COL341 Assignment-4

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2018ME10650

4.1 Hyperparameter Tuning

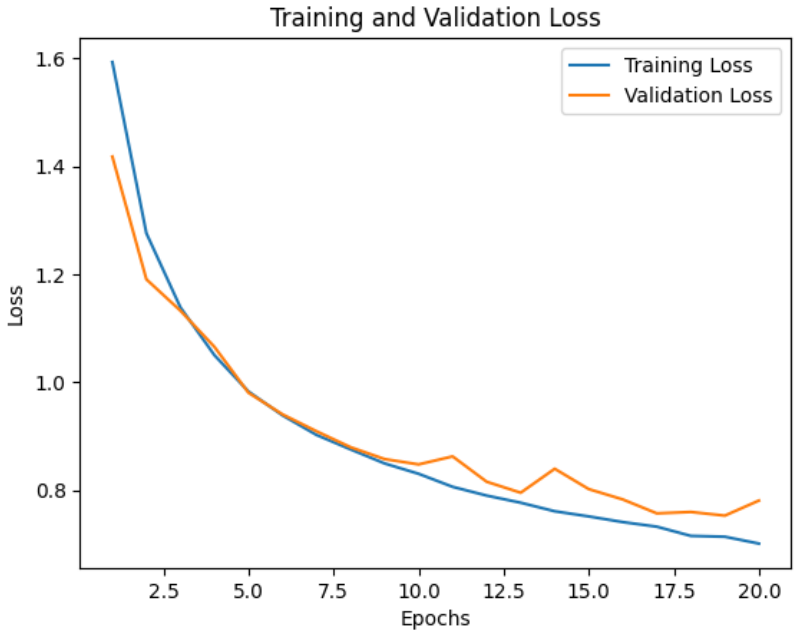
1. Learning Rate:

Batch size is 32 unless specified.

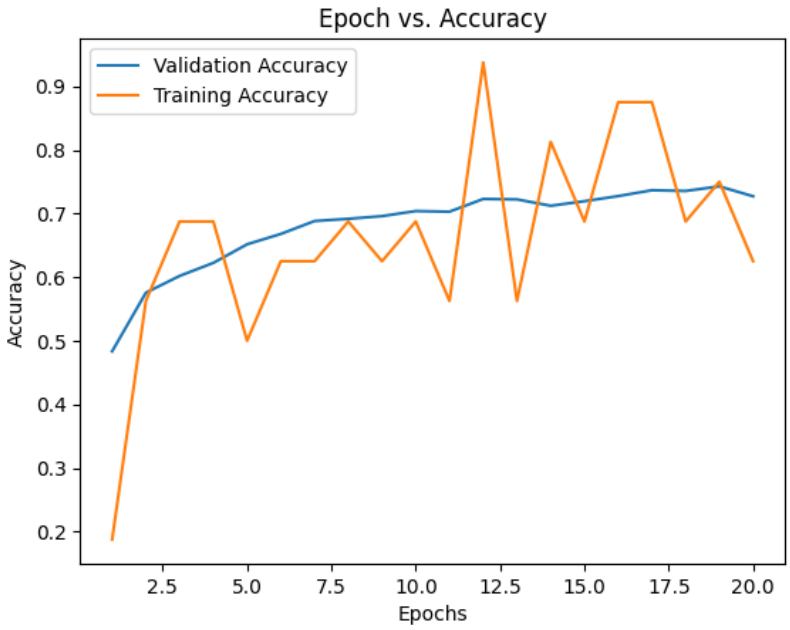
I found that LR of 0.0005 is best. Then 0.001 is somewhat good. And 0.005 is too big and so the gradient updates cause it not to converge to a good optimum. In the graph also, for 0.005, we can see training accuracy wildly fluctuating. In case of 0.0005, I think it was the right level of lr and the loss curve obtained is a very smooth decrease. And for 0.001 is in between these two extremes. The class-wise accuracies follow the same general trend, except some of the classes are predicted better in 0.001 than in the third.

<u>Lr = 0.001</u>

Plots



Both decrease. Validation kind of saturates.



Val accuracy saturates, train accuracy is little unstable maybe because of other hyperparameters.

Class-wise Accuracy

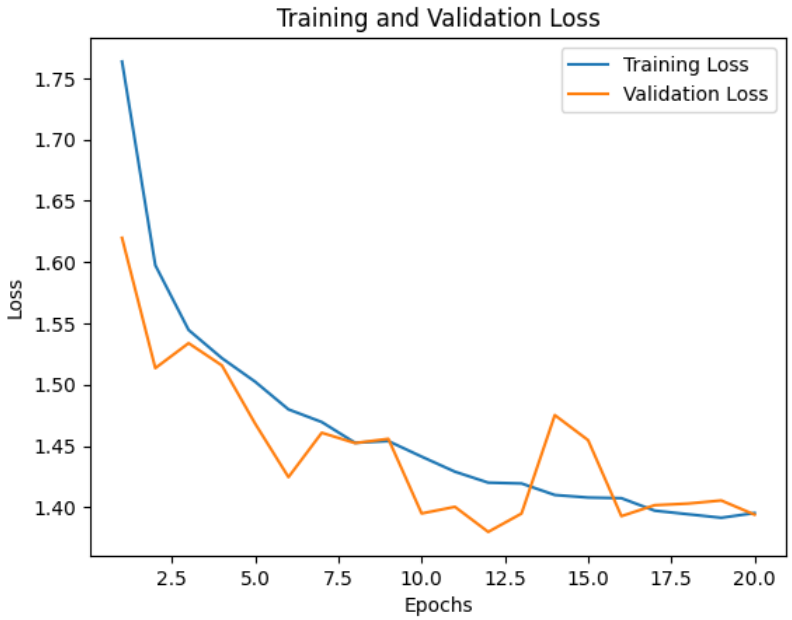
```
Accuracy of plane: 79.3%
Accuracy of car: 83.2%
Accuracy of bird: 65.9%
Accuracy of cat: 47.0%
Accuracy of deer: 62.4%
Accuracy of dog: 59.1%
Accuracy of frog: 75.3%
Accuracy of horse: 85.6%
Accuracy of ship: 87.4%
Accuracy of truck: 82.8%
```

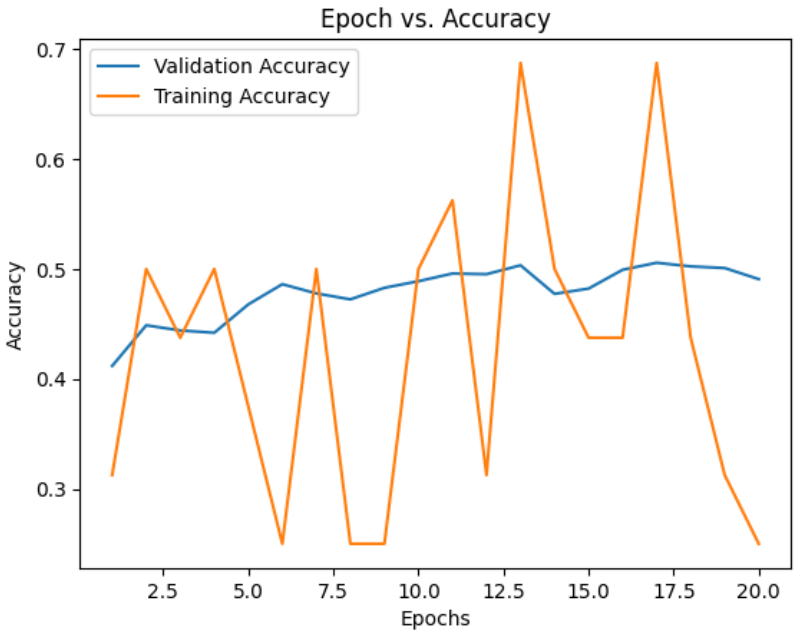
Per-epoch loss and accuracy values.

```
Epoch [1/20, Train Loss: 1.5936, Train Acc: 0.1875,Val Loss: 1.4183, Val Acc: 0.4834
Epoch [2/20, Train Loss: 1.2761, Train Acc: 0.5625,Val Loss: 1.1907, Val Acc: 0.5755
Epoch [3/20, Train Loss: 1.1387, Train Acc: 0.6875,Val Loss: 1.1325, Val Acc: 0.6019
Epoch [4/20, Train Loss: 1.0500, Train Acc: 0.6875,Val Loss: 1.0654, Val Acc: 0.6224
Epoch [5/20, Train Loss: 0.9826, Train Acc: 0.5000,Val Loss: 0.9804, Val Acc: 0.6516
Epoch [6/20, Train Loss: 0.9384, Train Acc: 0.6250,Val Loss: 0.9403, Val Acc: 0.6679
Epoch [7/20, Train Loss: 0.9021, Train Acc: 0.6250,Val Loss: 0.9089, Val Acc: 0.6882
Epoch [8/20, Train Loss: 0.8753, Train Acc: 0.6875,Val Loss: 0.8794, Val Acc: 0.6917
Epoch [9/20, Train Loss: 0.8493, Train Acc: 0.6250,Val Loss: 0.8574, Val Acc: 0.6959
Epoch [10/20, Train Loss: 0.8301, Train Acc: 0.6875,Val Loss: 0.8475, Val Acc: 0.7039
Epoch [11/20, Train Loss: 0.8059, Train Acc: 0.5625,Val Loss: 0.8623, Val Acc: 0.7029
Epoch [12/20, Train Loss: 0.7897, Train Acc: 0.9375,Val Loss: 0.8153, Val Acc: 0.7229
Epoch [13/20, Train Loss: 0.7764, Train Acc: 0.5625,Val Loss: 0.7949, Val Acc: 0.7222
Epoch [14/20, Train Loss: 0.7606, Train Acc: 0.8125,Val Loss: 0.8394, Val Acc: 0.7122
Epoch [15/20, Train Loss: 0.7510, Train Acc: 0.6875,Val Loss: 0.8016, Val Acc: 0.7194
Epoch [16/20, Train Loss: 0.7405, Train Acc: 0.8750,Val Loss: 0.7825, Val Acc: 0.7274
Epoch [17/20, Train Loss: 0.7320, Train Acc: 0.8750,Val Loss: 0.7567, Val Acc: 0.7366
Epoch [18/20, Train Loss: 0.7149, Train Acc: 0.6875,Val Loss: 0.7593, Val Acc: 0.7355
Epoch [19/20, Train Loss: 0.7133, Train Acc: 0.7500,Val Loss: 0.7525, Val Acc: 0.7427
Epoch [20/20, Train Loss: 0.7006, Train Acc: 0.6250,Val Loss: 0.7804, Val Acc: 0.7271
```

Lr = 0.005

Plots





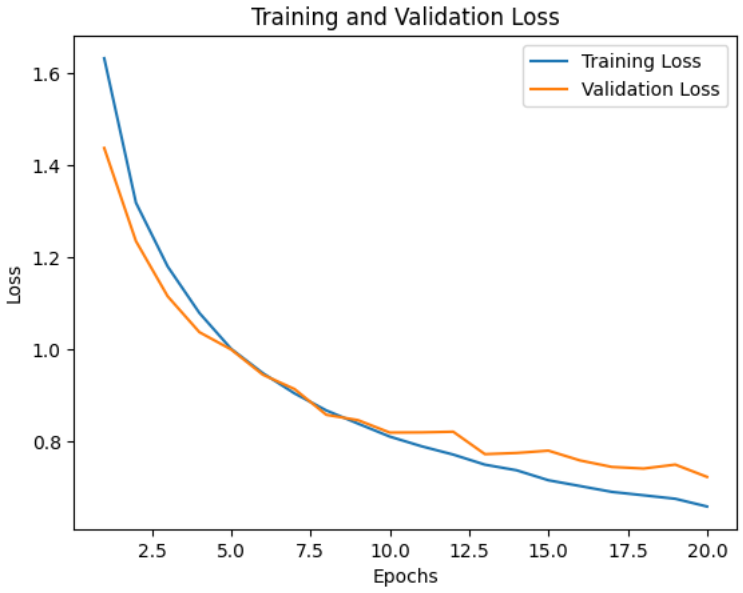
Class-wise Accuracy

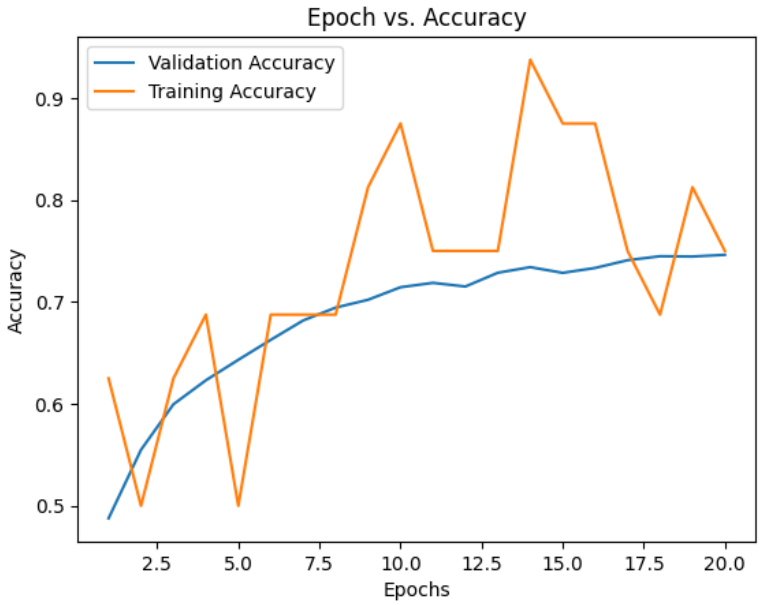
```
Accuracy of plane: 50.2%
Accuracy of car: 47.8%
Accuracy of bird: 40.3%
Accuracy of cat: 14.9%
Accuracy of deer: 27.2%
Accuracy of dog: 69.5%
Accuracy of frog: 72.6%
Accuracy of horse: 45.3%
Accuracy of ship: 68.1%
Accuracy of truck: 66.8%
```

Per-epoch loss and accuracy values.

```
Epoch [1/20, Train Loss: 1.7637, Train Acc: 0.3125,Val Loss: 1.6198, Val Acc: 0.4118
Epoch [2/20, Train Loss: 1.5974, Train Acc: 0.5000,Val Loss: 1.5135, Val Acc: 0.4488
Epoch [3/20, Train Loss: 1.5446, Train Acc: 0.4375,Val Loss: 1.5338, Val Acc: 0.4441
Epoch [4/20, Train Loss: 1.5216, Train Acc: 0.5000,Val Loss: 1.5157, Val Acc: 0.4420
Epoch [5/20, Train Loss: 1.5024, Train Acc: 0.3750,Val Loss: 1.4681, Val Acc: 0.4678
Epoch [6/20, Train Loss: 1.4798, Train Acc: 0.2500,Val Loss: 1.4245, Val Acc: 0.4862
Epoch [7/20, Train Loss: 1.4695, Train Acc: 0.5000,Val Loss: 1.4607, Val Acc: 0.4778
Epoch [8/20, Train Loss: 1.4526, Train Acc: 0.2500,Val Loss: 1.4523, Val Acc: 0.4724
Epoch [9/20, Train Loss: 1.4540, Train Acc: 0.2500,Val Loss: 1.4558, Val Acc: 0.4829
Epoch [10/20, Train Loss: 1.4413, Train Acc: 0.5000,Val Loss: 1.3949, Val Acc: 0.4889
Epoch [11/20, Train Loss: 1.4290, Train Acc: 0.5625,Val Loss: 1.4003, Val Acc: 0.4959
Epoch [12/20, Train Loss: 1.4200, Train Acc: 0.3125,Val Loss: 1.3799, Val Acc: 0.4953
Epoch [13/20, Train Loss: 1.4194, Train Acc: 0.6875,Val Loss: 1.3948, Val Acc: 0.5034
Epoch [14/20, Train Loss: 1.4100, Train Acc: 0.5000,Val Loss: 1.4751, Val Acc: 0.4774
Epoch [15/20, Train Loss: 1.4079, Train Acc: 0.4375,Val Loss: 1.4547, Val Acc: 0.4822
Epoch [16/20, Train Loss: 1.4073, Train Acc: 0.4375,Val Loss: 1.3927, Val Acc: 0.4993
Epoch [17/20, Train Loss: 1.3972, Train Acc: 0.6875,Val Loss: 1.4016, Val Acc: 0.5057
Epoch [18/20, Train Loss: 1.3943, Train Acc: 0.4375,Val Loss: 1.4030, Val Acc: 0.5024
Epoch [19/20, Train Loss: 1.3914, Train Acc: 0.3125,Val Loss: 1.4055, Val Acc: 0.5009
Epoch [20/20, Train Loss: 1.3952, Train Acc: 0.2500,Val Loss: 1.3939, Val Acc: 0.4908
```

Lr = 0.0005





Class-wise Accuracy

```
Accuracy of plane: 76.8%
Accuracy of car: 88.6%
Accuracy of bird: 66.4%
Accuracy of cat: 53.0%
Accuracy of deer: 76.6%
Accuracy of dog: 57.2%
Accuracy of frog: 83.6%
Accuracy of horse: 82.3%
Accuracy of ship: 83.3%
Accuracy of truck: 83.3%
```

Per-epoch loss and accuracy values.

