AER 1515: Perception for Robotics

Homework 1

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Presented to Dr.Steven Waslander

October 14th, 2022

Content

Section 1 Run and Extend to Multi-Class Classification (15 pts)

Question 1

1. ***(5 pts) Run the code "train.py" and train a CNN model with at least 30 epochs. Save your trained model ("model.pt") on the disk and show a plot of the training loss. Here we show an example of the plot with only ten epochs.***

After running the train file with 30 epochs, we obtain the following plot Figure 1. We can see that the training loss diminished as the number of epochs increased. The training loss at the first epoch was 0.601 and at the 30th epoch, the training loss was 0.012. The table containing the training loss at each epoch can be found in Table 1.

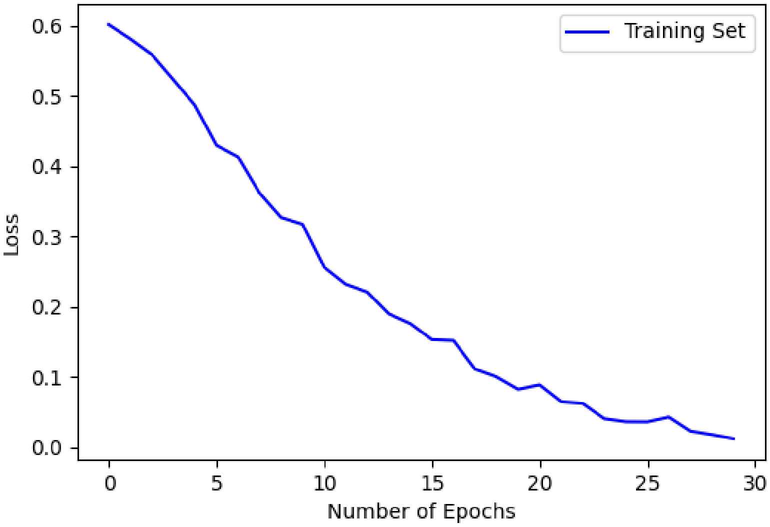


Figure 1 Loss function by number of Epochs for 2 classifications

Question 2

2. ***(5pts) Run the code 'test.py' with your saved CNN model ('model.pt') , and report the overall classification accuracy.***

After running the 'test.py' code, the following was observed for a binary classification between Dogs and Cats. The number of test samples was 10 number of samples, and the **test accuracy was 90%.**

Question 3

3. ***(5 pts) Modify the code 'train.py' and 'test.py' to extend the binary classification to a multi-class classification (20 classes) task. Show your training loss plot and report***

For this question, the code was modified to extend the binary classification to a multi-class classification of 20 classes. After running the train.py and test.py code, the following results were obtained. The number of test samples was 100, and the **test accuracy was 61%.** This is lower by 29% than the result obtained when doing a binary classification but the results makes sense since the classification was increased to 20.

The figure obtained of the training loss can be seen underneath Figure 2. From the figure, the training loss diminishes as the number of epochs increases. When the simulation was done for 20 classes instead of 2 classes, the loss was higher. For the 1st epoch, the training loss for 20 classes was 2.92 compared to 0.601 for 2 classes. At the 30th epoch, the training loss for 20 classes was 0.585 compared to 0.012 for 2 classes. The table containing the training loss at each epoch for 20 classes can be found in the appendix Table 2.

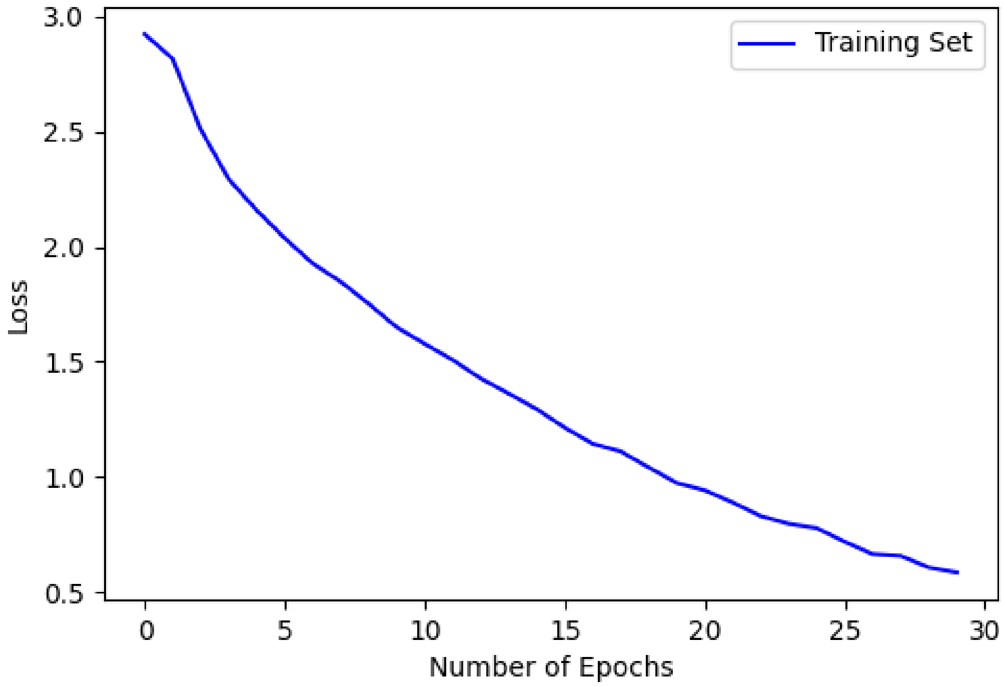


Figure 2 Loss function by number of Epochs for 20 classifications

Section 2 Change CNN Architecture (25 pts)

Question 1

1. ***(15 pts) Based on current CNN architecture, add batch normalization layers, and show your training loss plot, and report the overall classification accuracy with the modified CNN architecture.***

For this question, batch normalization layers were added to increase the test accuracy. Four batch normalization were implemented, the code can be seen in the appendix Figure 16. After adding the batch normalization layers, the test accuracy went from **61% to 68%**. The training loss function can be seen in the figure underneath Figure 3. The training loss converges near 0 much quicker than the previous simulations. It took 10 epochs for the training loss to be under 0.1 and its smallest value is 0.0008. Those values are much smaller than when no batch normalization layers were applied. When they were not implemented, the smallest value of the training loss was 0.585. The table containing the training loss at each epoch for this simulation can be found in the appendix Table 2.

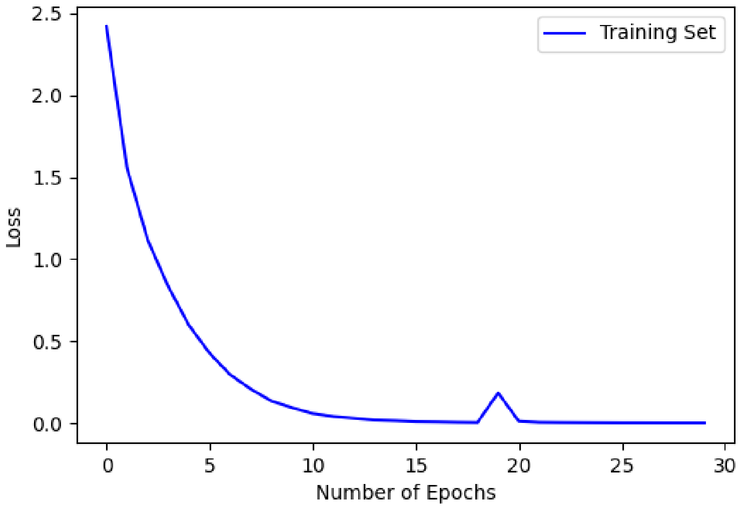


Figure 3 Training Loss Function by Epochs (20 classification and 4 Normalization layers)

Question 2

2. (10 pts) Based on the modified CNN architecture from the previous Question, add dropout layers and show your training loss plot and report the overall classification accuracy.

For this question, 2 dropout layers were added. The chosen **dropout rate was 0.2**. The training loss graph can be seen underneath Figure 4. **The test accuracy increased from 68% to 74%.** From Figure 4, the training loss converges to 0, but their values are higher than when the simulation was only performed with the 4 normalization layers. After 30 epochs, the training loss was 0.198. The training loss by epoch can be found in the appendix Table 4.

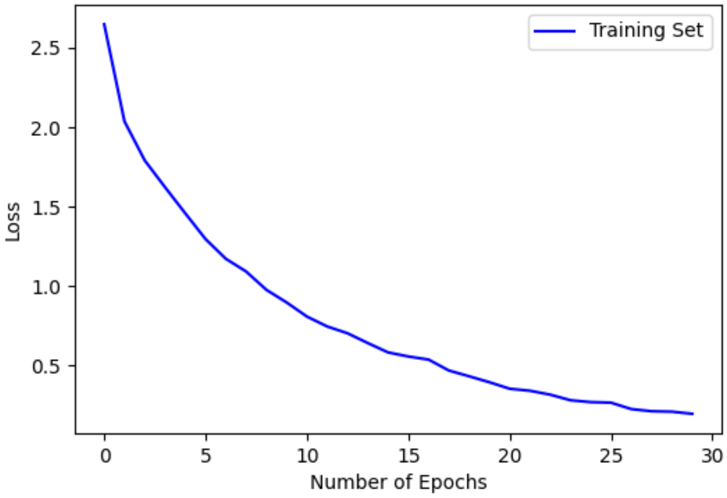


Figure 4 Training Loss Function by Epochs (20 classification, 4 Normalization layers and 2 dropout layers)

Section 3 Training Neural Network with Validation (35 pts)

Question 1

1. ***(25 pts) Based on your modified CNN architecture, add the validation loop within the training epochs and save the CNN model that corresponds to the least validation loss. Please also show a plot that includes both training loss and validation loss with at least 30 epochs. Here we show an example of the plot with only ten epochs.***

In this question, a validation loop was added. The model was saved for the epoch that had the biggest validation loss. The figure underneath illustrates the training loss and validation loss for 30 epochs Figure 5. The biggest validation loss occurred right after the 27th epoch. Hence, the last time the model saved was for the 27th epoch. The training loss and validation loss and for which epoch the model was saved can be found in the appendix Table 5, Table 6.

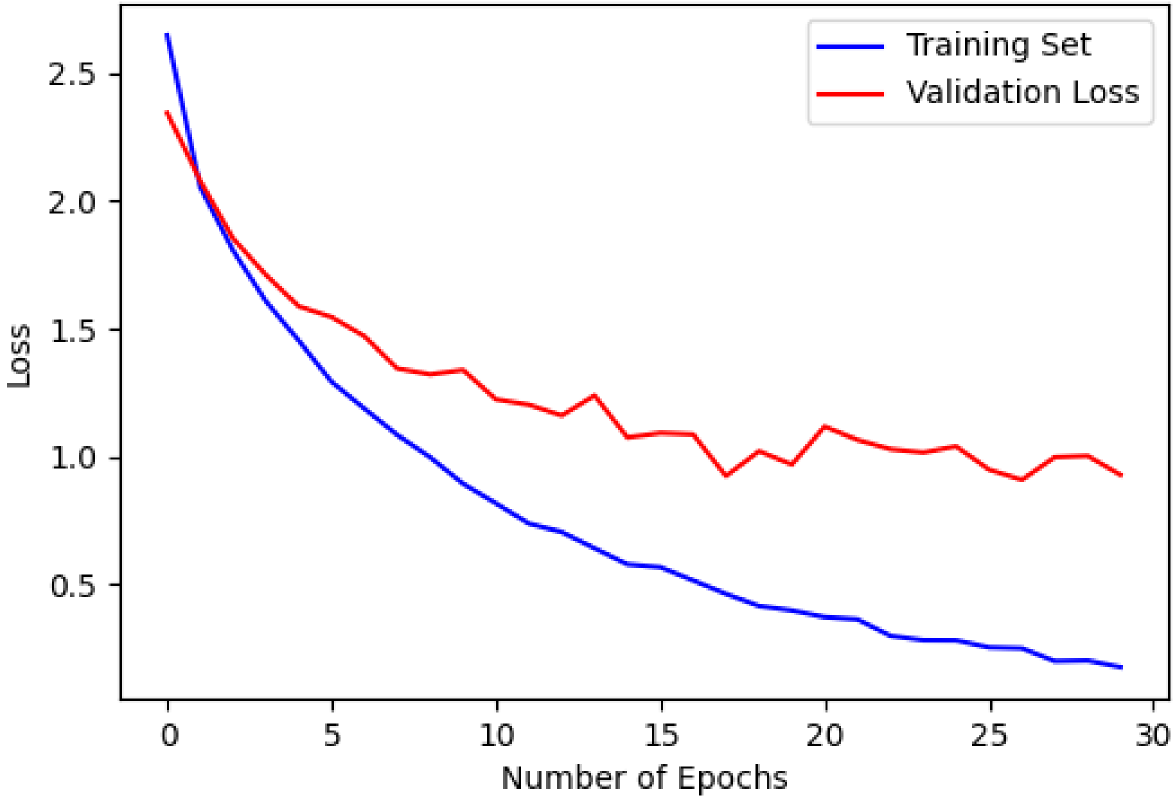


Figure 5 Training Loss and Validation Loss by Epoch

Question 2

2. ***(10 pts) Run the evaluation on the test dataset with your saved CNN model. Please compare the classification accuracy with the one that does not use the validation set.***

After running the test file, the accuracy **increased from 74% to 77%** with 1850 number of train samples and 100 test samples. This is expected since in the previous simulation, the model was only saved at the 30th epoch. However, the last epoch is not necessarily the one that gave the least loss. In this case, the model was saved when the least loss occurred, which was at the 27th epoch. This explains the increase in the test accuracy.

