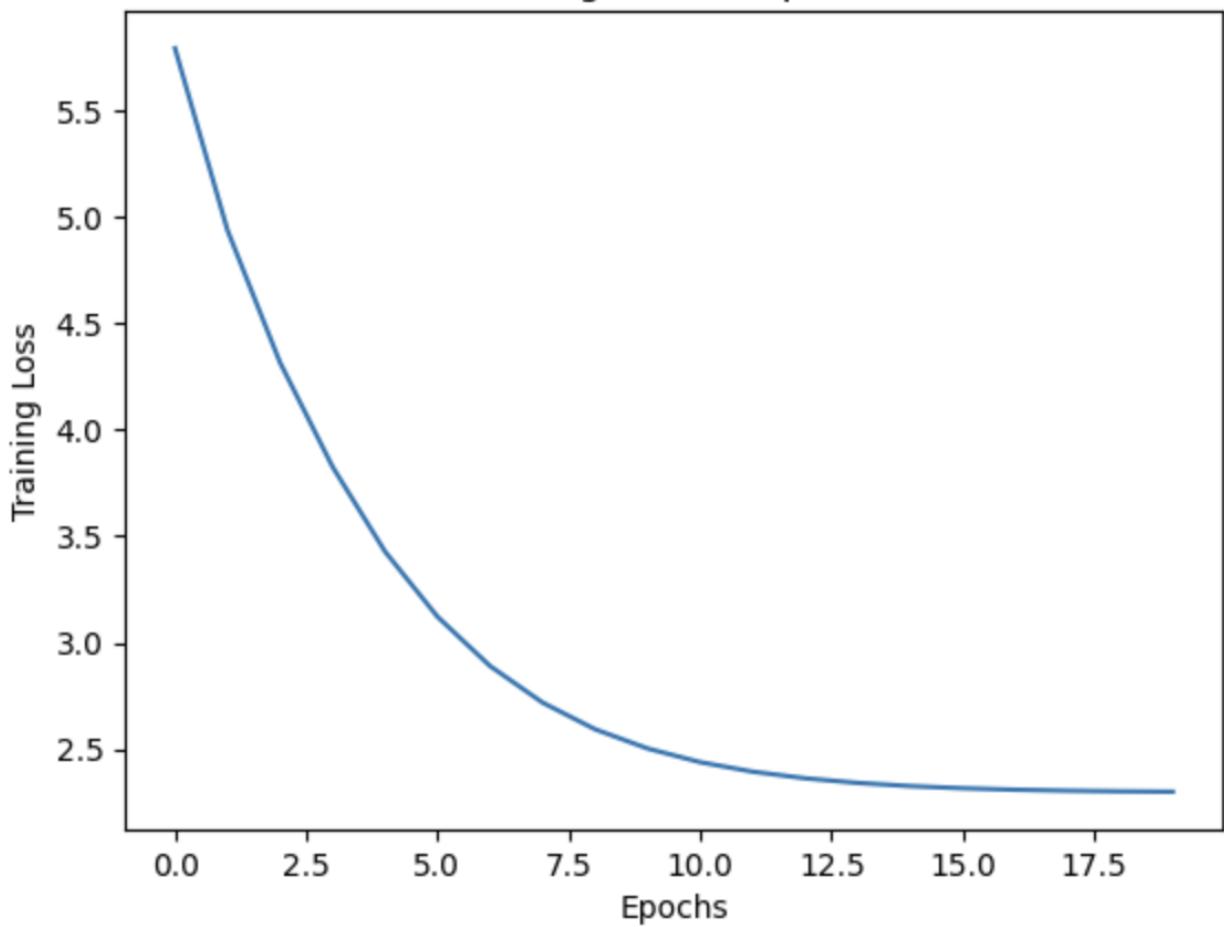


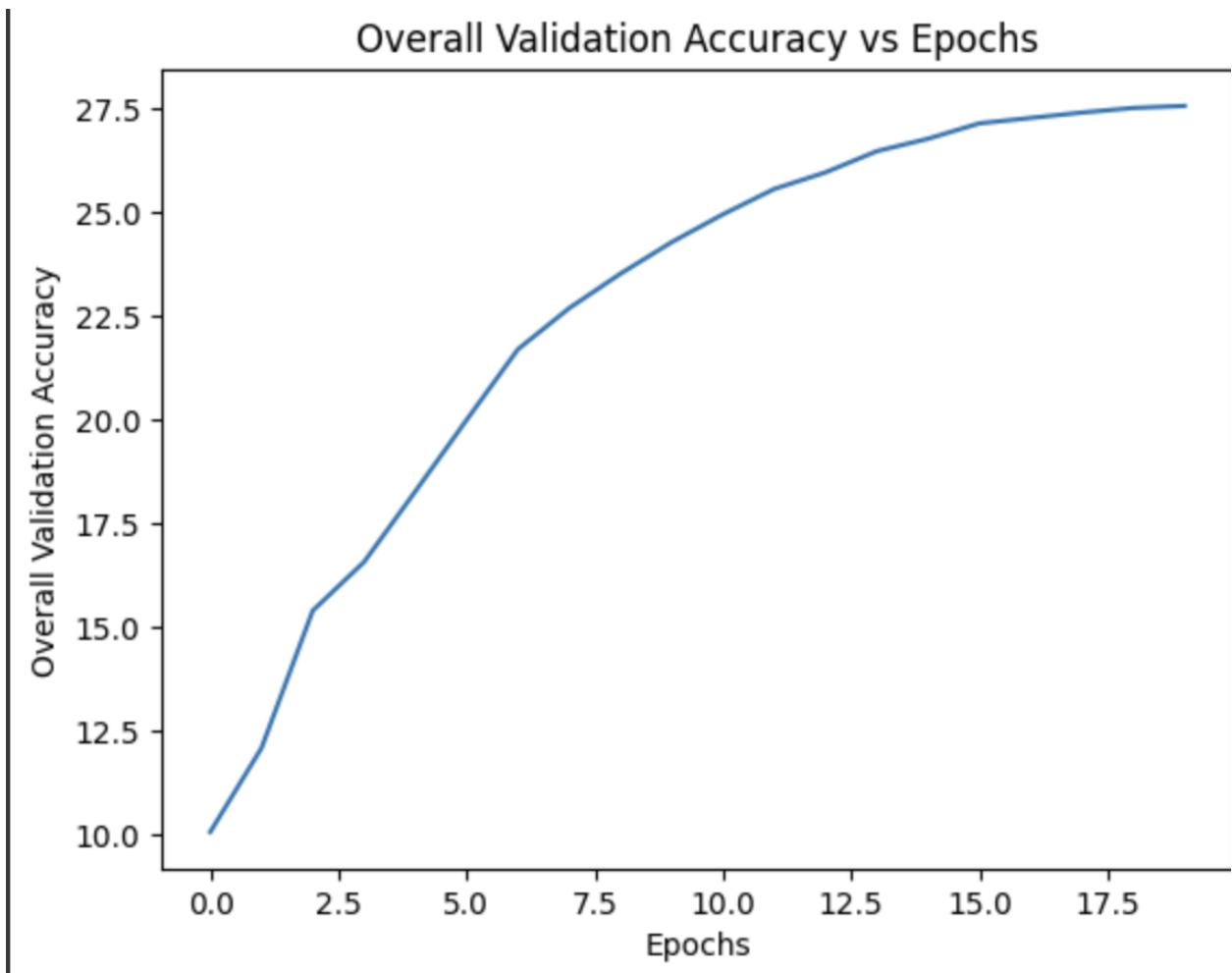
**COL341 - Assignment 4 Report**  
**Eshan Jain**  
**2020CS50424**

**3)**

Iteration: 00000 - Training Loss: 5.78942  
Iteration: 00001 - Training Loss: 4.93530  
Iteration: 00002 - Training Loss: 4.31466  
Iteration: 00003 - Training Loss: 3.82530  
Iteration: 00004 - Training Loss: 3.42730  
Iteration: 00005 - Training Loss: 3.12114  
Iteration: 00006 - Training Loss: 2.88994  
Iteration: 00007 - Training Loss: 2.71838  
Iteration: 00008 - Training Loss: 2.59311  
Iteration: 00009 - Training Loss: 2.50289  
Iteration: 00010 - Training Loss: 2.43873  
Iteration: 00011 - Training Loss: 2.39417  
Iteration: 00012 - Training Loss: 2.36304  
Iteration: 00013 - Training Loss: 2.34140  
Iteration: 00014 - Training Loss: 2.32647  
Iteration: 00015 - Training Loss: 2.31627  
Iteration: 00016 - Training Loss: 2.30939  
Iteration: 00017 - Training Loss: 2.30484  
Iteration: 00018 - Training Loss: 2.30190  
Iteration: 00019 - Training Loss: 2.30008

Training Loss vs Epochs





### Classwise Accuracy:

Class 0 Accuracy: 20.10000  
Class 1 Accuracy: 29.40000  
Class 2 Accuracy: 8.80000  
Class 3 Accuracy: 9.90000  
Class 4 Accuracy: 14.40000  
Class 5 Accuracy: 13.40000  
Class 6 Accuracy: 29.40000  
Class 7 Accuracy: 22.70000  
Class 8 Accuracy: 33.20000  
Class 9 Accuracy: 19.50000

As per my observations, the validation accuracy does constantly increase over the epochs although quite slowly because of the small value of the learning rate. The training loss also decreases consistently over the epochs as expected. Also, 20 epochs turn out to be quite less because the overall validation accuracy could reach only around 30%. Training the model for larger number of epochs would definitely lead to much higher validation accuracies, but it could not be done because of runtime constraints (of 12 hours) on colab.

## 4.1 Hyper-Paramater Tuning

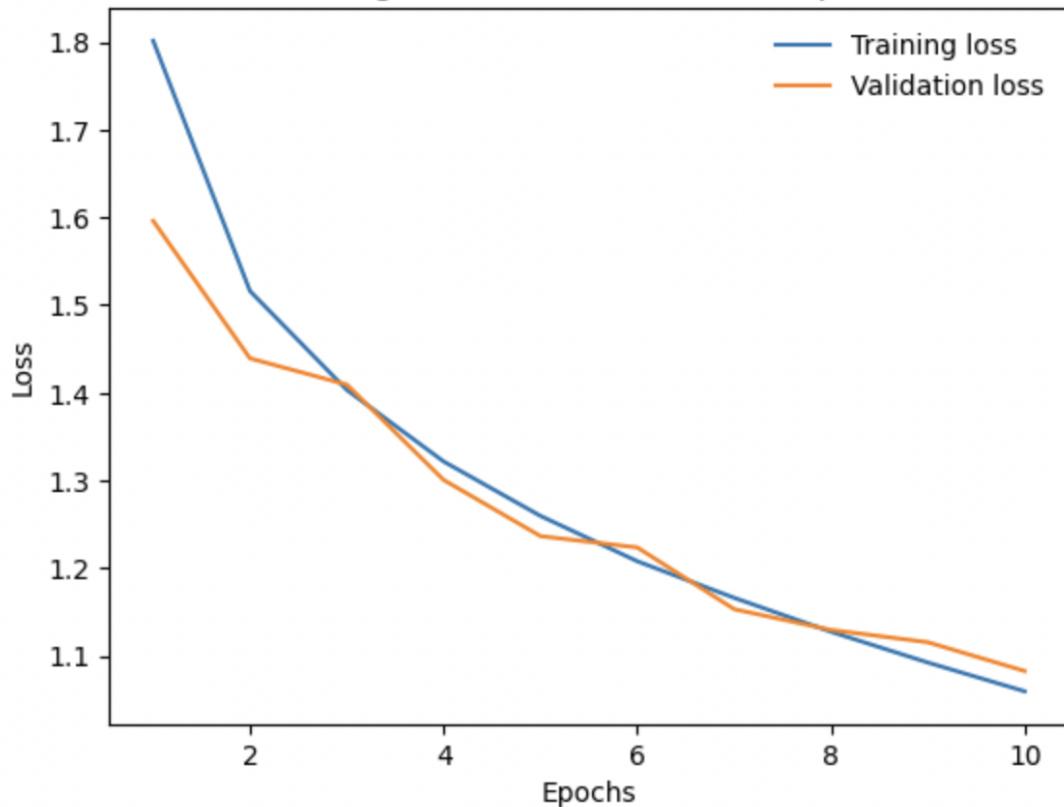
### 1) Learning Rate (LR):

No of epochs = 10, Batch size = 32, Loss Function = Cross Entropy  
a) LR = 0.0001

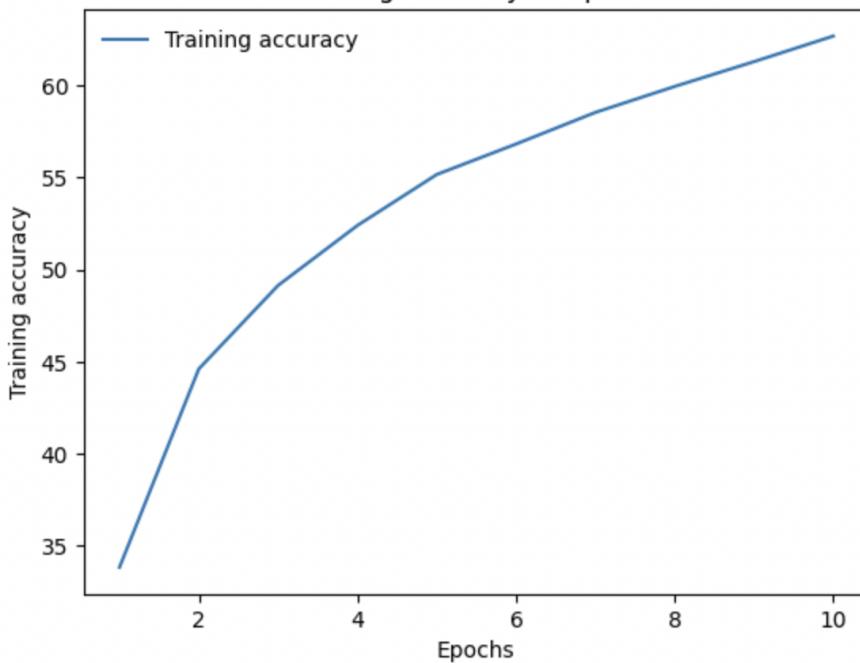
Adam Optimiser:

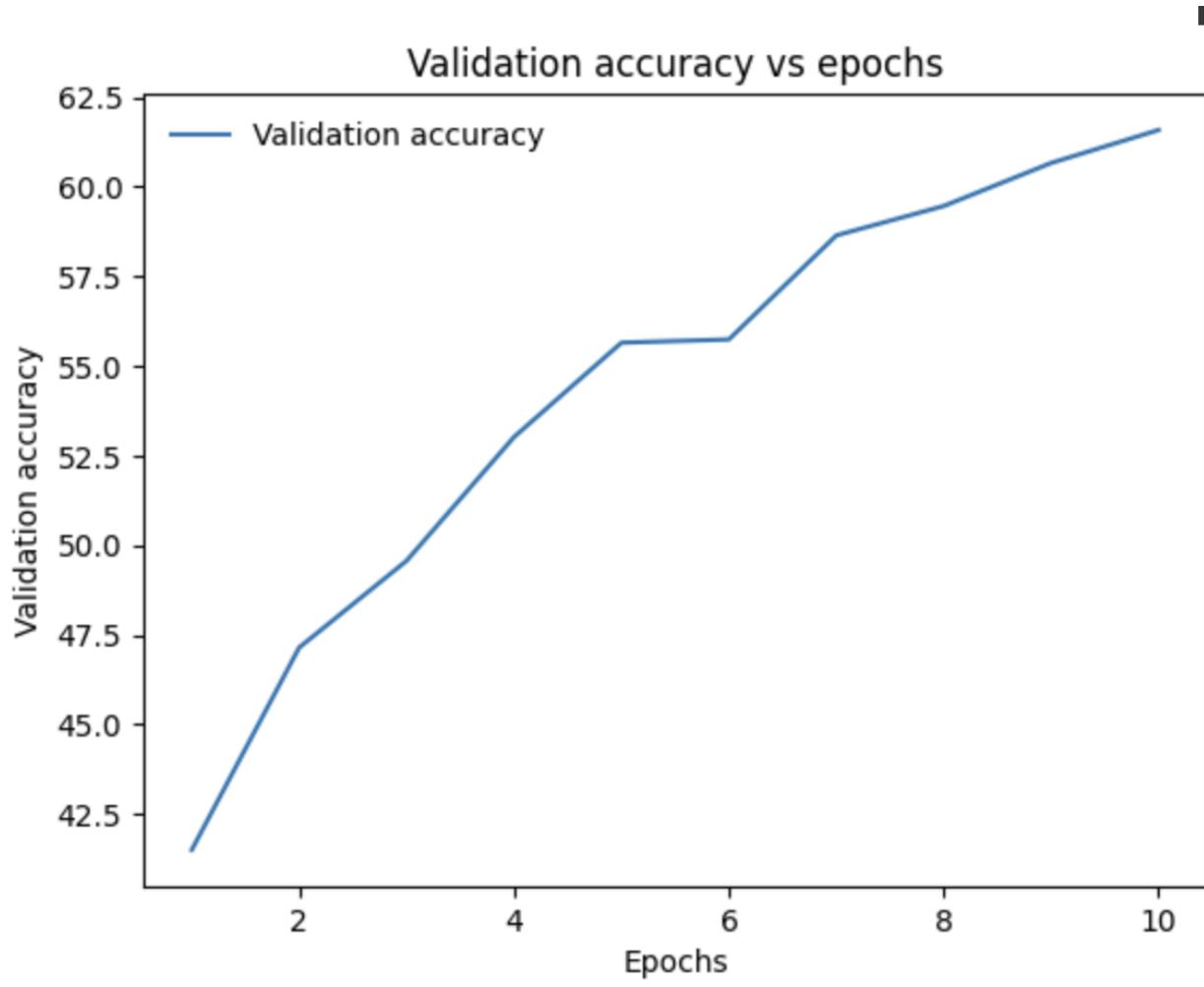
Epoch 1 train loss: 1.801 val loss: 1.596 train accuracy: 33.842 val accuracy: 41.510  
Epoch 2 train loss: 1.516 val loss: 1.439 train accuracy: 44.604 val accuracy: 47.150  
Epoch 3 train loss: 1.403 val loss: 1.409 train accuracy: 49.134 val accuracy: 49.570  
Epoch 4 train loss: 1.322 val loss: 1.301 train accuracy: 52.386 val accuracy: 53.020  
Epoch 5 train loss: 1.260 val loss: 1.237 train accuracy: 55.150 val accuracy: 55.650  
Epoch 6 train loss: 1.208 val loss: 1.224 train accuracy: 56.804 val accuracy: 55.740  
Epoch 7 train loss: 1.166 val loss: 1.153 train accuracy: 58.518 val accuracy: 58.640  
Epoch 8 train loss: 1.128 val loss: 1.130 train accuracy: 59.926 val accuracy: 59.460  
Epoch 9 train loss: 1.093 val loss: 1.116 train accuracy: 61.272 val accuracy: 60.660  
Epoch 10 train loss: 1.060 val loss: 1.083 train accuracy: 62.660 val accuracy: 61.580

Training and validation losses vs epochs



Training accuracy vs epochs



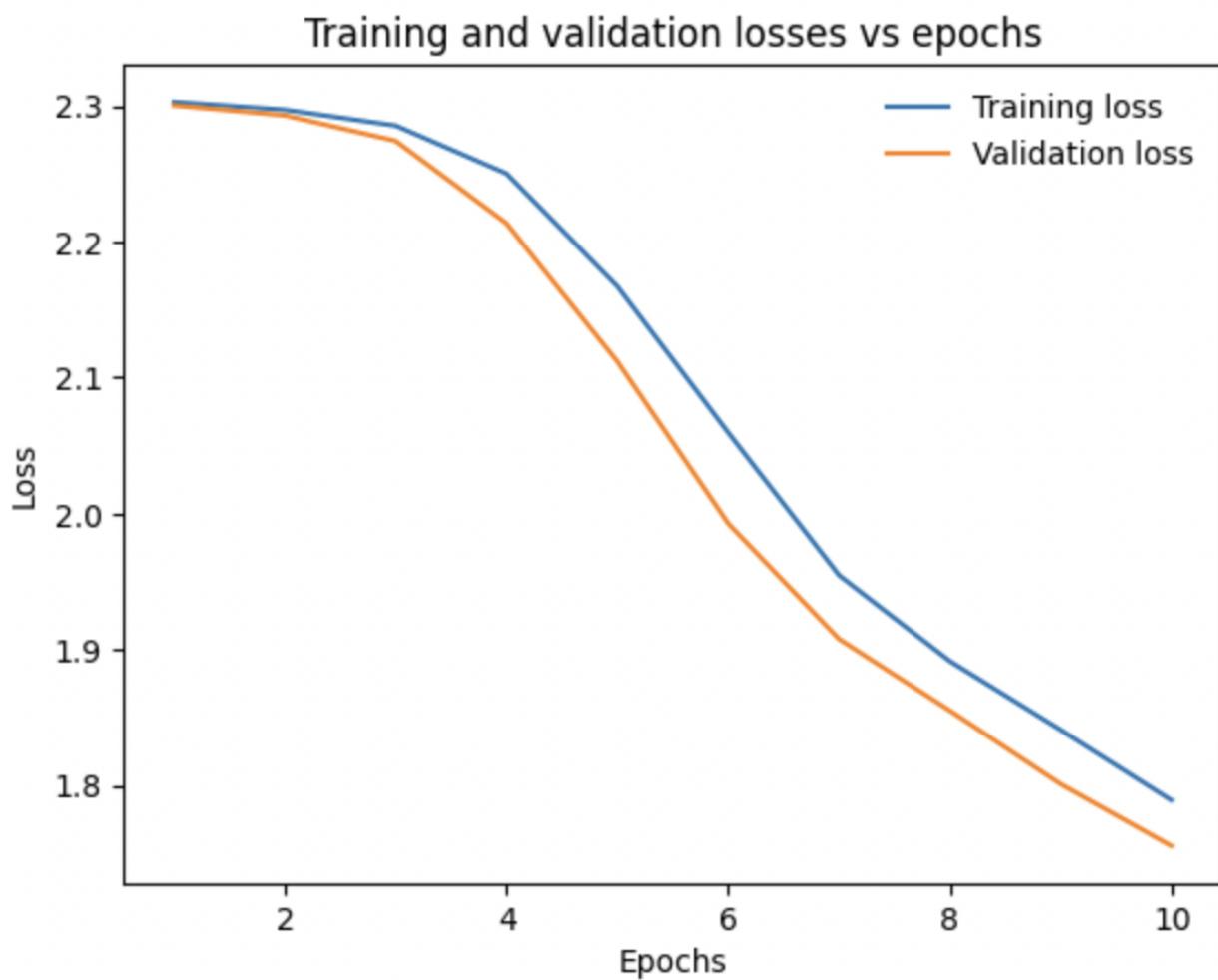


### Classwise Accuracy:

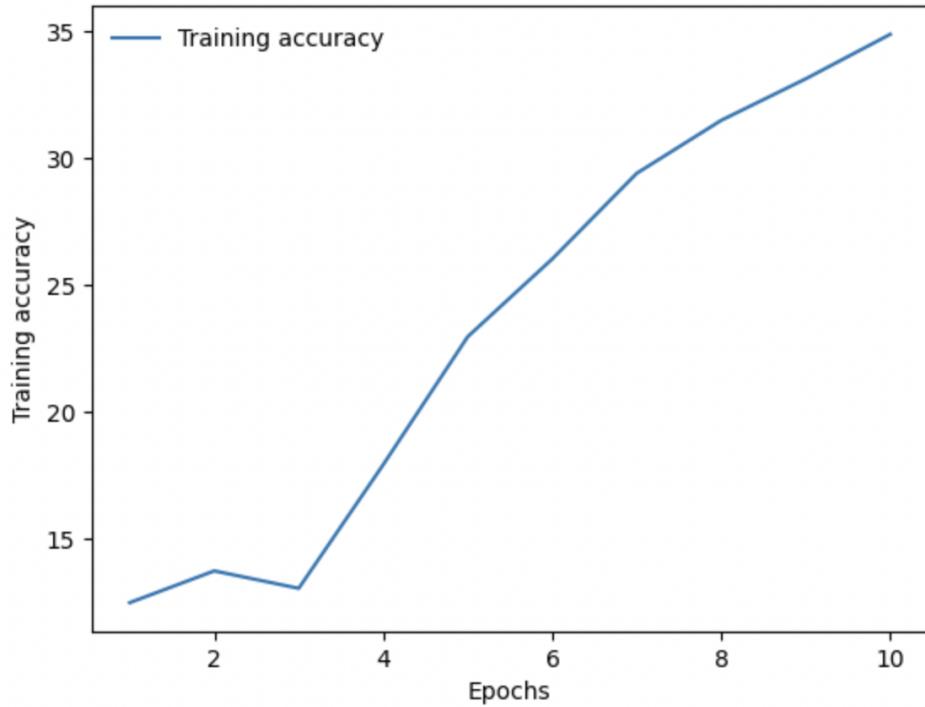
Accuracy for class: plane is 61.7 %  
Accuracy for class: car is 71.6 %  
Accuracy for class: bird is 51.1 %  
Accuracy for class: cat is 44.9 %  
Accuracy for class: deer is 47.7 %  
Accuracy for class: dog is 49.1 %  
Accuracy for class: frog is 66.8 %  
Accuracy for class: horse is 78.6 %  
Accuracy for class: ship is 76.7 %  
Accuracy for class: truck is 67.6 %

## SGD Optimiser:

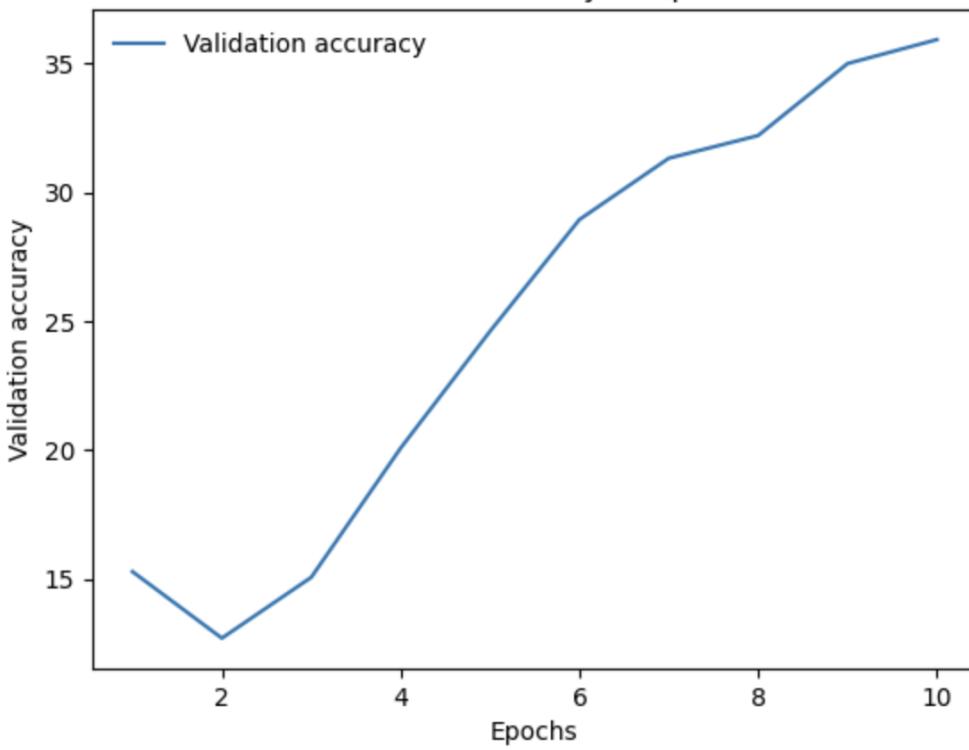
Epoch 1 train loss: 2.303 val loss: 2.301 train accuracy: 12.478 val accuracy: 15.290  
Epoch 2 train loss: 2.297 val loss: 2.293 train accuracy: 13.732 val accuracy: 12.710  
Epoch 3 train loss: 2.286 val loss: 2.274 train accuracy: 13.044 val accuracy: 15.070  
Epoch 4 train loss: 2.250 val loss: 2.214 train accuracy: 17.924 val accuracy: 20.080  
Epoch 5 train loss: 2.167 val loss: 2.112 train accuracy: 22.972 val accuracy: 24.610  
Epoch 6 train loss: 2.060 val loss: 1.993 train accuracy: 26.038 val accuracy: 28.940  
Epoch 7 train loss: 1.955 val loss: 1.908 train accuracy: 29.416 val accuracy: 31.320  
Epoch 8 train loss: 1.891 val loss: 1.855 train accuracy: 31.506 val accuracy: 32.200  
Epoch 9 train loss: 1.841 val loss: 1.801 train accuracy: 33.144 val accuracy: 34.990  
Epoch 10 train loss: 1.789 val loss: 1.755 train accuracy: 34.900 val accuracy: 35.920



Training accuracy vs epochs



Validation accuracy vs epochs



## Classwise Accuracy:

Accuracy for class: plane is 50.0 %

Accuracy for class: car is 56.9 %

Accuracy for class: bird is 5.1 %

Accuracy for class: cat is 9.3 %

Accuracy for class: deer is 10.4 %

Accuracy for class: dog is 50.3 %

Accuracy for class: frog is 63.9 %

Accuracy for class: horse is 43.5 %

Accuracy for class: ship is 26.5 %

Accuracy for class: truck is 43.3 %

b)  $LR = 0.001$

## Adam optimiser:

Epoch 1 train loss: 1.549 val loss: 1.294 train accuracy: 42.884 val accuracy: 52.490

Epoch 2 train loss: 1.179 val loss: 1.125 train accuracy: 57.976 val accuracy: 59.550

Epoch 3 train loss: 1.011 val loss: 1.001 train accuracy: 64.142 val accuracy: 64.740

Epoch 4 train loss: 0.905 val loss: 0.916 train accuracy: 68.018 val accuracy: 68.310

Epoch 5 train loss: 0.832 val loss: 0.899 train accuracy: 70.774 val accuracy: 68.680

Epoch 6 train loss: 0.767 val loss: 0.879 train accuracy: 73.078 val accuracy: 69.550

Epoch 7 train loss: 0.717 val loss: 0.884 train accuracy: 74.946 val accuracy: 69.800

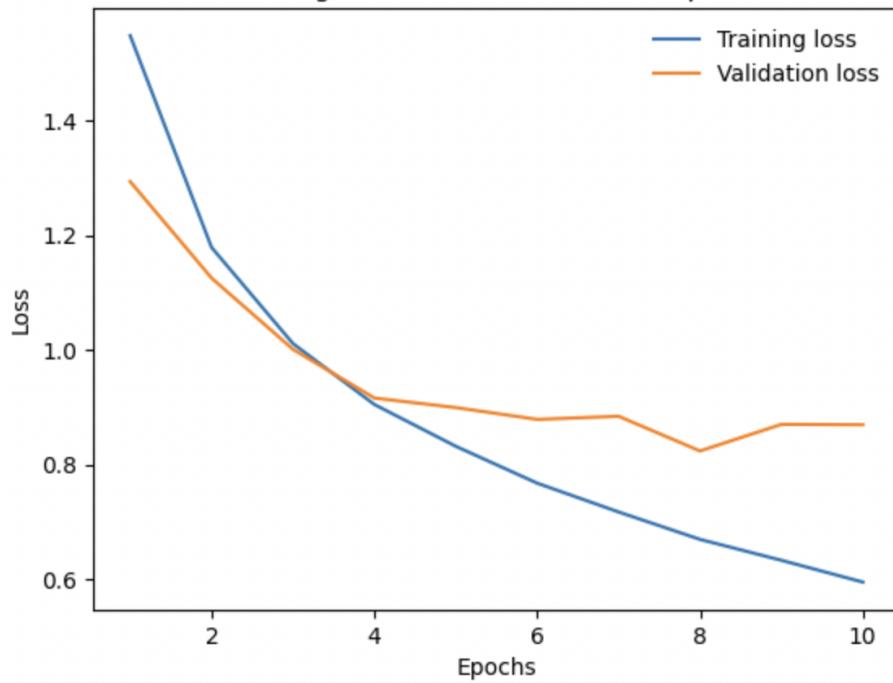
Epoch 8 train loss: 0.669 val loss: 0.824 train accuracy: 76.474 val accuracy: 71.290

Epoch 9 train loss: 0.633 val loss: 0.870 train accuracy: 77.766 val accuracy: 70.940

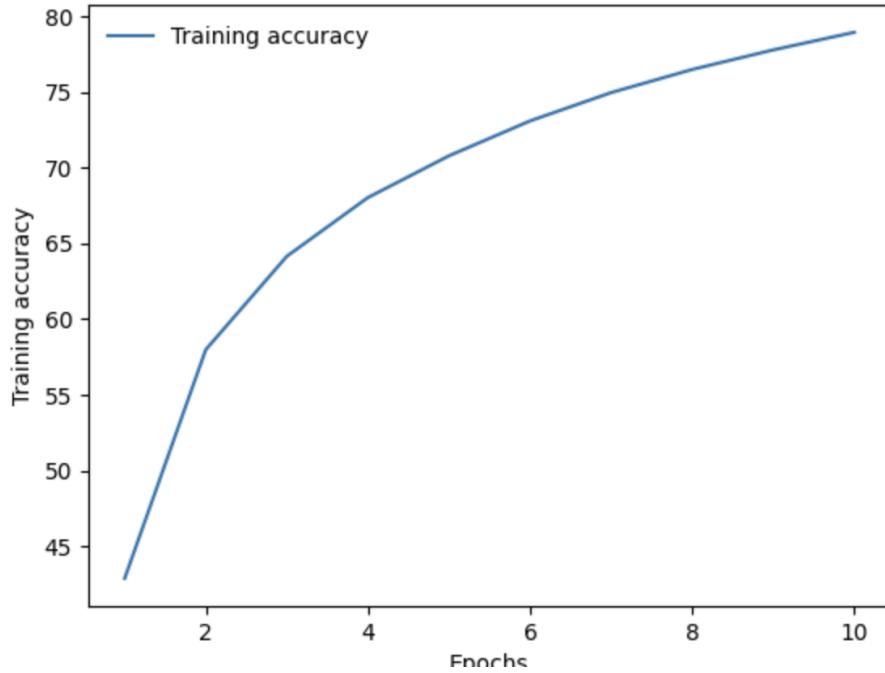
Epoch 10 train loss: 0.595 val loss: 0.869 train accuracy: 78.928 val accuracy: 71.910

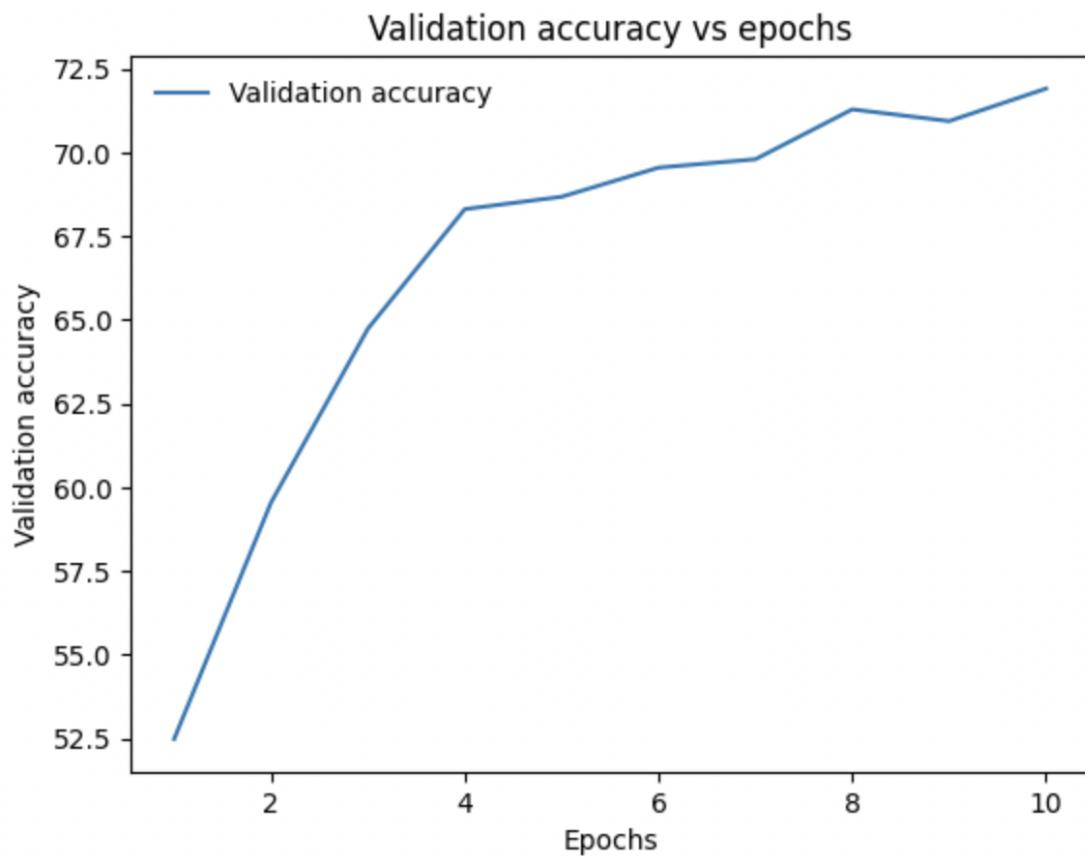
---

Training and validation losses vs epochs



Training accuracy vs epochs





### Classwise Accuracy:

Accuracy for class: plane is 73.1 %

Accuracy for class: car is 88.4 %

Accuracy for class: bird is 57.8 %

Accuracy for class: cat is 44.2 %

Accuracy for class: deer is 74.2 %

Accuracy for class: dog is 66.9 %

Accuracy for class: frog is 82.0 %

Accuracy for class: horse is 74.0 %

Accuracy for class: ship is 81.8 %

Accuracy for class: truck is 76.7 %

### SGD Optimiser:

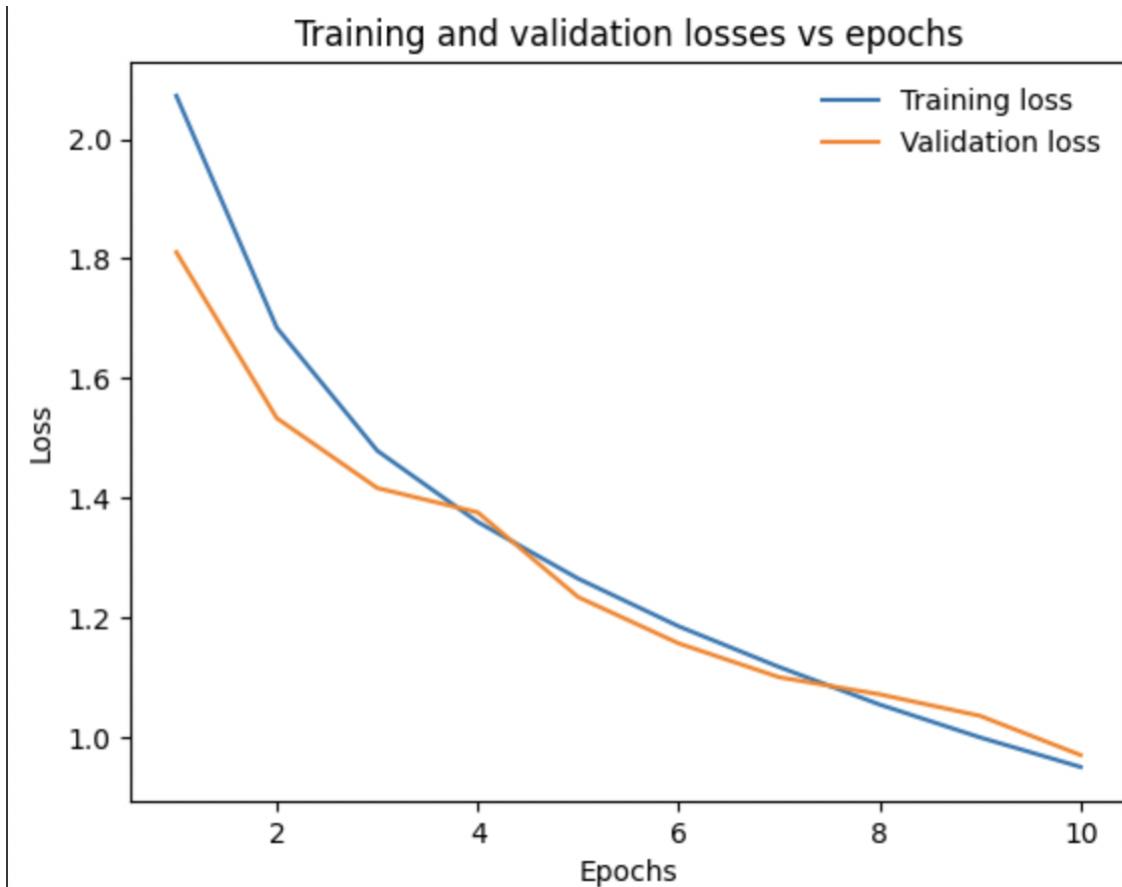
Epoch 1 train loss: 2.072 val loss: 1.811 train accuracy: 22.740 val accuracy: 32.890

Epoch 2 train loss: 1.684 val loss: 1.533 train accuracy: 37.830 val accuracy: 43.550

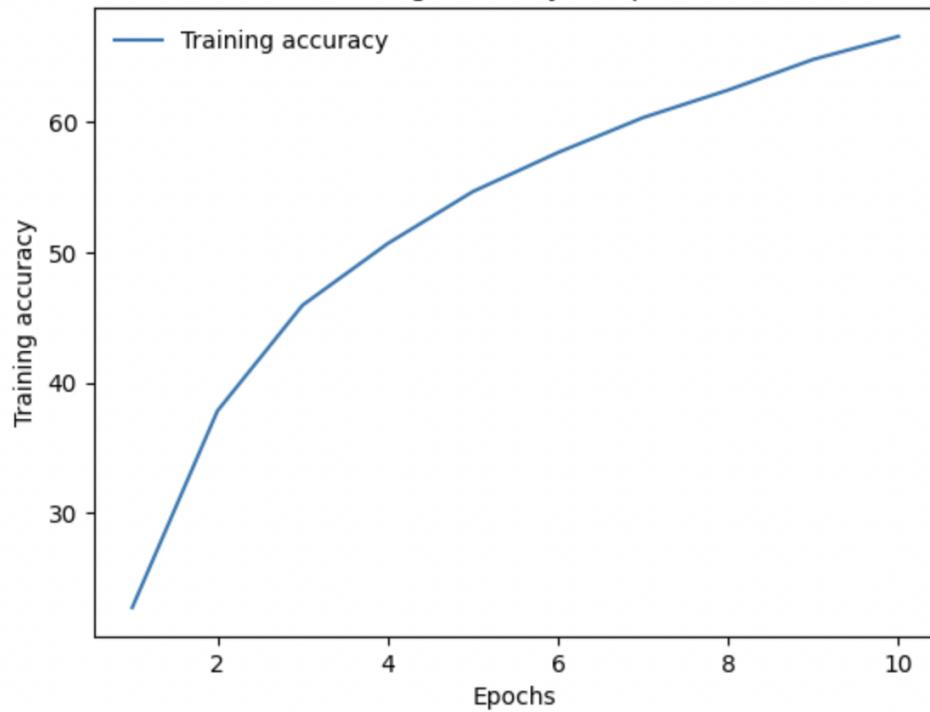
Epoch 3 train loss: 1.479 val loss: 1.417 train accuracy: 45.950 val accuracy: 48.400

Epoch 4 train loss: 1.360 val loss: 1.376 train accuracy: 50.684 val accuracy: 50.440

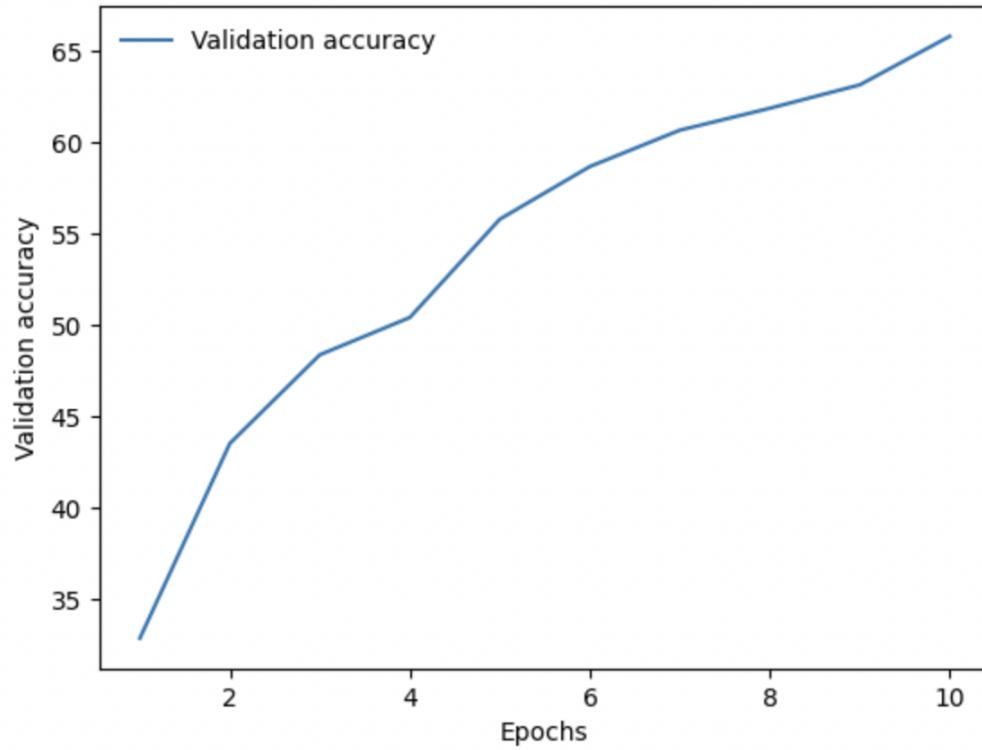
Epoch 5 train loss: 1.265 val loss: 1.234 train accuracy: 54.674 val accuracy: 55.820  
Epoch 6 train loss: 1.186 val loss: 1.157 train accuracy: 57.674 val accuracy: 58.700  
Epoch 7 train loss: 1.118 val loss: 1.100 train accuracy: 60.356 val accuracy: 60.690  
Epoch 8 train loss: 1.055 val loss: 1.072 train accuracy: 62.474 val accuracy: 61.890  
Epoch 9 train loss: 1.000 val loss: 1.036 train accuracy: 64.828 val accuracy: 63.170  
Epoch 10 train loss: 0.950 val loss: 0.970 train accuracy: 66.592 val accuracy: 65.830



Training accuracy vs epochs



Validation accuracy vs epochs



## Classwise Accuracy:

Accuracy for class: plane is 66.5 %

Accuracy for class: car is 69.6 %

Accuracy for class: bird is 49.1 %

Accuracy for class: cat is 42.3 %

Accuracy for class: deer is 64.6 %

Accuracy for class: dog is 50.9 %

Accuracy for class: frog is 75.6 %

Accuracy for class: horse is 76.2 %

Accuracy for class: ship is 82.5 %

Accuracy for class: truck is 81.0 %

c) LR = 0.01

## Adam Optimiser:

Epoch 1 train loss: 1.828 val loss: 1.743 train accuracy: 31.428 val accuracy: 34.550

Epoch 2 train loss: 1.729 val loss: 1.704 train accuracy: 36.244 val accuracy: 37.450

Epoch 3 train loss: 1.694 val loss: 1.690 train accuracy: 37.582 val accuracy: 37.270

Epoch 4 train loss: 1.684 val loss: 1.664 train accuracy: 38.014 val accuracy: 38.540

Epoch 5 train loss: 1.667 val loss: 1.654 train accuracy: 38.662 val accuracy: 39.820

Epoch 6 train loss: 1.655 val loss: 1.642 train accuracy: 39.118 val accuracy: 39.520

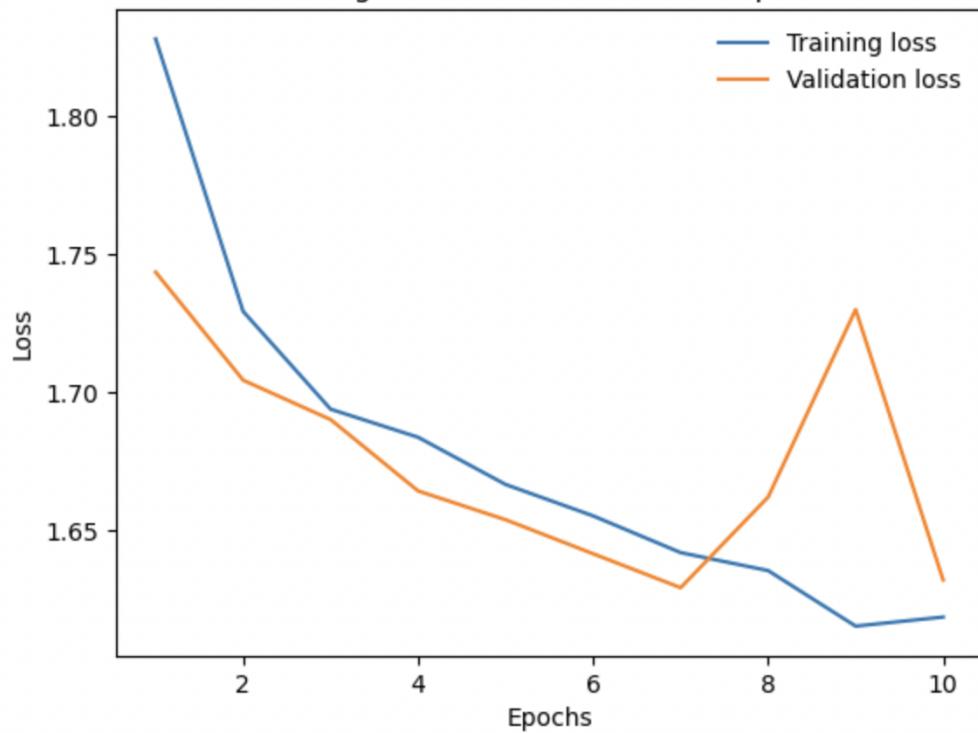
Epoch 7 train loss: 1.642 val loss: 1.629 train accuracy: 39.956 val accuracy: 40.630

Epoch 8 train loss: 1.635 val loss: 1.662 train accuracy: 40.076 val accuracy: 40.240

Epoch 9 train loss: 1.615 val loss: 1.730 train accuracy: 40.624 val accuracy: 37.580

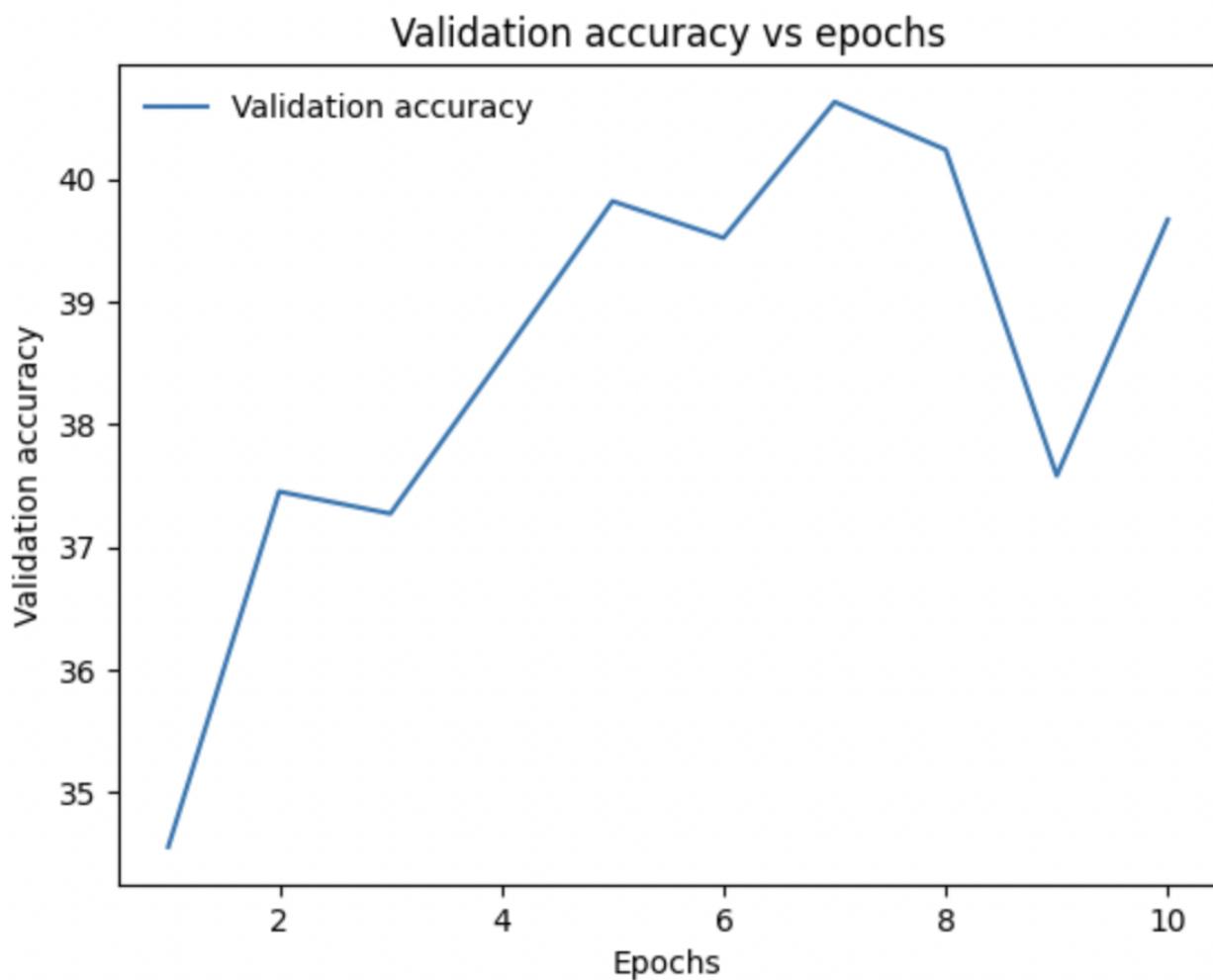
Epoch 10 train loss: 1.619 val loss: 1.632 train accuracy: 40.786 val accuracy: 39.670

Training and validation losses vs epochs



Training accuracy vs epochs



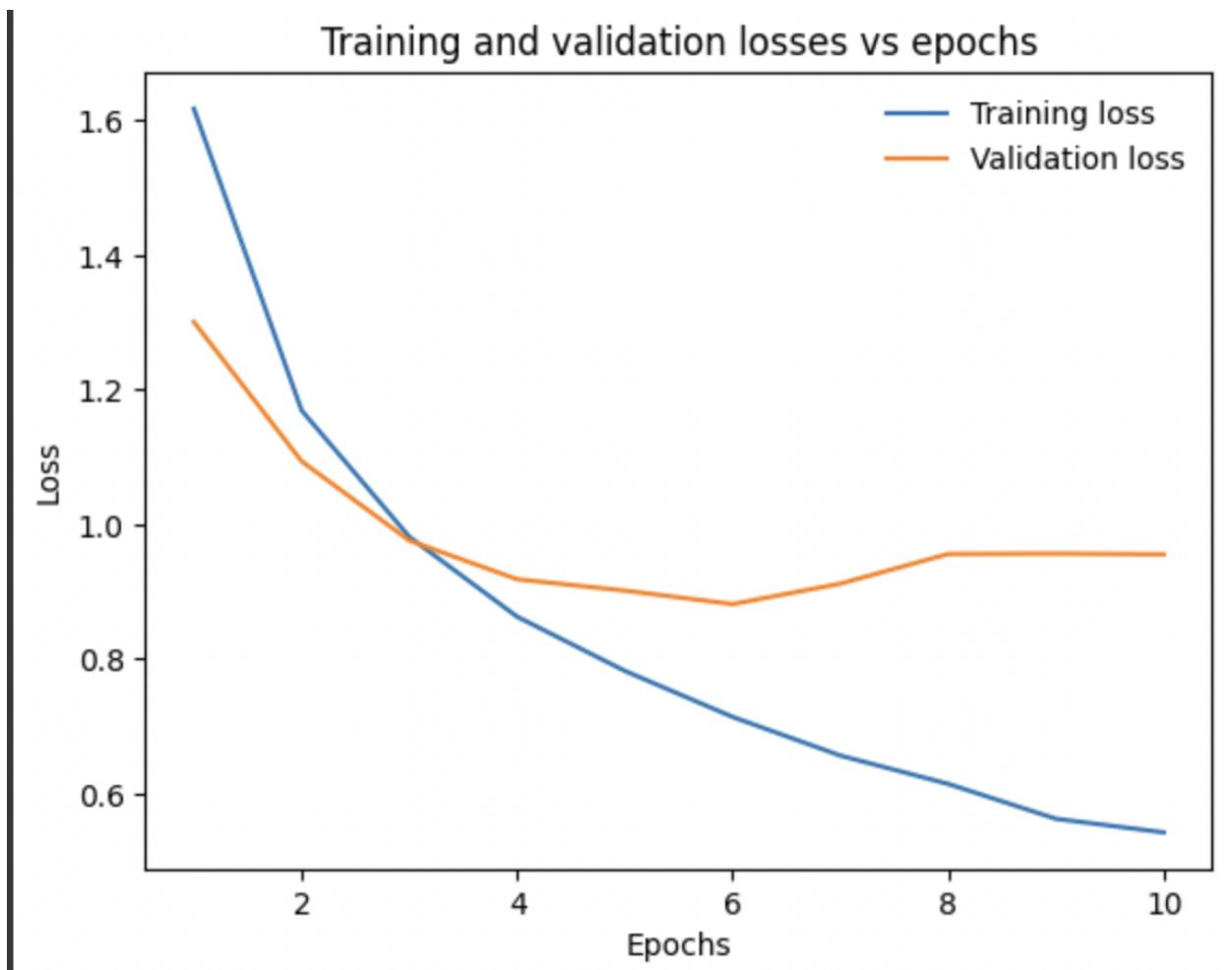


### Classwise Accuracy:

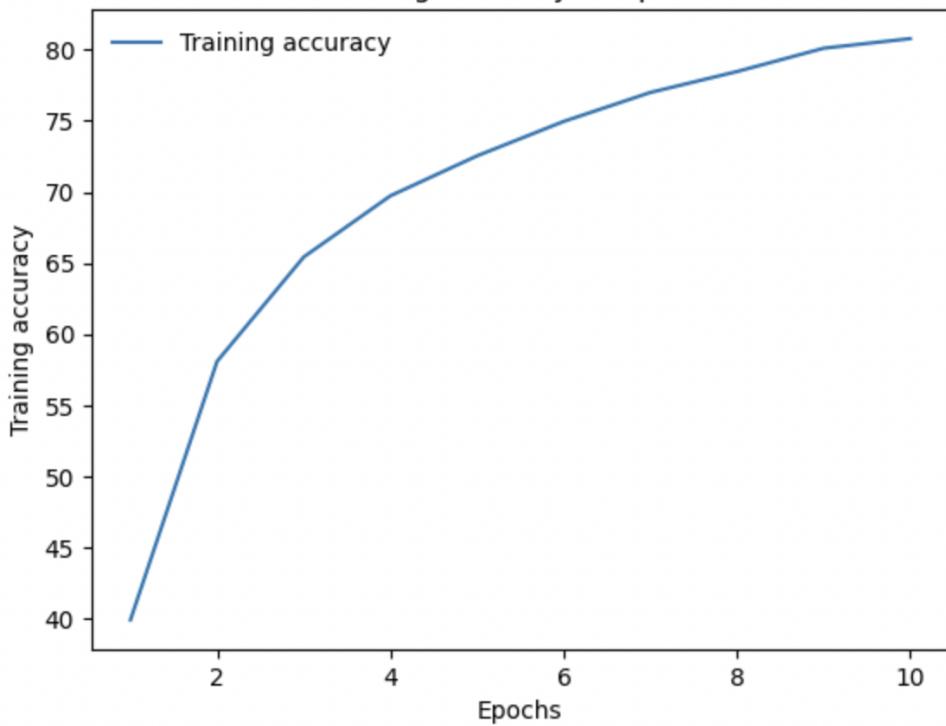
Accuracy for class: plane is 49.0 %  
Accuracy for class: car is 28.5 %  
Accuracy for class: bird is 29.0 %  
Accuracy for class: cat is 15.1 %  
Accuracy for class: deer is 24.7 %  
Accuracy for class: dog is 48.7 %  
Accuracy for class: frog is 47.6 %  
Accuracy for class: horse is 45.9 %  
Accuracy for class: ship is 52.4 %  
Accuracy for class: truck is 55.8 %

## SGD Optimiser:

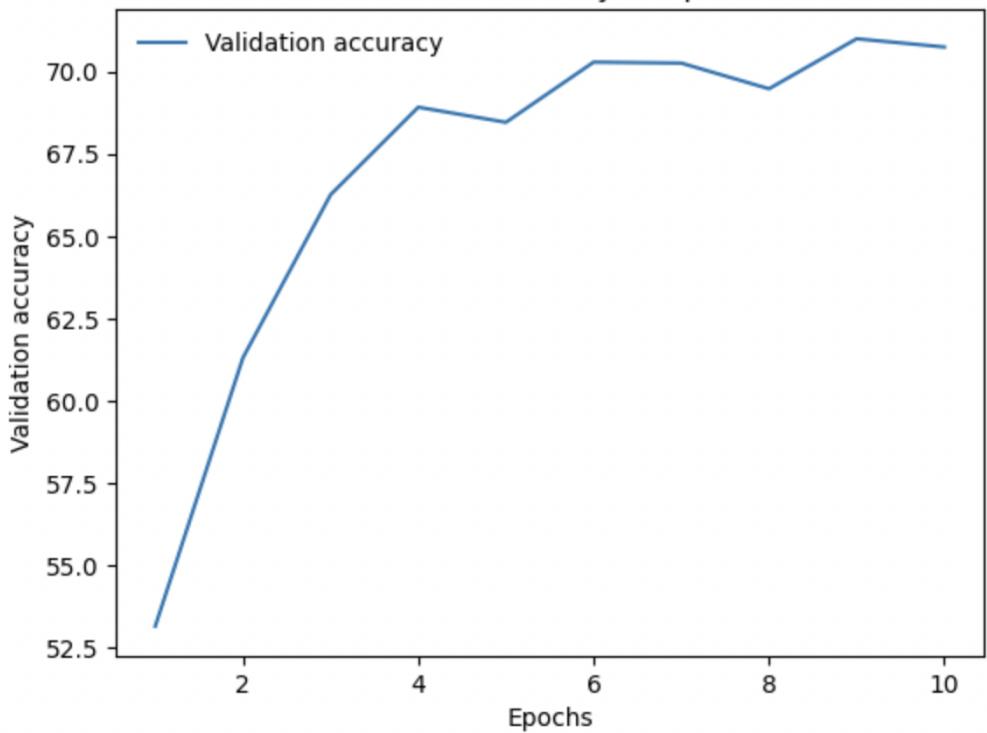
```
Epoch 1 train loss: 1.617 val loss: 1.301 train accuracy: 39.916 val accuracy: 53.140
Epoch 2 train loss: 1.169 val loss: 1.094 train accuracy: 58.090 val accuracy: 61.300
Epoch 3 train loss: 0.981 val loss: 0.976 train accuracy: 65.424 val accuracy: 66.260
Epoch 4 train loss: 0.863 val loss: 0.918 train accuracy: 69.724 val accuracy: 68.920
Epoch 5 train loss: 0.782 val loss: 0.901 train accuracy: 72.532 val accuracy: 68.460
Epoch 6 train loss: 0.714 val loss: 0.881 train accuracy: 74.952 val accuracy: 70.290
Epoch 7 train loss: 0.656 val loss: 0.912 train accuracy: 76.988 val accuracy: 70.260
Epoch 8 train loss: 0.614 val loss: 0.956 train accuracy: 78.458 val accuracy: 69.480
Epoch 9 train loss: 0.562 val loss: 0.956 train accuracy: 80.098 val accuracy: 71.000
Epoch 10 train loss: 0.542 val loss: 0.955 train accuracy: 80.774 val accuracy: 70.750
```



Training accuracy vs epochs



Validation accuracy vs epochs



## Classwise Accuracy:

Accuracy for class: plane is 77.0 %

Accuracy for class: car is 90.2 %

Accuracy for class: bird is 59.1 %

Accuracy for class: cat is 53.7 %

Accuracy for class: deer is 64.2 %

Accuracy for class: dog is 67.2 %

Accuracy for class: frog is 69.7 %

Accuracy for class: horse is 70.7 %

Accuracy for class: ship is 81.6 %

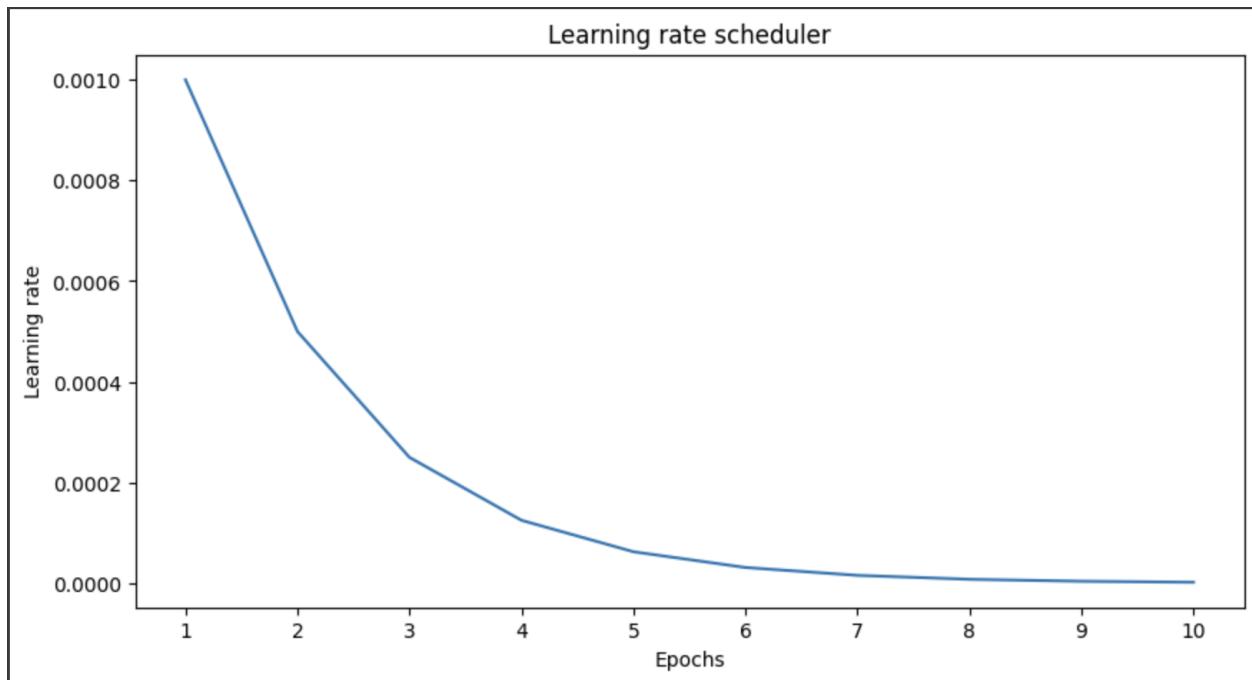
Accuracy for class: truck is 74.1 %

## 2) Variation in LR:

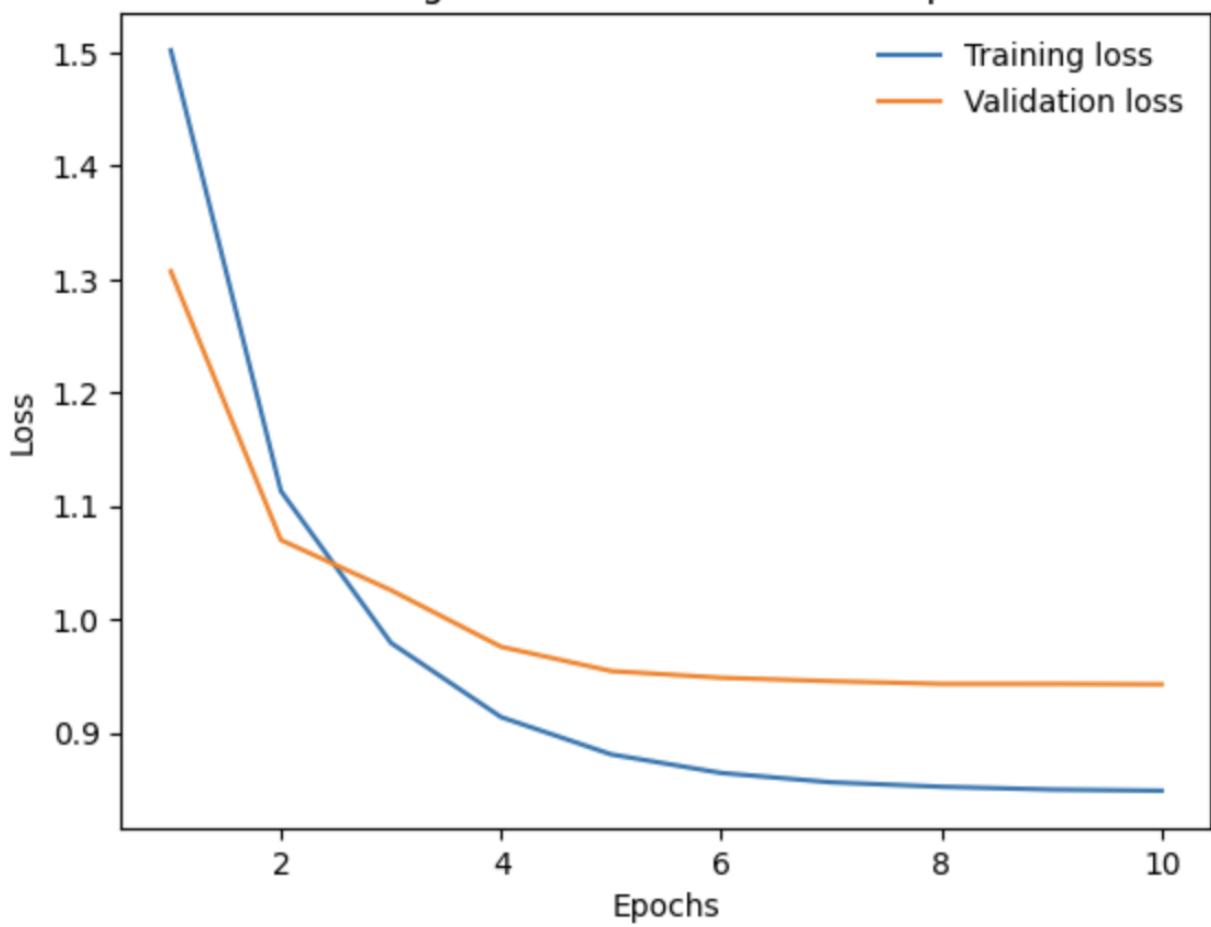
Model with learning rate: 0.001 epochs: 10 batch size: 32 learning rate scheduler: True

Adam Optimiser:

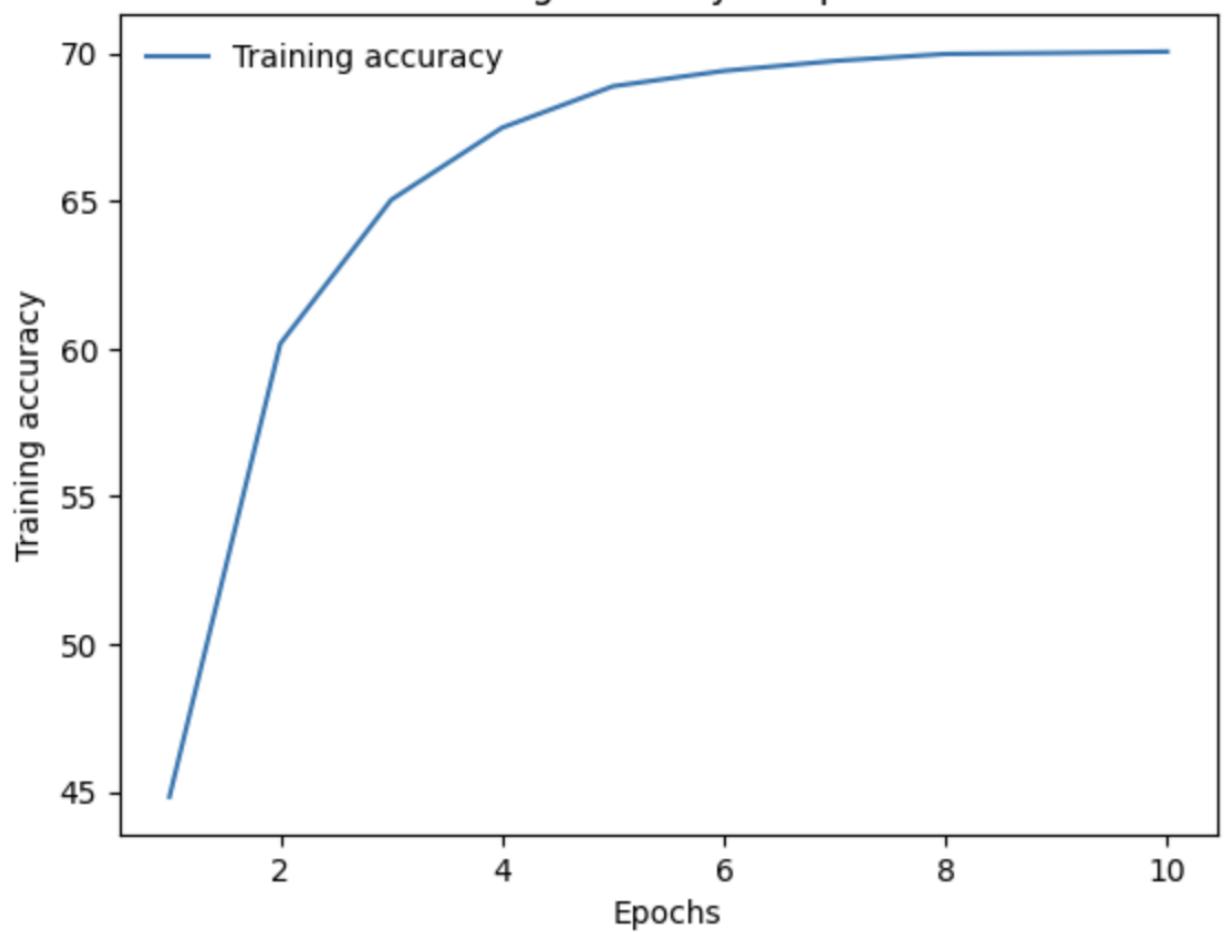
Epoch 1 train loss: 1.502 val loss: 1.307 train accuracy: 44.826 val accuracy: 53.550  
Epoch 2 train loss: 1.113 val loss: 1.070 train accuracy: 60.162 val accuracy: 61.340  
Epoch 3 train loss: 0.979 val loss: 1.026 train accuracy: 65.032 val accuracy: 63.300  
Epoch 4 train loss: 0.914 val loss: 0.976 train accuracy: 67.474 val accuracy: 65.290  
Epoch 5 train loss: 0.881 val loss: 0.954 train accuracy: 68.878 val accuracy: 66.210  
Epoch 6 train loss: 0.864 val loss: 0.948 train accuracy: 69.398 val accuracy: 66.600  
Epoch 7 train loss: 0.856 val loss: 0.945 train accuracy: 69.734 val accuracy: 66.570  
Epoch 8 train loss: 0.852 val loss: 0.943 train accuracy: 69.970 val accuracy: 66.560  
Epoch 9 train loss: 0.850 val loss: 0.943 train accuracy: 70.004 val accuracy: 66.490  
Epoch 10 train loss: 0.849 val loss: 0.943 train accuracy: 70.050 val accuracy: 66.430



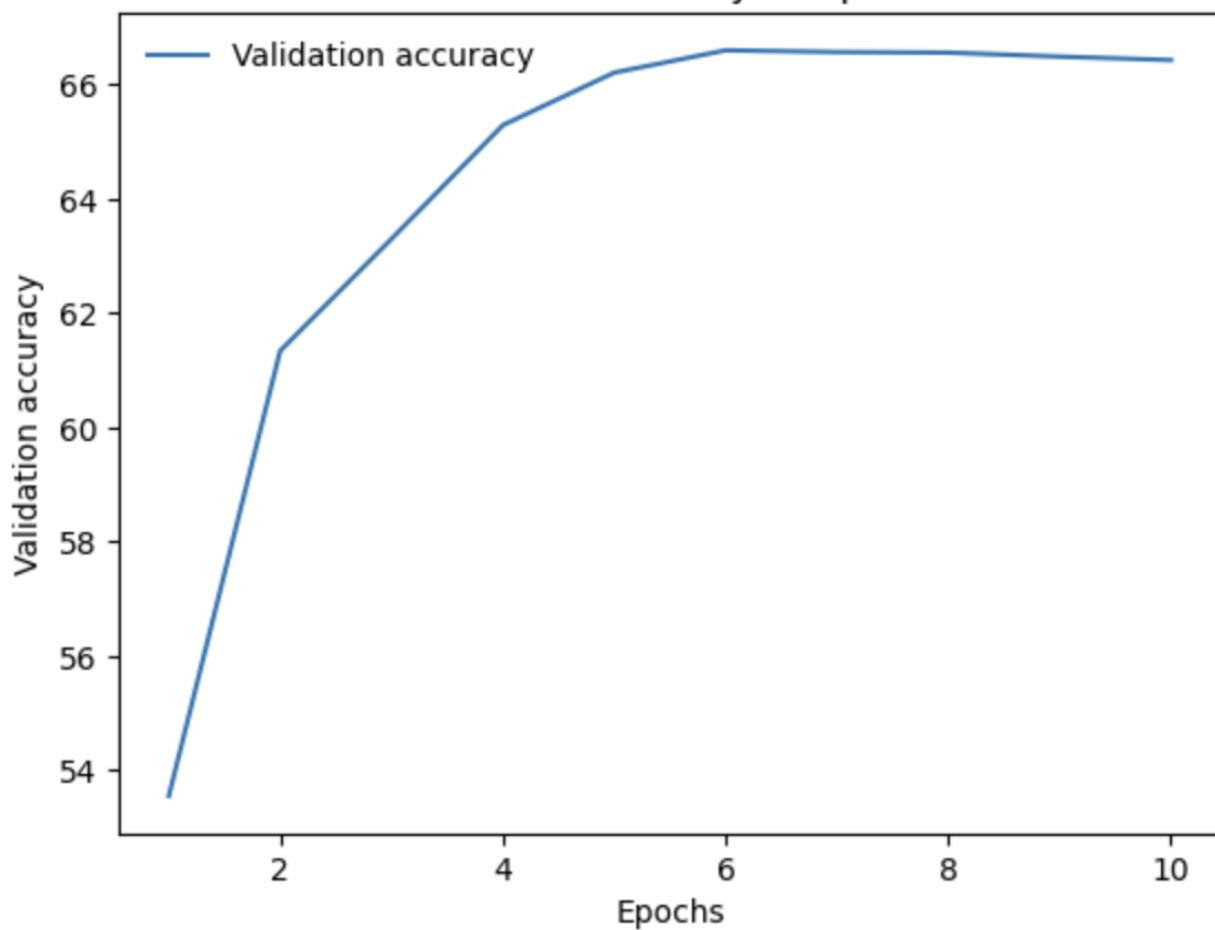
Training and validation losses vs epochs



Training accuracy vs epochs



### Validation accuracy vs epochs

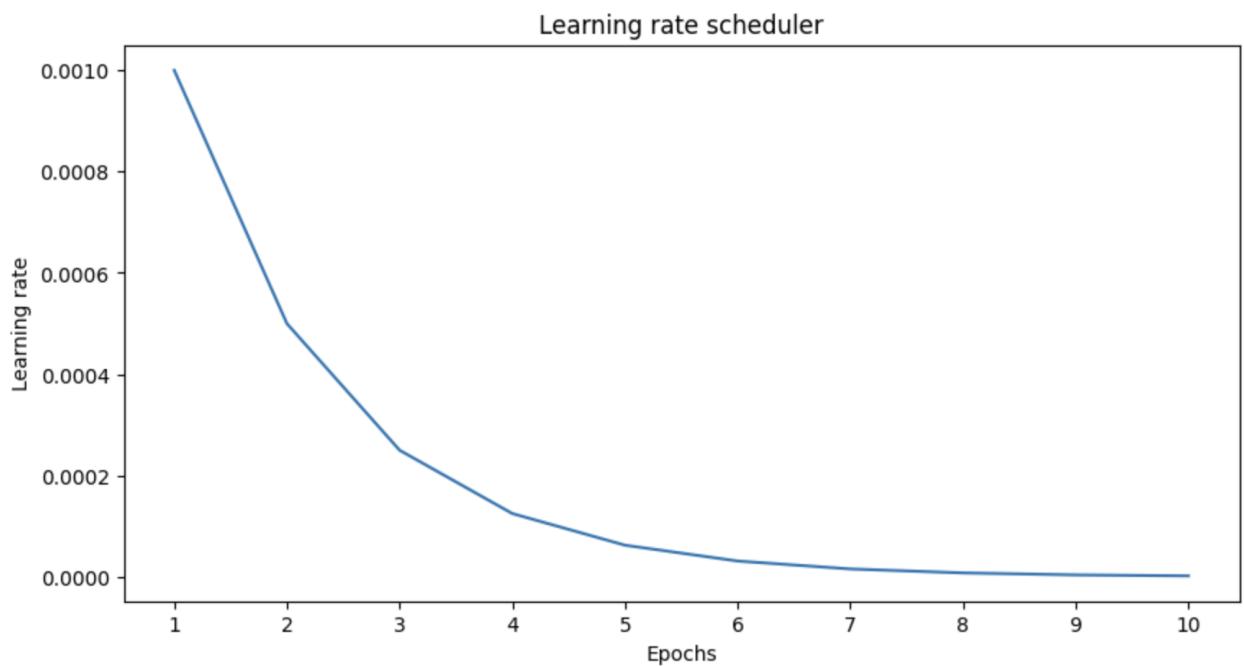


#### Classwise Accuracy:

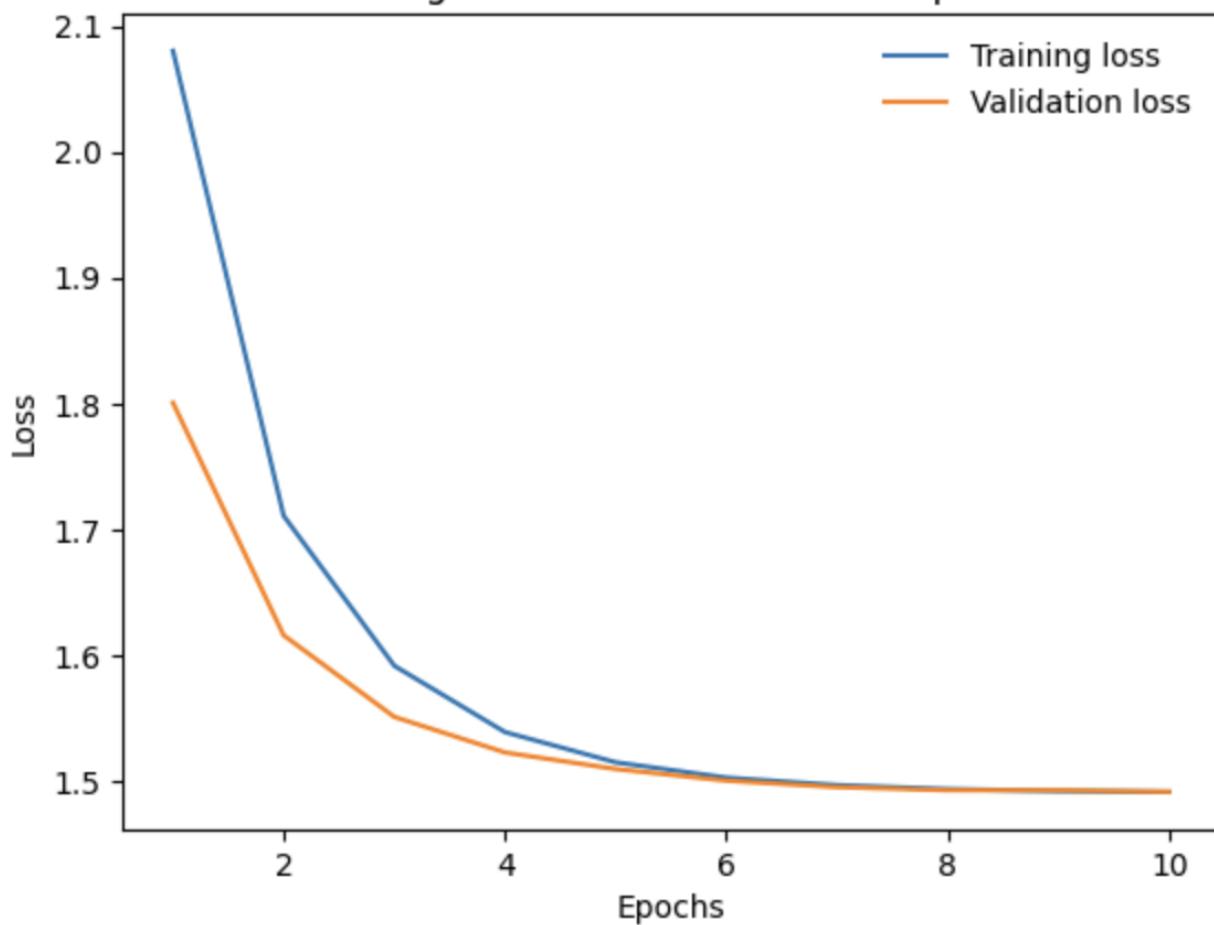
Accuracy for class: plane is 69.7 %  
Accuracy for class: car is 80.5 %  
Accuracy for class: bird is 51.8 %  
Accuracy for class: cat is 44.7 %  
Accuracy for class: deer is 59.0 %  
Accuracy for class: dog is 55.4 %  
Accuracy for class: frog is 78.4 %  
Accuracy for class: horse is 72.0 %  
Accuracy for class: ship is 76.6 %  
Accuracy for class: truck is 76.2 %

## SGD Optimiser:

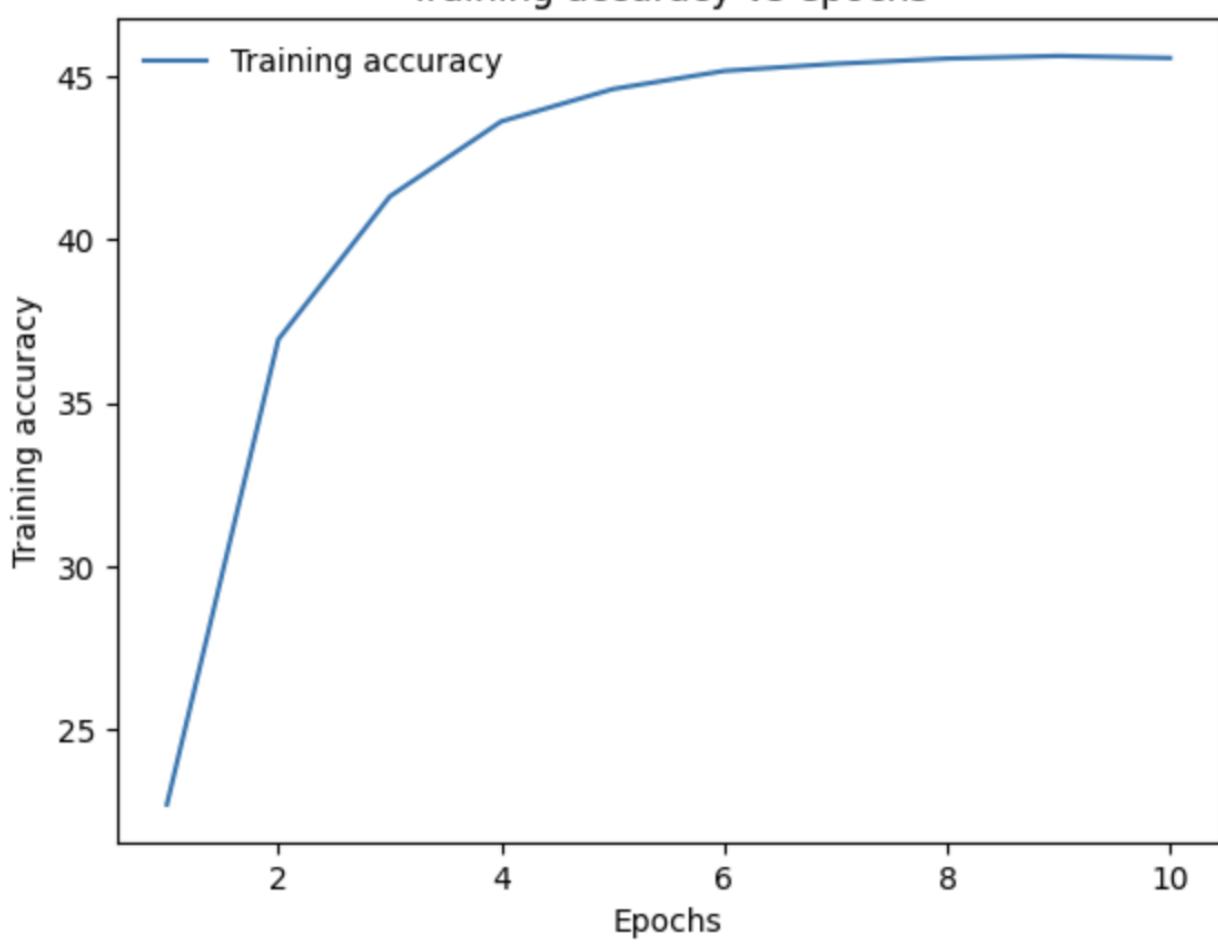
Epoch 1 train loss: 2.080 val loss: 1.801 train accuracy: 22.718 val accuracy: 33.040  
Epoch 2 train loss: 1.711 val loss: 1.616 train accuracy: 36.950 val accuracy: 39.940  
Epoch 3 train loss: 1.592 val loss: 1.551 train accuracy: 41.326 val accuracy: 42.930  
Epoch 4 train loss: 1.539 val loss: 1.523 train accuracy: 43.622 val accuracy: 43.610  
Epoch 5 train loss: 1.515 val loss: 1.510 train accuracy: 44.612 val accuracy: 44.700  
Epoch 6 train loss: 1.503 val loss: 1.501 train accuracy: 45.168 val accuracy: 45.080  
Epoch 7 train loss: 1.497 val loss: 1.496 train accuracy: 45.386 val accuracy: 45.120  
Epoch 8 train loss: 1.494 val loss: 1.493 train accuracy: 45.546 val accuracy: 45.340  
Epoch 9 train loss: 1.493 val loss: 1.493 train accuracy: 45.626 val accuracy: 45.380  
Epoch 10 train loss: 1.492 val loss: 1.492 train accuracy: 45.564 val accuracy: 45.330

