

Outline

- [Introduction](#)
- [Part 1: Importing the dataset](#)
 - [1.1 Encode & Decode helper functions](#)
 - [1.2 Defining parameters](#)
 - [1.3 Exploring the data](#)
- [Part 2: Summarization with transformer](#)
 - [2.1 Dot product attention](#)
 - [Exercise 01](#)
 - [2.2 Causal Attention](#)
 - [Exercise 02](#)
 - [2.3 Transformer decoder block](#)
 - [Exercise 03](#)
 - [2.4 Transformer Language model](#)
 - [Exercise 04](#)
- [Part 3: Training](#)
 - [3.1 Training the model](#)
 - [Exercise 05](#)
- [Part 4: Evaluation](#)
 - [4.1 Loading in a trained model](#)
- [Part 5: Testing with your own input](#)
 - [Exercise 6](#)
 - [5.1 Greedy decoding](#)
 - [Exercise 07](#)

Introduction

Summarization is an important task in natural language processing and could be useful for a consumer enterprise. For example, bots can be used to scrape articles, summarize them, and then you can use sentiment analysis to identify the sentiment about certain stocks. Anyways who wants to read an article or a long email today, when you can build a transformer to summarize text for you. Let's get started, by completing this assignment you will learn to:

- Use built-in functions to preprocess your data
- Implement DotProductAttention
- Implement Causal Attention
- Understand how attention works
- Build the transformer model
- Evaluate your model
- Summarize an article

As you can tell, this model is slightly different than the ones you have already implemented. This is heavily based on attention and does not rely on sequences, which allows for parallel computing.

```
In [1]: import sys
import os
```

```
import numpy as np
```

```

import textwrap
wrapper = textwrap.TextWrapper(width=70)

import trax
from trax import layers as tl
from trax.fastmath import numpy as jnp

# to print the entire np array
np.set_printoptions(threshold=sys.maxsize)

```

INFO:tensorflow:tokens_length=568 inputs_length=512 targets_length=114 noise_density=0.15 mean_noise_span_length=3.0

Part 1: Importing the dataset

Trax makes it easy to work with Tensorflow's datasets:

```

In [2]: # This will download the dataset if no data_dir is specified.
# Downloading and processing can take bit of time,
# so we have the data already in 'data/' for you

# Importing CNN/DailyMail articles dataset
train_stream_fn = trax.data.TFDS('cnn_dailymail',
                                 data_dir='data/',
                                 keys=('article', 'highlights'),
                                 train=True)

# This should be much faster as the data is downloaded already.
eval_stream_fn = trax.data.TFDS('cnn_dailymail',
                                data_dir='data/',
                                keys=('article', 'highlights'),
                                train=False)

```

1.1 Tokenize & Detokenize helper functions

Just like in the previous assignment, the cell above loads in the encoder for you. Given any data set, you have to be able to map words to their indices, and indices to their words. The inputs and outputs to your Trax models are usually tensors of numbers where each number corresponds to a word. If you were to process your data manually, you would have to make use of the following:

- `word2Ind`: a dictionary mapping the word to its index.
- `ind2Word`: a dictionary mapping the index to its word.
- `word2Count`: a dictionary mapping the word to the number of times it appears.
- `num_words`: total number of words that have appeared.

Since you have already implemented these in previous assignments of the specialization, we will provide you with helper functions that will do this for you. Run the cell below to get the following functions:

- `tokenize`: converts a text sentence to its corresponding token list (i.e. list of indices). Also converts words to subwords.
- `detokenize`: converts a token list to its corresponding sentence (i.e. string).

```

In [3]: def tokenize(input_str, EOS=1):
    """Input str to features dict, ready for inference"""

    # Use the trax.data.tokenize method. It takes streams and returns streams,
    # we get around it by making a 1-element stream with `iter`.
    inputs = next(trax.data.tokenize(iter([input_str]),
                                      vocab_dir='vocab_dir/',
                                      vocab_file='summarize32k.subword.subwords'))

    # Mark the end of the sentence with EOS
    return list(inputs) + [EOS]

def detokenize(integers):
    """List of ints to str"""

    s = trax.data.detokenize(integers,
                            vocab_dir='vocab_dir/',
                            vocab_file='summarize32k.subword.subwords')

    return wrapper.fill(s)

```

1.2 Preprocessing for Language Models: Concatenate It!

This week you will use a language model -- Transformer Decoder -- to solve an input-output problem. As you know, language models only predict the next word, they have no notion of inputs. To create a single input suitable for a language model, we concatenate inputs with targets putting a separator in between. We also need to create a mask -- with 0s at inputs and 1s at targets -- so that the model is not penalized for mis-predicting the article and only focuses on the summary. See the preprocess function below for how this is done.

```

In [4]: # Special tokens
SEP = 0 # Padding or separator token
EOS = 1 # End of sentence token

# Concatenate tokenized inputs and targets using 0 as separator.
def preprocess(stream):
    for (article, summary) in stream:
        joint = np.array(list(article) + [EOS, SEP] + list(summary) + [EOS])
        mask = [0] * (len(list(article)) + 2) + [1] * (len(list(summary)) + 1) # Accounting for EOS and SEP
        yield joint, joint, np.array(mask)

# You can combine a few data preprocessing steps into a pipeline like this.
input_pipeline = trax.data.Serial(
    # Tokenizes
    trax.data.Tokenize(vocab_dir='vocab_dir/',
                        vocab_file='summarize32k.subword.subwords'),
    ...
)

```

```

# uses function defined above
preprocess,
# Filters out examples longer than 2048
trax.data.FilterByLength(2048)
)

# Apply preprocessing to data streams.
train_stream = input_pipeline(train_stream_fn())
eval_stream = input_pipeline(eval_stream_fn())

train_input, train_target, train_mask = next(train_stream)

assert sum((train_input - train_target)**2) == 0 # They are the same in Language Model (LM).

```

```
In [5]: # prints mask, 0s on article, 1s on summary  
print(f'Single example mask:\n\n {train_mask}')
```

Single example mask:

```
In [6]: # prints: [Example][<EOS>][<pad>][Example Summary][<EOS>]
print(f'Single example:\n\n {detokenize(train_input)})')
```

Single example:

By . Anna Edwards . PUBLISHED: . 11:51 EST, 5 March 2013 . | . UPDATED: . 02:51 EST, 6 March 2013 . Singer Paige Flaherty, 19, was caught out after she took a pink Mini and then appeared on the X Factor . A singer was caught after knocking down a pedestrian in a stolen car - when her victim spotted her on X Factor . Paige Flaherty stole a pink Mini from outside a house in Jarrow, South Tyneside, and drove to Newcastle where she collided with Chris Brown at a pelican crossing . Mr Brown, who was left bruised, ended up with the wrong details for Flaherty after the accident and thought that would be the last he, or the police, saw of her . But the 19-year-old, who was a member of girl band 'Twisted', was arrested when Mr Brown spotted her on the TV talent show . At Newcastle Crown Court today Flaherty, of Jarrow, pleaded guilty to aggravated vehicle taking and driving with no insurance on August 29, 2011 . Flaherty, who has never been in trouble before, will be sentenced in April after the preparation of probation and medical reports . Judge Esmond Faulks granted her bail in the meantime and did not give any indication of what the sentence would be . And the judge said at the end of the short hearing: 'I don't watch X Factor so I am out of the loop .' VIDEO: Caught out on the X Factor! Paige Flaherty (far left) was spotted on TV after she gave Chris Brown the wrong contact details . Flaherty took the pink Mini, which belonged to bandmate Katie Orrock, from outside a house in Jarrow, South Tyneside . Paige Flaherty will be sentenced in April after she pleaded guilty to aggravated vehicle taking in court . Jeanette . Smith who prosecuted the case during an earlier hearing at South . Tyneside Magistrates' Court, said the victim claimed he realised it was . Flaherty who had hit him after he saw her on the television show . She added: 'He had been trying to get in touch with her by text message, but it became clear she had given him the wrong details . Then, weeks later, he saw the defendant auditioning on X Factor and thought it was the same person, and got in touch with the police .' Flaherty's band 'Twisted' hit the headlines after the X-factor judge Kelly Rowland told band member Chrissie Pitt, from South Shields, to ditch the rest of the band and continue as a solo artist . Miss Pitt chose to leave the girl group, leaving the other members, including Cheryl Moody, Flaherty and Miss Orrock, furious and out of the competition . Last year, the threesome came back as 'KISSABEAT', covering Jessie J's 'Domino' for a competition with Sky's Starz TV . The band won the contest, which saw the threesome record their own song 'Just Jealousy' . But when the song was released, Flaherty's vocals were erased from the final version . Made headlines: The group made headlines when fellow bandmate Chrissie . Pitt, right, was told by judge Kelly Rowland, left, to drop her band mates and continue on solo in the . competition . Bitter rumours: The three remaining band members were rumoured to be bitter about Ms Pitt's decision to continue on solo in the competition and the trio made a comeback, winning Sky's Starz TV competition . <EOS>PaigeFlaherty was a member of band 'Twisted', which appeared on X Factor . Collided with pedestrian Chris Brown and gave him wrong contact details . Arrested when Mr Brown spotted her on the talent show and called police . Pleaded guilty to aggravated vehicle taking and driving with no insurance . 19-year-old will be sentenced at Newcastle Crown Court . Scroll down for girl band video on X Factor . <EOS>

1.3 Batching with bucketing

As in the previous week, we use bucketing to create batches of data.

In [7]: # Bucketing to create batched generators.

```
# Buckets are defined in terms of boundaries and batch sizes.  
# Batch_sizes[i] determines the batch size for items with Length < boundaries[i]  
# So below, we'll take a batch of 16 sentences of length < 128 , 8 of length < 256,  
# 4 of length < 512. And so on.  
boundaries = [128, 256, 512, 1024]  
batch_sizes = [16, 8, 4, 2, 1]  
  
# Create the streams.  
train_batch_stream = trax.data.BucketByLength(  
    boundaries, batch_sizes)(train_stream)  
  
eval_batch_stream = trax.data.BucketByLength(  
    boundaries, batch_sizes)(eval_stream)
```

In [8]: # Every execution will result in generation of a different article
Try running this cell multiple times to see how the length of the examples affects the batch size
input_batch, _, mask_batch = next(train_batch_stream)

```
# Shape of the input_batch  
input_batch.shape
```

Out[8]: (1, 1719)

In [9]: # print corresponding integer values
print(input_batch[0])

```
[ 52  23  46 2663  285 16915 2846  78 213 927 145 213  
17418 1287  78 213 184 10 59 3 14026 532 132 6178  
7344 6758 3060 1065 1819 4215 320 399 12506 2475 14747 186  
3060 25 793 320 1670 246 3 4142 1466 432 145 213  
17418 635 6 1807 7726 18 127 285 28 16626 220 2418  
1019 726 2479 640 213 16915 880 408 155 1287 1353 6503  
2 188 536 6400 5689 6 8155 1582 25 86 72 926  
463 3 244 103 23 46 2663 77 1353 444 2178 111  
213 16915 16441 4 132 6178 7344 6758 186 213 184 18  
59 3 726 2 13884 501 9291 5 78 213 4217 1945  
7 5 17872 4 285 77 1793 7 26 811 215 320  
21427 4 1221 70 20297 16 213 2854 95 31 8242 527  
213 1287 78 493 8864 186 50 19432 379 9175 6851 4  
246 1019 846 379 10401 10068 11 52 23 46 2663 592  
285 16915 21148 1551 809 213 6178 7344 6758 23647 587 10071  
10161 40 31 7658 1019 399 6503 145 213 17418 7726 78  
493 253 379 9 24128 84 7726 1480 375 320 213 583  
527 12506 14747 186 150 54 184 10 59 3 2013 559  
809 128 10 668 142 10 75 3 412 213 184 10  
... 11220 128 10 668 142 10 75 3 412 213 184 10
```

Things to notice:

- First we see the corresponding values of the words.
- The first 1, which represents the <EOS> tag of the article.
- Followed by a 0, which represents a <pad> tag.
- After the first 0 (<pad> tag) the corresponding values are of the words that are used for the summary of the article.
- The second 1 represents the <EOS> tag for the summary.
- All the trailing 0s represent <pad> tags which are appended to maintain consistent length (If you don't see them then it would mean it is already of max length)

In [10]: # print the article and its summary
print('Article:\n\n', detokenize(input_batch[0]))

Article:

It has been claimed that CIA agents on the ground during the deadly attack on the U.S. Consulate in Benghazi twice asked for permission to help Ambassador Chris Stevens and twice were told to stand down. Furthermore sources present during the deadly six-hour assault have said that a desperate last request for military assistance once the CIA themselves came under attack was denied, even though elite counter-terrorism units were only two hours away. And it has been claimed there was full communication between the CIA annex in Benghazi and the U.S. military, casting further doubts on the Obama administration's assertion that there wasn't enough information to deploy forces - deepening the crisis over their handling of the attack on September 11th and its aftermath . Scroll down for video . Revelations: It has been claimed today that CIA operatives at the Benghazi consulate compound repeatedly had their requests for help denied during the deadly assault on September 11 . The lethal assault which led to the death of Ambassador Stevens and three other U.S. citizens began at 9.40 p.m. as the U.S Consulate came under fire from

You can see that the data has the following structure:

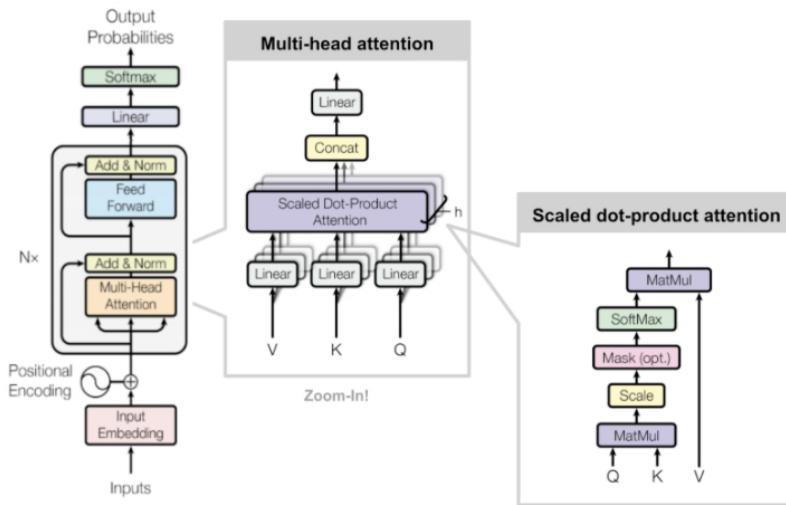
- [Article] -> <EOS> -> <pad> -> [Article Summary] -> <EOS> -> (possibly multiple <pad>)

The loss is taken only on the summary using cross_entropy as loss function.

