidates → constituency tree
   - Linguistically uninformed algorithm
3. Compare to standard syntactic trees: ~40%; baseline ~30%









Experiment setup

- Balusters: Transformer NMT system
  - Encoder: 6 layers x 16 heads

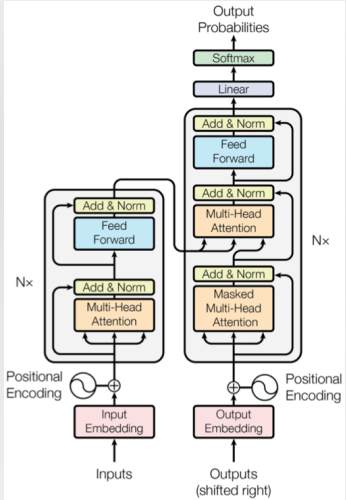


Figure 1: The Transformer - model architecture.

Experiment setup

- Balusters: Transformer NMT system
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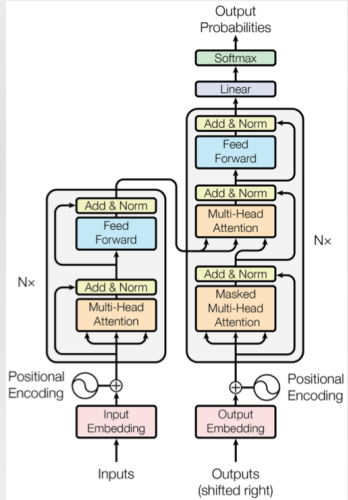
  - Europarl: French ↔ English,
    German ↔ English, French ↔ German



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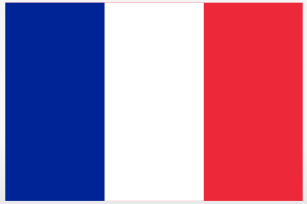
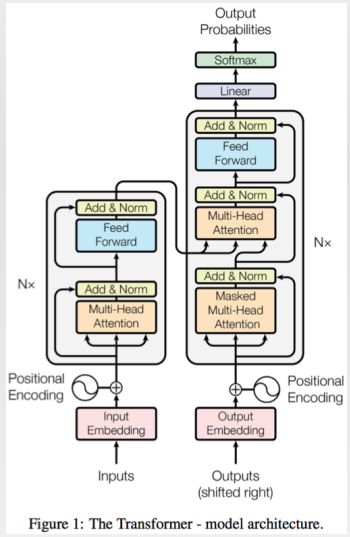
Experiment setup

- Balusters: Transformer NMT system
  - Encoder: 6 layers x 16 heads
  - Europarl: French ↔ English,
    German ↔ English, French ↔ German
- Standard syntactic trees: Stanford parser
  - Penn Treebank, French Treebank, Negra Corpus
  - Only for evaluation





