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In *Chapter 3, Emergent vs Downstream Tasks: The Unseen Depths of Transformers*, we explored tasks through pre-trained models that could perform efficiently. However, in some cases, a pre-trained model will not produce the desired outputs. We can pre-train a model from scratch, as we will see in *Chapter 6, Pretraining a Transformer from Scratch through RoBERTa*. However, pre-training a model can require a large amount of machine, data, and human resources. The alternative can be fine-tuning a transformer model. This chapter will dive into fine-tuning transformer models through a Hugging Face pre-trained BERT model. By the end of the chapter, you should be able to fine-tune other Hugging Face models such as GPT, T5, RoBERTa, and more. The chapter is divided into two parts. We will first go through the architecture of BERT models. Then, we will explore fine-tuning a transformer model through BERT. We will first explore the architecture of **Bidirectional Encoder Representations from Transformers (BERT)**. BERT only uses the blocks of the encoders of the Transformer in a novel way and does not use the decoder stack. BERT added a new piece to the Transformer building kit: a bidirectional multi-head attention sub-layer. When we humans have problems understanding a sentence, we do not just look at the past words. BERT, like us, looks at all the words in the same sentence at the same time. Then, we will fine-tune a BERT model trained by a third party and uploaded to Hugging Face. This shows that transformers (for example, can be fine-tuned on several NLP tasks). In this chapter, you will gain the experience of fine-tuning a transformer using building an interface with **ipywidgets** to interact with the model. This chapter covers the following topics:

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BERT architecture

the encoder stack of transformers and bidirectional attention.

fine-tuning process for the Acceptability Judgment task

creating training data, labels, and BERT tokens

processing the training data with a BERT tokenizer and attention masks.

splitting data into training and validation sets.

setting up a Hugging Face BERT uncased base model

grouping parameters

setting hyperparameters

running training loop

post-training evaluation with holdout

evaluation with Matthews Correlation Coefficient (MCC)

Our first step will be to explore the background of the BERT model.

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## The architecture of BERT

In *Chapter 2, Getting Started with the Architecture of the Transformer Model*, we defined the building blocks of the architecture of the original Transformer. Think of the original Transformer as a model built with LEGO® bricks. The construction set contains bricks such as encoders, decoders, embedding layers, positional encoding methods, multi-head attention layers, masked multi-head attention layers, post-layer normalization, feed-forward sub-layers, and linear output layers. The bricks come in various sizes and forms. As a result, you can spend hours building all sorts of models using the same building kit! Some constructions will only require some of the bricks. Other structures will add a new piece, like when we obtain additional bricks for a model built using LEGO® components. BERT is a transformer model. Bidirectional attention is a key feature of the original Transformer model. We will not go through the details described in *Chapter 2, Getting Started with the Architecture of the Transformer Model*. You can consult *Chapter 2* at any time. Instead, this section v

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models. We will focus on the evolutions designed by *Devlin et al. (2018)*, which describe the encoder stack. We will first go through the encoder stack and then the preparation of the pretraining input environment. Then, we will explain the two-step framework of BERT: pretraining and fine-tuning. Let's first explore the encoder stack.

## The encoder stack

The first building block we will take from the original Transformer model is an encoder layer. The encoder layer, as described in *Chapter 2, Getting Started with the Architecture of the Transformer Model*, is shown in *Figure 5.1*:

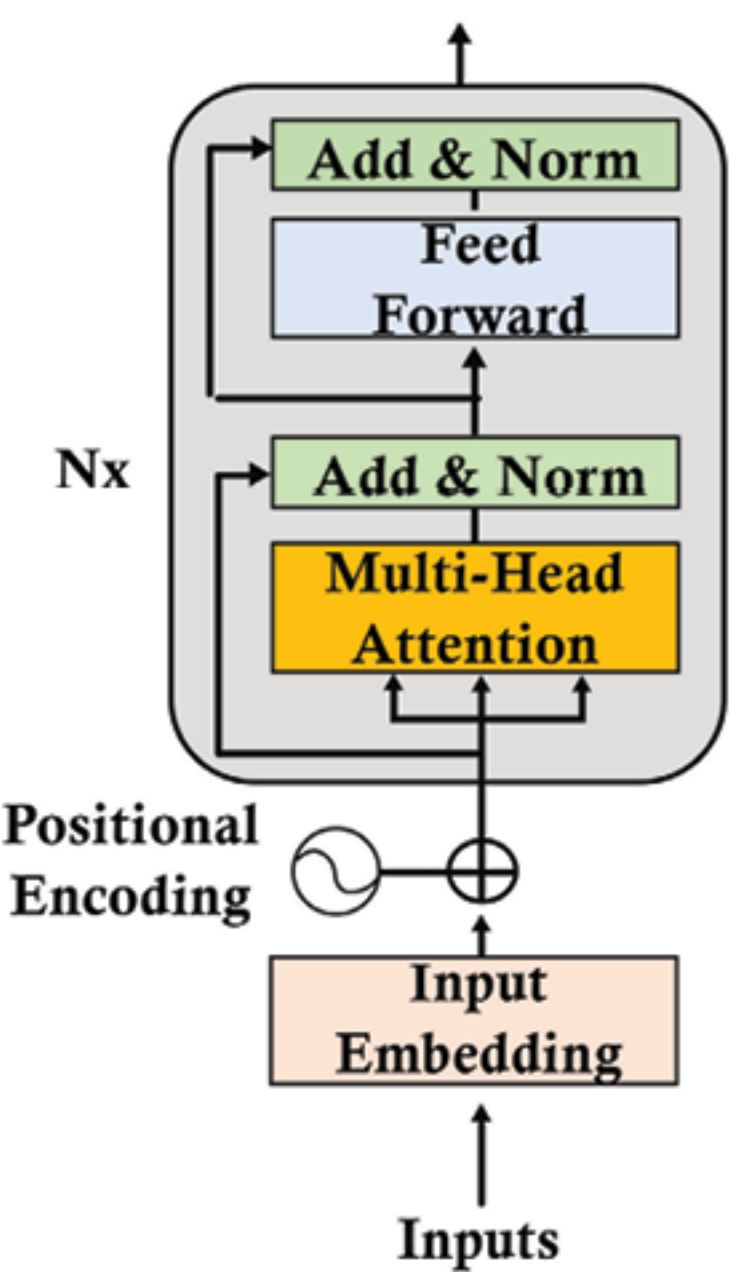


Figure 5.1: The encoder layer

The BERT model does not use decoder layers. A BERT model has an encoder stack but no decoder stacks. The BERT model uses Masked Language Modeling (MLM) in which some input tokens are hidden("masked"), and the attention layers must learn to understand the context. The model will predict the hidden tokens, as we will see when we zoom into a BERT encoder layer in the following sections. The original Transformer contains a stack of  $N=6$  layers. The number of dimensions of the original Transformer is  $d_{model} = 512$ . The number of attention heads

The dimensions of the head of the original Transformer

$$d_k = \frac{d_{model}}{A} = \frac{512}{8} = 64$$

BERT encoder layers are larger than the original Transformer model. Different sizes of BERT models can be built with the encoder layers: BERTBASE, which contains a stack of  $N=12$  encoder layers.  $d_{model} = 768$  and can also be expressed as  $H=768$ , as in the BERT paper. A multi-head attention sub-layer contains  $A=12$  heads. The dimension of each head  $z_A$  remains 64 as in the original Transformer model:

$$d_k = \frac{d_{model}}{A} = \frac{768}{12} = 64$$

The output of each multi-head attention sub-layer before concatenation will be the output of the 12 heads:  $output\_multi\_head\_attention=\{z_0, z_1, z_2,..., z_{11}\}$  BERTLARGE, which contains a stack of  $N=24$  encoder layers.  $d_{model} = 1024$ . A multi-head attention sub-layer contains  $A=16$  heads. The dimension of each head  $z_A$  also remains 64 as in the original Transformer model:

$$d_k = \frac{d_{model}}{A} = \frac{1024}{16} = 64$$

The output of each multi-head attention sub-layer before concatenation will be the output of the 16 heads:  $output\_multi\_head\_attention=\{z_0, z_1, z_2,..., z_{15}\}$  The sizes of the models can be summed up as follows:

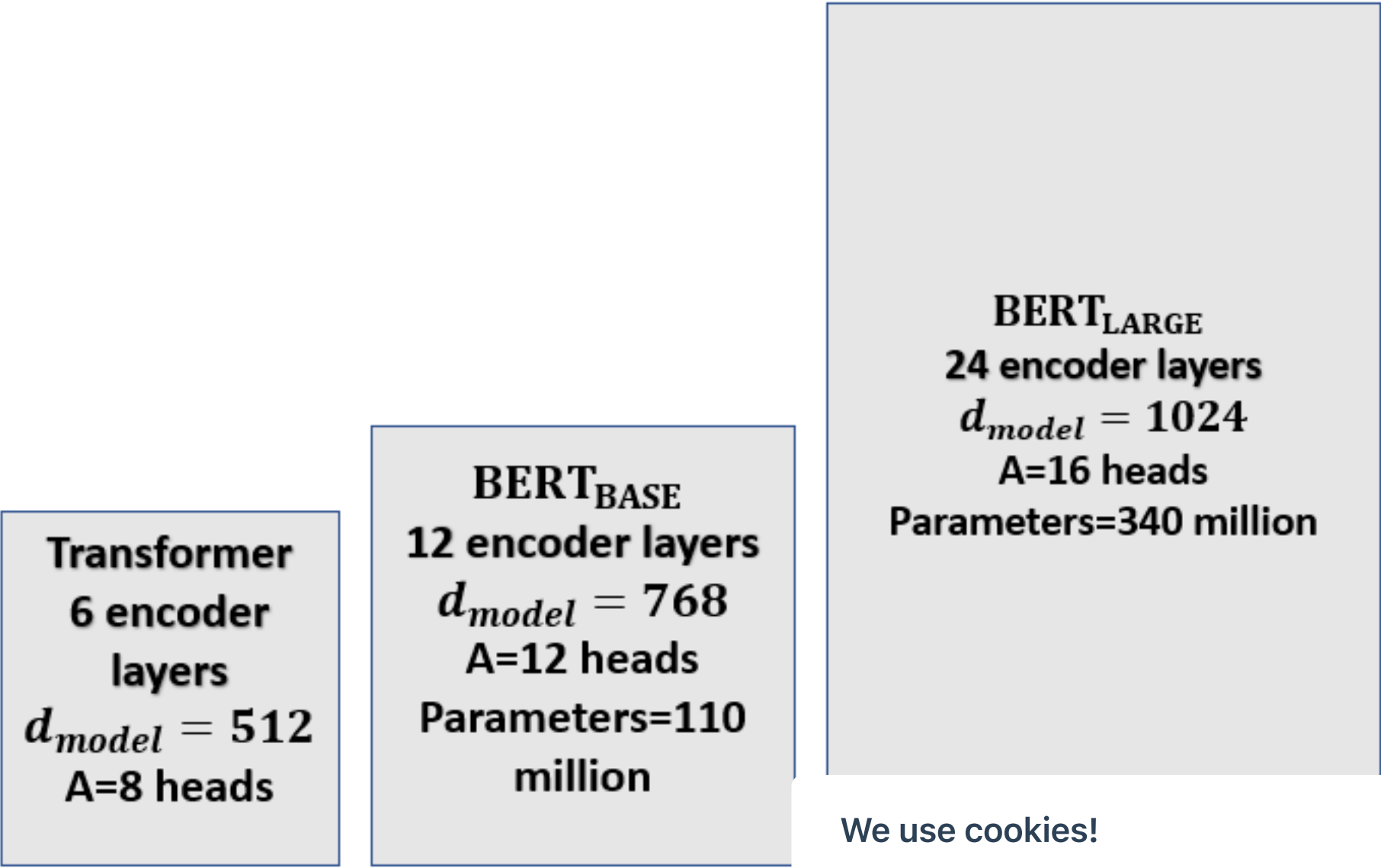


Figure 5.2: Transformer models

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BERT models are not limited to these configurations, which illustrate the main aspects of BERT models. Numerous variations are possible. Size and dimensions play an essential role in BERT-style pretraining. BERT models are like humans. BERT models produce better results with more working memory (dimensions) and knowledge (data). Large transformer models that learn large amounts of data will pretrain better for downstream NLP tasks. Let's go to the first sub-layer and see the fundamental aspects of input embedding and positional encoding in a BERT model.

### Preparing the pretraining input environment

The BERT model only has encoder layers and no decoder stack. Its architecture features a multi-head self-attention mechanism that allows each token to learn to understand all the surrounding tokens (masked or not). This bidirectional method enables BERT to understand the context on both sides of each token. A masked multi-head attention layer masks some tokens randomly to force this system to learn contexts. For example, take the following sentence:

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Explain

The cat sat on it because it was a nice rug.

If we have just reached the word *it*, the input of the encoder could be:

Copy

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The cat sat on it<masked sequence>

The authors enhanced their bidirectional attention model, letting an attention head attend to *all* the words from left to right and right to left. In other words, the self-attention mask of an encoder could do the job without being hindered by the masked multi-head attention sub-layer of the decoder. The model was trained with two tasks. The first method is **Masked Language Modeling (MLM)**. The second method is **Next Sentence Prediction (NSP)**. Let's start with masked language modeling.

### Masked language modeling

Masked language modeling does not require training a model with a sequence of visible words followed by a masked sequence *bidirectional* analysis of a sentence with a random mask. It is important to note that BERT applies **WordPiece** tokenization method, to the inputs. It also uses a sine-cosine approach. A potential input sequence

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Copy Explain

```
The cat sat on it because it was a nice rug.
```

The decoder could potentially mask the attention sequence after the model reaches the word **it**:

Copy Explain

```
The cat sat on it <masked sequence>.
```

But the BERT encoder masks a random token to make a prediction, which makes it more powerful:

Copy Explain

```
The cat sat on it [MASK] it was a nice rug.
```

The multi-attention sub-layer can now see the whole sequence, run the self-attention process, and predict the masked token. The input tokens were masked in a tricky way *to force the model to train longer but produce better results* with three methods: Surprise the model by not masking a single token on 10% of the dataset; for example:

Copy Explain

```
The cat sat on it [because] it was a nice rug.
```

Surprise the model by replacing the token with a random token on 10% of the dataset; for example:

Copy Explain

```
The cat sat on it [often] it was a nice rug.
```

Replace a token with a **[MASK]** token on 80%

```
The cat sat on it [MASK] it was a nice rug.
```

... ..

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The authors' bold approach avoids overfitting and forces the model to train efficiently. BERT was also trained to perform next-sentence prediction.

Next sentence prediction

The second method invented was to train BERT is **Next Sentence Prediction (NSP)**. The input contains two sentences. In 50% of the cases, the second sentence is the actual second sentence of a document. In 50% of the cases, the second sentence was selected randomly and had no relation to the first one. Two new tokens were added: **[CLS]** is a binary classification token added to the beginning of the first sequence to predict if the second sequence follows the first sequence. A positive sample is usually a pair of consecutive sentences taken from a dataset. A negative sample is created using sequences from different documents. **[SEP]** is a separation token that signals the end of a sequence, such as a sentence, sentence part, or question, depending on the task at hand. For example, the input sentences taken out of a book could be:

Copy

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The cat slept on the rug. It likes sleeping all day.

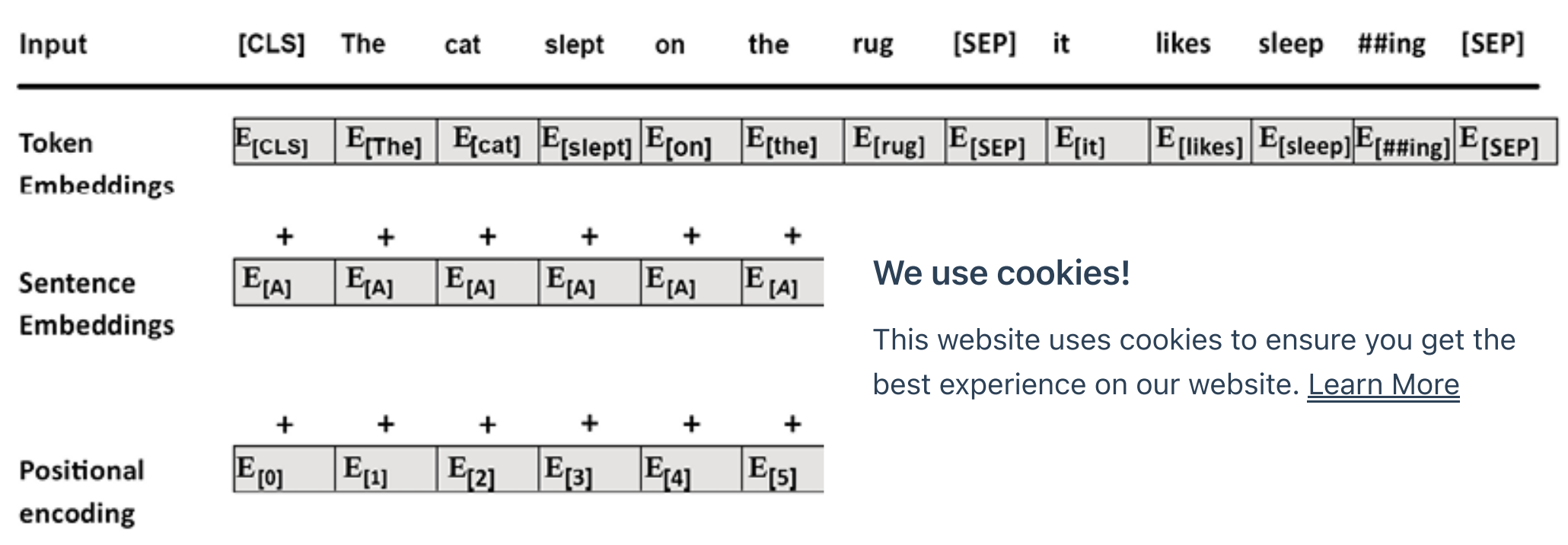
These two sentences will become one complete input sequence:

Copy

Explain

[CLS] the cat slept on the rug [SEP] it likes sleep ##ing all day[SEP]

This approach requires additional encoding information to distinguish sequence A from sequence B. Note that the double hash(##) is because of the WordPiece tokenization used. The word "sleep" was tokenized separately from "ing." This enables the tokenizer to work on a smaller dictionary of subwords, WordPiece, and then assemble them through the training process. If we put the whole embedding process together, we obtain the following:



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Figure 5.3: Input embeddings

The input embeddings are obtained by summing the token embeddings, the segment (sentence, phrase, word) embeddings, and the positional encoding embeddings. The input embedding and positional encoding sub-layer of a BERT model can be summed up as follows: A sequence of words is broken down into **WordPiece** tokens. A **[MASK]** token will randomly replace the initial word tokens for masked language modeling training. A **[CLS]** classification token is inserted at the beginning of a sequence for classification purposes. A **[SEP]** token separates two sentences (segments, phrases) for NSP training. Sentence embedding is added to token embedding, so that sentence A has a different sentence embedding value than sentence B. Positional encoding is learned. The sine-cosine positional encoding method of the original Transformer is not applied. Some additional key features of BERT are:

It uses bidirectional attention in its multi-head attention sub-layers, opening vast horizons of learning and understanding relationships between tokens.

It introduces scenarios of unsupervised embedding and pretraining models with unlabeled text. Unsupervised methods force the model to think harder during the multi-head attention learning process. This makes BERT learn how languages are built and apply this knowledge to downstream tasks without having to pretrain each time.

It also uses supervised learning, covering all bases in the pretraining process.

BERT has improved the training environment of transformers. Let's now see the motivation for pretraining and how it helps the fine-tuning process.

Pretraining and fine-tuning a BERT model

BERT is a two-step framework. The first step is pretraining, and the second is fine-tuning, as shown in *Figure 5.4*:

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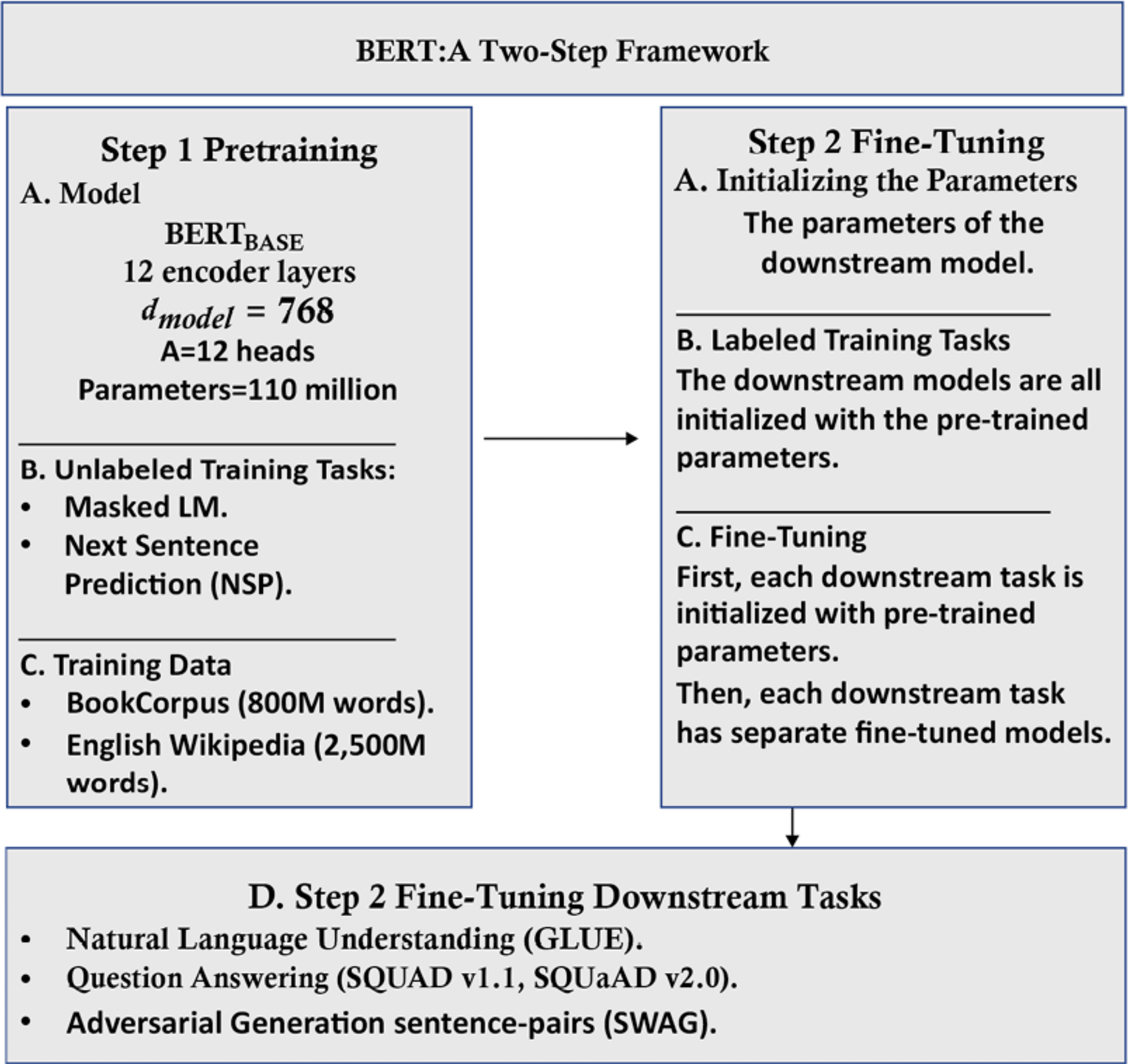


Figure 5.4: The BERT framework

Training a transformer model can take hours, if not days. Therefore, it takes quite some time to engineer the architecture and parameters and select the proper datasets to train a transformer model. Pretraining is the first step of the BERT framework, which can be broken down into two sub-steps: Defining the model's architecture: number of layers, number of heads, dimensions, and the other building blocks of the model. Training the model on **MLM** and **NSP** tasks. The second step of the BERT framework is fine-tuning, which can also be broken down into two sub-steps: Initializing the downstream model with the pre-trained BERT model. Fine-tuning the parameters for specific tasks such as **Recognizing Textual Entailment (RTE)**, **SQuAD v2.0**, and **Situations With Adversarial Examples (SWAG)**. The BERT model we will fine-tune will be trained on tasks like **Acceptability (CoLA)**. The downstream task is

*Acceptability Judgments* paper by *Alex Warstadt, Amanpreet Singh, and Samuel R. Bowman*. We will fine-tune a BERT model that will determine the grammatical acceptability of a sentence. The fine-tuned model will have acquired a certain level of linguistic competence. We have gone through BERT architecture and its pretraining and fine-tuning framework. Let's now fine-tune a BERT model.

---

# Fine-tuning BERT

In this section, we will fine-tune a BERT model using Hugging Face. Hugging Face provides a large amount of resources for transformer models. Hugging Face offers a significant number of pre-trained models such as BERT, GPT-2, RoBERTa, T5, and DistilBERT. These models can perform many tasks, such as those we went through in *Chapter 3, Emergent vs Downstream Tasks: The Unseen Depths of Transformers*. In addition, these models can be fine-tuned to fit your needs. This chapter focuses on the process of fine-tuning a Hugging Face BERT model. You can then apply the same method to other Hugging Face transformer models. In *Chapter 15, Guarding the Giants: Mitigating Risks in Large Language Models*, we will use another platform, OpenAI, to fine-tune one of OpenAI's GPT models. For this chapter, we will begin with fine-tuning BERT, which involves the following main steps:

Retrieving the datasets. In this case, the CoLA datasets.

Loading and configuring the pre-trained model

Loading and preparing the data

Setting up the training parameters

Training the pre-trained model for a new task. In this case, the trained model will learn how to assess linguistic acceptability.

Evaluating the trained model

**Note:** It is essential to remember that this san Hugging Face transformer models such as Rc Hugging Face provides documentation and a information on Hugging Face, explore their si

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Let's apply the fine-tuning process to a BERT model by first defining the goal we wish to achieve.

## Defining a goal

The goal of fine-tuning BERT in this chapter is to focus on learning the ability to judge the grammatical acceptability of a text with the CoLA dataset, as seen in *Chapter 3, Emergent vs Downstream Tasks: The Unseen Depths of Transformers*. So, take time to go back to the CoLA section of Chapter 3 if necessary.

Note: You can choose other tasks, including trying some of those we went through in Chapter 3, to fine-tune depending on your project.

We will measure the predictions with the **Matthews Correlation Coefficient (MCC)**, which will be explained in the *Evaluating using the Matthews Correlation Coefficient* section. Open `BERT_Fine_Tuning_Sentence_Classification_GPU.ipynb` in Google Colab (make sure you have a Gmail account). The notebook is in `Chapter05` in the GitHub repository of this book. The title of each cell in the notebook is also the same as or very close to the title of each chapter subsection. We will first examine why transformer models must take hardware constraints into account.

## Hardware constraints

The scale of computation required to train and fine-tune transformer models makes them hardware-driven. This rapidly becomes a resource constraint. Small transformer models can be trained and fine-tuned on local machines or limited server configurations. However, large models such as state-of-the-art large OpenAI models and Google AI models require unique machine power. The machine power required by Large Language Models (LLMs) has created a financial accessibility threshold. Therefore, Hugging Face offers a reasonable entry point to explore and implement transformer models. Transformer models thus benefit from the parallel processing capability of GPUs. GPUs perform computational tasks far more efficiently than CPUs and will accelerate the training or fine-tuning process. Go to the **Runtime** menu in Google Colab, select **Change runtime type**, and select **GPU** in the **Hardware Accelerator** drop-down list. The program will use Hugging Face modules, which we'll install next.

## Installing Hugging Face Trai

Hugging Face provides a pretrained BERT model class named `PreTrainedModel`. We can load configuration by installing this class. Hugging

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and PyTorch. I recommend that a developer be comfortable with both environments. AI research teams may use either or both environments. In this chapter, we will install the modules required as follows:

CopyExplain

```
try:
    import transformers
except:
    print("Installing transformers")
    !pip -q install transformers
```

The installation will run with the `-q` option, limiting the verbose and only displaying a warning or error messages. We can now import the modules needed for the program.

## Importing the modules

We will import the pretrained modules required, such as the pretrained `BERT tokenizer` and the configuration of the BERT model. The `BERT Adam` optimizer is also imported along with the sequence classification module:

CopyExplain

```
import torch
import torch.nn as nn
from torch.utils.data import TensorDataset, DataLoader, RandomSampler, SequentialSampler
from keras.utils import pad_sequences
from sklearn.model_selection import train_test_split
from transformers import BertTokenizer, BertConfig
from transformers import AdamW, BertForSequenceClassification, get_linear_schedule_with_warmup
```

We will progress bar module is imported from `tqdm`:

CopyExplain

```
from tqdm import tqdm, trange #for progress bars
```

We can now import the widely used standard

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```
import pandas as pd
import io
import numpy as np
import matplotlib.pyplot as plt
from IPython.display import Image #for image rendering
```

If all goes well, no message will be displayed, bearing in mind that Google Colab has pre-installed several of the modules we need on their VMs.

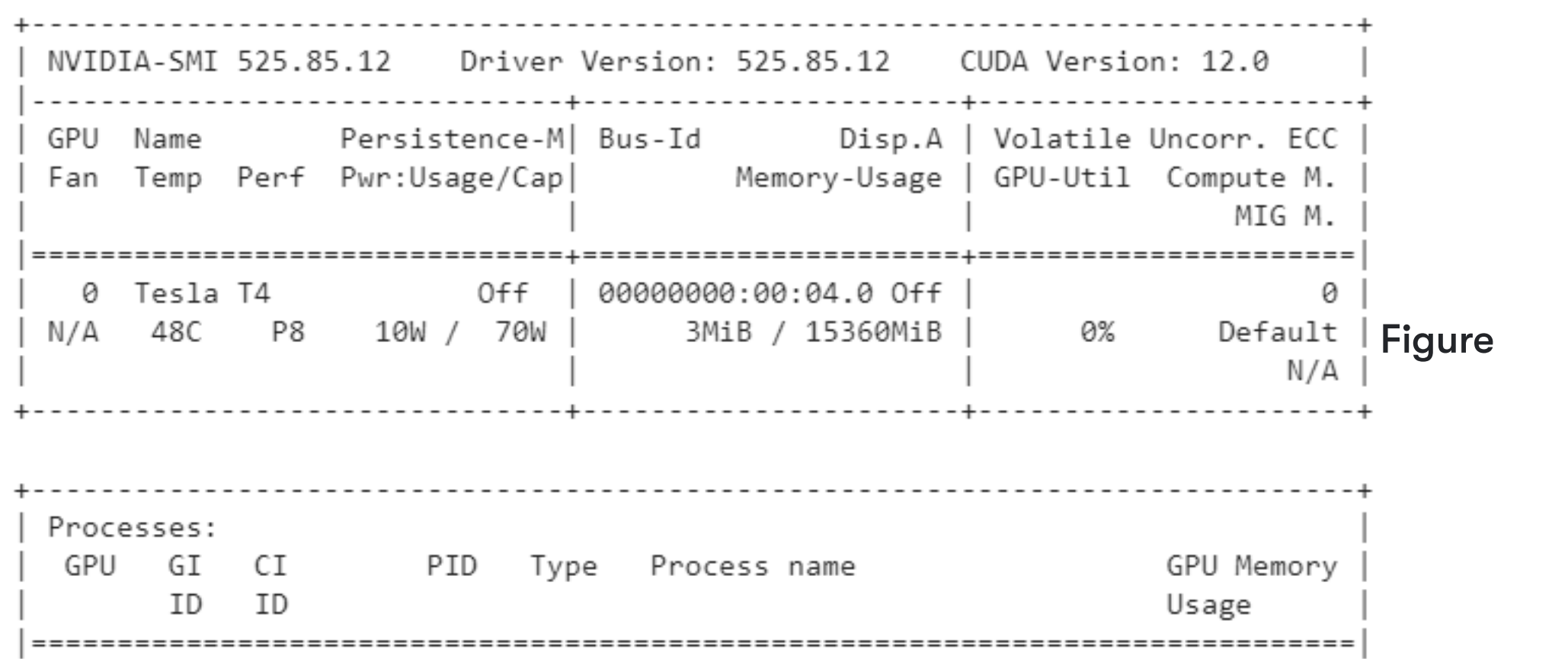
## Specifying CUDA as the device for torch

We will now specify that torch uses the **Compute Unified Device Architecture (CUDA)** to put the parallel computing power of the NVIDIA card to work for our multi-head attention model:

CopyExplain

```
#@title Harware verification and device attribution
device = torch.device("cuda" if torch.cuda.is_available() else "cpu")
!nvidia-smi
```

The output may vary with Google Colab configurations. For example:



Figure

### 5.5: Output of !nvidia-smiWe will now load the dataset.

## Loading the CoLA dataset

We will load the *CoLA* based on the *Warstadt*. Acceptability is critical in Natural Language I moment to review the CoLA section of *Chapt The Unseen Depths of Transformers*.The data:

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obtained on the CoLA homepage: <https://nyu-ml.github.io/CoLA/> and uploaded to the GitHub directory of this chapter. The following cells in the notebook automatically download the necessary files for fine-tuning, `in_domain_train.tsv`, and evaluating the predictions of the fine-tuned model, `out_of_domain_dev.tsv`:

Copy Explain

```
import os
!curl -L https://raw.githubusercontent.com/Denis2054/Transformers-for-NLP-and-Computer-Vision-3rd-Edition/master/Chapter05/in_domain_train.tsv --output "in_domain_train.tsv"
!curl -L https://raw.githubusercontent.com/Denis2054/Transformers-for-NLP-and-Computer-Vision-3rd-Edition/master/Chapter05/out_of_domain_dev.tsv --output "out_of_domain_dev.tsv"
```

You should see them appear in the file manager:



Figure 5.6: Uploading the datasets

Now, the program will load the datasets:

Copy Explain

```
#source of dataset : https://nyu-ml.github.io/CoLA/
df = pd.read_csv("in_domain_train.tsv", delimiter='\t', header=None, names=
['sentence_source', 'label', 'label_notes', 'sentence'])
df.shape
```

The output displays the shape of the dataset we have imported:

```
(8551, 4)
```

A 10-line sample is displayed to visualize the

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```
df.sample(10)
```

The output shows **10** lines of the labeled dataset, which may change after each run:

|      | sentence_source | label | label_notes | sentence                                    |
|------|-----------------|-------|-------------|---|
| 4517 | ks08            | 1     | NaN         | do n't you even touch that !                |
| 7622 | sks13           | 1     | NaN         | sharks seem to swim slowly in the tropics . |
| 6549 | g_81            | 0     | *           | the talkative and a bully man entered .     |
| 5336 | b_73            | 1     | NaN         | jack eats caviar more than he eats mush .   |
| 460  | bc01            | 0     | *           | the boat sank to collect the insurance .    |
| 1110 | r-67            | 1     | NaN         | i ran an old man down .                     |
| 8427 | ad03            | 0     | *           | the dragons were slain all .                |
| 5140 | ks08            | 0     | *           | it is kim on whom sandy relies on .         |
| 5639 | c_13            | 1     | NaN         | the man loved peanut butter cookies .       |
| 5916 | c_13            | 1     | NaN         | molly gave calvin a kiss .                  |

Each sample in the **.tsv** files contains four tab-separated columns(Column 0 is an index):

- Column 1: the source of the sentence (code)
- Column 2: the label (0=unacceptable, 1=acceptable)
- Column 3: the label annotated by the author
- Column 4: the sentence to be classified

You can open the **.tsv** files locally to read a few samples of the dataset. The program will now process the data for the BERT model.

# Creating sentences, label lists. and adding BERT tokens

The program will now create the sentences as *pretraining input environment* section of this

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```
sentences = df.sentence.values
# Adding CLS and SEP tokens at the beginning and end of each sentence for BERT
sentences = ["[CLS] " + sentence + " [SEP]" for sentence in sentences]
labels = df.label.values
```

The **[CLS]** and **[SEP]** have now been added for the BERT model to find the start and end of a sentence. The program now activates the tokenizer.

## Activating the BERT tokenizer

In this section, we will initialize a pretrained BERT tokenizer. This will save the time it would take to train it from scratch. The program selects an uncased tokenizer, activates it, and displays the first tokenized sentence:

[Copy](#)[Explain](#)

```
tokenizer = BertTokenizer.from_pretrained('bert-base-uncased', do_lower_case=True)
tokenized_texts = [tokenizer.tokenize(sent) for sent in sentences]
print ("Tokenize the first sentence:")
print (tokenized_texts[0])
```

The output contains the classification token and the sequence segmentation token:

[Copy](#)[Explain](#)

```
Tokenize the first sentence:
['[CLS]', 'our', 'friends', 'wo', 'n', '"', 't', 'buy', 'this', 'analysis', ',', 'let', 'alone', 'the', 'next', 'one', 'we', 'propose', '.', '[SEP]']
```

The program will now process the data.

## Processing the data

We need to determine a fixed maximum length and process the data for the model. This is because the sentences in the datasets are short. But, to make sure of this, the program sets the maximum length of a sequence to **128**, and the sequences are padded:

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```
# Set the maximum sequence length. The longest sequence in our training set is 47, but
we'll leave room on the end anyway.
# In the original paper, the authors used a length of 512.
MAX_LEN = 128
# Use the BERT tokenizer to convert the tokens to their index numbers in the BERT
vocabulary
input_ids = [tokenizer.convert_tokens_to_ids(x) for x in tokenized_texts]
# Pad our input tokens
input_ids = pad_sequences(input_ids, maxlen=MAX_LEN, dtype="long", truncating="post",
padding="post")
```

The sequences have been processed, and now the program creates the attention masks.

## Creating attention masks

Now comes a tricky part of the process. We padded the sequences in the previous cell. But we want to prevent the model from performing attention to those padded tokens! The idea is to apply a mask with a value of **1** for each token, then 0s will follow for padding:

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```
attention_masks = []
# Create a mask of 1s for each token followed by 0s for padding
for seq in input_ids:
    seq_mask = [float(i>0) for i in seq]
    attention_masks.append(seq_mask)
```

The program will now split the data.

## Splitting the data into training and validation sets

The program now performs the standard process of splitting the in-domain dataset data into training and validation sets:

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```
# Use train_test_split to split our data into train and validation sets for training
train_inputs, validation_inputs, train_labels, validation_labels = \
train_test_split(input_ids, labels, random_state=2018, test_size=0.1)
train_masks, validation_masks, _, _ = train_test_split(
input_ids, random_state=2018, test_size=0.1)
```

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The data is ready to be trained but needs to be

# Converting all the data into torch tensors

The fine-tuning model uses torch tensors. PyTorch tensors:

Optimize the usage of GPUs.

Facilitate GPU/CPU Control. In this notebook, notice that the Hugging Face model and our datasets will be transferred to the GPU through the to-device command in the code of training loop if the GPU is available as defined in the *Specifying CUDO as the device for torch* section of this chapter and the notebook.

The program will thus convert the data into torch tensors:

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Explain

```
# Torch tensors are the required datatype for our model
train_inputs = torch.tensor(train_inputs)
validation_inputs = torch.tensor(validation_inputs)
train_labels = torch.tensor(train_labels)
validation_labels = torch.tensor(validation_labels)
train_masks = torch.tensor(train_masks)
validation_masks = torch.tensor(validation_masks)
```

The conversion is over. Now, we need to create an iterator.

## Selecting a batch size and creating an iterator

The program selects a batch size in this cell and creates an iterator. The iterator is an efficient way of looping through the data and loading batches instead of loading all the data in memory. The iterator, coupled with the torch **DataLoader**, can batch-train massive datasets without crashing the machine's memory. In this model, the batch size is **32**:

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```
# Select a batch size for training. For fine-tuning BERT on a specific task, the
authors recommend a batch size of 16 or 32
batch_size = 32
# Create an iterator of our data with torch DataLoader. This helps save on memory
during training because, unlike a for loop,
# with an iterator the entire dataset does not need to be loaded into memory
train_data = TensorDataset(train_inputs, train_masks, train_labels)
train_sampler = RandomSampler(train_data)
train_dataloader = DataLoader(train_data, sampler=train_sampler, batch_size=batch_size)
validation_data = TensorDataset(validation_inputs, validation_masks, validation_labels)
validation_sampler = SequentialSampler(validation_data)
validation_dataloader = DataLoader(validation_data, sampler=validation_sampler,
batch_size=batch_size)
```

The data has been processed and is all set. The program can now load and configure the BERT model.

## BERT model configuration

The program now initializes a BERT uncased configuration:

[Copy](#)[Explain](#)

```
# Initializing a BERT bert-base-uncased style configuration
from transformers import BertModel, BertConfig
configuration = BertConfig()
# Initializing a model from the bert-base-uncased style configuration
model = BertModel(configuration)
# Accessing the model configuration
configuration = model.config
print(configuration)
```

The output displays the main Hugging Face parameters similar to the following (the library is often updated):

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```
BertConfig {
  "attention_probs_dropout_prob": 0.1,
  "hidden_act": "gelu",
  "hidden_dropout_prob": 0.1,
  "hidden_size": 768,
  "initializer_range": 0.02,
  "intermediate_size": 3072,
  "layer_norm_eps": 1e-12,
  "max_position_embeddings": 512,
  "model_type": "bert",
  "num_attention_heads": 12,
  "num_hidden_layers": 12,
  "pad_token_id": 0,
  "type_vocab_size": 2,
  "vocab_size": 30522
}
```

Let's go through some of the main parameters

displayed: **attention\_probs\_dropout\_prob: 0.1** applies a **0.1** dropout ratio to the attention probabilities. **hidden\_act: "gelu"** is a non-linear activation function in the encoder. It is a **Gaussian Error Linear Units** activation function. The input is weighted by its magnitude, which makes it non-linear. **hidden\_dropout\_prob: 0.1** is the dropout probability applied to the fully connected layers. Full connections can be found in the embeddings, encoder, and pooler layers. The output is not always a good reflection of the content of a sequence. Pooling the sequence of hidden states improves the output sequence. **hidden\_size: 768** is the dimension of the encoded layers and also the pooler layer. **initializer\_range: 0.02** is the standard deviation value when initializing the weight matrices. **intermediate\_size: 3072** is the dimension of the feed-forward layer of the encoder. **layer\_norm\_eps: 1e-12** is the epsilon value for layer normalization layers. **max\_position\_embeddings: 512** is the maximum length the model uses. **model\_type: "bert"** is the name of the model. **num\_attention\_heads: 12** is the number of heads. **num\_hidden\_layers: 12** is the number of layers. **pad\_token\_id: 0** is the ID of the padding token to avoid training padding tokens. **type\_vocab\_size: 2** is the size of the **token\_type\_ids**, which identify the sequences. For example, "the dog [SEP] The cat [SEP]" can be represented with token IDs **[0, 0, 0, 1, 1, 1]**. We use cookies!

tokens the model uses to represent the input. This website uses cookies to ensure you get the best experience on our website. [Learn More](#)

we can load the pretrained model.

## Loading the Hugging Face E

# model

The program now loads the pretrained BERT model:

Copy

Explain

```
model = BertForSequenceClassification.from_pretrained("bert-base-uncased",
num_labels=2)
model = nn.DataParallel(model)
model.to(device)
```

We have defined the model, defined parallel processing, and sent the model to the device. This pretrained model can be trained further if necessary. It is interesting to explore the architecture in detail to visualize the parameters of each sublayer, as shown in the following excerpt:

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```
DataParallel(
  (module): BertForSequenceClassification(
    (bert): BertModel(
      (embeddings): BertEmbeddings(
        (word_embeddings): Embedding(30522, 768, padding_idx=0)
        (position_embeddings): Embedding(512, 768)
        (token_type_embeddings): Embedding(2, 768)
        (LayerNorm): LayerNorm((768,), eps=1e-12, elementwise_affine=True)
        (dropout): Dropout(p=0.1, inplace=False)
      )
      (encoder): BertEncoder(
        (layer): ModuleList(
          (0-11): 12 x BertLayer(
            (attention): BertAttention(
              (self): BertSelfAttention(
                (query): Linear(in_features=768, out_features=768, bias=True)
                (key): Linear(in_features=768, out_features=768, bias=True)
                (value): Linear(in_features=768, out_features=768, bias=True)
                (dropout): Dropout(p=0.1, inplace=False)
              )
              (output): BertSelfOutput(
                (dense): Linear(in_features=768, out_features=768, bias=True)
                (LayerNorm): LayerNorm((768,), eps=1e-12, elementwise_affine=True)
                (dropout): Dropout(p=0.1, inplace=False)
              )
            )
            (intermediate): BertIntermediate(
              (dense): Linear(in_features=768, out_features=3072, bias=True)
              (intermediate_act_fn): GELUActivation()
            )
            (output): BertOutput(
              (dense): Linear(in_features=3072, out_features=768, bias=True)
              (LayerNorm): LayerNorm((768,), eps=1e-12, elementwise_affine=True)
              (dropout): Dropout(p=0.1, inplace=False)
            )
          )
        )
      )
      (pooler): BertPooler(
        (dense): Linear(in_features=768, out_features=768, bias=True)
        (activation): Tanh()
      )
    )
    (dropout): Dropout(p=0.1, inplace=False)
    (classifier): Linear(in_features=768, out_features=1)
  )
)
```

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Let's now go through the main parameters of

# Optimizer grouped parameters

The program will now initialize the optimizer for the model's parameters. Fine-tuning a model begins with initializing the pretrained model parameter values (not their names).The parameters of the optimizer include a weight decay rate to avoid overfitting, and some parameters are filtered.The goal is to prepare the model's parameters for the training loop:

Copy Explain

