Assignment 1

COL870 : Deep Learning

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Part 1 - ResNet over Convolution Networks and different Normalization schemes

1.1 - Image Classification using Residual Network

1. **Implement ResNet**

   The ResNet architecture as in the paper has been constructed as follows:

   - A block class has been created which outputs 2 layers where each layer includes: a convolution layer, a normalization layer as specified by input from the user, and a ReLU activation layer.

   - For the value of ‘n’ as input, the resnet class constructs a ResNet architecture with 6n+2 layers. There are three stacks created, each of which creates ‘n’ number of blocks, each block has two layers - a total of 6n layers. This included with initial convolution layer and the final linear layer completes the desired layout.

Layer 1	Convolution + normalization + ReLU
Stack1	n blocks with 2 layers each i.e. 2n layers
Stack2	n blocks with 2 layers each i.e. 2n layers
Stack 3	n blocks with 2 layers each i.e. 2n layers
Final Layer	Average pooling + Linear Layer

2. **The model has been trained with the following hyperparameters:**

   - batch_size = 128
   - epochs = 100
   - momentum = 0.9
   - weight_decay = 0.0001
   - SGD optimizer with initial learning rate = 0.1, multiplied by 10 at each milestone implemented with the optim.lr_scheduler having gamma = 0.1.

3. **Statistics/ Analysis:**

   - The metrics have been calculated using sklearn.metrics.
   - The model with inbuilt batch normalization performs with 96%,96%,89% accuracy on training, validation , and test data respectively.

	precision	recall	f1-score	support
plane	0.97	0.97	0.97	3963
car	0.99	0.98	0.98	4017
bird	0.95	0.94	0.95	4019
cat	0.92	0.90	0.91	4015
deer	0.96	0.95	0.95	4071
dog	0.92	0.93	0.93	3975
frog	0.96	0.97	0.97	3964
horse	0.97	0.97	0.97	3968
ship	0.98	0.99	0.98	3979
truck	0.97	0.98	0.98	4029
accuracy			0.96	40000
macro avg	0.96	0.96	0.96	40000
weighted avg	0.96	0.96	0.96	40000

Metrics on Training Data

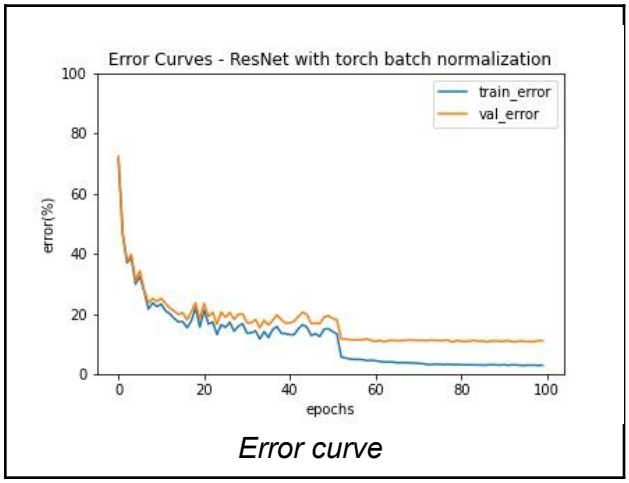
	precision	recall	f1-score	support
plane	0.96	0.96	0.96	1037
car	0.99	0.98	0.98	983
bird	0.95	0.95	0.95	981
cat	0.90	0.90	0.90	985
deer	0.97	0.95	0.96	929
dog	0.91	0.93	0.92	1025
frog	0.96	0.97	0.97	1036
horse	0.98	0.96	0.97	1032
ship	0.98	0.98	0.98	1021
truck	0.98	0.98	0.98	971
accuracy			0.96	10000
macro avg	0.96	0.96	0.96	10000
weighted avg	0.96	0.96	0.96	10000

Metrics on Validation Data

	precision	recall	f1-score	support
plane	0.89	0.90	0.89	1000
car	0.95	0.95	0.95	1000
bird	0.85	0.85	0.85	1000
cat	0.80	0.76	0.78	1000
deer	0.88	0.89	0.88	1000
dog	0.84	0.85	0.84	1000
frog	0.91	0.93	0.92	1000
horse	0.93	0.90	0.92	1000
ship	0.93	0.94	0.93	1000
truck	0.92	0.93	0.93	1000
accuracy			0.89	10000
macro avg	0.89	0.89	0.89	10000
weighted avg	0.89	0.89	0.89	10000

Metrics on Test Data

   - Error Curves: The error curve shows an expected gradual decrease in training and validation error. Validation error is a bit higher than training.

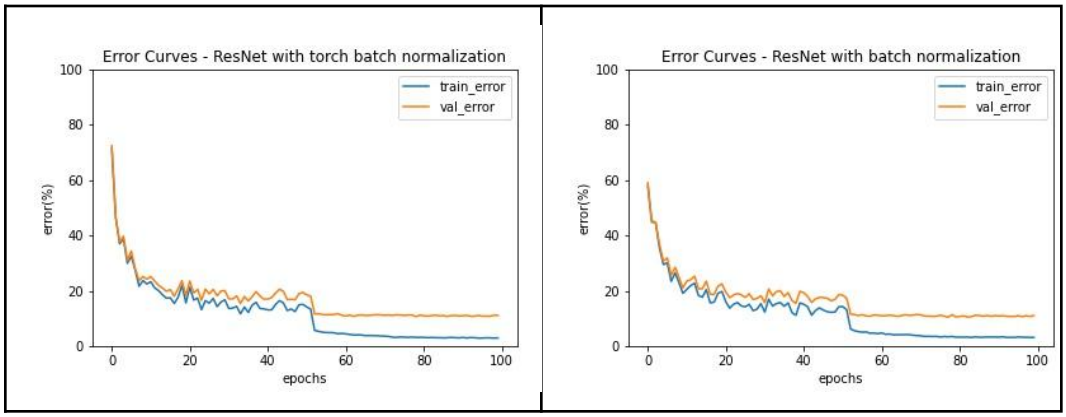


Error curve

1.2 - Impact of Normalization

1. **Sanity Check with self-implemented BN variant:**

    - The error curves for the inbuilt and implemented Batch normalization are shown below. The curves are almost similar, thus both the variants are working similarly.



- The metrics for training, validation, and test data are shown below. Both the variants perform similarly on all three datasets.

	precision	recall	f1-score	support
plane	0.97	0.97	0.97	3963
car	0.99	0.98	0.98	4017
bird	0.95	0.94	0.95	4019
cat	0.92	0.90	0.91	4015
deer	0.96	0.95	0.95	4071
dog	0.92	0.93	0.93	3975
frog	0.96	0.97	0.97	3964
horse	0.97	0.97	0.97	3968
ship	0.98	0.99	0.98	3979
truck	0.97	0.98	0.98	4029
accuracy			0.96	40000
macro avg	0.96	0.96	0.96	40000
weighted avg	0.96	0.96	0.96	40000

Metrics on Training Data

	precision	recall	f1-score	support
plane	0.96	0.97	0.96	3963
car	0.98	0.98	0.98	4017
bird	0.94	0.95	0.94	4019
cat	0.92	0.89	0.90	4015
deer	0.95	0.96	0.96	4071
dog	0.91	0.93	0.92	3975
frog	0.96	0.97	0.97	3964
horse	0.97	0.97	0.97	3968
ship	0.98	0.98	0.98	3979
truck	0.98	0.98	0.98	4029
accuracy			0.96	40000
macro avg	0.96	0.96	0.96	40000
weighted avg	0.96	0.96	0.96	40000

Metrics on Training Data

	precision	recall	f1-score	support
plane	0.96	0.96	0.96	1037
car	0.99	0.98	0.98	983
bird	0.95	0.95	0.95	981
cat	0.90	0.90	0.90	985
deer	0.97	0.95	0.96	929
dog	0.91	0.93	0.92	1025
frog	0.96	0.97	0.97	1036
horse	0.98	0.96	0.97	1032
ship	0.98	0.98	0.98	1021
truck	0.98	0.98	0.98	971
accuracy			0.96	10000
macro avg	0.96	0.96	0.96	10000
weighted avg	0.96	0.96	0.96	10000

Metrics on Validation Data

	precision	recall	f1-score	support
plane	0.96	0.97	0.97	1037
car	0.99	0.98	0.99	983
bird	0.94	0.94	0.94	981
cat	0.91	0.89	0.90	985
deer	0.96	0.96	0.96	929
dog	0.91	0.95	0.93	1025
frog	0.96	0.97	0.97	1036
horse	0.98	0.96	0.97	1032
ship	0.98	0.98	0.98	1021
truck	0.97	0.98	0.98	971
accuracy			0.96	10000
macro avg	0.96	0.96	0.96	10000
weighted avg	0.96	0.96	0.96	10000

Metrics on Validation Data

	precision	recall	f1-score	support
plane	0.89	0.90	0.89	1000
car	0.95	0.95	0.95	1000
bird	0.85	0.85	0.85	1000
cat	0.80	0.76	0.78	1000
deer	0.88	0.89	0.88	1000
dog	0.84	0.85	0.84	1000
frog	0.91	0.93	0.92	1000
horse	0.93	0.90	0.92	1000
ship	0.93	0.94	0.93	1000
truck	0.92	0.93	0.93	1000
accuracy			0.89	10000
macro avg	0.89	0.89	0.89	10000
weighted avg	0.89	0.89	0.89	10000

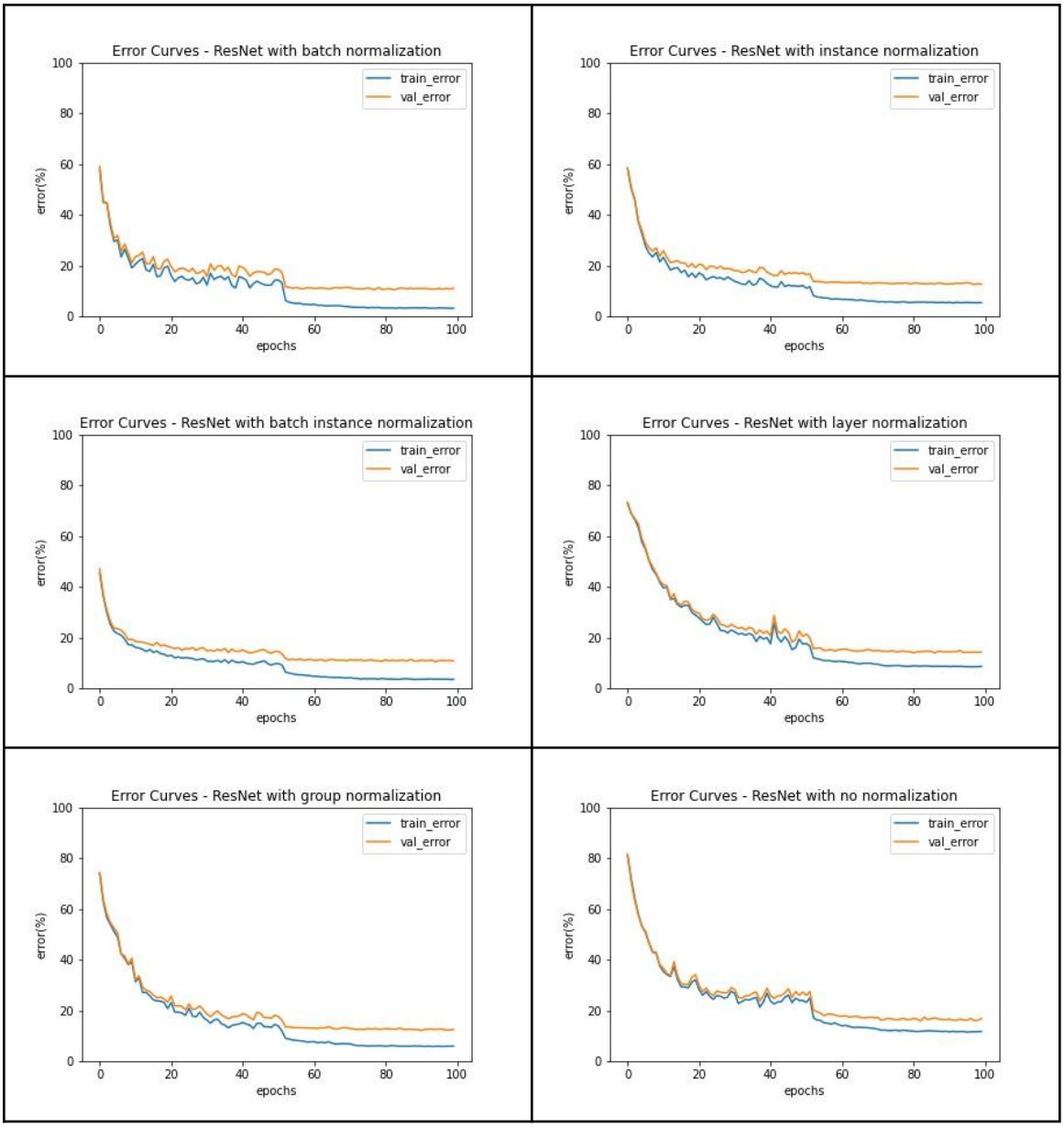
Metrics on Test Data

	precision	recall	f1-score	support
plane	0.89	0.92	0.90	1000
car	0.95	0.94	0.94	1000
bird	0.86	0.86	0.86	1000
cat	0.81	0.76	0.78	1000
deer	0.89	0.90	0.89	1000
dog	0.84	0.86	0.85	1000
frog	0.92	0.93	0.92	1000
horse	0.92	0.91	0.92	1000
ship	0.94	0.95	0.94	1000
truck	0.93	0.93	0.93	1000
accuracy			0.90	10000
macro avg	0.89	0.90	0.89	10000
weighted avg	0.89	0.90	0.89	10000

Metrics on Test Data

2. Comparison of six variants

- The error curves for training, validation, and test data are shown below.



