Assignment_2_C

May 1, 2025

1 ΕΠΕΞΕΡΓΑΣΙΑ ΦΥΣΙΚΗΣ ΓΛΩΣΣΑΣ - Ε 2

1.1 Γ. Text Classification with RNNs

Μ : Ε Φ Γ

Σ : Ι Κ

Ε : 2025-04-25 | v.0.0.1

2 Π Π

Τ **Mac** **Apple Silicon (M1/M2/M3)**, **GPU** **Neural Engine** `torch.backends.mps`.

Γ , `torch` `torchtext`. Η runtime conflicts, Apple-based .

[155]:
```
%pip install datasets numpy matplotlib --quiet
```

```
Note: you may need to restart the kernel to use updated packages.
```

[ ]:
```
%pip install numpy==1.24.4 --force-reinstall --quiet
```

```
Collecting numpy==1.24.4
  Using cached numpy-1.24.4-cp311-cp311-macosx_11_0_arm64.whl.metadata (5.6 kB)
Using cached numpy-1.24.4-cp311-cp311-macosx_11_0_arm64.whl (13.8 MB)
Installing collected packages: numpy
  Attempting uninstall: numpy
    Found existing installation: numpy 1.24.4
    Uninstalling numpy-1.24.4:
      Successfully uninstalled numpy-1.24.4
Successfully installed numpy-1.24.4
Note: you may need to restart the kernel to use updated packages.
```

[156]:
```
%pip install torch==2.1.0 torchtext==0.16.0  --quiet #
```

```
Note: you may need to restart the kernel to use updated packages.
```

[158]:
```python
import torch

if torch.backends.mps.is_available():
    device = torch.device("mps")
    print("  X             : Apple Silicon GPU (MPS)")
elif torch.cuda.is_available():
    device = torch.device("cuda")
    print("  X             : NVIDIA CUDA")
else:
    device = torch.device("cpu")
    print("  X             : CPU")
```

```
X             : Apple Silicon GPU (MPS)
```

2.1 E B

O :

- torch, torchtext: .
- datasets: IMDB dataset .
- numpy, matplotlib, collections, re: , .

[ ]:
```python
import torch.nn as nn
from torch.utils.data import DataLoader, Dataset

from datasets import load_dataset
import numpy as np
from collections import Counter
import re
import random
```

2.2 Φ Δ – AG News Dataset

T AG News dataset : Kaggle - AG News Classification Dataset

A `.csv`: - `train.csv` 120.000 - `test.csv` 7.600

K : - K (`Class Index`) - T (`Title`) - Σ (`Description`)

O string .

[194]:
```python
import pandas as pd

# Φ       CSV
train_data = pd.read_csv('train.csv')
test_data = pd.read_csv('test.csv')

# Δ      datasets (label,     )
```

```
train_dataset = [(label, train_data['Title'][i] + ' ' +␣
↪train_data['Description'][i]) for i, label in enumerate(train_data['Class␣
↪Index'])]
test_dataset = [(label, test_data['Title'][i] + ' ' +␣
↪test_data['Description'][i]) for i, label in enumerate(test_data['Class␣
↪Index'])]

print(f"Training samples: {len(train_dataset)}")
print(f"Test samples: {len(test_dataset)}")
```

```
Training samples: 120000
Test samples: 7600
```

2.3 Tokenization – Basic English Tokenizer

Γ tokens tokenizer torchtext, basic_english.

A tokenizer:

- M
- A
- Δ

[160]:
```
#device = torch.device("cpu")

from torchtext.data import get_tokenizer

# Basic English tokenizer (lowercase,                    )
tokenizer = get_tokenizer("basic_english")
```

2.4 Δ Λ (Vocabulary)

Σ , (vocab) :

- Ø **10** training test .
- T tokens:
  - <PAD> padding
  - <UNK> (out-of-vocabulary)

H `build_vocab_from_iterator` `torchtext`.

[161]:
```
from torchtext.vocab import build_vocab_from_iterator

# Σ                tokenized
def build_vocabulary(datasets):
    for dataset in datasets:
        for _, text in dataset:
            yield tokenizer(text)
```

```
# Δ                train + test dataset
vocab = build_vocab_from_iterator(
    build_vocabulary([train_dataset, test_dataset]),
    min_freq=10,
    specials=["<PAD>", "<UNK>"]
)

# Ο     default index    <UNK> (unknown words)
vocab.set_default_index(vocab["<UNK>"])

print(f"Vocabulary size: {len(vocab)}")
```

```
Vocabulary size: 21254
```

2.5 Δ Σ collate_batch

Γ DataLoader, custom collate_fn batch raw labels tensors .

Η collate_batch() :

- Tokenization
- Μ indices (vocab)
- Truncation Padding
- Optionally: -1 labels, 1 (. . AGNews)

[162]:
```
import torch

MAX_WORDS = 25

def collate_batch(batch, shift_labels=True):
    Y, X = list(zip(*batch))
    Y = torch.tensor(Y)

    if shift_labels:
        Y = Y - 1  #         datasets     AGNews
    else:
        Y


    # Tokenization +          indices
    X = [vocab(tokenizer(text)) for text in X]

    # Truncation/Padding        MAX_WORDS
    X = [
        tokens + [vocab['<PAD>']] * (MAX_WORDS - len(tokens)) if len(tokens) <␣
↪MAX_WORDS else tokens[:MAX_WORDS]
        for tokens in X
    ]
```

```
    return torch.tensor(X, dtype=torch.int64).to(device), Y.to(device)
```

2.6 Δ DataLoaders

Γ DataLoader, :

- T batches
- T custom `collate_batch` tokenization padding
- Shuffle training set
- E lazy-loading, batch-wise GPU/MPS

H `BATCH_SIZE` 1024 batch.

[163]:
```
from torch.utils.data import DataLoader

# HYPER-PARAMETERS
BATCH_SIZE = 1024

# DataLoader   training set
train_loader = DataLoader(
    train_dataset,
    batch_size=BATCH_SIZE,
    shuffle=True,
    collate_fn=collate_batch
)

# DataLoader   test set
test_loader = DataLoader(
    test_dataset,
    batch_size=BATCH_SIZE,
    shuffle=False,
    collate_fn=collate_batch
)
```

2.7 O M – RNNClassifier (AGNews & IMDB)

H `RNNClassifier` :

- T RNN (RNN, LSTM)
- T (bidirectional)
- T embeddings
- T “ ” (freeze) embeddings

[164]:
```
import torch.nn as nn
import torch.nn.functional as F

class RNNClassifier(nn.Module):
    def __init__(self,
```

```python
                 vocab_size,
                 embedding_dim,
                 hidden_dim,
                 output_dim,
                 rnn_type="rnn",          # "rnn"   "lstm"
                 num_layers=1,
                 bidirectional=False,
                 pretrained_embeddings=None,    #             4
                 freeze_embeddings=False        #             5
                 ):

        super(RNNClassifier, self).__init__()

        self.embedding = nn.Embedding(vocab_size, embedding_dim)

        if pretrained_embeddings is not None:                          #     ␣
        ↪       4
            self.embedding.weight.data.copy_(pretrained_embeddings)     #     ␣
        ↪       4

        if freeze_embeddings:                                #             5
            self.embedding.weight.requires_grad = False      #             5

        if rnn_type == "rnn":
            self.rnn = nn.RNN(
                input_size=embedding_dim,
                hidden_size=hidden_dim,
                num_layers=num_layers,
                bidirectional=bidirectional,
                batch_first=True
            )
        elif rnn_type == "lstm":
            self.rnn = nn.LSTM(
                input_size=embedding_dim,
                hidden_size=hidden_dim,
                num_layers=num_layers,
                bidirectional=bidirectional,
                batch_first=True
            )
        else:
            raise ValueError("Unsupported rnn_type. Choose 'rnn' or 'lstm'.")

        direction_factor = 2 if bidirectional else 1
        self.fc = nn.Linear(hidden_dim * direction_factor, output_dim)

    def forward(self, x):
        x = self.embedding(x)
```

```
        rnn_out, _ = self.rnn(x)
        out = self.fc(rnn_out[:, -1, :])  #                output    sequence
        return F.softmax(out, dim=1)
```

2.8 Π M

A RNNClassifier:

2.8.1 1-layer RNN

T : RNN , .
X benchmarking .

2.8.2 2-layer Bidirectional LSTM (BiLSTM)

I : LSTM, (biLSTM), 2 . A
.

[165]:
```
# 1-layer RNN
model = RNNClassifier(
    vocab_size=len(vocab),
    embedding_dim=100,
    hidden_dim=64,
    output_dim=4,
    rnn_type="rnn",
    num_layers=1,
    bidirectional=False
).to(device)


# 2-layer BiLSTM
model = RNNClassifier(
    vocab_size=len(vocab),
    embedding_dim=100,
    hidden_dim=64,
    output_dim=4,
    rnn_type="lstm",
    num_layers=2,
    bidirectional=True
).to(device)
```

2.9 Ο Υ

O :

[ ]:
```
MAX_WORDS = 25          # M   token sequence (      padding/truncation)
EPOCHS = 15             # Π                    training set
LEARNING_RATE = 1e-3    # P                 optimizer
```

```
BATCH_SIZE = 1024        # M     mini-batch (          &      )
EMBEDDING_DIM = 100      # Δ        word embeddings
HIDDEN_DIM = 64          # Δ        hidden states    RNN
```

2.10 Σ A B

Γ :

- H CrossEntropyLoss, multi-class classification
- O Adam,

[167]:
```
loss_fn = nn.CrossEntropyLoss()
optimizer = torch.optim.Adam(model.parameters(), lr=LEARNING_RATE)
```

2.11 Σ A – evaluate_model

H evaluate_model() test set (validation set), gradients.

E :

- T dataset (total_loss / len(dataloader))
- T labels (true_labels)
- T (pred_labels)

[168]:
```
def evaluate_model(model, dataloader, loss_fn):
    model.eval()
    total_loss = 0
    true_labels = []
    pred_labels = []

    with torch.no_grad():
        for X_batch, y_batch in dataloader:
            outputs = model(X_batch)
            loss = loss_fn(outputs, y_batch)
            total_loss += loss.item()

            preds = outputs.argmax(dim=1)
            true_labels.append(y_batch.cpu())
            pred_labels.append(preds.cpu())

    true_labels = torch.cat(true_labels)
    pred_labels = torch.cat(pred_labels)

    return total_loss / len(dataloader), true_labels.numpy(), pred_labels.
 ↪numpy()
```

2.12 Σ E – train_model

H train_model() epochs .

Γ :

- E training set
- A test set
- E : train loss, val loss val accuracy

[169]:
```python
from tqdm import tqdm
from sklearn.metrics import accuracy_score

def train_model(model, train_loader, test_loader, optimizer, loss_fn, epochs):
    for epoch in range(1, epochs + 1):
        model.train()
        train_losses = []

        print(f"Epoch {epoch}")

        for X_batch, y_batch in tqdm(train_loader):
            optimizer.zero_grad()
            outputs = model(X_batch)
            loss = loss_fn(outputs, y_batch)
            loss.backward()
            optimizer.step()

            train_losses.append(loss.item())

        avg_train_loss = sum(train_losses) / len(train_losses)

        # Evaluation on test set
        val_loss, y_true, y_pred = evaluate_model(model, test_loader, loss_fn)
        val_acc = accuracy_score(y_true, y_pred)

        print(f"Train Loss: {avg_train_loss:.4f} | Val Loss: {val_loss:.4f} | Val Accuracy: {val_acc:.4f}\n")
```

2.13 E RNN M (1-Layer RNN)

Π 1-layer RNN AGNews dataset:

- RNN (LSTM)
- 1 (layer)
- M (bidirectional)
- 4 (World, Sports, Business, Sci/Tech)

[ ]:
```python
# Δ       1-layer RNN
model = RNNClassifier(
    vocab_size=len(vocab),
    embedding_dim=EMBEDDING_DIM,
    hidden_dim=HIDDEN_DIM,
    output_dim=4,            # 4        (World, Sports, Business, Sci/Tech)
```

```
    rnn_type="rnn",           #    RNN
    num_layers=1,             # 1 layer
    bidirectional=False       #    bidirectional
).to(device)

# Loss    Optimizer
loss_fn = nn.CrossEntropyLoss()
optimizer = torch.optim.Adam(model.parameters(), lr=LEARNING_RATE)

train_model(
    model=model,
    train_loader=train_loader,
    test_loader=test_loader,
    optimizer=optimizer,
    loss_fn=loss_fn,
    epochs=EPOCHS
)
```

2.14 Ο Μ Π

Ό Ε 1, RNN-based :

- Τ RNN: `RNN` `LSTM`
- Μ (bidirectional)
- Ε (layers)

Ο configurations :

[173]:
```
model_configs = [
    {"name": "1RNN",       "rnn_type": "rnn",  "num_layers": 1, "bidirectional":
↪ False},
    {"name": "1Bi-RNN",    "rnn_type": "rnn",  "num_layers": 1, "bidirectional":
↪ True},
    {"name": "2Bi-RNN",    "rnn_type": "rnn",  "num_layers": 2, "bidirectional":
↪ True},
    {"name": "1LSTM",      "rnn_type": "lstm", "num_layers": 1, "bidirectional":
↪ False},
    {"name": "1Bi-LSTM",   "rnn_type": "lstm", "num_layers": 1, "bidirectional":
↪ True},
    {"name": "2Bi-LSTM",   "rnn_type": "lstm", "num_layers": 2, "bidirectional":
↪ True}
]
```

2.15 Σ Ε Κ Μ – `run_single_model()`

Η `run_single_model()` :

- Ν configuration (`config`)
- Ν `EPOCHS`

- N
- N error analysis

2.15.1 E (Arguments):

Π	Π
config	Λ (, layers . .)
pretrained_embeddings	Embedding matrix (GloVe . .) None
freeze_embeddings	A embeddings
vocab_to_use	T
output_dim	A (4 AGNews, 2 IMDB)
train_loader	DataLoader training set
test_loader	DataLoader test set

[174]:
```python
import time

def run_single_model(config,
                     pretrained_embeddings=None,  #             4
                     freeze_embeddings=False,  #             5
                     vocab_to_use=vocab,  #            6
                     output_dim=4,              #             6
                     train_loader=train_loader,        #              6
                     test_loader=test_loader          #              6
                     ):
    print(f"\n  Training: {config['name']}")



    model = RNNClassifier(
        vocab_size=len(vocab_to_use),
        embedding_dim=EMBEDDING_DIM,
        hidden_dim=HIDDEN_DIM,
        output_dim=output_dim,
        rnn_type=config["rnn_type"],
        num_layers=config["num_layers"],
        bidirectional=config["bidirectional"],
        pretrained_embeddings=pretrained_embeddings,  #             4
        freeze_embeddings=freeze_embeddings #             5
    ).to(device)

    optimizer = torch.optim.Adam(model.parameters(), lr=LEARNING_RATE)
    loss_fn = nn.CrossEntropyLoss()

    start = time.time()
    train_model(model, train_loader, test_loader, optimizer, loss_fn, epochs=EPOCHS)
```

```
    end = time.time()

    total_params = sum(p.numel() for p in model.parameters() if p.requires_grad)
    val_loss, y_true, y_pred = evaluate_model(model, test_loader, loss_fn)
    val_acc = accuracy_score(y_true, y_pred)

    return {
        "Model": config['name'],
        "Accuracy": round(val_acc * 100, 2),
        "Parameters": total_params,
        "Time (sec)": round((end - start) / EPOCHS, 2),
        "y_pred": y_pred    # <-- Π         predictions
    }
```

2.16 E Ø M – `run_experiments()`

H `run_experiments()` **`model_configs`**, :

- E DataFrame
- E dictionary predicted labels (`y_pred`) ( )

[175]:

```
import pandas as pd

def run_experiments(configs, pretrained_embeddings=None,␣
 ↪freeze_embeddings=False, vocab_to_use=vocab, output_dim=4,␣
 ↪train_loader=train_loader, test_loader=test_loader): # pretrained_embeddings␣
 ↪           4 | freeze_embeddings              5
    results = []
    preds_dict = {}

    for cfg in configs:
        result = run_single_model(cfg,␣
 ↪pretrained_embeddings=pretrained_embeddings,␣
 ↪freeze_embeddings=freeze_embeddings,
        vocab_to_use=vocab_to_use,
        output_dim=output_dim,
        train_loader=train_loader,
        test_loader=test_loader
            ) # pretrained_embeddings            4 | freeze_embeddings     ␣
 ↪      5
        preds_dict[cfg['name']] = result.pop('y_pred')  # A       y_preds
        results.append(result)

    df_results = pd.DataFrame(results)
    return df_results, preds_dict
```

3 A E

3.1 E Γ.1 – E Π & Σ Π

Σ :

- T RNN (RNN LSTM)
- T bidirectional
- T (layers): 1 2

[176]:
```
results_table, preds_dict = run_experiments(model_configs)
```

```
 Training: 1RNN
Epoch 1

100%|      | 118/118 [00:03<00:00, 36.01it/s]

Train Loss: 1.2895 | Val Loss: 1.1397 | Val Accuracy: 0.6053

Epoch 2

100%|      | 118/118 [00:03<00:00, 37.01it/s]

Train Loss: 1.0579 | Val Loss: 1.0076 | Val Accuracy: 0.7370

Epoch 3

100%|      | 118/118 [00:03<00:00, 37.33it/s]

Train Loss: 0.9659 | Val Loss: 0.9579 | Val Accuracy: 0.7862

Epoch 4

100%|      | 118/118 [00:03<00:00, 37.23it/s]

Train Loss: 0.9256 | Val Loss: 0.9394 | Val Accuracy: 0.8026

Epoch 5

100%|      | 118/118 [00:03<00:00, 30.15it/s]

Train Loss: 0.9030 | Val Loss: 0.9171 | Val Accuracy: 0.8253

Epoch 6

100%|      | 118/118 [00:03<00:00, 34.03it/s]

Train Loss: 0.8868 | Val Loss: 0.9066 | Val Accuracy: 0.8346

Epoch 7

100%|      | 118/118 [00:03<00:00, 36.72it/s]
```

```
Train Loss: 0.8743 | Val Loss: 0.8973 | Val Accuracy: 0.8449

Epoch 8

100%|      | 118/118 [00:03<00:00, 36.43it/s]

Train Loss: 0.8661 | Val Loss: 0.8969 | Val Accuracy: 0.8443

Epoch 9

100%|      | 118/118 [00:03<00:00, 36.89it/s]

Train Loss: 0.8579 | Val Loss: 0.8910 | Val Accuracy: 0.8503

Epoch 10

100%|      | 118/118 [00:03<00:00, 37.28it/s]

Train Loss: 0.8529 | Val Loss: 0.8847 | Val Accuracy: 0.8574

Epoch 11

100%|      | 118/118 [00:03<00:00, 37.08it/s]

Train Loss: 0.8477 | Val Loss: 0.8820 | Val Accuracy: 0.8596

Epoch 12

100%|      | 118/118 [00:03<00:00, 36.94it/s]

Train Loss: 0.8437 | Val Loss: 0.8817 | Val Accuracy: 0.8603

Epoch 13

100%|      | 118/118 [00:03<00:00, 35.07it/s]

Train Loss: 0.8398 | Val Loss: 0.8764 | Val Accuracy: 0.8646

Epoch 14

100%|      | 118/118 [00:03<00:00, 36.79it/s]

Train Loss: 0.8356 | Val Loss: 0.8784 | Val Accuracy: 0.8650

Epoch 15

100%|      | 118/118 [00:03<00:00, 35.67it/s]

Train Loss: 0.8329 | Val Loss: 0.8748 | Val Accuracy: 0.8664


 Training: 1Bi-RNN
Epoch 1

100%|      | 118/118 [00:04<00:00, 23.67it/s]
```

```
Train Loss: 1.2968 | Val Loss: 1.1575 | Val Accuracy: 0.5787

Epoch 2
100%|     | 118/118 [00:04<00:00, 28.84it/s]
Train Loss: 1.0878 | Val Loss: 1.0124 | Val Accuracy: 0.7339

Epoch 3
100%|     | 118/118 [00:04<00:00, 28.66it/s]
Train Loss: 0.9724 | Val Loss: 0.9546 | Val Accuracy: 0.7920

Epoch 4
100%|     | 118/118 [00:04<00:00, 29.05it/s]
Train Loss: 0.9249 | Val Loss: 0.9286 | Val Accuracy: 0.8142

Epoch 5
100%|     | 118/118 [00:05<00:00, 22.48it/s]
Train Loss: 0.9008 | Val Loss: 0.9130 | Val Accuracy: 0.8295

Epoch 6
100%|     | 118/118 [00:04<00:00, 27.45it/s]
Train Loss: 0.8841 | Val Loss: 0.9030 | Val Accuracy: 0.8382

Epoch 7
100%|     | 118/118 [00:04<00:00, 27.15it/s]
Train Loss: 0.8716 | Val Loss: 0.8920 | Val Accuracy: 0.8492

Epoch 8
100%|     | 118/118 [00:04<00:00, 28.92it/s]
Train Loss: 0.8634 | Val Loss: 0.8890 | Val Accuracy: 0.8525

Epoch 9
100%|     | 118/118 [00:04<00:00, 29.10it/s]
Train Loss: 0.8548 | Val Loss: 0.8870 | Val Accuracy: 0.8536

Epoch 10
100%|     | 118/118 [00:04<00:00, 29.07it/s]
Train Loss: 0.8489 | Val Loss: 0.8838 | Val Accuracy: 0.8561

Epoch 11
```

```
100%|     | 118/118 [00:04<00:00, 28.56it/s]

Train Loss: 0.8442 | Val Loss: 0.8770 | Val Accuracy: 0.8638

Epoch 12

100%|     | 118/118 [00:04<00:00, 27.70it/s]

Train Loss: 0.8395 | Val Loss: 0.8821 | Val Accuracy: 0.8588

Epoch 13

100%|     | 118/118 [00:04<00:00, 26.49it/s]

Train Loss: 0.8368 | Val Loss: 0.8732 | Val Accuracy: 0.8667

Epoch 14

100%|     | 118/118 [00:04<00:00, 26.94it/s]

Train Loss: 0.8348 | Val Loss: 0.8709 | Val Accuracy: 0.8700

Epoch 15

100%|     | 118/118 [00:04<00:00, 29.03it/s]

Train Loss: 0.8303 | Val Loss: 0.8731 | Val Accuracy: 0.8680


 Training: 2Bi-RNN
Epoch 1

100%|     | 118/118 [00:06<00:00, 19.38it/s]

Train Loss: 1.2619 | Val Loss: 1.1031 | Val Accuracy: 0.6339

Epoch 2

100%|     | 118/118 [00:06<00:00, 19.22it/s]

Train Loss: 1.0447 | Val Loss: 0.9992 | Val Accuracy: 0.7399

Epoch 3

100%|     | 118/118 [00:06<00:00, 18.37it/s]

Train Loss: 0.9715 | Val Loss: 0.9635 | Val Accuracy: 0.7784

Epoch 4

100%|     | 118/118 [00:06<00:00, 19.28it/s]

Train Loss: 0.9361 | Val Loss: 0.9345 | Val Accuracy: 0.8072

Epoch 5

100%|     | 118/118 [00:06<00:00, 19.58it/s]
```

```
Train Loss: 0.9117 | Val Loss: 0.9255 | Val Accuracy: 0.8129

Epoch 6

100%|      | 118/118 [00:06<00:00, 18.40it/s]

Train Loss: 0.8998 | Val Loss: 0.9091 | Val Accuracy: 0.8308

Epoch 7

100%|      | 118/118 [00:06<00:00, 19.36it/s]

Train Loss: 0.8921 | Val Loss: 0.9082 | Val Accuracy: 0.8308

Epoch 8

100%|      | 118/118 [00:06<00:00, 19.44it/s]

Train Loss: 0.8798 | Val Loss: 0.9030 | Val Accuracy: 0.8353

Epoch 9

100%|      | 118/118 [00:07<00:00, 16.22it/s]

Train Loss: 0.8760 | Val Loss: 0.9025 | Val Accuracy: 0.8371

Epoch 10

100%|      | 118/118 [00:08<00:00, 13.25it/s]

Train Loss: 0.8725 | Val Loss: 0.9068 | Val Accuracy: 0.8320

Epoch 11

100%|      | 118/118 [00:08<00:00, 13.50it/s]

Train Loss: 0.8675 | Val Loss: 0.8929 | Val Accuracy: 0.8478

Epoch 12

100%|      | 118/118 [00:06<00:00, 19.41it/s]

Train Loss: 0.8701 | Val Loss: 0.8934 | Val Accuracy: 0.8474

Epoch 13

100%|      | 118/118 [00:06<00:00, 18.52it/s]

Train Loss: 0.8599 | Val Loss: 0.8854 | Val Accuracy: 0.8557

Epoch 14

100%|      | 118/118 [00:06<00:00, 19.47it/s]

Train Loss: 0.8581 | Val Loss: 0.8798 | Val Accuracy: 0.8611

Epoch 15
```

```
100%|          | 118/118 [00:06<00:00, 16.89it/s]
Train Loss: 0.8622 | Val Loss: 0.8841 | Val Accuracy: 0.8567


 Training: 1LSTM
Epoch 1
100%|          | 118/118 [00:04<00:00, 28.86it/s]
Train Loss: 1.2385 | Val Loss: 1.0363 | Val Accuracy: 0.7105

Epoch 2
100%|          | 118/118 [00:04<00:00, 28.78it/s]
Train Loss: 0.9723 | Val Loss: 0.9350 | Val Accuracy: 0.8121

Epoch 3
100%|          | 118/118 [00:03<00:00, 30.24it/s]
Train Loss: 0.9088 | Val Loss: 0.9013 | Val Accuracy: 0.8405

Epoch 4
100%|          | 118/118 [00:04<00:00, 28.78it/s]
Train Loss: 0.8810 | Val Loss: 0.8861 | Val Accuracy: 0.8568

Epoch 5
100%|          | 118/118 [00:04<00:00, 25.36it/s]
Train Loss: 0.8619 | Val Loss: 0.8808 | Val Accuracy: 0.8613

Epoch 6
100%|          | 118/118 [00:04<00:00, 27.54it/s]
Train Loss: 0.8509 | Val Loss: 0.8725 | Val Accuracy: 0.8695

Epoch 7
100%|          | 118/118 [00:04<00:00, 28.62it/s]
Train Loss: 0.8412 | Val Loss: 0.8702 | Val Accuracy: 0.8716

Epoch 8
100%|          | 118/118 [00:04<00:00, 28.48it/s]
Train Loss: 0.8345 | Val Loss: 0.8705 | Val Accuracy: 0.8718

Epoch 9
100%|          | 118/118 [00:03<00:00, 31.00it/s]
```

```
Train Loss: 0.8287 | Val Loss: 0.8631 | Val Accuracy: 0.8787

Epoch 10

100%|      | 118/118 [00:03<00:00, 29.91it/s]

Train Loss: 0.8231 | Val Loss: 0.8638 | Val Accuracy: 0.8792

Epoch 11

100%|      | 118/118 [00:03<00:00, 29.57it/s]

Train Loss: 0.8206 | Val Loss: 0.8612 | Val Accuracy: 0.8805

Epoch 12

100%|      | 118/118 [00:03<00:00, 30.24it/s]

Train Loss: 0.8167 | Val Loss: 0.8581 | Val Accuracy: 0.8833

Epoch 13

100%|      | 118/118 [00:03<00:00, 30.61it/s]

Train Loss: 0.8135 | Val Loss: 0.8582 | Val Accuracy: 0.8846

Epoch 14

100%|      | 118/118 [00:04<00:00, 27.96it/s]

Train Loss: 0.8113 | Val Loss: 0.8567 | Val Accuracy: 0.8843

Epoch 15

100%|      | 118/118 [00:04<00:00, 29.11it/s]

Train Loss: 0.8095 | Val Loss: 0.8565 | Val Accuracy: 0.8859


 Training: 1Bi-LSTM
Epoch 1

100%|      | 118/118 [00:04<00:00, 27.17it/s]

Train Loss: 1.2642 | Val Loss: 1.0614 | Val Accuracy: 0.6859

Epoch 2

100%|      | 118/118 [00:04<00:00, 27.52it/s]

Train Loss: 0.9814 | Val Loss: 0.9370 | Val Accuracy: 0.8067

Epoch 3

100%|      | 118/118 [00:04<00:00, 28.45it/s]
```

```
Train Loss: 0.9100 | Val Loss: 0.9086 | Val Accuracy: 0.8332

Epoch 4

100%|     | 118/118 [00:04<00:00, 27.64it/s]

Train Loss: 0.8801 | Val Loss: 0.8891 | Val Accuracy: 0.8522

Epoch 5

100%|     | 118/118 [00:05<00:00, 20.07it/s]

Train Loss: 0.8622 | Val Loss: 0.8800 | Val Accuracy: 0.8622

Epoch 6

100%|     | 118/118 [00:05<00:00, 23.15it/s]

Train Loss: 0.8502 | Val Loss: 0.8757 | Val Accuracy: 0.8651

Epoch 7

100%|     | 118/118 [00:04<00:00, 27.40it/s]

Train Loss: 0.8420 | Val Loss: 0.8694 | Val Accuracy: 0.8728

Epoch 8

100%|     | 118/118 [00:04<00:00, 28.36it/s]

Train Loss: 0.8348 | Val Loss: 0.8680 | Val Accuracy: 0.8739

Epoch 9

100%|     | 118/118 [00:04<00:00, 27.71it/s]

Train Loss: 0.8288 | Val Loss: 0.8646 | Val Accuracy: 0.8755

Epoch 10

100%|     | 118/118 [00:05<00:00, 19.97it/s]

Train Loss: 0.8248 | Val Loss: 0.8633 | Val Accuracy: 0.8783

Epoch 11

100%|     | 118/118 [00:07<00:00, 15.27it/s]

Train Loss: 0.8202 | Val Loss: 0.8617 | Val Accuracy: 0.8797

Epoch 12

100%|     | 118/118 [00:04<00:00, 27.56it/s]

Train Loss: 0.8171 | Val Loss: 0.8635 | Val Accuracy: 0.8772

Epoch 13
```

```
100%|      | 118/118 [00:04<00:00, 28.32it/s]

Train Loss: 0.8148 | Val Loss: 0.8620 | Val Accuracy: 0.8793

Epoch 14
100%|      | 118/118 [00:04<00:00, 24.84it/s]

Train Loss: 0.8118 | Val Loss: 0.8591 | Val Accuracy: 0.8812

Epoch 15
100%|      | 118/118 [00:04<00:00, 28.04it/s]

Train Loss: 0.8092 | Val Loss: 0.8595 | Val Accuracy: 0.8812


 Training: 2Bi-LSTM
Epoch 1
100%|      | 118/118 [00:10<00:00, 10.85it/s]

Train Loss: 1.1963 | Val Loss: 1.0044 | Val Accuracy: 0.7392

Epoch 2
100%|      | 118/118 [00:07<00:00, 15.49it/s]

Train Loss: 0.9465 | Val Loss: 0.9130 | Val Accuracy: 0.8289

Epoch 3
100%|      | 118/118 [00:06<00:00, 18.02it/s]

Train Loss: 0.8916 | Val Loss: 0.8974 | Val Accuracy: 0.8434

Epoch 4
100%|      | 118/118 [00:06<00:00, 18.15it/s]

Train Loss: 0.8684 | Val Loss: 0.8800 | Val Accuracy: 0.8600

Epoch 5
100%|      | 118/118 [00:11<00:00, 10.17it/s]

Train Loss: 0.8528 | Val Loss: 0.8752 | Val Accuracy: 0.8658

Epoch 6
100%|      | 118/118 [00:09<00:00, 12.58it/s]

Train Loss: 0.8421 | Val Loss: 0.8701 | Val Accuracy: 0.8709

Epoch 7
100%|      | 118/118 [00:06<00:00, 18.19it/s]
```

```
Train Loss: 0.8342 | Val Loss: 0.8684 | Val Accuracy: 0.8730

Epoch 8

100%|     | 118/118 [00:06<00:00, 18.00it/s]

Train Loss: 0.8283 | Val Loss: 0.8639 | Val Accuracy: 0.8779

Epoch 9

100%|     | 118/118 [00:08<00:00, 14.27it/s]

Train Loss: 0.8228 | Val Loss: 0.8601 | Val Accuracy: 0.8799

Epoch 10

100%|     | 118/118 [00:06<00:00, 17.86it/s]

Train Loss: 0.8191 | Val Loss: 0.8585 | Val Accuracy: 0.8841

Epoch 11

100%|     | 118/118 [00:06<00:00, 18.22it/s]

Train Loss: 0.8174 | Val Loss: 0.8601 | Val Accuracy: 0.8808

Epoch 12

100%|     | 118/118 [00:08<00:00, 13.80it/s]

Train Loss: 0.8134 | Val Loss: 0.8568 | Val Accuracy: 0.8837

Epoch 13

100%|     | 118/118 [00:12<00:00,  9.47it/s]

Train Loss: 0.8107 | Val Loss: 0.8607 | Val Accuracy: 0.8804

Epoch 14

100%|     | 118/118 [00:06<00:00, 18.06it/s]

Train Loss: 0.8101 | Val Loss: 0.8571 | Val Accuracy: 0.8838

Epoch 15

100%|     | 118/118 [00:06<00:00, 18.29it/s]

Train Loss: 0.8068 | Val Loss: 0.8579 | Val Accuracy: 0.8841
```

3.1.1 Κ Π Ε Γ.1

[179]:
```python
# Transpose results to match the table format in the assignment
df_transposed = results_table.set_index("Model").T

# Round accuracy to 2 decimals, format numbers
df_display = pd.DataFrame({
    col: [
        f"{df_transposed.loc['Accuracy', col]:.2f}",
        f"{int(df_transposed.loc['Parameters', col]):,}",
        f"{df_transposed.loc['Time (sec)', col]:.2f}"
    ]
    for col in df_transposed.columns
}, index=["Accuracy", "Parameters", "Time cost"])

df_display
```

[179]:

	1RNN	1Bi-RNN	2Bi-RNN	1LSTM	1Bi-LSTM	2Bi-LSTM
Accuracy	86.64	86.80	85.67	88.59	88.12	88.41
Parameters	2,136,284	2,147,164	2,171,996	2,168,156	2,210,908	2,310,236
Time cost	3.42	4.47	6.84	4.27	4.98	8.32

3.1.2 Ε Γ.1 – Σ

Α (RNN & LSTM, / bidirectionality 1 2) :

- **Η** ( ). Τ 2Bi-LSTM, , accuracy .
- **Η** (85.88% 88.59%). Α .
- **Η bidirectional** . Ο Bi-models .

Σ , : / .

3.2 Ε Γ.2 – Ε Κ Λ Π

Σ .

3.2.1 Δ DataFrame Ο Π

Γ sample test set, DataFrame :

- Τ (Title + Description)
- Τ ground truth label (0–3)
- Τ (World, Sports, . .)
- Τ (1RNN, 1Bi-RNN, …)

```
[180]: # Ground truth labels (0-3)
y_true = test_data["Class Index"].values - 1

# Map index → category
label_names = ["World", "Sports", "Business", "Sci/Tech"]

# Δ           DataFrame
df_errors = pd.DataFrame({
    "text": test_data['Title'] + ' ' + test_data['Description'],
    "true_label": y_true
})

# Π
for model_name, preds in preds_dict.items():
    df_errors[model_name] = preds

# Α                (text)
df_errors["true_category"] = df_errors["true_label"].apply(lambda i:␣
 ↪label_names[i])
for model_name in preds_dict:
    df_errors[model_name] = df_errors[model_name].apply(lambda i:␣
 ↪label_names[i])
```

3.2.2 Ε Κ Λ

Ο :

```
[182]: from collections import Counter


def majority_vote(row):
    preds = [row[m] for m in preds_dict]
    return Counter(preds).most_common(1)[0][0]


# Β
all_wrong_mask = df_errors.apply(
    lambda row: all(row[m] != row["true_category"] for m in preds_dict),
    axis=1
)

# Φ
df_all_wrong = df_errors[all_wrong_mask].copy()

# Τ       majority vote
df_all_wrong["majority_vote"] = df_all_wrong.apply(majority_vote, axis=1)
```

```
print(f" * Σ                      : {len(df_all_wrong)}")
print("\n * K                    :")
print(df_all_wrong["true_category"].value_counts())
```

```
 * Σ                      : 333

 * K                    :
true_category
Business    125
World       116
Sci/Tech     77
Sports       15
Name: count, dtype: int64
```

[183]:
```
# E         10
df_all_wrong[["text", "true_category", *preds_dict.keys(), "majority_vote"]].
 ↪head(10)
```

[183]:
```
                                                  text true_category  \
79   Live: Olympics day four Richard Faulds and Ste…         World
83   Intel to delay product aimed for high-definiti…      Business
88   U.S. Misses Cut in Olympic 100 Free ATHENS, Gr…         World
89   Consumers Would Pay In Phone Proposal A propos…      Sci/Tech
106  Stocks Climb on Drop in Consumer Prices NEW YO…         World
110  Yahoo! Ups Ante for Small Businesses Web giant…      Business
120  Oil prices bubble to record high The price of …         World
154  Google Lowers Its IPO Price Range SAN JOSE, Ca…         World
196  Stock Prices Climb Ahead of Google IPO NEW YOR…         World
200  Strong Family Equals Strong Education Single m…      Sci/Tech

         1RNN   1Bi-RNN   2Bi-RNN     1LSTM  1Bi-LSTM  2Bi-LSTM majority_vote
79     Sports    Sports    Sports    Sports    Sports    Sports        Sports
83   Sci/Tech  Sci/Tech  Sci/Tech  Sci/Tech  Sci/Tech  Sci/Tech      Sci/Tech
88     Sports    Sports    Sports    Sports    Sports    Sports        Sports
89   Business  Business  Business  Business  Business  Business      Business
106  Business  Business  Business  Business  Business  Business      Business
110  Sci/Tech  Sci/Tech  Sci/Tech  Sci/Tech  Sci/Tech  Sci/Tech      Sci/Tech
120  Business  Business  Business  Business  Business  Business      Business
154  Sci/Tech  Business  Sci/Tech  Business  Business  Sci/Tech      Sci/Tech
196  Business  Business  Business  Business  Business  Business      Business
200  Business     World  Business     World  Business     World      Business
```

3.2.3 E Γ.2 – Σ

A test set **RNN-based** , :

- **Σ** **333** .
- H :

  - World: 125
  - Business: 116
  - Sci/Tech: 77
  - Sports: **15**

- Η Sports , .
- Σ :
  - **Σ** (. . "Business" "World").
  - Η **(majority vote)** label, .
- Σ B' (Naive Bayes & SVM), :
  - Π .
  - Α World Business.

Γ : > Π RNN-based , , .

3.3 Ε Γ.3 – Μ MAX_WORDS

Σ MAX_WORDS **25** **50**, .

3.3.1 Σ

Ν :

- Η (accuracy)
- Ο
- Η **input** (sequences)

[184]:
```
MAX_WORDS = 50

results_50, preds_50 = run_experiments(model_configs)
```

```
 Training: 1RNN
Epoch 1

100%|      | 118/118 [00:05<00:00, 23.46it/s]

Train Loss: 1.3765 | Val Loss: 1.3508 | Val Accuracy: 0.3312

Epoch 2

100%|      | 118/118 [00:04<00:00, 24.45it/s]

Train Loss: 1.3350 | Val Loss: 1.3147 | Val Accuracy: 0.3858

Epoch 3

100%|      | 118/118 [00:04<00:00, 24.34it/s]
```

```
Train Loss: 1.2998 | Val Loss: 1.3028 | Val Accuracy: 0.3853

Epoch 4

100%|     | 118/118 [00:04<00:00, 24.14it/s]

Train Loss: 1.3022 | Val Loss: 1.2859 | Val Accuracy: 0.4058

Epoch 5

100%|     | 118/118 [00:06<00:00, 19.14it/s]

Train Loss: 1.2738 | Val Loss: 1.2727 | Val Accuracy: 0.4218

Epoch 6

100%|     | 118/118 [00:05<00:00, 23.14it/s]

Train Loss: 1.2611 | Val Loss: 1.2595 | Val Accuracy: 0.4397

Epoch 7

100%|     | 118/118 [00:04<00:00, 25.26it/s]

Train Loss: 1.2739 | Val Loss: 1.2661 | Val Accuracy: 0.4355

Epoch 8

100%|     | 118/118 [00:04<00:00, 24.16it/s]

Train Loss: 1.2829 | Val Loss: 1.2809 | Val Accuracy: 0.4300

Epoch 9

100%|     | 118/118 [00:04<00:00, 24.88it/s]

Train Loss: 1.2629 | Val Loss: 1.2297 | Val Accuracy: 0.4874

Epoch 10

100%|     | 118/118 [00:04<00:00, 25.74it/s]

Train Loss: 1.2789 | Val Loss: 1.2759 | Val Accuracy: 0.4339

Epoch 11

100%|     | 118/118 [00:04<00:00, 25.69it/s]

Train Loss: 1.2644 | Val Loss: 1.2605 | Val Accuracy: 0.4328

Epoch 12

100%|     | 118/118 [00:04<00:00, 25.76it/s]

Train Loss: 1.2490 | Val Loss: 1.2511 | Val Accuracy: 0.4408

Epoch 13
```

```
100%|     | 118/118 [00:04<00:00, 25.29it/s]

Train Loss: 1.2091 | Val Loss: 1.1665 | Val Accuracy: 0.5518

Epoch 14

100%|     | 118/118 [00:05<00:00, 22.15it/s]

Train Loss: 1.2429 | Val Loss: 1.2772 | Val Accuracy: 0.4596

Epoch 15

100%|     | 118/118 [00:04<00:00, 23.94it/s]

Train Loss: 1.2618 | Val Loss: 1.3132 | Val Accuracy: 0.4203


 Training: 1Bi-RNN
Epoch 1

100%|     | 118/118 [00:06<00:00, 18.36it/s]

Train Loss: 1.3781 | Val Loss: 1.3461 | Val Accuracy: 0.3393

Epoch 2

100%|     | 118/118 [00:06<00:00, 18.34it/s]

Train Loss: 1.3373 | Val Loss: 1.3376 | Val Accuracy: 0.3591

Epoch 3

100%|     | 118/118 [00:06<00:00, 18.37it/s]

Train Loss: 1.3443 | Val Loss: 1.3420 | Val Accuracy: 0.3509

Epoch 4

100%|     | 118/118 [00:09<00:00, 12.48it/s]

Train Loss: 1.2878 | Val Loss: 1.2828 | Val Accuracy: 0.3986

Epoch 5

100%|     | 118/118 [00:09<00:00, 12.20it/s]

Train Loss: 1.2909 | Val Loss: 1.3102 | Val Accuracy: 0.3680

Epoch 6

100%|     | 118/118 [00:09<00:00, 12.20it/s]

Train Loss: 1.2694 | Val Loss: 1.2621 | Val Accuracy: 0.4416

Epoch 7

100%|     | 118/118 [00:07<00:00, 15.14it/s]
```

```
Train Loss: 1.2814 | Val Loss: 1.2778 | Val Accuracy: 0.4038

Epoch 8

100%|      | 118/118 [00:06<00:00, 17.40it/s]

Train Loss: 1.2612 | Val Loss: 1.2576 | Val Accuracy: 0.4295

Epoch 9

100%|      | 118/118 [00:06<00:00, 17.44it/s]

Train Loss: 1.2428 | Val Loss: 1.2683 | Val Accuracy: 0.4238

Epoch 10

100%|      | 118/118 [00:07<00:00, 15.46it/s]

Train Loss: 1.2442 | Val Loss: 1.2363 | Val Accuracy: 0.4495

Epoch 11

100%|      | 118/118 [00:06<00:00, 17.09it/s]

Train Loss: 1.2286 | Val Loss: 1.2635 | Val Accuracy: 0.4246

Epoch 12

100%|      | 118/118 [00:06<00:00, 17.77it/s]

Train Loss: 1.2289 | Val Loss: 1.2349 | Val Accuracy: 0.4530

Epoch 13

100%|      | 118/118 [00:07<00:00, 15.89it/s]

Train Loss: 1.2236 | Val Loss: 1.2420 | Val Accuracy: 0.4464

Epoch 14

100%|      | 118/118 [00:09<00:00, 11.87it/s]

Train Loss: 1.2362 | Val Loss: 1.2527 | Val Accuracy: 0.4292

Epoch 15

100%|      | 118/118 [00:06<00:00, 16.95it/s]

Train Loss: 1.2194 | Val Loss: 1.2312 | Val Accuracy: 0.4503


 Training: 2Bi-RNN
Epoch 1

100%|      | 118/118 [00:10<00:00, 10.84it/s]
```

```
Train Loss: 1.3570 | Val Loss: 1.3230 | Val Accuracy: 0.3995

Epoch 2

100%|     | 118/118 [00:11<00:00, 10.00it/s]

Train Loss: 1.3243 | Val Loss: 1.3657 | Val Accuracy: 0.2954

Epoch 3

100%|     | 118/118 [00:10<00:00, 10.81it/s]

Train Loss: 1.3132 | Val Loss: 1.2958 | Val Accuracy: 0.4029

Epoch 4

100%|     | 118/118 [00:10<00:00, 10.86it/s]

Train Loss: 1.2746 | Val Loss: 1.2862 | Val Accuracy: 0.4105

Epoch 5

100%|     | 118/118 [00:11<00:00, 10.35it/s]

Train Loss: 1.2756 | Val Loss: 1.2771 | Val Accuracy: 0.4204

Epoch 6

100%|     | 118/118 [00:10<00:00, 10.91it/s]

Train Loss: 1.2560 | Val Loss: 1.2965 | Val Accuracy: 0.4067

Epoch 7

100%|     | 118/118 [00:12<00:00,  9.36it/s]

Train Loss: 1.2336 | Val Loss: 1.2454 | Val Accuracy: 0.4855

Epoch 8

100%|     | 118/118 [00:11<00:00, 10.72it/s]

Train Loss: 1.2386 | Val Loss: 1.2708 | Val Accuracy: 0.4676

Epoch 9

100%|     | 118/118 [00:10<00:00, 10.91it/s]

Train Loss: 1.2563 | Val Loss: 1.2393 | Val Accuracy: 0.4857

Epoch 10

100%|     | 118/118 [00:15<00:00,  7.42it/s]

Train Loss: 1.3468 | Val Loss: 1.3730 | Val Accuracy: 0.3154

Epoch 11
```

```
100%|     | 118/118 [00:15<00:00,  7.49it/s]

Train Loss: 1.3598 | Val Loss: 1.3566 | Val Accuracy: 0.3339

Epoch 12

100%|     | 118/118 [00:12<00:00,  9.24it/s]

Train Loss: 1.3031 | Val Loss: 1.3222 | Val Accuracy: 0.3782

Epoch 13

100%|     | 118/118 [00:10<00:00, 10.85it/s]

Train Loss: 1.2819 | Val Loss: 1.2739 | Val Accuracy: 0.4483

Epoch 14

100%|     | 118/118 [00:11<00:00, 10.37it/s]

Train Loss: 1.2575 | Val Loss: 1.2609 | Val Accuracy: 0.4637

Epoch 15

100%|     | 118/118 [00:11<00:00, 10.54it/s]

Train Loss: 1.2495 | Val Loss: 1.2567 | Val Accuracy: 0.4487


 Training: 1LSTM
Epoch 1

100%|     | 118/118 [00:04<00:00, 24.75it/s]

Train Loss: 1.3209 | Val Loss: 1.1462 | Val Accuracy: 0.6049

Epoch 2

100%|     | 118/118 [00:04<00:00, 25.59it/s]

Train Loss: 1.0443 | Val Loss: 0.9873 | Val Accuracy: 0.7630

Epoch 3

100%|     | 118/118 [00:04<00:00, 27.11it/s]

Train Loss: 0.9544 | Val Loss: 0.9408 | Val Accuracy: 0.8004

Epoch 4

100%|     | 118/118 [00:04<00:00, 25.45it/s]

Train Loss: 0.9125 | Val Loss: 0.9155 | Val Accuracy: 0.8262

Epoch 5

100%|     | 118/118 [00:07<00:00, 16.31it/s]
```

```
Train Loss: 0.8979 | Val Loss: 0.9019 | Val Accuracy: 0.8395

Epoch 6

100%|     | 118/118 [00:08<00:00, 14.59it/s]

Train Loss: 0.8901 | Val Loss: 0.9045 | Val Accuracy: 0.8370

Epoch 7

100%|     | 118/118 [00:05<00:00, 20.05it/s]

Train Loss: 0.8742 | Val Loss: 0.8870 | Val Accuracy: 0.8539

Epoch 8

100%|     | 118/118 [00:04<00:00, 27.25it/s]

Train Loss: 0.8619 | Val Loss: 0.8704 | Val Accuracy: 0.8701

Epoch 9

100%|     | 118/118 [00:04<00:00, 27.20it/s]

Train Loss: 0.8624 | Val Loss: 0.8724 | Val Accuracy: 0.8676

Epoch 10

100%|     | 118/118 [00:04<00:00, 26.82it/s]

Train Loss: 0.8540 | Val Loss: 0.8744 | Val Accuracy: 0.8678

Epoch 11

100%|     | 118/118 [00:05<00:00, 20.63it/s]

Train Loss: 0.8474 | Val Loss: 0.8635 | Val Accuracy: 0.8780

Epoch 12

100%|     | 118/118 [00:08<00:00, 14.69it/s]

Train Loss: 0.8433 | Val Loss: 0.8619 | Val Accuracy: 0.8789

Epoch 13

100%|     | 118/118 [00:04<00:00, 27.13it/s]

Train Loss: 0.8402 | Val Loss: 0.8647 | Val Accuracy: 0.8758

Epoch 14

100%|     | 118/118 [00:04<00:00, 26.83it/s]

Train Loss: 0.8456 | Val Loss: 0.8656 | Val Accuracy: 0.8747

Epoch 15
```

```
100%|      | 118/118 [00:05<00:00, 23.59it/s]

Train Loss: 0.8427 | Val Loss: 0.8610 | Val Accuracy: 0.8801


  Training: 1Bi-LSTM
Epoch 1

100%|      | 118/118 [00:08<00:00, 14.24it/s]

Train Loss: 1.3149 | Val Loss: 1.1649 | Val Accuracy: 0.5651

Epoch 2

100%|      | 118/118 [00:13<00:00,  8.55it/s]

Train Loss: 1.0847 | Val Loss: 1.0248 | Val Accuracy: 0.7233

Epoch 3

100%|      | 118/118 [00:13<00:00,  8.59it/s]

Train Loss: 0.9878 | Val Loss: 0.9648 | Val Accuracy: 0.7786

Epoch 4

100%|      | 118/118 [00:13<00:00,  8.52it/s]

Train Loss: 0.9363 | Val Loss: 0.9441 | Val Accuracy: 0.7987

Epoch 5

100%|      | 118/118 [00:09<00:00, 12.98it/s]

Train Loss: 0.9098 | Val Loss: 0.9160 | Val Accuracy: 0.8251

Epoch 6

100%|      | 118/118 [00:08<00:00, 13.43it/s]

Train Loss: 0.8916 | Val Loss: 0.9051 | Val Accuracy: 0.8378

Epoch 7

100%|      | 118/118 [00:08<00:00, 13.19it/s]

Train Loss: 0.8769 | Val Loss: 0.8946 | Val Accuracy: 0.8468

Epoch 8

100%|      | 118/118 [00:09<00:00, 12.45it/s]

Train Loss: 0.8655 | Val Loss: 0.8868 | Val Accuracy: 0.8550

Epoch 9

100%|      | 118/118 [00:07<00:00, 16.36it/s]
```

```
Train Loss: 0.8611 | Val Loss: 0.8833 | Val Accuracy: 0.8574

Epoch 10

100%|     | 118/118 [00:07<00:00, 15.98it/s]

Train Loss: 0.8619 | Val Loss: 0.8850 | Val Accuracy: 0.8575

Epoch 11

100%|     | 118/118 [00:12<00:00,  9.28it/s]

Train Loss: 0.8608 | Val Loss: 0.8820 | Val Accuracy: 0.8599

Epoch 12

100%|     | 118/118 [00:07<00:00, 16.25it/s]

Train Loss: 0.8536 | Val Loss: 0.8778 | Val Accuracy: 0.8637

Epoch 13

100%|     | 118/118 [00:07<00:00, 16.22it/s]

Train Loss: 0.8586 | Val Loss: 0.8765 | Val Accuracy: 0.8643

Epoch 14

100%|     | 118/118 [00:10<00:00, 11.61it/s]

Train Loss: 0.8444 | Val Loss: 0.8764 | Val Accuracy: 0.8649

Epoch 15

100%|     | 118/118 [00:13<00:00,  8.54it/s]

Train Loss: 0.8404 | Val Loss: 0.8676 | Val Accuracy: 0.8730


 Training: 2Bi-LSTM
Epoch 1

100%|     | 118/118 [00:12<00:00,  9.49it/s]

Train Loss: 1.2969 | Val Loss: 1.1574 | Val Accuracy: 0.5792

Epoch 2

100%|     | 118/118 [00:13<00:00,  8.59it/s]

Train Loss: 1.1084 | Val Loss: 1.0865 | Val Accuracy: 0.6562

Epoch 3

100%|     | 118/118 [00:19<00:00,  6.05it/s]
```

```
Train Loss: 1.0314 | Val Loss: 0.9964 | Val Accuracy: 0.7454

Epoch 4

100%|     | 118/118 [00:19<00:00,  5.90it/s]

Train Loss: 0.9692 | Val Loss: 0.9531 | Val Accuracy: 0.7866

Epoch 5

100%|     | 118/118 [00:16<00:00,  7.28it/s]

Train Loss: 0.9283 | Val Loss: 0.9252 | Val Accuracy: 0.8141

Epoch 6

100%|     | 118/118 [00:12<00:00,  9.82it/s]

Train Loss: 0.9024 | Val Loss: 0.9067 | Val Accuracy: 0.8334

Epoch 7

100%|     | 118/118 [00:15<00:00,  7.48it/s]

Train Loss: 0.8851 | Val Loss: 0.8942 | Val Accuracy: 0.8467

Epoch 8

100%|     | 118/118 [00:17<00:00,  6.65it/s]

Train Loss: 0.8733 | Val Loss: 0.8890 | Val Accuracy: 0.8522

Epoch 9

100%|     | 118/118 [00:12<00:00,  9.67it/s]

Train Loss: 0.8641 | Val Loss: 0.8798 | Val Accuracy: 0.8605

Epoch 10

100%|     | 118/118 [00:14<00:00,  8.16it/s]

Train Loss: 0.8557 | Val Loss: 0.8723 | Val Accuracy: 0.8686

Epoch 11

100%|     | 118/118 [00:19<00:00,  6.16it/s]

Train Loss: 0.8506 | Val Loss: 0.8671 | Val Accuracy: 0.8734

Epoch 12

100%|     | 118/118 [00:19<00:00,  6.03it/s]

Train Loss: 0.8437 | Val Loss: 0.8655 | Val Accuracy: 0.8733

Epoch 13
```

```
100%|          | 118/118 [00:12<00:00,  9.54it/s]

Train Loss: 0.8401 | Val Loss: 0.8577 | Val Accuracy: 0.8821

Epoch 14

100%|          | 118/118 [00:14<00:00,  8.24it/s]

Train Loss: 0.8360 | Val Loss: 0.8612 | Val Accuracy: 0.8796

Epoch 15

100%|          | 118/118 [00:19<00:00,  6.03it/s]

Train Loss: 0.8347 | Val Loss: 0.8627 | Val Accuracy: 0.8779
```

[185]:
```python
# Transpose results to match the table format in the assignment
df_transposed_50 = results_50.set_index("Model").T

# Round accuracy to 2 decimals, format numbers
df_display_50 = pd.DataFrame({
    col: [
        f"{df_transposed_50.loc['Accuracy', col]:.2f}",
        f"{int(df_transposed_50.loc['Parameters', col]):,}",
        f"{df_transposed_50.loc['Time (sec)', col]:.2f}"
    ]
    for col in df_transposed_50.columns
}, index=["Accuracy", "Parameters", "Time cost"])

df_display_50
```

[185]:

	1RNN	1Bi-RNN	2Bi-RNN	1LSTM	1Bi-LSTM	2Bi-LSTM
Accuracy	42.03	45.03	44.87	88.01	87.30	87.79
Parameters	2,136,284	2,147,164	2,171,996	2,168,156	2,210,908	2,310,236
Time cost	5.10	7.88	12.25	5.54	10.44	16.42

3.3.2 E Γ.3 – Σ

A MAX_WORDS 25 50 .

T :

- **T accuracies RNN (1RNN, 1Bi-RNN, 2Bi-RNN)** , !
  - Π. . 1RNN ~87% ~42%.
- **T LSTM-based (1LSTM, 1Bi-LSTM, 2Bi-LSTM)** (87–88%).
- **O** :
- Π. . 2Bi-LSTM ~8 sec ~16 sec epoch.

- **O** :
  - A , :
    - T
    - T embeddings
    - T hidden layer
  - K (`MAX_WORDS`).

Γ Σ :

- H 50 tokens:
  - Δ RNN ("vanishing gradient").
  - Δ LSTM , .
- Υ **LSTM** **context**.

3.4 E Γ.4 – E Π GloVe Embeddings

Σ **(GloVe)** randomly initialized embeddings .

3.4.1 Φ GloVe Embeddings

T GloVe vectors `glove.6B.100d.txt`, 400.000 100.

[186]:
```
# Δ
def load_glove_embeddings(glove_path):
    embeddings_index = {}
    with open(glove_path, encoding='utf8') as f:
        for line in f:
            values = line.strip().split()
            word = values[0]
            vector = torch.tensor([float(x) for x in values[1:]], dtype=torch.
↪float32)
            embeddings_index[word] = vector
    return embeddings_index

# Π
glove_embeddings = load_glove_embeddings('glove.6B.100d.txt')
print(f"Loaded {len(glove_embeddings)} word vectors from GloVe.")
```

```
Loaded 400000 word vectors from GloVe.
```

3.4.2 Δ Pretrained Embedding Matrix

Γ vectors , embedding matrix:

[187]:
```
def create_embedding_matrix(vocab, glove_embeddings, embedding_dim):
    matrix = torch.zeros(len(vocab), embedding_dim)
```

```
    for word, idx in vocab.get_stoi().items():
        if word in glove_embeddings:
            matrix[idx] = glove_embeddings[word]
        else:
            matrix[idx] = torch.randn(embedding_dim) * 0.01  #     random init␣
↪
    return matrix
```

[188]:
```
embedding_matrix = create_embedding_matrix(vocab, glove_embeddings,␣
↪EMBEDDING_DIM)
```

3.4.3 Σ Υ – Τ Π Ε 4

Γ GloVe embeddings, :

- Ο **inline** :

  “‘python # 4

3.4.4 Ε Π GloVe Embeddings

Τ embedding_matrix

[ ]:
```
MAX_WORDS = 25

# E      -      GloVe embeddings
results_glove, preds_glove = run_experiments(model_configs,␣
↪pretrained_embeddings=embedding_matrix)
```

```
  Training: 1RNN
Epoch 1

100%|      | 118/118 [00:03<00:00, 30.60it/s]

Train Loss: 1.0526 | Val Loss: 0.9051 | Val Accuracy: 0.8411

Epoch 2

100%|      | 118/118 [00:03<00:00, 31.82it/s]

Train Loss: 0.8857 | Val Loss: 0.8724 | Val Accuracy: 0.8705

Epoch 3

100%|      | 118/118 [00:03<00:00, 31.62it/s]

Train Loss: 0.8729 | Val Loss: 0.8904 | Val Accuracy: 0.8530

Epoch 4

100%|      | 118/118 [00:03<00:00, 31.19it/s]
```

```
Train Loss: 0.8719 | Val Loss: 0.8813 | Val Accuracy: 0.8632

Epoch 5
100%|      | 118/118 [00:03<00:00, 30.53it/s]
Train Loss: 0.8731 | Val Loss: 0.8791 | Val Accuracy: 0.8620

Epoch 6
100%|      | 118/118 [00:03<00:00, 29.52it/s]
Train Loss: 0.8750 | Val Loss: 0.8761 | Val Accuracy: 0.8663

Epoch 7
100%|      | 118/118 [00:03<00:00, 31.22it/s]
Train Loss: 0.8606 | Val Loss: 0.8628 | Val Accuracy: 0.8789

Epoch 8
100%|      | 118/118 [00:03<00:00, 30.44it/s]
Train Loss: 0.8558 | Val Loss: 0.8723 | Val Accuracy: 0.8707

Epoch 9
100%|      | 118/118 [00:03<00:00, 31.49it/s]
Train Loss: 0.8501 | Val Loss: 0.8596 | Val Accuracy: 0.8818

Epoch 10
100%|      | 118/118 [00:03<00:00, 32.43it/s]
Train Loss: 0.8495 | Val Loss: 0.8644 | Val Accuracy: 0.8780

Epoch 11
100%|      | 118/118 [00:03<00:00, 31.74it/s]
Train Loss: 0.8921 | Val Loss: 0.9048 | Val Accuracy: 0.8387

Epoch 12
100%|      | 118/118 [00:03<00:00, 30.58it/s]
Train Loss: 0.8826 | Val Loss: 0.8896 | Val Accuracy: 0.8513

Epoch 13
100%|      | 118/118 [00:04<00:00, 27.21it/s]
Train Loss: 0.8577 | Val Loss: 0.8630 | Val Accuracy: 0.8789

Epoch 14
```

```
100%|      | 118/118 [00:04<00:00, 28.31it/s]

Train Loss: 0.8488 | Val Loss: 0.8634 | Val Accuracy: 0.8775

Epoch 15

100%|      | 118/118 [00:03<00:00, 32.33it/s]

Train Loss: 0.8532 | Val Loss: 0.8791 | Val Accuracy: 0.8633


 Training: 1Bi-RNN
Epoch 1

100%|      | 118/118 [00:04<00:00, 23.72it/s]

Train Loss: 1.0482 | Val Loss: 0.8979 | Val Accuracy: 0.8536

Epoch 2

100%|      | 118/118 [00:04<00:00, 26.83it/s]

Train Loss: 0.8860 | Val Loss: 0.8850 | Val Accuracy: 0.8600

Epoch 3

100%|      | 118/118 [00:04<00:00, 26.49it/s]

Train Loss: 0.8712 | Val Loss: 0.8885 | Val Accuracy: 0.8562

Epoch 4

100%|      | 118/118 [00:04<00:00, 26.86it/s]

Train Loss: 0.8695 | Val Loss: 0.8707 | Val Accuracy: 0.8725

Epoch 5

100%|      | 118/118 [00:05<00:00, 22.80it/s]

Train Loss: 0.8604 | Val Loss: 0.8707 | Val Accuracy: 0.8709

Epoch 6

100%|      | 118/118 [00:04<00:00, 25.24it/s]

Train Loss: 0.8612 | Val Loss: 0.8672 | Val Accuracy: 0.8745

Epoch 7

100%|      | 118/118 [00:04<00:00, 27.41it/s]

Train Loss: 0.8560 | Val Loss: 0.8627 | Val Accuracy: 0.8789

Epoch 8

100%|      | 118/118 [00:04<00:00, 27.22it/s]
```

```
Train Loss: 0.8556 | Val Loss: 0.8752 | Val Accuracy: 0.8674

Epoch 9

100%|     | 118/118 [00:04<00:00, 26.74it/s]

Train Loss: 0.8482 | Val Loss: 0.8586 | Val Accuracy: 0.8832

Epoch 10

100%|     | 118/118 [00:05<00:00, 23.48it/s]

Train Loss: 0.8528 | Val Loss: 0.8646 | Val Accuracy: 0.8786

Epoch 11

100%|     | 118/118 [00:04<00:00, 25.20it/s]

Train Loss: 0.8526 | Val Loss: 0.8876 | Val Accuracy: 0.8532

Epoch 12

100%|     | 118/118 [00:04<00:00, 24.13it/s]

Train Loss: 0.8553 | Val Loss: 0.8979 | Val Accuracy: 0.8437

Epoch 13

100%|     | 118/118 [00:04<00:00, 26.57it/s]

Train Loss: 0.8468 | Val Loss: 0.8561 | Val Accuracy: 0.8849

Epoch 14

100%|     | 118/118 [00:04<00:00, 25.01it/s]

Train Loss: 0.8409 | Val Loss: 0.8543 | Val Accuracy: 0.8867

Epoch 15

100%|     | 118/118 [00:04<00:00, 27.17it/s]

Train Loss: 0.8449 | Val Loss: 0.8568 | Val Accuracy: 0.8850


 Training: 2Bi-RNN
Epoch 1

100%|     | 118/118 [00:07<00:00, 16.33it/s]

Train Loss: 0.9818 | Val Loss: 0.8718 | Val Accuracy: 0.8700

Epoch 2

100%|     | 118/118 [00:06<00:00, 17.22it/s]
```

```
Train Loss: 0.8795 | Val Loss: 0.8761 | Val Accuracy: 0.8645

Epoch 3
100%|     | 118/118 [00:06<00:00, 18.27it/s]
Train Loss: 0.8601 | Val Loss: 0.8661 | Val Accuracy: 0.8753

Epoch 4
100%|     | 118/118 [00:06<00:00, 17.56it/s]
Train Loss: 0.8534 | Val Loss: 0.8657 | Val Accuracy: 0.8757

Epoch 5
100%|     | 118/118 [00:09<00:00, 12.88it/s]
Train Loss: 0.8489 | Val Loss: 0.8680 | Val Accuracy: 0.8741

Epoch 6
100%|     | 118/118 [00:08<00:00, 13.77it/s]
Train Loss: 0.8462 | Val Loss: 0.8530 | Val Accuracy: 0.8880

Epoch 7
100%|     | 118/118 [00:06<00:00, 17.70it/s]
Train Loss: 0.8461 | Val Loss: 0.8799 | Val Accuracy: 0.8625

Epoch 8
100%|     | 118/118 [00:06<00:00, 18.29it/s]
Train Loss: 0.8426 | Val Loss: 0.8545 | Val Accuracy: 0.8874

Epoch 9
100%|     | 118/118 [00:08<00:00, 14.72it/s]
Train Loss: 0.8421 | Val Loss: 0.8588 | Val Accuracy: 0.8838

Epoch 10
100%|     | 118/118 [00:09<00:00, 13.02it/s]
Train Loss: 0.8406 | Val Loss: 0.8601 | Val Accuracy: 0.8812

Epoch 11
100%|     | 118/118 [00:09<00:00, 13.02it/s]
Train Loss: 0.8326 | Val Loss: 0.8467 | Val Accuracy: 0.8963

Epoch 12
```

```
100%|     | 118/118 [00:09<00:00, 12.99it/s]

Train Loss: 0.8327 | Val Loss: 0.8436 | Val Accuracy: 0.8976

Epoch 13

100%|     | 118/118 [00:08<00:00, 13.95it/s]

Train Loss: 0.8314 | Val Loss: 0.8520 | Val Accuracy: 0.8905

Epoch 14

100%|     | 118/118 [00:06<00:00, 18.45it/s]

Train Loss: 0.8290 | Val Loss: 0.8499 | Val Accuracy: 0.8913

Epoch 15

100%|     | 118/118 [00:06<00:00, 18.44it/s]

Train Loss: 0.8289 | Val Loss: 0.8471 | Val Accuracy: 0.8949


 Training: 1LSTM
Epoch 1

100%|     | 118/118 [00:04<00:00, 29.46it/s]

Train Loss: 1.0227 | Val Loss: 0.8759 | Val Accuracy: 0.8697

Epoch 2

100%|     | 118/118 [00:03<00:00, 30.12it/s]

Train Loss: 0.8569 | Val Loss: 0.8532 | Val Accuracy: 0.8901

Epoch 3

100%|     | 118/118 [00:03<00:00, 29.51it/s]

Train Loss: 0.8402 | Val Loss: 0.8447 | Val Accuracy: 0.8963

Epoch 4

100%|     | 118/118 [00:03<00:00, 29.81it/s]

Train Loss: 0.8305 | Val Loss: 0.8406 | Val Accuracy: 0.8991

Epoch 5

100%|     | 118/118 [00:03<00:00, 29.72it/s]

Train Loss: 0.8230 | Val Loss: 0.8423 | Val Accuracy: 0.8988

Epoch 6

100%|     | 118/118 [00:04<00:00, 27.48it/s]
```

```
Train Loss: 0.8184 | Val Loss: 0.8415 | Val Accuracy: 0.9005

Epoch 7

100%|     | 118/118 [00:03<00:00, 30.18it/s]

Train Loss: 0.8138 | Val Loss: 0.8347 | Val Accuracy: 0.9062

Epoch 8

100%|     | 118/118 [00:04<00:00, 28.67it/s]

Train Loss: 0.8110 | Val Loss: 0.8333 | Val Accuracy: 0.9078

Epoch 9

100%|     | 118/118 [00:03<00:00, 29.76it/s]

Train Loss: 0.8073 | Val Loss: 0.8349 | Val Accuracy: 0.9057

Epoch 10

100%|     | 118/118 [00:04<00:00, 29.23it/s]

Train Loss: 0.8062 | Val Loss: 0.8327 | Val Accuracy: 0.9083

Epoch 11

100%|     | 118/118 [00:04<00:00, 26.62it/s]

Train Loss: 0.8037 | Val Loss: 0.8339 | Val Accuracy: 0.9067

Epoch 12

100%|     | 118/118 [00:04<00:00, 29.03it/s]

Train Loss: 0.8017 | Val Loss: 0.8344 | Val Accuracy: 0.9066

Epoch 13

100%|     | 118/118 [00:04<00:00, 29.20it/s]

Train Loss: 0.8001 | Val Loss: 0.8341 | Val Accuracy: 0.9071

Epoch 14

100%|     | 118/118 [00:04<00:00, 27.23it/s]

Train Loss: 0.7993 | Val Loss: 0.8331 | Val Accuracy: 0.9076

Epoch 15

100%|     | 118/118 [00:03<00:00, 29.85it/s]

Train Loss: 0.7979 | Val Loss: 0.8347 | Val Accuracy: 0.9059
```

```
 Training: 1Bi-LSTM
Epoch 1

100%|      | 118/118 [00:04<00:00, 26.84it/s]

Train Loss: 1.0325 | Val Loss: 0.8733 | Val Accuracy: 0.8737

Epoch 2

100%|      | 118/118 [00:04<00:00, 27.60it/s]

Train Loss: 0.8574 | Val Loss: 0.8564 | Val Accuracy: 0.8866

Epoch 3

100%|      | 118/118 [00:04<00:00, 27.41it/s]

Train Loss: 0.8415 | Val Loss: 0.8466 | Val Accuracy: 0.8963

Epoch 4

100%|      | 118/118 [00:04<00:00, 27.16it/s]

Train Loss: 0.8320 | Val Loss: 0.8408 | Val Accuracy: 0.9005

Epoch 5

100%|      | 118/118 [00:06<00:00, 18.69it/s]

Train Loss: 0.8242 | Val Loss: 0.8370 | Val Accuracy: 0.9028

Epoch 6

100%|      | 118/118 [00:05<00:00, 20.71it/s]

Train Loss: 0.8189 | Val Loss: 0.8383 | Val Accuracy: 0.9028

Epoch 7

100%|      | 118/118 [00:04<00:00, 27.02it/s]

Train Loss: 0.8156 | Val Loss: 0.8362 | Val Accuracy: 0.9045

Epoch 8

100%|      | 118/118 [00:04<00:00, 28.01it/s]

Train Loss: 0.8115 | Val Loss: 0.8367 | Val Accuracy: 0.9046

Epoch 9

100%|      | 118/118 [00:04<00:00, 25.41it/s]

Train Loss: 0.8096 | Val Loss: 0.8352 | Val Accuracy: 0.9066

Epoch 10
```

```
100%|     | 118/118 [00:05<00:00, 22.42it/s]
Train Loss: 0.8064 | Val Loss: 0.8338 | Val Accuracy: 0.9087

Epoch 11
100%|     | 118/118 [00:04<00:00, 27.76it/s]
Train Loss: 0.8043 | Val Loss: 0.8337 | Val Accuracy: 0.9068

Epoch 12
100%|     | 118/118 [00:04<00:00, 27.62it/s]
Train Loss: 0.8021 | Val Loss: 0.8338 | Val Accuracy: 0.9068

Epoch 13
100%|     | 118/118 [00:04<00:00, 26.31it/s]
Train Loss: 0.8015 | Val Loss: 0.8334 | Val Accuracy: 0.9084

Epoch 14
100%|     | 118/118 [00:04<00:00, 24.71it/s]
Train Loss: 0.7998 | Val Loss: 0.8378 | Val Accuracy: 0.9041

Epoch 15
100%|     | 118/118 [00:07<00:00, 16.84it/s]
Train Loss: 0.7996 | Val Loss: 0.8330 | Val Accuracy: 0.9091


 Training: 2Bi-LSTM
Epoch 1
100%|     | 118/118 [00:06<00:00, 18.32it/s]
Train Loss: 0.9845 | Val Loss: 0.8640 | Val Accuracy: 0.8788

Epoch 2
100%|     | 118/118 [00:08<00:00, 13.40it/s]
Train Loss: 0.8566 | Val Loss: 0.8505 | Val Accuracy: 0.8901

Epoch 3
100%|     | 118/118 [00:09<00:00, 12.36it/s]
Train Loss: 0.8404 | Val Loss: 0.8459 | Val Accuracy: 0.8959

Epoch 4
100%|     | 118/118 [00:09<00:00, 11.84it/s]
```

```
Train Loss: 0.8323 | Val Loss: 0.8414 | Val Accuracy: 0.9001

Epoch 5
100%|     | 118/118 [00:09<00:00, 12.14it/s]
Train Loss: 0.8253 | Val Loss: 0.8415 | Val Accuracy: 0.8999

Epoch 6
100%|     | 118/118 [00:11<00:00, 10.19it/s]
Train Loss: 0.8203 | Val Loss: 0.8392 | Val Accuracy: 0.9020

Epoch 7
100%|     | 118/118 [00:09<00:00, 12.82it/s]
Train Loss: 0.8168 | Val Loss: 0.8367 | Val Accuracy: 0.9046

Epoch 8
100%|     | 118/118 [00:08<00:00, 13.28it/s]
Train Loss: 0.8127 | Val Loss: 0.8369 | Val Accuracy: 0.9042

Epoch 9
100%|     | 118/118 [00:09<00:00, 12.08it/s]
Train Loss: 0.8098 | Val Loss: 0.8351 | Val Accuracy: 0.9067

Epoch 10
100%|     | 118/118 [00:09<00:00, 12.39it/s]
Train Loss: 0.8084 | Val Loss: 0.8392 | Val Accuracy: 0.9026

Epoch 11
100%|     | 118/118 [00:08<00:00, 14.07it/s]
Train Loss: 0.8064 | Val Loss: 0.8349 | Val Accuracy: 0.9061

Epoch 12
100%|     | 118/118 [00:09<00:00, 12.39it/s]
Train Loss: 0.8044 | Val Loss: 0.8326 | Val Accuracy: 0.9079

Epoch 13
100%|     | 118/118 [00:08<00:00, 14.00it/s]
Train Loss: 0.8037 | Val Loss: 0.8347 | Val Accuracy: 0.9054

Epoch 14
```

```
100%|      | 118/118 [00:09<00:00, 12.65it/s]

Train Loss: 0.8017 | Val Loss: 0.8326 | Val Accuracy: 0.9097

Epoch 15

100%|      | 118/118 [00:08<00:00, 13.68it/s]

Train Loss: 0.8006 | Val Loss: 0.8333 | Val Accuracy: 0.9079
```

[190]:

```python
# Transpose results to match the table format in the assignment
df_transposed_glove_25 = results_glove.set_index("Model").T

# Round accuracy to 2 decimals, format numbers
df_display_glove_25 = pd.DataFrame({
    col: [
        f"{df_transposed_glove_25.loc['Accuracy', col]:.2f}",
        f"{int(df_transposed_glove_25.loc['Parameters', col]):,}",
        f"{df_transposed_glove_25.loc['Time (sec)', col]:.2f}"
    ]
    for col in df_transposed_glove_25.columns
}, index=["Accuracy", "Parameters", "Time cost"])

df_display_glove_25
```

[190]:

	1RNN	1Bi-RNN	2Bi-RNN	1LSTM	1Bi-LSTM	2Bi-LSTM
Accuracy	86.33	88.50	89.49	90.59	90.91	90.79
Parameters	2,136,284	2,147,164	2,171,996	2,168,156	2,210,908	2,310,236
Time cost	4.02	4.80	7.86	4.24	5.03	9.56

3.4.5 E Γ.4 – X Π Word Embeddings (GloVe) MAX_WORDS = 25

M MAX_WORDS 25 ( ) - embeddings (GloVe 6B, 100d), :

- **B** , **1–2%** randomly initialized embeddings.
- **M** (~0.5–1 sec epoch).
- Π , .
- **K** .
  - T , embeddings.

Γ : > H GloVe embeddings , computational overhead.

3.5 Ε Γ.5 – Χ Π GloVe Embeddings `freeze=True`

Σ Ε 4 **(frozen) embeddings**,

.

3.5.1 Ε Π

Η `run_experiments()` `freeze_embeddings=True`:

[79]:
```
results_glove_frozen, preds_glove_frozen = run_experiments(model_configs,␣
↪pretrained_embeddings=embedding_matrix, freeze_embeddings=True)
```

```
 Training: 1RNN
Epoch 1

100%|     | 118/118 [00:05<00:00, 22.18it/s]

Train Loss: 1.0680 | Val Loss: 0.9012 | Val Accuracy: 0.8471

Epoch 2

100%|     | 118/118 [00:03<00:00, 35.35it/s]

Train Loss: 0.9006 | Val Loss: 0.9069 | Val Accuracy: 0.8354

Epoch 3

100%|     | 118/118 [00:03<00:00, 35.16it/s]

Train Loss: 0.8909 | Val Loss: 0.8859 | Val Accuracy: 0.8562

Epoch 4

100%|     | 118/118 [00:03<00:00, 34.51it/s]

Train Loss: 0.8858 | Val Loss: 0.8815 | Val Accuracy: 0.8612

Epoch 5

100%|     | 118/118 [00:03<00:00, 35.66it/s]

Train Loss: 0.8859 | Val Loss: 0.8833 | Val Accuracy: 0.8597

Epoch 6

100%|     | 118/118 [00:03<00:00, 34.94it/s]

Train Loss: 0.8852 | Val Loss: 0.8818 | Val Accuracy: 0.8603

Epoch 7

100%|     | 118/118 [00:03<00:00, 32.22it/s]
```

```
Train Loss: 0.8834 | Val Loss: 0.8767 | Val Accuracy: 0.8649

Epoch 8

100%|      | 118/118 [00:03<00:00, 32.65it/s]

Train Loss: 0.8799 | Val Loss: 0.8789 | Val Accuracy: 0.8630

Epoch 9

100%|      | 118/118 [00:03<00:00, 35.37it/s]

Train Loss: 0.8821 | Val Loss: 0.8775 | Val Accuracy: 0.8639

Epoch 10

100%|      | 118/118 [00:03<00:00, 35.38it/s]

Train Loss: 0.8771 | Val Loss: 0.8828 | Val Accuracy: 0.8601

Epoch 11

100%|      | 118/118 [00:03<00:00, 35.58it/s]

Train Loss: 0.8765 | Val Loss: 0.8799 | Val Accuracy: 0.8638

Epoch 12

100%|      | 118/118 [00:03<00:00, 35.77it/s]

Train Loss: 0.8761 | Val Loss: 0.8765 | Val Accuracy: 0.8654

Epoch 13

100%|      | 118/118 [00:03<00:00, 32.87it/s]

Train Loss: 0.8857 | Val Loss: 0.8773 | Val Accuracy: 0.8646

Epoch 14

100%|      | 118/118 [00:03<00:00, 35.60it/s]

Train Loss: 0.8766 | Val Loss: 0.8823 | Val Accuracy: 0.8597

Epoch 15

100%|      | 118/118 [00:03<00:00, 32.27it/s]

Train Loss: 0.8859 | Val Loss: 0.8765 | Val Accuracy: 0.8645


 Training: 1Bi-RNN
Epoch 1

100%|      | 118/118 [00:05<00:00, 22.71it/s]
```

```
Train Loss: 1.0896 | Val Loss: 0.9450 | Val Accuracy: 0.8109

Epoch 2
100%|     | 118/118 [00:05<00:00, 22.83it/s]
Train Loss: 0.9178 | Val Loss: 0.9045 | Val Accuracy: 0.8396

Epoch 3
100%|     | 118/118 [00:05<00:00, 22.38it/s]
Train Loss: 0.8996 | Val Loss: 0.8975 | Val Accuracy: 0.8472

Epoch 4
100%|     | 118/118 [00:05<00:00, 22.51it/s]
Train Loss: 0.9083 | Val Loss: 0.8997 | Val Accuracy: 0.8418

Epoch 5
100%|     | 118/118 [00:05<00:00, 22.61it/s]
Train Loss: 0.8979 | Val Loss: 0.8915 | Val Accuracy: 0.8521

Epoch 6
100%|     | 118/118 [00:05<00:00, 21.14it/s]
Train Loss: 0.8922 | Val Loss: 0.9059 | Val Accuracy: 0.8371

Epoch 7
100%|     | 118/118 [00:05<00:00, 21.69it/s]
Train Loss: 0.8901 | Val Loss: 0.8903 | Val Accuracy: 0.8534

Epoch 8
100%|     | 118/118 [00:05<00:00, 22.83it/s]
Train Loss: 0.9151 | Val Loss: 0.8914 | Val Accuracy: 0.8509

Epoch 9
100%|     | 118/118 [00:05<00:00, 21.41it/s]
Train Loss: 0.8846 | Val Loss: 0.8808 | Val Accuracy: 0.8617

Epoch 10
100%|     | 118/118 [00:05<00:00, 22.61it/s]
Train Loss: 0.8845 | Val Loss: 0.8816 | Val Accuracy: 0.8603

Epoch 11
```

```
100%|     | 118/118 [00:05<00:00, 22.42it/s]

Train Loss: 0.8961 | Val Loss: 0.8831 | Val Accuracy: 0.8593

Epoch 12

100%|     | 118/118 [00:05<00:00, 21.90it/s]

Train Loss: 0.8803 | Val Loss: 0.8751 | Val Accuracy: 0.8661

Epoch 13

100%|     | 118/118 [00:05<00:00, 19.77it/s]

Train Loss: 0.8915 | Val Loss: 0.8928 | Val Accuracy: 0.8497

Epoch 14

100%|     | 118/118 [00:05<00:00, 21.99it/s]

Train Loss: 0.8967 | Val Loss: 0.8890 | Val Accuracy: 0.8526

Epoch 15

100%|     | 118/118 [00:05<00:00, 22.46it/s]

Train Loss: 0.8896 | Val Loss: 0.8891 | Val Accuracy: 0.8518


 Training: 2Bi-RNN
Epoch 1

100%|     | 118/118 [00:08<00:00, 13.11it/s]

Train Loss: 1.0156 | Val Loss: 0.9186 | Val Accuracy: 0.8229

Epoch 2

100%|     | 118/118 [00:08<00:00, 13.33it/s]

Train Loss: 0.8944 | Val Loss: 0.8864 | Val Accuracy: 0.8547

Epoch 3

100%|     | 118/118 [00:09<00:00, 12.98it/s]

Train Loss: 0.8857 | Val Loss: 0.8911 | Val Accuracy: 0.8521

Epoch 4

100%|     | 118/118 [00:08<00:00, 13.13it/s]

Train Loss: 0.8919 | Val Loss: 0.8827 | Val Accuracy: 0.8582

Epoch 5

100%|     | 118/118 [00:08<00:00, 13.43it/s]
```

```
Train Loss: 0.8838 | Val Loss: 0.8848 | Val Accuracy: 0.8566

Epoch 6
100%|     | 118/118 [00:08<00:00, 13.63it/s]
Train Loss: 0.8834 | Val Loss: 0.8800 | Val Accuracy: 0.8614

Epoch 7
100%|     | 118/118 [00:08<00:00, 13.65it/s]
Train Loss: 0.8820 | Val Loss: 0.8793 | Val Accuracy: 0.8616

Epoch 8
100%|     | 118/118 [00:08<00:00, 13.13it/s]
Train Loss: 0.9006 | Val Loss: 0.9015 | Val Accuracy: 0.8396

Epoch 9
100%|     | 118/118 [00:08<00:00, 13.70it/s]
Train Loss: 0.8803 | Val Loss: 0.8887 | Val Accuracy: 0.8551

Epoch 10
100%|     | 118/118 [00:08<00:00, 13.80it/s]
Train Loss: 0.8836 | Val Loss: 0.8800 | Val Accuracy: 0.8625

Epoch 11
100%|     | 118/118 [00:08<00:00, 13.63it/s]
Train Loss: 0.8810 | Val Loss: 0.8785 | Val Accuracy: 0.8638

Epoch 12
100%|     | 118/118 [00:08<00:00, 13.86it/s]
Train Loss: 0.8804 | Val Loss: 0.8809 | Val Accuracy: 0.8600

Epoch 13
100%|     | 118/118 [00:08<00:00, 14.01it/s]
Train Loss: 0.8838 | Val Loss: 0.8838 | Val Accuracy: 0.8591

Epoch 14
100%|     | 118/118 [00:08<00:00, 13.38it/s]
Train Loss: 0.8919 | Val Loss: 0.8907 | Val Accuracy: 0.8511

Epoch 15
```

```
100%|     | 118/118 [00:08<00:00, 13.64it/s]

Train Loss: 0.9047 | Val Loss: 0.8913 | Val Accuracy: 0.8492


 Training: 1LSTM
Epoch 1

100%|     | 118/118 [00:06<00:00, 17.68it/s]

Train Loss: 1.0298 | Val Loss: 0.8855 | Val Accuracy: 0.8616

Epoch 2

100%|     | 118/118 [00:06<00:00, 17.21it/s]

Train Loss: 0.8760 | Val Loss: 0.8706 | Val Accuracy: 0.8718

Epoch 3

100%|     | 118/118 [00:06<00:00, 18.07it/s]

Train Loss: 0.8647 | Val Loss: 0.8685 | Val Accuracy: 0.8741

Epoch 4

100%|     | 118/118 [00:06<00:00, 17.98it/s]

Train Loss: 0.8586 | Val Loss: 0.8605 | Val Accuracy: 0.8808

Epoch 5

100%|     | 118/118 [00:06<00:00, 17.63it/s]

Train Loss: 0.8543 | Val Loss: 0.8557 | Val Accuracy: 0.8855

Epoch 6

100%|     | 118/118 [00:06<00:00, 17.81it/s]

Train Loss: 0.8507 | Val Loss: 0.8527 | Val Accuracy: 0.8867

Epoch 7

100%|     | 118/118 [00:06<00:00, 18.01it/s]

Train Loss: 0.8484 | Val Loss: 0.8525 | Val Accuracy: 0.8886

Epoch 8

100%|     | 118/118 [00:07<00:00, 16.82it/s]

Train Loss: 0.8465 | Val Loss: 0.8511 | Val Accuracy: 0.8904

Epoch 9

100%|     | 118/118 [00:06<00:00, 17.21it/s]
```

```
Train Loss: 0.8435 | Val Loss: 0.8478 | Val Accuracy: 0.8943

Epoch 10

100%|      | 118/118 [00:06<00:00, 18.02it/s]

Train Loss: 0.8412 | Val Loss: 0.8526 | Val Accuracy: 0.8892

Epoch 11

100%|      | 118/118 [00:06<00:00, 18.18it/s]

Train Loss: 0.8393 | Val Loss: 0.8513 | Val Accuracy: 0.8893

Epoch 12

100%|      | 118/118 [00:06<00:00, 17.76it/s]

Train Loss: 0.8372 | Val Loss: 0.8487 | Val Accuracy: 0.8921

Epoch 13

100%|      | 118/118 [00:07<00:00, 16.78it/s]

Train Loss: 0.8373 | Val Loss: 0.8444 | Val Accuracy: 0.8949

Epoch 14

100%|      | 118/118 [00:06<00:00, 18.11it/s]

Train Loss: 0.8348 | Val Loss: 0.8452 | Val Accuracy: 0.8961

Epoch 15

100%|      | 118/118 [00:06<00:00, 17.65it/s]

Train Loss: 0.8327 | Val Loss: 0.8436 | Val Accuracy: 0.8976


 Training: 1Bi-LSTM
Epoch 1

100%|      | 118/118 [00:12<00:00,  9.77it/s]

Train Loss: 1.0464 | Val Loss: 0.8823 | Val Accuracy: 0.8661

Epoch 2

100%|      | 118/118 [00:11<00:00, 10.33it/s]

Train Loss: 0.8750 | Val Loss: 0.8689 | Val Accuracy: 0.8743

Epoch 3

100%|      | 118/118 [00:11<00:00, 10.39it/s]
```

```
Train Loss: 0.8648 | Val Loss: 0.8624 | Val Accuracy: 0.8791

Epoch 4
100%|     | 118/118 [00:11<00:00, 10.35it/s]
Train Loss: 0.8594 | Val Loss: 0.8596 | Val Accuracy: 0.8822

Epoch 5
100%|     | 118/118 [00:11<00:00, 10.37it/s]
Train Loss: 0.8543 | Val Loss: 0.8554 | Val Accuracy: 0.8879

Epoch 6
100%|     | 118/118 [00:11<00:00, 10.01it/s]
Train Loss: 0.8510 | Val Loss: 0.8536 | Val Accuracy: 0.8883

Epoch 7
100%|     | 118/118 [00:11<00:00,  9.93it/s]
Train Loss: 0.8482 | Val Loss: 0.8499 | Val Accuracy: 0.8901

Epoch 8
100%|     | 118/118 [00:11<00:00, 10.28it/s]
Train Loss: 0.8455 | Val Loss: 0.8496 | Val Accuracy: 0.8912

Epoch 9
100%|     | 118/118 [00:11<00:00, 10.18it/s]
Train Loss: 0.8434 | Val Loss: 0.8512 | Val Accuracy: 0.8888

Epoch 10
100%|     | 118/118 [00:11<00:00, 10.28it/s]
Train Loss: 0.8417 | Val Loss: 0.8467 | Val Accuracy: 0.8943

Epoch 11
100%|     | 118/118 [00:11<00:00,  9.99it/s]
Train Loss: 0.8389 | Val Loss: 0.8451 | Val Accuracy: 0.8950

Epoch 12
100%|     | 118/118 [00:13<00:00,  9.01it/s]
Train Loss: 0.8379 | Val Loss: 0.8472 | Val Accuracy: 0.8933

Epoch 13
```

```
100%|     | 118/118 [00:14<00:00,  8.15it/s]

Train Loss: 0.8352 | Val Loss: 0.8458 | Val Accuracy: 0.8949

Epoch 14

100%|     | 118/118 [00:17<00:00,  6.74it/s]

Train Loss: 0.8345 | Val Loss: 0.8442 | Val Accuracy: 0.8967

Epoch 15

100%|     | 118/118 [00:15<00:00,  7.39it/s]

Train Loss: 0.8334 | Val Loss: 0.8424 | Val Accuracy: 0.8983


 Training: 2Bi-LSTM
Epoch 1

100%|     | 118/118 [00:32<00:00,  3.65it/s]

Train Loss: 0.9900 | Val Loss: 0.8798 | Val Accuracy: 0.8613

Epoch 2

100%|     | 118/118 [00:28<00:00,  4.15it/s]

Train Loss: 0.8711 | Val Loss: 0.8709 | Val Accuracy: 0.8686

Epoch 3

100%|     | 118/118 [00:27<00:00,  4.37it/s]

Train Loss: 0.8635 | Val Loss: 0.8624 | Val Accuracy: 0.8797

Epoch 4

100%|     | 118/118 [00:29<00:00,  4.06it/s]

Train Loss: 0.8585 | Val Loss: 0.8589 | Val Accuracy: 0.8808

Epoch 5

100%|     | 118/118 [00:27<00:00,  4.30it/s]

Train Loss: 0.8547 | Val Loss: 0.8545 | Val Accuracy: 0.8867

Epoch 6

100%|     | 118/118 [00:25<00:00,  4.67it/s]

Train Loss: 0.8519 | Val Loss: 0.8520 | Val Accuracy: 0.8896

Epoch 7

100%|     | 118/118 [00:24<00:00,  4.80it/s]
```

```
Train Loss: 0.8492 | Val Loss: 0.8510 | Val Accuracy: 0.8899

Epoch 8

100%|      | 118/118 [00:25<00:00,  4.65it/s]

Train Loss: 0.8470 | Val Loss: 0.8494 | Val Accuracy: 0.8913

Epoch 9

100%|      | 118/118 [00:25<00:00,  4.60it/s]

Train Loss: 0.8455 | Val Loss: 0.8471 | Val Accuracy: 0.8943

Epoch 10

100%|      | 118/118 [00:25<00:00,  4.59it/s]

Train Loss: 0.8426 | Val Loss: 0.8486 | Val Accuracy: 0.8914

Epoch 11

100%|      | 118/118 [00:25<00:00,  4.60it/s]

Train Loss: 0.8396 | Val Loss: 0.8463 | Val Accuracy: 0.8953

Epoch 12

100%|      | 118/118 [00:26<00:00,  4.49it/s]

Train Loss: 0.8382 | Val Loss: 0.8443 | Val Accuracy: 0.8975

Epoch 13

100%|      | 118/118 [00:26<00:00,  4.43it/s]

Train Loss: 0.8373 | Val Loss: 0.8437 | Val Accuracy: 0.8972

Epoch 14

100%|      | 118/118 [00:26<00:00,  4.49it/s]

Train Loss: 0.8355 | Val Loss: 0.8428 | Val Accuracy: 0.8987

Epoch 15

100%|      | 118/118 [00:27<00:00,  4.32it/s]

Train Loss: 0.8337 | Val Loss: 0.8474 | Val Accuracy: 0.8934
```

[80]:
```
# Transpose results to match the table format in the assignment
df_transposed_glove_25_freeze = results_glove_frozen.set_index("Model").T

# Round accuracy to 2 decimals, format numbers
```

```
df_display_glove_25_freeze = pd.DataFrame({
    col: [
        f"{df_transposed_glove_25_freeze.loc['Accuracy', col]:.2f}",
        f"{int(df_transposed_glove_25_freeze.loc['Parameters', col]):,}",
        f"{df_transposed_glove_25_freeze.loc['Time (sec)', col]:.2f}"
    ]
    for col in df_transposed_glove_25_freeze.columns
}, index=["Accuracy", "Parameters", "Time cost"])

df_display_glove_25_freeze
```

[80]:

	1RNN	1Bi-RNN	2Bi-RNN	1LSTM	1Bi-LSTM	2Bi-LSTM
Accuracy	86.45	85.18	84.92	89.76	89.83	89.34
Parameters	10,884	21,764	46,596	42,756	85,508	184,836
Time cost	3.72	5.58	9.10	6.96	13.03	27.73

3.5.2 Ε Γ.5 – Σ

Σ , GloVe embeddings (`glove.6B.100d`), embedding layer **"frozen"** ( ).

Τ :

- **Μ** (~1%) embeddings trainable.
  - Ε RNN-based , .
- **Μ** (~0.5–1 sec epoch), gradients embedding layer.
- **Σ** :
  - Τ frozen embedding layer trainable parameters , .
  - Π. . `1RNN` ~10.884 frozen embeddings, ~2 trainable.

Γ Σ : > Τ " " embeddings , . Τ embeddings task.

3.6 Ε Γ.6 – Ε Dataset: IMDB Movie Reviews

Σ , **dataset**: IMDB dataset 50.000 , .

3.6.1 Ε Π Δ

- Τ dataset Kaggle :
  - `review` →
  - `sentiment` → (`positive`, `negative`)

- O : positive = 1, negative = 0
- T dataset **training (80%)** **test (20%)** train_test_split stratify
  .

[191]:
```
# Φ IMDB dataset
dataset_imdb = pd.read_csv("IMDB Dataset.csv")

# Mapping "positive"/"negative" 1/0
dataset_imdb["label"] = dataset_imdb["sentiment"].map({"positive": 1,␣
↪"negative": 0})

# Split 80/20
from sklearn.model_selection import train_test_split

X_train_imdb, X_test_imdb, y_train_imdb, y_test_imdb = train_test_split(
    dataset_imdb["review"],
    dataset_imdb["label"],
    test_size=0.2,
    random_state=42,
    stratify=dataset_imdb["label"]
)
```

[195]:
```
# Δ dataset
train_dataset_imdb = [(label, text) for label, text in zip(y_train_imdb,␣
↪X_train_imdb)]
test_dataset_imdb = [(label, text) for label, text in zip(y_test_imdb,␣
↪X_test_imdb)]
```

3.6.2 E Π

- X (vocab_imdb) train/test IMDB.
- O 6 (RNN / LSTM, 1-layer / 2-layer, uni/bidirectional).
- T collate function shift_labels=False 0 1.

[196]:
```
# X vocab_imdb IMDB
vocab_imdb = build_vocab_from_iterator(
    build_vocabulary([train_dataset_imdb, test_dataset_imdb]),
    min_freq=10,
    specials=["<PAD>", "<UNK>"]
)
vocab_imdb.set_default_index(vocab_imdb["<UNK>"])

print(f"Vocabulary size (IMDB): {len(vocab_imdb)}")
```

```
Vocabulary size (IMDB): 29065
```

[197]:
```
from torch.utils.data import DataLoader
```

```
train_loader_imdb = DataLoader(train_dataset_imdb, batch_size=BATCH_SIZE,␣
↪shuffle=True, collate_fn=lambda batch: collate_batch(batch,␣
↪shift_labels=False))
test_loader_imdb = DataLoader(test_dataset_imdb, batch_size=BATCH_SIZE,␣
↪shuffle=False, collate_fn=lambda batch: collate_batch(batch,␣
↪shift_labels=False))
```

[198]:
```
df_imdb_results, preds_imdb = run_experiments(
    configs=model_configs,
    pretrained_embeddings=None,
    freeze_embeddings=False,
    vocab_to_use=vocab_imdb,
    output_dim=2,
    train_loader=train_loader_imdb,
    test_loader=test_loader_imdb
)
```

```
 Training: 1RNN
Epoch 1

100%|      | 40/40 [00:03<00:00, 10.61it/s]

Train Loss: 0.6943 | Val Loss: 0.6918 | Val Accuracy: 0.5215

Epoch 2

100%|      | 40/40 [00:03<00:00, 13.29it/s]

Train Loss: 0.6844 | Val Loss: 0.6728 | Val Accuracy: 0.5850

Epoch 3

100%|      | 40/40 [00:02<00:00, 13.35it/s]

Train Loss: 0.6599 | Val Loss: 0.6537 | Val Accuracy: 0.6211

Epoch 4

100%|      | 40/40 [00:03<00:00, 13.28it/s]

Train Loss: 0.6348 | Val Loss: 0.6368 | Val Accuracy: 0.6516

Epoch 5

100%|      | 40/40 [00:03<00:00, 12.93it/s]

Train Loss: 0.6178 | Val Loss: 0.6258 | Val Accuracy: 0.6639

Epoch 6

100%|      | 40/40 [00:03<00:00, 13.22it/s]
```

```
Train Loss: 0.5977 | Val Loss: 0.6225 | Val Accuracy: 0.6687

Epoch 7
100%|     | 40/40 [00:03<00:00, 12.95it/s]
Train Loss: 0.5786 | Val Loss: 0.6128 | Val Accuracy: 0.6801

Epoch 8
100%|     | 40/40 [00:03<00:00, 12.30it/s]
Train Loss: 0.5701 | Val Loss: 0.6124 | Val Accuracy: 0.6823

Epoch 9
100%|     | 40/40 [00:03<00:00, 13.14it/s]
Train Loss: 0.5562 | Val Loss: 0.6066 | Val Accuracy: 0.6908

Epoch 10
100%|     | 40/40 [00:03<00:00, 13.09it/s]
Train Loss: 0.5435 | Val Loss: 0.6059 | Val Accuracy: 0.6887

Epoch 11
100%|     | 40/40 [00:03<00:00, 12.71it/s]
Train Loss: 0.5332 | Val Loss: 0.6023 | Val Accuracy: 0.6949

Epoch 12
100%|     | 40/40 [00:03<00:00, 13.10it/s]
Train Loss: 0.5288 | Val Loss: 0.6058 | Val Accuracy: 0.6885

Epoch 13
100%|     | 40/40 [00:03<00:00, 13.09it/s]
Train Loss: 0.5208 | Val Loss: 0.6033 | Val Accuracy: 0.6919

Epoch 14
100%|     | 40/40 [00:03<00:00, 13.12it/s]
Train Loss: 0.5090 | Val Loss: 0.5998 | Val Accuracy: 0.6996

Epoch 15
100%|     | 40/40 [00:03<00:00, 13.14it/s]
Train Loss: 0.5019 | Val Loss: 0.6039 | Val Accuracy: 0.6949
```

```
 Training: 1Bi-RNN
Epoch 1

100%|     | 40/40 [00:03<00:00, 10.83it/s]

Train Loss: 0.6943 | Val Loss: 0.6919 | Val Accuracy: 0.5236

Epoch 2

100%|     | 40/40 [00:03<00:00, 11.84it/s]

Train Loss: 0.6888 | Val Loss: 0.6908 | Val Accuracy: 0.5250

Epoch 3

100%|     | 40/40 [00:03<00:00, 11.70it/s]

Train Loss: 0.6783 | Val Loss: 0.6764 | Val Accuracy: 0.5803

Epoch 4

100%|     | 40/40 [00:03<00:00, 11.69it/s]

Train Loss: 0.6530 | Val Loss: 0.6644 | Val Accuracy: 0.6117

Epoch 5

100%|     | 40/40 [00:03<00:00, 11.28it/s]

Train Loss: 0.6327 | Val Loss: 0.6402 | Val Accuracy: 0.6424

Epoch 6

100%|     | 40/40 [00:03<00:00, 11.70it/s]

Train Loss: 0.6099 | Val Loss: 0.6257 | Val Accuracy: 0.6620

Epoch 7

100%|     | 40/40 [00:04<00:00,  9.87it/s]

Train Loss: 0.5890 | Val Loss: 0.6160 | Val Accuracy: 0.6784

Epoch 8

100%|     | 40/40 [00:03<00:00, 10.93it/s]

Train Loss: 0.5727 | Val Loss: 0.6135 | Val Accuracy: 0.6823

Epoch 9

100%|     | 40/40 [00:03<00:00, 11.42it/s]

Train Loss: 0.5608 | Val Loss: 0.6079 | Val Accuracy: 0.6868

Epoch 10
```

```
100%|     | 40/40 [00:03<00:00, 11.47it/s]

Train Loss: 0.5442 | Val Loss: 0.6048 | Val Accuracy: 0.6933

Epoch 11

100%|     | 40/40 [00:03<00:00, 11.65it/s]

Train Loss: 0.5350 | Val Loss: 0.5990 | Val Accuracy: 0.6955

Epoch 12

100%|     | 40/40 [00:03<00:00, 11.81it/s]

Train Loss: 0.5255 | Val Loss: 0.6112 | Val Accuracy: 0.6816

Epoch 13

100%|     | 40/40 [00:03<00:00, 11.76it/s]

Train Loss: 0.5200 | Val Loss: 0.6005 | Val Accuracy: 0.6998

Epoch 14

100%|     | 40/40 [00:03<00:00, 11.54it/s]

Train Loss: 0.5086 | Val Loss: 0.5973 | Val Accuracy: 0.7023

Epoch 15

100%|     | 40/40 [00:03<00:00, 11.66it/s]

Train Loss: 0.5035 | Val Loss: 0.6003 | Val Accuracy: 0.6972


 Training: 2Bi-RNN
Epoch 1

100%|     | 40/40 [00:04<00:00,  9.68it/s]

Train Loss: 0.6933 | Val Loss: 0.6923 | Val Accuracy: 0.5180

Epoch 2

100%|     | 40/40 [00:04<00:00,  9.67it/s]

Train Loss: 0.6806 | Val Loss: 0.6762 | Val Accuracy: 0.5808

Epoch 3

100%|     | 40/40 [00:04<00:00,  9.90it/s]

Train Loss: 0.6636 | Val Loss: 0.6683 | Val Accuracy: 0.6020

Epoch 4

100%|     | 40/40 [00:04<00:00,  9.88it/s]
```

```
Train Loss: 0.6417 | Val Loss: 0.6533 | Val Accuracy: 0.6214

Epoch 5

100%|     | 40/40 [00:04<00:00,  9.77it/s]

Train Loss: 0.6184 | Val Loss: 0.6314 | Val Accuracy: 0.6561

Epoch 6

100%|     | 40/40 [00:04<00:00,  8.84it/s]

Train Loss: 0.5980 | Val Loss: 0.6306 | Val Accuracy: 0.6570

Epoch 7

100%|     | 40/40 [00:04<00:00,  9.86it/s]

Train Loss: 0.5774 | Val Loss: 0.6117 | Val Accuracy: 0.6810

Epoch 8

100%|     | 40/40 [00:04<00:00,  9.60it/s]

Train Loss: 0.5623 | Val Loss: 0.6103 | Val Accuracy: 0.6811

Epoch 9

100%|     | 40/40 [00:04<00:00,  9.85it/s]

Train Loss: 0.5468 | Val Loss: 0.6043 | Val Accuracy: 0.6912

Epoch 10

100%|     | 40/40 [00:04<00:00,  9.73it/s]

Train Loss: 0.5353 | Val Loss: 0.6038 | Val Accuracy: 0.6937

Epoch 11

100%|     | 40/40 [00:04<00:00,  8.35it/s]

Train Loss: 0.5231 | Val Loss: 0.6050 | Val Accuracy: 0.6926

Epoch 12

100%|     | 40/40 [00:04<00:00,  9.54it/s]

Train Loss: 0.5145 | Val Loss: 0.6044 | Val Accuracy: 0.6932

Epoch 13

100%|     | 40/40 [00:04<00:00,  9.51it/s]

Train Loss: 0.5071 | Val Loss: 0.6030 | Val Accuracy: 0.6946

Epoch 14
```

```
100%|     | 40/40 [00:04<00:00,  9.72it/s]

Train Loss: 0.4948 | Val Loss: 0.6051 | Val Accuracy: 0.6920

Epoch 15

100%|     | 40/40 [00:04<00:00,  9.69it/s]

Train Loss: 0.4884 | Val Loss: 0.6028 | Val Accuracy: 0.6988


 Training: 1LSTM
Epoch 1

100%|     | 40/40 [00:03<00:00, 11.82it/s]

Train Loss: 0.6922 | Val Loss: 0.6901 | Val Accuracy: 0.5354

Epoch 2

100%|     | 40/40 [00:03<00:00, 12.43it/s]

Train Loss: 0.6790 | Val Loss: 0.6631 | Val Accuracy: 0.6021

Epoch 3

100%|     | 40/40 [00:03<00:00, 12.28it/s]

Train Loss: 0.6351 | Val Loss: 0.6287 | Val Accuracy: 0.6521

Epoch 4

100%|     | 40/40 [00:03<00:00, 11.38it/s]

Train Loss: 0.5966 | Val Loss: 0.6061 | Val Accuracy: 0.6781

Epoch 5

100%|     | 40/40 [00:03<00:00, 12.00it/s]

Train Loss: 0.5716 | Val Loss: 0.6008 | Val Accuracy: 0.6823

Epoch 6

100%|     | 40/40 [00:03<00:00, 12.64it/s]

Train Loss: 0.5561 | Val Loss: 0.5940 | Val Accuracy: 0.6940

Epoch 7

100%|     | 40/40 [00:03<00:00, 12.41it/s]

Train Loss: 0.5406 | Val Loss: 0.5900 | Val Accuracy: 0.6980

Epoch 8

100%|     | 40/40 [00:03<00:00, 12.38it/s]
```

```
Train Loss: 0.5253 | Val Loss: 0.5900 | Val Accuracy: 0.7009

Epoch 9

100%|      | 40/40 [00:03<00:00, 12.18it/s]

Train Loss: 0.5128 | Val Loss: 0.5884 | Val Accuracy: 0.7034

Epoch 10

100%|      | 40/40 [00:03<00:00, 12.35it/s]

Train Loss: 0.5011 | Val Loss: 0.5891 | Val Accuracy: 0.7019

Epoch 11

100%|      | 40/40 [00:03<00:00, 12.42it/s]

Train Loss: 0.4901 | Val Loss: 0.5889 | Val Accuracy: 0.7068

Epoch 12

100%|      | 40/40 [00:03<00:00, 12.91it/s]

Train Loss: 0.4850 | Val Loss: 0.5988 | Val Accuracy: 0.6953

Epoch 13

100%|      | 40/40 [00:03<00:00, 12.59it/s]

Train Loss: 0.4720 | Val Loss: 0.5981 | Val Accuracy: 0.6968

Epoch 14

100%|      | 40/40 [00:03<00:00, 12.38it/s]

Train Loss: 0.4670 | Val Loss: 0.5952 | Val Accuracy: 0.7026

Epoch 15

100%|      | 40/40 [00:03<00:00, 12.86it/s]

Train Loss: 0.4567 | Val Loss: 0.5995 | Val Accuracy: 0.6990


 Training: 1Bi-LSTM
Epoch 1

100%|      | 40/40 [00:03<00:00, 11.62it/s]

Train Loss: 0.6919 | Val Loss: 0.6900 | Val Accuracy: 0.5335

Epoch 2

100%|      | 40/40 [00:03<00:00, 11.96it/s]
```

```
Train Loss: 0.6768 | Val Loss: 0.6615 | Val Accuracy: 0.6074

Epoch 3
100%|      | 40/40 [00:03<00:00, 10.99it/s]
Train Loss: 0.6365 | Val Loss: 0.6278 | Val Accuracy: 0.6535

Epoch 4
100%|      | 40/40 [00:03<00:00, 11.58it/s]
Train Loss: 0.6007 | Val Loss: 0.6061 | Val Accuracy: 0.6791

Epoch 5
100%|      | 40/40 [00:03<00:00, 11.80it/s]
Train Loss: 0.5807 | Val Loss: 0.5985 | Val Accuracy: 0.6888

Epoch 6
100%|      | 40/40 [00:03<00:00, 11.90it/s]
Train Loss: 0.5604 | Val Loss: 0.5969 | Val Accuracy: 0.6892

Epoch 7
100%|      | 40/40 [00:03<00:00, 10.50it/s]
Train Loss: 0.5449 | Val Loss: 0.5871 | Val Accuracy: 0.7029

Epoch 8
100%|      | 40/40 [00:03<00:00, 10.67it/s]
Train Loss: 0.5307 | Val Loss: 0.5874 | Val Accuracy: 0.7049

Epoch 9
100%|      | 40/40 [00:03<00:00, 11.04it/s]
Train Loss: 0.5179 | Val Loss: 0.5884 | Val Accuracy: 0.7027

Epoch 10
100%|      | 40/40 [00:03<00:00, 11.63it/s]
Train Loss: 0.5081 | Val Loss: 0.5862 | Val Accuracy: 0.7048

Epoch 11
100%|      | 40/40 [00:03<00:00, 11.62it/s]
Train Loss: 0.4994 | Val Loss: 0.5897 | Val Accuracy: 0.7004

Epoch 12
```

```
100%|     | 40/40 [00:03<00:00, 11.63it/s]

Train Loss: 0.4887 | Val Loss: 0.5944 | Val Accuracy: 0.6973

Epoch 13

100%|     | 40/40 [00:03<00:00, 10.15it/s]

Train Loss: 0.4780 | Val Loss: 0.5897 | Val Accuracy: 0.7045

Epoch 14

100%|     | 40/40 [00:03<00:00, 11.29it/s]

Train Loss: 0.4708 | Val Loss: 0.5880 | Val Accuracy: 0.7074

Epoch 15

100%|     | 40/40 [00:03<00:00, 10.94it/s]

Train Loss: 0.4586 | Val Loss: 0.5935 | Val Accuracy: 0.7046


 Training: 2Bi-LSTM
Epoch 1

100%|     | 40/40 [00:04<00:00,  9.99it/s]

Train Loss: 0.6864 | Val Loss: 0.6753 | Val Accuracy: 0.5768

Epoch 2

100%|     | 40/40 [00:04<00:00,  8.58it/s]

Train Loss: 0.6488 | Val Loss: 0.6379 | Val Accuracy: 0.6343

Epoch 3

100%|     | 40/40 [00:03<00:00, 10.00it/s]

Train Loss: 0.6090 | Val Loss: 0.6099 | Val Accuracy: 0.6759

Epoch 4

100%|     | 40/40 [00:04<00:00,  9.99it/s]

Train Loss: 0.5815 | Val Loss: 0.5999 | Val Accuracy: 0.6826

Epoch 5

100%|     | 40/40 [00:04<00:00,  9.98it/s]

Train Loss: 0.5575 | Val Loss: 0.5942 | Val Accuracy: 0.6944

Epoch 6

100%|     | 40/40 [00:04<00:00,  9.91it/s]
```

```
Train Loss: 0.5402 | Val Loss: 0.5970 | Val Accuracy: 0.6954

Epoch 7
100%|     | 40/40 [00:03<00:00, 10.08it/s]
Train Loss: 0.5237 | Val Loss: 0.5968 | Val Accuracy: 0.6939

Epoch 8
100%|     | 40/40 [00:03<00:00, 10.05it/s]
Train Loss: 0.5120 | Val Loss: 0.5969 | Val Accuracy: 0.6912

Epoch 9
100%|     | 40/40 [00:03<00:00, 10.16it/s]
Train Loss: 0.4993 | Val Loss: 0.5945 | Val Accuracy: 0.7022

Epoch 10
100%|     | 40/40 [00:04<00:00,  8.21it/s]
Train Loss: 0.4878 | Val Loss: 0.5910 | Val Accuracy: 0.7071

Epoch 11
100%|     | 40/40 [00:04<00:00,  9.87it/s]
Train Loss: 0.4751 | Val Loss: 0.5944 | Val Accuracy: 0.7067

Epoch 12
100%|     | 40/40 [00:03<00:00, 10.11it/s]
Train Loss: 0.4672 | Val Loss: 0.6014 | Val Accuracy: 0.6997

Epoch 13
100%|     | 40/40 [00:04<00:00,  9.80it/s]
Train Loss: 0.4565 | Val Loss: 0.5989 | Val Accuracy: 0.7028

Epoch 14
100%|     | 40/40 [00:04<00:00,  9.02it/s]
Train Loss: 0.4536 | Val Loss: 0.6015 | Val Accuracy: 0.7013

Epoch 15
100%|     | 40/40 [00:05<00:00,  7.28it/s]
Train Loss: 0.4497 | Val Loss: 0.6036 | Val Accuracy: 0.7004
```

```python
[206]: # Transpose results to match the table format in the assignment
df_transposed_imdb = df_imdb_results.set_index("Model").T

# Round accuracy to 2 decimals, format numbers
df_display_imdb = pd.DataFrame({
    col: [
        f"{df_transposed_imdb.loc['Accuracy', col]:.2f}",
        f"{int(df_transposed_imdb.loc['Parameters', col]):,}",
        f"{df_transposed_imdb.loc['Time (sec)', col]:.2f}"
    ]
    for col in df_transposed_imdb.columns
}, index=["Accuracy", "Parameters", "Time cost"])

df_display_imdb
```

[206]:

	1RNN	1Bi-RNN	2Bi-RNN	1LSTM	1Bi-LSTM	2Bi-LSTM
Accuracy	69.49	69.72	69.88	69.90	70.46	70.04
Parameters	2,917,254	2,928,006	2,952,838	2,949,126	2,991,750	3,091,078
Time cost	3.76	4.18	4.92	3.98	4.29	5.06

3.6.3 Ε Γ.56 – Σ

- Ό , **Bi-Directional** .
- Τ **LSTM** **RNN**,
  .
- Ο (2Bi-LSTM).
- Α , **1RNN** :
  - Α
  - Χ
  - Α

Σ , **1RNN** ,
.