Semester II, Academic Year 2022–2023

Machine Learning

[Course Code: COL341]

Submission: Assignment 2

Name : Mayand Dangi

Entry Number : 2019PH10637

System Specifications

Processor	Intel(R) Core(TM) i7-9750H CPU @ 2.60GHz
RAM	16 GB
Operating System	Windows 10
GPU	NVIDIA GTX 1650

1 Part 1: Implement a Neural Network

1.1 Network Architecture

The architecture of the CNN used in this assignment is as follows:

- CONV1: Kernel size (3×3), In channels 3, Out channels 32.
- POOL1: Kernel size (2×2).
- CONV2: Kernel size (5×5), In channels 32, Out channels 64.
- POOL2: Kernel size (2×2).
- CONV3: Kernel size (3×3), In channels 64, Out channels 64.
- FC1: Fully connected layer with 64 output neurons.
- FC2: Fully connected layer with 10 output neurons.

Implementation is in jupyter notebook (.ipynb) file.

2 Part 2: Implement a PyTorch-based Solution

2.1 Network Architecture

The architecture of the CNN used in this assignment is as follows:

- CONV1: Kernel size (3×3), In channels 3, Out channels 32.

- POOL1: Kernel size (2×2).
- CONV2: Kernel size (5×5), In channels 32, Out channels 64.
- POOL2: Kernel size (2×2).
- CONV3: Kernel size (3×3), In channels 64, Out channels 64.
- FC1: Fully connected layer with 64 output neurons.
- FC2: Fully connected layer with 10 output neurons.

2.2 Training

The network was trained for 20 epochs using an Adam optimizer with learning rate 0.001 and batch size 32. The categorical cross-entropy loss was used as the loss function. The training epochs vs. the training and validation losses are shown in Figure 1. The class-wise validation accuracy is reported in Table 1. The epoch vs. overall validation accuracy is shown in Figure 2.

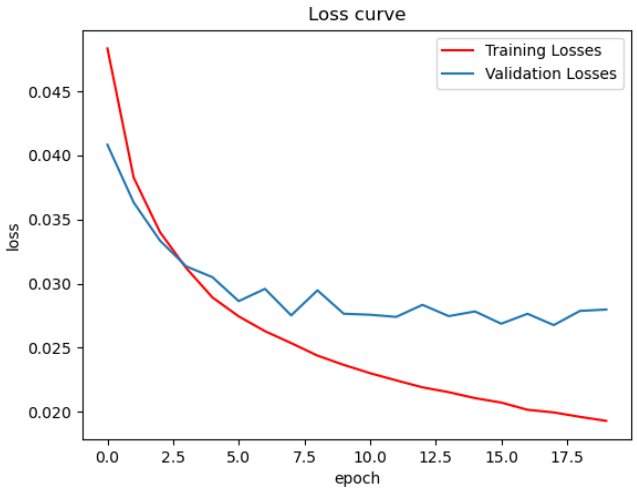

Figure 1: Training epochs vs. training and validation losses

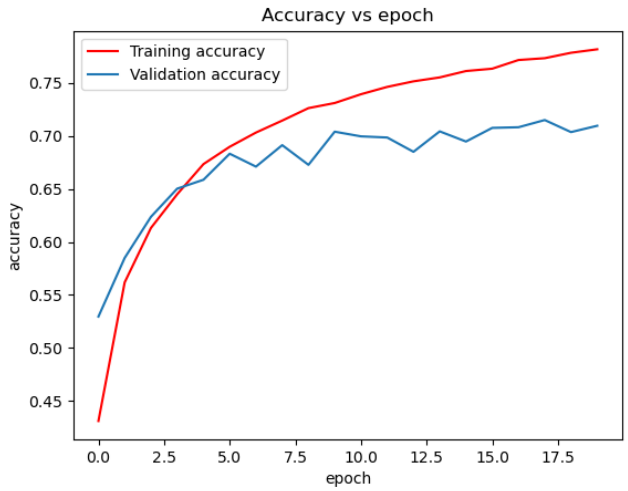

Figure 2: Training epochs vs. training and validation accuracies

Class	Accuracy
plane	84.6 %
car	85.6 %
bird	81.8 %
cat	70.0 %
deer	68.9 %
dog	59.9 %
frog	88.7 %
horse	74.0 %
ship	89.0 %
truck	84.0 %
Overall	78.7%

Table 1: Class-wise validation accuracy

2.3 Hyper-parameter Tuning

2.3.1 Learning Rates

Optimizer: Adam

- Learning rate: 0.01, Batch size: 32, epochs: 75

Figure 3: Training epochs vs. training and validation losses

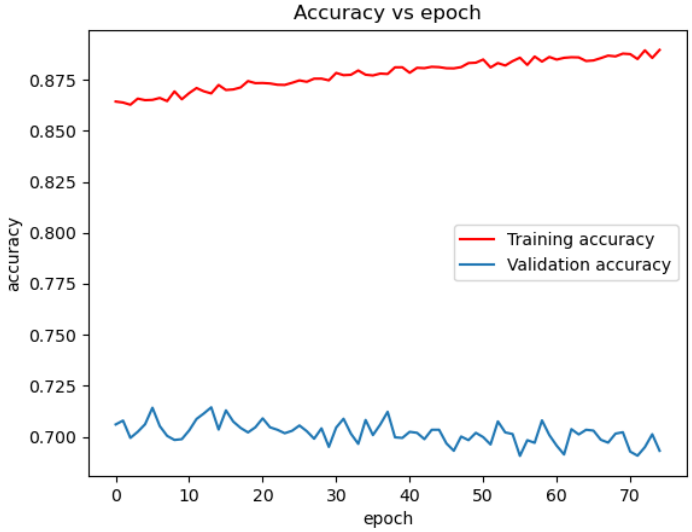

Figure 4: Training epochs vs. training and validation accuracies

Class	Accuracy
plane	76.8 %
car	85.0 %
bird	66.7 %
cat	50.8 %
deer	62.9 %
dog	55.0 %
frog	73.8 %
horse	76.8 %
ship	79.2 %
truck	68.2 %
Overall	69.5%

Table 2: Class-wise validation accuracy

- Learning rate: 0.001, Batch size: 32, epochs: 75

Figure 5: Training epochs vs. training and validation losses

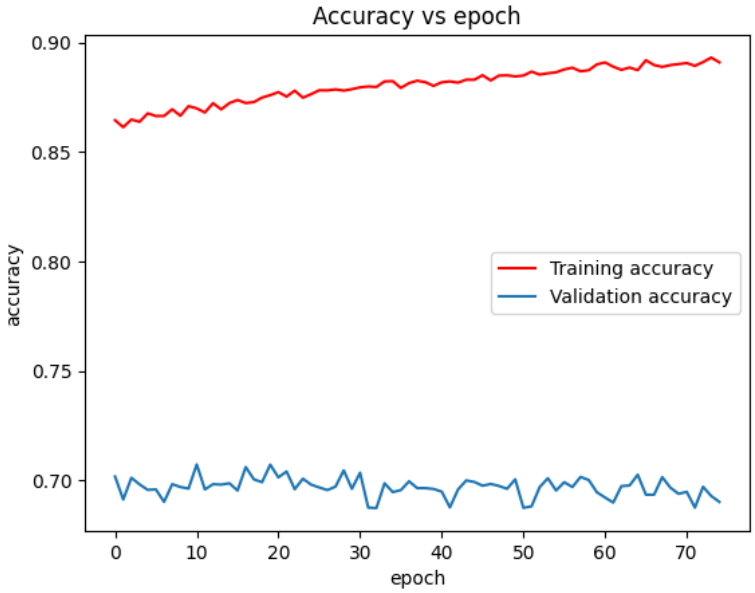

Figure 6: Training epochs vs. training and validation accuracies

Class	Accuracy
plane	71.5 %
car	80.0 %
bird	52.7 %
cat	53.1 %
deer	68.0 %
dog	56.4 %
frog	79.2 %
horse	76.7 %
ship	79.8 %
truck	79.2 %
Overall	69.6%

Table 3: Class-wise validation accuracy

- Learning rate: 0.0001, Batch size: 32, epochs: 75

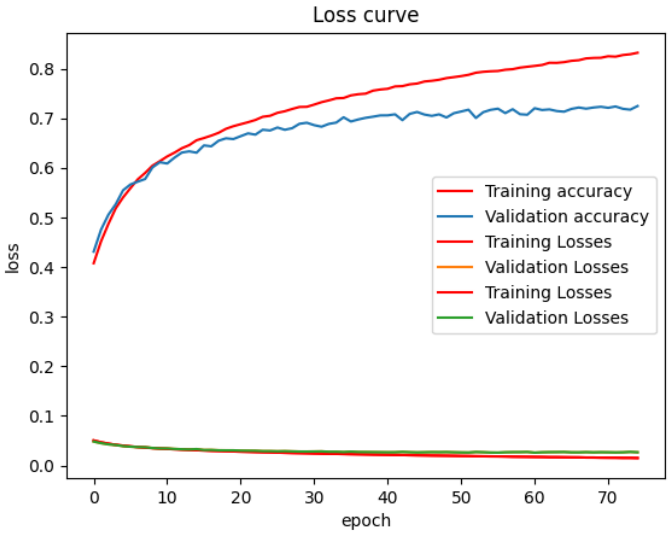

Figure 7: Training epochs vs. training and validation losses

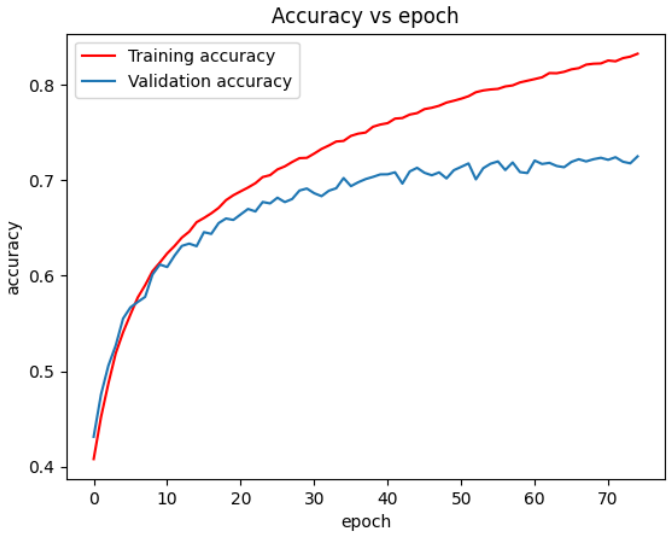

Figure 8: Training epochs vs. training and validation accuracies

Class	Accuracy
plane	76.0 %
car	86.8%
bird	63.1 %
cat	54.8 %
deer	70.1 %
dog	63.2 %
frog	81.7 %
horse	75.5 %
ship	81.8 %
truck	75.5 %
Overall	72.8%

Table 4: Class-wise validation accuracy

Optimizer: SGD

- Learning rate: 0.01, Batch size: 32, epochs: 75

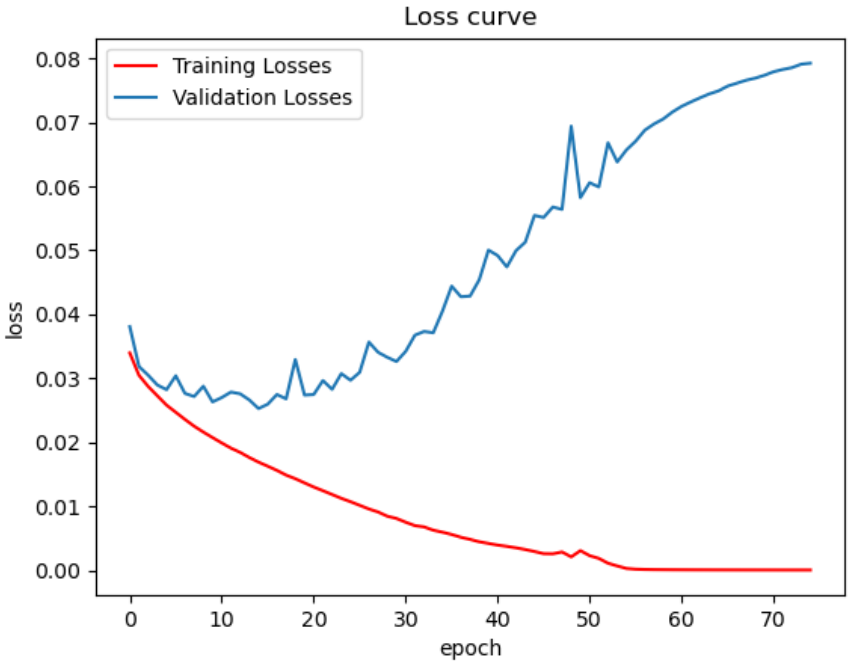

Figure 9: Training epochs vs. training and validation losses

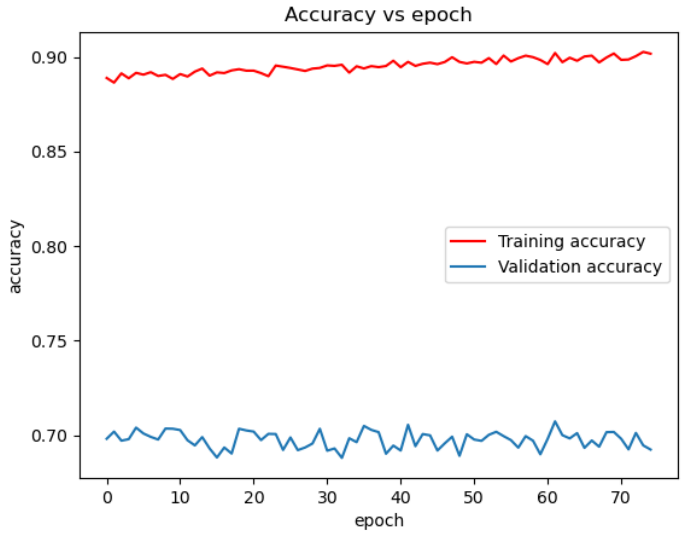

Figure 10: Training epochs vs. training and validation accuracies

Class	Accuracy
plane	76.2 %
car	82.1 %
bird	60.8 %
cat	55.7 %
deer	67.7 %
dog	64.1 %
frog	80.3 %
horse	74.2 %
ship	82.9 %
truck	81.5 %
Overall	72.6%

Table 5: Class-wise validation accuracy

- Learning rate: 0.001, Batch size: 32, epochs: 75

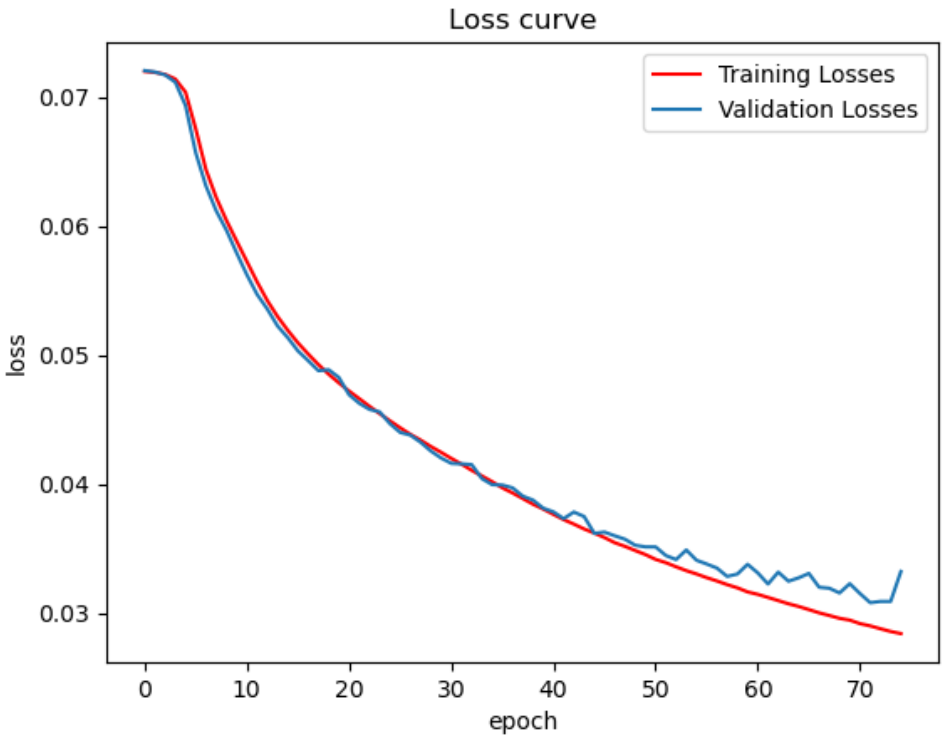

Figure 11: Training epochs vs. training and validation losses

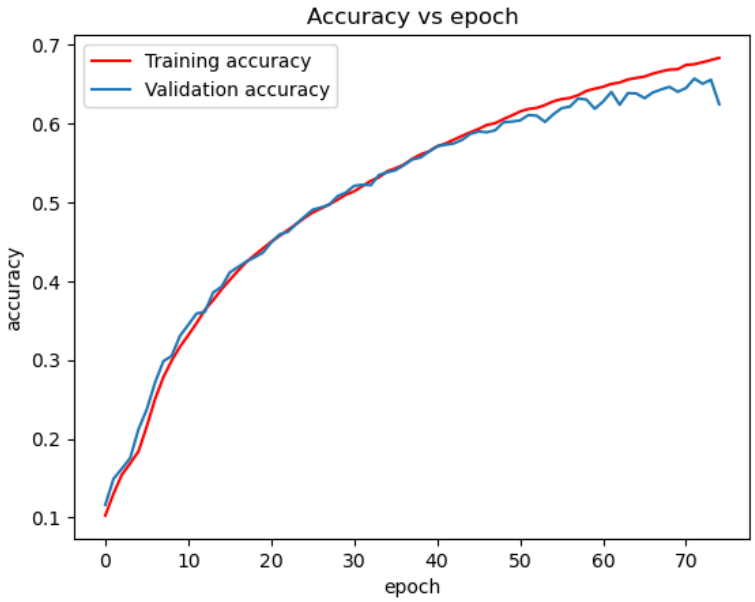

Figure 12: Training epochs vs. training and validation accuracies

Class	Accuracy
plane	52.3 %
car	65.8 %
bird	51.9 %
cat	56.1 %
deer	65.9 %
dog	41.3 %
frog	79.3 %
horse	60.6 %
ship	93.3 %
truck	57.9 %
Overall	62.4%

Table 6: Class-wise validation accuracy

- Learning rate: 0.0001, Batch size: 32, epochs: 75

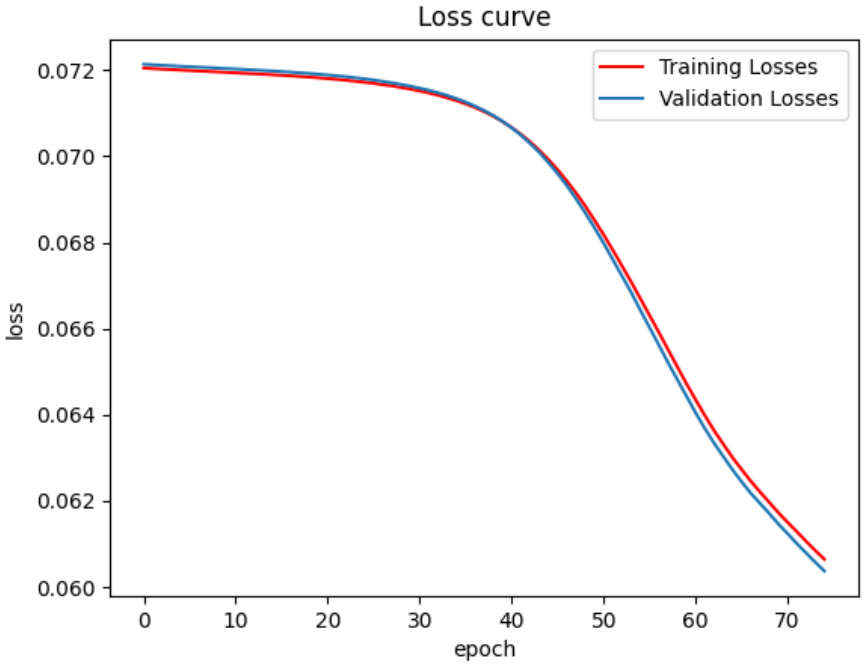

Figure 13: Training epochs vs. training and validation losses

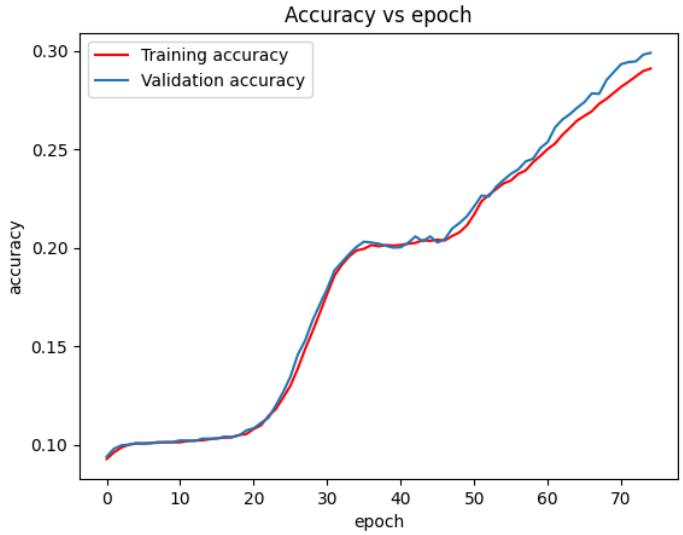

Figure 14: Training epochs vs. training and validation accuracies

Class	Accuracy
plane	42.7 %
car	38.3 %
bird	0.9 %
cat	4.6 %
deer	9.6 %
dog	41.2 %
frog	64.8 %
horse	28.7 %
ship	33.7 %
truck	33.9 %
Overall	29.8%

Table 7: Class-wise validation accuracy

In our experiments, we observed that decreasing the learning rate resulted in an increase in the validation accuracy of the CNN, and the loss curve was less oscillating. This is because a smaller learning rate allows for smaller updates to the model weights during training, which can help the optimizer to avoid oscillations and converge to a better solution.

On the other hand, we observed that the SGD optimizer gave less accuracy in comparison to Adam. The reason for this observation is that Adam optimizes the learning rate for each parameter individually, which can result in better convergence and improved performance. On the other hand, SGD optimizes the same learning rate for all parameters, which can lead to slower convergence but better have generalization. This is because SGD tends to be less aggressive in updating the model weights and can explore the search space more thoroughly.

In conclusion, our experiments suggest that decreasing the learning rate can be a useful strategy for improving the training of CNNs, especially when combined with a learning rate scheduler and careful selection of other hyperparameters. Moreover, the choice of optimizer can also play a critical role in the performance of the model, and it is important to evaluate different options carefully to find the best one for the specific problem at hand.

2.3.2 Variation in LR

Scheduler StepLR

- Learning rate: 0.001, Batch size: 32, epochs: 75 Optimizer: SGD

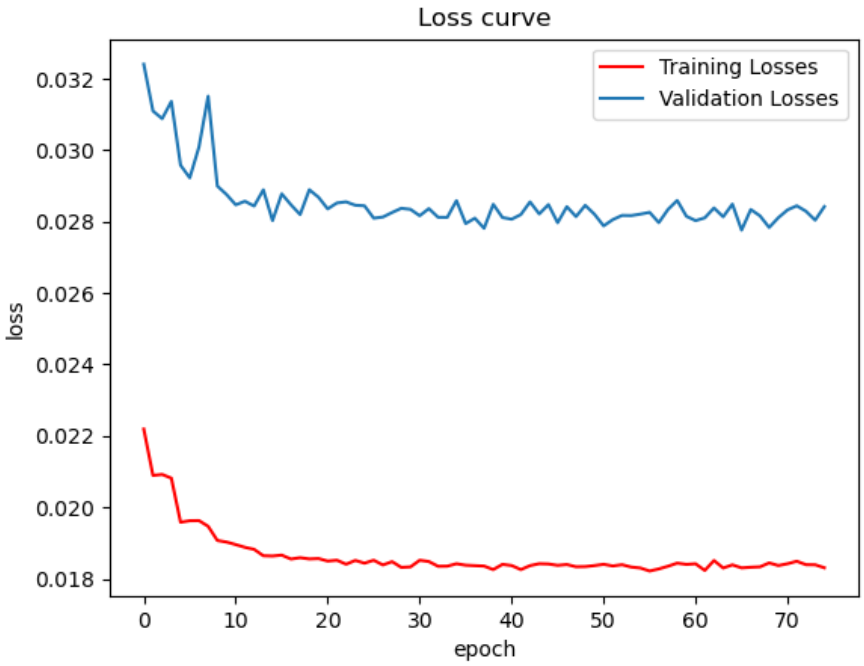

Figure 15: Training epochs vs. training and validation losses

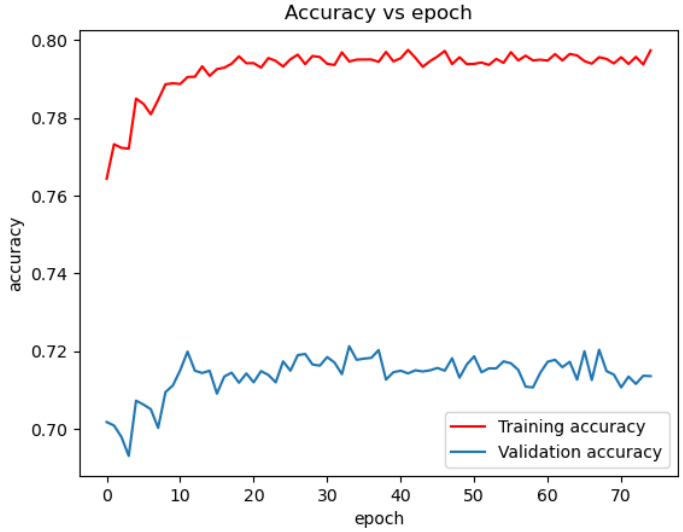

Figure 16: Training epochs vs. training and validation accuracies

Class	Accuracy
plane	74.7 %
car	84.5 %
bird	59.5 %
cat	53.7 %
deer	68.7 %
dog	55.9 %
frog	78.4 %
horse	73.3 %
ship	80.9 %
truck	82.2 %
Overall	71.2%

Table 8: Class-wise validation accuracy

- Learning rate: 0.001, Batch size: 32, epochs: 75 Optimizer: adam

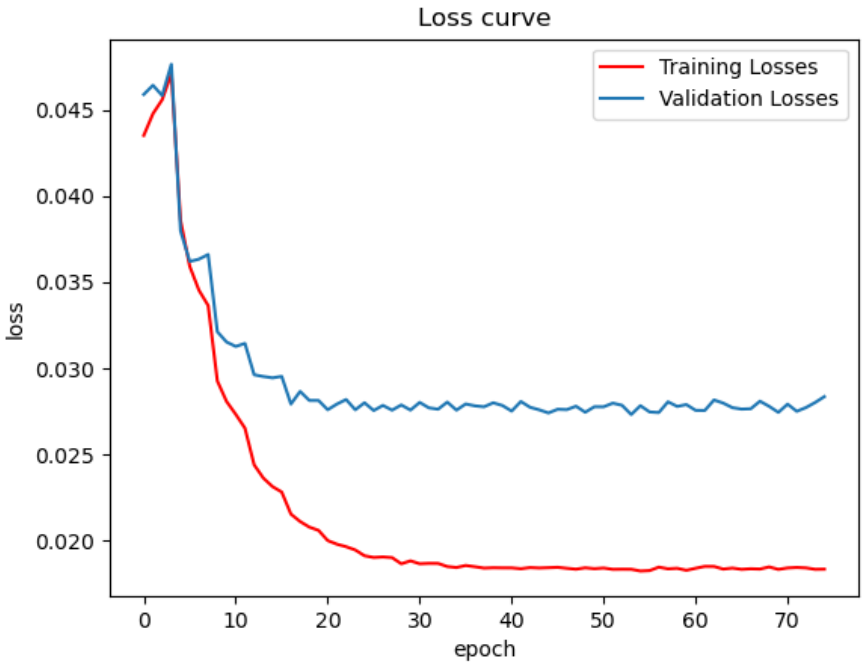

Figure 17: Training epochs vs. training and validation losses

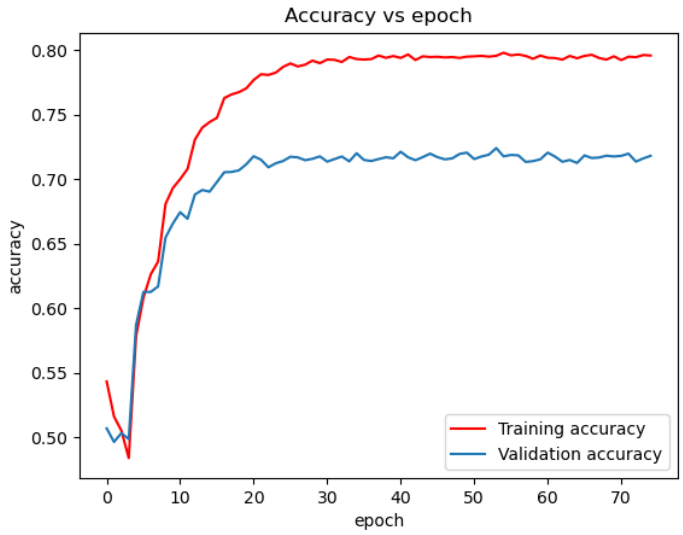

Figure 18: Training epochs vs. training and validation accuracies

Class	Accuracy
plane	76.5 %
car	85.6 %
bird	59.5 %
cat	53.7 %
deer	68.2 %
dog	57.2 %
frog	78.4 %
horse	75.5 %
ship	82.2 %
truck	82.2 %
Overall	71.9%

Table 9: Class-wise validation accuracy

Scheduler: ExponentialLR

- Learning rate: 0.001, Batch size: 32, epochs: 75 Optimizer: SGD

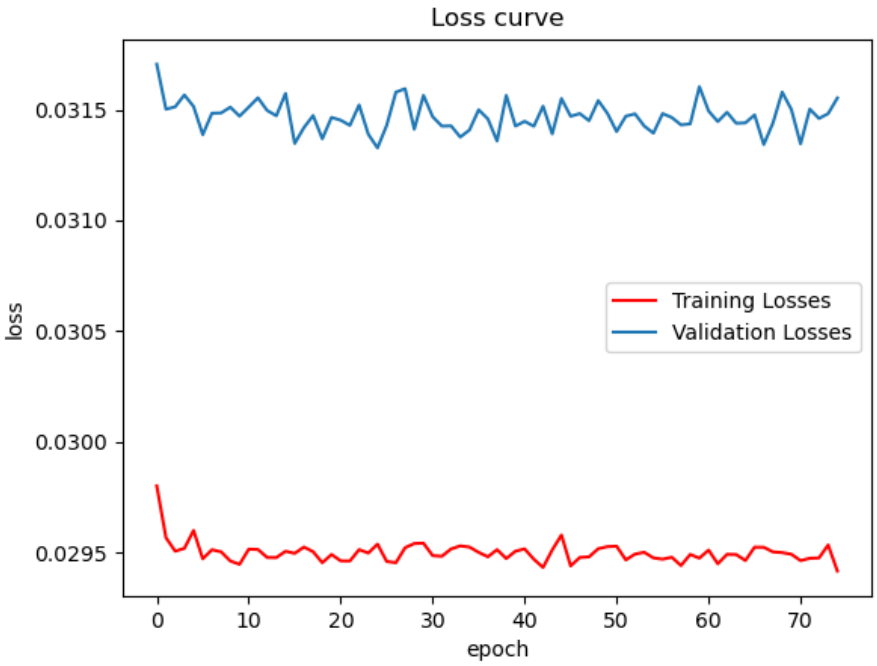

Figure 19: Training epochs vs. training and validation losses

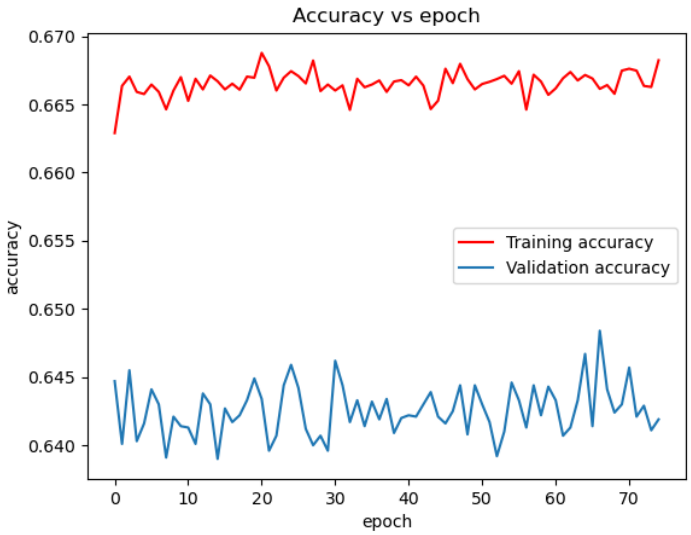

Figure 20: Training epochs vs. training and validation accuracies

Class	Accuracy
plane	69.4 %
car	76.5 %
bird	49.4 %
cat	42.6 %
deer	56.8 %
dog	54.5 %
frog	73.1 %
horse	70.6 %
ship	78.9 %
truck	72.2 %
Overall	64.4%

Table 10: Class-wise validation accuracy

- Learning rate: 0.001, Batch size: 32, epochs: 75 Optimizer: adam

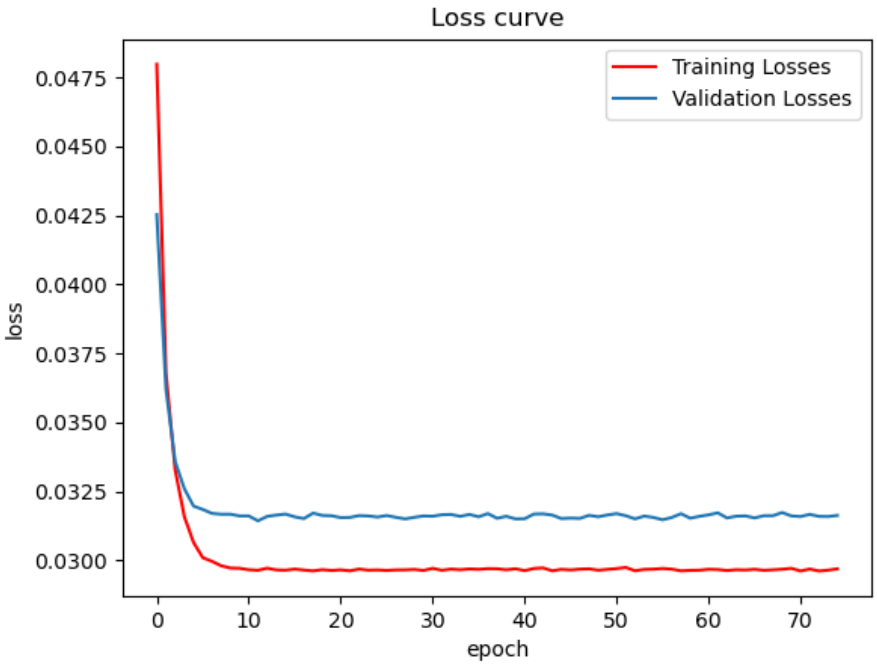

Figure 21: Training epochs vs. training and validation losses

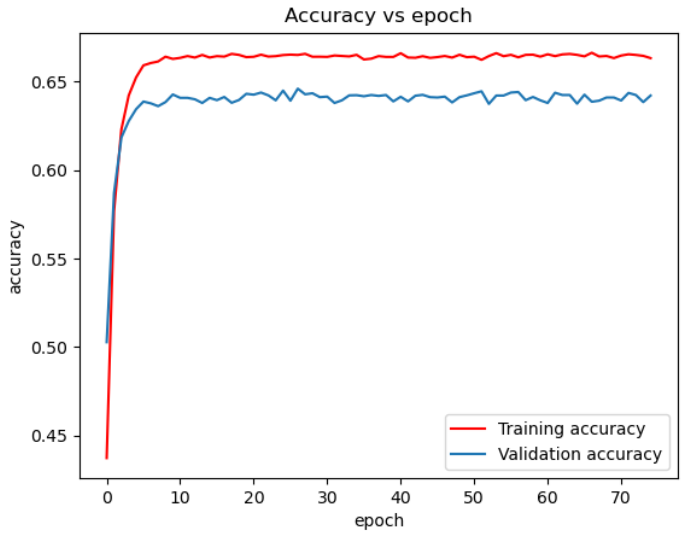

Figure 22: Training epochs vs. training and validation accuracies

Class	Accuracy
plane	69.7 %
car	77.2 %
bird	49.9 %
cat	43.5 %
deer	55.9 %
dog	53.9%
frog	73.9 %
horse	70.2 %
ship	77.5 %
truck	71.6 %
Overall	64.3%

Table 11: Class-wise validation accuracy

Scheduler: MultiLR

- Learning rate: 0.001, Batch size: 32, epochs: 75 Optimizer: SGD

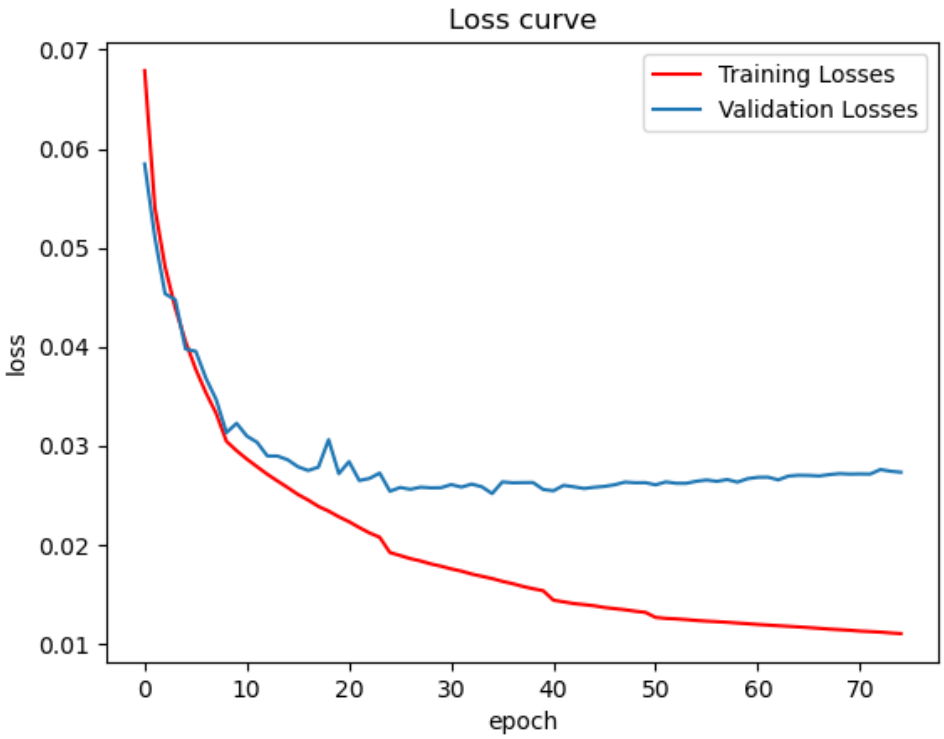

Figure 23: Training epochs vs. training and validation losses

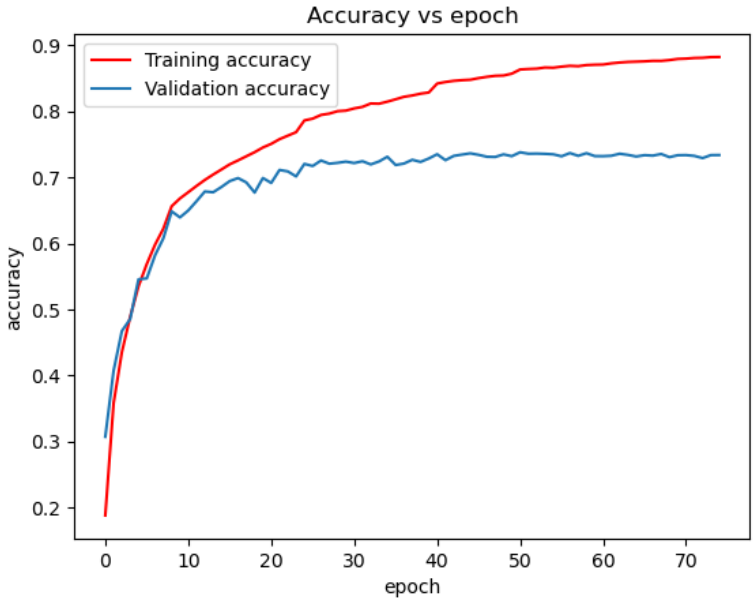

Figure 24: Training epochs vs. training and validation accuracies

Class	Accuracy
plane	77.6 %
car	84.5 %
bird	62.2 %
cat	55.6 %
deer	75.6 %
dog	63.5 %
frog	80.8 %
horse	73.6 %
ship	81.9 %
truck	78.4 %
Overall	73.4%

Table 12: Class-wise validation accuracy

- Learning rate: 0.001, Batch size: 32, epochs: 75 Optimizer: adam

Figure 25: Training epochs vs. training and validation losses

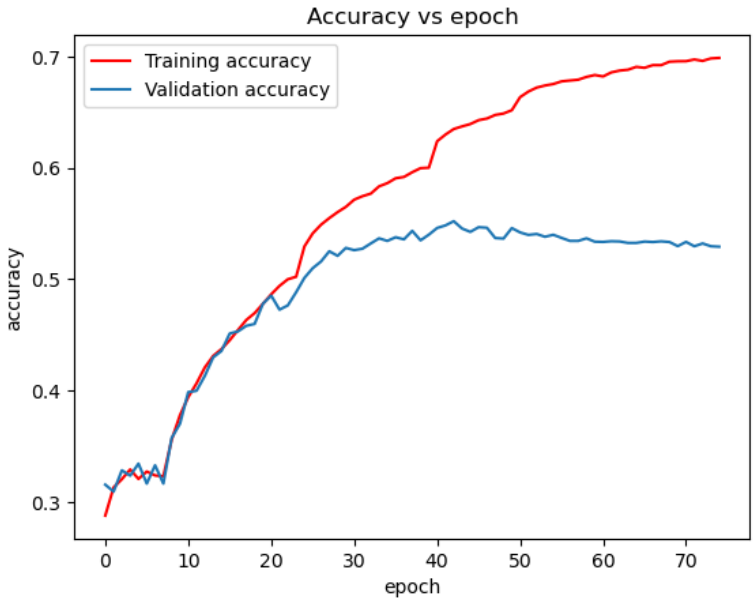

Figure 26: Training epochs vs. training and validation accuracies

Class	Accuracy
plane	54.2 %
car	68.8 %
bird	33.6 %
cat	35.3 %
deer	45.0 %
dog	48.9%
frog	68.1 %
horse	59.5 %
ship	59.6 %
truck	56.2 %
Overall	52.9%

Table 13: Class-wise validation accuracy

2.3.3 Number of Training Epochs

For this experiment, `batch size` = 32, `learning_rate` = 0.0005 and `optimizer` = adam

- `number_of_epochs` = 25

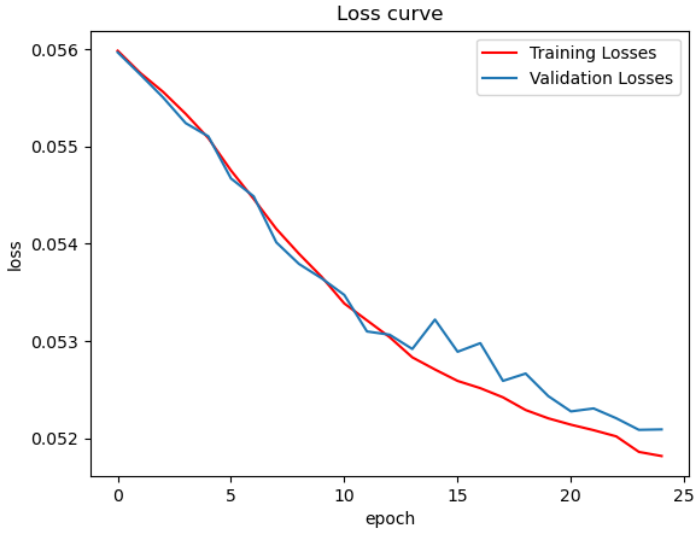

Figure 27: Training epochs vs. training and validation losses

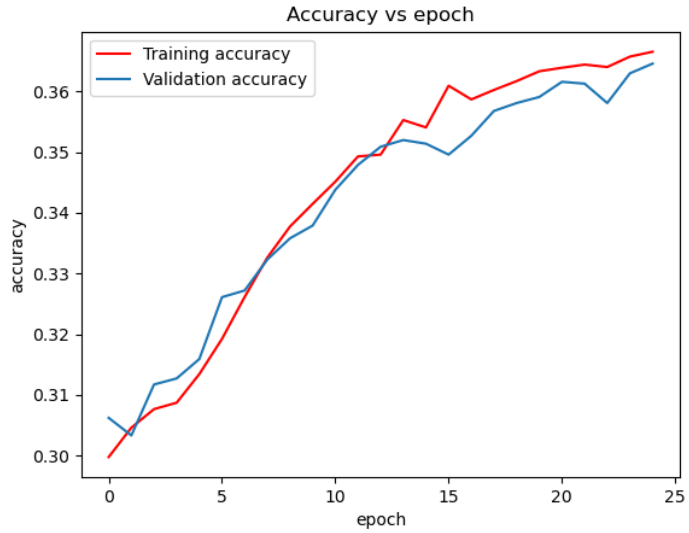

Figure 28: Training epochs vs. training and validation accuracies

Accuracy of the network on the 50000 train images: 37.2 %
Accuracy for class: plane is 27.9 %
Accuracy for class: car is 56.3 %
Accuracy for class: bird is 11.5 %
Accuracy for class: cat is 30.9 %
Accuracy for class: deer is 29.8 %
Accuracy for class: dog is 30.6 %
Accuracy for class: frog is 34.4 %
Accuracy for class: horse is 52.2 %
Accuracy for class: ship is 62.1 %
Accuracy for class: truck is 36.0 %

Accuracy of the network on the 10000 test images: 36.0 %
Accuracy for class: plane is 29.3 %
Accuracy for class: car is 53.4 %
Accuracy for class: bird is 11.3 %
Accuracy for class: cat is 25.9 %
Accuracy for class: deer is 28.3 %
Accuracy for class: dog is 31.3 %
Accuracy for class: frog is 33.6 %
Accuracy for class: horse is 50.6 %
Accuracy for class: ship is 61.3 %
Accuracy for class: truck is 34.6 %

- `number_of_epochs` = 50

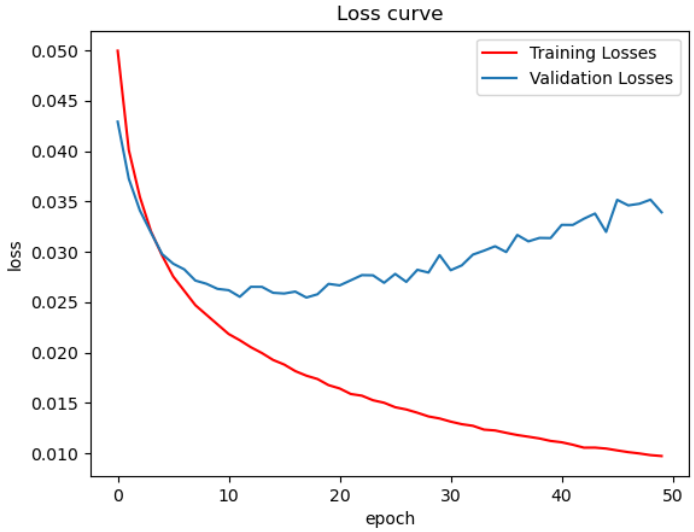

Figure 29: Training epochs vs. training and validation losses

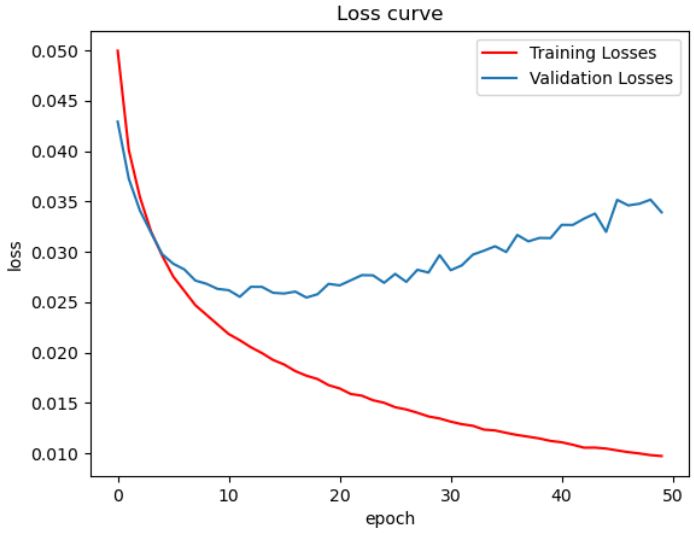

Figure 30: Training epochs vs. training and validation accuracies

Accuracy of the network on the 50000 train images: 90.4 %
Accuracy for class: plane is 93.4 %
Accuracy for class: car is 94.2 %
Accuracy for class: bird is 88.7 %
Accuracy for class: cat is 77.1 %
Accuracy for class: deer is 90.2 %
Accuracy for class: dog is 87.5 %
Accuracy for class: frog is 91.8 %
Accuracy for class: horse is 92.5 %
Accuracy for class: ship is 97.6 %
Accuracy for class: truck is 91.4 %

Accuracy of the network on the 10000 test images: 71.7 %
Accuracy for class: plane is 75.6 %
Accuracy for class: car is 81.2 %
Accuracy for class: bird is 62.3 %
Accuracy for class: cat is 48.0 %
Accuracy for class: deer is 68.1 %
Accuracy for class: dog is 66.2 %
Accuracy for class: frog is 77.7 %
Accuracy for class: horse is 74.2 %
Accuracy for class: ship is 86.5 %
Accuracy for class: truck is 77.0 %

- `number_of_epochs` = 75

Accuracy of the network on the 50000 train images: 93.0 %
Accuracy for class: plane is 89.8 %
Accuracy for class: car is 96.7 %
Accuracy for class: bird is 86.3 %
Accuracy for class: cat is 91.4 %
Accuracy for class: deer is 93.7 %
Accuracy for class: dog is 87.3 %
Accuracy for class: frog is 97.5 %
Accuracy for class: horse is 94.5 %
Accuracy for class: ship is 96.1 %
Accuracy for class: truck is 96.3 %

Accuracy of the network on the 10000 test images: 71.6 %
Accuracy for class: plane is 70.4 %
Accuracy for class: car is 83.2 %
Accuracy for class: bird is 54.1 %
Accuracy for class: cat is 60.0 %
Accuracy for class: deer is 71.6 %
Accuracy for class: dog is 57.8 %
Accuracy for class: frog is 82.9 %
Accuracy for class: horse is 74.7 %
Accuracy for class: ship is 79.4 %
Accuracy for class: truck is 81.6 %

- `number_of_epochs` = 100

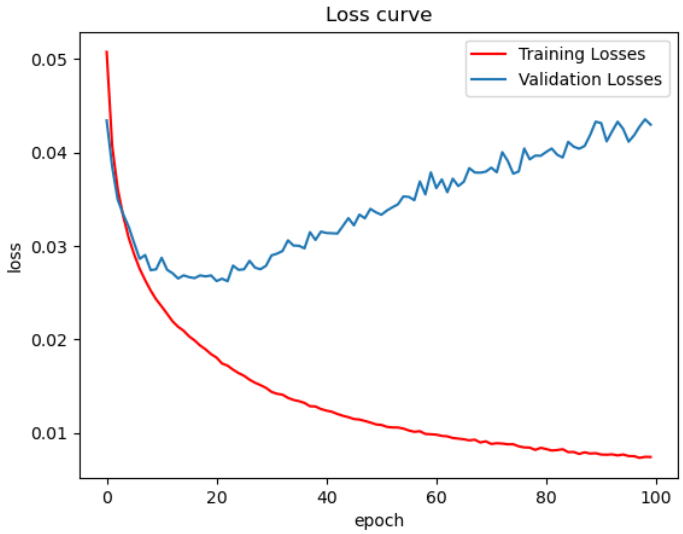

Figure 31: Training epochs vs. training and validation losses

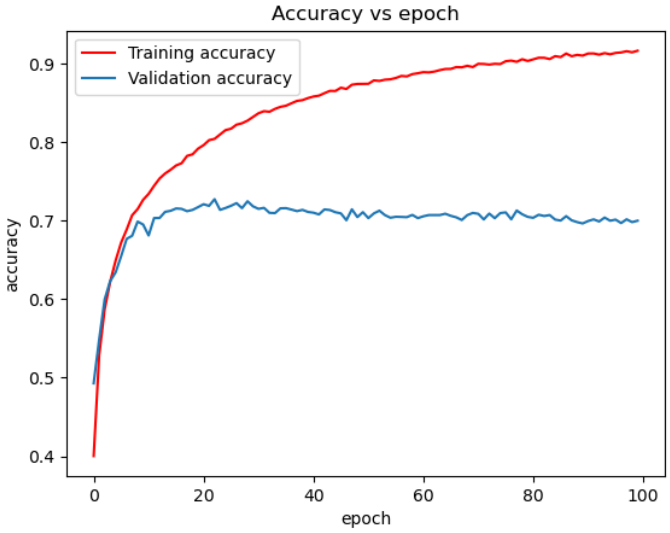

Figure 32: Training epochs vs. training and validation accuracies

Accuracy of the network on the 50000 train images: 92.9 %
Accuracy for class: plane is 93.1 %
Accuracy for class: car is 96.9 %
Accuracy for class: bird is 92.5 %
Accuracy for class: cat is 87.8 %
Accuracy for class: deer is 88.3 %
Accuracy for class: dog is 87.1 %
Accuracy for class: frog is 97.4 %
Accuracy for class: horse is 96.2 %
Accuracy for class: ship is 94.0 %
Accuracy for class: truck is 95.5 %

Accuracy of the network on the 10000 test images: 70.7 %
Accuracy for class: plane is 72.4 %
Accuracy for class: car is 84.9 %
Accuracy for class: bird is 62.1 %
Accuracy for class: cat is 51.1 %
Accuracy for class: deer is 62.5 %
Accuracy for class: dog is 56.5 %
Accuracy for class: frog is 81.0 %
Accuracy for class: horse is 79.1 %
Accuracy for class: ship is 77.9 %
Accuracy for class: truck is 79.4 %

As we increase the number of training epochs, the accuracy of the model on the training set generally improves. This is because the model learn more and adjust its parameters to better

fit the training set. However, increasing the number of epochs beyond a certain point may not result in significant improvements in accuracy and might lead to overfitting.

During training, the loss typically decreases as the model learns to fit the training data better. However, if the number of epochs is too high, the loss may start increasing again due to overfitting which can be observed in loss curve for `number_of_epochs` = 100 in the validation set. Therefore, it is important to monitor the validation accuracy and stop training when it starts to decrease.

The effect of increasing the number of epochs on accuracy and loss also depends on other hyperparameters such as the learning rate and the batch size.

2.3.4 Batch Size

For this experiment, `batch size` = 32, `learning_rate` = 0.001 and `optimizer` = adam

- `batch_size` = 32

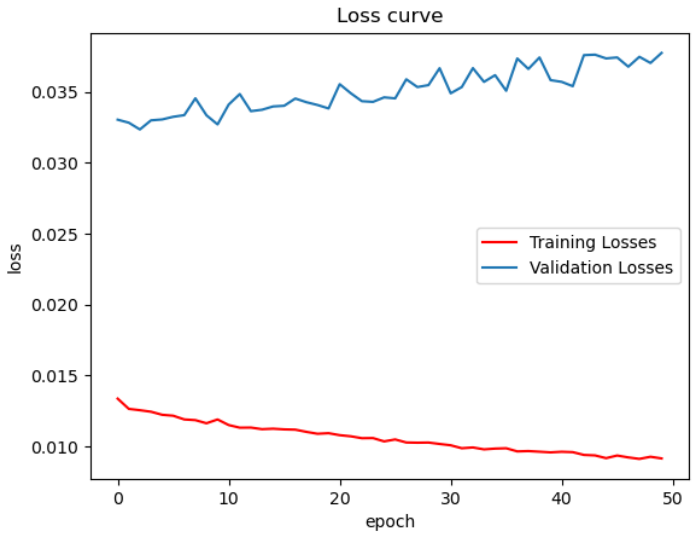

Figure 33: Training epochs vs. training and validation losses

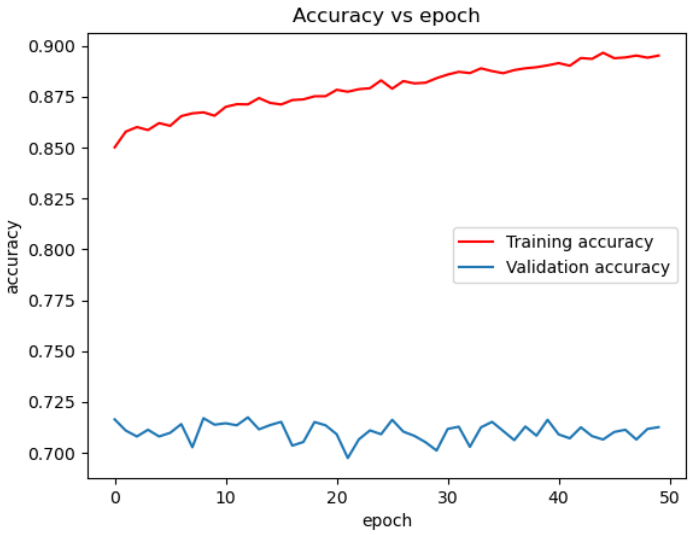

Figure 34: Training epochs vs. training and validation accuracies

Accuracy of the network on the 50000 train images: 89.9 %
Accuracy for class: plane is 91.0 %
Accuracy for class: car is 91.1 %
Accuracy for class: bird is 85.3 %
Accuracy for class: cat is 81.9 %
Accuracy for class: deer is 91.8 %
Accuracy for class: dog is 79.6 %
Accuracy for class: frog is 95.1 %
Accuracy for class: horse is 91.7 %
Accuracy for class: ship is 96.4 %
Accuracy for class: truck is 95.2 %

Accuracy of the network on the 10000 test images: 70.8 %
Accuracy for class: plane is 73.0 %
Accuracy for class: car is 76.4 %
Accuracy for class: bird is 56.4 %
Accuracy for class: cat is 54.3 %
Accuracy for class: deer is 71.1 %
Accuracy for class: dog is 57.6 %
Accuracy for class: frog is 79.7 %
Accuracy for class: horse is 72.7 %
Accuracy for class: ship is 84.2 %
Accuracy for class: truck is 82.2 %

- `batch_size` = 16

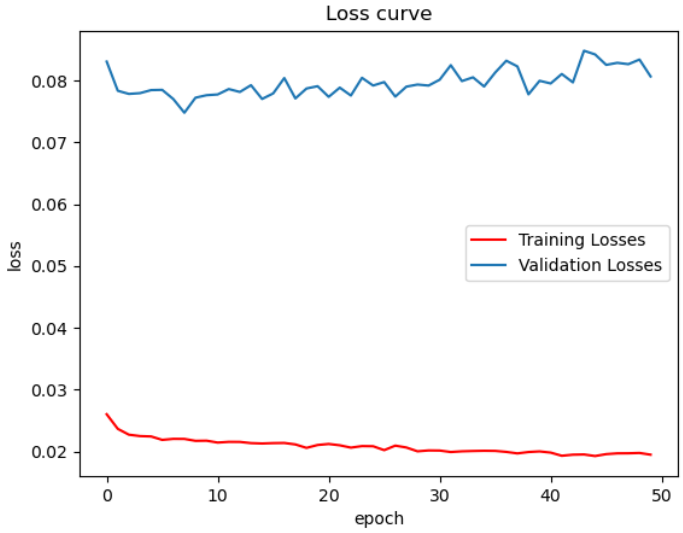

Figure 35: Training epochs vs. training and validation losses

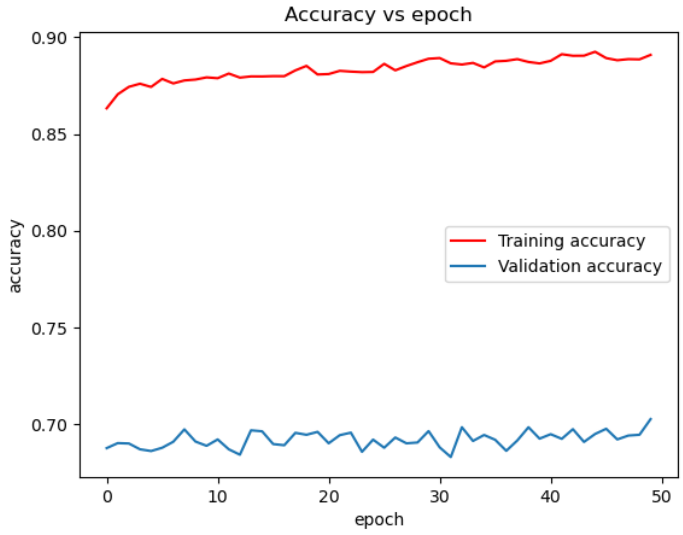

Figure 36: Training epochs vs. training and validation accuracies

Accuracy of the network on the 50000 train images: 90.5 %
Accuracy for class: plane is 92.5 %
Accuracy for class: car is 94.9 %
Accuracy for class: bird is 87.6 %
Accuracy for class: cat is 79.1 %
Accuracy for class: deer is 87.0 %
Accuracy for class: dog is 88.8 %
Accuracy for class: frog is 93.2 %
Accuracy for class: horse is 95.0 %
Accuracy for class: ship is 93.6 %
Accuracy for class: truck is 93.3 %

Accuracy of the network on the 10000 test images: 69.8 %
Accuracy for class: plane is 75.4 %
Accuracy for class: car is 84.9 %
Accuracy for class: bird is 57.8 %
Accuracy for class: cat is 46.9 %
Accuracy for class: deer is 61.7 %
Accuracy for class: dog is 61.1 %
Accuracy for class: frog is 78.0 %
Accuracy for class: horse is 77.7 %
Accuracy for class: ship is 77.9 %
Accuracy for class: truck is 76.9 %

- `batch_size` = 8

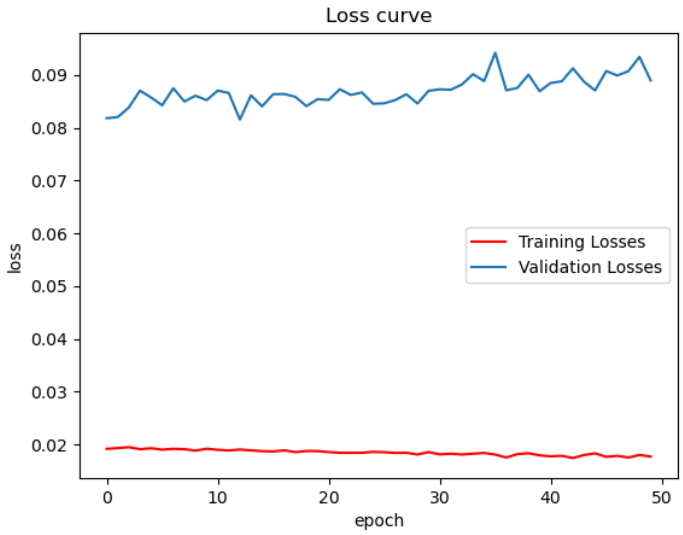

Figure 37: Training epochs vs. training and validation losses

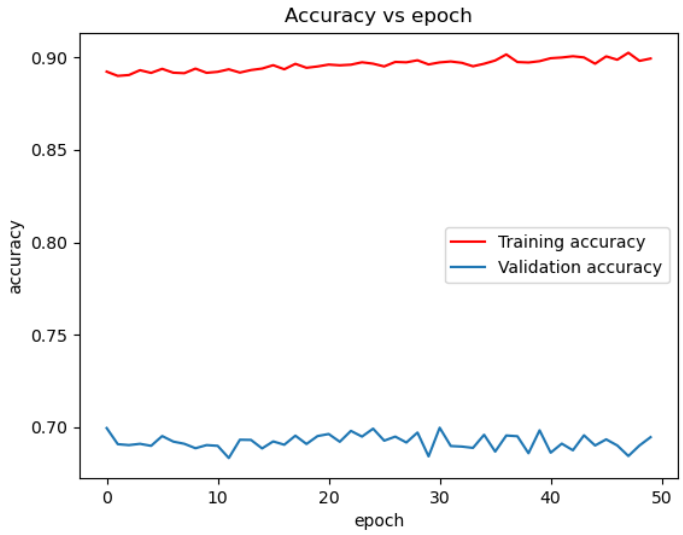

Figure 38: Training epochs vs. training and validation accuracies

Accuracy of the network on the 50000 train images: 90.7 %
Accuracy for class: plane is 90.7 %
Accuracy for class: car is 94.1 %
Accuracy for class: bird is 90.1 %
Accuracy for class: cat is 82.7 %
Accuracy for class: deer is 92.0 %
Accuracy for class: dog is 81.0 %
Accuracy for class: frog is 90.5 %
Accuracy for class: horse is 95.3 %
Accuracy for class: ship is 96.4 %
Accuracy for class: truck is 93.7 %

Accuracy of the network on the 10000 test images: 69.9 %
Accuracy for class: plane is 70.0 %
Accuracy for class: car is 82.2 %
Accuracy for class: bird is 62.0 %
Accuracy for class: cat is 50.4 %
Accuracy for class: deer is 67.7 %
Accuracy for class: dog is 52.2 %
Accuracy for class: frog is 74.6 %
Accuracy for class: horse is 77.9 %
Accuracy for class: ship is 81.6 %
Accuracy for class: truck is 77.7 %

- `batch_size` = 4

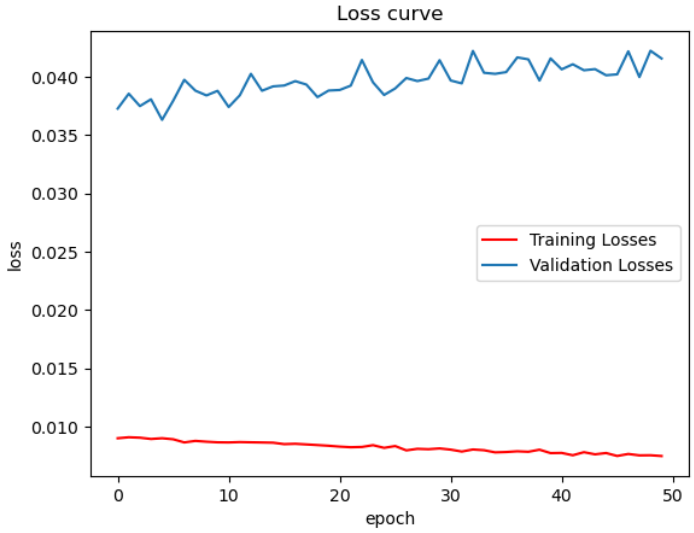

Figure 39: Training epochs vs. training and validation losses

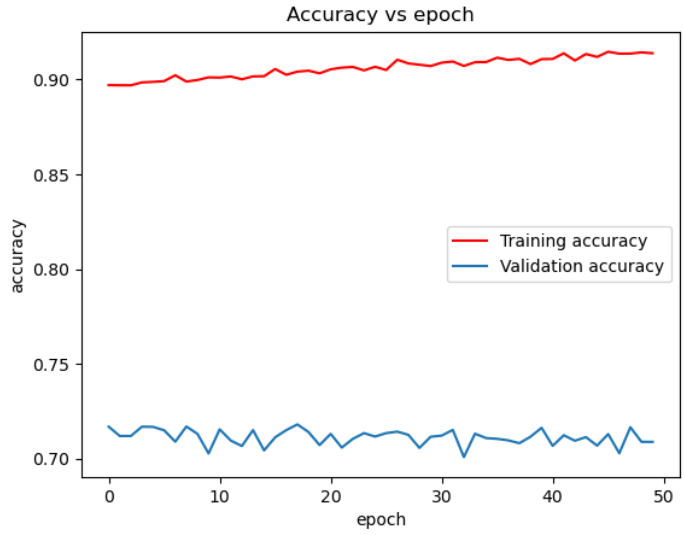

Figure 40: Training epochs vs. training and validation accuracies

Accuracy of the network on the 50000 train images: 91.7 %
Accuracy for class: plane is 93.5 %
Accuracy for class: car is 93.7 %
Accuracy for class: bird is 84.9 %
Accuracy for class: cat is 81.7 %
Accuracy for class: deer is 95.1 %
Accuracy for class: dog is 89.6 %
Accuracy for class: frog is 97.0 %
Accuracy for class: horse is 92.1 %
Accuracy for class: ship is 94.7 %
Accuracy for class: truck is 94.8 %

Accuracy of the network on the 10000 test images: 71.2 %
Accuracy for class: plane is 74.0 %
Accuracy for class: car is 80.5 %
Accuracy for class: bird is 56.9 %
Accuracy for class: cat is 49.5 %
Accuracy for class: deer is 72.0 %
Accuracy for class: dog is 63.7 %
Accuracy for class: frog is 83.6 %
Accuracy for class: horse is 72.7 %
Accuracy for class: ship is 81.0 %
Accuracy for class: truck is 78.0 %

`batch size`	training accuracy	validation
4	91.7%	71.2 %
8	90.7%	69.9 %
16	90.5%	69.8 %
32	89.9%	70.8 %

Table 14: batch-wise accuracy

For this experiment, SGD is used as optimizer.

- `batch_size` = 32

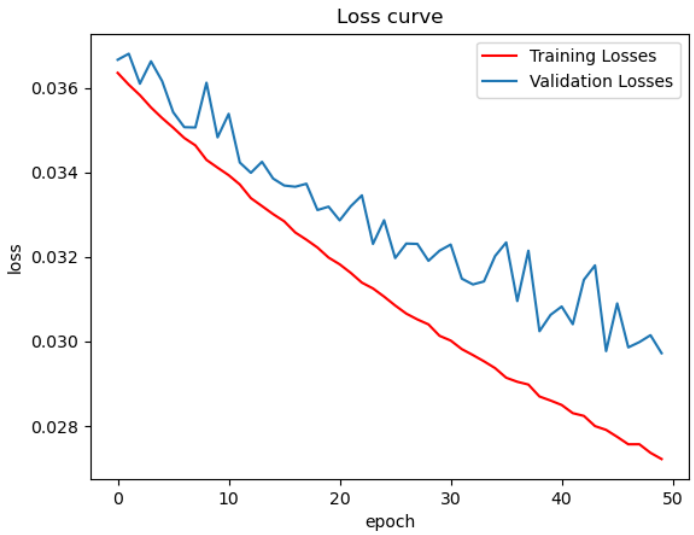

Figure 41: Training epochs vs. training and validation losses

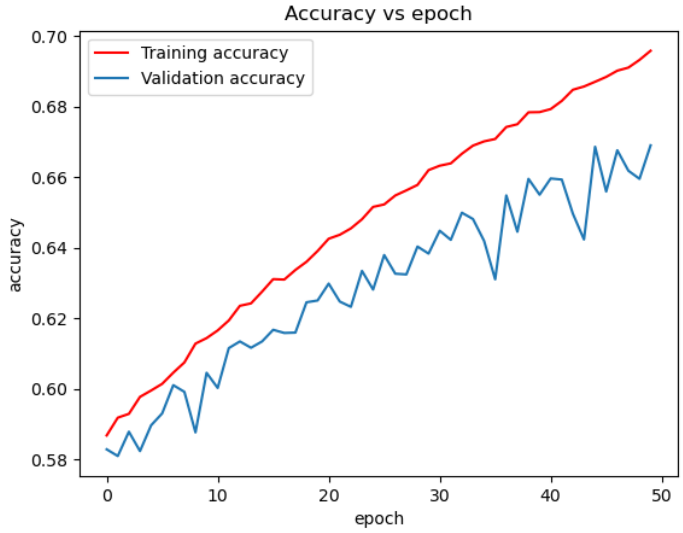

Figure 42: Training epochs vs. training and validation accuracies

Accuracy of the network on the 50000 train images: 70.7 %
Accuracy for class: plane is 72.8 %
Accuracy for class: car is 81.5 %
Accuracy for class: bird is 47.5 %
Accuracy for class: cat is 54.1 %
Accuracy for class: deer is 76.6 %
Accuracy for class: dog is 54.3 %
Accuracy for class: frog is 72.4 %
Accuracy for class: horse is 70.7 %
Accuracy for class: ship is 88.9 %
Accuracy for class: truck is 77.7 %

Accuracy of the network on the 10000 test images: 66.5 %
Accuracy for class: plane is 70.9 %
Accuracy for class: car is 78.8 %
Accuracy for class: bird is 43.7 %
Accuracy for class: cat is 48.5 %
Accuracy for class: deer is 73.4 %
Accuracy for class: dog is 51.6 %
Accuracy for class: frog is 70.1 %
Accuracy for class: horse is 67.0 %
Accuracy for class: ship is 87.3 %
Accuracy for class: truck is 74.1 %

- `batch_size` = 16

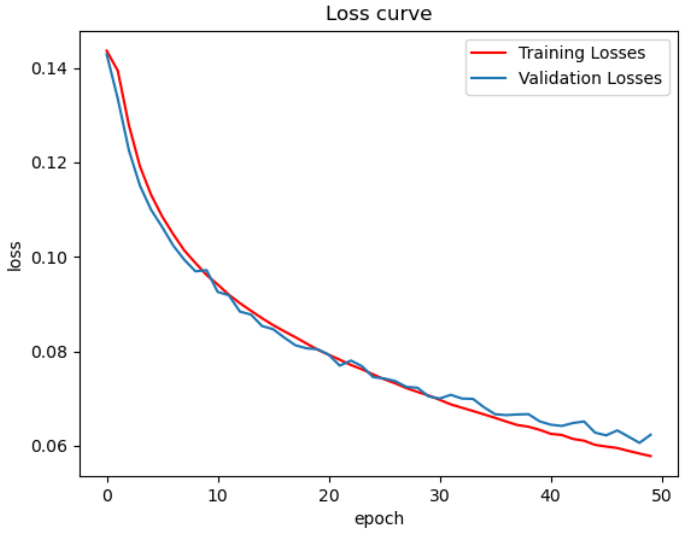

Figure 43: Training epochs vs. training and validation losses

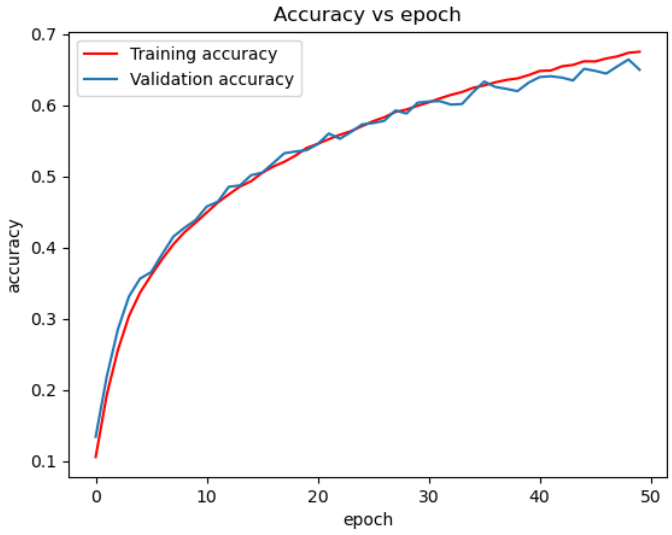

Figure 44: Training epochs vs. training and validation accuracies

Accuracy of the network on the 50000 train images: 67.5 %
Accuracy for class: plane is 74.1 %
Accuracy for class: car is 87.5 %
Accuracy for class: bird is 52.3 %
Accuracy for class: cat is 46.2 %
Accuracy for class: deer is 58.6 %
Accuracy for class: dog is 57.4 %
Accuracy for class: frog is 79.9 %
Accuracy for class: horse is 79.0 %
Accuracy for class: ship is 65.5 %
Accuracy for class: truck is 74.3 %

Accuracy of the network on the 10000 test images: 65.2 %
Accuracy for class: plane is 72.8 %
Accuracy for class: car is 86.5 %
Accuracy for class: bird is 48.4 %
Accuracy for class: cat is 43.7 %
Accuracy for class: deer is 53.2 %
Accuracy for class: dog is 57.6 %
Accuracy for class: frog is 79.5 %
Accuracy for class: horse is 76.8 %
Accuracy for class: ship is 62.1 %
Accuracy for class: truck is 71.2 %

- `batch_size` = 8

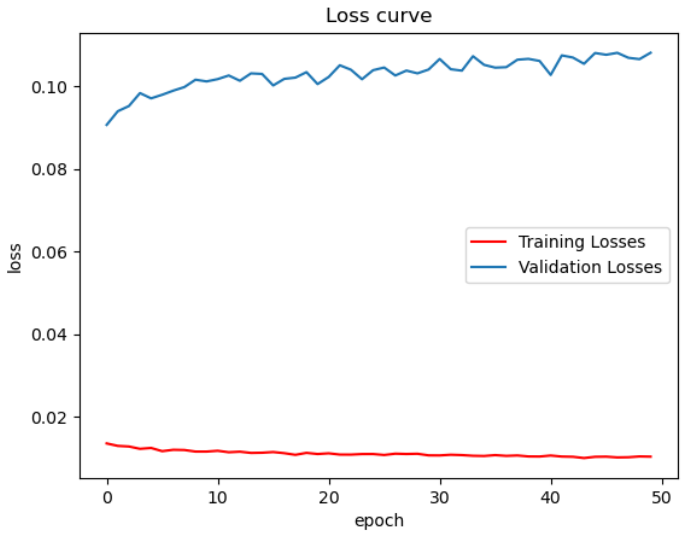

Figure 45: Training epochs vs. training and validation losses

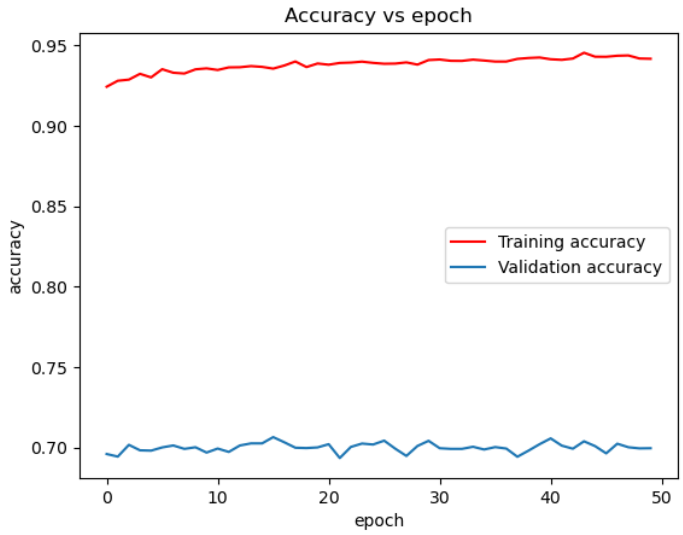

Figure 46: Training epochs vs. training and validation accuracies

Accuracy of the network on the 50000 train images: 94.3 %
Accuracy for class: plane is 95.4 %
Accuracy for class: car is 98.0 %
Accuracy for class: bird is 91.0 %
Accuracy for class: cat is 90.9 %
Accuracy for class: deer is 95.5 %
Accuracy for class: dog is 92.9 %
Accuracy for class: frog is 93.8 %
Accuracy for class: horse is 94.1 %
Accuracy for class: ship is 96.2 %
Accuracy for class: truck is 95.4 %

Accuracy of the network on the 10000 test images: 69.9 %
Accuracy for class: plane is 70.0 %
Accuracy for class: car is 82.2 %
Accuracy for class: bird is 62.0 %
Accuracy for class: cat is 50.4 %
Accuracy for class: deer is 67.7 %
Accuracy for class: dog is 52.2 %
Accuracy for class: frog is 74.6 %
Accuracy for class: horse is 77.9 %
Accuracy for class: ship is 81.6 %
Accuracy for class: truck is 77.7 %

- `batch_size` = 4

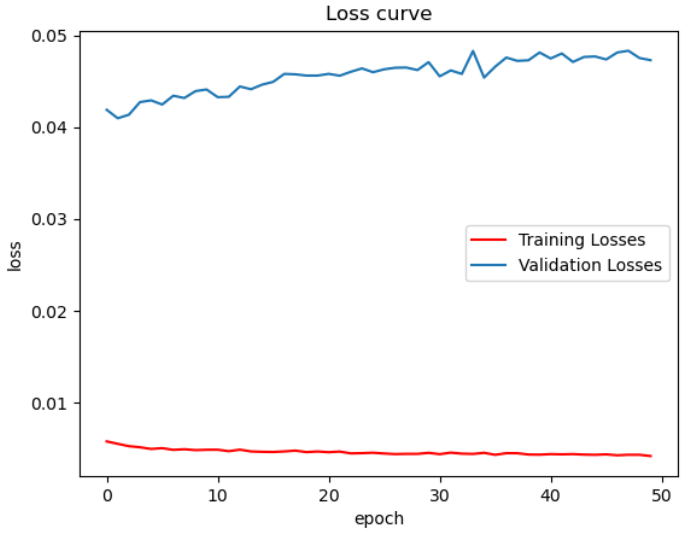

Figure 47: Training epochs vs. training and validation losses

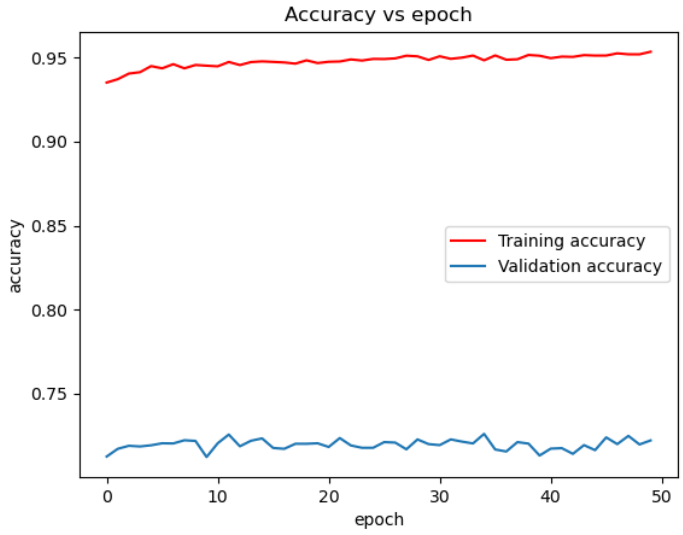

Figure 48: Training epochs vs. training and validation accuracies

Accuracy of the network on the 50000 train images: 94.8 %
Accuracy for class: plane is 95.3 %
Accuracy for class: car is 97.3 %
Accuracy for class: bird is 92.8 %
Accuracy for class: cat is 87.6 %
Accuracy for class: deer is 94.2 %
Accuracy for class: dog is 95.5 %
Accuracy for class: frog is 96.6 %
Accuracy for class: horse is 95.6 %
Accuracy for class: ship is 97.6 %
Accuracy for class: truck is 95.7 %

Accuracy of the network on the 10000 test images: 71.8 %
Accuracy for class: plane is 74.0 %
Accuracy for class: car is 82.6 %
Accuracy for class: bird is 61.0 %
Accuracy for class: cat is 51.7 %
Accuracy for class: deer is 68.1 %
Accuracy for class: dog is 67.2 %
Accuracy for class: frog is 77.3 %
Accuracy for class: horse is 75.3 %
Accuracy for class: ship is 81.0 %
Accuracy for class: truck is 79.4 %

In this experiment, we varied the batch size from 4 to 32 and trained a CNN model for 50 epochs using a learning rate of 0.0005. The overall validation accuracy was recorded for each batch size. The results showed that as the batch size decreased, the overall validation accuracy increased may be because, when uses a smaller batch size, the model updates its parameters more frequently as it is trained on fewer examples at a time. This allows the model to learn more from the data and improve its accuracy over time. On the other hand, when using a larger batch size, the model updates its parameters less frequently because it is trained on more examples at a time. This can lead to slower convergence and lower accuracy since the model is not able to learn as much from the data with each update. Furthermore, the experiment also revealed that the SGD optimizer achieved higher accuracy than the Adam optimizer, regardless of the batch size. This could be due to the fact that the Adam optimizer uses a more complex adaptive learning rate that can sometimes hinder the learning process, while SGD optimizer with a properly tuned learning rate can be more effective.

Also, as described in paper "The effect of batch size on the generalizability of the convolutional neural networks on a histopathology dataset by Ibrahem Kandel" suggest that for lower learning rate low batch size gives higher accuracies.

2.4 Effect of Loss Function

In this experiment, hyperparameters are fixed to: `batch_size` = 8, `num_epochs` = 50, `learning_rate` = 0.001.

Using KL Divergence as loss function reported class wise accuracy is Accuracy of the network on the 50000 train images: 77.9 %
Accuracy for class: plane is 82.6 %
Accuracy for class: car is 87.4 %
Accuracy for class: bird is 65.8 %
Accuracy for class: cat is 62.0 %
Accuracy for class: deer is 75.1 %

Accuracy for class: dog is 75.9 %
Accuracy for class: frog is 81.9 %
Accuracy for class: horse is 75.1 %
Accuracy for class: ship is 91.1 %
Accuracy for class: truck is 82.3 %

Accuracy of the network on the 10000 test images: 69.0 %
Accuracy for class: plane is 74.7 %
Accuracy for class: car is 79.2 %
Accuracy for class: bird is 52.2 %
Accuracy for class: cat is 48.5 %
Accuracy for class: deer is 65.0 %
Accuracy for class: dog is 67.0 %
Accuracy for class: frog is 75.5 %
Accuracy for class: horse is 66.3 %
Accuracy for class: ship is 85.2 %
Accuracy for class: truck is 76.8 %

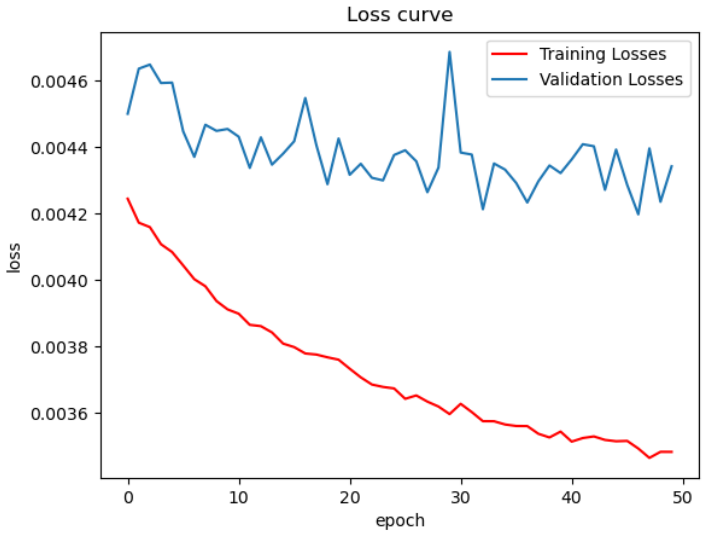

Figure 49: Training epochs vs. training and validation losses

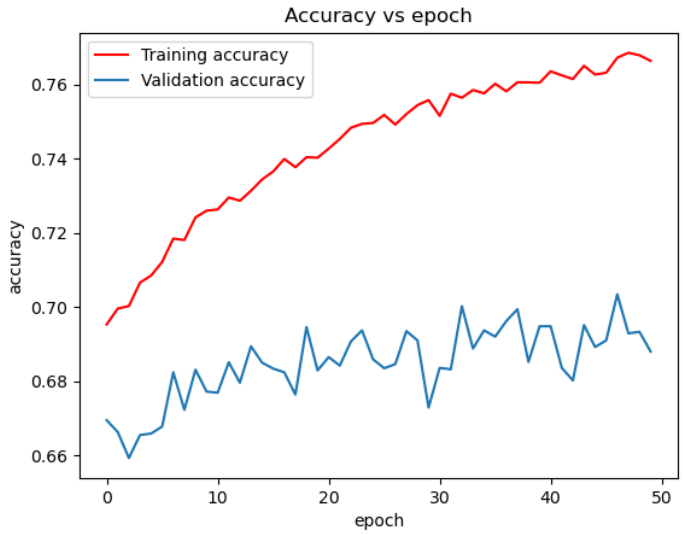

Figure 50: Training epochs vs. training and validation accuracies

The reported accuracies for KL divergence are lower than those for CrossEntropy, both for the overall accuracy and the class-wise accuracy. This could be due to the fact that KL divergence is a more complex loss function than CrossEntropy and may not be suitable for this particular problem. CrossEntropy loss is a more common choice for multi-class classification tasks and has been shown to perform well in practice. Taking about the convergence, referring to the plot of loss curve for two cases KL divergence loss function shows better convergence.

2.5 Effect of Data Augmentation

In this experiment, hyperparameters are fixed to: `batch_size` = 8, `num_epochs` = 50, `learning_rate` = 0.001. The result reported with using data augmentation is following: Accuracy of the network on the 50000 train images: 79.2 %
Accuracy for class: plane is 82.1 %
Accuracy for class: car is 84.2 %
Accuracy for class: bird is 74.4 %
Accuracy for class: cat is 66.3 %
Accuracy for class: deer is 83.4 %
Accuracy for class: dog is 64.6 %
Accuracy for class: frog is 81.1 %
Accuracy for class: horse is 78.4 %
Accuracy for class: ship is 86.6 %
Accuracy for class: truck is 90.5 %

Accuracy of the network on the 10000 test images: 72.7 %
Accuracy for class: plane is 75.3 %
Accuracy for class: car is 78.3 %
Accuracy for class: bird is 66.2 %

Accuracy for class: cat is 55.8 %
Accuracy for class: deer is 76.4 %
Accuracy for class: dog is 60.2 %
Accuracy for class: frog is 74.7 %
Accuracy for class: horse is 72.5 %
Accuracy for class: ship is 82.2 %
Accuracy for class: truck is 85.5 %

and without using data augmentation results reported are following: Accuracy of the network on the 50000 train images: 89.9 %
Accuracy for class: plane is 91.8 %
Accuracy for class: car is 96.3 %
Accuracy for class: bird is 90.1 %
Accuracy for class: cat is 80.9 %
Accuracy for class: deer is 88.3 %
Accuracy for class: dog is 78.2 %
Accuracy for class: frog is 96.6 %
Accuracy for class: horse is 93.1 %
Accuracy for class: ship is 96.0 %
Accuracy for class: truck is 88.0 %

Accuracy of the network on the 10000 test images: 65.7 %
Accuracy for class: plane is 69.5 %
Accuracy for class: car is 80.6 %
Accuracy for class: bird is 57.8 %
Accuracy for class: cat is 45.1 %
Accuracy for class: deer is 55.6 %
Accuracy for class: dog is 49.0 %
Accuracy for class: frog is 80.2 %
Accuracy for class: horse is 71.1 %
Accuracy for class: ship is 78.5 %
Accuracy for class: truck is 69.1 %

In this experiment, we can observed that without using data augmentation training accuracy is 89.9 % while with data augmentation is 79.2 %. However, if we compare the result of validation accuracies, then we can conclude that, model without data augmentation has overfitted as when data augmentation is turned off during training, the model will be trained on the original data without any additional variations introduced which lead to overfitting, as the model will only learn to classify the specific examples in the training set and may not generalize well to new, unseen data. As a result, we might expect the validation accuracy to decrease and the training accuracy to increase compared to training with data augmentations.

The specific effect on class-wise and overall validation accuracy depend on the data and the model being trained. However, in general, the accuracy is lower for classes that are less well-represented in the training data, as the lack of data augmentation makes it harder for the model to learn to recognize these classes. On the other hand, classes that are well-represented in the training data may still achieve high accuracy, as the model can more easily memorize the examples for these classes.

3 Part 3: Improve the CNN Model

I have increased the number of convolutional layers, each with increasing number of filters, allows for the extraction of more complex and high-level features from the input images. The addition of more convolutional layers with smaller filters instead of fewer layers with larger filters has been found to be more effective in some cases. Batch normalisation is also added after every convolution layer to improve the training speed and generalization.

Model architecture developed is given below:

```
class Net(nn.Module):
    def __init__(self):
        super(Net, self).__init__()
        self.conv1 = nn.Conv2d(3, 32, 3)
        self.bn1 = nn.BatchNorm2d(32)
        self.conv2 = nn.Conv2d(32, 64, 3)
        self.bn2 = nn.BatchNorm2d(64)
        self.pool1 = nn.MaxPool2d(2,stride = 2)
        self.conv3 = nn.Conv2d(64, 64, 3)
        self.bn3 = nn.BatchNorm2d(64)
        self.conv4 = nn.Conv2d(64, 128, 3)
        self.bn4 = nn.BatchNorm2d(128)
        self.pool2 = nn.MaxPool2d(2, stride = 2)
        self.conv5 = nn.Conv2d(128,64,3)
        self.fc1 = nn.Linear(64*3*3, 512)
        self.fc2 = nn.Linear(512,128)
        self.fc3 = nn.Linear(128, 10)

    def forward(self, x):
        # -> n, 3, 32, 32
        y =
            self.pool1(F.relu(self.bn2(self.conv2(F.relu(self.bn1(self.conv1(x)))))))
        y =
            self.pool2(F.relu(self.bn4(self.conv4(F.relu(self.bn3(self.conv3(y)))))))
        y = F.relu(self.conv5(y))
        y = torch.flatten(y, 1)  # Flatten
        y = F.relu(self.fc1(y))
        y = F.relu(self.fc2(y))
```

```
27          y = self.fc3(y)
28          return y
```

Hyperparamters are: `batch_size` = 32, `num_epochs` = 20 and `learning_rate` =0.001

Reported accruacies are:

Accuracy of the network on the 50000 train images: 84.7 %
Accuracy for class: plane is 86.7 %
Accuracy for class: car is 87.6 %
Accuracy for class: bird is 71.0 %
Accuracy for class: cat is 77.5 %
Accuracy for class: deer is 85.4 %
Accuracy for class: dog is 78.6 %
Accuracy for class: frog is 91.2 %
Accuracy for class: horse is 80.5 %
Accuracy for class: ship is 94.4 %
Accuracy for class: truck is 94.3 %
Accuracy of the network on the 10000 test images: 80.5 %
Accuracy for class: plane is 83.1 %
Accuracy for class: car is 86.2 %
Accuracy for class: bird is 57.5 %
Accuracy for class: cat is 74.8 %
Accuracy for class: deer is 82.7 %
Accuracy for class: dog is 73.7 %
Accuracy for class: frog is 84.4 %
Accuracy for class: horse is 79.0 %
Accuracy for class: ship is 88.3 %
Accuracy for class: truck is 95.1 %

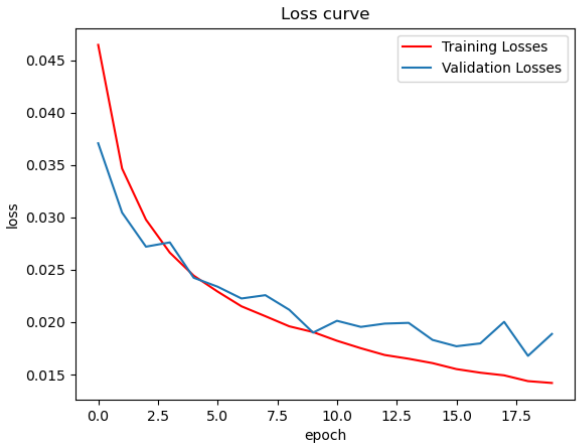

Figure 51: Training epochs vs. training and validation losses

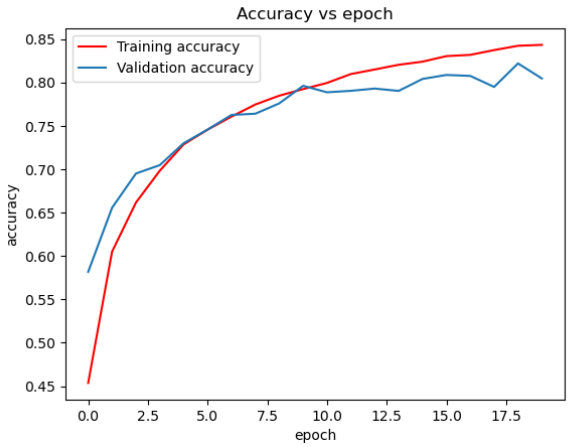

Figure 52: Training epochs vs. training and validation accuracies

For hyperparamters:

`batch_size` = 16, `num_epochs` = 50 and `learning_rate` =0.002

Reported accruacies are:

Accuracy of the network on the 50000 train images: 93.7 %
Accuracy for class: plane is 95.8 %
Accuracy for class: car is 97.4 %
Accuracy for class: bird is 93.5 %
Accuracy for class: cat is 80.1 %
Accuracy for class: deer is 94.7 %
Accuracy for class: dog is 92.2 %
Accuracy for class: frog is 97.0 %
Accuracy for class: horse is 94.5 %
Accuracy for class: ship is 97.3 %
Accuracy for class: truck is 94.6 %
Accuracy of the network on the 10000 test images: 84.5 %
Accuracy for class: plane is 88.0 %
Accuracy for class: car is 93.6 %
Accuracy for class: bird is 79.1 %
Accuracy for class: cat is 69.4 %
Accuracy for class: deer is 83.1 %
Accuracy for class: dog is 77.6 %
Accuracy for class: frog is 87.6 %
Accuracy for class: horse is 87.2 %
Accuracy for class: ship is 89.2 %
Accuracy for class: truck is 90.0 %

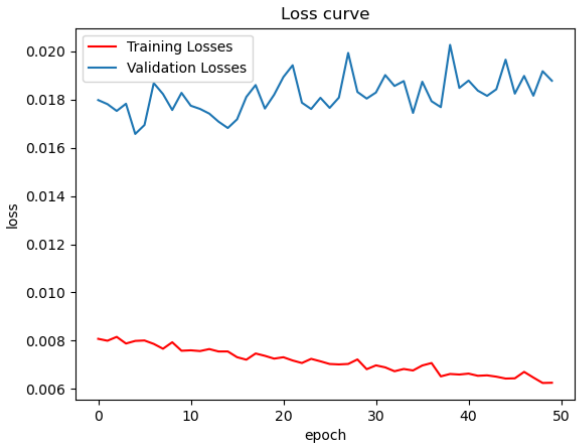

Figure 53: Training epochs vs. training and validation losses

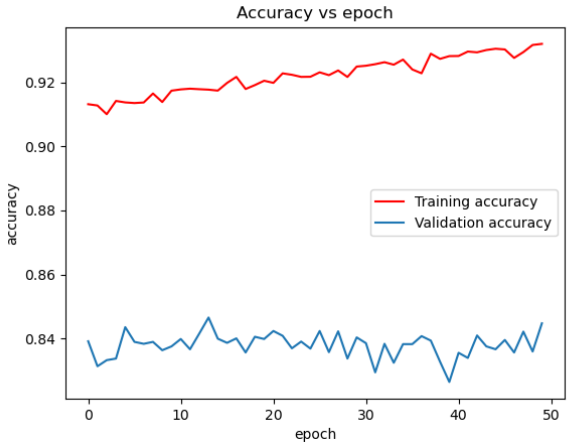

Figure 54: Training epochs vs. training and validation accuracies

For hyperparamters:

`batch_size` = 16, `num_epochs` = 50 and `learning_rate` =0.002

Reported accruacies are:

Accuracy of the network on the 50000 train images: 94.6 %

Accuracy for class: plane is 96.3 %

Accuracy for class: car is 97.5 %

Accuracy for class: bird is 94.6 %

Accuracy for class: cat is 88.7 %

Accuracy for class: deer is 95.1 %

Accuracy for class: dog is 90.1 %

Accuracy for class: frog is 95.7 %

Accuracy for class: horse is 95.2 %

Accuracy for class: ship is 96.2 %

Accuracy for class: truck is 96.8 %

Accuracy of the network on the 10000 test images: 83.6 %

Accuracy for class: plane is 87.1 %

Accuracy for class: car is 92.7 %
Accuracy for class: bird is 79.3 %
Accuracy for class: cat is 72.4 %
Accuracy for class: deer is 82.2 %
Accuracy for class: dog is 72.8 %
Accuracy for class: frog is 85.4 %
Accuracy for class: horse is 86.9 %
Accuracy for class: ship is 85.6 %
Accuracy for class: truck is 91.7 %

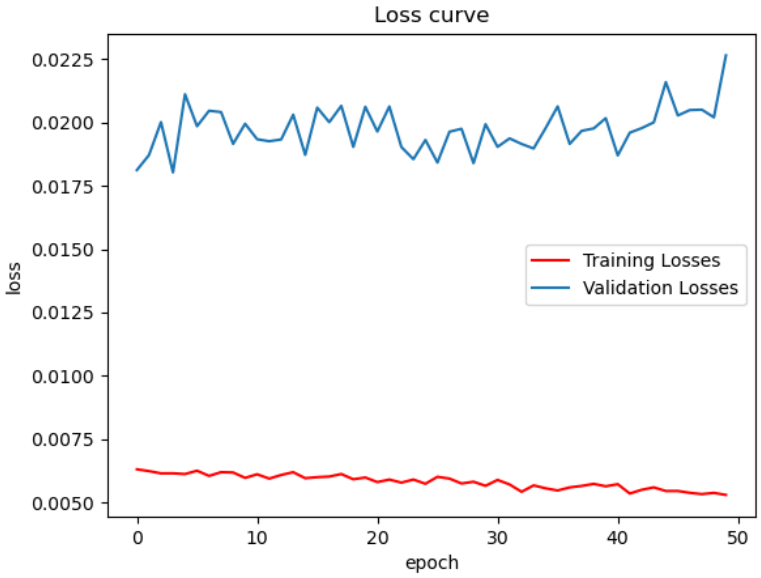

Figure 55: Training epochs vs. training and validation losses

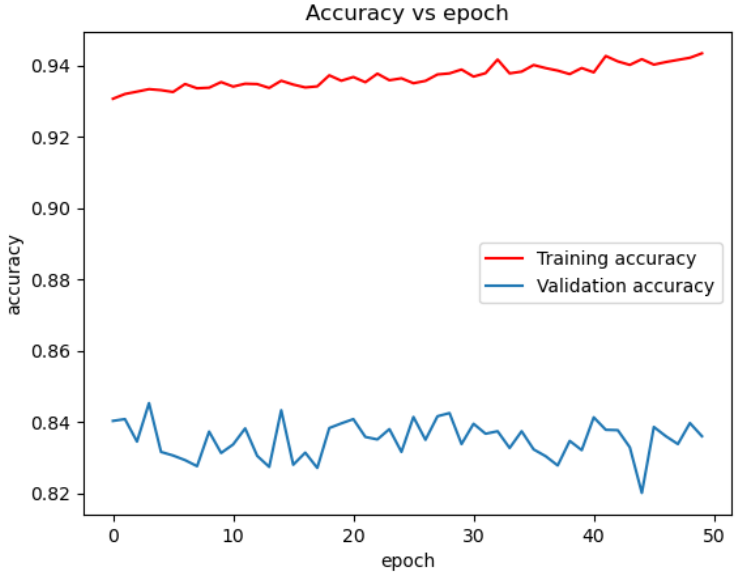

Figure 56: Training epochs vs. training and validation accuracies