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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

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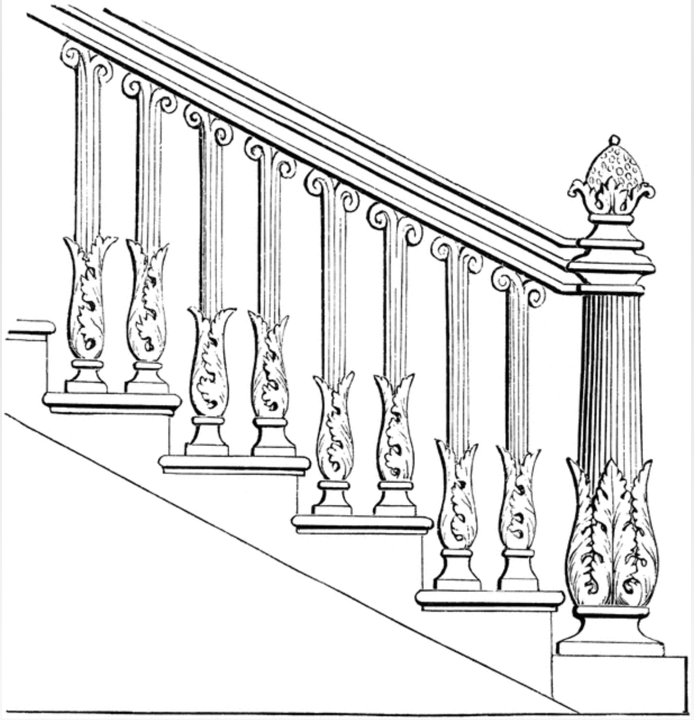
From balustrades to Pierre Vinken



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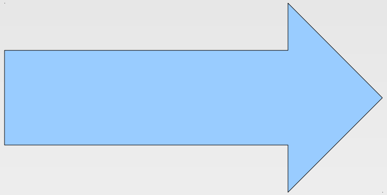
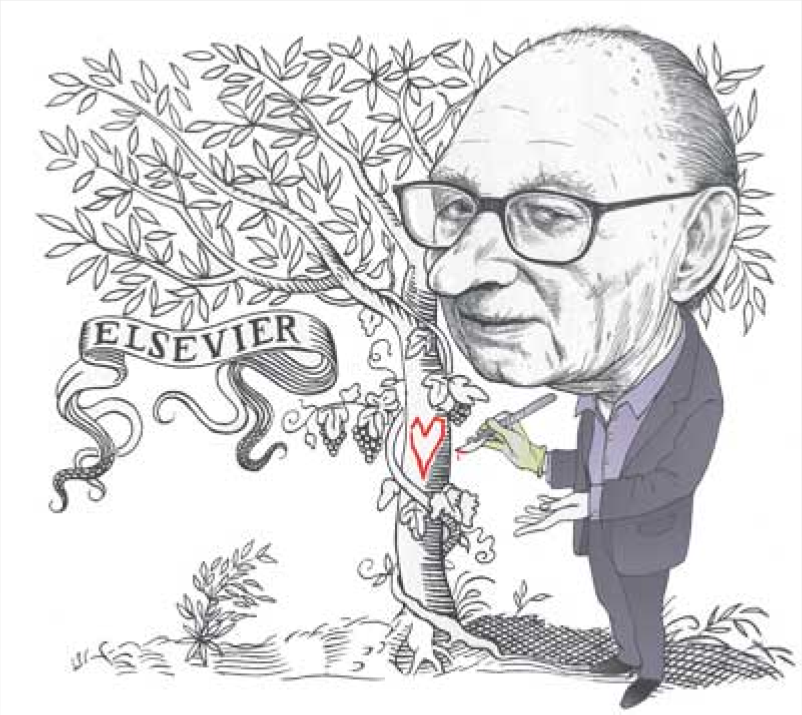
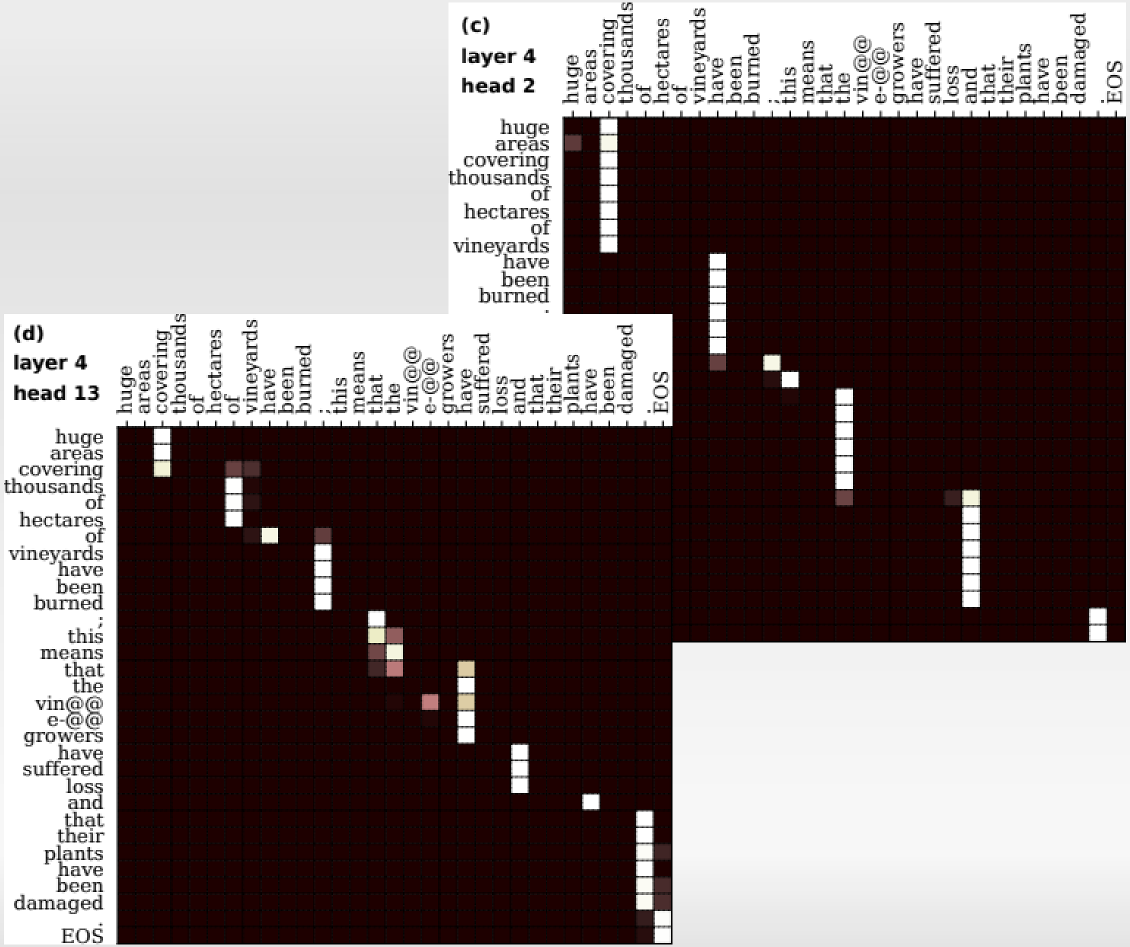
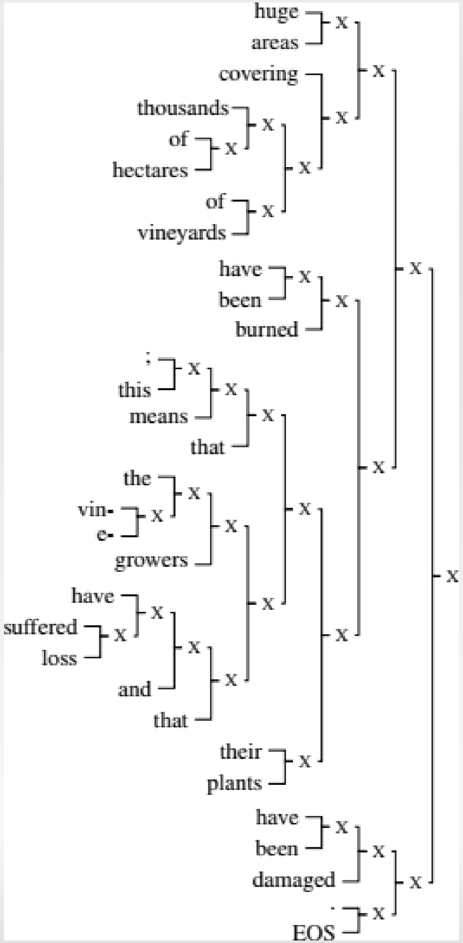




by Jan Hein van Dierendonck

Transformer self-attentions → syntactic trees





Observation

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- Common pattern in Transformer NMT self-attention heads

