Importing required libraries

```
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D
import pandas as pd
import numpy as np
from datetime import datetime
```

Sampling 1 million data points

importing the sampled data

```
train_df = pd.read_csv('q2train.csv')
train_df.describe()
```

| | X_1 | X_2 | error | Y |
|---|---|---|---|---|
| count | 1000000.000000 | 1000000.000000 | 1000000.000000 | 1000000.000000 |
| mean | 3.001920 | -1.002969 | 0.000988 | 3.996970 |
| std | 1.999661 | 1.999670 | 1.414039 | 4.687888 |
| min | -7.362117 | -11.048858 | -6.718731 | -17.936119 |
| 25% | 1.653318 | -2.352003 | -0.954292 | 0.832440 |
| 50% | 3.000204 | -1.002240 | -0.000541 | 3.994005 |
| 75% | 4.351186 | 0.344908 | 0.954976 | 7.157533 |
| max | 12.266605 | 8.495347 | 6.786142 | 27.296368 |

Plotting the data points on a 3D plane

```
# fig = plt.figure()
# ax = fig.add_subplot(projection='3d')

# x_1 = train_df["X_1"]
# x_2 = train_df["X_2"]
# y = train_df["Y"]
# ax.scatter(x_1, x_2, y, marker='o')

# ax.set_xlabel('x_1')
# ax.set_ylabel('x_2')
# ax.set_zlabel('y')

# plt.show()
```

Stochastic Gradient Descent

```
eta = 0.001

sliding_win_size = 10
gamma = 3

theta = np.zeros((3,1))

gamma_count = 0
m = train_df["X_1"].count()
```

```
r = 1000000

phi = 0.000001

print("Learning rate: ", eta)
print("Batch size: ", r)
```

```
Learning rate:  0.001
Batch size:  1000000
```

Stopping criterion

```
def convergence(J_theta_mov_avg_t_1,J_theta_mov_avg_t, gamma):
    global gamma_count
    global phi

    # print("converge criteria ",abs(J_theta_mov_avg_t_1 -
J_theta_mov_avg_t))
    # print("limit: ",phi)
    if abs(J_theta_mov_avg_t_1 - J_theta_mov_avg_t) < phi:
        gamma_count += 1
    else:
        gamma_count = 0
    if gamma_count >= gamma:
        return True
    else:
        return False
```

Algorithm

```
# For plotting purpose
theta_and_J_theta = []
```

Shuffling the rows to create uniform batches

```
train_sdf = train_df.sample(frac = 1)
curr_block = 0
```

Vector Notation

```
# X = np.hstack(np.array(train_df["X_1"]), np.array(train_df["X_2"]))
a = np.array(train_sdf["X_1"], ndmin=2)
b = np.array(train_sdf["X_2"], ndmin=2)
c = np.ones((m,1))
X = np.hstack((c,a.T,b.T))
print("Shape of X is ",X.shape)
print(X)
```

```
Shape of X is  (1000000, 3)
[[ 1.          5.44783409 -0.36102535]
 [ 1.          3.83119216 -2.27782221]
 [ 1.         -0.20925251 -1.51625447]
```

```
 ...
 [ 1.          4.32553027 -4.13900058]
 [ 1.          1.12212276 -2.91522608]
 [ 1.          2.94265981 -1.10346303]]
```

```
Y = np.array(train_sdf["Y"])
Y.resize(m,1)
print("Shape of Y is ",Y.shape)
print(Y)
```

```
Shape of Y is  (1000000, 1)
[[ 8.86977385]
 [ 1.80740912]
 [ 0.99056358]
 ...
 [-1.6605508 ]
 [-3.35761501]
 [ 3.45998133]]
```

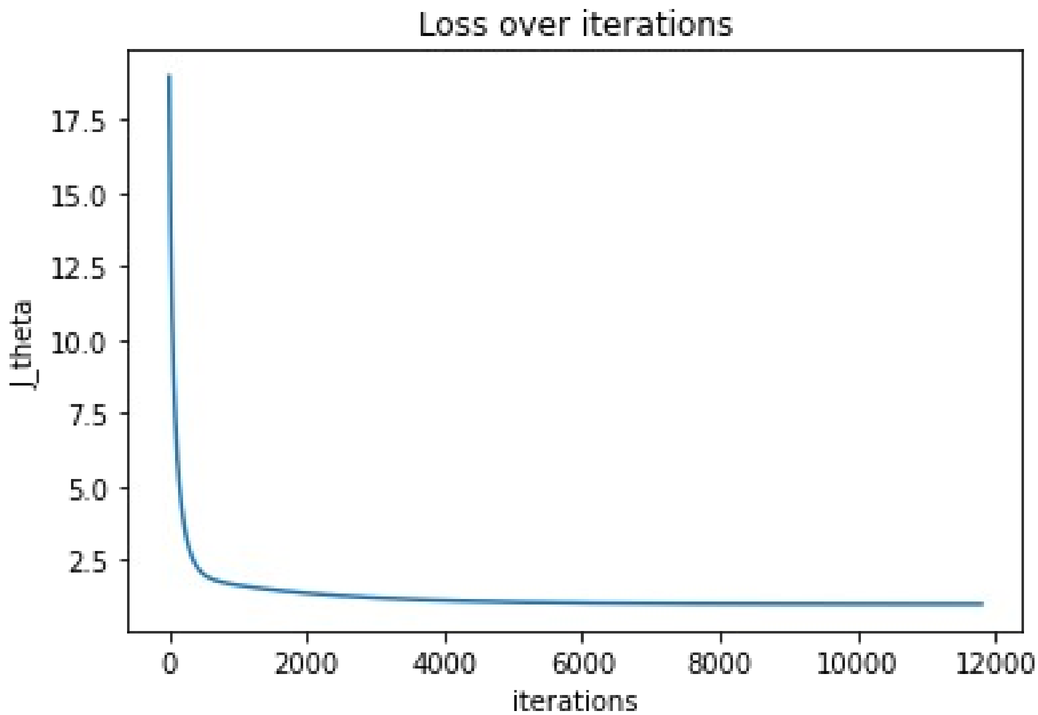
```
count_iterations = 1
J_theta_mov_avg_t = 0
J_theta_mov_avg_t_1 = 0

start = datetime.now()
while(True):
    X_b = X[curr_block*r:(curr_block+1)*r]
    Y_b = Y[curr_block*r:(curr_block+1)*r]

    H_theta = np.matmul(X_b,theta)

    J_theta = np.matmul((Y_b - H_theta).T, (Y_b -
H_theta)).sum()/(2*r)

    grad_J_theta = np.array(((Y_b - H_theta)*(-1)*X_b).sum(axis=0)/r,
ndmin=2)
    grad_J_theta = grad_J_theta.T

    # print("theta ",theta[0][0], theta[1][0], theta[2][0])
    # print("loss ", J_theta)

    theta_and_J_theta.append((theta[0][0], theta[1][0], theta[2][0],
J_theta))

    # No converge check in first "sliding window" phase
    if count_iterations <= sliding_win_size:
        J_theta_mov_avg_t += J_theta
        if count_iterations == sliding_win_size:
            J_theta_mov_avg_t /= sliding_win_size

    # Moving average for the first time
```

```
    if count_iterations == sliding_win_size+1:
        J_theta_mov_avg_t_1 = (J_theta_mov_avg_t*(sliding_win_size-1)+
J_theta)/(sliding_win_size)

    # Convergence after "sliding window + 1" iterations
    if count_iterations > sliding_win_size+1:
        J_theta_mov_avg_t = J_theta_mov_avg_t_1
        J_theta_mov_avg_t_1 = (J_theta_mov_avg_t*(sliding_win_size-1)+
J_theta)/(sliding_win_size)
        if convergence(J_theta_mov_avg_t_1,J_theta_mov_avg_t, gamma):
            break

    theta = theta - (eta*grad_J_theta)

    curr_block = (curr_block+1)%(m//r)

    count_iterations += 1
    if(count_iterations%3000==0):
        print(str(count_iterations)+" Iterations over ,"+"theta =
",theta.T)

end = datetime.now()
td = (end - start).total_seconds() * (10**3)
```

```
3000 Iterations over ,theta =  [[1.76953219 1.26879081 1.91028187]]
6000 Iterations over ,theta =  [[2.45637179 1.11877277 1.96029964]]
9000 Iterations over ,theta =  [[2.76070615 1.05229882 1.98245655]]
```

Loss curve

```
zs = [theta_and_J_theta[i][3] for i in range(len(theta_and_J_theta))]
t = [i for i in range(len(theta_and_J_theta))]
fig2 = plt.figure()
plt.plot(t,zs)
plt.title("Loss over iterations")
plt.ylabel("J_theta")
plt.xlabel("iterations")
plt.show()
```




Final Theta values

```
print("Theta: ",theta)

Theta:  [[2.88963331]
 [1.02413802]
 [1.99184302]]
```

Number of iterations

```
print("count iterations: ", count_iterations)

count iterations:  11802
```

Time Taken

```
print(f"The time of execution of above program is {td:.03f} ms")

The time of execution of above program is 916911.383 ms

# Loop implementation (not the vector implementation)

# while(True):
#     J_theta = 0.0
#     grad_J_theta = np.array([0.0,0.0,0.0])

#     for j in range(r):
#         i = curr_block*r+j
#         x_1i, x_2i, yi = train_sdf["X_1"][i], train_sdf["X_2"][i],
train_sdf["Y"][i]
```

```
#         h_theta_xi = theta[0] + theta[1]*x_1i + theta[2]*x_2i
#         J_theta += ((yi - h_theta_xi)**2)
#         grad_J_theta += (yi - h_theta_xi)*(-1)*np.array([1.0, x_1i, 
x_2i])

#     J_theta /= (2*r)
#     grad_J_theta /= r

#     print("curr block - loss: ",curr_block,J_theta)
#     print("theta = ",theta)

#     #Storing theta and its corresponding J_theta for every iteration
#     theta_and_J_theta.append((theta[0], theta[1], theta[2], 
J_theta))

#     #Stopping criteria
#     if convergence(grad_J_theta):
#         break

#     #Updating parameters
#     theta = theta - (eta*grad_J_theta)

#     #Go to next block
#     curr_block = (curr_block+1)%(m//r)
```

Reading test data from file

```
test_df = pd.read_csv('/home/tkarthikeyan/IIT Delhi/COL774-Machine 
Learning/Assignment 1/ass1_data/data/q2/q2test.csv')
```

Describing the dataframe

```
test_df.describe()
```

| | X_1 | X_2 | Y |
|---|---|---|---|
| count | 10000.000000 | 10000.000000 | 10000.000000 |
| mean | 1.177548 | -1.083901 | 2.015905 |
| std | 10.003417 | 10.037702 | 22.447849 |
| min | -34.302000 | -44.929000 | -86.309000 |
| 25% | -5.545000 | -7.788750 | -13.087500 |
| 50% | 1.139500 | -1.163500 | 2.087000 |
| 75% | 7.972750 | 5.499500 | 16.907000 |
| max | 40.044000 | 35.402000 | 81.121000 |

```
test_df
```

| | X_1 | X_2 | Y |
|---|---|---|---|
| 0 | 16.678 | 13.018 | 45.537 |
| 1 | 6.583 | -5.539 | -1.170 |
| 2 | -19.837 | 6.089 | -3.646 |
| 3 | -8.412 | 6.110 | 8.137 |

```
4       1.052  11.595  25.781
...       ...     ...     ...
9995   -1.476  16.595  31.906
9996    0.203  26.920  58.418
9997    6.381   2.484  13.018
9998    3.138  -5.425  -6.873
9999    5.502  -8.332  -7.749

[10000 rows x 3 columns]
```

Test data in the vector form

```
n = len(test_df["X_1"])
at = np.array(test_df["X_1"], ndmin=2)
bt = np.array(test_df["X_2"], ndmin=2)
ct = np.ones((n,1))
Xtest = np.hstack((ct,at.T,bt.T))
Ytest = np.array(test_df["Y"], ndmin=2)
print(Xtest)

[[  1.     16.678  13.018]
 [  1.      6.583  -5.539]
 [  1.    -19.837   6.089]
 ...
 [  1.      6.381   2.484]
 [  1.      3.138  -5.425]
 [  1.      5.502  -8.332]]
```

Computing the Mean Square error with test data

```
H_theta = Ytest.T - np.matmul(Xtest,theta)
(1/n)*np.matmul(H_theta.T,H_theta)

array([[2.03702316]])
```

Final Theta values

```
theta

array([[2.88963331],
       [1.02413802],
       [1.99184302]])
```

Computing the Mean Square error with original hypothesis

```
theta = np.array([[3],[1],[2]])

H_theta = Ytest.T - np.matmul(Xtest,theta)
(1/n)*np.matmul(H_theta.T,H_theta)

array([[1.96589384]])
```

Movement of theta over time

```
%matplotlib notebook

fig = plt.figure()
ax = fig.add_subplot(projection='3d')

xs = [theta_and_J_theta[i][0] for i in
range(0,len(theta_and_J_theta),5)]
ys = [theta_and_J_theta[i][1] for i in
range(0,len(theta_and_J_theta),5)]
zs = [theta_and_J_theta[i][2] for i in
range(0,len(theta_and_J_theta),5)]
ax.scatter(xs[1:-1], ys[1:-1], zs[1:-1], marker='o')
ax.scatter(xs[-1], ys[-1], zs[-1], marker='*',s=100, color="red")
ax.scatter(xs[0], ys[0], zs[0], marker='*',s=100,color="green")

ax.set_xlabel('theta_0')
ax.set_ylabel('theta_1')
ax.set_zlabel('theta_2')
plt.savefig("3d_plot_"+str(r)+".png")
plt.show()
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.HTML object>
```