Model Training: Discriminative & Generative Models on SLAKE

This notebook provides an end-to-end pipeline for:

1. Loading and preprocessing the SLAKE dataset (English-only)
2. Training a CNN–LSTM discriminative baseline (answer classification)
3. Fine-tuning BLIP using LoRA (generative VQA)
4. Evaluating both models fairly using:
    - Overall / OPEN / CLOSED
    - CNN–LSTM: Accuracy, Top-5 Accuracy, Macro-F1
    - BLIP: Exact Match, Token-F1 (+ optional BLEU/ROUGE-L/BERTScore for OPEN)

Key Hyperparameters (inferred from 02_eda.ipynb):

- Max question length: 32
- Max question vocab size: 290
- Answer classes (Top-K): 220 +

1. Setup & Imports

```
# Mount Google Drive if running in Google Colab
try:
    import os
    from pathlib import Path

    from google.colab import drive

    drive.mount("/content/drive")
    print("Session is running on Google Colab.")
    print(f"Current working directory: {Path.cwd()}")
    os.chdir(
        "/content/drive/MyDrive/insync/masters/courses/year2526_sem1/woa7015_advanced_machine_learning/alt_assessment/woa7015-medvqa"
    )
    print(f"Current working directory (After): {Path.cwd()}")

    if not Path("/content/data/SLAKE").exists():
        !uvx hf download BoKelvin/SLAKE --repo-type=dataset --local-dir /content/data/SLAKE/
        !unzip /content/data/SLAKE/imgs.zip -d /content/data/SLAKE/

    PROJECT_DIR = Path.cwd()
    DATASET_DIR = Path("/content/data/SLAKE/")

except ImportError:
    %load_ext autoreload
    %autoreload 2
    print("Session is not running on Google Colab.")
    print(f"Current working directory: {Path.cwd()}")

    PROJECT_DIR = Path.cwd().parent
    DATASET_DIR = PROJECT_DIR / "data" / "SLAKE"  # Or any other dataset path

assert DATASET_DIR.exists(), f"Dataset directory {DATASET_DIR} does not exist."
print(f"Dataset directory: {DATASET_DIR}")
!nvidia-smi
```

```
Mounted at /content/drive
Session is running on Google Colab.
Current working directory: /content
Current working directory (After): /content/drive/MyDrive/insync/masters/courses/year2526_sem1/woa7015_advanced_machine_learni
Installed 18 packages in 26ms
Downloading (incomplete total...): 0.00B [00:00, ?B/s]
Downloading (incomplete total...): 2.31kB [00:00, 9.22kB/s]
Downloading (incomplete total...):   2% 4.32M/212M [00:01<01:27, 2.37MB/s]
Downloading (incomplete total...):  70% 150M/212M [00:02<00:00, 90.3MB/s]
Fetching 8 files: 100% 8/8 [00:03<00:00,  2.65it/s]
Download complete: : 217MB [00:03, 90.3MB/s]                             /content/data/SLAKE
Download complete: : 217MB [00:03, 71.1MB/s]
Archive:  /content/data/SLAKE/imgs.zip
   creating: /content/data/SLAKE/imgs/
  inflating: /content/data/SLAKE/__MACOSX/._imgs
   creating: /content/data/SLAKE/imgs/xmlab29/
   creating: /content/data/SLAKE/imgs/xmlab198/
   creating: /content/data/SLAKE/imgs/xmlab508/
   creating: /content/data/SLAKE/imgs/xmlab395/
   creating: /content/data/SLAKE/imgs/xmlab16/
   creating: /content/data/SLAKE/imgs/xmlab537/
   creating: /content/data/SLAKE/imgs/xmlab361/
   creating: /content/data/SLAKE/imgs/xmlab153/
   creating: /content/data/SLAKE/imgs/xmlab359/
   creating: /content/data/SLAKE/imgs/xmlab154/
   creating: /content/data/SLAKE/imgs/xmlab366/
   creating: /content/data/SLAKE/imgs/xmlab530/
   creating: /content/data/SLAKE/imgs/xmlab11/
   creating: /content/data/SLAKE/imgs/xmlab392/
   creating: /content/data/SLAKE/imgs/xmlab539/
   creating: /content/data/SLAKE/imgs/xmlab18/
   creating: /content/data/SLAKE/imgs/xmlab506/
   creating: /content/data/SLAKE/imgs/xmlab162/
   creating: /content/data/SLAKE/imgs/xmlab350/
   creating: /content/data/SLAKE/imgs/xmlab27/
   creating: /content/data/SLAKE/imgs/xmlab196/
   creating: /content/data/SLAKE/imgs/xmlab368/
   creating: /content/data/SLAKE/imgs/xmlab20/
   creating: /content/data/SLAKE/imgs/xmlab191/
   creating: /content/data/SLAKE/imgs/xmlab357/
   creating: /content/data/SLAKE/imgs/xmlab165/
   creating: /content/data/SLAKE/imgs/xmlab501/
   creating: /content/data/SLAKE/imgs/xmlab74/
   creating: /content/data/SLAKE/imgs/xmlab131/
   creating: /content/data/SLAKE/imgs/xmlab80/
   creating: /content/data/SLAKE/imgs/xmlab303/
   creating: /content/data/SLAKE/imgs/xmlab555/
   creating: /content/data/SLAKE/imgs/xmlab4/
   creating: /content/data/SLAKE/imgs/xmlab552/
   creating: /content/data/SLAKE/imgs/xmlab304/
   creating: /content/data/SLAKE/imgs/xmlab136/
   creating: /content/data/SLAKE/imgs/xmlab87/
   creating: /content/data/SLAKE/imgs/xmlab73/
   creating: /content/data/SLAKE/imgs/xmlab109/
   creating: /content/data/SLAKE/imgs/xmlab599/
   creating: /content/data/SLAKE/imgs/xmlab3/
```

```python
# Weird bug on colab, we need to import this first before installing our package, even though transformers version is the same
from transformers import BlipProcessor
```

```python
# Build and install the package
!uv build .
!uv pip install ./dist/woa7015_medvqa-0.1.0-py3-none-any.whl
```

```
Building source distribution (uv build backend)...
Building wheel from source distribution (uv build backend)...
Successfully built dist/woa7015_medvqa-0.1.0.tar.gz
Successfully built dist/woa7015_medvqa-0.1.0-py3-none-any.whl
Using Python 3.12.12 environment at: /usr
Resolved 107 packages in 1.22s
Prepared 10 packages in 635ms
Uninstalled 6 packages in 138ms
Installed 10 packages in 39ms
 + bert-score==0.3.13
 + evaluate==0.4.6
 - matplotlib==3.10.0
 + matplotlib==3.10.8
 - nltk==3.9.1
 + nltk==3.9.2
 - numpy==2.0.2
 + numpy==2.4.1
 - pandas==2.2.2
 + pandas==2.3.3
 - peft==0.18.0
 + peft==0.18.1
 - rich==13.9.4
 + rich==14.2.0
 + rouge-score==0.1.2
 + woa7015-medvqa==0.1.0 (from file:///content/drive/MyDrive/insync/masters/courses/year2526_sem1/woa7015_advanced_machine_lear
```

```python
import os
import time

import json
import random
```

```
from functools import partial
from pathlib import Path

import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
import torch
from torch.utils.data import DataLoader

from woa7015_medvqa.v2.data.collate import collate_fn_blip, collate_fn_classify
from woa7015_medvqa.v2.data.slake import SLAKEDataset
from woa7015_medvqa.v2.data.tokenizers import (
    build_answer_vocab,
    build_question_vocab,
    make_answer_encoder,
    make_question_encoder,
)
from woa7015_medvqa.v2.data.transforms import image_transform
from woa7015_medvqa.v2.eval.evaluate_blip import evaluate_blip
from woa7015_medvqa.v2.eval.evaluate_cnn_lstm import evaluate_cnn_lstm
from woa7015_medvqa.v2.eval.metrics import (
    compute_classification_metrics,
    compute_text_metrics,
)
from woa7015_medvqa.v2.models.blip_lora import build_blip_with_lora
from woa7015_medvqa.v2.models.cnn_lstm import CNNLSTMClassifier
from woa7015_medvqa.v2.train.train_blip import BLIPTrainConfig, train_blip
from woa7015_medvqa.v2.train.train_cnn_lstm import CNNLSTMTrainConfig, train_cnn_lstm
from woa7015_medvqa.v2.utils import (
    count_params,
    load_checkpoint,
    plot_history,
    seed_everything,
)