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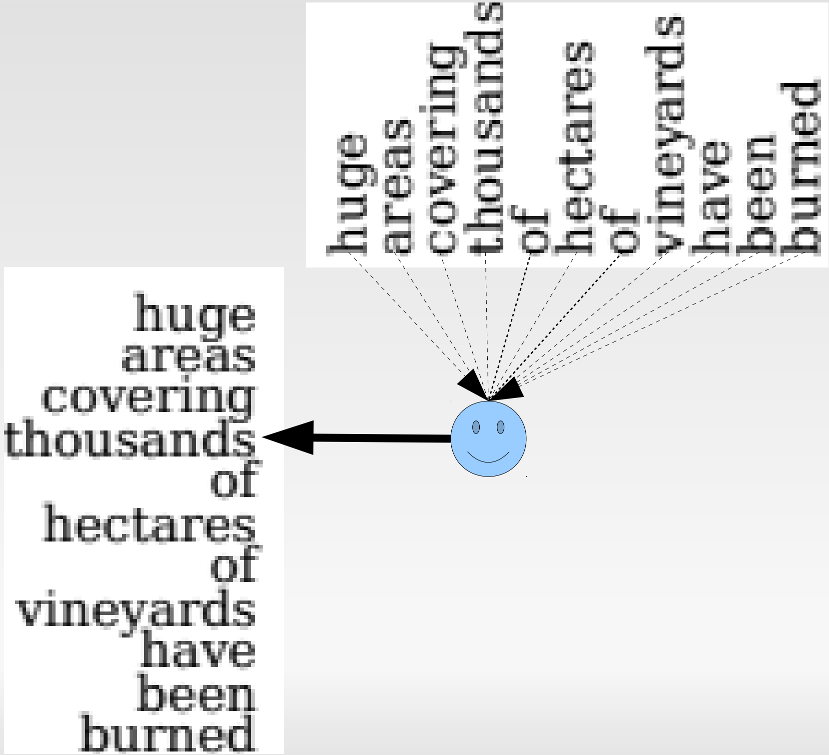

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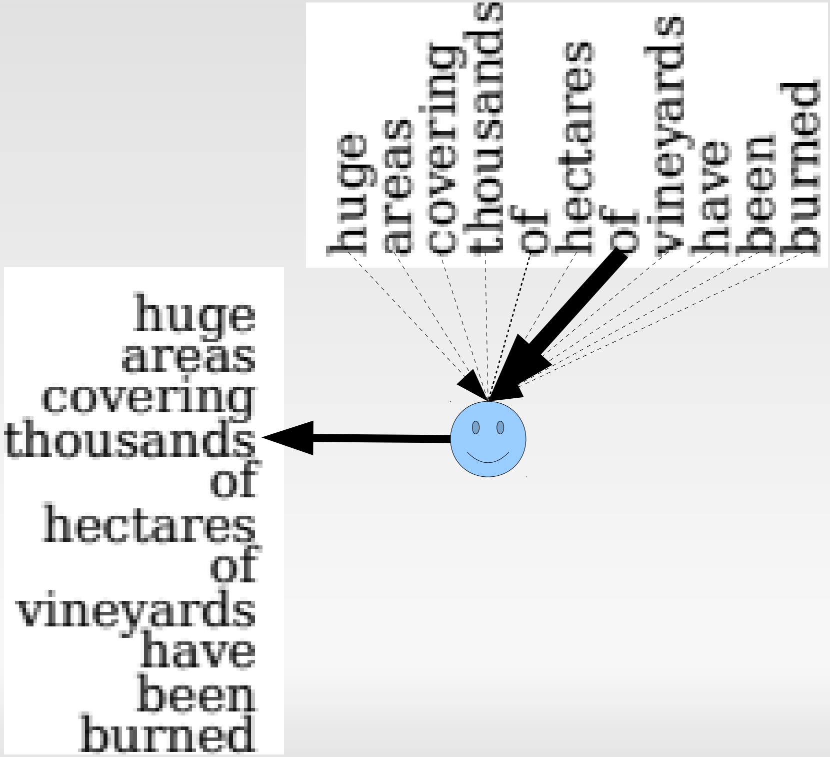

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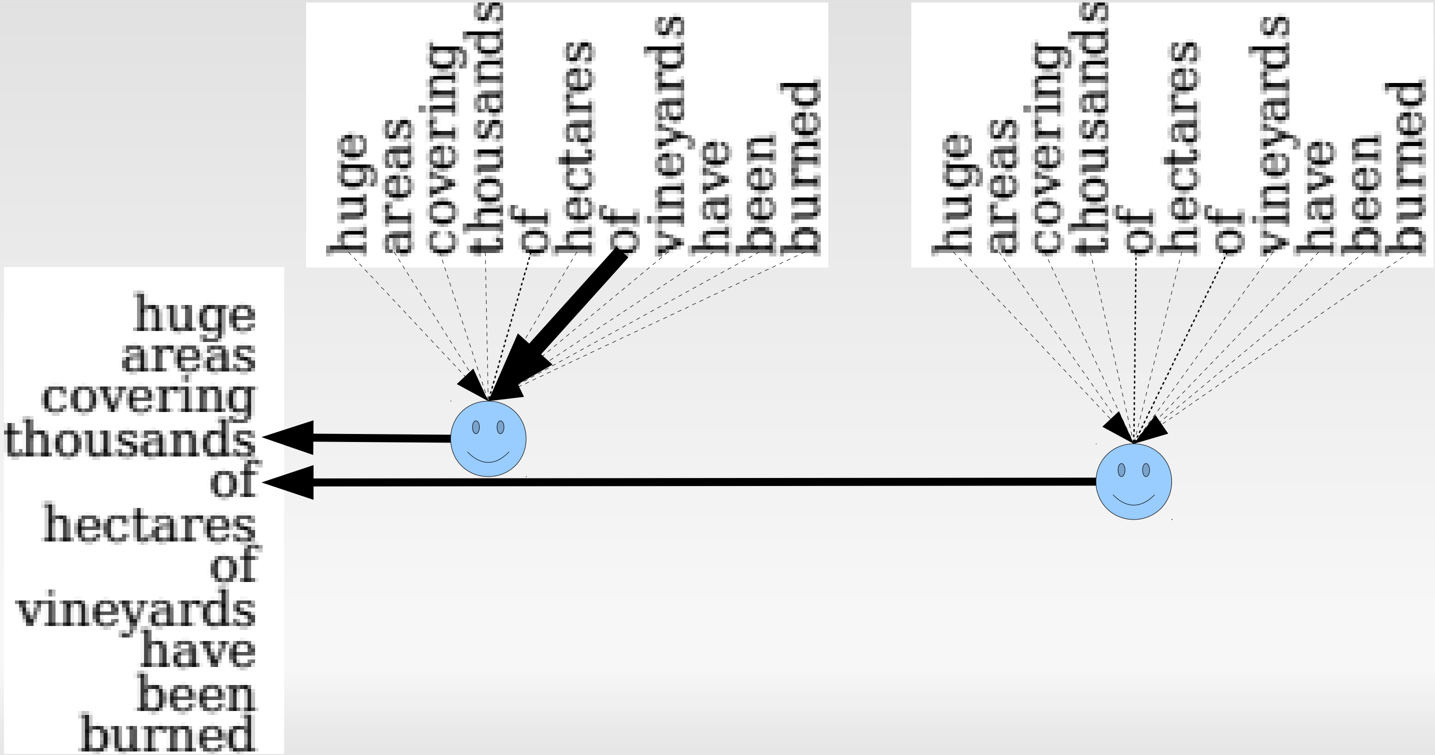

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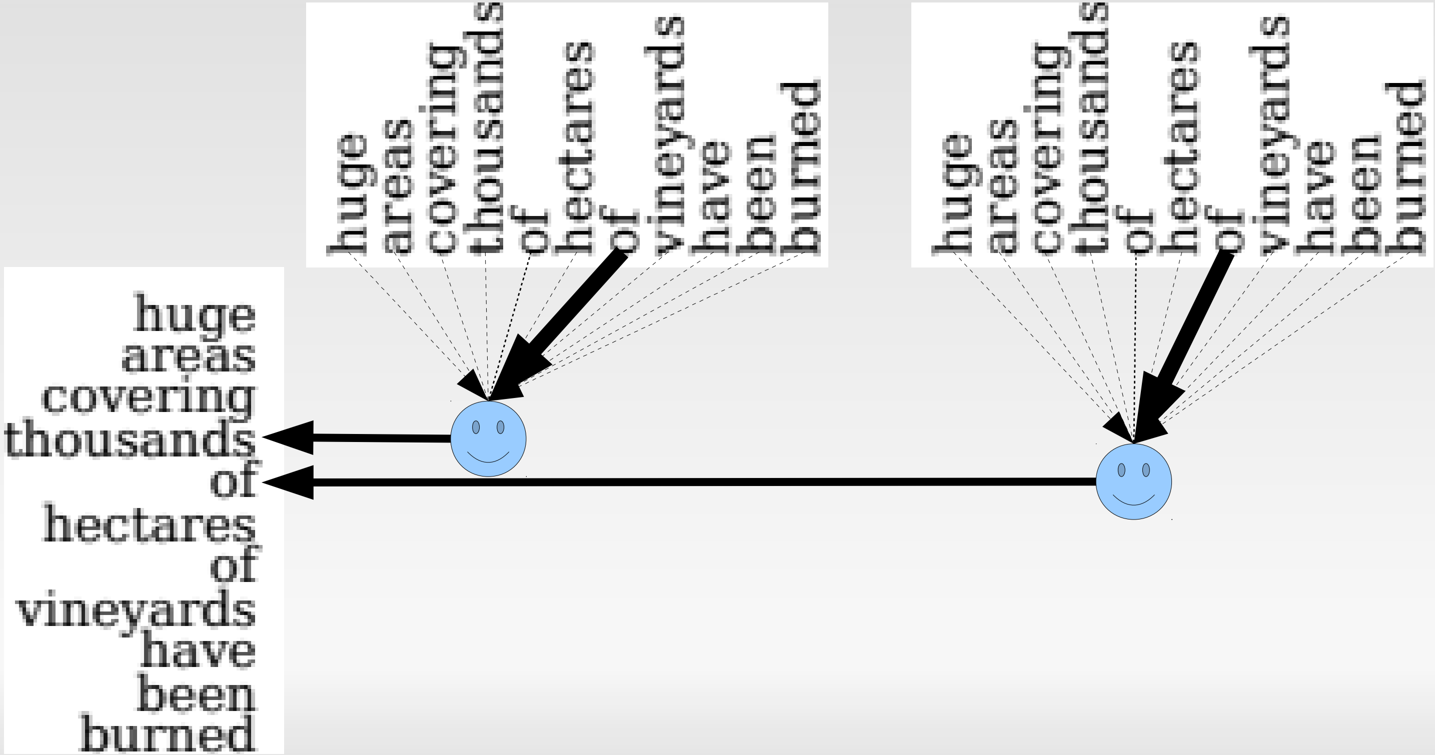

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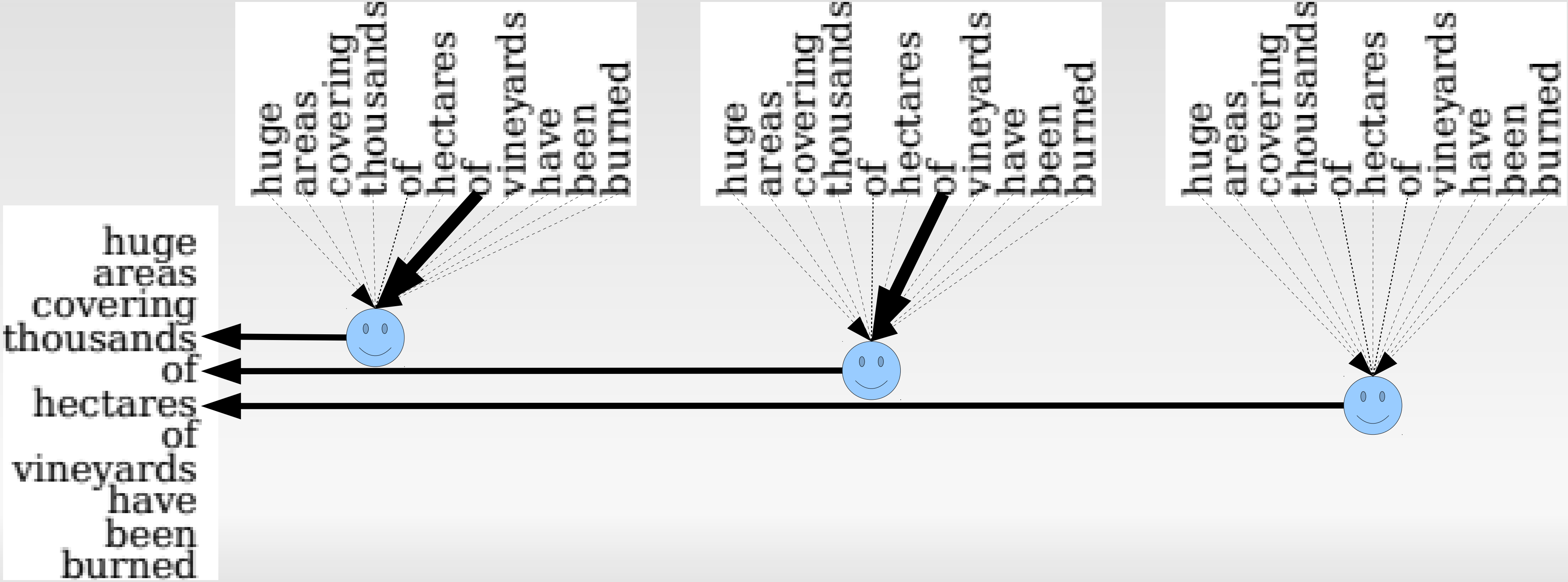

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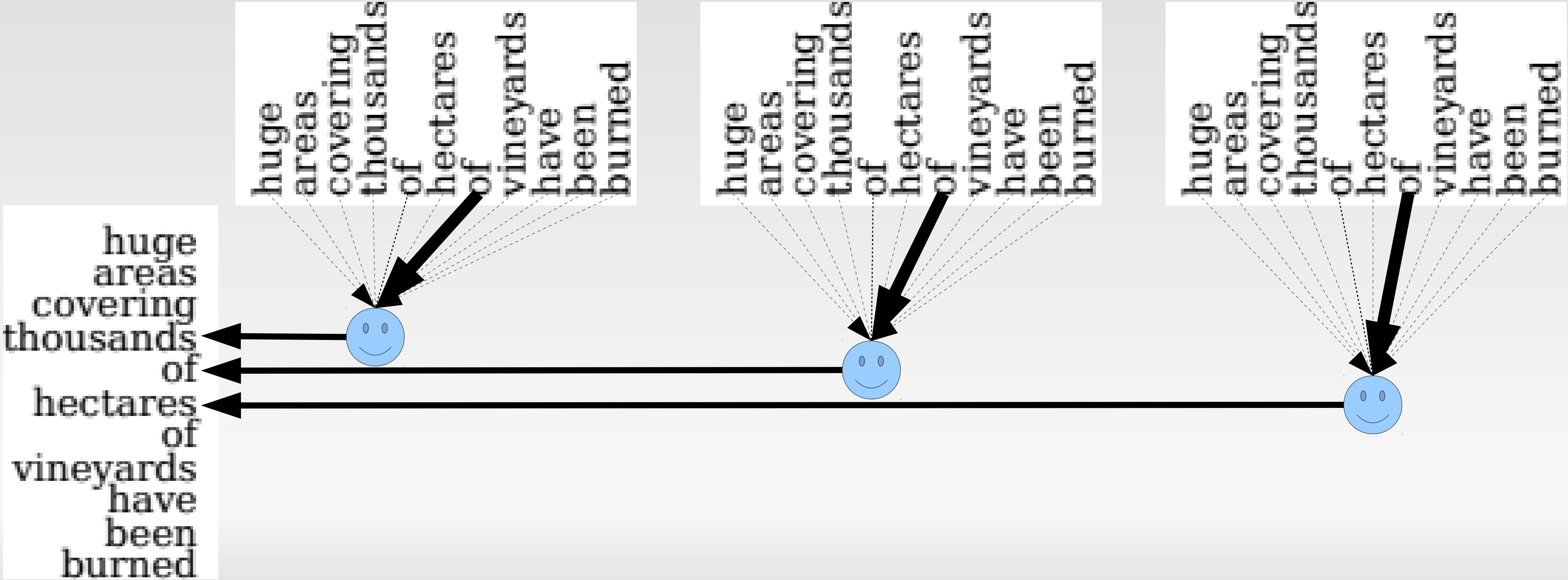

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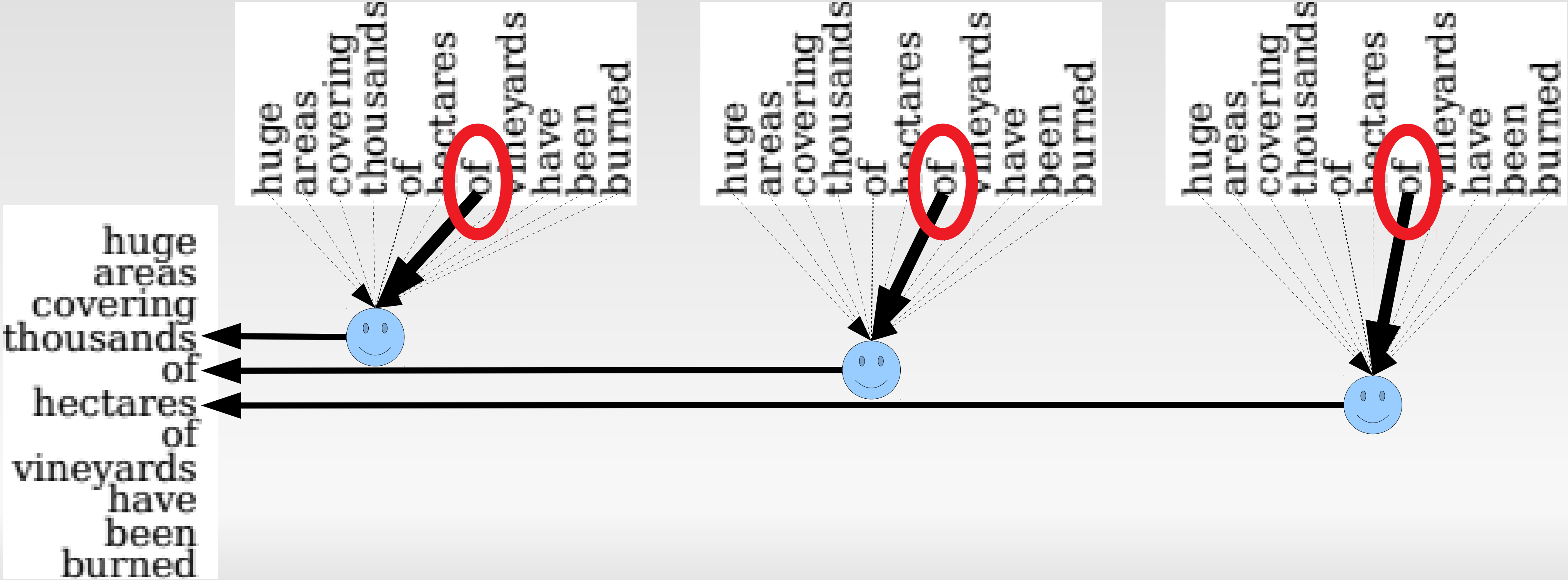

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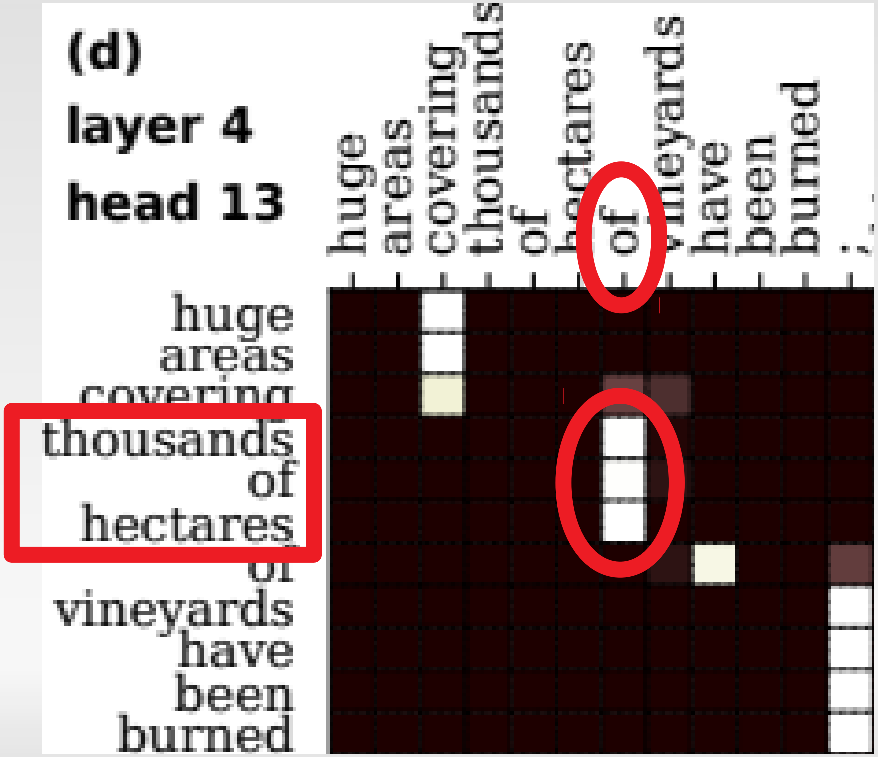
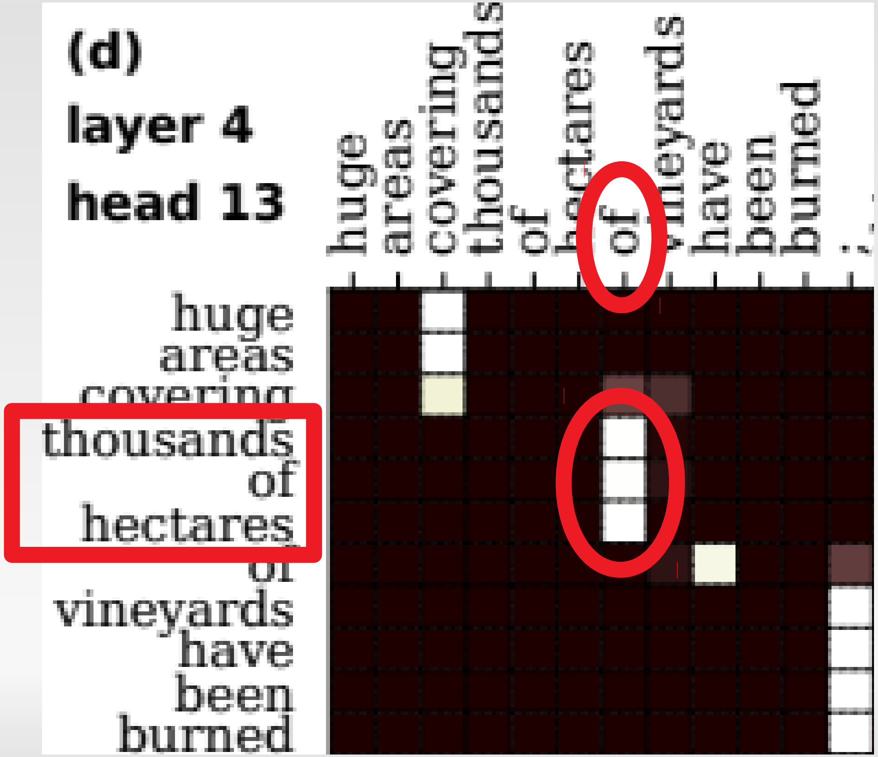


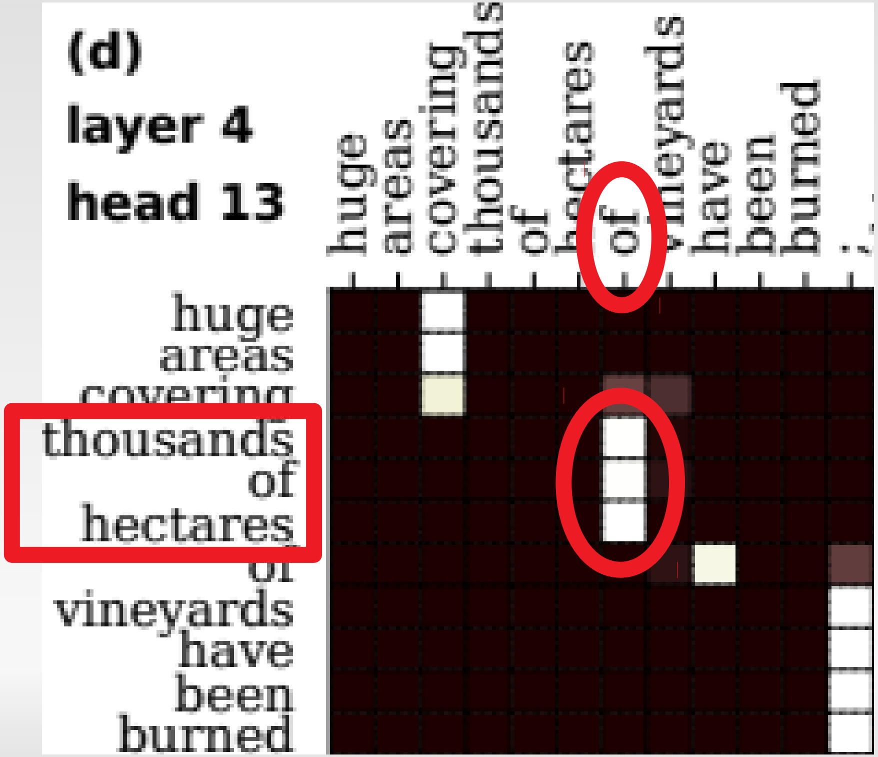
Observation

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



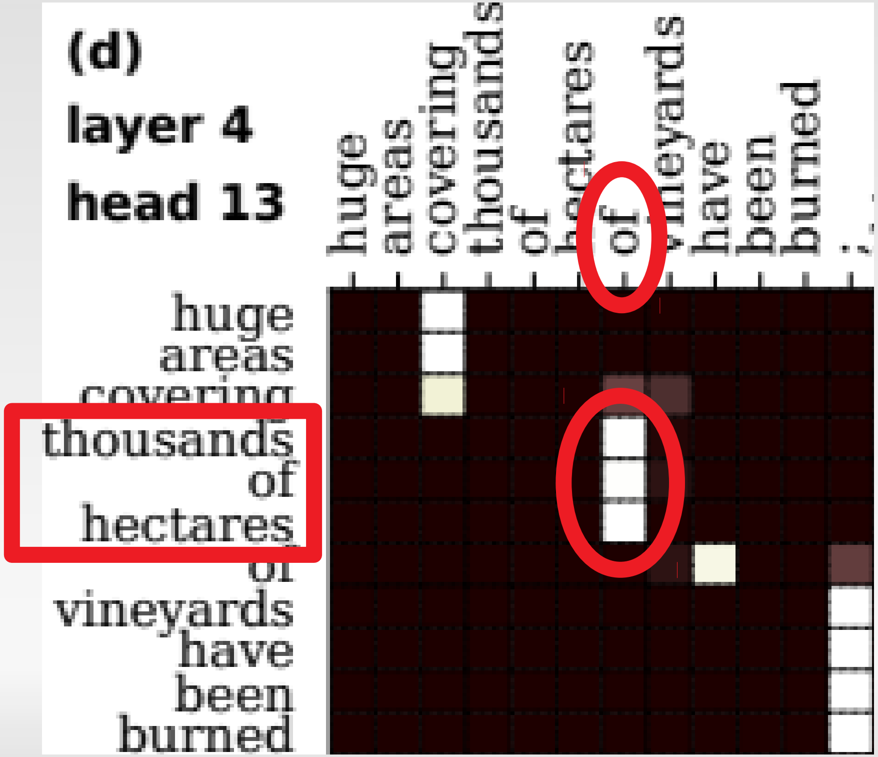
Observation

- Common pattern in Transformer NMT self-attention heads
  - “balusters”
- 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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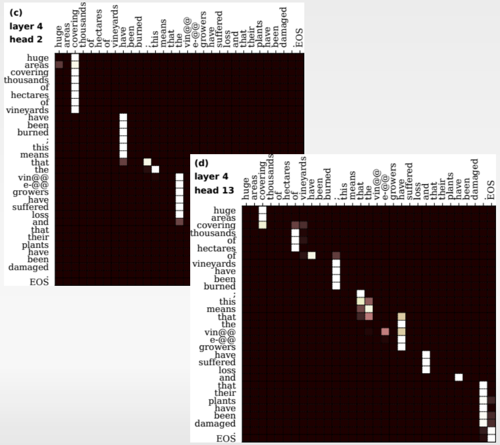
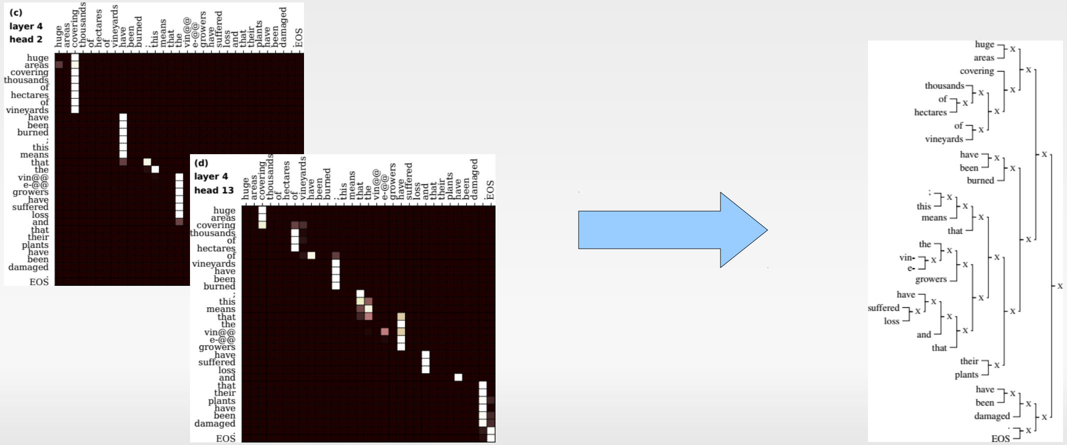
1. Balusters → phrase candidates



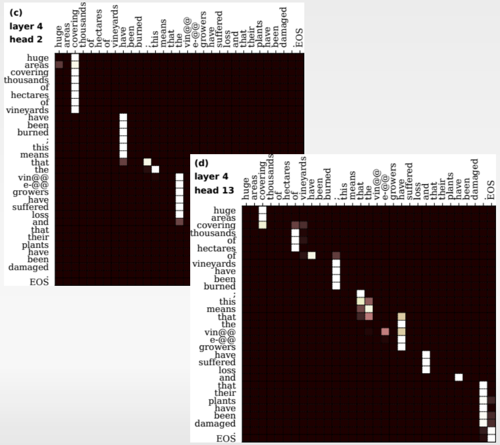
Approach

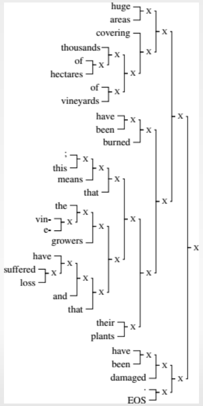
1. Balusters → phrase candidates
2. Phrase candidates → constituency tree
   - Linguistically uninformed algorithm


(c)
layer 4
head 2
(d)
layer 4
head 13
huge areas covering thousands of hectares of vineyards have been burned ; this means that the vin@@ e-@@ growers have suffered loss and that their plants have been damaged . EOS
huge areas covering thousands of hectares of vineyards have been burned ; this means that the vin- e- growers have suffered loss and that their plants have been damaged . EOS
x

Approach

1. Balusters → phrase candidates
2. Phrase candidates → constituency tree
   - Linguistically uninformed algorithm
3. Compare to standard syntactic trees

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x

?

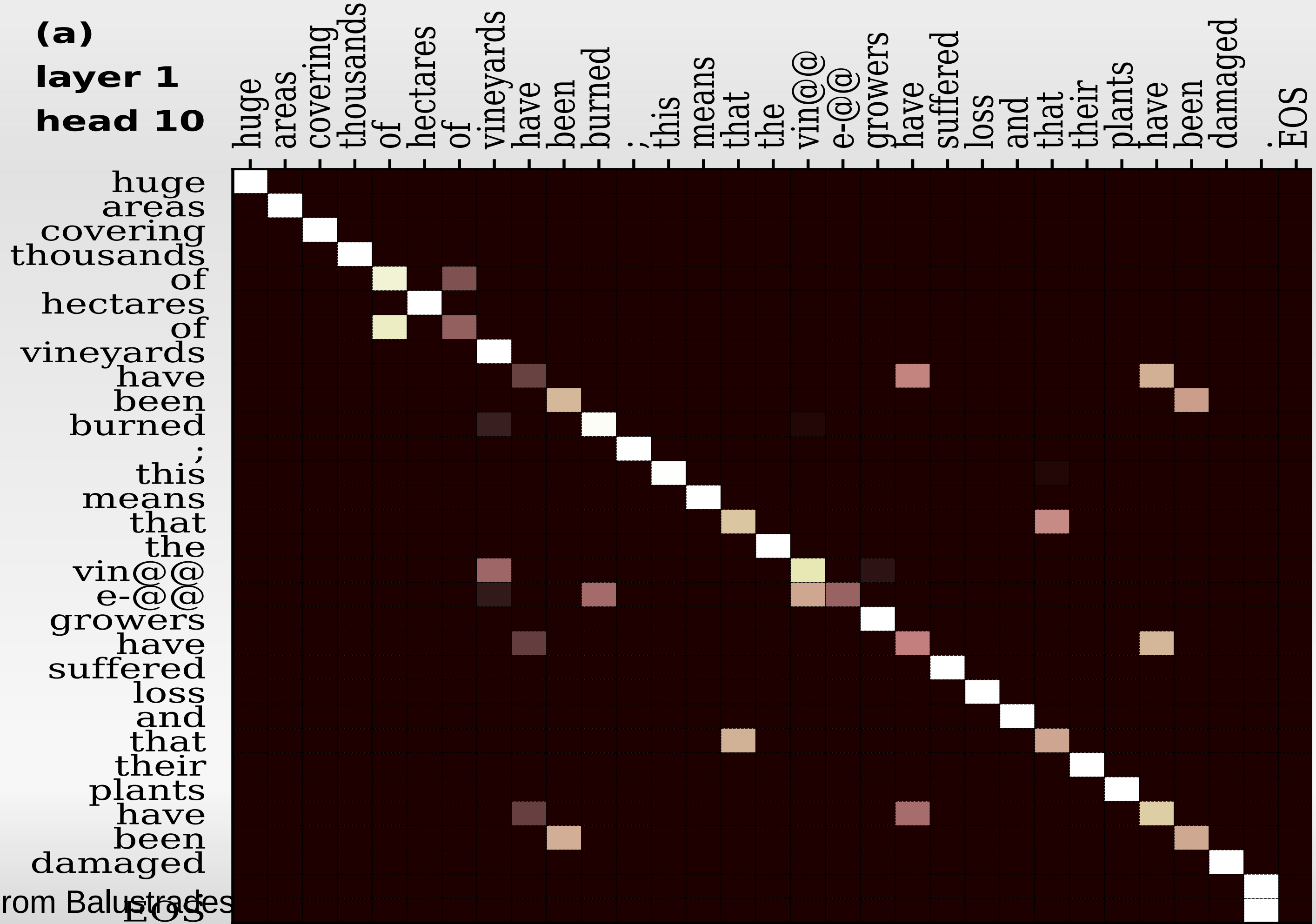
Experiment setup

- transformer neural machine translation encoder
  - 6 layers x 16 heads, 100k shared BPEs…
- 6 language pairs: fr ↔ en, de ↔ en, fr ↔ de
  - Europarl training data
- analyze encoder self-attention matrices
- extract constituency syntax trees
- compare against Stanford parser syntax trees
  - trained on linguistically annotated treebanks:
    Penn Treebank, Negra Corpus, French Treebank

