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 = 100

phi = 0.001

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

```
Learning rate:  0.001
Batch size:  100
```

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.         -1.334731    1.71251307]
 [ 1.          4.92093111  0.13817789]
 [ 1.          0.78640769  0.1903004 ]
```

```
 ...
 [ 1.          3.57024884 -2.83111976]
 [ 1.          4.26440257 -2.81759698]
 [ 1.         -0.08364802 -2.84191098]]
```

```
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)
[[ 4.79358205]
 [ 9.42420567]
 [ 3.32127815]
 ...
 [ 1.54662435]
 [ 0.55376185]
 [-3.77780321]]
```

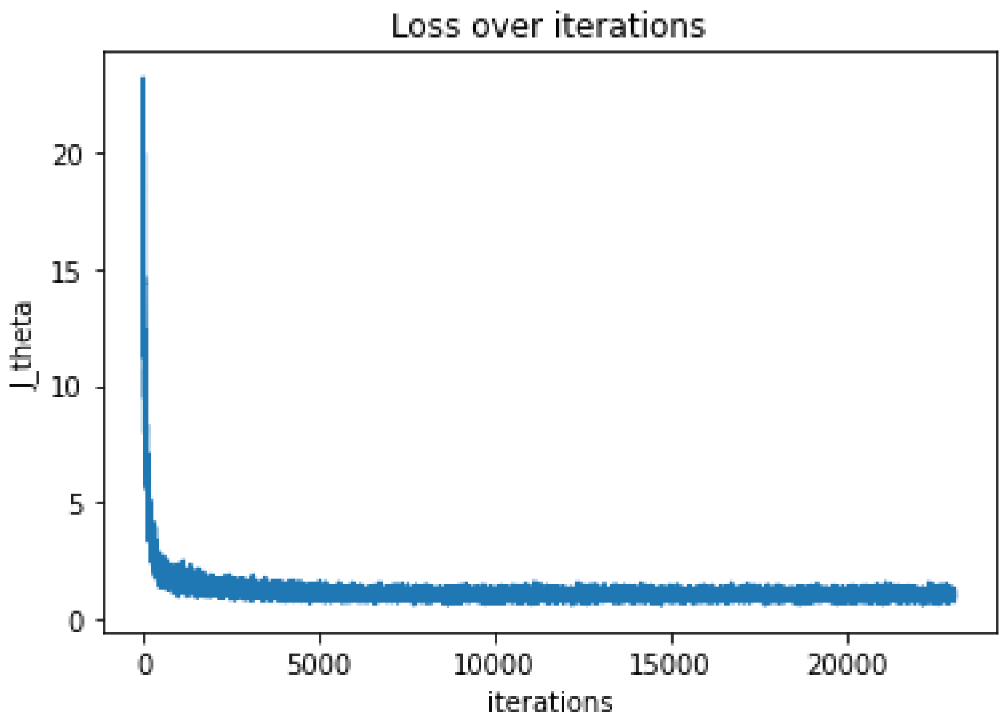
```
count_iterations = 1
J_theta_mov_avg_t = 0
J_theta_mov_avg_t_1 = 0

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%1000==0):
        print(str(count_iterations)+" Iterations over")

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

```
1000 Iterations over
2000 Iterations over
3000 Iterations over
4000 Iterations over
5000 Iterations over
6000 Iterations over
7000 Iterations over
8000 Iterations over
9000 Iterations over
10000 Iterations over
11000 Iterations over
12000 Iterations over
13000 Iterations over
14000 Iterations over
15000 Iterations over
16000 Iterations over
17000 Iterations over
18000 Iterations over
19000 Iterations over
20000 Iterations over
21000 Iterations over
22000 Iterations over
23000 Iterations over
```

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:  [[2.99283814]
 [1.00084866]
 [2.00248258]]
```

Number of iterations

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

count iterations:  23107
```

Time Taken

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

The time of execution of above program is 723.384 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([[1.96596322]])
```

Final Theta values

```
theta
```

```
array([[2.99283814],
       [1.00084866],
       [2.00248258]])
```

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>
```