```
#This code is taken from:
#
https://github.com/huggingface/transformers/blob/5bfcd0485ece086ebcbed2d008813037968a9e58/
# Don't apply weight decay to any parameters whose names include these tokens.
# (Here, the BERT doesn't have 'gamma' or 'beta' parameters, only 'bias' terms)
param_optimizer = list(model.named_parameters())
no_decay = ['bias', 'LayerNorm.weight']
# Separate the 'weight' parameters from the 'bias' parameters.
# - For the 'weight' parameters, this specifies a 'weight_decay_rate' of 0.01.
# - For the 'bias' parameters, the 'weight_decay_rate' is 0.0.
optimizer_grouped_parameters = [
    # Filter for all parameters which *don't* include 'bias', 'gamma', 'beta'.
    {'params': [p for n, p in param_optimizer if not any(nd in n for nd in no_decay)],
     'weight_decay_rate': 0.1},

    # Filter for parameters which *do* include those.
    {'params': [p for n, p in param_optimizer if any(nd in n for nd in no_decay)],
     'weight_decay_rate': 0.0}
]
# Note - 'optimizer_grouped_parameters' only includes the parameter values, not the
names.
```

Let's go through some of the main parameters in the following cells:

Looking into layer 3 of the `param_optimizer`.

All the parameters of the `model` and their names are collected in `param_optimizer`.

This function produces an iterator. The iterator contains tuples. Each tuple contains the name of a parameter and the value `p` of the parameters of layer 3:

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```
# Displaying a sample of the parameter_optimizer: layer 3
layer_parameters = [p for n, p in model.named_parameters() if 'layer.3' in n]
The following excerpt of the output displays a string and the value of its parameters:
'module.bert.embeddings.word_embeddings.weight', Parameter containing:
tensor([[ -0.0102, -0.0615, -0.0265, ..., -0.0199, -0.0372, -0.0098], [ -0.0117,
-0.0600, -0.0323, ..., -0.0168, -0.0401, -0.0107], [ -0.0198, -0.0627, -0.0326, ...,
-0.0165, -0.0420, -0.0032], ..., [ -0.0218, -0.0556, -0.0135, ..., -0.0043, -0.0151,
-0.0249], [ -0.0462, -0.0565, -0.0019, ..., 0.0157, -0.0139, -0.0095], [ 0.0015,
-0.0821, -0.0160, ..., -0.0081, -0.0475, 0.0753]], device='cuda:0',
requires_grad=True)),
```

Note that additional information is displayed. **cuda:0** means that the first enable CUDA enabled GPU has been activated. **requires\_grad=True** means that the gradients will be computed and the tensors updated during the training process. The model is "learning."

[Copy](#)[Explain](#)

```
Looking into no_decay
no_decay = ['bias', 'LayerNorm.weight']
Weight decay regularization will not be applied to the bias and LayerNorm.weight to
avoid overfitting.
The optimizer_grouped_parameters variable contains two dictionaries. These two groups
of parameters contain the weight decay rate.
Group 1: contains the parameters for which weight decay will be applied:
    Group 1:
    Weight decay rate: 0.1
Parameter 1: Parameter containing:
    tensor([[ -0.0102, -0.0615, -0.0265, ..., -0.0199, -0.0372, ...
Group 2: contains the parameters for which weight decay will not be applied, such as
bias and LayerNorm.weight :
Group 2:
Weight decay rate: 0.0
Parameter 1: Parameter containing:
tensor([0.9257, 0.8852, 0.8587, 0.8617, 0.8934, 0.8964, 0.9290, ...
```

The parameter names are not included because the optimizer does not require them. The parameters have been retrieved, and the model is ready for the training loop.

## The hyperparameters for the

The hyperparameters for the training loop are. For example, the **Adam** optimizer will activate phase. The number of **epochs** and **steps** will "learn." Several runs may prove helpful in det

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training. The learning rate (**lr**) and warmup rate (**warmup**) should be set to a very small value early in the optimization phase and gradually increase after a certain number of iterations. This avoids large gradients and overshooting the optimization goals. Some researchers argue that the gradients at the output level of the sub-layers before layer normalization do not require a warmup rate. However, solving this problem requires many experimental runs. The optimizer is a BERT version of Adam called **BertAdam**:

Copy Explain

```
optimizer = BertAdam(optimizer_grouped_parameters,
                    lr=2e-5,
                    warmup=.1)
```

The program adds an accuracy measurement function to compare the predictions to the labels:

Copy Explain

```
#Creating the Accuracy Measurement Function
# Function to calculate the accuracy of our predictions vs labels
def flat_accuracy(preds, labels):
    pred_flat = np.argmax(preds, axis=1).flatten()
    labels_flat = labels.flatten()
    return np.sum(pred_flat == labels_flat) / len(labels_flat)
```

The data is ready. The parameters are prepared. It's time to activate the training loop!

## The training loop

The training loop follows standard learning processes. The number of epochs is set to **4**, and measurements for loss and accuracy will be plotted. Next, the training loop uses the **data loader** to load and train batches. Finally, the training process is measured and evaluated. The code starts by initializing the **train\_loss\_set**, which will store the loss and accuracy, which will be plotted. It starts training its epochs and runs a standard training loop, as shown in the following excerpt:

[Copy](#)[Explain](#)

```
t = []
# Store our loss and accuracy for plotting
train_loss_set = []
# Number of training epochs (authors recommend between 2 and 4)
epochs = 4
# trange is a tqdm wrapper around the normal python range
for _ in trange(epochs, desc="Epoch"):
    .../...
    tmp_eval_accuracy = flat_accuracy(logits, label_ids)

    eval_accuracy += tmp_eval_accuracy
    nb_eval_steps += 1
print("Validation Accuracy: {}".format(eval_accuracy/nb_eval_steps))
```

The output displays the information for each **epoch** with the **trange** wrapper, **for \_ in trange(epochs, desc="Epoch")**:

[Copy](#)[Explain](#)

```
Epoch:   0%|          | 0/4 [00:00<?, ?it/s]
Train loss: 0.5381132976395461
Epoch:  25%|█          | 1/4 [07:54<23:43, 474.47s/it]
Validation Accuracy: 0.788966049382716
Train loss: 0.315329696132929
Epoch:  50%|██         | 2/4 [15:49<15:49, 474.55s/it]
Validation Accuracy: 0.836033950617284
Train loss: 0.1474070605354314
Epoch:  75%|████       | 3/4 [23:43<07:54, 474.53s/it]
Validation Accuracy: 0.814429012345679
Train loss: 0.07655430570461196
Epoch: 100%|██████████ | 4/4 [31:38<00:00, 474.58s/it]
Validation Accuracy: 0.810570987654321
```

**Note.** Transformer models are evolving quickly, and deprecation messages and errors might occur. Hugging Face is no exception, and we must update our code accordingly when this happens.

The model is trained. We can now display the training evaluation.

## Training evaluation

The loss and accuracy values were stored in `train_loss_set` at the beginning of the training loop. The program now

