

## RNN & Attention Mechanisms

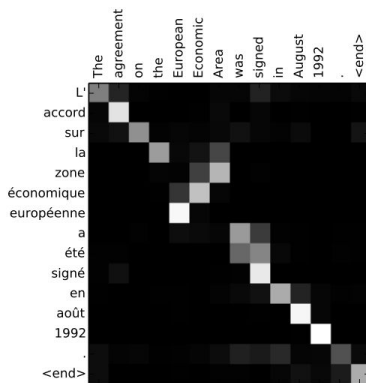
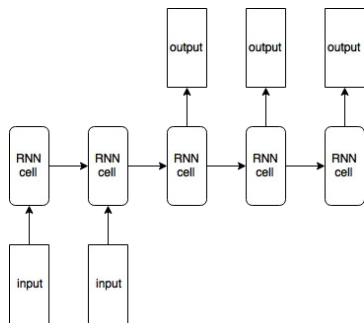
2110572: Natural Language Processing Systems

Peerapon Vateekul & Ekapol Chuangsuwanich  
Department of Computer Engineering,  
Faculty of Engineering, Chulalongkorn University

Credit: Can Udomcharoenchaikit & Nattachai Tretasayuth

## RNN & Attention Mechanism

- RNN
- Attention Mechanism

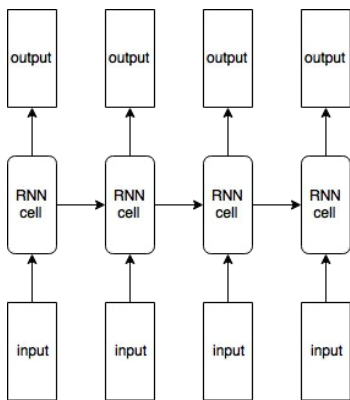




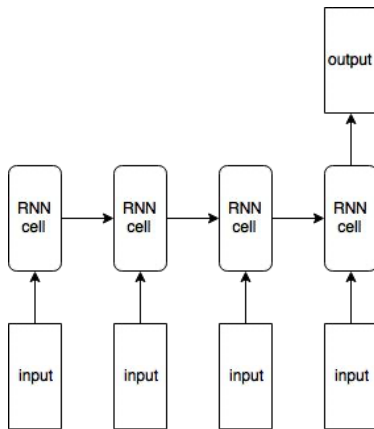
## RNN Architectures

# Different types of RNN architectures

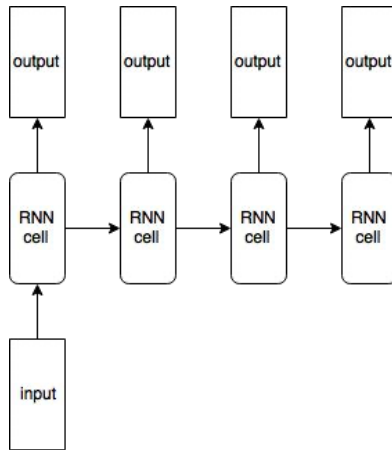
many-to-many



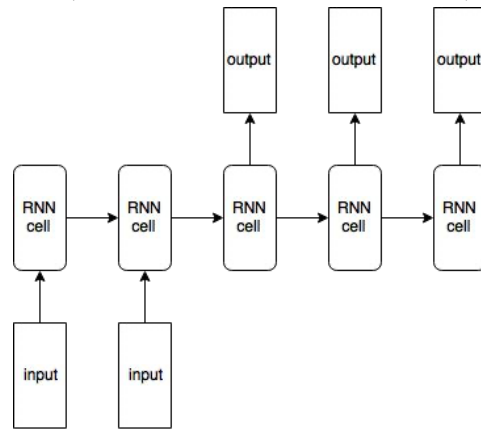
many-to-one



one-to-many



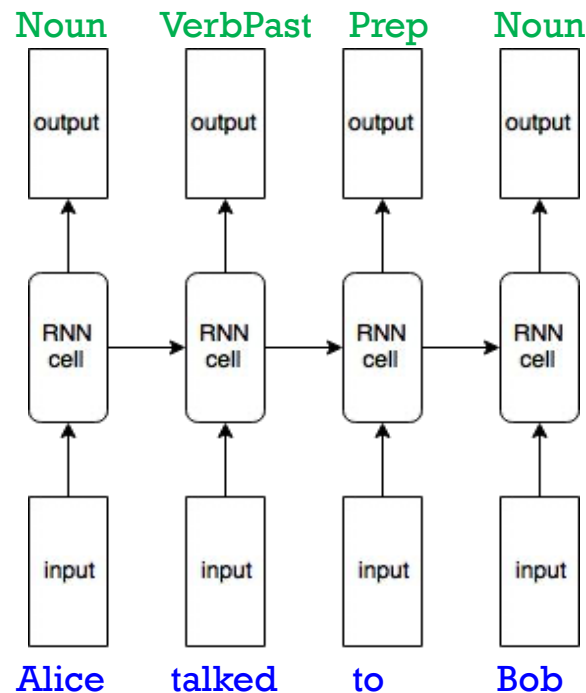
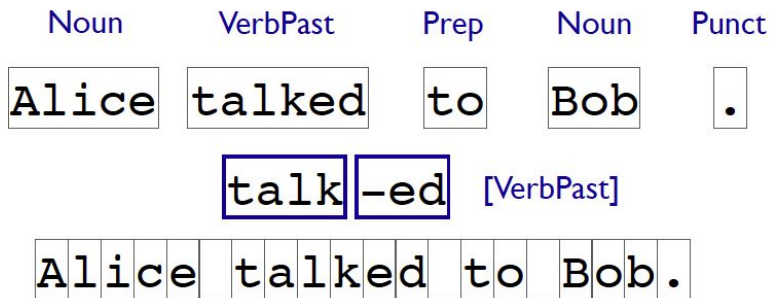
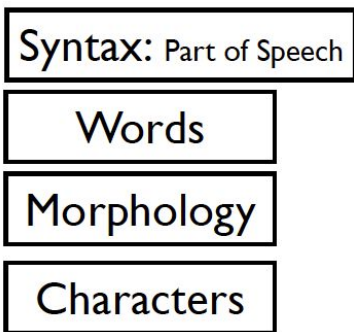
many-to-many  
(encoder-decoder)





# Many-to-many

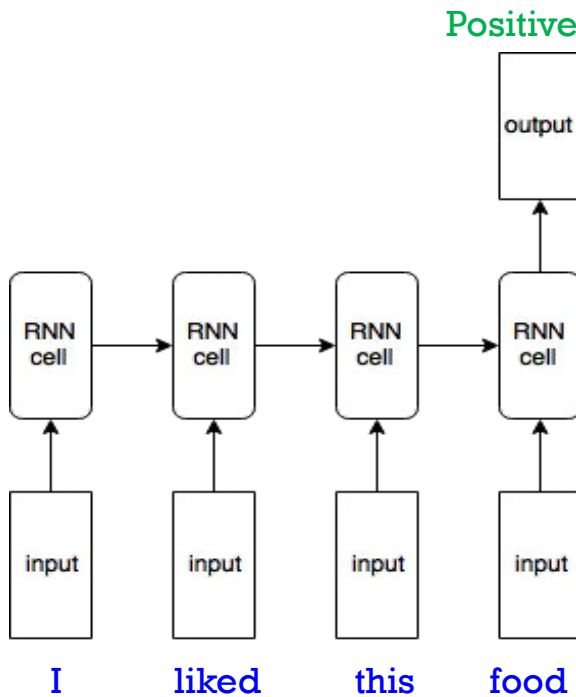
- You have seen and implemented this type of RNN architecture in your homework already.
- E.g. Tokenization, POS tagging
- Sequence Input, Sequence Output





# Many-to-one

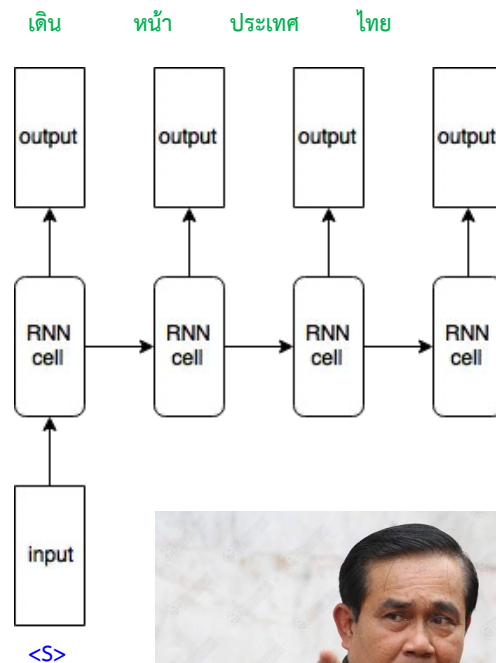
- E.g. Sentiment Analysis, Text classification
- Sequence input





# One-to-many

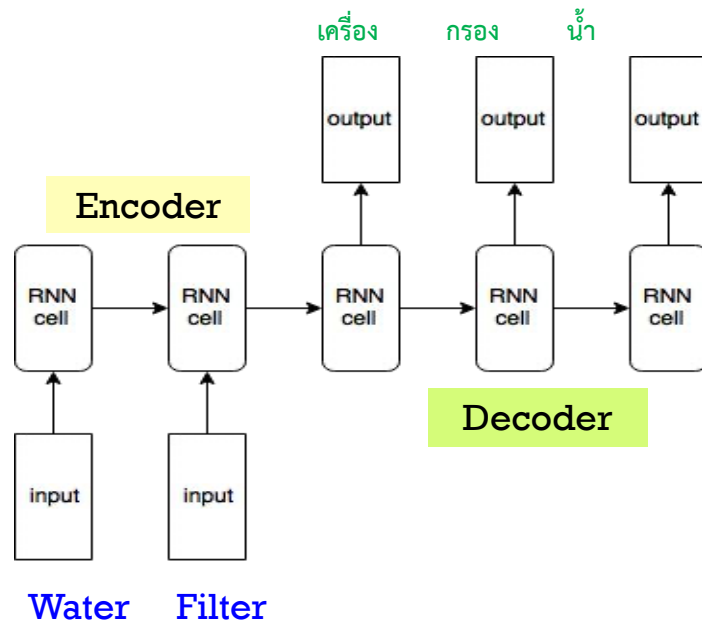
- Sequence output
- E.g. Music Generation, Image caption generation
- Music **generation**
  - Input: Initial seed
  - Output: Sequence of music notes
- Image caption **generation**
  - Input: Image features extracted by CNN
  - Output: Sequence of text





# Many-to-many (encoder-decoder)

- Sequence Input, Sequence output
- These two sequences can be of different length
- E.g. **Machine Translation**
  - Input: English Sentence
  - Output: Thai Sentence
- Machine Translation is also a **text generation task**



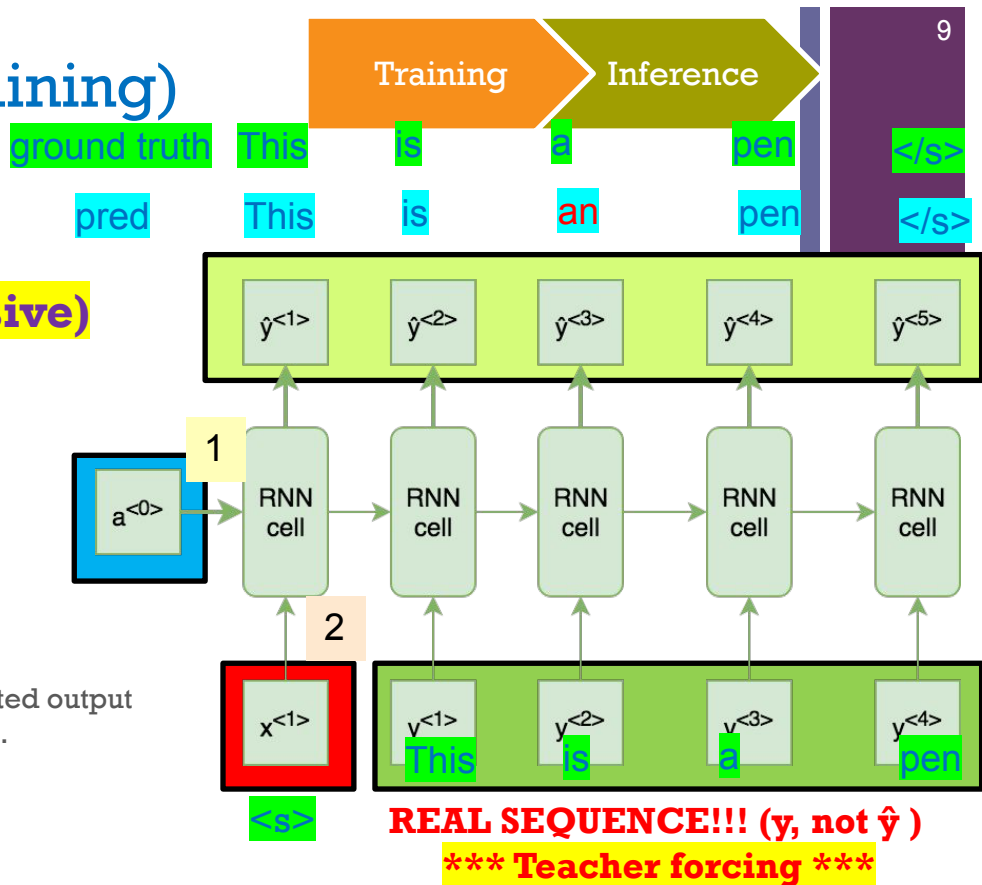


# + Text generation model (training)

## ■ One-to-Many RNN (autoregressive)

- The only real input is  $x^{<1>}$
- $a^{<0>}$  is the initial hidden state.
- $\hat{y}$  is the predicted output.
- $y$  is an actual output.
- During **the training phase**, instead of using the predicted output to feed into the next time-step, we use the actual output.

$$a^{<t>} = W a^{<t-1>} + W x^{<t>} + b$$





ground truth   This   is   a   pen   </s>

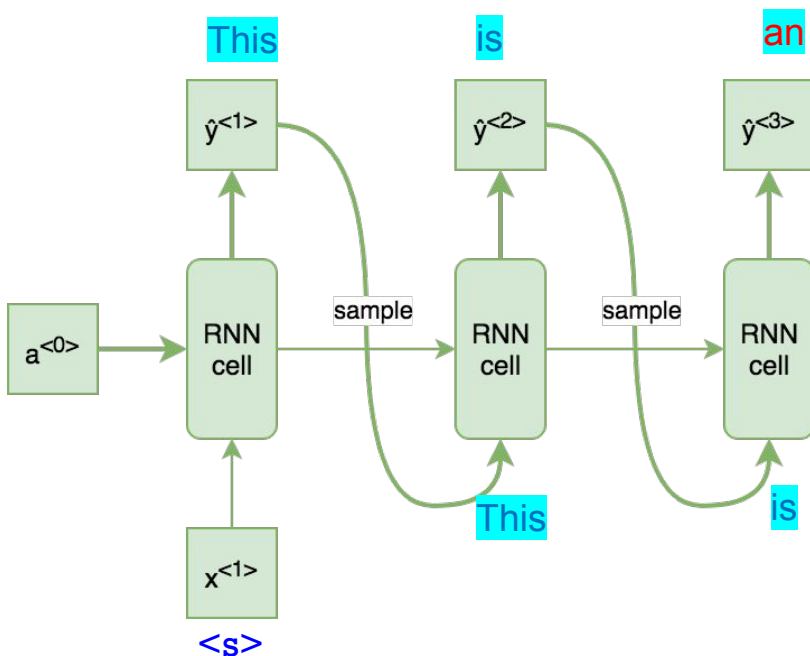
# Text generation model (inference; testing)

Training

Inference

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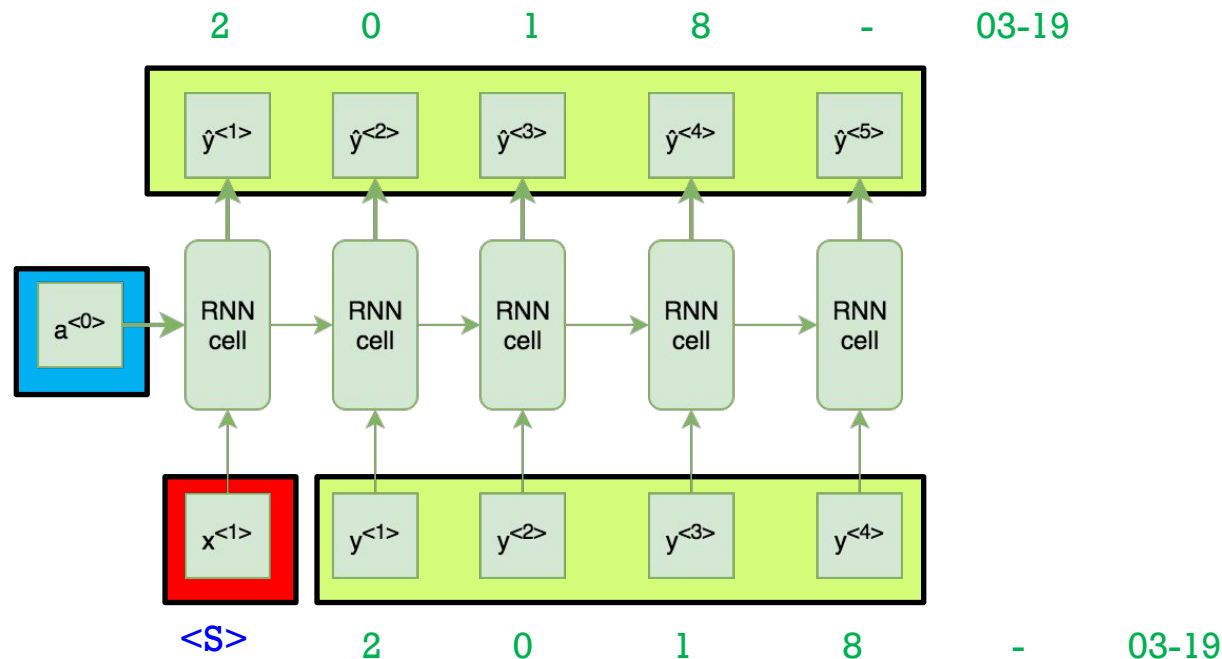
- To generate a novel sequence, the inference model (testing phase) randomly samples an output from a softmax distribution.





# In class demo1: One-to-Many RNN Text generation

In-class demo: Generating a piece of text using RNN; [Random Date Generation](#) “2018-03-19”





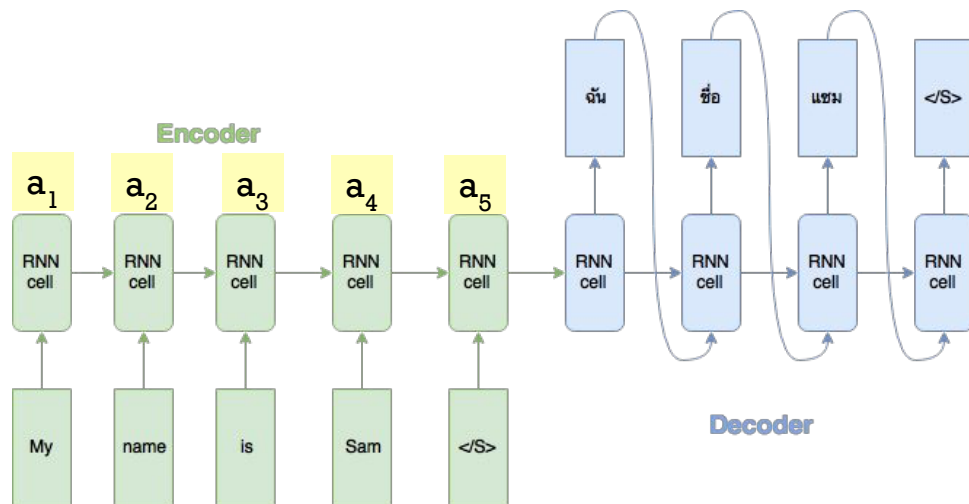
## Attention Mechanism

# Attention Mechanism (Many-to-Many)

**Attention** is commonly used in sequence-to-sequence model, it allows **the decoder part** of the network to focus/**attend** on a different part of **the encoder outputs** for every step of the decoder's own outputs.

Why attention?

This is what we want you to think about: How can information travel from one end to another in neural networks?

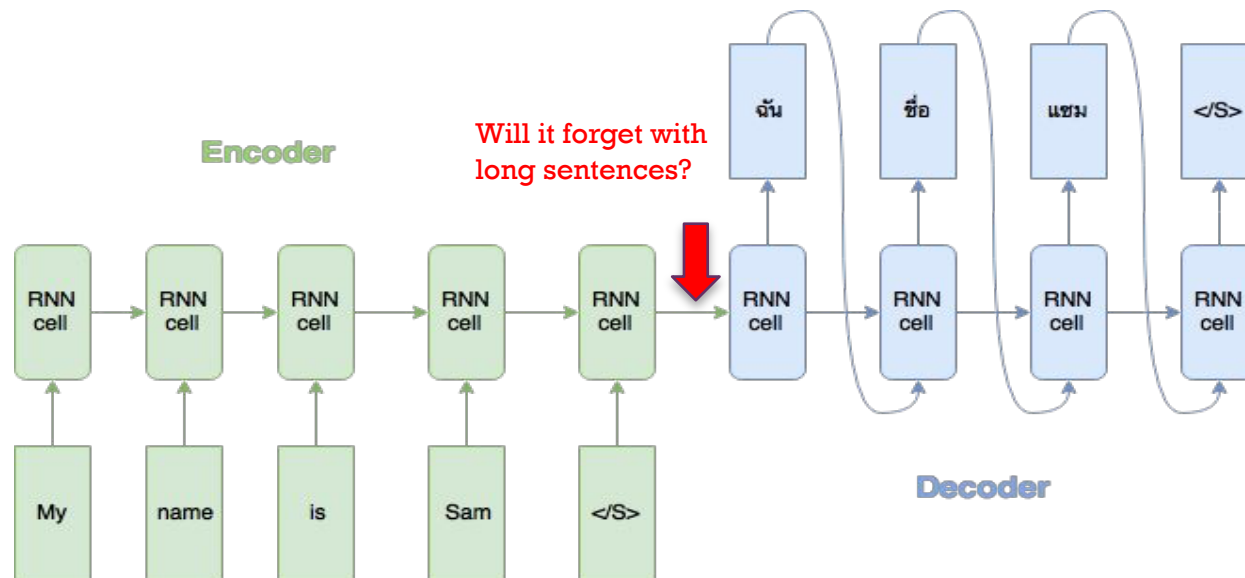


Machine Translation Problem: English to Thai

# Attention Mechanism (cont.)

Why attention?

“You can’t cram the meaning of a whole sentence into a single vector!” - Raymond Mooney (2014)



Reference: <http://yoavartzi.com/sp14/slides/mooney.sp14.pdf>

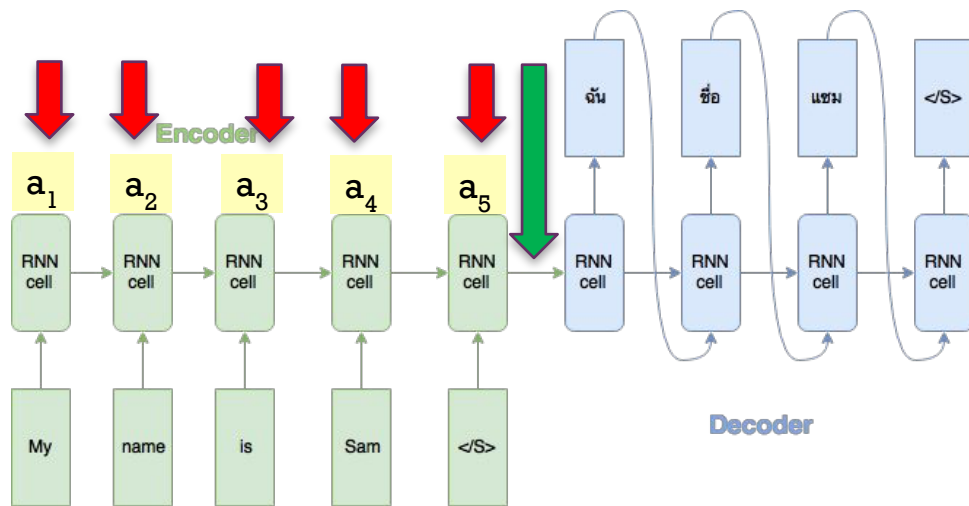


# Attention Mechanism (cont.)

Why attention?

Main idea: We can use **multiple vectors** based on the length of the sentence instead of **one**.

Attention mechanism = Instead of encoding all the information into a fixed-length vector, the decoder gets to decide parts of the input source to pay attention.



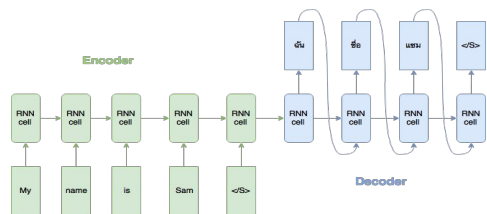
Machine Translation Problem: English to Thai



## Graphical Example: English-to-Thai machine translation

- This is a rough estimate of what might occur for English-to-Thai translation

	My	name	is	Sam	<u>encoder</u>
ฉัน					
ชื่อ					
แซ่ม					
<u>decoder</u>					



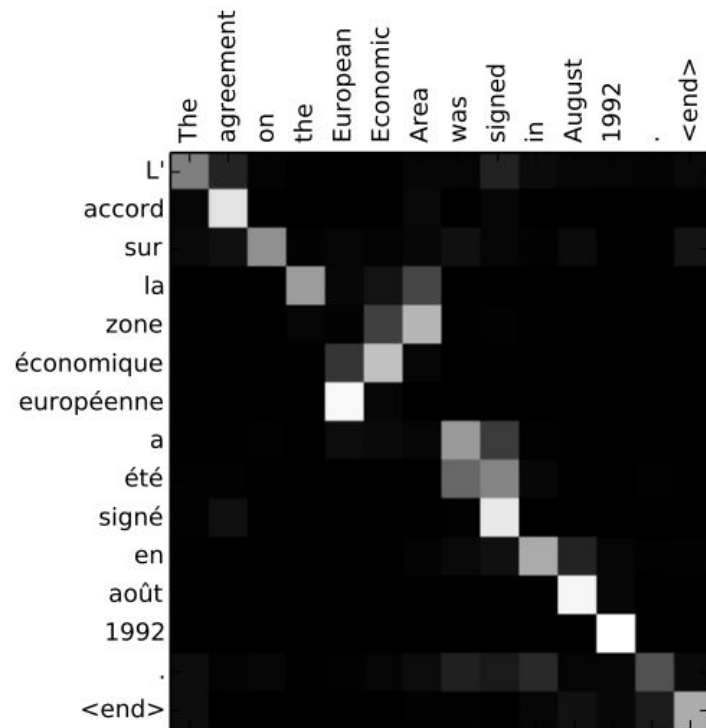
Machine Translation Problem: English to Thai





## Graphical Example: English-to-French machine translation

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Reference: Bahdanau, Dzmitry, Kyunghyun Cho, and Yoshua Bengio. "Neural machine translation by jointly learning to align and translate." ICLR(2015).

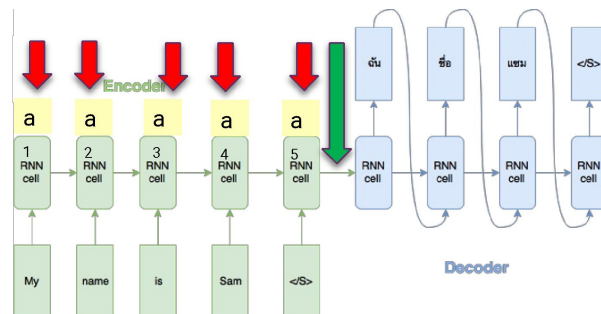
# Attention Mechanism: Recap Basic Idea

- **Encode** each word in the sequence into a vector
- When **DECODING**, perform a linear combination of these encoded vectors from the encoding step with their corresponding “attention weights”.
  - (scalar 1)(encoded vector1) + (scalar 2)(encoded vector 2) + (scalar 3)(encoded vector 3)

$$\mathbf{c}_i = \sum_j a_{ij} \mathbf{h}_j$$

j = each encoder's input  
i = each decoder's input

- A vector formed by this linear combination is called “**context vector**”
- Use context vectors as inputs for the decoding step



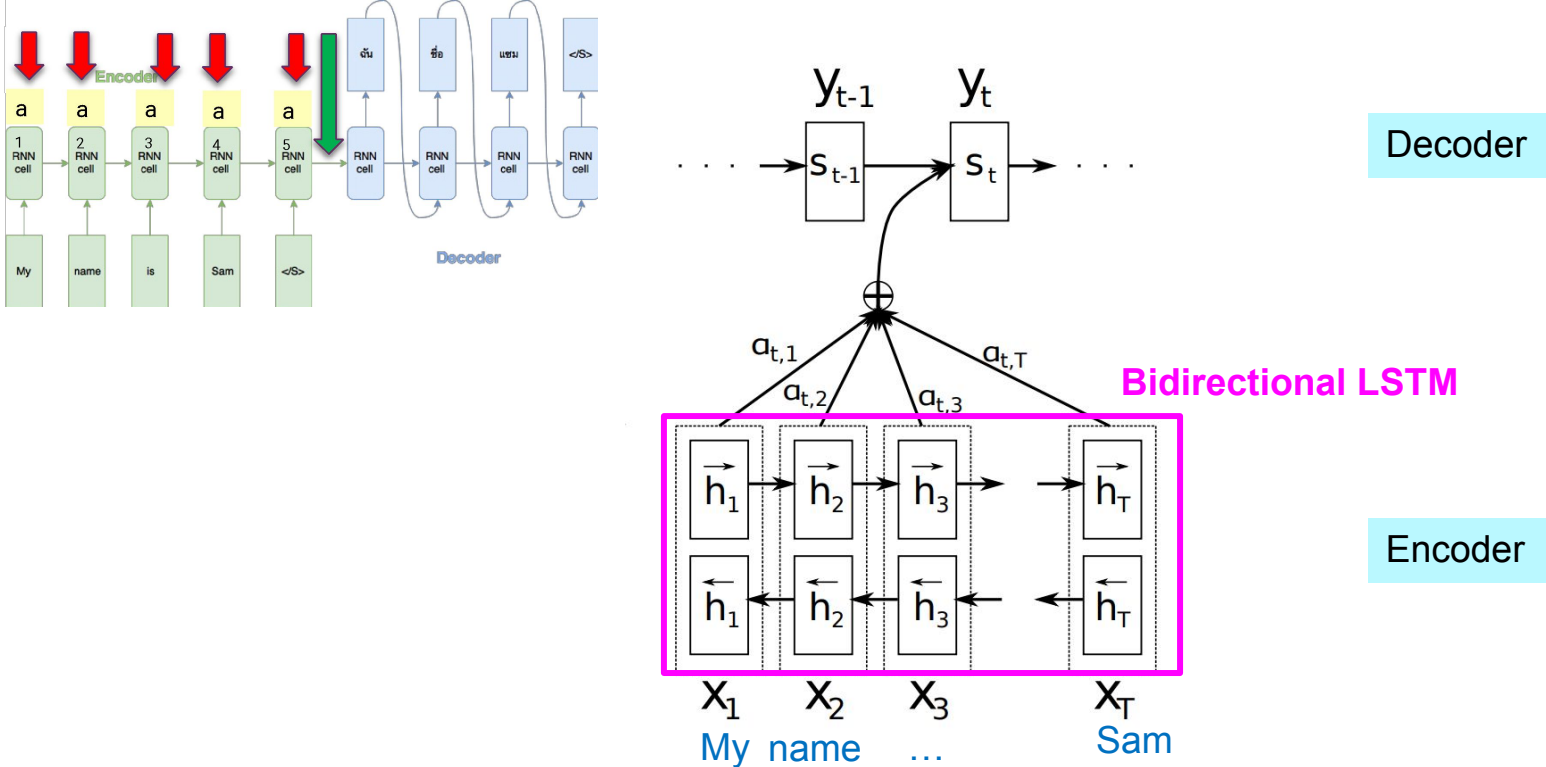
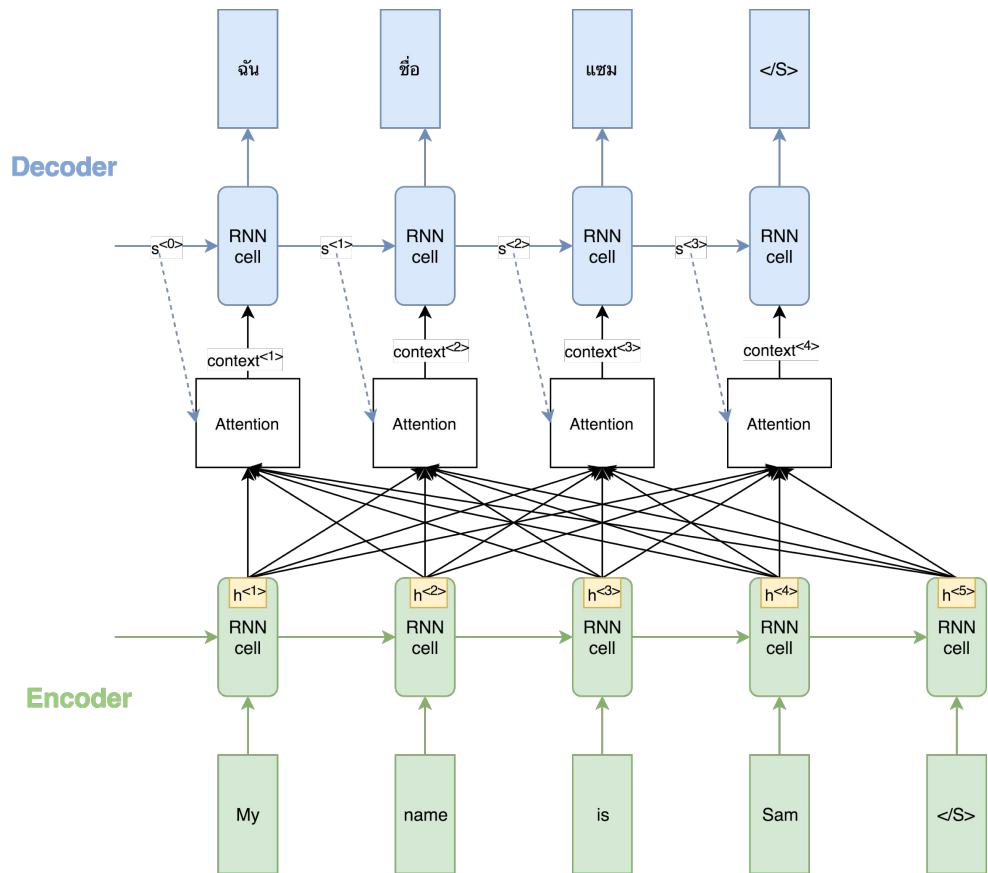


Figure 1: The graphical illustration of the proposed model trying to generate the  $t$ -th target word  $y_t$  given a source sentence  $(x_1, x_2, \dots, x_T)$ .

source = encoder

target word = decoder

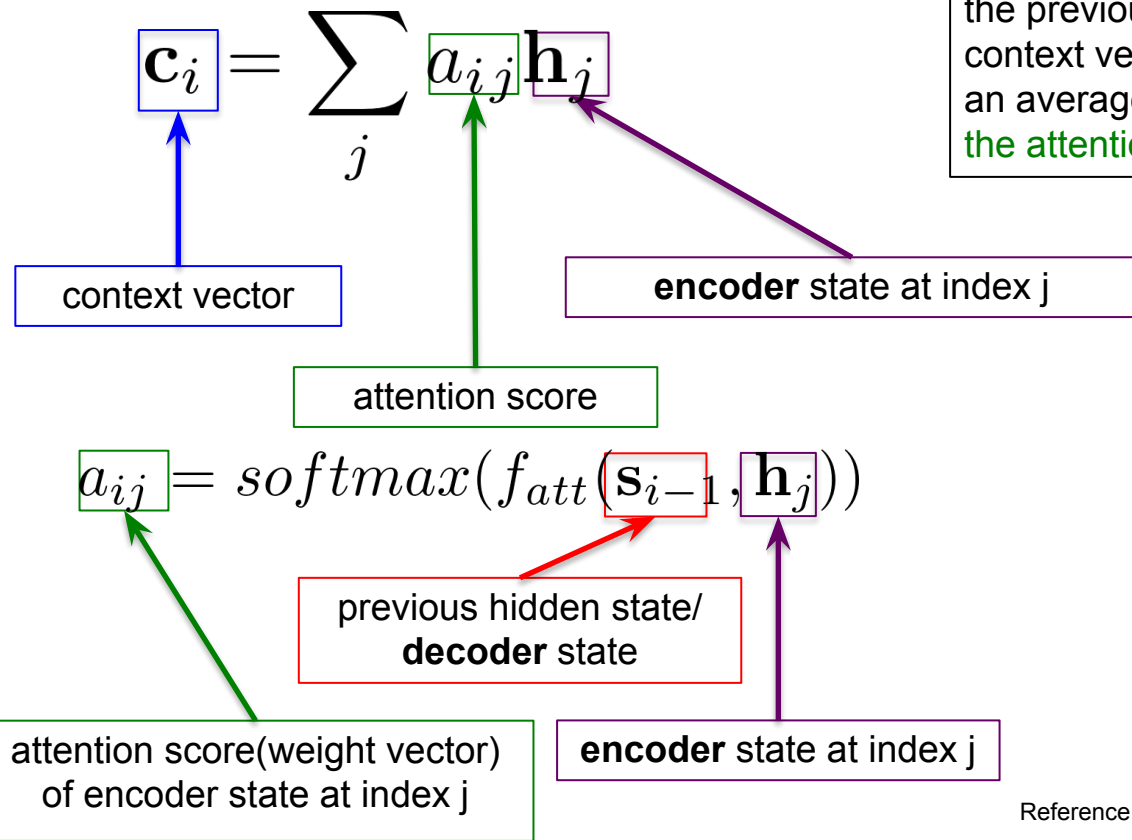
# + RNN and attention mechanism



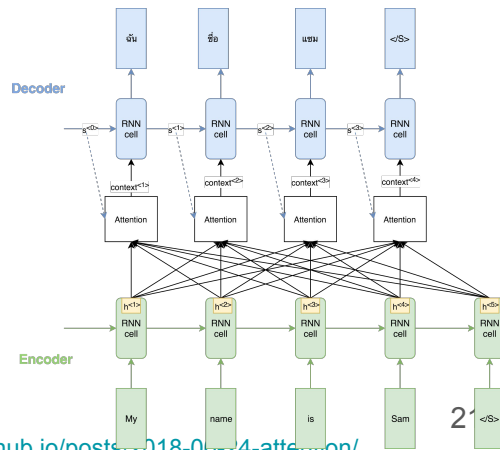
	My	name	is	Sam
ฉัน				
ชื่อ				
แชน				

# Attention Mechanism (1): $C_i$

We want to calculate a context vector  $\mathbf{c}$  based on hidden states  $\mathbf{h}_0 \dots \mathbf{h}_j$  that can be used with the previous state  $\mathbf{s}_{i-1}$  for prediction. The context vector  $\mathbf{c}_i$  at position “i” is calculated as an average of the previous states weighted with the attention scores  $\mathbf{a}_i$ .



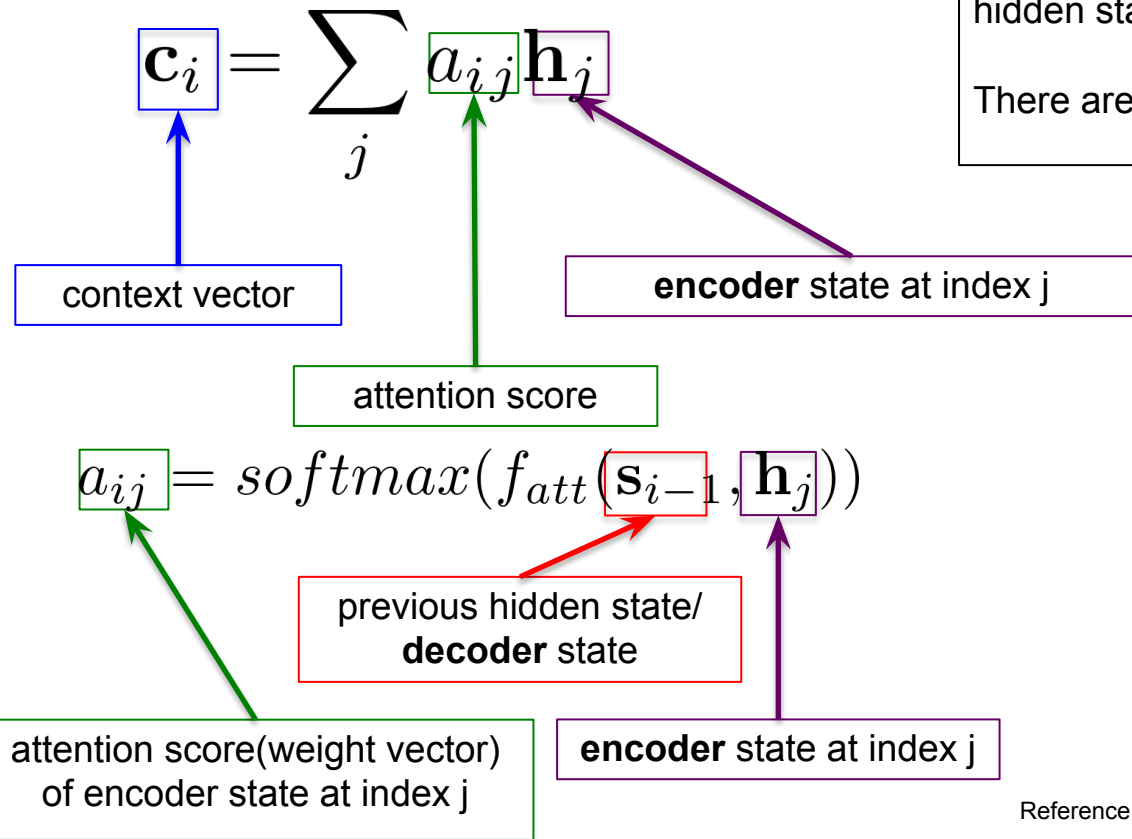
$i$  = decoder index  
 $j$  = encoder index



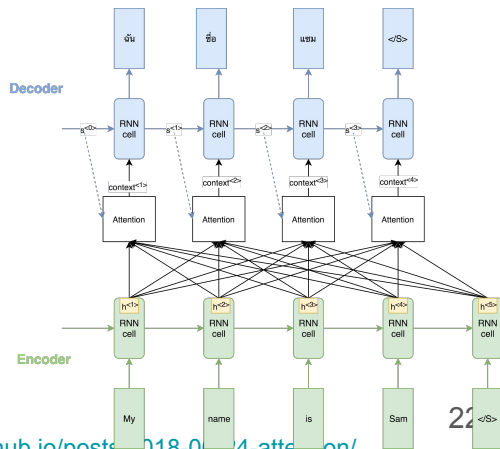
# Attention Mechanism (2): $f_{att}$

The attention function  $f_{att}(\mathbf{s}_{i-1}, \mathbf{h}_j)$  calculates an unnormalized alignment score between the current hidden state  $\mathbf{s}_{i-1}$  and the previous hidden state  $\mathbf{h}_j$ .

There are many variants of the attention function  $f_{att}$ .

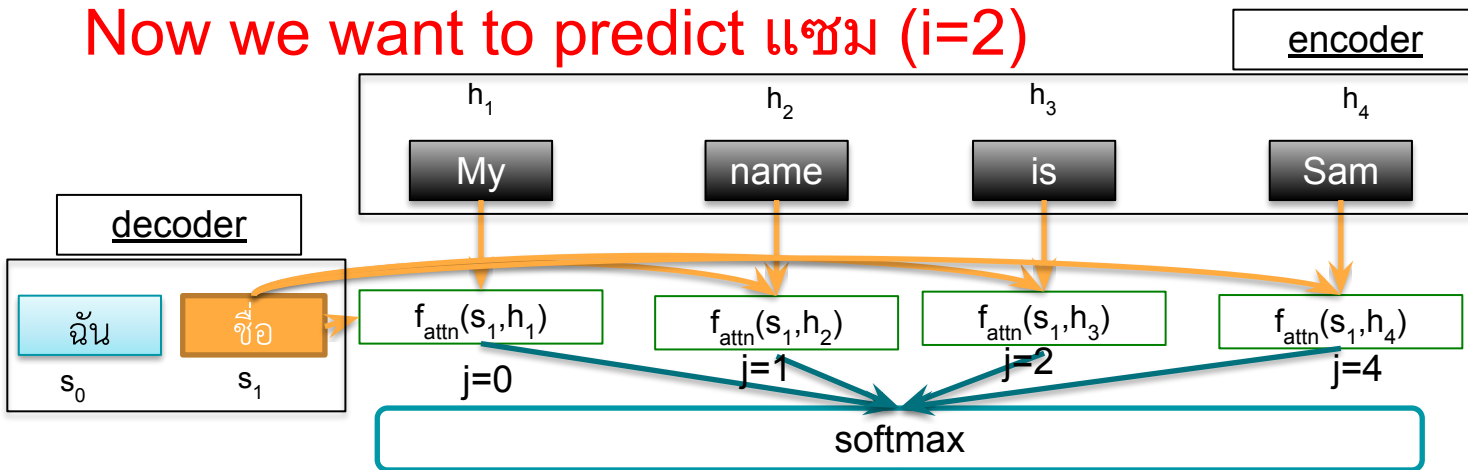


$i$  = decoder index  
 $j$  = encoder index



# Attention Calculation Example (1): Attention Scores

Now we want to predict ချစ် (i=2)



$$a_{ij} = \text{softmax}(f_{\text{attn}}(s_{i-1}, h_j))$$

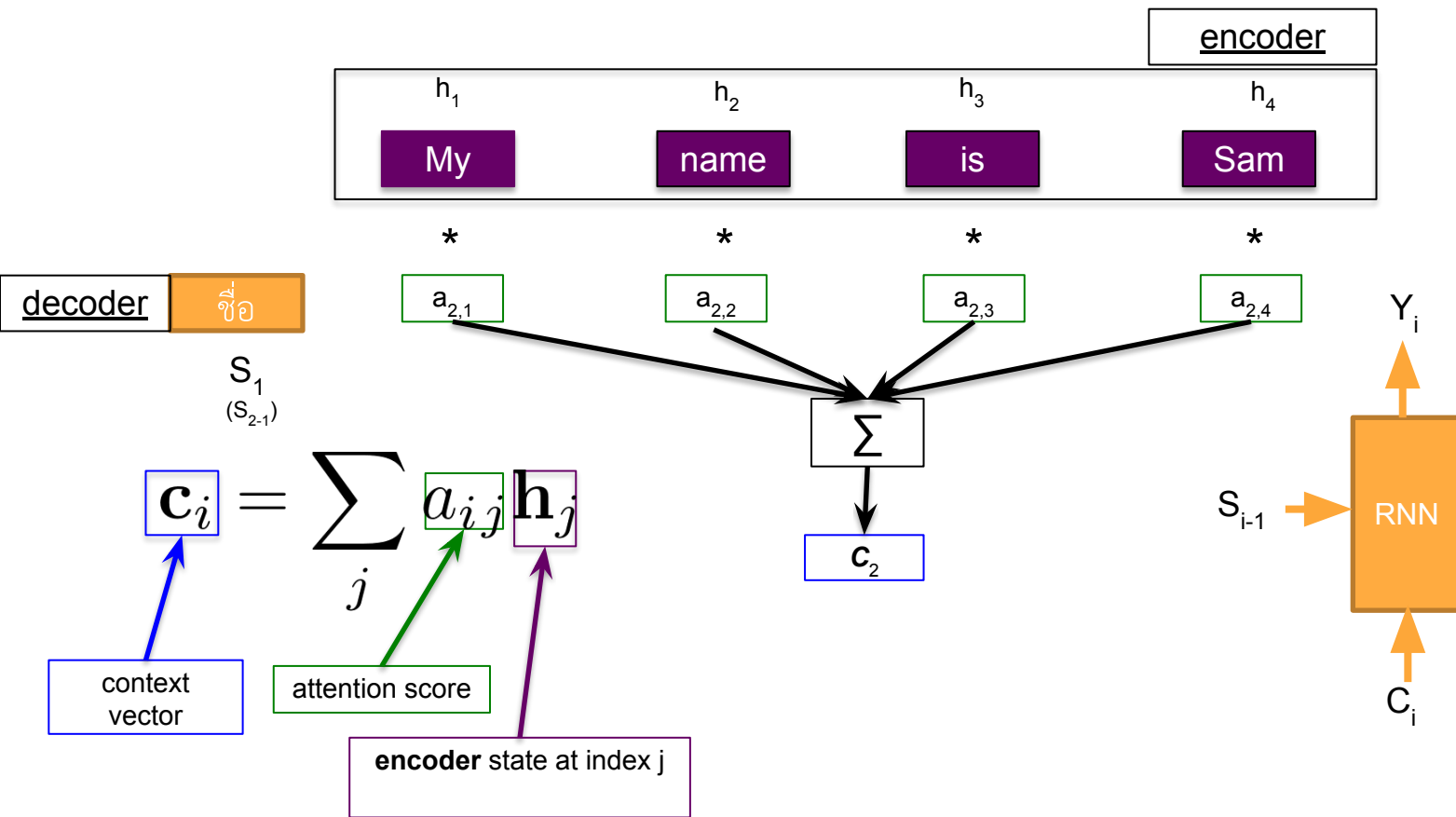
$i$  = decoder index  
 $j$  = encoder index

attention scores

previous hidden state/  
decoder state

encoder state at index  $j$

# Attention Calculation Example (2): Context Vector







$$a_{ij} = \text{softmax}(f_{\text{att}}(\mathbf{s}_{i-1}, \mathbf{h}_j))$$

	My	name	is	Sam	encoder
၁၀					
၁၁					
၁၂					
decoder					

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## Type of Attention mechanisms

(Remember that there are many variants of attention function  $f_{\text{attn}}$ )

**Additive attention:** The original attention mechanism (Bahdanau et al., 2015) uses a one-hidden layer feed-forward network to calculate the attention alignment:

$$f_{\text{attn}}(\mathbf{s}_{i-1}, \mathbf{h}_j) = \tanh(\mathbf{W}_a[\mathbf{s}_{i-1}; \mathbf{h}_j])$$

**Multiplicative attention:** Multiplicative attention (Luong et al., 2015) simplifies the attention operation by calculating the following function:

$$f_{\text{attn}}(\mathbf{s}_{i-1}, \mathbf{h}_j) = \mathbf{s}_{i-1}^\top \mathbf{W}_a \mathbf{h}_j$$

**Self-attention:** Without any additional information, however, we can still extract relevant aspects from the sentence by allowing it to attend to itself using self-attention (Lin et al., 2017)

$$\mathbf{a} = \text{softmax}(\mathbf{w}_{s_2} \tanh(\mathbf{W}_{s_1} \mathbf{H}^T))$$

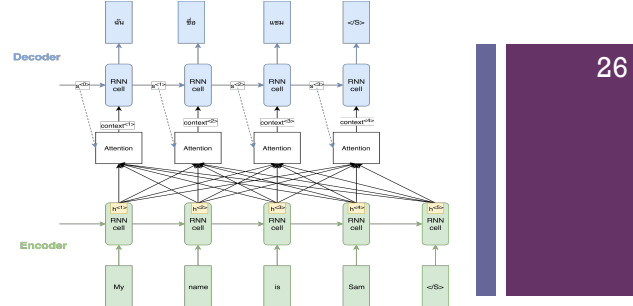
**Key-value attention:** key-value attention (Daniluk et al., 2017) is a recent attention variant that separates form from function by keeping separate vectors for the attention calculation.

+

$$a_{ij} = \text{softmax}(f_{att}(\mathbf{s}_{i-1}, \mathbf{h}_j))$$

# 1) Additive Attention

	My	name	is	Sam	encoder
$\mathbf{s}_0$					
$\mathbf{s}_1$					
$\mathbf{s}_2$					
decoder					



- The original attention mechanism (Bahdanau et al., 2015) uses a **one-hidden layer feed-forward network** to calculate the attention alignment:

$$f_{attn}(\mathbf{s}_{i-1}, \mathbf{h}_j) = \tanh(\mathbf{W}_a[\mathbf{s}_{i-1}; \mathbf{h}_j])$$

concatenation  
One-hidden layer  
(Dense)

- Where  $\mathbf{W}_a$  are learned attention parameters. Analogously, we can also use matrices  $\mathbf{W}_1$  and  $\mathbf{W}_2$  to learn separate transformations for  $\mathbf{s}_{i-1}$  and  $\mathbf{h}_j$  respectively, which are then summed (hence the name **additive**):

$$f_{attn}(\mathbf{s}_{i-1}, \mathbf{h}_j) = \tanh(\mathbf{W}_1\mathbf{s}_{i-1} + \mathbf{W}_2\mathbf{h}_j)$$

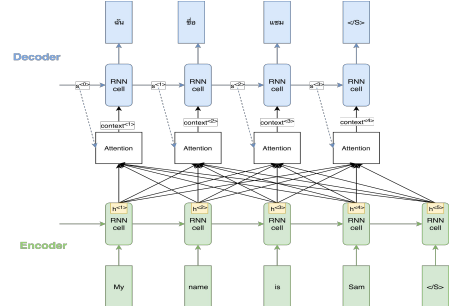
Reference: <https://lilianweng.github.io/posts/2018-06-24-attention/>

+

$$a_{ij} = \text{softmax}(f_{att}(\mathbf{s}_{i-1}, \mathbf{h}_j))$$

## 2) Multiplicative Attention

	My	name	is	Sam	encoder
ฉัน					
ชื่อ					
ของ					
ใคร					
decoder					



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- Multiplicative attention (Luong et al., 2015) [16] **simplifies** the attention operation by calculating the following function:

$$f_{attn}(\mathbf{s}_{i-1}, \mathbf{h}_j) = \mathbf{s}_{i-1}^\top \mathbf{W}_a \mathbf{h}_j$$

- Faster**, more efficient than additive attention **BUT additive attention performs better** for larger dimensions

- One way to mitigate this is to scale  $f_{attn}$  by  $\frac{1}{\sqrt{d_s}}$

$d_s$  = #dimensions of hidden states in LSTM  
(context vector; latent factors)

- Dot product of high dimensional vectors has high variance -> softmax is peaky -> small gradient -> harder to train

+

$$a_{ij} = \text{softmax}(f_{\text{att}}(\mathbf{s}_{i-1}, \mathbf{h}_j))$$

### 3) Self Attention (1)

	My	name	is	Sam	encoder
ฉัน					
ชื่อ					
นาม					
decoder					

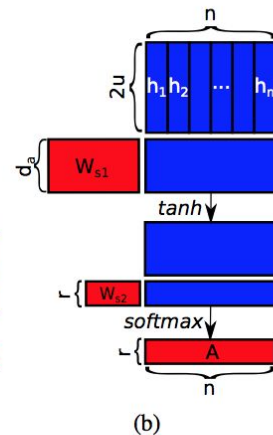
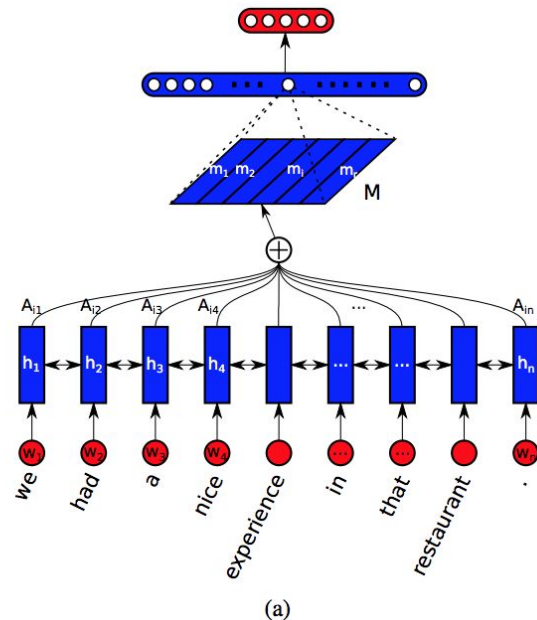
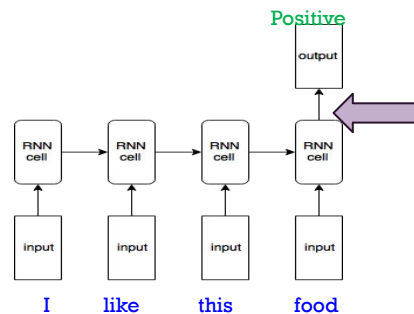
- Without any additional information, we can still extract relevant aspects from the sentence by allowing it to attend to itself using self-attention (Lin et al., 2017)

$$H = (\mathbf{h}_1, \mathbf{h}_2, \dots, \mathbf{h}_n)$$

Fully connected layer

$$\mathbf{a} = \text{softmax}(\mathbf{w}_{s_2} \underbrace{\tanh(\mathbf{W}_{s_1} \mathbf{H}^T)}_{\text{One-hidden layer (Dense)}})$$

- $\mathbf{w}_{s_1}$  is a weight matrix,  $\mathbf{w}_{s_2}$  is a vector of parameters. Note that these parameters are tuned by the neural networks.
- The objective is to improve a quality of embedding vector by adding context information.





## Self-attention (2)

- if I can give this restaurant **a 0** I will be just ask our waitress leave because someone with a reservation be wait for our table my father and father-in-law be still finish up their coffee and we have not yet finish our dessert I have never be so humiliated do not go to this restaurant their food **be mediocre at best** if you want excellent Italian in a small intimate restaurant go to dish on the South Side I will not be go back
- **this place suck the food be gross and taste like grease** I will never go here again ever sure the entrance look cool and the waiter can be very nice but the food simply be gross taste like cheap 99cent food do not go here the food shot out of me quick then it go in
- **everything be pre cook and dry its crazy most** Filipino people be used to very cheap ingredient and they do not know quality the food **be disgusting** I have eat at least 20 different Filipino family home this not **even mediocre**
- **seriously f \*\*\* this place disgust food and shitty service** ambience be great if you like dine in a hot cellar engulf in stagnate air truly it be over rate over price and they just under deliver forget try order a drink here it will take forever get and when it finally do arrive you will be ready pass out from heat exhaustion and lack of oxygen how be that a head change you do not even have pay for it I will not disgust you with the detailed review of everything I have try here but make it simple it all suck and after you get the bill you will be walk out with a sore ass save your money and spare your self **the disappointment**
- **i be so angry about my horrible experience** at Medusa today my previous visit be amaze 5/5 however my go to out of town and I land an appointment with Stephanie I go in with a picture of roughly what I want and come out look absolutely nothing like it my hair be **a horrible ashy** blonde not anywhere close to the platinum blonde I request she will not do any of the pop of colour I want and even after specifically tell her I do not like blunt cut my hair have lot of straight edge she do not listen to a single thing I want and when I tell her I be unhappy with the colour she basically tell me I be wrong and I have do it this way no no I do not if I can go from Little Mermaid red to golden blonde in 1 sitting that leave my hair fine I shall be able go from golden blonde to a shade of platinum blonde in 1 sitting thanks for ruin my New Year's with 1 **the bad hair job** I have ever have

### (a) 1 star reviews

- **I really enjoy** Ashley and Ami salon she do a great job be friendly and professional I usually get my hair do when I go to MI because of the quality of the highlight and the price the price be **very affordable the highlight fantastic** thank Ashley i highly recommend you and ill be back
- **love this place it really be my favorite restaurant** in Charlotte they use charcoal for their grill and you can taste it steak with chimichurri be always perfect Fried yucca cilantro rice pork sandwich and **the good tres lech** I have had.The desert be **all incredible if** you do not like it you be a mutant if you will like diabeetus try the Inca Cola
- this place be **so much fun** I have never go at night because it seem a little too busy for my taste but that just prove how great this restaurant be they have amazing food and the staff definitely remember us every time we be in town I love when a waitress or waiter come over and ask if you want the cab or the Pinot even when there be a rush and the staff be run around like crazy whenever I grab someone they instantly smile acknowledge us the food be also killer I love when everyone know the special and can tell you they have try them all and what they pair well with this be a first last stop whenever we be in Charlotte and I highly recommend them
- **great food and good service** .... what else can you ask for everything that I have ever try here have be great
- first off I hardly remember waiter name because its rare you have an unforgettable experience the day I go I be celebrate my birthday and let me say I leave feel extra special our waiter be the best ever Carlos and the staff as well I be with a party of 4 and we order the potato salad shrimp cocktail lobster amongst other thing and boy be the food great the lobster be **the good lobster** I have ever eat if you eat a dessert I will recommend the cheese cake that be also the good I have ever have it be expensive but **so worth every penny** I will definitely be back there go again for the second time in a week and it be **even good .....** this place **be amazing**

### (b) 5 star reviews

Figure 2: Heatmap of Yelp reviews with the two extreme score.

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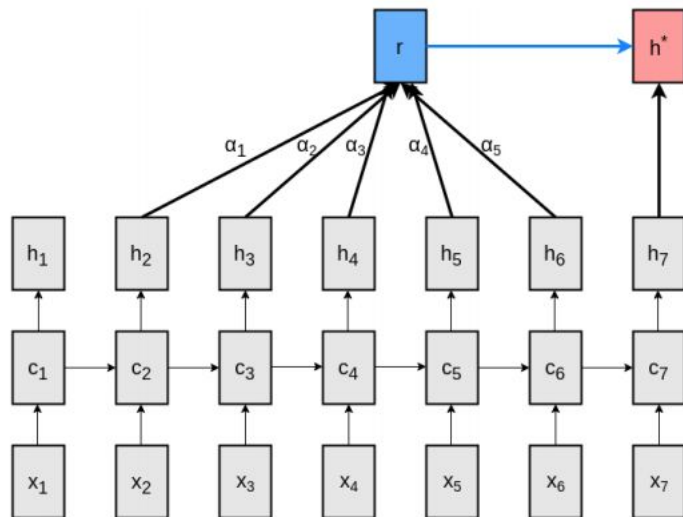
$$a_{ij} = \text{softmax}(f_{\text{att}}(\mathbf{s}_{i-1}, \mathbf{h}_j))$$

#### 4) Key-value attention (1)

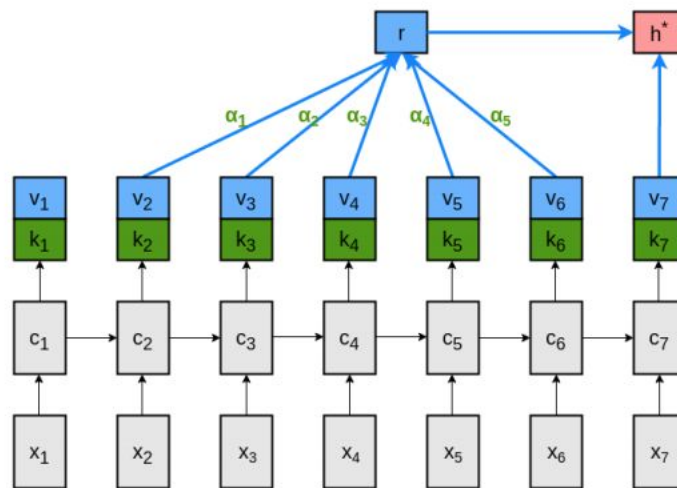
$$\mathbf{c}_i = \sum_j a_{ij} \mathbf{h}_j$$

search    value

30



(a) Neural language model with attention.

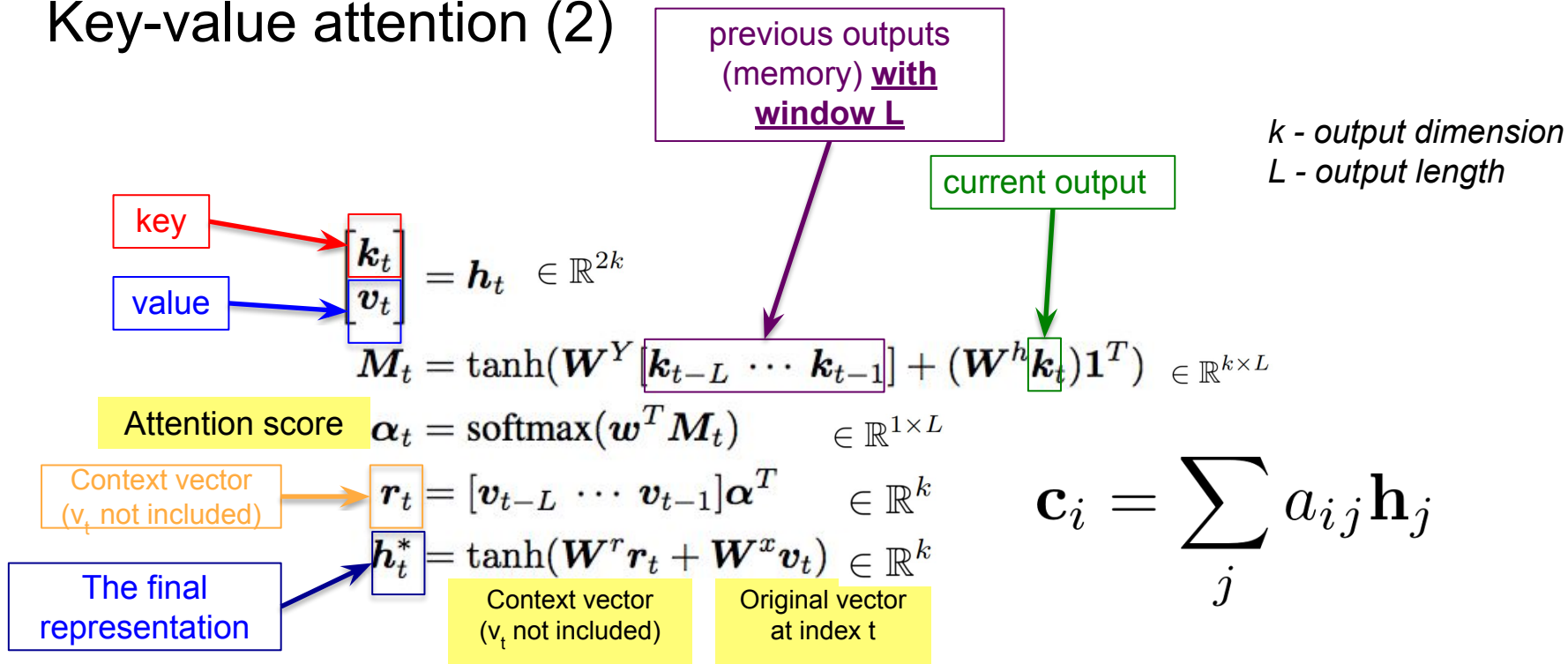


(b) Key-value separation.

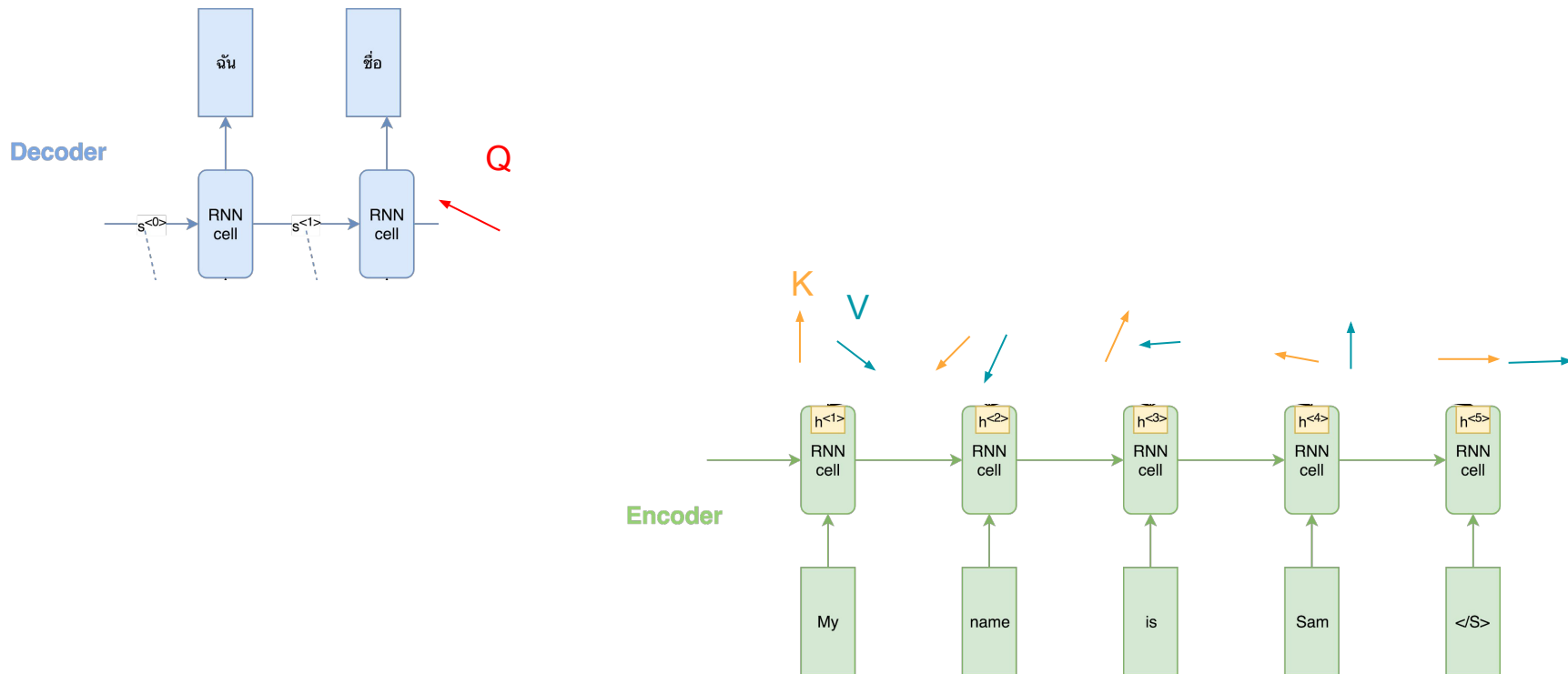
Value=encoded vector  
Key=used for attention score calculation

Reference: Daniluk, M., Rockt, T., Welbl, J., & Riedel, S. (2017). Frustratingly Short Attention Spans in Neural Language Modeling. In ICLR 2017.

## Key-value attention (2)



# Pictorial view of KV attention



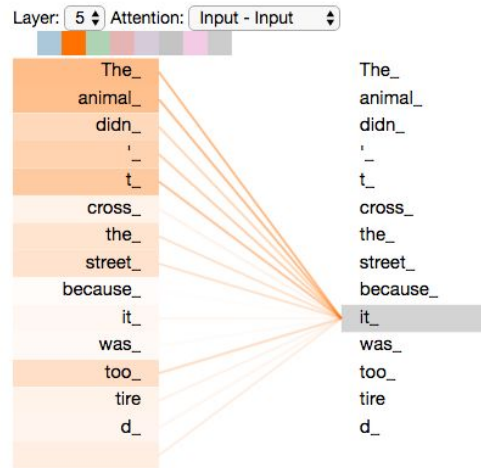


# Scaled Dot-Product Attention (1)

- Introduced in Attention is all you need (Vaswani et al., 2017)
- **NO** recurrence nor convolution
- Widely used today in all Transformer-based model
- “Relating different positions of a single sequence in order to compute a representation of the sequence”

$$\text{Attention}(Q, K, V) = \text{softmax}\left(\frac{QK^T}{\sqrt{d_k}}\right)V$$

where the query, keys, values, and output are all vectors  
and  $d_k$  is a number.





# Scaled Dot-Product Attention (2)

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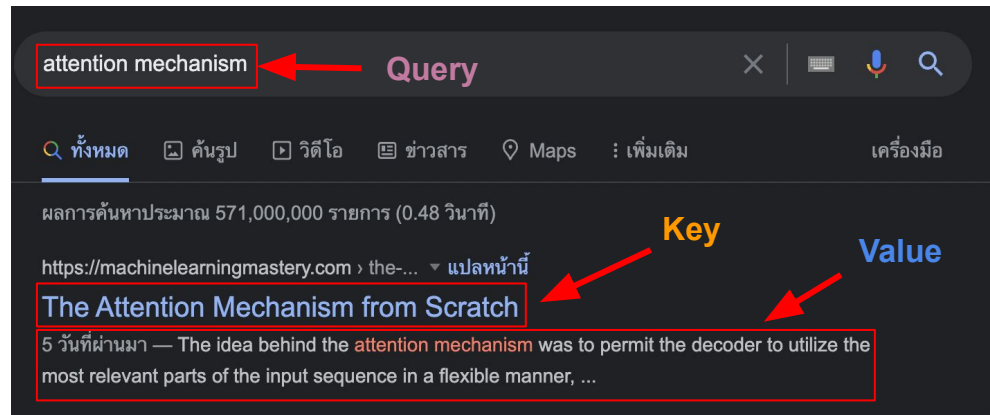
What are the “query”, “key”, and “value” vectors?

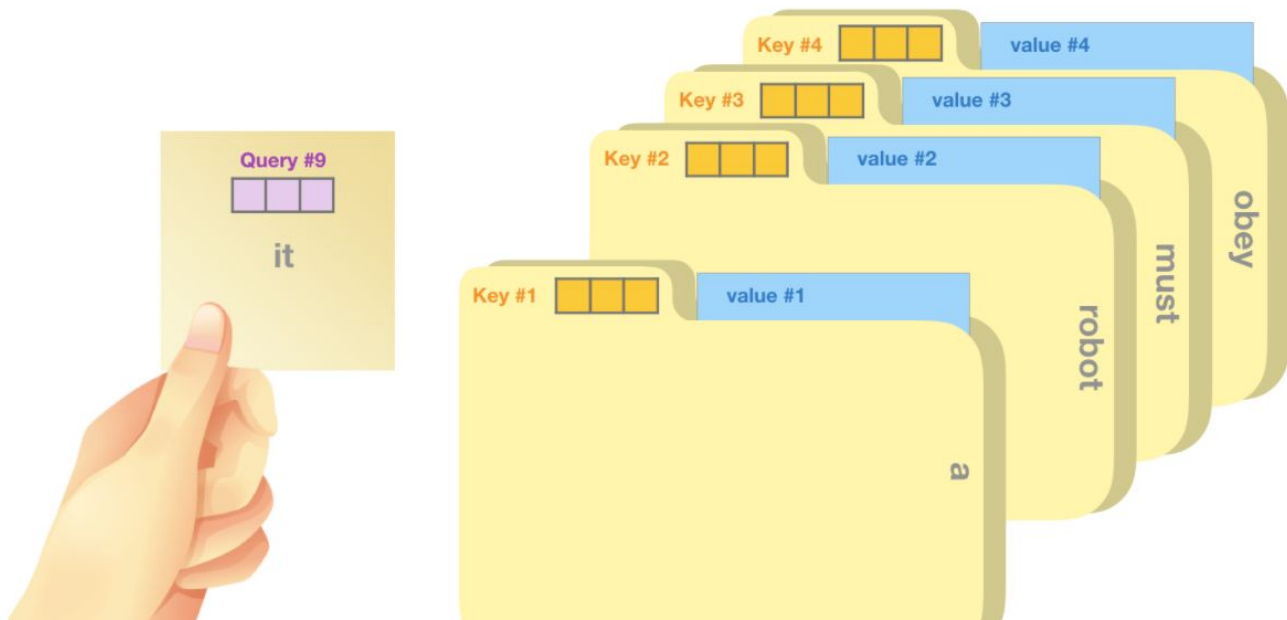
As an analogy, think of Google Search.

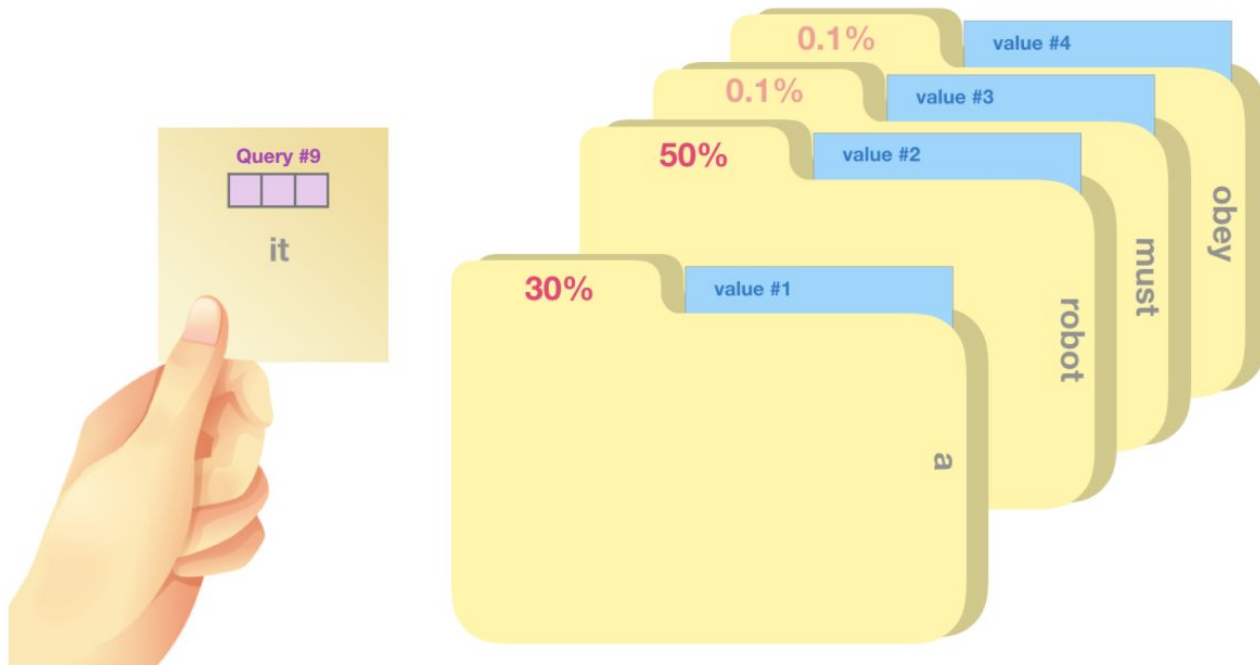
Query - what we want to know

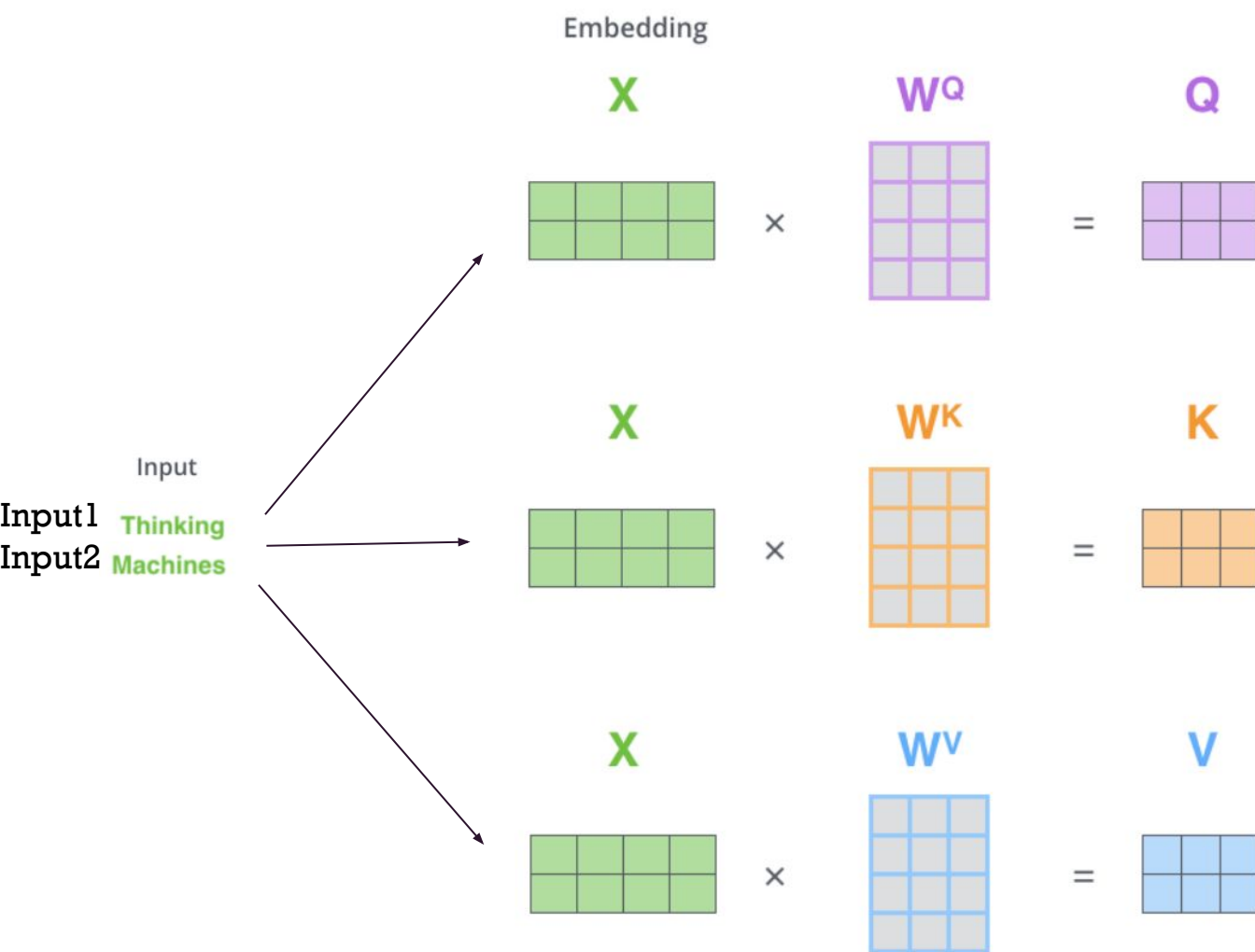
Key - how to index information

Value - what kind of info is in each website









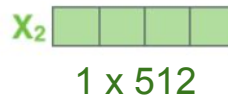
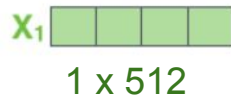
$W^Q$ ,  $W^K$ , and  $W^V$  are linear layers

Input

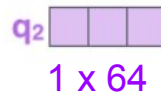
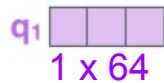
Thinking

Machines

Embedding

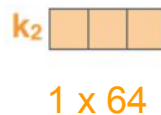
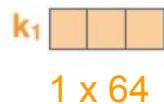


Queries



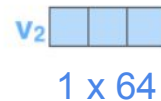
$W^Q$

Keys



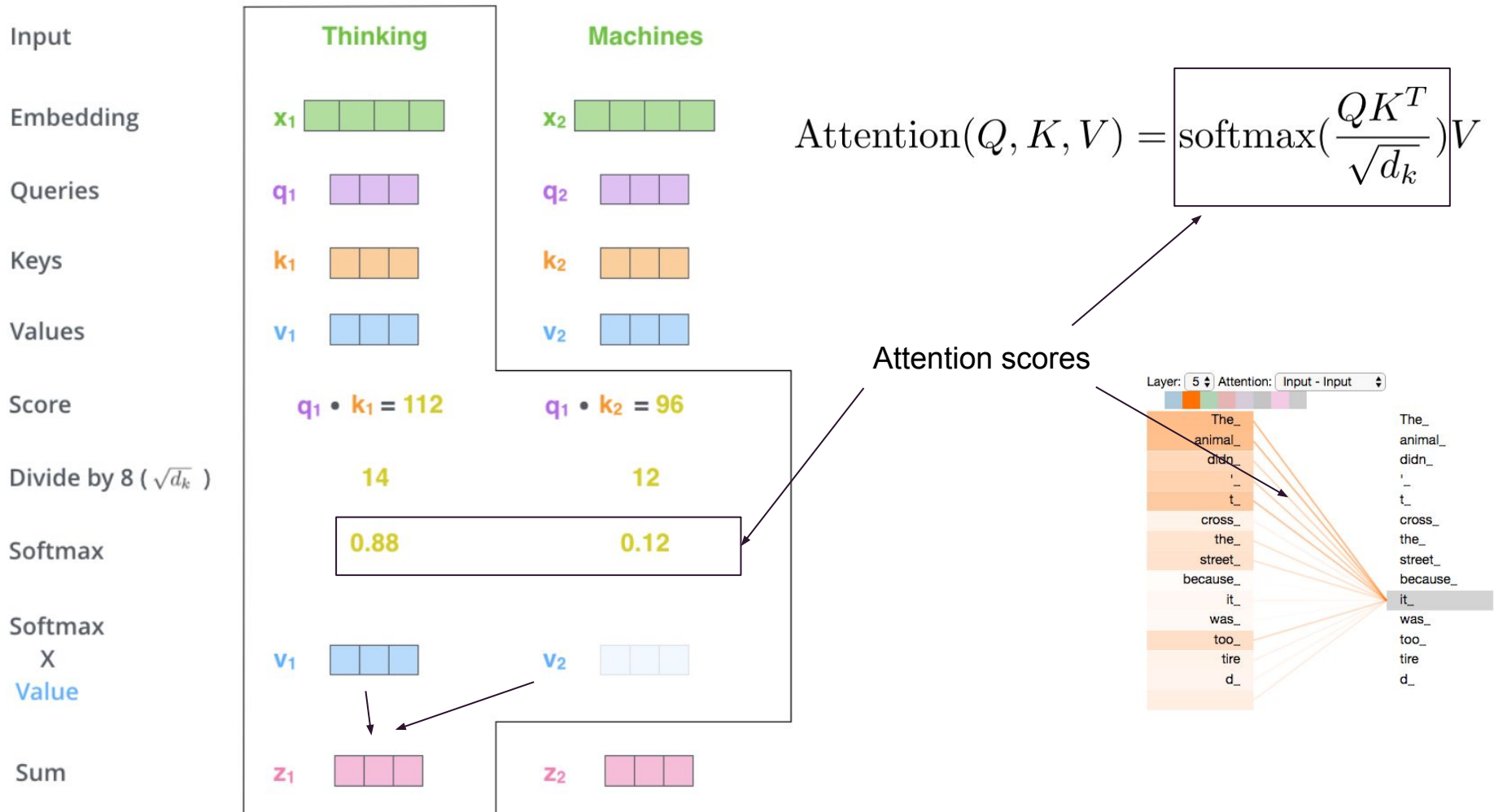
$W^K$

Values

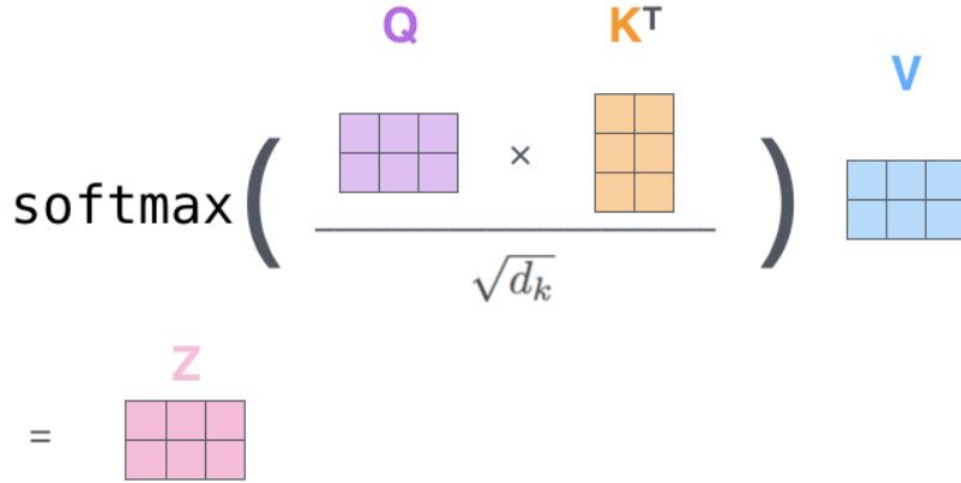


$W^V$

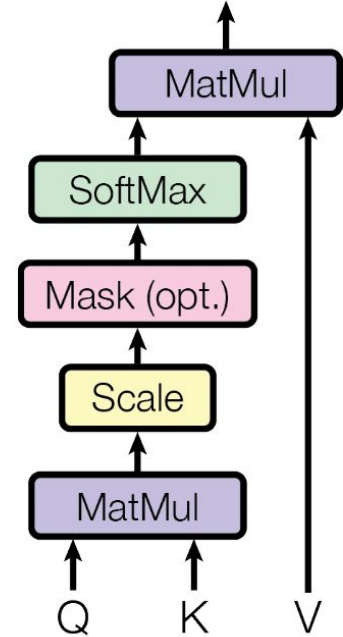
Multiplying  $x_1$  by the  $W^Q$  weight matrix produces  $q_1$ , the "query" vector associated with that word. We end up creating a "query", a "key", and a "value" projection of each word in the input sentence.



$$\text{Attention}(Q, K, V) = \text{softmax}\left(\frac{QK^T}{\sqrt{d_k}}\right)V$$



## Scaled Dot-Product Attention







## Demo2: Neural Machine Translation with Attention (Additive Attention)

- Translate: various date formats to ISO date format

- 27 January 2018                      2018-01-27

- 27 JAN 2018                            2018-01-27



## Homework 3.1: Neural Machine Translation with Attention (Key-Value Attention)

- Translate: Thai name to English name

ไกรสิทธิ์ kraisi  
พัชรี phatri  
ธีระ thira  
วุฒิกร wutthikon  
ไสว sawai  
สัมภาษณ์ samphat  
วสิน wasin  
ทินวัฒน์ thinwat  
ศักดิ์นัย sakdinai  
สุรศักดิ์ surasak