- The metrics for training, validation, and test data are shown below.
- The no normalization variant performs worst among the six variants.

Variants	Training Data	Validation Data	Test Data
Batch normalization			
Instance Normalization			
Batch-Instance Normalization			
Layer Normalization			

Batch normalization

	precision	recall	f1-score	support
plane	0.96	0.97	0.96	3963
car	0.98	0.98	0.98	4017
bird	0.94	0.95	0.94	4019
cat	0.92	0.89	0.90	4015
deer	0.95	0.96	0.96	4071
dog	0.91	0.93	0.92	3975
frog	0.96	0.97	0.97	3964
horse	0.97	0.97	0.97	3968
ship	0.98	0.98	0.98	3979
truck	0.98	0.98	0.98	4029
accuracy			0.96	40000
macro avg	0.96	0.96	0.96	40000
weighted avg	0.96	0.96	0.96	40000

	precision	recall	f1-score	support
plane	0.96	0.97	0.97	1037
car	0.99	0.98	0.99	983
bird	0.94	0.94	0.94	981
cat	0.91	0.89	0.90	985
deer	0.96	0.96	0.96	929
dog	0.91	0.95	0.93	1025
frog	0.96	0.97	0.97	1036
horse	0.98	0.96	0.97	1032
ship	0.98	0.98	0.98	1021
truck	0.97	0.98	0.98	971
accuracy			0.96	10000
macro avg	0.96	0.96	0.96	10000
weighted avg	0.96	0.96	0.96	10000

	precision	recall	f1-score	support
plane	0.89	0.92	0.90	1000
car	0.95	0.94	0.94	1000
bird	0.86	0.86	0.86	1000
cat	0.81	0.76	0.78	1000
deer	0.89	0.90	0.89	1000
dog	0.84	0.86	0.85	1000
frog	0.92	0.93	0.92	1000
horse	0.92	0.91	0.92	1000
ship	0.94	0.95	0.94	1000
truck	0.93	0.93	0.93	1000
accuracy			0.90	10000
macro avg	0.89	0.90	0.89	10000
weighted avg	0.89	0.90	0.89	10000

