



UNIVERSITY OF TECHNOLOGY
IN THE EUROPEAN CAPITAL OF CULTURE
CHEMNITZ

Neurocomputing

Transformers

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1 - Transformers

Attention Is All You Need

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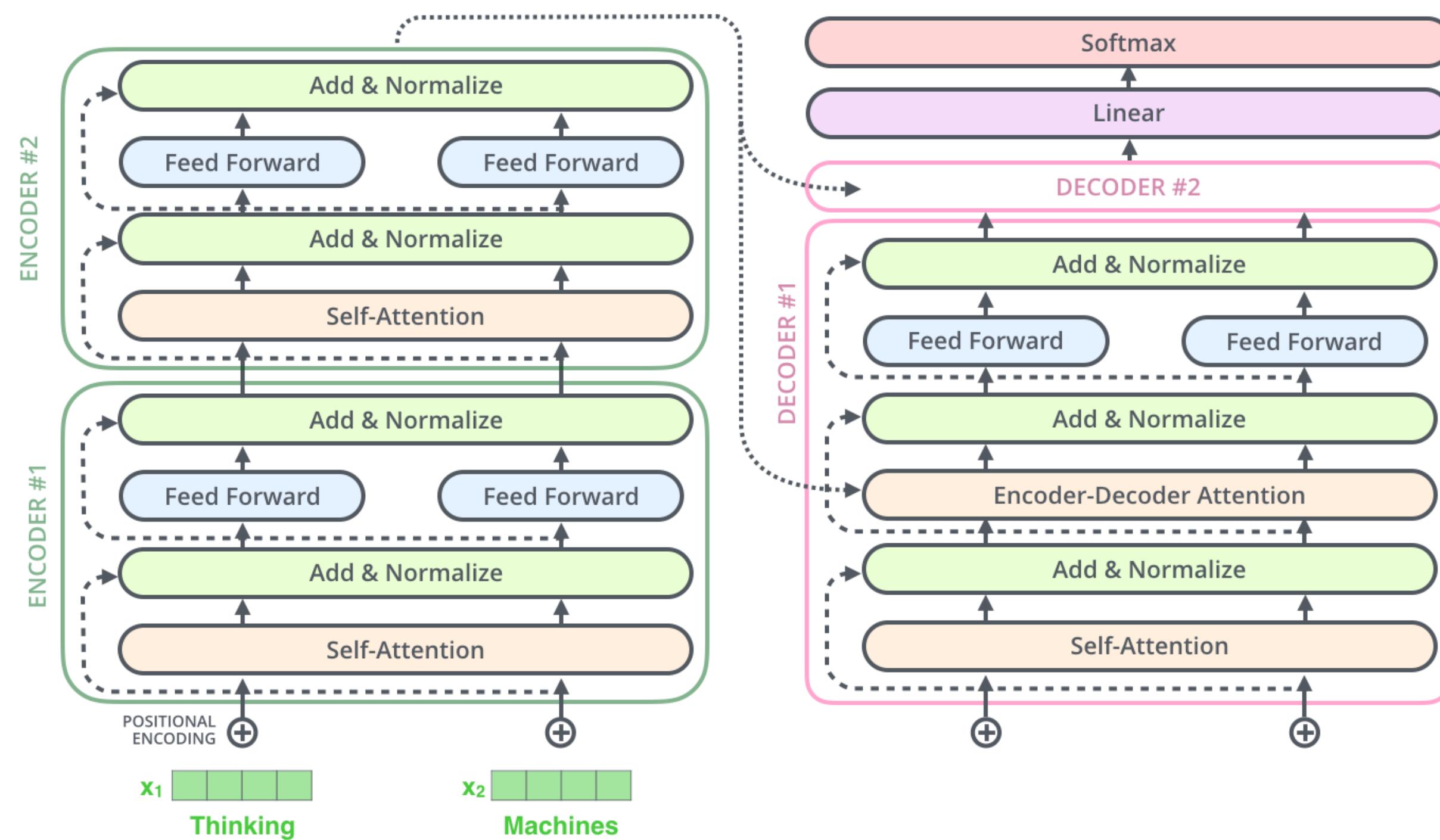
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Transformer networks

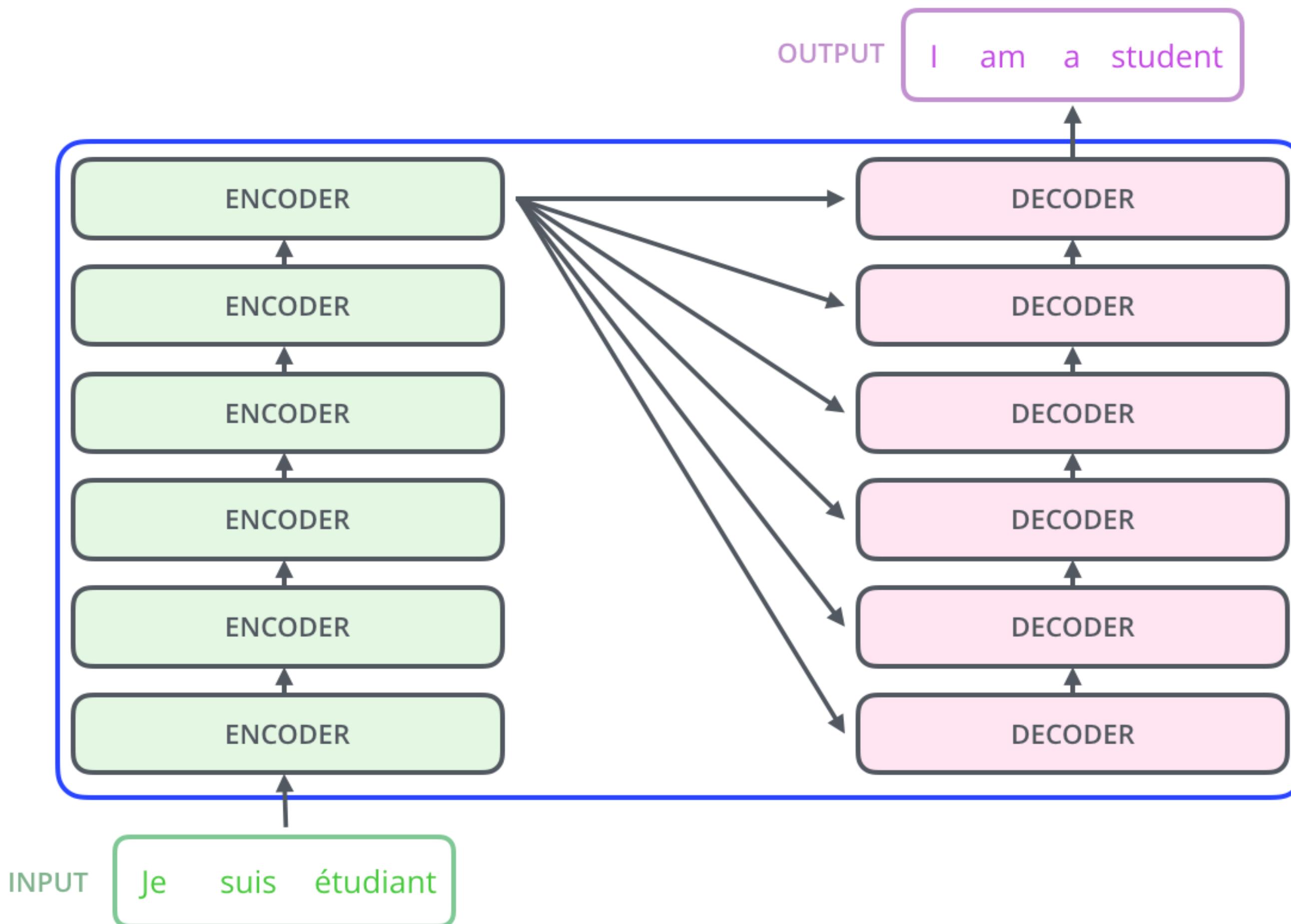
- Attentional mechanisms are so powerful that recurrent networks are not even needed anymore.
- **Transformer networks** use **self-attention** in a purely feedforward architecture and outperform recurrent architectures.
- Used in Google BERT and OpenAI GPT-3 for text understanding (e.g. search engine queries) and generation.



Source: <http://jalammar.github.io/illustrated-transformer/>

Transformer networks

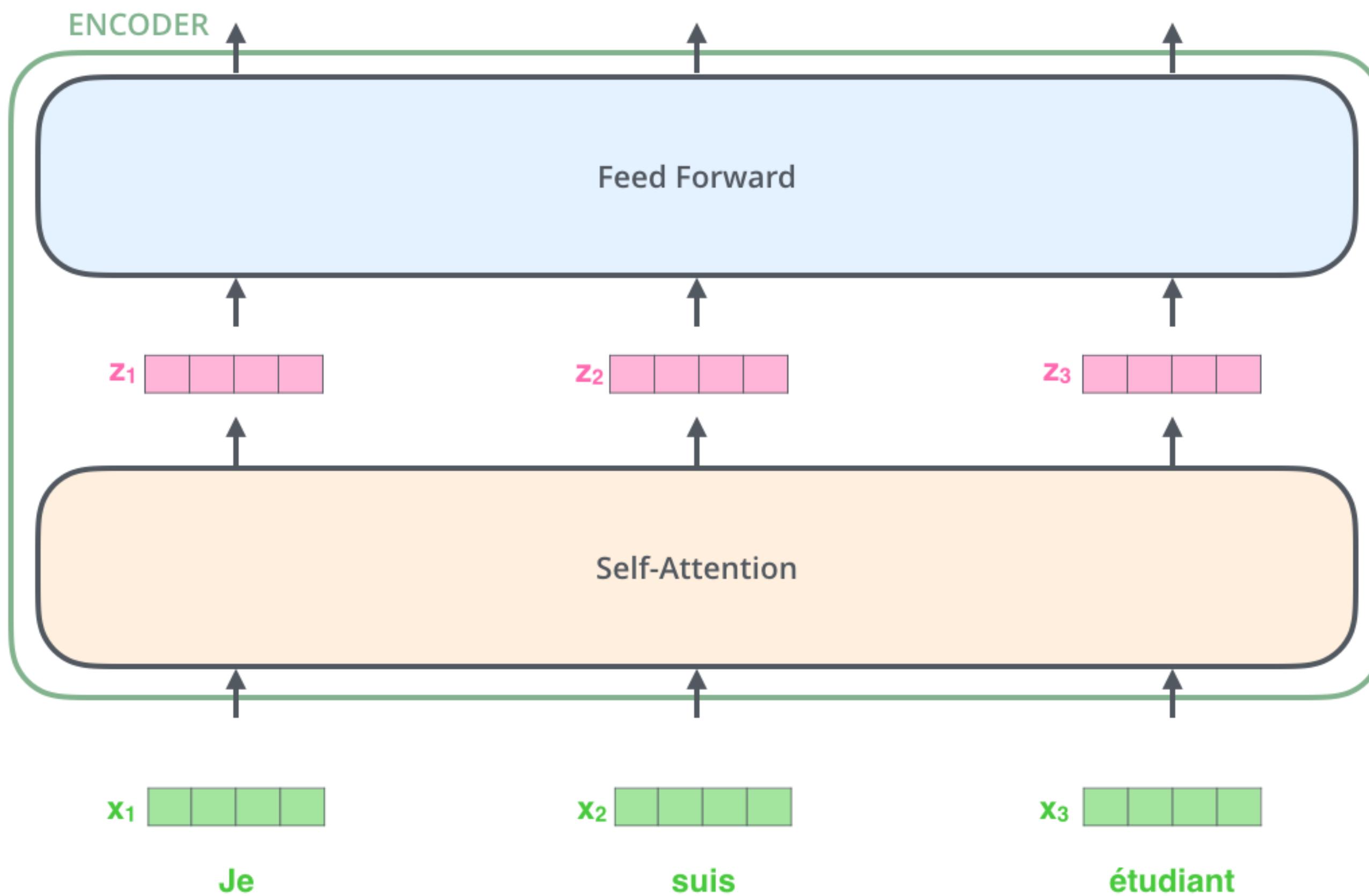
- Transformer networks use an **encoder-decoder** architecture, each with 6 stacked layers.



Source: <http://jalammar.github.io/illustrated-transformer/>

Encoder layer

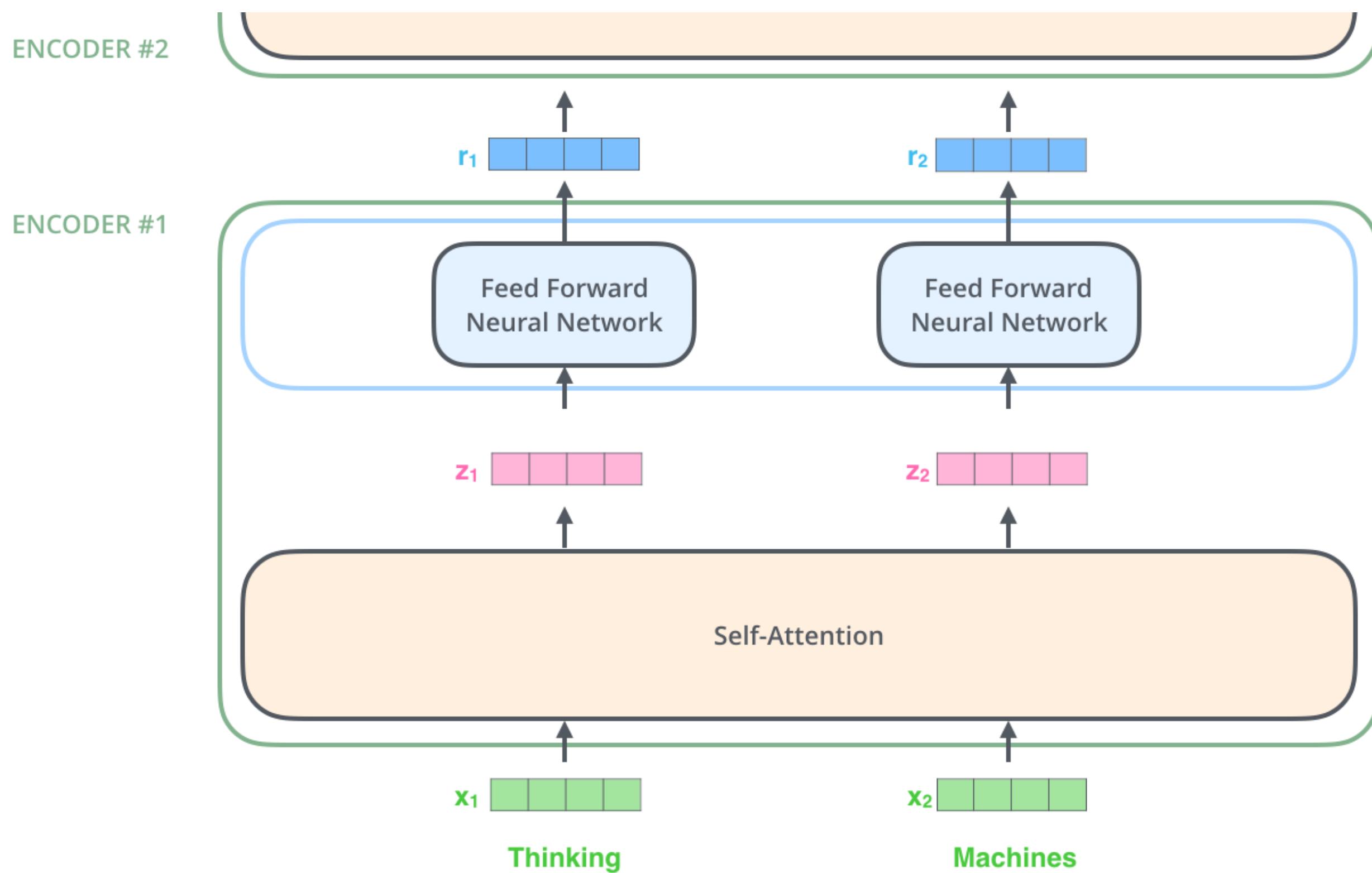
- Each layer of the encoder processes the n words of the input sentence **in parallel**.
- Word embeddings (as in word2vec) of dimension 512 are used as inputs (but learned end-to-end).



Source: <http://jalammar.github.io/illustrated-transformer/>

Encoder layer

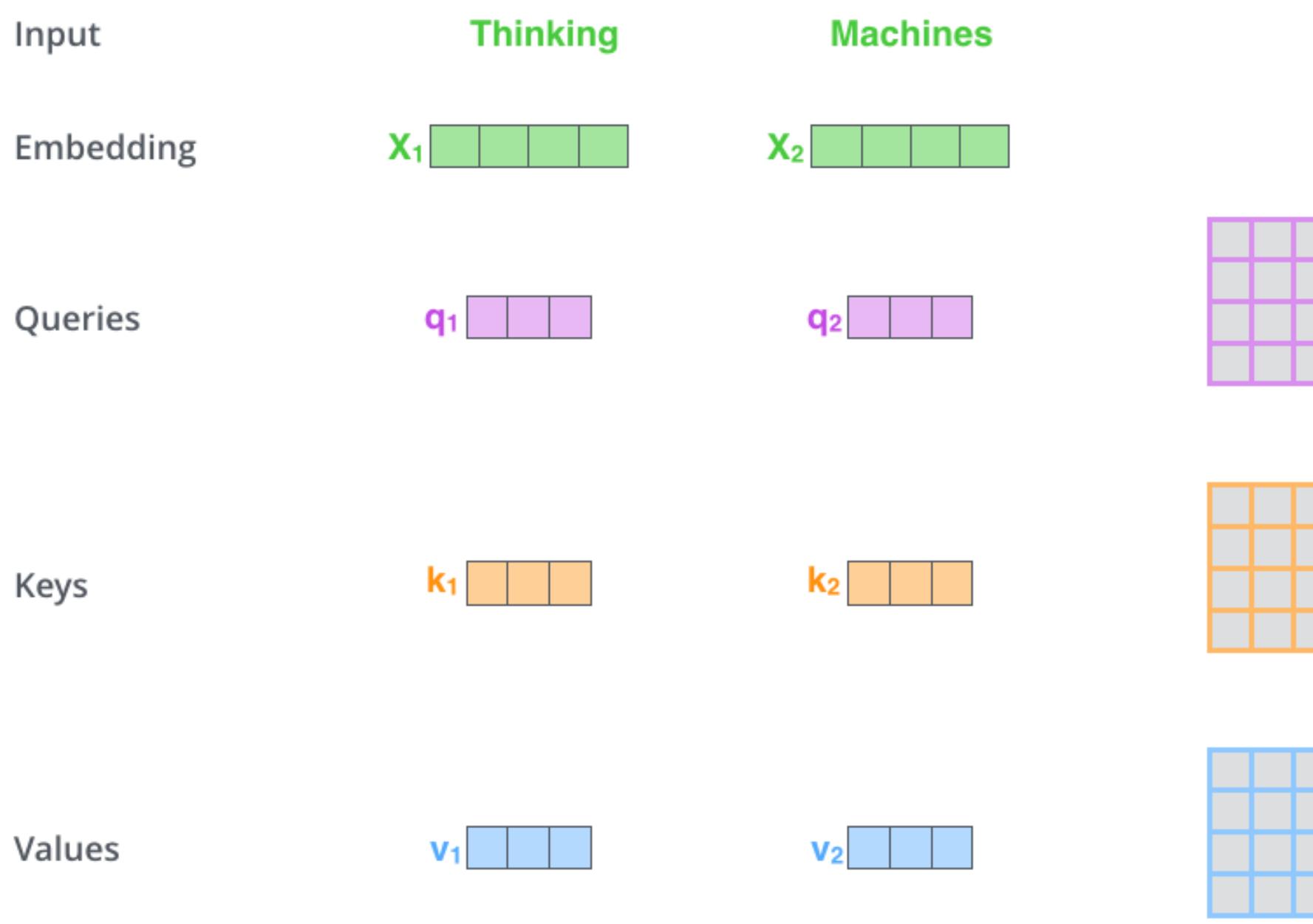
- Two operations are performed on each word embedding \mathbf{x}_i :
 - self-attention vector \mathbf{z}_i depending on the other words.
 - a regular feedforward layer to obtain a new representation \mathbf{r}_i (shared among all words).



Source: <http://jalammar.github.io/illustrated-transformer/>

Self-attention

- The first step of self-attention is to compute for each word three vectors of length $d_k = 64$ from the embeddings \mathbf{x}_i or previous representations \mathbf{r}_i ($d = 512$).
 - The **query** \mathbf{q}_i using W^Q .
 - The **key** \mathbf{k}_i using W^K .
 - The **value** \mathbf{v}_i using W^V .



- This operation can be done in parallel over all words:

$$\begin{array}{ccc} \mathbf{X} & \times & \mathbf{W}^Q \\ \begin{matrix} \text{---} \\ \mathbf{x}_1 \\ \text{---} \\ \mathbf{x}_2 \\ \text{---} \end{matrix} & \times & \begin{matrix} \text{---} \\ \mathbf{q}_1 \\ \text{---} \\ \mathbf{q}_2 \\ \text{---} \end{matrix} \\ = & \begin{matrix} \text{---} \\ \mathbf{Q}_1 \\ \text{---} \\ \mathbf{Q}_2 \\ \text{---} \end{matrix} \end{array}$$
$$\begin{array}{ccc} \mathbf{X} & \times & \mathbf{W}^K \\ \begin{matrix} \text{---} \\ \mathbf{x}_1 \\ \text{---} \\ \mathbf{x}_2 \\ \text{---} \end{matrix} & \times & \begin{matrix} \text{---} \\ \mathbf{k}_1 \\ \text{---} \\ \mathbf{k}_2 \\ \text{---} \end{matrix} \\ = & \begin{matrix} \text{---} \\ \mathbf{K}_1 \\ \text{---} \\ \mathbf{K}_2 \\ \text{---} \end{matrix} \end{array}$$
$$\begin{array}{ccc} \mathbf{X} & \times & \mathbf{W}^V \\ \begin{matrix} \text{---} \\ \mathbf{x}_1 \\ \text{---} \\ \mathbf{x}_2 \\ \text{---} \end{matrix} & \times & \begin{matrix} \text{---} \\ \mathbf{v}_1 \\ \text{---} \\ \mathbf{v}_2 \\ \text{---} \end{matrix} \\ = & \begin{matrix} \text{---} \\ \mathbf{V}_1 \\ \text{---} \\ \mathbf{V}_2 \\ \text{---} \end{matrix} \end{array}$$

Source: <http://jalammar.github.io/illustrated-transformer/>

Self-attention

- Why query / key / value? This a concept inspired from recommendation systems / databases.
- A Python dictionary is a set of key / value entries:

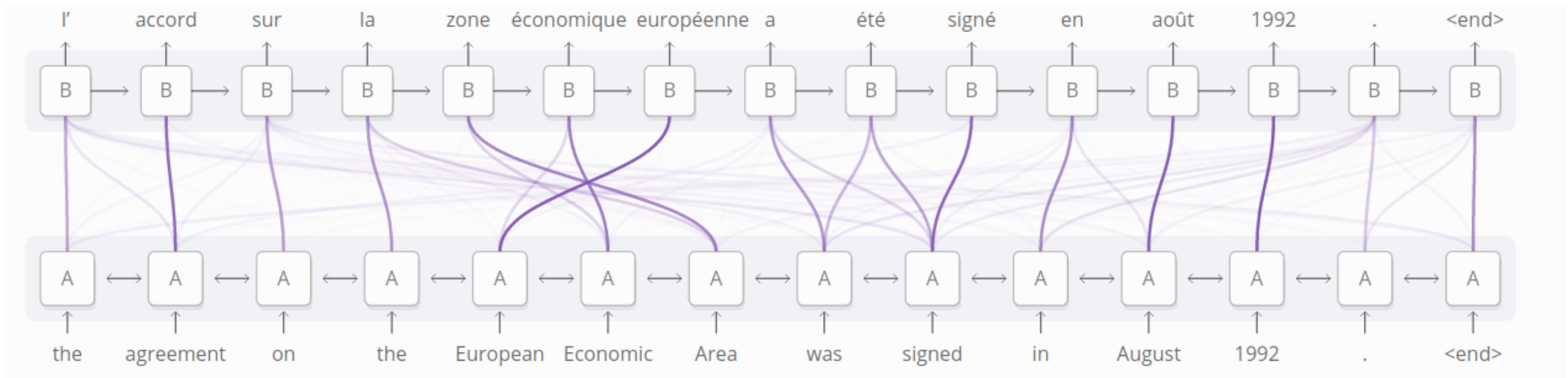
```
tel = {  
    'jack': 4098,  
    'sape': 4139  
}
```

- The query would ask the dictionary to iterate over all entries and return the value associated to the key **equal or close to** the query.

```
tel['jacky'] # 4098
```

- This would be some sort of **fuzzy** dictionary.