```

2. Paths & Configurations

```
SEED = 42
DEVICE = torch.device("cuda" if torch.cuda.is_available() else "cpu")

# From EDA
MAX_Q_LEN = 32
MAX_Q_WORDS = 290
TOPK_ANS = 220

# Training hyperparameters
BATCH_SIZE_BASELINE = 128
BATCH_SIZE_BLIP = 64

NUM_WORKERS = 4

seed_everything(SEED)
print(f"Using device: {DEVICE}")
```

```
Using device: cuda
```

3. Build Question & Answer Tokenizers for CNN–LSTM

```
# Question vocab
q_vocab, q2id = build_question_vocab(
    str(DATASET_DIR / "train.json"),
    max_words=MAX_Q_WORDS,
    english_only=True,
)
encode_question = make_question_encoder(q2id, max_len=MAX_Q_LEN)

# Answer vocab
ans_vocab, ans2id, id2ans = build_answer_vocab(
    str(DATASET_DIR / "train.json"),
    topk=TOPK_ANS,
    english_only=True,
)
encode_answer = make_answer_encoder(ans2id)

```

```
print("Question vocab size (<pad> + <unk> + actual tokens):", len(q_vocab))
print("Answer vocab size (TopK + <unk>):", len(ans_vocab))
```

```
Question vocab size (<pad> + <unk> + actual tokens): 292
Answer vocab size (TopK + <unk>): 221
```

4. Build Datasets

```
# -----------------------------
# CNN-LSTM baseline datasets (tokenized)
# -----------------------------
train_ds_cls = SLAKEDataset(
    root_dir=DATASET_DIR,
    split="train",
    english_only=True,
    image_transform=image_transform,
    question_transform=encode_question,
    answer_transform=encode_answer,
)

val_ds_cls = SLAKEDataset(
    root_dir=DATASET_DIR,
    split="validation",
    english_only=True,
    image_transform=image_transform,
    question_transform=encode_question,
    answer_transform=encode_answer,
)

test_ds_cls = SLAKEDataset(
    root_dir=DATASET_DIR,
    split="test",
    english_only=True,
    image_transform=image_transform,
    question_transform=encode_question,
    answer_transform=encode_answer,
)

print("Classification datasets:")
print(
    "Train:", len(train_ds_cls), "| Val:", len(val_ds_cls), "| Test:", len(test_ds_cls)
)


# -----------------------------
# BLIP datasets (raw PIL + strings)
# -----------------------------
train_ds_blip = SLAKEDataset(
    root_dir=DATASET_DIR,
    split="train",
    english_only=True,
)

val_ds_blip = SLAKEDataset(
    root_dir=DATASET_DIR,
    split="validation",
    english_only=True,
)

test_ds_blip = SLAKEDataset(
    root_dir=DATASET_DIR,
    split="test",
    english_only=True,
)

print("BLIP datasets:")
print(
    "Train:",
    len(train_ds_blip),
    "| Val:",
    len(val_ds_blip),
    "| Test:",
    len(test_ds_blip),
)

```

```
Classification datasets:
Train: 4919 | Val: 1053 | Test: 1061
```

```
BLIP datasets:
Train: 4919 | Val: 1053 | Test: 1061
```

5. Model Definitions

```
cnn_lstm_frozen_backbone = CNNLSTMClassifier(
    num_answers=len(ans_vocab),
    question_vocab_size=len(q_vocab),
    freeze_cnn=True,
)

cnn_lstm_unfrozen_backbone = CNNLSTMClassifier(
    num_answers=len(ans_vocab),
    question_vocab_size=len(q_vocab),
    freeze_cnn=False,
)

processor, blip_lora = build_blip_with_lora(
    model_name="Salesforce/blip-vqa-base", r=8, alpha=32, dropout=0.05
)

