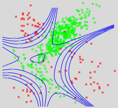

Natural Language Processing and Transformers

Lecture *Machine Learning* vom 29-31.3.2023

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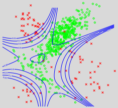
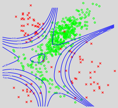
Background image AI-generated by Midjourney



What is Natural Language Processing (NLP)?

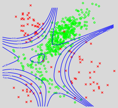
Process and analyze large amounts of natural human language data using computer programs (in the modern context: deep learning models).

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 usually a word. There are also special tokens for specific purposes e.g. to mark the end of sentences.

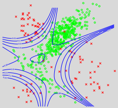
Input: Friends, Romans, Countrymen, lend me your ears;

Output: $\boxed{\text{Friends}}$ $\boxed{\text{Romans}}$ $\boxed{\text{Countrymen}}$ $\boxed{\text{lend}}$ $\boxed{\text{me}}$ $\boxed{\text{your}}$ $\boxed{\text{ears}}$

[1]

There are details we omit here for simplicity e.g. how to tokenize words like o'neill, aren't or equivalence classing (e.g. anti-discriminatory and antidiscriminatory).

[1] nlp.stanford.edu/IR-book/html/htmledition/tokenization-1.html



Embedding

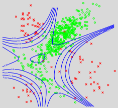
A high dimensional vector representing a specific sequence position (and potentially its context).

Sequence

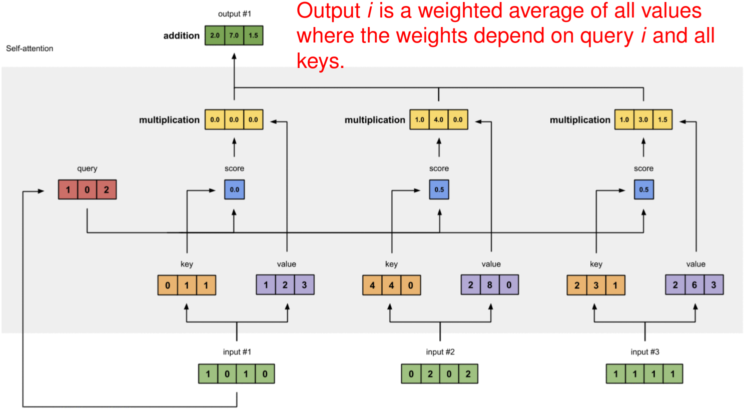
A series of tokens or embeddings in a spatial or temporal relationship.

Sequence-to-sequence model

Maps an input sequence of tokens to an output sequence. The sequences are not required to have the same length and no 1:1 token correspondence is assumed. Predicting a correct output length is responsibility of the model.



Self-attention

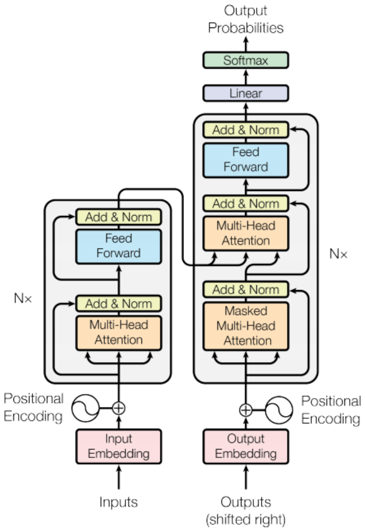


Output i is a weighted average of all values where the weights depend on query i and all keys.

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

The transformer architecture

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



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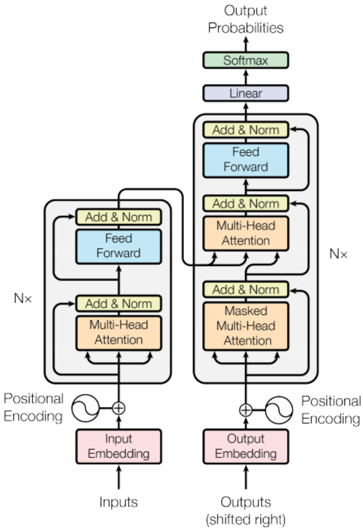

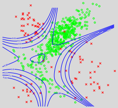

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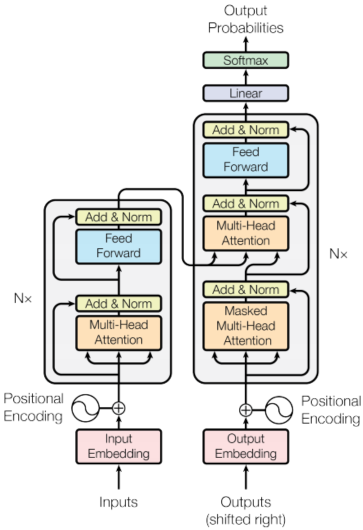

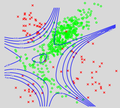

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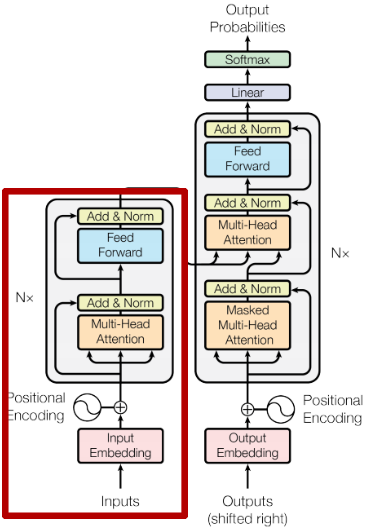

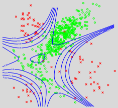

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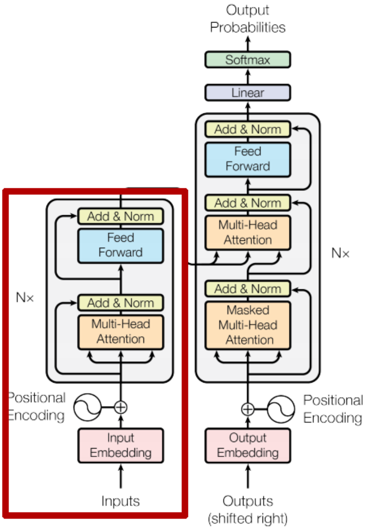
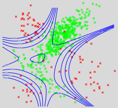
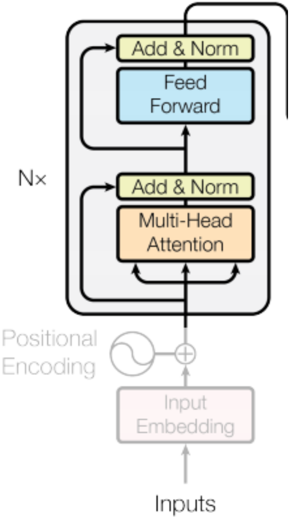
- The encoders task is to learn a model of the input language (e.g. english or the "language" of protein sequences)

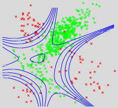




The transformer encoder

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





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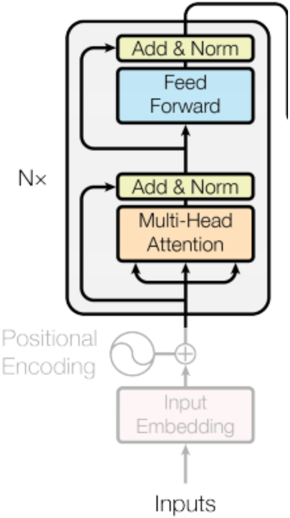

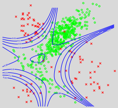

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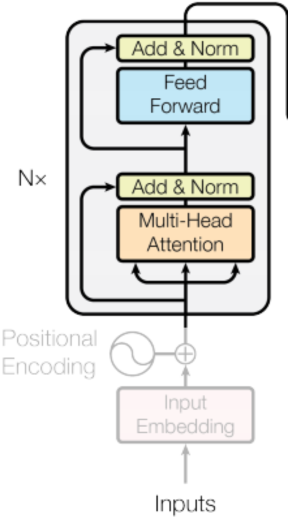

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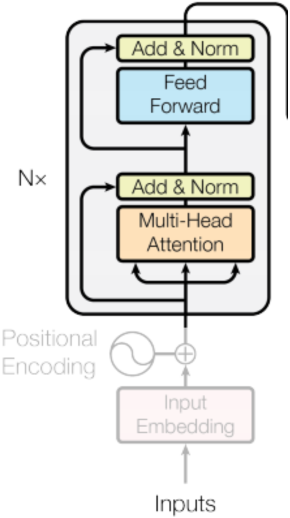
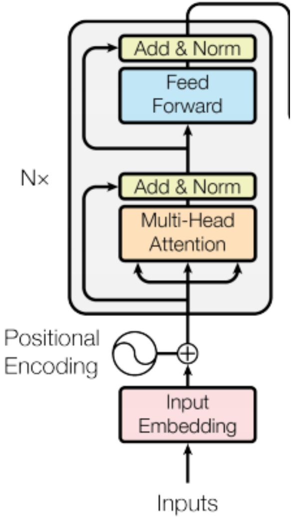
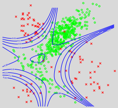


The transformer encoder

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





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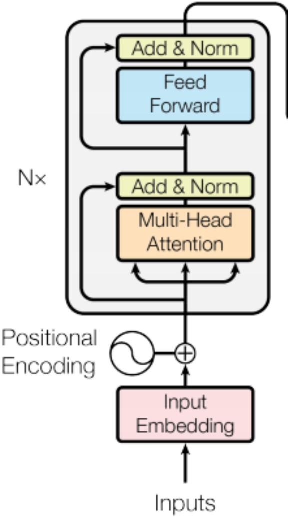

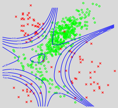

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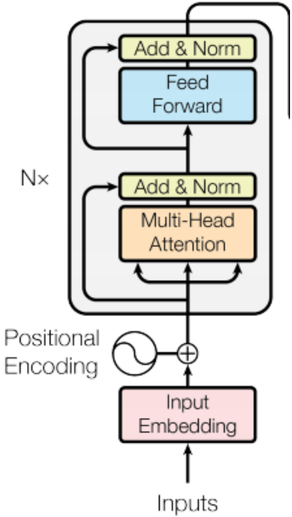

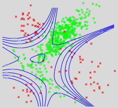

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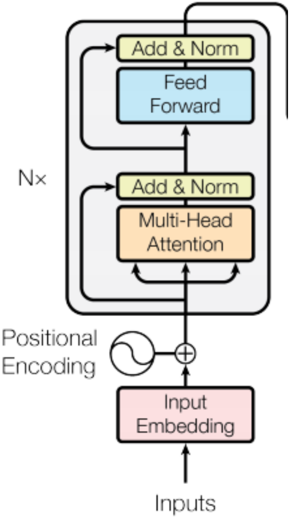

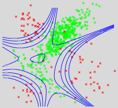

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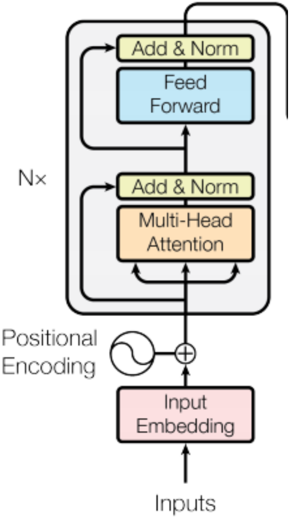
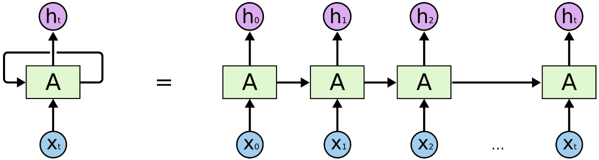
- **Add and Norm** means we introduce so called **skip-connections** and **Layer Normalization** (details omitted)

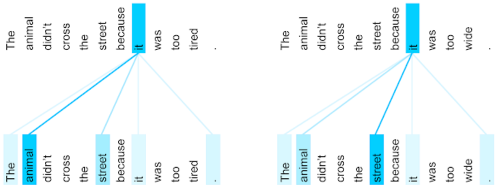


Comparison to recurrent neural networks (RNNs)

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



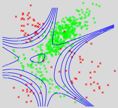
[2]



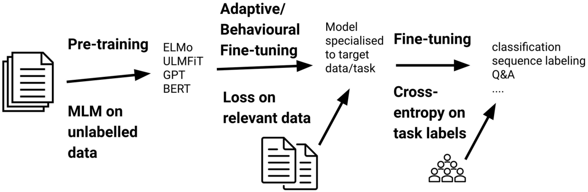
[3]

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

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



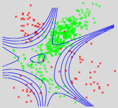
Fine-tuning



[4]

- Pre-train a large model on a general dataset (like Wikipedia)
- 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

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



Masked language modeling

Inputs

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

Expected outputs

```
movie  book  classic
sings  the
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