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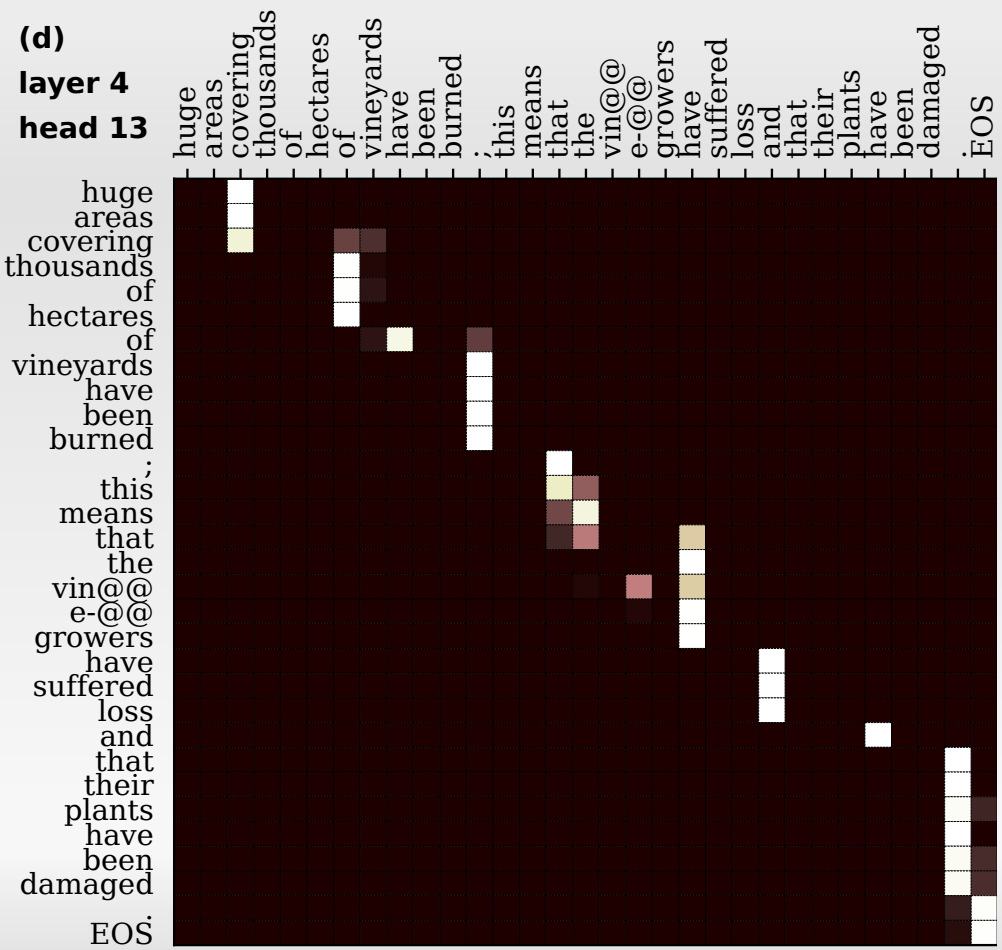
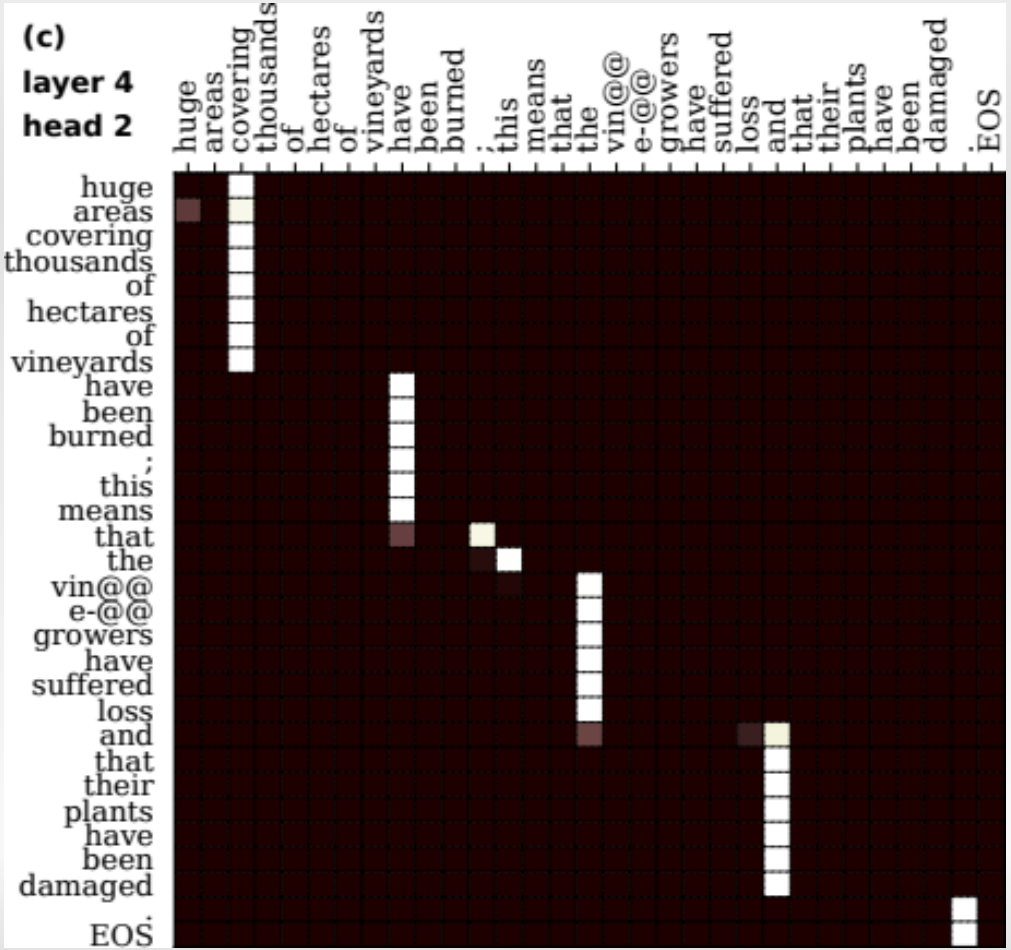
