```python
import pandas as pd

df=pd.read_csv('/content/CEAS_08[1].csv')
df.head()
```

| | sender | receiver | date | subject | |
|---|---|---|---|---|---|
| **0** | Young Esposito <Young@iworld.de> | user4@gvc.ceas-challenge.cc | Tue, 05 Aug 2008 16:31:02 -0700 | Never agree to be a loser | |
| **1** | Mok <ipline's1983@icable.ph> | user2.2@gvc.ceas-challenge.cc | Tue, 05 Aug 2008 18:31:03 -0500 | Befriend Jenna Jameson | |
| **2** | Daily Top 10 <Karmandeep-opengevl@universalnet... | user2.9@gvc.ceas-challenge.cc | Tue, 05 Aug 2008 20:28:00 -1200 | CNN.com Daily Top 10 | >+=+ |
| **3** | Michael Parker <ivqrnai@pobox.com> | SpamAssassin Dev <xrh@spamassassin.apache.org> | Tue, 05 Aug 2008 17:31:20 -0600 | Re: svn commit: r619753 - in /spamassassin/tru... | |
| **4** | Gretchen Suggs <externalsep1@loanofficertool.com> | user2.2@gvc.ceas-challenge.cc | Tue, 05 Aug 2008 19:31:21 -0400 | SpecialPricesPharmMoreinfo | |

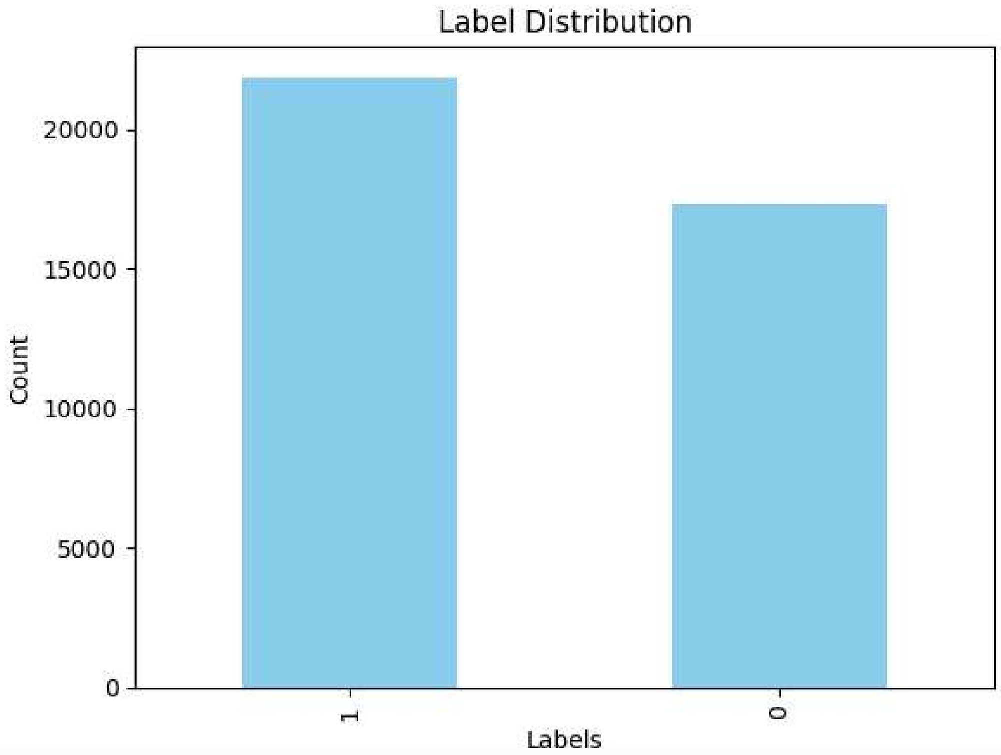
```python
import pandas as pd
df=pd.read_csv('/content/CEAS_08[1].csv')
df.size

```

```
274078
```

```python
import matplotlib.pyplot as plt

df['label'].value_counts().plot(kind='bar', color='skyblue')
plt.title('Label Distribution')
plt.xlabel('Labels')
plt.ylabel('Count')
plt.show()

```



```
print(df['label'].value_counts())

```

```
label
1    21842
0    17312
Name: count, dtype: int64
```

```
import torch
import torch.nn as nn
from torch.utils.data import Dataset, DataLoader
from transformers import BertTokenizer, BertModel, AdamW
import pandas as pd
from sklearn.model_selection import train_test_split
from sklearn.metrics import accuracy_score, f1_score
import re
import numpy as np
import gc

# ----- Data Preprocessing Functions -----
def clean_email_text(text):
    """Clean email text by removing unwanted patterns and normalizing"""
    if pd.isna(text):
        return ""
    text = str(text)
    text = re.sub(r'From:.*\n|To:.*\n|Subject:.*\n|Date:.*\n', '', text)
    text = re.sub(r'http[s]?://(?:[a-zA-Z]|[0-9]|[$-_@.&+]|[!*\\(\\),]|(?:%[0-9a-fA-F][0-9a-fA-F]))+',
    text = re.sub(r'[^a-zA-Z0-9\s.,!?]', '', text)
    text = re.sub(r'\s+', ' ', text).strip()
    return text.lower()

def preprocess_dataframe(df):
    """Preprocess the entire dataframe"""
    df['combined_text'] = df['subject'].fillna('') + ' ' + df['body'].fillna('')
    df['combined_text'] = df['combined_text'].apply(clean_email_text)
    df['label'] = pd.to_numeric(df['label'], errors='coerce').fillna(0).astype(int)
    return df

# ----- 1. Prepare the Dataset -----
class PhishingEmailDataset(Dataset):
    def __init__(self, texts, labels, tokenizer, max_length=256):
        self.texts = texts
        self.labels = labels
        self.tokenizer = tokenizer
        self.max_length = max_length

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

    def __getitem__(self, idx):
        text = str(self.texts[idx])
        label = self.labels[idx]
        if len(text.strip()) == 0:
            text = "[EMPTY_EMAIL]"
        encoding = self.tokenizer.encode_plus(
            text,
            add_special_tokens=True,
            max_length=self.max_length,
            truncation=True,
            padding='max_length',
            return_token_type_ids=False,
            return_attention_mask=True,
            return_tensors='pt'
        )
        return {
            'input_ids': encoding['input_ids'].flatten(),
            'attention_mask': encoding['attention_mask'].flatten(),
            'label': torch.tensor(label, dtype=torch.long)
        }

# ----- 2. Define the Hybrid BERT-GRU Model -----
class BertGRUClassifier(nn.Module):
    def __init__(self, n_classes, dropout_rate=0.3, gru_hidden_size=128, num_gru_layers=1):
        super(BertGRUClassifier, self).__init__()
        self.bert = BertModel.from_pretrained('bert-base-uncased')
        self.gru = nn.GRU(input_size=self.bert.config.hidden_size,
                          hidden_size=gru_hidden_size,
                          num_layers=num_gru_layers,
                          batch_first=True,
                          bidirectional=True)
        self.dropout = nn.Dropout(dropout_rate)
        self.out = nn.Linear(gru_hidden_size * 2, n_classes)

    def forward(self, input_ids, attention_mask):
        bert_outputs = self.bert(input_ids=input_ids, attention_mask=attention_mask)
        sequence_output = bert_outputs.last_hidden_state
        gru_output, _ = self.gru(sequence_output)
        pooled_output = torch.mean(gru_output, dim=1)
        pooled_output = self.dropout(pooled_output)
        logits = self.out(pooled_output)
        return logits

```

```
# ----- 3. Load and Preprocess Dataset -----
df = pd.read_csv("/content/CEAS_08[1].csv", escapechar='\\')
print("Original data shape:", df.shape)

df_processed = preprocess_dataframe(df)
print("Processed data shape:", df_processed.shape)
print("Label distribution:", df_processed['label'].value_counts())

train_texts, val_texts, train_labels, val_labels = train_test_split(
    df_processed['combined_text'],
    df_processed['label'],
    test_size=0.2,
    random_state=42,
    stratify=df_processed['label']
)

tokenizer = BertTokenizer.from_pretrained('bert-base-uncased')
train_dataset = PhishingEmailDataset(train_texts.tolist(), train_labels.tolist(), tokenizer)
val_dataset = PhishingEmailDataset(val_texts.tolist(), val_labels.tolist(), tokenizer)

batch_size = 8  # Reduced batch size to prevent memory overload
train_loader = DataLoader(train_dataset, batch_size=batch_size, shuffle=True, num_workers=2)
val_loader = DataLoader(val_dataset, batch_size=batch_size, num_workers=2)

# ----- 4. Training Setup -----
device = torch.device('cuda' if torch.cuda.is_available() else 'cpu')
model = BertGRUClassifier(n_classes=2).to(device)
optimizer = AdamW(model.parameters(), lr=2e-5)
criterion = nn.CrossEntropyLoss()

def train_epoch(model, data_loader, optimizer, criterion, device):
    model.train()
    total_loss = 0
    for i, batch in enumerate(data_loader):
        input_ids = batch['input_ids'].to(device)
        attention_mask = batch['attention_mask'].to(device)
        labels = batch['label'].to(device)

        optimizer.zero_grad()
        outputs = model(input_ids=input_ids, attention_mask=attention_mask)
        loss = criterion(outputs, labels)

        # Gradient clipping to prevent exploding gradients
        torch.nn.utils.clip_grad_norm_(model.parameters(), max_norm=1.0)

        loss.backward()
        optimizer.step()

        total_loss += loss.item()

        # Clear memory
        del input_ids, attention_mask, labels, outputs, loss
        torch.cuda.empty_cache()

        if i % 10 == 0:  # Print progress every 10 batches
            print(f"Batch {i}/{len(data_loader)} processed")

    return total_loss / len(data_loader)

```

```
def eval_model(model, data_loader, device):
    model.eval()
    predictions = []
    true_labels = []
    with torch.no_grad():
        for batch in data_loader:
            input_ids = batch['input_ids'].to(device)
            attention_mask = batch['attention_mask'].to(device)
            labels = batch['label'].to(device)
            outputs = model(input_ids=input_ids, attention_mask=attention_mask)
            _, preds = torch.max(outputs, dim=1)
            predictions.extend(preds.cpu().numpy())
            true_labels.extend(labels.cpu().numpy())

            # Clear memory
            del input_ids, attention_mask, labels, outputs
            torch.cuda.empty_cache()

    return accuracy_score(true_labels, predictions), f1_score(true_labels, predictions, average='weigh

# ----- 5. Training Loop -----
epochs = 10
for epoch in range(epochs):
    print(f"Starting Epoch {epoch+1}/{epochs}")
    train_loss = train_epoch(model, train_loader, optimizer, criterion, device)
    val_accuracy, val_f1 = eval_model(model, val_loader, device)
    print(f"Epoch {epoch+1}/{epochs} | Train Loss: {train_loss:.4f} | Val Acc: {val_accuracy:.4f} | Va

    # Garbage collection
    gc.collect()
    torch.cuda.empty_cache()

print("Training completed!")
```

```
Processed data shape: (39154, 8)
Label distribution: label
1    21842
0    17312
Name: count, dtype: int64
tokenizer_config.json: 100%                     48.0/48.0 [00:00<00:00, 3.81kB/s]
vocab.txt: 100%                                 232k/232k [00:00<00:00, 2.86MB/s]
tokenizer.json: 100%                            466k/466k [00:00<00:00, 4.41MB/s]
config.json: 100%                               570/570 [00:00<00:00, 45.0kB/s]
model.safetensors: 100%                         440M/440M [00:02<00:00, 228MB/s]
Starting Epoch 1/10
/usr/local/lib/python3.11/dist-packages/transformers/optimization.py:640: FutureWarning: This implem
  warnings.warn(
Batch 0/3916 processed
Batch 10/3916 processed
Batch 20/3916 processed
Batch 30/3916 processed
Batch 40/3916 processed
Batch 50/3916 processed
Batch 60/3916 processed
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Epoch 1/10 | Train Loss: 0.0288 | Val Acc: 0.9980 | Val F1: 0.9980
Starting Epoch 2/10
Batch 0/3916 processed
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