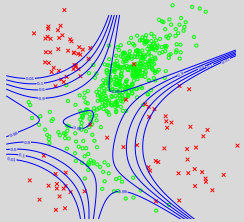


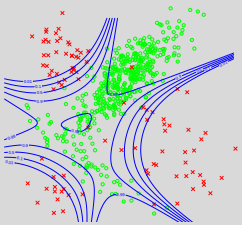


# Natural Language Processing and Transformers

Lecture *Machine Learning* vom 29-31.3.2023

Felix Becker
(material in collaboration with Lars Gabriel and Mario Stanke)
Institut für Mathematik und Informatik
Universität Greifswald

Background image AI-generated by Midjourney

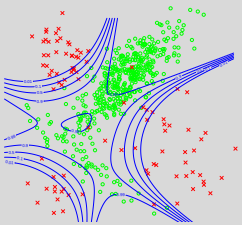




## What is Natural Language Processing (NLP)?

Process and analyze large amounts of natural human language data using computer programs (in the modern context: deep learning models).

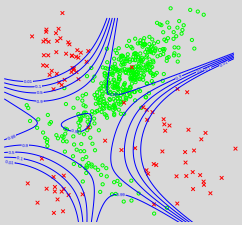
The goal is to understand the contents of text, in particular understand the context of a word in its surrounding sentence(s).





## Some NLP problems

- Translation:
  - Input: "I love you."
  - Output: "Je t'aime."
- Text generation (example output generated by GPT-3):
  - Input: "Write a joke about machine learning."
  - Output: "Why did the machine learning model break up with its training data? Because it found a better fit!"
- Question answering (related to text generation):
  - Input: "Do I need my car in New York City?"
  - Output: "No. Please keep your car at home."
- Language understanding
- Text summary
- Speech recognition



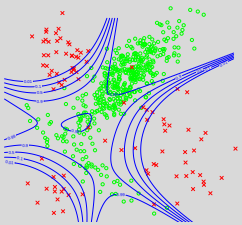


## Token

The inputs to NLP models are sequences of tokens. A token is a building block of natural language that can be:

- A word
- Part of a composed word: **countrymen** → country, men
- Part of a contraction: **aren't** → are, not
- An equivalence class of multiple words:
  {anti-discriminatory, antidiscriminatory}
- A specific indicator for the model e.g. EOS (end of sequence)
  or MASK

For example, the tokenizer of the Distilbert model knows 30,522 tokens, whereas the Oxford English Dictionary has about 172,000 words.





## Embedding

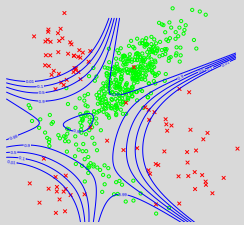
A high dimensional vector representing a specific sequence position (and potentially its context).

## Sequence

A series of tokens or embeddings in a spatial or temporal relationship.

## Language model

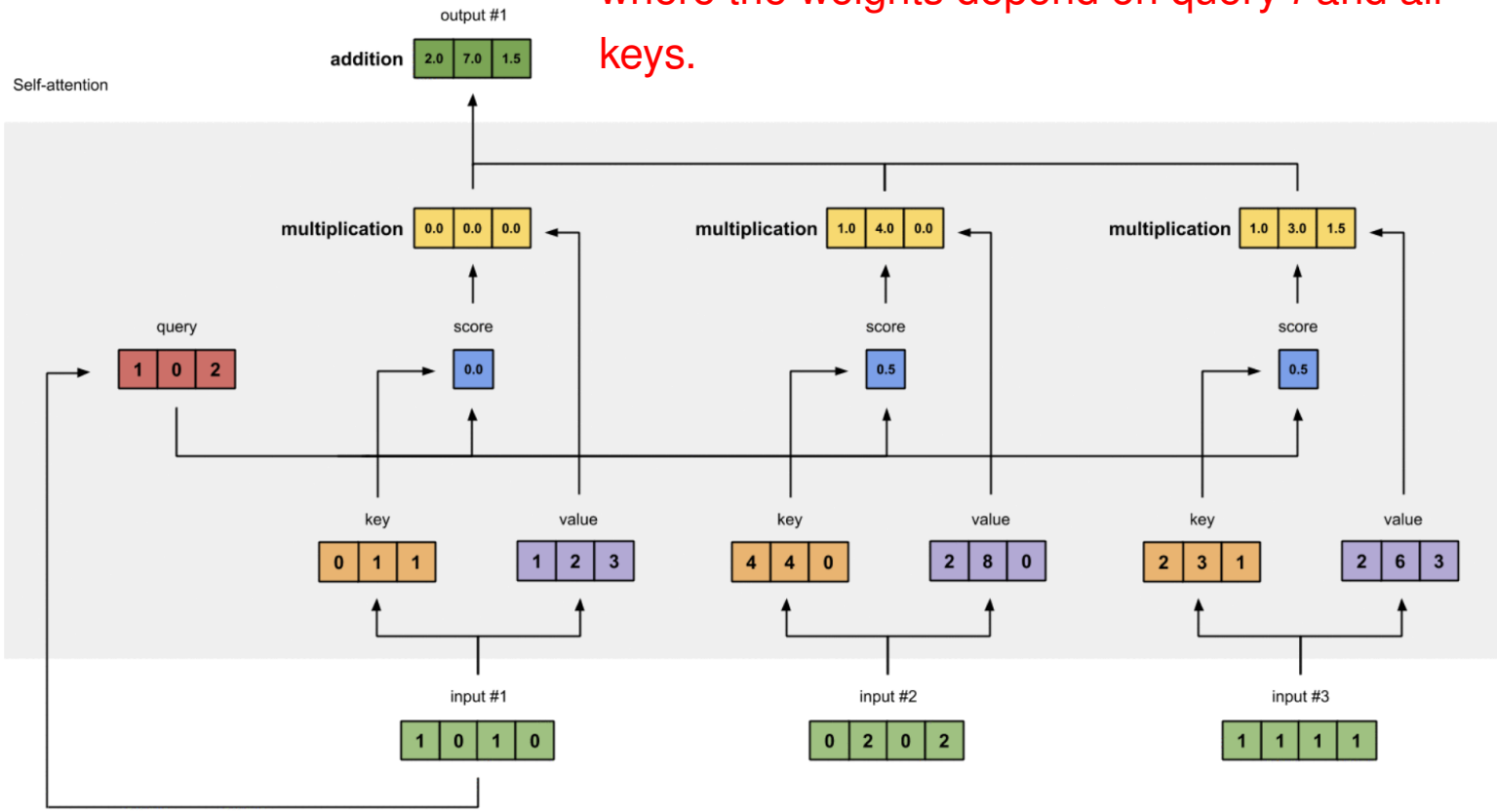
A (part of a) model where the inputs are sequences of tokens and the outputs are sequences of high dimensional embeddings that encode the context of each token. The language model is usually trained unsupervised on large amounts of text. In most cases another model comes on top of the language model that solves a downstream task.





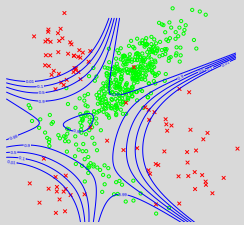
# Self-attention

Output *i* is a weighted average of all values where the weights depend on query *i* and all keys.




towardsdatascience.com/illustrated-self-attention-2d627e33b20a

The scores in the figure are rounded to one digit after the comma.

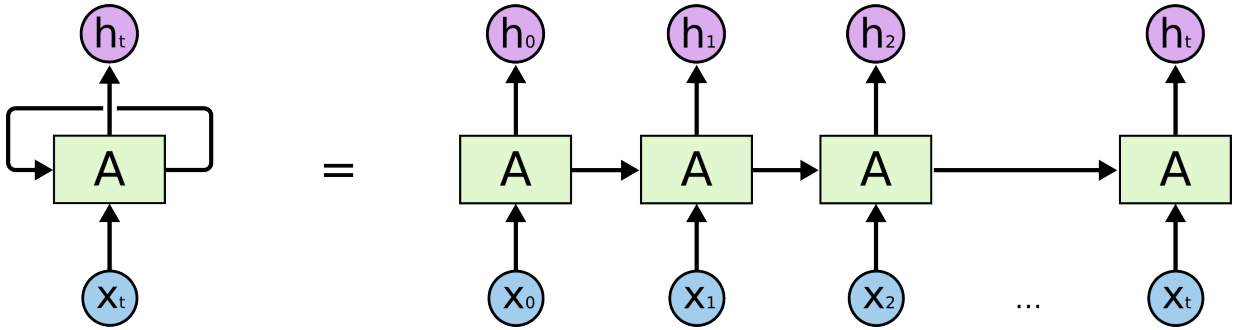




# Comparison to recurrent neural networks (RNNs)

- RNNs lost popularity since the Transformer
- usually slower (because sequential, not parallel) and can not capture long-range interactions as good as attention can

RNN:

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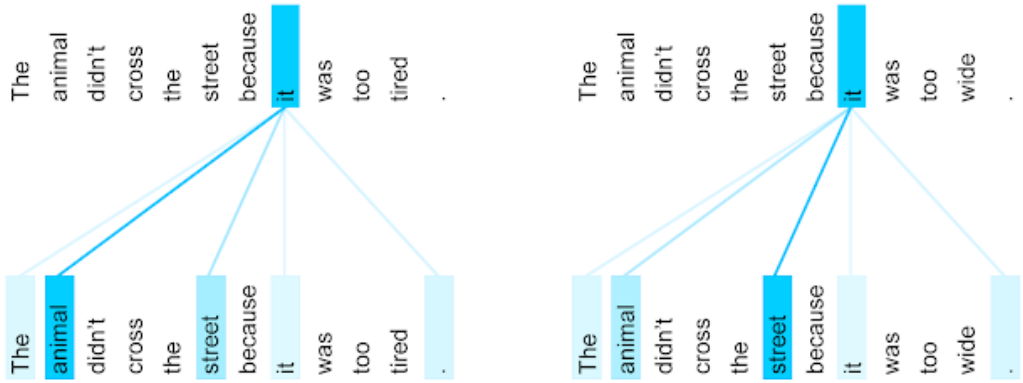
Attention:

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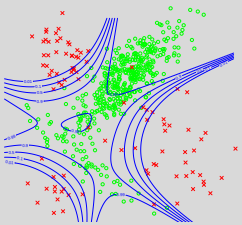
[4] colah.github.io/posts/2015-08-Understanding-LSTMs

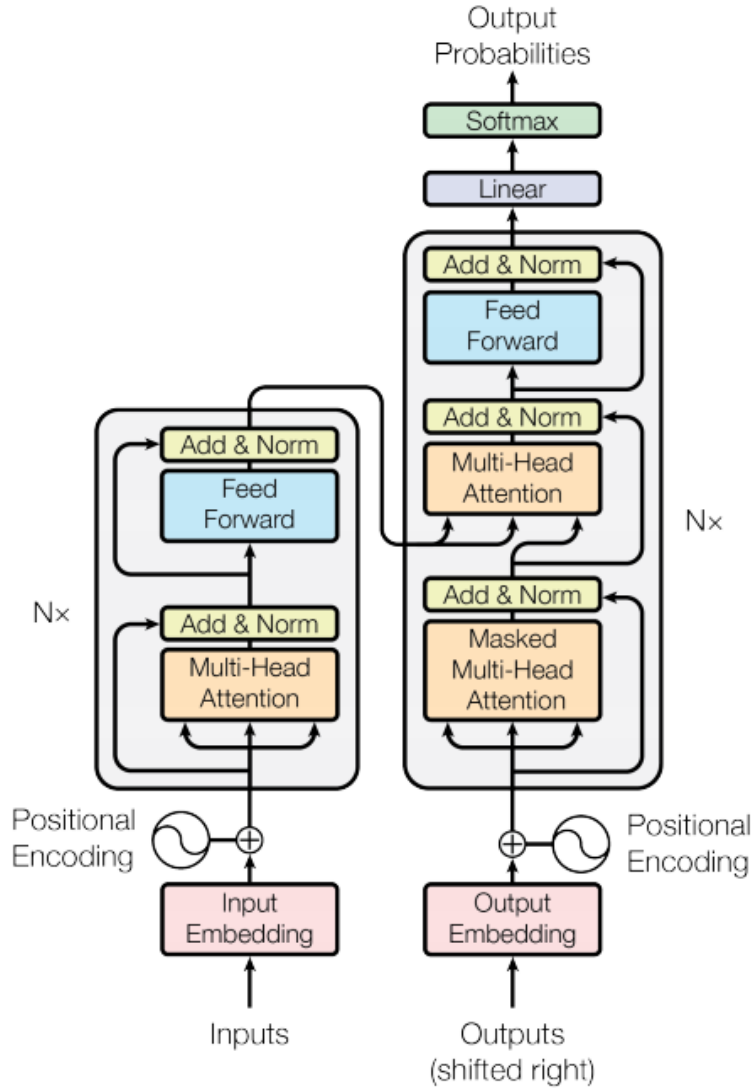
[5] ai.googleblog.com/2017/08/transformer-novel-neural-network.html





# The transformer architecture

- Based on self-attention and cross-attention (attention between input- and output sequence)

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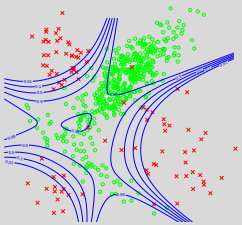
[1] Vaswani et al., Attention is all you need, 2017





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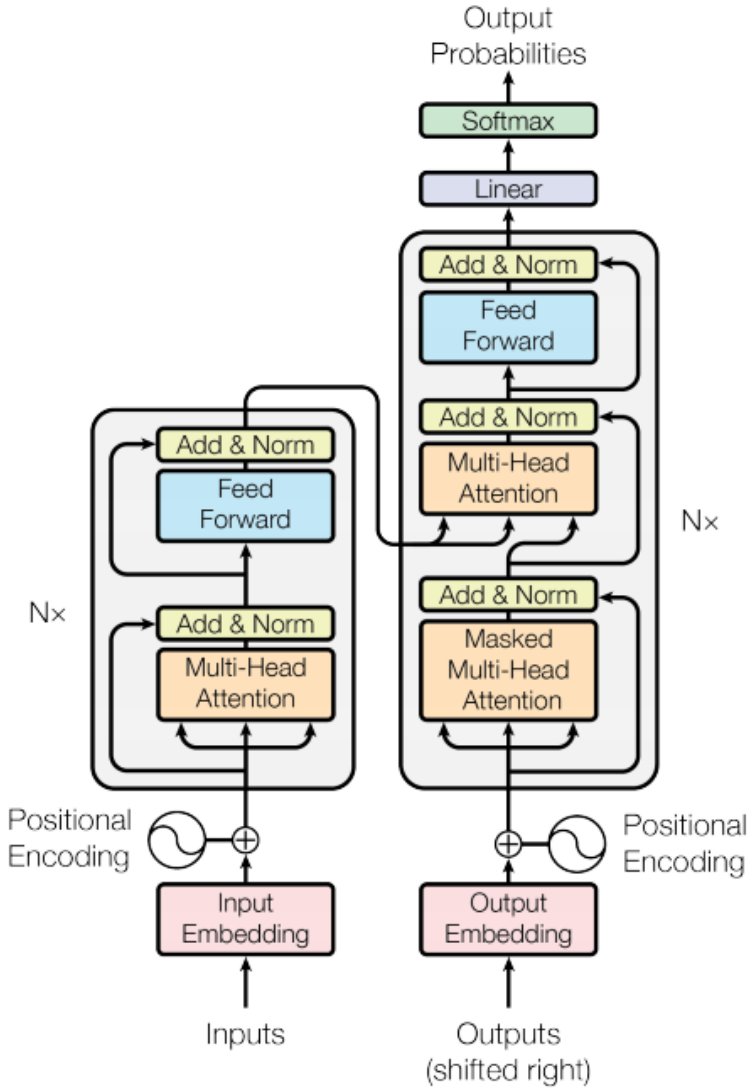


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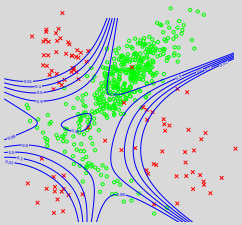



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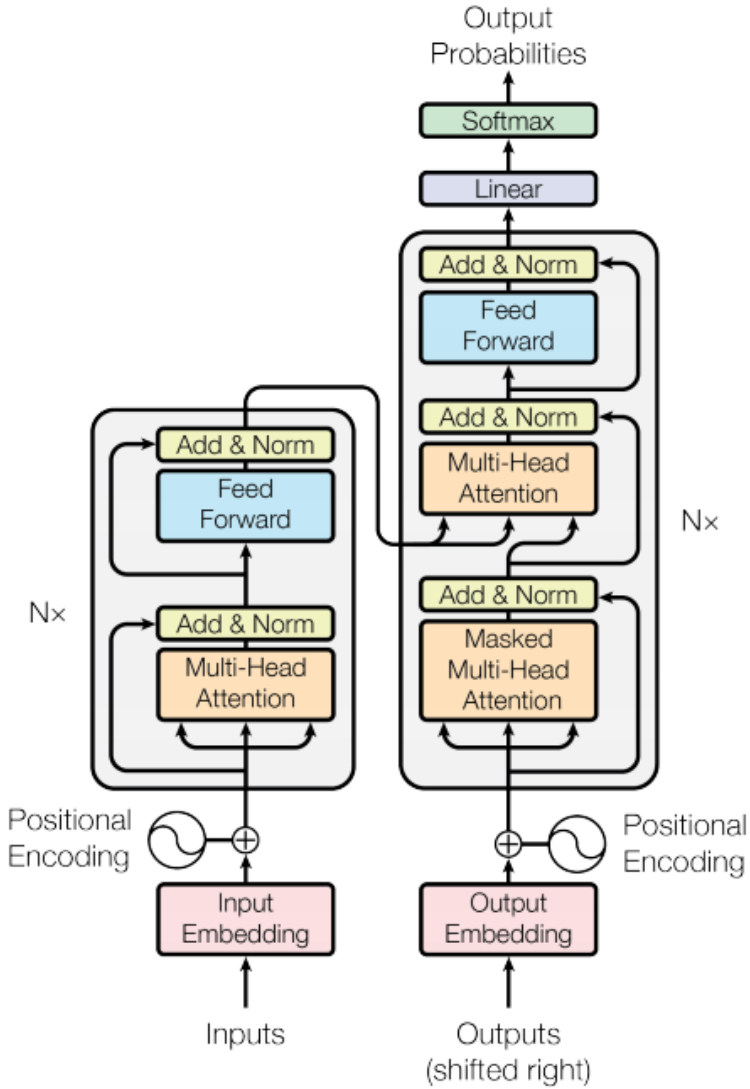




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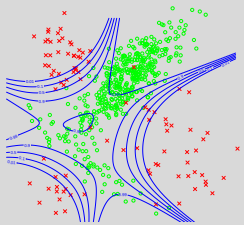



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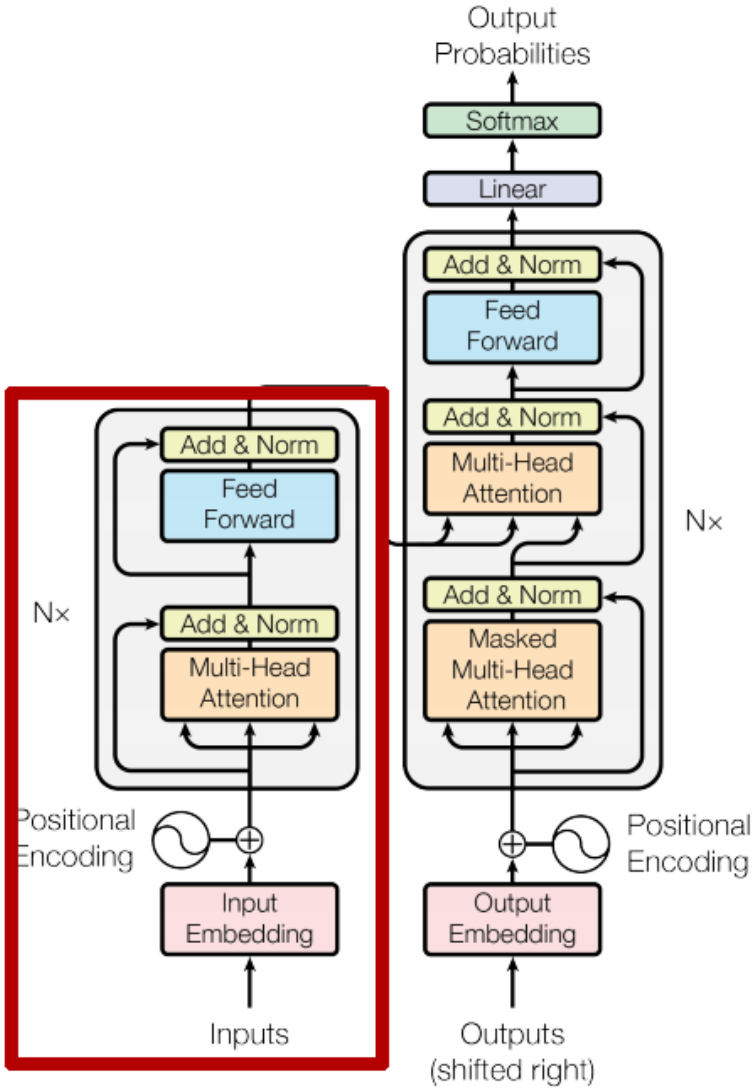


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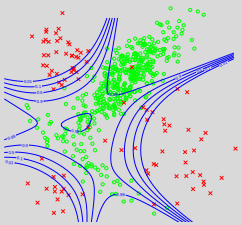



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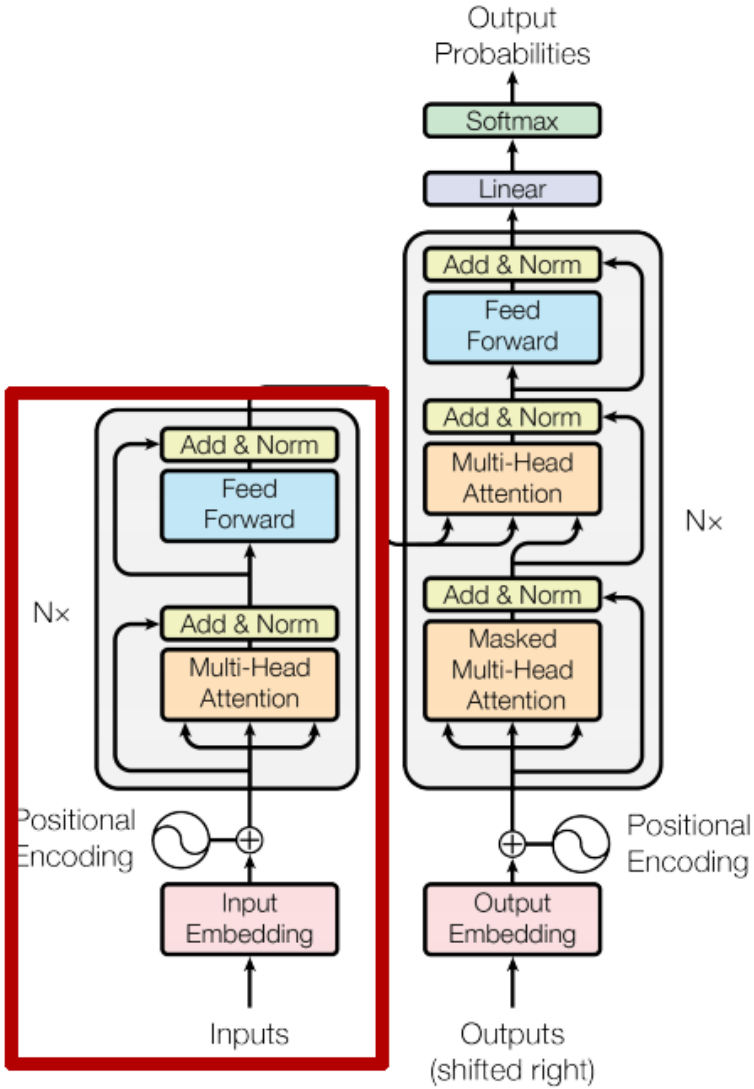
- Here, we will focus on the encoder
- The encoders task is to learn a model of the input language (e.g. english or the "language" of protein sequences)

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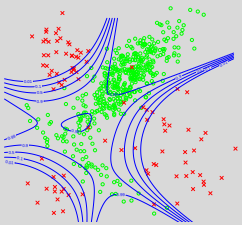



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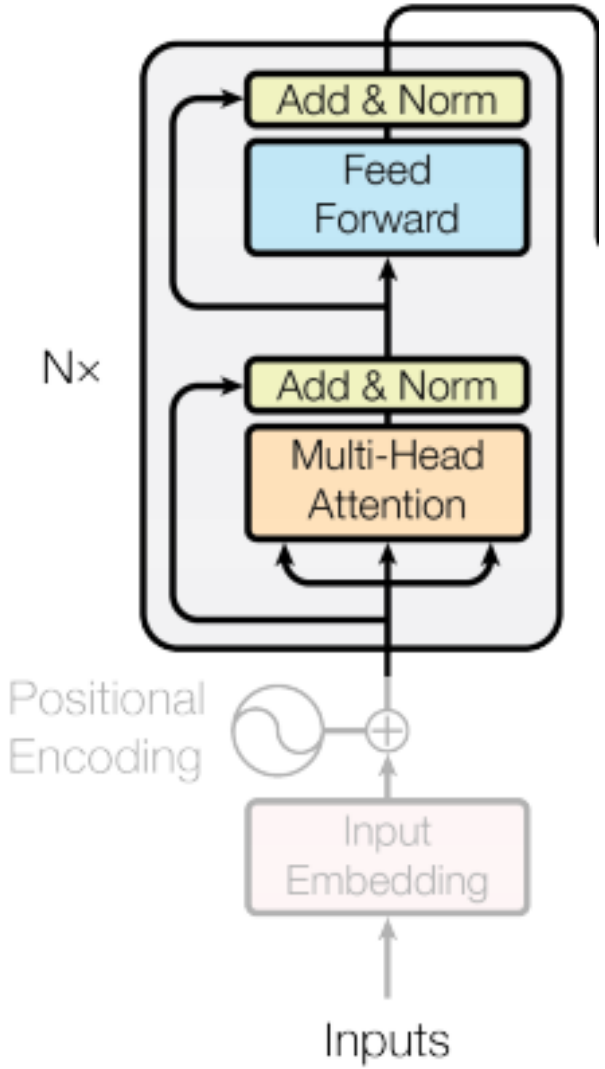
- Consumes a tensor of (embedded) input sequences and outputs a tensor with the same shape and updated embeddings



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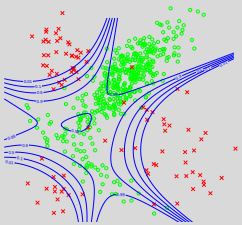



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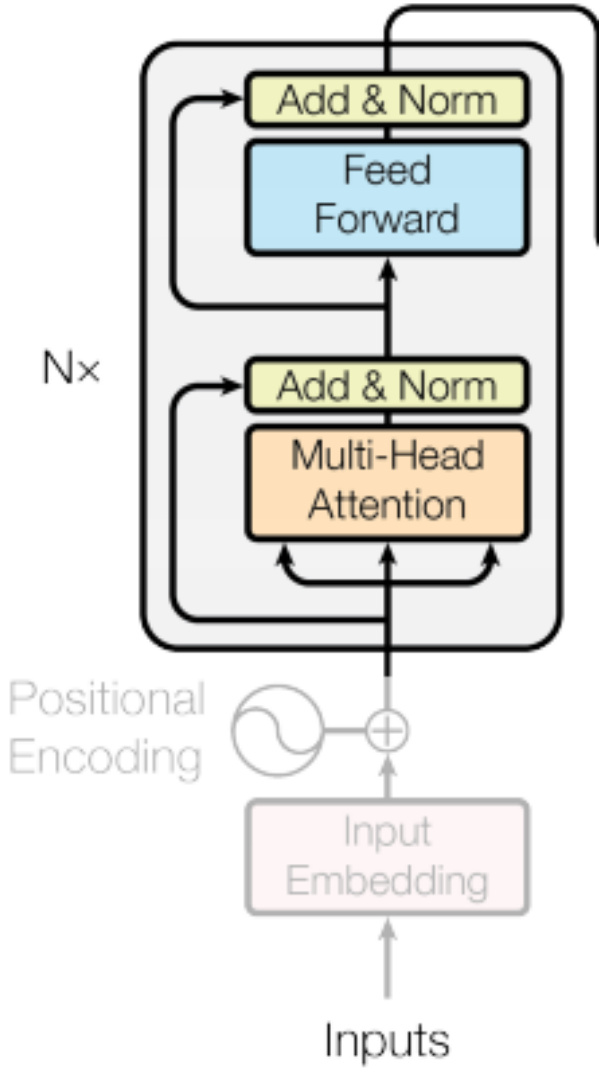


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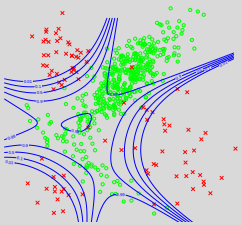



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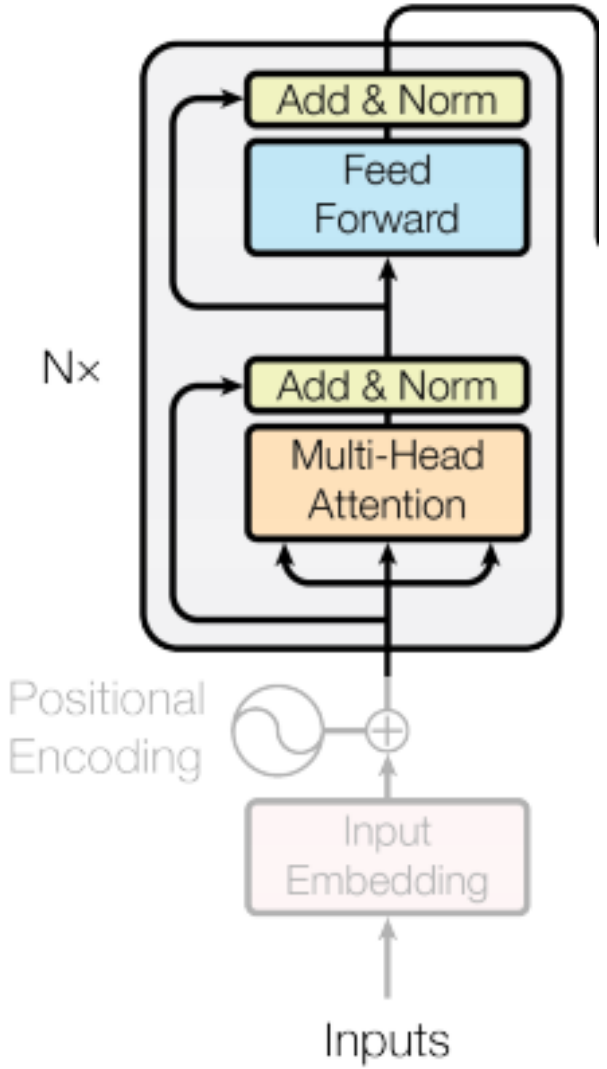


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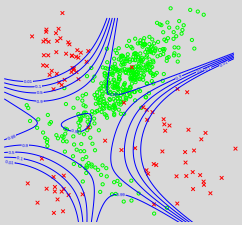



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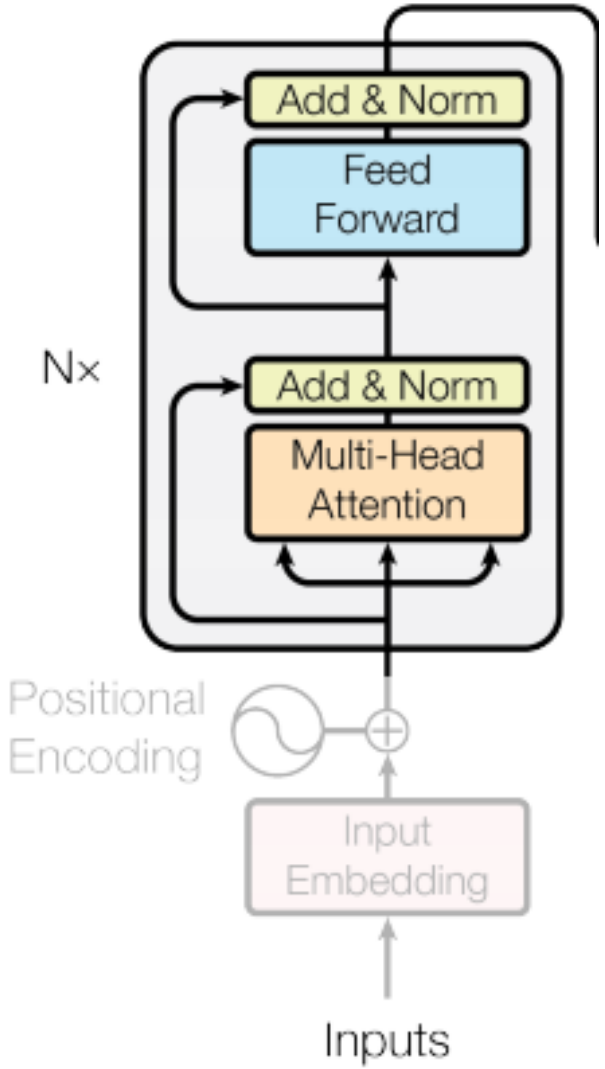


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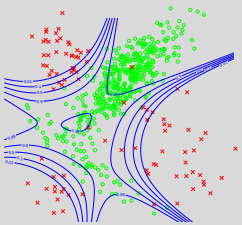



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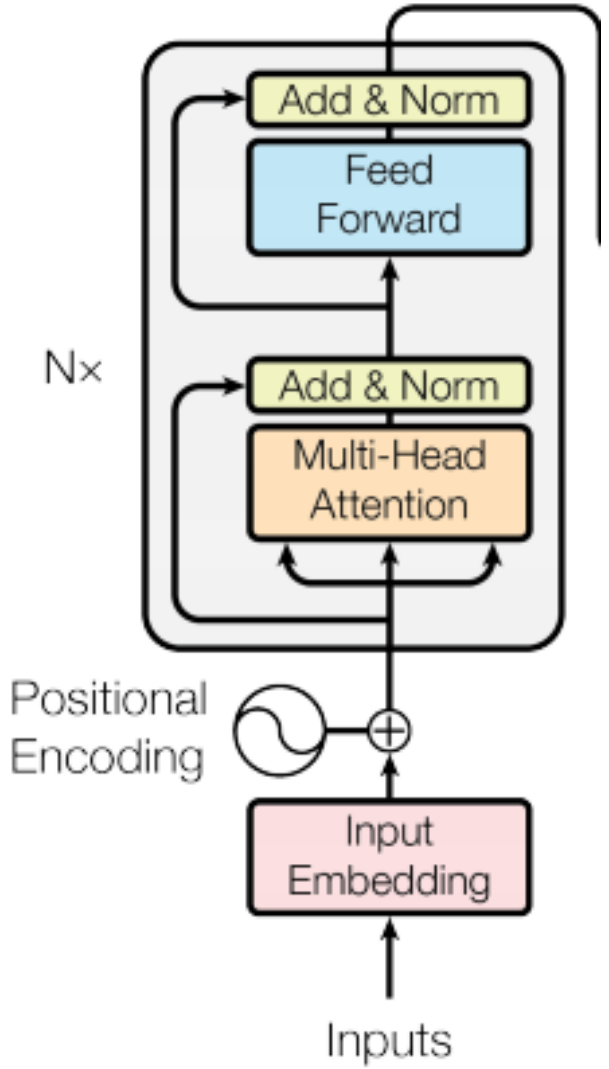
- **Input Embedding** replaces tokens with high dimensional embeddings

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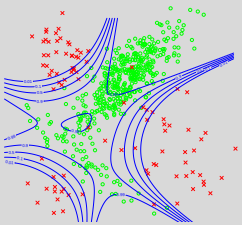



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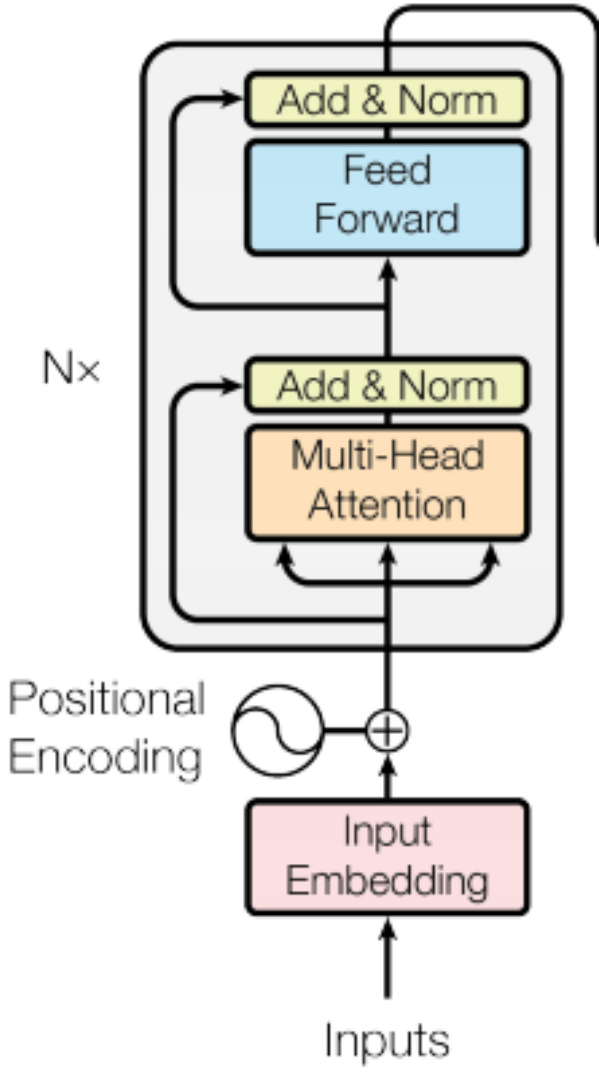


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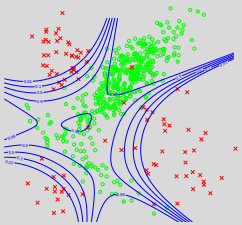



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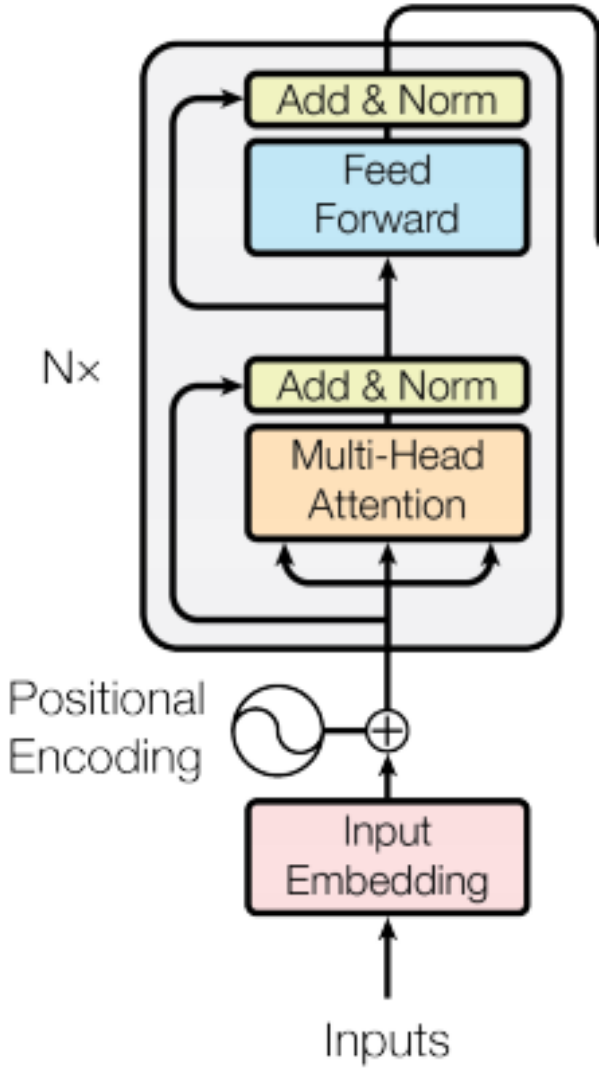




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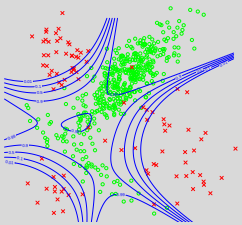



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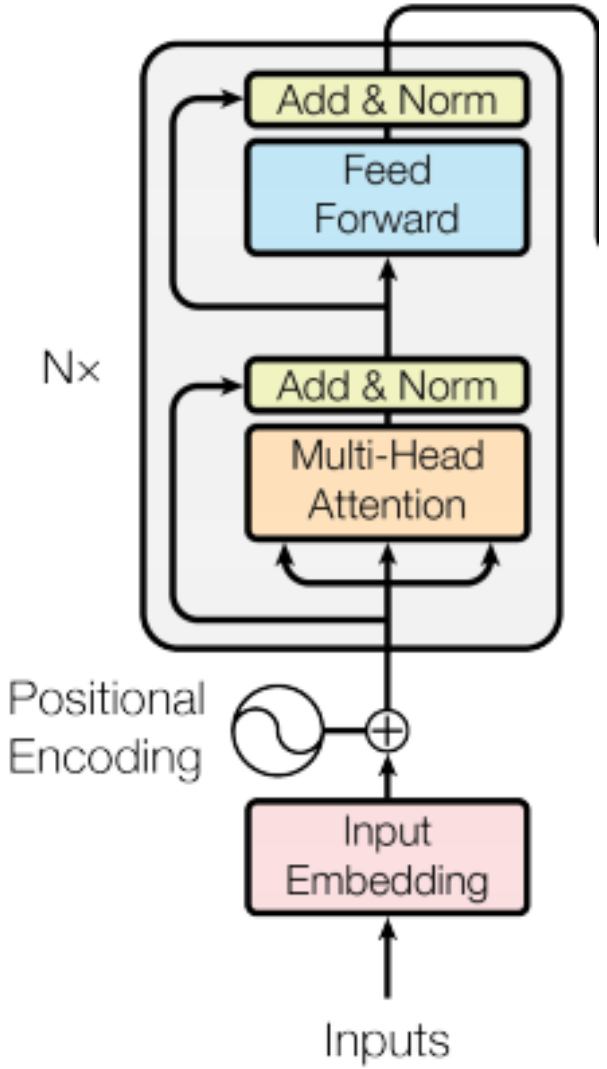


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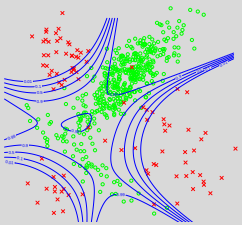



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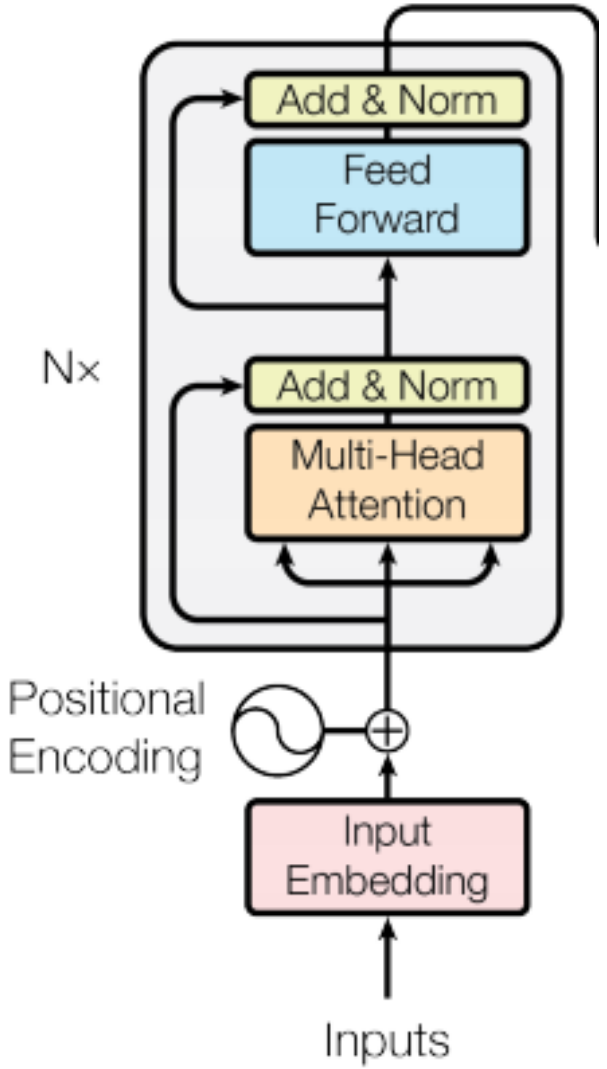
- **Add and Norm** means we introduce so called **skip-connections** and **Layer Normalization** (details omitted)

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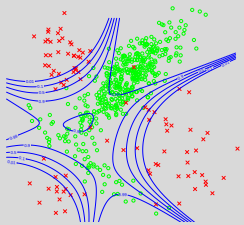
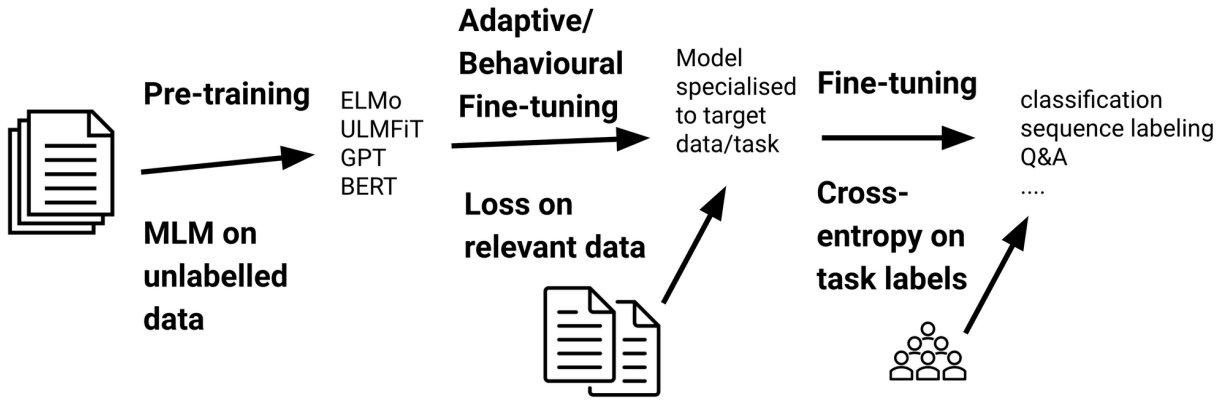
[3] Vaswani et al., Attention is all you need, 2017 (modified)





# Fine-tuning

- Pre-train a large model on a general dataset (like Wikipedia) with Masked language modeling (MLM)
- Reuse the weights as initialization for further training on more specific datasets (e.g. movie reviews) to solve more specific tasks
- The fine-tuning step is usually much faster than the pre-training
- A single pre-trained model can be reused many times

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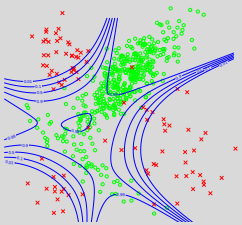
[6] www.ruder.io/recent-advances-lm-fine-tuning/





# Masked language modeling

## Inputs

'>>> Review: This [MASK] is a great. The plot is very true to the [MASK] which is a [MASK] written by Mark Twain. The movie starts of with a scene where Hank [MASK] a song with a bunch of kids called "when you stub your toe on [MASK] moon" It reminds me of Sinatra's song High Hopes, it [MASK] fun and inspirational. The [MASK] is great throughout and my favorite song is [MASK] by the King, Hank (bing Crosby) and [MASK] "Saggy" Sagamore. OVerall a great family movie or even a [MASK] Date movie. This is a movie you can watch over and over [MASK]. The [MASK] played by Rhonda Fleming is gorgeous. I love this movie!! If you liked Danny Kaye [MASK] the Court Jester then you will definitely like this movie.'

## Expected outputs

movie, book, classic, the, sings, is, Music, sung, Sir, great, great, again, princess, in

- Mask a percentage of the input tokens (i.e. the model receives a special MASK token instead of the actual token)
- Unsupervised (or sometimes called semi-supervised) training of a model with the goal to fill the gaps correctly using the cross-entropy loss function
- Can train models on large amounts of text from the internet without requiring any labeling