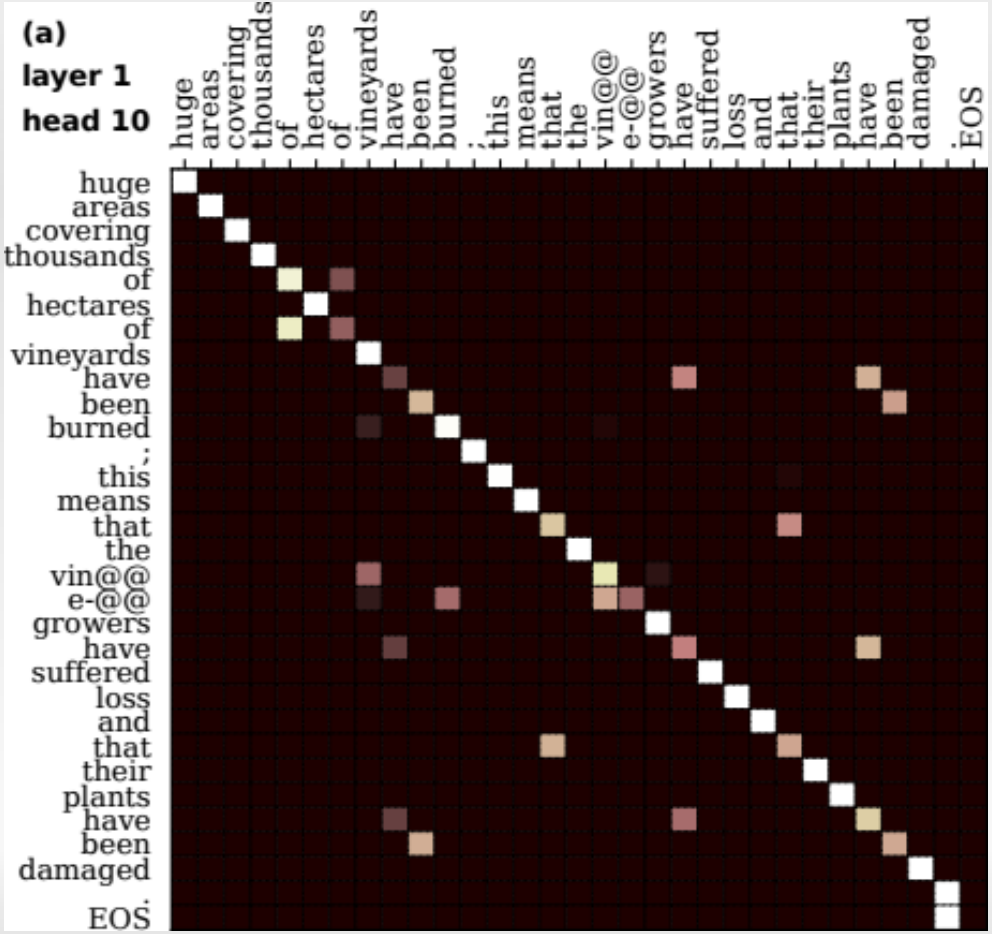
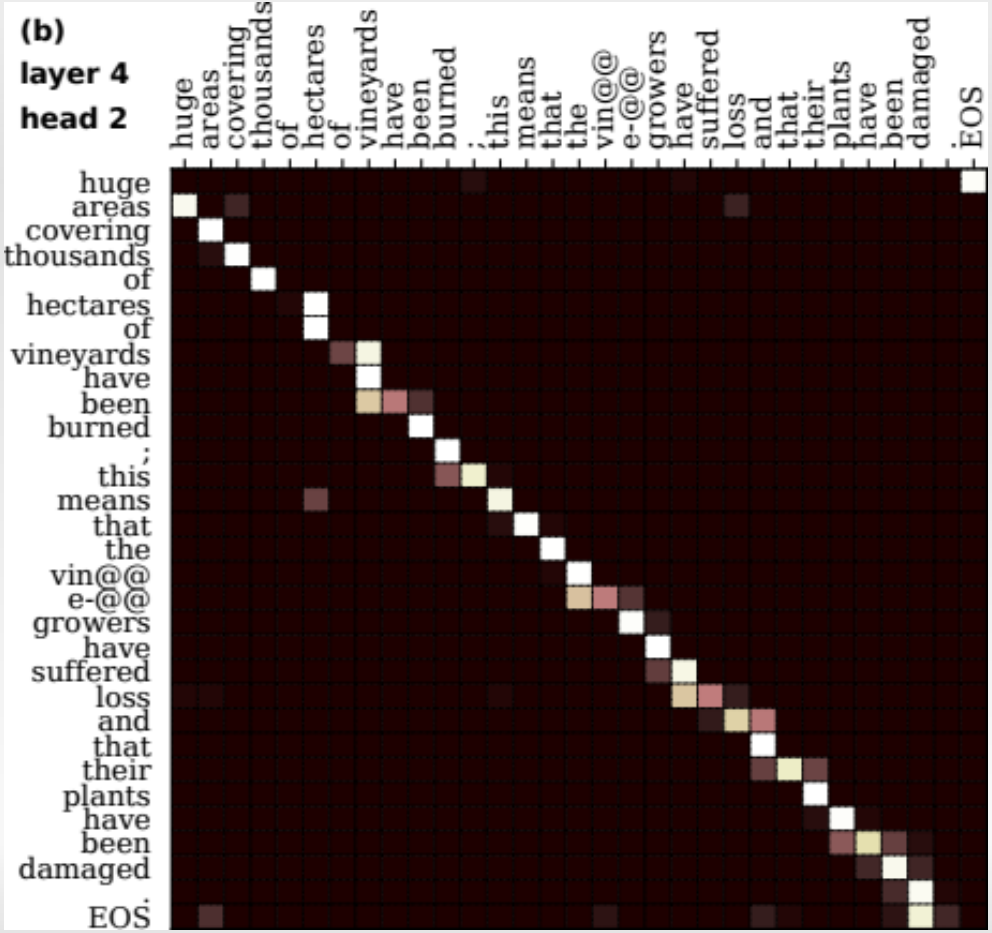
Balustrades (~70% of the attention heads)



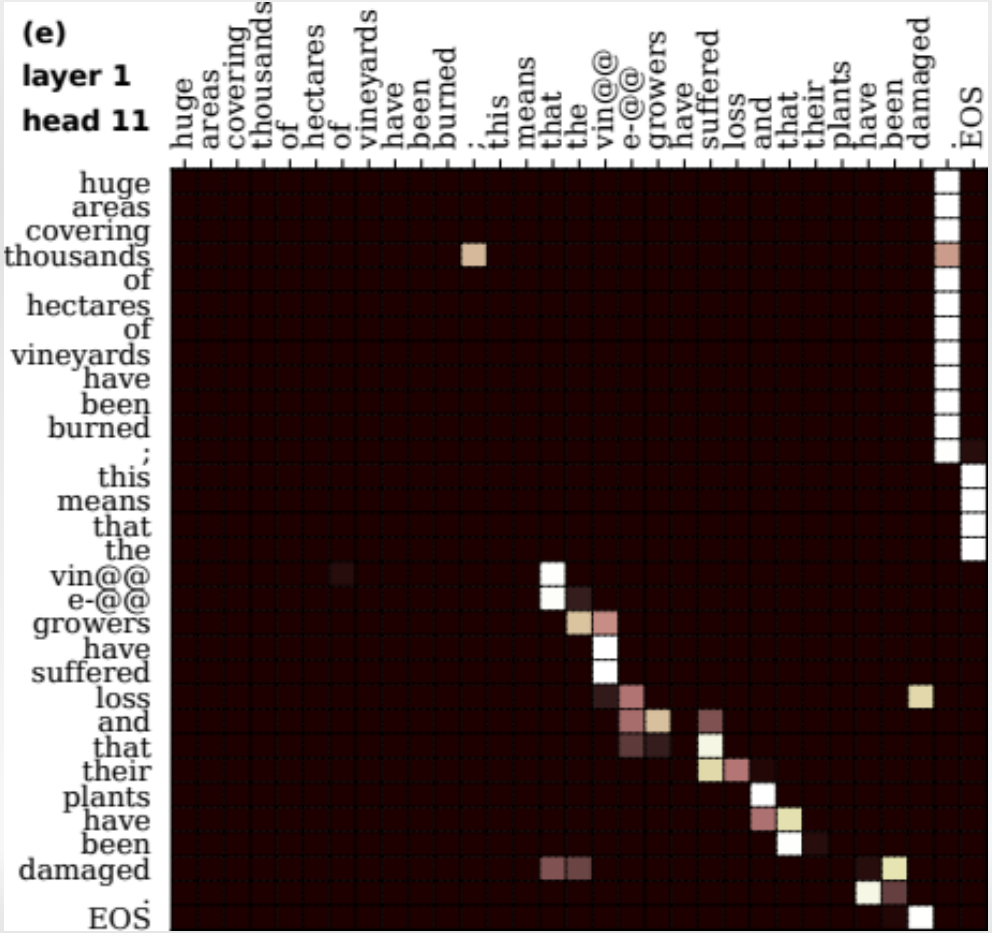


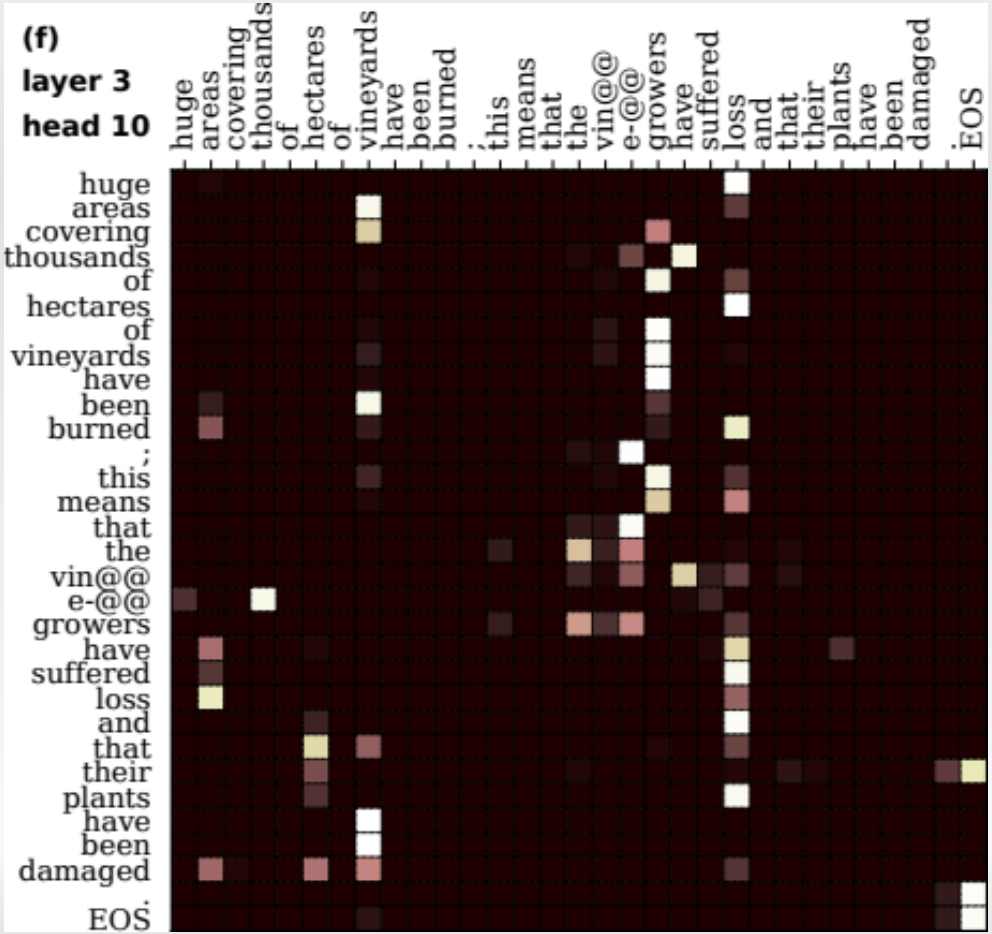
Diagonals (especially 1st layer)





