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Recurrent Neural Networks

Why sequence models?

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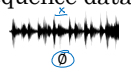
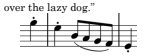
Examples of sequence data

Speech recognition		"The quick brown fox jumped over the lazy dog."
Music generation	∅	
Sentiment classification	"There is nothing to like in this movie."	★☆☆☆☆
DNA sequence analysis	AGCCCCTGTGAGGAACTAG	AGCCCCTGTGAGGAACTAG
Machine translation	Voulez-vous chanter avec moi?	Do you want to sing with me?
Video activity recognition		Running
Name entity recognition	Yesterday, Harry Potter met Hermione Granger.	Yesterday, Harry Potter met Hermione Granger.

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Notation

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Motivating example

NLP

x: Harry Potter and Hermione Granger invented a new spell.

$x^{<1>}$ $x^{<2>}$ $x^{<3>}$ ..... $x^{<t>}$ ..... $x^{<9>}$

$T_x = 9$

y: 1 1 0 1 1 0 0 0 0

$y^{<1>}$ $y^{<2>}$ $y^{<3>}$ ..... $y^{<9>}$

$T_y = 9$

$x^{(i)<t>}$ $T_x^{(i)} = 9$ 15

$y^{(i)<t>}$ $T_y^{(i)}$

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Representing words

$x^{<t>}$ (x, y)

$x \to y$

x: Harry Potter and Hermione Granger invented a new spell.

$x^{<1>}$ $x^{<2>}$ $x^{<3>}$ ... $x^{<t>}$ $x^{<9>}$

Vocabulary

a	1
aaron	2
and	367
harry	4075
potter	6830
zulu	10,000

<UNK> 10,000

$\leftarrow 4075$ $\leftarrow 6830$ $\leftarrow 367$ 10,000

One-hot

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Representing words

x: Harry Potter and Hermione Granger invented a new spell.

$x^{<1>}$ $x^{<2>}$ $x^{<3>}$ ... $x^{<9>}$

And = 367
Invented = 4700
A = 1
New = 5976
Spell = 8376
Harry = 4075
Potter = 6830
Hermione = 4200
Gran... = 4000

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Recurrent Neural Networks

Recurrent Neural Network Model

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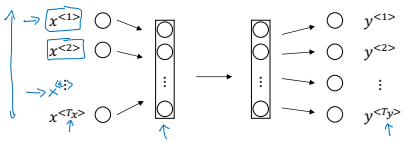
Why not a standard network?



Problems:

- Inputs, outputs can be different lengths in different examples.
- Doesn't share features learned across different positions of text.

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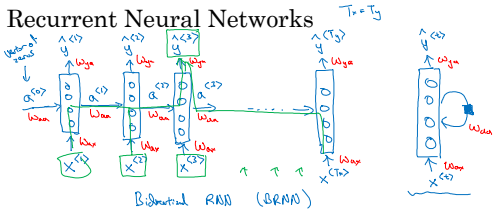
Recurrent Neural Networks



He said, "Teddy Roosevelt was a great President."

He said, "Teddy bears are on sale!"

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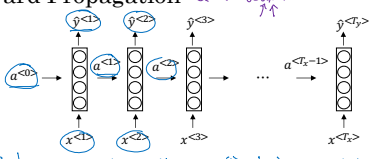
Forward Propagation



$a^{<0>} = \vec{0}$

$a^{<1>} = g_1(W_{aa}a^{<0>} + W_{ax}x^{<1>} + b_a)$ ← tanh / ReLU

$\hat{y}^{<1>} = g_2(W_{ya}a^{<1>} + b_y)$ ← sigmoid

$$\boxed{\begin{aligned} a^{<t>} &= g(W_{aa}a^{<t-1>} + W_{ax}x^{<t>} + b_a) \\ \hat{y}^{<t>} &= g(W_{ya}a^{<t>} + b_y) \end{aligned}}$$

