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Sequence to sequence models

Basic models

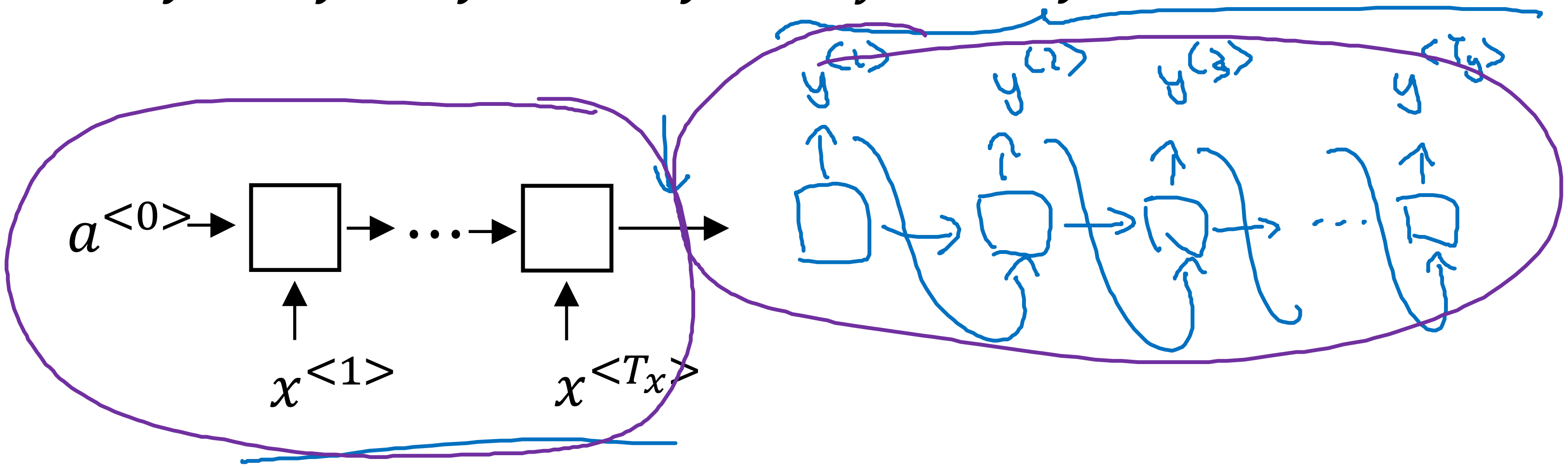
Sequence to sequence model

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

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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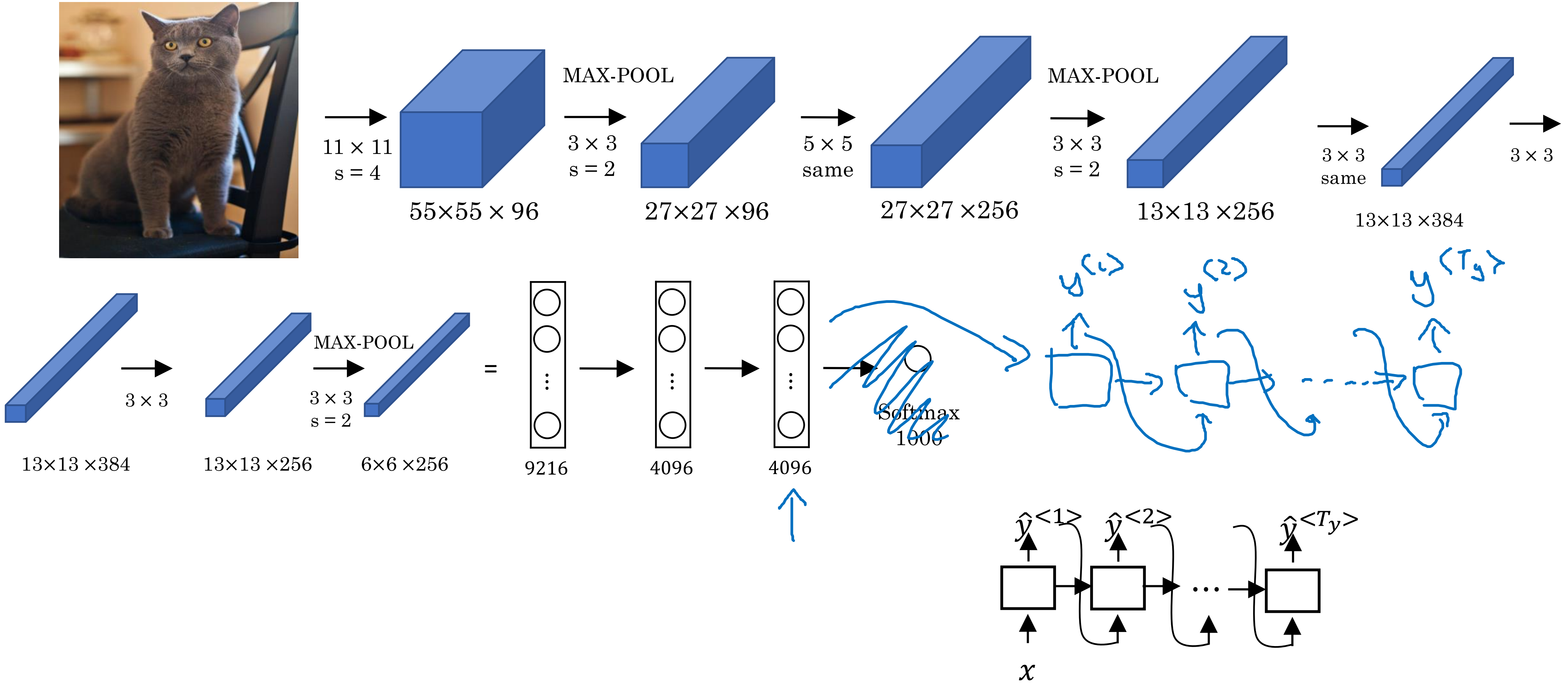
Image captioning

$y^{<1>}$	$y^{<2>}$	$y^{<3>}$	$y^{<4>}$	$y^{<5>}$	$y^{<6>}$
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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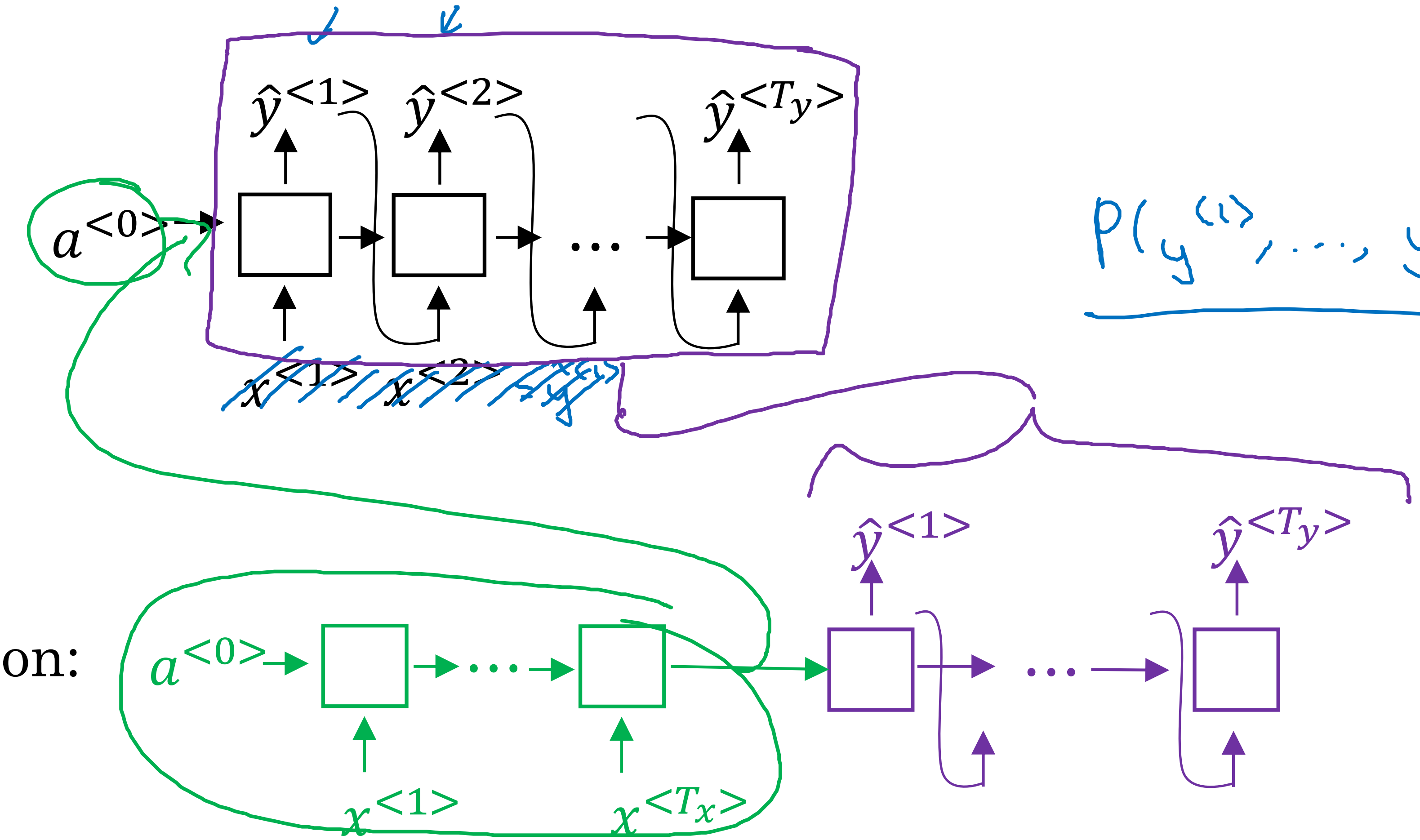
Sequence to sequence models