Attend to end, mixed, scattered…





Phrase candidates

- All balusters of length ≥ 2 from **all** heads
  - Subselecting only some of the heads: see the paper!

Phrase candidates

- All balusters of length ≥ 2 from **all** heads
  - Subselecting only some of the heads: see the paper!
- Phrase score
  - Average attention weight
  - Sum over all heads
  - Equalize over different phrase lengths

Phrase candidates → constituency tree

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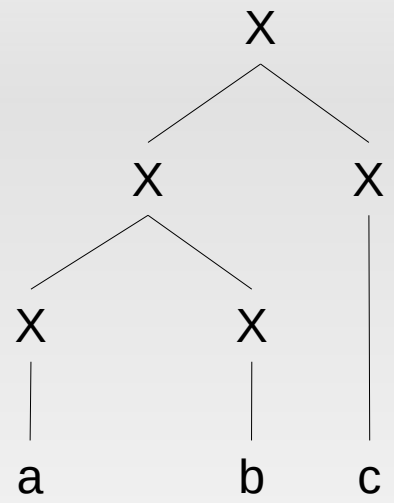
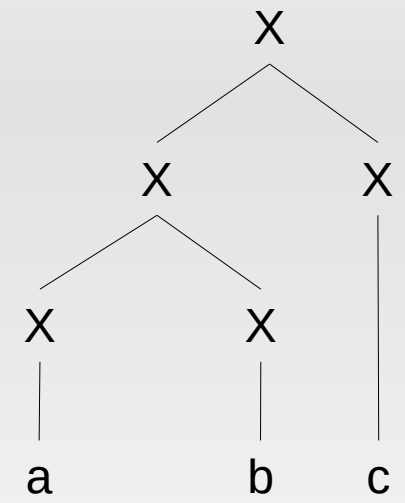
- Binary constituency tree



Phrase candidates → constituency tree

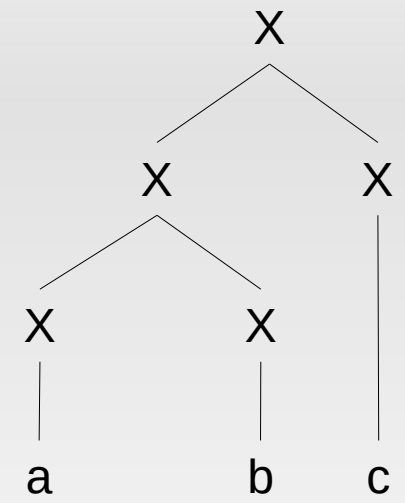
- Binary constituency tree
- Tree score = sum of phrase scores



$s(T) = s(ab) + s(abc)$

Phrase candidates → constituency tree

- Binary constituency tree
- Tree score = sum of phrase scores
- CKY algorithm
  - Finds tree (set of phrases) with maximal score



