Fake News Detection (CNN-LSTM Hybrid Model)

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We have developed a Automated fake news detection model using a hybrid neural network architecture that integrates Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) networks.

This model leverages a Hybrid approach, to enhance the classification performance by reducing the complexity of feature vectors before passing them through the neural network.

1. Import Modules

Run this for installing the required modules

In [1]:
```
# %pip install -r requirements.txt
```

To use GPU even if Display is using Nvidia GPU instead of Intel GPU

In [2]:
```
import os
os.environ["CUDA_VISIBLE_DEVICES"] = "0" # Removes CUDA errors as GPU mi
```

Downloading NLTK Data

In [3]:

```
import nltk
from nltk.corpus import stopwords
from nltk.stem import WordNetLemmatizer
from nltk import word_tokenize

current_dir = os.getcwd()
nltk_data_dir = os.path.join(current_dir, 'nltk_data')

if not os.path.exists(nltk_data_dir):
    os.makedirs(nltk_data_dir)

nltk.data.path = [nltk_data_dir]
os.environ['NLTK_DATA'] = nltk_data_dir

try:
    print(f"NLTK data path: {nltk.data.path}")
    stop_words = nltk.corpus.stopwords.words('english')
    wordnet = nltk.corpus.wordnet
    nltk.word_tokenize('sample text')
    print("NLTK data is already available.")
except LookupError:
    print("Downloading NLTK data...")
    nltk.download('stopwords', download_dir=nltk_data_dir)
    nltk.download('wordnet', download_dir=nltk_data_dir)
    nltk.download('punkt', download_dir=nltk_data_dir)
    nltk.download('punkt_tab', download_dir=nltk_data_dir)
    print("NLTK data downloaded successfully.")

stop_words = nltk.corpus.stopwords.words('english')
lemmatizer = nltk.WordNetLemmatizer()
```

```
NLTK data path: ['/home/anirudh/Data/Anirudh/BITS/4-1/DL/FakeNewsDetectio
n/backend/nltk_data']
NLTK data is already available.
```

In [4]:

```
import gensim.downloader

loaded_glove_model = gensim.downloader.load("glove-wiki-gigaword-300")
loaded_glove_embeddings = loaded_glove_model.vectors
```

In [5]:
```
import torch
import torch.nn as nn
import torch.nn.functional as F
from torch.nn.utils.rnn import pad_sequence
from torch.utils.data import DataLoader
from torch.optim import Adam

from sklearn.model_selection import train_test_split
from sklearn.feature_extraction.text import CountVectorizer
from sklearn.metrics import confusion_matrix
from sklearn.metrics import classification_report
from sklearn.metrics import precision_score, recall_score, f1_score, acc
from sklearn.metrics import roc_curve, auc
from sklearn.metrics import precision_recall_curve

import itertools

from wordcloud import WordCloud, STOPWORDS

import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns

from tqdm import tqdm
tqdm.pandas(bar_format='{l_bar}{bar:30}{r_bar}')
```

In [6]:
```
from statistics import mean
from datetime import datetime
import re
import json
```

In [7]:
```
import warnings
warnings.filterwarnings('ignore')
```

Check if CUDA is Available

In [8]:
```
print("CUDA available:", torch.cuda.is_available())
print("Current device:", torch.cuda.get_device_name(0) if torch.cuda.is_

print(torch.version.cuda)
print(torch.backends.cudnn.version())

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

```
CUDA available: True
Current device: NVIDIA GeForce MX250
12.4
90100
```

Out[8]:
```
device(type='cuda')
```

In [9]:

```
params = {
    'target': 'True',
    'data': 'article',
    'embeddingDim': 300,
    'hiddenDim': 256,
    'learningRate': 0.0025,
    'numEpochs': 10,
    'batchSize': 64
}

target = params['target']
data = params['data']
embeddingDim = params['embeddingDim']
hiddenDim = params['hiddenDim']
learningRate = params['learningRate']
numEpochs = params['numEpochs']
batchSize = params['batchSize']
```

2. Import Data

In [10]:

```
realData = pd.read_csv('./datasets/True.csv')
fakeData = pd.read_csv('./datasets/Fake.csv')

# Add the 'real or fake' column to label each dataset
realData[target] = 1
fakeData[target] = 0

combinedData = pd.concat([realData, fakeData], ignore_index=True)
combinedData = combinedData.sample(frac=1, random_state=42).reset_index(

combinedData.head(5)
```

Out[10]:

	title	text	subject	date	True
0	BREAKING: GOP Chairman Grassley Has Had Enoug...	Donald Trump s White House is in chaos, and th...	News	July 21, 2017	0
1	Failed GOP Candidates Remembered In Hilarious...	Now that Donald Trump is the presumptive GOP n...	News	May 7, 2016	0
2	Mike Pence's New DC Neighbors Are HILARIOUSLY...	Mike Pence is a huge homophobe. He supports ex...	News	December 3, 2016	0
3	California AG pledges to defend birth control ...	SAN FRANCISCO (Reuters) - California Attorney ...	politicsNews	October 6, 2017	1
4	AZ RANCHERS Living On US-Mexico Border Destroy...	Twisted reasoning is all that comes from Pelos...	politics	Apr 25, 2017	0

3. Text Preprocessing

In [11]:
```
def preprocess(text):
        text = text.lower()
        text = re.sub(r'[^a-zA-Z0-9\s]', '', text)

        words = [word for word in text.split() if word not in stop_words
        words = [lemmatizer.lemmatize(word) for word in words]

        return ' '.join(words)

from multiprocessing import Pool, cpu_count

def preprocessText(texts):
    with Pool(cpu_count()) as p:
        return list(tqdm(p.imap(preprocess, texts), total=len(texts), de

combinedData['title'] = preprocessText(combinedData['title'])
combinedData['text'] = preprocessText(combinedData['text'])

combinedData.head(5)
```

```
Preprocessing: |██████████████████████████████| 100%
Preprocessing: |██████████████████████████████| 100%
```

Out[11]:

	title	text	subject	date	True
0	breaking gop chairman grassley enough demand t...	donald trump white house chaos trying cover ru...	News	July 21, 2017	0
1	failed gop candidate remembered hilarious mock...	donald trump presumptive gop nominee time reme...	News	May 7, 2016	0
2	mike pences new dc neighbor hilariously trolli...	mike penny huge homophobe support exgay conver...	News	December 3, 2016	0
3	california ag pledge defend birth control insu...	san francisco reuters california attorney gene...	politicsNews	October 6, 2017	1
4	az rancher living usmexico border destroy nanc...	twisted reasoning come pelosi day especially 2...	politics	Apr 25, 2017	0

4. Exploratory Data Preparation & Analysis

Remove (Reuters) from text

In [12]:
```
for i in range(0, len(combinedData["text"])):
    try:
        start = re.search("(Reuters)", combinedData["text"][i][0:49]).en
    except:
        start = 0
    combinedData.loc[i, "text"] = combinedData.loc[i, "text"][start:]
```

In [13]:
```
remaining = combinedData[combinedData['text'].str.contains('Reuters', na

if remaining.empty:
    print("No occurrences of 'Reuters'")
else:
    print("Found remaining occurrences of 'Reuters':")
    print(remaining)
```

```
No occurrences of 'Reuters'
```

Remove Duplicates from Text

In [14]:
```
combinedData['text'].value_counts()[combinedData['text'].value_counts()>
```

```
Out[14]: text

         632
         reuters highlight u president donald trump administration thursday united
         state drop massive gbu43 bomb largest nonnuclear bomb ever used combat af
         ghanistan series cave used islamic state militant pentagon say trump say
         pyongyang problem taken care amid speculation north korea verge sixth nuc
         lear test military force cannot resolve tension north korea china warns i
         nfluential chinese newspaper urge pyongyang halt nuclear program exchange
         beijing protection trump administration focusing north korea strategy tou
         gher economic sanction possibly including intercepting cargo ship punishi
         ng chinese bank business pyongyang u official say trump say thing work fi
         ne united state russia day declaring usrussian relation may alltime low t
         rump signal could moving closer mainstream monetary policy saying ruled r
         eappointment janet yellen federal reserve chair considers choice u centra
         l bank nl1n1hl14b trump sign resolution allow u state restrict federal fu
         nd contraception reproductive health spent move cheered antiabortion camp
         aigner democratic senator chris van hollen press deutsche bank release in
         formation issue including trump debt bank meeting trump administration of
         ficial saying great concern possible conflict interest exportimport bank
         trump office say plan revive hobbled exportimport bank united state victo
         ry american manufacturer boeing co general electric co overseas customer
         use agency governmentbacked loan purchase product top wall street banker
         say positive discussion financial regulation washington downplay idea u p
         olicymakers may force institution split united state pushing trade key is
         sue toplevel economic talk japan source say unwelcome development tokyo s
         eeking fend u pressure reduce bilateral trade imbalance trump administrat
         ion focused one group illegal immigrant others woman child according eigh
         t department homeland security official interviewed reuters agency planni
         ng
         8
         enjoy
         6
         watch
         5
         reuters highlight day u president donald trump administration friday trum
         p back decision former national security adviser michael flynn seek immun
         ity congressional investigation possible tie campaign russia immediate si
         gn request granted trump administration slam china range trade issue chro
         nic industrial overcapacity forced technology transfer longstanding ban u
         beef electronic payment service beijing seek play tension united state pu
         t positive face ahead president xi jinpings first meeting trump next week
         senate democrat step closer enough vote block confirmation vote trump sup
         reme court nominee three democratic senator coming neil gorsuch lifetime
         job justice trump seek push plan fair trade manufacturing job back top ag
         enda ordering study cause u trade deficit clampdown import duty evasion t
         rump neither clear white house tax plan adequate staff yet see planned ta
         x overhaul according interview people administration congress among u tax
         expert democrat trying counter trump boldest move yet defang u consumer f
         inancial watchdog 40 current former lawmaker defending agency court u env
         ironmental protection agency scientific integrity watchdog reviewing whet
         her epa chief scott pruitt violated agency policy said television intervi
         ew believe carbon dioxide driving global climate change according email s
         een reuters trump seek rebuild u relationship egypt meeting monday egypti
         an president abdel fattah alsisi focused security issue military aid seni
         or white house official say trump host jordan king abdullah white house n
         ext week discus fight islamic state militant syria crisis advancing peace
         israeli palestinian white house say u judge approves 25 million settlemen
         t resolve class action lawsuit claimed fraud trump trump university real
         estate seminar
         5

         ...
```

seoul reuters south korea plan buy additional 20 f35a stealth fighter air
craft united state south korean newspaper reported thursday less two mont
h u president donald trump announced seoul would purchasing billion dolla
r new military equipment south korea defence acquisition program administ
ration established process procuring 20 additional aircraft joongang ilbo
newspaper reported citing multiple government source 2014 south korea for
mally announced plan buy 40 f35as american defense contractor lockheed ma
rtin
2
professor olga cox teach human sexuality orange coast college told class
december election donald trump act terrorism despite cox recently nominat
ed selected fellow faculty member professor year awardaccording student o
range coast college tradition recipient annual professor year award keyno
te speaker school graduation ceremony year act terrorism professor cox sa
id class december regarding president trump election one frightening thin
g people life continued people committing assault among u stranger countr
y coming attacking sense mean american thing stand make painful video cap
ture professor olga cox disgusting remarksher comment videotaped occ stud
ent caleb neil suspended school allegedly unlawfully recording indignant
professor school retracted punishment face backlashthe selection professo
r year award made committee consists faculty staff administrator based ru
bric take account multiple factor including teaching service campus commu
nity involvement despite nationwide negative attention condemnation commu
nity wake incident committee recommended professor cox choice receive pro
fessor year occ administration accepted committee nominationdoug bennett
executive director college advancement occ confirmed red alert politics e
mail professor cox nomination professor year award declined accept member
campus community nominated professor cox award committee selected rubric
award made declined say bennett red alert politics
2
omg two gem social medium tv show comedy genius rockstars diamondandsilk
comedyplatinum httpstcoiflm83kmkl james wood realjameswoods april 20 2017
diamond silk happy hypocrite maxine water attack president trump mincing
word latest possible funniest video brutally admonish water great thing d
iamond silk able voice opinion failure black politician like maxine water
without fear labeled racist disagreeing herif know diamond silk missing o
ne entertaining downright unexplainable element donald trump campaign pre
sidentdiamond silk people sister north carolina exact outspoken surrogate
trump description obscures however made pair mustsee act campaign trail i
ndeed anything distinguishes diamond silk runofthemill protrump talking h
ead black woman pretty remarkable undeniable gift debate punditrylynnette
hardaway diamond rochelle richardson silk seek limelight two say launched
youtube channel viewer view simply tired talked medium elite wanted talk
back first video posted viewer view black life matter tribute take long s
ister set sight trump week trump announced entering presidential race dia
mond uploaded first protrump video entitled dump rest chump vote donald t
rump 2016 diamond joined silk next video discussion investigation sandra
bland death police custody second video together however went viral event
ually led diamond silk joining trump campaign trail complexleftists perpl
exed support president trump two outspoken black woman realize diamond si
lk speaking million frustrated american every race across america watch d
iamond silk call problem illegal immigration america video video lady abl
e expose truth serious social economic issue facing nation reported liber
al view mainstream medium perfect blend comedy seriousness able tap feeli
ng frustrated american feel like voice ignored watching one video lady al
most always leave feeling like want stand cheerwhen sister act diamond si
lk take stage though audience sparse erupts cheer ditch switch holler bar
relbellied man love woman vote trump shirt referring duo campaign encoura
ge democrat register republicansdiamond silk beam back crowd oh goodness
diamond taller one coo appreciatively cut chase first noticed black black
found mean vote democrat uproarious applause come democratic plantation v
ote whoever want vote silk standing diamond left bob head agreementdiamon
d possesses timbre timing revivalist minister go need medium spoonfeeding

```
u narrative think started thinking donald j trump see man never waver bac
k love pause emphasis love everything donald j trump wrong eye diamond si
lk loving everything donald trump mean loving spite yearslong racist birt
her campaign various degrading remark black people like laziness trait bl
ack living poverty school good job hell lose mean loving spite bogus stat
istic africanamerican community repeat 58 percent youth unemployed retwee
ts black killed 81 white homicide victim overlooking department justice l
awsuit accusing trump father housing discrimination long demonstrated his
tory racial bias trump propertiesand mean loving right alongside supporte
r one affiliated kkk neonazis white nationalist movement assorted militia
groupsdiamond silk know love anywayanyone think lady give hoot liberal me
dium say beloved new president donald trump watching video      2
looking job american transformation america continuesan illegal immigrant
prosecutor said deported u dozen time arraigned yellowstone county distri
ct court thursday drug chargesalejandro gonzales marquez 37 denied thursd
ay charge felony criminal possession intent distributedeputy chief county
attorney juli pierce said marquez already deported 14 time montana highwa
y patrol trooper arrested billing highway julymarquez speak understand en
glish assisted court translatoraccording court record marquez passenger v
ehicle interstate 90 mhp trooper pulled vehicle obstructed platesthe troo
per reported smelling strong odor alcohol coming vehicle asked driver per
form field sobriety testin vehicle trooper allegedly found one pound meth
amphetamine along loaded 9 mm semiautomatic pistolboth men found country
illegally arrestedmarquez held yellowstone county jail 10000 bondkrtvcom
great fall montanathe codefendant ignacio figueroa rodriguez charged driv
ing influence possession dangerous drug illegal alien addition felony cha
rge possession drug intent distributevia krtv
2
reminds u list demand made american prisoner mexico oh wait never mind bo
rder hot topic country since flood illegal immigrant pouring border make
matter worse illegals receiving benefit hardworking american paid continu
e show lack respect culture make attempt assimilate law enforcement hand
tied every step way able finally detain illegals cause issuesa group 200
illegal immigrant launched hunger strike eloy detention center outside ph
oenix saturday morning men sat recreation yard 945 declared strike advoca
cy group puente movement said taking action called brutal inhumane condit
ionsthe recent death jos de jes denizsahag n rallying cry offender claim
died mysterious circumstance want question answered denizsahag n found de
ad cell show sign injury detainee joined strike saturday said guard beat
locked solitary confinement diedthese criminal also say forced work cente
r 1 per day sometimes receive needed medical treatment francisca porcha d
irector puente movement said outraged one heard scream mercy straw broke
camel back criminal list demand need met strike end includethe independen
t investigation two recent death mysterious circumstance problem guard us
ing excessive forcethe condition detainment improved would include medica
l mental health carethey must access legal resource court hearing request
edthe exploitation detainee work endedthere criminalization detention dep
ortationthe offender say pressured work long shift barely compensation ki
nd hypocrisy united state picking people working without document perfect
ly legal work private corporation 1 day porcha saidin response demand u i
mmigration custom enforcement ice released statement saturday u immigrati
on custom enforcement ice committed ensuring welfare custody ice manager
detention center staff communicate detainee regularly respect right peopl
e express opinion ice detainee continuous observation center staff medica
l personnel sure get behind idea people receive proper medical mental car
e demand really special treatment given since american citizen gall deman
d threat criminalization detention deportation absolute madness would det
ained broken law entered country illegallyvia mad world news
2
Name: count, Length: 5262, dtype: int64
```

In [15]:
```
combinedData['text'].value_counts()[combinedData['text'].value_counts()>
combinedData = combinedData.drop_duplicates(subset=['text'], ignore_inde
```

Checking for Date Length

In [16]:
```
combinedData['dateLen'] = [len(x) for x in combinedData['date']]
print(combinedData['dateLen'].value_counts())
```