```

```
Downloading: "https://download.pytorch.org/models/resnet18-f37072fd.pth" to /root/.cache/torch/hub/checkpoints/resnet18-f37072f
100%|██████████| 44.7M/44.7M [00:00<00:00, 230MB/s]
/usr/local/lib/python3.12/dist-packages/huggingface_hub/utils/_auth.py:94: UserWarning:
The secret `HF_TOKEN` does not exist in your Colab secrets.
To authenticate with the Hugging Face Hub, create a token in your settings tab (https://huggingface.co/settings/tokens), set it
You will be able to reuse this secret in all of your notebooks.
Please note that authentication is recommended but still optional to access public models or datasets.
  warnings.warn(
preprocessor_config.json: 100%                                   445/445 [00:00<00:00, 54.3kB/s]
tokenizer_config.json: 100%                                      592/592 [00:00<00:00, 82.1kB/s]
vocab.txt:     232k/? [00:00<00:00, 20.9MB/s]
tokenizer.json:     711k/? [00:00<00:00, 49.9MB/s]
special_tokens_map.json: 100%                                    125/125 [00:00<00:00, 16.4kB/s]
config.json:     4.56k/? [00:00<00:00, 559kB/s]
model.safetensors: 100%                                          1.54G/1.54G [00:03<00:00, 751MB/s]
trainable params: 2,064,384 || all params: 363,294,524 || trainable%: 0.5682
```

```
# Print model parameter counts
total, trainable = count_params(cnn_lstm_frozen_backbone)
print(
    f"CNN-LSTM Baseline (Frozen Backbone) - Total params: {total:,}, Trainable params: {trainable:,}"
)

total, trainable = count_params(cnn_lstm_unfrozen_backbone)
print(
    f"CNN-LSTM Baseline (Unfrozen Backbone) - Total params: {total:,}, Trainable params: {trainable:,}"
)

total, trainable = count_params(blip_lora)
print(f"BLIP with LoRA - Total params: {total:,}, Trainable params: {trainable:,}")
```

```
CNN-LSTM Baseline (Frozen Backbone) - Total params: 12,943,901, Trainable params: 1,767,389
CNN-LSTM Baseline (Unfrozen Backbone) - Total params: 12,943,901, Trainable params: 12,943,901
BLIP with LoRA - Total params: 363,294,524, Trainable params: 2,064,384
```

6. Training Utils

```
# CNN-LSTM dataloaders
train_loader_cls = DataLoader(
    train_ds_cls,
    batch_size=BATCH_SIZE_BASELINE,
    shuffle=True,
    num_workers=NUM_WORKERS,
    collate_fn=collate_fn_classify,
)

```

```
val_loader_cls = DataLoader(
    val_ds_cls,
    batch_size=BATCH_SIZE_BASELINE,
    shuffle=False,
    num_workers=NUM_WORKERS,
    collate_fn=collate_fn_classify,
)

test_loader_cls = DataLoader(
    test_ds_cls,
    batch_size=BATCH_SIZE_BASELINE,
    shuffle=False,
    num_workers=NUM_WORKERS,
    collate_fn=collate_fn_classify,
)

# BLIP processor + dataloaders
train_loader_blip = DataLoader(
    train_ds_blip,
    batch_size=BATCH_SIZE_BLIP,
    shuffle=True,
    num_workers=NUM_WORKERS,
    collate_fn=partial(collate_fn_blip, processor=processor),
)

val_loader_blip = DataLoader(
    val_ds_blip,
    batch_size=BATCH_SIZE_BLIP,
    shuffle=False,
    num_workers=NUM_WORKERS,
    collate_fn=partial(collate_fn_blip, processor=processor),
)

test_loader_blip = DataLoader(
    test_ds_blip,
    batch_size=BATCH_SIZE_BLIP,
    shuffle=False,
    num_workers=NUM_WORKERS,
    collate_fn=partial(collate_fn_blip, processor=processor),
)

print("Loaders ready")
```

```
Loaders ready
```

```
CNNLSTM_UF_CKPT_DIR = PROJECT_DIR / "checkpoints/cnn_lstm_unfrozen"
CNNLSTM_F_CKPT_DIR = PROJECT_DIR / "checkpoints/cnn_lstm_frozen"
BLIP_CKPT_DIR = PROJECT_DIR / "checkpoints/blip_lora"

CNNLSTM_UF_BEST = CNNLSTM_UF_CKPT_DIR / "best.pt"
CNNLSTM_F_BEST = CNNLSTM_F_CKPT_DIR / "best.pt"
BLIP_BEST = BLIP_CKPT_DIR / "best.pt"

print("CNN-LSTM (Unfrozen Backbone) best exists:", CNNLSTM_UF_BEST.exists())
print("CNN-LSTM (Frozen Backbone) best exists:", CNNLSTM_F_BEST.exists())
print("BLIP best exists:", BLIP_BEST.exists())
```

```
CNN-LSTM (Unfrozen Backbone) best exists: True
CNN-LSTM (Frozen Backbone) best exists: True
BLIP best exists: True
```

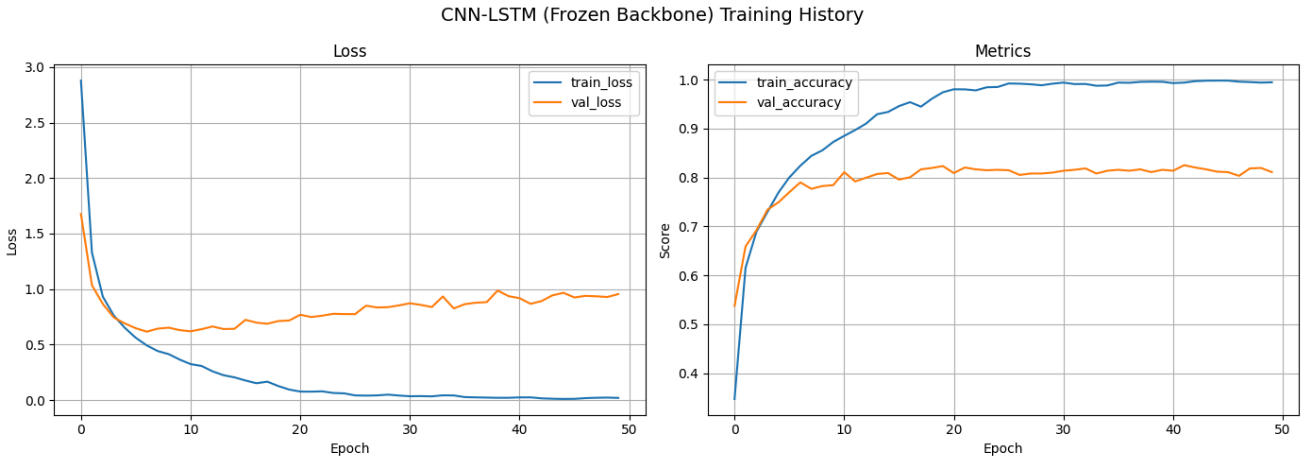
7. Model Training

7.1. Train CNN–LSTM (Frozen Backbone)

```
train_cnnlstm_frozen = True  # switch off to skip training

start_time = time.time()
if train_cnnlstm_frozen:
    cfg = CNNLSTMTrainConfig(
        epochs=50,
        lr=1e-3,
        device=DEVICE,
        ckpt_dir=str(CNNLSTM_F_CKPT_DIR),
        best_metric="val_accuracy",
        maximize_metric=True,
    )

    cnnlstm_frozen_history = train_cnn_lstm(
        model=cnn_lstm_frozen_backbone,
        train_loader=train_loader_cls,
        val_loader=val_loader_cls,
        cfg=cfg,
        num_classes=len(ans_vocab),
    )

else:
    cnnlstm_frozen_history = None

end_time = time.time()
elapsed_seconds = end_time - start_time
elapsed_minutes = elapsed_seconds / 60

print(f"\nTotal execution time: {elapsed_minutes:.2f} minutes ({elapsed_seconds:.2f} seconds)")

```

```
Training CNN-LSTM (50 epochs)
Epoch 1/50: 100%|██████████| 39/39 [00:10<00:00,  3.58it/s, loss=1.8332]
Epoch 1 | TrainLoss=2.8775 TrainAcc=0.3472 | ValLoss=1.6766 ValAcc=0.5375
-> Best updated: val_accuracy=0.5375
Epoch 2/50: 100%|██████████| 39/39 [00:10<00:00,  3.86it/s, loss=1.1113]
Epoch 2 | TrainLoss=1.3305 TrainAcc=0.6154 | ValLoss=1.0357 ValAcc=0.6591
-> Best updated: val_accuracy=0.6591
Epoch 3/50: 100%|██████████| 39/39 [00:10<00:00,  3.66it/s, loss=0.8058]
Epoch 3 | TrainLoss=0.9304 TrainAcc=0.6894 | ValLoss=0.8652 ValAcc=0.6923
-> Best updated: val_accuracy=0.6923
Epoch 4/50: 100%|██████████| 39/39 [00:10<00:00,  3.75it/s, loss=1.0115]
Epoch 4 | TrainLoss=0.7616 TrainAcc=0.7296 | ValLoss=0.7440 ValAcc=0.7341
-> Best updated: val_accuracy=0.7341
Epoch 5/50: 100%|██████████| 39/39 [00:10<00:00,  3.84it/s, loss=0.5169]
Epoch 5 | TrainLoss=0.6508 TrainAcc=0.7693 | ValLoss=0.6907 ValAcc=0.7493
-> Best updated: val_accuracy=0.7493
Epoch 6/50: 100%|██████████| 39/39 [00:10<00:00,  3.83it/s, loss=0.4421]
Epoch 6 | TrainLoss=0.5616 TrainAcc=0.8004 | ValLoss=0.6476 ValAcc=0.7702
-> Best updated: val_accuracy=0.7702
Epoch 7/50: 100%|██████████| 39/39 [00:10<00:00,  3.86it/s, loss=0.6535]
Epoch 7 | TrainLoss=0.4930 TrainAcc=0.8242 | ValLoss=0.6168 ValAcc=0.7901
-> Best updated: val_accuracy=0.7901
Epoch 8/50: 100%|██████████| 39/39 [00:10<00:00,  3.86it/s, loss=0.5858]
Epoch 8 | TrainLoss=0.4423 TrainAcc=0.8443 | ValLoss=0.6439 ValAcc=0.7768
Epoch 9/50: 100%|██████████| 39/39 [00:10<00:00,  3.89it/s, loss=0.2565]
Epoch 9 | TrainLoss=0.4145 TrainAcc=0.8555 | ValLoss=0.6527 ValAcc=0.7825
Epoch 10/50: 100%|██████████| 39/39 [00:10<00:00,  3.89it/s, loss=0.5445]
Epoch 10 | TrainLoss=0.3654 TrainAcc=0.8727 | ValLoss=0.6306 ValAcc=0.7844
Epoch 11/50: 100%|██████████| 39/39 [00:10<00:00,  3.87it/s, loss=0.3329]
Epoch 11 | TrainLoss=0.3245 TrainAcc=0.8851 | ValLoss=0.6200 ValAcc=0.8110
-> Best updated: val_accuracy=0.8110
Epoch 12/50: 100%|██████████| 39/39 [00:10<00:00,  3.84it/s, loss=0.3589]
Epoch 12 | TrainLoss=0.3079 TrainAcc=0.8971 | ValLoss=0.6391 ValAcc=0.7920
Epoch 13/50: 100%|██████████| 39/39 [00:10<00:00,  3.86it/s, loss=0.2882]
Epoch 13 | TrainLoss=0.2596 TrainAcc=0.9103 | ValLoss=0.6634 ValAcc=0.7996
Epoch 14/50: 100%|██████████| 39/39 [00:10<00:00,  3.84it/s, loss=0.2243]
Epoch 14 | TrainLoss=0.2246 TrainAcc=0.9295 | ValLoss=0.6404 ValAcc=0.8072
Epoch 15/50: 100%|██████████| 39/39 [00:10<00:00,  3.86it/s, loss=0.2483]
Epoch 15 | TrainLoss=0.2052 TrainAcc=0.9341 | ValLoss=0.6423 ValAcc=0.8091
Epoch 16/50: 100%|██████████| 39/39 [00:10<00:00,  3.86it/s, loss=0.2376]
Epoch 16 | TrainLoss=0.1770 TrainAcc=0.9461 | ValLoss=0.7234 ValAcc=0.7958
Epoch 17/50: 100%|██████████| 39/39 [00:10<00:00,  3.87it/s, loss=0.1554]
Epoch 17 | TrainLoss=0.1523 TrainAcc=0.9541 | ValLoss=0.6980 ValAcc=0.8006
Epoch 18/50: 100%|██████████| 39/39 [00:10<00:00,  3.88it/s, loss=0.2077]
Epoch 18 | TrainLoss=0.1662 TrainAcc=0.9449 | ValLoss=0.6881 ValAcc=0.8167
-> Best updated: val_accuracy=0.8167
Epoch 19/50: 100%|██████████| 39/39 [00:09<00:00,  3.91it/s, loss=0.0378]
Epoch 19 | TrainLoss=0.1271 TrainAcc=0.9612 | ValLoss=0.7122 ValAcc=0.8196
-> Best updated: val_accuracy=0.8196
Epoch 20/50: 100%|██████████| 39/39 [00:09<00:00,  3.93it/s, loss=0.0898]
Epoch 20 | TrainLoss=0.0953 TrainAcc=0.9744 | ValLoss=0.7178 ValAcc=0.8234
-> Best updated: val_accuracy=0.8234
Epoch 21/50: 100%|██████████| 39/39 [00:09<00:00,  3.92it/s, loss=0.0861]
Epoch 21 | TrainLoss=0.0773 TrainAcc=0.9805 | ValLoss=0.7693 ValAcc=0.8091
Epoch 22/50: 100%|██████████| 39/39 [00:09<00:00,  3.95it/s, loss=0.1060]
Epoch 22 | TrainLoss=0.0767 TrainAcc=0.9803 | ValLoss=0.7486 ValAcc=0.8205
Epoch 23/50: 100%|██████████| 39/39 [00:10<00:00,  3.83it/s, loss=0.2568]
Epoch 23 | TrainLoss=0.0794 TrainAcc=0.9782 | ValLoss=0.7608 ValAcc=0.8167
```

```
plot_history(cnnlstm_frozen_history, "CNN-LSTM (Frozen Backbone) Training History")
```

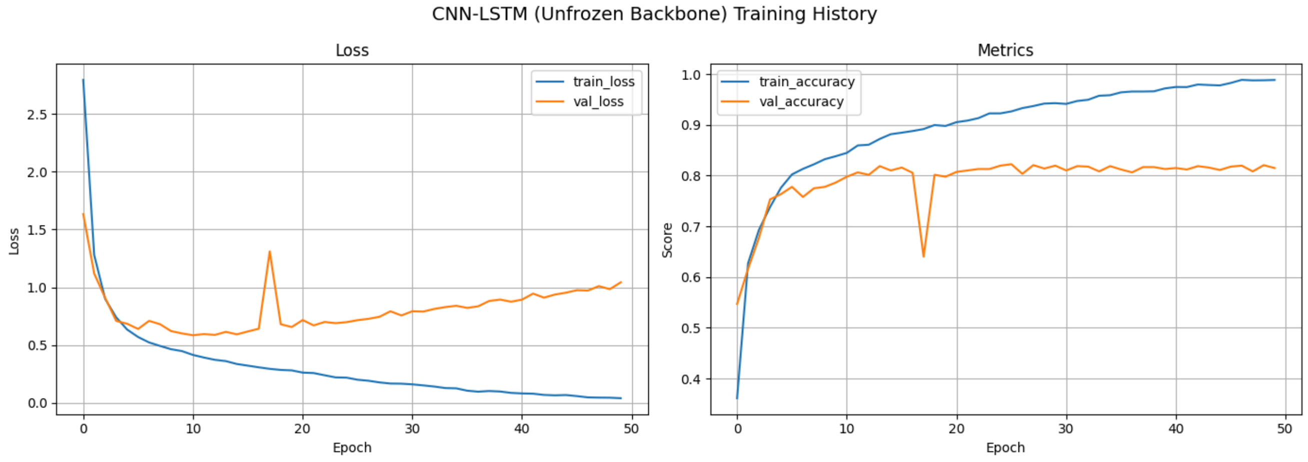


7.2. Train CNN–LSTM (Unfrozen Backbone)

```
train_cnnlstm_unfrozen = True  # switch off to skip training

start_time = time.time()
if train_cnnlstm_unfrozen:
    cfg = CNNLSTMTrainConfig(
        epochs=50,
        lr=1e-3,
        device=DEVICE,
        ckpt_dir=str(CNNLSTM_UF_CKPT_DIR),
        best_metric="val_accuracy",
        maximize_metric=True,
    )

    cnnlstm_unfrozen_history = train_cnn_lstm(
        model=cnn_lstm_unfrozen_backbone,
        train_loader=train_loader_cls,
        val_loader=val_loader_cls,
        cfg=cfg,
        num_classes=len(ans_vocab),
    )

else:
    cnnlstm_unfrozen_history = None

end_time = time.time()
elapsed_seconds = end_time - start_time
elapsed_minutes = elapsed_seconds / 60

print(f"\nTotal execution time: {elapsed_minutes:.2f} minutes ({elapsed_seconds:.2f} seconds)")
```

```
Training CNN-LSTM (50 epochs)
Epoch 1/50: 100%|██████████| 39/39 [00:10<00:00,  3.76it/s, loss=1.5140]
Epoch 1 | TrainLoss=2.7938 TrainAcc=0.3613 | ValLoss=1.6330 ValAcc=0.5470
-> Best updated: val_accuracy=0.5470
Epoch 2/50: 100%|██████████| 39/39 [00:10<00:00,  3.84it/s, loss=1.1490]
Epoch 2 | TrainLoss=1.2784 TrainAcc=0.6272 | ValLoss=1.1173 ValAcc=0.6163
-> Best updated: val_accuracy=0.6163
Epoch 3/50: 100%|██████████| 39/39 [00:10<00:00,  3.77it/s, loss=0.8802]
Epoch 3 | TrainLoss=0.8993 TrainAcc=0.6934 | ValLoss=0.9078 ValAcc=0.6781
-> Best updated: val_accuracy=0.6781
Epoch 4/50: 100%|██████████| 39/39 [00:10<00:00,  3.84it/s, loss=0.6797]
Epoch 4 | TrainLoss=0.7404 TrainAcc=0.7378 | ValLoss=0.7091 ValAcc=0.7531
-> Best updated: val_accuracy=0.7531
Epoch 5/50: 100%|██████████| 39/39 [00:10<00:00,  3.78it/s, loss=0.4582]
Epoch 5 | TrainLoss=0.6346 TrainAcc=0.7760 | ValLoss=0.6843 ValAcc=0.7635
-> Best updated: val_accuracy=0.7635
Epoch 6/50: 100%|██████████| 39/39 [00:10<00:00,  3.82it/s, loss=0.6213]
Epoch 6 | TrainLoss=0.5699 TrainAcc=0.8022 | ValLoss=0.6392 ValAcc=0.7778
-> Best updated: val_accuracy=0.7778
Epoch 7/50: 100%|██████████| 39/39 [00:10<00:00,  3.85it/s, loss=0.5437]
Epoch 7 | TrainLoss=0.5228 TrainAcc=0.8132 | ValLoss=0.7093 ValAcc=0.7578
Epoch 8/50: 100%|██████████| 39/39 [00:10<00:00,  3.75it/s, loss=0.5165]
Epoch 8 | TrainLoss=0.4926 TrainAcc=0.8221 | ValLoss=0.6803 ValAcc=0.7749
Epoch 9/50: 100%|██████████| 39/39 [00:10<00:00,  3.79it/s, loss=0.6718]
Epoch 9 | TrainLoss=0.4645 TrainAcc=0.8323 | ValLoss=0.6210 ValAcc=0.7778
Epoch 10/50: 100%|██████████| 39/39 [00:10<00:00,  3.84it/s, loss=0.5630]
Epoch 10 | TrainLoss=0.4480 TrainAcc=0.8382 | ValLoss=0.6007 ValAcc=0.7863
-> Best updated: val_accuracy=0.7863
Epoch 11/50: 100%|██████████| 39/39 [00:10<00:00,  3.81it/s, loss=0.4122]
Epoch 11 | TrainLoss=0.4149 TrainAcc=0.8447 | ValLoss=0.5850 ValAcc=0.7977
-> Best updated: val_accuracy=0.7977
Epoch 12/50: 100%|██████████| 39/39 [00:10<00:00,  3.72it/s, loss=0.4343]
Epoch 12 | TrainLoss=0.3924 TrainAcc=0.8593 | ValLoss=0.5951 ValAcc=0.8063
-> Best updated: val_accuracy=0.8063
Epoch 13/50: 100%|██████████| 39/39 [00:10<00:00,  3.86it/s, loss=0.6611]
Epoch 13 | TrainLoss=0.3726 TrainAcc=0.8607 | ValLoss=0.5880 ValAcc=0.8015
Epoch 14/50: 100%|██████████| 39/39 [00:10<00:00,  3.84it/s, loss=0.2495]
Epoch 14 | TrainLoss=0.3613 TrainAcc=0.8721 | ValLoss=0.6144 ValAcc=0.8186
-> Best updated: val_accuracy=0.8186
Epoch 15/50: 100%|██████████| 39/39 [00:10<00:00,  3.78it/s, loss=0.2705]
Epoch 15 | TrainLoss=0.3364 TrainAcc=0.8815 | ValLoss=0.5928 ValAcc=0.8101
Epoch 16/50: 100%|██████████| 39/39 [00:10<00:00,  3.75it/s, loss=0.2889]
Epoch 16 | TrainLoss=0.3222 TrainAcc=0.8845 | ValLoss=0.6177 ValAcc=0.8158
Epoch 17/50: 100%|██████████| 39/39 [00:10<00:00,  3.76it/s, loss=0.3918]
Epoch 17 | TrainLoss=0.3077 TrainAcc=0.8878 | ValLoss=0.6414 ValAcc=0.8053
Epoch 18/50: 100%|██████████| 39/39 [00:10<00:00,  3.76it/s, loss=0.1902]
Epoch 18 | TrainLoss=0.2945 TrainAcc=0.8916 | ValLoss=1.3106 ValAcc=0.6401
Epoch 19/50: 100%|██████████| 39/39 [00:10<00:00,  3.76it/s, loss=0.4203]
Epoch 19 | TrainLoss=0.2851 TrainAcc=0.8996 | ValLoss=0.6804 ValAcc=0.8015
Epoch 20/50: 100%|██████████| 39/39 [00:10<00:00,  3.74it/s, loss=0.1660]
Epoch 20 | TrainLoss=0.2812 TrainAcc=0.8977 | ValLoss=0.6560 ValAcc=0.7977
Epoch 21/50: 100%|██████████| 39/39 [00:10<00:00,  3.87it/s, loss=0.1453]
Epoch 21 | TrainLoss=0.2620 TrainAcc=0.9053 | ValLoss=0.7163 ValAcc=0.8072
Epoch 22/50: 100%|██████████| 39/39 [00:10<00:00,  3.71it/s, loss=0.1697]
Epoch 22 | TrainLoss=0.2580 TrainAcc=0.9083 | ValLoss=0.6702 ValAcc=0.8101
Epoch 23/50: 100%|██████████| 39/39 [00:10<00:00,  3.83it/s, loss=0.2802]
Epoch 23 | TrainLoss=0.2392 TrainAcc=0.9132 | ValLoss=0.7000 ValAcc=0.8129
Epoch 24/50: 100%|██████████| 39/39 [00:10<00:00,  3.81it/s, loss=0.5387]
```

```
plot_history(cnnlstm_unfrozen_history, "CNN-LSTM (Unfrozen Backbone) Training History")
```



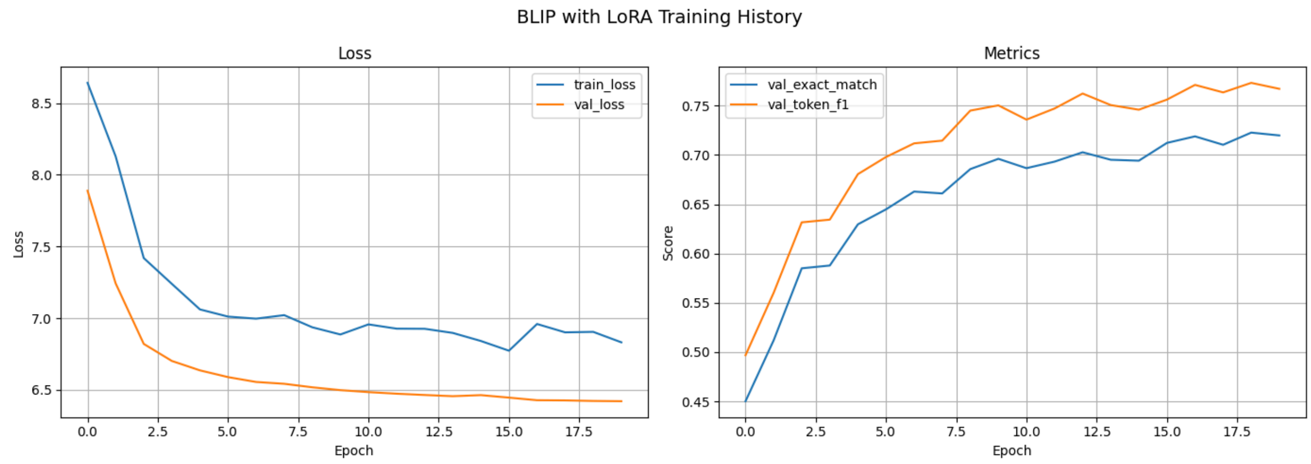
7.3. Train BLIP with LoRA

```
train_blip_flag = True  # switch off to skip training

start_time = time.time()
if train_blip_flag:
    cfg_blip = BLIPTrainConfig(
        epochs=20,
        lr=1e-4,
        device=DEVICE,
        ckpt_dir=str(BLIP_CKPT_DIR),
        best_metric="val_token_f1",
        maximize_metric=True,
        max_new_tokens=20,
    )

    blip_history = train_blip(
        model=blip_lora,
        processor=processor,
        train_loader=train_loader_blip,
        val_loader=val_loader_blip,
        cfg=cfg_blip,
    )
```

```
else:
    blip_history = None

end_time = time.time()
elapsed_seconds = end_time - start_time
elapsed_minutes = elapsed_seconds / 60

print(f"\nTotal execution time: {elapsed_minutes:.2f} minutes ({elapsed_seconds:.2f} seconds)")

```

```
Training BLIP+LoRA (20 epochs)
Epoch 1/20:   0%|          | 0/77 [00:00<?, ?it/s]We strongly recommend passing in an `attention_mask` since your input_ids ma
Epoch 1/20: 100%|██████████| 77/77 [01:57<00:00,  1.53s/it, loss=7.4372]
Evaluating: 100%|██████████| 17/17 [00:13<00:00,  1.25it/s]
Epoch 1 | TrainLoss=8.6413 | ValLoss=7.8889 | ValEM=0.4501 ValTokenF1=0.4968
-> Best updated: val_token_f1=0.4968
Epoch 2/20: 100%|██████████| 77/77 [01:57<00:00,  1.53s/it, loss=7.3986]
Evaluating: 100%|██████████| 17/17 [00:13<00:00,  1.23it/s]
Epoch 2 | TrainLoss=8.1289 | ValLoss=7.2432 | ValEM=0.5119 ValTokenF1=0.5601
-> Best updated: val_token_f1=0.5601
Epoch 3/20: 100%|██████████| 77/77 [01:57<00:00,  1.53s/it, loss=7.2318]
Evaluating: 100%|██████████| 17/17 [00:13<00:00,  1.23it/s]
Epoch 3 | TrainLoss=7.4196 | ValLoss=6.8210 | ValEM=0.5850 ValTokenF1=0.6316
-> Best updated: val_token_f1=0.6316
Epoch 4/20: 100%|██████████| 77/77 [01:57<00:00,  1.53s/it, loss=7.4949]
Evaluating: 100%|██████████| 17/17 [00:14<00:00,  1.15it/s]
Epoch 4 | TrainLoss=7.2396 | ValLoss=6.7020 | ValEM=0.5878 ValTokenF1=0.6344
-> Best updated: val_token_f1=0.6344
Epoch 5/20: 100%|██████████| 77/77 [01:57<00:00,  1.53s/it, loss=5.9109]
Evaluating: 100%|██████████| 17/17 [00:15<00:00,  1.13it/s]
Epoch 5 | TrainLoss=7.0615 | ValLoss=6.6364 | ValEM=0.6296 ValTokenF1=0.6806
-> Best updated: val_token_f1=0.6806
Epoch 6/20: 100%|██████████| 77/77 [01:57<00:00,  1.53s/it, loss=7.4754]
Evaluating: 100%|██████████| 17/17 [00:14<00:00,  1.16it/s]
Epoch 6 | TrainLoss=7.0113 | ValLoss=6.5893 | ValEM=0.6448 ValTokenF1=0.6980
-> Best updated: val_token_f1=0.6980
Epoch 7/20: 100%|██████████| 77/77 [01:57<00:00,  1.53s/it, loss=7.4696]
Evaluating: 100%|██████████| 17/17 [00:14<00:00,  1.15it/s]
Epoch 7 | TrainLoss=6.9969 | ValLoss=6.5554 | ValEM=0.6629 ValTokenF1=0.7118
-> Best updated: val_token_f1=0.7118
Epoch 8/20: 100%|██████████| 77/77 [01:57<00:00,  1.53s/it, loss=7.4778]
Evaluating: 100%|██████████| 17/17 [00:14<00:00,  1.14it/s]
Epoch 8 | TrainLoss=7.0214 | ValLoss=6.5427 | ValEM=0.6610 ValTokenF1=0.7145
-> Best updated: val_token_f1=0.7145
Epoch 9/20: 100%|██████████| 77/77 [01:57<00:00,  1.53s/it, loss=5.7239]
Evaluating: 100%|██████████| 17/17 [00:15<00:00,  1.09it/s]
Epoch 9 | TrainLoss=6.9367 | ValLoss=6.5183 | ValEM=0.6857 ValTokenF1=0.7450
-> Best updated: val_token_f1=0.7450
Epoch 10/20: 100%|██████████| 77/77 [01:58<00:00,  1.53s/it, loss=5.2385]
Evaluating: 100%|██████████| 17/17 [00:15<00:00,  1.10it/s]
Epoch 10 | TrainLoss=6.8866 | ValLoss=6.4984 | ValEM=0.6961 ValTokenF1=0.7504
-> Best updated: val_token_f1=0.7504
Epoch 11/20: 100%|██████████| 77/77 [01:57<00:00,  1.53s/it, loss=7.6413]
Evaluating: 100%|██████████| 17/17 [00:15<00:00,  1.08it/s]
Epoch 11 | TrainLoss=6.9570 | ValLoss=6.4846 | ValEM=0.6866 ValTokenF1=0.7359
Epoch 12/20: 100%|██████████| 77/77 [01:57<00:00,  1.53s/it, loss=7.4219]
Evaluating: 100%|██████████| 17/17 [00:15<00:00,  1.09it/s]
Epoch 12 | TrainLoss=6.9272 | ValLoss=6.4736 | ValEM=0.6933 ValTokenF1=0.7472
Epoch 13/20: 100%|██████████| 77/77 [01:57<00:00,  1.53s/it, loss=8.1223]
Evaluating: 100%|██████████| 17/17 [00:15<00:00,  1.07it/s]
Epoch 13 | TrainLoss=6.9263 | ValLoss=6.4646 | ValEM=0.7028 ValTokenF1=0.7624
-> Best updated: val_token_f1=0.7624
Epoch 14/20: 100%|██████████| 77/77 [01:57<00:00,  1.53s/it, loss=6.0978]
Evaluating: 100%|██████████| 17/17 [00:15<00:00,  1.11it/s]
Epoch 14 | TrainLoss=6.8975 | ValLoss=6.4562 | ValEM=0.6952 ValTokenF1=0.7506
Epoch 15/20: 100%|██████████| 77/77 [01:57<00:00,  1.53s/it, loss=7.3700]
Evaluating: 100%|██████████| 17/17 [00:16<00:00,  1.04it/s]
Epoch 15 | TrainLoss=6.8413 | ValLoss=6.4637 | ValEM=0.6942 ValTokenF1=0.7460
```

```
plot_history(blip_history, "BLIP with LoRA Training History")
```



```
# Sava blip_history, cnnlstm_frozen_history, cnnlstm_unfrozen_history to json file
with open(PROJECT_DIR / "checkpoints/blip_lora/history.json", "w") as f:
    json.dump(blip_history, f)
    print("Saved blip_history to json file")

with open(PROJECT_DIR / "checkpoints/cnn_lstm_frozen/history.json", "w") as f:
    json.dump(cnnlstm_frozen_history, f)
    print("Saved cnnlstm_frozen_history to json file")

with open(PROJECT_DIR / "checkpoints/cnn_lstm_unfrozen/history.json", "w") as f:
    json.dump(cnnlstm_unfrozen_history, f)
    print("Saved cnnlstm_unfrozen_history to json file")
```

```
Saved blip_history to json file
Saved cnnlstm_frozen_history to json file
Saved cnnlstm_unfrozen_history to json file
```

8. Evaluate Models

```
if CNNLSTM_F_BEST.exists():
    load_checkpoint(cnn_lstm_frozen_backbone, str(CNNLSTM_F_BEST), device=DEVICE)
    print("Loaded CNN-LSTM frozen best checkpoint")

if CNNLSTM_UF_BEST.exists():
    load_checkpoint(cnn_lstm_unfrozen_backbone, str(CNNLSTM_UF_BEST), device=DEVICE)
    print("Loaded CNN-LSTM unfrozen best checkpoint")

if BLIP_BEST.exists():
    load_checkpoint(blip_lora, str(BLIP_BEST), device=DEVICE)
    print("Loaded BLIP with LoRA best checkpoint")
```

```
Loaded CNN-LSTM frozen best checkpoint
Loaded CNN-LSTM unfrozen best checkpoint
Loaded BLIP with LoRA best checkpoint
```

8.1. Evaluate CNN–LSTM (Frozen Backbone)

```
cnnlstm_frozen_test_results = evaluate_cnn_lstm(
    model=cnn_lstm_frozen_backbone,
    loader=test_loader_cls,
    device=DEVICE,
    num_classes=len(ans_vocab),
)

cnnlstm_frozen_test_results
```

```
Evaluating CNN-LSTM: 100%|██████████| 9/9 [00:03<00:00,  2.59it/s]CNN-LSTM Test Evaluation Results:
[OVERALL]
  accuracy: 0.7983
  macro_f1: 0.4758
  top5_accuracy: 0.9576
  loss: 0.9709
[OPEN]
  accuracy: 0.7767
  macro_f1: 0.4718
  top5_accuracy: 0.9318
[CLOSED]
  accuracy: 0.8317
  macro_f1: 0.6095
  top5_accuracy: 0.9976

{'overall': {'accuracy': 0.7983034872761545,
  'macro_f1': 0.4758365935229792,
  'top5_accuracy': 0.9575871819038643,
  'loss': 0.9709336928440421},
 'open': {'accuracy': 0.7767441860465116,
  'macro_f1': 0.4717856622597686,
  'top5_accuracy': 0.931782945736434},
 'closed': {'accuracy': 0.8317307692307693,
  'macro_f1': 0.6095090089790796,
  'top5_accuracy': 0.9975961538461539}}
```

8.2. Evaluate CNN–LSTM (Unfrozen Backbone)

```
cnnlstm_unfrozen_test_results = evaluate_cnn_lstm(
    model=cnn_lstm_unfrozen_backbone,
    loader=test_loader_cls,
    device=DEVICE,
    num_classes=len(ans_vocab),
)

cnnlstm_unfrozen_test_results
```

```
Evaluating CNN-LSTM: 100%|██████████| 9/9 [00:03<00:00,  2.71it/s]CNN-LSTM Test Evaluation Results:
[OVERALL]
  accuracy: 0.7766
  macro_f1: 0.4350
  top5_accuracy: 0.9576
  loss: 0.8657
[OPEN]
  accuracy: 0.7473
  macro_f1: 0.4238
  top5_accuracy: 0.9318
[CLOSED]
  accuracy: 0.8221
  macro_f1: 0.6600
  top5_accuracy: 0.9976

{'overall': {'accuracy': 0.7766258246936852,
  'macro_f1': 0.4349948134894027,
  'top5_accuracy': 0.9575871819038643,
  'loss': 0.865717133410577},
 'open': {'accuracy': 0.7472868217054264,
  'macro_f1': 0.4238194689621836,
  'top5_accuracy': 0.931782945736434},
 'closed': {'accuracy': 0.8221153846153846,
  'macro_f1': 0.6600430343465338,
  'top5_accuracy': 0.9975961538461539}}
```

8.3. Evaluate BLIP with LoRA

```
blip_test_results = evaluate_blip(
    model=blip_lora,
    processor=processor,
    loader=test_loader_blip,
    device=DEVICE,
    max_new_tokens=20,
)

blip_test_results
```

```
Evaluating BLIP: 100%|██████████| 17/17 [00:15<00:00,  1.07it/s]
Computing Overall Metrics...
Computing OPEN Metrics...
  - Found 645 OPEN questions. Running BERTScore...
Downloading builder script:    5.94k/? [00:00<00:00, 602kB/s]

Downloading extra modules:                                                4.07k/? [00:00<00:00, 486kB/s]

Downloading extra modules:    3.34k/? [00:00<00:00, 346kB/s]

Downloading builder script:    6.14k/? [00:00<00:00, 624kB/s]

Downloading builder script:    7.95k/? [00:00<00:00, 838kB/s]

tokenizer_config.json: 100%                                               48.0/48.0 [00:00<00:00, 5.71kB/s]

config.json: 100%                                                   483/483 [00:00<00:00, 63.6kB/s]

vocab.txt: 100%                                                   232k/232k [00:00<00:00, 20.2MB/s]

tokenizer.json: 100%                                                 466k/466k [00:00<00:00, 774kB/s]

model.safetensors: 100%                                               268M/268M [00:01<00:00, 161MB/s]

Computing CLOSED Metrics...

BLIP Test Evaluation Results:
[OVERALL]
  exact_match: 0.6927
  token_f1: 0.7364
[OPEN]
  exact_match: 0.6202
  token_f1: 0.6919
  bleu: 0.0311
  rougeL: 0.7259
  bertscore_precision: 0.9194
  bertscore_recall: 0.9136
  bertscore_f1: 0.9162
[CLOSED]
  exact_match: 0.8053
  token_f1: 0.8053
Warning: Empty candidate sentence detected; setting raw BERTscores to 0.
Warning: Empty candidate sentence detected; setting raw BERTscores to 0.
Warning: Empty candidate sentence detected; setting raw BERTscores to 0.
Warning: Empty candidate sentence detected; setting raw BERTscores to 0.
Warning: Empty candidate sentence detected; setting raw BERTscores to 0.
```

```python
# Save test_results into json file
with open(PROJECT_DIR / "checkpoints/blip_lora/test_results.json", "w") as f:
    json.dump(blip_test_results, f)
    print("Saved blip_test_results to json file")

with open(PROJECT_DIR / "checkpoints/cnn_lstm_frozen/test_results.json", "w") as f:
    json.dump(cnnlstm_frozen_test_results, f)
    print("Saved cnnlstm_frozen_test_results to json file")

with open(
    PROJECT_DIR / "checkpoints/cnn_lstm_unfrozen/test_results.json", "w"
) as f:
    json.dump(cnnlstm_unfrozen_test_results, f)
    print("Saved cnnlstm_unfrozen_test_results to json file")
```

```
Saved blip_test_results to json file
Saved cnnlstm_frozen_test_results to json file
Saved cnnlstm_unfrozen_test_results to json file
```