Section 4 Hyperparameter Tuning (25 pts)

Question 1

1. ***(7 pts) Change the optimizer to another one and report the classification results on the test set.***

For the following test, the optimizer was **switched from optim.RMSprop to optim.SGD**. A learning rate of 0.01 and a momentum of 0.9 was selected. The training loss and validation loss can be seen in the figure underneath Figure 6.. The model was saved at the 18th epoch and the **test accuracy increased from 77% to 83%.** The training loss and validation loss at each epoch can be found in the appendix Table 7, Table 8.

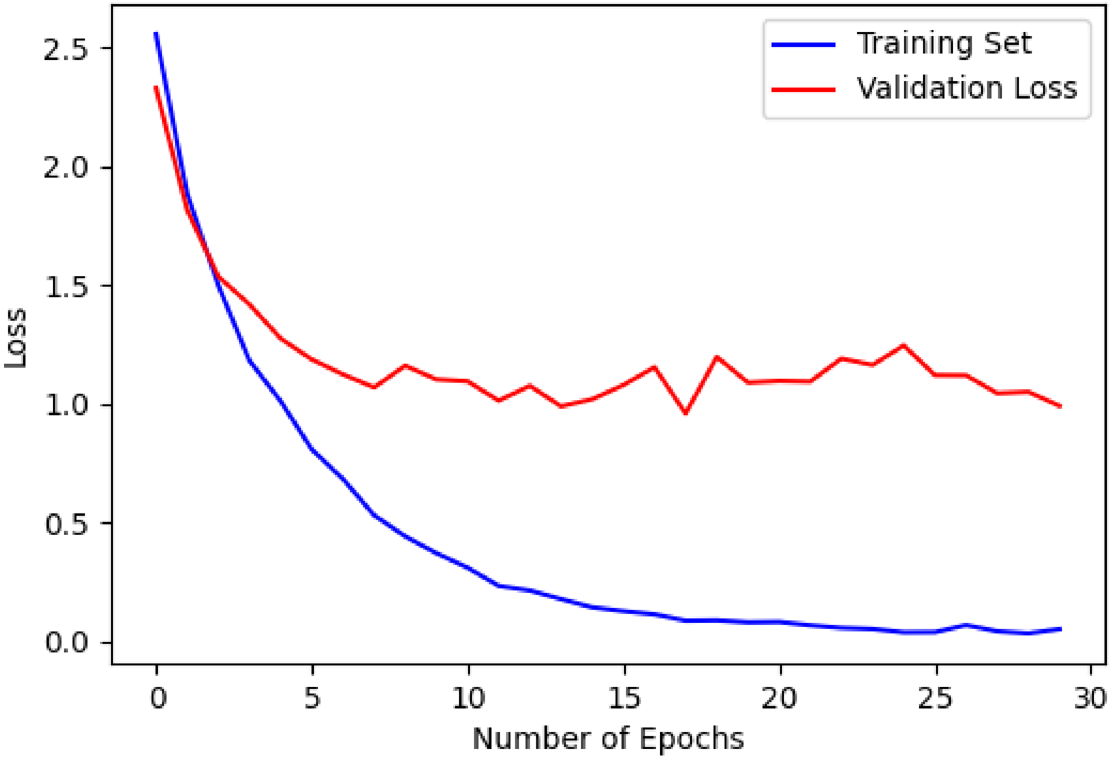


Figure 6 Training Loss and Validation Loss by Epoch using SGD (lr = 0.01, momentum = 0.9)

Question 2

2. (9 pts) Select an optimizer and tune the learning rate. Please show the training and validation loss plots with different learning rates and report the classification result on the test set. Briefly describe how the training rate affects the training progress (training and validation loss) and the final result on the test set.

For this question the SGD optimizer was tested for the following learning rates (0.001, 0.005, 0.01). The figure underneath shows the training loss and validation loss for each learning rate and their accuracy test. The learning rate controls how quickly the model changes. If the learning rate is low, the training and validation will progress slowly because small updates are made to the weights of the network. Also, with a smaller learning rate, there are more risk of overfitting. We can see that in Figure 7. There was probably not enough epoch number since the learning rate was so small as we can see the validation loss continuing to go down.

If the learning rate is too big, it can cause divergent behavior in the loss function since the steps are too big and there is a risk of underfitting. As shown in Figure 10, the validation loss starts increasing after only 16 epochs. The size of the learning rate made it get to that point a lot quicker, but with less accuracy. For this reason, choosing the right learning rate is important for a good test accuracy. A shown below, when the learning rate was too high or low, the test accuracy rate decreased.

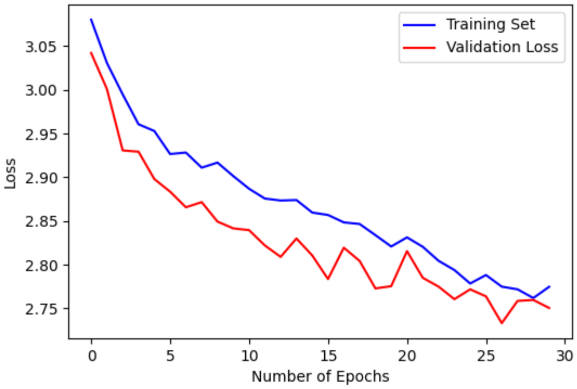


Figure 7 Training Loss and Validation Loss for learning rate = 0.001

Test Accuracy = 7%

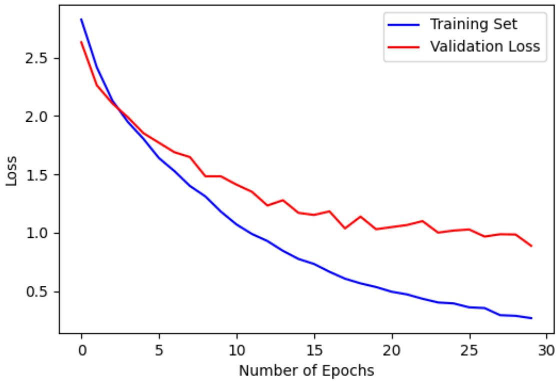


Figure 8 Training Loss and Validation Loss for learning rate = 0.005

Test Accuracy = 78%

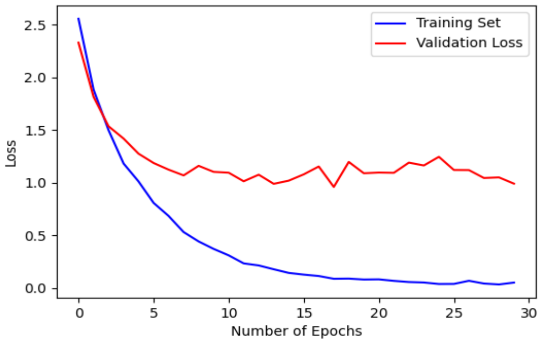


Figure 9 Training Loss and Validation Loss for learning rate = 0.01

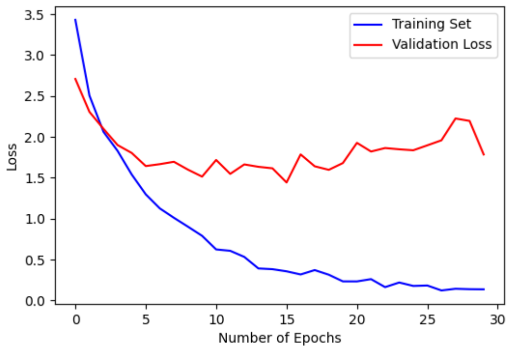


Figure 10 Training Loss and Validation Loss for learning rate = 0.05

Test Accuracy = 83%

Test Accuracy = 74%

Question 3

3. (9 pts) Select an optimizer and tune the batch size. Please show the training and validation plots with different batch sizes and report the classification result on the test set. Briefly describe how the batch size affects the training progress and the final result on the test set.

In this question, the training and validation loss was observed after changing the batch size. The following batch size were tested 8, 16,32, 48, and 64. Generally, the batch size is power of two, between 16 and 512. A rule of thumb is to start with a size of 32 as the initial choice [1]. In our case, the batch size that resulted in the highest accuracy was a batch size of 32. This batch size gave a test accuracy of 83%. We obtained the lowest test accuracy for low batch sizes 69% and 76%. We observed for both low batch sizes that the validation loss started increasing after a few numbers of epochs which is a sign of overfitting. Also, we can see that the training set curve gets smoother as the batch size is increased.

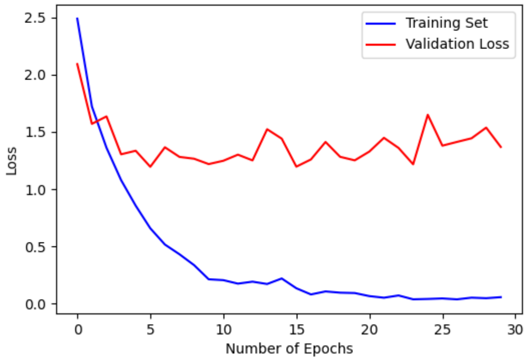


Figure 11 Training Loss and Validation Loss by epoch for batch size of 8

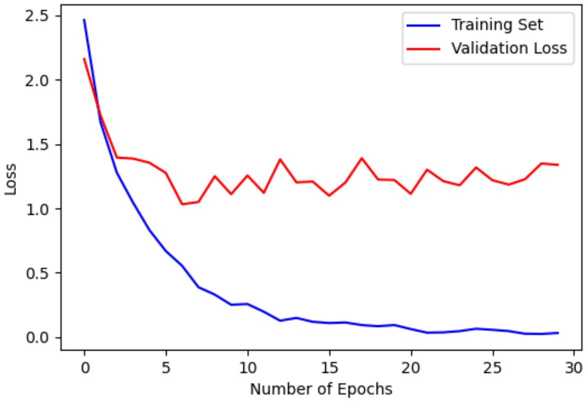


Figure 12 Training Loss and Validation Loss by epoch for batch size of 16

Test Accuracy = 69%

Test accuracy = 76%

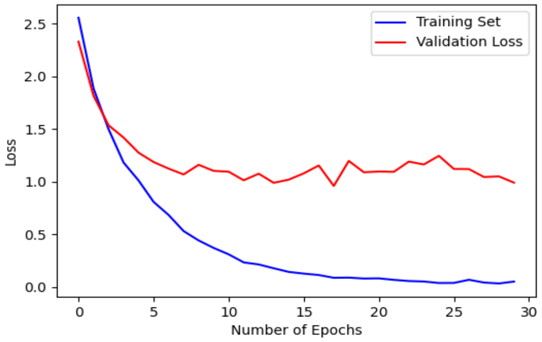


Figure 13 Training Loss and Validation Loss by epoch for batch size of 32

Test accuracy 83%

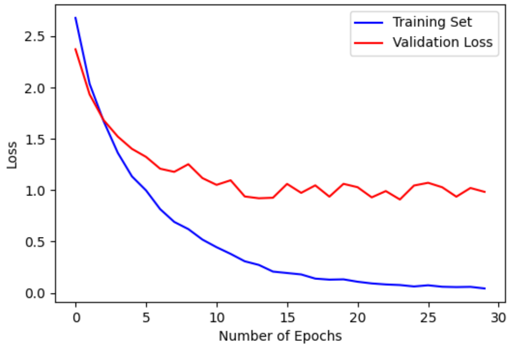


Figure 14 Training Loss and Validation Loss by epoch for batch size of 48

Test accuracy 81%

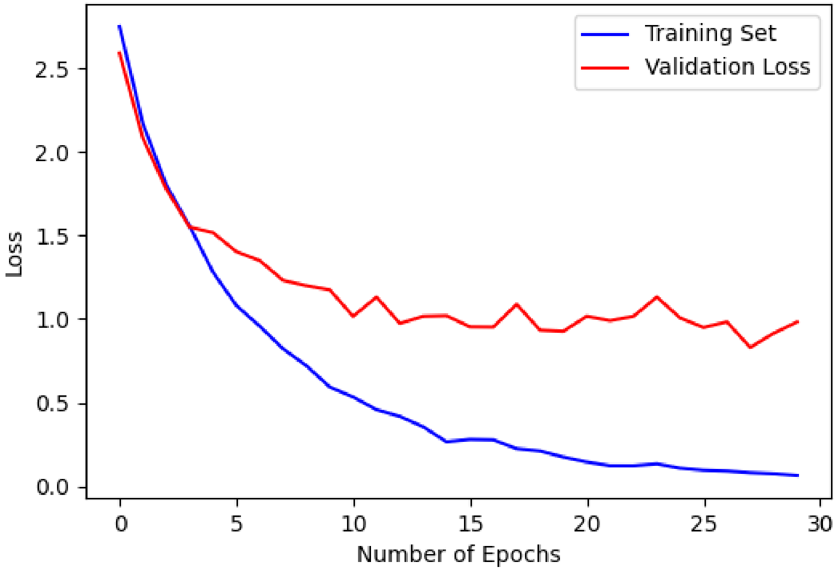


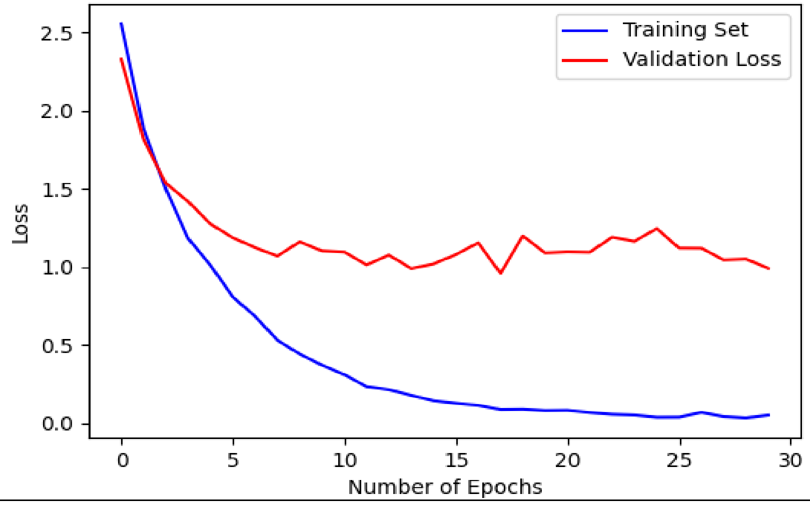
Figure 15 Training Loss and Validation Loss by epoch for batch size of 64

