

CS11-731  
Machine Translation and  
Sequence-to-Sequence Models  
**Attention**

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Site

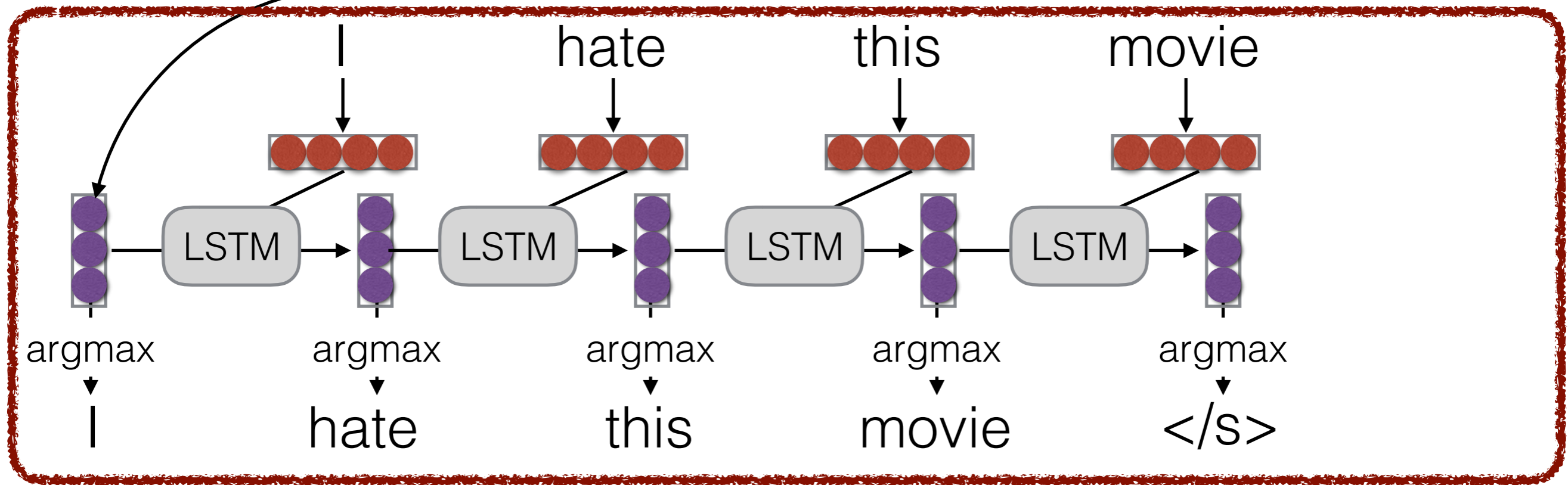
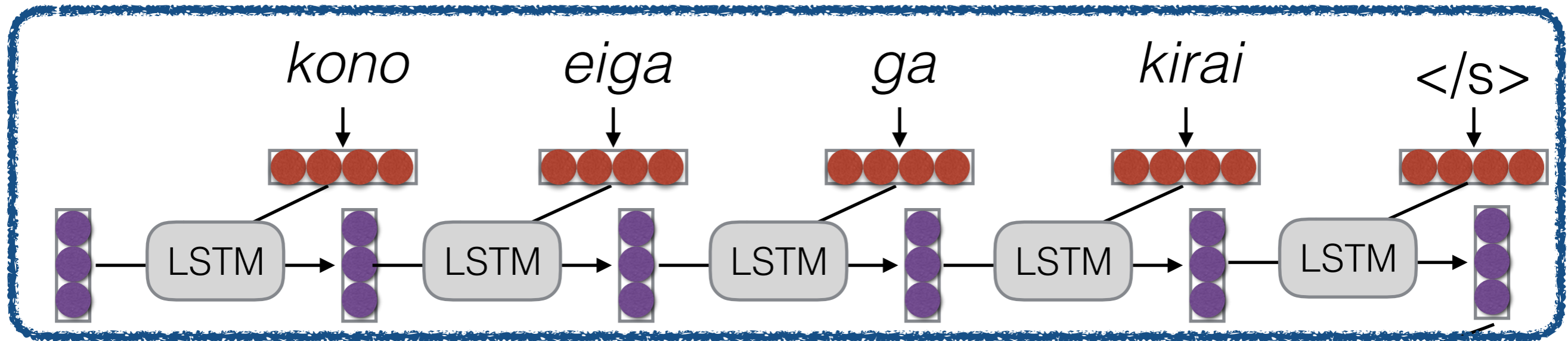
<https://phontron.com/class/mtandseq2seq2019/>

(Slides by Graham Neubig and Antonis Anastasopoulos)

# Encoder-decoder Models

(Sutskever et al. 2014)

Encoder



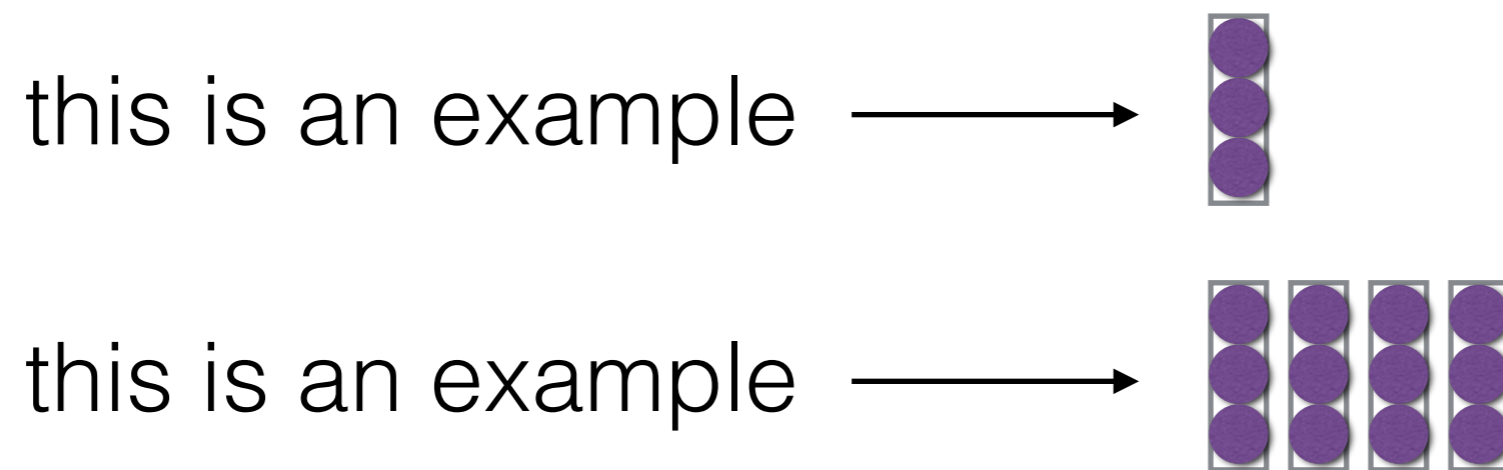
Decoder

# Sentence Representations

## Problem!

“You can’t cram the meaning of a whole sentence into a single vector!”  
— Ray Mooney

- But what if we could use multiple vectors, based on the length of the sentence.



