SecuDroid - Android Malware Detection using ML Claasifiers

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In [1]:
```
pip install --upgrade scipy
```

```
Requirement already satisfied: scipy in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (1.12.0)
Requirement already satisfied: numpy<1.29.0,>=1.22.4 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from scipy) (1.24.3)
Note: you may need to restart the kernel to use updated packages.
```

In [2]:
```
pip install seaborn scikit-learn
```

```
Requirement already satisfied: seaborn in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (0.13.2)
Requirement already satisfied: scikit-learn in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (1.4.1.post1)
Requirement already satisfied: numpy!=1.24.0,>=1.20 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from seaborn) (1.24.3)
Requirement already satisfied: pandas>=1.2 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from seaborn) (2.2.0)
Requirement already satisfied: matplotlib!=3.6.1,>=3.4 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from seaborn) (3.8.3)
Requirement already satisfied: scipy>=1.6.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from scikit-learn) (1.12.0)
Requirement already satisfied: joblib>=1.2.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from scikit-learn) (1.3.2)
Requirement already satisfied: threadpoolctl>=2.0.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from scikit-learn) (3.3.0)
Requirement already satisfied: contourpy>=1.0.1 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from matplotlib!=3.6.1,>=3.4->seaborn) (1.2.0)
Requirement already satisfied: cycler>=0.10 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from matplotlib!=3.6.1,>=3.4->seaborn) (0.12.1)
Requirement already satisfied: fonttools>=4.22.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from matplotlib!=3.6.1,>=3.4->seaborn) (4.49.0)
Requirement already satisfied: kiwisolver>=1.3.1 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from matplotlib!=3.6.1,>=3.4->seaborn) (1.4.5)
Requirement already satisfied: packaging>=20.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from matplotlib!=3.6.1,>=3.4->seaborn) (23.2)
Requirement already satisfied: pillow>=8 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from matplotlib!=3.6.1,>=3.4->seaborn) (10.2.0)
Requirement already satisfied: pyparsing>=2.3.1 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from matplotlib!=3.6.1,>=3.4->seaborn) (3.1.1)
Requirement already satisfied: python-dateutil>=2.7 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from matplotlib!=3.6.1,>=3.4->seaborn) (2.8.2)
Requirement already satisfied: pytz>=2020.1 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from pandas>=1.2->seaborn) (2024.1)
Requirement already satisfied: tzdata>=2022.7 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from pandas>=1.2->seaborn) (2024.1)
Requirement already satisfied: six>=1.5 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from python-dateutil>=2.7->matplotlib!=3.6.1,>=3.4->seaborn) (1.16.0)
Note: you may need to restart the kernel to use updated packages.
```

In [3]:
```
pip install tensorflow==2.13.1 tensorflow-io==0.34.0
```

```
Requirement already satisfied: tensorflow==2.13.1 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/
lib/python3.11/site-packages (2.13.1)
Requirement already satisfied: tensorflow-io==0.34.0 in /Users/abkumjha/.local/share/mise/installs/python/3.1
1.7/lib/python3.11/site-packages (0.34.0)
Requirement already satisfied: tensorflow-macos==2.13.1 in /Users/abkumjha/.local/share/mise/installs/python/
3.11.7/lib/python3.11/site-packages (from tensorflow==2.13.1) (2.13.1)
Requirement already satisfied: tensorflow-io-gcs-filesystem==0.34.0 in /Users/abkumjha/.local/share/mise/insta
lls/python/3.11.7/lib/python3.11/site-packages (from tensorflow-io==0.34.0) (0.34.0)
Requirement already satisfied: absl-py>=1.0.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/
python3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (2.1.0)
Requirement already satisfied: astunparse>=1.6.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/l
ib/python3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (1.6.3)
Requirement already satisfied: flatbuffers>=23.1.21 in /Users/abkumjha/.local/share/mise/installs/python/3.11.
7/lib/python3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (23.5.26)
Requirement already satisfied: gast<=0.4.0,>=0.2.1 in /Users/abkumjha/.local/share/mise/installs/python/3.11.
7/lib/python3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (0.4.0)
Requirement already satisfied: google-pasta>=0.1.1 in /Users/abkumjha/.local/share/mise/installs/python/3.11.
7/lib/python3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (0.2.0)
Requirement already satisfied: h5py>=2.9.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/pyt
hon3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (3.10.0)
Requirement already satisfied: libclang>=13.0.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/li
b/python3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (16.0.6)
Requirement already satisfied: numpy<=1.24.3,>=1.22 in /Users/abkumjha/.local/share/mise/installs/python/3.11.
7/lib/python3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (1.24.3)
Requirement already satisfied: opt-einsum>=2.3.2 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/l
ib/python3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (3.3.0)
Requirement already satisfied: packaging in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/pytho
n3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (23.2)
Requirement already satisfied: protobuf!=4.21.0,!=4.21.1,!=4.21.2,!=4.21.3,!=4.21.4,!=4.21.5,<5.0.0dev,>=3.20.
3 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.11/site-packages (from tensorflow-ma
cos==2.13.1->tensorflow==2.13.1) (4.25.3)
Requirement already satisfied: setuptools in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/pyth
on3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (65.5.0)
Requirement already satisfied: six>=1.12.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/pyt
hon3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (1.16.0)
Requirement already satisfied: termcolor>=1.1.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/li
b/python3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (2.4.0)
Requirement already satisfied: typing-extensions<4.6.0,>=3.6.6 in /Users/abkumjha/.local/share/mise/installs/p
ython/3.11.7/lib/python3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (4.5.0)
Requirement already satisfied: wrapt>=1.11.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/p
ython3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (1.16.0)
Requirement already satisfied: grpcio<2.0,>=1.24.3 in /Users/abkumjha/.local/share/mise/installs/python/3.11.
7/lib/python3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (1.62.0)
Requirement already satisfied: tensorboard<2.14,>=2.13 in /Users/abkumjha/.local/share/mise/installs/python/3.
11.7/lib/python3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (2.13.0)
Requirement already satisfied: tensorflow-estimator<2.14,>=2.13.0 in /Users/abkumjha/.local/share/mise/install
s/python/3.11.7/lib/python3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (2.13.0)
Requirement already satisfied: keras<2.14,>=2.13.1 in /Users/abkumjha/.local/share/mise/installs/python/3.11.
7/lib/python3.11/site-packages (from tensorflow-macos==2.13.1->tensorflow==2.13.1) (2.13.1)
Requirement already satisfied: wheel<1.0,>=0.23.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/
lib/python3.11/site-packages (from astunparse>=1.6.0->tensorflow-macos==2.13.1->tensorflow==2.13.1) (0.42.0)
Requirement already satisfied: google-auth<3,>=1.6.3 in /Users/abkumjha/.local/share/mise/installs/python/3.1
1.7/lib/python3.11/site-packages (from tensorboard<2.14,>=2.13->tensorflow-macos==2.13.1->tensorflow==2.13.1)
(2.28.1)
Requirement already satisfied: google-auth-oauthlib<1.1,>=0.5 in /Users/abkumjha/.local/share/mise/installs/py
thon/3.11.7/lib/python3.11/site-packages (from tensorboard<2.14,>=2.13->tensorflow-macos==2.13.1->tensorflow==
2.13.1) (1.0.0)
Requirement already satisfied: markdown>=2.6.8 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/li
b/python3.11/site-packages (from tensorboard<2.14,>=2.13->tensorflow-macos==2.13.1->tensorflow==2.13.1) (3.5.
2)
Requirement already satisfied: requests<3,>=2.21.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.
7/lib/python3.11/site-packages (from tensorboard<2.14,>=2.13->tensorflow-macos==2.13.1->tensorflow==2.13.1)
(2.31.0)
Requirement already satisfied: tensorboard-data-server<0.8.0,>=0.7.0 in /Users/abkumjha/.local/share/mise/inst
alls/python/3.11.7/lib/python3.11/site-packages (from tensorboard<2.14,>=2.13->tensorflow-macos==2.13.1->tenso
rflow==2.13.1) (0.7.2)
Requirement already satisfied: werkzeug>=1.0.1 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/li
b/python3.11/site-packages (from tensorboard<2.14,>=2.13->tensorflow-macos==2.13.1->tensorflow==2.13.1) (3.0.
1)
Requirement already satisfied: cachetools<6.0,>=2.0.0 in /Users/abkumjha/.local/share/mise/installs/python/3.1
1.7/lib/python3.11/site-packages (from google-auth<3,>=1.6.3->tensorboard<2.14,>=2.13->tensorflow-macos==2.13.
1->tensorflow==2.13.1) (5.3.2)
Requirement already satisfied: pyasn1-modules>=0.2.1 in /Users/abkumjha/.local/share/mise/installs/python/3.1
1.7/lib/python3.11/site-packages (from google-auth<3,>=1.6.3->tensorboard<2.14,>=2.13->tensorflow-macos==2.13.
1->tensorflow==2.13.1) (0.3.0)
Requirement already satisfied: rsa<5,>=3.1.4 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/p
ython3.11/site-packages (from google-auth<3,>=1.6.3->tensorboard<2.14,>=2.13->tensorflow-macos==2.13.1->tensor
flow==2.13.1) (4.9)
Requirement already satisfied: requests-oauthlib>=0.7.0 in /Users/abkumjha/.local/share/mise/installs/python/
3.11.7/lib/python3.11/site-packages (from google-auth-oauthlib<1.1,>=0.5->tensorboard<2.14,>=2.13->tensorflow-
macos==2.13.1->tensorflow==2.13.1) (1.3.1)
Requirement already satisfied: charset-normalizer<4,>=2 in /Users/abkumjha/.local/share/mise/installs/python/
3.11.7/lib/python3.11/site-packages (from requests<3,>=2.21.0->tensorboard<2.14,>=2.13->tensorflow-macos==2.13
.1->tensorflow==2.13.1) (3.3.2)
Requirement already satisfied: idna<4,>=2.5 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/py
thon3.11/site-packages (from requests<3,>=2.21.0->tensorboard<2.14,>=2.13->tensorflow-macos==2.13.1->tensorflo
```

```
w==2.13.1) (3.6)
Requirement already satisfied: urllib3<3,>=1.21.1 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/
lib/python3.11/site-packages (from requests<3,>=2.21.0->tensorboard<2.14,>=2.13->tensorflow-macos==2.13.1->ten
sorflow==2.13.1) (2.2.1)
Requirement already satisfied: certifi>=2017.4.17 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/
lib/python3.11/site-packages (from requests<3,>=2.21.0->tensorboard<2.14,>=2.13->tensorflow-macos==2.13.1->ten
sorflow==2.13.1) (2024.2.2)
Requirement already satisfied: MarkupSafe>=2.1.1 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/l
ib/python3.11/site-packages (from werkzeug>=1.0.1->tensorboard<2.14,>=2.13->tensorflow-macos==2.13.1->tensorfl
ow==2.13.1) (2.1.5)
Requirement already satisfied: pyasn1<0.6.0,>=0.4.6 in /Users/abkumjha/.local/share/mise/installs/python/3.11.
7/lib/python3.11/site-packages (from pyasn1-modules>=0.2.1->google-auth<3,>=1.6.3->tensorboard<2.14,>=2.13->te
nsorflow-macos==2.13.1->tensorflow==2.13.1) (0.5.1)
Requirement already satisfied: oauthlib>=3.0.0 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/li
b/python3.11/site-packages (from requests-oauthlib>=0.7.0->google-auth-oauthlib<1.1,>=0.5->tensorboard<2.14,>=
2.13->tensorflow-macos==2.13.1->tensorflow==2.13.1) (3.2.2)
Note: you may need to restart the kernel to use updated packages.
```

In [4]:
```
pip install pydot
```

```
Requirement already satisfied: pydot in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/python3.1
1/site-packages (2.0.0)
Requirement already satisfied: pyparsing>=3 in /Users/abkumjha/.local/share/mise/installs/python/3.11.7/lib/py
thon3.11/site-packages (from pydot) (3.1.1)
Note: you may need to restart the kernel to use updated packages.
```

Importing and pre-processing Dataset

In [5]:
```
import pandas as pd
import numpy as np
np.random.seed(0)
from sklearn.metrics import precision_score,recall_score,f1_score
import tensorflow as tf
tf.compat.v1.set_random_seed(0)
from tensorflow import keras
import matplotlib.pyplot as plt
from sklearn.model_selection import train_test_split
from sklearn.preprocessing import LabelEncoder
from sklearn.metrics import ConfusionMatrixDisplay
from sklearn.metrics import confusion_matrix
```

```
/var/folders/mj/zz2t97c53ds0_py7bfbm80s00000gr/T/ipykernel_53012/2223888169.py:1: DeprecationWarning:
Pyarrow will become a required dependency of pandas in the next major release of pandas (pandas 3.0),
(to allow more performant data types, such as the Arrow string type, and better interoperability with other li
braries)
but was not found to be installed on your system.
If this would cause problems for you,
please provide us feedback at https://github.com/pandas-dev/pandas/issues/54466

  import pandas as pd
```

In [6]:
```
data = pd.read_csv("~/Desktop/SecuDroid/dataset/drebin/drebin-215-dataset-5560malware-9476-benign.csv")
print("Total missing values : ",sum(list(data.isna().sum())))
data
```

```
Total missing values :  0
/var/folders/mj/zz2t97c53ds0_py7bfbm80s00000gr/T/ipykernel_53012/2941368734.py:1: DtypeWarning: Columns (92) h
ave mixed types. Specify dtype option on import or set low_memory=False.
  data = pd.read_csv("~/Desktop/SecuDroid/dataset/drebin/drebin-215-dataset-5560malware-9476-benign.csv")
```

Out[6]:

	transact	onServiceConnected	bindService	attachInterface	ServiceConnection	android.os.Binder	SEND_SMS	Ljava.lang.Class
0	0	0	0	0	0	0	1	
1	0	0	0	0	0	0	1	
2	0	0	0	0	0	0	1	
3	0	0	0	0	0	0	0	
4	0	0	0	0	0	0	0	
...	...	...	...	...	...	...	...	
15031	1	1	1	1	1	1	0	
15032	0	0	0	0	0	0	0	
15033	0	0	0	0	0	0	0	
15034	1	1	1	1	1	1	0	
15035	1	1	1	1	1	1	0	

15036 rows × 216 columns

In [7]:
```
classes,count = np.unique(data['class'],return_counts=True)
#Perform Label Encoding
lbl_enc = LabelEncoder()
print(lbl_enc.fit_transform(classes),classes)
data = data.replace(classes,lbl_enc.fit_transform(classes))

#Dataset contains special characters like ''?' and 'S'. Set them to NaN and use dropna() to remove them
data=data.replace('[?,S]',np.NaN,regex=True)
print("Total missing values : ",sum(list(data.isna().sum())))
data.dropna(inplace=True)
for c in data.columns:
    data[c] = pd.to_numeric(data[c])
data
```

```
[0 1] ['B' 'S']
Total missing values :  5
```

```
/var/folders/mj/zz2t97c53ds0_py7bfbm80s00000gr/T/ipykernel_53012/410007786.py:5: FutureWarning: Downcasting behavior in `replace` is deprecated and will be removed in a future version. To retain the old behavior, explicitly call `result.infer_objects(copy=False)`. To opt-in to the future behavior, set `pd.set_option('future.no_silent_downcasting', True)`
  data = data.replace(classes,lbl_enc.fit_transform(classes))
```

Out[7]:

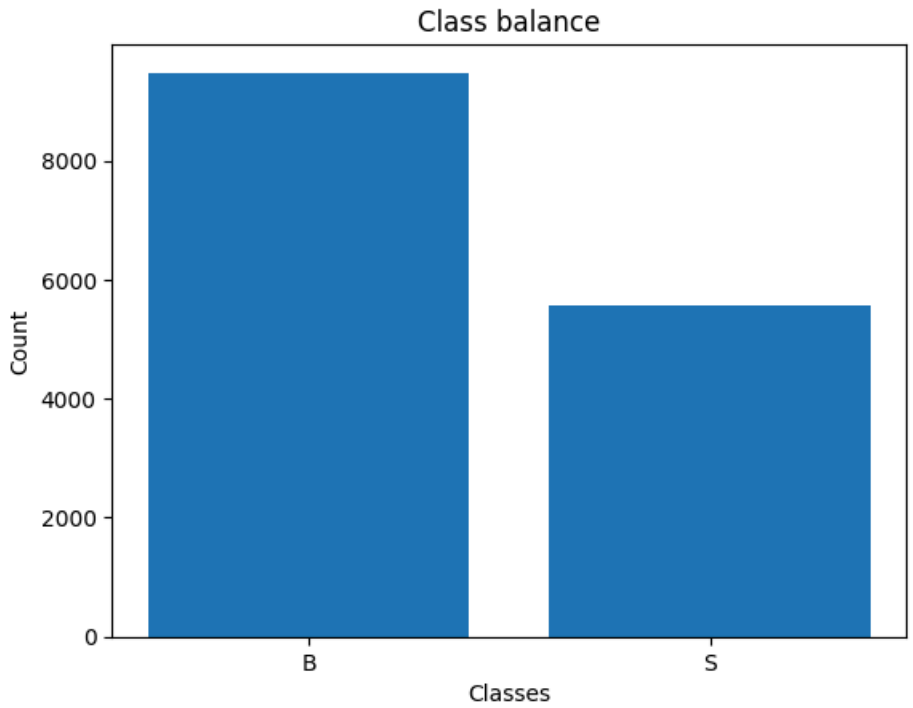
	transact	onServiceConnected	bindService	attachInterface	ServiceConnection	android.os.Binder	SEND_SMS	Ljava.lang.Class
0	0	0	0	0	0	0	1	
1	0	0	0	0	0	0	1	
2	0	0	0	0	0	0	1	
3	0	0	0	0	0	0	0	
4	0	0	0	0	0	0	0	
...	...	...	...	...	...	...	...	
15031	1	1	1	1	1	1	0	
15032	0	0	0	0	0	0	0	
15033	0	0	0	0	0	0	0	
15034	1	1	1	1	1	1	0	
15035	1	1	1	1	1	1	0	

15031 rows × 216 columns

In [8]:
```
print("Total Features : ",len(data.columns)-1)
```

```
Total Features :  215
```

In [9]:
```
plt.bar(classes,count)
plt.title("Class balance")
plt.xlabel("Classes")
plt.ylabel("Count")
plt.show()
```



Balancing Dataset

In [10]:
```
from sklearn.utils import resample
# Separate features and labels
X = data.drop("class", axis=1)
y = data["class"]

# Count the occurrences of each class
class_counts = y.value_counts()

# Calculate the majority and minority class labels
majority_class = class_counts.idxmax()
minority_class = class_counts.idxmin()

# Separate majority and minority class samples
majority_samples = data[data["class"] == majority_class]
minority_samples = data[data["class"] == minority_class]

# Oversample the minority class to match the majority class
minority_oversampled = resample(minority_samples,
                                replace=True,      # Sample with replacement
                                n_samples=len(majority_samples),  # Match majority class
                                random_state=0)    # Set random seed for reproducibility

# Combine the oversampled minority class with the majority class
balanced_data = pd.concat([majority_samples, minority_oversampled])

# Shuffle the balanced dataset
balanced_data = balanced_data.sample(frac=1, random_state=0)

# Now, balanced_data contains the balanced dataset with equal instances of both classes
```

In [11]:
```
# Count the occurrences of each class in the balanced dataset
balanced_class_counts = balanced_data["class"].value_counts()

# Print the class counts
print(balanced_class_counts)
```

```
class
1    9476
0    9476
Name: count, dtype: int64
```

Test Split Ratio

In [12]:
```
TEST_SPLIT = 0.25
```

Splitting Dataset

In [13]:
```
from sklearn.model_selection import train_test_split
train_x,test_x,train_y,test_y = train_test_split(data[data.columns[:len(data.columns)-1]].to_numpy(),
                                                 data[data.columns[-1]].to_numpy(),
                                                  test_size = TEST_SPLIT,
                                                  shuffle=True)
```

In [14]:
```
print("Train features size : ",len(train_x))
print("Train labels size : ",len(train_y))
print("Test features size : ",len(test_x))
print("Test features size : ",len(test_y))
```

```
Train features size :  11273
Train labels size :  11273
Test features size :  3758
Test features size :  3758
```

In [15]:
```
print("Train features : ",train_x.shape)
print("Train labels : ",train_y.shape)
print("Test Features : ",test_x.shape)
print("Test labels : ",test_y.shape)
```

```
Train features :  (11273, 215)
Train labels :  (11273,)
Test Features :  (3758, 215)
Test labels :  (3758,)
```