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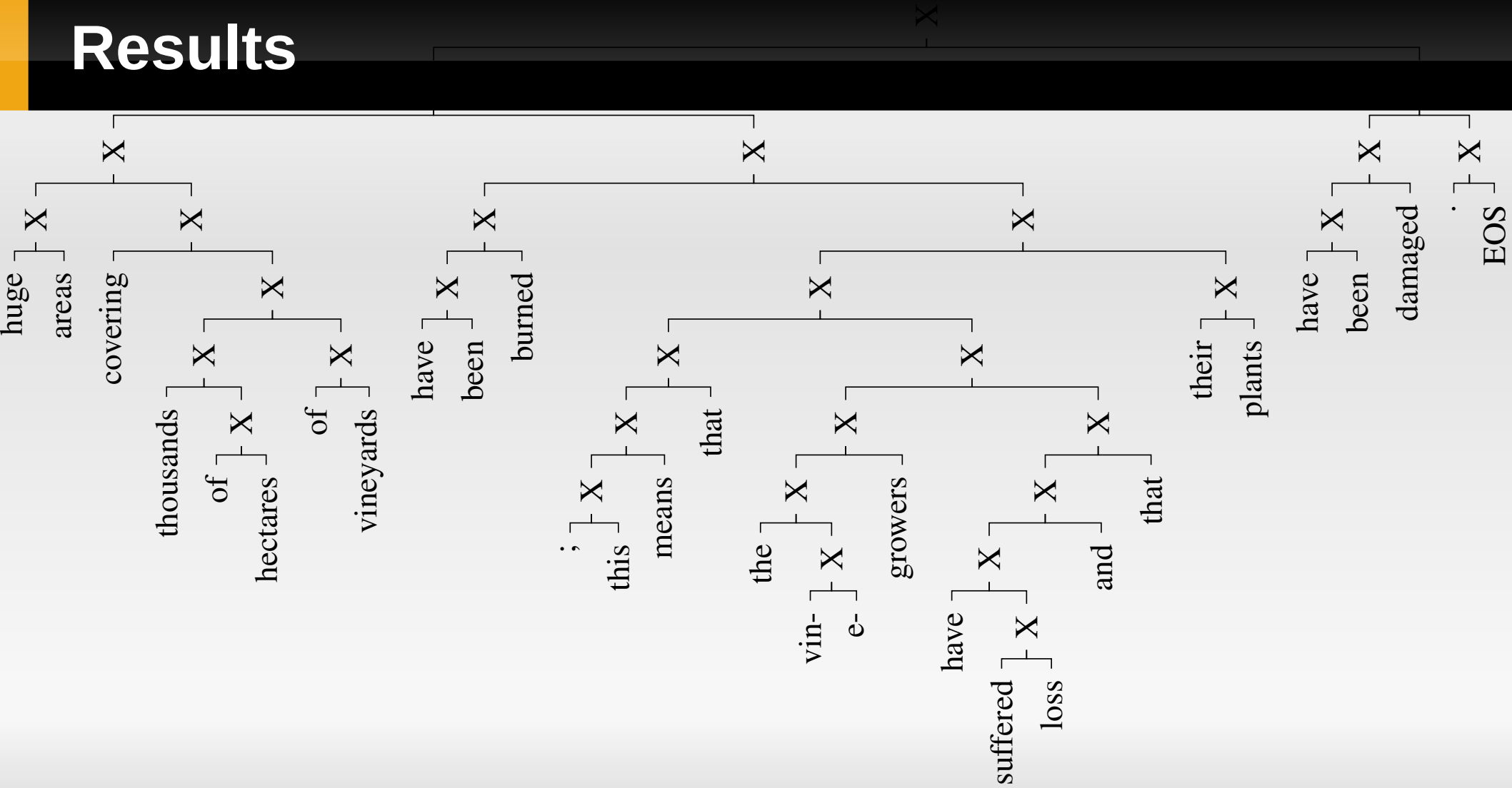
Results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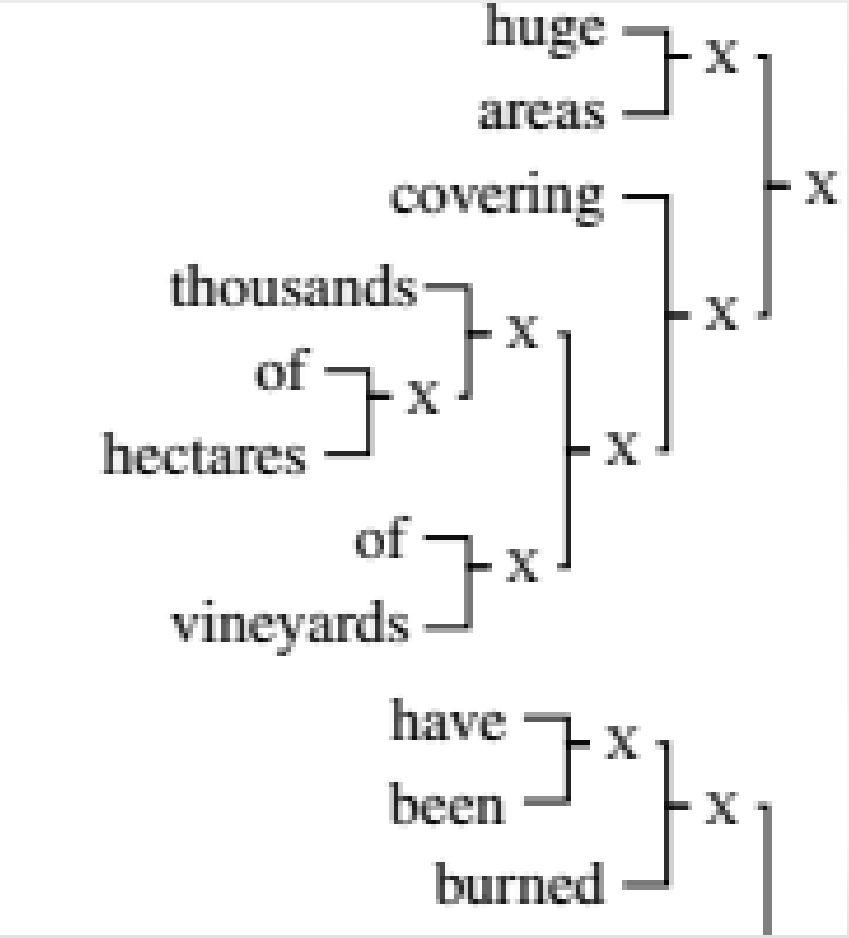
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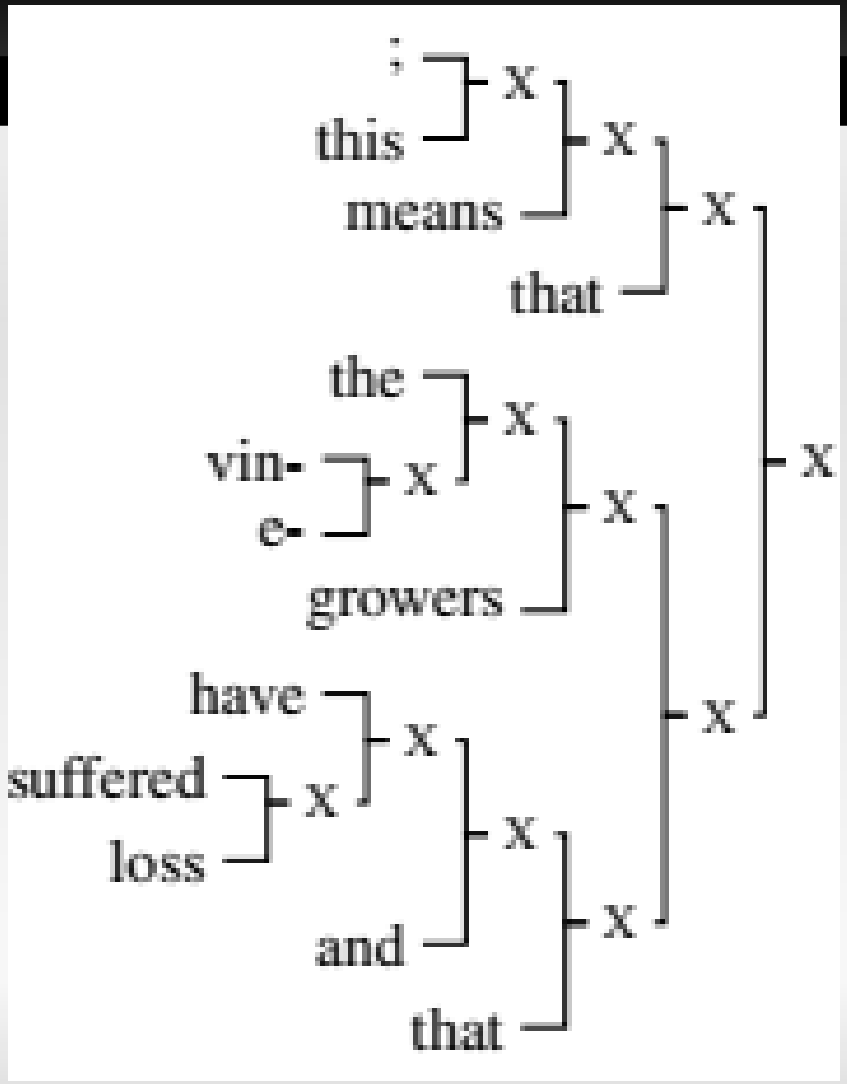
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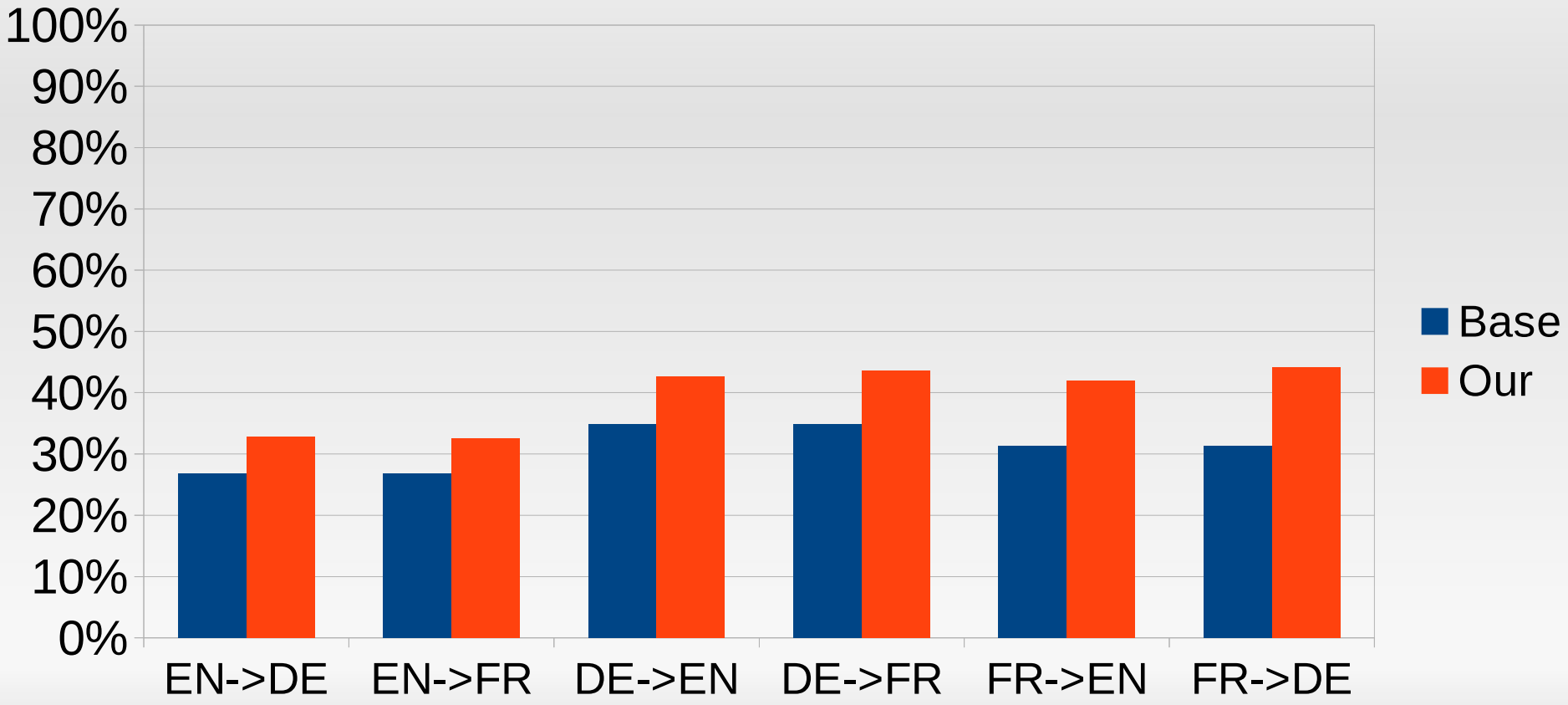
Comparison to standard syntactic trees



