

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 = 10000

phi = 0.0002

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

```

```

Learning rate: 0.001
Batch size: 10000

```

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.          3.11523232 -1.13824052]
 [ 1.          3.49666555 -1.36485065]
 [ 1.          5.44697585 -0.96456964]

```

```

...
[ 1.          2.95771407 -0.54467034]
[ 1.          0.84377141 -1.1472089 ]
[ 1.          4.2693262  -3.24936437]]

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)
[[5.51633075]
 [4.52657781]
 [7.10396237]
 ...
 [3.97045431]
 [1.31683526]
 [1.03912059]]

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%10000==0):
        print(str(count_iterations)+" Iterations over ,"+"theta =
",theta.T,abs(J_theta_mov_avg_t_1 - J_theta_mov_avg_t))

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

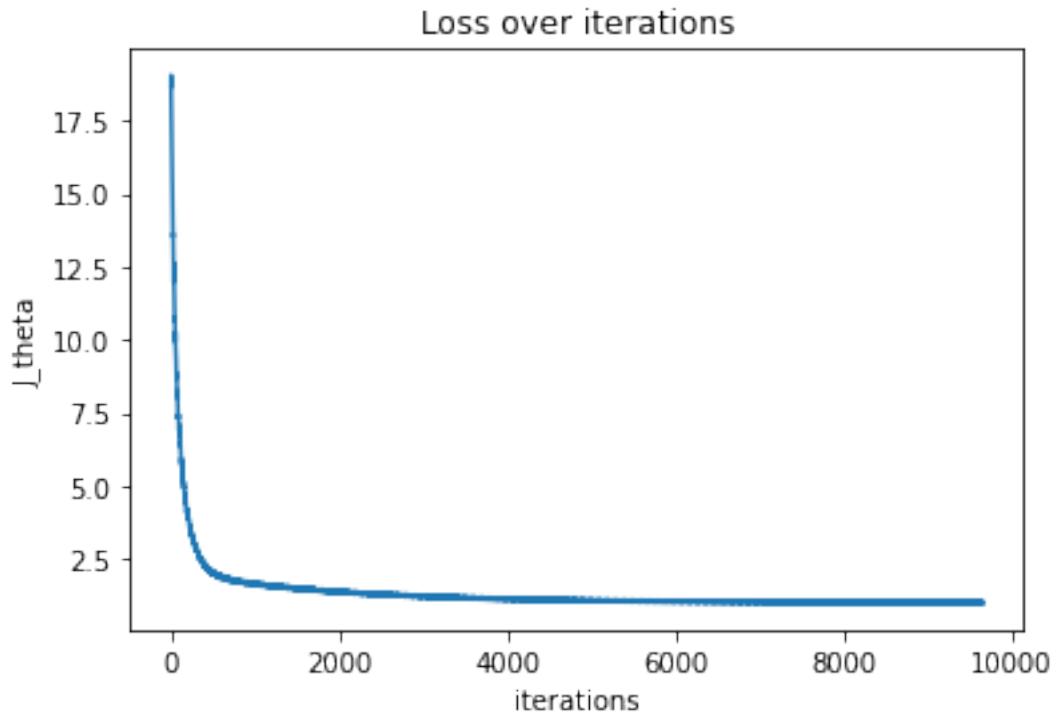
```

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:  [[2.80072196]
 [1.0437344 ]
 [1.98525517]]
```

Number of iterations

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

```
count iterations: 9665
```

Time Taken

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

```
The time of execution of above program is 7057.081 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([[2.19821553]])

```

Final Theta values

```

theta

array([[2.80072196],
       [1.0437344 ],
       [1.98525517]])

```

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>
```