Attention

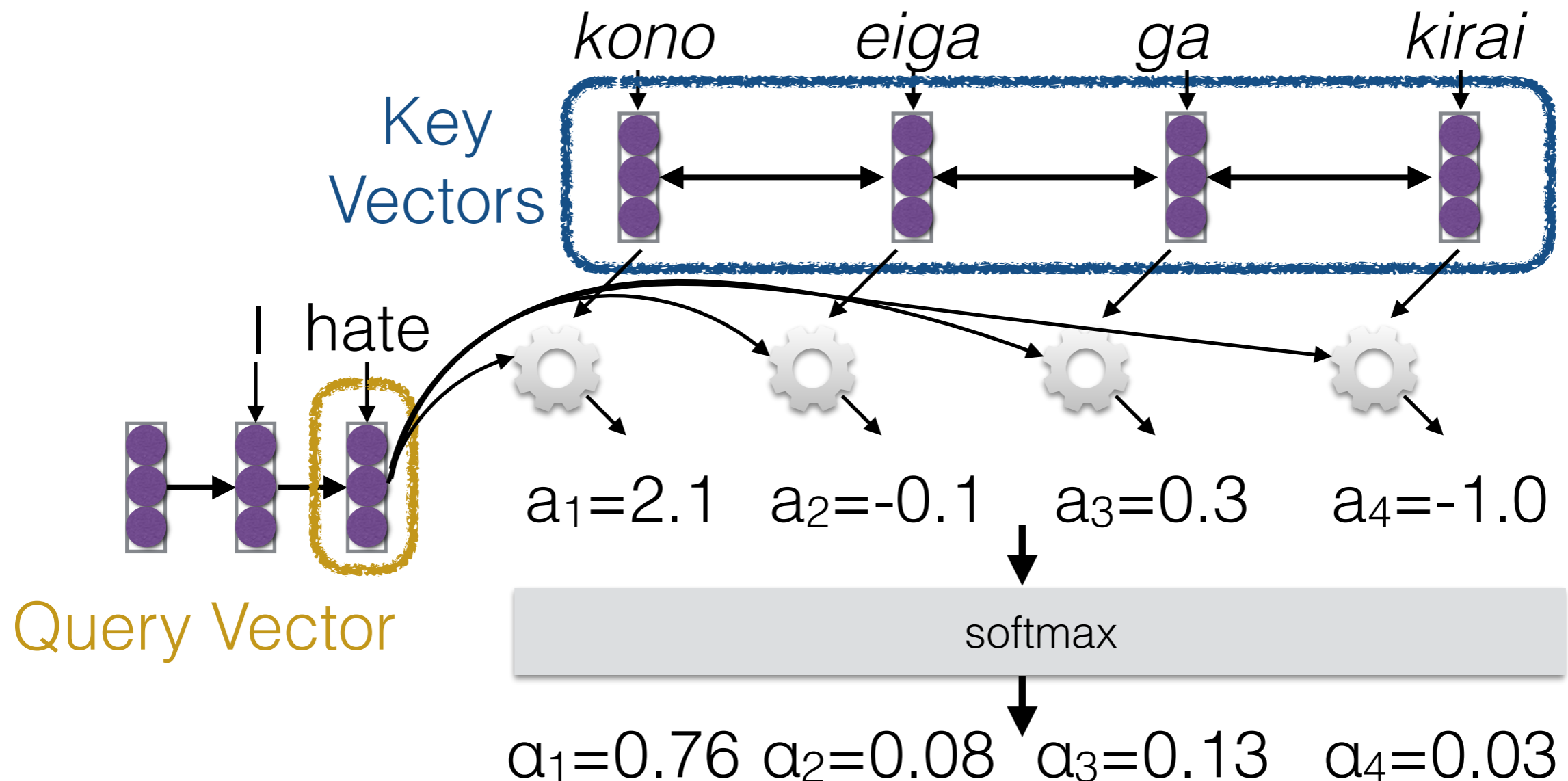
# Basic Idea

(Bahdanau et al. 2015)

- Encode each word in the sentence into a vector
- When decoding, perform a linear combination of these vectors, weighted by “attention weights”
- Use this combination in picking the next word

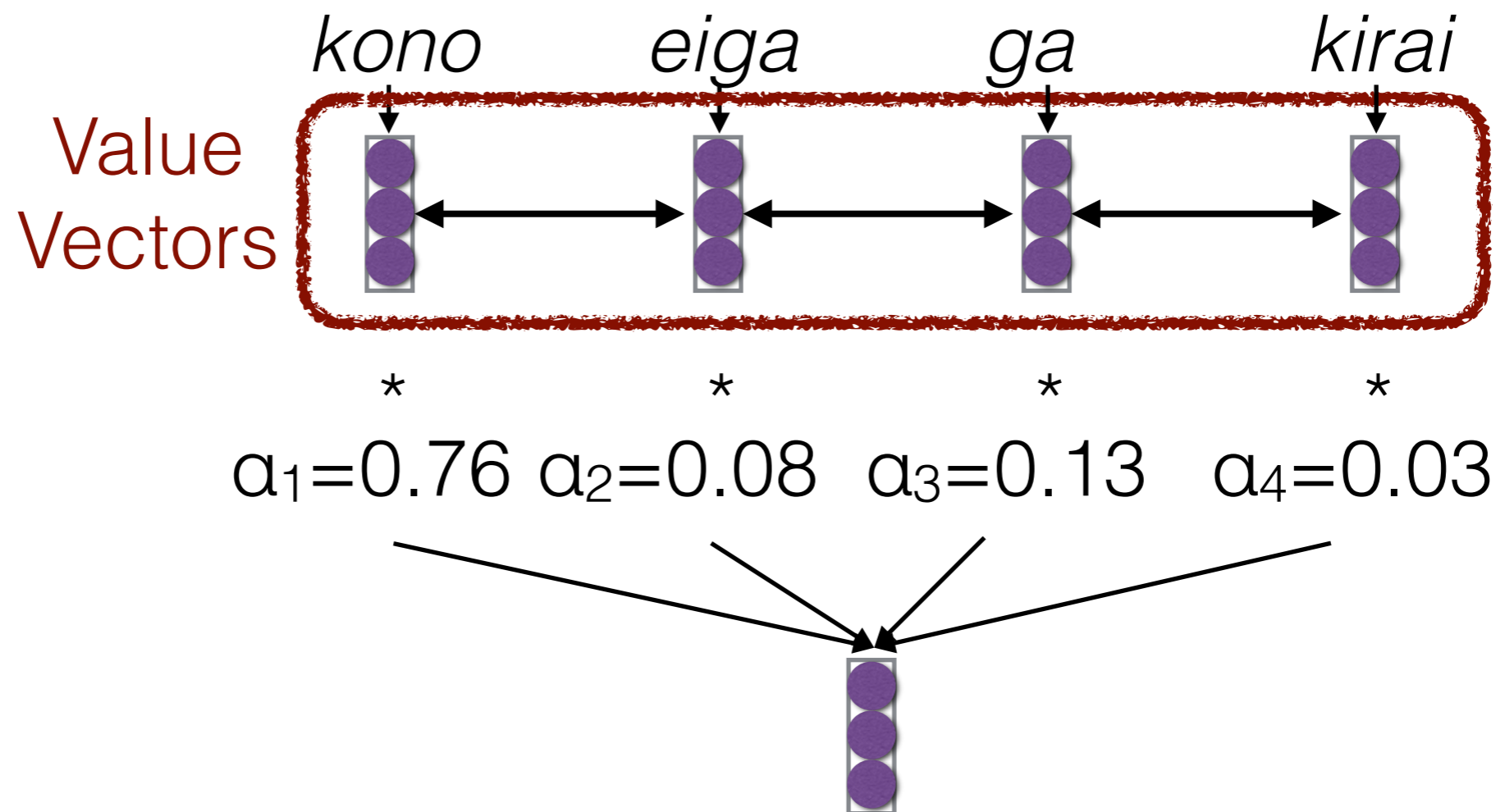
# Calculating Attention (1)

- Use “query” vector (decoder state) and “key” vectors (all encoder states)
- For each query-key pair, calculate weight
- Normalize to add to one using softmax



# Calculating Attention (2)

- Combine together value vectors (usually encoder states, like key vectors) by taking the weighted sum



- Use this in any part of the model you like





# Attention Score Functions (1)

- $\mathbf{q}$  is the query and  $\mathbf{k}$  is the key
- **Multi-layer Perceptron** (Bahdanau et al. 2015)

$$a(\mathbf{q}, \mathbf{k}) = \mathbf{w}_2^\top \tanh(W_1[\mathbf{q}; \mathbf{k}])$$

- Flexible, often very good with large data
- **Bilinear** (Luong et al. 2015)

$$a(\mathbf{q}, \mathbf{k}) = \mathbf{q}^\top W \mathbf{k}$$

# Attention Score Functions (2)

- **Dot Product** (Luong et al. 2015)

$$a(\mathbf{q}, \mathbf{k}) = \mathbf{q}^\top \mathbf{k}$$

- No parameters! But requires sizes to be the same.
- **Scaled Dot Product** (Vaswani et al. 2017)
  - Problem: scale of dot product increases as dimensions get larger
  - Fix: scale by size of the vector

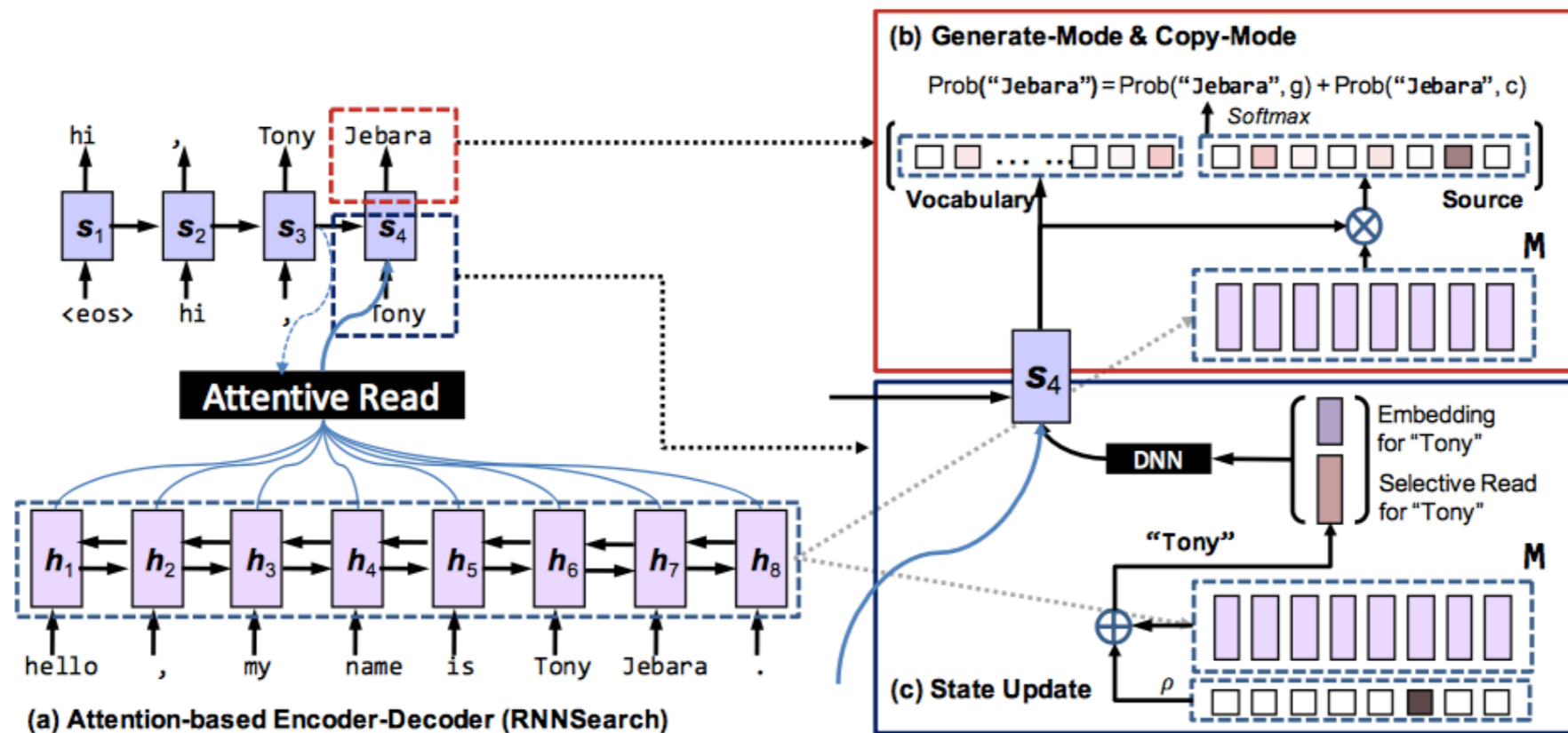
$$a(\mathbf{q}, \mathbf{k}) = \frac{\mathbf{q}^\top \mathbf{k}}{\sqrt{|\mathbf{k}|}}$$

Let's Try it Out!  
`attention.py`

What do we Attend To?

# Input Sentence

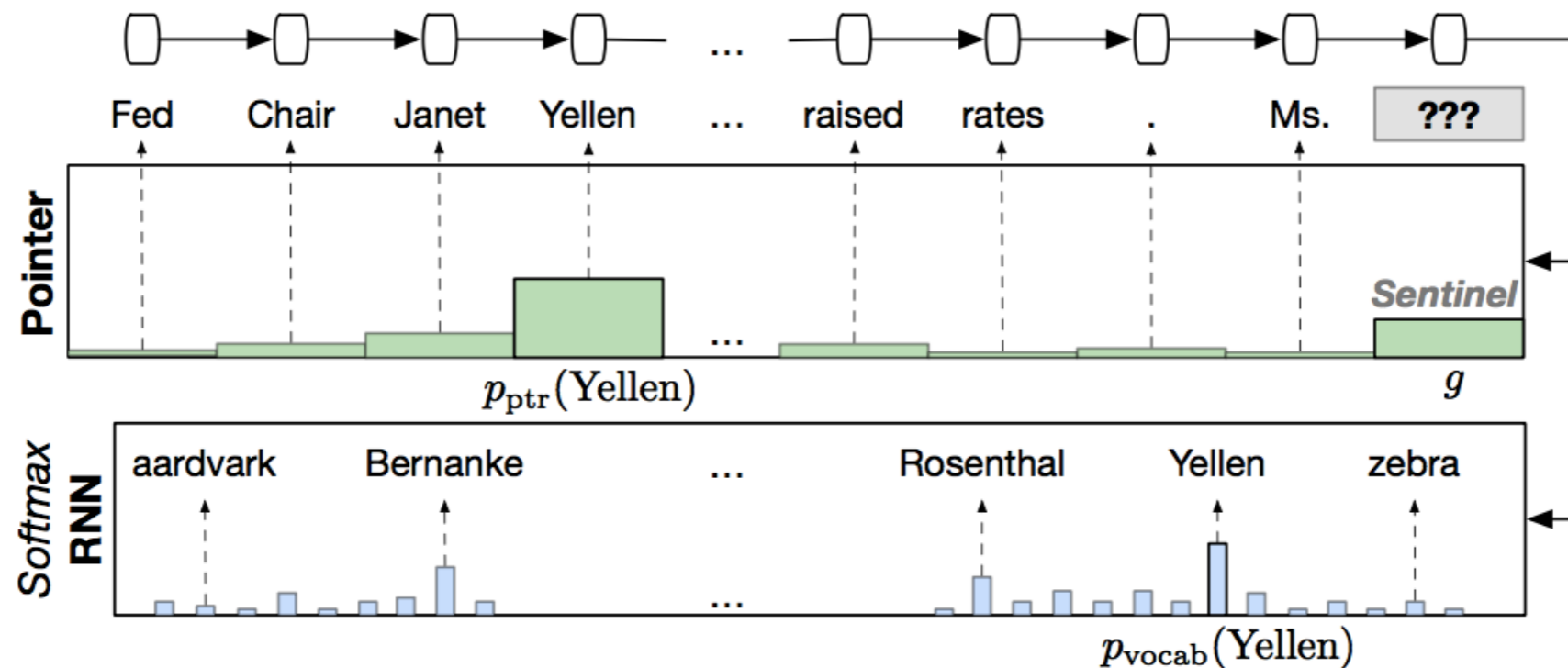
- Like the previous explanation
- But also, more directly
- **Copying mechanism** (Gu et al. 2016)



- **Lexicon bias** (Arthur et al. 2016)

# Previously Generated Things

- In language modeling, attend to the previous words (Merity et al. 2016)

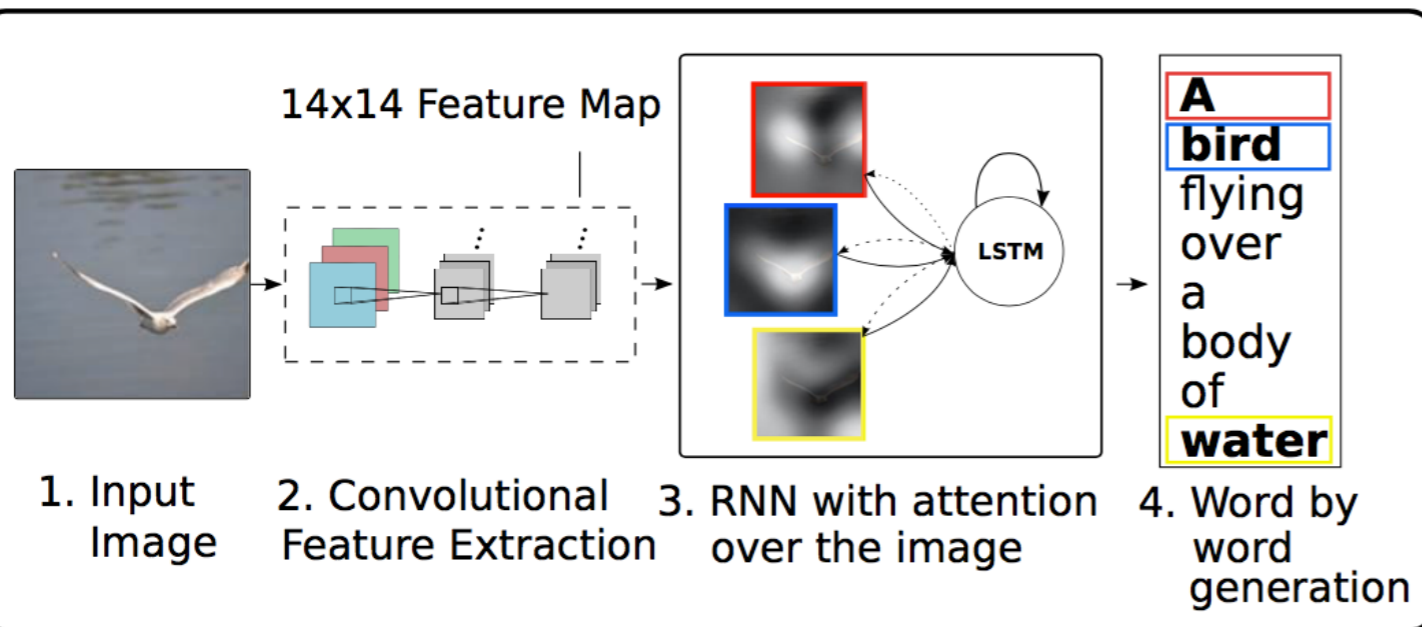


$$p(\text{Yellen}) = g p_{\text{vocab}}(\text{Yellen}) + (1 - g) p_{\text{ptr}}(\text{Yellen})$$

