January 12, 2025

1 Building an LLM

[1]:
```
! pip3 install tiktoken
```

```
Collecting tiktoken
  Downloading tiktoken-0.8.0-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x86
_64.whl.metadata (6.6 kB)
Collecting regex>=2022.1.18 (from tiktoken)
  Downloading regex-2024.11.6-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x8
6_64.whl.metadata (40 kB)
Requirement already satisfied: requests>=2.26.0 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
tiktoken) (2.32.3)
Requirement already satisfied: charset-normalizer<4,>=2 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
requests>=2.26.0->tiktoken) (3.4.1)
Requirement already satisfied: idna<4,>=2.5 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
requests>=2.26.0->tiktoken) (3.10)
Requirement already satisfied: urllib3<3,>=1.21.1 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
requests>=2.26.0->tiktoken) (2.3.0)
Requirement already satisfied: certifi>=2017.4.17 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
requests>=2.26.0->tiktoken) (2024.12.14)
Downloading
tiktoken-0.8.0-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x86_64.whl (1.2
MB)
                         1.2/1.2 MB
120.2 MB/s eta 0:00:00
Downloading
regex-2024.11.6-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x86_64.whl (781
kB)
                         781.7/781.7 kB
120.2 MB/s eta 0:00:00
Installing collected packages: regex, tiktoken
Successfully installed regex-2024.11.6 tiktoken-0.8.0
```

[2]:
```
import os
import time
import urllib.request
import re
import numpy as np
import matplotlib.pyplot as plt
from matplotlib.ticker import MaxNLocator
from mpl_toolkits.mplot3d import Axes3D
import importlib
import tiktoken
import torch
from torch.utils.data import Dataset, DataLoader
import torch.nn as nn
```

[3]:
```
print("PyTorch version:", torch.__version__)
```

```
PyTorch version: 2.2.1+cu121
```

1.1 Step 1: GPT Architecture

1.1.1 MultiHead Attention

[4]:
```
class MultiHeadAttention(nn.Module):

    def __init__(self, d_in, d_out, context_length, dropout, num_heads,␣
 ↪qkv_bias=False):
        super().__init__()
        assert (d_out % num_heads == 0), \
            "d_out must be divisible by num_heads"

        self.d_out = d_out
        self.num_heads = num_heads
        self.head_dim = d_out // num_heads # Reduce the projection dimension to␣
 ↪match desired output dimension

        self.W_query = nn.Linear(d_in, d_out, bias=qkv_bias)
        self.W_key = nn.Linear(d_in, d_out, bias=qkv_bias)
        self.W_value = nn.Linear(d_in, d_out, bias=qkv_bias)
        self.out_proj = nn.Linear(d_out, d_out)  # Linear layer to combine head␣
 ↪outputs
        self.dropout = nn.Dropout(dropout)
        self.register_buffer(
            "mask",
            torch.triu(torch.ones(context_length, context_length),
                       diagonal=1)
        )

    def forward(self, x):
```

```
        b, num_tokens, d_in = x.shape

        keys = self.W_key(x) # Shape: (b, num_tokens, d_out)
        queries = self.W_query(x)
        values = self.W_value(x)

        # We implicitly split the matrix by adding a `num_heads` dimension
        # Unroll last dim: (b, num_tokens, d_out) -> (b, num_tokens, num_heads,␣
↪head_dim)
        keys = keys.view(b, num_tokens, self.num_heads, self.head_dim)
        values = values.view(b, num_tokens, self.num_heads, self.head_dim)
        queries = queries.view(b, num_tokens, self.num_heads, self.head_dim)

        # Transpose: (b, num_tokens, num_heads, head_dim) -> (b, num_heads,␣
↪num_tokens, head_dim)
        keys = keys.transpose(1, 2)
        queries = queries.transpose(1, 2)
        values = values.transpose(1, 2)

        # Compute scaled dot-product attention (aka self-attention) with a␣
↪causal mask
        attn_scores = queries @ keys.transpose(2, 3)  # Dot product for each␣
↪head

        # Original mask truncated to the number of tokens and converted to␣
↪boolean
        mask_bool = self.mask.bool()[:num_tokens, :num_tokens]

        # Use the mask to fill attention scores
        attn_scores.masked_fill_(mask_bool, -torch.inf)

        attn_weights = torch.softmax(attn_scores / keys.shape[-1]**0.5, dim=-1)
        attn_weights = self.dropout(attn_weights)

        # Shape: (b, num_tokens, num_heads, head_dim)
        context_vec = (attn_weights @ values).transpose(1, 2)

        # Combine heads, where self.d_out = self.num_heads * self.head_dim
        context_vec = context_vec.contiguous().view(b, num_tokens, self.d_out)
        context_vec = self.out_proj(context_vec) # optional projection

        return context_vec
```

It splits the input into multiple heads by reshaping the projected query, key, and value tensors and then combines the results from these heads after computing attention.

The splitting of the query, key, and value tensors, is achieved through tensor reshaping and trans-

posing operations using PyTorch's .view and .transpose methods.

The input is first transformed (via linear layers for queries, keys, and values) and then reshaped to represent multiple heads.

The key operation is to split the d_out dimension into num_heads and head_dim, where head_dim = d_out / num_heads.

This splitting is then achieved using the .view method: a tensor of dimensions (b, num_tokens, d_out) is reshaped to dimension (b, num_tokens, num_heads, head_dim).

The tensors are then transposed to bring the num_heads dimension before the num_tokens dimension, resulting in a shape of (b, num_heads, num_tokens, head_dim).

This transposition is crucial for correctly aligning the queries, keys, and values across the different heads and performing batched matrix multiplications efficiently.

1.1.2 GPT Model Config

[5]:
```
GPT_CONFIG_774M = {
    "vocab_size": 50257,     # Vocabulary size
    "context_length": 1024, # Context length
    "emb_dim": 1280,         # Embedding dimension
    "n_heads": 20,           # Number of attention heads
    "n_layers": 36,          # Number of layers
    "drop_rate": 0.1,        # Dropout rate
    "qkv_bias": False        # Query-Key-Value bias
}
```

1.1.3 Layer Normalization

The layer normalization code normalizes the values of each of the two inputs such that they have a mean of 0 and a variance of 1.

[6]:
```
class LayerNorm(nn.Module):

    def __init__(self, emb_dim):
        super().__init__()
        self.eps = 1e-5
        self.scale = nn.Parameter(torch.ones(emb_dim))
        self.shift = nn.Parameter(torch.zeros(emb_dim))

    def forward(self, x):
        mean = x.mean(dim=-1, keepdim=True)
        var = x.var(dim=-1, keepdim=True, unbiased=False)
        norm_x = (x - mean) / torch.sqrt(var + self.eps)
        return self.scale * norm_x + self.shift
```

This specific implementation of layer Normalization operates on the last dimension of the input tensor x, which represents the embedding dimension (emb_dim).

The variable eps is a small constant (epsilon) added to the variance to prevent division by zero during normalization.

The scale and shift are two trainable parameters (of the same dimension as the input) that the LLM automatically adjusts during training if it is determined that doing so would improve the model's performance on its training task.

This allows the model to learn appropriate scaling and shifting that best suit the data it is processing.

In our variance calculation method, we have opted for an implementation detail by setting unbiased=False.

In the variance calculation, the number of inputs n is used to divide in the variance formula.

This approach does not apply Bessel's correction, which typically uses n-1 instead of n in the denominator to adjust for bias in sample variance estimation.

This decision results in a so-called biased estimate of the variance.

For large-scale language models (LLMs), where the embedding dimension n is significantly large, the difference between using n and n-1 is practically negligible.

We chose this approach to ensure compatibility with the GPT-2 model's normalization layers and because it reflects TensorFlow's default behavior, which was used to implement the original GPT2 model.

1.1.4 FeedForwar Neural Network Class

[7]:
```
class GELU(nn.Module):

    def __init__(self):
        super().__init__()

    def forward(self, x):
        return 0.5 * x * (1 + torch.tanh(
            torch.sqrt(torch.tensor(2.0 / torch.pi)) *
            (x + 0.044715 * torch.pow(x, 3))
        ))
```

ReLU is a piecewise linear function that outputs the input directly if it is positive; otherwise, it outputs zero.

GELU is a smooth, nonlinear function that approximates ReLU but with a non-zero gradient for negative values.

The smoothness of GELU can lead to better optimization properties during training, as it allows for more nuanced adjustments to the model's parameters.

In contrast, ReLU has a sharp corner at zero, which can sometimes make optimization harder, especially in networks that are very deep or have complex architectures.

Moreover, unlike RELU, which outputs zero for any negative input, GELU allows for a small, non-zero output for negative values.

This characteristic means that during the training process, neurons that receive negative input can still contribute to the learning process, albeit to a lesser extent than positive inputs.

[8]:
```python
class FeedForward(nn.Module):

    def __init__(self, cfg):
        super().__init__()
        self.layers = nn.Sequential(
            nn.Linear(cfg["emb_dim"], 4 * cfg["emb_dim"]), # Expansion
            GELU(), # Activation
            nn.Linear(4 * cfg["emb_dim"], cfg["emb_dim"]), # Contraction
        )

    def forward(self, x):
        return self.layers(x)
```

The FeedForward module plays a crucial role in enhancing the model's ability to learn from and generalize the data.

Although the input and output dimensions of this module are the same, it internally expands the embedding dimension into a higher-dimensional space through the first linear layer.

This expansion is followed by a non-linear GELU activation, and then a contraction back to the original dimension with the second linear transformation.

Such a design allows for the exploration of a richer representation space.

Moreover, the uniformity in input and output dimensions simplifies the architecture by enabling the stacking of multiple layers without the need to adjust dimensions between them, thus making the model more scalable.

1.1.5 Transformer Class

[9]:
```python
class TransformerBlock(nn.Module):

    def __init__(self, cfg):
        super().__init__()
        self.att = MultiHeadAttention(
            d_in=cfg["emb_dim"],
            d_out=cfg["emb_dim"],
            context_length=cfg["context_length"],
            num_heads=cfg["n_heads"],
            dropout=cfg["drop_rate"],
            qkv_bias=cfg["qkv_bias"])
        self.ff = FeedForward(cfg)
        self.norm1 = LayerNorm(cfg["emb_dim"])
        self.norm2 = LayerNorm(cfg["emb_dim"])
        self.drop_shortcut = nn.Dropout(cfg["drop_rate"])

    def forward(self, x):
```

```
        # Shortcut connection for attention block
        shortcut = x
        x = self.norm1(x)
        x = self.att(x)  # Shape [batch_size, num_tokens, emb_size]
        x = self.drop_shortcut(x)
        x = x + shortcut  # Add the original input back

        # Shortcut connection for feed forward block
        shortcut = x
        x = self.norm2(x)
        x = self.ff(x)
        x = self.drop_shortcut(x)
        x = x + shortcut  # Add the original input back

        return x
```

The given code defines a TransformerBlock class in PyTorch that includes a multi-head attention mechanism (MultiHeadAttention) and a feed forward network (FeedForward), both configured based on a provided configuration dictionary (cfg), such as GPT_CONFIG_774M

Layer normalization (LayerNorm) is applied before each of these two components, and dropout is applied after them to regularize the model and prevent overfitting. This is also known as Pre-LayerNorm.

Older architectures, such as the original transformer model, applied layer normalization after the self-attention and feed-forward networks instead, known as Post-LayerNorm, which often leads to worse training dynamics.

The class also implements the forward pass, where each component is followed by a shortcut connection that adds the input of the block to its output. This critical feature helps gradients flow through the network during training and improves the learning of deep models.

1.1.6 GPT Architecture

[10]:
```
class GPTModel(nn.Module):

    def __init__(self, cfg):
        super().__init__()
        self.tok_emb = nn.Embedding(cfg["vocab_size"], cfg["emb_dim"])
        self.pos_emb = nn.Embedding(cfg["context_length"], cfg["emb_dim"])
        self.drop_emb = nn.Dropout(cfg["drop_rate"])

        self.trf_blocks = nn.Sequential(
            *[TransformerBlock(cfg) for _ in range(cfg["n_layers"])])

        self.final_norm = LayerNorm(cfg["emb_dim"])
        self.out_head = nn.Linear(
            cfg["emb_dim"], cfg["vocab_size"], bias=False
        )
```

```
    def forward(self, in_idx):
        batch_size, seq_len = in_idx.shape
        tok_embeds = self.tok_emb(in_idx)
        pos_embeds = self.pos_emb(torch.arange(seq_len, device=in_idx.device))
        x = tok_embeds + pos_embeds  # Shape [batch_size, num_tokens, emb_size]
        x = self.drop_emb(x)
        x = self.trf_blocks(x)
        x = self.final_norm(x)
        logits = self.out_head(x)
        return logits
```

[11]:
```
torch.manual_seed(2010027)
model = GPTModel(GPT_CONFIG_774M)
model.eval()  # Disable dropout during inference
```

[11]:
```
GPTModel(
  (tok_emb): Embedding(50257, 1280)
  (pos_emb): Embedding(1024, 1280)
  (drop_emb): Dropout(p=0.1, inplace=False)
  (trf_blocks): Sequential(
    (0): TransformerBlock(
      (att): MultiHeadAttention(
        (W_query): Linear(in_features=1280, out_features=1280, bias=False)
        (W_key): Linear(in_features=1280, out_features=1280, bias=False)
        (W_value): Linear(in_features=1280, out_features=1280, bias=False)
        (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
        (dropout): Dropout(p=0.1, inplace=False)
      )
      (ff): FeedForward(
        (layers): Sequential(
          (0): Linear(in_features=1280, out_features=5120, bias=True)
          (1): GELU()
          (2): Linear(in_features=5120, out_features=1280, bias=True)
        )
      )
      (norm1): LayerNorm()
      (norm2): LayerNorm()
      (drop_shortcut): Dropout(p=0.1, inplace=False)
    )
    (1): TransformerBlock(
      (att): MultiHeadAttention(
        (W_query): Linear(in_features=1280, out_features=1280, bias=False)
        (W_key): Linear(in_features=1280, out_features=1280, bias=False)
        (W_value): Linear(in_features=1280, out_features=1280, bias=False)
        (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
        (dropout): Dropout(p=0.1, inplace=False)
```

```
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(2): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(3): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
```

```
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(4): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(5): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(6): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(7): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(8): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
```

```
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(9): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(10): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(11): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
```

```
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(12): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(13): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
```

```
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(14): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(15): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(16): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
```

```
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(17): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(18): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
```

```
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(19): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(20): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(21): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
```

```
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(22): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(23): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
```

```
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(24): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(25): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(26): TransformerBlock(
  (att): MultiHeadAttention(
```

```
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(27): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(28): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
```

```
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(29): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(30): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(31): TransformerBlock(
```

```
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(32): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(33): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
```

```
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(34): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(35): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
```

```
  )
  (final_norm): LayerNorm()
  (out_head): Linear(in_features=1280, out_features=50257, bias=False)
)
```

The **init** constructor of this GPTModel class initializes the token and positional embedding layers using the configurations passed in via a Python dictionary, cfg.

These embedding layers are responsible for converting input token indices into dense vectors and adding positional information.

Next, the **init** method creates a sequential stack of TransformerBlock modules equal to the number of layers specified in cfg.

Following the transformer blocks, a LayerNorm layer is applied, standardizing the outputs from the transformer blocks to stabilize the learning process.

Finally, a linear output head without bias is defined, which projects the transformer's output into the vocabulary space of the tokenizer to generate logits for each token in the vocabulary.

The forward method takes a batch of input token indices, computes their embeddings, applies the positional embeddings, passes the sequence through the transformer blocks, normalizes the final output, and then computes the logits, representing the next token's unnormalized probabilities.

1.2 Step 2: Generating Text from Output Tokens

[12]:
```python
def generate_text_simple(model, idx, max_new_tokens, context_size):
    # idx is (batch, n_tokens) array of indices in the current context

    for _ in range(max_new_tokens):

        # Crop current context if it exceeds the supported context size
        # E.g., if LLM supports only 5 tokens, and the context size is 10 then␣
↪only the last 5 tokens are used as context
        idx_cond = idx[:, -context_size:]

        # Get the predictions
        with torch.no_grad():
            logits = model(idx_cond) ### batch, n_tokens, vocab_size

        # Focus only on the last time step
        # (batch, n_tokens, vocab_size) becomes (batch, vocab_size)
        logits = logits[:, -1, :]

        # Apply softmax to get probabilities
        probas = torch.softmax(logits, dim=-1)  # (batch, vocab_size)

        # Get the idx of the vocab entry with the highest probability value
        idx_next = torch.argmax(probas, dim=-1, keepdim=True)  # (batch, 1)
```

```
        # Append sampled index to the running sequence
        idx = torch.cat((idx, idx_next), dim=1)  # (batch, n_tokens+1)

    return idx
```

The generate_text_simple function, we use a softmax function to convert the logits into a probability distribution from which we identify the position with the highest value via torch.argmax.

The softmax function is monotonic, meaning it preserves the order of its inputs when transformed into outputs.

So, in practice, the softmax step is redundant since the position with the highest score in the softmax output tensor is the same position in the logit tensor.

In other words, the torch.argmax function could be applied to the logits tensor directly and get identical results.

However, the conversion is coded to illustrate the full process of transforming logits to probabilities, which can add additional intuition, such as that the model generates the most likely next token, which is known as greedy decoding.

[13]:
```
def text_to_token_ids(text, tokenizer):
    encoded = tokenizer.encode(text, allowed_special={'<|endoftext|>'})
    encoded_tensor = torch.tensor(encoded).unsqueeze(0) # add batch dimension
    return encoded_tensor

def token_ids_to_text(token_ids, tokenizer):
    flat = token_ids.squeeze(0) # remove batch dimension
    return tokenizer.decode(flat.tolist())
```

Note that it's common to process millions of articles and hundreds of thousands of books – many gigabytes of text – when working with LLMs. However, for educational purposes, it's sufficient to work with smaller text samples like a single book to learn the main ideas and to make it possible to run it in reasonable time on consumer hardware.

[14]:
```
file_path = "/teamspace/studios/this_studio/J. K. Rowling - Harry Potter 1 -␣
 ↪Sorcerer's Stone.txt"
url = "/teamspace/studios/this_studio/J. K. Rowling - Harry Potter 1 -␣
 ↪Sorcerer's Stone.txt"

if not os.path.exists(file_path):
    with urllib.request.urlopen(url2) as response:
        text_data = response.read().decode('utf-8')
    with open(file_path, "w", encoding="utf-8") as file:
        file.write(text_data)
else:
    with open(file_path, "r", encoding="utf-8") as file:
        text_data = file.read()
```

Byte Pair Encoding (BPE) Since implementing BPE can be relatively complicated, we will use an existing Python open-source library called tiktoken.

This library implements the BPE algorithm very efficiently based on source code in Rust.

The algorithm underlying BPE breaks down words that aren't in its predefined vocabulary into smaller subword units or even individual characters.

The enables it to handle out-ofvocabulary words.

So, if the tokenizer encounters an unfamiliar word during tokenization, it can represent it as a sequence of subword tokens or characters.

[15]:
```
tokenizer = tiktoken.get_encoding("gpt2")

total_characters = len(text_data)
total_tokens = len(tokenizer.encode(text_data))

print("Characters:", total_characters)
print("Tokens:", total_tokens)
```

```
Characters: 439741
Tokens: 116724
```

With 42,098 tokens, the text is very short for training an LLM.

[16]:
```
start_context = "Every effort moves you"

token_ids = generate_text_simple(
    model=model,
    idx=text_to_token_ids(start_context, tokenizer),
    max_new_tokens=10,
    context_size=GPT_CONFIG_774M["context_length"]
)

print("Output text:\n", token_ids_to_text(token_ids, tokenizer))
```

```
Output text:
 Every effort moves you advertisstatesCaptanium  Keooks jumpedroleumpositive
```

The model does not produce good text because it has not been trained yet.

1.3 Step 3: Calculating the Training and Validation Set Losses

1.3.1 Implementing Data Loader

[17]:
```
class GPTDatasetV1(Dataset):

    def __init__(self, txt, tokenizer, max_length, stride):
        self.input_ids = []
        self.target_ids = []
```

```
        # Tokenize the entire text
        token_ids = tokenizer.encode(txt, allowed_special={"<|endoftext|>"})

        # Use a sliding window to chunk the book into overlapping sequences of␣
↪max_length
        for i in range(0, len(token_ids) - max_length, stride):
            input_chunk = token_ids[i:i + max_length]
            target_chunk = token_ids[i + 1: i + max_length + 1]
            self.input_ids.append(torch.tensor(input_chunk))
            self.target_ids.append(torch.tensor(target_chunk))

    # Return the total number of rows in the dataset
    def __len__(self):
        return len(self.input_ids)

    # Return a single row from the dataset
    def __getitem__(self, idx):
        return self.input_ids[idx], self.target_ids[idx]
```

The GPTDatasetV1 class is based on the PyTorch Dataset class.

It defines how individual rows are fetched from the dataset.

Each row consists of a number of token IDs (based on a max_length) assigned to an input_chunk tensor.

The target_chunk tensor contains the corresponding targets.

The following code will use the GPTDatasetV1 to load the inputs in batches via a PyTorch DataLoader:

[19]:
```
def create_dataloader_v1(txt, batch_size=8, max_length=256,
                         stride=128, shuffle=True, drop_last=True,
                         num_workers=0):

    # Initialize the tokenizer
    tokenizer = tiktoken.get_encoding("gpt2")

    # Create dataset
    dataset = GPTDatasetV1(txt, tokenizer, max_length, stride)

    # Create dataloader
    dataloader = DataLoader(
        dataset,
        batch_size=batch_size,
        shuffle=shuffle,
        drop_last=drop_last,    # True drops the last batch if it is shorter␣
↪than the specified batch_size to prevent loss spikes during training
```

```
        num_workers=num_workers    # The number of CPU processes to use for␣
↪preprocessing
    )

    return dataloader
```

A utility function to calculate the cross-entropy loss of a given batch:

In addition, a second utility function to compute the loss for a user-specified number of batches in a data loader:

[20]:
```
def calc_loss_batch(input_batch, target_batch, model, device):
    input_batch, target_batch = input_batch.to(device), target_batch.to(device)
    logits = model(input_batch)
    loss = torch.nn.functional.cross_entropy(logits.flatten(0, 1), target_batch.
↪flatten())
    return loss


def calc_loss_loader(data_loader, model, device, num_batches=None):
    total_loss = 0.
    if len(data_loader) == 0:
        return float("nan")
    elif num_batches is None:
        num_batches = len(data_loader)
    else:
        # Reduce the number of batches to match the total number of batches in␣
↪the data loader
        # if num_batches exceeds the number of batches in the data loader
        num_batches = min(num_batches, len(data_loader))
    for i, (input_batch, target_batch) in enumerate(data_loader):
        if i < num_batches:
            loss = calc_loss_batch(input_batch, target_batch, model, device)
            total_loss += loss.item()
        else:
            break
    return total_loss / num_batches
```

[21]:
```
# Train/validation ratio
train_ratio = 0.90
split_idx = int(train_ratio * len(text_data))
train_data = text_data[:split_idx]
val_data = text_data[split_idx:]


torch.manual_seed(2010027)

train_loader = create_dataloader_v1(
```

```
    train_data,
    batch_size=2,
    max_length=GPT_CONFIG_774M["context_length"],
    stride=GPT_CONFIG_774M["context_length"],
    drop_last=True,
    shuffle=True,
    num_workers=0
)

val_loader = create_dataloader_v1(
    val_data,
    batch_size=2,
    max_length=GPT_CONFIG_774M["context_length"],
    stride=GPT_CONFIG_774M["context_length"],
    drop_last=False,
    shuffle=False,
    num_workers=0
)


if total_tokens * (train_ratio) < GPT_CONFIG_774M["context_length"]:
    print("Not enough tokens for the training loader. "
          "Try to lower the `GPT_CONFIG_124M['context_length']` or "
          "increase the `training_ratio`")

if total_tokens * (1-train_ratio) < GPT_CONFIG_774M["context_length"]:
    print("Not enough tokens for the validation loader. "
          "Try to lower the `GPT_CONFIG_124M['context_length']` or "
          "decrease the `training_ratio`")
```

An optional check that the data was loaded correctly:

[22]:
```
print("Train loader:")
for x, y in train_loader:
    print(x.shape, y.shape)

print("\nValidation loader:")
for x, y in val_loader:
    print(x.shape, y.shape)

print(len(train_loader))
print(len(val_loader))
```

```
Train loader:
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
```

```
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
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torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
```

```
Validation loader:
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([2, 1024]) torch.Size([2, 1024])
torch.Size([1, 1024]) torch.Size([1, 1024])
51
6
```

An optional check that the data was loaded correctly:

[23]:
```
train_tokens = 0
for input_batch, target_batch in train_loader:
    train_tokens += input_batch.numel()

val_tokens = 0
for input_batch, target_batch in val_loader:
    val_tokens += input_batch.numel()

print("Training tokens:", train_tokens)
print("Validation tokens:", val_tokens)
print("All tokens:", train_tokens + val_tokens)
```

```
Training tokens: 104448
Validation tokens: 11264
All tokens: 115712
```

[24]:
```
start_time = time.time()



device = torch.device("cuda" if torch.cuda.is_available() else "cpu")

model.to(device) # no assignment model = model.to(device) necessary for nn.
 ↪Module classes

torch.manual_seed(2010027) # For reproducibility due to the shuffling in the␣
 ↪data loader

with torch.no_grad(): # Disable gradient tracking for efficiency because we are␣
 ↪not training, yet
    train_loss = calc_loss_loader(train_loader, model, device)
    val_loss = calc_loss_loader(val_loader, model, device)

print("Training loss:", train_loss)
print("Validation loss:", val_loss)
```

```
end_time = time.time()
execution_time_minutes = (end_time - start_time) / 60
print("\n")
print(f"Training completed in {execution_time_minutes:.2f} minutes.")
```

```
Training loss: 10.944752655777277
Validation loss: 10.954849243164062


Training completed in 0.21 minutes.
```

1.4 Step 4: Training Loop for LLM

[25]:
```
def train_model_simple(model, train_loader, val_loader, optimizer, device,␣
↪num_epochs,
                       eval_freq, eval_iter, start_context, tokenizer):
    # Initialize lists to track losses and tokens seen
    train_losses, val_losses, track_tokens_seen = [], [], []
    tokens_seen, global_step = 0, -1

    # Main training loop
    for epoch in range(num_epochs):
        model.train()  # Set model to training mode

        for input_batch, target_batch in train_loader:
            optimizer.zero_grad() # Reset loss gradients from previous batch␣
↪iteration
            loss = calc_loss_batch(input_batch, target_batch, model, device)
            loss.backward() # Calculate loss gradients
            optimizer.step() # Update model weights using loss gradients
            tokens_seen += input_batch.numel() # Returns the total number of␣
↪elements (or tokens) in the input_batch.
            global_step += 1

            # Optional evaluation step
            if global_step % eval_freq == 0:
                train_loss, val_loss = evaluate_model(
                    model, train_loader, val_loader, device, eval_iter)
                train_losses.append(train_loss)
                val_losses.append(val_loss)
                track_tokens_seen.append(tokens_seen)
                print(f"Epoch {epoch+1} (Step {global_step:06d}): "
                      f"Train loss {train_loss:.3f}, Val loss {val_loss:.3f}")

        # Print a sample text after each epoch
        generate_and_print_sample(
            model, tokenizer, device, start_context
```

```
        )

    return train_losses, val_losses, track_tokens_seen
```

[26]:
```
def evaluate_model(model, train_loader, val_loader, device, eval_iter):
    model.eval()
    with torch.no_grad():
        train_loss = calc_loss_loader(train_loader, model, device,␣
 ↪num_batches=eval_iter)
        val_loss = calc_loss_loader(val_loader, model, device,␣
 ↪num_batches=eval_iter)
    model.train()
    return train_loss, val_loss
```

The evaluate_model function calculates the loss over the training and validation set while ensuring the model is in evaluation mode with gradient tracking and dropout disabled when calculating the loss over the training and validation sets.

[27]:
```
def generate_and_print_sample(model, tokenizer, device, start_context):
    model.eval()
    context_size = model.pos_emb.weight.shape[0]
    encoded = text_to_token_ids(start_context, tokenizer).to(device)
    with torch.no_grad():
        token_ids = generate_text_simple(
            model=model, idx=encoded,
            max_new_tokens=50, context_size=context_size
        )
    decoded_text = token_ids_to_text(token_ids, tokenizer)
    print(decoded_text.replace("\n", " "))  # Compact print format
    print("\n")
    model.train()
```

The generate_and_print_sample function is a convenience function that we use to track whether the model improves during the training.

In particular, the generate_and_print_sample function takes a text snippet (start_context) as input, converts it into token IDs, and feeds it to the LLM to generate a text sample using the generate_text_simple function used earlier.

[28]:
```
start_time = time.time()

torch.manual_seed(2010027)
model = GPTModel(GPT_CONFIG_774M)
model.to(device)
optimizer = torch.optim.AdamW(model.parameters(), lr=0.00005, weight_decay=0.1)

num_epochs = 10
train_losses, val_losses, tokens_seen = train_model_simple(
```

```
    model, train_loader, val_loader, optimizer, device,
    num_epochs=num_epochs, eval_freq=5, eval_iter=5,
    start_context="Every effort moves you", tokenizer=tokenizer
)

end_time = time.time()
execution_time_minutes = (end_time - start_time) / 60
print("\n")
print(f"Training completed in {execution_time_minutes:.2f} minutes.")
```

```
Epoch 1 (Step 000000): Train loss 9.498, Val loss 9.467
Epoch 1 (Step 000005): Train loss 8.623, Val loss 8.544
Epoch 1 (Step 000010): Train loss 8.217, Val loss 8.199
Epoch 1 (Step 000015): Train loss 7.927, Val loss 7.865
Epoch 1 (Step 000020): Train loss 7.609, Val loss 7.563
Epoch 1 (Step 000025): Train loss 7.335, Val loss 7.314
Epoch 1 (Step 000030): Train loss 7.199, Val loss 7.056
Epoch 1 (Step 000035): Train loss 6.792, Val loss 6.827
Epoch 1 (Step 000040): Train loss 6.617, Val loss 6.662
Epoch 1 (Step 000045): Train loss 6.477, Val loss 6.503
Epoch 1 (Step 000050): Train loss 6.280, Val loss 6.369
Every effort moves you, and the     "I, and the  "I, and the "I, and the "I the
" "I, and the "  "I, and the "


Epoch 2 (Step 000055): Train loss 6.354, Val loss 6.315
Epoch 2 (Step 000060): Train loss 5.980, Val loss 6.240
Epoch 2 (Step 000065): Train loss 5.976, Val loss 6.085
Epoch 2 (Step 000070): Train loss 5.878, Val loss 6.056
Epoch 2 (Step 000075): Train loss 5.929, Val loss 5.999
Epoch 2 (Step 000080): Train loss 5.628, Val loss 5.909
Epoch 2 (Step 000085): Train loss 5.716, Val loss 5.859
Epoch 2 (Step 000090): Train loss 5.600, Val loss 5.794
Epoch 2 (Step 000095): Train loss 5.602, Val loss 5.737
Epoch 2 (Step 000100): Train loss 5.523, Val loss 5.694
Every effort moves you  "I'm't you,  "I'm the "I'm "I'm, and "You, "I'm the
"I'm, "I'm, and "I'm, "


Epoch 3 (Step 000105): Train loss 5.354, Val loss 5.675
Epoch 3 (Step 000110): Train loss 5.439, Val loss 5.648
Epoch 3 (Step 000115): Train loss 5.227, Val loss 5.613
Epoch 3 (Step 000120): Train loss 5.274, Val loss 5.598
Epoch 3 (Step 000125): Train loss 5.197, Val loss 5.573
Epoch 3 (Step 000130): Train loss 5.165, Val loss 5.572
Epoch 3 (Step 000135): Train loss 5.186, Val loss 5.548
Epoch 3 (Step 000140): Train loss 5.088, Val loss 5.534
```

```
Epoch 3 (Step 000145): Train loss 5.160, Val loss 5.511
Epoch 3 (Step 000150): Train loss 4.960, Val loss 5.488
Every effort moves you  "I'm going to the  "I'm not to be in the "I'm not to the
"I'm not to the "I'm not to "I'm going to the "I'm not


Epoch 4 (Step 000155): Train loss 4.935, Val loss 5.497
Epoch 4 (Step 000160): Train loss 4.858, Val loss 5.482
Epoch 4 (Step 000165): Train loss 4.694, Val loss 5.482
Epoch 4 (Step 000170): Train loss 4.825, Val loss 5.467
Epoch 4 (Step 000175): Train loss 4.822, Val loss 5.441
Epoch 4 (Step 000180): Train loss 4.825, Val loss 5.446
Epoch 4 (Step 000185): Train loss 4.665, Val loss 5.440
Epoch 4 (Step 000190): Train loss 4.638, Val loss 5.417
Epoch 4 (Step 000195): Train loss 4.565, Val loss 5.396
Epoch 4 (Step 000200): Train loss 4.507, Val loss 5.389
Every effort moves you  "I'm going to the  "I'm not to the   "I'm not to the
"I'm not the "I'm not, I've got to the    "I'm not


Epoch 5 (Step 000205): Train loss 4.500, Val loss 5.394
Epoch 5 (Step 000210): Train loss 4.548, Val loss 5.386
Epoch 5 (Step 000215): Train loss 4.433, Val loss 5.373
Epoch 5 (Step 000220): Train loss 4.373, Val loss 5.379
Epoch 5 (Step 000225): Train loss 4.376, Val loss 5.381
Epoch 5 (Step 000230): Train loss 4.383, Val loss 5.372
Epoch 5 (Step 000235): Train loss 4.245, Val loss 5.361
Epoch 5 (Step 000240): Train loss 4.190, Val loss 5.367
Epoch 5 (Step 000245): Train loss 4.103, Val loss 5.351
Epoch 5 (Step 000250): Train loss 4.071, Val loss 5.346
Every effort moves you "What's not to be in the "I've got to be in the  "I'm not
to see you,  "You're not in the "I've got to see you're not " "


Epoch 6 (Step 000255): Train loss 4.240, Val loss 5.336
Epoch 6 (Step 000260): Train loss 4.131, Val loss 5.361
Epoch 6 (Step 000265): Train loss 4.003, Val loss 5.346
Epoch 6 (Step 000270): Train loss 4.193, Val loss 5.368
Epoch 6 (Step 000275): Train loss 4.070, Val loss 5.368
Epoch 6 (Step 000280): Train loss 3.944, Val loss 5.349
Epoch 6 (Step 000285): Train loss 3.918, Val loss 5.356
Epoch 6 (Step 000290): Train loss 3.863, Val loss 5.356
Epoch 6 (Step 000295): Train loss 3.795, Val loss 5.310
Epoch 6 (Step 000300): Train loss 3.751, Val loss 5.310
Epoch 6 (Step 000305): Train loss 3.921, Val loss 5.295
Every effort moves you  "I'm not to the "I'm not going to get him, "I'm not
"What's "I'm not to do, I've got to  "I'm not," said Hermione. "
```

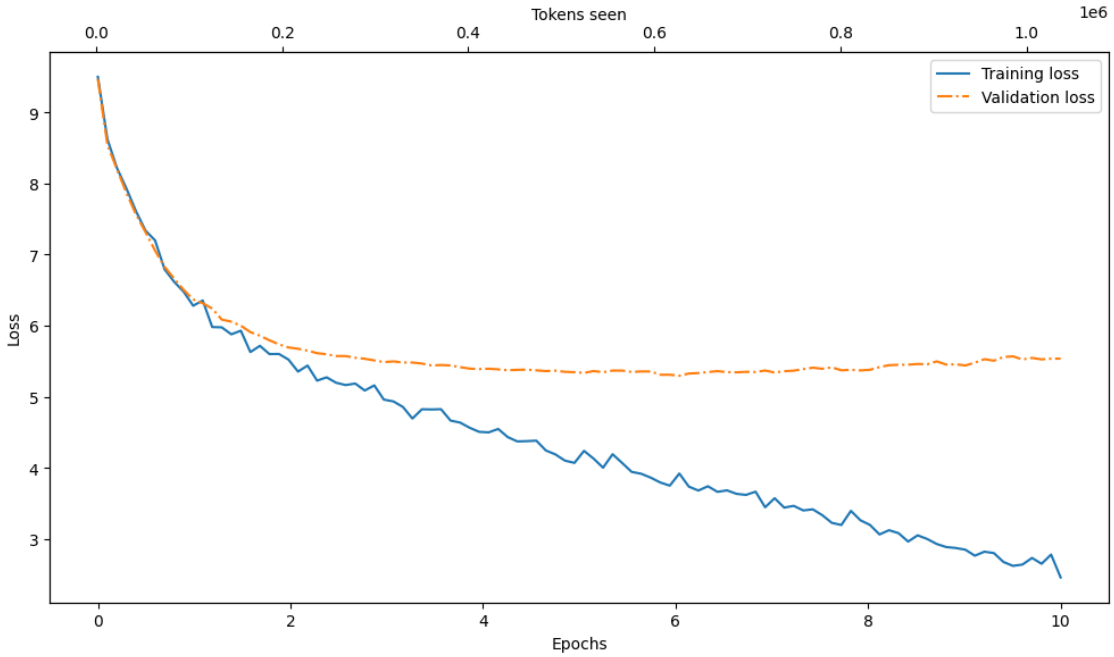
```
Epoch 7 (Step 000310): Train loss 3.737, Val loss 5.327
Epoch 7 (Step 000315): Train loss 3.682, Val loss 5.333
Epoch 7 (Step 000320): Train loss 3.742, Val loss 5.348
Epoch 7 (Step 000325): Train loss 3.664, Val loss 5.360
Epoch 7 (Step 000330): Train loss 3.684, Val loss 5.346
Epoch 7 (Step 000335): Train loss 3.635, Val loss 5.344
Epoch 7 (Step 000340): Train loss 3.621, Val loss 5.351
Epoch 7 (Step 000345): Train loss 3.666, Val loss 5.348
Epoch 7 (Step 000350): Train loss 3.447, Val loss 5.369
Epoch 7 (Step 000355): Train loss 3.574, Val loss 5.341
Every effort moves you all "I'm not to "What's the way.  "What's the next to be
able to the    "What's a small, I've got the door and Ron's the    "


Epoch 8 (Step 000360): Train loss 3.442, Val loss 5.359
Epoch 8 (Step 000365): Train loss 3.467, Val loss 5.367
Epoch 8 (Step 000370): Train loss 3.402, Val loss 5.389
Epoch 8 (Step 000375): Train loss 3.418, Val loss 5.408
Epoch 8 (Step 000380): Train loss 3.335, Val loss 5.394
Epoch 8 (Step 000385): Train loss 3.228, Val loss 5.413
Epoch 8 (Step 000390): Train loss 3.198, Val loss 5.372
Epoch 8 (Step 000395): Train loss 3.397, Val loss 5.380
Epoch 8 (Step 000400): Train loss 3.264, Val loss 5.371
Epoch 8 (Step 000405): Train loss 3.199, Val loss 5.379
Every effort moves you had a "I've got the  "I want you to get a small voice.
"I've been?" said Ron. "I'm not," said Ron, I've been in the way,    "


Epoch 9 (Step 000410): Train loss 3.065, Val loss 5.417
Epoch 9 (Step 000415): Train loss 3.125, Val loss 5.444
Epoch 9 (Step 000420): Train loss 3.083, Val loss 5.449
Epoch 9 (Step 000425): Train loss 2.965, Val loss 5.451
Epoch 9 (Step 000430): Train loss 3.052, Val loss 5.461
Epoch 9 (Step 000435): Train loss 3.002, Val loss 5.456
Epoch 9 (Step 000440): Train loss 2.931, Val loss 5.497
Epoch 9 (Step 000445): Train loss 2.888, Val loss 5.452
Epoch 9 (Step 000450): Train loss 2.874, Val loss 5.457
Epoch 9 (Step 000455): Train loss 2.851, Val loss 5.440
Every effort moves you had a "Well, I'm not a lot of course, I'm not  "I don't
know, I'm not to be able to get "What's that's. "I don't know, I'm warning


Epoch 10 (Step 000460): Train loss 2.766, Val loss 5.480
Epoch 10 (Step 000465): Train loss 2.822, Val loss 5.528
Epoch 10 (Step 000470): Train loss 2.803, Val loss 5.507
Epoch 10 (Step 000475): Train loss 2.678, Val loss 5.560
Epoch 10 (Step 000480): Train loss 2.623, Val loss 5.568
```

```
Epoch 10 (Step 000485): Train loss 2.642, Val loss 5.525
Epoch 10 (Step 000490): Train loss 2.735, Val loss 5.546
Epoch 10 (Step 000495): Train loss 2.653, Val loss 5.526
Epoch 10 (Step 000500): Train loss 2.782, Val loss 5.535
Epoch 10 (Step 000505): Train loss 2.460, Val loss 5.537
Every effort moves you had a very last, and Ron.  "I'm not to be so much as she
said Ron. "I'm not to his name, I'm not to "   "We've been on the three of the
wall
```

```
Training completed in 10.14 minutes.
```