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```
plt.figure(figsize=(15,8))
plt.title("Training loss")
plt.xlabel("Batch")
plt.ylabel("Loss")
plt.plot(train_loss_set)
plt.show()
```

The output is a graph that shows that the training process went well and was relatively efficient:

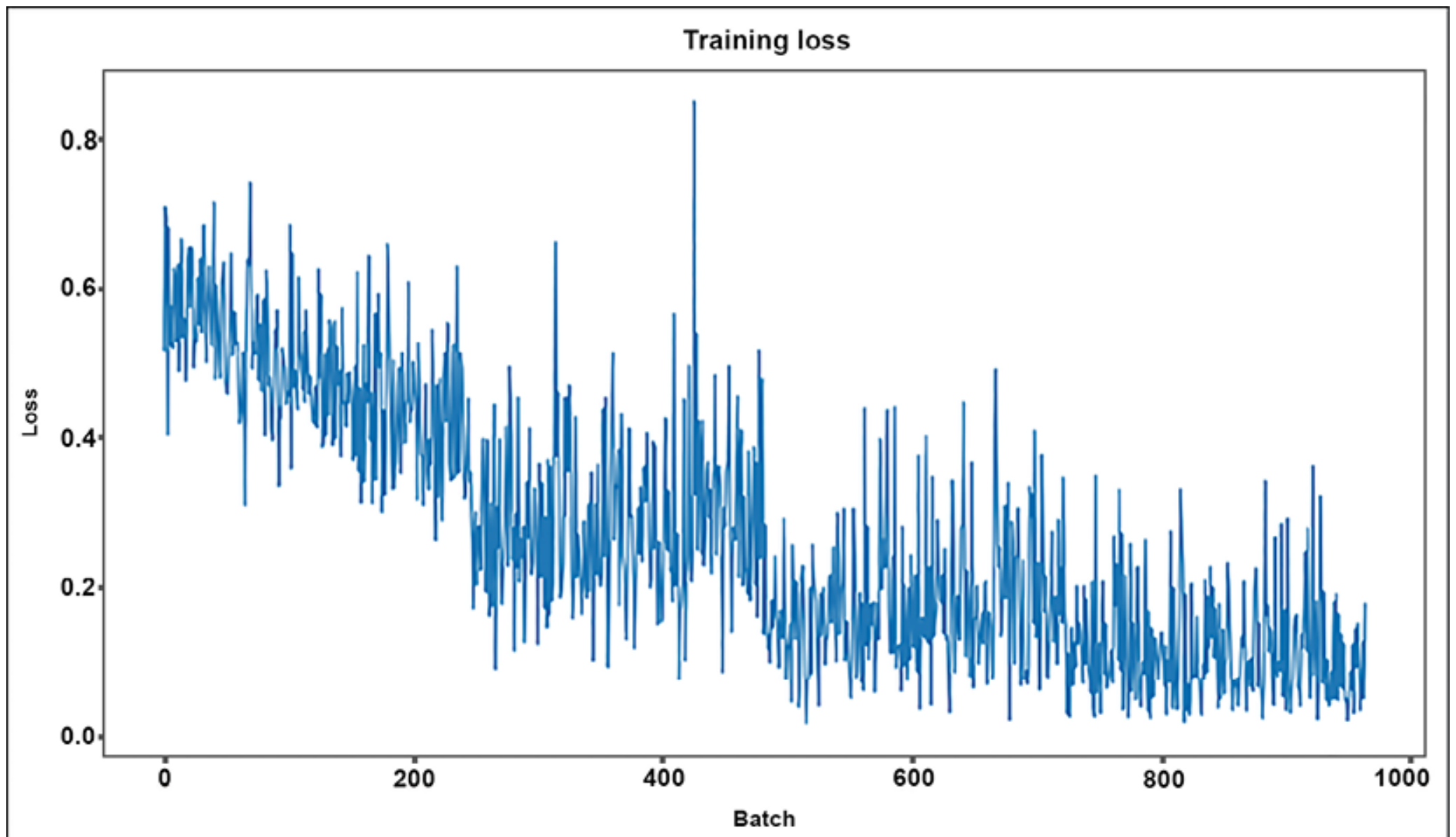


Figure 5.7: Training loss per batch

The model has been fine-tuned. We can now run predictions.

## Predicting and evaluating using the holdout dataset

The BERT downstream model has been trained with the `in_domain_train.tsv` dataset. The program will now make predictions using the holdout (testing and evaluation) dataset in the `out_of_domain_dev.tsv` file. The goal is to predict whether the sentence is grammatically correct. The following excerpts of the code show the main steps of the evaluation process applied to the training data is repeated in the dataset:

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```
df = pd.read_csv("out_of_domain_dev.tsv", delimiter='\t', header=None, names=
['sentence_source', 'label', 'label_notes', 'sentence'])
df.shape
```

The output of `df.shape` displays the number of lines to assess and the shape of the dataset:

[Copy](#)[Explain](#)

```
(516, 4)
```

Then, the evaluation process begins by creating the sentences to assess and their labels:

[Copy](#)[Explain](#)

```
# Create sentence and label lists
sentences = df.sentence.values
# We need to add special tokens at the beginning and end of each sentence for BERT to
work properly
sentences = ["[CLS] " + sentence + " [SEP]" for sentence in sentences]
labels = df.label.values
tokenized_texts = [tokenizer.tokenize(sent) for sent in sentences]
.../...
```

The program then runs batch predictions using the **data loader**:

[Copy](#)[Explain](#)

```
# Predict
for batch in prediction_dataloader:
    # Add batch to GPU
    batch = tuple(t.to(device) for t in batch)
    # Unpack the inputs from our dataloader
    b_input_ids, b_input_mask, b_labels = batch
    # Telling the model not to compute or store gradients, saving memory and speeding up
prediction
    with torch.no_grad():
        # Forward pass, calculate logit prediction
logits = model(b_input_ids, token_type_ids=None)
```

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The logits and labels of the predictions are m



[Copy](#)[Explain](#)

```
# Move logits and labels to CPU
logits = logits['logits'].detach().cpu().numpy()
label_ids = b_labels.to('cpu').numpy()
```

Then, the assessment is made by choosing the class with the highest probability:

[Copy](#)[Explain](#)

```
# The predicted class is the one with the highest probability
batch_predictions = np.argmax(probabilities, axis=1)
```

Let's go deeper into this process in the following subsection.

### Exploring the prediction process

It is interesting to dig into the output of the prediction process. Let's take a look at the code that follows **batch\_predictions**. We can sum up the process by creating five steps and adding a function of our own:

[Copy](#)[Explain](#)

```
print(f"Sentence: {sentence}")
```

This will display the sentence to assess. For example: Sentence: somebody just left - guess who.

[Copy](#)[Explain](#)

```
print(f"Prediction: {logits[i]}")
```

Now, we can display the fine-tuned model's prediction:

[Copy](#)[Explain](#)

```
Prediction: [-2.6922598  2.1979954]
```

The first element, **-2.6922598**, is the first class of the sentences in this case. The second element, **2**, is the value, which, in this case represents the accuracy function to interpret the result.

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```
print(f"Sofmax probabilities", softmax(logits[i]))
```

A softmax function was added to the notebook just above the prediction cell

```
#Softmax logits
import numpy as np
def softmax(logits):
    e = np.exp(logits)
    return e / np.sum(e)
```

The result is an interpretable array of two probabilities that sum up to 1:

```
Sofmax probabilities [0.00746338 0.9925366 ]
```

The first element, the unacceptable class, has a probability of 0.00746338.  
The second element, the acceptable class, has a probability of 0.9925366.  
We can see that the probability of the acceptable class exceeds that of the unacceptable class.

We can now look at the results produced by the fine-tuned model.

```
Print(f"Prediction: {batch_predictions[i]}")
```

The prediction of the model for the sentence is:

```
Prediction: 1
```

This matches the detailed analysis of the output we made.

```
print(f"True label: {label_ids[i]}")
```

The label of the dataset is:

[Copy](#)[Explain](#)

```
True label: 1
```

We can see that, in this case, the prediction matches the true label in the dataset. Once the predictions are made, the raw predictions and their true labels are stored:

[Copy](#)[Explain](#)

```
predictions.append(logits)
true_labels.append(label_ids)
```

The program can now evaluate the predictions.

## Evaluating using the Matthews Correlation Coefficient

The **Matthews Correlation Coefficient (MCC)** quality of binary classifications and can be n coefficient. A two-class classification can be prediction:

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TP = True Positive

TN = True Negative

FP = False Positive

FN = False Negative

*Brian W. Matthews*, a biochemist, designed it in 1975, inspired by his predecessors' *phi* function. Since then, it has evolved into various formats, such as the following one:

$$MCC = \frac{TP \times TN - FP \times FN}{\sqrt{(TP + FP)(TP + FN)(TN + FP)(TN + FN)}}$$

The value produced by MCC is between **-1** and **+1**. **+1** is the maximum positive value of a prediction. **-1** is an inverse prediction. **0** is an average random prediction. *Linguistic Acceptability* can be measured with MCC. MCC is imported from **sklearn.metrics**:

Copy

Explain

```
# Import and evaluate each test batch using Matthew's correlation coefficient
from sklearn.metrics import matthews_corrcoef
```

A set of predictions is created:

Copy

Explain

```
matthews_set = []
```

The MCC value is calculated and stored in **matthews\_set**:

Copy

Explain

```
for i in range(len(true_labels)):
    matthews = matthews_corrcoef(true_labels[i],
                                np.argmax(predictions[i], axis=1).flatten())
    matthews_set.append(matthews)
```

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You may see messages due to library and mo  
be based on the entire test set.

# Matthews Correlation Coefficient evaluation for the whole dataset

The MCC is a practical way to evaluate a classification model. The program will now aggregate the true values for the whole dataset:

[Copy](#)[Explain](#)

```
# Flatten the predictions and true values for aggregate Matthew's evaluation on the whole dataset
flat_predictions = [item for sublist in predictions for item in sublist]
flat_predictions = np.argmax(flat_predictions, axis=1).flatten()
flat_true_labels = [item for sublist in true_labels for item in sublist]
matthews_corrcoef(flat_true_labels, flat_predictions)
```

The metric compares the labels (0 or 1) provided by the evaluation dataset and the labels produced by the prediction using the MCC. The result might vary from one run to another because of the stochastic nature of model predictions. The result, in this case, is: **MCC: 0.524309707232222** The Matthews Correlation Coefficient measures the quality of binary classifications with an output value ranging from -1 to +1:

**+1** means that the predictions were 100% accurate

**0** is the same as a random calculation

**-1** indicates that the predictions are totally false.

In this case, an MCC of 0.54 is relatively efficient. The model has learned a significant amount of information but can be improved. With this final evaluation of the fine-tuning of the BERT model, we have an overall view of the fine-tuning framework. We now interact with the model to explore its scope and limits.

---

## Building a Python interface with the model

In this section, we will first save the model and our trained model. Let's first save the model if we choose to.

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# Saving the model

The following code will save the model's files:

Copy Explain

