# Training a Custom BERT Model for Spam Document Classification (1 of 2)

May 1, 2023

This project on training a custom BERT model for document classification serves as the end-semester course project for semester VI's natural language processing course.

## 1 About this notebook

This notebook is 1 of 2 notebooks with the objective to train a custom BERT model with a dataset of labelled spam documents. I intend for the model to accurately distinguish between spam and non-spam documents with high efficiency after rigorous training. The second notebook then analyses the training and validation losses of the model over the epochs.

## 2 Import Libraries

[ ]:
```
import time
import numpy as np
import pandas as pd
import json

import torch
import torch.nn as nn
from torch.utils.data import TensorDataset, DataLoader, RandomSampler,␣
↪SequentialSampler

from sklearn.model_selection import train_test_split
from sklearn.metrics import classification_report
from sklearn.utils.class_weight import compute_class_weight

import transformers
from transformers import AutoModel, BertTokenizerFast

import matplotlib.pyplot as plt
```

```
/home/volt/code/train-and-save/BERTTrainAndSave/lib/python3.10/site-
packages/tqdm/auto.py:21: TqdmWarning: IProgress not found. Please update
jupyter and ipywidgets. See
```

```
https://ipywidgets.readthedocs.io/en/stable/user_install.html
  from .autonotebook import tqdm as notebook_tqdm
```

**Define GPU Here if Available**

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

## 3 Check if the GPU is in Use

[ ]:
```
!nvidia-smi
```

```
huggingface/tokenizers: The current process just got forked, after parallelism
has already been used. Disabling parallelism to avoid deadlocks…
To disable this warning, you can either:
        - Avoid using `tokenizers` before the fork if possible
        - Explicitly set the environment variable TOKENIZERS_PARALLELISM=(true |
false)
Sun Apr 30 07:02:27 2023
+-------------------------------------------------------------------------------
--------+
| NVIDIA-SMI 530.30.02              Driver Version: 530.30.02    CUDA Version:
12.1     |
|-----------------------------------------+----------------------+--------------
--------+
| GPU  Name                  Persistence-M| Bus-Id        Disp.A | Volatile
Uncorr. ECC |
| Fan  Temp  Perf            Pwr:Usage/Cap|         Memory-Usage | GPU-Util
Compute M. |
|                                         |                      |
MIG M. |
|=========================================+======================+==============
========|
|   0  NVIDIA GeForce GTX 1650 Ti      On | 00000000:01:00.0 Off |
N/A |
| N/A   52C    P5               12W /  50W|   1093MiB /  4096MiB |      7%
Default |
|                                         |                      |
N/A |
+-----------------------------------------+----------------------+--------------
--------+

+-------------------------------------------------------------------------------
--------+
| Processes:
|
|  GPU   GI   CI        PID   Type   Process name                            GPU
Memory |
|        ID   ID
```

```
Usage      |
|===========================================================================
========|
|    0   N/A  N/A      2431      G   /usr/lib/xorg/Xorg
222MiB |
|    0   N/A  N/A      2849      G   /usr/bin/gnome-shell
48MiB |
|    0   N/A  N/A      4355      G   x-terminal-emulator
8MiB |
|    0   N/A  N/A     35688      G   …21009604,4413684056739584576,131072
32MiB |
|    0   N/A  N/A     46337      G   …sion,SpareRendererForSitePerProcess
110MiB |
|    0   N/A  N/A     49003      C   /usr/bin/python3
664MiB |
+---------------------------------------------------------------------------
--------+
```

# 4 Preprocessing

## 4.1 Import the Corpus of Raw Text

[ ]:
```python
# Use this when running the notebook locally
data = pd.read_csv(r"./assets/data/spam-data.csv")

# Running the notebook on Kaggle
# data = pd.read_csv(r"/kaggle/input/spamdatatest/spamdata_v2.csv")

data.head()
```

[ ]:

| | label | text |
|---|---|---|
| 0 | 0 | Go until jurong point, crazy.. Available only … |
| 1 | 0 | Ok lar… Joking wif u oni… |
| 2 | 1 | Free entry in 2 a wkly comp to win FA Cup fina… |
| 3 | 0 | U dun say so early hor… U c already then say… |
| 4 | 0 | Nah I don't think he goes to usf, he lives aro… |

## 4.2 Check the Shape of Data

[ ]:
```python
data.shape
```

[ ]: (5572, 2)

### 4.3 Check the Way Labels are Distributed

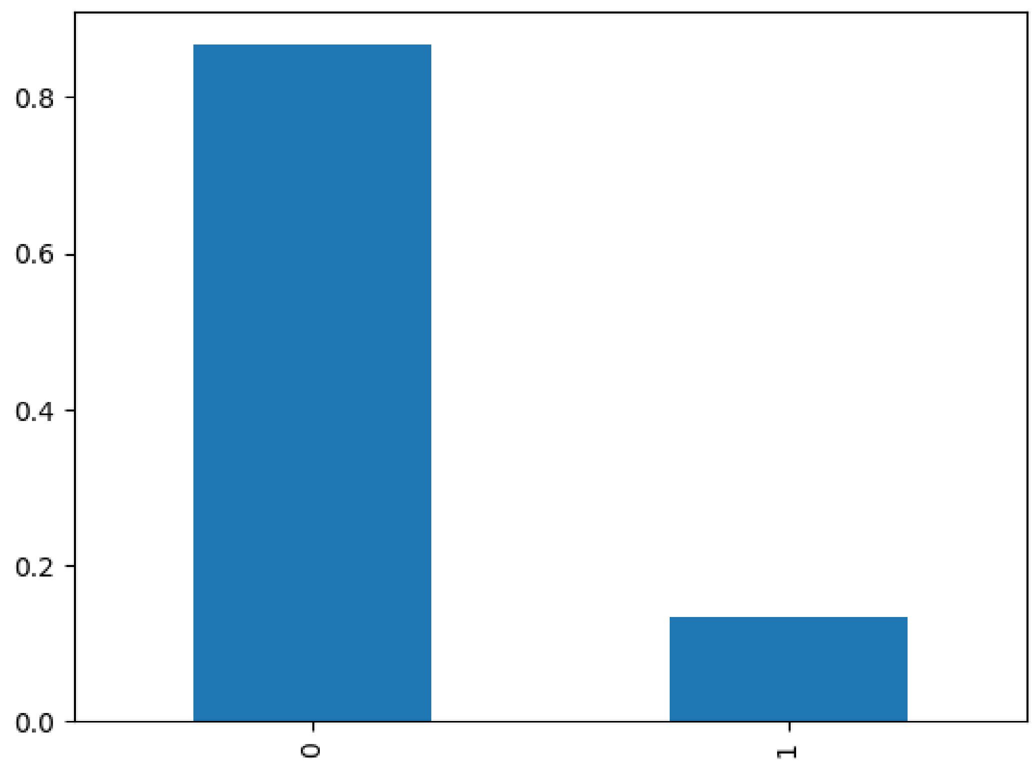
[ ]:
```
data['label'].value_counts(normalize=True)
```

[ ]:
```
0    0.865937
1    0.134063
Name: label, dtype: float64
```

### 4.4 Plot the Bar Plot for the Distribution

[ ]:
```
data['label'].value_counts(normalize=True).plot.bar()
```

[ ]: <AxesSubplot: >




## 5 Split the Data into Training, Testing and Validation Sets

### 5.1 Train-test Split

[ ]:
```
XTrain, XTest, yTrain, yTest = train_test_split(data['text'], data['label'],␣
↪random_state=42, test_size=0.3, stratify=data['label'])
```

### 5.2 Validation Split

[ ]:
```
XValidationTrain, XValidationTest, yValidationTrain, yValidationTest = train_test_split(
    XTest,
    yTest,
    random_state=42,
    test_size=0.5,
    stratify=yTest
)
```

## 6 Download and Import the Pre-trained BERT Model from Huggingface

[ ]:
```
# Import the BERT-base pretrained model
BERT = AutoModel.from_pretrained('bert-base-uncased')

# Load the BERT tokenizer
tokenizer = BertTokenizerFast.from_pretrained('bert-base-uncased')
```

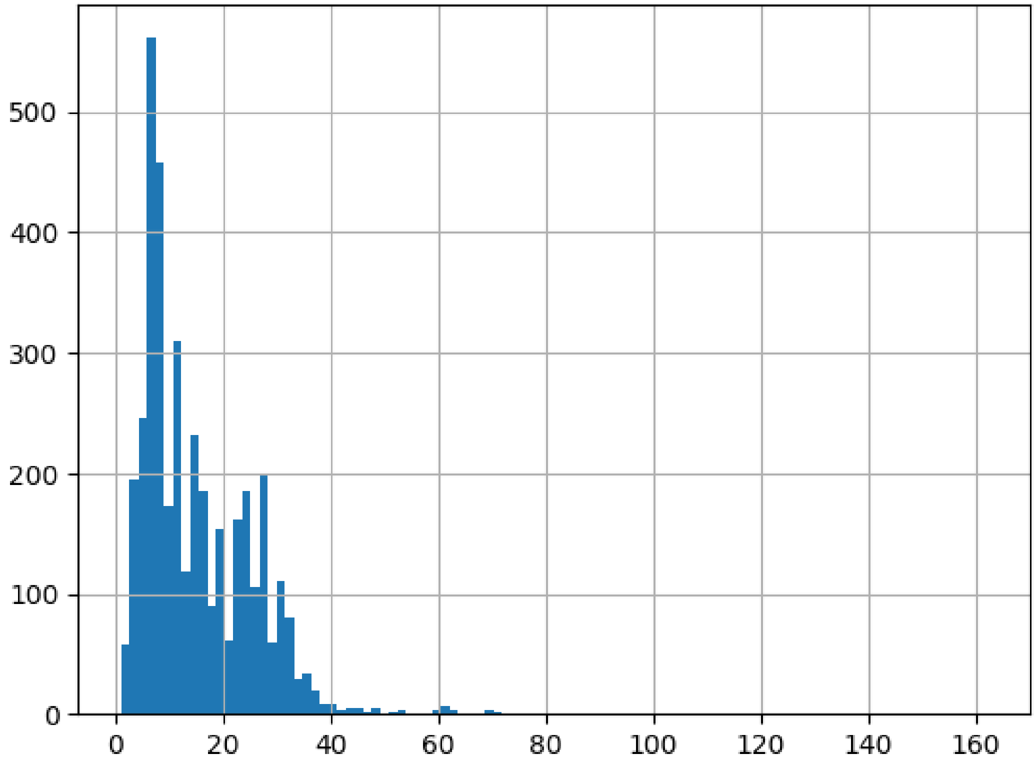
```
Some weights of the model checkpoint at bert-base-uncased were not used when
initializing BertModel: ['cls.predictions.transform.dense.bias',
'cls.predictions.decoder.weight', 'cls.predictions.transform.LayerNorm.weight',
'cls.seq_relationship.bias', 'cls.predictions.bias',
'cls.seq_relationship.weight', 'cls.predictions.transform.dense.weight',
'cls.predictions.transform.LayerNorm.bias']
- This IS expected if you are initializing BertModel from the checkpoint of a
model trained on another task or with another architecture (e.g. initializing a
BertForSequenceClassification model from a BertForPreTraining model).
- This IS NOT expected if you are initializing BertModel from the checkpoint of
a model that you expect to be exactly identical (initializing a
BertForSequenceClassification model from a BertForSequenceClassification model).
```

## 7 Get the Length of each Sequence of Text and Plot their Distributions

[ ]:
```
# get length of all the messages in the train set
sequenceLength = [len(sample.split()) for sample in XTrain]

pd.Series(sequenceLength).hist(bins = 100)
```

[ ]:
```
<AxesSubplot: >
```




## 8 Tokenise and Encode Sequences

[ ]:
```
# Tokenize and encode sequences in the training set
trainTokens = tokenizer.batch_encode_plus(
    XTrain.tolist(),
    max_length = 25,
    pad_to_max_length=True,
    truncation=True
)

# Tokenize and encode sequences in the validation set
validationTokens = tokenizer.batch_encode_plus(
    XValidationTrain.tolist(),
    max_length = 25,
    pad_to_max_length=True,
    truncation=True
)

# Tokenize and encode sequences in the test set
testTokens = tokenizer.batch_encode_plus(
    XValidationTest.tolist(),
```

```
    max_length = 25,
    pad_to_max_length=True,
    truncation=True
)
```

```
/home/volt/.local/lib/python3.10/site-
packages/transformers/tokenization_utils_base.py:2339: FutureWarning: The
`pad_to_max_length` argument is deprecated and will be removed in a future
version, use `padding=True` or `padding='longest'` to pad to the longest
sequence in the batch, or use `padding='max_length'` to pad to a max length. In
this case, you can give a specific length with `max_length` (e.g.
`max_length=45`) or leave max_length to None to pad to the maximal input size of
the model (e.g. 512 for Bert).
  warnings.warn(
```

[ ]:
```
type(trainTokens)
```

[ ]:
```
transformers.tokenization_utils_base.BatchEncoding
```

# 9 Convert these Lists to Tensors

[ ]:
```
trainSequenceTensor = torch.tensor(trainTokens['input_ids'])
trainMaskTensor = torch.tensor(trainTokens['attention_mask'])
trainYTensor = torch.tensor(yTrain.tolist())

validationSequenceTensor = torch.tensor(validationTokens['input_ids'])
validationMaskTensor = torch.tensor(validationTokens['attention_mask'])
validationYTensor = torch.tensor(yValidationTrain.tolist())

testSequenceTensor = torch.tensor(testTokens['input_ids'])
testMaskTensor = torch.tensor(testTokens['attention_mask'])
testYTensor = torch.tensor(yValidationTest.tolist())
```

Here're the created tensors.

[ ]:
```
trainSequenceTensor, trainSequenceTensor.shape
```

[ ]:
```
(tensor([[  101,  3125,   999,  …,  1037,  3413,   102],
         [  101,  1045,  2123,  …,     0,     0,     0],
         [  101,  9779,  2232,  …,     0,     0,     0],
         …,
         [  101,  2469,  1010,  …,  1998,  3227,   102],
         [  101,  2498,  2021,  …,  2253, 11047,   102],
         [  101,  7087,  1012,  …,  2061,  1045,   102]]),
 torch.Size([3900, 25]))
```

[ ]:
```
testSequenceTensor, testSequenceTensor.shape
```

[ ]: (tensor([[  101,  4067,  2017,  …,      0,      0,      0],
        [  101,  6203,  5718,  …,   2345,   3535,    102],
        [  101,  2073,  2024,  …,      0,      0,      0],
        …,
        [  101,  2053,  1012,  …,   4309,   2489,    102],
        [  101,  1015,  1045,  …,   1005,   1040,    102],
        [  101,  2524,  2444,  …,  21472,  21472,    102]]),
 torch.Size([836, 25]))

```
[ ]: validationSequenceTensor, validationSequenceTensor.shape
```

[ ]: (tensor([[  101,  5003,  2132,  …,      0,      0,      0],
        [  101, 11948,  2072,  …,   1012,  20228,    102],
        [  101, 13433,  2139,  …,   2050,   1012,    102],
        …,
        [  101,  2053,  3291,  …,      0,      0,      0],
        [  101,  1998,  2011,  …,      0,      0,      0],
        [  101,  2002,  2758,  …,   1055,   5791,    102]]),
 torch.Size([836, 25]))

# 10 Using the Data Loader in PyTorch to Load the Dataset

## 10.1 Define Hyper-parameter(s)

```
[ ]: batchSize = 16
```

## 10.2 Create Training Tensors

```
[ ]: # Wrapping the training tensors
trainingTensor = TensorDataset(trainSequenceTensor, trainMaskTensor,␣
 ↪trainYTensor)

# Randomly Sampling the Wrapped Tensor
trainingSampler = RandomSampler(trainingTensor)

# Putting the training sampled data in a data loader
trainingDataLoader = DataLoader(trainingTensor, sampler=trainingSampler,␣
 ↪batch_size=batchSize)
```

```
[ ]: type(trainingTensor), type(trainingSampler), type(trainingDataLoader)
```

[ ]: (torch.utils.data.dataset.TensorDataset,
 torch.utils.data.sampler.RandomSampler,
 torch.utils.data.dataloader.DataLoader)

### 10.3 Create Validation Tensors

[ ]:
```
# Wrapping the validation tensors
validationTensor = TensorDataset(validationSequenceTensor,␣
 ↪validationMaskTensor, validationYTensor)

# Randomly Sampling the Wrapped Tensor
validationSampler = RandomSampler(validationTensor)

# Putting the training sampled data in a data loader
validationDataLoader = DataLoader(validationTensor, sampler=validationSampler,␣
 ↪batch_size=batchSize)
```

## 11 Write Tensors to a JSON File

[ ]:
```
def saveToJSON(filePath, **kwargs):
    """
    Save PyTorch tensors to a JSON file.

    Args:
        file_path (str): Path to the JSON file to save to.
        **kwargs: Key-value pairs where the key is the name of the tensor and␣
 ↪the value is the tensor to save.
    """
    toSave = {}

    for name, variable in kwargs.items():
        variableType = type(variable)

        if variableType == list or variableType == int:
            toSave[name] = variable
        else:
            toSave[name] = variable.tolist()

    with open(filePath, 'w') as f:
        json.dump(toSave, f)
```

## 12 Construct the BERT Model

[ ]:
```
# Freeze all the parameters
for parameter in BERT.parameters():
    parameter.requires_grad = False
```

[ ]:
```
class BERTArchitecture(nn.Module):
    def __init__(self, bert):
        super(BERTArchitecture, self).__init__()
```

```python
        self.bert = bert

        # Dropout layer
        self.dropout = nn.Dropout(0.1)

        # ReLU activation function
        self.relu =  nn.ReLU()

        # Dense layer 1
        self.fullyConnected1 = nn.Linear(768, 512)

        # Dense layer 2 (Output layer)
        self.fullyConnected2 = nn.Linear(512, 2)

        # Softmax activation function
        self.softmax = nn.LogSoftmax(dim=1)

    # Define the forward pass
    def forward(self, sent_id, mask):
        # Pass the inputs to the model
        _, cls_hs = self.bert(sent_id, attention_mask=mask, return_dict=False)

        # Input layer
        x = self.fullyConnected1(cls_hs)

        x = self.relu(x)

        x = self.dropout(x)

        # Output layer
        x = self.fullyConnected2(x)

        # Apply softmax activation
        x = self.softmax(x)

        return x
```

# 13 Pass the Pre-trained BERT from Huggingface to our Defined Architecture

[ ]:
```python
model = BERTArchitecture(BERT)
```

## 14 Push our Model to the Device

[ ]:
```python
model = model.to(device)
```

## 15 Create an Optimiser

[ ]:
```python
# Optimizer from hugging face transformers
from transformers import AdamW

# Define the optimizer
optimizer = AdamW(model.parameters(), lr=1e-5)
```

```
/home/volt/.local/lib/python3.10/site-packages/transformers/optimization.py:306:
FutureWarning: This implementation of AdamW is deprecated and will be removed in
a future version. Use the PyTorch implementation torch.optim.AdamW instead, or
set `no_deprecation_warning=True` to disable this warning
  warnings.warn(
```

## 16 Compute Class Weights

[ ]:
```python
weightsList = compute_class_weight(class_weight='balanced', classes=np.
 ↪unique(yTrain), y=yTrain)

print("Class Weights:", weightsList)
```

```
Class Weights: [0.57743559 3.72848948]
```

## 17 Convert Class Weights List to Tensor

[ ]:
```python
# Converting list of class weights to a tensor
weights = torch.tensor(weightsList, dtype=torch.float)

# Push to GPU
weights = weights.to(device)
```

## 18 Define Hyper-parameters to Train

[ ]:
```python
# Define the loss function
crossEntropy  = nn.NLLLoss(weight=weights)

# Define the number of training epochs
EPOCHS = 500

# Define how many steps before printing an update
```

```
trainingStepsUpdate = 20
validationStepsUpdate = 10
```

## 19 Training the Model - Fine Tuning

Define a function to train the model.

```
[ ]: def train():
    model.train()
    totalLoss = 0

    # Empty list to save model predictions
    totalPredictions = []

    # Iterate over batches
    for step, batch in enumerate(trainingDataLoader):
        # Progress update after every 50 batches.
        if step % trainingStepsUpdate == 0 and not step == 0:
            print('\tBatch {:>3,} of {:>3,}.'.format(step,␣
↪len(trainingDataLoader)))

        # Push the batch to gpu
        batch = [r.to(device) for r in batch]

        sent_id, mask, labels = batch

        # Clear previously calculated gradients
        model.zero_grad()

        # Get model predictions for the current batch
        preds = model(sent_id, mask)

        # Compute the loss between actual and predicted values
        loss = crossEntropy(preds, labels)

        # Add on to the total loss
        totalLoss = totalLoss + loss.item()

        # Backward pass to calculate the gradients
        loss.backward()

        # Clip the the gradients to 1.0. It helps in preventing the exploding␣
↪gradient problem
        torch.nn.utils.clip_grad_norm_(model.parameters(), 1.0)

        # Update parameters
```

```
        optimizer.step()

        # Model predictions are stored on GPU. So, push it to CPU
        preds = preds.detach().cpu().numpy()

    # Append the model predictions
    totalPredictions.append(preds)

    # Compute the training loss of the epoch
    averageLoss = totalLoss / len(trainingDataLoader)

    # Predictions are in the form of (no. of batches, size of batch, no. of␣
↪classes). Reshape the predictions in form of (number of samples, no. of␣
↪classes)
    totalPredictions  = np.concatenate(totalPredictions, axis=0)

    # Returns the loss and predictions
    return averageLoss, totalPredictions
```

## 20 Evaluating the Model - Using the Validation Set

Define a function to evaluate the model.

[ ]:
```
def evaluate():
    print("\nEvaluating...")

    # Deactivate dropout layers
    model.eval()

    totalLoss = 0

    # Empty list to save the model predictions
    totalPredictions = []

    # Iterate over batches
    for step, batch in enumerate(validationDataLoader):
        # Progress update every 50 batches.
        if step % validationStepsUpdate == 0 and not step == 0:
            # Report progress.
            print('\tBatch {:>3,} of {:>3,}.'.format(step,␣
↪len(validationDataLoader)))

        # Push the batch to gpu
        batch = [t.to(device) for t in batch]

        sent_id, mask, labels = batch
```

```python
        # Deactivate autograd
        with torch.no_grad():

            # Model predictions
            preds = model(sent_id, mask)

            # Compute the validation loss between actual and predicted values
            loss = crossEntropy(preds,labels)

            totalLoss = totalLoss + loss.item()

            preds = preds.detach().cpu().numpy()

            totalPredictions.append(preds)

    # Compute the validation loss of the epoch
    averageLoss = totalLoss / len(validationDataLoader)

    # Reshape the predictions in form of (number of samples, no. of classes)
    totalPredictions  = np.concatenate(totalPredictions, axis=0)

    return averageLoss, totalPredictions
```

# 21 Running the Model to Train and Evaluate

[ ]:
```python
# Set initial loss to infinite
bestValidationLoss = float('inf')

# Empty lists to store training and validation loss of each epoch
trainingLosses = []
validationLosses = []

# Initialize total time taken to 0
totalTimeTaken = 0

# For each epoch
for epoch in range(EPOCHS):
    print('\nEpoch {:} of {:}'.format(epoch + 1, EPOCHS))

    # Train model and record time taken
    startTime = time.time()
    trainingLoss, _ = train()
    trainingTimeTaken = time.time() - startTime

    # Evaluate model and record time taken
```

```python
    startTime = time.time()
    validationLoss, _ = evaluate()
    validationTimeTaken = time.time() - startTime

    # Save the best model
    if validationLoss < bestValidationLoss:
        bestValidationLoss = validationLoss

        # When running the notebook on a Kaggle kernel
        # torch.save(model.state_dict(), r'/kaggle/working/weights.pt')

        # When saving the weights locally
        torch.save(model.state_dict(), r'./assets/weights/weights.pt')

    # Append training and validation losses
    trainingLosses.append(trainingLoss)
    validationLosses.append(validationLoss)

    # Print epoch results and times taken
    print(f'\nTraining Loss: {trainingLoss:.3f}')
    print(f'Training Time Taken: {trainingTimeTaken:.2f} seconds')
    print(f'Validation Loss: {validationLoss:.3f}')
    print(f'Validation Time Taken: {validationTimeTaken:.2f} seconds')

    # Update total time taken
    totalTimeTaken += trainingTimeTaken + validationTimeTaken
```

```
Epoch 1 of 500
        Batch  20 of 244.
        Batch  40 of 244.
        Batch  60 of 244.
        Batch  80 of 244.
        Batch 100 of 244.
        Batch 120 of 244.
        Batch 140 of 244.
        Batch 160 of 244.
        Batch 180 of 244.
        Batch 200 of 244.
        Batch 220 of 244.
        Batch 240 of 244.

Evaluating…
        Batch  10 of  53.
        Batch  20 of  53.
        Batch  30 of  53.
        Batch  40 of  53.
```

```
        Batch  50 of  53.

Training Loss: 0.669
Training Time Taken: 12.19 seconds
Validation Loss: 0.643
Validation Time Taken: 2.23 seconds

Epoch 2 of 500
        Batch  20 of 244.
        Batch  40 of 244.
        Batch  60 of 244.
        Batch  80 of 244.
        Batch 100 of 244.
        Batch 120 of 244.
        Batch 140 of 244.
        Batch 160 of 244.
        Batch 180 of 244.
        Batch 200 of 244.
        Batch 220 of 244.
        Batch 240 of 244.

Evaluating…
        Batch  10 of  53.
        Batch  20 of  53.
        Batch  30 of  53.
        Batch  40 of  53.
        Batch  50 of  53.

Training Loss: 0.627
Training Time Taken: 10.92 seconds
Validation Loss: 0.599
Validation Time Taken: 2.25 seconds

Epoch 3 of 500
        Batch  20 of 244.
        Batch  40 of 244.
        Batch  60 of 244.
        Batch  80 of 244.
        Batch 100 of 244.
        Batch 120 of 244.
        Batch 140 of 244.
        Batch 160 of 244.
        Batch 180 of 244.
        Batch 200 of 244.
        Batch 220 of 244.
        Batch 240 of 244.

Evaluating…
```

```
        Batch 180 of 244.
        Batch 200 of 244.
        Batch 220 of 244.
        Batch 240 of 244.

Evaluating…
        Batch  10 of  53.
        Batch  20 of  53.
        Batch  30 of  53.
        Batch  40 of  53.
        Batch  50 of  53.

Training Loss: 0.115
Training Time Taken: 10.11 seconds
Validation Loss: 0.179
Validation Time Taken: 2.09 seconds

Epoch 499 of 500
        Batch  20 of 244.
        Batch  40 of 244.
        Batch  60 of 244.
        Batch  80 of 244.
        Batch 100 of 244.
        Batch 120 of 244.
        Batch 140 of 244.
        Batch 160 of 244.
        Batch 180 of 244.
        Batch 200 of 244.
        Batch 220 of 244.
        Batch 240 of 244.

Evaluating…
        Batch  10 of  53.
        Batch  20 of  53.
        Batch  30 of  53.
        Batch  40 of  53.
        Batch  50 of  53.

Training Loss: 0.130
Training Time Taken: 10.15 seconds
Validation Loss: 0.189
Validation Time Taken: 2.09 seconds

Epoch 500 of 500
        Batch  20 of 244.
        Batch  40 of 244.
        Batch  60 of 244.
        Batch  80 of 244.
```

```
        Batch 100 of 244.
        Batch 120 of 244.
        Batch 140 of 244.
        Batch 160 of 244.
        Batch 180 of 244.
        Batch 200 of 244.
        Batch 220 of 244.
        Batch 240 of 244.

Evaluating…
        Batch  10 of  53.
        Batch  20 of  53.
        Batch  30 of  53.
        Batch  40 of  53.
        Batch  50 of  53.

Training Loss: 0.157
Training Time Taken: 10.13 seconds
Validation Loss: 0.264
Validation Time Taken: 2.09 seconds
```

[ ]:
```
# Print total time taken for all epochs
print(f'\nTotal Time Taken: {totalTimeTaken:.2f} seconds | {(totalTimeTaken /␣
↪60):.2f} minutes | {(totalTimeTaken / 3600):.2f} hours')
```

```
Total Time Taken: 6125.29 seconds | 102.09 minutes | 1.70 hours
```

[ ]:
```
# Save tensors to a JSON file
saveToJSON('./assets/tensors/tensors.json',␣
↪testSequenceTensor=testSequenceTensor, testMaskTensor=testMaskTensor,␣
↪testYTensor=testYTensor, trainingLossTensor=trainingLosses,␣
↪validationLossTensor=validationLosses, epochs=EPOCHS)
```

---

# Training a Custom BERT Model for Spam Document Classification (2 of 2)

May 1, 2023

This project on training a custom BERT model for document classification serves as the end-semester course project for semester VI's natural language processing course.

## 1 About this notebook

This notebook is 2 of 2 notebooks with the objective to analyse the custom BERT model we trained in the last notebook on a dataset of labelled spam documents. I hope to see if the model can accurately distinguish between spam and non-spam documents with high efficiency.

## 2 Import Libraries

[ ]:
```
import torch
import torch
import torch.nn as nn
from torchsummary import summary

import transformers
from transformers import BertForSequenceClassification
from transformers import AutoModel, BertTokenizerFast

from sklearn.metrics import classification_report
from sklearn.metrics import accuracy_score

import matplotlib.pyplot as plt
import seaborn as sns

import numpy as np
import json
```

# 3 Loading our Trained Model

## 3.1 Define the Default BERT Architecture

[ ]:
```
# Import the BERT-base pretrained model
BERT = AutoModel.from_pretrained('bert-base-uncased')

# Load the BERT tokenizer
# tokenizer = BertTokenizerFast.from_pretrained('bert-base-uncased')
```

```
Some weights of the model checkpoint at bert-base-uncased were not used when
initializing BertModel: ['cls.predictions.transform.LayerNorm.bias',
'cls.predictions.transform.dense.weight',
'cls.predictions.transform.LayerNorm.weight', 'cls.predictions.bias',
'cls.predictions.transform.dense.bias', 'cls.seq_relationship.bias',
'cls.predictions.decoder.weight', 'cls.seq_relationship.weight']
- This IS expected if you are initializing BertModel from the checkpoint of a
model trained on another task or with another architecture (e.g. initializing a
BertForSequenceClassification model from a BertForPreTraining model).
- This IS NOT expected if you are initializing BertModel from the checkpoint of
a model that you expect to be exactly identical (initializing a
BertForSequenceClassification model from a BertForSequenceClassification model).
```

## 3.2 Define Custom BERT Architecture

[ ]:
```
class customBERTArchitecture(nn.Module):
    def __init__(self, bert):
        super(customBERTArchitecture, self).__init__()
        self.bert = bert

        # Dropout layer
        self.dropout = nn.Dropout(0.1)

        # ReLU activation function
        self.relu =  nn.ReLU()

        # Dense layer 1
        self.fullyConnected1 = nn.Linear(768, 512)

        # Dense layer 2 (Output layer)
        self.fullyConnected2 = nn.Linear(512, 2)

        # Softmax activation function
        self.softmax = nn.LogSoftmax(dim=1)

    # Define the forward pass
    def forward(self, sent_id, mask):
        # Pass the inputs to the model
```

```
        _, cls_hs = self.bert(sent_id, attention_mask=mask, return_dict=False)

        # Input layer
        x = self.fullyConnected1(cls_hs)
        x = self.relu(x)
        x = self.dropout(x)

        # Output layer
        x = self.fullyConnected2(x)

        # Apply softmax activation
        x = self.softmax(x)
        return x
```

## 4 Define GPU Here if Available

[ ]:
```
deviceName = "cuda" if torch.cuda.is_available() else "cpu"
```

[ ]:
```
device = torch.device(deviceName)
```

[ ]:
```
!nvidia-smi
```

```
NVIDIA-SMI has failed because it couldn't communicate with the NVIDIA driver.
Make sure that the latest NVIDIA driver is installed and running.
```

## 5 Load the Weights of our Pre-trained Custom BERT Model

[ ]:
```
# Create an instance of the model
model = customBERTArchitecture(BERT)

# Load the saved weights
model.load_state_dict(torch.load('./assets/weights/weights.pt',␣
 ↪map_location=torch.device(deviceName)))

# Set the model to evaluation mode
model.eval()
```

[ ]:
```
customBERTArchitecture(
  (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)
  (relu): ReLU()
  (fullyConnected1): Linear(in_features=768, out_features=512, bias=True)
  (fullyConnected2): Linear(in_features=512, out_features=2, bias=True)
  (softmax): LogSoftmax(dim=1)
)
```

## 6 Loading Pre-generated Tensors

### 6.1 Define a Function to Read Tensor Data from a JSON file

[ ]:
```
def loadTensorsFromJSON(filePath):
    """
    Load PyTorch tensors from a JSON file.

    Args:
        file_path (str): Path to the JSON file to load from.

    Returns:
        A dictionary where the keys are the names of the tensors and the values␣
↪are the PyTorch tensors loaded from the file.
    """
    with open(filePath, 'r') as f:
        toLoad = json.load(f)

    tensors = {}

    for name, variable in toLoad.items():
        tensors[name] = torch.tensor(variable)

    return tensors
```

[ ]:
```
tensors = loadTensorsFromJSON('./assets/tensors/tensors.json')
tensors
```

[ ]:
```
{'testSequenceTensor': tensor([[  101,  4067,  2017,  …,     0,     0,     0],
         [  101,  6203,  5718,  …,  2345,  3535,   102],
         [  101,  2073,  2024,  …,     0,     0,     0],
         …,
         [  101,  2053,  1012,  …,  4309,  2489,   102],
         [  101,  1015,  1045,  …,  1005,  1040,   102],
         [  101,  2524,  2444,  …, 21472, 21472,   102]]),
 'testMaskTensor': tensor([[1, 1, 1,  …, 0, 0, 0],
         [1, 1, 1,  …, 1, 1, 1],
         [1, 1, 1,  …, 0, 0, 0],
         …,
         [1, 1, 1,  …, 1, 1, 1],
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         [1, 1, 1,  …, 1, 1, 1]]),
 'testYTensor': tensor([0, 1, 0, 0, 0, 1, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0,
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         0, 0, 0, 1, 0, 1, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1, 0,
         0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 1, 0, 0,
         0, 0, 0, 1, 1, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 1,
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```

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```
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        0.1612, 0.1423, 0.1417, 0.1405, 0.1451, 0.1595, 0.1697, 0.1430, 0.1417,
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        0.1445, 0.1344, 0.1540, 0.1497, 0.1217, 0.1407, 0.1400, 0.1093, 0.1350,
        0.1398, 0.1275, 0.1211, 0.1263, 0.1213, 0.1243, 0.1467, 0.1254, 0.1272,
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        0.1323, 0.1302, 0.1533, 0.1339, 0.1488, 0.1169, 0.1240, 0.1250, 0.1304,
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```

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0.1879, 0.1499, 0.1621, 0.1613, 0.1898, 0.1617, 0.1869, 0.1716, 0.1868,
0.2104, 0.2042, 0.2280, 0.1961, 0.2708, 0.1995, 0.1975, 0.1605, 0.1862,
0.2081, 0.1592, 0.2099, 0.2072, 0.1579, 0.2324, 0.1578, 0.2117, 0.1931,
0.1832, 0.1544, 0.1576, 0.1983, 0.1592, 0.2223, 0.2550, 0.1984, 0.1656,
0.1608, 0.2107, 0.1862, 0.2257, 0.2255, 0.1743, 0.2246, 0.1622, 0.1928,
0.1968, 0.2121, 0.2625, 0.1890, 0.1743, 0.2222, 0.2319, 0.1809, 0.1869,
0.1803, 0.2094, 0.1649, 0.1572, 0.1797, 0.1917, 0.2036, 0.2088, 0.1750,
0.2286, 0.2299, 0.2286, 0.2362, 0.2930, 0.1544, 0.1732, 0.1687, 0.1579,
0.2794, 0.1436, 0.1765, 0.1862, 0.1930, 0.2135, 0.2386, 0.1378, 0.2365,
0.1657, 0.1875, 0.1593, 0.1836, 0.1337, 0.1811, 0.2358, 0.1992, 0.1912,
0.1977, 0.1656, 0.2098, 0.2726, 0.1748, 0.2024, 0.2002, 0.1705, 0.1527,
0.2304, 0.1965, 0.1514, 0.1983, 0.1790, 0.2132, 0.2053, 0.1933, 0.1683,
0.2753, 0.1992, 0.2257, 0.1812, 0.1938, 0.1819, 0.1725, 0.2336, 0.2127,
0.1845, 0.2281, 0.1863, 0.2002, 0.1648, 0.1908, 0.2186, 0.1632, 0.1956,
0.1859, 0.1830, 0.1970, 0.2822, 0.2137, 0.2138, 0.1972, 0.1856, 0.2353,
0.1719, 0.2002, 0.1769, 0.2313, 0.1965, 0.1835, 0.1859, 0.2513, 0.1781,
0.1365, 0.2122, 0.1737, 0.1553, 0.1771, 0.1919, 0.1820, 0.1660, 0.2069,
0.2032, 0.2054, 0.2024, 0.1990, 0.1678, 0.2410, 0.1628, 0.1762, 0.1722,

```
        0.1887, 0.1799, 0.2400, 0.1644, 0.1937, 0.1604, 0.1421, 0.1784, 0.1651,
        0.2199, 0.2101, 0.2851, 0.2092, 0.1873, 0.2243, 0.1813, 0.2353, 0.1952,
        0.2153, 0.2096, 0.1789, 0.1890, 0.2640]),
 'epochs': tensor(500)}
```

### 6.2 Saving the Tensors

[ ]:
```
testSequenceTensor = tensors['testSequenceTensor']
testMaskTensor = tensors['testMaskTensor']
testYTensor = tensors['testYTensor']
trainingLossTensor = tensors['trainingLossTensor']
validationLossTensor = tensors['validationLossTensor']
epochs = tensors['epochs']
```

## 7 Using Trained Model to Predict

[ ]:
```
# Get predictions for test data
with torch.no_grad():
    preds = model(testSequenceTensor.to(device), testMaskTensor.to(device))
    preds = preds.detach().cpu().numpy()
```

## 8 Check Model's Performance on Testing Data

[ ]:
```
# Model's performance as a classification report
predications = np.argmax(preds, axis=1)

print(classification_report(testYTensor, predications))
```

```
              precision    recall  f1-score   support

           0       0.99      0.98      0.99       724
           1       0.90      0.96      0.93       112

    accuracy                           0.98       836
   macro avg       0.95      0.97      0.96       836
weighted avg       0.98      0.98      0.98       836
```

[ ]:
```
# Calculate the accuracy on the test set
accuracy = accuracy_score(testYTensor, predications)

print(f"Test accuracy: {accuracy*100:.2f}%")
```

```
Test accuracy: 98.09%
```

# 9 Plotting Change in Training and Validation Losses

## 9.1 Convert Lists to Arrays

[ ]:
```
# Convert trainingLosses into a numpy array
trainingLosses = np.array(trainingLossTensor)

# Convert validationLosses into a numpy array
validationLosses = np.array(validationLossTensor)
```

## 9.2 Creating an x-axis

[ ]:
```
X = np.arange(0, epochs)
```

[ ]:
```
X.shape, trainingLosses.shape
```

[ ]:
```
((500,), (500,))
```

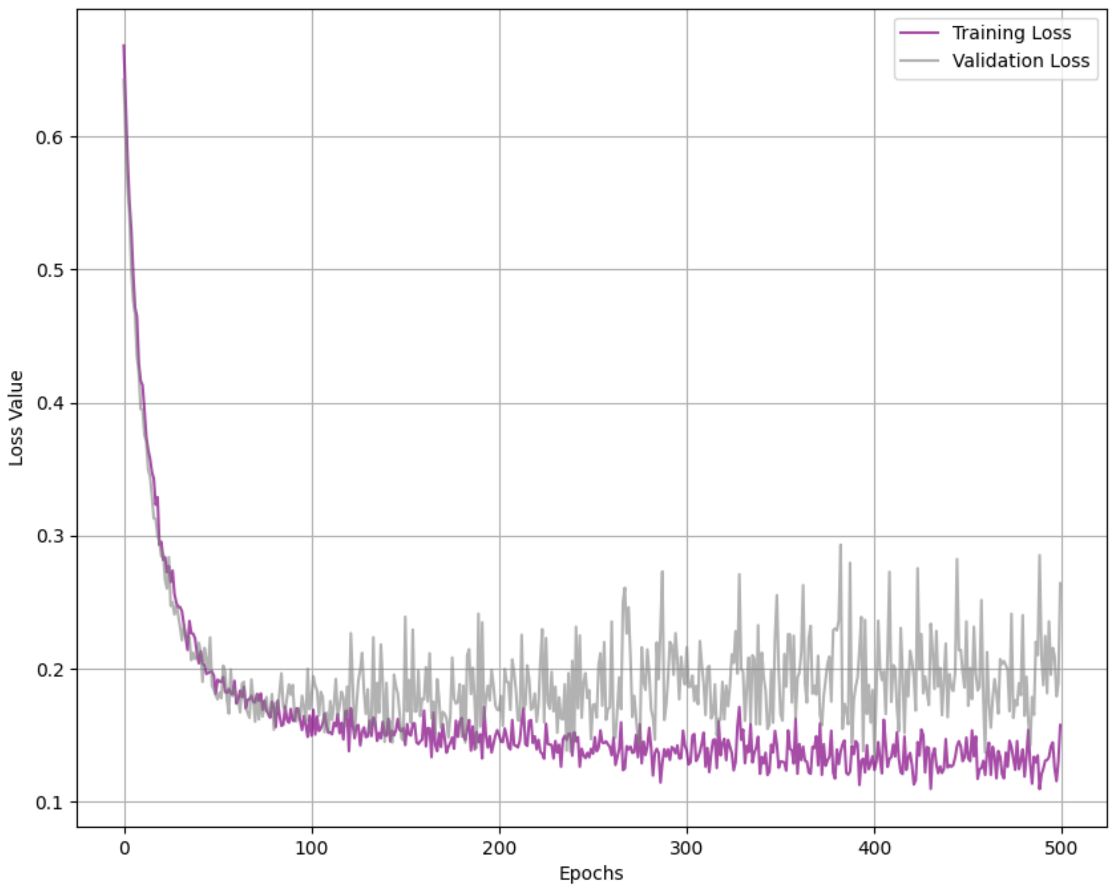
## 9.3 Plotting losses

[ ]:
```
plt.figure(figsize=(10, 8))
plt.grid()

plt.xlabel("Epochs")
plt.ylabel("Loss Value")

plt.plot(X, trainingLosses, label='Training Loss', color='purple', alpha=0.7)
plt.plot(X, validationLosses, label='Validation Loss', color='gray', alpha=0.6)

plt.legend()
plt.show()
```


Training Loss
Validation Loss
Loss Value
Epochs
0.1
0.2
0.3
0.4
0.5
0.6
0
100
200
300
400
500