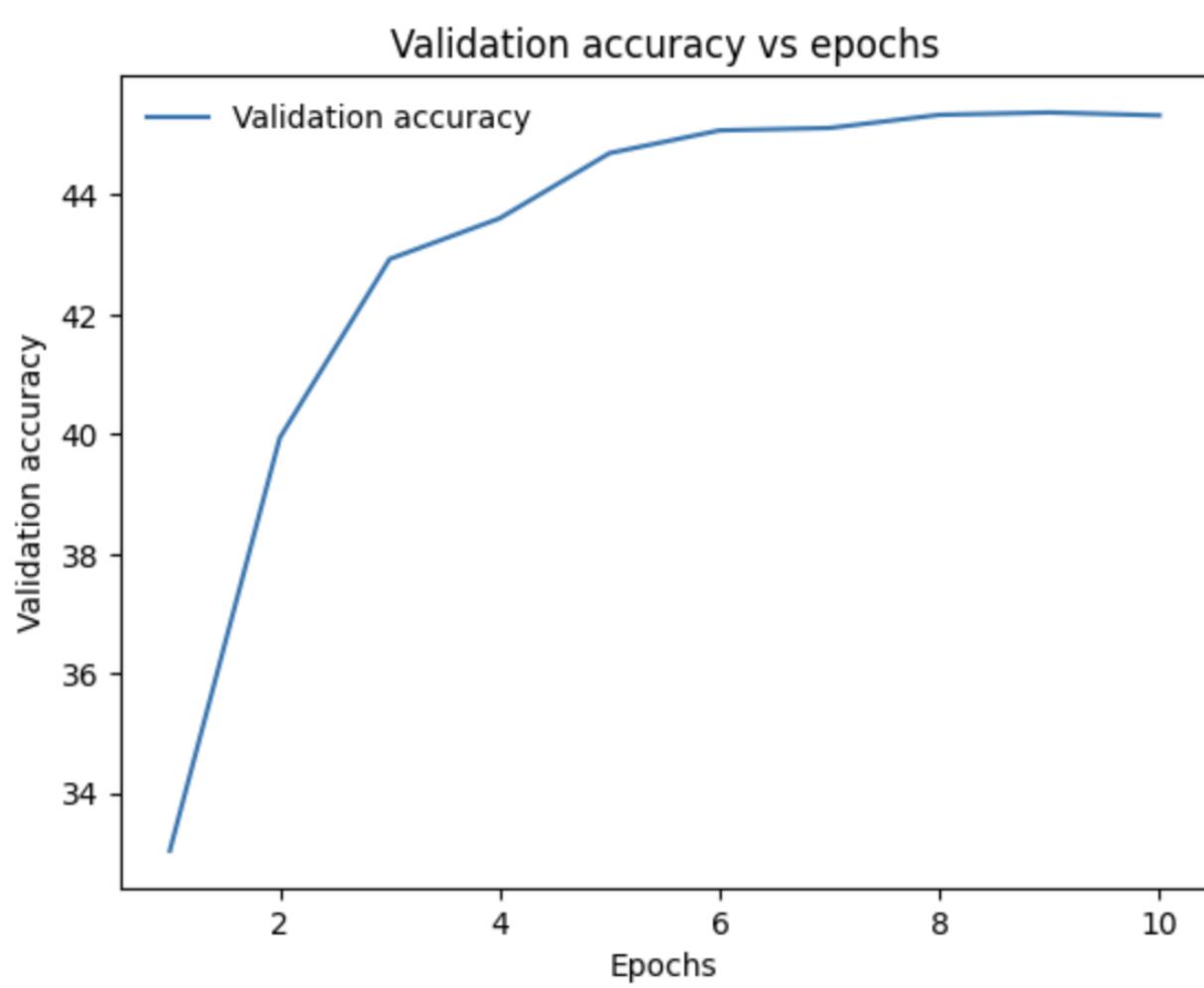


Training and validation losses vs epochs



Training accuracy vs epochs





#### Classwise Accuracy:

Accuracy for class: plane is 52.2 %  
Accuracy for class: car is 60.6 %  
Accuracy for class: bird is 19.7 %  
Accuracy for class: cat is 25.7 %  
Accuracy for class: deer is 37.4 %  
Accuracy for class: dog is 42.7 %  
Accuracy for class: frog is 64.7 %  
Accuracy for class: horse is 54.2 %  
Accuracy for class: ship is 44.6 %  
Accuracy for class: truck is 51.5 %

### 3) Number of Training Epochs:

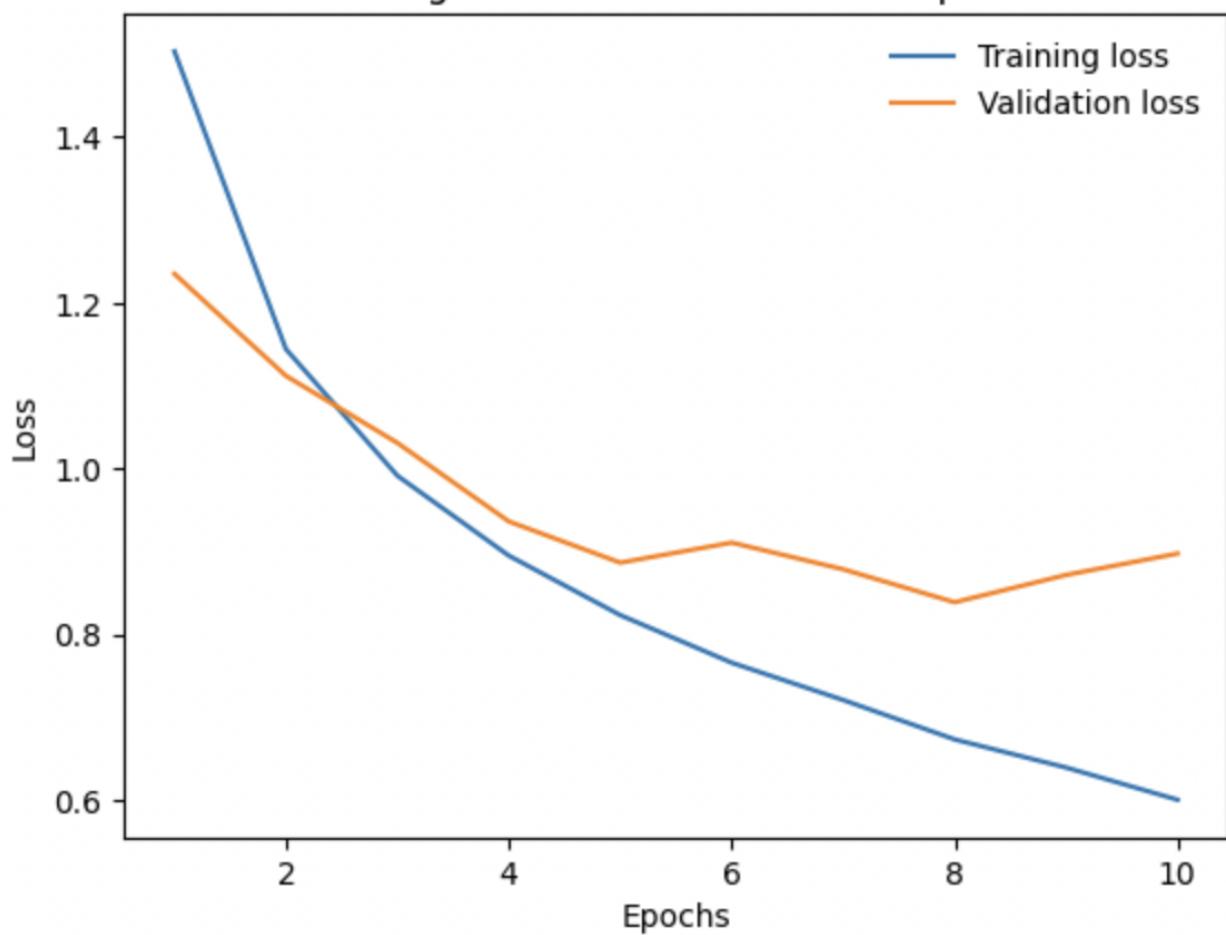
LR = 0.001, Batch size = 32, Loss Function = Cross Entropy

a) Epochs = 10

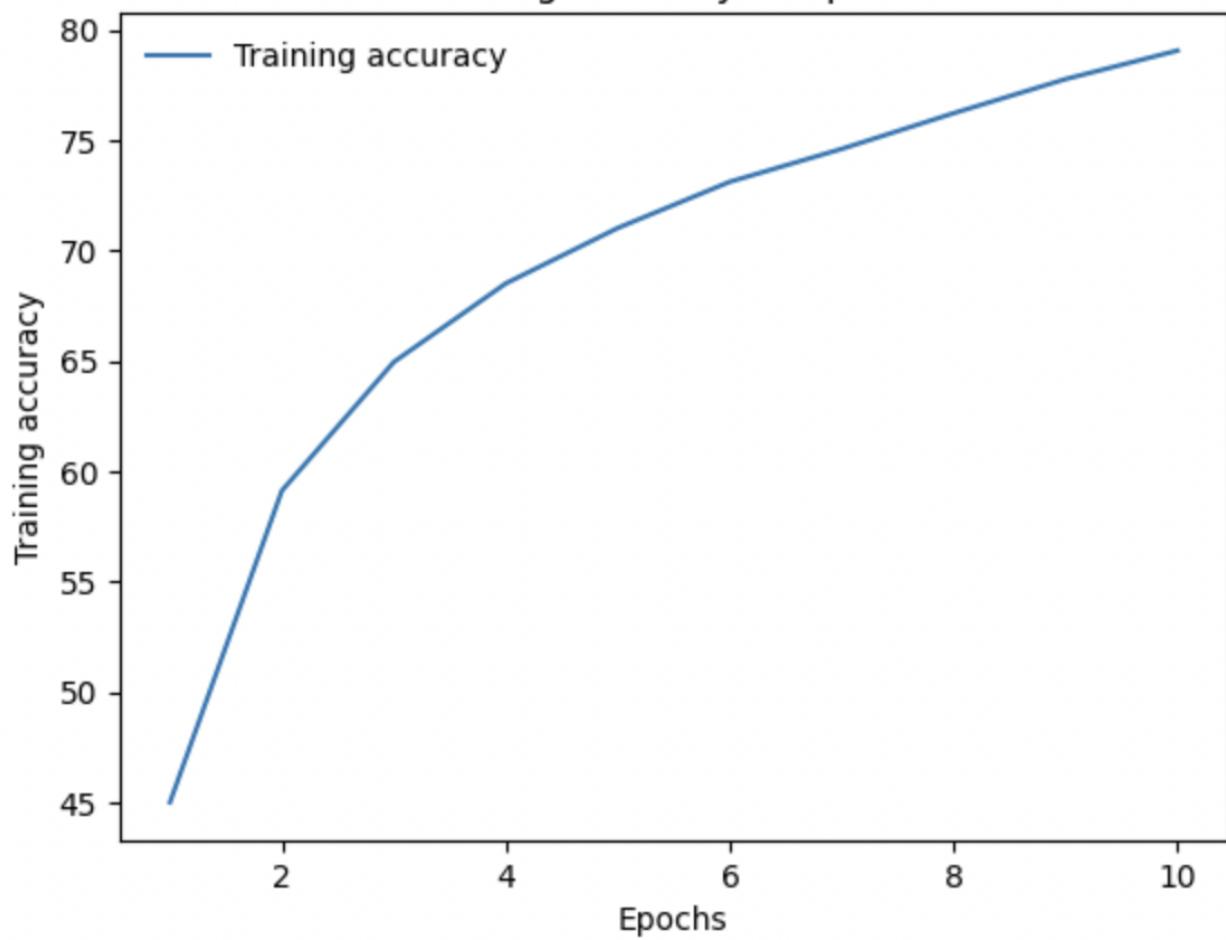
Adam optimiser:

Epoch 1 train loss: 1.503 val loss: 1.235 train accuracy: 45.024 val accuracy: 55.790  
Epoch 2 train loss: 1.144 val loss: 1.112 train accuracy: 59.130 val accuracy: 61.200  
Epoch 3 train loss: 0.991 val loss: 1.031 train accuracy: 64.954 val accuracy: 64.110  
Epoch 4 train loss: 0.895 val loss: 0.936 train accuracy: 68.508 val accuracy: 67.460  
Epoch 5 train loss: 0.823 val loss: 0.887 train accuracy: 71.016 val accuracy: 69.120  
Epoch 6 train loss: 0.766 val loss: 0.911 train accuracy: 73.106 val accuracy: 68.960  
Epoch 7 train loss: 0.721 val loss: 0.879 train accuracy: 74.596 val accuracy: 70.060  
Epoch 8 train loss: 0.673 val loss: 0.839 train accuracy: 76.212 val accuracy: 70.920  
Epoch 9 train loss: 0.639 val loss: 0.872 train accuracy: 77.756 val accuracy: 70.700  
Epoch 10 train loss: 0.600 val loss: 0.898 train accuracy: 79.048 val accuracy: 70.720

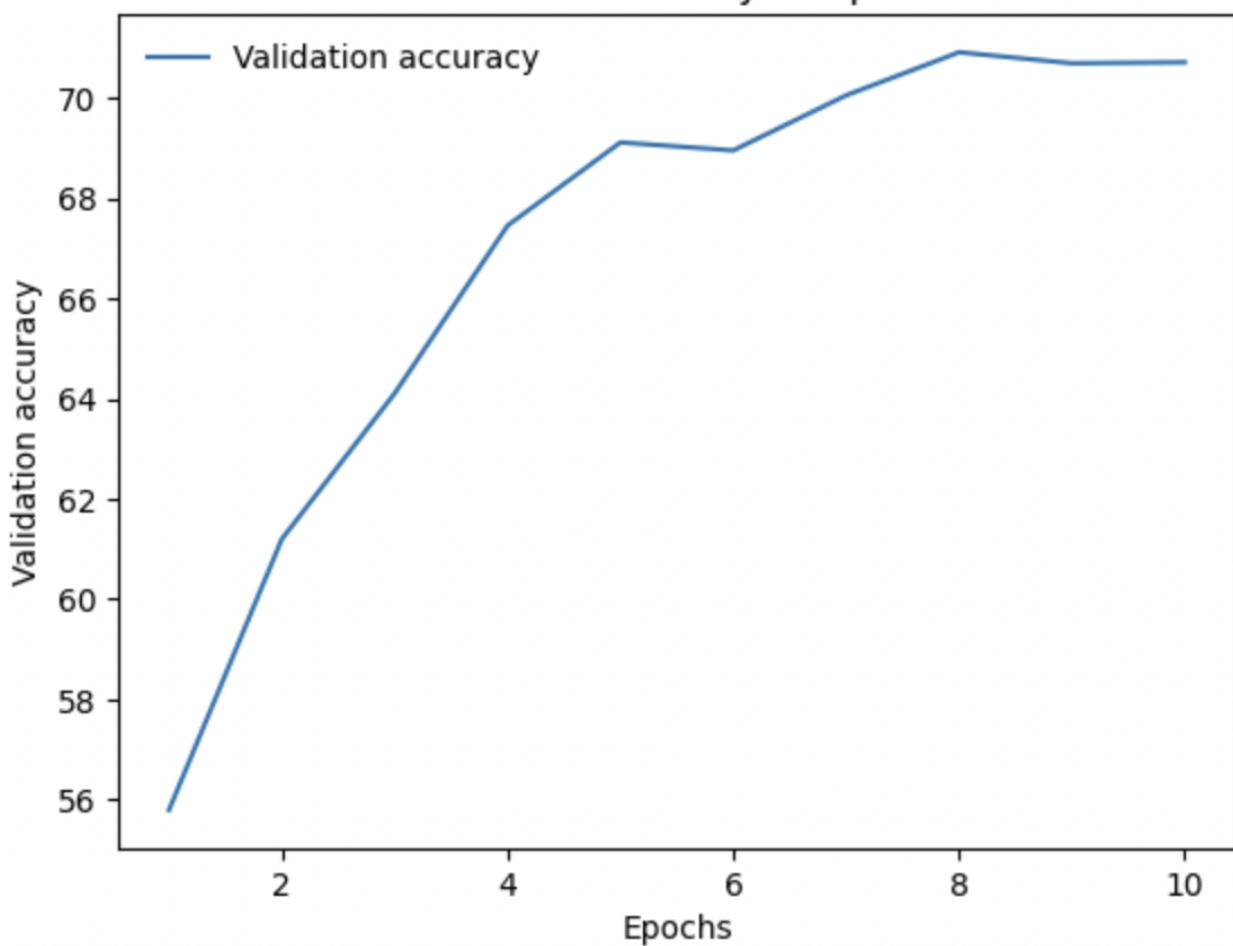
Training and validation losses vs epochs



Training accuracy vs epochs



### Validation accuracy vs epochs

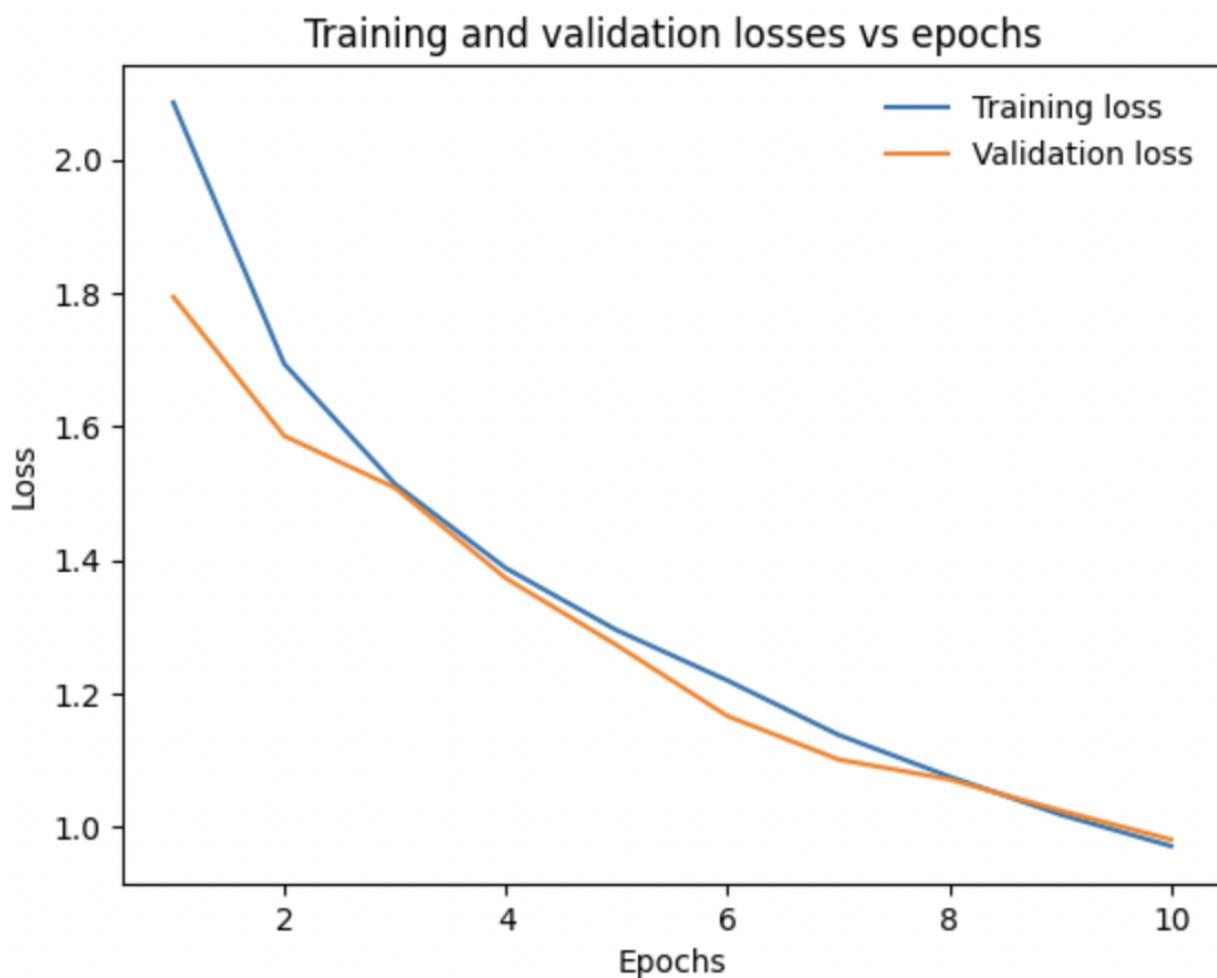


### Classwise Accuracy:

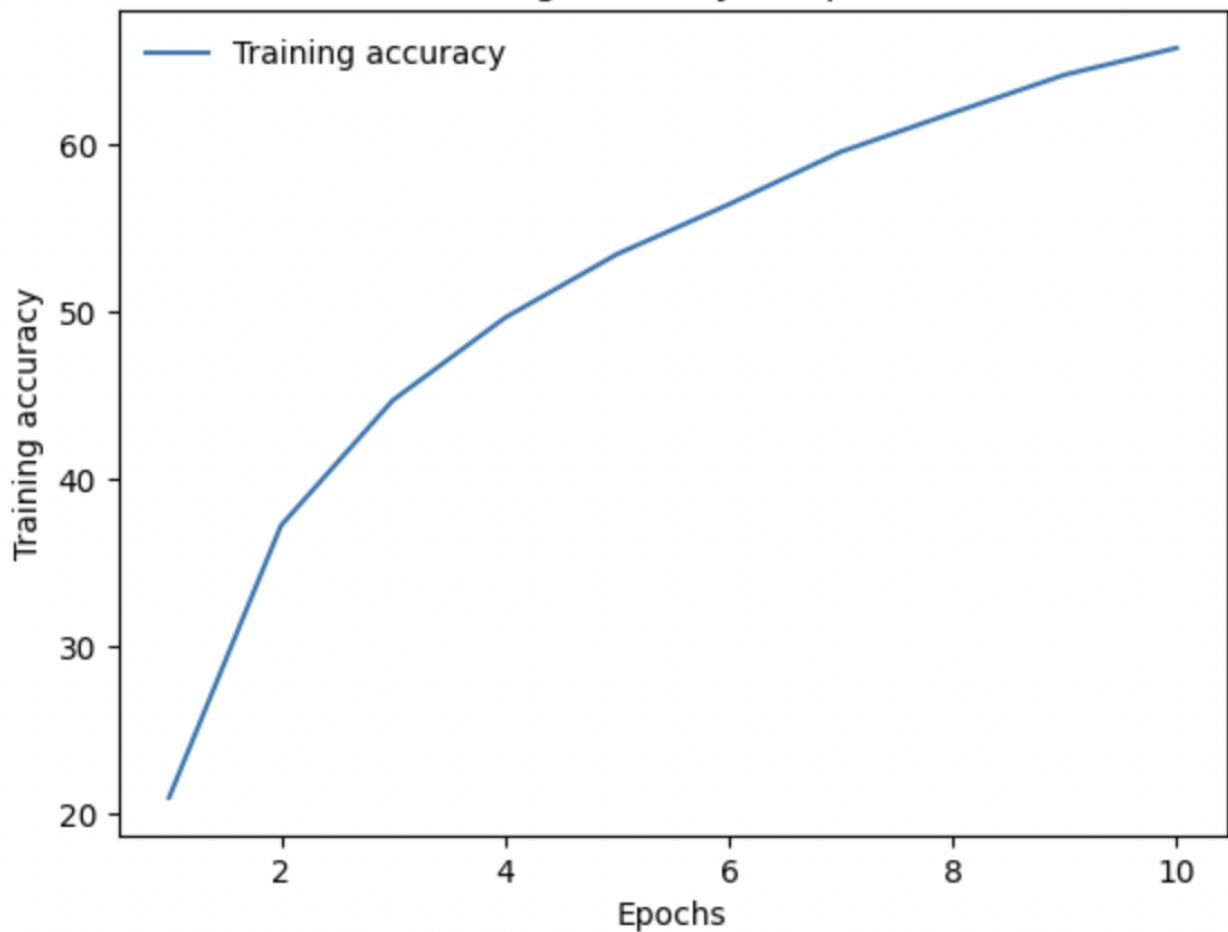
Accuracy for class: plane is 73.0 %  
Accuracy for class: car is 78.9 %  
Accuracy for class: bird is 63.7 %  
Accuracy for class: cat is 56.1 %  
Accuracy for class: deer is 73.2 %  
Accuracy for class: dog is 64.8 %  
Accuracy for class: frog is 67.1 %  
Accuracy for class: horse is 72.5 %  
Accuracy for class: ship is 82.0 %  
Accuracy for class: truck is 75.9 %

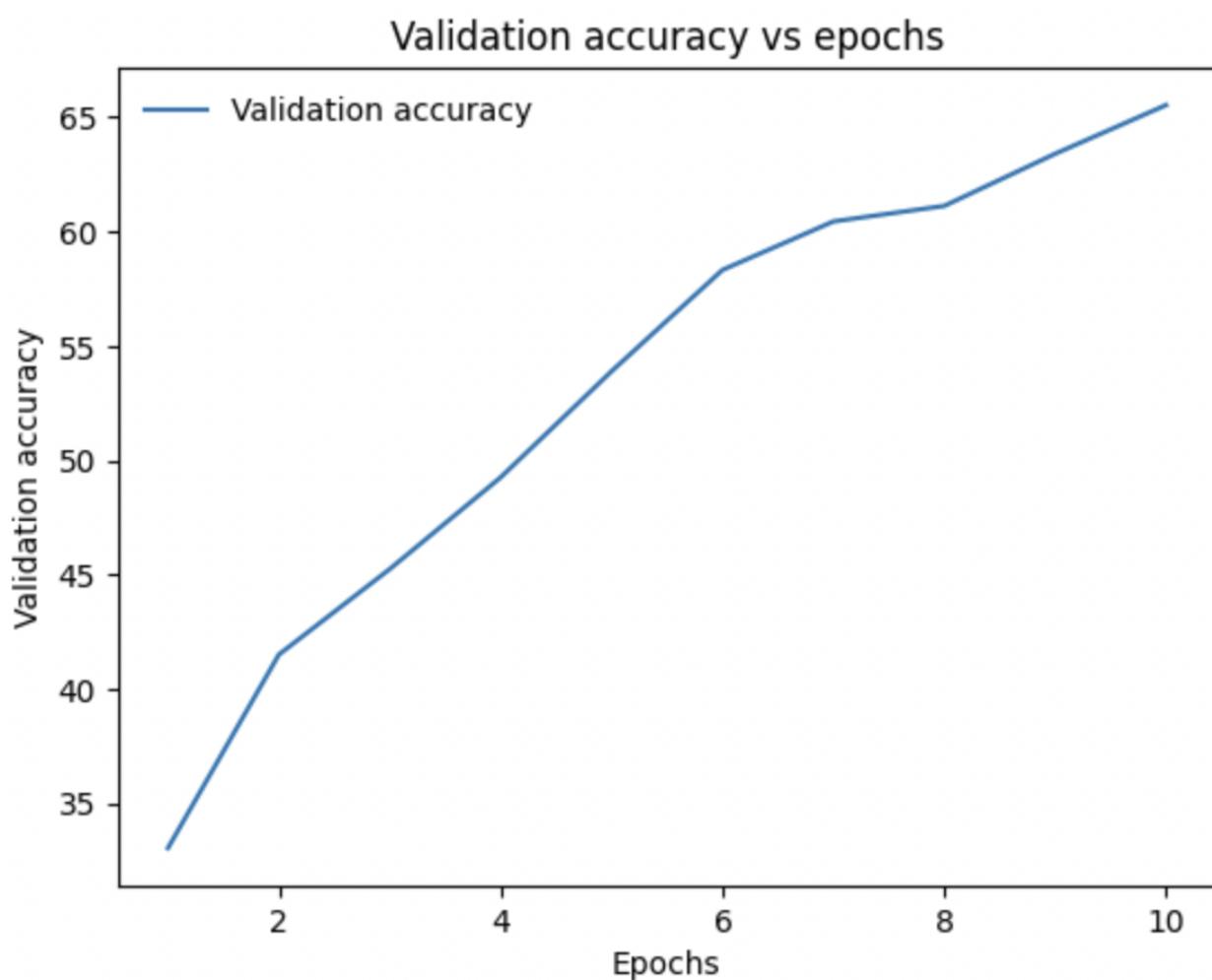
## SGD Optimiser:

Epoch 1 train loss: 2.086 val loss: 1.794 train accuracy: 20.980 val accuracy: 33.040  
Epoch 2 train loss: 1.694 val loss: 1.586 train accuracy: 37.216 val accuracy: 41.500  
Epoch 3 train loss: 1.514 val loss: 1.508 train accuracy: 44.700 val accuracy: 45.240  
Epoch 4 train loss: 1.388 val loss: 1.372 train accuracy: 49.616 val accuracy: 49.250  
Epoch 5 train loss: 1.295 val loss: 1.272 train accuracy: 53.410 val accuracy: 53.890  
Epoch 6 train loss: 1.219 val loss: 1.166 train accuracy: 56.386 val accuracy: 58.320  
Epoch 7 train loss: 1.138 val loss: 1.101 train accuracy: 59.522 val accuracy: 60.440  
Epoch 8 train loss: 1.075 val loss: 1.071 train accuracy: 61.846 val accuracy: 61.120  
Epoch 9 train loss: 1.018 val loss: 1.024 train accuracy: 64.122 val accuracy: 63.400  
Epoch 10 train loss: 0.971 val loss: 0.981 train accuracy: 65.720 val accuracy: 65.530



Training accuracy vs epochs





#### Classwise Accuracy:

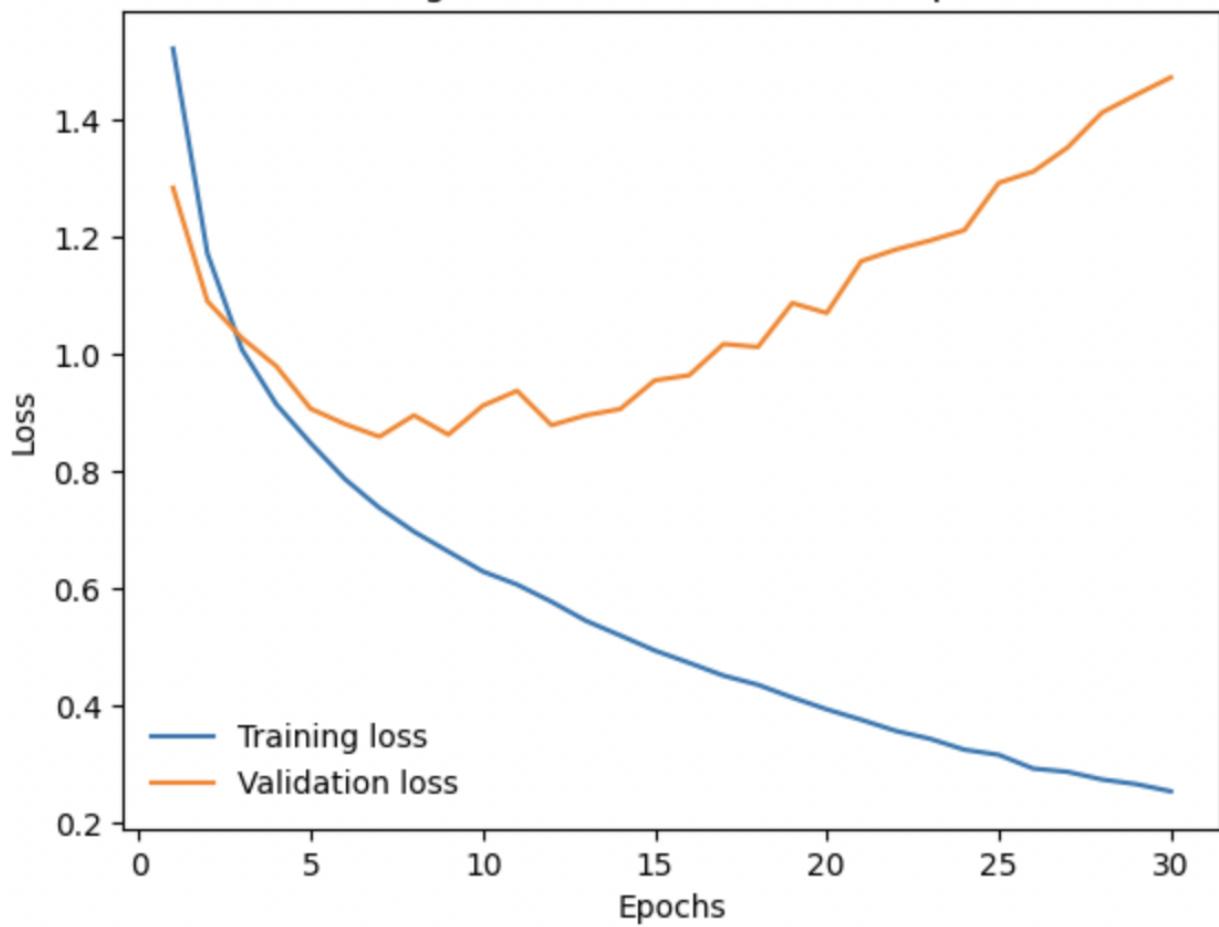
Accuracy for class: plane is 60.1 %  
Accuracy for class: car is 75.7 %  
Accuracy for class: bird is 57.6 %  
Accuracy for class: cat is 38.4 %  
Accuracy for class: deer is 59.4 %  
Accuracy for class: dog is 58.8 %  
Accuracy for class: frog is 74.6 %  
Accuracy for class: horse is 77.0 %  
Accuracy for class: ship is 75.6 %  
Accuracy for class: truck is 78.1 %

## b) Epochs = 30

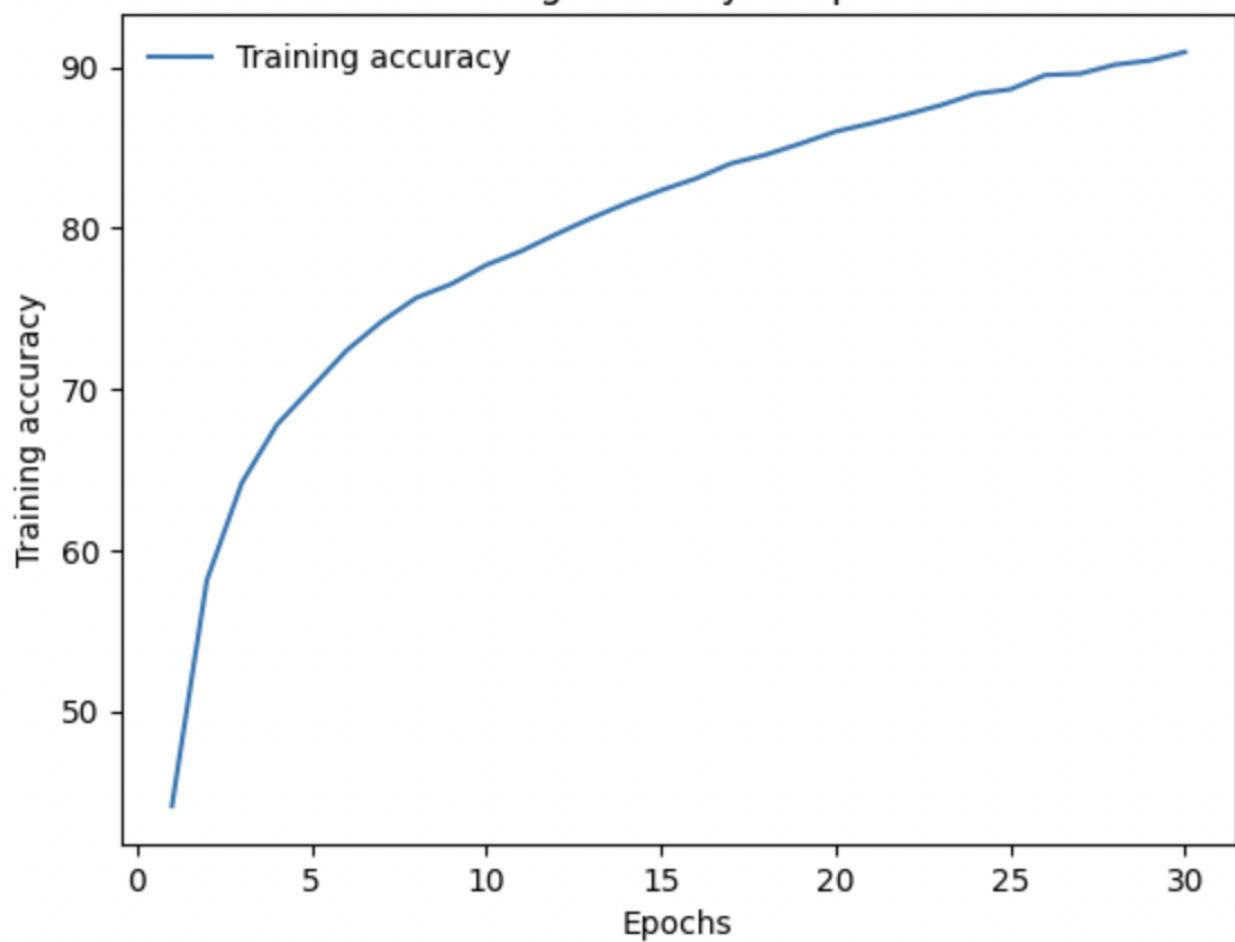
### Adam Optimiser:

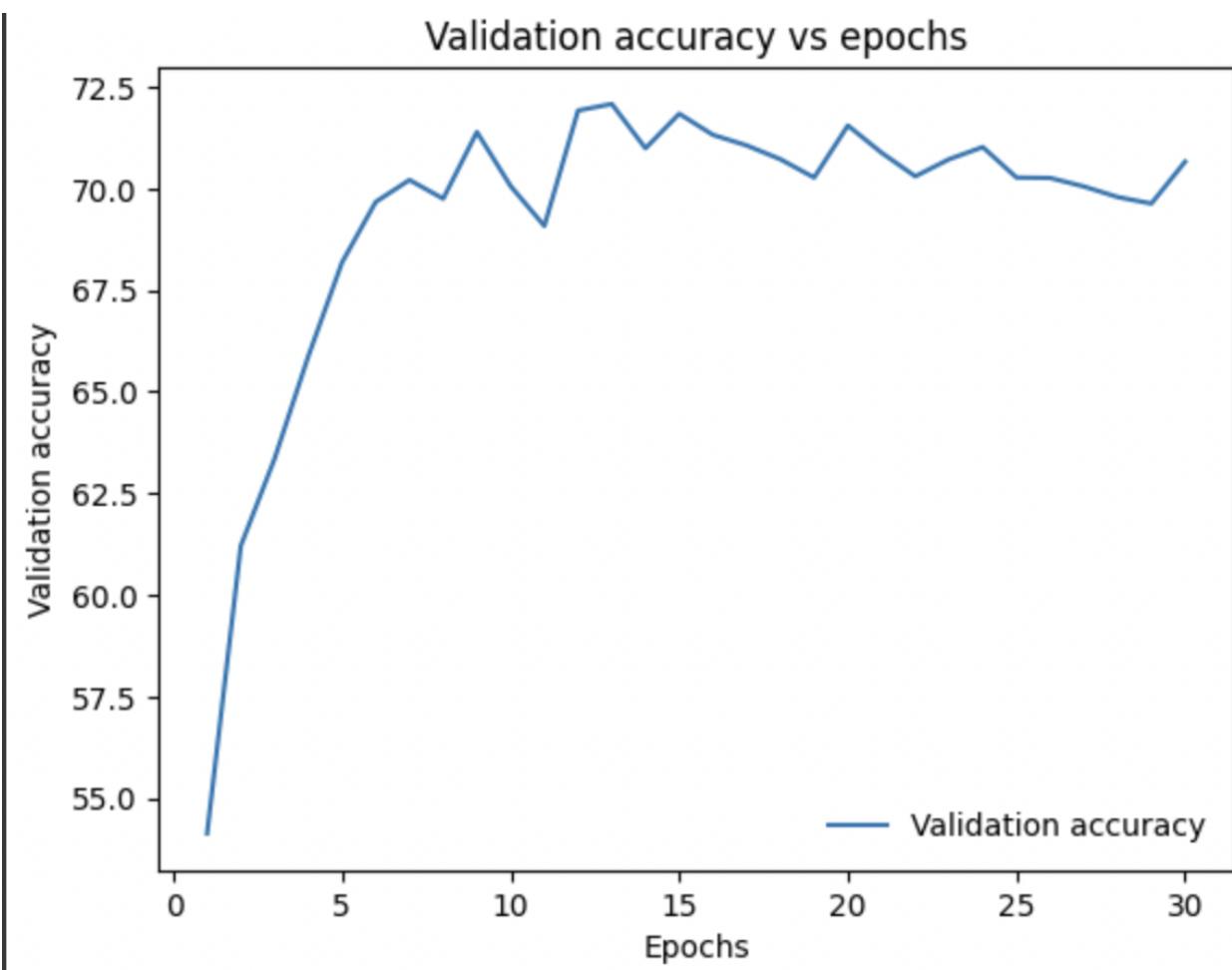
Epoch 1 train loss: 1.521 val loss: 1.284 train accuracy: 44.122 val accuracy: 54.130  
Epoch 2 train loss: 1.172 val loss: 1.090 train accuracy: 58.138 val accuracy: 61.210  
Epoch 3 train loss: 1.008 val loss: 1.028 train accuracy: 64.172 val accuracy: 63.350  
Epoch 4 train loss: 0.915 val loss: 0.980 train accuracy: 67.770 val accuracy: 65.870  
Epoch 5 train loss: 0.848 val loss: 0.907 train accuracy: 70.082 val accuracy: 68.180  
Epoch 6 train loss: 0.787 val loss: 0.881 train accuracy: 72.394 val accuracy: 69.670  
Epoch 7 train loss: 0.738 val loss: 0.859 train accuracy: 74.190 val accuracy: 70.210  
Epoch 8 train loss: 0.697 val loss: 0.896 train accuracy: 75.668 val accuracy: 69.750  
Epoch 9 train loss: 0.663 val loss: 0.863 train accuracy: 76.522 val accuracy: 71.390  
Epoch 10 train loss: 0.629 val loss: 0.912 train accuracy: 77.704 val accuracy: 70.060  
Epoch 11 train loss: 0.607 val loss: 0.938 train accuracy: 78.564 val accuracy: 69.080  
Epoch 12 train loss: 0.578 val loss: 0.879 train accuracy: 79.612 val accuracy: 71.920  
Epoch 13 train loss: 0.545 val loss: 0.896 train accuracy: 80.604 val accuracy: 72.080  
Epoch 14 train loss: 0.520 val loss: 0.906 train accuracy: 81.520 val accuracy: 70.990  
Epoch 15 train loss: 0.495 val loss: 0.955 train accuracy: 82.336 val accuracy: 71.840  
Epoch 16 train loss: 0.473 val loss: 0.964 train accuracy: 83.068 val accuracy: 71.320  
Epoch 17 train loss: 0.452 val loss: 1.017 train accuracy: 84.000 val accuracy: 71.060  
Epoch 18 train loss: 0.436 val loss: 1.012 train accuracy: 84.544 val accuracy: 70.720  
Epoch 19 train loss: 0.414 val loss: 1.087 train accuracy: 85.240 val accuracy: 70.270  
Epoch 20 train loss: 0.394 val loss: 1.070 train accuracy: 85.988 val accuracy: 71.550  
Epoch 21 train loss: 0.376 val loss: 1.159 train accuracy: 86.484 val accuracy: 70.880  
Epoch 22 train loss: 0.357 val loss: 1.178 train accuracy: 87.032 val accuracy: 70.300  
Epoch 23 train loss: 0.344 val loss: 1.194 train accuracy: 87.614 val accuracy: 70.720  
Epoch 24 train loss: 0.325 val loss: 1.211 train accuracy: 88.324 val accuracy: 71.020  
Epoch 25 train loss: 0.317 val loss: 1.292 train accuracy: 88.602 val accuracy: 70.270  
Epoch 26 train loss: 0.293 val loss: 1.311 train accuracy: 89.494 val accuracy: 70.260  
Epoch 27 train loss: 0.288 val loss: 1.353 train accuracy: 89.574 val accuracy: 70.050  
Epoch 28 train loss: 0.274 val loss: 1.412 train accuracy: 90.136 val accuracy: 69.790  
Epoch 29 train loss: 0.267 val loss: 1.443 train accuracy: 90.392 val accuracy: 69.630  
Epoch 30 train loss: 0.254 val loss: 1.472 train accuracy: 90.922 val accuracy: 70.660

Training and validation losses vs epochs



Training accuracy vs epochs





### Classwise Accuracy:

Accuracy for class: plane is 70.4 %  
Accuracy for class: car is 85.0 %  
Accuracy for class: bird is 65.0 %  
Accuracy for class: cat is 51.6 %  
Accuracy for class: deer is 64.7 %  
Accuracy for class: dog is 62.5 %  
Accuracy for class: frog is 75.4 %  
Accuracy for class: horse is 74.3 %  
Accuracy for class: ship is 77.8 %  
Accuracy for class: truck is 79.9 %

As per the analysis above, it can be seen that increasing the number of epochs is not always helpful. Too large a number of epochs could lead to overfitting and therefore reduce the validation accuracy. Similarly, too few epochs could lead to underfitting and poor performance. Therefore finding the right balance is the key.

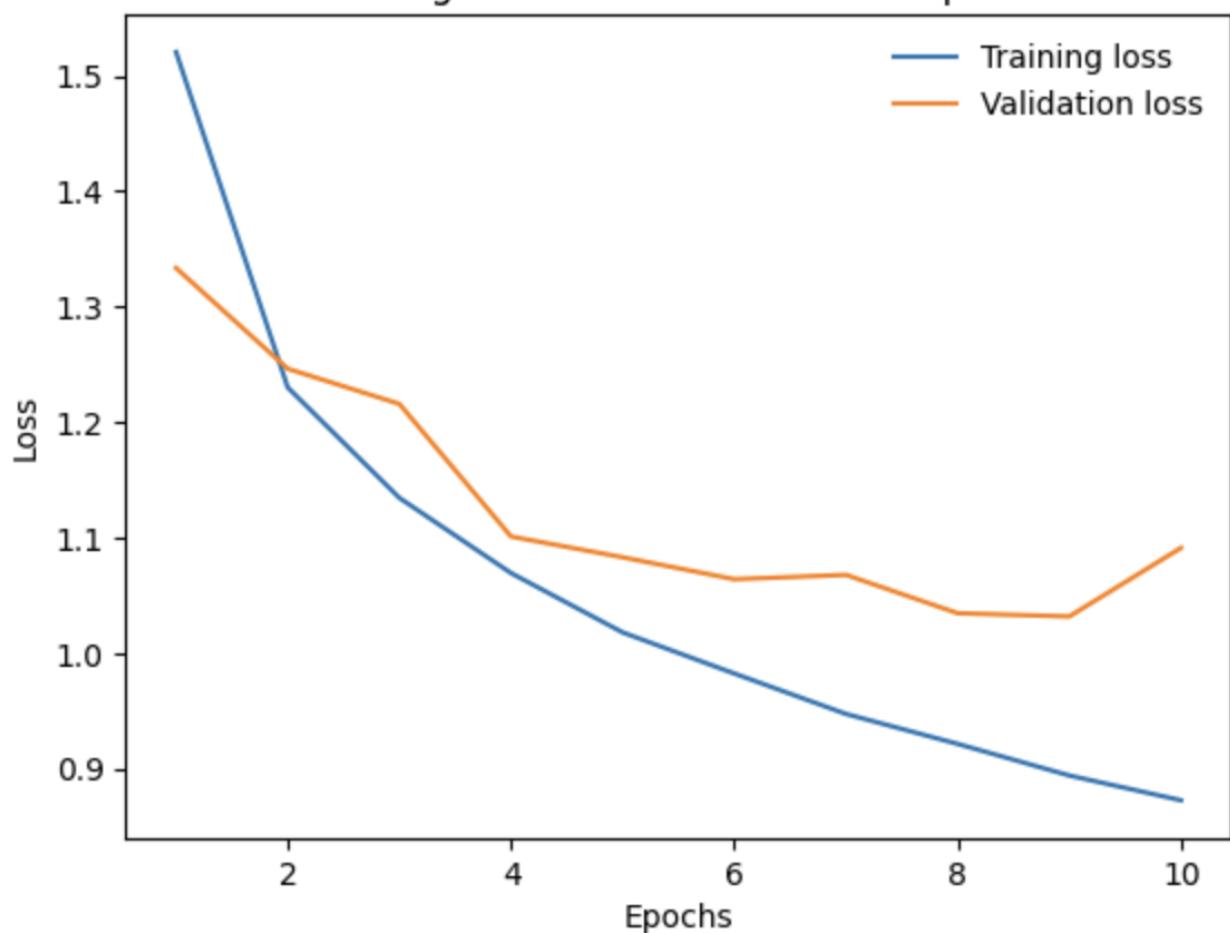
#### 4) Batch Size:

LR = 0.001, No of Epochs = 10, Loss Function = Cross Entropy,  
Optimiser = Adam

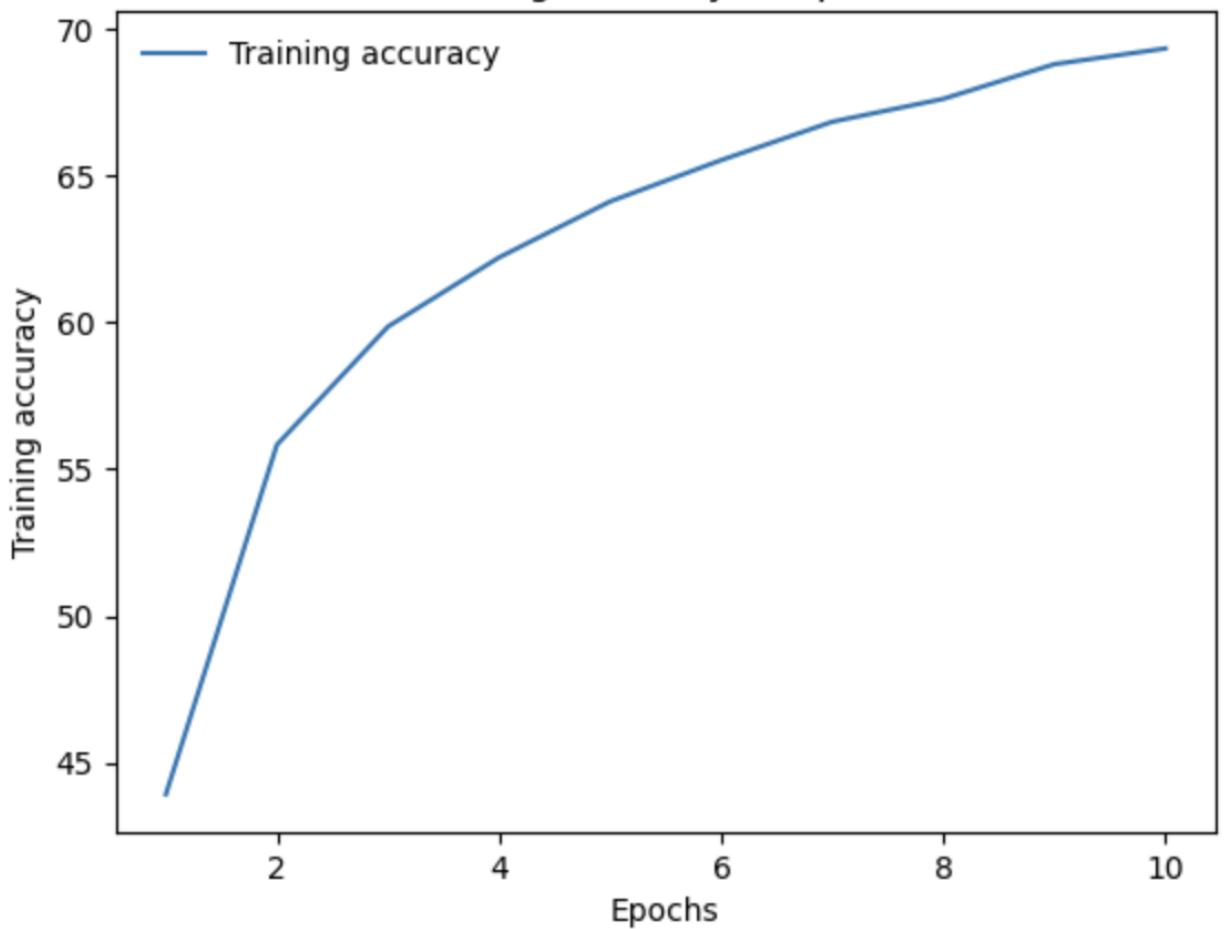
##### a) Batch Size = 4:

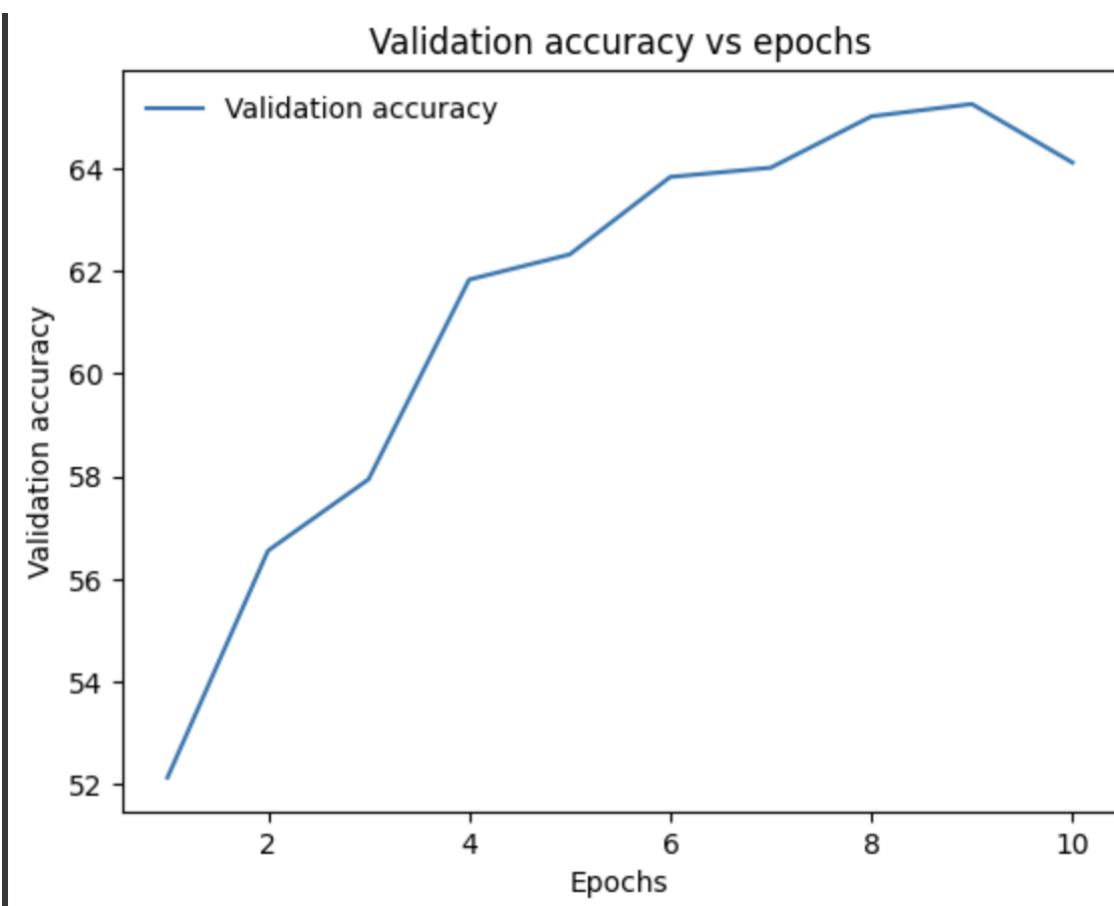
Epoch 1 train loss: 1.520 val loss: 1.333 train accuracy: 43.920 val accuracy: 52.130  
Epoch 2 train loss: 1.230 val loss: 1.246 train accuracy: 55.834 val accuracy: 56.550  
Epoch 3 train loss: 1.134 val loss: 1.216 train accuracy: 59.860 val accuracy: 57.940  
Epoch 4 train loss: 1.069 val loss: 1.101 train accuracy: 62.216 val accuracy: 61.830  
Epoch 5 train loss: 1.018 val loss: 1.083 train accuracy: 64.124 val accuracy: 62.320  
Epoch 6 train loss: 0.982 val loss: 1.064 train accuracy: 65.532 val accuracy: 63.830  
Epoch 7 train loss: 0.947 val loss: 1.068 train accuracy: 66.840 val accuracy: 64.010  
Epoch 8 train loss: 0.921 val loss: 1.035 train accuracy: 67.620 val accuracy: 65.010  
Epoch 9 train loss: 0.894 val loss: 1.032 train accuracy: 68.802 val accuracy: 65.250  
Epoch 10 train loss: 0.873 val loss: 1.091 train accuracy: 69.338 val accuracy: 64.110

Training and validation losses vs epochs



Training accuracy vs epochs



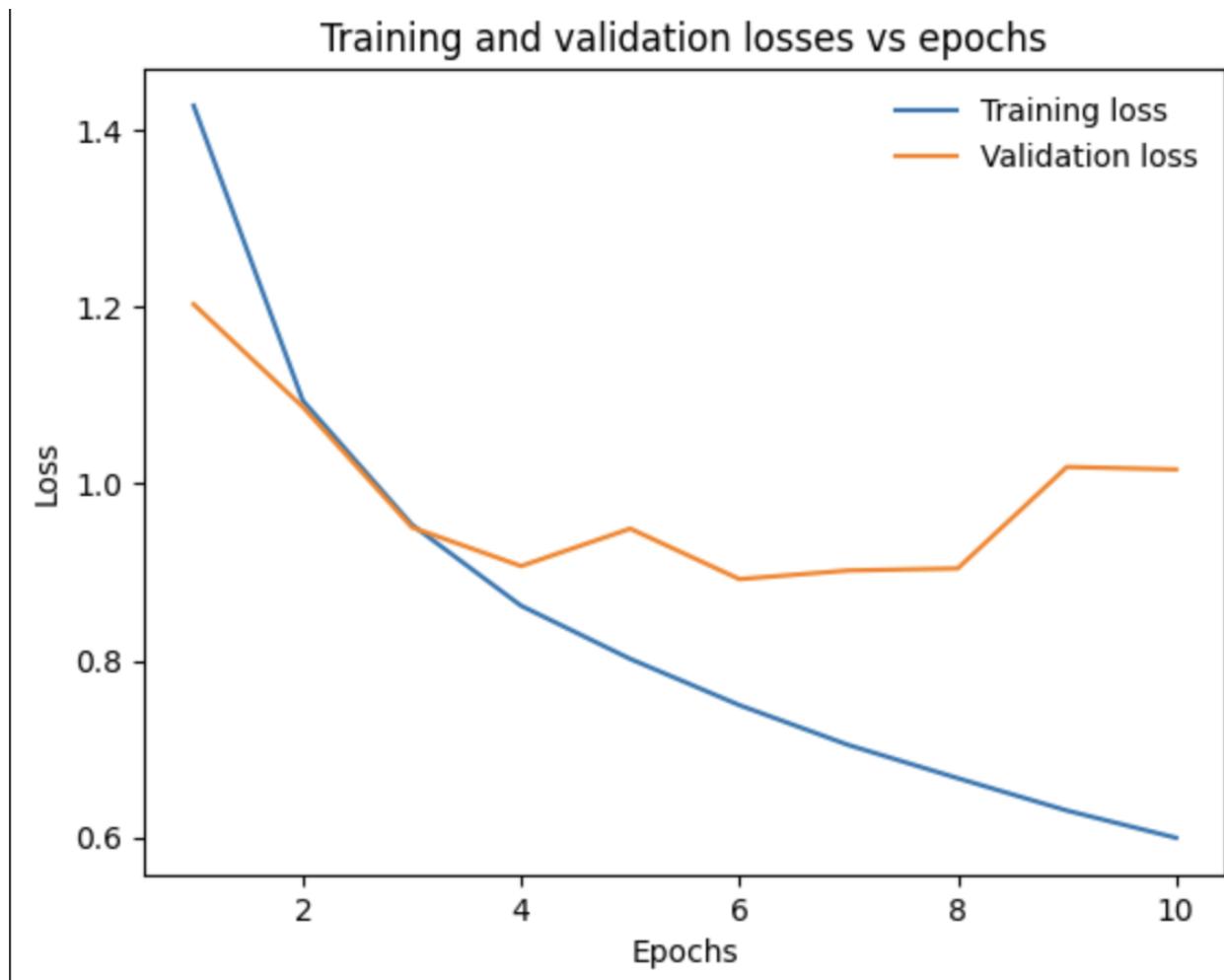


#### Classwise Accuracy:

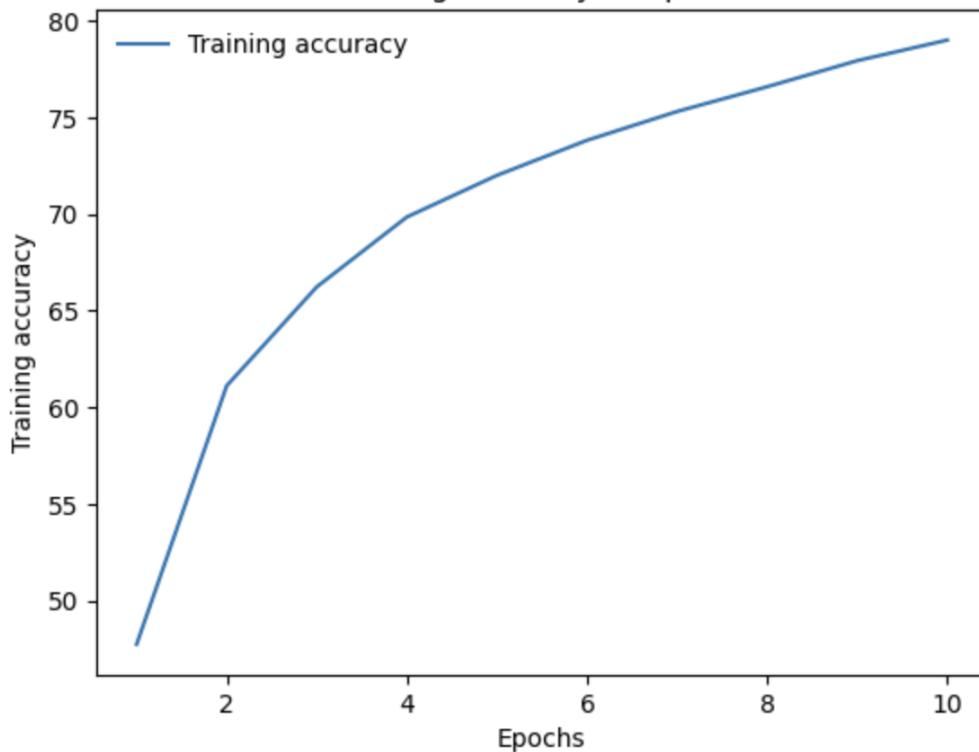
Accuracy for class: plane is 54.8 %  
Accuracy for class: car is 86.4 %  
Accuracy for class: bird is 39.9 %  
Accuracy for class: cat is 55.0 %  
Accuracy for class: deer is 54.2 %  
Accuracy for class: dog is 47.7 %  
Accuracy for class: frog is 79.4 %  
Accuracy for class: horse is 72.7 %  
Accuracy for class: ship is 78.3 %  
Accuracy for class: truck is 72.7 %

### b) Batch Size = 8

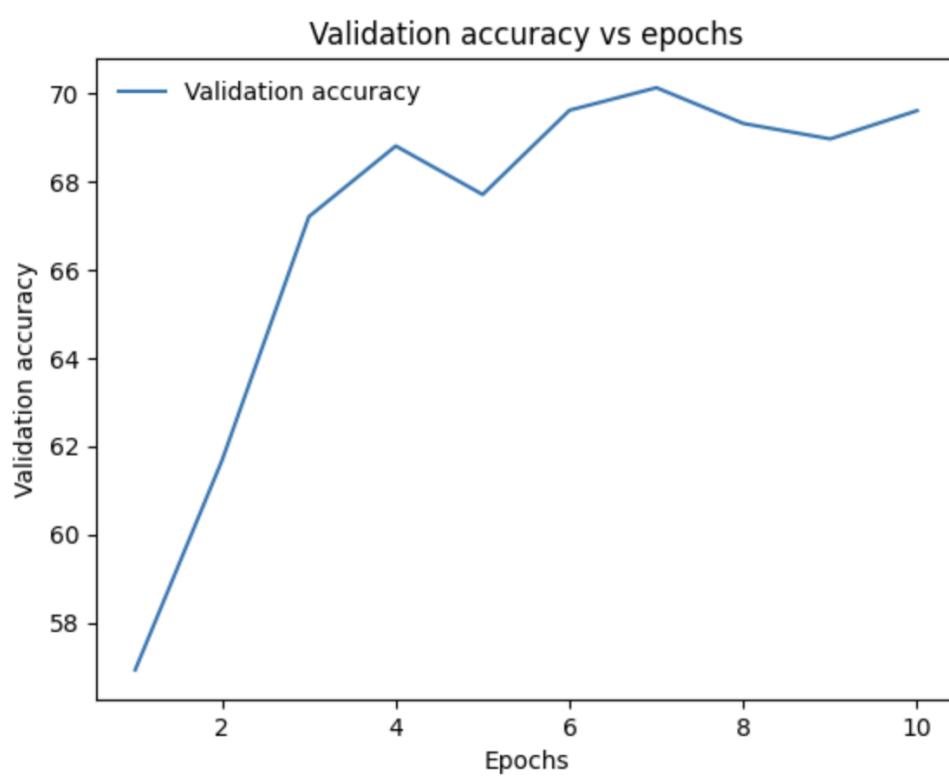
Epoch 1 train loss: 1.428 val loss: 1.203 train accuracy: 47.742 val accuracy: 56.930  
Epoch 2 train loss: 1.094 val loss: 1.087 train accuracy: 61.122 val accuracy: 61.680  
Epoch 3 train loss: 0.954 val loss: 0.951 train accuracy: 66.240 val accuracy: 67.200  
Epoch 4 train loss: 0.862 val loss: 0.907 train accuracy: 69.856 val accuracy: 68.800  
Epoch 5 train loss: 0.802 val loss: 0.949 train accuracy: 72.012 val accuracy: 67.700  
Epoch 6 train loss: 0.749 val loss: 0.892 train accuracy: 73.826 val accuracy: 69.610  
Epoch 7 train loss: 0.704 val loss: 0.902 train accuracy: 75.318 val accuracy: 70.120  
Epoch 8 train loss: 0.667 val loss: 0.904 train accuracy: 76.598 val accuracy: 69.310  
Epoch 9 train loss: 0.630 val loss: 1.019 train accuracy: 77.948 val accuracy: 68.960  
Epoch 10 train loss: 0.599 val loss: 1.016 train accuracy: 79.014 val accuracy: 69.600



Training accuracy vs epochs



Validation accuracy vs epochs



## Classwise Accuracy:

Accuracy for class: plane is 82.1 %

Accuracy for class: car is 76.1 %

Accuracy for class: bird is 50.5 %

Accuracy for class: cat is 62.8 %

Accuracy for class: deer is 70.7 %

Accuracy for class: dog is 56.6 %

Accuracy for class: frog is 74.9 %

Accuracy for class: horse is 70.2 %

Accuracy for class: ship is 74.5 %

Accuracy for class: truck is 77.6 %

## c) Batch Size = 16

Epoch 1 train loss: 1.502 val loss: 1.240 train accuracy: 44.718 val accuracy: 55.270

Epoch 2 train loss: 1.155 val loss: 1.100 train accuracy: 58.890 val accuracy: 61.690

Epoch 3 train loss: 1.017 val loss: 0.998 train accuracy: 64.092 val accuracy: 64.740

Epoch 4 train loss: 0.934 val loss: 0.960 train accuracy: 67.052 val accuracy: 66.120

Epoch 5 train loss: 0.873 val loss: 1.003 train accuracy: 69.294 val accuracy: 65.380

Epoch 6 train loss: 0.824 val loss: 0.966 train accuracy: 70.994 val accuracy: 67.050

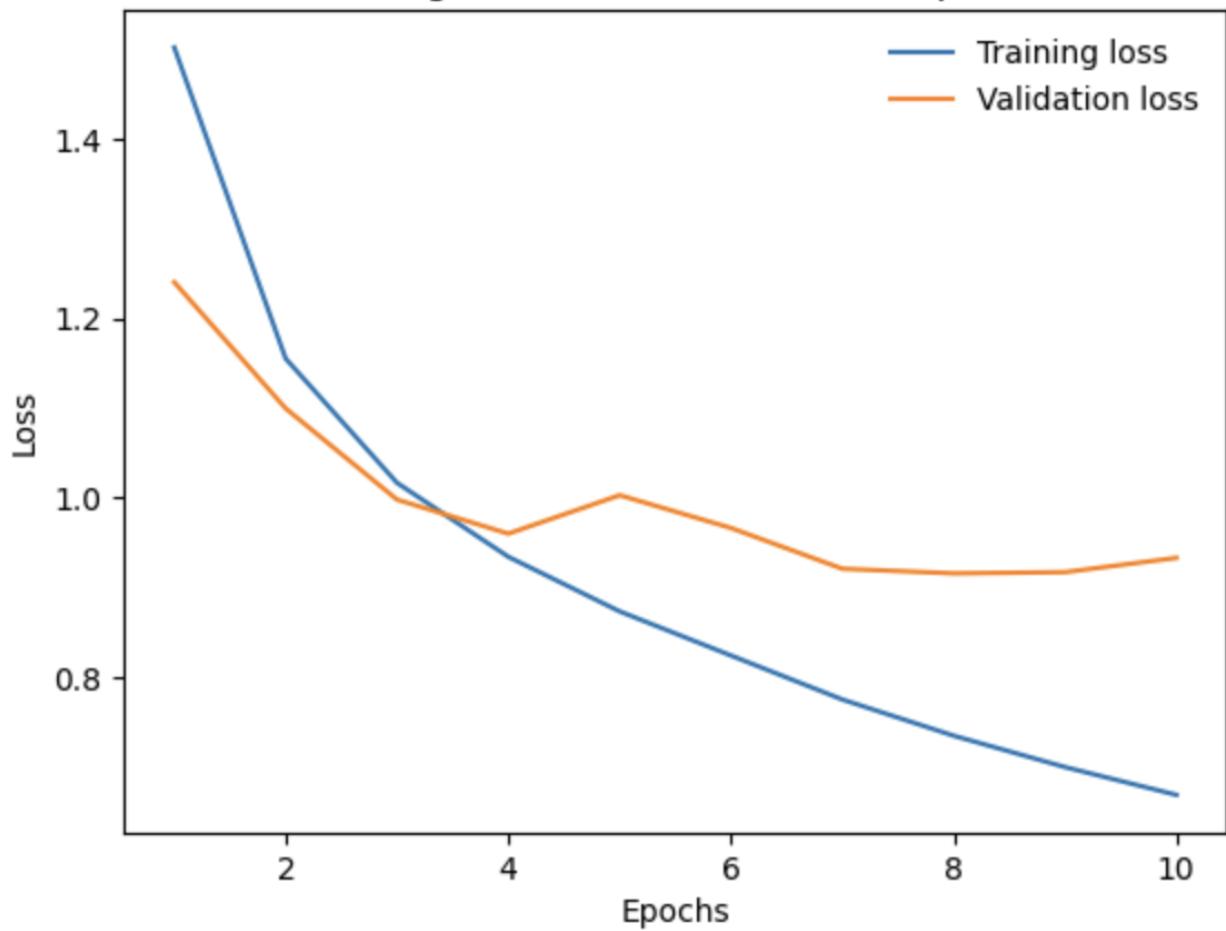
Epoch 7 train loss: 0.775 val loss: 0.921 train accuracy: 72.690 val accuracy: 68.300

Epoch 8 train loss: 0.735 val loss: 0.916 train accuracy: 74.178 val accuracy: 68.860

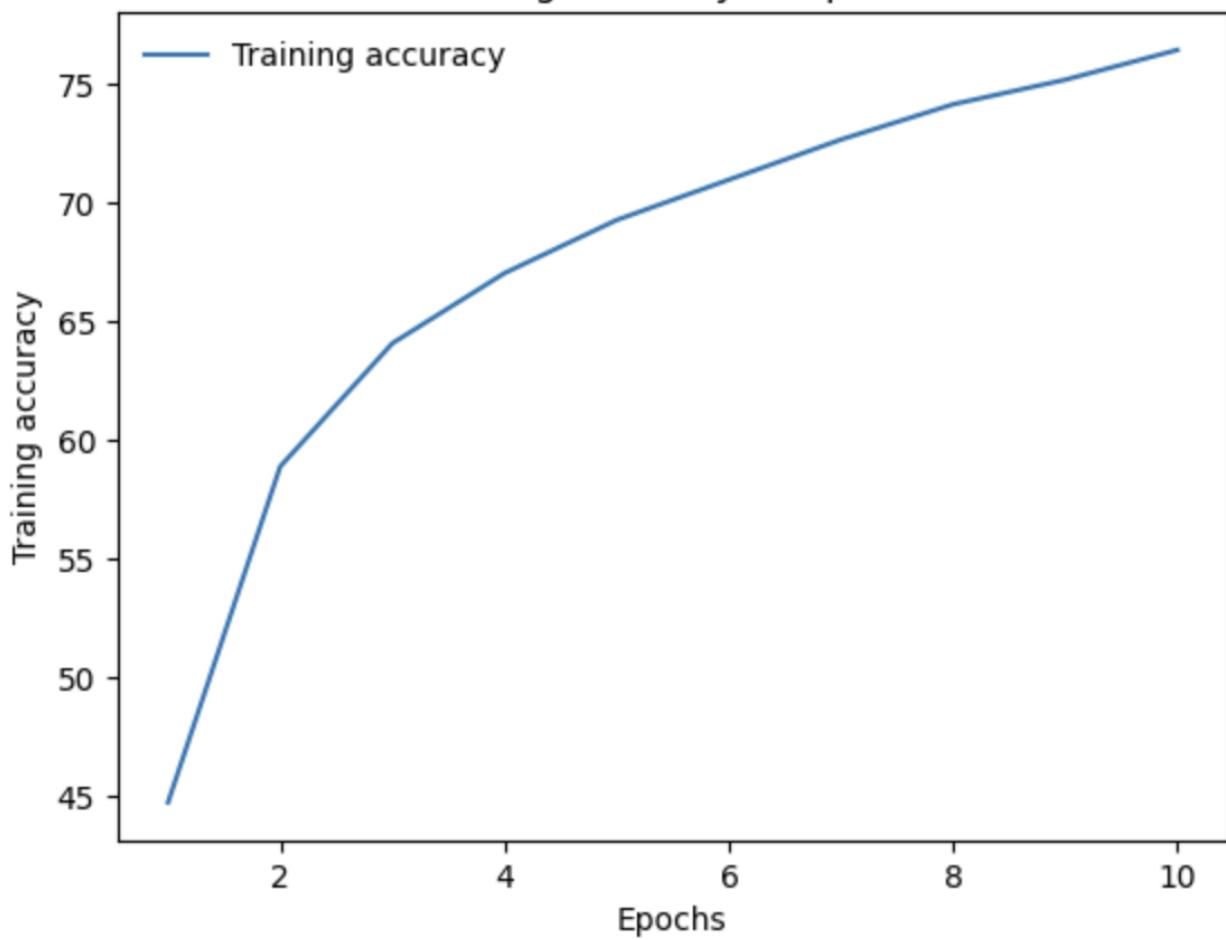
Epoch 9 train loss: 0.700 val loss: 0.917 train accuracy: 75.214 val accuracy: 69.660

Epoch 10 train loss: 0.669 val loss: 0.933 train accuracy: 76.472 val accuracy: 68.750

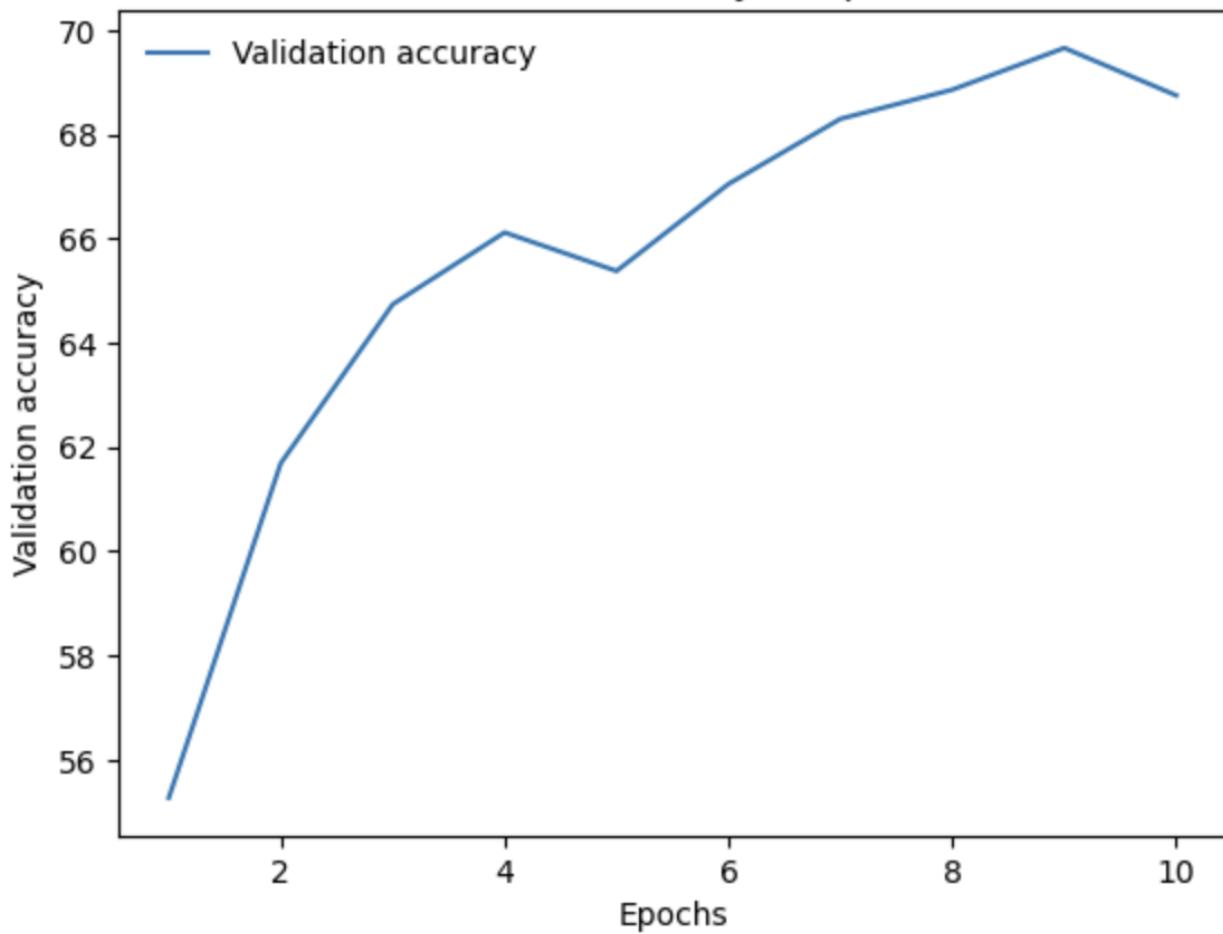
Training and validation losses vs epochs



Training accuracy vs epochs



### Validation accuracy vs epochs



#### Classwise Accuracy:

Accuracy for class: plane is 68.4 %

Accuracy for class: car is 81.6 %

Accuracy for class: bird is 60.7 %

Accuracy for class: cat is 64.3 %

Accuracy for class: deer is 58.0 %

Accuracy for class: dog is 52.4 %

Accuracy for class: frog is 73.1 %

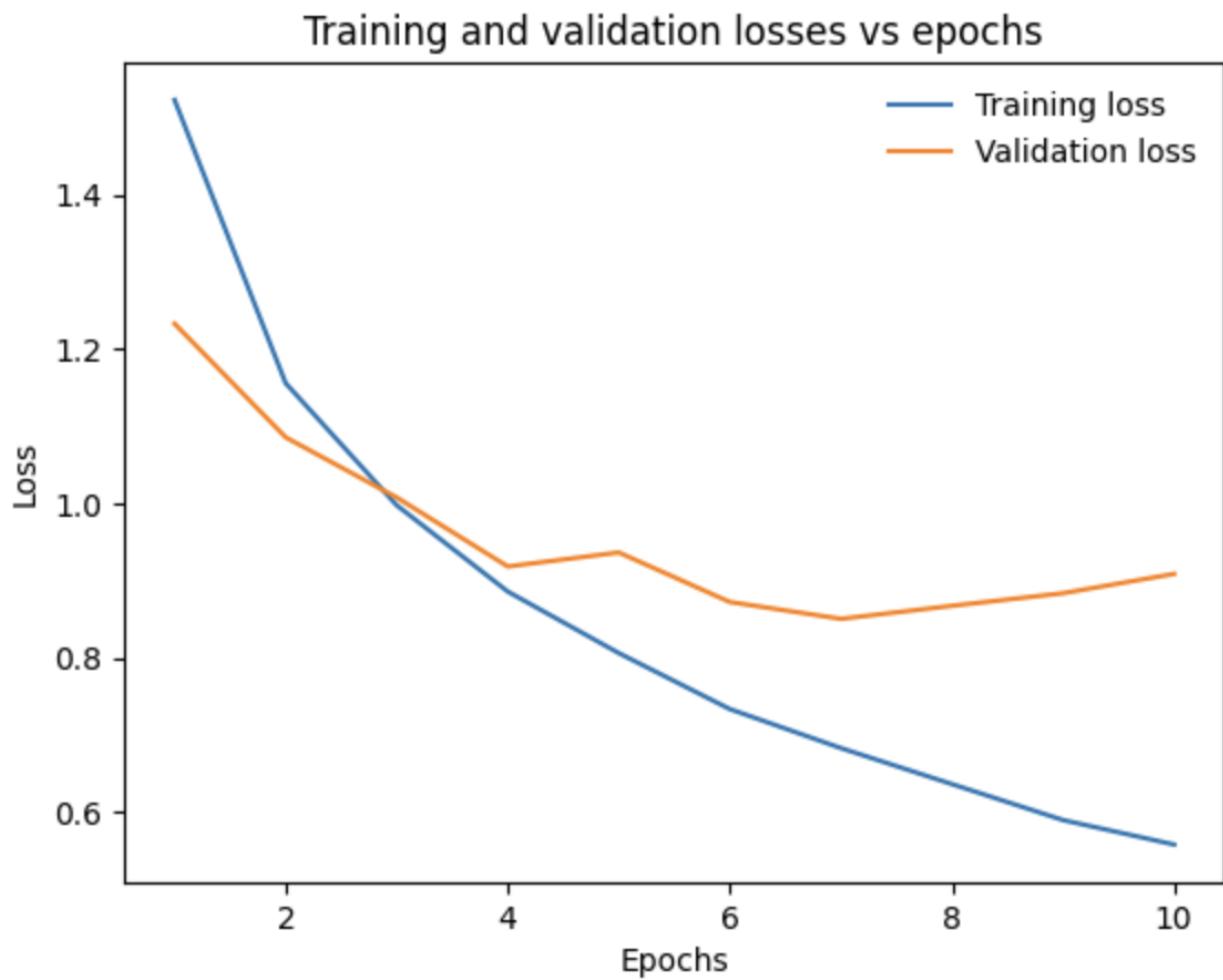
Accuracy for class: horse is 75.0 %

Accuracy for class: ship is 75.7 %

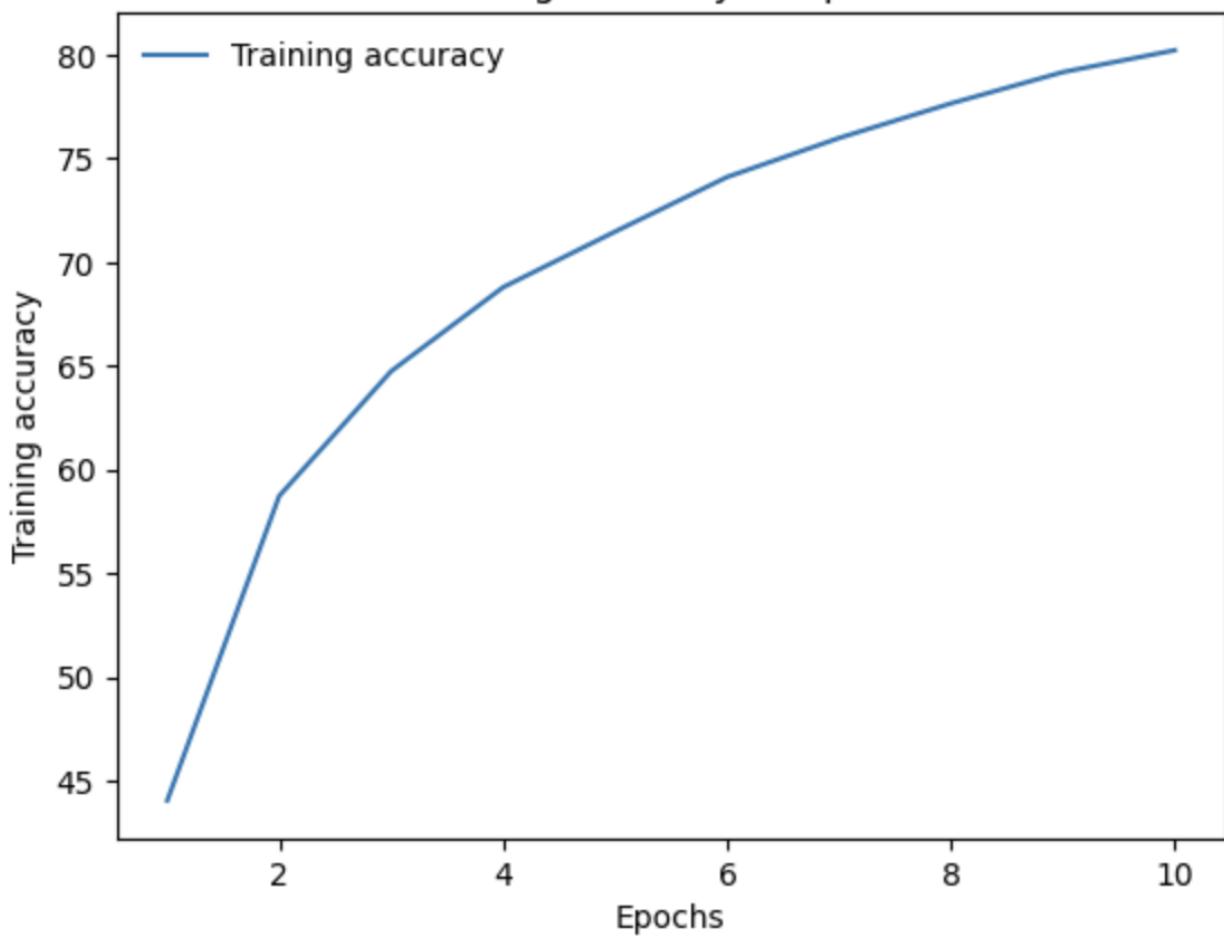
Accuracy for class: truck is 78.3 %

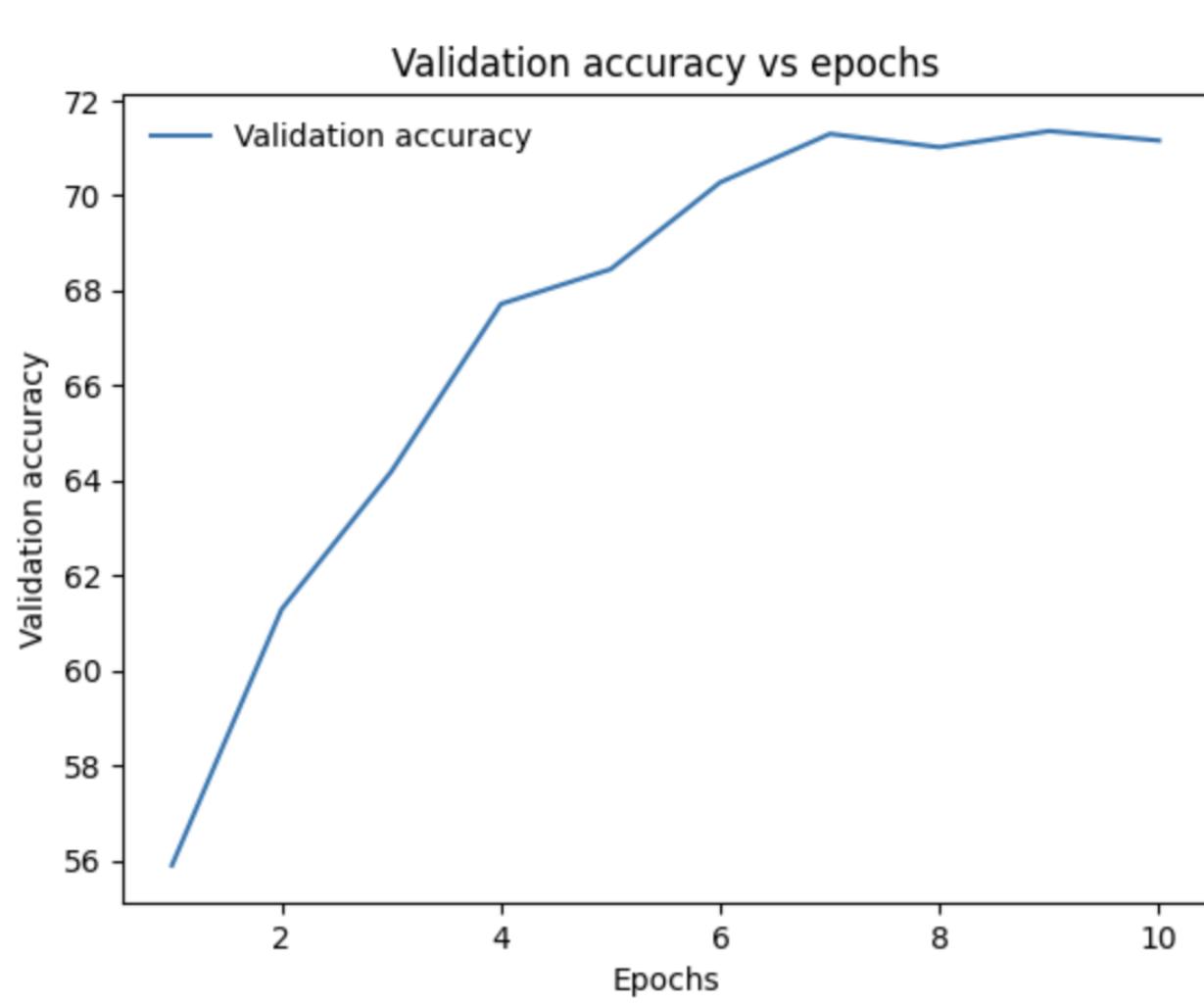
#### d) Batch Size = 32

Epoch 1 train loss: 1.522 val loss: 1.233 train accuracy: 44.038 val accuracy: 55.890  
Epoch 2 train loss: 1.156 val loss: 1.086 train accuracy: 58.726 val accuracy: 61.280  
Epoch 3 train loss: 0.998 val loss: 1.008 train accuracy: 64.744 val accuracy: 64.180  
Epoch 4 train loss: 0.886 val loss: 0.918 train accuracy: 68.792 val accuracy: 67.710  
Epoch 5 train loss: 0.806 val loss: 0.937 train accuracy: 71.474 val accuracy: 68.440  
Epoch 6 train loss: 0.734 val loss: 0.872 train accuracy: 74.106 val accuracy: 70.270  
Epoch 7 train loss: 0.683 val loss: 0.851 train accuracy: 75.988 val accuracy: 71.290  
Epoch 8 train loss: 0.637 val loss: 0.868 train accuracy: 77.658 val accuracy: 71.010  
Epoch 9 train loss: 0.590 val loss: 0.884 train accuracy: 79.168 val accuracy: 71.350  
Epoch 10 train loss: 0.559 val loss: 0.909 train accuracy: 80.224 val accuracy: 71.150



Training accuracy vs epochs

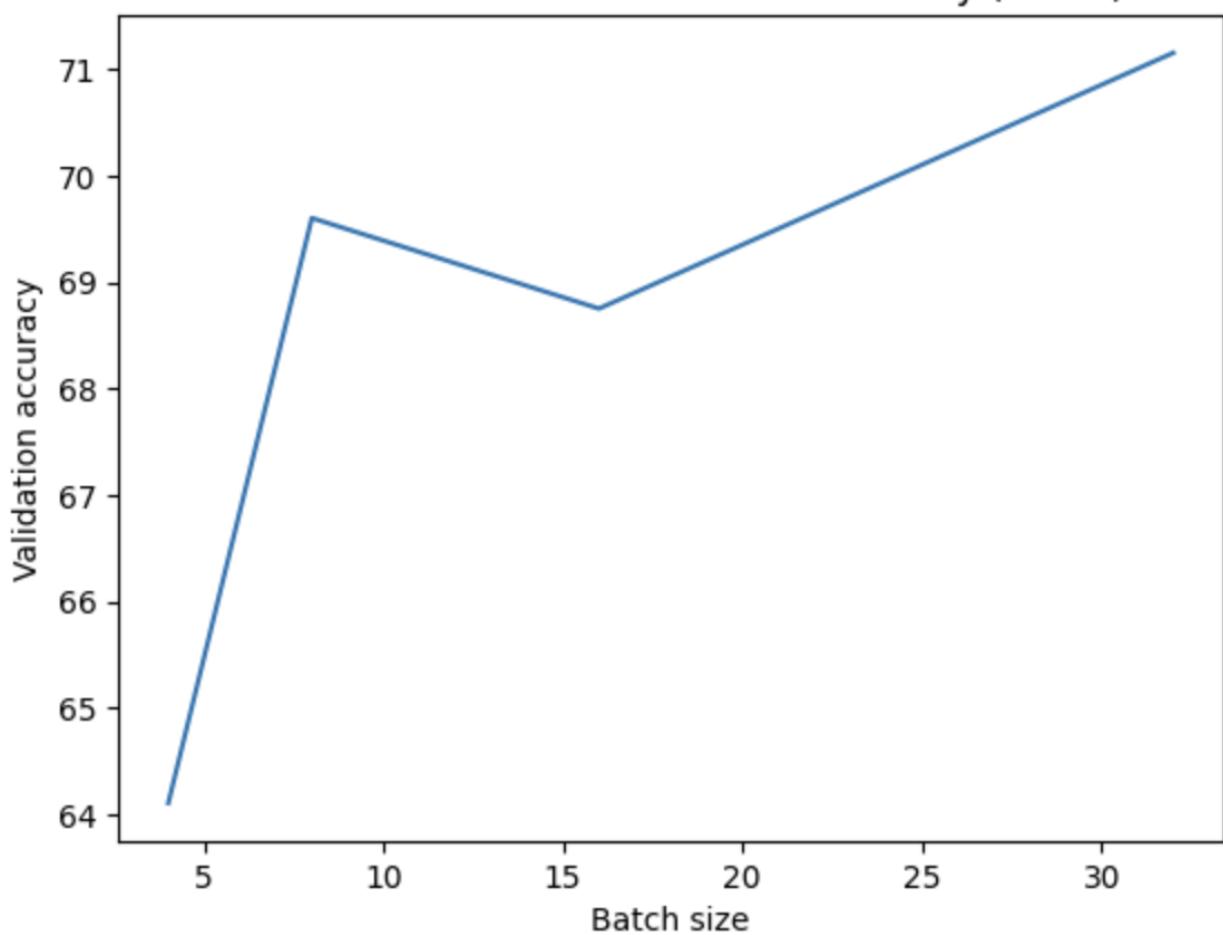




### Classwise Accuracy:

Accuracy for class: plane is 77.1 %  
Accuracy for class: car is 80.4 %  
Accuracy for class: bird is 70.5 %  
Accuracy for class: cat is 47.7 %  
Accuracy for class: deer is 64.7 %  
Accuracy for class: dog is 54.7 %  
Accuracy for class: frog is 85.7 %  
Accuracy for class: horse is 70.6 %  
Accuracy for class: ship is 78.4 %  
Accuracy for class: truck is 81.7 %

Batch size vs Overall validation accuracy (Adam)

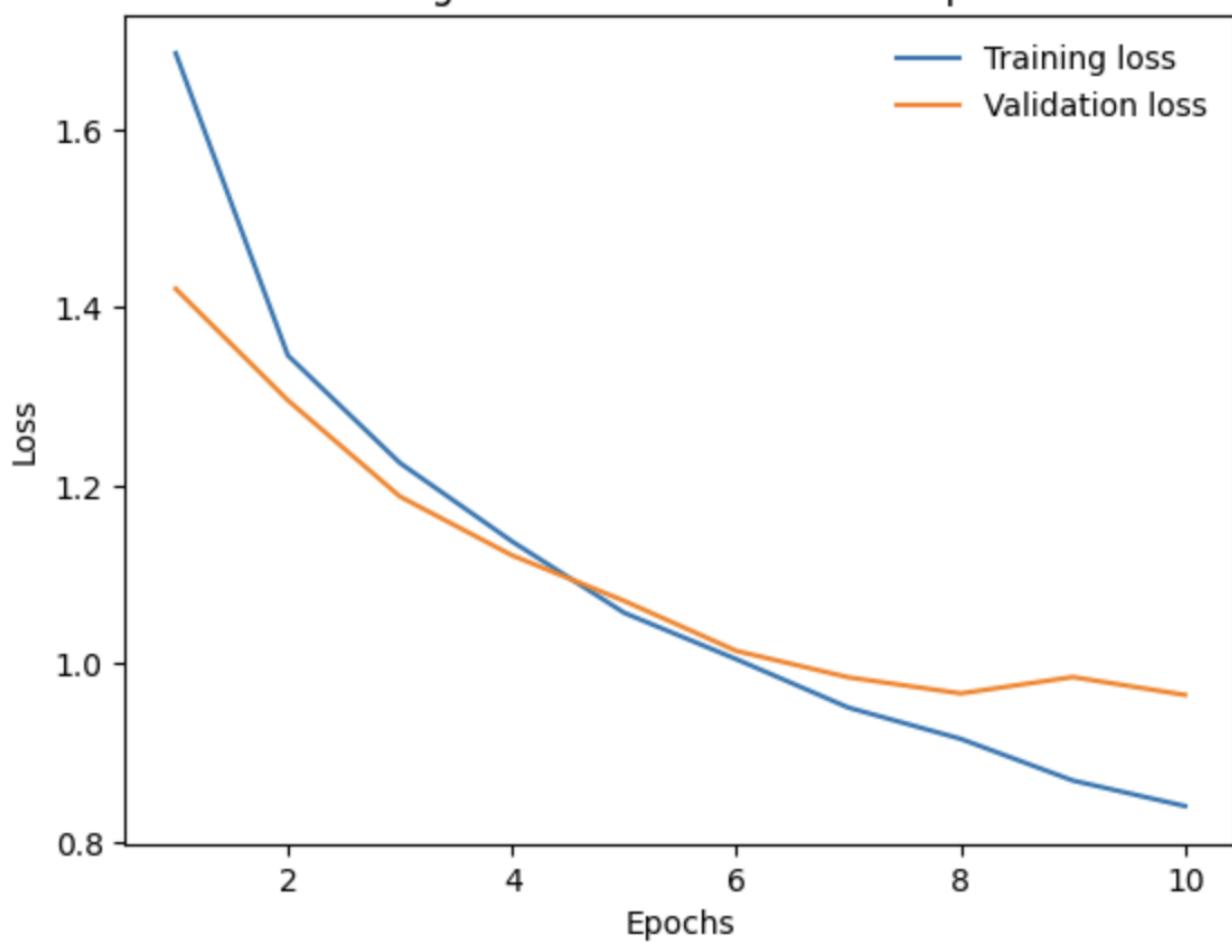


### 4.3) Effect of Data Augmentation

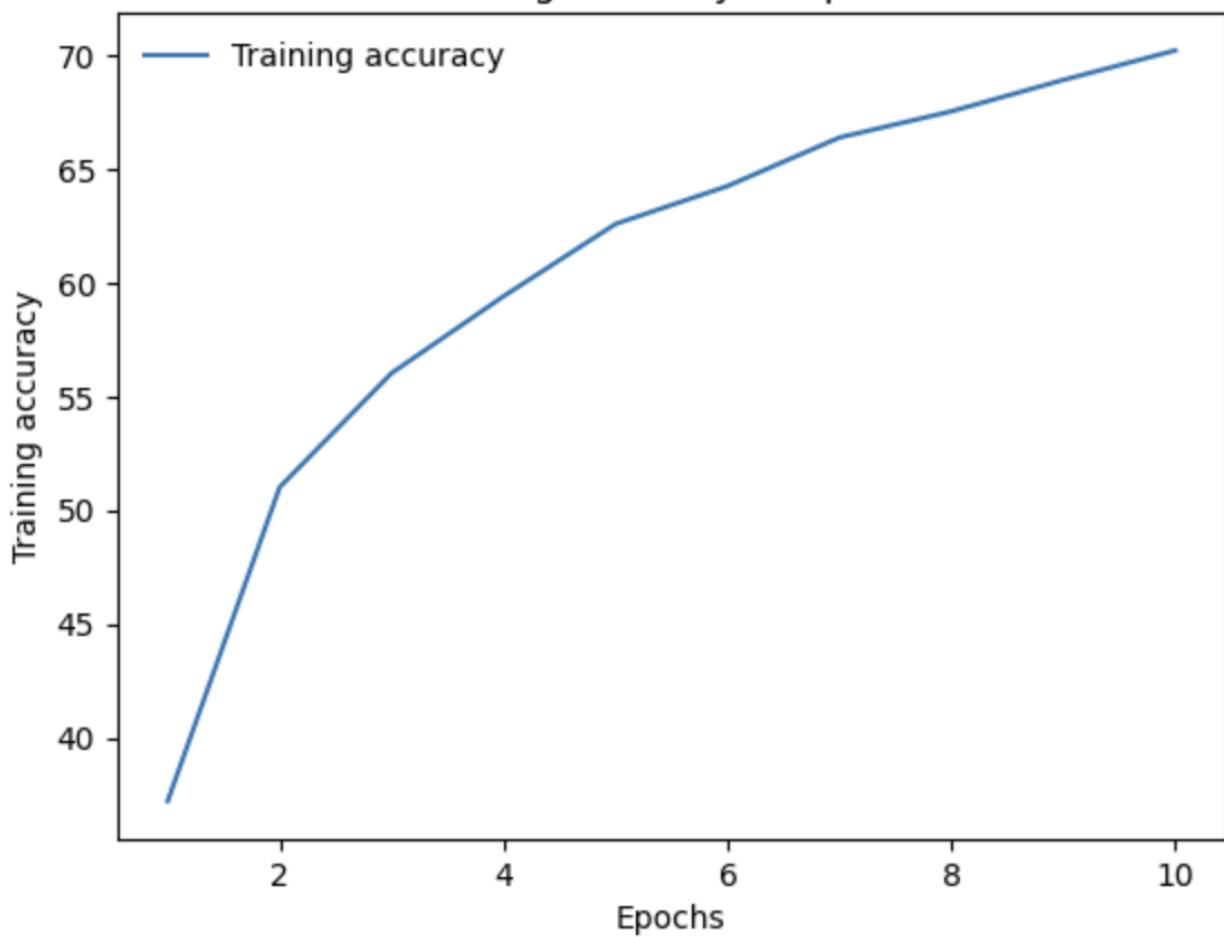
Learning rate: 0.001 No of epochs: 10 batch size: 32 optimizer: adam data augmentation: Turned Off loss function: cross\_entropy

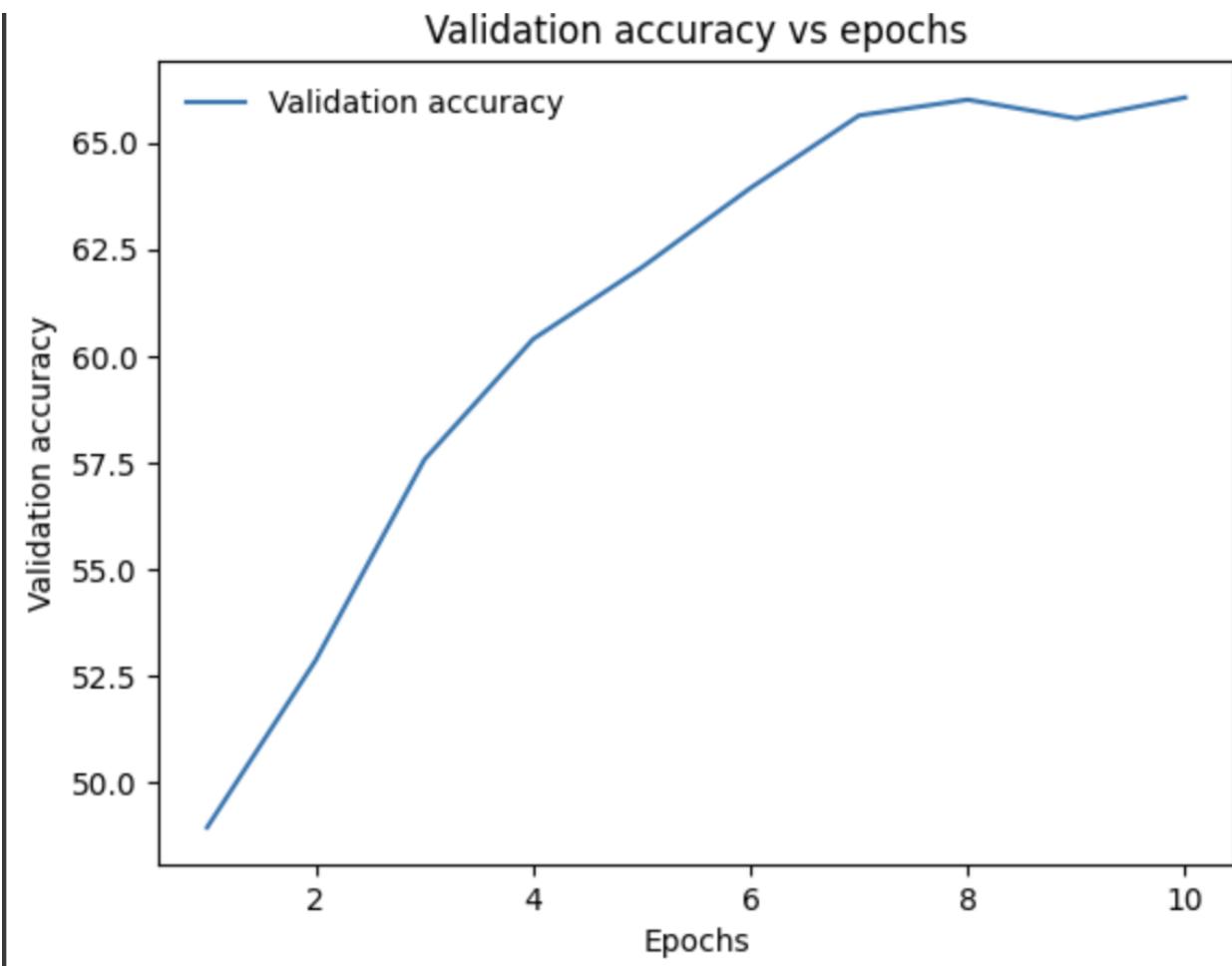
Epoch 1 train loss: 1.686 val loss: 1.421 train accuracy: 37.210 val accuracy: 48.950  
Epoch 2 train loss: 1.346 val loss: 1.296 train accuracy: 51.010 val accuracy: 52.870  
Epoch 3 train loss: 1.225 val loss: 1.188 train accuracy: 56.028 val accuracy: 57.570  
Epoch 4 train loss: 1.137 val loss: 1.122 train accuracy: 59.408 val accuracy: 60.390  
Epoch 5 train loss: 1.057 val loss: 1.070 train accuracy: 62.586 val accuracy: 62.070  
Epoch 6 train loss: 1.005 val loss: 1.014 train accuracy: 64.252 val accuracy: 63.930  
Epoch 7 train loss: 0.951 val loss: 0.985 train accuracy: 66.388 val accuracy: 65.630  
Epoch 8 train loss: 0.915 val loss: 0.966 train accuracy: 67.540 val accuracy: 66.000  
Epoch 9 train loss: 0.869 val loss: 0.985 train accuracy: 68.920 val accuracy: 65.560  
Epoch 10 train loss: 0.840 val loss: 0.965 train accuracy: 70.218 val accuracy: 66.050

Training and validation losses vs epochs



Training accuracy vs epochs





#### Classwise Accuracy:

Accuracy for class: plane is 62.0 %  
Accuracy for class: car is 76.0 %  
Accuracy for class: bird is 50.7 %  
Accuracy for class: cat is 36.3 %  
Accuracy for class: deer is 71.9 %  
Accuracy for class: dog is 58.2 %  
Accuracy for class: frog is 78.8 %  
Accuracy for class: horse is 69.0 %  
Accuracy for class: ship is 77.2 %  
Accuracy for class: truck is 80.4 %

In this case we observe a decline in the validation accuracy (although an increase in training accuracy) as compared to the part when data augmentation was turned on. This is because turning off data augmentation

means the model is trained on the original data without any changes and hence loses its diversity thereby leading to overfitting. Also, a lower classwise accuracy is observed because of this overfitting behaviour of this trained model.

## 5) Improving the Model:

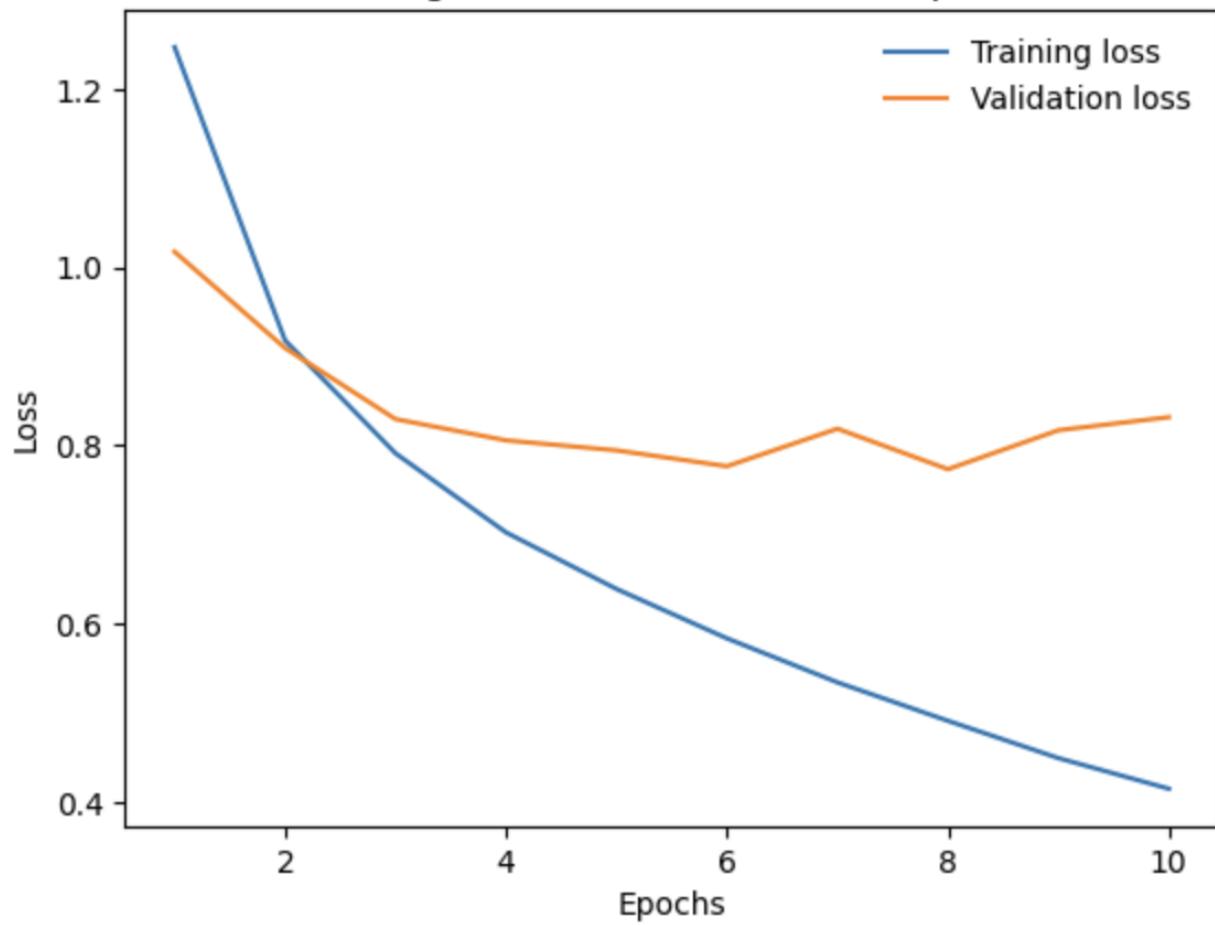
Model with learning rate: 0.001 epochs: 10 batch size: 32 optimizer: adam

I have made the following changes to the neural network based on extensive testing and logical reasoning.

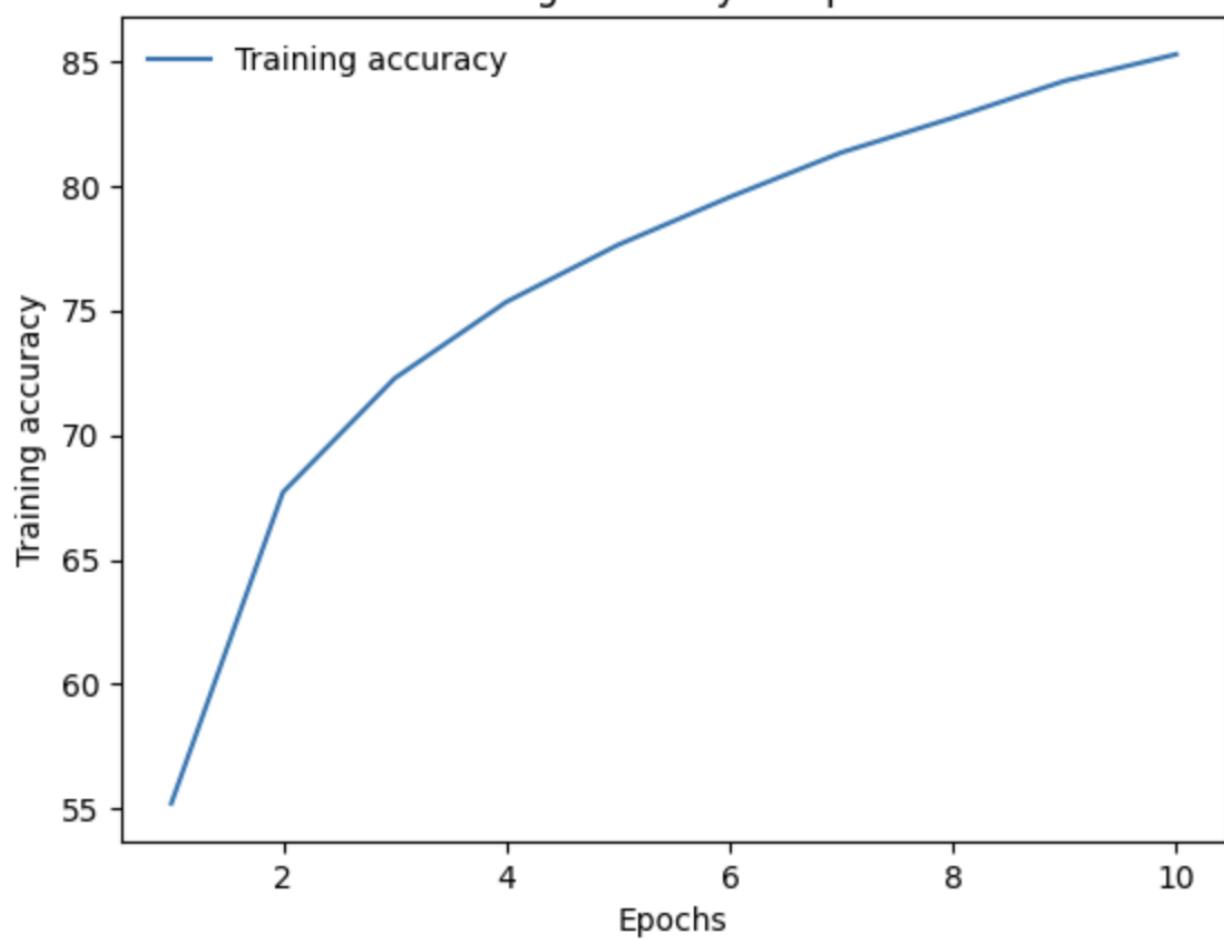
- 1) Adding batch normalization after each convolution layer: By normalizing the output of each convolution layer, I ensured that the input to every layer is normalized, thereby making the optimization process easier and faster. So the model would converge faster, and better results could be seen in a smaller number of epochs. This is because the gradients become more stable, and therefore it becomes easier for the model to learn the underlying patterns in the dataset. It also has a regularizing effect on the model, helps prevent overfitting, and promotes generalization by reducing the dependence on specific network parameters.

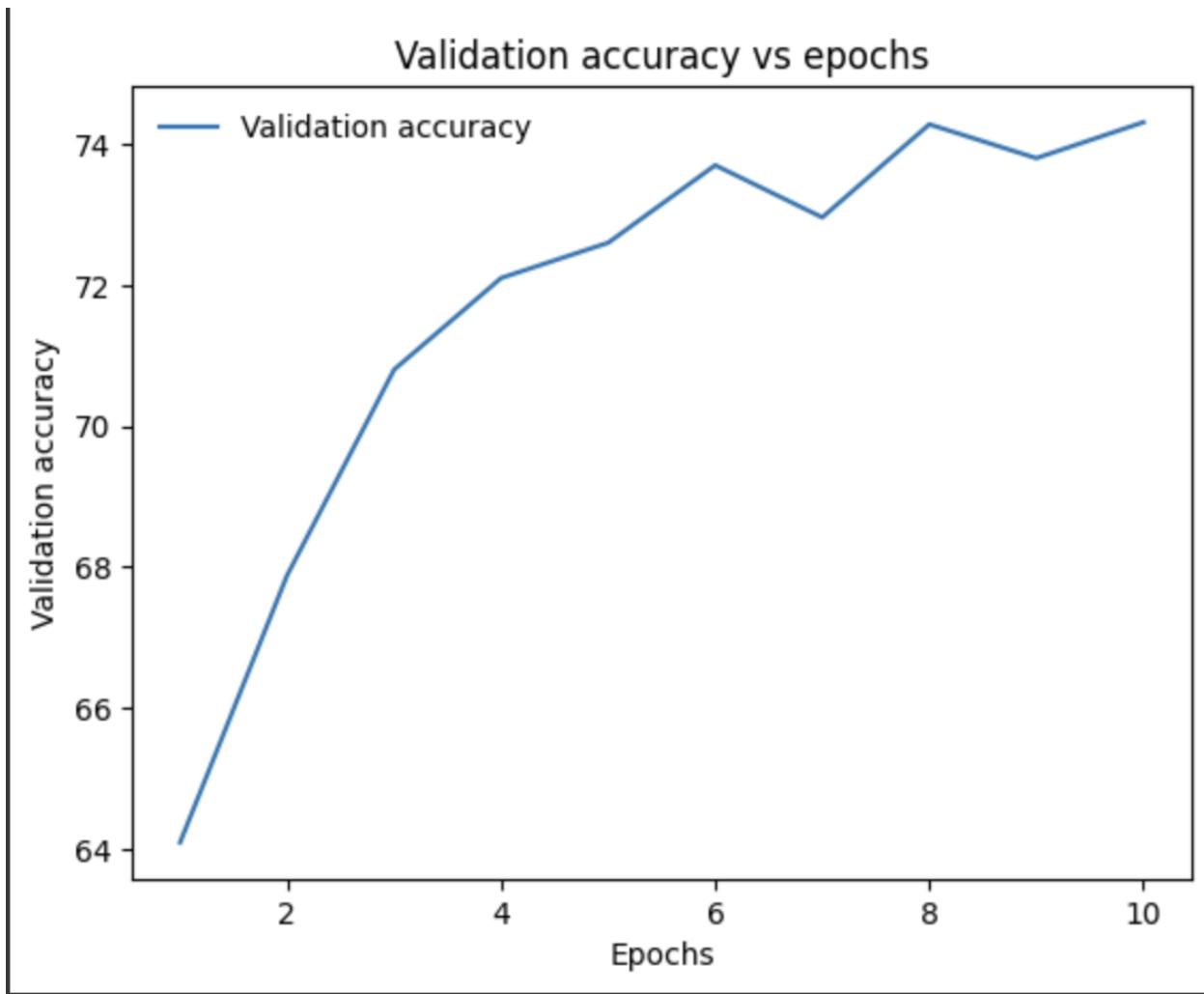
Epoch 1 train loss: 1.247 val loss: 1.018 train accuracy: 55.222 val accuracy: 64.090  
Epoch 2 train loss: 0.918 val loss: 0.909 train accuracy: 67.704 val accuracy: 67.880  
Epoch 3 train loss: 0.791 val loss: 0.830 train accuracy: 72.272 val accuracy: 70.800  
Epoch 4 train loss: 0.703 val loss: 0.806 train accuracy: 75.338 val accuracy: 72.100  
Epoch 5 train loss: 0.639 val loss: 0.795 train accuracy: 77.624 val accuracy: 72.600  
Epoch 6 train loss: 0.584 val loss: 0.777 train accuracy: 79.542 val accuracy: 73.700  
Epoch 7 train loss: 0.534 val loss: 0.819 train accuracy: 81.330 val accuracy: 72.960  
Epoch 8 train loss: 0.491 val loss: 0.774 train accuracy: 82.724 val accuracy: 74.280  
Epoch 9 train loss: 0.449 val loss: 0.817 train accuracy: 84.204 val accuracy: 73.800  
Epoch 10 train loss: 0.415 val loss: 0.832 train accuracy: 85.272 val accuracy: 74.310

Training and validation losses vs epochs



Training accuracy vs epochs





#### Classwise Accuracy:

Accuracy for class: plane is 78.2 %  
Accuracy for class: car is 83.9 %  
Accuracy for class: bird is 60.3 %  
Accuracy for class: cat is 52.2 %  
Accuracy for class: deer is 68.4 %  
Accuracy for class: dog is 64.5 %  
Accuracy for class: frog is 88.9 %  
Accuracy for class: horse is 78.7 %  
Accuracy for class: ship is 82.3 %  
Accuracy for class: truck is 85.7 %

Overall Validation Accuracy:- 74.31%

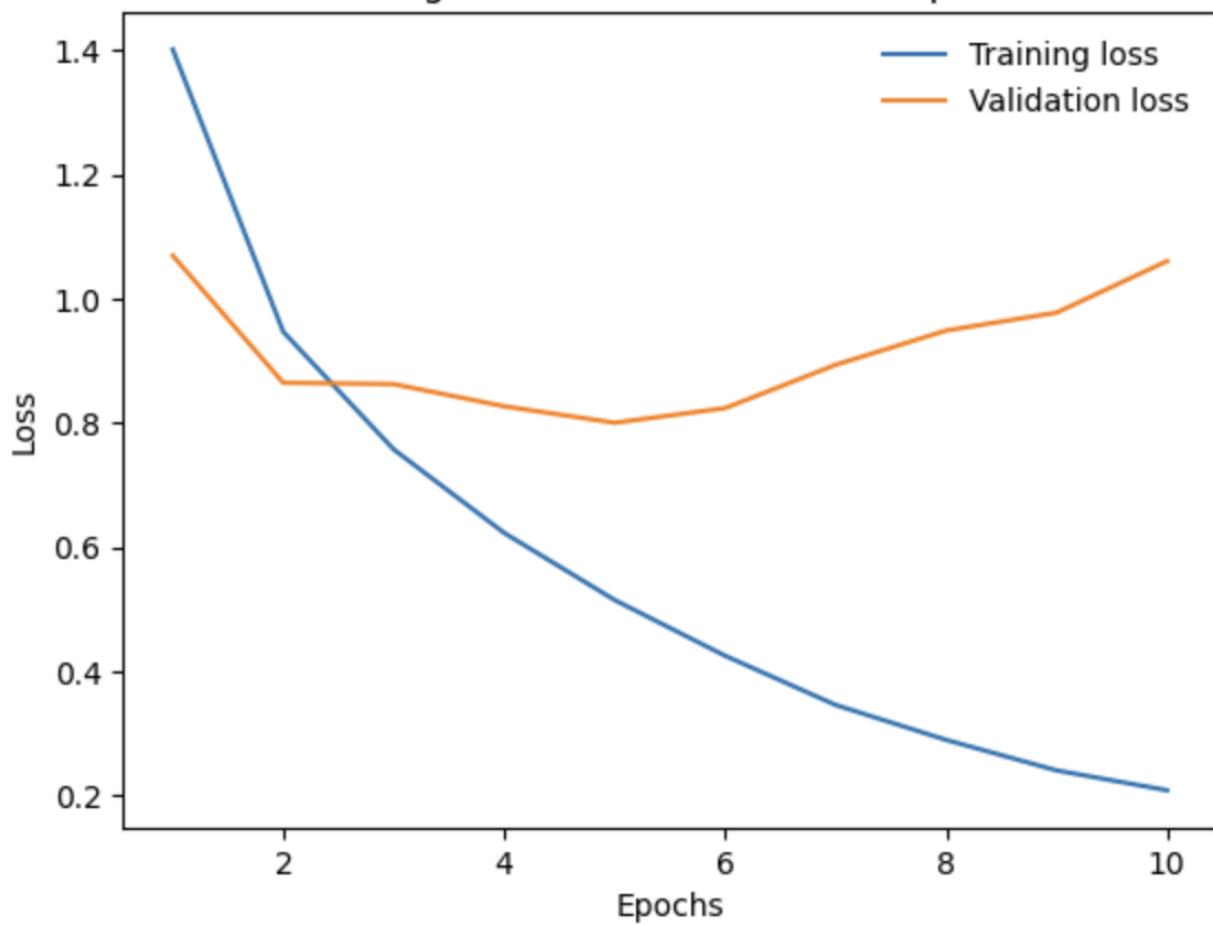
2) Adding more convolutional layers: This would help in capturing more complex patterns and features in the image and therefore improve the performance of the model. It helps the network extract more global and local features and, therefore, a better understanding of the image and a better classification accuracy.

So, I changed the number of output channels of the CONV3 layer to 128, and then added a CONV4 layer with 256 output channels, to increase the depth of the network.

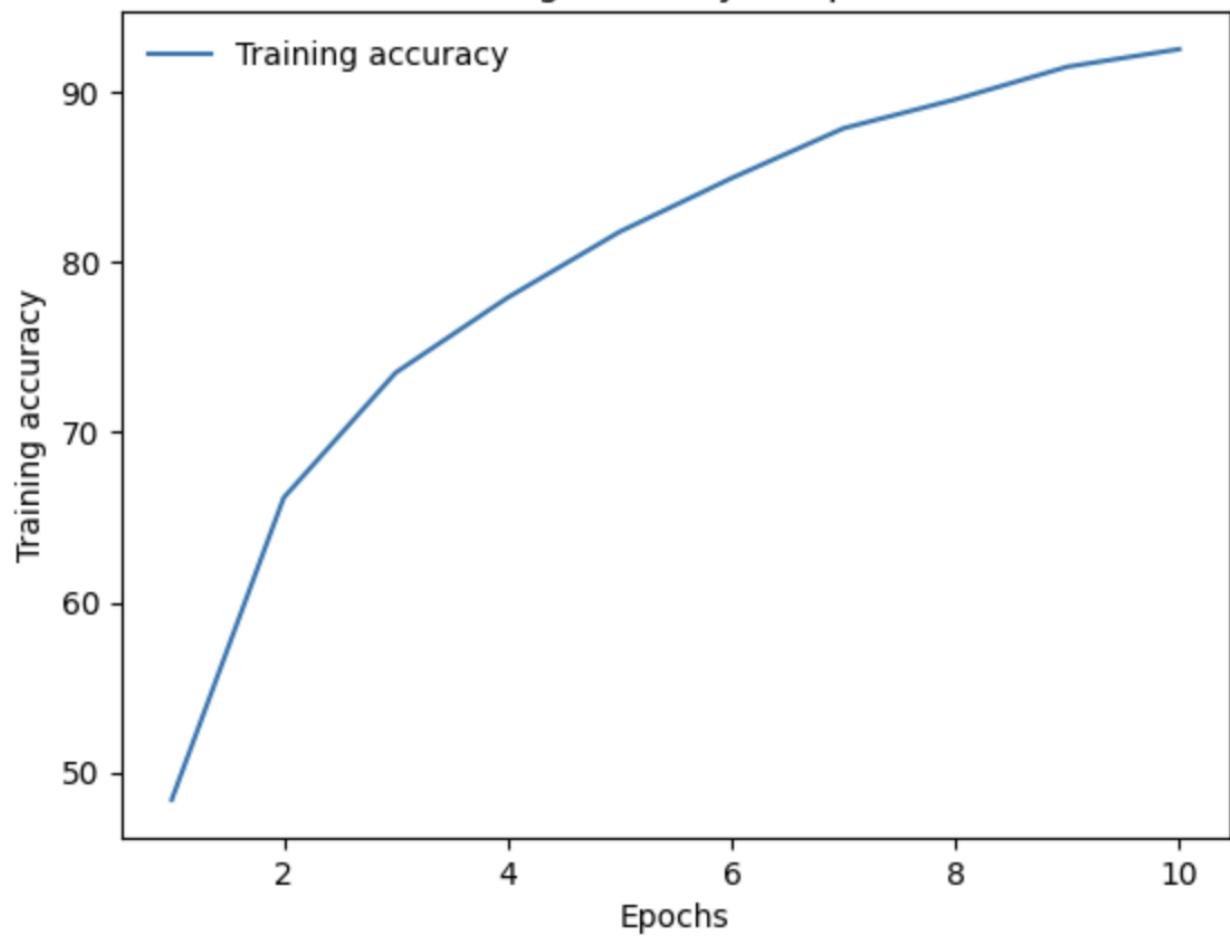
I also added padding to the layers in order to preserve the spatial information, which otherwise gets lost due to shrinking during convolution. It also helps prevent information loss in pooling layers and therefore leads the network to extract better and learn more relevant features.

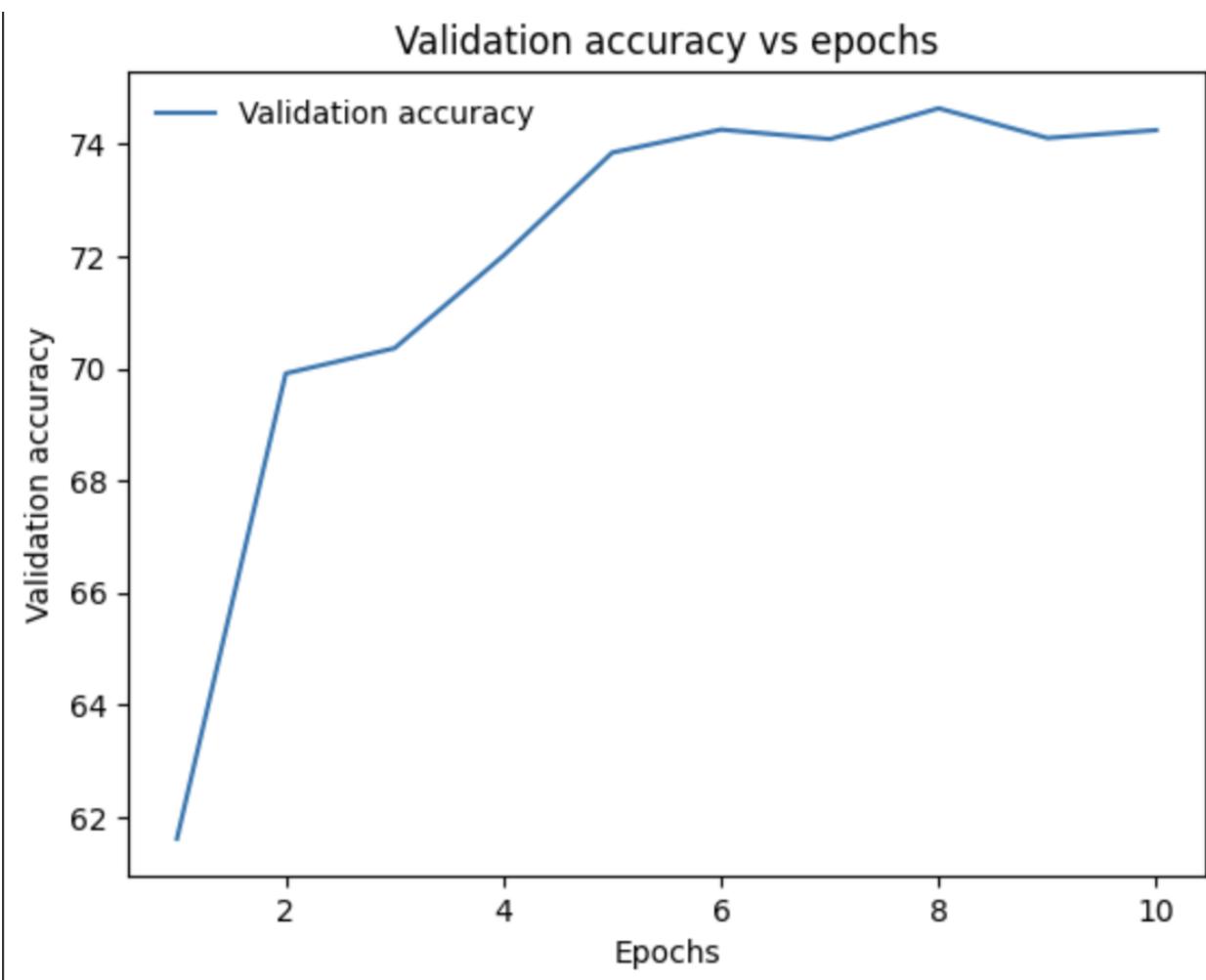
```
Epoch 1 train loss: 1.401 val loss: 1.070 train accuracy: 48.406 val accuracy: 61.610
Epoch 2 train loss: 0.947 val loss: 0.865 train accuracy: 66.142 val accuracy: 69.910
Epoch 3 train loss: 0.758 val loss: 0.863 train accuracy: 73.488 val accuracy: 70.360
Epoch 4 train loss: 0.623 val loss: 0.827 train accuracy: 77.896 val accuracy: 72.010
Epoch 5 train loss: 0.515 val loss: 0.801 train accuracy: 81.762 val accuracy: 73.850
Epoch 6 train loss: 0.425 val loss: 0.824 train accuracy: 84.912 val accuracy: 74.260
Epoch 7 train loss: 0.346 val loss: 0.894 train accuracy: 87.842 val accuracy: 74.090
Epoch 8 train loss: 0.290 val loss: 0.949 train accuracy: 89.540 val accuracy: 74.640
Epoch 9 train loss: 0.241 val loss: 0.978 train accuracy: 91.458 val accuracy: 74.110
Epoch 10 train loss: 0.209 val loss: 1.061 train accuracy: 92.492 val accuracy: 74.250
```

Training and validation losses vs epochs



Training accuracy vs epochs





Accuracy for class: plane is 78.4 %

Accuracy for class: car is 82.7 %

Accuracy for class: bird is 64.4 %

Accuracy for class: cat is 55.0 %

Accuracy for class: deer is 74.5 %

Accuracy for class: dog is 67.9 %

Accuracy for class: frog is 78.9 %

Accuracy for class: horse is 74.2 %

Accuracy for class: ship is 86.3 %

Accuracy for class: truck is 80.2 %

Overall Validation accuracy: 74.250%

- 3) Adding dropout layer: Dropout helps reduce overfitting by dropping some neurons during the training of the model. This helps in generalizing the model by decreasing the dependence on specific network features. It also helps reduce the interdependence of neurons in order to learn more general features.

Epoch 1 train loss: 1.429 val loss: 1.064 train accuracy: 47.558 val accuracy: 61.870

Epoch 2 train loss: 0.948 val loss: 0.877 train accuracy: 66.456 val accuracy: 69.080

Epoch 3 train loss: 0.742 val loss: 0.828 train accuracy: 74.020 val accuracy: 72.010

Epoch 4 train loss: 0.616 val loss: 0.755 train accuracy: 78.266 val accuracy: 74.540

Epoch 5 train loss: 0.519 val loss: 0.774 train accuracy: 81.740 val accuracy: 75.220

Epoch 6 train loss: 0.434 val loss: 0.850 train accuracy: 84.654 val accuracy: 73.980

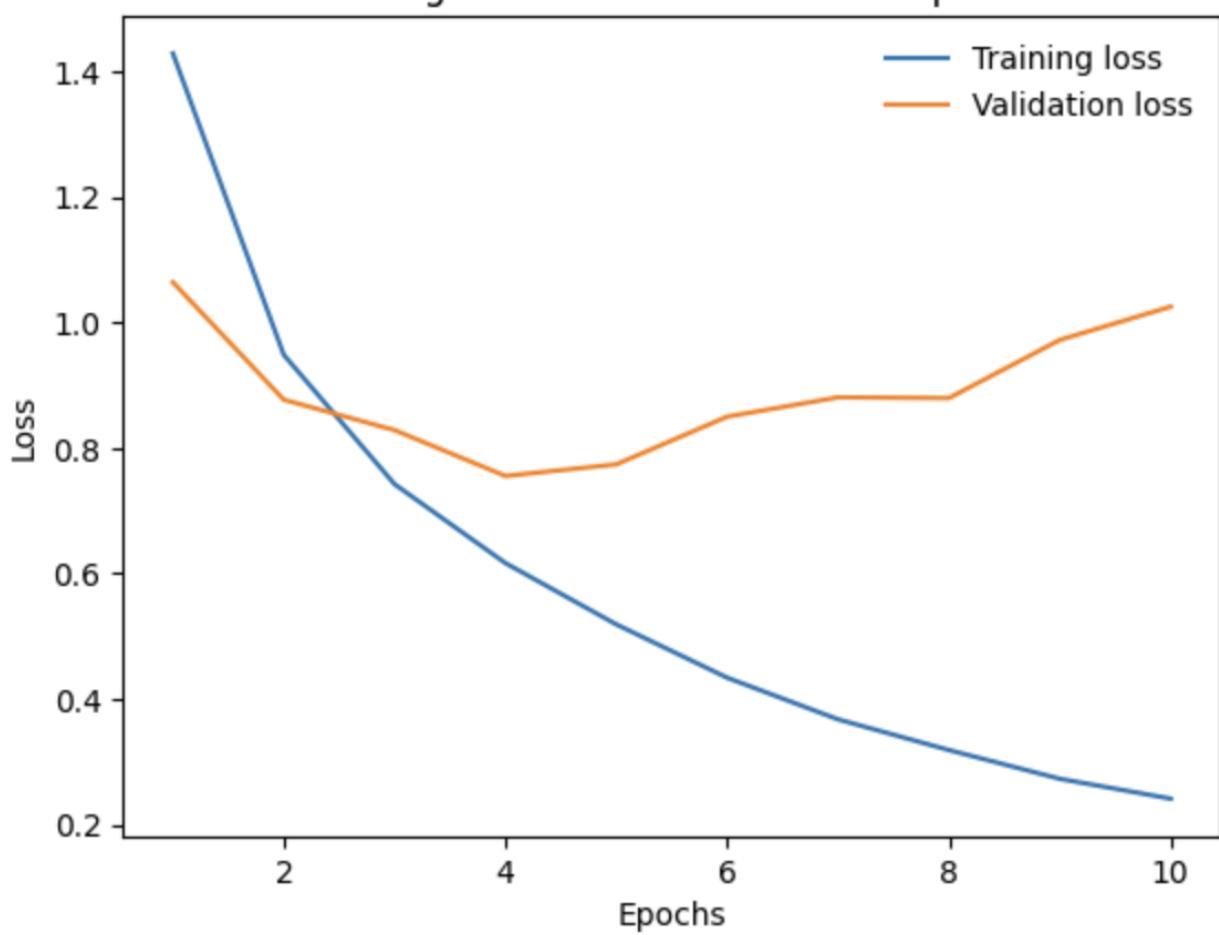
Epoch 7 train loss: 0.367 val loss: 0.881 train accuracy: 86.882 val accuracy: 74.080

Epoch 8 train loss: 0.318 val loss: 0.879 train accuracy: 88.806 val accuracy: 75.450

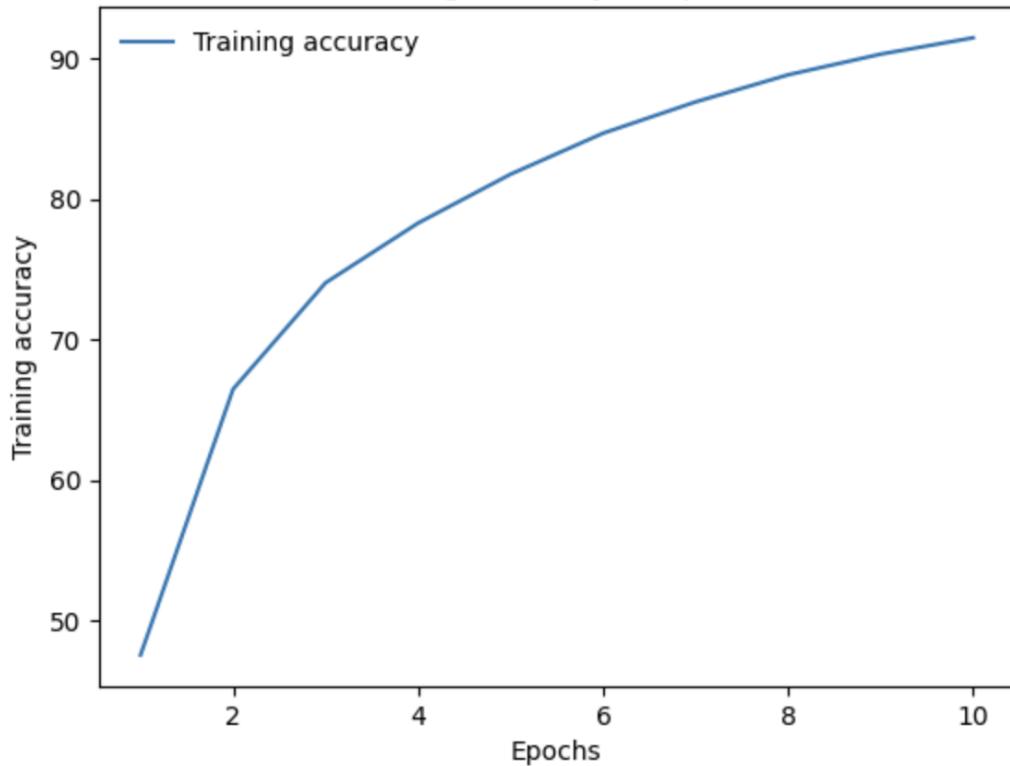
Epoch 9 train loss: 0.273 val loss: 0.972 train accuracy: 90.276 val accuracy: 74.640

Epoch 10 train loss: 0.241 val loss: 1.025 train accuracy: 91.440 val accuracy: 74.850

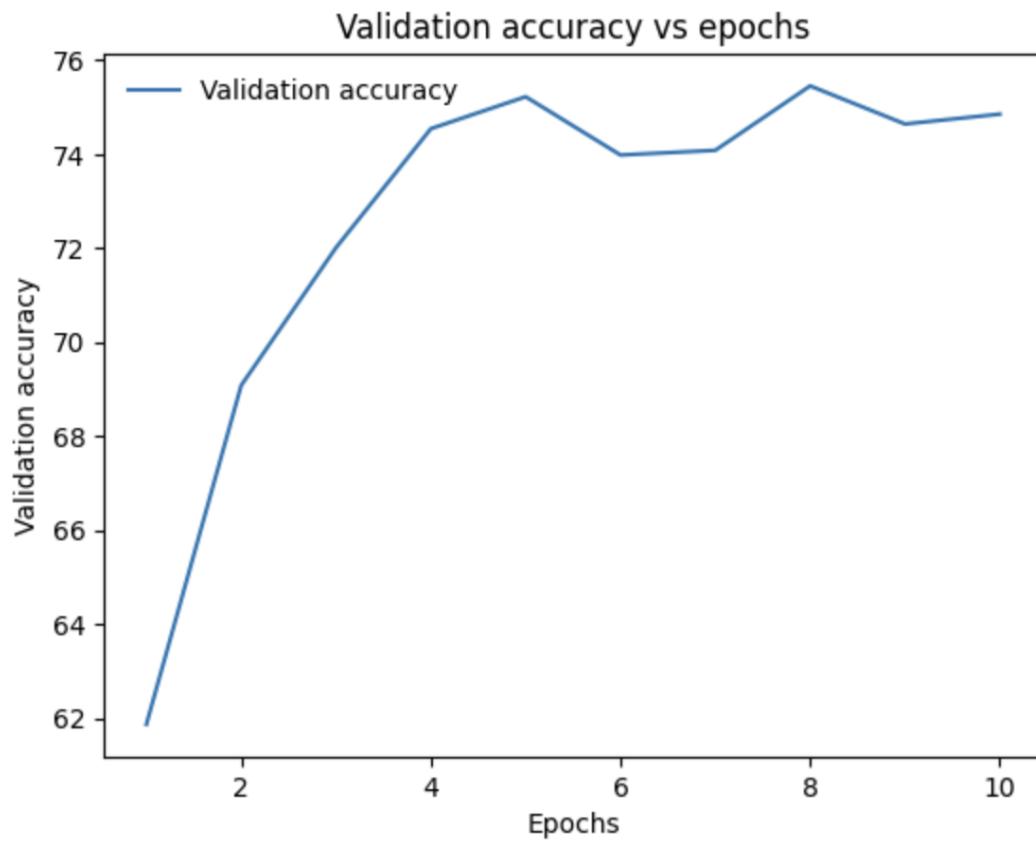
Training and validation losses vs epochs



Training accuracy vs epochs



Validation accuracy vs epochs



## Classwise Accuracy:

Accuracy for class: plane is 84.8 %

Accuracy for class: car is 88.2 %

Accuracy for class: bird is 61.8 %

Accuracy for class: cat is 56.7 %

Accuracy for class: deer is 71.8 %

Accuracy for class: dog is 64.4 %

Accuracy for class: frog is 74.1 %

Accuracy for class: horse is 78.8 %

Accuracy for class: ship is 83.0 %

Accuracy for class: truck is 84.5 %

Overall Validation accuracy: 74.850%

As can be seen, the validation accuracy has increased thus indicating less overfitting and more generalization. Since the no of epochs is quite less, the increase in accuracy is not much. Greater improvements in performance could be seen for larger number of epochs (which could not be run due to limitations of GPU availability on colab and time constraints).