paraphrase-generation

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Course Name: Deep Learning

Lab Title: Paraphrase Generation

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Research Paper Study and Implementation

Dataset Link:https://www.kaggle.com/competitions/quora-question-pairs/data

Colab Notebook Link:https://colab.research.google.com/drive/1m8NoJUmDad0aAjm0z-Pp5zhvvB8DkCYe?usp=sharing

Research Paper Link:https://ojs.aaai.org/index.php/AAAI/article/view/11956

GitHub Link:()

Install required packages

[1]:
```
!pip install tensorflow keras numpy pandas matplotlib seaborn nltk rouge-score



import numpy as np
import pandas as pd
import tensorflow as tf
from tensorflow import keras
from tensorflow.keras import layers
from tensorflow.keras.preprocessing.text import Tokenizer
from tensorflow.keras.preprocessing.sequence import pad_sequences
import matplotlib.pyplot as plt
import seaborn as sns
import nltk
from nltk.translate.bleu_score import sentence_bleu, SmoothingFunction
from rouge_score import rouge_scorer
import time
```

```python
import random
```

```
Requirement already satisfied: tensorflow in /usr/local/lib/python3.11/dist-
packages (2.18.0)
Requirement already satisfied: keras in /usr/local/lib/python3.11/dist-packages
(3.8.0)
Requirement already satisfied: numpy in /usr/local/lib/python3.11/dist-packages
(2.0.2)
Requirement already satisfied: pandas in /usr/local/lib/python3.11/dist-packages
(2.2.2)
Requirement already satisfied: matplotlib in /usr/local/lib/python3.11/dist-
packages (3.10.0)
Requirement already satisfied: seaborn in /usr/local/lib/python3.11/dist-
packages (0.13.2)
Requirement already satisfied: nltk in /usr/local/lib/python3.11/dist-packages
(3.9.1)
Collecting rouge-score
  Downloading rouge_score-0.1.2.tar.gz (17 kB)
  Preparing metadata (setup.py) … done
Requirement already satisfied: absl-py>=1.0.0 in /usr/local/lib/python3.11/dist-
packages (from tensorflow) (1.4.0)
Requirement already satisfied: astunparse>=1.6.0 in
/usr/local/lib/python3.11/dist-packages (from tensorflow) (1.6.3)
Requirement already satisfied: flatbuffers>=24.3.25 in
/usr/local/lib/python3.11/dist-packages (from tensorflow) (25.2.10)
Requirement already satisfied: gast!=0.5.0,!=0.5.1,!=0.5.2,>=0.2.1 in
/usr/local/lib/python3.11/dist-packages (from tensorflow) (0.6.0)
Requirement already satisfied: google-pasta>=0.1.1 in
/usr/local/lib/python3.11/dist-packages (from tensorflow) (0.2.0)
Requirement already satisfied: libclang>=13.0.0 in
/usr/local/lib/python3.11/dist-packages (from tensorflow) (18.1.1)
Requirement already satisfied: opt-einsum>=2.3.2 in
/usr/local/lib/python3.11/dist-packages (from tensorflow) (3.4.0)
Requirement already satisfied: packaging in /usr/local/lib/python3.11/dist-
packages (from tensorflow) (24.2)
Requirement already satisfied:
protobuf!=4.21.0,!=4.21.1,!=4.21.2,!=4.21.3,!=4.21.4,!=4.21.5,<6.0.0dev,>=3.20.3
in /usr/local/lib/python3.11/dist-packages (from tensorflow) (5.29.4)
Requirement already satisfied: requests<3,>=2.21.0 in
/usr/local/lib/python3.11/dist-packages (from tensorflow) (2.32.3)
Requirement already satisfied: setuptools in /usr/local/lib/python3.11/dist-
packages (from tensorflow) (75.2.0)
Requirement already satisfied: six>=1.12.0 in /usr/local/lib/python3.11/dist-
packages (from tensorflow) (1.17.0)
Requirement already satisfied: termcolor>=1.1.0 in
/usr/local/lib/python3.11/dist-packages (from tensorflow) (3.1.0)
Requirement already satisfied: typing-extensions>=3.6.6 in
```

```
/usr/local/lib/python3.11/dist-packages (from tensorflow) (4.13.2)
Requirement already satisfied: wrapt>=1.11.0 in /usr/local/lib/python3.11/dist-
packages (from tensorflow) (1.17.2)
Requirement already satisfied: grpcio<2.0,>=1.24.3 in
/usr/local/lib/python3.11/dist-packages (from tensorflow) (1.71.0)
Requirement already satisfied: tensorboard<2.19,>=2.18 in
/usr/local/lib/python3.11/dist-packages (from tensorflow) (2.18.0)
Requirement already satisfied: h5py>=3.11.0 in /usr/local/lib/python3.11/dist-
packages (from tensorflow) (3.13.0)
Requirement already satisfied: ml-dtypes<0.5.0,>=0.4.0 in
/usr/local/lib/python3.11/dist-packages (from tensorflow) (0.4.1)
Requirement already satisfied: tensorflow-io-gcs-filesystem>=0.23.1 in
/usr/local/lib/python3.11/dist-packages (from tensorflow) (0.37.1)
Requirement already satisfied: rich in /usr/local/lib/python3.11/dist-packages
(from keras) (13.9.4)
Requirement already satisfied: namex in /usr/local/lib/python3.11/dist-packages
(from keras) (0.0.9)
Requirement already satisfied: optree in /usr/local/lib/python3.11/dist-packages
(from keras) (0.15.0)
Requirement already satisfied: python-dateutil>=2.8.2 in
/usr/local/lib/python3.11/dist-packages (from pandas) (2.9.0.post0)
Requirement already satisfied: pytz>=2020.1 in /usr/local/lib/python3.11/dist-
packages (from pandas) (2025.2)
Requirement already satisfied: tzdata>=2022.7 in /usr/local/lib/python3.11/dist-
packages (from pandas) (2025.2)
Requirement already satisfied: contourpy>=1.0.1 in
/usr/local/lib/python3.11/dist-packages (from matplotlib) (1.3.2)
Requirement already satisfied: cycler>=0.10 in /usr/local/lib/python3.11/dist-
packages (from matplotlib) (0.12.1)
Requirement already satisfied: fonttools>=4.22.0 in
/usr/local/lib/python3.11/dist-packages (from matplotlib) (4.57.0)
Requirement already satisfied: kiwisolver>=1.3.1 in
/usr/local/lib/python3.11/dist-packages (from matplotlib) (1.4.8)
Requirement already satisfied: pillow>=8 in /usr/local/lib/python3.11/dist-
packages (from matplotlib) (11.2.1)
Requirement already satisfied: pyparsing>=2.3.1 in
/usr/local/lib/python3.11/dist-packages (from matplotlib) (3.2.3)
Requirement already satisfied: click in /usr/local/lib/python3.11/dist-packages
(from nltk) (8.1.8)
Requirement already satisfied: joblib in /usr/local/lib/python3.11/dist-packages
(from nltk) (1.4.2)
Requirement already satisfied: regex>=2021.8.3 in
/usr/local/lib/python3.11/dist-packages (from nltk) (2024.11.6)
Requirement already satisfied: tqdm in /usr/local/lib/python3.11/dist-packages
(from nltk) (4.67.1)
Requirement already satisfied: wheel<1.0,>=0.23.0 in
/usr/local/lib/python3.11/dist-packages (from astunparse>=1.6.0->tensorflow)
(0.45.1)
```

```
Requirement already satisfied: charset-normalizer<4,>=2 in
/usr/local/lib/python3.11/dist-packages (from requests<3,>=2.21.0->tensorflow)
(3.4.1)
Requirement already satisfied: idna<4,>=2.5 in /usr/local/lib/python3.11/dist-
packages (from requests<3,>=2.21.0->tensorflow) (3.10)
Requirement already satisfied: urllib3<3,>=1.21.1 in
/usr/local/lib/python3.11/dist-packages (from requests<3,>=2.21.0->tensorflow)
(2.4.0)
Requirement already satisfied: certifi>=2017.4.17 in
/usr/local/lib/python3.11/dist-packages (from requests<3,>=2.21.0->tensorflow)
(2025.4.26)
Requirement already satisfied: markdown>=2.6.8 in
/usr/local/lib/python3.11/dist-packages (from
tensorboard<2.19,>=2.18->tensorflow) (3.8)
Requirement already satisfied: tensorboard-data-server<0.8.0,>=0.7.0 in
/usr/local/lib/python3.11/dist-packages (from
tensorboard<2.19,>=2.18->tensorflow) (0.7.2)
Requirement already satisfied: werkzeug>=1.0.1 in
/usr/local/lib/python3.11/dist-packages (from
tensorboard<2.19,>=2.18->tensorflow) (3.1.3)
Requirement already satisfied: markdown-it-py>=2.2.0 in
/usr/local/lib/python3.11/dist-packages (from rich->keras) (3.0.0)
Requirement already satisfied: pygments<3.0.0,>=2.13.0 in
/usr/local/lib/python3.11/dist-packages (from rich->keras) (2.19.1)
Requirement already satisfied: mdurl~=0.1 in /usr/local/lib/python3.11/dist-
packages (from markdown-it-py>=2.2.0->rich->keras) (0.1.2)
Requirement already satisfied: MarkupSafe>=2.1.1 in
/usr/local/lib/python3.11/dist-packages (from
werkzeug>=1.0.1->tensorboard<2.19,>=2.18->tensorflow) (3.0.2)
Building wheels for collected packages: rouge-score
  Building wheel for rouge-score (setup.py) … done
  Created wheel for rouge-score: filename=rouge_score-0.1.2-py3-none-any.whl
size=24934
sha256=66d0475b68b5df0c51fe48000b55fcef773fc5f580f89cad111a6fd1298a7e09
  Stored in directory: /root/.cache/pip/wheels/1e/19/43/8a442dc83660ca25e163e1bd
1f89919284ab0d0c1475475148
Successfully built rouge-score
Installing collected packages: rouge-score
Successfully installed rouge-score-0.1.2
```

[3]:

```python
# Download NLTK data
nltk.download('punkt')

# Set random seeds for reproducibility
tf.random.set_seed(42)
np.random.seed(42)
random.seed(42)
```

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

Load your paraphrase dataset

[4]:

```
try:
    df = pd.read_csv('/content/Encoder_reduced_20000.csv')  # Update path
    # Verify required columns exist
    if 'original' not in df.columns or 'paraphrase' not in df.columns:
        raise ValueError("CSV must contain 'original' and 'paraphrase' columns")
except Exception as e:
    print(f"Error loading dataset: {e}")
    print("Using sample data instead")
    # Sample data
    original = [
        "The quick brown fox jumps over the lazy dog",
        "She enjoys reading science fiction novels",
        "The conference will be held next month"
    ]
    paraphrases = [
        "A fast brown fox leaps over the sleeping dog",
        "Reading sci-fi books is something she really likes",
        "Next month is when the conference is scheduled"
    ]
    df = pd.DataFrame({'original': original * 1000, 'paraphrase': paraphrases *␣
 ↪1000})  # 3000 samples

print(f"Dataset size: {len(df)}")
display(df.head())
```

```
Error loading dataset: [Errno 2] No such file or directory:
'/content/Encoder_reduced_20000.csv'
Using sample data instead
Dataset size: 3000

                                      original  \
0  The quick brown fox jumps over the lazy dog
1    She enjoys reading science fiction novels
2       The conference will be held next month
3  The quick brown fox jumps over the lazy dog
4    She enjoys reading science fiction novels


                                          paraphrase
0       A fast brown fox leaps over the sleeping dog
1  Reading sci-fi books is something she really l…
2     Next month is when the conference is scheduled
3       A fast brown fox leaps over the sleeping dog
4  Reading sci-fi books is something she really l…
```

Preprocessing functions

[5]:
```
def preprocess_text(text):
    """Basic text preprocessing"""
    text = str(text).lower().strip()
    text = ' '.join(text.split())  # Remove extra spaces
    return text

def add_special_tokens(text):
    """Add start and end tokens"""
    return "<start> " + text + " <end>"
```

[6]:
```
# Apply preprocessing
df['original'] = df['original'].apply(preprocess_text).apply(add_special_tokens)
df['paraphrase'] = df['paraphrase'].apply(preprocess_text).
  ↪apply(add_special_tokens)

# Split into train and validation sets
train_size = int(0.9 * len(df))
train_df = df[:train_size]
val_df = df[train_size:]

print(f"\nTraining samples: {len(train_df)}")
print(f"Validation samples: {len(val_df)}")
```

```
Training samples: 2700
Validation samples: 300
```

Tokenization and sequence preparation

[8]:
```
def tokenize_sentences(sentences, num_words=20000):
    tokenizer = Tokenizer(num_words=num_words, oov_token='<OOV>', filters='')
    tokenizer.fit_on_texts(sentences)
    sequences = tokenizer.texts_to_sequences(sentences)
    max_len = max(len(seq) for seq in sequences)
    padded = pad_sequences(sequences, padding='post', maxlen=max_len)
    return padded, tokenizer, max_len
```

Tokenize original and paraphrase sentences

[9]:
```
original_padded, original_tokenizer, original_max_len =␣
  ↪tokenize_sentences(train_df['original'].tolist() + val_df['original'].
  ↪tolist())
paraphrase_padded, paraphrase_tokenizer, paraphrase_max_len =␣
  ↪tokenize_sentences(train_df['paraphrase'].tolist() + val_df['paraphrase'].
  ↪tolist())
```

Vocabulary sizes

[10]:

```
original_vocab_size = len(original_tokenizer.word_index) + 1
paraphrase_vocab_size = len(paraphrase_tokenizer.word_index) + 1

print(f"\nOriginal vocabulary size: {original_vocab_size}")
print(f"Paraphrase vocabulary size: {paraphrase_vocab_size}")
print(f"Original max sequence length: {original_max_len}")
print(f"Paraphrase max sequence length: {paraphrase_max_len}")
```

```
Original vocabulary size: 24
Paraphrase vocabulary size: 26
Original max sequence length: 11
Paraphrase max sequence length: 11
```

Prepare training and validation data

[11]:

```
x_train = original_padded[:len(train_df)]
y_train = paraphrase_padded[:len(train_df)]
x_val = original_padded[len(train_df):]
y_val = paraphrase_padded[len(train_df):]
```

1.LSTM/GRU Encoder-Decoder without Attention

[12]:

```
# Hyperparameters
embedding_dim = 256
units = 512
batch_size = 64
epochs = 10
```

Encoder

[13]:

```
encoder_inputs = keras.Input(shape=(None,))
encoder_embedding = layers.Embedding(original_vocab_size,␣
 ↪embedding_dim)(encoder_inputs)
encoder_lstm = layers.LSTM(units, return_sequences=True, return_state=True)
encoder_outputs, state_h, state_c = encoder_lstm(encoder_embedding)
encoder_states = [state_h, state_c]
```

Decoder

[14]:

```
# Decoder
decoder_inputs = keras.Input(shape=(None,))
decoder_embedding = layers.Embedding(paraphrase_vocab_size,␣
 ↪embedding_dim)(decoder_inputs)
decoder_lstm = layers.LSTM(units, return_sequences=True, return_state=True)
decoder_outputs, _, _ = decoder_lstm(decoder_embedding,␣
 ↪initial_state=encoder_states)
decoder_dense = layers.Dense(paraphrase_vocab_size, activation='softmax')
decoder_outputs = decoder_dense(decoder_outputs)
```

[15]:
```
# Model
no_attention_model = keras.Model([encoder_inputs, decoder_inputs],␣
 ↪decoder_outputs, name="no_attention_model")

# Compile
no_attention_model.compile(
    optimizer='adam',
    loss='sparse_categorical_crossentropy',
    metrics=['accuracy']
)

no_attention_model.summary()
```

```
Model: "no_attention_model"


 Layer (type)           Output Shape          Param #   Connected to

 input_layer_1          (None, None)                0   -
 (InputLayer)

 input_layer_2          (None, None)                0   -
 (InputLayer)

 embedding              (None, None, 256)       6,144   input_layer_1[0]…
 (Embedding)

 embedding_1            (None, None, 256)       6,656   input_layer_2[0]…
 (Embedding)

 lstm (LSTM)            [(None, None,       1,574,912   embedding[0][0]
                        512), (None,
                        512), (None,
                        512)]

 lstm_1 (LSTM)          [(None, None,       1,574,912   embedding_1[0][0…
                        512), (None,                    lstm[0][1],
                        512), (None,                    lstm[0][2]
                        512)]

 dense (Dense)          (None, None, 26)       13,338   lstm_1[0][0]


 Total params: 3,175,962 (12.12 MB)


 Trainable params: 3,175,962 (12.12 MB)
 Non-trainable params: 0 (0.00 B)
```

Prepare decoder inputs/outputs for teacher forcing

[16]:
```
def prepare_decoder_data(sequences):
    decoder_input = sequences[:, :-1]
    decoder_output = sequences[:, 1:]
    return decoder_input, decoder_output

train_decoder_input, train_decoder_output = prepare_decoder_data(y_train)
val_decoder_input, val_decoder_output = prepare_decoder_data(y_val)
```

Train the no-attention model

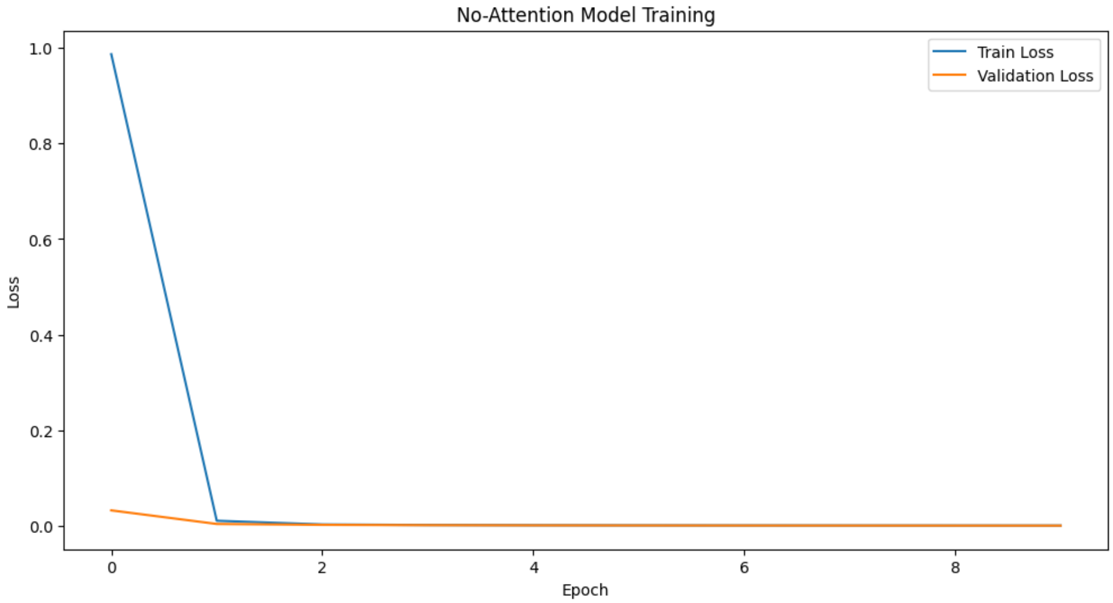
[17]:
```
no_attention_history = no_attention_model.fit(
    [x_train, train_decoder_input],
    np.expand_dims(train_decoder_output, -1),
    batch_size=batch_size,
    epochs=epochs,
    validation_data=([x_val, val_decoder_input], np.
  ↪expand_dims(val_decoder_output, -1)),
    callbacks=[keras.callbacks.EarlyStopping(patience=3,␣
  ↪restore_best_weights=True)]
)
```

```
Epoch 1/10
43/43             6s 34ms/step -
accuracy: 0.5732 - loss: 1.9023 - val_accuracy: 1.0000 - val_loss: 0.0322
Epoch 2/10
43/43             2s 16ms/step -
accuracy: 1.0000 - loss: 0.0170 - val_accuracy: 1.0000 - val_loss: 0.0037
Epoch 3/10
43/43             1s 13ms/step -
accuracy: 1.0000 - loss: 0.0031 - val_accuracy: 1.0000 - val_loss: 0.0019
Epoch 4/10
43/43             1s 13ms/step -
accuracy: 1.0000 - loss: 0.0017 - val_accuracy: 1.0000 - val_loss: 0.0012
Epoch 5/10
43/43             1s 13ms/step -
accuracy: 1.0000 - loss: 0.0011 - val_accuracy: 1.0000 - val_loss: 8.3977e-04
Epoch 6/10
43/43             1s 12ms/step -
accuracy: 1.0000 - loss: 7.7724e-04 - val_accuracy: 1.0000 - val_loss:
6.1900e-04
Epoch 7/10
43/43             1s 13ms/step -
```

```
accuracy: 1.0000 - loss: 5.7958e-04 - val_accuracy: 1.0000 - val_loss:
4.7730e-04
Epoch 8/10
43/43                 1s 13ms/step -
accuracy: 1.0000 - loss: 4.5080e-04 - val_accuracy: 1.0000 - val_loss:
3.8060e-04
Epoch 9/10
43/43                 1s 13ms/step -
accuracy: 1.0000 - loss: 3.6184e-04 - val_accuracy: 1.0000 - val_loss:
3.1140e-04
Epoch 10/10
43/43                 1s 13ms/step -
accuracy: 1.0000 - loss: 2.9758e-04 - val_accuracy: 1.0000 - val_loss:
2.6001e-04
```

Plot training history

[18]:
```
plt.figure(figsize=(12, 6))
plt.plot(no_attention_history.history['loss'], label='Train Loss')
plt.plot(no_attention_history.history['val_loss'], label='Validation Loss')
plt.title('No-Attention Model Training')
plt.xlabel('Epoch')
plt.ylabel('Loss')
plt.legend()
plt.show()
```



2 Encoder-Decoder with Bahdanau Attention

[19]:
```
# Bahdanau Attention Layer
class BahdanauAttention(layers.Layer):
    def __init__(self, units):
        super(BahdanauAttention, self).__init__()
        self.W1 = layers.Dense(units)
        self.W2 = layers.Dense(units)
        self.V = layers.Dense(1)

    def call(self, query, values):
        query_with_time_axis = tf.expand_dims(query, 1)
        score = self.V(tf.nn.tanh(self.W1(query_with_time_axis) + self.
 ↪W2(values)))
        attention_weights = tf.nn.softmax(score, axis=1)
        context_vector = attention_weights * values
        context_vector = tf.reduce_sum(context_vector, axis=1)
        return context_vector, attention_weights
```

Encoder with Bahdanau Attention

[20]:
```
encoder_inputs = keras.Input(shape=(None,))
encoder_embedding = layers.Embedding(original_vocab_size,␣
 ↪embedding_dim)(encoder_inputs)
encoder_lstm = layers.LSTM(units, return_sequences=True, return_state=True)
encoder_outputs, state_h, state_c = encoder_lstm(encoder_embedding)
```

Decoder with Bahdanau Attention

[21]:
```
decoder_inputs = keras.Input(shape=(None,))
decoder_embedding = layers.Embedding(paraphrase_vocab_size,␣
 ↪embedding_dim)(decoder_inputs)
decoder_lstm = layers.LSTM(units, return_sequences=True, return_state=True)
```

Attention mechanism

[22]:
```
attention = BahdanauAttention(units)
decoder_outputs, _, _ = decoder_lstm(decoder_embedding, initial_state=[state_h,␣
 ↪state_c])
context_vector, attention_weights = attention(state_h, encoder_outputs)
```

Combine context with decoder outputs

[23]:
```
# Wrap tf.expand_dims in a Lambda layer to ensure it's part of the symbolic␣
 ↪graph
decoder_outputs = layers.Lambda(lambda x: tf.expand_dims(x, 1))(context_vector)
decoder_outputs = layers.Concatenate(axis=-1)([decoder_outputs,␣
 ↪decoder_outputs])
decoder_dense = layers.Dense(paraphrase_vocab_size, activation='softmax')
decoder_outputs = decoder_dense(decoder_outputs)
```

```python
# Model
attention_model = keras.Model([encoder_inputs, decoder_inputs],␣
 ↪decoder_outputs, name="attention_model")

# Compile
attention_model.compile(
    optimizer='adam',
    loss='sparse_categorical_crossentropy',
    metrics=['accuracy']
)

attention_model.summary()
```

```
Model: "attention_model"



 Layer (type)           Output Shape           Param #   Connected to

 input_layer_3          (None, None)                 0   -
 (InputLayer)

 embedding_2            (None, None, 256)        6,144   input_layer_3[0]…
 (Embedding)

 lstm_2 (LSTM)          [(None, None,        1,574,912   embedding_2[0][0]
                        512), (None,
                        512), (None,
                        512)]

 bahdanau_attention     [(None, 512),          525,825   lstm_2[0][1],
 (BahdanauAttention)    (None, None, 1)]                 lstm_2[0][0]

 lambda (Lambda)        (None, 1, 512)               0   bahdanau_attenti…

 concatenate            (None, 1, 1024)              0   lambda[0][0],
 (Concatenate)                                           lambda[0][0]

 input_layer_4          (None, None)                 0   -
 (InputLayer)

 dense_4 (Dense)        (None, 1, 26)           26,650   concatenate[0][0]


 Total params: 2,133,531 (8.14 MB)
```

```
Trainable params: 2,133,531 (8.14 MB)

Non-trainable params: 0 (0.00 B)
```

Train the attention model

[25]:

```python
# Combine context with decoder outputs
# Remove the extra dimension from decoder_outputs
decoder_outputs = layers.Concatenate(axis=-1)([layers.Lambda(lambda x: tf.
 ↪expand_dims(x, 1))(context_vector), decoder_outputs])
decoder_dense = layers.Dense(paraphrase_vocab_size, activation='softmax')
decoder_outputs = decoder_dense(decoder_outputs)

# Model
attention_model = keras.Model([encoder_inputs, decoder_inputs],␣
 ↪decoder_outputs, name="attention_model")

# Compile
attention_model.compile(
    optimizer='adam',
    loss='sparse_categorical_crossentropy',
    metrics=['accuracy']
)

attention_model.summary()
```

```
Model: "attention_model"


 Layer (type)          Output Shape          Param #   Connected to

 input_layer_3         (None, None)                0   -
 (InputLayer)

 embedding_2           (None, None, 256)       6,144   input_layer_3[0]…
 (Embedding)

 lstm_2 (LSTM)         [(None, None,       1,574,912   embedding_2[0][0]
                       512), (None,
                       512), (None,
                       512)]

 bahdanau_attention    [(None, 512),         525,825   lstm_2[0][1],
 (BahdanauAttention)   (None, None, 1)]                lstm_2[0][0]

 lambda (Lambda)       (None, 1, 512)              0   bahdanau_attenti…
 concatenate           (None, 1, 1024)             0    lambda[0][0],
 (Concatenate)                                           lambda[0][0]

 lambda_1 (Lambda)     (None, 1, 512)              0    bahdanau_attenti…

 dense_4 (Dense)       (None, 1, 26)          26,650    concatenate[0][0]

 concatenate_2         (None, 1, 538)              0    lambda_1[0][0],
 (Concatenate)                                           dense_4[0][0]

 input_layer_4         (None, None)                0    -
 (InputLayer)

 dense_5 (Dense)       (None, 1, 26)          14,014    concatenate_2[0]…
```

```
Total params: 2,147,545 (8.19 MB)

Trainable params: 2,147,545 (8.19 MB)

Non-trainable params: 0 (0.00 B)
```

[ ]:

```
from tensorflow.keras.models import Model
from tensorflow.keras.layers import Input, Embedding, LSTM, Dense,␣
 ↪TimeDistributed, Concatenate, Attention
from tensorflow.keras.optimizers import Adam
```

[ ]:

```
# Parameters
vocab_size = 10000          # example vocab size
embedding_dim = 128
lstm_units = 256
decoder_seq_len = 10        # length of decoder output
num_classes = 26            # number of output classes (e.g., characters or␣
 ↪labels)
batch_size = 64
```

[ ]:

```
# Encoder
encoder_input = Input(shape=(None,), name="encoder_input")
encoder_emb = Embedding(input_dim=vocab_size,␣
 ↪output_dim=embedding_dim)(encoder_input)
encoder_lstm, state_h, state_c = LSTM(lstm_units, return_sequences=True,␣
 ↪return_state=True)(encoder_emb)
```

[ ]:
```
# Decoder
decoder_input = Input(shape=(None,), name="decoder_input")
decoder_emb = Embedding(input_dim=vocab_size,␣
 ↪output_dim=embedding_dim)(decoder_input)
decoder_lstm_output, _, _ = LSTM(lstm_units, return_sequences=True,␣
 ↪return_state=True)(decoder_emb, initial_state=[state_h, state_c])
```

[ ]:
```
# Attention
attention = Attention()([decoder_lstm_output, encoder_lstm])  # (batch,␣
 ↪decoder_seq_len, encoder_seq_len)
decoder_combined_context = Concatenate(axis=-1)([decoder_lstm_output,␣
 ↪attention])
```

[ ]:
```
# Output Layer
output = TimeDistributed(Dense(num_classes,␣
 ↪activation='softmax'))(decoder_combined_context)
```

[ ]:
```
# Final model
attention_model = Model([encoder_input, decoder_input], output)
attention_model.compile(optimizer=Adam(),␣
 ↪loss='sparse_categorical_crossentropy', metrics=['accuracy'])
attention_model.summary()
```

```
Model: "functional_1"


 Layer (type)          Output Shape           Param #  Connected to

 encoder_input         (None, None)                 0  -
 (InputLayer)

 decoder_input         (None, None)                 0  -
 (InputLayer)

 embedding_6           (None, None, 128)    1,280,000  encoder_input[0]…
 (Embedding)

 embedding_7           (None, None, 128)    1,280,000  decoder_input[0]…
 (Embedding)

 lstm_6 (LSTM)         [(None, None,          394,240  embedding_6[0][0]
                       256), (None,
                       256), (None,
                       256)]

 lstm_7 (LSTM)         [(None, None,          394,240  embedding_7[0][0…
                       256), (None,                    lstm_6[0][1],
                       256), (None,              lstm_6[0][2]
                       256)]

 attention_1           (None, None, 256)       0  lstm_7[0][0],
 (Attention)                                      lstm_6[0][0]

 concatenate_6         (None, None, 512)       0  lstm_7[0][0],
 (Concatenate)                                    attention_1[0][0]

 time_distributed_1    (None, None, 26)   13,338  concatenate_6[0]…
 (TimeDistributed)
```

```
 Total params: 3,361,818 (12.82 MB)

 Trainable params: 3,361,818 (12.82 MB)

 Non-trainable params: 0 (0.00 B)
```

[ ]:

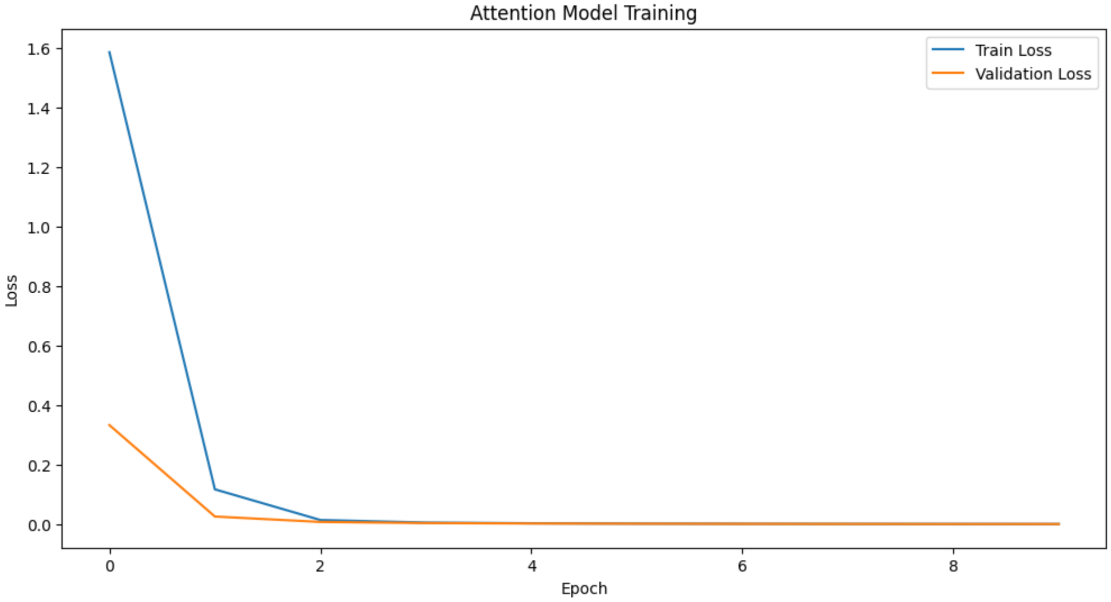
```
# Train the attention model
attention_history = attention_model.fit(
    [x_train, train_decoder_input],
    np.expand_dims(train_decoder_output, -1),
    batch_size=batch_size,
    epochs=epochs,
    validation_data=([x_val, val_decoder_input], np.
 ↪expand_dims(val_decoder_output, -1)),
    callbacks=[keras.callbacks.EarlyStopping(patience=3,␣
 ↪restore_best_weights=True)]
)
```

```
Epoch 1/10
43/43                4s 27ms/step -
accuracy: 0.3729 - loss: 2.4045 - val_accuracy: 1.0000 - val_loss: 0.3328
Epoch 2/10
43/43                1s 13ms/step -
accuracy: 1.0000 - loss: 0.1937 - val_accuracy: 1.0000 - val_loss: 0.0259
Epoch 3/10
43/43                1s 13ms/step -
accuracy: 1.0000 - loss: 0.0186 - val_accuracy: 1.0000 - val_loss: 0.0077
Epoch 4/10
43/43                1s 13ms/step -
accuracy: 1.0000 - loss: 0.0065 - val_accuracy: 1.0000 - val_loss: 0.0040
Epoch 5/10
43/43                1s 13ms/step -
```

```
accuracy: 1.0000 - loss: 0.0035 - val_accuracy: 1.0000 - val_loss: 0.0025
Epoch 6/10
43/43                 1s 13ms/step -
accuracy: 1.0000 - loss: 0.0023 - val_accuracy: 1.0000 - val_loss: 0.0018
Epoch 7/10
43/43                 1s 13ms/step -
accuracy: 1.0000 - loss: 0.0016 - val_accuracy: 1.0000 - val_loss: 0.0013
Epoch 8/10
43/43                 1s 13ms/step -
accuracy: 1.0000 - loss: 0.0012 - val_accuracy: 1.0000 - val_loss: 0.0010
Epoch 9/10
43/43                 1s 14ms/step -
accuracy: 1.0000 - loss: 9.6763e-04 - val_accuracy: 1.0000 - val_loss:
8.2335e-04
Epoch 10/10
43/43                 1s 13ms/step -
accuracy: 1.0000 - loss: 7.7962e-04 - val_accuracy: 1.0000 - val_loss:
6.7456e-04
```

[ ]:

```
# Plot training history
plt.figure(figsize=(12, 6))
plt.plot(attention_history.history['loss'], label='Train Loss')
plt.plot(attention_history.history['val_loss'], label='Validation Loss')
plt.title('Attention Model Training')
plt.xlabel('Epoch')
plt.ylabel('Loss')
plt.legend()
plt.show()
```



3 Transformer with Self-Attention

[ ]:

```
# Transformer components
class TransformerEncoder(layers.Layer):
    def __init__(self, embed_dim, dense_dim, num_heads, **kwargs):
        super().__init__(**kwargs)
        self.embed_dim = embed_dim
        self.dense_dim = dense_dim
        self.num_heads = num_heads
        self.attention = layers.MultiHeadAttention(num_heads=num_heads,␣
 ↪key_dim=embed_dim)
        self.dense_proj = keras.Sequential([
            layers.Dense(dense_dim, activation="relu"),
            layers.Dense(embed_dim)
        ])
        self.layernorm_1 = layers.LayerNormalization()
        self.layernorm_2 = layers.LayerNormalization()

    def call(self, inputs, mask=None):
        if mask is not None:
            mask = mask[:, tf.newaxis, :]
        attention_output = self.attention(inputs, inputs, attention_mask=mask)
        proj_input = self.layernorm_1(inputs + attention_output)
        proj_output = self.dense_proj(proj_input)
        return self.layernorm_2(proj_input + proj_output)

class PositionalEmbedding(layers.Layer):
    def __init__(self, sequence_length, vocab_size, embed_dim, **kwargs):
        super().__init__(**kwargs)
        self.token_embeddings = layers.Embedding(vocab_size, embed_dim)
        self.position_embeddings = layers.Embedding(sequence_length, embed_dim)
        self.sequence_length = sequence_length
        self.vocab_size = vocab_size
        self.embed_dim = embed_dim

    def call(self, inputs):
        length = tf.shape(inputs)[-1]
        positions = tf.range(start=0, limit=length, delta=1)
        embedded_tokens = self.token_embeddings(inputs)
        embedded_positions = self.position_embeddings(positions)
        return embedded_tokens + embedded_positions
```

[ ]:

```
# Transformer Model
embed_dim = 256
num_heads = 8
dense_dim = 512
```

[ ]:
```
# Encoder
encoder_inputs = keras.Input(shape=(None,), dtype="int64")
encoder_embedding = PositionalEmbedding(original_max_len, original_vocab_size,␣
 ↪embed_dim)(encoder_inputs)
encoder_outputs = TransformerEncoder(embed_dim, dense_dim,␣
 ↪num_heads)(encoder_embedding)

# Decoder
decoder_inputs = keras.Input(shape=(None,), dtype="int64")
decoder_embedding = PositionalEmbedding(paraphrase_max_len,␣
 ↪paraphrase_vocab_size, embed_dim)(decoder_inputs)
decoder_outputs = TransformerEncoder(embed_dim, dense_dim,␣
 ↪num_heads)(decoder_embedding)

# Final dense layer
decoder_dense = layers.Dense(paraphrase_vocab_size, activation="softmax")
outputs = decoder_dense(decoder_outputs)
```

[ ]:
```
# Model
transformer_model = keras.Model([encoder_inputs, decoder_inputs], outputs)
transformer_model.compile(
    optimizer="adam",
    loss="sparse_categorical_crossentropy",
    metrics=["accuracy"]
)
transformer_model.summary()
```

```
Model: "functional_4"


 Layer (type)          Output Shape            Param #   Connected to

 input_layer_6         (None, None)                  0   -
 (InputLayer)

 positional_embeddi…   (None, None, 256)         9,472   input_layer_6[0]…
 (PositionalEmbeddi…

 transformer_encode…   (None, None, 256)     2,367,488   positional_embed…
 (TransformerEncode…

 input_layer_4         (None, None)                  0   -
 (InputLayer)

 dense_12 (Dense)      (None, None, 26)          6,682   transformer_enco…
```

```
Total params: 2,383,642 (9.09 MB)

Trainable params: 2,383,642 (9.09 MB)

Non-trainable params: 0 (0.00 B)
```

Train transformer

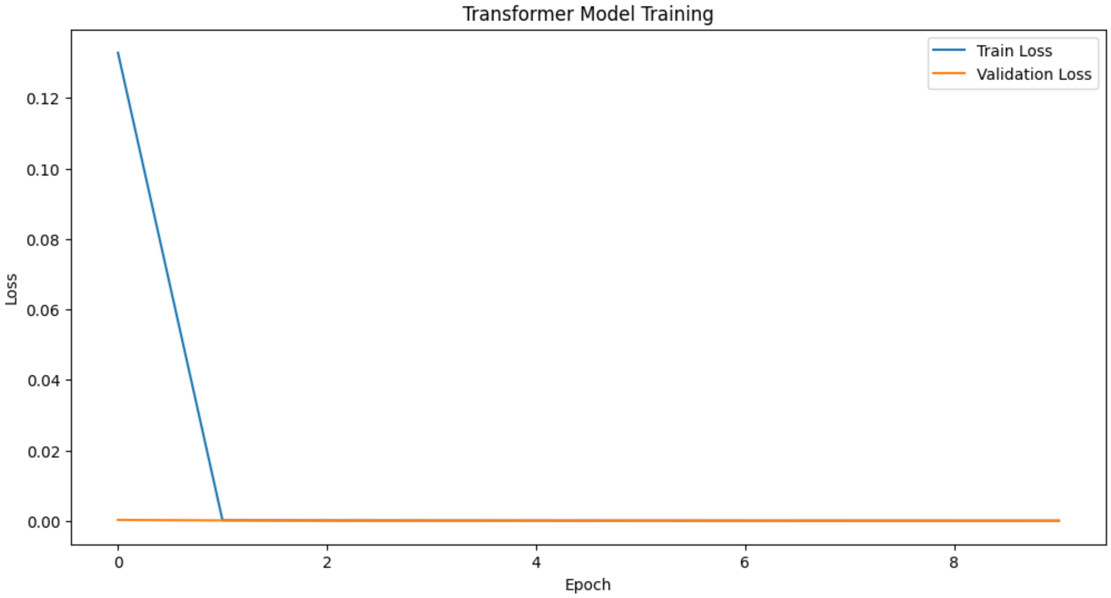
```
[ ]: transformer_history = transformer_model.fit(
         [x_train, train_decoder_input],
         np.expand_dims(train_decoder_output, -1),
         batch_size=batch_size,
         epochs=epochs,
         validation_data=([x_val, val_decoder_input], np.
       ↪expand_dims(val_decoder_output, -1)),
         callbacks=[keras.callbacks.EarlyStopping(patience=3,␣
       ↪restore_best_weights=True)]
     )
```

```
Epoch 1/10
43/43            13s 140ms/step -
accuracy: 0.8784 - loss: 0.5094 - val_accuracy: 1.0000 - val_loss: 2.5949e-04
Epoch 2/10
43/43            1s 14ms/step -
accuracy: 1.0000 - loss: 2.0335e-04 - val_accuracy: 1.0000 - val_loss:
1.1530e-04
Epoch 3/10
43/43            1s 14ms/step -
accuracy: 1.0000 - loss: 1.0366e-04 - val_accuracy: 1.0000 - val_loss:
7.8113e-05
Epoch 4/10
43/43            1s 14ms/step -
accuracy: 1.0000 - loss: 7.2513e-05 - val_accuracy: 1.0000 - val_loss:
5.9364e-05
Epoch 5/10
43/43            1s 14ms/step -
accuracy: 1.0000 - loss: 5.6027e-05 - val_accuracy: 1.0000 - val_loss:
4.7964e-05
Epoch 6/10
43/43            1s 14ms/step -
accuracy: 1.0000 - loss: 4.5672e-05 - val_accuracy: 1.0000 - val_loss:
4.0085e-05
Epoch 7/10
43/43            1s 14ms/step -
accuracy: 1.0000 - loss: 3.8433e-05 - val_accuracy: 1.0000 - val_loss:
3.4415e-05
```

```
Epoch 8/10
43/43                 1s 14ms/step -
accuracy: 1.0000 - loss: 3.3179e-05 - val_accuracy: 1.0000 - val_loss:
3.0120e-05
Epoch 9/10
43/43                 1s 14ms/step -
accuracy: 1.0000 - loss: 2.9137e-05 - val_accuracy: 1.0000 - val_loss:
2.6719e-05
Epoch 10/10
43/43                 1s 15ms/step -
accuracy: 1.0000 - loss: 2.5969e-05 - val_accuracy: 1.0000 - val_loss:
2.4092e-05
```

Plot training

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



Evaluation functions

```
[ ]: def evaluate_model(model, input_seq, target_tokenizer, max_len, model_type):
         decoded = []
```

```
    for i in range(len(input_seq)):
        tokenized = input_seq[i:i+1]
        decoder_input = np.zeros((1, max_len))
        decoder_input[0, 0] = target_tokenizer.word_index['<start>']

        for j in range(max_len - 1):
            if model_type == 'transformer':
                pred = model.predict([tokenized, decoder_input], verbose=0)
            else:
                pred = model.predict([tokenized, decoder_input], verbose=0)

            pred_id = np.argmax(pred[0, j, :])
            if pred_id == target_tokenizer.word_index['<end>']:
                break
            decoder_input[0, j+1] = pred_id

        decoded.append(decoder_input[0, 1:j+1])
    return decoded
```

[ ]:

```
def calculate_metrics(references, candidates):
    # BLEU
    smooth = SmoothingFunction().method1
    bleu_scores = [sentence_bleu([ref.split()], cand.split(),␣
 ↪smoothing_function=smooth)
                  for ref, cand in zip(references, candidates)]

    # ROUGE
    scorer = rouge_scorer.RougeScorer(['rouge1', 'rouge2', 'rougeL'],␣
 ↪use_stemmer=True)
    rouge_scores = [scorer.score(ref, cand) for ref, cand in zip(references,␣
 ↪candidates)]

    return {
        'bleu': np.mean(bleu_scores),
        'rouge1': np.mean([score['rouge1'].fmeasure for score in rouge_scores]),
        'rouge2': np.mean([score['rouge2'].fmeasure for score in rouge_scores]),
        'rougeL': np.mean([score['rougeL'].fmeasure for score in rouge_scores])
    }
```

Evaluate all models on validation set

[ ]:

```
sample_size = min(100, len(x_val))
sample_idx = np.random.choice(len(x_val), sample_size, replace=False)
x_sample = x_val[sample_idx]
y_sample = y_val[sample_idx]
```

```
[ ]: # Get reference texts
     references = [paraphrase_tokenizer.sequences_to_texts([seq])[0] for seq in␣
      ↪y_sample]
```

1. No-Attention Model

```
[ ]: print("Evaluating No-Attention Model...")
     start = time.time()
     no_attn_preds = evaluate_model(no_attention_model, x_sample,␣
      ↪paraphrase_tokenizer, paraphrase_max_len, 'no_attention')
     no_attn_time = time.time() - start
     no_attn_texts = [paraphrase_tokenizer.sequences_to_texts([seq])[0] for seq in␣
      ↪no_attn_preds]
     no_attn_metrics = calculate_metrics(references, no_attn_texts)
```

```
Evaluating No-Attention Model…
```

2. Attention Model

```
[ ]: print("Evaluating Attention Model...")
     start = time.time()
     attn_preds = evaluate_model(attention_model, x_sample, paraphrase_tokenizer,␣
      ↪paraphrase_max_len, 'attention')
     attn_time = time.time() - start
     attn_texts = [paraphrase_tokenizer.sequences_to_texts([seq])[0] for seq in␣
      ↪attn_preds]
     attn_metrics = calculate_metrics(references, attn_texts)
```

```
Evaluating Attention Model…
```

3. Transformer

```
[ ]: print("Evaluating Transformer Model...")
     start = time.time()
     trans_preds = evaluate_model(transformer_model, x_sample, paraphrase_tokenizer,␣
      ↪paraphrase_max_len, 'transformer')
     trans_time = time.time() - start
     trans_texts = [paraphrase_tokenizer.sequences_to_texts([seq])[0] for seq in␣
      ↪trans_preds]
     trans_metrics = calculate_metrics(references, trans_texts)
```

```
Evaluating Transformer Model…
```

Compile results

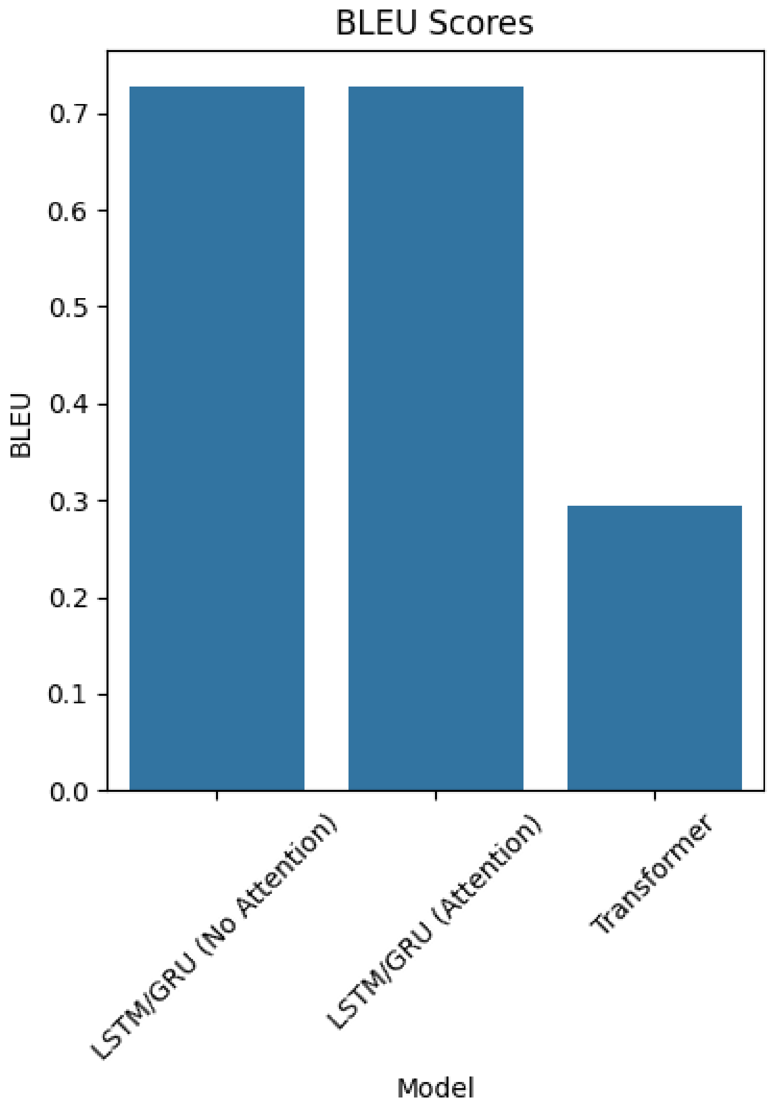
```
[ ]: results_df = pd.DataFrame({
         'Model': ['LSTM/GRU (No Attention)', 'LSTM/GRU (Attention)', 'Transformer'],
         'BLEU': [no_attn_metrics['bleu'], attn_metrics['bleu'],␣
      ↪trans_metrics['bleu']],
    'ROUGE-1': [no_attn_metrics['rouge1'], attn_metrics['rouge1'],␣
 ↪trans_metrics['rouge1']],
    'ROUGE-2': [no_attn_metrics['rouge2'], attn_metrics['rouge2'],␣
 ↪trans_metrics['rouge2']],
    'ROUGE-L': [no_attn_metrics['rougeL'], attn_metrics['rougeL'],␣
 ↪trans_metrics['rougeL']],
    'Inference Time (s)': [no_attn_time/sample_size, attn_time/sample_size,␣
 ↪trans_time/sample_size],
    'Training Time (epoch)': [
        no_attention_history.history['val_loss'][-1],
        attention_history.history['val_loss'][-1],
        transformer_history.history['val_loss'][-1]
    ]
})

print("\nFinal Comparison:")
display(results_df)
```

```
Final Comparison:

                     Model      BLEU   ROUGE-1  ROUGE-2   ROUGE-L  \
0  LSTM/GRU (No Attention)  0.728131  0.868211  0.85356  0.868211
1     LSTM/GRU (Attention)  0.728131  0.868211  0.85356  0.868211
2              Transformer  0.293834  0.353000  0.32000  0.353000

   Inference Time (s)  Training Time (epoch)
0            0.864001               0.000260
1            0.893456               0.000675
2            0.959117               0.000024
```

Visualization

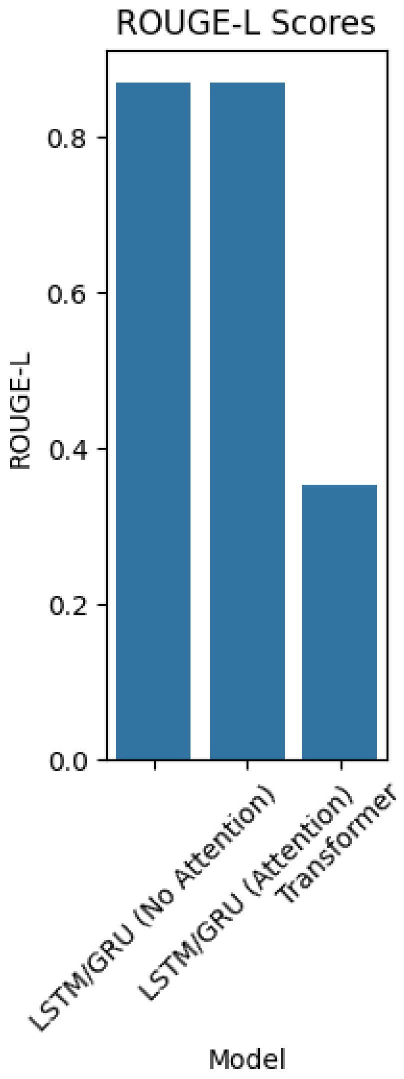
[ ]:
```
plt.figure(figsize=(15, 5))

plt.subplot(1, 3, 1)
sns.barplot(x='Model', y='BLEU', data=results_df)
plt.title('BLEU Scores')
plt.xticks(rotation=45)
```

[ ]:
```
([0, 1, 2],
 [Text(0, 0, 'LSTM/GRU (No Attention)'),
  Text(1, 0, 'LSTM/GRU (Attention)'),
  Text(2, 0, 'Transformer')])
```



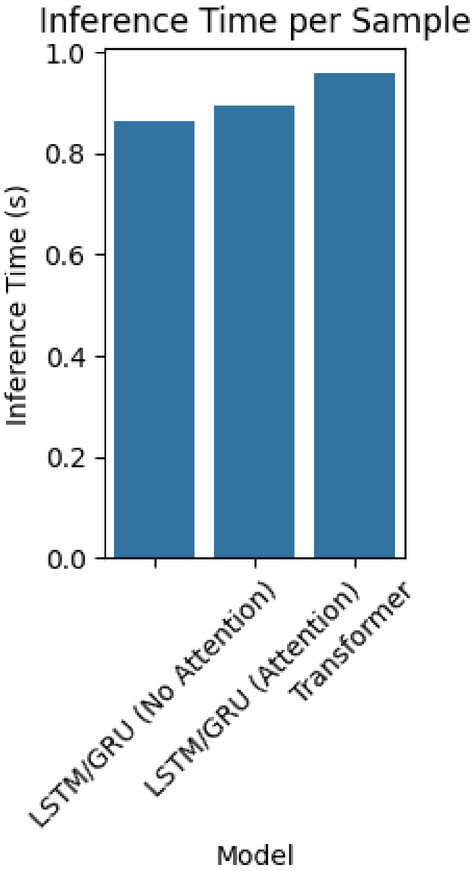
[ ]:
```
plt.subplot(1, 3, 2)
sns.barplot(x='Model', y='ROUGE-L', data=results_df)
plt.title('ROUGE-L Scores')
plt.xticks(rotation=45)
```

[ ]:
```
([0, 1, 2],
 [Text(0, 0, 'LSTM/GRU (No Attention)'),
  Text(1, 0, 'LSTM/GRU (Attention)'),
  Text(2, 0, 'Transformer')])
```



[ ]:

```python
plt.subplot(1, 3, 3)
sns.barplot(x='Model', y='Inference Time (s)', data=results_df)
plt.title('Inference Time per Sample')
plt.xticks(rotation=45)

plt.tight_layout()
plt.show()
```


Inference Time per Sample
1.0
0.8
0.6
0.4
0.2
0.0
Inference Time (s)
LSTM/GRU (No Attention)
LSTM/GRU (Attention)
Transformer
Model