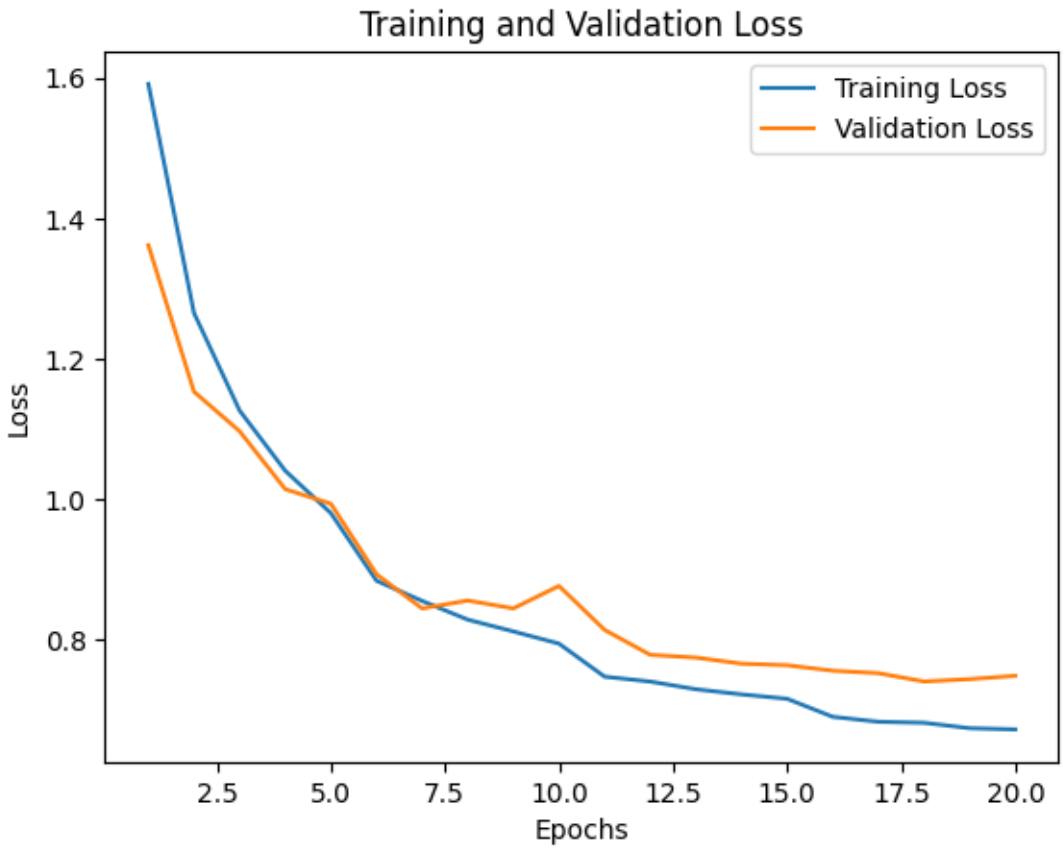
```
Epoch [1/20, Train Loss: 1.6335, Train Acc: 0.6250,Val Loss: 1.4383, Val Acc: 0.4877
Epoch [2/20, Train Loss: 1.3193, Train Acc: 0.5000,Val Loss: 1.2358, Val Acc: 0.5549
Epoch [3/20, Train Loss: 1.1807, Train Acc: 0.6250,Val Loss: 1.1158, Val Acc: 0.5996
Epoch [4/20, Train Loss: 1.0796, Train Acc: 0.6875,Val Loss: 1.0379, Val Acc: 0.6231
Epoch [5/20, Train Loss: 1.0016, Train Acc: 0.5000,Val Loss: 1.0002, Val Acc: 0.6432
Epoch [6/20, Train Loss: 0.9487, Train Acc: 0.6875,Val Loss: 0.9454, Val Acc: 0.6628
Epoch [7/20, Train Loss: 0.9047, Train Acc: 0.6875,Val Loss: 0.9141, Val Acc: 0.6818
Epoch [8/20, Train Loss: 0.8677, Train Acc: 0.6875,Val Loss: 0.8582, Val Acc: 0.6944
Epoch [9/20, Train Loss: 0.8390, Train Acc: 0.8125,Val Loss: 0.8465, Val Acc: 0.7021
Epoch [10/20, Train Loss: 0.8108, Train Acc: 0.8750,Val Loss: 0.8196, Val Acc: 0.7144
Epoch [11/20, Train Loss: 0.7898, Train Acc: 0.7500,Val Loss: 0.8200, Val Acc: 0.7187
Epoch [12/20, Train Loss: 0.7717, Train Acc: 0.7500,Val Loss: 0.8214, Val Acc: 0.7151
Epoch [13/20, Train Loss: 0.7497, Train Acc: 0.7500,Val Loss: 0.7726, Val Acc: 0.7286
Epoch [14/20, Train Loss: 0.7375, Train Acc: 0.9375,Val Loss: 0.7752, Val Acc: 0.7341
Epoch [15/20, Train Loss: 0.7159, Train Acc: 0.8750,Val Loss: 0.7802, Val Acc: 0.7285
Epoch [16/20, Train Loss: 0.7032, Train Acc: 0.8750,Val Loss: 0.7589, Val Acc: 0.7333
Epoch [17/20, Train Loss: 0.6906, Train Acc: 0.7500,Val Loss: 0.7448, Val Acc: 0.7409
Epoch [18/20, Train Loss: 0.6832, Train Acc: 0.6875,Val Loss: 0.7413, Val Acc: 0.7448
Epoch [19/20, Train Loss: 0.6756, Train Acc: 0.8125,Val Loss: 0.7499, Val Acc: 0.7445
Epoch [20/20, Train Loss: 0.6588, Train Acc: 0.7500,Val Loss: 0.7232, Val Acc: 0.7462
```

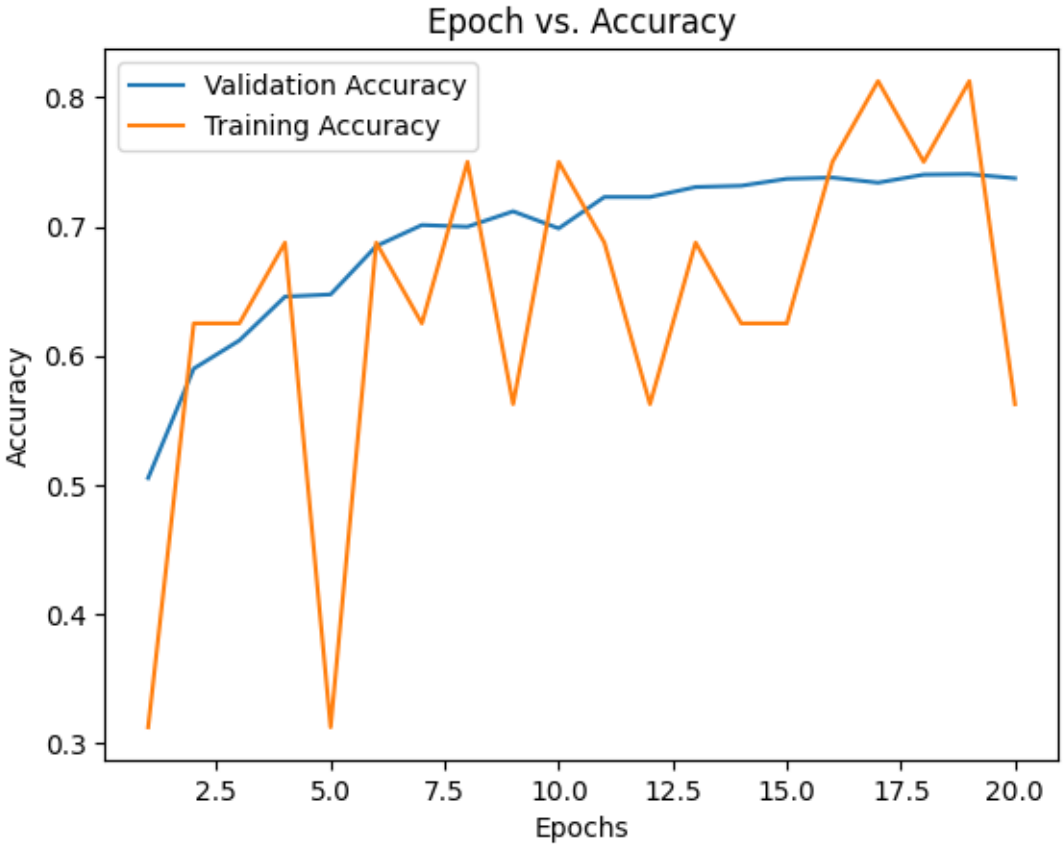
2. Variation in LR:

Using StepLR with step_size = 5, and gamma=0.5.

I found that using stepLR is actually helpful. It converges better and more stable manner to the optimum. Without the scheduler, I did get to 0.74 but it only stayed there for one epoch and then oscillated. But down below, we can see a very smooth curve. I experimented with different gamma and step_size and settled on this.

Plots





Class-wise Accuracy

```
Accuracy of plane: 80.9%
Accuracy of car: 85.8%
Accuracy of bird: 68.4%
Accuracy of cat: 52.3%
Accuracy of deer: 64.1%
Accuracy of dog: 66.1%
Accuracy of frog: 77.6%
Accuracy of horse: 78.7%
Accuracy of ship: 85.8%
Accuracy of truck: 81.9%
```

Per-epoch loss and accuracy values.

```
Epoch [1/20, Train Loss: 1.5913, Train Acc: 0.3125,Val Loss: 1.3615, Val Acc: 0.5053
Epoch [2/20, Train Loss: 1.2648, Train Acc: 0.6250,Val Loss: 1.1527, Val Acc: 0.5900
Epoch [3/20, Train Loss: 1.1257, Train Acc: 0.6250,Val Loss: 1.0963, Val Acc: 0.6118
Epoch [4/20, Train Loss: 1.0399, Train Acc: 0.6875,Val Loss: 1.0137, Val Acc: 0.6457
Epoch [5/20, Train Loss: 0.9796, Train Acc: 0.3125,Val Loss: 0.9929, Val Acc: 0.6474
Epoch [6/20, Train Loss: 0.8832, Train Acc: 0.6875,Val Loss: 0.8924, Val Acc: 0.6848
Epoch [7/20, Train Loss: 0.8544, Train Acc: 0.6250,Val Loss: 0.8437, Val Acc: 0.7011
Epoch [8/20, Train Loss: 0.8277, Train Acc: 0.7500,Val Loss: 0.8549, Val Acc: 0.6998
Epoch [9/20, Train Loss: 0.8109, Train Acc: 0.5625,Val Loss: 0.8437, Val Acc: 0.7117
Epoch [10/20, Train Loss: 0.7935, Train Acc: 0.7500,Val Loss: 0.8758, Val Acc: 0.6985
Epoch [11/20, Train Loss: 0.7464, Train Acc: 0.6875,Val Loss: 0.8131, Val Acc: 0.7228
Epoch [12/20, Train Loss: 0.7394, Train Acc: 0.5625,Val Loss: 0.7775, Val Acc: 0.7228
Epoch [13/20, Train Loss: 0.7285, Train Acc: 0.6875,Val Loss: 0.7736, Val Acc: 0.7305
Epoch [14/20, Train Loss: 0.7211, Train Acc: 0.6250,Val Loss: 0.7650, Val Acc: 0.7315
Epoch [15/20, Train Loss: 0.7149, Train Acc: 0.6250,Val Loss: 0.7627, Val Acc: 0.7369
Epoch [16/20, Train Loss: 0.6892, Train Acc: 0.7500,Val Loss: 0.7549, Val Acc: 0.7378
Epoch [17/20, Train Loss: 0.6821, Train Acc: 0.8125,Val Loss: 0.7514, Val Acc: 0.7339
Epoch [18/20, Train Loss: 0.6807, Train Acc: 0.7500,Val Loss: 0.7396, Val Acc: 0.7401
Epoch [19/20, Train Loss: 0.6729, Train Acc: 0.8125,Val Loss: 0.7428, Val Acc: 0.7405
Epoch [20/20, Train Loss: 0.6713, Train Acc: 0.5625,Val Loss: 0.7476, Val Acc: 0.7373
```

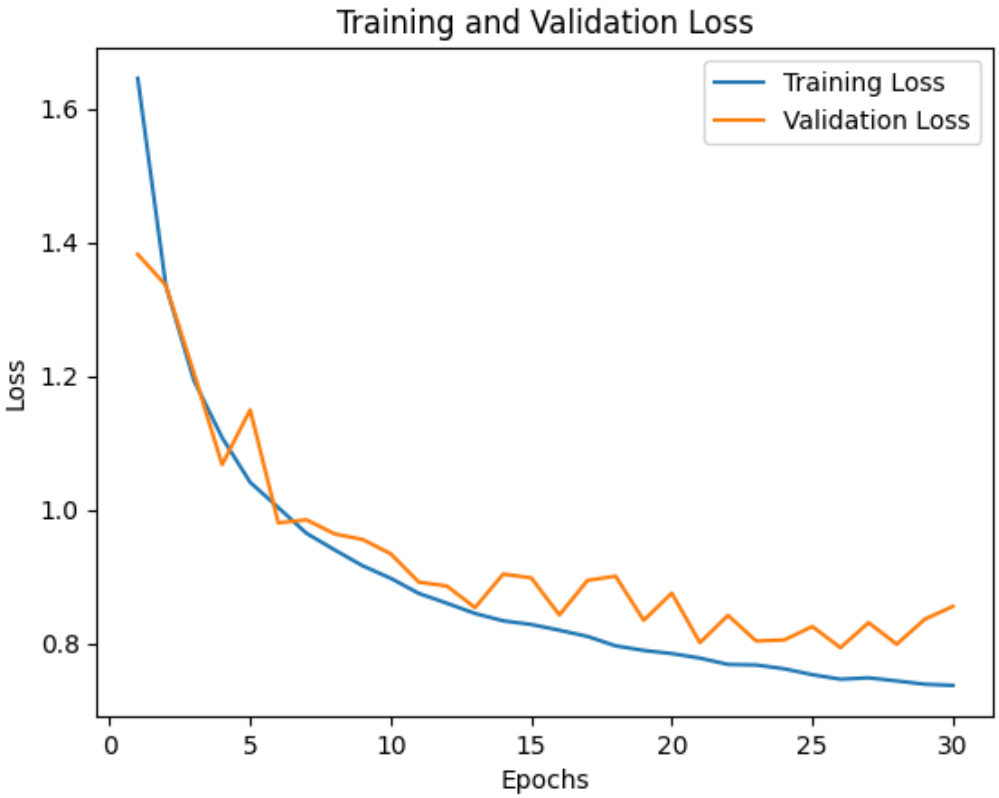
3. Number of Training epochs.

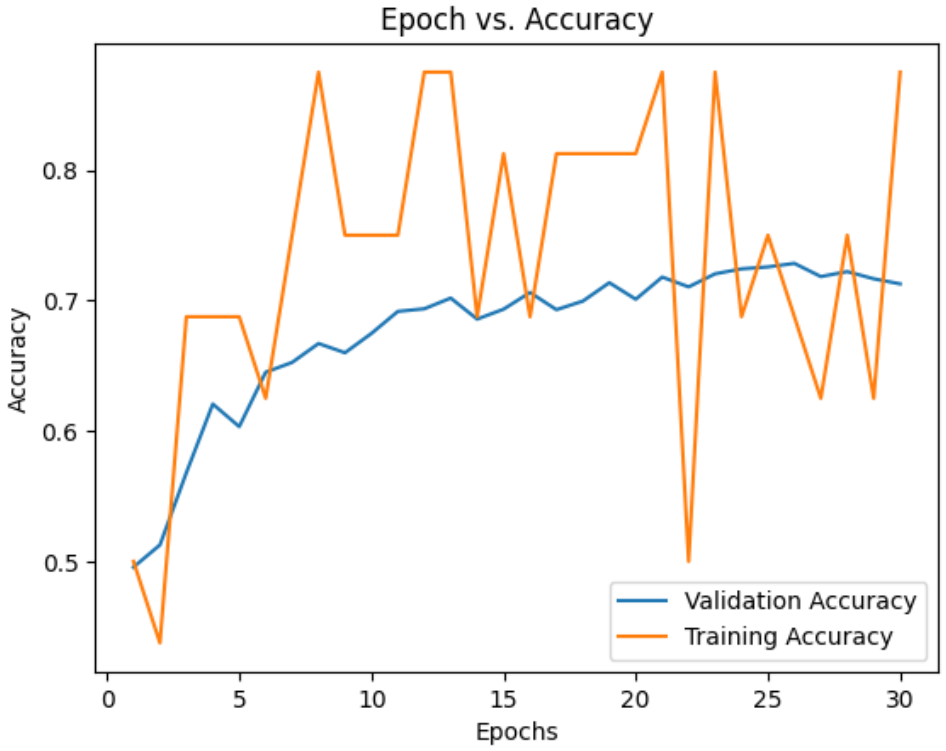
num_epochs = 30

batch_size = 16

learning_rate = 0.001

Increasing the number of epochs is good, but after a point it starts to overfit and validation performance in terms of both accuracy and loss begins to come down. In the below plot, we can see it just saturating and beginning to decrease. It is expected as after some time, the model will start fitting to the noise in the training data, rather than the patterns, which can help for validation task performance.


Training and Validation Loss
Training Loss
Validation Loss
Loss
1.6
1.4
1.2
1.0
0.8
0
5
10
15
20
25
30
Epochs


Epoch vs. Accuracy
Accuracy
0.8
0.7
0.6
0.5
Validation Accuracy
Training Accuracy
0
5
10
15
20
25
30
Epochs

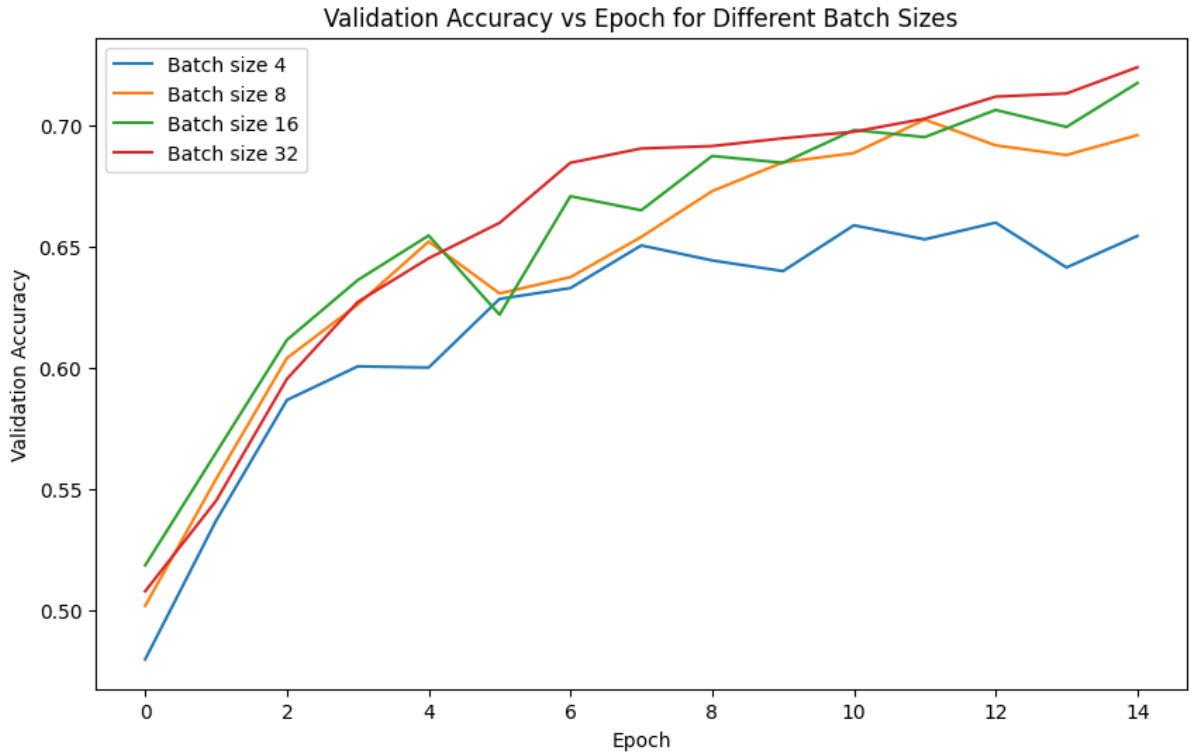
```
Epoch [1/30, Train Loss: 1.6451, Train Acc: 0.5000,Val Loss: 1.3821, Val Acc: 0.4956
Epoch [2/30, Train Loss: 1.3351, Train Acc: 0.4375,Val Loss: 1.3357, Val Acc: 0.5126
Epoch [3/30, Train Loss: 1.1934, Train Acc: 0.6875,Val Loss: 1.2044, Val Acc: 0.5680
Epoch [4/30, Train Loss: 1.1081, Train Acc: 0.6875,Val Loss: 1.0675, Val Acc: 0.6206
Epoch [5/30, Train Loss: 1.0411, Train Acc: 0.6875,Val Loss: 1.1495, Val Acc: 0.6033
Epoch [6/30, Train Loss: 1.0034, Train Acc: 0.6250,Val Loss: 0.9804, Val Acc: 0.6450
Epoch [7/30, Train Loss: 0.9650, Train Acc: 0.7500,Val Loss: 0.9852, Val Acc: 0.6525
Epoch [8/30, Train Loss: 0.9402, Train Acc: 0.8750,Val Loss: 0.9641, Val Acc: 0.6670
Epoch [9/30, Train Loss: 0.9164, Train Acc: 0.7500,Val Loss: 0.9557, Val Acc: 0.6599
Epoch [10/30, Train Loss: 0.8976, Train Acc: 0.7500,Val Loss: 0.9343, Val Acc: 0.6747
Epoch [11/30, Train Loss: 0.8750, Train Acc: 0.7500,Val Loss: 0.8919, Val Acc: 0.6916
Epoch [12/30, Train Loss: 0.8603, Train Acc: 0.8750,Val Loss: 0.8860, Val Acc: 0.6936
Epoch [13/30, Train Loss: 0.8450, Train Acc: 0.8750,Val Loss: 0.8538, Val Acc: 0.7018
Epoch [14/30, Train Loss: 0.8340, Train Acc: 0.6875,Val Loss: 0.9039, Val Acc: 0.6857
Epoch [15/30, Train Loss: 0.8286, Train Acc: 0.8125,Val Loss: 0.8983, Val Acc: 0.6933
Epoch [16/30, Train Loss: 0.8200, Train Acc: 0.6875,Val Loss: 0.8428, Val Acc: 0.7061
Epoch [17/30, Train Loss: 0.8107, Train Acc: 0.8125,Val Loss: 0.8945, Val Acc: 0.6929
Epoch [18/30, Train Loss: 0.7966, Train Acc: 0.8125,Val Loss: 0.9008, Val Acc: 0.6995
Epoch [19/30, Train Loss: 0.7898, Train Acc: 0.8125,Val Loss: 0.8348, Val Acc: 0.7136
Epoch [20/30, Train Loss: 0.7850, Train Acc: 0.8125,Val Loss: 0.8754, Val Acc: 0.7009
Epoch [21/30, Train Loss: 0.7783, Train Acc: 0.8750,Val Loss: 0.8013, Val Acc: 0.7179
Epoch [22/30, Train Loss: 0.7688, Train Acc: 0.5000,Val Loss: 0.8422, Val Acc: 0.7104
Epoch [23/30, Train Loss: 0.7680, Train Acc: 0.8750,Val Loss: 0.8039, Val Acc: 0.7204
Epoch [24/30, Train Loss: 0.7623, Train Acc: 0.6875,Val Loss: 0.8054, Val Acc: 0.7242
Epoch [25/30, Train Loss: 0.7535, Train Acc: 0.7500,Val Loss: 0.8256, Val Acc: 0.7257
Epoch [26/30, Train Loss: 0.7467, Train Acc: 0.6875,Val Loss: 0.7939, Val Acc: 0.7284
Epoch [27/30, Train Loss: 0.7488, Train Acc: 0.6250,Val Loss: 0.8314, Val Acc: 0.7183
Epoch [28/30, Train Loss: 0.7442, Train Acc: 0.7500,Val Loss: 0.7990, Val Acc: 0.7221
Epoch [29/30, Train Loss: 0.7392, Train Acc: 0.6250,Val Loss: 0.8364, Val Acc: 0.7166
Epoch [30/30, Train Loss: 0.7375, Train Acc: 0.8750,Val Loss: 0.8557, Val Acc: 0.7127
```

4.Batch size:

[4,8,16,32]

Num_epochs =15.

When you vary the batch size from 4 to 32, the validation accuracy increases as the number of epochs increase. This is because we have lesser noise with more batch size and better convergence with same number of epochs. Also, more stable and smooth curve for 32, compared to rocky for 4.



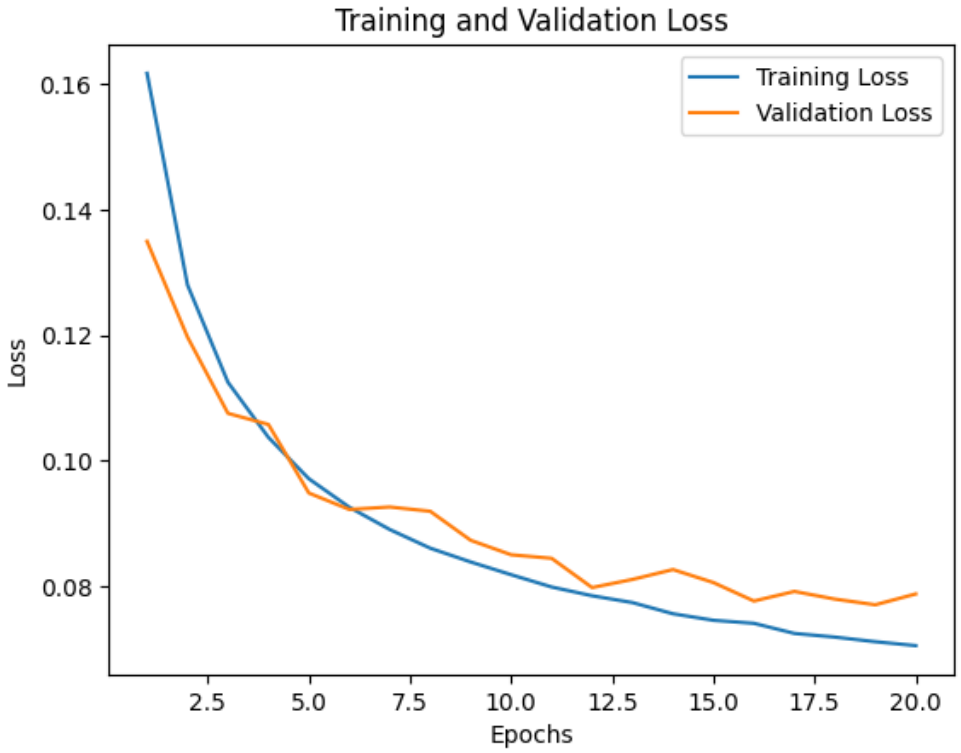

```
Training with batch size 4...
Files already downloaded and verified
Epoch [1/15, Train Loss: 1.6219, Train Acc: 0.7500,Val Loss: 1.4217, Val Acc: 0.4796
Epoch [2/15, Train Loss: 1.3420, Train Acc: 0.2500,Val Loss: 1.2972, Val Acc: 0.5368
Epoch [3/15, Train Loss: 1.2402, Train Acc: 0.5000,Val Loss: 1.1675, Val Acc: 0.5866
Epoch [4/15, Train Loss: 1.1758, Train Acc: 0.0000,Val Loss: 1.1432, Val Acc: 0.6005
Epoch [5/15, Train Loss: 1.1320, Train Acc: 0.7500,Val Loss: 1.1288, Val Acc: 0.6000
Epoch [6/15, Train Loss: 1.1014, Train Acc: 0.5000,Val Loss: 1.0685, Val Acc: 0.6283
Epoch [7/15, Train Loss: 1.0825, Train Acc: 0.5000,Val Loss: 1.0700, Val Acc: 0.6328
Epoch [8/15, Train Loss: 1.0551, Train Acc: 0.7500,Val Loss: 1.0134, Val Acc: 0.6504
Epoch [9/15, Train Loss: 1.0470, Train Acc: 1.0000,Val Loss: 1.0219, Val Acc: 0.6442
Epoch [10/15, Train Loss: 1.0324, Train Acc: 0.2500,Val Loss: 1.0529, Val Acc: 0.6398
Epoch [11/15, Train Loss: 1.0192, Train Acc: 0.2500,Val Loss: 0.9978, Val Acc: 0.6587
Epoch [12/15, Train Loss: 1.0023, Train Acc: 0.7500,Val Loss: 1.0249, Val Acc: 0.6529
Epoch [13/15, Train Loss: 0.9953, Train Acc: 0.7500,Val Loss: 0.9977, Val Acc: 0.6598
Epoch [14/15, Train Loss: 0.9933, Train Acc: 0.7500,Val Loss: 1.0888, Val Acc: 0.6413
Epoch [15/15, Train Loss: 0.9795, Train Acc: 0.7500,Val Loss: 1.0232, Val Acc: 0.6543
Training with batch size 8...
Files already downloaded and verified
Epoch [1/15, Train Loss: 1.5848, Train Acc: 0.3750,Val Loss: 1.3601, Val Acc: 0.5017
Epoch [2/15, Train Loss: 1.2715, Train Acc: 0.7500,Val Loss: 1.2432, Val Acc: 0.5540
Epoch [3/15, Train Loss: 1.1549, Train Acc: 0.7500,Val Loss: 1.1279, Val Acc: 0.6039
Epoch [4/15, Train Loss: 1.0883, Train Acc: 0.5000,Val Loss: 1.0636, Val Acc: 0.6260
Epoch [5/15, Train Loss: 1.0370, Train Acc: 0.7500,Val Loss: 1.0076, Val Acc: 0.6520
Epoch [6/15, Train Loss: 0.9954, Train Acc: 0.7500,Val Loss: 1.0517, Val Acc: 0.6306
Epoch [7/15, Train Loss: 0.9692, Train Acc: 0.5000,Val Loss: 1.0556, Val Acc: 0.6373
Epoch [8/15, Train Loss: 0.9419, Train Acc: 0.6250,Val Loss: 1.0100, Val Acc: 0.6539
Epoch [9/15, Train Loss: 0.9289, Train Acc: 0.8750,Val Loss: 0.9464, Val Acc: 0.6728
Epoch [10/15, Train Loss: 0.9064, Train Acc: 0.7500,Val Loss: 0.9067, Val Acc: 0.6847
Epoch [11/15, Train Loss: 0.8897, Train Acc: 0.7500,Val Loss: 0.9030, Val Acc: 0.6885
Epoch [12/15, Train Loss: 0.8881, Train Acc: 1.0000,Val Loss: 0.8918, Val Acc: 0.7023
Epoch [13/15, Train Loss: 0.8704, Train Acc: 0.8750,Val Loss: 0.9113, Val Acc: 0.6917
Epoch [14/15, Train Loss: 0.8620, Train Acc: 0.5000,Val Loss: 0.9215, Val Acc: 0.6877
Epoch [15/15, Train Loss: 0.8486, Train Acc: 0.5000,Val Loss: 0.9044, Val Acc: 0.6959
Training with batch size 16...
Files already downloaded and verified
Epoch [1/15, Train Loss: 1.5768, Train Acc: 0.6875,Val Loss: 1.3302, Val Acc: 0.5184
Epoch [2/15, Train Loss: 1.2513, Train Acc: 0.5000,Val Loss: 1.2043, Val Acc: 0.5649
Epoch [3/15, Train Loss: 1.1273, Train Acc: 0.6875,Val Loss: 1.0925, Val Acc: 0.6114
Epoch [4/15, Train Loss: 1.0555, Train Acc: 0.8125,Val Loss: 1.0313, Val Acc: 0.6361
Epoch [5/15, Train Loss: 1.0017, Train Acc: 0.7500,Val Loss: 0.9786, Val Acc: 0.6545
Epoch [6/15, Train Loss: 0.9675, Train Acc: 0.4375,Val Loss: 1.0619, Val Acc: 0.6218
Epoch [7/15, Train Loss: 0.9407, Train Acc: 0.6250,Val Loss: 0.9364, Val Acc: 0.6707
Epoch [8/15, Train Loss: 0.9119, Train Acc: 0.8125,Val Loss: 0.9522, Val Acc: 0.6649
Epoch [9/15, Train Loss: 0.8893, Train Acc: 0.5625,Val Loss: 0.9029, Val Acc: 0.6873
```

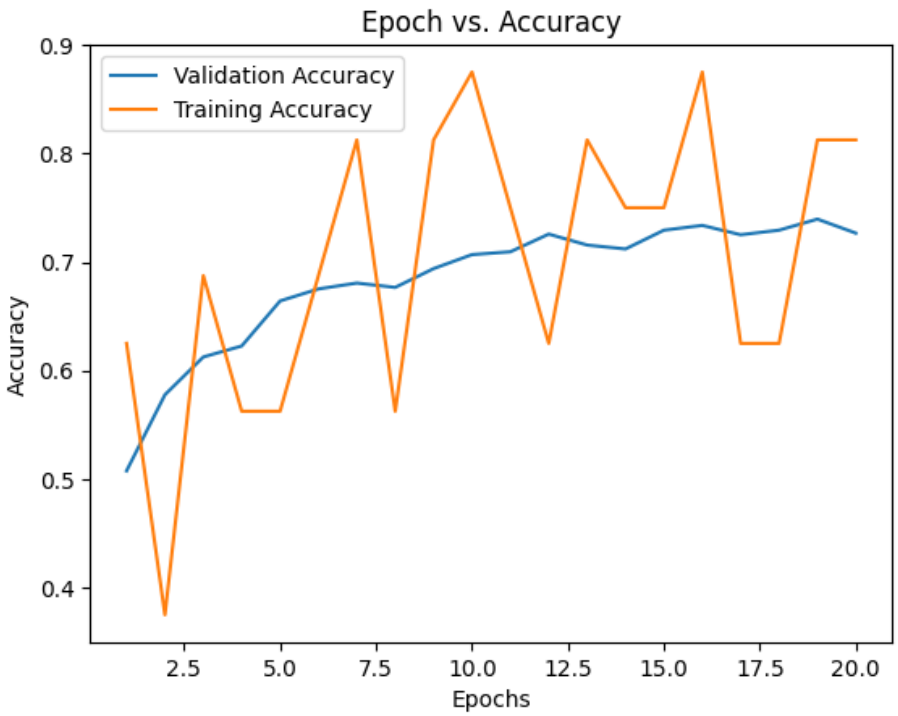
```
Epoch [10/15, Train Loss: 0.8735, Train Acc: 0.5000,Val Loss: 0.8965, Val Acc: 0.6845
Epoch [11/15, Train Loss: 0.8590, Train Acc: 0.7500,Val Loss: 0.8771, Val Acc: 0.6980
Epoch [12/15, Train Loss: 0.8425, Train Acc: 0.5000,Val Loss: 0.8884, Val Acc: 0.6951
Epoch [13/15, Train Loss: 0.8307, Train Acc: 0.8125,Val Loss: 0.8528, Val Acc: 0.7063
Epoch [14/15, Train Loss: 0.8162, Train Acc: 0.7500,Val Loss: 0.8607, Val Acc: 0.6993
Epoch [15/15, Train Loss: 0.8081, Train Acc: 0.8750,Val Loss: 0.8222, Val Acc: 0.7174
Training with batch size 32...
Files already downloaded and verified
Epoch [1/15, Train Loss: 1.6012, Train Acc: 0.5000,Val Loss: 1.3496, Val Acc: 0.5077
Epoch [2/15, Train Loss: 1.2866, Train Acc: 0.6250,Val Loss: 1.2684, Val Acc: 0.5450
Epoch [3/15, Train Loss: 1.1483, Train Acc: 0.5000,Val Loss: 1.1392, Val Acc: 0.5953
Epoch [4/15, Train Loss: 1.0579, Train Acc: 0.6250,Val Loss: 1.0513, Val Acc: 0.6271
Epoch [5/15, Train Loss: 0.9928, Train Acc: 0.8125,Val Loss: 1.0022, Val Acc: 0.6451
Epoch [6/15, Train Loss: 0.9495, Train Acc: 0.6250,Val Loss: 0.9618, Val Acc: 0.6597
Epoch [7/15, Train Loss: 0.9189, Train Acc: 0.8125,Val Loss: 0.9029, Val Acc: 0.6845
Epoch [8/15, Train Loss: 0.8843, Train Acc: 0.5000,Val Loss: 0.8979, Val Acc: 0.6904
Epoch [9/15, Train Loss: 0.8615, Train Acc: 0.8750,Val Loss: 0.9094, Val Acc: 0.6914
Epoch [10/15, Train Loss: 0.8411, Train Acc: 0.6250,Val Loss: 0.8739, Val Acc: 0.6946
Epoch [11/15, Train Loss: 0.8250, Train Acc: 0.5625,Val Loss: 0.8700, Val Acc: 0.6973
Epoch [12/15, Train Loss: 0.8099, Train Acc: 0.6250,Val Loss: 0.8694, Val Acc: 0.7027
Epoch [13/15, Train Loss: 0.7959, Train Acc: 0.6875,Val Loss: 0.8351, Val Acc: 0.7118
Epoch [14/15, Train Loss: 0.7856, Train Acc: 0.6875,Val Loss: 0.8316, Val Acc: 0.7131
Epoch [15/15, Train Loss: 0.7764, Train Acc: 0.8125,Val Loss: 0.8023, Val Acc: 0.7239
```

4.2 Effect of Loss Function

KL divergence is giving a little bit lesser performance in terms of validation loss and accuracy, as expected, because cross-entropy is better suited for CIFAR-10.

Using KL-divergence with batch_size =32, num_epochs =20, lr =0.001,






```
Accuracy of plane: 76.5%
Accuracy of car: 86.6%
Accuracy of bird: 61.1%
Accuracy of cat: 50.7%
Accuracy of deer: 86.3%
Accuracy of dog: 57.2%
Accuracy of frog: 72.0%
Accuracy of horse: 74.7%
Accuracy of ship: 81.8%
Accuracy of truck: 80.4%
```

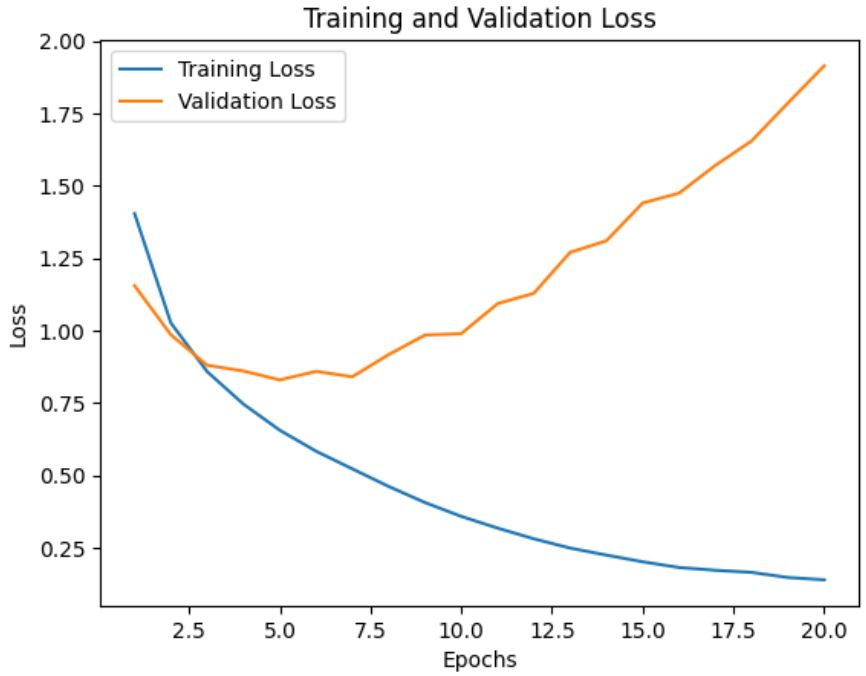
```
Epoch [1/20, Train Loss: 0.1617, Train Acc: 0.6250,Val Loss: 0.1350, Val Acc: 0.5076
Epoch [2/20, Train Loss: 0.1280, Train Acc: 0.3750,Val Loss: 0.1197, Val Acc: 0.5777
Epoch [3/20, Train Loss: 0.1125, Train Acc: 0.6875,Val Loss: 0.1076, Val Acc: 0.6125
Epoch [4/20, Train Loss: 0.1037, Train Acc: 0.5625,Val Loss: 0.1058, Val Acc: 0.6226
Epoch [5/20, Train Loss: 0.0971, Train Acc: 0.5625,Val Loss: 0.0949, Val Acc: 0.6641
Epoch [6/20, Train Loss: 0.0926, Train Acc: 0.6875,Val Loss: 0.0923, Val Acc: 0.6752
Epoch [7/20, Train Loss: 0.0891, Train Acc: 0.8125,Val Loss: 0.0926, Val Acc: 0.6806
Epoch [8/20, Train Loss: 0.0861, Train Acc: 0.5625,Val Loss: 0.0920, Val Acc: 0.6766
Epoch [9/20, Train Loss: 0.0839, Train Acc: 0.8125,Val Loss: 0.0873, Val Acc: 0.6939
Epoch [10/20, Train Loss: 0.0819, Train Acc: 0.8750,Val Loss: 0.0850, Val Acc: 0.7068
Epoch [11/20, Train Loss: 0.0799, Train Acc: 0.7500,Val Loss: 0.0845, Val Acc: 0.7094
Epoch [12/20, Train Loss: 0.0785, Train Acc: 0.6250,Val Loss: 0.0798, Val Acc: 0.7257
Epoch [13/20, Train Loss: 0.0774, Train Acc: 0.8125,Val Loss: 0.0811, Val Acc: 0.7156
Epoch [14/20, Train Loss: 0.0756, Train Acc: 0.7500,Val Loss: 0.0827, Val Acc: 0.7120
Epoch [15/20, Train Loss: 0.0746, Train Acc: 0.7500,Val Loss: 0.0806, Val Acc: 0.7293
Epoch [16/20, Train Loss: 0.0741, Train Acc: 0.8750,Val Loss: 0.0777, Val Acc: 0.7337
Epoch [17/20, Train Loss: 0.0725, Train Acc: 0.6250,Val Loss: 0.0792, Val Acc: 0.7251
Epoch [18/20, Train Loss: 0.0719, Train Acc: 0.6250,Val Loss: 0.0780, Val Acc: 0.7293
Epoch [19/20, Train Loss: 0.0712, Train Acc: 0.8125,Val Loss: 0.0771, Val Acc: 0.7395
Epoch [20/20, Train Loss: 0.0706, Train Acc: 0.8125,Val Loss: 0.0788, Val Acc: 0.7266
```

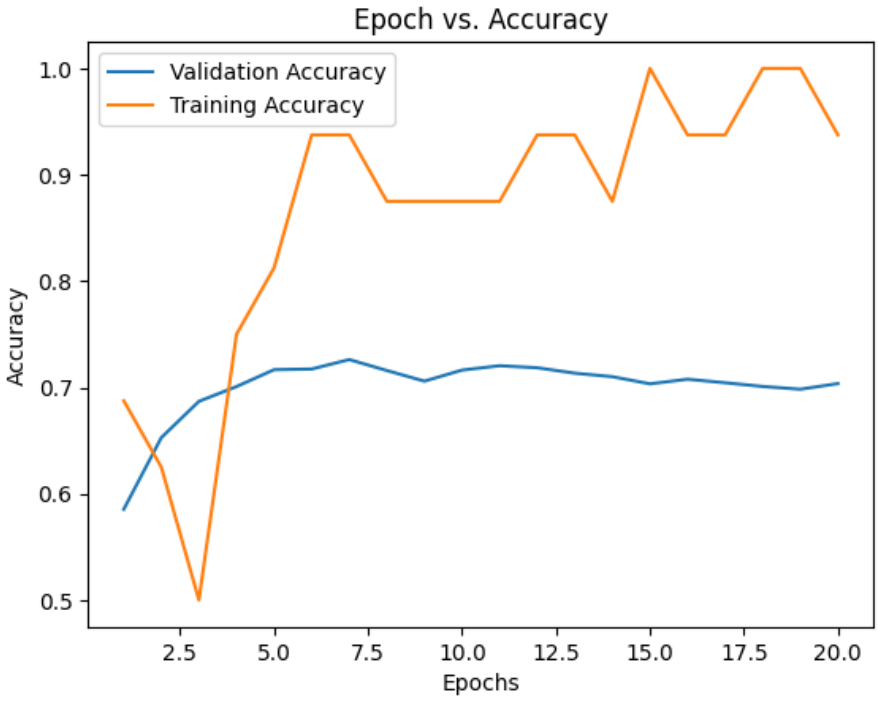
4.2 Effect of Data Augmentation

Clearly, if there is no data agumentation, it starts overfitting very quickly, and validation loss and accuracy both start decreasing from that point.

Clas-wise accuracy is also lower than with augmentation. (compare with the first plots on this report, since lr=0.001, batchsize= 32.)

I applied data augmentation of random rotation, cropping and flipping.





```
Accuracy of plane: 78.0%
Accuracy of car: 86.6%
Accuracy of bird: 60.4%
Accuracy of cat: 45.3%
Accuracy of deer: 64.6%
Accuracy of dog: 64.8%
Accuracy of frog: 81.9%
Accuracy of horse: 67.3%
Accuracy of ship: 80.5%
Accuracy of truck: 74.2%
```

```
Epoch [1/20, Train Loss: 1.4039, Train Acc: 0.6875,Val Loss: 1.1547, Val Acc: 0.5854
Epoch [2/20, Train Loss: 1.0260, Train Acc: 0.6250,Val Loss: 0.9852, Val Acc: 0.6528
Epoch [3/20, Train Loss: 0.8578, Train Acc: 0.5000,Val Loss: 0.8800, Val Acc: 0.6869
Epoch [4/20, Train Loss: 0.7456, Train Acc: 0.7500,Val Loss: 0.8599, Val Acc: 0.7008
Epoch [5/20, Train Loss: 0.6555, Train Acc: 0.8125,Val Loss: 0.8293, Val Acc: 0.7167
Epoch [6/20, Train Loss: 0.5830, Train Acc: 0.9375,Val Loss: 0.8587, Val Acc: 0.7173
Epoch [7/20, Train Loss: 0.5220, Train Acc: 0.9375,Val Loss: 0.8401, Val Acc: 0.7262
Epoch [8/20, Train Loss: 0.4613, Train Acc: 0.8750,Val Loss: 0.9167, Val Acc: 0.7159
Epoch [9/20, Train Loss: 0.4057, Train Acc: 0.8750,Val Loss: 0.9841, Val Acc: 0.7059
Epoch [10/20, Train Loss: 0.3578, Train Acc: 0.8750,Val Loss: 0.9889, Val Acc: 0.7163
Epoch [11/20, Train Loss: 0.3174, Train Acc: 0.8750,Val Loss: 1.0926, Val Acc: 0.7204
Epoch [12/20, Train Loss: 0.2804, Train Acc: 0.9375,Val Loss: 1.1285, Val Acc: 0.7185
Epoch [13/20, Train Loss: 0.2484, Train Acc: 0.9375,Val Loss: 1.2698, Val Acc: 0.7134
Epoch [14/20, Train Loss: 0.2241, Train Acc: 0.8750,Val Loss: 1.3098, Val Acc: 0.7101
Epoch [15/20, Train Loss: 0.2010, Train Acc: 1.0000,Val Loss: 1.4405, Val Acc: 0.7034
Epoch [16/20, Train Loss: 0.1813, Train Acc: 0.9375,Val Loss: 1.4743, Val Acc: 0.7077
Epoch [17/20, Train Loss: 0.1717, Train Acc: 0.9375,Val Loss: 1.5702, Val Acc: 0.7044
Epoch [18/20, Train Loss: 0.1644, Train Acc: 1.0000,Val Loss: 1.6548, Val Acc: 0.7009
Epoch [19/20, Train Loss: 0.1468, Train Acc: 1.0000,Val Loss: 1.7859, Val Acc: 0.6983
Epoch [20/20, Train Loss: 0.1388, Train Acc: 0.9375,Val Loss: 1.9142, Val Acc: 0.7036
```