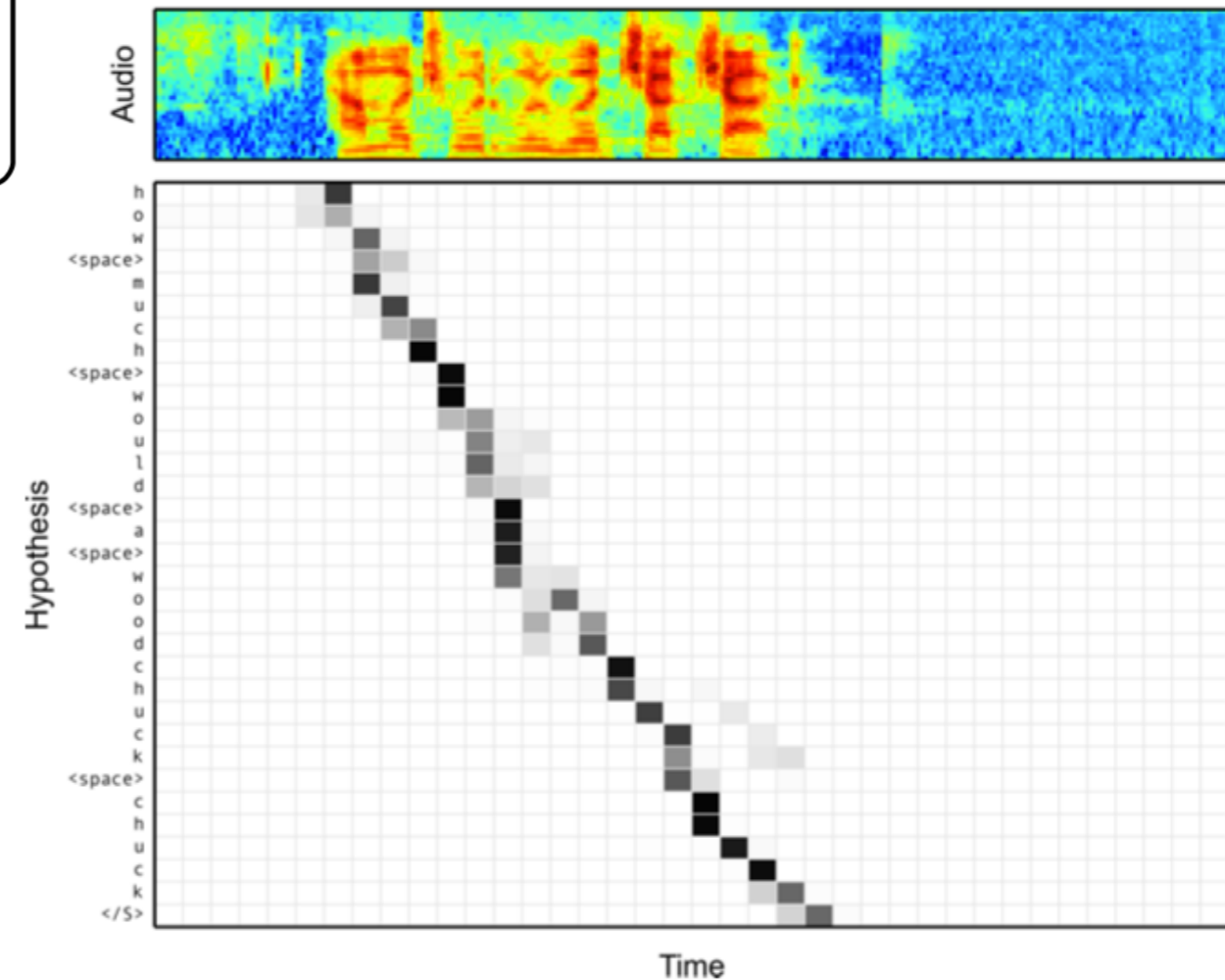
- In translation, attend to either input or previous output (Vaswani et al. 2017)

# Various Modalities

- Images (Xu et al. 2015)



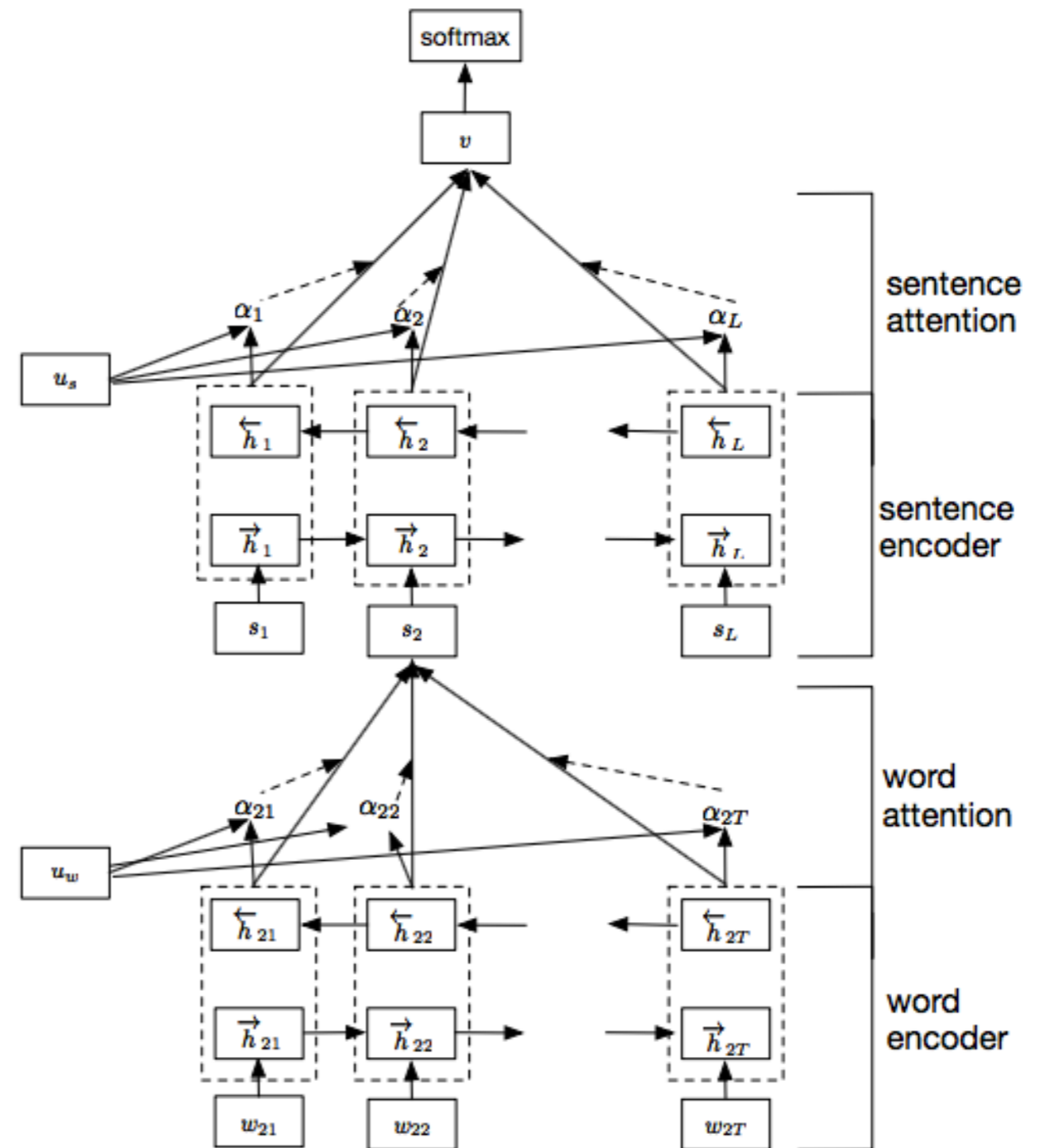
- Speech (Chan et al. 2015)



# Hierarchical Structures

(Yang et al. 2016)

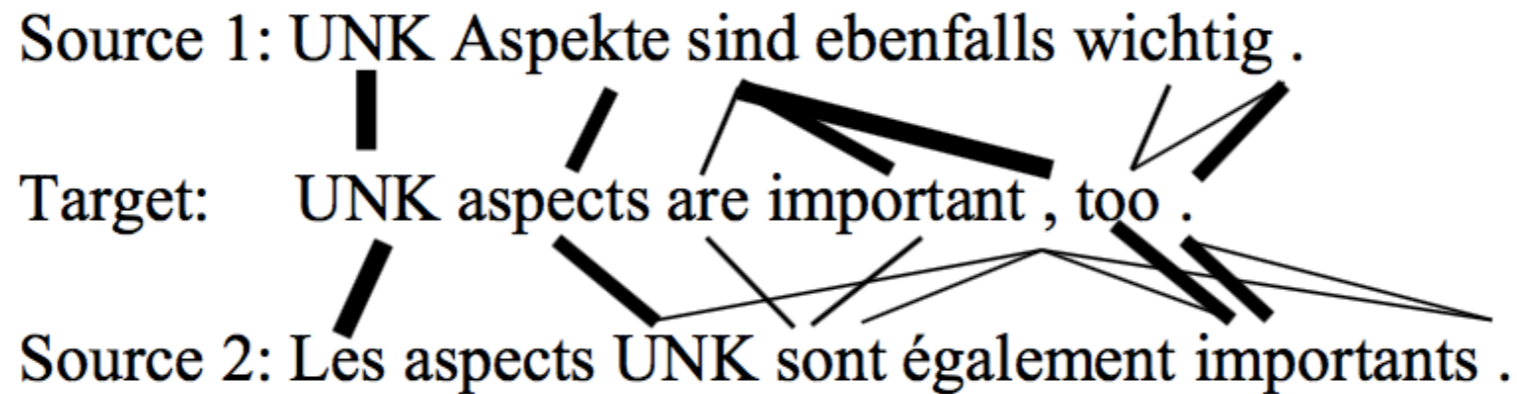
- Encode with attention over each sentence, then attention over each sentence in the document



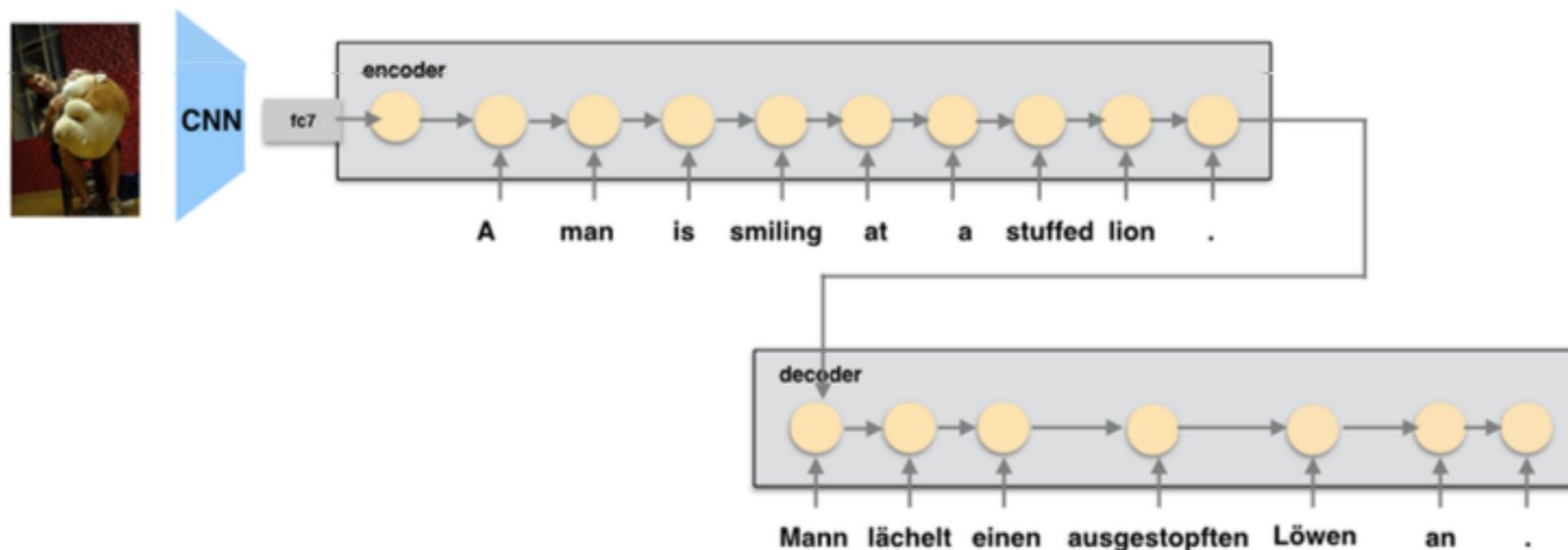


# Multiple Sources

- Attend to multiple sentences (Zoph et al. 2015)



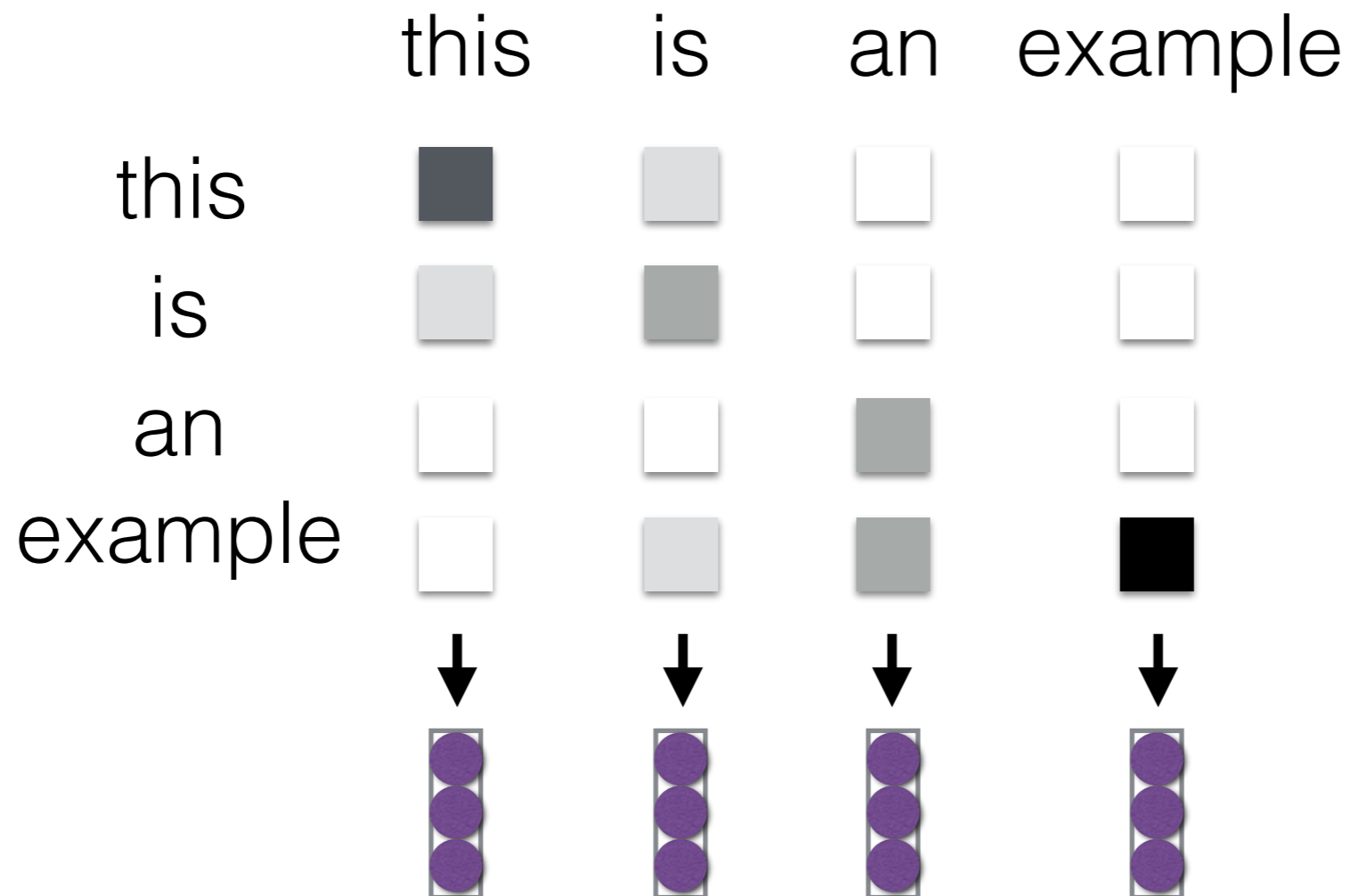
- Libovicky and Helcl (2017) compare multiple strategies
- Attend to a sentence and an image (Huang et al. 2016)



# Intra-Attention / Self Attention

(Cheng et al. 2016)

- Each element in the sentence attends to other elements → context sensitive encodings!



# Improvements to Attention

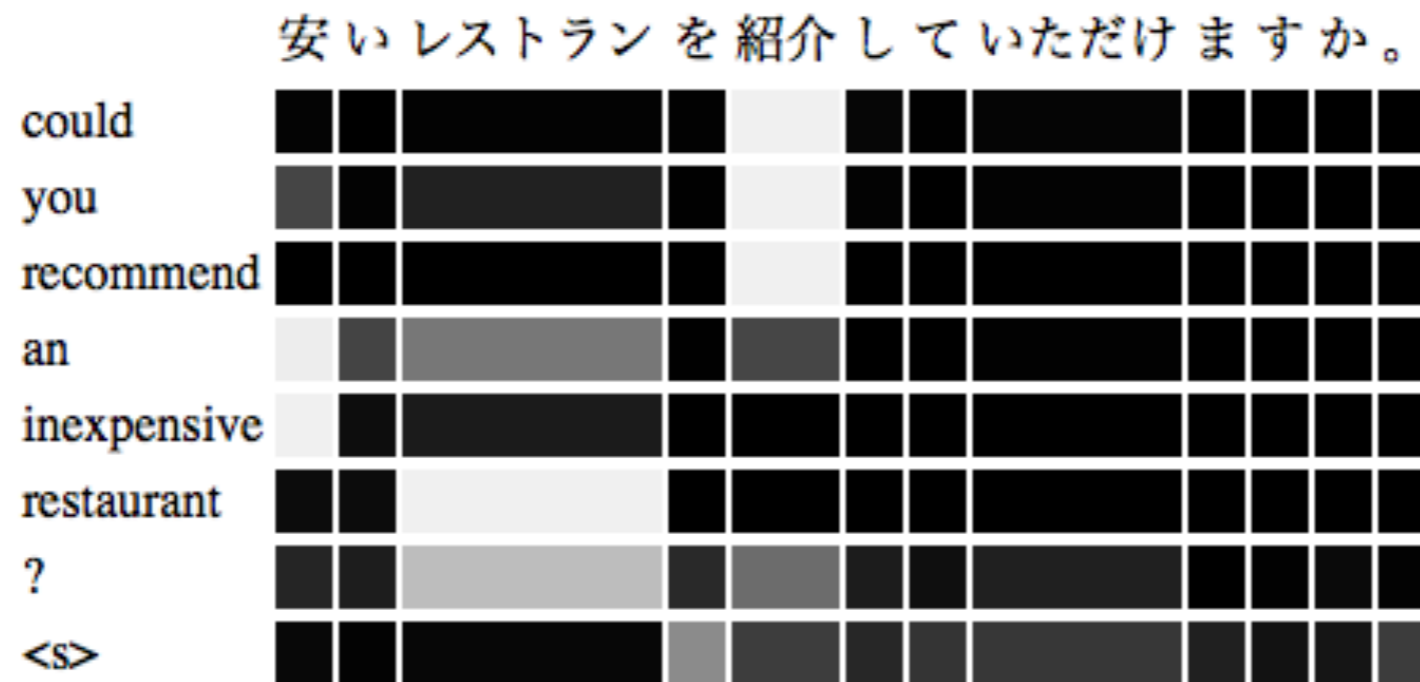
# Coverage

- **Problem:** Neural models tends to drop or repeat content
- **Solution:** Model how many times words have been covered
  - Impose a penalty if attention not approx. 1 (Cohn et al. 2015)
  - Add embeddings indicating coverage (Mi et al. 2016)

# Incorporating Markov Properties

(Cohn et al. 2015)

- **Intuition:** attention from last time tends to be correlated with attention this time



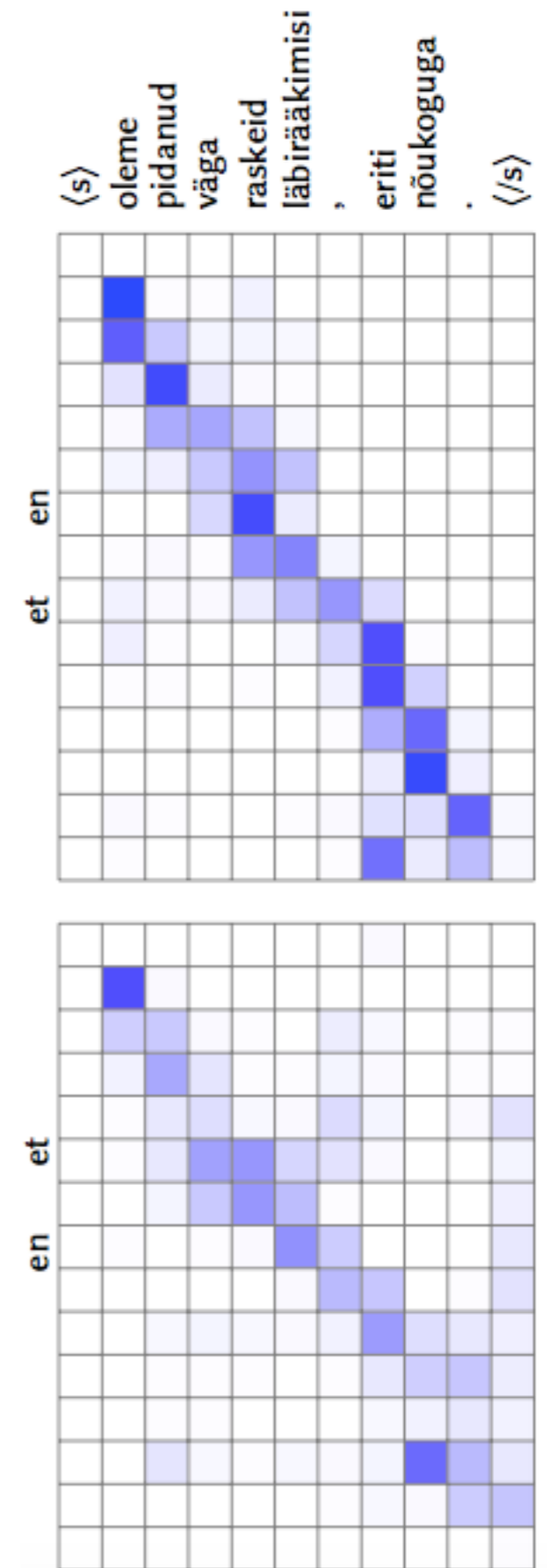
- Add information about the last attention when making the next decision

# Bidirectional Training

(Cohn et al. 2015)

- **Intuition:** Our attention should be roughly similar in forward and backward directions
- **Method:** Train so that we get a bonus based on the trace of the matrix product for training in both directions

$$\text{tr}(A_{X \rightarrow Y} A_{Y \rightarrow X}^T)$$



# Supervised Training

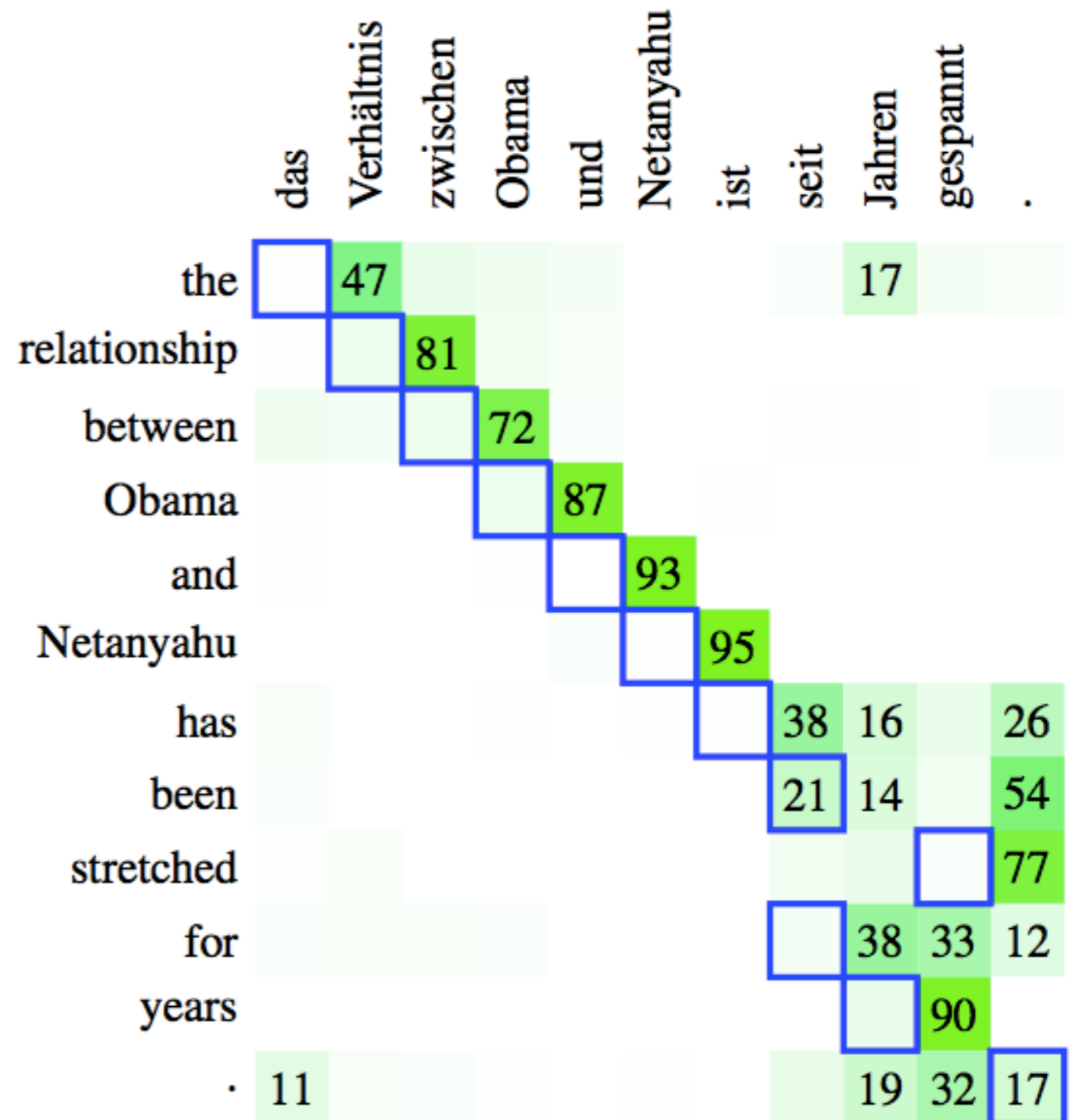
(Mi et al. 2016)