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Simplified RNN notation

$$a^{<t>} = g(W_{aa}a^{<t-1>} + W_{ax}x^{<t>} + b_a)$$

$$\hat{y}^{<t>} = g(W_{ya}a^{<t>} + b_y)$$

$$\hat{y}^{<t>} = g(W_y a^{<t>} + b_y)$$

$$a^{<t>} = g(W_a[a^{<t-1>}, x^{<t>}] + b_a)$$

$$[W_{aa} \vdots W_{ax}] = W_a$$

$$[a^{<t-1>}, x^{<t>}] = \begin{bmatrix} a^{<t-1>} \\ x^{<t>} \end{bmatrix}$$

$$[W_{aa} \vdots W_{ax}] \begin{bmatrix} a^{<t-1>} \\ x^{<t>} \end{bmatrix} = W_{aa}a^{<t-1>} + W_{ax}x^{<t>}$$

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Recurrent Neural Networks

Different types of RNNs

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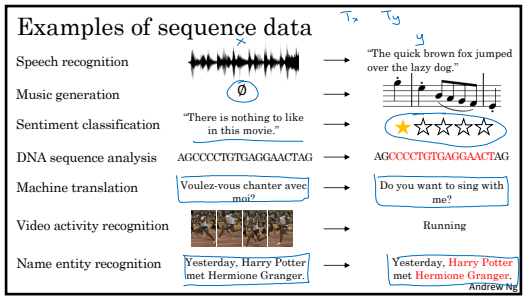
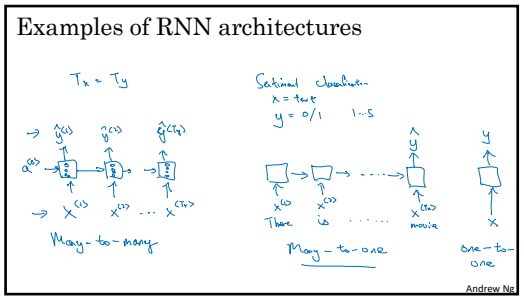
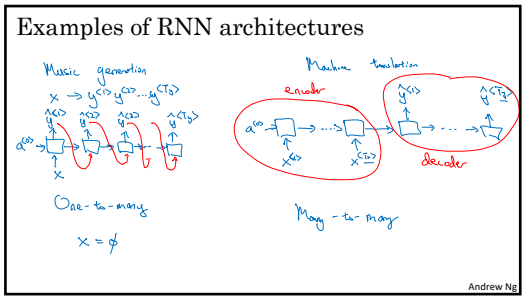


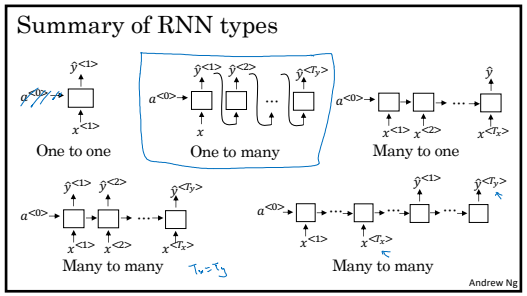
13



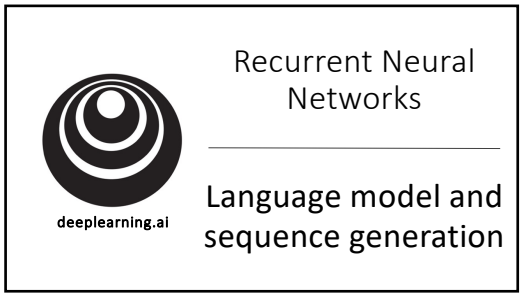
14



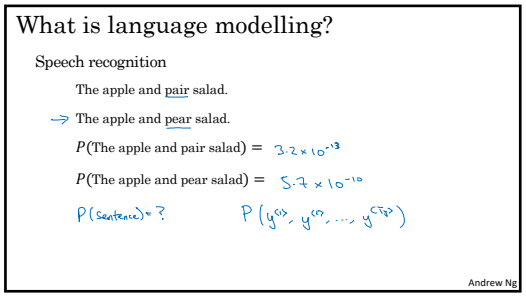
15



16



17



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Language modelling with an RNN

Training set: large corpus of english text.

Tokenize

Cats average 15 hours of sleep a day. <EOS>

The Egyptian Mau is a bread of cat. <EOS>

10,000 <UNK>

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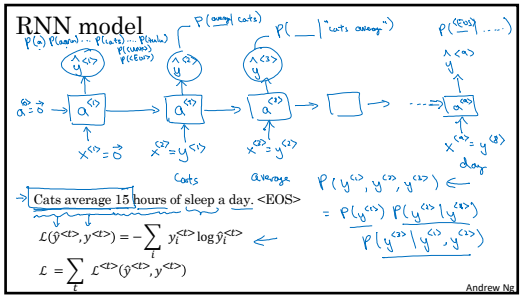
RNN model



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Sampling novel sequences

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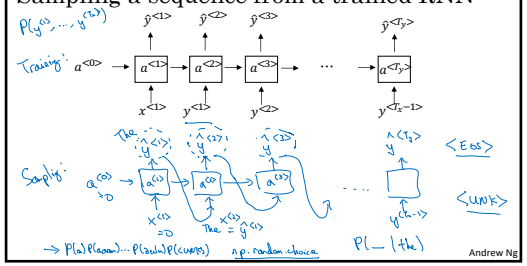
Sampling a sequence from a trained RNN



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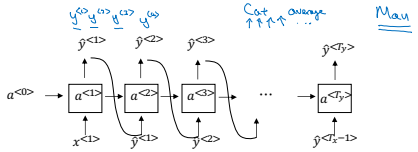
Character-level language model

Vocabulary = [a, aaron, …, zulu, <UNK>]

Vocabulary = [a, b, c, …, z, ␣, ., ,, ;, 0, …, 9, A, …, Z]



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Sequence generation

News

President enrique peña nieto, announced sench's sulk former coming football langston paring.

"I was not at all surprised," said hich langston.

"Concussion epidemic", to be examined.

The gray football the told some and this has on the uefa icon, should money as.

Shakespeare

The mortal moon hath her eclipse in love.

And subject of this thou art another this fold.

When besser be my love to me see sabl's.

For whose are ruse of mine eyes heaves.

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Recurrent Neural Networks

Vanishing gradients with RNNs

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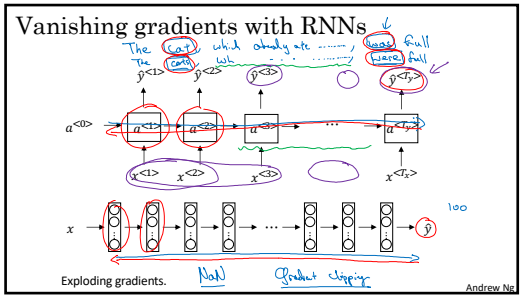
Vanishing gradients with RNNs



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Recurrent Neural Networks

Gated Recurrent Unit (GRU)

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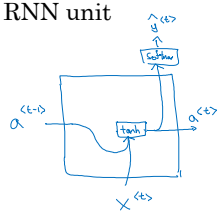
RNN unit



$$a^{<t>} = g(W_a[a^{<t-1>}, x^{<t>}] + b_a)$$

tanh

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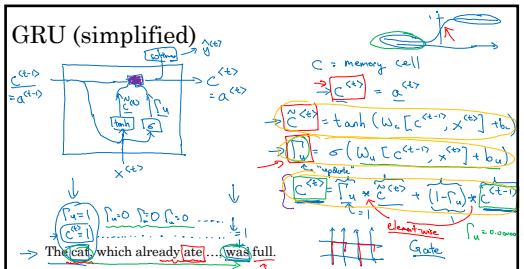
GRU (simplified)



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Full GRU

$$\tilde{c}^{<t>} = \tanh(W_c[\Gamma_r * c^{<t-1>}, x^{<t>}] + b_c)$$

$$\Gamma_u = \sigma(W_u[c^{<t-1>}, x^{<t>}] + b_u)$$

$$\Gamma_r = \sigma(W_r[c^{<t-1>}, x^{<t>}] + b_r)$$

$$c^{<t>} = \Gamma_u * \tilde{c}^{<t>} + (1 - \Gamma_u) + c^{<t-1>}$$

LSTM

The cat, which ate already, was full.

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Recurrent Neural Networks

LSTM (long short term memory) unit

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GRU and LSTM

GRU

$$\tilde{c}^{<t>} = \tanh(W_c[\Gamma_r * c^{<t-1>}, x^{<t>}] + b_c)$$

$$\Gamma_u = \sigma(W_u[c^{<t-1>}, x^{<t>}] + b_u)$$

$$\Gamma_r = \sigma(W_r[c^{<t-1>}, x^{<t>}] + b_r)$$

$$c^{<t>} = \Gamma_u * \tilde{c}^{<t>} + (1 - \Gamma_u) * c^{<t-1>}$$

$$a^{<t>} = c^{<t>}$$

Γ_f

LSTM

$$\tilde{c}^{<t>} = \tanh(W_c[a^{<t-1>}, x^{<t>}] + b_c)$$

(update) $\Gamma_u = \sigma(W_u[a^{<t-1>}, x^{<t>}] + b_u)$

(forget) $\Gamma_f = \sigma(W_f[a^{<t-1>}, x^{<t>}] + b_f)$

(output) $\Gamma_o = \sigma(W_o[a^{<t-1>}, x^{<t>}] + b_o)$

$$c^{<t>} = \Gamma_u * \tilde{c}^{<t>} + \Gamma_f * c^{<t-1>}$$

$$a^{<t>} = \Gamma_o * c^{<t>}$$

Hochreiter & Schmidhuber 1997. Long short-term memory

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LSTM in pictures

$$\tilde{c}^{<t>} = \tanh(W_c[a^{<t-1>}, x^{<t>}] + b_c)$$

$$\Gamma_u = \sigma(W_u[a^{<t-1>}, x^{<t>}] + b_u)$$

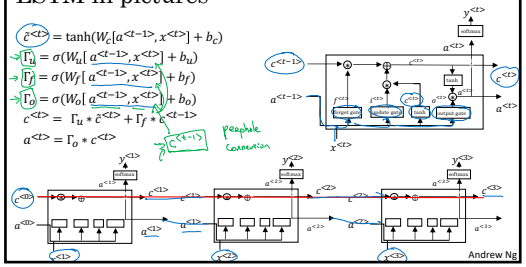
$$\Gamma_f = \sigma(W_f[a^{<t-1>}, x^{<t>}] + b_f)$$

$$\Gamma_o = \sigma(W_o[a^{<t-1>}, x^{<t>}] + b_o)$$

$$c^{<t>} = \Gamma_u * \tilde{c}^{<t>} + \Gamma_f * c^{<t-1>}$$

$$a^{<t>} = \Gamma_o * c^{<t>}$$

Peephole connection



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Bidirectional RNN

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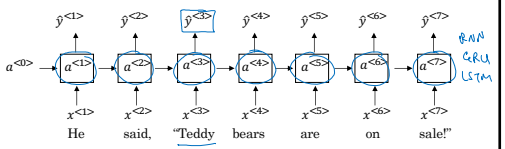
Getting information from the future

He said, "Teddy bears are on sale!"

He said, "Teddy Roosevelt was a great President!"



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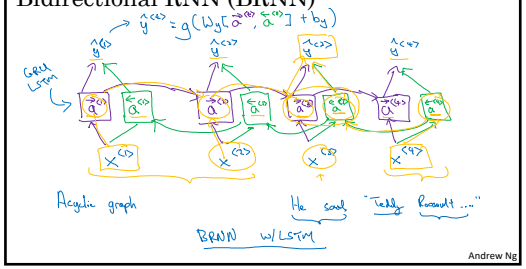
Bidirectional RNN (BRNN)

$$\hat{y}^{<t>} = g(W_y[\vec{a}^{<t>}, \overleftarrow{a}^{<t>}] + b_y)$$



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Deep RNNs

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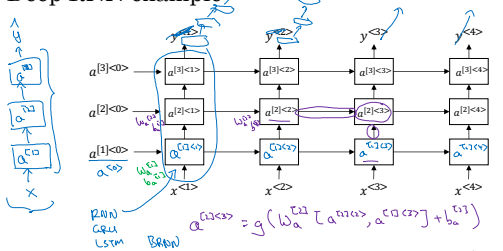
Deep RNN example



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Sequence to sequence models

Basic models

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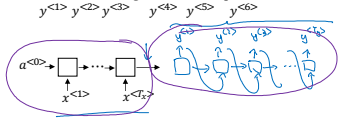
Sequence to sequence model

$x^{<1>}$ $x^{<2>}$ $x^{<3>}$ $x^{<4>}$ $x^{<5>}$

Jane visite l'Afrique en septembre

→ Jane is visiting Africa in September.

$y^{<1>}$ $y^{<2>}$ $y^{<3>}$ $y^{<4>}$ $y^{<5>}$ $y^{<6>}$



[Sutskever et al., 2014. Sequence to sequence learning with neural networks]
[Cho et al., 2014. Learning phrase representations using RNN encoder-decoder for statistical machine translation]

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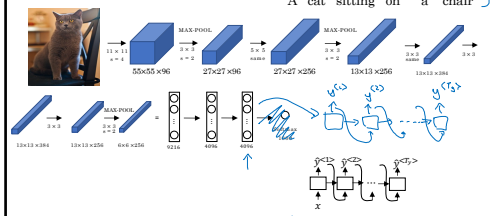
Image captioning

$y^{<1>}$ $y^{<2>}$ $y^{<3>}$ $y^{<4>}$ $y^{<5>}$ $y^{<6>}$

A cat sitting on a chair



Mao et. al., 2014. Deep captioning with multimodal recurrent neural networks]
Vinyals et. al., 2014. Show and tell: Neural image caption generator]
Karpathy and Li, 2015. Deep visual-semantic alignments for generating image descriptions]

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Sequence to sequence models

Picking the most likely sentence

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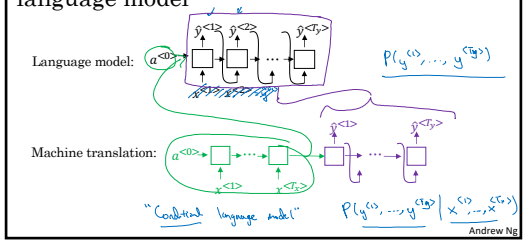
Machine translation as building a conditional language model



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Finding the most likely translation

Jane visite l'Afrique en septembre.

$P(y^{<1>}, \ldots, y^{<T_y>} \mid x)$

- Jane is visiting Africa in September.
- Jane is going to be visiting Africa in September.
- In September, Jane will visit Africa.
- Her African friend welcomed Jane in September.

$$\underset{y^{<1>},\ldots,y^{<T_y>}}{\arg\max}\ P(y^{<1>}, \ldots, y^{<T_y>} \mid x)$$

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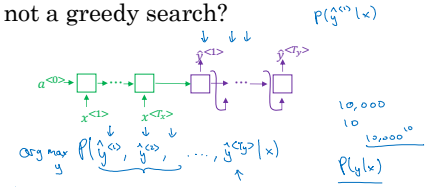
Why not a greedy search?



- Jane is visiting Africa in September.
- Jane is going to be visiting Africa in September.

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Sequence to sequence models

Beam search

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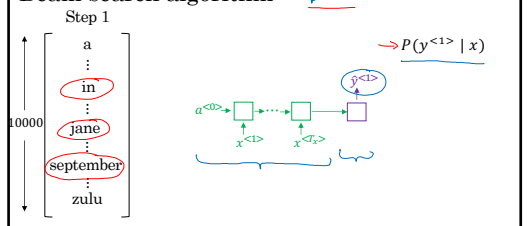
Beam search algorithm

B = 3 (beam width)



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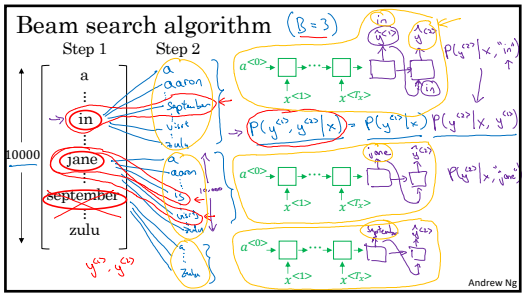
Beam search algorithm (B = 3)



