Machine Learning I
MATH80629A

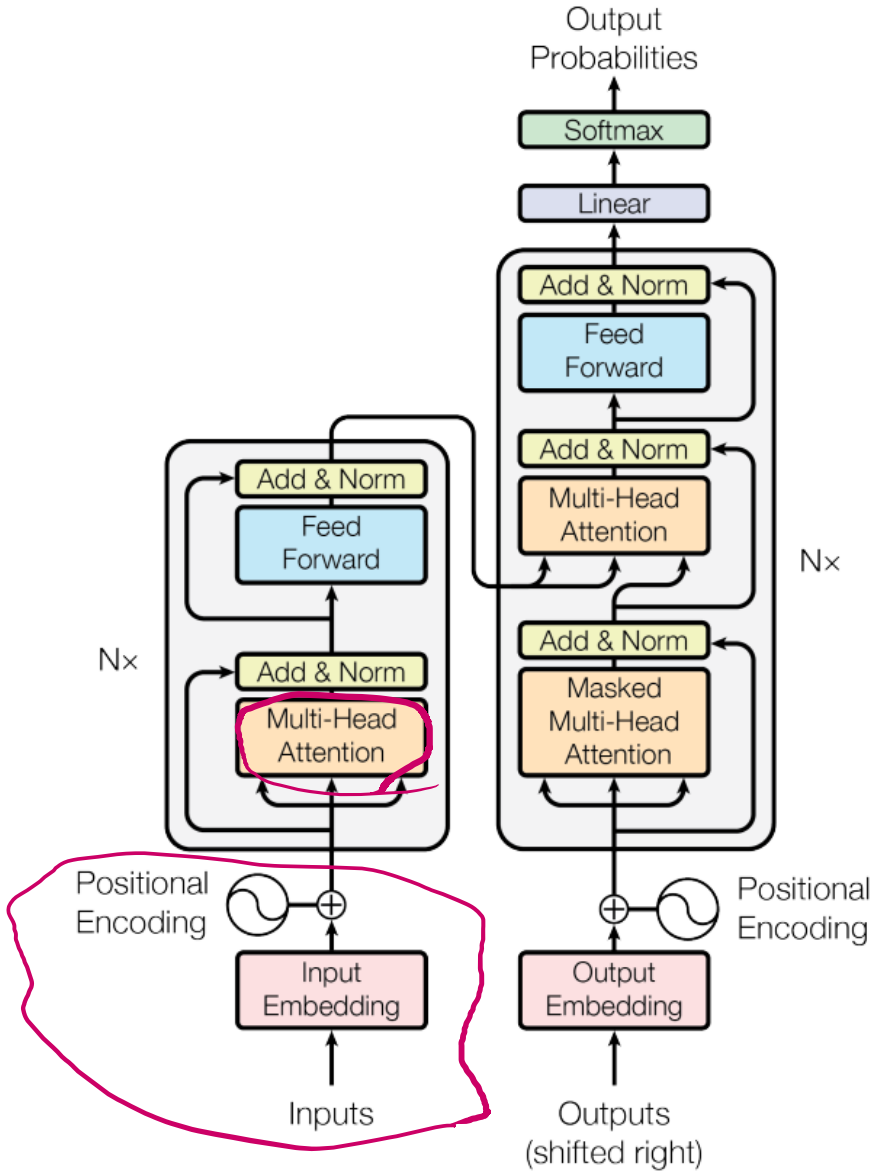
Apprentissage Automatique I
MATH80629

Attention and Transformers
— Week #6

Transformers

The architecture

Transformers

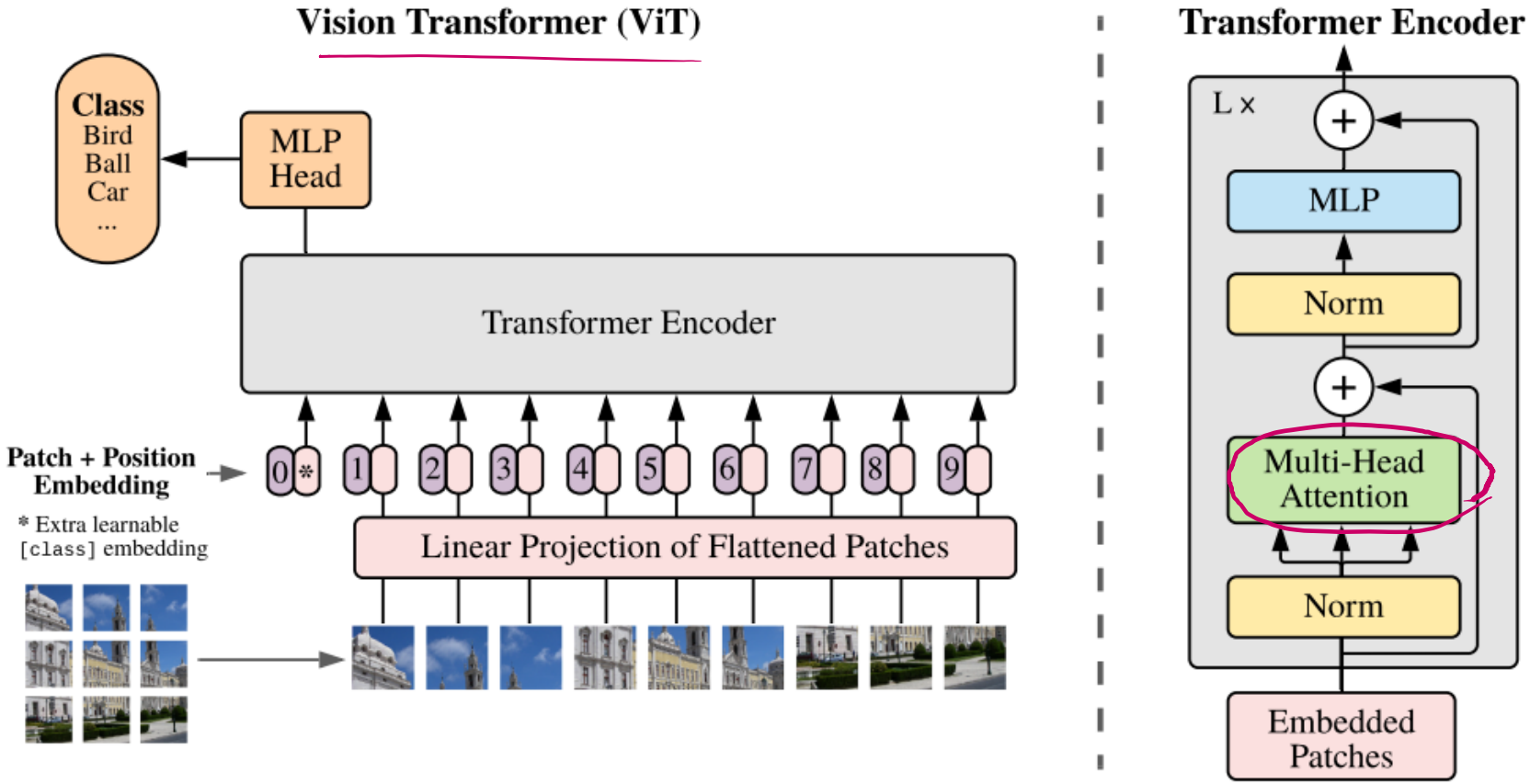


Vaswani, Ashish, et al. "Attention is all you need." Advances in neural information processing systems 30 (2017).

Transformers

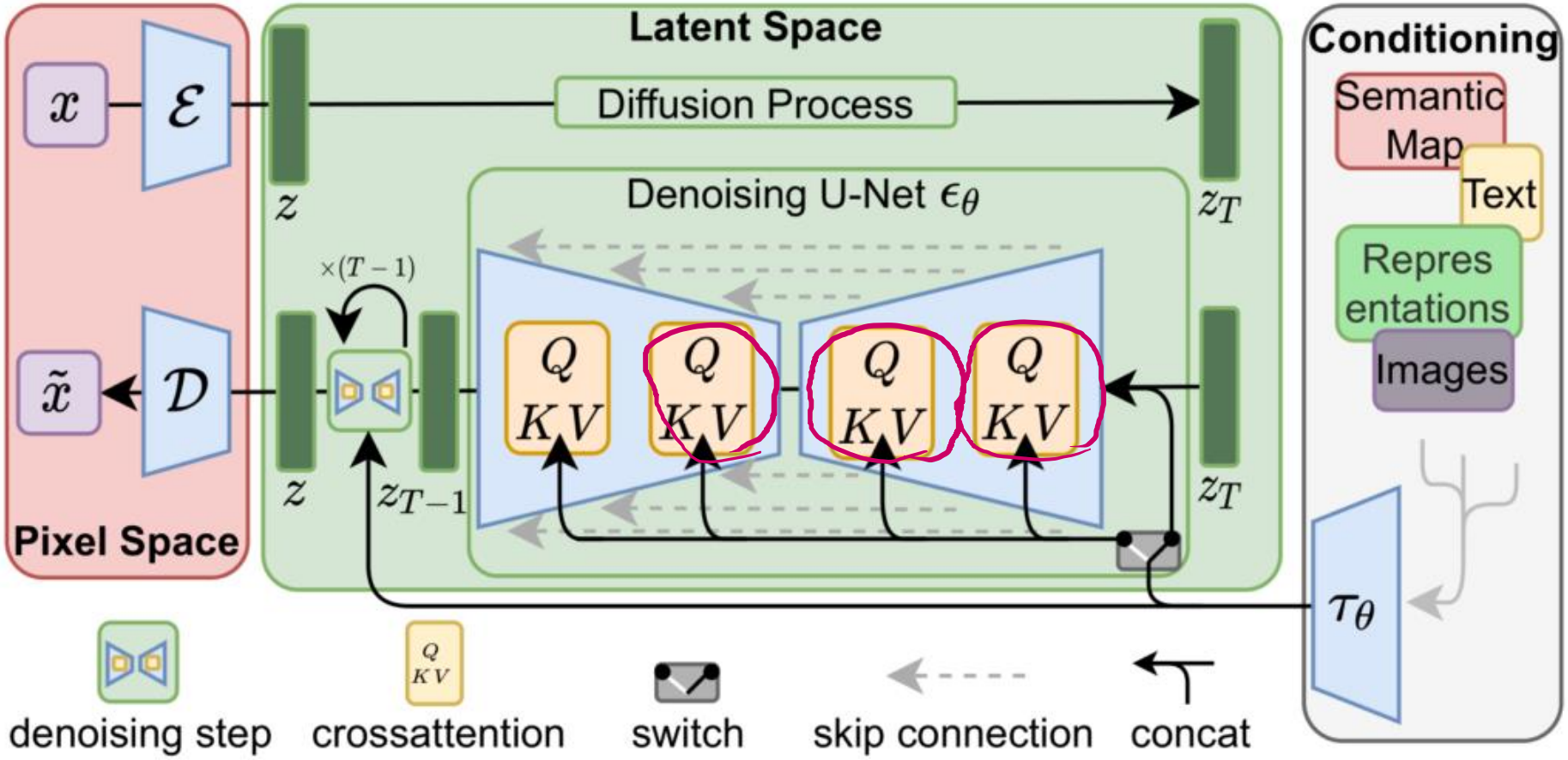
Applications

Vision Transformers



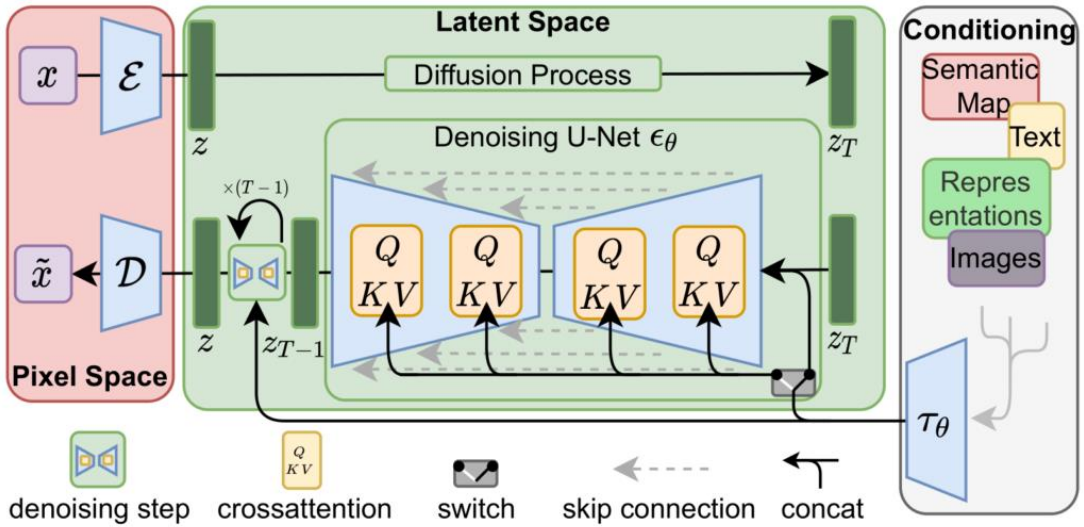
Dosovitskiy, Alexey, et al. "An image is worth 16x16 words: Transformers for image recognition at scale." *arXiv preprint arXiv:2010.11929* (2020).

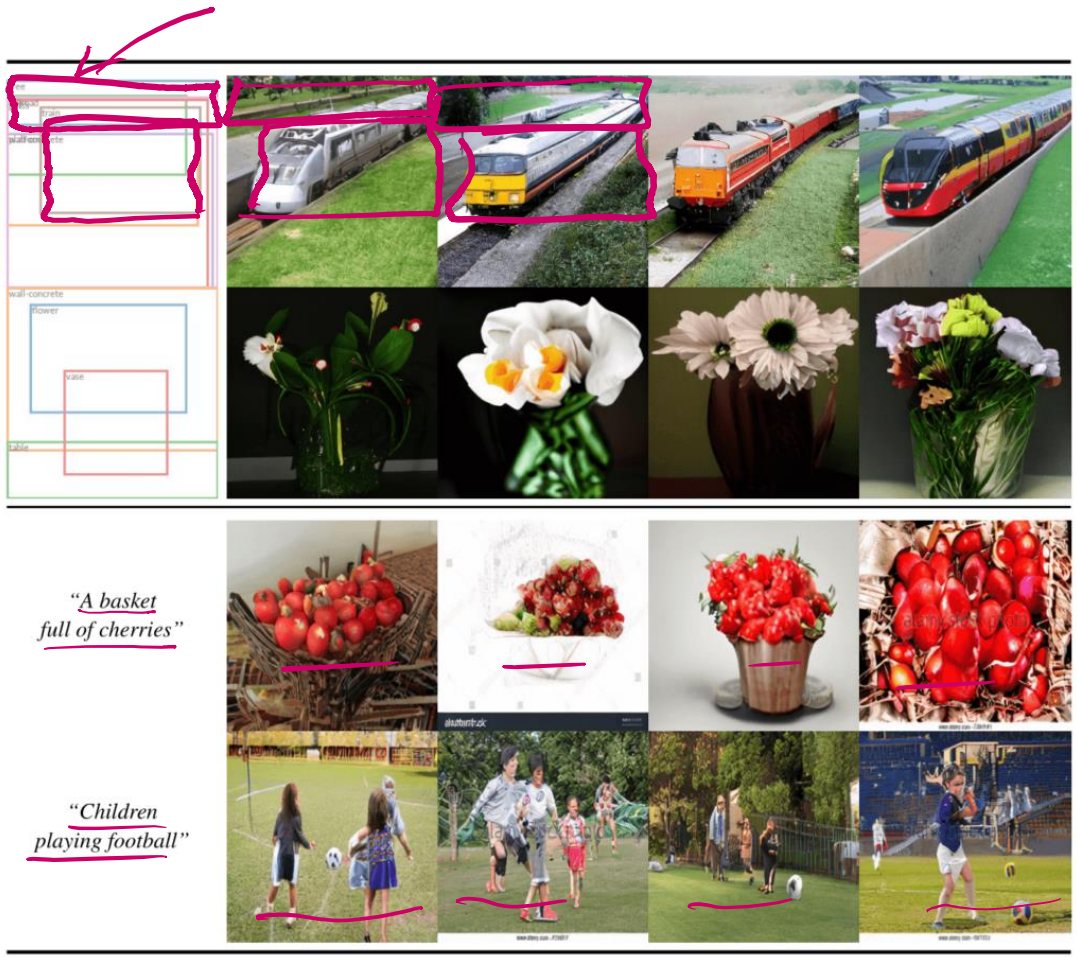
Stable diffusion



Rombach, Robin, et al. "High-resolution image synthesis with latent diffusion models." *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*. 2022.

Stable diffusion





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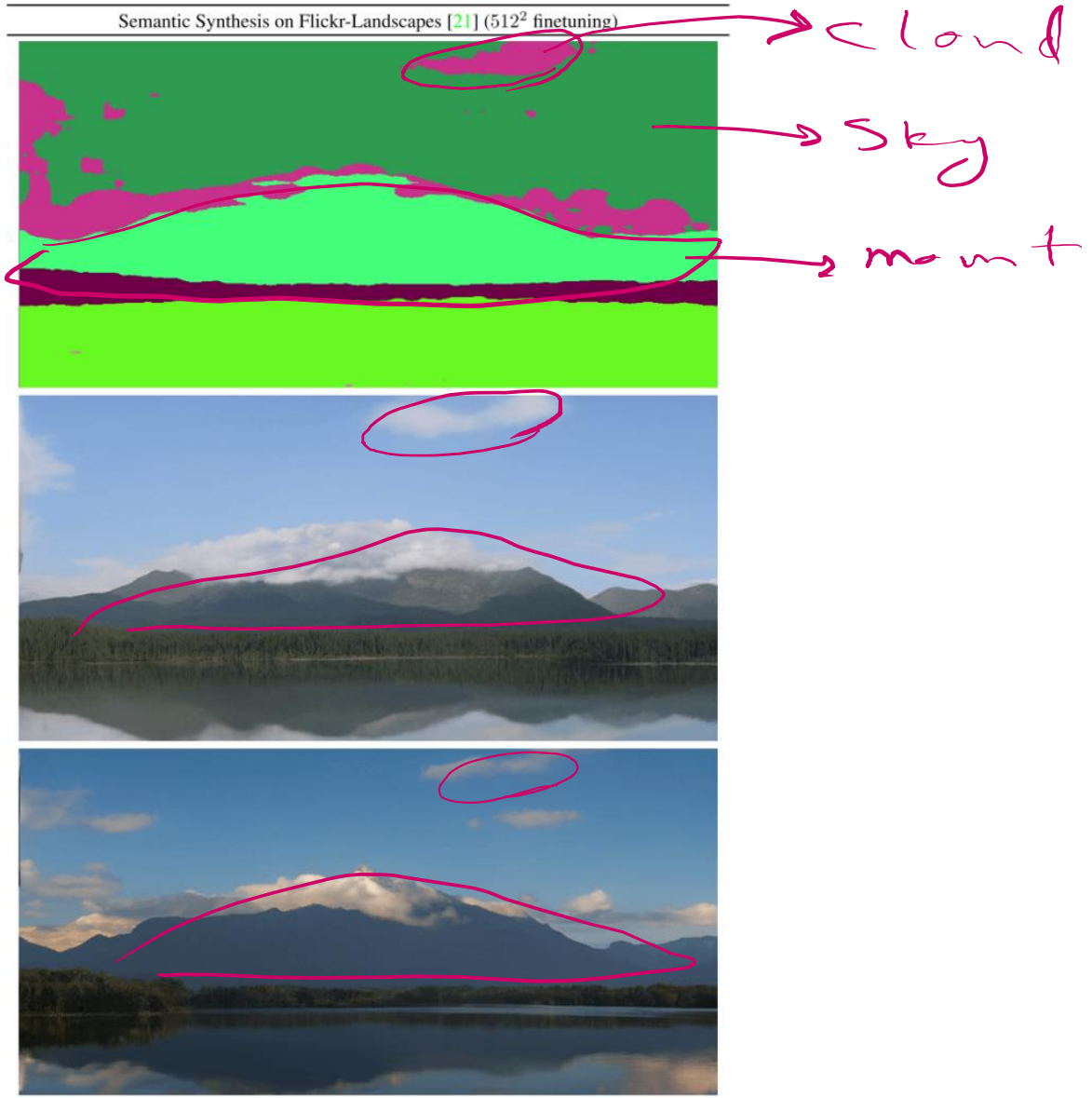
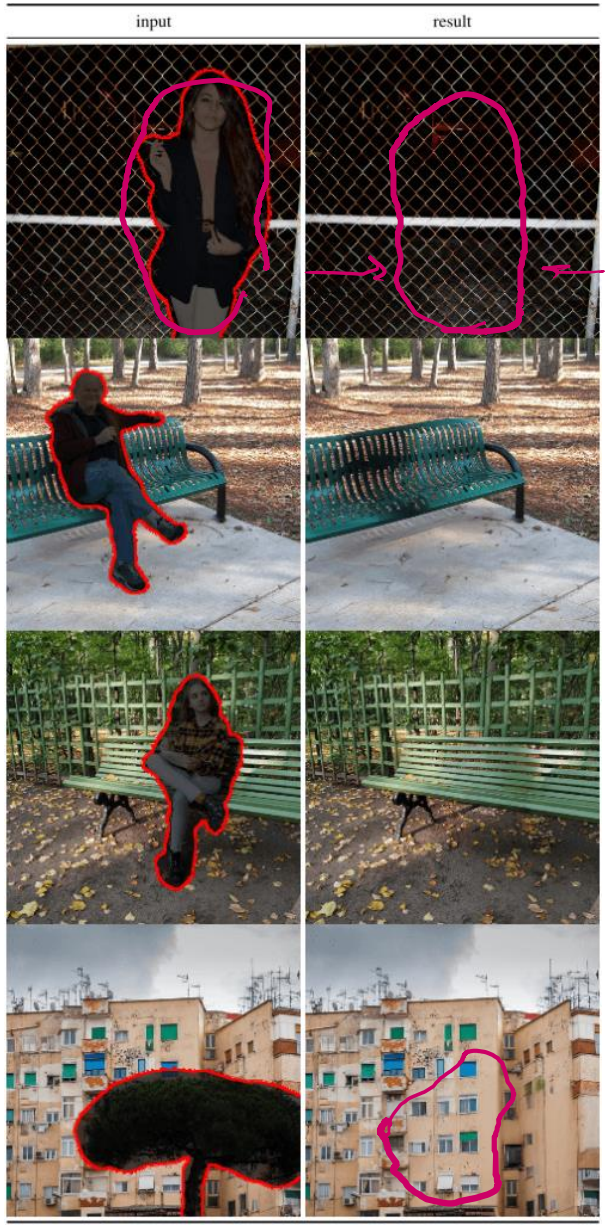
Stable diffusion



Rombach, Robin, et al. "High-resolution image synthesis with latent diffusion models." *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*. 2022.

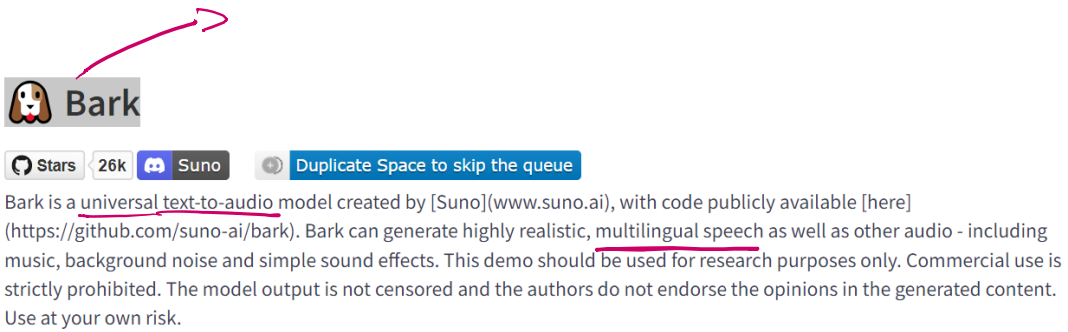
Stable diffusion

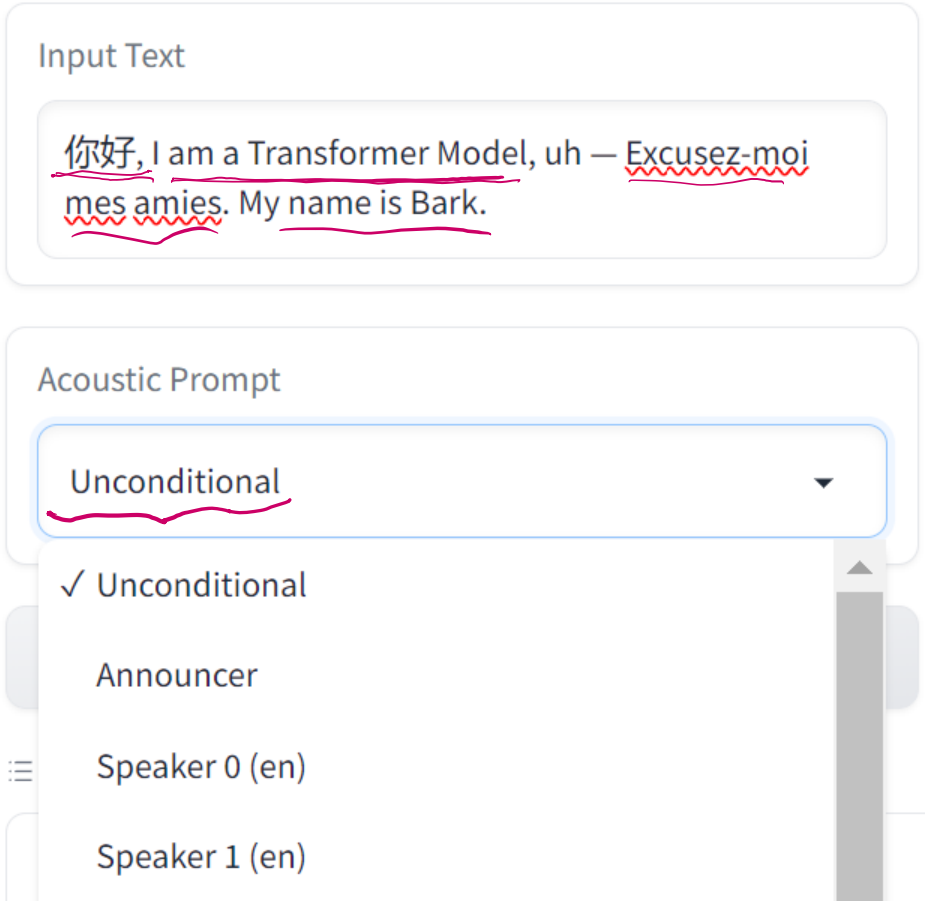
in-painting



Rombach, Robin, et al. "High-resolution image synthesis with latent diffusion models." *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*. 2022.

Speech



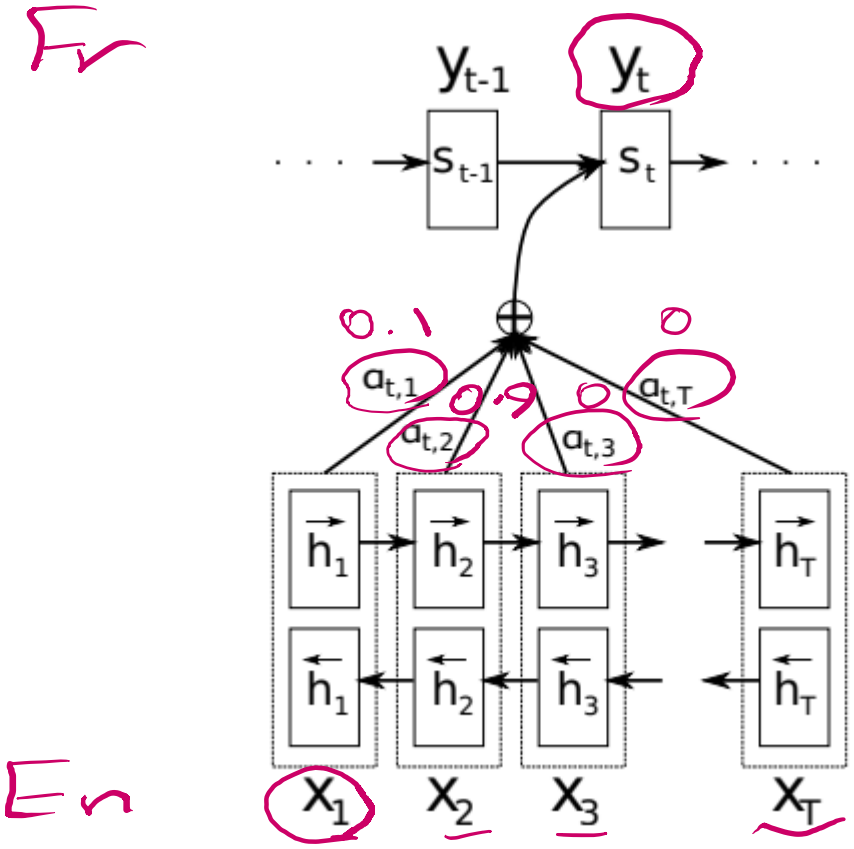


https://github.com/suno-ai/bark

History

Attention layers to Transformers

Attention and RNNs



Bahdanau, Dzmitry, Kyunghyun Cho, and Yoshua Bengio. "Neural machine translation by jointly learning to align and translate." *arXiv preprint arXiv:1409.0473* (2014).

