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Sequence to
sequence models

Basic models

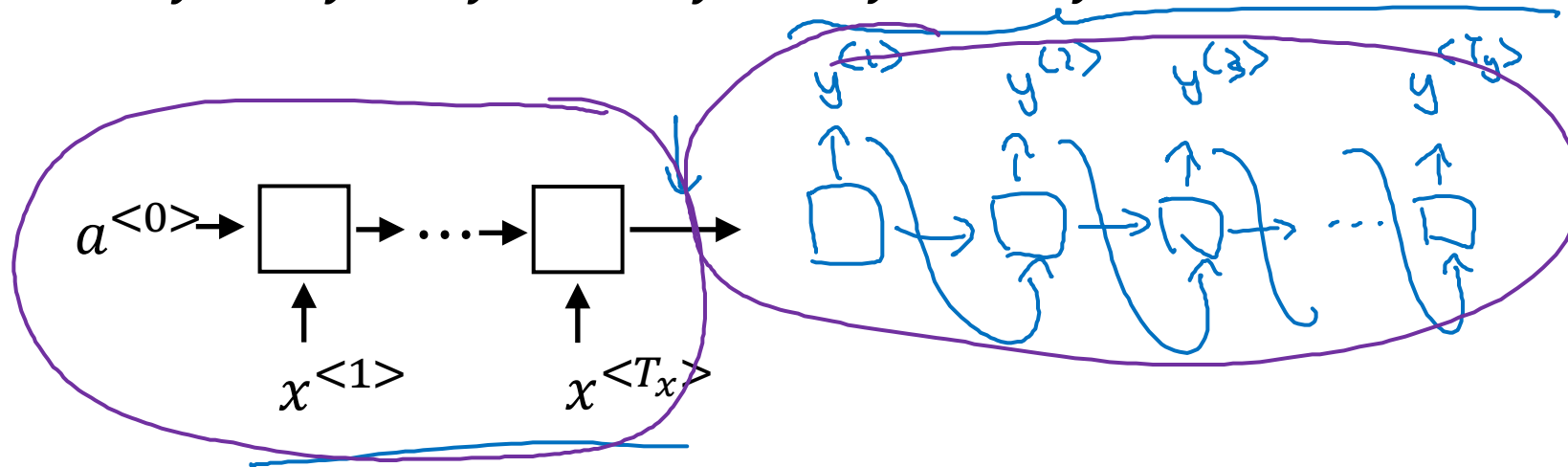
Sequence to sequence model

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

Jane visite l'Afrique en septembre

→ Jane is visiting Africa in September.

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

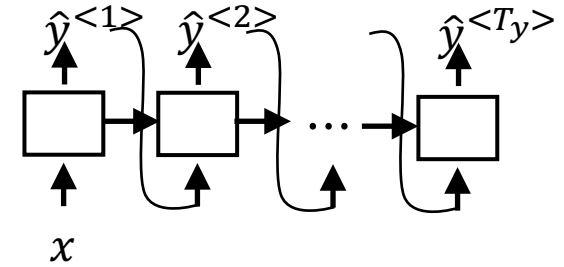
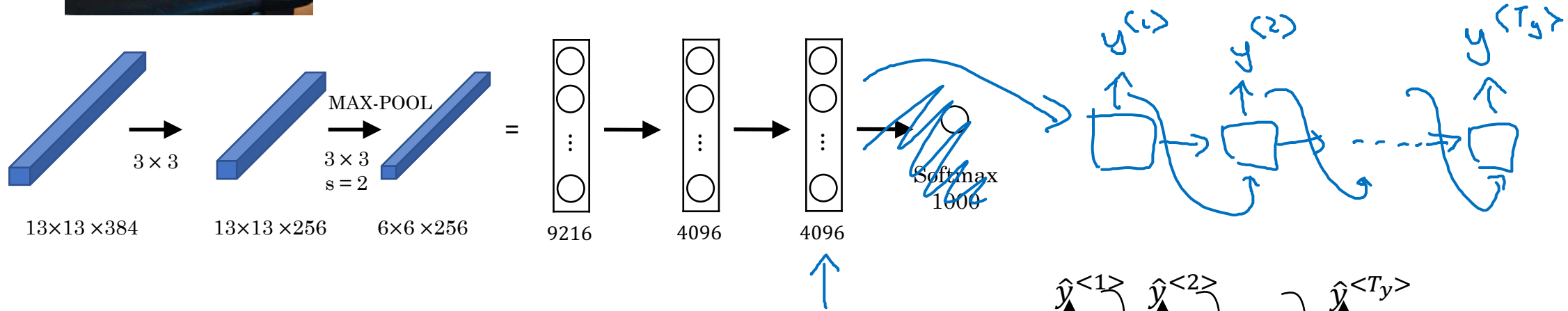
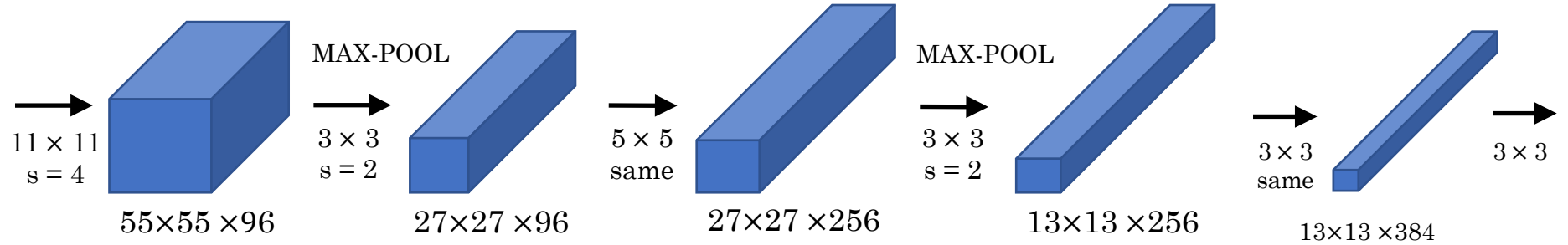
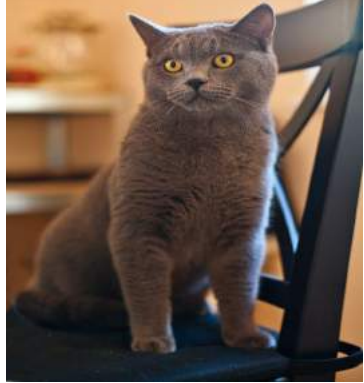


[Sutskever et al., 2014. Sequence to sequence learning with neural networks] ←

[Cho et al., 2014. Learning phrase representations using RNN encoder-decoder for statistical machine translation] ←

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] ←



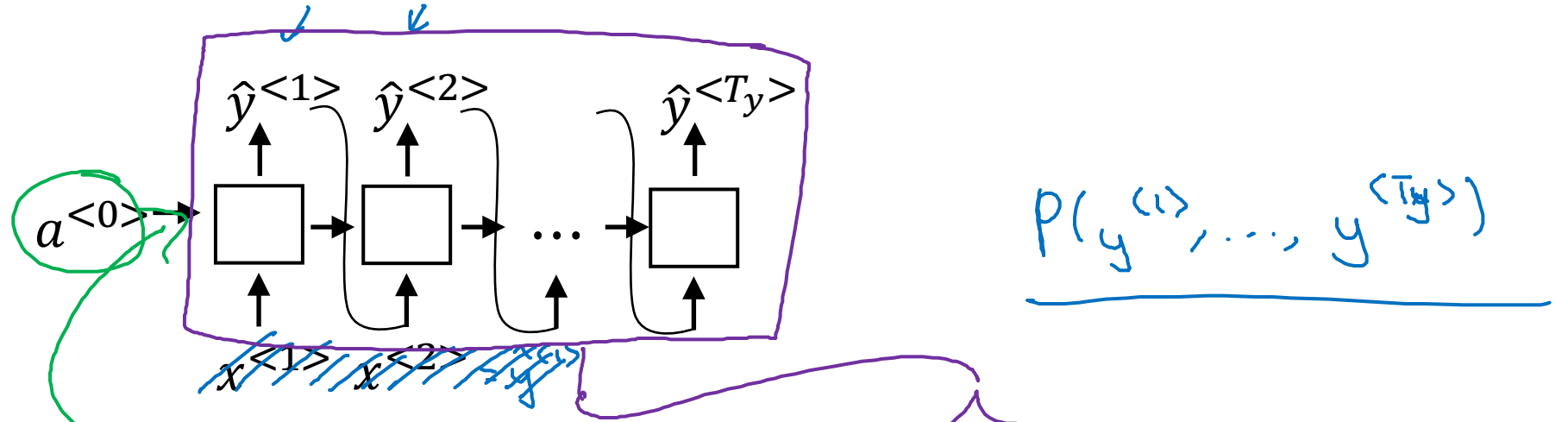
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Sequence to
sequence models

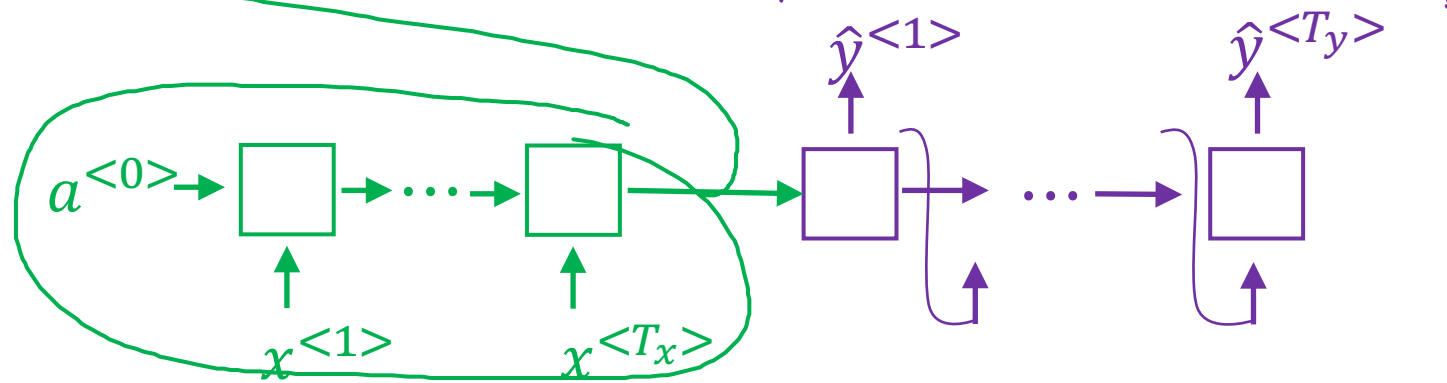
Picking the most
likely sentence

Machine translation as building a conditional language model

Language model:



Machine translation:



“Conditional language model” $P(y^{<1>}, \dots, y^{<T_y>} | x^{<1>}, \dots, x^{<T_x>})$

Finding the most likely translation

Jane visite l'Afrique en septembre.

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

English

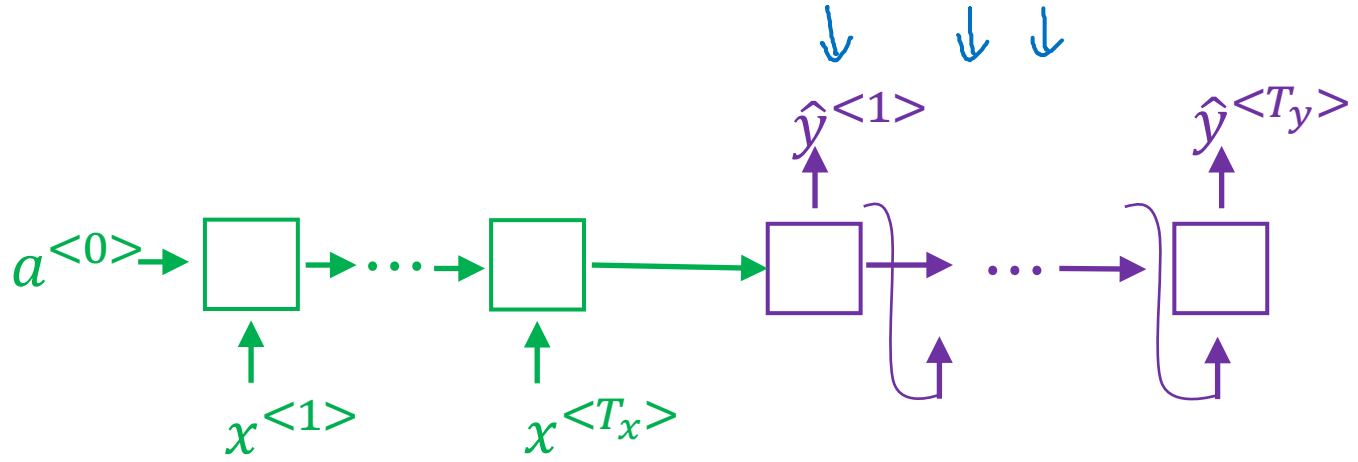
French

- 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.

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

Why not a greedy search?

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



$$\arg \max_y P(\hat{y}^{(1)}, \hat{y}^{(2)}, \dots, \hat{y}^{(T_y)} | x)$$

$$\frac{10,000 \times 10}{10,000^{10}}$$

$$P(y | x)$$

→ 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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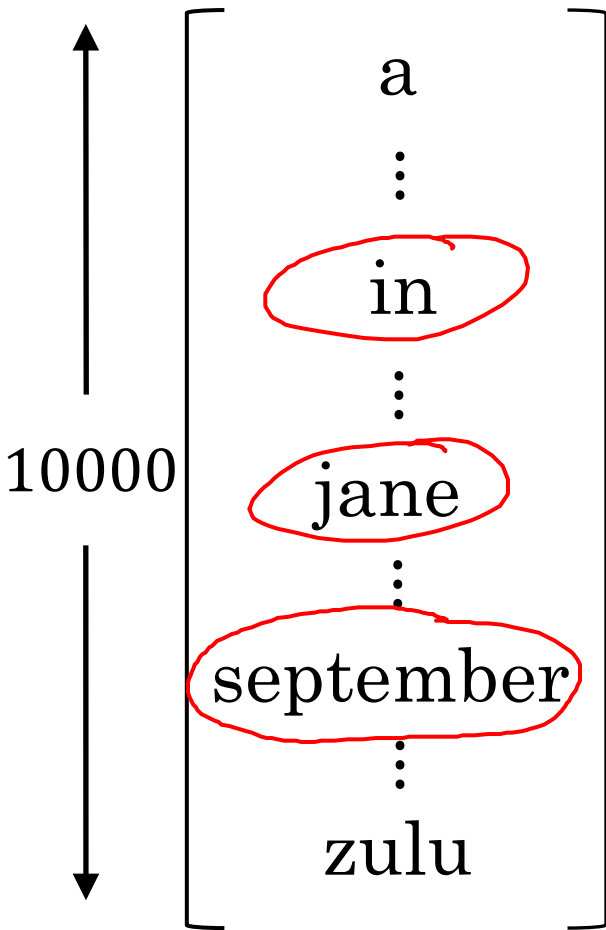
Sequence to
sequence models

Beam search

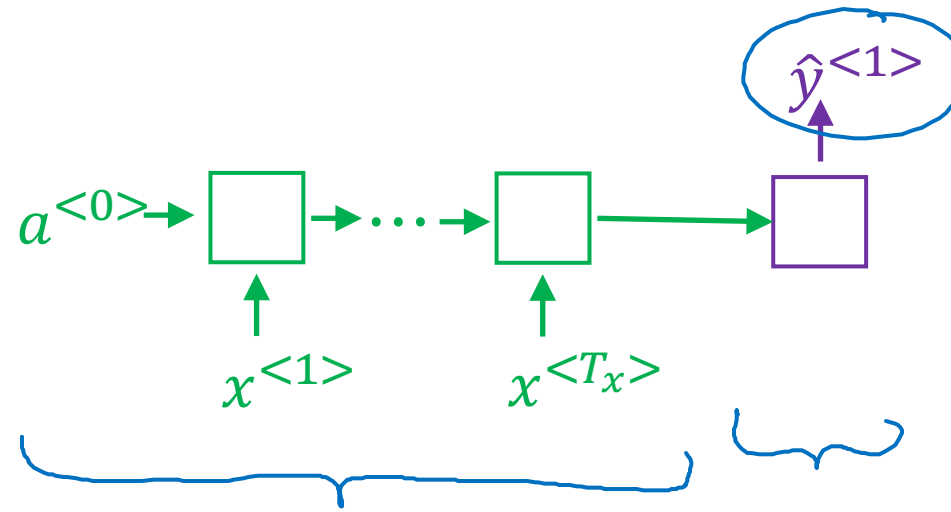
Beam search algorithm

$B = 3$ (beam width)

Step 1

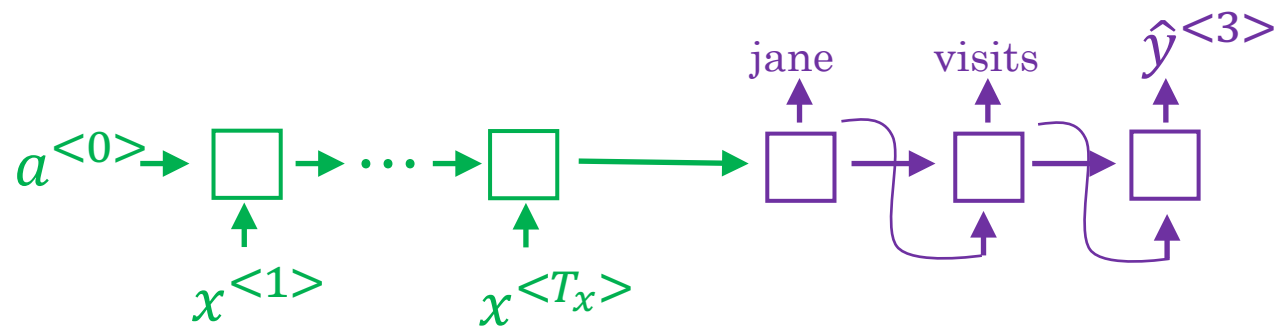
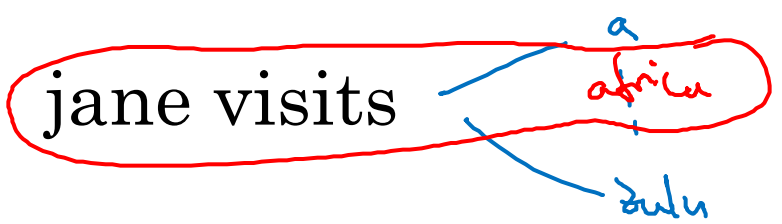
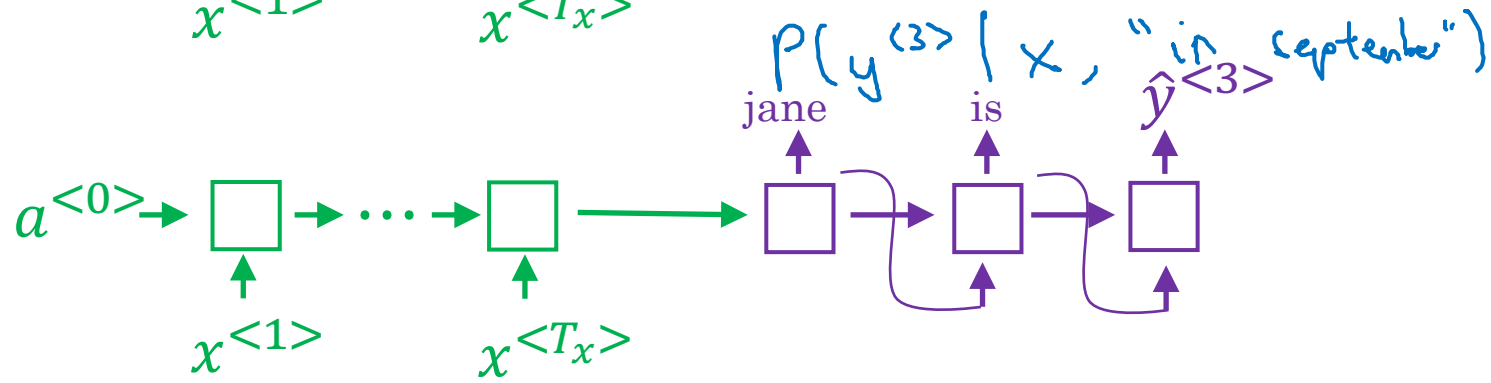
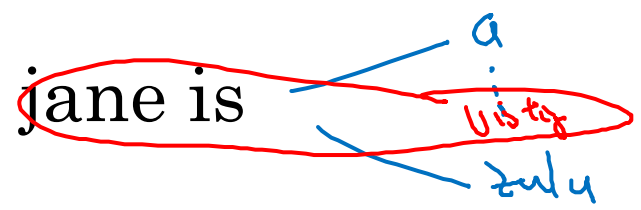
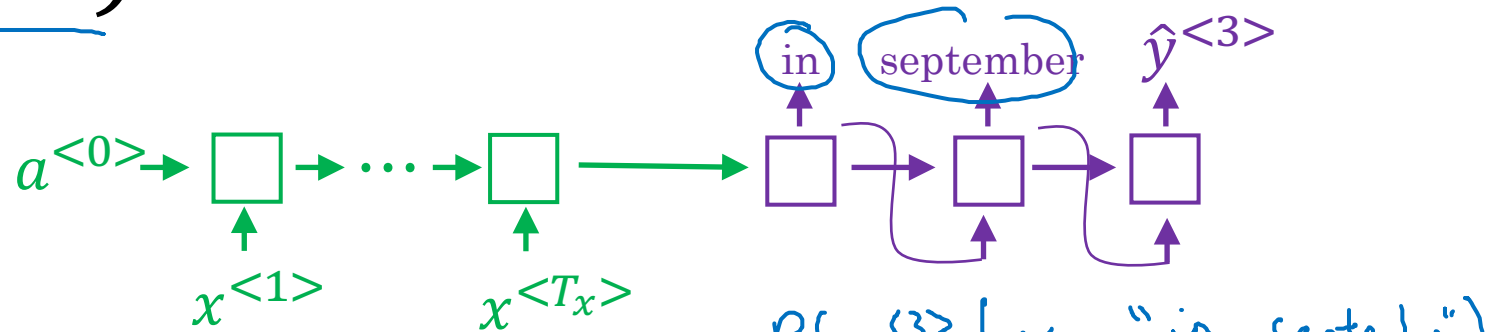


→ $P(y^{<1>} | x)$



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

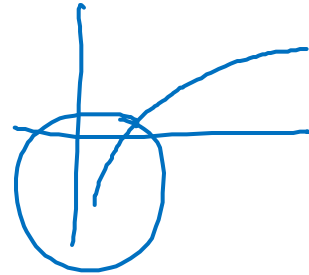
Length normalization

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

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

log

$$\arg \max_y \sum_{t=1}^{T_y} \log P(y^{(t)} | x, y^{(1)}, \dots, y^{(t-1)})$$



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

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

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

$\alpha = 0.7$

$\alpha = 1$
 $\alpha = 0$

Beam search discussion

Beam width B?

$1 \rightarrow 3 \rightarrow 10, 100, 1000 \rightarrow 3000$

large B: better result, slower
small B: worse result, faster

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

Jane visite l'Afrique en septembre.

→ RNN

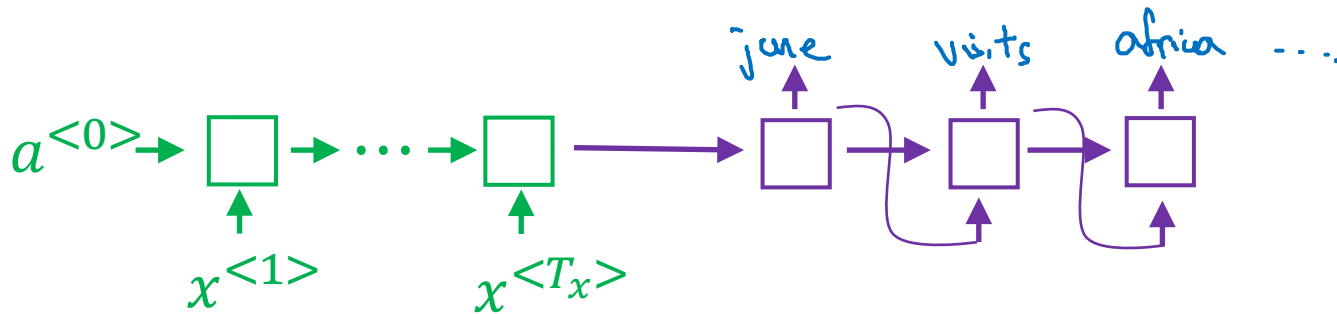
→ Beam Search

BT

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

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

RNN computes $P(y^*|x) \gg P(\hat{y}|x)$



Error analysis on beam search

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

$$P(y^*|x)$$

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

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

Case 1: $P(y^*|x) > P(\hat{y}|x)$ ←

$$\arg \max_y P(y|x)$$

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

Conclusion: Beam search is at fault.

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

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

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.	$\frac{2 \times 10^{-10}}{\text{---}}$ ---	$\frac{1 \times 10^{-10}}{\text{---}}$ ---	<u>B</u> <u>R</u> ... R R R

Figures out what fraction of errors are “due to” beam search vs. RNN model



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Sequence to
sequence models

Bleu score
(optional)

Evaluating machine translation

French: Le chat est sur le tapis.

Bleu
bilingual evaluation understudy

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:

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	4
cat on	1 ←	1 ←	—
on the	1 ←	1 ←	6
the mat	1 ←	1 ←	
	↑		

Bleu score on unigrams

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

Reference 2: There is a cat on the mat.

$P_1, P_2 = 1.0$

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

$$P_1 = \frac{\sum_{unigram \in \hat{y}} \text{count}_{clip}(unigram)}{\sum_{unigram \in \hat{y}} \text{count}(unigram)}$$

(Handwritten annotations: \hat{y} above the numerator sum, $\text{count}_{clip}(unigram)$ next to the numerator sum, $\text{count}(unigram)$ next to the denominator sum, and unigram below the denominator sum.)

$$P_n = \frac{\sum_{ngram \in \hat{y}} \text{count}_{clip}(ngram)}{\sum_{ngram \in \hat{y}} \text{count}(ngram)}$$

(Handwritten annotations: $ngram$ above the numerator sum, $\text{count}_{clip}(ngram)$ next to the numerator sum, $\text{count}(ngram)$ next to the denominator sum, and \hat{y} next to both sums.)

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

$$BP = \begin{cases} 1 & \text{if } \underline{MT_output_length} > \underline{reference_output_length} \\ \exp(1 - MT_output_length/reference_output_length) & \text{otherwise} \end{cases}$$

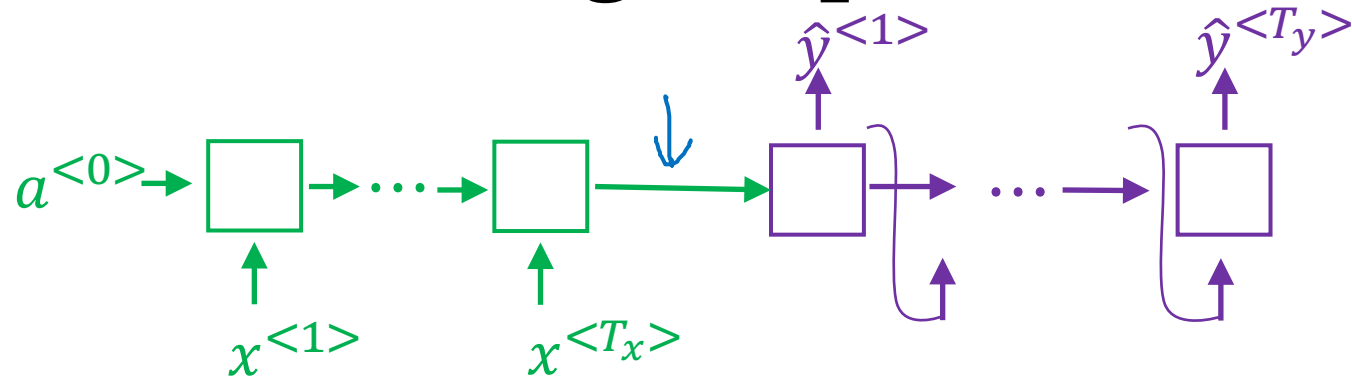


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Sequence to
sequence models

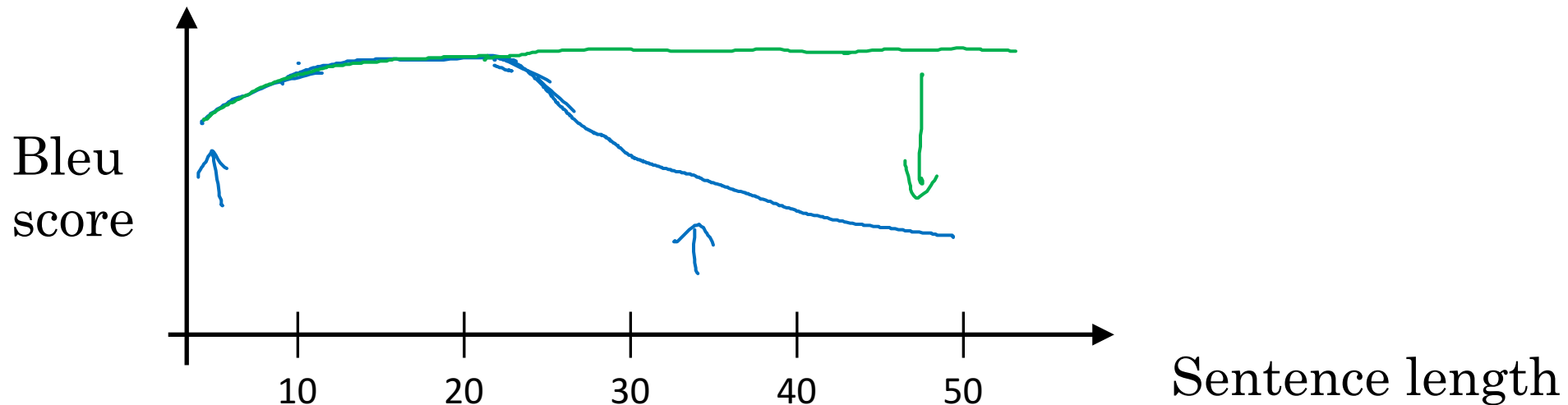
Attention model
intuition

The problem of long sequences

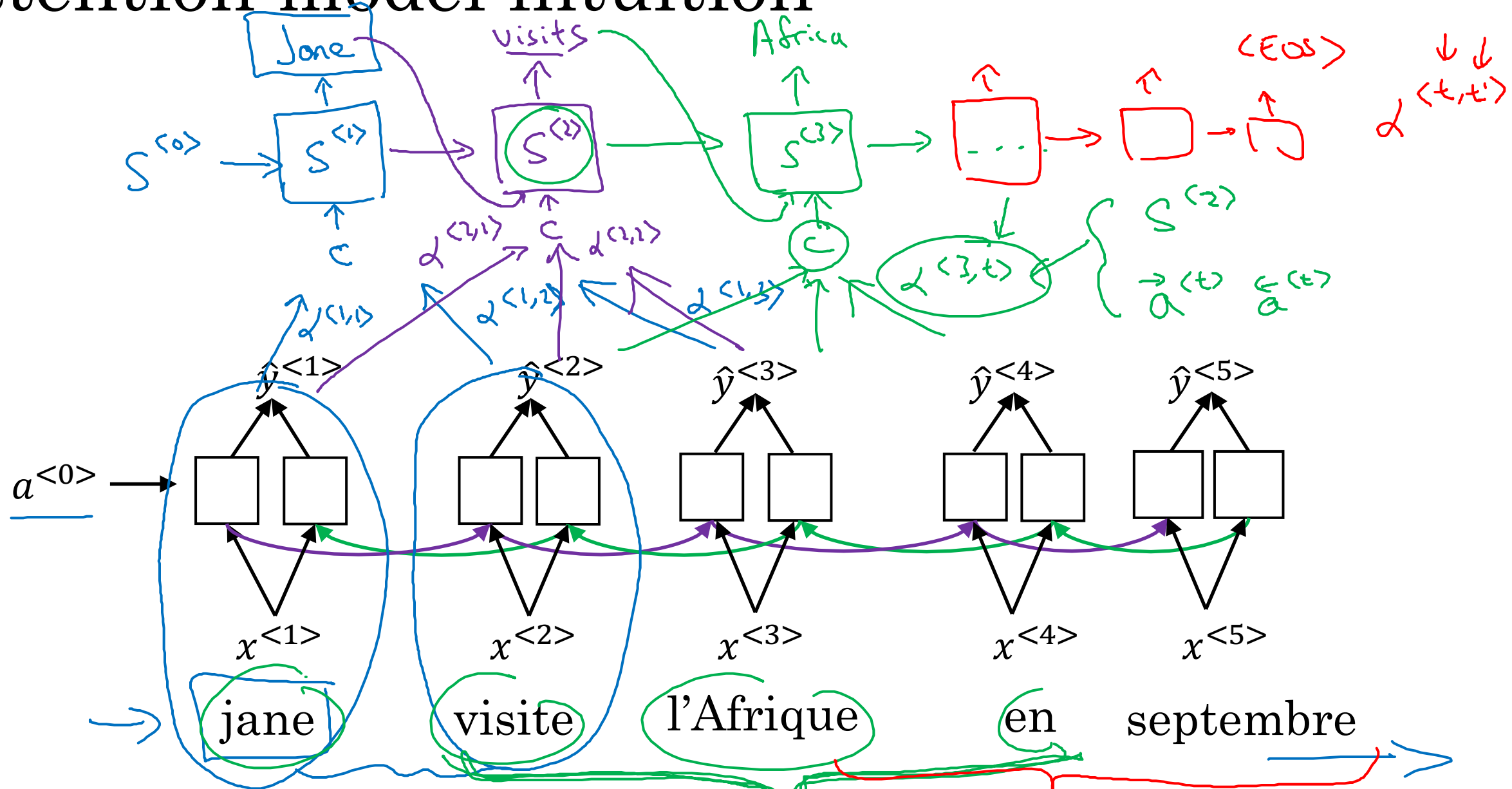


Jane s'est rendue en Afrique en septembre dernier, a apprécié la culture et a rencontré beaucoup de gens merveilleux; elle est revenue en parlant comment son voyage était merveilleux, et elle me tente d'y aller aussi.

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.



Attention model intuition





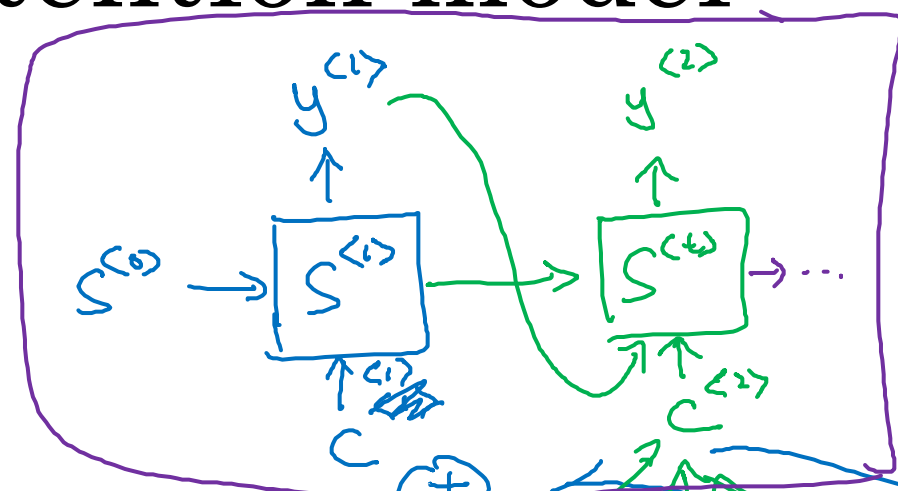
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Sequence to
sequence models

Attention model

Attention model

$\alpha^{(t,t')}$ = amount of "attention" should pay to $a^{(t')}$.

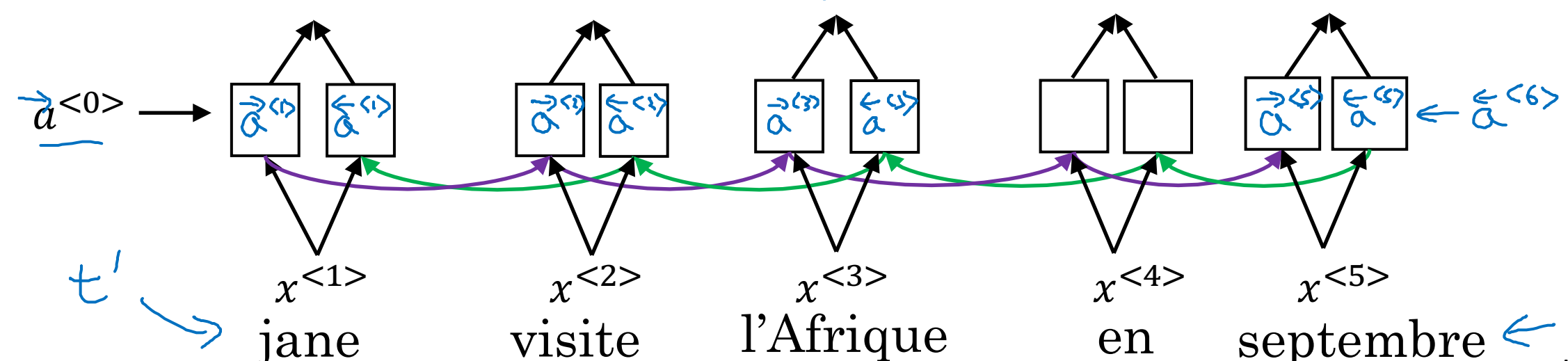


$$c^{(2)} = \sum_{t'} \alpha^{(2,t')} a^{(t')}$$

$$a^{(t')} = \left(\vec{a}^{(t')}, \leftarrow a^{(t')} \right)$$

$$\sum_{t'} \alpha^{(1,t')} = 1$$

$$c^{(1)} = \sum_{t'} \alpha^{(1,t')} a^{(t')}$$

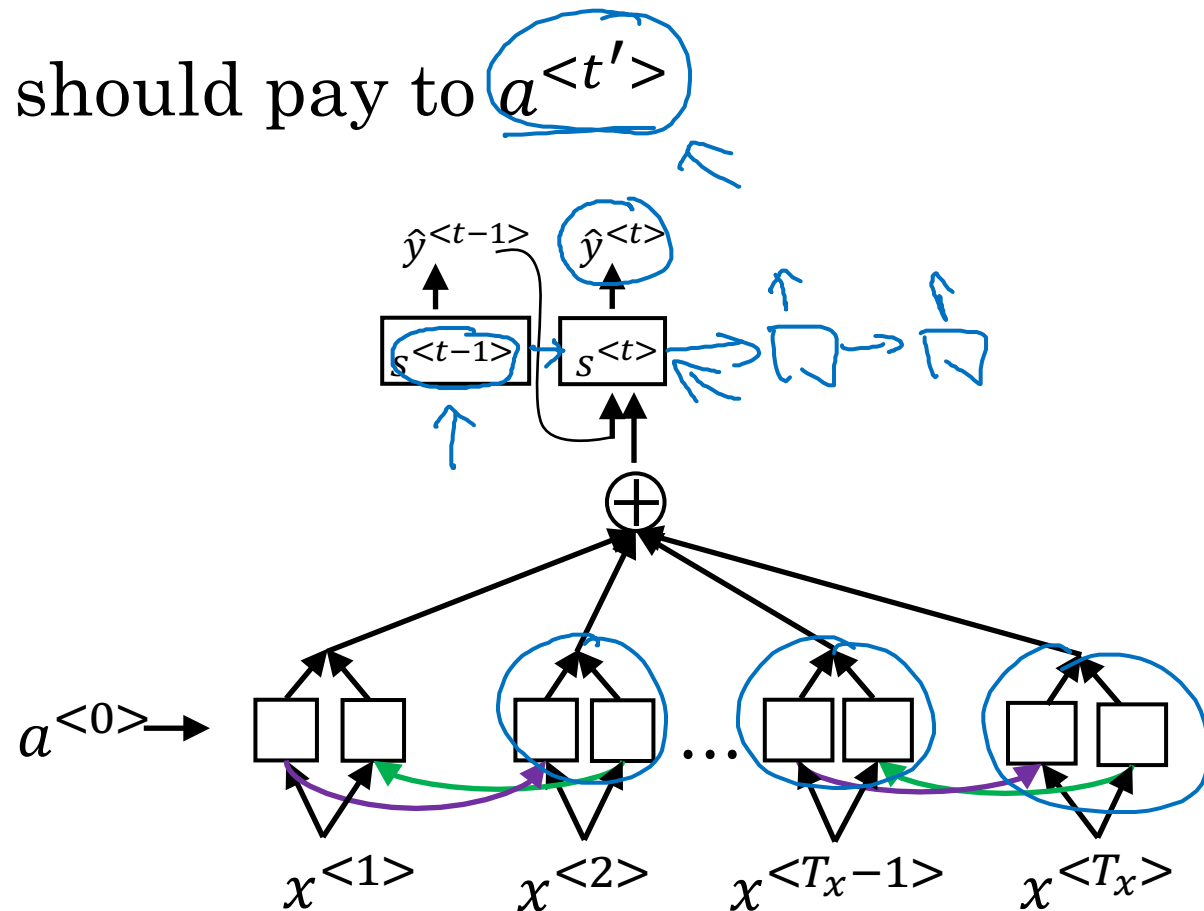
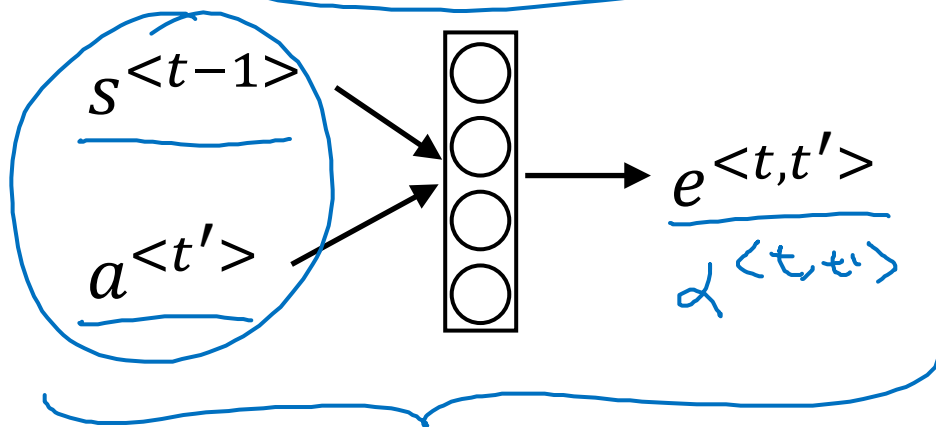


Computing attention $\alpha^{<t,t'>}$

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]

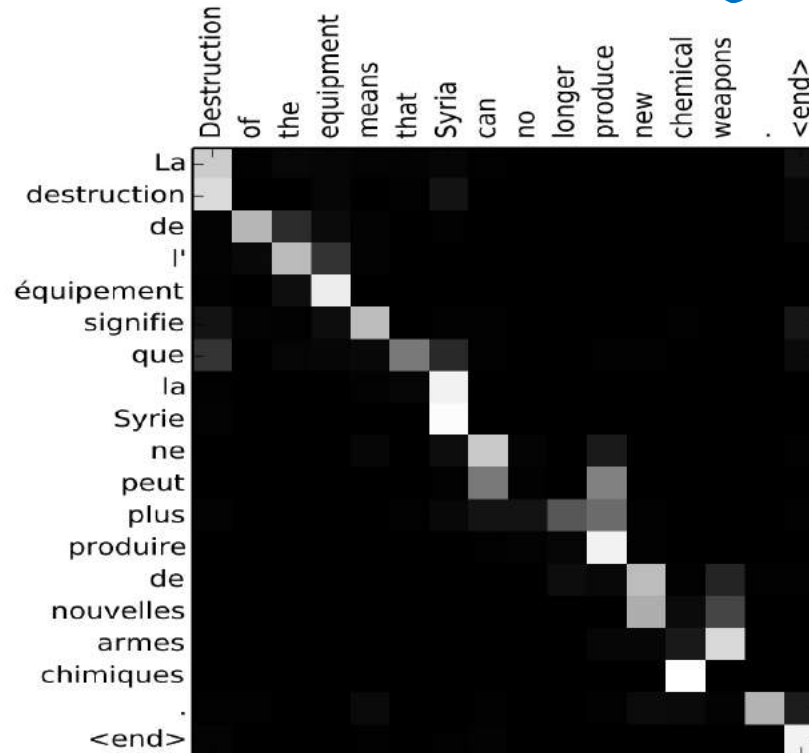
[Xu et. al., 2015. Show, attend and tell: Neural image caption generation with visual attention]

Attention examples

July 20th 1969 → 1969 – 07 – 20

23 April, 1564 → 1564 – 04 – 23

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





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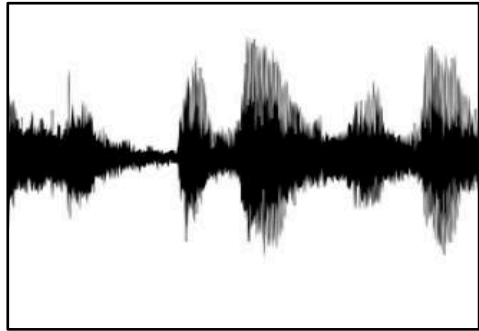
Audio data

Speech recognition

Speech recognition problem

x

audio clip



y

transcript

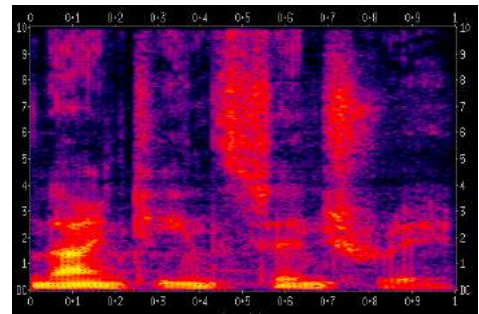
“the quick brown fox”

→ phonemes: de kwik braun

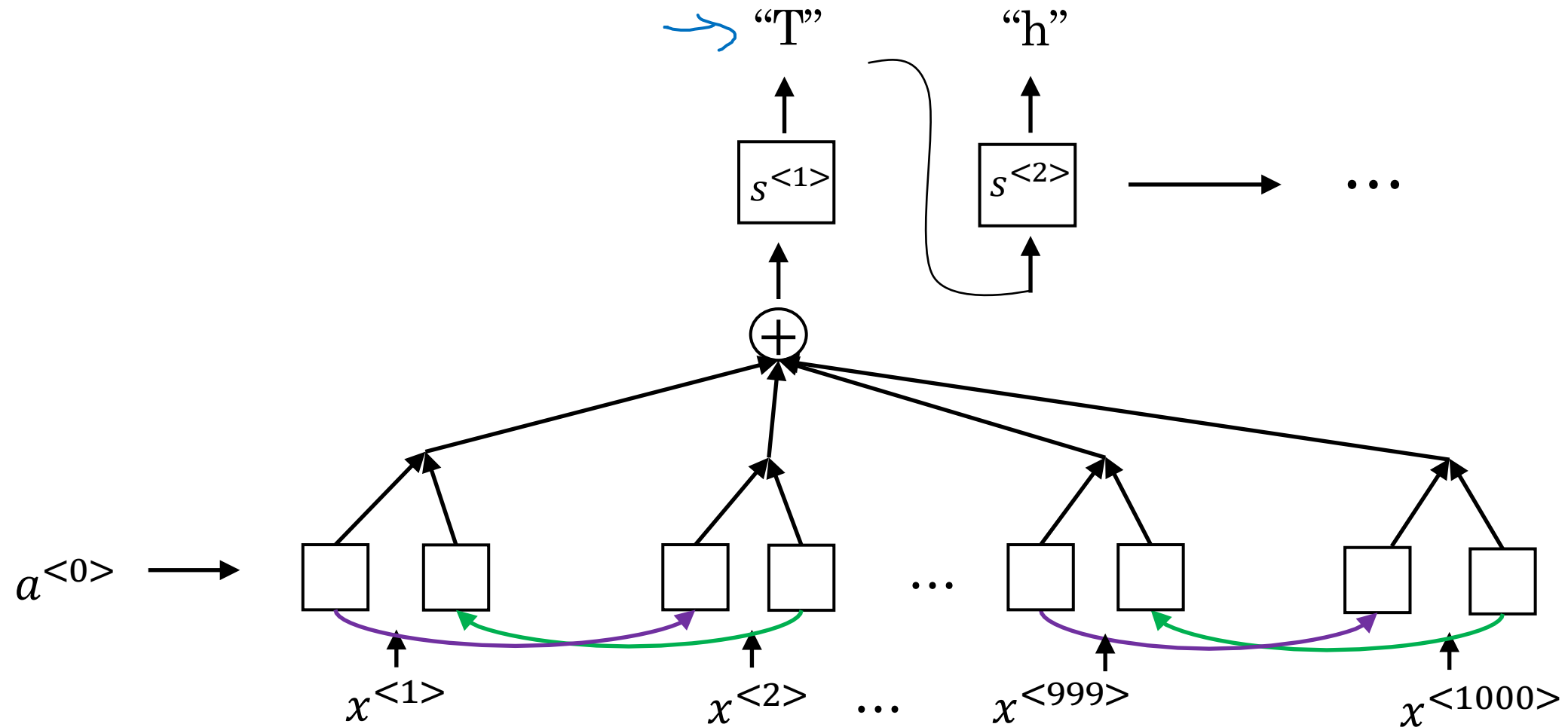
300h

3000h

100,000h

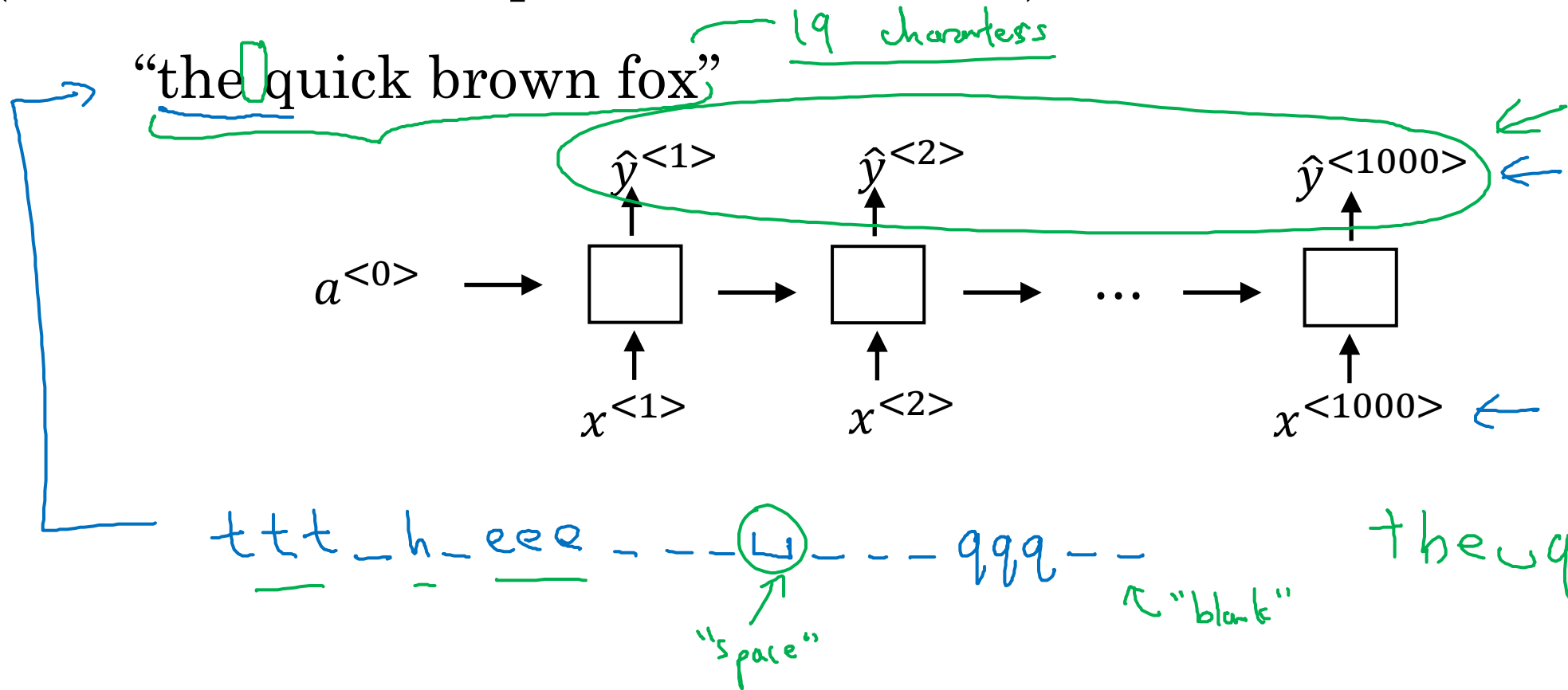


Attention model for speech recognition



CTC cost for speech recognition

(Connectionist temporal classification)



Basic rule: collapse repeated characters not separated by “blank”

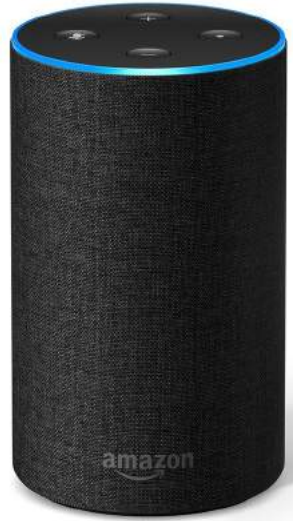


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Audio data

Trigger word
detection

What is trigger word detection?



Amazon Echo
(Alexa)



Baidu DuerOS
(xiaodunihao)

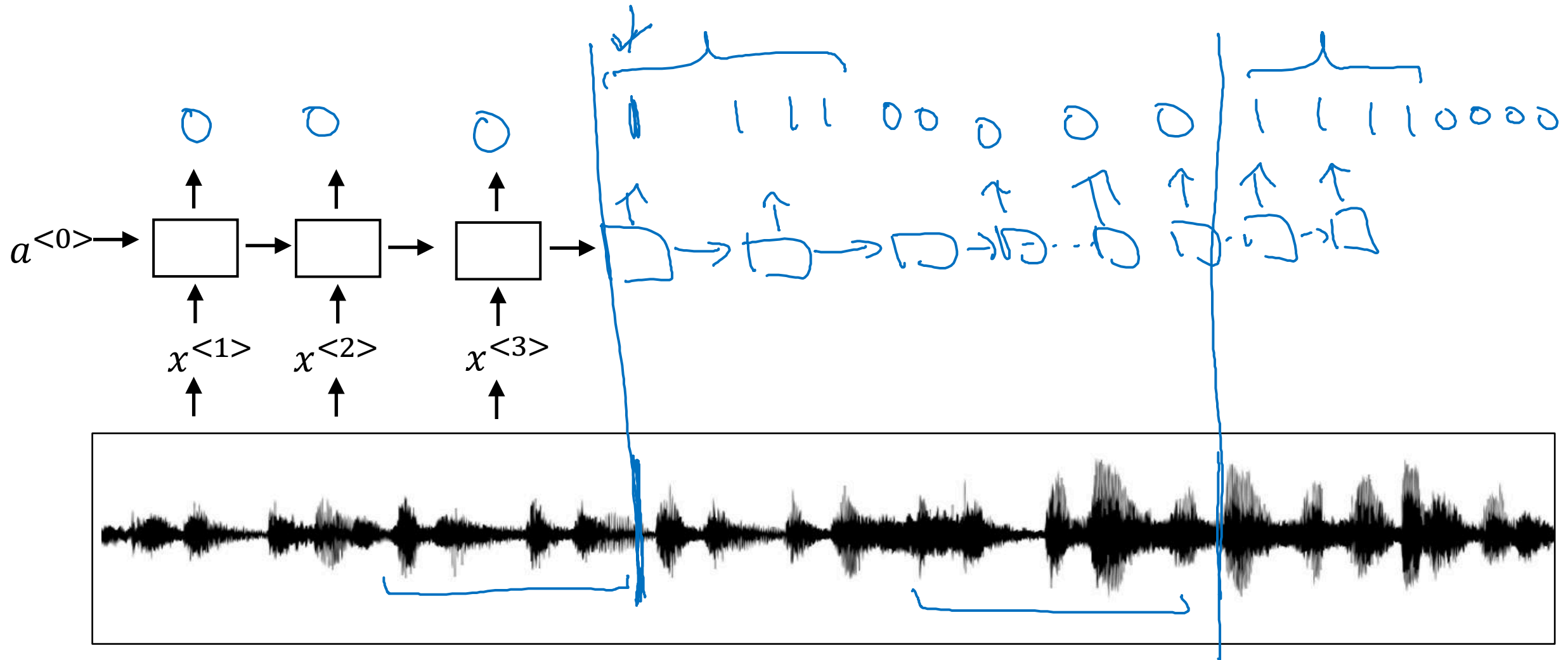


Apple Siri
(Hey Siri)



Google Home
(Okay Google)

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