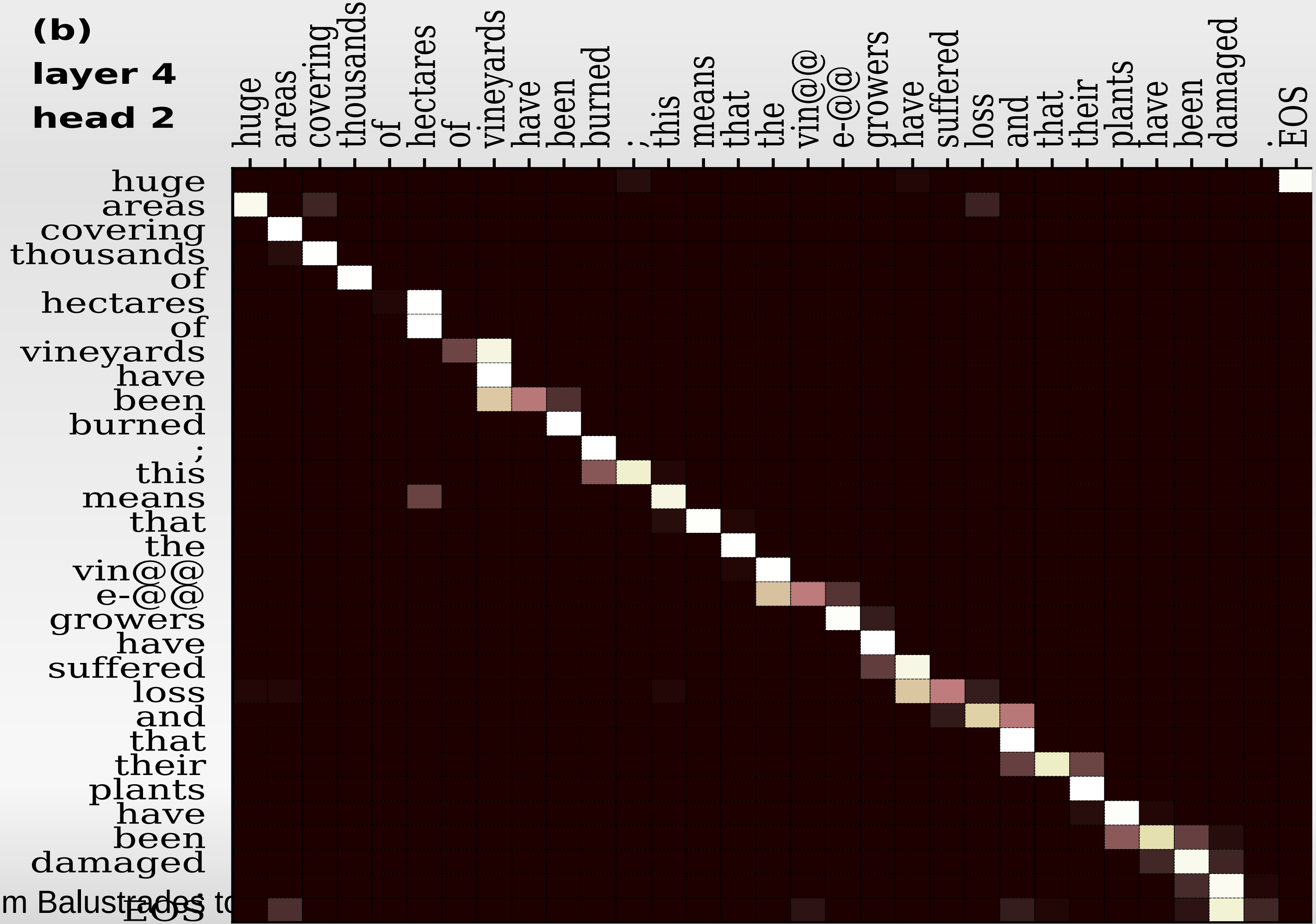
Transformer NMT

- tady asi srtukturu tranformera trochu
- ať je jasný odkuď tahám ty self attention matrices
- positions ~ input words (actually subwords)
- each head attends to some words…
- one example sentence throughout all slides
  - Huge areas covering thousands of hectares of vineyards have been burned; this means that the vine-growers have suffered loss and that their plants have been damaged.

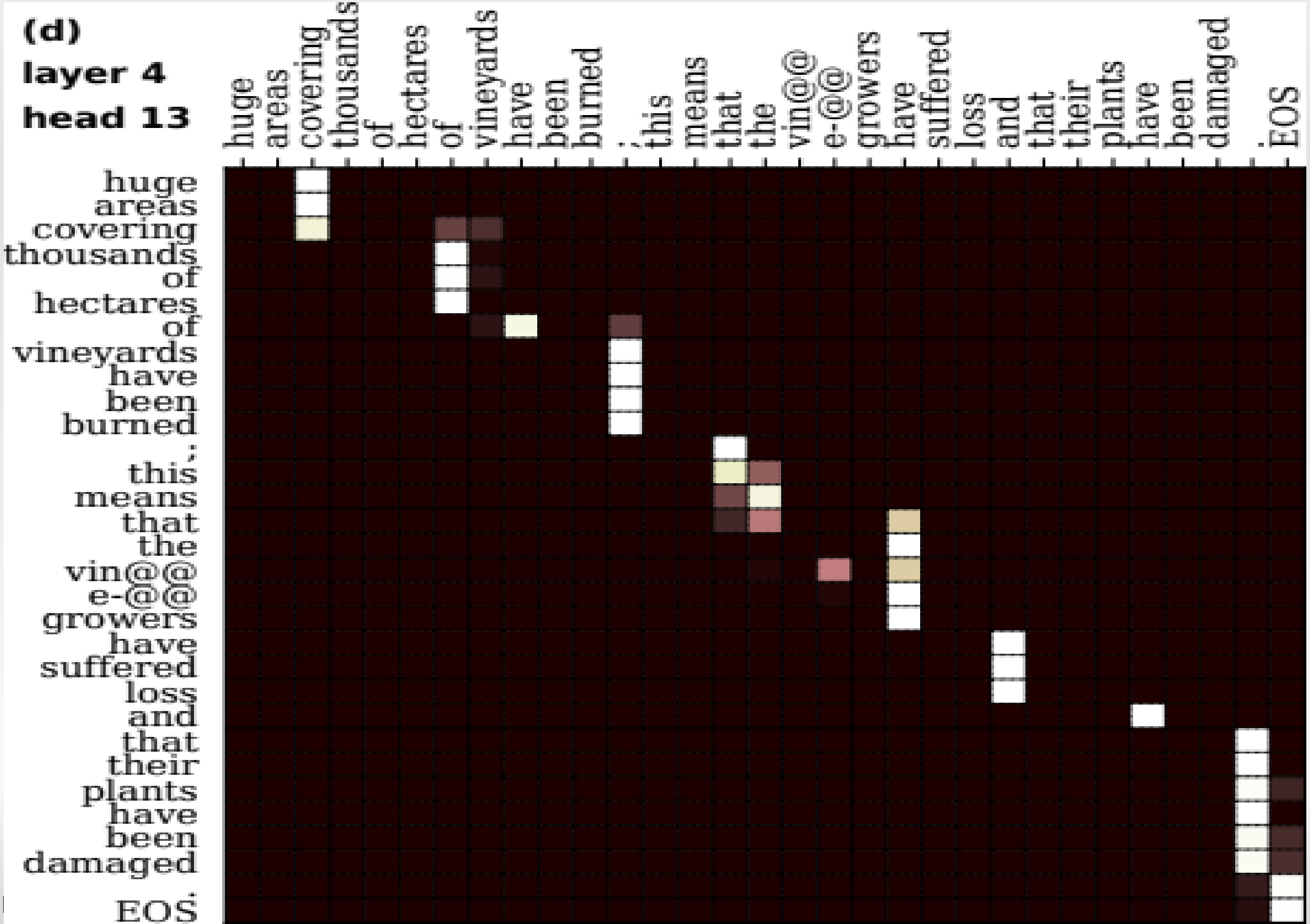
Diagonal (current word)



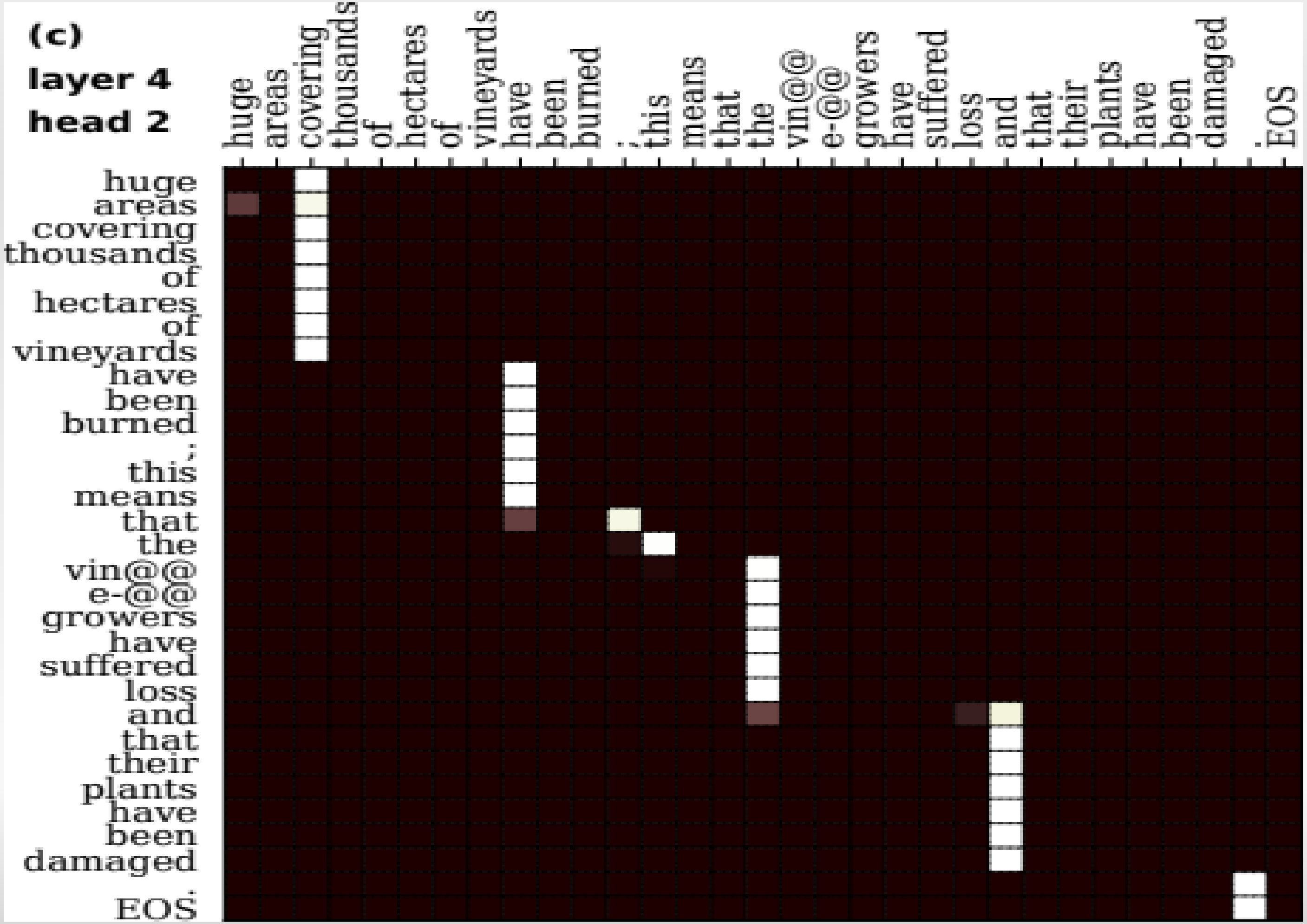
Shifted diagonal (previous word)



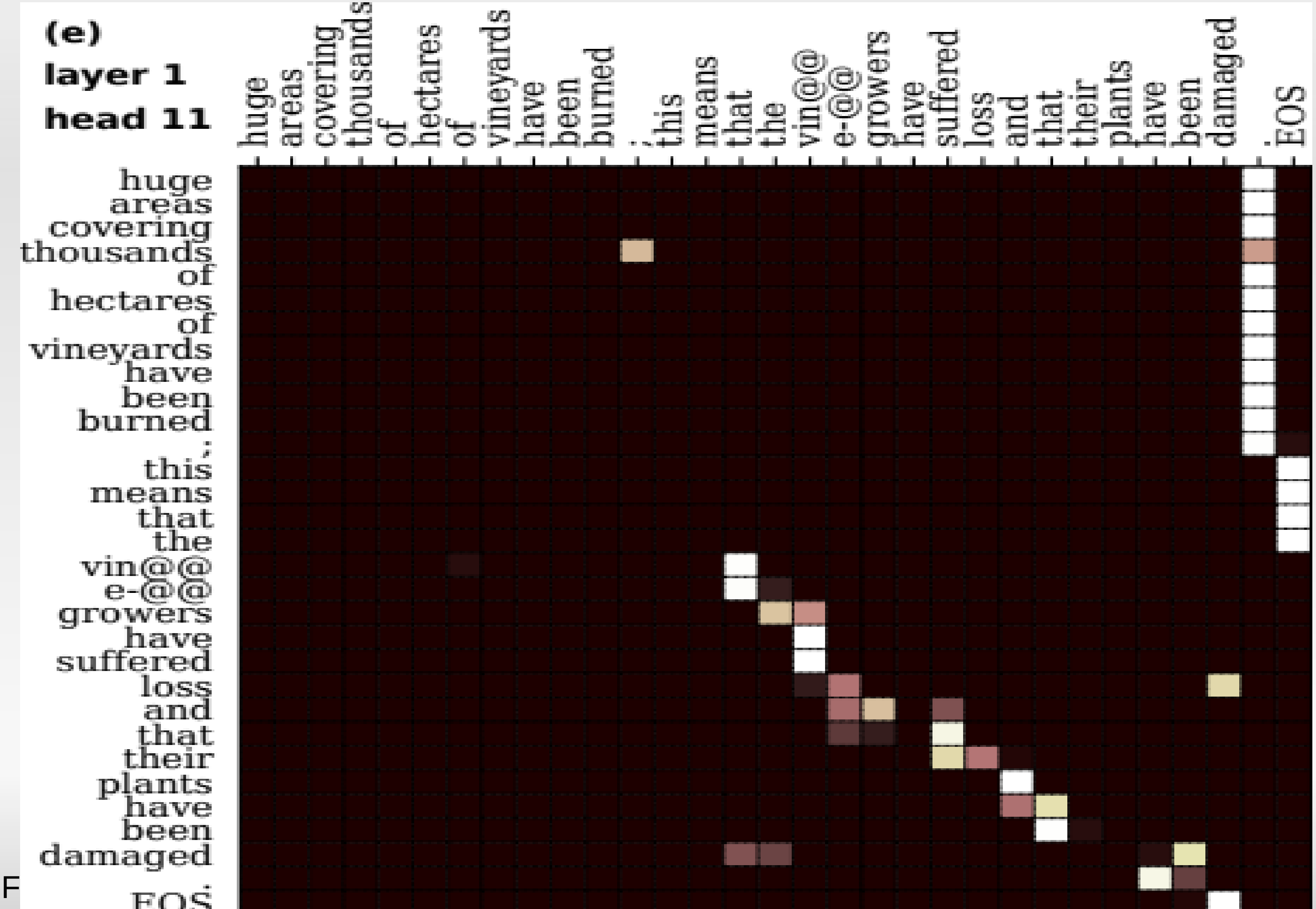
Short balusters (“phrases”)



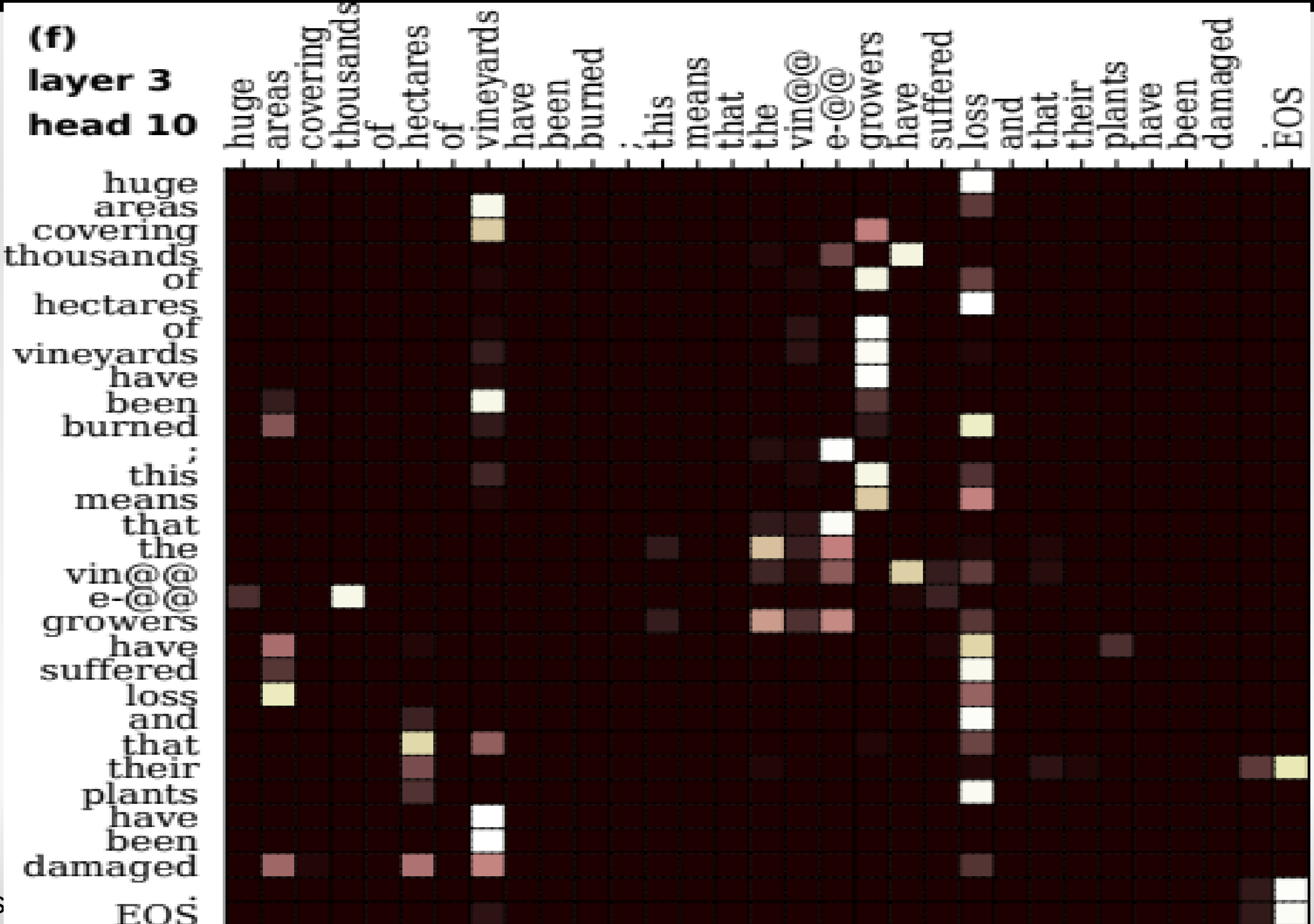
Long balusters ("phrases")



