Exercise 4

In this exercise we implemented a two, three, four and five fully-connected MLP image classifier on CIFAR10 dataset. CIFAR-10 contains 60000 labeled images of 10 classes with 32x32 in size for each RGB channel. Our train set has 49000 images, validation set has 1000 and test set has 10000 of which 1000 used for testing. The classes are: plane, car, bird, cat, deer, dog, frog, horse, ship and truck.
Also, we used cross entropy loss for loss function, Adam for optimizer and relu activation on hidden layers. You can find the implementation of these networks and results in the attached Exercise_4_Experiments.ipynb file.

1. **Network with 2 layers:**

Layer	Input Dimension	Output Dimension
1	3072	500
2	500	10

With a learning rate of 0.001 final validation accuracy of this network is above 52 %. Training and validation accuracies for this model are,

```
Epoch [1/10], Step [100/245], Loss: 1.6314
Epoch [1/10], Step [200/245], Loss: 1.5330
Validataion accuracy is: 45.8 %
Epoch [2/10], Step [100/245], Loss: 1.5452
Epoch [2/10], Step [200/245], Loss: 1.5033
Validataion accuracy is: 49.9 %
Epoch [3/10], Step [100/245], Loss: 1.5246
Epoch [3/10], Step [200/245], Loss: 1.3690
Validataion accuracy is: 48.4 %
Epoch [4/10], Step [100/245], Loss: 1.3742
Epoch [4/10], Step [200/245], Loss: 1.4363
Validataion accuracy is: 51.4 %
Epoch [5/10], Step [100/245], Loss: 1.2449
Epoch [5/10], Step [200/245], Loss: 1.2926
Validataion accuracy is: 53.0 %
Epoch [6/10], Step [100/245], Loss: 1.2469
Epoch [6/10], Step [200/245], Loss: 1.2596
Validataion accuracy is: 53.5 %
Epoch [7/10], Step [100/245], Loss: 1.1382
Epoch [7/10], Step [200/245], Loss: 1.3431
Validataion accuracy is: 53.3 %
Epoch [8/10], Step [100/245], Loss: 1.1810
Epoch [8/10], Step [200/245], Loss: 1.2218
Validataion accuracy is: 54.1 %
Epoch [9/10], Step [100/245], Loss: 1.1290
Epoch [9/10], Step [200/245], Loss: 1.2420
Validataion accuracy is: 53.3 %
Epoch [10/10], Step [100/245], Loss: 1.1501
Epoch [10/10], Step [200/245], Loss: 1.2244
Validataion accuracy is: 52.6 %
```

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2. Network with 3 layers:

Layer	Input Dimension	Output Dimension
1	3072	500
2	500	300
3	300	10

With a learning rate of 0.001 final validation accuracy of this network is above 55 %. Training and validation accuracies for this model are,

```
Epoch [1/10], Step [100/245], Loss: 1.6939
Epoch [1/10], Step [200/245], Loss: 1.6657
Validataion accuracy is: 45.2 %
Epoch [2/10], Step [100/245], Loss: 1.5038
Epoch [2/10], Step [200/245], Loss: 1.5271
Validataion accuracy is: 47.9 %
Epoch [3/10], Step [100/245], Loss: 1.5551
Epoch [3/10], Step [200/245], Loss: 1.4144
Validataion accuracy is: 50.6 %
Epoch [4/10], Step [100/245], Loss: 1.2555
Epoch [4/10], Step [200/245], Loss: 1.3444
Validataion accuracy is: 51.4 %
Epoch [5/10], Step [100/245], Loss: 1.2936
Epoch [5/10], Step [200/245], Loss: 1.1419
Validataion accuracy is: 51.1 %
Epoch [6/10], Step [100/245], Loss: 1.2043
Epoch [6/10], Step [200/245], Loss: 1.3113
Validataion accuracy is: 53.1 %
Epoch [7/10], Step [100/245], Loss: 1.2651
Epoch [7/10], Step [200/245], Loss: 1.2344
Validataion accuracy is: 53.2 %
Epoch [8/10], Step [100/245], Loss: 1.1451
Epoch [8/10], Step [200/245], Loss: 1.1623
Validataion accuracy is: 52.5 %
Epoch [9/10], Step [100/245], Loss: 1.2746
Epoch [9/10], Step [200/245], Loss: 1.0933
Validataion accuracy is: 55.8 %
Epoch [10/10], Step [100/245], Loss: 1.0704
Epoch [10/10], Step [200/245], Loss: 1.1444
Validataion accuracy is: 55.7 %
```

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3. Network with 4 layer:

Layer	Input Dimension	Output Dimension
1	3072	300
2	300	200
3	200	200
4	200	10

With a learning rate of 0.001 final validation accuracy of this network is around 53 %. Training and validation accuracies for this model are,

```
Epoch [1/10], Step [100/245], Loss: 2.3024
Epoch [1/10], Step [200/245], Loss: 2.3025
Validataion accuracy is: 15.6 %
Epoch [2/10], Step [100/245], Loss: 1.8728
Epoch [2/10], Step [200/245], Loss: 1.6884
Validataion accuracy is: 43.2 %
Epoch [3/10], Step [100/245], Loss: 1.6256
Epoch [3/10], Step [200/245], Loss: 1.6096
Validataion accuracy is: 47.1 %
Epoch [4/10], Step [100/245], Loss: 1.2912
Epoch [4/10], Step [200/245], Loss: 1.5068
Validataion accuracy is: 48.9 %
Epoch [5/10], Step [100/245], Loss: 1.3381
Epoch [5/10], Step [200/245], Loss: 1.3364
Validataion accuracy is: 50.8 %
Epoch [6/10], Step [100/245], Loss: 1.3126
Epoch [6/10], Step [200/245], Loss: 1.2502
Validataion accuracy is: 52.4 %
Epoch [7/10], Step [100/245], Loss: 1.3239
Epoch [7/10], Step [200/245], Loss: 1.2511
Validataion accuracy is: 51.4 %
Epoch [8/10], Step [100/245], Loss: 1.3204
Epoch [8/10], Step [200/245], Loss: 1.1547
Validataion accuracy is: 53.3 %
Epoch [9/10], Step [100/245], Loss: 1.1155
Epoch [9/10], Step [200/245], Loss: 1.1649
Validataion accuracy is: 52.3 %
Epoch [10/10], Step [100/245], Loss: 1.1237
Epoch [10/10], Step [200/245], Loss: 1.3292
Validataion accuracy is: 53.0 %
```

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4. Network with 5 layer:

Layer	Input Dimension	Output Dimension
1	3072	200
2	200	200
3	200	200
4	200	200
5	200	10

With a learning rate of 0.01 final validation accuracy of this network is around 42 %. Training and validation accuracies for this model are,

```
Epoch [1/10], Step [100/245], Loss: 1.9694
Epoch [1/10], Step [200/245], Loss: 1.8622
Validataion accuracy is: 34.6 %
Epoch [2/10], Step [100/245], Loss: 1.8576
Epoch [2/10], Step [200/245], Loss: 1.8442
Validataion accuracy is: 36.7 %
Epoch [3/10], Step [100/245], Loss: 1.8217
Epoch [3/10], Step [200/245], Loss: 1.7955
Validataion accuracy is: 35.7 %
Epoch [4/10], Step [100/245], Loss: 1.6908
Epoch [4/10], Step [200/245], Loss: 1.7307
Validataion accuracy is: 40.3 %
Epoch [5/10], Step [100/245], Loss: 1.6268
Epoch [5/10], Step [200/245], Loss: 1.6403
Validataion accuracy is: 40.7 %
Epoch [6/10], Step [100/245], Loss: 1.7082
Epoch [6/10], Step [200/245], Loss: 1.7197
Validataion accuracy is: 39.5 %
Epoch [7/10], Step [100/245], Loss: 1.6632
Epoch [7/10], Step [200/245], Loss: 1.5134
Validataion accuracy is: 41.8 %
Epoch [8/10], Step [100/245], Loss: 1.4923
Epoch [8/10], Step [200/245], Loss: 1.6171
Validataion accuracy is: 41.3 %
Epoch [9/10], Step [100/245], Loss: 1.6981
Epoch [9/10], Step [200/245], Loss: 1.6093
Validataion accuracy is: 43.5 %
Epoch [10/10], Step [100/245], Loss: 1.5679
Epoch [10/10], Step [200/245], Loss: 1.7867
Validataion accuracy is: 42.6 %
```

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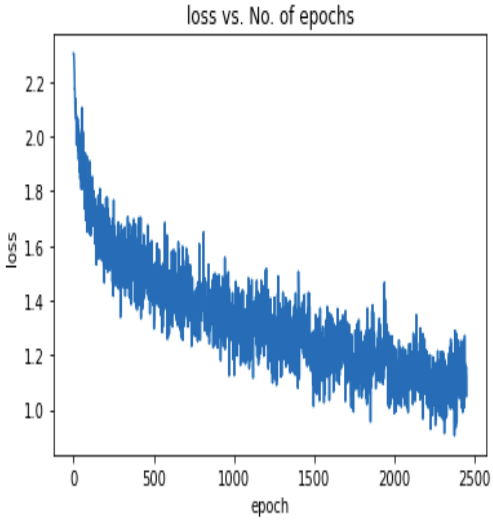
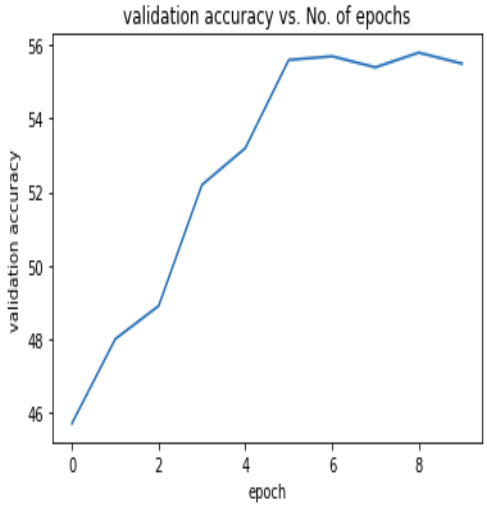
Considering the above information, the network with 3 layers performs better than others with test accuracy above 56 % on 1000 test images. By evaluating it on ten images it gives following predictions with satisfactory results:

```
GroundTruth:    cat  ship  ship plane  frog  frog   car  frog   cat   car
Predicted:      cat truck plane plane  frog  frog   car  frog   dog   car
```





Above plots show gradual reduction of training loss (left) and respective gradual increase of validation accuracy (right).

When we increase the number of hidden units and/or layers then it leads to overfitting as the network learns a function that perfectly separates the training set but that does not generalize to test data.