```
# Specify a directory to save your model and tokenizer
save_directory = "/content/model"
# If your model is wrapped in DataParallel, access the original model using .module
and then save
if isinstance(model, torch.nn.DataParallel):
    model.module.save_pretrained(save_directory)
else:
    model.save_pretrained(save_directory)
# Save the tokenizer
tokenizer.save_pretrained(save_directory)
```

The saved `/content/model` directory contains:

- `tokenizer_config.json` - configuration details specific to the tokenizer.
- `special_tokens_map.json` - mappings for any special tokens.
- `vocab.txt` - the vocabulary of tokens that the tokenizer can recognize.
- `added_tokens.json` - any tokens that were added to the tokenizer after its initial creation.

When a model is wrapped in `DataParallel` for multi-GPU training in PyTorch, the original model becomes an attribute of the `DataParallel` object. When saving files in Google Colab, store them, as files in the Colab environment are discarded once the session ends. The saved model can be large. In this case, one solution is to mount Google Drive if you wish to implement this method:

Copy Explain

```
from google.colab import drive
drive.mount('/content/drive')
```

Then, save the files in the `/content/model` directory. The files can then be loaded in another session, as shown in this example:

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```
from transformers import BertTokenizer, BertForSequenceClassification
# Directory where the model and tokenizer were saved
load_directory = "/content/model/"
```

The next step is to build an interface to interact with the trained model.

## Creating an interface for the trained model

First, make sure the model is in evaluation mode:

[Copy](#)[Explain](#)

```
from transformers import BertTokenizer, BertForSequenceClassification
import torch
model.eval() # set the model to evaluation mode
```

Now, we create a function to interact with the model, as shown in the following excerpt:

[Copy](#)[Explain](#)

```
def predict(sentence, model, tokenizer):
    # Add [CLS] and [SEP] tokens
    sentence = "[CLS] " + sentence + " [SEP]"
    # Tokenize the sentence
    tokenized_text = tokenizer.tokenize(sentence)
```

We can sum up the function as follows:

1. The function takes in three parameters: a sentence, a model, and a tokenizer.
2. The sentence is preprocessed by adding [CLS] and [SEP] tokens, which are special tokens used in BERT-like models.
3. The sentence is then tokenized into sub-words using the provided tokenizer.
4. The tokens are converted into corresponding IDs from the model's vocabulary.
5. A segment ID is defined for each token, set to 0 since there's only one sequence.
6. The list of token IDs and segment IDs are converted into PyTorch tensors.
7. A prediction is made using the model with the tensors.
8. The model outputs logits, which represent the probability of each class.
9. The label with the highest logit is selected.
10. The predicted label is returned.

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We can now interact with the model.

## Interacting with the model

To build the interface, install `ipywidgets`:

Copy

Explain

```
import ipywidgets as widgets
from IPython.display import display
def model_predict_interface(sentence):
    prediction = predict(sentence, model, tokenizer)
    if prediction == 0:
        return "Grammatically Incorrect"
    elif prediction == 1:
        return "Grammatically Correct"
    else:
        return f"Label: {prediction}"
text_input = widgets.Textarea(
    placeholder='Type something',
    description='Sentence:',
    disabled=False,
    layout=widgets.Layout(width='100%', height='50px') # Adjust width and height here
)
output_label = widgets.Label(
    value='',
    layout=widgets.Layout(width='100%', height='25px'), # Adjust width and height here
    style={'description_width': 'initial'}
)
def on_text_submit(change):
    output_label.value = model_predict_interface(change.new)
text_input.observe(on_text_submit, names='value')
display(text_input, output_label)
```

Finally, we interact by entering sentences that are classified in real time as correct or incorrect, as shown in Figure 5.8.

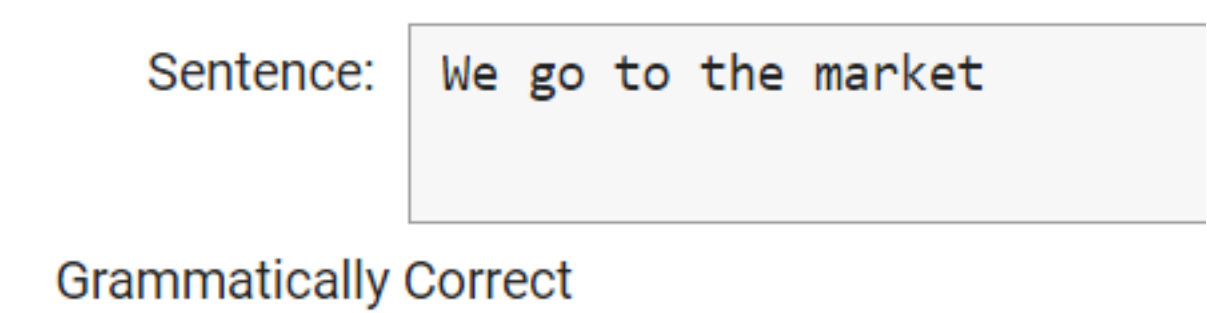


Figure 5.8 A grammatically correct sentence

Or grammatrically incorrect as shown in Figu

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Sentence: We no go to the market

Grammatically Incorrect

Figure 5.9 A grammatically incorrect sentence

sentence

They went to the movies.

Clear

If we click on **Interpret**, we obtain an interpretation of why the sentence was correct or incorrect. In this case, the sentence is correct, as shown in Figure 5.9.If we click on **Clear** and then enter "They no go to the movies" which is incorrect, the model will detect the error as shown in Figure 5.10.

sentence

They no go movies.

Figure 5.10 A grammatically incorrect sentence.

Enter more examples to explore the scope and find the limits when the model is generalized. We now went through a complete training process and interacted with our trained model!Let's now summarize our fine-tuning journey.

# Summary

In this chapter, we explored the process of fine-tuning a BERT model.We began by analyzing the architecture of transformers and uses bidirectional as a two-step framework. The first step of the

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second step is to fine-tune the model. We then configured a fine-tuning BERT model for an *Acceptability Judgment* downstream task. The fine-tuning process went through all phases of the process. We installed the Hugging Face transformers and considered the hardware constraints, including selecting CUDA as the device for torch. We retrieved the CoLA dataset from GitHub. We loaded and created in-domain (training data) sentences, label lists, and BERT tokens. The training data was processed with the BERT tokenizer and other data preparation functions, including the attention masks. Then, the data was split into training and validation sets. We selected a batch size to optimize the process and created an iterator. We then loaded a Hugging Face BERT uncased base model. The process could have been implemented with another tokenizer and another Hugging Face pretrained model such as GPT-2, T5, RoBERTa, or others. We grouped the parameters, defined the hyperparameters, and ran the training loop, including evaluations during the process. Once the training was over, we used the out-of-domain holdout dataset to evaluate the output of the fined-tuned model. We explored the prediction process and implemented the Matthews Correlation Coefficient to evaluate the results. Finally, we built an interface with [ipywidgets](#) to interact with our trained model. Fine-tuning a pretrained model takes fewer machine resources than training a model for downstream tasks from scratch. Fine-tuned models can perform a variety of tasks. However, in some cases, fine-tuning a model is insufficient to reach our goals. For example, we might need to pretrain a transformer model practically from scratch. In the next chapter, *Chapter 6, Pretraining a Transformer from Scratch through RoBERTa*, we will build and pretrain a transformer model from scratch.

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# Questions

- 1. BERT stands for Bidirectional Encoder Representations from Transformers. (True/False)
- 2. BERT is a two-step framework. *Step 1* is pretraining. *Step 2* is fine-tuning. (True/False)
- 3. Fine-tuning a BERT model implies training
- 4. BERT only pretrains using all downstream
- 5. BERT pretrains with **Masked Language Mo**
- 6. BERT pretrains with **Next Sentence Predict**
- 7. BERT pretrains mathematical functions. (T
- 8. A question-answer task is a downstream task. (True/False)

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9. A BERT pretraining model does not require tokenization. (True/False)
10. Fine-tuning a BERT model takes less time than pretraining. (True/False)
- 

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**The Corpus of Linguistic Acceptability (CoLA):**  
<https://nyu-ml.github.io/CoLA/> Documentation on Hugging Face models:  
[https://huggingface.co/transformers/pretrained\\_models.html](https://huggingface.co/transformers/pretrained_models.html)  
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## Further Reading

*Fine-Tuning Transformers: Vocabulary Transfer*, Mosin et al. (2021):  
<https://arxiv.org/abs/2112.14569>

Scale Efficiently: Insights from Pre-training and Fine-tuning Transformers, Tay et al. (2022): <https://arxiv.org/abs/2109.10686>

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