Deep Learning- CSE641

Assignment - 3

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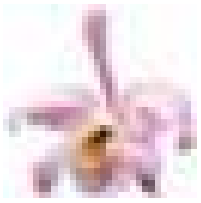
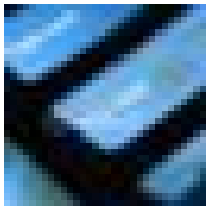
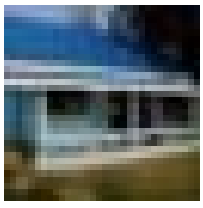
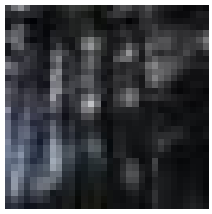
FILES SUBMITTED : submitted .py file , .ipynb file and readme.pdf and output.pdf

1. Convolutional Neural Network (CNN):

1.1 Visualize 10 Samples From Each Class:

Class	Image 1	Image 2
0		
1		
2		
3		
4		
5		

6		
7		
8		
9		

1.2 CNN Architecture

1.2.1 Activation function: Tanh

- Block 1

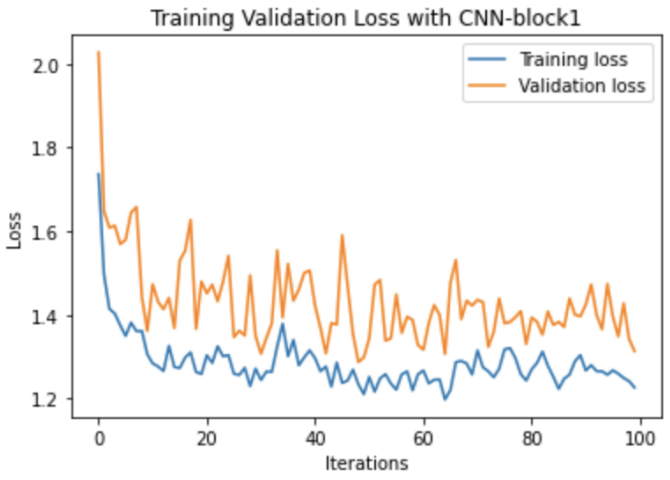
```
Model_B1(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1),
padding=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): Tanh()
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1),
padding=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): Tanh()
    (6): MaxPool2d(kernel_size=4, stride=3, padding=0, dilation=1,
ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=1600, out_features=512, bias=True)
```

```
    (1): Tanh()
    (2): Linear(in_features=512, out_features=256, bias=True)
    (3): Tanh()
    (4): Linear(in_features=256, out_features=64, bias=True)
    (5): Tanh()
    (6): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

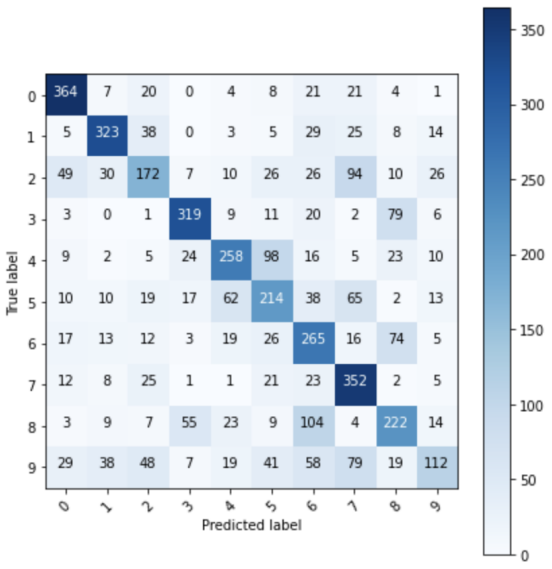
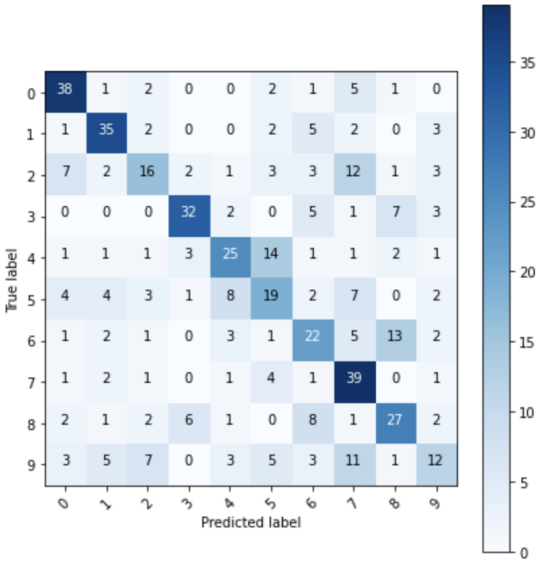
❖ Accuracy and Loss

Block 1	Train	Test
Accuracy	57%	53%
Loss	1.200912	1.292314

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

- Block 1,2

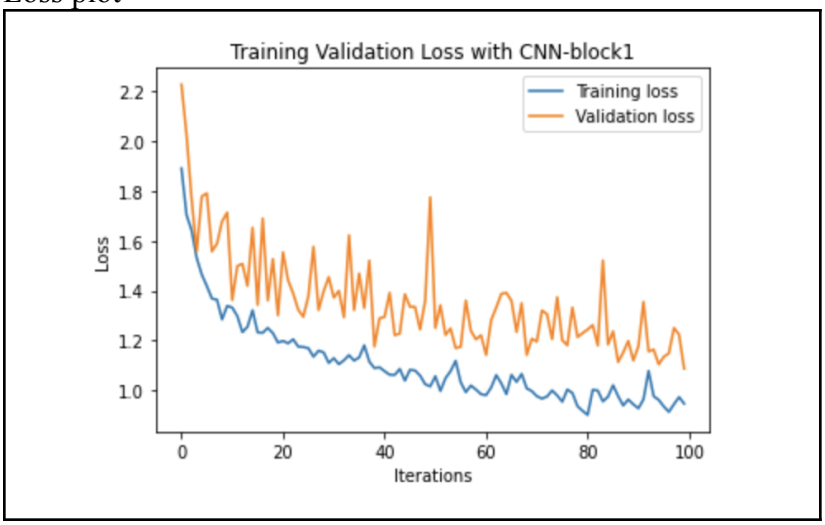
```
Model_B12(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): Tanh()
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): Tanh()
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (7): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (8): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (9): Tanh()
    (10): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (11): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): Tanh()
    (13): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (14): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (15): Tanh()
    (16): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=512, out_features=256, bias=True)
    (1): Tanh()
```

```
    (2): Linear(in_features=256, out_features=64, bias=True)
    (3): Tanh()
    (4): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

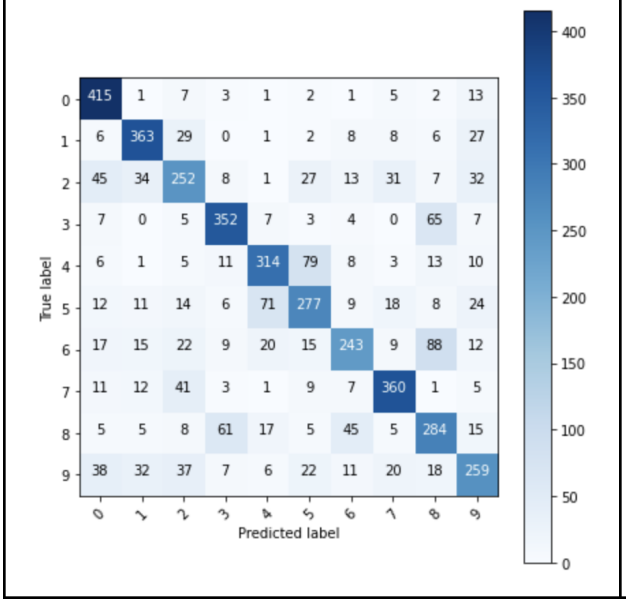
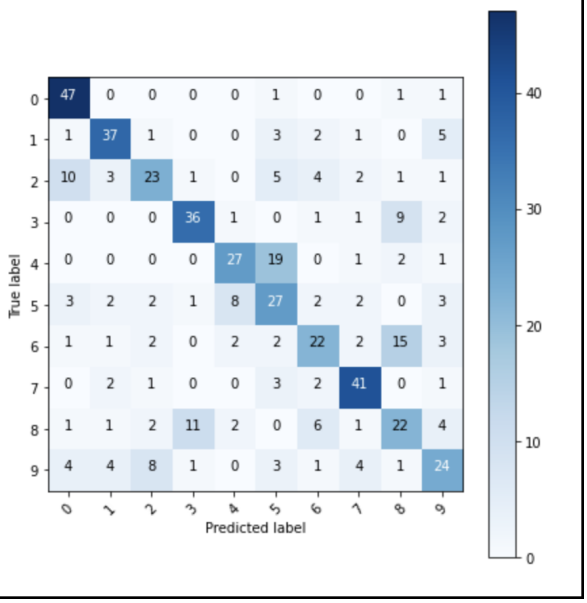
❖ Accuracy and Loss

Block 1,2	Train	Test
Accuracy	69%	61%
Loss	0.894667	1.89120

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

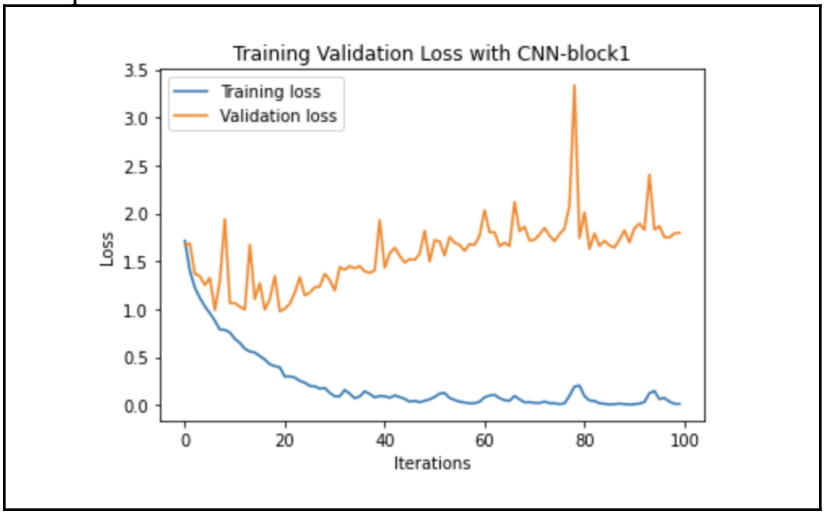
- Block 1,2,3

```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): Tanh()
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): Tanh()
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (7): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (8): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (9): Tanh()
    (10): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (11): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): Tanh()
    (13): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (14): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (15): Tanh()
    (16): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (17): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (18): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (19): Tanh()
    (20): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

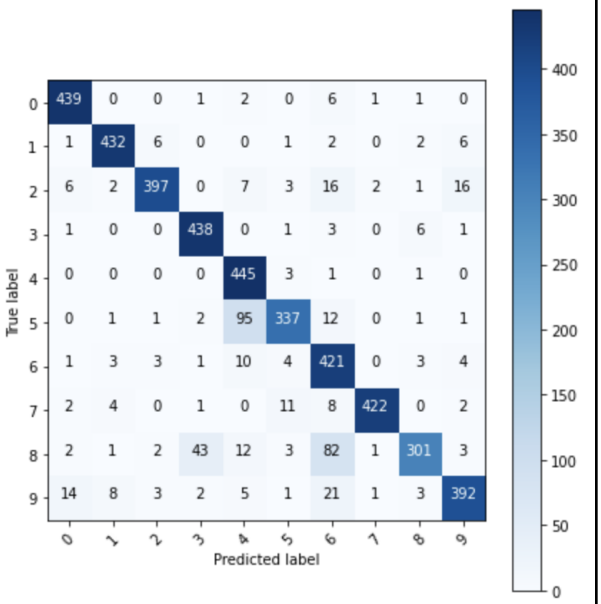
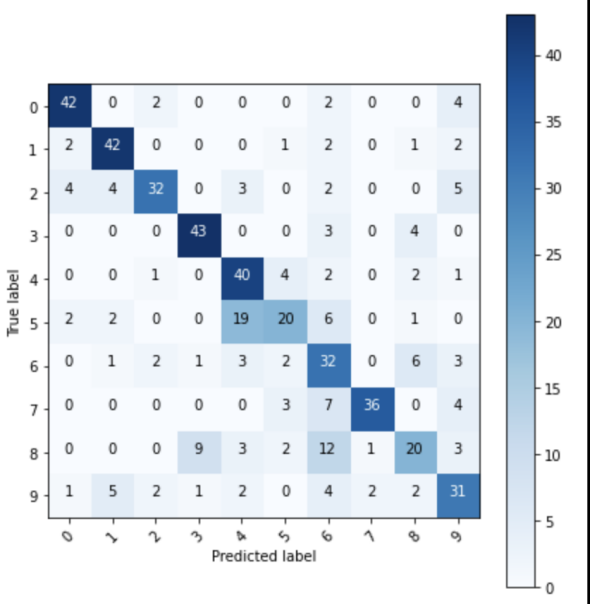
❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	89%	67%
Loss	0.301188	0.963042

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

1.2.2 Activation function: ReLU

- Block 1

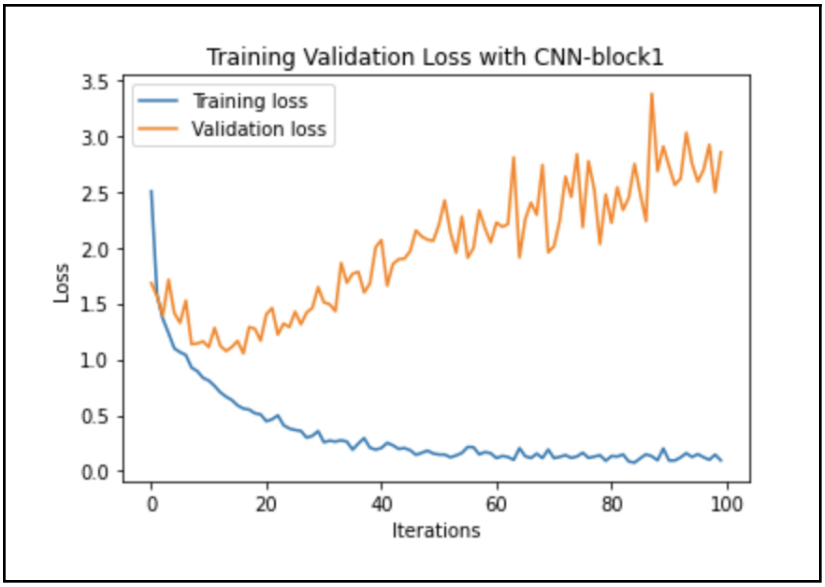
```
Model_B1(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1),
padding=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1),
padding=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
```

```
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): MaxPool2d(kernel_size=4, stride=3, padding=0, dilation=1,
ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=1600, out_features=512, bias=True)
    (1): ReLU(inplace=True)
    (2): Linear(in_features=512, out_features=256, bias=True)
    (3): ReLU(inplace=True)
    (4): Linear(in_features=256, out_features=64, bias=True)
    (5): ReLU(inplace=True)
    (6): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

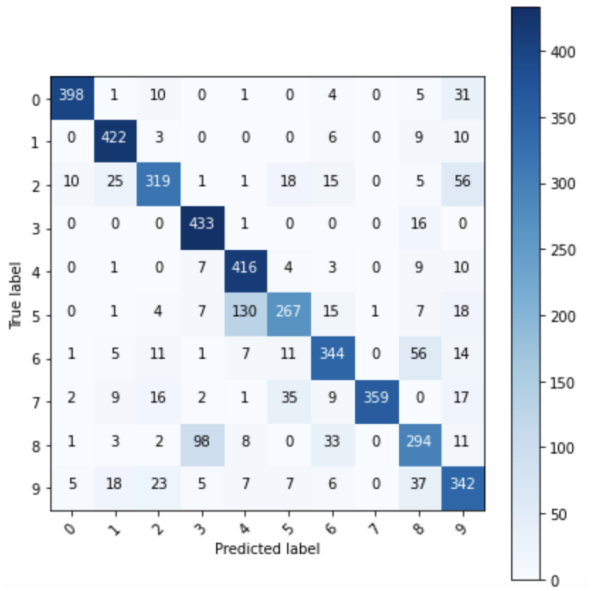
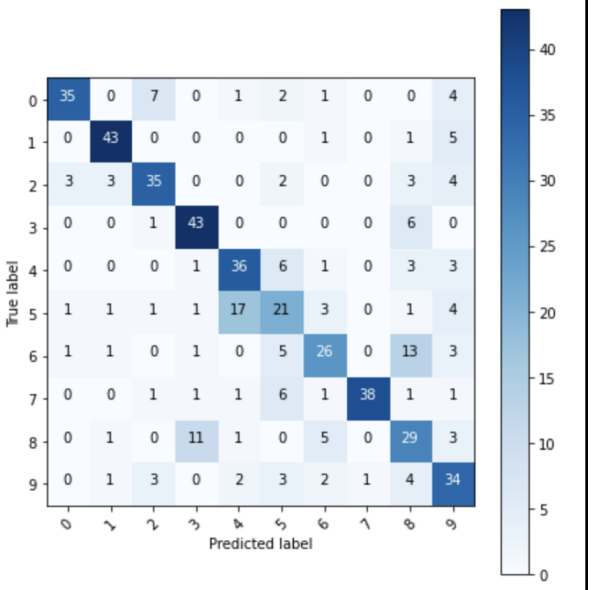
❖ Accuracy and Loss

Block 1	Train	Test
Accuracy	79%	68%
Loss	0.549036	1.057941

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

- Block 1,2

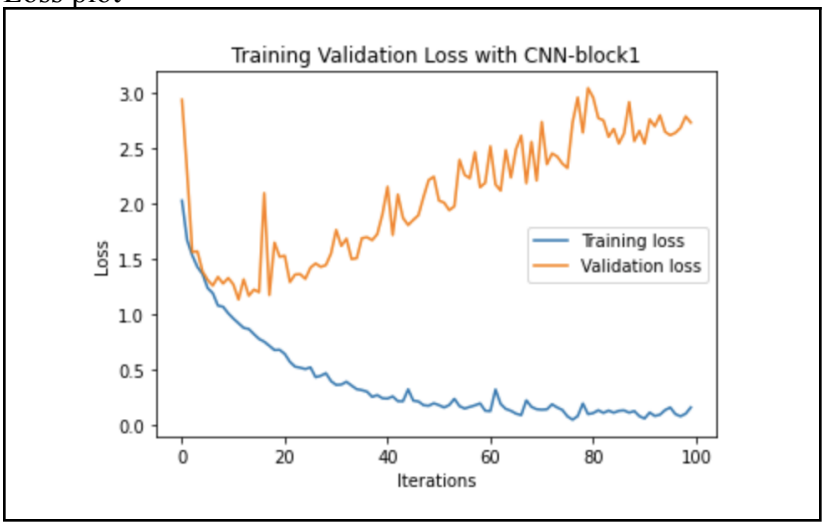
```
Model_B12(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (7): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (8): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (9): ReLU(inplace=True)
    (10): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (11): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): ReLU(inplace=True)
    (13): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (14): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (15): ReLU(inplace=True)
    (16): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=512, out_features=256, bias=True)
```

```
    (1): ReLU(inplace=True)
    (2): Linear(in_features=256, out_features=64, bias=True)
    (3): ReLU(inplace=True)
    (4): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

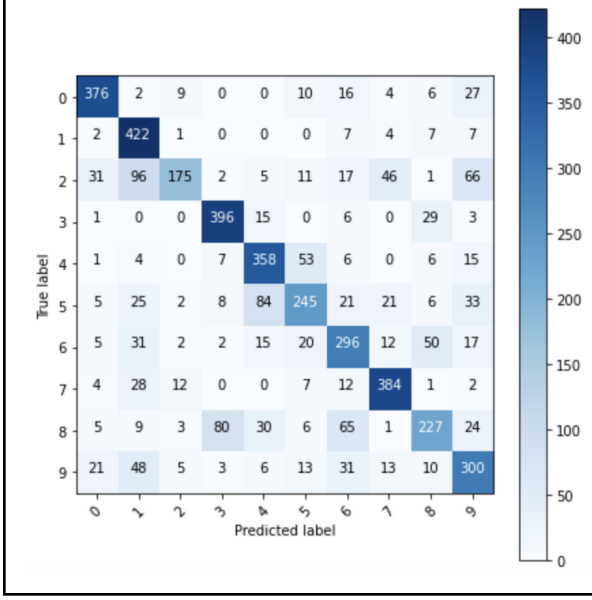
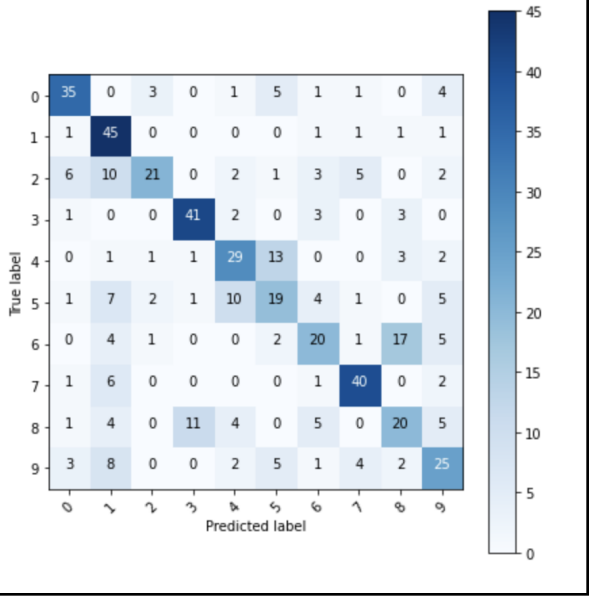
❖ Accuracy and Loss

Block 1,2	Train	Test
Accuracy	70%	59%
Loss	0.837771	1.137523

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

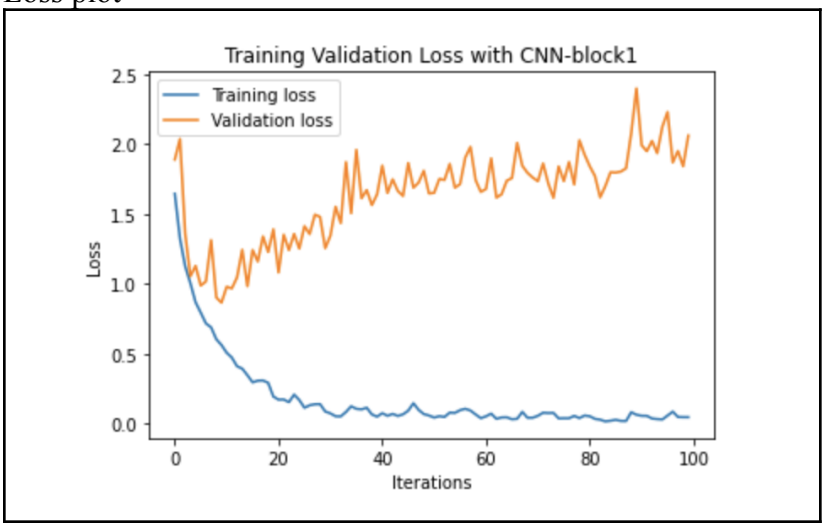
- Block 1,2,3

```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (7): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (8): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (9): ReLU(inplace=True)
    (10): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (11): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): ReLU(inplace=True)
    (13): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (14): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (15): ReLU(inplace=True)
    (16): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (17): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (18): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (19): ReLU(inplace=True)
    (20): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

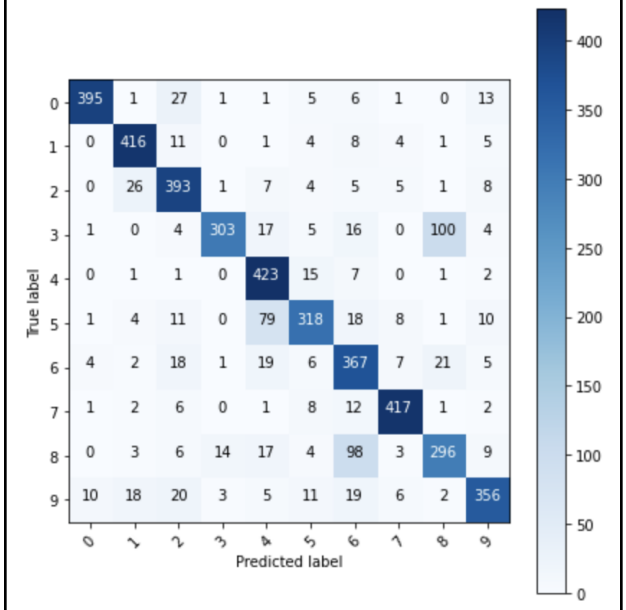
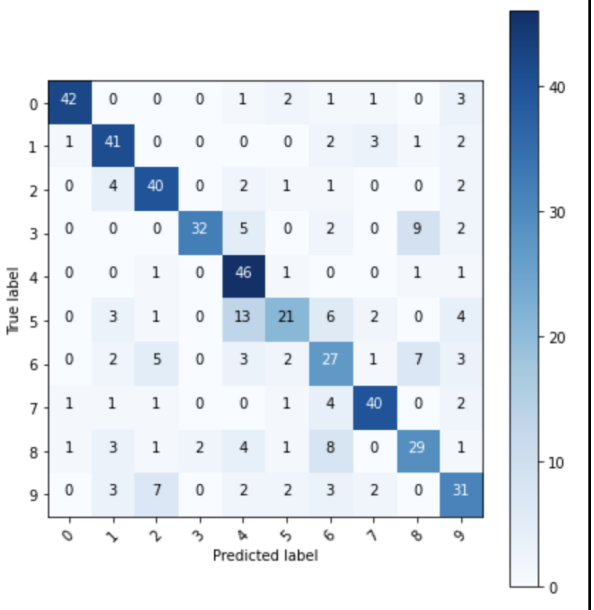
❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	81%	69%
Loss	0.512706	0.868855

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

Analysis:

- Blocks were added one at a time and performance was evaluated for each model.
- With the addition of blocks, the performance increased, i.e. accuracy increased and loss decreased in both cases (tanh and ReLU).
- ReLU performed better on average than tanh Therefore, for the rest of the question, ReLU activation function is used.

1.3 Dropout Probability

1.3.1 Dropout after Convolutional layers

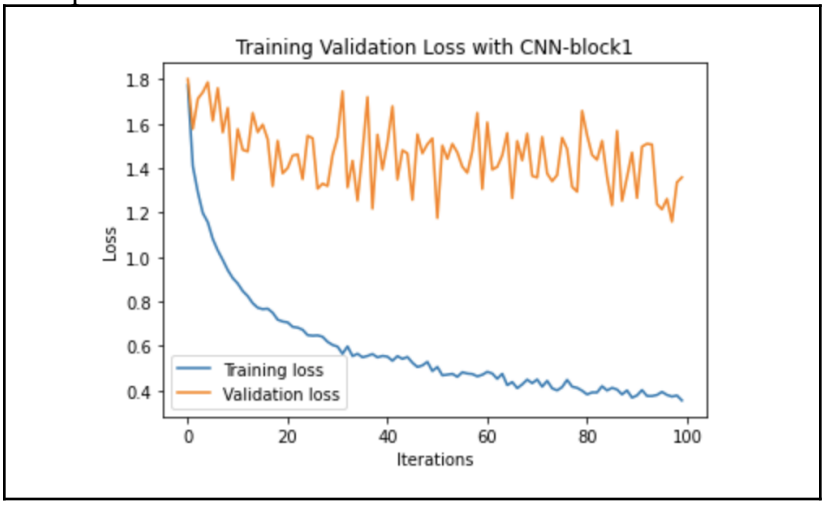
1.3.1.1 Dropout = 0.3

```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Dropout(p=0.3, inplace=False)
    (4): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (5): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (6): ReLU(inplace=True)
    (7): Dropout(p=0.3, inplace=False)
    (8): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (9): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (10): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (11): ReLU(inplace=True)
    (12): Dropout(p=0.3, inplace=False)
    (13): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (14): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (15): ReLU(inplace=True)
    (16): Dropout(p=0.3, inplace=False)
    (17): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (18): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (19): ReLU(inplace=True)
    (20): Dropout(p=0.3, inplace=False)
    (21): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (22): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (23): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (24): ReLU(inplace=True)
    (25): Dropout(p=0.3, inplace=False)
    (26): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

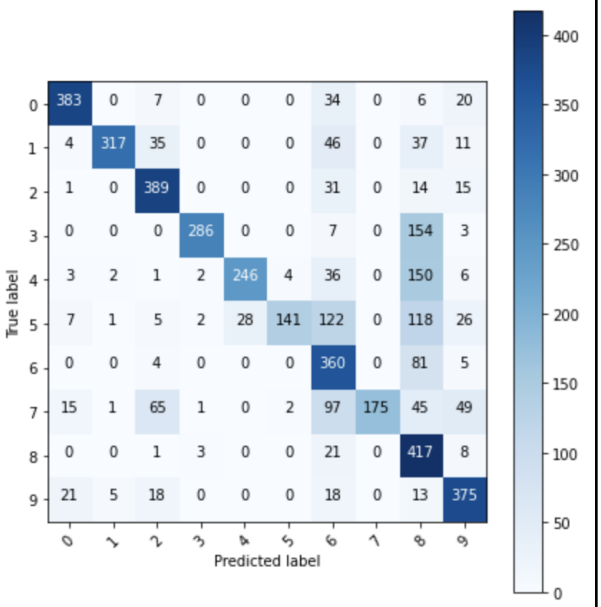
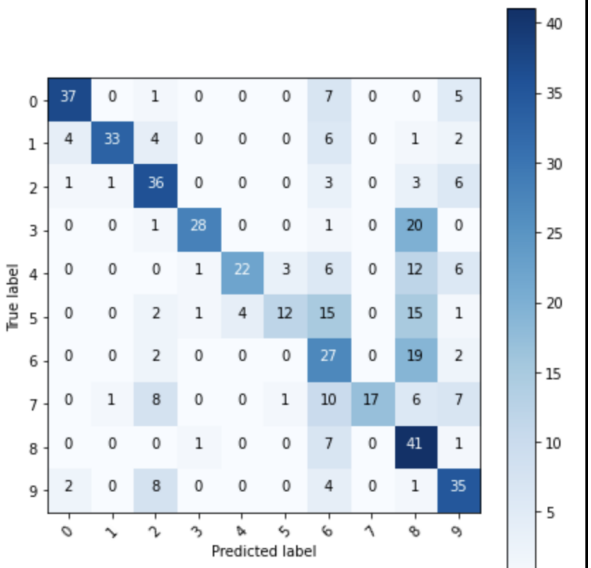
❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	68%	57%
Loss	0.903236	1.165431

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

1.3.1.2 Dropout = 0.5

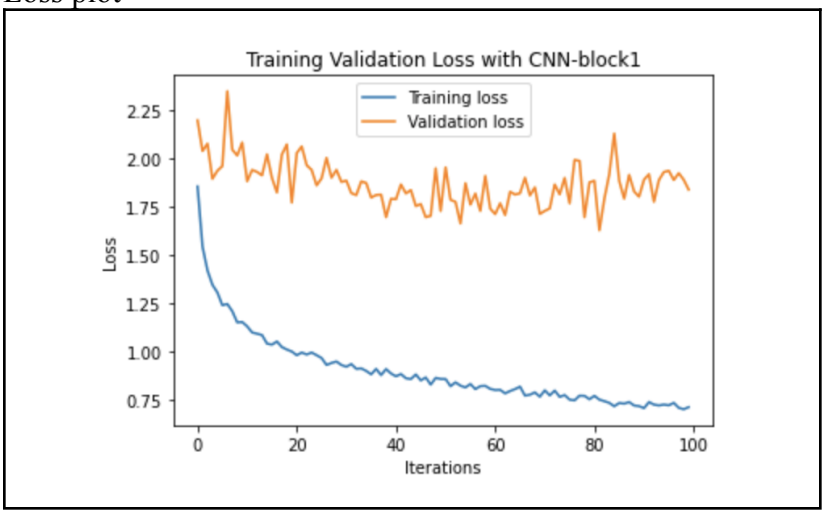
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Dropout(p=0.5, inplace=False)
    (4): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (5): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (6): ReLU(inplace=True)
```

```
    (7): Dropout(p=0.5, inplace=False)
    (8): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (9): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (10): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (11): ReLU(inplace=True)
    (12): Dropout(p=0.5, inplace=False)
    (13): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (14): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (15): ReLU(inplace=True)
    (16): Dropout(p=0.5, inplace=False)
    (17): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (18): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (19): ReLU(inplace=True)
    (20): Dropout(p=0.5, inplace=False)
    (21): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (22): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (23): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (24): ReLU(inplace=True)
    (25): Dropout(p=0.5, inplace=False)
    (26): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

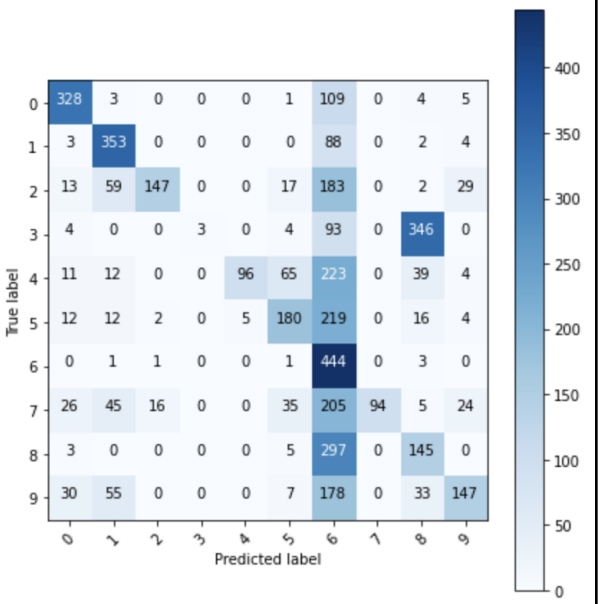
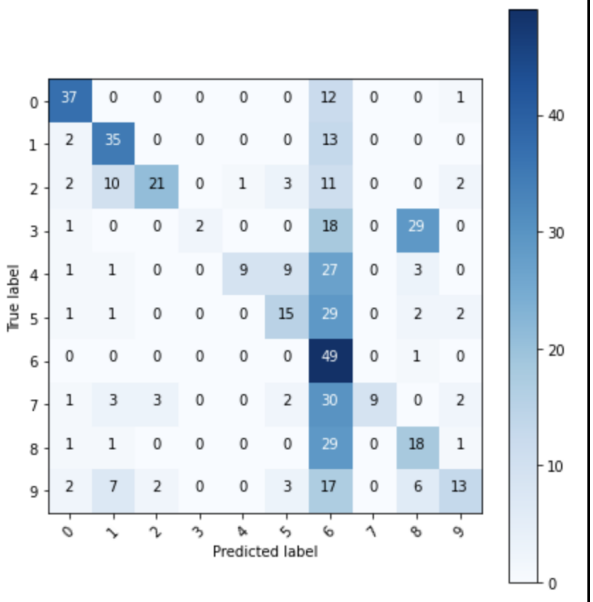
❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	43%	41%
Loss	1.542332	1.630709

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

1.3.1.2 Dropout = 0.7

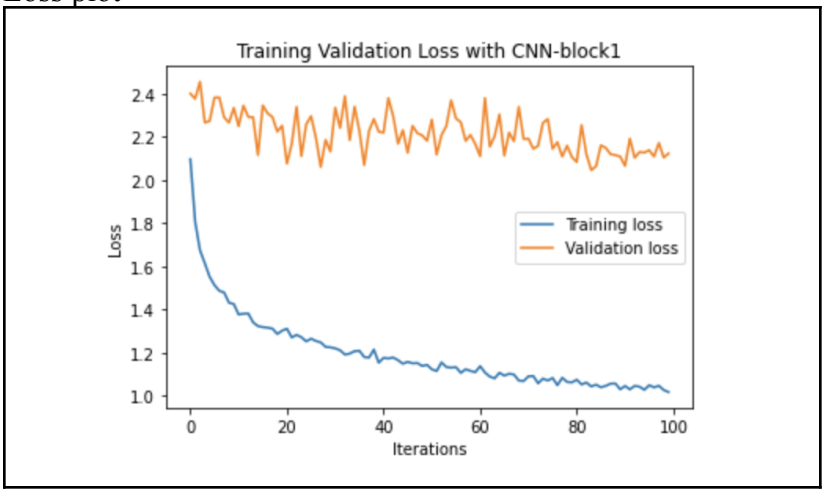
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Dropout(p=0.7, inplace=False)
    (4): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (5): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (6): ReLU(inplace=True)
    (7): Dropout(p=0.7, inplace=False)
    (8): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
```

```
ceil_mode=False)
    (9): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (10): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (11): ReLU(inplace=True)
    (12): Dropout(p=0.7, inplace=False)
    (13): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (14): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (15): ReLU(inplace=True)
    (16): Dropout(p=0.7, inplace=False)
    (17): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (18): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (19): ReLU(inplace=True)
    (20): Dropout(p=0.7, inplace=False)
    (21): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (22): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (23): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (24): ReLU(inplace=True)
    (25): Dropout(p=0.7, inplace=False)
    (26): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

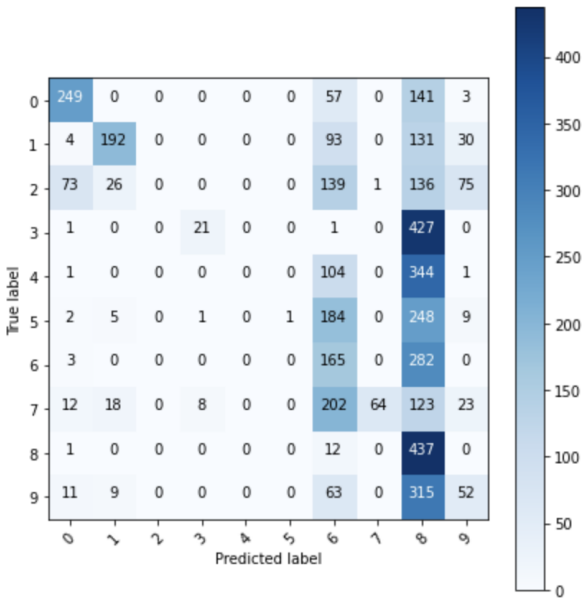
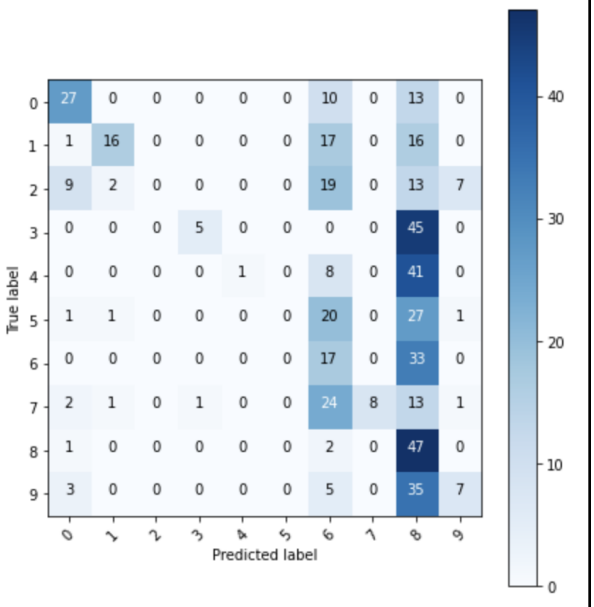
❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	26%	25%
Loss	2.020246	2.043498

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

1.3.2 Dropout between fully-connected layers

1.3.2.1 Dropout = 0.3

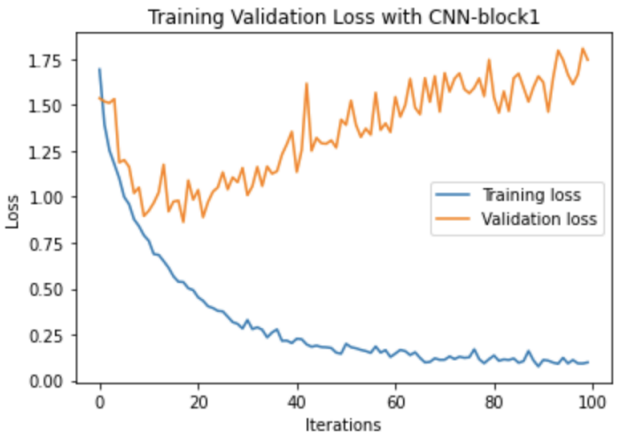
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (7): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (8): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (9): ReLU(inplace=True)
    (10): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (11): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): ReLU(inplace=True)
    (13): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (14): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (15): ReLU(inplace=True)
    (16): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (17): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
```

```
    (18): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (19): ReLU(inplace=True)
    (20): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Dropout(p=0.3, inplace=False)
    (1): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

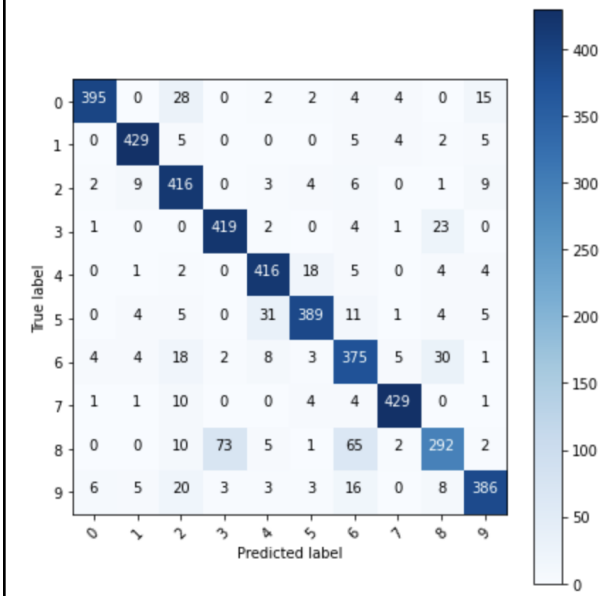
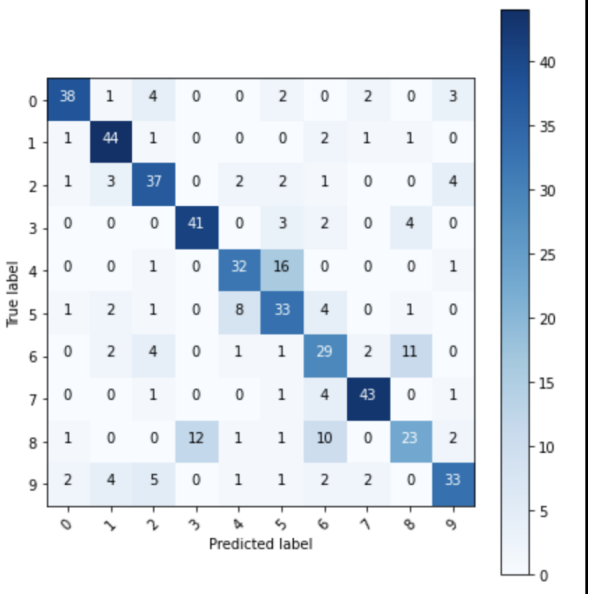
❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	87%	70%
Loss	0.355316	0.854087

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

1.3.2.2 Dropout = 0.5

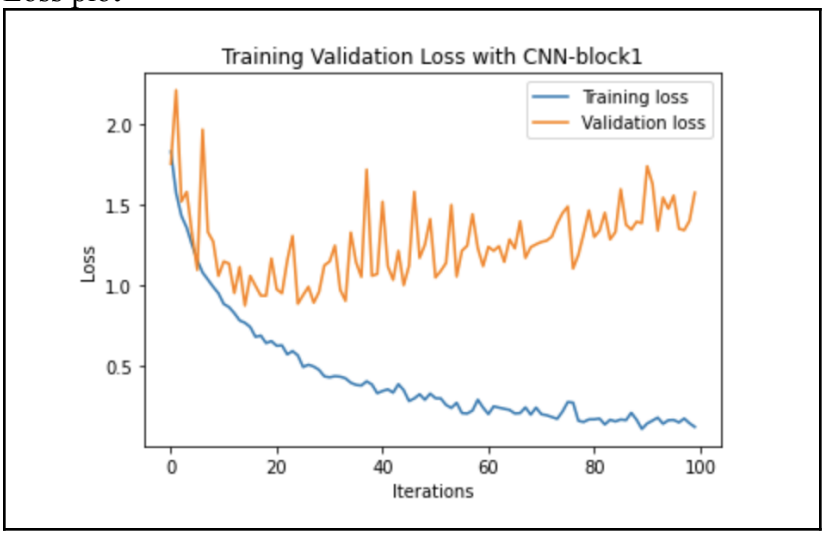
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (7): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (8): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (9): ReLU(inplace=True)
    (10): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (11): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): ReLU(inplace=True)
    (13): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (14): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (15): ReLU(inplace=True)
    (16): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (17): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (18): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
```

```
    (19): ReLU(inplace=True)
    (20): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Dropout(p=0.5, inplace=False)
    (1): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

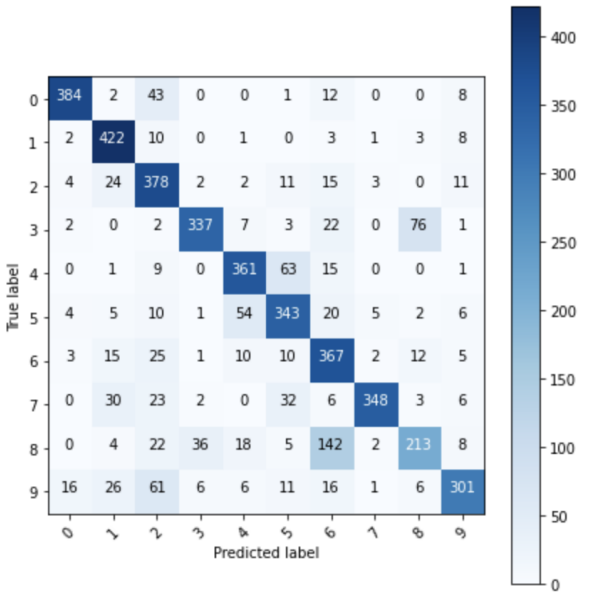
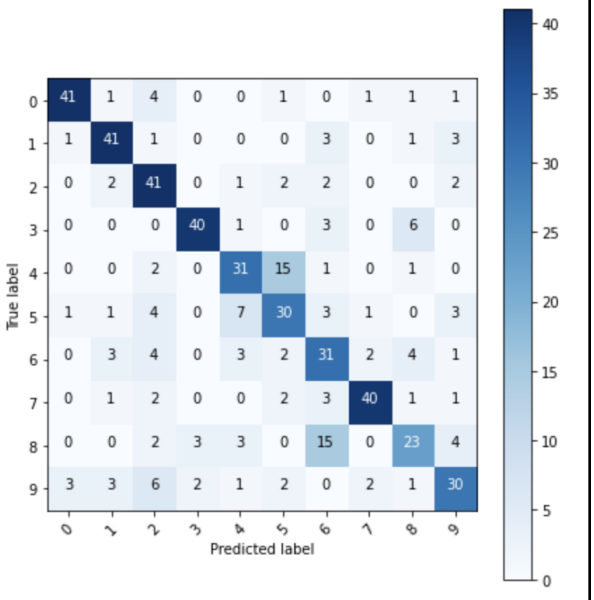
❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	76%	69%
Loss	0.660881	0.876783

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

1.3.2.2 Dropout = 0.7

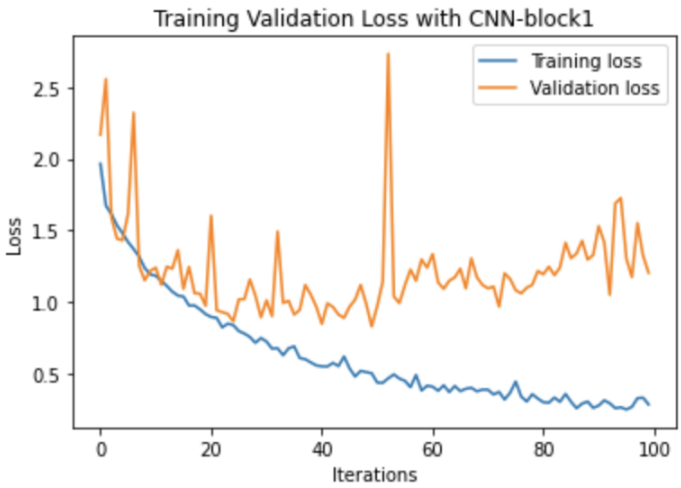
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (7): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (8): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (9): ReLU(inplace=True)
    (10): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (11): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): ReLU(inplace=True)
    (13): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (14): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (15): ReLU(inplace=True)
    (16): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (17): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (18): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (19): ReLU(inplace=True)
```

```
    (20): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Dropout(p=0.7, inplace=False)
    (1): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

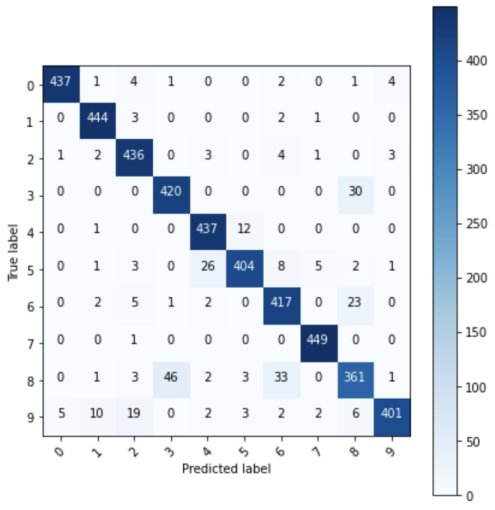
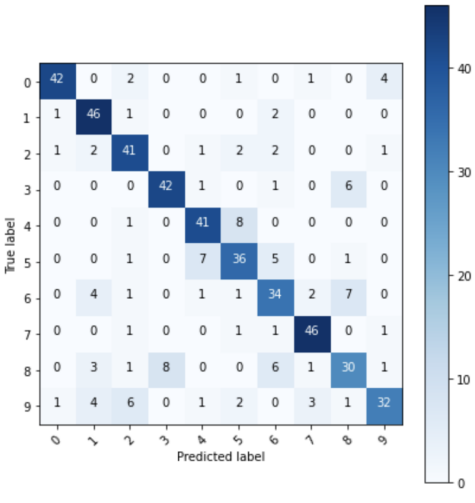
❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	93%	78%
Loss	0.213234	0.833252

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

1.3.3 Dropout after each block

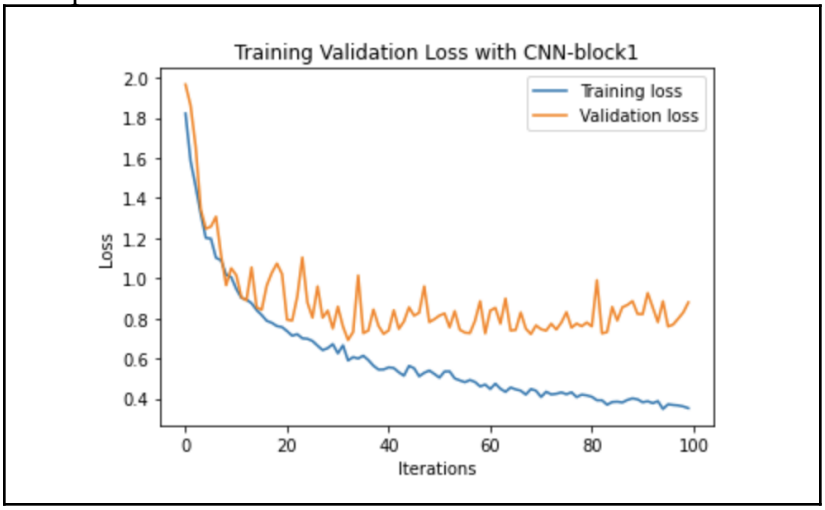
1.3.3.1 Dropout = 0.3

```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (7): Dropout(p=0.3, inplace=False)
    (8): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (9): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (10): ReLU(inplace=True)
    (11): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (12): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (13): ReLU(inplace=True)
    (14): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (15): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (16): ReLU(inplace=True)
    (17): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (18): Dropout(p=0.3, inplace=False)
    (19): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (20): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (21): ReLU(inplace=True)
    (22): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (23): Dropout(p=0.3, inplace=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

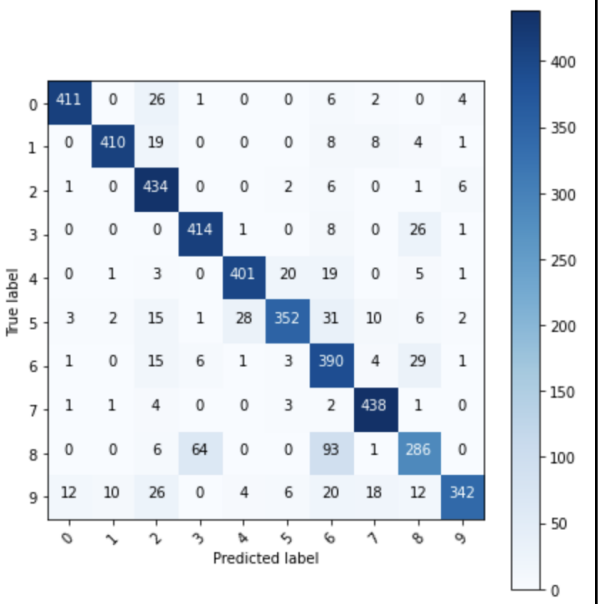
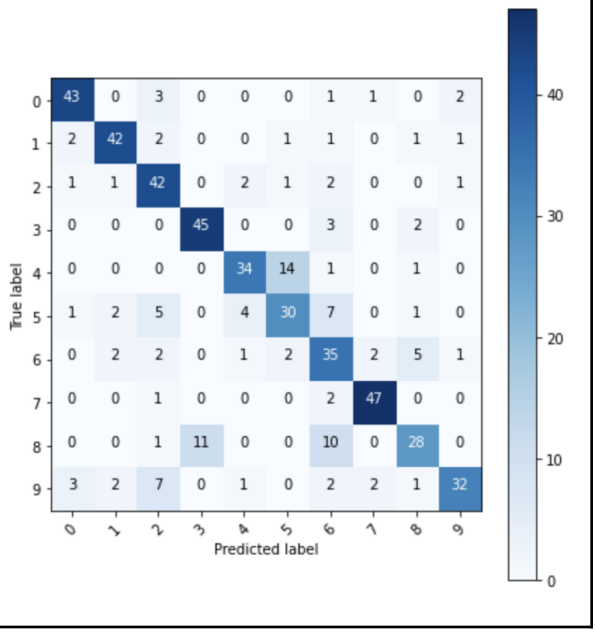
❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	86%	75%
Loss	0.415009	0.690495

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

1.3.3.2 Dropout = 0.5

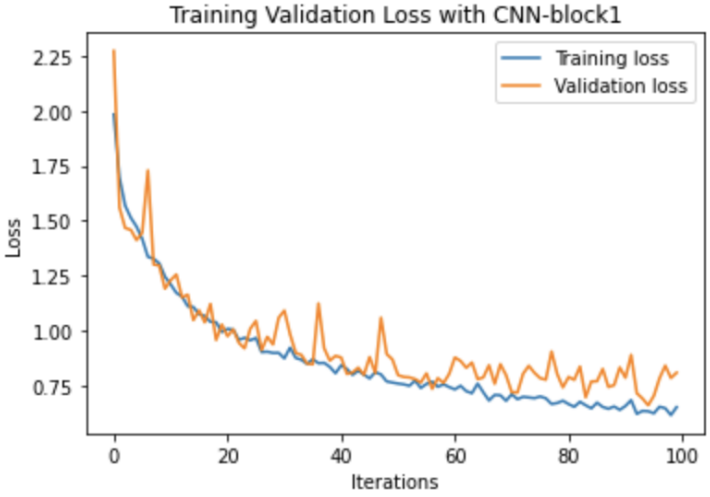
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
```

```
    (7): Dropout(p=0.5, inplace=False)
    (8): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (9): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (10): ReLU(inplace=True)
    (11): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (12): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (13): ReLU(inplace=True)
    (14): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (15): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (16): ReLU(inplace=True)
    (17): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (18): Dropout(p=0.5, inplace=False)
    (19): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (20): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (21): ReLU(inplace=True)
    (22): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (23): Dropout(p=0.5, inplace=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

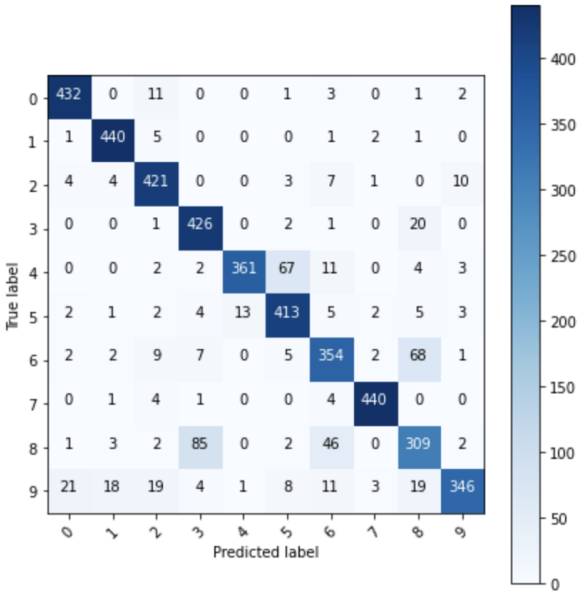
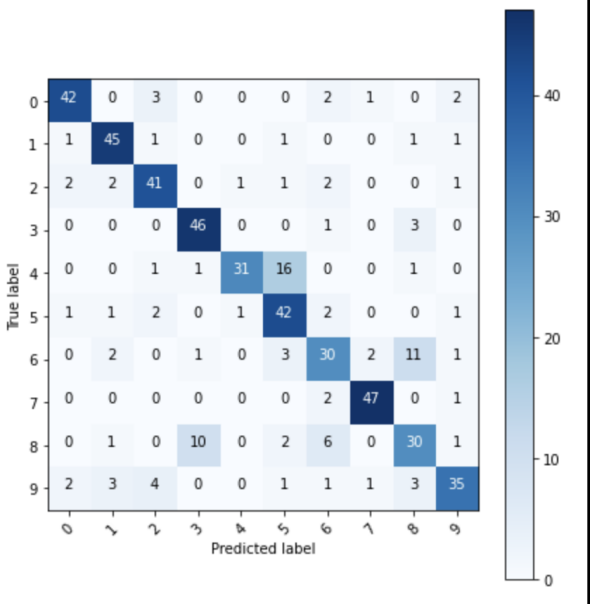
❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	87%	77%
Loss	0.380031	0.662487

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

1.3.3.3 Dropout = 0.7

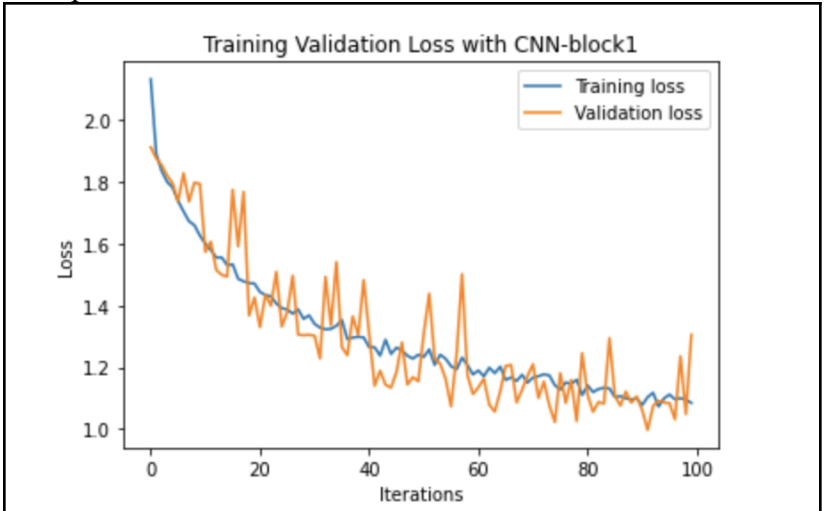
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (7): Dropout(p=0.7, inplace=False)
    (8): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (9): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (10): ReLU(inplace=True)
    (11): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (12): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (13): ReLU(inplace=True)
    (14): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (15): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (16): ReLU(inplace=True)
    (17): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (18): Dropout(p=0.7, inplace=False)
    (19): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
```

```
    (20): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (21): ReLU(inplace=True)
    (22): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (23): Dropout(p=0.7, inplace=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

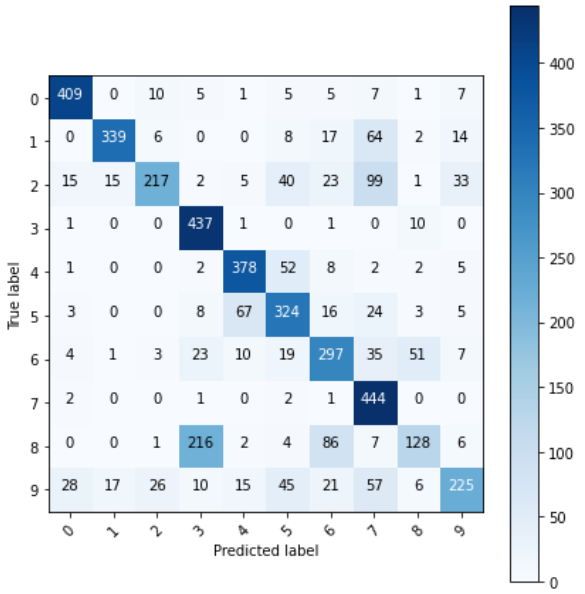
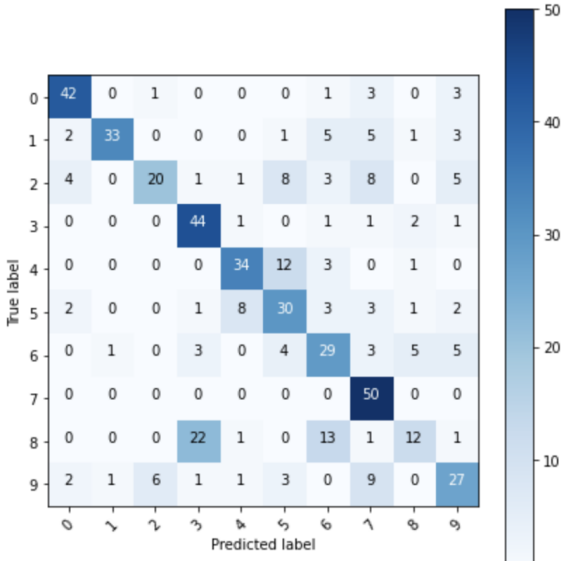
❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	71%	64%
Loss	0.834854	0.997905

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

Analysis:

- Dropout was implemented in all three cases with 3 dropout probabilities in each case.
- Inclusion of dropout prevented overfitting. The extent of the prevention depended on the dropout probability.
- In every case, 0.3 dropout probability still tends to overfit while 0.7 dropout probability tends to underfit. Therefore, 0.5 dropout probability is the best out of the 3 probabilities tested.
- Out of the 3 architectures, best results are obtained if dropout is applied after each block.
- Dropout applied after convolutional layers is not successful, as we might lose important information in images by dropping out some nodes also CNN already has shared weights so dropping out can have adverse effects.
- From the graphs it is clearly visible at 0.3 after some point test loss keeps on increasing while train loss keeps on increasing i.e overfitting. In our case 0.5 works the best with between the blocks.

1.4 Hyperparameters and best architecture

1.4.1 Number of layers (X,Y,Z)

1.4.1.1. X = 2, Y = 2, Z = 2

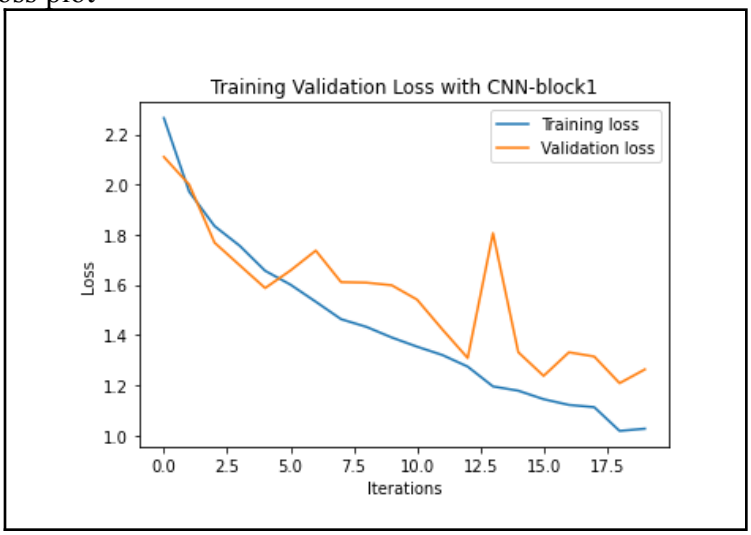
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
```

```
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): MaxPool2d(kernel_size=2, stride=1, padding=0, dilation=1,
ceil_mode=False)
    (7): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (8): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (9): ReLU(inplace=True)
    (10): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (11): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): ReLU(inplace=True)
    (13): MaxPool2d(kernel_size=2, stride=1, padding=0,
dilation=1, ceil_mode=False)
    (14): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (15): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (16): ReLU(inplace=True)
    (17): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1))
    (18): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (19): ReLU(inplace=True)
    (20): MaxPool2d(kernel_size=4, stride=3, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=1600, out_features=512, bias=True)
    (1): ReLU(inplace=True)
    (2): Linear(in_features=512, out_features=256, bias=True)
    (3): ReLU(inplace=True)
    (4): Linear(in_features=256, out_features=64, bias=True)
    (5): ReLU(inplace=True)
    (6): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	65%	55%
Loss	1.011410	1.203690

❖ Loss plot



1.4.1.2. X = 3, Y = 2, Z = 1

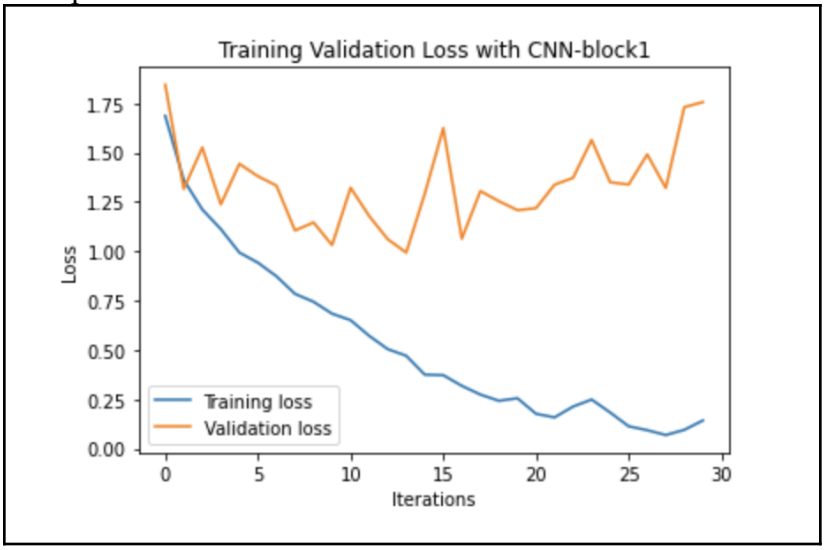
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (7): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (8): ReLU(inplace=True)
    (9): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (10): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (11): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): ReLU(inplace=True)
    (13): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (14): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (15): ReLU(inplace=True)
    (16): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (17): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (18): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (19): ReLU(inplace=True)
    (20): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
```

```
)
```

❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	87%	66%
Loss	0.376737	0.995357

❖ Loss plot



1.4.1.3. X = 2, Y = 3, Z = 1

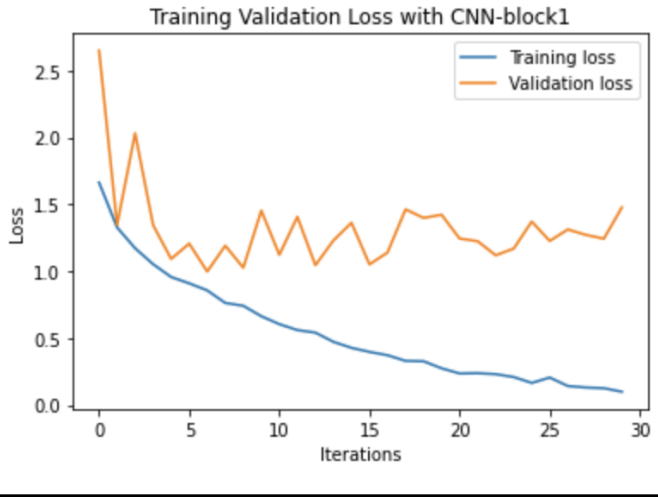
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (7): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (8): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (9): ReLU(inplace=True)
    (10): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (11): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): ReLU(inplace=True)
    (13): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (14): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
```

```
    (15): ReLU(inplace=True)
    (16): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (17): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (18): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (19): ReLU(inplace=True)
    (20): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	74%	64%
Loss	0.718399	0.995629

❖ Loss plot



Best value: X = 2, Y = 3, Z = 1

- The architecture gave best testing accuracy and minimum loss.
- X = 2, Y = 3, Z = 1 and X = 3, Y = 2, Z = 1 are almost similar so we chose first one.
- Keeping higher X value worked better as it helped in better feature extraction. Hence, X = 1 gave low accuracy while X = 2 and X = 3 gave better accuracy.

1.4.2 Batch Normalization (With Max Pooling)

1.4.2.1. Without Batch Normalization

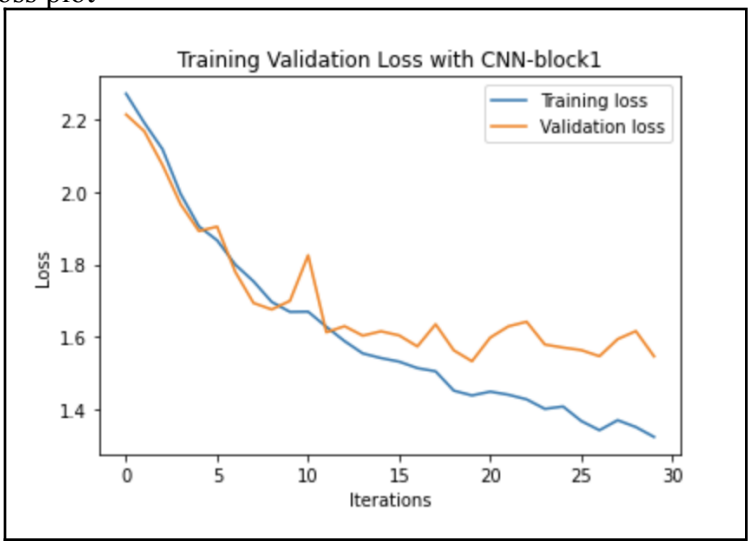
```
Model_B123(
  (features): Sequential(
```

```
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): ReLU(inplace=True)
    (2): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (3): ReLU(inplace=True)
    (4): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (5): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (6): ReLU(inplace=True)
    (7): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (8): ReLU(inplace=True)
    (9): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (10): ReLU(inplace=True)
    (11): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (12): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (13): ReLU(inplace=True)
    (14): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	52%	45%
Loss	1.349049	1.532184

❖ Loss plot



1.4.2.2. With Batch Normalization

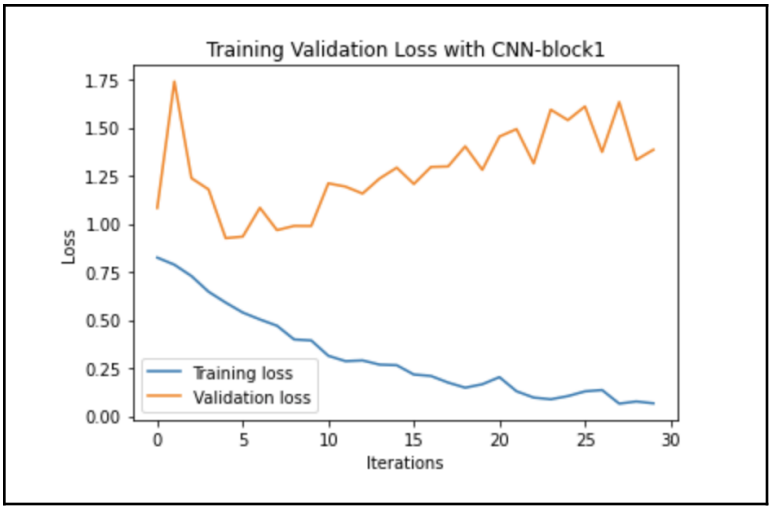
```
Model_B123(
  (features): Sequential(
```

```
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (7): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (8): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (9): ReLU(inplace=True)
    (10): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (11): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): ReLU(inplace=True)
    (13): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (14): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (15): ReLU(inplace=True)
    (16): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
    (17): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (18): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (19): ReLU(inplace=True)
    (20): MaxPool2d(kernel_size=2, stride=2, padding=0,
dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	81%	69%
Loss	0.521781	0.919671

❖ Loss plot



Best value: The model performed better with batch normalization as it normalizes value in a range (0,1) which helps the model learn faster and perform better.

1.4.3 Pooling

1.4.3.1. Max Pooling

The model is the same as that in section 1.4.2.2 (with batch normalization and max pooling).

1.4.3.2. Average Pooling

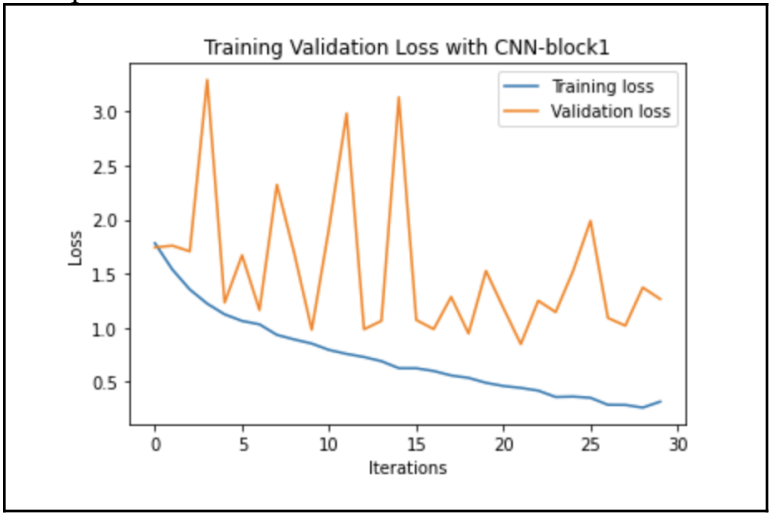
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (7): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (8): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (9): ReLU(inplace=True)
    (10): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (11): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): ReLU(inplace=True)
    (13): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (14): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (15): ReLU(inplace=True)
    (16): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (17): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (18): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (19): ReLU(inplace=True)
    (20): AvgPool2d(kernel_size=2, stride=2, padding=0)
```

```
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	88%	72%
Loss	0.347223	0.853640

❖ Loss plot



Best value: The model performed better with Average Pooling because Average Pooling considers every feature of the image. Looking at the dataset images, the sharpness and intensity in different areas of images is different. Therefore, average pooling takes into account all of them rather than the highest (like Max Pooling does).

1.4.4 Dropout

From the analysis of section 1.3, the optimal dropout probability was chosen as 0.5 and the dropout was applied after each block for best performance.

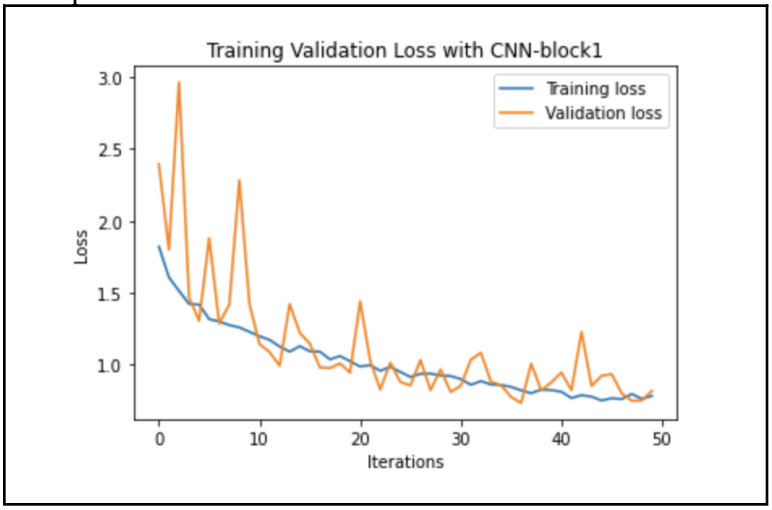
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (7): Dropout(p=0.5, inplace=False)
    (8): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
```

```
    (9): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (10): ReLU(inplace=True)
    (11): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (12): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (13): ReLU(inplace=True)
    (14): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (15): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (16): ReLU(inplace=True)
    (17): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (18): Dropout(p=0.5, inplace=False)
    (19): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (20): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (21): ReLU(inplace=True)
    (22): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (23): Dropout(p=0.5, inplace=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	81%	73%
Loss	0.529796	0.738360

❖ Loss plot



1.4.5 Optimizer and weight decay

Adam optimizer has been chosen for the model as Adam generally is the optimal choice because of its adaptive learning rate property.

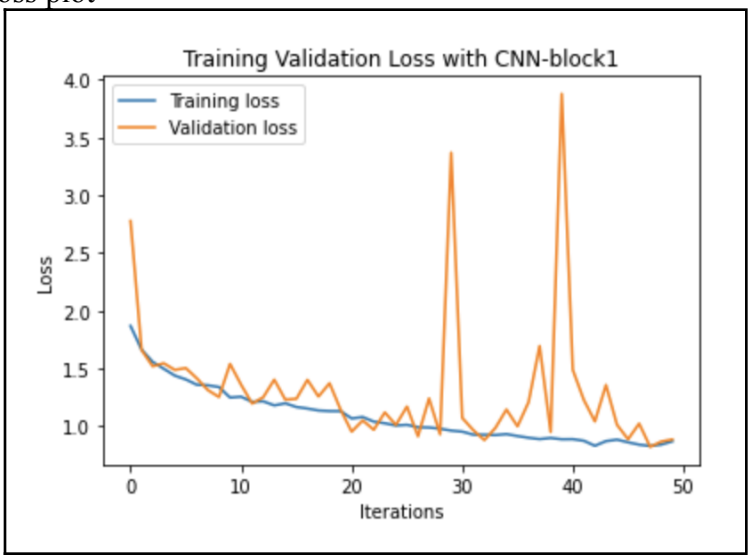
1.4.5.1 With weight decay

```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (7): Dropout(p=0.5, inplace=False)
    (8): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (9): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (10): ReLU(inplace=True)
    (11): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (12): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (13): ReLU(inplace=True)
    (14): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (15): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (16): ReLU(inplace=True)
    (17): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (18): Dropout(p=0.5, inplace=False)
    (19): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (20): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (21): ReLU(inplace=True)
    (22): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (23): Dropout(p=0.5, inplace=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

- Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	78%	71%
Loss	0.598614	0.823383

❖ Loss plot



1.4.5.2. Without Weight Decay

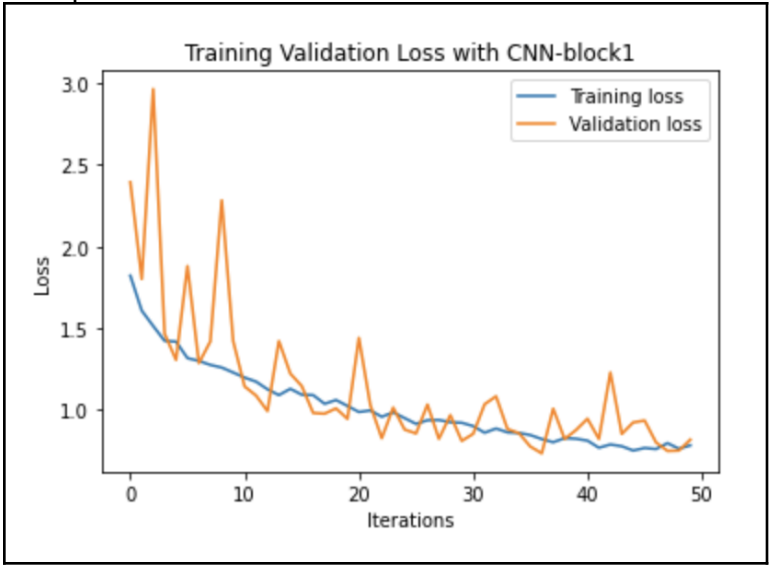
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (7): Dropout(p=0.5, inplace=False)
    (8): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (9): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (10): ReLU(inplace=True)
    (11): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (12): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (13): ReLU(inplace=True)
    (14): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (15): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (16): ReLU(inplace=True)
    (17): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (18): Dropout(p=0.5, inplace=False)
    (19): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (20): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (21): ReLU(inplace=True)
    (22): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (23): Dropout(p=0.5, inplace=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
```

```
    )
)
```

❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	81%	73%
Loss	0.529796	0.738360

❖ Loss plot



Best value: Adam optimizer performed well. Using weight decay did not improve performance. If the value of weight decay was kept small, no improvement was seen whereas if weight decay was kept large then the model underfit. Therefore, no weight decay was done.

1.4.6 Learning Rate

1.4.6.1 Learning rate = 0.01

The results are the same as section 1.4.5.2 as the learning rate was 0.01 by default in all of the above results.

1.4.6.2. Learning rate = 0.001

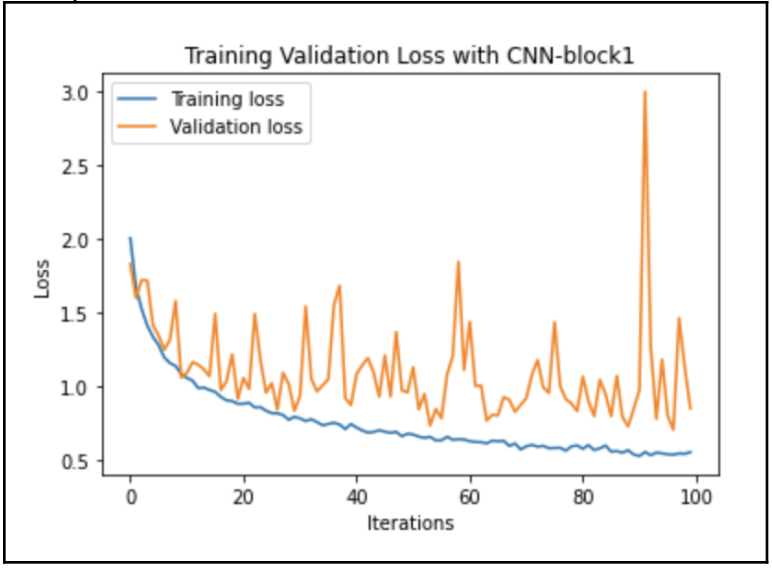
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): AvgPool2d(kernel_size=2, stride=2, padding=0)
```

```
    (7): Dropout(p=0.5, inplace=False)
    (8): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (9): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (10): ReLU(inplace=True)
    (11): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (12): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (13): ReLU(inplace=True)
    (14): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (15): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (16): ReLU(inplace=True)
    (17): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (18): Dropout(p=0.5, inplace=False)
    (19): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (20): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (21): ReLU(inplace=True)
    (22): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (23): Dropout(p=0.5, inplace=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	86%	76%
Loss	0.370939	0.703236

❖ Loss plot



Best value: Learning rate = 0.001 performed better as, at value 0.01, the model oscillated around the minima and could not reach it which indicated that the value had to be decreased.

1.4.7 Data Augmentation

1.4.7.1 Without Data Augmentation

The results are the same as section 1.4.6.2 as the model in the section did not use data augmentation and had optimal hyperparameters.

1.4.7.2. With Data Augmentation

Random Horizontal flips were used for data augmentation.

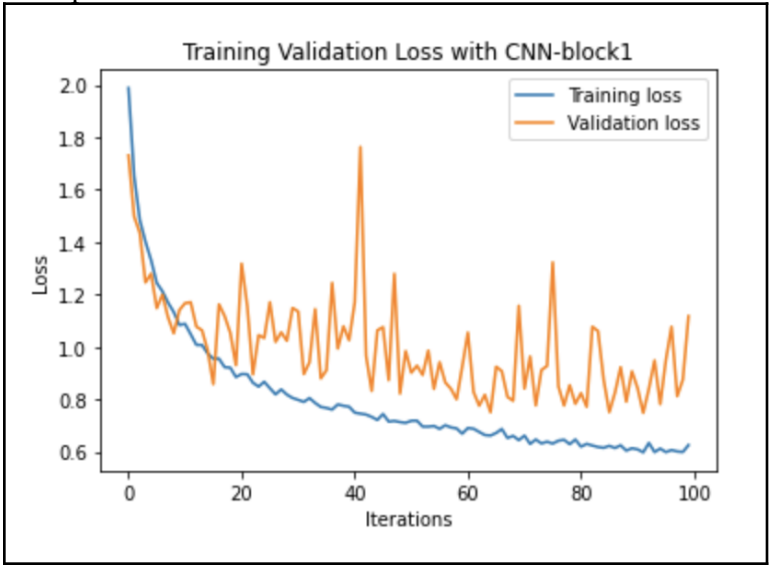
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (7): Dropout(p=0.5, inplace=False)
    (8): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (9): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (10): ReLU(inplace=True)
    (11): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (12): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (13): ReLU(inplace=True)
    (14): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (15): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (16): ReLU(inplace=True)
    (17): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (18): Dropout(p=0.5, inplace=False)
    (19): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (20): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (21): ReLU(inplace=True)
    (22): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (23): Dropout(p=0.5, inplace=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

- Accuracy and Loss

Block 1,2,3	Train	Test

Accuracy	83%	74%
Loss	0.461166	0.749098

- Loss plot



Best value: Data augmentation improved the performance of the model by making it more generalised. It made the model more generic and helped the model make more accurate predictions.

1.4.8 Epochs

The model was run for 500 epochs.

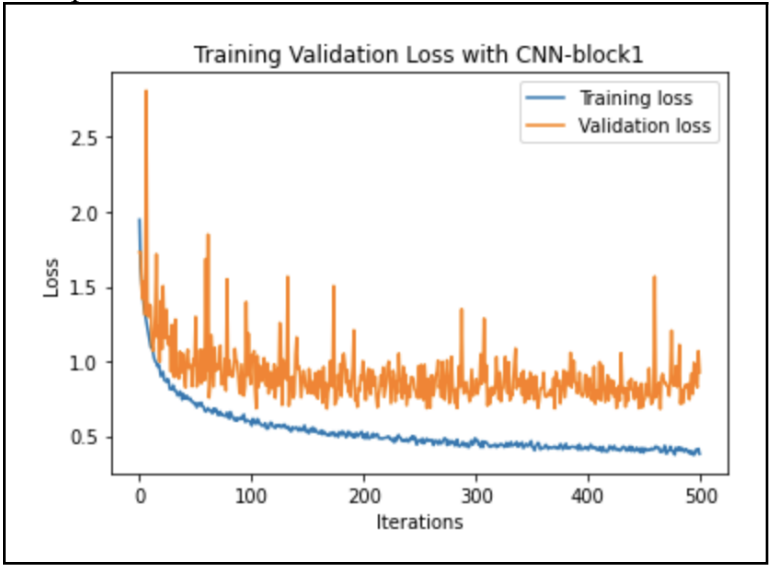
```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (7): Dropout(p=0.5, inplace=False)
    (8): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (9): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (10): ReLU(inplace=True)
    (11): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (12): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (13): ReLU(inplace=True)
    (14): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (15): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (16): ReLU(inplace=True)
```

```
    (17): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (18): Dropout(p=0.5, inplace=False)
    (19): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (20): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (21): ReLU(inplace=True)
    (22): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (23): Dropout(p=0.5, inplace=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

- Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	92%	78%
Loss	0.207575	0.683457

- Loss plot



Best value: From the plot and model performance, it was found that optimal epoch value was 100. After that, the model learning saturates i.e there is no significant change in test loss.

Best model:

Layers: X = 2, Y = 3, Z = 1
Batch Normalization
Average Pooling
Dropout = 0.5 after each block
Adam optimizer
No weight decay
Learning rate = 0.001