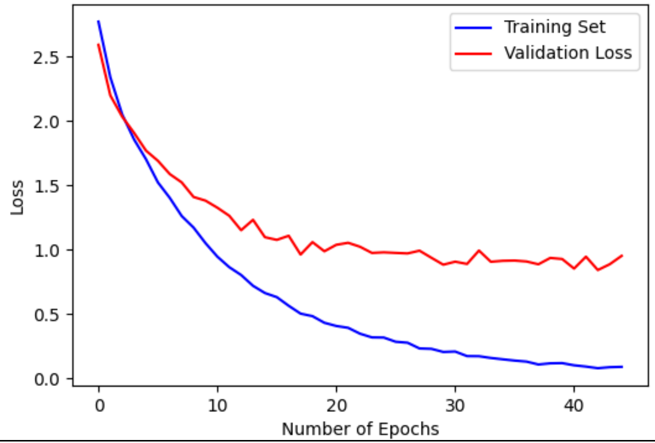
Test accuracy = 76%

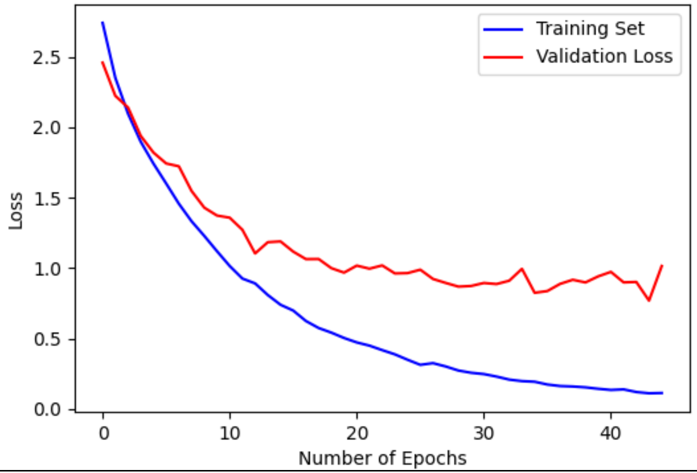
Question 4 (Bonus)

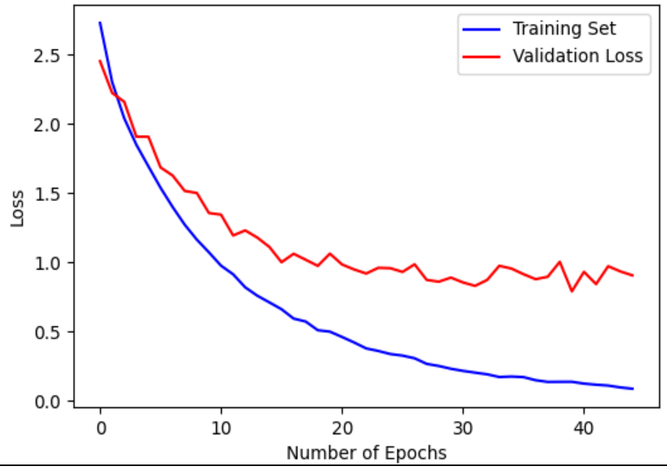
4 (10pts) Try your best to discover different combinations of hyperparameters (different optimizer, learning rate and batch size), and report the best classification result you have achieved on the test set. Please also report the corresponding hyperparameters for your best result.

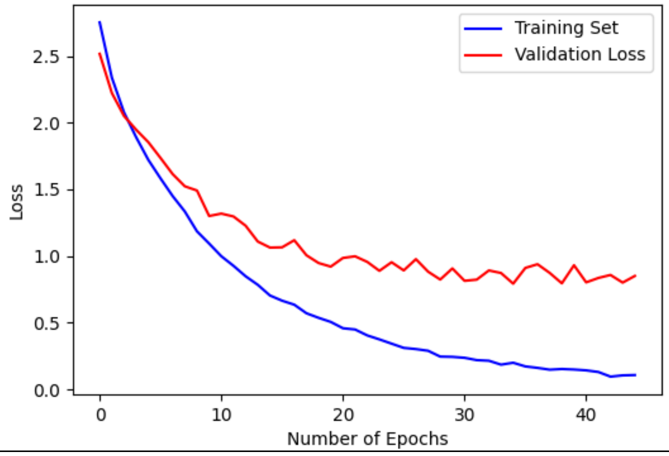
In this question, multiple combinations of different hyperparameters have been tried to obtain the highest test accuracy. The highest one obtained **was 83%.** All the results are shown underneath from highest accuracy to lowest.

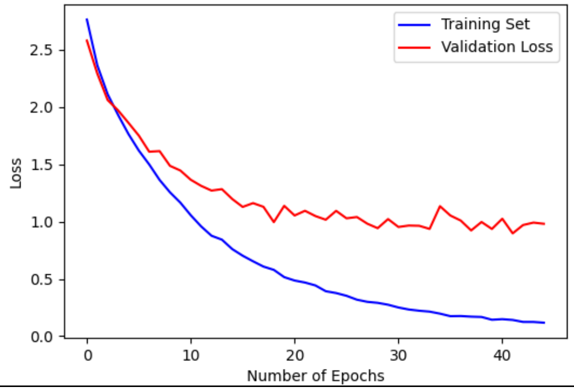
Test Accuracy	83%
Hyperparameters	
Batch Size	32
Epoch Number	30
Validation_Per	0.2
Learning Rate	0.01
momentum	0.9
Optimizer	SGD
	

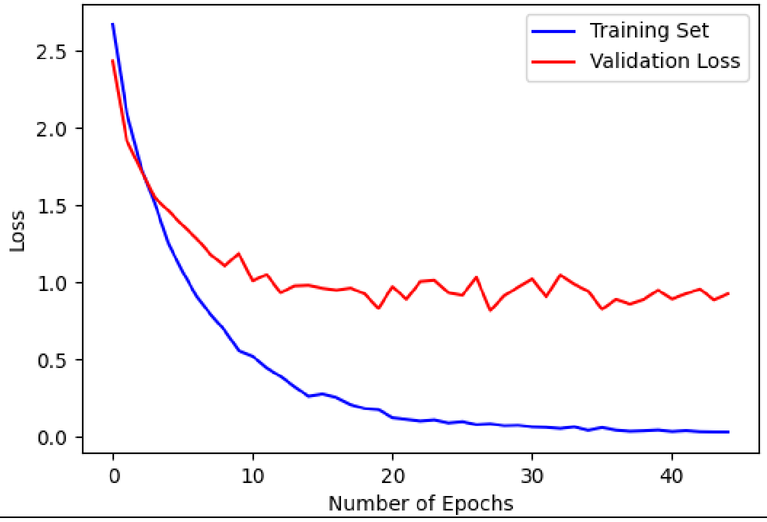
Test Accuracy	81%
Hyperparameters	
Batch Size	32
Epoch Number	45
Validation_Per	0.2
Learning Rate	0.0001
Optimizer	Adam
	

Test Accuracy	81%
Hyperparameters	
Batch Size	64
Epoch Number	45
Validation_Per	0.175
Learning Rate	0.01
momentum	0.5
Optimizer	SGD
	

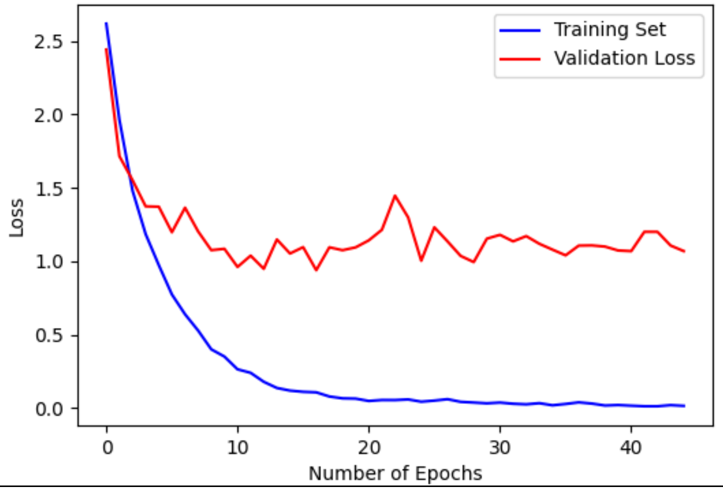
Test Accuracy	78%
Hyperparameters	
Batch Size	64
Epoch Number	45
Validation_Per	0.1
Learning Rate	0.01
momentum	0.5
Optimizer	SGD
	

Test Accuracy	78%
Hyperparameters	
Batch Size	64
Epoch Number	45
Validation_Per	0.15
Learning Rate	0.01
momentum	0.5
Optimizer	SGD
	

Test Accuracy	76%
Hyperparameters	
Batch Size	64
Epoch Number	45
Validation_Per	0.225
Learning Rate	0.01
momentum	0.5
Optimizer	SGD
	

Test Accuracy	76%
Hyperparameters	
Batch Size	64
Epoch Number	45
Validation_Per	0.2
Learning Rate	0.01
momentum	0.8
Optimizer	SGD
	

<table>
<tr><td>Test Accuracy</td><td>76%</td></tr>
<tr><td colspan="2">Hyperparameters</td></tr>
<tr><td>Batch Size</td><td>64</td></tr>
<tr><td>Epoch Number</td><td>45</td></tr>
<tr><td>Validation_Per</td><td>0.2</td></tr>
<tr><td>Learning Rate</td><td>0.015</td></tr>
<tr><td>momentum</td><td>0.9</td></tr>
<tr><td>Optimizer</td><td>SGD</td></tr>
<tr><td colspan="2">