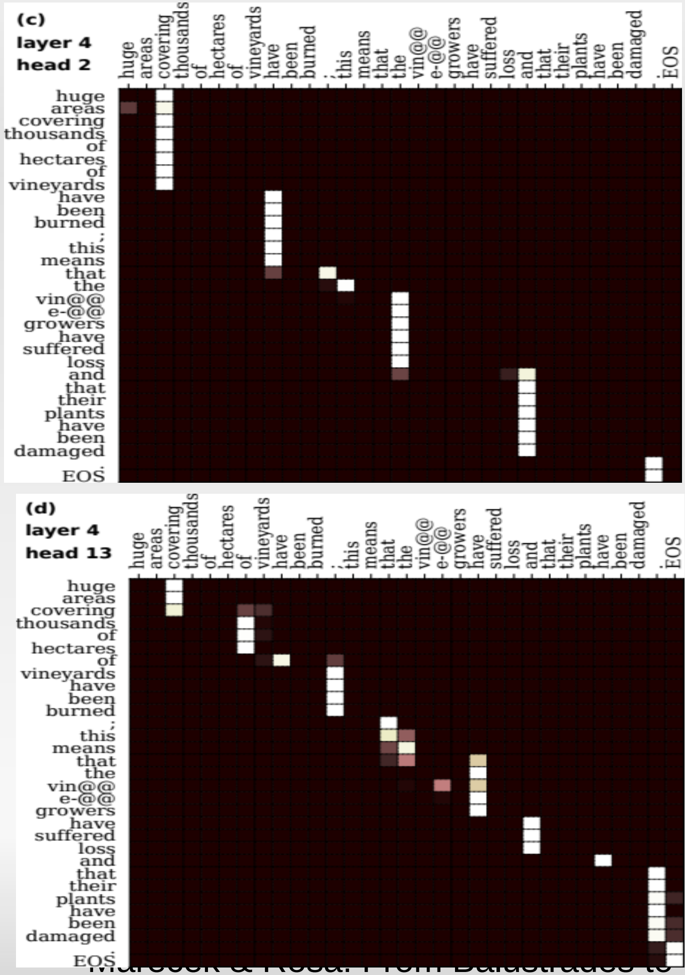
Partial balustrades + attend to end



Scattered attention (uninterpreted)



Phrase candidates & scoring



- keep only max on each line
- phrase candidate
  - each contiguous baluster
  - sequence of words attending to the same position
- phrase score
  - average attention weight
  - sum over all layers and heads
  - short phrases more common → equalization
- linguistically uninformed!

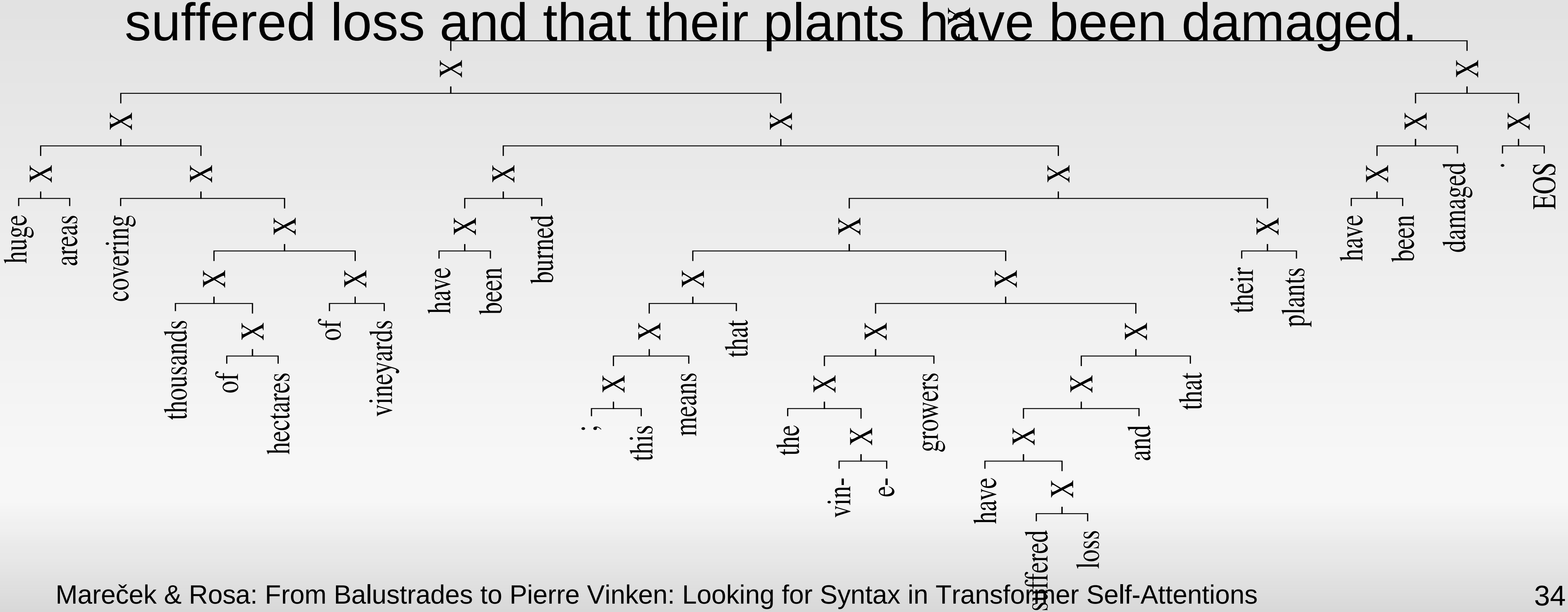
Binary constituency CKY parsing

- standard recursive algorithm
- constructs a binary constituency tree which maximizes the sum of scores of phrases in the tree
- split each phrase into a pair of subphrases so as to maximize the sum of phrase scores
- linguistically uninformed!

$$s_{a,b} = \max_{k} \frac{s_{a,k} + s_{k+1,b} + w_{a,k} + w_{k+1,b}}{4}$$

Results

Huge areas covering thousands of hectares of vineyards have been burned; this means that the vine-growers have suffered loss and that their plants have been damaged.



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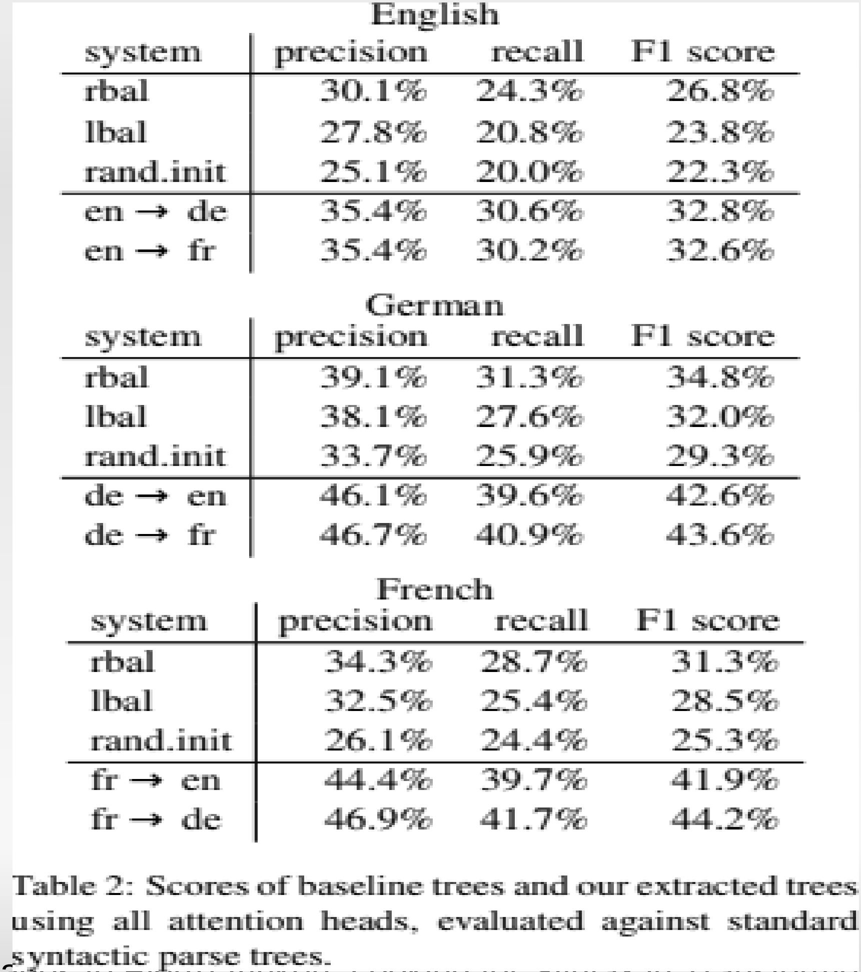

English

system	precision	recall	F1 score
rbal	30.1%	24.3%	26.8%
lbal	27.8%	20.8%	23.8%
rand.init	25.1%	20.0%	22.3%
en → de	35.4%	30.6%	32.8%
en → fr	35.4%	30.2%	32.6%

German

system	precision	recall	F1 score
rbal	39.1%	31.3%	34.8%
lbal	38.1%	27.6%	32.0%
rand.init	33.7%	25.9%	29.3%
de → en	46.1%	39.6%	42.6%
de → fr	46.7%	40.9%	43.6%

French

system	precision	recall	F1 score
rbal	34.3%	28.7%	31.3%
lbal	32.5%	25.4%	28.5%
rand.init	26.1%	24.4%	25.3%
fr → en	44.4%	39.7%	41.9%
fr → de	46.9%	41.7%	44.2%

Table 2: Scores of baseline trees and our extracted trees using all attention heads, evaluated against standard syntactic parse trees.

Summary

- Transformer NMT encoder self-attentions
  - diagonals, shifted diagonals, scattered attention…
  - balustrades: can be interpreted as phrases
- Linguistically uninformed syntax extraction
  - baluster → phrase, attention weight → phrase score
  - binary constituency parsing using CKY
  - no training, no hyperparameters, using all heads
    - see the paper for subselecting only some heads
- Resulting structures are quite syntactically sane
  - F1 score 6 – 13 points above baseline (30% → 40%)

Thank you for your attention

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