Attention and RNNs

- RNN

LSTM

$$p(y_t \mid \{y_1, \cdots, y_{t-1}\}, c) = g(y_{t-1}, s_t, c),$$

context vector

single

hidden states

Bahdanau, Dzmitry, Kyunghyun Cho, and Yoshua Bengio. "Neural machine translation by jointly learning to align and translate." *arXiv preprint arXiv:1409.0473* (2014).

Attention and RNNs

- RNN

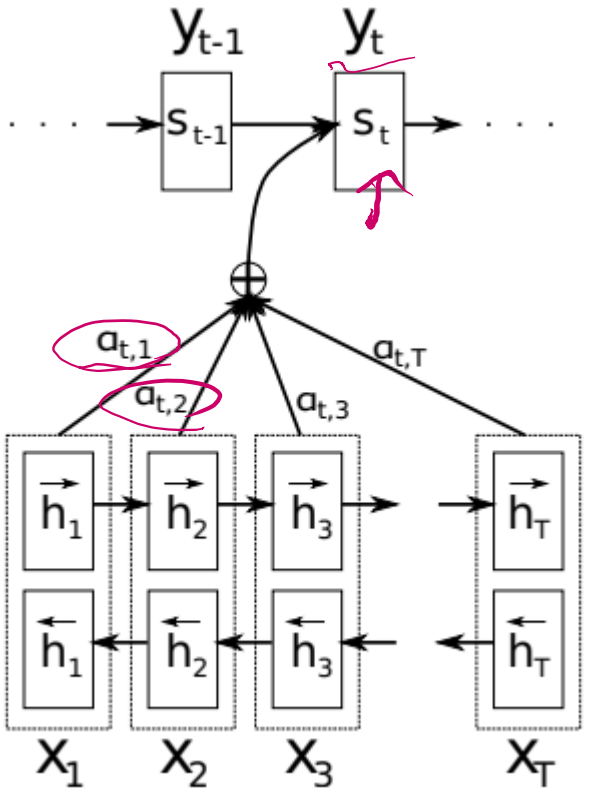
$$p(y_t \mid \{y_1, \cdots, y_{t-1}\}, c) = g(y_{t-1}, s_t, c),$$

- Self-attention + RNN

$$p(y_i|y_1, \ldots, y_{i-1}, \mathbf{x}) = g(y_{i-1}, s_i, c_i),$$

$$c_i = \sum_{j=1}^{T_x} \alpha_{ij} h_j.$$

$$\alpha_{ij} = \frac{\exp(e_{ij})}{\sum_{k=1}^{T_x} \exp(e_{ik})},$$



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Attention and RNNs

- RNN

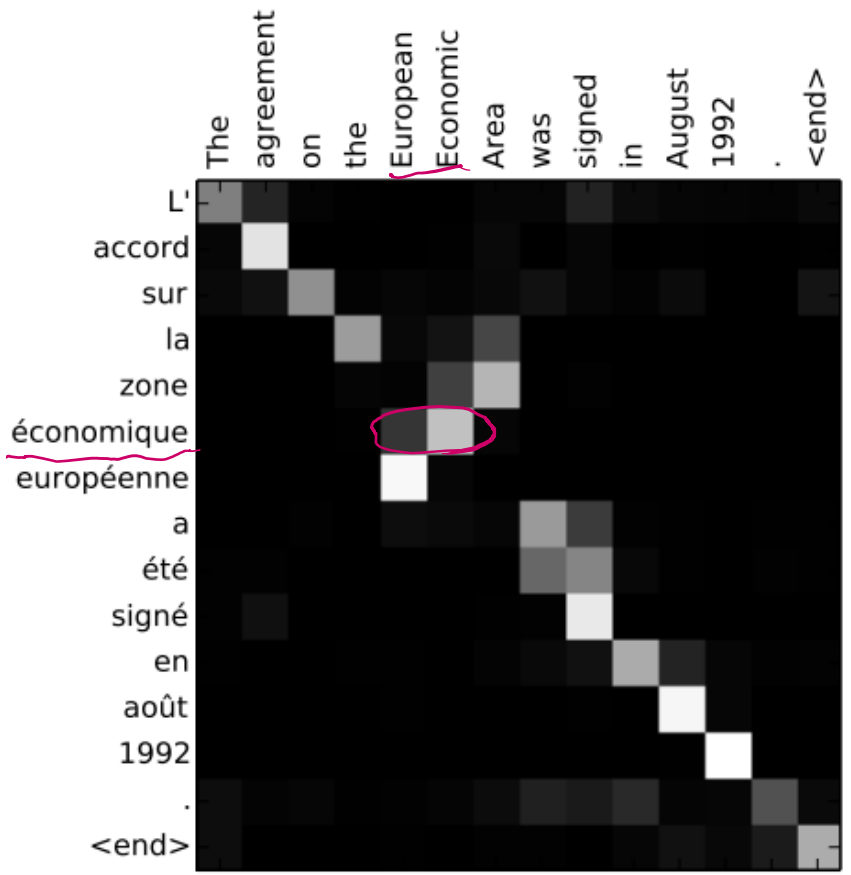
$$p(y_t \mid \{y_1, \cdots, y_{t-1}\}, c) = g(y_{t-1}, s_t, c),$$

- Self-attention + RNN

$$p(y_i|y_1, \ldots, y_{i-1}, \mathbf{x}) = g(y_{i-1}, s_i, c_i),$$

$$c_i = \sum_{j=1}^{T_x} \alpha_{ij} h_j.$$

$$\alpha_{ij} = \frac{\exp(e_{ij})}{\sum_{k=1}^{T_x} \exp(e_{ik})},$$



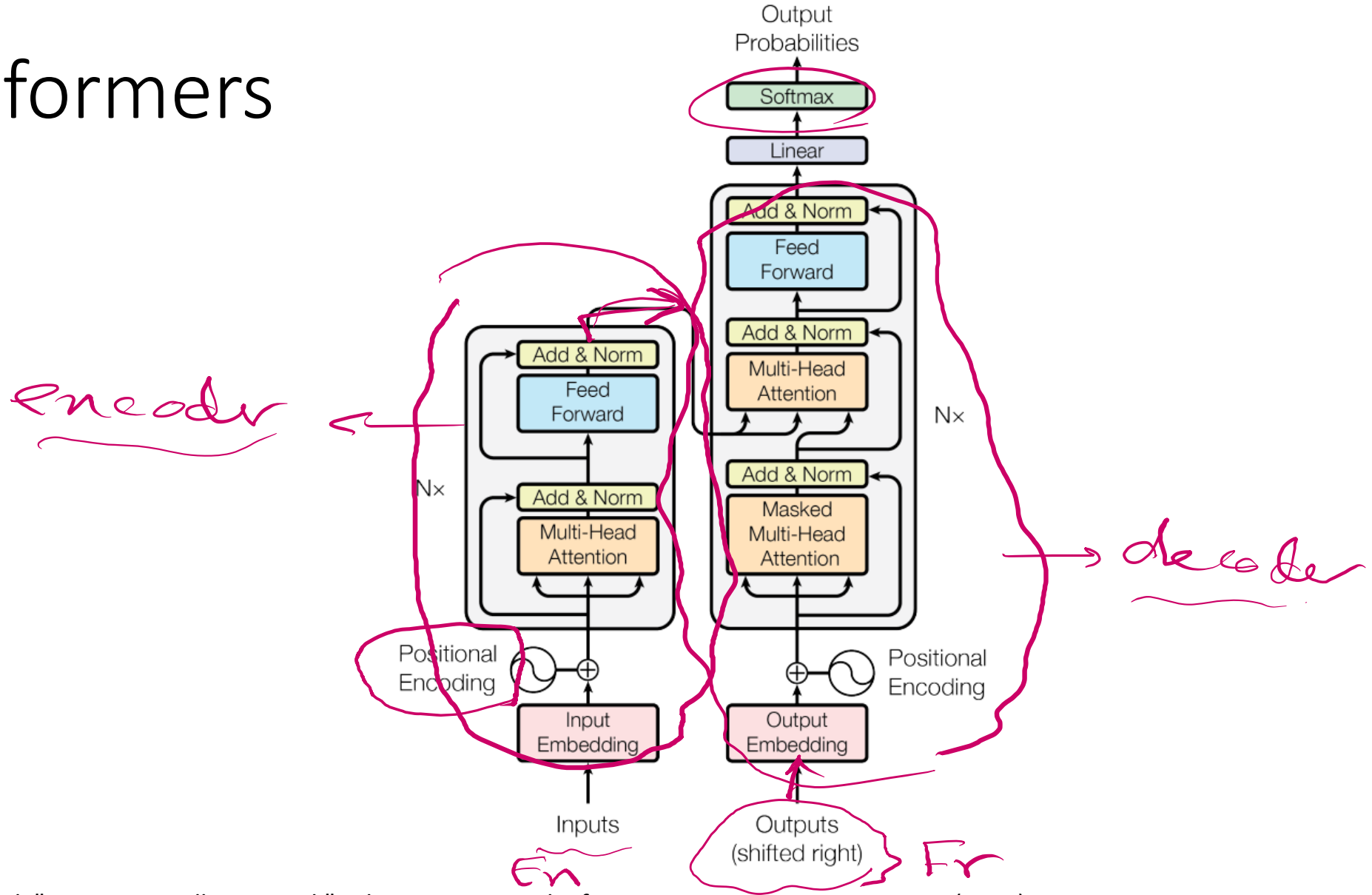
Bahdanau, Dzmitry, Kyunghyun Cho, and Yoshua Bengio. "Neural machine translation by jointly learning to align and translate." *arXiv preprint arXiv:1409.0473* (2014).

Attention and RNNs

- RNNs
  - Computation cost
  - Sequential (not parallel)
  - BPTT (retain computation graph)

- Alternative way to capture word dependency

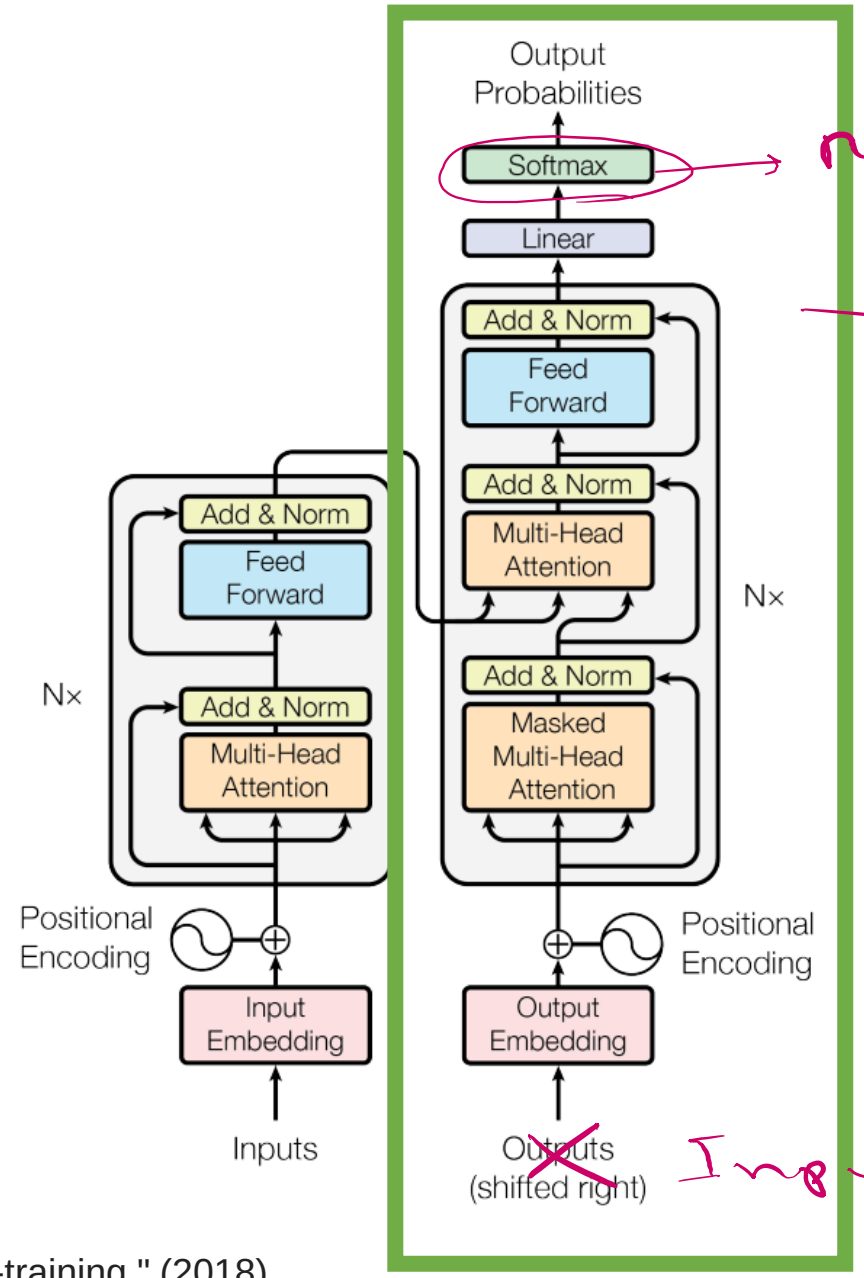
Transformers



Vaswani, Ashish, et al. "Attention is all you need." Advances in neural information processing systems 30 (2017).

GPT
(**G**enerative **P**re-**T**raining)

- Auto-regressive,
- Decoder language model



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GPT
(**G**enerative **P**re-**T**raining)

- Auto-regressive,
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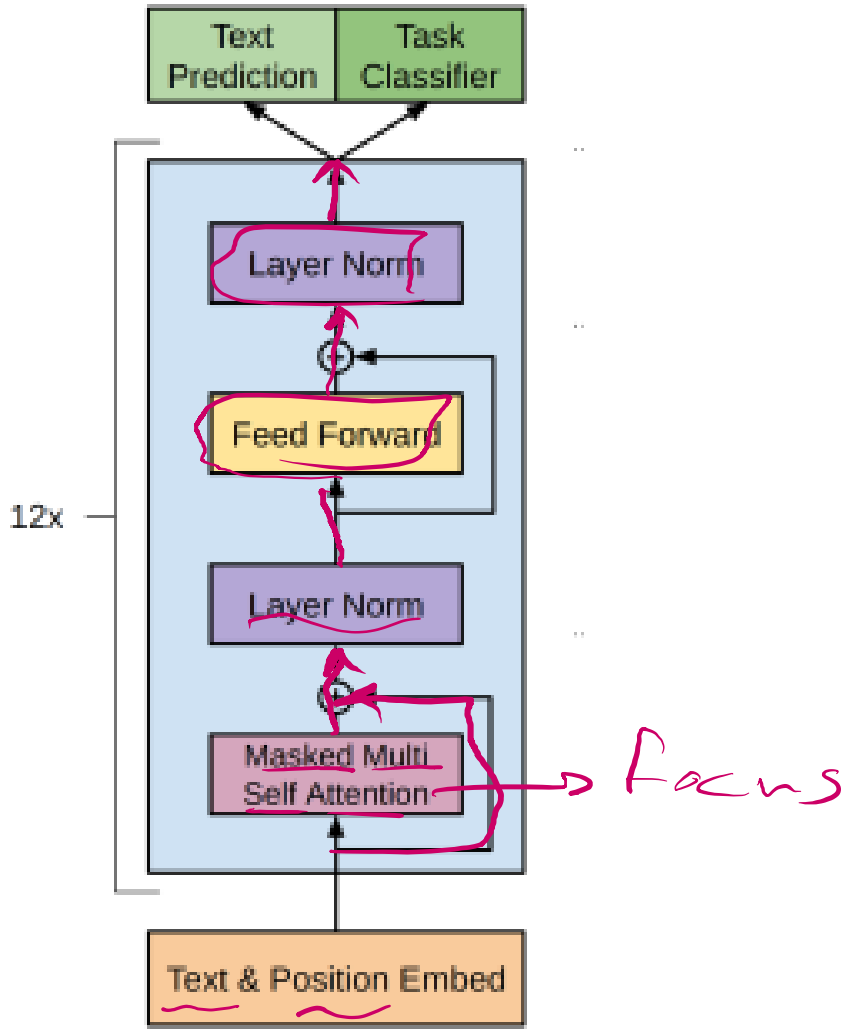
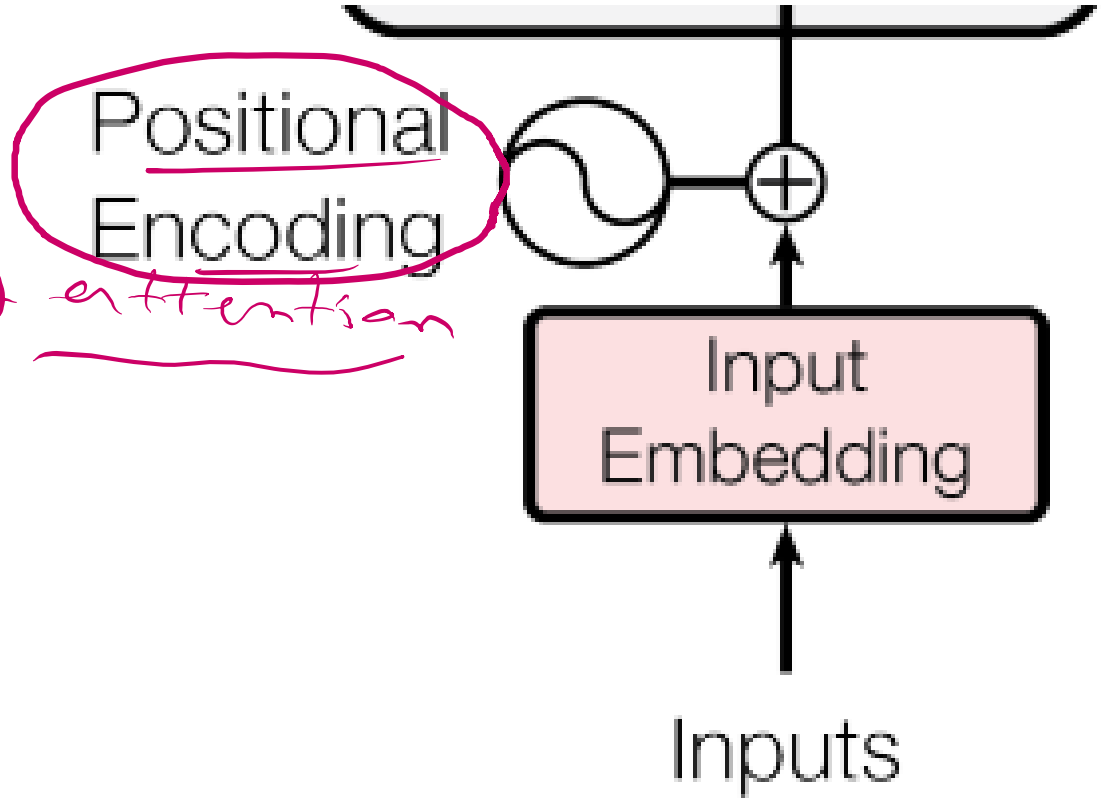


Radford, Alec, et al. "Improving language understanding by generative pre-training." (2018).

GPT

RNN → Fully attention



1	2	3
Answer	the	following

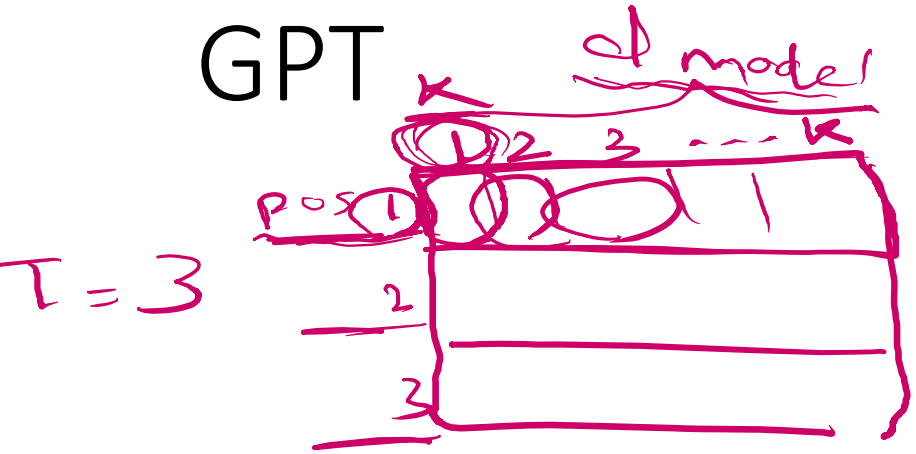
$T = 3$

1	2	3
the	following	question

$T' = 3$

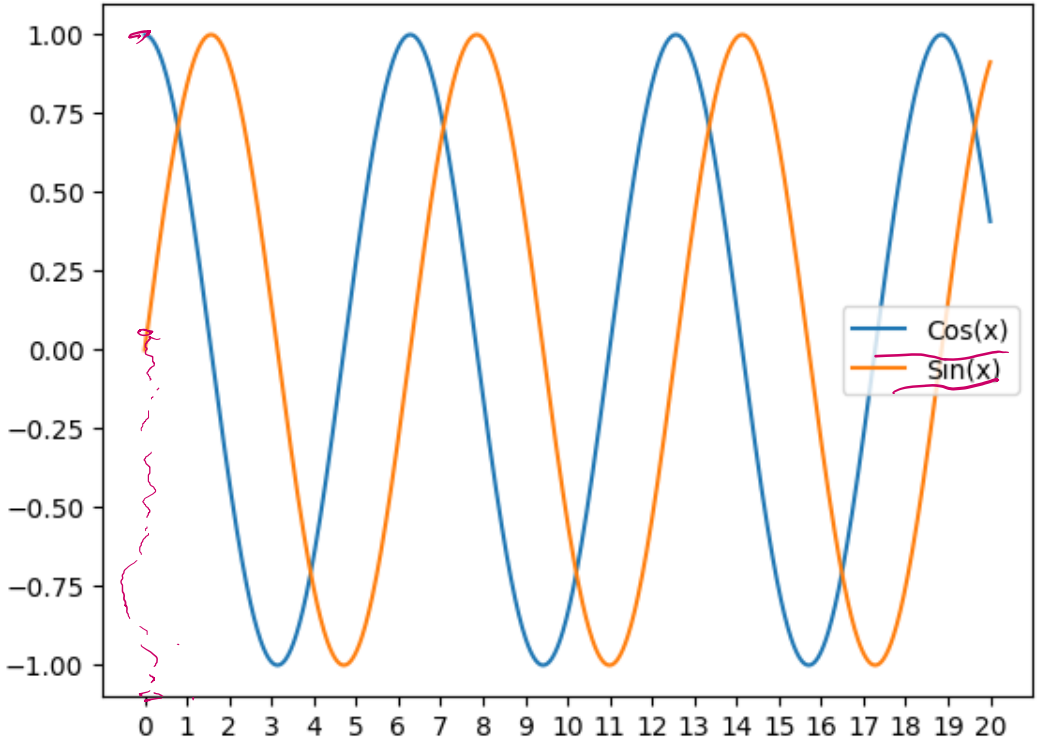
Vaswani, Ashish, et al. "Attention is all you need." Advances in neural information processing systems 30 (2017).

GPT



$$PE_{(pos,2i)} = sin(pos/10000^{2i/d_{\text{model}}})$$

$$PE_{(pos,2i+1)} = cos(pos/10000^{2i/d_{\text{model}}})$$



| 1 | 2 | 3 |

|Answer | the | following |

$T = 3$

|1 | 2 | 3 |

|the | following | question |

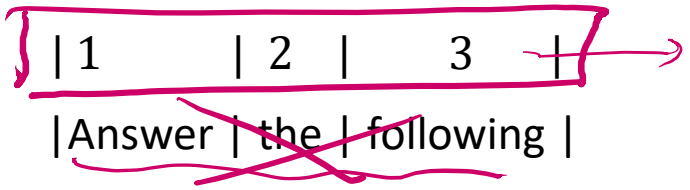
$T' = 3$

Vaswani, Ashish, et al. "Attention is all you need." Advances in neural information processing systems 30 (2017).

GPT

$T = 3$

$d_{model} = 10$



$$PE_{(pos,2i)} = sin(pos/10000^{2i/d_{\text{model}}})$$
$$PE_{(pos,2i+1)} = cos(pos/10000^{2i/d_{\text{model}}})$$

- Position embedding

```
[[ 0.    1.    0.    1.    0.    1.    0.    1.    0.    1. ]
 [ 0.84  0.54  0.16  0.99  0.03  1.    0.    1.    0.    1. ]
 [ 0.91 -0.42  0.31  0.95  0.05  1.    0.01  1.    0.    1. ]]
```

GPT

$T = 3$

$d_{model} = 10$

$vocab\ size = 6$

1	2	3
Answer	the	following

- Input Embedding

Answer	[[-0.68 0.49 -0.08 0.57 0.22 -0.19 0.53 -1.19 0.75 -0.19]
Following	[0.09 0.04 -0.39 0.27 1.03 -0.01 0.07 -0.47 1.21 -0.28]
Here	[1.2 0.09 -0.44 0.12 0.06 0.08 1. -0.64 -0.52 0.05]
Please	[-1.28 -1.38 -0.26 -1.5 0.93 0.16 0.56 1.84 -0.41 -1.45]
Question	[-0.43 0.09 0.67 -0.06 -1.52 1.78 0.5 -1.38 -0.47 -2.]
The	[-0.8 0.54 1.66 -0.55 1.2 -2.73 1.02 -0.25 -0.36 -1.85]]

numpy pytorch emb[[1,6,2],:]

GPT

$T = 3$

$d_{model} = 10$

$vocab\ size = 6$

| 1 | 2 | 3 |

+

|Answer | the | following |

Input Embedding

+

Position Embedding

Answer [[-0.68 0.49 -0.08 0.57 0.22 -0.19 0.53 -1.19 0.75 -0.19]

The [-0.8 0.54 1.66 -0.55 1.2 -2.73 1.02 -0.25 -0.36 -1.85]

Following [0.09 0.04 -0.39 0.27 1.03 -0.01 0.07 -0.47 1.21 -0.28]]

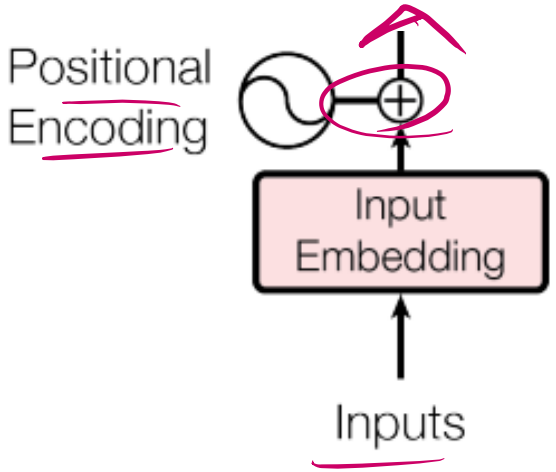
+

1 [[0. 1. 0. 1. 0. 1. 0. 1. 0. 1.]

2 [0.84 0.54 0.16 0.99 0.03 1. 0. 1. 0. 1.]

3 [0.91 -0.42 0.31 0.95 0.05 1. 0.01 1. 0. 1.]]

GPT



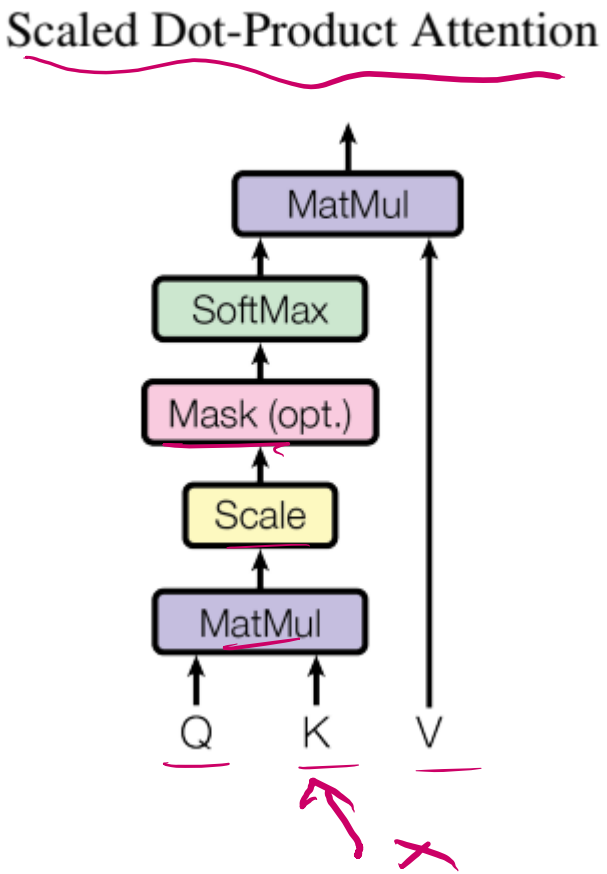
1	2	3
Answer	the	following

Answer	[[-0.68	0.49	-0.08	0.57	0.22	-0.19	0.53	-1.19	0.75	-0.19]
The	[-0.8	0.54	1.66	-0.55	1.2	-2.73	1.02	-0.25	-0.36	-1.85]
Following	[0.09	0.04	-0.39	0.27	1.03	-0.01	0.07	-0.47	1.21	-0.28]]

+

1	[[0.	1.	0.	1.	0.	1.	0.	1.	0.	1.]
2	[0.84	0.54	0.16	0.99	0.03	1.	0.	1.	0.	1.]
3	[0.91	-0.42	0.31	0.95	0.05	1.	0.01	1.	0.	1.]]