- Sometimes we can get “gold standard” alignments *a-priori*
  - Manual alignments
  - Pre-trained with strong alignment model
- **Train the model to match** these strong alignments

# Attention is not Alignment!

(Koehn and Knowles 2017)

- Attention is often blurred
- Attention is often off by one





# Specialized Attention Varieties

# Hard Attention

- Instead of a soft interpolation, make a **zero-one decision** about where to attend (Xu et al. 2015)
  - Harder to train, requires methods such as reinforcement learning (see later classes)
- Perhaps this helps interpretability? (Lei et al. 2016)

## *Review*

the beer was n't what i expected, and i'm not sure it's "true to style", but i thought it was delicious. **a very pleasant ruby red-amber color** with a relatively brilliant finish, but a limited amount of carbonation, from the look of it. aroma is what i think an amber ale should be - a nice blend of caramel and happiness bound together.

## *Ratings*

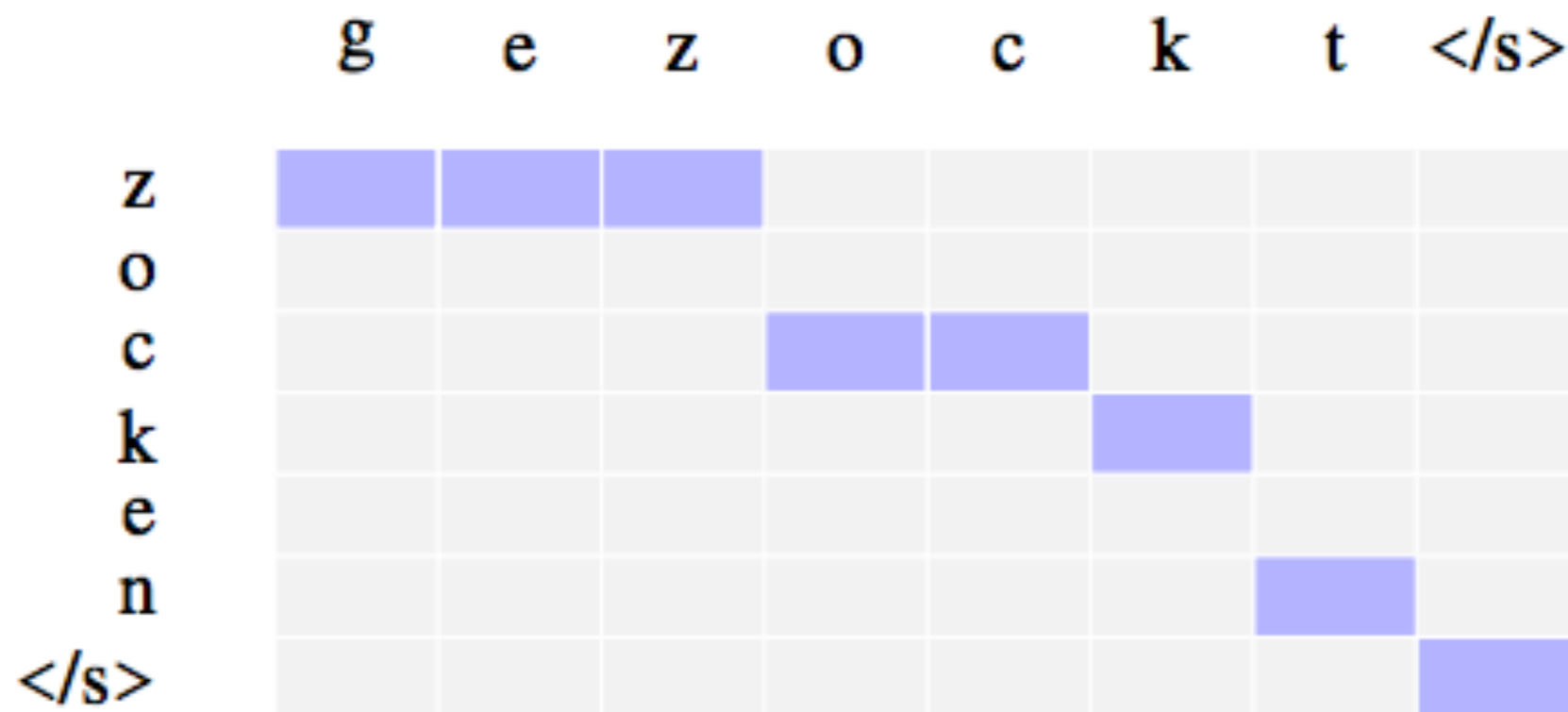
**Look: 5 stars**

**Smell: 4 stars**

# Monotonic Attention

(e.g. Yu et al. 2016)

- In some cases, we might know the output will be the same order as the input
  - Speech recognition, incremental translation, morphological inflection (?), summarization (?)

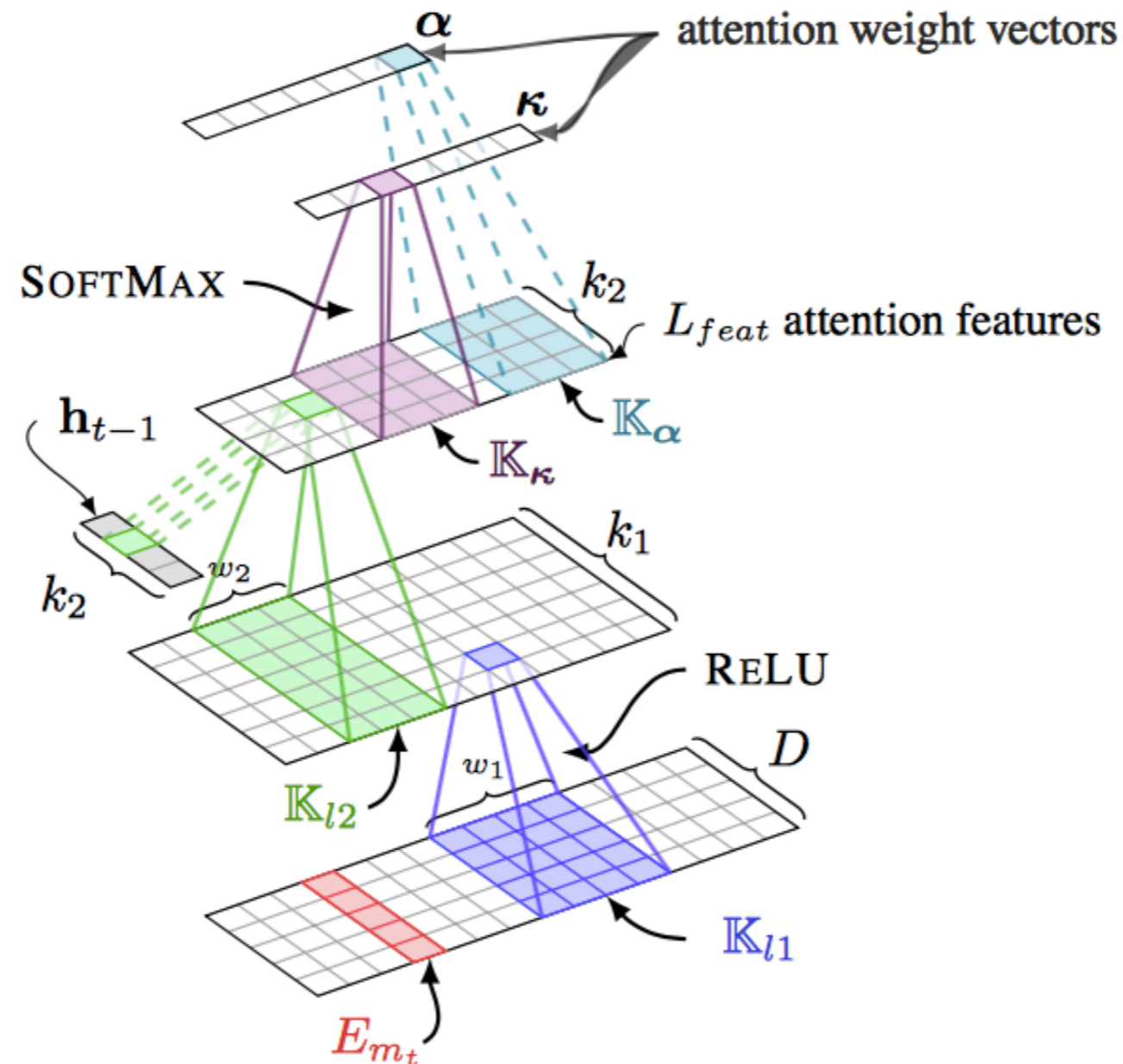


- **Basic idea:** hard decisions about whether to read more

# Convolutional Attention

(Allamanis et al. 2016)

- **Intuition:** we might want to be able to attend to “the word after ‘Mr.’”, etc.



