In [1]:
```python
import matplotlib.pyplot as plt
import pandas as pd
import seaborn as sns
```

In [5]:
```python
filter0, filter1, weight0, bias0, loss_training_set ,loss_test_set = CNN()
```

```
0.0 % proceeding
------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------
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------------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.94433685   0.04137146]
 [ -5.78303531 -25.75520418]] [[  1.14944205   2.44013671  -4.59932328]
 [ 20.24954362  -0.62890586 -13.38398682]
 [  6.79403157 -18.03979232  -0.58239126]]


training loss is 8.003639884524588
test loss is 4.977614911653973
0.642 accuracy!
2.0 % proceeding
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------------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.93684997  -0.21642669]
 [ -6.15443437 -26.96640717]] [[  1.15607207   2.44929106  -4.62500252]
 [ 20.21473097  -0.80585084 -14.02510843]
 [  6.72239544 -18.07591874  -0.46975341]]


training loss is 4.193071658468663
test loss is 3.4713092306728717
0.714 accuracy!
4.0 % proceeding
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------------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.9336302   -0.36068088]
 [ -6.3902654  -27.72466848]] [[  1.15270744   2.45318333  -4.65398408]
 [ 20.1919348   -0.91681943 -14.3898473 ]
 [  6.66505236 -18.11666224  -0.41988831]]


training loss is 3.259235034314103
test loss is 2.9390850867588516
0.722 accuracy!
6.0 % proceeding
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------------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.9317505   -0.44960596]
 [ -6.57794075 -28.29133791]] [[  1.14629541   2.45502173  -4.68135756]
 [ 20.17135488  -0.99909505 -14.62594272]
 [  6.61422686 -18.16696102  -0.40796971]]


training loss is 2.64117681184015
test loss is 2.3579486998365446
0.716 accuracy!
8.0 % proceeding
------------------------------------------------------------------------------------------------------------------
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------------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.93028928  -0.50689941]
 [ -6.73931053 -28.72524031]] [[  1.13955834   2.45577622  -4.70437314]
 [ 20.15119189  -1.06366314 -14.78655269]
 [  6.57178147 -18.21692109  -0.41262023]]


training loss is 2.0838387640238
test loss is 1.8596418309413887
0.719 accuracy!
```

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10.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92943522  -0.5489492 ]
 [ -6.88308688 -29.08118041]] [[  1.13325155   2.45605938  -4.72294079]
 [ 20.13226668  -1.11588044 -14.89953569]
 [  6.53731321 -18.26421116  -0.42348227]]


training loss is 1.6468740984536188
test loss is 1.5102513735304761
0.7010000000000001 accuracy!
12.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------[[  4.92884221  -0.58114836]
 [ -7.00183854 -29.36588167]] [[  1.12794265   2.45615451  -4.73658054]
 [ 20.11672307  -1.15689666 -14.98497325]
 [  6.51120106 -18.30297667  -0.43269181]]


training loss is 1.4266864493695475
test loss is 1.3674599870524156
0.706 accuracy!
14.000000000000002 % proceeding
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-----------------------------------[[  4.92833892  -0.60477631]
 [ -7.09803042 -29.58629074]] [[  1.12410677   2.45627961  -4.7464686 ]
 [ 20.10461932  -1.18926877 -15.05392182]
 [  6.49100745 -18.33201077  -0.43783459]]


training loss is 1.322407102200045
test loss is 1.2953234076302347
0.7030000000000001 accuracy!
16.0 % proceeding
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92795552  -0.62289366]
 [ -7.17466163 -29.75377004]] [[  1.12148263   2.45645794  -4.7538237 ]
 [ 20.09563764  -1.2144128  -15.11087499]
 [  6.47543744 -18.35258975  -0.43942606]]


training loss is 1.2519212019936354
test loss is 1.2442857786734063
0.698 accuracy!
18.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------------------------------------------------------------------------------------
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92771905  -0.63537731]
 [ -7.23206892 -29.87518344]] [[  1.11988992   2.45667964  -4.75939616]
 [ 20.08923628  -1.23354604 -15.15814141]
 [  6.46347837 -18.36658737  -0.43868308]]


training loss is 1.1907586210894245
test loss is 1.201915254324404
0.696 accuracy!
20.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92759511  -0.64352256]
 [ -7.27454142 -29.96133808]] [[  1.11890038   2.45693139  -4.76385701]
```

```
 [ 20.08496302  -1.24777013 -15.19766777]
 [  6.45438257 -18.37560738  -0.43646998]]


training loss is 1.1421427446682928
test loss is 1.138595704890959
0.696 accuracy!
22.0 % proceeding
--------------------------------------------------------------------------------------------------------------------
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--------------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92753173  -0.64844036]
 [ -7.30584047 -30.02190477]] [[  1.11831927   2.45720628  -4.7674215 ]
 [ 20.08235754  -1.25810725 -15.23096281]
 [  6.44771015 -18.38117549  -0.43344535]]


training loss is 1.094222806014637
test loss is 1.0696523843354897
0.6950000000000001 accuracy!
24.0 % proceeding
--------------------------------------------------------------------------------------------------------------------
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--------------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92746724  -0.65137162]
 [ -7.33148833 -30.06875864]] [[  1.11801516   2.45749674  -4.77017661]
 [ 20.08084829  -1.26584741 -15.25974321]
 [  6.44256005 -18.38510421  -0.4303051 ]]


training loss is 1.0599526016115133
test loss is 1.0299392908220248
0.696 accuracy!
26.0 % proceeding
--------------------------------------------------------------------------------------------------------------------
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--------------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92740098  -0.65329187]
 [ -7.3543042  -30.10871716]] [[  1.11788885   2.45778303  -4.77243328]
 [ 20.08017223  -1.27183347 -15.28515997]
 [  6.43825001 -18.38829971  -0.42731999]]


training loss is 1.034899674288894
test loss is 1.0035842504328654
0.6930000000000001 accuracy!
28.000000000000004 % proceeding
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-----------------------------------[[  4.92730709  -0.65448013]
 [ -7.37493166 -30.14351266]] [[  1.11789546   2.45807316  -4.77439301]
 [ 20.08024187  -1.27627005 -15.30771382]
 [  6.43464993 -18.39095417  -0.42449837]]


training loss is 1.0153014903815953
test loss is 0.9839442360806112
0.692 accuracy!
30.0 % proceeding
--------------------------------------------------------------------------------------------------------------------
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--------------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92721836  -0.65509132]
 [ -7.39338491 -30.17381712]] [[  1.11800245   2.45837161  -4.77612456]
 [ 20.08097342  -1.27934198 -15.32788026]
 [  6.43166415 -18.39321686  -0.42183117]]


