INM427 Neural Computing

Group work

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In [1]:
```
# Import the relevant libraries.

import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
import torch
import torch.nn as nn
import random
```

In [2]:
```
# Generate random numbers.


random.seed(123)
```

In [3]:
```
# The dataset is from Kaggle, and this dataset is about whether a customer will keep their bank account or not.
# Dataset URL: https://www.kaggle.com/competitions/playground-series-s4e1

# We use only the train set in Kaggle
# since the test set does not have their target data(the column name with 'Exited') due to the competition.
# We renamed the file of the train set into 'bank_churn_data.csv'.


df = pd.read_csv('bank_churn_data.csv')
df
```

Out[3]:

	id	CustomerId	Surname	CreditScore	Geography	Gender	Age	Tenure	Balance	NumOfProducts	HasCrCard	IsActiveMember	EstimatedSalary	Exited
0	0	15674932	Okwudilichukwu	668	France	Male	33.0	3	0.00	2	1	0	181449.97	0
1	1	15749177	Okwudiliolisa	627	France	Male	33.0	1	0.00	2	1	1	49503.50	0
2	2	15694510	Hsueh	678	France	Male	40.0	10	0.00	2	1	0	184866.69	0
3	3	15741417	Kao	581	France	Male	34.0	2	148882.54	1	1	1	84560.88	0
4	4	15766172	Chiemenam	716	Spain	Male	33.0	5	0.00	2	1	1	15068.83	0
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
165029	165029	15667085	Meng	667	Spain	Female	33.0	2	0.00	1	1	1	131834.75	0
165030	165030	15665521	Okechukwu	792	France	Male	35.0	3	0.00	1	0	0	131834.45	0
165031	165031	15664752	Hsia	565	France	Male	31.0	5	0.00	1	1	1	127429.56	0
165032	165032	15689614	Hsiung	554	Spain	Female	30.0	7	161533.00	1	0	1	71173.03	0
165033	165033	15732798	Ulyanov	850	France	Male	31.0	1	0.00	1	1	0	61581.79	1

165034 rows × 14 columns

Data wrangling

In [4]:
```
df.dtypes
```

Out[4]:
```
id                 int64
CustomerId         int64
Surname           object
CreditScore        int64
Geography         object
Gender            object
Age              float64
Tenure             int64
Balance          float64
NumOfProducts      int64
HasCrCard          int64
IsActiveMember     int64
EstimatedSalary  float64
Exited             int64
dtype: object
```

In [5]:
```
df.isnull().sum()
```

Out[5]:
```
id                 0
CustomerId         0
Surname            0
CreditScore        0
Geography          0
Gender             0
Age                0
Tenure             0
Balance            0
NumOfProducts      0
HasCrCard          0
IsActiveMember     0
EstimatedSalary    0
Exited             0
dtype: int64
```

In [6]:
```
# Check the number of values in 'Gender' and 'Geography'.

print(df['Gender'].nunique())
print(df['Geography'].nunique())
```

```
2
3
```

In [7]:
```
# Remove irrelevant features for a model.

df = df.drop(['id', 'CustomerId', 'Surname'], axis=1)
df
```

Out[7]:

	CreditScore	Geography	Gender	Age	Tenure	Balance	NumOfProducts	HasCrCard	IsActiveMember	EstimatedSalary	Exited
0	668	France	Male	33.0	3	0.00	2	1	0	181449.97	0
1	627	France	Male	33.0	1	0.00	2	1	1	49503.50	0
2	678	France	Male	40.0	10	0.00	2	1	0	184866.69	0
3	581	France	Male	34.0	2	148882.54	1	1	1	84560.88	0
4	716	Spain	Male	33.0	5	0.00	2	1	1	15068.83	0
...	...	...	...	...	...	...	...	...	...	...	...
165029	667	Spain	Female	33.0	2	0.00	1	1	1	131834.75	0
165030	792	France	Male	35.0	3	0.00	1	0	0	131834.45	0
165031	565	France	Male	31.0	5	0.00	1	1	1	127429.56	0
165032	554	Spain	Female	30.0	7	161533.00	1	0	1	71173.03	0
165033	850	France	Male	31.0	1	0.00	1	1	0	61581.79	1

165034 rows × 11 columns

In [8]:
```
# Change the string data to numeric one in 'Gender'.

map_dict = {'Female' : 0, 'Male' : 1}
df['Gender'] = df['Gender'].map(map_dict).astype(int)
```

In [9]:
```
df['Gender'].value_counts()
```

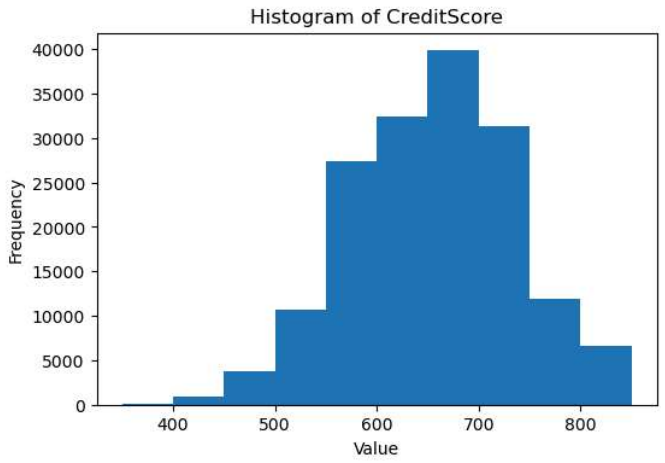
Out[9]:
```
1    93150
0    71884
Name: Gender, dtype: int64
```

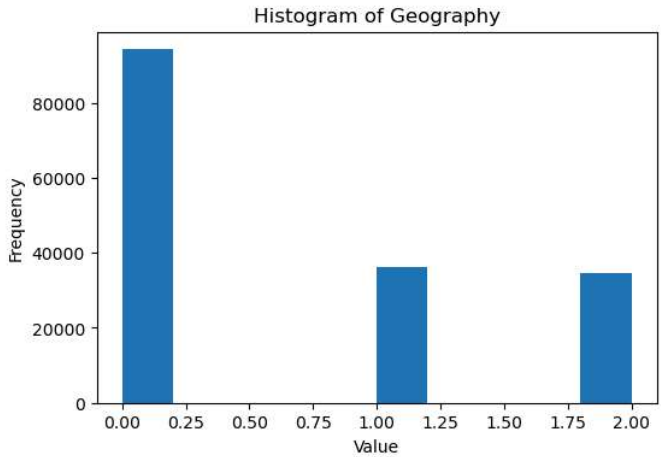
In [10]:
```
df['Geography'].value_counts()
```

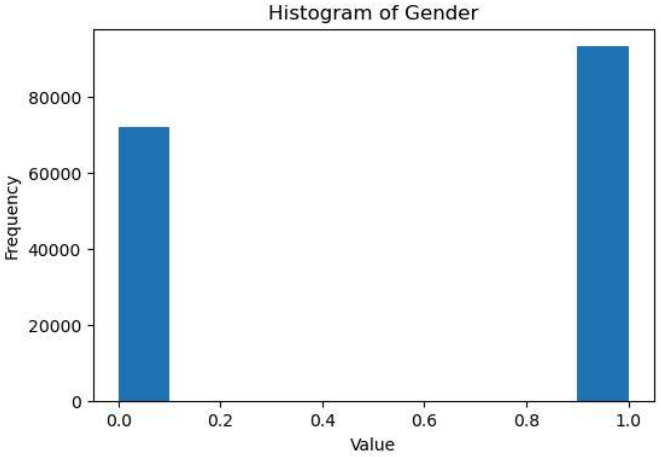
Out[10]:
```
France     94215
Spain      36213
Germany    34606
Name: Geography, dtype: int64
```

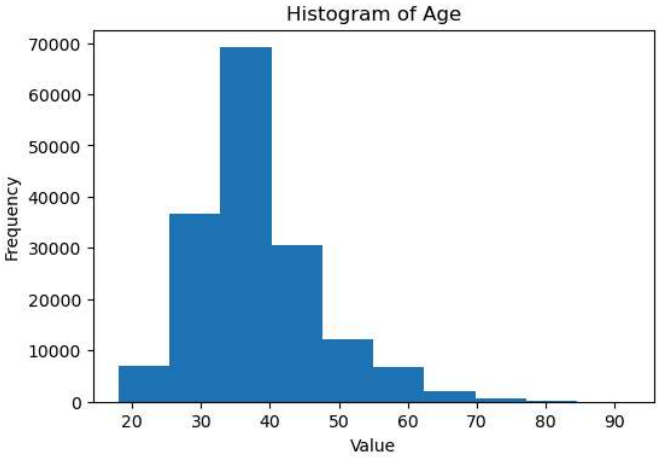
In [11]:
```
# Change the string data to numeric one in 'Geography'.

map_dict = {'France' : 0, 'Spain' : 1, 'Germany' : 2}
df['Geography'] = df['Geography'].map(map_dict).astype(int)
```

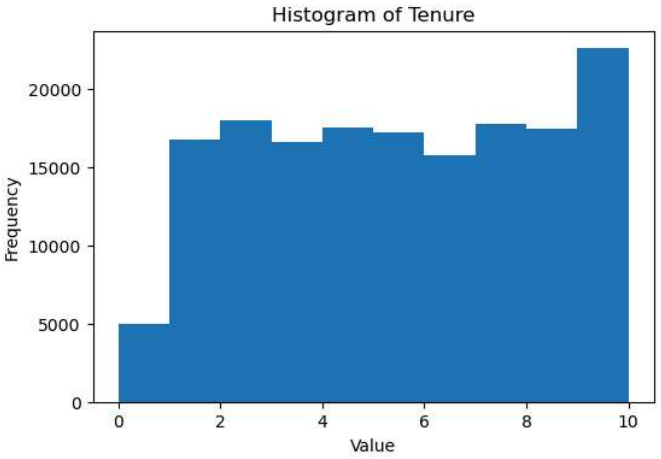
In [12]:
```
# Check each distribution.

for column in df.columns:
    plt.figure(figsize=(6, 4))
    plt.hist(df[column], bins=10)
    plt.title('Histogram of {}'.format(column))
    plt.xlabel('Value')
    plt.ylabel('Frequency')
    plt.show()
```

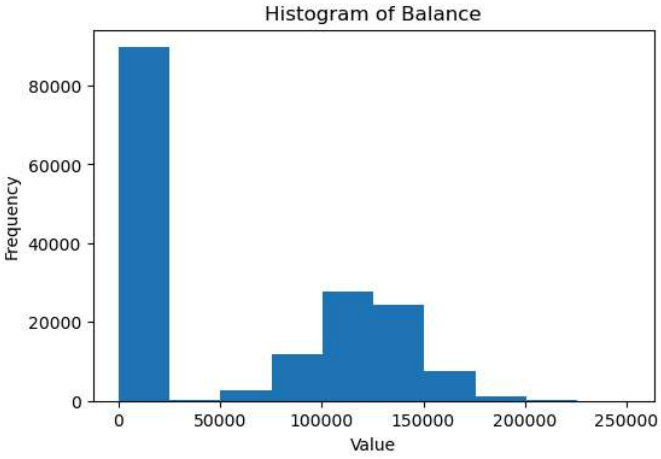


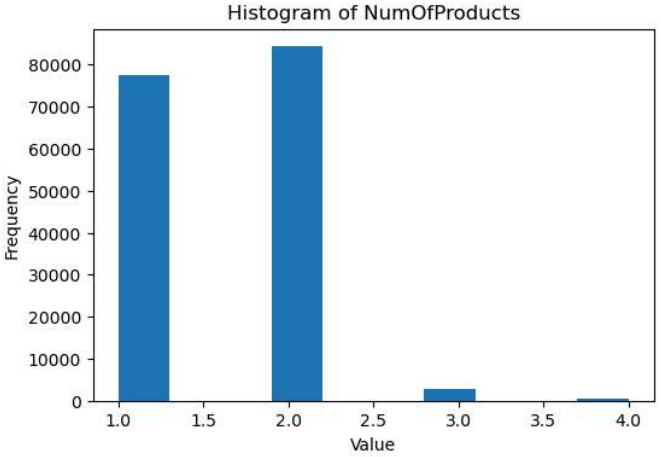


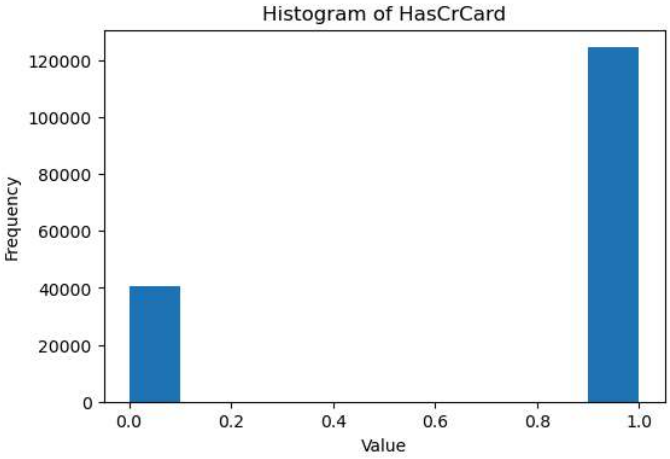

Histogram of Gender
Frequency
Value
0
20000
40000
60000
80000
0.0
0.2
0.4
0.6
0.8
1.0

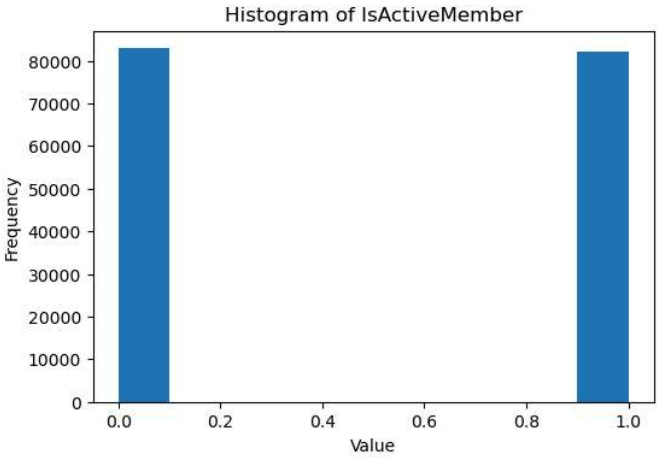

Histogram of Age
Frequency
Value
0
10000
20000
30000
40000
50000
60000
70000
20
30
40
50
60
70
80
90

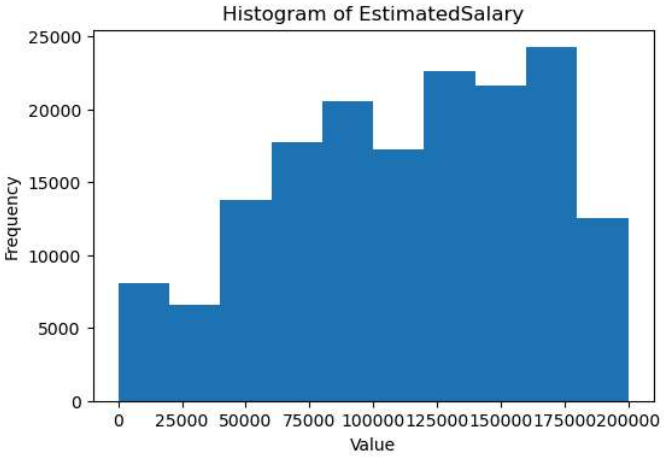

Histogram of Tenure
Frequency
Value
0
5000
10000
15000
20000
0
2
4
6
8
10

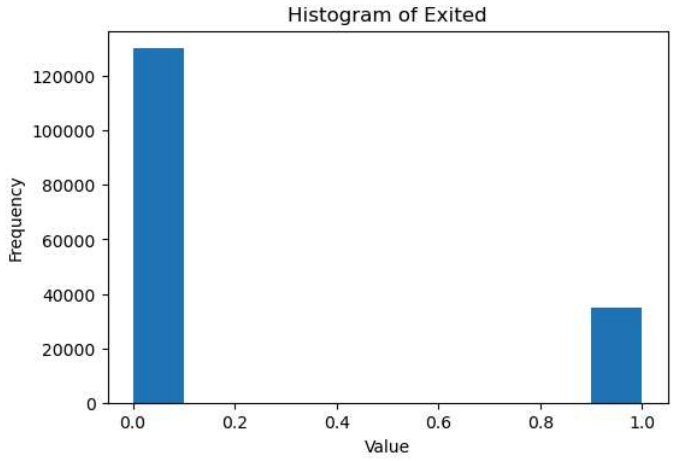

Histogram of Balance
Frequency
Value
0
20000
40000
60000
80000
0
50000
100000
150000
200000
250000


Histogram of NumOfProducts
Frequency
Value
0
10000
20000
30000
40000
50000
60000
70000
80000
1.0
1.5
2.0
2.5
3.0
3.5
4.0


Histogram of HasCrCard
Frequency
Value
0
20000
40000
60000
80000
100000
120000
0.0
0.2
0.4
0.6
0.8
1.0


Histogram of IsActiveMember
Frequency
Value
0
10000
20000
30000
40000
50000
60000
70000
80000
0.0
0.2
0.4
0.6
0.8
1.0


Histogram of EstimatedSalary
Frequency
Value
0
5000
10000
15000
20000
25000
0
25000
50000
75000
100000
125000
150000
175000
200000



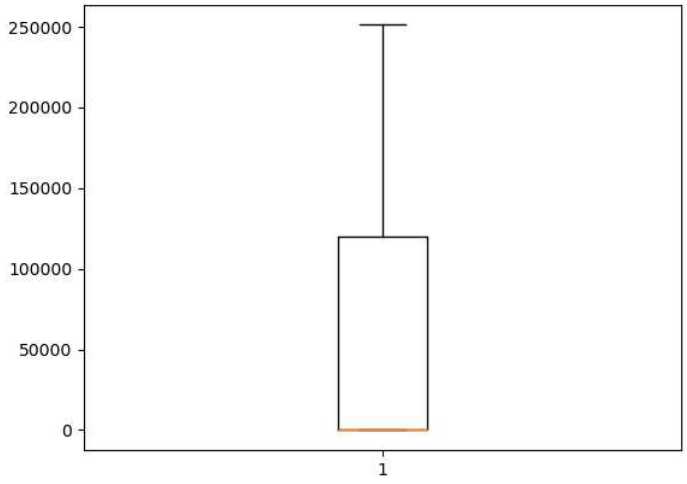
In [13]:
```
# There is a large proportion of the 'Balance' being 0.
# We will determine whether to remove the data with 0 in 'Balance'
# by conducting statistical analysis on the 'Balance'
# and rechecking the distribution of the other features and 'Exited'(target) that appear when the balance is 0.

df['Balance'].value_counts()
```

