Project 2
Deep learning by PyTorch

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Part 1
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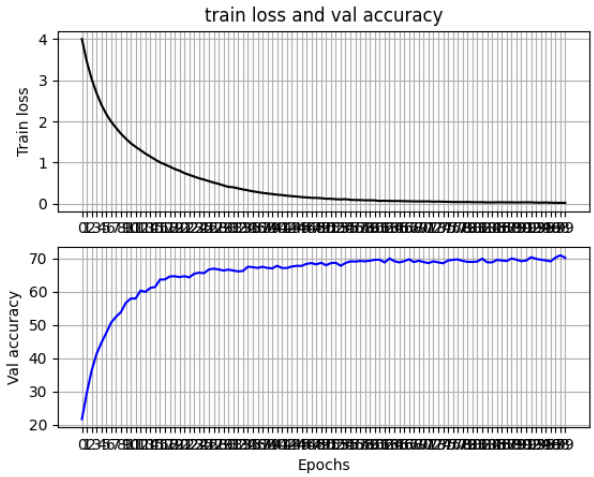
In part1, we borrowed and modified the bottleneck block from the resent structure. we added a total of 3 bottleneck blocks inside 12 convolutional layers. They are used on the fifth convolutional layer, the ninth convolutional layer and the tenth convolutional layer respectively. We finally used 4 linear layers to reduce the output channel to 100.For image processing, the normalized range was changed to [-1,1] using mean and standard deviation equal to 0.5 on all three channels.

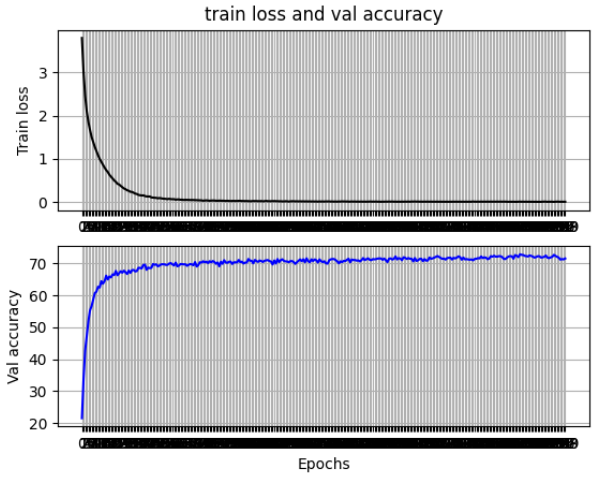
The figure below shows the structure of our network model.

Layer No.	Layer Type	Kernel Size (for Conv Layer)	Inoput|Ouput dimension	Input|Output Channels (for Conv Layer)
1	Conv2d	3	32|32	3|64
2	Bn	-	32|32	
3	Relu	-	32|32	
4	Conv2d	3	32|32	64|128
5	Bn	-	32|32	
6	Relu	-	32|32	
7	Conv2d	3	32|32	128|256
8	Bn	-	32|32	
9	Relu	-	32|32	
10	Conv2d	3	32|32	256|512
11	Bn	-	32|32	
12	Relu	-	32|32	
13	Maxpool2d	2	32|16	
14	Conv2d	3	16|16	512|256
15	Bn	-	16|16	
16	Relu	-	16|16	
17	Conv2d	3	16|16	256|512
18	Bn	-	16|16	
19	Relu	-	16|16	
20	Conv2d	3	16|16	512|1024
21	Bn	-	16|16	

22	Relu	-	16|16	
23	Conv2d	3	16|16	1024|512
24	Bn	-	16|16	
25	Relu	-	16|16	
26	Maxpool2d	2	16|8	
27	Conv2d	3	8|8	512|1024
28	Bn	-	8|8	
29	Relu	-	8|8	
30	Conv2d	3	8|8	1024|512
31	Bn	-	8|8	
32	Relu	-	8|8	
33	Conv2d	3	8|8	512|1024
34	Bn	-	8|8	
35	Relu	-	8|8	
36	Conv2d	3	8|8	1024|2048
37	Bn	-	8|8	
38	Relu	-	8|8	
39	Linear	-	2048*8*8|1024	
40	Bn1d	-	1024|1024	
41	Relu	-	1024|1024	
42	Linear	-	1024|512	
43	Bn1d	-	512|512	
44	Relu	-	512|512	
45	Linear	-	512|256	
46	Bn1d	-	256|256	
47	Relu	-	256|256	
48	Linear	-	256|100	