Instance Normalization

	precision	recall	f1-score	support
plane	0.94	0.93	0.94	3973
car	0.97	0.97	0.97	4067
bird	0.93	0.91	0.92	4006
cat	0.86	0.88	0.87	4044
deer	0.95	0.93	0.94	3962
dog	0.90	0.89	0.89	3937
frog	0.94	0.96	0.95	4032
horse	0.95	0.96	0.95	3978
ship	0.97	0.97	0.97	4036
truck	0.96	0.97	0.96	3965
accuracy			0.94	40000
macro avg	0.94	0.94	0.94	40000
weighted avg	0.94	0.94	0.94	40000

	precision	recall	f1-score	support
plane	0.96	0.93	0.94	1027
car	0.97	0.97	0.97	933
bird	0.93	0.91	0.92	994
cat	0.84	0.88	0.86	956
deer	0.94	0.92	0.93	1038
dog	0.90	0.88	0.89	1063
frog	0.94	0.96	0.95	968
horse	0.93	0.96	0.95	1022
ship	0.95	0.97	0.96	964
truck	0.97	0.97	0.97	1035
accuracy			0.93	10000
macro avg	0.93	0.93	0.93	10000
weighted avg	0.93	0.93	0.93	10000

	precision	recall	f1-score	support
plane	0.87	0.87	0.87	1000
car	0.95	0.94	0.94	1000
bird	0.85	0.81	0.83	1000
cat	0.75	0.74	0.75	1000
deer	0.88	0.87	0.87	1000
dog	0.82	0.82	0.82	1000
frog	0.88	0.91	0.89	1000
horse	0.91	0.92	0.91	1000
ship	0.91	0.92	0.92	1000
truck	0.90	0.93	0.92	1000
accuracy			0.87	10000
macro avg	0.87	0.87	0.87	10000
weighted avg	0.87	0.87	0.87	10000

Batch-Instance Normalization

	precision	recall	f1-score	support
plane	0.93	0.93	0.93	4025
car	0.97	0.96	0.96	4017
bird	0.92	0.91	0.91	3984
cat	0.84	0.89	0.87	4005
deer	0.93	0.93	0.93	3991
dog	0.90	0.87	0.89	4022
frog	0.95	0.95	0.95	3983
horse	0.95	0.95	0.95	3961
ship	0.96	0.96	0.96	4031
truck	0.95	0.95	0.95	3981
accuracy			0.93	40000
macro avg	0.93	0.93	0.93	40000
weighted avg	0.93	0.93	0.93	40000

	precision	recall	f1-score	support
plane	0.92	0.93	0.93	975
car	0.97	0.96	0.97	983
bird	0.91	0.91	0.91	1016
cat	0.84	0.87	0.86	995
deer	0.92	0.93	0.92	1009
dog	0.90	0.86	0.88	978
frog	0.95	0.94	0.95	1017
horse	0.95	0.95	0.95	1039
ship	0.95	0.96	0.95	969
truck	0.96	0.95	0.96	1019
accuracy			0.93	10000
macro avg	0.93	0.93	0.93	10000
weighted avg	0.93	0.93	0.93	10000

	precision	recall	f1-score	support
plane	0.92	0.93	0.93	975
car	0.97	0.96	0.97	983
bird	0.91	0.91	0.91	1016
cat	0.84	0.87	0.86	995
deer	0.92	0.93	0.92	1009
dog	0.90	0.86	0.88	978
frog	0.95	0.94	0.95	1017
horse	0.95	0.95	0.95	1039
ship	0.95	0.96	0.95	969
truck	0.96	0.95	0.96	1019
accuracy			0.93	10000
macro avg	0.93	0.93	0.93	10000
weighted avg	0.93	0.93	0.93	10000

Layer Normalization

	precision	recall	f1-score	support
plane	0.91	0.91	0.91	3979
car	0.96	0.95	0.95	4027
bird	0.88	0.86	0.87	4036
cat	0.78	0.78	0.78	4018
deer	0.89	0.90	0.89	4029
dog	0.81	0.82	0.81	3957
frog	0.93	0.92	0.92	3997
horse	0.91	0.92	0.92	3989
ship	0.95	0.95	0.95	3989
truck	0.92	0.94	0.93	3979
accuracy			0.89	40000
macro avg	0.89	0.89	0.89	40000
weighted avg	0.89	0.89	0.89	40000

