

## Homework 4: Intro to Deep Learning (Spring 2020)

Name: Pratik Mistry

NetID: pdm79

RUID: 194008675

### Solution: Part 1

- I used NN Sequential Module of Pytorch for training and testing the model.
- I used Cross Entropy Loss Layer in model training as Pytorch Cross Entropy Layer calculates the Softmax as well as the loss simultaneously. Also, since this problem was **MULTICLASS CLASSIFICATION** problem, I had used this layer while training for calculating loss.
- For Part 1, I have used CNN having layers as per the standard Lenet Architecture defined in slide 3 and 4 of lecture 10.
- As per architecture:
  - Starting layer is Convolution2d layer with input of 3 channels and output as 6 channel with Kernel filter size as 5,5 followed by Relu function – **c1 and relu1**
  - Then I perform sub-sampling using MaxPool2d with kernel size as 2,2 and stride of 2 – **s2**
  - Further, then comes Convolution2d layer with input as 6 channels and outputs as 16 channels with Kernel filter size as 5,5 followed by Relu function – **c3 and relu3**
  - Again, I perform sub-sampling using MaxPool2d with kernel size as 2,2 and stride of 2 – **s4**
  - In the last convolution network, I have Convolution2d layer with input as 16 channels and outputs as 120 channels with Kernel filter size as 5,5 followed by Relu function – **c5, relu5**
  - Now very important task – I have to flatten the images i.e. output from convolution network so that they can be fed into fully connected layers. Thus, I have flattened the output of convolution network using torch.view() function in forward pass.
  - Then, once data is flattened, I fed it to fully connected Linear layer with input as 120 and output as 84 followed by Relu function. – **f6 and relu6**
  - Further, I again pass the data to Linear Layer with input as 84 and final output as 10 – **f7**
  - This output is passed to final LogSoftmax layer – **sig7**
- Please find the below attached image of the output. The image shows the Training Loss for each epoch, training time taken, total images tested and model accuracy.
- As seen in the images, it took around **12585.094 seconds i.e. 209.75 minutes** for training the model with 50000 training and 10000 testing CIFAR-10 images in 50 epochs. The test accuracy of the model as shown in screenshots below is **63%** (with maximum accuracy of **64%** and minimum accuracy of **42%**).
- The working code is uploaded in the assignment submitted on Sakai with name of the file as: **lenet\_cifar\_fill\_simpleLenet.py**

### Output Screenshot:

Train Epoch: 49 [31200/50000 (100%)] Loss: 1.029504

Test set: Average loss: 1.1152, Accuracy: 6174/10000 (62%)

Train Epoch: 50 [0/50000 (0%)] Loss: 1.125229

Train Epoch: 50 [1280/50000 (3%)] Loss: 1.244860

Train Epoch: 50 [2560/50000 (5%)] Loss: 1.204697

Train Epoch: 50 [3840/50000 (8%)] Loss: 1.356763

Train Epoch: 50 [5120/50000 (10%)] Loss: 1.199417

Train Epoch: 50 [6400/50000 (13%)] Loss: 1.280531

Train Epoch: 50 [7680/50000 (15%)] Loss: 1.135599

Train Epoch: 50 [8960/50000 (18%)] Loss: 1.282965

Train Epoch: 50 [10240/50000 (20%)] Loss: 1.212782

Train Epoch: 50 [11520/50000 (23%)] Loss: 1.075583

Train Epoch: 50 [12800/50000 (26%)] Loss: 1.178569

Train Epoch: 50 [14080/50000 (28%)] Loss: 1.068668

Train Epoch: 50 [15360/50000 (31%)] Loss: 1.086745

Train Epoch: 50 [16640/50000 (33%)] Loss: 1.201256

Train Epoch: 50 [17920/50000 (36%)] Loss: 1.125980

Train Epoch: 50 [19200/50000 (38%)] Loss: 1.064926

Train Epoch: 50 [20480/50000 (41%)] Loss: 1.135885

Train Epoch: 50 [21760/50000 (43%)] Loss: 1.095317

Train Epoch: 50 [23040/50000 (46%)] Loss: 1.206732

Train Epoch: 50 [24320/50000 (49%)] Loss: 1.197496

Train Epoch: 50 [25600/50000 (51%)] Loss: 1.246310

Train Epoch: 50 [26880/50000 (54%)] Loss: 1.258483

Train Epoch: 50 [28160/50000 (56%)] Loss: 1.231535

Train Epoch: 50 [29440/50000 (59%)] Loss: 1.248938

Train Epoch: 50 [30720/50000 (61%)] Loss: 1.277099

Train Epoch: 50 [32000/50000 (64%)] Loss: 1.251486

Train Epoch: 50 [33280/50000 (66%)] Loss: 1.330734

Train Epoch: 50 [34560/50000 (69%)] Loss: 1.076360

Train Epoch: 50 [35840/50000 (72%)] Loss: 1.095374

Train Epoch: 50 [37120/50000 (74%)] Loss: 1.365658

Train Epoch: 50 [38400/50000 (77%)] Loss: 1.284784

Train Epoch: 50 [39680/50000 (79%)] Loss: 1.264337

Train Epoch: 50 [40960/50000 (82%)] Loss: 1.266416

Train Epoch: 50 [42240/50000 (84%)] Loss: 1.258486

Train Epoch: 50 [43520/50000 (87%)] Loss: 1.078267

Train Epoch: 50 [44800/50000 (90%)] Loss: 1.084862

Train Epoch: 50 [46080/50000 (92%)] Loss: 1.397866

Train Epoch: 50 [47360/50000 (95%)] Loss: 1.161763

Train Epoch: 50 [48640/50000 (97%)] Loss: 1.282543

Train Epoch: 50 [31200/50000 (100%)] Loss: 0.974206

Test set: Average loss: 1.0760, Accuracy: 6299/10000 (63%)

Training and Testing total execution time is: 12585.094002962112 seconds  
(base) suketuvs-macbook:Homework 4 learning\$

## Highest and Lowest Accuracy Instances Screenshots:

```
Train Epoch: 46 [47360/50000 (95%)] Loss: 1.103572
Train Epoch: 46 [48640/50000 (97%)] Loss: 1.191046
Train Epoch: 46 [31200/50000 (100%)] Loss: 0.999330
```

Test set: Average loss: 1.1143, Accuracy: 6233/10000 (62%)

```
Train Epoch: 47 [0/50000 (0%)] Loss: 1.191525
```

```
Train Epoch: 47 [1280/50000 (3%)] Loss: 1.219772
```

```
Train Epoch: 47 [2560/50000 (5%)] Loss: 1.152667
```

```
Train Epoch: 47 [3840/50000 (8%)] Loss: 1.197093
```

```
Train Epoch: 47 [5120/50000 (10%)] Loss: 1.221347
```

```
Train Epoch: 47 [6400/50000 (13%)] Loss: 1.254939
```

```
Train Epoch: 47 [7680/50000 (15%)] Loss: 1.089707
```

```
Train Epoch: 47 [8960/50000 (18%)] Loss: 1.037553
```

```
Train Epoch: 47 [10240/50000 (20%)] Loss: 1.171953
```

```
Train Epoch: 47 [11520/50000 (23%)] Loss: 1.503402
```

```
Train Epoch: 47 [12800/50000 (26%)] Loss: 1.202148
```

```
Train Epoch: 47 [14080/50000 (28%)] Loss: 1.201825
```

```
Train Epoch: 47 [15360/50000 (31%)] Loss: 1.309072
```

```
Train Epoch: 47 [16640/50000 (33%)] Loss: 1.144891
```

```
Train Epoch: 47 [17920/50000 (36%)] Loss: 1.206199
```

```
Train Epoch: 47 [19200/50000 (38%)] Loss: 1.156717
```

```
Train Epoch: 47 [20480/50000 (41%)] Loss: 1.431814
```

```
Train Epoch: 47 [21760/50000 (43%)] Loss: 1.263548
```

```
Train Epoch: 47 [23040/50000 (46%)] Loss: 1.179080
```

```
Train Epoch: 47 [24320/50000 (49%)] Loss: 1.371322
```

```
Train Epoch: 47 [25600/50000 (51%)] Loss: 1.326530
```

```
Train Epoch: 47 [26880/50000 (54%)] Loss: 1.230185
```

```
Train Epoch: 47 [28160/50000 (56%)] Loss: 1.244146
```

```
Train Epoch: 47 [29440/50000 (59%)] Loss: 1.213389
```

```
Train Epoch: 47 [30720/50000 (61%)] Loss: 1.191503
```

```
Train Epoch: 47 [32000/50000 (64%)] Loss: 1.263563
```

```
Train Epoch: 47 [33280/50000 (66%)] Loss: 1.053294
```

```
Train Epoch: 47 [34560/50000 (69%)] Loss: 0.951773
```

```
Train Epoch: 47 [35840/50000 (72%)] Loss: 1.260698
```

```
Train Epoch: 47 [37120/50000 (74%)] Loss: 1.254975
```

```
Train Epoch: 47 [38400/50000 (77%)] Loss: 1.158039
```

```
Train Epoch: 47 [39680/50000 (79%)] Loss: 1.264743
```

```
Train Epoch: 47 [40960/50000 (82%)] Loss: 1.247883
```

```
Train Epoch: 47 [42240/50000 (84%)] Loss: 1.220163
```

```
Train Epoch: 47 [43520/50000 (87%)] Loss: 1.314612
```

```
Train Epoch: 47 [44800/50000 (90%)] Loss: 1.406667
```

```
Train Epoch: 47 [46080/50000 (92%)] Loss: 1.086889
```

```
Train Epoch: 47 [47360/50000 (95%)] Loss: 1.240705
```

```
Train Epoch: 47 [48640/50000 (97%)] Loss: 1.358618
```

```
Train Epoch: 47 [31200/50000 (100%)] Loss: 1.004008
```

Test set: Average loss: 1.0857, Accuracy: 6358/10000 (64%)

```
==> Preparing data..
```

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Files already downloaded and verified
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```
Train Epoch: 1 [0/50000 (0%)] Loss: 2.306113
```

```
Train Epoch: 1 [1280/50000 (3%)] Loss: 2.289235
```

```
Train Epoch: 1 [2560/50000 (5%)] Loss: 2.249223
```

```
Train Epoch: 1 [3840/50000 (8%)] Loss: 2.117498
```

```
Train Epoch: 1 [5120/50000 (10%)] Loss: 2.122227
```

```
Train Epoch: 1 [6400/50000 (13%)] Loss: 2.072846
```

```
Train Epoch: 1 [7680/50000 (15%)] Loss: 1.949904
```

```
Train Epoch: 1 [8960/50000 (18%)] Loss: 1.909206
```

```
Train Epoch: 1 [10240/50000 (20%)] Loss: 1.950759
```

```
Train Epoch: 1 [11520/50000 (23%)] Loss: 2.058961
```

```
Train Epoch: 1 [12800/50000 (26%)] Loss: 2.016342
```

```
Train Epoch: 1 [14080/50000 (28%)] Loss: 1.857335
```

```
Train Epoch: 1 [15360/50000 (31%)] Loss: 2.122981
```

```
Train Epoch: 1 [16640/50000 (33%)] Loss: 2.003169
```

```
Train Epoch: 1 [17920/50000 (36%)] Loss: 1.782558
```

```
Train Epoch: 1 [19200/50000 (38%)] Loss: 1.698505
```

```
Train Epoch: 1 [20480/50000 (41%)] Loss: 1.654454
```

```
Train Epoch: 1 [21760/50000 (43%)] Loss: 1.754847
```

```
Train Epoch: 1 [23040/50000 (46%)] Loss: 1.696190
```

```
Train Epoch: 1 [24320/50000 (49%)] Loss: 1.665604
```

```
Train Epoch: 1 [25600/50000 (51%)] Loss: 1.775698
```

```
Train Epoch: 1 [26880/50000 (54%)] Loss: 1.867196
```

```
Train Epoch: 1 [28160/50000 (56%)] Loss: 1.794928
```

```
Train Epoch: 1 [29440/50000 (59%)] Loss: 1.835672
```

```
Train Epoch: 1 [30720/50000 (61%)] Loss: 1.723791
```

```
Train Epoch: 1 [32000/50000 (64%)] Loss: 1.803810
```

```
Train Epoch: 1 [33280/50000 (66%)] Loss: 1.797782
```

```
Train Epoch: 1 [34560/50000 (69%)] Loss: 1.666463
```

```
Train Epoch: 1 [35840/50000 (72%)] Loss: 1.662516
```

```
Train Epoch: 1 [37120/50000 (74%)] Loss: 1.659364
```

```
Train Epoch: 1 [38400/50000 (77%)] Loss: 1.788631
```

```
Train Epoch: 1 [39680/50000 (79%)] Loss: 1.697206
```

```
Train Epoch: 1 [40960/50000 (82%)] Loss: 1.673193
```

```
Train Epoch: 1 [42240/50000 (84%)] Loss: 1.655344
```

```
Train Epoch: 1 [43520/50000 (87%)] Loss: 1.726182
```

```
Train Epoch: 1 [44800/50000 (90%)] Loss: 1.682515
```

```
Train Epoch: 1 [46080/50000 (92%)] Loss: 1.775005
```

```
Train Epoch: 1 [47360/50000 (95%)] Loss: 1.670917
```

```
Train Epoch: 1 [48640/50000 (97%)] Loss: 1.536364
```

```
Train Epoch: 1 [31200/50000 (100%)] Loss: 1.684888
```

Test set: Average loss: 1.6082, Accuracy: 4171/10000 (42%)

## Solution: Part 2

- The model used in this part is same but only additional layer added here is Drop Out Layer with dropping rate of 0.5 (commonly rate used widely).
- As per previous architecture, I have added dropout layer after c3 and relu3 – **drop3**
- Please find the below attached image of the output. The image shows the Training Loss for each epoch, training time taken, total images tested and model accuracy.
- As seen in the images, it took around **12313.83 seconds i.e. 205.23 minutes** for training the model with 50000 training and 10000 testing CIFAR-10 images in 50 epochs. The test accuracy of the model as shown in screenshots below is **50%** (with maximum accuracy of **51%** and minimum accuracy of **35%**).
- The working code is uploaded in the assignment submitted on Sakai with name of the file as: **lenet\_cifar\_fill\_withDropout.py**



### Output Screenshot:

Train Epoch: 49 [31200/50000 (100%)] Loss: 1.573358

Test set: Average loss: 1.4641, Accuracy: 5052/10000 (51%)

Train Epoch: 50 [0/50000 (0%)] Loss: 1.689967

Train Epoch: 50 [1280/50000 (3%)] Loss: 1.820355

Train Epoch: 50 [2560/50000 (5%)] Loss: 1.663943

Train Epoch: 50 [3840/50000 (8%)] Loss: 1.592295

Train Epoch: 50 [5120/50000 (10%)] Loss: 1.739825

Train Epoch: 50 [6400/50000 (13%)] Loss: 1.666566

Train Epoch: 50 [7680/50000 (15%)] Loss: 1.594639

Train Epoch: 50 [8960/50000 (18%)] Loss: 1.756143

Train Epoch: 50 [10240/50000 (20%)] Loss: 1.714026

Train Epoch: 50 [11520/50000 (23%)] Loss: 1.566132

Train Epoch: 50 [12800/50000 (26%)] Loss: 1.620073

Train Epoch: 50 [14080/50000 (28%)] Loss: 1.705844

Train Epoch: 50 [15360/50000 (31%)] Loss: 1.689781

Train Epoch: 50 [16640/50000 (33%)] Loss: 1.589747

Train Epoch: 50 [17920/50000 (36%)] Loss: 1.648528

Train Epoch: 50 [19200/50000 (38%)] Loss: 1.575086

Train Epoch: 50 [20480/50000 (41%)] Loss: 1.689997

Train Epoch: 50 [21760/50000 (43%)] Loss: 1.631271

Train Epoch: 50 [23040/50000 (46%)] Loss: 1.576110

Train Epoch: 50 [24320/50000 (49%)] Loss: 1.597651

Train Epoch: 50 [25600/50000 (51%)] Loss: 1.529920

Train Epoch: 50 [26880/50000 (54%)] Loss: 1.662527

Train Epoch: 50 [28160/50000 (56%)] Loss: 1.600183

Train Epoch: 50 [29440/50000 (59%)] Loss: 1.622052

Train Epoch: 50 [30720/50000 (61%)] Loss: 1.545488

Train Epoch: 50 [32000/50000 (64%)] Loss: 1.831696

Train Epoch: 50 [33280/50000 (66%)] Loss: 1.607157

Train Epoch: 50 [34560/50000 (69%)] Loss: 1.680118

Train Epoch: 50 [35840/50000 (72%)] Loss: 1.606895

Train Epoch: 50 [37120/50000 (74%)] Loss: 1.627849

Train Epoch: 50 [38400/50000 (77%)] Loss: 1.628053

Train Epoch: 50 [39680/50000 (79%)] Loss: 1.823901

Train Epoch: 50 [40960/50000 (82%)] Loss: 1.742696

Train Epoch: 50 [42240/50000 (84%)] Loss: 1.592051

Train Epoch: 50 [43520/50000 (87%)] Loss: 1.585951

Train Epoch: 50 [44800/50000 (90%)] Loss: 1.670985

Train Epoch: 50 [46080/50000 (92%)] Loss: 1.506367

Train Epoch: 50 [47360/50000 (95%)] Loss: 1.576654

Train Epoch: 50 [48640/50000 (97%)] Loss: 1.712317

Train Epoch: 50 [31200/50000 (100%)] Loss: 1.885422

Test set: Average loss: 1.4248, Accuracy: 5046/10000 (50%)

Training and Testing total execution time is: 12313.83422589302 seconds  
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### Highest and Lowest Accuracy Instances Screenshots:

```
Train Epoch: 48 [46080/50000 (92%)] Loss: 1.653619 ==> Preparing data..
Train Epoch: 48 [47360/50000 (95%)] Loss: 1.713233 Files already downloaded and verified
Train Epoch: 48 [48640/50000 (97%)] Loss: 1.646441 Files already downloaded and verified
Train Epoch: 48 [31200/50000 (100%)] Loss: 1.721749 Train Epoch: 1 [0/50000 (0%)] Loss: 2.306469

Test set: Average loss: 1.4469, Accuracy: 5056/10000 (51%) Train Epoch: 1 [1280/50000 (3%)] Loss: 2.286315
Train Epoch: 1 [2560/50000 (5%)] Loss: 2.280072
Train Epoch: 1 [3840/50000 (8%)] Loss: 2.189555
Train Epoch: 1 [5120/50000 (10%)] Loss: 2.156658
Train Epoch: 1 [6400/50000 (13%)] Loss: 2.144702
Train Epoch: 1 [7680/50000 (15%)] Loss: 2.132850
Train Epoch: 1 [8960/50000 (18%)] Loss: 2.104632
Train Epoch: 1 [10240/50000 (20%)] Loss: 2.150396
Train Epoch: 1 [11520/50000 (23%)] Loss: 2.125503
Train Epoch: 1 [12800/50000 (26%)] Loss: 2.163872
Train Epoch: 1 [14080/50000 (28%)] Loss: 2.078036
Train Epoch: 1 [15360/50000 (31%)] Loss: 2.054228
Train Epoch: 1 [16640/50000 (33%)] Loss: 2.093958
Train Epoch: 1 [17920/50000 (36%)] Loss: 2.052346
Train Epoch: 1 [19200/50000 (38%)] Loss: 1.943268
Train Epoch: 1 [20480/50000 (41%)] Loss: 1.911382
Train Epoch: 1 [21760/50000 (43%)] Loss: 2.024103
Train Epoch: 1 [23040/50000 (46%)] Loss: 2.010751
Train Epoch: 1 [24320/50000 (49%)] Loss: 1.805103
Train Epoch: 1 [25600/50000 (51%)] Loss: 1.902311
Train Epoch: 1 [26880/50000 (54%)] Loss: 2.025701
Train Epoch: 1 [28160/50000 (56%)] Loss: 1.950711
Train Epoch: 1 [29440/50000 (59%)] Loss: 2.012343
Train Epoch: 1 [30720/50000 (61%)] Loss: 1.997214
Train Epoch: 1 [32000/50000 (64%)] Loss: 2.007530
Train Epoch: 1 [33280/50000 (66%)] Loss: 2.034030
Train Epoch: 1 [34560/50000 (69%)] Loss: 1.967550
Train Epoch: 1 [35840/50000 (72%)] Loss: 1.809634
Train Epoch: 1 [37120/50000 (74%)] Loss: 1.821248
Train Epoch: 1 [38400/50000 (77%)] Loss: 1.989944
Train Epoch: 1 [39680/50000 (79%)] Loss: 1.829383
Train Epoch: 1 [40960/50000 (82%)] Loss: 1.936717
Train Epoch: 1 [42240/50000 (84%)] Loss: 1.773548
Train Epoch: 1 [43520/50000 (87%)] Loss: 1.921857
Train Epoch: 1 [44800/50000 (90%)] Loss: 1.911771
Train Epoch: 1 [46080/50000 (92%)] Loss: 2.022832
Train Epoch: 1 [47360/50000 (95%)] Loss: 1.856020
Train Epoch: 1 [48640/50000 (97%)] Loss: 1.838208
Train Epoch: 1 [31200/50000 (100%)] Loss: 1.945603

Train Epoch: 49 [0/50000 (0%)] Loss: 1.670865
Train Epoch: 49 [1280/50000 (3%)] Loss: 1.466738
Train Epoch: 49 [2560/50000 (5%)] Loss: 1.525600
Train Epoch: 49 [3840/50000 (8%)] Loss: 1.630831
Train Epoch: 49 [5120/50000 (10%)] Loss: 1.565377
Train Epoch: 49 [6400/50000 (13%)] Loss: 1.508455
Train Epoch: 49 [7680/50000 (15%)] Loss: 1.598625
Train Epoch: 49 [8960/50000 (18%)] Loss: 1.678858
Train Epoch: 49 [10240/50000 (20%)] Loss: 1.752916
Train Epoch: 49 [11520/50000 (23%)] Loss: 1.542841
Train Epoch: 49 [12800/50000 (26%)] Loss: 1.631749
Train Epoch: 49 [14080/50000 (28%)] Loss: 1.591885
Train Epoch: 49 [15360/50000 (31%)] Loss: 1.555028
Train Epoch: 49 [16640/50000 (33%)] Loss: 1.771459
Train Epoch: 49 [17920/50000 (36%)] Loss: 1.573587
Train Epoch: 49 [19200/50000 (38%)] Loss: 1.668903
Train Epoch: 49 [20480/50000 (41%)] Loss: 1.631507
Train Epoch: 49 [21760/50000 (43%)] Loss: 1.517300
Train Epoch: 49 [23040/50000 (46%)] Loss: 1.680740
Train Epoch: 49 [24320/50000 (49%)] Loss: 1.586239
Train Epoch: 49 [25600/50000 (51%)] Loss: 1.669891
Train Epoch: 49 [26880/50000 (54%)] Loss: 1.617434
Train Epoch: 49 [28160/50000 (56%)] Loss: 1.582016
Train Epoch: 49 [29440/50000 (59%)] Loss: 1.649186
Train Epoch: 49 [30720/50000 (61%)] Loss: 1.673118
Train Epoch: 49 [32000/50000 (64%)] Loss: 1.542012
Train Epoch: 49 [33280/50000 (66%)] Loss: 1.636902
Train Epoch: 49 [34560/50000 (69%)] Loss: 1.609767
Train Epoch: 49 [35840/50000 (72%)] Loss: 1.651263
Train Epoch: 49 [37120/50000 (74%)] Loss: 1.768163
Train Epoch: 49 [38400/50000 (77%)] Loss: 1.585757
Train Epoch: 49 [39680/50000 (79%)] Loss: 1.711917
Train Epoch: 49 [40960/50000 (82%)] Loss: 1.666886
Train Epoch: 49 [42240/50000 (84%)] Loss: 1.537219
Train Epoch: 49 [43520/50000 (87%)] Loss: 1.701667
Train Epoch: 49 [44800/50000 (90%)] Loss: 1.641025
Train Epoch: 49 [46080/50000 (92%)] Loss: 1.752250
Train Epoch: 49 [47360/50000 (95%)] Loss: 1.547186
Train Epoch: 49 [48640/50000 (97%)] Loss: 1.800546
Train Epoch: 49 [31200/50000 (100%)] Loss: 1.573358

Test set: Average loss: 1.4641, Accuracy: 5052/10000 (51%) Test set: Average loss: 1.7612, Accuracy: 3485/10000 (35%)
```

### Solution: Part 3

- The model used in this part is same as Part 2, but only additional layer added here is Batch Normalization Layer with dropping rate of 0.5 (commonly rate used widely).
- As per previous architecture, I have added batch normalization layer between c1 and relu1 – **bn1**
- Please find the below attached image of the output. The image shows the Training Loss for each epoch, training time taken, total images tested and model accuracy.



- As seen in the images, it took around **12906.69 seconds i.e. 215.11 minutes** for training the model with 50000 training and 10000 testing CIFAR-10 images in 50 epochs. The test accuracy of the model as shown in screenshots below is **53%** (with maximum accuracy of **55%** and minimum accuracy of **37%**).
- The working code is uploaded in the assignment submitted on Sakai with name of the file as: **lenet\_cifar\_fill\_withDropout\_BatchNorm.py**

#### Output Screenshot:

```

Train Epoch: 49 [31200/50000 (100%)]    Loss: 1.526820

Test set: Average loss: 1.3870, Accuracy: 5402/10000 (54%)

Train Epoch: 50 [0/50000 (0%)]    Loss: 1.457172
Train Epoch: 50 [1280/50000 (3%)]    Loss: 1.640078
Train Epoch: 50 [2560/50000 (5%)]    Loss: 1.583542
Train Epoch: 50 [3840/50000 (8%)]    Loss: 1.560820
Train Epoch: 50 [5120/50000 (10%)]    Loss: 1.548097
Train Epoch: 50 [6400/50000 (13%)]    Loss: 1.607303
Train Epoch: 50 [7680/50000 (15%)]    Loss: 1.413543
Train Epoch: 50 [8960/50000 (18%)]    Loss: 1.597417
Train Epoch: 50 [10240/50000 (20%)]    Loss: 1.559616
Train Epoch: 50 [11520/50000 (23%)]    Loss: 1.451694
Train Epoch: 50 [12800/50000 (26%)]    Loss: 1.487520
Train Epoch: 50 [14080/50000 (28%)]    Loss: 1.600344
Train Epoch: 50 [15360/50000 (31%)]    Loss: 1.496168
Train Epoch: 50 [16640/50000 (33%)]    Loss: 1.449176
Train Epoch: 50 [17920/50000 (36%)]    Loss: 1.586135
Train Epoch: 50 [19200/50000 (38%)]    Loss: 1.448774
Train Epoch: 50 [20480/50000 (41%)]    Loss: 1.520930
Train Epoch: 50 [21760/50000 (43%)]    Loss: 1.563508
Train Epoch: 50 [23040/50000 (46%)]    Loss: 1.418606
Train Epoch: 50 [24320/50000 (49%)]    Loss: 1.470488
Train Epoch: 50 [25600/50000 (51%)]    Loss: 1.450127
Train Epoch: 50 [26880/50000 (54%)]    Loss: 1.535187
Train Epoch: 50 [28160/50000 (56%)]    Loss: 1.315289
Train Epoch: 50 [29440/50000 (59%)]    Loss: 1.455583
Train Epoch: 50 [30720/50000 (61%)]    Loss: 1.394466
Train Epoch: 50 [32000/50000 (64%)]    Loss: 1.519540
Train Epoch: 50 [33280/50000 (66%)]    Loss: 1.511952
Train Epoch: 50 [34560/50000 (69%)]    Loss: 1.555609
Train Epoch: 50 [35840/50000 (72%)]    Loss: 1.337845
Train Epoch: 50 [37120/50000 (74%)]    Loss: 1.626447
Train Epoch: 50 [38400/50000 (77%)]    Loss: 1.641446
Train Epoch: 50 [39680/50000 (79%)]    Loss: 1.612864
Train Epoch: 50 [40960/50000 (82%)]    Loss: 1.513570
Train Epoch: 50 [42240/50000 (84%)]    Loss: 1.492908
Train Epoch: 50 [43520/50000 (87%)]    Loss: 1.446671
Train Epoch: 50 [44800/50000 (90%)]    Loss: 1.407869
Train Epoch: 50 [46080/50000 (92%)]    Loss: 1.466178
Train Epoch: 50 [47360/50000 (95%)]    Loss: 1.582310
Train Epoch: 50 [48640/50000 (97%)]    Loss: 1.413536
Train Epoch: 50 [31200/50000 (100%)]    Loss: 1.530218

Test set: Average loss: 1.3977, Accuracy: 5338/10000 (53%)

Traning and Testing total excution time is: 12906.694432973862 seconds
(base) suketuvs@macbook:Homework 4 learning$

```

### Highest and Lowest Accuracy Instances Screenshots:

Train Epoch: 41 [47360/50000 (95%)]	Loss: 1.507240	==> Preparing data..
Train Epoch: 41 [48640/50000 (97%)]	Loss: 1.795637	Files already downloaded and verified
Train Epoch: 41 [31200/50000 (100%)]	Loss: 1.365326	Files already downloaded and verified
Test set: Average loss: 1.4179, Accuracy: 5247/10000 (52%)		Train Epoch: 1 [0/50000 (0%)] Loss: 2.306641
Train Epoch: 42 [0/50000 (0%)]	Loss: 1.637617	Train Epoch: 1 [1280/50000 (3%)] Loss: 2.291321
Train Epoch: 42 [1280/50000 (3%)]	Loss: 1.486123	Train Epoch: 1 [2560/50000 (5%)] Loss: 2.268549
Train Epoch: 42 [2560/50000 (5%)]	Loss: 1.532227	Train Epoch: 1 [3840/50000 (8%)] Loss: 2.149189
Train Epoch: 42 [3840/50000 (8%)]	Loss: 1.415230	Train Epoch: 1 [5120/50000 (10%)] Loss: 2.109068
Train Epoch: 42 [5120/50000 (10%)]	Loss: 1.399195	Train Epoch: 1 [6400/50000 (13%)] Loss: 2.152636
Train Epoch: 42 [6400/50000 (13%)]	Loss: 1.443047	Train Epoch: 1 [7680/50000 (15%)] Loss: 2.121168
Train Epoch: 42 [7680/50000 (15%)]	Loss: 1.496415	Train Epoch: 1 [8960/50000 (18%)] Loss: 2.038963
Train Epoch: 42 [8960/50000 (18%)]	Loss: 1.611631	Train Epoch: 1 [10240/50000 (20%)] Loss: 2.029815
Train Epoch: 42 [10240/50000 (20%)]	Loss: 1.505659	Train Epoch: 1 [11520/50000 (23%)] Loss: 2.024567
Train Epoch: 42 [11520/50000 (23%)]	Loss: 1.769446	Train Epoch: 1 [12800/50000 (26%)] Loss: 2.141508
Train Epoch: 42 [12800/50000 (26%)]	Loss: 1.712527	Train Epoch: 1 [14080/50000 (28%)] Loss: 2.027798
Train Epoch: 42 [14080/50000 (28%)]	Loss: 1.538794	Train Epoch: 1 [15360/50000 (31%)] Loss: 1.971882
Train Epoch: 42 [15360/50000 (31%)]	Loss: 1.536543	Train Epoch: 1 [16640/50000 (33%)] Loss: 2.062033
Train Epoch: 42 [16640/50000 (33%)]	Loss: 1.656585	Train Epoch: 1 [17920/50000 (36%)] Loss: 2.015906
Train Epoch: 42 [17920/50000 (36%)]	Loss: 1.495070	Train Epoch: 1 [19200/50000 (38%)] Loss: 1.863750
Train Epoch: 42 [19200/50000 (38%)]	Loss: 1.560279	Train Epoch: 1 [20480/50000 (41%)] Loss: 1.890240
Train Epoch: 42 [20480/50000 (41%)]	Loss: 1.541649	Train Epoch: 1 [21760/50000 (43%)] Loss: 1.995157
Train Epoch: 42 [21760/50000 (43%)]	Loss: 1.586586	Train Epoch: 1 [23040/50000 (46%)] Loss: 1.931956
Train Epoch: 42 [23040/50000 (46%)]	Loss: 1.524149	Train Epoch: 1 [24320/50000 (49%)] Loss: 1.768385
Train Epoch: 42 [24320/50000 (49%)]	Loss: 1.735563	Train Epoch: 1 [25600/50000 (51%)] Loss: 1.817309
Train Epoch: 42 [25600/50000 (51%)]	Loss: 1.505457	Train Epoch: 1 [26880/50000 (54%)] Loss: 1.914566
Train Epoch: 42 [26880/50000 (54%)]	Loss: 1.322319	Train Epoch: 1 [28160/50000 (56%)] Loss: 1.840719
Train Epoch: 42 [28160/50000 (56%)]	Loss: 1.418275	Train Epoch: 1 [29440/50000 (59%)] Loss: 1.829760
Train Epoch: 42 [29440/50000 (59%)]	Loss: 1.661244	Train Epoch: 1 [30720/50000 (61%)] Loss: 1.909276
Train Epoch: 42 [30720/50000 (61%)]	Loss: 1.634753	Train Epoch: 1 [32000/50000 (64%)] Loss: 1.913740
Train Epoch: 42 [32000/50000 (64%)]	Loss: 1.457524	Train Epoch: 1 [33280/50000 (66%)] Loss: 1.935599
Train Epoch: 42 [33280/50000 (66%)]	Loss: 1.258572	Train Epoch: 1 [34560/50000 (69%)] Loss: 1.835263
Train Epoch: 42 [34560/50000 (69%)]	Loss: 1.503434	Train Epoch: 1 [35840/50000 (72%)] Loss: 1.884797
Train Epoch: 42 [35840/50000 (72%)]	Loss: 1.600702	Train Epoch: 1 [37120/50000 (74%)] Loss: 1.766270
Train Epoch: 42 [37120/50000 (74%)]	Loss: 1.452882	Train Epoch: 1 [38400/50000 (77%)] Loss: 1.861121
Train Epoch: 42 [38400/50000 (77%)]	Loss: 1.630399	Train Epoch: 1 [39680/50000 (79%)] Loss: 1.824954
Train Epoch: 42 [39680/50000 (79%)]	Loss: 1.506703	Train Epoch: 1 [40960/50000 (82%)] Loss: 1.733149
Train Epoch: 42 [40960/50000 (82%)]	Loss: 1.587360	Train Epoch: 1 [42240/50000 (84%)] Loss: 1.759499
Train Epoch: 42 [42240/50000 (84%)]	Loss: 1.589426	Train Epoch: 1 [43520/50000 (87%)] Loss: 1.973155
Train Epoch: 42 [43520/50000 (87%)]	Loss: 1.505974	Train Epoch: 1 [44800/50000 (90%)] Loss: 1.881741
Train Epoch: 42 [44800/50000 (90%)]	Loss: 1.678017	Train Epoch: 1 [46080/50000 (92%)] Loss: 1.853950
Train Epoch: 42 [46080/50000 (92%)]	Loss: 1.693745	Train Epoch: 1 [47360/50000 (95%)] Loss: 1.921476
Train Epoch: 42 [47360/50000 (95%)]	Loss: 1.529320	Train Epoch: 1 [48640/50000 (97%)] Loss: 1.765898
Train Epoch: 42 [48640/50000 (97%)]	Loss: 1.554502	Train Epoch: 1 [31200/50000 (100%)] Loss: 1.924117
Train Epoch: 42 [31200/50000 (100%)]	Loss: 1.607275	
Test set: Average loss: 1.3520, Accuracy: 5463/10000 (55%)		Test set: Average loss: 1.7259, Accuracy: 3693/10000 (37%)

### **Conclusions and Analysis:**

- Simple Lenet model has the best accuracy with maximum of 64% compared to other two variations in model.
- Adding dropout layer in Simple Lenet model after the second convolution and relu layer decreases the overall testing and training time but it results in the worst accuracy compared to Simple and third variation in Lenet Model. The maximum accuracy achieved was 51%. The total time taken was 12313.83 seconds i.e. 205.23 minutes compared to total time taken for Simple Lenet model which was 12585.094 seconds i.e. 209.75 minutes.
- The main reason why total time taken after adding dropout layer decreased by approximately 4 minutes is because dropout layer randomly drops some neurons while training and deeper layers will have to train less data. Also, reason for lower accuracy is because the common rate of 0.5 would have caused model to drop important features from images during training to avoid overfitting. Another important reason I analyze is that dropout layer with rate 0.5 **after second** convolution and relu layer would have dropped more important features because after passing training images from convolution-relu-maxpool-convolution-relu layers the images would just have important features left in them some of which gets randomly dropped in dropout layer.
- Now, adding a batch normalization to existing Lenet model having dropout layer, increased some performance accuracy with maximum of 55% which is greater than Lenet with dropout layer but less than simple lenet model.
- The reason again why accuracy in third variation is bad than Simple lenet model is because of dropout layer as mentioned in above explanation. But, the reason of better accuracy than Lenet model with dropout layer is it normalizes the data before passing the data through further layers.
- Now, the time taken was 12906.69 seconds i.e. 215.11 minutes, which is quite large, compared to earlier two variations because in each epoch for all images, it has to do data preprocessing/normalization for all images. Also, other reason is batch normalization layer is added after first convolution layer and data after first layer will be huge (comprising of important or unimportant features) compared to deeper layers where only important features remains in data.
- Lastly, the reason why my machine takes very huge total time for training and testing in 50 epochs is because of low machine configurations. Below are the relevant details:

#### ***Machine specifications are:***

- Processor: 2 GHz Intel Core 2 Duo
- Memory: 8 GB 1067 MHz DDR3
- Graphics: NVIDIA GeForce 9400M 256MB
- OS: Mac OS Yosemite 10.10.5