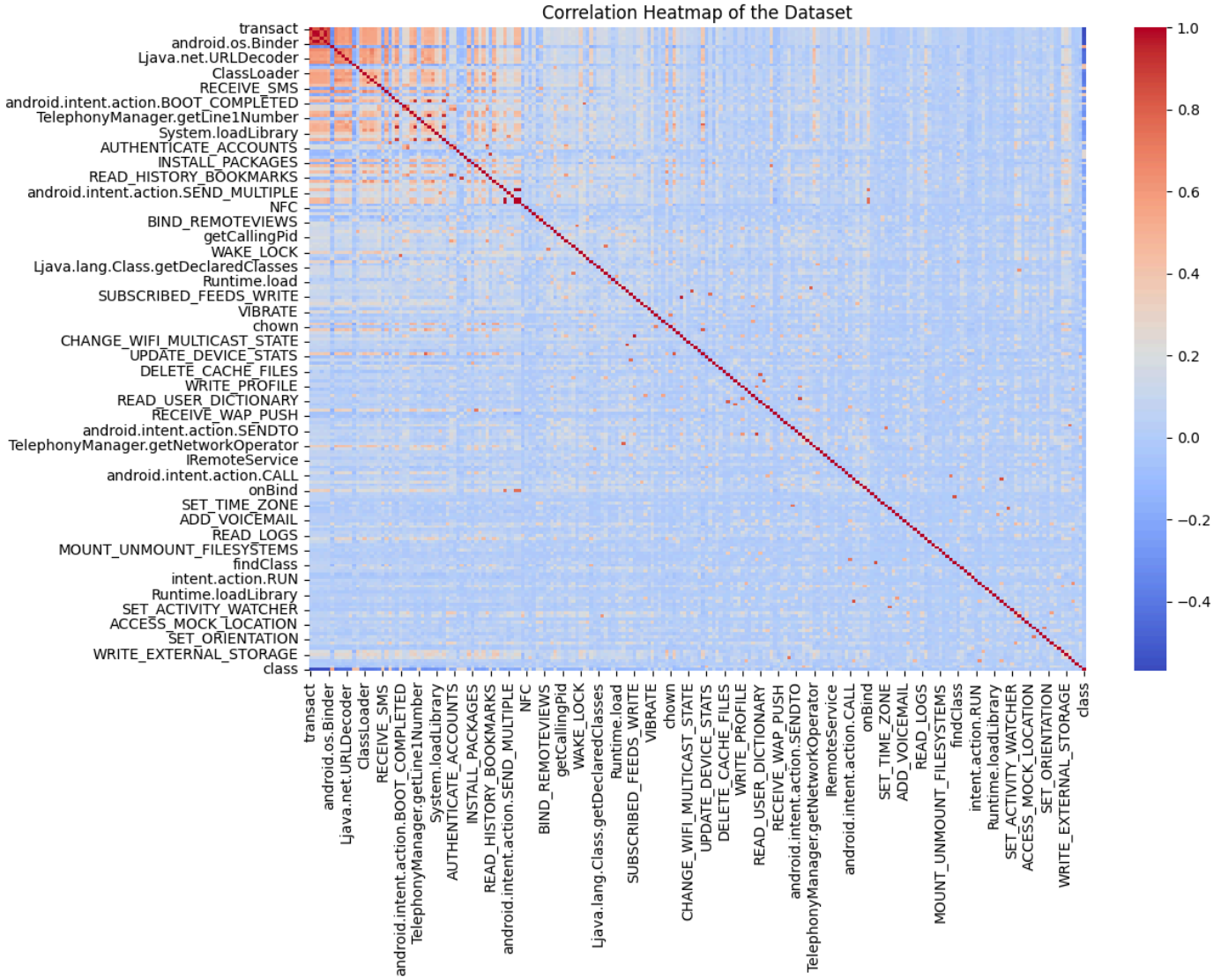
In [16]:
```
train_y = train_y.reshape((-1,1))
test_y = test_y.reshape((-1,1))
```

In [17]:
```
print("Train features : ",train_x.shape)
print("Train labels : ",train_y.shape)
print("Test Features : ",test_x.shape)
print("Test labels : ",test_y.shape)
```

```
Train features :  (11273, 215)
Train labels :  (11273, 1)
Test Features :  (3758, 215)
Test labels :  (3758, 1)
```

HEATMAP

In [18]:
```python
import pandas as pd
import seaborn as sns
import matplotlib.pyplot as plt

# Plot the heatmap
plt.figure(figsize=(12, 8))
heatmap = sns.heatmap(data.corr(), annot=False, cmap="coolwarm")
plt.title("Correlation Heatmap of the Dataset")
plt.show()
```



Helper function to display all performance metrics

In [19]:
```python
from sklearn.metrics import confusion_matrix, accuracy_score, precision_score, recall_score, f1_score, roc_cur
import matplotlib.pyplot as plt

def evaluate_classification_model(y_test, y_pred, y_prob):
    # 1. Confusion Matrix
    conf_matrix = confusion_matrix(y_test, y_pred)
    print("Confusion Matrix:")
    print(conf_matrix.astype(float))  # Ensure all elements are treated as float for formatting
    print("\n")

    # 2. Accuracy, Precision, Recall, F1 Score
    accuracy = accuracy_score(y_test, y_pred)
    precision = precision_score(y_test, y_pred, average='binary')
    recall = recall_score(y_test, y_pred, average='binary')
    f1 = f1_score(y_test, y_pred, average='binary')

    print(f"Accuracy: {accuracy:.4f}")
    print(f"Precision: {precision:.4f}")
    print(f"Recall: {recall:.4f}")
    print(f"F1 Score: {f1:.4f}")
```

```
    print("\n")

    # 3. ROC Curve and AUC
    if len(np.unique(y_test)) == 2:  # Check if it's a binary classification task
        fpr, tpr, _ = roc_curve(y_test, y_prob)
        auc = roc_auc_score(y_test, y_prob)

        plt.figure(figsize=(8, 6))
        plt.plot(fpr, tpr, label=f'AUC = {auc:.4f}')
        plt.plot([0, 1], [0, 1], '--', color='gray', label='Random')
        plt.xlabel('False Positive Rate')
        plt.ylabel('True Positive Rate')
        plt.title('ROC Curve')
        plt.legend()
        plt.show()
        print(f"AUC: {auc:.4f}")
        print("\n")
    else:
        print("ROC Curve and AUC not applicable for multiclass classification.")

    # 4. Classification Report
    report = classification_report(y_test, y_pred, digits=4)
    print("Classification Report:")
    print(report)
```

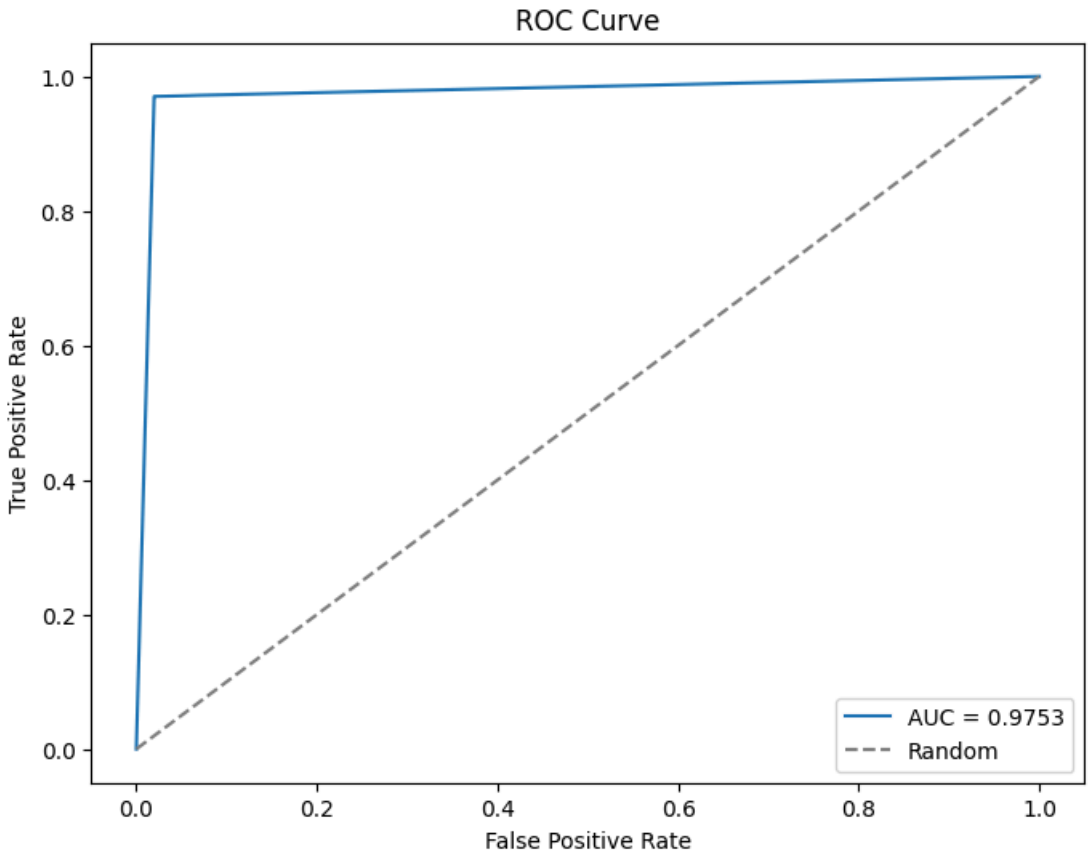
DECISION TREE

In [20]:
```
import pandas as pd
from sklearn.model_selection import train_test_split
from sklearn.tree import DecisionTreeClassifier
from sklearn.metrics import accuracy_score, classification_report
from sklearn.model_selection import StratifiedKFold, cross_val_predict
from sklearn.model_selection import GridSearchCV
```

In [21]:
```
X = data.drop('class', axis=1)  # Features
y = data['class']  # Target variabl

# Declaring Decision Tree Classifier
dt_clf = DecisionTreeClassifier(random_state=42, max_depth=28, min_samples_split=2, min_samples_leaf=1)
```

In [22]:
```
# Stratified 4-fold cross-validation
cv = StratifiedKFold(n_splits=4, shuffle=True, random_state=42)

# Perform cross-validation and get predictions
y_pred_cv = cross_val_predict(dt_clf, X, y, cv=cv, method='predict')
y_prob_cv = cross_val_predict(dt_clf, X, y, cv=cv, method='predict_proba')[:, 1]

evaluate_classification_model(y, y_pred_cv, y_prob_cv)
```

```
Confusion Matrix:
[[9289.  187.]
 [ 166. 5389.]]


Accuracy: 0.9765
Precision: 0.9665
Recall: 0.9701
F1 Score: 0.9683
```




```
AUC: 0.9753


Classification Report:
              precision    recall  f1-score   support

           0     0.9824    0.9803    0.9814      9476
           1     0.9665    0.9701    0.9683      5555

    accuracy                         0.9765     15031
   macro avg     0.9745    0.9752    0.9748     15031
weighted avg     0.9765    0.9765    0.9765     15031
```

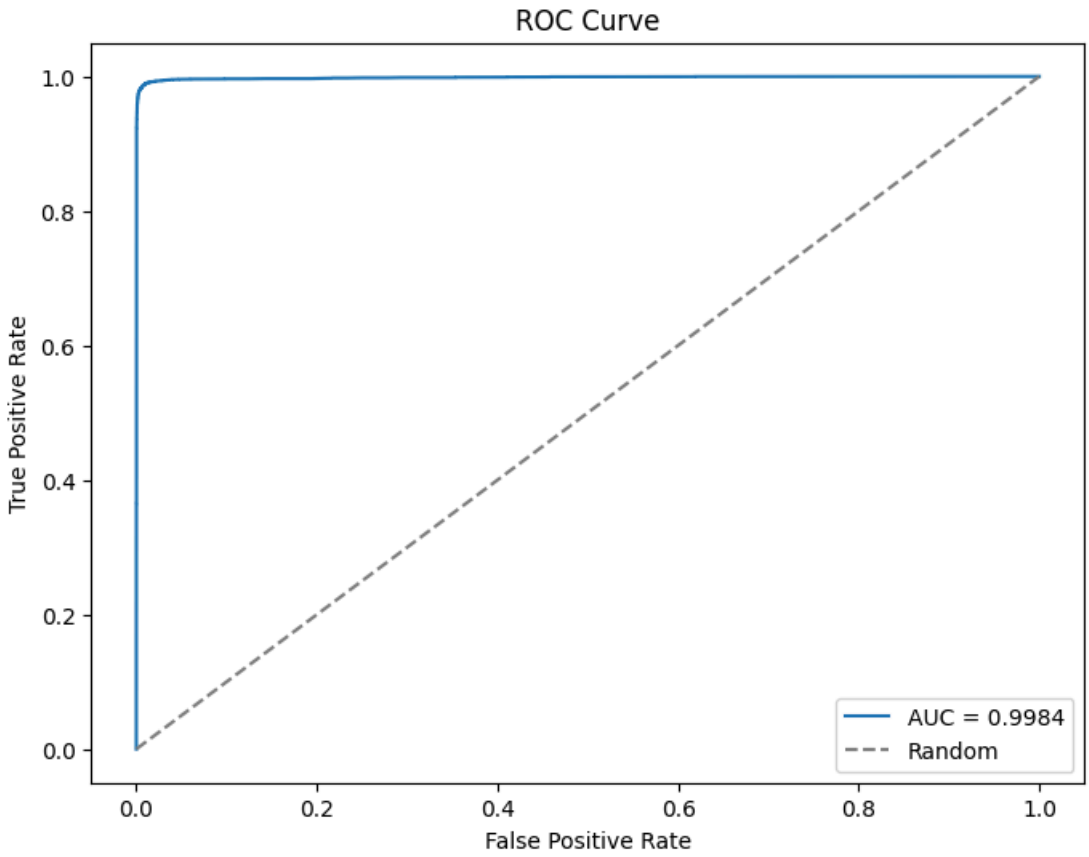
SUPPORT VECTOR MACHINE

In [23]:
```
import pandas as pd
from sklearn.model_selection import train_test_split
from sklearn.svm import SVC
from sklearn.metrics import accuracy_score
from sklearn.model_selection import StratifiedKFold, cross_val_predict
```

In [24]:
```
X = data.drop('class', axis=1)  # Features
y = data['class']  # Target variable

# Declaring Support Vector Machine Classifier
svm_clf = SVC(kernel='rbf', C=15, gamma=0.1, probability=True)
```

In [25]:
```
# Use StratifiedKFold for cross-validation
cv = StratifiedKFold(n_splits=4, shuffle=True, random_state=42)

# Perform cross-validation and get predictions
y_pred_cv = cross_val_predict(svm_clf, X, y, cv=cv, method='predict')
y_prob_cv = cross_val_predict(svm_clf, X, y, cv=cv, method='predict_proba')[:, 1]
evaluate_classification_model(y, y_pred_cv, y_prob_cv)
```

```
Confusion Matrix:
[[9426.   50.]
 [  95. 5460.]]


Accuracy: 0.9904
Precision: 0.9909
Recall: 0.9829
F1 Score: 0.9869
```




```
AUC: 0.9984


Classification Report:
              precision    recall  f1-score   support

           0     0.9900    0.9947    0.9924      9476
           1     0.9909    0.9829    0.9869      5555

    accuracy                         0.9904     15031
   macro avg     0.9905    0.9888    0.9896     15031
weighted avg     0.9904    0.9904    0.9903     15031
```

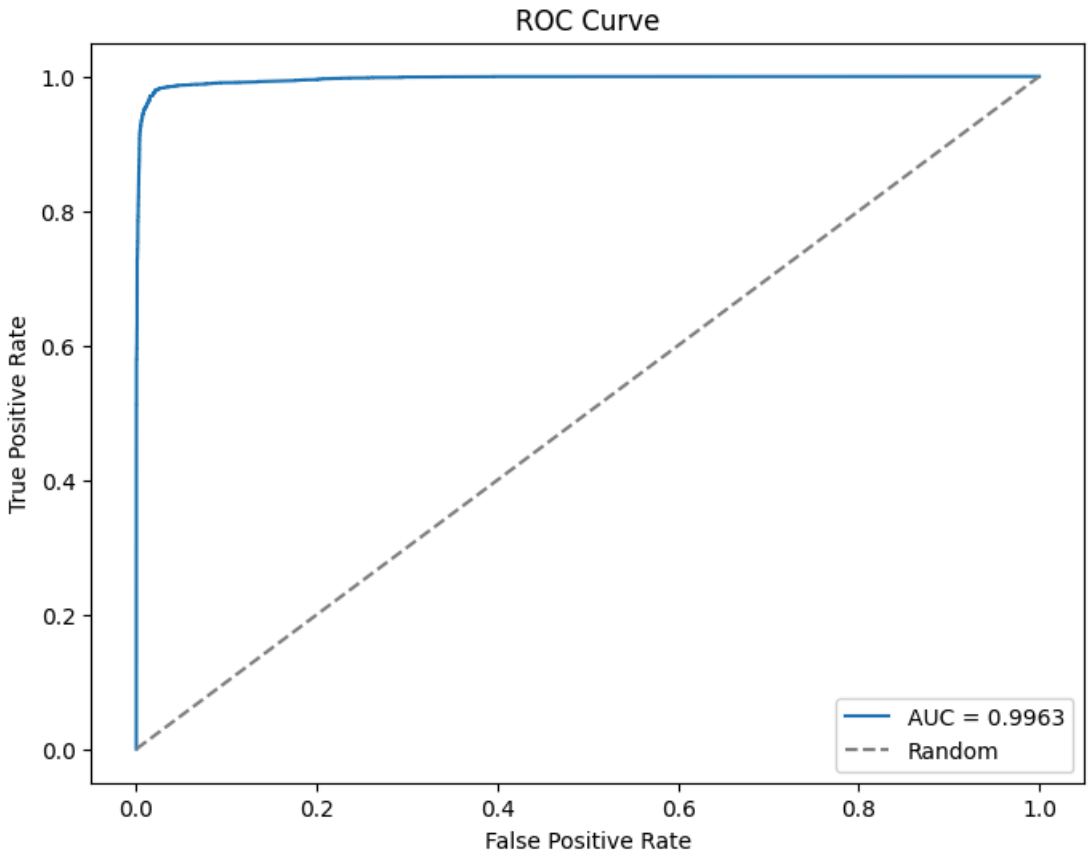
LOGISTIC REGRESSION

In [26]:
```
import pandas as pd
from sklearn.model_selection import train_test_split
from sklearn.linear_model import LogisticRegression
from sklearn.metrics import accuracy_score
```

In [27]:
```
X = data.drop('class', axis=1)  # Features
y = data['class']  # Target variable

# Declaring Logistic Regression Classifier
lr_clf = LogisticRegression(C=5, random_state=42, max_iter=1000)
```

In [28]:
```
# Use StratifiedKFold for cross-validation
cv = StratifiedKFold(n_splits=4, shuffle=True, random_state=42)

# Perform cross-validation and get predictions
y_pred_cv = cross_val_predict(lr_clf, X, y, cv=cv, method='predict')
y_prob_cv = cross_val_predict(lr_clf, X, y, cv=cv, method='predict_proba')[:, 1]
evaluate_classification_model(y, y_pred_cv, y_prob_cv)
```

```
Confusion Matrix:
[[9339.  137.]
 [ 191. 5364.]]


Accuracy: 0.9782
Precision: 0.9751
Recall: 0.9656
F1 Score: 0.9703
```




```
AUC: 0.9963


Classification Report:
              precision    recall  f1-score   support

           0     0.9800    0.9855    0.9827      9476
           1     0.9751    0.9656    0.9703      5555

    accuracy                         0.9782     15031
   macro avg     0.9775    0.9756    0.9765     15031
weighted avg     0.9782    0.9782    0.9782     15031
```

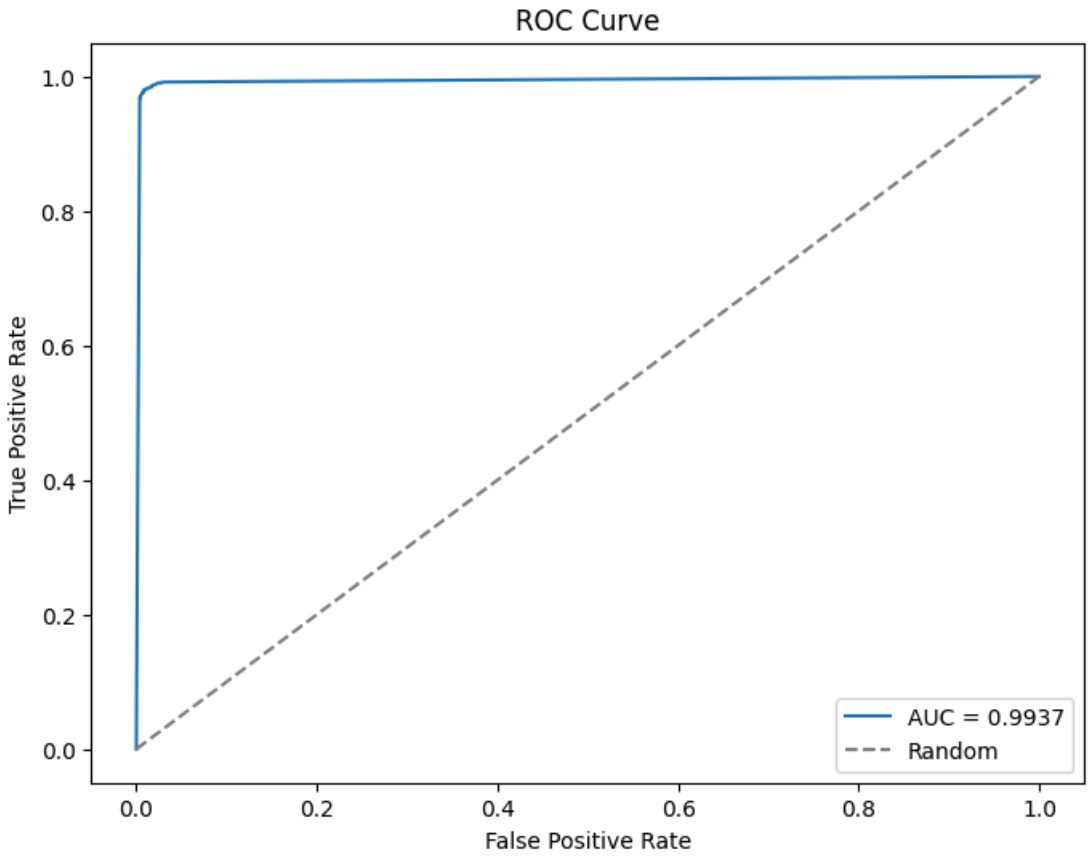
K - Nearest Neighbor

In [29]:
```
import pandas as pd
from sklearn.model_selection import train_test_split
from sklearn.neighbors import KNeighborsClassifier
from sklearn.metrics import accuracy_score
```