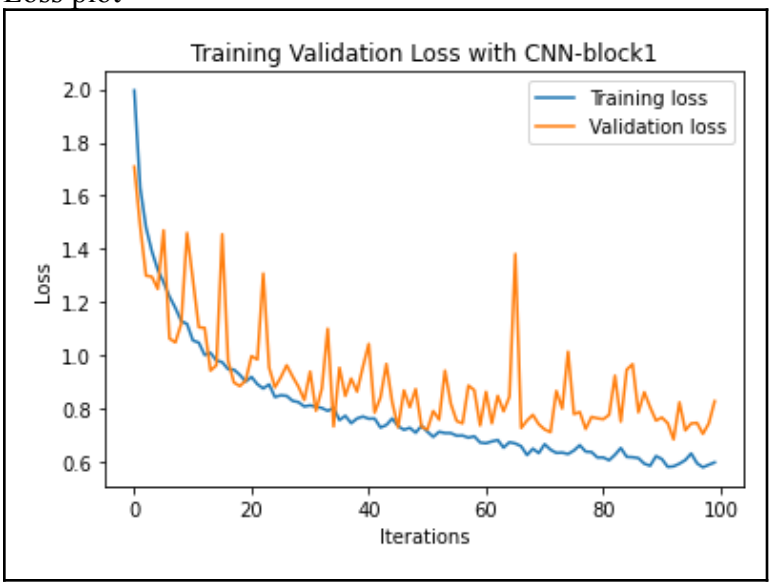
Data Augmentation - Random Horizontal Flips
Epochs = 100

```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (4): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (7): Dropout(p=0.5, inplace=False)
    (8): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (9): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (10): ReLU(inplace=True)
    (11): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (12): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (13): ReLU(inplace=True)
    (14): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (15): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (16): ReLU(inplace=True)
    (17): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (18): Dropout(p=0.5, inplace=False)
    (19): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (20): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (21): ReLU(inplace=True)
    (22): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (23): Dropout(p=0.5, inplace=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

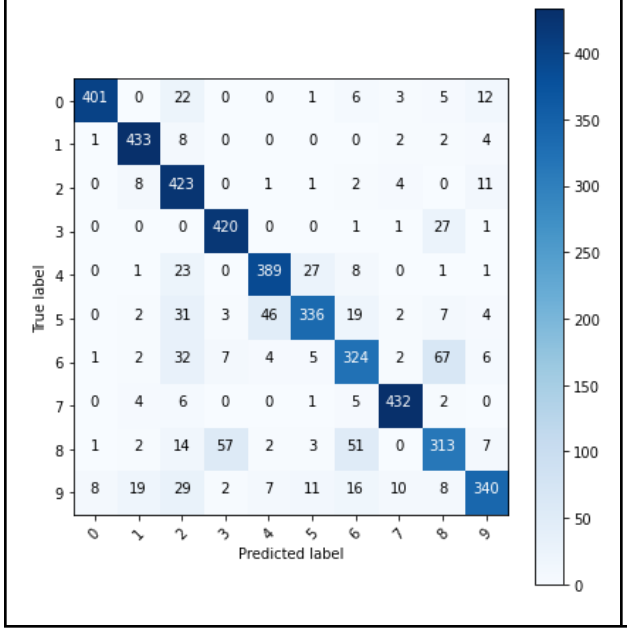
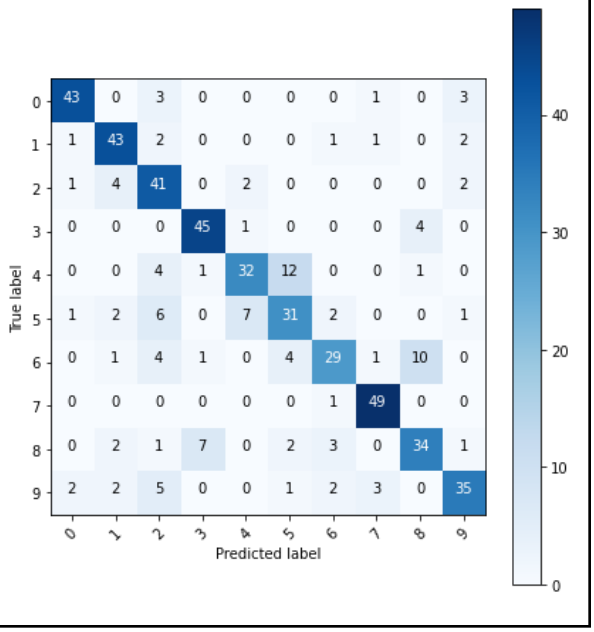
❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	84%	76%
Loss	0.420687	0.682963

❖ Loss plot



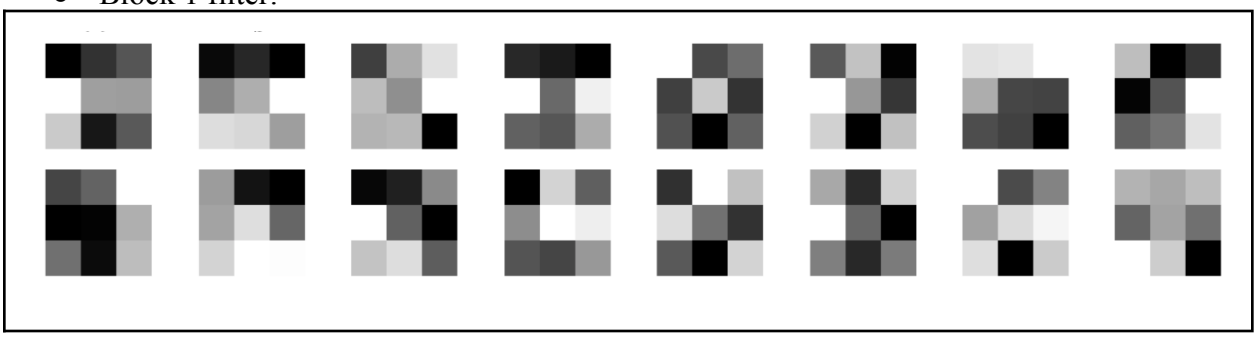
❖ Confusion Matrix

Train	Test
	

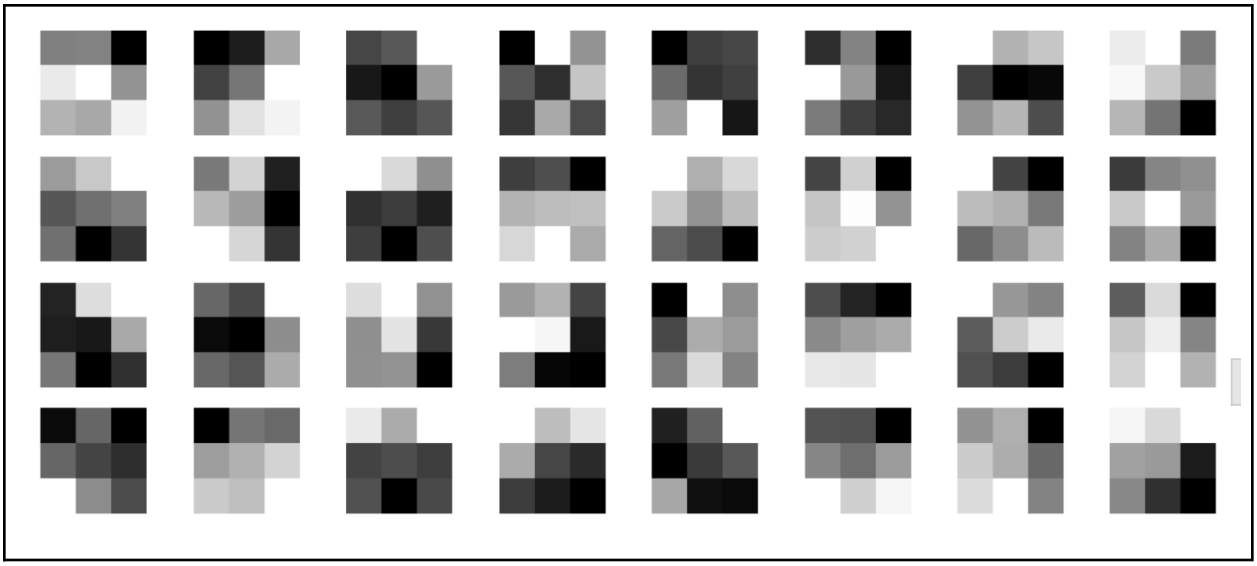
1.5 Visualize Convolutional Filters and Feature Maps

1.5.1 Visualize Convolutional Filters

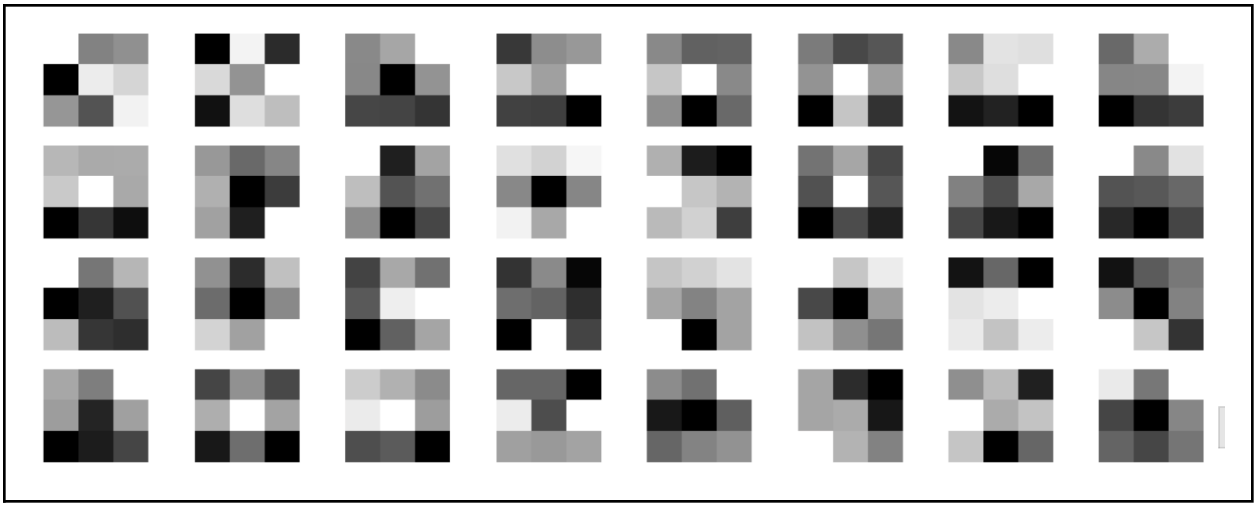
- Block 1 filter:



- Block 2 filter:

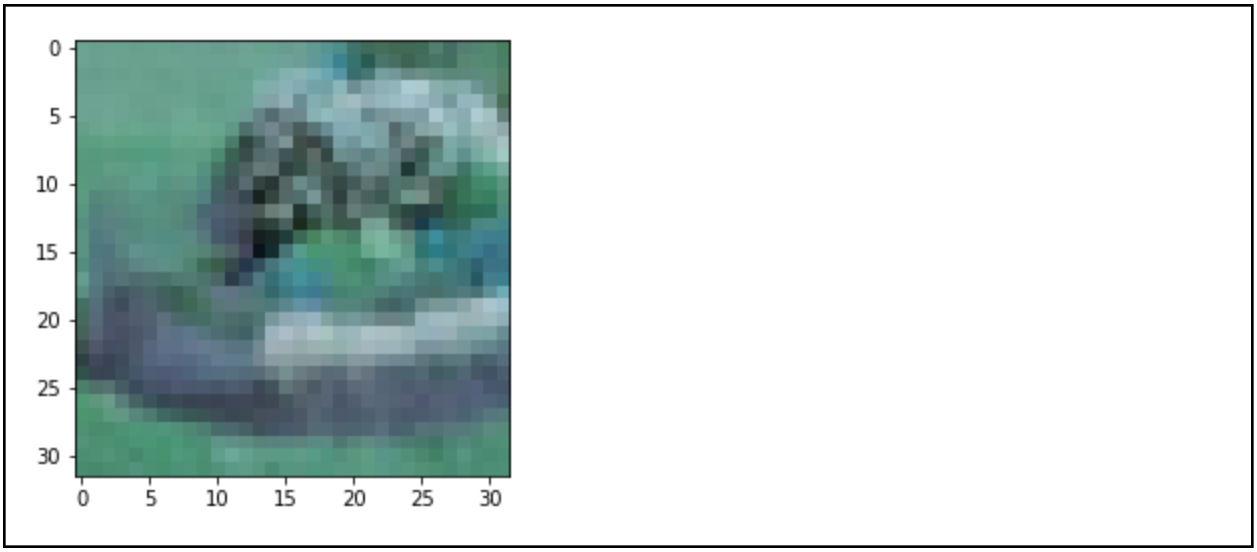


- Block 3 filter:

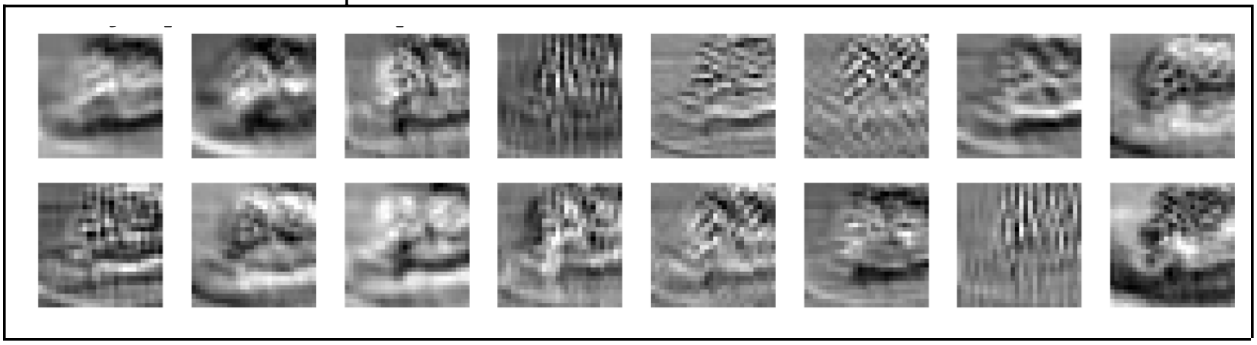


1.5.2 Visualize Feature Maps

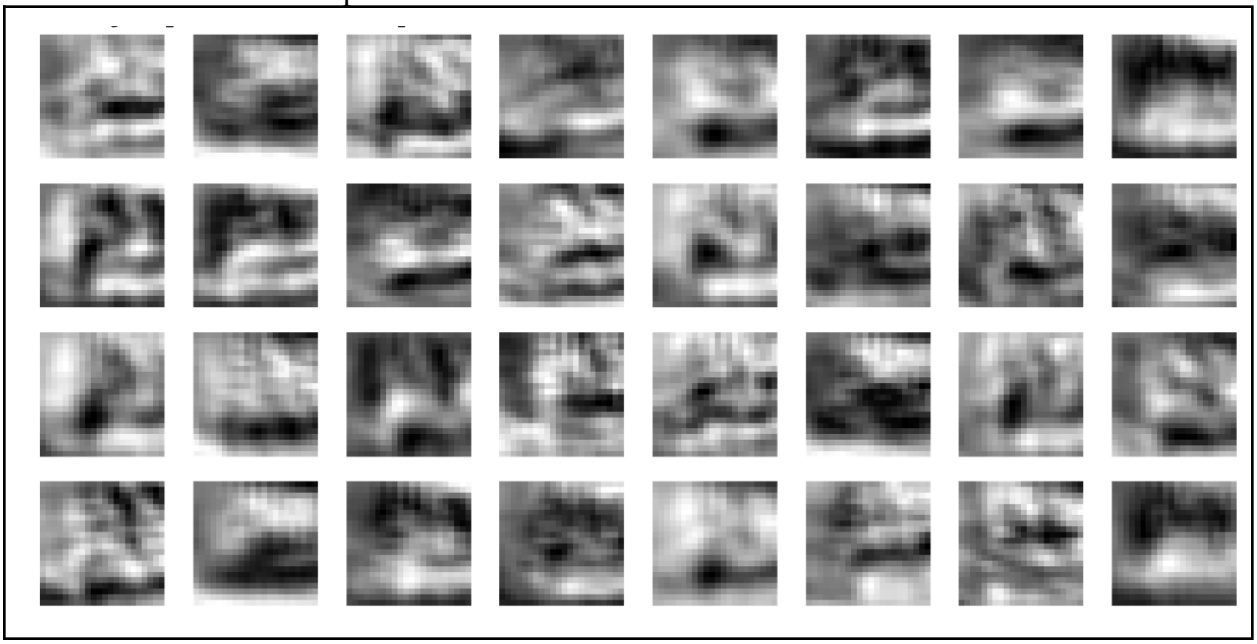
For the following image feature maps visualised are:



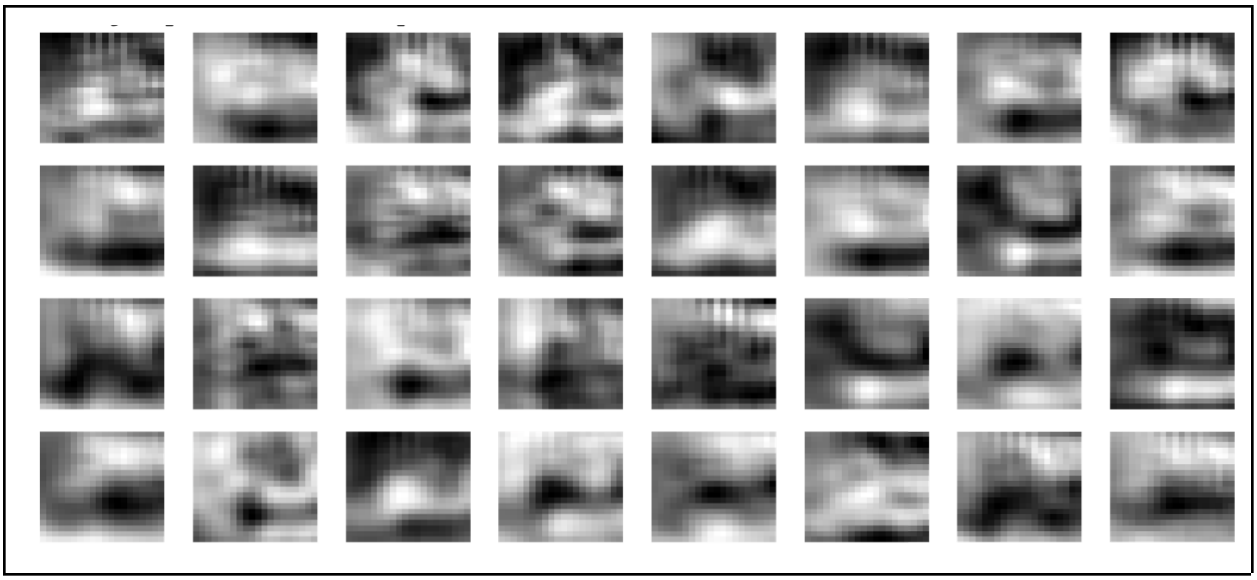
- Block 1 feature maps:



- Block 2 feature maps:



- Some of the block 3 feature maps:



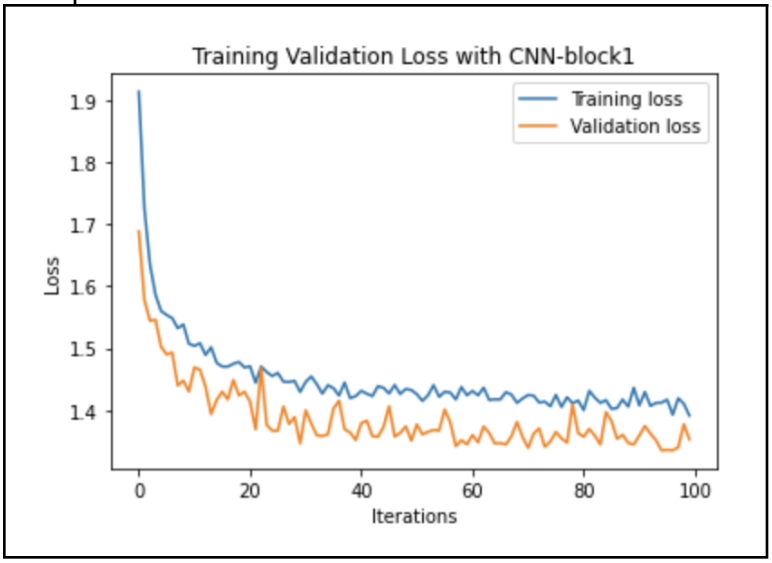
1.6 Best Model Without Activation Function

```
Model_B123(
  (features): Sequential(
    (0): Conv2d(3, 16, kernel_size=(3, 3), stride=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): Conv2d(16, 16, kernel_size=(3, 3), stride=(1, 1))
    (3): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (4): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (5): Dropout(p=0.5, inplace=False)
    (6): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1))
    (7): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (8): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (9): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (10): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1))
    (11): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (13): Dropout(p=0.5, inplace=False)
    (14): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1))
    (15): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (16): AvgPool2d(kernel_size=2, stride=2, padding=0)
    (17): Dropout(p=0.5, inplace=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=64, out_features=10, bias=True)
  )
)
```

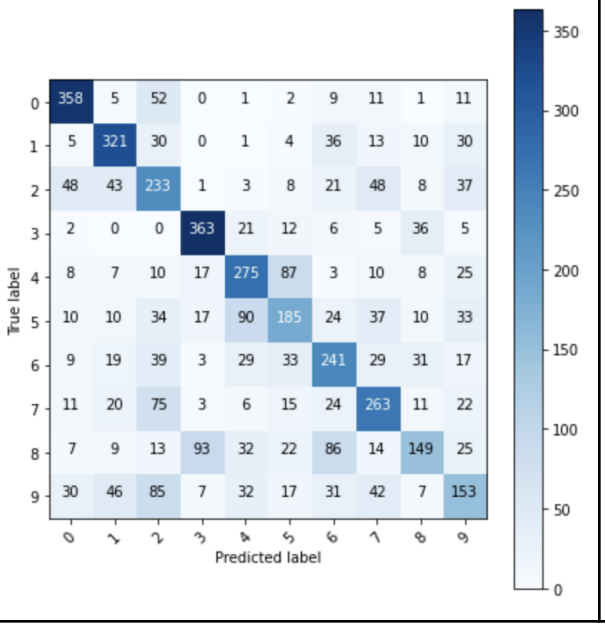
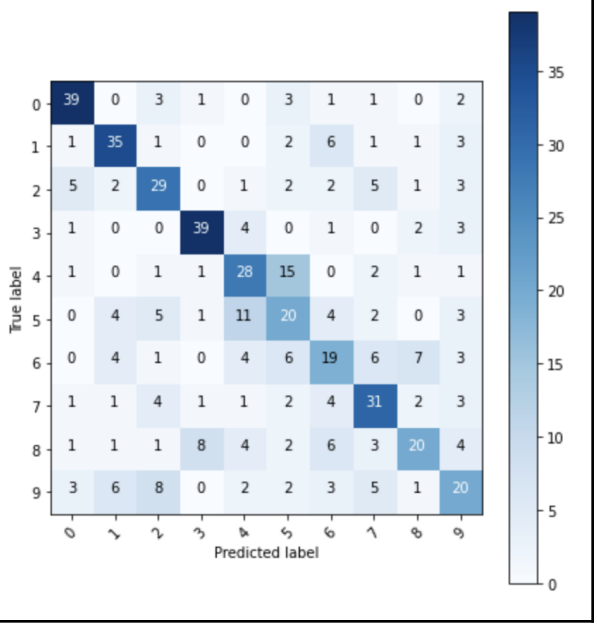
❖ Accuracy and Loss

Block 1,2,3	Train	Test
Accuracy	56%	56%
Loss	1.278515	1.338608

❖ Loss plot



❖ Confusion Matrix

Train	Test
	

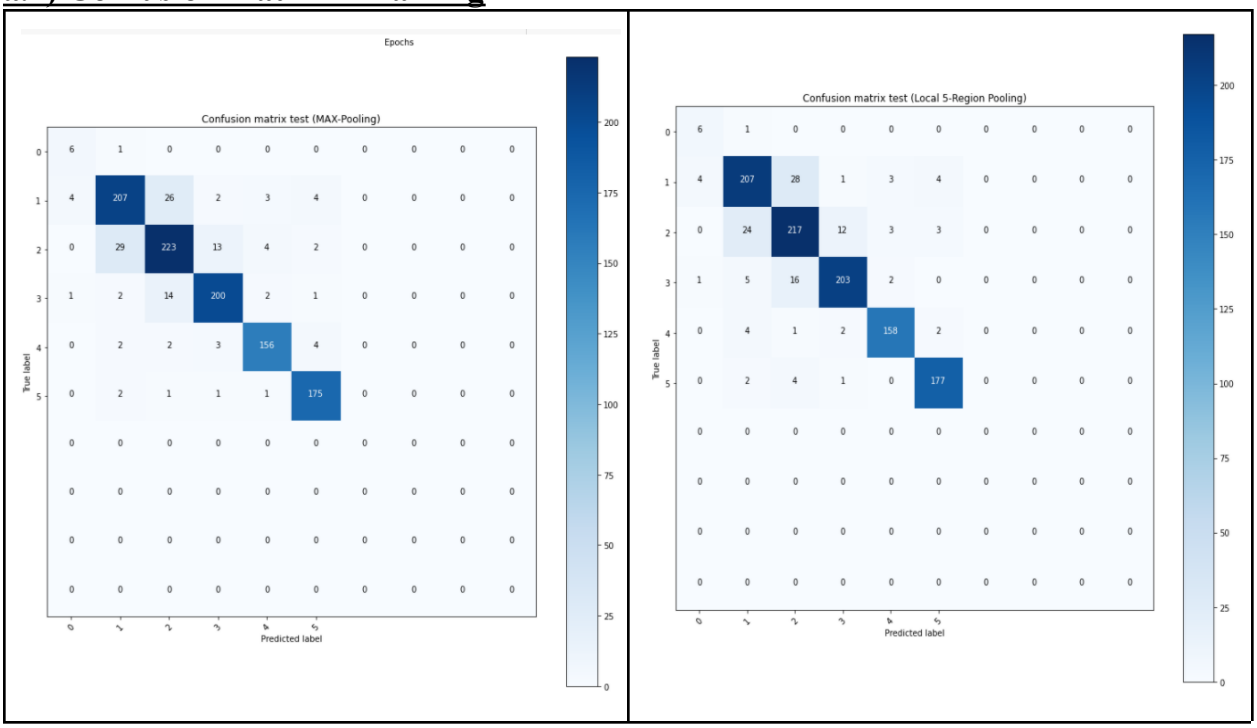
Analysis:

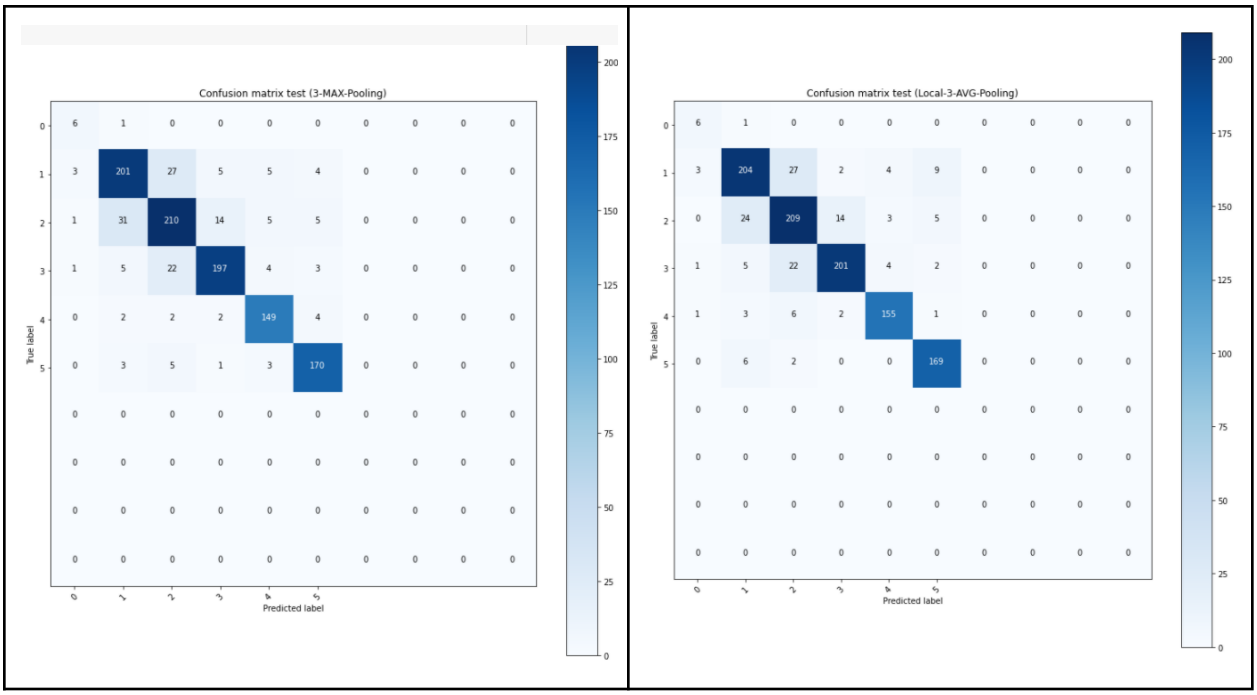
- Removal of activation function has a significant drop in accuracy (from 76% to 56%) on test data.
- The drop in performance is because, without activation function, the model cannot capture non-linearity in the data.
- The model also might have a vanishing/exploding gradient problem without activation function.

2. Sentence Classification

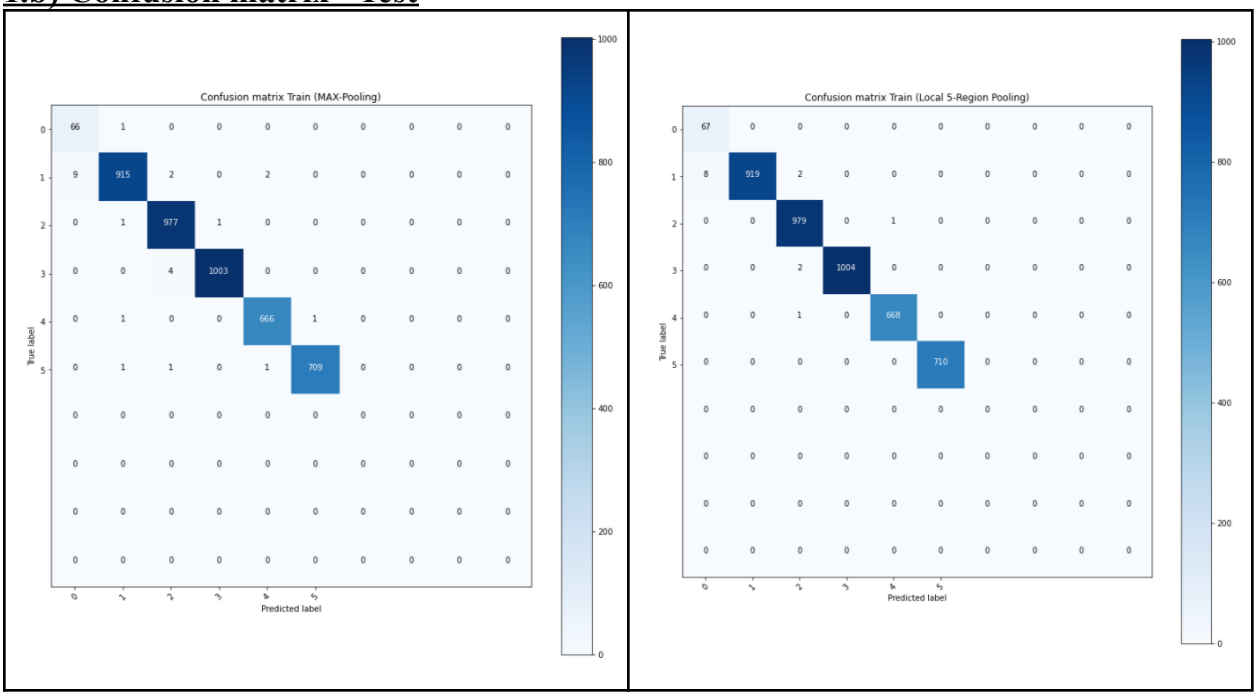
Description	Values
input word vectors	Google word2vec
filter region size	(3,4,5)
feature maps	100
activation function	ReLU
pooling	1-max pooling
dropout rate	0.5
*l*2 norm constraint	3

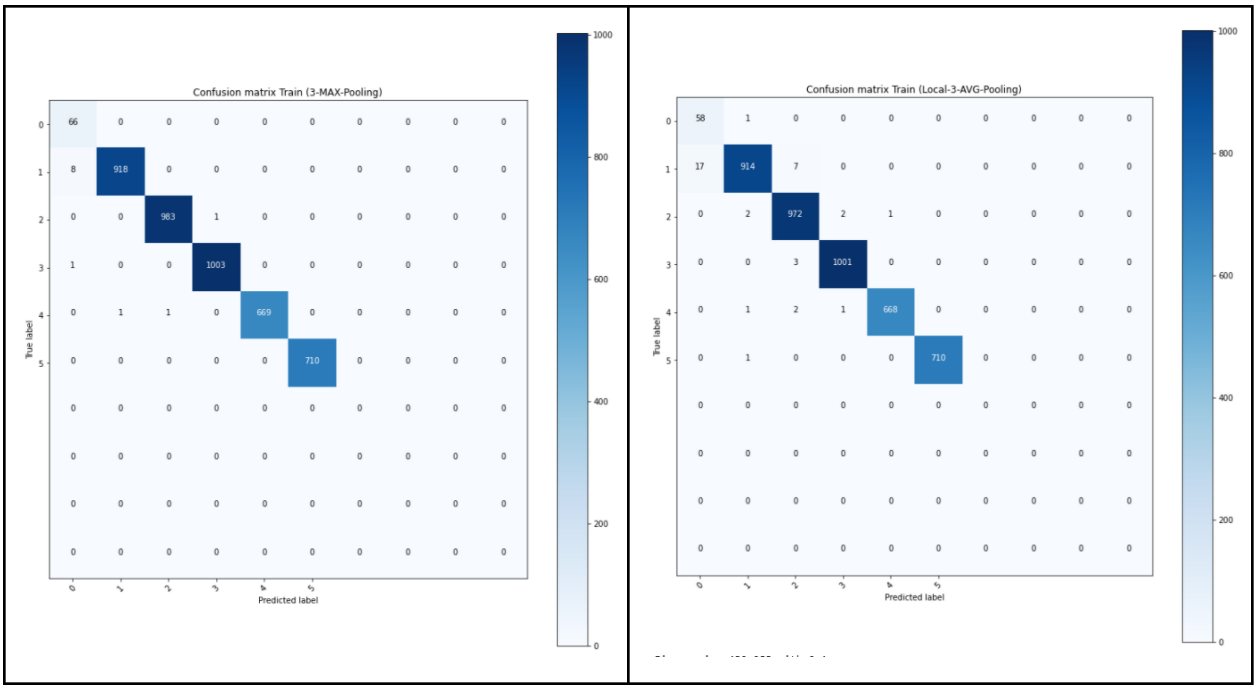
a.1) Confusion matrix - Training



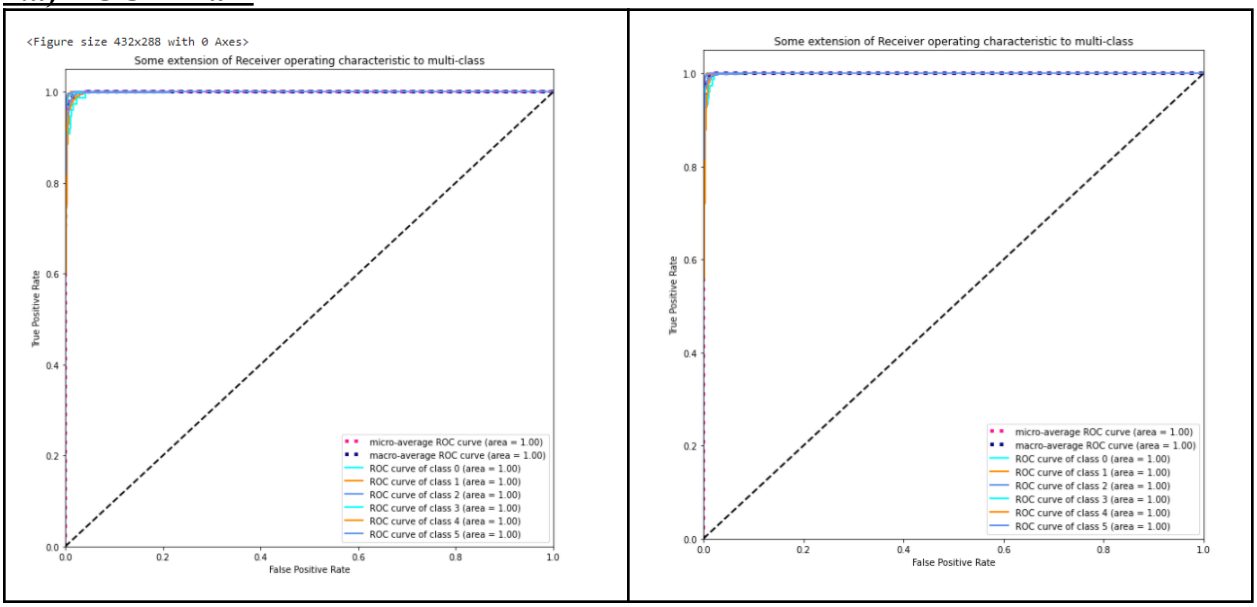


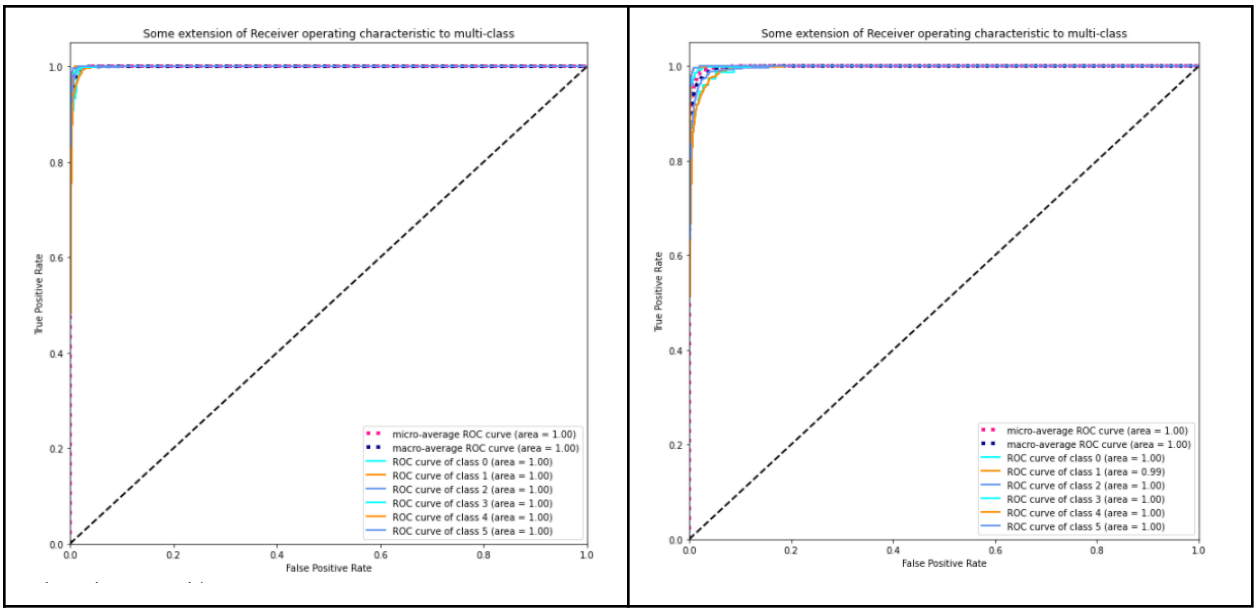
1.b) Confusion matrix - Test



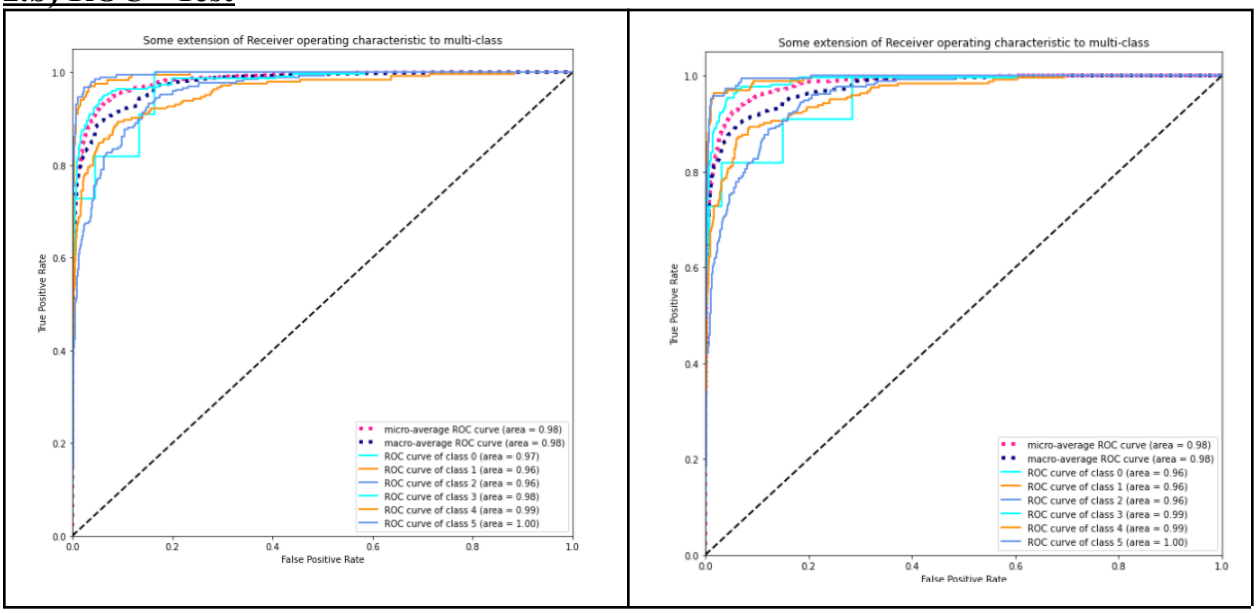

Confusion matrix Train (3-MAX-Pooling)
True label
Predicted label
Confusion matrix Train (Local-3-AVG-Pooling)
True label
Predicted label

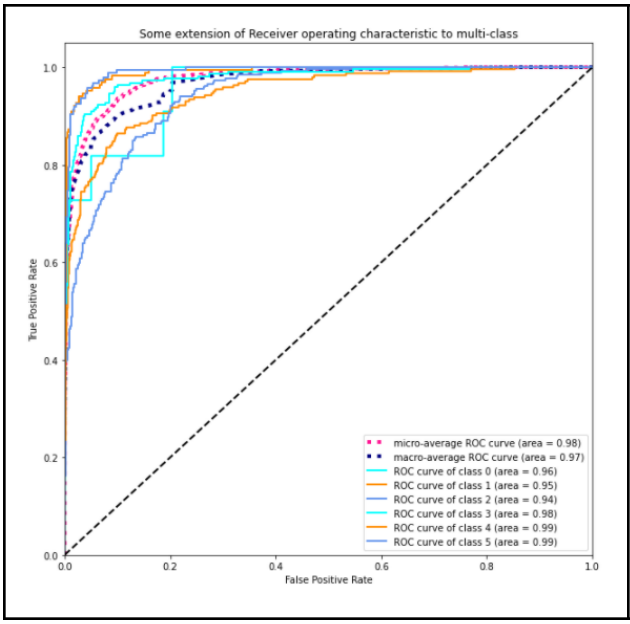
2.a) ROC - Train

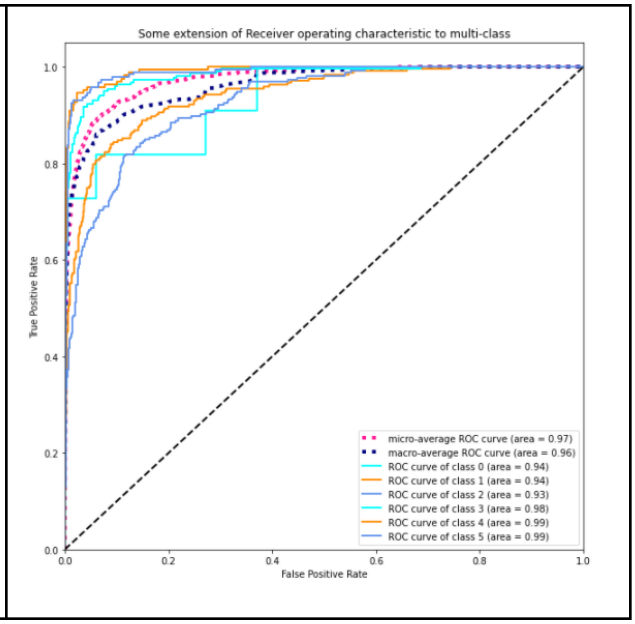

<Figure size 432x288 with 0 Axes>
Some extension of Receiver operating characteristic to multi-class
True Positive Rate
False Positive Rate
micro-average ROC curve (area = 1.00)
macro-average ROC curve (area = 1.00)
ROC curve of class 0 (area = 1.00)
ROC curve of class 1 (area = 1.00)
ROC curve of class 2 (area = 1.00)
ROC curve of class 3 (area = 1.00)
ROC curve of class 4 (area = 1.00)
ROC curve of class 5 (area = 1.00)
Some extension of Receiver operating characteristic to multi-class
True Positive Rate
False Positive Rate
micro-average ROC curve (area = 1.00)
macro-average ROC curve (area = 1.00)
ROC curve of class 0 (area = 1.00)
ROC curve of class 1 (area = 1.00)
ROC curve of class 2 (area = 1.00)
ROC curve of class 3 (area = 1.00)
ROC curve of class 4 (area = 1.00)
ROC curve of class 5 (area = 1.00)


Some extension of Receiver operating characteristic to multi-class
True Positive Rate
False Positive Rate
micro-average ROC curve (area = 1.00)
macro-average ROC curve (area = 1.00)
ROC curve of class 0 (area = 1.00)
ROC curve of class 1 (area = 1.00)
ROC curve of class 2 (area = 1.00)
ROC curve of class 3 (area = 1.00)
ROC curve of class 4 (area = 1.00)
ROC curve of class 5 (area = 1.00)
Some extension of Receiver operating characteristic to multi-class
True Positive Rate
False Positive Rate
micro-average ROC curve (area = 1.00)
macro-average ROC curve (area = 1.00)
ROC curve of class 0 (area = 1.00)
ROC curve of class 1 (area = 0.99)
ROC curve of class 2 (area = 1.00)
ROC curve of class 3 (area = 1.00)
ROC curve of class 4 (area = 1.00)
ROC curve of class 5 (area = 1.00)

2.b) ROC - Test


Some extension of Receiver operating characteristic to multi-class
True Positive Rate
False Positive Rate
micro-average ROC curve (area = 0.98)
macro-average ROC curve (area = 0.98)
ROC curve of class 0 (area = 0.97)
ROC curve of class 1 (area = 0.96)
ROC curve of class 2 (area = 0.96)
ROC curve of class 3 (area = 0.98)
ROC curve of class 4 (area = 0.99)
ROC curve of class 5 (area = 1.00)
Some extension of Receiver operating characteristic to multi-class
True Positive Rate
False Positive Rate
micro-average ROC curve (area = 0.98)
macro-average ROC curve (area = 0.98)
ROC curve of class 0 (area = 0.96)
ROC curve of class 1 (area = 0.96)
ROC curve of class 2 (area = 0.96)
ROC curve of class 3 (area = 0.99)
ROC curve of class 4 (area = 0.99)
ROC curve of class 5 (area = 1.00)





3) F1 Measure - train vs test

	precision	recall	f1-score	support
0	0.857	0.545	0.667	11
1	0.841	0.852	0.847	243
2	0.823	0.838	0.831	266
3	0.909	0.913	0.911	219
4	0.934	0.940	0.937	166
5	0.972	0.941	0.956	186
accuracy			0.886	1091
macro avg	0.889	0.838	0.858	1091
weighted avg	0.887	0.886	0.886	1091

	precision	recall	f1-score	support
0	0.985	0.880	0.930	75
1	0.986	0.996	0.991	919
2	0.998	0.993	0.995	984
3	0.996	0.999	0.998	1004
4	0.997	0.996	0.996	669
5	0.996	0.999	0.997	710
accuracy			0.994	4361
macro avg	0.993	0.977	0.984	4361
weighted avg	0.994	0.994	0.994	4361

	precision	recall	f1-score	support
0	0.857	0.545	0.667	11
1	0.838	0.852	0.845	243
2	0.838	0.816	0.827	266
3	0.894	0.927	0.910	219
4	0.946	0.952	0.949	166
5	0.962	0.952	0.957	186
accuracy			0.887	1091
macro avg	0.889	0.841	0.859	1091
weighted avg	0.887	0.887	0.887	1091

	precision	recall	f1-score	support
0	1.000	0.893	0.944	75
1	0.989	1.000	0.995	919
2	0.999	0.995	0.997	984
3	0.998	1.000	0.999	1004
4	0.999	0.999	0.999	669
5	1.000	1.000	1.000	710
accuracy			0.997	4361
macro avg	0.997	0.981	0.989	4361
weighted avg	0.997	0.997	0.997	4361

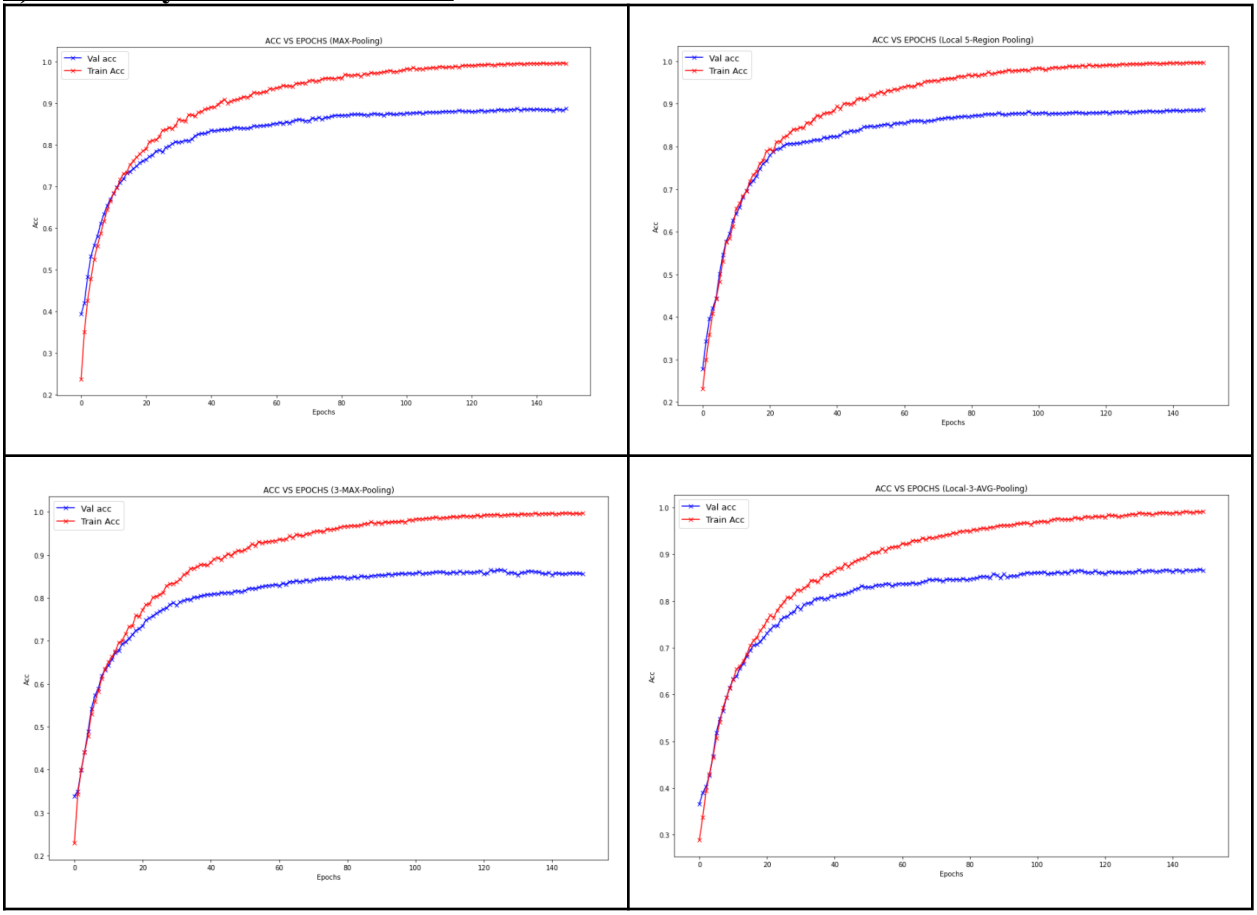
	precision	recall	f1-score	support
0	0.857	0.545	0.667	11
1	0.819	0.840	0.829	243
2	0.820	0.786	0.802	266
3	0.855	0.918	0.885	219
4	0.923	0.934	0.928	166
5	0.955	0.909	0.931	186
accuracy			0.865	1091
macro avg	0.871	0.822	0.840	1091
weighted avg	0.866	0.865	0.865	1091

	precision	recall	f1-score	support
0	0.983	0.773	0.866	75
1	0.974	0.995	0.984	919
2	0.995	0.988	0.991	984
3	0.997	0.997	0.997	1004
4	0.994	0.999	0.996	669
5	0.999	1.000	0.999	710
accuracy			0.991	4361
macro avg	0.990	0.959	0.972	4361
weighted avg	0.991	0.991	0.991	4361

	precision	recall	f1-score	support
0	0.857	0.545	0.667	11
1	0.820	0.827	0.824	243
2	0.789	0.789	0.789	266
3	0.849	0.900	0.874	219
4	0.937	0.898	0.917	166
5	0.934	0.914	0.924	186
accuracy			0.855	1091
macro avg	0.865	0.812	0.832	1091
weighted avg	0.856	0.855	0.855	1091

	precision	recall	f1-score	support
0	1.000	0.880	0.936	75
1	0.991	0.999	0.995	919
2	0.999	0.999	0.999	984
3	0.999	0.999	0.999	1004
4	0.997	1.000	0.999	669
5	1.000	1.000	1.000	710
accuracy			0.997	4361
macro avg	0.998	0.979	0.988	4361
weighted avg	0.997	0.997	0.997	4361

4) Accuracy curve train vs test



5) Accuracy curve train vs test (Epochs)

```
1-max
Epoch: 10 | Epoch Time: 0m 0s
        Train Loss: 1.154 | Train Acc: 66.46%
         Val. Loss: 1.147 |  Test. Acc: 66.91%
Epoch: 20 | Epoch Time: 0m 0s
        Train Loss: 0.748 | Train Acc: 78.48%
         Val. Loss: 0.781 |  Test. Acc: 76.17%
Epoch: 30 | Epoch Time: 0m 0s
        Train Loss: 0.530 | Train Acc: 84.60%
         Val. Loss: 0.602 |  Test. Acc: 80.66%
Epoch: 40 | Epoch Time: 0m 0s
        Train Loss: 0.402 | Train Acc: 88.63%
         Val. Loss: 0.508 |  Test. Acc: 82.95%
Epoch: 50 | Epoch Time: 0m 0s
        Train Loss: 0.317 | Train Acc: 91.10%
         Val. Loss: 0.455 |  Test. Acc: 83.96%
Epoch: 60 | Epoch Time: 0m 0s
        Train Loss: 0.254 | Train Acc: 93.32%
         Val. Loss: 0.418 |  Test. Acc: 84.97%
Epoch: 70 | Epoch Time: 0m 0s
        Train Loss: 0.204 | Train Acc: 94.77%
         Val. Loss: 0.393 |  Test. Acc: 85.70%
Epoch: 80 | Epoch Time: 0m 0s
        Train Loss: 0.167 | Train Acc: 96.10%
         Val. Loss: 0.375 |  Test. Acc: 86.98%
Epoch: 90 | Epoch Time: 0m 0s
        Train Loss: 0.133 | Train Acc: 97.28%
         Val. Loss: 0.361 |  Test. Acc: 87.35%
Epoch: 100 | Epoch Time: 0m 0s
        Train Loss: 0.103 | Train Acc: 97.89%
         Val. Loss: 0.353 |  Test. Acc: 87.35%
Epoch: 110 | Epoch Time: 0m 0s
        Train Loss: 0.084 | Train Acc: 98.46%
         Val. Loss: 0.348 |  Test. Acc: 87.81%
Epoch: 120 | Epoch Time: 0m 0s
        Train Loss: 0.065 | Train Acc: 99.07%
         Val. Loss: 0.345 |  Test. Acc: 88.08%
Epoch: 130 | Epoch Time: 0m 0s
        Train Loss: 0.055 | Train Acc: 99.30%
         Val. Loss: 0.344 |  Test. Acc: 88.36%
Epoch: 140 | Epoch Time: 0m 0s
        Train Loss: 0.045 | Train Acc: 99.48%
         Val. Loss: 0.343 |  Test. Acc: 88.36%
Epoch: 150 | Epoch Time: 0m 0s
        Train Loss: 0.038 | Train Acc: 99.43%
         Val. Loss: 0.345 |  Test. Acc: 88.63%
```

```
5-local
Epoch: 10 | Epoch Time: 0m 0s
        Train Loss: 1.263 | Train Acc: 61.31%
         Val. Loss: 1.251 |  Test. Acc: 62.69%
Epoch: 20 | Epoch Time: 0m 0s
        Train Loss: 0.785 | Train Acc: 78.89%
         Val. Loss: 0.819 |  Test. Acc: 76.63%
Epoch: 30 | Epoch Time: 0m 0s
        Train Loss: 0.546 | Train Acc: 84.51%
         Val. Loss: 0.610 |  Test. Acc: 80.75%
Epoch: 40 | Epoch Time: 0m 0s
        Train Loss: 0.402 | Train Acc: 88.36%
         Val. Loss: 0.507 |  Test. Acc: 82.31%
Epoch: 50 | Epoch Time: 0m 0s
        Train Loss: 0.311 | Train Acc: 91.23%
         Val. Loss: 0.449 |  Test. Acc: 84.60%
Epoch: 60 | Epoch Time: 0m 0s
        Train Loss: 0.238 | Train Acc: 93.86%
         Val. Loss: 0.413 |  Test. Acc: 85.52%
Epoch: 70 | Epoch Time: 0m 0s
        Train Loss: 0.189 | Train Acc: 95.54%
         Val. Loss: 0.387 |  Test. Acc: 86.16%
Epoch: 80 | Epoch Time: 0m 0s
        Train Loss: 0.147 | Train Acc: 96.83%
         Val. Loss: 0.370 |  Test. Acc: 86.98%
Epoch: 90 | Epoch Time: 0m 0s
        Train Loss: 0.117 | Train Acc: 97.44%
         Val. Loss: 0.358 |  Test. Acc: 87.53%
Epoch: 100 | Epoch Time: 0m 0s
        Train Loss: 0.094 | Train Acc: 98.26%
         Val. Loss: 0.349 |  Test. Acc: 87.72%
Epoch: 110 | Epoch Time: 0m 0s
        Train Loss: 0.072 | Train Acc: 98.91%
         Val. Loss: 0.344 |  Test. Acc: 87.90%
Epoch: 120 | Epoch Time: 0m 0s
        Train Loss: 0.060 | Train Acc: 99.09%
         Val. Loss: 0.342 |  Test. Acc: 87.99%
Epoch: 130 | Epoch Time: 0m 0s
        Train Loss: 0.045 | Train Acc: 99.39%
         Val. Loss: 0.341 |  Test. Acc: 87.99%
Epoch: 140 | Epoch Time: 0m 0s
        Train Loss: 0.036 | Train Acc: 99.59%
         Val. Loss: 0.342 |  Test. Acc: 88.36%
Epoch: 150 | Epoch Time: 0m 0s
        Train Loss: 0.029 | Train Acc: 99.68%
         Val. Loss: 0.344 |  Test. Acc: 88.73%
```

```
3-max
Epoch: 10 | Epoch Time: 0m 0s
        Train Loss: 1.196 | Train Acc: 63.47%
         Val. Loss: 1.201 |  Test. Acc: 63.24%
Epoch: 20 | Epoch Time: 0m 0s
        Train Loss: 0.778 | Train Acc: 75.65%
         Val. Loss: 0.832 |  Test. Acc: 72.87%
Epoch: 30 | Epoch Time: 0m 0s
        Train Loss: 0.552 | Train Acc: 83.31%
         Val. Loss: 0.645 |  Test. Acc: 78.83%
Epoch: 40 | Epoch Time: 0m 0s
        Train Loss: 0.420 | Train Acc: 87.56%
         Val. Loss: 0.550 |  Test. Acc: 80.75%
Epoch: 50 | Epoch Time: 0m 0s
        Train Loss: 0.319 | Train Acc: 90.80%
         Val. Loss: 0.494 |  Test. Acc: 81.39%
Epoch: 60 | Epoch Time: 0m 0s
        Train Loss: 0.251 | Train Acc: 93.23%
         Val. Loss: 0.458 |  Test. Acc: 83.13%
Epoch: 70 | Epoch Time: 0m 0s
        Train Loss: 0.198 | Train Acc: 94.90%
         Val. Loss: 0.434 |  Test. Acc: 83.87%
Epoch: 80 | Epoch Time: 0m 0s
        Train Loss: 0.159 | Train Acc: 96.63%
         Val. Loss: 0.418 |  Test. Acc: 84.78%
Epoch: 90 | Epoch Time: 0m 0s
        Train Loss: 0.122 | Train Acc: 97.55%
         Val. Loss: 0.409 |  Test. Acc: 85.33%
Epoch: 100 | Epoch Time: 0m 0s
        Train Loss: 0.096 | Train Acc: 98.07%
         Val. Loss: 0.402 |  Test. Acc: 85.61%
Epoch: 110 | Epoch Time: 0m 0s
        Train Loss: 0.074 | Train Acc: 98.62%
         Val. Loss: 0.400 |  Test. Acc: 85.79%
Epoch: 120 | Epoch Time: 0m 0s
        Train Loss: 0.062 | Train Acc: 98.91%
         Val. Loss: 0.403 |  Test. Acc: 86.25%
Epoch: 130 | Epoch Time: 0m 0s
        Train Loss: 0.046 | Train Acc: 99.37%
         Val. Loss: 0.406 |  Test. Acc: 85.79%
Epoch: 140 | Epoch Time: 0m 0s
        Train Loss: 0.039 | Train Acc: 99.55%
         Val. Loss: 0.412 |  Test. Acc: 85.88%
Epoch: 150 | Epoch Time: 0m 0s
        Train Loss: 0.029 | Train Acc: 99.73%
         Val. Loss: 0.419 |  Test. Acc: 85.52%
```

```
3-local-average
Epoch: 10 | Epoch Time: 0m 0s
        Train Loss: 1.220 | Train Acc: 61.29%
         Val. Loss: 1.216 |  Test. Acc: 61.50%
Epoch: 20 | Epoch Time: 0m 0s
        Train Loss: 0.814 | Train Acc: 74.47%
         Val. Loss: 0.846 |  Test. Acc: 72.14%
Epoch: 30 | Epoch Time: 0m 0s
        Train Loss: 0.573 | Train Acc: 82.40%
         Val. Loss: 0.661 |  Test. Acc: 78.74%
Epoch: 40 | Epoch Time: 0m 0s
        Train Loss: 0.449 | Train Acc: 86.11%
         Val. Loss: 0.562 |  Test. Acc: 81.12%
Epoch: 50 | Epoch Time: 0m 0s
        Train Loss: 0.351 | Train Acc: 89.20%
         Val. Loss: 0.506 |  Test. Acc: 82.95%
Epoch: 60 | Epoch Time: 0m 0s
        Train Loss: 0.284 | Train Acc: 91.64%
         Val. Loss: 0.471 |  Test. Acc: 83.68%
Epoch: 70 | Epoch Time: 0m 0s
        Train Loss: 0.232 | Train Acc: 93.41%
         Val. Loss: 0.448 |  Test. Acc: 84.42%
Epoch: 80 | Epoch Time: 0m 0s
        Train Loss: 0.188 | Train Acc: 95.02%
         Val. Loss: 0.434 |  Test. Acc: 84.42%
Epoch: 90 | Epoch Time: 0m 0s
        Train Loss: 0.154 | Train Acc: 96.08%
         Val. Loss: 0.426 |  Test. Acc: 84.88%
Epoch: 100 | Epoch Time: 0m 0s
        Train Loss: 0.129 | Train Acc: 96.83%
         Val. Loss: 0.420 |  Test. Acc: 85.98%
Epoch: 110 | Epoch Time: 0m 0s
        Train Loss: 0.103 | Train Acc: 97.37%
         Val. Loss: 0.419 |  Test. Acc: 85.88%
Epoch: 120 | Epoch Time: 0m 0s
        Train Loss: 0.087 | Train Acc: 98.08%
         Val. Loss: 0.422 |  Test. Acc: 85.98%
Epoch: 130 | Epoch Time: 0m 0s
        Train Loss: 0.069 | Train Acc: 98.44%
         Val. Loss: 0.424 |  Test. Acc: 86.25%
Epoch: 140 | Epoch Time: 0m 0s
        Train Loss: 0.059 | Train Acc: 98.75%
         Val. Loss: 0.431 |  Test. Acc: 86.53%
Epoch: 150 | Epoch Time: 0m 0s
        Train Loss: 0.049 | Train Acc: 99.14%
         Val. Loss: 0.438 |  Test. Acc: 86.53%
```

Contribution of Each Member

1. **Shivam Sharma**
   Implemented part(2) and report
2. **Akanksha Shrimal**
   Implemented part(1) and report
3. **Vaibhav Goswami**
   Implemented part(2) and report