```
dateLen
17     7838
12     6689
18     6136
16     3706
14     3631
13     2905
15     2637
11     2472
19     2456
9        35
149       1
66        1
74        1
88        1
120       1
145       1
Name: count, dtype: int64
```

In [17]:
```
print(combinedData[combinedData['dateLen']<10]['date'])
```

```
1073     15-Feb-18
1800     18-Feb-18
2101     17-Feb-18
2217     16-Feb-18
2253     19-Feb-18
2474     15-Feb-18
8770     19-Feb-18
8961     16-Feb-18
10350    17-Feb-18
14834    15-Feb-18
14843    14-Feb-18
16642    16-Feb-18
18364    16-Feb-18
18723    18-Feb-18
18974    19-Feb-18
20360    18-Feb-18
20609    15-Feb-18
21063    16-Feb-18
21304    16-Feb-18
24604    15-Feb-18
25317    18-Feb-18
25401    16-Feb-18
27300    17-Feb-18
28148    17-Feb-18
28557    16-Feb-18
28988    18-Feb-18
29411    15-Feb-18
29618    17-Feb-18
30101    18-Feb-18
33029    15-Feb-18
33930    17-Feb-18
34553    15-Feb-18
35380    18-Feb-18
35833    15-Feb-18
36248    17-Feb-18
Name: date, dtype: object
```

In [18]:

```
print(combinedData[combinedData['dateLen']>18]['date'])
del combinedData['dateLen']
```

```
17       September 26, 2017
68       September 16, 2016
81       September 10, 2017
96       September 12, 2017
98       September 22, 2017
                ...
38469    September 24, 2017
38488    September 25, 2017
38491    September 27, 2017
38497    September 18, 2017
38502    September 19, 2017
Name: date, Length: 2462, dtype: object
```

Fixing Dates

In [19]:
```
indexes = []
for x in combinedData["date"]:
    if re.search("http", x):
        ind = np.where(combinedData["date"] == x)
        (indLst,) = ind
        indexes.append(indLst.tolist())
    elif re.search("MSNBC", x):
        ind = np.where(combinedData["date"] == x)
        (indLst,) = ind
        indexes.append(indLst.tolist())

indexes_ = [element for indLst in indexes for element in indLst]
indexes = list(dict.fromkeys(indexes_))
```

In [20]:
```
indexes
combinedData = combinedData.drop(index=indexes)
```

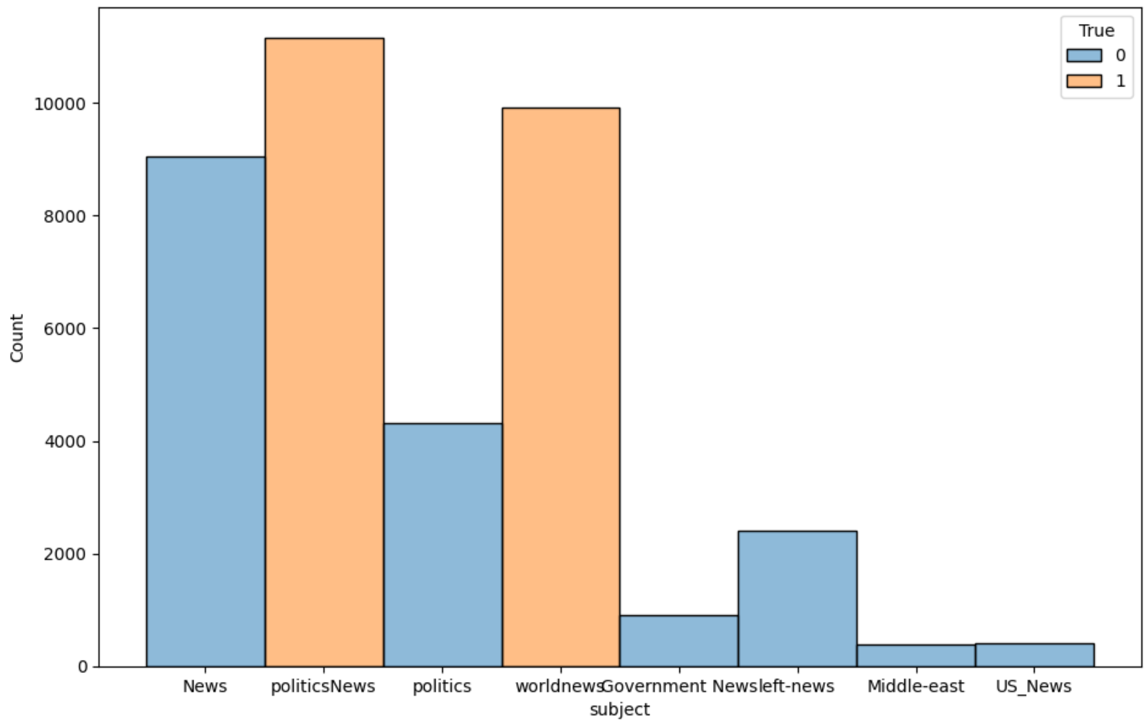
In [21]:
```
dates = []
for x in combinedData["date"]:
    try:
        date = datetime.strptime(x, "%B %d, %Y")
    except ValueError:
        try:
            date = datetime.strptime(x, "%d-%b-%y")
        except ValueError:
            try:
                date = datetime.strptime(x, "%b %d, %Y")
            except ValueError:
                date = datetime.strptime(x, "%B %d, %Y ")
    dates.append(date)
combinedData["date"] = dates
```

In [22]:
```
combinedData['date'].nunique
```

Out[22]:
```
<bound method IndexOpsMixin.nunique of 0       2017-07-21
1       2016-05-07
2       2016-12-03
3       2017-10-06
4       2017-04-25
           ...
38506   2017-10-21
38507   2017-01-18
38508   2016-02-27
38509   2017-11-02
38510   2017-11-01
Name: date, Length: 38505, dtype: datetime64[ns]>
```

Subject Analysis

In [23]:
```
fig, hist = plt.subplots(figsize = (11,7))
hist = sns.histplot(data=combinedData, x = 'subject', hue="True")
```



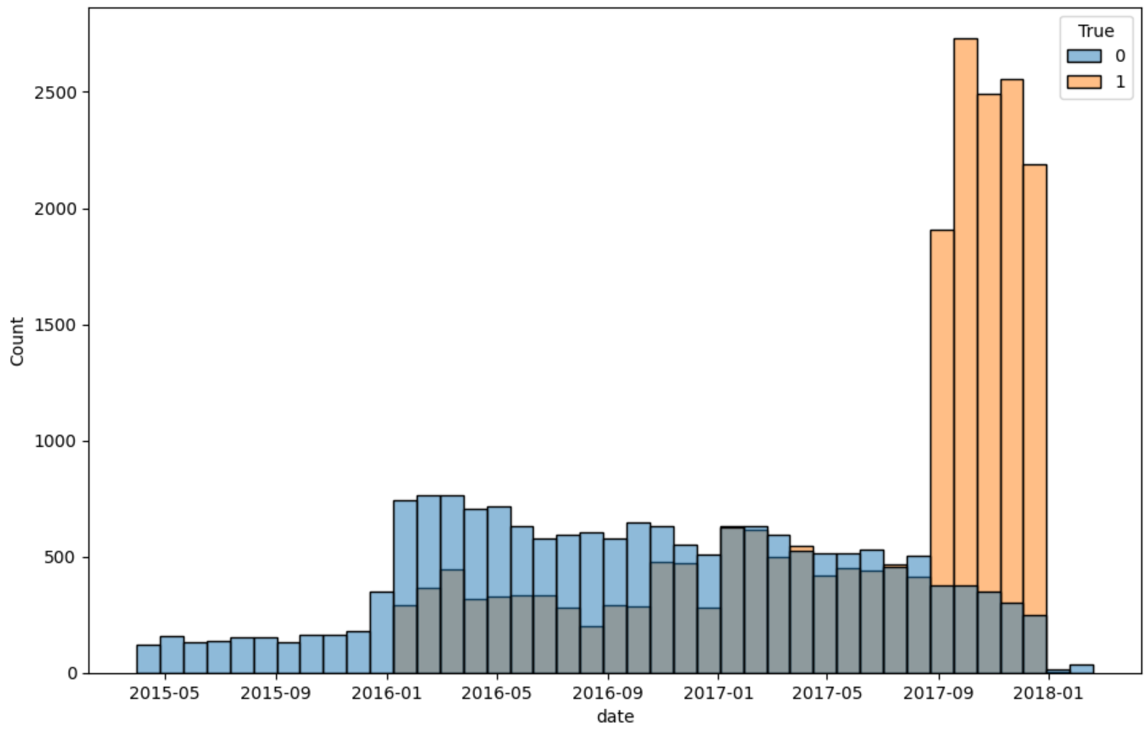
In [24]:
```
combinedData = combinedData.drop(columns=['subject'])
combinedData.head(5)
```

Out[24]:

	title	text	date	True
0	breaking gop chairman grassley enough demand t...	donald trump white house chaos trying cover ru...	2017-07-21	0
1	failed gop candidate remembered hilarious mock...	donald trump presumptive gop nominee time reme...	2016-05-07	0
2	mike pences new dc neighbor hilariously trolli...	mike penny huge homophobe support exgay conver...	2016-12-03	0
3	california ag pledge defend birth control insu...	san francisco reuters california attorney gene...	2017-10-06	1
4	az rancher living usmexico border destroy nanc...	twisted reasoning come pelosi day especially 2...	2017-04-25	0

Date Analysis

In [25]:
```
fig, hist = plt.subplots(figsize = (11,7))
hist = sns.histplot(data=combinedData, x = 'date', hue="True")
```



In [26]:

```
combinedData = combinedData.drop(columns=['date'])
combinedData.head(5)
```

Out[26]:

	title	text	True
0	breaking gop chairman grassley enough demand t...	donald trump white house chaos trying cover ru...	0
1	failed gop candidate remembered hilarious mock...	donald trump presumptive gop nominee time reme...	0
2	mike pences new dc neighbor hilariously trolli...	mike penny huge homophobe support exgay conver...	0
3	california ag pledge defend birth control insu...	san francisco reuters california attorney gene...	1
4	az rancher living usmexico border destroy nanc...	twisted reasoning come pelosi day especially 2...	0

Concatenating Title and Text into one Column

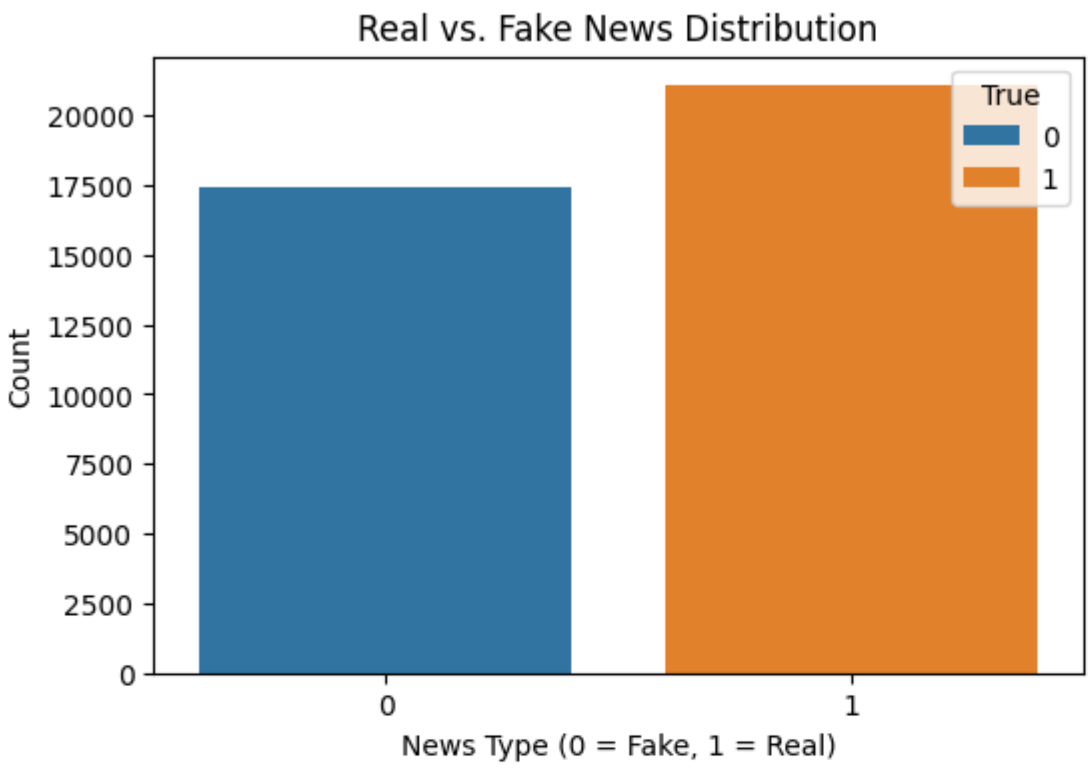
In [27]:

```
combinedData['article'] = combinedData['title'] + '.' + combinedData['te
combinedData = combinedData.drop(columns=['title', 'text'])
```

Real Vs Fake

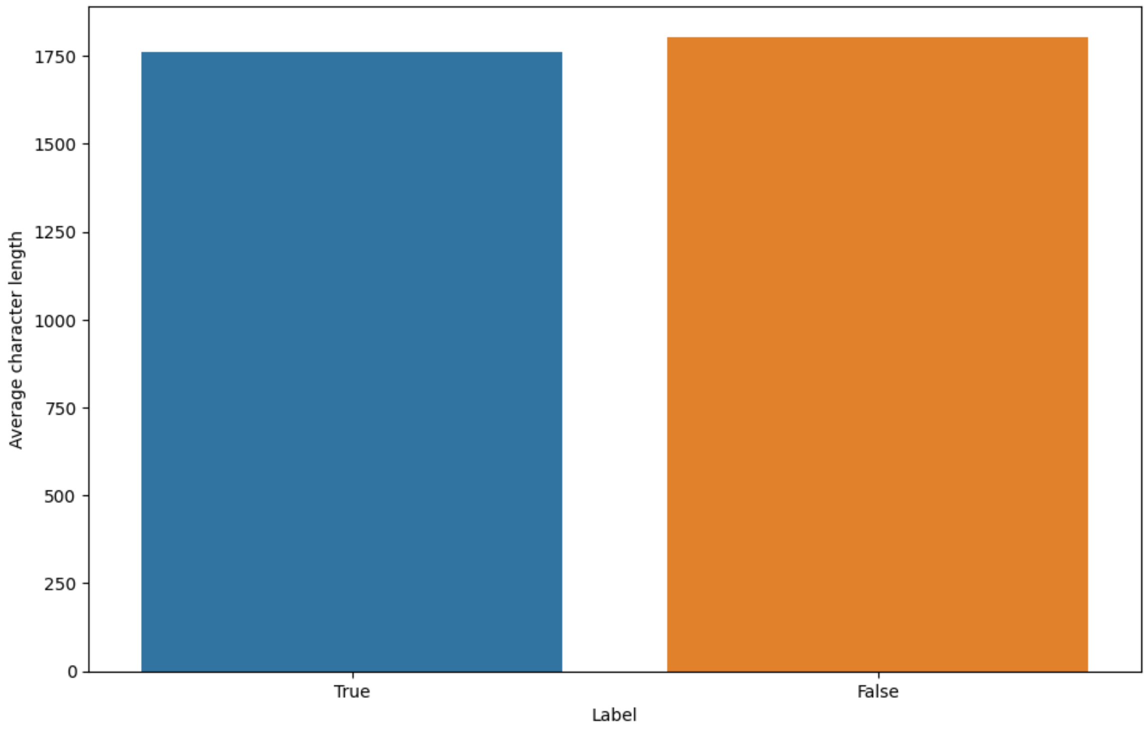
In [28]:

```
plt.figure(figsize=(6, 4))
sns.countplot(x=target, data=combinedData, hue=target)
plt.title("Real vs. Fake News Distribution")
plt.xlabel("News Type (0 = Fake, 1 = Real)")
plt.ylabel("Count")
plt.show()
```



Text Length Analysis

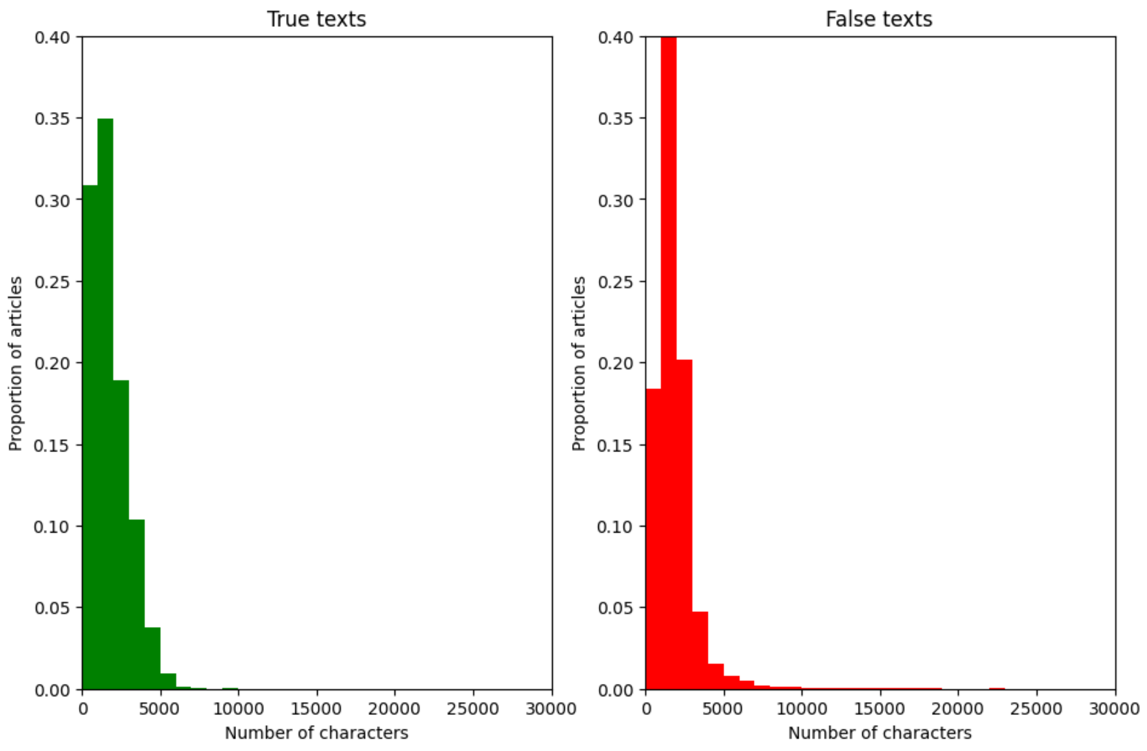
In [29]:
```
trueLen = combinedData[combinedData[target] == 1][data].apply(lambda x: 
fakeLen = combinedData[combinedData[target] == 0][data].apply(lambda x: 
av = pd.DataFrame(data = {'Average character length': [trueLen, fakeLen]
fig, bar = plt.subplots(figsize = (11,7))
bar = sns.barplot(y='Average character length', x='Label',data=av, hue='
```



Character Length Analysis

In [30]:
```
trueCharLen = combinedData[combinedData[target] == 1][data].apply(lambda
falseCharLen = combinedData[combinedData[target] == 0][data].apply(lambda

bins_ = [i * 1000 for i in range(0,31)]

fig, (hist1, hist2) = plt.subplots(1,2, figsize = (11,7))
hist1.hist(trueCharLen, bins = bins_, weights = np.ones(len(trueCharLen)
hist1.set_ylim(0, top=0.4)
hist1.set_xlim(0, 30000)
hist1.set_xlabel('Number of characters')
hist1.set_ylabel('Proportion of articles')
hist1.set_title('True texts')

hist2.hist(falseCharLen, bins = bins_, weights = np.ones(len(falseCharLe
hist2.set_ylim(0, top=0.4)
hist2.set_xlim(0, 30000)
hist2.set_xlabel('Number of characters')
hist2.set_ylabel('Proportion of articles')
hist2.set_title('False texts')
```

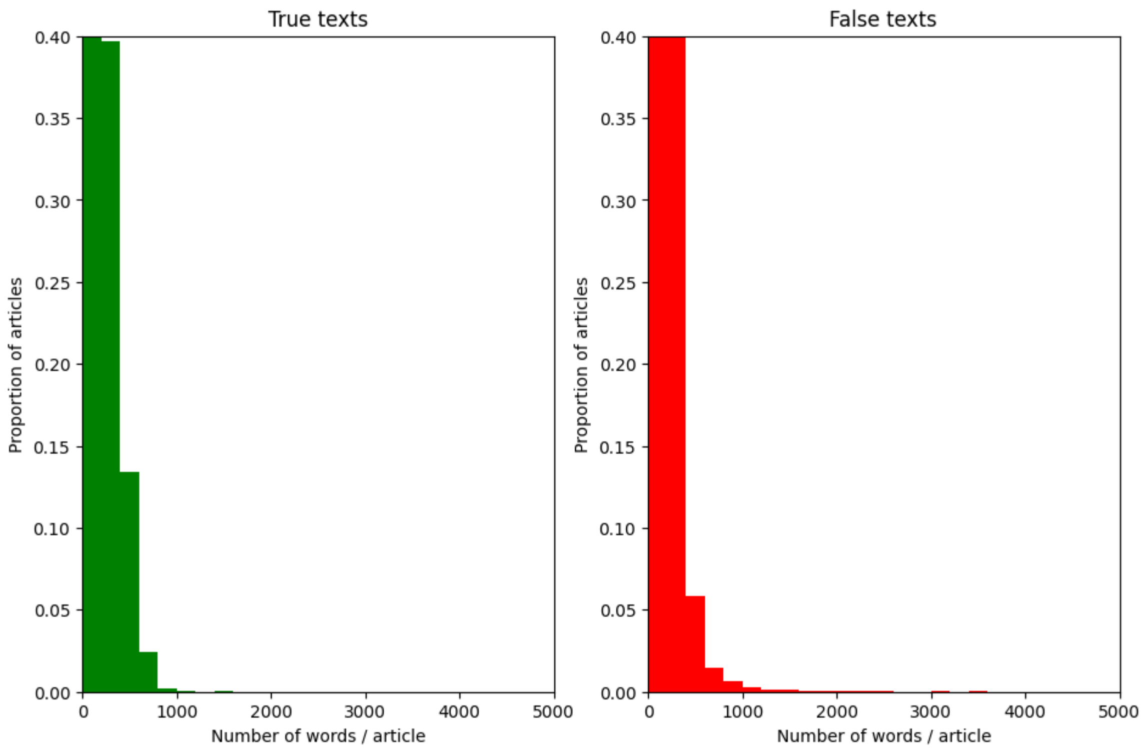
Out[30]:
```
Text(0.5, 1.0, 'False texts')
```



Number of words per article

In [31]:
```
trueWords = combinedData[combinedData[target] == 1][data].str.split().ma
falseWords = combinedData[combinedData[target] == 0][data].str.split().m

bins_ = [i * 200 for i in range(0,26)]

fig, (hist1, hist2) = plt.subplots(1,2, figsize = (11,7))
hist1.hist(trueWords, bins = bins_, weights = np.ones(len(trueWords))/le
hist1.set_ylim(0, top=0.4)
hist1.set_xlim(0, 5000)
hist1.set_xlabel('Number of words / article')
hist1.set_ylabel('Proportion of articles')
hist1.set_title('True texts')

hist2.hist(falseWords, bins = bins_, weights = np.ones(len(falseWords))/
hist2.set_ylim(0, top=0.4)
hist2.set_xlim(0, 5000)
hist2.set_xlabel('Number of words / article')
hist2.set_ylabel('Proportion of articles')
hist2.set_title('False texts')
```

Out[31]:
```
Text(0.5, 1.0, 'False texts')
```

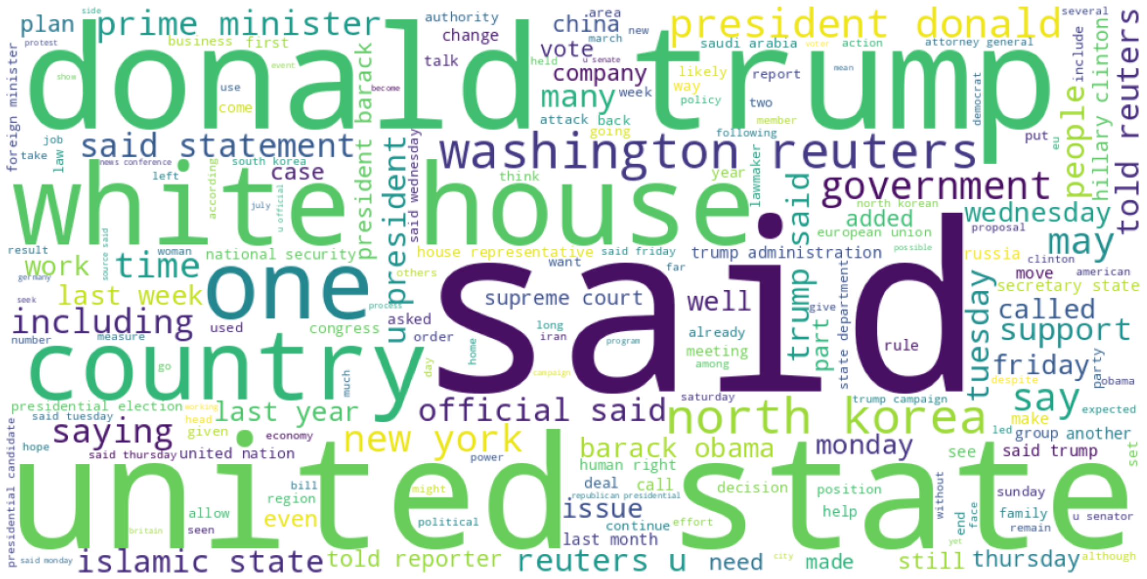


Finding common words for Real and Fake Data using Word Cloud

In [32]:
```
def wordcloud(corpus, title):
    wordcloud = WordCloud(width=1000, height=500, stopwords=STOPWORDS, b
    plt.figure(figsize=(15, 8))
    plt.imshow(wordcloud)
    plt.title(title)
    plt.axis("off")
    plt.show()
```

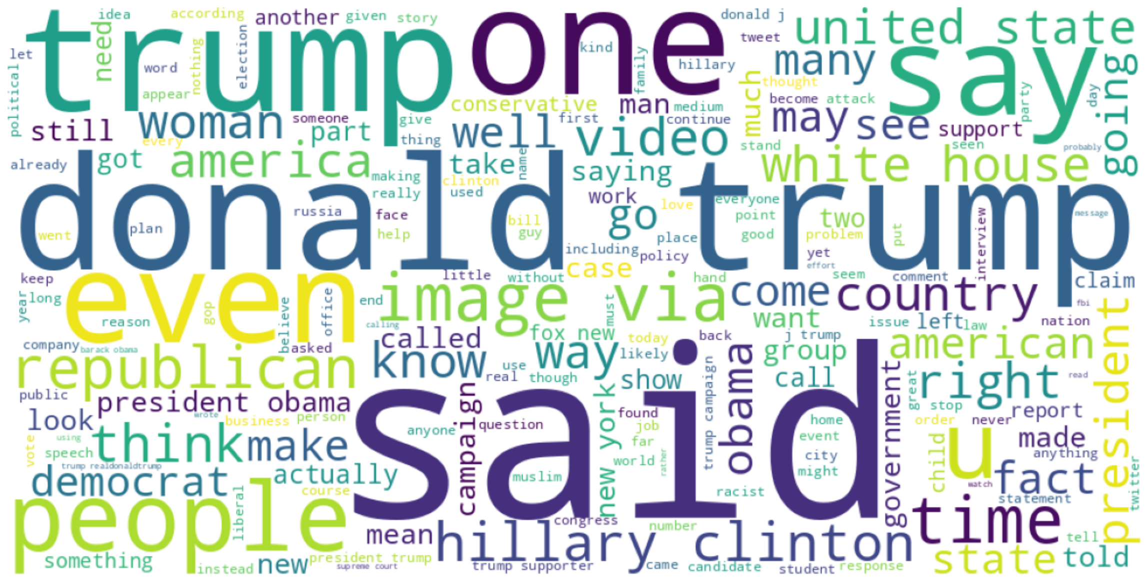
In [33]:
```
wordcloud(combinedData[combinedData[target]==1][data], "WordCloud for Tr
```

WordCloud for True News



In [34]:
```
wordcloud(combinedData[combinedData[target]==0][data], "WordCloud for Fal
```

WordCloud for Fake News

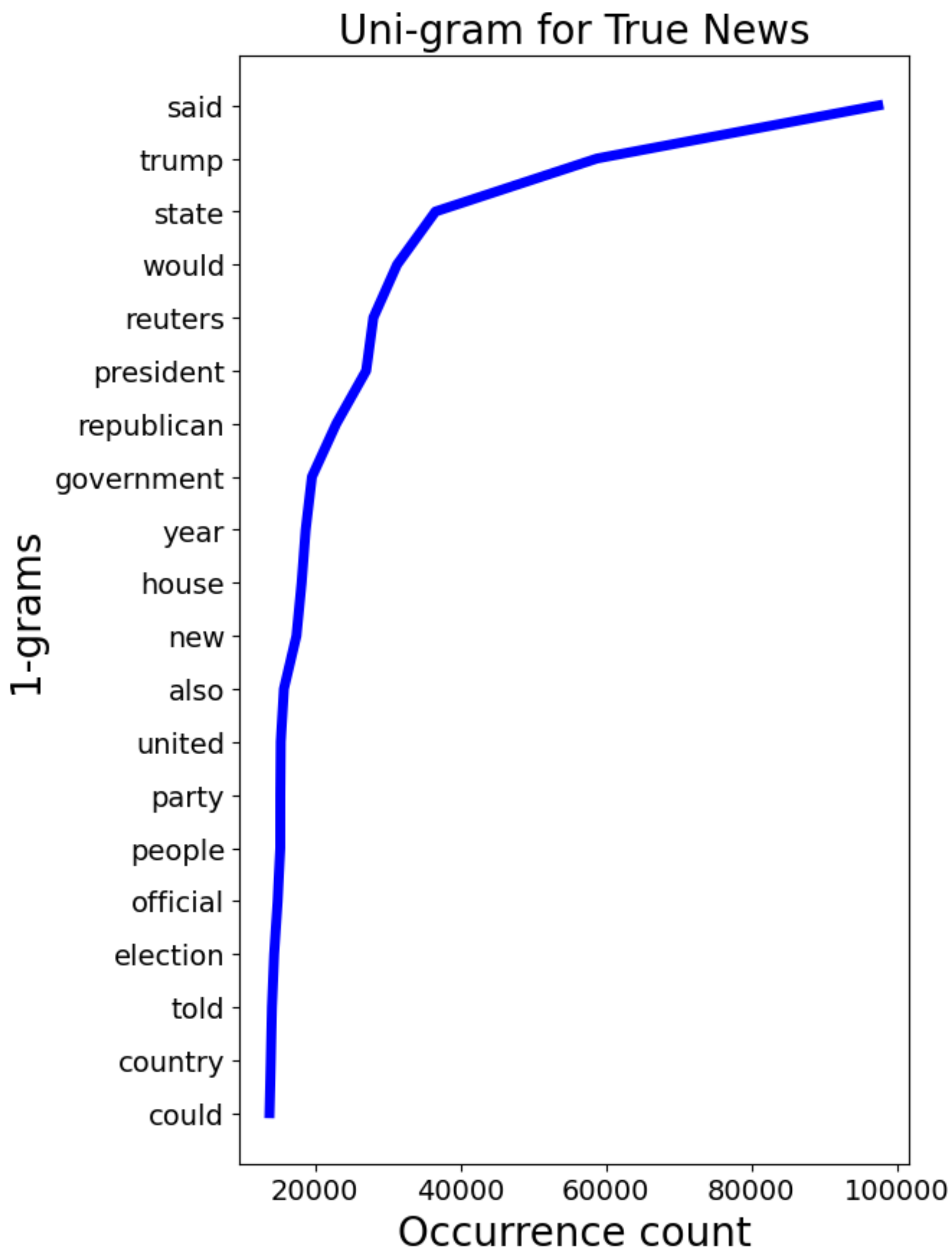


N-Grams

In [35]:
```
def nGrams(corpus, nbGrams, nbWords):
    count = CountVectorizer(ngram_range=(nbGrams, nbGrams)).fit(corpus)
    ensemble = count.transform(corpus).sum(axis=0)
    freq = [(word, ensemble[0, idx]) for word, idx in count.vocabulary_.i
    freq = sorted(freq, key = lambda x: x[1], reverse=True)
    return freq[:nbWords]
```

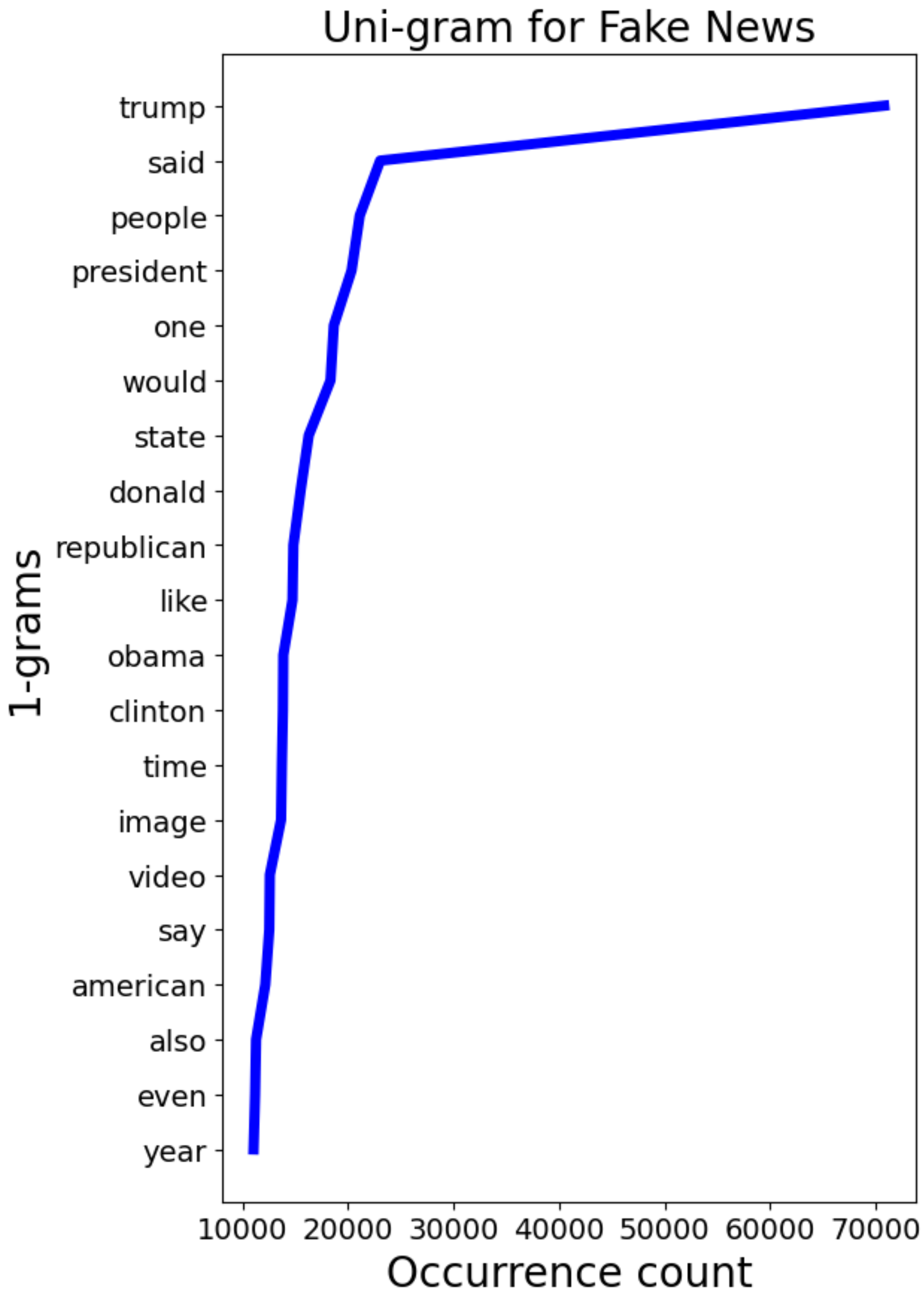
In [36]:
```
def plotnGrams(topnGrams, title, n, num_to_show=20):
    df = pd.DataFrame(topnGrams, columns=["ngram", "count"])

