CAP 5415 Fall 2023

Programming Assignment 4

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Objective

1. To implement a convolutional neural network (CNN) with fully connected (FC) layers in two settings and compare the results

Four convolutional layers and three fully connected layers

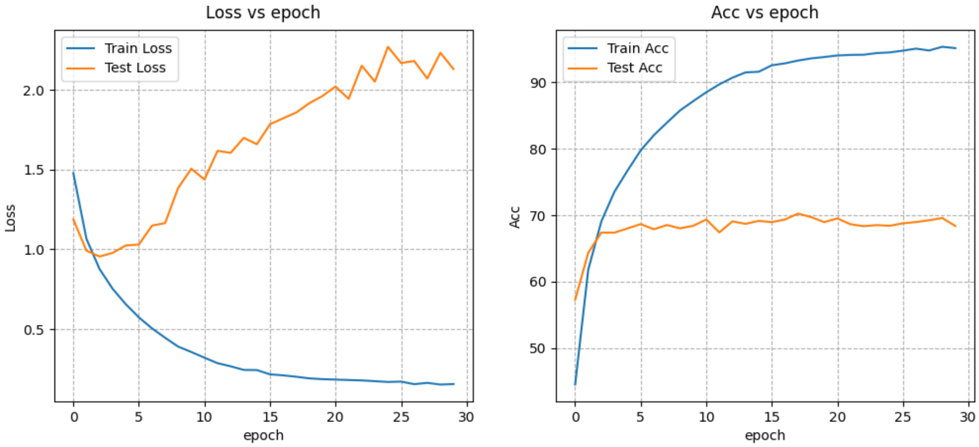
Code output

The output of the python file ‘cnn_with_4_layers.py’ is given below. It had a batch size of 32, learning rate 0.001 and it was ran for 30 epochs.

```
running on cpu
Files already downloaded and verified
Files already downloaded and verified
epoch: 1/30         train loss: 1.4781    train accuracy: 44.5520
validation loss: 1.1883  validation accuracy: 57.3000
epoch: 2/30         train loss: 1.0660    train accuracy: 61.8360
validation loss: 0.9921  validation accuracy: 64.3700
epoch: 3/30         train loss: 0.8767    train accuracy: 69.0880
validation loss: 0.9552  validation accuracy: 67.3900
epoch: 4/30         train loss: 0.7524    train accuracy: 73.5420
validation loss: 0.9783  validation accuracy: 67.3800
epoch: 5/30         train loss: 0.6560    train accuracy: 76.7260
validation loss: 1.0248  validation accuracy: 68.0200
epoch: 6/30         train loss: 0.5734    train accuracy: 79.7420
validation loss: 1.0305  validation accuracy: 68.6600
epoch: 7/30         train loss: 0.5044    train accuracy: 82.0200
validation loss: 1.1491  validation accuracy: 67.8900
epoch: 8/30         train loss: 0.4455    train accuracy: 83.9100
validation loss: 1.1652  validation accuracy: 68.5200
epoch: 9/30         train loss: 0.3898    train accuracy: 85.7460
validation loss: 1.3864  validation accuracy: 68.0300
epoch: 10/30        train loss: 0.3562    train accuracy: 87.1320
validation loss: 1.5062  validation accuracy: 68.4000
epoch: 11/30        train loss: 0.3206    train accuracy: 88.4800
validation loss: 1.4385  validation accuracy: 69.3500
epoch: 12/30        train loss: 0.2859    train accuracy: 89.6680
validation loss: 1.6185  validation accuracy: 67.4200
```

```
epoch: 13/30        train loss: 0.2665    train accuracy: 90.6740
validation loss: 1.6058  validation accuracy: 69.0700
epoch: 14/30        train loss: 0.2438    train accuracy: 91.4620
validation loss: 1.7001  validation accuracy: 68.7000
epoch: 15/30        train loss: 0.2428    train accuracy: 91.5600
validation loss: 1.6600  validation accuracy: 69.1500
epoch: 16/30        train loss: 0.2160    train accuracy: 92.5300
validation loss: 1.7852  validation accuracy: 68.9600
epoch: 17/30        train loss: 0.2096    train accuracy: 92.8220
validation loss: 1.8227  validation accuracy: 69.3500
epoch: 18/30        train loss: 0.2009    train accuracy: 93.2420
validation loss: 1.8587  validation accuracy: 70.2400
epoch: 19/30        train loss: 0.1907    train accuracy: 93.5640
validation loss: 1.9174  validation accuracy: 69.7200
epoch: 20/30        train loss: 0.1859    train accuracy: 93.7720
validation loss: 1.9625  validation accuracy: 68.9600
epoch: 21/30        train loss: 0.1831    train accuracy: 94.0040
validation loss: 2.0222  validation accuracy: 69.5200
epoch: 22/30        train loss: 0.1804    train accuracy: 94.0920
validation loss: 1.9446  validation accuracy: 68.6400
epoch: 23/30        train loss: 0.1780    train accuracy: 94.1200
validation loss: 2.1529  validation accuracy: 68.3500
epoch: 24/30        train loss: 0.1732    train accuracy: 94.3680
validation loss: 2.0526  validation accuracy: 68.5100
epoch: 25/30        train loss: 0.1683    train accuracy: 94.4720
validation loss: 2.2715  validation accuracy: 68.4100
epoch: 26/30        train loss: 0.1705    train accuracy: 94.7320
validation loss: 2.1697  validation accuracy: 68.7800
epoch: 27/30        train loss: 0.1545    train accuracy: 95.0340
validation loss: 2.1825  validation accuracy: 68.9700
epoch: 28/30        train loss: 0.1625    train accuracy: 94.7580
validation loss: 2.0722  validation accuracy: 69.2400
epoch: 29/30        train loss: 0.1520    train accuracy: 95.3120
validation loss: 2.2341  validation accuracy: 69.5800
epoch: 30/30        train loss: 0.1550    train accuracy: 95.1100
validation loss: 2.1317  validation accuracy: 68.3800
```

Following is the loss and accuracy curve that we get, the one in the left shows training and testing loss trends. Here, although the training loss gradually decreases to the end, the test loss starts to increase after 4 epochs. This shows that the model starts to overfit from this point. The effect is further shown in the right subplot where the test accuracy stops increasing after 4 epochs and even decreases a bit afterward. On the other hand, the training accuracy gradually increases till the end.



Six convolutional layers and three fully connected layers

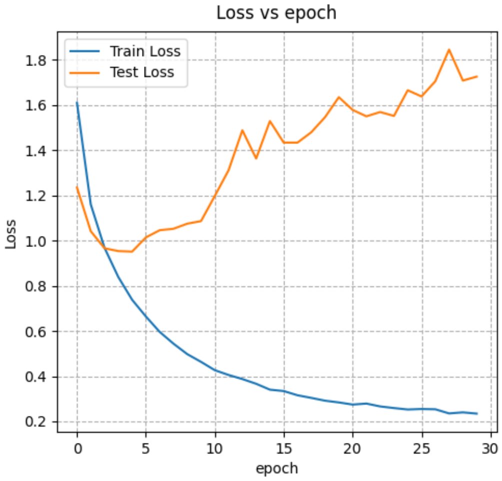
Code output

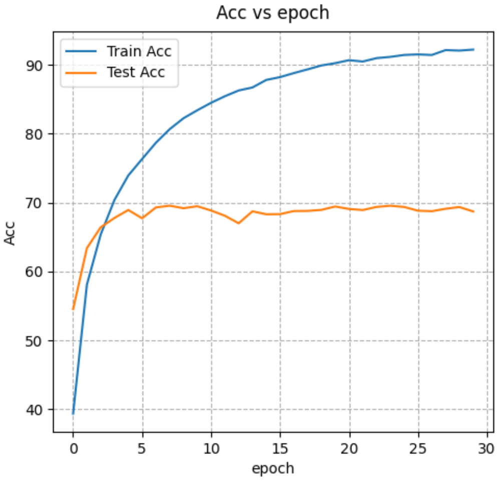
The output of the python file ‘cnn_with_6_layers.py’ is given below. It had a batch size of 32, learning rate 0.001 and it was ran for 30 epochs.

```
running on cpu
Files already downloaded and verified
Files already downloaded and verified
epoch: 1/30       train loss: 1.6091   train accuracy: 39.3460
validation loss: 1.2342  validation accuracy: 54.5300
epoch: 2/30       train loss: 1.1597   train accuracy: 58.0900
validation loss: 1.0412  validation accuracy: 63.3900
epoch: 3/30       train loss: 0.9673   train accuracy: 65.3780
validation loss: 0.9655  validation accuracy: 66.4200
epoch: 4/30       train loss: 0.8384   train accuracy: 70.4080
validation loss: 0.9532  validation accuracy: 67.7800
epoch: 5/30       train loss: 0.7379   train accuracy: 73.9520
validation loss: 0.9508  validation accuracy: 68.9300
epoch: 6/30       train loss: 0.6639   train accuracy: 76.3380
validation loss: 1.0135  validation accuracy: 67.7300
epoch: 7/30       train loss: 0.5958   train accuracy: 78.7000
validation loss: 1.0455  validation accuracy: 69.3000
epoch: 8/30       train loss: 0.5438   train accuracy: 80.6760
validation loss: 1.0518  validation accuracy: 69.5600
epoch: 9/30       train loss: 0.4975   train accuracy: 82.2660
validation loss: 1.0743  validation accuracy: 69.1900
epoch: 10/30      train loss: 0.4633   train accuracy: 83.4220
validation loss: 1.0858  validation accuracy: 69.4800
epoch: 11/30      train loss: 0.4264   train accuracy: 84.5080
```

```
validation loss: 1.1968  validation accuracy: 68.8600
epoch: 12/30          train loss: 0.4052    train accuracy: 85.4640
validation loss: 1.3108  validation accuracy: 68.1000
epoch: 13/30          train loss: 0.3872    train accuracy: 86.2980
validation loss: 1.4874  validation accuracy: 67.0000
epoch: 14/30          train loss: 0.3663    train accuracy: 86.7360
validation loss: 1.3626  validation accuracy: 68.7400
epoch: 15/30          train loss: 0.3403    train accuracy: 87.8300
validation loss: 1.5280  validation accuracy: 68.3100
epoch: 16/30          train loss: 0.3342    train accuracy: 88.2400
validation loss: 1.4329  validation accuracy: 68.3300
epoch: 17/30          train loss: 0.3155    train accuracy: 88.8260
validation loss: 1.4329  validation accuracy: 68.7800
epoch: 18/30          train loss: 0.3039    train accuracy: 89.3680
validation loss: 1.4786  validation accuracy: 68.8000
epoch: 19/30          train loss: 0.2916    train accuracy: 89.9340
validation loss: 1.5454  validation accuracy: 68.9500
epoch: 20/30          train loss: 0.2838    train accuracy: 90.2700
validation loss: 1.6337  validation accuracy: 69.4400
epoch: 21/30          train loss: 0.2744    train accuracy: 90.7000
validation loss: 1.5775  validation accuracy: 69.0800
epoch: 22/30          train loss: 0.2788    train accuracy: 90.5060
validation loss: 1.5492  validation accuracy: 68.9300
epoch: 23/30          train loss: 0.2661    train accuracy: 91.0020
validation loss: 1.5681  validation accuracy: 69.3800
epoch: 24/30          train loss: 0.2589    train accuracy: 91.1820
validation loss: 1.5510  validation accuracy: 69.5500
epoch: 25/30          train loss: 0.2525    train accuracy: 91.4620
validation loss: 1.6644  validation accuracy: 69.3700
epoch: 26/30          train loss: 0.2548    train accuracy: 91.5420
validation loss: 1.6370  validation accuracy: 68.8300
epoch: 27/30          train loss: 0.2535    train accuracy: 91.4580
validation loss: 1.7043  validation accuracy: 68.7600
epoch: 28/30          train loss: 0.2352    train accuracy: 92.1680
validation loss: 1.8443  validation accuracy: 69.1100
epoch: 29/30          train loss: 0.2399    train accuracy: 92.0960
validation loss: 1.7074  validation accuracy: 69.3600
epoch: 30/30          train loss: 0.2344    train accuracy: 92.2400
validation loss: 1.7246  validation accuracy: 68.7200
```

Just like the previous settings, from the loss curve at the left in the following, we can see that the model starts to overfit after epoch 5. However, the training loss decreases more slowly here. In terms of accuracy, the training and test accuracy shows a similar trend to the previous setting. Although the training accuracy increases gradually, the test accuracy almost stops increasing after 4 epochs.


Loss vs epoch
Train Loss
Test Loss
Loss
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
5
10
15
20
25
30
epoch


Acc vs epoch
Train Acc
Test Acc
Acc
90
80
70
60
50
40
0
5
10
15
20
25
30
epoch