	precision	recall	f1-score	support
plane	0.91	0.93	0.92	1021
car	0.96	0.95	0.96	973
bird	0.87	0.86	0.87	964
cat	0.77	0.79	0.78	982
deer	0.90	0.91	0.90	971
dog	0.83	0.84	0.83	1043
frog	0.93	0.90	0.92	1003
horse	0.92	0.91	0.91	1011
ship	0.95	0.95	0.95	1011
truck	0.94	0.95	0.94	1021
accuracy			0.90	10000
macro avg	0.90	0.90	0.90	10000
weighted avg	0.90	0.90	0.90	10000

	precision	recall	f1-score	support
plane	0.83	0.87	0.85	1000
car	0.94	0.92	0.93	1000
bird	0.80	0.78	0.79	1000
cat	0.72	0.69	0.70	1000
deer	0.82	0.86	0.84	1000
dog	0.77	0.77	0.77	1000
frog	0.89	0.88	0.88	1000
horse	0.88	0.85	0.87	1000
ship	0.92	0.91	0.91	1000
truck	0.87	0.92	0.89	1000
accuracy			0.84	10000
macro avg	0.84	0.84	0.84	10000
weighted avg	0.84	0.84	0.84	10000

Group Normalization			
No Normalization			

Group Normalization

	precision	recall	f1-score	support
plane	0.93	0.94	0.94	3973
car	0.97	0.97	0.97	4067
bird	0.91	0.91	0.91	4006
cat	0.84	0.86	0.85	4044
deer	0.95	0.92	0.93	3962
dog	0.89	0.87	0.88	3937
frog	0.95	0.95	0.95	4032
horse	0.95	0.95	0.95	3978
ship	0.97	0.97	0.97	4036
truck	0.95	0.97	0.96	3965
accuracy			0.93	40000
macro avg	0.93	0.93	0.93	40000
weighted avg	0.93	0.93	0.93	40000

	precision	recall	f1-score	support
plane	0.94	0.94	0.94	1027
car	0.97	0.98	0.97	933
bird	0.92	0.90	0.91	994
cat	0.83	0.87	0.85	956
deer	0.94	0.93	0.93	1038
dog	0.90	0.87	0.89	1063
frog	0.94	0.94	0.94	968
horse	0.94	0.94	0.94	1022
ship	0.97	0.97	0.97	964
truck	0.96	0.97	0.96	1035
accuracy			0.93	10000
macro avg	0.93	0.93	0.93	10000
weighted avg	0.93	0.93	0.93	10000

	precision	recall	f1-score	support
plane	0.87	0.87	0.87	1000
car	0.93	0.95	0.94	1000
bird	0.84	0.84	0.84	1000
cat	0.76	0.77	0.77	1000
deer	0.86	0.87	0.87	1000
dog	0.83	0.80	0.82	1000
frog	0.91	0.90	0.90	1000
horse	0.91	0.90	0.91	1000
ship	0.94	0.91	0.93	1000
truck	0.90	0.93	0.91	1000
accuracy			0.88	10000
macro avg	0.88	0.88	0.88	10000
weighted avg	0.88	0.88	0.88	10000

No Normalization

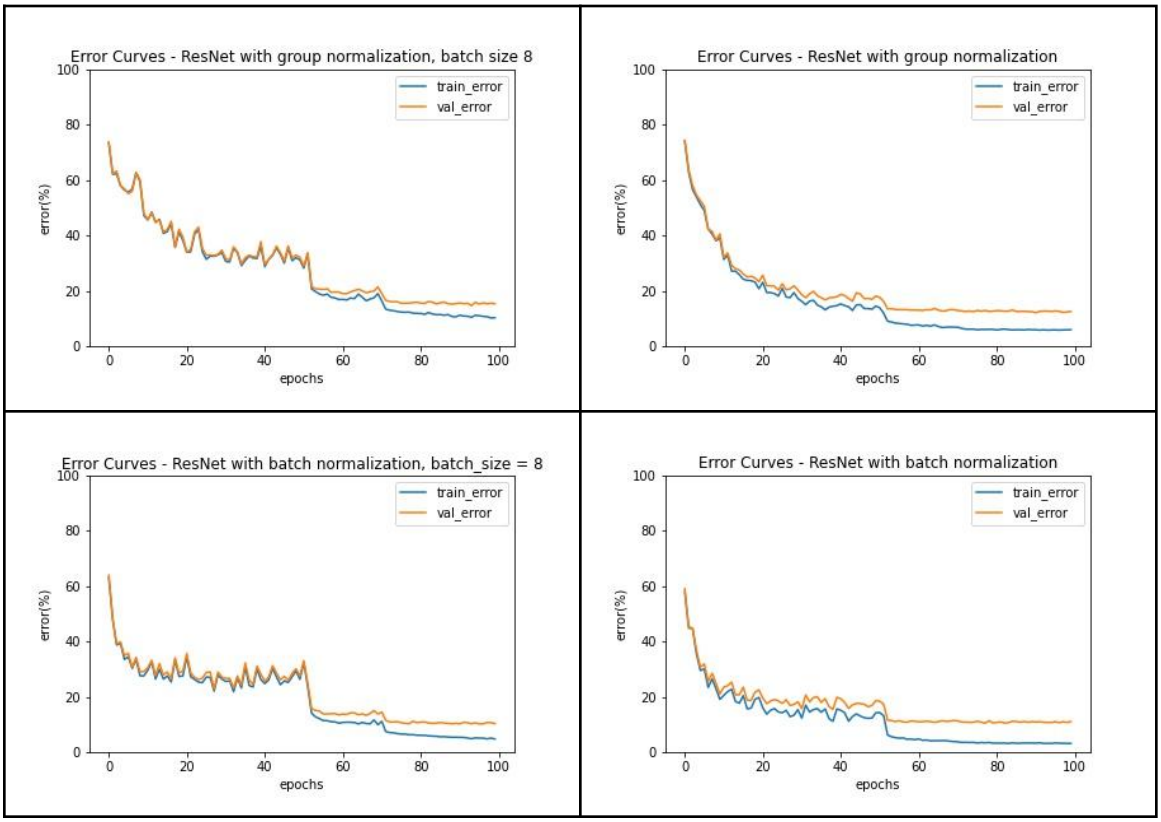
	precision	recall	f1-score	support
plane	0.88	0.91	0.90	3973
car	0.96	0.95	0.95	4067
bird	0.85	0.83	0.84	4006
cat	0.76	0.75	0.76	4044
deer	0.88	0.86	0.87	3962
dog	0.79	0.81	0.80	3937
frog	0.91	0.90	0.91	4032
horse	0.91	0.91	0.91	3978
ship	0.94	0.95	0.95	4036
truck	0.93	0.94	0.94	3965
accuracy			0.88	40000
macro avg	0.88	0.88	0.88	40000
weighted avg	0.88	0.88	0.88	40000

	precision	recall	f1-score	support
plane	0.90	0.92	0.91	1027
car	0.97	0.95	0.96	933
bird	0.85	0.84	0.84	994
cat	0.74	0.75	0.74	956
deer	0.88	0.87	0.88	1038
dog	0.81	0.79	0.80	1063
frog	0.90	0.90	0.90	968
horse	0.90	0.91	0.91	1022
ship	0.94	0.96	0.95	964
truck	0.94	0.95	0.95	1035
accuracy			0.88	10000
macro avg	0.88	0.88	0.88	10000
weighted avg	0.88	0.88	0.88	10000

	precision	recall	f1-score	support
plane	0.81	0.88	0.84	1000
car	0.93	0.92	0.92	1000
bird	0.79	0.76	0.77	1000
cat	0.70	0.66	0.68	1000
deer	0.84	0.81	0.83	1000
dog	0.72	0.76	0.74	1000
frog	0.87	0.87	0.87	1000
horse	0.89	0.86	0.88	1000
ship	0.90	0.91	0.91	1000
truck	0.88	0.91	0.89	1000
accuracy			0.83	10000
macro avg	0.83	0.83	0.83	10000
weighted avg	0.83	0.83	0.83	10000

3. Impact of Batch Size

- Group normalization has a similar trajectory with slight perturbations, while batch normalization shows large changes.



4. **Evolution of feature distributions**
    - The feature evolutions were calculated from the penultimate layer, i.e., global average pooling layer, having a dimension of 640000 for the 10000 image data from the validation set.