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<table>
<tr><td>Test Accuracy</td><td>75%</td></tr>
<tr><td colspan="2">Hyperparameters</td></tr>
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<tr><td>Epoch Number</td><td>45</td></tr>
<tr><td>Validation_Per</td><td>0.2</td></tr>
<tr><td>Learning Rate</td><td>0.00025</td></tr>
<tr><td>Optimizer</td><td>Adam</td></tr>
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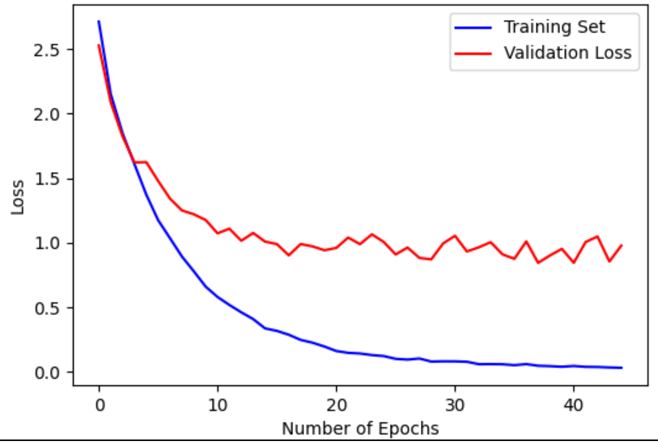
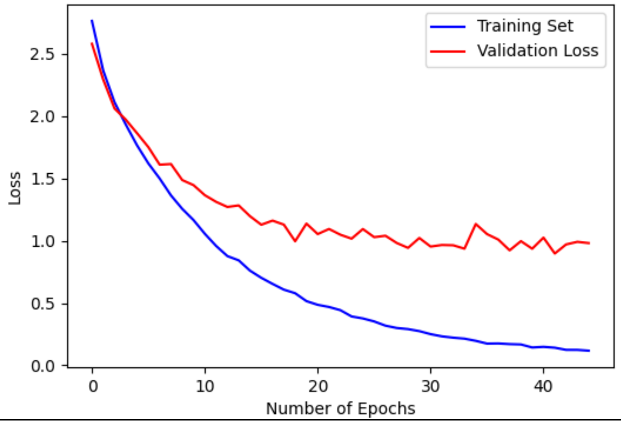
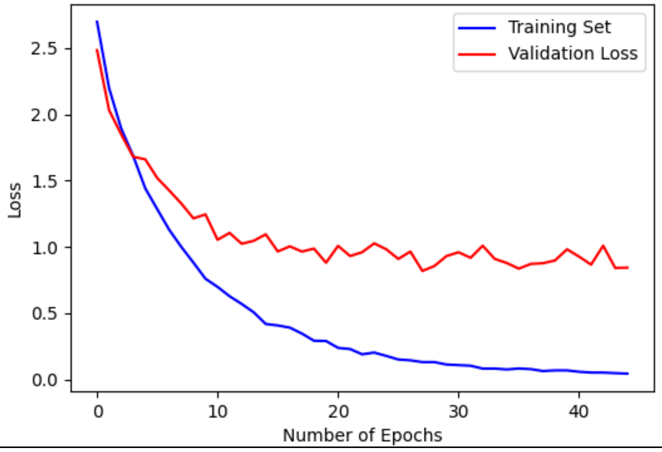
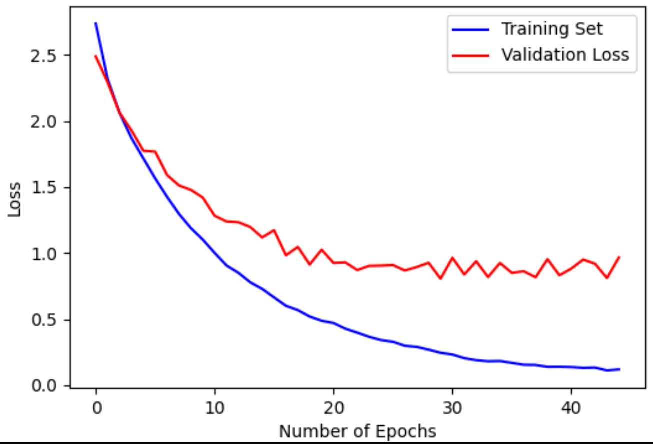


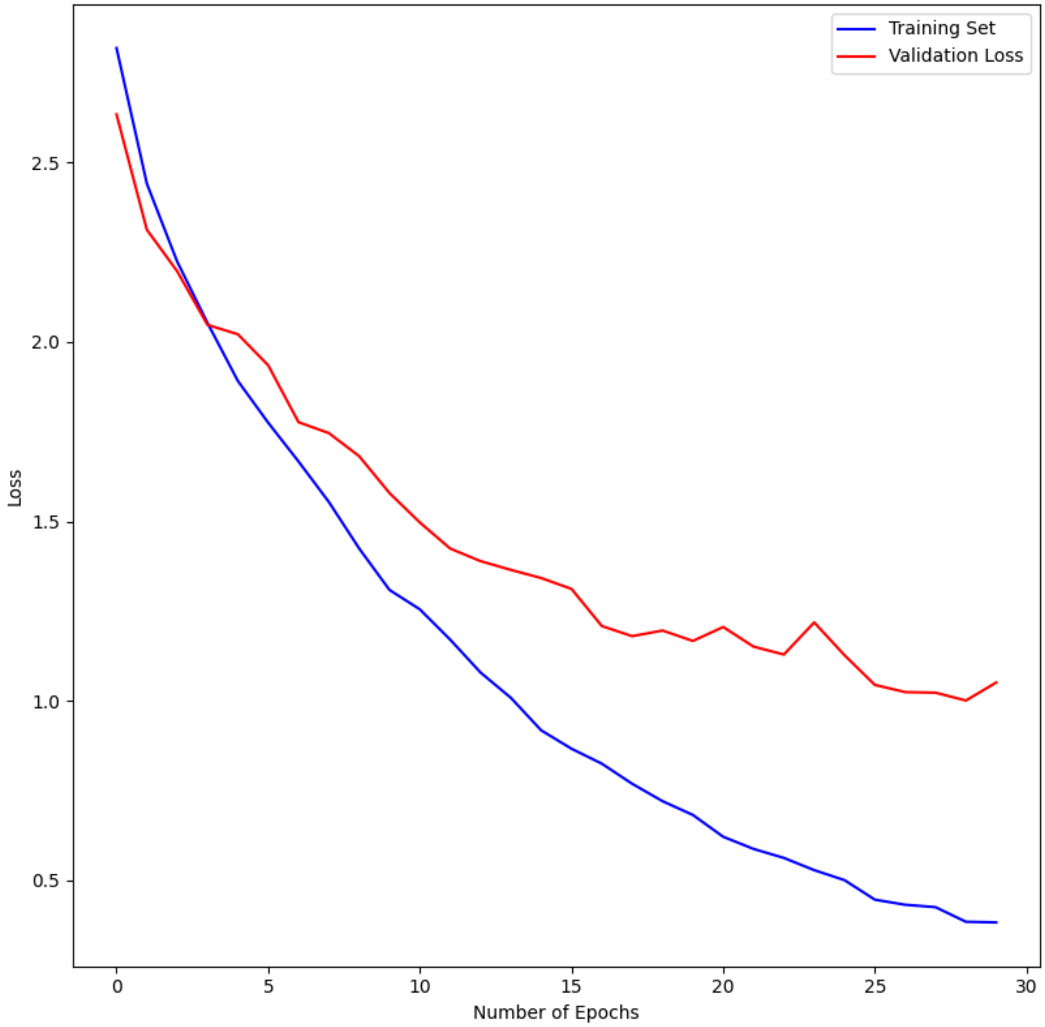
</td></tr>
</table>

Test Accuracy	74%
Hyperparameters	
Batch Size	64
Epoch Number	45
Validation_Per	0.2
Learning Rate	0.01
momentum	0.6
Optimizer	SGD
	

Test Accuracy	74%
Hyperparameters	
Batch Size	64
Epoch Number	45
Validation_Per	0.2
Learning Rate	0.01
momentum	0.7
Optimizer	SGD
	

Test Accuracy	73%
Hyperparameters	
Batch Size	64
Epoch Number	45
Validation_Per	0.125
Learning Rate	0.01
momentum	0.5
Optimizer	SGD
	

Test Accuracy	71%
Hyperparameters	
Batch Size	64
Epoch Number	30
Validation_Per	0.2
Learning Rate	0.0001
Optimizer	Adam



Reference

[1] Zvornicanin, E. (2022, March 4). *Relation between learning rate and batch size*. Baeldung on Computer Science. Retrieved October 11, 2022, from https://www.baeldung.com/cs/learning-rate-batch-size

Appendix

Question 1

Question 1.1 Appendix

Table 1 Training Loss by Epoch for 2 classifications

# Epoch	Training Loss
Epoch 1	0.601
Epoch 2	0.581
Epoch 3	0.559
Epoch 4	0.523
Epoch 5	0.487
Epoch 6	0.430
Epoch 7	0.413
Epoch 8	0.362
Epoch 9	0.327
Epoch 10	0.317
Epoch 11	0.256
Epoch 12	0.232
Epoch 13	0.221
Epoch 14	0.190
Epoch 15	0.176
Epoch 16	0.153
Epoch 17	0.152
Epoch 18	0.111
Epoch 19	0.100
Epoch 20	0.082
Epoch 21	0.089
Epoch 22	0.065
Epoch 23	0.062
Epoch 24	0.041
Epoch 25	0.036
Epoch 26	0.036
Epoch 27	0.043
Epoch 28	0.023
Epoch 29	0.018
Epoch 30	0.012

Question 1.3

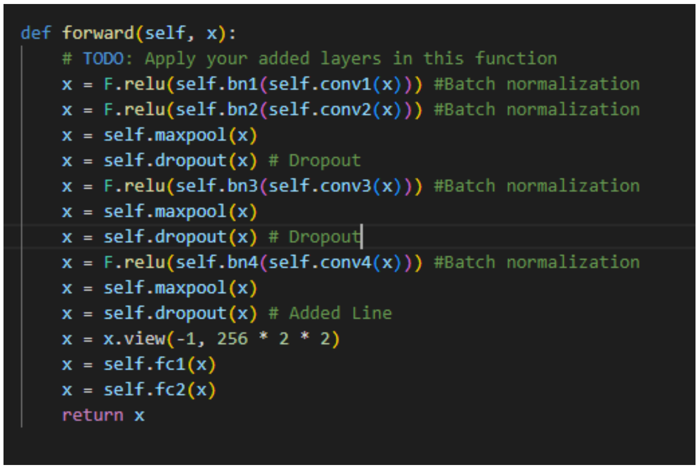
Table 2 Training Loss by Epoch for 20 classifications

# Epochs	Training Loss
Epoch 1	2.923
Epoch 2	2.816
Epoch 3	2.509
Epoch 4	2.293
Epoch 5	2.158
Epoch 6	2.037
Epoch 7	1.927
Epoch 8	1.848
Epoch 9	1.752
Epoch 10	1.650
Epoch 11	1.578
Epoch 12	1.508
Epoch 13	1.428
Epoch 14	1.362
Epoch 15	1.295
Epoch 16	1.214
Epoch 17	1.144
Epoch 18	1.111
Epoch 19	1.041
Epoch 20	0.974
Epoch 21	0.942
Epoch 22	0.889
Epoch 23	0.830
Epoch 24	0.797
Epoch 25	0.778
Epoch 26	0.718
Epoch 27	0.665
Epoch 28	0.658
Epoch 29	0.607
Epoch 30	0.585

Question 2

Question 2.1

It is to note that for question 2.1, the dropout lines were not added yet.



```python
def forward(self, x):
    # TODO: Apply your added layers in this function
    x = F.relu(self.bn1(self.conv1(x))) #Batch normalization
    x = F.relu(self.bn2(self.conv2(x))) #Batch normalization
    x = self.maxpool(x)
    x = self.dropout(x) # Dropout
    x = F.relu(self.bn3(self.conv3(x))) #Batch normalization
    x = self.maxpool(x)
    x = self.dropout(x) # Dropout
    x = F.relu(self.bn4(self.conv4(x))) #Batch normalization
    x = self.maxpool(x)
    x = self.dropout(x) # Added Line
    x = x.view(-1, 256 * 2 * 2)
    x = self.fc1(x)
    x = self.fc2(x)
    return x
```

Figure 16 Batch Normalization Code

Table 3 Training Loss by Epoch for 20 classifications with batch normalization

# Epochs	Training Loss
Epoch 1	2.4209
Epoch 2	1.5548
Epoch 3	1.1172
Epoch 4	0.8320
Epoch 5	0.5967
Epoch 6	0.4264
Epoch 7	0.2947
Epoch 8	0.2067
Epoch 9	0.1342
Epoch 10	0.0934
Epoch 11	0.0579
Epoch 12	0.0397
Epoch 13	0.0290
Epoch 14	0.0180
Epoch 15	0.0143
Epoch 16	0.0087
Epoch 17	0.0071
Epoch 18	0.0048
Epoch 19	0.0033
Epoch 20	0.1838
Epoch 21	0.0113
Epoch 22	0.0044
Epoch 23	0.0033
Epoch 24	0.0026
Epoch 25	0.0020
Epoch 26	0.0015
Epoch 27	0.0014
Epoch 28	0.0011
Epoch 29	0.0008
Epoch 30	0.0008

Question 2.2

Table 4 Training Loss by Epoch for 20 classifications with batch normalization and dropout layers

# Epoch	Training Loss
Epoch 1	2.648
Epoch 2	2.037
Epoch 3	1.791
Epoch 4	1.623
Epoch 5	1.459
Epoch 6	1.296
Epoch 7	1.173
Epoch 8	1.093
Epoch 9	0.977
Epoch 10	0.898
Epoch 11	0.809
Epoch 12	0.747
Epoch 13	0.704
Epoch 14	0.643
Epoch 15	0.584
Epoch 16	0.558
Epoch 17	0.539
Epoch 18	0.470
Epoch 19	0.434
Epoch 20	0.396
Epoch 21	0.355
Epoch 22	0.343
Epoch 23	0.318
Epoch 24	0.283
Epoch 25	0.271
Epoch 26	0.268
Epoch 28	0.214
Epoch 29	0.211
Epoch 30	0.198

Question 3

Question 3.1

Table 5 Training and Validation Loss by Epoch (Part 1)

Epoch 1, Training Loss: 2.6480159184028365
Epoch 1, Validation Loss: 2.34480136235555
The Validation Loss decrease inf ---> 35.17202043533325 Saving Model ...
Epoch 2, Training Loss: 2.0545274450861175
Epoch 2, Validation Loss: 2.0793906688690185
The Validation Loss decrease 35.17202043533325 ---> 31.19086003303528 Saving Model ...
Epoch 3, Training Loss: 1.8063799533350715
Epoch 3, Validation Loss: 1.8533087015151977
The Validation Loss decrease 31.19086003303528 ---> 27.799630522727966 Saving Model ...
Epoch 4, Training Loss: 1.6084070308455105
Epoch 4, Validation Loss: 1.7116939703623453
The Validation Loss decrease 27.799630522727966 ---> 25.67540955543518 Saving Model ...
Epoch 5, Training Loss: 1.4531252815805633
Epoch 5, Validation Loss: 1.5875767469406128
The Validation Loss decrease 25.67540955543518 ---> 23.813651204109192 Saving Model ...
Epoch 6, Training Loss: 1.2922638284748997
Epoch 6, Validation Loss: 1.5455762306849161
The Validation Loss decrease 23.813651204109192 ---> 23.183643460273743 Saving Model ...
Epoch 7, Training Loss: 1.1873587544622093
Epoch 7, Validation Loss: 1.4704303423563638
The Validation Loss decrease 23.183643460273743 ---> 22.05645513534546 Saving Model ...
Epoch 8, Training Loss: 1.0842583929670269
Epoch 8, Validation Loss: 1.3446245114008586
The Validation Loss decrease 22.05645513534546 ---> 20.16936767101288 Saving Model ...
Epoch 9, Training Loss: 0.9970377786406155
Epoch 9, Validation Loss: 1.3215408682823182
The Validation Loss decrease 20.16936767101288 ---> 19.82311302423477 Saving Model ...
Epoch 10, Training Loss: 0.8936205866007969
Epoch 10, Validation Loss: 1.3389918327331543
Epoch 11, Training Loss: 0.8169274299309172
Epoch 11, Validation Loss: 1.2239925146102906
The Validation Loss decrease 19.82311302423477 ---> 18.359887719154358 Saving Model ...
Epoch 12, Training Loss: 0.7374423613836025
Epoch 12, Validation Loss: 1.2025040189425151
The Validation Loss decrease 18.359887719154358 ---> 18.037560284137726 Saving Model ...
Epoch 13, Training Loss: 0.7049616683146049
Epoch 13, Validation Loss: 1.1602561513582865
The Validation Loss decrease 18.037560284137726 ---> 17.403842270374298 Saving Model ...
Epoch 14, Training Loss: 0.6415053534096685

Table 6 Training and Validation Loss by Epoch (Part 2)

Epoch 14, Validation Loss: 1.2390666643778483
Epoch 15, Training Loss: 0.578396563386095
Epoch 15, Validation Loss: 1.0748430212338766
The Validation Loss decrease 17.403842270374298 ---> 16.122645318508148 Saving Model ...
Epoch 16, Training Loss: 0.56729345177782
Epoch 16, Validation Loss: 1.0919467608133953
Epoch 17, Training Loss: 0.5152214375035516
Epoch 17, Validation Loss: 1.0866581638654074
Epoch 18, Training Loss: 0.4625260924984669
Epoch 18, Validation Loss: 0.923936273654302
The Validation Loss decrease 16.122645318508148 ---> 13.85904410481453 Saving Model ...
Epoch 19, Training Loss: 0.4148385951231266
Epoch 19, Validation Loss: 1.0213474293549856
Epoch 20, Training Loss: 0.39769221790905657
Epoch 20, Validation Loss: 0.9692322611808777
Epoch 21, Training Loss: 0.3719227355102013
Epoch 21, Validation Loss: 1.117143658796946
Epoch 22, Training Loss: 0.36295254605597466
Epoch 22, Validation Loss: 1.065217125415802
Epoch 23, Training Loss: 0.298849715497987
Epoch 23, Validation Loss: 1.0292319814364115
Epoch 24, Training Loss: 0.28197307113943426
Epoch 24, Validation Loss: 1.016214946905772
Epoch 25, Training Loss: 0.2812833992828583
Epoch 25, Validation Loss: 1.0402361512184144
Epoch 26, Training Loss: 0.2532961892670599
Epoch 26, Validation Loss: 0.94881485303243
Epoch 27, Training Loss: 0.2501045325449828
Epoch 27, Validation Loss: 0.9089692433675131
The Validation Loss decrease 13.85904410481453 ---> 13.634538650512695 Saving Model ...
Epoch 28, Training Loss: 0.19962392304221105
Epoch 28, Validation Loss: 0.9978716969490051
Epoch 29, Training Loss: 0.20189610560392512
Epoch 29, Validation Loss: 1.0026931643486023
Epoch 30, Training Loss: 0.17611431327230972
Epoch 30, Validation Loss: 0.9283342838287354

Question 4

Question 4.1

Table 7 Training Loss and Validation Loss by Epoch using SGD (lr = 0.01, momentum = 0.9) Part 1

Epoch 1, Training Loss: 2.555621593162931
Epoch 1, Validation Loss: 2.329118013381958
The Validation Loss decrease inf ---> 34.93677020072937 Saving Model ...
Epoch 2, Training Loss: 1.8844003369068276
Epoch 2, Validation Loss: 1.8155637979507446
The Validation Loss decrease 34.93677020072937 ---> 27.23345696926117 Saving Model ...
Epoch 3, Training Loss: 1.499124341997607
Epoch 3, Validation Loss: 1.5358037948608398
The Validation Loss decrease 27.23345696926117 ---> 23.037056922912598 Saving Model ...
Epoch 4, Training Loss: 1.1822106766289677
Epoch 4, Validation Loss: 1.418835949897766
The Validation Loss decrease 23.037056922912598 ---> 21.28253924846649 Saving Model ...
Epoch 5, Training Loss: 1.0115251787777604
Epoch 5, Validation Loss: 1.275316023826599
The Validation Loss decrease 21.28253924846649 ---> 19.129740357398987 Saving Model ...
Epoch 6, Training Loss: 0.8087658959216085
Epoch 6, Validation Loss: 1.1870907346407573
The Validation Loss decrease 19.129740357398987 ---> 17.80636101961136 Saving Model ...
Epoch 7, Training Loss: 0.684344168367057
Epoch 7, Validation Loss: 1.1240932941436768
The Validation Loss decrease 17.80636101961136 ---> 16.86139941215515 Saving Model ...
Epoch 8, Training Loss: 0.5316187729095591
Epoch 8, Validation Loss: 1.069313911596934
The Validation Loss decrease 16.86139941215515 ---> 16.03970867395401 Saving Model ...
Epoch 9, Training Loss: 0.4427638906857063
Epoch 9, Validation Loss: 1.1605143348375957
Epoch 10, Training Loss: 0.3718054846956812
Epoch 10, Validation Loss: 1.1029389142990111
Epoch 11, Training Loss: 0.31096369567616233
Epoch 11, Validation Loss: 1.0952089587847391
Epoch 12, Training Loss: 0.23457706938016004
Epoch 12, Validation Loss: 1.013623599211375
The Validation Loss decrease 16.03970867395401 ---> 15.204353988170624 Saving Model ...
Epoch 13, Training Loss: 0.21501124207058858
Epoch 13, Validation Loss: 1.0760867953300477

Table 8 Training Loss and Validation Loss by Epoch using SGD (lr = 0.01, momentum = 0.9) Part 2

Epoch 14, Training Loss: 0.17877683698617178
Epoch 14, Validation Loss: 0.9895705819129944
The Validation Loss decrease 15.204353988170624 ---> 14.843558728694916 Saving Model ...
Epoch 15, Training Loss: 0.14429931503174634
Epoch 15, Validation Loss: 1.0195180376370747
Epoch 16, Training Loss: 0.12812114718916087
Epoch 16, Validation Loss: 1.0792999585469565
Epoch 17, Training Loss: 0.11470729334215665
Epoch 17, Validation Loss: 1.154092013835907
Epoch 18, Training Loss: 0.08836655366908887
Epoch 18, Validation Loss: 0.9598310321569443
The Validation Loss decrease 14.843558728694916 ---> 14.397465482354164 Saving Model ...
Epoch 19, Training Loss: 0.08993013588518932
Epoch 19, Validation Loss: 1.1974106629689534
Epoch 20, Training Loss: 0.08128879135795708
Epoch 20, Validation Loss: 1.089775844415029
Epoch 21, Training Loss: 0.08283149300078893
Epoch 21, Validation Loss: 1.096606324116389
Epoch 22, Training Loss: 0.06873207863677165
Epoch 22, Validation Loss: 1.0939669410387676
Epoch 23, Training Loss: 0.05770318529664956
Epoch 23, Validation Loss: 1.190639364719391
Epoch 24, Training Loss: 0.05321192020421912
Epoch 24, Validation Loss: 1.1636713484923045
Epoch 25, Training Loss: 0.03902095956085571
Epoch 25, Validation Loss: 1.2457432011763254
Epoch 26, Training Loss: 0.03970805659954404
Epoch 26, Validation Loss: 1.1209267616271972
Epoch 27, Training Loss: 0.06954755589911907
Epoch 27, Validation Loss: 1.119916041692098
Epoch 28, Training Loss: 0.04341957145691689
Epoch 30, Training Loss: 0.05260920879463184
Epoch 30, Validation Loss: 0.9911890645821889

Question 4.2

Table 9 Training Loss and Validation Loss by Epoch using SGD (lr = 0.001, momentum = 0.9) Part 1

Epoch 1, Training Loss: 3.080208211109556
Epoch 1, Validation Loss: 3.042105499903361
The Validation Loss decrease inf ---> 45.631582498550415 Saving Model ...
Epoch 2, Training Loss: 3.0307212492515303
Epoch 2, Validation Loss: 3.000883913040161
The Validation Loss decrease 45.631582498550415 ---> 45.01325869560242 Saving Model ...
Epoch 3, Training Loss: 2.9947075062784654
Epoch 3, Validation Loss: 2.9306694984436037
The Validation Loss decrease 45.01325869560242 ---> 43.96004247665405 Saving Model ...
Epoch 4, Training Loss: 2.9605903419955024
Epoch 4, Validation Loss: 2.9292075951894123
The Validation Loss decrease 43.96004247665405 ---> 43.93811392784119 Saving Model ...
Epoch 5, Training Loss: 2.9528967882024832
Epoch 5, Validation Loss: 2.8979207038879395
The Validation Loss decrease 43.93811392784119 ---> 43.46881055831909 Saving Model ...
Epoch 6, Training Loss: 2.926540999576963
Epoch 6, Validation Loss: 2.883512846628825
The Validation Loss decrease 43.46881055831909 ---> 43.25269269943237 Saving Model ...
Epoch 7, Training Loss: 2.9282307090430426
Epoch 7, Validation Loss: 2.86561754544576
The Validation Loss decrease 43.25269269943237 ---> 42.9842631816864 Saving Model ...
Epoch 8, Training Loss: 2.910941325384995
Epoch 8, Validation Loss: 2.871535587310791
Epoch 9, Training Loss: 2.916742912654219
Epoch 9, Validation Loss: 2.849250809351603
The Validation Loss decrease 42.9842631816864 ---> 42.73876214027405 Saving Model ...
Epoch 10, Training Loss: 2.901325427252671
Epoch 10, Validation Loss: 2.84150865872701
The Validation Loss decrease 42.73876214027405 ---> 42.62262988090515 Saving Model ...
Epoch 11, Training Loss: 2.8868305724242638
Epoch 11, Validation Loss: 2.8394867420196532
The Validation Loss decrease 42.62262988090515 ---> 42.5923011302948 Saving Model ...
Epoch 12, Training Loss: 2.875605821609497
Epoch 12, Validation Loss: 2.8219543933868407
The Validation Loss decrease 42.5923011302948 ---> 42.32931590080261 Saving Model ...

Table 10 Training Loss and Validation Loss by Epoch using SGD (lr = 0.001, momentum = 0.9) Part 2

Epoch 13, Training Loss: 2.873369812965393
Epoch 13, Validation Loss: 2.80890105565389
The Validation Loss decrease 42.32931590080261 ---> 42.13351583480835 Saving Model ...
Epoch 14, Training Loss: 2.8739178304014534
Epoch 14, Validation Loss: 2.829944388071696
Epoch 15, Training Loss: 2.859593913472932
Epoch 15, Validation Loss: 2.8105320930480957
Epoch 16, Training Loss: 2.856819613226529
Epoch 16, Validation Loss: 2.783538230260213
The Validation Loss decrease 42.13351583480835 ---> 41.7530734539032 Saving Model ...
Epoch 17, Training Loss: 2.8483394343277504
Epoch 17, Validation Loss: 2.819417937596639
Epoch 18, Training Loss: 2.8465286082234877
Epoch 18, Validation Loss: 2.804245710372925
Epoch 19, Training Loss: 2.8337734526601333
Epoch 19, Validation Loss: 2.7728210926055907
The Validation Loss decrease 41.7530734539032 ---> 41.59231638908386 Saving Model ...
Epoch 20, Training Loss: 2.820780610216075
Epoch 20, Validation Loss: 2.775397364298503
Epoch 21, Training Loss: 2.831217153318997
Epoch 21, Validation Loss: 2.8154506206512453
Epoch 22, Training Loss: 2.820409758337613
Epoch 22, Validation Loss: 2.7849575837453204
Epoch 23, Training Loss: 2.8043970815066634
Epoch 23, Validation Loss: 2.774873399734497
Epoch 24, Training Loss: 2.7938585692438584
Epoch 24, Validation Loss: 2.760510269800822
The Validation Loss decrease 41.59231638908386 ---> 41.40765404701233 Saving Model ...
Epoch 25, Training Loss: 2.778448302170326
Epoch 25, Validation Loss: 2.7717455705006917
Epoch 26, Training Loss: 2.7881408847611526
Epoch 30, Training Loss: 2.7746783906015855
Epoch 30, Validation Loss: 2.750463914871216

Table 11 Training Loss and Validation Loss by Epoch using SGD (lr = 0.005, momentum = 0.9) Part 1

Epoch 1, Validation Loss: 2.631989574432373
The Validation Loss decrease inf ---> 39.479843616485596 Saving Model ...
Epoch 2, Training Loss: 2.4178959377880753
Epoch 2, Validation Loss: 2.2637804826100667
The Validation Loss decrease 39.479843616485596 ---> 33.956707239151 Saving Model ...
Epoch 3, Training Loss: 2.132983069995354
Epoch 3, Validation Loss: 2.1086222251256306
The Validation Loss decrease 33.956707239151 ---> 31.62933337688446 Saving Model ...
Epoch 4, Training Loss: 1.9495107346567615
Epoch 4, Validation Loss: 1.9895727316538492
The Validation Loss decrease 31.62933337688446 ---> 29.84359097480774 Saving Model ...
Epoch 5, Training Loss: 1.8055076003074646
Epoch 5, Validation Loss: 1.853692928949992
The Validation Loss decrease 29.84359097480774 ---> 27.805393934249878 Saving Model ...
Epoch 6, Training Loss: 1.6404536613102616
Epoch 6, Validation Loss: 1.771492568651835
The Validation Loss decrease 27.805393934249878 ---> 26.572388529777527 Saving Model ...
Epoch 7, Training Loss: 1.5285438175859123
Epoch 7, Validation Loss: 1.6898749272028606
The Validation Loss decrease 26.572388529777527 ---> 25.348123908042908 Saving Model ...
Epoch 8, Training Loss: 1.4009777862450172
Epoch 8, Validation Loss: 1.6482466538747151
The Validation Loss decrease 25.348123908042908 ---> 24.723699808120728 Saving Model ...
Epoch 9, Training Loss: 1.3108545757573227
Epoch 9, Validation Loss: 1.4834071397781372
The Validation Loss decrease 24.723699808120728 ---> 22.251107096672058 Saving Model ...
Epoch 10, Training Loss: 1.180593604671544
Epoch 10, Validation Loss: 1.4830169439315797
The Validation Loss decrease 22.251107096672058 ---> 22.245254158973694 Saving Model ...
Epoch 11, Training Loss: 1.0712430251055751
Epoch 11, Validation Loss: 1.4123114824295044
The Validation Loss decrease 22.245254158973694 ---> 21.184672236442566 Saving Model ...
Epoch 12, Training Loss: 0.9891113155874712
Epoch 12, Validation Loss: 1.350580064455668
The Validation Loss decrease 21.184672236442566 ---> 20.258700966835022 Saving Model ...
Epoch 13, Training Loss: 0.9285538001307125
Epoch 13, Validation Loss: 1.232938543955485
The Validation Loss decrease 20.258700966835022 ---> 18.494078159332275 Saving Model ...
Epoch 14, Training Loss: 0.8445828741994398
Epoch 14, Validation Loss: 1.2782650033632914
Epoch 15, Training Loss: 0.7749821312468628

Epoch 15, Validation Loss: 1.1700648307800292

Table 12 Training Loss and Validation Loss by Epoch using SGD (lr = 0.005, momentum = 0.9) Part 2

Epoch 16, Training Loss: 0.7324099134782265
Epoch 16, Validation Loss: 1.1522056897481283
The Validation Loss decrease 17.55097246170044 ---> 17.283085346221924 Saving Model ...
Epoch 17, Training Loss: 0.6649737507104874
Epoch 17, Validation Loss: 1.1828081130981445
Epoch 18, Training Loss: 0.6060325225879406
Epoch 18, Validation Loss: 1.036463886499405
The Validation Loss decrease 17.283085346221924 ---> 15.546958297491074 Saving Model ...
Epoch 19, Training Loss: 0.5657897596729213
Epoch 19, Validation Loss: 1.1378894646962483
Epoch 20, Training Loss: 0.5343536652367691
Epoch 20, Validation Loss: 1.029760479927063
The Validation Loss decrease 15.546958297491074 ---> 15.446407198905945 Saving Model ...
Epoch 21, Training Loss: 0.4945593738350375
Epoch 21, Validation Loss: 1.047900734345118
Epoch 22, Training Loss: 0.4711132067544707
Epoch 22, Validation Loss: 1.0659703135490417
Epoch 23, Training Loss: 0.4338776083855793
Epoch 23, Validation Loss: 1.0992236336072285
Epoch 24, Training Loss: 0.401962589344074
Epoch 24, Validation Loss: 1.0007176280021668
The Validation Loss decrease 15.446407198905945 ---> 15.010764420032501 Saving Model ...
Epoch 25, Training Loss: 0.3940806586680741
Epoch 25, Validation Loss: 1.0181136071681975
Epoch 26, Training Loss: 0.36055216039049215
Epoch 26, Validation Loss: 1.0278276840845744
Epoch 27, Training Loss: 0.3542961586138298
Epoch 27, Validation Loss: 0.9669010599454244
The Validation Loss decrease 15.010764420032501 ---> 14.503515899181366 Saving Model ...
Epoch 28, Training Loss: 0.2931060076787554
Epoch 28, Validation Loss: 0.9866516311963399
Epoch 29, Training Loss: 0.2873824752610305
Epoch 29, Validation Loss: 0.9842883149782816
Epoch 30, Training Loss: 0.26784105123630886
Epoch 30, Validation Loss: 0.887847077846527
The Validation Loss decrease 14.503515899181366 ---> 13.317706167697906 Saving Model ...

Table 13 Training Loss and Validation Loss by Epoch using SGD (lr = 0.05, momentum = 0.9) Part 1

Epoch 1, Training Loss: 3.4313802390263
Epoch 1, Validation Loss: 2.7087340195973715
The Validation Loss decrease inf ---> 40.63101029396057 Saving Model ...
Epoch 2, Training Loss: 2.5057768369543143
Epoch 2, Validation Loss: 2.3060593605041504
The Validation Loss decrease 40.63101029396057 ---> 34.590890407562256 Saving Model ...
Epoch 3, Training Loss: 2.0617681515627893
Epoch 3, Validation Loss: 2.0983408133188886
The Validation Loss decrease 34.590890407562256 ---> 31.475112199783325 Saving Model ...
Epoch 4, Training Loss: 1.8287345088761429
Epoch 4, Validation Loss: 1.8997501055399577
The Validation Loss decrease 31.475112199783325 ---> 28.496251583099365 Saving Model ...
Epoch 5, Training Loss: 1.540757569773444
Epoch 5, Validation Loss: 1.8038838068644205
The Validation Loss decrease 28.496251583099365 ---> 27.05825710296631 Saving Model ...
Epoch 6, Training Loss: 1.2973119133505329
Epoch 6, Validation Loss: 1.6432639598846435
The Validation Loss decrease 27.05825710296631 ---> 24.648959398269653 Saving Model ...
Epoch 7, Training Loss: 1.1251371800899506
Epoch 7, Validation Loss: 1.6665456453959147
Epoch 8, Training Loss: 1.0103474464909783
Epoch 8, Validation Loss: 1.6957120259602865
Epoch 9, Training Loss: 0.9014916322354612
Epoch 9, Validation Loss: 1.5991597890853881
The Validation Loss decrease 24.648959398269653 ---> 23.987396836280823 Saving Model ...
Epoch 10, Training Loss: 0.7900795849232838
Epoch 10, Validation Loss: 1.5141082843144735
The Validation Loss decrease 23.987396836280823 ---> 22.711624264717102 Saving Model ...
Epoch 11, Training Loss: 0.6232505836363497
Epoch 11, Validation Loss: 1.7178670008977255
Epoch 12, Training Loss: 0.6064351031492496
Epoch 12, Validation Loss: 1.5476312279701232
Epoch 13, Training Loss: 0.5320169370749901
Epoch 13, Validation Loss: 1.6634023666381836
Epoch 14, Training Loss: 0.39087756980082083
Epoch 14, Validation Loss: 1.6342475096384683
Epoch 15, Training Loss: 0.3817623707241026
Epoch 15, Validation Loss: 1.6156546433766683

Table 14 Training Loss and Validation Loss by Epoch using SGD (lr = 0.05, momentum = 0.9) Part 2

Epoch 16, Training Loss: 0.35579459587561674
Epoch 16, Validation Loss: 1.4424564123153687
The Validation Loss decrease 22.711624264717102 ---> 21.63684618473053 Saving Model ...
Epoch 17, Training Loss: 0.31739854478630525
Epoch 17, Validation Loss: 1.7856848557790121
Epoch 18, Training Loss: 0.3708913468852125
Epoch 18, Validation Loss: 1.640457304318746
Epoch 19, Training Loss: 0.3142153440878309
Epoch 19, Validation Loss: 1.597037637233734
Epoch 20, Training Loss: 0.23248435055901265
Epoch 20, Validation Loss: 1.679985805352529
Epoch 21, Training Loss: 0.23208767830811697
Epoch 21, Validation Loss: 1.9270034233729045
Epoch 22, Training Loss: 0.2599999675976819
Epoch 22, Validation Loss: 1.820997993151347
Epoch 23, Training Loss: 0.16235222079759015
Epoch 23, Validation Loss: 1.8637524565060934
Epoch 24, Training Loss: 0.21877432958190812
Epoch 24, Validation Loss: 1.8482990741729737
Epoch 25, Training Loss: 0.17710720789458217
Epoch 25, Validation Loss: 1.8363221605618796
Epoch 26, Training Loss: 0.18227181747427273
Epoch 26, Validation Loss: 1.89680012067159
Epoch 27, Training Loss: 0.12188540852692878
Epoch 27, Validation Loss: 1.9581127564112346
Epoch 28, Training Loss: 0.14246988638127545
Epoch 28, Validation Loss: 2.225070349375407
Epoch 29, Training Loss: 0.1372490995081848
Epoch 29, Validation Loss: 2.19535973072052
Epoch 30, Training Loss: 0.13563482809394342
Epoch 30, Validation Loss: 1.7850841204325358

Question 3

Table 15 Training Loss and Validation Loss by Epoch batch size of 8 Part 1

Epoch 1, Training Loss: 2.4878561203849725
Epoch 1, Validation Loss: 2.0909492887299637
The Validation Loss decrease inf ---> 121.27505874633789 Saving Model ...
Epoch 2, Training Loss: 1.7211972228411971
Epoch 2, Validation Loss: 1.5695063554007431
The Validation Loss decrease 121.27505874633789 ---> 91.0313686132431 Saving Model ...
Epoch 3, Training Loss: 1.360826372329531
Epoch 3, Validation Loss: 1.6344911178638195
Epoch 4, Training Loss: 1.0784563709949624
Epoch 4, Validation Loss: 1.3037969550952828
The Validation Loss decrease 91.0313686132431 ---> 75.62022339552641 Saving Model ...
Epoch 5, Training Loss: 0.8552240130395211
Epoch 5, Validation Loss: 1.3347654131979778
Epoch 6, Training Loss: 0.6577465111421871
Epoch 6, Validation Loss: 1.1948158529041142
The Validation Loss decrease 75.62022339552641 ---> 69.29931946843863 Saving Model ...
Epoch 7, Training Loss: 0.5161008520838644
Epoch 7, Validation Loss: 1.3649995693101966
Epoch 8, Training Loss: 0.4309221706052054
Epoch 8, Validation Loss: 1.2809173744814148
Epoch 9, Training Loss: 0.33613710138336594
Epoch 9, Validation Loss: 1.2650644601932888
Epoch 10, Training Loss: 0.21256677857861084
Epoch 10, Validation Loss: 1.2183565847447206
Epoch 11, Training Loss: 0.2053164625078729
Epoch 11, Validation Loss: 1.247359231307075
Epoch 12, Training Loss: 0.17480372640577493
Epoch 12, Validation Loss: 1.300568027871436
Epoch 13, Training Loss: 0.19195906098772458
Epoch 13, Validation Loss: 1.2506588249756345
Epoch 14, Training Loss: 0.17161776552303967
Epoch 14, Validation Loss: 1.522460496631162
Epoch 15, Training Loss: 0.2197401558642641

Table 16 Training Loss and Validation Loss by Epoch batch size of 8 Part 2

Epoch 16, Training Loss: 0.13455218818075834
Epoch 16, Validation Loss: 1.1959937961194023
Epoch 17, Training Loss: 0.08056859281927685
Epoch 17, Validation Loss: 1.2587958662770689
Epoch 18, Training Loss: 0.10679332256702388
Epoch 18, Validation Loss: 1.4114401194684465
Epoch 19, Training Loss: 0.09590294532834628
Epoch 19, Validation Loss: 1.281746211236921
Epoch 20, Training Loss: 0.09275339706161095
Epoch 20, Validation Loss: 1.2510318382932195
Epoch 21, Training Loss: 0.06598015898114305
Epoch 21, Validation Loss: 1.3275289553506622
Epoch 22, Training Loss: 0.05182866399439357
Epoch 22, Validation Loss: 1.4475613461470167
Epoch 23, Training Loss: 0.07159335842136678
Epoch 23, Validation Loss: 1.3593323439488123
Epoch 24, Training Loss: 0.03797205617075665
Epoch 24, Validation Loss: 1.2166308742217269
Epoch 25, Training Loss: 0.04101235525983439
Epoch 25, Validation Loss: 1.6487139189166242
Epoch 26, Training Loss: 0.04559204261583373
Epoch 26, Validation Loss: 1.3791587330914776
Epoch 27, Training Loss: 0.03762158811174106
Epoch 27, Validation Loss: 1.4118144020181278
Epoch 28, Training Loss: 0.05235690872926029
Epoch 28, Validation Loss: 1.4435739558960856
Epoch 29, Training Loss: 0.04760390023206724
Epoch 29, Validation Loss: 1.5366451925596079
Epoch 30, Training Loss: 0.05678692009634339
Epoch 30, Validation Loss: 1.3679835698085612

Table 17 Training Loss and Validation Loss by Epoch batch size of 16 Part 1

Epoch 1, Training Loss: 2.4639683859101655
Epoch 1, Validation Loss: 2.1605908706270416
The Validation Loss decrease inf ---> 62.657135248184204 Saving Model ...
Epoch 2, Training Loss: 1.6713674890583958
Epoch 2, Validation Loss: 1.7220699643266613
The Validation Loss decrease 62.657135248184204 ---> 49.940028965473175 Saving Model ...
Epoch 3, Training Loss: 1.277093569266385
Epoch 3, Validation Loss: 1.3947955411055992
The Validation Loss decrease 49.940028965473175 ---> 40.44907069206238 Saving Model ...
Epoch 4, Training Loss: 1.0433139939760339
Epoch 4, Validation Loss: 1.3866003320134919
The Validation Loss decrease 40.44907069206238 ---> 40.211409628391266 Saving Model ...
Epoch 5, Training Loss: 0.8307399988688272
Epoch 5, Validation Loss: 1.3544621323717052
The Validation Loss decrease 40.211409628391266 ---> 39.27940183877945 Saving Model ...
Epoch 6, Training Loss: 0.668513760869873
Epoch 6, Validation Loss: 1.27508141973923
The Validation Loss decrease 39.27940183877945 ---> 36.97736117243767 Saving Model ...
Epoch 7, Training Loss: 0.553470438924329
Epoch 7, Validation Loss: 1.0317943353077461
The Validation Loss decrease 36.97736117243767 ---> 29.922035723924637 Saving Model ...
Epoch 8, Training Loss: 0.3872408615746375
Epoch 8, Validation Loss: 1.0495768723816707
Epoch 9, Training Loss: 0.3297122312581231
Epoch 9, Validation Loss: 1.2499389319584286
Epoch 10, Training Loss: 0.2512001261628907
Epoch 10, Validation Loss: 1.110171399239836
Epoch 11, Training Loss: 0.2565721993752081
Epoch 11, Validation Loss: 1.255250178534409
Epoch 12, Training Loss: 0.19697991687531485
Epoch 12, Validation Loss: 1.1206500828266144
Epoch 13, Training Loss: 0.1271909120701382
Epoch 13, Validation Loss: 1.3804382106353497
Epoch 14, Training Loss: 0.1485558316103536
Epoch 14, Validation Loss: 1.2021443615185803
Epoch 15, Training Loss: 0.11857985676434854
Epoch 15, Validation Loss: 1.2082566279789497

Table 18 Training Loss and Validation Loss by Epoch batch size of 16 Part 2

Epoch 16, Training Loss: 0.10894004940376456
Epoch 16, Validation Loss: 1.098362304013351
Epoch 17, Training Loss: 0.11324852397103377
Epoch 17, Validation Loss: 1.2008966371930878
Epoch 18, Training Loss: 0.09331019325502987
Epoch 18, Validation Loss: 1.3894597867439533
Epoch 19, Training Loss: 0.08421563959664441
Epoch 19, Validation Loss: 1.2241500102240463
Epoch 20, Training Loss: 0.09341607187023579
Epoch 20, Validation Loss: 1.2203925108087474
Epoch 21, Training Loss: 0.06207279626135554
Epoch 21, Validation Loss: 1.1129942510662407
Epoch 22, Training Loss: 0.03403096646973703
Epoch 22, Validation Loss: 1.30062211381978
Epoch 23, Training Loss: 0.03646879556919007
Epoch 23, Validation Loss: 1.2111393002600506
Epoch 24, Training Loss: 0.046249496364155145
Epoch 24, Validation Loss: 1.1794324093337716
Epoch 25, Training Loss: 0.06454651001820758
Epoch 25, Validation Loss: 1.3180098605567012
Epoch 26, Training Loss: 0.0563043382280739
Epoch 26, Validation Loss: 1.2186669943661526
Epoch 27, Training Loss: 0.04638847969532623
Epoch 27, Validation Loss: 1.1846380508665382
Epoch 28, Training Loss: 0.025842684411427713
Epoch 28, Validation Loss: 1.2262607383830795
Epoch 29, Training Loss: 0.024183499871688927
Epoch 29, Validation Loss: 1.3486633948211013
Epoch 30, Training Loss: 0.03171997226534837
Epoch 30, Validation Loss: 1.338179804127792

Table 19 Training Loss and Validation Loss by Epoch batch size of 48 Part 1

Epoch 1, Training Loss: 2.559220986488538
Epoch 1, Validation Loss: 2.329679322242737
The Validation Loss decrease inf ---> 23.296793222427368 Saving Model ...
Epoch 2, Training Loss: 1.932506038592412
Epoch 2, Validation Loss: 1.8363594889640809
The Validation Loss decrease 23.296793222427368 ---> 18.363594889640808 Saving Model ...
Epoch 3, Training Loss: 1.4497521687776616
Epoch 3, Validation Loss: 1.6197745203971863
The Validation Loss decrease 18.363594889640808 ---> 16.197745203971863 Saving Model ...
Epoch 4, Training Loss: 1.1975837579140296
Epoch 4, Validation Loss: 1.330473005771637
The Validation Loss decrease 16.197745203971863 ---> 13.30473005771637 Saving Model ...
Epoch 5, Training Loss: 0.913324100848956
Epoch 5, Validation Loss: 1.3290779829025268
The Validation Loss decrease 13.30473005771637 ---> 13.290779829025269 Saving Model ...
Epoch 6, Training Loss: 0.7957207262516022
Epoch 6, Validation Loss: 1.3345074653625488
Epoch 7, Training Loss: 0.6184612619571197
Epoch 7, Validation Loss: 1.1232265532016754
The Validation Loss decrease 13.290779829025269 ---> 11.232265532016754 Saving Model ...
Epoch 8, Training Loss: 0.4742441803981096
Epoch 8, Validation Loss: 1.2335366666316987
Epoch 9, Training Loss: 0.43210804577057177
Epoch 9, Validation Loss: 1.2973430573940277
Epoch 10, Training Loss: 0.3660000199690843
Epoch 10, Validation Loss: 1.1382431864738465
Epoch 11, Training Loss: 0.29797756595489305
Epoch 11, Validation Loss: 1.2248603582382203
Epoch 12, Training Loss: 0.24022320734384733
Epoch 12, Validation Loss: 1.1901048958301543
Epoch 13, Training Loss: 0.18564293686396036
Epoch 13, Validation Loss: 1.2424210071563722
Epoch 14, Training Loss: 0.181406776396892
Epoch 14, Validation Loss: 1.1496985793113708
Epoch 15, Training Loss: 0.13846506665532404
Epoch 15, Validation Loss: 1.1590547502040862

Table 20 Training Loss and Validation Loss by Epoch batch size of 48 Part 2

Epoch 16, Training Loss: 0.13472266459407714
Epoch 16, Validation Loss: 1.1271601021289825
Epoch 17, Training Loss: 0.11110767015279868
Epoch 17, Validation Loss: 1.1287201046943665
Epoch 18, Training Loss: 0.07761838974860999
Epoch 18, Validation Loss: 1.2168364584445954
Epoch 19, Training Loss: 0.07635913526591583
Epoch 19, Validation Loss: 1.1775518000125884
Epoch 20, Training Loss: 0.07767526385111687
Epoch 20, Validation Loss: 1.2353966295719148
Epoch 21, Training Loss: 0.066044238419869
Epoch 21, Validation Loss: 1.2437007248401641
Epoch 22, Training Loss: 0.06470721714103068
Epoch 22, Validation Loss: 1.111813986301422
The Validation Loss decrease 11.232265532016754 ---> 11.118139863014221 Saving Model ...
Epoch 23, Training Loss: 0.046219901157877386
Epoch 23, Validation Loss: 1.250548040866852
Epoch 24, Training Loss: 0.049940755375875875
Epoch 24, Validation Loss: 1.209940105676651
Epoch 25, Training Loss: 0.04673353121735346
Epoch 25, Validation Loss: 1.1661736428737641
Epoch 26, Training Loss: 0.041394434857349366
Epoch 26, Validation Loss: 1.2774239361286164
Epoch 27, Training Loss: 0.043207310002822526
Epoch 27, Validation Loss: 1.119510966539383
Epoch 28, Training Loss: 0.04565813553591187
Epoch 28, Validation Loss: 1.0602549970149995
The Validation Loss decrease 11.118139863014221 ---> 10.602549970149994 Saving Model ...
Epoch 29, Training Loss: 0.03332610910710616
Epoch 29, Validation Loss: 1.1597623944282531
Epoch 30, Training Loss: 0.03102306081638791
Epoch 30, Validation Loss: 1.0379008293151855
The Validation Loss decrease 10.602549970149994 ---> 10.379008293151855 Saving Model ...

Table 21 Training Loss and Validation Loss by Epoch batch size of 64 Part 1

Epoch 1, Training Loss: 2.679146873539892
Epoch 1, Validation Loss: 2.436879724264145
The Validation Loss decrease inf ---> 19.49503779411316 Saving Model ...
Epoch 2, Training Loss: 2.0124747917569916
Epoch 2, Validation Loss: 1.8123286813497543
The Validation Loss decrease 19.49503779411316 ---> 14.498629450798035 Saving Model ...
Epoch 3, Training Loss: 1.5431908040211118
Epoch 3, Validation Loss: 1.617660790681839
The Validation Loss decrease 14.498629450798035 ---> 12.941286325454712 Saving Model ...
Epoch 4, Training Loss: 1.2421027812464485
Epoch 4, Validation Loss: 1.3900204747915268
The Validation Loss decrease 12.941286325454712 ---> 11.120163798332214 Saving Model ...
Epoch 5, Training Loss: 1.0177595779813569
Epoch 5, Validation Loss: 1.2656383141875267
The Validation Loss decrease 11.120163798332214 ---> 10.125106513500214 Saving Model ...
Epoch 6, Training Loss: 0.8295604586601257
Epoch 6, Validation Loss: 1.3370337337255478
Epoch 7, Training Loss: 0.6932566422840645
Epoch 7, Validation Loss: 1.332139015197754
Epoch 8, Training Loss: 0.5558367577092401
Epoch 8, Validation Loss: 1.1445667445659637
The Validation Loss decrease 10.125106513500214 ---> 9.15653395652771 Saving Model ...
Epoch 9, Training Loss: 0.46219967870876705
Epoch 9, Validation Loss: 1.0041559115052223
The Validation Loss decrease 9.15653395652771 ---> 8.033247292041779 Saving Model ...
Epoch 10, Training Loss: 0.35575555932932884
Epoch 10, Validation Loss: 1.0994827523827553
Epoch 11, Training Loss: 0.29949474899933254
Epoch 11, Validation Loss: 0.9348316192626953
The Validation Loss decrease 8.033247292041779 ---> 7.4786529541015625 Saving Model ...
Epoch 12, Training Loss: 0.2603230882307579
Epoch 12, Validation Loss: 1.1100293546915054
Epoch 13, Training Loss: 0.20451078204245404
Epoch 13, Validation Loss: 0.8963061328977346
The Validation Loss decrease 7.4786529541015625 ---> 7.170449063181877 Saving Model ...
Epoch 14, Training Loss: 0.16873989023011307
Epoch 14, Validation Loss: 1.1356105655431747
Epoch 15, Training Loss: 0.1359710719051032
Epoch 15, Validation Loss: 1.0747024565935135

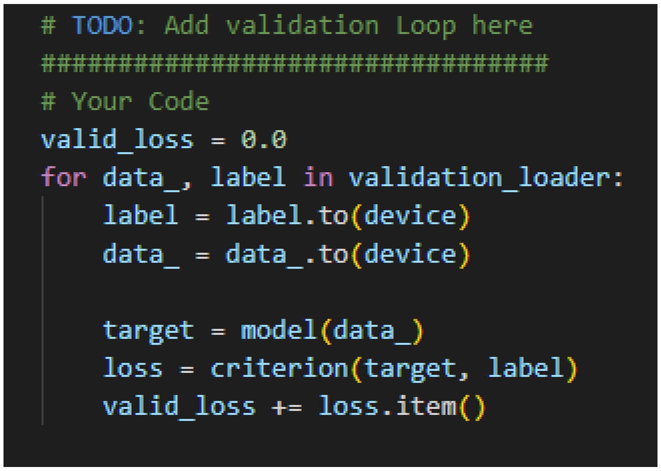
Table 22 Training Loss and Validation Loss by Epoch batch size of 64 Part 2

Epoch 16, Training Loss: 0.14872118843526677
Epoch 16, Validation Loss: 0.9746574386954308
Epoch 17, Training Loss: 0.11669610928872536
Epoch 17, Validation Loss: 0.9806378558278084
Epoch 18, Training Loss: 0.09806962837946825
Epoch 18, Validation Loss: 1.0342333167791367
Epoch 19, Training Loss: 0.0860361594321399
Epoch 19, Validation Loss: 1.0304230451583862
Epoch 20, Training Loss: 0.07954765303895392
Epoch 20, Validation Loss: 0.9369053095579147
Epoch 21, Training Loss: 0.0651670019945194
Epoch 21, Validation Loss: 1.0847882702946663
Epoch 22, Training Loss: 0.06370435738614921
Epoch 22, Validation Loss: 1.0407067835330963
Epoch 23, Training Loss: 0.0628054853978342
Epoch 23, Validation Loss: 1.081730104982853
Epoch 24, Training Loss: 0.06461019023995974
Epoch 24, Validation Loss: 1.1455040127038956
Epoch 25, Training Loss: 0.04172289217340535
Epoch 25, Validation Loss: 0.9638026803731918
Epoch 26, Training Loss: 0.04655421348609801
Epoch 26, Validation Loss: 1.0962398499250412
Epoch 27, Training Loss: 0.0472527206714811
Epoch 27, Validation Loss: 1.1911435574293137
Epoch 28, Training Loss: 0.04415572543853316
Epoch 28, Validation Loss: 0.9738586097955704
Epoch 29, Training Loss: 0.03775018463232394
Epoch 29, Validation Loss: 1.0604590326547623
Epoch 30, Training Loss: 0.033709513023495674
Epoch 30, Validation Loss: 1.058081477880478

Code

Train

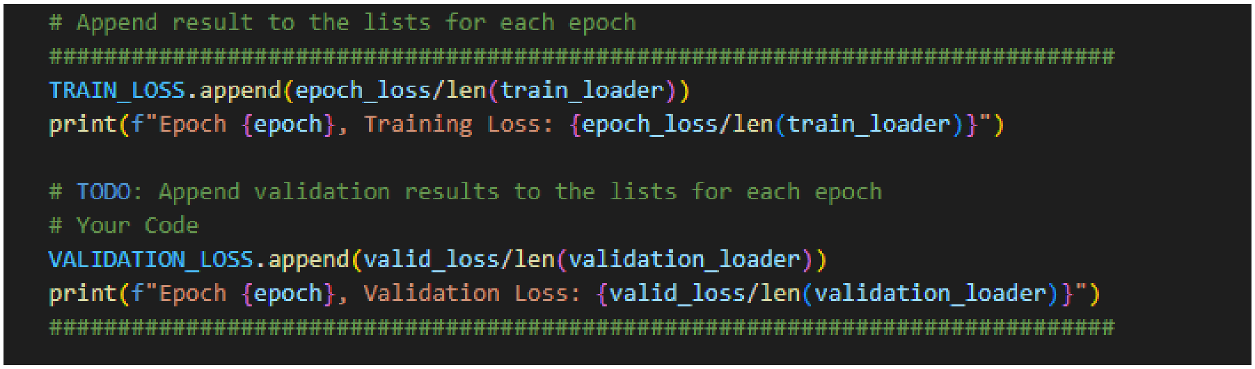
Validation Loop



```
# TODO: Add validation Loop here
#################################
# Your Code
valid_loss = 0.0
for data_, label in validation_loader:
    label = label.to(device)
    data_ = data_.to(device)

    target = model(data_)
    loss = criterion(target, label)
    valid_loss += loss.item()
```

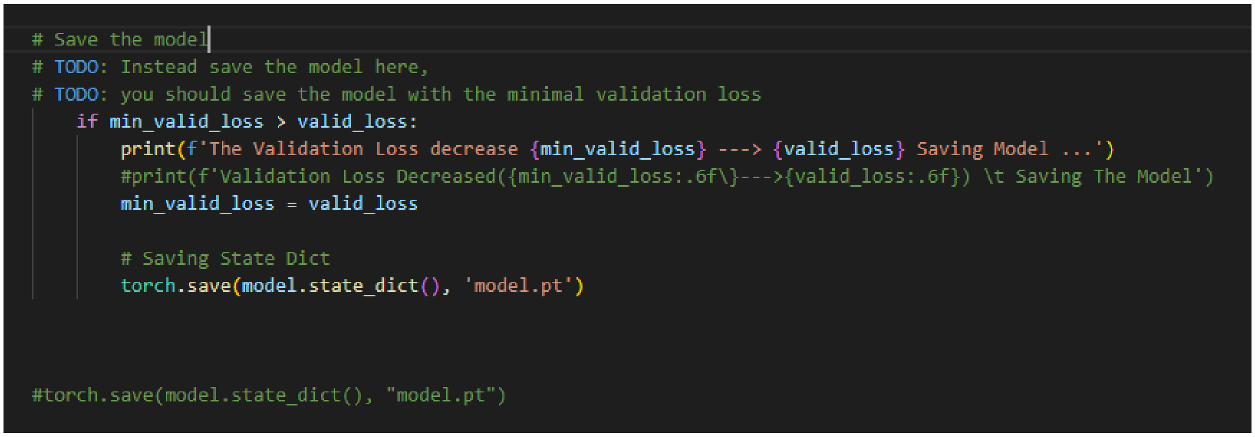
Append List for each epoch



```
# Append result to the lists for each epoch
##############################################################################
TRAIN_LOSS.append(epoch_loss/len(train_loader))
print(f"Epoch {epoch}, Training Loss: {epoch_loss/len(train_loader)}")

# TODO: Append validation results to the lists for each epoch
# Your Code
VALIDATION_LOSS.append(valid_loss/len(validation_loader))
print(f"Epoch {epoch}, Validation Loss: {valid_loss/len(validation_loader)}")
##############################################################################
```

Saving Model



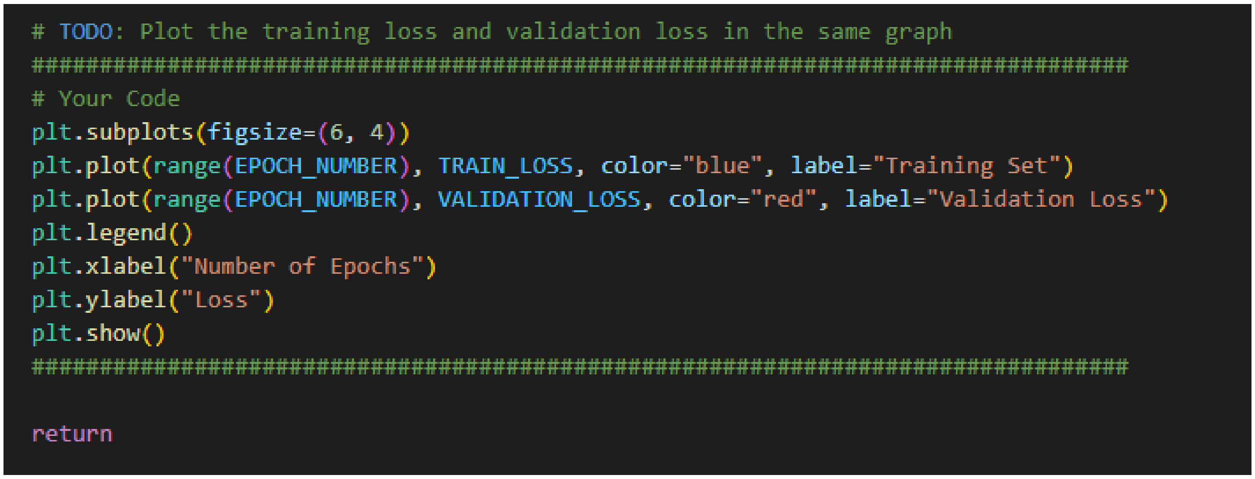
```
# Save the model
# TODO: Instead save the model here,
# TODO: you should save the model with the minimal validation loss
    if min_valid_loss > valid_loss:
        print(f'The Validation Loss decrease {min_valid_loss} ---> {valid_loss} Saving Model ...')
        #print(f'Validation Loss Decreased({min_valid_loss:.6f\}--->{valid_loss:.6f}) \t Saving The Model')
        min_valid_loss = valid_loss

        # Saving State Dict
        torch.save(model.state_dict(), 'model.pt')



#torch.save(model.state_dict(), "model.pt")
```

Plotting Graph

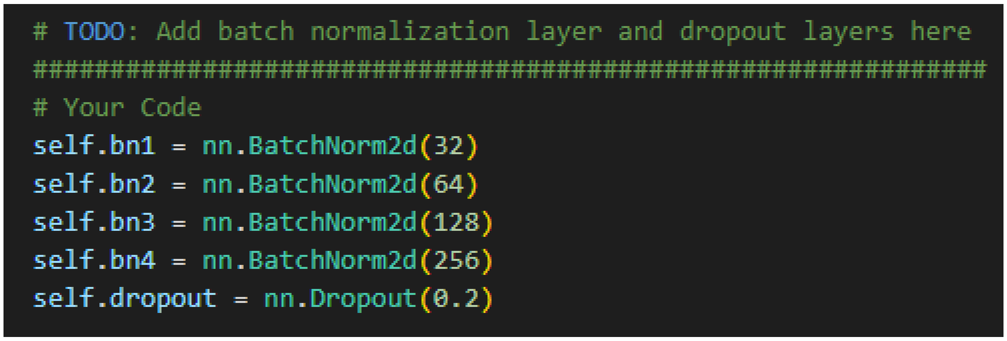


```
# TODO: Plot the training loss and validation loss in the same graph
##################################################################################
# Your Code
plt.subplots(figsize=(6, 4))
plt.plot(range(EPOCH_NUMBER), TRAIN_LOSS, color="blue", label="Training Set")
plt.plot(range(EPOCH_NUMBER), VALIDATION_LOSS, color="red", label="Validation Loss")
plt.legend()
plt.xlabel("Number of Epochs")
plt.ylabel("Loss")
plt.show()
##################################################################################

return
```

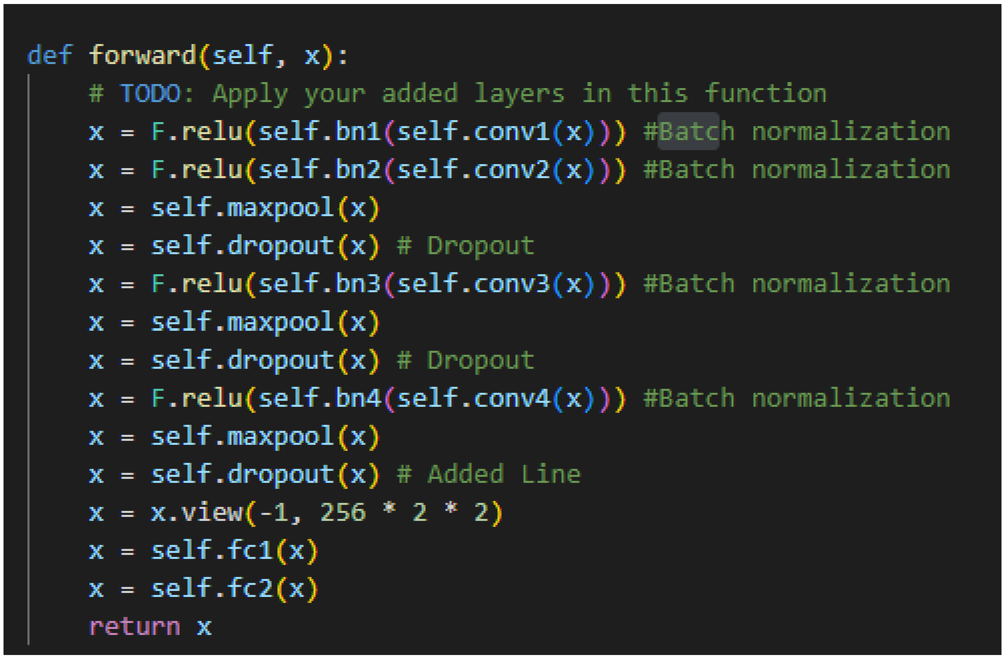
Animal Classification

Batch Normalization and Dropout



```
# TODO: Add batch normalization layer and dropout layers here
##############################################################
# Your Code
self.bn1 = nn.BatchNorm2d(32)
self.bn2 = nn.BatchNorm2d(64)
self.bn3 = nn.BatchNorm2d(128)
self.bn4 = nn.BatchNorm2d(256)
self.dropout = nn.Dropout(0.2)
```

Forward



```
def forward(self, x):
    # TODO: Apply your added layers in this function
    x = F.relu(self.bn1(self.conv1(x))) #Batch normalization
    x = F.relu(self.bn2(self.conv2(x))) #Batch normalization
    x = self.maxpool(x)
    x = self.dropout(x) # Dropout
    x = F.relu(self.bn3(self.conv3(x))) #Batch normalization
    x = self.maxpool(x)
    x = self.dropout(x) # Dropout
    x = F.relu(self.bn4(self.conv4(x))) #Batch normalization
    x = self.maxpool(x)
    x = self.dropout(x) # Added Line
    x = x.view(-1, 256 * 2 * 2)
    x = self.fc1(x)
    x = self.fc2(x)
    return x
```