cation-diabetesdataset-16-11-24-1

November 24, 2024

1 Binary Classification

Problem Statement - The goal of this project is to build, evaluate, and compare three different models to classify whether a patient has diabetes.

Dataset Overview - We are using the Pima Indians Diabetes Dataset, which is a well-known dataset in machine learning for binary classification tasks. The dataset consists of medical diagnostic measurements to predict whether a patient has diabetes (Outcome = 1) or not (Outcome = 0). The dataset has 768 rows and 8 input features:

- Pregnancies: Number of times pregnant.
- Glucose: Plasma glucose concentration (mg/dL).
- BloodPressure: Diastolic blood pressure (mm Hg).
- SkinThickness: Triceps skinfold thickness (mm).
- Insulin: 2-hour serum insulin (mu U/ml).
- BMI: Body mass index (weight in kg/(height in m)^2).
- DiabetesPedigreeFunction: A function that represents diabetes hereditary risk.
- Age: Age of the patient (years).
- Outcome: Target variable (0 = No diabetes, 1 = Diabetes).

1.0.1 Install all necessary packages

[1]:

```
!pip install pandas
!pip install numpy
!pip install matplotlib
!pip install seaborn
!pip install scikit-learn
!pip install tensorflow
!pip install keras-models
```

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Requirement already satisfied: pandas in /usr/local/lib/python3.10/dist-packages
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Requirement already satisfied: numpy>=1.22.4 in /usr/local/lib/python3.10/dist-
packages (from pandas) (1.26.4)
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Requirement already satisfied: pytz>=2020.1 in /usr/local/lib/python3.10/dist-
packages (from pandas) (2024.2)
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Requirement already satisfied: six>=1.5 in /usr/local/lib/python3.10/dist-
packages (from python-dateutil>=2.8.2->pandas) (1.16.0)
Requirement already satisfied: numpy in /usr/local/lib/python3.10/dist-packages
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Requirement already satisfied: numpy<2,>=1.21 in /usr/local/lib/python3.10/dist-
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/usr/local/lib/python3.10/dist-packages (from seaborn) (1.26.4)
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/usr/local/lib/python3.10/dist-packages (from seaborn) (3.8.0)
Requirement already satisfied: contourpy>=1.0.1 in
/usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.4->seaborn)
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(1.4.7)
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/usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.4->seaborn)
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Requirement already satisfied: six>=1.5 in /usr/local/lib/python3.10/dist-
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Requirement already satisfied: scikit-learn in /usr/local/lib/python3.10/dist-
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Requirement already satisfied: scipy>=1.6.0 in /usr/local/lib/python3.10/dist-
packages (from scikit-learn) (1.13.1)
Requirement already satisfied: joblib>=1.2.0 in /usr/local/lib/python3.10/dist-
packages (from scikit-learn) (1.4.2)
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/usr/local/lib/python3.10/dist-packages (from scikit-learn) (3.5.0)
Requirement already satisfied: tensorflow in /usr/local/lib/python3.10/dist-
packages (2.17.1)
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packages (from tensorflow) (1.4.0)
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/usr/local/lib/python3.10/dist-packages (from tensorflow) (1.6.3)
Requirement already satisfied: flatbuffers>=24.3.25 in
/usr/local/lib/python3.10/dist-packages (from tensorflow) (24.3.25)
Requirement already satisfied: gast!=0.5.0,!=0.5.1,!=0.5.2,>=0.2.1 in
/usr/local/lib/python3.10/dist-packages (from tensorflow) (0.6.0)
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/usr/local/lib/python3.10/dist-packages (from tensorflow) (0.2.0)
Requirement already satisfied: h5py>=3.10.0 in /usr/local/lib/python3.10/dist-
packages (from tensorflow) (3.12.1)
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/usr/local/lib/python3.10/dist-packages (from tensorflow) (18.1.1)
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/usr/local/lib/python3.10/dist-packages (from tensorflow) (0.4.1)
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packages (from tensorflow) (24.2)
Requirement already satisfied:
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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 /usr/local/lib/python3.10/dist-packages (from tensorflow) (4.25.5)
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/usr/local/lib/python3.10/dist-packages (from tensorflow) (2.32.3)
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Requirement already satisfied: six>=1.12.0 in /usr/local/lib/python3.10/dist-
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Requirement already satisfied: typing-extensions>=3.6.6 in
/usr/local/lib/python3.10/dist-packages (from tensorflow) (4.12.2)
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packages (from tensorflow) (1.16.0)
Requirement already satisfied: grpcio<2.0,>=1.24.3 in
/usr/local/lib/python3.10/dist-packages (from tensorflow) (1.68.0)
Requirement already satisfied: tensorboard<2.18,>=2.17 in
/usr/local/lib/python3.10/dist-packages (from tensorflow) (2.17.1)
Requirement already satisfied: keras>=3.2.0 in /usr/local/lib/python3.10/dist-
packages (from tensorflow) (3.5.0)
Requirement already satisfied: tensorflow-io-gcs-filesystem>=0.23.1 in
/usr/local/lib/python3.10/dist-packages (from tensorflow) (0.37.1)
Requirement already satisfied: numpy<2.0.0,>=1.23.5 in
/usr/local/lib/python3.10/dist-packages (from tensorflow) (1.26.4)
Requirement already satisfied: wheel<1.0,>=0.23.0 in
/usr/local/lib/python3.10/dist-packages (from astunparse>=1.6.0->tensorflow)
(0.45.0)
Requirement already satisfied: rich in /usr/local/lib/python3.10/dist-packages
(from keras>=3.2.0->tensorflow) (13.9.4)
Requirement already satisfied: namex in /usr/local/lib/python3.10/dist-packages
(from keras>=3.2.0->tensorflow) (0.0.8)
Requirement already satisfied: optree in /usr/local/lib/python3.10/dist-packages
(from keras>=3.2.0->tensorflow) (0.13.1)
Requirement already satisfied: charset-normalizer<4,>=2 in
/usr/local/lib/python3.10/dist-packages (from requests<3,>=2.21.0->tensorflow)
(3.4.0)
Requirement already satisfied: idna<4,>=2.5 in /usr/local/lib/python3.10/dist-
packages (from requests<3,>=2.21.0->tensorflow) (3.10)
Requirement already satisfied: urllib3<3,>=1.21.1 in
/usr/local/lib/python3.10/dist-packages (from requests<3,>=2.21.0->tensorflow)
(2.2.3)
Requirement already satisfied: certifi>=2017.4.17 in
/usr/local/lib/python3.10/dist-packages (from requests<3,>=2.21.0->tensorflow)
(2024.8.30)
Requirement already satisfied: markdown>=2.6.8 in
/usr/local/lib/python3.10/dist-packages (from
tensorboard<2.18,>=2.17->tensorflow) (3.7)
Requirement already satisfied: tensorboard-data-server<0.8.0,>=0.7.0 in
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/usr/local/lib/python3.10/dist-packages (from
tensorboard<2.18,>=2.17->tensorflow) (0.7.2)
Requirement already satisfied: werkzeug>=1.0.1 in
/usr/local/lib/python3.10/dist-packages (from
tensorboard<2.18,>=2.17->tensorflow) (3.1.3)
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/usr/local/lib/python3.10/dist-packages (from
werkzeug>=1.0.1->tensorboard<2.18,>=2.17->tensorflow) (3.0.2)
Requirement already satisfied: markdown-it-py>=2.2.0 in
/usr/local/lib/python3.10/dist-packages (from rich->keras>=3.2.0->tensorflow)
(3.0.0)
Requirement already satisfied: pygments<3.0.0,>=2.13.0 in
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Collecting keras-models
  Downloading keras_models-0.0.7-py3-none-any.whl.metadata (3.4 kB)
Requirement already satisfied: keras in /usr/local/lib/python3.10/dist-packages
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Requirement already satisfied: numpy in /usr/local/lib/python3.10/dist-packages
(from keras-models) (1.26.4)
Requirement already satisfied: spacy in /usr/local/lib/python3.10/dist-packages
(from keras-models) (3.7.5)
Requirement already satisfied: Pillow in /usr/local/lib/python3.10/dist-packages
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Requirement already satisfied: opencv-python in /usr/local/lib/python3.10/dist-
packages (from keras-models) (4.10.0.84)
Requirement already satisfied: pathlib in /usr/local/lib/python3.10/dist-
packages (from keras-models) (1.0.1)
Requirement already satisfied: absl-py in /usr/local/lib/python3.10/dist-
packages (from keras->keras-models) (1.4.0)
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(from keras->keras-models) (13.9.4)
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(from keras->keras-models) (0.0.8)
Requirement already satisfied: h5py in /usr/local/lib/python3.10/dist-packages
(from keras->keras-models) (3.12.1)
Requirement already satisfied: optree in /usr/local/lib/python3.10/dist-packages
(from keras->keras-models) (0.13.1)
Requirement already satisfied: ml-dtypes in /usr/local/lib/python3.10/dist-
packages (from keras->keras-models) (0.4.1)
Requirement already satisfied: packaging in /usr/local/lib/python3.10/dist-
packages (from keras->keras-models) (24.2)
Requirement already satisfied: spacy-legacy<3.1.0,>=3.0.11 in
/usr/local/lib/python3.10/dist-packages (from spacy->keras-models) (3.0.12)
Requirement already satisfied: spacy-loggers<2.0.0,>=1.0.0 in
/usr/local/lib/python3.10/dist-packages (from spacy->keras-models) (1.0.5)
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Requirement already satisfied: murmurhash<1.1.0,>=0.28.0 in
/usr/local/lib/python3.10/dist-packages (from spacy->keras-models) (1.0.10)
Requirement already satisfied: cymem<2.1.0,>=2.0.2 in
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Requirement already satisfied: preshed<3.1.0,>=3.0.2 in
/usr/local/lib/python3.10/dist-packages (from spacy->keras-models) (3.0.9)
Requirement already satisfied: thinc<8.3.0,>=8.2.2 in
/usr/local/lib/python3.10/dist-packages (from spacy->keras-models) (8.2.5)
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/usr/local/lib/python3.10/dist-packages (from spacy->keras-models) (1.1.3)
Requirement already satisfied: srsly<3.0.0,>=2.4.3 in
/usr/local/lib/python3.10/dist-packages (from spacy->keras-models) (2.4.8)
Requirement already satisfied: catalogue<2.1.0,>=2.0.6 in
/usr/local/lib/python3.10/dist-packages (from spacy->keras-models) (2.0.10)
Requirement already satisfied: weasel<0.5.0,>=0.1.0 in
/usr/local/lib/python3.10/dist-packages (from spacy->keras-models) (0.4.1)
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/usr/local/lib/python3.10/dist-packages (from spacy->keras-models) (0.13.0)
Requirement already satisfied: tqdm<5.0.0,>=4.38.0 in
/usr/local/lib/python3.10/dist-packages (from spacy->keras-models) (4.66.6)
Requirement already satisfied: requests<3.0.0,>=2.13.0 in
/usr/local/lib/python3.10/dist-packages (from spacy->keras-models) (2.32.3)
Requirement already satisfied: pydantic!=1.8,!=1.8.1,<3.0.0,>=1.7.4 in
/usr/local/lib/python3.10/dist-packages (from spacy->keras-models) (2.9.2)
Requirement already satisfied: jinja2 in /usr/local/lib/python3.10/dist-packages
(from spacy->keras-models) (3.1.4)
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Requirement already satisfied: language-data>=1.2 in
/usr/local/lib/python3.10/dist-packages (from
langcodes<4.0.0,>=3.2.0->spacy->keras-models) (1.2.0)
Requirement already satisfied: annotated-types>=0.6.0 in
/usr/local/lib/python3.10/dist-packages (from
pydantic!=1.8,!=1.8.1,<3.0.0,>=1.7.4->spacy->keras-models) (0.7.0)
Requirement already satisfied: pydantic-core==2.23.4 in
/usr/local/lib/python3.10/dist-packages (from
pydantic!=1.8,!=1.8.1,<3.0.0,>=1.7.4->spacy->keras-models) (2.23.4)
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pydantic!=1.8,!=1.8.1,<3.0.0,>=1.7.4->spacy->keras-models) (4.12.2)
Requirement already satisfied: charset-normalizer<4,>=2 in
/usr/local/lib/python3.10/dist-packages (from
requests<3.0.0,>=2.13.0->spacy->keras-models) (3.4.0)
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packages (from requests<3.0.0,>=2.13.0->spacy->keras-models) (3.10)
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/usr/local/lib/python3.10/dist-packages (from
requests<3.0.0,>=2.13.0->spacy->keras-models) (2.2.3)
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requests<3.0.0,>=2.13.0->spacy->keras-models) (2024.8.30)
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models) (0.7.11)
Requirement already satisfied: confection<1.0.0,>=0.0.1 in
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models) (0.1.5)
Requirement already satisfied: click>=8.0.0 in /usr/local/lib/python3.10/dist-
packages (from typer<1.0.0,>=0.3.0->spacy->keras-models) (8.1.7)
Requirement already satisfied: shellingham>=1.3.0 in
/usr/local/lib/python3.10/dist-packages (from typer<1.0.0,>=0.3.0->spacy->keras-
models) (1.5.4)
Requirement already satisfied: markdown-it-py>=2.2.0 in
/usr/local/lib/python3.10/dist-packages (from rich->keras->keras-models) (3.0.0)
Requirement already satisfied: pygments<3.0.0,>=2.13.0 in
/usr/local/lib/python3.10/dist-packages (from rich->keras->keras-models)
(2.18.0)
Requirement already satisfied: cloudpathlib<1.0.0,>=0.7.0 in
/usr/local/lib/python3.10/dist-packages (from
weasel<0.5.0,>=0.1.0->spacy->keras-models) (0.20.0)
Requirement already satisfied: smart-open<8.0.0,>=5.2.1 in
/usr/local/lib/python3.10/dist-packages (from
weasel<0.5.0,>=0.1.0->spacy->keras-models) (7.0.5)
Requirement already satisfied: MarkupSafe>=2.0 in
/usr/local/lib/python3.10/dist-packages (from jinja2->spacy->keras-models)
(3.0.2)
Requirement already satisfied: marisa-trie>=0.7.7 in
/usr/local/lib/python3.10/dist-packages (from language-
data>=1.2->langcodes<4.0.0,>=3.2.0->spacy->keras-models) (1.2.1)
Requirement already satisfied: mdurl~=0.1 in /usr/local/lib/python3.10/dist-
packages (from markdown-it-py>=2.2.0->rich->keras->keras-models) (0.1.2)
Requirement already satisfied: wrapt in /usr/local/lib/python3.10/dist-packages
(from smart-open<8.0.0,>=5.2.1->weasel<0.5.0,>=0.1.0->spacy->keras-models)
(1.16.0)
Downloading keras_models-0.0.7-py3-none-any.whl (18 kB)
Installing collected packages: keras-models
Successfully installed keras-models-0.0.7
```

1.0.2 Import All Necessary Libraries & Packages

[2]:

```python
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
from sklearn.model_selection import train_test_split, GridSearchCV,␣
 ↪StratifiedKFold
from sklearn.ensemble import RandomForestClassifier
from sklearn.svm import SVC
from sklearn.preprocessing import StandardScaler
from sklearn.metrics import (
    confusion_matrix, roc_auc_score, roc_curve, classification_report,␣
 ↪log_loss, matthews_corrcoef
)
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, Dropout, LSTM
from tensorflow.keras.optimizers import Adam
from tensorflow.keras.utils import to_categorical
```

1.0.3 Load the dataset

[3]:

```
# Load Dataset
data = pd.read_csv("diabetes.csv")
data.head()
```

[3]:

```
   Pregnancies  Glucose  BloodPressure  SkinThickness  Insulin   BMI  \
0            6      148             72             35        0  33.6
1            1       85             66             29        0  26.6
2            8      183             64              0        0  23.3
3            1       89             66             23       94  28.1
4            0      137             40             35      168  43.1

   DiabetesPedigreeFunction  Age  Outcome
0                     0.627   50        1
1                     0.351   31        0
2                     0.672   32        1
3                     0.167   21        0
4                     2.288   33        1
```

Basic Information on Dataset

[4]:

```
# Display Shape and Info
print("Dataset Shape:", data.shape)
print("\nDataset Info:")
print(data.info())
```

```
Dataset Shape: (768, 9)

Dataset Info:
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 768 entries, 0 to 767
```

```
Data columns (total 9 columns):
 #   Column                    Non-Null Count  Dtype  
---  ------                    --------------  -----  
 0   Pregnancies               768 non-null    int64  
 1   Glucose                   768 non-null    int64  
 2   BloodPressure             768 non-null    int64  
 3   SkinThickness             768 non-null    int64  
 4   Insulin                   768 non-null    int64  
 5   BMI                       768 non-null    float64
 6   DiabetesPedigreeFunction  768 non-null    float64
 7   Age                       768 non-null    int64  
 8   Outcome                   768 non-null    int64  
dtypes: float64(2), int64(7)
memory usage: 54.1 KB
None
```

1.0.4 EDA

[5]:
```python
# Basic EDA
print("\nNull Values:\n", data.isnull().sum())
data.drop_duplicates(inplace=True)
print("\nAfter Removing Duplicates - Shape:", data.shape)
```