training loss is 0.9995644016097224
test loss is 0.96787691095104
0.6930000000000001 accuracy!
32.0 % proceeding
```

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-----------------------------------[[  4.92714124  -0.65523647]
 [ -7.4094518  -30.19980622]] [[  1.118202     2.4586812   -4.77761257]
 [ 20.08228804  -1.28123195 -15.34602835]
 [  6.42916196 -18.39516137  -0.4193051 ]]


training loss is 0.9861675937462557
test loss is 0.9548874697059625
0.694 accuracy!
34.0 % proceeding
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92708465  -0.65524522]
 [ -7.42357827 -30.22256489]] [[  1.11847021   2.45899599  -4.77887335]
 [ 20.08406413  -1.28222708 -15.36254322]
 [  6.42700253 -18.39680355  -0.41682647]]


training loss is 0.9758015912864914
test loss is 0.9445409064520675
0.696 accuracy!
36.0 % proceeding
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92704532  -0.65521529]
 [ -7.43626242 -30.24290204]] [[  1.11880529   2.45931395  -4.77991722]
 [ 20.08617067  -1.28254195 -15.37778595]
 [  6.42508462 -18.39817975  -0.41428568]]


training loss is 0.9683697058295507
test loss is 0.9372986468638074
0.698 accuracy!
38.0 % proceeding
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-----------------------------------[[  4.9270116   -0.65524545]
 [ -7.44773007 -30.26145761]] [[  1.11918047   2.4596341   -4.7807745 ]
 [ 20.08844397  -1.28244145 -15.39211979]
 [  6.42332073 -18.39927492  -0.4115963 ]]


training loss is 0.9634715107767409
test loss is 0.9332774227010151
0.7 accuracy!
40.0 % proceeding
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92697539  -0.65530813]
 [ -7.45828086 -30.27856401]] [[  1.11959776   2.45995597  -4.78147221]
 [ 20.09078629  -1.2821072  -15.40579307]
 [  6.42164694 -18.40006743  -0.40872252]]


training loss is 0.9598591283259228
test loss is 0.9305213644658691
0.7 accuracy!
42.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92694133  -0.65539777]
 [ -7.46776148 -30.2940585 ]] [[  1.12003999   2.4602781   -4.78202588]
 [ 20.09316633  -1.28161556 -15.41891991]
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 [  6.42004229 -18.40053208  -0.40569546]]


training loss is 0.9566553516970187
test loss is 0.9278036063094377
0.698 accuracy!
44.0 % proceeding
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-----------------------------------[[  4.92691073  -0.65543507]
 [ -7.47614734 -30.30778539]] [[  1.1205205    2.46060131  -4.78244715]
 [ 20.09556103  -1.28100277 -15.43156555]
 [  6.41849683 -18.40066848  -0.40255059]]


training loss is 0.9536371499691187
test loss is 0.9246432829244149
0.698 accuracy!
46.0 % proceeding
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-----------------------------------[[  4.92688443  -0.65540488]
 [ -7.48354289 -30.31990461]] [[  1.12102013   2.46092378  -4.7827542 ]
 [ 20.09797515  -1.28027848 -15.44375598]
 [  6.41700182 -18.40050153  -0.39929011]]


training loss is 0.9507608462865061
test loss is 0.9214789877739745
0.698 accuracy!
48.0 % proceeding
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-----------------------------------[[  4.92686692  -0.65522483]
 [ -7.48997641 -30.33028651]] [[  1.12154297   2.46124793  -4.78296943]
 [ 20.10039025  -1.27946976 -15.45552432]
 [  6.41555862 -18.40003579  -0.39592429]]


training loss is 0.947963954178294
test loss is 0.9185885552602256
0.698 accuracy!
50.0 % proceeding
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-----------------------------------[[  4.92685551  -0.65486026]
 [ -7.49553239 -30.33899852]] [[  1.12209162   2.46157225  -4.78309946]
 [ 20.10282361  -1.27857958 -15.46688731]
 [  6.41414886 -18.39928851  -0.39244939]]


training loss is 0.9451830208238162
test loss is 0.9159398742210301
0.698 accuracy!
52.0 % proceeding
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92684746  -0.65443559]
 [ -7.50037801 -30.34640034]] [[  1.1226573    2.46189708  -4.78314471]
 [ 20.10527637  -1.27760789 -15.47786968]
 [  6.41277391 -18.39828047  -0.38886598]]


training loss is 0.9424001941921551
test loss is 0.9131980065899373
0.6990000000000001 accuracy!
54.0 % proceeding
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-----------------------------------[[  4.92683983  -0.65395753]
 [ -7.50455563 -30.35256773]] [[  1.12323691   2.46222262  -4.78310881]
 [ 20.10774449  -1.27656301 -15.48850185]
 [  6.41143233 -18.39702976  -0.38519048]]


training loss is 0.9396220442041564
test loss is 0.9100343070626784
0.698 accuracy!
56.00000000000001 % proceeding
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-----------------------------------[[  4.92683394  -0.65337671]
 [ -7.50797032 -30.35739234]] [[  1.12383158   2.46254887  -4.78300215]
 [ 20.11021765  -1.27545881 -15.49882036]
 [  6.41011953 -18.3955435   -0.38144003]]


training loss is 0.9369684938149693
test loss is 0.9069711970736034
0.698 accuracy!
57.99999999999999 % proceeding
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-----------------------------------[[  4.92682935  -0.65276623]
 [ -7.51067996 -30.36105614]] [[  1.12443465   2.46287597  -4.78282169]
 [ 20.1126955   -1.2742957  -15.50885616]
 [  6.40883184 -18.39384757  -0.37762795]]


training loss is 0.9345568179854897
test loss is 0.9044848982659157
0.698 accuracy!
60.0 % proceeding
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-----------------------------------[[  4.92682494  -0.65211192]
 [ -7.51268182 -30.36374039]] [[  1.12502827   2.46320122  -4.78257702]
 [ 20.11518734  -1.27308332 -15.5186323 ]
 [  6.40757106 -18.39197568  -0.37375981]]


training loss is 0.9324194894843837
test loss is 0.9026605446228219
0.6990000000000001 accuracy!
62.0 % proceeding
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-----------------------------------[[  4.92681953  -0.65144241]
 [ -7.51406821 -30.3654983 ]] [[  1.12562803   2.46352658  -4.78227349]
 [ 20.11768861  -1.27181433 -15.52818171]
 [  6.40633316 -18.38992933  -0.3698334 ]]


training loss is 0.9304513499158469
test loss is 0.9013235268462263
0.698 accuracy!
64.0 % proceeding
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-----------------------------------[[  4.92681266  -0.65077447]
 [ -7.51491667 -30.36653615]] [[  1.12623366   2.46385108  -4.78193536]
 [ 20.12019814  -1.2705039  -15.53752393]
 [  6.40510781 -18.38774443  -0.36584528]]
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training loss is 0.92843516252572
test loss is 0.8997219831284374
0.698 accuracy!
66.0 % proceeding
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-----------------------------------[[  4.92680298  -0.65013057]
 [ -7.51534196 -30.36704989]] [[  1.12685474   2.46417567  -4.78155735]
 [ 20.12271585  -1.26915233 -15.54667643]
 [  6.40388797 -18.38545242  -0.36180589]]


training loss is 0.9261793869489717
test loss is 0.8969607648276419
0.698 accuracy!
68.0 % proceeding
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92679028  -0.64956034]
 [ -7.51544559 -30.3673123 ]] [[  1.1274812    2.46449986  -4.78114822]
 [ 20.12523653  -1.26776844 -15.55565455]
 [  6.40267229 -18.38308812  -0.35772371]]


training loss is 0.9238745223602366
test loss is 0.8940413634363094
0.698 accuracy!
70.0 % proceeding
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-----------------------------------[[  4.92677329  -0.64905396]
 [ -7.51530201 -30.36742495]] [[  1.12810524   2.46482643  -4.78072213]
 [ 20.12776601  -1.26635175 -15.56446592]
 [  6.40145546 -18.38067719  -0.35361181]]


training loss is 0.9217560603579604
test loss is 0.8914994411696999
0.6990000000000001 accuracy!
72.0 % proceeding
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-----------------------------------[[  4.92675478  -0.64862811]
 [ -7.51496879 -30.3674962 ]] [[  1.12871865   2.46515231  -4.78028377]
 [ 20.13030659  -1.26490818 -15.5731381 ]
 [  6.40024015 -18.37823304  -0.34947492]]


training loss is 0.9200946032241998
test loss is 0.889507535178336
0.698 accuracy!
74.0 % proceeding
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92673615  -0.64823156]
 [ -7.51446659 -30.36746793]] [[  1.1293422    2.46547825  -4.77984056]
 [ 20.13284779  -1.26344707 -15.58172172]
 [  6.3990291  -18.37575452  -0.34531119]]


training loss is 0.9191120575721087
test loss is 0.8881745827496368
0.6990000000000001 accuracy!
76.0 % proceeding
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-----------------------------------[[  4.92671583  -0.64785052]
 [ -7.51386834 -30.36729741]] [[  1.12996499   2.46580405  -4.77939958]
 [ 20.13539133  -1.26198234 -15.59025496]
 [  6.39782658 -18.37324502  -0.34112845]]


training loss is 0.9186100023744963
test loss is 0.8874170930956741
0.7010000000000001 accuracy!
78.0 % proceeding
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-----------------------------------[[  4.92669404  -0.64747883]
 [ -7.51325854 -30.36706785]] [[  1.13058624   2.46612904  -4.7789559 ]
 [ 20.13793171  -1.26051773 -15.59876531]
 [  6.39662956 -18.37071841  -0.3369374 ]]


training loss is 0.918296921520483
test loss is 0.8869937655933281
0.7 accuracy!
80.0 % proceeding
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92667106  -0.64709982]
 [ -7.51261366 -30.36679497]] [[  1.13120538   2.46645472  -4.77851332]
 [ 20.14046906  -1.25904579 -15.60725707]
 [  6.39544178 -18.36818358  -0.33274619]]


training loss is 0.9180477543228991
test loss is 0.8867354459624197
0.7 accuracy!
82.0 % proceeding
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-----------------------------------[[  4.92664559  -0.64674209]
 [ -7.51201094 -30.36658117]] [[  1.13182395   2.46678106  -4.77807312]
 [ 20.14300609  -1.25758112 -15.61573363]
 [  6.39425713 -18.36565121  -0.32855625]]


training loss is 0.9178260087382377
test loss is 0.8865611339067304
0.7 accuracy!
84.0 % proceeding
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-----------------------------------[[  4.92662043  -0.64638643]
 [ -7.51143287 -30.3663536 ]] [[  1.13243504   2.46710632  -4.77763885]
 [ 20.14554041  -1.25612231 -15.62420102]
 [  6.39307425 -18.3631177   -0.32436834]]


training loss is 0.917619768425272
test loss is 0.8864343844705276
0.7 accuracy!
86.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------------------------------------------------------------------------------------
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92659505  -0.64602769]
 [ -7.51085786 -30.36616161]] [[  1.13304712   2.46743112  -4.77720347]
 [ 20.14807402  -1.25466312 -15.63265953]
 [  6.39189352 -18.36059251  -0.32018455]]
```

```
training loss is 0.9174244834089438
test loss is 0.8863364301097091
0.7 accuracy!
88.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------[[  4.92656825  -0.64567331]
 [ -7.51030819 -30.36604972]] [[  1.13365936   2.46775591  -4.7767669 ]
 [ 20.15060694  -1.2532023  -15.64111057]
 [  6.39071106 -18.35807849  -0.31600926]]


training loss is 0.9172370833697676
test loss is 0.8862558242807257
0.7010000000000001 accuracy!
90.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
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-----------------------------------[[  4.92654249  -0.64532773]
 [ -7.50976083 -30.36593555]] [[  1.13426967   2.4680799   -4.77633448]
 [ 20.1531406   -1.25174154 -15.64955381]
 [  6.38953409 -18.35556117  -0.31183544]]


training loss is 0.9170548194329042
test loss is 0.8861850791968385
0.7010000000000001 accuracy!
92.0 % proceeding
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-----------------------------------[[  4.92651965  -0.64497026]
 [ -7.50921593 -30.36579618]] [[  1.13487259   2.46840309  -4.77590746]
 [ 20.15566748  -1.25028113 -15.65799443]
 [  6.38836915 -18.35304183  -0.30765924]]


training loss is 0.9168779036867174
test loss is 0.8861201429954124
0.7010000000000001 accuracy!
94.0 % proceeding
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-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92649617  -0.64461248]
 [ -7.50867721 -30.36567335]] [[  1.13548439   2.46872592  -4.7754878 ]
 [ 20.15819096  -1.24882274 -15.66643049]
 [  6.38721123 -18.35052048  -0.30348423]]


training loss is 0.9167046341711819
test loss is 0.8860580237362455
0.7010000000000001 accuracy!
96.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92647196  -0.64425364]
 [ -7.50815519 -30.36557149]] [[  1.13608658   2.46904721  -4.77507085]
 [ 20.16071376  -1.24736358 -15.67486324]
 [  6.38605642 -18.34800279  -0.29931453]]


training loss is 0.9165338581471204
test loss is 0.8859967370932528
0.7010000000000001 accuracy!
98.0 % proceeding
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
```

```
-------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------------
-----------------------------------[[  4.92644686  -0.64388612]
 [ -7.50762122 -30.36547113]] [[  1.13669327   2.46936908  -4.77465317]
 [ 20.16323359  -1.24590789 -15.68329472]
 [  6.38490621 -18.34548464  -0.29514632]]


training loss is 0.9163660519809752
test loss is 0.8859356175800358
0.7010000000000001 accuracy!
```

In [10]:

```
confusionmatrix, top3matrix, top3matrix_index = ConfusionMatrix_n_top3(filter0, filter1, weight0, bias0, test_dat
```

Loader

In [2]:

```python
import gzip
import numpy as np
from pathlib import Path
import math
import random

class Dataloader():
    def __init__(self, path, is_train=True, shuffle=True, batch_size=8):
        path = Path(path)
        imagePath = Path(path/'train-images-idx3-ubyte.gz') if is_train else Path(path/'t10k-images-idx3-ubyte.gz
        labelPath = Path(path/'train-labels-idx1-ubyte.gz') if is_train else Path(path/'t10k-labels-idx1-ubyte.gz

        self.batch_size = batch_size
        self.images = self.loadImages(imagePath)
        self.labels = self.loadLabels(labelPath)
        self.index = 0
        self.idx = np.arange(0, self.images.shape[0])
        if shuffle: np.random.shuffle(self.idx) # shuffle images

    def __len__(self):
        n_images, _, _, _ = self.images.shape
        n_images = math.ceil(n_images / self.batch_size)
        return n_images

    def __iter__(self):
        return datasetIterator(self)

    def __getitem__(self, index):
        image = self.images[self.idx[index * self.batch_size:(index + 1) * self.batch_size]]
        label = self.labels[self.idx[index * self.batch_size:(index + 1) * self.batch_size]]
        image = image/255.0
        return image, label

    def loadImages(self, path):
        with gzip.open(path) as f:
            images = np.frombuffer(f.read(), 'B', offset=16)
            images = images.reshape(-1, 1, 28, 28).astype(np.float32)
            return images

    def loadLabels(self, path):
        with gzip.open(path) as f:
            labels = np.frombuffer(f.read(), 'B', offset=8)
            rows = len(labels)
            cols = labels.max() + 1
            one_hot = np.zeros((rows, cols)).astype(np.uint8)
            one_hot[np.arange(rows), labels] = 1
            one_hot = one_hot.astype(np.float64)
            return one_hot

# for enumerate magic python function returns Iterator
class datasetIterator():
    def __init__(self, dataloader):
        self.index = 0
        self.dataloader = dataloader

    def __next__(self):
        if self.index < len(self.dataloader):
            item = self.dataloader[self.index]
            self.index += 1
            return item
        # end of iteration
        raise StopIteration
```

function

function

In [21]:

```
def ReLU(value):
    return max(0, value)

def converter_ReLU(array):
    return np.array([ReLU(x) for x in array])

def converter_ReLU_2D(array):
    return np.array([converter_ReLU(x) for x in array])

def zeroorone(value):
    if value > 0:
        return 1
    else:
        return 0

def converter_zeroorone_10(array):
    return np.array([zeroorone(x) for x in array.reshape(10)])

def converter_zeroorone_784(array):
    return np.array([zeroorone(x) for x in array.reshape(784)])

def converter_zeroorone(array):
    k = len(array.shape)
    n = 1
    for i in range(0,k):
        n = n*array.shape[i]
        #print(n)
    return np.array([zeroorone(x) for x in array.reshape(n)]).reshape(math.ceil(math.sqrt(n)),math.ceil(math.sqrt

def SoftMax(z):
    c = np.max(z)
    exp_z = np.exp(z-c)
    sum_exp_z = np.sum(exp_z)
    y = exp_z / sum_exp_z
    return y

def Conv(array, filter):
    filter = np.flipud(np.fliplr(filter))
    sub_matrices = np.lib.stride_tricks.as_strided(array,shape = tuple(np.subtract(array.shape, filter.shape))+fi
    return np.einsum('ij,klij->kl', filter, sub_matrices)

def Cross_entropy_loss(y_label, y_prediction):
    return -np.sum(y_label*np.log(y_prediction+1e-7))

def Maxpooling(array):
    n = array.shape[0]
    m = math.ceil(n/2)
    MAX_array = np.zeros(m*m).reshape(m,m)
    MAX_array_indexed = np.zeros(n*n).reshape(n,n)
    for i in range(0,m):
        for j in range(0,m):
            new_array = array[2*i:2*i+2,2*j:2*j+2]
            MAX_array[i][j] = new_array.max()
            Index = (np.where(new_array==new_array.max())[0][0],np.where(new_array==new_array.max())[1][0])
            MAX_array_indexed[2*i+Index[0]][2*j+Index[1]] = 1
    return MAX_array,MAX_array_indexed

def rotate_180(m):
    N = len(m)
    ret = [[0] * N for _ in range(N)]
    for r in range(N):
        for c in range(N):
            ret[N-1-r][N-1-c] = m[r][c]
    return ret
```

In [4]:

```
def CNN(batchsize=100, epoch=50, testing = 1000):
    #ready for dataset
    learning_rate = batchsize/60000
    iteration = math.ceil(60000/batchsize)
    loss_training_set = []
    loss_test_set = []

    training_data = Dataloader(
        path="./",
        shuffle=True,
        batch_size=batchsize
    )
    test_data = Dataloader(
        path="./",
        shuffle=True,
        is_train = False,
        batch_size = 1
    )
```

```python
    #initialize function
    filter0 = np.random.randn(2,2)*10
    filter1 = np.random.randn(3,3)*10
    weight0 = np.random.randn(25,10) #수정해
    bias0 = np.random.randn(10)
    for k in range(0,epoch):
        print(100*(k/epoch),"% proceeding")
        training_loss = 0
        error = 0
        test_loss = 0
        for i in range(0,iteration):
        #foward porpagation
            print("-",end='')
            delta_3 = 0
            chain_delta_3 = np.zeros(250).reshape(25,10) #수정해
            chain_delta_2 = np.zeros(9).reshape(3,3)
            chain_delta_1 = np.zeros(4).reshape(2,2)

            for j in range(0, batchsize):
                delta_1_b = 0
                delta_2_b = 0
                delta_3_b = 0
                chain_delta_3_b = np.zeros(250).reshape(25,10) #수정해
                chain_delta_2_b = np.zeros(9).reshape(3,3)
                chain_delta_1_b = np.zeros(4).reshape(2,2)

                y_label = training_data.__getitem__(i)[1][j]
                #layer 0 foward propagation
                layer_0 = training_data.__getitem__(i)[0][j].reshape(28,28) #28,28
                layer_0_conv = Conv(layer_0,filter0) #26*26
                #print(layer_0_conv.shape)
                layer_0_relu = converter_ReLU_2D(layer_0_conv) #26*26
                layer_0_pooling,layer_0_pooling_index = Maxpooling(layer_0_relu) #13*13,26*26
                #layer 1 foward propagation
                layer_1_conv = Conv(layer_0_pooling,filter1) #10*10
                layer_1_relu = converter_ReLU_2D(layer_1_conv) #10*10
                layer_1_pooling,layer_1_pooling_index = Maxpooling(layer_1_relu) #5*5,10*10
                #layer 2 foward propagation
                layer_2 = layer_1_pooling.reshape(25)
                layer_2_weight = np.dot(layer_2, weight0) + bias0
                layer_2_softmax = SoftMax(layer_2_weight)
                training_loss += Cross_entrophy_loss(y_label,layer_2_softmax)

                #layer 2 backward propagation
                delta_3_b = ((layer_2_softmax - y_label))/batchsize #batchsize
                chain_delta_3_b = np.dot(layer_2.reshape(25,1), delta_3_b.reshape(1,10))

                #layer 1 backward propagation
                delta_2_b = (((np.dot(weight0,delta_3_b).reshape(5,5)).repeat(2, axis=0)).repeat(2, axis=1))*laye
                chain_delta_2_b = Conv(layer_0_pooling,rotate_180(delta_2_b))
                #print(chain_delta_2_b.shape)

                #layer 0 backward propagation
                delta_1_b = Conv(np.pad(delta_2_b, ((3,3),(3,3)), 'constant', constant_values=0),filter1).reshape

                chain_delta_1_b = Conv(layer_0,rotate_180(delta_1_b))


                #update value
                delta_3 += delta_3_b
                chain_delta_3 += chain_delta_3_b
                chain_delta_2 += chain_delta_2_b
                chain_delta_1 += chain_delta_1_b
            weight0 -= (learning_rate * chain_delta_3)
            filter1 -= (learning_rate * chain_delta_2)
            filter0 -= (learning_rate * chain_delta_1)
            bias0 -= delta_3.reshape(10)*learning_rate
            #print(filter1,filter0)
        print(filter0,filter1)
        print("\n")
        print("training loss is",training_loss/60000)
        loss_training_set.append(training_loss/60000)

        for i in range(0,testing):
            y_label = test_data.__getitem__(i)[1]
            #layer 0 foward propagation
            layer_0 = test_data.__getitem__(i)[0].reshape(28,28) #28,28
            layer_0_conv = Conv(layer_0,filter0) #26*26
            #print(layer_0_conv.shape)
            layer_0_relu = converter_ReLU_2D(layer_0_conv) #26*26
            layer_0_pooling,layer_0_pooling_index = Maxpooling(layer_0_relu) #13*13,26*26
            #layer 1 foward propagation
            layer_1_conv = Conv(layer_0_pooling,filter1) #10*10
            layer_1_relu = converter_ReLU_2D(layer_1_conv) #10*10
            layer_1_pooling,layer_1_pooling_index = Maxpooling(layer_1_relu) #5*5,10*10
            #layer 2 foward propagation
            layer_2 = layer_1_pooling.reshape(25)
            layer_2_weight = np.dot(layer_2, weight0) + bias0
            layer_2_softmax = SoftMax(layer_2_weight)
```

```
            test_loss += Cross_entropy_loss(y_label,layer_2_softmax)
            if(np.argmax(layer_2_softmax)!=np.argmax(test_data.__getitem__(i)[1])):
                error += 1
        print("test loss is",test_loss/testing)
        print(1-(error/testing),"accuracy!")
        loss_test_set.append(test_loss/testing)
    return filter0, filter1, weight0, bias0, loss_training_set ,loss_test_set
```

In [6]:

```
test_data = Dataloader(
    path="./",
    shuffle=True,
    is_train = False,
    batch_size = 1
)
```

In [8]:

```
def ConfusionMatrix_n_top3(filter0, filter1, weight0, bias0, test_data):
    confusionmatrix = np.zeros(100).reshape(10,10)
    top3matrix = np.zeros(30).reshape(10,3)
    top3matrix_index = np.zeros(30).reshape(10,3)
    for i in range(0,10000):
        y_label = test_data.__getitem__(i)[1]
        #layer 0 foward propagation
        layer_0 = test_data.__getitem__(i)[0].reshape(28,28) #28,28
        layer_0_conv = Conv(layer_0,filter0) #26*26
        #print(layer_0_conv.shape)
        layer_0_relu = converter_ReLU_2D(layer_0_conv) #26*26
        layer_0_pooling,layer_0_pooling_index = Maxpooling(layer_0_relu) #13*13,26*26
        #layer 1 foward propagation
        layer_1_conv = Conv(layer_0_pooling,filter1) #10*10
        layer_1_relu = converter_ReLU_2D(layer_1_conv) #10*10
        layer_1_pooling,layer_1_pooling_index = Maxpooling(layer_1_relu) #5*5,10*10
        #layer 2 foward propagation
        layer_2 = layer_1_pooling.reshape(25)
        layer_2_weight = np.dot(layer_2, weight0) + bias0
        layer_2_softmax = SoftMax(layer_2_weight)
        y_prediction = layer_2_softmax

        #confusionmatrix
        confusionmatrix[np.argmax(y_label)][np.argmax(y_prediction)]+=1
        index = np.argmin(top3matrix[np.argmax(y_prediction)])
        if top3matrix[np.argmax(y_prediction)][index] <= y_prediction[np.argmax(y_prediction)]:
            top3matrix[np.argmax(y_prediction)][index] =  y_prediction[np.argmax(y_prediction)]
            top3matrix_index[np.argmax(y_prediction)][index] = i

    return confusionmatrix , top3matrix, top3matrix_index
```

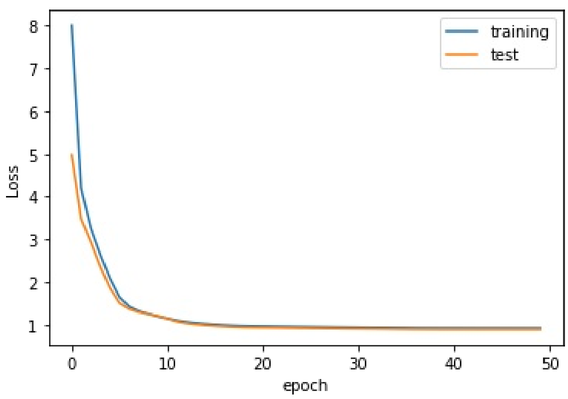
Loss graph

In [13]:

```
index = [x for x in range(50)]
```

In [14]:

```
plt.xlabel('epoch')
plt.ylabel("Loss")
plt.plot(index,loss_training_set)
plt.plot(index,loss_test_set)
plt.legend(['training', 'test'])
plt.show()
```



Confusion Matrix

```
In [15]: confusionmatrix_visualization = np.array([(100*x)/np.sum(x) for x in confusionmatrix])
```

```
In [16]: confusionmatrix_visualization = np.array([ np.fix(x) for x in confusionmatrix])
```

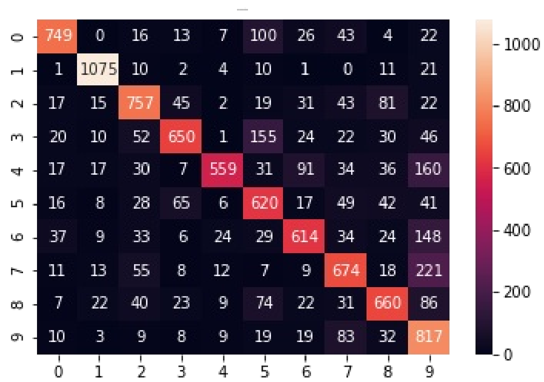
```
In [17]: confusionmatrix_visualization.astype(int)
```

```
Out[17]: array([[ 749,    0,   16,   13,    7,  100,   26,   43,    4,   22],
               [   1, 1075,   10,    2,    4,   10,    1,    0,   11,   21],
               [  17,   15,  757,   45,    2,   19,   31,   43,   81,   22],
               [  20,   10,   52,  650,    1,  155,   24,   22,   30,   46],
               [  17,   17,   30,    7,  559,   31,   91,   34,   36,  160],
               [  16,    8,   28,   65,    6,  620,   17,   49,   42,   41],
               [  37,    9,   33,    6,   24,   29,  614,   34,   24,  148],
               [  11,   13,   55,    8,   12,    7,    9,  674,   18,  221],
               [   7,   22,   40,   23,    9,   74,   22,   31,  660,   86],
               [  10,    3,    9,    8,    9,   19,   19,   83,   32,  817]])
```

```
In [18]: sns.heatmap(confusionmatrix_visualization.astype(int), annot=True, fmt='d')

         plt.title('confusionmatrix', fontsize=1)

         plt.show()
```



Top-3 images with probability

```
In [20]: print(top3matrix)
```

```
[[0.99481065 0.9985179  0.99343434]
 [0.99789017 0.99818423 0.99817173]
 [0.99993893 0.99995042 0.99995912]
 [0.98797295 0.98717337 0.98916809]
 [0.9996782  0.99968892 0.99941684]
 [0.99863    0.99947199 0.99863329]
 [0.99994764 0.99979571 0.99979019]
 [0.99682825 0.9966656  0.99590167]
 [0.99964454 0.99972902 0.99952306]
 [0.99807871 0.99715717 0.99810951]]
```

```
In [19]: fig, axes = plt.subplots(10,3, figsize=(3,10))
         j=0
         for i,ax in enumerate(axes.flat):
             index = math.ceil(top3matrix_index.reshape(30)[j])
             ax.imshow(test_data.__getitem__(index)[0].reshape(28,28))
             j+=1
```