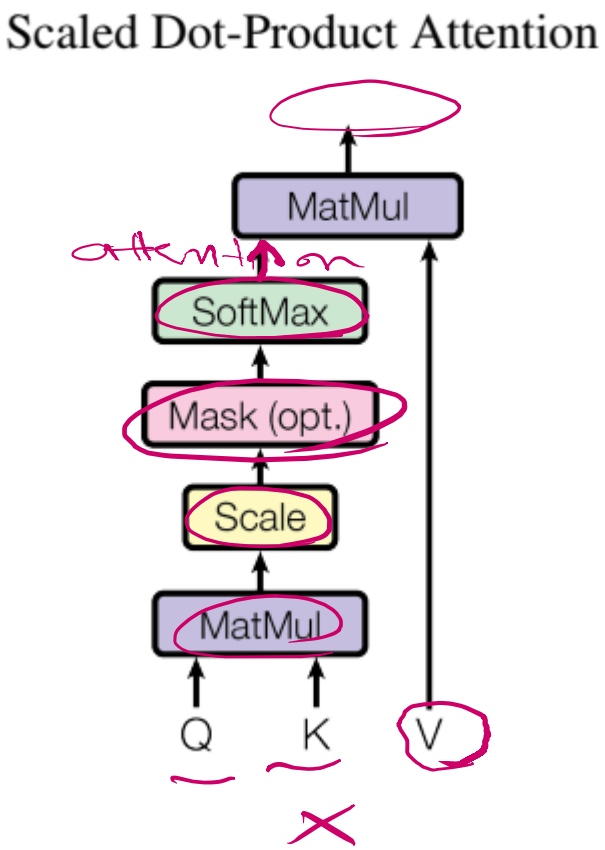
Self-attention



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

Vaswani, Ashish, et al. "Attention is all you need." Advances in neural information processing systems 30 (2017).

Self-attention



- **Q**uery
- **K**ey
- **V**alue

- Projections of input

Vaswani, Ashish, et al. "Attention is all you need." Advances in neural information processing systems 30 (2017).

Self-attention

- $x = pos + token$

$$(3 \times 10)$$

- Fully Connected (x)

$$(3 \times 10 * 3)$$

- Reshape

$$Q = (3 \times 10)$$
$$K = (3 \times 10)$$
$$V = (3 \times 10)$$

- Q

```
[[ 0.84  1.22 -0.1   0.68 -0.11 -0.54 -0.54 -0.74 -0.71  0.09]
 [-0.42  1.38  0.96  1.87 -0.58  0.05  0.45 -1.06  0.21 -1.24]
 [-0.19  0.33 -1.1  -0.27 -0.64  0.75 -0.42  0.51 -1.44 -0.48]]
```

- K

```
[[ 0.16 -1.08 -0.9   0.33 -0.65 -0.09  0.83 -0.3   0.51 -0.03]
 [-0.22 -0.74 -1.61  0.89  1.08  1.66  0.2   1.18  0.24 -1.74]
 [ 0.15  0.49  0.43  0.16 -1.04 -0.7   0.33 -0.61  0.94  0.5 ]]
```

- V

```
[[ 0.54 -0.7   0.14  0.96 -0.74 -0.04  0.11  0.33 -0.03  0.6 ]
 [-0.02  0.49  1.3   1.81 -0.94 -0.6  -0.02  1.24 -0.47  0.89]
 [-0.04 -1.8  -0.44 -0.74  0.05  0.19  0.35 -0.85 -0.43  0.03]]
```

Self-attention

1. $\frac{QK^T}{\sqrt[2]{d_{model}}}$
2. Mask
3. Softmax

1.
```
[[-0.42  -0.83   0.29]
 [-0.19  -0.1    0.71]
 [-0.12   0.92  -0.73]]
```

3.
```
[[-0.42  -inf  -inf]
 [-0.19 -0.1   -inf]
 [-0.12  0.92 -0.73]]
```

5.
```
[[1.    0.    0.  ]
 [0.48  0.52  0.  ]
 [0.23  0.65  0.13]]
```

Self-attention

4. Attention(Q,K,V) = $\text{softmax}\left(\frac{QK^T}{\sqrt[2]{d_k}}\right)V$

4.
```
[[ 0.54 -0.7   0.14  0.96 -0.74 -0.04  0.11  0.33 -0.03  0.6 ]
 [ 0.24 -0.08  0.75  1.4  -0.84 -0.33  0.04  0.81 -0.26  0.75]
 [ 0.1  -0.07  0.82  1.3  -0.77 -0.37  0.06  0.77 -0.36  0.72]]
```

5. Logits = Fully Connected (Attention)
$(3 \times vocab\ size)$

5.
```
[[ 0.27  0.04 -0.69  0.35 -0.04 -0.38]
 [ 0.44 -0.11 -0.84  0.29 -0.43 -0.23]
 [ 0.51 -0.1  -0.83  0.27 -0.45 -0.15]]
```

6. Pred = softmax(logits)

6.
```
[[0.22 0.18 0.08 0.24 0.16 0.12]
 [0.27 0.16 0.08 0.24 0.12 0.14]
 [0.29 0.15 0.08 0.23 0.11 0.15]]
```

Self-attention

1. Answer
2. Following
3. Here
4. Please
5. Question
6. The

6.

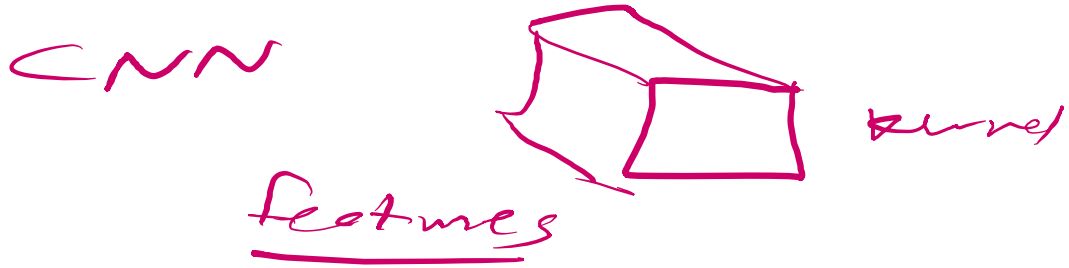
```
[[0.22 0.18 0.08 0.24 0.16 0.12]
 [0.27 0.16 0.08 0.24 0.12 0.14]
 [0.29 0.15 0.08 0.23 0.11 0.15]]
```

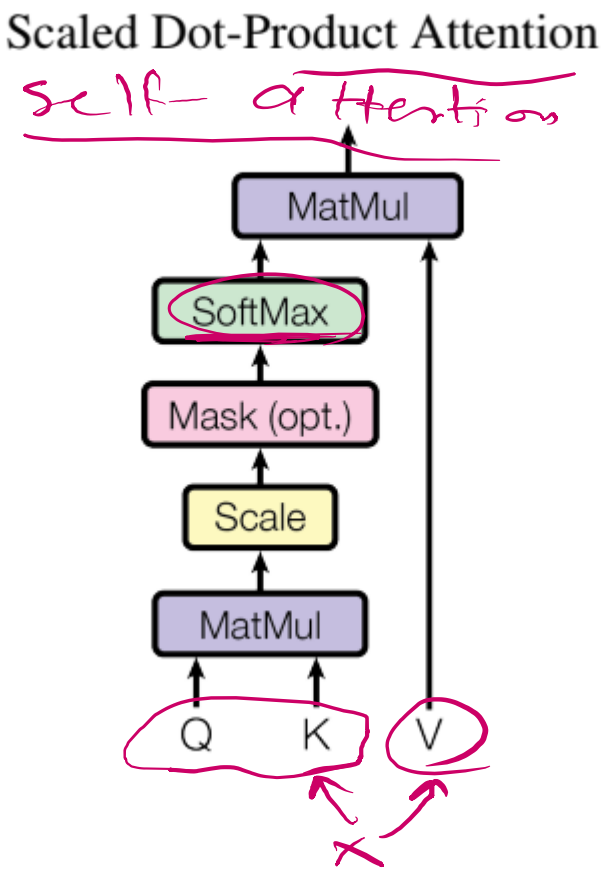
6. Pred = softmax(logits)

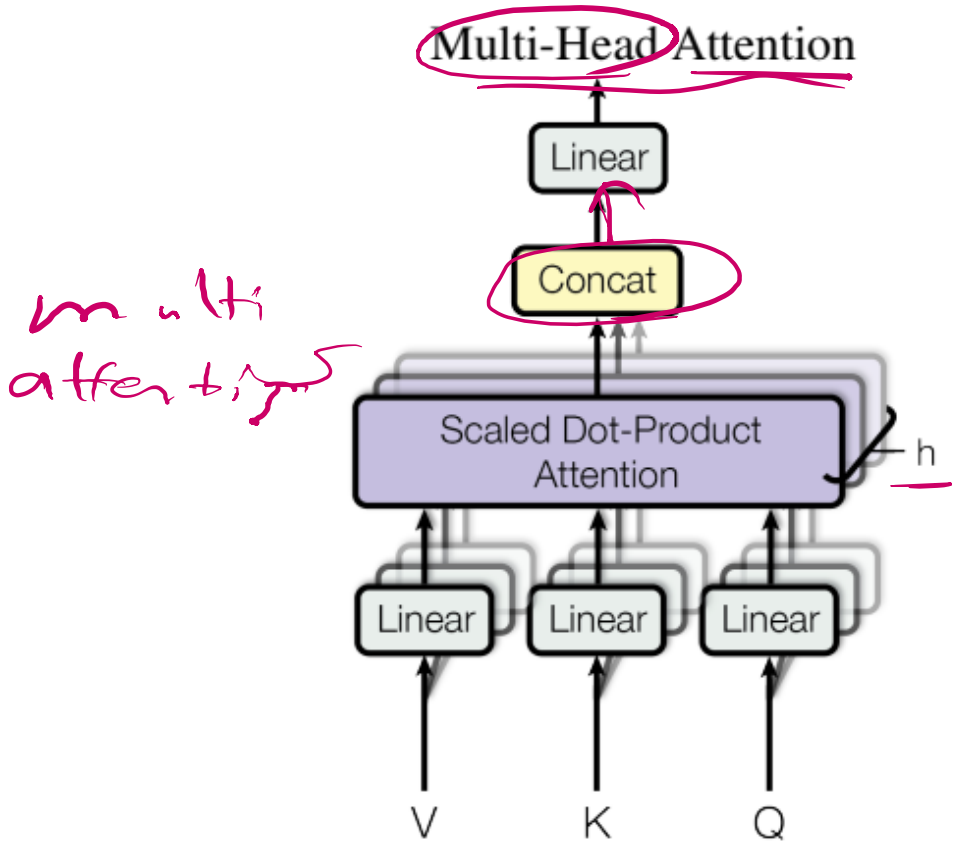
please answer answer

1 2 3

Multi-head attention



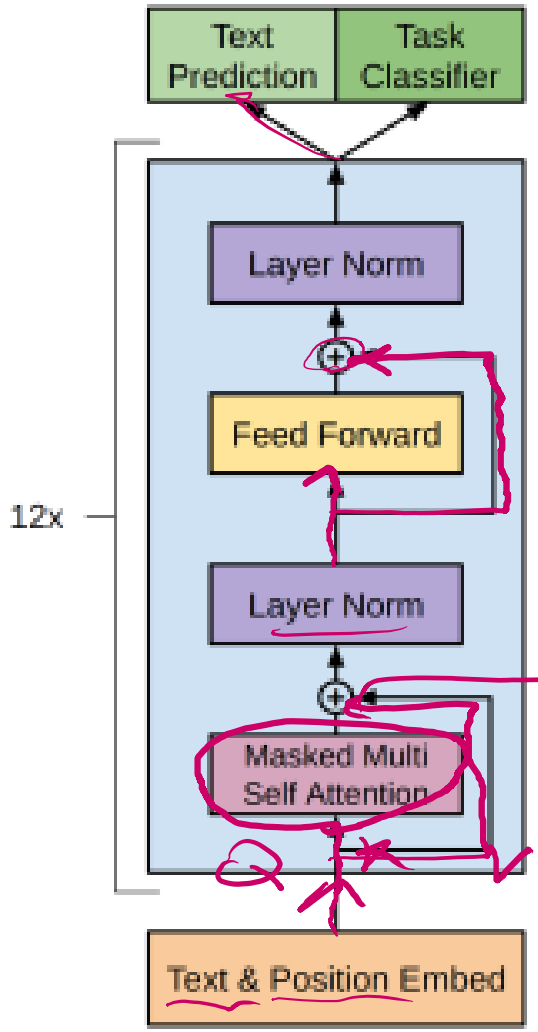




Vaswani, Ashish, et al. "Attention is all you need." Advances in neural information processing systems 30 (2017).

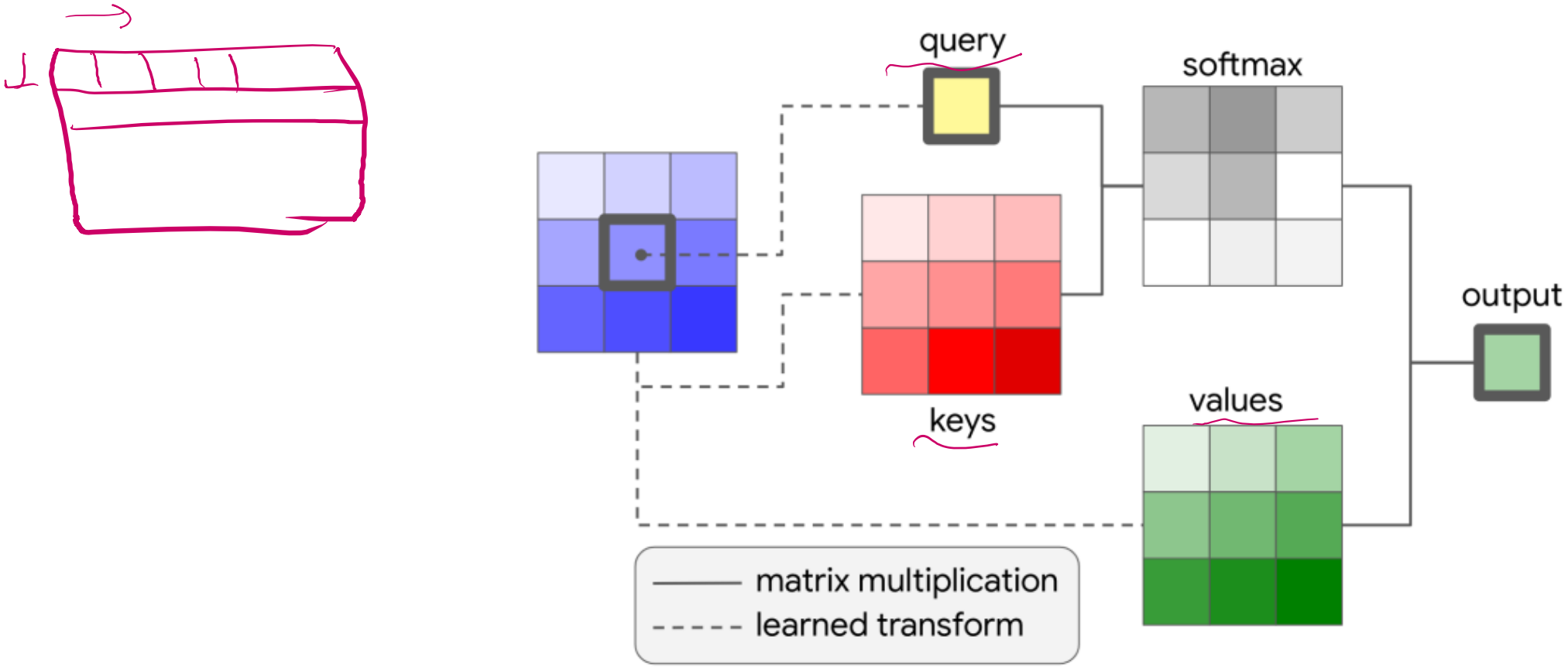
GPT
(**G**enerative **P**re-**T**raining)

- Auto-regressive,
- Decoder language model



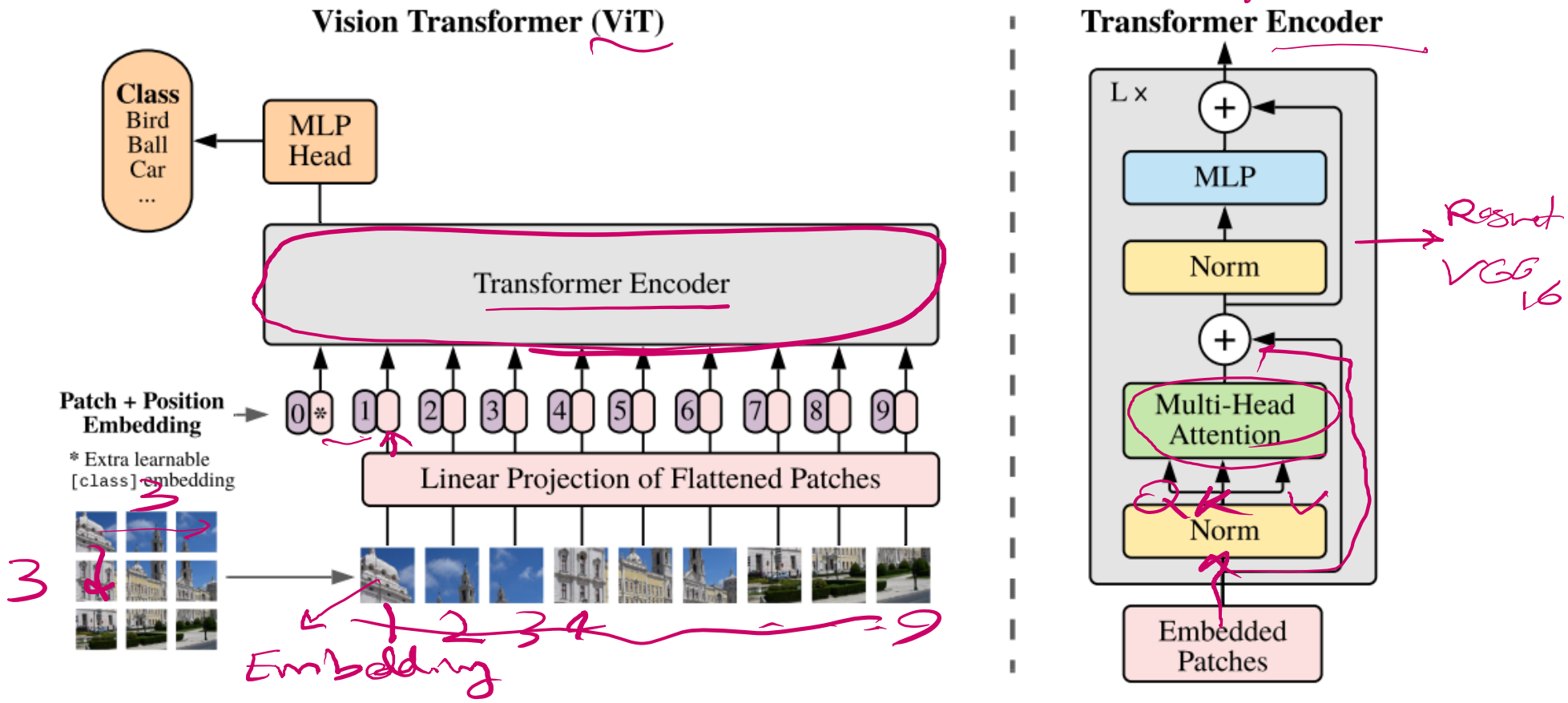
Radford, Alec, et al. "Improving language understanding by generative pre-training." (2018).

Attention to Vision



Ramachandran, Prajit, et al. "Stand-alone self-attention in vision models." *Advances in neural information processing systems* 32 (2019).

Vision Transformers



Dosovitskiy, Alexey, et al. "An image is worth 16x16 words: Transformers for image recognition at scale." *arXiv preprint arXiv:2010.11929* (2020).