    counts, word = df["count"], df["ngram"]
    zippedLists = zip(counts, word)
    sortedPairs = sorted(zippedLists)

    tuples = zip(*sortedPairs)
    counts, word = [list(tuple) for tuple in tuples]

    plt.figure(figsize=[6, 10])
    plt.plot(counts[-num_to_show:], word[-num_to_show:], lw=5, c="b")
    plt.ylabel("{}-grams".format(n), fontsize=20)
    plt.yticks(fontsize=14)
    plt.xlabel("Occurrence count", fontsize=20)
    plt.xticks(fontsize=14)
    plt.title(title, fontsize=20)
    plt.show()
```

In [37]:
```
b = nGrams(combinedData[combinedData[target]==1][data],1,20)
plotnGrams(b,"Uni-gram for True News" , 1, num_to_show=20)
```

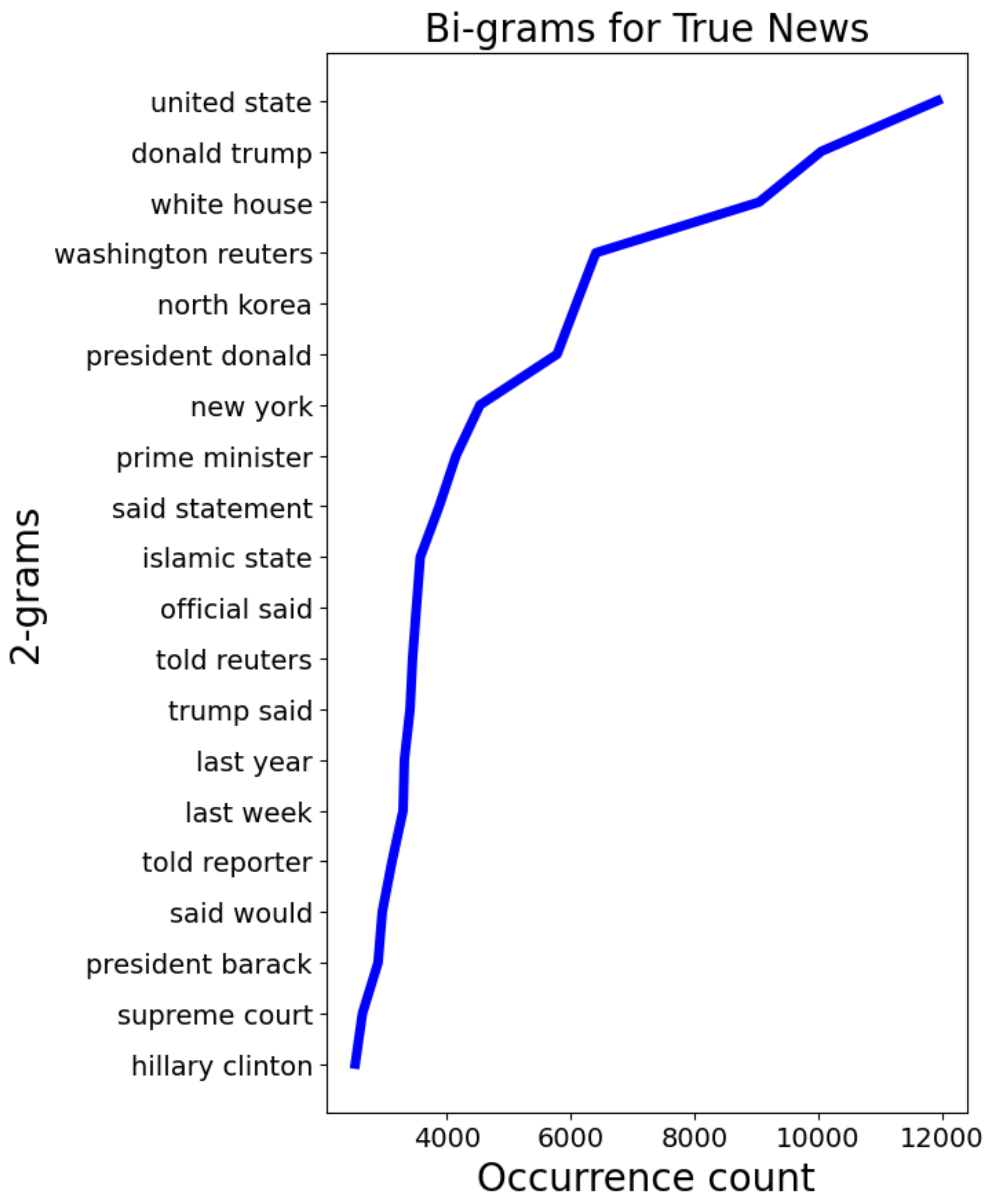


In [38]:

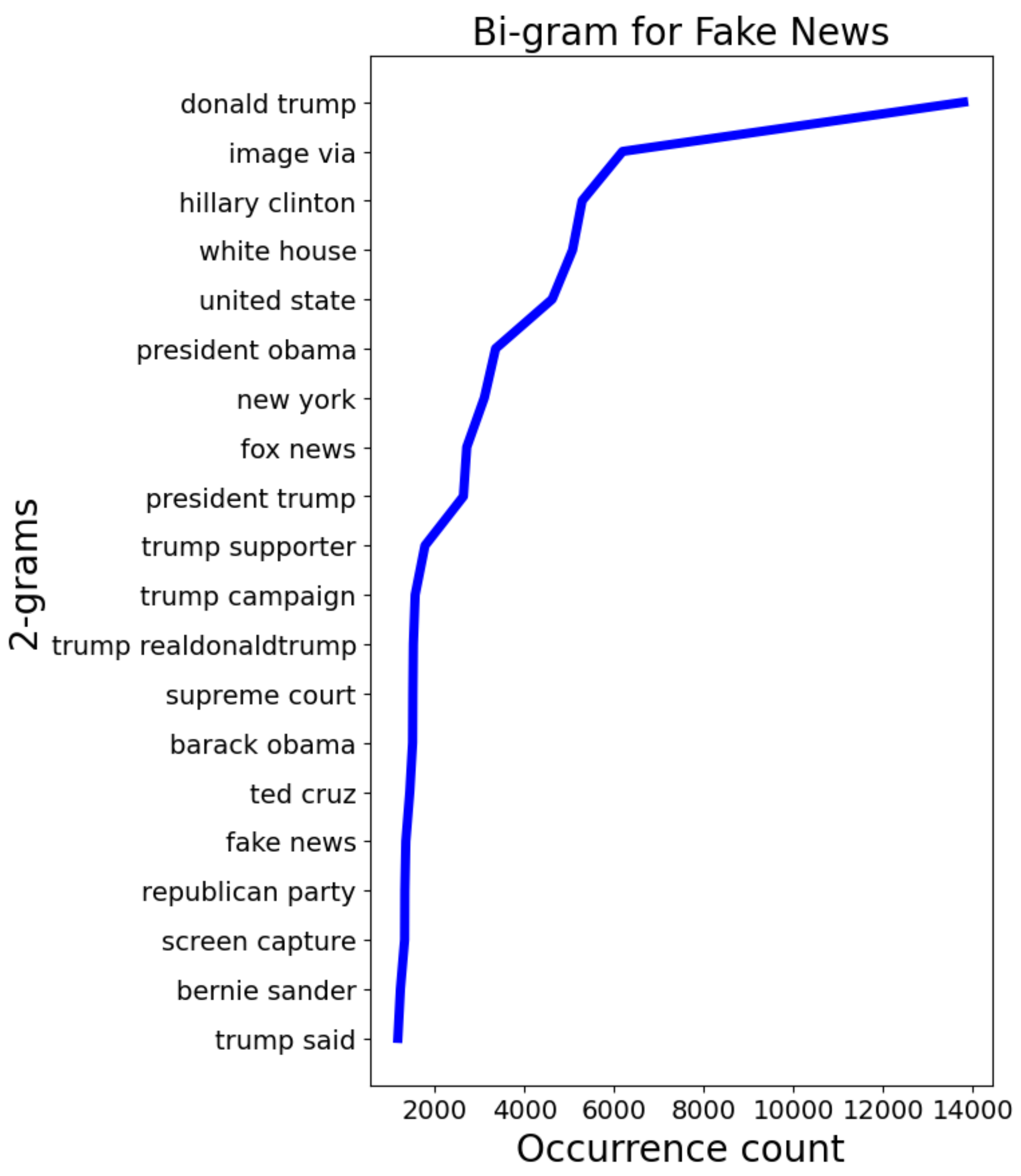
```
b = nGrams(combinedData[combinedData[target]==0][data],1,20)
plotnGrams(b,"Uni-gram for Fake News", 1, num_to_show=20)
```



In [39]:
```
b = nGrams(combinedData[combinedData[target]==1][data],2,20)
plotnGrams(b,"Bi-grams for True News", 2, num_to_show=20)
```



In [40]:
```
b = nGrams(combinedData[combinedData[target]==0][data],2,20)
plotnGrams(b,"Bi-gram for Fake News", 2, num_to_show=20)
```



Save in CSV

```
In [41]:  combinedData.to_csv('datasets/combinedData.csv', index=False)
```

5. Splitting Data and Model Params

```
In [42]:  if 'combinedData' not in globals() and os.path.exists('datasets/combinedD
              combinedData = pd.read_csv('datasets/combinedData.csv')

          else:
              os.error('combinedData not available')

          combinedData.head(5)
```

Out[42]:

	True	article
0	0	breaking gop chairman grassley enough demand t...
1	0	failed gop candidate remembered hilarious mock...
2	0	mike pences new dc neighbor hilariously trolli...
3	1	california ag pledge defend birth control insu...
4	0	az rancher living usmexico border destroy nanc...

In [43]:

```
trainData, tempData, trainLabels, tempLabels = train_test_split(
    combinedData, combinedData[target],
    stratify=combinedData[target],
    test_size=0.4,
    random_state=42
)

valData, testData, valLabels, testLabels = train_test_split(
    tempData, tempLabels,
    stratify=tempLabels,
    test_size=0.5,
    random_state=42
)

print(f"Train size: {len(trainData)}, Percentage: {round(len(trainData) /
print(f"Validation size: {len(valData)}, Percentage: {round(len(valData)
print(f"Test size: {len(testData)}, Percentage: {round(len(testData) / le
```

```
Train size: 23103, Percentage: 0.6
Validation size: 7701, Percentage: 0.2
Test size: 7701, Percentage: 0.2
```

In [44]:

```
x_train = trainData[data]
y_train = trainData[target]

x_val = valData[data]
y_val = valData[target]

x_test = testData[data]
y_test = testData[target]
```

In [45]:

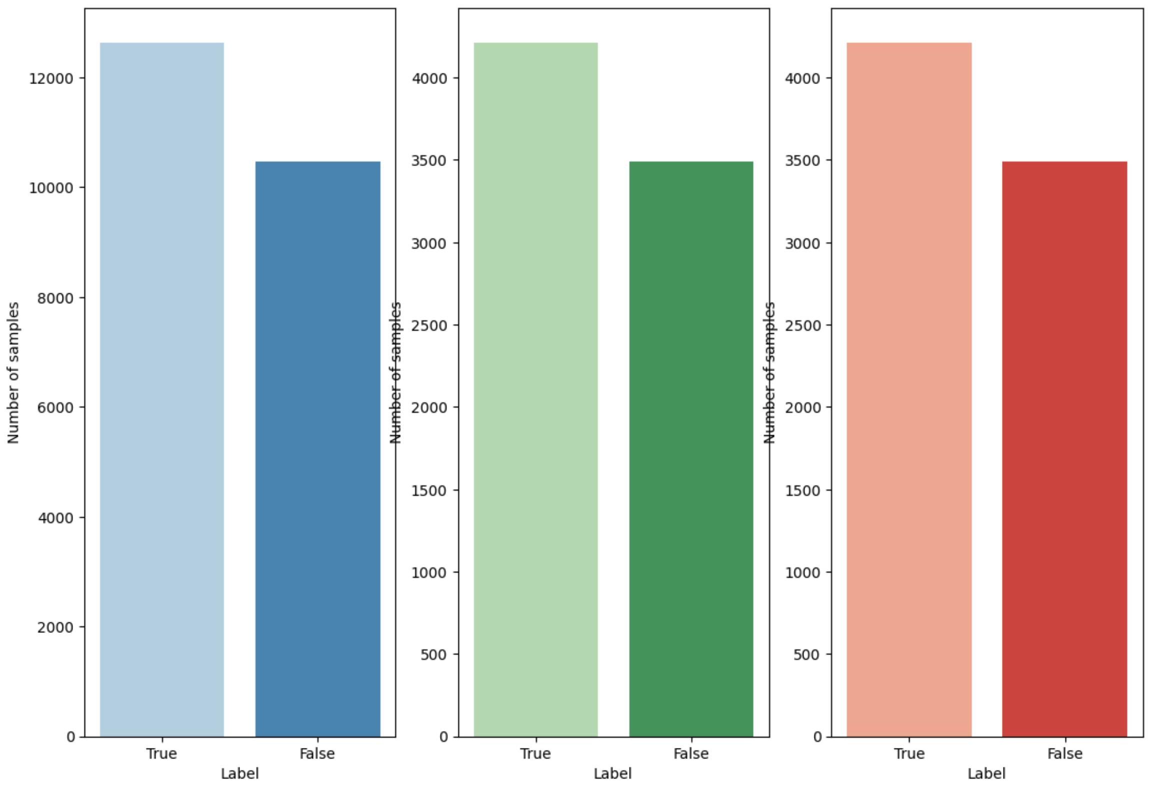
```
def distribution(corpus):
    true = corpus.sum()
    false = len(corpus) - true
    distro = pd.DataFrame(
        data={"Number of samples": [true, false], "Label": ["True", "Fals
    )
    return distro
```

In [46]:

```
trainDistro = distribution(trainData[target])
validDistro = distribution(valData[target])
testDistro = distribution(testData[target])
```

In [47]:
```
fig, (bar1, bar2, bar3) = plt.subplots(1,3, figsize = (13,9))
sns.barplot(y='Number of samples', x='Label', data=trainDistro, ax=bar1,
sns.barplot(y='Number of samples', x='Label', data=validDistro, ax=bar2,
sns.barplot(y='Number of samples', x='Label', data=testDistro, ax=bar3,
```

Out[47]:
```
<Axes: xlabel='Label', ylabel='Number of samples'>
```



6. Tokenization and Padding

In [48]:
```
def buildVocab(corpus, count_threshold):
    word_counts = {}
    for sent in corpus:
        for word in word_tokenize(sent.lower()):
            if word not in word_counts:
                word_counts[word] = 0
            word_counts[word] += 1

    filteredWordCounts = {word: count for word, count in word_counts.iter
    words = sorted(filteredWordCounts.keys(), key=word_counts.get, revers
    word_index = {words[i]: (i + 1) for i in range(len(words))}
    idx_word = {(i + 1): words[i] for i in range(len(words))}
    return word_index, idx_word
```

In [49]:
```
def preprocessArticles(data, vocab=None, max_length=100, min_freq=5):
    if vocab is None:
        word2idx, idx2word = buildVocab(data, min_freq)
    else:
        word2idx, idx2word = vocab

    tokenizedData = [word_tokenize(file.lower()) for file in data]
    indexedData = [[word2idx.get(word, word2idx['UNK']) for word in file
    tensorData = [torch.LongTensor(file) for file in indexedData]
    truncatedData = [tensor[:max_length] for tensor in tensorData]
    paddedData = pad_sequence(truncatedData, batch_first=True, padding_va
    return paddedData, (word2idx, idx2word)
```

In [50]:
```
train_x, train_y = trainData[data], trainData[target]
valid_x, valid_y = valData[data], valData[target]
test_x, test_y = testData[data], testData[target]

trainPadded, (train_word2idx, train_idx2word) = preprocessArticles(train_
validPadded, _ = preprocessArticles(valid_x, (train_word2idx, train_idx2w
testPadded, _ = preprocessArticles(test_x, (train_word2idx, train_idx2wo
```

In [51]:
```
trainLabels = torch.FloatTensor(np.array(train_y))
validLabels = torch.FloatTensor(np.array(valid_y))
testLabels = torch.FloatTensor(np.array(test_y))
```

In [52]:
```
# Create DataLoaders
def createDL(paddedData, labels, batch_size=32, shuffle=False):
    dataset = list(zip(paddedData, labels))
    return DataLoader(dataset, batch_size=batch_size, shuffle=shuffle)

trainingDL = createDL(trainPadded, trainLabels, batch_size=64, shuffle=T
validDL = createDL(validPadded, validLabels, batch_size=32)
testDL = createDL(testPadded, testLabels, batch_size=32)
```

In [53]:
```
VOCAB_SIZE = len(train_word2idx)
```

In [54]:
```
VOCAB_SIZE
```

Out[54]:
```
33844
```

In [55]:
```
# save vocab
with open('vocab.json', 'w') as f:
        json.dump(train_word2idx, f)
```

In [56]:
```
trainPadded[1].shape
```

Out[56]:
```
torch.Size([100])
```

7. Generating Word Embedding using GloVe

In [57]:
```
def get_glove_adapted_embeddings(glove_model, input_voc):
    # Use key_to_index instead of vocab
    keys = {i: glove_model.key_to_index.get(w, None) for w, i in input_vo
    index_dict = {i: key for i, key in keys.items() if key is not None}
    embeddings = np.zeros((len(input_voc) + 1, glove_model.vectors.shape
    for i, ind in index_dict.items():
        embeddings[i] = glove_model[ind]
    return embeddings


GloveEmbeddings = get_glove_adapted_embeddings(loaded_glove_model, train_
```

In [58]:
```
GloveEmbeddings.shape
```

Out[58]:
```
(33845, 300)
```

In [59]:
```
np.save('glove_embeddings.npy', GloveEmbeddings)
```

8.LSTM

In [60]:

```
class LSTMModel(nn.Module):
    def __init__(self, embedding_dim, vocabulary_size, hidden_dim, embedd
        super(LSTMModel, self).__init__()

        # Set up embeddings
        if embeddings is not None:
            # Use pre-trained embeddings if provided
            self.embeddings = nn.Embedding.from_pretrained(
                torch.FloatTensor(embeddings),
                freeze=not fine_tuning,  # Allows fine-tuning if require
                padding_idx=0  # Use 0 as the padding index
            )
        else:
            # If no embeddings provided, create a random embedding matri
            self.embeddings = nn.Embedding(
                num_embeddings=vocabulary_size + 1,
                embedding_dim=embedding_dim,
                padding_idx=0
            )

        # LSTM layer: 2 layers as specified
        self.lstm = nn.LSTM(
            input_size=embedding_dim,
            hidden_size=hidden_dim,
            batch_first=True,
            num_layers=2,
            bidirectional=True  # Adds bidirectional capability
        )

        # Fully connected layer
        self.linear = nn.Linear(
            in_features=2 * hidden_dim,  # Since LSTM is bidirectional, 
            out_features=1  # Output layer size
        )

    def forward(self, inputs):
        emb = self.embeddings(inputs)
        lstm_out, (ht, ct) = self.lstm(emb)
        h = torch.cat((ht[-2], ht[-1]), dim=1)
        x = self.linear(h)
        return x.view(-1)
```

In [61]:
```
def loadCheckpoint(model, optimizer, checkpoint_path):
    checkpoint = torch.load(checkpoint_path)
    model.load_state_dict(checkpoint["model_state_dict"])
    optimizer.load_state_dict(checkpoint["optimizer_state_dict"])
    epoch = checkpoint["epoch"]

    train_losses = checkpoint.get("train_losses", None)
    valid_losses = checkpoint.get("valid_losses", None)
    test_loss = checkpoint.get("test_loss", None)
    train_accs = checkpoint.get("train_accs", None)
    valid_accs = checkpoint.get("valid_accs", None)
    test_acc = checkpoint.get("test_acc", None)
    test_preds = checkpoint.get("test_preds", None)

    print(f"Checkpoint loaded from {checkpoint_path}, epoch {epoch}")

    return (
        model,
        optimizer,
        epoch,
        train_losses,
        valid_losses,
        test_loss,
        train_accs,
        valid_accs,
        test_acc,
        test_preds,
    )
```

In [62]:
```
def train_epoch(model, opt, criterion, dataloader, device):
    model.train()
    losses = []
    accs = []
    for i, (x, y) in enumerate(dataloader):
        # Move inputs and targets to the specified device
        x, y = x.to(device), y.to(device)

        opt.zero_grad()
        # Forward pass
        pred = model(x)
        # Loss computation
        y = y.view(-1)
        loss = criterion(pred, y)
        # Backward pass
        loss.backward()
        # Weights update
        opt.step()

        losses.append(loss.item())

        # Compute accuracy
        num_corrects = torch.sum((torch.sigmoid(pred) > 0.5) == y)
        acc = 100.0 * num_corrects / len(y)
        accs.append(acc.item())

        if i % 100 == 0:
            print(
                f"Batch {i}: training loss = {loss.item():.4f}; training
            )

    return losses, accs


def eval_model(model, criterion, evalloader, device):
    model.eval()
    total_epoch_loss = 0
    total_epoch_acc = 0
    preds = []

    with torch.no_grad():
        for i, (x, y) in enumerate(evalloader):
            # Move inputs and targets to the specified device
            x, y = x.to(device), y.to(device)

            y = y.view(-1)

            pred = model(x)
            loss = criterion(pred, y)

            num_corrects = torch.sum((torch.sigmoid(pred) > 0.5) == y)
            acc = 100.0 * num_corrects / len(y)

            total_epoch_loss += loss.item()
            total_epoch_acc += acc.item()
            preds.append(pred)

    return total_epoch_loss / (i + 1), total_epoch_acc / (i + 1), preds


def experiment(
    model,
    opt,
    criterion,
    trainingDL,
    validDL,
    testDL,
    numEpochs=5,
    device=torch.device("cuda"),
):
    model.to(device)
    train_losses = []
    valid_losses = []
    train_accs = []
    valid_accs = []

    print("Beginning training...")
    for e in range(numEpochs):
        print(f"\nEpoch {e + 1}:")
        losses, accs = train_epoch(model, opt, criterion, trainingDL, dev
        train_losses.append(losses)
        train_accs.append(accs)

        valid_loss, valid_acc, val_preds = eval_model(model, criterion, v
        valid_losses.append(valid_loss)
        valid_accs.append(valid_acc)

        print(
            f"\nEpoch {e + 1}: Validation loss = {valid_loss:.4f}; Valida
        )

    test_loss, test_acc, test_preds = eval_model(model, criterion, testDl
    print(f"\nTest loss = {test_loss:.4f}; Test acc = {test_acc:.2f}%")

    return (
        train_losses,
        valid_losses,
        test_loss,
        train_accs,
        valid_accs,
        test_acc,
        test_preds,
    )
```

In [63]:

```
model_lstm = LSTMModel(embeddingDim, VOCAB_SIZE, hiddenDim, embeddings=G
optimizer_lstm = Adam(model_lstm.parameters(), lr=learningRate, betas=(0
criterion = nn.BCEWithLogitsLoss()
```

In [64]:

```
torch.cuda.empty_cache()
```

In [65]:

```
if not os.path.exists("Model_LSTM_checkpoint.pth"):
    train_losses_lstm, valid_losses_lstm, test_loss_lstm, train_accs_lstm
        model_lstm, optimizer_lstm, criterion, trainingDL, validDL, testD
    )
else:
    model_lstm, optimizer, epoch_lstm, train_losses_lstm, valid_losses_ls
        model_lstm, optimizer_lstm, "Model_LSTM_checkpoint.pth")
```

```
Beginning training...

Epoch 1:
Batch 0: training loss = 0.6935; training acc = 42.19%
Batch 100: training loss = 0.0467; training acc = 98.44%
Batch 200: training loss = 0.1179; training acc = 96.88%
Batch 300: training loss = 0.0076; training acc = 100.00%

Epoch 1: Validation loss = 0.0449; Validation acc = 98.43%

Epoch 2:
Batch 0: training loss = 0.0791; training acc = 95.31%
Batch 100: training loss = 0.0231; training acc = 98.44%
Batch 200: training loss = 0.0141; training acc = 98.44%
Batch 300: training loss = 0.0231; training acc = 100.00%

Epoch 2: Validation loss = 0.0397; Validation acc = 98.48%

Epoch 3:
Batch 0: training loss = 0.0077; training acc = 100.00%
Batch 100: training loss = 0.0297; training acc = 98.44%
Batch 200: training loss = 0.0225; training acc = 98.44%
Batch 300: training loss = 0.0032; training acc = 100.00%

Epoch 3: Validation loss = 0.0283; Validation acc = 99.05%

Epoch 4:
Batch 0: training loss = 0.0086; training acc = 100.00%
Batch 100: training loss = 0.0013; training acc = 100.00%
Batch 200: training loss = 0.0307; training acc = 98.44%
Batch 300: training loss = 0.0105; training acc = 100.00%

Epoch 4: Validation loss = 0.0253; Validation acc = 99.31%

Epoch 5:
Batch 0: training loss = 0.0014; training acc = 100.00%
Batch 100: training loss = 0.0014; training acc = 100.00%
Batch 200: training loss = 0.0021; training acc = 100.00%
Batch 300: training loss = 0.0300; training acc = 96.88%

Epoch 5: Validation loss = 0.0228; Validation acc = 99.36%

Epoch 6:
Batch 0: training loss = 0.0007; training acc = 100.00%
Batch 100: training loss = 0.0011; training acc = 100.00%
Batch 200: training loss = 0.0007; training acc = 100.00%
Batch 300: training loss = 0.0400; training acc = 98.44%

Epoch 6: Validation loss = 0.0358; Validation acc = 99.17%

Epoch 7:
Batch 0: training loss = 0.0002; training acc = 100.00%
Batch 100: training loss = 0.0086; training acc = 100.00%
Batch 200: training loss = 0.0006; training acc = 100.00%
Batch 300: training loss = 0.0005; training acc = 100.00%

Epoch 7: Validation loss = 0.0544; Validation acc = 98.26%

Epoch 8:
Batch 0: training loss = 0.0468; training acc = 96.88%
Batch 100: training loss = 0.0007; training acc = 100.00%
Batch 200: training loss = 0.0005; training acc = 100.00%
Batch 300: training loss = 0.0006; training acc = 100.00%
```

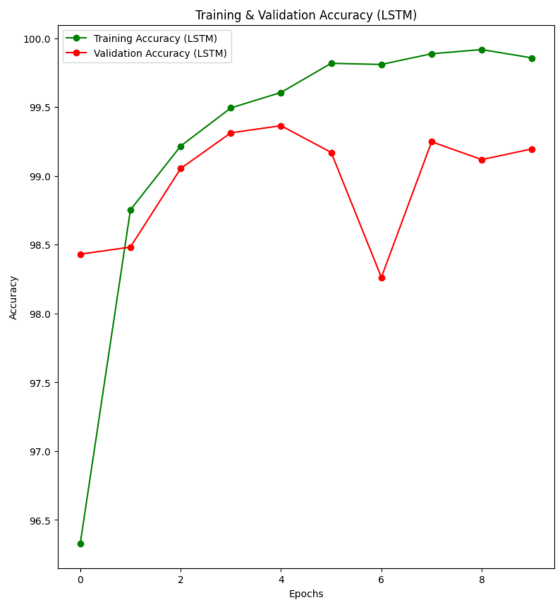
```
Epoch 8: Validation loss = 0.0323; Validation acc = 99.25%

Epoch 9:
Batch 0: training loss = 0.0001; training acc = 100.00%
Batch 100: training loss = 0.0002; training acc = 100.00%
Batch 200: training loss = 0.0001; training acc = 100.00%
Batch 300: training loss = 0.0001; training acc = 100.00%

Epoch 9: Validation loss = 0.0380; Validation acc = 99.12%

Epoch 10:
Batch 0: training loss = 0.0001; training acc = 100.00%
Batch 100: training loss = 0.0000; training acc = 100.00%
Batch 200: training loss = 0.0040; training acc = 100.00%
Batch 300: training loss = 0.0005; training acc = 100.00%

Epoch 10: Validation loss = 0.0313; Validation acc = 99.20%

Test loss = 0.0466; Test acc = 98.81%
```

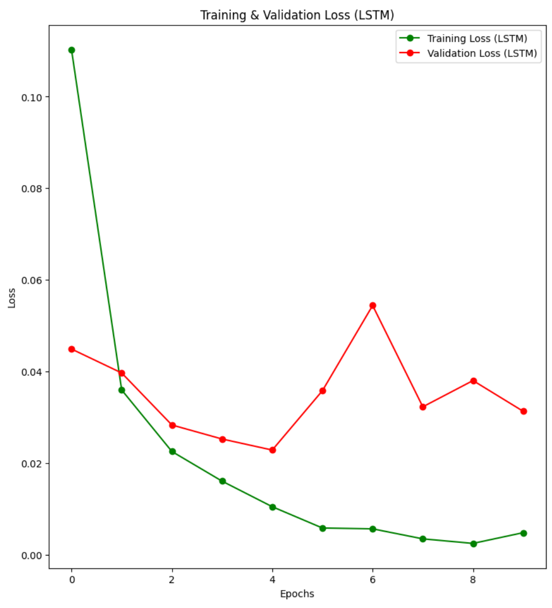
In [66]:

```
train_losses = [mean(train_loss) for train_loss in train_losses_lstm]
train_accs = [mean(train_acc) for train_acc in train_accs_lstm]
```

In [67]:

```
epochs = [i for i in range(numEpochs)]
fig , ax = plt.subplots(1,2)
fig.set_size_inches(20,10)

ax[0].plot(epochs , train_accs , 'go-' , label = 'Training Accuracy (LST
ax[0].plot(epochs , valid_accs_lstm , 'ro-' , label = 'Validation Accura
ax[0].set_title('Training & Validation Accuracy (LSTM)')
ax[0].legend()
ax[0].set_xlabel("Epochs")
ax[0].set_ylabel("Accuracy")

ax[1].plot(epochs , train_losses , 'go-' , label = 'Training Loss (LSTM)
ax[1].plot(epochs , valid_losses_lstm , 'ro-' , label = 'Validation Loss
ax[1].set_title('Training & Validation Loss (LSTM)')
ax[1].legend()
ax[1].set_xlabel("Epochs")
ax[1].set_ylabel("Loss")
plt.show()
```


Training & Validation Accuracy (LSTM)
Training Accuracy (LSTM)
Validation Accuracy (LSTM)
Accuracy
Epochs


Training & Validation Loss (LSTM)
Training Loss (LSTM)
Validation Loss (LSTM)
Loss
Epochs

9. CNN

In [68]:
```
class CNNModel(nn.Module):
    def __init__(
        self,
        embedding_dim,
        vocabulary_size,
        window_size: int = 16,
        filter_multiplier = 64,
        embeddings = None,
        fine_tuning = False,
    ):
        super().__init__()
        self.embedding_dim = embedding_dim
        if embeddings:
            self.embeddings = nn.Embedding.from_pretrained(
                torch.FloatTensor(GloveEmbeddings),
                freeze=not fine_tuning,
                padding_idx=0,
            )

        else:
            self.embeddings = nn.Embedding(
                num_embeddings=vocabulary_size + 1,
                embedding_dim=embedding_dim,
                padding_idx=0,
            )

        self.conv1d = nn.Conv1d(embedding_dim, filter_multiplier, window_
        self.dropout = nn.Dropout(0.5)
        self.linear = nn.Linear(filter_multiplier, 1)

    def forward(self, inputs):
        x = self.embeddings(inputs)
        x = x.permute(0, 2, 1)
        x = self.conv1d(x)
        x = F.relu(x)
        x = F.max_pool1d(x, x.shape[2]).squeeze(2)
        x = self.dropout(x)
        output = self.linear(x).view(-1)

        return output
```

In [69]:
```
model_cnn = CNNModel(embeddingDim, len(train_word2idx), 16, 64, embeddin
optimizer_cnn = Adam(model_cnn.parameters(), lr=learningRate, betas=(0.9
```

In [70]:
```
if not os.path.exists("Model_CNN_checkpoint.pth"):
        train_losses_cnn, valid_losses_cnn, test_loss_cnn, train_accs_cn
                model_cnn,
                optimizer_cnn,
                criterion,
                trainingDL,
                validDL,
                testDL,
                numEpochs,
                device
        )
else: model_cnn, optimizer, epoch_cnn, train_losses_cnn, valid_losses_cn
    model_cnn, optimizer_cnn, "Model_CNN_checkpoint.pth")
```

```
Beginning training...

Epoch 1:
Batch 0: training loss = 0.7256; training acc = 45.31%
Batch 100: training loss = 0.0136; training acc = 100.00%
Batch 200: training loss = 0.0242; training acc = 100.00%
Batch 300: training loss = 0.0384; training acc = 98.44%

Epoch 1: Validation loss = 0.0323; Validation acc = 99.18%

Epoch 2:
Batch 0: training loss = 0.0071; training acc = 100.00%
Batch 100: training loss = 0.0015; training acc = 100.00%
Batch 200: training loss = 0.0040; training acc = 100.00%
Batch 300: training loss = 0.0047; training acc = 100.00%

Epoch 2: Validation loss = 0.0333; Validation acc = 99.07%

Epoch 3:
Batch 0: training loss = 0.0002; training acc = 100.00%
Batch 100: training loss = 0.0012; training acc = 100.00%
Batch 200: training loss = 0.0007; training acc = 100.00%
Batch 300: training loss = 0.0010; training acc = 100.00%

Epoch 3: Validation loss = 0.0311; Validation acc = 99.22%

Epoch 4:
Batch 0: training loss = 0.0216; training acc = 98.44%
Batch 100: training loss = 0.0007; training acc = 100.00%
Batch 200: training loss = 0.0000; training acc = 100.00%
Batch 300: training loss = 0.0002; training acc = 100.00%

Epoch 4: Validation loss = 0.0416; Validation acc = 99.08%

Epoch 5:
Batch 0: training loss = 0.0005; training acc = 100.00%
Batch 100: training loss = 0.0001; training acc = 100.00%
Batch 200: training loss = 0.0000; training acc = 100.00%
Batch 300: training loss = 0.0010; training acc = 100.00%

Epoch 5: Validation loss = 0.0512; Validation acc = 98.98%

Epoch 6:
Batch 0: training loss = 0.0001; training acc = 100.00%
Batch 100: training loss = 0.0001; training acc = 100.00%
Batch 200: training loss = 0.0000; training acc = 100.00%
Batch 300: training loss = 0.0019; training acc = 100.00%

Epoch 6: Validation loss = 0.0598; Validation acc = 98.99%

Epoch 7:
Batch 0: training loss = 0.0001; training acc = 100.00%
Batch 100: training loss = 0.0001; training acc = 100.00%
Batch 200: training loss = 0.0000; training acc = 100.00%
Batch 300: training loss = 0.0009; training acc = 100.00%

Epoch 7: Validation loss = 0.0726; Validation acc = 98.92%

Epoch 8:
Batch 0: training loss = 0.0000; training acc = 100.00%
Batch 100: training loss = 0.0000; training acc = 100.00%
Batch 200: training loss = 0.0000; training acc = 100.00%
Batch 300: training loss = 0.0000; training acc = 100.00%
```

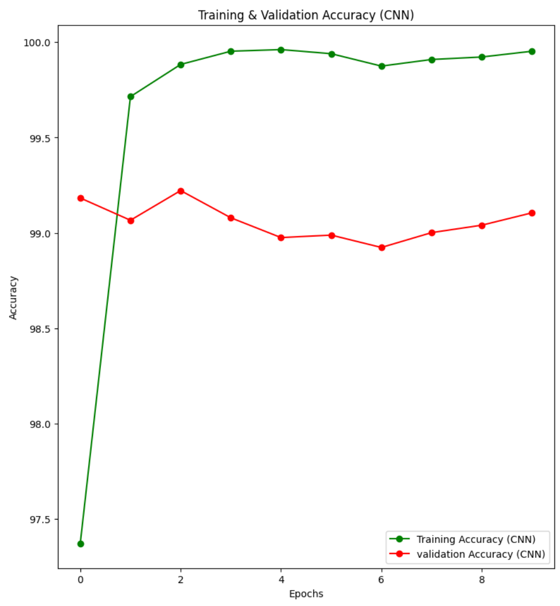
```
Epoch 8: Validation loss = 0.0640; Validation acc = 99.00%

Epoch 9:
Batch 0: training loss = 0.0000; training acc = 100.00%
Batch 100: training loss = 0.0000; training acc = 100.00%
Batch 200: training loss = 0.0001; training acc = 100.00%
Batch 300: training loss = 0.0000; training acc = 100.00%

Epoch 9: Validation loss = 0.0797; Validation acc = 99.04%

Epoch 10:
Batch 0: training loss = 0.0000; training acc = 100.00%
Batch 100: training loss = 0.0001; training acc = 100.00%
Batch 200: training loss = 0.0188; training acc = 98.44%
Batch 300: training loss = 0.0000; training acc = 100.00%

Epoch 10: Validation loss = 0.0692; Validation acc = 99.11%

Test loss = 0.0674; Test acc = 99.12%
```

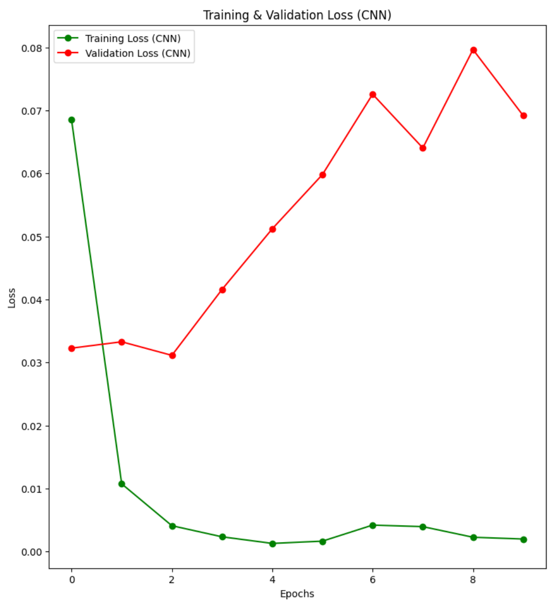
In [71]:

```
train_losses_cnn = [mean(train_loss) for train_loss in train_losses_cnn]
train_accs_cnn = [mean(train_acc) for train_acc in train_accs_cnn]
```

In [72]:

```
epochs = [i for i in range(numEpochs)]
fig , ax = plt.subplots(1,2)
fig.set_size_inches(20,10)

ax[0].plot(epochs , train_accs_cnn , 'go-' , label = 'Training Accuracy
ax[0].plot(epochs , valid_accs_cnn , 'ro-' , label = 'validation Accurac
ax[0].set_title('Training & Validation Accuracy (CNN)')
ax[0].legend()
ax[0].set_xlabel("Epochs")
ax[0].set_ylabel("Accuracy")

ax[1].plot(epochs , train_losses_cnn , 'go-' , label = 'Training Loss (C
ax[1].plot(epochs , valid_losses_cnn , 'ro-' , label = 'Validation Loss
ax[1].set_title('Training & Validation Loss (CNN)')
ax[1].legend()
ax[1].set_xlabel("Epochs")
ax[1].set_ylabel("Loss")
plt.show()
```





10. CNN-LSTM Hybrid Model

In [73]:

```
class Hybrid(nn.Module):
    def __init__(
        self,
        embedding_dim,
        vocabulary_size,
        hidden_dim,
        window_size=16,
        filter_multiplier=64,
        embeddings=None,
        fine_tuning=False
    ):
        super(Hybrid, self).__init__()

        # Embedding Layer
        if embeddings is not None:
            self.embeddings = nn.Embedding.from_pretrained(
                torch.FloatTensor(embeddings),
                freeze=not fine_tuning,
                padding_idx=0
            )
        else:
            self.embeddings = nn.Embedding(
                num_embeddings=vocabulary_size + 1,
                embedding_dim=embedding_dim,
                padding_idx=0
            )

        # CNN Component
        self.conv1d = nn.Conv1d(embedding_dim, filter_multiplier, window_
        self.dropout_cnn = nn.Dropout(0.5)

        # LSTM Component
        self.lstm = nn.LSTM(
            input_size=filter_multiplier,
            hidden_size=hidden_dim,
            num_layers=2,
            batch_first=True,
            bidirectional=True
        )

        # Fully Connected Layer
        self.fc = nn.Linear(2 * hidden_dim, 1)  # Bidirectional LSTM dou

    def forward(self, inputs):
        # Embedding
        x = self.embeddings(inputs)

        # CNN Forward Pass
        x = x.permute(0, 2, 1)  # For Conv1d input (batch, channels, seq
        x = self.conv1d(x)
        x = F.relu(x)
        x = F.max_pool1d(x, x.shape[2]).squeeze(2)  # Global Max Pooling
        x = self.dropout_cnn(x)

        # Prepare for LSTM
        x = x.unsqueeze(1).repeat(1, inputs.size(1), 1)  # Repeat CNN fe

        # LSTM Forward Pass
        lstm_out, (ht, ct) = self.lstm(x)

        # Concatenate final hidden states from both directions
        h = torch.cat((ht[-2], ht[-1]), dim=1)
        # Fully Connected Layer
        output = self.fc(h)
        return output.view(-1)
```

In [74]:

```
model_hybrid = Hybrid(embeddingDim, VOCAB_SIZE, hiddenDim, embeddings=Gl
optimizer_hybrid = Adam(model_hybrid.parameters(), lr=learningRate, beta
```

In [75]:

```
if not os.path.exists("Model_Hybrid_checkpoint.pth"):
        train_losses_hybrid, valid_losses_hybrid, test_loss_hybrid, trai
                model_hybrid,
                optimizer_hybrid,
                criterion,
                trainingDL,
                validDL,
                testDL,
                numEpochs,
                device
        )
else:
        model_hybrid, optimizer_hybrid, epoch_hybrid, train_losses_hybri
        model_hybrid, optimizer_hybrid, "Model_Hybrid_checkpoint.pth")
```

```
Beginning training...

Epoch 1:
Batch 0: training loss = 0.6929; training acc = 50.00%
Batch 100: training loss = 0.1380; training acc = 95.31%
Batch 200: training loss = 0.0499; training acc = 98.44%
Batch 300: training loss = 0.0356; training acc = 98.44%

Epoch 1: Validation loss = 0.0353; Validation acc = 99.04%

Epoch 2:
Batch 0: training loss = 0.0069; training acc = 100.00%
Batch 100: training loss = 0.0019; training acc = 100.00%
Batch 200: training loss = 0.0199; training acc = 98.44%
Batch 300: training loss = 0.0118; training acc = 100.00%

Epoch 2: Validation loss = 0.0344; Validation acc = 99.16%

Epoch 3:
Batch 0: training loss = 0.0138; training acc = 100.00%
Batch 100: training loss = 0.0001; training acc = 100.00%
Batch 200: training loss = 0.0011; training acc = 100.00%
Batch 300: training loss = 0.0003; training acc = 100.00%

Epoch 3: Validation loss = 0.0742; Validation acc = 98.77%

Epoch 4:
Batch 0: training loss = 0.0038; training acc = 100.00%
Batch 100: training loss = 0.0002; training acc = 100.00%
Batch 200: training loss = 0.1451; training acc = 96.88%
Batch 300: training loss = 0.0621; training acc = 98.44%

Epoch 4: Validation loss = 0.0320; Validation acc = 99.11%

Epoch 5:
Batch 0: training loss = 0.0008; training acc = 100.00%
Batch 100: training loss = 0.0003; training acc = 100.00%
Batch 200: training loss = 0.0060; training acc = 100.00%
Batch 300: training loss = 0.0000; training acc = 100.00%

Epoch 5: Validation loss = 0.0374; Validation acc = 99.13%

Epoch 6:
Batch 0: training loss = 0.0006; training acc = 100.00%
Batch 100: training loss = 0.0004; training acc = 100.00%
Batch 200: training loss = 0.0001; training acc = 100.00%
Batch 300: training loss = 0.0000; training acc = 100.00%

Epoch 6: Validation loss = 0.0508; Validation acc = 99.14%

Epoch 7:
Batch 0: training loss = 0.0000; training acc = 100.00%
Batch 100: training loss = 0.0034; training acc = 100.00%
Batch 200: training loss = 0.0000; training acc = 100.00%
Batch 300: training loss = 0.0000; training acc = 100.00%

Epoch 7: Validation loss = 0.0540; Validation acc = 98.94%

Epoch 8:
Batch 0: training loss = 0.0000; training acc = 100.00%
Batch 100: training loss = 0.0001; training acc = 100.00%
Batch 200: training loss = 0.0001; training acc = 100.00%
Batch 300: training loss = 0.0305; training acc = 98.44%
```

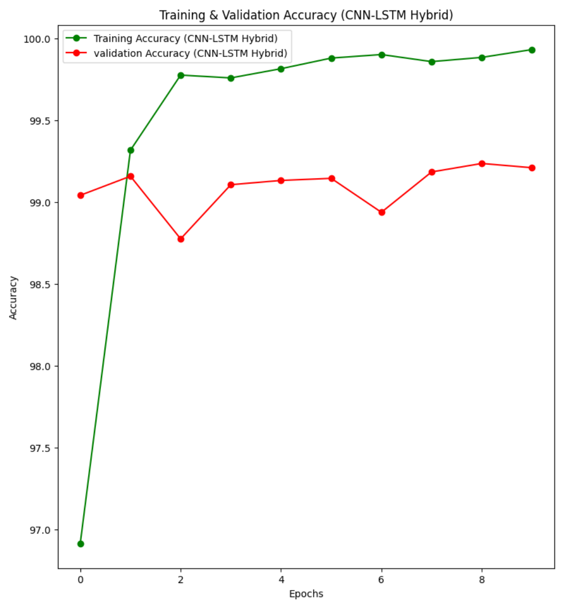
```
Epoch 8: Validation loss = 0.0381; Validation acc = 99.18%

Epoch 9:
Batch 0: training loss = 0.0007; training acc = 100.00%
Batch 100: training loss = 0.0001; training acc = 100.00%
Batch 200: training loss = 0.0001; training acc = 100.00%
Batch 300: training loss = 0.0003; training acc = 100.00%

Epoch 9: Validation loss = 0.0427; Validation acc = 99.23%

Epoch 10:
Batch 0: training loss = 0.0000; training acc = 100.00%
Batch 100: training loss = 0.0000; training acc = 100.00%
Batch 200: training loss = 0.0003; training acc = 100.00%
Batch 300: training loss = 0.0003; training acc = 100.00%

Epoch 10: Validation loss = 0.0506; Validation acc = 99.21%

Test loss = 0.0583; Test acc = 99.05%
```

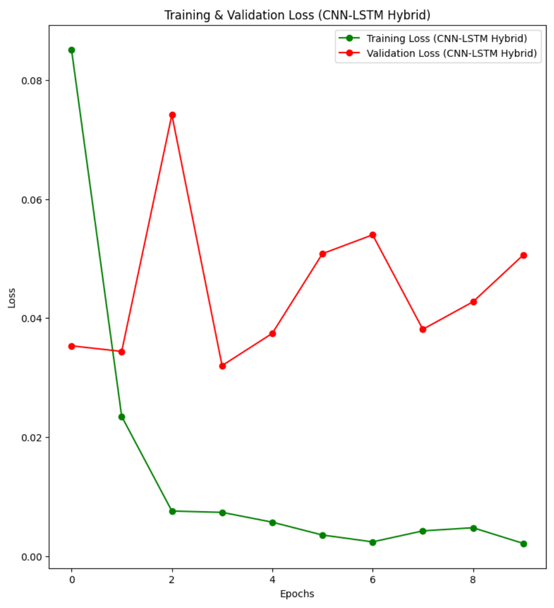
In [76]:

```
train_losses_hybrid = [mean(train_loss) for train_loss in train_losses_hy
train_accs_hybrid = [mean(train_acc) for train_acc in train_accs_hybrid]
```

In [77]:

```
epochs = [i for i in range(numEpochs)]
fig , ax = plt.subplots(1,2)
fig.set_size_inches(20,10)

ax[0].plot(epochs , train_accs_hybrid , 'go-' , label = 'Training Accura
ax[0].plot(epochs , valid_accs_hybrid , 'ro-' , label = 'validation Accu
ax[0].set_title('Training & Validation Accuracy (CNN-LSTM Hybrid)')
ax[0].legend()
ax[0].set_xlabel("Epochs")
ax[0].set_ylabel("Accuracy")

ax[1].plot(epochs , train_losses_hybrid , 'go-' , label = 'Training Loss
ax[1].plot(epochs , valid_losses_hybrid , 'ro-' , label = 'Validation Lo
ax[1].set_title('Training & Validation Loss (CNN-LSTM Hybrid)')
ax[1].legend()
ax[1].set_xlabel("Epochs")
ax[1].set_ylabel("Loss")
plt.show()
```





11. Save & Load Models

In [78]:

```
def saveCheckpoint(
    model,
    optimizer,
    epoch,
    name,
    train_losses,
    valid_losses,
    test_loss,
    train_accs,
    valid_accs,
    test_acc,
    test_preds,
):
    checkpoint = {
        "epoch": epoch,
        "model_state_dict": model.state_dict(),
        "optimizer_state_dict": optimizer.state_dict(),
        "train_losses": train_losses,
        "valid_losses": valid_losses,
        "test_loss": test_loss,
        "train_accs": train_accs,
        "valid_accs": valid_accs,
        "test_acc": test_acc,
        "test_preds": test_preds,
    }

    path = name + "_checkpoint.pth"
    torch.save(checkpoint, path)
    print(f"Checkpoint saved at epoch {epoch} to {path}")
```

In [79]:
```
saveCheckpoint(
    model_lstm,
    optimizer_lstm,
    numEpochs,
    "Model_LSTM",
    train_losses_lstm,
    valid_losses_lstm,
    test_loss_lstm,
    train_accs_lstm,
    valid_accs_lstm,
    test_acc_lstm,
    test_preds_lstm,
)

saveCheckpoint(
    model_cnn,
    optimizer_cnn,
    numEpochs,
    "Model_CNN",
    train_losses_cnn,
    valid_losses_cnn,
    test_loss_cnn,
    train_accs_cnn,
    valid_accs_cnn,
    test_acc_cnn,
    test_preds_cnn,
)

saveCheckpoint(
    model_hybrid,
    optimizer_hybrid,
    numEpochs,
    "Model_Hybrid",
    train_losses_hybrid,
    valid_losses_hybrid,
    test_loss_hybrid,
    train_accs_hybrid,
    valid_accs_hybrid,
    test_acc_hybrid,
    test_preds_hybrid,
)
```

```
Checkpoint saved at epoch 10 to Model_LSTM_checkpoint.pth
Checkpoint saved at epoch 10 to Model_CNN_checkpoint.pth
Checkpoint saved at epoch 10 to Model_Hybrid_checkpoint.pth
```

In [80]:
```
(
    model_lstm,
    optimizer_lstm,
    epoch_lstm,
    train_losses_lstm,
    valid_losses_lstm,
    test_loss_lstm,
    train_accs_lstm,
    valid_accs_lstm,
    test_acc_lstm,
    test_preds_lstm,
) = loadCheckpoint(model_lstm, optimizer_lstm, "Model_LSTM_checkpoint.pt

(
    model_cnn,
    optimizer_cnn,
    epoch_cnn,
    train_losses_cnn,
    valid_losses_cnn,
    test_loss_cnn,
    train_accs_cnn,
    valid_accs_cnn,
    test_acc_cnn,
    test_preds_cnn,
) = loadCheckpoint(model_cnn, optimizer_cnn, "Model_CNN_checkpoint.pth")

(
    model_hybrid,
    optimizer_hybrid,
    epoch_hybrid,
    train_losses_hybrid,
    valid_losses_hybrid,
    test_loss_hybrid,
    train_accs_hybrid,
    valid_accs_hybrid,
    test_acc_hybrid,
    test_preds_hybrid,
) = loadCheckpoint(model_hybrid, optimizer_hybrid, "Model_Hybrid_checkpo
```

```
Checkpoint loaded from Model_LSTM_checkpoint.pth, epoch 10
Checkpoint loaded from Model_CNN_checkpoint.pth, epoch 10
Checkpoint loaded from Model_Hybrid_checkpoint.pth, epoch 10
```

12. Statistics

Test Predictions

In [81]:
```
preds = [
    (torch.sigmoid(t) > 0.5).int().tolist() if isinstance(t, torch.Tenso
    for t in test_preds_hybrid
]

preds = [item for sublist in preds for item in sublist]
```

In [82]:
```
preds[:20]
```

Out[82]:
```
[0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 1, 0, 0, 1]
```

In [83]:
```
test_y[:20]
```

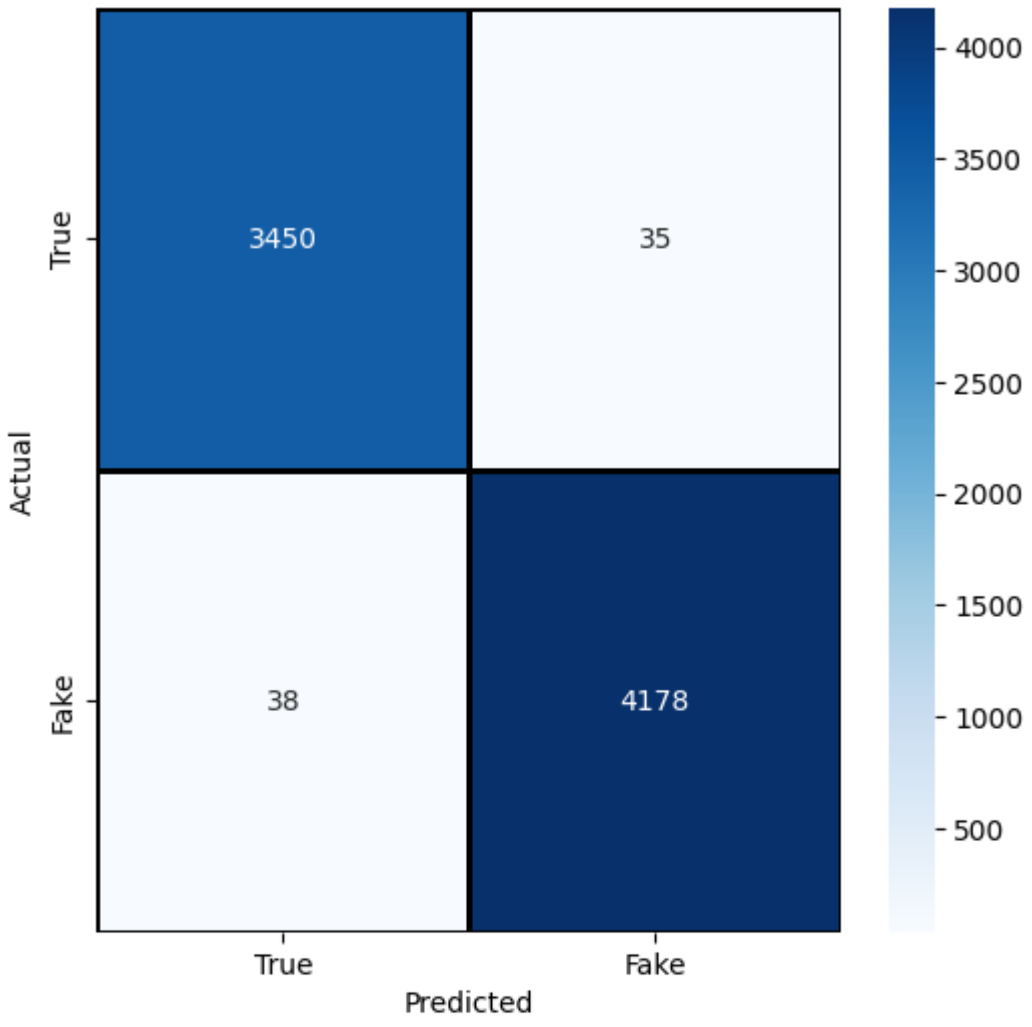
Out[83]:
```
19472    0
2051     1
34636    0
7123     1
38050    0
31334    1
6430     1
9828     1
16417    1
3716     1
14430    0
13967    1
37385    1
3804     1
28593    0
29827    1
34968    1
31447    0
16847    0
22182    1
Name: True, dtype: int64
```

Confusion Matrix & Normalization

In [84]:
```
cm = confusion_matrix(preds,test_y)
```

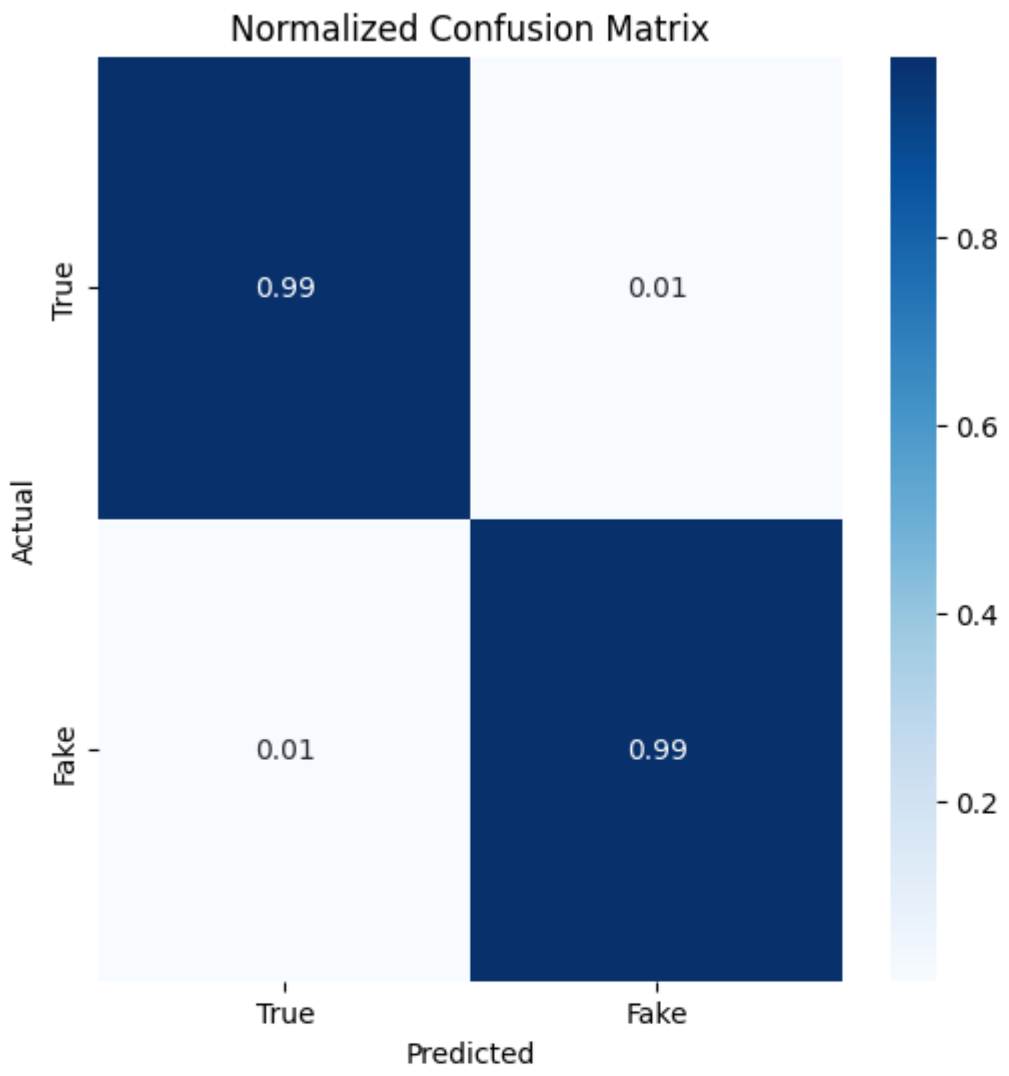
In [85]:
```
plt.figure(figsize = (6,6))
sns.heatmap(cm,cmap= "Blues", linecolor = 'black' , linewidth = 1 , anno
plt.xlabel("Predicted")
plt.ylabel("Actual")
```

Out[85]:
```
Text(45.722222222222214, 0.5, 'Actual')
```



In [86]:

```
cm_normalized = cm.astype('float') / cm.sum(axis=1)[:, np.newaxis]

plt.figure(figsize=(6,6))
sns.heatmap(cm_normalized, annot=True, fmt=".2f", cmap="Blues", xticklab
plt.xlabel("Predicted")
plt.ylabel("Actual")
plt.title("Normalized Confusion Matrix")
plt.show()
```



Error Analysis

In [87]:
```
compare =  pd.DataFrame({'Ground truth' : test_y, 'Predicted': preds})
index_fn = np.nonzero(compare['Ground truth'] - compare['Predicted'] ==
index_fp = np.nonzero(compare['Ground truth'] - compare['Predicted'] ==
```

In [88]:
```
print(f"False Negatives: {index_fn[0][0]}")
```

```
False Negatives: 72
```

In [89]:
```
print(f"False Positives: {index_fp[0][0]}")
```

```
False Positives: 101
```

Accuracy, Precision, Recall, F1-Score (for each class)

In [90]:

```
test_y_numpy = np.array(test_y)
preds_numpy = np.array(preds)

accuracy = accuracy_score(test_y_numpy, preds_numpy)
accuracy_true = accuracy_score(test_y_numpy[test_y_numpy == 1], preds_nu
accuracy_fake = accuracy_score(test_y_numpy[test_y_numpy == 0], preds_nu

print(f"Accuracy for True class: {accuracy_true:.4f}")
print(f"Accuracy for Fake class: {accuracy_fake:.4f}")
precision_true = precision_score(test_y_numpy, preds_numpy, pos_label=1)
precision_fake = precision_score(test_y_numpy, preds_numpy, pos_label=0)
recall_true = recall_score(test_y_numpy, preds_numpy, pos_label=1)
recall_fake = recall_score(test_y_numpy, preds_numpy, pos_label=0)
f1_true = f1_score(test_y_numpy, preds_numpy, pos_label=1)
f1_fake = f1_score(test_y_numpy, preds_numpy, pos_label=0)

print(f"Accuracy: {accuracy:.4f}")
print(f"Precision (True): {precision_true:.4f}")
print(f"Precision (Fake): {precision_fake:.4f}")
print(f"Recall (True): {recall_true:.4f}")
print(f"Recall (Fake): {recall_fake:.4f}")
print(f"F1 Score (True): {f1_true:.4f}")
print(f"F1 Score (Fake): {f1_fake:.4f}")
```

```
Accuracy for True class: 0.9917
Accuracy for Fake class: 0.9891
Accuracy: 0.9905
Precision (True): 0.9910
Precision (Fake): 0.9900
Recall (True): 0.9917
Recall (Fake): 0.9891
F1 Score (True): 0.9913
F1 Score (Fake): 0.9895
Accuracy: 0.9905
Precision (True): 0.9910
Precision (Fake): 0.9900
Recall (True): 0.9917
Recall (Fake): 0.9891
F1 Score (True): 0.9913
F1 Score (Fake): 0.9895
```

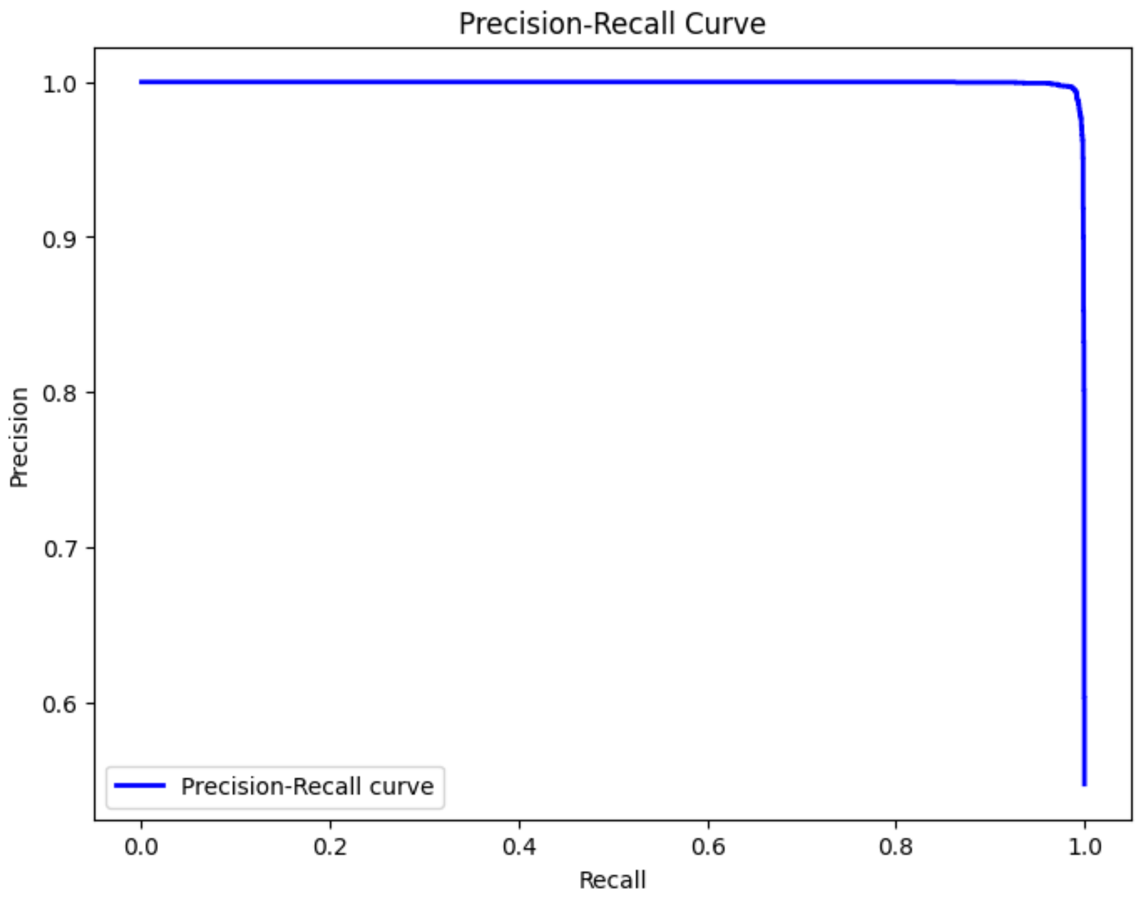
In [91]:

```
print(classification_report(test_y, preds, target_names = ['Predicted Fa
```

```
                precision    recall  f1-score   support

Predicted Fake       0.99      0.99      0.99      3488
Predicted True       0.99      0.99      0.99      4213

      accuracy                           0.99      7701
     macro avg       0.99      0.99      0.99      7701
  weighted avg       0.99      0.99      0.99      7701
```

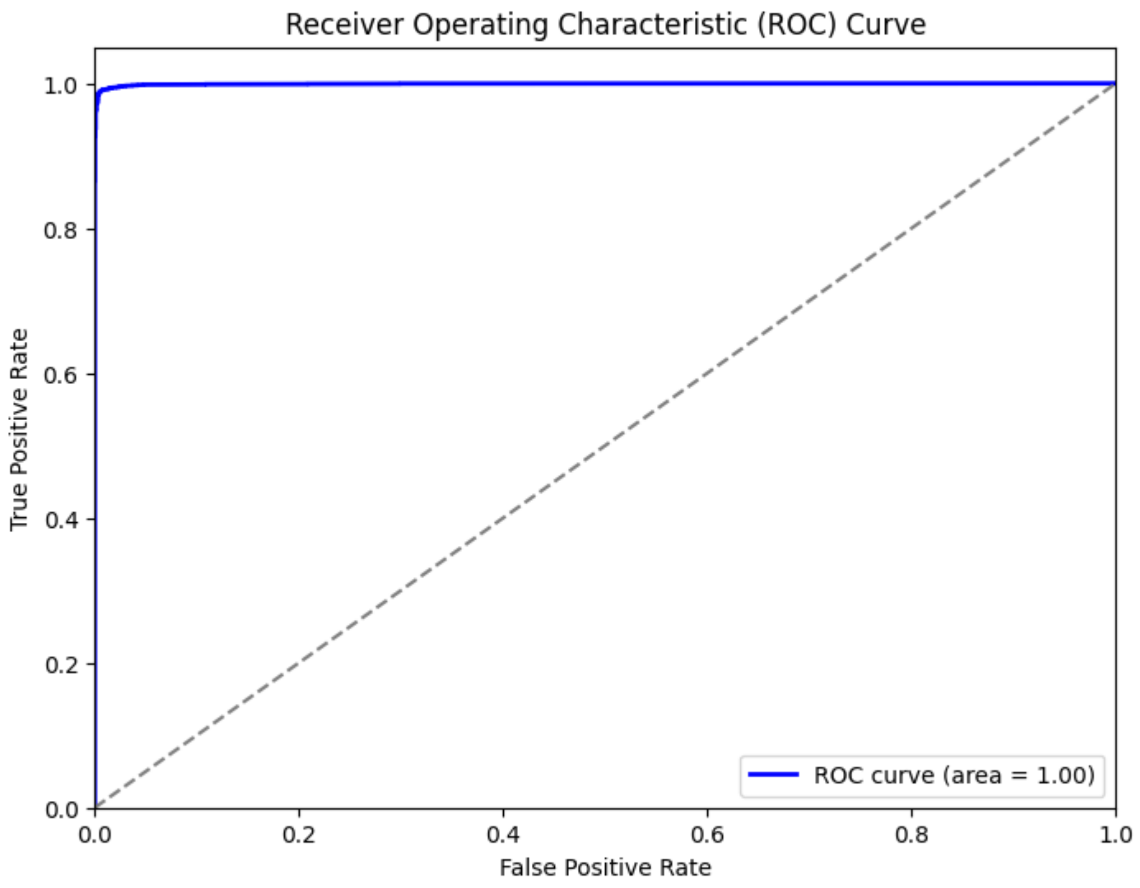
Precision-Recall Curve

In [92]:
```
if isinstance(test_preds_hybrid, list):
    test_preds_hybrid_tensor = torch.cat([torch.tensor(t) if isinstance(
else:
    test_preds_hybrid_tensor = torch.tensor(test_preds_hybrid)

predictions = torch.sigmoid(test_preds_hybrid_tensor).cpu().detach().num
precision, recall, _ = precision_recall_curve(test_y_numpy, predictions)

plt.figure(figsize=(8, 6))
plt.plot(recall, precision, color='blue', lw=2, label='Precision-Recall 
plt.xlabel('Recall')
plt.ylabel('Precision')
plt.title('Precision-Recall Curve')
plt.legend(loc="lower left")
plt.show()
```



ROC Curve and AUC

In [93]:
```
fpr, tpr, thresholds = roc_curve(test_y, [torch.sigmoid(t).item() for t 
roc_auc = auc(fpr, tpr)

plt.figure(figsize=(8, 6))
plt.plot(fpr, tpr, color='blue', lw=2, label='ROC curve (area = %0.2f)' 
plt.plot([0, 1], [0, 1], color='gray', linestyle='--')
plt.xlim([0.0, 1.0])
plt.ylim([0.0, 1.05])
plt.xlabel('False Positive Rate')
plt.ylabel('True Positive Rate')
plt.title('Receiver Operating Characteristic (ROC) Curve')
plt.legend(loc="lower right")
plt.show()
```



Classification Accuracy per Class

In [94]:

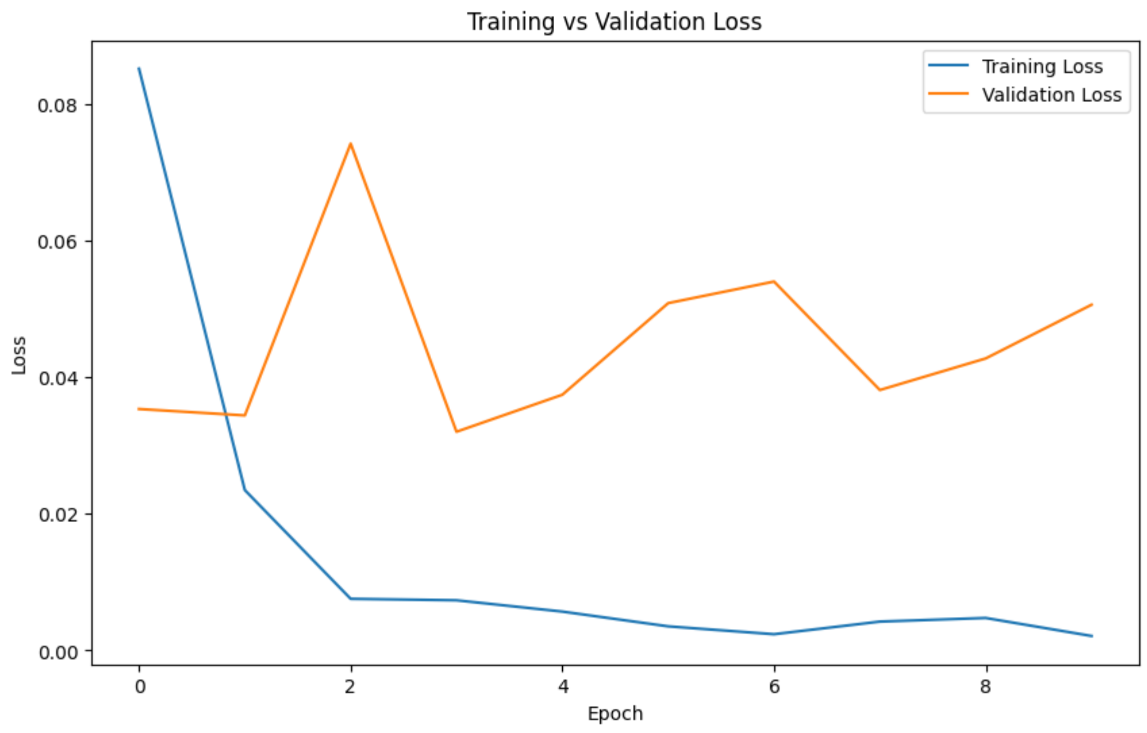
```
# True class (1 = True, 0 = Fake)
accuracy_true = accuracy_score(test_y_numpy[test_y_numpy == 1], preds_nu
accuracy_fake = accuracy_score(test_y_numpy[test_y_numpy == 0], preds_nu

print(f"Accuracy for True class: {accuracy_true:.4f}")
print(f"Accuracy for Fake class: {accuracy_fake:.4f}")
```

```
Accuracy for True class: 0.9917
Accuracy for Fake class: 0.9891
```

Learning Curves (Training vs Validation Loss)

In [95]:

```
plt.figure(figsize=(10, 6))
plt.plot(train_losses_hybrid, label='Training Loss')
plt.plot(valid_losses_hybrid, label='Validation Loss')
plt.xlabel('Epoch')
plt.ylabel('Loss')
plt.title('Training vs Validation Loss')
plt.legend()
plt.show()
```



13. Grid Search for Hyperparameter Tuning

In [96]:

```
learning_rates = [0.005, 0.01]
batch_sizes = [32, 64]
hidden_dims = [128, 256, 512]
filter_multipliers = [64, 128, 256]

param_grid = list(itertools.product(
    learning_rates,
    batch_sizes,
    hidden_dims,
    filter_multipliers
))
```

In [97]:

```
def createNewDL(paddedData, labels, batch_size, shuffle=False):
    dataset = list(zip(paddedData, labels))
    return DataLoader(dataset, batch_size=batch_size, shuffle=shuffle)
```

In [98]:
```
def gridSearch(model_class, param_grid, train_data, valid_data, test_data
    best_valid_acc = 0
    best_params = None
    best_model = None

    for params in param_grid:
        learning_rate, batch_size, hidden_dim, filter_multiplier = params

        # Create the DataLoaders with current batch size using raw data
        trainPadded, trainLabels = train_data
        validPadded, validLabels = valid_data
        testPadded, testLabels = test_data

        # Create DataLoaders
        trainDL = createNewDL(trainPadded, trainLabels, batch_size, shuf
        validDL = createNewDL(validPadded, validLabels, batch_size, shuf
        testDL = createNewDL(testPadded, testLabels, batch_size, shuffle

        # Initialize the model, optimizer, and criterion with current hy
        model = model_class(300, VOCAB_SIZE, hidden_dim, filter_multipli
        optimizer = Adam(model.parameters(), lr=learning_rate, betas=(0.
        criterion = nn.BCEWithLogitsLoss()

        # Train the model
        print(f"Training with: lr={learning_rate}, batch_size={batch_siz
        train_losses, valid_losses, test_loss, train_accs, valid_accs, t
            model, optimizer, criterion, trainDL, validDL, testDL, numEp
        )

        valid_acc = valid_accs[-1]

        # Check if this model is better
        if valid_acc > best_valid_acc:
            best_valid_acc = valid_acc
            best_params = params
            best_model = model
            print(f"New best model found with validation accuracy: {vali

    print(f"\nBest Validation Accuracy: {best_valid_acc:.4f}")
    print(f"Best Hyperparameters: {best_params}")

    # Return best model and its performance on test set
    test_loss, test_acc, test_preds = eval_model(best_model, criterion, 
    print(f"Test Accuracy for Best Model: {test_acc:.4f}")
    print(f"Test Loss for Best Model: {test_loss:.4f}")
    return best_model, best_params
```

In [99]:
```
# best_model, best_params = gridSearch(
#     Hybrid, param_grid, (trainPadded, trainLabels), (validPadded, vali
# )

# test_preds_flat = [t.item() for t in best_model(test_preds_hybrid)]
# test_preds_tensor = torch.tensor(test_preds_flat)
# predictions = torch.sigmoid(test_preds_tensor).cpu().detach().numpy()
# print(classification_report(test_y, predictions))
```