distilation-bert

March 23, 2025

1 DistilBERT, a distilled version of BERT: smaller, faster, cheaper and lighter

In this lecture, we will explore the architecture of DistilBERT, its key components, and how it can be utilized for various natural language processing tasks. Additionally, we'll discuss its advantages, limitations, and provide hands-on examples to showcase its effectiveness.

Reference : The Theory | Code

[ ]:
```
# TODO
# Find dataset - done
# train two students odd and even - process
# LORA train
# Make table evaluation and analysis - Evaluate the models on the test set, and␣
↪analyze the performance of the models trained with Odd
 # Layers, Even Layers, and LoRA. Discuss the differences in performance across␣
↪the three methods.
 # Discuss the challenges encountered during the implementation, specifically␣
↪comparing distillation
```

[ ]:
```
import os
import copy
# Set GPU device
# os.environ["CUDA_VISIBLE_DEVICES"] = "2"

# os.environ['http_proxy']  = 'http://192.41.170.23:3128'
# os.environ['https_proxy'] = 'http://192.41.170.23:3128'

!pip install datasets transformers evaluate
import datasets

import torch
import torch.nn as nn
import torch.optim as optim
from torch.nn import Module
import torch.nn.functional as F
from torch.utils.data import DataLoader
```

```
from tqdm.auto import tqdm
import random, math, time
import numpy as np

!pip install opencv-python opencv-python-headless
import transformers
from transformers import TrainingArguments, Trainer, default_data_collator
from transformers import AutoModelForSequenceClassification, AutoTokenizer,␣
 ↪DataCollatorWithPadding
from transformers.models.bert.modeling_bert import BertPreTrainedModel,␣
 ↪BertConfig
from transformers.models.bert.modeling_bert import BertEncoder, BertModel
from transformers import get_scheduler

print(datasets.__version__, transformers.__version__, torch.__version__)

import evaluate

from sklearn.metrics import accuracy_score, precision_score, recall_score,␣
 ↪f1_score, ConfusionMatrixDisplay
from sklearn.metrics import classification_report

import matplotlib.pyplot as plt

!pip install peft
from peft import LoraConfig, TaskType, get_peft_model
```

```
Requirement already satisfied: datasets in /usr/local/lib/python3.10/dist-
packages (3.3.1)
Requirement already satisfied: transformers in /usr/local/lib/python3.10/dist-
packages (4.47.0)
Collecting evaluate
  Downloading evaluate-0.4.3-py3-none-any.whl.metadata (9.2 kB)
Requirement already satisfied: filelock in /usr/local/lib/python3.10/dist-
packages (from datasets) (3.17.0)
Requirement already satisfied: numpy>=1.17 in /usr/local/lib/python3.10/dist-
packages (from datasets) (1.26.4)
Requirement already satisfied: pyarrow>=15.0.0 in
/usr/local/lib/python3.10/dist-packages (from datasets) (19.0.1)
Requirement already satisfied: dill<0.3.9,>=0.3.0 in
/usr/local/lib/python3.10/dist-packages (from datasets) (0.3.8)
Requirement already satisfied: pandas in /usr/local/lib/python3.10/dist-packages
(from datasets) (2.2.3)
Requirement already satisfied: requests>=2.32.2 in
/usr/local/lib/python3.10/dist-packages (from datasets) (2.32.3)
Requirement already satisfied: tqdm>=4.66.3 in /usr/local/lib/python3.10/dist-
packages (from datasets) (4.67.1)
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Requirement already satisfied: xxhash in /usr/local/lib/python3.10/dist-packages
(from datasets) (3.5.0)
Requirement already satisfied: multiprocess<0.70.17 in
/usr/local/lib/python3.10/dist-packages (from datasets) (0.70.16)
Requirement already satisfied: fsspec<=2024.12.0,>=2023.1.0 in
/usr/local/lib/python3.10/dist-packages (from
fsspec[http]<=2024.12.0,>=2023.1.0->datasets) (2024.12.0)
Requirement already satisfied: aiohttp in /usr/local/lib/python3.10/dist-
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/usr/local/lib/python3.10/dist-packages (from datasets) (0.29.0)
Requirement already satisfied: packaging in /usr/local/lib/python3.10/dist-
packages (from datasets) (24.2)
Requirement already satisfied: pyyaml>=5.1 in /usr/local/lib/python3.10/dist-
packages (from datasets) (6.0.2)
Requirement already satisfied: regex!=2019.12.17 in
/usr/local/lib/python3.10/dist-packages (from transformers) (2024.11.6)
Requirement already satisfied: tokenizers<0.22,>=0.21 in
/usr/local/lib/python3.10/dist-packages (from transformers) (0.21.0)
Requirement already satisfied: safetensors>=0.4.1 in
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/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets) (2.4.6)
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/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets) (1.3.2)
Requirement already satisfied: async-timeout<6.0,>=4.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets) (5.0.1)
Requirement already satisfied: attrs>=17.3.0 in /usr/local/lib/python3.10/dist-
packages (from aiohttp->datasets) (25.1.0)
Requirement already satisfied: frozenlist>=1.1.1 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets) (1.5.0)
Requirement already satisfied: multidict<7.0,>=4.5 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets) (6.1.0)
Requirement already satisfied: propcache>=0.2.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets) (0.2.1)
Requirement already satisfied: yarl<2.0,>=1.17.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets) (1.18.3)
Requirement already satisfied: typing-extensions>=3.7.4.3 in
/usr/local/lib/python3.10/dist-packages (from huggingface-hub>=0.24.0->datasets)
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Requirement already satisfied: mkl_fft in /usr/local/lib/python3.10/dist-
packages (from numpy>=1.17->datasets) (1.3.8)
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Requirement already satisfied: mkl_umath in /usr/local/lib/python3.10/dist-
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(from numpy>=1.17->datasets) (2025.0.1)
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Requirement already satisfied: tbb4py in /usr/local/lib/python3.10/dist-packages
(from numpy>=1.17->datasets) (2022.0.0)
Requirement already satisfied: mkl-service in /usr/local/lib/python3.10/dist-
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/usr/local/lib/python3.10/dist-packages (from requests>=2.32.2->datasets)
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Requirement already satisfied: certifi>=2017.4.17 in
/usr/local/lib/python3.10/dist-packages (from requests>=2.32.2->datasets)
(2025.1.31)
Requirement already satisfied: python-dateutil>=2.8.2 in
/usr/local/lib/python3.10/dist-packages (from pandas->datasets) (2.9.0.post0)
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Requirement already satisfied: intel-openmp>=2024 in
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/usr/local/lib/python3.10/dist-packages (from intel-
openmp>=2024->mkl->numpy>=1.17->datasets) (2024.2.0)
Downloading evaluate-0.4.3-py3-none-any.whl (84 kB)
                          84.0/84.0 kB
2.7 MB/s eta 0:00:00
Installing collected packages: evaluate
Successfully installed evaluate-0.4.3
Requirement already satisfied: opencv-python in /usr/local/lib/python3.10/dist-
packages (4.10.0.84)
Requirement already satisfied: opencv-python-headless in
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packages (from numpy>=1.21.2->opencv-python) (1.3.8)
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(from peft) (5.9.5)
Requirement already satisfied: pyyaml in /usr/local/lib/python3.10/dist-packages
(from peft) (6.0.2)
Requirement already satisfied: torch>=1.13.0 in /usr/local/lib/python3.10/dist-
packages (from peft) (2.5.1+cu121)
Requirement already satisfied: transformers in /usr/local/lib/python3.10/dist-
packages (from peft) (4.47.0)
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Requirement already satisfied: safetensors in /usr/local/lib/python3.10/dist-
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Requirement already satisfied: huggingface-hub>=0.25.0 in
/usr/local/lib/python3.10/dist-packages (from peft) (0.29.0)
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packages (from huggingface-hub>=0.25.0->peft) (3.17.0)
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(from numpy>=1.17->peft) (2025.0.1)
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(from numpy>=1.17->peft) (2022.0.0)
Requirement already satisfied: mkl-service in /usr/local/lib/python3.10/dist-
packages (from numpy>=1.17->peft) (2.4.1)
Requirement already satisfied: networkx in /usr/local/lib/python3.10/dist-
packages (from torch>=1.13.0->peft) (3.4.2)
Requirement already satisfied: jinja2 in /usr/local/lib/python3.10/dist-packages
(from torch>=1.13.0->peft) (3.1.4)
Requirement already satisfied: sympy==1.13.1 in /usr/local/lib/python3.10/dist-
packages (from torch>=1.13.0->peft) (1.13.1)
Requirement already satisfied: mpmath<1.4,>=1.1.0 in
/usr/local/lib/python3.10/dist-packages (from
sympy==1.13.1->torch>=1.13.0->peft) (1.3.0)
Requirement already satisfied: regex!=2019.12.17 in
/usr/local/lib/python3.10/dist-packages (from transformers->peft) (2024.11.6)
Requirement already satisfied: tokenizers<0.22,>=0.21 in
/usr/local/lib/python3.10/dist-packages (from transformers->peft) (0.21.0)
Requirement already satisfied: MarkupSafe>=2.0 in
/usr/local/lib/python3.10/dist-packages (from jinja2->torch>=1.13.0->peft)
(3.0.2)
Requirement already satisfied: intel-openmp>=2024 in
/usr/local/lib/python3.10/dist-packages (from mkl->numpy>=1.17->peft) (2024.2.0)
Requirement already satisfied: tbb==2022.* in /usr/local/lib/python3.10/dist-
packages (from mkl->numpy>=1.17->peft) (2022.0.0)
Requirement already satisfied: tcmlib==1.* in /usr/local/lib/python3.10/dist-
packages (from tbb==2022.*->mkl->numpy>=1.17->peft) (1.2.0)
Requirement already satisfied: intel-cmplr-lib-rt in
/usr/local/lib/python3.10/dist-packages (from mkl_umath->numpy>=1.17->peft)
(2024.2.0)
Requirement already satisfied: charset-normalizer<4,>=2 in
/usr/local/lib/python3.10/dist-packages (from requests->huggingface-
```

```
hub>=0.25.0->peft) (3.4.1)
Requirement already satisfied: idna<4,>=2.5 in /usr/local/lib/python3.10/dist-
packages (from requests->huggingface-hub>=0.25.0->peft) (3.10)
Requirement already satisfied: urllib3<3,>=1.21.1 in
/usr/local/lib/python3.10/dist-packages (from requests->huggingface-
hub>=0.25.0->peft) (2.3.0)
Requirement already satisfied: certifi>=2017.4.17 in
/usr/local/lib/python3.10/dist-packages (from requests->huggingface-
hub>=0.25.0->peft) (2025.1.31)
Requirement already satisfied: intel-cmplr-lib-ur==2024.2.0 in
/usr/local/lib/python3.10/dist-packages (from intel-
openmp>=2024->mkl->numpy>=1.17->peft) (2024.2.0)
```

[ ]:
```python
device = torch.device('cuda' if torch.cuda.is_available() else 'cpu')
print(device)

#make our work comparable if restarted the kernel
SEED = 1234
torch.manual_seed(SEED)
torch.backends.cudnn.deterministic = True
```

```
cuda
```

[ ]:
```python
# from huggingface_hub import login
# login()
```

1.1 1. Loading our MNLI part of the GLUE dataset

[ ]:
```python
###1. Load Dataset
task_to_keys = {
    "cola": ("sentence", None),
    "mnli": ("premise", "hypothesis"),
    "mrpc": ("sentence1", "sentence2"),
    "qnli": ("question", "sentence"),
    "qqp": ("question1", "question2"),
    "rte": ("sentence1", "sentence2"),
    "sst2": ("comment_text", None),
    "stsb": ("sentence1", "sentence2"),
    "wnli": ("sentence1", "sentence2"),
    "cstm": ("comment_text", None),
}

task_name = "cstm"
# dataset: https://huggingface.co/datasets/OxAISH-AL-LLM/wiki_toxic
# https://huggingface.co/datasets/mteb/toxic_conversations_50k
# raw_datasets = datasets.load_dataset("glue", task_name)
raw_datasets = datasets.load_dataset("OxAISH-AL-LLM/wiki_toxic")
raw_datasets
```

```
README.md:   0%|          | 0.00/4.30k [00:00<?, ?B/s]

wiki_toxic.py:   0%|          | 0.00/4.55k [00:00<?, ?B/s]

0000.parquet:   0%|          | 0.00/35.2M [00:00<?, ?B/s]

0000.parquet:   0%|          | 0.00/8.85M [00:00<?, ?B/s]

0000.parquet:   0%|          | 0.00/17.3M [00:00<?, ?B/s]

0000.parquet:   0%|          | 0.00/6.18M [00:00<?, ?B/s]

Generating train split:   0%|          | 0/127656 [00:00<?, ? examples/s]

Generating validation split:   0%|          | 0/31915 [00:00<?, ? examples/s]

Generating test split:   0%|          | 0/63978 [00:00<?, ? examples/s]

Generating balanced_train split:   0%|          | 0/25868 [00:00<?, ? examples/s]
```

[ ]:
```
DatasetDict({
    train: Dataset({
        features: ['id', 'comment_text', 'label'],
        num_rows: 127656
    })
    validation: Dataset({
        features: ['id', 'comment_text', 'label'],
        num_rows: 31915
    })
    test: Dataset({
        features: ['id', 'comment_text', 'label'],
        num_rows: 63978
    })
    balanced_train: Dataset({
        features: ['id', 'comment_text', 'label'],
        num_rows: 25868
    })
})
```

[ ]:
```python
label_list = raw_datasets['balanced_train'].features['label'].names
label2id = {v: i for i, v in enumerate(label_list)}
label2id
```

[ ]:
```
{'non': 0, 'tox': 1}
```

[ ]:
```python
id2label = {i: v for v, i in label2id.items()}
id2label
```

[ ]:
```
{0: 'non', 1: 'tox'}
```

1.2 2. Model & Tokenization

[ ]:
```
num_labels = np.unique(raw_datasets['balanced_train']['label']).size
num_labels
```

[ ]: 2

[ ]:
```
teacher_id = "bert-base-uncased"
tokenizer = AutoTokenizer.from_pretrained(teacher_id)

teacher_model = AutoModelForSequenceClassification.from_pretrained(
    teacher_id,
    num_labels = num_labels,
    id2label = id2label,
    label2id = label2id,
)

teacher_model
```

```
tokenizer_config.json:   0%|          | 0.00/48.0 [00:00<?, ?B/s]

config.json:   0%|          | 0.00/570 [00:00<?, ?B/s]

vocab.txt:   0%|          | 0.00/232k [00:00<?, ?B/s]

tokenizer.json:   0%|          | 0.00/466k [00:00<?, ?B/s]

model.safetensors:   0%|          | 0.00/440M [00:00<?, ?B/s]

Some weights of BertForSequenceClassification were not initialized from the
model checkpoint at bert-base-uncased and are newly initialized:
['classifier.bias', 'classifier.weight']
You should probably TRAIN this model on a down-stream task to be able to use it
for predictions and inference.
```

[ ]:
```
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): BertSdpaSelfAttention(
              (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=2, bias=True)
)
```

1.3 3. Preprocessing

[ ]:
```
def tokenize_function(examples):
    sentence1_key, sentence2_key = task_to_keys[task_name]
    args = (
        (examples[sentence1_key],) if sentence2_key is None else␣
 ↪(examples[sentence1_key], examples[sentence2_key])
    )
    result = tokenizer(*args, max_length=128, truncation=True)
    return result
```

[ ]:
```
tokenized_datasets = raw_datasets.map(tokenize_function, batched=True)
tokenized_datasets
```

```
Map:   0%|          | 0/127656 [00:00<?, ? examples/s]

Map:   0%|          | 0/31915 [00:00<?, ? examples/s]

Map:   0%|          | 0/63978 [00:00<?, ? examples/s]
```

```
Map:   0%|          | 0/25868 [00:00<?, ? examples/s]
```

[ ]:
```
DatasetDict({
    train: Dataset({
        features: ['id', 'comment_text', 'label', 'input_ids', 'token_type_ids',
'attention_mask'],
        num_rows: 127656
    })
    validation: Dataset({
        features: ['id', 'comment_text', 'label', 'input_ids', 'token_type_ids',
'attention_mask'],
        num_rows: 31915
    })
    test: Dataset({
        features: ['id', 'comment_text', 'label', 'input_ids', 'token_type_ids',
'attention_mask'],
        num_rows: 63978
    })
    balanced_train: Dataset({
        features: ['id', 'comment_text', 'label', 'input_ids', 'token_type_ids',
'attention_mask'],
        num_rows: 25868
    })
})
```

[ ]:
```
# list(task_to_keys[task_name])
column_dataset = [item for item in task_to_keys[task_name] if item is not None]
column_dataset
```

[ ]:
```
['comment_text']
```

[ ]:
```
#remove column : 'premise', 'hypothesis', 'idx'
tokenized_datasets = tokenized_datasets.remove_columns(column_dataset + ["id"])
#rename column : 'labels'
tokenized_datasets = tokenized_datasets.rename_column("label", "labels")
tokenized_datasets.set_format("torch")
tokenized_datasets
```

[ ]:
```
DatasetDict({
    train: Dataset({
        features: ['labels', 'input_ids', 'token_type_ids', 'attention_mask'],
        num_rows: 127656
    })
    validation: Dataset({
        features: ['labels', 'input_ids', 'token_type_ids', 'attention_mask'],
        num_rows: 31915
    })
    test: Dataset({
```

```
        features: ['labels', 'input_ids', 'token_type_ids', 'attention_mask'],
        num_rows: 63978
    })
    balanced_train: Dataset({
        features: ['labels', 'input_ids', 'token_type_ids', 'attention_mask'],
        num_rows: 25868
    })
})
```

[ ]:
```
tokenized_datasets['balanced_train'][0]['input_ids']
```

[ ]:
```
tensor([  101,  1000,  2025,  2065,  1045,  2064,  2393,  2009,  1012,  8494,
        14540,  5178,  2003,  2062,  2066,  2009,  1012,  1012,  1012,  1012,
        13029,  1000,   102])
```

[ ]:
```
tokenizer.decode(tokenized_datasets['balanced_train'][0]['input_ids'])
```

[ ]:
```
'[CLS] " not if i can help it. mudslide is more like it… 127 " [SEP]'
```

1.4 4. Preparing the dataloader

[ ]:
```
data_collator = DataCollatorWithPadding(tokenizer=tokenizer)
#Data collator that will dynamically pad the inputs received.
```

[ ]:
```
small_train_dataset = tokenized_datasets["balanced_train"].shuffle(seed=1150).
 ↪select(range(25868))
small_eval_dataset = tokenized_datasets["validation"].shuffle(seed=1150).
 ↪select(range(1000))
small_test_dataset = tokenized_datasets["test"].shuffle(seed=1150).
 ↪select(range(1000))
```

[ ]:
```
train_dataloader = DataLoader(
    small_train_dataset, shuffle=True, batch_size=32, collate_fn=data_collator)
test_dataloader = DataLoader(
    small_test_dataset, batch_size=32, collate_fn=data_collator)
eval_dataloader = DataLoader(
    small_eval_dataset, batch_size=32, collate_fn=data_collator)
```

[ ]:
```
for batch in train_dataloader:
    break

batch['labels'].shape, batch['input_ids'].shape, batch['attention_mask'].shape
```

[ ]:
```
(torch.Size([32]), torch.Size([32, 128]), torch.Size([32, 128]))
```

1.5 5. Design the model and losses

1.5.1 5.1 Teacher Model & Student Model

Architecture In the present work, the student - DistilBERT - has the same general architecture as BERT. - The `token-type embeddings` and the `pooler` are removed while `the number of layers` is reduced by a factor of 2. - Most of the operations used in the Transformer architecture `linear layer` and `layer normalisation` are highly optimized in modern linear algebra frameworks. - our investigations showed that variations on the last dimension of the tensor (hidden size dimension) have a smaller impact on computation efficiency (for a fixed parameters budget) than variations on other factors like the number of layers. - Thus we focus on reducing the number of layers.

Initialize Student Model

- To initialize a new model from an existing one, we need to access the weights of the old model (the teacher).
- In order to get the weights, we first have to know how to access them. We'll use BERT as our teacher model.

[ ]:
```
teacher_model.config
```

[ ]:
```
BertConfig {
  "_attn_implementation_autoset": true,
  "_name_or_path": "bert-base-uncased",
  "architectures": [
    "BertForMaskedLM"
  ],
  "attention_probs_dropout_prob": 0.1,
  "classifier_dropout": null,
  "gradient_checkpointing": false,
  "hidden_act": "gelu",
  "hidden_dropout_prob": 0.1,
  "hidden_size": 768,
  "id2label": {
    "0": "non",
    "1": "tox"
  },
  "initializer_range": 0.02,
  "intermediate_size": 3072,
  "label2id": {
    "non": 0,
    "tox": 1
  },
  "layer_norm_eps": 1e-12,
  "max_position_embeddings": 512,
  "model_type": "bert",
  "num_attention_heads": 12,
  "num_hidden_layers": 12,
```

```
  "pad_token_id": 0,
  "position_embedding_type": "absolute",
  "transformers_version": "4.47.0",
  "type_vocab_size": 2,
  "use_cache": true,
  "vocab_size": 30522
}
```

- The student model has the same configuration, except the number of layers is reduced by a factor of 2
- The student layers are initilized by copying one out of two layers of the teacher, starting with layer 0.
- The head of the teacher is also copied.

[ ]:
```python
# Get teacher configuration as a dictionnary
configuration = teacher_model.config.to_dict()
# configuration
```

[ ]:
```python
# Half the number of hidden layer
configuration['num_hidden_layers'] //= 2
# Convert the dictionnary to the student configuration
conf_odd  = BertConfig.from_dict(configuration)
conf_even = copy.deepcopy(BertConfig.from_dict(configuration))
```

[ ]:
```python
# Create uninitialized student model
model_odd = type(teacher_model)(conf_odd)
model_odd

# Create uninitialized student model
model_even = type(teacher_model)(conf_even)
model_even
```

[ ]:
```
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(
        (0-5): 6 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=2, bias=True)
)
```

- Recursively copies the weights of the (teacher) to the (student).
- This function is meant to be first called on a BertFor... model, but is then called on every children of that model recursively.
- The only part that's not fully copied is the encoder, of which only half is copied.

[ ]:
```
def distill_bert_weights(
    teacher : Module,
    student : Module,
    iseven: bool,
) -> None:
    """
    Recursively copies the weights of the (teacher) to the (student).
    This function is meant to be first called on a BertFor... model, but is␣
 ↪then called on every children of that model recursively.
```

```
    The only part that's not fully copied is the encoder, of which only half is␣
↪copied.
    """
    # If the part is an entire BERT model or a BERTFor..., unpack and iterate
    if isinstance(teacher, BertModel) or type(teacher).__name__.
↪startswith('BertFor'):
        for teacher_part, student_part in zip(teacher.children(), student.
↪children()):
            distill_bert_weights(teacher_part, student_part, iseven)
    # Else if the part is an encoder, copy one out of every layer
    elif isinstance(teacher, BertEncoder):
        teacher_encoding_layers = [layer for layer in next(teacher.children())]␣
↪#12 layers
        student_encoding_layers = [layer for layer in next(student.children())]␣
↪#6 layers
        # for i in range(len(student_encoding_layers)):
        #     student_encoding_layers[i].
↪load_state_dict(teacher_encoding_layers[2*i].state_dict())
        j = 0
        for i in range(len(teacher_encoding_layers)):
            # ODD
            if not iseven and i % 2:
                student_encoding_layers[j].
↪load_state_dict(teacher_encoding_layers[i].state_dict())
                j += 1
            elif iseven and i % 2 == 0:
                student_encoding_layers[j].
↪load_state_dict(teacher_encoding_layers[i].state_dict())
                j += 1

    # Else the part is a head or something else, copy the state_dict
    else:
        student.load_state_dict(teacher.state_dict())

    return student
```

[ ]:
```
model_odd = distill_bert_weights(teacher=teacher_model, student=model_odd,␣
↪iseven=False)
model_even = distill_bert_weights(teacher=teacher_model, student=model_even,␣
↪iseven=True)
```

[ ]:
```
def count_parameters(model):
    return sum(p.numel() for p in model.parameters() if p.requires_grad)

print('Teacher parameters :', count_parameters(teacher_model))
print('Student parameters even layers:', count_parameters(model_even))
```

```python
print('Student parameters odd layers:', count_parameters(model_odd))
```

```
Teacher parameters : 109483778
Student parameters even layers: 66956546
Student parameters odd layers: 66956546
```

[ ]:
```python
print(count_parameters(model_even)/count_parameters(teacher_model) * 100)
print(count_parameters(model_odd)/count_parameters(teacher_model) * 100)
```

```
61.156590705154514
61.156590705154514
```

[ ]:
```python
#It has 61% less parameters than bert-base-uncased
```

1.5.2 5.2 Loss function

Softmax

$$P_i(\mathbf{z}_i, T) = \frac{\exp(\mathbf{z}_i/T)}{\sum_{q=0}^{k} \exp(\mathbf{z}_q/T)}$$

Knowledge Distillation

CE Loss

$$\mathcal{L}_{\text{CE}} = -\sum_{j=0}^{N} \sum_{i=0}^{k} y_i^{(j)} \log(P_i(v_i^{(j)}, 1))$$

KL Loss

$$\mathcal{L}_{\text{KD}} = -\sum_{j=0}^{N} \sum_{i=0}^{k} P_i(z_i^{(j)}, T) \log(P_i(v_i^{(j)}, T))$$

Cosine Embedding Loss

$$\mathcal{L}_{\text{cosine}}(x_1, x_2, y) = \frac{1}{N} \sum_{i=1}^{N} (1 - y_i \cdot \cos(\theta_i))$$

Total Loss

$$\mathcal{L} = \mathcal{L}_{\text{KD}} + \mathcal{L}_{\text{CE}} + \mathcal{L}_{\text{cosine}}$$

[ ]:
```python
class DistillKL(nn.Module):
    """
    Distilling the Knowledge in a Neural Network
    Compute the knowledge-distillation (KD) loss given outputs, labels.
    "Hyperparameters": temperature and alpha

    NOTE: the KL Divergence for PyTorch comparing the softmaxs of teacher
    and student expects the input tensor to be log probabilities!
    """
```

```
    def __init__(self):
        super(DistillKL, self).__init__()

    def forward(self, output_student, output_teacher, temperature=1):
        '''
        Note: the output_student and output_teacher are logits
        '''
        T = temperature #.cuda()

        KD_loss = nn.KLDivLoss(reduction='batchmean')(
            F.log_softmax(output_student/T, dim=-1),
            F.softmax(output_teacher/T, dim=-1)
        ) * T * T

        return KD_loss
```

[ ]:
```
criterion_div = DistillKL()
criterion_cos = nn.CosineEmbeddingLoss()
```

1.6 6. Optimizer

[ ]:
```
lr = 5e-5

#training hyperparameters
optimizer_even = optim.Adam(params=model_even.parameters(), lr=lr)
optimizer_odd  = optim.Adam(params=model_odd.parameters(), lr=lr)
```

[ ]:
```
model_even = model_even.to(device)
model_odd  = model_odd.to(device)
teacher_model = teacher_model.to(device)
```

1.7 7. Learning rate scheduler

[ ]:
```
num_epochs = 5
num_update_steps_per_epoch = len(train_dataloader)
num_training_steps = num_epochs * num_update_steps_per_epoch

lr_scheduler_even = get_scheduler(
    name="linear",
    optimizer=optimizer_even,
    num_warmup_steps=0,
    num_training_steps=num_training_steps
)

lr_scheduler_odd = get_scheduler(
    name="linear",
    optimizer=optimizer_odd,
```

```
    num_warmup_steps=0,
    num_training_steps=num_training_steps
)
```

1.8 8. Metric

[ ]:
```
# !pip3 install evaluate
```

[ ]:
```
# Get the metric function
# if task_name is not None:
#     metric = evaluate.load("glue", "sst2")
# else:
metric = evaluate.load("accuracy")
```

```
Downloading builder script:   0%|          | 0.00/4.20k [00:00<?, ?B/s]
```

1.9 9. Train

[ ]:
```
progress_bar = tqdm(range(num_training_steps))
eval_metrics = 0

# Lists to store losses for each epoch
train_losses_odd = []
train_losses_cls_odd = []
train_losses_div_odd = []
train_losses_cos_odd = []
eval_losses_odd = []

for epoch in range(num_epochs):
    model_odd.train()
    teacher_model.eval()
    train_loss = 0
    train_loss_cls = 0
    train_loss_div = 0
    train_loss_cos = 0

    for batch in train_dataloader:
        batch = {k: v.to(device) for k, v in batch.items()}
        # compute student output
        outputs = model_odd(**batch)
        # compute teacher output
        with torch.no_grad():
            output_teacher = teacher_model(**batch)

        # assert size
        assert outputs.logits.size() == output_teacher.logits.size()

        # cls loss
```

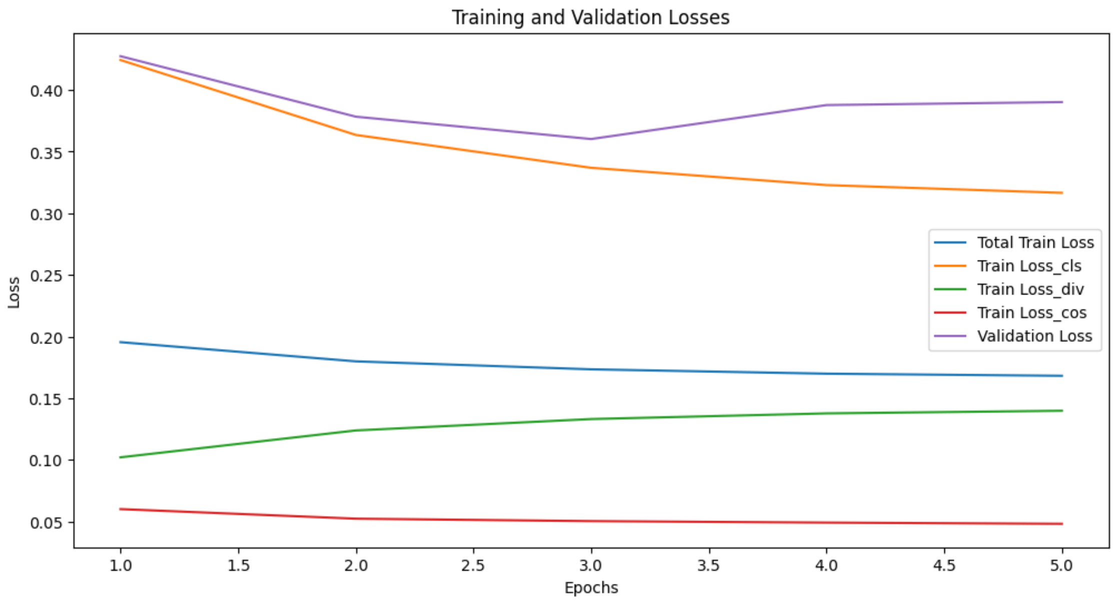
```
        loss_cls  = outputs.loss
        train_loss_cls += loss_cls.item()
        # distillation loss
        loss_div = criterion_div(outputs.logits, output_teacher.logits)
        train_loss_div += loss_div.item()
        # cosine loss
        loss_cos = criterion_cos(output_teacher.logits, outputs.logits, torch.
↪ones(output_teacher.logits.size()[0]).to(device))
        train_loss_cos += loss_cos.item()

        # Average the loss and return it
        loss = (loss_cls + loss_div + loss_cos) / 3

        train_loss += loss.item()
        loss.backward()
        # accelerator.backward(loss)
        # Step with optimizer
        optimizer_odd.step()
        lr_scheduler_odd.step()
        optimizer_odd.zero_grad()
        progress_bar.update(1)

    train_losses_odd.append(train_loss / len(train_dataloader))
    train_losses_cls_odd.append(train_loss_cls / len(train_dataloader))
    train_losses_div_odd.append(train_loss_div / len(train_dataloader))
    train_losses_cos_odd.append(train_loss_cos / len(train_dataloader))

    print(f'Epoch at {epoch+1}: Train loss {train_loss/len(train_dataloader):.
↪4f}:')
    print(f'  - Loss_cls: {train_loss_cls/len(train_dataloader):.4f}')
    print(f'  - Loss_div: {train_loss_div/len(train_dataloader):.4f}')
    print(f'  - Loss_cos: {train_loss_cos/len(train_dataloader):.4f}')

    model_odd.eval()
    eval_loss = 0
    for batch in eval_dataloader:
        batch = {k: v.to(device) for k, v in batch.items()}
        with torch.no_grad():
            outputs = model_odd(**batch)

        loss_cls = outputs.loss
        predictions = outputs.logits.argmax(dim=-1)

        eval_loss += loss_cls.item()
        # predictions, references = accelerator.gather((predictions,␣
↪batch["labels"]))
        metric.add_batch(
```

```
            predictions=predictions,
            references=batch["labels"])

    eval_metric = metric.compute()
    eval_metrics += eval_metric['accuracy']
    eval_losses_odd.append(eval_loss / len(eval_dataloader))  # Save the␣
↪evaluation loss for plotting

    print(f"Epoch at {epoch+1}: Test Acc {eval_metric['accuracy']:.4f}")

print('Avg Metric', eval_metrics/num_epochs)
```

```
  0%|          | 0/4045 [00:00<?, ?it/s]

Epoch at 1: Train loss 0.1955:
  - Loss_cls: 0.4242
  - Loss_div: 0.1021
  - Loss_cos: 0.0601
Epoch at 1: Test Acc 0.8940
Epoch at 2: Train loss 0.1799:
  - Loss_cls: 0.3635
  - Loss_div: 0.1239
  - Loss_cos: 0.0524
Epoch at 2: Test Acc 0.9390
Epoch at 3: Train loss 0.1735:
  - Loss_cls: 0.3368
  - Loss_div: 0.1332
  - Loss_cos: 0.0504
Epoch at 3: Test Acc 0.9390
Epoch at 4: Train loss 0.1699:
  - Loss_cls: 0.3228
  - Loss_div: 0.1378
  - Loss_cos: 0.0492
Epoch at 4: Test Acc 0.9210
Epoch at 5: Train loss 0.1682:
  - Loss_cls: 0.3166
  - Loss_div: 0.1399
  - Loss_cos: 0.0482
Epoch at 5: Test Acc 0.9280
Avg Metric 0.9241999999999999
```

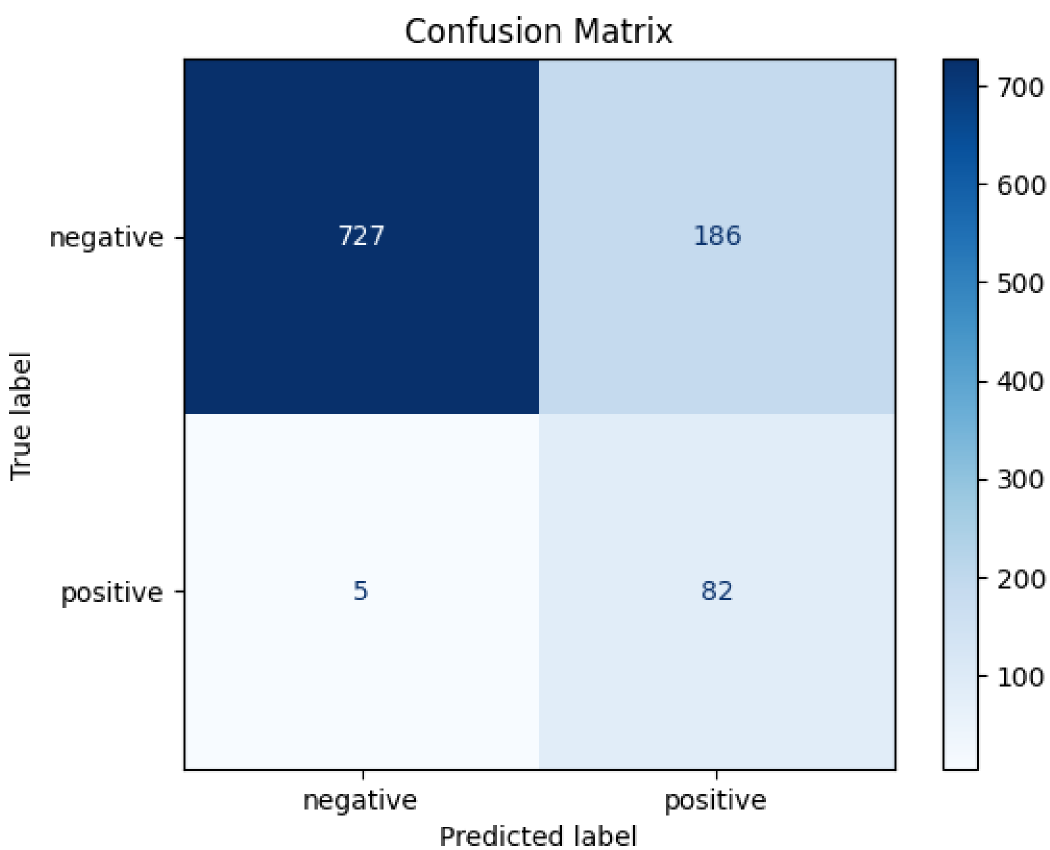
[ ]:
```
# Plotting
epochs_list = range(1, num_epochs + 1)

plt.figure(figsize=(12, 6))
plt.plot(epochs_list, train_losses_odd, label='Total Train Loss')
plt.plot(epochs_list, train_losses_cls_odd, label='Train Loss_cls')
plt.plot(epochs_list, train_losses_div_odd, label='Train Loss_div')
```

```
plt.plot(epochs_list, train_losses_cos_odd, label='Train Loss_cos')
plt.plot(epochs_list, eval_losses_odd, label='Validation Loss')

plt.title('Training and Validation Losses')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.legend()
plt.show()
```



[ ]:
```
y_true_odd = []
y_pred_odd = []

for batch in test_dataloader:
    input_ids, attention_mask, labels = batch['input_ids'],␣
 ↪batch['attention_mask'], batch['labels']
    input_ids, attention_mask, labels = input_ids.to(device), attention_mask.
 ↪to(device), labels.to(device)
    with torch.no_grad():
        outputs = model_odd(input_ids, attention_mask=attention_mask)
        logits = outputs.logits
        batch_predictions = torch.argmax(logits, dim=1)

        y_true_odd.extend(labels.cpu().numpy())
        y_pred_odd.extend(batch_predictions.cpu().numpy())

accuracy_odd = accuracy_score(y_true_odd, y_pred_odd)
precision_odd = precision_score(y_true_odd, y_pred_odd, average='weighted')
```

```python
recall_odd = recall_score(y_true_odd, y_pred_odd, average='weighted')
f1_odd = f1_score(y_true_odd, y_pred_odd, average='weighted')

labels = ["negative", "positive"]

ConfusionMatrixDisplay.from_predictions(
    y_true_odd,
    y_pred_odd,
    display_labels=labels,
    cmap=plt.cm.Blues,
    xticks_rotation='horizontal'
)

plt.title('Confusion Matrix')
plt.show()

print(classification_report(y_true_odd, y_pred_odd, target_names=labels))
```




```
              precision    recall  f1-score   support
```

```
    negative       0.99      0.80      0.88       913
    positive       0.31      0.94      0.46        87

    accuracy                           0.81      1000
   macro avg       0.65      0.87      0.67      1000
weighted avg       0.93      0.81      0.85      1000
```

[ ]:
```python
progress_bar = tqdm(range(num_training_steps))
eval_metrics = 0

# Lists to store losses for each epoch
train_losses_even = []
train_losses_cls_even = []
train_losses_div_even = []
train_losses_cos_even = []
eval_losses_even = []

for epoch in range(num_epochs):
    model_even.train()
    teacher_model.eval()
    train_loss = 0
    train_loss_cls = 0
    train_loss_div = 0
    train_loss_cos = 0

    for batch in train_dataloader:
        batch = {k: v.to(device) for k, v in batch.items()}
        # compute student output
        outputs = model_even(**batch)
        # compute teacher output
        with torch.no_grad():
            output_teacher = teacher_model(**batch)

        # assert size
        assert outputs.logits.size() == output_teacher.logits.size()

        # cls loss
        loss_cls  = outputs.loss
        train_loss_cls += loss_cls.item()
        # distillation loss
        loss_div = criterion_div(outputs.logits, output_teacher.logits)
        train_loss_div += loss_div.item()
        # cosine loss
        loss_cos = criterion_cos(output_teacher.logits, outputs.logits, torch.
 ↪ones(output_teacher.logits.size()[0]).to(device))
        train_loss_cos += loss_cos.item()
```

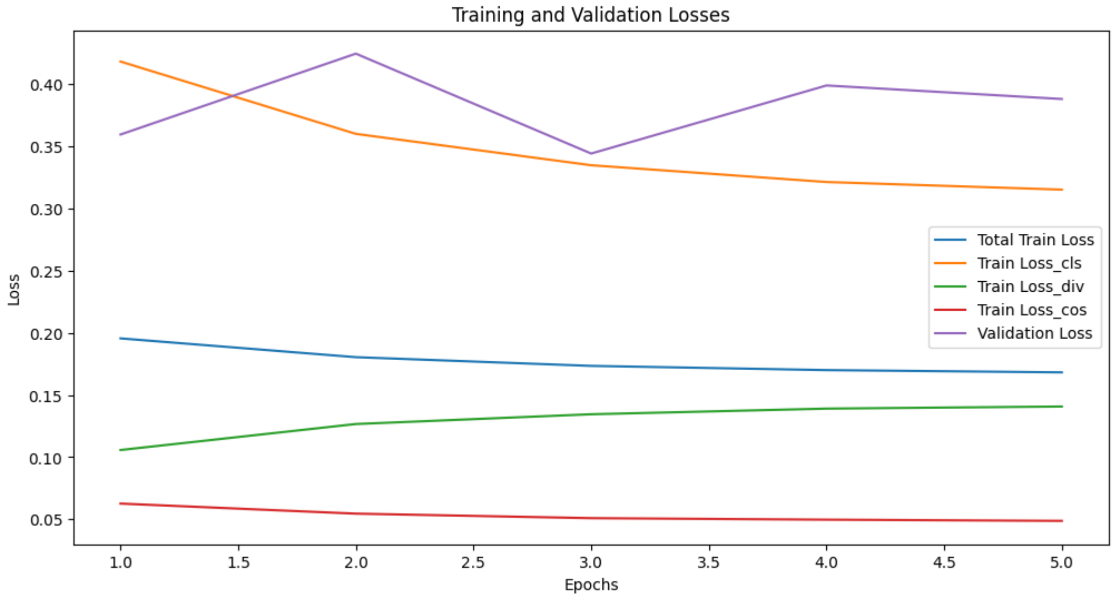
```
        # Average the loss and return it
        loss = (loss_cls + loss_div + loss_cos) / 3

        train_loss += loss.item()
        loss.backward()
        # accelerator.backward(loss)
        # Step with optimizer
        optimizer_even.step()
        lr_scheduler_even.step()
        optimizer_even.zero_grad()
        progress_bar.update(1)

    train_losses_even.append(train_loss / len(train_dataloader))
    train_losses_cls_even.append(train_loss_cls / len(train_dataloader))
    train_losses_div_even.append(train_loss_div / len(train_dataloader))
    train_losses_cos_even.append(train_loss_cos / len(train_dataloader))

    print(f'Epoch at {epoch+1}: Train loss {train_loss/len(train_dataloader):.
↪4f}:')
    print(f'  - Loss_cls: {train_loss_cls/len(train_dataloader):.4f}')
    print(f'  - Loss_div: {train_loss_div/len(train_dataloader):.4f}')
    print(f'  - Loss_cos: {train_loss_cos/len(train_dataloader):.4f}')

    model_even.eval()
    eval_loss = 0
    for batch in eval_dataloader:
        batch = {k: v.to(device) for k, v in batch.items()}
        with torch.no_grad():
            outputs = model_even(**batch)

        loss_cls = outputs.loss
        predictions = outputs.logits.argmax(dim=-1)

        eval_loss += loss_cls.item()
        # predictions, references = accelerator.gather((predictions,␣
↪batch["labels"]))
        metric.add_batch(
            predictions=predictions,
            references=batch["labels"])

    eval_metric = metric.compute()
    eval_metrics += eval_metric['accuracy']
    eval_losses_even.append(eval_loss / len(eval_dataloader))  # Save the␣
↪evaluation loss for plotting

    print(f"Epoch at {epoch+1}: Test Acc {eval_metric['accuracy']:.4f}")
```

```
print('Avg Metric', eval_metrics/num_epochs)
```

```
  0%|          | 0/4045 [00:00<?, ?it/s]

Epoch at 1: Train loss 0.1955:
  - Loss_cls: 0.4183
  - Loss_div: 0.1057
  - Loss_cos: 0.0626
Epoch at 1: Test Acc 0.9270
Epoch at 2: Train loss 0.1804:
  - Loss_cls: 0.3601
  - Loss_div: 0.1266
  - Loss_cos: 0.0545
Epoch at 2: Test Acc 0.9100
Epoch at 3: Train loss 0.1734:
  - Loss_cls: 0.3349
  - Loss_div: 0.1345
  - Loss_cos: 0.0509
Epoch at 3: Test Acc 0.9390
Epoch at 4: Train loss 0.1700:
  - Loss_cls: 0.3214
  - Loss_div: 0.1390
  - Loss_cos: 0.0497
Epoch at 4: Test Acc 0.9190
Epoch at 5: Train loss 0.1682:
  - Loss_cls: 0.3153
  - Loss_div: 0.1407
  - Loss_cos: 0.0487
Epoch at 5: Test Acc 0.9230
Avg Metric 0.9236000000000001
```

[ ]:

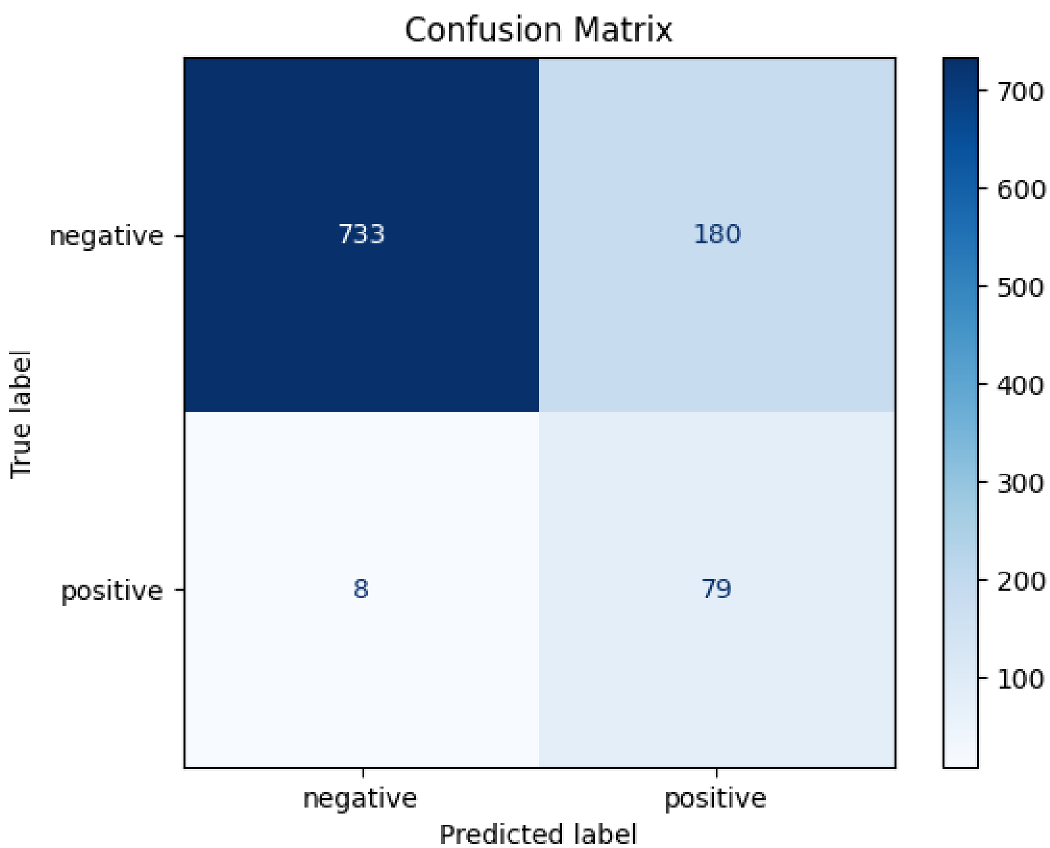
```
# Plotting
epochs_list = range(1, num_epochs + 1)

plt.figure(figsize=(12, 6))
plt.plot(epochs_list, train_losses_even, label='Total Train Loss')
plt.plot(epochs_list, train_losses_cls_even, label='Train Loss_cls')
plt.plot(epochs_list, train_losses_div_even, label='Train Loss_div')
plt.plot(epochs_list, train_losses_cos_even, label='Train Loss_cos')
plt.plot(epochs_list, eval_losses_even, label='Validation Loss')

plt.title('Training and Validation Losses')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.legend()
plt.show()
```



[ ]:
```
y_true_even = []
y_pred_even = []

for batch in test_dataloader:
    input_ids, attention_mask, labels = batch['input_ids'],␣
↪batch['attention_mask'], batch['labels']
    input_ids, attention_mask, labels = input_ids.to(device), attention_mask.
↪to(device), labels.to(device)
    with torch.no_grad():
        outputs = model_even(input_ids, attention_mask=attention_mask)
        logits = outputs.logits
        batch_predictions = torch.argmax(logits, dim=1)

        y_true_even.extend(labels.cpu().numpy())
        y_pred_even.extend(batch_predictions.cpu().numpy())

accuracy_even = accuracy_score(y_true_even, y_pred_even)
precision_even = precision_score(y_true_even, y_pred_even, average='weighted')
recall_even = recall_score(y_true_even, y_pred_even, average='weighted')
f1_even = f1_score(y_true_even, y_pred_even, average='weighted')

labels = ["negative", "positive"]

ConfusionMatrixDisplay.from_predictions(
    y_true_even,
    y_pred_even,
    display_labels=labels,
```

```
    cmap=plt.cm.Blues,
    xticks_rotation='horizontal'
)

plt.title('Confusion Matrix')
plt.show

print(classification_report(y_true_even, y_pred_even, target_names=labels))
```

```
              precision    recall  f1-score   support

    negative       0.99      0.80      0.89       913
    positive       0.31      0.91      0.46        87

    accuracy                           0.81      1000
   macro avg       0.65      0.86      0.67      1000
weighted avg       0.93      0.81      0.85      1000
```



1.9.1 Appendix (Teacher Model)

[ ]:
```
lr = 5e-5
#training hyperparameters
optimizer = optim.Adam(params=teacher_model.parameters(), lr=lr)

progress_bar = tqdm(range(num_training_steps))
eval_metrics = 0

for epoch in range(num_epochs):
    teacher_model.train()
    train_loss = 0
    for step, batch in enumerate(train_dataloader):
        batch = {k: v.to(device) for k, v in batch.items()}
        output_teacher = teacher_model(**batch)
        # cls loss
        loss = output_teacher.loss
        train_loss += loss.item()
        loss.backward()
        # accelerator.backward(loss)
        # Step with optimizer
        optimizer.step()
        lr_scheduler_even.step()
        optimizer.zero_grad()
        progress_bar.update(1)

    print(f'Epoch at {epoch+1}: Train loss {train_loss/len(train_dataloader):.
 ↪4f}:')

    teacher_model.eval()
    for step, batch in enumerate(eval_dataloader):
        batch = {k: v.to(device) for k, v in batch.items()}
        with torch.no_grad():
            outputs = teacher_model(**batch)

        predictions = outputs.logits.argmax(dim=-1)
        # predictions, references = accelerator.gather((predictions,␣
 ↪batch["labels"]))
        metric.add_batch(
            predictions=predictions,
            references=batch["labels"])

    eval_metric = metric.compute()
    eval_metrics += eval_metric['accuracy']
    print(f"Epoch at {epoch+1}: Test Acc {eval_metric['accuracy']:.4f}")

print('Avg Metric', eval_metrics/num_epochs)
```

```
  0%|          | 0/4045 [00:00<?, ?it/s]

Epoch at 1: Train loss 0.2022:
Epoch at 1: Test Acc 0.8980
Epoch at 2: Train loss 0.1137:
Epoch at 2: Test Acc 0.9250
Epoch at 3: Train loss 0.0588:
Epoch at 3: Test Acc 0.8930
Epoch at 4: Train loss 0.0365:
Epoch at 4: Test Acc 0.8900
Epoch at 5: Train loss 0.0243:
Epoch at 5: Test Acc 0.9390
Avg Metric 0.909
```

[ ]:
```python
save_directory = "./models/bert_odd_st"

model_odd.save_pretrained(save_directory)
tokenizer.save_pretrained(save_directory)

save_directory = "./models/bert_even_st"
model_even.save_pretrained(save_directory)
tokenizer.save_pretrained(save_directory)
```

[ ]:
```
('./models/bert_even_st/tokenizer_config.json',
 './models/bert_even_st/special_tokens_map.json',
 './models/bert_even_st/vocab.txt',
 './models/bert_even_st/added_tokens.json',
 './models/bert_even_st/tokenizer.json')
```

1.9.2 LoRA

[ ]:
```python
lora_model = AutoModelForSequenceClassification.from_pretrained(
    teacher_id,
    num_labels = num_labels,
    id2label = id2label,
    label2id = label2id,
)
print(lora_model)

cfgs = LoraConfig(
    task_type=TaskType.SEQ_CLS,
    inference_mode=False,
    r=8,
    lora_alpha=32,
    lora_dropout=0.1,
    bias="none",
    target_modules=["query", "key", "value"]
)
```

```python
lora_model = get_peft_model(lora_model, cfgs)

def compute_metrics(eval_preds):
    """
    Compute accuracy and other metrics for evaluation.

    Args:
    eval_preds: A tuple (predictions, labels) where:
        - predictions: model's predictions (logits or class probabilities)
        - labels: ground truth labels

    Returns:
    A dictionary with the evaluation metric(s).
    """
    logits, labels = eval_preds
    predictions = np.argmax(logits, axis=-1)

    accuracy = accuracy_score(labels, predictions)

    return {"accuracy": accuracy}


training_args = TrainingArguments(
    output_dir="./models/bert-lora",
    logging_dir="./logs",
    logging_steps=50,
    evaluation_strategy="steps",
    eval_steps=100,
    save_steps=100,
    report_to=["tensorboard"]
)

trainer = Trainer(
    model=lora_model,
    args=training_args,
    train_dataset=small_train_dataset,
    eval_dataset=small_eval_dataset,
    tokenizer=tokenizer,
)
```

```
Some weights of BertForSequenceClassification were not initialized from the
model checkpoint at bert-base-uncased and are newly initialized:
['classifier.bias', 'classifier.weight']
You should probably TRAIN this model on a down-stream task to be able to use it
for predictions and inference.
/usr/local/lib/python3.10/dist-packages/transformers/training_args.py:1575:
FutureWarning: `evaluation_strategy` is deprecated and will be removed in
version 4.46 of   Transformers. Use `eval_strategy` instead
```

```
  warnings.warn(
<ipython-input-44-c7ec1e3816f7>:50: FutureWarning: `tokenizer` is deprecated and
will be removed in version 5.0.0 for `Trainer.__init__`. Use `processing_class`
instead.
  trainer = Trainer(
```

```
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): BertSdpaSelfAttention(
              (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=2, bias=True)
)
```

[ ]:
```
trainer.train()
trainer.save_model()
lora_model.save_pretrained("./models/bert-lora")
```

```
<IPython.core.display.HTML object>
```

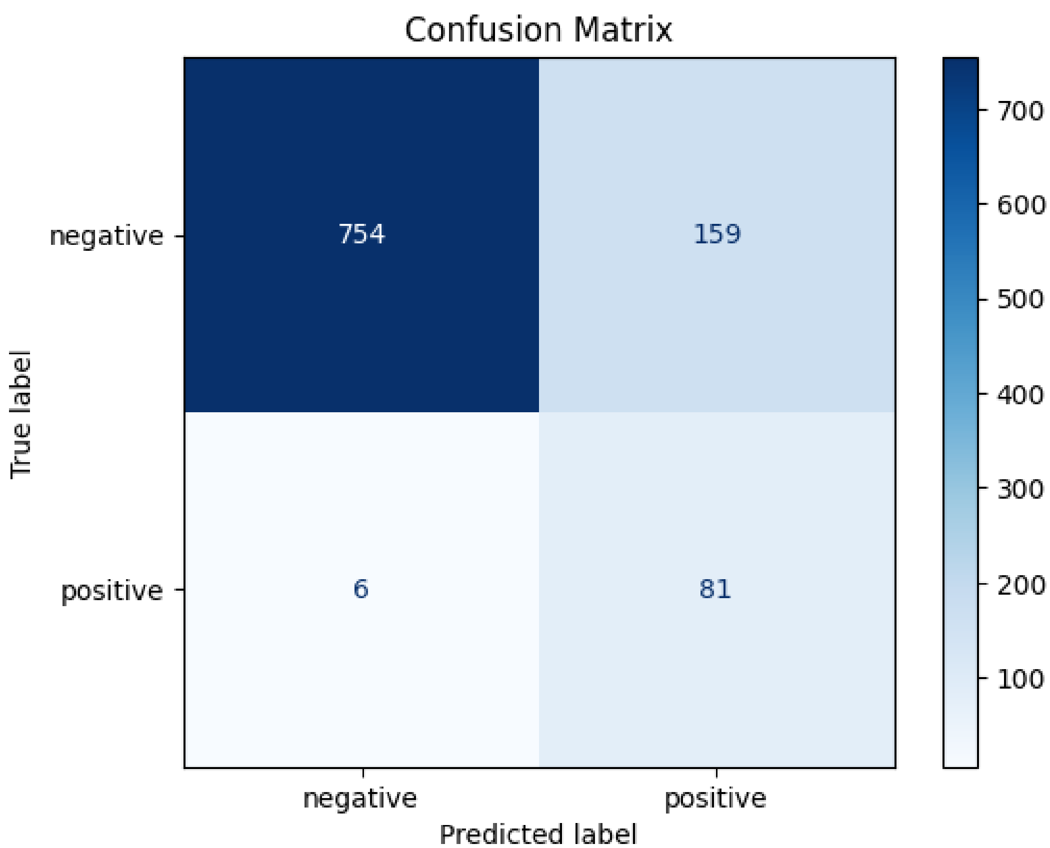
```
/usr/local/lib/python3.10/dist-packages/peft/utils/other.py:716: UserWarning:
Unable to fetch remote file due to the following error
(ReadTimeoutError("HTTPSConnectionPool(host='huggingface.co', port=443): Read
timed out. (read timeout=10)"), '(Request ID:
6baa4e07-0ff7-41ae-a9d8-6ca2609b8772)') - silently ignoring the lookup for the
file config.json in bert-base-uncased.
  warnings.warn(
/usr/local/lib/python3.10/dist-packages/peft/utils/save_and_load.py:246:
UserWarning: Could not find a config file in bert-base-uncased - will assume
that the vocabulary was not modified.
  warnings.warn(
```

[ ]:
```
import matplotlib.pyplot as plt

loss_values = [entry["loss"] for entry in trainer.state.log_history if "loss"␣
↪in entry]
eval_values = [entry["eval_loss"] for entry in trainer.state.log_history if␣
↪"eval_loss" in entry]

plt.figure(figsize=(8, 4))
plt.plot(loss_values, label="Training Loss")
plt.plot(eval_values, label="Validation Loss")
plt.xlabel("Logging Steps")
plt.ylabel("Loss")
plt.title("Training Loss over Steps")
plt.legend()
plt.show()
```

[ ]:
```
y_true_lora = []
y_pred_lora = []

for batch in test_dataloader:
    input_ids, attention_mask, labels = batch['input_ids'],␣
 ↪batch['attention_mask'], batch['labels']
    input_ids, attention_mask, labels = input_ids.to(device), attention_mask.
 ↪to(device), labels.to(device)
    with torch.no_grad():
        outputs = lora_model(input_ids, attention_mask=attention_mask)
        logits = outputs.logits
        batch_predictions = torch.argmax(logits, dim=1)
        y_true_lora.extend(labels.cpu().numpy())
        y_pred_lora.extend(batch_predictions.cpu().numpy())

accuracy_lora = accuracy_score(y_true_lora, y_pred_lora)
precision_lora = precision_score(y_true_lora, y_pred_lora, average='weighted')
recall_lora = recall_score(y_true_lora, y_pred_lora, average='weighted')
f1_lora = f1_score(y_true_lora, y_pred_lora, average='weighted')

labels = ["negative", "positive"]

ConfusionMatrixDisplay.from_predictions(
    y_true_lora,
    y_pred_lora,
    display_labels=labels,
```

```
    cmap=plt.cm.Blues,
    xticks_rotation='horizontal'
)

plt.title('Confusion Matrix')
plt.show

print(classification_report(y_true_lora, y_pred_lora, target_names=labels))
```

```
              precision    recall  f1-score   support

    negative       0.99      0.83      0.90       913
    positive       0.34      0.93      0.50        87

    accuracy                           0.83      1000
   macro avg       0.66      0.88      0.70      1000
weighted avg       0.94      0.83      0.87      1000
```



[ ]:
```
!zip -r models.zip ./models
# !zip -r models.zip ./logs
```

```
adding: models/ (stored 0%)
adding: models/bert_even_st/ (stored 0%)
adding: models/bert_even_st/tokenizer.json (deflated 71%)
adding: models/bert_even_st/vocab.txt (deflated 53%)
adding: models/bert_even_st/config.json (deflated 49%)
adding: models/bert_even_st/model.safetensors (deflated 8%)
adding: models/bert_even_st/special_tokens_map.json (deflated 42%)
adding: models/bert_even_st/tokenizer_config.json (deflated 75%)
adding: models/bert_odd_st/ (stored 0%)
adding: models/bert_odd_st/tokenizer.json (deflated 71%)
adding: models/bert_odd_st/vocab.txt (deflated 53%)
adding: models/bert_odd_st/config.json (deflated 49%)
adding: models/bert_odd_st/model.safetensors (deflated 8%)
adding: models/bert_odd_st/special_tokens_map.json (deflated 42%)
adding: models/bert_odd_st/tokenizer_config.json (deflated 75%)
```

[ ]:
```python
from IPython.display import FileLink

FileLink(r'models.zip')
```

[ ]: /kaggle/working/models.zip