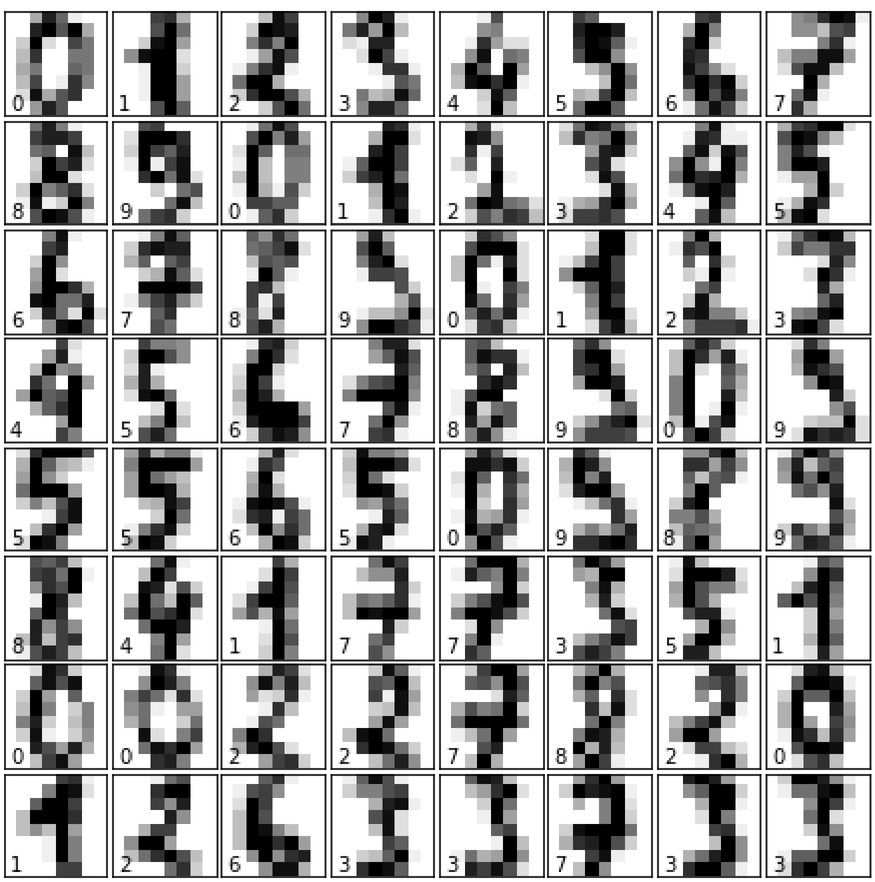
SETTING UP DEPENDENCIES NEEDED

In [2]:
```
#Import data and dependencies
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

from sklearn.datasets import load_digits
from sklearn.model_selection import train_test_split
from sklearn import preprocessing
```

CREATING A VISUALIZATION OF THE DATASET

In [3]:

```
#taken from https://www.datacamp.com/community/tutorials/machine-learning-python
digits = load_digits()

# Import matplotlib
import matplotlib.pyplot as plt

# Figure size (width, height) in inches
fig = plt.figure(figsize=(6, 6))

# Adjust the subplots
fig.subplots_adjust(left=0, right=1, bottom=0, top=1, hspace=0.05, wspace=0.05)

# For each of the 64 images
for i in range(64):
    # Initialize the subplots: add a subplot in the grid of 8 by 8, at the i+1-th position
    ax = fig.add_subplot(8, 8, i + 1, xticks=[], yticks=[])
    # Display an image at the i-th position
    ax.imshow(digits.images[i], cmap=plt.cm.binary, interpolation='nearest')
    # label the image with the target value
    ax.text(0, 7, str(digits.target[i]))

# Show the plot
plt.show()
```



CREATING PRE-PROCESSING DIGITS DATA

In [6]:
```
X = digits['data']
X
```

Out[6]:
```
array([[ 0.,  0.,  5., ...,  0.,  0.,  0.],
       [ 0.,  0.,  0., ..., 10.,  0.,  0.],
       [ 0.,  0.,  0., ..., 16.,  9.,  0.],
       ...,
       [ 0.,  0.,  1., ...,  6.,  0.,  0.],
       [ 0.,  0.,  2., ..., 12.,  0.,  0.],
       [ 0.,  0., 10., ..., 12.,  1.,  0.]])
```

In [7]:
```
X = np.c_[np.ones(digits['data'].shape[0]),X]
```

SPLITTING DATA SET INTO TRAINING AND TESTING DATA SETS

In [633]:
```
#Splitting Data Set into Training and Testing Data Sets
X_train, X_test, y_train, y_test = train_test_split(X, digits['target'],
test_size = .80, random_state = 1)
```

CREATING THE SIGMOID FUNCTION, COST, AND GRADIENT DESCENT FUNCTIONS

In [10]:
```
#creating the sigmoid function for the prediction hypothesis

def sigmoid(z):
    return 1 / (1 + np.exp(-z))
```

In [114]:
```
#Calculating the regularized cost function

def cost_function(X_train, y_train, thetas_array, n, reg):
    prediction = sigmoid(np.dot(X_train,np.transpose(thetas_array)))
    prediction[prediction == 1] = 0.999
    cost = -(np.sum((y_train * np.log(prediction)) + ((1 - y_train) * np
.log(1-prediction)))/n) + ((reg/(2*n))*np.sum(thetas_array[1:]**2))
    return cost
```

In [115]:
```
def gradient_descent(X_train, y_train, alpha, thetas_array,n, reg):
    thetas = thetas_array[1:] - alpha * (((np.dot((sigmoid(np.dot(X_trai
n,np.transpose(thetas_array))) - y_train), X_train[:,1:]))))/n + ((reg/n
)*thetas_array[1:])
    return thetas
```

CREATING THE ONE-VS-ALL FUNCTION FOR

In [607]:
```
def training(X_train, y_train, alpha, iters, reg):
    n = len(X_train)
    thetas_array = np.zeros(65)
    thetas_j = 0
    theta_0 = 0
    cost = []
    #final_thetas = []
    for i in range(iters):
        theta_0 = thetas_array[0] - ((alpha/n)*(np.sum(np.dot(X_train,th
etas_array) - y_train) * 1))
        thetas_j = gradient_descent(X_train, y_train, alpha, thetas_arra
y,n, reg)
        thetas_array = np.insert(thetas_j, 0, theta_0)
        cost.append(cost_function(X_train, y_train, thetas_array, n, reg
))
    #final_thetas.append(thetas_array)

    #Plot cost function error per iteration
    """x = np.arange(0, len(cost), step=1)
    plt.plot(x, cost, "-b", label="Cost Function Curve")
    plt.title("Learning Curve")
    plt.xlabel("Number Of Iterations")
    plt.ylabel("Cost Function Value")
    plt.legend()
    plt.show()"""

    return thetas_array, cost
```

In [624]:
```
def one_vs_all(X_train, y_train, alpha, iters, reg):
    cost = []
    thetas_i = []
    for i in range(len(digits['target_names'])):
        thetas_i.append(training(X_train, np.where(y_train==i,1,0), alph
a, iters, reg)[0])
        cost.append(training(X_train, np.where(y_train==i,1,0), alpha, i
ters, reg)[1])

    return np.array(thetas_i), np.array(cost)
```

In [625]:
```
one_vs_all(X_train, y_train, .001, 1000, .08)
```

Out[625]:
```
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         -8.94011603e-02, -3.87765466e-02, -4.21101941e-03,
         -9.99696592e-05, -2.38004912e-02, -9.07233286e-03,
         -2.65147094e-02,  1.16204230e-02,  3.98905142e-02,
         -2.90055917e-02, -3.31653156e-03, -3.58844316e-05,
          8.37994303e-03, -2.01334339e-03, -5.38649951e-02,
         -9.17960627e-02,  7.76863714e-02,  5.57654613e-03,
         -6.78008531e-04,  0.00000000e+00,  2.67664589e-02,
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```

```
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        -3.91590830e-02,  3.44661910e-02, -7.22911214e-02,
        -7.52393949e-02, -1.12113202e-02],
       [ 4.24764117e+00,  0.00000000e+00, -8.18174019e-03,
        -4.09195720e-02, -4.35970689e-02, -7.41376448e-02,
        -1.33645074e-01, -1.82026270e-02,  1.73239021e-02,
        -6.95179904e-05, -2.76610087e-02,  6.35486175e-03,
        -5.85164146e-02, -2.29702256e-02, -3.12872853e-02,
        -1.10787067e-02,  1.21706338e-02, -9.37735306e-05,
        -1.78904633e-02,  2.50172087e-02, -3.19416060e-02,
        -2.51705549e-02,  9.30578250e-02,  3.24325235e-02,
         4.97862446e-04,  0.00000000e+00, -2.53395300e-02,
         2.27420709e-02,  5.19726582e-02,  5.05984836e-02,
         1.41021763e-01,  2.93056563e-02,  0.00000000e+00,
         0.00000000e+00, -7.90698608e-02, -8.45924803e-02,
         3.15301727e-02, -1.10086972e-01, -1.08496963e-02,
         2.44155282e-02,  0.00000000e+00,  0.00000000e+00,
        -2.69255207e-02, -1.68336073e-01, -1.33552549e-01,
        -1.28204324e-01, -3.31004469e-02,  9.95908327e-04,
        -6.15246856e-04,  0.00000000e+00, -5.84926944e-03,
        -2.38770588e-02, -8.67004826e-02, -9.99042582e-02,
        -7.30864267e-02,  1.76451747e-02, -3.12369353e-03,
         0.00000000e+00, -7.86374229e-03, -4.81988679e-02,
        -6.01906578e-02, -1.12998313e-02, -1.92764864e-03,
        -2.53774864e-02, -5.00346649e-03]]),
 array([[0.43484911, 0.38524676, 0.36393725, ..., 0.02068795, 0.0206784
8,
        0.02066902],
       [0.39396703, 0.3406495 , 0.32121488, ..., 0.08884629, 0.0888460
1,
        0.08884578],
       [0.39419662, 0.33923507, 0.31791476, ..., 0.027304  , 0.0272837
7,
```
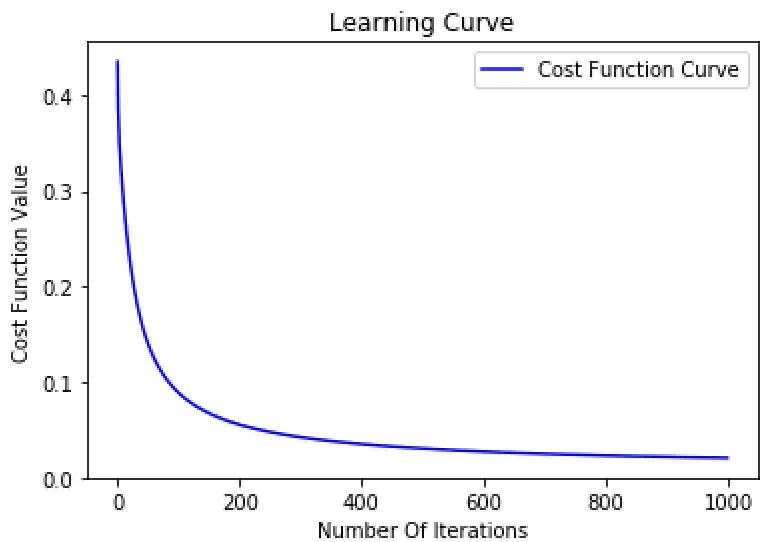

```
         0.02726357],
        ...,
        [0.3995314 , 0.34496806, 0.32324576, ..., 0.01944164, 0.0194258
1,
         0.01941   ],
        [0.43774161, 0.39519345, 0.3813745 , ..., 0.12302737, 0.1229978
2,
         0.12296833],
        [0.36665805, 0.30788297, 0.28634522, ..., 0.06140076, 0.0613822
1,
         0.06136372]]))
```

CHECKING IF GRADIENT DESCENT WORKS AS INTENDED

In [626]:
```python
cost = one_vs_all(X_train, y_train, .001, 1000, .08)[1]
x = np.arange(0, len(cost[0]), step=1)
plt.plot(x, cost[0], "-b", label="Cost Function Curve")
plt.title("Learning Curve")
plt.xlabel("Number Of Iterations")
plt.ylabel("Cost Function Value")
plt.legend()
plt.show()
```



CREATING ARRAY OF PREDICTED VALUES

In [628]:
```python
def predict_one_vs_all(X_train, all_thetas):
    prediction = sigmoid(np.dot(X_train,np.transpose(all_thetas)))
    pred_argmax = np.argmax(prediction,axis = 1)
    return pred_argmax
```

In [629]:
```
predict_one_vs_all(X_train, all_thetas)
```

Out[629]:
```
array([4, 2, 4, 6, 0, 7, 8, 1, 3, 3, 8, 9, 4, 9, 7, 1, 0, 0, 6, 7, 4,
9,
       7, 6, 7, 5, 8, 8, 7, 0, 0, 8, 8, 0, 7, 2, 8, 3, 5, 0, 6, 9, 2,
2,
       2, 9, 5, 7, 7, 6, 9, 8, 8, 3, 5, 7, 7, 2, 6, 0, 8, 7, 0, 9, 7,
6,
       7, 4, 3, 0, 5, 0, 0, 6, 5, 8, 0, 1, 4, 1, 2, 4, 7, 5, 0, 7, 0,
4,
       0, 0, 9, 7, 7, 4, 6, 6, 5, 8, 0, 1, 5, 7, 9, 0, 7, 7, 0, 3, 8,
7,
       2, 0, 4, 4, 0, 1, 0, 2, 5, 5, 8, 7, 5, 3, 6, 7, 3, 4, 8, 0, 6,
8,
       8, 7, 2, 0, 9, 3, 7, 8, 6, 3, 7, 9, 8, 0, 3, 7, 6, 8, 0, 0, 8,
5,
       5, 1, 8, 2, 7, 3, 1, 5, 1, 8, 1, 6, 3, 9, 4, 4, 7, 5, 6, 2, 5,
0,
       7, 5, 6, 0, 9, 2, 3, 9, 0, 7, 8, 1, 0, 1, 4, 1, 2, 8, 0, 8, 0,
9,
       0, 1, 5, 5, 3, 6, 2, 4, 0, 1, 0, 0, 3, 3, 2, 5, 3, 8, 1, 3, 7,
0,
       1, 2, 2, 9, 3, 5, 3, 8, 1, 5, 8, 8, 6, 9, 3, 6, 6, 9, 0, 6, 2,
7,
       0, 9, 6, 8, 5, 3, 0, 2, 5, 5, 6, 6, 0, 8, 3, 9, 2, 1, 1, 2, 2,
9,
       2, 1, 7, 5, 2, 5, 0, 2, 8, 5, 1, 7, 6, 8, 3, 7, 1, 2, 9, 9, 6,
5,
       6, 7, 5, 2, 6, 1, 9, 9, 1, 9, 8, 4, 6, 3, 8, 6, 1, 3, 4, 4, 6,
1,
       5, 3, 4, 0, 6, 1, 0, 3, 8, 2, 3, 8, 3, 2, 2, 1, 3, 4, 7, 8, 4,
6,
       4, 5, 2, 2, 1, 0, 2, 6, 9, 0, 4, 3, 7, 8, 8, 8, 3, 4, 1, 4, 6,
5,
       2, 9, 1, 4, 9, 1, 5])
```

CALCULATING THE TRAINING ACCURACY

In [631]:
```
def training_accuracy(X_train, y_train, all_thetas):
    prediction_train = predict_one_vs_all(X_train, all_thetas)
    correct = 0
    incorrect = 0

    for i in range(len(prediction_train)):
        if prediction_train[i] == y_train[i]:
            correct += 1
        else:
            incorrect += 1
    accuracy = round((correct/len(prediction_train)) * 100, 2)
    print(f'Training Accuracy: {accuracy}%')
    #return correct
```

In [632]:
```
training_accuracy(X_train, y_train, all_thetas)
```

```
Training Accuracy: 96.94%
```

CALCULATIN THE TESTING ACCURACY

In [635]:
```
def test_accuracy(X_test, y_test, all_thetas):
    prediction_train = predict_one_vs_all(X_test, all_thetas)
    correct = 0
    incorrect = 0

    for i in range(len(prediction_train)):
        if prediction_train[i] == y_test[i]:
            correct += 1
        else:
            incorrect += 1
    accuracy = round((correct/len(prediction_train)) * 100, 2)
    print(f'Training Accuracy: {accuracy}%')
```

In [636]:
```
test_accuracy(X_test, y_test, all_thetas)
```

```
Training Accuracy: 92.84%
```

In [ ]:
```

```