In [30]:
```
X = data.drop('class', axis=1)  # Features
y = data['class']  # Target variable

# Declaring K-Nearest Neighbor Classifier
knn_clf = KNeighborsClassifier(n_neighbors=4, weights='distance', p=1)
```

In [31]:
```
# Use StratifiedKFold for cross-validation
cv = StratifiedKFold(n_splits=4, shuffle=True, random_state=42)

# Perform cross-validation and get predictions
y_pred_cv = cross_val_predict(knn_clf, X, y, cv=cv, method='predict')
y_prob_cv = cross_val_predict(knn_clf, X, y, cv=cv, method='predict_proba')[:, 1]
evaluate_classification_model(y, y_pred_cv, y_prob_cv)
```

```
Confusion Matrix:
[[9376.  100.]
 [ 104. 5451.]]


Accuracy: 0.9864
Precision: 0.9820
Recall: 0.9813
F1 Score: 0.9816
```




```
AUC: 0.9937


Classification Report:
              precision    recall  f1-score   support

           0     0.9890    0.9894    0.9892      9476
           1     0.9820    0.9813    0.9816      5555

    accuracy                         0.9864     15031
   macro avg     0.9855    0.9854    0.9854     15031
weighted avg     0.9864    0.9864    0.9864     15031
```

Helper function to plot history curve

In [32]:

```python
def plot_history_curve(history_obj):
    # Extracting the history records
    training_loss = history_obj.history['loss']
    validation_loss = history_obj.history['val_loss']
    accuracy_scr = history_obj.history['accuracy']

    # Extracting the number of epochs
    epochs = range(1, len(training_loss) + 1)

    # Plotting the training and validation loss
    plt.figure(figsize=(10, 6))
    plt.plot(epochs, training_loss, 'bo-', label='Training loss')
    plt.plot(epochs, validation_loss, 'ro-', label='Validation loss')
    plt.plot(epochs, accuracy_scr, 'go-', label='Accuracy')
    plt.title('Accuracy, Training and Validation Loss')
    plt.xlabel('Epochs')
    plt.ylabel('Value')
    plt.legend()

    plt.show()
```

SEQUENTIAL NEURAL NETWORK

In [33]:
```
import pandas as pd
import numpy as np
from sklearn.model_selection import train_test_split
from sklearn.preprocessing import LabelEncoder
import tensorflow as tf
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, Dropout
from tensorflow.keras.optimizers import Adam
from sklearn.metrics import accuracy_score
from keras.models import clone_model
```

In [34]:
```
X = data.drop('class', axis=1).values  # Features
y = data['class'].values  # Target variable

label_encoder = LabelEncoder()
y = label_encoder.fit_transform(y)
```

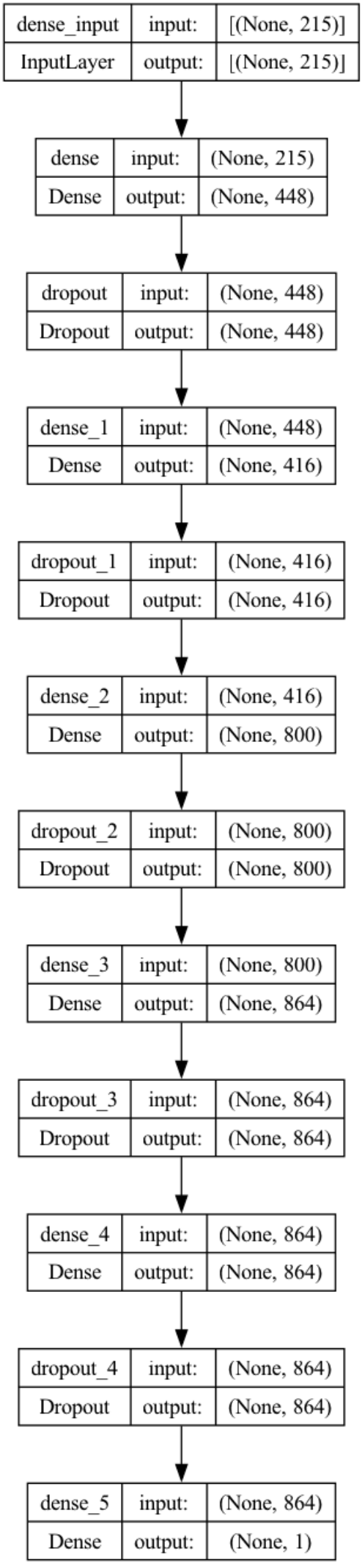
In [35]:
```
# model = Sequential([
#     Dense(448, activation='relu', input_shape=(X.shape[1],)),
#     Dropout(0.3),
#     Dense(416, activation='relu'),
#     Dropout(0.3),
#     Dense(800, activation='relu'),
#     Dropout(0.2),
#     Dense(864, activation='relu'),
#     Dropout(0.5),
#     Dense(1, activation='sigmoid')  # Binary classification, so using sigmoid activation
# ])

model = Sequential([
    Dense(448, activation='relu', input_shape=(X.shape[1],)),
    Dropout(0.3),
    Dense(416, activation='relu'),
    Dropout(0.3),
    Dense(800, activation='relu'),
    Dropout(0.2),
    Dense(864, activation='relu'),
    Dropout(0.2),
    Dense(864, activation='relu'),
    Dropout(0.5),
    Dense(1, activation='sigmoid')  # Binary classification, so using sigmoid activation
])

model.compile(optimizer=Adam(learning_rate=0.001), loss='binary_crossentropy', metrics=['accuracy'])

# Print model summary
model.summary()
```

```
WARNING:absl:At this time, the v2.11+ optimizer `tf.keras.optimizers.Adam` runs slowly on M1/M2 Macs, please use the legacy Keras optimizer instead, located at `tf.keras.optimizers.legacy.Adam`.
WARNING:absl:There is a known slowdown when using v2.11+ Keras optimizers on M1/M2 Macs. Falling back to the legacy Keras optimizer, i.e., `tf.keras.optimizers.legacy.Adam`.
Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 dense (Dense)               (None, 448)               96768

 dropout (Dropout)           (None, 448)               0

 dense_1 (Dense)             (None, 416)               186784

 dropout_1 (Dropout)         (None, 416)               0

 dense_2 (Dense)             (None, 800)               333600

 dropout_2 (Dropout)         (None, 800)               0

 dense_3 (Dense)             (None, 864)               692064

 dropout_3 (Dropout)         (None, 864)               0

 dense_4 (Dense)             (None, 864)               747360

 dropout_4 (Dropout)         (None, 864)               0

 dense_5 (Dense)             (None, 1)                 865

=================================================================
Total params: 2057441 (7.85 MB)
Trainable params: 2057441 (7.85 MB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
```

In [36]:

```
from keras.utils import plot_model

# Assuming your model is named 'model'
plot_model(model, to_file='model_architecture.png', show_shapes=True, show_layer_names=True)
```

Out[36]:

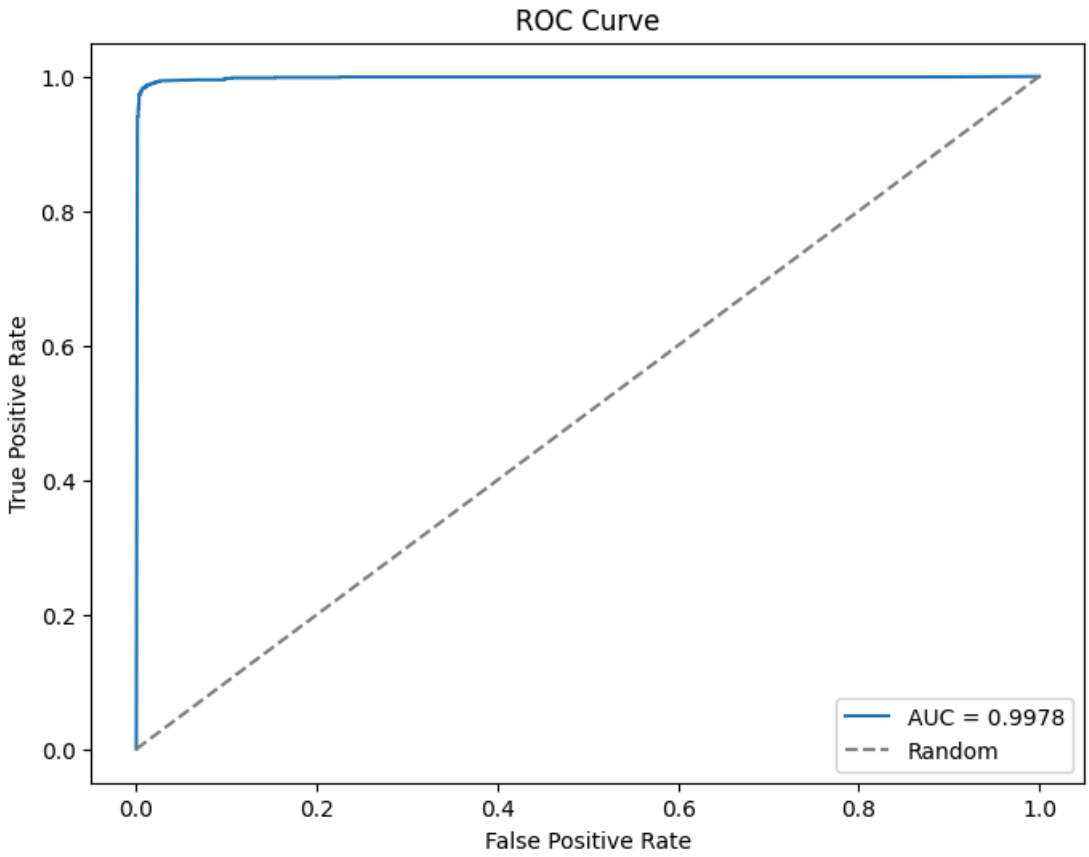


In [37]:

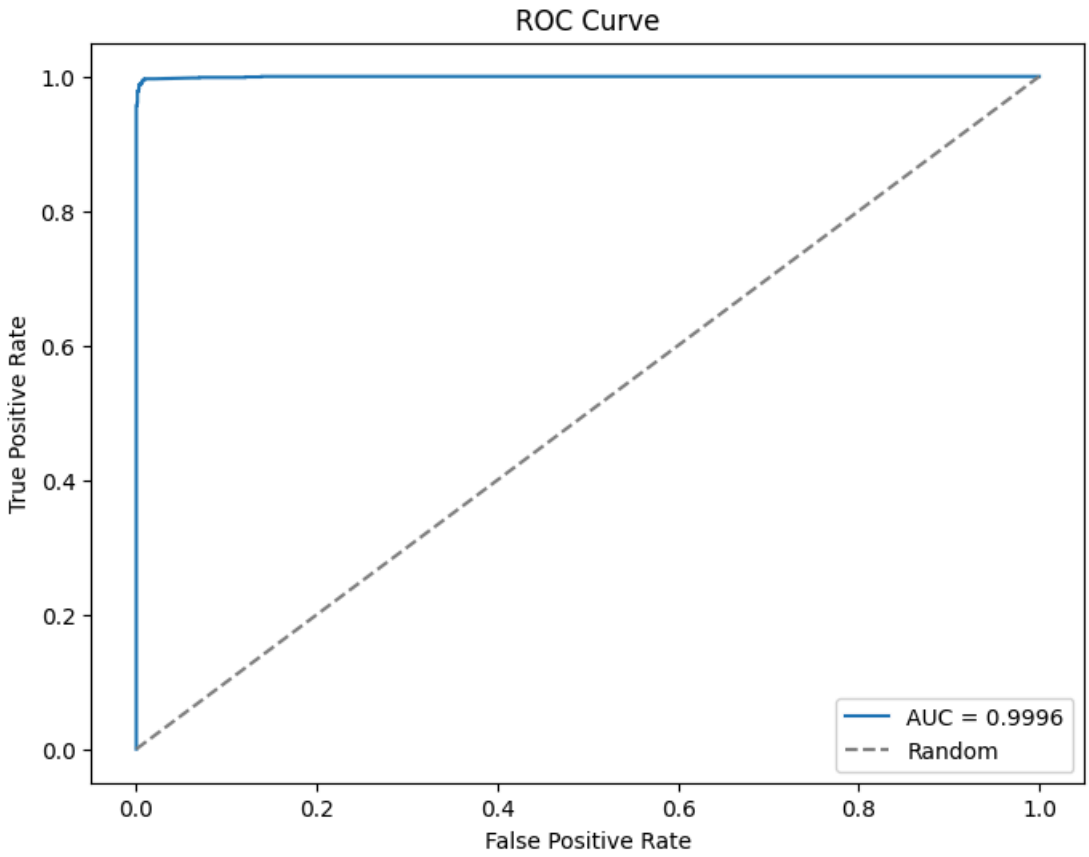
```
# Initialize StratifiedKFold
cv = StratifiedKFold(n_splits=4, shuffle=True, random_state=42)
```

```python
# To store fold-wise results
acc_scores = []
prec_scores = []
rec_scores = []
f1_scores = []
auc_scores = []
# To store learning curves for each fold
folds_history = []

for train_index, val_index in cv.split(X, y):
    # Splitting the data into training and validation sets for the current fold
    X_train_fold, X_val_fold = X[train_index], X[val_index]
    y_train_fold, y_val_fold = y[train_index], y[val_index]

    # Training the model on the training fold
    history = model.fit(X_train_fold, y_train_fold, epochs=10, batch_size=32, validation_split=0.1, verbose=0)
    folds_history.append(history)

    # Evaluating the model on the validation fold
    y_pred = (model.predict(X_val_fold) > 0.5).astype(np.int32)
    y_prob = model.predict(X_val_fold)[:,0]

    evaluate_classification_model(y_val_fold, y_pred, y_prob)

    #Storing metrics to aggregate later
    acc_scores.append(accuracy_score(y_val_fold, y_pred))
    prec_scores.append(precision_score(y_val_fold, y_pred, average='binary'))
    rec_scores.append(recall_score(y_val_fold, y_pred, average='binary'))
    f1_scores.append(f1_score(y_val_fold, y_pred, average='binary'))
    auc_scores.append(roc_auc_score(y_val_fold, y_prob))

# Dsiplaying the average performance across all folds
print("Average Scores Across All Folds:")
print(f"Average Accuracy: {np.mean(acc_scores):.4f}")
print(f"Average Precision: {np.mean(prec_scores):.4f}")
print(f"Average Recall: {np.mean(rec_scores):.4f}")
print(f"Average F1 Score: {np.mean(f1_scores):.4f}")
print(f"Average AUC: {np.mean(auc_scores):.4f}")

#Print all learning curves
for history in folds_history:
    plot_history_curve(history)
```

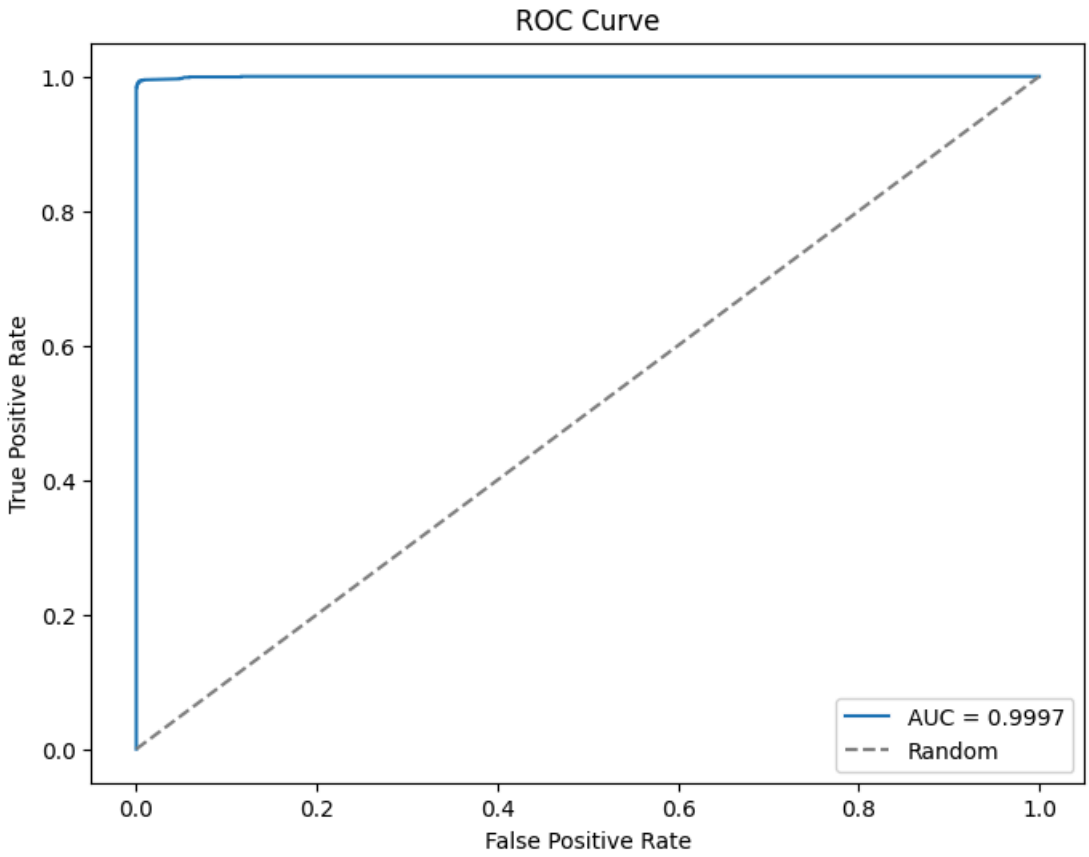
```
118/118 [==============================] - 0s 2ms/step
118/118 [==============================] - 0s 2ms/step
Confusion Matrix:
[[2353.   16.]
 [  27. 1362.]]


Accuracy: 0.9886
Precision: 0.9884
Recall: 0.9806
F1 Score: 0.9845
```



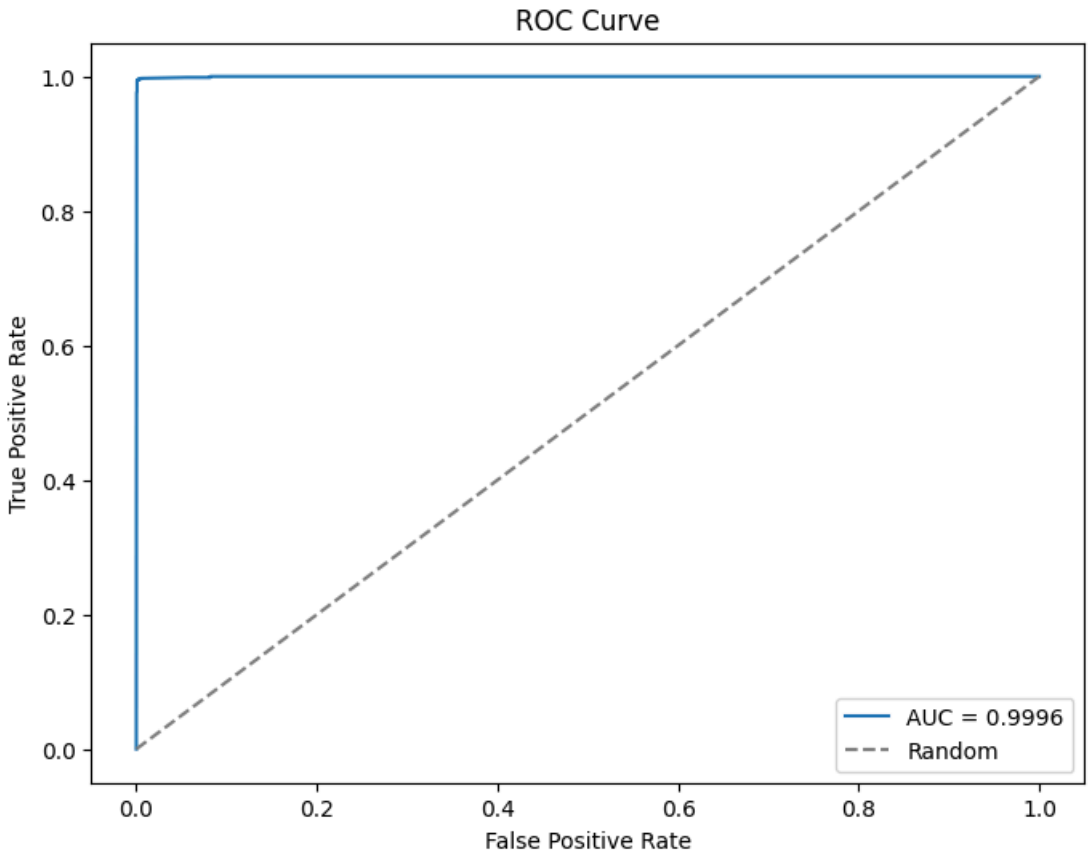

```
AUC: 0.9978


Classification Report:
              precision    recall  f1-score   support

           0     0.9887    0.9932    0.9909      2369
           1     0.9884    0.9806    0.9845      1389

    accuracy                         0.9886      3758
   macro avg     0.9885    0.9869    0.9877      3758
weighted avg     0.9886    0.9886    0.9885      3758

118/118 [==============================] - 0s 2ms/step
118/118 [==============================] - 0s 2ms/step
Confusion Matrix:
[[2356.   13.]
 [  16. 1373.]]


Accuracy: 0.9923
Precision: 0.9906
Recall: 0.9885
F1 Score: 0.9895
```



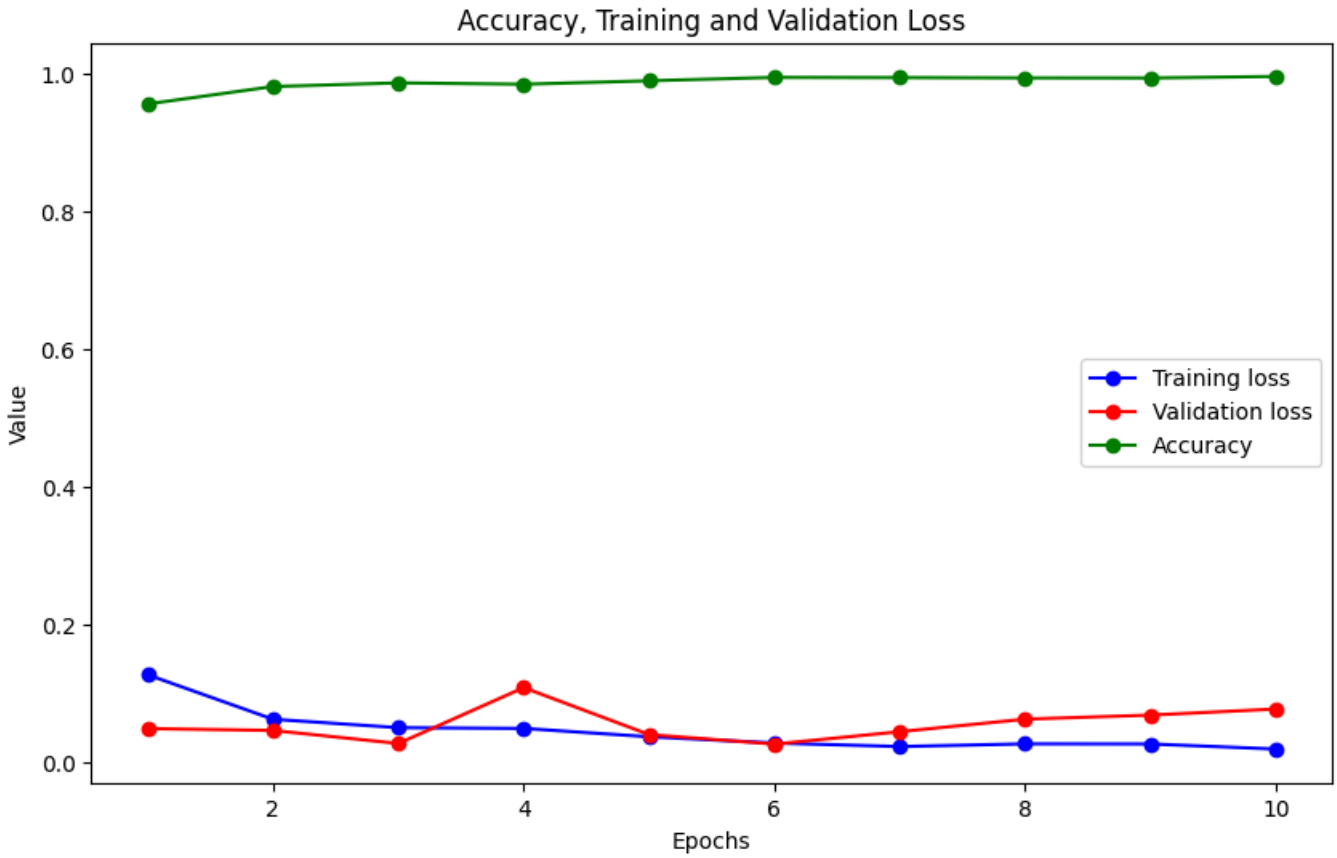

```
AUC: 0.9996


Classification Report:
              precision    recall  f1-score   support

           0     0.9933    0.9945    0.9939      2369
           1     0.9906    0.9885    0.9895      1389

    accuracy                         0.9923      3758
   macro avg     0.9919    0.9915    0.9917      3758
weighted avg     0.9923    0.9923    0.9923      3758

118/118 [==============================] - 0s 2ms/step
118/118 [==============================] - 0s 2ms/step
Confusion Matrix:
[[2361.    8.]
 [   9. 1380.]]


Accuracy: 0.9955
Precision: 0.9942
Recall: 0.9935
F1 Score: 0.9939
```

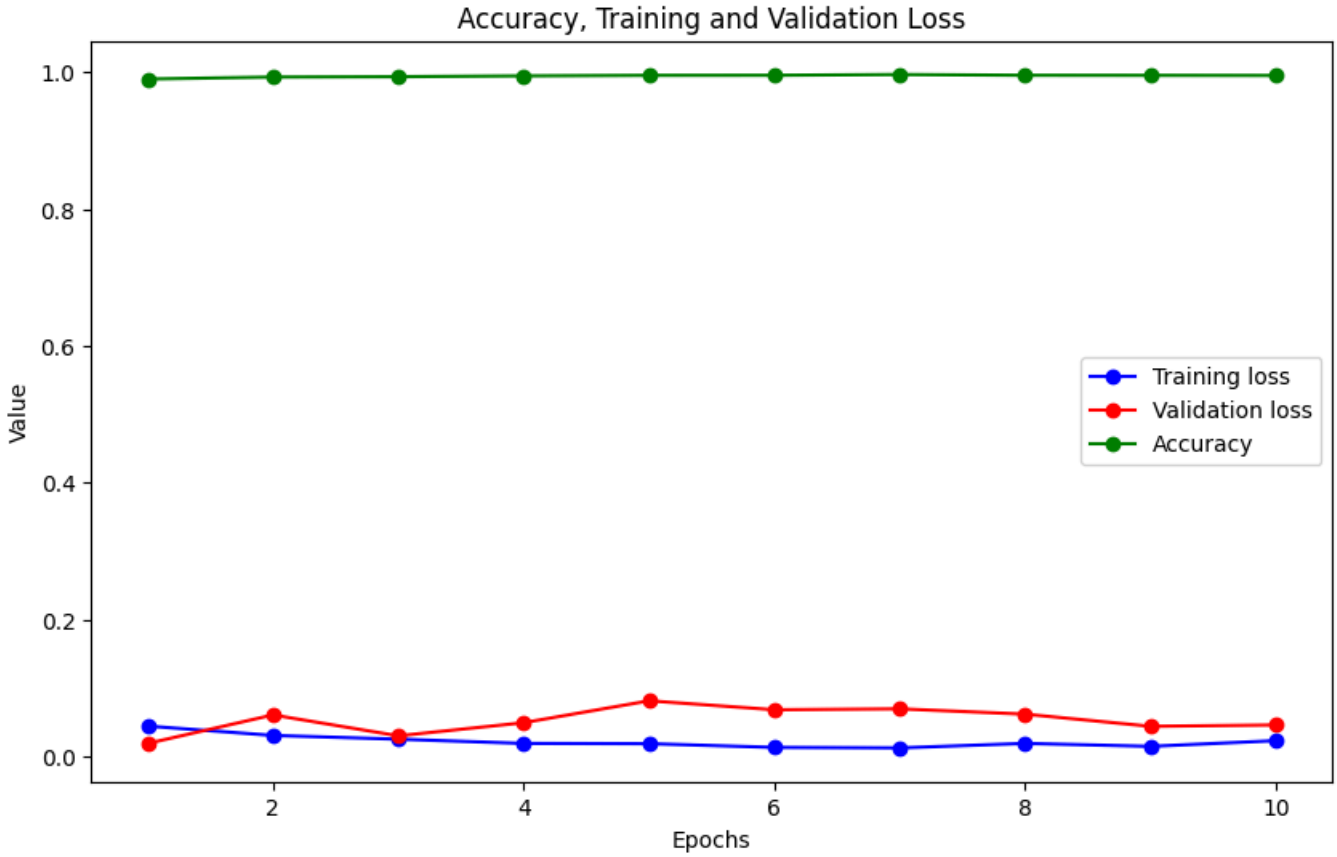


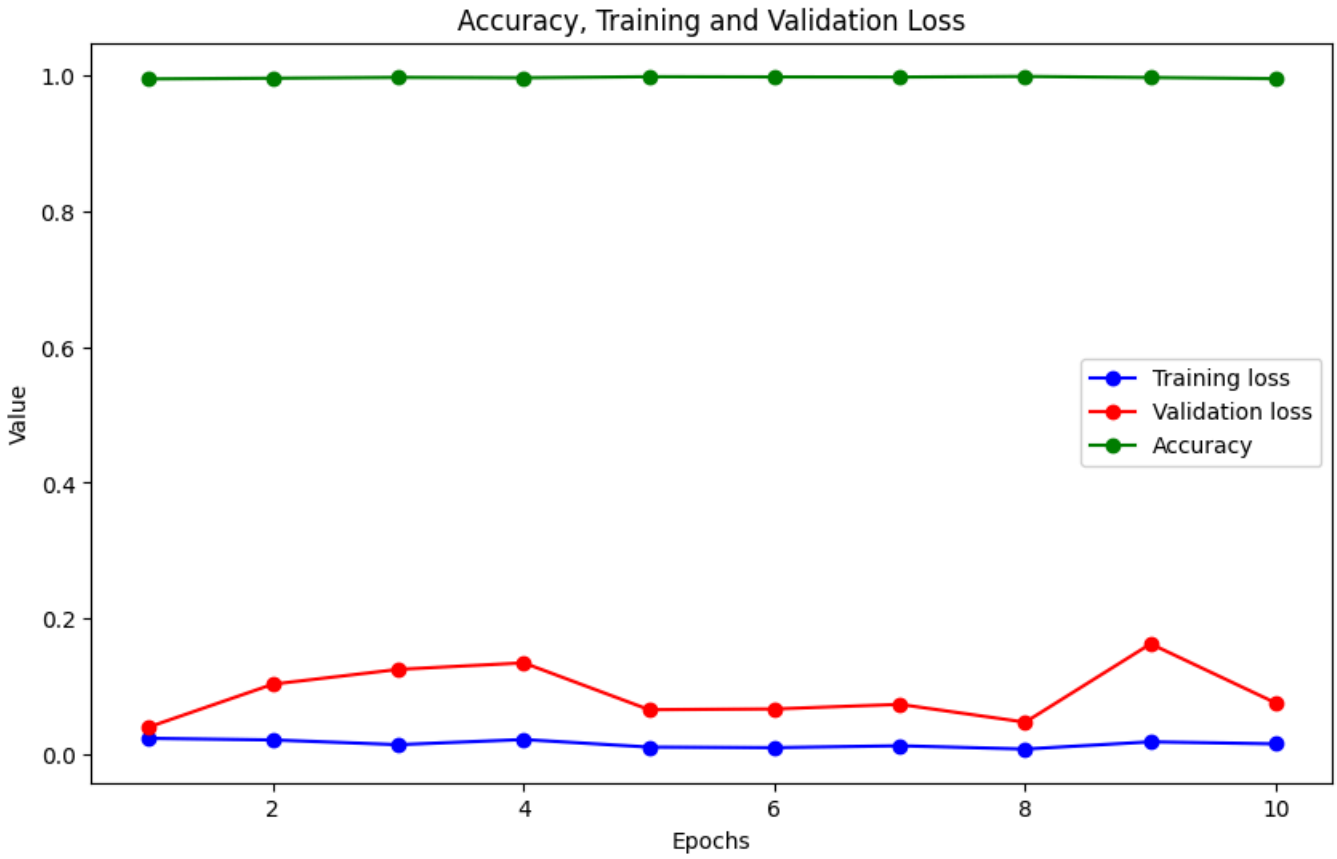

```
AUC: 0.9997


Classification Report:
              precision    recall  f1-score   support

           0     0.9962    0.9966    0.9964      2369
           1     0.9942    0.9935    0.9939      1389

    accuracy                         0.9955      3758
   macro avg     0.9952    0.9951    0.9951      3758
weighted avg     0.9955    0.9955    0.9955      3758

118/118 [==============================] - 0s 2ms/step
118/118 [==============================] - 0s 2ms/step
Confusion Matrix:
[[2364.    5.]
 [   6. 1382.]]


Accuracy: 0.9971
Precision: 0.9964
Recall: 0.9957
F1 Score: 0.9960
```

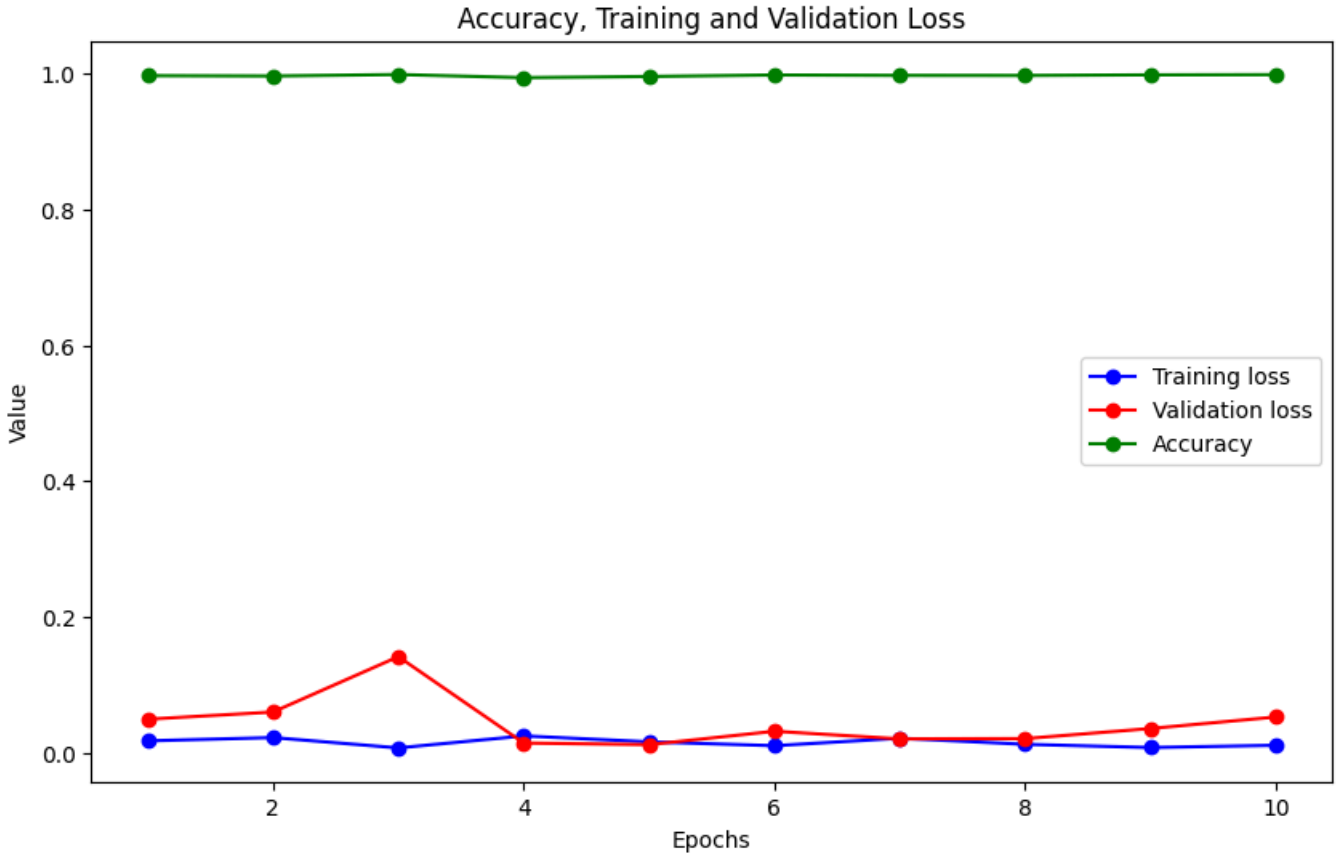



```
AUC: 0.9996


Classification Report:
              precision    recall  f1-score   support

           0     0.9975    0.9979    0.9977      2369
           1     0.9964    0.9957    0.9960      1388

    accuracy                         0.9971      3757
   macro avg     0.9969    0.9968    0.9969      3757
weighted avg     0.9971    0.9971    0.9971      3757

Average Scores Across All Folds:
Average Accuracy: 0.9933
Average Precision: 0.9924
Average Recall: 0.9896
Average F1 Score: 0.9910
Average AUC: 0.9992
```


Accuracy, Training and Validation Loss
Value
Epochs
Training loss
Validation loss
Accuracy
1.0
0.8
0.6
0.4
0.2
0.0
2
4
6
8
10


Accuracy, Training and Validation Loss
Value
Epochs
Training loss
Validation loss
Accuracy
1.0
0.8
0.6
0.4
0.2
0.0
2
4
6
8
10



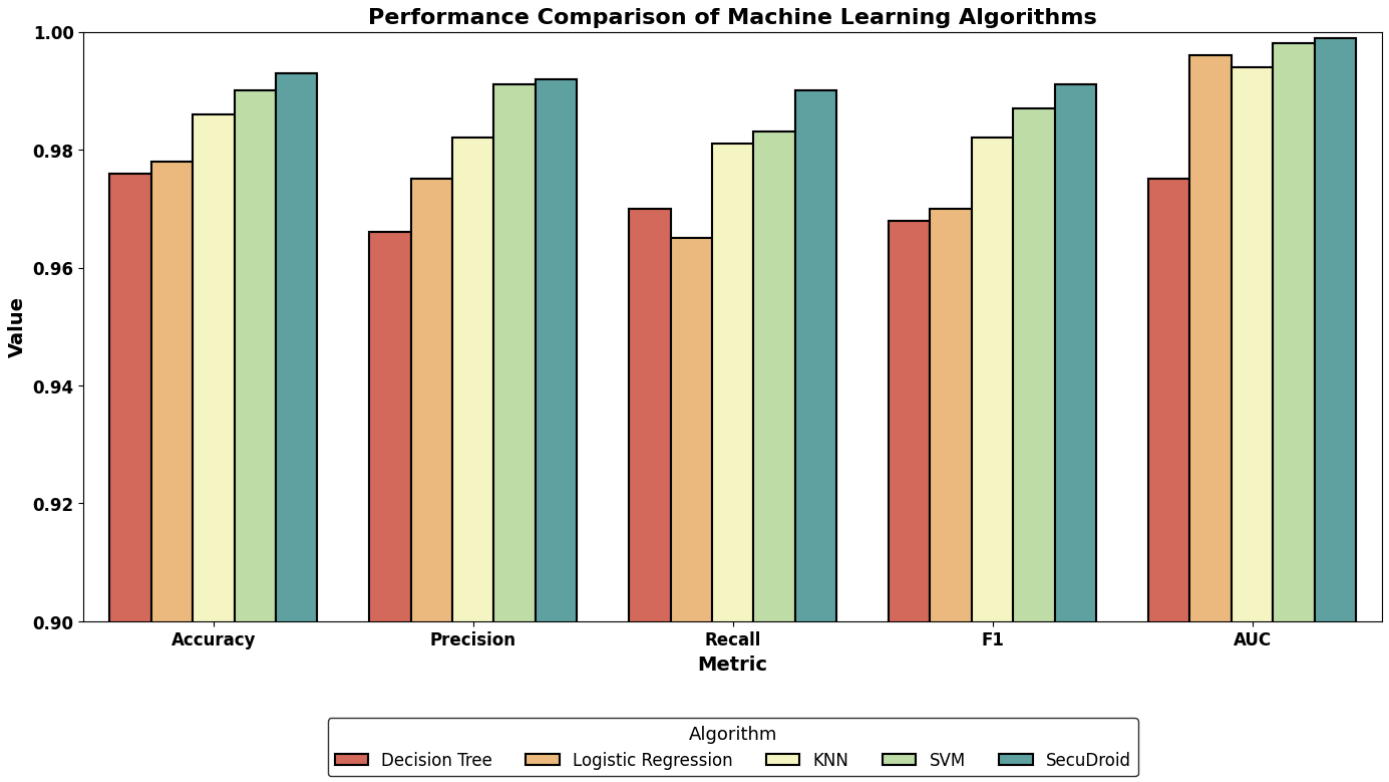


VISUALISING ALL ACCURACIES IN TERMS OF THE GRAPH

In [39]:

```
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns

# Data
data = {
    'Algorithm': ['Decision Tree', 'SVM', 'Logistic Regression', 'KNN', 'SecuDroid'],
    'Accuracy': [0.976, 0.990, 0.978, 0.986, 0.993],
    'Precision': [0.966, 0.991, 0.975, 0.982, 0.992],
    'Recall': [0.970, 0.983, 0.965, 0.981, 0.990],
    'F1': [0.968, 0.987, 0.970, 0.982, 0.991],
    'AUC': [0.975, 0.998, 0.996, 0.994, 0.999]
}
```

```
# Create DataFrame
df = pd.DataFrame(data)

# Melting the DataFrame
df_melted = df.melt(id_vars='Algorithm', var_name='Metric', value_name='Value')

# Calculate the mean performance for each algorithm
mean_scores = df.set_index('Algorithm').mean(axis=1).sort_values()

# Reorder the algorithms based on their mean performance
df_melted['Algorithm'] = pd.Categorical(df_melted['Algorithm'], categories=mean_scores.index, ordered=True)

# Plotting
plt.figure(figsize=(14, 8))
barplot = sns.barplot(x='Metric', y='Value', hue='Algorithm', data=df_melted, palette='Spectral', edgecolor='b
plt.title('Performance Comparison of Machine Learning Algorithms', fontsize=16, fontweight='bold', color='blac
plt.xlabel('Metric', fontsize=14, fontweight='bold', color='black')
plt.ylabel('Value', fontsize=14, fontweight='bold', color='black')
plt.ylim(0.9, 1.0)  # Setting the Y-axis scale from 0.9 to 1.0
plt.xticks(fontsize=12, fontweight='bold', color='black')
plt.yticks(fontsize=12, fontweight='bold', color='black')
plt.legend(title='Algorithm', loc='upper center', bbox_to_anchor=(0.5, -0.15), ncol=len(df_melted['Algorithm']
plt.tight_layout()
plt.show()
```



In [ ]: