ECGR 4106 Real-time Machine Learning
Homework 3
Jonathon Nguyen
ID: 801093003
Github link: https://github.com/nguyjd/ecgr-4106-homeworks/tree/main/homework%203

Problem 1
The goal of the problem is to build a convolutional neural network that will classify images on 10 different classes in CIFAR 10. This is the same dataset from homework 2. The network will not have any skip connections. The full connected layer at the end of network will have to be adjusted to work with 10 classifications. The model will be trained for 300 epochs and the training loss, validation loss, and the accuracy will be reported.

For **problem 1 part a**, I created a class for the new CNN in Cell **IN[2]**. The CNN class function takes in the number of channels for the first layer. The number of channels is defaulted to 32 if not provided. The network is composed of two convolutional layers in series that use 3x3 kernals and a padding of 1. Then the output of the second convolutional layer is resized to fit the full connected layer. The output layer ouputs to 10 classes.

I made a training loop in IN[3], this will be used for all the training and validation. In side the training loop, There are four list, two to store the losses and two to store the accuracies for graphing. In cell IN[4] the transform function is made to normalize the data set. IN[5] downloads the cirfar dataset and IN[6] makes sure that the gpu can be used.

To improve my training time, I did four things to improve my training time. When using the dataloader, I set the pin_memory to True, persistent_worker to True, set num_workers to 6 or 3 depending on if it was the training set or the validation set. Then I trained on my GPU. Pin_memory improved the speed of moving the tensor to the GPU, num_workers made new threads to load the data, and the persistent_worker made sure that the threads did not respawn each epoch, slowing down the training. I did this dataloader configuration for all the trainings seen in IN[7], IN[12], IN[19], IN[26], IN[30], IN[37].

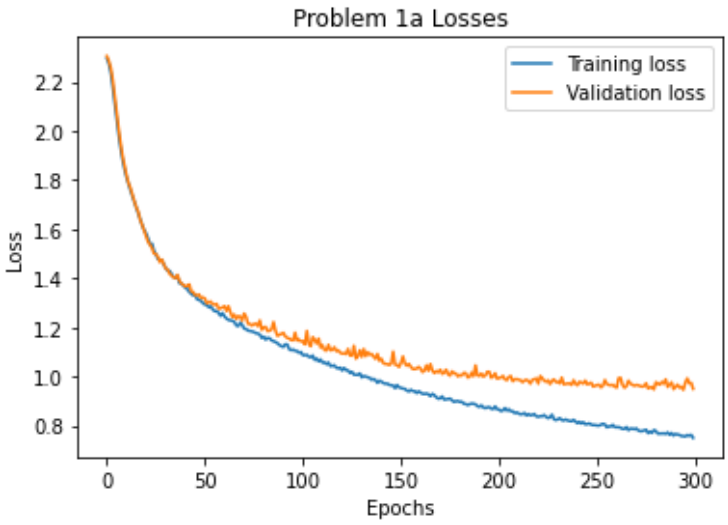
In cell IN[7], I defined the CNN and moved it to the GPU. In cell[8] I start the first training loop for 300 epochs and the training loop prints every 10 epochs.

Problem 1 part A output

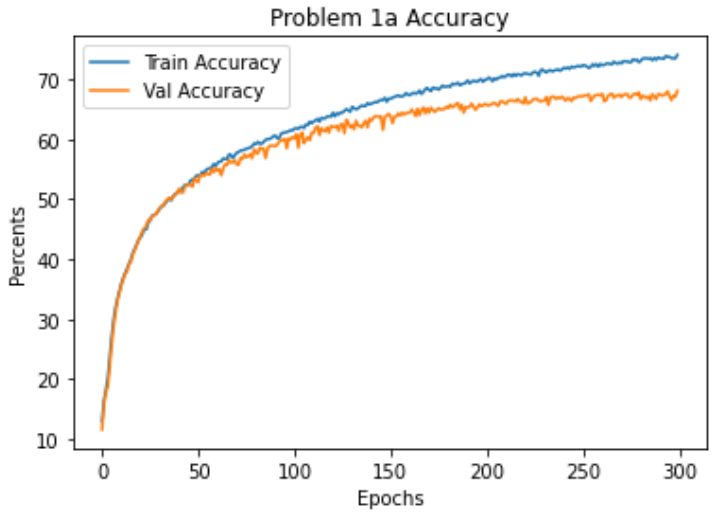
```
Epoch: 1, Training Loss: 2.2955425126211986, Validation Loss: 2.3042561054229735, Train Accuracy: 12.952%,
Validation Accuracy: 11.59%
Epoch: 10, Training Loss: 1.8442904462619705, Validation Loss: 1.8580263018608094, Train Accuracy: 34.618%,
Validation Accuracy: 34.27%
Epoch: 20, Training Loss: 1.596616151381512, Validation Loss: 1.5941105604171752, Train Accuracy: 43.284%,
Validation Accuracy: 43.03%
Epoch: 30, Training Loss: 1.4580550437070885, Validation Loss: 1.4589152812957764, Train Accuracy: 47.914%,
Validation Accuracy: 48.04%
Epoch: 40, Training Loss: 1.3700478685145476, Validation Loss: 1.3732717990875245, Train Accuracy: 51.06%,
Validation Accuracy: 51.11%
Epoch: 50, Training Loss: 1.299148433062495, Validation Loss: 1.3218871116638184, Train Accuracy: 53.93%,
Validation Accuracy: 53.14%
Epoch: 60, Training Loss: 1.2585597962749249, Validation Loss: 1.281577503681183, Train Accuracy: 55.47%,
Validation Accuracy: 55.120000000000005%
Epoch: 70, Training Loss: 1.2105555874960763, Validation Loss: 1.227596378326416, Train Accuracy: 57.348%,
Validation Accuracy: 56.49999999999999%
Epoch: 80, Training Loss: 1.156944608201786, Validation Loss: 1.1904311299324035, Train Accuracy: 59.294000000000004%,
Validation Accuracy: 58.32000000000001%
Epoch: 90, Training Loss: 1.1238568875254418, Validation Loss: 1.1731510996818542, Train Accuracy: 60.504000000000005%,
Validation Accuracy: 58.98%
Epoch: 100, Training Loss: 1.0997404079048, Validation Loss: 1.1430832743644714, Train Accuracy: 61.466%,
Validation Accuracy: 60.370000000000005%
Epoch: 110, Training Loss: 1.0694901189025567, Validation Loss: 1.1183802962303162, Train Accuracy: 62.676%,
Validation Accuracy: 61.14000000000001%
Epoch: 120, Training Loss: 1.036156491357453, Validation Loss: 1.0973090887069703, Train Accuracy: 63.79%,
Validation Accuracy: 62.23%
Epoch: 130, Training Loss: 1.0129343563196611, Validation Loss: 1.1071391582489014, Train Accuracy: 64.614%,
Validation Accuracy: 61.970000000000006%
Epoch: 140, Training Loss: 0.983330095300869, Validation Loss: 1.0640487849712372, Train Accuracy: 65.816%,
Validation Accuracy: 63.42%
Epoch: 150, Training Loss: 0.9556920929830901, Validation Loss: 1.0387795269489288, Train Accuracy: 66.792%,
Validation Accuracy: 64.25999999999999%
Epoch: 160, Training Loss: 0.9400383258352474, Validation Loss: 1.0393112361431123, Train Accuracy: 67.432%,
Validation Accuracy: 64.44%
Epoch: 170, Training Loss: 0.9099398535125109, Validation Loss: 1.0176909506320952, Train Accuracy: 68.572%,
Validation Accuracy: 65.14999999999999%
Epoch: 180, Training Loss: 0.9003039209210143, Validation Loss: 1.000786578655243, Train Accuracy: 68.818%,
Validation Accuracy: 65.44%
Epoch: 190, Training Loss: 0.8795796292168754, Validation Loss: 1.005182832479477, Train Accuracy: 69.422%,
Validation Accuracy: 65.36999999999999%
Epoch: 200, Training Loss: 0.8669570781746689, Validation Loss: 0.9910204708576202, Train Accuracy: 69.94200000000001%,
Validation Accuracy: 65.93%
Epoch: 210, Training Loss: 0.8542824959268376, Validation Loss: 0.9895675480365753, Train Accuracy: 70.35%,
Validation Accuracy: 66.10000000000001%
Epoch: 220, Training Loss: 0.8380790121701299, Validation Loss: 0.9922572553157807, Train Accuracy: 70.954%,
Validation Accuracy: 65.96%
Epoch: 230, Training Loss: 0.8228327194038703, Validation Loss: 0.977374941110611, Train Accuracy: 71.63199999999999%,
Validation Accuracy: 66.44%
Epoch: 240, Training Loss: 0.8162860055359042, Validation Loss: 0.971097332239151, Train Accuracy: 71.628%,
Validation Accuracy: 67.12%
Epoch: 250, Training Loss: 0.802828561286537, Validation Loss: 0.9624959230422974, Train Accuracy: 72.11%,
Validation Accuracy: 67.19000000000001%
Epoch: 260, Training Loss: 0.7943886360343622, Validation Loss: 0.9591034173965454, Train Accuracy: 72.568%,
Validation Accuracy: 67.32000000000001%
Epoch: 270, Training Loss: 0.7854912475663789, Validation Loss: 0.962449711561203, Train Accuracy: 72.83800000000001%,
Validation Accuracy: 67.47%
Epoch: 280, Training Loss: 0.7822473560060773, Validation Loss: 0.9477557480335236, Train Accuracy: 72.868%,
Validation Accuracy: 67.83%
Epoch: 290, Training Loss: 0.760169694618303, Validation Loss: 0.9485102534294129, Train Accuracy: 73.65%,
Validation Accuracy: 67.52%
Epoch: 300, Training Loss: 0.7506052644885316, Validation Loss: 0.9500561714172363, Train Accuracy: 74.086%,
Validation Accuracy: 68.08%

Final Loss: 0.7506052644885316, Final Training Accuracy: 74.086%,
Final Val Accuracy: 68.08%
Training Time: 919.63 seconds
```

In cell In[9], I plot the losses and in cell IN[10], I plotted the accuracy of the model.

Problem 1 part A Loss Graph



Problem 1 part A Accuracy Graph



Training Time: **919.63 Seconds**
Final Training loss: **0.7506052644885316**
Final Validation Loss: **0.9500561714172363**
Final Training Accuracy: **74.086 %**
Final Validation Accuracy: **68.08 %**

The model achieved a accuracy of 68.08 %. The model accuracy is better than the fully connected model by around 18%. The model also seemed to overfit less than the fully connected model but there is some evidence that that it is starting to. The fully connected model size was 1.58 M while this model size much smaller at 38.65 k. Found at IN[16]. The training time is also 4 times smaller at 919.63 compared to 4272 seconds. This speed up is from using threads.

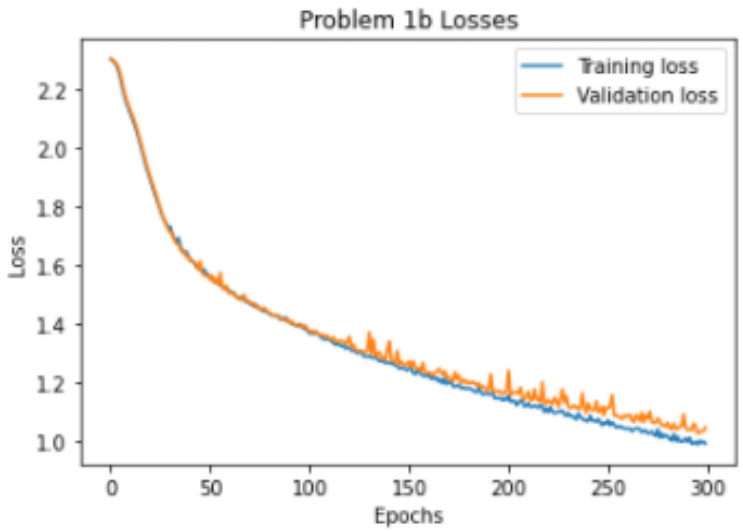
For **problem 1 part B**, I reuse the training loop and redefined the model in IN[11]. The new model has a thrid convolution layers instead. The conv layer sports a 16 channels input to 8 channels output. The forward pass function also included a new relu activation function and a max poolling function on the output of the new convolution layer. The training was started in IN[12] and was ran for 300 epochs in the same way problem 1 part a was.

Problem 1 part b output

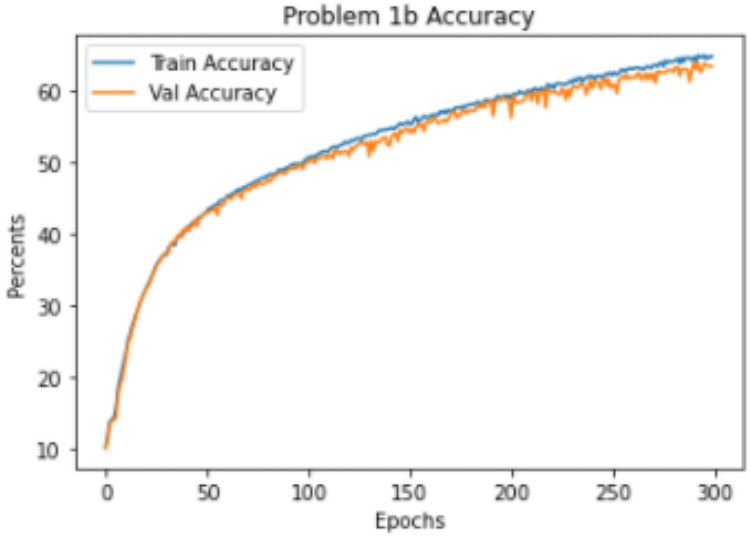
```
Epoch: 1, Training Loss: 2.301606762165926, Validation Loss: 2.30378520488739, Train Accuracy: 10.158000000000001%,
Validation Accuracy: 9.969999999999999%
Epoch: 10, Training Loss: 2.1319300009279836, Validation Loss: 2.1419822692871096, Train Accuracy: 22.142%,
Validation Accuracy: 21.05%
Epoch: 20, Training Loss: 1.9084616777848225, Validation Loss: 1.918773889541626, Train Accuracy: 31.8%,
Validation Accuracy: 31.630000000000003%
Epoch: 30, Training Loss: 1.7271657987516753, Validation Loss: 1.7192156076431275, Train Accuracy: 37.128%,
Validation Accuracy: 37.269999999999996%
Epoch: 40, Training Loss: 1.6316196894159123, Validation Loss: 1.6280341506004334, Train Accuracy: 40.472%,
Validation Accuracy: 40.45%
Epoch: 50, Training Loss: 1.5687541110174996, Validation Loss: 1.5646364450454713, Train Accuracy: 42.936%,
Validation Accuracy: 42.809999999999995%
Epoch: 60, Training Loss: 1.5181748137182118, Validation Loss: 1.5059452295303344, Train Accuracy: 44.808%,
Validation Accuracy: 44.78%
Epoch: 70, Training Loss: 1.4770508688323352, Validation Loss: 1.4714210629463196, Train Accuracy: 46.478%,
Validation Accuracy: 46.21%
Epoch: 80, Training Loss: 1.4374104665250194, Validation Loss: 1.4401942849159242, Train Accuracy: 48.098%,
Validation Accuracy: 47.22%
Epoch: 90, Training Loss: 1.406398673446811, Validation Loss: 1.4164637446403503, Train Accuracy: 49.328%,
Validation Accuracy: 48.67%
Epoch: 100, Training Loss: 1.3747797328598645, Validation Loss: 1.3795557379722596, Train Accuracy: 50.51%,
Validation Accuracy: 50.029999999999994%
Epoch: 110, Training Loss: 1.3477652145891774, Validation Loss: 1.3578344702720642, Train Accuracy: 51.55800000000001%,
Validation Accuracy: 50.519999999999996%
Epoch: 120, Training Loss: 1.3203445016121378, Validation Loss: 1.3394025802612304, Train Accuracy: 52.769999999999996%,
Validation Accuracy: 51.470000000000006%
Epoch: 130, Training Loss: 1.2892763030772307, Validation Loss: 1.3060084104537963, Train Accuracy: 53.788000000000004%,
Validation Accuracy: 52.910000000000004%
Epoch: 140, Training Loss: 1.2674669805838137, Validation Loss: 1.31036274433136, Train Accuracy: 54.65%,
Validation Accuracy: 52.459999999999994%
Epoch: 150, Training Loss: 1.240694345260153, Validation Loss: 1.2608980536460876, Train Accuracy: 55.788000000000004%,
Validation Accuracy: 54.65%
Epoch: 160, Training Loss: 1.221480172507617, Validation Loss: 1.2328736186027527, Train Accuracy: 56.39999999999999%,
Validation Accuracy: 55.989999999999995%
Epoch: 170, Training Loss: 1.1939981640601645, Validation Loss: 1.2161322474479674, Train Accuracy: 57.408%,
Validation Accuracy: 56.13%
Epoch: 180, Training Loss: 1.1775222457185084, Validation Loss: 1.1958510518074035, Train Accuracy: 58.10999999999999%,
Validation Accuracy: 57.35%
Epoch: 190, Training Loss: 1.1626266751970564, Validation Loss: 1.1733281493186951, Train Accuracy: 58.584%,
Validation Accuracy: 58.489999999999995%
Epoch: 200, Training Loss: 1.1394536130282344, Validation Loss: 1.1730970859527587, Train Accuracy: 59.474000000000004%,
Validation Accuracy: 58.43000000000001%
Epoch: 210, Training Loss: 1.1208114088798056, Validation Loss: 1.1552870988845825, Train Accuracy: 60.132%,
Validation Accuracy: 59.489999999999995%
Epoch: 220, Training Loss: 1.1112168054191434, Validation Loss: 1.1283663630485534, Train Accuracy: 60.629999999999995%,
Validation Accuracy: 60.17%
Epoch: 230, Training Loss: 1.0852455168354267, Validation Loss: 1.1539132714271545, Train Accuracy: 61.45%,
Validation Accuracy: 59.31999999999999%
Epoch: 240, Training Loss: 1.070779029203921, Validation Loss: 1.0957736253738404, Train Accuracy: 62.03999999999999%,
Validation Accuracy: 61.61%
Epoch: 250, Training Loss: 1.0585996447777262, Validation Loss: 1.1143147945404053, Train Accuracy: 62.629999999999995%,
Validation Accuracy: 60.51%
Epoch: 260, Training Loss: 1.042268164303838, Validation Loss: 1.0812086105346679, Train Accuracy: 63.214000000000006%,
Validation Accuracy: 61.919999999999995%
Epoch: 270, Training Loss: 1.036059883176064, Validation Loss: 1.087683951854706, Train Accuracy: 63.232%,
Validation Accuracy: 61.760000000000005%
Epoch: 280, Training Loss: 1.0194789292861004, Validation Loss: 1.0503705978393554, Train Accuracy: 64.122%,
Validation Accuracy: 62.949999999999996%
Epoch: 290, Training Loss: 1.0089996019188239, Validation Loss: 1.044353437423706, Train Accuracy: 64.338%,
Validation Accuracy: 62.849999999999994%
Epoch: 300, Training Loss: 0.9915532652212649, Validation Loss: 1.0467054963111877, Train Accuracy: 64.958%,
Validation Accuracy: 63.470000000000006%

Final Loss: 0.9915532652212649, Final Training Accuracy: 64.958%, Final Val Accuracy: 63.470000000000006%
Training Time: 892.96 seconds
```

In cell In[14], I plot the losses and in cell IN[15], I plotted the accuracy of the model.

Problem 1 part b Loss Graph



Problem 1 part b Accuracy Graph



Training Time: **892.96 seconds**
Final Training loss: **0.9915532652212649**
Final Validation Loss: **1.0467054963111877**
Final Training Accuracy: **64.958%**
Final Validation Accuracy: **63.47%**

The accuracy of the model is slightly less than problem 1 part a. However it seems like the model has not fully converged. Looking at the graph, the model is not overfitting yet and can go more. If the training was more than 300 epochs, I assume that the model would be better than the baseline. The model is less than the baseline at 11.14 k. I do not see over fitting. If the training was allow to go on, then the model would overfit.

Problem 2

The goal of the problem is also create a ResNet like CNN with skip connection to classify the 10 classes in CIFAR-10. There will be 10 blocks for the model.

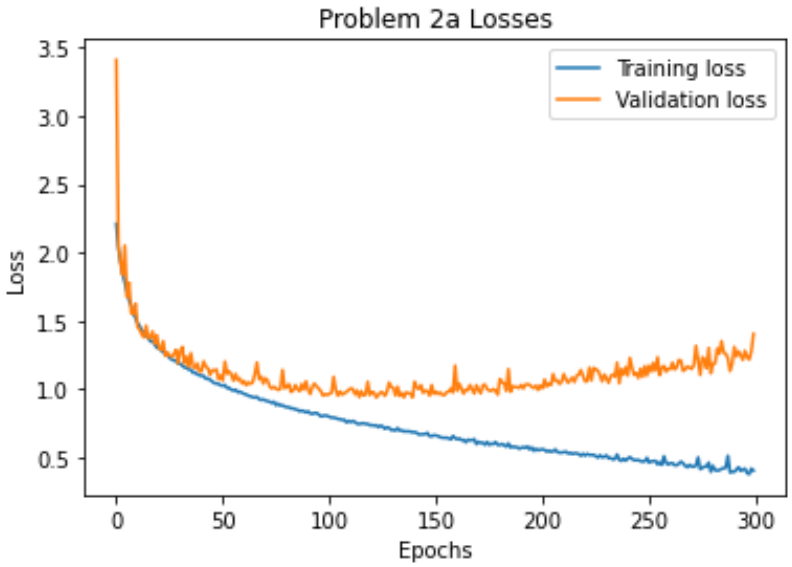
For problem 2 part a, A class was made for the block in the ResNet like CNN in IN[17]. It consist of one conv layer and one relu activation layer. At the end of forward pass function, the input is added to the output of the layers to make a skip conneciton. In IN[18], The CNN was made in the class with one conv layer, 10 blocks of the ResBlocks and a fully connected section. The training was started in IN[20] for 300 epochs.

Problem 1 part b output

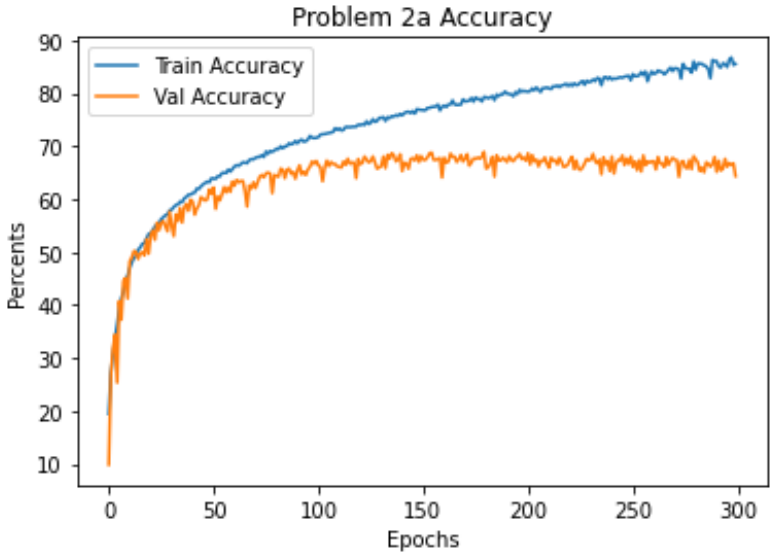
```
Epoch: 1, Training Loss: 2.2091207601586165, Validation Loss: 3.409150791168213, Train Accuracy: 19.464000000000002%,
Validation Accuracy: 9.87%
Epoch: 10, Training Loss: 1.5232609534750179, Validation Loss: 1.6260629892349243, Train Accuracy: 45.564%,
Validation Accuracy: 41.24%
Epoch: 20, Training Loss: 1.3039579488793198, Validation Loss: 1.3965609073638916, Train Accuracy: 53.434000000000005%,
Validation Accuracy: 49.7%
Epoch: 30, Training Loss: 1.1880691197453712, Validation Loss: 1.1879597783088685, Train Accuracy: 57.888%,
Validation Accuracy: 57.65%
Epoch: 40, Training Loss: 1.1038207010347016, Validation Loss: 1.1301270127296448, Train Accuracy: 60.866%,
Validation Accuracy: 59.91%
Epoch: 50, Training Loss: 1.0277478548945214, Validation Loss: 1.0989624857902527, Train Accuracy: 63.944%,
Validation Accuracy: 61.07%
Epoch: 60, Training Loss: 0.9741090134698518, Validation Loss: 1.0422486066818237, Train Accuracy: 65.666%,
Validation Accuracy: 63.32%
Epoch: 70, Training Loss: 0.925658178572752, Validation Loss: 1.041062694787979, Train Accuracy: 67.514%,
Validation Accuracy: 63.18%
Epoch: 80, Training Loss: 0.8733080491727713, Validation Loss: 1.0066020011901855, Train Accuracy: 69.174%,
Validation Accuracy: 64.55%
Epoch: 90, Training Loss: 0.8297736170340557, Validation Loss: 1.0580503582954406, Train Accuracy: 70.99%,
Validation Accuracy: 63.85999999999999%
Epoch: 100, Training Loss: 0.8050880578099465, Validation Loss: 0.9575101196765899, Train Accuracy: 71.592%,
Validation Accuracy: 67.22%
Epoch: 110, Training Loss: 0.7680785376198438, Validation Loss: 0.9932644784450531, Train Accuracy: 73.074%,
Validation Accuracy: 66.18%
Epoch: 120, Training Loss: 0.7362398541703516, Validation Loss: 0.9578771591186523, Train Accuracy: 74.068%,
Validation Accuracy: 67.58%
Epoch: 130, Training Loss: 0.7008889864902107, Validation Loss: 1.0174954891204835, Train Accuracy: 75.342%,
Validation Accuracy: 66.02%
Epoch: 140, Training Loss: 0.6841176286035654, Validation Loss: 0.9404460966587067, Train Accuracy: 76.102%,
Validation Accuracy: 68.46%
Epoch: 150, Training Loss: 0.6641073141779218, Validation Loss: 0.9659663140773773, Train Accuracy: 76.86%,
Validation Accuracy: 68.13%
Epoch: 160, Training Loss: 0.6420031615665981, Validation Loss: 1.172751522064209, Train Accuracy: 77.446%,
Validation Accuracy: 64.09%
Epoch: 170, Training Loss: 0.5981552783323794, Validation Loss: 1.0293115496635437, Train Accuracy: 78.85799999999999%,
Validation Accuracy: 67.11%
Epoch: 180, Training Loss: 0.5930914270634554, Validation Loss: 0.9609642207622529, Train Accuracy: 79.292%,
Validation Accuracy: 68.92%
Epoch: 190, Training Loss: 0.5648371346142828, Validation Loss: 1.0092516183853149, Train Accuracy: 80.316%,
Validation Accuracy: 67.46%
Epoch: 200, Training Loss: 0.5589074717492474, Validation Loss: 1.0281811714172364, Train Accuracy: 80.348%,
Validation Accuracy: 67.28%
Epoch: 210, Training Loss: 0.5365018893261345, Validation Loss: 1.0564041078090667, Train Accuracy: 81.098%,
Validation Accuracy: 66.71000000000001%
Epoch: 220, Training Loss: 0.5275622515045867, Validation Loss: 1.1001995086669922, Train Accuracy: 81.382%,
Validation Accuracy: 66.53%
Epoch: 230, Training Loss: 0.5058481012071881, Validation Loss: 1.1075478792190552, Train Accuracy: 82.08800000000001%,
Validation Accuracy: 67.30000000000001%
Epoch: 240, Training Loss: 0.47735033959758527, Validation Loss: 1.1601692676544189, Train Accuracy: 83.06%,
Validation Accuracy: 65.32%
Epoch: 250, Training Loss: 0.49791465730083234, Validation Loss: 1.099630731344223, Train Accuracy: 82.46%,
Validation Accuracy: 68.04%
Epoch: 260, Training Loss: 0.44949058610565806, Validation Loss: 1.1515549540519714, Train Accuracy: 84.11999999999999%,
Validation Accuracy: 67.14%
Epoch: 270, Training Loss: 0.4470905661582947, Validation Loss: 1.1578999638557435, Train Accuracy: 84.172%,
Validation Accuracy: 67.80000000000001%
Epoch: 280, Training Loss: 0.39618328943544506, Validation Loss: 1.1172569274902344, Train Accuracy: 85.99799999999999%,
Validation Accuracy: 68.11%
Epoch: 290, Training Loss: 0.3969786282704801, Validation Loss: 1.1859701156616211, Train Accuracy: 86.034%,
Validation Accuracy: 67.96%
Epoch: 300, Training Loss: 0.4046458425570507, Validation Loss: 1.4038283228874207, Train Accuracy: 85.54%,
Validation Accuracy: 64.35%

Final Loss: 0.4046458425570507, Final Training Accuracy: 85.54%, Final Val Accuracy: 64.35%
Training Time: 1331.39 seconds
```

In cell In[21], I plot the losses and in cell IN[22], I plotted the accuracy of the model.

Problem 2 part A Loss Graph



Problem 2 part A Accuracy Graph



Training Time: **1331.39 seconds**
Final Training loss: **0.4046458425570507**
Final Validation Loss: **1.4038283228874207**
Final Training Accuracy: **85.54%**
Final Validation Accuracy: **64.35%**

The training time was longer than the problem 1 part b by around 400 seconds. This is make sense because of the model size. The ResNet CNN has a model size of 76.04 k compared to the 11.14 k params for problem 1b. The validation accuracy is better for the ResNet CNN than problem 2b.

For **Problem 2 part b,** The goal was to make train with three different regulaization methods and compare them. The methods were L2 regulazation with a lambda of 0.001, Dropout of 0.3 and batch normalization.
In cell IN[23], I made a new class for the dropout. The ResBlock class is the same as problem 2 part a but there is a new dropout layer between the conv layer and the activation layer. The ResNet class has the same layout as the resnet class in problem 2 part a.
In cell IN[24], I made a batch normalization class. The Resblock class now includes a batch normalization layer after the activation layer. In the resnet class, there is a batch normalization layer after the first convolution layer.
In cell IN[25], The default training loop was modifed. The code to perform L2 regularization was added.

L2 Regularization
Training Time: **1394.76 seconds**
Final Training loss: **0.46078920546843083**
Final Validation Loss: **1.3157394528388977**
Final Training Accuracy: **85.502%**
Final Validation Accuracy: **64.12%**

Dropout
Training Time: **1071.67 seconds**
Final Training loss: **0.8524240194534769**
Final Validation Loss: **0.9911846339702606**
Final Training Accuracy: **70.37%**
Final Validation Accuracy: **65.82%**

Batch Normalization
Training Time: **1085.71 seconds**
Final Training loss: **0.24973155406056619**
Final Validation Loss: **2.0405576109886168**
Final Training Accuracy: **92.374%**
Final Validation Accuracy: **45.61%**

The Dropout is the fastest out of all regulatation methods while L2 Regularization is the slowest. Batch normalization had the smallest training loss but the highest validation loss. This make sense because batch normalization can converge the training fast. Dropout had the least difference between loss of validation and training. L2 regularization difference between losses was better than the baseline but not by much. Dropout had the best accuracy of the three training. Dropout and L2 had near the same validation accuracy by Batch was much less.

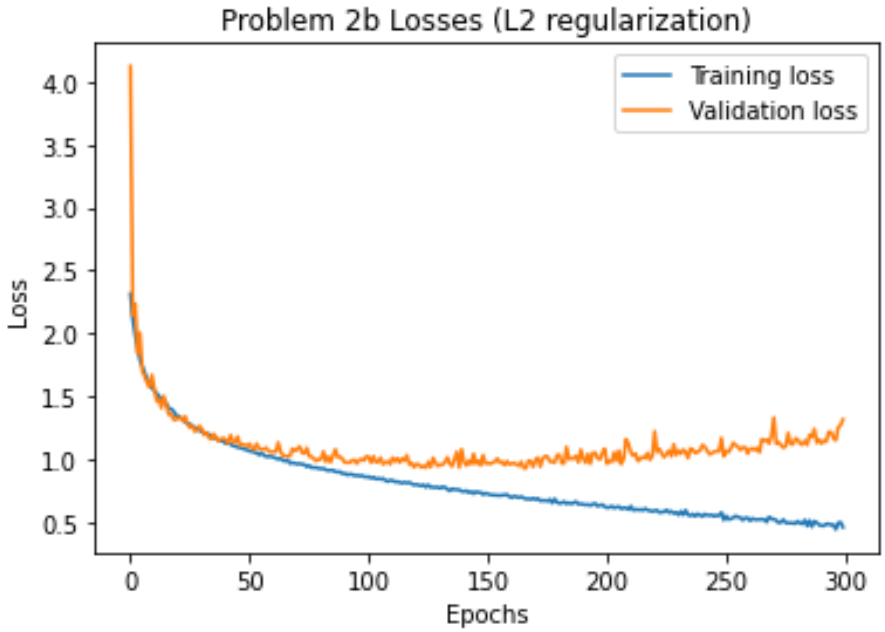
Comparing the three training to problem 1 part a, the CNN in problem 1a had a better accuracy and shorter training time then all the three training.

Problem 2 part b output (L2 regularization)

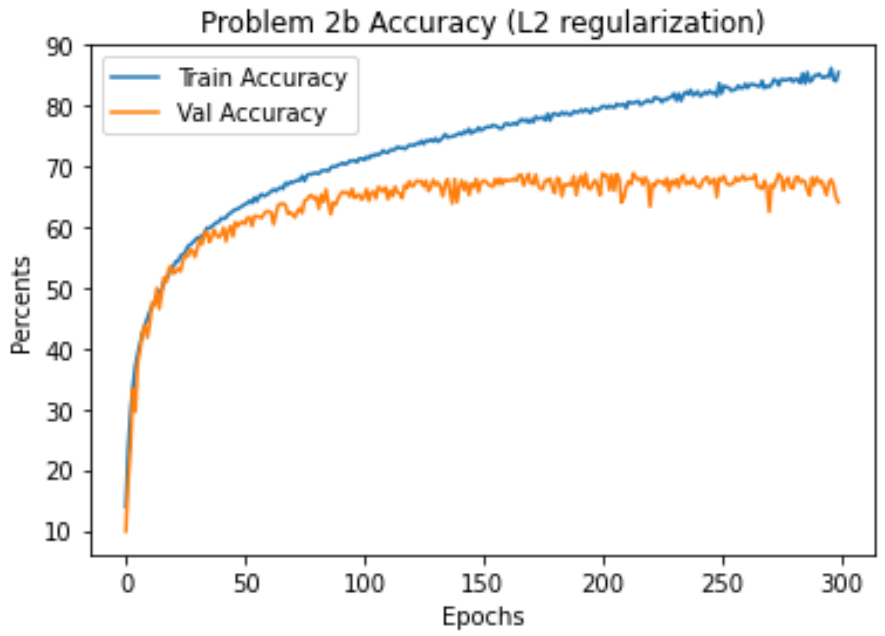
```
Epoch: 1, Training Loss: 2.3142274545163524, Validation Loss: 4.1238309144973755, Train Accuracy: 13.919999999999998%,
Validation Accuracy: 9.85%
Epoch: 10, Training Loss: 1.575825394416342, Validation Loss: 1.6705918431282043, Train Accuracy: 44.882%,
Validation Accuracy: 41.8%
Epoch: 20, Training Loss: 1.3500861221430254, Validation Loss: 1.3114459753036498, Train Accuracy: 53.33%,
Validation Accuracy: 53.63%
Epoch: 30, Training Loss: 1.2328011794966094, Validation Loss: 1.263883078098297, Train Accuracy: 57.838%,
Validation Accuracy: 55.11000000000001%
Epoch: 40, Training Loss: 1.143428019114903, Validation Loss: 1.1672658324241638, Train Accuracy: 60.870000000000005%,
Validation Accuracy: 58.34%
Epoch: 50, Training Loss: 1.0749626183996395, Validation Loss: 1.1074361205101013, Train Accuracy: 63.528%,
Validation Accuracy: 60.9%
Epoch: 60, Training Loss: 1.0209610316218163, Validation Loss: 1.0571848034858704, Train Accuracy: 65.346%,
Validation Accuracy: 62.61%
Epoch: 70, Training Loss: 0.9682030166898455, Validation Loss: 1.064701998233795, Train Accuracy: 67.45400000000001%,
Validation Accuracy: 62.45%
Epoch: 80, Training Loss: 0.9278382756272141, Validation Loss: 0.9997530221939087, Train Accuracy: 68.94%,
Validation Accuracy: 64.67%
Epoch: 90, Training Loss: 0.8847817717766275, Validation Loss: 1.0017371594905853, Train Accuracy: 70.256%,
Validation Accuracy: 64.7%
Epoch: 100, Training Loss: 0.8583354305247871, Validation Loss: 1.023037165403366, Train Accuracy: 71.344%,
Validation Accuracy: 64.56%
Epoch: 110, Training Loss: 0.8333709507572408, Validation Loss: 0.9612559080123901, Train Accuracy: 72.304%,
Validation Accuracy: 66.57%
Epoch: 120, Training Loss: 0.7956217393583181, Validation Loss: 0.936178320646286, Train Accuracy: 73.556%,
Validation Accuracy: 67.57%
Epoch: 130, Training Loss: 0.7784959917165795, Validation Loss: 0.9468644380569458, Train Accuracy: 74.144%,
Validation Accuracy: 67.78999999999999%
Epoch: 140, Training Loss: 0.7455706669359791, Validation Loss: 1.0789949893951416, Train Accuracy: 75.30799999999999%,
Validation Accuracy: 64.16%
Epoch: 150, Training Loss: 0.7303874249361, Validation Loss: 0.9646796762943268, Train Accuracy: 75.94800000000001%,
Validation Accuracy: 67.32000000000001%
Epoch: 160, Training Loss: 0.7034203264178062, Validation Loss: 0.9589688122272492, Train Accuracy: 77.006%,
Validation Accuracy: 67.86%
Epoch: 170, Training Loss: 0.6908224468328514, Validation Loss: 0.940428364276886, Train Accuracy: 77.24600000000001%,
Validation Accuracy: 68.78999999999999%
Epoch: 180, Training Loss: 0.6585673568200092, Validation Loss: 1.0318988144397736, Train Accuracy: 78.598%,
Validation Accuracy: 66.59%
Epoch: 190, Training Loss: 0.6455984954931298, Validation Loss: 1.076586651802063, Train Accuracy: 78.988%,
Validation Accuracy: 65.31%
Epoch: 200, Training Loss: 0.6235856596304445, Validation Loss: 1.082159197330475, Train Accuracy: 79.586%,
Validation Accuracy: 65.31%
Epoch: 210, Training Loss: 0.6012028662525878, Validation Loss: 1.1216039180755615, Train Accuracy: 80.318%,
Validation Accuracy: 64.87%
Epoch: 220, Training Loss: 0.5846772029691812, Validation Loss: 1.02495020031929, Train Accuracy: 80.952%,
Validation Accuracy: 67.52%
Epoch: 230, Training Loss: 0.5780847638237233, Validation Loss: 1.0342690408229829, Train Accuracy: 81.478%,
Validation Accuracy: 67.61%
Epoch: 240, Training Loss: 0.5573226505396317, Validation Loss: 1.0671584606170654, Train Accuracy: 81.972%,
Validation Accuracy: 67.11%
Epoch: 250, Training Loss: 0.5171754281131589, Validation Loss: 1.023002988100052, Train Accuracy: 83.74000000000001%,
Validation Accuracy: 68.08%
Epoch: 260, Training Loss: 0.533476430542615, Validation Loss: 1.0454317808151246, Train Accuracy: 82.966%,
Validation Accuracy: 68.52000000000001%
Epoch: 270, Training Loss: 0.5258905692976348, Validation Loss: 1.1837811112403869, Train Accuracy: 83.314%,
Validation Accuracy: 66.60000000000001%
Epoch: 280, Training Loss: 0.4889177211693355, Validation Loss: 1.163470995426178, Train Accuracy: 84.52%,
Validation Accuracy: 66.53999999999999%
Epoch: 290, Training Loss: 0.4787518388154555, Validation Loss: 1.1583162307739259, Train Accuracy: 85.026%,
Validation Accuracy: 66.95%
Epoch: 300, Training Loss: 0.46078920546843083, Validation Loss: 1.3157394528388977, Train Accuracy: 85.502%,
Validation Accuracy: 64.12%

Final Loss: 0.46078920546843083, Final Training Accuracy: 85.502%, Final Val Accuracy: 64.12%
Training Time: 1394.76 seconds
```

In cell In[28], I plot the losses and in cell IN[29], I plotted the accuracy of the model.

Problem 2 part B Loss Graph (L2 regularization)



Problem 2 part B Accuracy Graph (L2 regularization)

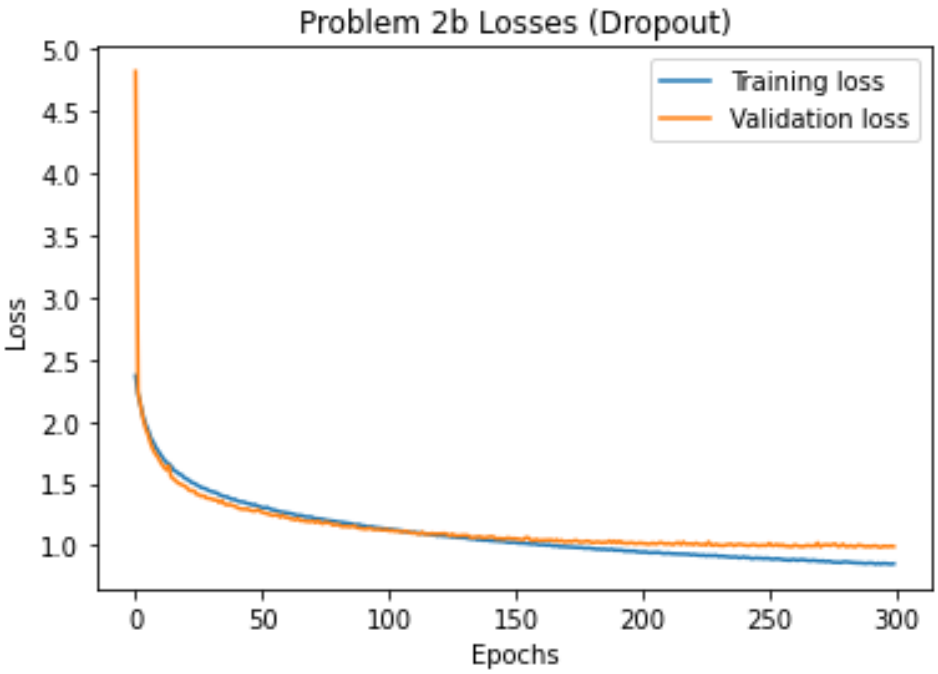


Problem 2 part b output (Dropout)

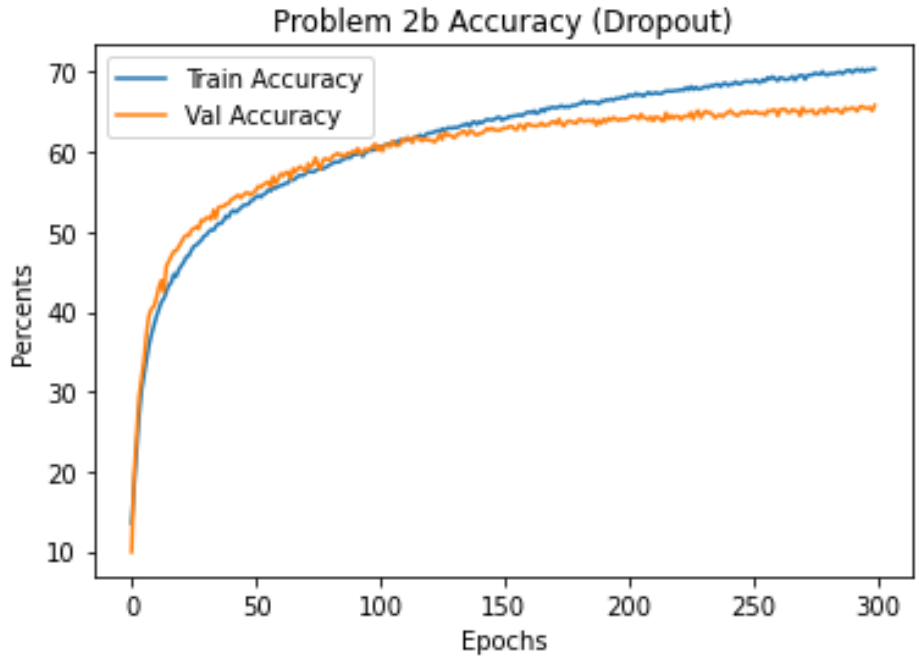
```
Epoch: 1, Training Loss: 2.367990965745887, Validation Loss: 4.822448825836181, Train Accuracy: 13.522%,
Validation Accuracy: 9.91%
Epoch: 10, Training Loss: 1.7582410938885746, Validation Loss: 1.70624897480011, Train Accuracy: 38.31800000000005%,
Validation Accuracy: 40.65%
Epoch: 20, Training Loss: 1.5501156996707528, Validation Loss: 1.4821787476539612, Train Accuracy: 45.245999999999995%,
Validation Accuracy: 48.18%
Epoch: 30, Training Loss: 1.4407451906982733, Validation Loss: 1.3800381898880005, Train Accuracy: 49.403999999999996%,
Validation Accuracy: 51.33%
Epoch: 40, Training Loss: 1.3726884905172854, Validation Loss: 1.3182076454162597, Train Accuracy: 51.803999999999995%,
Validation Accuracy: 53.49%
Epoch: 50, Training Loss: 1.312596819838699, Validation Loss: 1.2776867508888246, Train Accuracy: 53.99%,
Validation Accuracy: 54.879999999999995%
Epoch: 60, Training Loss: 1.2667997005034466, Validation Loss: 1.2258456230163575, Train Accuracy: 55.65%,
Validation Accuracy: 56.69%
Epoch: 70, Training Loss: 1.2298871376076523, Validation Loss: 1.1914692521095276, Train Accuracy: 57.06%,
Validation Accuracy: 57.85%
Epoch: 80, Training Loss: 1.1932431556740586, Validation Loss: 1.168636178970337, Train Accuracy: 58.211999999999996%,
Validation Accuracy: 59.019999999999996%
Epoch: 90, Training Loss: 1.15898504305859, Validation Loss: 1.1378766655921937, Train Accuracy: 59.67400000000001%,
Validation Accuracy: 60.07%
Epoch: 100, Training Loss: 1.132236833475074, Validation Loss: 1.129099977016449, Train Accuracy: 60.626000000000005%,
Validation Accuracy: 60.199999999999996%
Epoch: 110, Training Loss: 1.1028731185562757, Validation Loss: 1.0999318957328796, Train Accuracy: 61.41799999999999%,
Validation Accuracy: 61.61%
Epoch: 120, Training Loss: 1.0765865335659104, Validation Loss: 1.0925630331039429, Train Accuracy: 62.342%,
Validation Accuracy: 61.5%
Epoch: 130, Training Loss: 1.060942534281283, Validation Loss: 1.0816362380981446, Train Accuracy: 62.978%,
Validation Accuracy: 61.91%
Epoch: 140, Training Loss: 1.0430015228232559, Validation Loss: 1.0669136047363281, Train Accuracy: 63.452%,
Validation Accuracy: 62.11%
Epoch: 150, Training Loss: 1.0274162365465749, Validation Loss: 1.0559451222419738, Train Accuracy: 63.968%,
Validation Accuracy: 62.849999999999994%
Epoch: 160, Training Loss: 1.0048301317253892, Validation Loss: 1.0397932827472687, Train Accuracy: 64.932%,
Validation Accuracy: 63.480000000000004%
Epoch: 170, Training Loss: 0.990006832443938, Validation Loss: 1.0275482296943665, Train Accuracy: 65.606%,
Validation Accuracy: 63.77%
Epoch: 180, Training Loss: 0.9793227278456396, Validation Loss: 1.0322331726551055, Train Accuracy: 65.852%,
Validation Accuracy: 63.59%
Epoch: 190, Training Loss: 0.9603690541520411, Validation Loss: 1.0353974938392638, Train Accuracy: 66.378%,
Validation Accuracy: 63.56%
Epoch: 200, Training Loss: 0.9484936680112567, Validation Loss: 1.021116954088211, Train Accuracy: 66.768%,
Validation Accuracy: 64.11%
Epoch: 210, Training Loss: 0.9347131471244656, Validation Loss: 1.0102991163730621, Train Accuracy: 67.23400000000001%,
Validation Accuracy: 64.4%
Epoch: 220, Training Loss: 0.9229391424023375, Validation Loss: 1.0135547995567322, Train Accuracy: 67.684%,
Validation Accuracy: 64.49000000000001%
Epoch: 230, Training Loss: 0.9202546963886339, Validation Loss: 1.0101924300193788, Train Accuracy: 67.91199999999999%,
Validation Accuracy: 64.31%
Epoch: 240, Training Loss: 0.9021264521443114, Validation Loss: 1.007382720708847, Train Accuracy: 68.61%,
Validation Accuracy: 64.79%
Epoch: 250, Training Loss: 0.8976141068400169, Validation Loss: 0.9992087543010711, Train Accuracy: 68.77%,
Validation Accuracy: 64.85%
Epoch: 260, Training Loss: 0.8869724662936463, Validation Loss: 0.9912411510944367, Train Accuracy: 69.144%,
Validation Accuracy: 65.28%
Epoch: 270, Training Loss: 0.8743213694922778, Validation Loss: 1.02087544798851, Train Accuracy: 69.57799999999999%,
Validation Accuracy: 64.53%
Epoch: 280, Training Loss: 0.8664016151914791, Validation Loss: 1.009973120689392, Train Accuracy: 69.702%,
Validation Accuracy: 64.85%
Epoch: 290, Training Loss: 0.8575294978764593, Validation Loss: 0.9940951764583588, Train Accuracy: 70.216%,
Validation Accuracy: 65.38000000000001%
Epoch: 300, Training Loss: 0.8524240194534769, Validation Loss: 0.9911846339702606, Train Accuracy: 70.37%,
Validation Accuracy: 65.82000000000001%

Final Loss: 0.8524240194534769, Final Training Accuracy: 70.37%, Final Val Accuracy: 65.82000000000001%
Training Time: 1071.67 seconds
```

In cell In[32], I plot the losses and in cell IN[33], I plotted the accuracy of the model.

Problem 2 part B Loss Graph (L2 regularization)



Problem 2 part B Accuracy Graph (L2 regularization)

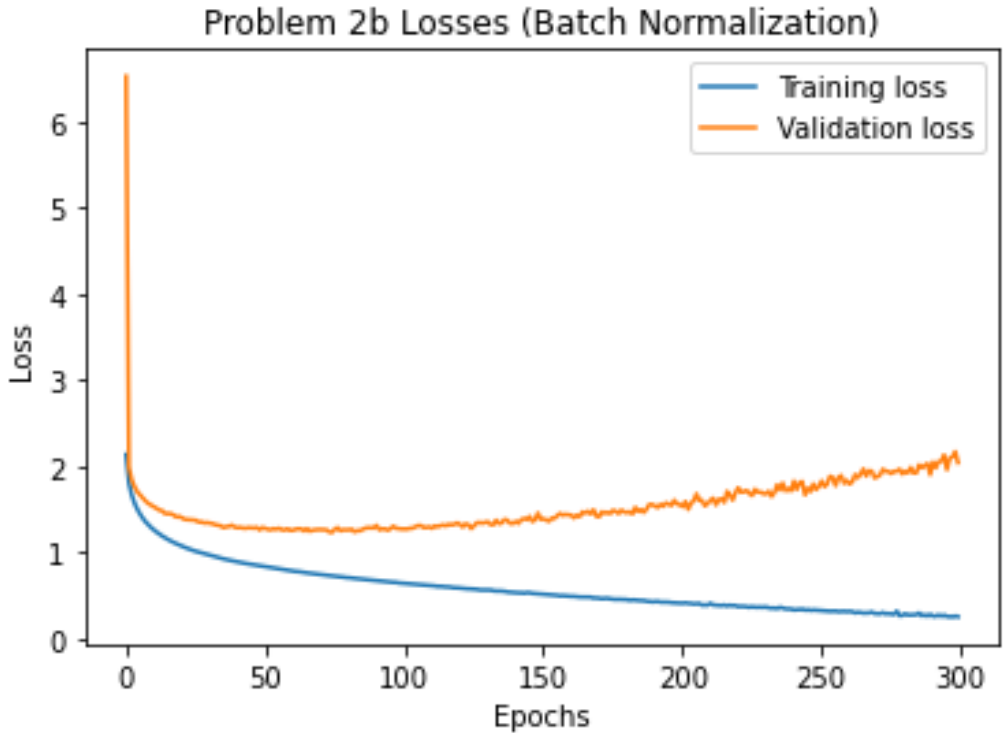


Problem 2 part b output (Batch Normalization)

```
Epoch: 1, Training Loss: 2.134947188046514, Validation Loss: 6.530372667312622, Train Accuracy: 23.188%,
Validation Accuracy: 9.030000000000001%
Epoch: 10, Training Loss: 1.2864108912798824, Validation Loss: 1.5457259178161622, Train Accuracy: 54.172%,
Validation Accuracy: 44.81%
Epoch: 20, Training Loss: 1.08544721287124, Validation Loss: 1.4156354308128356, Train Accuracy: 61.756%,
Validation Accuracy: 49.78%
Epoch: 30, Training Loss: 0.971721483736622, Validation Loss: 1.343389105796814, Train Accuracy: 66.12599999999999%,
Validation Accuracy: 52.28%
Epoch: 40, Training Loss: 0.8942666820117405, Validation Loss: 1.2909228205680847, Train Accuracy: 68.958%,
Validation Accuracy: 54.6%
Epoch: 50, Training Loss: 0.8348093774853921, Validation Loss: 1.2875849723815918, Train Accuracy: 71.084%,
Validation Accuracy: 54.620000000000005%
Epoch: 60, Training Loss: 0.7852898629344239, Validation Loss: 1.2532994747161865, Train Accuracy: 72.95%,
Validation Accuracy: 55.589999999999996%
Epoch: 70, Training Loss: 0.7439052280114622, Validation Loss: 1.2634387493133545, Train Accuracy: 74.39%,
Validation Accuracy: 55.08%
Epoch: 80, Training Loss: 0.7049869894981384, Validation Loss: 1.2581091284751893, Train Accuracy: 75.878%,
Validation Accuracy: 55.489999999999995%
Epoch: 90, Training Loss: 0.6733198019922996, Validation Loss: 1.2819584727287292, Train Accuracy: 77.00399999999999%,
Validation Accuracy: 54.37%
Epoch: 100, Training Loss: 0.6414083011296331, Validation Loss: 1.2699986219406127, Train Accuracy: 78.14%,
Validation Accuracy: 54.96%
Epoch: 110, Training Loss: 0.6174328217701036, Validation Loss: 1.2938064575195312, Train Accuracy: 79.018%,
Validation Accuracy: 54.43%
Epoch: 120, Training Loss: 0.5867059632223479, Validation Loss: 1.3400663495063783, Train Accuracy: 80.258%,
Validation Accuracy: 53.010000000000005%
Epoch: 130, Training Loss: 0.5620757992170295, Validation Loss: 1.3434906244277953, Train Accuracy: 81.03200000000001%,
Validation Accuracy: 53.23%
Epoch: 140, Training Loss: 0.5340441799893672, Validation Loss: 1.3343704223632813, Train Accuracy: 81.988%,
Validation Accuracy: 53.890000000000001%
Epoch: 150, Training Loss: 0.5114255517112966, Validation Loss: 1.3825472593307495, Train Accuracy: 82.98%,
Validation Accuracy: 52.59%
Epoch: 160, Training Loss: 0.48648300158734226, Validation Loss: 1.434782087802887, Train Accuracy: 83.76599999999999%,
Validation Accuracy: 51.38%
Epoch: 170, Training Loss: 0.4695691435920949, Validation Loss: 1.4183242678642274, Train Accuracy: 84.332%,
Validation Accuracy: 52.23%
Epoch: 180, Training Loss: 0.45027968591573286, Validation Loss: 1.4675779461860656, Train Accuracy: 85.04599999999999%,
Validation Accuracy: 51.160000000000004%
Epoch: 190, Training Loss: 0.42316525627155693, Validation Loss: 1.5538283824920653, Train Accuracy: 86.08200000000001%,
Validation Accuracy: 49.36%
Epoch: 200, Training Loss: 0.40919872935937374, Validation Loss: 1.5522674679756165, Train Accuracy: 86.53999999999999%,
Validation Accuracy: 49.75%
Epoch: 210, Training Loss: 0.384913474929576, Validation Loss: 1.5654204487800598, Train Accuracy: 87.488%,
Validation Accuracy: 49.96%
Epoch: 220, Training Loss: 0.38104309354509625, Validation Loss: 1.6905890941619872, Train Accuracy: 87.464%,
Validation Accuracy: 47.23%
Epoch: 230, Training Loss: 0.3586162900438114, Validation Loss: 1.6812225699424743, Train Accuracy: 88.446%,
Validation Accuracy: 47.949999999999996%
Epoch: 240, Training Loss: 0.34025941150529043, Validation Loss: 1.7125178694725036, Train Accuracy: 89.144%,
Validation Accuracy: 47.760000000000005%
Epoch: 250, Training Loss: 0.3203951649519862, Validation Loss: 1.7660947442054749, Train Accuracy: 89.67399999999999%,
Validation Accuracy: 47.620000000000005%
Epoch: 260, Training Loss: 0.3095585916723524, Validation Loss: 1.8329430937767028, Train Accuracy: 90.08800000000001%,
Validation Accuracy: 46.650000000000006%
Epoch: 270, Training Loss: 0.2880407568751549, Validation Loss: 1.863990604877472, Train Accuracy: 91.014%,
Validation Accuracy: 46.489999999999995%
Epoch: 280, Training Loss: 0.2655640280976587, Validation Loss: 1.9084888696670532, Train Accuracy: 92.078%,
Validation Accuracy: 46.29%
Epoch: 290, Training Loss: 0.277166161001945, Validation Loss: 1.901686668395996, Train Accuracy: 91.036%,
Validation Accuracy: 47.28%
Epoch: 300, Training Loss: 0.24973155406056619, Validation Loss: 2.0405576109886168, Train Accuracy: 92.374%,
Validation Accuracy: 45.61%

Final Loss: 0.24973155406056619, Final Training Accuracy: 92.374%, Final Val Accuracy: 45.61%
Training Time: 1085.71 seconds
```

In cell In[41], I plot the losses and in cell IN[42], I plotted the accuracy of the model.

Problem 2 part B Loss Graph (Batch Normalization)



Problem 2 part B Accuracy Graph (Batch Normalization)