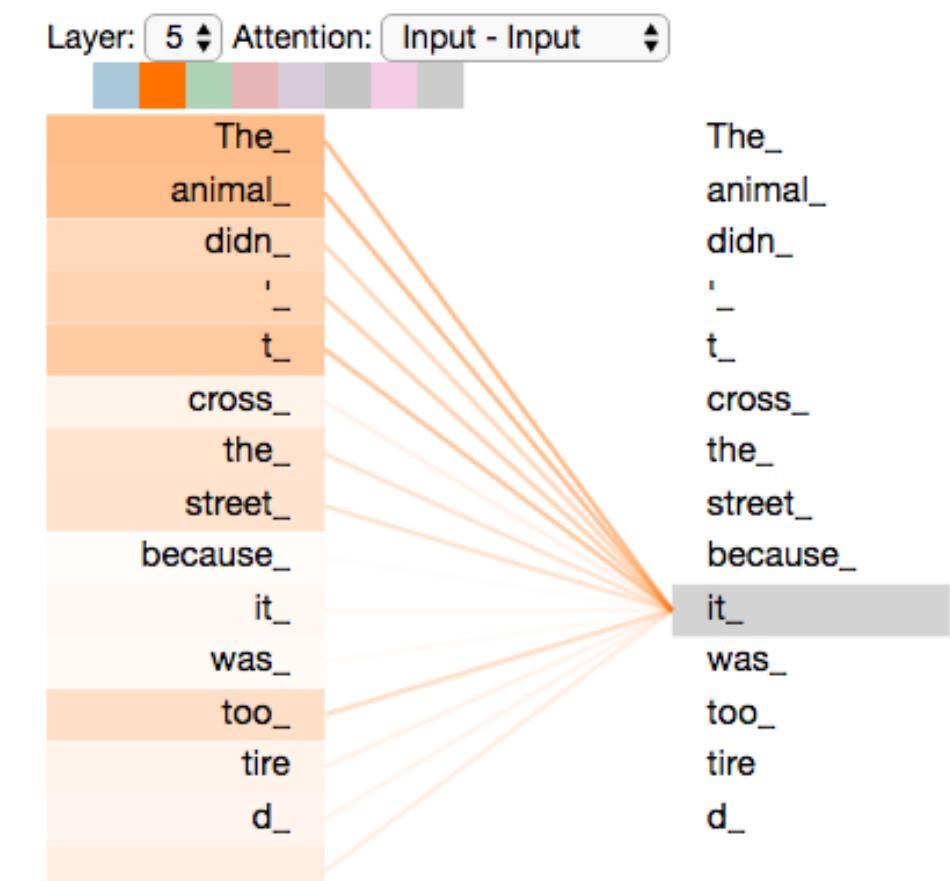
Self-attention



- In attentional RNNs, the attention scores were used by each word generated by the decoder to decide which **input word** is relevant.
- If we apply the same idea to the **same sentence** (self-attention), the attention score tells how much words of the same sentence are related to each other (context).

The animal didn't cross the street because it was too tired.

- The goal is to learn a representation for the word **it** that contains information about **the animal**, not **the street**.



Self-attention

- Each word \mathbf{x}_i of the sentence generates its query \mathbf{q}_i , key \mathbf{k}_i and value \mathbf{v}_i .
- For all other words \mathbf{x}_j , we compute the **match** between the query \mathbf{q}_i and the keys \mathbf{k}_j with a dot product:

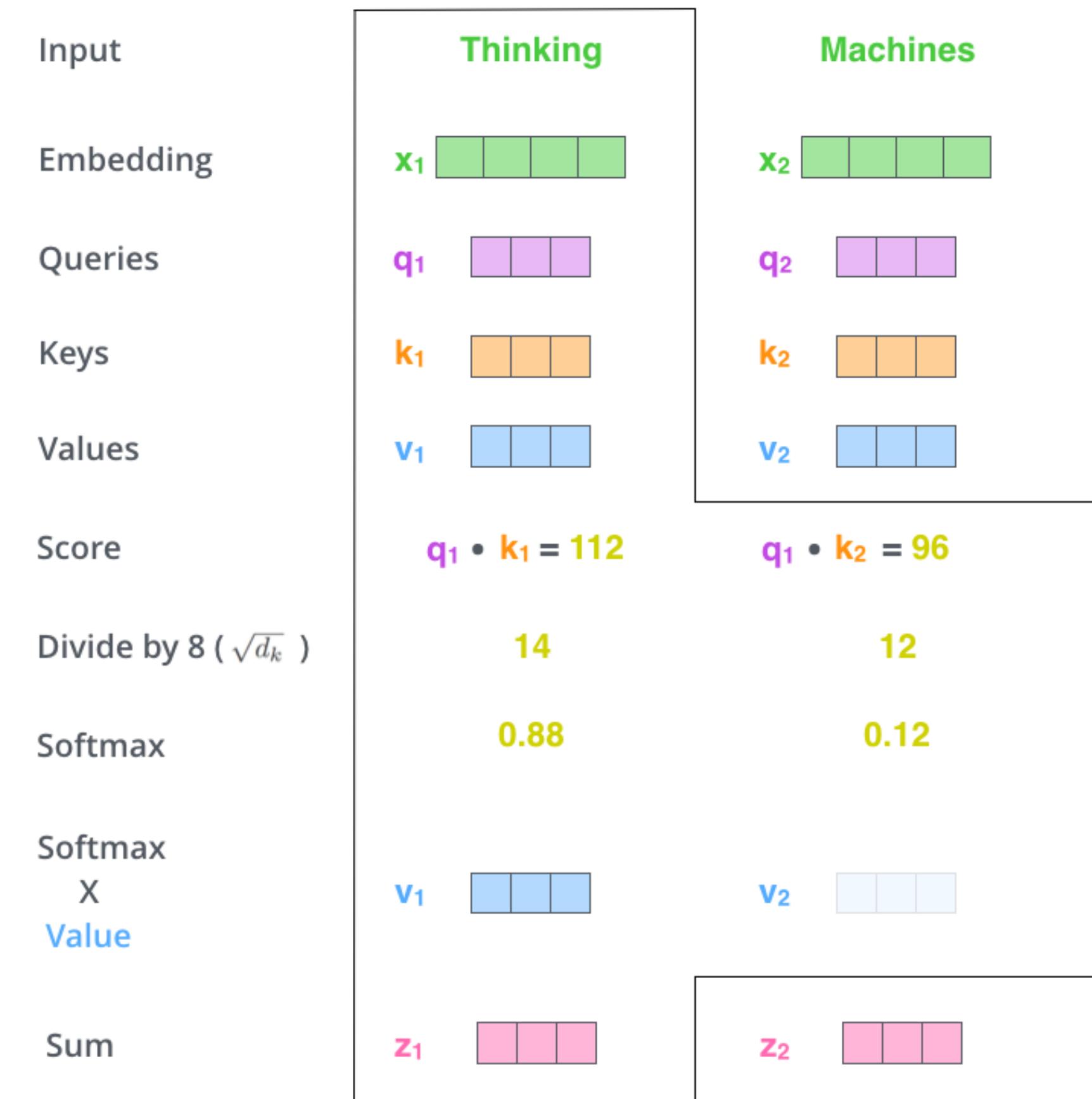
$$e_{i,j} = \mathbf{q}_i^T \mathbf{k}_j$$

- We normalize the scores by dividing by $\sqrt{d_k} = 8$ and apply a softmax:

$$a_{i,j} = \text{softmax}\left(\frac{\mathbf{q}_i^T \mathbf{k}_j}{\sqrt{d_k}}\right)$$

- The new representation \mathbf{z}_i of the word \mathbf{x}_i is a weighted sum of the values of all other words, weighted by the attention score:

$$\mathbf{z}_i = \sum_j a_{i,j} \mathbf{v}_j$$



Source: <http://jalammar.github.io/illustrated-transformer/>

Self-attention

$$\begin{matrix} \mathbf{x} \\ \begin{array}{|c|c|c|}\hline & & \\ \hline & & \\ \hline & & \\ \hline \end{array} \end{matrix} \times \begin{matrix} \mathbf{W}^Q \\ \begin{array}{|c|c|c|}\hline & & \\ \hline & & \\ \hline & & \\ \hline \end{array} \end{matrix} = \begin{matrix} \mathbf{Q} \\ \begin{array}{|c|c|c|}\hline & & \\ \hline & & \\ \hline & & \\ \hline \end{array} \end{matrix}$$

$$\begin{matrix} \mathbf{x} \\ \begin{array}{|c|c|c|}\hline & & \\ \hline & & \\ \hline & & \\ \hline \end{array} \end{matrix} \times \begin{matrix} \mathbf{W}^K \\ \begin{array}{|c|c|c|}\hline & & \\ \hline & & \\ \hline & & \\ \hline \end{array} \end{matrix} = \begin{matrix} \mathbf{K} \\ \begin{array}{|c|c|c|}\hline & & \\ \hline & & \\ \hline & & \\ \hline \end{array} \end{matrix}$$

$$\begin{matrix} \mathbf{x} \\ \begin{array}{|c|c|c|}\hline & & \\ \hline & & \\ \hline & & \\ \hline \end{array} \end{matrix} \times \begin{matrix} \mathbf{W}^V \\ \begin{array}{|c|c|c|}\hline & & \\ \hline & & \\ \hline & & \\ \hline \end{array} \end{matrix} = \begin{matrix} \mathbf{V} \\ \begin{array}{|c|c|c|}\hline & & \\ \hline & & \\ \hline & & \\ \hline \end{array} \end{matrix}$$

- If we concatenate the word embeddings into a $n \times d$ matrix X , self-attention only implies matrix multiplications and a row-based softmax:

$$\left\{ \begin{array}{l} Q = X \times W^Q \\ K = X \times W^K \\ V = X \times W^V \\ Z = \text{softmax}\left(\frac{Q \times K^T}{\sqrt{d_k}}\right) \times V \end{array} \right.$$

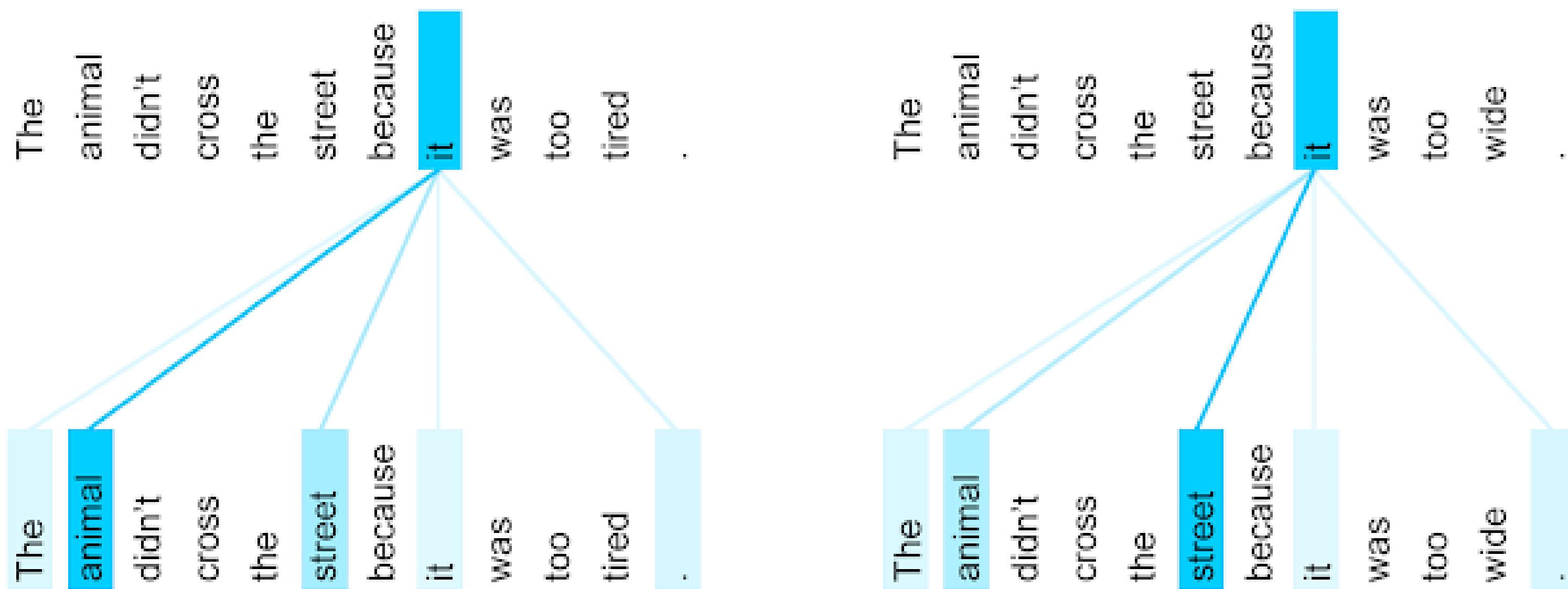
$$\text{softmax}\left(\frac{\begin{matrix} \mathbf{Q} & \mathbf{K}^T \\ \begin{array}{|c|c|c|}\hline & & \\ \hline & & \\ \hline & & \\ \hline \end{array} \times \begin{array}{|c|c|c|}\hline & & \\ \hline & & \\ \hline & & \\ \hline \end{array} \end{matrix}}{\sqrt{d_k}}\right) \begin{matrix} \mathbf{V} \\ \begin{array}{|c|c|c|}\hline & & \\ \hline & & \\ \hline & & \\ \hline \end{array} \end{matrix} = \begin{matrix} \mathbf{Z} \\ \begin{array}{|c|c|c|}\hline & & \\ \hline & & \\ \hline & & \\ \hline \end{array} \end{matrix}$$

Source: <http://jalammar.github.io/illustrated-transformer/>

- Note 1: everything is differentiable, backpropagation will work.
- Note 2: the weight matrices do not depend on the length n of the sentence.

Multi-headed self-attention

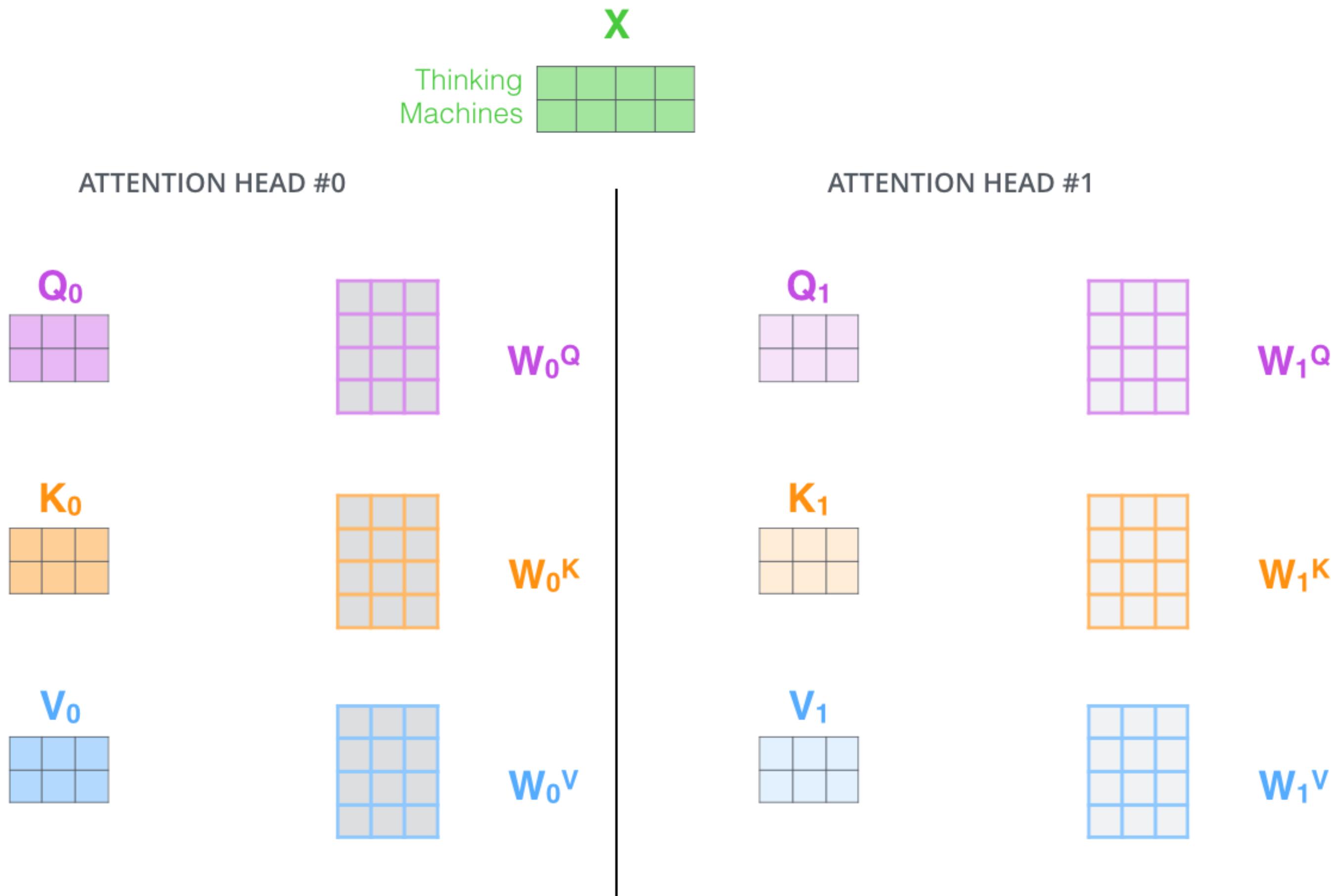
- In the sentence *The animal didn't cross the street because it was too tired.*, the new representation for the word **it** will hopefully contain features of the word **animal** after training.
- But what if the sentence was *The animal didn't cross the street because it was too wide.*? The representation of **it** should be linked to **street** in that context.
- This is not possible with a single set of matrices W^Q , W^K and W^V , as they would average every possible context and end up being useless.



Source: <https://ai.googleblog.com/2017/08/transformer-novel-neural-network.html>

Multi-headed self-attention

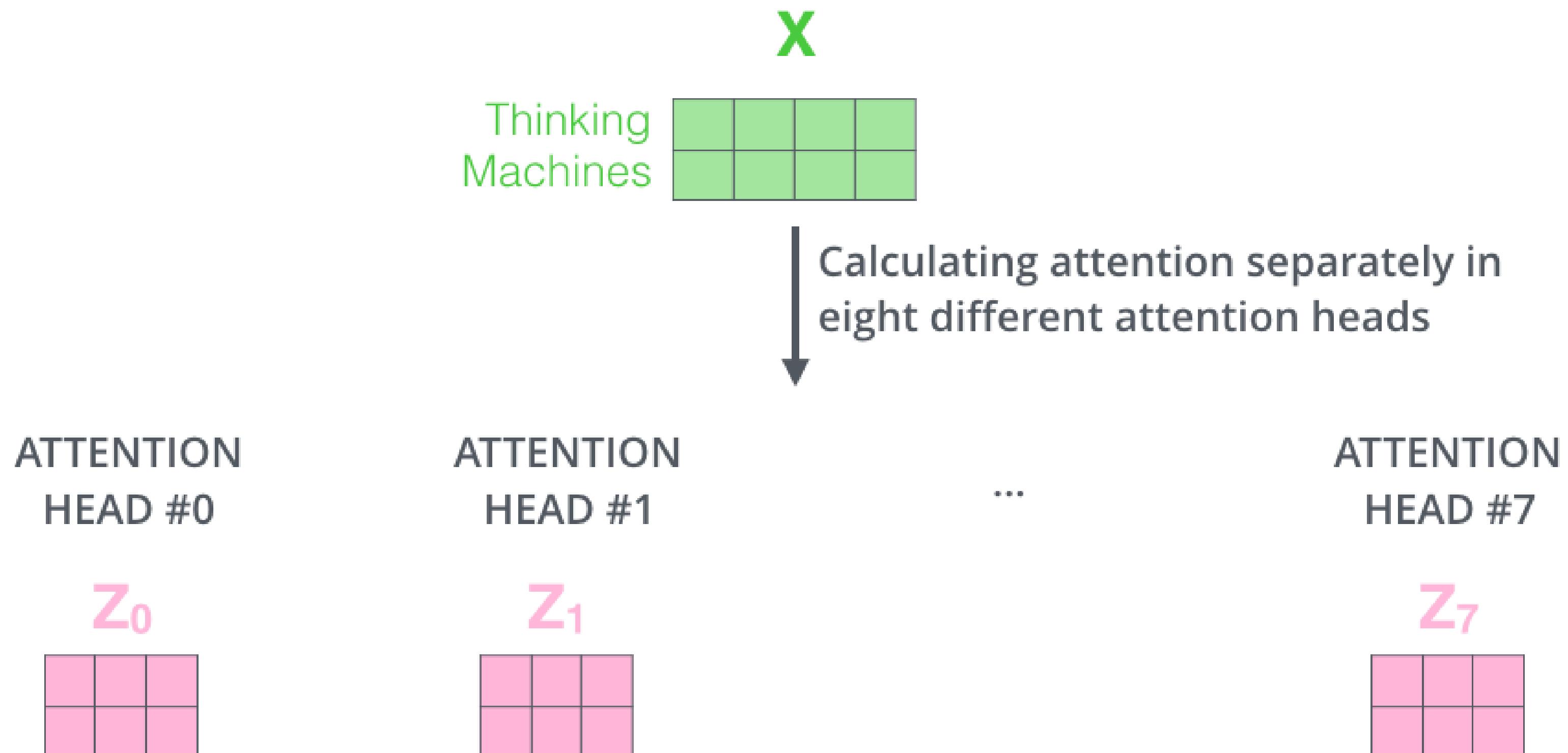
- The solution is to use **multiple attention heads** ($h = 8$) with their own matrices W_k^Q , W_k^K and W_k^V .



Source: <http://jalammar.github.io/illustrated-transformer/>

Multi-headed self-attention

- Each **attention head** will output a vector \mathbf{z}_i of size $d_k = 64$ for each word.
- How do we combine them?



Source: <http://jalammar.github.io/illustrated-transformer/>

Multi-headed self-attention

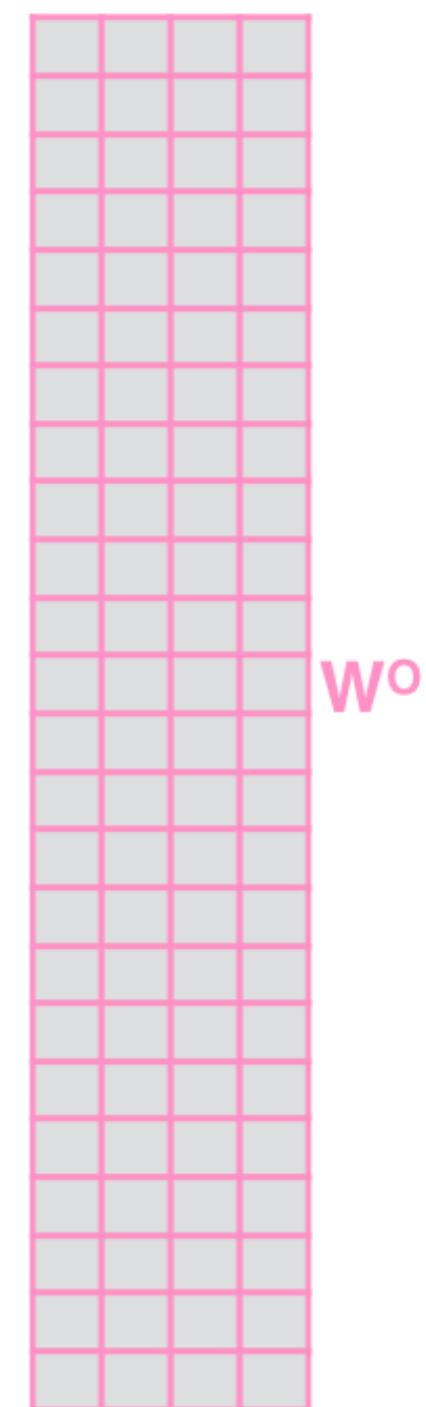
- The proposed solution is based on **ensemble learning** (stacking):
 - let another matrix W^O decide which attention head to trust...
 - 8×64 rows, 512 columns.

1) Concatenate all the attention heads



2) Multiply with a weight matrix W^o that was trained jointly with the model

\times



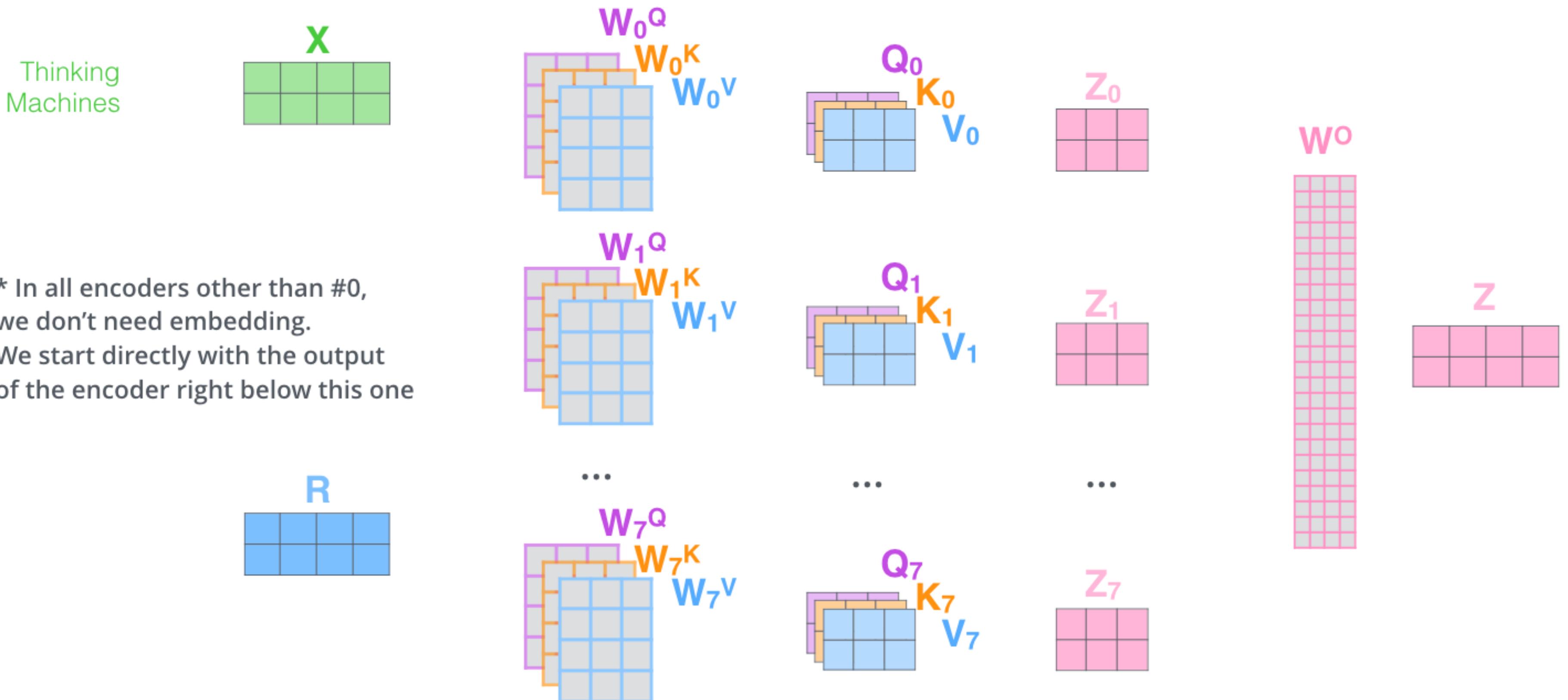
3) The result would be the Z matrix that captures information from all the attention heads. We can send this forward to the FFNN

$$= \begin{matrix} Z \\ \begin{matrix} \text{---} & \text{---} & \text{---} & \text{---} \end{matrix} \end{matrix}$$

Source: <http://jalammar.github.io/illustrated-transformer/>

Multi-headed self-attention

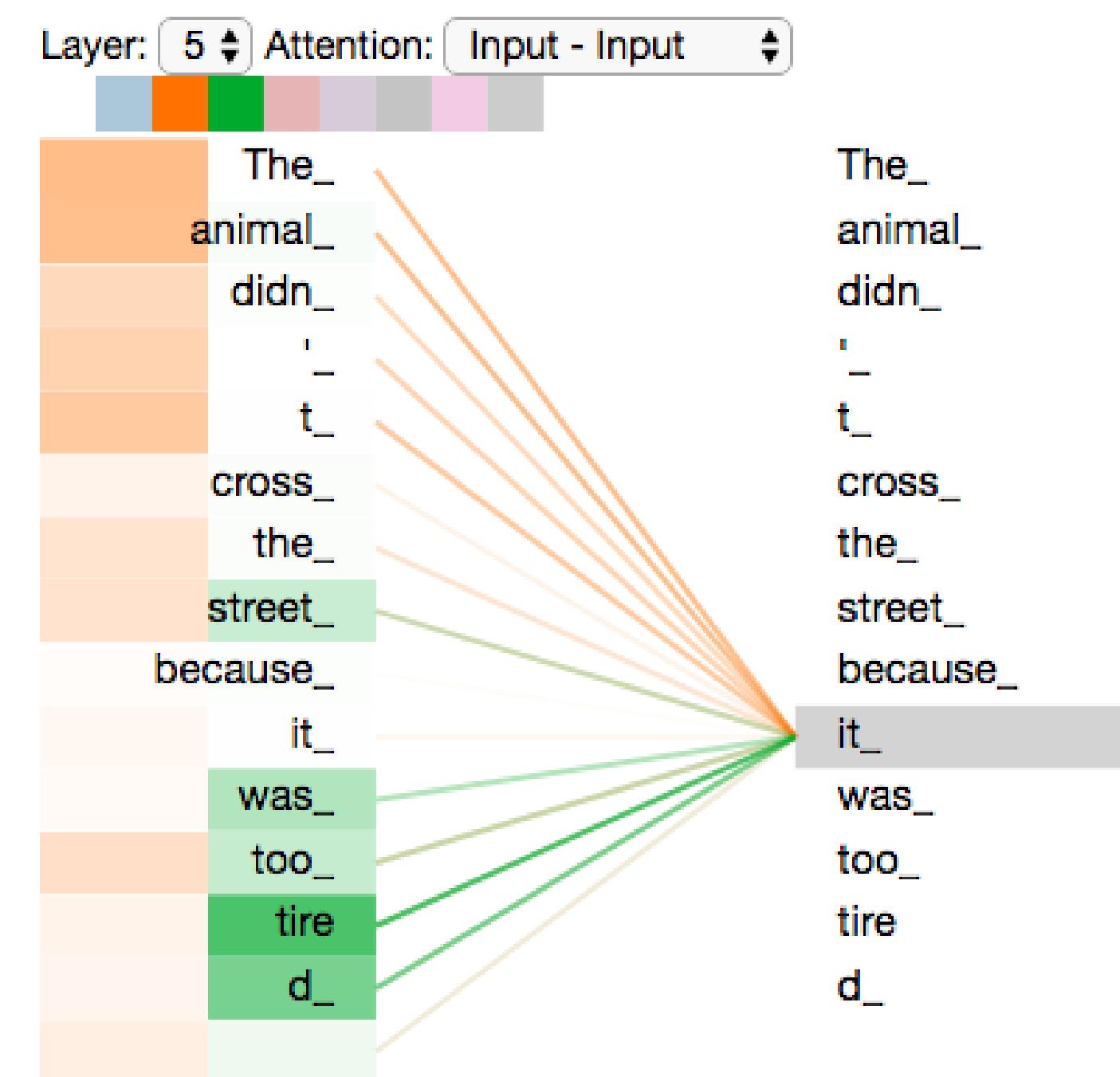
- 1) This is our input sentence* X
- 2) We embed each word* R
- 3) Split into 8 heads. We multiply X or R with weight matrices W_0^Q, W_0^K, W_0^V , W_1^Q, W_1^K, W_1^V , ..., W_7^Q, W_7^K, W_7^V
- 4) Calculate attention using the resulting $Q/K/V$ matrices
- 5) Concatenate the resulting Z matrices, then multiply with weight matrix W^O to produce the output of the layer



Source: <http://jalammar.github.io/illustrated-transformer/>

Multi-headed self-attention

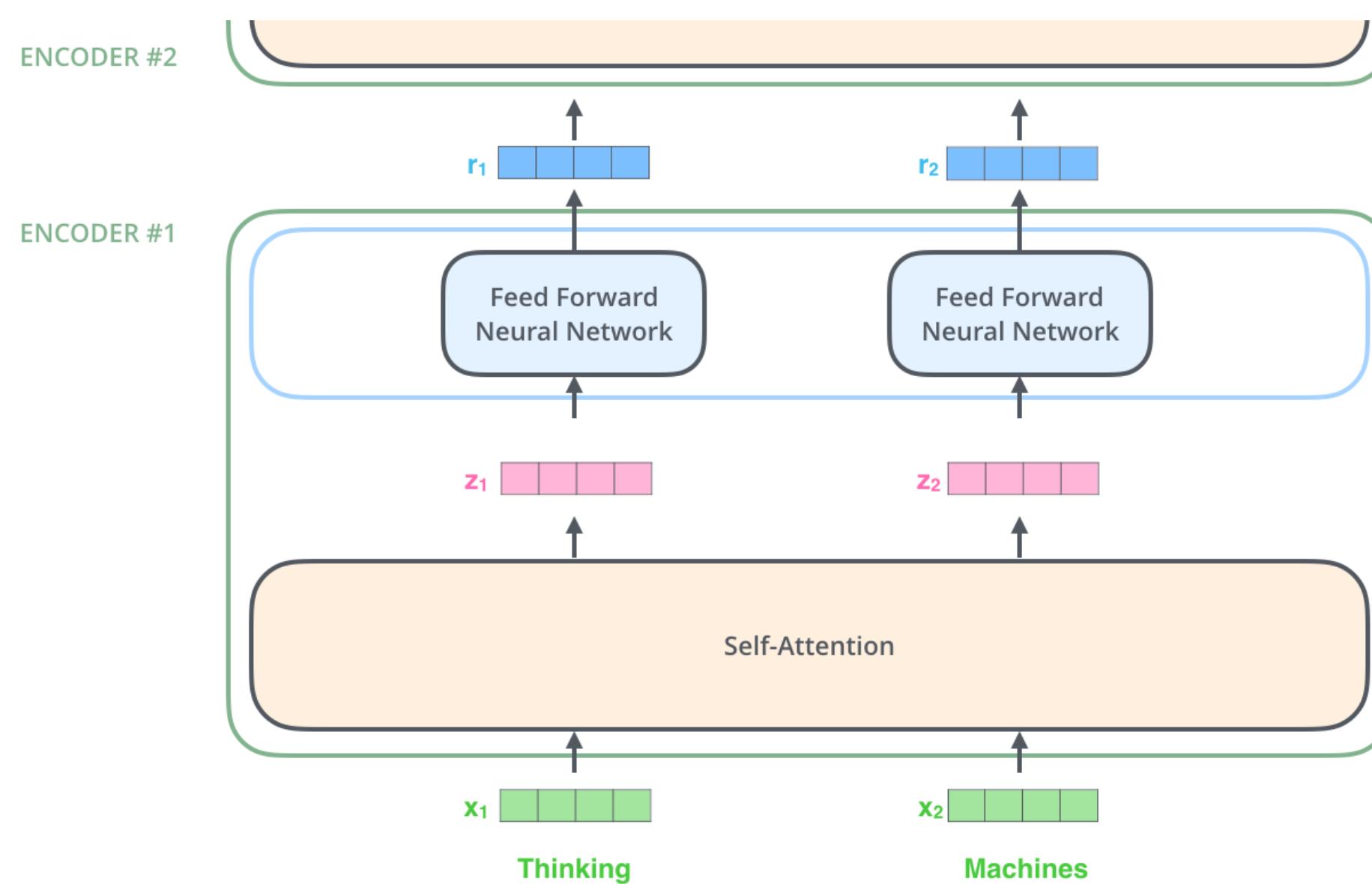
- Each attention head learns a different context:
 - *it* refers to *animal*.
 - *it* refers to *street*.
 - etc.
- The original transformer paper in 2017 used 8 attention heads.
- OpenAI's GPT-3 uses 96 attention heads...



Source: <http://jalammar.github.io/illustrated-transformer/>

Encoder layer

- Multi-headed self-attention produces a vector \mathbf{z}_i for each word of the sentence.
- A regular feedforward MLP transforms it into a new representation \mathbf{r}_i .
 - one input layer with 512 neurons.
 - one hidden layer with 2048 neurons and a ReLU activation function.
 - one output layer with 512 neurons.
- The same NN is applied on all words, it does not depend on the length n of the sentence.



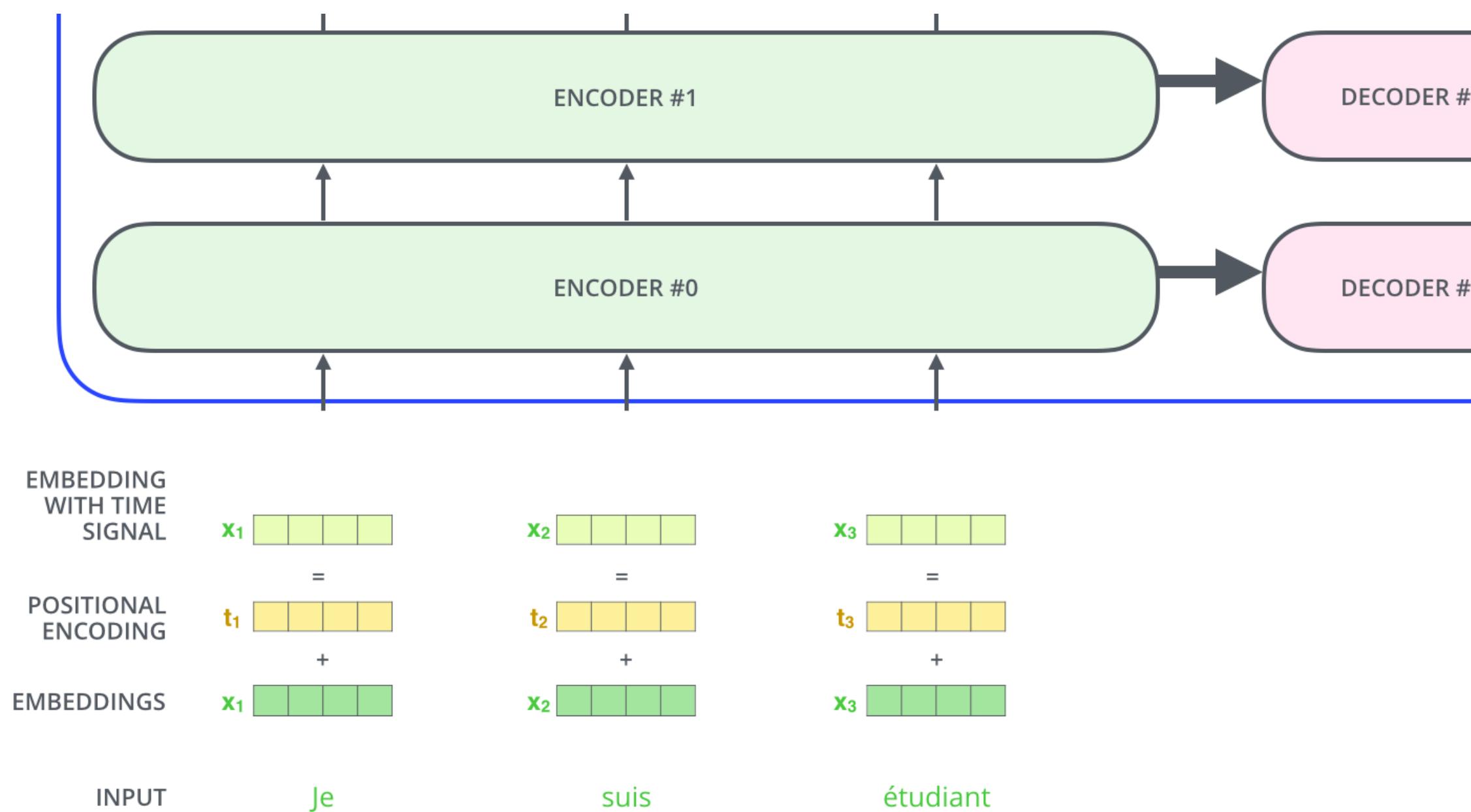
Source: <http://jalammar.github.io/illustrated-transformer/>

Positional encoding

- As each word is processed in parallel, the order of the words in the sentence is lost.

street was animal tired the the because it cross too didn't

- We need to explicitly provide that information in the **input** using positional encoding.
- A simple method would be to append an index $i = 1, 2, \dots, n$ to the word embeddings, but it is not very robust.



Source: <http://jalammar.github.io/illustrated-transformer/>

Positional encoding

- If the elements of the 512-d embeddings are numbers between 0 and 1, concatenating an integer between 1 and n will unbalance the dimensions.
- Normalizing that integer between 0 and 1 requires to know n in advance, this introduces a maximal sentence length...
- How about we append the binary code of that integer?

0 :	0 0 0 0	8 :	1 0 0 0
1 :	0 0 0 1	9 :	1 0 0 1
2 :	0 0 1 0	10 :	1 0 1 0
3 :	0 0 1 1	11 :	1 0 1 1
4 :	0 1 0 0	12 :	1 1 0 0
5 :	0 1 0 1	13 :	1 1 0 1
6 :	0 1 1 0	14 :	1 1 1 0
7 :	0 1 1 1	15 :	1 1 1 1

Source: https://kazemnejad.com/blog/transformer_architecture_positional_encoding/

- Sounds good, we have numbers between 0 and 1, and we just need to use enough bits to encode very long sentences.
- However, representing a binary value (0 or 1) with a 64 bits floating number is a waste of computational resources.

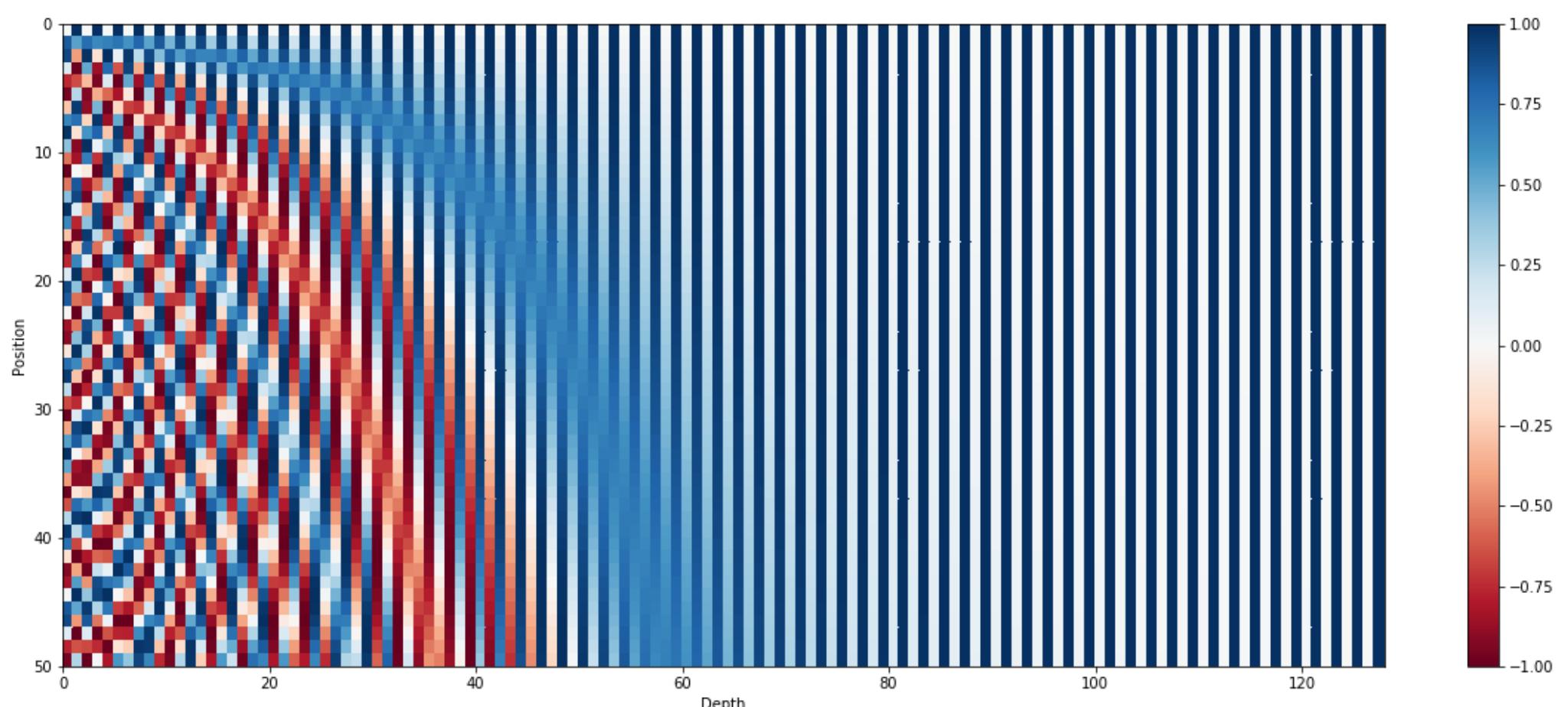
Positional encoding

- We can notice that the bits of the integers oscillate at various frequencies:

- the lower bit oscillates every number.
 - the bit before oscillates every two numbers.
 - etc.

0 :	0	0	0	0	8 :	1	0	0	0
1 :	0	0	0	1	9 :	1	0	0	1
2 :	0	0	1	0	10 :	1	0	1	0
3 :	0	0	1	1	11 :	1	0	1	1
4 :	0	1	0	0	12 :	1	1	0	0
5 :	0	1	0	1	13 :	1	1	0	1
6 :	0	1	1	0	14 :	1	1	1	0
7 :	0	1	1	1	15 :	1	1	1	1

- We could also represent the position of a word using sine and cosine functions at different frequencies (Fourier basis).
- We create a vector, where each element oscillates at increasing frequencies.
- The “code” for each position in the sentence is unique.

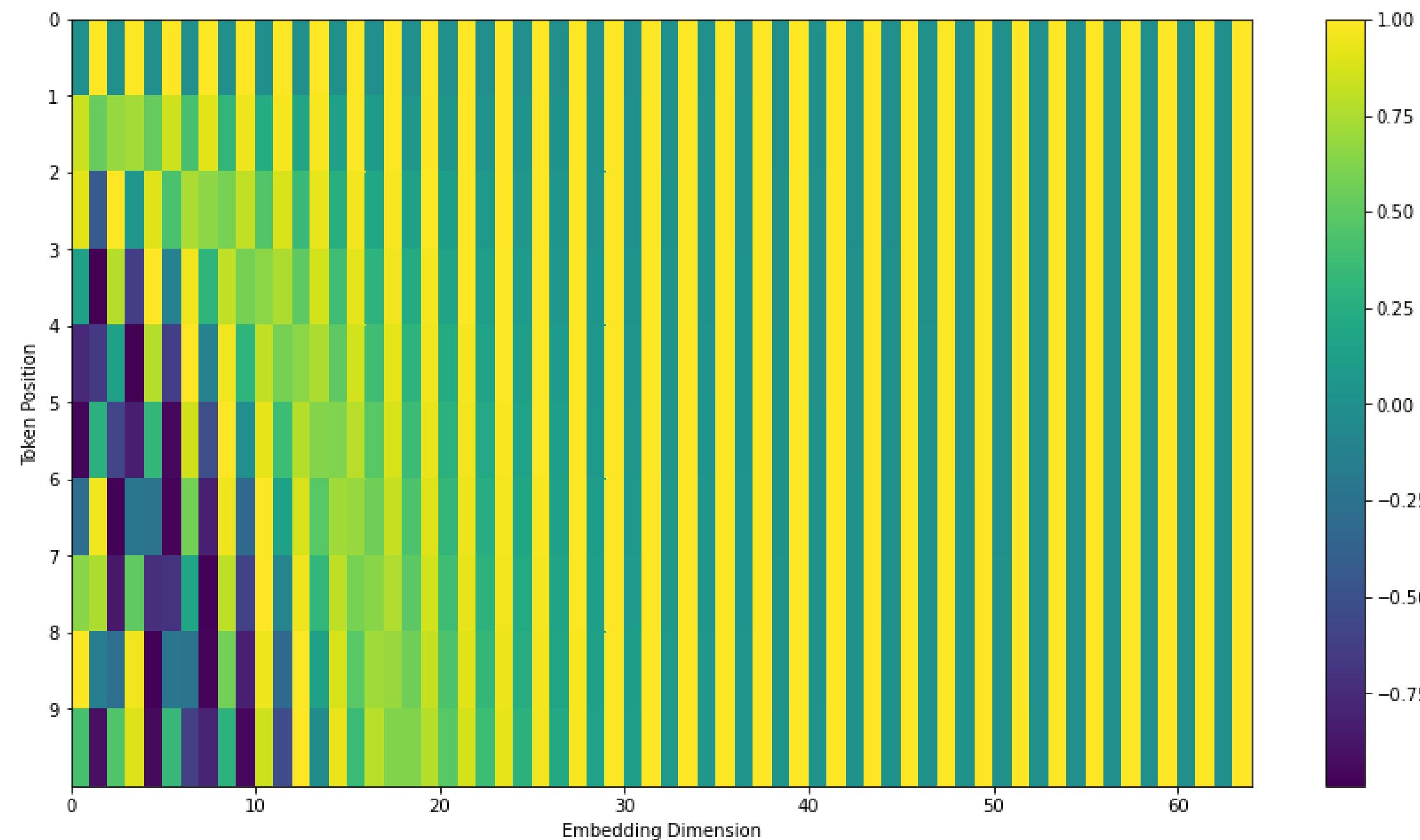


Source: https://kazemnejad.com/blog/transformer_architecture_positional_encoding/

Positional encoding

- In practice, a 512-d vector is created using sine and cosine functions.

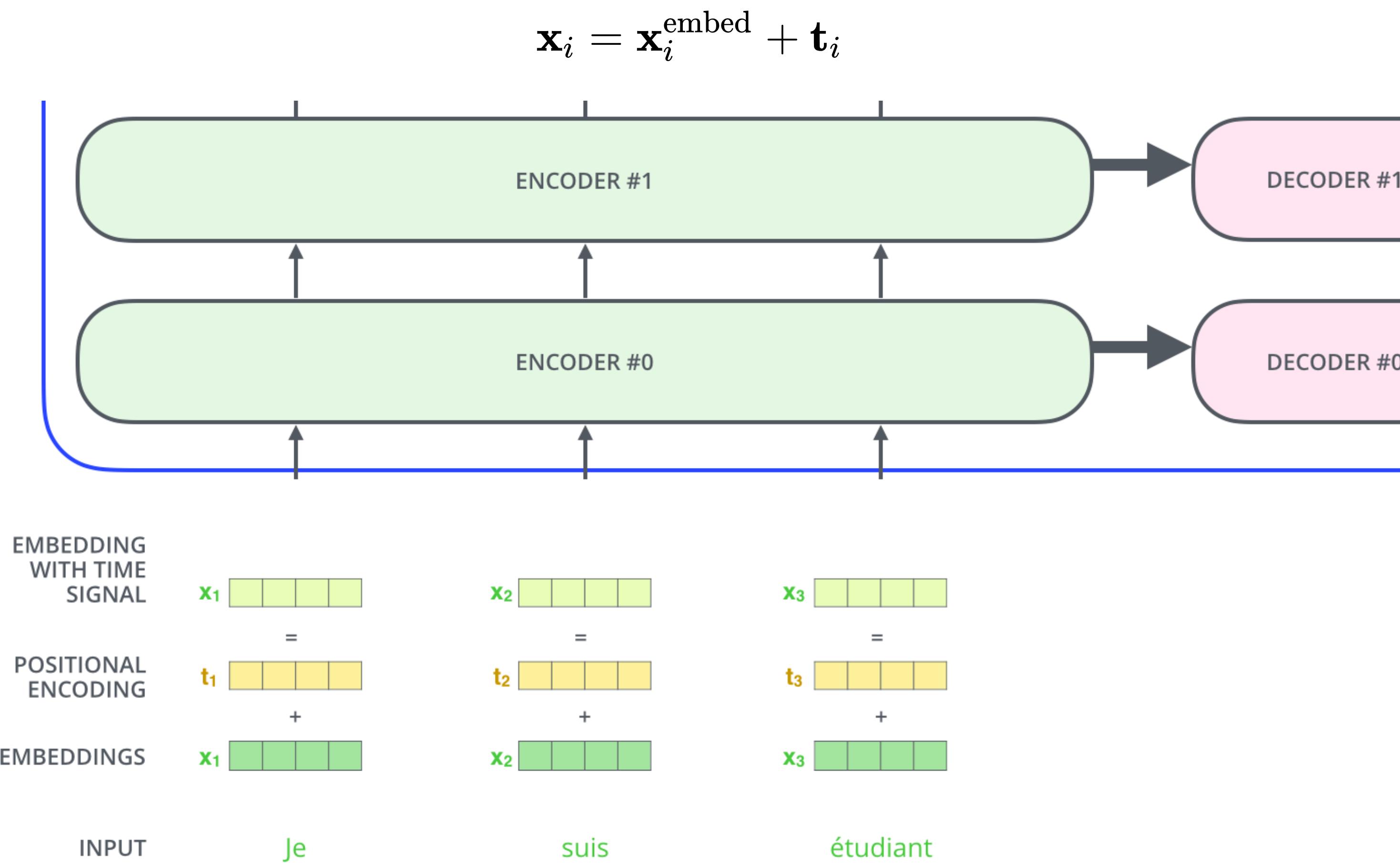
$$\begin{cases} t(\text{pos}, 2i) = \sin\left(\frac{\text{pos}}{10000^{2i/512}}\right) \\ t(\text{pos}, 2i + 1) = \cos\left(\frac{\text{pos}}{10000^{2i/512}}\right) \end{cases}$$



Source: <http://jalammar.github.io/illustrated-transformer/>

Positional encoding

- The positional encoding vector is **added** element-wise to the embedding, not concatenated!



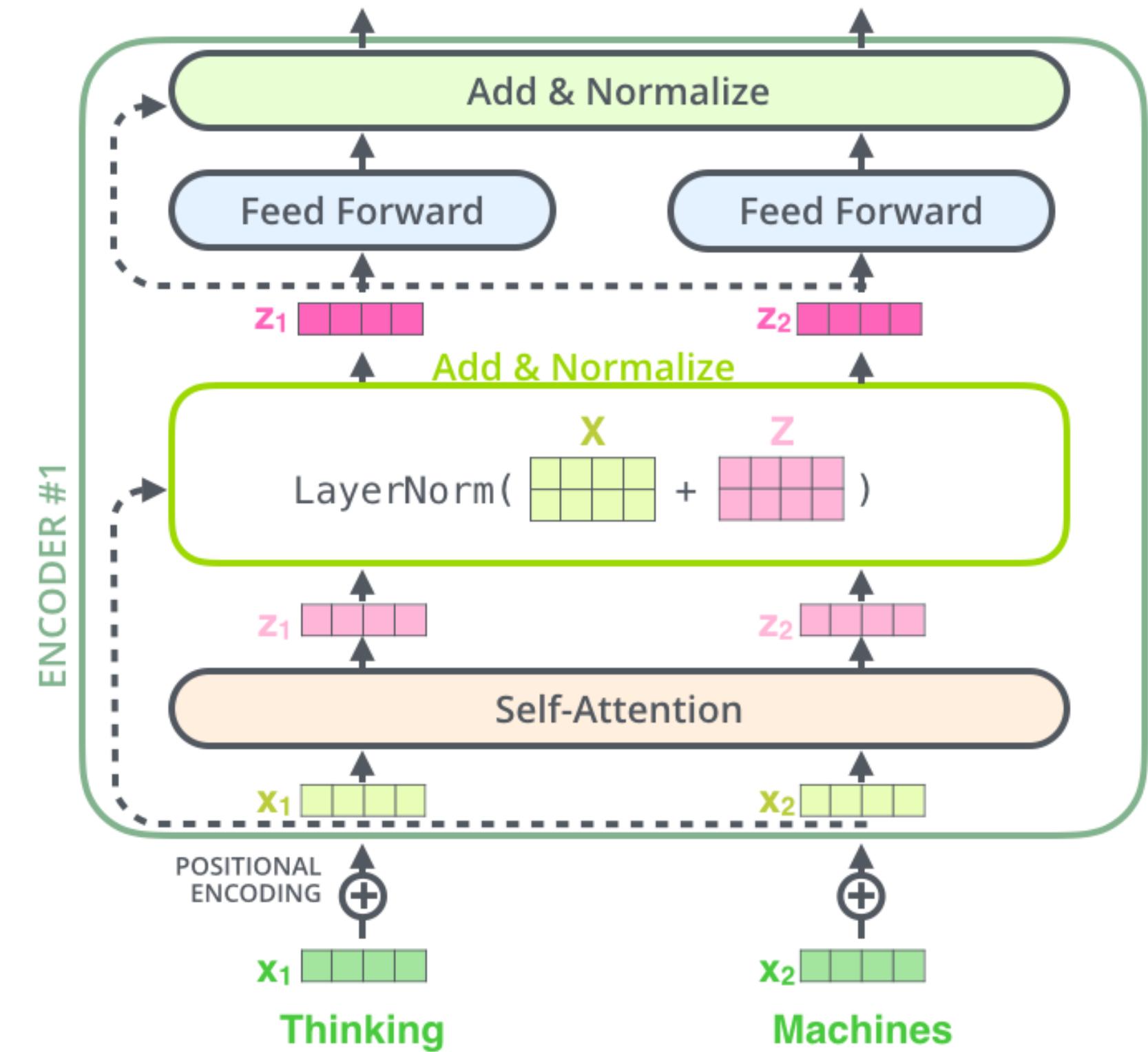
Source: <http://jalammar.github.io/illustrated-transformer/>

Encoder layer

- Last tricks of the encoder layers:
 - skip connections (residual layer)
 - layer normalization
- The input X is added to the output of the multi-headed self-attention and normalized (zero mean, unit variance).
- **Layer normalization** (Ba et al., 2016) is an alternative to batch normalization, where the mean and variance are computed over single vectors, not over a minibatch:

$$\mathbf{z} \leftarrow \frac{\mathbf{z} - \mu}{\sigma}$$

with $\mu = \frac{1}{d} \sum_{i=1}^d z_i$ and $\sigma = \sqrt{\frac{1}{d} \sum_{i=1}^d (z_i - \mu)^2}$.

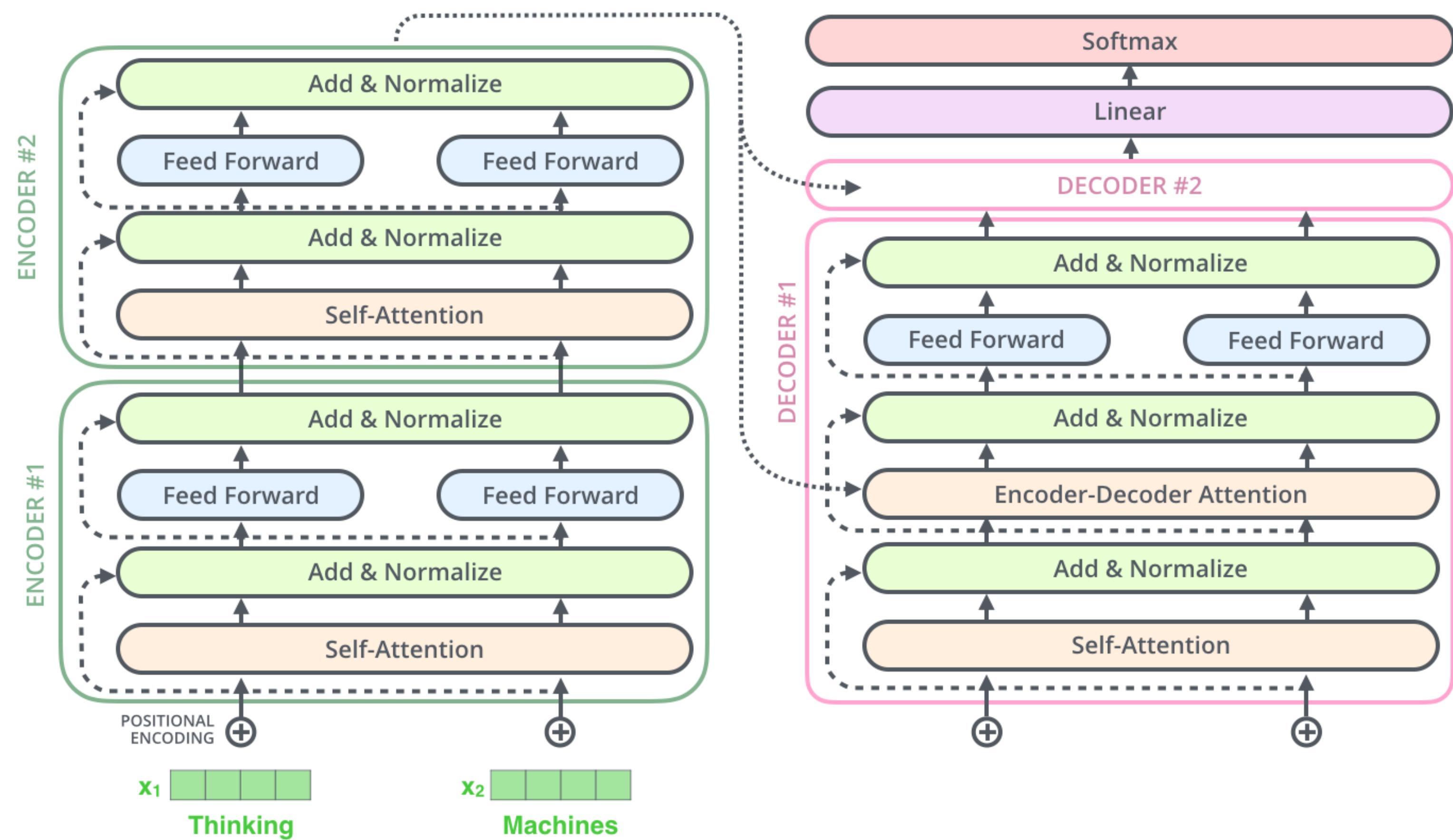


Source: <http://jalammar.github.io/illustrated-transformer/>

- The feedforward network also uses a skip connection and layer normalization.

Encoder

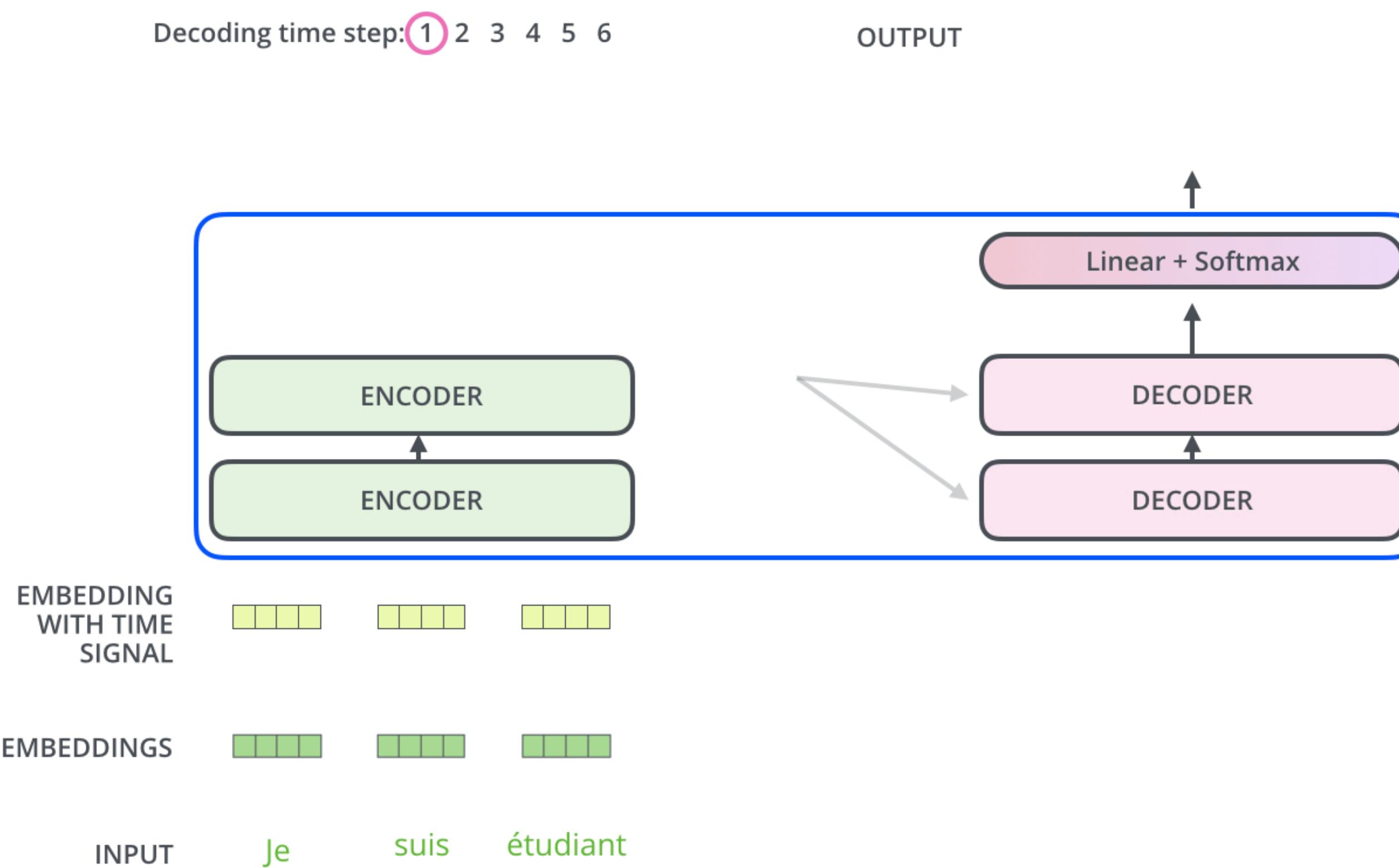
- We can now stack 6 (or more, 96 in GPT-3) of these encoder layers and use the final representation of each word as an input to the decoder.



Source: <http://jalammar.github.io/illustrated-transformer/>

Decoder

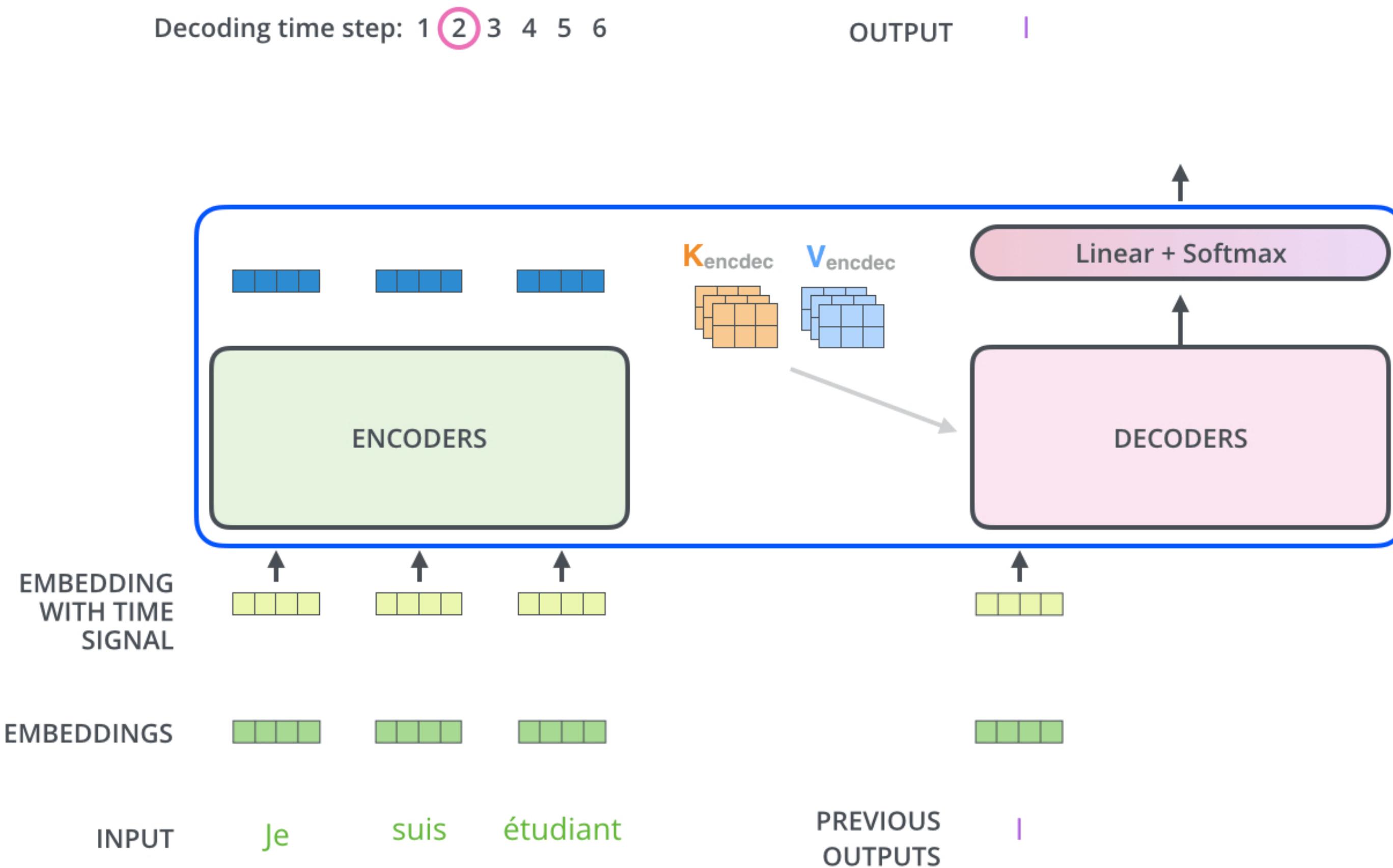
- In the first step of decoding, the final representations of the encoder are used as query and value vectors of the decoder to produce the first word.
- The input to the decoder is a “start of sentence” symbol.



Source: <http://jalammar.github.io/illustrated-transformer/>

Decoder

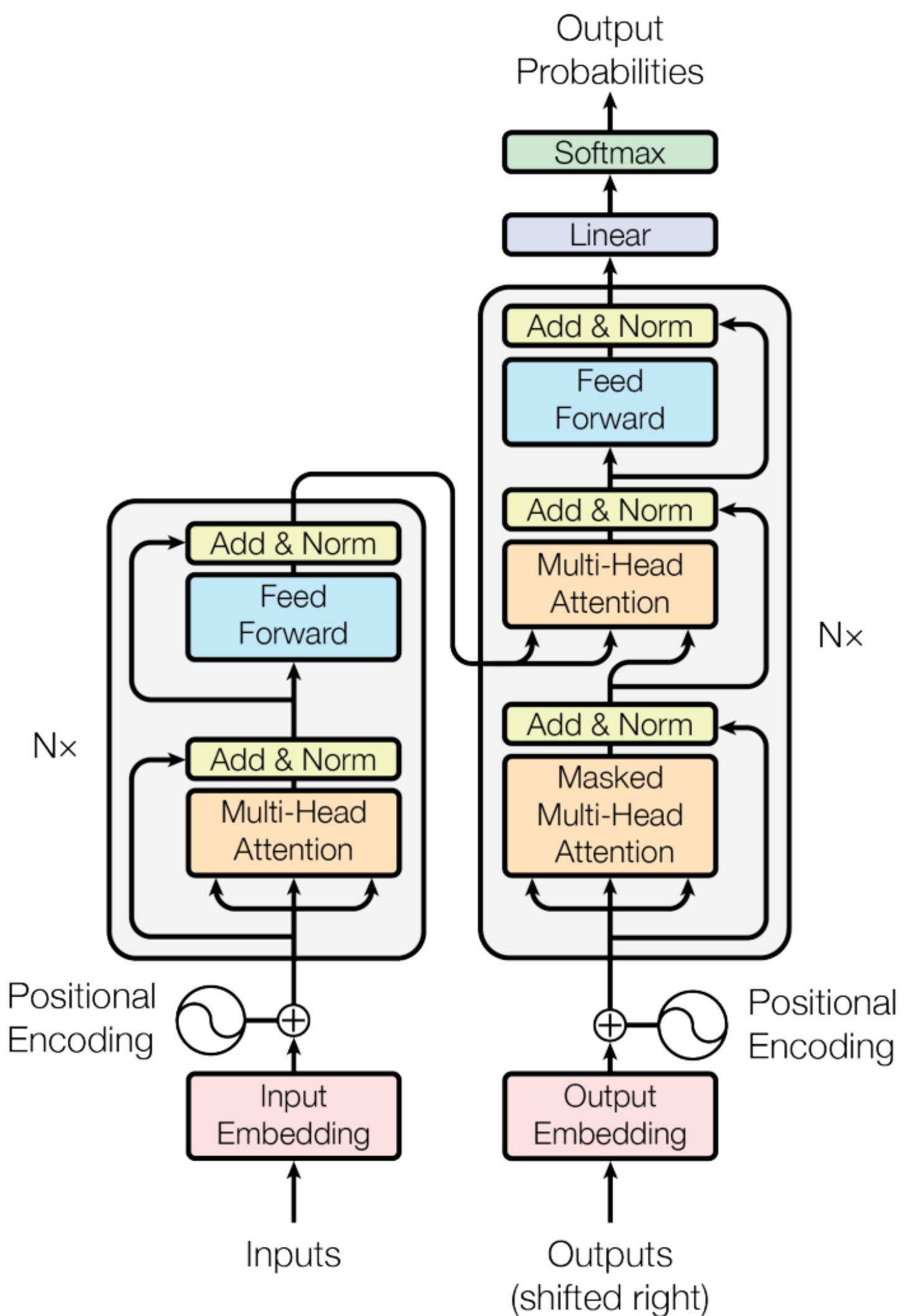
- The decoder is **autoregressive**: it outputs words one at a time, using the previously generated words as an input.



Source: <http://jalammar.github.io/illustrated-transformer/>

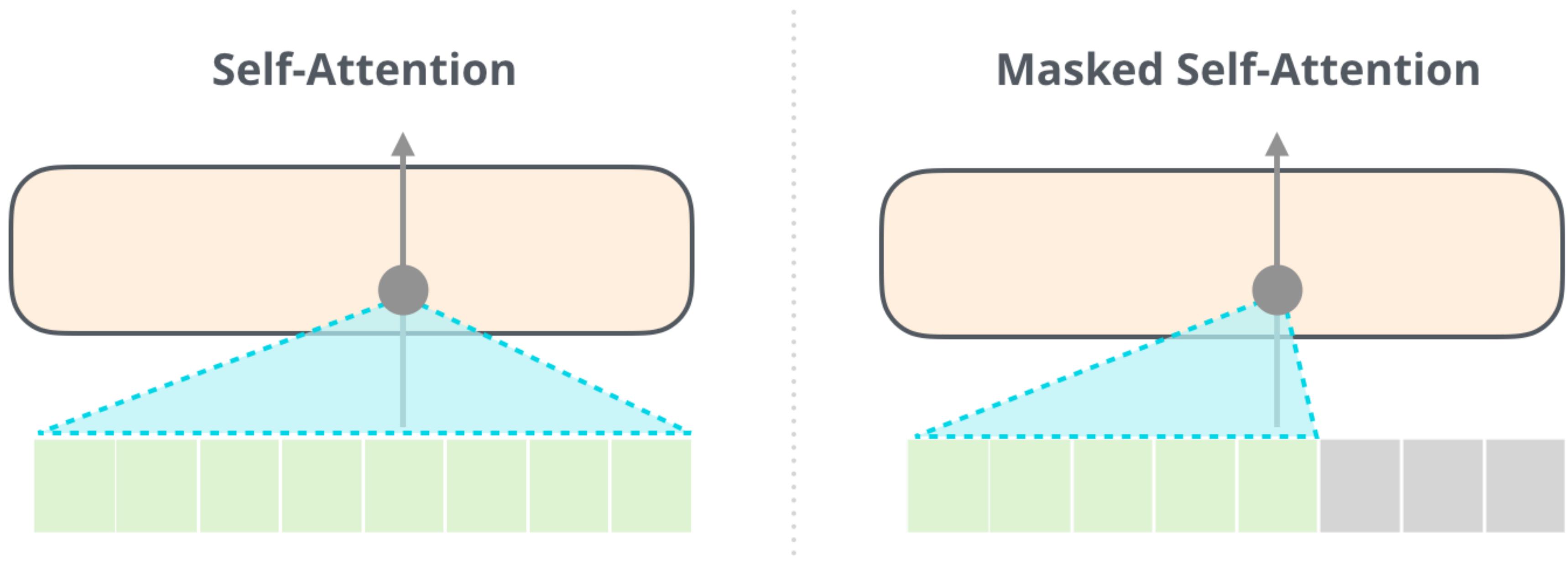
Decoder layer

- Each decoder layer has two multi-head attention sub-layers:
 - A self-attention sub-layer with query/key/values coming from the generated sentence.
 - An **encoder-decoder** attention sub-layer, with the query coming from the generated sentence and the key/value from the encoder.
- The encoder-decoder attention is the regular attentional mechanism used in seq2seq architectures.
- Apart from this additional sub-layer, the same residual connection and layer normalization mechanisms are used.



Masked self-attention

- When the sentence has been fully generated (up to the `<eos>` symbol), **masked self-attention** has to be applied in order for a word in the middle of the sentence to not “see” the solution in the input when learning.
- As usual, learning occurs on minibatches of sentences, not on single words.



Source: <https://jalammar.github.io/illustrated-gpt2/>

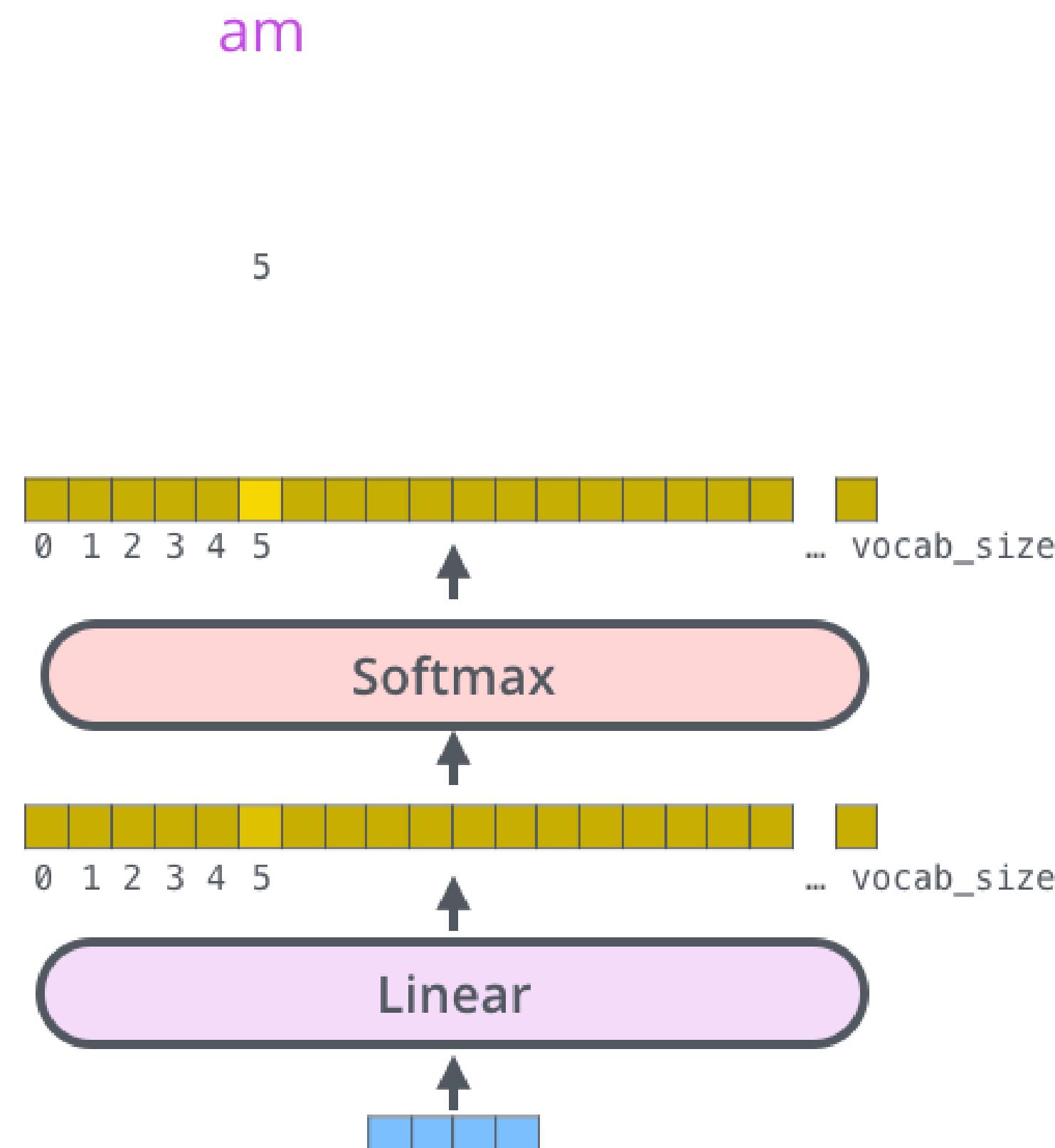
Output

- The output of the decoder is a simple softmax classification layer, predicting the one-hot encoding of the word using a vocabulary (`vocab_size=25000`).

Which word in our vocabulary
is associated with this index?

Get the index of the cell
with the highest value
(`argmax`)

`log_probs`
`logits`
Decoder stack output



Source: <http://jalammar.github.io/illustrated-transformer/>

Training procedure

- The transformer is trained on the WMT datasets:
 - English-French: 36M sentences, 32000 unique words.
 - English-German: 4.5M sentences, 37000 unique words.
- Cross-entropy loss, Adam optimizer with scheduling, dropout. Training took 3.5 days on 8 P100 GPUs.
- The sentences can have different lengths, as the decoder is autoregressive.
- The transformer network beat the state-of-the-art performance in translation with less computations and without any RNN.

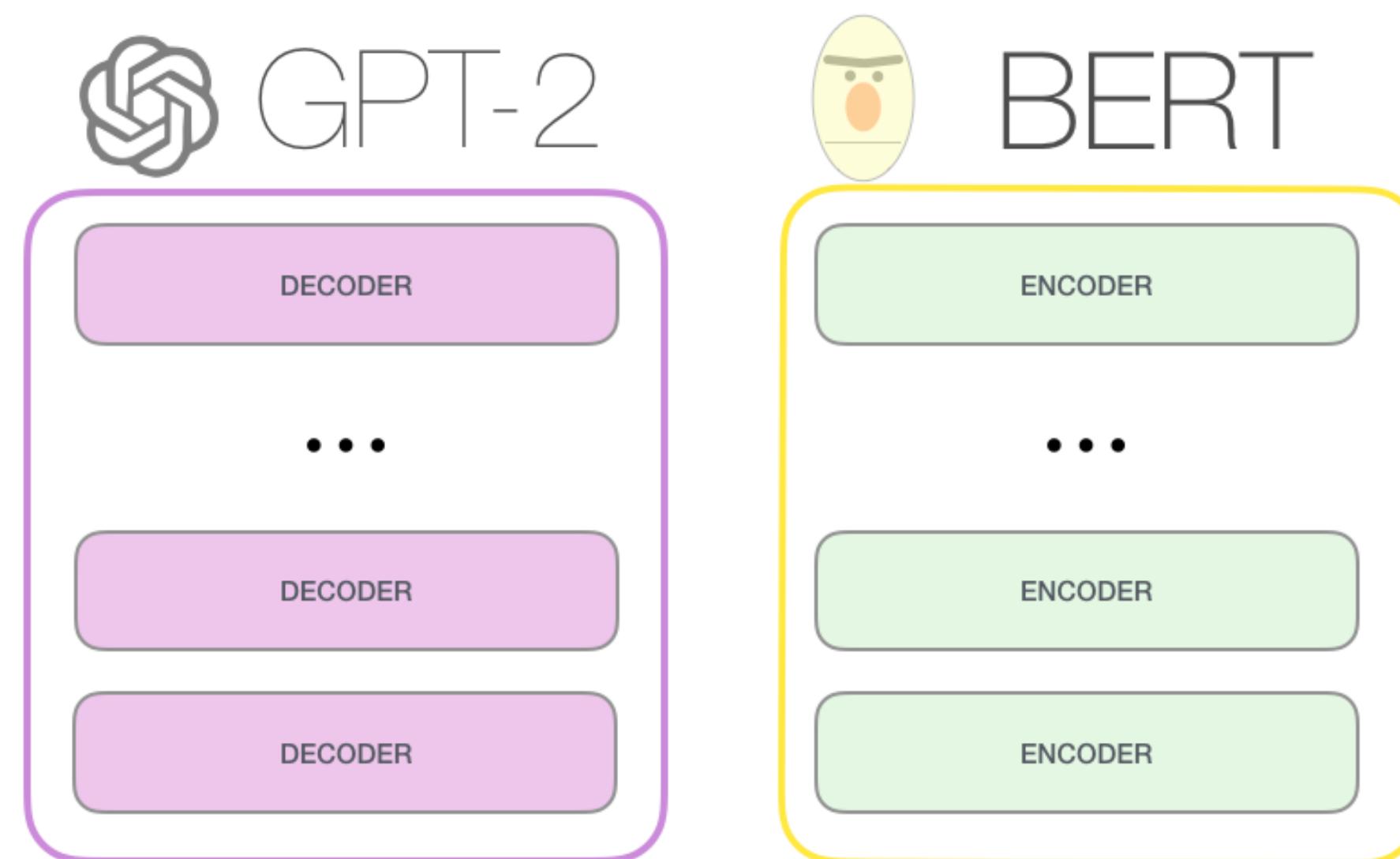
Table 2: The Transformer achieves better BLEU scores than previous state-of-the-art models on the English-to-German and English-to-French newstest2014 tests at a fraction of the training cost.

Model	BLEU		Training Cost (FLOPs)	
	EN-DE	EN-FR	EN-DE	EN-FR
ByteNet [18]	23.75			
Deep-Att + PosUnk [39]		39.2		$1.0 \cdot 10^{20}$
GNMT + RL [38]	24.6	39.92	$2.3 \cdot 10^{19}$	$1.4 \cdot 10^{20}$
ConvS2S [9]	25.16	40.46	$9.6 \cdot 10^{18}$	$1.5 \cdot 10^{20}$
MoE [32]	26.03	40.56	$2.0 \cdot 10^{19}$	$1.2 \cdot 10^{20}$
Deep-Att + PosUnk Ensemble [39]		40.4		$8.0 \cdot 10^{20}$
GNMT + RL Ensemble [38]	26.30	41.16	$1.8 \cdot 10^{20}$	$1.1 \cdot 10^{21}$
ConvS2S Ensemble [9]	26.36	41.29	$7.7 \cdot 10^{19}$	$1.2 \cdot 10^{21}$
Transformer (base model)	27.3	38.1		$3.3 \cdot 10^{18}$
Transformer (big)	28.4	41.8		$2.3 \cdot 10^{19}$

2 - Self-supervised transformers

Transformer-based language models

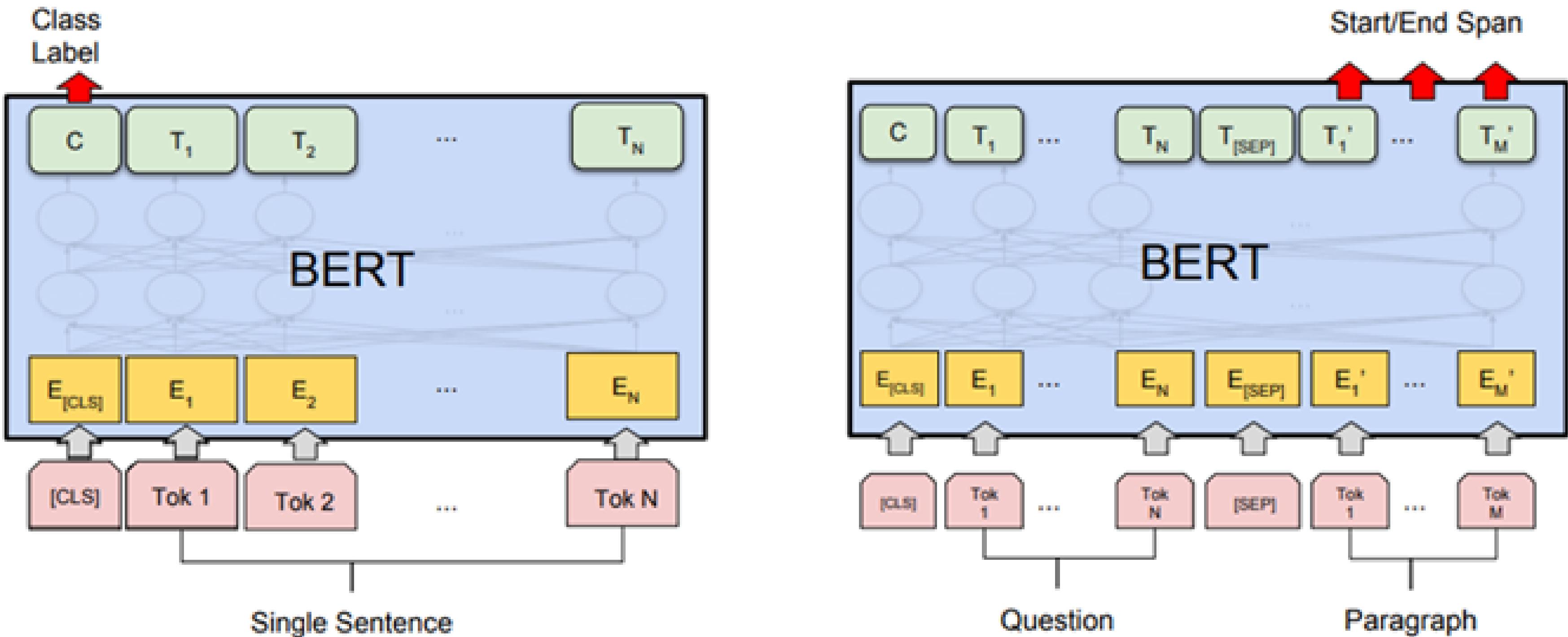
- The Transformer is considered as the **AlexNet** moment of natural language processing (NLP).
- However, it is limited to supervised learning of sentence-based translation.
- Two families of architectures have been developed from that idea to perform all NLP tasks using **unsupervised pretraining** or **self-supervised training**:
 - BERT (Bidirectional Encoder Representations from Transformers) from Google.
 - GPT (Generative Pre-trained Transformer) from OpenAI <https://openai.com/blog/better-language-models/>.



Source: <https://jalammar.github.io/illustrated-gpt2/>

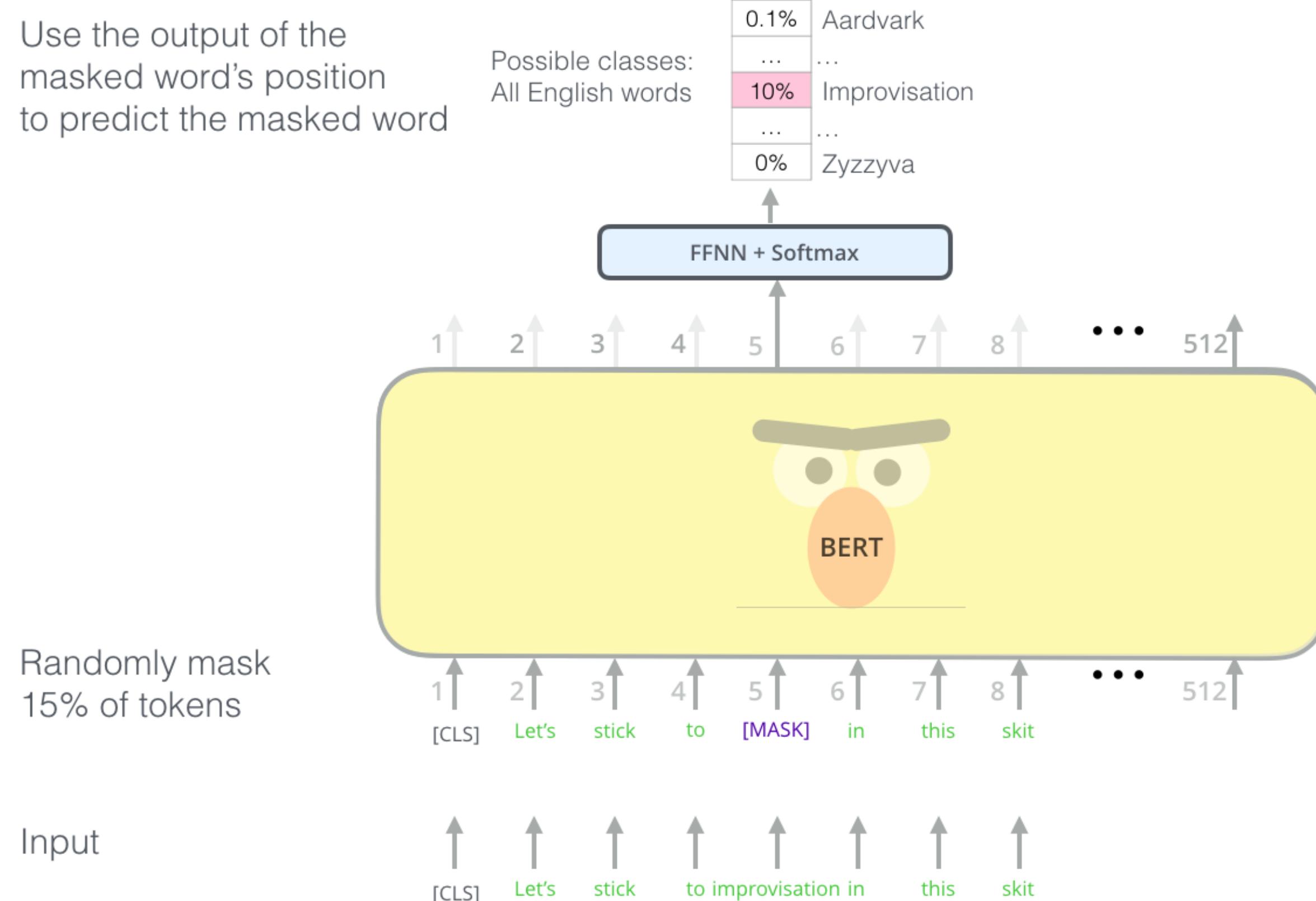
BERT - Bidirectional Encoder Representations from Transformers

- BERT only uses the encoder of the transformer (12 layers, 12 attention heads, $d = 768$).
- BERT is pretrained on two different unsupervised tasks before being fine-tuned on supervised tasks.



BERT - Bidirectional Encoder Representations from Transformers

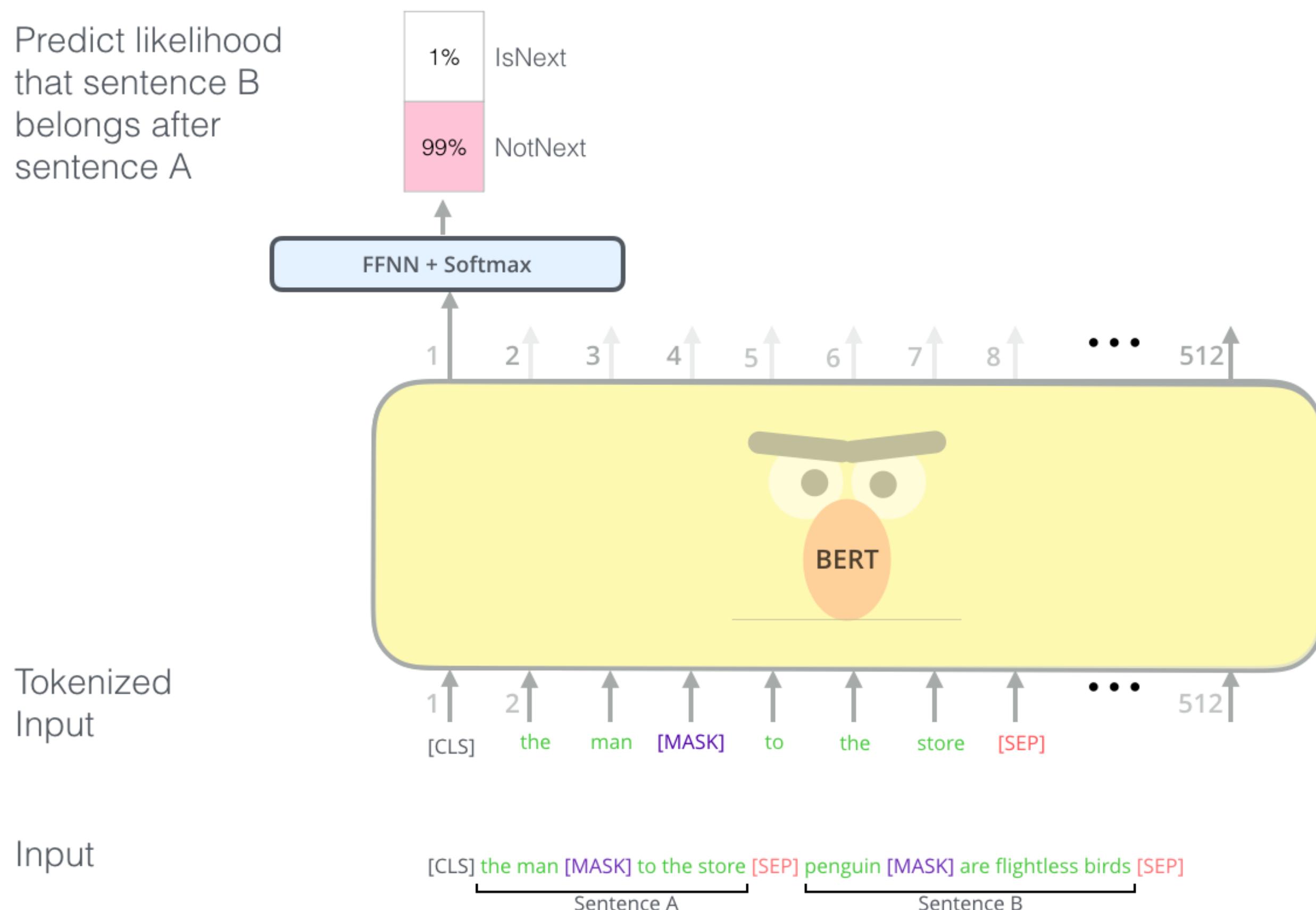
- **Task 1:** Masked language model. Sentences from BooksCorpus and Wikipedia (3.3G words) are presented to BERT during pre-training, with 15% of the words masked.
- The goal is to predict the masked words from the final representations using a shallow FNN.



Source: <https://jalammar.github.io/illustrated-bert/>

BERT - Bidirectional Encoder Representations from Transformers

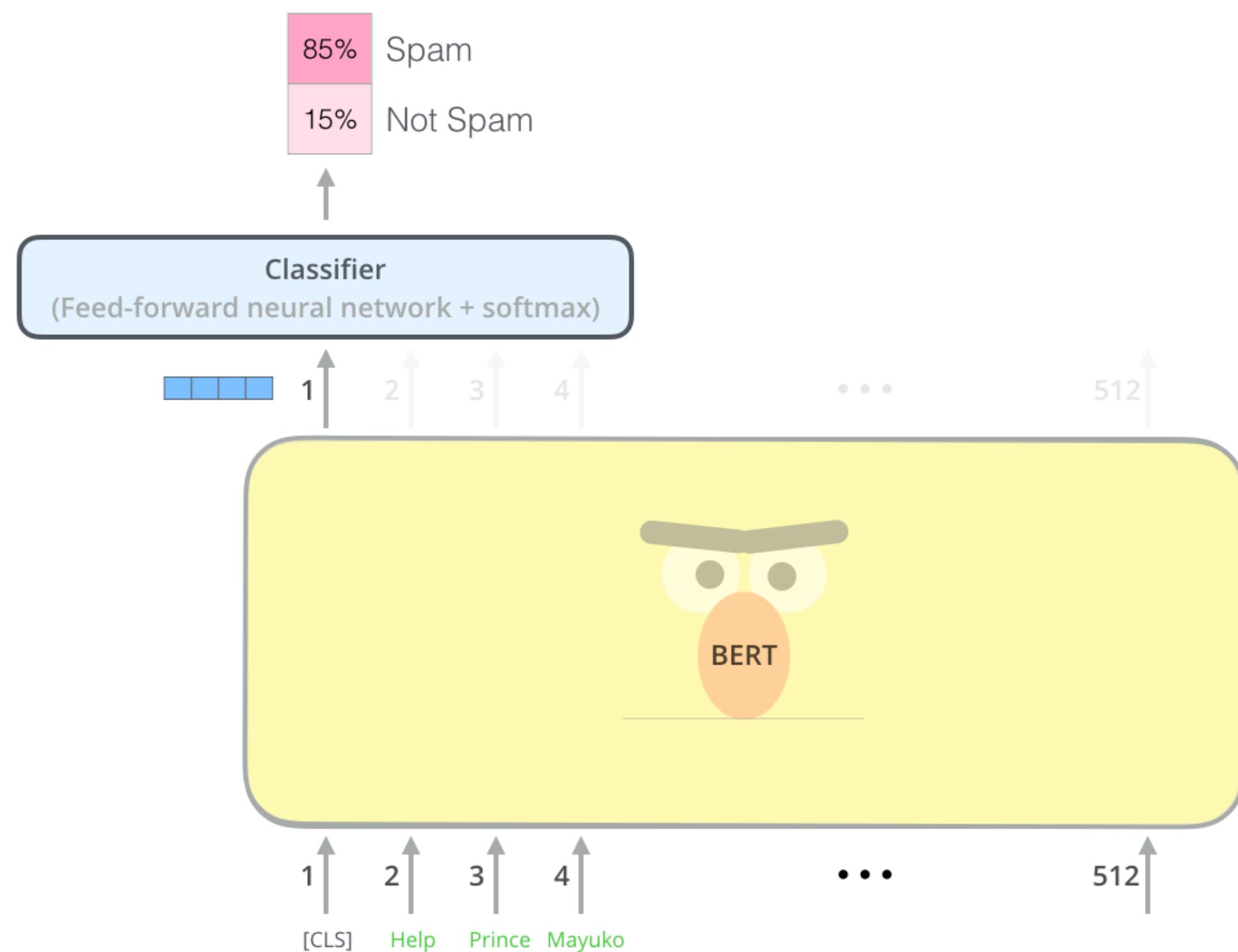
- **Task 2:** Next sentence prediction. Two sentences are presented to BERT.
- The goal is to predict from the first representation whether the second sentence should follow the first.



Source: <https://jalammar.github.io/illustrated-bert/>

BERT - Bidirectional Encoder Representations from Transformers

- Once BERT is pretrained, one can use **transfer learning** with or without fine-tuning from the high-level representations to perform:
 - sentiment analysis / spam detection
 - question answering

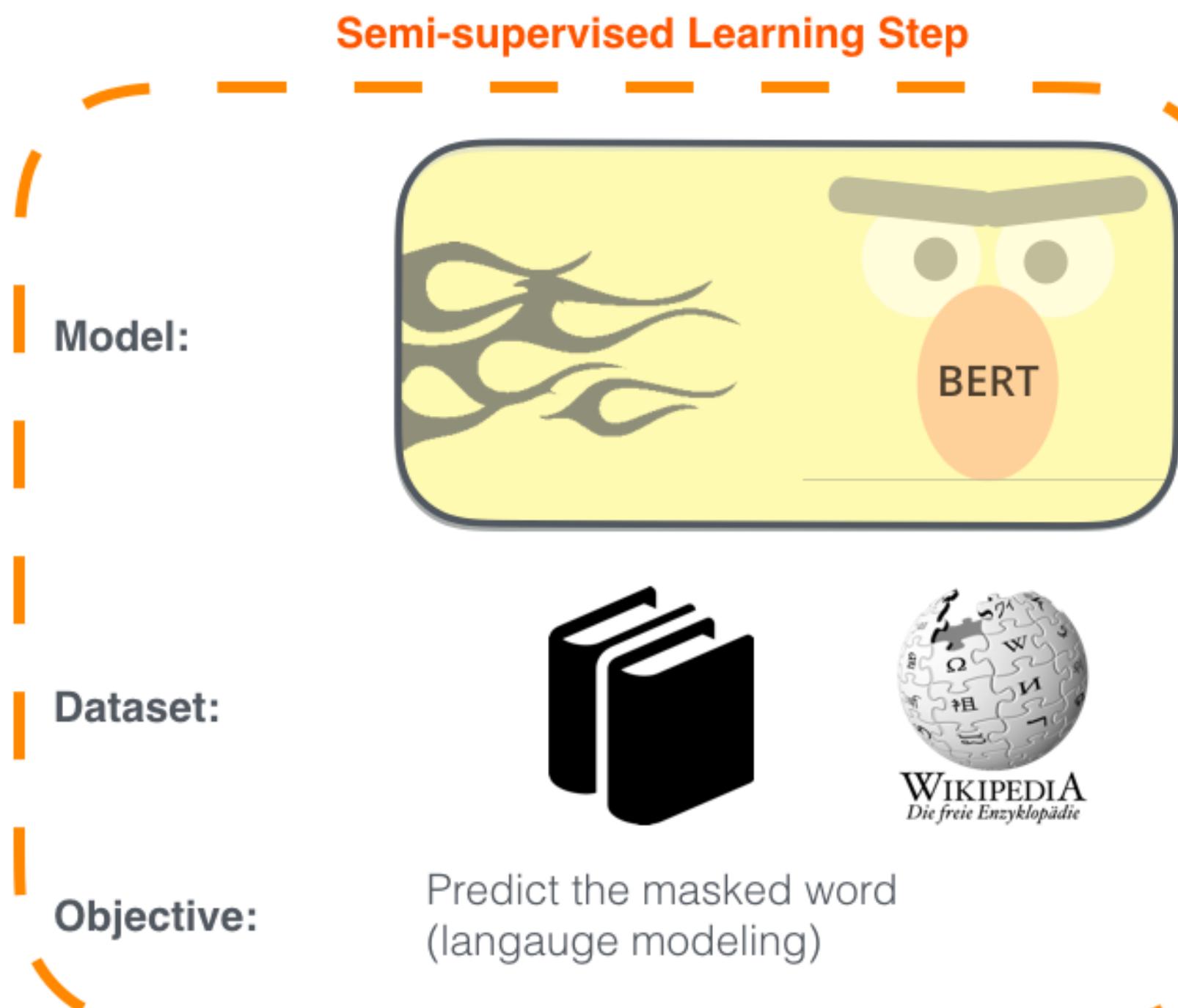


Source: <https://jalammar.github.io/illustrated-bert/>

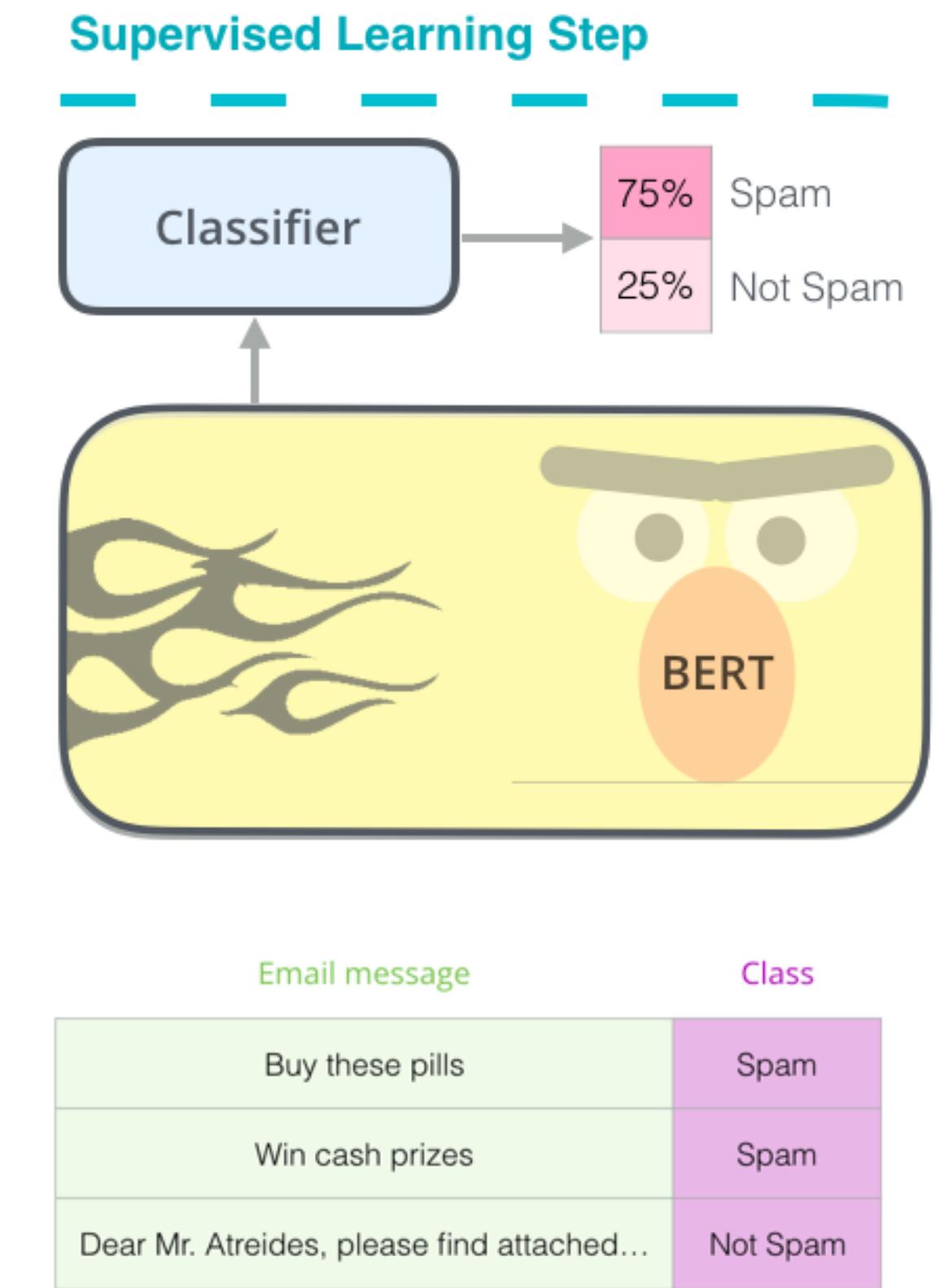
BERT - Bidirectional Encoder Representations from Transformers

1 - **Semi-supervised** training on large amounts of text (books, wikipedia..etc).

The model is trained on a certain task that enables it to grasp patterns in language. By the end of the training process, BERT has language-processing abilities capable of empowering many models we later need to build and train in a supervised way.



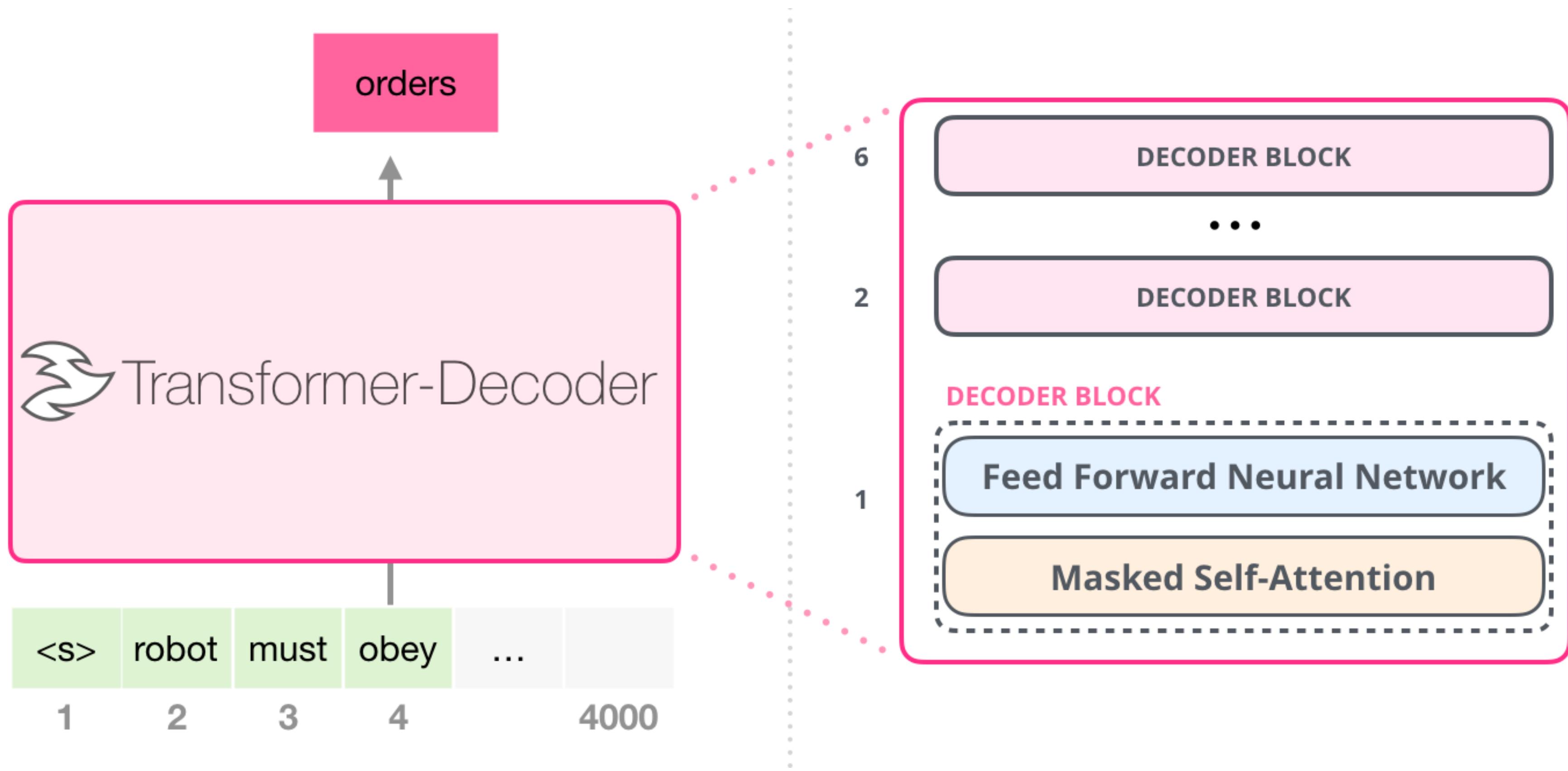
2 - **Supervised** training on a specific task with a labeled dataset.



Source: <https://jalammar.github.io/illustrated-bert/>

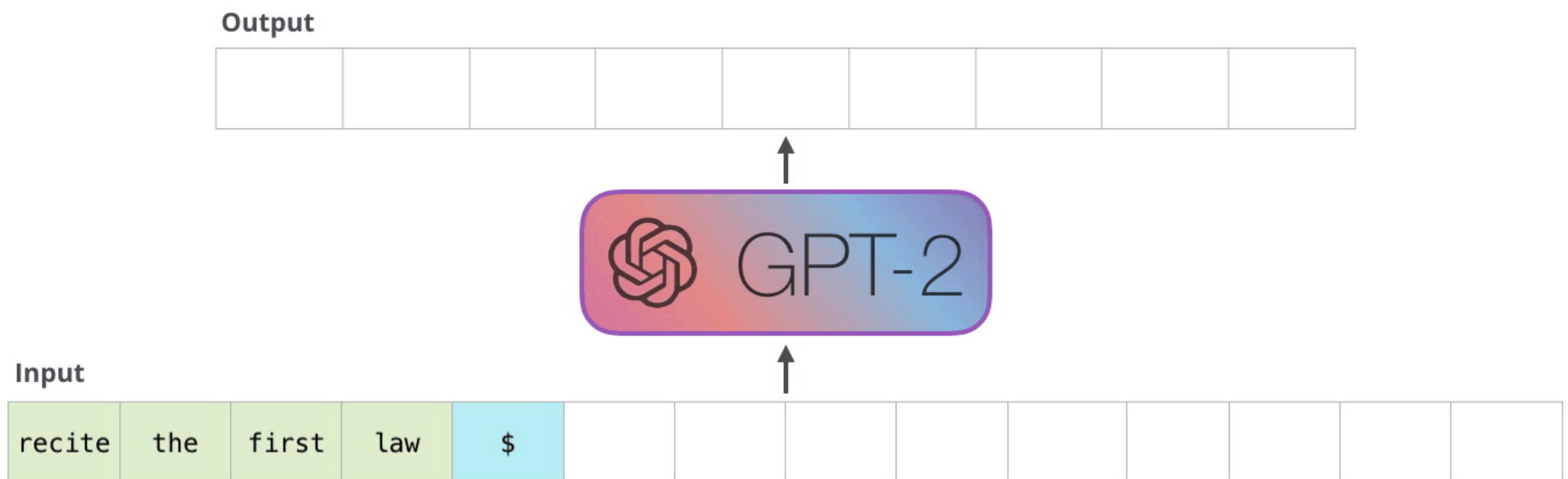
GPT - Generative Pre-trained Transformer

- As the Transformer, GPT is an **autoregressive** language model learning to predict the next word using only the transformer's **decoder**.



Source: <https://jalammar.github.io/illustrated-gpt2/>

GPT - Generative Pre-trained Transformer



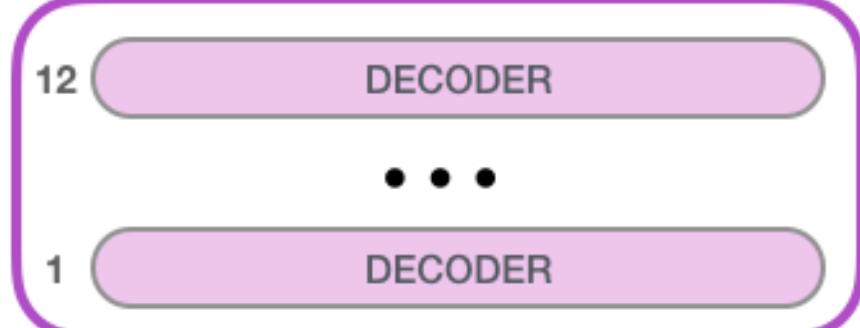
Source: <https://jalammar.github.io/illustrated-gpt2/>

GPT - Generative Pre-trained Transformer

- GPT-2 comes in various sizes, with increasing performance.
- GPT-3 is even bigger, with 175 **billion** parameters and a much larger training corpus.



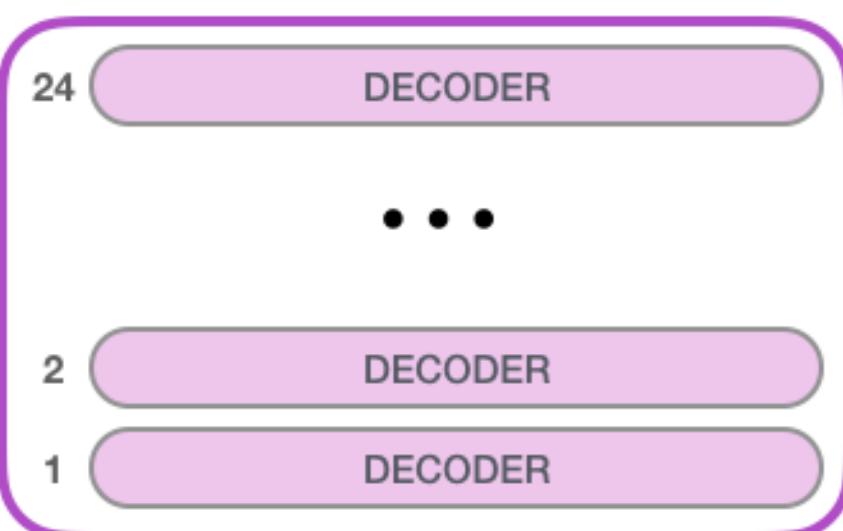
GPT-2
SMALL



Model Dimensionality: 768



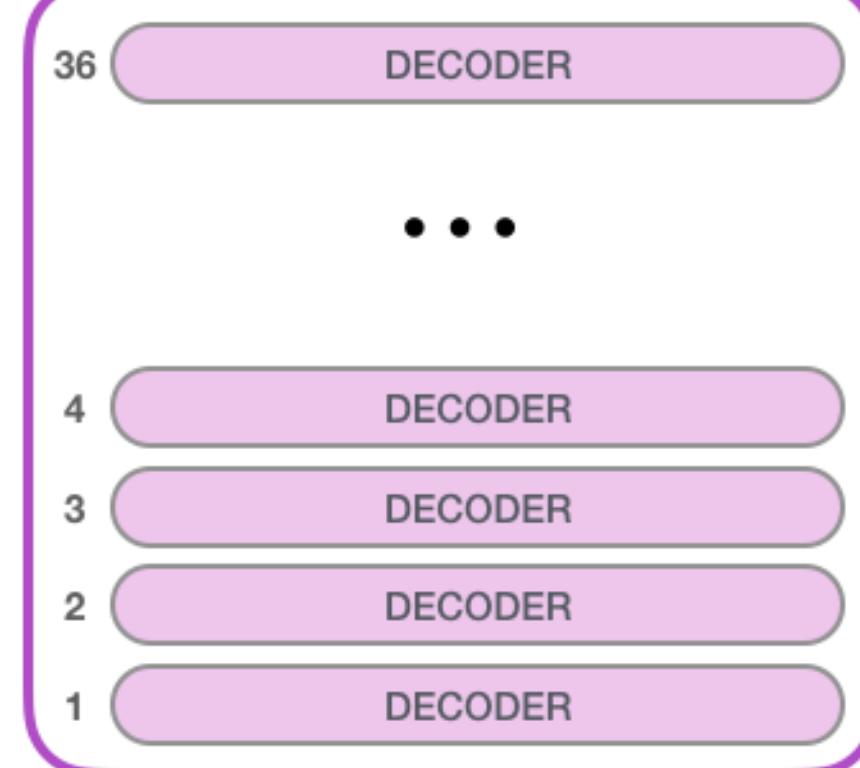
GPT-2
MEDIUM



Model Dimensionality: 1024



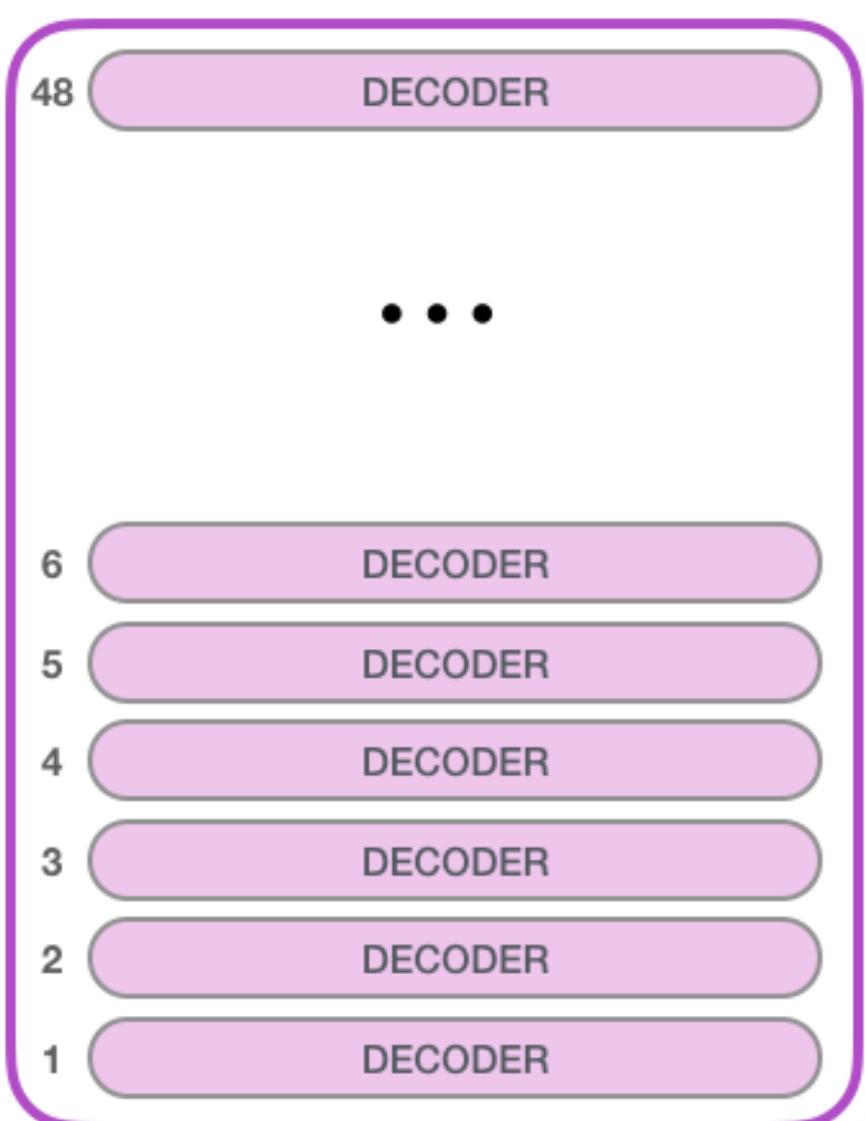
GPT-2
LARGE



Model Dimensionality: 1280



GPT-2
EXTRA
LARGE



Model Dimensionality: 1600

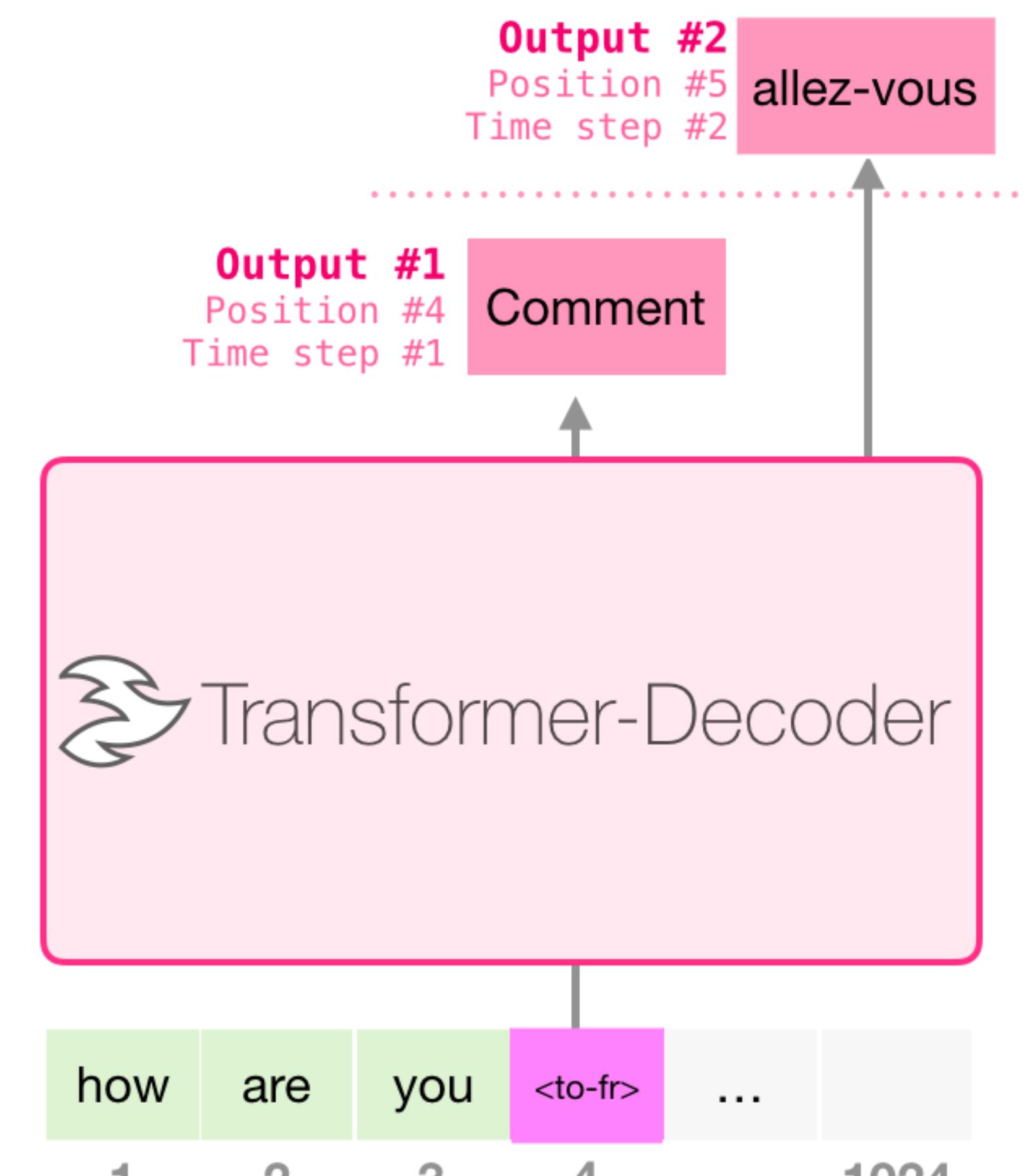
Source: <https://jalammar.github.io/illustrated-gpt2/>

GPT - Generative Pre-trained Transformer

- GPT can be fine-tuned (transfer learning) to perform **machine translation**.

Training Dataset

I	am	a	student	<to-fr>	je	suis	étudiant
let	them	eat	cake	<to-fr>	Qu'ils	mangent	de
good	morning	<to-fr>	Bonjour				



Source: <https://jalammar.github.io/illustrated-gpt2/>

GPT - Generative Pre-trained Transformer

- GPT can be fine-tuned to summarize Wikipedia articles.

The image shows two versions of the same Wikipedia article: "Positronic brain". The left version is the full, detailed article with all sections and references. The right version is a summary of the same article, where most of the content has been removed, leaving only the title, a small introductory snippet, and a large pink box at the bottom containing the word "SUMMARY".

Original Wikipedia Article (Left):

- Header:** Article | Talk | Read | Edit | View history | Search Wikipedia | Log in
- Content:** This article is about a fictional technological device. For the manufacturing company based in Springfield, Missouri, see [Positronic \(company\)](#).
This article needs additional citations for verification. Please help improve this article by adding citations to reliable sources. Unsourced material may be challenged and removed.
A positronic brain is a fictional technological device, originally conceived by science fiction writer Isaac Asimov.^{[1][2]} It functions as a central processing unit (CPU) for robots, and, in some unspecified way, provides them with a form of consciousness recognizable to humans. When Asimov wrote his first robot stories in 1939 and 1940, the positron was a newly discovered particle, and so the buzz word positronic added a contemporary gloss of popular science to the concept. The short story "Runaround", by Asimov, elaborates on the concept, in the context of his fictional Three Laws of Robotics.
- Navigation:** Main page | Contents | Featured content | Current events | Random article | Donate to Wikipedia | Wikipedia store | Interaction | Help | About Wikipedia | Community portal | Recent changes | Contact page | Tools | What links here | Related changes | Upload file | Special pages | Permanent link | Page information | Wikipedia item | Cite this page | Print/export | Create a book | Download as PDF | Printable version | Languages | Español | Français | Italiano | 中文 | Português | Svenska | Türkçe | 3 more | Edit links
- Section Headers:** Contents [hide] | Conceptual overview | In Allen's trilogy | References in other fiction and films | 1. Abbott and Costello Go To Mars | 2. The Avengers | 3. Doctor Who | 4. Star Trek | 5. Perry Rhodan | 6. I, Robot, 2004 Film | 7. Bicentennial Man | 8. Buck Rogers in the 25th Century | 9. Mystery Science Theater 3000 | 10. Specimen | 11. Stellaris | 4. References | 5. External links
- Text Content:** Asimov remained vague about the technical details of positronic brains except to assert that their substructure was formed from an alloy of platinum and iridium. They were said to be vulnerable to radiation and apparently involve a type of volatile memory (since robots in storage required a power source keeping their brains "alive"). The focus of Asimov's stories was directed more towards the software of robots—such as the Three Laws of Robotics—than the hardware in which it was implemented, although it is stated in his stories that to create a positronic brain without the Three Laws, it would have been necessary to spend years redesigning the fundamental approach towards the brain itself.
Within his stories of robotics on Earth and their development by U.S. Robots, Asimov's positronic brain is less of a plot device and more of a technological item worthy of study.
A positronic brain cannot ordinarily be built without incorporating the Three Laws; any modification thereof would drastically modify robot behavior. Behavioral dilemmas resulting from conflicting potentials set by inexperienced and/or malicious users of the robot for the Three Laws make up the bulk of Asimov's stories concerning robots. They are resolved by applying the science of logic and psychology together with mathematics, the supreme solution finder being Dr. Susan Calvin, Chief Robopsychologist of U.S. Robots.
The Three Laws are also a bottleneck in brain sophistication. Very complex brains designed to handle world economy interpret the First Law in expanded sense to include humanity as opposed to a single human; in Asimov's later works like *Robots and Empire* this is referred to as the "Zeroth Law". At least one brain constructed as a calculating machine, as opposed to being a robot control circuit, was designed to have a flexible, childlike personality so that it was able to pursue difficult problems without the Three Laws inhibiting it completely. Specialized brains created for overseeing world economics were stated to have no personality at all.
Under specific conditions, the Three Laws can be obviated, with the modification of the actual robotic design.
 - Robots that are of low enough value can have the **Third Law** deleted; they do not have to protect themselves from harm, and the brain size can be reduced by half.
 - Robots that do not require orders from a human being may have the **Second Law** deleted, and therefore require smaller brains again, providing they do not require the **Third Law**.
 - Robots that are disposable, cannot receive orders from a human being and are not able to harm a human, will not require even the **First Law**. The sophistication of positronic circuitry renders a brain so small that it could comfortably fit within the skull of an insect.Robots of the latter type directly parallel contemporary industrial robotics practice, though real-life robots do contain safety sensors and systems, in a concern for human safety (a weak form of the First Law; the robot is a safe tool to use, but has no "judgment", which is implicit in Asimov's own stories).
- Section Headers:** In Allen's trilogy | edit
- Text Content:** Several robot stories have been written by other authors following Asimov's death. For example, in Roger MacBride Allen's Caliban trilogy, a Spacer robotologist called Gubber Anshaw invents the gravitonic brain. It offers speed and capacity improvements over traditional positronic designs, but the strong influence of tradition make robotics labs reject Anshaw's work. Only one robotologist, Fredd Leving, chooses to adopt gravitonics, because it offers her a blank slate on which she could explore alternatives to the Three Laws. Because they are not dependent upon centuries of earlier research, gravitonic brains can be programmed with the standard Laws, variations of the Laws, or even empty pathways which specify no Laws at all.

Summary Wikipedia Article (Right):

- Header:** Article | Talk | Read | Edit | View history | Search Wikipedia | Log in
- Content:** This article is about a fictional technological device. For the manufacturing company based in Springfield, Missouri, see [Positronic \(company\)](#).
This article needs additional citations for verification. Please help improve this article by adding citations to reliable sources. Unsourced material may be challenged and removed.
A positronic brain is a fictional technological device, originally conceived by science fiction writer Isaac Asimov.^{[1][2]} It functions as a central processing unit (CPU) for robots, and, in some unspecified way, provides them with a form of consciousness recognizable to humans. When Asimov wrote his first robot stories in 1939 and 1940, the positron was a newly discovered particle, and so the buzz word positronic added a contemporary gloss of popular science to the concept. The short story "Runaround", by Asimov, elaborates on the concept, in the context of his fictional Three Laws of Robotics.
- Section Headers:** Contents [hide] | Conceptual overview | In Allen's trilogy | References in other fiction and films | 1. Abbott and Costello Go To Mars | 2. The Avengers | 3. Doctor Who | 4. Star Trek | 5. Perry Rhodan | 6. I, Robot, 2004 Film | 7. Bicentennial Man | 8. Buck Rogers in the 25th Century | 9. Mystery Science Theater 3000 | 10. Specimen | 11. Stellaris | 4. References | 5. External links
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- Section Headers:** In Allen's trilogy | edit
- Text Content:** Several robot stories have been written by other authors following Asimov's death. For example, in Roger MacBride Allen's Caliban trilogy, a Spacer robotologist called Gubber Anshaw invents the gravitonic brain. It offers speed and capacity improvements over traditional positronic designs, but the strong influence of tradition make robotics labs reject Anshaw's work. Only one robotologist, Fredd Leving, chooses to adopt gravitonics, because it offers her a blank slate on which she could explore alternatives to the Three Laws. Because they are not dependent upon centuries of earlier research, gravitonic brains can be programmed with the standard Laws, variations of the Laws, or even empty pathways which specify no Laws at all.

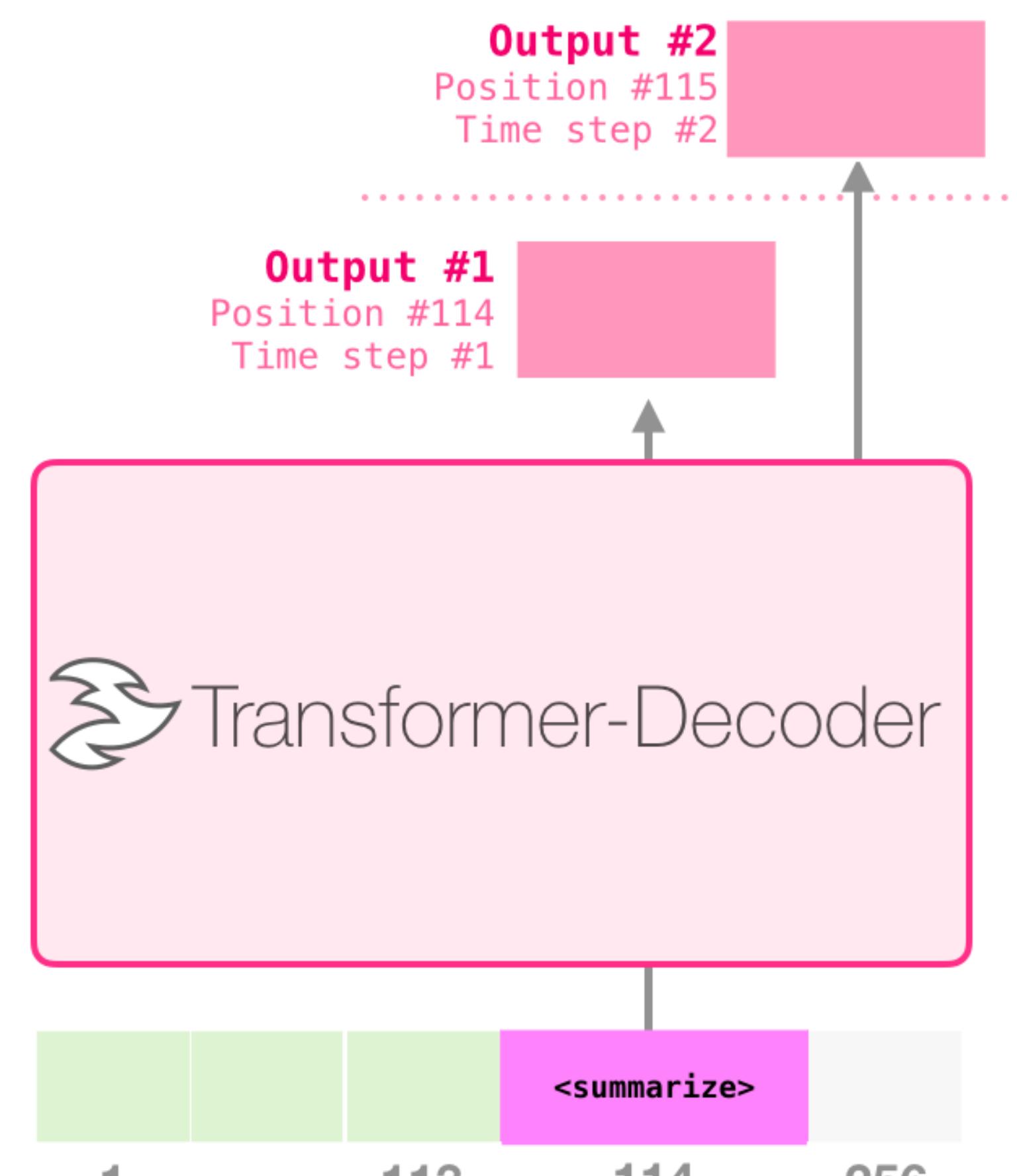
Source: <https://jalammar.github.io/illustrated-gpt2/>

GPT - Generative Pre-trained Transformer

- GPT can be fine-tuned to summarize Wikipedia articles.

Training Dataset

Article #1 tokens		<summarize>	Article #1 Summary	
Article #2 tokens	<summarize>	Article #2 Summary	padding	
Article #3 tokens		<summarize>	Article #3 Summary	



Source: <https://jalammar.github.io/illustrated-gpt2/>

Try transformers at <https://huggingface.co/>

`pip install transformers`

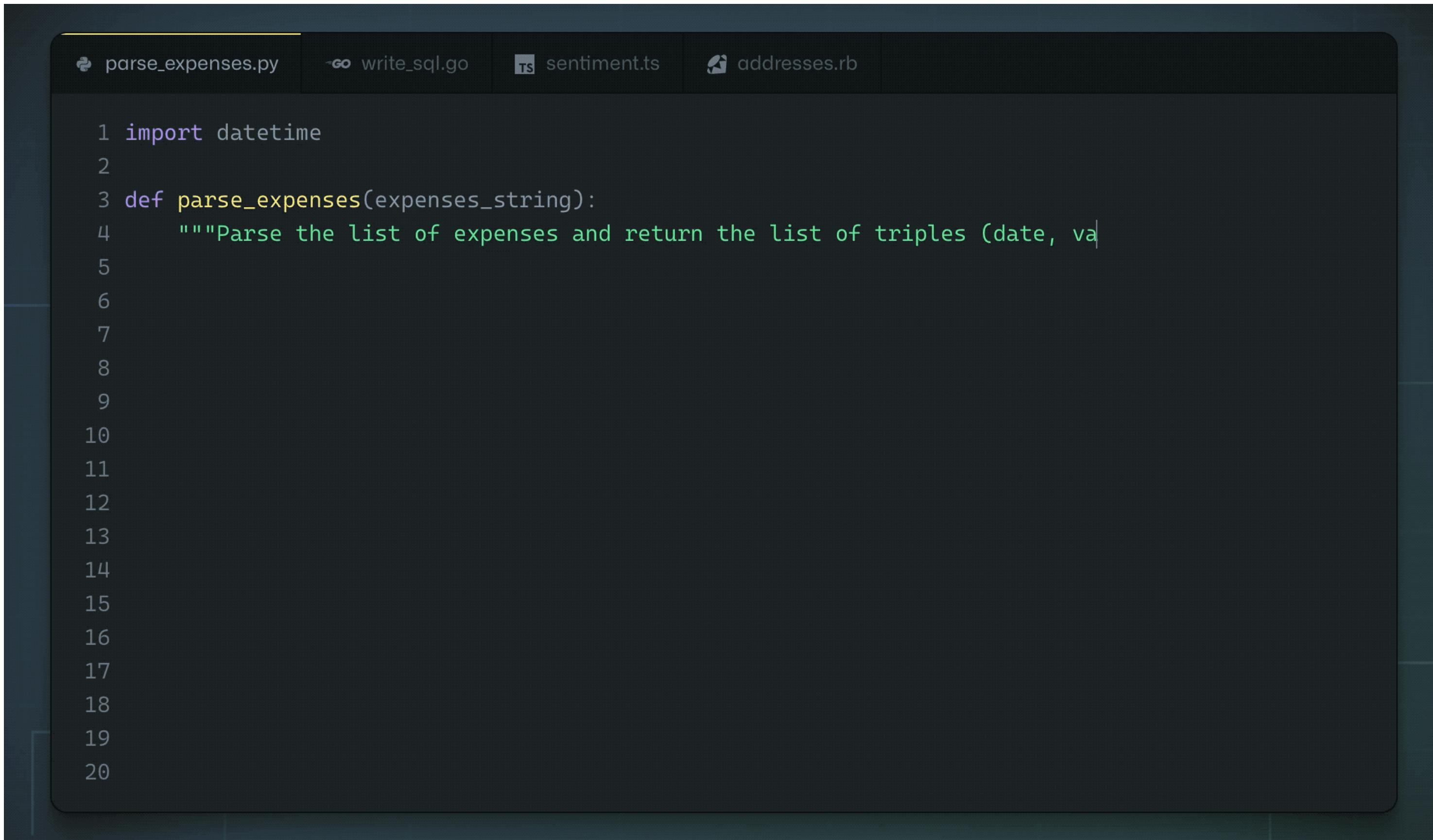
The screenshot shows the Hugging Face Write With Transformer interface. At the top, there's a purple unicorn logo, followed by the text "Write With Transformer" and a model selection dropdown set to "distil-gpt2". Below the header are several control buttons: "Shuffle initial text", "Trigger autocomplete" (with a blue arrow icon), "Select suggestion" (with up and down arrow icons), and "Cancel suggestion" (with an esc key icon). On the right side, there's a "Save & Publish" button with a blue arrow icon. The main area contains a text input field with the partial sentence "Neurocomputing is|". A light gray box overlays the text, containing three suggested completions:

- the leading topic of the next century.
- now more popular than a year ago, wit...
- a new field of study that explores the w...

Github copilot

- Github and OpenAI trained a GPT-3-like architecture on the available open source code.
- Copilot is able to “autocomplete” the code based on a simple comment/docstring.

<https://copilot.github.com/>



```
1 import datetime
2
3 def parse_expenses(expenses_string):
4     """Parse the list of expenses and return the list of triples (date, va
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
```

ChatGPT

The screenshot shows the ChatGPT interface on a web browser. The URL in the address bar is chat.openai.com/chat. The page has a dark mode theme.

User Question: Why can you only apply backpropagation through time (BPTT) for a limited number of steps on a RNN and when is this a problem? Explain and provide an example.

AI Response: Backpropagation through time (BPTT) is an algorithm for training recurrent neural networks (RNNs) that involves unrolling the RNN through time and applying the backpropagation algorithm to each time step. However, BPTT can only be applied for a limited number of steps on an RNN because it suffers from the vanishing and exploding gradients problem.

The vanishing gradients problem occurs when the gradients of the weights in the network become very small, which can make it difficult for the optimization algorithm to update the weights in a meaningful way. This can slow down the training process and make it difficult for the network to learn.

The exploding gradients problem occurs when the gradients of the weights in the network become very large, which can cause the weights to become unstable and may even cause the network to diverge.

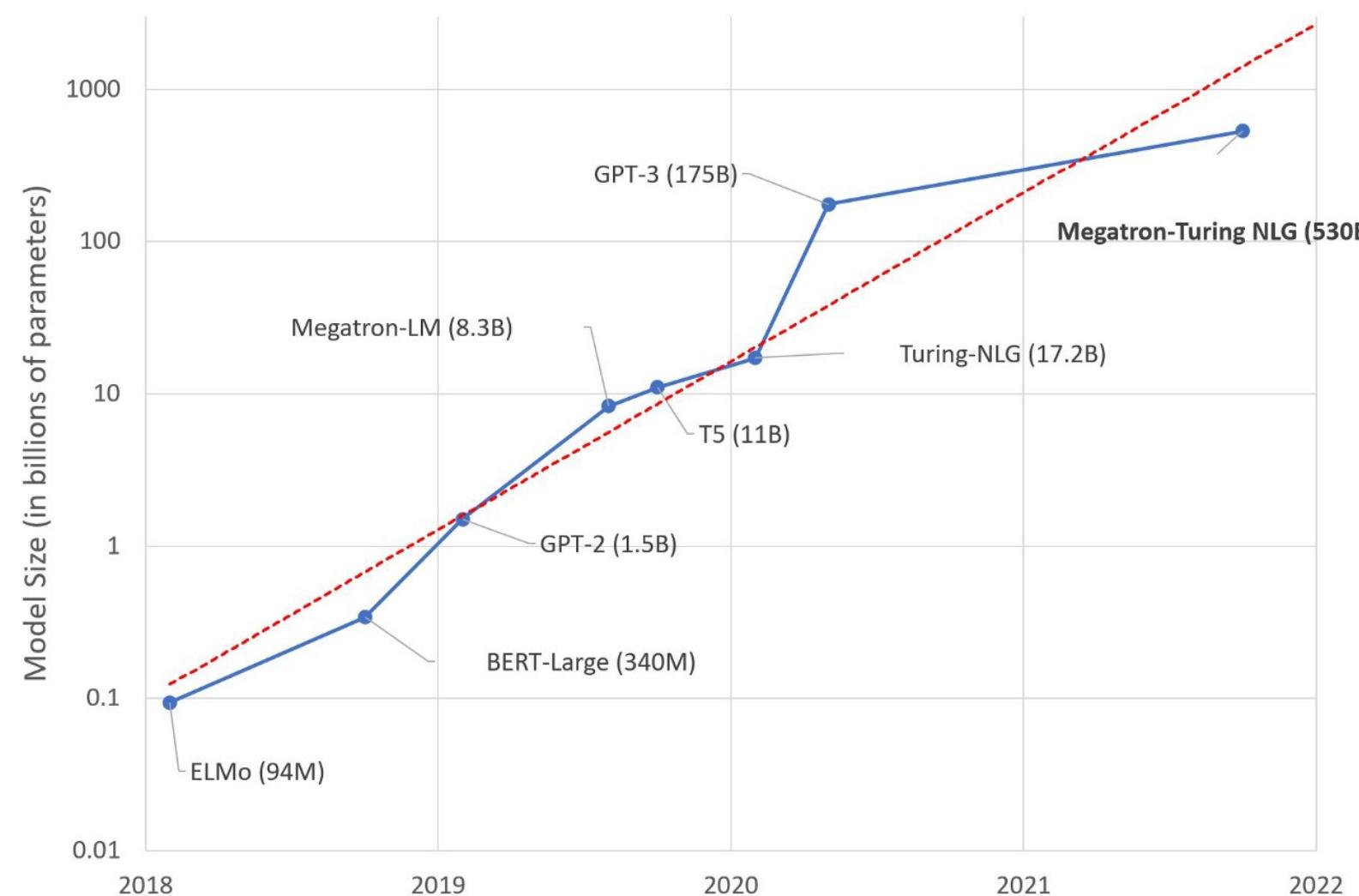
Both of these problems can be exacerbated when BPTT is applied for a large number of time steps, as the gradients can become increasingly small or large as they are propagated through the network. This can make it difficult for the optimization algorithm to find a good set of weights and can lead to poor performance on the task.

For example, suppose we are training an RNN to predict the next word in a sentence given the previous words. If we try to apply BPTT for a very long sequence of words (e.g., a paragraph or an entire book), the gradients may become very small or large as they are propagated through the network, making it difficult for the optimization algorithm to find a good set of weights. In this case, it would be advisable to limit the number of time steps for which BPTT is applied in order to avoid the vanishing and exploding gradients problems.

Buttons: A "Regenerate response" button is visible at the bottom right of the AI's response area. The sidebar on the left includes links for "New chat", "Adding Regularization", "Clear conversations", "Dark mode", "OpenAI Discord", and "Updates & FAQ".

Transformers and NLP

- All NLP tasks (translation, sentence classification, text generation) are now done using **Large Language Models (LLM)**, **self-supervisedly** pre-trained on huge corpuses.
- BERT can be used for feature extraction, while GPT is more generative.
- Transformer architectures seem to **scale**: more parameters = better performance. Is there a limit?



- The price to pay is that these models are very expensive to train (training one instance of GPT-3 costs 12M\$) and to use (GPT-3 is only accessible with an API).
- Many attempts have been made to reduce the size of these models while keeping a satisfying performance.
 - DistilBERT, RoBERTa, BART, T5, XLNet...
- See <https://medium.com/mlearning-ai/recent-language-models-9fcf1b5f17f5>

Source: <https://julsimon.medium.com/large-language-models-a-new-moores-law-66623de5631b>

3 - Vision transformers

Vision transformer (ViT)

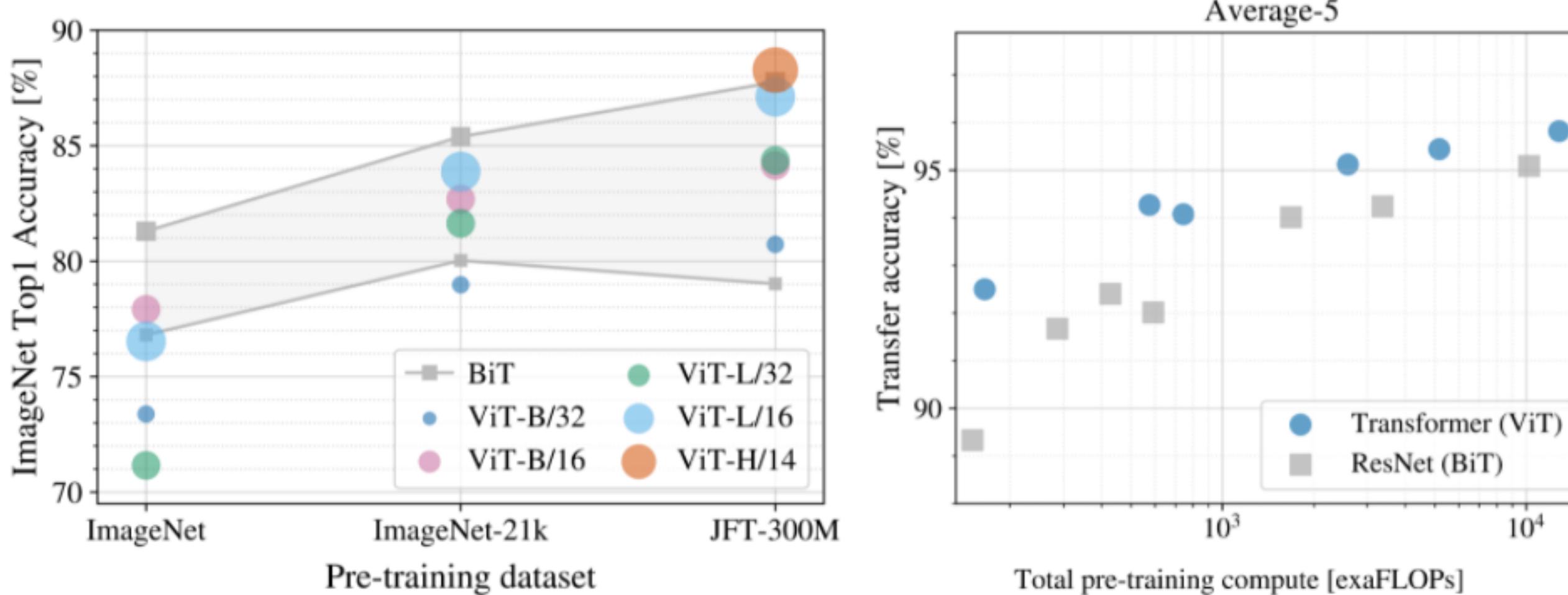
- The transformer architecture can also be applied to computer vision, by splitting images into a **sequence** of small patches (16x16).
- The sequence of vectors can then be classified by the output of the transformer using labels.



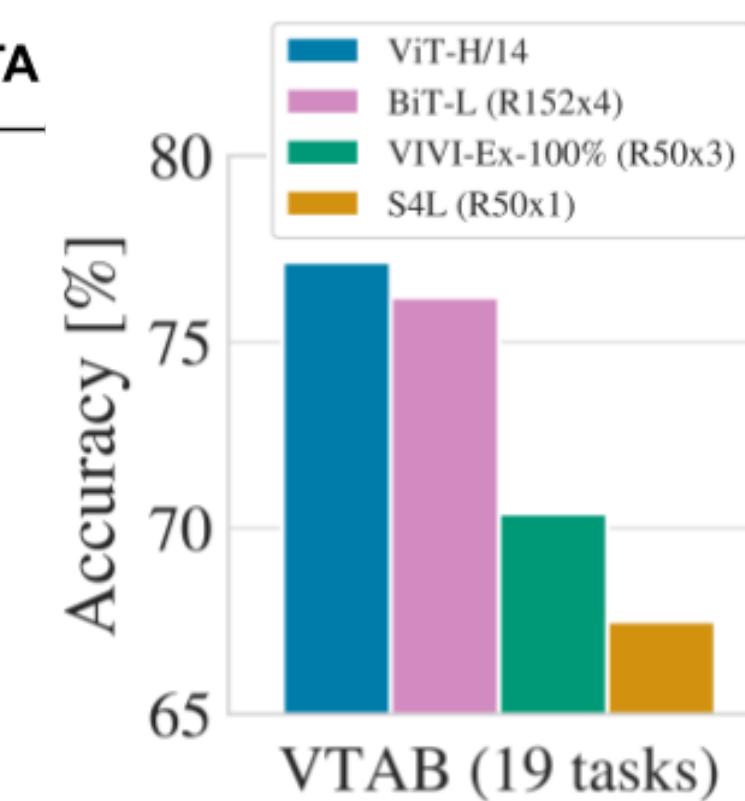
Source: <https://ai.googleblog.com/2020/12/transformers-for-image-recognition-at.html>

Vision transformer (ViT)

- The Vision Transformer (ViT) outperforms state-of-the-art CNNs while requiring less computations.

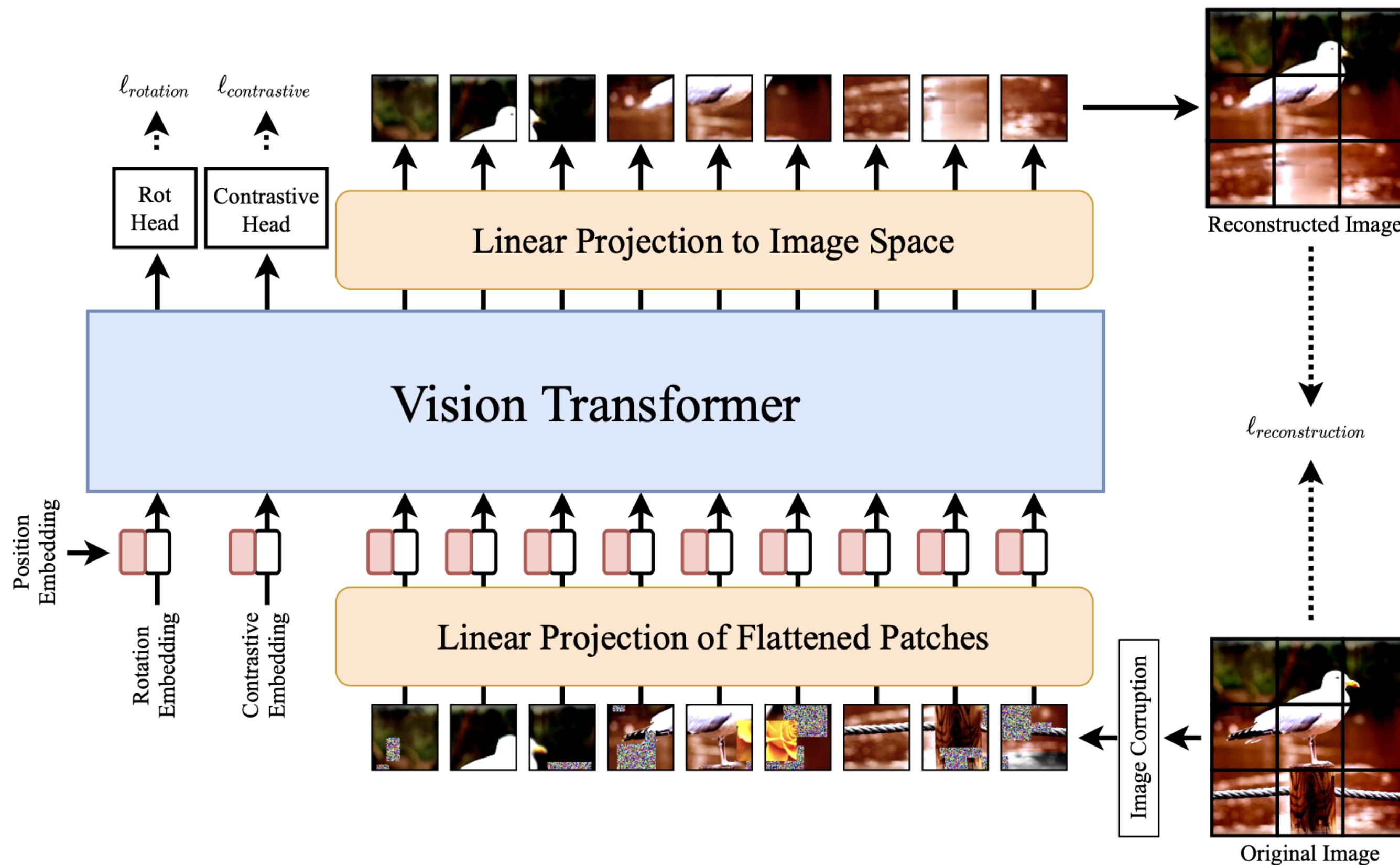


	ViT-H	Previous SOTA
ImageNet	88.55	88.5
ImageNet-Real	90.72	90.55
Cifar-10	99.50	99.37
Cifar-100	94.55	93.51
Pets	97.56	96.62
Flowers	99.68	99.63



Self-supervised Vision Transformer (SiT)

- ViT only works on big supervised datasets (ImageNet). Can we benefit from self-supervised learning as in BERT or GPT?
- The Self-supervised Vision Transformer (SiT) has an denoising autoencoder-like structure, reconstructing corrupted patches autoregressively.



Self-supervised Vision Transformer (SiT)

- Self-supervised learning is possible through from **data augmentation** techniques.
- Various corruptions (masking, replacing, color distortion, blurring) are applied to the input image, but SiT must reconstruct the original image (denoising autoencoder).

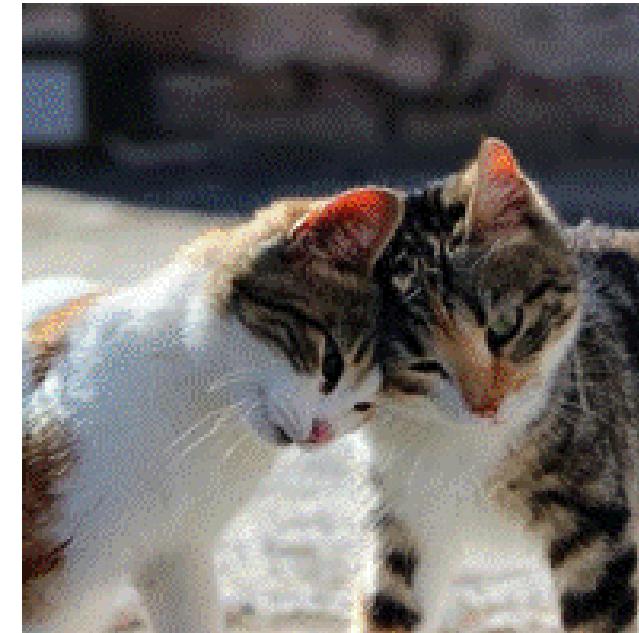


- An auxiliary **rotation loss** forces SiT to predict the orientation of the image (e.g. 30°). Another auxiliary **contrastive loss** ensures that high-level representations are different for different images.

Method	Backbone	Linear Evaluation			Domain Transfer	
		CIFAR10	CIFAR100	Tiny-ImageNet	C100 → C10	C10 → C100
DeepCluster [19]	ResNet-32	43.31% ± 0.62	20.44% ± 0.80	11.64% ± 0.21	43.39% ± 1.84	18.37% ± 0.41
RotationNet [23]	ResNet-32	62.00% ± 0.79	29.02% ± 0.18	14.73% ± 0.48	52.22% ± 0.70	27.02% ± 0.20
Deep InfoMax [20]	ResNet-32	47.13% ± 0.45	24.07% ± 0.05	17.51% ± 0.15	45.05% ± 0.24	23.73% ± 0.04
SimCLR [8]	ResNet-32	77.02% ± 0.64	42.13% ± 0.35	25.79% ± 0.4	65.59% ± 0.76	36.21% ± 0.16
SimCLR [8]	ResNet-56	78.75% ± 0.24	44.33% ± 0.48	n/a	66.19% ± 0.80	36.79% ± 0.45
Relational Reasoning [21]	ResNet-32	74.99% ± 0.07	46.17% ± 0.16	30.54% ± 0.42	67.81% ± 0.42	41.50% ± 0.35
Relational Reasoning [21]	ResNet-56	77.51% ± 0.00	47.90% ± 0.27	n/a	68.66% ± 0.21	42.19% ± 0.28
SiT (ours) - Linear projection	Transformer	81.98% ± 0.24	54.31% ± 0.13	40.35% ± 0.27	73.79% ± 0.15	55.72% ± 0.13
SiT (ours) - Non-Linear projection	Transformer	83.50% ± 0.11	57.75% ± 0.21	43.06% ± 0.14	75.52% ± 0.11	57.89% ± 0.14

Self-distillation with no labels (DINO)

- A recent approach for self-supervised learning has been proposed by Facebook AI researchers using **self-distillation**.
- The images are split into **global** and **local patches** at different scales.
- Global patches contain label-related information (whole objects) while local patches contain finer details.

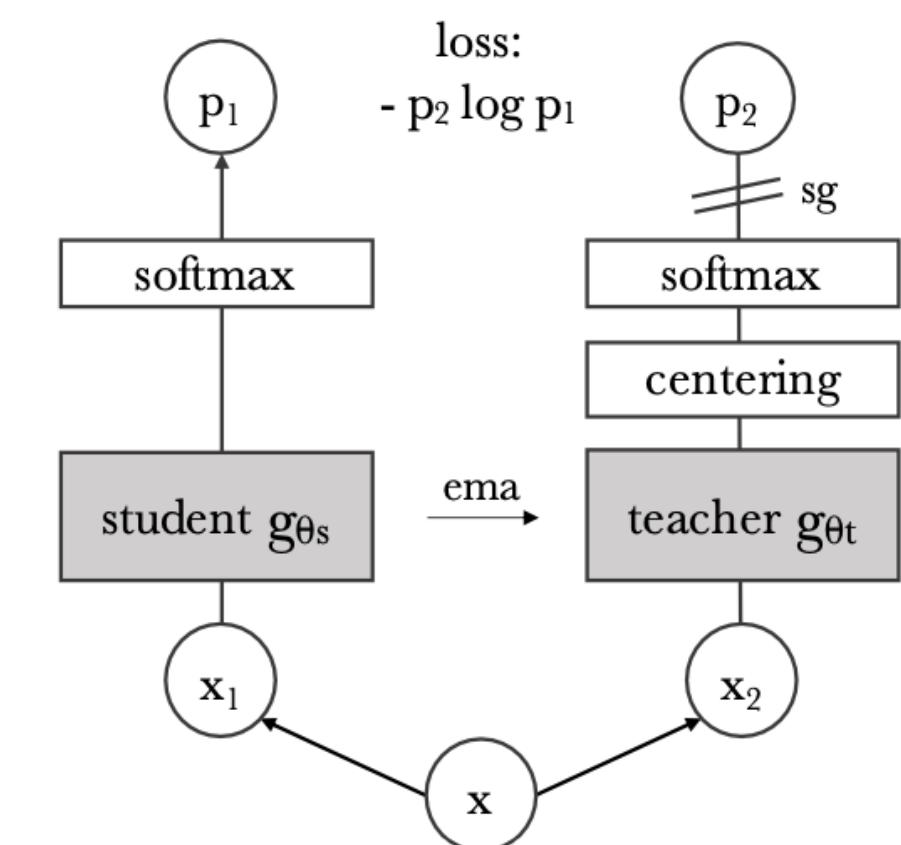


Davide Cacomin | 2021

Source: <https://towardsdatascience.com/on-dino-self-distillation-with-no-labels-c29e9365e382>

Self-distillation with no labels (DINO)

- The idea of **self-distillation** in DINO is to use two similar ViT networks to classify the patches.
- The **teacher** network gets the global views as an input, while the **student** network get both the local and global ones.
- Both have a MLP head to predict the softmax probabilities, but do **not** use any labels.



- The student tries to imitate the output of the teacher, by minimizing the **cross-entropy** (or KL divergence) between the two probability distributions.
- The teacher slowly integrates the weights of the student (momentum or exponentially moving average ema):

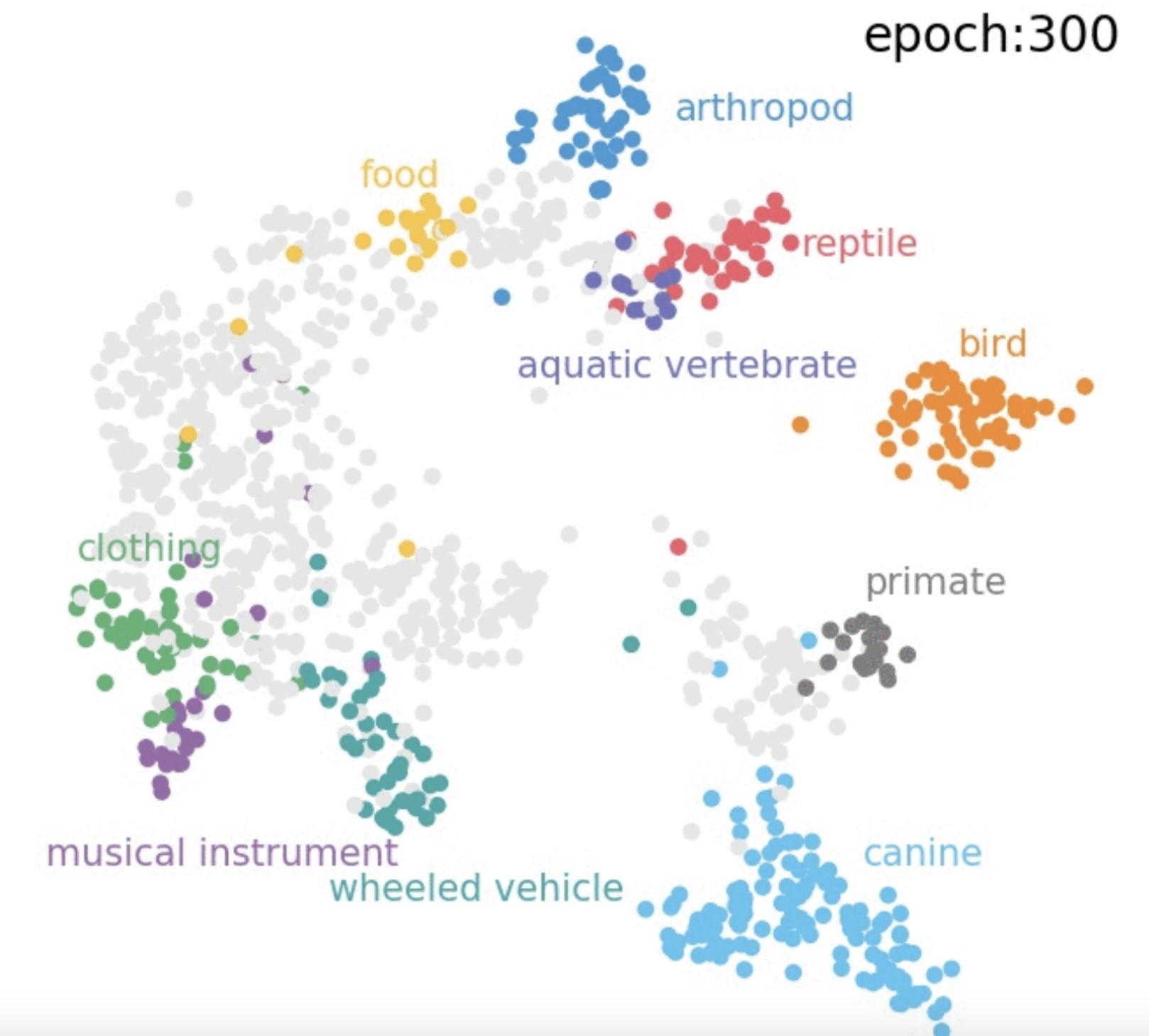
$$\theta_{\text{teacher}} \leftarrow \beta \theta_{\text{teacher}} + (1 - \beta) \theta_{\text{student}}$$

Self-distillation with no labels (DINO)

Source: <https://ai.facebook.com/blog/dino-paws-computer-vision-with-self-supervised-transformers-and-10x-more-efficient-training/>

Self-distillation with no labels (DINO)

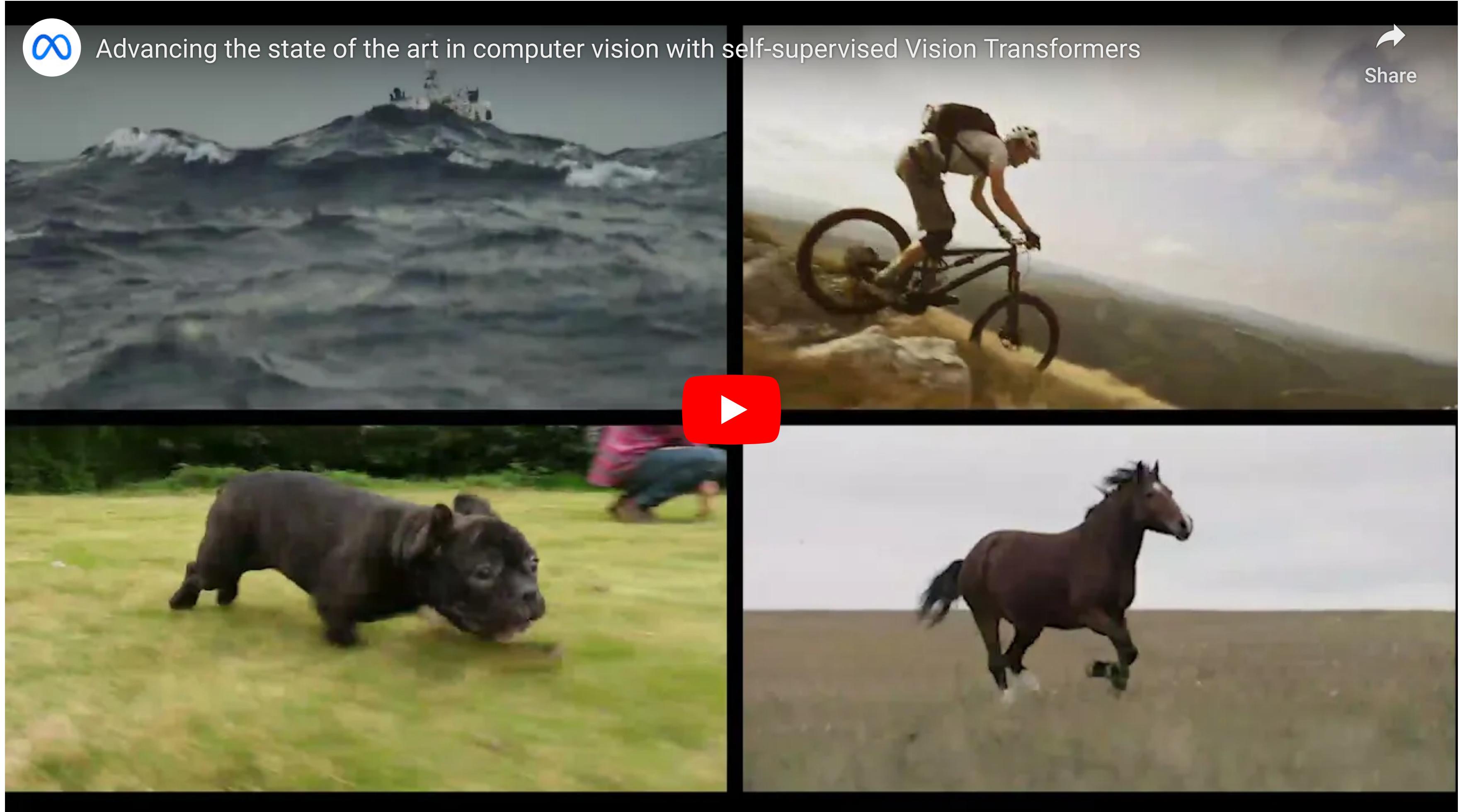
- The predicted classes do not matter when pre-training, as there is no ground truth.
- The only thing that matters is the **high-level representation** of an image before the softmax output, which can be used for transfer learning.
- Self-distillation forces the representations to be meaningful at both the global and local scales, as the teacher gets global views.
- ImageNet classes are already separated in the high-level representations: a simple kNN (k-nearest neighbour) classifier achieves 74.5% accuracy (vs. 79.3% for a supervised ResNet50).



<https://ai.facebook.com/blog/dino-paws-computer-vision-with-self-supervised-transformers-and-10x-more-efficient-training>

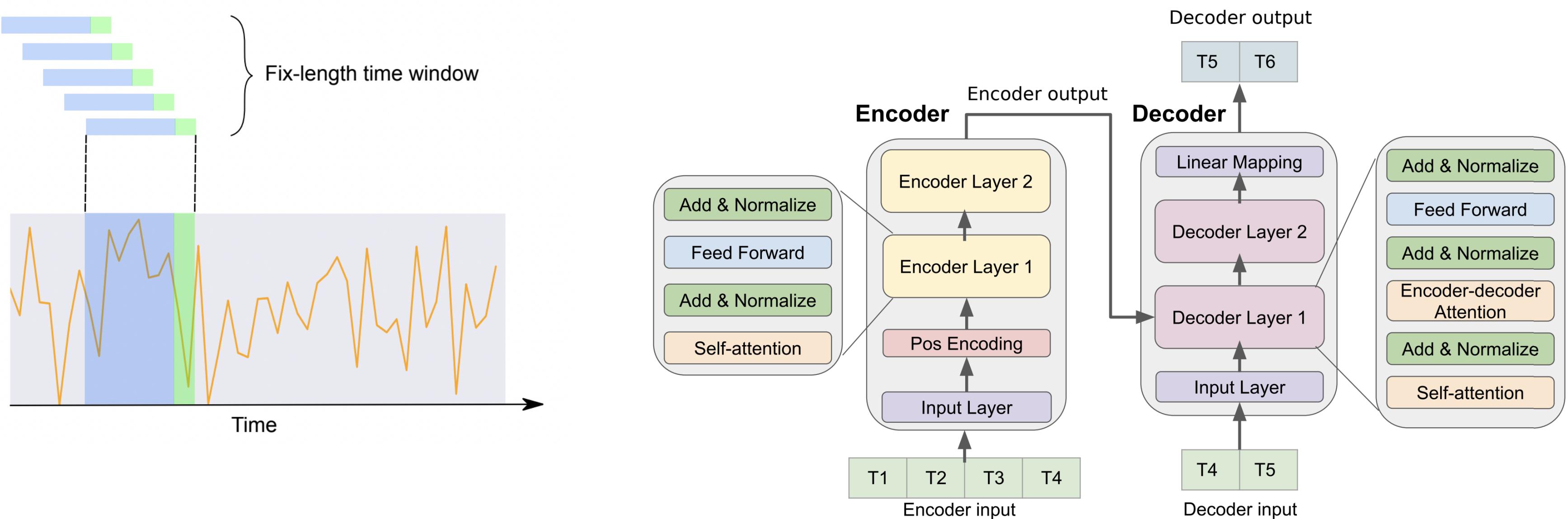
Self-distillation with no labels (DINO)

- More interestingly, by looking at the self-attention layers, one can obtain saliency maps that perform **object segmentation** without ever having been trained to!



Transformer for time series

- Transformers can also be used for time-series classification or forecasting instead of RNNs.
- Example: weather forecasting, market prices, etc.



References

- Various great blog posts by Jay Alammar to understand attentional networks, transformers, etc:

<https://jalammar.github.io/visualizing-neural-machine-translation-mechanics-of-seq2seq-models-with-attention/>

<http://jalammar.github.io/illustrated-transformer/>

<https://jalammar.github.io/illustrated-bert/>

<https://jalammar.github.io/illustrated-gpt2/>

- Application of transformers outside NLP:

<https://medium.com/swlh/transformers-are-not-only-for-nlp-cd837c9f175>

- Extensions of the Vision Transformer:

<https://theaisummer.com/transformers-computer-vision/>