Project Documentation: Arabic-English Translation using MarianMT

Project Title

Arabic-English Neural Machine Translation using MarianMT

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Overview

This project focuses on building a neural machine translation (NMT) system that translates English text into Arabic using the pre-trained MarianMT model from Hugging Face. The system is trained and evaluated using a parallel corpus of English-Arabic sentence pairs. The implementation is based on the `transformers` library, and the training pipeline leverages Hugging Face's `Seq2SeqTrainer`.

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1. Dataset Information

Dataset Source: Kaggle

- **Name:** Arabic to English Translation Sentences

- **File Used:** `ara_eng.txt`
- **Columns:** `english`, `arabic`
- **Format:** Tab-separated values (TSV)

Dataset Preprocessing

- Removed punctuation and unnecessary characters.
- Lowercased English text.
- Cleaned Arabic text using Unicode ranges for Arabic.
- Filtered out sentence pairs with less than 3 words or less than 5 characters.
- Removed duplicate English entries.

Data Split

- **Training Set:** 80%
- **Testing Set:** 20%

Preprocessing Steps

.English Text:

Converted text to lowercase.

Removed brackets and their content: (...), [...].

Removed unnecessary characters while keeping useful punctuation: ., ,, !, ?.

Normalized characters using unicodedata.normalize() to standardize accented letters.

.Arabic Text:

Removed all non-Arabic characters using Unicode range: \u0600-\u06FF.

Removed diacritics and decorative marks, such as: ً.

Removed digits and non-alphabetic symbols.

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2. Model Information

Pre-trained Model

- **Model Name:** `Helsinki-NLP/opus-mt-tc-big-en-ar`
- **Library:** `transformers` by Hugging Face

- **Architecture:** MarianMT (based on Transformer architecture)

Tokenizer

- **Type:** SentencePiece
- **Tokenizer:** `MarianTokenizer` from Hugging Face

Input Length

- **Maximum Sequence Length:** 128 tokens

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3. Training Details

Preprocessing

- Tokenization applied to both English input and Arabic target.
- Padding and truncation used for fixed-length inputs (max length = 128).

Training Configuration

- **Epochs:** 10
- **Training Batch Size:** 16
- **Evaluation Batch Size:** 16
- **Output Directory:** `./results`
- **Logging Directory:** `./logs`

- **Logging Steps:** 10
- **Save Steps:** 1000
- **Evaluation Strategy:** Custom bertscore callback
- **Prediction:** Enabled with `predict_with_generate=True`

Training Loss (last few steps):

- Decreased from ~6.5 to ~0.2 over 10 epochs
- Indicates effective learning and convergence

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4. Evaluation Metrics

Metric Used: BERTScore

- **Library:** `bert_score` (from HuggingFace)
- **Language Models Used:** Pre-trained multilingual BERT models (`bert-base-multilingual-cased`)
- **Method:**
  - Computes similarity between reference and generated translation using contextual embeddings
  - Captures semantic meaning better than lexical match-based metrics like BLEU
- **Evaluation Frequency:**
  - Evaluated on 100 random test samples at the end of each epoch
  - Provides F1 score for precision-recall balance
- **Why BERTScore?**
  - More reliable for low-resource language pairs
  - Better reflects human judgment of translation quality

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5. Model Limitations

- **Limited Domain Generalization:**
  - Trained on a small parallel corpus; may not generalize to other domains (e.g., medical, legal).
- **Token Truncation:**
  - Long sentences may be truncated, potentially affecting translation accuracy.
- **Vocabulary Limitation:**
  - Pre-trained tokenizer might not handle rare or domain-specific tokens well.
- **Cultural and Contextual Nuances:**
  - May miss idiomatic expressions or cultural references that require contextual understanding.
- **BERTScore Reliability:**
  - While more semantically aware than BLEU, still limited by the capabilities of the underlying BERT model
  - Sensitive to language-specific pretraining and sentence structure nuances.

6.Parameters Model

1. **`model_name`**
   - **Type:** `str`

    - **Description:** The name of the pre-trained Marian model used for English-to-Arabic translation. It is used to load the model and tokenizer.
2. **`max_length`**
    - **Type:** `int`
    - **Description:** The maximum token length for the input and output sequences during tokenization.
3. **`train_dataset` & `test_dataset`**
    - **Type:** `Dataset`
    - **Description:** The training and testing datasets that are used for training and evaluation. These are instances of the `Dataset` class from the `datasets` library.
4. **`training_args`**
    - **Type:** `Seq2SeqTrainingArguments`
    - **Description:** This contains all the hyperparameters required for training the model. It specifies batch size, number of epochs, logging settings, save steps, etc.
    - **Important fields:**
        - `per_device_train_batch_size`: The batch size for training.
        - `num_train_epochs`: The number of epochs for training.
        - `logging_dir`: Directory where logs will be saved.
        - `save_steps`: Frequency at which the model is saved.
5. **`generation_config`**
    - **Type:** `GenerationConfig`
    - **Description:** Configuration for controlling the generation of text by the model.
    - **Important fields:**
        - `max_length`: Maximum length of the generated sequence.
        - `num_beams`: Number of beams for beam search (controls the search size during translation).
        - `length_penalty`: Penalty for longer translations.
        - `early_stopping`: Whether to stop generating early if the sequence is finished.

        - `bad_words_ids`: A list of words to avoid in the generated text.
6. **`batch_size`**
    - **Type:** `int`
    - **Description:** The number of samples in each batch during translation.
7. **`inputs` (in `preprocess` function)**
    - **Type:** `dict`
    - **Description:** This is the tokenized input for the English text. It is a dictionary containing keys like `input_ids` and `attention_mask`, which are used by the model to process the input.
8. **`labels` (in `preprocess` function)**
    - **Type:** `dict`
    - **Description:** The tokenized version of the Arabic text (target). It also contains `input_ids` which represent the tokens for the target language.
9. **`decoded_preds` and `decoded_labels`**
    - **Type:** `list of str`
    - **Description:** The translated output (`decoded_preds`) and the reference translation (`decoded_labels`). These are lists of strings containing the decoded translations.
10. **`P`, `R`, `F1`**
    - **Type:** `Tensor`
    - **Description:** The Precision (P), Recall (R), and F1 scores computed using the BERTScore metric to evaluate the translation quality.
11. **`preds` and `labels` (in `compute_metrics`)**
    - **Type:** `list of int`
    - **Description:** These are the predicted and true label sequences (after tokenization) used for computing metrics like BERTScore.
12. **`texts` (in `generate_translation`)**
    - **Type:** `list of str`
    - **Description:** The English text to be translated. This is passed in batches to the model for translation.
13. **`input_ids` and `attention_mask` (in `generate_translation`)**

- **Type:** `Tensor`
- **Description:** These are the inputs to the model during generation. `input_ids` are the tokenized representation of the input texts, and `attention_mask` is used to indicate which tokens should be attended to (ignores padding tokens).

14. **`interface` (in Gradio UI)**
    - **Type:** `gr.Interface`
    - **Description:** This is the Gradio interface that takes an English sentence as input and displays the predicted Arabic translation as output. It uses the `generate_translation` function as its backend processing logic.

7. Future Enhancements

- **Data Augmentation:**
  - Use back-translation or synonym replacement to enrich dataset.
- **Fine-Tuning:**
  - Use a larger or more domain-specific dataset.
- **UI Integration:**
  - Integrate with a GUI (e.g., Gradio or Streamlit) for easy testing and deployment.
- **Deploy API:**
  - Wrap the model in a Flask or FastAPI service and deploy to Vercel or Hugging Face Spaces.

8. Dependencies

- `transformers`
- `datasets`
- `sentencepiece`
- `scikit-learn`
- `nltk`
- `torch`
- bert_score

9. Potential Improvements

- Incorporate domain-specific data for fine-tuning
- Use larger context-aware models (e.g., mBART or T5 multilingual)
- Introduce post-processing grammar correction or reranking
- Utilize semantic-aware metrics (e.g., BERTScore) alongside BLEU
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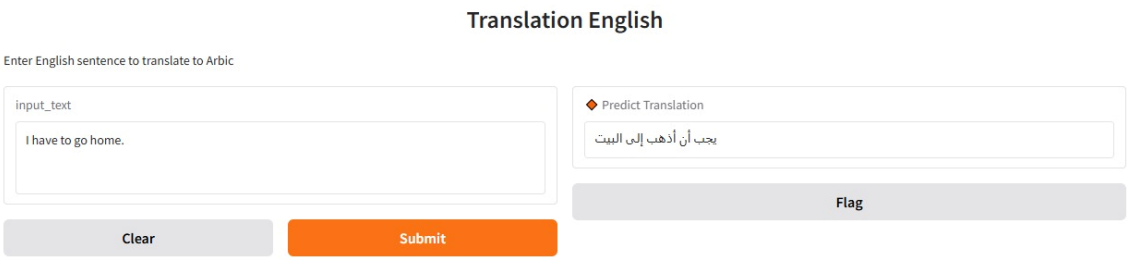
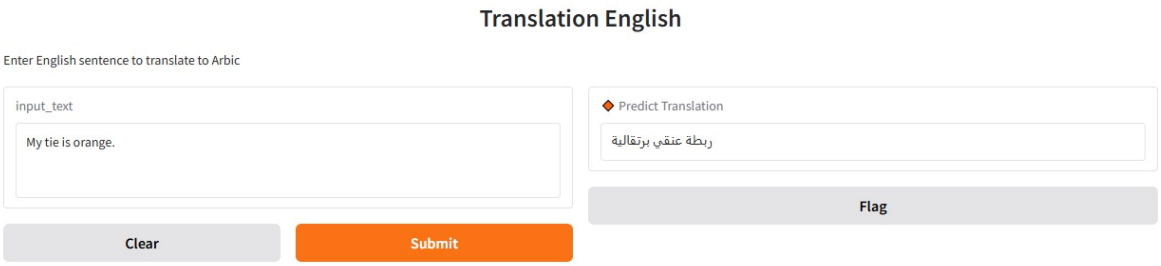
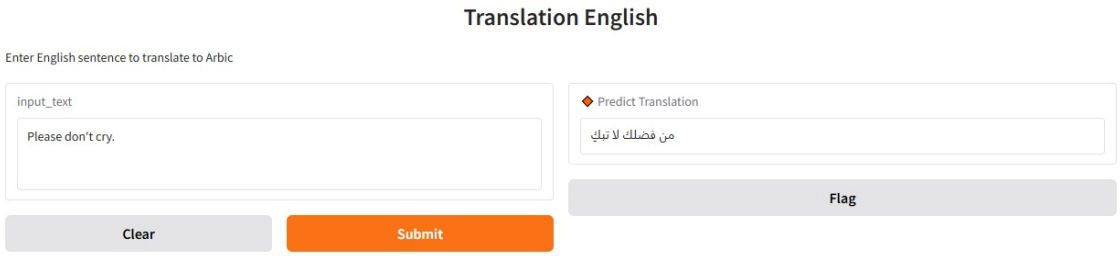
10.RUN







11. Conclusion

This project successfully demonstrates the application of a pre-trained MarianMT model for Arabic-English translation. Through fine-tuning and bertscore evaluation, the model achieved good performance on a general dataset, with opportunities for further enhancement in specialized applications.

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