Picking the most likely sentence

Machine translation as building a conditional language model

Language model:

Machine translation:



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

"Conditional language model"

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

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Finding the most likely translation

Jane visite l'Afrique en septembre.

$$\underline{P(\overbrace{y^{<1>}, \dots, y^{<T_y>}}^{\text{English}} \mid \overset{\substack{\text{French}\\ \downarrow}}{x})}$$

→ Jane is visiting Africa in September.

→ Jane is going to be visiting Africa in September.

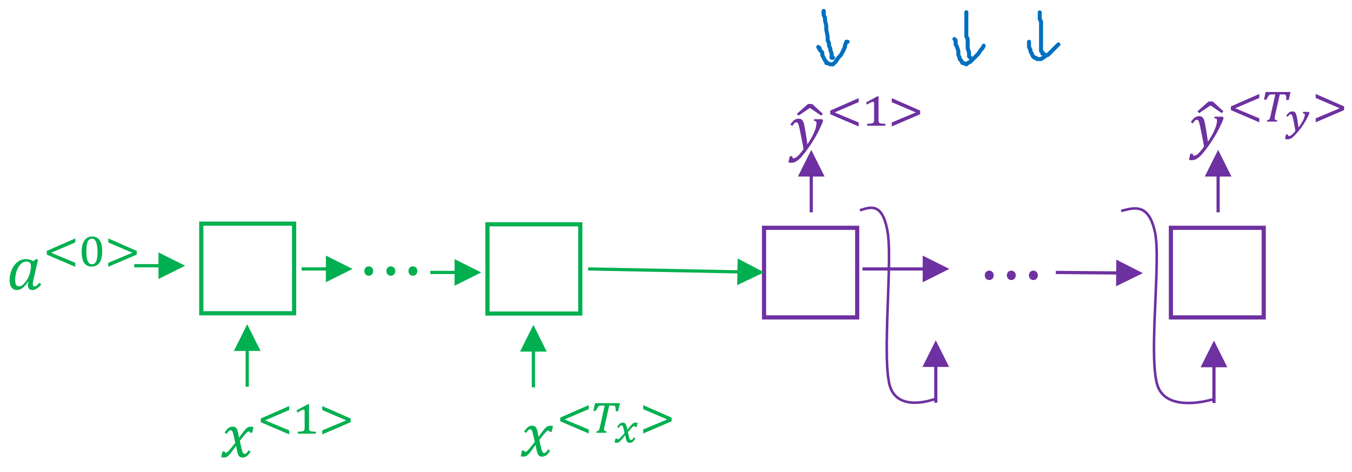
→ In September, Jane will visit Africa.

→ Her African friend welcomed Jane in September.

$$\arg\max_{y^{<1>},\dots,y^{<T_y>}} \underline{P(y^{<1>}, \dots, y}^{<T_y>} \mid x)$$

Why not a greedy search?

$P(\hat{y}^{<1>} | x)$



$$\arg\max_{y} P(\underbrace{\hat{y}^{<1>}, \hat{y}^{<2>},} \ldots, \hat{y}^{<T_y>} | x)$$

10,000

10

$10{,}000^{10}$

$P(y|x)$

→ Jane is visiting Africa in September.

→ Jane is going to be visiting Africa in September.

$P(\text{Jane is going} | x) > P(\text{Jane is visiting} | x)$

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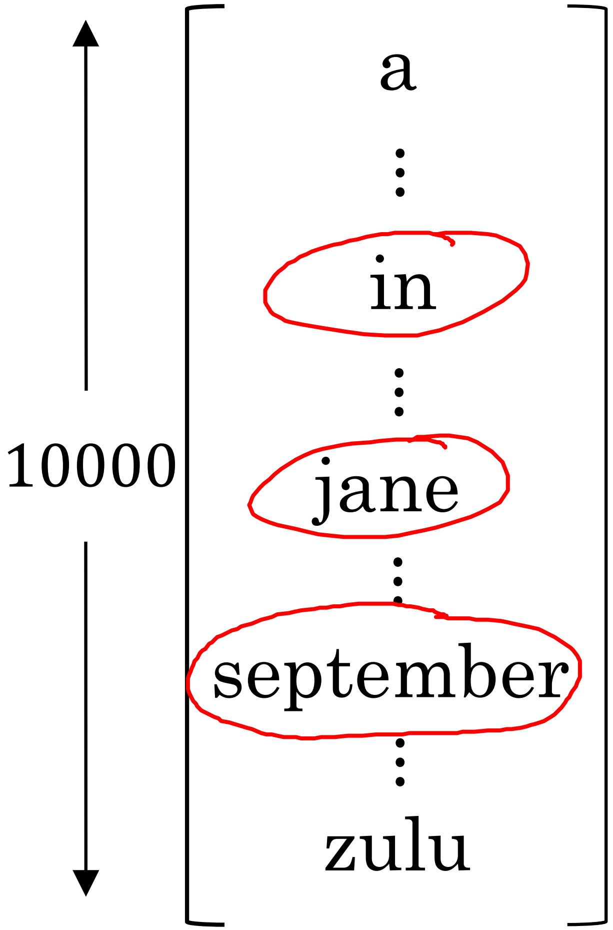
Sequence to sequence models

Beam search

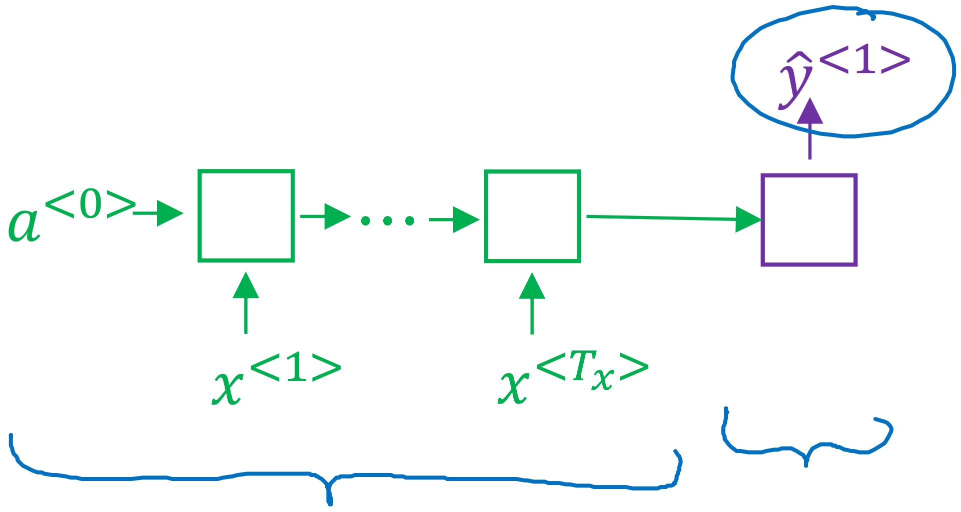
Beam search algorithm

$B = 3$ (beam width)

Step 1

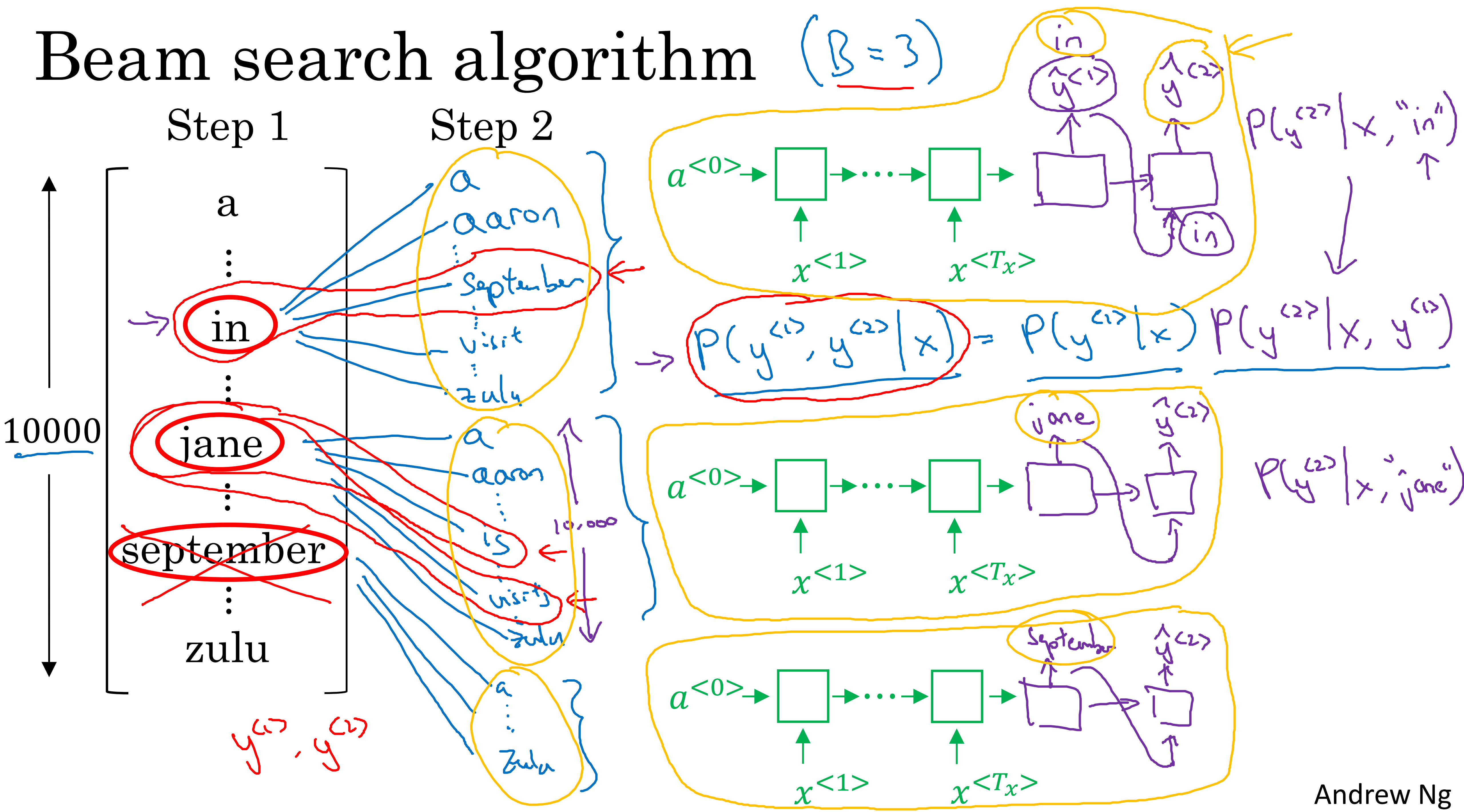


$\rightarrow P(y^{<1>} \mid x)$



Beam search algorithm

$(B=3)$



$$P(y^{<1>}, y^{<2>} | x) = P(y^{<1>} | x)\, P(y^{<2>} | x, y^{<1>})$$

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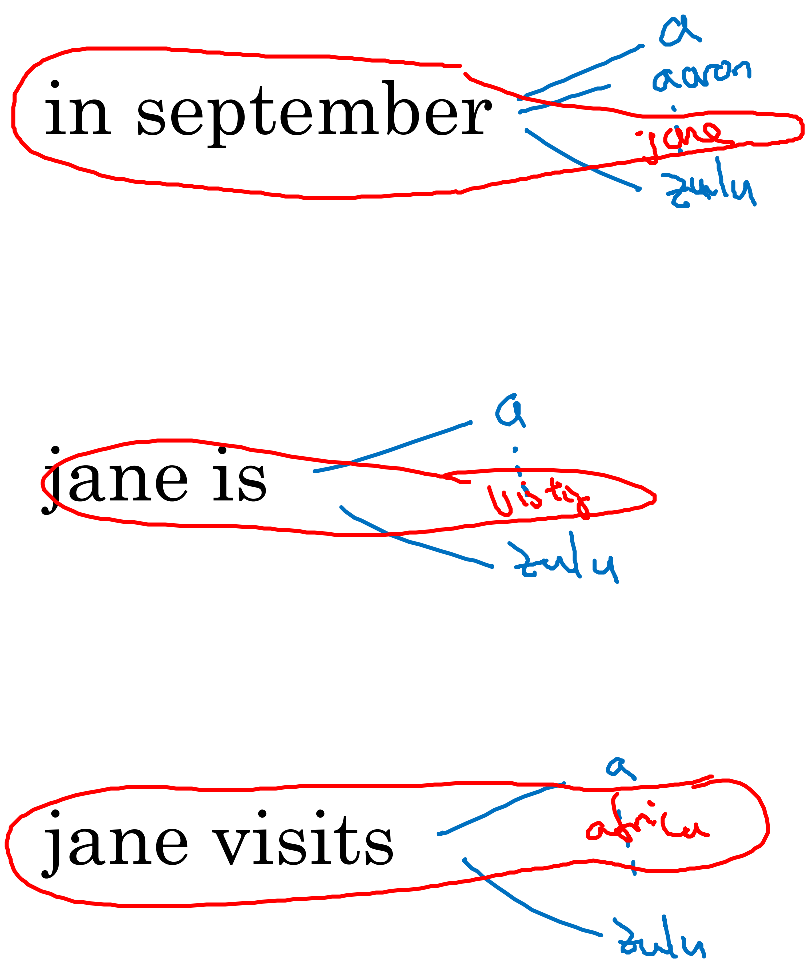
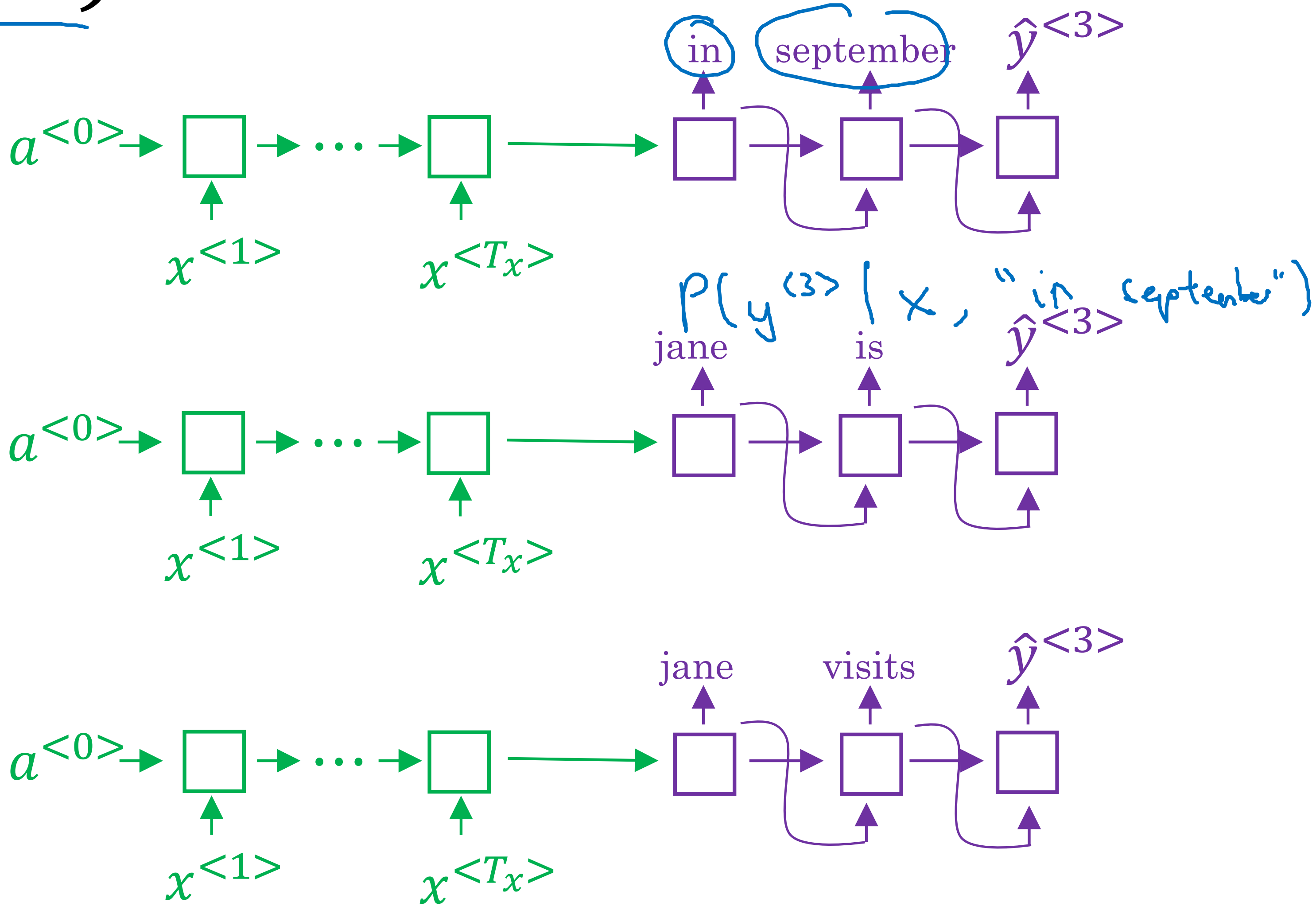
Beam search ($B = 3$)