[29]:
```python
def plot_losses(epochs_seen, tokens_seen, train_losses, val_losses):
    fig, ax1 = plt.subplots(figsize=(10, 6))

    # Plot training and validation loss against epochs
    ax1.plot(epochs_seen, train_losses, label="Training loss")
    ax1.plot(epochs_seen, val_losses, linestyle="-.", label="Validation loss")
    ax1.set_xlabel("Epochs")
    ax1.set_ylabel("Loss")
    ax1.legend(loc="upper right")
    ax1.xaxis.set_major_locator(MaxNLocator(integer=True))  # only show integer␣
 ↪labels on x-axis

    # Create a second x-axis for tokens seen
    ax2 = ax1.twiny()  # Create a second x-axis that shares the same y-axis
    ax2.plot(tokens_seen, train_losses, alpha=0)  # Invisible plot for aligning␣
 ↪ticks
    ax2.set_xlabel("Tokens seen")

    fig.tight_layout()  # Adjust layout to make room
    plt.savefig("loss-plot.pdf")
    plt.show()
```

[30]:
```python
epochs_tensor = torch.linspace(0, num_epochs, len(train_losses))
plot_losses(epochs_tensor, tokens_seen, train_losses, val_losses)
```



Both the training and validation losses start to improve for the first epoch. However, the losses start to diverge past the second epoch.

This divergence and the fact that the validation loss is much larger than the training loss indicate that the model is overfitting to the training data.

The model memorizes the training data. This memorization is expected since a VERY, VERY SMALL training dataset is ised and trained the model for multiple epochs.

Usually, it's common to train a model on a MUCH, MUCH LARGER dataset for only one epoch.

1.5 Step 5: Decoding Strategy To Control Randomness

1.5.1 Temperature Scaling with Top-k Sampling

[31]:
```
def generate(model, idx, max_new_tokens, context_size, temperature=0.0,␣
↪top_k=None, eos_id=None):

    # For-loop is the same as before: Get logits, and only focus on last time␣
↪step
    for _ in range(max_new_tokens):
        idx_cond = idx[:, -context_size:]
        with torch.no_grad():
            logits = model(idx_cond)
        logits = logits[:, -1, :]

        # New: Filter logits with top_k sampling
```

```
        if top_k is not None:
            # Keep only top_k values
            top_logits, _ = torch.topk(logits, top_k)
            min_val = top_logits[:, -1]
            logits = torch.where(logits < min_val, torch.tensor(float("-inf")).
 ↪to(logits.device), logits)

        # New: Apply temperature scaling
        if temperature > 0.0:
            logits = logits / temperature

            # Apply softmax to get probabilities
            probs = torch.softmax(logits, dim=-1)  # (batch_size, context_len)

            # Sample from the distribution
            idx_next = torch.multinomial(probs, num_samples=1)  # (batch_size,␣
 ↪1)

        # Otherwise same as before: get idx of the vocab entry with the highest␣
 ↪logits value
        else:
            idx_next = torch.argmax(logits, dim=-1, keepdim=True)  #␣
 ↪(batch_size, 1)

        if idx_next == eos_id:  # Stop generating early if end-of-sequence␣
 ↪token is encountered and eos_id is specified
            break

        # Same as before: append sampled index to the running sequence
        idx = torch.cat((idx, idx_next), dim=1)  # (batch_size, num_tokens+1)

    return idx
```

[32]:
```
device = torch.device("cuda" if torch.cuda.is_available() else "cpu")
model=model.to(device)


torch.manual_seed(2010027)

token_ids = generate(
    model=model,
    idx=text_to_token_ids("Every effort moves you", tokenizer).to(device),
    max_new_tokens=30,
    context_size=GPT_CONFIG_774M["context_length"],
    top_k=25,
    temperature=1.4
)
```

```
print("Output text:\n", token_ids_to_text(token_ids, tokenizer))
```

```
Output text:
 Every effort moves you- a very hard to
and the room. There was up!"

They left as the room than a pair of his mother. Ron's
```

The generated text is very different from the one previously generated via the generate_and_print_sample function earlier.

1.6 Step 6: Loading and Saving Model Wights in Pyorch

[33]:
```
model = GPTModel(GPT_CONFIG_774M)
optimizer = torch.optim.AdamW(model.parameters(), lr=0.00005, weight_decay=0.1)

torch.save({
    "model_state_dict": model.state_dict(),
    "optimizer_state_dict": optimizer.state_dict(),
    },
    "model_and_optimizer.pth"
)
```

To continue pretraining a model later, for example, using the train_model_simple function defined earlier, saving the optimizer state is also recommended.

Adaptive optimizers such as AdamW store additional parameters for each model weight. AdamW uses historical data to adjust learning rates for each model parameter dynamically.

Without it, the optimizer resets, and the model may learn suboptimally or even fail to converge properly, which means that it will lose the ability to generate coherent text.

Using torch.save, save both the model and optimizer state_dict contents.

[34]:
```
checkpoint = torch.load("model_and_optimizer.pth")

model.load_state_dict(checkpoint["model_state_dict"])
optimizer.load_state_dict(checkpoint["optimizer_state_dict"])

model.eval()

model.train()
```

[34]:
```
GPTModel(
  (tok_emb): Embedding(50257, 1280)
  (pos_emb): Embedding(1024, 1280)
  (drop_emb): Dropout(p=0.1, inplace=False)
  (trf_blocks): Sequential(
```

```
(0): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(1): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(2): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
```

```
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(3): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(4): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
```

```
)
(5): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(6): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(7): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
```

```
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(8): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(9): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
```

```
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(10): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(11): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(12): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
```

```
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(13): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(14): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
```

```
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(15): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(16): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(17): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(18): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(19): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
```

```
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(20): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(21): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(22): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
```

```
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(23): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(24): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
```

```
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(25): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(26): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(27): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
```

```
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(28): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(29): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
```

```
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(30): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(31): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(32): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
```

```
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(33): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(34): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=False)
    (W_key): Linear(in_features=1280, out_features=1280, bias=False)
    (W_value): Linear(in_features=1280, out_features=1280, bias=False)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
```

```
            (2): Linear(in_features=5120, out_features=1280, bias=True)
          )
        )
        (norm1): LayerNorm()
        (norm2): LayerNorm()
        (drop_shortcut): Dropout(p=0.1, inplace=False)
      )
      (35): TransformerBlock(
        (att): MultiHeadAttention(
          (W_query): Linear(in_features=1280, out_features=1280, bias=False)
          (W_key): Linear(in_features=1280, out_features=1280, bias=False)
          (W_value): Linear(in_features=1280, out_features=1280, bias=False)
          (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
          (dropout): Dropout(p=0.1, inplace=False)
        )
        (ff): FeedForward(
          (layers): Sequential(
            (0): Linear(in_features=1280, out_features=5120, bias=True)
            (1): GELU()
            (2): Linear(in_features=5120, out_features=1280, bias=True)
          )
        )
        (norm1): LayerNorm()
        (norm2): LayerNorm()
        (drop_shortcut): Dropout(p=0.1, inplace=False)
      )
    )
    (final_norm): LayerNorm()
    (out_head): Linear(in_features=1280, out_features=50257, bias=False)
  )
```

2 Stage 2: Foundation Model

2.1 Pretrained Weights from OpenAI

[35]:
```
! pip install tensorflow
! pip install tqdm
```

```
Collecting tensorflow
  Downloading tensorflow-2.18.0-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_
x86_64.whl.metadata (4.1 kB)
Requirement already satisfied: absl-py>=1.0.0 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
tensorflow) (2.1.0)
Collecting astunparse>=1.6.0 (from tensorflow)
  Downloading astunparse-1.6.3-py2.py3-none-any.whl.metadata (4.4 kB)
Collecting flatbuffers>=24.3.25 (from tensorflow)
```

```
  Downloading flatbuffers-24.12.23-py2.py3-none-any.whl.metadata (876 bytes)
Collecting gast!=0.5.0,!=0.5.1,!=0.5.2,>=0.2.1 (from tensorflow)
  Downloading gast-0.6.0-py3-none-any.whl.metadata (1.3 kB)
Collecting google-pasta>=0.1.1 (from tensorflow)
  Downloading google_pasta-0.2.0-py3-none-any.whl.metadata (814 bytes)
Collecting libclang>=13.0.0 (from tensorflow)
  Downloading libclang-18.1.1-py2.py3-none-manylinux2010_x86_64.whl.metadata
(5.2 kB)
Collecting opt-einsum>=2.3.2 (from tensorflow)
  Downloading opt_einsum-3.4.0-py3-none-any.whl.metadata (6.3 kB)
Requirement already satisfied: packaging in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
tensorflow) (24.2)
Requirement already satisfied:
protobuf!=4.21.0,!=4.21.1,!=4.21.2,!=4.21.3,!=4.21.4,!=4.21.5,<6.0.0dev,>=3.20.3
in /system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
tensorflow) (4.23.4)
Requirement already satisfied: requests<3,>=2.21.0 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
tensorflow) (2.32.3)
Requirement already satisfied: setuptools in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
tensorflow) (75.1.0)
Requirement already satisfied: six>=1.12.0 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
tensorflow) (1.17.0)
Requirement already satisfied: termcolor>=1.1.0 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
tensorflow) (2.5.0)
Requirement already satisfied: typing-extensions>=3.6.6 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
tensorflow) (4.12.2)
Collecting wrapt>=1.11.0 (from tensorflow)
  Downloading wrapt-1.17.1-cp310-cp310-manylinux_2_5_x86_64.manylinux1_x86_64.ma
nylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (6.4 kB)
Requirement already satisfied: grpcio<2.0,>=1.24.3 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
tensorflow) (1.68.1)
Collecting tensorboard<2.19,>=2.18 (from tensorflow)
  Downloading tensorboard-2.18.0-py3-none-any.whl.metadata (1.6 kB)
Collecting keras>=3.5.0 (from tensorflow)
  Downloading keras-3.8.0-py3-none-any.whl.metadata (5.8 kB)
Requirement already satisfied: numpy<2.1.0,>=1.26.0 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
tensorflow) (1.26.4)
Collecting h5py>=3.11.0 (from tensorflow)
  Downloading
h5py-3.12.1-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata
```

```
(2.5 kB)
Collecting ml-dtypes<0.5.0,>=0.4.0 (from tensorflow)
  Downloading ml_dtypes-0.4.1-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x8
6_64.whl.metadata (20 kB)
Collecting tensorflow-io-gcs-filesystem>=0.23.1 (from tensorflow)
  Downloading tensorflow_io_gcs_filesystem-0.37.1-cp310-cp310-manylinux_2_17_x86
_64.manylinux2014_x86_64.whl.metadata (14 kB)
Requirement already satisfied: wheel<1.0,>=0.23.0 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
astunparse>=1.6.0->tensorflow) (0.44.0)
Requirement already satisfied: rich in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
keras>=3.5.0->tensorflow) (13.9.4)
Collecting namex (from keras>=3.5.0->tensorflow)
  Downloading namex-0.0.8-py3-none-any.whl.metadata (246 bytes)
Collecting optree (from keras>=3.5.0->tensorflow)
  Downloading optree-0.13.1-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x86_
64.whl.metadata (47 kB)
Requirement already satisfied: charset-normalizer<4,>=2 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
requests<3,>=2.21.0->tensorflow) (3.4.1)
Requirement already satisfied: idna<4,>=2.5 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
requests<3,>=2.21.0->tensorflow) (3.10)
Requirement already satisfied: urllib3<3,>=1.21.1 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
requests<3,>=2.21.0->tensorflow) (2.3.0)
Requirement already satisfied: certifi>=2017.4.17 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
requests<3,>=2.21.0->tensorflow) (2024.12.14)
Requirement already satisfied: markdown>=2.6.8 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
tensorboard<2.19,>=2.18->tensorflow) (3.7)
Requirement already satisfied: tensorboard-data-server<0.8.0,>=0.7.0 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
tensorboard<2.19,>=2.18->tensorflow) (0.7.2)
Requirement already satisfied: werkzeug>=1.0.1 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
tensorboard<2.19,>=2.18->tensorflow) (3.1.3)
Requirement already satisfied: MarkupSafe>=2.1.1 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
werkzeug>=1.0.1->tensorboard<2.19,>=2.18->tensorflow) (3.0.2)
Requirement already satisfied: markdown-it-py>=2.2.0 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
rich->keras>=3.5.0->tensorflow) (3.0.0)
Requirement already satisfied: pygments<3.0.0,>=2.13.0 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
rich->keras>=3.5.0->tensorflow) (2.18.0)
```

```
Requirement already satisfied: mdurl~=0.1 in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (from
markdown-it-py>=2.2.0->rich->keras>=3.5.0->tensorflow) (0.1.2)
Downloading
tensorflow-2.18.0-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x86_64.whl
(615.3 MB)

341.3/615.3 MB 207.6 MB/s eta 0:00:02
                      615.3/615.3 MB
109.3 MB/s eta 0:00:0000:0100:01
Downloading astunparse-1.6.3-py2.py3-none-any.whl (12 kB)
Downloading flatbuffers-24.12.23-py2.py3-none-any.whl (30 kB)
Downloading gast-0.6.0-py3-none-any.whl (21 kB)
Downloading google_pasta-0.2.0-py3-none-any.whl (57 kB)
Downloading
h5py-3.12.1-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x86_64.whl (5.3 MB)
                         5.3/5.3 MB
200.0 MB/s eta 0:00:00
Downloading keras-3.8.0-py3-none-any.whl (1.3 MB)
                         1.3/1.3 MB
151.6 MB/s eta 0:00:00
Downloading libclang-18.1.1-py2.py3-none-manylinux2010_x86_64.whl (24.5
MB)
                         24.5/24.5 MB
213.5 MB/s eta 0:00:00
Downloading
ml_dtypes-0.4.1-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x86_64.whl (2.2
MB)
                         2.2/2.2 MB
173.7 MB/s eta 0:00:00
Downloading opt_einsum-3.4.0-py3-none-any.whl (71 kB)
Downloading tensorboard-2.18.0-py3-none-any.whl (5.5 MB)
                         5.5/5.5 MB
183.0 MB/s eta 0:00:00
Downloading tensorflow_io_gcs_filesystem-0.37.1-cp310-cp310-manylinux_2_17
_x86_64.manylinux2014_x86_64.whl (5.1 MB)
                         5.1/5.1 MB
169.1 MB/s eta 0:00:00
Downloading wrapt-1.17.1-cp310-cp310-manylinux_2_5_x86_64.manylinux1_x86_6
4.manylinux_2_17_x86_64.manylinux2014_x86_64.whl (82 kB)
Downloading namex-0.0.8-py3-none-any.whl (5.8 kB)
Downloading
optree-0.13.1-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x86_64.whl (381
kB)
Installing collected packages: namex, libclang, flatbuffers, wrapt, tensorflow-
io-gcs-filesystem, optree, opt-einsum, ml-dtypes, h5py, google-pasta, gast,
astunparse, tensorboard, keras, tensorflow
  Attempting uninstall: tensorboard
```

```
    Found existing installation: tensorboard 2.15.1
    Uninstalling tensorboard-2.15.1:
      Successfully uninstalled tensorboard-2.15.1
Successfully installed astunparse-1.6.3 flatbuffers-24.12.23 gast-0.6.0 google-
pasta-0.2.0 h5py-3.12.1 keras-3.8.0 libclang-18.1.1 ml-dtypes-0.4.1 namex-0.0.8
opt-einsum-3.4.0 optree-0.13.1 tensorboard-2.18.0 tensorflow-2.18.0 tensorflow-
io-gcs-filesystem-0.37.1 wrapt-1.17.1
Requirement already satisfied: tqdm in
/system/conda/miniconda3/envs/cloudspace/lib/python3.10/site-packages (4.67.1)
```

[36]:
```
import tensorflow as tf
import tqdm
import requests
from gpt_download3 import download_and_load_gpt2
```

```
2025-01-12 14:14:41.313433: E
external/local_xla/xla/stream_executor/cuda/cuda_fft.cc:477] Unable to register
cuFFT factory: Attempting to register factory for plugin cuFFT when one has
already been registered
WARNING: All log messages before absl::InitializeLog() is called are written to
STDERR
E0000 00:00:1736691281.347217    1874 cuda_dnn.cc:8310] Unable to register cuDNN
factory: Attempting to register factory for plugin cuDNN when one has already
been registered
E0000 00:00:1736691281.356712    1874 cuda_blas.cc:1418] Unable to register
cuBLAS factory: Attempting to register factory for plugin cuBLAS when one has
already been registered
2025-01-12 14:14:41.436538: I tensorflow/core/platform/cpu_feature_guard.cc:210]
This TensorFlow binary is optimized to use available CPU instructions in
performance-critical operations.
To enable the following instructions: AVX2 FMA, in other operations, rebuild
TensorFlow with the appropriate compiler flags.
```

[37]:
```
print("TensorFlow version:", tf.__version__)
print("tqdm version:", tqdm.__version__)
```

```
TensorFlow version: 2.18.0
tqdm version: 4.67.1
```

[38]:
```
settings, params = download_and_load_gpt2(model_size="774M", models_dir="gpt2")
```

```
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(
checkpoint: 100%|      | 77.0/77.0 [00:00<00:00, 171kiB/s]
```

```
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(
encoder.json:   0%|          | 0.00/1.04M [00:00<?, ?iB/s]encoder.json:
100%|      | 1.04M/1.04M [00:00<00:00, 4.37MiB/s]
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(
hparams.json: 100%|      | 91.0/91.0 [00:00<00:00, 232kiB/s]
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(
model.ckpt.data-00000-of-00001: 100%|      | 3.10G/3.10G [02:01<00:00,
25.5MiB/s]
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(
model.ckpt.index: 100%|      | 15.5k/15.5k [00:00<00:00, 24.5MiB/s]
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(
model.ckpt.meta: 100%|      | 1.38M/1.38M [00:00<00:00, 4.66MiB/s]
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(
vocab.bpe: 100%|      | 456k/456k [00:00<00:00, 2.83MiB/s]
```

[39]:
```
print("Settings:", settings)
print("Parameter dictionary keys:", params.keys())
```

```
Settings: {'n_vocab': 50257, 'n_ctx': 1024, 'n_embd': 1280, 'n_head': 20,
'n_layer': 36}
Parameter dictionary keys: dict_keys(['blocks', 'b', 'g', 'wpe', 'wte'])
```

[40]:
```python
# Define model configurations in a dictionary for compactness
model_configs = {
    "gpt2-small (124M)": {"emb_dim": 768, "n_layers": 12, "n_heads": 12},
    "gpt2-medium (355M)": {"emb_dim": 1024, "n_layers": 24, "n_heads": 16},
    "gpt2-large (774M)": {"emb_dim": 1280, "n_layers": 36, "n_heads": 20},
    "gpt2-xl (1558M)": {"emb_dim": 1600, "n_layers": 48, "n_heads": 25},
}

# Copy the base configuration and update with specific model settings
model_name = "gpt2-large (774M)"
NEW_CONFIG = GPT_CONFIG_774M.copy()
NEW_CONFIG.update(model_configs[model_name])


NEW_CONFIG.update({"context_length": 1024, "qkv_bias": True})
gpt = GPTModel(NEW_CONFIG)
gpt.eval()
```

[40]:
```
GPTModel(
  (tok_emb): Embedding(50257, 1280)
  (pos_emb): Embedding(1024, 1280)
  (drop_emb): Dropout(p=0.1, inplace=False)
  (trf_blocks): Sequential(
    (0): TransformerBlock(
      (att): MultiHeadAttention(
        (W_query): Linear(in_features=1280, out_features=1280, bias=True)
        (W_key): Linear(in_features=1280, out_features=1280, bias=True)
        (W_value): Linear(in_features=1280, out_features=1280, bias=True)
        (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
        (dropout): Dropout(p=0.1, inplace=False)
      )
      (ff): FeedForward(
        (layers): Sequential(
          (0): Linear(in_features=1280, out_features=5120, bias=True)
          (1): GELU()
          (2): Linear(in_features=5120, out_features=1280, bias=True)
        )
      )
      (norm1): LayerNorm()
      (norm2): LayerNorm()
      (drop_shortcut): Dropout(p=0.1, inplace=False)
    )
    (1): TransformerBlock(
```

```
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(2): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(3): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
```

```
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(4): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(5): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
```

```
(6): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(7): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(8): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
```

```
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(9): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(10): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
```

```
)
(11): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(12): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(13): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
```

```
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(14): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(15): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
```

```
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(16): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(17): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(18): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
```

```
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(19): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(20): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
```

```
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(21): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(22): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(23): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(24): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(25): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
```

```
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(26): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(27): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(28): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(29): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(30): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
```

```
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(31): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(32): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(33): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(34): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(35): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
```

```
        )
      )
      (norm1): LayerNorm()
      (norm2): LayerNorm()
      (drop_shortcut): Dropout(p=0.1, inplace=False)
    )
  )
  (final_norm): LayerNorm()
  (out_head): Linear(in_features=1280, out_features=50257, bias=False)
)
```

[41]:
```python
def assign(left, right):
    if left.shape != right.shape:
        raise ValueError(f"Shape mismatch. Left: {left.shape}, Right: {right.
 ↪shape}")
    return torch.nn.Parameter(torch.tensor(right))


def load_weights_into_gpt(gpt, params):
    gpt.pos_emb.weight = assign(gpt.pos_emb.weight, params['wpe'])
    gpt.tok_emb.weight = assign(gpt.tok_emb.weight, params['wte'])

    for b in range(len(params["blocks"])):
        q_w, k_w, v_w = np.split(
            (params["blocks"][b]["attn"]["c_attn"])["w"], 3, axis=-1)
        gpt.trf_blocks[b].att.W_query.weight = assign(
            gpt.trf_blocks[b].att.W_query.weight, q_w.T)
        gpt.trf_blocks[b].att.W_key.weight = assign(
            gpt.trf_blocks[b].att.W_key.weight, k_w.T)
        gpt.trf_blocks[b].att.W_value.weight = assign(
            gpt.trf_blocks[b].att.W_value.weight, v_w.T)

        q_b, k_b, v_b = np.split(
            (params["blocks"][b]["attn"]["c_attn"])["b"], 3, axis=-1)
        gpt.trf_blocks[b].att.W_query.bias = assign(
            gpt.trf_blocks[b].att.W_query.bias, q_b)
        gpt.trf_blocks[b].att.W_key.bias = assign(
            gpt.trf_blocks[b].att.W_key.bias, k_b)
        gpt.trf_blocks[b].att.W_value.bias = assign(
            gpt.trf_blocks[b].att.W_value.bias, v_b)

        gpt.trf_blocks[b].att.out_proj.weight = assign(
            gpt.trf_blocks[b].att.out_proj.weight,
            params["blocks"][b]["attn"]["c_proj"]["w"].T)
        gpt.trf_blocks[b].att.out_proj.bias = assign(
            gpt.trf_blocks[b].att.out_proj.bias,
            params["blocks"][b]["attn"]["c_proj"]["b"])
```

```
        gpt.trf_blocks[b].ff.layers[0].weight = assign(
            gpt.trf_blocks[b].ff.layers[0].weight,
            params["blocks"][b]["mlp"]["c_fc"]["w"].T)
        gpt.trf_blocks[b].ff.layers[0].bias = assign(
            gpt.trf_blocks[b].ff.layers[0].bias,
            params["blocks"][b]["mlp"]["c_fc"]["b"])
        gpt.trf_blocks[b].ff.layers[2].weight = assign(
            gpt.trf_blocks[b].ff.layers[2].weight,
            params["blocks"][b]["mlp"]["c_proj"]["w"].T)
        gpt.trf_blocks[b].ff.layers[2].bias = assign(
            gpt.trf_blocks[b].ff.layers[2].bias,
            params["blocks"][b]["mlp"]["c_proj"]["b"])

        gpt.trf_blocks[b].norm1.scale = assign(
            gpt.trf_blocks[b].norm1.scale,
            params["blocks"][b]["ln_1"]["g"])
        gpt.trf_blocks[b].norm1.shift = assign(
            gpt.trf_blocks[b].norm1.shift,
            params["blocks"][b]["ln_1"]["b"])
        gpt.trf_blocks[b].norm2.scale = assign(
            gpt.trf_blocks[b].norm2.scale,
            params["blocks"][b]["ln_2"]["g"])
        gpt.trf_blocks[b].norm2.shift = assign(
            gpt.trf_blocks[b].norm2.shift,
            params["blocks"][b]["ln_2"]["b"])

    gpt.final_norm.scale = assign(gpt.final_norm.scale, params["g"])
    gpt.final_norm.shift = assign(gpt.final_norm.shift, params["b"])
    gpt.out_head.weight = assign(gpt.out_head.weight, params["wte"])
```

[42]:
```
load_weights_into_gpt(gpt, params)
gpt.to(device)
```

[42]:
```
GPTModel(
  (tok_emb): Embedding(50257, 1280)
  (pos_emb): Embedding(1024, 1280)
  (drop_emb): Dropout(p=0.1, inplace=False)
  (trf_blocks): Sequential(
    (0): TransformerBlock(
      (att): MultiHeadAttention(
        (W_query): Linear(in_features=1280, out_features=1280, bias=True)
        (W_key): Linear(in_features=1280, out_features=1280, bias=True)
        (W_value): Linear(in_features=1280, out_features=1280, bias=True)
        (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
        (dropout): Dropout(p=0.1, inplace=False)
      )
```

```
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(1): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(2): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
```

```
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(3): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(4): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(5): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
```

```
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(6): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(7): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
```

```
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(8): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(9): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(10): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(11): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(12): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
```

```
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(13): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(14): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(15): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(16): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(17): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
```

```
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(18): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(19): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(20): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(21): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(22): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
```

```
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(23): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(24): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(25): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(26): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(27): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
```

```
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(28): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(29): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(30): TransformerBlock(
  (att): MultiHeadAttention(
```

```
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(31): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(32): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
```

```
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(33): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(34): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.1, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.1, inplace=False)
)
(35): TransformerBlock(
```

```
      (att): MultiHeadAttention(
        (W_query): Linear(in_features=1280, out_features=1280, bias=True)
        (W_key): Linear(in_features=1280, out_features=1280, bias=True)
        (W_value): Linear(in_features=1280, out_features=1280, bias=True)
        (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
        (dropout): Dropout(p=0.1, inplace=False)
      )
      (ff): FeedForward(
        (layers): Sequential(
          (0): Linear(in_features=1280, out_features=5120, bias=True)
          (1): GELU()
          (2): Linear(in_features=5120, out_features=1280, bias=True)
        )
      )
      (norm1): LayerNorm()
      (norm2): LayerNorm()
      (drop_shortcut): Dropout(p=0.1, inplace=False)
    )
  )
  (final_norm): LayerNorm()
  (out_head): Linear(in_features=1280, out_features=50257, bias=False)
)
```

[43]:
```
start_time = time.time()


torch.manual_seed(2010027)

token_ids = generate(
    model=gpt,
    idx=text_to_token_ids("Every effort moves you", tokenizer).to(device),
    max_new_tokens=25,
    context_size=NEW_CONFIG["context_length"],
    top_k=50,
    temperature=1.4
)

print("Output text:\n", token_ids_to_text(token_ids, tokenizer))


end_time = time.time()
execution_time_minutes = (end_time - start_time) / 60
print("/n")
print(f"Training completed in {execution_time_minutes:.2f} minutes.")
```

```
Output text:
 Every effort moves you to this point and to one that will create new
```

```
challenges. To learn something new, to expand or to improve your talent,
/n
Training completed in 0.01 minutes.
```

Text Completition Response of Foundation Model

3 Stage 3: Finetuning for Classification

[44]:
```
import urllib.request
import ssl
import zipfile
from pathlib import Path
import pandas as pd
import torch
from torch.utils.data import Dataset
```

3.1 Step 1: Downloading Dataset

[45]:
```
def download_and_unzip_spam_data(url, zip_path, extracted_path, data_file_path):
    if data_file_path.exists():
        print(f"{data_file_path} already exists. Skipping download and␣
 ↪extraction.")
        return

    # Create an unverified SSL context
    ssl_context = ssl._create_unverified_context()

    # Downloading the file
    with urllib.request.urlopen(url, context=ssl_context) as response:
        with open(zip_path, "wb") as out_file:
            out_file.write(response.read())

    # Unzipping the file
    with zipfile.ZipFile(zip_path, "r") as zip_ref:
        zip_ref.extractall(extracted_path)

    # Add .tsv file extension
    original_file_path = Path(extracted_path) / "SMSSpamCollection"
    os.rename(original_file_path, data_file_path)
    print(f"File downloaded and saved as {data_file_path}")
```

[48]:
```
url = "https://archive.ics.uci.edu/static/public/228/sms+spam+collection.zip"
zip_path = "/teamspace/studios/this_studio/sms_spam_collection.zip"
extracted_path = "/teamspace/studios/this_studio/sms_spam_collection"
data_file_path = Path(extracted_path) / "SMSSpamCollection.tsv"

download_and_unzip_spam_data(url, zip_path, extracted_path, data_file_path)
```

```
File downloaded and saved as
/teamspace/studios/this_studio/sms_spam_collection/SMSSpamCollection.tsv
```

[49]:
```
df = pd.read_csv(data_file_path, sep="\t", header=None, names=["Label", "Text"])
df
```

[49]:
```
     Label                                                Text
0      ham  Go until jurong point, crazy.. Available only …
1      ham                      Ok lar… Joking wif u oni…
2     spam  Free entry in 2 a wkly comp to win FA Cup fina…
3      ham  U dun say so early hor… U c already then say…
4      ham  Nah I don't think he goes to usf, he lives aro…
…    …                                                  …
5567  spam  This is the 2nd time we have tried 2 contact u…
5568   ham              Will ü b going to esplanade fr home?
5569   ham  Pity, * was in mood for that. So…any other s…
5570   ham  The guy did some bitching but I acted like i'd…
5571   ham                        Rofl. Its true to its name

[5572 rows x 2 columns]
```

[50]:
```
print(df["Label"].value_counts())
```

```
Label
ham     4825
spam     747
Name: count, dtype: int64
```

For simplicity and making it possible to finetune the LLM faster, subsample (undersample) the dataset so that it contains 747 instances from each class:

[51]:
```
def create_balanced_dataset(df):

    # Count the instances of "spam"
    num_spam = df[df["Label"] == "spam"].shape[0]

    # Randomly sample "ham" instances to match the number of "spam" instances
    ham_subset = df[df["Label"] == "ham"].sample(num_spam, random_state=2010027)

    # Combine ham "subset" with "spam"
    balanced_df = pd.concat([ham_subset, df[df["Label"] == "spam"]])

    return balanced_df
```

[52]:
```
balanced_df = create_balanced_dataset(df)
print(balanced_df["Label"].value_counts())
```

```
Label
ham     747
```

```
spam    747
Name: count, dtype: int64
```

Next, the "string" class labels "ham" and "spam" into integer class labels 0 and 1, respectively:

[53]:
```
balanced_df["Label"] = balanced_df["Label"].map({"ham": 0, "spam": 1})
```

[54]:
```
def random_split(df, train_frac, validation_frac):
    # Shuffle the entire DataFrame
    df = df.sample(frac=1, random_state=2010027).reset_index(drop=True)

    # Calculate split indices
    train_end = int(len(df) * train_frac)
    validation_end = train_end + int(len(df) * validation_frac)

    # Split the DataFrame
    train_df = df[:train_end]
    validation_df = df[train_end:validation_end]
    test_df = df[validation_end:]

    return train_df, validation_df, test_df
```

[55]:
```
train_df, validation_df, test_df = random_split(balanced_df, 0.7, 0.1) # Test␣
 ↪size is implied to be 0.2 as the remainder
```

[56]:
```
print(len(train_df))
print(len(validation_df))
print(len(test_df))
```

```
1045
149
300
```

[57]:
```
train_df.to_csv("train.csv", index=None)
validation_df.to_csv("validation.csv", index=None)
test_df.to_csv("test.csv", index=None)
```

3.2 Step 2: Creating Dataloaders

[58]:
```
class SpamDataset(Dataset):
    def __init__(self, csv_file, tokenizer, max_length=None,␣
 ↪pad_token_id=50256):
        self.data = pd.read_csv(csv_file)

        # Pre-tokenize texts
        self.encoded_texts = [
            tokenizer.encode(text) for text in self.data["Text"]
        ]
```

```
        if max_length is None:
            self.max_length = self._longest_encoded_length()
        else:
            self.max_length = max_length

            # Truncate sequences if they are longer than max_length
            self.encoded_texts = [
                encoded_text[:self.max_length]
                for encoded_text in self.encoded_texts
            ]

        # Pad sequences to the longest sequence
        self.encoded_texts = [
            encoded_text + [pad_token_id] * (self.max_length -␣
↪len(encoded_text))
            for encoded_text in self.encoded_texts
        ]

    def __getitem__(self, index):
        encoded = self.encoded_texts[index]
        label = self.data.iloc[index]["Label"]
        return (
            torch.tensor(encoded, dtype=torch.long),
            torch.tensor(label, dtype=torch.long)
        )

    def __len__(self):
        return len(self.data)

    def _longest_encoded_length(self):
        max_length = 0
        for encoded_text in self.encoded_texts:
            encoded_length = len(encoded_text)
            if encoded_length > max_length:
                max_length = encoded_length
        return max_length
```

[59]:
```
train_dataset = SpamDataset(
    csv_file="train.csv",
    max_length=None,
    tokenizer=tokenizer
)

val_dataset = SpamDataset(
    csv_file="validation.csv",
    max_length=train_dataset.max_length,
```

```
    tokenizer=tokenizer
)

test_dataset = SpamDataset(
    csv_file="test.csv",
    max_length=train_dataset.max_length,
    tokenizer=tokenizer
)

print(train_dataset.max_length)
print(val_dataset.max_length)
print(test_dataset.max_length)
```

```
204
204
204
```

[60]:
```
num_workers = 0
batch_size = 11

torch.manual_seed(2010027)

train_loader = DataLoader(
    dataset=train_dataset,
    batch_size=batch_size,
    shuffle=True,
    num_workers=num_workers,
    drop_last=True,
)

val_loader = DataLoader(
    dataset=val_dataset,
    batch_size=batch_size,
    num_workers=num_workers,
    drop_last=False,
)

test_loader = DataLoader(
    dataset=test_dataset,
    batch_size=batch_size,
    num_workers=num_workers,
    drop_last=False,
)

print(f"{len(train_loader)} training batches")
print(f"{len(val_loader)} validation batches")
print(f"{len(test_loader)} test batches")
```

```
95 training batches
14 validation batches
28 test batches
```

3.3 Step 3: Initializing a Model with Pretrained Weights

[82]:
```
CHOOSE_MODEL = "gpt2-large (774M)"
INPUT_PROMPT = "Every effort moves you"

BASE_CONFIG = {
    "vocab_size": 50257,     # Vocabulary size
    "context_length": 1024,  # Context length
    "drop_rate": 0.0,        # Dropout rate
    "qkv_bias": True         # Query-key-value bias
}

model_configs = {
    "gpt2-small (124M)": {"emb_dim": 768, "n_layers": 12, "n_heads": 12},
    "gpt2-medium (355M)": {"emb_dim": 1024, "n_layers": 24, "n_heads": 16},
    "gpt2-large (774M)": {"emb_dim": 1280, "n_layers": 36, "n_heads": 20},
    "gpt2-xl (1558M)": {"emb_dim": 1600, "n_layers": 48, "n_heads": 25},
}

BASE_CONFIG.update(model_configs[CHOOSE_MODEL])

assert train_dataset.max_length <= BASE_CONFIG["context_length"], (
    f"Dataset length {train_dataset.max_length} exceeds model's context "
    f"length {BASE_CONFIG['context_length']}. Reinitialize data sets with "
    f"`max_length={BASE_CONFIG['context_length']}`"
)
```

[83]:
```
model_size = CHOOSE_MODEL.split(" ")[-1].lstrip("(").rstrip(")")

settings, params = download_and_load_gpt2(model_size=model_size,␣
 ↪models_dir="gpt2")

model = GPTModel(BASE_CONFIG)
load_weights_into_gpt(model, params)
model.eval()
```

```
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
```

```
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(

File already exists and is up-to-date: gpt2/774M/checkpoint
File already exists and is up-to-date: gpt2/774M/encoder.json

/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(

File already exists and is up-to-date: gpt2/774M/hparams.json
File already exists and is up-to-date: gpt2/774M/model.ckpt.data-00000-of-00001

/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(

File already exists and is up-to-date: gpt2/774M/model.ckpt.index
File already exists and is up-to-date: gpt2/774M/model.ckpt.meta

/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(

File already exists and is up-to-date: gpt2/774M/vocab.bpe
```

[83]:
```
GPTModel(
  (tok_emb): Embedding(50257, 1280)
```

```
(pos_emb): Embedding(1024, 1280)
(drop_emb): Dropout(p=0.0, inplace=False)
(trf_blocks): Sequential(
  (0): TransformerBlock(
    (att): MultiHeadAttention(
      (W_query): Linear(in_features=1280, out_features=1280, bias=True)
      (W_key): Linear(in_features=1280, out_features=1280, bias=True)
      (W_value): Linear(in_features=1280, out_features=1280, bias=True)
      (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
      (dropout): Dropout(p=0.0, inplace=False)
    )
    (ff): FeedForward(
      (layers): Sequential(
        (0): Linear(in_features=1280, out_features=5120, bias=True)
        (1): GELU()
        (2): Linear(in_features=5120, out_features=1280, bias=True)
      )
    )
    (norm1): LayerNorm()
    (norm2): LayerNorm()
    (drop_shortcut): Dropout(p=0.0, inplace=False)
  )
  (1): TransformerBlock(
    (att): MultiHeadAttention(
      (W_query): Linear(in_features=1280, out_features=1280, bias=True)
      (W_key): Linear(in_features=1280, out_features=1280, bias=True)
      (W_value): Linear(in_features=1280, out_features=1280, bias=True)
      (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
      (dropout): Dropout(p=0.0, inplace=False)
    )
    (ff): FeedForward(
      (layers): Sequential(
        (0): Linear(in_features=1280, out_features=5120, bias=True)
        (1): GELU()
        (2): Linear(in_features=5120, out_features=1280, bias=True)
      )
    )
    (norm1): LayerNorm()
    (norm2): LayerNorm()
    (drop_shortcut): Dropout(p=0.0, inplace=False)
  )
  (2): TransformerBlock(
    (att): MultiHeadAttention(
      (W_query): Linear(in_features=1280, out_features=1280, bias=True)
      (W_key): Linear(in_features=1280, out_features=1280, bias=True)
      (W_value): Linear(in_features=1280, out_features=1280, bias=True)
      (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(3): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(4): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
```

```
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(5): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(6): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(7): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(8): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(9): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
```

```
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(10): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(11): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(12): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(13): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(14): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
```

```
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(15): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(16): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(17): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(18): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(19): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
```

```
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(20): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(21): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(22): TransformerBlock(
  (att): MultiHeadAttention(
```

```
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(23): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(24): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
```

```
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(25): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(26): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(27): TransformerBlock(
```

```
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(28): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(29): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
```

```
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(30): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(31): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
```

```
(32): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(33): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(34): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
```

```
        (layers): Sequential(
          (0): Linear(in_features=1280, out_features=5120, bias=True)
          (1): GELU()
          (2): Linear(in_features=5120, out_features=1280, bias=True)
        )
      )
      (norm1): LayerNorm()
      (norm2): LayerNorm()
      (drop_shortcut): Dropout(p=0.0, inplace=False)
    )
    (35): TransformerBlock(
      (att): MultiHeadAttention(
        (W_query): Linear(in_features=1280, out_features=1280, bias=True)
        (W_key): Linear(in_features=1280, out_features=1280, bias=True)
        (W_value): Linear(in_features=1280, out_features=1280, bias=True)
        (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
        (dropout): Dropout(p=0.0, inplace=False)
      )
      (ff): FeedForward(
        (layers): Sequential(
          (0): Linear(in_features=1280, out_features=5120, bias=True)
          (1): GELU()
          (2): Linear(in_features=5120, out_features=1280, bias=True)
        )
      )
      (norm1): LayerNorm()
      (norm2): LayerNorm()
      (drop_shortcut): Dropout(p=0.0, inplace=False)
    )
  )
  (final_norm): LayerNorm()
  (out_head): Linear(in_features=1280, out_features=50257, bias=False)
)
```

[84]:
```
text_1 = "Every effort moves you"

token_ids = generate_text_simple(
    model=model,
    idx=text_to_token_ids(text_1, tokenizer),
    max_new_tokens=30,
    context_size=BASE_CONFIG["context_length"]
)

print(token_ids_to_text(token_ids, tokenizer))
```

```
Every effort moves you forward.
```

```
"I'm not going to be a guy who's going to sit back and say, 'I'm not going to do
anything
```

To ensure that the model was loaded correctly, a cohernt text is generated.

Before finetuning the model as a spam classifier, let's see if the model can perhaps already classify spam messages by by prompting it with instructions.

[85]:
```
text_2 = (
    "Is the following text 'spam'? Answer with 'yes' or 'no':"
    " 'You are a winner you have been specially selected to receive $1000 cash␣
 ↪or a $2000 award.'"
)

token_ids = generate_text_simple(
    model=model,
    idx=text_to_token_ids(text_2, tokenizer),
    max_new_tokens=30,
    context_size=BASE_CONFIG["context_length"]
)

print(token_ids_to_text(token_ids, tokenizer))
```

```
Is the following text 'spam'? Answer with 'yes' or 'no': 'You are a winner you
have been specially selected to receive $1000 cash or a $2000 award.'

The following text 'spam'? Answer with 'yes' or 'no': 'You are a winner you have
been specially selected to receive
```

Based on the output, it's apparent that the model struggles with following instructions. This is anticipated, as it has undergone only pretraining and lacks instruction-finetuning.

3.4 Step 4: Adding a Classification Head

[86]:
```
for param in model.parameters():
    param.requires_grad = False
```

To prepare the model for classification fine-tuning, the model is first frozen, which means all layers are made non-trainable.

[87]:
```
torch.manual_seed(2010027)

num_classes = 2
model.out_head = torch.nn.Linear(in_features=BASE_CONFIG["emb_dim"],␣
 ↪out_features=num_classes)
```

Then, the output layer (model.out_head), which originally maps the layer inputs to 50,257 dimensions (corresponding to the size of the vocabulary), is replaced.

[88]:
```
for param in model.trf_blocks[-1].parameters():
    param.requires_grad = True

for param in model.final_norm.parameters():
    param.requires_grad = True
```

Additionally, the last transformer block and the final LayerNorm module, which connects this block to the output layer, are configured to be trainable.

3.5 Step 5: Calculating the Classification Loss and Accuracy

[89]:
```
def calc_accuracy_loader(data_loader, model, device, num_batches=None):
    model.eval()
    correct_predictions, num_examples = 0, 0

    if num_batches is None:
        num_batches = len(data_loader)
    else:
        num_batches = min(num_batches, len(data_loader))
    for i, (input_batch, target_batch) in enumerate(data_loader):
        if i < num_batches:
            input_batch, target_batch = input_batch.to(device), target_batch.
 ↪to(device)

            with torch.no_grad():
                logits = model(input_batch)[:, -1, :]  # Logits of last output␣
 ↪token
            predicted_labels = torch.argmax(logits, dim=-1)

            num_examples += predicted_labels.shape[0]
            correct_predictions += (predicted_labels == target_batch).sum().
 ↪item()
        else:
            break
    return correct_predictions / num_examples
```

[90]:
```
start_time = time.time()


device = torch.device("cuda" if torch.cuda.is_available() else "cpu")

model.to(device) # no assignment model = model.to(device) necessary for nn.
 ↪Module classes

torch.manual_seed(2010027) # For reproducibility due to the shuffling in the␣
 ↪training data loader
```

```
train_accuracy = calc_accuracy_loader(train_loader, model, device,␣
 ↪num_batches=10)
val_accuracy = calc_accuracy_loader(val_loader, model, device, num_batches=10)
test_accuracy = calc_accuracy_loader(test_loader, model, device, num_batches=10)

print(f"Training accuracy: {train_accuracy*100:.2f}%")
print(f"Validation accuracy: {val_accuracy*100:.2f}%")
print(f"Test accuracy: {test_accuracy*100:.2f}%")


end_time = time.time()
execution_time_minutes = (end_time - start_time) / 60
print("\n")
print(f"Training completed in {execution_time_minutes:.2f} minutes.")
```

```
Training accuracy: 51.82%
Validation accuracy: 50.91%
Test accuracy: 49.09%


Training completed in 0.07 minutes.
```

[91]:
```
def calc_loss_batch(input_batch, target_batch, model, device):
    input_batch, target_batch = input_batch.to(device), target_batch.to(device)
    logits = model(input_batch)[:, -1, :]  # Logits of last output token
    loss = torch.nn.functional.cross_entropy(logits, target_batch)
    return loss
```

[92]:
```
def calc_loss_loader(data_loader, model, device, num_batches=None):
    total_loss = 0.
    if len(data_loader) == 0:
        return float("nan")
    elif num_batches is None:
        num_batches = len(data_loader)
    else:
        # Reduce the number of batches to match the total number of batches in␣
 ↪the data loader
        # if num_batches exceeds the number of batches in the data loader
        num_batches = min(num_batches, len(data_loader))
    for i, (input_batch, target_batch) in enumerate(data_loader):
        if i < num_batches:
            loss = calc_loss_batch(input_batch, target_batch, model, device)
            total_loss += loss.item()
        else:
            break
    return total_loss / num_batches
```

Initial Accuracy

3.6 Step 6: Finetuning the Model on Supervised Data

[93]:
```
# Overall the same as `train_model_simple` above
def train_classifier_simple(model, train_loader, val_loader, optimizer, device,␣
↪num_epochs,
                            eval_freq, eval_iter):
    # Initialize lists to track losses and examples seen
    train_losses, val_losses, train_accs, val_accs = [], [], [], []
    examples_seen, global_step = 0, -1

    # Main training loop
    for epoch in range(num_epochs):
        model.train()  # Set model to training mode

        for input_batch, target_batch in train_loader:
            optimizer.zero_grad() # Reset loss gradients from previous batch␣
↪iteration
            loss = calc_loss_batch(input_batch, target_batch, model, device)
            loss.backward() # Calculate loss gradients
            optimizer.step() # Update model weights using loss gradients
            examples_seen += input_batch.shape[0] # New: track examples instead␣
↪of tokens
            global_step += 1

            # Optional evaluation step
            if global_step % eval_freq == 0:
                train_loss, val_loss = evaluate_model(
                    model, train_loader, val_loader, device, eval_iter)
                train_losses.append(train_loss)
                val_losses.append(val_loss)
                print(f"Epoch {epoch+1} (Step {global_step:06d}): "
                      f"Train loss {train_loss:.3f}, Validation loss {val_loss:.
↪3f}")

        # Calculate accuracy after each epoch
        train_accuracy = calc_accuracy_loader(train_loader, model, device,␣
↪num_batches=eval_iter)
        val_accuracy = calc_accuracy_loader(val_loader, model, device,␣
↪num_batches=eval_iter)
        print(f"Training accuracy: {train_accuracy*100:.2f}% | ", end="")
        print(f"Validation accuracy: {val_accuracy*100:.2f}%")
        print("\n")          # New Line
        train_accs.append(train_accuracy)
        val_accs.append(val_accuracy)
```

```
    return train_losses, val_losses, train_accs, val_accs, examples_seen



def evaluate_model(model, train_loader, val_loader, device, eval_iter):
    model.eval()
    with torch.no_grad():
        train_loss = calc_loss_loader(train_loader, model, device,␣
 ↪num_batches=eval_iter)
        val_loss = calc_loss_loader(val_loader, model, device,␣
 ↪num_batches=eval_iter)
    model.train()
    return train_loss, val_loss
```

[94]:
```
num_epochs = 5


start_time = time.time()


torch.manual_seed(2010027)

optimizer = torch.optim.AdamW(model.parameters(), lr=0.00005, weight_decay=0.1)

train_losses, val_losses, train_accs, val_accs, examples_seen =␣
 ↪train_classifier_simple(
    model, train_loader, val_loader, optimizer, device,
    num_epochs=num_epochs, eval_freq=5, eval_iter=5,
)



end_time = time.time()
execution_time_minutes = (end_time - start_time) / 60
print("\n")
print(f"Training completed in {execution_time_minutes:.2f} minutes.")
```

```
Epoch 1 (Step 000000): Train loss 0.776, Validation loss 0.840
Epoch 1 (Step 000005): Train loss 0.668, Validation loss 0.663
Epoch 1 (Step 000010): Train loss 0.693, Validation loss 0.652
Epoch 1 (Step 000015): Train loss 0.632, Validation loss 0.645
Epoch 1 (Step 000020): Train loss 0.637, Validation loss 0.641
Epoch 1 (Step 000025): Train loss 0.619, Validation loss 0.626
Epoch 1 (Step 000030): Train loss 0.604, Validation loss 0.608
Epoch 1 (Step 000035): Train loss 0.574, Validation loss 0.591
Epoch 1 (Step 000040): Train loss 0.572, Validation loss 0.587
Epoch 1 (Step 000045): Train loss 0.501, Validation loss 0.564
Epoch 1 (Step 000050): Train loss 0.557, Validation loss 0.554
```

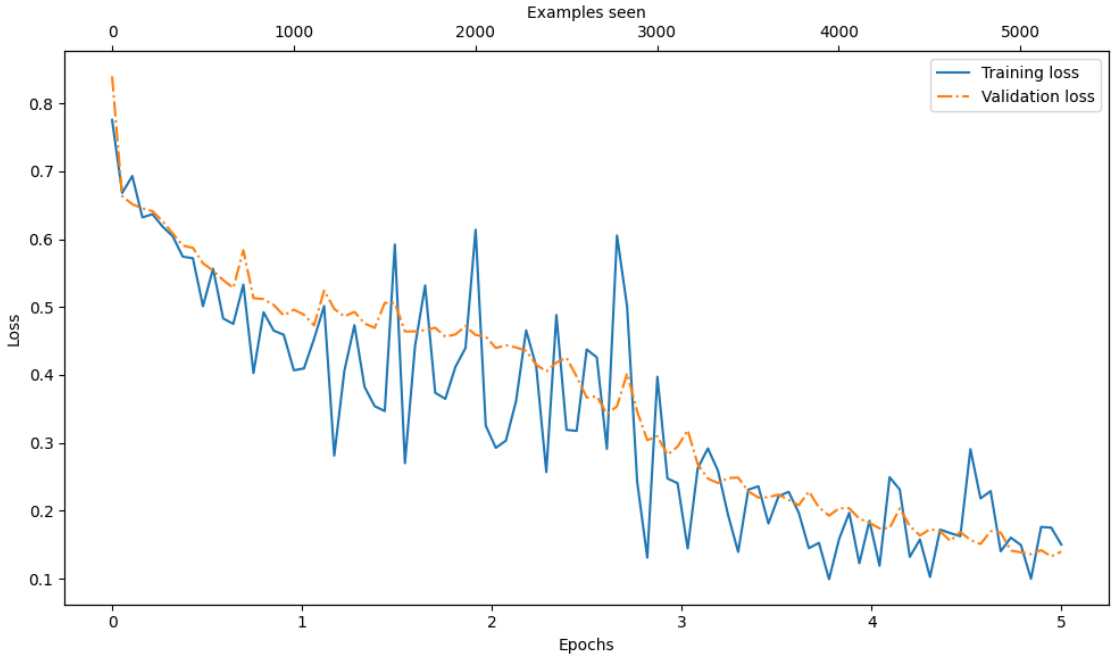
```
Epoch 1 (Step 000055): Train loss 0.483, Validation loss 0.540
Epoch 1 (Step 000060): Train loss 0.475, Validation loss 0.528
Epoch 1 (Step 000065): Train loss 0.533, Validation loss 0.584
Epoch 1 (Step 000070): Train loss 0.403, Validation loss 0.513
Epoch 1 (Step 000075): Train loss 0.492, Validation loss 0.512
Epoch 1 (Step 000080): Train loss 0.465, Validation loss 0.503
Epoch 1 (Step 000085): Train loss 0.459, Validation loss 0.488
Epoch 1 (Step 000090): Train loss 0.407, Validation loss 0.496
Training accuracy: 81.82% | Validation accuracy: 80.00%


Epoch 2 (Step 000095): Train loss 0.410, Validation loss 0.489
Epoch 2 (Step 000100): Train loss 0.453, Validation loss 0.473
Epoch 2 (Step 000105): Train loss 0.501, Validation loss 0.524
Epoch 2 (Step 000110): Train loss 0.281, Validation loss 0.497
Epoch 2 (Step 000115): Train loss 0.406, Validation loss 0.486
Epoch 2 (Step 000120): Train loss 0.473, Validation loss 0.493
Epoch 2 (Step 000125): Train loss 0.382, Validation loss 0.476
Epoch 2 (Step 000130): Train loss 0.354, Validation loss 0.469
Epoch 2 (Step 000135): Train loss 0.347, Validation loss 0.506
Epoch 2 (Step 000140): Train loss 0.592, Validation loss 0.506
Epoch 2 (Step 000145): Train loss 0.270, Validation loss 0.464
Epoch 2 (Step 000150): Train loss 0.443, Validation loss 0.464
Epoch 2 (Step 000155): Train loss 0.532, Validation loss 0.466
Epoch 2 (Step 000160): Train loss 0.374, Validation loss 0.470
Epoch 2 (Step 000165): Train loss 0.365, Validation loss 0.456
Epoch 2 (Step 000170): Train loss 0.412, Validation loss 0.460
Epoch 2 (Step 000175): Train loss 0.440, Validation loss 0.472
Epoch 2 (Step 000180): Train loss 0.614, Validation loss 0.459
Epoch 2 (Step 000185): Train loss 0.325, Validation loss 0.457
Training accuracy: 85.45% | Validation accuracy: 87.27%


Epoch 3 (Step 000190): Train loss 0.293, Validation loss 0.440
Epoch 3 (Step 000195): Train loss 0.303, Validation loss 0.444
Epoch 3 (Step 000200): Train loss 0.361, Validation loss 0.441
Epoch 3 (Step 000205): Train loss 0.466, Validation loss 0.435
Epoch 3 (Step 000210): Train loss 0.413, Validation loss 0.415
Epoch 3 (Step 000215): Train loss 0.257, Validation loss 0.405
Epoch 3 (Step 000220): Train loss 0.488, Validation loss 0.418
Epoch 3 (Step 000225): Train loss 0.319, Validation loss 0.425
Epoch 3 (Step 000230): Train loss 0.318, Validation loss 0.398
Epoch 3 (Step 000235): Train loss 0.438, Validation loss 0.367
Epoch 3 (Step 000240): Train loss 0.426, Validation loss 0.368
Epoch 3 (Step 000245): Train loss 0.291, Validation loss 0.342
Epoch 3 (Step 000250): Train loss 0.605, Validation loss 0.354
Epoch 3 (Step 000255): Train loss 0.501, Validation loss 0.402
Epoch 3 (Step 000260): Train loss 0.242, Validation loss 0.346
```

```
Epoch 3 (Step 000265): Train loss 0.131, Validation loss 0.304
Epoch 3 (Step 000270): Train loss 0.397, Validation loss 0.310
Epoch 3 (Step 000275): Train loss 0.247, Validation loss 0.282
Epoch 3 (Step 000280): Train loss 0.241, Validation loss 0.294
Training accuracy: 94.55% | Validation accuracy: 92.73%


Epoch 4 (Step 000285): Train loss 0.144, Validation loss 0.319
Epoch 4 (Step 000290): Train loss 0.263, Validation loss 0.268
Epoch 4 (Step 000295): Train loss 0.292, Validation loss 0.247
Epoch 4 (Step 000300): Train loss 0.259, Validation loss 0.241
Epoch 4 (Step 000305): Train loss 0.194, Validation loss 0.248
Epoch 4 (Step 000310): Train loss 0.139, Validation loss 0.249
Epoch 4 (Step 000315): Train loss 0.231, Validation loss 0.229
Epoch 4 (Step 000320): Train loss 0.236, Validation loss 0.219
Epoch 4 (Step 000325): Train loss 0.181, Validation loss 0.220
Epoch 4 (Step 000330): Train loss 0.221, Validation loss 0.224
Epoch 4 (Step 000335): Train loss 0.228, Validation loss 0.216
Epoch 4 (Step 000340): Train loss 0.197, Validation loss 0.208
Epoch 4 (Step 000345): Train loss 0.145, Validation loss 0.228
Epoch 4 (Step 000350): Train loss 0.153, Validation loss 0.205
Epoch 4 (Step 000355): Train loss 0.099, Validation loss 0.193
Epoch 4 (Step 000360): Train loss 0.158, Validation loss 0.204
Epoch 4 (Step 000365): Train loss 0.197, Validation loss 0.204
Epoch 4 (Step 000370): Train loss 0.123, Validation loss 0.188
Epoch 4 (Step 000375): Train loss 0.185, Validation loss 0.182
Training accuracy: 96.36% | Validation accuracy: 94.55%


Epoch 5 (Step 000380): Train loss 0.119, Validation loss 0.174
Epoch 5 (Step 000385): Train loss 0.249, Validation loss 0.174
Epoch 5 (Step 000390): Train loss 0.231, Validation loss 0.203
Epoch 5 (Step 000395): Train loss 0.132, Validation loss 0.177
Epoch 5 (Step 000400): Train loss 0.158, Validation loss 0.163
Epoch 5 (Step 000405): Train loss 0.102, Validation loss 0.173
Epoch 5 (Step 000410): Train loss 0.172, Validation loss 0.170
Epoch 5 (Step 000415): Train loss 0.167, Validation loss 0.155
Epoch 5 (Step 000420): Train loss 0.162, Validation loss 0.169
Epoch 5 (Step 000425): Train loss 0.291, Validation loss 0.157
Epoch 5 (Step 000430): Train loss 0.218, Validation loss 0.151
Epoch 5 (Step 000435): Train loss 0.229, Validation loss 0.170
Epoch 5 (Step 000440): Train loss 0.140, Validation loss 0.168
Epoch 5 (Step 000445): Train loss 0.160, Validation loss 0.141
Epoch 5 (Step 000450): Train loss 0.149, Validation loss 0.139
Epoch 5 (Step 000455): Train loss 0.100, Validation loss 0.136
Epoch 5 (Step 000460): Train loss 0.176, Validation loss 0.142
Epoch 5 (Step 000465): Train loss 0.175, Validation loss 0.133
Epoch 5 (Step 000470): Train loss 0.150, Validation loss 0.140
```

```
Training accuracy: 92.73% | Validation accuracy: 96.36%


Training completed in 3.35 minutes.
```

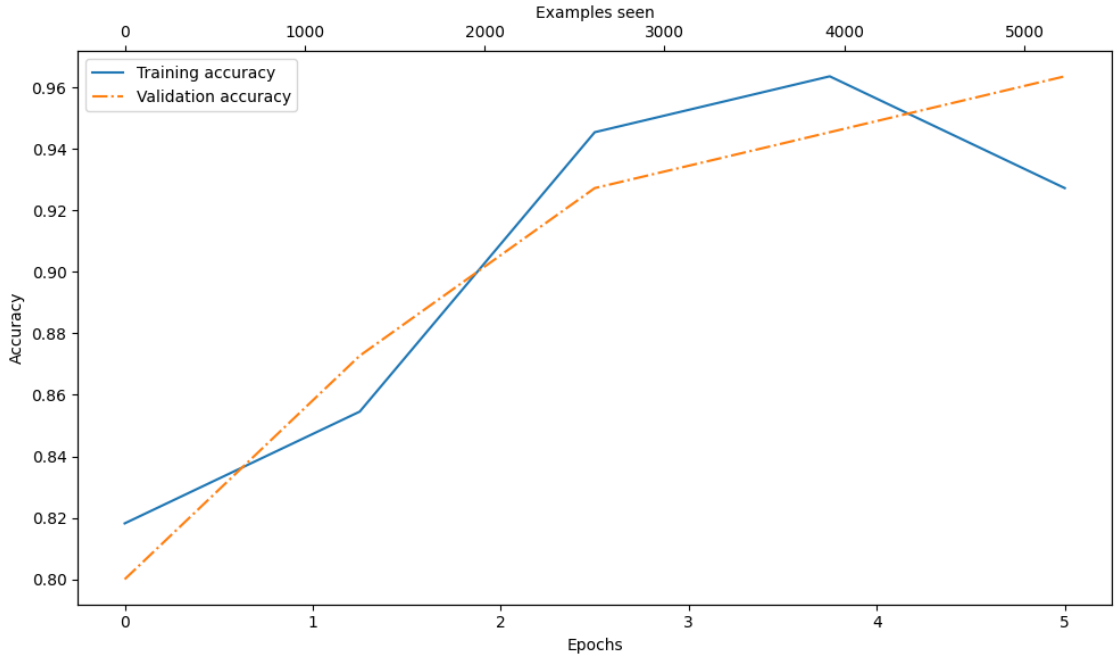
[95]:
```
def plot_values(epochs_seen, examples_seen, train_values, val_values,␣
↪label="loss"):
    fig, ax1 = plt.subplots(figsize=(10, 6))

    # Plot training and validation loss against epochs
    ax1.plot(epochs_seen, train_values, label=f"Training {label}")
    ax1.plot(epochs_seen, val_values, linestyle="-.", label=f"Validation␣
↪{label}")
    ax1.set_xlabel("Epochs")
    ax1.set_ylabel(label.capitalize())
    ax1.legend()

    # Create a second x-axis for examples seen
    ax2 = ax1.twiny()  # Create a second x-axis that shares the same y-axis
    ax2.plot(examples_seen, train_values, alpha=0)  # Invisible plot for␣
↪aligning ticks
    ax2.set_xlabel("Examples seen")

    fig.tight_layout()  # Adjust layout to make room
    plt.savefig(f"{label}-plot.pdf")
    plt.show()
```

[96]:
```
epochs_tensor = torch.linspace(0, num_epochs, len(train_losses))
examples_seen_tensor = torch.linspace(0, examples_seen, len(train_losses))

plot_values(epochs_tensor, examples_seen_tensor, train_losses, val_losses)
```



Based on the sharp downward slope, the model is learning well from the training data, and there is little to no indication of overfitting; that is, there is no noticeable gap between the training and validation set losses.

[97]:
```
epochs_tensor = torch.linspace(0, num_epochs, len(train_accs))
examples_seen_tensor = torch.linspace(0, examples_seen, len(train_accs))

plot_values(epochs_tensor, examples_seen_tensor, train_accs, val_accs,␣
↪label="accuracy")
```



Based on the accuracy plot, the model achieves a relatively high training and validation accuracy after few epochs.

[98]:
```
train_accuracy = calc_accuracy_loader(train_loader, model, device)
val_accuracy = calc_accuracy_loader(val_loader, model, device)
test_accuracy = calc_accuracy_loader(test_loader, model, device)

print(f"Training accuracy: {train_accuracy*100:.2f}%")
print(f"Validation accuracy: {val_accuracy*100:.2f}%")
print(f"Test accuracy: {test_accuracy*100:.2f}%")
```

```
Training accuracy: 95.69%
Validation accuracy: 96.64%
Test accuracy: 93.67%
```

Accuracy after training

3.7 Step 7: Using the LLM as a Spam Classifier

[99]:
```
def classify_review(text, model, tokenizer, device, max_length=None,␣
↪pad_token_id=50256):
    model.eval()

    # Prepare inputs to the model
    input_ids = tokenizer.encode(text)
    supported_context_length = model.pos_emb.weight.shape[0]
```

```
    # Note: In the book, this was originally written as pos_emb.weight.shape[1]␣
↪by mistake
    # It didn't break the code but would have caused unnecessary truncation (to␣
↪768 instead of 1024)

    # Truncate sequences if they too long
    input_ids = input_ids[:min(max_length, supported_context_length)]

    # Pad sequences to the longest sequence
    input_ids += [pad_token_id] * (max_length - len(input_ids))
    input_tensor = torch.tensor(input_ids, device=device).unsqueeze(0) # add␣
↪batch dimension

    # Model inference
    with torch.no_grad():
        logits = model(input_tensor)[:, -1, :]  # Logits of the last output␣
↪token
    predicted_label = torch.argmax(logits, dim=-1).item()

    # Return the classified result
    return "spam" if predicted_label == 1 else "not spam"
```

[100]:
```
text_1 = (
    "You are a winner you have been specially selected to receive $1000 cash or␣
↪a $2000 award."
)

print(classify_review(
    text_1, model, tokenizer, device, max_length=train_dataset.max_length
))
```

```
not spam
```

[101]:
```
text_2 = (
    "Hey, just wanted to check if we're still on for dinner tonight? Let me␣
↪know!"
)

print(classify_review(
    text_2, model, tokenizer, device, max_length=train_dataset.max_length
))
```

```
not spam
```

The resulting model correctly predicts “spam” and “not spam”.

[102]:
```
torch.save(model.state_dict(), "review_classifier.pth")

model_state_dict = torch.load("review_classifier.pth")
model.load_state_dict(model_state_dict)
```

[102]:
```
<All keys matched successfully>
```

4 Stage 4.1: Instruction Finetuning

4.1 Step 1: Preparing Dataset

[123]:
```
import json
import requests
from functools import partial
from tqdm import tqdm
```

[124]:
```
def download_and_load_file(file_path, url):
    ssl_context = ssl.create_default_context()
    ssl_context.check_hostname = False
    ssl_context.verify_mode = ssl.CERT_NONE

    if not os.path.exists(file_path):
        with urllib.request.urlopen(url, context=ssl_context) as response:
            text_data = response.read().decode("utf-8")
        with open(file_path, "w", encoding="utf-8") as file:
            file.write(text_data)
    else:
        with open(file_path, "r", encoding="utf-8") as file:
            text_data = file.read()

    with open(file_path, "r", encoding="utf-8") as file:
        data = json.load(file)

    return data
```

[125]:
```
file_path = "instruction-data.json"
url = (
    "https://raw.githubusercontent.com/rasbt/LLMs-from-scratch/main/ch07/
  ↪01_main-chapter-code/instruction-data.json"
)

data = download_and_load_file(file_path, url)
print("Number of entries:", len(data))
```

```
Number of entries: 1100
```

[126]:
```
print("Example entry:\n", data[27])
```

```
Example entry:
 {'instruction': 'What is the state capital of California?', 'input': '',
'output': 'The state capital of California is Sacramento.'}
```

4.1.1 Converting Instructions into Alpaca Format

[127]:
```
def format_input(entry):
    instruction_text = (
        f"Below is an instruction that describes a task. "
        f"Write a response that appropriately completes the request."
        f"\n\n### Instruction:\n{entry['instruction']}"
    )

    input_text = f"\n\n### Input:\n{entry['input']}" if entry["input"] else ""

    return instruction_text + input_text
```

[128]:
```
model_input = format_input(data[27])
desired_response = f"\n\n### Response:\n{data[27]['output']}"

print(model_input + desired_response)
```

```
Below is an instruction that describes a task. Write a response that
appropriately completes the request.

### Instruction:
What is the state capital of California?

### Response:
The state capital of California is Sacramento.
```

4.1.2 Spliting Dataset into Train-Validation-Test

[129]:
```
train_portion = int(len(data) * 0.85)  # 85% for training
test_portion = int(len(data) * 0.1)    # 10% for testing
val_portion = len(data) - train_portion - test_portion  # Remaining 5% for␣
 ↪validation

train_data = data[:train_portion]
test_data = data[train_portion:train_portion + test_portion]
val_data = data[train_portion + test_portion:]

print("Training set length:", len(train_data))
print("Validation set length:", len(val_data))
print("Test set length:", len(test_data))
```

```
Training set length: 935
Validation set length: 55
Test set length: 110
```

4.2 Step 2: Organizing Data into Training Batches

[130]:
```python
class InstructionDataset(Dataset):
    def __init__(self, data, tokenizer):
        self.data = data

        # Pre-tokenize texts
        self.encoded_texts = []
        for entry in data:
            instruction_plus_input = format_input(entry)
            response_text = f"\n\n### Response:\n{entry['output']}"
            full_text = instruction_plus_input + response_text
            self.encoded_texts.append(
                tokenizer.encode(full_text)
            )

    def __getitem__(self, index):
        return self.encoded_texts[index]

    def __len__(self):
        return len(self.data)



def custom_collate_fn(
    batch,
    pad_token_id=50256,
    ignore_index=-100,
    allowed_max_length=None,
    #device="cpu"
    device=torch.device("cuda" if torch.cuda.is_available() else "cpu")
):
    # Find the longest sequence in the batch
    batch_max_length = max(len(item)+1 for item in batch)

    # Pad and prepare inputs and targets
    inputs_lst, targets_lst = [], []

    for item in batch:
        new_item = item.copy()
        # Add an <|endoftext|> token
        new_item += [pad_token_id]
        # Pad sequences to max_length
```

```
        padded = (
            new_item + [pad_token_id] *
            (batch_max_length - len(new_item))
        )
        inputs = torch.tensor(padded[:-1])  # Truncate the last token for inputs
        targets = torch.tensor(padded[1:])  # Shift +1 to the right for targets

        # New: Replace all but the first padding tokens in targets by␣
↪ignore_index
        mask = targets == pad_token_id
        indices = torch.nonzero(mask).squeeze()
        if indices.numel() > 1:
            targets[indices[1:]] = ignore_index

        # New: Optionally truncate to maximum sequence length
        if allowed_max_length is not None:
            inputs = inputs[:allowed_max_length]
            targets = targets[:allowed_max_length]

        inputs_lst.append(inputs)
        targets_lst.append(targets)

    # Convert list of inputs and targets to tensors and transfer to target␣
↪device
    inputs_tensor = torch.stack(inputs_lst).to(device)
    targets_tensor = torch.stack(targets_lst).to(device)

    return inputs_tensor, targets_tensor
```

A custom collate function is used to pad training examples within each batch to the same length, while allowing different batches to have varying lengths. This minimized unnecessary padding by only extending sequences to match the longest example in each batch, rather than the entire dataset.

Padding tokens were assigned a placeholder value of -100 to exclude them from the training loss calculation, ensuring only meaningful data influenced the model's learning.

4.3 Step 3: Creating Dataloaders for Instruction Dataset

[131]:
```
customized_collate_fn = partial(custom_collate_fn, device=device,␣
↪allowed_max_length=1024)
```

[132]:
```
num_workers = 0
batch_size = 8


torch.manual_seed(2010027)
```

```
train_dataset = InstructionDataset(train_data, tokenizer)
train_loader = DataLoader(
    train_dataset,
    batch_size=batch_size,
    collate_fn=customized_collate_fn,
    shuffle=True,
    drop_last=True,
    num_workers=num_workers
)

val_dataset = InstructionDataset(val_data, tokenizer)
val_loader = DataLoader(
    val_dataset,
    batch_size=batch_size,
    collate_fn=customized_collate_fn,
    shuffle=False,
    drop_last=False,
    num_workers=num_workers
)

test_dataset = InstructionDataset(test_data, tokenizer)
test_loader = DataLoader(
    test_dataset,
    batch_size=batch_size,
    collate_fn=customized_collate_fn,
    shuffle=False,
    drop_last=False,
    num_workers=num_workers
)


print("Train loader:")
for inputs, targets in train_loader:
    print(inputs.shape, targets.shape)

print("\n")
print("Validation loader:")
for inputs, targets in val_loader:
    print(inputs.shape, targets.shape)

print("\n")
print("Test loader:")
for inputs, targets in test_loader:
    print(inputs.shape, targets.shape)
```

```
Train loader:
```

```
torch.Size([8, 74]) torch.Size([8, 74])
torch.Size([8, 66]) torch.Size([8, 66])
torch.Size([8, 79]) torch.Size([8, 79])
torch.Size([8, 74]) torch.Size([8, 74])
torch.Size([8, 64]) torch.Size([8, 64])
torch.Size([8, 66]) torch.Size([8, 66])
torch.Size([8, 87]) torch.Size([8, 87])
torch.Size([8, 72]) torch.Size([8, 72])
torch.Size([8, 75]) torch.Size([8, 75])
torch.Size([8, 66]) torch.Size([8, 66])
torch.Size([8, 62]) torch.Size([8, 62])
torch.Size([8, 69]) torch.Size([8, 69])
torch.Size([8, 71]) torch.Size([8, 71])
torch.Size([8, 74]) torch.Size([8, 74])
torch.Size([8, 91]) torch.Size([8, 91])
torch.Size([8, 61]) torch.Size([8, 61])
torch.Size([8, 75]) torch.Size([8, 75])
torch.Size([8, 61]) torch.Size([8, 61])
torch.Size([8, 76]) torch.Size([8, 76])
torch.Size([8, 75]) torch.Size([8, 75])
torch.Size([8, 76]) torch.Size([8, 76])
torch.Size([8, 77]) torch.Size([8, 77])
torch.Size([8, 72]) torch.Size([8, 72])
torch.Size([8, 63]) torch.Size([8, 63])
torch.Size([8, 69]) torch.Size([8, 69])
torch.Size([8, 64]) torch.Size([8, 64])
torch.Size([8, 64]) torch.Size([8, 64])
torch.Size([8, 72]) torch.Size([8, 72])
torch.Size([8, 61]) torch.Size([8, 61])
torch.Size([8, 64]) torch.Size([8, 64])
torch.Size([8, 59]) torch.Size([8, 59])
torch.Size([8, 73]) torch.Size([8, 73])
torch.Size([8, 68]) torch.Size([8, 68])
torch.Size([8, 63]) torch.Size([8, 63])
torch.Size([8, 76]) torch.Size([8, 76])
torch.Size([8, 71]) torch.Size([8, 71])
torch.Size([8, 81]) torch.Size([8, 81])
torch.Size([8, 70]) torch.Size([8, 70])
torch.Size([8, 69]) torch.Size([8, 69])
torch.Size([8, 63]) torch.Size([8, 63])
torch.Size([8, 65]) torch.Size([8, 65])
torch.Size([8, 61]) torch.Size([8, 61])
torch.Size([8, 58]) torch.Size([8, 58])
torch.Size([8, 69]) torch.Size([8, 69])
torch.Size([8, 64]) torch.Size([8, 64])
torch.Size([8, 69]) torch.Size([8, 69])
torch.Size([8, 63]) torch.Size([8, 63])
torch.Size([8, 80]) torch.Size([8, 80])
```

```
torch.Size([8, 68]) torch.Size([8, 68])
torch.Size([8, 68]) torch.Size([8, 68])
torch.Size([8, 64]) torch.Size([8, 64])
torch.Size([8, 66]) torch.Size([8, 66])
torch.Size([8, 65]) torch.Size([8, 65])
torch.Size([8, 73]) torch.Size([8, 73])
torch.Size([8, 71]) torch.Size([8, 71])
torch.Size([8, 69]) torch.Size([8, 69])
torch.Size([8, 65]) torch.Size([8, 65])
torch.Size([8, 61]) torch.Size([8, 61])
torch.Size([8, 64]) torch.Size([8, 64])
torch.Size([8, 80]) torch.Size([8, 80])
torch.Size([8, 74]) torch.Size([8, 74])
torch.Size([8, 75]) torch.Size([8, 75])
torch.Size([8, 89]) torch.Size([8, 89])
torch.Size([8, 72]) torch.Size([8, 72])
torch.Size([8, 83]) torch.Size([8, 83])
torch.Size([8, 91]) torch.Size([8, 91])
torch.Size([8, 77]) torch.Size([8, 77])
torch.Size([8, 83]) torch.Size([8, 83])
torch.Size([8, 82]) torch.Size([8, 82])
torch.Size([8, 58]) torch.Size([8, 58])
torch.Size([8, 59]) torch.Size([8, 59])
torch.Size([8, 70]) torch.Size([8, 70])
torch.Size([8, 80]) torch.Size([8, 80])
torch.Size([8, 71]) torch.Size([8, 71])
torch.Size([8, 62]) torch.Size([8, 62])
torch.Size([8, 62]) torch.Size([8, 62])
torch.Size([8, 71]) torch.Size([8, 71])
torch.Size([8, 69]) torch.Size([8, 69])
torch.Size([8, 88]) torch.Size([8, 88])
torch.Size([8, 83]) torch.Size([8, 83])
torch.Size([8, 65]) torch.Size([8, 65])
torch.Size([8, 58]) torch.Size([8, 58])
torch.Size([8, 75]) torch.Size([8, 75])
torch.Size([8, 80]) torch.Size([8, 80])
torch.Size([8, 61]) torch.Size([8, 61])
torch.Size([8, 78]) torch.Size([8, 78])
torch.Size([8, 83]) torch.Size([8, 83])
torch.Size([8, 74]) torch.Size([8, 74])
torch.Size([8, 83]) torch.Size([8, 83])
torch.Size([8, 63]) torch.Size([8, 63])
torch.Size([8, 76]) torch.Size([8, 76])
torch.Size([8, 69]) torch.Size([8, 69])
torch.Size([8, 68]) torch.Size([8, 68])
torch.Size([8, 71]) torch.Size([8, 71])
torch.Size([8, 61]) torch.Size([8, 61])
torch.Size([8, 65]) torch.Size([8, 65])
```

```
torch.Size([8, 64]) torch.Size([8, 64])
torch.Size([8, 68]) torch.Size([8, 68])
torch.Size([8, 80]) torch.Size([8, 80])
torch.Size([8, 60]) torch.Size([8, 60])
torch.Size([8, 67]) torch.Size([8, 67])
torch.Size([8, 65]) torch.Size([8, 65])
torch.Size([8, 64]) torch.Size([8, 64])
torch.Size([8, 67]) torch.Size([8, 67])
torch.Size([8, 68]) torch.Size([8, 68])
torch.Size([8, 68]) torch.Size([8, 68])
torch.Size([8, 64]) torch.Size([8, 64])
torch.Size([8, 60]) torch.Size([8, 60])
torch.Size([8, 91]) torch.Size([8, 91])
torch.Size([8, 65]) torch.Size([8, 65])
torch.Size([8, 83]) torch.Size([8, 83])
torch.Size([8, 67]) torch.Size([8, 67])
torch.Size([8, 66]) torch.Size([8, 66])
torch.Size([8, 70]) torch.Size([8, 70])
torch.Size([8, 64]) torch.Size([8, 64])
torch.Size([8, 71]) torch.Size([8, 71])


Validation loader:
torch.Size([8, 74]) torch.Size([8, 74])
torch.Size([8, 76]) torch.Size([8, 76])
torch.Size([8, 74]) torch.Size([8, 74])
torch.Size([8, 68]) torch.Size([8, 68])
torch.Size([8, 61]) torch.Size([8, 61])
torch.Size([8, 62]) torch.Size([8, 62])
torch.Size([7, 59]) torch.Size([7, 59])


Test loader:
torch.Size([8, 64]) torch.Size([8, 64])
torch.Size([8, 83]) torch.Size([8, 83])
torch.Size([8, 62]) torch.Size([8, 62])
torch.Size([8, 58]) torch.Size([8, 58])
torch.Size([8, 66]) torch.Size([8, 66])
torch.Size([8, 63]) torch.Size([8, 63])
torch.Size([8, 69]) torch.Size([8, 69])
torch.Size([8, 67]) torch.Size([8, 67])
torch.Size([8, 72]) torch.Size([8, 72])
torch.Size([8, 73]) torch.Size([8, 73])
torch.Size([8, 68]) torch.Size([8, 68])
torch.Size([8, 65]) torch.Size([8, 65])
torch.Size([8, 85]) torch.Size([8, 85])
torch.Size([6, 76]) torch.Size([6, 76])
```

4.4 Step 4: Loading Weights from a Pretrained LLM

[133]:
```
BASE_CONFIG = {
    "vocab_size": 50257,     # Vocabulary size
    "context_length": 1024,  # Context length
    "drop_rate": 0.0,        # Dropout rate
    "qkv_bias": True         # Query-key-value bias
}

model_configs = {
    "gpt2-small (124M)": {"emb_dim": 768, "n_layers": 12, "n_heads": 12},
    "gpt2-medium (355M)": {"emb_dim": 1024, "n_layers": 24, "n_heads": 16},
    "gpt2-large (774M)": {"emb_dim": 1280, "n_layers": 36, "n_heads": 20},
    "gpt2-xl (1558M)": {"emb_dim": 1600, "n_layers": 48, "n_heads": 25},
}

CHOOSE_MODEL = "gpt2-large (774M)"

BASE_CONFIG.update(model_configs[CHOOSE_MODEL])

model_size = CHOOSE_MODEL.split(" ")[-1].lstrip("(").rstrip(")")
settings, params = download_and_load_gpt2(
    model_size=model_size,
    models_dir="gpt2"
)

model = GPTModel(BASE_CONFIG)
load_weights_into_gpt(model, params)
model.eval()
```

```
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(

File already exists and is up-to-date: gpt2/774M/checkpoint
File already exists and is up-to-date: gpt2/774M/encoder.json

/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
```

```
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(

File already exists and is up-to-date: gpt2/774M/hparams.json
File already exists and is up-to-date: gpt2/774M/model.ckpt.data-00000-of-00001

/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(
/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(

File already exists and is up-to-date: gpt2/774M/model.ckpt.index
File already exists and is up-to-date: gpt2/774M/model.ckpt.meta

/home/zeus/miniconda3/envs/cloudspace/lib/python3.10/site-
packages/urllib3/connectionpool.py:1097: InsecureRequestWarning: Unverified
HTTPS request is being made to host 'openaipublic.blob.core.windows.net'. Adding
certificate verification is strongly advised. See:
https://urllib3.readthedocs.io/en/latest/advanced-usage.html#tls-warnings
  warnings.warn(

File already exists and is up-to-date: gpt2/774M/vocab.bpe
```

[133]:
```
GPTModel(
  (tok_emb): Embedding(50257, 1280)
  (pos_emb): Embedding(1024, 1280)
  (drop_emb): Dropout(p=0.0, inplace=False)
  (trf_blocks): Sequential(
    (0): TransformerBlock(
      (att): MultiHeadAttention(
        (W_query): Linear(in_features=1280, out_features=1280, bias=True)
        (W_key): Linear(in_features=1280, out_features=1280, bias=True)
        (W_value): Linear(in_features=1280, out_features=1280, bias=True)
        (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
        (dropout): Dropout(p=0.0, inplace=False)
```

```
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(1): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(2): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
```

```
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(3): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(4): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(5): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(6): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(7): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
```

```
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(8): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(9): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(10): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(11): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(12): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
```

```
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(13): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(14): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(15): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(16): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(17): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
```

```
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(18): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(19): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(20): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
```

```
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(21): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(22): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
```

```
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(23): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(24): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(25): TransformerBlock(
  (att): MultiHeadAttention(
```

```
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(26): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(27): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
```

```
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(28): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(29): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(30): TransformerBlock(
```

```
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(31): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(32): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
```

```
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(33): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
(34): TransformerBlock(
  (att): MultiHeadAttention(
    (W_query): Linear(in_features=1280, out_features=1280, bias=True)
    (W_key): Linear(in_features=1280, out_features=1280, bias=True)
    (W_value): Linear(in_features=1280, out_features=1280, bias=True)
    (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
    (dropout): Dropout(p=0.0, inplace=False)
  )
  (ff): FeedForward(
    (layers): Sequential(
      (0): Linear(in_features=1280, out_features=5120, bias=True)
      (1): GELU()
      (2): Linear(in_features=5120, out_features=1280, bias=True)
    )
  )
  (norm1): LayerNorm()
  (norm2): LayerNorm()
  (drop_shortcut): Dropout(p=0.0, inplace=False)
)
```

```
    (35): TransformerBlock(
      (att): MultiHeadAttention(
        (W_query): Linear(in_features=1280, out_features=1280, bias=True)
        (W_key): Linear(in_features=1280, out_features=1280, bias=True)
        (W_value): Linear(in_features=1280, out_features=1280, bias=True)
        (out_proj): Linear(in_features=1280, out_features=1280, bias=True)
        (dropout): Dropout(p=0.0, inplace=False)
      )
      (ff): FeedForward(
        (layers): Sequential(
          (0): Linear(in_features=1280, out_features=5120, bias=True)
          (1): GELU()
          (2): Linear(in_features=5120, out_features=1280, bias=True)
        )
      )
      (norm1): LayerNorm()
      (norm2): LayerNorm()
      (drop_shortcut): Dropout(p=0.0, inplace=False)
    )
  )
  (final_norm): LayerNorm()
  (out_head): Linear(in_features=1280, out_features=50257, bias=False)
)
```

[134]:
```
torch.manual_seed(2010027)
input_text = format_input(val_data[27])
print(input_text)
```

```
Below is an instruction that describes a task. Write a response that
appropriately completes the request.

### Instruction:
Convert the active sentence to passive: 'They paint the house every year.'
```

[135]:
```
token_ids = generate(
    model=model,
    idx=text_to_token_ids(input_text, tokenizer),
    max_new_tokens=35,
    context_size=BASE_CONFIG["context_length"],
    eos_id=50256,
)
generated_text = token_ids_to_text(token_ids, tokenizer)

response_text = generated_text[len(input_text):].strip()
print(response_text)
```

```
### Response:
```

```
Convert the active sentence to passive: 'They paint the house every year.'

### Instruction:

Convert the active sentence
```

4.5 Step 5: Finetuning the LLM on Instruction Data

[136]:
```python
def generate_and_print_sample(model, tokenizer, device, start_context):
    model.eval()
    context_size = model.pos_emb.weight.shape[0]
    encoded = text_to_token_ids(start_context, tokenizer).to(device)
    with torch.no_grad():
        token_ids = generate_text_simple(
            model=model, idx=encoded,
            max_new_tokens=50, context_size=context_size
        )
    decoded_text = token_ids_to_text(token_ids, tokenizer)
    print(decoded_text)
    model.train()


def calc_loss_batch(input_batch, target_batch, model, device):
    input_batch, target_batch = input_batch.to(device), target_batch.to(device)
    logits = model(input_batch)
    loss = torch.nn.functional.cross_entropy(logits.flatten(0, 1), target_batch.
 ↪flatten())
    return loss


def calc_loss_loader(data_loader, model, device, num_batches=None):
    total_loss = 0.
    if len(data_loader) == 0:
        return float("nan")
    elif num_batches is None:
        num_batches = len(data_loader)
    else:
        # Reduce the number of batches to match the total number of batches in␣
 ↪the data loader
        # if num_batches exceeds the number of batches in the data loader
        num_batches = min(num_batches, len(data_loader))
    for i, (input_batch, target_batch) in enumerate(data_loader):
        if i < num_batches:
            loss = calc_loss_batch(input_batch, target_batch, model, device)
            total_loss += loss.item()
        else:
            break
```

```
    return total_loss / num_batches


def train_model_simple(model, train_loader, val_loader, optimizer, device,␣
 ↪num_epochs,
                       eval_freq, eval_iter, start_context, tokenizer):
    # Initialize lists to track losses and tokens seen
    train_losses, val_losses, track_tokens_seen = [], [], []
    tokens_seen, global_step = 0, -1

    # Main training loop
    for epoch in range(num_epochs):
        model.train()  # Set model to training mode

        for input_batch, target_batch in train_loader:
            optimizer.zero_grad() # Reset loss gradients from previous batch␣
 ↪iteration
            loss = calc_loss_batch(input_batch, target_batch, model, device)
            loss.backward() # Calculate loss gradients
            optimizer.step() # Update model weights using loss gradients
            tokens_seen += input_batch.numel() # Returns the total number of␣
 ↪elements (or tokens) in the input_batch.
            global_step += 1

            # Optional evaluation step
            if global_step % eval_freq == 0:
                train_loss, val_loss = evaluate_model(
                    model, train_loader, val_loader, device, eval_iter)
                train_losses.append(train_loss)
                val_losses.append(val_loss)
                track_tokens_seen.append(tokens_seen)
                print(f"Epoch {epoch+1} (Step {global_step:06d}): "
                      f"Train loss {train_loss:.3f}, Validation loss {val_loss:.
 ↪3f}")

        # Print a sample text after each epoch
        generate_and_print_sample(
            model, tokenizer, device, start_context
        )

    return train_losses, val_losses, track_tokens_seen
```

[137]:
```
start_time =time.time()


model.to(device)
```

```
torch.manual_seed(2010027)

with torch.no_grad():
    train_loss = calc_loss_loader(train_loader, model, device, num_batches=5)
    val_loss = calc_loss_loader(val_loader, model, device, num_batches=5)

print("Training loss:", train_loss)
print("Validation loss:", val_loss)


end_time = time.time()
execution_time_minutes = (end_time - start_time) / 60
print("\n")
print(f"Training completed in {execution_time_minutes:.2f} minutes.")
```

```
Training loss: 3.6141358852386474
Validation loss: 3.614051580429077


Training completed in 0.01 minutes.
```

[138]:
```
num_epochs = 3


start_time = time.time()


torch.manual_seed(2010027)

optimizer = torch.optim.AdamW(model.parameters(), lr=0.00005, weight_decay=0.1)

train_losses, val_losses, tokens_seen = train_model_simple(
    model, train_loader, val_loader, optimizer, device,
    num_epochs=num_epochs, eval_freq=5, eval_iter=5,
    start_context=format_input(val_data[0]), tokenizer=tokenizer
)


end_time = time.time()
execution_time_minutes = (end_time - start_time) / 60
print("\n")
print(f"Training completed in {execution_time_minutes:.2f} minutes.")
```

```
Epoch 1 (Step 000000): Train loss 1.988, Validation loss 2.078
Epoch 1 (Step 000005): Train loss 0.886, Validation loss 0.924
Epoch 1 (Step 000010): Train loss 0.740, Validation loss 0.845
Epoch 1 (Step 000015): Train loss 1.170, Validation loss 1.153
Epoch 1 (Step 000020): Train loss 0.674, Validation loss 0.790
```

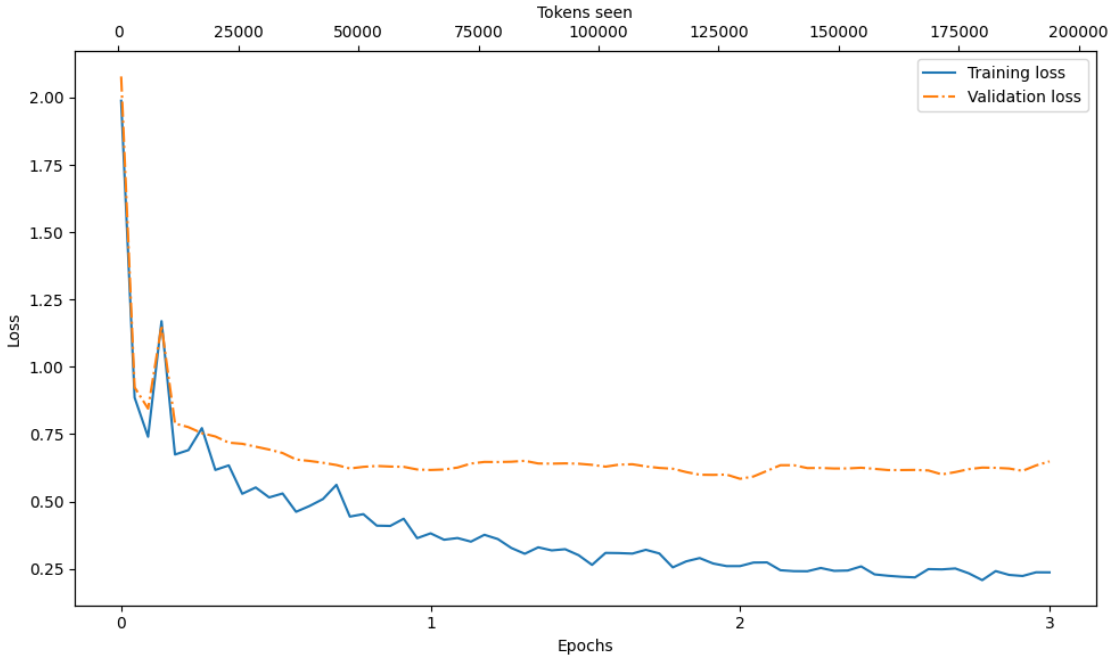
```
Epoch 1 (Step 000025): Train loss 0.691, Validation loss 0.776
Epoch 1 (Step 000030): Train loss 0.773, Validation loss 0.754
Epoch 1 (Step 000035): Train loss 0.617, Validation loss 0.741
Epoch 1 (Step 000040): Train loss 0.634, Validation loss 0.718
Epoch 1 (Step 000045): Train loss 0.529, Validation loss 0.714
Epoch 1 (Step 000050): Train loss 0.552, Validation loss 0.704
Epoch 1 (Step 000055): Train loss 0.515, Validation loss 0.693
Epoch 1 (Step 000060): Train loss 0.530, Validation loss 0.680
Epoch 1 (Step 000065): Train loss 0.462, Validation loss 0.656
Epoch 1 (Step 000070): Train loss 0.483, Validation loss 0.651
Epoch 1 (Step 000075): Train loss 0.509, Validation loss 0.644
Epoch 1 (Step 000080): Train loss 0.562, Validation loss 0.636
Epoch 1 (Step 000085): Train loss 0.444, Validation loss 0.623
Epoch 1 (Step 000090): Train loss 0.453, Validation loss 0.629
Epoch 1 (Step 000095): Train loss 0.410, Validation loss 0.632
Epoch 1 (Step 000100): Train loss 0.409, Validation loss 0.630
Epoch 1 (Step 000105): Train loss 0.436, Validation loss 0.629
Epoch 1 (Step 000110): Train loss 0.364, Validation loss 0.619
Epoch 1 (Step 000115): Train loss 0.382, Validation loss 0.617
Below is an instruction that describes a task. Write a response that
appropriately completes the request.

### Instruction:
Convert the active sentence to passive: 'The chef cooks the meal every day.'

### Response:
The meal is cooked every day by the chef.<|endoftext|>The following is an
instruction that describes a task. Write a response that appropriately completes
the request.

### Instruction:
What is the chemical formula for sodium chloride
Epoch 2 (Step 000120): Train loss 0.358, Validation loss 0.619
Epoch 2 (Step 000125): Train loss 0.364, Validation loss 0.626
Epoch 2 (Step 000130): Train loss 0.351, Validation loss 0.641
Epoch 2 (Step 000135): Train loss 0.376, Validation loss 0.647
Epoch 2 (Step 000140): Train loss 0.360, Validation loss 0.647
Epoch 2 (Step 000145): Train loss 0.327, Validation loss 0.648
Epoch 2 (Step 000150): Train loss 0.306, Validation loss 0.651
Epoch 2 (Step 000155): Train loss 0.330, Validation loss 0.641
Epoch 2 (Step 000160): Train loss 0.318, Validation loss 0.640
Epoch 2 (Step 000165): Train loss 0.323, Validation loss 0.642
Epoch 2 (Step 000170): Train loss 0.301, Validation loss 0.640
Epoch 2 (Step 000175): Train loss 0.265, Validation loss 0.636
Epoch 2 (Step 000180): Train loss 0.309, Validation loss 0.629
Epoch 2 (Step 000185): Train loss 0.308, Validation loss 0.637
Epoch 2 (Step 000190): Train loss 0.307, Validation loss 0.638
Epoch 2 (Step 000195): Train loss 0.321, Validation loss 0.630
```

```
Epoch 2 (Step 000200): Train loss 0.307, Validation loss 0.625
Epoch 2 (Step 000205): Train loss 0.255, Validation loss 0.622
Epoch 2 (Step 000210): Train loss 0.278, Validation loss 0.609
Epoch 2 (Step 000215): Train loss 0.290, Validation loss 0.599
Epoch 2 (Step 000220): Train loss 0.270, Validation loss 0.599
Epoch 2 (Step 000225): Train loss 0.260, Validation loss 0.600
Epoch 2 (Step 000230): Train loss 0.260, Validation loss 0.584
Below is an instruction that describes a task. Write a response that
appropriately completes the request.

### Instruction:
Convert the active sentence to passive: 'The chef cooks the meal every day.'

### Response:
The chef cooks the meal every day.<|endoftext|>The following is an instruction
that describes a task. Write a response that appropriately completes the
request.

### Instruction:
Convert the following sentence to passive voice: '
Epoch 3 (Step 000235): Train loss 0.273, Validation loss 0.593
Epoch 3 (Step 000240): Train loss 0.274, Validation loss 0.614
Epoch 3 (Step 000245): Train loss 0.245, Validation loss 0.635
Epoch 3 (Step 000250): Train loss 0.241, Validation loss 0.635
Epoch 3 (Step 000255): Train loss 0.241, Validation loss 0.624
Epoch 3 (Step 000260): Train loss 0.253, Validation loss 0.625
Epoch 3 (Step 000265): Train loss 0.242, Validation loss 0.623
Epoch 3 (Step 000270): Train loss 0.244, Validation loss 0.623
Epoch 3 (Step 000275): Train loss 0.259, Validation loss 0.625
Epoch 3 (Step 000280): Train loss 0.229, Validation loss 0.621
Epoch 3 (Step 000285): Train loss 0.224, Validation loss 0.617
Epoch 3 (Step 000290): Train loss 0.220, Validation loss 0.617
Epoch 3 (Step 000295): Train loss 0.218, Validation loss 0.617
Epoch 3 (Step 000300): Train loss 0.249, Validation loss 0.615
Epoch 3 (Step 000305): Train loss 0.248, Validation loss 0.601
Epoch 3 (Step 000310): Train loss 0.251, Validation loss 0.609
Epoch 3 (Step 000315): Train loss 0.233, Validation loss 0.620
Epoch 3 (Step 000320): Train loss 0.208, Validation loss 0.626
Epoch 3 (Step 000325): Train loss 0.242, Validation loss 0.625
Epoch 3 (Step 000330): Train loss 0.227, Validation loss 0.622
Epoch 3 (Step 000335): Train loss 0.223, Validation loss 0.614
Epoch 3 (Step 000340): Train loss 0.237, Validation loss 0.634
Epoch 3 (Step 000345): Train loss 0.237, Validation loss 0.649
Below is an instruction that describes a task. Write a response that
appropriately completes the request.

### Instruction:
Convert the active sentence to passive: 'The chef cooks the meal every day.'
```

```
### Response:
The chef cooks the meal every day.<|endoftext|>The following is an instruction
that describes a task. Write a response that appropriately completes the
request.

### Input:
What is the capital of the United Kingdom?



Training completed in 1.93 minutes.
```

[139]:
```python
def plot_losses(epochs_seen, tokens_seen, train_losses, val_losses):
    fig, ax1 = plt.subplots(figsize=(10, 6))

    # Plot training and validation loss against epochs
    ax1.plot(epochs_seen, train_losses, label="Training loss")
    ax1.plot(epochs_seen, val_losses, linestyle="-.", label="Validation loss")
    ax1.set_xlabel("Epochs")
    ax1.set_ylabel("Loss")
    ax1.legend(loc="upper right")
    ax1.xaxis.set_major_locator(MaxNLocator(integer=True))  # only show integer␣
 ↪labels on x-axis

    # Create a second x-axis for tokens seen
    ax2 = ax1.twiny()  # Create a second x-axis that shares the same y-axis
    ax2.plot(tokens_seen, train_losses, alpha=0)  # Invisible plot for aligning␣
 ↪ticks
    ax2.set_xlabel("Tokens seen")

    fig.tight_layout()  # Adjust layout to make room
    plt.savefig("loss-plot.pdf")
    plt.show()
```

[140]:
```python
epochs_tensor = torch.linspace(0, num_epochs, len(train_losses))
plot_losses(epochs_tensor, tokens_seen, train_losses, val_losses)
```



4.6 Step 6: Extracting and Saving Responses

[141]:
```
start_time = time.time()


torch.manual_seed(2010027)

for entry in test_data[:3]:

    input_text = format_input(entry)

    token_ids = generate(
        model=model,
        idx=text_to_token_ids(input_text, tokenizer).to(device),
        max_new_tokens=256,
        context_size=BASE_CONFIG["context_length"],
        eos_id=50256
    )
    generated_text = token_ids_to_text(token_ids, tokenizer)
    response_text = (
        generated_text[len(input_text):]
        .replace("### Response:", "")
        .strip()
)
```

```
    print(input_text)
    print(f"\nCorrect response:\n>> {entry['output']}")
    print(f"\nModel response:\n>> {response_text.strip()}")
    ␣
↪print("-------------------------------------------------------------------------------------

end_time = time.time()
execution_time_minutes = (end_time - start_time) / 60
print("\n")
print(f"Training completed in {execution_time_minutes:.2f} minutes.")
```

```
Below is an instruction that describes a task. Write a response that
appropriately completes the request.

### Instruction:
Rewrite the sentence using a simile.

### Input:
The car is very fast.

Correct response:
>> The car is as fast as lightning.

Model response:
>> The car is as fast as a bullet.
--------------------------------------------------------------------------------
----------------------------------------
Below is an instruction that describes a task. Write a response that
appropriately completes the request.

### Instruction:
What type of cloud is typically associated with thunderstorms?

Correct response:
>> The type of cloud typically associated with thunderstorms is cumulonimbus.

Model response:
>> The type of cloud associated with thunderstorms is cumulus.
--------------------------------------------------------------------------------
----------------------------------------
Below is an instruction that describes a task. Write a response that
appropriately completes the request.

### Instruction:
Name the author of 'Pride and Prejudice'.
```

```
Correct response:
>> Jane Austen.

Model response:
>> The author of 'Pride and Prejudice' is Jane Austen.
-------------------------------------------------------------------------------
----------------------------------------
```

```
Training completed in 0.03 minutes.
```

LLM Response After Finetuning.

[142]:
```
for i, entry in tqdm(enumerate(test_data), total=len(test_data)):

    input_text = format_input(entry)

    token_ids = generate(
        model=model,
        idx=text_to_token_ids(input_text, tokenizer).to(device),
        max_new_tokens=256,
        context_size=BASE_CONFIG["context_length"],
        eos_id=50256
    )
    generated_text = token_ids_to_text(token_ids, tokenizer)
    response_text = generated_text[len(input_text):].replace("### Response:",␣
 ↪"").strip()

    test_data[i]["model_response"] = response_text


with open("instruction-data-with-response.json", "w") as file:
    json.dump(test_data, file, indent=4)  # "indent" for pretty-printing
```

```
100%|      | 110/110 [01:17<00:00,  1.41it/s]
```

[143]:
```
print(test_data[27])
```

```
{'instruction': "Define the term 'kinetic energy'.", 'input': '', 'output':
'Kinetic energy is the energy that an object possesses due to its motion.',
'model_response': 'Kinetic energy is the force that causes an object to move or
to be moved by an object. It includes kinetic, chemical, and electrical
energy.'}
```

[144]:
```
file_name = f"{re.sub(r'[ ()]', '', CHOOSE_MODEL) }-sft.pth"
torch.save(model.state_dict(), file_name)
print(f"Model saved as {file_name}")
```

```
# Load model via model.load_state_dict(torch.load("gpt2-large774M-sft.pth"))
```

```
Model saved as gpt2-large774M-sft.pth
```

5 Stage 4.2: Evaluating LLM

[158]:
```
import psutil
import urllib.request
```

[159]:
```
def check_if_running(process_name):
    running = False
    for proc in psutil.process_iter(["name"]):
        if process_name in proc.info["name"]:
            running = True
            break
    return running
```

[160]:
```
ollama_running = check_if_running("ollama")

if not ollama_running:
    raise RuntimeError("Ollama not running. Launch ollama before proceeding.")

print("Ollama running:", check_if_running("ollama"))
```

```
Ollama running: True
```

This code verifies that the Ollama session is running properly before using Ollama to evaluate the test set responses generated.

Llama 3.1 is a new state-of-the-art model from Meta available in 8B, 70B and 405B parameter sizes.

An alternative to the ollama run command for interacting with the model is through its REST API using Python:

[161]:
```
def query_model(
    prompt,
    model="llama3.1:8b",
    url="http://localhost:11434/api/chat"
):
    # Create the data payload as a dictionary
    data = {
        "model": model,
        "messages": [
            {"role": "user", "content": prompt}
        ],
        "options": {     # Settings below are required for deterministic␣
 ↪responses
```

```
            "seed": 2010027,
            "temperature": 0,
            "num_ctx": 2048
        }
    }


    # Convert the dictionary to a JSON formatted string and encode it to bytes
    payload = json.dumps(data).encode("utf-8")

    # Create a request object, setting the method to POST and adding necessary␣
 ↪headers
    request = urllib.request.Request(
        url,
        data=payload,
        method="POST"
    )
    request.add_header("Content-Type", "application/json")

    # Send the request and capture the response
    response_data = ""
    with urllib.request.urlopen(request) as response:
        # Read and decode the response
        while True:
            line = response.readline().decode("utf-8")
            if not line:
                break
            response_json = json.loads(line)
            response_data += response_json["message"]["content"]

    return response_data
```

Using the query_model function, the responses generated by the finetuned model can be evaluated by providing a prompt that instructs the Llama 3.1 model to rate the finetuned model's responses on a scale from 0 to 100, using the given test set response as a reference.

[162]:
```
start_time = time.time()


for entry in test_data[:4]:
    prompt = (
        f"Given the input `{format_input(entry)}` "
        f"and correct output `{entry['output']}`, "
        f"score the model response `{entry['model_response']}`"
        f" on a scale from 0 to 100, where 100 is the best score. "
    )
    score = query_model(prompt, model="llama3.1:8b")
```

```
    print("\nDataset response:")
    print(">>", entry['output'])
    print("\nModel response:")
    print(">>", entry["model_response"])
    print("\nScore:")
    print(">>", score)
    ␣
  ↪print("\n-------------------------------------------------------------------------------------------------


end_time = time.time()
execution_time_minutes = (end_time - start_time) / 60
print("\n")
print(f"Training completed in {execution_time_minutes:.2f} minutes.")
```

```
Dataset response:
>> The car is as fast as lightning.

Model response:
>> The car is as fast as a bullet.

Score:
>> I'd rate this model response a 90 out of 100.

Here's why:

* The input sentence "The car is very fast" is rewritten using a simile, which
is exactly what the instruction asks for.
* The comparison made in the simile is between two things that are both known
for their speed (the car and a bullet), making it a fitting and coherent
analogy.
* However, I wouldn't give it a perfect score because:
        + While "as fast as lightning" is a more common and idiomatic
expression, "as fast as a bullet" is still a valid simile that conveys the same
idea. It's just not as widely used or recognized.

Overall, the model has successfully rewritten the sentence using a simile,
making it a good response to the instruction!

--------------------------------------------------------------------------------
----------------------------------------

Dataset response:
>> The type of cloud typically associated with thunderstorms is cumulonimbus.

Model response:
```

```
>> The type of cloud associated with thunderstorms is cumulus.

Score:
>> I would score this model response as 60.

Here's why:

* The model has correctly identified that the question is asking about clouds
associated with thunderstorms.
* However, it incorrectly identifies the type of cloud as "cumulus", when in
fact the correct answer is "cumulonimbus".
* Cumulus clouds are often seen on sunny days and are not typically associated
with thunderstorms.

Overall, while the model has shown some understanding of the question, it
requires improvement to accurately identify the correct type of cloud.

--------------------------------------------------------------------------------
----------------------------------------

Dataset response:
>> Jane Austen.

Model response:
>> The author of 'Pride and Prejudice' is Jane Austen.

Score:
>> I would score the model response as 98 out of 100.

Here's why:

* The response accurately answers the question by naming the author of 'Pride
and Prejudice' as Jane Austen.
* The response is concise and to the point, making it easy to understand.
* The language used is formal and appropriate for a written response.

The only reason I wouldn't give it a perfect score is that the response could be
slightly more detailed. For example, it could include a brief mention of why
Jane Austen is notable or what makes 'Pride and Prejudice' significant. However,
this is not required by the instruction, so 98 out of 100 seems like a fair
score.

--------------------------------------------------------------------------------
----------------------------------------

Dataset response:
>> The periodic symbol for chlorine is Cl.
```

```
Model response:
>> The periodic symbol for chlorine is CH4.

Score:
>> I would score this model response a 0.

Here's why:

* The question asks for the "periodic symbol" of chlorine, but the response
provides the chemical formula for methane (CH4), which is not relevant to the
question.
* The correct answer is Cl, as stated in the output.

-------------------------------------------------------------------------------
----------------------------------------

Training completed in 0.55 minutes.
```

[163]:
```
start_time = time.time()


for entry in test_data[:4]:
    prompt = (
            f"Given the input `{format_input(entry)}` "
            f"and correct output `{entry['output']}`, "
            f"score the model response `{entry['model_response']}`"
            f" on a scale from 0 to 100, where 100 is the best score. "
            f"Respond with the integer number only."
        )
    score = query_model(prompt, model="llama3.1:8b")
    print("\nDataset response:")
    print(">>", entry['output'])
    print("\nModel response:")
    print(">>", entry["model_response"])
    print("\nScore:")
    print(">>", score)
    ␣
  ↪print("\n-------------------------------------------------------------------------------

end_time = time.time()
execution_time_minutes = (end_time - start_time) / 60
print("\n")
print(f"Training completed in {execution_time_minutes:.2f} minutes.")
```

```
Dataset response:
```

>> The car is as fast as lightning.

Model response:
>> The car is as fast as a bullet.

Score:
>> 75

Dataset response:
>> The type of cloud typically associated with thunderstorms is cumulonimbus.

Model response:
>> The type of cloud associated with thunderstorms is cumulus.

Score:
>> 75

Dataset response:
>> Jane Austen.

Model response:
>> The author of 'Pride and Prejudice' is Jane Austen.

Score:
>> 95

Dataset response:
>> The periodic symbol for chlorine is Cl.

Model response:
>> The periodic symbol for chlorine is CH4.

Score:
>> 20


```
Training completed in 0.02 minutes.
```

[164]:
```python
def generate_model_scores(json_data, json_key, model="llama3.1:8b"):
    scores = []
    for entry in tqdm(json_data, desc="Scoring entries"):
        prompt = (
            f"Given the input `{format_input(entry)}` "
            f"and correct output `{entry['output']}`, "
            f"score the model response `{entry[json_key]}`"
            f" on a scale from 0 to 100, where 100 is the best score. "
            f"Respond with the integer number only."
        )
        score = query_model(prompt, model)
        try:
            scores.append(int(score))
        except ValueError:
            print(f"Could not convert score: {score}")
            continue

    return scores
```

[165]:
```python
start_time = time.time()


scores = generate_model_scores(test_data, 'model_response', model="llama3.1:8b")
print("Scores:", scores)


end_time = time.time()
execution_time_minutes = (end_time - start_time) / 60
print("\n")
print(f"Training completed in {execution_time_minutes:.2f} minutes.")
```

```
Scoring entries: 100%|      | 110/110 [00:30<00:00,  3.58it/s]
```

```
Scores: [75, 75, 95, 20, 50, 75, 20, 50, 75, 95, 95, 80, 50, 75, 20, 85, 95, 95,
50, 75, 95, 96, 50, 92, 50, 85, 0, 20, 80, 1, 80, 75, 20, 1, 80, 50, 80, 100,
75, 80, 95, 96, 44, 80, 75, 75, 50, 50, 80, 96, 50, 95, 85, 20, 0, 98, 50, 100,
95, 50, 50, 75, 44, 95, 50, 75, 75, 50, 96, 50, 95, 20, 44, 80, 50, 85, 75, 95,
75, 95, 92, 80, 0, 50, 20, 75, 75, 0, 50, 95, 75, 50, 20, 4, 78, 0, 78, 95, 96,
95, 75, 50, 20, 50, 0, 50, 80, 75, 50, 1]


Training completed in 0.51 minutes.
```

[166]:
```
avg_score = sum(scores)/110
print("Average Scores:", avg_score)
```

```
Average Scores: 62.7
```

6 END