AhmedHesham_EnglishArabicTranslation

August 30, 2023

[1]:
```
!pip install datasets
!pip install dataset
!pip install transformers
!pip install sacrebleu
!pip install SentencePiece
!pip install transformers[torch]
```

```
Collecting datasets
  Downloading datasets-2.14.4-py3-none-any.whl (519 kB)
                           519.3/519.3

kB 6.3 MB/s eta 0:00:00
Requirement already satisfied: numpy>=1.17 in
/usr/local/lib/python3.10/dist-packages (from datasets) (1.23.5)
Requirement already satisfied: pyarrow>=8.0.0 in /usr/local/lib/python3.10/dist-
packages (from datasets) (9.0.0)
Collecting dill<0.3.8,>=0.3.0 (from datasets)
  Downloading dill-0.3.7-py3-none-any.whl (115 kB)
                          115.3/115.3 kB
13.4 MB/s eta 0:00:00
Requirement already satisfied: pandas in /usr/local/lib/python3.10/dist-
packages (from datasets) (1.5.3)
Requirement already satisfied: requests>=2.19.0 in
/usr/local/lib/python3.10/dist-packages (from datasets) (2.31.0)
Requirement already satisfied: tqdm>=4.62.1 in /usr/local/lib/python3.10/dist-
packages (from datasets) (4.66.1)
Collecting xxhash (from datasets)
  Downloading
xxhash-3.3.0-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x86_64.whl (194 kB)
                          194.1/194.1 kB
21.8 MB/s eta 0:00:00
Collecting multiprocess (from datasets)
  Downloading multiprocess-0.70.15-py310-none-any.whl (134 kB)
                          134.8/134.8 kB
12.6 MB/s eta 0:00:00
Requirement already satisfied: fsspec[http]>=2021.11.1 in
/usr/local/lib/python3.10/dist-packages (from datasets) (2023.6.0)
Requirement already satisfied: aiohttp in /usr/local/lib/python3.10/dist-
```

```
packages (from datasets) (3.8.5)
Collecting huggingface-hub<1.0.0,>=0.14.0 (from datasets)
  Downloading huggingface_hub-0.16.4-py3-none-any.whl (268 kB)
                          268.8/268.8 kB
18.5 MB/s eta 0:00:00
Requirement already satisfied: packaging in
/usr/local/lib/python3.10/dist-packages (from datasets) (23.1)
Requirement already satisfied: pyyaml>=5.1 in /usr/local/lib/python3.10/dist-
packages (from datasets) (6.0.1)
Requirement already satisfied: attrs>=17.3.0 in /usr/local/lib/python3.10/dist-
packages (from aiohttp->datasets) (23.1.0)
Requirement already satisfied: charset-normalizer<4.0,>=2.0 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets) (3.2.0)
Requirement already satisfied: multidict<7.0,>=4.5 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets) (6.0.4)
Requirement already satisfied: async-timeout<5.0,>=4.0.0a3 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets) (4.0.3)
Requirement already satisfied: yarl<2.0,>=1.0 in /usr/local/lib/python3.10/dist-
packages (from aiohttp->datasets) (1.9.2)
Requirement already satisfied: frozenlist>=1.1.1 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets) (1.4.0)
Requirement already satisfied: aiosignal>=1.1.2 in
/usr/local/lib/python3.10/dist-packages (from aiohttp->datasets) (1.3.1)
Requirement already satisfied: filelock in /usr/local/lib/python3.10/dist-
packages (from huggingface-hub<1.0.0,>=0.14.0->datasets) (3.12.2)
Requirement already satisfied: typing-extensions>=3.7.4.3 in
/usr/local/lib/python3.10/dist-packages (from huggingface-
hub<1.0.0,>=0.14.0->datasets) (4.7.1)
Requirement already satisfied: idna<4,>=2.5 in /usr/local/lib/python3.10/dist-
packages (from requests>=2.19.0->datasets) (3.4)
Requirement already satisfied: urllib3<3,>=1.21.1 in
/usr/local/lib/python3.10/dist-packages (from requests>=2.19.0->datasets)
(2.0.4)
Requirement already satisfied: certifi>=2017.4.17 in
/usr/local/lib/python3.10/dist-packages (from requests>=2.19.0->datasets)
(2023.7.22)
Requirement already satisfied: python-dateutil>=2.8.1 in
/usr/local/lib/python3.10/dist-packages (from pandas->datasets) (2.8.2)
Requirement already satisfied: pytz>=2020.1 in /usr/local/lib/python3.10/dist-
packages (from pandas->datasets) (2023.3)
Requirement already satisfied: six>=1.5 in /usr/local/lib/python3.10/dist-
packages (from python-dateutil>=2.8.1->pandas->datasets) (1.16.0)
Installing collected packages: xxhash, dill, multiprocess, huggingface-hub,
datasets
Successfully installed datasets-2.14.4 dill-0.3.7 huggingface-hub-0.16.4
multiprocess-0.70.15 xxhash-3.3.0
Collecting dataset
  Downloading dataset-1.6.2-py2.py3-none-any.whl (18 kB)
```

```
Collecting sqlalchemy<2.0.0,>=1.3.2 (from dataset)
  Downloading SQLAlchemy-1.4.49-cp310-cp310-
manylinux_2_5_x86_64.manylinux1_x86_64.manylinux_2_17_x86_64.manylinux2014_x86_6
4.whl (1.6 MB)
                           1.6/1.6 MB
7.1 MB/s eta 0:00:00
Collecting alembic>=0.6.2 (from dataset)
  Downloading alembic-1.11.3-py3-none-any.whl (225 kB)
                           225.4/225.4

kB 7.7 MB/s eta 0:00:00
Collecting banal>=1.0.1 (from dataset)
  Downloading banal-1.0.6-py2.py3-none-any.whl (6.1 kB)
Collecting Mako (from alembic>=0.6.2->dataset)
  Downloading Mako-1.2.4-py3-none-any.whl (78 kB)
                           78.7/78.7 kB
10.6 MB/s eta 0:00:00
Requirement already satisfied: typing-extensions>=4 in
/usr/local/lib/python3.10/dist-packages (from alembic>=0.6.2->dataset) (4.7.1)
Requirement already satisfied: greenlet!=0.4.17 in
/usr/local/lib/python3.10/dist-packages (from sqlalchemy<2.0.0,>=1.3.2->dataset)
(2.0.2)
Requirement already satisfied: MarkupSafe>=0.9.2 in
/usr/local/lib/python3.10/dist-packages (from Mako->alembic>=0.6.2->dataset)
(2.1.3)
Installing collected packages: banal, sqlalchemy, Mako, alembic, dataset
  Attempting uninstall: sqlalchemy
    Found existing installation: SQLAlchemy 2.0.20
    Uninstalling SQLAlchemy-2.0.20:
      Successfully uninstalled SQLAlchemy-2.0.20
ERROR: pip's dependency resolver does not currently take into account all

the packages that are installed. This behaviour is the source of the following

dependency conflicts.

ipython-sql 0.5.0 requires sqlalchemy>=2.0, but you have sqlalchemy 1.4.49 which

is incompatible.

Successfully installed Mako-1.2.4 alembic-1.11.3 banal-1.0.6 dataset-1.6.2
sqlalchemy-1.4.49
Collecting transformers
  Downloading transformers-4.32.1-py3-none-any.whl (7.5 MB)
                           7.5/7.5 MB
50.0 MB/s eta 0:00:00
Requirement already satisfied: filelock in /usr/local/lib/python3.10/dist-
packages (from transformers) (3.12.2)
Requirement already satisfied: huggingface-hub<1.0,>=0.15.1 in
/usr/local/lib/python3.10/dist-packages (from transformers) (0.16.4)
```

```
Requirement already satisfied: numpy>=1.17 in /usr/local/lib/python3.10/dist-
packages (from transformers) (1.23.5)
Requirement already satisfied: packaging>=20.0 in
/usr/local/lib/python3.10/dist-packages (from transformers) (23.1)
Requirement already satisfied: pyyaml>=5.1 in /usr/local/lib/python3.10/dist-
packages (from transformers) (6.0.1)
Requirement already satisfied: regex!=2019.12.17 in
/usr/local/lib/python3.10/dist-packages (from transformers) (2023.6.3)
Requirement already satisfied: requests in /usr/local/lib/python3.10/dist-
packages (from transformers) (2.31.0)
Collecting tokenizers!=0.11.3,<0.14,>=0.11.1 (from transformers)
  Downloading
tokenizers-0.13.3-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x86_64.whl
(7.8 MB)
                           7.8/7.8 MB
107.8 MB/s eta 0:00:00
Collecting safetensors>=0.3.1 (from transformers)
  Downloading
safetensors-0.3.3-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x86_64.whl
(1.3 MB)
                           1.3/1.3 MB
68.3 MB/s eta 0:00:00
Requirement already satisfied: tqdm>=4.27 in
/usr/local/lib/python3.10/dist-packages (from transformers) (4.66.1)
Requirement already satisfied: fsspec in /usr/local/lib/python3.10/dist-packages
(from huggingface-hub<1.0,>=0.15.1->transformers) (2023.6.0)
Requirement already satisfied: typing-extensions>=3.7.4.3 in
/usr/local/lib/python3.10/dist-packages (from huggingface-
hub<1.0,>=0.15.1->transformers) (4.7.1)
Requirement already satisfied: charset-normalizer<4,>=2 in
/usr/local/lib/python3.10/dist-packages (from requests->transformers) (3.2.0)
Requirement already satisfied: idna<4,>=2.5 in /usr/local/lib/python3.10/dist-
packages (from requests->transformers) (3.4)
Requirement already satisfied: urllib3<3,>=1.21.1 in
/usr/local/lib/python3.10/dist-packages (from requests->transformers) (2.0.4)
Requirement already satisfied: certifi>=2017.4.17 in
/usr/local/lib/python3.10/dist-packages (from requests->transformers)
(2023.7.22)
Installing collected packages: tokenizers, safetensors, transformers
Successfully installed safetensors-0.3.3 tokenizers-0.13.3 transformers-4.32.1
Collecting sacrebleu
  Downloading sacrebleu-2.3.1-py3-none-any.whl (118 kB)
                           118.9/118.9

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Collecting portalocker (from sacrebleu)
  Downloading portalocker-2.7.0-py2.py3-none-any.whl (15 kB)
Requirement already satisfied: regex in /usr/local/lib/python3.10/dist-packages
```

```
(from sacrebleu) (2023.6.3)
Requirement already satisfied: tabulate>=0.8.9 in
/usr/local/lib/python3.10/dist-packages (from sacrebleu) (0.9.0)
Requirement already satisfied: numpy>=1.17 in /usr/local/lib/python3.10/dist-
packages (from sacrebleu) (1.23.5)
Collecting colorama (from sacrebleu)
  Downloading colorama-0.4.6-py2.py3-none-any.whl (25 kB)
Requirement already satisfied: lxml in /usr/local/lib/python3.10/dist-packages
(from sacrebleu) (4.9.3)
Installing collected packages: portalocker, colorama, sacrebleu
Successfully installed colorama-0.4.6 portalocker-2.7.0 sacrebleu-2.3.1
Collecting SentencePiece
  Downloading
sentencepiece-0.1.99-cp310-cp310-manylinux_2_17_x86_64.manylinux2014_x86_64.whl
(1.3 MB)
                           1.3/1.3 MB
9.0 MB/s eta 0:00:00
Installing collected packages: SentencePiece
Successfully installed SentencePiece-0.1.99
Requirement already satisfied: transformers[torch] in
/usr/local/lib/python3.10/dist-packages (4.32.1)
Requirement already satisfied: filelock in /usr/local/lib/python3.10/dist-
packages (from transformers[torch]) (3.12.2)
Requirement already satisfied: huggingface-hub<1.0,>=0.15.1 in
/usr/local/lib/python3.10/dist-packages (from transformers[torch]) (0.16.4)
Requirement already satisfied: numpy>=1.17 in /usr/local/lib/python3.10/dist-
packages (from transformers[torch]) (1.23.5)
Requirement already satisfied: packaging>=20.0 in
/usr/local/lib/python3.10/dist-packages (from transformers[torch]) (23.1)
Requirement already satisfied: pyyaml>=5.1 in /usr/local/lib/python3.10/dist-
packages (from transformers[torch]) (6.0.1)
Requirement already satisfied: regex!=2019.12.17 in
/usr/local/lib/python3.10/dist-packages (from transformers[torch]) (2023.6.3)
Requirement already satisfied: requests in /usr/local/lib/python3.10/dist-
packages (from transformers[torch]) (2.31.0)
Requirement already satisfied: tokenizers!=0.11.3,<0.14,>=0.11.1 in
/usr/local/lib/python3.10/dist-packages (from transformers[torch]) (0.13.3)
Requirement already satisfied: safetensors>=0.3.1 in
/usr/local/lib/python3.10/dist-packages (from transformers[torch]) (0.3.3)
Requirement already satisfied: tqdm>=4.27 in /usr/local/lib/python3.10/dist-
packages (from transformers[torch]) (4.66.1)
Requirement already satisfied: torch!=1.12.0,>=1.9 in
/usr/local/lib/python3.10/dist-packages (from transformers[torch]) (2.0.1+cu118)
Collecting accelerate>=0.20.3 (from transformers[torch])
  Downloading accelerate-0.22.0-py3-none-any.whl (251 kB)
                          251.2/251.2

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```

```
Requirement already satisfied: psutil in /usr/local/lib/python3.10/dist-
packages (from accelerate>=0.20.3->transformers[torch]) (5.9.5)
Requirement already satisfied: fsspec in /usr/local/lib/python3.10/dist-packages
(from huggingface-hub<1.0,>=0.15.1->transformers[torch]) (2023.6.0)
Requirement already satisfied: typing-extensions>=3.7.4.3 in
/usr/local/lib/python3.10/dist-packages (from huggingface-
hub<1.0,>=0.15.1->transformers[torch]) (4.7.1)
Requirement already satisfied: sympy in /usr/local/lib/python3.10/dist-packages
(from torch!=1.12.0,>=1.9->transformers[torch]) (1.12)
Requirement already satisfied: networkx in /usr/local/lib/python3.10/dist-
packages (from torch!=1.12.0,>=1.9->transformers[torch]) (3.1)
Requirement already satisfied: jinja2 in /usr/local/lib/python3.10/dist-packages
(from torch!=1.12.0,>=1.9->transformers[torch]) (3.1.2)
Requirement already satisfied: triton==2.0.0 in /usr/local/lib/python3.10/dist-
packages (from torch!=1.12.0,>=1.9->transformers[torch]) (2.0.0)
Requirement already satisfied: cmake in /usr/local/lib/python3.10/dist-packages
(from triton==2.0.0->torch!=1.12.0,>=1.9->transformers[torch]) (3.27.2)
Requirement already satisfied: lit in /usr/local/lib/python3.10/dist-packages
(from triton==2.0.0->torch!=1.12.0,>=1.9->transformers[torch]) (16.0.6)
Requirement already satisfied: charset-normalizer<4,>=2 in
/usr/local/lib/python3.10/dist-packages (from requests->transformers[torch])
(3.2.0)
Requirement already satisfied: idna<4,>=2.5 in /usr/local/lib/python3.10/dist-
packages (from requests->transformers[torch]) (3.4)
Requirement already satisfied: urllib3<3,>=1.21.1 in
/usr/local/lib/python3.10/dist-packages (from requests->transformers[torch])
(2.0.4)
Requirement already satisfied: certifi>=2017.4.17 in
/usr/local/lib/python3.10/dist-packages (from requests->transformers[torch])
(2023.7.22)
Requirement already satisfied: MarkupSafe>=2.0 in
/usr/local/lib/python3.10/dist-packages (from
jinja2->torch!=1.12.0,>=1.9->transformers[torch]) (2.1.3)
Requirement already satisfied: mpmath>=0.19 in /usr/local/lib/python3.10/dist-
packages (from sympy->torch!=1.12.0,>=1.9->transformers[torch]) (1.3.0)
Installing collected packages: accelerate
Successfully installed accelerate-0.22.0
```

[2]:
```python
import pandas as pd
import numpy as np
import re
import string
import warnings
from collections import Counter
from unicodedata import normalize
from scipy.stats import pearsonr
```

```
import tensorflow as tf
import torch
import torch.nn.functional as F
from sklearn.model_selection import train_test_split
from keras.models import Sequential, Model, load_model
from keras.layers import LSTM, Dense, Embedding, RepeatVector, TimeDistributed,␣
 ↪Bidirectional, Dropout, Input
from keras.preprocessing.text import Tokenizer
from keras.preprocessing.sequence import pad_sequences
from keras.utils import pad_sequences, to_categorical
from keras.callbacks import EarlyStopping
from keras.optimizers import Adam
from tensorflow.keras.layers import Attention, Concatenate
from transformers import MT5ForConditionalGeneration, T5Tokenizer,␣
 ↪TrainingArguments, Trainer, MBartForConditionalGeneration, MBartTokenizer,␣
 ↪MarianTokenizer, MarianMTModel
from torch.utils.data import Dataset

import nltk
from nltk.util import ngrams
from nltk.probability import FreqDist
from nltk.corpus import stopwords
from bidi.algorithm import get_display
import arabic_reshaper

import sacrebleu
from nltk.translate.bleu_score import corpus_bleu, sentence_bleu

import matplotlib.pyplot as plt
from wordcloud import WordCloud
from IPython.display import Markdown, display
```

[3]:
```
nltk.download('punkt')
nltk.download('stopwords')
```

```
[nltk_data] Downloading package punkt to /root/nltk_data…
[nltk_data]   Unzipping tokenizers/punkt.zip.
[nltk_data] Downloading package stopwords to /root/nltk_data…
[nltk_data]   Unzipping corpora/stopwords.zip.
```

[3]:
```
True
```

[4]:
```
def clean_english_text(text):
    text = text.lower()
    text = re.sub(r'\n', '', text)
    text = re.sub(r'\d+', '', text)
    text = re.sub(f'[{string.punctuation}]', '', text)
    text = re.sub(r'\s+', ' ', text)
    return text

def clean_arabic_text(text):
    text = re.sub("[]", "", text)
    text = re.sub(" ", "", text)
    text = re.sub("[  ]", " ", text)
    text = re.sub(" ", " ", text)
    text = re.sub("[ ]", " ", text)
    text = re.sub(" ", " ", text)
    text = re.sub(f'[{string.punctuation}]', '', text)
    text = re.sub(r'\d+', '', text)
    text = re.sub(r'[^\s - ]', '', text)
    return text

df = pd.read_csv("ara_eng.txt", delimiter="\t", names=["english", "arabic"])
df.dropna(inplace=True)

english_sentences = df['english'].tolist()
arabic_sentences = df['arabic'].tolist()

df['arabic_length'] = df['arabic'].apply(lambda x: len(x.split()))
df['english_length'] = df['english'].apply(lambda x: len(x.split()))

english_sentences_clean = [clean_english_text(sentence) for sentence in␣
 ↪english_sentences]
arabic_sentences_clean = [clean_arabic_text(sentence) for sentence in␣
 ↪arabic_sentences]

zero_length_english_indices = [i for i, sentence in␣
 ↪enumerate(english_sentences_clean) if len(sentence.split()) == 0]
zero_length_arabic_indices = [i for i, sentence in␣
 ↪enumerate(arabic_sentences_clean) if len(sentence.split()) == 0]

indices_to_remove = set(zero_length_english_indices +␣
 ↪zero_length_arabic_indices)

english_sentences_clean = ["<bos> " + sentence + " <eos>"for i, sentence in␣
 ↪enumerate(english_sentences_clean) if i not in indices_to_remove]
arabic_sentences_clean =  ["<bos> " + sentence + " <eos>"for i, sentence in␣
 ↪enumerate(arabic_sentences_clean) if i not in indices_to_remove]
```

```
[10]: portion_length = int(0.4 * len(arabic_sentences_clean))
arabic_sentences_clean = arabic_sentences_clean[:portion_length]
english_sentences_clean = english_sentences_clean[:portion_length]
```

```python
test_proportion = 0.1
train_test_threshold = int((1 - test_proportion) * len(arabic_sentences_clean))

train_ar, test_ar = arabic_sentences_clean[:train_test_threshold],␣
 ↪arabic_sentences_clean[train_test_threshold:]
train_en, test_en = english_sentences_clean[:train_test_threshold],␣
 ↪english_sentences_clean[train_test_threshold:]

def create_tokenizer(lines):
    tokenizer = Tokenizer()
    tokenizer.fit_on_texts(lines)
    return tokenizer

def max_len(lines):
    return max(len(line.split()) for line in lines)

def encode_sequences(tokenizer, length, lines):
    X = tokenizer.texts_to_sequences(lines)
    X = pad_sequences(X, maxlen=length, padding='post')
    return X

def encode_output(sequences, vocab_size):
    ylist = [to_categorical(sequence, num_classes=vocab_size) for sequence in␣
 ↪sequences]
    y = np.array(ylist)
    y = y.reshape(sequences.shape[0], sequences.shape[1], vocab_size)
    return y

tar_tokenizer = create_tokenizer(english_sentences_clean)
tar_vocab_size = len(tar_tokenizer.word_index) + 1
tar_length = max_len(english_sentences_clean)

src_tokenizer = create_tokenizer(arabic_sentences_clean)
src_vocab_size = len(src_tokenizer.word_index) + 1
src_length = max_len(arabic_sentences_clean)

trainX = encode_sequences(src_tokenizer, src_length, train_ar)
trainY = encode_sequences(tar_tokenizer, tar_length, train_en)
trainY = encode_output(trainY, tar_vocab_size)

testX = encode_sequences(src_tokenizer, src_length, test_ar)
testY = encode_sequences(tar_tokenizer, tar_length, test_en)
testY = encode_output(testY, tar_vocab_size)
```

1 Descriptive Analytics

1.1 Data Exploration:

[ ]:
```python
english_sentence_lengths = [len(sentence.split()) for sentence in␣
 ↪english_sentences_clean]
arabic_sentence_lengths = [len(sentence.split()) for sentence in␣
 ↪arabic_sentences_clean]

english_vocab_size = len(tokenizer_eng.word_index) + 1
arabic_vocab_size = len(tokenizer_ar.word_index) + 1

avg_word_length_eng = np.mean([len(word) for sentence in␣
 ↪english_sentences_clean for word in sentence.split()])
avg_word_length_ar = np.mean([len(word) for sentence in arabic_sentences_clean␣
 ↪for word in sentence.split()])

avg_words_per_sentence_eng = np.mean([len(sentence.split()) for sentence in␣
 ↪english_sentences_clean])
avg_words_per_sentence_ar = np.mean([len(sentence.split()) for sentence in␣
 ↪arabic_sentences_clean])

print(f"English: \n Average word length: {avg_word_length_eng} \n Average␣
 ↪number of words per sentence: {avg_words_per_sentence_eng} \n Max sentence␣
 ↪length: {max(english_sentence_lengths)} \n Min sentence length:␣
 ↪{min(english_sentence_lengths)} \n Average sentence length:␣
 ↪{sum(english_sentence_lengths)/len(english_sentence_lengths)} \n Vocabulary␣
 ↪Size: {english_vocab_size}")
print("\n")
print(f"Arabic: \n Average word length: {avg_word_length_ar} \n Average number␣
 ↪of words per sentence: {avg_words_per_sentence_ar} \n Max sentence length:␣
 ↪{max(arabic_sentence_lengths)} \n Min sentence length:␣
 ↪{min(arabic_sentence_lengths)} \n Average sentence length:␣
 ↪{sum(arabic_sentence_lengths)/len(arabic_sentence_lengths)} \n Vocabulary␣
 ↪Size: {arabic_vocab_size}")
```

```
English:
 Average word length: 4.7768838806086995
 Average number of words per sentence: 17.62807971749807
 Max sentence length: 225
 Min sentence length: 1
 Average sentence length: 17.62807971749807
 Vocabulary Size: 25998


Arabic:
 Average word length: 4.793183536782975
 Average number of words per sentence: 15.029427284166092
 Max sentence length: 225
 Min sentence length: 1
 Average sentence length: 15.029427284166092
 Vocabulary Size: 52737
```

[ ]:
```python
correlation, _ = pearsonr(english_sentence_lengths, arabic_sentence_lengths)
print('Pearson correlation (correlation between english and arabic sentence␣
↪lengths): %.3f' % correlation)
```

```
Pearson correlation: 0.978
```

Findings based on the above statistics:

- The vocabulary size of Arabic is about twice as much as English. This isn't surprising considering Arabic is a morphologically rich language and tends to have more unique words due to variations in word forms.
- English sentences tend to be longer, which indicates that English translations might use more words to express the same concepts as in Arabic, or the English dataset could contain more detailed or elaborate sentences.
- The average word length for both English and Arabic sentences is quite close. This similarity might indicate that, in general, the complexity in terms of individual word length is comparable between the two languages in your dataset.

1.2 Word Frequency Analysis:

[ ]:
```python
stop_words_eng = set(stopwords.words('english'))
stop_words_ar = set(nltk.corpus.stopwords.words("arabic"))

english_word_lengths = [len(word) for word in nltk.word_tokenize(' '.
↪join(english_sentences_clean)) if word.lower() not in stop_words_eng]
arabic_word_lengths = [len(word) for word in nltk.word_tokenize(' '.
↪join(arabic_sentences_clean)) if word not in stop_words_ar]

english_word_length_freq = FreqDist(english_word_lengths)
arabic_word_length_freq = FreqDist(arabic_word_lengths)

english_most_common_word_lengths = english_word_length_freq.most_common(10)
arabic_most_common_word_lengths = arabic_word_length_freq.most_common(10)

num_unique_words_eng = len(set(word for sentence in english_sentences_clean for␣
↪word in sentence.split()))
num_unique_words_ar = len(set(word for sentence in arabic_sentences_clean for␣
↪word in sentence.split()))

english_word_freq = FreqDist(nltk.word_tokenize(' '.
↪join(english_sentences_clean)))
```

```
arabic_word_freq = FreqDist(nltk.word_tokenize(' '.
 ↪join(arabic_sentences_clean)))

english_rare_words = [word for word, count in english_word_freq.items() if␣
 ↪count == 1]
arabic_rare_words = [word for word, count in arabic_word_freq.items() if count␣
 ↪== 1]

english_sample_rare_words = english_rare_words[:10]
arabic_sample_rare_words = arabic_rare_words[:10]

freq_dist_eng_no_stopwords = FreqDist(word for sentence in␣
 ↪english_sentences_clean for word in sentence.split() if word.lower() not in␣
 ↪stop_words_eng)
freq_dist_ar_no_stopwords = FreqDist(word for sentence in␣
 ↪arabic_sentences_clean for word in sentence.split() if word not in␣
 ↪stop_words_ar)

english_most_common_no_stopwords = freq_dist_eng_no_stopwords.most_common(10)
arabic_most_common_no_stopwords = freq_dist_ar_no_stopwords.most_common(10)

freq_dist_eng = FreqDist(word for sentence in english_sentences_clean for word␣
 ↪in sentence.split())
freq_dist_ar = FreqDist(word for sentence in arabic_sentences_clean for word in␣
 ↪sentence.split())

num_stop_words_eng = len([word for sentence in english_sentences_clean for word␣
 ↪in sentence.split() if word in stop_words_eng])
english_stop_word_counts = {word: freq_dist_eng[word] for word in␣
 ↪stop_words_eng if word in freq_dist_eng}
most_common_stop_words_eng = sorted(english_stop_word_counts.items(),␣
 ↪key=lambda x: x[1], reverse=True)[:10]

num_stop_words_ar = len([word for sentence in arabic_sentences_clean for word␣
 ↪in sentence.split() if word in stop_words_ar])
arabic_stop_word_counts = {word: freq_dist_ar[word] for word in stop_words_ar␣
 ↪if word in freq_dist_ar}
most_common_stop_words_ar = sorted(arabic_stop_word_counts.items(), key=lambda␣
 ↪x: x[1], reverse=True)[:10]

def extract_ngrams(sentences, n):
    ngram_list = []
    for sentence in sentences:
        tokens = sentence.split()
        ngram_list.extend(list(nltk.ngrams(tokens, n)))
    return ngram_list
```

```
english_bigrams = extract_ngrams(english_sentences_clean, 2)
english_trigrams = extract_ngrams(english_sentences_clean, 3)

arabic_bigrams = extract_ngrams(arabic_sentences_clean, 2)
arabic_trigrams = extract_ngrams(arabic_sentences_clean, 3)

english_bigram_freq = nltk.FreqDist(english_bigrams)
english_trigram_freq = nltk.FreqDist(english_trigrams)

arabic_bigram_freq = nltk.FreqDist(arabic_bigrams)
arabic_trigram_freq = nltk.FreqDist(arabic_trigrams)

print(f"English: \n Word length distribution:␣
 ↪{english_most_common_word_lengths} \n Number of unique words:␣
 ↪{num_unique_words_eng} \n Number of rare words: {len(english_rare_words)} \n␣
 ↪Number of stop words: {num_stop_words_eng} \n Most common stop words:␣
 ↪{most_common_stop_words_eng} \n Most common unique words(unigrams):␣
 ↪{english_most_common_no_stopwords} \n Sample of rare words:␣
 ↪{english_sample_rare_words} \n Most common bigrams: {english_bigram_freq.
 ↪most_common(10)} \n Most common trigrams: {english_trigram_freq.
 ↪most_common(10)}")
print("\n")
print(f"Arabic: \n Word length distribution: {arabic_most_common_word_lengths}␣
 ↪\n Number of unique words: {num_unique_words_ar} \n Number of rare words:␣
 ↪{len(arabic_rare_words)} \n Number of stop words: {num_stop_words_ar} \n␣
 ↪Most common stop words: {most_common_stop_words_ar} \n Most common unique␣
 ↪words(unigrams): {arabic_most_common_no_stopwords} \n Sample of rare words
```

```
English:
 Word length distribution: [(6, 43059), (5, 41125), (4, 39546), (7, 35365), (8,
26764), (9, 17854), (3, 16163), (10, 11574), (11, 6310), (2, 5599)]
 Number of unique words: 25997
 Number of rare words: 11842
 Number of stop words: 184508
 Most common stop words: [('the', 23882), ('of', 11606), ('to', 11292), ('in',
9824), ('and', 9761), ('a', 9324), ('is', 5216), ('on', 4171), ('i', 4046),
('for', 3963)]
 Most common unique words(unigrams): [('global', 2708), ('voices', 2691),
('people', 1035), ('one', 1012), ('tom', 971), ('like', 776), ('also', 761),
('new', 726), ('media', 721), ('world', 719)]
 Sample of rare words: ['waved', 'unsure', 'yawned', 'discreet', 'merciful',
'windy', 'tvs', 'gawking', 'observant', 'lasagna']
 Most common bigrams: [(('of', 'the'), 2775), (('global', 'voices'), 2532),
(('in', 'the'), 2033), (('to', 'the'), 1109), (('on', 'the'), 1030), (('for',
'the'), 632), (('is', 'a'), 578), (('and', 'the'), 559), (('from', 'the'), 544),
(('in', 'a'), 521)]
```

```
 Most common trigrams: [(('one', 'of', 'the'), 205), (('used', 'with',
'permission'), 154), (('as', 'well', 'as'), 137), (('around', 'the', 'world'),
130), (('is', 'part', 'of'), 117), (('a', 'lot', 'of'), 101), (('this', 'post',
'is'), 100), (('part', 'of', 'our'), 99), (('post', 'is', 'part'), 96), (('our',
'special', 'coverage'), 91)]


Arabic:
 Word length distribution: [(5, 63371), (4, 59634), (6, 52043), (7, 41089), (3,
34536), (8, 22076), (2, 9888), (9, 8078), (10, 3331), (11, 1233)]
 Number of unique words: 52736
 Number of rare words: 28077
 Number of stop words: 74587
 Most common stop words: [(' ', 12661), (' ', 10929), ('  ', 6542), (' ',
2895), ('  ', 2030), (' ', 1997), (' ', 1784), ('  ', 1720), ('  ', 1467),
(' ', 1335)]
 Most common unique words(unigrams): [(' ', 4361), ('  ', 2826), ('    ',
2817), ('    ', 2733), (' ', 1031), ('    ', 1029), ('  ', 959),
('  ', 793), ('  ', 768), ('  ', 709)]
 Sample of rare words: ['  ', '   ', '   ', '  ', '  ', '   ',
'   ', '   ', '   ', '  '[
 Most common bigrams: [(('    ', '    '(, 2637), ((' ', '  '(, 443),
(('   ', ' '(, 347), (('  ', '    '(, 345), (('  ', ' '(, 317),
((' ', '  '(, 295), ((' ', '  '(, 241), (('   ', ' '(, 224), (('  ',
'  '(, 224), (('  ', '    '(, 208)]
 Most common trigrams: [(('  ', '   ', '    '(, 186), (('  ', '  ',
'   '(, 180), (('  ', '  ', ' '(, 86), ((' ', '    ', '   '(,
85), ((' ', ' ', '    '(, 84), (('   ', ' ', ' '(, 76), (('  ',
'   ', ' '(, 74), (('   ', '  ', '   '(, 74), (('   ', '  ',
'   '(, 64), (('   ', '  ', '   '(, 64)]
```

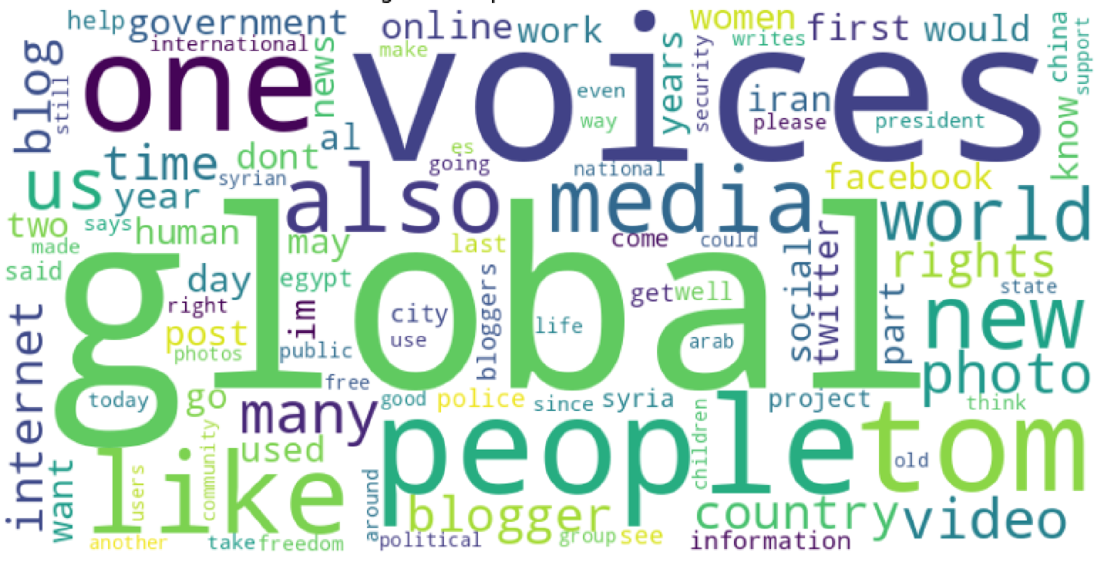
Findings based on the above statistics:

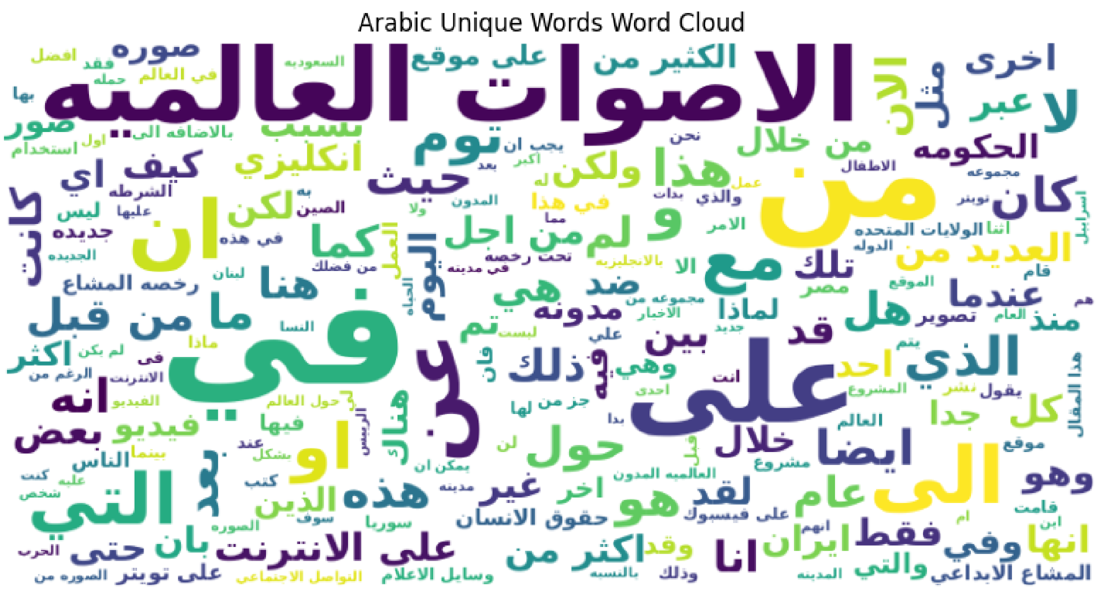
- There is a minor shift in the peak word lengths in Arabic when compared to English.
- The dataset appears to have recurring themes or expressions like ‘global voices’, ‘used with permission’, and ‘special coverage’. These can provide insights into the type of content (perhaps news articles or blog posts) and their sourcing and categorization.
- There seems to be an overlap in the core themes and topics between the English and Arabic datasets. Terms related to global voices, media, and the internet consistently appear in both, implying that the dataset might be from a source discussing global events, trends, or news.
- The vast difference in vocabulary size between the two languages could pose challenges in translation. Given that Arabic has a more extensive vocabulary in this dataset, ensuring a comprehensive translation without loss of nuanced meanings can be tricky.
- The average word length for both English and Arabic sentences is quite close. This similarity might indicate that, in general, the complexity in terms of individual word length is comparable between the two languages in your dataset.

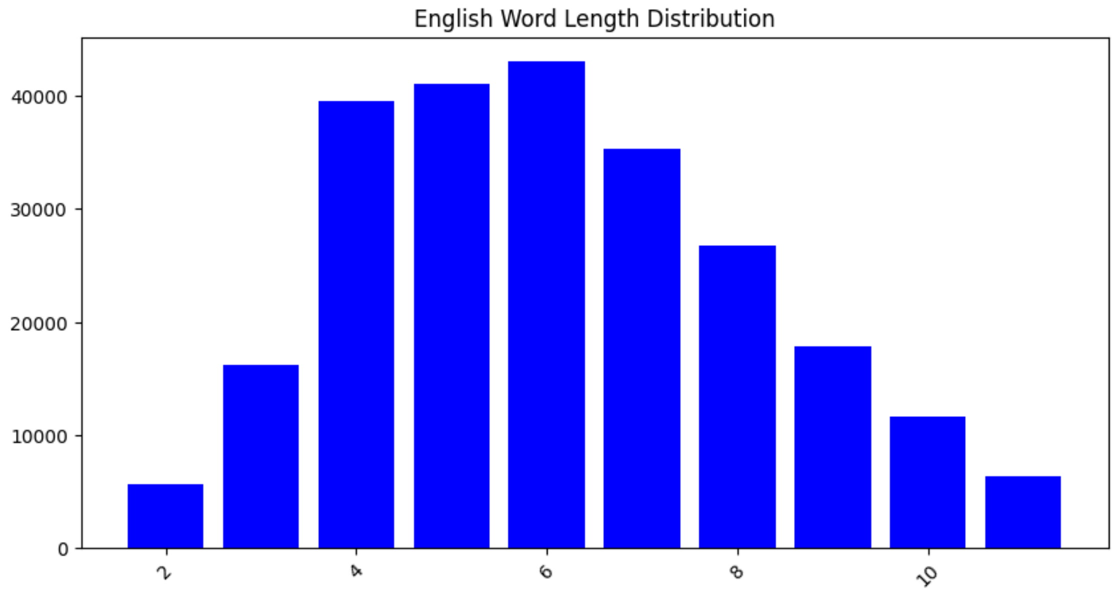
1.3 Visualizations:

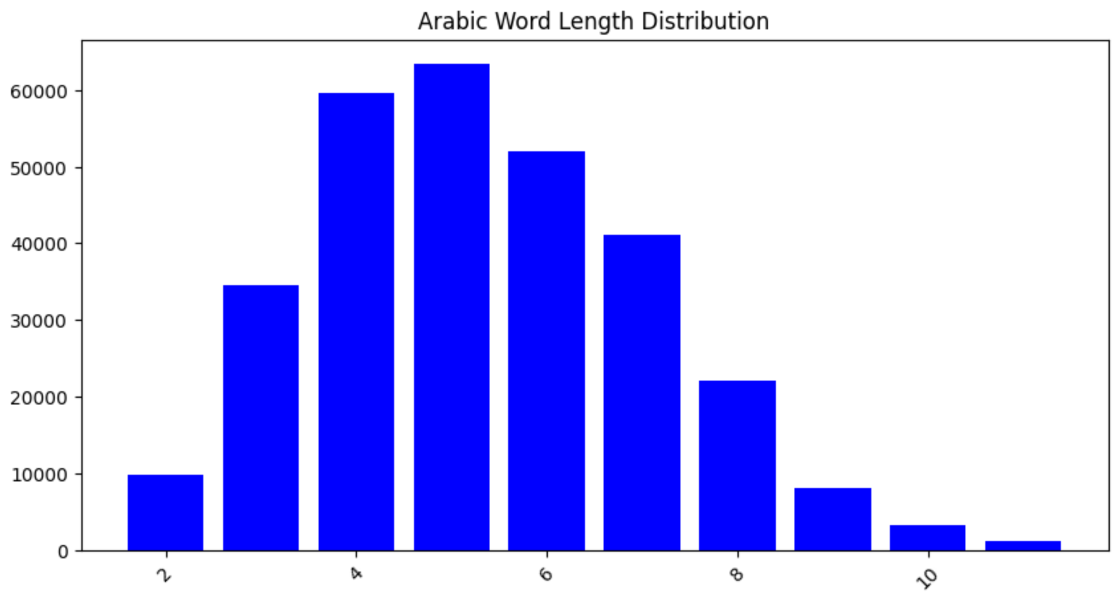
```
[ ]: def generate_bar_chart_eng(freq_list, title):
         words = [i[0] for i in freq_list]
         counts = [i[1] for i in freq_list]
         plt.figure(figsize=(10,5))
         plt.bar(words, counts, color='blue')
         plt.title(title)
         plt.xticks(rotation=45)
         plt.show()

     def generate_bar_chart_ar(freq_list, title):
         words = [i[0] for i in freq_list]
         counts = [i[1] for i in freq_list]
         reshaped_words = [get_display(arabic_reshaper.reshape(word)) for word in␣
       ↪words]
         plt.figure(figsize=(10,5))
         plt.bar(reshaped_words, counts, color='blue')
         plt.title(title)
         plt.xticks(rotation=45)
         plt.show()

     def generate_word_cloud(freq_dict, title):
         wordcloud = WordCloud(width=800, height=400, max_words=100,␣
       ↪background_color='white').generate_from_frequencies(freq_dict)
         plt.figure(figsize=(10,5))
         plt.imshow(wordcloud, interpolation="bilinear")
         plt.axis('off')
         plt.title(title)
         plt.show()

     generate_word_cloud(freq_dist_eng_no_stopwords, 'English Unique Words Word␣
       ↪Cloud')

     wordcloud = WordCloud(font_path='/usr/local/lib/python3.10/dist-packages/cv2/qt/
       ↪fonts/DejaVuSans-Bold.ttf',
                           width=800,
                           height=400,
                           random_state=21,
                           max_font_size=110,
                           background_color='white',
                           relative_scaling=0.5,
                           colormap='viridis').generate(' '.
       ↪join(arabic_sentences_clean))
     plt.figure(figsize=(10, 7))
     plt.imshow(wordcloud, interpolation="bilinear")
     plt.axis('off')
     plt.title('Arabic Unique Words Word Cloud')
     plt.show()

     generate_bar_chart_eng(english_most_common_word_lengths, 'English Word Length␣
       ↪Distribution')
     generate_bar_chart_eng(arabic_most_common_word_lengths, 'Arabic Word Length␣
       ↪Distribution')
     generate_bar_chart_eng(english_most_common_no_stopwords, 'Most Common English␣
       ↪Unique Words (Unigrams)')
     generate_bar_chart_ar(arabic_most_common_no_stopwords, 'Most Common Arabic␣
       ↪Unique Words (Unigrams)')

     english_bigrams_counts = [(str(bigram), count) for bigram, count in␣
       ↪english_bigram_freq.most_common(10)]
     arabic_bigrams_counts = [(str(bigram), count) for bigram, count in␣
       ↪arabic_bigram_freq.most_common(10)]
     generate_bar_chart_eng(english_bigrams_counts, 'Most Common English Bigrams')
     generate_bar_chart_ar(arabic_bigrams_counts, 'Most Common Arabic Bigrams')
```

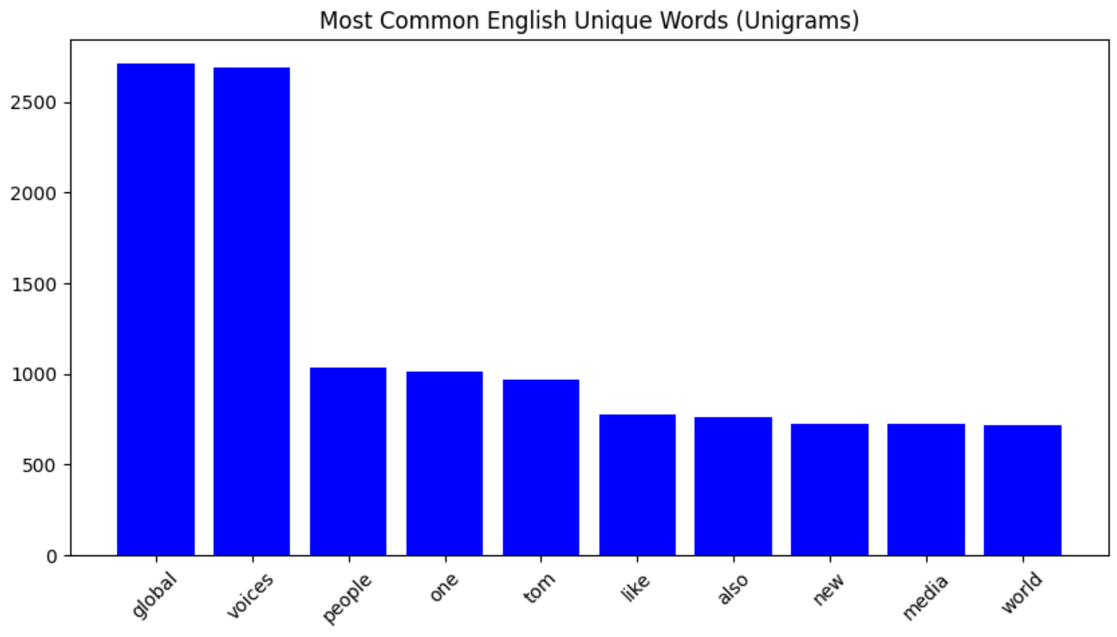
English Unique Words Word Cloud

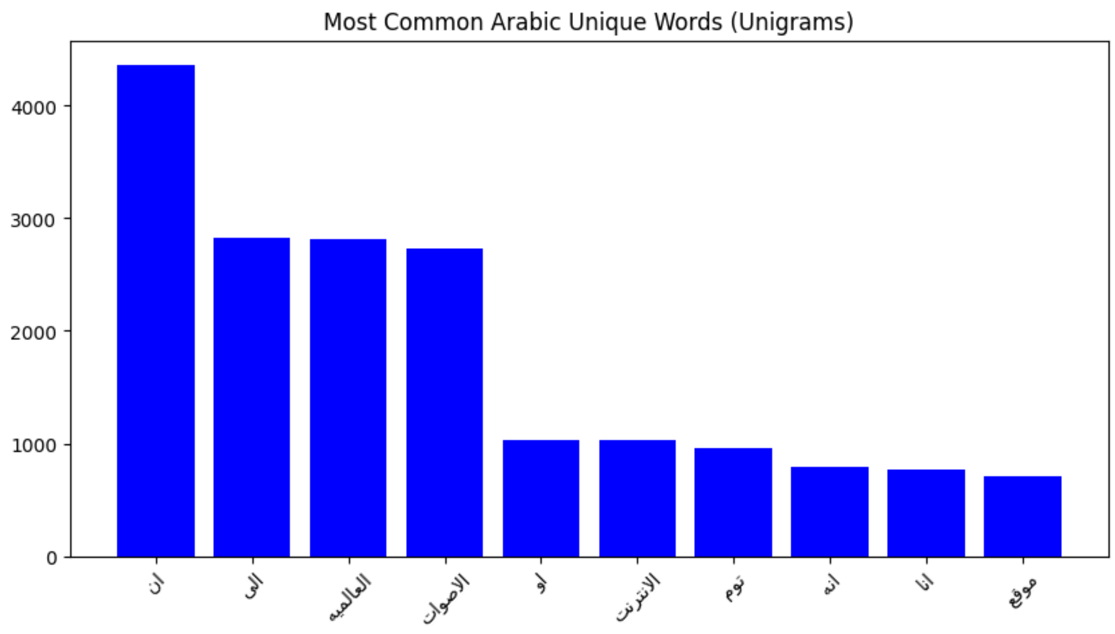



Arabic Unique Words Word Cloud
الاصوات العالميه
في
على
من
عن
ان
الى
التي
مع
او
بعد
الذي
كان
هذا
ولكن
الكثير من
على موقع
اخرى
الحكومه
حيث
توم
انكليزي
كيف
لكن
كما
من اجل
لم
العديد من
تلك
هل
ما
من قبل
هنا
ذلك
بين
قد
احد
كل
جدا
حول
خلال
ايضا
غير
هذه
هو
لقد
عام
وهو
الانترنت
اكثر من
ايران
فقط
وفي
انها
حقوق الانسان
وسائل الاعلام
المشاع الابداعي

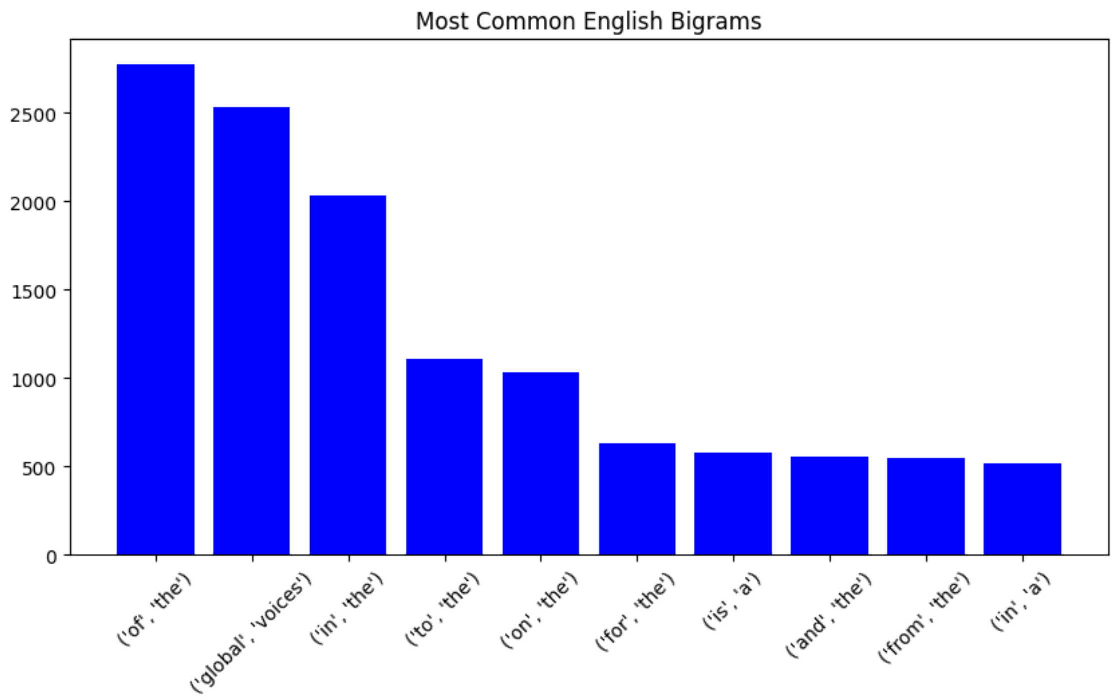

English Word Length Distribution
0
10000
20000
30000
40000
2
4
6
8
10


Arabic Word Length Distribution
60000
50000
40000
30000
20000
10000
0
2
4
6
8
10

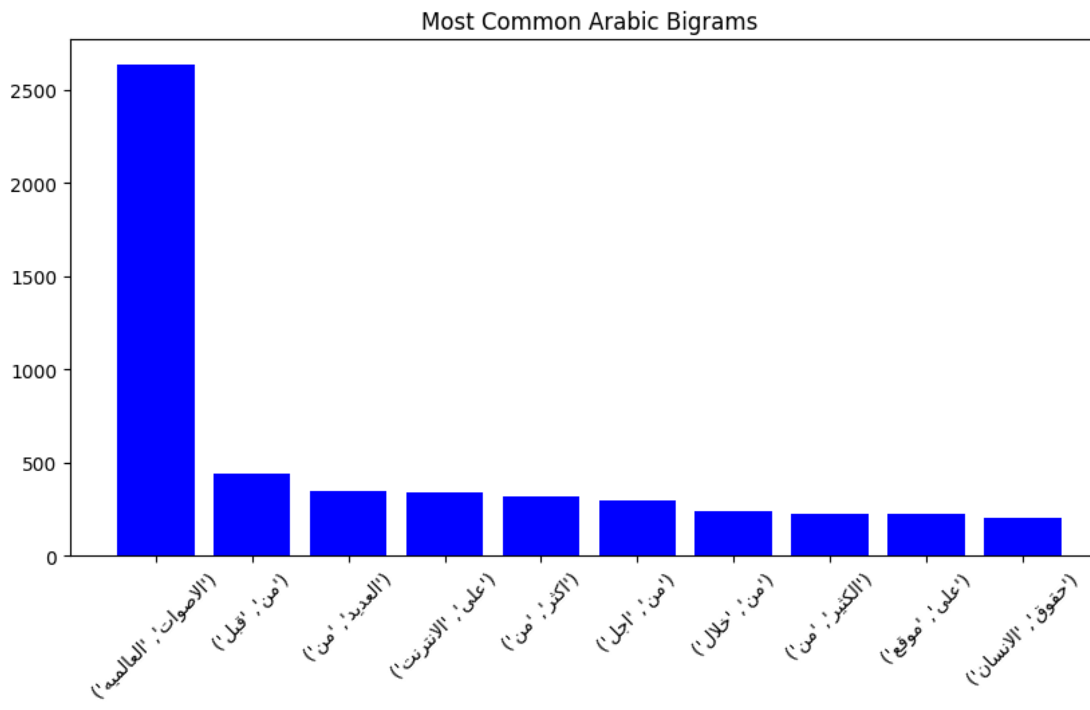

Most Common English Unique Words (Unigrams)
2500
2000
1500
1000
500
0
global
voices
people
one
tom
like
also
new
media
world



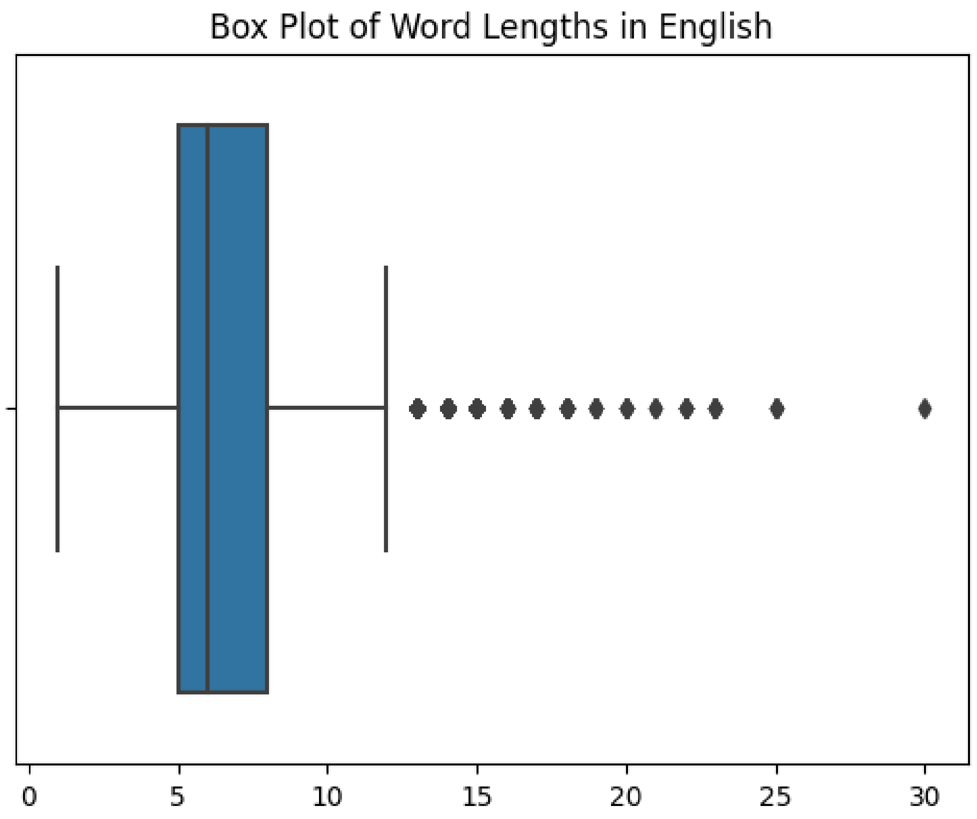
Most Common Arabic Unique Words (Unigrams)
4000
3000
2000
1000
0
ان
الى
العالميه
الاصوات
او
الانترنت
توم
انه
انا
موقع

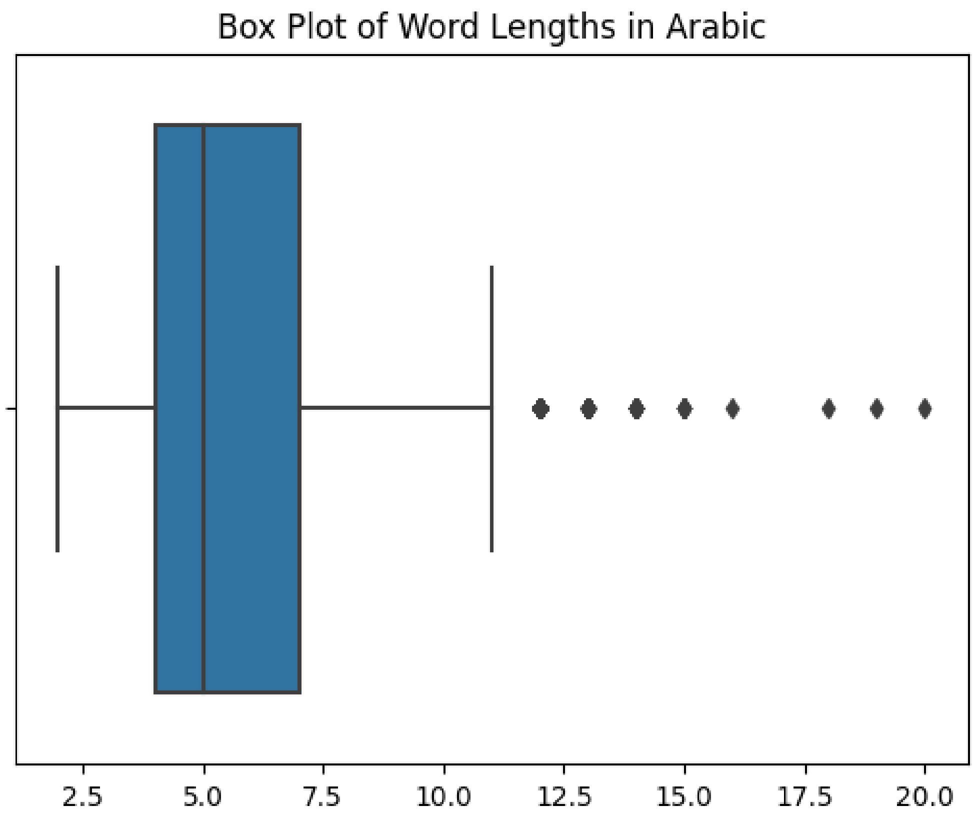


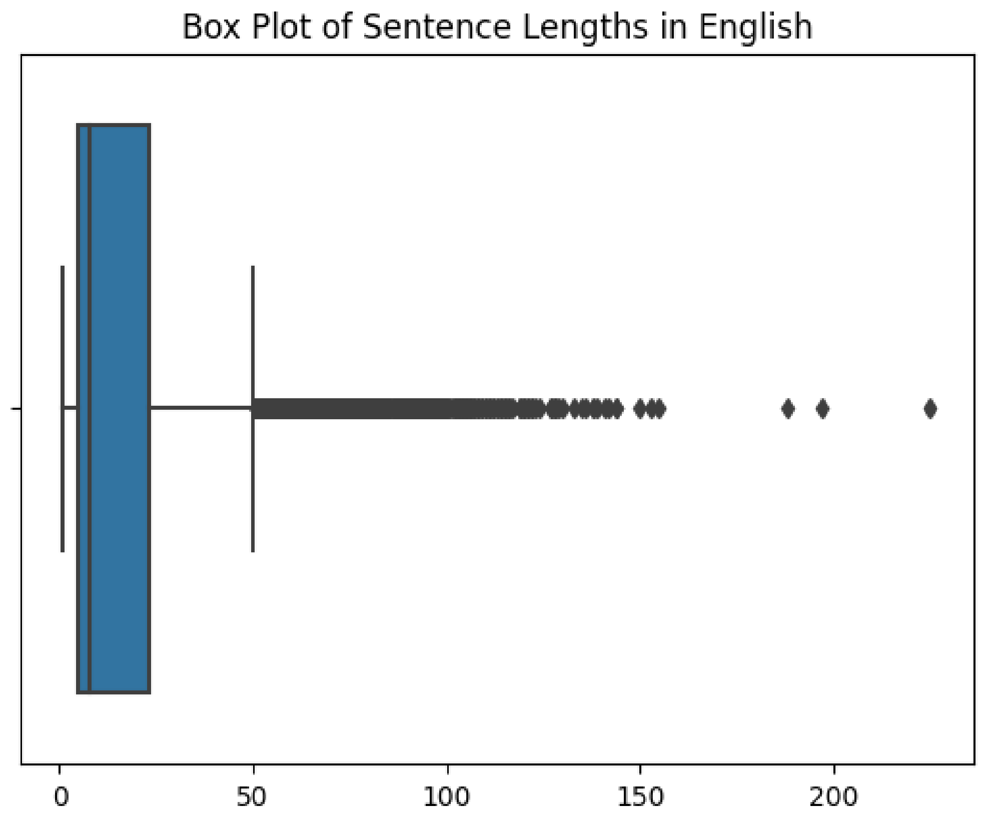
Most Common English Bigrams
2500
2000
1500
1000
500
0
('of', 'the')
('global', 'voices')
('in', 'the')
('to', 'the')
('on', 'the')
('for', 'the')
('is', 'a')
('and', 'the')
('from', 'the')
('in', 'a')

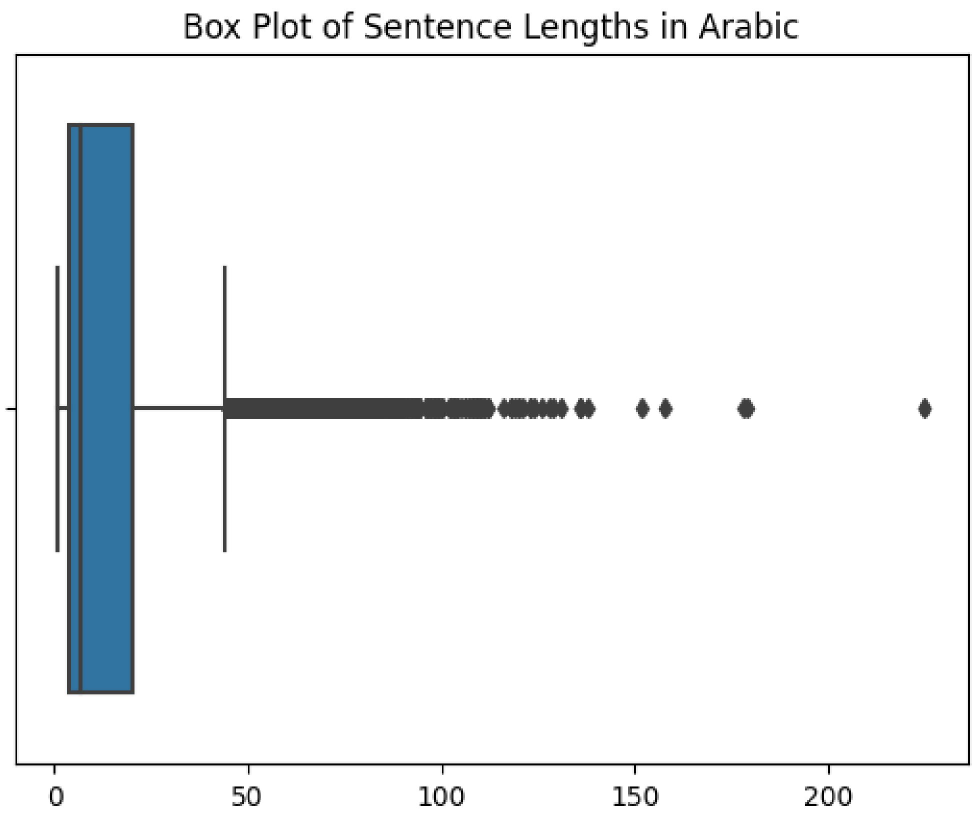


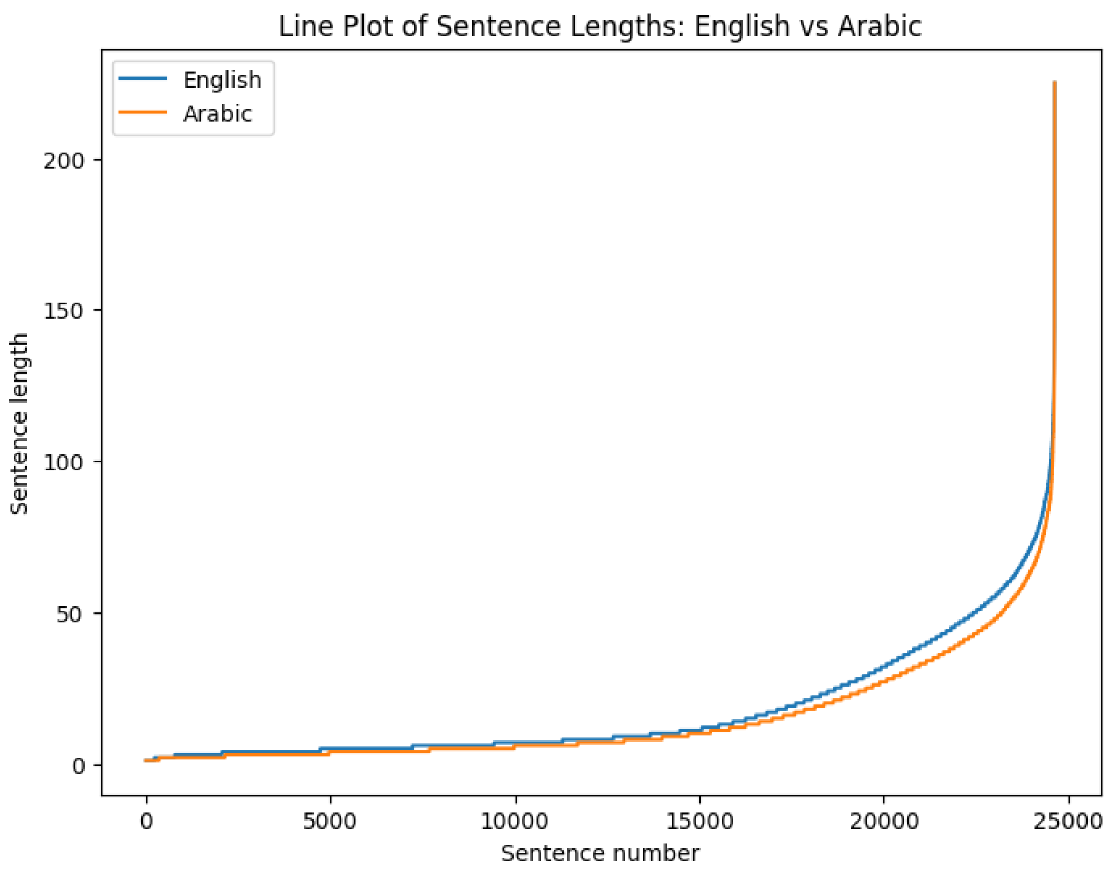
```
[ ]: import seaborn as sns

     # Create box plots for word lengths
     sns.boxplot(x=english_word_lengths).set_title('Box Plot of Word Lengths in␣
      ↪English')
     plt.show()
     sns.boxplot(x=arabic_word_lengths).set_title('Box Plot of Word Lengths in␣
      ↪Arabic')
     plt.show()

     # Create box plots for sentence lengths
     sns.boxplot(x=english_sentence_lengths).set_title('Box Plot of Sentence Lengths␣
      ↪in English')
     plt.show()
     sns.boxplot(x=arabic_sentence_lengths).set_title('Box Plot of Sentence Lengths␣
      ↪in Arabic')
     plt.show()

     # Sort sentence lengths for line plot
     english_sentence_lengths_sorted = sorted(english_sentence_lengths)
     arabic_sentence_lengths_sorted = sorted(arabic_sentence_lengths)

     # Plotting sentence lengths over the sentences
     plt.figure(figsize=(8,6))
     plt.plot(english_sentence_lengths_sorted, label='English')
     plt.plot(arabic_sentence_lengths_sorted, label='Arabic')
     plt.title('Line Plot of Sentence Lengths: English vs Arabic')
     plt.xlabel('Sentence number')
     plt.ylabel('Sentence length')
     plt.legend()
     plt.show()
```




Box Plot of Word Lengths in Arabic
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0


Box Plot of Sentence Lengths in English
0
50
100
150
200


Box Plot of Sentence Lengths in Arabic
0
50
100
150
200



2 Translation Models

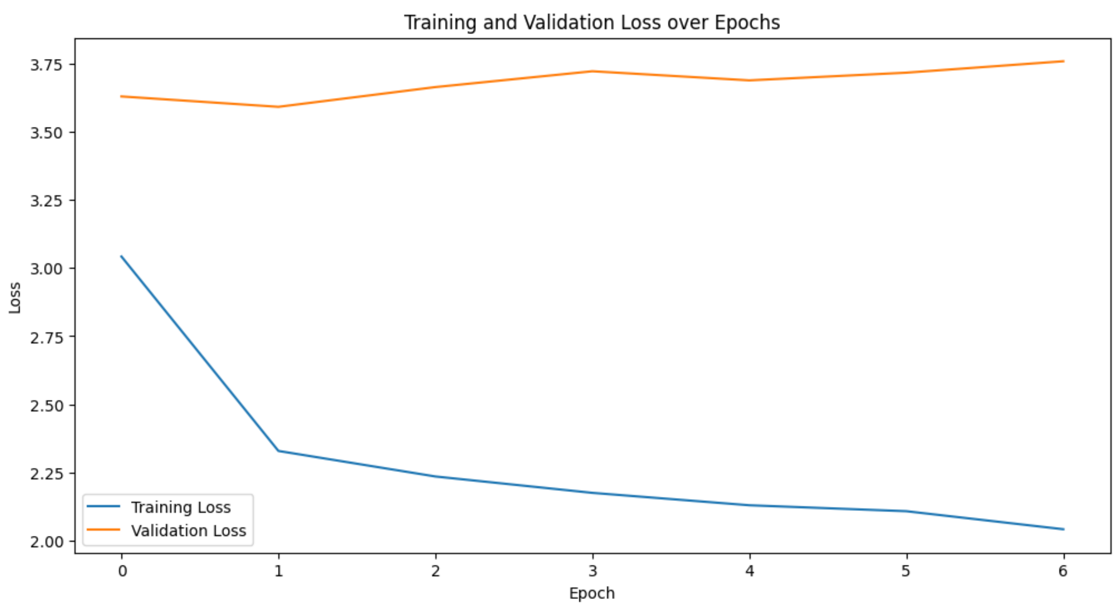
2.1 Simple LSTM Model

```
[11]: src_vocab = src_vocab_size
      tar_vocab = tar_vocab_size
      src_timesteps = src_length
      tar_timesteps = tar_length
      n_units = 512

      model = Sequential()
      model.add(Embedding(src_vocab, n_units, input_length=src_timesteps,␣
       ↪mask_zero=True))
      model.add(LSTM(n_units))
      model.add(RepeatVector(tar_timesteps))
      model.add(LSTM(n_units, return_sequences=True))
      model.add(TimeDistributed(Dense(tar_vocab, activation='softmax')))
      model.compile(optimizer='adam', loss='categorical_crossentropy')
```

```
history = model.fit(trainX, trainY, epochs=200, batch_size=64,␣
↪validation_split=0.1, verbose=1,␣
↪callbacks=[EarlyStopping(monitor='val_loss', patience=5,␣
↪restore_best_weights=True)])
```

```
Epoch 1/200
125/125 [==============================] - 27s 112ms/step - loss: 3.0419 -
val_loss: 3.6289
Epoch 2/200
125/125 [==============================] - 5s 42ms/step - loss: 2.3290 -
val_loss: 3.5909
Epoch 3/200
125/125 [==============================] - 4s 35ms/step - loss: 2.2353 -
val_loss: 3.6633
Epoch 4/200
125/125 [==============================] - 4s 31ms/step - loss: 2.1753 -
val_loss: 3.7213
Epoch 5/200
125/125 [==============================] - 4s 28ms/step - loss: 2.1298 -
val_loss: 3.6879
Epoch 6/200
125/125 [==============================] - 4s 30ms/step - loss: 2.1080 -
val_loss: 3.7161
Epoch 7/200
125/125 [==============================] - 4s 32ms/step - loss: 2.0419 -
val_loss: 3.7580
```

[12]:
```
plt.figure(figsize=(12, 6))
plt.plot(history.history['loss'], label='Training Loss')
plt.plot(history.history['val_loss'], label='Validation Loss')
plt.title('Training and Validation Loss over Epochs')
plt.xlabel('Epoch')
plt.ylabel('Loss')
plt.legend()
plt.show()
```



[15]:
```python
def word_for_id(integer, tokenizer):
    for word, index in tokenizer.word_index.items():
        if index == integer:
            return word
    return None

def predict_seq(model, tokenizer, source):
    prediction = model.predict(source, verbose=0)[0]
    integers = [np.argmax(vector) for vector in prediction]
    target = [word_for_id(i, tokenizer) for i in integers if word_for_id(i,␣
 ↪tokenizer) is not None]
    return ' '.join(target)

def compare_prediction(model, tokenizer, sources, raw_dataset_ar,␣
 ↪raw_dataset_en, limit=20):
    print(f"{'(SOURCE) Arabic':30} {'(TARGET) English':25} {'AUTOMATIC␣
 ↪TRANSLATION IN English'}")
    for i, source in enumerate(sources):
        source = source.reshape((1, source.shape[0]))
        translation = predict_seq(model, tokenizer, source)
        raw_target, raw_src = raw_dataset_en[i], raw_dataset_ar[i]
        print(f"{raw_src:30} {raw_target:25} {translation}")
        if i >= limit:
            break

compare_prediction(model, tar_tokenizer, trainX, train_ar, train_en)
compare_prediction(model, tar_tokenizer, testX, test_ar, test_en)
```

```
### Result on the Training Set ###
(SOURCE) Arabic                (TARGET) English          AUTOMATIC TRANSLATION
IN English

<bos>     <eos>              <bos> hi <eos>            bos i eos eos
<bos>    <eos>               <bos> run <eos>            bos i you eos
<bos>     <eos>             <bos> help <eos>           bos i eos
<bos>    <eos>               <bos> jump <eos>           bos i you eos
<bos>   <eos>                 <bos> stop <eos>           bos i you eos
<bos>    <eos>               <bos> go on <eos>          bos i you eos
<bos>     <eos>              <bos> go on <eos>         bos i eos eos
<bos>     <eos>              <bos> hello <eos>         bos i eos eos
<bos>    <eos>               <bos> hurry <eos>          bos i eos eos
<bos>     <eos>             <bos> hurry <eos>          bos i eos eos
<bos>      <eos>            <bos> i see <eos>          bos i you eos
<bos>      <eos>            <bos> i won <eos>          bos i eos eos
<bos>     <eos>              <bos> relax <eos>         bos i you eos eos
<bos>     <eos>              <bos> smile <eos>         bos i eos
<bos>      <eos>            <bos> cheers <eos>         bos i is eos eos
<bos>      <eos>            <bos> got it <eos>         bos i is you eos eos
<bos>    <eos>                <bos> he ran <eos>        bos i eos eos
<bos>    <eos>               <bos> i know <eos>         bos i you eos eos
<bos>       <eos>           <bos> i know <eos>        bos i is you eos eos
<bos>       <eos>           <bos> i know <eos>        bos i is eos eos
<bos>       <eos>            <bos> im  <eos>           bos i you eos eos


### Result on the Test Set ###
(SOURCE) Arabic                (TARGET) English          AUTOMATIC TRANSLATION
IN English

<bos>                  <eos> <bos> when i grow up i want to be a king
<eos> bos i is is to to eos eos eos
<bos>                     <eos> <bos> when did you begin studying
english <eos> bos i is you to eos eos eos
<bos>                  <eos> <bos> when do you plan to leave for japan
<eos> bos i is you to to eos eos
<bos>           <eos>    <bos> where is the entrance to the museum <eos>
bos i is you to eos eos
<bos>                    <eos> <bos> why dont we just agree to
disagree <eos> bos i is you to to eos eos
<bos>                  <eos> <bos> will you allow me to play the
piano <eos> bos i is you eos eos eos
<bos>                <eos> <bos> would you prefer to speak in french
<eos> bos i is you to eos eos
<bos>             <eos>  <bos> you are responsible for what you do <eos>
bos i is you to eos eos
<bos>                  <eos> <bos> you dont seem to care what happens
```

```
<eos> bos i is you to eos eos
<bos>                 <eos> <bos> you may have read this book already
<eos> bos i is you to eos eos
<bos>                      <eos> <bos> you must gather further
information <eos> bos i is you to eos eos eos
<bos>                     <eos> <bos> you ought to have come here
earlier <eos> bos i is you to eos eos eos
<bos>              <eos> <bos> you should acknowledge your failure <eos>
bos i is you to eos eos
<bos>              <eos> <bos> you should have accepted his advice <eos>
bos i is you to eos eos
<bos>               <eos> <bos> youre either with us or against us <eos>
bos i is you to eos eos
<bos>            <eos>  <bos> a drowning man will catch at a straw <eos>
bos i is you eos eos eos
<bos>                   <eos> <bos> a lot of tourists invaded the
island <eos> bos i is you to eos eos eos
<bos>                     <eos> <bos> a lot of tourists invaded the
island <eos> bos i is you to eos eos eos
<bos>                    <eos> <bos> a loud noise in the night
scared him <eos> bos i is you to eos eos eos
<bos>              <eos> <bos> all of a sudden a dog began barking <eos>
bos i is you to eos eos eos
<bos>                      <eos> <bos> any student can answer that
question <eos> bos i is you to to eos eos
```

[16]:
```python
def calculate_bleu_score(model, tokenizer, sources, raw_targets):
    actual, predicted = [], []
    for i, source in enumerate(sources):
        source = source.reshape((1, source.shape[0]))
        translation = predict_seq(model, tokenizer, source)
        raw_target = raw_targets[i].split()
        predicted.append(translation.split())
        actual.append([raw_target])
    return corpus_bleu(actual, predicted)

test_bleu = calculate_bleu_score(model, tar_tokenizer, testX, test_en)
print(f"Testing BLEU Score: {test_bleu:.4f}")
```

```
Testing BLEU Score: 0.0000
```

Inference Function

[ ]:
```python
def translate(model, src_tokenizer, tar_tokenizer, src_length, source):
    source_seq = encode_sequences(src_tokenizer, src_length, [source])
    prediction = model.predict(source_seq, verbose=0)[0]
    int_seq = [np.argmax(vector) for vector in prediction]
    target_text = ' '.join([tar_tokenizer.index_word[i] for i in int_seq if i >␣
 ↪0])
    return target_text

sentence = "   "
translation = translate(model, src_tokenizer, tar_tokenizer, src_length,␣
 ↪sentence)
print(f'Arabic: {sentence}\nPredicted English: {translation}')
```

```
Arabic:
Predicted English: though though though painful painful painful painful painful
painful painful painful painful painful
```

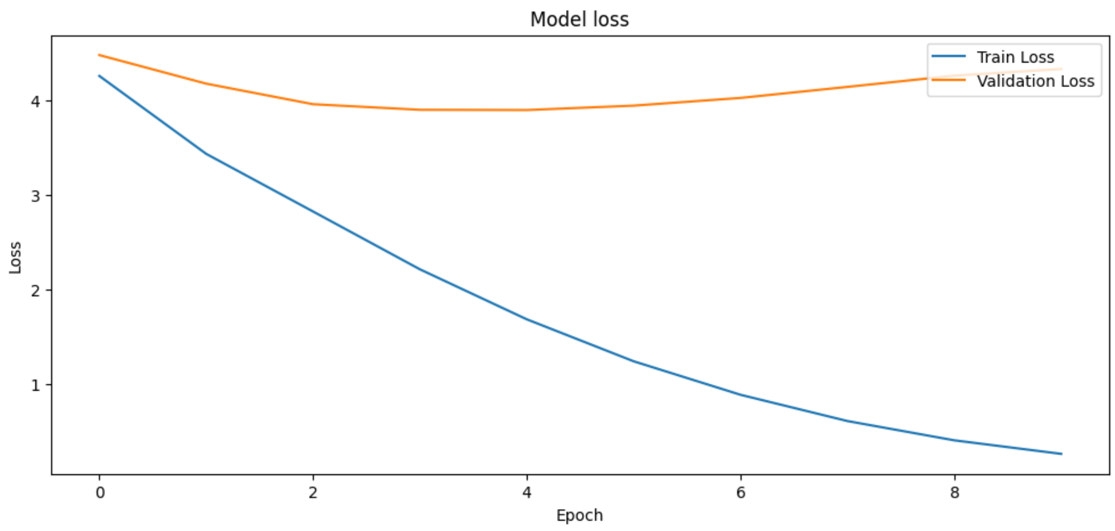
2.2 enc-dec model

2.2.1 without Attention

[17]:
```
src_vocab = src_vocab_size
tar_vocab = tar_vocab_size
src_timesteps = src_length
tar_timesteps = tar_length
n_units = 512

encoder_inputs = Input(shape=(src_timesteps,))
enc_emb = Embedding(src_vocab, n_units, mask_zero=True)(encoder_inputs)
encoder_lstm = LSTM(n_units, return_sequences=True, return_state=True)
encoder_outputs, state_h, state_c = encoder_lstm(enc_emb)
encoder_states = [state_h, state_c]

decoder_inputs = Input(shape=(tar_timesteps,))
dec_emb_layer = Embedding(tar_vocab, n_units, mask_zero=True)
dec_emb = dec_emb_layer(decoder_inputs)
decoder_lstm = LSTM(n_units, return_sequences=True, return_state=True)
decoder_outputs, _, _ = decoder_lstm(dec_emb, initial_state=encoder_states)
decoder_dense = TimeDistributed(Dense(tar_vocab, activation='softmax'))
decoder_outputs = decoder_dense(decoder_outputs)

model = Model([encoder_inputs, decoder_inputs], decoder_outputs)
opt = Adam(learning_rate=0.001, clipnorm=1.0)
model.compile(optimizer=opt, loss='categorical_crossentropy')

decoder_input_data = np.zeros_like(trainY)
decoder_input_data[:, 1:] = trainY[:, :-1]
decoder_input_data = np.argmax(decoder_input_data, axis=-1)

history = model.fit(
    [trainX, decoder_input_data],
    trainY,
    epochs=200,
    batch_size=18,
    validation_split=0.1,
    verbose=1,
    callbacks=[
        EarlyStopping(
            monitor='val_loss',
            patience=5,
            restore_best_weights=True
        )
    ]
)
```

```
Epoch 1/200
444/444 [==============================] - 41s 73ms/step - loss: 4.2583 -
val_loss: 4.4788
Epoch 2/200
444/444 [==============================] - 34s 76ms/step - loss: 3.4352 -
val_loss: 4.1769
Epoch 3/200
444/444 [==============================] - 31s 71ms/step - loss: 2.8264 -
val_loss: 3.9597
Epoch 4/200
444/444 [==============================] - 31s 69ms/step - loss: 2.2157 -
val_loss: 3.9010
Epoch 5/200
444/444 [==============================] - 31s 69ms/step - loss: 1.6877 -
val_loss: 3.8983
Epoch 6/200
444/444 [==============================] - 30s 68ms/step - loss: 1.2444 -
val_loss: 3.9448
Epoch 7/200
444/444 [==============================] - 30s 68ms/step - loss: 0.8907 -
val_loss: 4.0263
Epoch 8/200
444/444 [==============================] - 30s 67ms/step - loss: 0.6135 -
val_loss: 4.1429
Epoch 9/200
444/444 [==============================] - 30s 68ms/step - loss: 0.4099 -
val_loss: 4.2615
Epoch 10/200
444/444 [==============================] - 32s 72ms/step - loss: 0.2670 -
val_loss: 4.3315
```

[18]:
```
plt.figure(figsize=(12, 5))
plt.plot(history.history['loss'], label='Train Loss')
plt.plot(history.history['val_loss'], label='Validation Loss')
plt.title('Model loss')
plt.ylabel('Loss')
plt.xlabel('Epoch')
plt.legend(loc='upper right')
plt.show()
```



[24]:
```
def predict_seq(encoder_model, decoder_model, tokenizer, source,␣
↪max_output_length):
    state_h, state_c = encoder_model.predict(source, verbose=0)
    encoder_states = [state_h, state_c]
    target_seq = np.zeros((1, 1))
    target_seq[0, 0] = tokenizer.word_index['<bos>']
    decoded_sentence = []

    for _ in range(max_output_length):
        output_tokens, h, c = decoder_model.predict([target_seq] +␣
↪encoder_states, verbose=0)
        sampled_token_index = np.argmax(output_tokens[0, -1, :])
        sampled_word = word_for_id(sampled_token_index, tokenizer)

        if sampled_word is None or sampled_word == '<eos>':
            break

        decoded_sentence.append(sampled_word)
        encoder_states = [h, c]
        target_seq = np.zeros((1, 1))
        target_seq[0, 0] = sampled_token_index
    return ' '.join(decoded_sentence)

def word_for_id(integer, tokenizer):
    for word, index in tokenizer.word_index.items():
        if index == integer:
            return word
    return None

def compare_prediction(encoder_model, decoder_model, tokenizer, sources,␣
 ↪raw_dataset_ar, raw_dataset_en, max_output_length, limit=20):
    actual, predicted = [], []
    src = '(SOURCE) Arabic'
    tgt = '(TARGET) English'
    pred = 'AUTOMATIC TRANSLATION IN English'
    print(f'{src:30} {tgt:25} {pred}\n')

    for i, source in enumerate(sources):
        source = source.reshape((1, source.shape[0]))
        translation = predict_seq(encoder_model, decoder_model, tokenizer,␣
 ↪source, max_output_length)
        raw_target, raw_src = raw_dataset_en[i], raw_dataset_ar[i]
        print(f'{raw_src:30} {raw_target:25} {translation}')
        if i >= limit:
            break

encoder_model = Model(encoder_inputs, encoder_states)

decoder_state_input_h = Input(shape=(n_units,))
decoder_state_input_c = Input(shape=(n_units,))
decoder_states_inputs = [decoder_state_input_h, decoder_state_input_c]

dec_emb2 = dec_emb_layer(decoder_inputs)

decoder_outputs2, state_h2, state_c2 = decoder_lstm(dec_emb2,␣
 ↪initial_state=decoder_states_inputs)
decoder_states2 = [state_h2, state_c2]
decoder_outputs2 = decoder_dense(decoder_outputs2)

decoder_model = Model(
    [decoder_inputs] + decoder_states_inputs,
    [decoder_outputs2] + decoder_states2
)

print('### Result on the Training Set ###')
compare_prediction(encoder_model, decoder_model, tar_tokenizer, trainX,␣
 ↪train_ar, train_en, tar_length)
```

```python
print('\n\n### Result on the Test Set ###')
compare_prediction(encoder_model, decoder_model, tar_tokenizer, testX, test_ar,␣
    ↪test_en, tar_length)
```

```
### Result on the Training Set ###
(SOURCE) Arabic                (TARGET) English          AUTOMATIC TRANSLATION
IN English

<bos>     <eos>              <bos> hi <eos>            eos
<bos>    <eos>               <bos> run <eos>           eos
<bos>     <eos>             <bos> help <eos>          eos
<bos>    <eos>               <bos> jump <eos>          eos
<bos>   <eos>                 <bos> stop <eos>          eos
<bos>    <eos>               <bos> go on <eos>         the car eos
<bos>     <eos>              <bos> go on <eos>         the room eos
<bos>     <eos>              <bos> hello <eos>         eos
<bos>    <eos>               <bos> hurry <eos>         eos
<bos>     <eos>             <bos> hurry <eos>         eos
<bos>      <eos>            <bos> i see <eos>         i am eos
<bos>      <eos>            <bos> i won <eos>         i am eos
<bos>     <eos>              <bos> relax <eos>         well eos
<bos>     <eos>              <bos> smile <eos>         eos
<bos>      <eos>            <bos> cheers <eos>        she is past past eos
<bos>      <eos>            <bos> got it <eos>        did you miss me eos
<bos>    <eos>                <bos> he ran <eos>        he is eos
<bos>    <eos>               <bos> i know <eos>        i know eos
<bos>       <eos>           <bos> i know <eos>        i know eos
<bos>       <eos>           <bos> i know <eos>        i know eos
<bos>       <eos>            <bos> im  <eos>           im in eos


### Result on the Test Set ###
(SOURCE) Arabic                (TARGET) English          AUTOMATIC TRANSLATION
IN English

<bos>                  <eos> <bos> when i grow up i want to be a king
<eos> my mother made me a lot of patients eos
<bos>                    <eos> <bos> when did you begin studying
english <eos> when did you go home eos
<bos>                  <eos> <bos> when do you plan to leave for japan
<eos> how long do you go to japan eos
<bos>           <eos>    <bos> where is the entrance to the museum <eos>
where is the pain eos
<bos>                    <eos> <bos> why dont we just agree to
disagree <eos> why dont we have any evidence eos
<bos>                  <eos> <bos> will you allow me to play the
piano <eos> may i use your book to your room eos
```

```
<bos>                <eos> <bos> would you prefer to speak in french
<eos> is there to do something eos
<bos>             <eos>  <bos> you are responsible for what you do <eos>
you are always complaining eos
<bos>                 <eos> <bos> you dont seem to care what happens
<eos> you look very tired eos
<bos>                 <eos> <bos> you may have read this book already
<eos> he is busy doing that eos
<bos>                    <eos> <bos> you must gather further
information <eos> you should have more than me eos
<bos>                    <eos> <bos> you ought to have come here
earlier <eos> you should have a lot to do eos
<bos>              <eos> <bos> you should acknowledge your failure <eos>
you must study hard eos
<bos>              <eos> <bos> you should have accepted his advice <eos>
you should have a car eos
<bos>               <eos> <bos> youre either with us or against us <eos>
you are always complaining eos
<bos>            <eos>  <bos> a drowning man will catch at a straw <eos>
she kept on the letter eos
<bos>                  <eos> <bos> a lot of tourists invaded the
island <eos> she was busy in the housework eos
<bos>                    <eos> <bos> a lot of tourists invaded the
island <eos> she asked me of being a liar eos
<bos>                   <eos> <bos> a loud noise in the night
scared him <eos> she asked me a lot of water eos
<bos>              <eos> <bos> all of a sudden a dog began barking <eos>
i wrote a book to my mother eos
<bos>                     <eos> <bos> any student can answer that
question <eos> that old woman lives by herself eos
```

[13]:
```python
import numpy as np
from nltk.translate.bleu_score import sentence_bleu

def generate_translation(encoder_model, decoder_model, tokenizer, source,␣
↪max_output_length):
    translation = predict_seq(encoder_model, decoder_model, tokenizer, source,␣
↪max_output_length)
    return translation.split()

def compute_bleu(encoder_model, decoder_model, tokenizer, sources, references,␣
↪max_output_length):
    predicted_translations = [generate_translation(encoder_model,␣
↪decoder_model, tokenizer, src.reshape((1, src.shape[0])), max_output_length)␣
↪for src in sources]
    bleu_scores = [sentence_bleu([ref.split()], pred) for ref, pred in␣
↪zip(references, predicted_translations)]
```

```
    return np.mean(bleu_scores)

bleu_score_test = compute_bleu(encoder_model, decoder_model, tar_tokenizer,␣
 ↪testX, test_en, tar_length)
print(f'BLEU score on the test set: {bleu_score_test:.4f}')
```

```
BLEU score on the test set: 0.0048
```

Inference Function

```
[25]: def translate_sentence(sentence, encoder_model, decoder_model, src_tokenizer,␣
       ↪tar_tokenizer, max_output_length):
          tokenized_sentence = src_tokenizer.texts_to_sequences([sentence])
          padded_tokenized_sentence = pad_sequences(tokenized_sentence,␣
       ↪maxlen=max_output_length, padding='post')

          translated_sentence = predict_seq(encoder_model, decoder_model,␣
       ↪tar_tokenizer, padded_tokenized_sentence, max_output_length)

          return translated_sentence
```

```
[29]: arabic_sentence = "                   "
      translation = translate_sentence(arabic_sentence, encoder_model, decoder_model,␣
       ↪src_tokenizer, tar_tokenizer, src_length)
      print(f"Original: {arabic_sentence}\nTranslation: {translation}")
```

```
Original:
Translation: i was busy for a doctor eos
```

2.2.2 With Attention

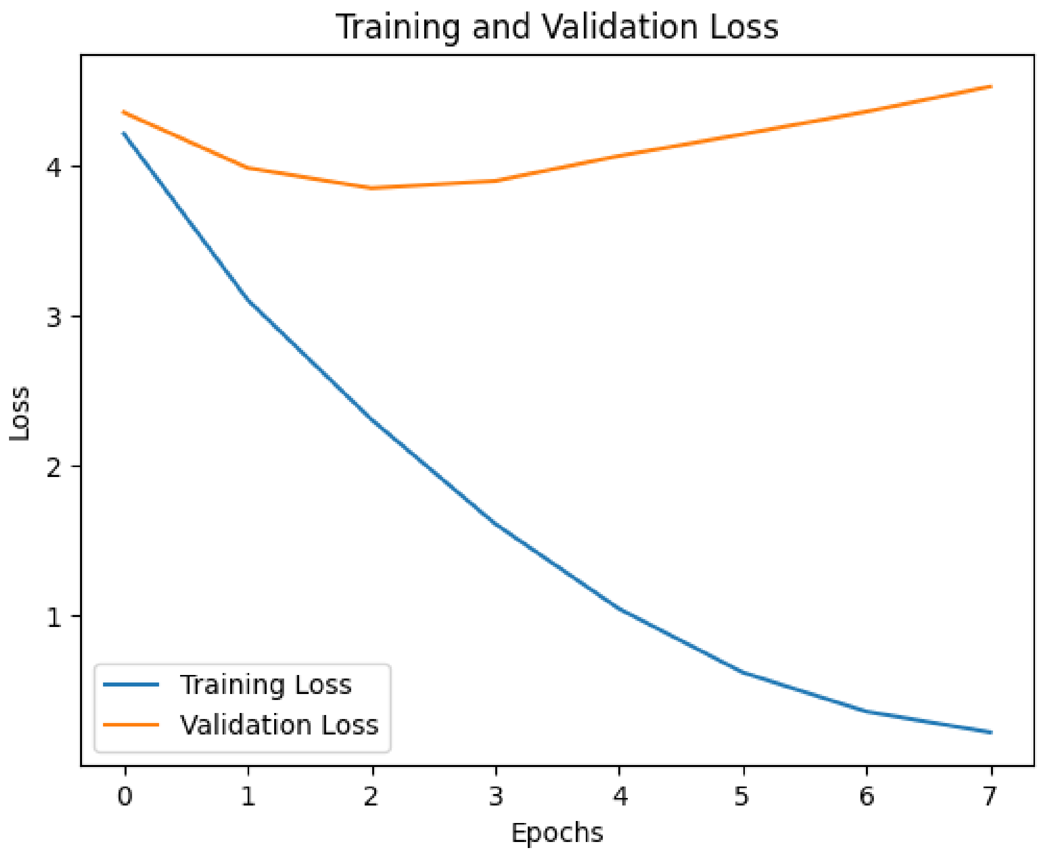
```
[30]: src_vocab = src_vocab_size
      tar_vocab = tar_vocab_size
      src_timesteps = src_length
      tar_timesteps = tar_length
      n_units = 512

      encoder_inputs = Input(shape=(src_timesteps,))
      enc_emb = Embedding(src_vocab, n_units, mask_zero=True)(encoder_inputs)
      encoder_lstm = LSTM(n_units, return_sequences=True, return_state=True)
      encoder_outputs, state_h, state_c = encoder_lstm(enc_emb)
      encoder_states = [state_h, state_c]

      decoder_inputs = Input(shape=(tar_timesteps,))
      dec_emb_layer = Embedding(tar_vocab, n_units, mask_zero=True)
      dec_emb = dec_emb_layer(decoder_inputs)
      decoder_lstm = LSTM(n_units, return_sequences=True, return_state=True)
      decoder_outputs, _, _ = decoder_lstm(dec_emb, initial_state=encoder_states)
```

```
attention = Attention(use_scale=True, name='attention')
attn_out = attention([decoder_outputs, encoder_outputs])

decoder_concat_input = tf.keras.layers.Concatenate(axis=-1,␣
 ↪name='concat_layer')([decoder_outputs, attn_out])

decoder_dense = TimeDistributed(Dense(tar_vocab, activation='softmax'))
decoder_outputs = decoder_dense(decoder_concat_input)

model = Model([encoder_inputs, decoder_inputs], decoder_outputs)

opt = Adam(learning_rate=0.001, clipnorm=1.0)
model.compile(optimizer=opt, loss='categorical_crossentropy')

decoder_input_data = np.zeros_like(trainY)
decoder_input_data[:, 1:] = trainY[:, :-1]

decoder_input_data = np.argmax(decoder_input_data, axis=-1)

history = model.fit(
    [trainX, decoder_input_data],
    trainY,
    epochs=200,
    batch_size=18,
    validation_split=0.1,
    verbose=1,
    callbacks=[
        EarlyStopping(
            monitor='val_loss',
            patience=5,
            restore_best_weights=True
        )
    ]
)
```

```
Epoch 1/200
444/444 [==============================] - 41s 76ms/step - loss: 4.2133 -
val_loss: 4.3549
Epoch 2/200
444/444 [==============================] - 32s 73ms/step - loss: 3.1055 -
val_loss: 3.9852
Epoch 3/200
444/444 [==============================] - 31s 70ms/step - loss: 2.3073 -
val_loss: 3.8499
Epoch 4/200
444/444 [==============================] - 31s 69ms/step - loss: 1.6108 -
```

```
val_loss: 3.8983
Epoch 5/200
444/444 [==============================] - 32s 71ms/step - loss: 1.0444 -
val_loss: 4.0650
Epoch 6/200
444/444 [==============================] - 31s 70ms/step - loss: 0.6194 -
val_loss: 4.2095
Epoch 7/200
444/444 [==============================] - 31s 71ms/step - loss: 0.3579 -
val_loss: 4.3600
Epoch 8/200
444/444 [==============================] - 32s 71ms/step - loss: 0.2198 -
val_loss: 4.5281
```

[31]:
```
import matplotlib.pyplot as plt

# Plotting the training and validation loss
plt.plot(history.history['loss'], label='Training Loss')
plt.plot(history.history['val_loss'], label='Validation Loss')
plt.legend()
plt.title('Training and Validation Loss')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.show()
```



```
[36]: def predict_seq(encoder_model, decoder_model, tokenizer, source,␣
       ↪max_output_length):
          encoder_out_and_states = encoder_model.predict(source, verbose=0)
          encoder_outputs = encoder_out_and_states[0]
          state_h, state_c = encoder_out_and_states[1], encoder_out_and_states[2]
          encoder_states = [state_h, state_c]

          target_seq = np.zeros((1, 1))
          target_seq[0, 0] = tokenizer.word_index['<bos>']

          decoded_sentence = []
          for _ in range(max_output_length):
              output_tokens, h, c = decoder_model.predict([target_seq,␣
       ↪encoder_outputs] + encoder_states, verbose=0)
              sampled_token_index = np.argmax(output_tokens[0, -1, :])
              sampled_word = word_for_id(sampled_token_index, tokenizer)

              if sampled_word is None or sampled_word == '<eos>':
                  break
```

```
        decoded_sentence.append(sampled_word)

        encoder_states = [h, c]
        target_seq = np.zeros((1, 1))
        target_seq[0, 0] = sampled_token_index

    return ' '.join(decoded_sentence)

def word_for_id(integer, tokenizer):
    for word, index in tokenizer.word_index.items():
        if index == integer:
            return word
    return None

def compare_prediction(encoder_model, decoder_model, tokenizer, sources,␣
 ↪raw_dataset_ar, raw_dataset_en, max_output_length, limit=20):
    actual, predicted = [], []
    src = '(SOURCE) Arabic'
    tgt = '(TARGET) English'
    pred = 'AUTOMATIC TRANSLATION IN English'
    print(f'{src:30} {tgt:25} {pred}\n')

    for i, source in enumerate(sources):
        source = source.reshape((1, source.shape[0]))
        translation = predict_seq(encoder_model, decoder_model, tokenizer,␣
 ↪source, max_output_length)
        raw_target, raw_src = raw_dataset_en[i], raw_dataset_ar[i]
        print(f'{raw_src:30} {raw_target:25} {translation}')
        if i >= limit:
            break

encoder_model = Model(encoder_inputs, [encoder_outputs] + encoder_states)


decoder_state_input_h = Input(shape=(n_units,))
decoder_state_input_c = Input(shape=(n_units,))
decoder_states_inputs = [decoder_state_input_h, decoder_state_input_c]

dec_emb2 = dec_emb_layer(decoder_inputs)

decoder_outputs2, state_h2, state_c2 = decoder_lstm(dec_emb2,␣
 ↪initial_state=decoder_states_inputs)
decoder_states2 = [state_h2, state_c2]

encoder_outputs_input = Input(shape=(src_timesteps, n_units))
attn_out2 = attention([decoder_outputs2, encoder_outputs_input])
```

```
decoder_concat_input2 = Concatenate(axis=-1,␣
 ↪name='concat_layer_2')([decoder_outputs2, attn_out2])
decoder_outputs2 = decoder_dense(decoder_concat_input2)

decoder_model = Model(
    [decoder_inputs, encoder_outputs_input] + decoder_states_inputs,
    [decoder_outputs2] + decoder_states2
)


print('### Result on the Training Set ###')
compare_prediction(encoder_model, decoder_model, tar_tokenizer, trainX,␣
 ↪train_ar, train_en, tar_length)

print('\n\n### Result on the Test Set ###')
compare_prediction(encoder_model, decoder_model, tar_tokenizer, testX, test_ar,␣
 ↪test_en, tar_length)
```

```
### Result on the Training Set ###
(SOURCE) Arabic                (TARGET) English          AUTOMATIC TRANSLATION
IN English


WARNING:tensorflow:5 out of the last 318 calls to <function
Model.make_predict_function.<locals>.predict_function at 0x7a01bfe6b1c0>
triggered tf.function retracing. Tracing is expensive and the excessive number
of tracings could be due to (1) creating @tf.function repeatedly in a loop, (2)
passing tensors with different shapes, (3) passing Python objects instead of
tensors. For (1), please define your @tf.function outside of the loop. For (2),
@tf.function has reduce_retracing=True option that can avoid unnecessary
retracing. For (3), please refer to
https://www.tensorflow.org/guide/function#controlling_retracing and
https://www.tensorflow.org/api_docs/python/tf/function for  more details.

<bos>     <eos>             <bos> hi <eos>            succeeded eos
<bos>    <eos>              <bos> run <eos>           succeeded succeeded
bunch bunch divorce divorce divorce divorce does it like me eos
<bos>     <eos>             <bos> help <eos>          eos
<bos>    <eos>              <bos> jump <eos>          eos
<bos>   <eos>                <bos> stop <eos>          eos
<bos>    <eos>              <bos> go on <eos>         eos
<bos>     <eos>             <bos> go on <eos>         eos
<bos>     <eos>             <bos> hello <eos>         succeeded eos
<bos>    <eos>              <bos> hurry <eos>         succeeded succeeded
bunch divorce divorce divorce divorce divorce course cab i have to
<bos>     <eos>             <bos> hurry <eos>         succeeded succeeded
succeeded divorce divorce divorce course those are you doing eos
<bos>      <eos>            <bos> i see <eos>         eos
```

```
<bos>      <eos>            <bos> i won <eos>         honest honest honest
honest honest meant unusual divorce divorce divorce divorce divorce divorce
<bos>     <eos>             <bos> relax <eos>         friend succeeded
succeeded divorce course are you talking
<bos>     <eos>             <bos> smile <eos>          eos
<bos>      <eos>            <bos> cheers <eos>        eye eos
<bos>      <eos>            <bos> got it <eos>        did do you remember eos
<bos>    <eos>               <bos> he ran <eos>         eos
<bos>    <eos>              <bos> i know <eos>         know i know eos
<bos>       <eos>          <bos> i know <eos>        i know eos
<bos>       <eos>          <bos> i know <eos>        know i know eos
<bos>       <eos>            <bos> im  <eos>           eos


### Result on the Test Set ###
(SOURCE) Arabic                (TARGET) English          AUTOMATIC TRANSLATION
IN English

<bos>                  <eos> <bos> when i grow up i want to be a king
<eos> would you have to do that eos
<bos>                    <eos> <bos> when did you begin studying
english <eos> when time will we do this eos
<bos>                  <eos> <bos> when do you plan to leave for japan
<eos> when shall we do what we do eos
<bos>           <eos>    <bos> where is the entrance to the museum <eos>
where where does it live eos
<bos>                    <eos> <bos> why dont we just agree to
disagree <eos> why i cant do it again eos
<bos>                  <eos> <bos> will you allow me to play the
piano <eos> may i have a lot of questions eos
<bos>                <eos> <bos> would you prefer to speak in french
<eos> is your own business eos
<bos>            <eos>  <bos> you are responsible for what you do <eos>
are you doing your mother eos
<bos>                  <eos> <bos> you dont seem to care what happens
<eos> dont look at you eos
<bos>                 <eos> <bos> you may have read this book already
<eos> its not a book to do that eos
<bos>                     <eos> <bos> you must gather further
information <eos> you must be a doctor eos
<bos>                     <eos> <bos> you ought to have come here
earlier <eos> you should go to the hospital eos
<bos>             <eos> <bos> you should acknowledge your failure <eos>
you must help your room eos
<bos>              <eos> <bos> you should have accepted his advice <eos>
was you look eos
<bos>               <eos> <bos> youre either with us or against us <eos>
are you doing the truth eos
```

```
<bos>            <eos>  <bos> a drowning man will catch at a straw <eos>
they took the same mistake eos
<bos>                  <eos> <bos> a lot of tourists invaded the
island <eos> cats was a lot of the garden eos
<bos>                    <eos> <bos> a lot of tourists invaded the
island <eos> dr leaves leaves smith cholesterol levels levels levels entered the
best key eos
<bos>                   <eos> <bos> a loud noise in the night
scared him <eos> leaves in the same floor in the floor eos
<bos>              <eos> <bos> all of a sudden a dog began barking <eos>
i was a good man eos
<bos>                     <eos> <bos> any student can answer that
question <eos> which car can do that eos
```

[15]:
```python
import numpy as np
from nltk.translate.bleu_score import sentence_bleu

def generate_translation(encoder_model, decoder_model, tokenizer, source,␣
  ↪max_output_length):
    translation = predict_seq(encoder_model, decoder_model, tokenizer, source,␣
  ↪max_output_length)
    return translation.split()

def compute_bleu(encoder_model, decoder_model, tokenizer, sources, references,␣
  ↪max_output_length):
    predicted_translations = [generate_translation(encoder_model,␣
  ↪decoder_model, tokenizer, src.reshape((1, src.shape[0])), max_output_length)␣
  ↪for src in sources]
    bleu_scores = [sentence_bleu([ref.split()], pred) for ref, pred in␣
  ↪zip(references, predicted_translations)]
    return np.mean(bleu_scores)

bleu_score_test = compute_bleu(encoder_model, decoder_model, tar_tokenizer,␣
  ↪testX, test_en, tar_length)
print(f'BLEU score on the test set: {bleu_score_test:.4f}')
```

```
BLEU score on the test set: 0.0063
```

Inference Function

[37]:
```python
def translate_sentence(sentence, encoder_model, decoder_model, src_tokenizer,␣
  ↪tar_tokenizer, max_output_length):
    tokenized_sentence = src_tokenizer.texts_to_sequences([sentence])
    padded_tokenized_sentence = pad_sequences(tokenized_sentence,␣
  ↪maxlen=max_output_length, padding='post')

    translated_sentence = predict_seq(encoder_model, decoder_model,␣
  ↪tar_tokenizer, padded_tokenized_sentence, max_output_length)
```

```
    return translated_sentence
```

[38]:
```
arabic_sentence = "                    "
translation = translate_sentence(arabic_sentence, encoder_model, decoder_model,␣
  ↪src_tokenizer, tar_tokenizer, src_length)
print(f"Original: {arabic_sentence}\nTranslation: {translation}")
```

```
Original:
Translation: would you want to do it eos
```

2.3 *Analysis:*

- **Overfitting:** All three models exhibit signs of overfitting. As training progresses, validation loss rises after a few epochs, while training loss steadily decreases. This suggests that while the models are fitting well to the training data dues to the amount of the data and the complexity of the models.
- **Translation Quality:** The Encoder-Decoder with Attention model delivered the highest BLEU score, indicating best translation performance. Yet, all models displayed challenges in generating entirely accurate translations, with repeated tokens commonly observed.
- **Model Complexity:** As the models progressed from the simple LSTM network to LSTM encoder-decoder and then to the attention mechanism, their complexity increased. This added complexity led to some improvements in translation quality.

2.4 Why the Encoder-Decoder with Attention Model is the Best:

- **Handles Long Sequences Better:** Traditional encoder-decoder models might forget some parts of a long input when converting it to a fixed-size vector. The attention mechanism lets the model focus on different input parts when producing each output, reducing information loss.
- **Selective Focus:** The model doesn't treat all input words equally. It gives more importance to the words that are more relevant to the current word being translated, which results in better translation accuracy.
- **Complex Sentences:** Especially when translating between languages with different sentence structures, having attention helps the model pick out and rearrange the right information.

2.5 Pretrained Models

[ ]:
```
english_sentences_clean = [clean_english_text(sentence) for sentence in␣
  ↪english_sentences]
arabic_sentences_clean = [clean_arabic_text(sentence) for sentence in␣
  ↪arabic_sentences]

zero_length_english_indices = [i for i, sentence in␣
  ↪enumerate(english_sentences_clean) if len(sentence.split()) == 0]
```

```
zero_length_arabic_indices = [i for i, sentence in␣
 ↪enumerate(arabic_sentences_clean) if len(sentence.split()) == 0]

indices_to_remove = set(zero_length_english_indices +␣
 ↪zero_length_arabic_indices)

english_sentences_clean = [sentence for i, sentence in␣
 ↪enumerate(english_sentences_clean) if i not in indices_to_remove]
arabic_sentences_clean = [sentence for i, sentence in␣
 ↪enumerate(arabic_sentences_clean) if i not in indices_to_remove]
```

2.5.1 Marian NMT

[23]:
```
model_name = "Helsinki-NLP/opus-mt-ar-en"
tokenizer = MarianTokenizer.from_pretrained(model_name)
MAX_LENGTH = 256

def tokenize_data(arabic, english):
    tokenized_data = tokenizer.prepare_seq2seq_batch(src_texts=arabic,
                                                     tgt_texts=english,
                                                     max_length=MAX_LENGTH,
                                                     padding="max_length",
                                                     return_tensors="pt",
                                                     truncation=True)
    return tokenized_data

tokenized_datasets = tokenize_data(arabic_sentences_clean,␣
 ↪english_sentences_clean)

class CustomDataset(Dataset):
    def __init__(self, tokenized_data):
        self.input_ids = tokenized_data["input_ids"]
        self.attention_mask = tokenized_data["attention_mask"]
        self.target_ids = tokenized_data["labels"]

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

    def __getitem__(self, idx):
        return {
            "input_ids": self.input_ids[idx],
            "attention_mask": self.attention_mask[idx],
            "labels": self.target_ids[idx]
        }

full_dataset = CustomDataset(tokenized_datasets)
train_size = int(0.8 * len(full_dataset))
```

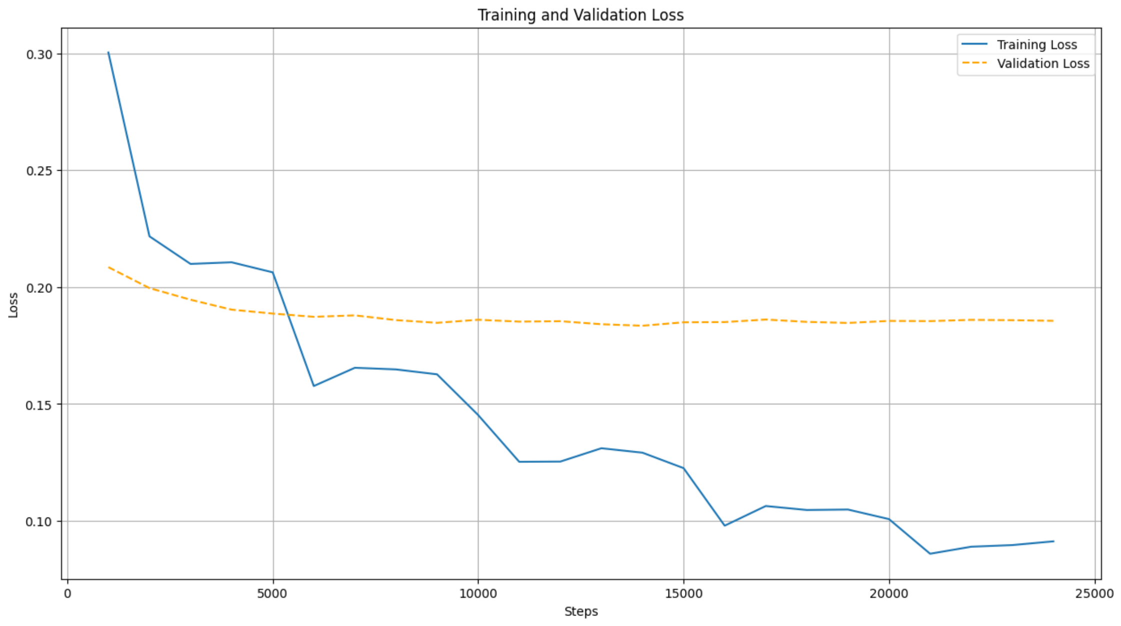
```
val_size = len(full_dataset) - train_size
train_dataset, val_dataset = torch.utils.data.random_split(full_dataset,␣
 ↪[train_size, val_size])
model = MarianMTModel.from_pretrained(model_name)

training_args = TrainingArguments(
    output_dir="./results_marian",
    per_device_train_batch_size=4,
    per_device_eval_batch_size=4,
    num_train_epochs=5,
    evaluation_strategy="steps",
    save_strategy="steps",
    logging_dir="./logs_marian",
    logging_steps=1000,
    eval_steps=1000,
    do_train=True,
    do_eval=True,
    no_cuda=False,
    push_to_hub=False,
    logging_first_step=True,
    report_to=["tensorboard"]
)

trainer = Trainer(
    model=model,
    args=training_args,
    train_dataset=train_dataset,
    eval_dataset=val_dataset,
    tokenizer=tokenizer,
)

trainer.train()
```

```
/usr/local/lib/python3.10/dist-
packages/transformers/models/marian/tokenization_marian.py:194: UserWarning:
Recommended: pip install sacremoses.
  warnings.warn("Recommended: pip install sacremoses.")
/usr/local/lib/python3.10/dist-
packages/transformers/tokenization_utils_base.py:3786: FutureWarning:
`prepare_seq2seq_batch` is deprecated and will be removed in version 5 of
HuggingFace Transformers. Use the regular
`__call__` method to prepare your inputs and targets.

Here is a short example:

model_inputs = tokenizer(src_texts, text_target=tgt_texts, …)
```

```
If you either need to use different keyword arguments for the source and target
texts, you should do two calls like
this:

model_inputs = tokenizer(src_texts, …)
labels = tokenizer(text_target=tgt_texts, …)
model_inputs["labels"] = labels["input_ids"]

See the documentation of your specific tokenizer for more details on the
specific arguments to the tokenizer of choice.
For a more complete example, see the implementation of `prepare_seq2seq_batch`.

  warnings.warn(formatted_warning, FutureWarning)
/usr/local/lib/python3.10/dist-
packages/transformers/tokenization_utils_base.py:3660: UserWarning:
`as_target_tokenizer` is deprecated and will be removed in v5 of Transformers.
You can tokenize your labels by using the argument `text_target` of the regular
`__call__` method (either in the same call as your input texts if you use the
same keyword arguments, or in a separate call.
  warnings.warn(

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

[23]:
```
TrainOutput(global_step=24640, training_loss=0.14302249024440716,
metrics={'train_runtime': 6968.6279, 'train_samples_per_second': 14.141,
'train_steps_per_second': 3.536, 'total_flos': 6681028743659520.0, 'train_loss':
0.14302249024440716, 'epoch': 5.0})
```

[24]:
```python
logs = trainer.state.log_history
train_steps = [x['step'] for x in logs if 'loss' in x][1:]
train_loss = [x['loss'] for x in logs if 'loss' in x][1:]
eval_steps = [x['step'] for x in logs if 'eval_loss' in x]
eval_loss = [x['eval_loss'] for x in logs if 'eval_loss' in x]

plt.figure(figsize=(15, 8))
plt.plot(train_steps, train_loss, label='Training Loss')
plt.plot(eval_steps, eval_loss, label='Validation Loss', linestyle='--',␣
  ↪color='orange')
plt.xlabel('Steps')
plt.ylabel('Loss')
plt.legend()
plt.title('Training and Validation Loss')
plt.grid(True)
plt.show()
```



[25]:
```
device = torch.device("cuda" if torch.cuda.is_available() else "cpu")

def compute_bleu(model, dataset, tokenizer):
    reference_texts = []
    translated_texts = []

    for data in dataset:
        data = {key: val.to(device) for key, val in data.items()}
        reference_text = tokenizer.decode(data["labels"],␣
 ↪skip_special_tokens=True)
        reference_texts.append(reference_text)

        model.eval()
        with torch.no_grad():
            output = model.generate(data["input_ids"].unsqueeze(0),␣
 ↪attention_mask=data["attention_mask"].unsqueeze(0))
        translated_texts.append(tokenizer.decode(output[0],␣
 ↪skip_special_tokens=True))

    bleu_score = sacrebleu.corpus_bleu(translated_texts, [reference_texts])
    return bleu_score.score

bleu = compute_bleu(model, val_dataset, tokenizer)
```

[26]:
```
print(f"Bleu Score: {bleu:.2f}")
```

```
Bleu Score: 28.65
```

Inference

[27]:
```
def translate(sentence, model, tokenizer, device="cuda"):
    model = model.to(device).eval()
    tokenized = tokenizer.encode(sentence, return_tensors="pt",␣
 ↪truncation=True, padding="max_length", max_length=MAX_LENGTH).to(device)
    translated = model.generate(tokenized, num_beams=4, max_length=40,␣
 ↪early_stopping=True)
    translated_text = tokenizer.decode(translated[0], skip_special_tokens=True)
    return translated_text

arabic_sentence = "     "
english_translation = translate(arabic_sentence, model, tokenizer)
print(f"Original: {arabic_sentence}\nTranslation: {english_translation}")
```

```
Original:
Translation: i want to eat
```

2.5.2 MBART

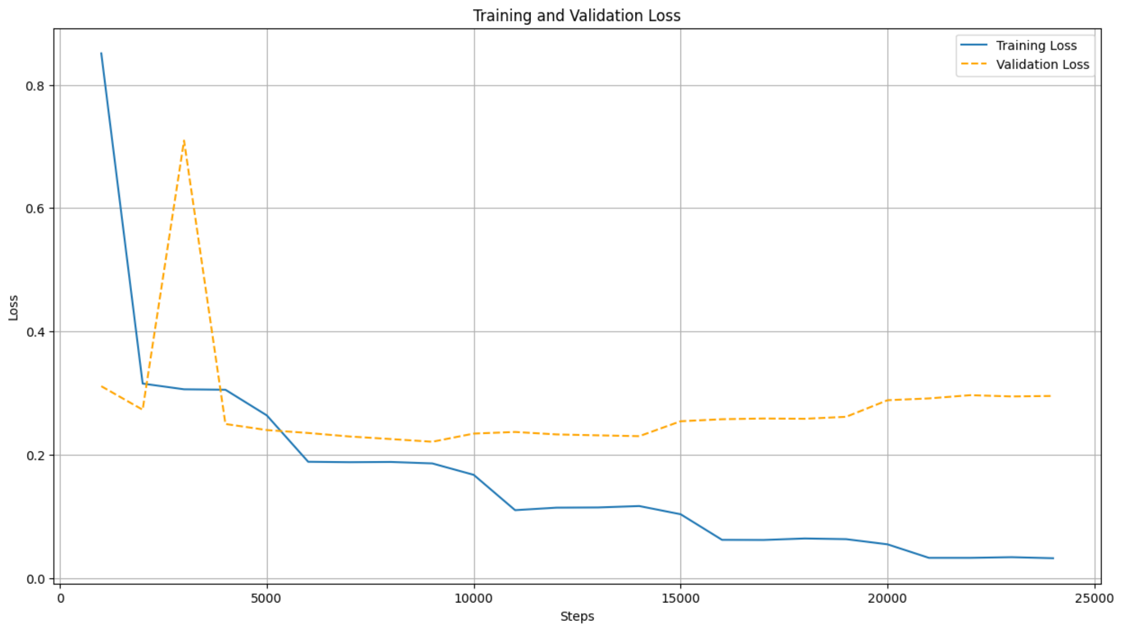
[ ]:
```
tokenizer = MBartTokenizer.from_pretrained("facebook/mbart-large-cc25")
MAX_LENGTH = 230

def tokenize_data(english, arabic):
    tokenized_data = tokenizer.prepare_seq2seq_batch(src_texts=arabic,
                                                     tgt_texts=english,
                                                     src_lang="ar_AR",
                                                     tgt_lang="en_XX",
                                                     max_length=MAX_LENGTH,
                                                     padding="max_length",
                                                     return_tensors="pt",
                                                     truncation=True)
    return tokenized_data

tokenized_datasets = tokenize_data(english_sentences_clean,␣
 ↪arabic_sentences_clean)

class CustomDataset(Dataset):
    def __init__(self, tokenized_data):
        self.input_ids = tokenized_data["input_ids"]
        self.attention_mask = tokenized_data["attention_mask"]
        self.target_ids = tokenized_data["labels"]

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

    def __getitem__(self, idx):
        return {
            "input_ids": self.input_ids[idx],
            "attention_mask": self.attention_mask[idx],
            "labels": self.target_ids[idx]
        }

full_dataset = CustomDataset(tokenized_datasets)
train_size = int(0.8 * len(full_dataset))
val_size = len(full_dataset) - train_size
train_dataset, val_dataset = torch.utils.data.random_split(full_dataset,␣
 ↪[train_size, val_size])
model = MBartForConditionalGeneration.from_pretrained("facebook/
 ↪mbart-large-cc25")
training_args = TrainingArguments(
    output_dir="./results",
    per_device_train_batch_size=4,
    per_device_eval_batch_size=4,
    num_train_epochs=5,
    evaluation_strategy="steps",
    save_strategy="steps",
    logging_dir="./logs",
    logging_steps=1000,
    eval_steps=1000,
    do_train=True,
    do_eval=True,
    no_cuda=False,
    push_to_hub=False,
    logging_first_step=True,
    report_to=["tensorboard"]
)

trainer = Trainer(
    model=model,
    args=training_args,
    train_dataset=train_dataset,
    eval_dataset=val_dataset,
    tokenizer=tokenizer,
)

trainer.train()
```

```
/l/users/ahmed.aboeitta/espnet/tools/anaconda/envs/espnet/lib/python3.8/site-
packages/transformers/tokenization_utils_base.py:3766: FutureWarning:
`prepare_seq2seq_batch` is deprecated and will be removed in version 5 of
HuggingFace Transformers. Use the regular
`__call__` method to prepare your inputs and targets.

Here is a short example:
```

```
model_inputs = tokenizer(src_texts, text_target=tgt_texts, …)

If you either need to use different keyword arguments for the source and target
texts, you should do two calls like
this:

model_inputs = tokenizer(src_texts, …)
labels = tokenizer(text_target=tgt_texts, …)
model_inputs["labels"] = labels["input_ids"]

See the documentation of your specific tokenizer for more details on the
specific arguments to the tokenizer of choice.
For a more complete example, see the implementation of `prepare_seq2seq_batch`.

  warnings.warn(formatted_warning, FutureWarning)
/l/users/ahmed.aboeitta/espnet/tools/anaconda/envs/espnet/lib/python3.8/site-
packages/transformers/tokenization_utils_base.py:3640: UserWarning:
`as_target_tokenizer` is deprecated and will be removed in v5 of Transformers.
You can tokenize your labels by using the argument `text_target` of the regular
`__call__` method (either in the same call as your input texts if you use the
same keyword arguments, or in a separate call.
  warnings.warn(
/l/users/ahmed.aboeitta/espnet/tools/anaconda/envs/espnet/lib/python3.8/site-
packages/transformers/optimization.py:411: 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(

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

```
[ ]: TrainOutput(global_step=24640, training_loss=0.1625452343519632,
     metrics={'train_runtime': 10758.7544, 'train_samples_per_second': 9.16,
     'train_steps_per_second': 2.29, 'total_flos': 4.79675338727424e+16,
     'train_loss': 0.1625452343519632, 'epoch': 5.0})
```

```
[ ]: logs = trainer.state.log_history
     train_steps = [x['step'] for x in logs if 'loss' in x][1:]
     train_loss = [x['loss'] for x in logs if 'loss' in x][1:]
     eval_steps = [x['step'] for x in logs if 'eval_loss' in x]
     eval_loss = [x['eval_loss'] for x in logs if 'eval_loss' in x]

     plt.figure(figsize=(15, 8))
     plt.plot(train_steps, train_loss, label='Training Loss')
     plt.plot(eval_steps, eval_loss, label='Validation Loss', linestyle='--',␣
      ↪color='orange')
     plt.xlabel('Steps')
     plt.ylabel('Loss')
     plt.legend()
     plt.title('Training and Validation Loss')
     plt.grid(True)
     plt.show()
```



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

def compute_bleu(model, dataset, tokenizer):
    reference_texts = []
    translated_texts = []

    for data in dataset:
        data = {key: val.to(device) for key, val in data.items()}
        reference_text = tokenizer.decode(data["labels"],␣
 ↪skip_special_tokens=True)
        reference_texts.append(reference_text)

        model.eval()
        with torch.no_grad():
            output = model.generate(data["input_ids"].unsqueeze(0),␣
 ↪attention_mask=data["attention_mask"].unsqueeze(0))
        translated_texts.append(tokenizer.decode(output[0],␣
 ↪skip_special_tokens=True))

    bleu_score = sacrebleu.corpus_bleu(translated_texts, [reference_texts])
    return bleu_score.score

bleu = compute_bleu(model, val_dataset, tokenizer)
```

```
/l/users/ahmed.aboeitta/espnet/tools/anaconda/envs/espnet/lib/python3.8/site-
packages/transformers/generation/utils.py:1369: UserWarning: Using
`max_length`'s default (1024) to control the generation length. This behaviour
is deprecated and will be removed from the config in v5 of Transformers -- we
recommend using `max_new_tokens` to control the maximum length of the
generation.
  warnings.warn(
```

[ ]:
```
print(f"Bleu Score: {bleu:.2f}")
```

```
Bleu Score: 20.47
```

Inference

[ ]:
```
def translate_arabic_to_english_mbart(model, tokenizer, arabic_sentence,␣
 ↪device):
    model.to(device).eval()
    inputs = tokenizer.prepare_seq2seq_batch(src_texts=[arabic_sentence],
                                             src_lang="ar_AR",
                                             tgt_lang="en_XX",
                                             return_tensors="pt",
                                             max_length=MAX_LENGTH,
                                             truncation=True)
    inputs = {k: v.to(device) for k, v in inputs.items()}

    with torch.no_grad():
        outputs = model.generate(**inputs, max_length=MAX_LENGTH, num_beams=4,␣
 ↪early_stopping=True)
    translated_text = tokenizer.decode(outputs[0], skip_special_tokens=True)
    return translated_text

arabic_test_sentence = "             "
translated_sentence = translate_arabic_to_english_mbart(model, tokenizer,␣
 ↪arabic_test_sentence, device)
print(translated_sentence)
```

```
welcome to the library
```

```
/l/users/ahmed.aboeitta/espnet/tools/anaconda/envs/espnet/lib/python3.8/site-
packages/transformers/tokenization_utils_base.py:3766: FutureWarning:
`prepare_seq2seq_batch` is deprecated and will be removed in version 5 of
HuggingFace Transformers. Use the regular
`__call__` method to prepare your inputs and targets.

Here is a short example:
```

```
model_inputs = tokenizer(src_texts, text_target=tgt_texts, …)

If you either need to use different keyword arguments for the source and target
texts, you should do two calls like
this:

model_inputs = tokenizer(src_texts, …)
labels = tokenizer(text_target=tgt_texts, …)
model_inputs["labels"] = labels["input_ids"]

See the documentation of your specific tokenizer for more details on the
specific arguments to the tokenizer of choice.
For a more complete example, see the implementation of `prepare_seq2seq_batch`.

  warnings.warn(formatted_warning, FutureWarning)
```

2.5.3 MT5

[ ]:
```python
tokenizer = T5Tokenizer.from_pretrained("google/mt5-small")
MAX_LENGTH = 230

def tokenize_data(english, arabic):
    source_texts = ['translate Arabic to English: ' + txt for txt in arabic]
    tokenized_data = tokenizer.prepare_seq2seq_batch(src_texts=source_texts,
                                                     tgt_texts=english,
                                                     max_length=MAX_LENGTH,
                                                     padding="max_length",
                                                     return_tensors="pt",
                                                     truncation=True)

    return tokenized_data

tokenized_datasets = tokenize_data(english_sentences_clean,␣
 ↪arabic_sentences_clean)

class CustomDataset(Dataset):
    def __init__(self, tokenized_data):
        self.input_ids = tokenized_data["input_ids"]
        self.attention_mask = tokenized_data["attention_mask"]
        self.target_ids = tokenized_data["labels"]

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

    def __getitem__(self, idx):
        return {
            "input_ids": self.input_ids[idx],
            "attention_mask": self.attention_mask[idx],
            "labels": self.target_ids[idx]
        }

full_dataset = CustomDataset(tokenized_datasets)
train_size = int(0.8 * len(full_dataset))
val_size = len(full_dataset) - train_size
train_dataset, val_dataset = torch.utils.data.random_split(full_dataset,␣
 ↪[train_size, val_size])

model = MT5ForConditionalGeneration.from_pretrained("google/mt5-base")
training_args = TrainingArguments(
    output_dir="./results_mt5",
    per_device_train_batch_size=4,
    per_device_eval_batch_size=4,
    num_train_epochs=10,
    evaluation_strategy="steps",
    save_strategy="steps",
    logging_dir="./logs_mt5",
    logging_steps=1000,
    eval_steps=1000,
    do_train=True,
    do_eval=True,
    no_cuda=False,
    push_to_hub=False,
    logging_first_step=True,
    report_to=["tensorboard"]
)

trainer = Trainer(
    model=model,
    args=training_args,
    train_dataset=train_dataset,
    eval_dataset=val_dataset,
    tokenizer=tokenizer
)

trainer.train()
```

```
You are using the legacy behaviour of the <class
'transformers.models.t5.tokenization_t5.T5Tokenizer'>. This means that tokens
that come after special tokens will not be properly handled. We recommend you to
read the related pull request available at
https://github.com/huggingface/transformers/pull/24565
/l/users/ahmed.aboeitta/espnet/tools/anaconda/envs/espnet/lib/python3.8/site-
packages/transformers/tokenization_utils_base.py:3766: FutureWarning:
`prepare_seq2seq_batch` is deprecated and will be removed in version 5 of
```

```
HuggingFace Transformers. Use the regular
`__call__` method to prepare your inputs and targets.

Here is a short example:

model_inputs = tokenizer(src_texts, text_target=tgt_texts, …)

If you either need to use different keyword arguments for the source and target
texts, you should do two calls like
this:

model_inputs = tokenizer(src_texts, …)
labels = tokenizer(text_target=tgt_texts, …)
model_inputs["labels"] = labels["input_ids"]

See the documentation of your specific tokenizer for more details on the
specific arguments to the tokenizer of choice.
For a more complete example, see the implementation of `prepare_seq2seq_batch`.

  warnings.warn(formatted_warning, FutureWarning)
/l/users/ahmed.aboeitta/espnet/tools/anaconda/envs/espnet/lib/python3.8/site-
packages/transformers/tokenization_utils_base.py:3640: UserWarning:
`as_target_tokenizer` is deprecated and will be removed in v5 of Transformers.
You can tokenize your labels by using the argument `text_target` of the regular
`__call__` method (either in the same call as your input texts if you use the
same keyword arguments, or in a separate call.
  warnings.warn(
/l/users/ahmed.aboeitta/espnet/tools/anaconda/envs/espnet/lib/python3.8/site-
packages/transformers/optimization.py:411: 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(
/home/ahmed.aboeitta/.local/lib/python3.8/site-
packages/torch/nn/parallel/_functions.py:68: UserWarning: Was asked to gather
along dimension 0, but all input tensors were scalars; will instead unsqueeze
and return a vector.
  warnings.warn('Was asked to gather along dimension 0, but all '
```

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

```
/home/ahmed.aboeitta/.local/lib/python3.8/site-
packages/torch/nn/parallel/_functions.py:68: UserWarning: Was asked to gather
along dimension 0, but all input tensors were scalars; will instead unsqueeze
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```

```
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along dimension 0, but all input tensors were scalars; will instead unsqueeze
and return a vector.
  warnings.warn('Was asked to gather along dimension 0, but all '
```
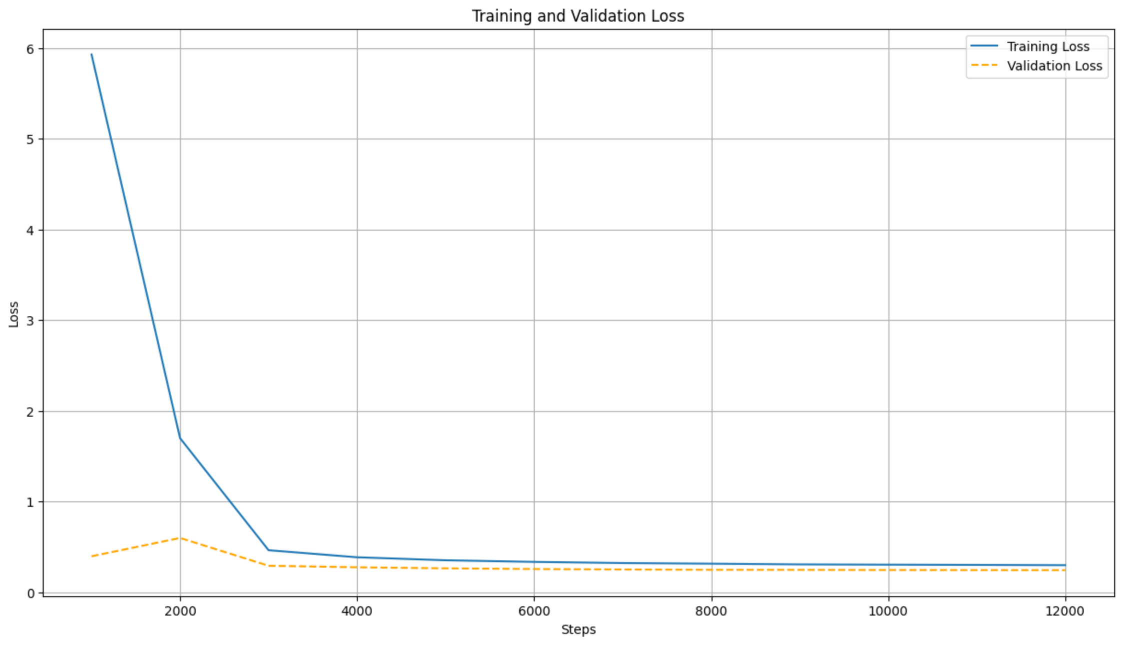

[ ]:
```
TrainOutput(global_step=12320, training_loss=0.9058312131212903,
metrics={'train_runtime': 7155.2974, 'train_samples_per_second': 27.545,
'train_steps_per_second': 1.722, 'total_flos': 1.061593759429632e+17,
'train_loss': 0.9058312131212903, 'epoch': 10.0})
```

[ ]:
```python
logs = trainer.state.log_history
train_steps = [x['step'] for x in logs if 'loss' in x][1:]
train_loss = [x['loss'] for x in logs if 'loss' in x][1:]
eval_steps = [x['step'] for x in logs if 'eval_loss' in x]
eval_loss = [x['eval_loss'] for x in logs if 'eval_loss' in x]

plt.figure(figsize=(15, 8))
plt.plot(train_steps, train_loss, label='Training Loss')
plt.plot(eval_steps, eval_loss, label='Validation Loss', linestyle='--',␣
  ↪color='orange')
plt.xlabel('Steps')
plt.ylabel('Loss')
plt.legend()
plt.title('Training and Validation Loss')
plt.grid(True)
plt.show()
```



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

     def compute_bleu(model, dataset, tokenizer):
         reference_texts = []
         translated_texts = []

         for data in dataset:
             data = {key: val.to(device) for key, val in data.items()}
             reference_text = tokenizer.decode(data["labels"],␣
       ↪skip_special_tokens=True)
             reference_texts.append(reference_text)
             model.eval()
             with torch.no_grad():
                 output = model.generate(data["input_ids"].unsqueeze(0),␣
       ↪attention_mask=data["attention_mask"].unsqueeze(0))
             translated_texts.append(tokenizer.decode(output[0],␣
       ↪skip_special_tokens=True))

         bleu_score = sacrebleu.corpus_bleu(translated_texts, [reference_texts])
         return bleu_score.score

     bleu = compute_bleu(model, val_dataset, tokenizer)
```

```
/l/users/ahmed.aboeitta/espnet/tools/anaconda/envs/espnet/lib/python3.8/site-
packages/transformers/generation/utils.py:1369: UserWarning: Using
`max_length`'s default (20) to control the generation length. This behaviour is
```

```
deprecated and will be removed from the config in v5 of Transformers -- we
recommend using `max_new_tokens` to control the maximum length of the
generation.
  warnings.warn(
```

[ ]:
```python
print(f"Bleu Score: {bleu:.2f}")
```

```
Bleu Score: 6.66
```

Inference

[ ]:
```python
def translate_arabic_to_english(model, tokenizer, arabic_sentence):
    model = model.to(device).eval()
    input_text = "translate Arabic to English: " + arabic_sentence
    inputs = tokenizer.encode(input_text, return_tensors="pt",␣
 ↪max_length=MAX_LENGTH, truncation=True).to(device)
    outputs = model.generate(inputs, max_length=MAX_LENGTH, num_beams=4,␣
 ↪early_stopping=True)
    translated_text = tokenizer.decode(outputs[0], skip_special_tokens=True)

    return translated_text

arabic_test_sentence = "             "
translated_sentence = translate_arabic_to_english(model, tokenizer,␣
 ↪arabic_test_sentence)
print(translated_sentence)
```

2.6 *Analysis:*

Marian NMT seems to be the best suited for this translation task, given its consistently decreasing losses and high BLEU score. MBART, despite its potential, might require more careful fine-tuning or hyperparameter adjustments to achieve optimal results. MT5's performance suggests that not all models, regardless of their size or complexity, are equally suited for all tasks; the initial state of the model and its pretraining tasks play crucial roles in its fine-tuning performance.

The core advantage Marian NMT holds over the other two models in terms of architecture is its specialization. Every aspect of Marian, from its attention mechanisms to its tokenization strategy, has been refined and optimized exclusively for machine translation.

2.7 Why MARIAN Model is the Best:

- **MARIAN:**
  - Marian NMT is specifically tailored for neural machine translation tasks. Its architecture, hyperparameters, and even the attention mechanisms are optimized for translation.
  - The attention mechanisms in Marian NMT, such as self-attention, are fine-tuned to better understand the nuances of source and target languages in translation tasks. This focused design enables the model to achieve more accurate and coherent translations.
  - The training and validation losses for Marian NMT tend to decrease over time indicating that the model is learning and generalizing well. The BLEU score is the highest among

the three models, suggesting very good translation quality.

- **MBART:**
  - While MBART is also a sequence-to-sequence model like Marian, its design is more generalized. MBART is built to handle a variety of tasks, from translation to text summarization.
  - MBART's unique pretraining approach involves reconstructing sentences with noise added. While this is useful for understanding context and generating coherent sequences, it might not always be as directly beneficial for translation as the specialized pretraining data Marian might use.
  - MBART's training loss shows more fluctuations compared to Marian NMT, suggesting a less smooth learning process and possible overfitting scenarios or learning rate issues.
- **MT5:**
  - MT5, derived from the T5 framework, is designed for various text-to-text transfer tasks. While this design offers flexibility, it may not be specialized enough for nuanced machine translation tasks.
  - MT5 uses a unified SentencePiece tokenizer which, while powerful and capable of handling multiple languages, might not capture the intricacies of specific language pairs as effectively as a specialized system.
  - MT5 starts with an alarmingly high training loss, which drastically drops later. This suggests that the model's pre-trained weights were initially not very conducive for the task at hand, but they adjusted considerably with more training.
  - The massive gap in the training loss and the final BLEU score suggests that while MT5 is capable of adapting its weights for the task, its architecture or pretraining might not be as suited for this particular translation task.