```
Null Values:
 Pregnancies                 0
Glucose                     0
BloodPressure               0
SkinThickness               0
Insulin                     0
BMI                         0
DiabetesPedigreeFunction    0
Age                         0
Outcome                     0
dtype: int64

After Removing Duplicates - Shape: (768, 9)
```

Describe Dataset

[6]:
```python
# Describe Dataset
print("\nDataset Description:")
print(data.describe())
```

```
Dataset Description:
       Pregnancies     Glucose  BloodPressure  SkinThickness     Insulin  \
count   768.000000  768.000000     768.000000     768.000000  768.000000   
mean      3.845052  120.894531      69.105469      20.536458   79.799479   
```

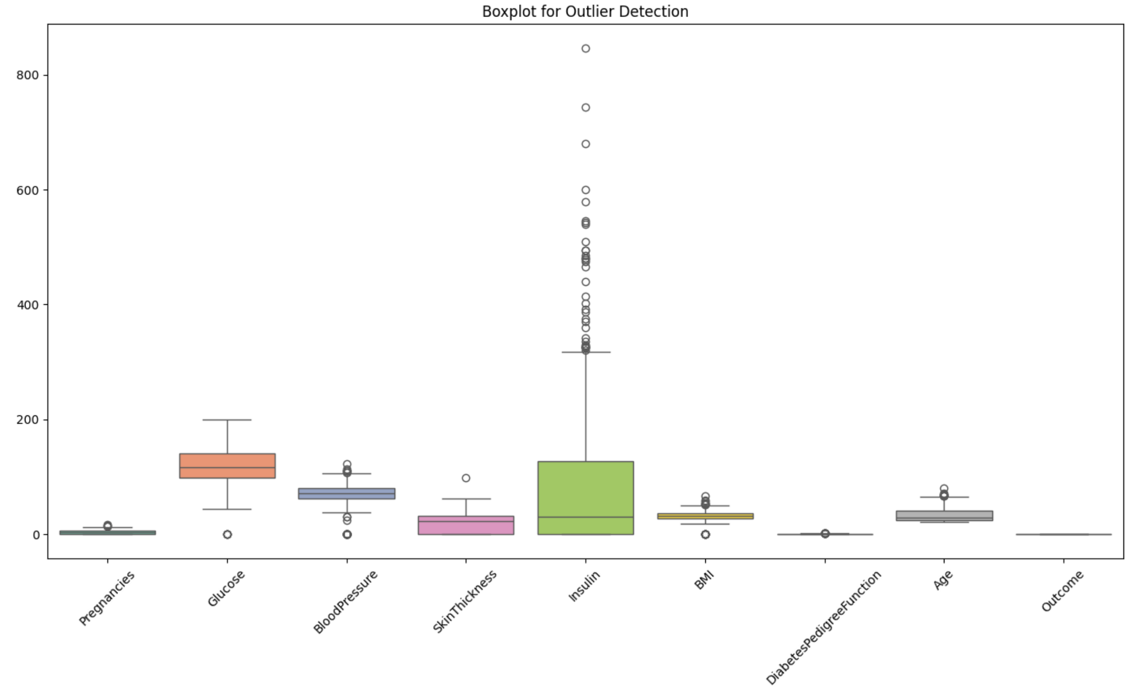
```
std        3.369578   31.972618      19.355807      15.952218  115.244002
min        0.000000    0.000000       0.000000       0.000000    0.000000
25%        1.000000   99.000000      62.000000       0.000000    0.000000
50%        3.000000  117.000000      72.000000      23.000000   30.500000
75%        6.000000  140.250000      80.000000      32.000000  127.250000
max       17.000000  199.000000     122.000000      99.000000  846.000000

              BMI  DiabetesPedigreeFunction         Age     Outcome
count  768.000000                768.000000  768.000000  768.000000
mean    31.992578                  0.471876   33.240885    0.348958
std      7.884160                  0.331329   11.760232    0.476951
min      0.000000                  0.078000   21.000000    0.000000
25%     27.300000                  0.243750   24.000000    0.000000
50%     32.000000                  0.372500   29.000000    0.000000
75%     36.600000                  0.626250   41.000000    1.000000
max     67.100000                  2.420000   81.000000    1.000000
```

Outlier Detection

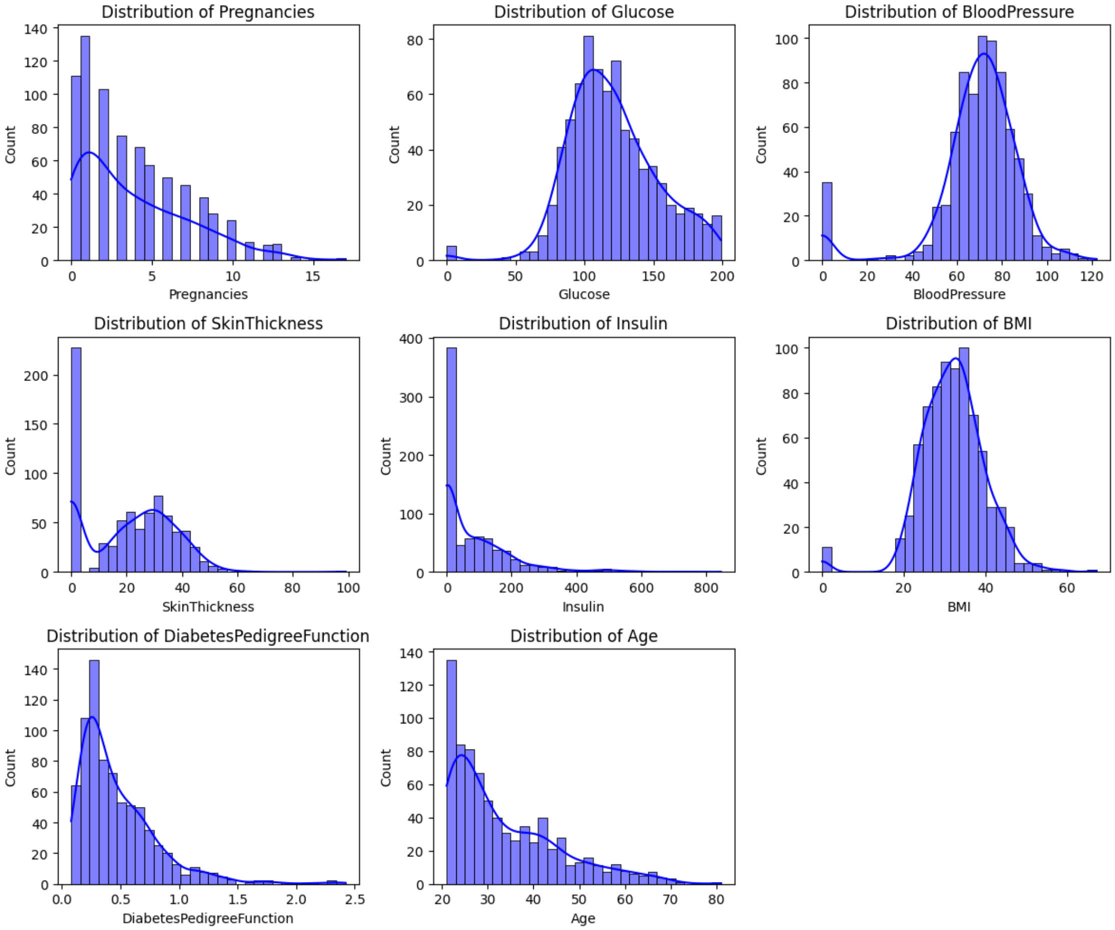
[7]:

```
# Detect Outliers with Boxplot
plt.figure(figsize=(16, 8))
sns.boxplot(data=data, palette="Set2")
plt.title("Boxplot for Outlier Detection")
plt.xticks(rotation=45)
plt.show()
```



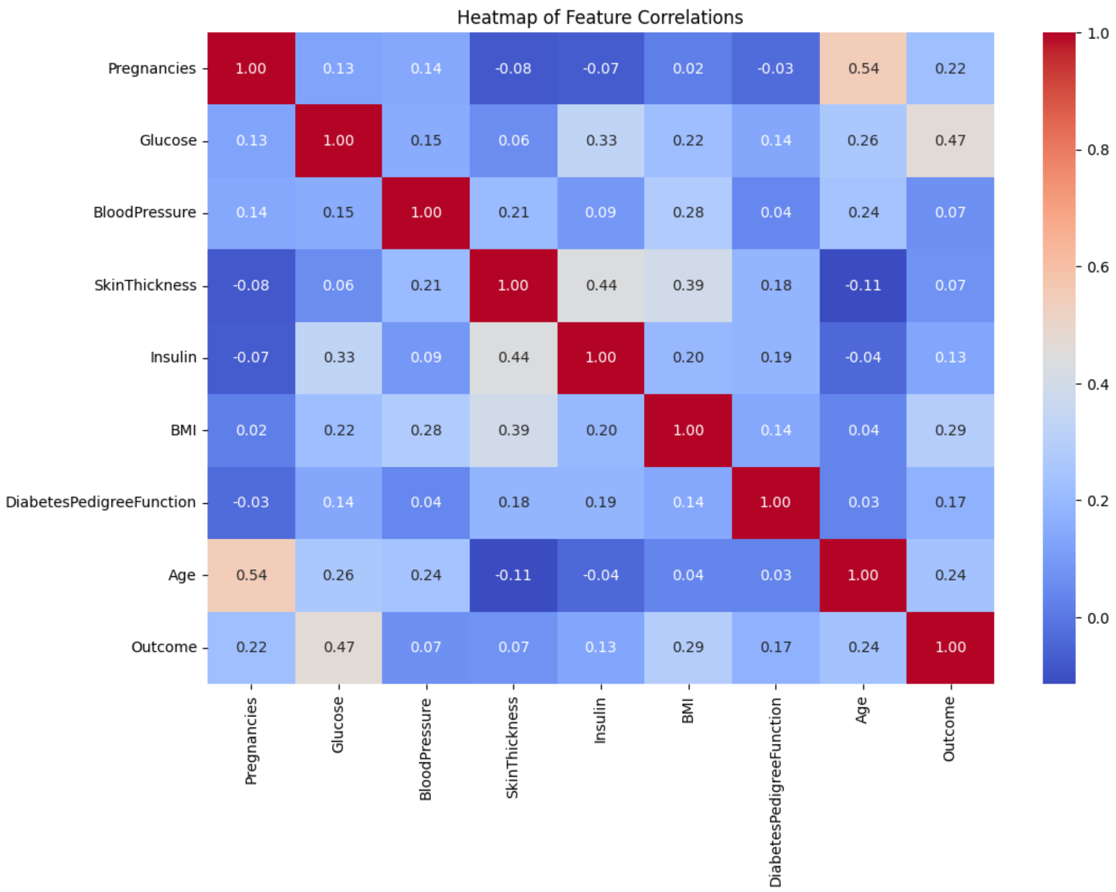
Some Basic Plots

[8]:
```
# Histograms for Feature Distribution
plt.figure(figsize=(12, 10))
for i, column in enumerate(data.columns[:-1], start=1):  # Exclude Outcome
    plt.subplot(3, 3, i)
    sns.histplot(data[column], kde=True, color='blue', bins=30)
    plt.title(f'Distribution of {column}')
plt.tight_layout()
plt.show()
```



Correlation Heatmap

[9]:
```
# Heatmap for Feature Correlations
plt.figure(figsize=(12, 8))
sns.heatmap(data.corr(), annot=True, cmap="coolwarm", fmt=".2f")
plt.title("Heatmap of Feature Correlations")
plt.show()
```



1.0.5 Standardization

```
[10]: # Preprocessing (Standardization)
scaler = StandardScaler()
X = scaler.fit_transform(data.iloc[:, :-1])  # Features
y = data['Outcome']  # Target
```

1.0.6 Machine Learning Models

1.0.7 GridSearchCV - Finding Best Hyperparameter

```
[11]: rf_params = {
    'n_estimators': [50, 100, 150],
    'max_depth': [3, 5, 10],
    'min_samples_split': [2, 5, 10]
}
rf_grid = GridSearchCV(RandomForestClassifier(random_state=42), rf_params,␣
 ↪cv=5, scoring='accuracy')
rf_grid.fit(X, y)
```

```
print("Best RF Hyperparameters:", rf_grid.best_params_)
```

```
Best RF Hyperparameters: {'max_depth': 5, 'min_samples_split': 2,
'n_estimators': 100}
```

```
/usr/local/lib/python3.10/dist-packages/numpy/ma/core.py:2820: RuntimeWarning:
invalid value encountered in cast
  _data = np.array(data, dtype=dtype, copy=copy,
```

[12]:

```
# Model Training - SVM
svm_params = {
    'C': [0.1, 1, 10],
    'kernel': ['linear', 'rbf'],
    'gamma': ['scale', 'auto']
}
svm_grid = GridSearchCV(SVC(probability=True), svm_params, cv=5,␣
  ↪scoring='accuracy')
svm_grid.fit(X, y)
print("Best SVM Hyperparameters:", svm_grid.best_params_)
```

```
Best SVM Hyperparameters: {'C': 1, 'gamma': 'scale', 'kernel': 'linear'}
```

Cross-Validation & Model Training

[13]:

```
def train_ml_model(model, X, y, model_name):
    skf = StratifiedKFold(n_splits=10, shuffle=True, random_state=42)
    metrics = []

    print(f"\nEvaluating {model_name} with 10-Fold Cross-Validation:")
    for fold, (train_index, test_index) in enumerate(skf.split(X, y), start=1):
        X_train, X_test = X[train_index], X[test_index]
        y_train, y_test = y[train_index], y[test_index]

        # Fit and Predict
        model.fit(X_train, y_train)
        y_pred = model.predict(X_test)
        y_prob = model.predict_proba(X_test)[:, 1]

        # Confusion Matrix
        cm = confusion_matrix(y_test, y_pred)
        tn, fp, fn, tp = cm.ravel()

        # Metrics Calculation
        tpr = tp / (tp + fn)
        tnr = tn / (tn + fp)
        fpr = fp / (tn + fp)
        fnr = fn / (tp + fn)
        precision = tp / (tp + fp)
        f1 = 2 * tp / (2 * tp + fp + fn)
        accuracy = (tp + tn) / (tp + fp + fn + tn)
        error_rate = (fp + fn) / (tp + fp + fn + tn)
        bacc = (tpr + tnr) / 2
        tss = tpr - fpr
        hss = 2 * (tp * tn - fp * fn) / ((tp + fn) * (fn + tn) + (tp + fp) * (fp + tn))
        recall = tp / tp + fn

        fold_metrics = {
            'Fold': fold,
            'TP': tp, 'TN': tn, 'FP': fp, 'FN': fn,
            "TPR": tpr, "TNR": tnr, "FPR": fpr, "FNR": fnr,
            'Accuracy': accuracy,
            'Precision': precision,
            'Recall': recall,
            'F1 Score': f1,
            "bacc": bacc,
            "tss": tss,
            "hss": hss,

        }
        metrics.append(fold_metrics)

        # Print Metrics for the Current Fold
        print(f"Fold {fold} Metrics:")
        for metric, value in fold_metrics.items():
            print(f"{metric}: {value}")
        print("_"*30+"\n")

    return model, pd.DataFrame(metrics)
```

1.0.8 Random Forest Model Training

[14]:

```
# Evaluate Random Forest
best_rf, rf_metrics = train_ml_model(
    RandomForestClassifier(**rf_grid.best_params_), X, y, "Random Forest"
)
```

```
Evaluating Random Forest with 10-Fold Cross-Validation:
Fold 1 Metrics:
Fold: 1
TP: 18
TN: 45
FP: 5
FN: 9
```

```
TPR: 0.6666666666666666
TNR: 0.9
FPR: 0.1
FNR: 0.3333333333333333
Accuracy: 0.8181818181818182
Precision: 0.782608695652174
Recall: 10.0
F1 Score: 0.72
bacc: 0.7833333333333333
tss: 0.5666666666666667
hss: 0.5866564417177914
------------------------------

Fold 2 Metrics:
Fold: 2
TP: 13
TN: 46
FP: 4
FN: 14
TPR: 0.48148148148148145
TNR: 0.92
FPR: 0.08
FNR: 0.5185185185185185
Accuracy: 0.7662337662337663
Precision: 0.7647058823529411
Recall: 15.0
F1 Score: 0.5909090909090909
bacc: 0.7007407407407408
tss: 0.40148148148148144
hss: 0.4388663967611336
------------------------------

Fold 3 Metrics:
Fold: 3
TP: 14
TN: 43
FP: 7
FN: 13
TPR: 0.5185185185185185
TNR: 0.86
FPR: 0.14
FNR: 0.48148148148148145
Accuracy: 0.7402597402597403
Precision: 0.6666666666666666
Recall: 14.0
F1 Score: 0.5833333333333334
bacc: 0.6892592592592592
tss: 0.3785185185185185
```

```
hss: 0.3989071038251366
------------------------------

Fold 4 Metrics:
Fold: 4
TP: 18
TN: 49
FP: 1
FN: 9
TPR: 0.6666666666666666
TNR: 0.98
FPR: 0.02
FNR: 0.3333333333333333
Accuracy: 0.8701298701298701
Precision: 0.9473684210526315
Recall: 10.0
F1 Score: 0.782608695652174
bacc: 0.8233333333333333
tss: 0.6466666666666666
hss: 0.6939586645468998
------------------------------

Fold 5 Metrics:
Fold: 5
TP: 18
TN: 47
FP: 3
FN: 9
TPR: 0.6666666666666666
TNR: 0.94
FPR: 0.06
FNR: 0.3333333333333333
Accuracy: 0.8441558441558441
Precision: 0.8571428571428571
Recall: 10.0
F1 Score: 0.75
bacc: 0.8033333333333332
tss: 0.6066666666666667
hss: 0.639344262295082
------------------------------

Fold 6 Metrics:
Fold: 6
TP: 14
TN: 46
FP: 4
FN: 13
TPR: 0.5185185185185185
```

```
TNR: 0.92
FPR: 0.08
FNR: 0.48148148148148145
Accuracy: 0.7792207792207793
Precision: 0.7777777777777778
Recall: 14.0
F1 Score: 0.6222222222222222
bacc: 0.7192592592592593
tss: 0.4385185185185185
hss: 0.47492980344965907
------------------------------

Fold 7 Metrics:
Fold: 7
TP: 12
TN: 45
FP: 5
FN: 15
TPR: 0.4444444444444444
TNR: 0.9
FPR: 0.1
FNR: 0.5555555555555556
Accuracy: 0.7402597402597403
Precision: 0.7058823529411765
Recall: 16.0
F1 Score: 0.5454545454545454
bacc: 0.6722222222222223
tss: 0.34444444444444444
hss: 0.3765182186234818
------------------------------

Fold 8 Metrics:
Fold: 8
TP: 15
TN: 41
FP: 9
FN: 12
TPR: 0.5555555555555556
TNR: 0.82
FPR: 0.18
FNR: 0.4444444444444444
Accuracy: 0.7272727272727273
Precision: 0.625
Recall: 13.0
F1 Score: 0.5882352941176471
bacc: 0.6877777777777778
tss: 0.3755555555555556
hss: 0.38540478905359177
```

```
------------------------------

Fold 9 Metrics:
Fold: 9
TP: 16
TN: 40
FP: 10
FN: 10
TPR: 0.6153846153846154
TNR: 0.8
FPR: 0.2
FNR: 0.38461538461538464
Accuracy: 0.7368421052631579
Precision: 0.6153846153846154
Recall: 11.0
F1 Score: 0.6153846153846154
bacc: 0.7076923076923077
tss: 0.4153846153846154
hss: 0.4153846153846154
------------------------------

Fold 10 Metrics:
Fold: 10
TP: 12
TN: 44
FP: 6
FN: 14
TPR: 0.46153846153846156
TNR: 0.88
FPR: 0.12
FNR: 0.5384615384615384
Accuracy: 0.7368421052631579
Precision: 0.6666666666666666
Recall: 15.0
F1 Score: 0.5454545454545454
bacc: 0.6707692307692308
tss: 0.34153846153846157
hss: 0.3687707641196013
------------------------------
```

1.0.9 SVM Model Training

[15]:
```
# Evaluate SVM
best_svm, svm_metrics = train_ml_model(
    SVC(probability=True, **svm_grid.best_params_), X, y, "SVM"
)
```

```
Evaluating SVM with 10-Fold Cross-Validation:
Fold 1 Metrics:
Fold: 1
TP: 16
TN: 44
FP: 6
FN: 11
TPR: 0.5925925925925926
TNR: 0.88
FPR: 0.12
FNR: 0.4074074074074074
Accuracy: 0.7792207792207793
Precision: 0.7272727272727273
Recall: 12.0
F1 Score: 0.6530612244897959
bacc: 0.7362962962962962
tss: 0.47259259259259256
hss: 0.49361702127659574
------------------------------

Fold 2 Metrics:
Fold: 2
TP: 14
TN: 45
FP: 5
FN: 13
TPR: 0.5185185185185185
TNR: 0.9
FPR: 0.1
FNR: 0.48148148148148145
Accuracy: 0.7662337662337663
Precision: 0.7368421052631579
Recall: 14.0
F1 Score: 0.6086956521739131
bacc: 0.7092592592592593
tss: 0.4185185185185185
hss: 0.4491255961844197
------------------------------

Fold 3 Metrics:
Fold: 3
TP: 15
TN: 43
FP: 7
FN: 12
TPR: 0.5555555555555556
TNR: 0.86
```

```
FPR: 0.14
FNR: 0.4444444444444444
Accuracy: 0.7532467532467533
Precision: 0.6818181818181818
Recall: 13.0
F1 Score: 0.6122448979591837
bacc: 0.7077777777777778
tss: 0.41555555555555557
hss: 0.4340425531914894
------------------------------

Fold 4 Metrics:
Fold: 4
TP: 15
TN: 48
FP: 2
FN: 12
TPR: 0.5555555555555556
TNR: 0.96
FPR: 0.04
FNR: 0.4444444444444444
Accuracy: 0.8181818181818182
Precision: 0.8823529411764706
Recall: 13.0
F1 Score: 0.6818181818181818
bacc: 0.7577777777777778
tss: 0.5155555555555555
hss: 0.5635627530364372
------------------------------

Fold 5 Metrics:
Fold: 5
TP: 15
TN: 47
FP: 3
FN: 12
TPR: 0.5555555555555556
TNR: 0.94
FPR: 0.06
FNR: 0.4444444444444444
Accuracy: 0.8051948051948052
Precision: 0.8333333333333334
Recall: 13.0
F1 Score: 0.6666666666666666
bacc: 0.7477777777777778
tss: 0.4955555555555556
hss: 0.5367027677496992
------------------------------
```

```
Fold 6 Metrics:
Fold: 6
TP: 17
TN: 44
FP: 6
FN: 10
TPR: 0.6296296296296297
TNR: 0.88
FPR: 0.12
FNR: 0.37037037037037035
Accuracy: 0.7922077922077922
Precision: 0.7391304347826086
Recall: 11.0
F1 Score: 0.68
bacc: 0.7548148148148148
tss: 0.5096296296296297
hss: 0.5276073619631901
------------------------------

Fold 7 Metrics:
Fold: 7
TP: 13
TN: 47
FP: 3
FN: 14
TPR: 0.48148148148148145
TNR: 0.94
FPR: 0.06
FNR: 0.5185185185185185
Accuracy: 0.7792207792207793
Precision: 0.8125
Recall: 15.0
F1 Score: 0.6046511627906976
bacc: 0.7107407407407407
tss: 0.42148148148148146
hss: 0.46505925623212097
------------------------------

Fold 8 Metrics:
Fold: 8
TP: 18
TN: 39
FP: 11
FN: 9
TPR: 0.6666666666666666
TNR: 0.78
FPR: 0.22
```

```
FNR: 0.3333333333333333
Accuracy: 0.7402597402597403
Precision: 0.6206896551724138
Recall: 10.0
F1 Score: 0.6428571428571429
bacc: 0.7233333333333334
tss: 0.44666666666666666
hss: 0.43918426802621996
------------------------------

Fold 9 Metrics:
Fold: 9
TP: 19
TN: 38
FP: 12
FN: 7
TPR: 0.7307692307692307
TNR: 0.76
FPR: 0.24
FNR: 0.2692307692307692
Accuracy: 0.75
Precision: 0.6129032258064516
Recall: 8.0
F1 Score: 0.6666666666666666
bacc: 0.7453846153846153
tss: 0.49076923076923074
hss: 0.46911764705882353
------------------------------

Fold 10 Metrics:
Fold: 10
TP: 13
TN: 44
FP: 6
FN: 13
TPR: 0.5
TNR: 0.88
FPR: 0.12
FNR: 0.5
Accuracy: 0.75
Precision: 0.6842105263157895
Recall: 14.0
F1 Score: 0.5777777777777777
bacc: 0.69
tss: 0.38
hss: 0.40625
------------------------------
```

1.0.10 Deep Learning Model - LSTM

[16]:

```
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, Dropout, LSTM
from tensorflow.keras.optimizers import Adam
from tensorflow.keras.utils import to_categorical
from sklearn.preprocessing import StandardScaler
from sklearn.metrics import confusion_matrix, roc_auc_score, roc_curve,␣
 ↪log_loss, matthews_corrcoef

def train_lstm_model(X, y, input_shape, model_name="LSTM"):
    skf = StratifiedKFold(n_splits=10, shuffle=True, random_state=42)
    metrics = []

    print(f"\nEvaluating {model_name} with 10-Fold Cross-Validation:")

    for fold, (train_index, test_index) in enumerate(skf.split(X, y), start=1):
        # Prepare train and test sets
        X_train, X_test = X[train_index], X[test_index]
        y_train, y_test = y[train_index], y[test_index]

        # Reshape for LSTM
        X_train = X_train.reshape((X_train.shape[0], input_shape[0],␣
 ↪input_shape[1]))
        X_test = X_test.reshape((X_test.shape[0], input_shape[0],␣
 ↪input_shape[1]))
        y_train = to_categorical(y_train)
        y_test_bin = to_categorical(y_test)

        # Build LSTM model
        model = Sequential([
            LSTM(128, activation='relu', input_shape=(input_shape[0],␣
 ↪input_shape[1])),
            Dropout(0.2),
            Dense(2, activation='softmax')
        ])
        model.compile(optimizer=Adam(learning_rate=0.001),␣
 ↪loss='binary_crossentropy', metrics=['accuracy'])

        # Train model
        model.fit(X_train, y_train, epochs=10, verbose=0, batch_size=32)

        # Evaluate model
        y_pred_prob = model.predict(X_test)[:, 1]
        y_pred = (y_pred_prob > 0.5).astype(int)

        cm = confusion_matrix(y_test, y_pred)
        tn, fp, fn, tp = cm.ravel()

        # Metrics Calculation
        tpr = tp / (tp + fn)
        tnr = tn / (tn + fp)
        fpr = fp / (tn + fp)
        fnr = fn / (tp + fn)
        precision = tp / (tp + fp)
        f1 = 2 * tp / (2 * tp + fp + fn)
        accuracy = (tp + tn) / (tp + fp + fn + tn)
        error_rate = (fp + fn) / (tp + fp + fn + tn)
        bacc = (tpr + tnr) / 2
        tss = tpr - fpr
        hss = 2 * (tp * tn - fp * fn) / ((tp + fn) * (fn + tn) + (tp + fp) * (fp + tn))
        recall = tp / tp + fn

        fold_metrics = {
            'Fold': fold,
            'TP': tp, 'TN': tn, 'FP': fp, 'FN': fn,
            "TPR": tpr, "TNR": tnr, "FPR": fpr, "FNR": fnr,
            'Accuracy': accuracy,
            'Precision': precision,
            'Recall': recall,
            'F1 Score': f1,
            "bacc": bacc,
            "tss": tss,
            "hss": hss,

        }

        metrics.append(fold_metrics)

        # Print Metrics for Current Fold
        print(f"Fold {fold} Metrics:")
        for metric, value in fold_metrics.items():
            print(f"{metric}: {value}")
        print("_"*30+"\n")

    return model, pd.DataFrame(metrics)

# Preprocessing: Scale and Reshape for LSTM
scaler = StandardScaler()
X_scaled = scaler.fit_transform(X)
input_shape = (X_scaled.shape[1], 1)  # Each feature is treated as a time step
X_scaled = X_scaled.reshape((X_scaled.shape[0], input_shape[0], input_shape[1]))
```

```
# Evaluate LSTM
best_lstm, lstm_metrics = train_lstm_model(X_scaled, y.values, input_shape)
```

```
Evaluating LSTM with 10-Fold Cross-Validation:
```

```
/usr/local/lib/python3.10/dist-packages/keras/src/layers/rnn/rnn.py:204:
UserWarning: Do not pass an `input_shape`/`input_dim` argument to a layer. When
using Sequential models, prefer using an `Input(shape)` object as the first
layer in the model instead.
  super().__init__(**kwargs)
```

```
3/3                0s 75ms/step
Fold 1 Metrics:
Fold: 1
TP: 18
TN: 39
FP: 11
FN: 9
TPR: 0.6666666666666666
TNR: 0.78
FPR: 0.22
FNR: 0.3333333333333333
Accuracy: 0.7402597402597403
Precision: 0.6206896551724138
Recall: 10.0
F1 Score: 0.6428571428571429
bacc: 0.7233333333333334
tss: 0.44666666666666666
hss: 0.43918426802621996
------------------------------
```

```
/usr/local/lib/python3.10/dist-packages/keras/src/layers/rnn/rnn.py:204:
UserWarning: Do not pass an `input_shape`/`input_dim` argument to a layer. When
using Sequential models, prefer using an `Input(shape)` object as the first
layer in the model instead.
  super().__init__(**kwargs)
```

```
3/3                0s 73ms/step
Fold 2 Metrics:
Fold: 2
TP: 12
TN: 43
FP: 7
FN: 15
TPR: 0.4444444444444444
TNR: 0.86
FPR: 0.14
```

```
FNR: 0.5555555555555556
Accuracy: 0.7142857142857143
Precision: 0.631578947368421
Recall: 16.0
F1 Score: 0.5217391304347826
bacc: 0.6522222222222223
tss: 0.3044444444444444
hss: 0.3267090620031797
------------------------------
```

```
/usr/local/lib/python3.10/dist-packages/keras/src/layers/rnn/rnn.py:204:
UserWarning: Do not pass an `input_shape`/`input_dim` argument to a layer. When
using Sequential models, prefer using an `Input(shape)` object as the first
layer in the model instead.
  super().__init__(**kwargs)
WARNING:tensorflow:5 out of the last 7 calls to <function
TensorFlowTrainer.make_predict_function.<locals>.one_step_on_data_distributed at
0x7d11fcbc16c0> triggered tf.function retracing. Tracing is expensive and the
excessive number of tracings could be due to (1) creating @tf.function
repeatedly in a loop, (2) passing tensors with different shapes, (3) passing
Python objects instead of tensors. For (1), please define your @tf.function
outside of the loop. For (2), @tf.function has reduce_retracing=True option that
can avoid unnecessary retracing. For (3), please refer to
https://www.tensorflow.org/guide/function#controlling_retracing and
https://www.tensorflow.org/api_docs/python/tf/function for  more details.
```

```
1/3           0s 155ms/step
```

```
WARNING:tensorflow:6 out of the last 9 calls to <function
TensorFlowTrainer.make_predict_function.<locals>.one_step_on_data_distributed at
0x7d11fcbc16c0> triggered tf.function retracing. Tracing is expensive and the
excessive number of tracings could be due to (1) creating @tf.function
repeatedly in a loop, (2) passing tensors with different shapes, (3) passing
Python objects instead of tensors. For (1), please define your @tf.function
outside of the loop. For (2), @tf.function has reduce_retracing=True option that
can avoid unnecessary retracing. For (3), please refer to
https://www.tensorflow.org/guide/function#controlling_retracing and
https://www.tensorflow.org/api_docs/python/tf/function for  more details.
```

```
3/3           0s 79ms/step
```

```
/usr/local/lib/python3.10/dist-packages/keras/src/layers/rnn/rnn.py:204:
UserWarning: Do not pass an `input_shape`/`input_dim` argument to a layer. When
using Sequential models, prefer using an `Input(shape)` object as the first
layer in the model instead.
  super().__init__(**kwargs)
```

```
Fold 3 Metrics:
Fold: 3
TP: 12
```

```
TN: 44
FP: 6
FN: 15
TPR: 0.4444444444444444
TNR: 0.88
FPR: 0.12
FNR: 0.5555555555555556
Accuracy: 0.7272727272727273
Precision: 0.6666666666666666
Recall: 16.0
F1 Score: 0.5333333333333333
bacc: 0.6622222222222223
tss: 0.3244444444444444
hss: 0.35138387484957884
------------------------------
```

```
3/3            0s 77ms/step
Fold 4 Metrics:
Fold: 4
TP: 18
TN: 46
FP: 4
FN: 9
TPR: 0.6666666666666666
TNR: 0.92
FPR: 0.08
FNR: 0.3333333333333333
Accuracy: 0.8311688311688312
Precision: 0.8181818181818182
Recall: 10.0
F1 Score: 0.7346938775510204
bacc: 0.7933333333333333
tss: 0.5866666666666667
hss: 0.6127659574468085
------------------------------
```

```
/usr/local/lib/python3.10/dist-packages/keras/src/layers/rnn/rnn.py:204:
UserWarning: Do not pass an `input_shape`/`input_dim` argument to a layer. When
using Sequential models, prefer using an `Input(shape)` object as the first
layer in the model instead.
  super().__init__(**kwargs)
```

```
3/3            1s 299ms/step
Fold 5 Metrics:
Fold: 5
TP: 18
TN: 37
FP: 13
```

```
FN: 9
TPR: 0.6666666666666666
TNR: 0.74
FPR: 0.26
FNR: 0.3333333333333333
Accuracy: 0.7142857142857143
Precision: 0.5806451612903226
Recall: 10.0
F1 Score: 0.6206896551724138
bacc: 0.7033333333333334
tss: 0.4066666666666666
hss: 0.39326647564469913
------------------------------
```

```
/usr/local/lib/python3.10/dist-packages/keras/src/layers/rnn/rnn.py:204:
UserWarning: Do not pass an `input_shape`/`input_dim` argument to a layer. When
using Sequential models, prefer using an `Input(shape)` object as the first
layer in the model instead.
  super().__init__(**kwargs)
```

```
3/3            0s 76ms/step
Fold 6 Metrics:
Fold: 6
TP: 14
TN: 41
FP: 9
FN: 13
TPR: 0.5185185185185185
TNR: 0.82
FPR: 0.18
FNR: 0.48148148148148145
Accuracy: 0.7142857142857143
Precision: 0.6086956521739131
Recall: 14.0
F1 Score: 0.56
bacc: 0.6692592592592592
tss: 0.3385185185185185
hss: 0.3504601226993865
------------------------------
```

```
/usr/local/lib/python3.10/dist-packages/keras/src/layers/rnn/rnn.py:204:
UserWarning: Do not pass an `input_shape`/`input_dim` argument to a layer. When
using Sequential models, prefer using an `Input(shape)` object as the first
layer in the model instead.
  super().__init__(**kwargs)
```

```
3/3            0s 118ms/step
Fold 7 Metrics:
```

```
Fold: 7
TP: 12
TN: 44
FP: 6
FN: 15
TPR: 0.4444444444444444
TNR: 0.88
FPR: 0.12
FNR: 0.5555555555555556
Accuracy: 0.7272727272727273
Precision: 0.6666666666666666
Recall: 16.0
F1 Score: 0.5333333333333333
bacc: 0.6622222222222223
tss: 0.3244444444444444
hss: 0.35138387484957884
------------------------------

/usr/local/lib/python3.10/dist-packages/keras/src/layers/rnn/rnn.py:204:
UserWarning: Do not pass an `input_shape`/`input_dim` argument to a layer. When
using Sequential models, prefer using an `Input(shape)` object as the first
layer in the model instead.
  super().__init__(**kwargs)

3/3            0s 77ms/step
Fold 8 Metrics:
Fold: 8
TP: 13
TN: 38
FP: 12
FN: 14
TPR: 0.48148148148148145
TNR: 0.76
FPR: 0.24
FNR: 0.5185185185185185
Accuracy: 0.6623376623376623
Precision: 0.52
Recall: 15.0
F1 Score: 0.5
bacc: 0.6207407407407407
tss: 0.24148148148148146
hss: 0.24566691785983422
------------------------------

/usr/local/lib/python3.10/dist-packages/keras/src/layers/rnn/rnn.py:204:
UserWarning: Do not pass an `input_shape`/`input_dim` argument to a layer. When
using Sequential models, prefer using an `Input(shape)` object as the first
```

```
layer in the model instead.
  super().__init__(**kwargs)

3/3            0s 82ms/step
Fold 9 Metrics:
Fold: 9
TP: 18
TN: 37
FP: 13
FN: 8
TPR: 0.6923076923076923
TNR: 0.74
FPR: 0.26
FNR: 0.3076923076923077
Accuracy: 0.7236842105263158
Precision: 0.5806451612903226
Recall: 9.0
F1 Score: 0.631578947368421
bacc: 0.7161538461538461
tss: 0.4323076923076923
hss: 0.41323529411764703
------------------------------

/usr/local/lib/python3.10/dist-packages/keras/src/layers/rnn/rnn.py:204:
UserWarning: Do not pass an `input_shape`/`input_dim` argument to a layer. When
using Sequential models, prefer using an `Input(shape)` object as the first
layer in the model instead.
  super().__init__(**kwargs)

3/3            0s 75ms/step
Fold 10 Metrics:
Fold: 10
TP: 14
TN: 35
FP: 15
FN: 12
TPR: 0.5384615384615384
TNR: 0.7
FPR: 0.3
FNR: 0.46153846153846156
Accuracy: 0.6447368421052632
Precision: 0.4827586206896552
Recall: 13.0
F1 Score: 0.509090909090909
bacc: 0.6192307692307693
tss: 0.23846153846153845
hss: 0.23203592814371257
------------------------------
```

1.0.11 ROC Curve

[17]:

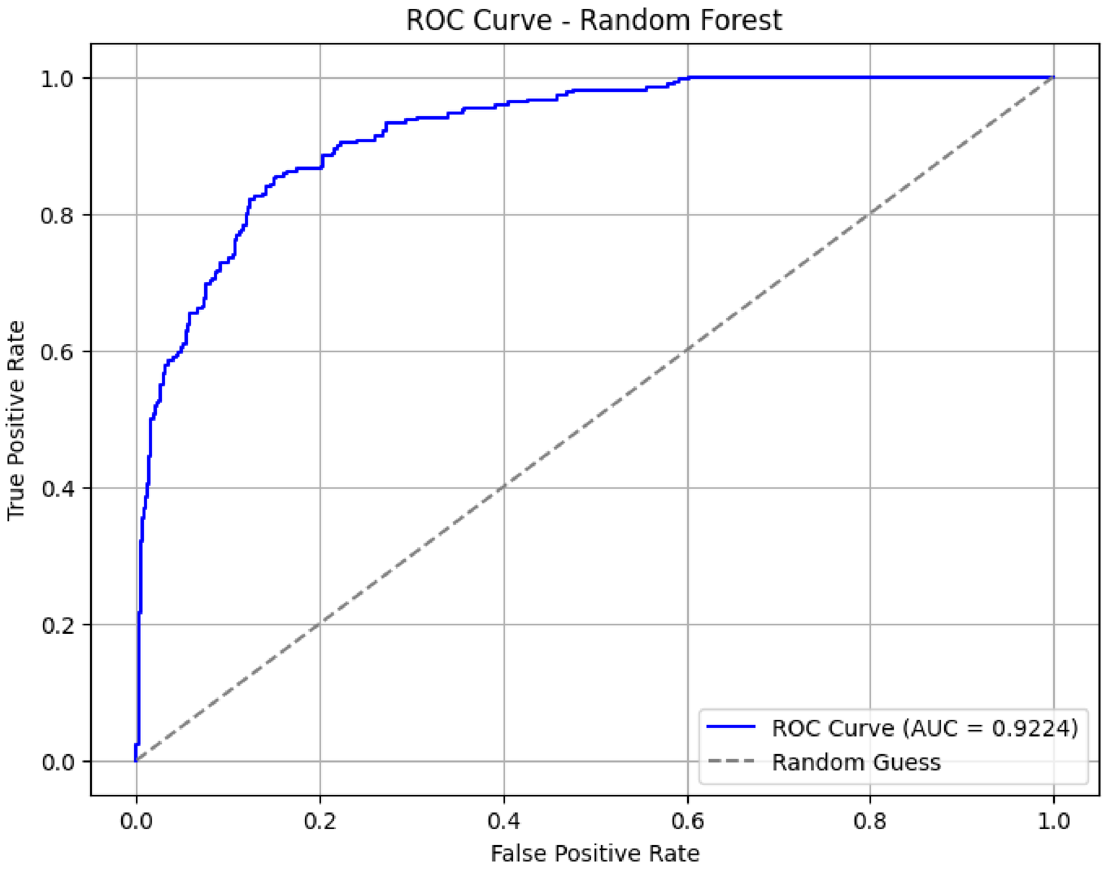
```python
import matplotlib.pyplot as plt
from sklearn.metrics import roc_curve, auc

# Function to plot ROC Curve
def plot_roc_curve(y_test, y_proba, model_name):
    fpr, tpr, _ = roc_curve(y_test, y_proba)
    roc_auc = auc(fpr, tpr)
    plt.figure(figsize=(8, 6))
    plt.plot(fpr, tpr, color='blue', label=f'ROC Curve (AUC = {roc_auc:.4f})')
    plt.plot([0, 1], [0, 1], color='gray', linestyle='--', label='Random Guess')
    plt.title(f'ROC Curve - {model_name}')
    plt.xlabel('False Positive Rate')
    plt.ylabel('True Positive Rate')
    plt.legend(loc='lower right')
    plt.grid()
    plt.show()
```

[18]:

```python
# Plot ROC Curve for Random Forest
print("\nRandom Forest ROC Curve:")
rf_y_proba = best_rf.predict_proba(X)[:, 1]
plot_roc_curve(y, rf_y_proba, 'Random Forest')
```

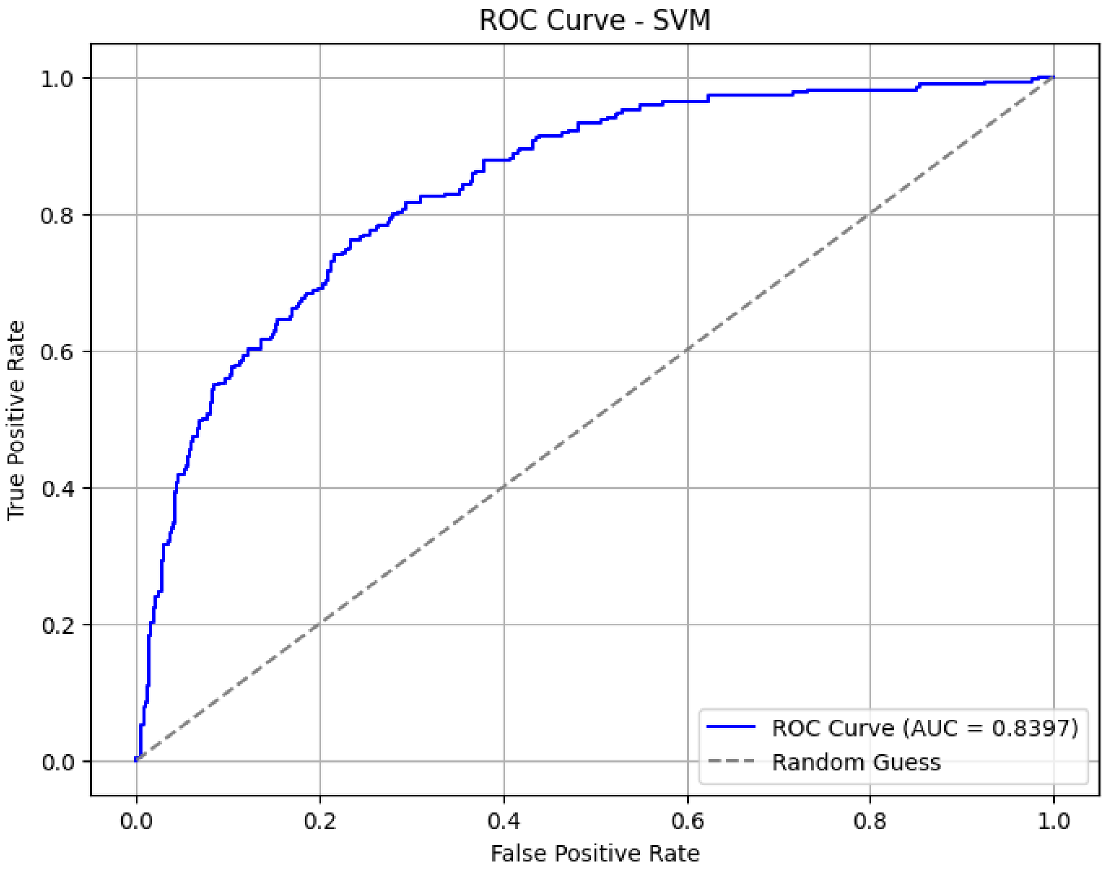
```
Random Forest ROC Curve:
```



[19]:

```
# Plot ROC Curve for SVM
print("\nSVM ROC Curve:")
svm_y_proba = best_svm.predict_proba(X)[:, 1]
plot_roc_curve(y, svm_y_proba, 'SVM')
```

```
SVM ROC Curve:
```



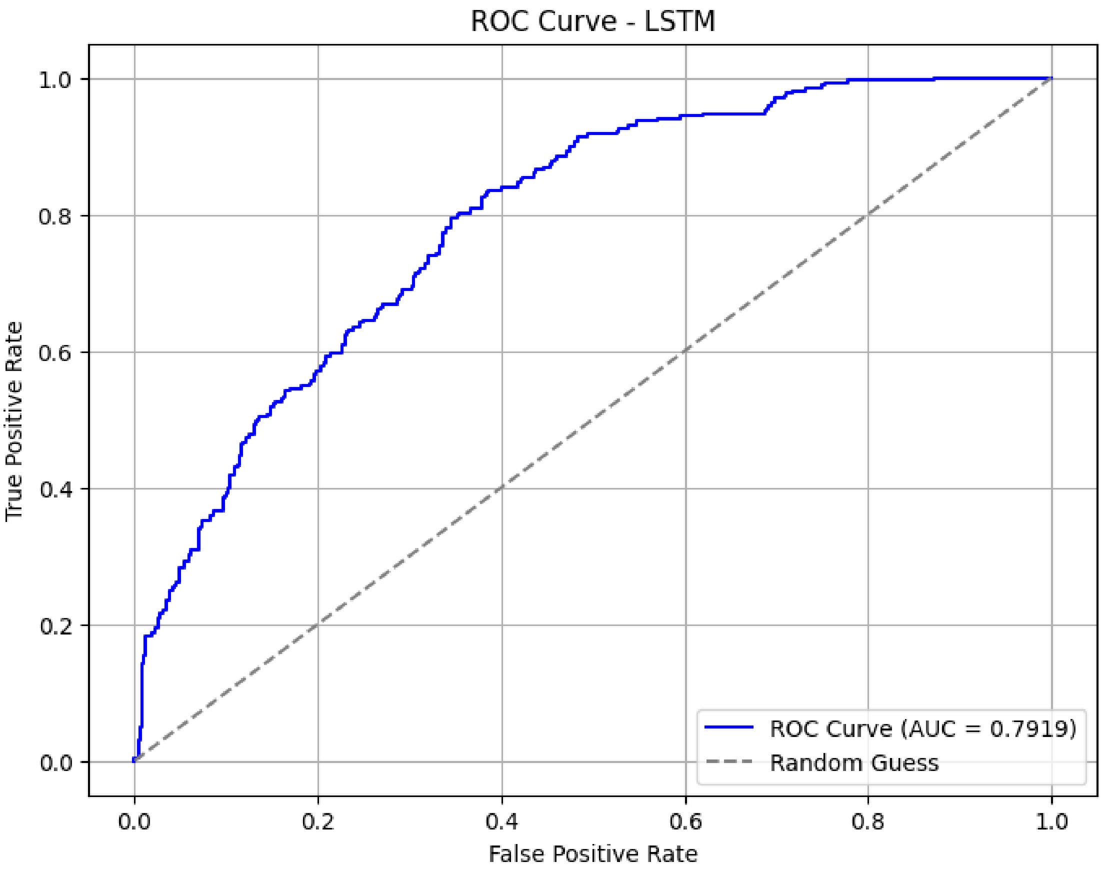
[20]:
```
# Plot ROC Curve for LSTM
print("\nLSTM ROC Curve:")
X_dl = np.expand_dims(X, axis=2)
lstm_model = Sequential([
    LSTM(64, input_shape=(X_dl.shape[1], 1), return_sequences=False),
    Dropout(0.3),
    Dense(32, activation='relu'),
    Dense(1, activation='sigmoid')
])
lstm_model.compile(optimizer='adam', loss='binary_crossentropy',␣
 ↪metrics=['accuracy'])
lstm_model.fit(X_dl, y, epochs=10, batch_size=16, verbose=0)
lstm_y_proba = lstm_model.predict(X_dl).flatten()
plot_roc_curve(y, lstm_y_proba, 'LSTM')
```

```
LSTM ROC Curve:
```

```
/usr/local/lib/python3.10/dist-packages/keras/src/layers/rnn/rnn.py:204:
UserWarning: Do not pass an `input_shape`/`input_dim` argument to a layer. When
```

```
using Sequential models, prefer using an `Input(shape)` object as the first
layer in the model instead.
  super().__init__(**kwargs)
```

```
24/24            0s 3ms/step
```



1.0.12 Model Comparision

```
[22]: # Combine Metrics DataFrames
rf_metrics['Model'] = 'Random Forest'
svm_metrics['Model'] = 'SVM'
lstm_metrics['Model'] = 'LSTM'

comparison_df = pd.concat([rf_metrics, svm_metrics, lstm_metrics])
comparison_df = comparison_df[comparison_df['Fold']==10]
columns_to_display = ['Model', 'TP', 'TN', 'FP', 'FN',
                      "TPR", "TNR", "FPR", "FNR",
                      "Accuracy", "Precision", "Recall", "F1 Score",
                      "bacc", "tss", "hss",]
comparison_df = comparison_df[columns_to_display]
```

```
comparison_df.set_index('Model', inplace=True)
comparison_df.T
```

```
[22]: Model      Random Forest        SVM       LSTM
      TP             12.000000  13.000000  14.000000
      TN             44.000000  44.000000  35.000000
      FP              6.000000   6.000000  15.000000
      FN             14.000000  13.000000  12.000000
      TPR             0.461538   0.500000   0.538462
      TNR             0.880000   0.880000   0.700000
      FPR             0.120000   0.120000   0.300000
      FNR             0.538462   0.500000   0.461538
      Accuracy        0.736842   0.750000   0.644737
      Precision       0.666667   0.684211   0.482759
      Recall         15.000000  14.000000  13.000000
      F1 Score        0.545455   0.577778   0.509091
      bacc            0.670769   0.690000   0.619231
      tss             0.341538   0.380000   0.238462
      hss             0.368771   0.406250   0.232036
```