$B = 1 \rightsquigarrow$ greedy search





$P(y^{<1>}, y^{<2>} | x)$

jane visits africa in september. <EOS>

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Sequence to sequence models

Refinements to beam search

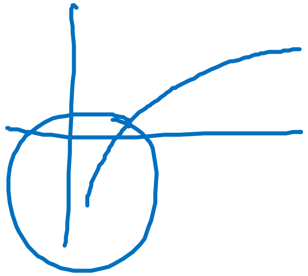
Length normalization

$$P(y^{<1>} \dots y^{<T_y>}|x) = \underline{P(y^{<1>}|x)}\ \underline{P(y^{<2>}|x, y^{<1>})} \dots \underline{P(y^{<T_y>}|x, y^{<1>}, \dots, y^{<T_y-1>})}$$

$$\arg\max_{y} \prod_{t=1}^{T_y} \underline{P(y^{<t>}|x, y^{<1>}, \dots, y^{<t-1>})}$$

log

$$\arg\max_{y} \sum_{t=1}^{T_y} \underline{\log P(y^{<t>}|x, y^{<1>}, \dots, y^{<t-1>})} \leftarrow$$



$\log P(y|x) \leftarrow$

$P(y|x) \leftarrow$

$T_y = 1, 2, 3, \dots, 30.$

$$\rightarrow \boxed{\frac{1}{T_y^{\alpha}} \sum_{t=1}^{T_y} \log P(y^{<t>}|x, y^{<1>}, \dots, y^{<t-1>})}$$

$\underline{\alpha = 0.7}$

$\underline{\alpha = 1}$

$\underline{\alpha = 0}$

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Beam search discussion

large B: better result, slower

small B: worse result, faster

Beam width B?

1 → 3 → 10, 100, 1000, → 3000

Unlike exact search algorithms like BFS (Breadth First Search) or DFS (Depth First Search), Beam Search runs faster but is not guaranteed to find exact maximum for $\arg\max_{y} P(y|x)$.

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Sequence to sequence models

Error analysis on beam search

Example

→ RNN

→ Beam Search

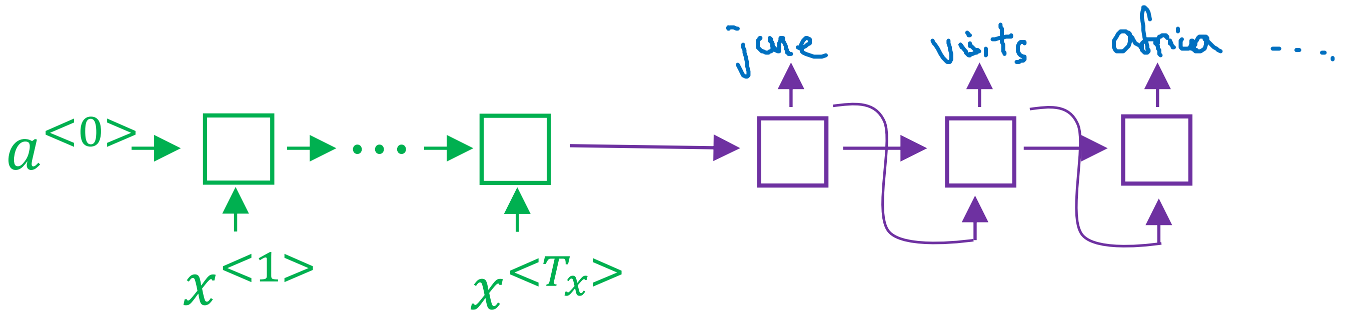
$\boxed{B\uparrow}$

Jane visite l'Afrique en septembre.

Human: Jane visits Africa in September. (y^*)

Algorithm: Jane visited Africa last September. $(\hat{y})$ ←

RNN computes $P(y^*|x) \overset{>}{\underset{\leq}{}} P(\hat{y}|x)$



Error analysis on beam search

$P(y^*|x)$

$P(\hat{y}|x)$

Human: Jane visits Africa in September. (y^*)

Algorithm: Jane visited Africa last September. ($\hat{y}$)

Case 1: $\underline{P(y^*|x) > P(\hat{y}|x)}$ ←

$\arg\max_{y} P(y|x)$

Beam search chose $\underset{\uparrow}{\underline{\hat{y}}}$. But $\underset{\uparrow}{\underline{y^*}}$ attains higher $\boxed{\underline{P(y|x)}}$.

Conclusion: Beam search is at fault.

Case 2: $\underline{P(y^*|x)} \le \underline{P(\hat{y}|x)}$ ←

y^* is a better translation than $\hat{y}$. But RNN predicted $\boxed{\underline{\overset{\downarrow}{P(y^*|x)}}} < \underline{\overset{\downarrow}{P(\hat{y}|x)}}$.

Conclusion: RNN model is at fault.

Error analysis process

Human	Algorithm	$P(y^*\|x)$	$P(\hat{y}\|x)$	At fault?
Jane visits Africa in September.	Jane visited Africa last September.	$\underline{2 \times 10^{-10}}$	$\underline{1 \times 10^{-10}}$	B
- - -	- - -	—	—	R
. . .	. . .	—	—	B
				R
				R
				⋮

Figures out what faction of errors are "due to" beam search vs. RNN model

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Sequence to sequence models

Bleu score (optional)

Evaluating machine translation

Bleu

bilingual evaluation understudy

French: Le chat est sur le tapis.

Reference 1: The cat is on the mat. ←

Reference 2: There is a cat on the mat. ←

MT output: the the the the the the the.

Precision:

Modified precision:

[Papineni et. al., 2002. Bleu: A method for automatic evaluation of machine translation]

Bleu score on bigrams

Example: Reference 1: The cat is on the mat.

Reference 2: There is a cat on the mat.

MT output: The cat the cat on the mat.

	Count	Count$_{clip}$
the cat	2	1
cat the	1	0
cat on	1	1
on the	1	1
the mat	1	1

$$\frac{4}{6}$$

[Papineni et. al., 2002. Bleu: A method for automatic evaluation of machine translation]

Bleu score on unigrams

Example: Reference 1: The cat is on the mat.

Reference 2: There is a cat on the mat.

→ MT output: The cat the cat on the mat. $(\hat{y})$

$p_1, p_2, = \underline{1.0}$

$$p_1 = \frac{\sum_{unigram \in \hat{y}} count_{clip}(unigram)}{\sum_{unigram \in \hat{y}} count(unigram)}$$

$$p_1 = \frac{\sum_{\text{unigram} \in \hat{y}} \text{Count}_{\text{clip}}(\text{unigram})}{\sum_{\text{Unigram} \in \hat{y}} \text{Count}(\text{unigram})}$$

↑ Unigram

$$p_n = \frac{\sum_{ngram \in \hat{y}} count_{clip}(ngram)}{\sum_{ngram \in \hat{y}} count(ngram)}$$

n-gram

$$P_n = \frac{\sum_{\text{n-grams} \in \hat{y}} \text{Count}_{\text{clip}}(\text{n-gram})}{\sum_{\text{n-grams} \in \hat{y}} \text{Count}(\text{n-gram})}$$

[Papineni et. al., 2002. Bleu: A method for automatic evaluation of machine translation]

Bleu details

p_n = Bleu score on n-grams only

p_1, p_2, p_3, p_4

Combined Bleu score: $BP \exp\left(\frac{1}{4}\sum_{n=1}^{4} p_n\right)$

BP = brevity penalty

$$BP = \begin{cases} 1 & \text{if } \underline{\text{MT\_output\_length}} > \underline{\text{reference\_output\_length}} \\ \exp(1 - \text{MT\_output\_length}/\text{reference\_output\_length}) & \text{otherwise} \end{cases}$$

[Papineni et. al., 2002. Bleu: A method for automatic evaluation of machine translation]

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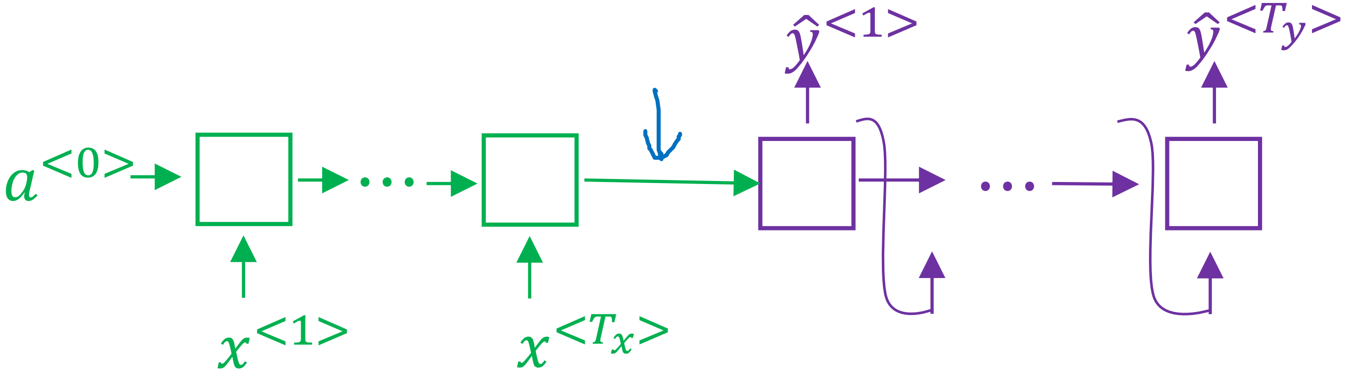
Sequence to sequence models

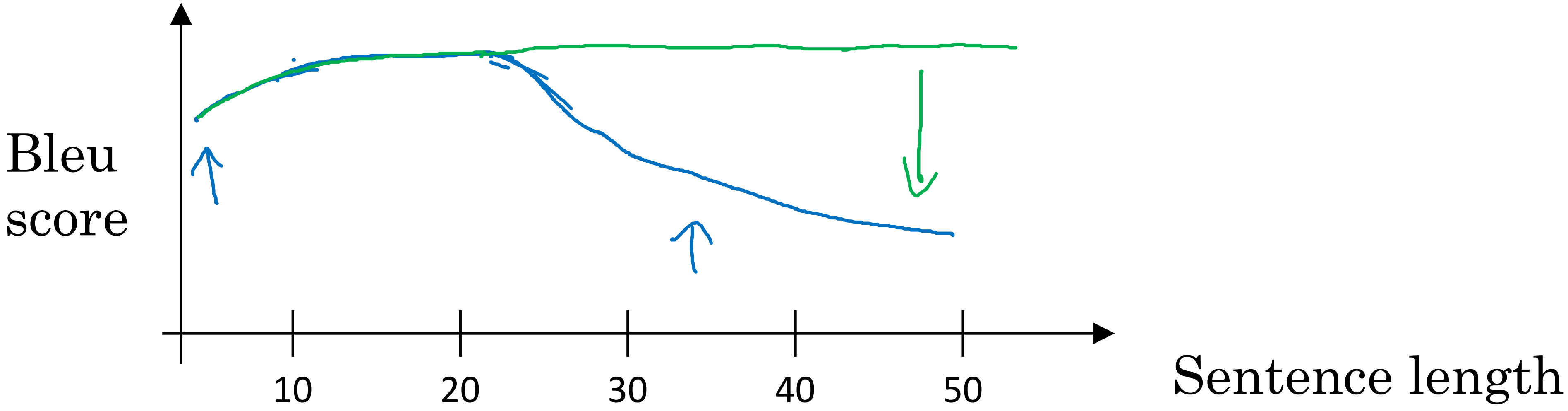
Attention model intuition

The problem of long sequences



Jane s'est rendue en Afrique en septembre dernier, a apprécié la culture et a rencontré beaucoup de gens merveilleux; elle est revenue en parlant comment son voyage était merveilleux, et elle me tente d'y aller aussi.

Jane went to Africa last September, and enjoyed the culture and met many wonderful people; she came back raving about how wonderful her trip was, and is tempting me to go too.



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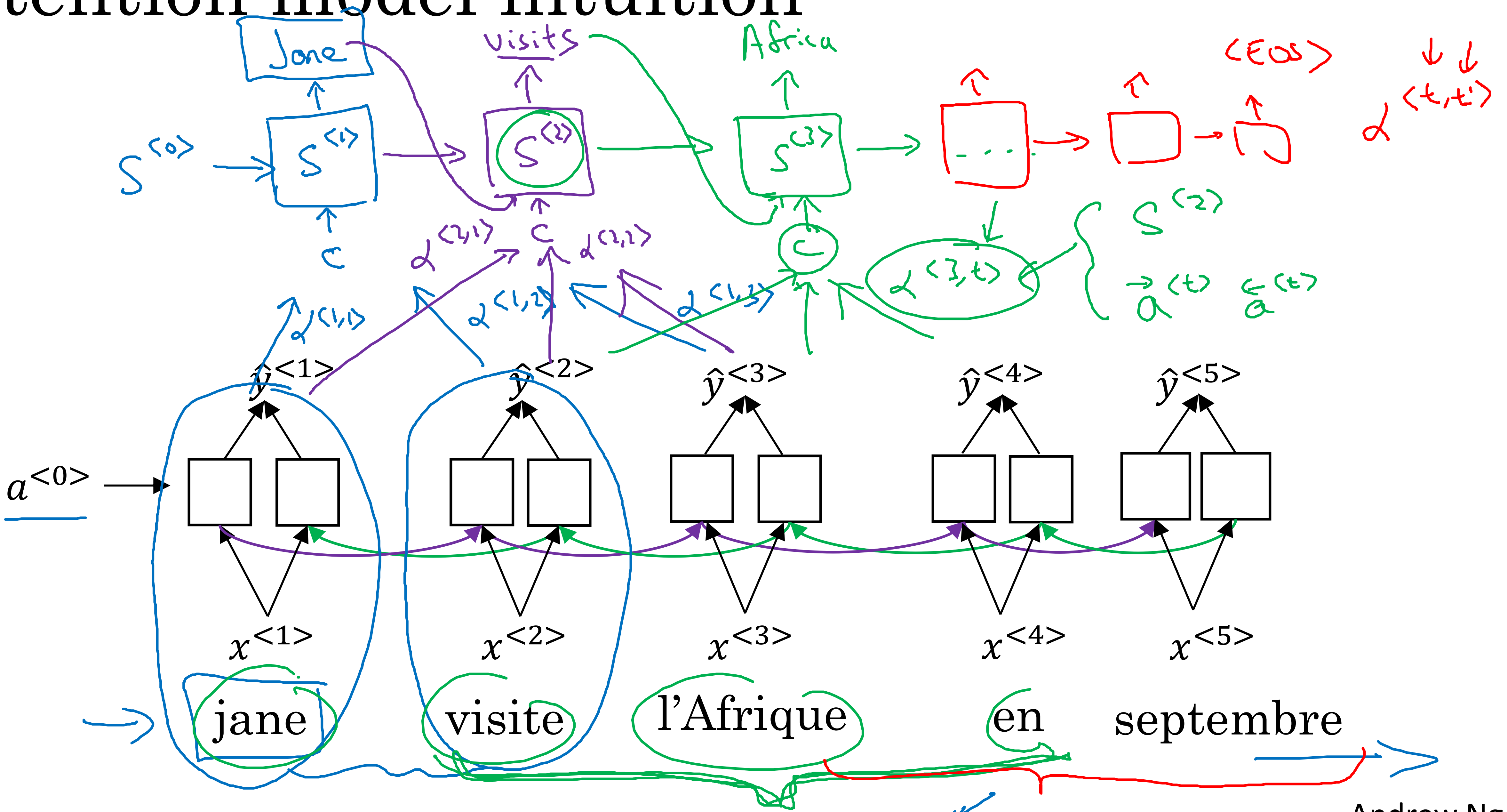
Attention model intuition



[Bahdanau et. al., 2014. Neural machine translation by jointly learning to align and translate]

Sequence to sequence models

Attention model

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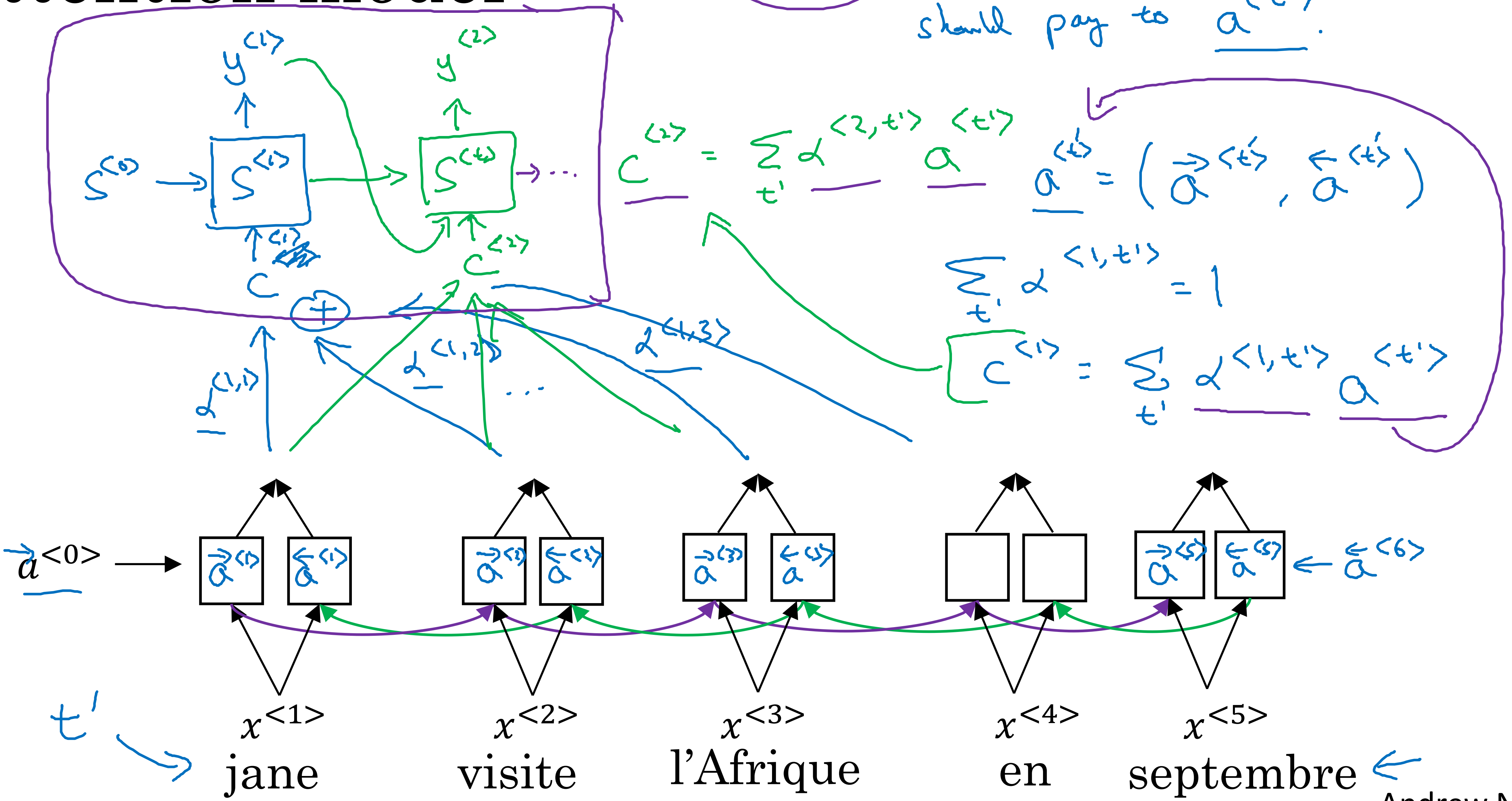
Attention model

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



$y^{<1>}$
$y^{<2>}$
$s^{<0>}$
$s^{<1>}$
$s^{<2>}$
$c^{<1>}$
$c^{<2>}$
$\alpha^{<1,1>}$
$\alpha^{<1,2>}$
$\alpha^{<1,3>}$
$\vec{a}^{<0>}$
$\overrightarrow{a}^{<1>}$ $\overleftarrow{a}^{<1>}$
$\overrightarrow{a}^{<2>}$ $\overleftarrow{a}^{<2>}$
$\overrightarrow{a}^{<3>}$ $\overleftarrow{a}^{<3>}$
$\overrightarrow{a}^{<5>}$ $\overleftarrow{a}^{<5>}$
$\overleftarrow{a}^{<6>}$
t'

$a^{<0>}$

$x^{<1>}$ jane

$x^{<2>}$ visite

$x^{<3>}$ l'Afrique

$x^{<4>}$ en

$x^{<5>}$ septembre

$$c^{<2>} = \sum_{t'} \alpha^{<2,t'>} a^{<t'>}$$

$$a^{<t'>} = (\overrightarrow{a}^{<t'>}, \overleftarrow{a}^{<t'>})$$

$$\sum_{t'} \alpha^{<1,t'>} = 1$$

$$\boxed{c^{<1>}} = \sum_{t'} \alpha^{<1,t'>} a^{<t'>}$$

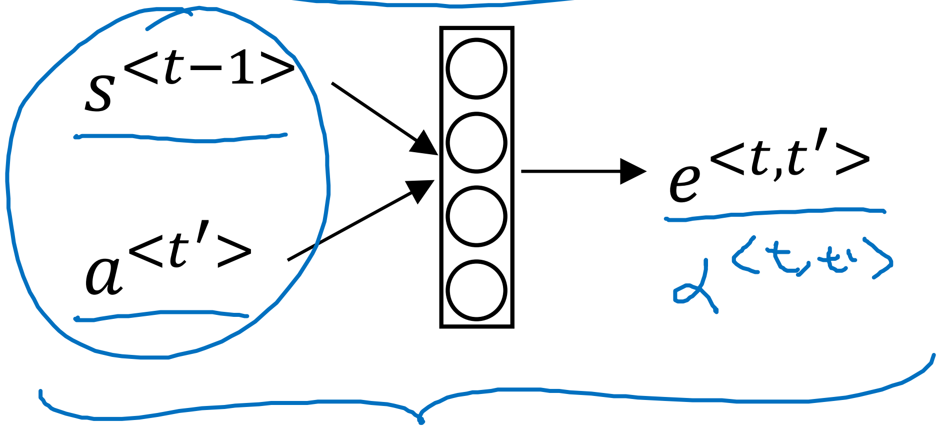
[Bahdanau et. al., 2014. Neural machine translation by jointly learning to align and translate]

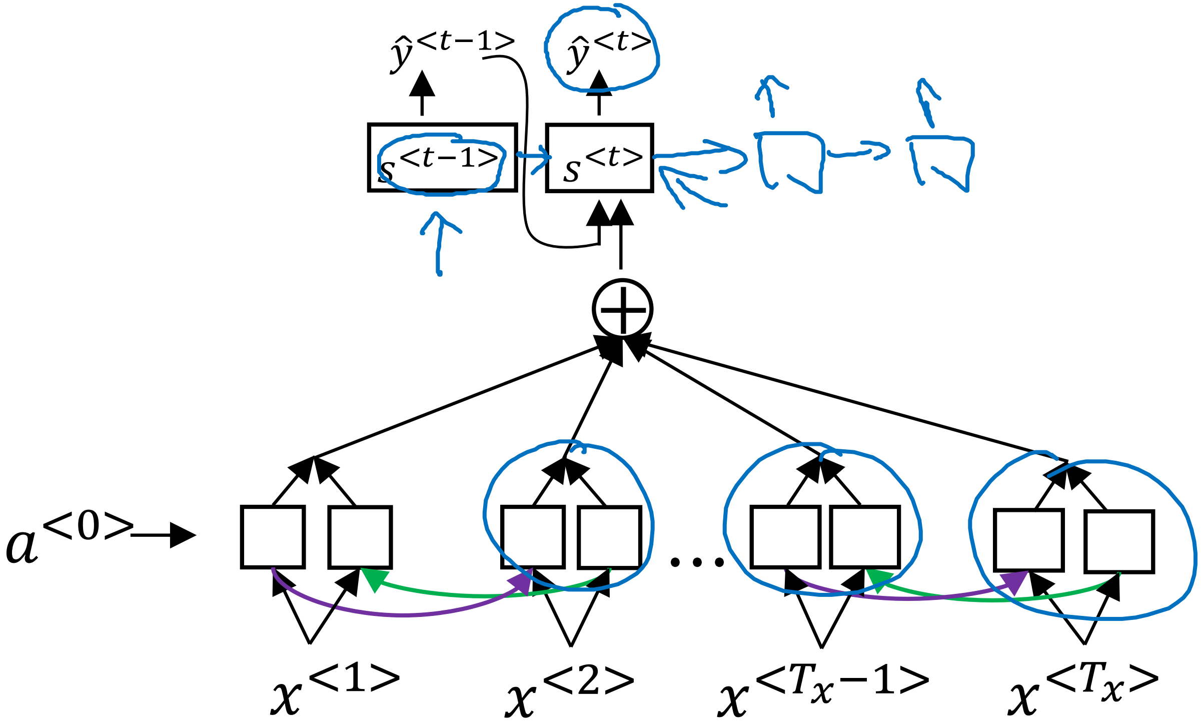
Computing attention $\alpha^{<t,t'>}$

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]

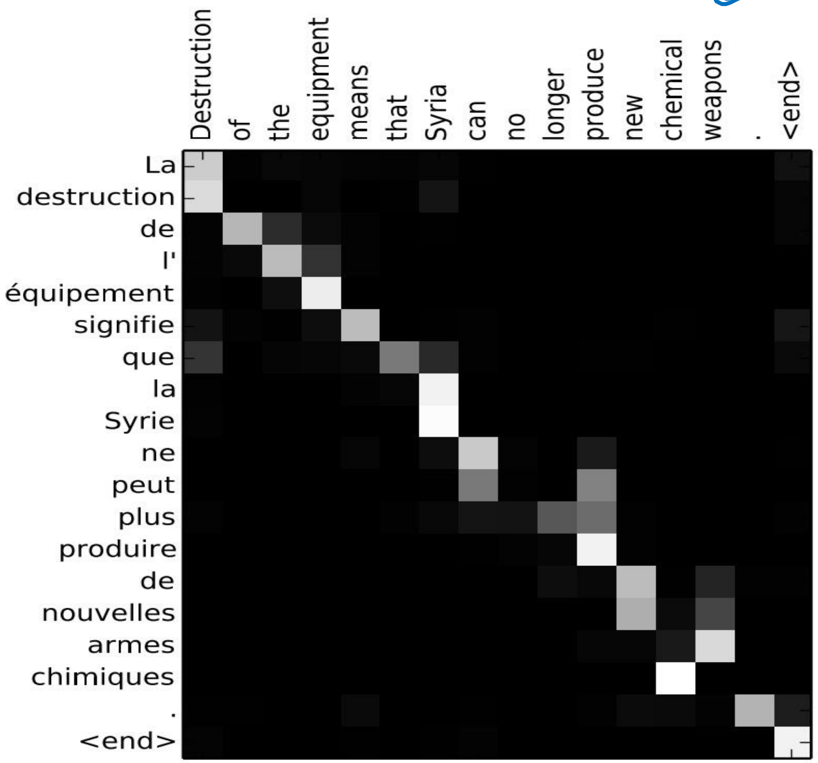
[Xu et. al., 2015. Show, attend and tell: Neural image caption generation with visual attention]

Attention examples

July 20th 1969 → 1969 – 07 – 20

23 April, 1564 → 1564 – 04 – 23

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



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Audio data

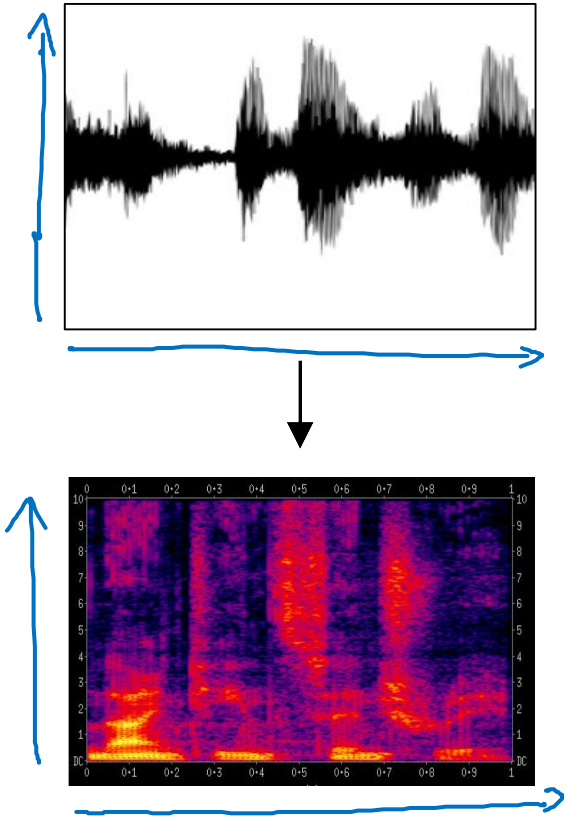
Speech recognition

Speech recognition problem

x → y

audio clip

transcript



→ “the quick brown fox”

→ phonemes: de kwik braun

300h

3000h

100,000h

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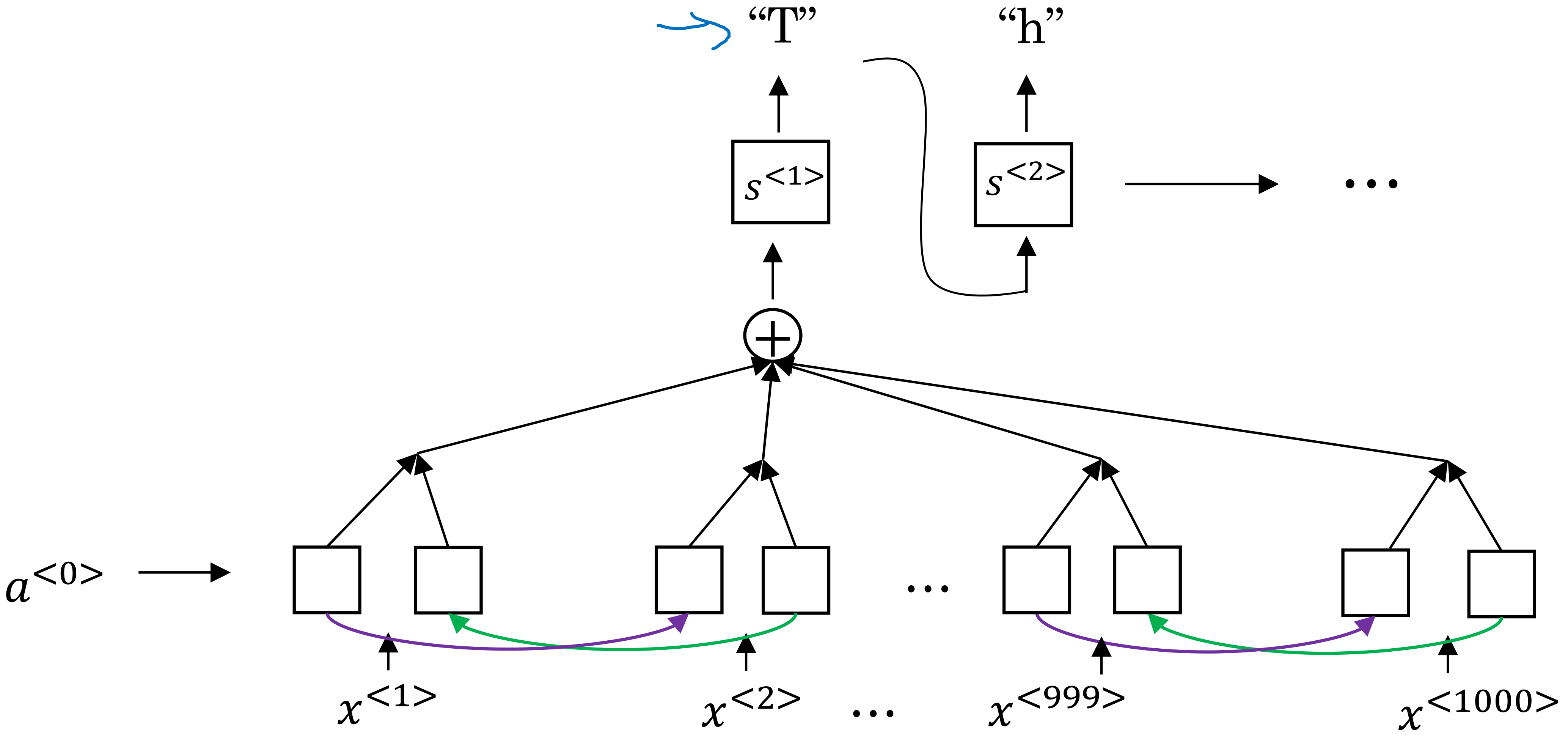
Attention model for speech recognition



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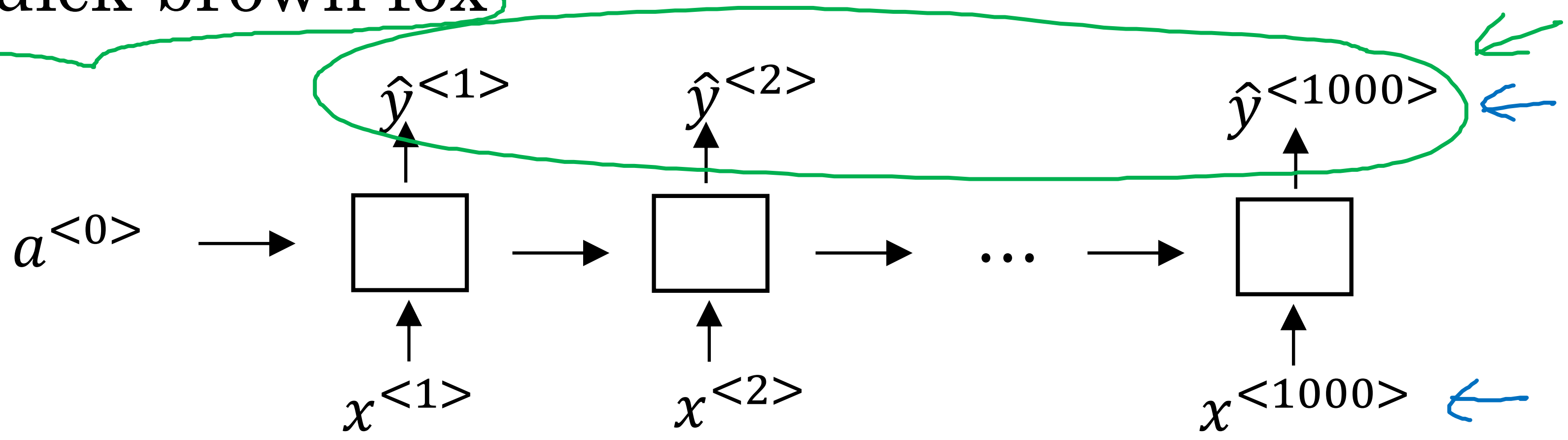
CTC cost for speech recognition

(Connectionist temporal classification)

"the quick brown fox"

19 charactess



ttt_h_eee___␣___qqq__ the␣q

"space"

"blank"

Basic rule: collapse repeated characters not separated by "blank"

[Graves et al., 2006. Connectionist Temporal Classification: Labeling unsegmented sequence data with recurrent neural networks]

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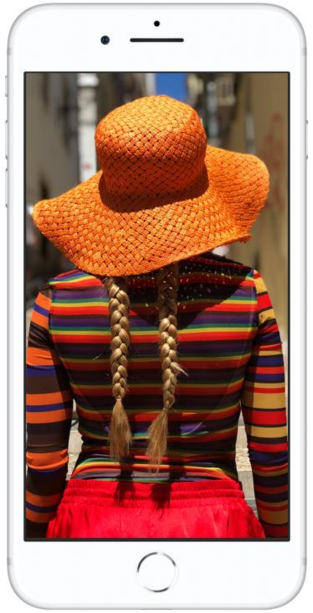
Audio data

Trigger word detection

What is trigger word detection?

Amazon Echo
(Alexa)

Baidu DuerOS
(xiaodunihao)



Apple Siri
(Hey Siri)

Google Home
(Okay Google)

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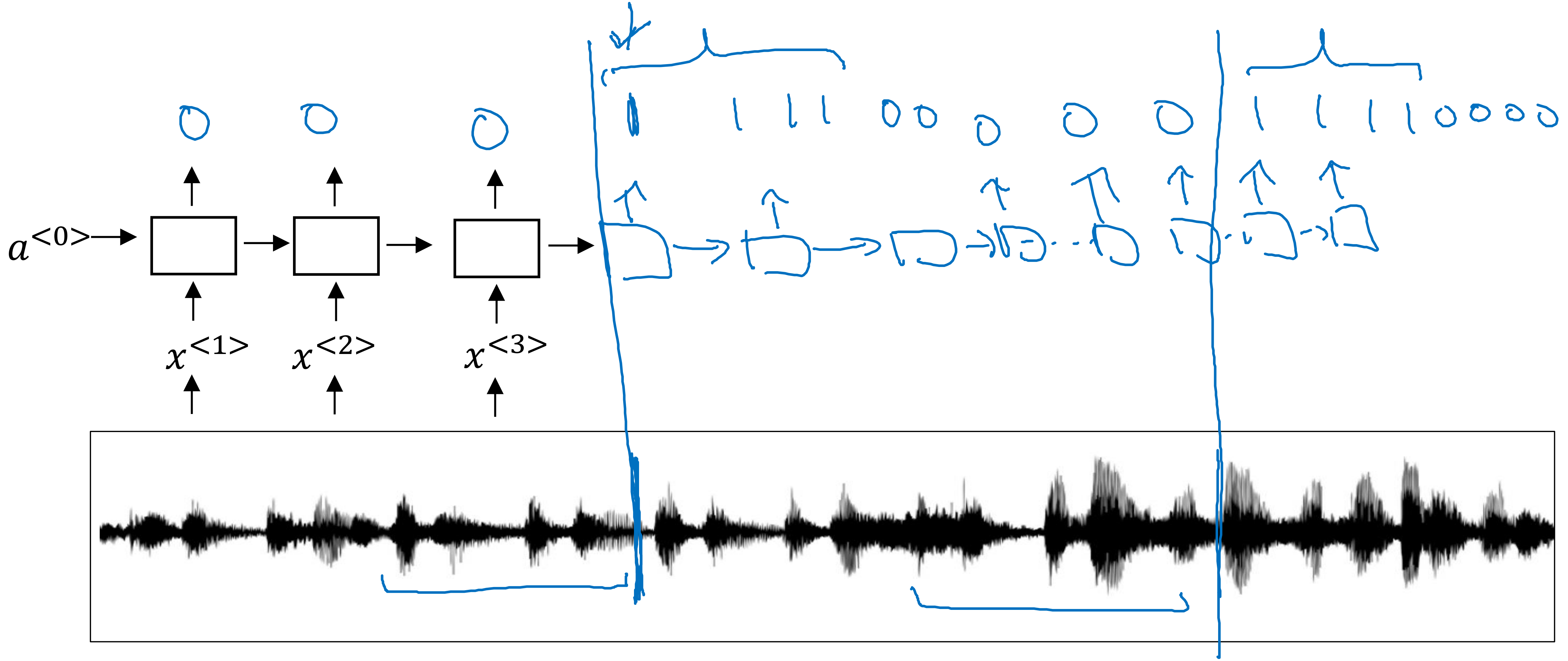
Trigger word detection algorithm



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Conclusion

Summary and thank you

Specialization outline

1. Neural Networks and Deep Learning
2. Improving Deep Neural Networks: Hyperparameter tuning, Regularization and Optimization
3. Structuring Machine Learning Projects
4. Convolutional Neural Networks
5. Sequence Models

Deep learning is a super power

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Thank you.

-Andrew Ng