We ran 100 epochs and 300 epochs respectively using this network structure model. it is clear to see that overfitting occurs when the accuracy runs up to roughly 70%, and although the loss is still decreasing, the accuracy does not improve much.






```
[255] loss: 0.006
Accuracy of the network on the val images: 72 %
[256] loss: 0.006
Accuracy of the network on the val images: 72 %
[257] loss: 0.006
Accuracy of the network on the val images: 72 %
[258] loss: 0.008
Accuracy of the network on the val images: 72 %
[259] loss: 0.005
Accuracy of the network on the val images: 72 %
[260] loss: 0.006
Accuracy of the network on the val images: 72 %
[261] loss: 0.007
Accuracy of the network on the val images: 71 %
[262] loss: 0.008
Accuracy of the network on the val images: 71 %
[263] loss: 0.009
Accuracy of the network on the val images: 71 %
[264] loss: 0.006
Accuracy of the network on the val images: 71 %
[265] loss: 0.006
Accuracy of the network on the val images: 72 %
[266] loss: 0.006
Accuracy of the network on the val images: 72 %
```

Ablation Study: We only trained until the accuracy reached 63.9% on Kaggle in the first training, when we used only 5 convolutional layers. For the second training, we boosted the convolutional layers to 9 layers and the accuracy increased to 70.9% on Kaggle. We finally boosted the convolutional layers to 12 layers and the accuracy reached up to 71.7%. Additionally, we experimented with boosting to 15 convolutional layers, but the accuracy did not improve with the increase in convolutional layers.

Part 2

ResNet as a fixed feature extractor:

```
TRAINING Epoch 28/50 Loss 0.5482 Accuracy 0.2150
TRAINING Epoch 29/50 Loss 0.5434 Accuracy 0.2297
TRAINING Epoch 30/50 Loss 0.5416 Accuracy 0.2327
TRAINING Epoch 31/50 Loss 0.5379 Accuracy 0.2273
TRAINING Epoch 32/50 Loss 0.5356 Accuracy 0.2413
TRAINING Epoch 33/50 Loss 0.5313 Accuracy 0.2523
TRAINING Epoch 34/50 Loss 0.5277 Accuracy 0.2603
TRAINING Epoch 35/50 Loss 0.5230 Accuracy 0.2610
TRAINING Epoch 36/50 Loss 0.5194 Accuracy 0.2623
TRAINING Epoch 37/50 Loss 0.5196 Accuracy 0.2570
TRAINING Epoch 38/50 Loss 0.5154 Accuracy 0.2807
TRAINING Epoch 39/50 Loss 0.5117 Accuracy 0.2753
TRAINING Epoch 40/50 Loss 0.5105 Accuracy 0.2817
TRAINING Epoch 41/50 Loss 0.5066 Accuracy 0.2963
TRAINING Epoch 42/50 Loss 0.5027 Accuracy 0.3083
TRAINING Epoch 43/50 Loss 0.4982 Accuracy 0.3183
TRAINING Epoch 44/50 Loss 0.4967 Accuracy 0.3150
TRAINING Epoch 45/50 Loss 0.4954 Accuracy 0.3043
TRAINING Epoch 46/50 Loss 0.4933 Accuracy 0.3057
TRAINING Epoch 47/50 Loss 0.4870 Accuracy 0.3270
TRAINING Epoch 48/50 Loss 0.4849 Accuracy 0.3343
TRAINING Epoch 49/50 Loss 0.4840 Accuracy 0.3227
TRAINING Epoch 50/50 Loss 0.4813 Accuracy 0.3277
Finished Training
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```
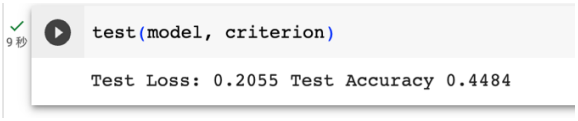

```
[16] test(model, criterion)

    Test Loss: 0.6188 Test Accuracy 0.0481
```

Fine-tuning the ResNet:
I changed the hyper parameter.

```
NUM_EPOCHS = 50
LEARNING_RATE = 0.001
BATCH_SIZE = 16
RESNET_LAST_ONLY = False
```

Using learning rate as 0.01:

```
TRAINING Epoch 26/50 Loss 0.0702 Accuracy 0.7147
TRAINING Epoch 27/50 Loss 0.0749 Accuracy 0.6927
TRAINING Epoch 28/50 Loss 0.0698 Accuracy 0.7100
TRAINING Epoch 29/50 Loss 0.0663 Accuracy 0.7370
TRAINING Epoch 30/50 Loss 0.0680 Accuracy 0.7233
TRAINING Epoch 31/50 Loss 0.0665 Accuracy 0.7210
TRAINING Epoch 32/50 Loss 0.0665 Accuracy 0.7333
TRAINING Epoch 33/50 Loss 0.0620 Accuracy 0.7473
TRAINING Epoch 34/50 Loss 0.0632 Accuracy 0.7380
TRAINING Epoch 35/50 Loss 0.0606 Accuracy 0.7500
TRAINING Epoch 36/50 Loss 0.0587 Accuracy 0.7690
TRAINING Epoch 37/50 Loss 0.0633 Accuracy 0.7443
TRAINING Epoch 38/50 Loss 0.0521 Accuracy 0.7923
TRAINING Epoch 39/50 Loss 0.0535 Accuracy 0.7850
TRAINING Epoch 40/50 Loss 0.0576 Accuracy 0.7737
TRAINING Epoch 41/50 Loss 0.0545 Accuracy 0.7773
TRAINING Epoch 42/50 Loss 0.0547 Accuracy 0.7817
TRAINING Epoch 43/50 Loss 0.0523 Accuracy 0.7850
TRAINING Epoch 44/50 Loss 0.0508 Accuracy 0.7947
TRAINING Epoch 45/50 Loss 0.0478 Accuracy 0.8017
TRAINING Epoch 46/50 Loss 0.0454 Accuracy 0.8173
TRAINING Epoch 47/50 Loss 0.0497 Accuracy 0.7950
TRAINING Epoch 48/50 Loss 0.0484 Accuracy 0.7993
TRAINING Epoch 49/50 Loss 0.0482 Accuracy 0.8073
TRAINING Epoch 50/50 Loss 0.0423 Accuracy 0.8357
Finished Training
----------
```



Using learning rate as 0.0001:

```
TRAINING Epoch 20/50 Loss 0.2596 Accuracy 0.2250
TRAINING Epoch 21/50 Loss 0.2547 Accuracy 0.2550
TRAINING Epoch 22/50 Loss 0.2508 Accuracy 0.2593
TRAINING Epoch 23/50 Loss 0.2473 Accuracy 0.2630
TRAINING Epoch 24/50 Loss 0.2432 Accuracy 0.2810
TRAINING Epoch 25/50 Loss 0.2396 Accuracy 0.3057
TRAINING Epoch 26/50 Loss 0.2374 Accuracy 0.3137
TRAINING Epoch 27/50 Loss 0.2322 Accuracy 0.3273
TRAINING Epoch 28/50 Loss 0.2289 Accuracy 0.3373
TRAINING Epoch 29/50 Loss 0.2265 Accuracy 0.3360
TRAINING Epoch 30/50 Loss 0.2228 Accuracy 0.3603
TRAINING Epoch 31/50 Loss 0.2205 Accuracy 0.3620
TRAINING Epoch 32/50 Loss 0.2169 Accuracy 0.3733
TRAINING Epoch 33/50 Loss 0.2145 Accuracy 0.3820
TRAINING Epoch 34/50 Loss 0.2106 Accuracy 0.3977
TRAINING Epoch 35/50 Loss 0.2077 Accuracy 0.4110
TRAINING Epoch 36/50 Loss 0.2058 Accuracy 0.4047
TRAINING Epoch 37/50 Loss 0.2037 Accuracy 0.4150
TRAINING Epoch 38/50 Loss 0.2000 Accuracy 0.4317
TRAINING Epoch 39/50 Loss 0.1979 Accuracy 0.4323
TRAINING Epoch 40/50 Loss 0.1954 Accuracy 0.4467
TRAINING Epoch 41/50 Loss 0.1933 Accuracy 0.4487
TRAINING Epoch 42/50 Loss 0.1922 Accuracy 0.4497
TRAINING Epoch 43/50 Loss 0.1893 Accuracy 0.4563
TRAINING Epoch 44/50 Loss 0.1859 Accuracy 0.4673
TRAINING Epoch 45/50 Loss 0.1852 Accuracy 0.4700
TRAINING Epoch 46/50 Loss 0.1823 Accuracy 0.4863
TRAINING Epoch 47/50 Loss 0.1807 Accuracy 0.4763
TRAINING Epoch 48/50 Loss 0.1790 Accuracy 0.4837
TRAINING Epoch 49/50 Loss 0.1760 Accuracy 0.5027
TRAINING Epoch 50/50 Loss 0.1749 Accuracy 0.4913
Finished Training
----------
```

```
[16] test(model, criterion)

     Test Loss: 0.1595 Test Accuracy 0.4303
```

The best performance learning rate is 0.001:

```
TRAINING Epoch 23/50 Loss 0.0718 Accuracy 0.7627
TRAINING Epoch 24/50 Loss 0.0694 Accuracy 0.7757
TRAINING Epoch 25/50 Loss 0.0662 Accuracy 0.7820
TRAINING Epoch 26/50 Loss 0.0649 Accuracy 0.7897
TRAINING Epoch 27/50 Loss 0.0613 Accuracy 0.7917
TRAINING Epoch 28/50 Loss 0.0595 Accuracy 0.8127
TRAINING Epoch 29/50 Loss 0.0583 Accuracy 0.8083
TRAINING Epoch 30/50 Loss 0.0571 Accuracy 0.8113
TRAINING Epoch 31/50 Loss 0.0578 Accuracy 0.8123
TRAINING Epoch 32/50 Loss 0.0552 Accuracy 0.8153
TRAINING Epoch 33/50 Loss 0.0544 Accuracy 0.8167
TRAINING Epoch 34/50 Loss 0.0518 Accuracy 0.8303
TRAINING Epoch 35/50 Loss 0.0500 Accuracy 0.8373
TRAINING Epoch 36/50 Loss 0.0504 Accuracy 0.8297
TRAINING Epoch 37/50 Loss 0.0497 Accuracy 0.8380
TRAINING Epoch 38/50 Loss 0.0475 Accuracy 0.8490
TRAINING Epoch 39/50 Loss 0.0462 Accuracy 0.8503
TRAINING Epoch 40/50 Loss 0.0470 Accuracy 0.8473
TRAINING Epoch 41/50 Loss 0.0460 Accuracy 0.8497
TRAINING Epoch 42/50 Loss 0.0456 Accuracy 0.8493
TRAINING Epoch 43/50 Loss 0.0432 Accuracy 0.8513
TRAINING Epoch 44/50 Loss 0.0426 Accuracy 0.8590
TRAINING Epoch 45/50 Loss 0.0444 Accuracy 0.8533
TRAINING Epoch 46/50 Loss 0.0413 Accuracy 0.8587
TRAINING Epoch 47/50 Loss 0.0411 Accuracy 0.8643
TRAINING Epoch 48/50 Loss 0.0397 Accuracy 0.8700
TRAINING Epoch 49/50 Loss 0.0387 Accuracy 0.8743
TRAINING Epoch 50/50 Loss 0.0402 Accuracy 0.8650
Finished Training
----------
```

```
test(model, criterion)

Test Loss: 0.1053 Test Accuracy 0.5747
```