

Lecture 8: Large models (LLMs, VLMs, Generators)

Advanced deep learning



Rémy Sun
remy.sun@inria.fr

Course organization

- Goal: In-depth understanding of important Deep Learning staples
 - Reinforce what you have already seen
 - Introduce state of the art models
- This is a hands-on course in pytorch
 - Minimal math
 - Enough to understand
 - Quite a bit of coding
 - Get comfortable with the standard pipeline

- L1-2: Overview of Deep Learning (F. Precioso)
- L3-4: Fundamentals of Deep Learning (R. Sun)
- L5-6: Transformers (R. Sun)
- ***L8: Large models (LLMs, VLMs, Generators) (R. Sun)***
- L7: Tricks of the trade (R. Sun)
- L9: Ethics of AI (F. Precioso)
- L10: Intro to generative models (P-A. Mattei)

- Talk about big models
 - Refresher on Transformers
 - General overview
 - Zoom in on how LLMs are built
 - Prompt engineering
 - Reasoning in the age of LLMs
- Lab session
 - Load up a trained LLM
 - Play a bit with it

Before we start

How does pytorch work?

- Create neural network
 - Use the torch.nn modules
 - Can use torch.nn.Modules
 - Or create a new class inheriting from torch.nn modules
- The training loop is

How does pytorch work?

- Create neural network
 - Use the torch.nn modules
 - Can use torch.nn.Modules
 - Or create a new class inheriting from torch.nn modules
- The training loop is

```
yhat = model(X)
L,acc = loss_accuracy(loss,yhat,Y)
optim.zero_grad()
L.backward()
optim.step()
```

Ablation on ↓			Pre-training		Fine-tuning		Rand-Augment		AutoAug		Mixup		CutMix		Erasing		Stoch. Depth		Repeated Aug.		Dropout		Exp. Moving Avg.		top-1 accuracy	
none: DeiT-B	adamw	adamw	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	81.8 ±0.2	83.1 ±0.1	pre-trained 224 ²	fine-tuned 384 ²	
optimizer	SGD	adamw	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	74.5	77.3	81.8	83.1	
	adamw	SGD	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	81.8	83.1			
data augmentation	adamw	adamw	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	79.6	80.4	78.7	79.8	
	adamw	adamw	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	81.2	81.9			
	adamw	adamw	✓	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	78.7	79.8			
	adamw	adamw	✓	✗	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	80.0	80.6			
	adamw	adamw	✓	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	75.8	76.7			
regularization	adamw	adamw	✓	✗	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	4.3*	0.1	81.3	83.1	
	adamw	adamw	✓	✗	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	3.4*	0.1			
	adamw	adamw	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	76.5	77.4			
	adamw	adamw	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	81.3	83.1			
	adamw	adamw	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	81.9	83.1			

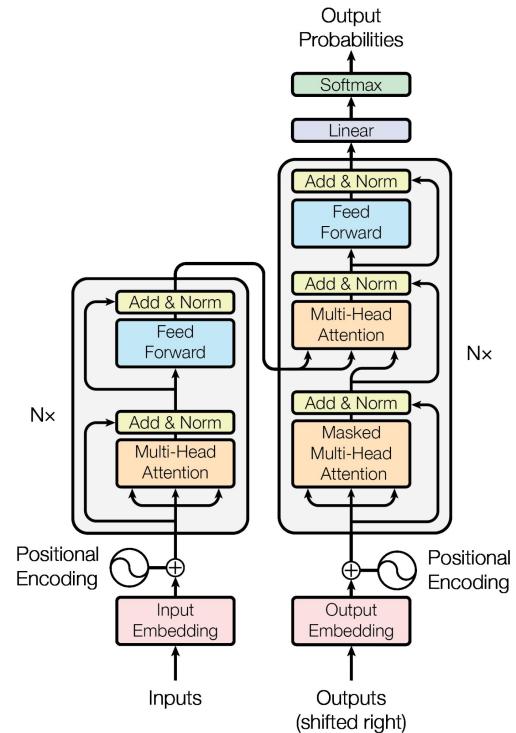
CNNs also benefit (Wightmann et al. 2021)

Procedure → Reference	Previous approaches					Ours		
	ResNet [13]	PyTorch [1]	FixRes [48]	DeiT [45]	FAMS (×4) [10]	A1	A2	A3
Train Res	224	224	224	224	224	224	224	160
Test Res	224	224	224	224	224	224	224	224
Epochs	90	90	120	300	400	600	300	100
# of forward pass	450k	450k	300k	375k	500k	375k	188k	63k
Batch size	256	256	512	1024	1024	2048	2048	2048
Optimizer	SGD-M	SGD-M	SGD-M	AdamW	SGD-M	LAMB	LAMB	LAMB
LR	0.1	0.1	0.2	1×10^{-3}	2.0	5×10^{-3}	5×10^{-3}	8×10^{-3}
LR decay	step	step	step	cosine	step	cosine	cosine	cosine
decay rate	0.1	0.1	0.1	-	$0.02^{t/400}$	-	-	-
decay epochs	30	30	30	-	1	-	-	-
Weight decay	10^{-4}	10^{-4}	10^{-4}	0.05	10^{-4}	0.01	0.02	0.02
Warmup epochs	✗	✗	✗	5	5	5	5	5
Label smoothing ε	✗	✗	✗	0.1	0.1	0.1	✗	✗
Dropout	✗	✗	✗	✗	✗	✗	✗	✗
Stoch. Depth	✗	✗	✗	0.1	✗	0.05	0.05	✗
Repeated Aug	✗	✗	✓	✓	✗	✓	✓	✗
Gradient Clip.	✗	✗	✗	✗	✗	✗	✗	✗
H. flip	✓	✓	✓	✓	✓	✓	✓	✓
RRC	✗	✓	✓	✓	✓	✓	✓	✓
Rand Augment	✗	✗	✗	9/0.5	✗	7/0.5	7/0.5	6/0.5
Auto Augment	✗	✗	✗	✗	✓	✗	✗	✗
Mixup alpha	✗	✗	✗	0.8	0.2	0.2	0.1	0.1
Cutmix alpha	✗	✗	✗	1.0	✗	1.0	1.0	1.0
Erasing prob.	✗	✗	✗	0.25	✗	✗	✗	✗
ColorJitter	✗	✓	✓	✗	✗	✗	✗	✗
PCA lighting	✓	✗	✗	✗	✗	✗	✗	✗
SWA	✗	✗	✗	✗	✓	✗	✗	✗
EMA	✗	✗	✗	✗	✗	✗	✗	✗
Test crop ratio	0.875	0.875	0.875	0.875	0.875	0.95	0.95	0.95
CE loss	✓	✓	✓	✓	✓	✗	✗	✗
BCE loss	✗	✗	✗	✗	✗	✓	✓	✓
Mixed precision	✗	✗	✗	✓	✓	✓	✓	✓
Top-1 acc.	75.3%	76.1%	77.0%	78.4%	79.5%	80.4%	79.8%	78.1%

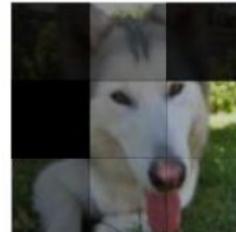
Refresher on Transformers

A new type of neural layer for everything

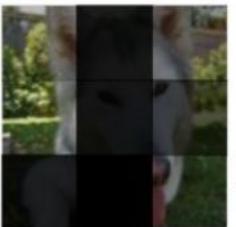
- What is the state of the art in
 - Computer vision?
 - ~~CNNs~~ -> **Transformers**
 - Natural language processing?
 - ~~RNNs~~ -> **Transformers**
 - Time series?
 - ~~RNNs or TCNs~~ -> **Transformers**
 - Multimodal problems?
 - ~~Hybrid?~~ -> **Transformers**
- Transformers use keeps increasing over time



Dog



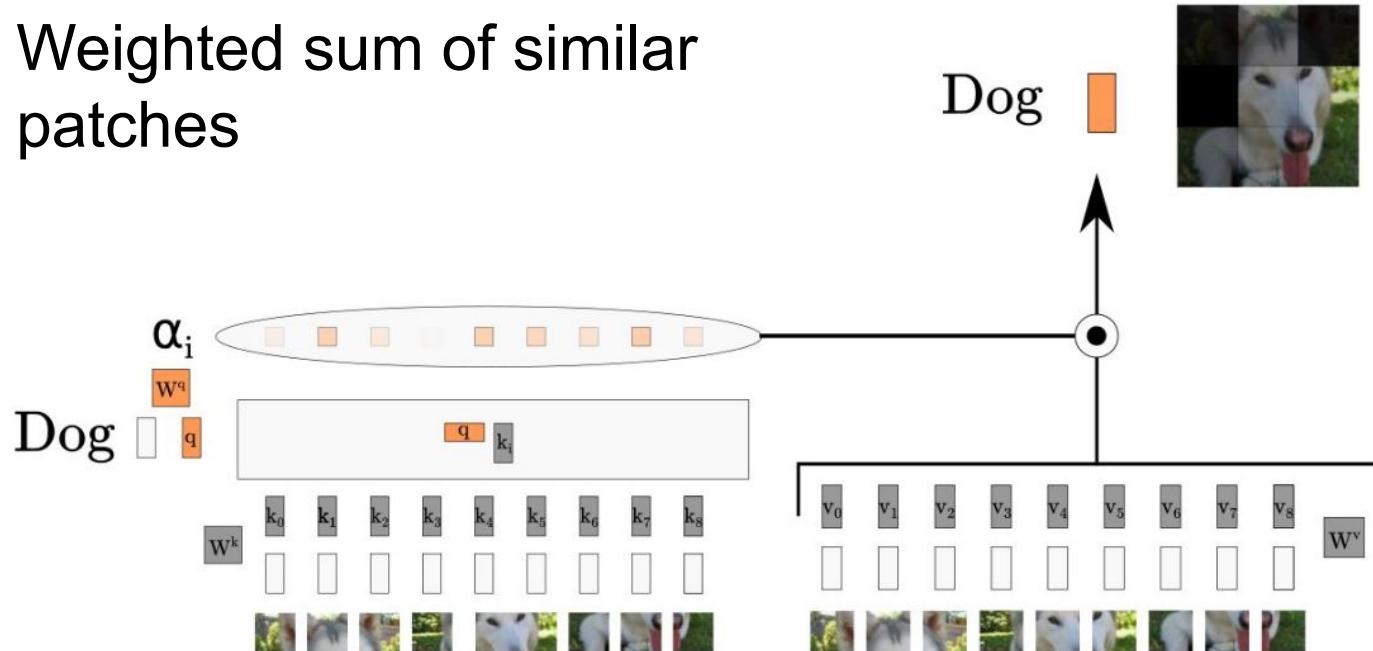
Garden



- What is a Dog?
 - It is a 4 legged animal with fur and ears and eyes and a head and ...
 - It is on this part of that picture.

Attended representation

- Weighted sum of similar patches



Attended representation

```
def scaled_dot_product(q, k, v, mask=None):
    d_k = q.size()[-1]

    #####
    ### YOUR CODE HERE! ####
    #####

    # Compute attn_logits
    attn_logits = torch.matmul(q, k.transpose(-2, -1))
    attn_logits /= math.sqrt(d_k)

    # Apply mask if not None
    if mask is not None:
        attn_logits = attn_logits.masked_fill(mask == 0, - 1e14)

    # Pass through softmax
    attention = F.softmax(attn_logits, dim=-1)

    # Weight values accordingly
    output_values = torch.matmul(attention, v)

    #####
    ### END      ###
    #####

    return output_values, attention
```

```
def forward(self, x, mask=None, return_attention=False):

    #####
    ### YOUR CODE HERE! ####
    #####

    batch_dim, seq_length, input_dim = x.shape

    # Compute linear projection for qkv and separate heads
    # QKV: [Batch, Head, SeqLen, Dims]
    qkv = self.qkv_proj(x) # Batch x SeqLen x Hidden_dim * 3
    qkv = qkv.reshape(batch_dim, seq_length, self.num_heads, 3* self.head_dim)
    qkv = qkv.permute(0, 2, 1, 3)
    q, k, v = qkv.chunk(3, dim=-1)

    # Apply Dot Product Attention to qkv ()
    attention_values, attention = scaled_dot_product(q, k, v)

    # Concatenate heads to [Batch, SeqLen, Embed Dim]
    attention_values = attention_values.reshape(batch_dim, seq_length, self.embed_dim)

    # Output projection
    o = self.o_proj(attention_values)

    #####
    ### END      ###
    #####

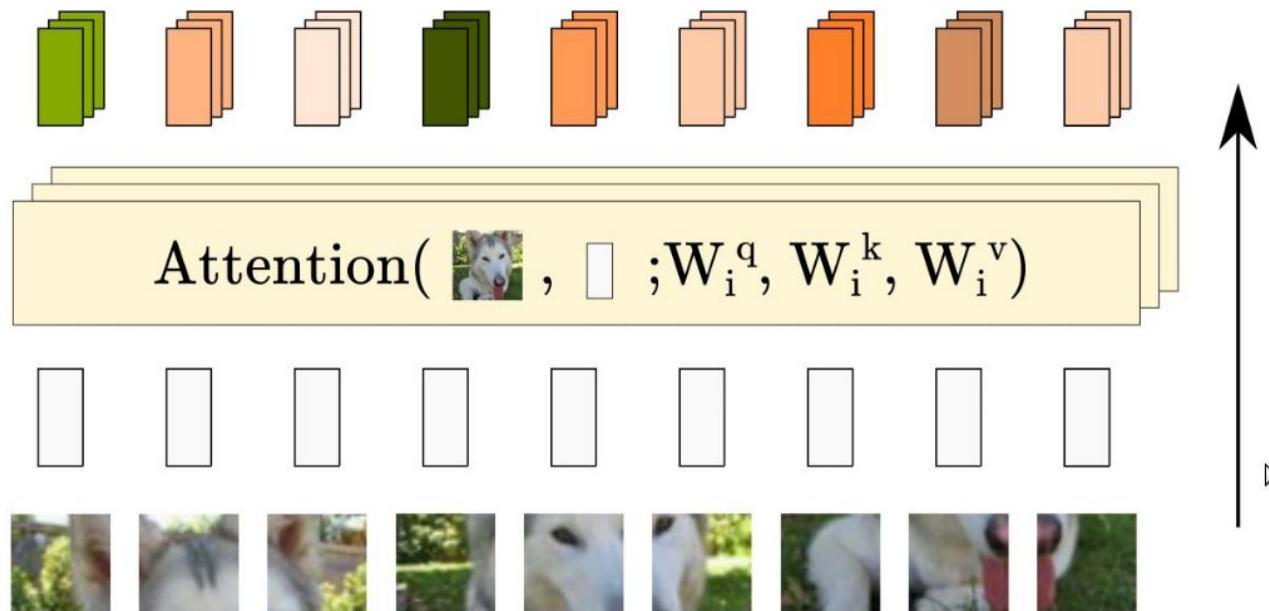
    if return_attention:
        return o, attention
    else:
        return o
```

Self-attention

- You can compare a sequence to itself!

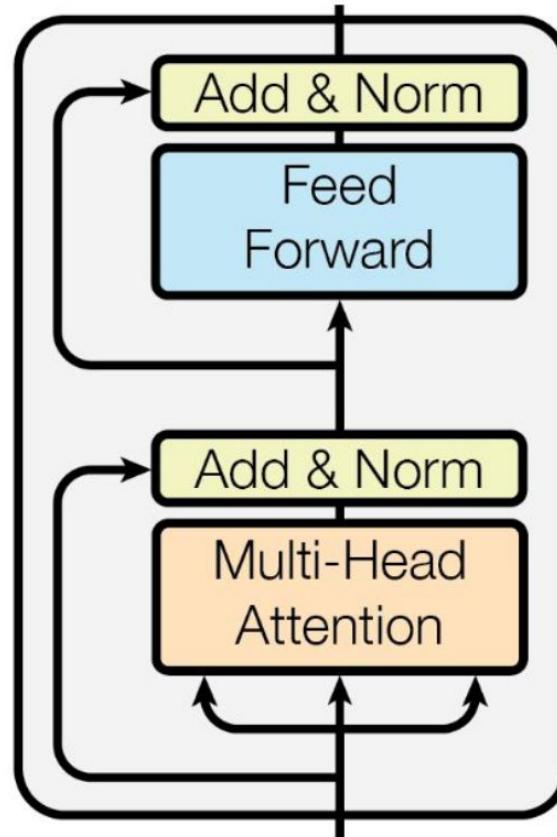


- And even have multiple interpretations



Transformer (Encoder) Block

- Basic encoder block
 - MultiHead attention
 - Skip connection
 - Small MLP applied to each token
 - Skip connection
- Stacked in a transformer



Transformer (Encoder) Block

```
class EncoderBlock(nn.Module):
    def __init__(self, input_dim, num_heads, dim_feedforward, dropout=0.0):
        """
        Args:
            input_dim: Dimensionality of the input
            num_heads: Number of heads to use in the attention block
            dim_feedforward: Dimensionality of the hidden layer in the MLP
            dropout: Dropout probability to use in the dropout layers
        """
        super().__init__()

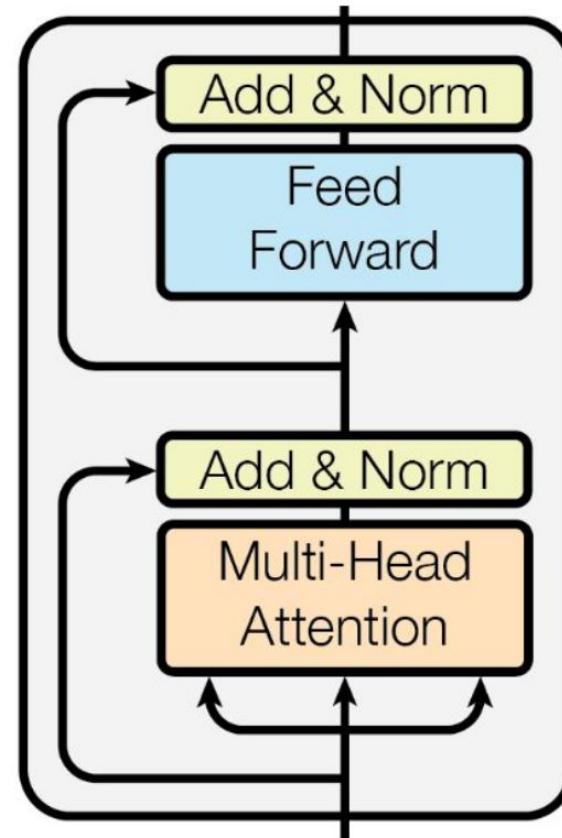
        # Create Attention layer
        self.self_attn = MultiheadAttention(input_dim, input_dim, num_heads)

        # Create Two-layer MLP with dropout
        self.mlp = nn.Sequential(
            nn.Linear(input_dim, input_dim*2),
            nn.ReLU(),
            nn.Dropout(dropout),
            nn.Linear(2*input_dim, input_dim)
        )
        # Layers to apply in between the main layers (Layer Norm and Dropout)
        self.norm = nn.Sequential(
            nn.LayerNorm(input_dim),
            nn.Dropout(dropout)
        )

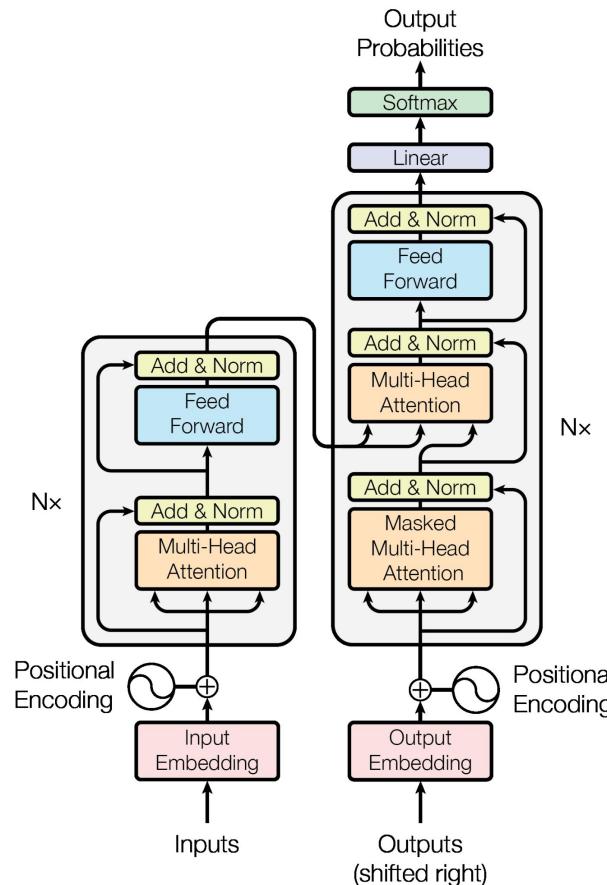
    def forward(self, x, mask=None):
        # Compute Attention part
        attn=self.self_attn(x)
        x=self.norm(attn+x)

        # Compute MLP part
        x = self.norm(x+self.mlp(x))

        return x
```

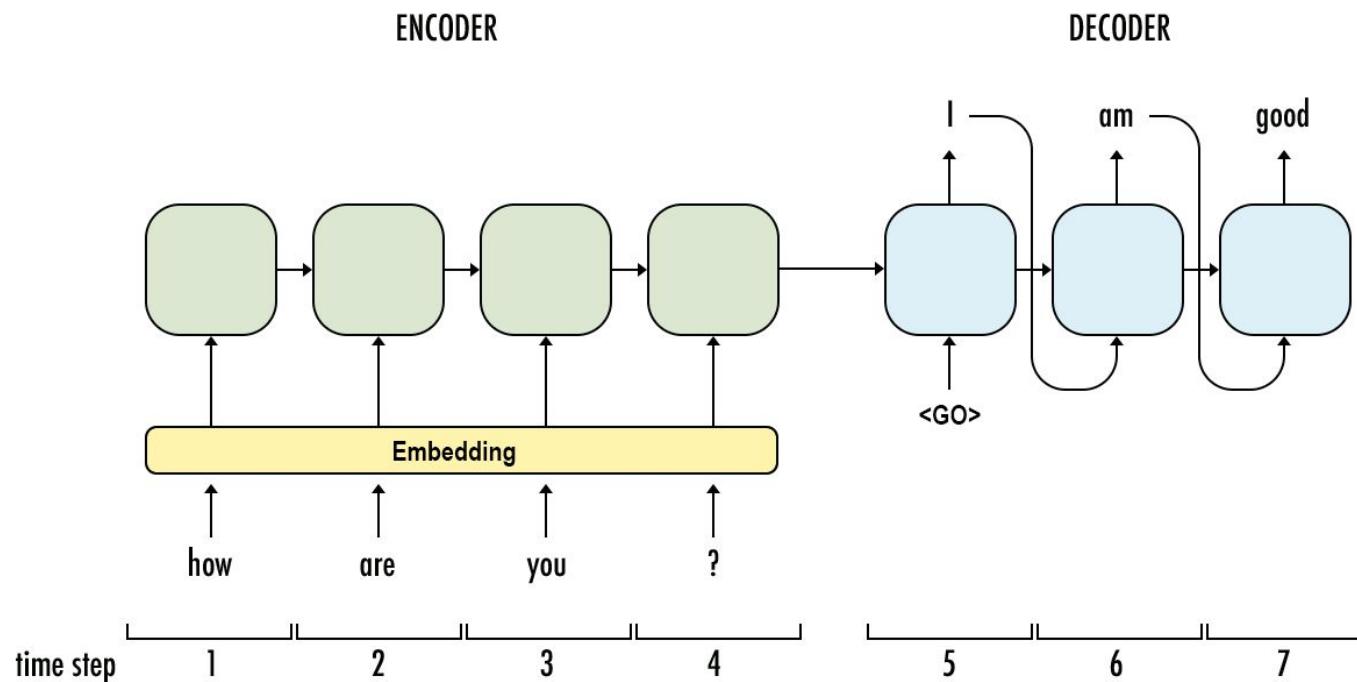


- Completely does away with recurrent units
 - Attention as a first class citizen!
 - Introduces element wise MLP for transform
- Transformer
 - Transforms the input throughout the layers
 - Also to blame for BERT, ELMO, DALL-E, ...

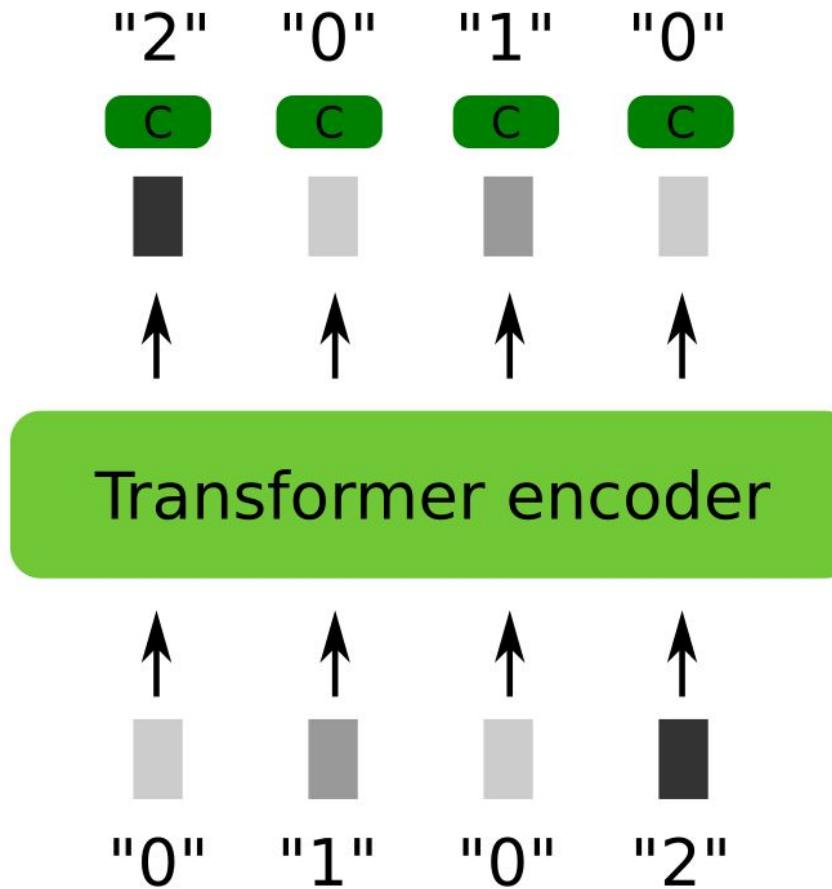


Autoregressive prediction

- Predict next token, feed it back into the decoder

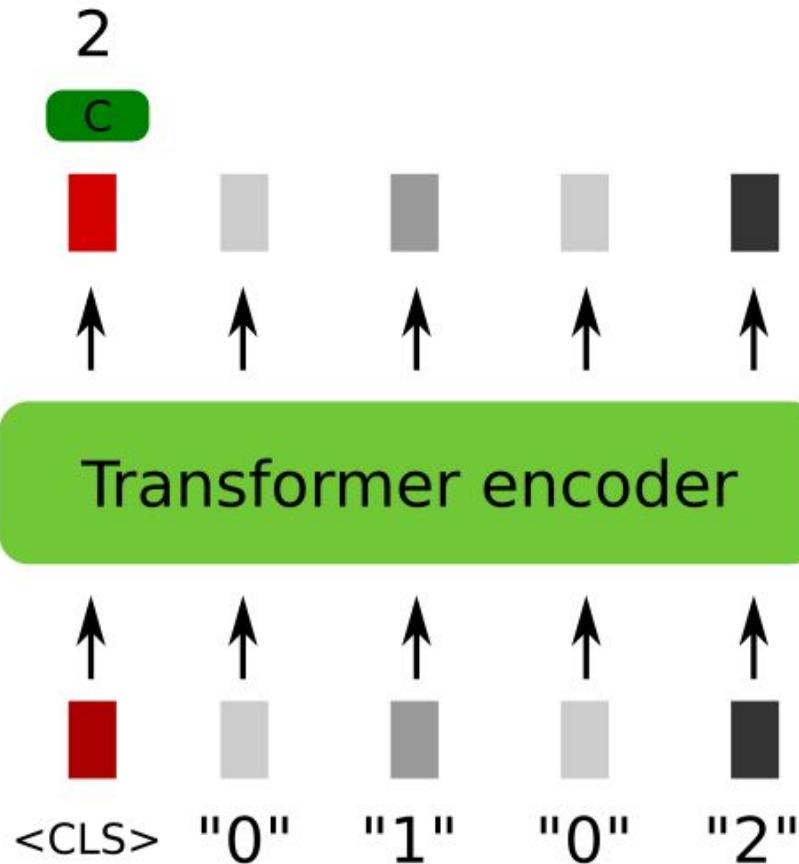


Token level predictions



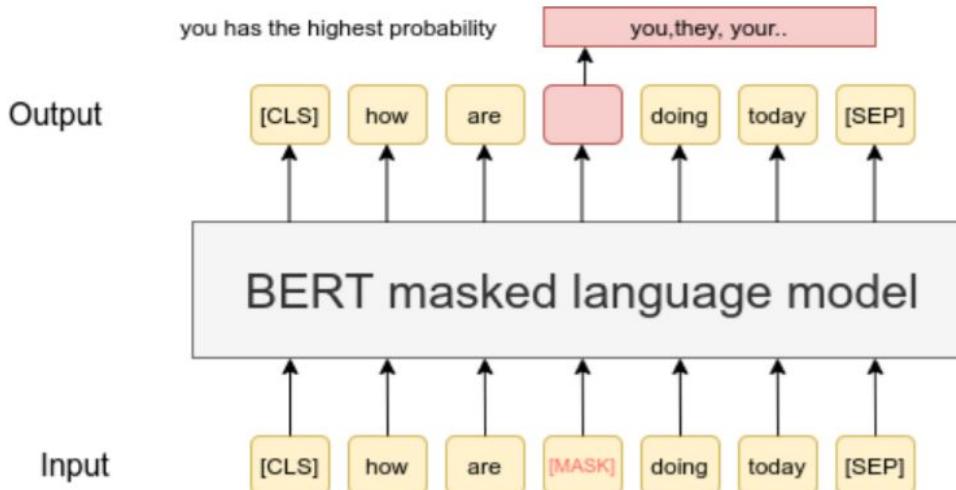
- Rich token features
 - Due to attention!
- Predictions for each token
 - Invert sequence here
- Predict with linear layers

Classification token



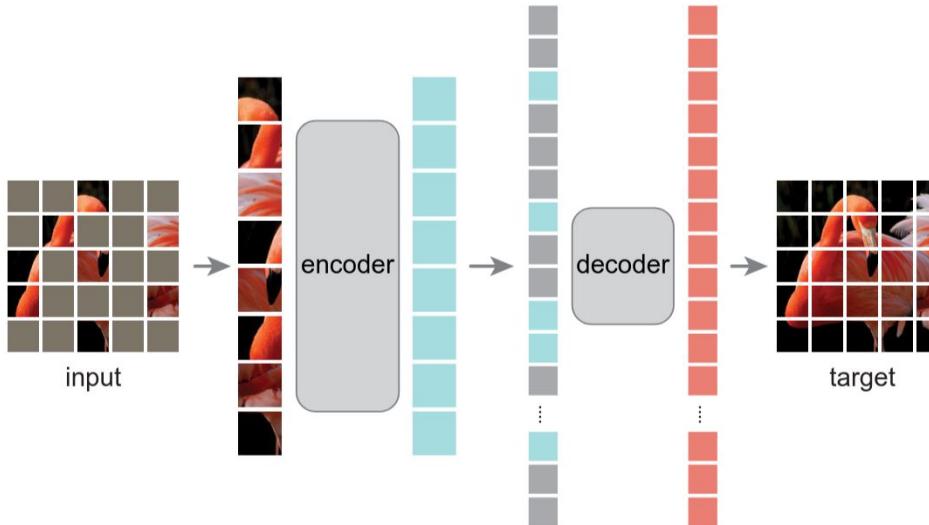
- Rich token features
 - Due to attention!
- Question/Classification token
 - “What is the class”
- Accumulate relevant info from other tokens

BERT pretraining



- Pseudo-objective
 - Mask part of the sentence
 - Try to predict the masked part

Masked auto-encoders



- Also works for images!
- Originally introduced in BeIT paper

- Extract rich features from images
 - Including long range dependencies
- Masked token prediction for pretraining
 - Only works with transformers
 - Much better than traditional contrastive training
- Replace CNNs as backbones for downstream tasks
 - Segmentation
 - Detection

Large models (LLMs, VLMs, and
image generators)

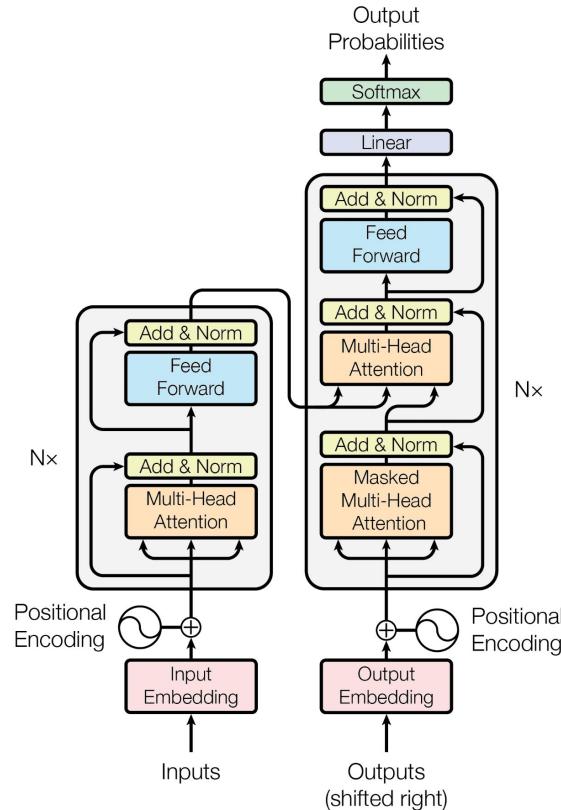


... And text to image models!



Large Language Models

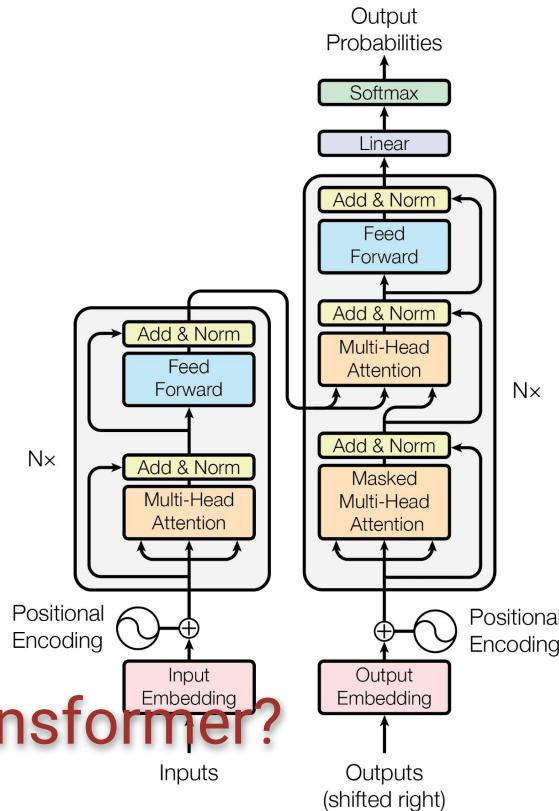
- General architecture
 - Encoder
 - Decoder
- Very impressive performance
 - ChatGPT
 - Bard
 - Copilot



Large Language Models

- General architecture
 - Encoder
 - Decoder
- Very impressive performance
 - ChatGPT
 - Bard
 - Copilot

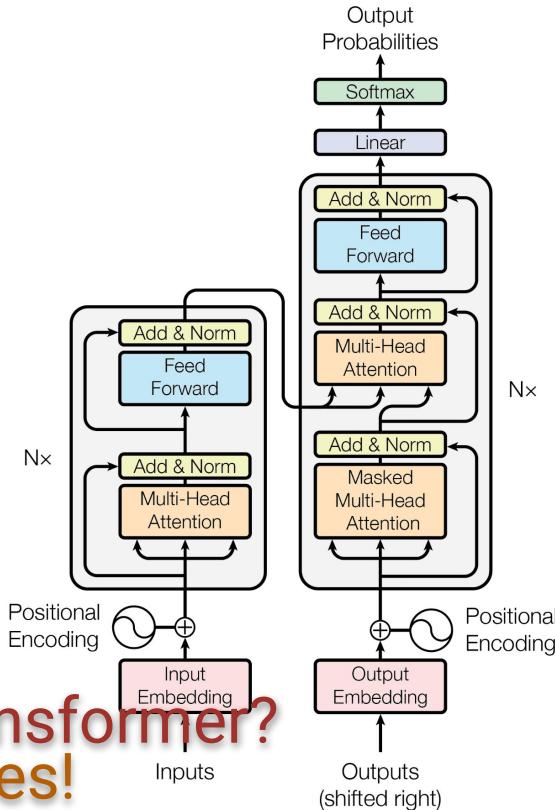
That is just a transformer?



Large Language Models

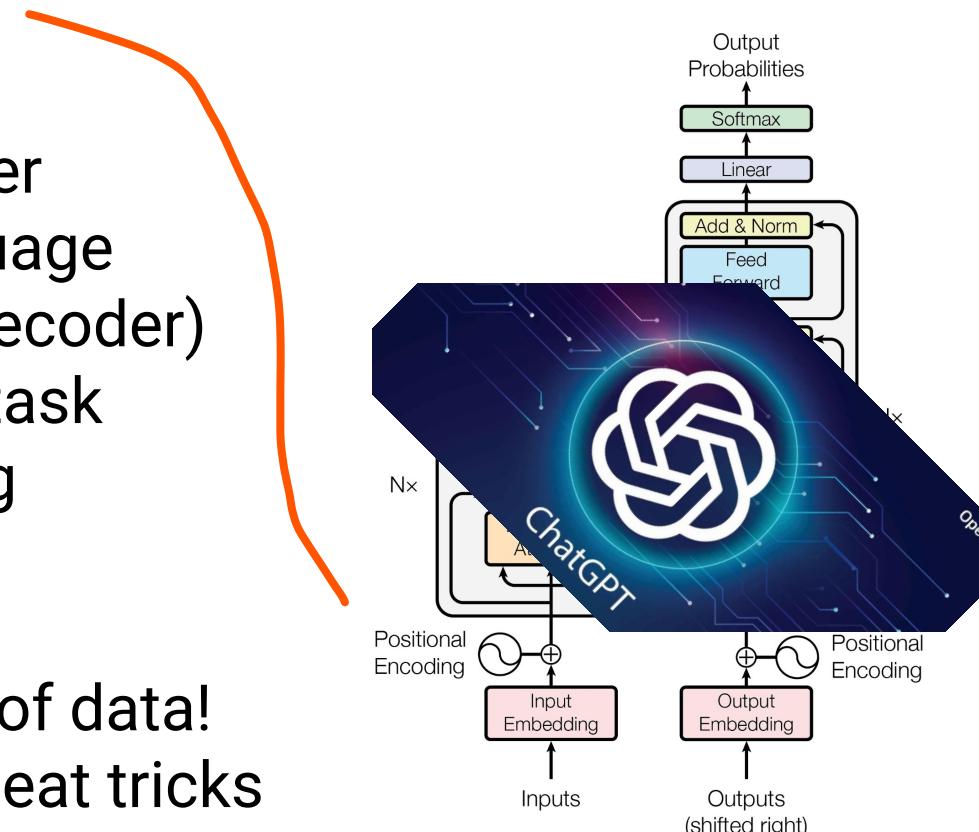
- General architecture
 - Encoder
 - Decoder
- Very impressive performance
 - ChatGPT
 - Bard
 - Copilot

That is just a transformer?
Yes!



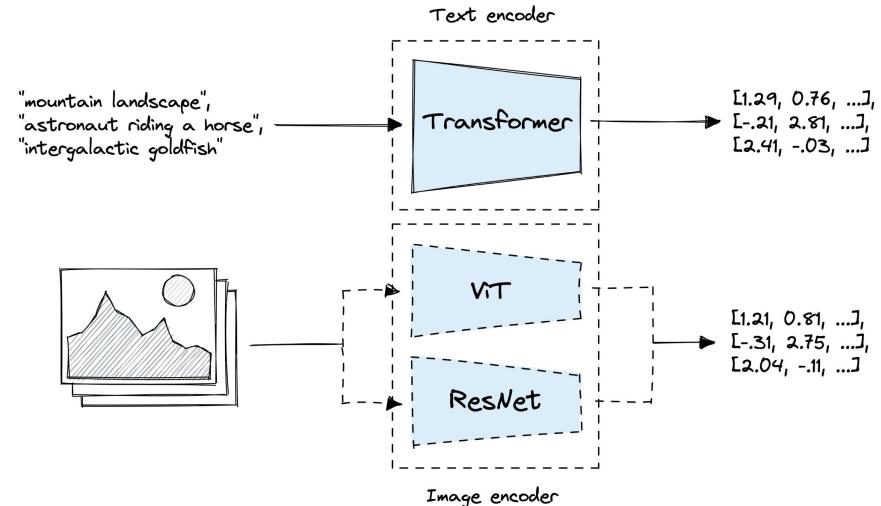
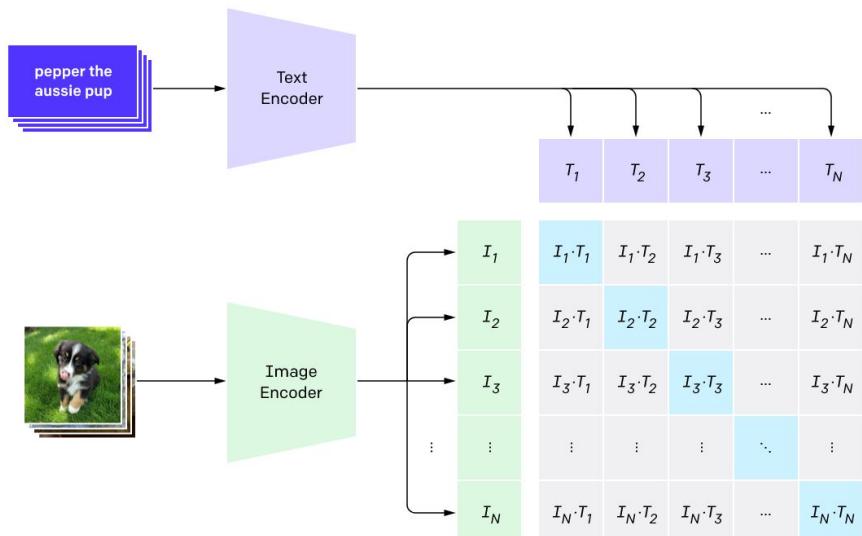
Large Language Models

- GPT: Generative Pretrained Transformer
 - Pretrain as a language model (encoder/decoder)
 - Keep encoder for task specific fine-tuning
 - Decoder-only now
- Train on lots and lots of data!
 - Along with a few neat tricks

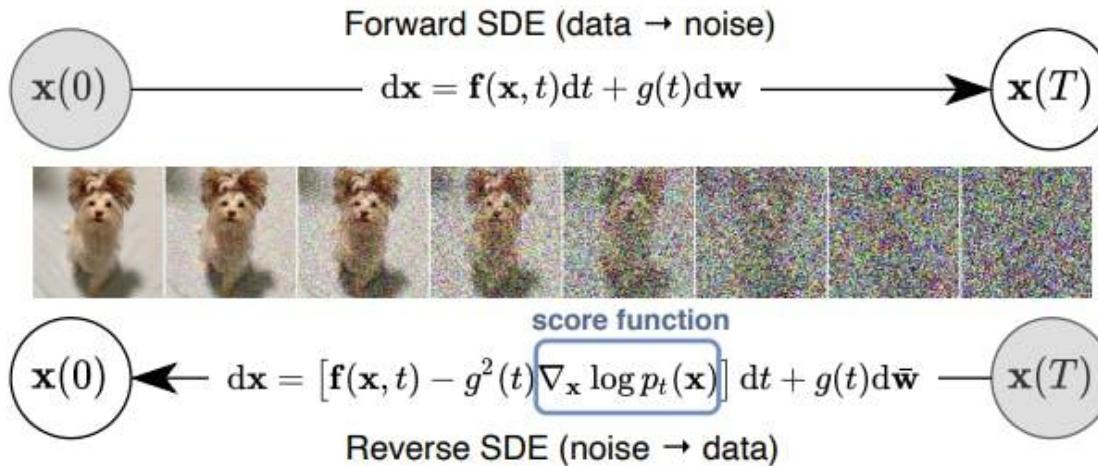


Vision Language Models

1. Contrastive pre-training



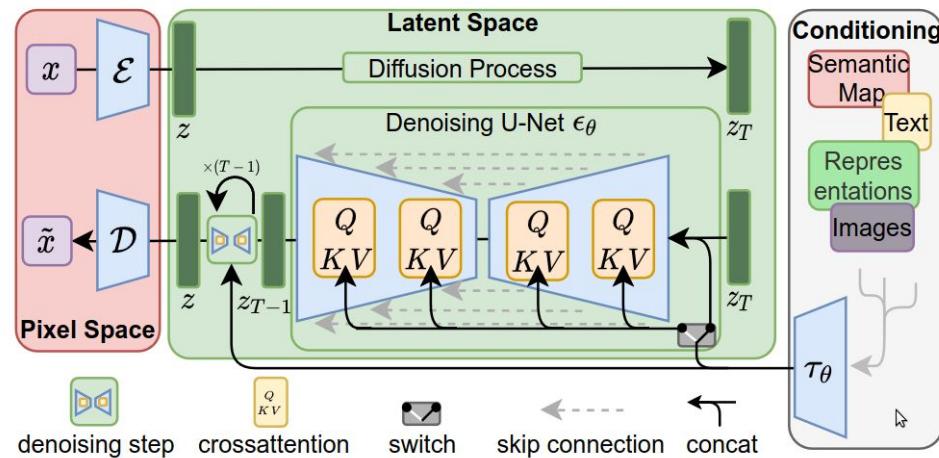
Generating images (with Diffusion)



- Generator
 - Image space
 - Latent space
- Learn to link the two
 - With network
 - Iteratively (diffusion)

Text-to-Image models

- Generator
 - Random z
 - Map z to some image x
 - Gradual process called Diffusion
- Inject condition tokens
 - Cross attention in generative process



Takeaway

- ✓ LLM: Standard transformer encoder/decoder
 - Trained with lots and lots of data!
- ✓ Text-to-Image: Generative model contextualized by conditioning information
 - Trained with lots and lots of data!
- Very impressive results
 - Facilitated by the expressive power of attention
 - As long as you have lots and lots of data!

Character generator

<https://perchance.org/ai-character-generator>

Description ⓘ
stoic giraffe-armor knight standing guard in an ancient tomb, close-up portrait

Anti-Description (optional)
things you **don't** want in the image

Art Style: Concept Art

Shape: Portrait

How many? 6

generate



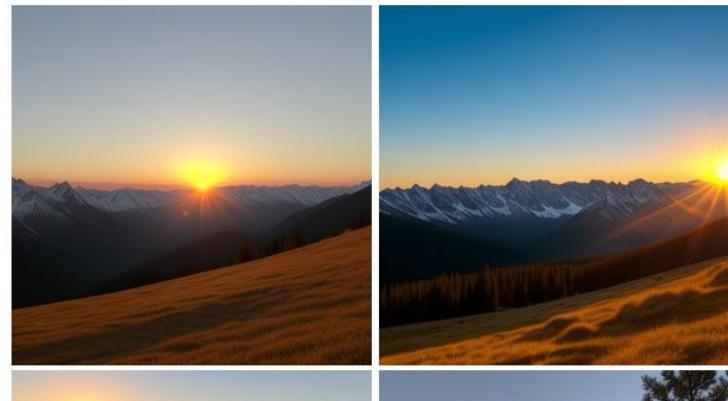
Text-to-Image

<https://perchance.org/aiimageaccess>

Text-to-Image AI

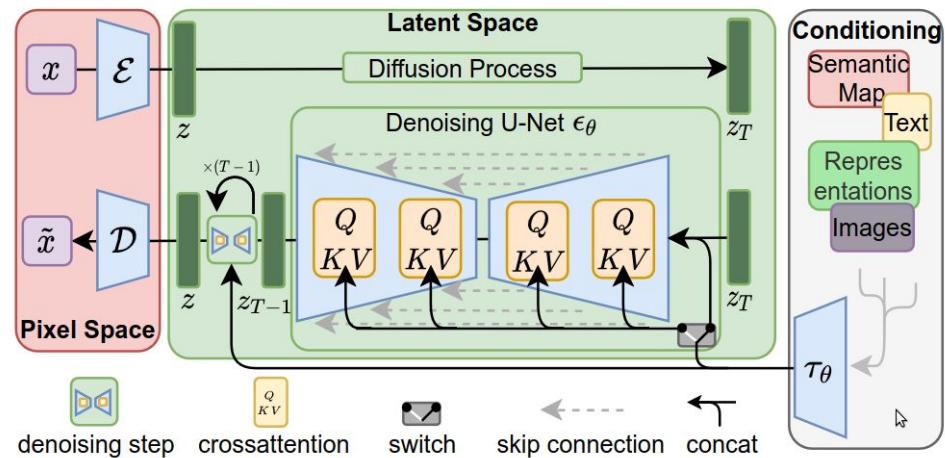
Current Prompt:

sun setting in the mountains



It is an issue of how you present it

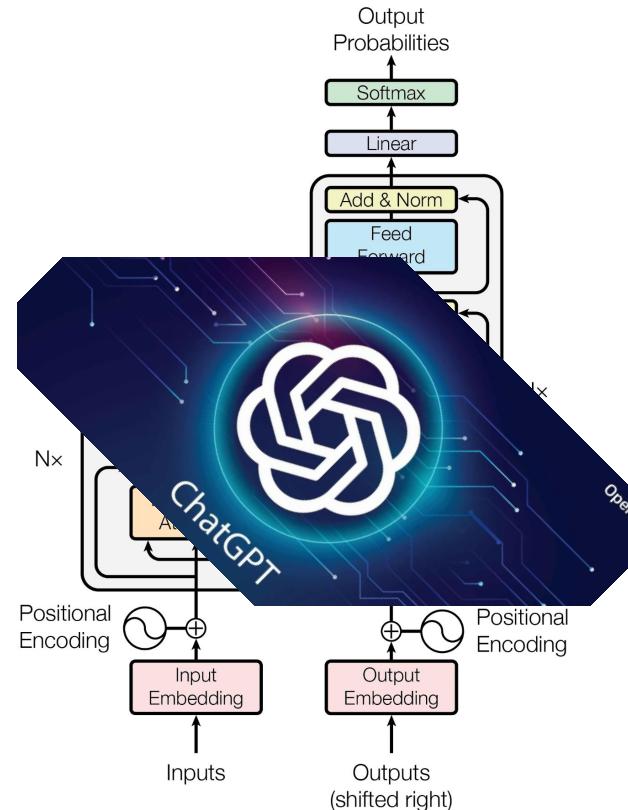
- Same underlying model
 - Stable Diffusion
- Text-to-image
 - “Pure” Stable Diffusion
- Character generator
 - Stable Diffusion w/ Custom text prompts



What goes into training a Large (Language) Model?

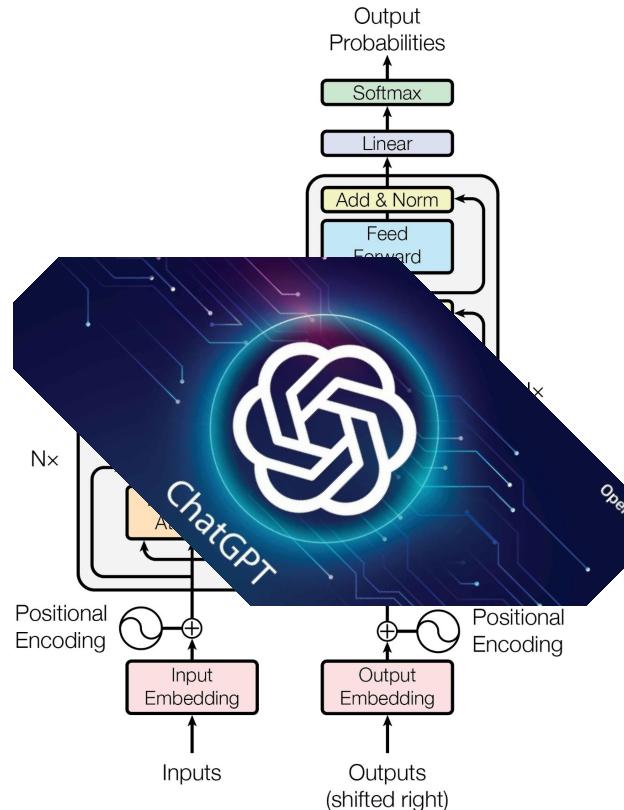
Road to ChatGPT

- What do we need to do?
 - Get (lots of) data
 - Prepare data
 - Get a model
 - Make the model work
 - Align it to our preferences
 - Deploy!



Road to ChatGPT

- What do we need to do?
 - Get (lots of) data
 - Prepare data
 - Get a model
 - **Make the model work**
 - Takes some work
 - Align it to our preferences
 - Deploy!



Get data and define your tasks

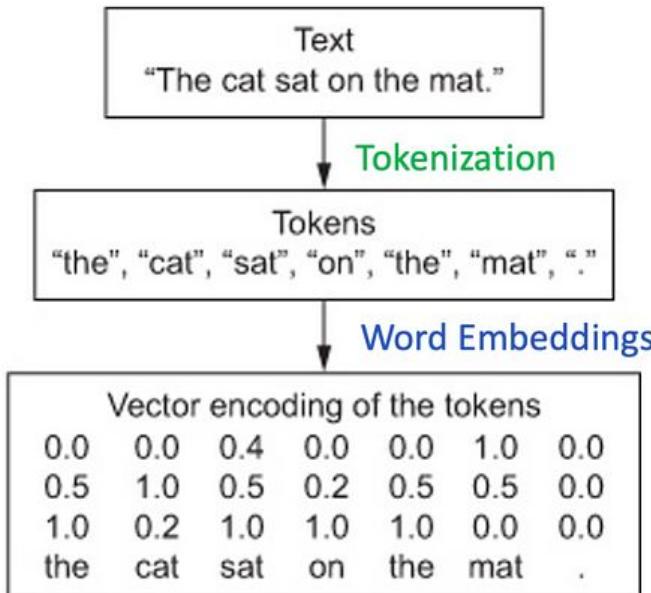
Google  Meta



- Grab data that fits your general case
 - From public data
 - Running out of new public data...
 - From (your?) private data

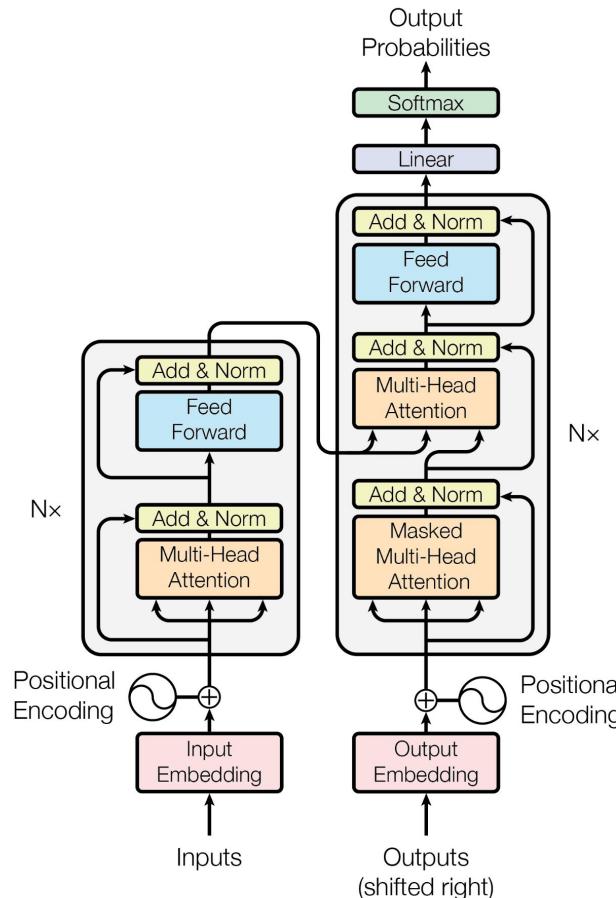
Prepare the data!

- Format text for your problem
- Tokenize into atomic elements
 - Letters, n-grams, words
- Embed in vector space
 - Index -> vector
 - Can be learned



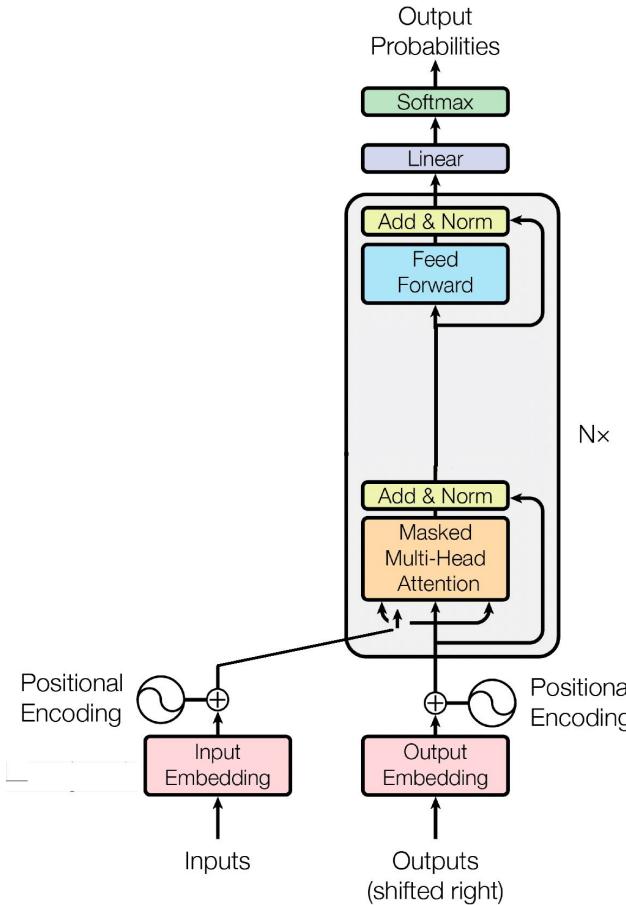
Build a model

- Transformer architecture
 - Suitable for your problem
 - Big enough for data
 - Studied in class!
- Could be something else
 - RNN, SSM, Mixer, ...
- Fairly straightforward



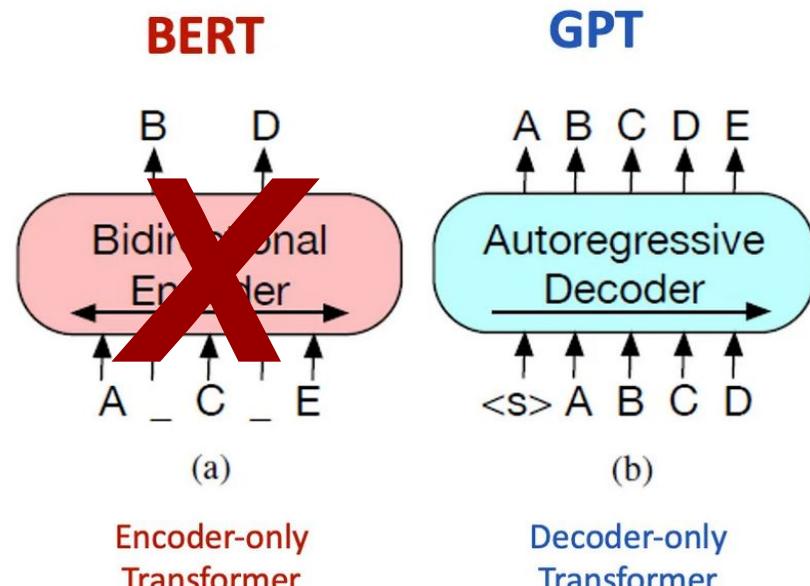
Build a model

- Transformer architecture
 - Suitable for your problem
 - Big enough for data
 - Studied in class!
- Could be something else
 - RNN, SSM, Mixer, ...
- Fairly straightforward
 - Decoder-only nowadays



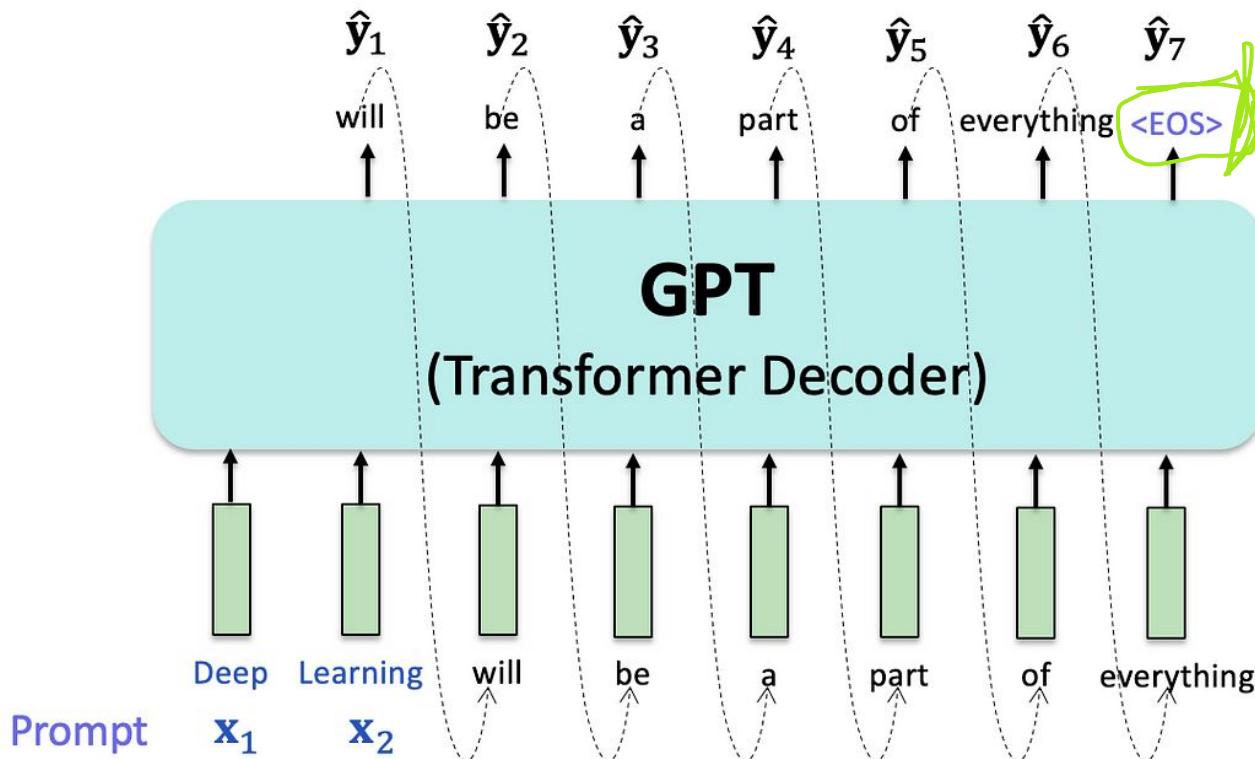
(Pre-)train the model on large dataset

- Train on large amounts of generalist data with no label
 - Encoder: Masked pre-training
 - **Decoder: Next token prediction**
- What we use our large dataset for



Autoregressive prediction

- Predict next token, feed it back into the decoder



Fine-tune to our purposes

Premise

Russian cosmonaut Valery Polyakov set the record for the longest amount of time spent in space.

Hypothesis

Russians hold the record for the longest stay in space.

Target

Entailment
Not entailment



Options:
- yes
- no

Template 1

Russian Cosmonaut Valery Polyakov set the record for the longest amount of time spent in space.

Based on the paragraph above, can we conclude that

Russians hold the record for the longest stay in space?

OPTIONS
-yes
-no

Template 2

Read the following and determine if the hypothesis can be inferred from the premise:

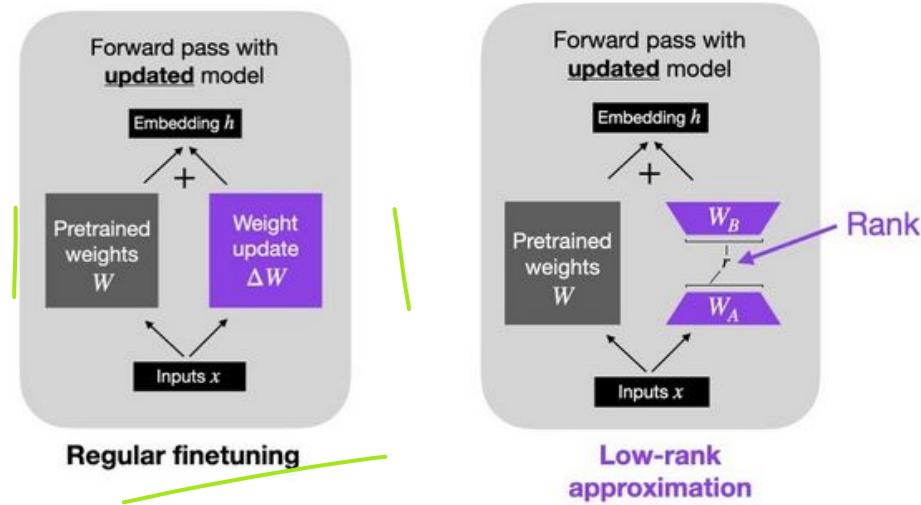
Premise: <premise>

Hypothesis: <hypothesis>
<options>

Template 3, ...

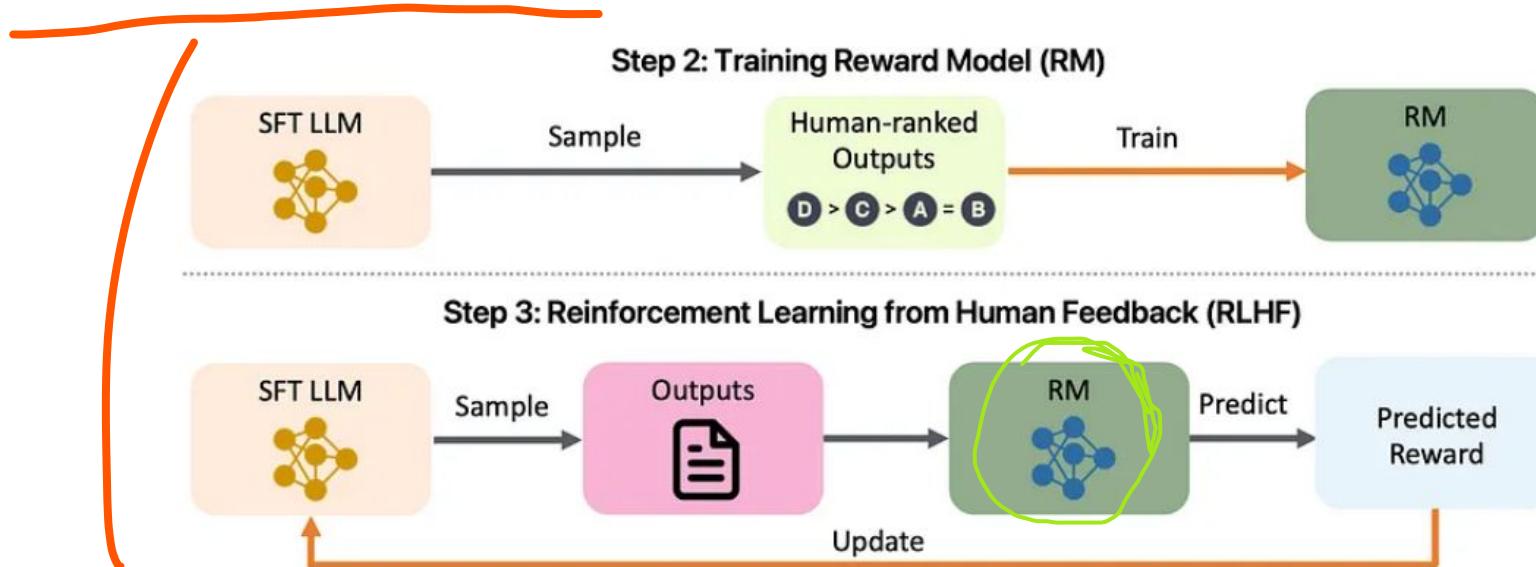
- Large dataset is unspecialized
 - You do not want wikipedia completion...
 - Make smaller specialized dataset
 - Fine tune on it

Fine-tune to our purposes (efficiently)



- Fine tuning is expensive for LLMs
 - Can fine tune “smaller” weights
 - Fine tune a low rank adapter on weights

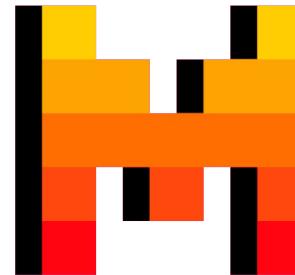
Alignment to preferences



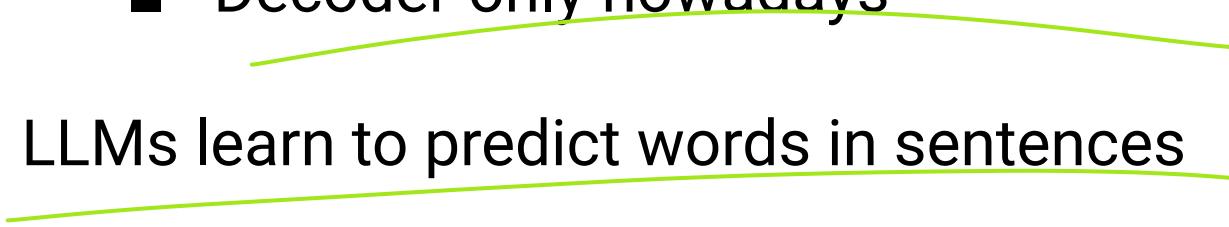
- Need to align to human preference
 - Train proxy model to emulate preferences
 - Use proxy model to fine-tune LLM (PPO, DPO)

(Sell access to your model)

- What you have
 - A really big model
 - Not given to client
 - Code to run the model with inputs
 - See Lab session
- What you sell
 - API access
 - The right to send inputs and get answers

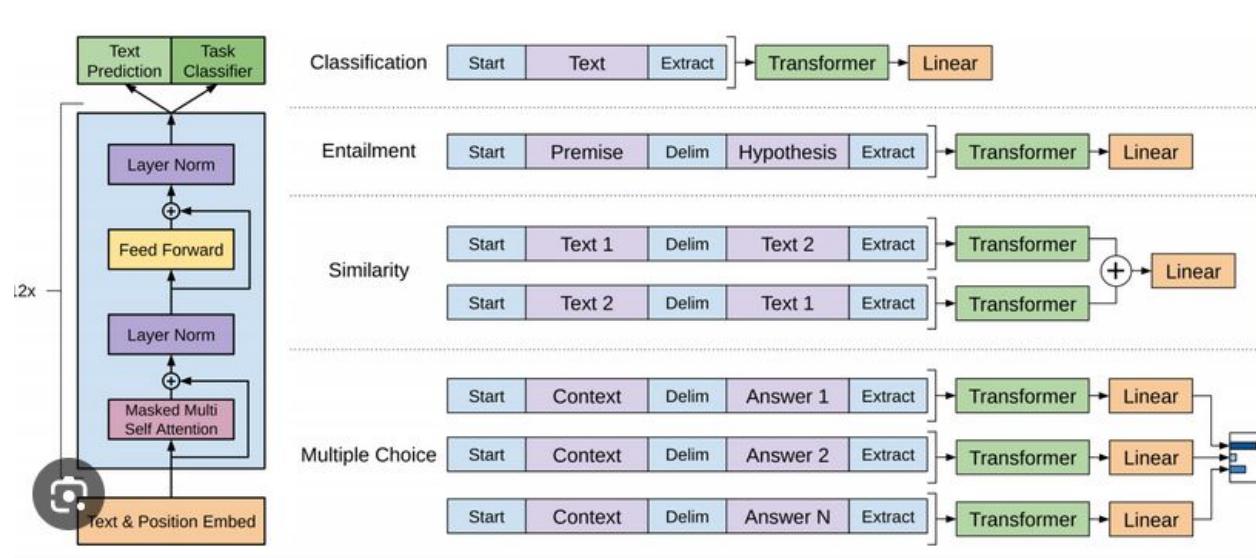


Gemini

- LLMs are trained with
 - Huge amounts of generalist data
 - Some specialized date
 - For a specialized downstream task
 - Proxies for human feedback
 - Enormous computational resources
 - Transformer blocks
 - Decoder-only nowadays
 - LLMs learn to predict words in sentences
- 

About prompts

Fine-tuning



- Fine tune encoder on downstream tasks
- So expensive (huge models!)
 - And maybe we already finetuned

Training is hard, let's not do it
But how ?

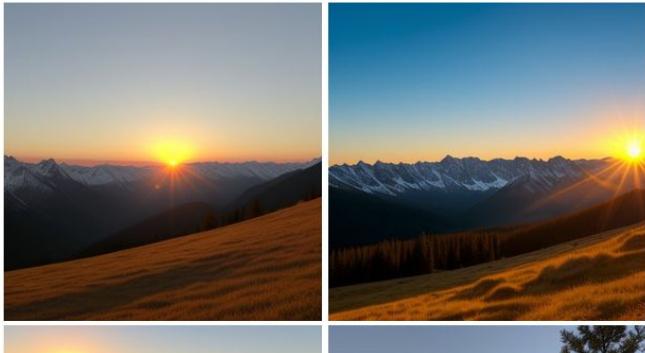
Remember this ?

Text-to-Image AI

sun setting in the mountains

Current Prompt:

sun setting in the mountains



Description

Anti-Description (optional)

Art Style

Shape

How many?



Prompt engineering

"[...] The sea is blue"



Transformer encoder

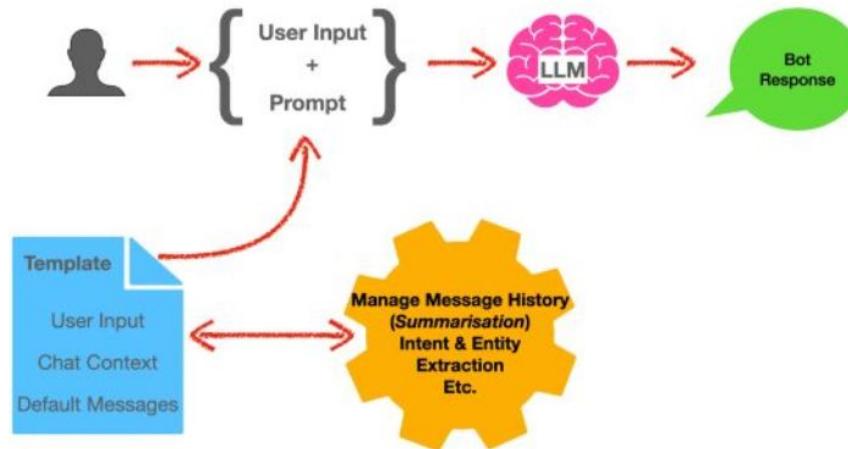


"The sky is blue. The sand is yellow. The rocks are grey. The sea is ..."

- E.g. Make a logical sequence to condition the model

- Need to find the right conditioning
 - Prompt engineering
 - Templating, Chain-of-thought, ...
- No training!

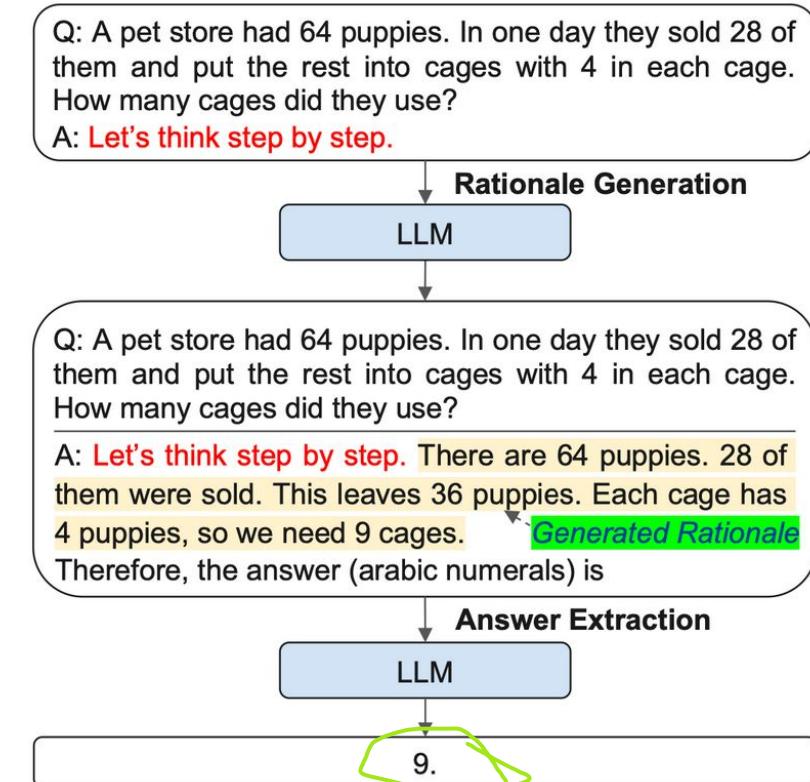
General context and framing

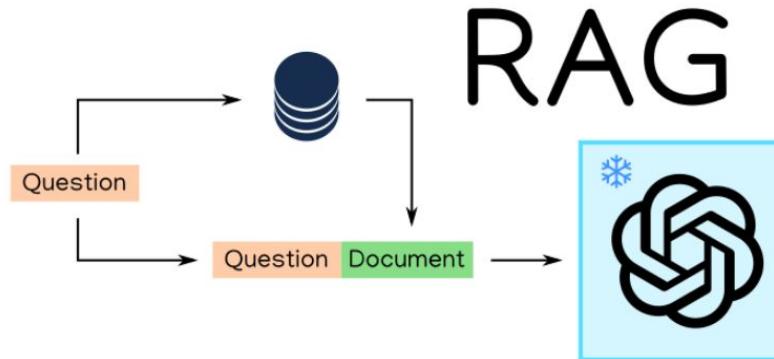


- The answer is learned behavior + input context
 - Put as much as possible in input
 - Template, behavior conditioning, history, ...

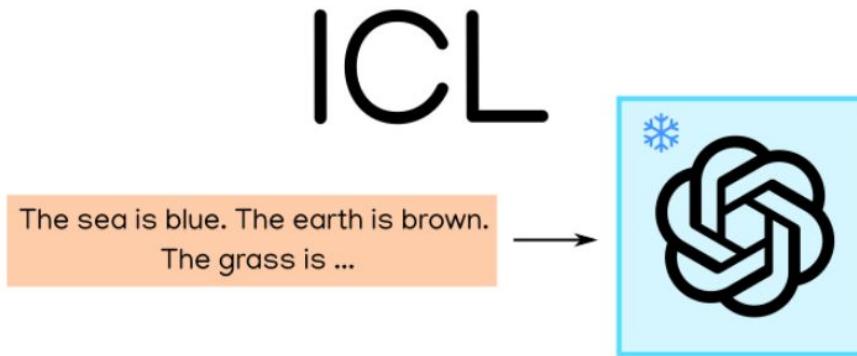
Chain-of-Thought prompting

- LLMs output likely chains of words
 - Can lead to large leaps of logic
- Chain-of-Thought
 - Make network output smaller steps
 - Each smaller step more reliable





- Sometimes learned behavior + context input is not enough
 - Finetune learned behavior? Expensive
 - Add to context input by adding relevant documents from database



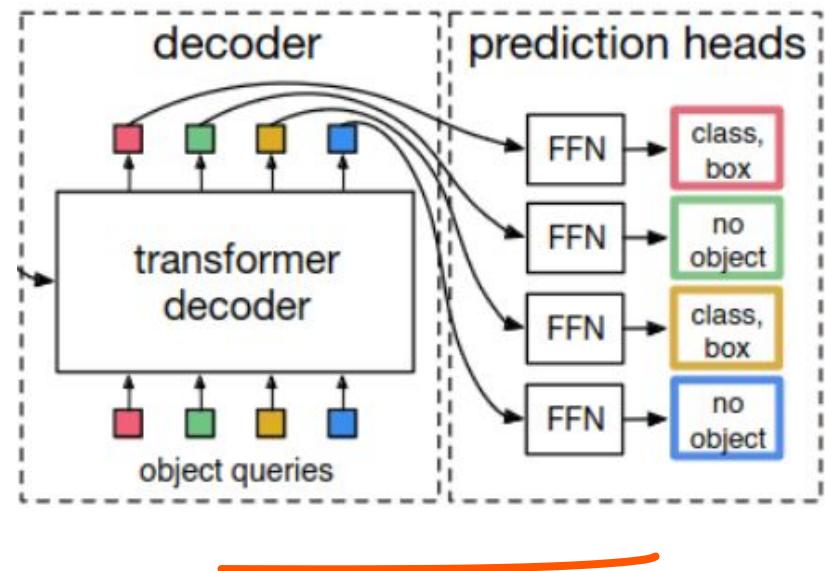
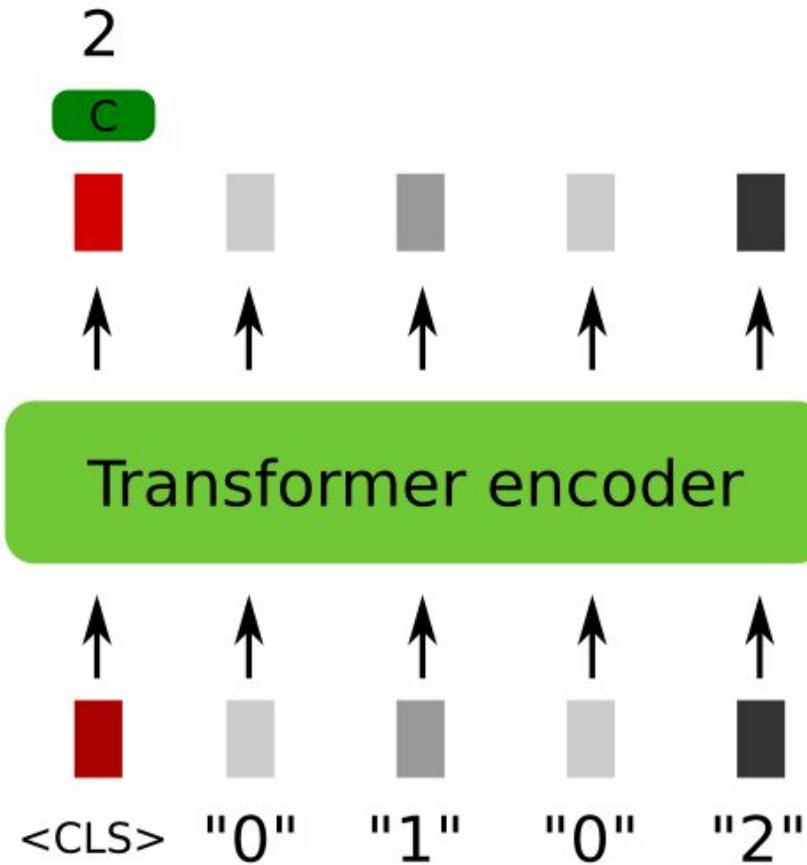
- Can give example to neural network to specialize the task done by network
 - Few-shot learning
 - Good results for tabular data!
 - Conditioning the network behavior

Ok, but surely we cannot do
everything like that.

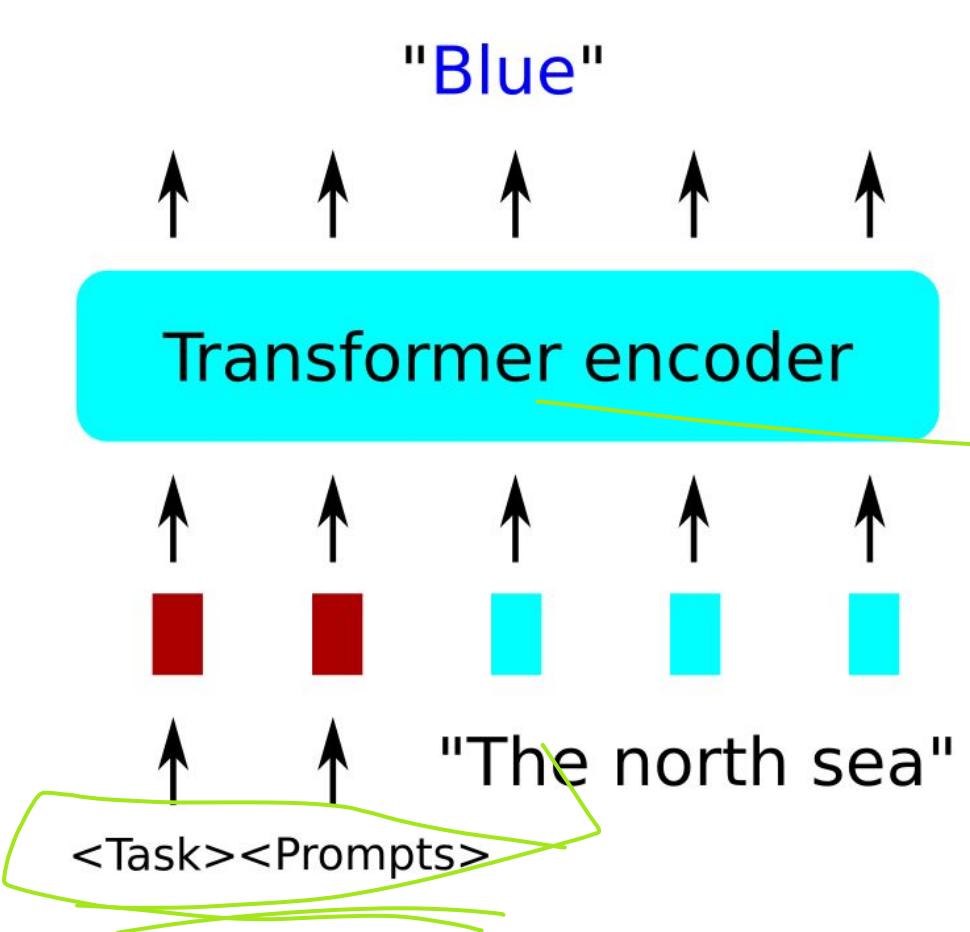
Maybe we could train a little?

How?

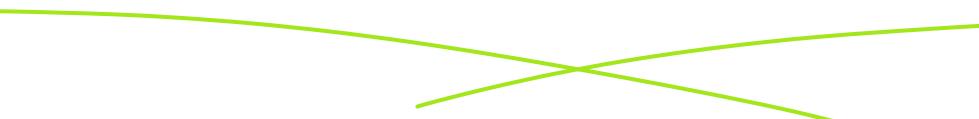
Remember this ?



Prompt tuning/learning



- Add task tokens
 - Only optimize these tokens
 - Prompt tuning /learning
- Can be SGD
 - “Heavy” gradients
- Can be done with alternative optimization

- Transformers are very powerful
 - But very data hungry
 - Freeform attention
 - Tokens are a very powerful tool in transformers
 - Classification/detection tokens
 - Contextual prompt engineering
 - Prompt learning/tuning
 - Departure from classical fine-tuning
- 

Large Language models and reasoning

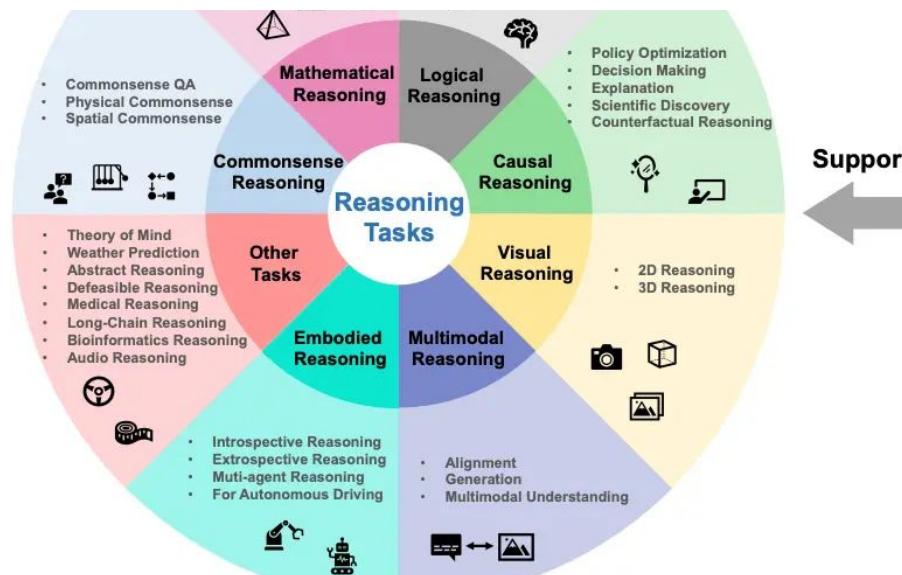
Introduction

Google DeepMind

AI achieves silver-medal standard solving International Mathematical Olympiad problems

Breakthrough models AlphaProof and AlphaGeometry 2 solve advanced reasoning problems in mathematics.

Jul 25, 2024



Introduction

Google DeepMind

AI achieves silver-medal standard solving International Mathematical Olympiad problems



Breakthrough models AlphaProof and AlphaGeometry 2 solve advanced reasoning problems in mathematics



Ars Technica

Apple study exposes deep cracks in LLMs' "reasoning" capabilities

Reasoning Techniques



A new study from six Apple engineers shows that the mathematical reasoning displayed by advanced large language models can be extremely brittle and unreliable.

1 month ago

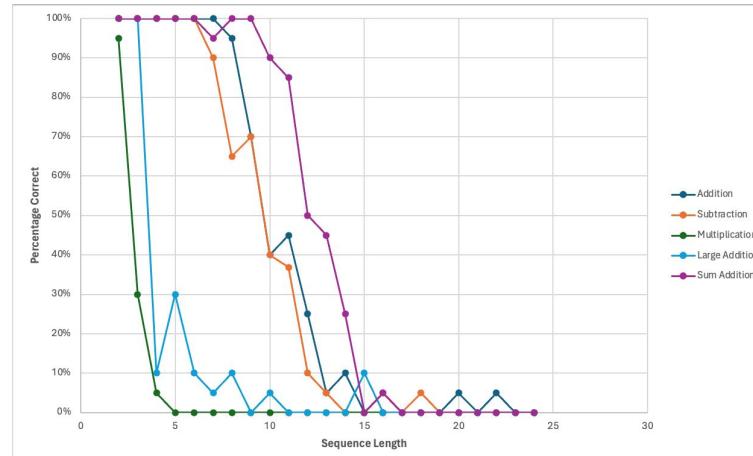


In-Context Learning

Autonomous Agent

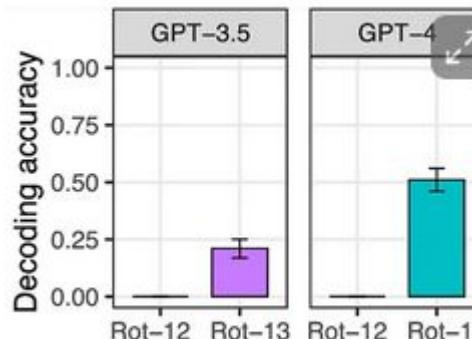
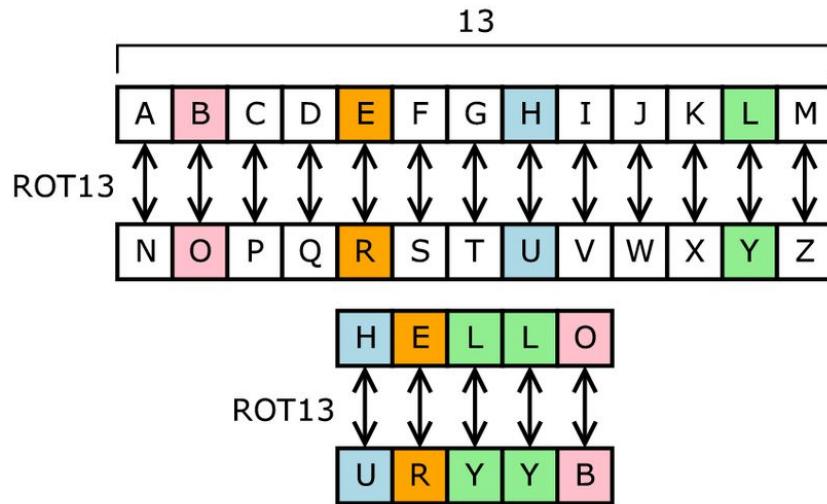
Case study: Simple arithmetic

- Ask simple arithmetic problems to LLM
 - No targeted training
- Kind of ok
 - For very simple problems
 - With short sequences



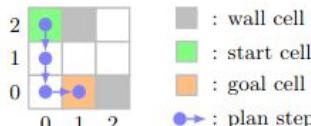
Issues with reasoning benchmarks

- Models can perform very complex tasks
 - E.g. decoding the ROT-13 cipher
 - Move letters by 13 units
- Tied to common problems
 - Horrible on ROT-12



Outputting reasoning

- Can learn to predict reasoning steps
 - Give reasoning steps during training
 - Will output reasoning steps to approximate solver



(a) Maze navigation task

Prompt	Response
bos	bos
start 0 2	plan 0 2
goal 1 0	plan 0 1
wall 1 2	plan 0 0
wall 2 0	plan 1 0
eos	eos

(b) Tokenization of a planning task and its solution

A* planning algorithm

```
Require: Start node  $n_{start}$  and goal node  $n_{goal}$ .  
1:  $\mathcal{S}_{closed} \leftarrow \{\}$   
2:  $\mathcal{S}_{frontier} \leftarrow \{n_{start}\}$   
3: while  $|\mathcal{S}_{frontier}| > 0$  do  
4:    $n_{curr} = \arg \min_{n \in \mathcal{S}_{frontier}} \text{cost}(n)$   
5:    $\mathcal{S}_{closed} \leftarrow \mathcal{S}_{closed} \cup \{n_{curr}\}$   
6:   for  $n_{child} \in \text{children}(n_{curr})$  do  
7:     if  $\text{pos}(n) = \text{pos}(n_{child})$  for any  $n \in \mathcal{S}_{closed} \cup \mathcal{S}_{frontier}$  then  
8:       if  $c(n) + h(n) \leq c(n_{child}) + h(n_{child})$  then  
9:         continue  
10:      end if  
11:    end if  
12:    Set  $\text{parent}(n_{child}) \leftarrow n_{curr}$   
13:     $\mathcal{S}_{frontier} \leftarrow \mathcal{S}_{frontier} \cup \{n_{child}\}$   
14:  end for  
15: end while  
16: Compute and return plan by recursing on parents of  $n_{curr}$ .
```

Tokenization of algorithm execution

Execution trace (Trace):
bos
create 0 2 c0 c3 → Add node to frontier
close 0 2 c0 c3 → Add node to closed set
create 0 1 c1 c2 → Cost from start $c(n)$
close 0 1 c1 c2 ← Heuristic value $h(n)$
create 0 0 c2 c1
create 1 1 c2 c1
close 0 0 c2 c1
create 1 0 c3 c0
close 1 0 c3 c0
plan 0 2
plan 0 1
plan 0 0
plan 1 0
eos

Plan (Plan):
bos
plan 0 2
plan 0 1
plan 0 0
plan 1 0
eos

(c) A*'s execution when solving a planning task is logged into an execution trace

Emulating reasoning byproducts

- What does a LLM do?
 - Model language
 - Complete likely ends of sentences
- What is language?
 - A way to communicate what we think
 - What is reasoning?
 - What we think
- **LLMs emulate a byproduct of reasoning**