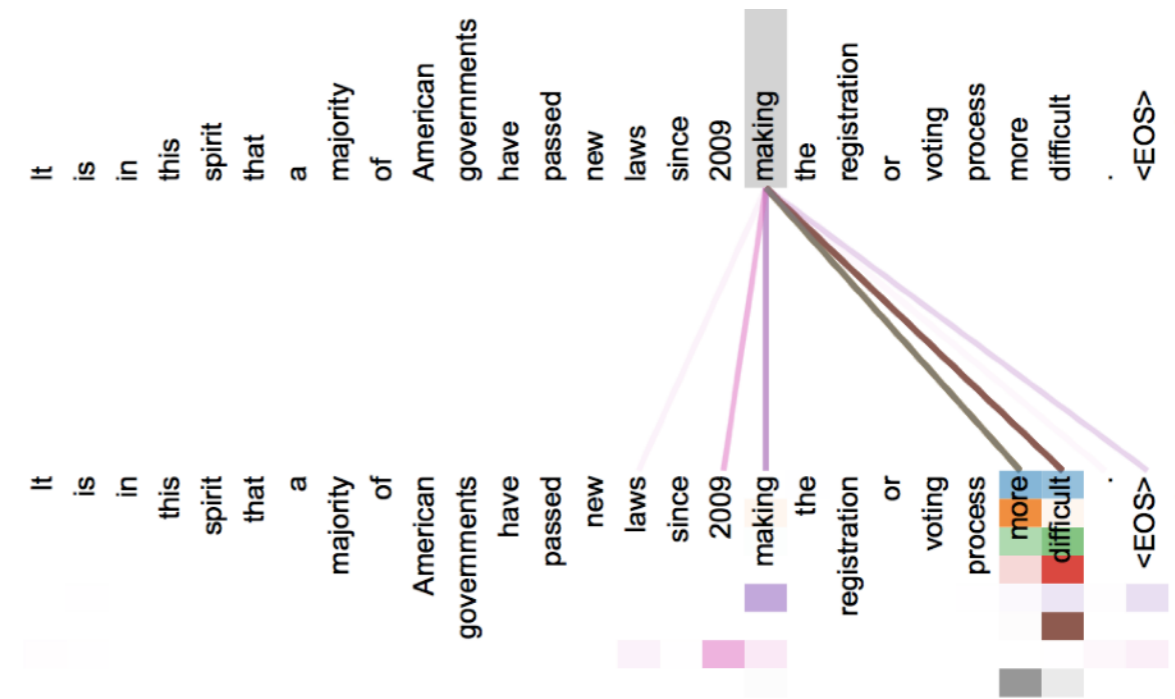
# Multi-headed Attention

- **Idea:** multiple attention “heads” focus on different parts of the sentence

- e.g. Different heads for “copy” vs regular (Allamanis et al. 2016)

Target		Attention Vectors	$\lambda$
$m_1$	set	$\alpha = \langle s \rangle \{ \text{this} . \text{use Browser Cache} = \text{use Browser Cache} ; \} \langle /s \rangle$ $\kappa = \langle s \rangle \{ \text{this} . \text{use Browser Cache} = \text{use Browser Cache} ; \} \langle /s \rangle$	0.012
$m_2$	use	$\alpha = \langle s \rangle \{ \text{this} . \text{use Browser Cache} = \text{use Browser Cache} ; \} \langle /s \rangle$ $\kappa = \langle s \rangle \{ \text{this} . \text{use Browser Cache} = \text{use Browser Cache} ; \} \langle /s \rangle$	0.974
$m_3$	browser	$\alpha = \langle s \rangle \{ \text{this} . \text{use Browser Cache} = \text{use Browser Cache} ; \} \langle /s \rangle$ $\kappa = \langle s \rangle \{ \text{this} . \text{use Browser Cache} = \text{use Browser Cache} ; \} \langle /s \rangle$	0.969
$m_4$	cache	$\alpha = \langle s \rangle \{ \text{this} . \text{use Browser Cache} = \text{use Browser Cache} ; \} \langle /s \rangle$ $\kappa = \langle s \rangle \{ \text{this} . \text{use Browser Cache} = \text{use Browser Cache} ; \} \langle /s \rangle$	0.583
$m_5$	END	$\alpha = \langle s \rangle \{ \text{this} . \text{use Browser Cache} = \text{use Browser Cache} ; \} \langle /s \rangle$ $\kappa = \langle s \rangle \{ \text{this} . \text{use Browser Cache} = \text{use Browser Cache} ; \} \langle /s \rangle$	0.066

- Or multiple independently learned heads (Vaswani et al. 2017)



- Or one head for every hidden node! (Choi et al. 2018)

# Is Attention Explanation?

- Attention is not explanation  
(Jain and Wallace, 2019)

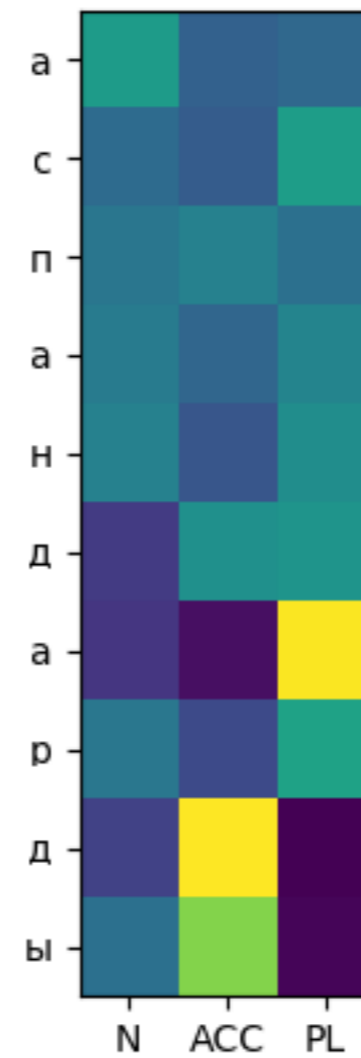
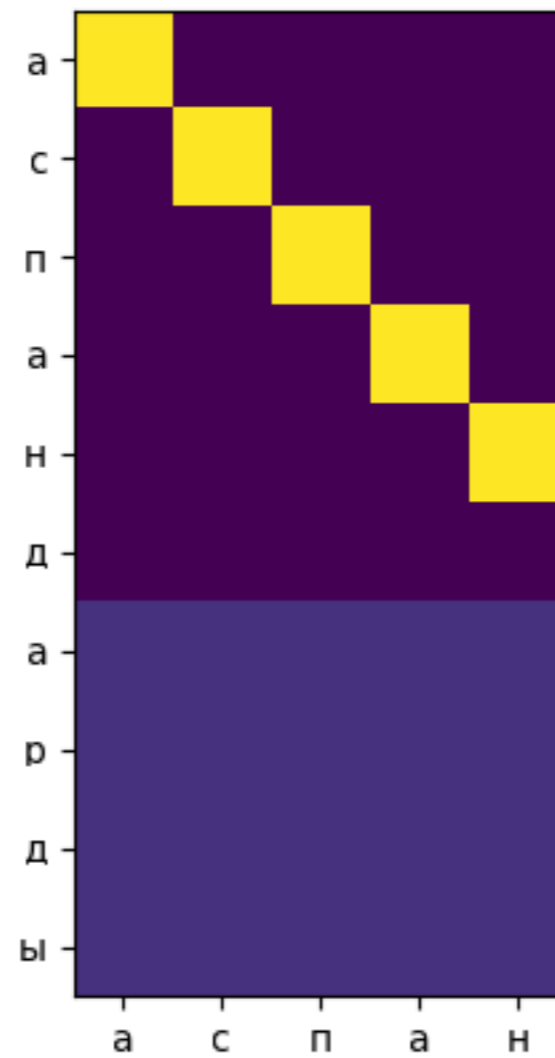
Attention does not correlate well with other, well-established feature importance metrics

- Attention is not not explanation  
(Wiegrefe and Pinter, 2019)

Attention can provide *a plausible* explanation about the link between input and output

— but not *the* explanation: it works in conjunction with all other model components, so it should not be singled-out.

# Examples (Kazakh)



# Examples (Occitan)

