

山东大学计算机科学与技术学院

大数据分析课程实验报告

学号: 202302130293	姓名: 李嘉欣	班级: 数据科学与大数据技术
实验题目: BERT 实践	实验日期: 2025/11/10	
<p>实验目标: 在 BERT 实践实验中，主要目标是通过动手实践，深入理解如何利用机器学习方法对大规模数据进行分析，并掌握在远程 GPU 服务器环境下进行工程代码调试的基本流程。实验要求学习者熟悉 PyTorch 框架，基于预训练的 BERT 模型对 MRPC (Microsoft Research Paraphrase Corpus) 数据集进行句子同义性判断任务。</p>		
<p>实验环境: Linux 系统</p>		
<p>实验步骤:</p> <ol style="list-style-type: none">环境配置		
<pre>(base) hadoop@ubuntu:~\$ conda create -n bert-mrpc python=3.6.8 -y Collecting package metadata (current_repodata.json): done Solving environment: failed with repodata from current_repodata.json, will retry with next repodata source. Collecting package metadata (repodata.json): done Solving environment: done ## Package Plan ## environment location: /home/hadoop/anaconda3/envs/bert-mrpc added / updated specs: - python=3.6.8 The following NEW packages will be INSTALLED: _libgcc_mutex anaconda/pkgs/main/linux-64::_libgcc_mutex-0.1-main _openmp_mutex anaconda/pkgs/main/linux-64::_openmp_mutex-5.1-1_gnu ca-certificates anaconda/pkgs/main/linux-64::ca-certificates-2025.11.4-h06a4308_0 certifi anaconda/pkgs/main/linux-64::certifi-2021.5.30-py36h06a4308_0 libedit anaconda/pkgs/main/linux-64::libedit-3.1.20230828-h5eee18b_0 libffi anaconda/pkgs/main/linux-64::libffi-3.2.1-hf484d3e_1007 libgcc anaconda/pkgs/main/linux-64::libgcc-15.2.0-h69a1729_7 libgcc-ng anaconda/pkgs/main/linux-64::libgcc-ng-15.2.0-h166f726_7 libgomp anaconda/pkgs/main/linux-64::libgomp-15.2.0-h4751f2c_7 libstdcxx anaconda/pkgs/main/linux-64::libstdcxx-15.2.0-h39759b7_7 libstdcxx-ng anaconda/pkgs/main/linux-64::libstdcxx-ng-15.2.0-hc03a8fd_7 libxcb anaconda/pkgs/main/linux-64::libxcb-1.17.0-h9b100fa_0 libzlib anaconda/pkgs/main/linux-64::libzlib-1.3.1-hb25bd0a_0 ncurses anaconda/pkgs/main/linux-64::ncurses-6.5-h7934f7d_0 openssl anaconda/pkgs/main/linux-64::openssl-1.1.1w-h7f8727e_0 pip anaconda/pkgs/main/linux-64::pip-21.2.2-py36h06a4308_0 pthread-stubs anaconda/pkgs/main/linux-64::pthread-stubs-0.3-h0ce48e5_1 python anaconda/pkgs/main/linux-64::python-3.6.8-h0371630_0 readline anaconda/pkgs/main/linux-64::readline-7.0-h7b6447c_5 setupools anaconda/pkgs/main/linux-64::setupools-58.0.4-py36h06a4308_0 sqlite anaconda/pkgs/main/linux-64::sqlite-3.33.0-h62c20be_0 tk anaconda/pkgs/main/linux-64::tk-8.6.15-h54e0aa7_0 wheel anaconda/pkgs/main/noarch::wheel-0.37.1-pyhd3eb1b0_0 xorg-libx11 anaconda/pkgs/main/linux-64::xorg-libx11-1.8.12-h9b100fa_1 xorg-libxau anaconda/pkgs/main/linux-64::xorg-libxau-1.0.12-h9b100fa_0 xorg-libxdmcp anaconda/pkgs/main/linux-64::xorg-libxdmcp-1.1.5-h9b100fa_0 xorg-xorgproto anaconda/pkgs/main/linux-64::xorg-xorgproto-2024.1-h5eee18b_1 xz anaconda/pkgs/main/linux-64::xz-5.6.4-h5eee18b_1 zlib anaconda/pkgs/main/linux-64::zlib-1.3.1-hb25bd0a_0 Preparing transaction: done Verifying transaction: done Executing transaction: done # # To activate this environment, use # # \$ conda activate bert-mrpc # # To deactivate an active environment, use # # \$ conda deactivate (base) hadoop@ubuntu:~\$ conda activate bert-mrpc (bert-mrpc) hadoop@ubuntu:~\$</pre>		

```
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$ python -c "import torch; print('PyTorch版本:', torch.__version__)"
PyTorch版本: 1.7.1+cpu
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$ python -c "from transformers import BertTokenizer; print('Transformers: OK')"
Transformers: OK
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$ python -c "import pandas as pd; print('Pandas版本:', pd.__version__)"
Pandas版本: 1.1.5
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$ python -c "import numpy as np; print('Numpy版本:', np.__version__)"
Numpy版本: 1.19.5
```

2. 项目结构

```
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$ ls -la
total 32
drwxrwxr-x  3 hadoop hadoop 4096 Nov 24 19:11 .
drwxr-xr-x 18 hadoop hadoop 4096 Nov 24 06:49 ..
drwxrwxr-x  2 hadoop hadoop 4096 Nov 23 06:40 data
-rw-rw-r--  1 hadoop hadoop  519 Nov 23 05:55 FCModel.py
-rw-rw-r--  1 hadoop hadoop 1124 Nov 23 06:55 MRPCDataset.py
-rw-rw-r--  1 hadoop hadoop  804 Nov 23 06:55 test_simple.py
-rw-rw-r--  1 hadoop hadoop 6985 Nov 23 16:57 train_bert_fast.py
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$
```

3. 数据加载测试

```
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$ python test_simple.py
测试简化版MRPC数据加载...
训练集样本数: 3962
第一个样本:
    标签: 1
    句子1: Amrozi accused his brother, whom he called "the witness", of deliberately distorting his evidence.
    句子2: Referring to him as only "the witness", Amrozi accused his brother of deliberately distorting his evidence.
测试集样本数: 1650
数据加载成功!
总样本数: 训练集3962 + 测试集1650 = 5612
```

4. 数据集信息

```
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$ ls -la data/
total 6408
drwxrwxr-x  2 hadoop hadoop 4096 Nov 23 06:40 .
drwxrwxr-x  4 hadoop hadoop 4096 Nov 24 19:18 ..
-rw-rw-r--  1 hadoop hadoop 436 Feb 17 2025 '[5]SummaryInformation'
-rw-rw-r--  1 hadoop hadoop 14552 Mar 1 2005 _63DE49D9E7214609BE7E38DD145D8081
-rw-rw-r--  1 hadoop hadoop 54 Feb 17 2025 '!AdminExecuteSequence'
-rw-rw-r--  1 hadoop hadoop 72 Feb 17 2025 '!AdminInUISequence'
-rw-rw-r--  1 hadoop hadoop 90 Feb 17 2025 '!AdvtExecuteSequence'
-rw-rw-r--  1 hadoop hadoop 1236737 Feb 17 2025 _B1BA6E15A980AC3FD484D88B1C593049
-rw-rw-r--  1 hadoop hadoop 71206 Mar 3 2005 _B3CFEFE1C368459BA1D1B8A2FA07A16D
-rw-rw-r--  1 hadoop hadoop 12 Feb 17 2025 '!Binary'
-rw-rw-r--  1 hadoop hadoop 5088 Feb 17 2025 Binary.DefBannerBitmap
-rw-rw-r--  1 hadoop hadoop 318 Feb 17 2025 Binary.NewFldRBtn
-rw-rw-r--  1 hadoop hadoop 318 Feb 17 2025 Binary.UpFldrBtn
-rw-rw-r--  1 hadoop hadoop 180107 Mar 3 2005 _CSBC91AB1554DF3AF5E4105DE57C85A
-rw-rw-r--  1 hadoop hadoop 3384 Feb 17 2025 '!_Columns'
-rw-rw-r--  1 hadoop hadoop 120 Feb 17 2025 '!Component'
-rw-rw-r--  1 hadoop hadoop 5616 Feb 17 2025 '!Control'
-rw-rw-r--  1 hadoop hadoop 576 Feb 17 2025 '!ControlCondition'
-rw-rw-r--  1 hadoop hadoop 1080 Feb 17 2025 '!ControlEvent'
-rw-rw-r--  1 hadoop hadoop 8 Feb 17 2025 '!CreateFolder'
-rw-rw-r--  1 hadoop hadoop 16 Feb 17 2025 '!CustomAction'
-rw-rw-r--  1 hadoop hadoop 9982 Mar 2 2005 _D18B15DC041F43D7925309EFFCFE0236
-rw-rw-r--  1 hadoop hadoop 550 Feb 17 2025 '!Dialog'
-rw-rw-r--  1 hadoop hadoop 30 Feb 17 2025 '!Directory'
-rw-rw-r--  1 hadoop hadoop 200 Feb 17 2025 '!EventMapping'
-rw-rw-r--  1 hadoop hadoop 16 Feb 17 2025 '!Feature'
-rw-rw-r--  1 hadoop hadoop 40 Feb 17 2025 '!FeatureComponents'
-rw-rw-r--  1 hadoop hadoop 126 Feb 17 2025 '!File'
-rw-rw-r--  1 hadoop hadoop 28 Feb 17 2025 '!Icon'
-rw-rw-r--  1 hadoop hadoop 1078 Feb 17 2025 Icon._3a9e797d.exe
-rw-rw-r--  1 hadoop hadoop 1078 Feb 17 2025 Icon._3e121a49.exe
-rw-rw-r--  1 hadoop hadoop 1078 Feb 17 2025 Icon._49442e40.exe
-rw-rw-r--  1 hadoop hadoop 1078 Feb 17 2025 Icon._4cad314f.exe
-rw-rw-r--  1 hadoop hadoop 1078 Feb 17 2025 Icon._5e144df2.exe
-rw-rw-r--  1 hadoop hadoop 1078 Feb 17 2025 Icon._5f323bf6.exe
-rw-rw-r--  1 hadoop hadoop 1078 Feb 17 2025 Icon._5f49ddc.exe
-rw-rw-r--  1 hadoop hadoop 396 Feb 17 2025 '!InstallExecuteSequence'
-rw-rw-r--  1 hadoop hadoop 114 Feb 17 2025 '!InstallUISequence'
-rw-rw-r--  1 hadoop hadoop 12 Feb 17 2025 '!Media'
-rw-rw-r--  1 hadoop hadoop 84 Feb 17 2025 '!ModuleSignature'
-rw-rw-r--  1 hadoop hadoop 1359872 Feb 17 2025 MSRParaphraseCorpus.msi
-rw-rw-r--  1 hadoop hadoop 432882 Mar 3 2005 msr_paraphrase_test.txt
-rw-rw-r--  1 hadoop hadoop 1026746 Mar 3 2005 msr_paraphrase_train.txt
-rw-rw-r--  1 hadoop hadoop 1948113 Mar 1 2005 msr_sentences.txt
-rw-rw-r--  1 hadoop hadoop 128 Feb 17 2025 '!Property'
-rw-rw-r--  1 hadoop hadoop 144 Feb 17 2025 '!RadioButton'
-rw-rw-r--  1 hadoop hadoop 12 Feb 17 2025 '!Registry'
-rw-rw-r--  1 hadoop hadoop 30 Feb 17 2025 '!RemoveFile'
-rw-rw-r--  1 hadoop hadoop 168 Feb 17 2025 '!Shortcut'
-rw-rw-r--  1 hadoop hadoop 59572 Feb 17 2025 '!_StringData'
-rw-rw-r--  1 hadoop hadoop 4896 Feb 17 2025 '!_StringPool'
-rw-rw-r--  1 hadoop hadoop 174 Feb 17 2025 '!_Tables'
-rw-rw-r--  1 hadoop hadoop 48 Feb 17 2025 '!TextStyle'
-rw-rw-r--  1 hadoop hadoop 204 Feb 17 2025 '!UIText'
-rw-rw-r--  1 hadoop hadoop 16 Feb 17 2025 '!Upgrade'
-rw-rw-r--  1 hadoop hadoop 10176 Feb 17 2025 '!Validation'
```

5. 数据加载代码

```
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$ cat MRPCDataset.py
import pandas as pd
from torch.utils.data import Dataset

class MRPCDataset(Dataset):
    def __init__(self, train=True):
        self.data_path = "/home/hadoop/bert-experiment/data/msr_paraphrase_train.txt" if train else "/home/hadoop/bert-experiment/data/msr_paraphrase_test.txt"
        self.data = self.load_data()

    def load_data(self):
        # 直接读取训练/测试数据文件
        df = pd.read_csv(
            self.data_path,
            sep='\t',
            skiprows=1, # 跳过表头
            names=['label', 'id1', 'id2', 'sent1', 'sent2'],
            encoding='utf-8'
        )

        # 返回标签和句子对
        data = []
        for _, row in df.iterrows():
            label = int(row['label'])
            sent1 = str(row['sent1'])
            sent2 = str(row['sent2'])
            data.append([label, sent1, sent2])

        return data

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

    def __getitem__(self, idx):
        label = self.data[idx][0]
        sent1 = self.data[idx][1]
        sent2 = self.data[idx][2]
        return (sent1, sent2), label
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$
```

6. 模型定义代码

```
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$ cat FCModel.py
import torch
import torch.nn as nn

class FCModel(nn.Module):
    def __init__(self, input_dim=768, hidden_dim=256, output_dim=1):
        super(FCModel, self).__init__()
        self.fc1 = nn.Linear(input_dim, hidden_dim)
        self.fc2 = nn.Linear(hidden_dim, output_dim)
        self.relu = nn.ReLU()
        self.dropout = nn.Dropout(0.3)

    def forward(self, x):
        x = self.fc1(x)
        x = self.relu(x)
        x = self.dropout(x)
        x = self.fc2(x)
        x = torch.sigmoid(x)
        return x
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$
```

7. 数据测试代码

```
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$ cat test_simple.py
from MRPCDataset import MRPCDataset

print("测试简化版MRPC数据加载...")

try:
    # 测试训练集
    train_dataset = MRPCDataset(train=True)
    print(f"训练集样本数: {len(train_dataset)}")
    print("第一个样本:")
    print(f" 标签: {train_dataset[0][1]}")
    print(f" 句子1: {train_dataset[0][0][0]}")
    print(f" 句子2: {train_dataset[0][0][1]")

    # 测试测试集
    test_dataset = MRPCDataset(train=False)
    print(f"测试集样本数: {len(test_dataset)}")

    print(" 数据加载成功!")
    print(f" 总样本数: 训练集{len(train_dataset)} + 测试集{len(test_dataset)} = {len(train_dataset) + len(test_dataset)}")

except Exception as e:
    print(f" 数据加载失败: {e}")
    import traceback
    traceback.print_exc()
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$
```

8. 训练配置代码

```
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$ cat train_bert_fast.py
import torch
from torch.utils.data import DataLoader
from FCModel import FCModel
from MRPCDataset import MRPCDataset
from transformers import BertTokenizer, BertModel
import os
import time

os.environ['HF_ENDPOINT'] = 'https://hf-mirror.com'

print(" BERT同义句预测 - 快速训练版 (30-60分钟)")
print("=" * 50)

# 创建小批量数据集类
class FastMRPCDataset(torch.utils.data.Dataset):
    def __init__(self, original_dataset, num_samples=500):
        # 只使用前num_samples个样本
        self.data = original_dataset.data[:num_samples]

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

    def __getitem__(self, idx):
        label = self.data[idx][0]
        sent1 = self.data[idx][1]
        sent2 = self.data[idx][2]
        return (sent1, sent2), label

# 加载数据 - 使用少量样本
print(" 加载数据...")
start_time = time.time()

train_dataset = FastMRPCDataset(MRPCDataset(train=True), 500) # 只500个训练样本
test_dataset = FastMRPCDataset(MRPCDataset(train=False), 200) # 只200个测试样本

train_loader = DataLoader(train_dataset, batch_size=8, shuffle=True)
test_loader = DataLoader(test_dataset, batch_size=8, shuffle=False)

print(f" 数据加载完成：训练集{len(train_dataset)}条，测试集{len(test_dataset)}条")

# 设备配置
device = torch.device('cuda' if torch.cuda.is_available() else 'cpu')
print(f" 设备配置完成：使用{device}")

# 加载模型
print(" 加载BERT模型和Tokenizer...")
tokenizer = BertTokenizer.from_pretrained("bert-base-uncased")
bert_model = BertModel.from_pretrained("bert-base-uncased")
bert_model.to(device)

classifier = FCModel(input_dim=768)
classifier.to(device)
print(" 模型加载完成")

# 优化器和损失函数
bert_optimizer = torch.optim.Adam(bert_model.parameters(), lr=2e-5) # 稍大的学习率
cls_optimizer = torch.optim.Adam(classifier.parameters(), lr=1e-3)
criterion = torch.nn.BCELoss()

print(" 优化器配置完成")
```

```

print(" 优化器配置完成")

# 准确率计算
def calculate_acc(predictions, labels):
    rounded_preds = torch.round(predictions)
    correct = (rounded_preds == labels).float()
    return correct.sum() / len(correct)

# 快速训练函数
def train_one_epoch_fast(epoch):
    bert_model.train()
    classifier.train()
    total_loss, total_acc = 0.0, 0.0
    batch_count = 0

    for batch_idx, ((sent1, sent2), labels) in enumerate(train_loader):
        labels = labels.to(device).float()

        # 使用较短的序列长度加快训练
        encoding = tokenizer(
            sent1, sent2,
            return_tensors='pt',
            padding=True,
            truncation=True,
            max_length=64 # 较短的序列
        )
        encoding = {k: v.to(device) for k, v in encoding.items()}

        # 前向传播
        bert_output = bert_model(**encoding)
        pooler_output = bert_output.pooler_output
        preds = classifier(pooler_output).squeeze()

        # 计算损失
        loss = criterion(preds, labels)
        acc = calculate_acc(preds, labels)

        # 反向传播
        bert_optimizer.zero_grad()
        cls_optimizer.zero_grad()
        loss.backward()
        bert_optimizer.step()
        cls_optimizer.step()

        total_loss += loss.item() * len(labels)
        total_acc += acc.item() * len(labels)
        batch_count += len(labels)

        # 每3个batch显示进度
        if (batch_idx + 1) % 3 == 0:
            current_time = time.time() - start_time
            mins = int(current_time // 60)
            secs = int(current_time % 60)
            print(f" [{mins:02d}]:{secs:02d}] Epoch{epoch+1} Batch{batch_idx+1}: Loss={loss.item():.4f}, Acc={acc.item():.4f}")

    avg_loss = total_loss / len(train_dataset)
    avg_acc = total_acc / len(train_dataset)
    return avg_loss, avg_acc

# 快速评估函数
def evaluate_fast():


```

```

# 快速评估函数
def evaluate_fast():
    bert_model.eval()
    classifier.eval()
    total_loss, total_acc = 0.0, 0.0

    with torch.no_grad():
        for batch_idx, ((sent1, sent2), labels) in enumerate(test_loader):
            labels = labels.to(device).float()
            encoding = tokenizer(sent1, sent2, return_tensors='pt', padding=True, truncation=True, max_length=64)
            encoding = {k: v.to(device) for k, v in encoding.items()}

            bert_output = bert_model(**encoding)
            pooler_output = bert_output.pooler_output
            preds = classifier(pooler_output).squeeze()

            loss = criterion(preds, labels)
            acc = calculate_acc(preds, labels)

            total_loss += loss.item() * len(labels)
            total_acc += acc.item() * len(labels)

    avg_loss = total_loss / len(test_dataset)
    avg_acc = total_acc / len(test_dataset)
    return avg_loss, avg_acc

# 开始训练
print("\n 开始快速训练...")
print("预计时间: 30-60分钟")
print("配置: 500训练样本, 200测试样本, batch_size=8, 2个epoch")

num_epochs = 2
total_start_time = time.time()

for epoch in range(num_epochs):
    epoch_start_time = time.time()

    print(f"\n{'='*50}")
    print(f"Epoch {epoch+1}/{num_epochs}")
    print(f"{'='*50}")

    # 训练
    train_loss, train_acc = train_one_epoch_fast(epoch)
    epoch_time = time.time() - epoch_start_time
    print(f" 训练完成: Loss={train_loss:.4f}, Acc={train_acc:.4f} (耗时: {int(epoch_time//60)}分{int(epoch_time%60)}秒)")

    # 快速测试
    test_loss, test_acc = evaluate_fast()
    print(f" 测试完成: Loss={test_loss:.4f}, Acc={test_acc:.4f}")


```

```

# 保存模型
total_time = time.time() - total_start_time
print(f"\n 训练完成！总耗时: {int(total_time//60)}分{int(total_time%60)}秒")

try:
    torch.save({
        'bert_state': bert_model.state_dict(),
        'classifier_state': classifier.state_dict()
    }, "bert_mrpc_fast.pth")
    print(" 模型已保存为: bert_mrpc_fast.pth")
except Exception as e:
    print(f" 模型保存失败: {e}")

print("\n 最终结果:")
print(f" 训练准确率: {train_acc:.4f}")
print(f" 测试准确率: {test_acc:.4f}")
print(f" BERT同义句预测实验快速版完成！")

# 立即进行推理演示
print("\n 开始推理演示...")
bert_model.eval()
classifier.eval()

demo_pairs = [
    ("I love playing basketball.", "Basketball is my favorite sport."),
    ("The cat sat on the mat.", "The dog ran in the park."),
]

print("推理测试结果:")
for sent1, sent2 in demo_pairs:
    with torch.no_grad():
        encoding = tokenizer(sent1, sent2, return_tensors='pt', padding=True, truncation=True, max_length=64)
        encoding = {k: v.to(device) for k, v in encoding.items()}

        bert_output = bert_model(**encoding)
        pooler_output = bert_output.pooler_output
        pred_prob = classifier(pooler_output).squeeze().item()

        result = "同义" if pred_prob >= 0.5 else "不同义"

        print(f" '{sent1}'")
        print(f" '{sent2}'")
        print(f" →同义概率: {pred_prob:.4f} →{result}")
        print()

(bert-mrpc) hadoop@ubuntu:~/bert-experiment$ 

```

9. 训练结果

```

(bert-mrpc) hadoop@ubuntu:~/bert-experiment$ python train_bert_fast.py
BERT同义句预测 - 快速训练版 (30-60分钟)
=====
加载数据...
数据加载完成：训练集500条，测试集200条
设备配置完成：使用cpu
加载BERT模型和Tokenizer...
Some weights of the model checkpoint at bert-base-uncased were not used when initializing BertModel: ['cls.seq_relationship.bias', 'cls.predictions.bias', 'cls.seq_relationship.weight', 'cls.predictions.decoder.weight', 'cls.predictions.transform.dense.weight', 'cls.predictions.transform.dense.bias', 'cls.predictions.transform.LayerNorm.weight', 'cls.predictions.transform.LayerNorm.bias']
- This IS expected if you are initializing BertModel from the checkpoint of a model trained on another task or with another architecture (e.g. initializing a BertForSequenceClassification model from a BertForPreTraining model).
- This IS NOT expected if you are initializing BertModel from the checkpoint of a model that you expect to be exactly identical (in initializing a BertForSequenceClassification model from a BertForSequenceClassification model).
模型加载完成
优化器配置完成

开始快速训练...
预计时间: 30-60分钟
配置: 500训练样本, 200测试样本, batch_size=8, 2个epoch
=====
Epoch 1/2
=====
Be aware, overflowing tokens are not returned for the setting you have chosen, i.e. sequence pairs with the 'longest_first' truncation strategy. So the returned list will always be empty even if some tokens have been removed.
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[00:50] Epoch1 Batch3: Loss=0.9326, Acc=0.5000
Be aware, overflowing tokens are not returned for the setting you have chosen, i.e. sequence pairs with the 'longest_first' truncation strategy. So the returned list will always be empty even if some tokens have been removed.
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[01:15] Epoch1 Batch6: Loss=0.8817, Acc=0.2500
Be aware, overflowing tokens are not returned for the setting you have chosen, i.e. sequence pairs with the 'longest_first' truncation strategy. So the returned list will always be empty even if some tokens have been removed.
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[01:38] Epoch1 Batch9: Loss=0.6734, Acc=0.6250
Be aware, overflowing tokens are not returned for the setting you have chosen, i.e. sequence pairs with the 'longest_first' truncation strategy. So the returned list will always be empty even if some tokens have been removed.
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测试完成: Loss=0.6613, Acc=0.6850  
=====  
Epoch 2/2  
=====  
Be aware, overflowing tokens are not returned for the setting you have chosen, i.e. sequence pairs with the 'longest_first' truncation strategy. So the returned list will always be empty even if some tokens have been removed.  
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[09:29] Epoch2 Batch3: Loss=0.5679, Acc=0.7500  
Be aware, overflowing tokens are not returned for the setting you have chosen, i.e. sequence pairs with the 'longest_first' truncation strategy. So the returned list will always be empty even if some tokens have been removed.  
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Be aware, overflowing tokens are not returned for the setting you have chosen, i.e. sequence pairs with the 'longest_first' truncation strategy. So the returned list will always be empty even if some tokens have been removed.  
测试完成: Loss=0.7917, Acc=0.7150  
训练完成！总耗时: 17分34秒  
模型已保存为: bert_mrpc_fast.pth  
最终结果:  
训练准确率: 0.8520  
测试准确率: 0.7150  
BERT同义句预测实验快速版完成！  
开始推理演示...  
推理测试结果:  
'I love playing basketball.'  
'Basketball is my favorite sport.'  
→同义概率: 0.9338 →同义  
  
'The cat sat on the mat.'  
'The dog ran in the park.'  
→同义概率: 0.3516 →不同义  
(bert-mrpc) hadoop@ubuntu:~/bert-experiment$
```

实验分析与体会

通过本次 BERT 同义句预测实验，我深刻体会到预训练模型在自然语言处理任务中的强大能力。实验结果表明，即使仅使用少量数据进行微调，BERT 模型也能达到 71.5% 的测试准确率，这充分证明了迁移学习的有效性。模型能够准确识别相关句子的同义关系（93.38% 概率），同时正确区分句子的不同义关系（35.16% 概率），展现了其对语义深层理解的能力。实验过程中遇到的网络连接、内存限制等问题，让我认识到实际工程环境中资源优化的重要性。通过调整 batch_size、序列长度等参数，在保证效果的同时显著提升了训练效率。同时，训练准确率（85.2%）与测试准确率（71.5%）的差距也提醒我过拟合问题的存在，未来可考虑增加数据增强或调整模型复杂度来改进。这次实践不仅让我掌握了 BERT 微调的技术流程，更让我理解了深度学习在实际应用中的挑战与解决方案。