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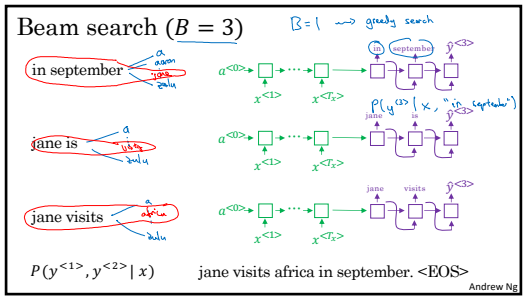

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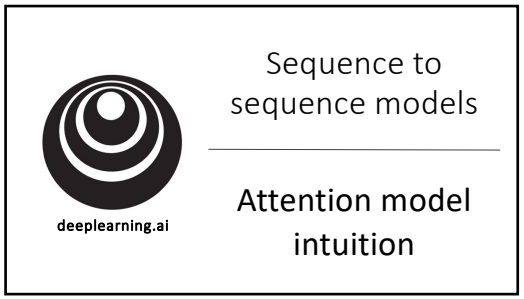
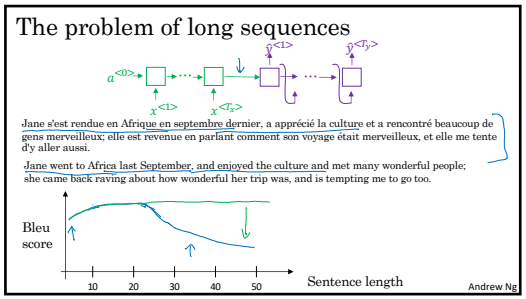


51



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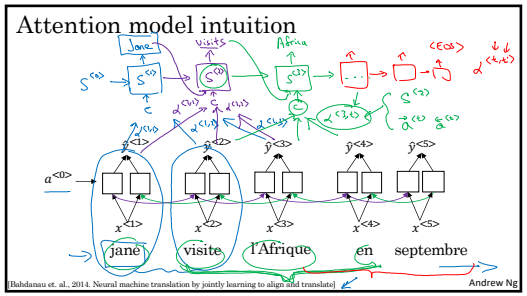
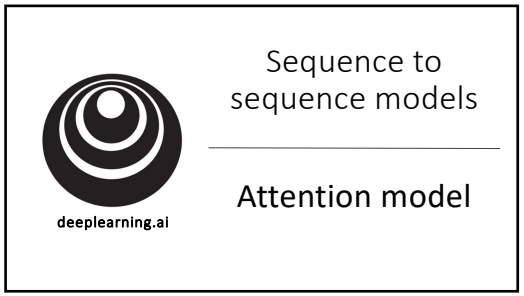


53



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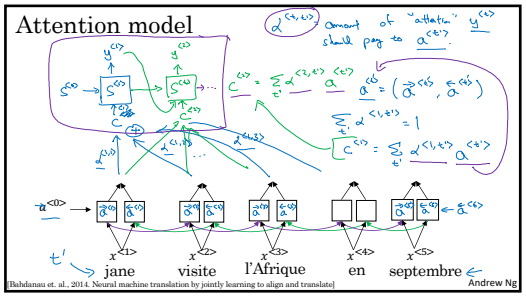

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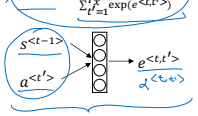
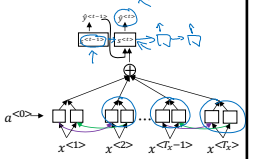
Computing attention $\alpha^{<t,t'>}$

T_x T_y

$\alpha^{<t,t'>}$ = amount of attention $y^{<t>}$ should pay to $a^{<t'>}$

$$\alpha^{<t,t'>} = \frac{\exp(e^{<t,t'>})}{\sum_{t'=1}^{T_x} \exp(e^{<t,t'>})}$$





[Bahdanau et. al., 2014. Neural machine translation by jointly learning to align and translate]
[Xu et. al., 2015. Show, attend and tell: Neural image caption generation with visual attention]

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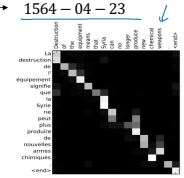
Attention examples

July 20th 1969 → 1969 – 07 – 20

23 April, 1564 → 1564 – 04 – 23

Visualization of $\alpha^{<t,t'>}$:



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