Part 2: Summarization with transformer

Now that we have given you the data generator and have handled the preprocessing for you, it is time for you to build your own model. We saved you some time because we know you have already preprocessed data before in this specialization, so we would rather you spend your time doing the next steps.

You will be implementing the attention from scratch and then using it in your transformer model. Concretely, you will understand how attention works, how you use it to connect the encoder and the decoder.



2.1 Dot product attention

Now you will implement dot product attention which takes in a query, key, value, and a mask. It returns the output.



Here are some helper functions that will help you create tensors and display useful information:

- `create_tensor` creates a `jax numpy array` from a list of lists.
- `display_tensor` prints out the shape and the actual tensor.

```
In [11]: def create_tensor(t):
    """Create tensor from list of lists"""
    return jnp.array(t)

def display_tensor(t, name):
    """Display shape and tensor"""
    print(f'{name} shape: {t.shape}\n')
    print(f'{t}\n')
```

Before implementing it yourself, you can play around with a toy example of `dot_product_attention` without the softmax operation. Technically it would not be `dot product attention` without the softmax but this is done to avoid giving away too much of the answer and the idea is to display these tensors to give you a sense of how they look like.

The formula for attention is this one:

$$\text{Attention}(Q, K, V) = \text{softmax}\left(\frac{QK^T}{\sqrt{d_k}} + M\right)V \quad (1)$$

d_k stands for the dimension of queries and keys.

The `query`, `key`, `value` and `mask` vectors are provided for this example.

Notice that the masking is done using very negative values that will yield a similar effect to using $-\infty$.

```
In [12]: q = create_tensor([[1, 0, 0], [0, 1, 0]])
display_tensor(q, 'query')
k = create_tensor([[1, 2, 3], [4, 5, 6]])
display_tensor(k, 'key')
v = create_tensor([[0, 1, 0], [1, 0, 1]])
display_tensor(v, 'value')
m = create_tensor([[0, 0], [-1e9, 0]])
display_tensor(m, 'mask')

query shape: (2, 3)
[[1 0 0]
 [0 1 0]]

key shape: (2, 3)
[[1 2 3]
 [4 5 6]]

value shape: (2, 3)
[[0 1 0]
 [1 0 1]]
```

```
mask shape: (2, 2)
[[ 0.e+00  0.e+00]
 [-1.e+09  0.e+00]]
```

Expected Output:

```
query shape: (2, 3)
```

```
[[1 0 0]
 [0 1 0]]
```

```
key shape: (2, 3)
```

```
[[1 2 3]
 [4 5 6]]
```

```
value shape: (2, 3)
```

```
[[0 1 0]
 [1 0 1]]
```

```
mask shape: (2, 2)
```

```
[[ 0.e+00  0.e+00]
 [-1.e+09  0.e+00]]
```

```
In [13]: q_dot_k = q @ k.T / jnp.sqrt(3)
display_tensor(q_dot_k, 'query dot key')
query dot key shape: (2, 2)
[[0.57735026 2.309401 ]
 [1.1547005  2.8867514]]
```

Expected Output:

```
query dot key shape: (2, 2)
```

```
[[0.57735026 2.309401 ]
 [1.1547005  2.8867514]]
```

```
In [14]: masked = q_dot_k + m
display_tensor(masked, 'masked query dot key')
masked query dot key shape: (2, 2)
[[ 5.7735026e-01  2.3094010e+00]
 [-1.0000000e+09  2.8867514e+00]]
```

Expected Output:

```
masked query dot key shape: (2, 2)
```

```
[[ 5.7735026e-01  2.3094010e+00]
 [-1.0000000e+09  2.8867514e+00]]
```

```
In [15]: display_tensor(masked @ v, 'masked query dot key dot value')
masked query dot key dot value shape: (2, 3)
[[ 2.3094010e+00  5.7735026e-01  2.3094010e+00]
 [ 2.8867514e+00 -1.0000000e+09  2.8867514e+00]]
```

Expected Output:

```
masked query dot key dot value shape: (2, 3)
```

```
[[ 2.3094010e+00  5.7735026e-01  2.3094010e+00]
 [ 2.8867514e+00 -1.0000000e+09  2.8867514e+00]]
```

In order to use the previous dummy tensors to test some of the graded functions, a batch dimension should be added to them so they mimic the shape of real-life examples. The mask is also replaced by a version of it that resembles the one that is used by trax:

```
In [16]: q_with_batch = q[None,:]
display_tensor(q_with_batch, 'query with batch dim')
k_with_batch = k[None,:]
display_tensor(k_with_batch, 'key with batch dim')
v_with_batch = v[None,:]
display_tensor(v_with_batch, 'value with batch dim')
m_bool = create_tensor([[True, True], [False, True]])
display_tensor(m_bool, 'boolean mask')

query with batch dim shape: (1, 2, 3)
[[[1 0 0]
 [0 1 0]]]
```

```

key with batch dim shape: (1, 2, 3)
[[[1 2 3]
 [4 5 6]]]

value with batch dim shape: (1, 2, 3)
[[[0 1 0]
 [1 0 1]]]

boolean mask shape: (2, 2)
[[ True  True]
 [False True]]

```

Expected Output:

```

query with batch dim shape: (1, 2, 3)
[[[1 0 0]
 [0 1 0]]]

key with batch dim shape: (1, 2, 3)
[[[1 2 3]
 [4 5 6]]]

value with batch dim shape: (1, 2, 3)
[[[0 1 0]
 [1 0 1]]]

boolean mask shape: (2, 2)
[[ True  True]
 [False True]]

```

Exercise 01

Instructions: Implement the dot product attention. Concretely, implement the following equation

$$\text{Attention } (\mathbf{Q}, \mathbf{K}, \mathbf{V}) = \text{softmax} \left(\frac{\mathbf{Q}\mathbf{K}^T}{\sqrt{d_k}} + \mathbf{M} \right) \mathbf{V} \quad (1)$$

\mathbf{Q} - query, \mathbf{K} - key, \mathbf{V} - values, \mathbf{M} - mask, d_k - depth/dimension of the queries and keys (used for scaling down)

You can implement this formula either by `trax` `numpy` (`trax.math.numpy`) or regular `numpy` but it is recommended to use `jnp`.

Something to take into consideration is that within `trax`, the masks are tensors of `True/False` values not 0's and $-\infty$ as in the previous example. Within the graded function don't think of applying the mask by summing up matrices, instead use `jnp.where()` and treat the **mask as a tensor of boolean values with `False` for values that need to be masked and `True` for the ones that don't**.

Also take into account that the real tensors are far more complex than the toy ones you just played with. Because of this avoid using shortened operations such as `@` for dot product or `.T` for transposing. Use `jnp.matmul()` and `jnp.swapaxes()` instead.

This is the self-attention block for the transformer decoder. Good luck!

```

In [17]: # UNQ_C1
# GRADED FUNCTION: DotProductAttention
def DotProductAttention(query, key, value, mask):
    """Dot product self-attention.

    Args:
        query (jax.interpreters.xla.DeviceArray): array of query representations with shape (L_q by d)
        key (jax.interpreters.xla.DeviceArray): array of key representations with shape (L_k by d)
        value (jax.interpreters.xla.DeviceArray): array of value representations with shape (L_k by d) where L_v = L_k
        mask (jax.interpreters.xla.DeviceArray): attention-mask, gates attention with shape (L_q by L_k)

    Returns:
        jax.interpreters.xla.DeviceArray: Self-attention array for q, k, v arrays. (L_q by L_k)
    """

    assert query.shape[-1] == key.shape[-1] == value.shape[-1], "Embedding dimensions of q, k, v aren't all the same"

    ### START CODE HERE (REPLACE INSTANCES OF 'None' with your code) #####
    # Save depth/dimension of the query embedding for scaling down the dot product
    depth = query.shape[-1]

    # Calculate scaled query key dot product according to formula above
    dots = jnp.matmul(query, jnp.swapaxes(key, -1, -2)) / jnp.sqrt(depth)

    # Apply the mask
    if mask is not None: # The 'None' in this line does not need to be replaced
        dots = jnp.where(mask, dots, jnp.full_like(dots, -1e9))

    # Softmax formula implementation
    # Use trax.fastmath.Logsumexp of dots to avoid underflow by division by large numbers
    # Hint: Last axis should be used and keepdims should be True
    # Note: softmax = e^(dots - Logsumexp(dots)) = E^dots / sumexp(dots)
    logsumexp = trax.fastmath.logsumexp(dots, axis=-1, keepdims=True)

    # Take exponential of dots minus logsumexp to get softmax
    # Use jnp.exp()
    dots = jnp.exp(dots - logsumexp)

    # Multinav dots by value to get self-attention
    
```

```

# Use jnp.matmul()
attention = jnp.matmul(dots, value)

## END CODE HERE ##

return attention

```

In [18]: DotProductAttention(q_with_batch, k_with_batch, v_with_batch, m_bool)

Out[18]: DeviceArray([[0.8496746 , 0.15032545, 0.8496746],
 [1. , 0. , 1.]]], dtype=float32)

Expected Output:

```

DeviceArray([[0.8496746 , 0.15032545, 0.8496746 ],
 [1.          , 0.          , 1.          ]]], dtype=float32)

```

2.2 Causal Attention

Now you are going to implement causal attention: multi-headed attention with a mask to attend only to words that occurred before.



In the image above, a word can see everything that is before it, but not what is after it. To implement causal attention, you will have to transform vectors and do many reshapes. You will need to implement the functions below.

Exercise 02

Implement the following functions that will be needed for Causal Attention:

- `compute_attention_heads`: Gets an input x of dimension (batch_size, seqlen, n_heads \times d_head) and splits the last (depth) dimension and stacks it to the zeroth dimension to allow matrix multiplication (batch_size \times n_heads, seqlen, d_head).
- `dot_product_self_attention`: Creates a mask matrix with `False` values above the diagonal and `True` values below and calls `DotProductAttention` which implements dot product self attention.
- `compute_attention_output`: Undoes `compute_attention_heads` by splitting first (vertical) dimension and stacking in the last (depth) dimension (batch_size, seqlen, n_heads \times d_head). These operations concatenate (stack/merge) the heads.

Next there are some toy tensors which may serve to give you an idea of the data shapes and operations involved in Causal Attention. They are also useful to test out your functions!

```

In [19]: tensor2d = create_tensor(q)
display_tensor(tensor2d, 'query matrix (2D tensor)')

tensor4d2b = create_tensor([[q, q], [q, q]])
display_tensor(tensor4d2b, 'batch of two (multi-head) collections of query matrices (4D tensor)')

tensor3dc = create_tensor([jnp.concatenate([q, q], axis = -1)])
display_tensor(tensor3dc, 'one batch of concatenated heads of query matrices (3d tensor)')

tensor3dc3b = create_tensor([jnp.concatenate([q, q], axis = -1), jnp.concatenate([q, q], axis = -1), jnp.concatenate([q, q], axis = -1)])
display_tensor(tensor3dc3b, 'three batches of concatenated heads of query matrices (3d tensor)')

```

query matrix (2D tensor) shape: (2, 3)

```

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

```

batch of two (multi-head) collections of query matrices (4D tensor) shape: (2, 2, 2, 3)

```

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

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

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

```

one batch of concatenated heads of query matrices (3d tensor) shape: (1, 2, 6)

```

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

```

three batches of concatenated heads of query matrices (3d tensor) shape: (3, 2, 6)

```

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

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

```

```
[[[1 0 0 1 0 0]
[0 1 0 0 1 0]]]
```

It is important to know that the following 3 functions would normally be defined within the `CausalAttention` function further below.

However this makes these functions harder to test. Because of this, these functions are shown individually using a `closure` (when necessary) that simulates them being inside of the `CausalAttention` function. This is done because they rely on some variables that can be accessed from within `CausalAttention`.

Support Functions

`compute_attention_heads` : Gets an input `x` of dimension (`batch_size, seqlen, n_heads X d_head`) and splits the last (depth) dimension and stacks it to the zeroth dimension to allow matrix multiplication (`batch_size X n_heads, seqlen, d_head`).

For the closures you only have to fill the inner function.

```
In [20]: # UNQ_C2
# GRADED FUNCTION: compute_attention_heads_closure
def compute_attention_heads_closure(n_heads, d_head):
    """ Function that simulates environment inside CausalAttention function.
    Args:
        d_head (int): dimensionality of heads.
        n_heads (int): number of attention heads.
    Returns:
        function: compute_attention_heads function
    """
    def compute_attention_heads(x):
        """ Compute the attention heads.
        Args:
            x (jax.interpreters.xla.DeviceArray): tensor with shape (batch_size, seqlen, n_heads X d_head).
        Returns:
            jax.interpreters.xla.DeviceArray: reshaped tensor with shape (batch_size X n_heads, seqlen, d_head).
        """
        ### START CODE HERE (REPLACE INSTANCES OF 'None' with your code) ###

        # Size of the x's batch dimension
        batch_size = x.shape[0]
        # Length of the sequence
        # Should be size of x's first dimension without counting the batch dim
        seqlen = x.shape[1]
        # Reshape x using jnp.reshape()
        # batch_size, seqlen, n_heads*d_head -> batch_size, seqlen, n_heads, d_head
        x = jnp.reshape(x, (batch_size, seqlen, n_heads, d_head))
        # Transpose x using jnp.transpose()
        # batch_size, seqlen, n_heads, d_head -> batch_size, n_heads, seqlen, d_head
        # Note that the values within the tuple are the indexes of the dimensions of x and you must rearrange them
        x = jnp.transpose(x, (0, 2, 1, 3))
        # Reshape x using jnp.reshape()
        # batch_size, n_heads, seqlen, d_head -> batch_size*n_heads, seqlen, d_head
        x = jnp.reshape(x, (-1, seqlen, d_head))

        ### END CODE HERE ###

        return x

    return compute_attention_heads
```

```
In [21]: display_tensor(tensor3dc3b, "input tensor")
result_cah = compute_attention_heads_closure(2,3)(tensor3dc3b)
display_tensor(result_cah, "output tensor")
```

input tensor shape: (3, 2, 6)

```
[[[1 0 0 1 0 0]
[0 1 0 0 1 0]]]
```

```
[[1 0 0 1 0 0]
[0 1 0 0 1 0]]]
```

```
[[1 0 0 1 0 0]
[0 1 0 0 1 0]]]
```

output tensor shape: (6, 2, 3)

```
[[[1 0 0]
[0 1 0]]]
```

```
[[1 0 0]
[0 1 0]]]
```

```
[[1 0 0]
[0 1 0]]]
```

```
[[1 0 0]
[0 1 0]]]
```

```
[[1 0 0]
[0 1 0]]]
```

```
[[1 0 0]
[0 1 0]]]
```

```
[[1 0 0]
[0 1 0]]]
```

```
[[1 0 0]
[0 1 0]]]
```

```
[[1 0 0]
[0 1 0]]]
```

Expected Output:

```
input tensor shape: (3, 2, 6)
```

```
[[[1 0 0 1 0 0]
[0 1 0 0 1 0]]]
```

```
[0 1 0 0 1 0]]]

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

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

output tensor shape: (6, 2, 3)

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

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

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

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

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

[[1 0 0]
 [0 1 0]]]
```

`dot_product_self_attention` : Creates a mask matrix with `False` values above the diagonal and `True` values below and calls `DotProductAttention` which implements dot product self attention.

```
In [22]: # UNQ_C3
# GRADED FUNCTION: dot_product_self_attention
def dot_product_self_attention(q, k, v):
    """ Masked dot product self attention.
    Args:
        q (jax.interpreters.xla.DeviceArray): queries.
        k (jax.interpreters.xla.DeviceArray): keys.
        v (jax.interpreters.xla.DeviceArray): values.
    Returns:
        jax.interpreters.xla.DeviceArray: masked dot product self attention tensor.
    """
    ### START CODE HERE (REPLACE INSTANCES OF 'None' with your code) ###

    # Hint: mask size should be equal to L_q. Remember that q has shape (batch_size, L_q, d)
    # NOTE: there is a revision underway with the autograder to tolerate better indexing.
    # Until then, please index q.shape using negative values (this is equivalent to counting from right to left)
    mask_size = q.shape[-2]

    # Creates a matrix with ones below the diagonal and 0s above. It should have shape (1, mask_size, mask_size)
    # Notice that 1's and 0's get casted to True/False by setting dtype to jnp.bool_
    # Use jnp.tril() - Lower triangle of an array and jnp.ones()
    mask = jnp.tril(jnp.ones((1, mask_size, mask_size), dtype=jnp.bool_), k=0)

    ### END CODE HERE ###

    return DotProductAttention(q, k, v, mask)
```

```
In [23]: dot_product_self_attention(q_with_batch, k_with_batch, v_with_batch)
```

```
Out[23]: DeviceArray([[[], 1., 0.],
 [0.8496746, 0.15032543, 0.8496746]]], dtype=float32)
```

Expected Output:

```
DeviceArray([[[], 1., 0.],
 [0.8496746, 0.15032543, 0.8496746]]], dtype=float32)
```

`compute_attention_output` : Undoes `compute_attention_heads` by splitting first (vertical) dimension and stacking in the last (depth) dimension (`batch_size`, `seqlen`, `n_heads` X `d_head`). These operations concatenate (stack/merge) the heads.

```
In [24]: # UNQ_C4
# GRADED FUNCTION: compute_attention_output_closure
def compute_attention_output_closure(n_heads, d_head):
    """ Function that simulates environment inside CausalAttention function.
    Args:
        d_head (int): dimensionality of heads.
        n_heads (int): number of attention heads.
    Returns:
        function: compute_attention_output function
    """

    def compute_attention_output(x):
        """ Compute the attention output.
        Args:
            x (jax.interpreters.xla.DeviceArray): tensor with shape (batch_size X n_heads, seqlen, d_head).
        Returns:
            jax.interpreters.xla.DeviceArray: reshaped tensor with shape (batch_size, seqlen, n_heads X d_head).
        """
        ### START CODE HERE (REPLACE INSTANCES OF 'None' with your code) ###

        # Length of the sequence
        # Should be size of x's first dimension without counting the batch dim
        seqlen = x.shape[1]
        # Reshape x using jnp.reshape() to shape (batch_size, n_heads, seqlen, d_head)
        x = jnp.reshape(x, (-1, n_heads, seqlen, d_head))

        # Compute attention scores
        # Use dot_product_self_attention() to calculate attention scores
        scores = dot_product_self_attention(q=x[:, :, :, 0], k=x[:, :, :, 1], v=x[:, :, :, 2])
```

```

    # Transpose x using jnp.transpose() to shape (batch_size, seqlen, n_heads)
    x = jnp.transpose(x, (0, 2, 1, 3))

    ### END CODE HERE ###

    # Reshape to allow to concatenate the heads
    return jnp.reshape(x, (-1, seqlen, n_heads * d_head))

return compute_attention_output

```

In [25]: `display_tensor(result_cah, "input tensor")
result_cao = compute_attention_output_closure(2,3)(result_cah)
display_tensor(result_cao, "output tensor")`

input tensor shape: (6, 2, 3)

`[[[1 0 0]
[0 1 0]]`

`[[1 0 0]
[0 1 0]]`

`[[1 0 0]
[0 1 0]]`

`[[1 0 0]
[0 1 0]]`

`[[1 0 0]
[0 1 0]]`

`[[1 0 0]
[0 1 0]]`

output tensor shape: (3, 2, 6)

`[[[1 0 0 1 0 0]
[0 1 0 0 1 0]]]`

`[[1 0 0 1 0 0]
[0 1 0 0 1 0]]`

`[[1 0 0 1 0 0]
[0 1 0 0 1 0]]]`

Expected Output:

input tensor shape: (6, 2, 3)

`[[[1 0 0]
[0 1 0]]`

`[[1 0 0]
[0 1 0]]`

`[[1 0 0]
[0 1 0]]`

`[[1 0 0]
[0 1 0]]`

`[[1 0 0]
[0 1 0]]`

`[[1 0 0]
[0 1 0]]`

output tensor shape: (3, 2, 6)

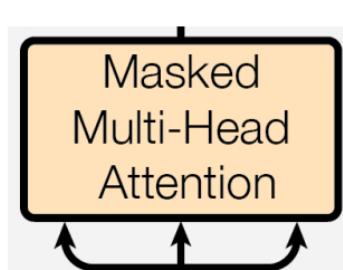
`[[[1 0 0 1 0 0]
[0 1 0 0 1 0]]]`

`[[1 0 0 1 0 0]
[0 1 0 0 1 0]]`

`[[1 0 0 1 0 0]
[0 1 0 0 1 0]]]`

Causal Attention Function

Now it is time for you to put everything together within the `CausalAttention` or Masked multi-head attention function:



Instructions: Implement the causal attention. Your model returns the causal attention through a `tl.Serial` with the following:

- `tl.Branch` : consisting of 3 [`tl.Dense(d_feature)`, `ComputeAttentionHeads`] to account for the queries, keys, and values.
- `tl.Fn`: Takes in `dot_product_self_attention` function and uses it to compute the dot product using Q, K, V .
- `tl.Fn`: Takes in `compute_attention_output_closure` to allow for parallel computing.
- `tl.Dense`: Final Dense layer, with dimension `d_feature`.

Remember that in order for trax to properly handle the functions you just defined, they need to be added as layers using the `tl.Fn()` function.

```
In [26]: # UNQ_C5
# GRADED FUNCTION: CausalAttention
def CausalAttention(d_feature,
                    n_heads,
                    compute_attention_heads_closure=compute_attention_heads_closure,
                    dot_product_self_attention=dot_product_self_attention,
                    compute_attention_output_closure=compute_attention_output_closure,
                    mode='train'):
    """Transformer-style multi-headed causal attention.

Args:
    d_feature (int): dimensionality of feature embedding.
    n_heads (int): number of attention heads.
    compute_attention_heads_closure (function): Closure around compute_attention heads.
    dot_product_self_attention (function): dot_product_self_attention function.
    compute_attention_output_closure (function): Closure around compute_attention_output.
    mode (str): 'train' or 'eval'.

Returns:
    trax.layers.combinators.Serial: Multi-headed self-attention model.
"""

assert d_feature % n_heads == 0
d_head = d_feature // n_heads

### START CODE HERE (REPLACE INSTANCES OF 'None' with your code) ###

# HINT: The second argument to tl.Fn() is an uncalled function (without the parentheses)
# Since you are dealing with closures you might need to call the outer
# function with the correct parameters to get the actual uncalled function.
ComputeAttentionHeads = tl.Fn('AttnHeads', compute_attention_heads_closure(n_heads, d_head), n_out=1)

return tl.Serial(
    tl.Branch( # creates three towers for one input, takes activations and creates queries keys and values
        [tl.Dense(d_feature), ComputeAttentionHeads], # queries
        [tl.Dense(d_feature), ComputeAttentionHeads], # keys
        [tl.Dense(d_feature), ComputeAttentionHeads], # values
    ),
    tl.Fn('DotProductAttn', dot_product_self_attention, n_out=1), # takes QKV
    # HINT: The second argument to tl.Fn() is an uncalled function
    # Since you are dealing with closures you might need to call the outer
    # function with the correct parameters to get the actual uncalled function.
    tl.Fn('AttnOutput', compute_attention_output_closure(n_heads, d_head), n_out=1), # to allow for parallel
    tl.Dense(d_feature) # Final dense layer
)
### END CODE HERE ###
```

```
In [27]: # Take a look at the causal attention model
print(CausalAttention(d_feature=512, n_heads=8))
```

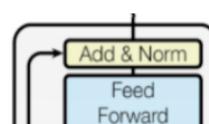
```
Serial[
  Branch_out3[
    [Dense_512, AttnHeads]
    [Dense_512, AttnHeads]
    [Dense_512, AttnHeads]
  ]
  DotProductAttn_in3
  AttnOutput
  Dense_512
]
```

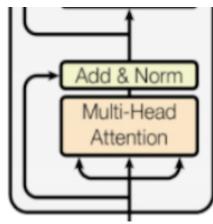
Expected Output:

```
Serial[
  Branch_out3[
    [Dense_512, AttnHeads]
    [Dense_512, AttnHeads]
    [Dense_512, AttnHeads]
  ]
  DotProductAttn_in3
  AttnOutput
  Dense_512
]
```

2.3 Transformer decoder block

Now that you have implemented the causal part of the transformer, you will implement the transformer decoder block. Concretely you will be implementing this image now.





To implement this function, you will have to call the `CausalAttention` or Masked multi-head attention function you implemented above. You will have to add a feedforward which consists of:

- `tl.LayerNorm` : used to layer normalize
- `tl.Dense` : the dense layer
- `ff_activation` : feed forward activation (we use ReLu) here.
- `tl.Dropout` : dropout layer
- `tl.Dense` : dense layer
- `tl.Dropout` : dropout layer

Finally once you implement the feedforward, you can go ahead and implement the entire block using:

- `tl.Residual` : takes in the `tl.LayerNorm()`, causal attention block, `tl.dropout`.
- `tl.Residual` : takes in the feedforward block you will implement.

Exercise 03

Instructions: Implement the transformer decoder block. Good luck!

```
In [28]: # UNQ_C6
# GRADED FUNCTION: DecoderBlock
def DecoderBlock(d_model, d_ff, n_heads,
                 dropout, mode, ff_activation):
    """Returns a list of layers that implements a Transformer decoder block.

    The input is an activation tensor.

    Args:
        d_model (int): depth of embedding.
        d_ff (int): depth of feed-forward layer.
        n_heads (int): number of attention heads.
        dropout (float): dropout rate (how much to drop out).
        mode (str): 'train' or 'eval'.
        ff_activation (function): the non-linearity in feed-forward layer.

    Returns:
        list: list of trax.layers.combinators.Serial that maps an activation tensor to an activation tensor.
    """

    ### START CODE HERE (REPLACE INSTANCES OF 'None' with your code) ###

    # Create masked multi-head attention block using CausalAttention function
    causal_attention = CausalAttention(
        d_model,
        n_heads=n_heads,
        mode=mode
    )

    # Create feed-forward block (list) with two dense layers with dropout and input normalized
    feed_forward = [
        # Normalize Layer inputs
        tl.LayerNorm(),
        # Add first feed forward (dense) Layer (don't forget to set the correct value for n_units)
        tl.Dense(d_ff),
        # Add activation function passed in as a parameter (you need to call it!)
        ff_activation(), # Generally ReLU
        # Add dropout with rate and mode specified (i.e., don't use dropout during evaluation)
        tl.Dropout(rate=dropout, mode=mode),
        # Add second feed forward Layer (don't forget to set the correct value for n_units)
        tl.Dense(d_model),
        # Add dropout with rate and mode specified (i.e., don't use dropout during evaluation)
        tl.Dropout(rate=dropout, mode=mode)
    ]

    # Add list of two Residual blocks: the attention with normalization and dropout and feed-forward blocks
    return [
        tl.Residual(
            # Normalize layer input
            tl.LayerNorm(),
            # Add causal attention block previously defined (without parentheses)
            causal_attention,
            # Add dropout with rate and mode specified
            tl.Dropout(rate=dropout, mode=mode)
        ),
        tl.Residual(
            # Add feed forward block (without parentheses)
            feed_forward
        ),
    ]
    ### END CODE HERE ###
```

```
In [29]: # Take a look at the decoder block
print(DecoderBlock(d_model=512, d_ff=2048, n_heads=8, dropout=0.1, mode='train', ff_activation=tl.Relu))

[Serial[
  Branch_out2[
    None
    Serial[
      LayerNorm
      Serial[
        Branch_out2[
```

```

        [Dense_512, AttnHeads]
        [Dense_512, AttnHeads]
        [Dense_512, AttnHeads]
    ]
    DotProductAttn_in3
    AttnOutput
    Dense_512
]
Dropout
]
]
Add_in2
], Serial[
Branch_out2[
None
Serial[
LayerNorm
Dense_2048
Relu
Dropout
Dense_512
Dropout
]
]
Add_in2
]]

```

Expected Output:

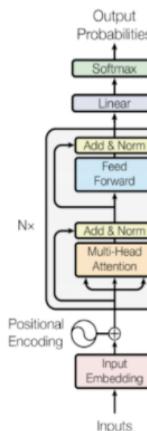
```

[Serial[
Branch_out2[
None
Serial[
LayerNorm
Serial[
Branch_out3[
[Dense_512, AttnHeads]
[Dense_512, AttnHeads]
[Dense_512, AttnHeads]
]
DotProductAttn_in3
AttnOutput
Dense_512
]
Dropout
]
]
Add_in2
], Serial[
Branch_out2[
None
Serial[
LayerNorm
Dense_2048
Relu
Dropout
Dense_512
Dropout
]
]
Add_in2
]]

```

2.4 Transformer Language Model

You will now bring it all together. In this part you will use all the subcomponents you previously built to make the final model. Concretely, here is the image you will be implementing.



Exercise 04

Instructions: Previously you coded the decoder block. Now you will code the transformer language model. Here is what you will need.

- `positional_encoder` - a list containing the following layers:
 - `tl.Embedding`
 - `tl.Dropout`
 - `tl.PositionalEncoding`
- A list of `n_layers` `decoder_blocks`.
- `tl.Serial`: takes in the following layers or lists of layers:
 - `tl.ShiftRight`: shift the tensor to the right by padding on axis 1.
 - `positional_encoder` : encodes the text positions.
 - `decoder_blocks` : the ones you created.
 - `tl.LayerNorm` : a layer norm.
 - `tl.Dense` : takes in the `vocab_size`.
 - `tl.LogSoftmax` : to predict.

Go go go!! You can do it :)

```
In [30]: # UNQ_C7
# GRADED FUNCTION: TransformerLM
def TransformerLM(vocab_size=33300,
                  d_model=512,
                  d_ff=2048,
                  n_layers=6,
                  n_heads=8,
                  dropout=0.1,
                  max_len=4096,
                  mode='train',
                  ff_activation=tl.Relu):
    """Returns a Transformer language model.

    The input to the model is a tensor of tokens. (This model uses only the
    decoder part of the overall Transformer.)

    Args:
        vocab_size (int): vocab size.
        d_model (int): depth of embedding.
        d_ff (int): depth of feed-forward layer.
        n_layers (int): number of decoder layers.
        n_heads (int): number of attention heads.
        dropout (float): dropout rate (how much to drop out).
        max_len (int): maximum symbol length for positional encoding.
        mode (str): 'train', 'eval' or 'predict', predict mode is for fast inference.
        ff_activation (function): the non-linearity in feed-forward layer.

    Returns:
        trax.layers.combinators.Serial: A Transformer language model as a layer that maps from a tensor of tokens
        to activations over a vocab set.
    """
    ### START CODE HERE (REPLACE INSTANCES OF 'None' with your code) ###

    # Embedding inputs and positional encoder
    positional_encoder = [
        # Add embedding layer of dimension (vocab_size, d_model)
        tl.Embedding(vocab_size, d_model),
        # Use dropout with rate and mode specified
        tl.Dropout(rate=dropout, mode=mode),
        # Add positional encoding layer with maximum input Length and mode specified
        tl.PositionalEncoding(max_len=max_len, mode=mode)]
    # Create stack (list) of decoder blocks with n_layers with necessary parameters
    decoder_blocks = [
        DecoderBlock(d_model, d_ff, n_heads,
                     dropout, mode, ff_activation) for _ in range(n_layers)]

    # Create the complete model as written in the figure
    return tl.Serial(
        # Use teacher forcing (feed output of previous step to current step)
        tl.ShiftRight(mode=mode), # Specify the mode!
        # Add positional encoder
        positional_encoder,
        # Add decoder blocks
        decoder_blocks,
        # Normalize layer
        tl.LayerNorm(),
        # Add dense Layer of vocab_size (since need to select a word to translate to)
        # (a.k.a., logits layer. Note: activation already set by ff_activation)
        tl.Dense(vocab_size),
        # Get probabilities with Logsoftmax
        tl.LogSoftmax()
    )
    ### END CODE HERE ###
```

```
In [31]: # Take a Look at the Transformer
print(TransformerLM(n_layers=1))
```

```
Serial[
  ShiftRight(1)
  Embedding_33300_512
  Dropout
  PositionalEncoding
  Serial[
    Serial[
      Branch_out2[
        None
        Serial[
          LayerNorm
          Serial[
            Branch_out3[
              [Dense_512, AttnHeads]
              [Dense_512, AttnHeads]
              [Dense_512, AttnHeads]
            ]
          ]
        ]
      ]
    ]
  ]
]
```

```

        DotProductAttn_in3
        AttnOutput
        Dense_512
    ]
    Dropout
]
Add_in2
]
Serial[
    Branch_out2[
        None
        Serial[
            LayerNorm
            Dense_2048
            Relu
            Dropout
            Dense_512
            Dropout
        ]
    ]
    Add_in2
]
LayerNorm
Dense_33300
LogSoftmax
]

```

Expected Output:

```

Serial[
    ShiftRight(1)
    Embedding_33300_512
    Dropout
    PositionalEncoding
    Serial[
        Serial[
            Branch_out2[
                None
                Serial[
                    LayerNorm
                    Serial[
                        Branch_out3[
                            [Dense_512, AttnHeads]
                            [Dense_512, AttnHeads]
                            [Dense_512, AttnHeads]
                        ]
                        DotProductAttn_in3
                        AttnOutput
                        Dense_512
                    ]
                    Dropout
                ]
            ]
            Add_in2
        ]
        Serial[
            Branch_out2[
                None
                Serial[
                    LayerNorm
                    Dense_2048
                    Relu
                    Dropout
                    Dense_512
                    Dropout
                ]
            ]
            Add_in2
        ]
        LayerNorm
        Dense_33300
        LogSoftmax
    ]

```

Part 3: Training

Now you are going to train your model. As usual, you have to define the cost function, the optimizer, and decide whether you will be training it on a `gpu` or `cpu`. In this case, you will train your model on a `cpu` for a few steps and we will load in a pre-trained model that you can use to predict with your own words.

3.1 Training the model

You will now write a function that takes in your model and trains it. To train your model you have to decide how many times you want to iterate over the entire data set. Each iteration is defined as an `epoch`. For each epoch, you have to go over all the data, using your training iterator.

Exercise 05

Instructions: Implement the `train_model` program below to train the neural network above. Here is a list of things you should do:

- Create the train task by calling `trax.supervised.training.TrainTask` and pass in the following:
 - `labeled_data = train_gen`

- `loss_fn = tl.CrossEntropyLoss()`
- `optimizer = trax.optimizers.Adam(0.01)`
- `lr_schedule = lr_schedule`
- Create the eval task by calling `trax.supervised.training.EvalTask` and pass in the following:
 - `labeled_data` = `eval_gen`
 - `metrics` = `tl.CrossEntropyLoss()` and `tl.Accuracy()`
- Create the training loop by calling `trax.supervised.TrainingLoop` and pass in the following:
 - `TransformerLM`
 - `train_task`
 - `eval_task` = [`eval_task`]
 - `output_dir` = `output_dir`

You will be using a cross entropy loss, with Adam optimizer. Please read the [Trax](#) documentation to get a full understanding.

The training loop that this function returns can be run using the `run()` method by passing in the desired number of steps.

```
In [32]: from trax.supervised import training

# UNQ_C8
# GRADED FUNCTION: train_model
def training_loop(TransformerLM, train_gen, eval_gen, output_dir = "~/model"):
    ...
    Input:
        TransformerLM (trax.layers.combinators.Serial): The model you are building.
        train_gen (generator): Training stream of data.
        eval_gen (generator): Evaluation stream of data.
        output_dir (str): folder to save your file.

    Returns:
        trax.supervised.training.TrainTask: Training loop.
    ...
    output_dir = os.path.expanduser(output_dir) # trainer is an object
    lr_schedule = trax.lr.warmup_and_sqrt_decay(n_warmup_steps=1000, max_value=0.01)

    ### START CODE HERE (REPLACE INSTANCES OF 'None' with your code) #####
    train_task = training.TrainTask(
        labeled_data=train_gen, # The training generator
        loss_layer=tl.CrossEntropyLoss(), # Loss function
        optimizer=trax.optimizers.Adam(0.01), # Optimizer (Don't forget to set LR to 0.01)
        lr_schedule=lr_schedule,
        n_steps_per_checkpoint=10
    )

    eval_task = training.EvalTask(
        labeled_data=eval_gen, # The evaluation generator
        metrics=[tl.CrossEntropyLoss(), tl.Accuracy()] # CrossEntropyLoss and Accuracy
    )

    ### END CODE HERE #####
    loop = training.TrainingLoop(TransformerLM(d_model=4,
                                                d_ff=16,
                                                n_layers=1,
                                                n_heads=2,
                                                mode='train'),
                                train_task,
                                eval_tasks=[eval_task],
                                output_dir=output_dir)

    return loop
```

Notice that the model will be trained for only 10 steps.

Even with this constraint the model with the original default arguments took a very long time to finish. Because of this some parameters are changed when defining the model that is fed into the training loop in the function above.

```
In [33]: # Should take around 1.5 minutes
!rm -f ~/model/model.pkl.gz
loop = training_loop(TransformerLM, train_batch_stream, eval_batch_stream)
loop.run(10)
```

```
Step      1: Ran 1 train steps in 8.30 secs
Step      1: train CrossEntropyLoss | 10.41320419
Step      1: eval   CrossEntropyLoss | 10.41462326
Step      1: eval       Accuracy | 0.00000000

Step     10: Ran 9 train steps in 58.45 secs
Step     10: train CrossEntropyLoss | 10.41416454
Step     10: eval   CrossEntropyLoss | 10.41425228
Step     10: eval       Accuracy | 0.00000000
```

Part 4: Evaluation

4.1 Loading in a trained model

In this part you will evaluate by loading in an almost exact version of the model you coded, but we trained it for you to save you time. Please run the cell below to load in the model.

As you may have already noticed the model that you trained and the pretrained model share the same overall architecture but they have different values for some of the parameters:

```
Original (pretrained) model:

TransformerLM(vocab_size=33300, d_model=512, d_ff=2048, n_layers=6, n_heads=8,
              dropout=0.1, max_len=4096, ff_activation=tl.Relu)
```

```
Your model:
TransformerLM(d_model=4, d_ff=16, n_layers=1, n_heads=2)

Only the parameters shown for your model were changed. The others stayed the same.
```

```
In [34]: # Get the model architecture
model = TransformerLM(mode='eval')

# Load the pre-trained weights
model.init_from_file('model.pkl.gz', weights_only=True)
```

Part 5: Testing with your own input

You will now test your input. You are going to implement greedy decoding. This consists of two functions. The first one allows you to identify the next symbol. It gets the argmax of the output of your model and then returns that index.

Exercise 06

Instructions: Implement the next_symbol function that takes in the cur_output_tokens and the trained model to return the index of the next word.

```
In [35]: # UNQ_C9
def next_symbol(cur_output_tokens, model):
    """Returns the next symbol for a given sentence.

    Args:
        cur_output_tokens (list): tokenized sentence with EOS and PAD tokens at the end.
        model (trax.layers.combinators.Serial): The transformer model.

    Returns:
        int: tokenized symbol.
    """
    ### START CODE HERE (REPLACE INSTANCES OF 'None' with your code) ###

    # current output tokens length
    token_length = len(cur_output_tokens)
    # calculate the minimum power of 2 big enough to store token_length
    # HINT: use np.ceil() and np.log2()
    # add 1 to token_length so np.log2() doesn't receive 0 when token_length is 0
    padded_length = 2**int(np.ceil(np.log2(token_length + 1)))

    # Fill cur_output_tokens with 0's until it reaches padded_length
    padded = cur_output_tokens + [0] * (padded_length - token_length)
    padded_with_batch = np.array(padded)[None, :] # Don't replace this 'None'! This is a way of setting the batch dim

    # model expects a tuple containing two padded tensors (with batch)
    output, _ = model((padded_with_batch, padded_with_batch))
    # HINT: output has shape (1, padded_length, vocab_size)
    # To get log_probs you need to index output with 0 in the first dim
    # token_length in the second dim and all of the entries for the last dim.
    log_probs = output[0, token_length, :]

    ### END CODE HERE ###

    return int(np.argmax(log_probs))
```

```
In [36]: # Test it out!
sentence_test_nxt_symbl = "I want to fly in the sky."
detokenize([next_symbol(tokenize(sentence_test_nxt_symbl)[0], model)])
```

```
Out[36]: 'The'
```

Expected Output:

```
'The'
```

5.1 Greedy decoding

Now you will implement the greedy_decode algorithm that will call the `next_symbol` function. It takes in the input_sentence, the trained model and returns the decoded sentence.

Exercise 07

Instructions: Implement the greedy_decode algorithm.

```
In [37]: # UNQ_C10
# Decoding functions.
def greedy_decode(input_sentence, model):
    """Greedy decode function.

    Args:
        input_sentence (string): a sentence or article.
        model (trax.layers.combinators.Serial): Transformer model.

    Returns:
        string: summary of the input.
    """
    ### START CODE HERE (REPLACE INSTANCES OF 'None' with your code) ###
    # Use tokenize()
    cur_output_tokens = tokenize(input_sentence) + [0]
    generated_output = []
    cur_output = 0
    EOS = 1
```

```

while cur_output != EOS:
    # Get next symbol
    cur_output = next_symbol(cur_output_tokens, model)
    # Append next symbol to original sentence
    cur_output_tokens.append(cur_output)
    # Append next symbol to generated sentence
    generated_output.append(cur_output)
    print(detokenize(generated_output))

### END CODE HERE ###

return detokenize(generated_output)

```

In [38]: # Test it out on a sentence!
test_sentence = "It was a sunny day when I went to the market to buy some flowers. But I only found roses, not tulips."
print(wrapper.fill(test_sentence), '\n')
print(greedy_decode(test_sentence, model))

It was a sunny day when I went to the market to buy some flowers. But
I only found roses, not tulips.

```

:
: I
: I just
: I just found
: I just found ros
: I just found roses
: I just found roses,
: I just found roses, not
: I just found roses, not tu
: I just found roses, not tulips
: I just found roses, not tulips
: I just found roses, not tulips.
: I just found roses, not tulips.<EOS>
: I just found roses, not tulips.<EOS>

```

Expected Output:

```

:
: I
: I just
: I just found
: I just found ros
: I just found roses
: I just found roses,
: I just found roses, not
: I just found roses, not tu
: I just found roses, not tulips
: I just found roses, not tulips.
: I just found roses, not tulips.<EOS>
: I just found roses, not tulips.<EOS>

```

In [39]: # Test it out with a whole article!
article = "It's the posing craze sweeping the U.S. after being brought to fame by skier Lindsey Vonn, soccer star Omar Cummings,
print(wrapper.fill(article), '\n')
print(greedy_decode(article, model))

```

suspended for one day. Four students were suspended for one day
because they allegedly did not heed to warnings that the 'Tebowing'
craze was blocking the
Jordan Fulcoly, Wayne Drexel, Tyler Carroll and Connor Carroll were
suspended for one day. Four students were suspended for one day
because they allegedly did not heed to warnings that the 'Tebowing'
craze was blocking the hallway
Jordan Fulcoly, Wayne Drexel, Tyler Carroll and Connor Carroll were
suspended for one day. Four students were suspended for one day
because they allegedly did not heed to warnings that the 'Tebowing'
craze was blocking the hallway and
Jordan Fulcoly, Wayne Drexel, Tyler Carroll and Connor Carroll were
suspended for one day. Four students were suspended for one day
because they allegedly did not heed to warnings that the 'Tebowing'
craze was blocking the hallway and presenting

```

Expected Output:

```

Jordan
Jordan Ful
Jordan Fulcol
Jordan Fulcoly
Jordan Fulcoly,
Jordan Fulcoly, Wayne
Jordan Fulcoly, Wayne Dre
Jordan Fulcoly, Wayne Drexel
Jordan Fulcoly, Wayne Drexel
Jordan Fulcoly, Wayne Drexel,
.
.
.

Final summary:

```

Jordan Fulcoly, Wayne Drexel, Tyler Carroll and Connor Carroll were

...
suspended for one day. Four students were suspended for one day because they allegedly did not heed to warnings that the 'Tebowing' craze was blocking the hallway and presenting a safety hazard to students.<EOS>

Congratulations on finishing this week's assignment! You did a lot of work and now you should have a better understanding of the encoder part of Transformers and how Transformers can be used for text summarization.

Keep it up!

In []: