

CS11-711 Advanced NLP

Attention

Graham Neubig



Carnegie Mellon University

Language Technologies Institute

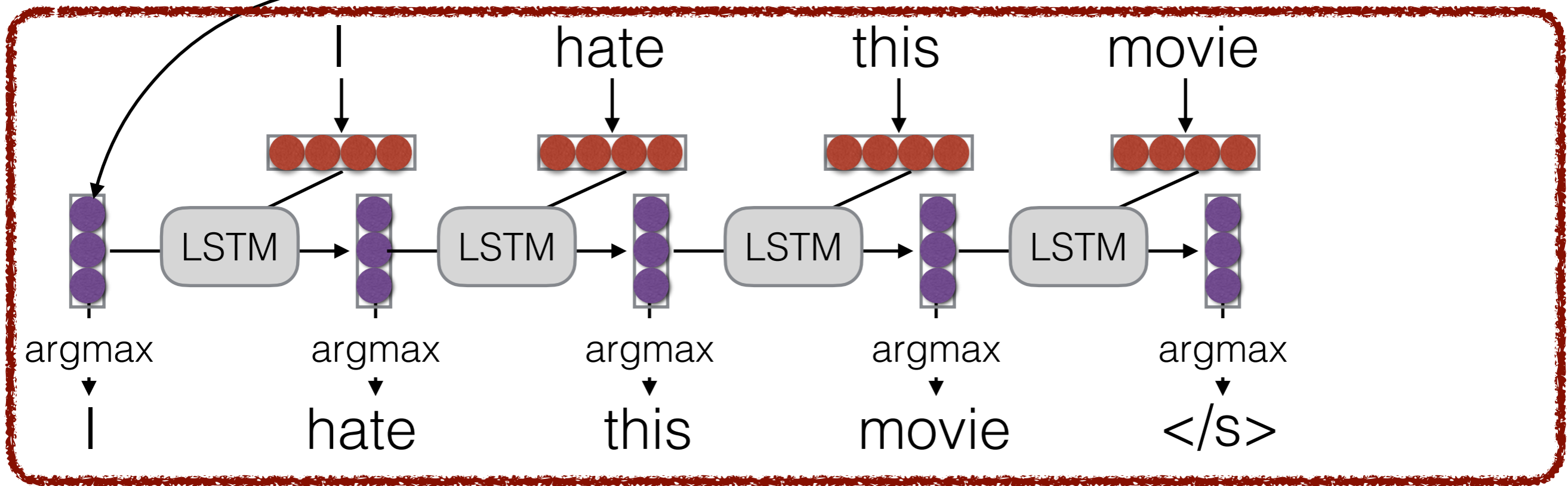
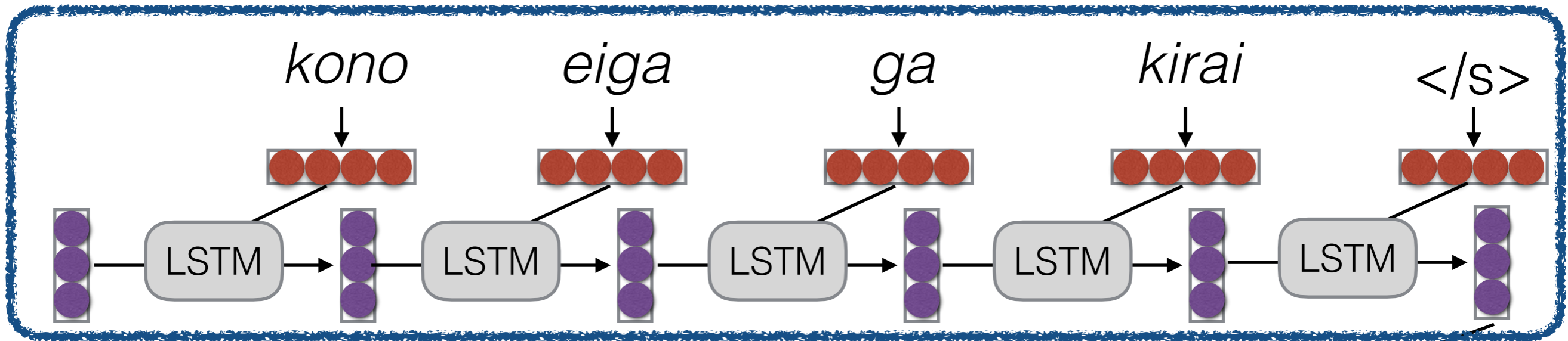
Site

<https://phontron.com/class/anlp2021/>

Encoder-decoder Models

(Sutskever et al. 2014)

Encoder



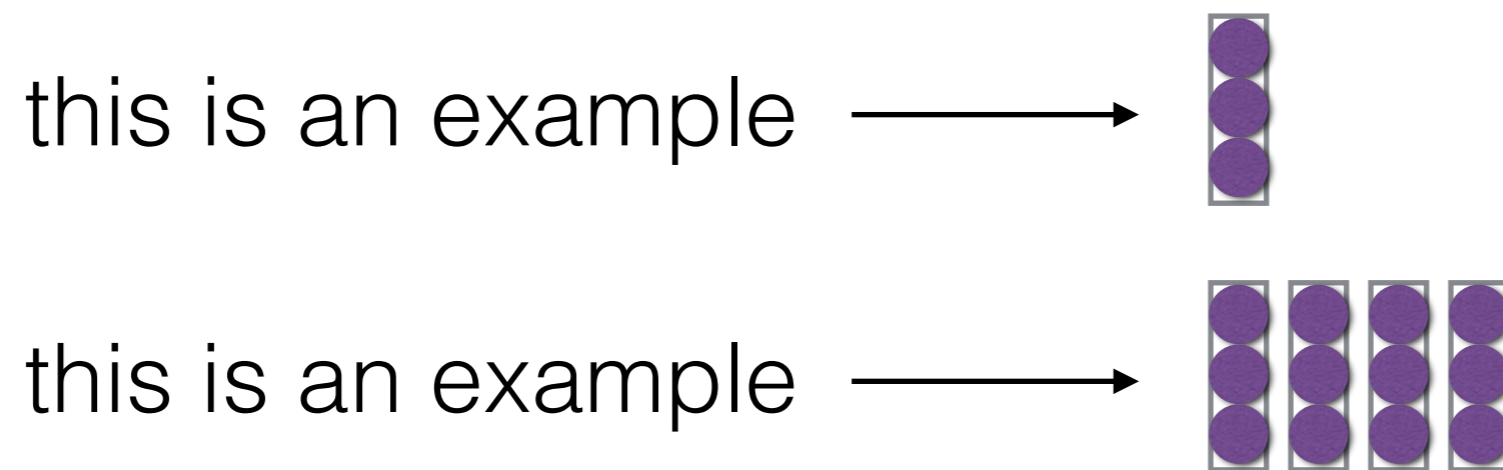
Decoder

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

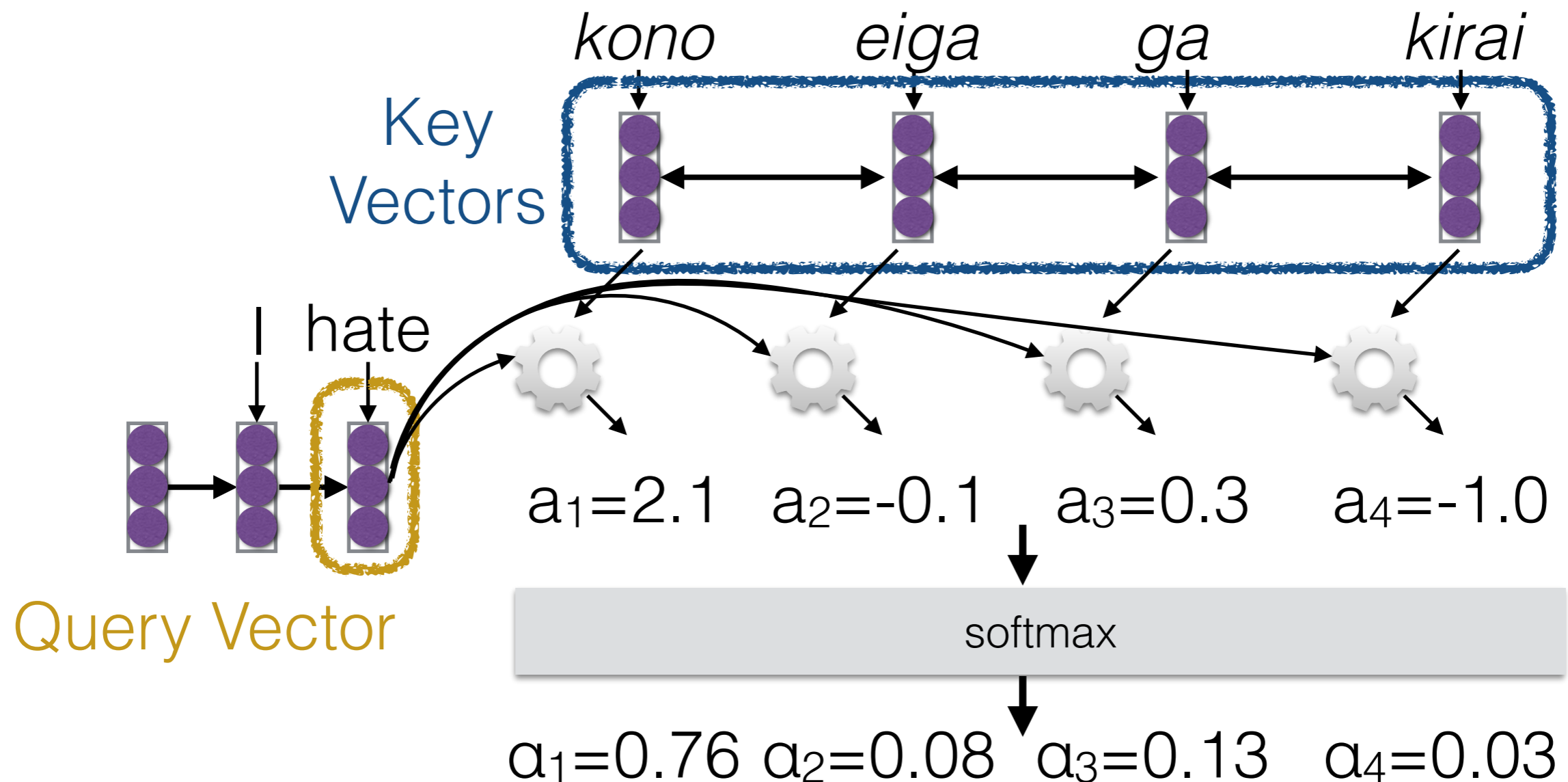
Basic Idea

(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

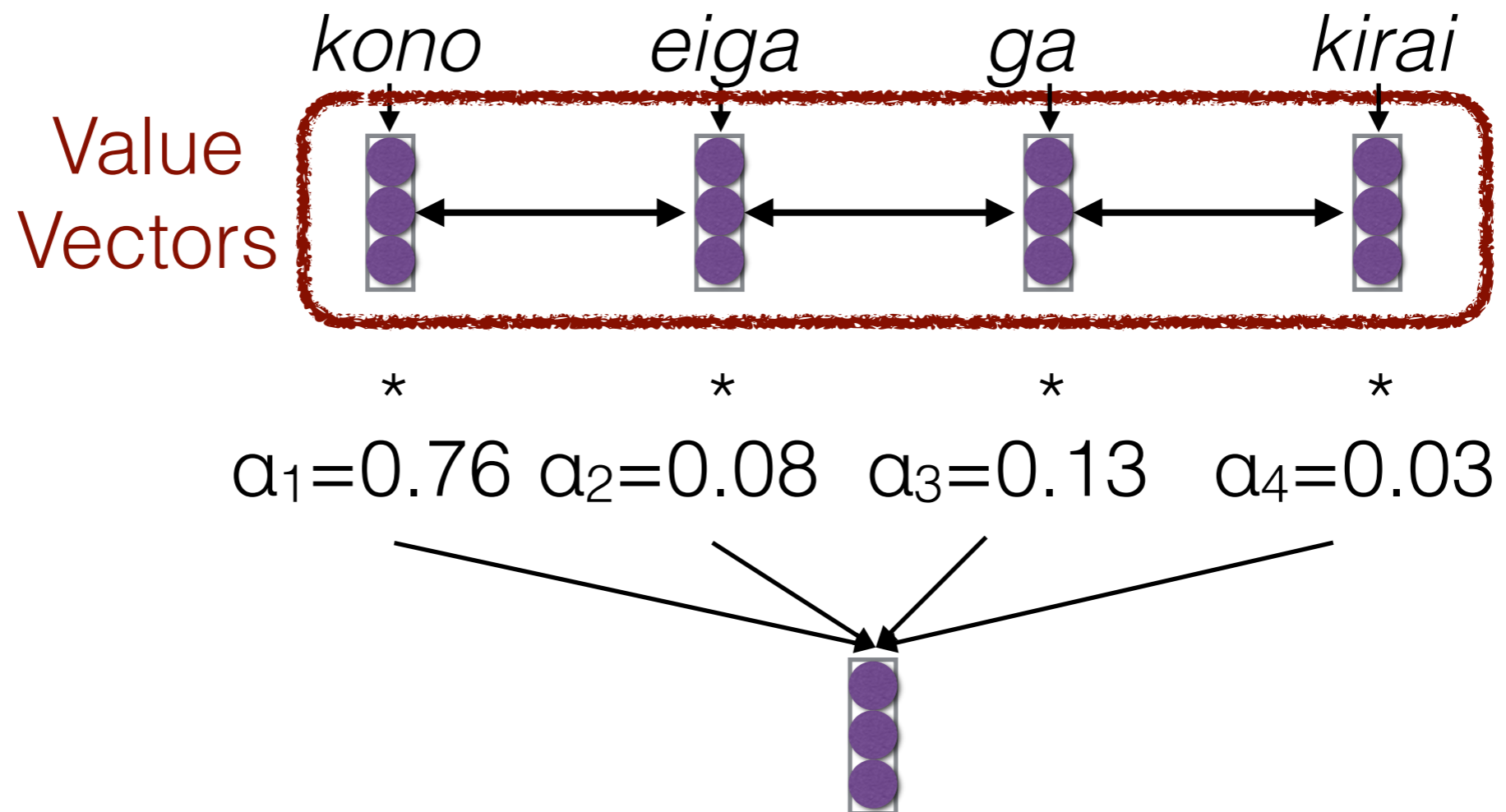
Calculating Attention (1)

- 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

A Graphical Example

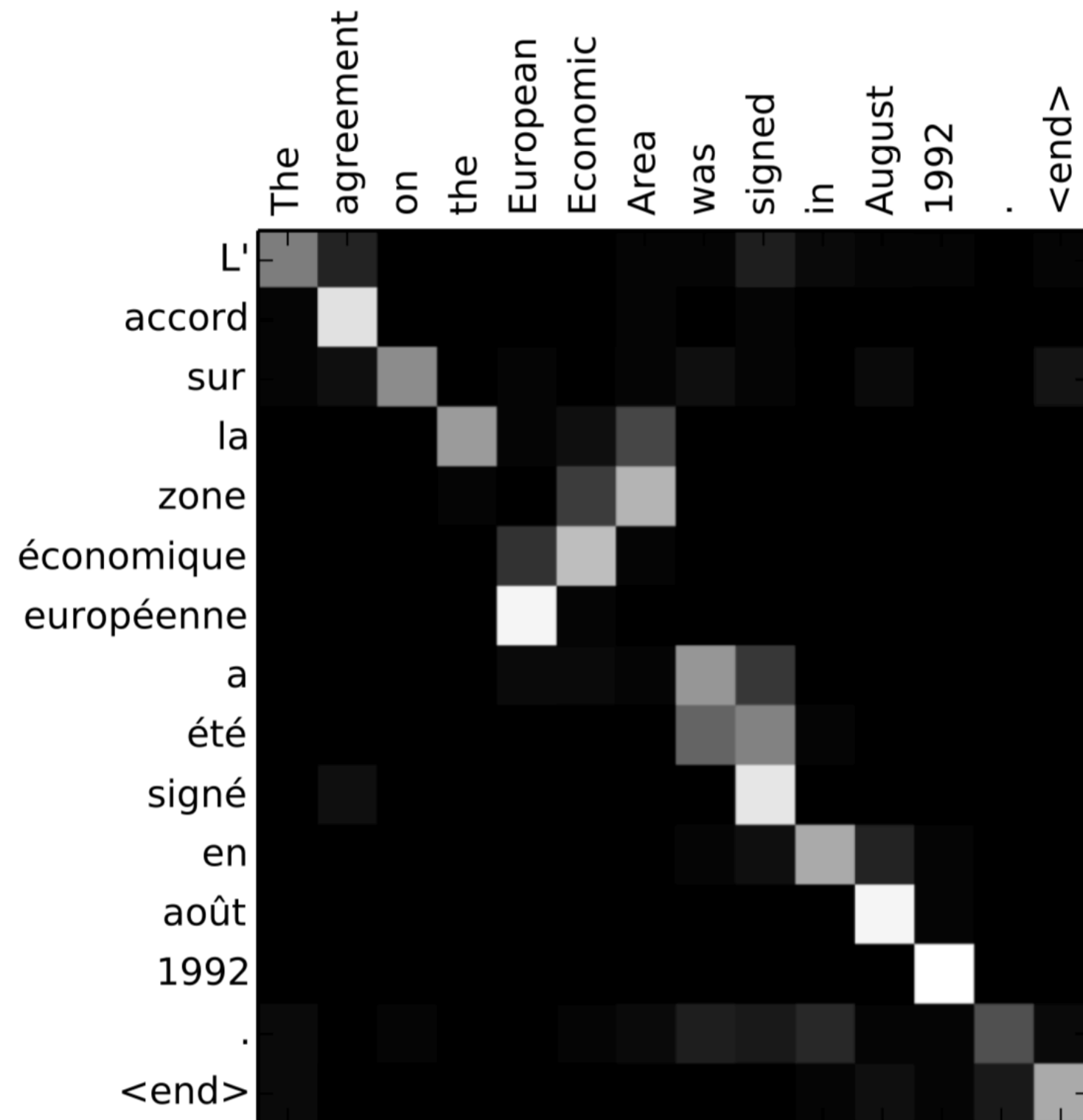


Image from Bahdanau et al. (2015)

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

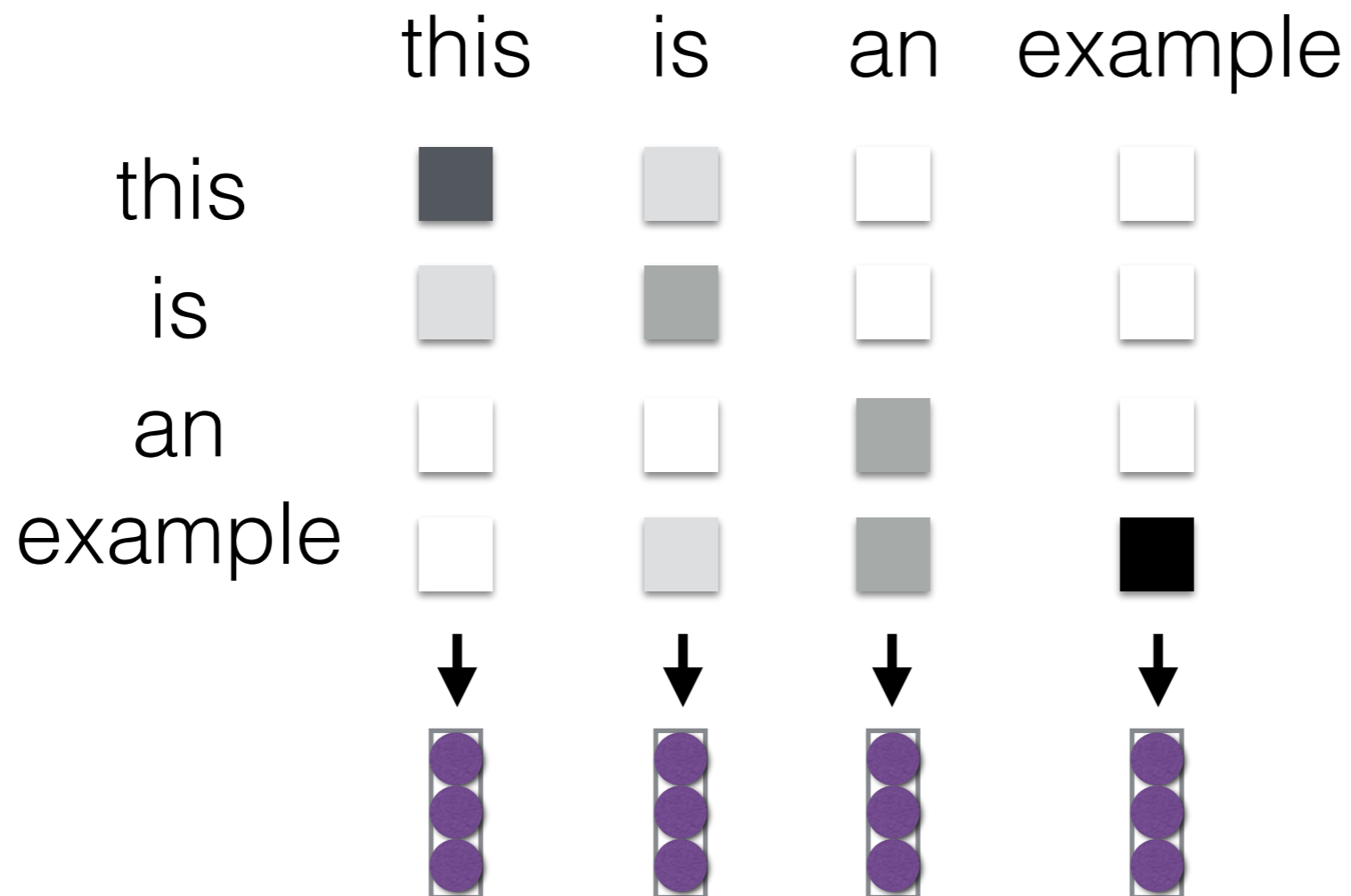
- *Fix:* scale by size of the vector

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

Self Attention

(Cheng et al. 2016, Vaswani et al. 2017)

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



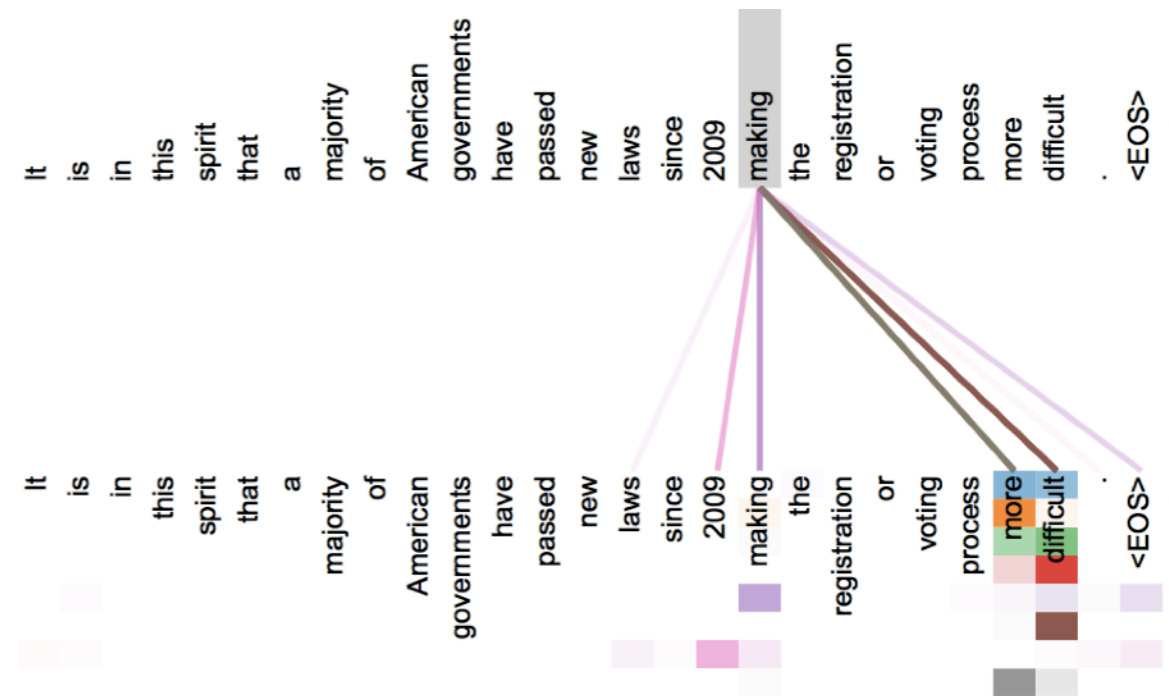
Multi-headed Attention

- **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	λ
m_1	set	$\alpha =$ <code><s> { this . use Browser Cache = use Browser Cache ; } </s></code> $\kappa =$ <code><s> { this . use Browser Cache = use Browser Cache ; } </s></code>	0.012
m_2	use	$\alpha =$ <code><s> { this . use Browser Cache = use Browser Cache ; } </s></code> $\kappa =$ <code><s> { this . use Browser Cache = use Browser Cache ; } </s></code>	0.974
m_3	browser	$\alpha =$ <code><s> { this . use Browser Cache = use Browser Cache ; } </s></code> $\kappa =$ <code><s> { this . use Browser Cache = use Browser Cache ; } </s></code>	0.969
m_4	cache	$\alpha =$ <code><s> { this . use Browser Cache = use Browser Cache ; } </s></code> $\kappa =$ <code><s> { this . use Browser Cache = use Browser Cache ; } </s></code>	0.583
m_5	END	$\alpha =$ <code><s> { this . use Browser Cache = use Browser Cache ; } </s></code> $\kappa =$ <code><s> { this . use Browser Cache = use Browser Cache ; } </s></code>	0.066

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

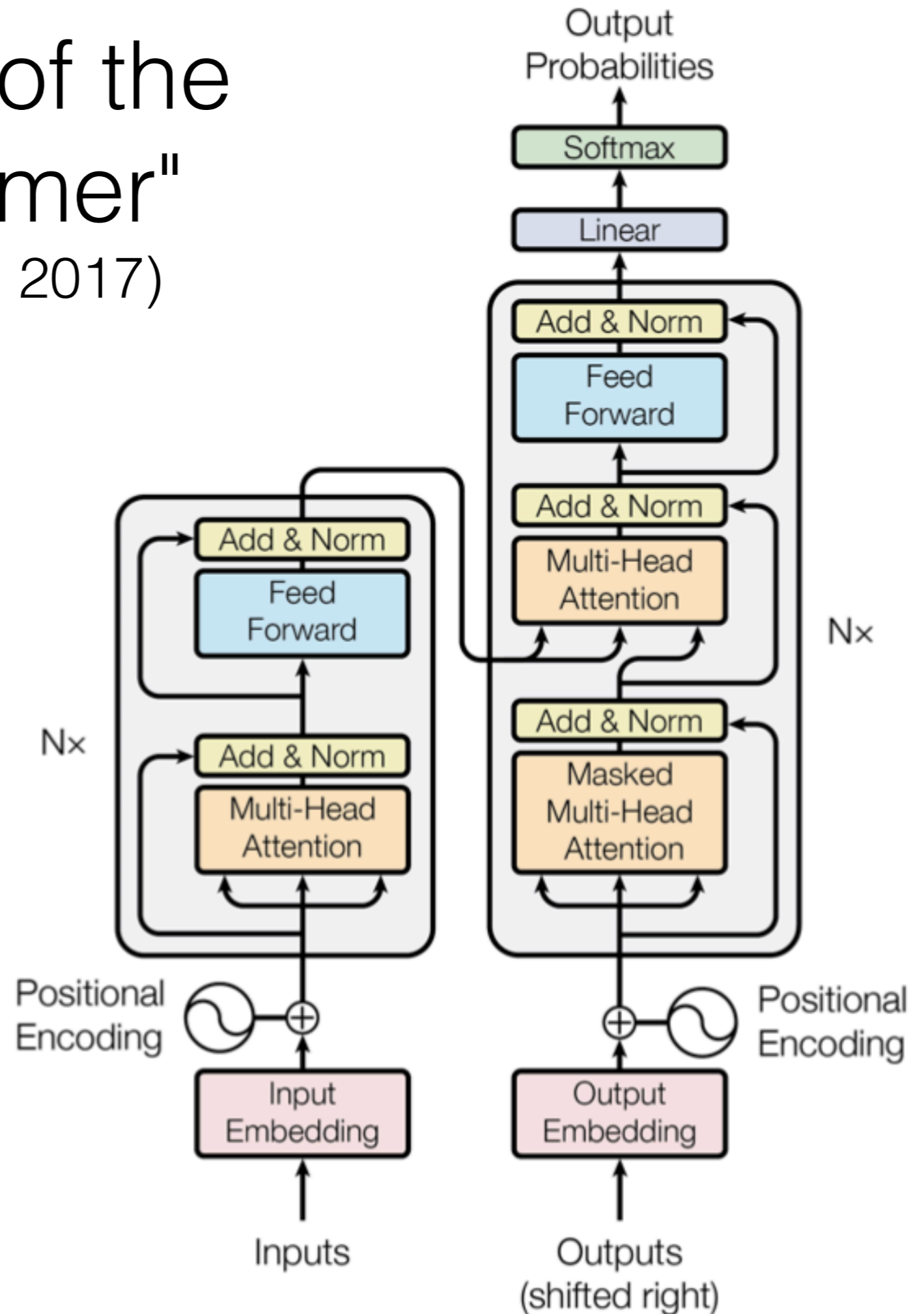


- Or one head for every hidden node! (Choi et al. 2018)

An Interesting Case Study: “Attention is All You Need” (Vaswani et al. 2017)

Summary of the “Transformer” (Vaswani et al. 2017)

- A sequence-to-sequence model based entirely on attention
- Strong results on translation, a wide variety of other tasks
- Fast: only matrix multiplications



Attention Tricks

- **Self Attention:** Each layer combines words with others
- **Multi-headed Attention:** 8 attention heads learned independently
- **Normalized Dot-product Attention:** Remove bias in dot product when using large networks
- **Positional Encodings:** Make sure that even if we don't have RNN, can still distinguish positions

Training Tricks

- **Layer Normalization:** Help ensure that layers remain in reasonable range
- **Specialized Training Schedule:** Adjust default learning rate of the Adam optimizer
- **Label Smoothing:** Insert some uncertainty in the training process
- **Masking for Efficient Training**

Code Walk: The Annotated Transformer

<https://nlp.seas.harvard.edu/2018/04/03/attention.html>

A Caveat: Attention Is Not All You Need?

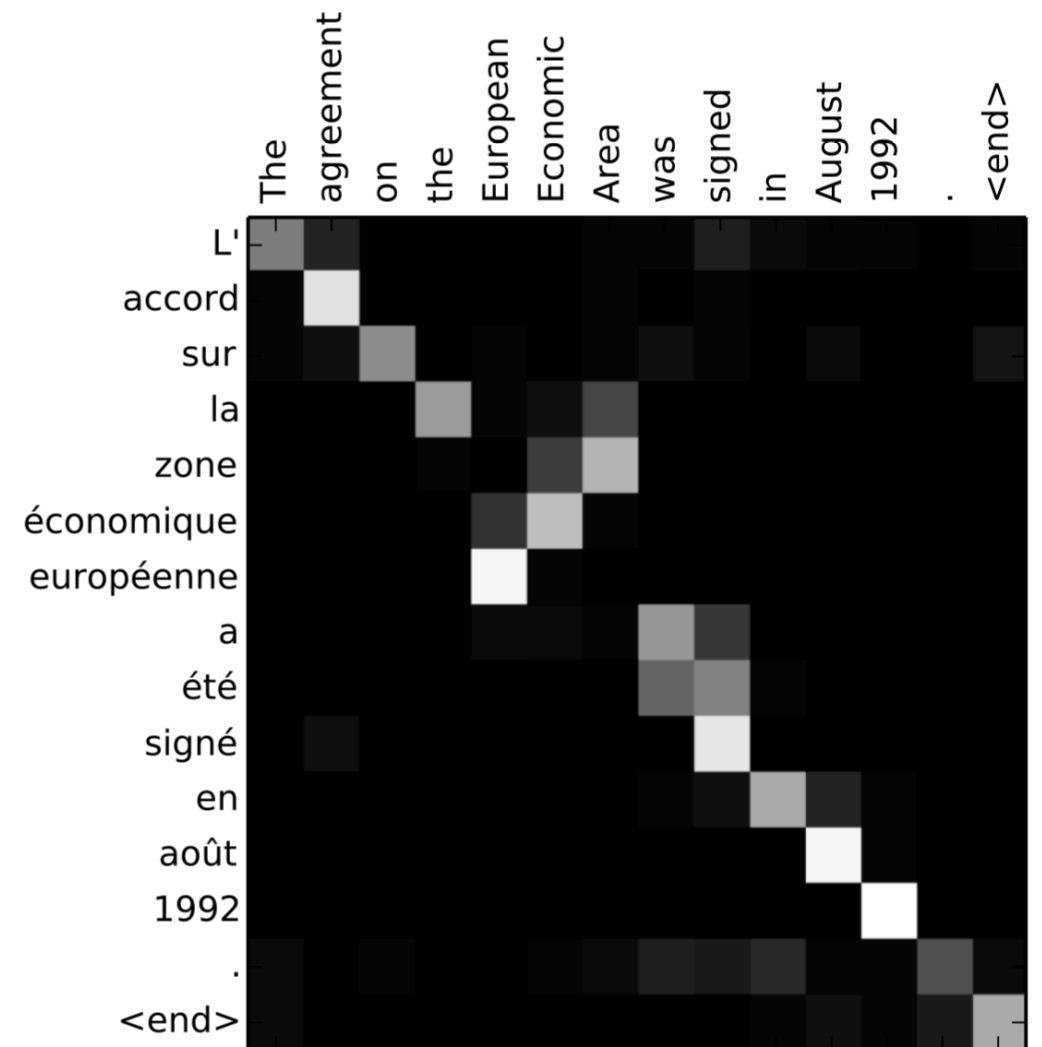
- Transformers are very popular, for good reason, but
- They can be **slow to decode** at test time (Zhang et al. 2018)
- They **don't necessarily outperform RNNs** on the decoder side of seq2seq tasks (Chen et al. 2018)
- They can be **hard to train on small data** (Nguyen and Salazar 2019)
- Use them, but also be aware of limitations!

Better Modeling for Attention

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

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

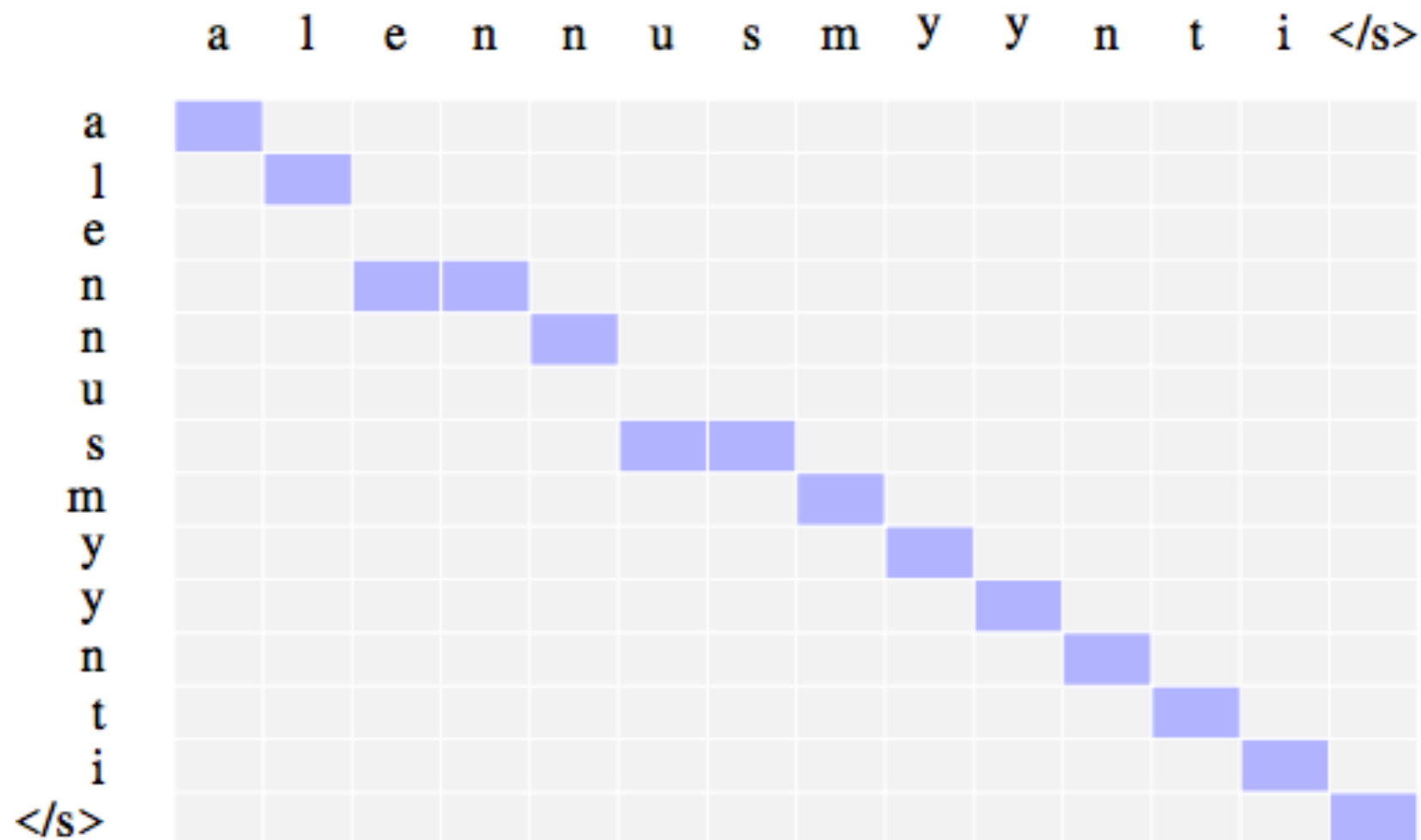
Look: 5 stars

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

Better Training for Attention

Coverage

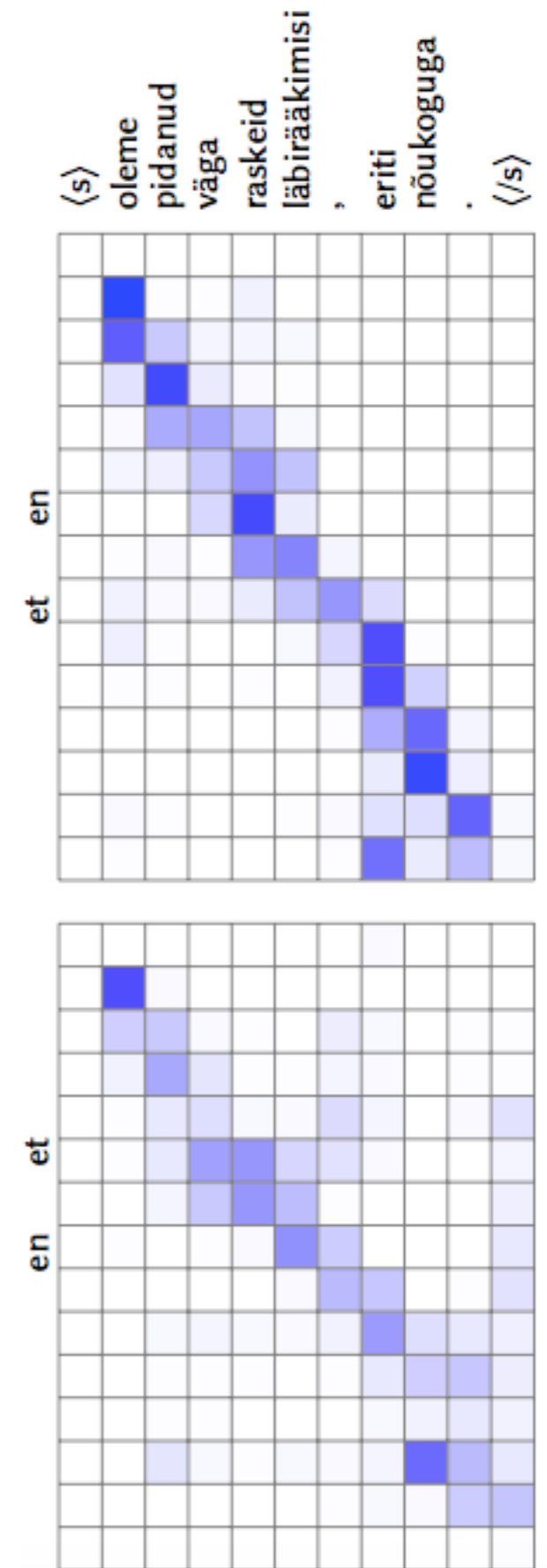
- **Problem:** Neural models tends to drop or repeat content
- **Solution:** Model how many times words have been covered
 - Impose a penalty if attention not approx.1 over each word (Cohn et al. 2015)
 - Add embeddings indicating coverage (Mi et al. 2016)

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

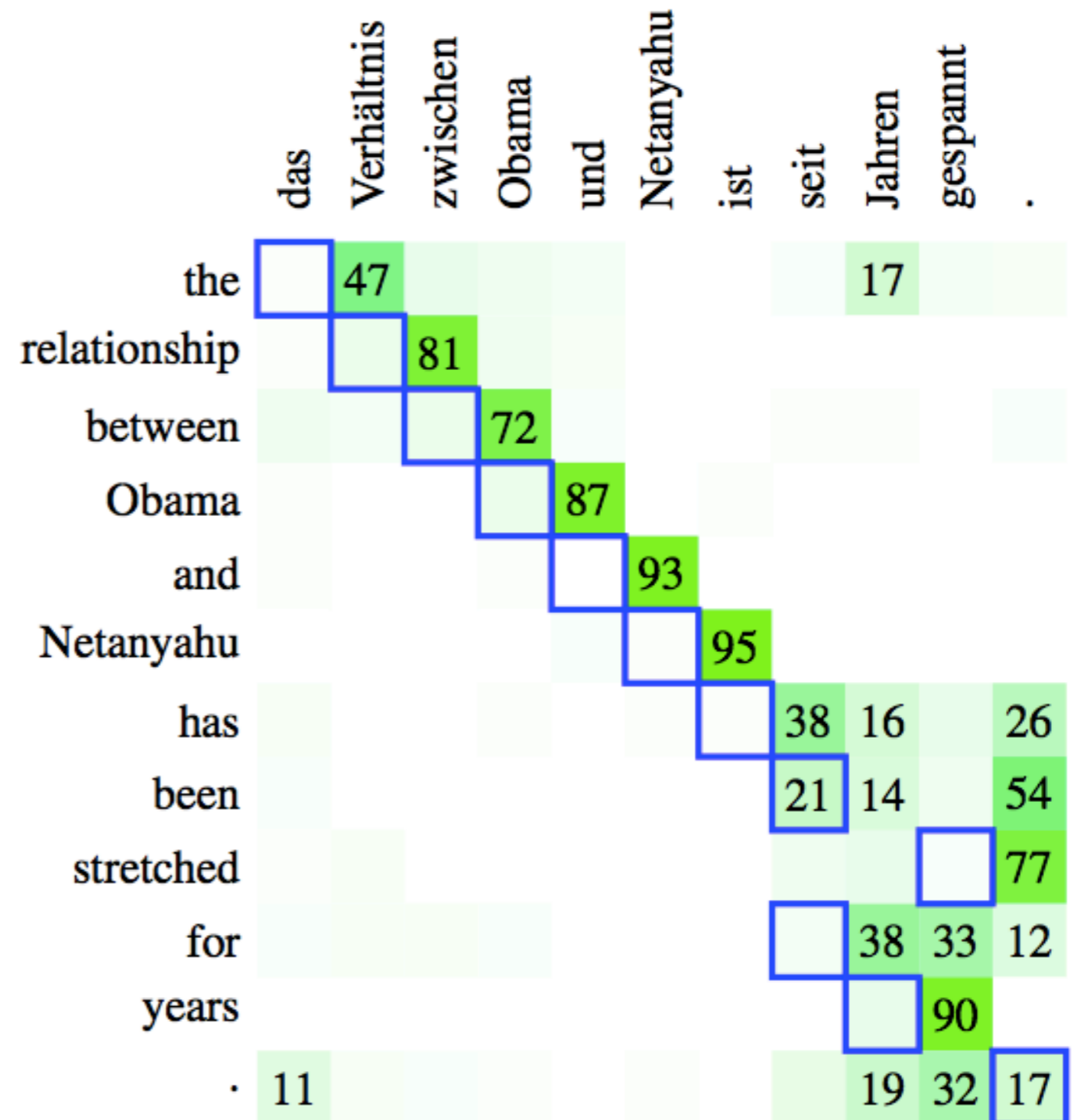
$$\text{tr}(A_{X \rightarrow Y} A_{Y \rightarrow X}^T)$$



Attention is not Alignment!

(Koehn and Knowles 2017)

- Attention is often blurred
- Attention is often off by one
- It can even be manipulated to be non-intuitive! (Jain and Wallace 2019, Pruthi et al. 2020)



Supervised Training

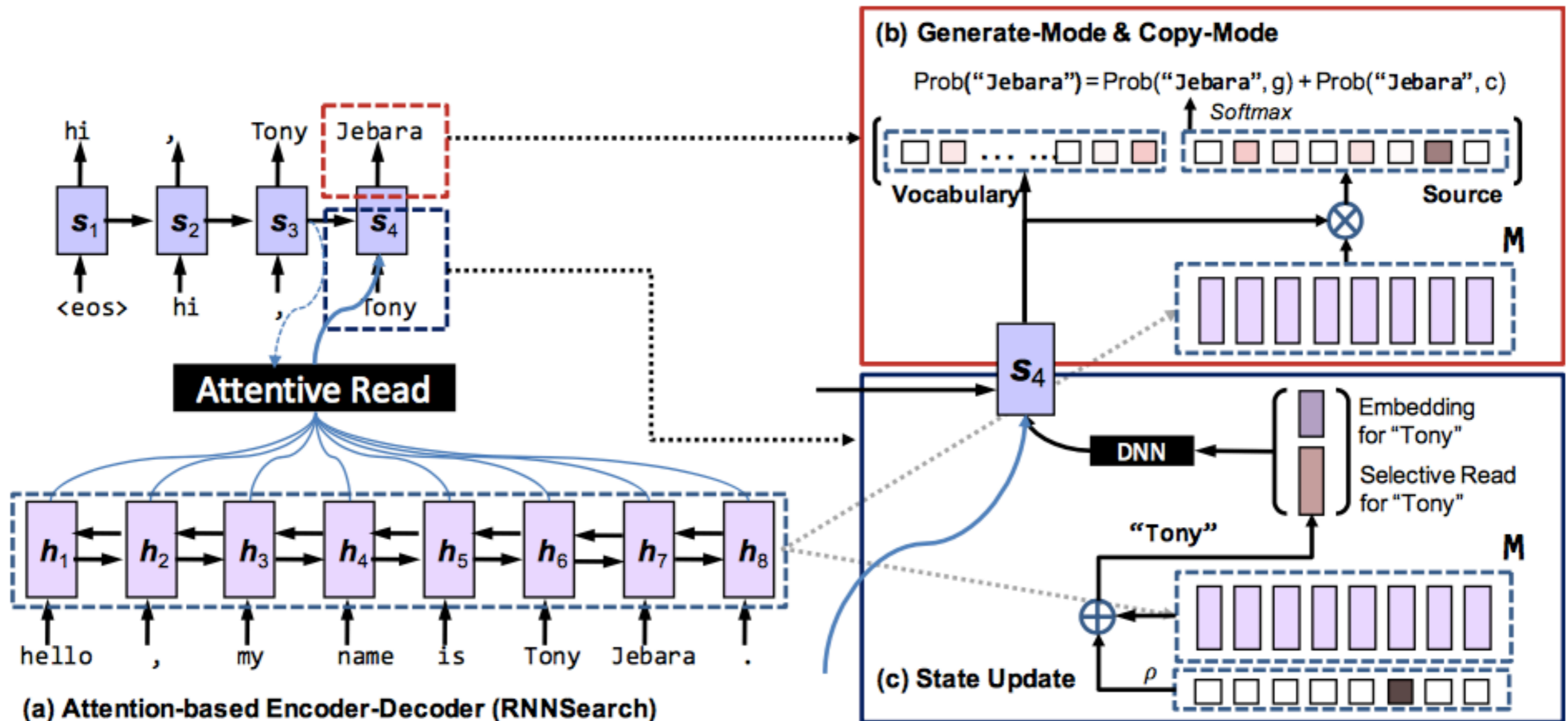
(Mi et al. 2016)

- 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

What Else Can
We Attend To?

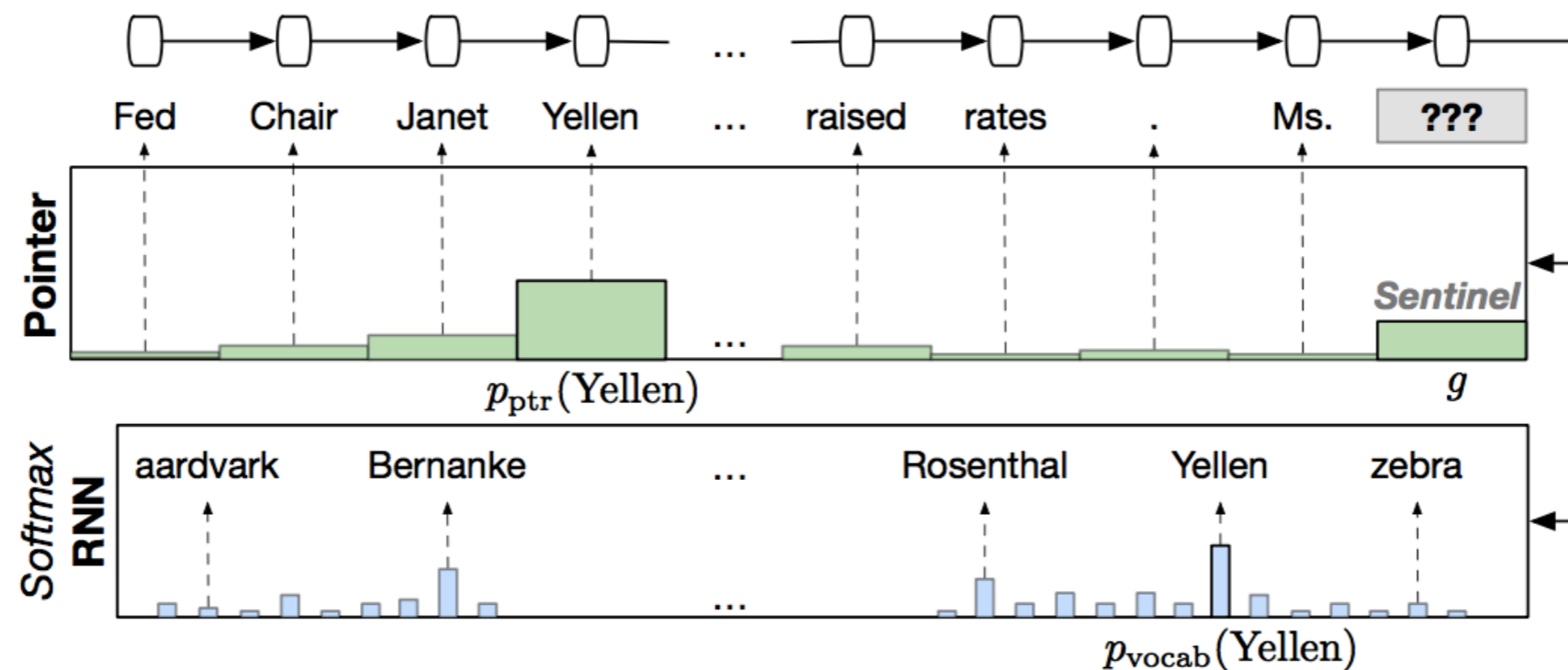
Copy Mechanisms

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



Copying from History

- 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)

Dictionary Probabilities

- If you have a translation dictionary, use it to bias outputs (Arthur et al. 2016)

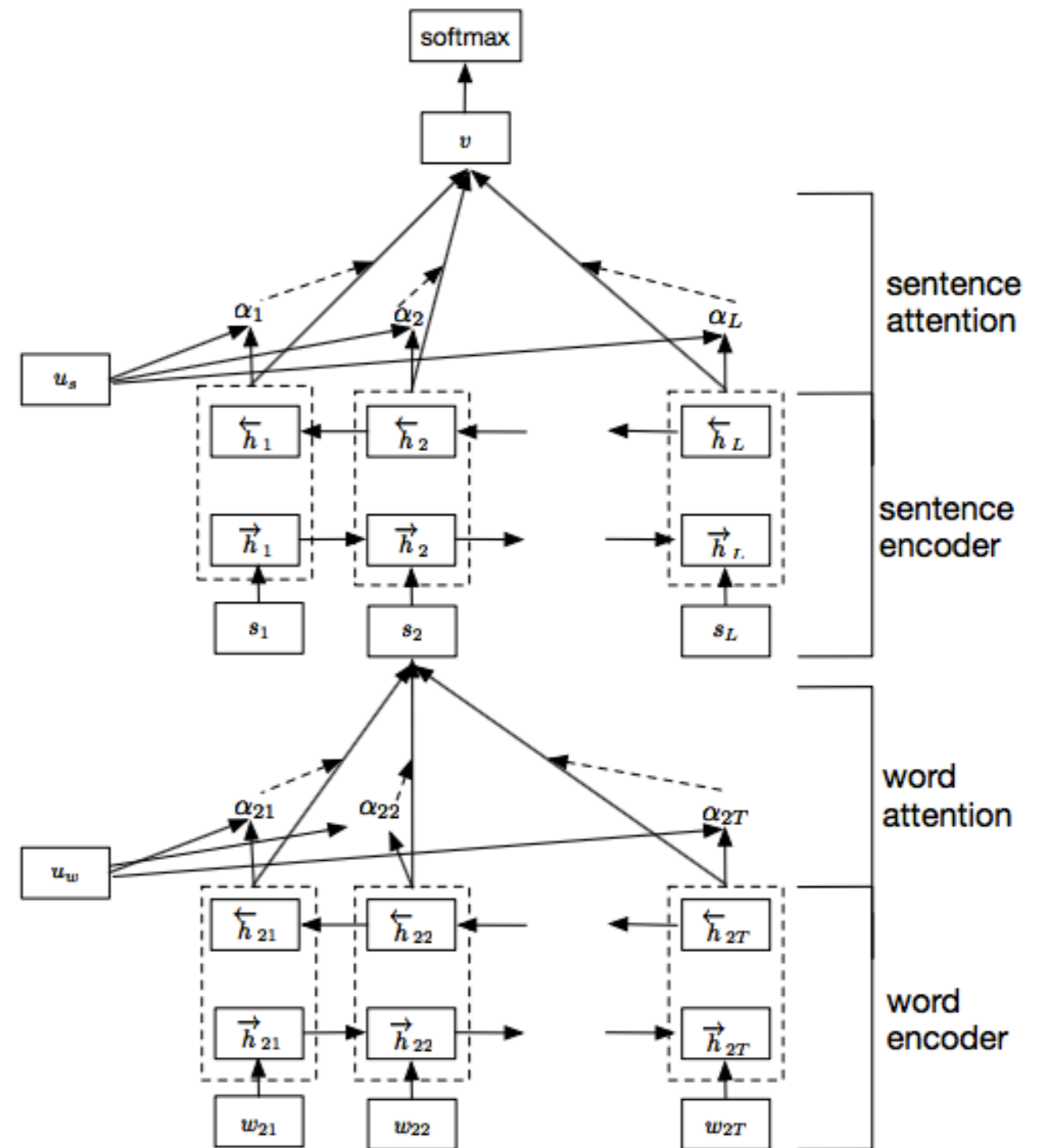
Attention		I	come	from	Tunisia	
		0.05	0.01	0.02	0.93	
watashi		0.6	0.03	0.01	0.0	0.03
ore		0.2	0.01	0.02	0.0	0.01
...	
kuru		0.01	0.3	0.01	0.0	0.00
kara		0.02	0.1	0.5	0.01	0.02
...	
chunijia		0.0	0.0	0.0	0.96	0.89
oranda		0.0	0.0	0.0	0.0	0.00

Sentence-level dictionary probability matrix **Dictionary probability for current word**

Hierarchical Structures

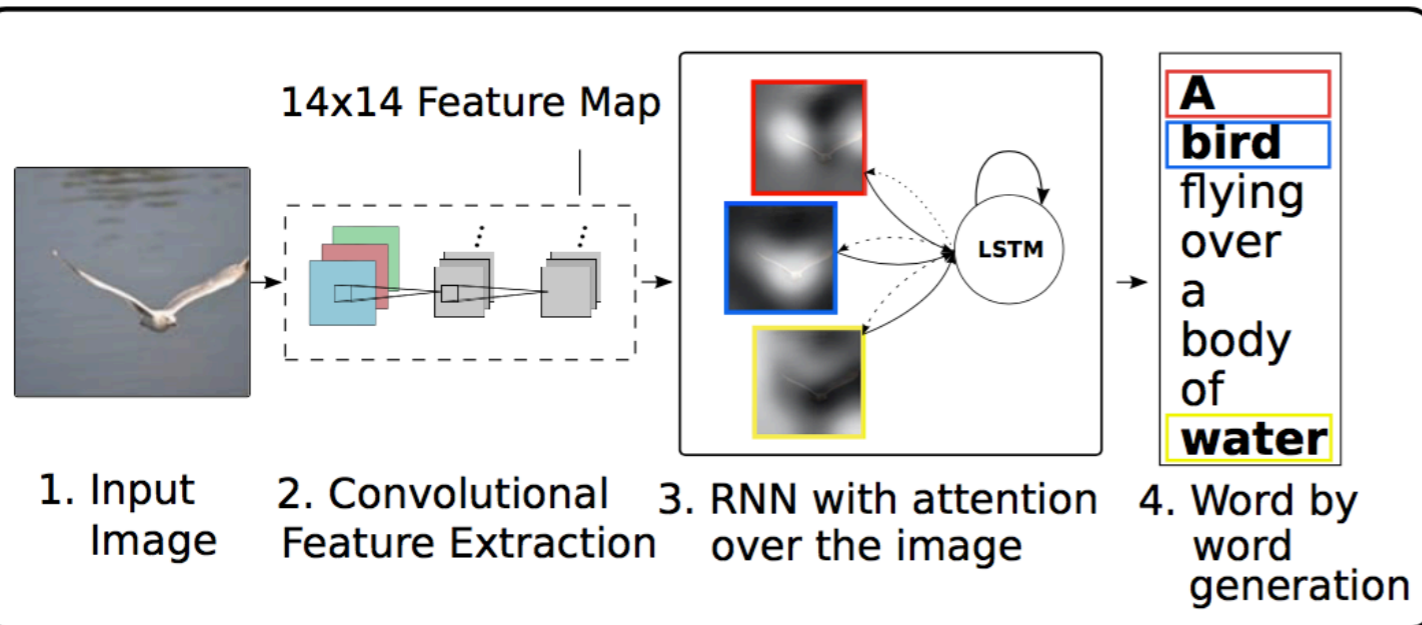
(Yang et al. 2016)

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

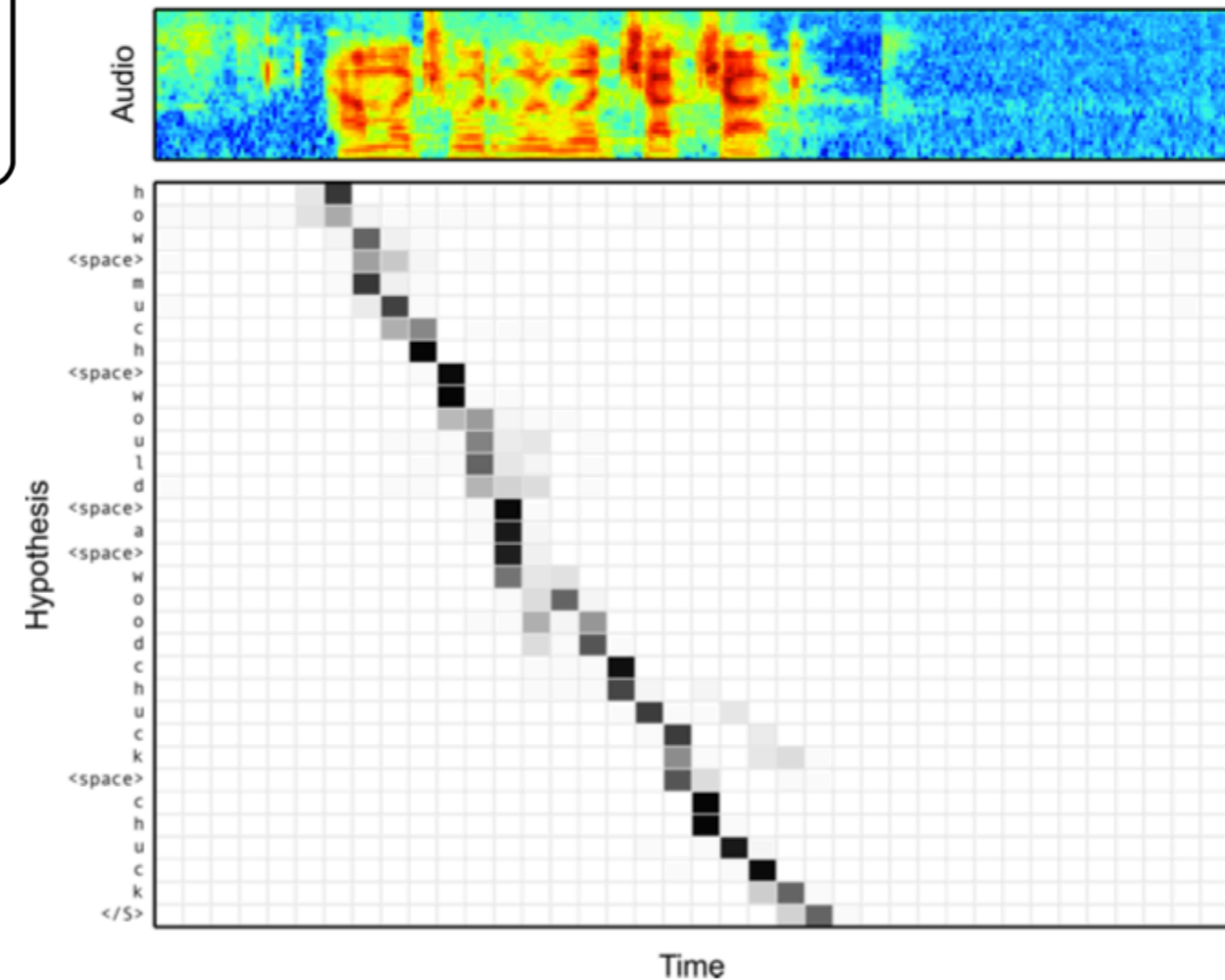


Various Modalities

- Images (Xu et al. 2015)

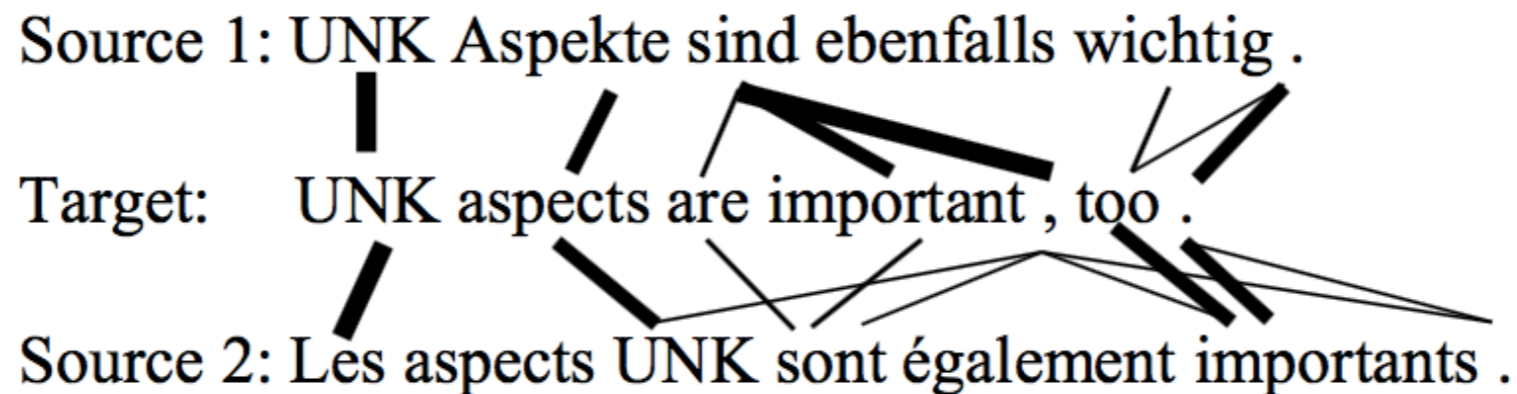


- Speech (Chan et al. 2015)

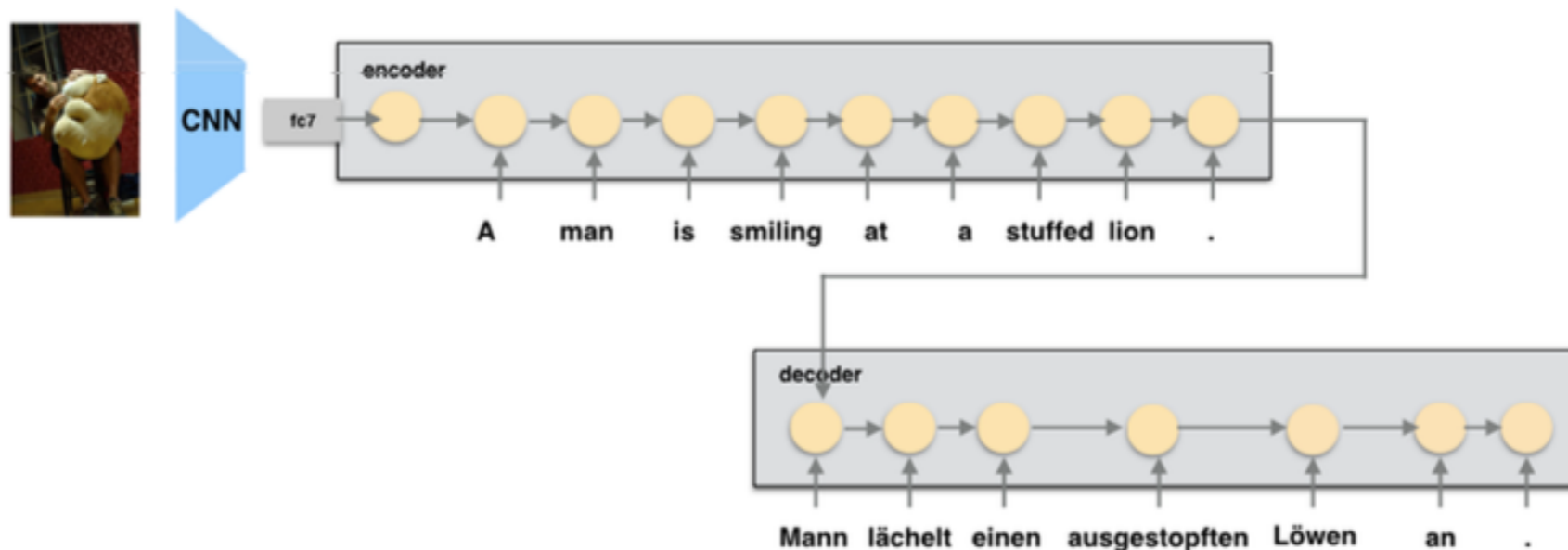


Multiple Sources

- 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)



Questions?