Summary

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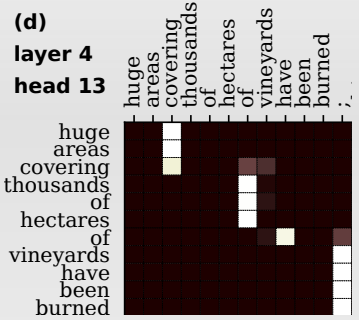
- **Balusters** in Transformer NMT encoder self-attentions
  - Contiguous sequence of output states
  - Attention to the same one input state



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- Construct a binary **constituency tree**
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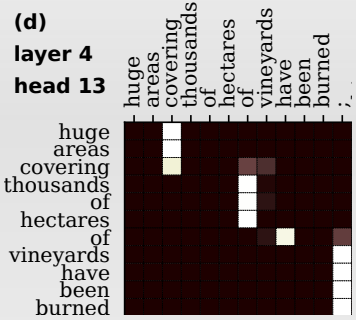

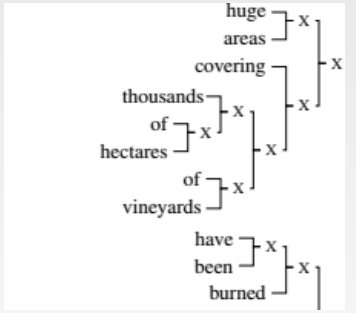

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- Interpret balusters as **syntactic phrases**
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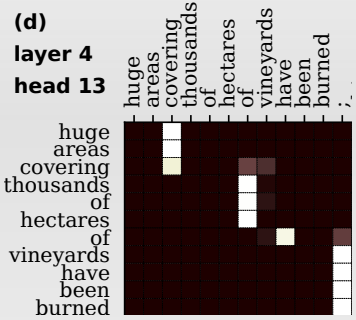
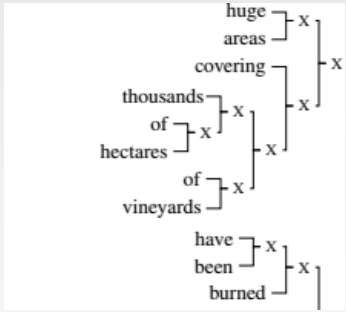
- Construct a binary **constituency tree**
  - CKY algorithm
- Compare to **standard syntactic trees**
  - **~40% match**; base ~30% match





Thank you for your attention

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