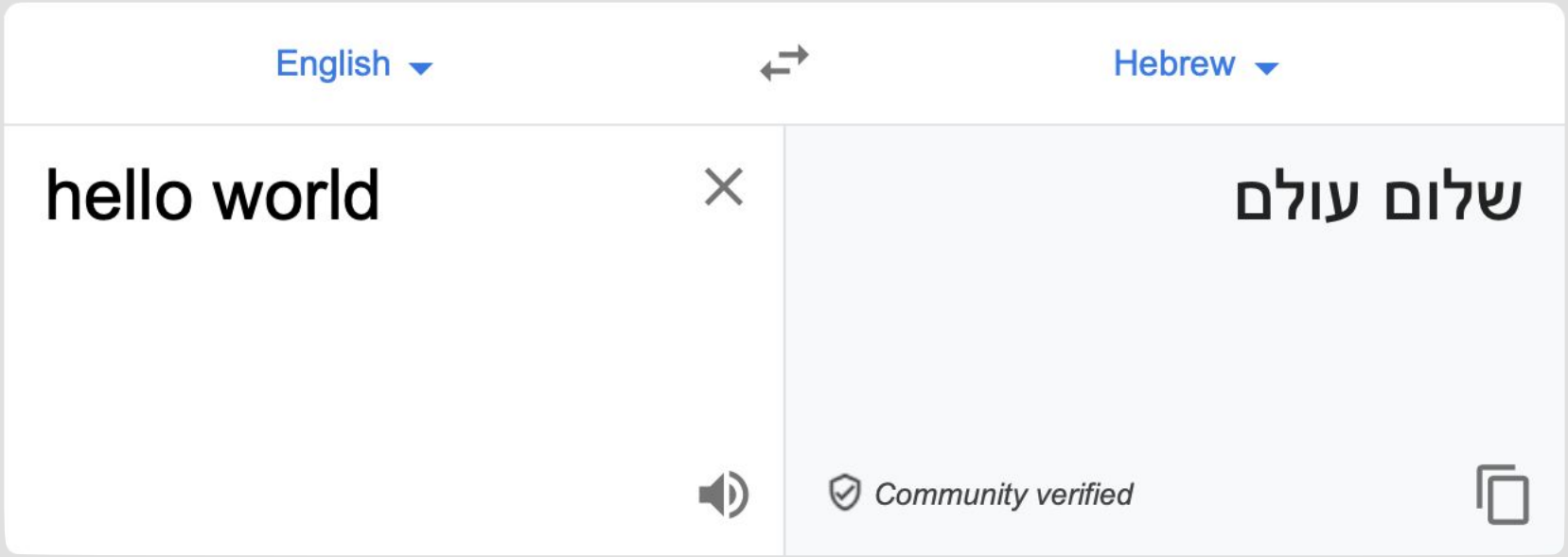
Machine translation

Based on lecture by Ekaterina Artemova

- **Encoder-decoder model**
- Attention mechanism
- Machine translation quality metrics

Encoder-decoder model

Machine translation



Machine translation

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- One of the first technologies in text preprocessing
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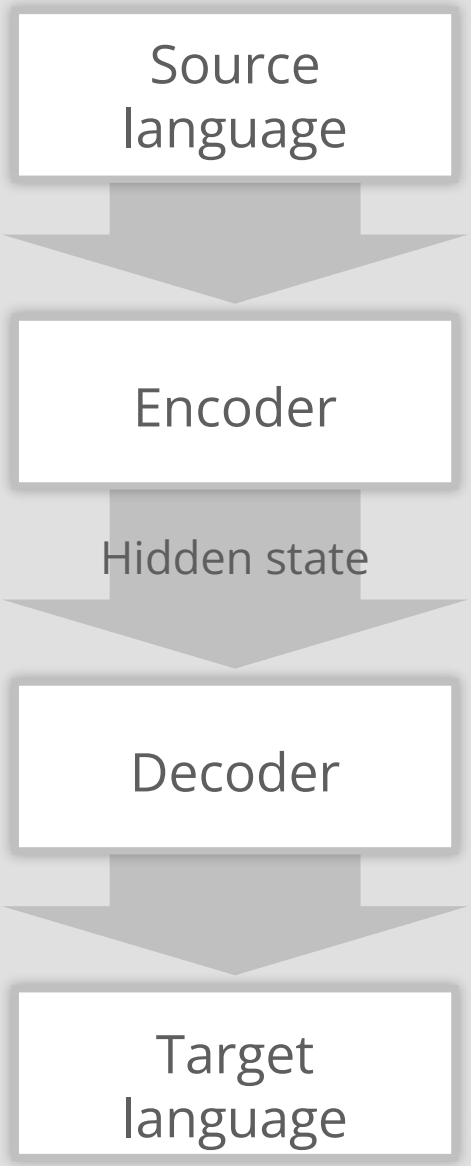
- Starting from 2016, neural machine translation (NMT) – industrial standard
- As for now, MT works good for simple or formal texts, MT for fiction is still a problem

Encoder-decoder model

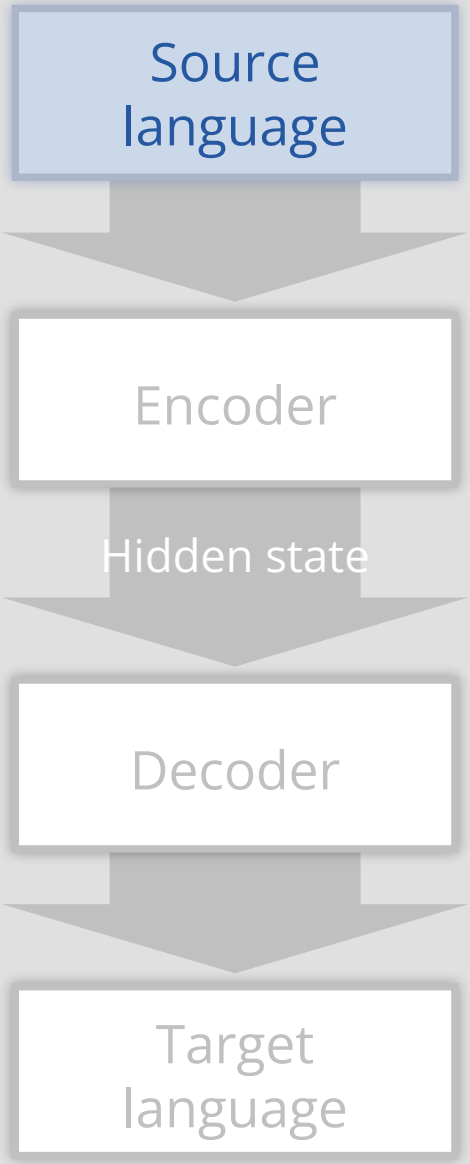
- Problem: translate text from one language to another



Problem formulation

- Given a sentence in source language:

$$\mathbf{x}_{source} = (x_1, \ldots, x_n), x_i \in V_{source}$$



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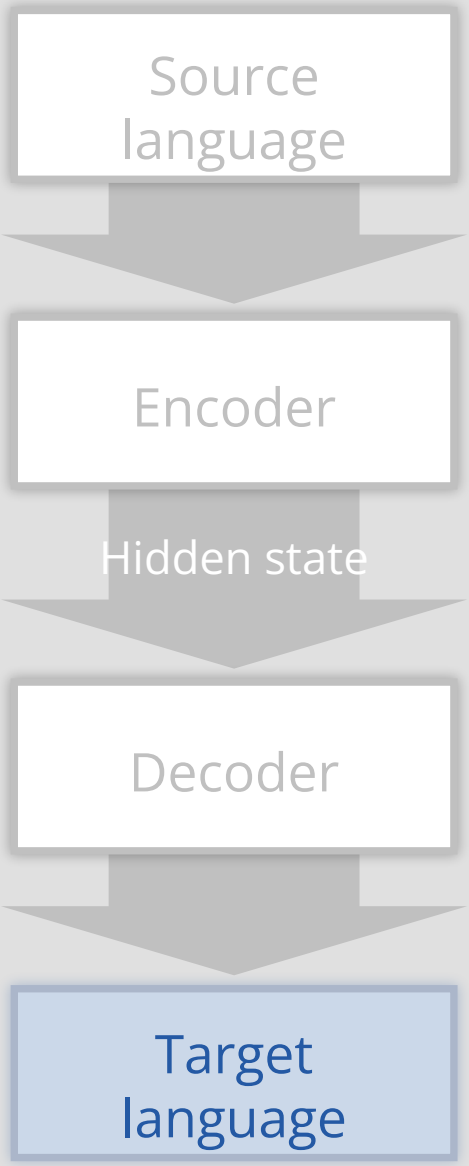

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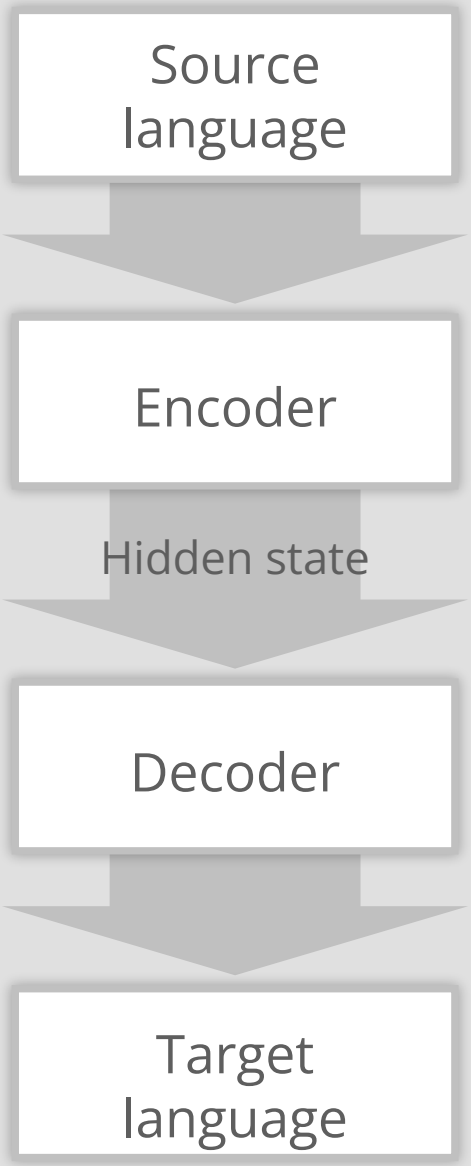
- A parallel corpus **C** of pairs (x, y)



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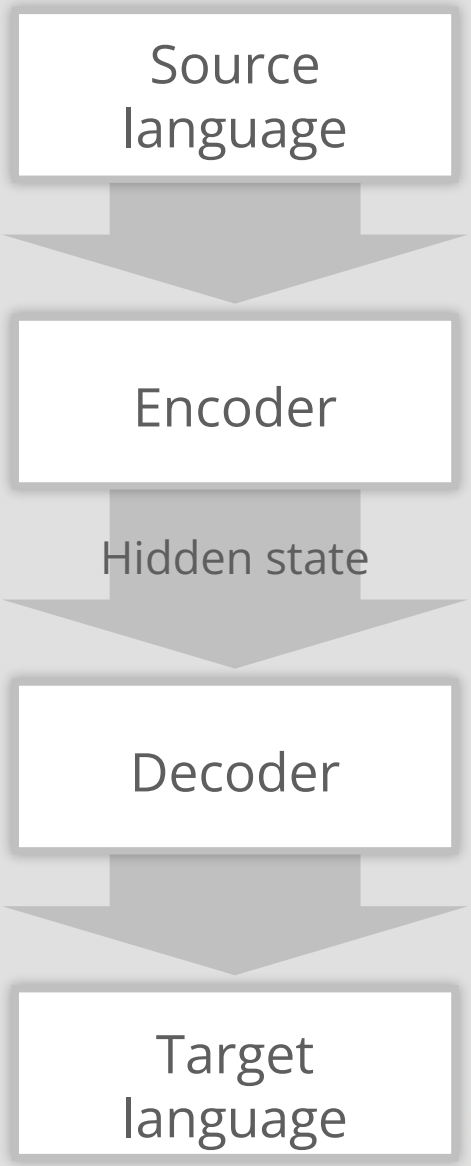
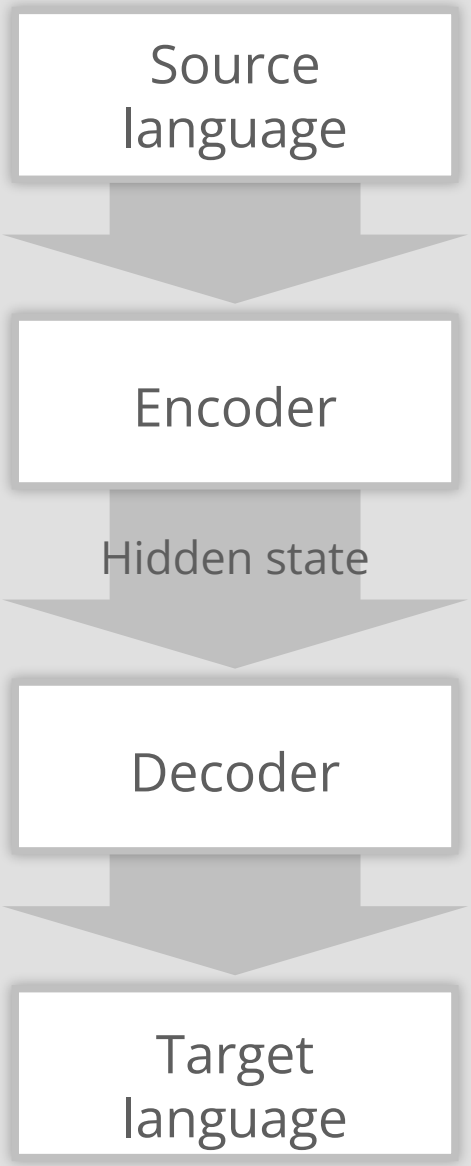
- A parallel corpus **C** of pairs (x, y)
- Maximize the likelihood p(y|x)
- Loss function $\mathcal{L}_\theta = \sum_{\mathbf{x},\mathbf{y} \in \mathbf{C}} \log p(\mathbf{y}|\mathbf{x};\theta)$



Problem formulation

- Probability of target sentence provided source sentence:

$$p(\mathbf{y}|\mathbf{x};\theta) = \prod_{j=1}^{m} p(\mathbf{y}_j|\mathbf{y}_{<j},\mathbf{x};\theta)$$



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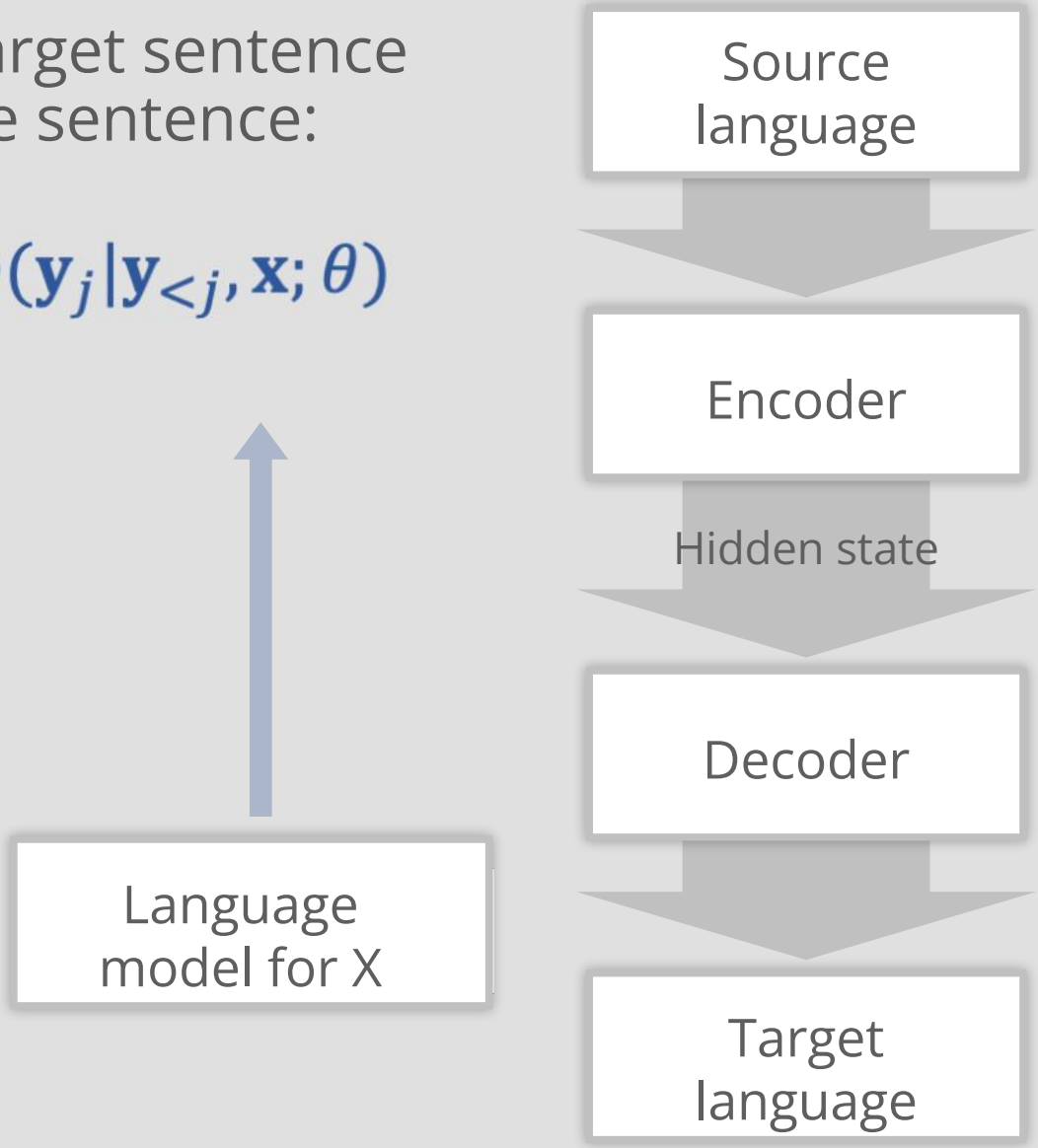
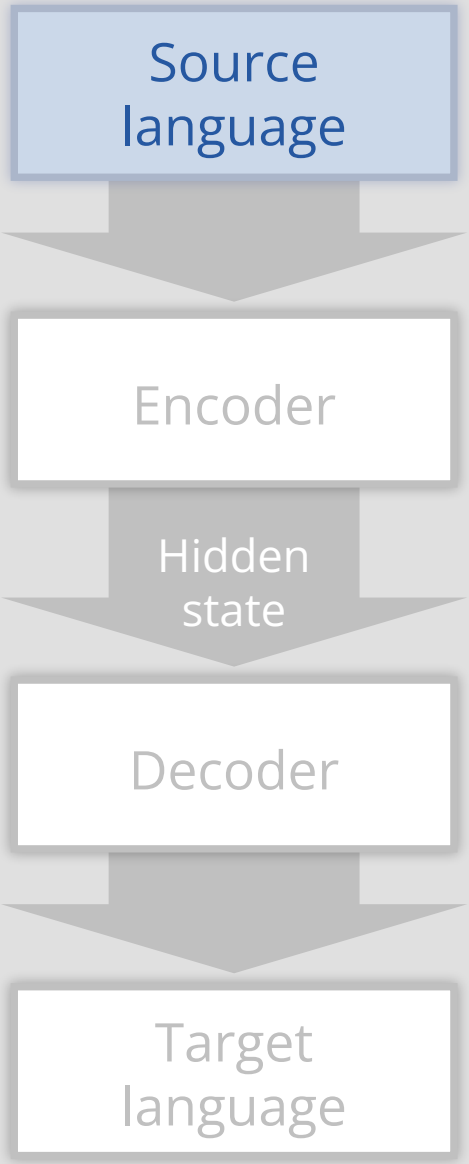


Neural machine translation

- Input embeddings:

$$f_i^s = E_{source} x_i$$



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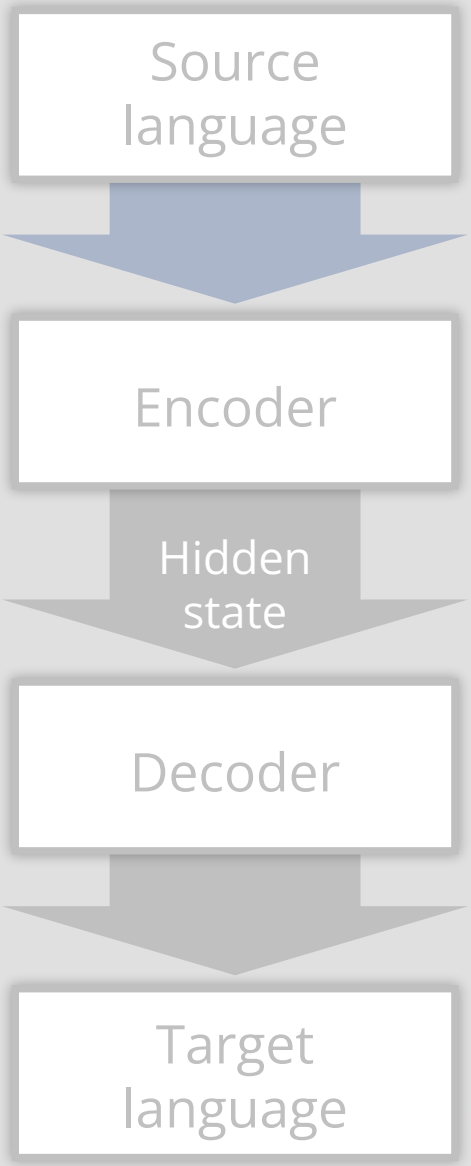
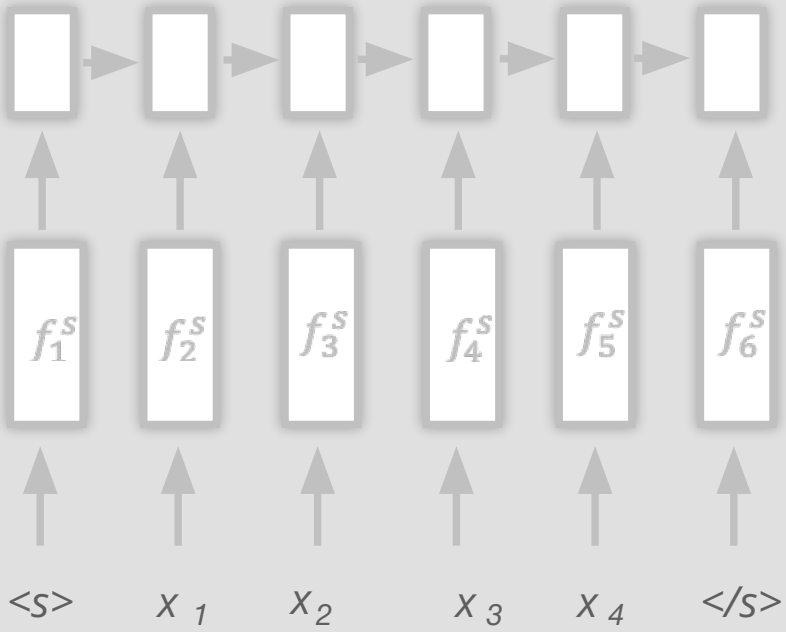
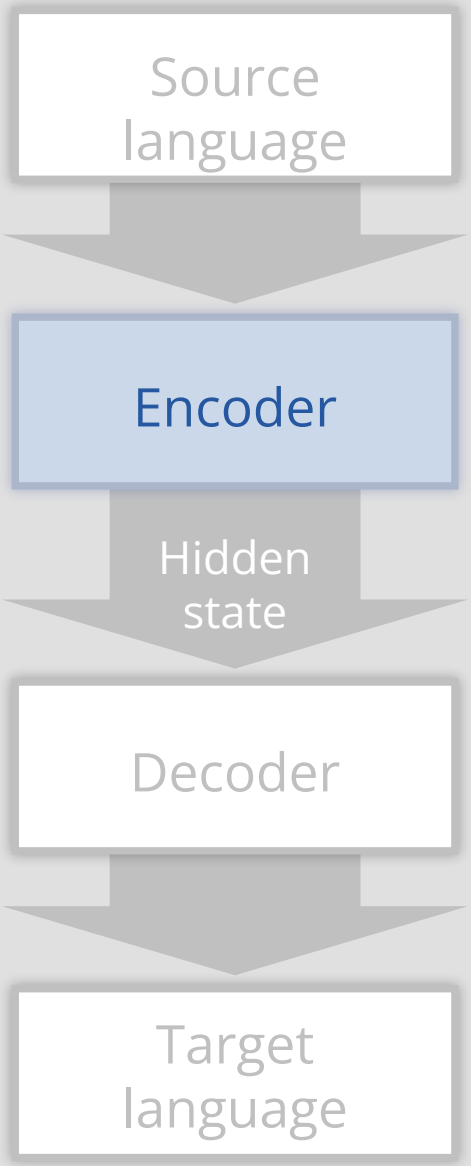


Neural machine translation

- Encoder architecture





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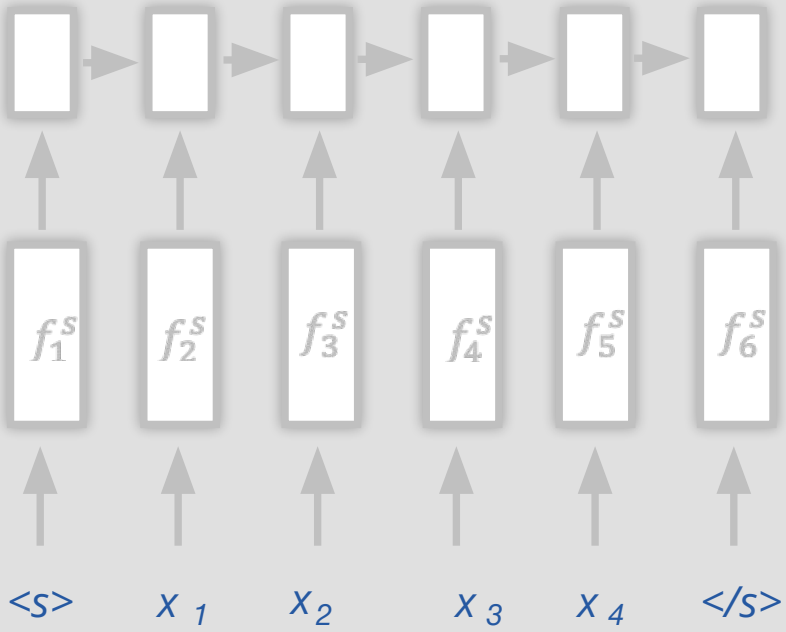

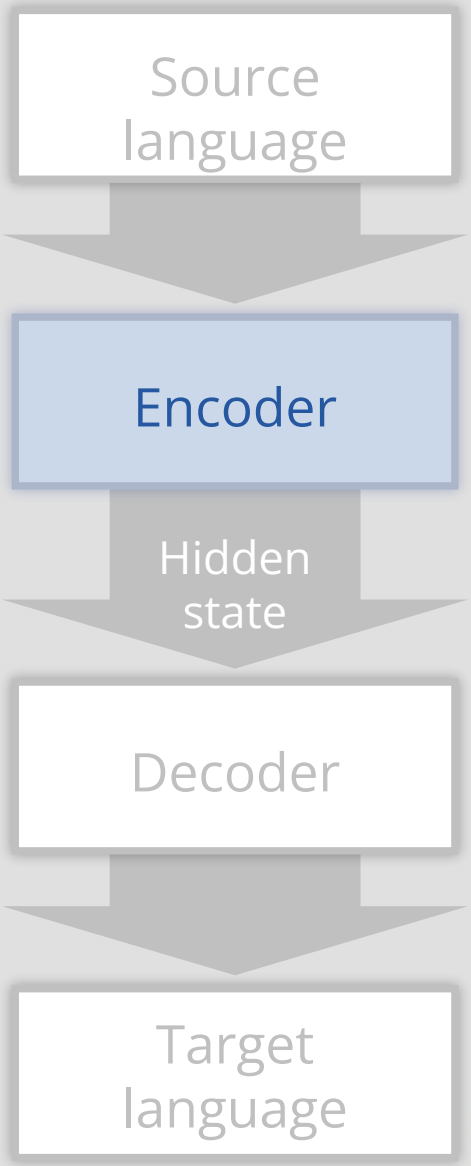

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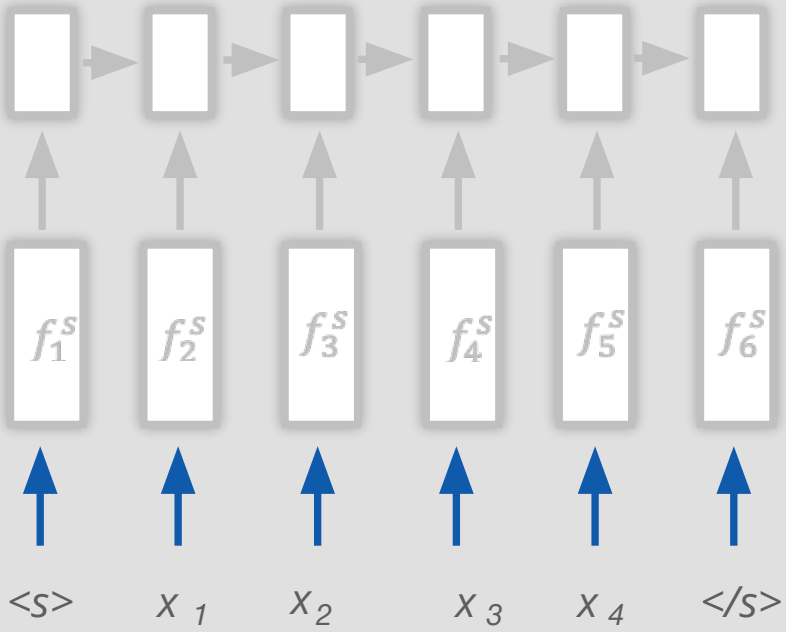

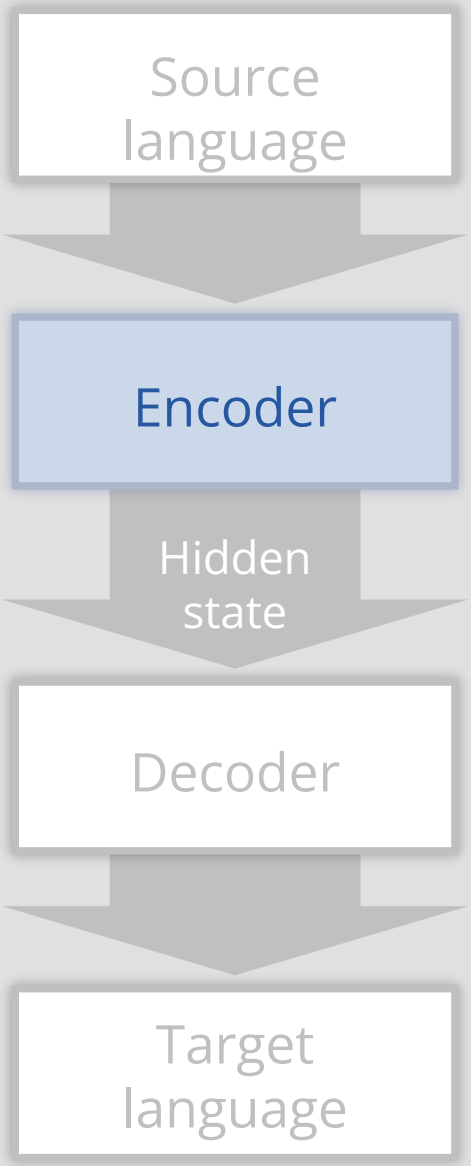

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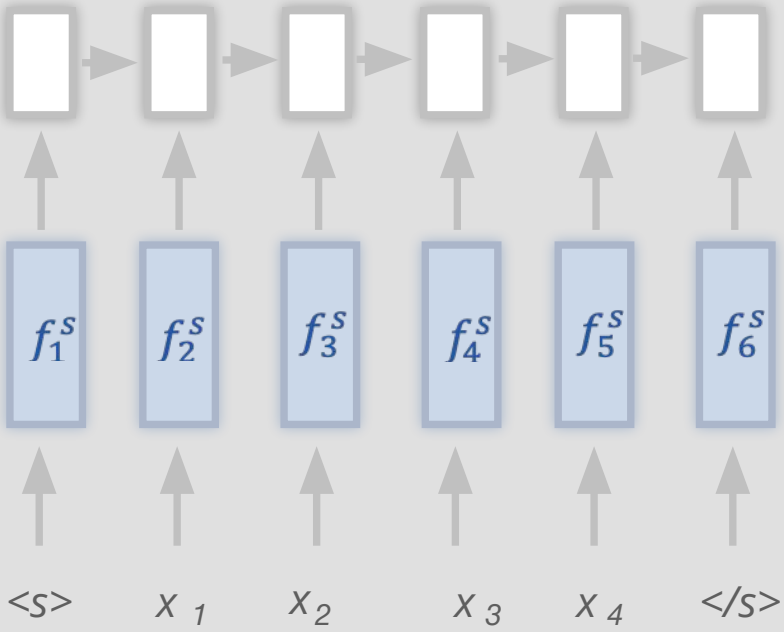

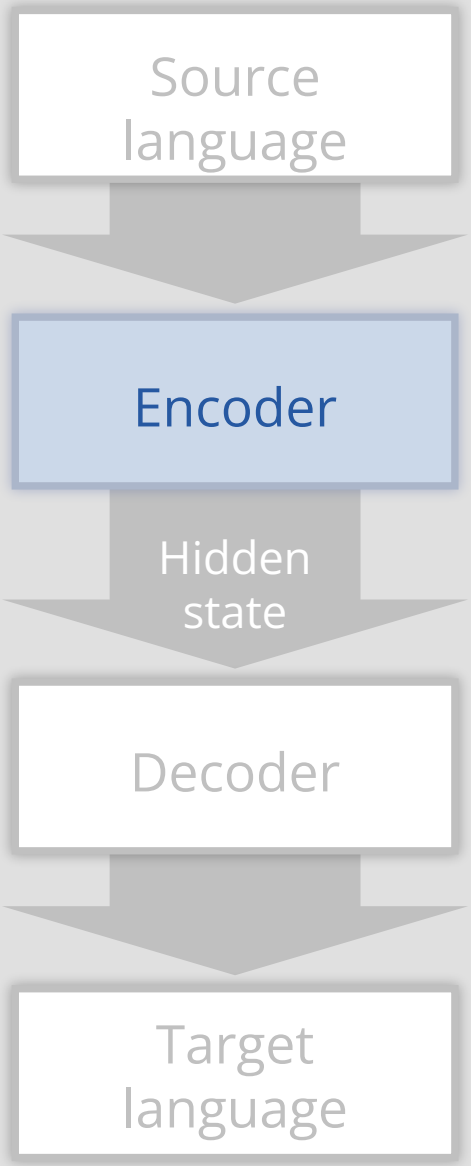

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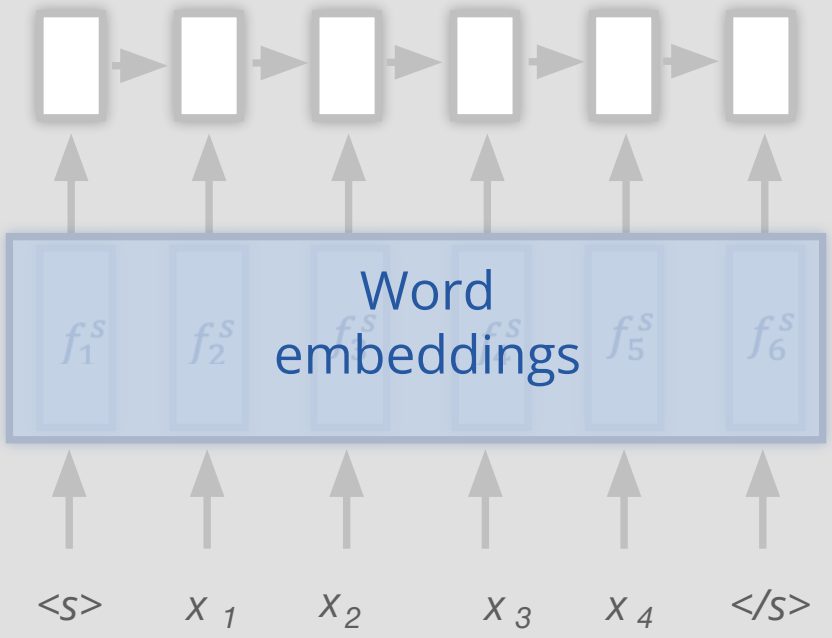

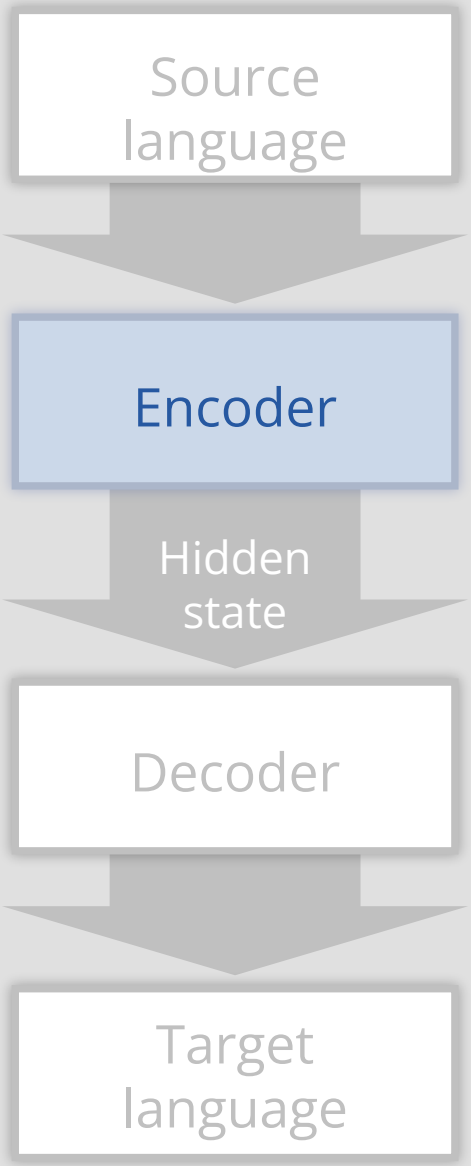

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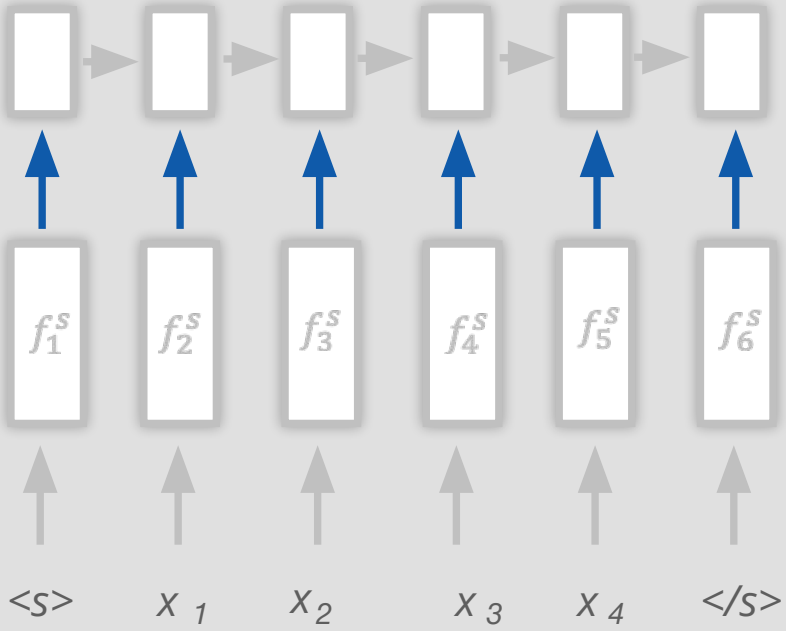

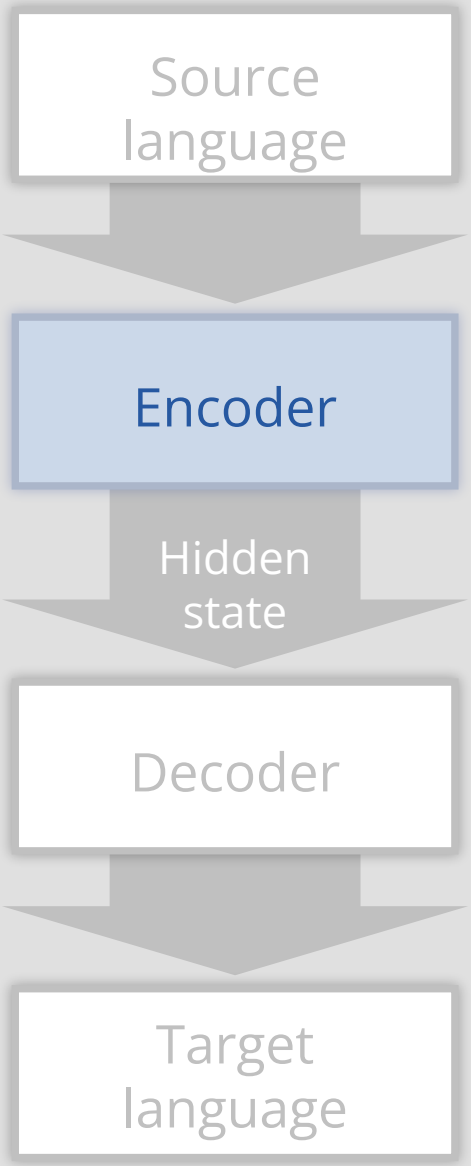

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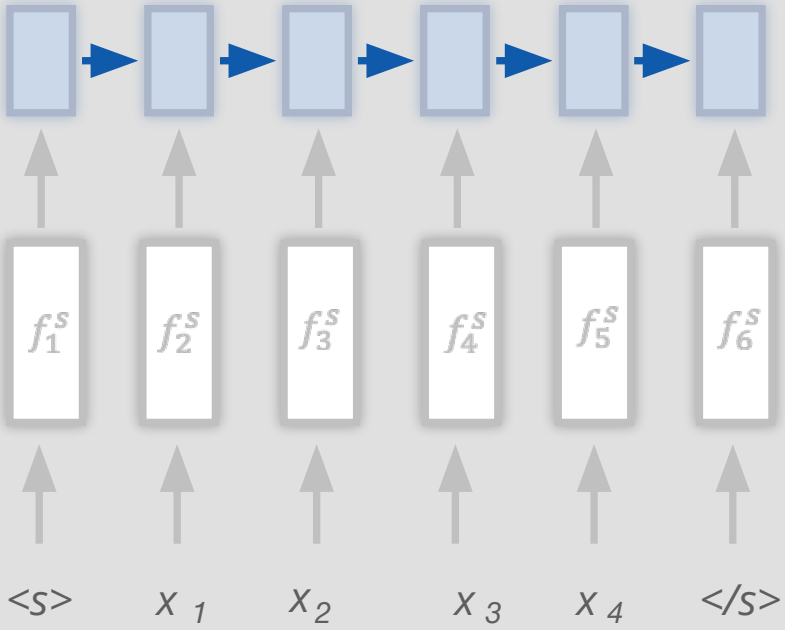

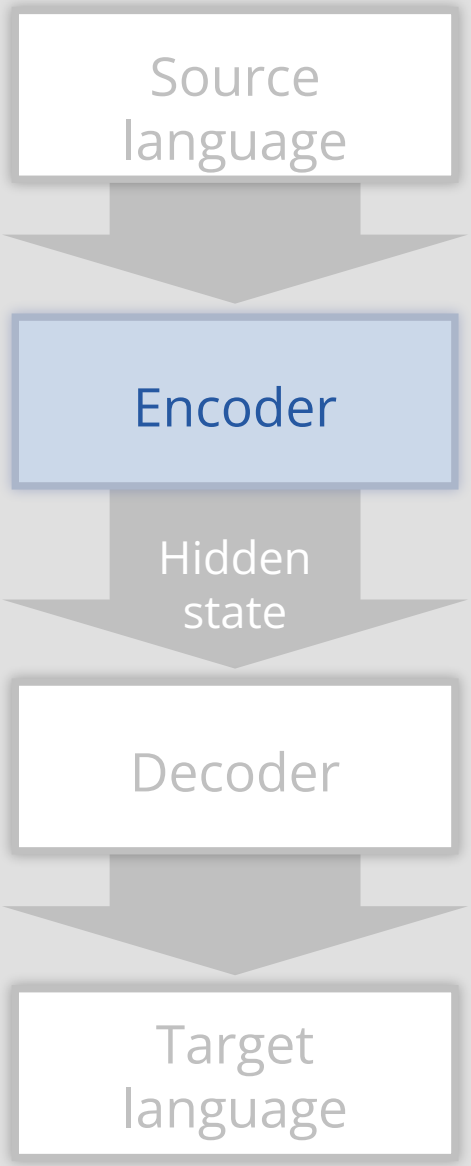

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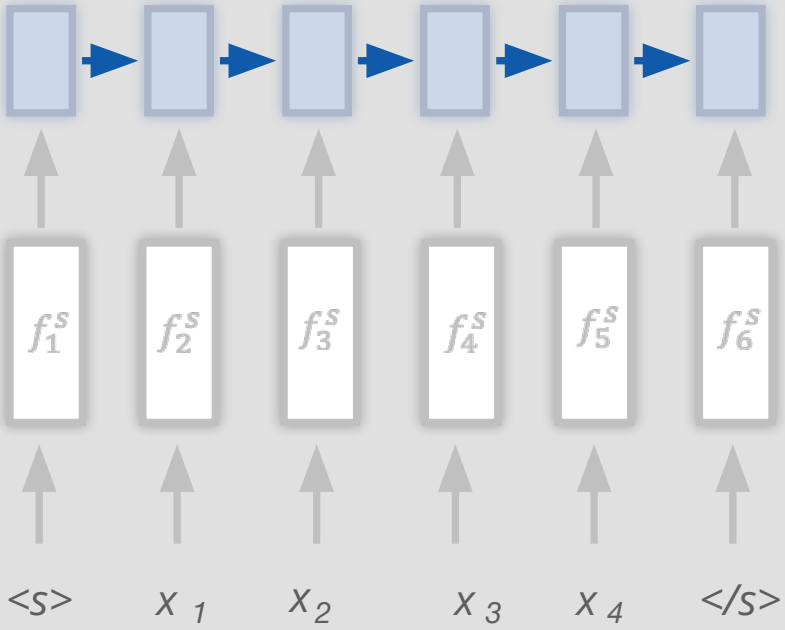
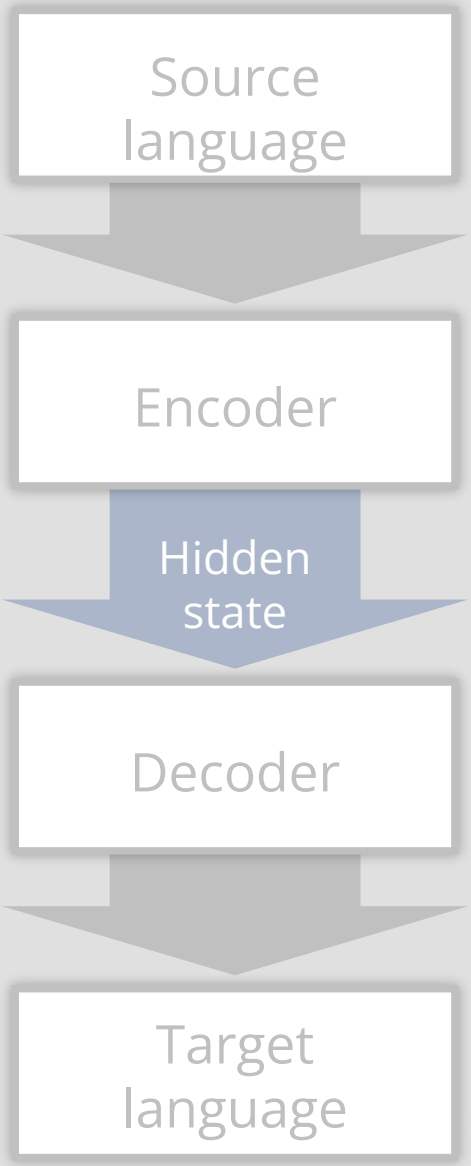
- Encode the input sentence

$$h^{encoder} = RNN(\mathbf{x})$$





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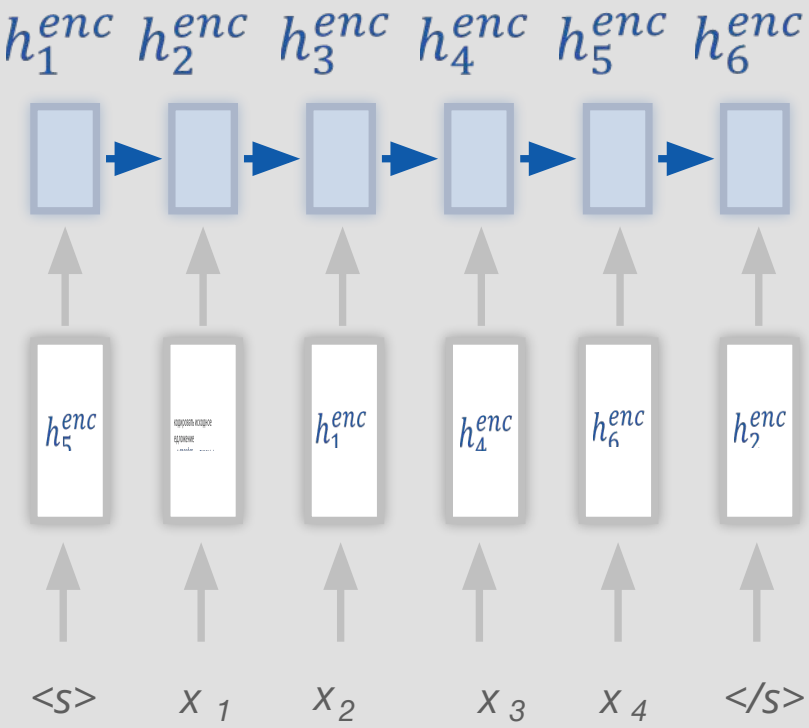

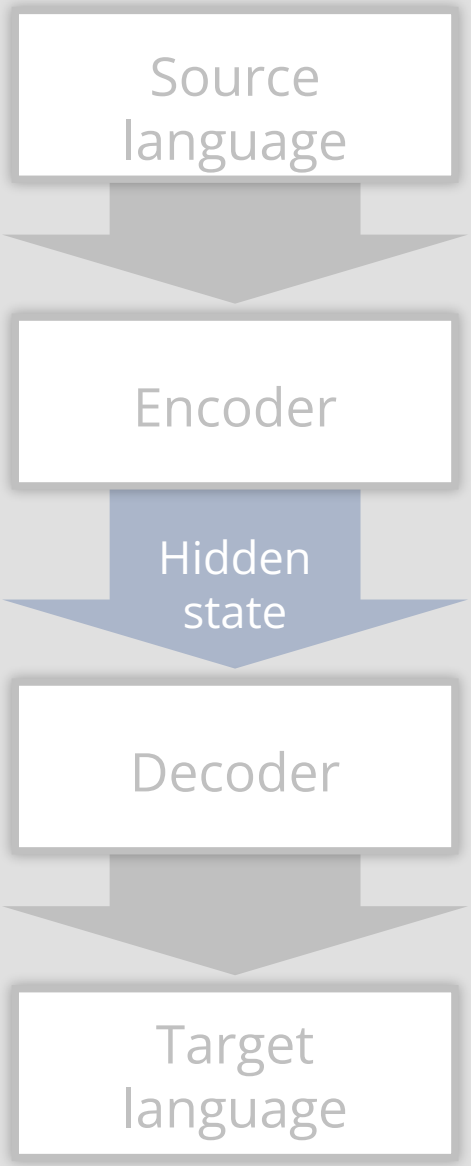

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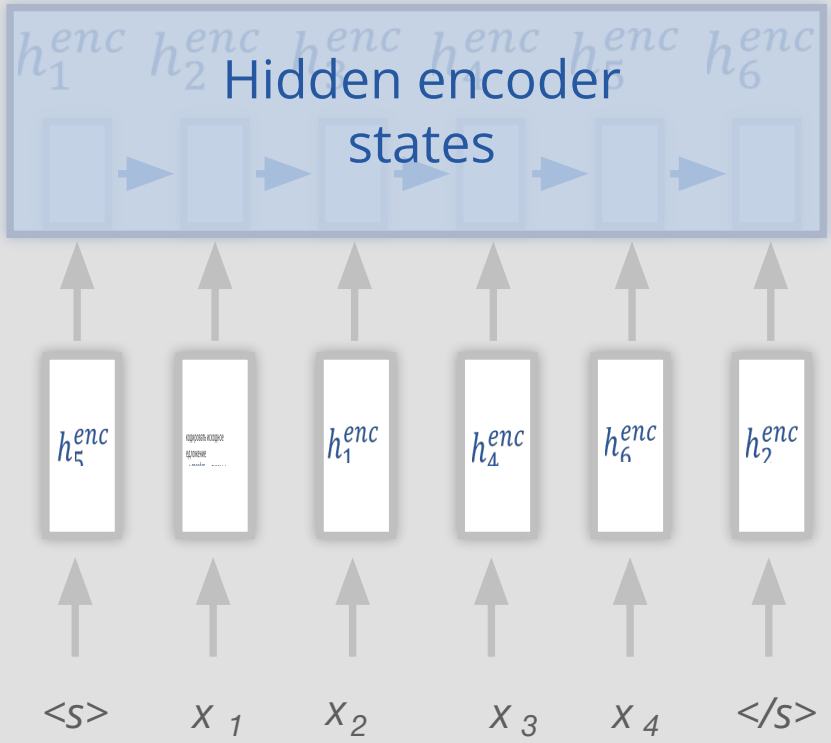

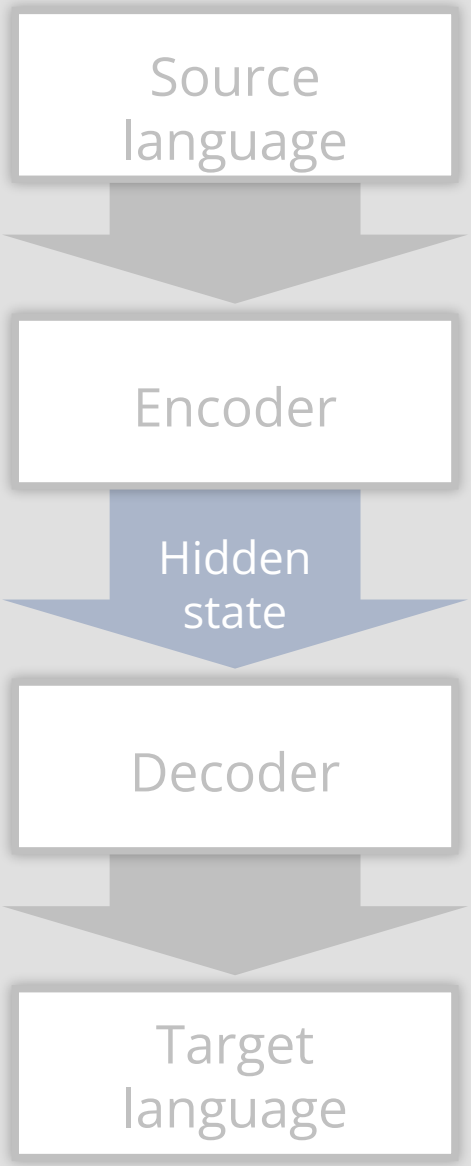

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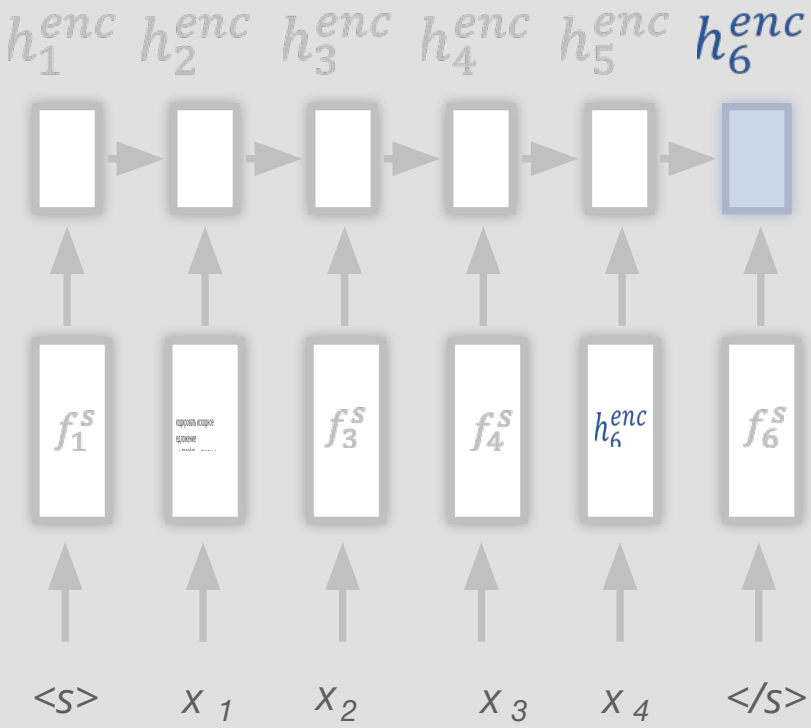

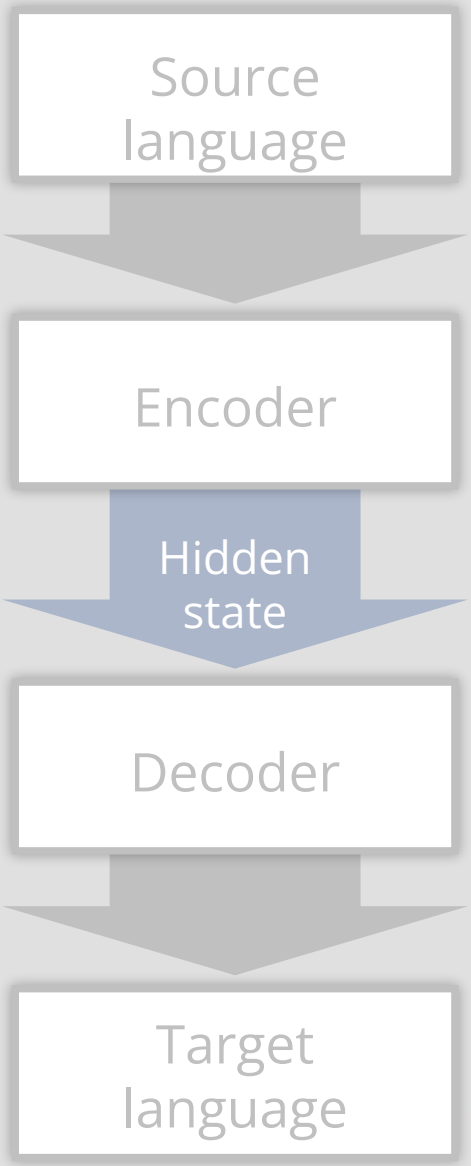

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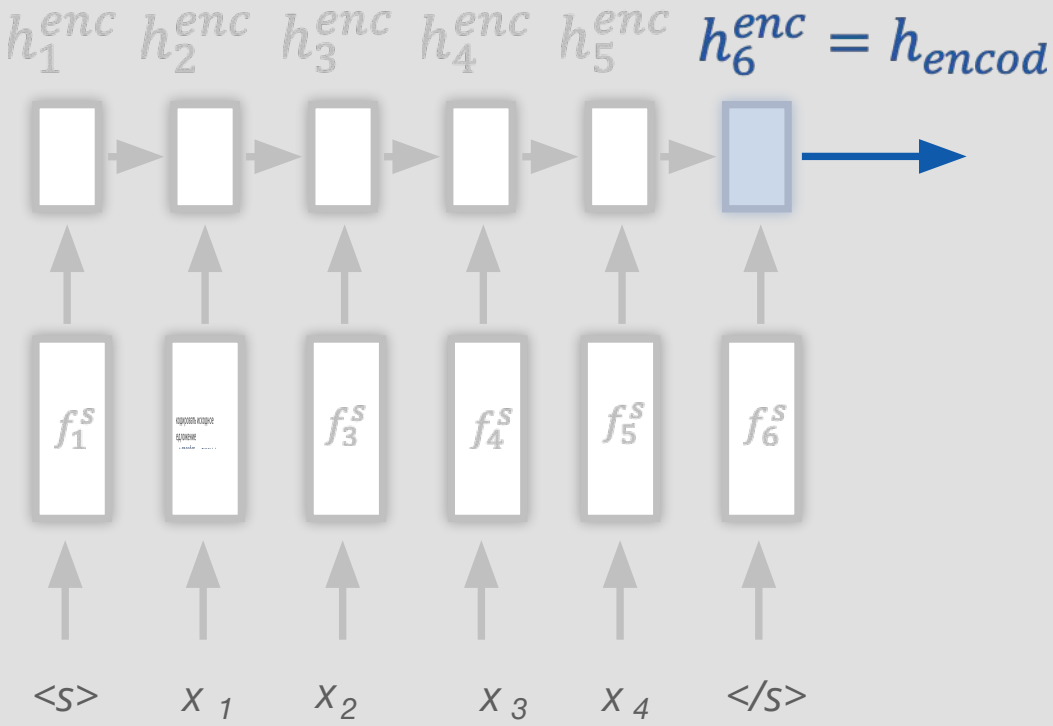
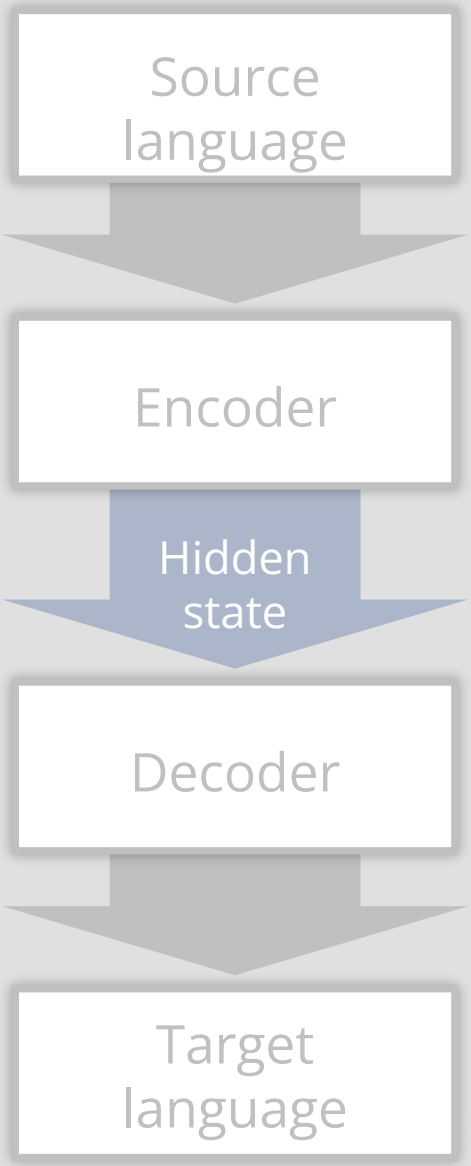
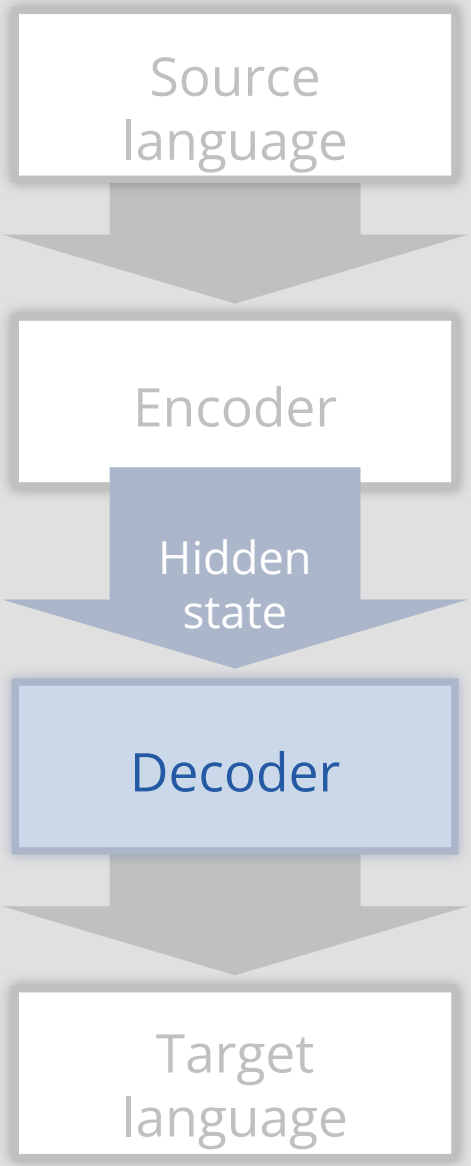




Decoder architecture

- Decode the whole sentence

h_{encode}



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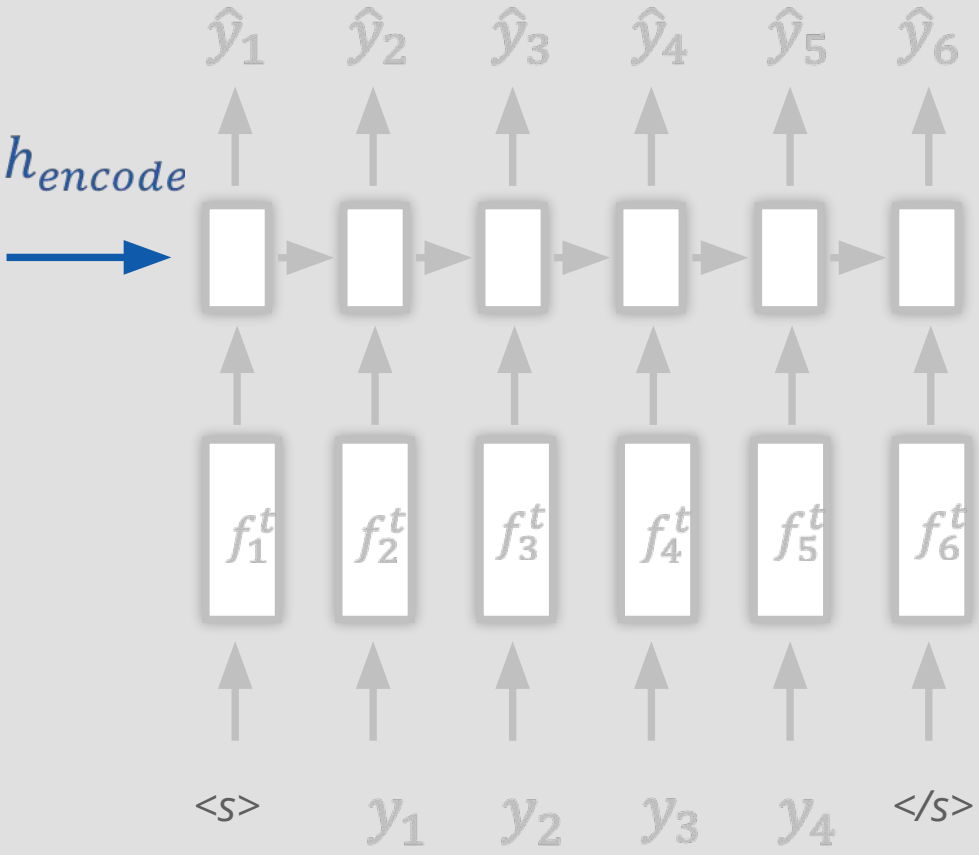

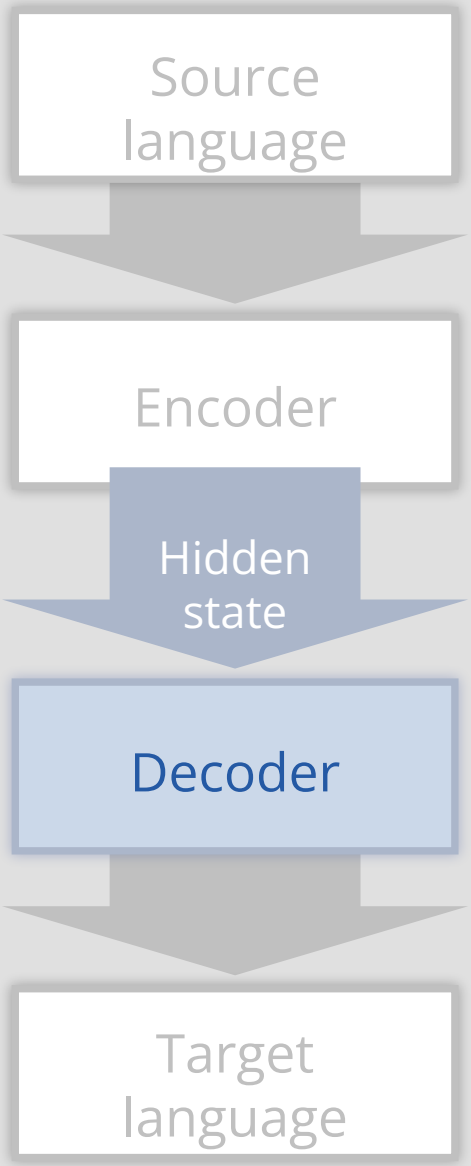

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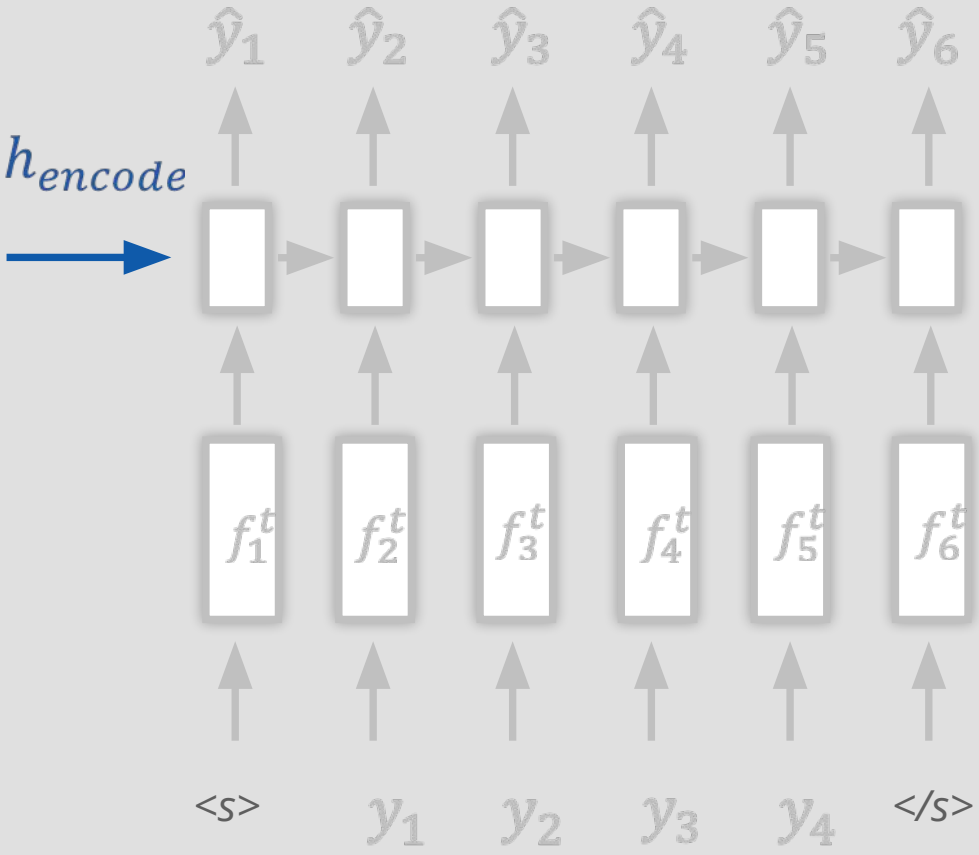
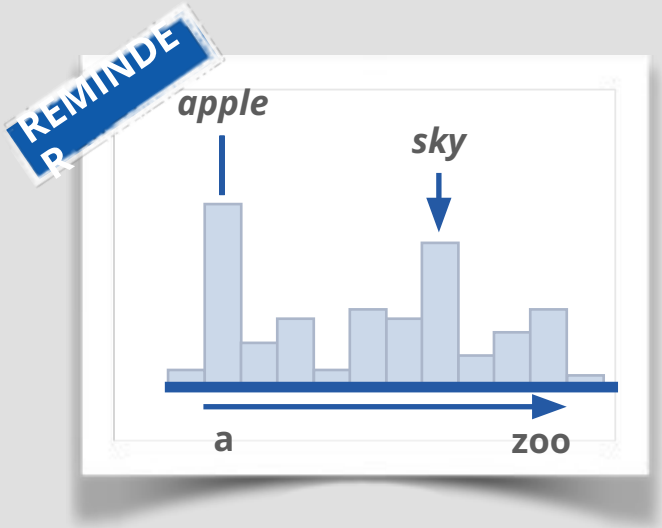
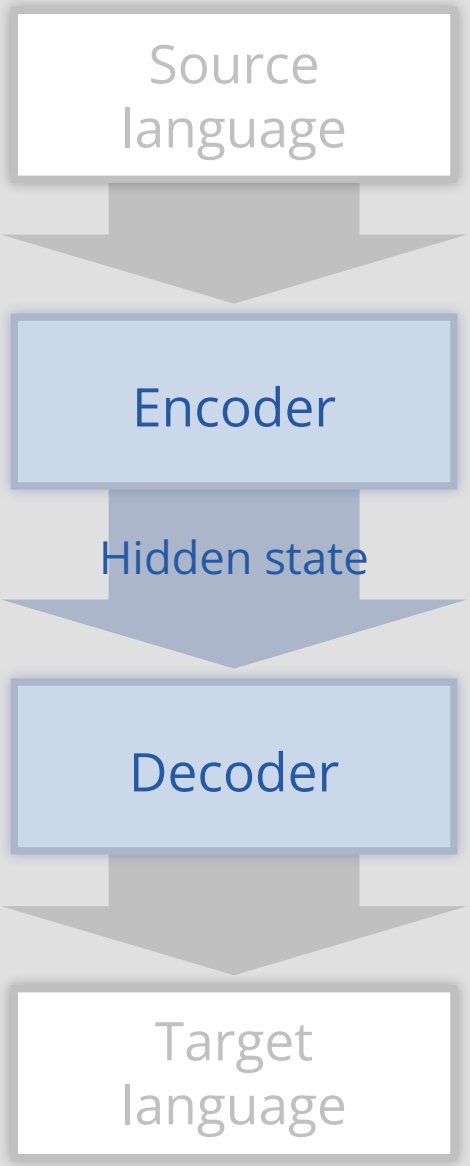




Training process

- Loss function

$$L(\mathbf{y}, \hat{\mathbf{y}}) = \sum_{j=1}^{V_{target}} y_j \log \hat{y}_j$$



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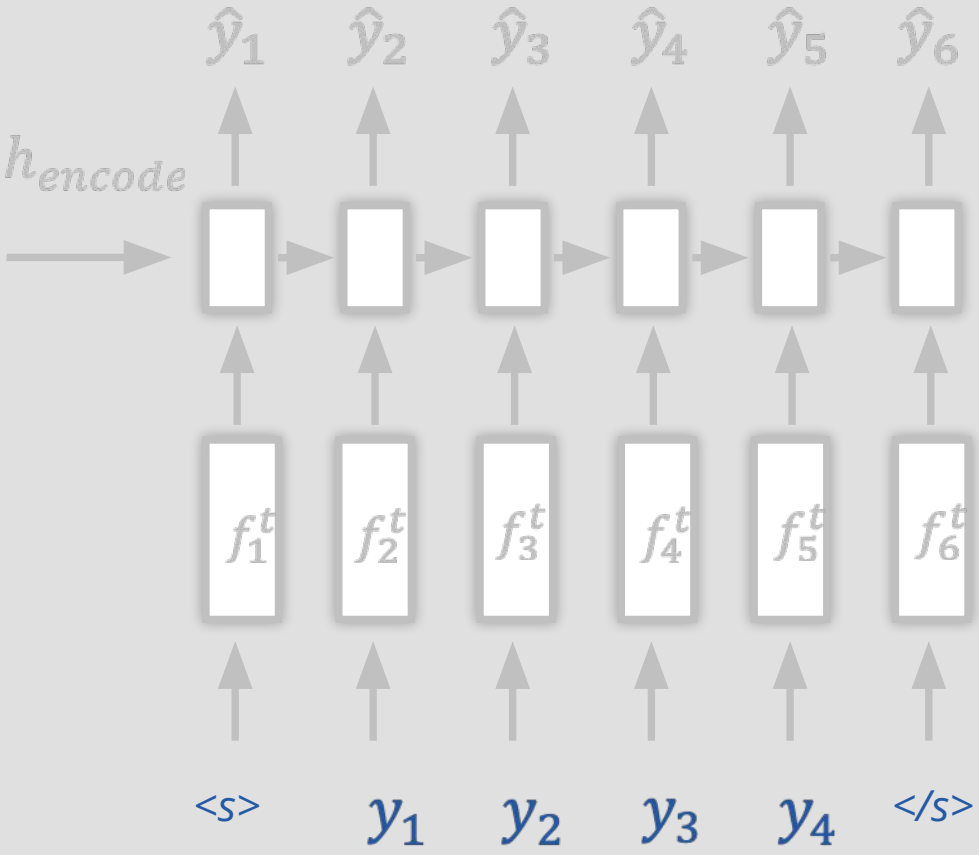

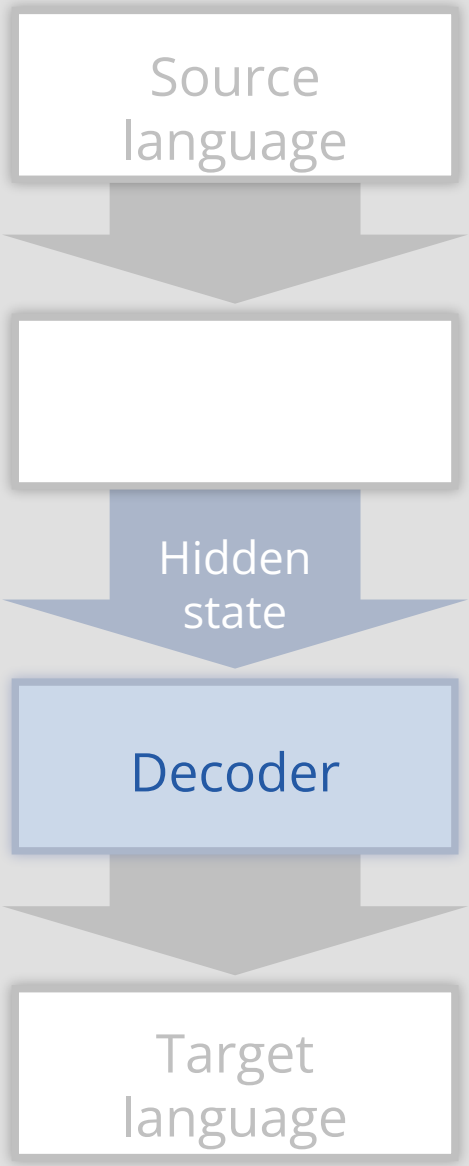

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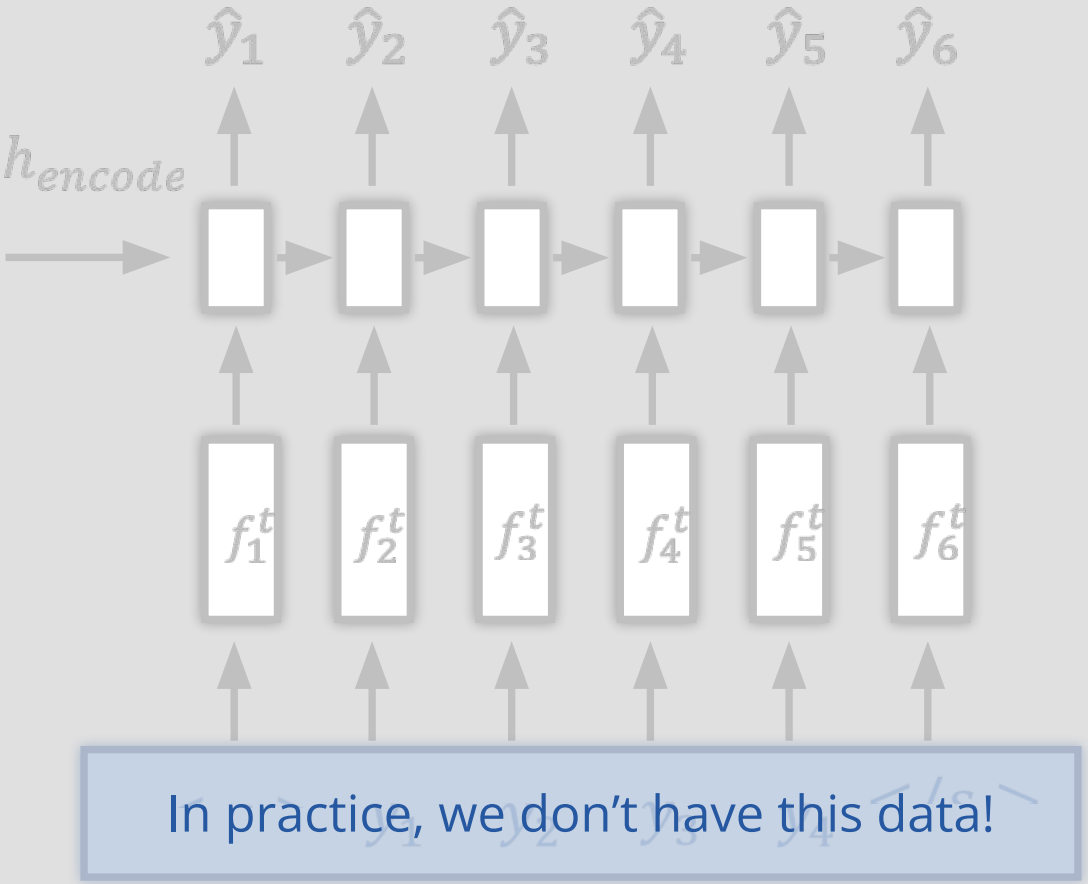

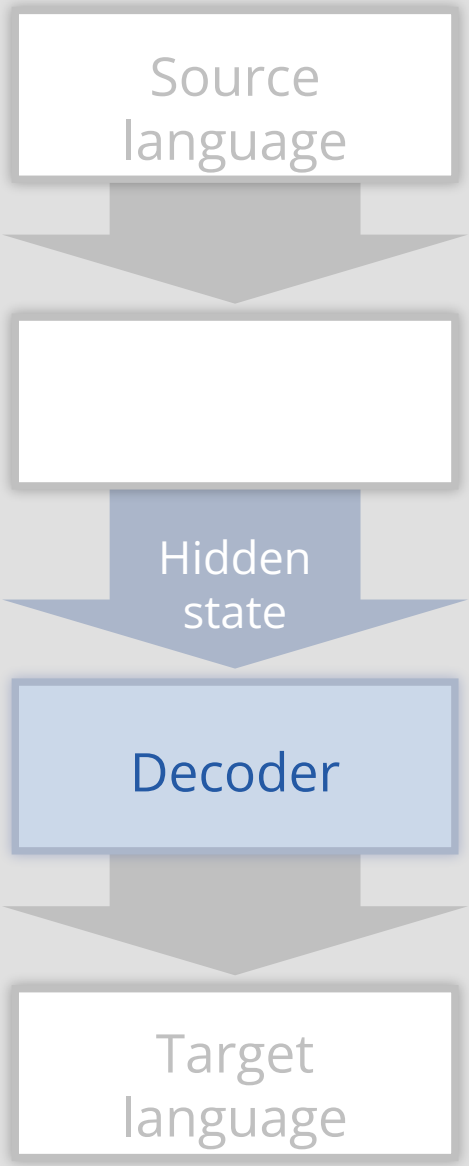

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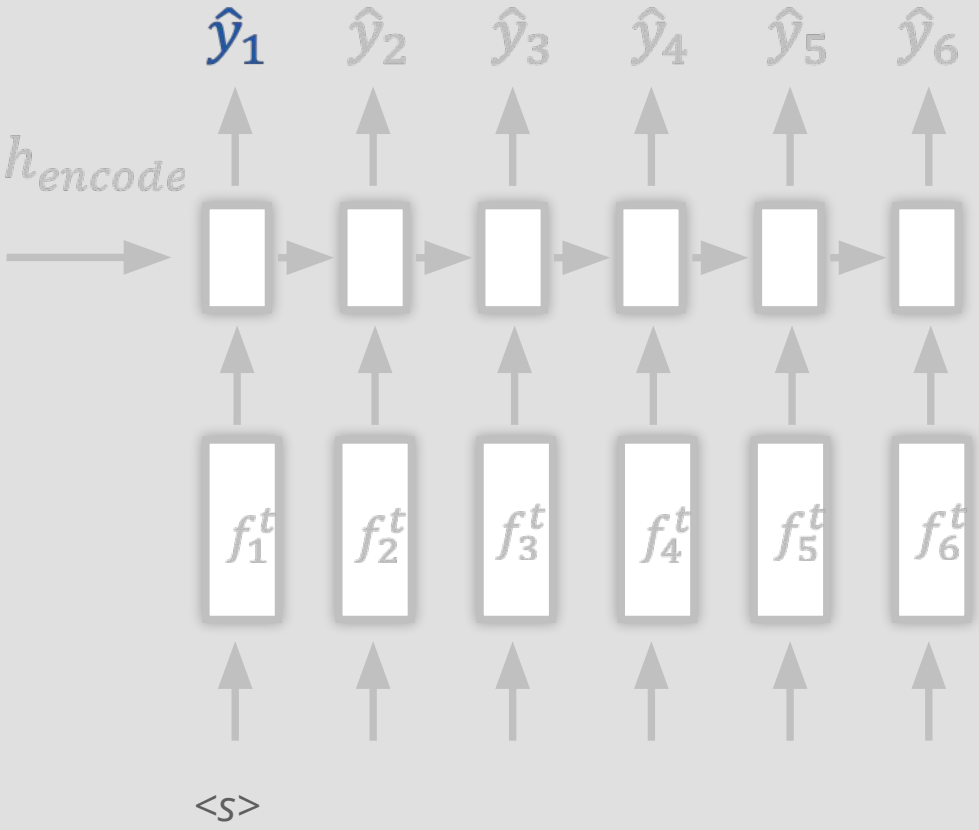

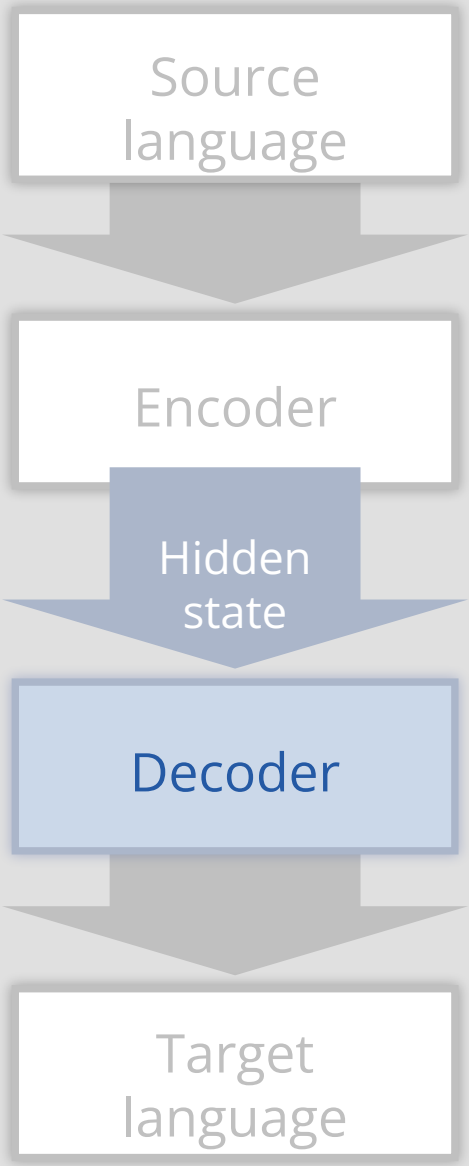

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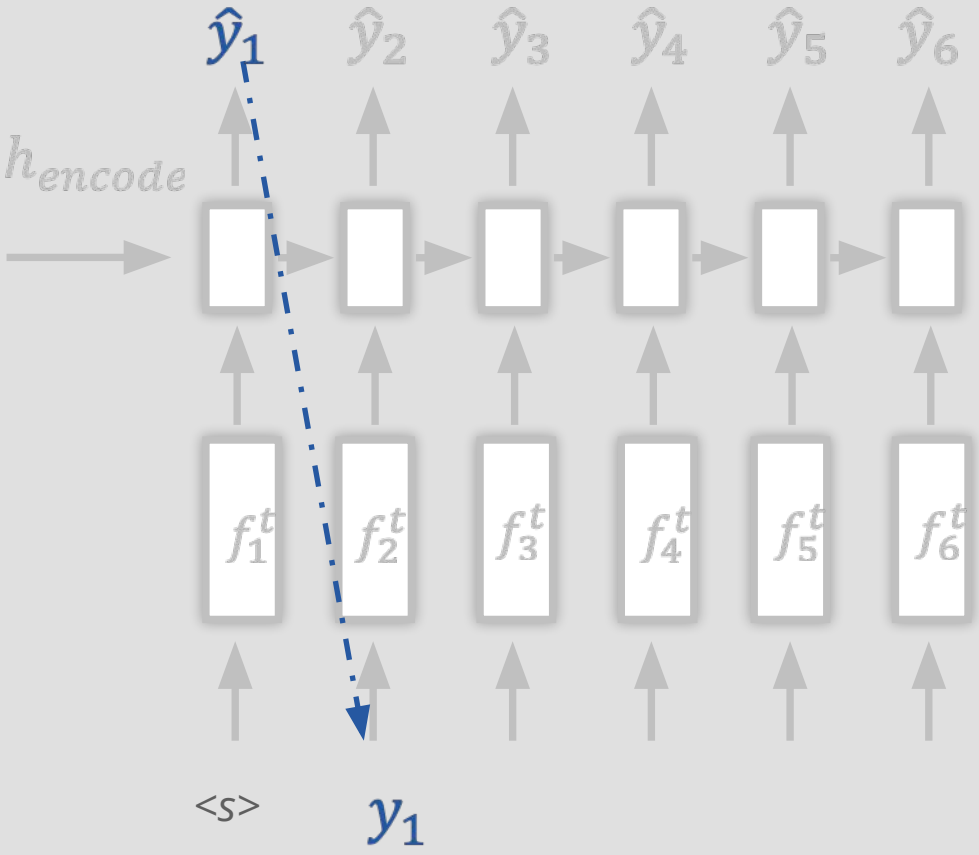

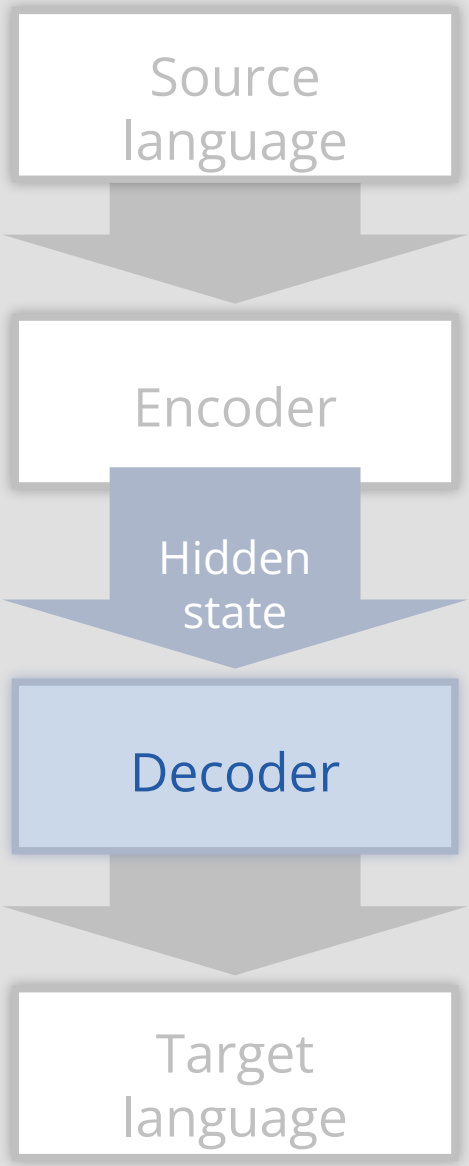

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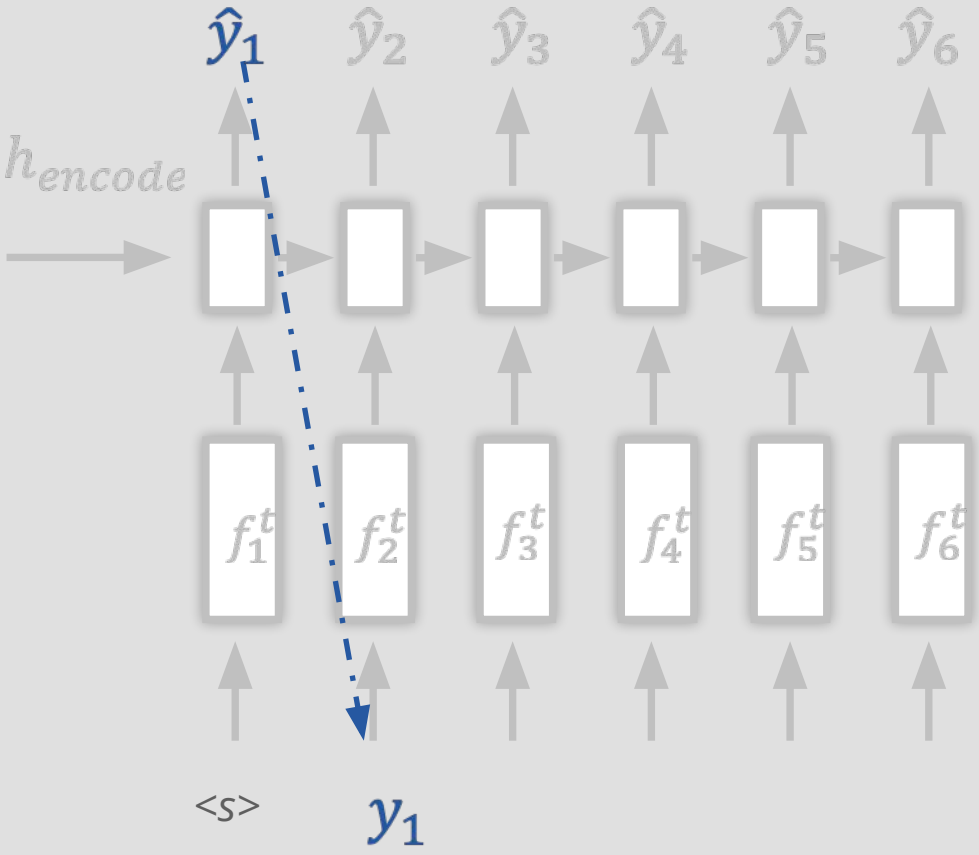

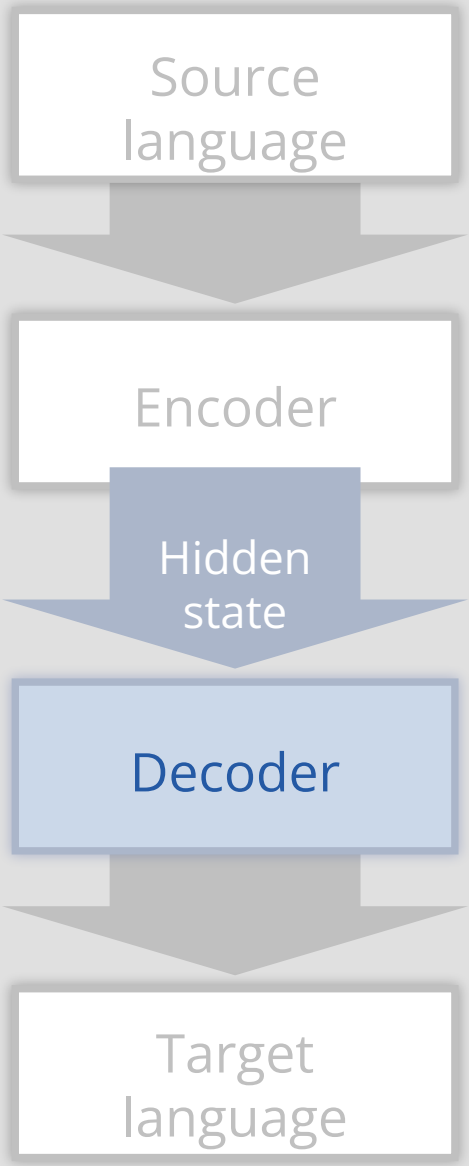

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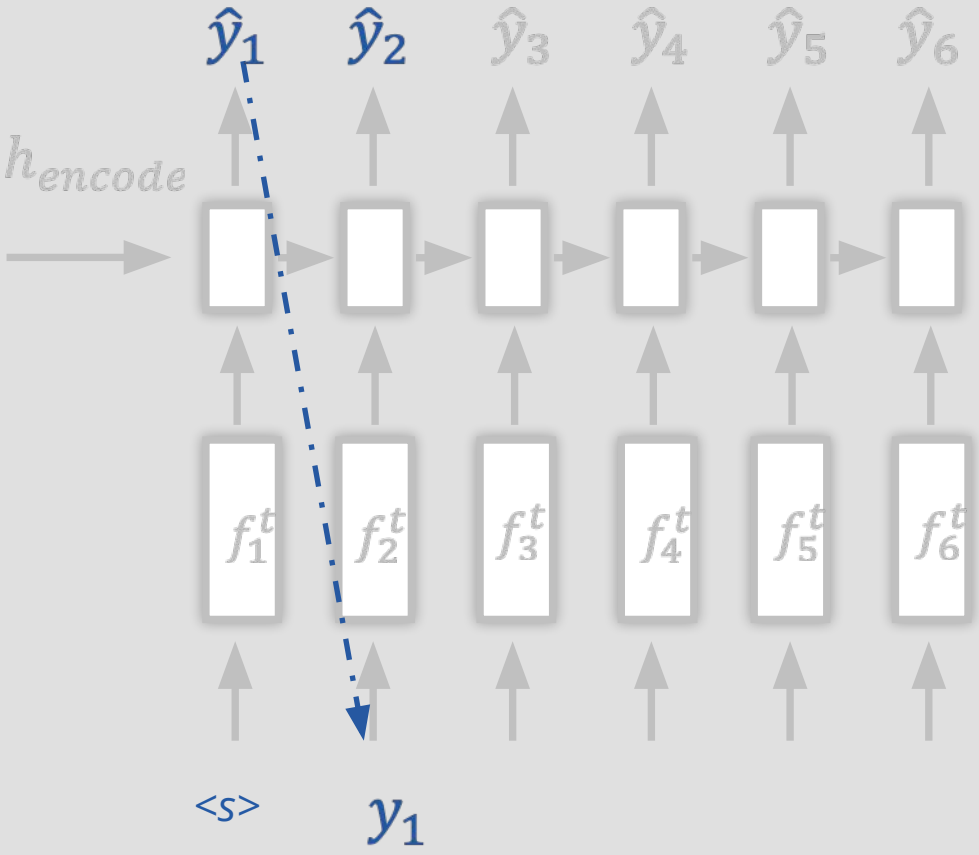

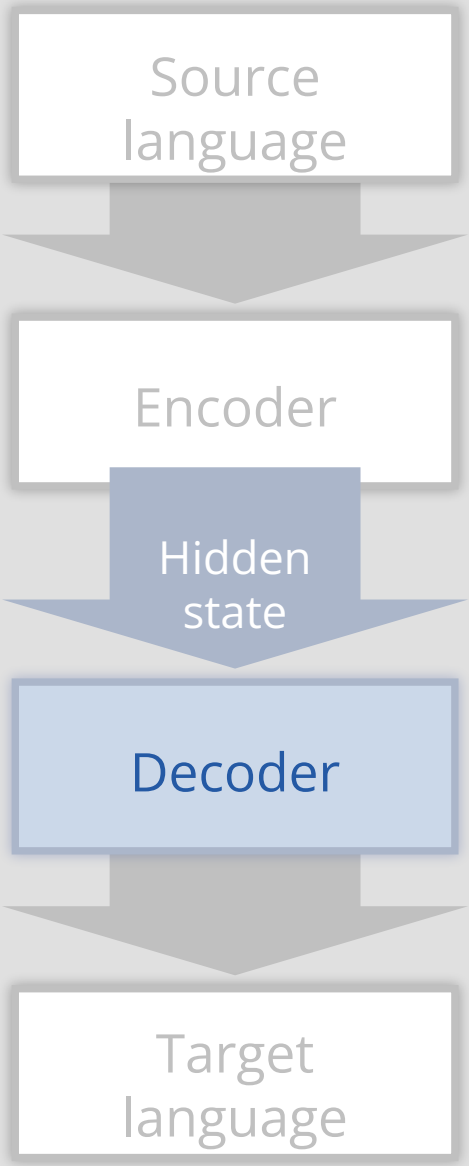

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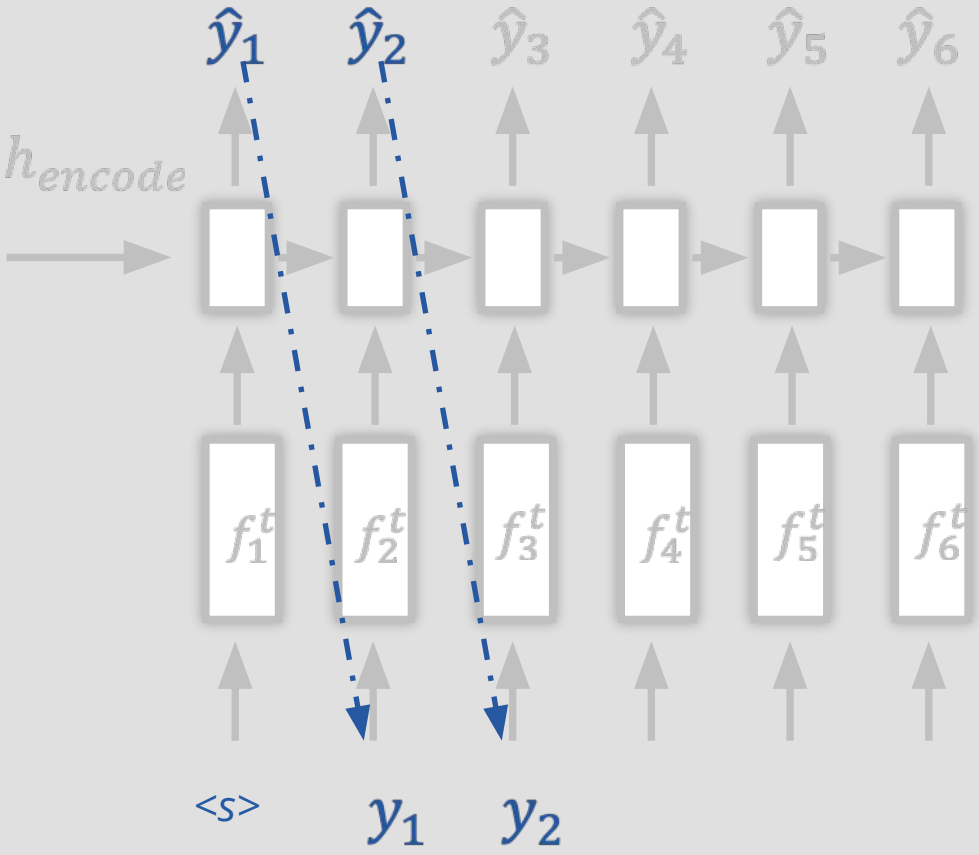

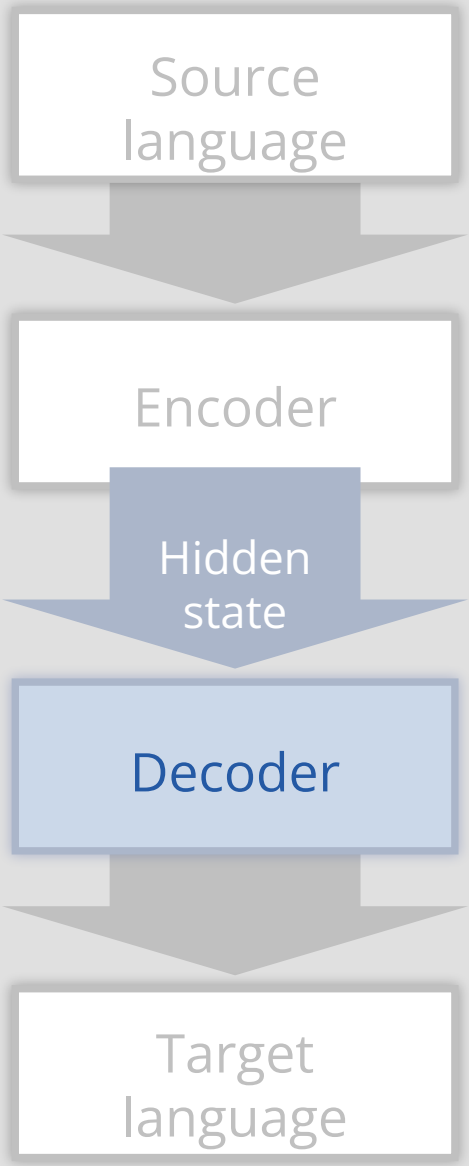

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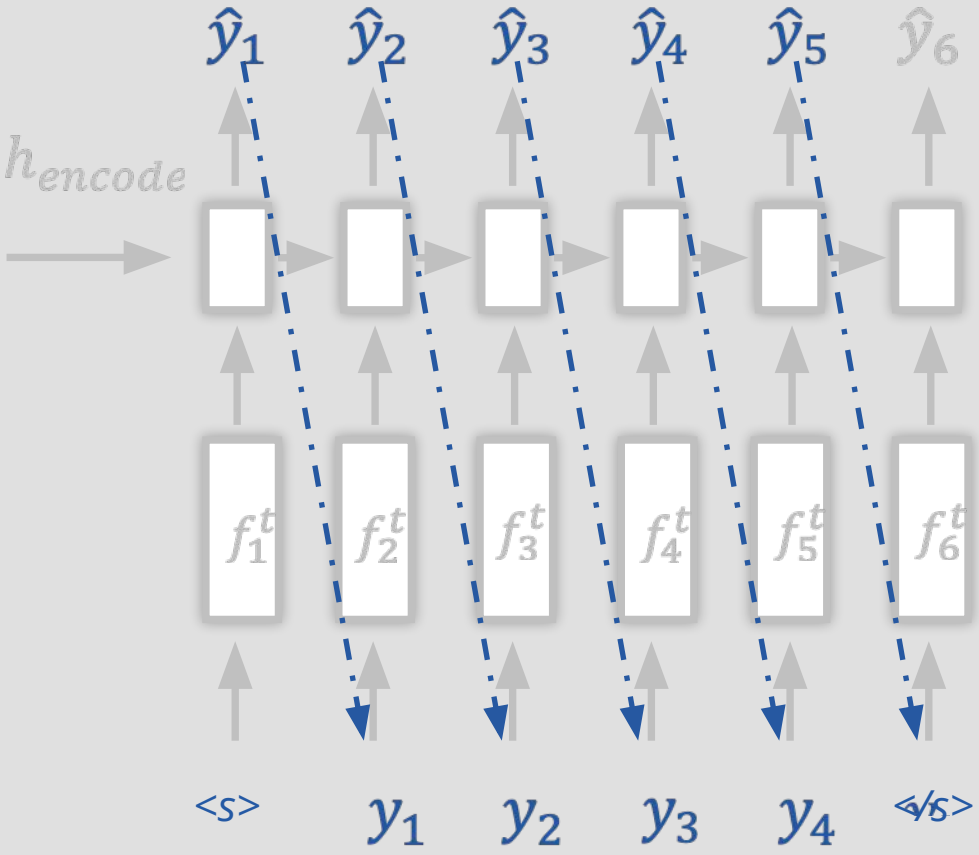
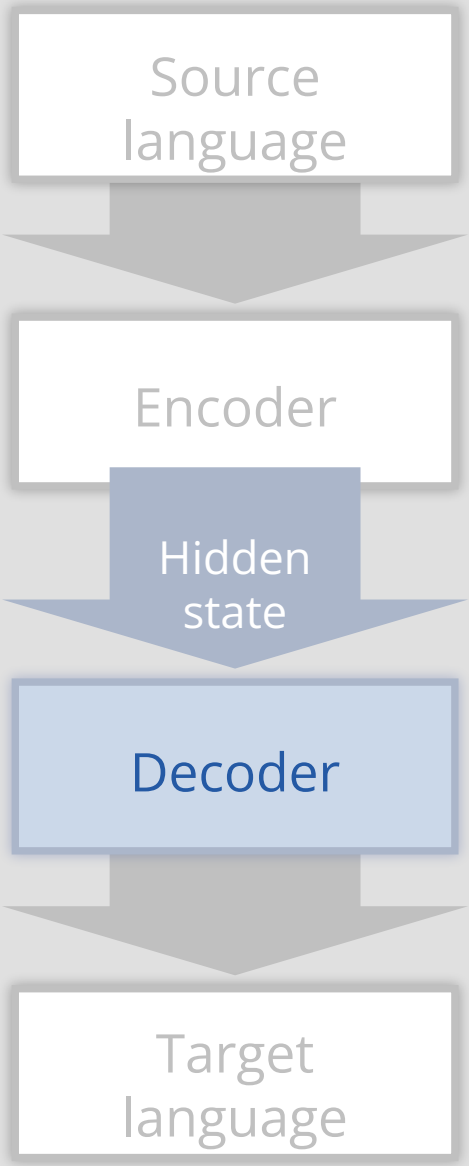
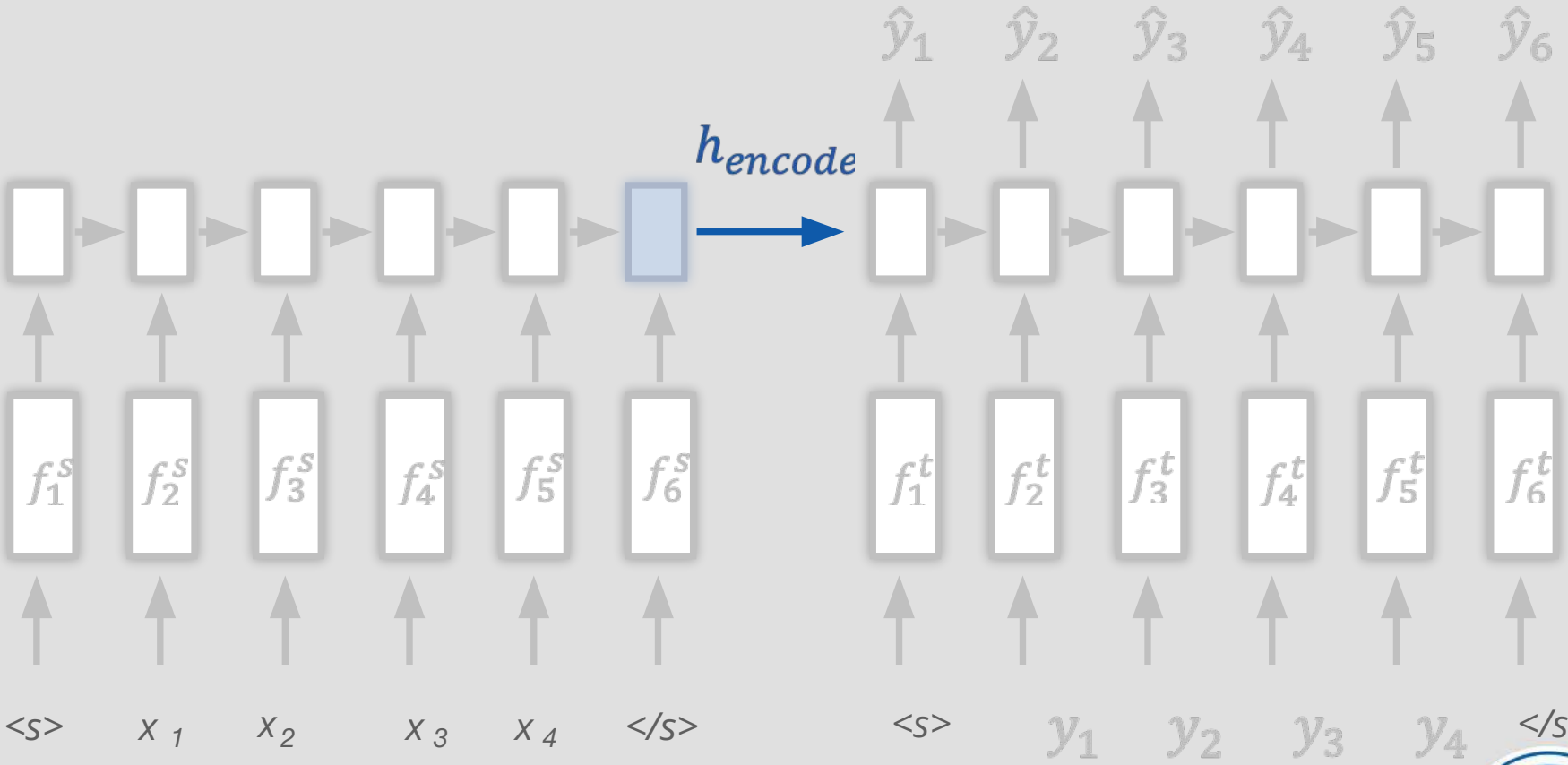


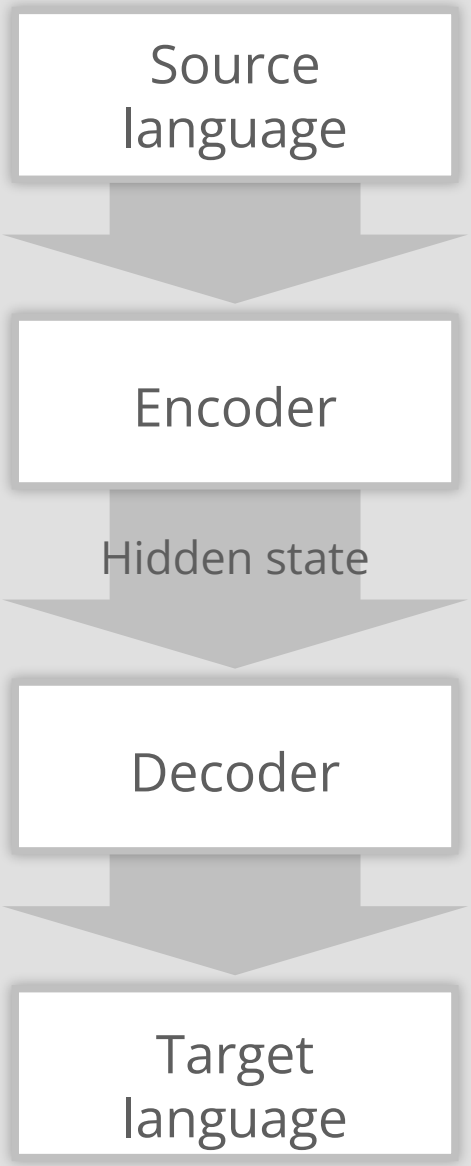


Neural machine translation



Encoder-decoder architecture

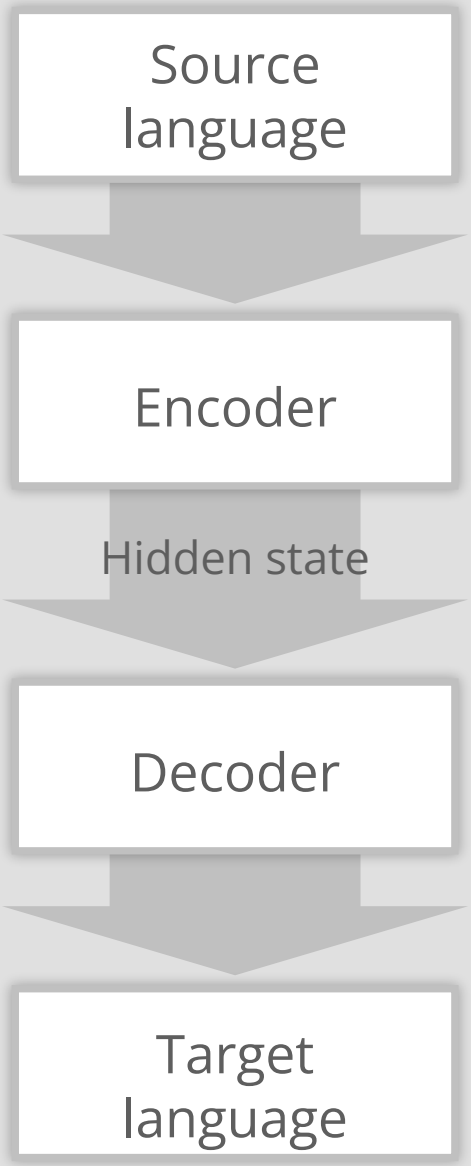
Consists of two parts:



Encoder-decoder architecture

Consists of two parts:

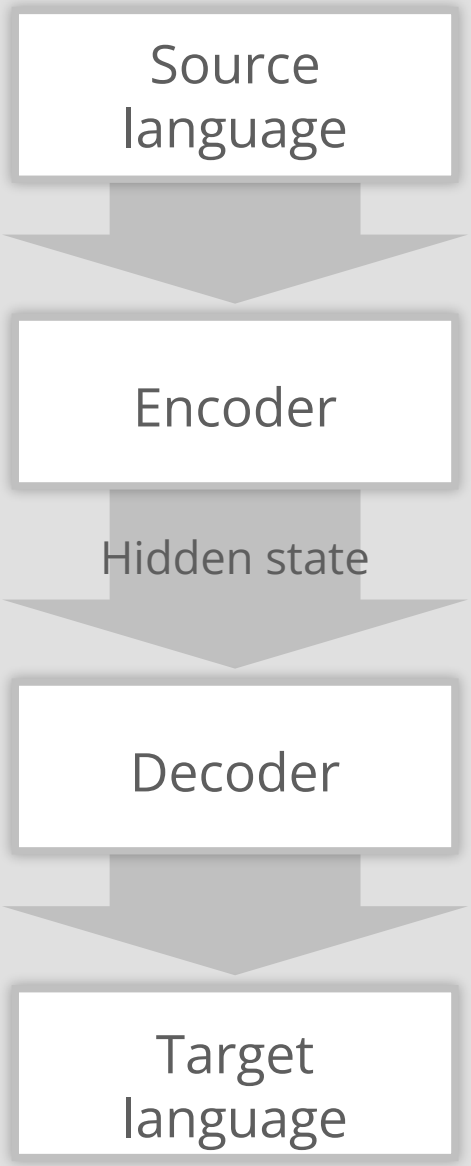
- Encoder encodes input word sequence



Encoder-decoder architecture

Consists of two parts:

- Encoder encodes input word sequence
- Decoder generates the output words sequence



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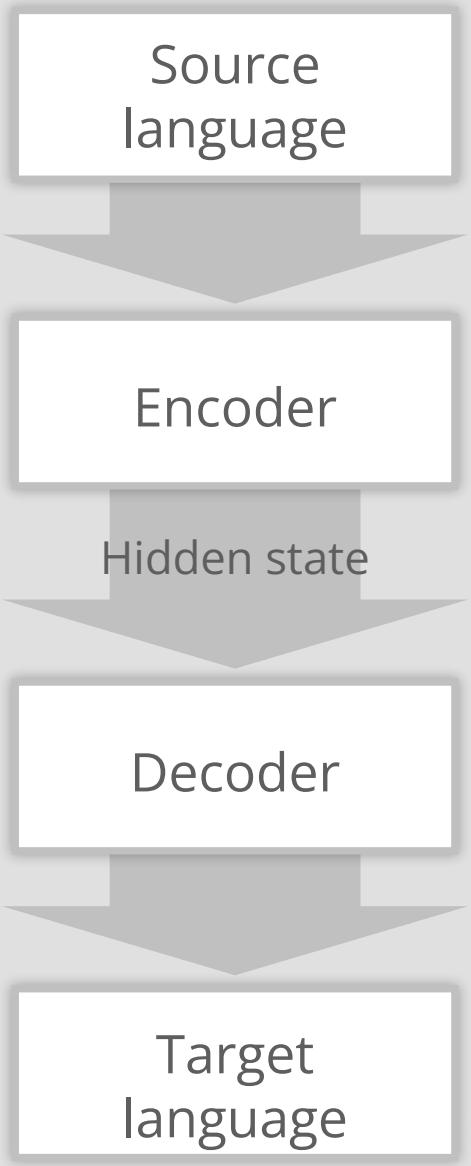
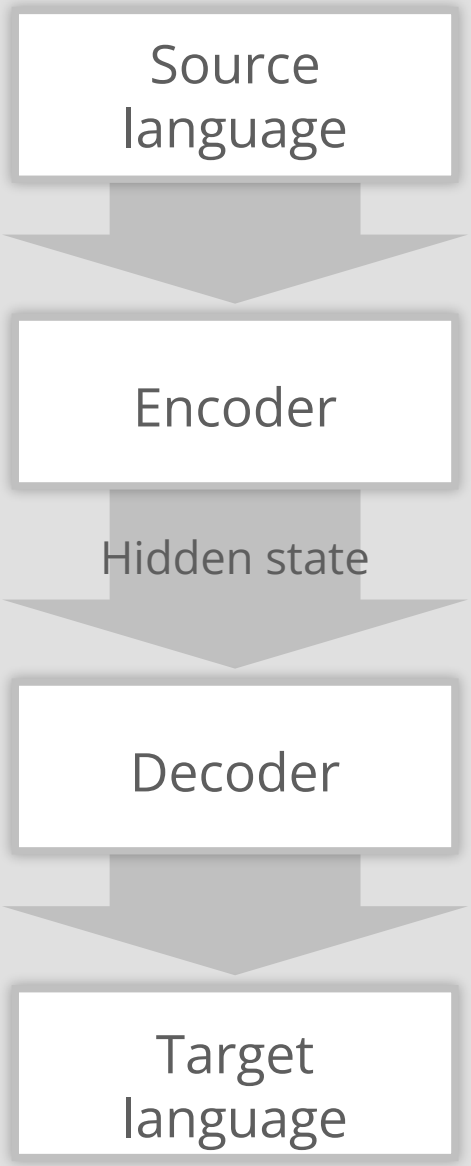
Decoder is a language model!



Encoder-decoder architecture

Encoder-decoder architectures can be used in various tasks:



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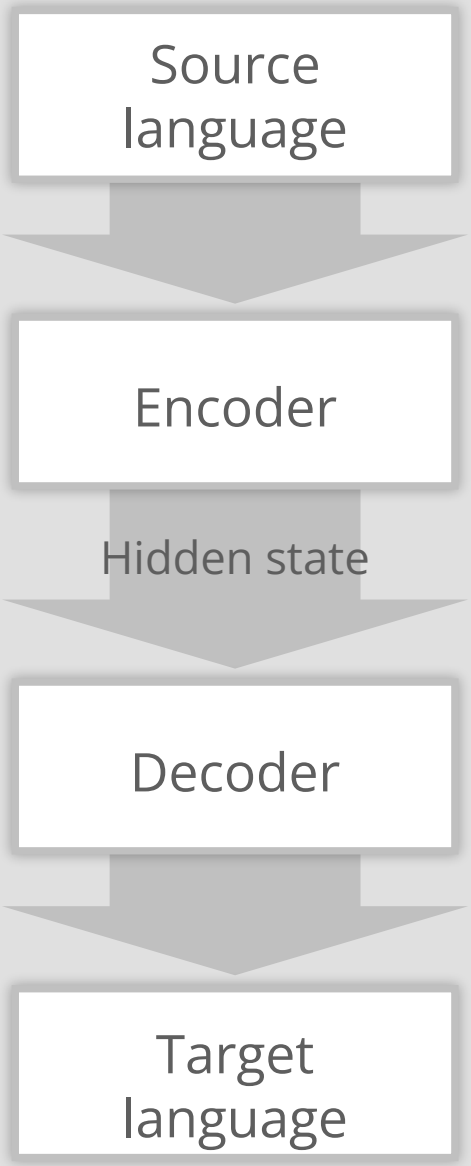

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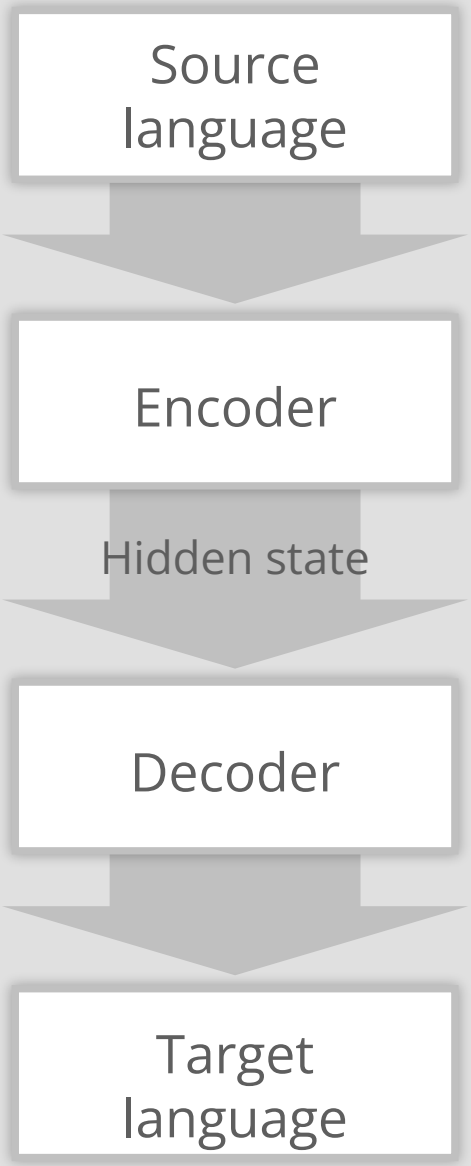

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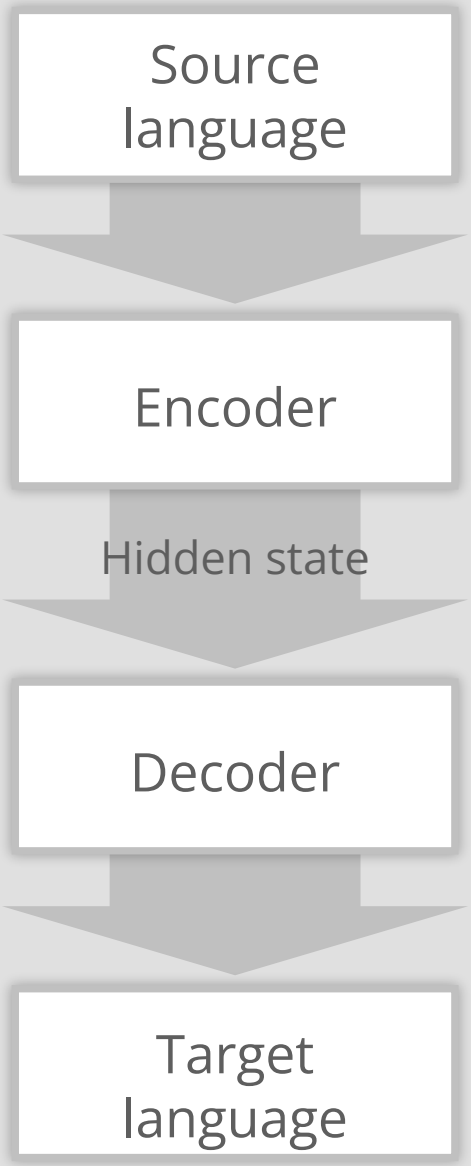

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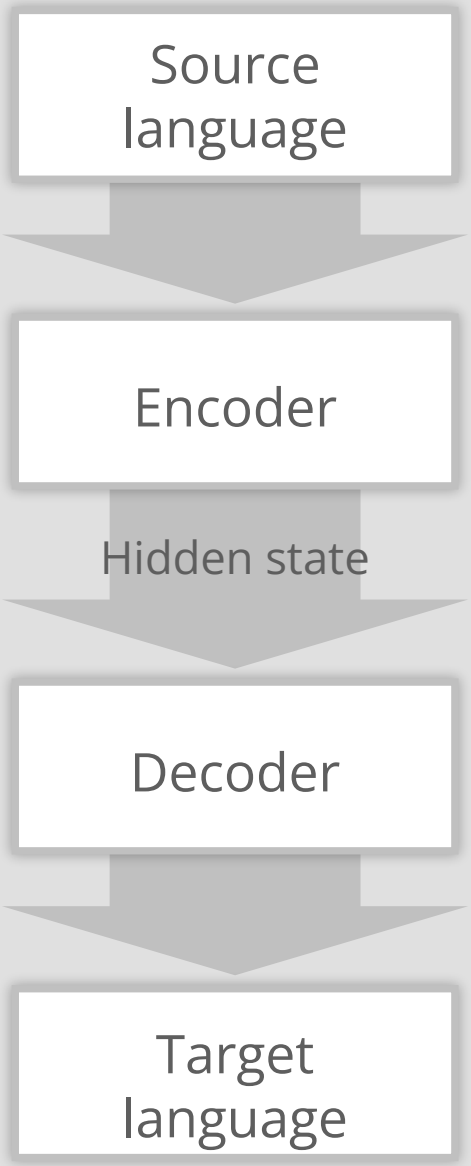
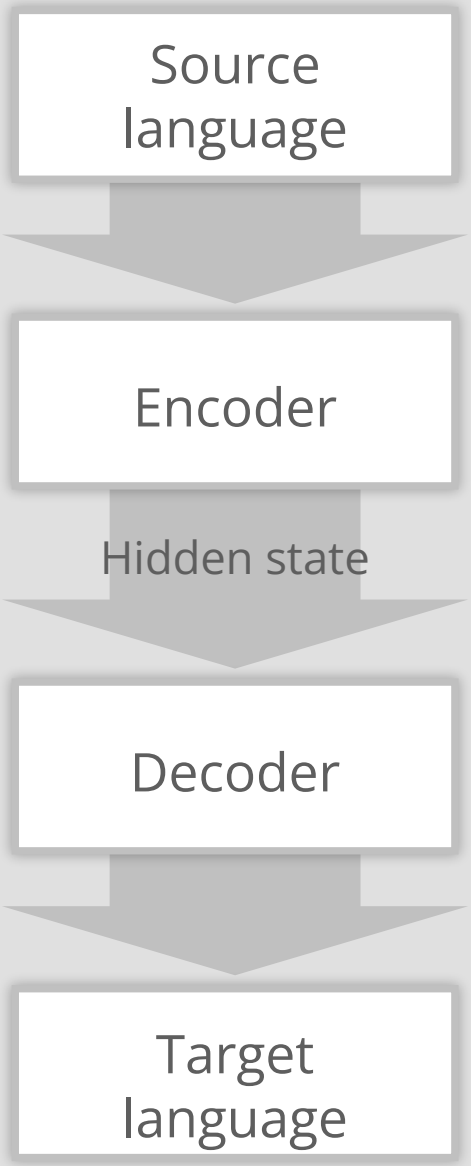


Encoder-decoder architecture

- Problem: only the last decoder state is used



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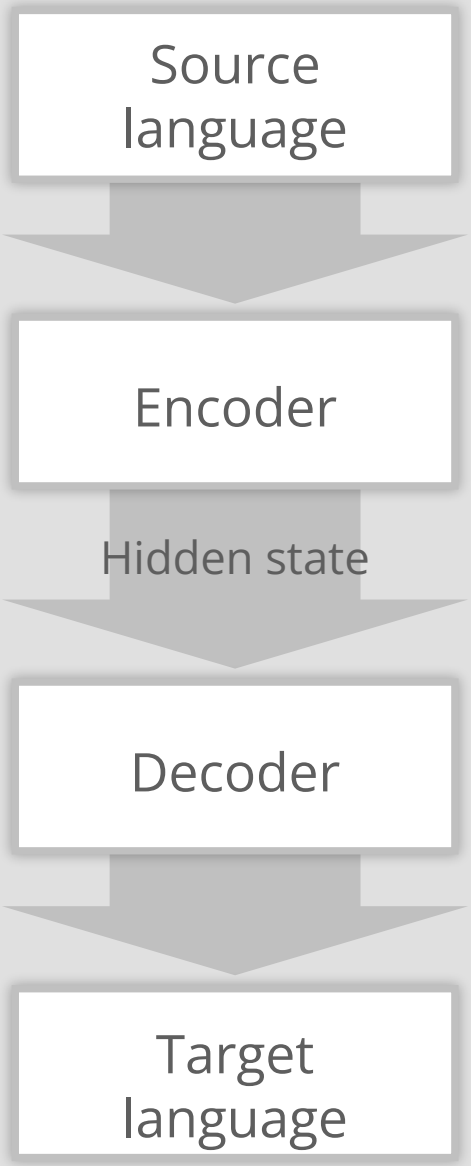

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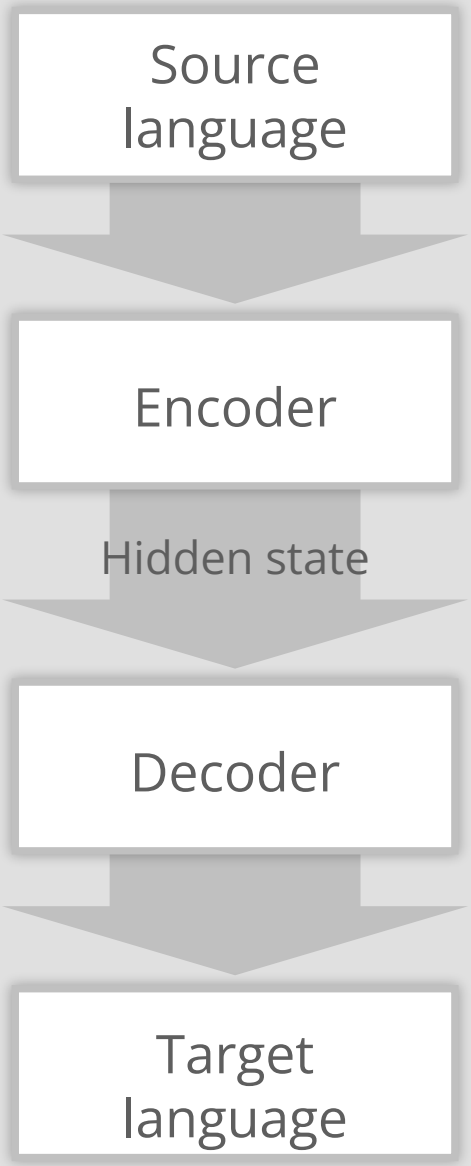

Encoder-decoder architecture

- Problem: only the last decoder state is used
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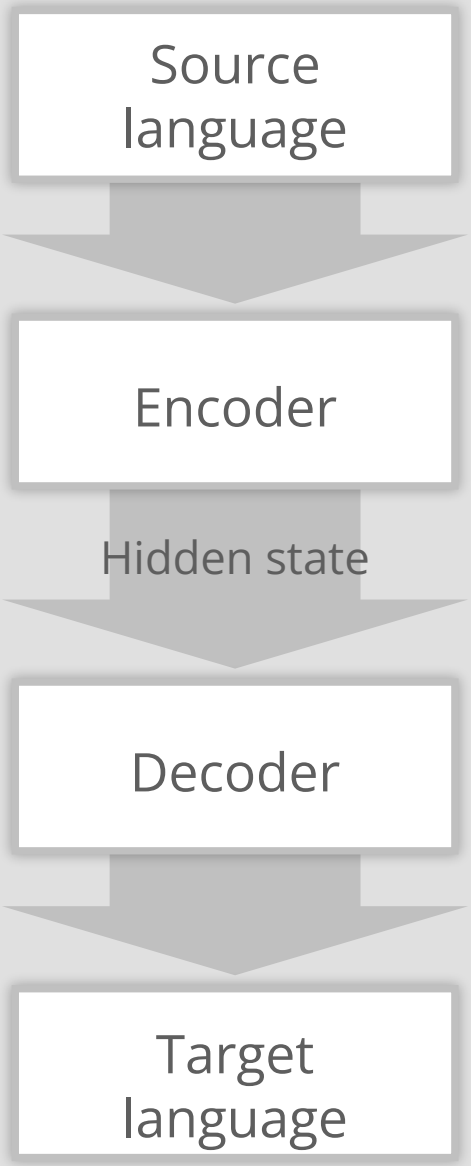
- Short sentences are processed better
- The architecture can be improved by adding attention mechanism



Attention mechanism

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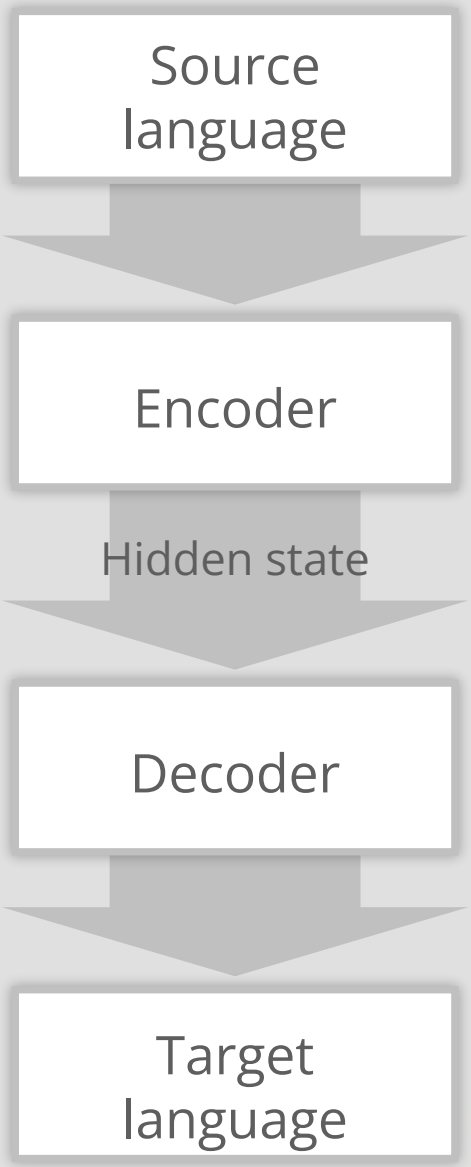

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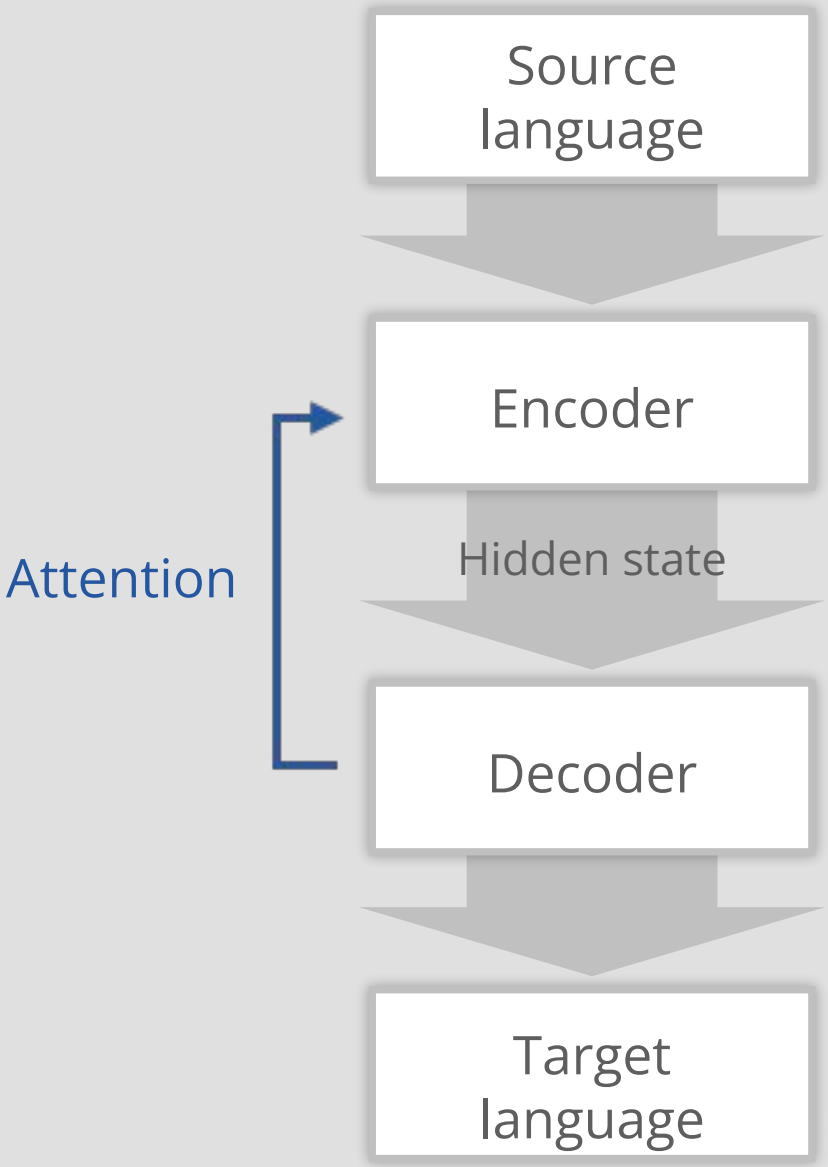

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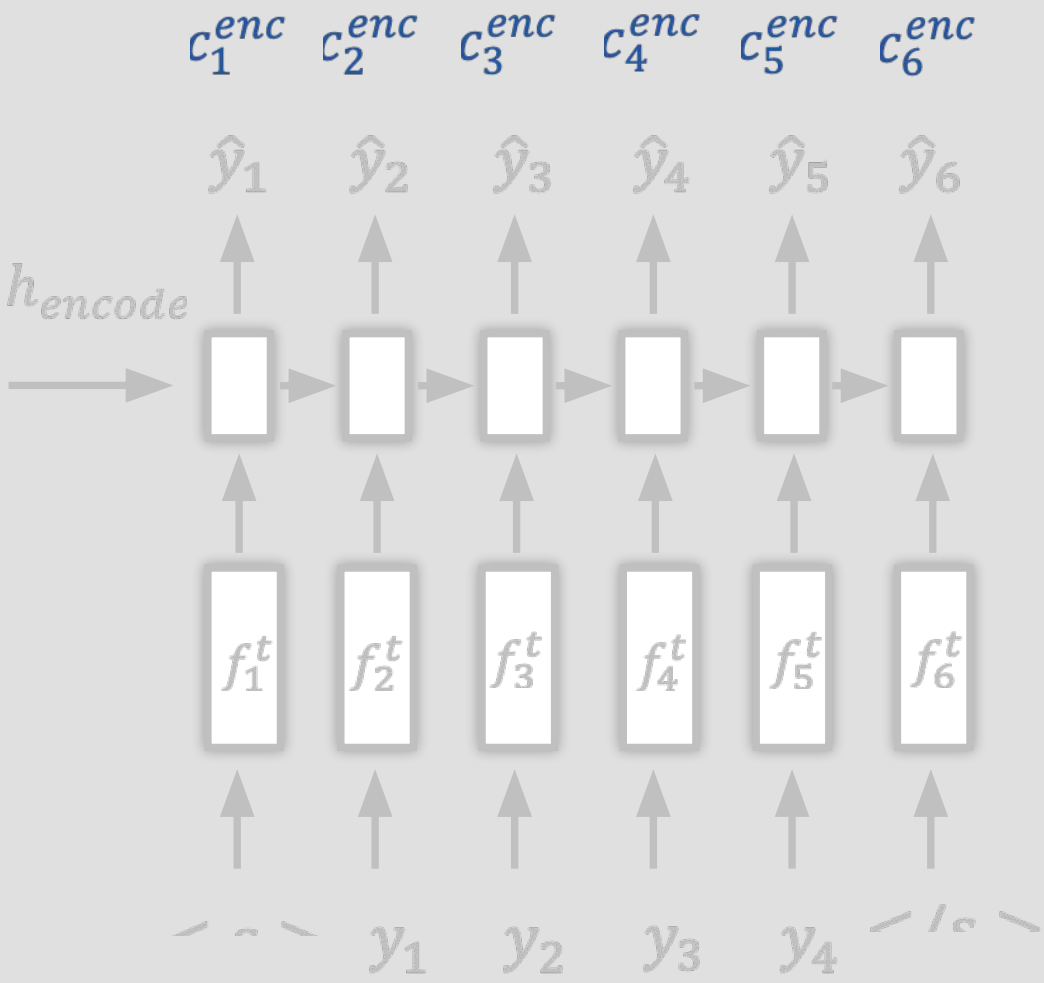

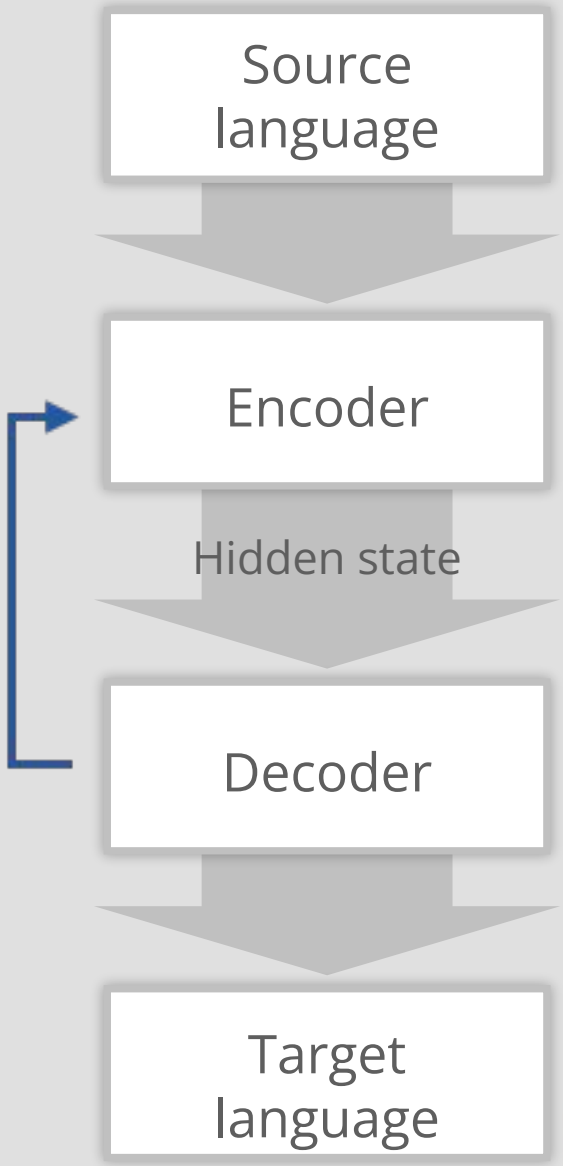

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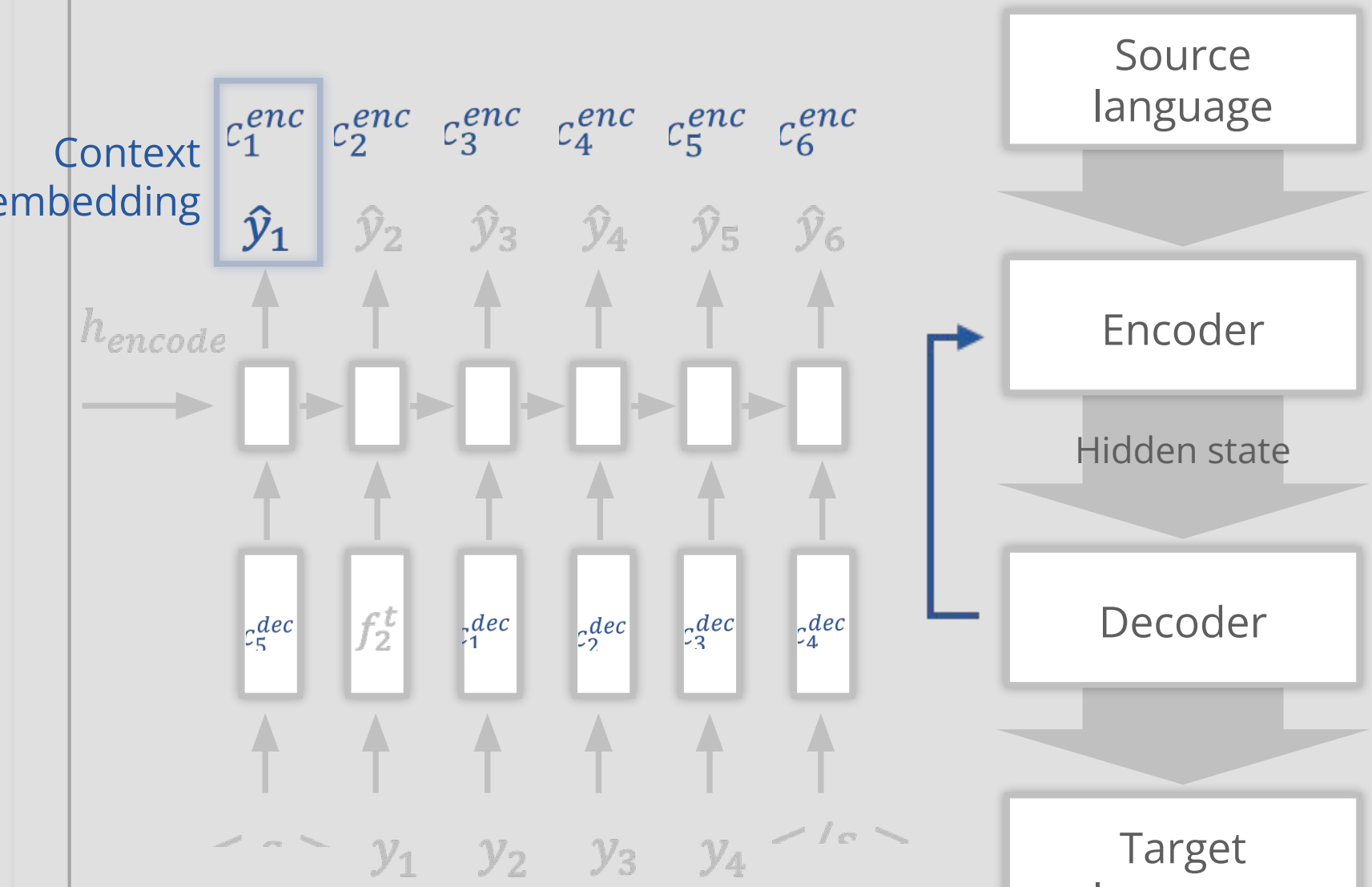


Attention mechanism

- Weights:

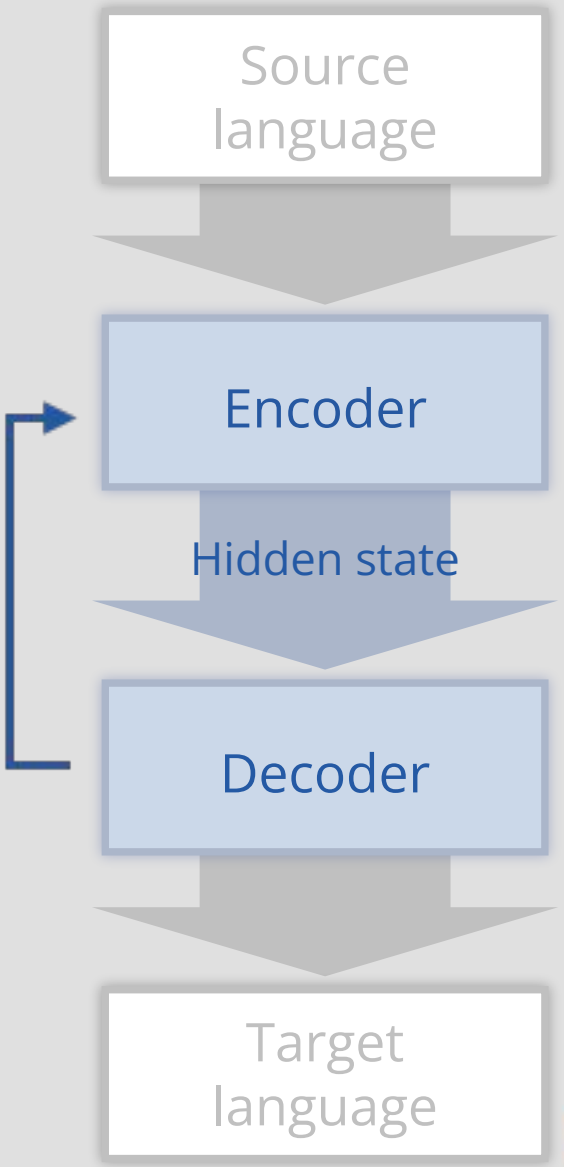
$$a_{ij} = sim(h_i^{enc}, h_j^{dec})$$

- Normalization:

$$\alpha_{ij} = \frac{e^{a_{ij}}}{\sum_k e^{a_{kj}}}$$

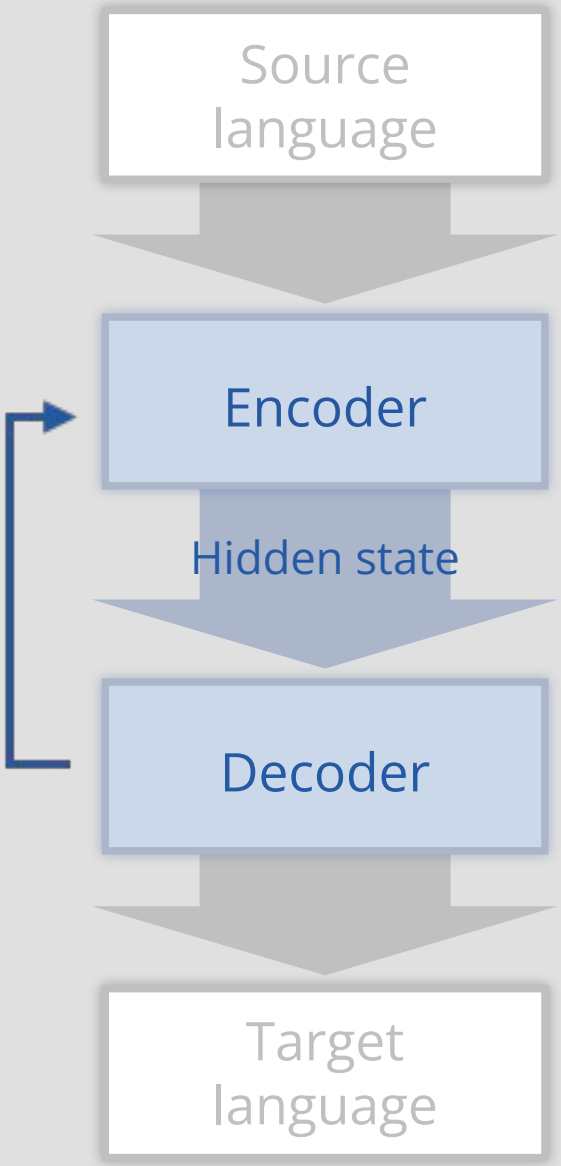
- Context embedding:

$$c_j = \sum_i \alpha_{ij} h_i^{enc}$$



Attention mechanism

- dot-product: $sim(h, s) = h^\top s$



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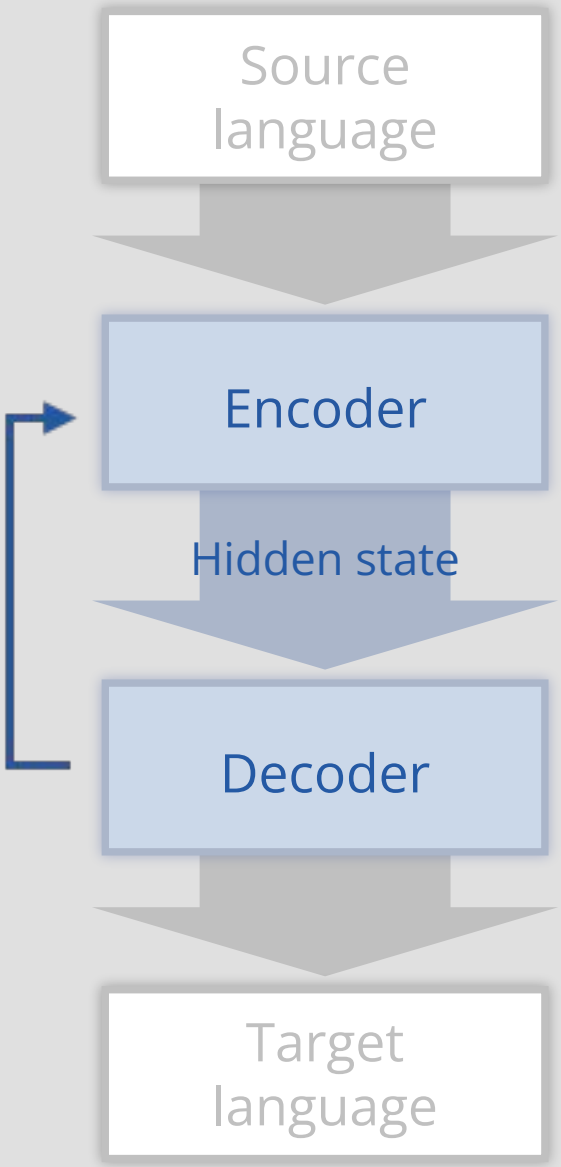
- dot-product: $sim(h, s) = h^\top s$

- Additive:

$sim(h, s) = w^\top \tanh(W_h h + W_s s)$



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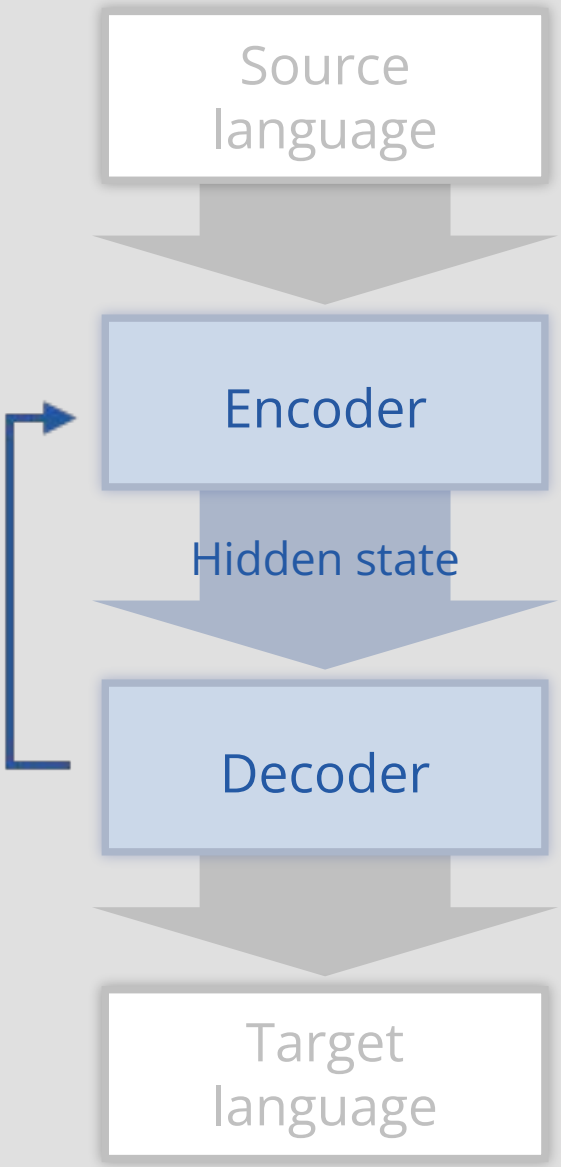

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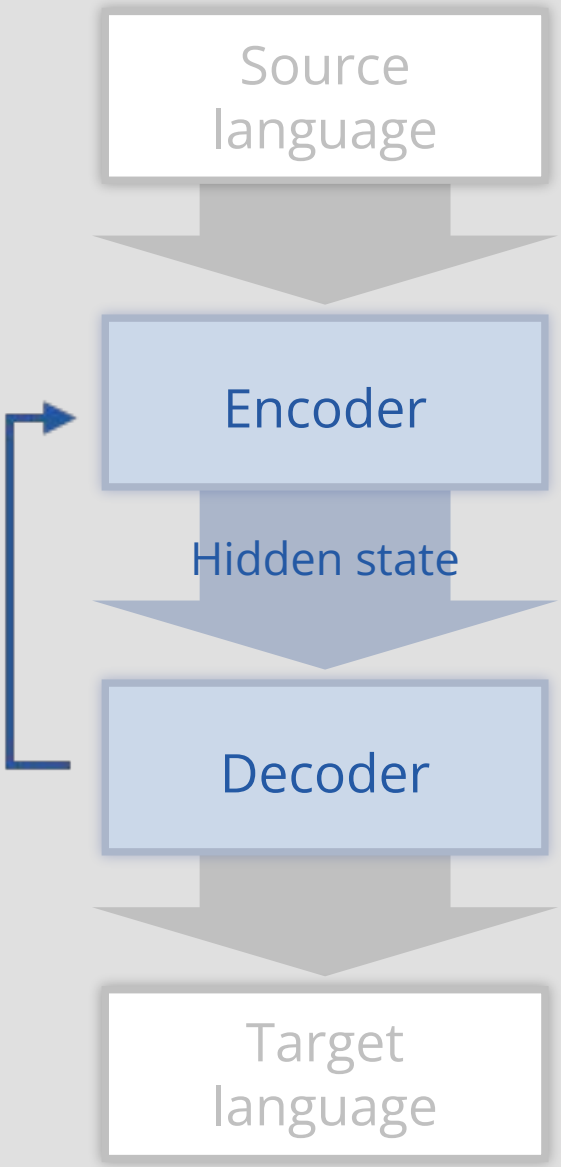
Weights are trained.



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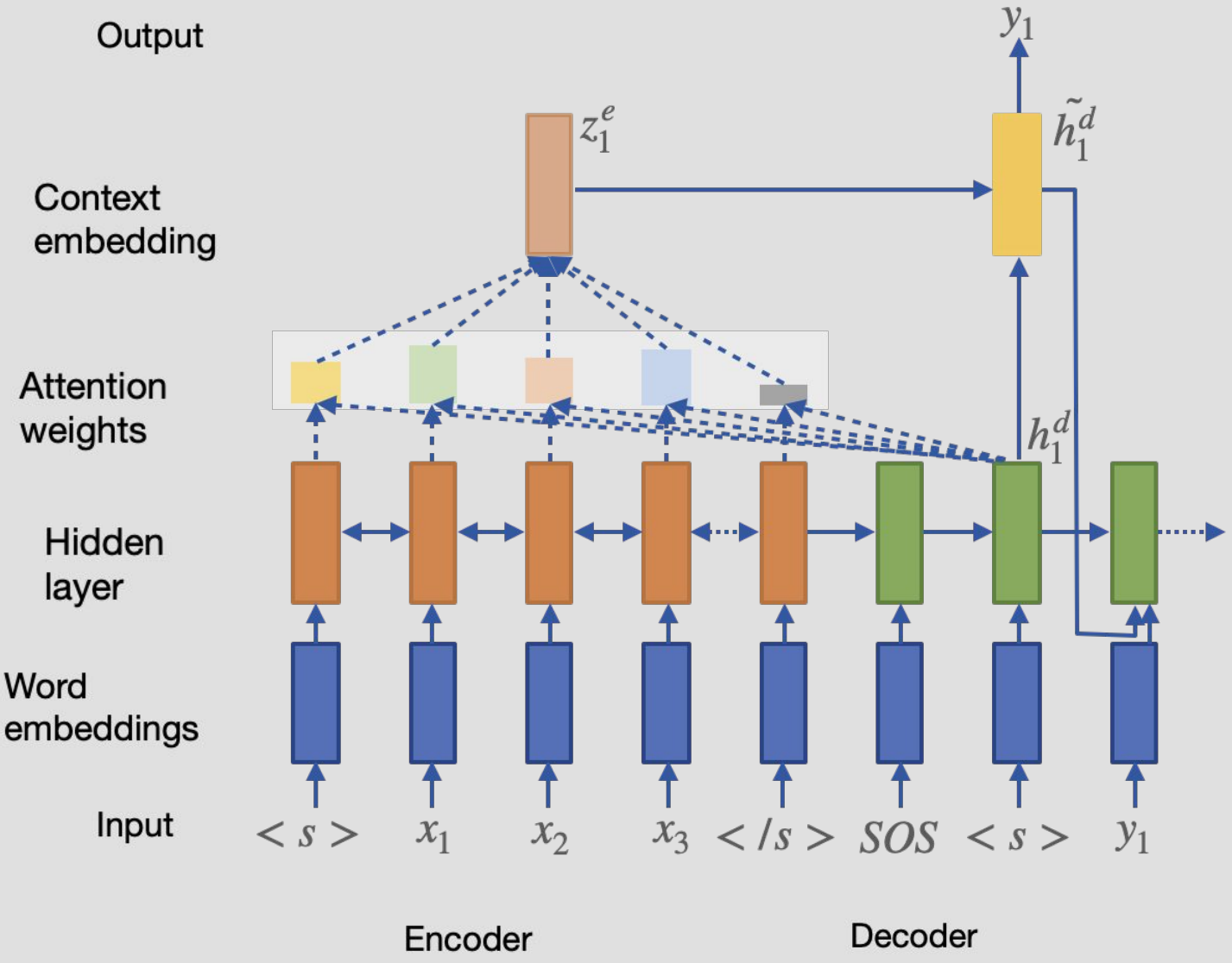
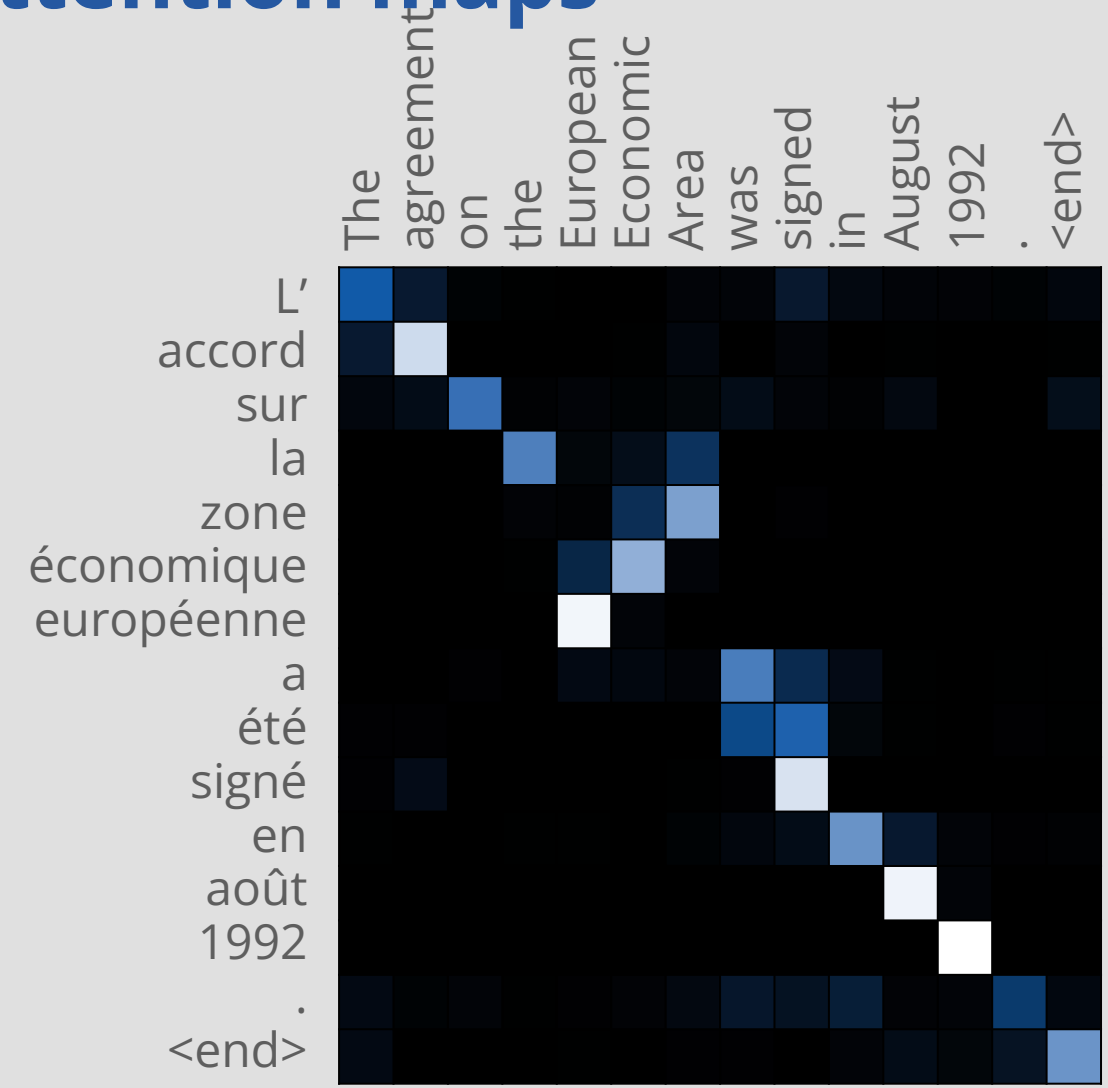


Attention maps



Source language

Encoder

Hidden state

Decoder

Target language

Machine translation quality metrics

Expert review

- We will show the sentence in the source language and the translation to the experts and ask them to rate the translation on a scale, for example, from 0 to 5

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Advantages	Disadvantages
• exact	• expensive • slow

Comparison with the gold standard

- Machine translation model is trained on a parallel corpus: sentence on a source language and several options of translations
- Split data into train and test

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Advantages	Disadvantages
• quick (if corpus is given)	• corpuses can become obsolete

Back translation

- Apply MT to translate sentence from source tp target language

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Back translation

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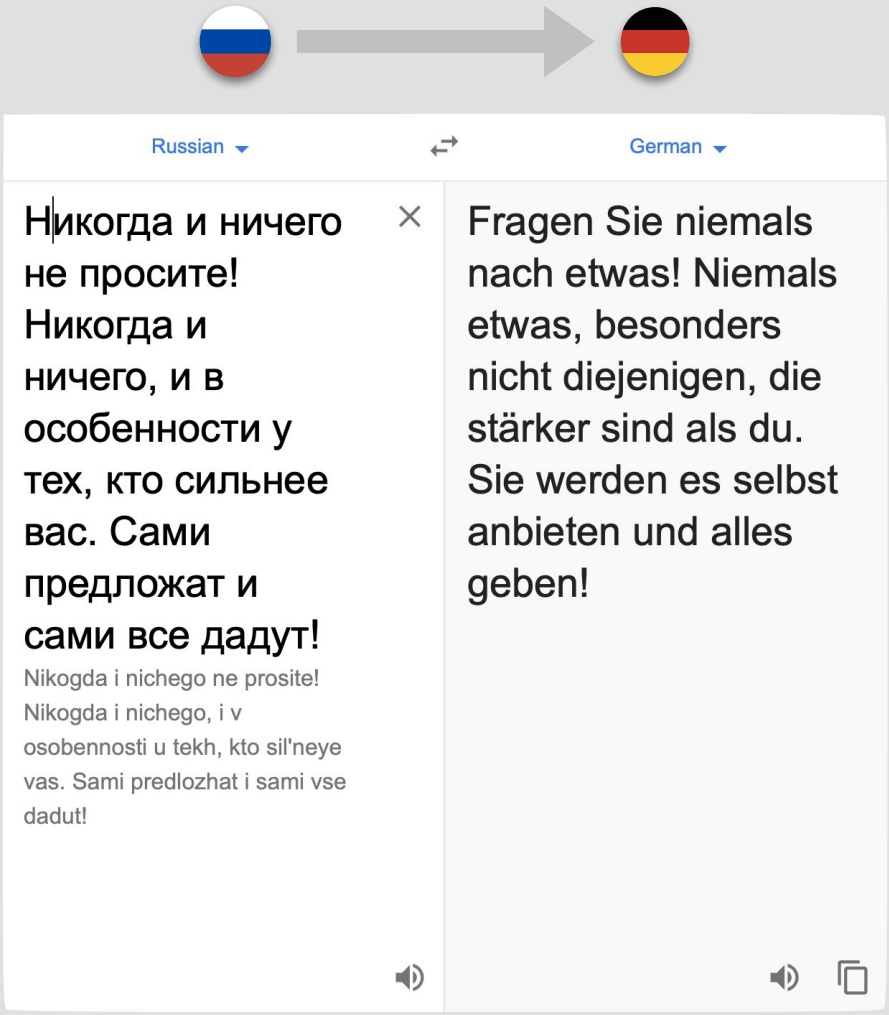

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Back translation

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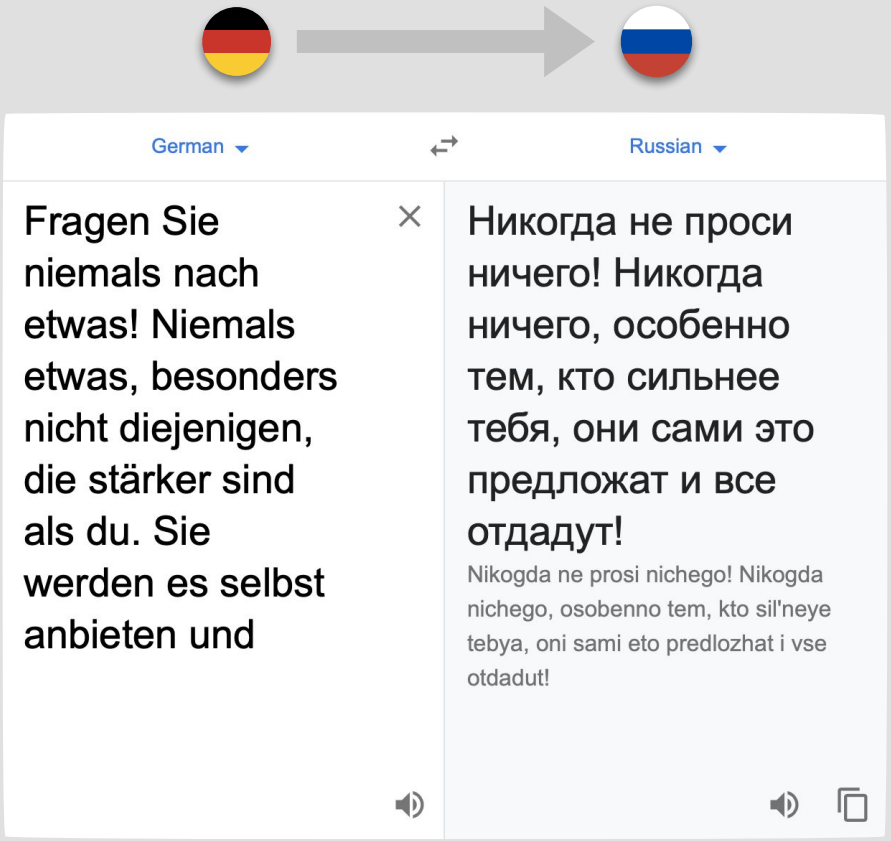

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Back translation

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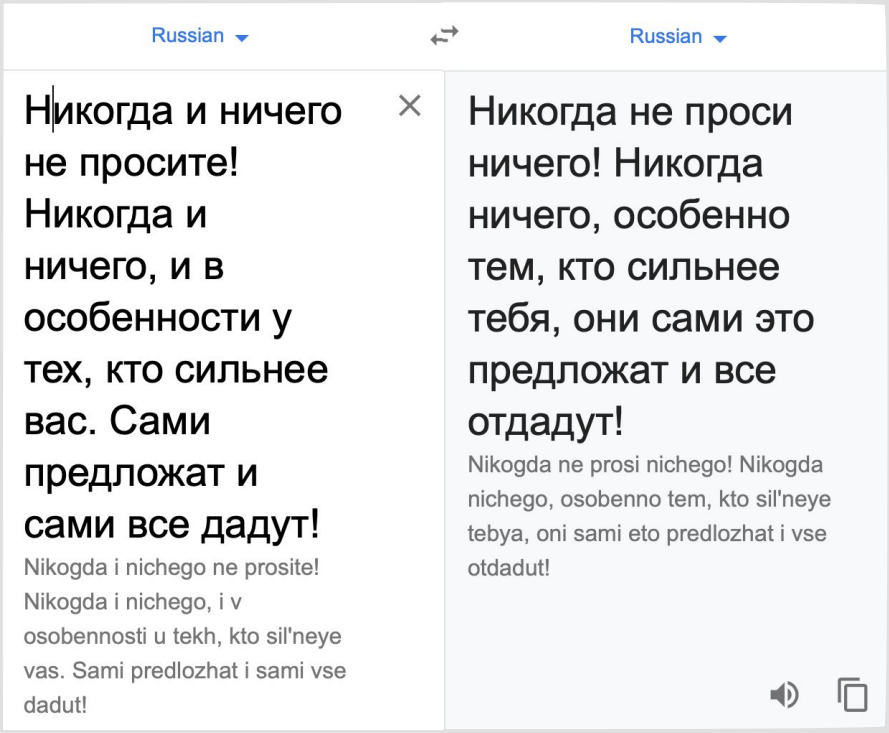
- Compare the original text and the resulting one after back translation



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BLEU (bilingual evaluation understudy)

- Compare sentences:
  - *Never ask for help!*
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Quote:

Remember that the most dangerous prison is the one in your head.

BLEU (bilingual evaluation understudy)

Quote:

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Gold standard:

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Помните, что самая опасная тюрьма находится в вашей голове.

MT2:

Помни, что самая опасная тюрьма – это тюрьма в твоей голове.

	MT1	MT2
Precision, n=1		
Precision, n=2		
Precision, n=3		
Precision, n=4		
Brevity penalty		
BLEU		

BLEU (bilingual evaluation understudy)

Quote:

Remember that the most dangerous prison is the one in your head.

Gold standard:

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MT2:

Помни, что самая опасная тюрьма – это тюрьма в твоей голове.

	MT1	MT2
Precision, n=1	5/9	
Precision, n=2	3/8	
Precision, n=3	2/7	
Precision, n=4	1/6	
Brevity penalty		
BLEU		

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	MT1	MT2
Precision, n=1	5/9	
Precision, n=2	3/8	
Precision, n=3	2/7	
Precision, n=4	1/6	
Brevity penalty	1	
BLEU		

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MT2:

Помни, что самая опасная тюрьма – это тюрьма в твоей голове.

	MT1	MT2
Precision, n=1	5/9	
Precision, n=2	3/8	
Precision, n=3	2/7	
Precision, n=4	1/6	
Brevity penalty	1	
BLEU	0.3303	

BLEU (bilingual evaluation understudy)

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MT2:

Помни, что самая опасная тюрьма – это тюрьма в твоей голове.

	MT1	MT2
Precision, n=1	5/9	7/10
Precision, n=2	3/8	5/9
Precision, n=3	2/7	3/8
Precision, n=4	1/6	2/7
Brevity penalty	1	1
BLEU	0.3303	**0.6389**

WER (word error rate)

- The minimum number of operations required for transforming MT result into gold standard
- Operations: replacement, deletion, adding words

$$WER = \frac{\#\text{deletion} + \#\text{adding words} + \#\text{replacement}}{\#\text{ (gold standard)}}$$

translate.google.com

WER (word error rate)

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WER (word error rate)

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MT2:

Помни, что самая опасная тюрьма – это тюрьма в твоей голове.

	MT1	MT2
# adding words		
# replacement		
# deletion		
WER		

WER (word error rate)

Quote:

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Gold standard:

Помни, что самая опасная тюрьма – в твоей голове.

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~~Помните~~ помни, что самая опасная тюрьма находится в вашей голове.

MT2:

Помни, что самая опасная тюрьма – это тюрьма в твоей голове.

	MT1	MT2
# adding words		
# замен	1	
# deletion		
WER		

WER (word error rate)

Quote:

Remember that the most dangerous prison is the one in your head.

Gold standard:

Помни, что самая опасная тюрьма – в твоей голове.

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~~Помните~~ помни, что самая опасная тюрьма находится в вашей голове.

MT2:

Помни, что самая опасная тюрьма – это тюрьма в твоей голове.

	MT1	MT2
# adding words		
# replacement	1	
# deletion		
WER		

WER (word error rate)

Quote:

Remember that the most dangerous prison is the one in your head.

Gold standard:

Помни, что самая опасная тюрьма – в твоей голове.

MT1:

~~Помните~~ помни, что самая опасная тюрьма ~~находится~~ в вашей голове.

MT2:

Помни, что самая опасная тюрьма – это тюрьма в твоей голове.

	MT1	MT2
# adding words		
# replacement	1	
# deletion	1	
WER		

WER (word error rate)

Quote:

Remember that the most dangerous prison is the one in your head.

Gold standard:

Помни, что самая опасная тюрьма – в твоей голове.

MT1:

~~*Помните*~~ *помни, что самая опасная тюрьма* ~~*находится*~~ *в* ~~*вашей*~~ *твоей голове.*

MT2:

Помни, что самая опасная тюрьма – это тюрьма в твоей голове.

	MT1	MT2
# adding words		
# replacement	2	
# deletion	1	
WER		

WER (word error rate)

Quote:

Remember that the most dangerous prison is the one in your head.

Gold standard:

Помни, что самая опасная тюрьма – в твоей голове.

MT1:

~~*Помните*~~ *помни, что самая опасная тюрьма* ~~*находится*~~ *в* ~~*вашей*~~ *твоей голове.*

MT2:

Помни, что самая опасная тюрьма – это тюрьма в твоей голове.

	MT1	MT2
# adding words	0	
# replacement	2	
# deletion	1	
WER		

WER (word error rate)

Quote:

Remember that the most dangerous prison is the one in your head.

Gold standard:

Помни, что самая опасная тюрьма – в твоей голове.

MT1:

~~*Помните*~~ *помни, что самая опасная тюрьма* ~~*находится*~~ *в* ~~*вашей*~~ *твоей голове.*

MT2:

Помни, что самая опасная тюрьма – это тюрьма в твоей голове.

	MT1	MT2
# adding words	0	
# replacement	2	
# deletion	1	
WER	0.33	

WER (word error rate)

Quote:

Remember that the most dangerous prison is the one in your head.

Gold standard:

Помни, что самая опасная тюрьма – в твоей голове.

MT1:

~~Помните~~ помни, что самая опасная тюрьма ~~находится~~ в ~~вашей~~ твоей голове.

MT2:

Помни, что самая опасная тюрьма – ~~это тюрьма~~ в твоей голове.

	MT1	MT2
# adding words	0	
# replacement	2	
# deletion	1	
WER	0.33	

WER (word error rate)

Quote:

Remember that the most dangerous prison is the one in your head.

Gold standard:

Помни, что самая опасная тюрьма – в твоей голове.

MT1:

~~*Помните*~~ *помни, что самая опасная тюрьма* ~~*находится*~~ *в* ~~*вашей*~~ *твоей голове.*

MT2:

Помни, что самая опасная тюрьма – ~~*это тюрьма*~~ *в твоей голове.*

	MT1	MT2
# adding words	0	0
# replacement	2	0
# deletion	1	2
WER	0.33	**0.2**

WER and BLEU

Advantages

- Simple and quick
- Correlate with expert review

Disadvantages

- Operate with short fragments
- Can’t estimate genre specifics
- The ratings are relative, difficult to compare with each other
- An important technical problem: estimates are not differentiable