Out[13]:
```
0.00         89648
124577.33       88
127864.40       64
122314.50       63
129855.32       59
             ...
125824.21        1
158741.56        1
126815.52        1
61172.57         1
110993.29        1
Name: Balance, Length: 30075, dtype: int64
```

In [14]:
```
df['Balance'].describe()
```

Out[14]:
```
count    165034.000000
mean      55478.086689
std       62817.663278
min           0.000000
25%           0.000000
50%           0.000000
75%      119939.517500
max      250898.090000
Name: Balance, dtype: float64
```

In [15]:
```
plt.boxplot(df['Balance']);
```



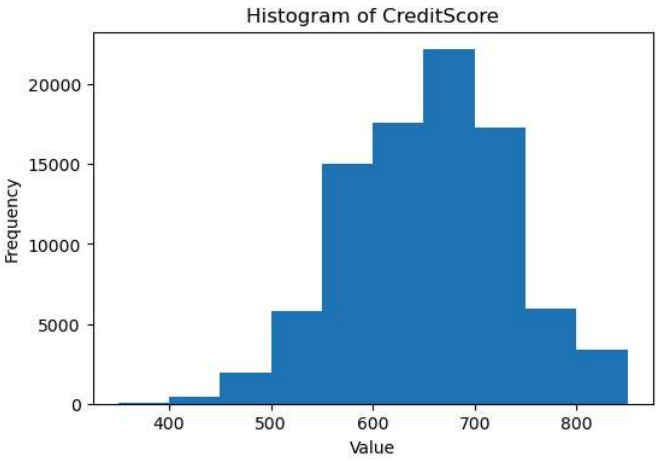
In [16]:
```
# Select the data with 0 in 'Balance'.

df_0_balance = df[df['Balance'] == 0]
df_0_balance
```

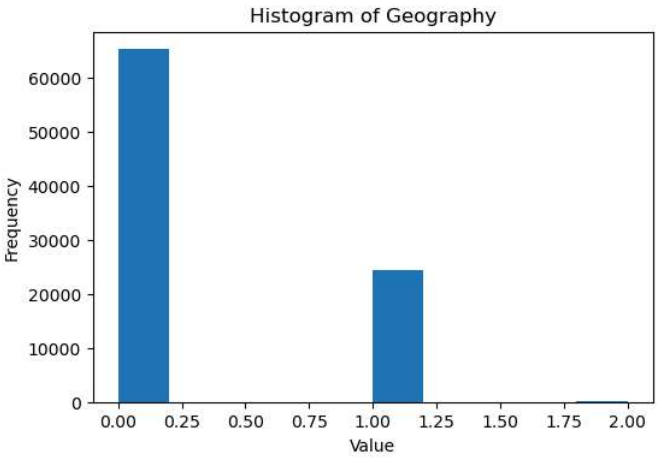
Out[16]:

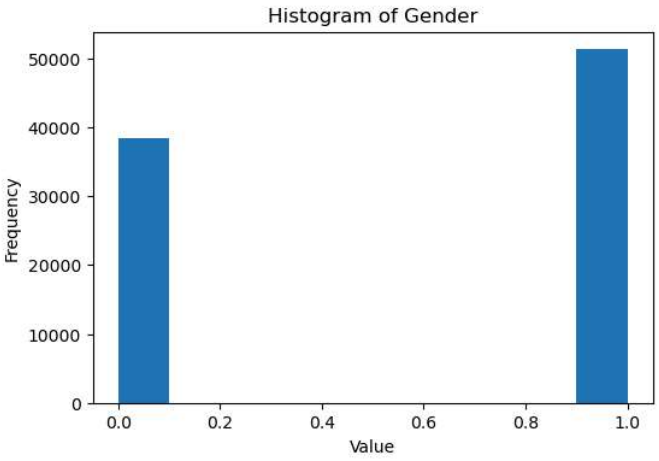
	CreditScore	Geography	Gender	Age	Tenure	Balance	NumOfProducts	HasCrCard	IsActiveMember	EstimatedSalary	Exited
0	668	0	1	33.0	3	0.0	2	1	0	181449.97	0
1	627	0	1	33.0	1	0.0	2	1	1	49503.50	0
2	678	0	1	40.0	10	0.0	2	1	0	184866.69	0
4	716	1	1	33.0	5	0.0	2	1	1	15068.83	0
8	676	0	1	43.0	4	0.0	2	1	0	142917.13	0
...	...	...	...	...	...	...	...	...	...	...	...
165028	630	0	1	50.0	8	0.0	2	1	1	5962.50	0
165029	667	1	0	33.0	2	0.0	1	1	1	131834.75	0
165030	792	0	1	35.0	3	0.0	1	0	0	131834.45	0
165031	565	0	1	31.0	5	0.0	1	1	1	127429.56	0
165033	850	0	1	31.0	1	0.0	1	1	0	61581.79	1

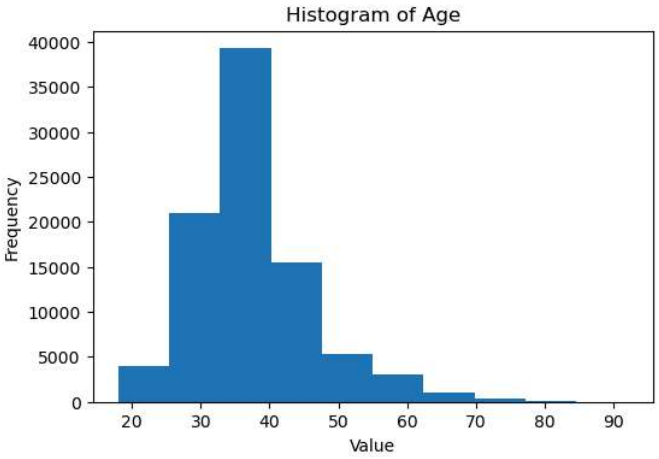
89648 rows × 11 columns

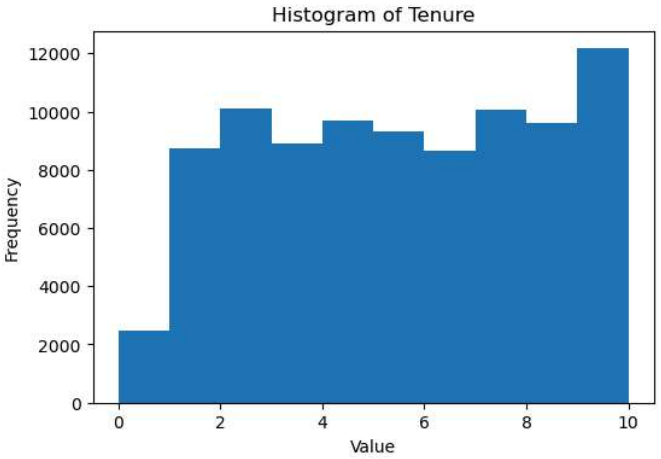
In [17]:
```
# Check each distribution of the features in 'df_0_balance'.

for column in df_0_balance.columns:
    plt.figure(figsize=(6, 4))
    plt.hist(df_0_balance[column], bins=10)
    plt.title('Histogram of {}'.format(column))
    plt.xlabel('Value')
    plt.ylabel('Frequency')
    plt.show()
```

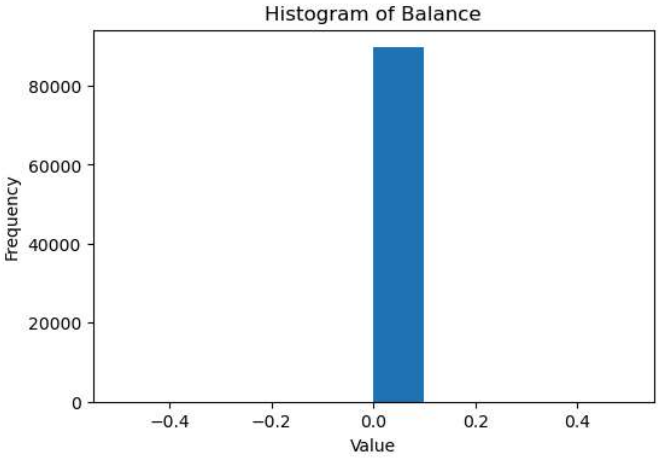


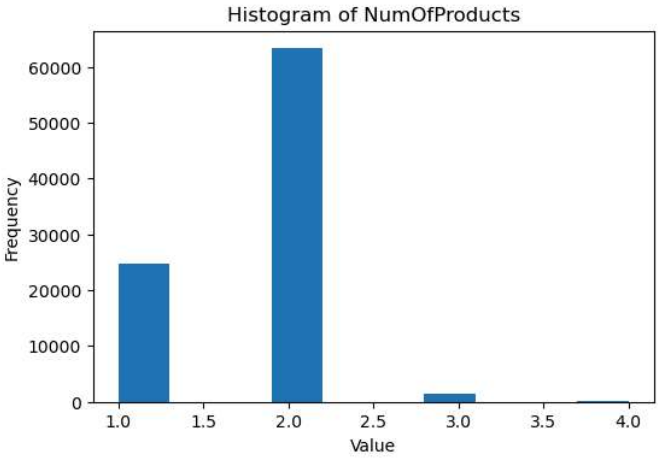


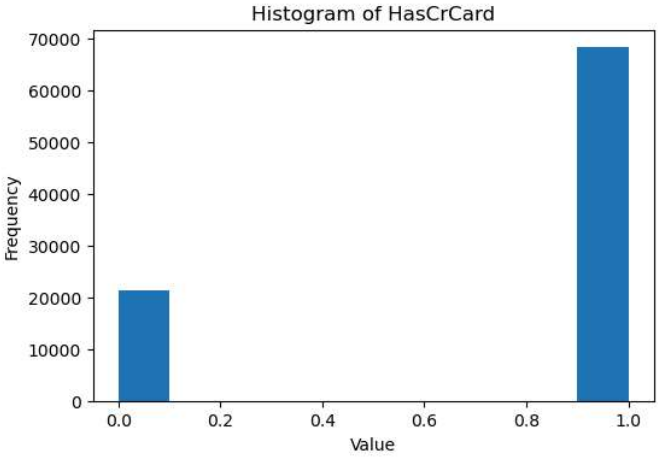


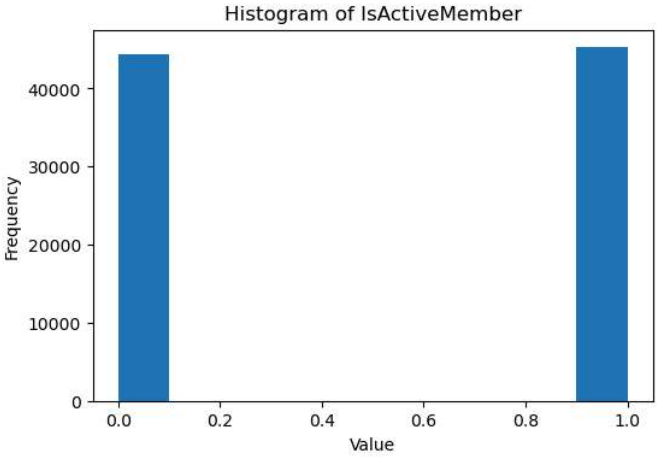


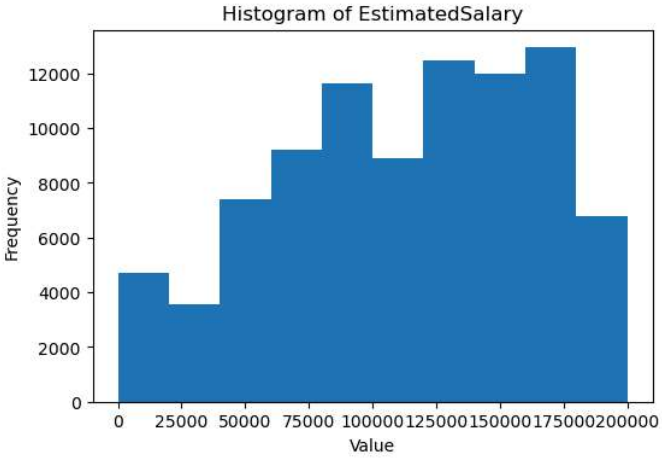

Histogram of Tenure
Frequency
Value
0
2000
4000
6000
8000
10000
12000
0
2
4
6
8
10

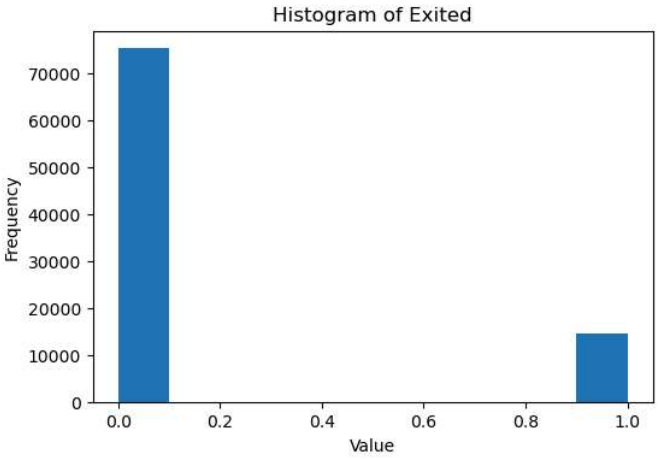

Histogram of Balance
Frequency
Value
0
20000
40000
60000
80000
−0.4
−0.2
0.0
0.2
0.4


Histogram of NumOfProducts
Frequency
Value
0
10000
20000
30000
40000
50000
60000
1.0
1.5
2.0
2.5
3.0
3.5
4.0


Histogram of HasCrCard
Frequency
Value
0
10000
20000
30000
40000
50000
60000
70000
0.0
0.2
0.4
0.6
0.8
1.0

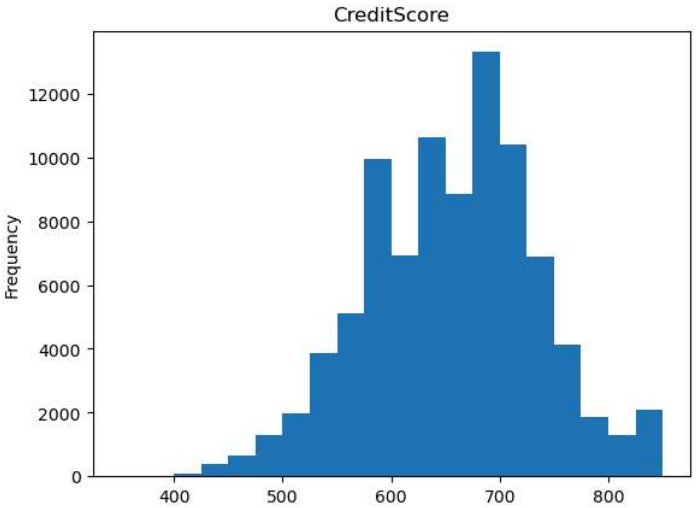






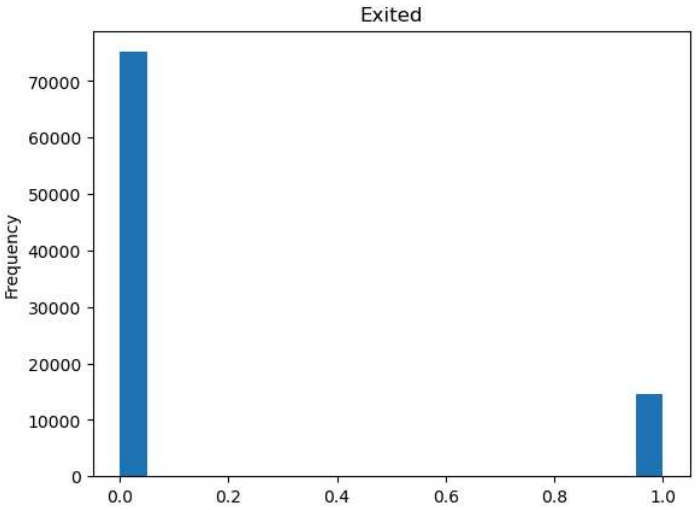
In [18]:
```
df_0_balance['CreditScore'].plot(kind='hist', bins=20, title='CreditScore')
```

Out[18]:
```
<Axes: title={'center': 'CreditScore'}, ylabel='Frequency'>
```



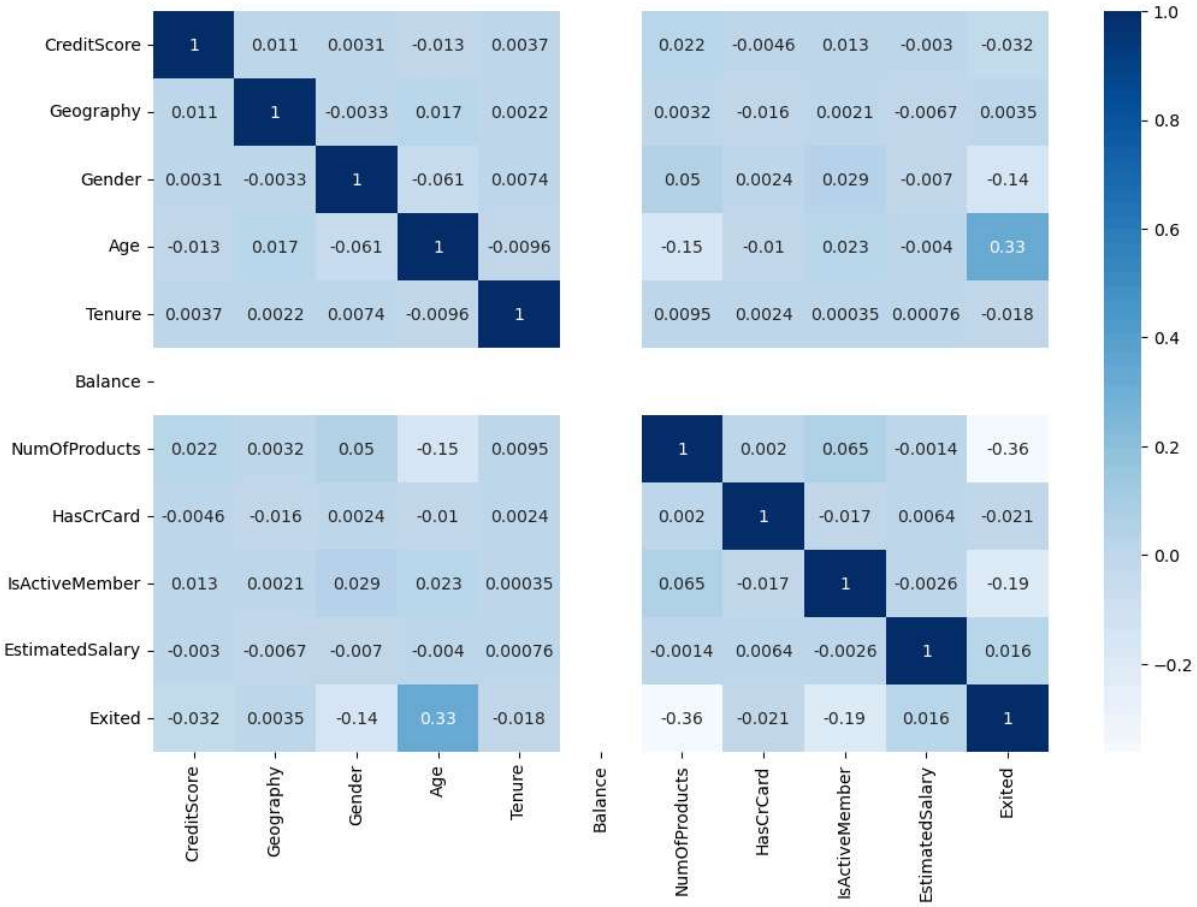
In [19]:
```
df_0_balance['Exited'].plot(kind='hist', bins=20, title='Exited')
```

Out[19]:
```
<Axes: title={'center': 'Exited'}, ylabel='Frequency'>
```



In [20]:
```
# Check the correlation coefficient of each feature.

correlation_matrix = df_0_balance.corr()
plt.figure(figsize=(12, 8))
sns.heatmap(correlation_matrix, cmap='Blues', annot=True)
```

Out[20]: <Axes: >



The data with the value of 0 in 'Balance' will be remained since 'Balance' has considerably low collinearity with 'Exited'. Although, it looks problematic as the quantile range of 'Balance' shows 0 in 25% and 0 in 50%, the data with 0 in 'Balance' is still meaningful as it shows a similar distribution of the features to the distribution in the data with 0 and the other values in 'Balance'.

Split the data set

In [21]:
```
# Split the dataset into features and the target.
X = df.iloc[:, 0:10]
y = df.iloc[:, 10]
print(X)
print(y)
```

```
        CreditScore  Geography  Gender   Age  Tenure    Balance  W
0               668          0       1  33.0       3       0.00
1               627          0       1  33.0       1       0.00
2               678          0       1  40.0      10       0.00
3               581          0       1  34.0       2  148882.54
4               716          1       1  33.0       5       0.00
...             ...        ...     ...   ...     ...        ...
165029          667          1       0  33.0       2       0.00
165030          792          0       1  35.0       3       0.00
165031          565          0       1  31.0       5       0.00
165032          554          1       0  30.0       7  161533.00
165033          850          0       1  31.0       1       0.00

        NumOfProducts  HasCrCard  IsActiveMember  EstimatedSalary
0                   2          1               0        181449.97
1                   2          1               1         49503.50
2                   2          1               0        184866.69
3                   1          1               1         84560.88
4                   2          1               1         15068.83
...               ...        ...             ...              ...
165029              1          1               1        131834.75
165030              1          0               0        131834.45
165031              1          1               1        127429.56
165032              1          0               1         71173.03
165033              1          1               0         61581.79

[165034 rows x 10 columns]
0         0
1         0
2         0
3         0
4         0
         ..
165029    0
165030    0
165031    0
165032    0
165033    1
Name: Exited, Length: 165034, dtype: int64
```

In [22]:
```
print(type(X))
print(type(y))
print(X.shape)
print(y.shape)
```

```
<class 'pandas.core.frame.DataFrame'>
<class 'pandas.core.series.Series'>
(165034, 10)
(165034,)
```

In [23]:
```
# Convert Pandas to Numpy array.
X = X.values
y = y.values

print(type(X))
print(type(y))
print(X.shape)
print(y.shape)
```

```
<class 'numpy.ndarray'>
<class 'numpy.ndarray'>
(165034, 10)
(165034,)
```

In [24]:
```
# Convert Numpy array to Tensor.
X = torch.tensor(X, dtype=torch.float32)
y = torch.tensor(y, dtype=torch.float32)
print(type(X))
print(type(y))
print(X.shape)
print(y.shape)
```

```
<class 'torch.Tensor'>
<class 'torch.Tensor'>
torch.Size([165034, 10])
torch.Size([165034])
```

In [25]:
```
# Set the number of random state to shuffle the data.
random_state = 123

# Split the training set into 70% and testing set into 30%.
from sklearn.model_selection import train_test_split
X_train, X_test, y_train, y_test = train_test_split(X,
                                                    y,
                                                    test_size=0.3,
                                                    random_state=random_state
)

# Check the data type.
print(X_train.dtype)

# Split the testing set into validation (50%) and test (50%).
X_test, X_vali, y_test, y_vali = train_test_split(X_test, y_test, test_size=0.5, random_state=random_state)
```

```
torch.float32
```

In [26]:
```
# Check the dimensionality and data type of each set.
print("Training dataset")
print(X_train.dtype, X_train.shape)
print(y_train.dtype, y_train.shape)

print("Validation dataset")
print(X_vali.dtype, X_vali.shape)
print(y_vali.dtype, y_vali.shape)

print("Testing dataset")
print(X_test.dtype, X_test.shape)
print(y_test.dtype, y_test.shape)
```

```
Training dataset
torch.float32 torch.Size([115523, 10])
torch.float32 torch.Size([115523])
Validation dataset
torch.float32 torch.Size([24756, 10])
torch.float32 torch.Size([24756])
Testing dataset
torch.float32 torch.Size([24755, 10])
torch.float32 torch.Size([24755])
```

In [27]:
```
# Import SMOTE to balance the target in training set.
from imblearn.over_sampling import SMOTE

# Create a variable for SMOTE
smote = SMOTE(random_state=random_state)

# Resampling the X and y in the training set using SMOTE.
X_train_smote, y_train_smote = smote.fit_resample(X_train, y_train)
```

In [28]:
```
# Check the dimensionality and data type of each set.
print("Training dataset")
print(X_train.dtype, X_train.shape)
print(y_train.dtype, y_train.shape)

print("Training dataset (Smote)")
print(X_train_smote.dtype, X_train_smote.shape)
print(y_train_smote.dtype, y_train_smote.shape)

print("Validation dataset")
print(X_vali.dtype, X_vali.shape)
print(y_vali.dtype, y_vali.shape)

print("Testing dataset")
print(X_test.dtype, X_test.shape)
print(y_test.dtype, y_test.shape)
```

```
Training dataset
torch.float32 torch.Size([115523, 10])
torch.float32 torch.Size([115523])
Training dataset (Smote)
float32 (182382, 10)
float32 (182382,)
Validation dataset
torch.float32 torch.Size([24756, 10])
torch.float32 torch.Size([24756])
Testing dataset
torch.float32 torch.Size([24755, 10])
torch.float32 torch.Size([24755])
```

Data scaling

In [29]:
```
# Normalise the features in each set.
from sklearn.preprocessing import MinMaxScaler
normal_scaler = MinMaxScaler()

X_train_smote_normalized = normal_scaler.fit_transform(X_train_smote)
X_vali_normalized = normal_scaler.transform(X_vali)
X_test_normalized = normal_scaler.transform(X_test)
```

In [30]:
```
# Convert to Tensor and rename the variables for the features in each set.
X_train = X_train_smote_normalized = torch.tensor(X_train_smote_normalized, dtype=torch.float32)
X_vali = X_vali_normalized = torch.tensor(X_vali_normalized, dtype=torch.float32)
X_test = X_test_normalized = torch.tensor(X_test_normalized, dtype=torch.float32)

# Rename y_train_smote to y_train.
y_train = torch.tensor(y_train_smote, dtype=torch.float32)
```

In [31]:
```
# Check the size and type of datasets after the splitting

print("Training dataset (Smote)")
print(X_train.dtype, X_train.shape)
print(y_train.dtype, y_train.shape)

print("Validation dataset")
print(X_vali.dtype, X_vali.shape)
print(y_vali.dtype, y_vali.shape)

print("Testing dataset")
print(X_test.dtype, X_test.shape)
print(y_test.dtype, y_test.shape)
```

```
Training dataset (Smote)
torch.float32 torch.Size([182382, 10])
torch.float32 torch.Size([182382])
Validation dataset
torch.float32 torch.Size([24756, 10])
torch.float32 torch.Size([24756])
Testing dataset
torch.float32 torch.Size([24755, 10])
torch.float32 torch.Size([24755])
```

In [32]:
```
# Increase the dimension of all target variables.
y_train = y_train.unsqueeze(1)
y_test = y_test.unsqueeze(1)
y_vali = y_vali.unsqueeze(1)

# Make sure that the data type and dimension of each set are all clear.
print("Training dataset")
print(X_train.dtype, X_train.shape, type(X_train))
print(y_train.dtype, y_train.shape, type(y_train))

print("Validation dataset")
print(X_vali.dtype, X_vali.shape, type(X_vali))
print(y_vali.dtype, y_vali.shape, type(y_vali))

print("Testing dataset")
print(X_test.dtype, X_test.shape, type(X_train))
print(y_test.dtype, y_test.shape, type(y_train))
```

```
Training dataset
torch.float32 torch.Size([182382, 10]) <class 'torch.Tensor'>
torch.float32 torch.Size([182382, 1]) <class 'torch.Tensor'>
Validation dataset
torch.float32 torch.Size([24756, 10]) <class 'torch.Tensor'>
torch.float32 torch.Size([24756, 1]) <class 'torch.Tensor'>
Testing dataset
torch.float32 torch.Size([24755, 10]) <class 'torch.Tensor'>
torch.float32 torch.Size([24755, 1]) <class 'torch.Tensor'>
```

In [33]:
```
# To ensure a fair comparison between Python and Matlab,
# we use the same split datasets to train, validate, and test a model in both environments.
# Tensors are converted into CSV files for application in Matlab.
# After conversion, the following codes are commented out.

# Convert the datasets from Tensor to Numpy
#X_train_ndarray = X_train.numpy()
#X_test_ndarray = X_test.numpy()
#X_vali_ndarray = X_vali.numpy()
#y_train_ndarray = y_train.numpy()
#y_test_ndarray = y_test.numpy()
#y_vali_ndarray = y_vali.numpy()

# Save all datasets to CSV file
#np.savetxt('X_train_ndarray.csv', X_train_ndarray, delimiter=',')
#np.savetxt('X_test_ndarray.csv', X_test_ndarray, delimiter=',')
#np.savetxt('X_vali_ndarray.csv', X_vali_ndarray, delimiter=',')
#np.savetxt('y_train_ndarray.csv', y_train_ndarray, delimiter=',')
#np.savetxt('y_test_ndarray.csv', y_test_ndarray, delimiter=',')
#np.savetxt('y_vali_ndarray.csv', y_vali_ndarray, delimiter=',')
```

Build a neural network model

In [34]:
```
# Define the structure of the neural network model.
input_features = 10
output_features = 1

# Set the list of hyperparameters for grid search.
learning_rates_grid = [0.01, 0.1, 0.2, 0.3]
hidden_neurons_grid = [10, 25, 50, 100, 200]

# Set the number of epochs.
number_of_epochs = 1000

# Define variables to store the item from the result of the model.
best_accuracy = 0.0
best_hyperparameters = {}

# Make empty lists to store the result of every combination of hyperparameters for visualisation.
learning_rates_list_heatmap = []
hidden_neurons_list_heatmap = []
accuracy_list_heatmap = []

# Make an empty list to store the elapsed time from 1000 epochs of the best model.
import time
python_training_time_bestmodel = []
```

In [35]:
```
# Make the class for the neural network model.
class Credit_Churn_NN_Model(nn.Module):
    def __init__(self, input_features, hidden_neurons, output_features):
        super(Credit_Churn_NN_Model, self).__init__()
        self.fc1 = nn.Linear(input_features, hidden_neurons)
        self.fc2 = nn.Linear(hidden_neurons, output_features)
        self.relu = nn.ReLU()
        self.sigmoid = nn.Sigmoid()

    def forward(self, x):
        output_layer1 = self.fc1(x)
        l1_activated = self.relu(output_layer1)
        output_layer2 = self.fc2(l1_activated)
        output_activated = self.sigmoid(output_layer2)
        return output_activated
```

In [36]:
```
# Make the function to train the model.
def train_NN_model(learning_rate, hidden_neurons, X_train, y_train, X_vali, y_vali, number_of_epochs):
    model = Credit_Churn_NN_Model(input_features, hidden_neurons, output_features)
    criterion = torch.nn.BCELoss(reduction='mean')
    optimizer = torch.optim.SGD(model.parameters(), lr=learning_rate)

    # Make lists to store the item from the loss and elapsed time in order to plot a graph.
    plot_train_loss = []
    plot_vali_loss = []
    plot_train_time = []

    # Iterate the model following each epoch.
    for e in range(number_of_epochs):
        # Train the model.
        model.train()
        # Start the timer.
        start_time = time.time()
        # Make the gradient descent start from 0
        optimizer.zero_grad()
        y_train_pred = model(X_train)
        # Call the loss function.
        train_loss = criterion(y_train_pred, y_train)
        # Implement backpropagation.
        train_loss.backward()
        optimizer.step()
        # Stop the timer.
        end_time = time.time()
        # Calculate the elapsed time.
        Total_time = end_time - start_time
        plot_train_time.append(Total_time)
        # Append the loss value from training to the following list.
        plot_train_loss.append(train_loss)

        # Validate the model.
        model.eval()
        with torch.no_grad():
            y_vali_pred = model(X_vali)
            vali_loss = criterion(y_vali_pred, y_vali)
```

```
            # Append the loss value from validation to the following list.
            plot_vali_loss.append(vali_loss)

    return model, plot_train_loss, plot_vali_loss, plot_train_time
```

Train the model with grid search

In [37]:
```
# Define an empty list to store the training time from the best model.
Total_time = []

# Apply a nested loop for grid search.
for learning_rate in learning_rates_grid:
    for hidden_neurons in hidden_neurons_grid:
        print(f"\nTraining the NNet model with learning rate={learning_rate} and hidden_neurons={hidden_neurons}")
        # Call the function to train and evaluate the model with the nested loop.
        trained_model, train_loss, vali_loss, train_time = train_NN_model(learning_rate, hidden_neurons,
                                                                          X_train, y_train,
                                                                          X_vali, y_vali,
                                                                          number_of_epochs)

        # Get the predictions from the X_val, and convert them to either 1 or 0.
        y_vali_pred = (trained_model(X_vali).detach().numpy() > 0.5).astype(int)
        # Calculate the validation accuracy.
        accuracy_validation_set = (y_vali_pred == y_vali.numpy()).mean()
        print("The validation accuracy = %.2f%%" % (accuracy_validation_set*100))

        # Append each value to the list for plotting.
        learning_rates_list_heatmap.append(learning_rate)
        hidden_neurons_list_heatmap.append(hidden_neurons)
        accuracy_list_heatmap.append(accuracy_validation_set)
        Total_time.append(train_time)

        # Pick the best model comparing the validation accuracy from each model.
        if accuracy_validation_set > best_accuracy: # If it is so,
            best_accuracy = accuracy_validation_set # Reassign the validation accuracy to the variable of 'best_accuracy'.
            # Define the best hyperparameters with the selected learning rate and the number of neurons.
            best_hyperparameters = {'learning_rate': learning_rate, 'hidden_neurons': hidden_neurons}
            # Pick the value of the loss and training time from the best model.
            train_loss_for_plotting = train_loss
            vali_loss_for_plotting = vali_loss
            python_training_time_bestmodel = train_time
            # Replace the model with the best model.
            best_model = trained_model

# Print the best hyperparameters from grid search.
print("\nThe Best Hyperparameters are ", best_hyperparameters)
```

```
Training the NNet model with learning rate=0.01 and hidden_neurons=10
The validation accuracy = 67.73%

Training the NNet model with learning rate=0.01 and hidden_neurons=25
The validation accuracy = 68.15%

Training the NNet model with learning rate=0.01 and hidden_neurons=50
The validation accuracy = 69.98%

Training the NNet model with learning rate=0.01 and hidden_neurons=100
The validation accuracy = 68.22%

Training the NNet model with learning rate=0.01 and hidden_neurons=200
The validation accuracy = 68.61%

Training the NNet model with learning rate=0.1 and hidden_neurons=10
The validation accuracy = 74.89%

Training the NNet model with learning rate=0.1 and hidden_neurons=25
The validation accuracy = 74.89%

Training the NNet model with learning rate=0.1 and hidden_neurons=50
The validation accuracy = 75.10%

Training the NNet model with learning rate=0.1 and hidden_neurons=100
The validation accuracy = 75.18%

Training the NNet model with learning rate=0.1 and hidden_neurons=200
The validation accuracy = 75.88%

Training the NNet model with learning rate=0.2 and hidden_neurons=10
The validation accuracy = 75.27%

Training the NNet model with learning rate=0.2 and hidden_neurons=25
The validation accuracy = 76.19%

Training the NNet model with learning rate=0.2 and hidden_neurons=50
The validation accuracy = 76.86%

Training the NNet model with learning rate=0.2 and hidden_neurons=100
The validation accuracy = 76.97%

Training the NNet model with learning rate=0.2 and hidden_neurons=200
The validation accuracy = 78.32%

Training the NNet model with learning rate=0.3 and hidden_neurons=10
The validation accuracy = 77.48%

Training the NNet model with learning rate=0.3 and hidden_neurons=25
The validation accuracy = 78.12%

Training the NNet model with learning rate=0.3 and hidden_neurons=50
The validation accuracy = 78.29%

Training the NNet model with learning rate=0.3 and hidden_neurons=100
The validation accuracy = 73.21%

Training the NNet model with learning rate=0.3 and hidden_neurons=200
The validation accuracy = 75.07%

The Best Hyperparameters are  {'learning_rate': 0.2, 'hidden_neurons': 200}
```

In [38]:
```
# Check the best combination of hyperparameters.
print(best_hyperparameters)
```

```
best_learning_rate = best_hyperparameters['learning_rate']
best_hidden_neurons = best_hyperparameters['hidden_neurons']

print(best_learning_rate)
print(best_hidden_neurons)
```

```
{'learning_rate': 0.2, 'hidden_neurons': 200}
0.2
200
```

In [39]:
```
# Check the loss values from the best model.
train_loss_for_plotting
```

Out[39]:
```
[tensor(0.7019, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6946, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6899, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6858, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6819, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6783, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6748, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6714, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6682, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6652, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6622, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6593, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6566, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6540, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6514, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6490, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6466, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6443, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6421, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6400, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6379, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6359, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6340, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6321, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6303, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6286, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6269, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6253, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6237, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6222, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6207, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6193, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6179, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6166, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6153, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6141, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6129, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6117, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6105, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6094, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6084, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6073, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6063, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6053, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6044, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6035, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6025, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6017, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6008, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.6000, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5992, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5984, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5976, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5968, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5961, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5953, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5946, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5939, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5932, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5925, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5919, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5912, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5906, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5899, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5893, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5887, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5881, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5875, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5869, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5863, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5857, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5852, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5846, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5841, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5835, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5830, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5824, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5819, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5814, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5808, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5803, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5798, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5793, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5788, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5783, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5777, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5772, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5767, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5763, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5758, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5753, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5748, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5743, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5738, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5733, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5729, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5724, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5719, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5714, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5710, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5705, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5700, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5696, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5691, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5687, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5682, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5677, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5673, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5668, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5664, grad_fn=<BinaryCrossEntropyBackward0>),
 tensor(0.5659, grad_fn=<BinaryCrossEntropyBackward0>),
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```

In [40]:
```
# Convert from Tensor to list to plot using seaborn.
train_loss_for_plotting = [tensor_item.item() for tensor_item in train_loss_for_plotting]
vali_loss_for_plotting = [tensor_item.item() for tensor_item in vali_loss_for_plotting]
print(type(train_loss_for_plotting))
print(type(vali_loss_for_plotting))

# Create a numpy list for epochs which starts from 1 and ends with  1000.
Epochs = np.arange(1, number_of_epochs + 1)
type(Epochs)
```

```
<class 'list'>
<class 'list'>
```

Out[40]:
```
numpy.ndarray
```

Model evaluation

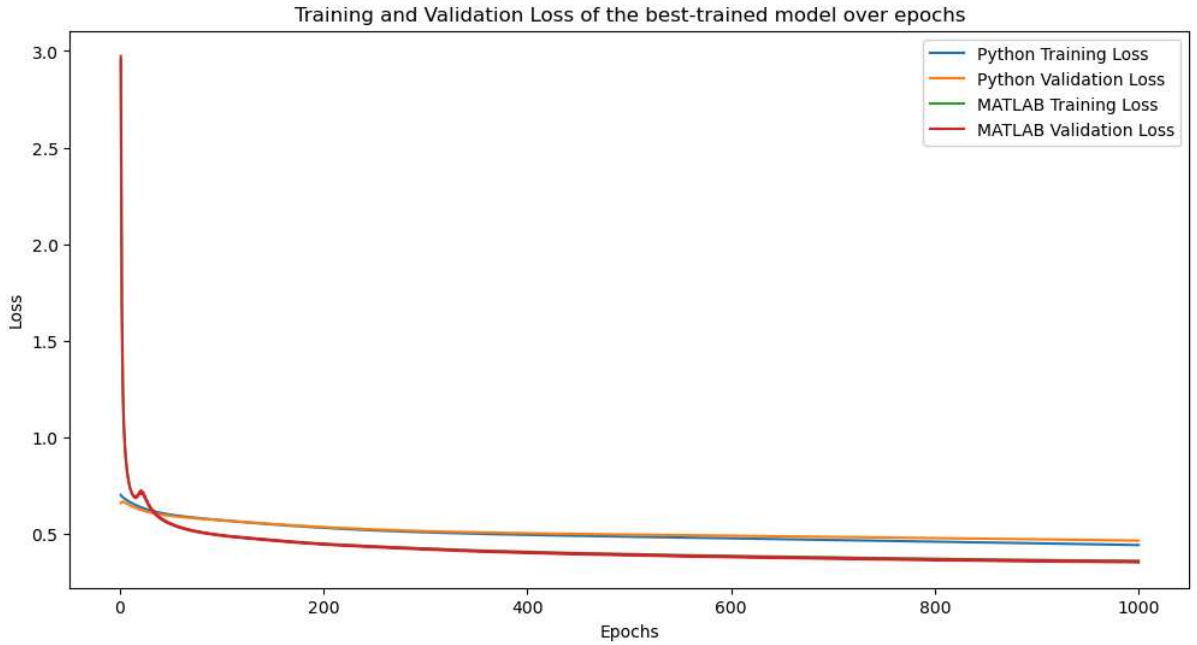
In [41]:
```
# Import the recorded performance from MATLAB to plot in Python.
import csv
with open('matlab_training_time_bestmodel.csv', 'r') as file1:
    reader1 = csv.reader(file1)
    matlab_training_time_bestmodel = np.array(list(reader1), dtype=float)

with open('matlab_train_loss_for_plotting.csv', 'r') as file2:
    reader2 = csv.reader(file2)
    matlab_train_loss_for_plotting = np.array(list(reader2), dtype=float)

with open('matlab_vali_loss_for_plotting.csv', 'r') as file3:
    reader3 = csv.reader(file3)
    matlab_vali_loss_for_plotting = np.array(list(reader3), dtype=float)
```

In [42]:
```
# Change the nested list to flat lists
matlab_training_time_bestmodel = matlab_training_time_bestmodel.tolist()[0]
matlab_train_loss_for_plotting = matlab_train_loss_for_plotting.tolist()[0]
matlab_vali_loss_for_plotting = matlab_vali_loss_for_plotting.tolist()[0]
```

In [43]:
```
# Plot the training time of the model in Python and that of the model in MATLAB.
fig = plt.figure(figsize=(12, 6))
plt.plot(Epochs, train_loss_for_plotting, label='Python Training Loss')
plt.plot(Epochs, vali_loss_for_plotting, label='Python Validation Loss')
plt.plot(Epochs, matlab_train_loss_for_plotting, label='MATLAB Training Loss')
plt.plot(Epochs, matlab_vali_loss_for_plotting, label='MATLAB Validation Loss')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.legend()
plt.title('Training and Validation Loss of the best-trained model over epochs')
plt.show()
```



In [44]:
```
# Since the value in the training time is continuous, it needs to be changed cumulatively.
python_training_time_bestmodel = np.cumsum(python_training_time_bestmodel)

len(python_training_time_bestmodel)
```

Out[44]:
```
1000
```

In [45]:
```
python_training_time_bestmodel
```

Out[45]:
```
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```
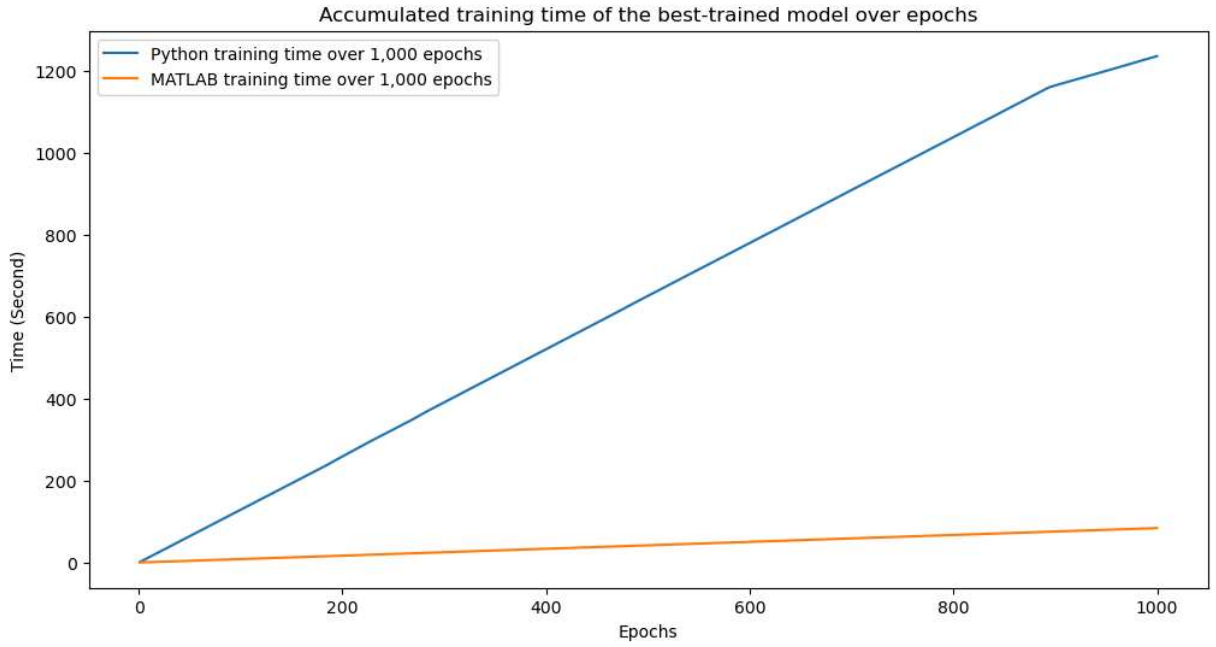
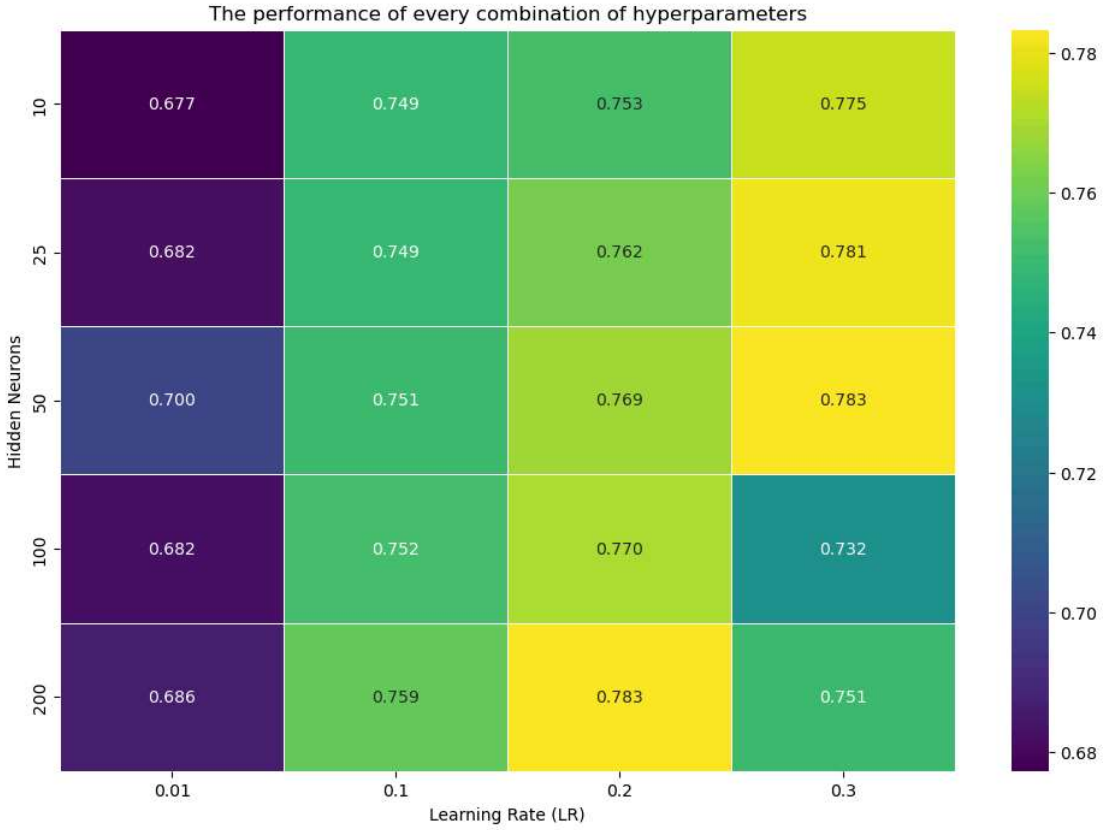

In [46]:
```python
# Plot the loss of the model in Python and that of the model in MATLAB.
fig = plt.figure(figsize=(12, 6))
plt.plot(Epochs, python_training_time_bestmodel, label='Python training time over 1,000 epochs')
plt.plot(Epochs, matlab_training_time_bestmodel, label='MATLAB training time over 1,000 epochs')
plt.xlabel('Epochs')
plt.ylabel('Time (Second)')
plt.legend()
plt.title('Accumulated training time of the best-trained model over epochs')
plt.show()
```



In [47]:
```python
# Combine the lists into a DataFrame
df_for_heatmap = pd.DataFrame({'Learning Rate': learning_rates_list_heatmap, 'Hidden Neurons': hidden_neurons_list_heatmap, 'Accuracy': accuracy_list_heatmap})

# Make a pivot table from the DataFrame to create a matrix which is suitable for a heatmap.
pivoted_heatmap_data = df_for_heatmap.pivot('Hidden Neurons', 'Learning Rate', 'Accuracy')

# Create a heatmap using seaborn.
plt.figure(figsize=(12, 8))
sns.heatmap(pivoted_heatmap_data, annot=True, cmap='viridis', fmt=".3f", linewidths=.5)
plt.title('The performance of every combination of hyperparameters')
plt.xlabel('Learning Rate (LR)')
plt.ylabel('Hidden Neurons')
plt.show()
```



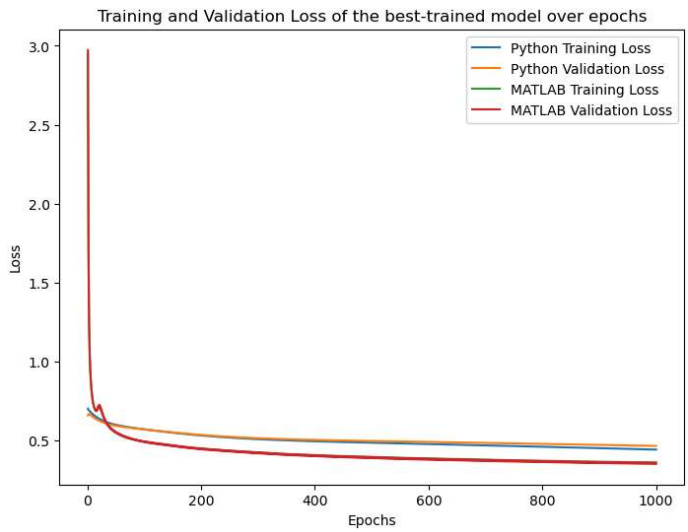
In [53]:
```
# Evaluate the model in Python with the testing set.
best_model.eval()

# Change the predictions into 0 or 1.
y_test_pred =  best_model(X_test)
y_test_pred = y_test_pred.round()

# Calculate the accuracy rate.
accuracy_rate_test_set = (y_test_pred == y_test).float().mean()
accuracy_rate_test_set = float(accuracy_rate_test_set)
accuracy_rate_test_set_python = accuracy_rate_test_set * 100
print("The test accuracy for the best-trained model in Python  =  %.2f%%" % (accuracy_rate_test_set_python))
```

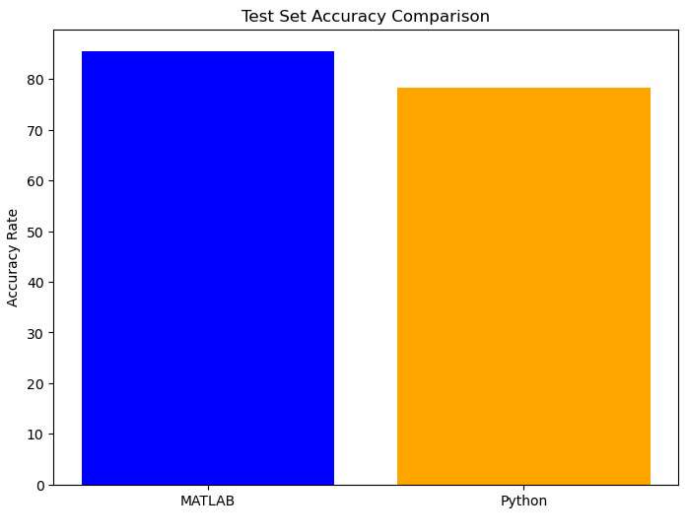
```
The test accuracy for the best-trained model in Python  =  78.22%
```

In [54]:
```
# The accuracy rate of the model in MATLAB.
# This number is derived from MATLAB.
accuracy_rate_test_set_MATLAB = 85.34
print("The test accuracy for the best-trained model in MATLAB  =  %.2f%%" % (accuracy_rate_test_set_MATLAB))
```

```
The test accuracy for the best-trained model in MATLAB  =  85.34%
```

In [50]:
```
# Make one figure for two graphs.
fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(18, 6))

# Line chart about the training loss from the best model in Python and MATLAB.
ax1.plot(Epochs, train_loss_for_plotting, label='Python Training Loss')
ax1.plot(Epochs, vali_loss_for_plotting, label='Python Validation Loss')
ax1.plot(Epochs, matlab_train_loss_for_plotting, label='MATLAB Training Loss')
ax1.plot(Epochs, matlab_vali_loss_for_plotting, label='MATLAB Validation Loss')
ax1.set_xlabel('Epochs')
ax1.set_ylabel('Loss')
ax1.legend()
ax1.set_title('Training and Validation Loss of the best-trained model over epochs')

# Bar graph about the accuracy from the best model in Python and MATLAB.
accuracy_labels = ['MATLAB', 'Python']
accuracy_values = [accuracy_rate_test_set_MATLAB, accuracy_rate_test_set_python]
ax2.bar(accuracy_labels, accuracy_values, color=['blue', 'orange'])
ax2.set_ylabel('Accuracy Rate')
ax2.set_title('Test Set Accuracy Comparison')

plt.show()
```





In [51]:
```
# Calculate = True Positive (TP), True Nagative (TN), False Positive (FP), False Nagative (FN)
TP = ((y_test_pred.round() == 1) & (y_test == 1)).sum().item()
TN = ((y_test_pred.round() == 0) & (y_test == 0)).sum().item()
FP = ((y_test_pred.round() == 1) & (y_test == 0)).sum().item()
FN = ((y_test_pred.round() == 0) & (y_test == 1)).sum().item()

# Calculate the confusion matrix.
# Apart from the accuracy rate, measure Precision, Recall, and F1 score.
precision = TP / (TP + FP) if (TP + FP) > 0 else 0
recall = TP / (TP + FN) if (TP + FN) > 0 else 0
f1 = 2 * (precision * recall) / (precision + recall) if (precision + recall) > 0 else 0

print("Precision of the best-trained model = %.2f%%" % (precision*100))
print("Recall of best-trained model = %.2f%%" % (recall*100))
print("F1 score of best-trained model = %.2f%%" % (f1*100))
```

```
Precision of the best-trained model = 48.78%
Recall of best-trained model = 69.30%
F1 score of best-trained model = 57.26%
```

In [ ]:

In [ ]: