

CS 7267- HW 2

Intro. Open file and Set matrix

```
import csv
import numpy as np
import numpy.linalg as lin
import matplotlib.pyplot as plt

#Open file and set matrix
tmpfile = open("MNIST_training.csv", "rt", encoding='utf-8')
trn = np.array(list(csv.reader(tmpfile)))
trnY = np.transpose(np.matrix(np.array(trn[1:, 0], dtype=int)))
trnX = np.array(trn[1:, :], dtype=int)
trnX[0:, 0] = 1 #set 0-th column value 1 for intercept

tmpfile = open("MNIST_test.csv", "rt", encoding='utf-8')
tst = np.array(list(csv.reader(tmpfile)))
tstY = np.transpose(np.matrix(np.array(tst[1:, 0], dtype=int)))
tstX = np.array(tst[1:, :], dtype=int)
tstX[0:, 0] = 1 #set 0-th column value 1 for intercept
```

To make trnY and tstY vector(column), I applied np.array and np.matrix and then np.transpose.

trnY is labels of training data.

trnX is features of training data.

tstY is labels of test data.

tstX is features of test data.

For intercept, I put 0-th column value 1.

Task 1. Classifying MNIST data

1. Train a linear regression model

Here is a function to get optimal coefficient by the equation: $b_{opt} = (X'X)^{-1}X'y$

```
# Get optimal coefficient
def getOptCoef(X,y) :
    Xt = np.transpose(X)
    optCoef = np.array(np.dot(np.dot(lin.pinv(np.dot(Xt, X)),Xt),y), dtype=float)
    return optCoef
```

2. Display the optimal coefficients (denoted by b_opt)

```
# Display the optimal coefficients (denoted by b_opt)
b_opt = getOptCoef(trnX,trnY)
print(b_opt)
```

OUTPUT : [Appendix \(1\) b_opt](#)

3. Classify test data (MNIST_test.csv) with a threshold of 0.5.

```
def binaryClassification(X, coef, threshold):
    y_pred = np.dot(X, coef)
    y_pred[y_pred > threshold] = 1
    y_pred[y_pred <= threshold] = 0
    return y_pred

y_pred = binaryClassification(tstX, b_opt, 0.5)
print(y_pred)
```

4. Display the accuracy

```
# Display the accuracy
Accuracy = (np.sum(y_pred == tstY))/len(tstY)
Accuracy
```

OUTPUT : 0.9799999999999998

Task 2. Implementation of Gradient Descent

1. Set the initial coefficient to zeros

```
b_est = np.zeros((len(trnX[0]), 1), dtype=float)
```

2. Determine hyper-parameters such as learning rate and iteration numbers

```
iteration = 50
learningRate = 0.000000003
sqError = np.zeros((iteration, 1), dtype=float)
```

3. Run "gradient descent" algorithm with the hyper-parameters and check "Learning Curve"

Learning curve shows whether it converges or not.

```
# Get estimated coefficient by Gradient Descend
def getGDcoef(coef, X, y, sqError, iteration, learningRate):
    Xt = np.transpose(X)
    for i in range(iteration):
        coef = coef - learningRate*(np.dot(np.dot(Xt,X), coef) - np.dot(Xt, y))
        sqError[i] = np.dot((np.transpose(y-np.dot(X, coef))), (y-np.dot(X, coef)))
    return coef

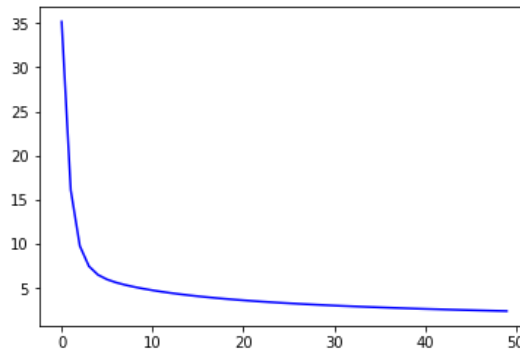
b_est = getGDcoef(b_est, trnX, trnY, sqError, iteration, learningRate)
```

The equation to get squared error: $J(b) = (y - Xb)'(y - Xb)$

Its gradient : $J'(b) = 2X'Xb - 2X'y$

In function getGDcoef(), it iterates { $\text{coef} = \text{coef} - J'(\text{coef})$ } until sqError(in other words, $J(\text{coef})$) is small enough.

```
# Check "Learning Curve"
print(sqError)
plt.plot(sqError, 'b-')
plt.show()
```



X-axis shows iteration, while y-axis shows cost.

OUTPUT of `print(sqError)` is on [Appendix \(2\) sqError](#) .

4. Display the optimal coefficients (denoted by `b_est`)

```
print(b_est)
```

OUTPUT : [Appendix \(3\) b_est](#) .

5. Classify test data (MNIST_test.csv) with a threshold of 0.5.

```
y_pred = binaryClassification(tstX, b_est, 0.5)
```

6. Display the accuracy

```
Accuracy = (np.sum(y_pred == tstY))/len(tstY)
print(Accuracy)
```

OUTPUT : 0.995

7. Display the total differences between `b_opt` and `b_est`

```
print(np.sum(np.abs(b_opt-b_est)))
```

OUTPUT : 0.0714927920412

Appendix

(1) b_opt

1. [[2.40400867e-05]
2. [-2.98266748e-15]
3. [1.25086097e-15]
4. [-2.00861170e-15]
5. [-1.19882534e-15]
6. [-1.79077110e-15]
7. [-7.02848199e-16]
8. [-1.86322444e-16]
9. [-3.27597648e-17]
10. [1.74581061e-15]
11. [2.52648588e-15]
12. [-3.76145751e-17]
13. [7.31453519e-16]
14. [-1.03854769e-16]
15. [-1.14091279e-15]
16. [-2.67291328e-15]
17. [-5.14460992e-16]
18. [-3.92841985e-17]
19. [-2.09386174e-17]
20. [-8.65017868e-17]
21. [4.66594705e-17]
22. [1.97129654e-16]
23. [-8.15227980e-17]
24. [3.13899657e-17]
25. [2.23349979e-18]
26. [4.48578379e-17]
27. [9.67890693e-17]
28. [-1.37310969e-17]
29. [2.46165350e-17]
30. [3.37096765e-17]
31. [-3.23305903e-17]
32. [5.76680288e-17]
33. [6.93970716e-17]
34. [3.36287512e-17]
35. [-2.81628282e-18]
36. [9.63685388e-18]
37. [-1.81824261e-17]
38. [1.90526527e-17]
39. [1.12487028e-18]
40. [9.55390051e-18]
41. [1.12379865e-17]
42. [-8.50999968e-18]
43. [1.32805781e-17]
44. [-1.59204172e-17]
45. [-5.62603886e-18]
46. [-1.08690808e-17]
47. [8.37056251e-18]
48. [1.01888503e-17]
49. [2.62563189e-17]
50. [-2.32905674e-17]
51. [-4.35581746e-17]
52. [4.19752866e-17]
53. [1.14534371e-17]
54. [-4.21925261e-17]
55. [-4.96499596e-19]
56. [5.53383321e-18]
57. [-7.20235719e-18]
58. [-8.87874297e-18]
59. [1.22156220e-17]
60. [-5.04421022e-19]
61. [-2.18976338e-17]
62. [-1.19058174e-17]
63. [-1.14492800e-17]
64. [7.18975395e-18]
65. [2.22618542e-17]
66. [6.28883000e-18]
67. [-6.96754891e-18]
68. [-6.33667822e-18]
69. [1.72017169e-05]
70. [1.72017169e-05]
71. [-4.40860885e-18]
72. [-1.16174489e-18]
73. [-9.94248509e-18]
74. [-1.25722225e-17]
75. [-1.31671056e-17]
76. [-7.16389771e-18]
77. [6.63768416e-18]
78. [6.84333240e-19]
79. [-2.07283547e-19]
80. [3.75287825e-18]
81. [4.38213947e-18]
82. [7.22992851e-18]
83. [5.59099856e-18]
84. [-2.09027222e-18]
85. [-2.80919449e-18]
86. [3.99813166e-18]
87. [-8.30773882e-18]
88. [-1.97869890e-18]
89. [3.21457971e-18]
90. [-4.73011558e-18]
91. [-4.82695155e-18]
92. [8.72914007e-18]
93. [2.63903647e-18]
94. [1.17311167e-17]
95. [-1.41175845e-18]
96. [6.72194365e-18]
97. [2.29656430e-05]
98. [2.29656430e-05]
99. [4.36276120e-05]
100. [1.92848033e-04]
101. [3.35856247e-04]
102. [3.35347938e-05]
103. [-8.04597284e-05]
104. [4.76007231e-05]
105. [1.16713311e-04]
106. [5.40085127e-05]
107. [-2.71975827e-18]
108. [7.26273503e-18]
109. [8.53688337e-18]
110. [1.20068123e-19]
111. [1.34100204e-17]
112. [-1.24994378e-18]
113. [-3.23710062e-18]
114. [-4.88230821e-18]
115. [3.60192462e-18]
116. [-3.26035991e-18]
117. [-2.65281400e-18]
118. [-2.20048757e-18]
119. [4.17993971e-05]
120. [9.19586737e-06]
121. [5.45688535e-18]
122. [2.88291350e-06]
123. [4.77694209e-05]
124. [3.99847697e-05]
125. [3.21603548e-04]
126. [3.50777153e-05]
127. [-2.83793667e-04]
128. [-2.19771577e-04]
129. [2.34289705e-04]
130. [-1.13022431e-04]
131. [-1.99635808e-04]
132. [-5.11785156e-05]
133. [-3.62496339e-04]
134. [1.87666793e-04]
135. [-5.09287960e-05]
136. [-1.25207169e-04]
137. [4.14240885e-05]
138. [1.26699790e-05]
139. [1.49805360e-18]
140. [3.66074207e-18]
141. [-4.49997291e-19]
142. [1.43809527e-18]
143. [1.10778841e-18]
144. [1.72691479e-18]
145. [-3.43593643e-18]
146. [8.74550199e-19]
147. [1.62181661e-04]
148. [1.82245371e-04]
149. [1.47133878e-04]
150. [5.96110730e-05]
151. [-3.47943807e-05]
152. [-1.03034145e-04]
153. [2.32362628e-06]
154. [3.42078027e-04]

155. [2.99963300e-04]	208. [-3.52850501e-05]	261. [-1.98606943e-04]
156. [-2.45800165e-04]	209. [-7.01595773e-05]	262. [5.46527013e-05]
157. [3.10565670e-04]	210. [2.25182694e-04]	263. [-7.00360197e-05]
158. [-2.14006160e-04]	211. [-1.90402512e-04]	264. [6.71383892e-06]
159. [6.34844872e-04]	212. [3.58923930e-04]	265. [1.34522763e-04]
160. [-1.59347826e-04]	213. [7.67921914e-05]	266. [-4.55808956e-04]
161. [1.91123288e-04]	214. [-6.07175025e-04]	267. [3.95544825e-04]
162. [1.46802945e-04]	215. [6.64030733e-04]	268. [4.96706238e-04]
163. [-4.52186187e-06]	216. [-1.60735206e-04]	269. [7.20364407e-05]
164. [-2.11737274e-05]	217. [-2.07529748e-04]	270. [-2.30154531e-05]
165. [-4.20197706e-06]	218. [4.50702849e-05]	271. [4.89823449e-04]
166. [5.95622930e-05]	219. [-3.81301231e-04]	272. [-1.60158758e-04]
167. [-8.66117605e-19]	220. [-3.35942938e-04]	273. [2.19970398e-04]
168. [-3.24310028e-20]	221. [1.99884402e-04]	274. [-4.06010326e-04]
169. [9.37959633e-19]	222. [-3.80290566e-05]	275. [1.20600537e-04]
170. [2.53257199e-19]	223. [0.00000000e+00]	276. [-2.43849594e-04]
171. [1.73124197e-19]	224. [0.00000000e+00]	277. [2.38322260e-04]
172. [3.39094332e-19]	225. [0.00000000e+00]	278. [2.04754040e-04]
173. [-8.38032132e-20]	226. [0.00000000e+00]	279. [0.00000000e+00]
174. [4.38374573e-05]	227. [0.00000000e+00]	280. [0.00000000e+00]
175. [1.10350408e-04]	228. [0.00000000e+00]	281. [0.00000000e+00]
176. [2.07325010e-04]	229. [0.00000000e+00]	282. [0.00000000e+00]
177. [2.46737836e-04]	230. [2.48436378e-06]	283. [0.00000000e+00]
178. [2.06140195e-05]	231. [2.11305906e-05]	284. [0.00000000e+00]
179. [1.57046216e-04]	232. [5.23708587e-05]	285. [0.00000000e+00]
180. [-4.75071762e-05]	233. [-1.23426620e-04]	286. [1.90149382e-05]
181. [-1.66915932e-04]	234. [-5.83907458e-05]	287. [6.06002010e-05]
182. [2.46584052e-04]	235. [-1.88813565e-04]	288. [-1.19206463e-04]
183. [-3.51074688e-04]	236. [1.19091791e-04]	289. [-1.58290608e-04]
184. [-1.45014511e-04]	237. [-1.96977588e-04]	290. [1.39178334e-04]
185. [1.32484386e-04]	238. [4.23414640e-05]	291. [-1.87092690e-04]
186. [1.42875626e-04]	239. [-3.53399390e-05]	292. [-2.49569923e-04]
187. [-4.45157289e-04]	240. [-1.89075779e-04]	293. [3.05126673e-04]
188. [3.44438499e-05]	241. [2.89148011e-04]	294. [-4.31590589e-04]
189. [2.15878881e-04]	242. [-3.06587825e-04]	295. [-3.40259682e-05]
190. [-5.09462972e-05]	243. [-2.42652073e-04]	296. [-5.22018892e-04]
191. [-1.00425939e-05]	244. [-9.70507311e-06]	297. [-3.17915169e-04]
192. [1.47978362e-04]	245. [-4.23264735e-05]	298. [-4.58381043e-05]
193. [1.96515301e-04]	246. [1.13043108e-04]	299. [1.98078061e-04]
194. [9.48504166e-05]	247. [1.64722002e-04]	300. [-7.90314260e-05]
195. [0.00000000e+00]	248. [2.11056596e-06]	301. [-1.57810719e-04]
196. [0.00000000e+00]	249. [-5.23457267e-05]	302. [-5.94149692e-05]
197. [0.00000000e+00]	250. [2.16670444e-05]	303. [6.79090446e-05]
198. [0.00000000e+00]	251. [0.00000000e+00]	304. [-7.70256417e-06]
199. [0.00000000e+00]	252. [0.00000000e+00]	305. [3.66115744e-04]
200. [0.00000000e+00]	253. [0.00000000e+00]	306. [2.89240390e-04]
201. [0.00000000e+00]	254. [0.00000000e+00]	307. [0.00000000e+00]
202. [0.00000000e+00]	255. [0.00000000e+00]	308. [0.00000000e+00]
203. [0.00000000e+00]	256. [0.00000000e+00]	309. [0.00000000e+00]
204. [1.13547181e-04]	257. [0.00000000e+00]	310. [0.00000000e+00]
205. [1.58831682e-04]	258. [1.12751895e-05]	311. [0.00000000e+00]
206. [7.50469821e-06]	259. [1.17256163e-04]	312. [0.00000000e+00]
207. [4.29301350e-05]	260. [-7.27252210e-05]	313. [0.00000000e+00]

314. [2.27520301e-05]	367. [0.00000000e+00]	420. [0.00000000e+00]
315. [-1.70375508e-04]	368. [0.00000000e+00]	421. [0.00000000e+00]
316. [-4.61799416e-06]	369. [0.00000000e+00]	422. [0.00000000e+00]
317. [3.67818359e-05]	370. [2.84112575e-05]	423. [0.00000000e+00]
318. [-2.20511115e-04]	371. [-1.56639322e-04]	424. [0.00000000e+00]
319. [-1.05161409e-05]	372. [2.87012539e-04]	425. [0.00000000e+00]
320. [1.80891884e-04]	373. [1.07607268e-04]	426. [2.02477386e-05]
321. [2.45771226e-04]	374. [1.54565413e-04]	427. [5.98009072e-05]
322. [-4.61530115e-04]	375. [-1.27033596e-04]	428. [-9.97764209e-05]
323. [-4.01440899e-05]	376. [-3.02047270e-05]	429. [-1.45278691e-04]
324. [5.69623030e-04]	377. [2.80543481e-04]	430. [1.29859390e-04]
325. [1.66565730e-05]	378. [-1.68943843e-04]	431. [-1.67901950e-04]
326. [-7.05972442e-05]	379. [-9.87358837e-05]	432. [4.95073292e-06]
327. [1.90431138e-04]	380. [4.33657558e-04]	433. [-1.50152175e-04]
328. [-1.91948932e-04]	381. [3.28486221e-04]	434. [-6.51645164e-04]
329. [8.19111156e-05]	382. [5.81432261e-04]	435. [-1.03158727e-04]
330. [2.29541191e-04]	383. [2.98561233e-05]	436. [8.71264047e-04]
331. [9.67563840e-05]	384. [8.44196822e-05]	437. [-7.61644750e-05]
332. [-3.33738306e-04]	385. [6.34509481e-05]	438. [-3.59928565e-04]
333. [1.66210125e-04]	386. [-4.02214824e-05]	439. [-6.25437532e-05]
334. [7.01119234e-05]	387. [1.15942685e-04]	440. [-1.07474123e-04]
335. [0.00000000e+00]	388. [2.12237398e-04]	441. [-4.28696300e-05]
336. [0.00000000e+00]	389. [-1.25516022e-04]	442. [-8.03256887e-05]
337. [0.00000000e+00]	390. [6.14872324e-05]	443. [5.41433548e-05]
338. [0.00000000e+00]	391. [0.00000000e+00]	444. [2.23608981e-04]
339. [0.00000000e+00]	392. [0.00000000e+00]	445. [-1.88741144e-04]
340. [0.00000000e+00]	393. [0.00000000e+00]	446. [-7.87703048e-05]
341. [0.00000000e+00]	394. [0.00000000e+00]	447. [0.00000000e+00]
342. [1.89562975e-05]	395. [0.00000000e+00]	448. [0.00000000e+00]
343. [-2.84429083e-04]	396. [0.00000000e+00]	449. [0.00000000e+00]
344. [5.13554067e-05]	397. [0.00000000e+00]	450. [0.00000000e+00]
345. [2.82107979e-05]	398. [-1.41374801e-04]	451. [0.00000000e+00]
346. [-1.97240726e-05]	399. [-1.29375576e-04]	452. [0.00000000e+00]
347. [-4.49071919e-05]	400. [-4.10315968e-05]	453. [0.00000000e+00]
348. [-2.74905241e-04]	401. [-1.44679024e-04]	454. [1.02509768e-04]
349. [-2.46840188e-04]	402. [1.81180447e-04]	455. [-2.24141778e-05]
350. [2.88911064e-04]	403. [-9.36861930e-05]	456. [1.81846654e-05]
351. [-3.18447042e-04]	404. [2.01984506e-04]	457. [-1.09384705e-04]
352. [2.05916184e-04]	405. [3.54735106e-04]	458. [-6.64953477e-05]
353. [5.99934892e-05]	406. [-5.08961930e-05]	459. [-2.99192817e-04]
354. [-5.88728417e-04]	407. [-8.37363857e-05]	460. [2.55743732e-06]
355. [-1.53141830e-04]	408. [1.67923684e-03]	461. [-5.45065554e-05]
356. [-1.28303645e-04]	409. [-5.43892140e-04]	462. [1.14126674e-04]
357. [-1.52755008e-04]	410. [2.59069383e-04]	463. [7.89289643e-04]
358. [7.89988617e-05]	411. [-4.39790366e-04]	464. [-4.66913691e-04]
359. [3.28667031e-05]	412. [1.17576046e-05]	465. [6.93435687e-05]
360. [-3.25411623e-05]	413. [-1.00266971e-04]	466. [2.94671544e-04]
361. [-4.65224531e-05]	414. [3.35752910e-05]	467. [3.25398195e-04]
362. [-1.30566435e-05]	415. [-1.90717472e-04]	468. [-3.87316145e-05]
363. [0.00000000e+00]	416. [1.24510452e-04]	469. [2.52124511e-04]
364. [0.00000000e+00]	417. [-2.43855057e-04]	470. [-1.38758427e-05]
365. [0.00000000e+00]	418. [-7.96196633e-05]	471. [-1.77734434e-04]
366. [0.00000000e+00]	419. [0.00000000e+00]	472. [5.06135766e-05]

473. [1.50373887e-05]	526. [-1.48005741e-04]	579. [-1.41528728e-04]
474. [-7.35620437e-06]	527. [-6.92158916e-05]	580. [9.03448044e-05]
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(2) sqError

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686. [-6.99434407e-06]	739. [0.00000000e+00]	

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