COURSE: DD2424 - ASSIGNMENT 3

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Q1: GRADIENT COMPUTATIONS

State how you checked your analytic gradient computations and whether you think that your gradient computations are bug free for your k-layer network with batch normalization.

A1:

I calculated the gradients numerically as it was suggested in the assignment and compared these values with the ones I derived analytically. The MEAN of the differences for W and b values were smaller than 1e-7 which means that the error-rate is very small. According to the reference given from Standford, having error values smaller than 1e-7 should make us happy.

Gradient discrepancies for W changes significantly from one layer to another. The discrepancy is higher at lower layers. There are small discrepancy changes for gradients of gammas and betas, higher layers have slightly lower values. However, discrepancy for gradients of b doesn't follow the same pattern.

Below, you can see the parameters and their values used for these tests. Also, you can see the discrepancy values of gradients for different types and networks layer by layer.

Parameter	Value
lambda_cost	0
Number of images used	3
Number of dimensions used	10
h	1e-5
Mu (for W initialization)	0
Hidden nodes	[50], [50, 50], [50, 50, 30]
Sigma (for W initialization)	1e-2
Batch Normalization	True

Table-1: Parameters used for Gradient Computations

Below tables show the mean gradient discrepancies (grad_numerical – grad_analytic) for different networks when Batch Normalization is used.

Layer	grad_W	grad_b	grad_gamma	grad_beta
1	3.4653659610592165e-07	2.6428512156506652e-17	1.1252590192370893e-11	1.440571455689748e-11
2	1.0910545735105803e-11	9.396558531271637e-12		

Table-2: Discrepancy between numerical and analytic Gradients – 2-layer Network [50]

Layer	grad_W	grad_b	grad_gamma	grad_beta
1	2.7389059050345976e-07	2.9178139216110936e-17	1.1117855059672475e-11	1.5014044591480967e-11
2	3.363769016160618e-09	1.0639637319324416e-17	1.309968732703874e-11	1.1983954365492256e-11
3	1.1286712148228518e-11	1.2367763757570317e-11		

Table-3: Discrepancy between numerical and analytic Gradients – 3-layer Network [50, 50]

Layer	grad_W	grad_b	grad_gamma	grad_beta
1	4.776375175642611e-06	1.3322856359798683e-12	6.081038442760922e-11	3.8791430904050114e-11
2	4.888949678919275e-07	1.3322765924688474e-12	1.3516458607154216e-11	1.1974045570524788e-11
3	5.8949647016560174e-08	7.403096316912741e-13	1.30570704042713e-11	1.0302963083380633e-11
4	1.0410893831053204e-11	1.5343132320211338e-11		

Table-4: Discrepancy between numerical and analytic Gradients – 4-layer Network [50, 50, 30]

Q2: 3-LAYER NETWORK WITH & WITHOUT BN

Include graphs of the evolution of the loss function when you train the 3-layer network with and without batch normalization with the given default parameter setting.

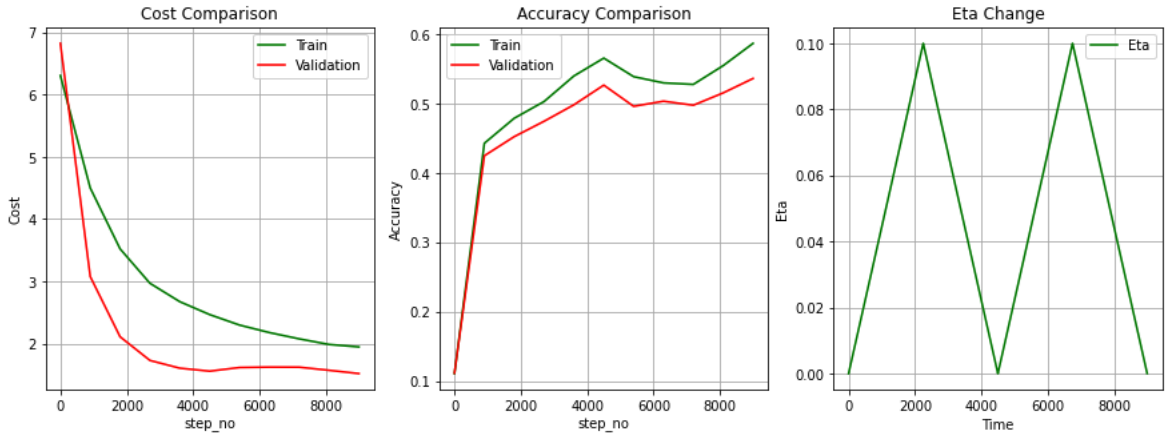
A2:

Parameter	Value
n_batch_size	100
n_cycles	2
lambda_cost	0.005
eta_min	1e-5
eta_max	1e-1
Hidden nodes	[50, 50]
k_cyckle	5 (n_s = 5 * 45000 / n_batch)
h	1e-5
init_type	'He'
alpha	0.9
plot_points	10
BN	False & True

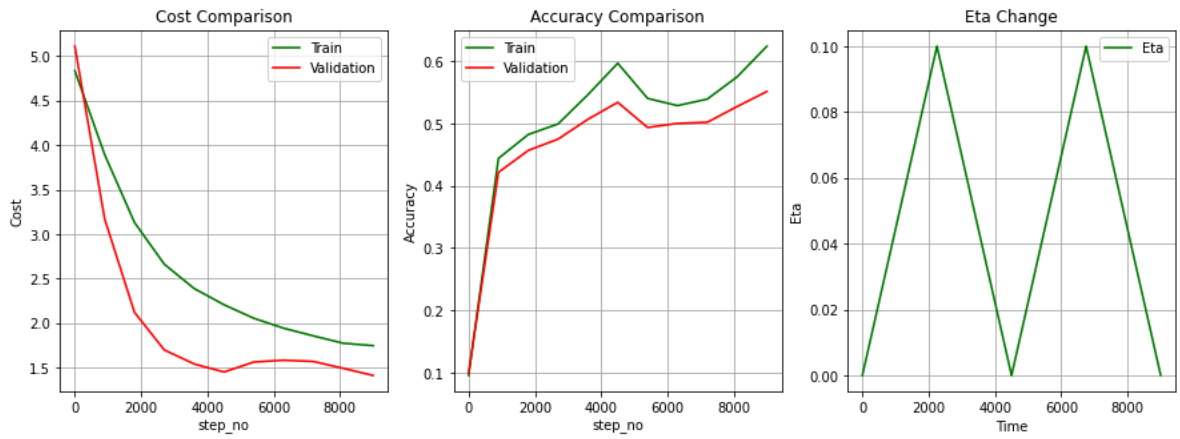
Table-5: Parameters used for 3-layer network accuracy computations

Network/Accuracy (%)	Training	Validation	Test
Without Batch Normalization	58.73	53.66	52.96
WITH Batch Normalization	62.4	55.14	53.71

Table-6: Accuracy results for 3-layer network



Picture-1: 3-layer Network – Without BN



Picture-2: 3-layer Network – WITH BN

NOTE: You can find the results for Xavier Initialization in the App2: 3-layer network with Xavier Initialization.

Q3: 9-LAYER NETWORK WITH & WITHOUT BN

Include graphs of the evolution of the loss function when you train the 9-layer network with and without batch normalization with the given default parameter setting.

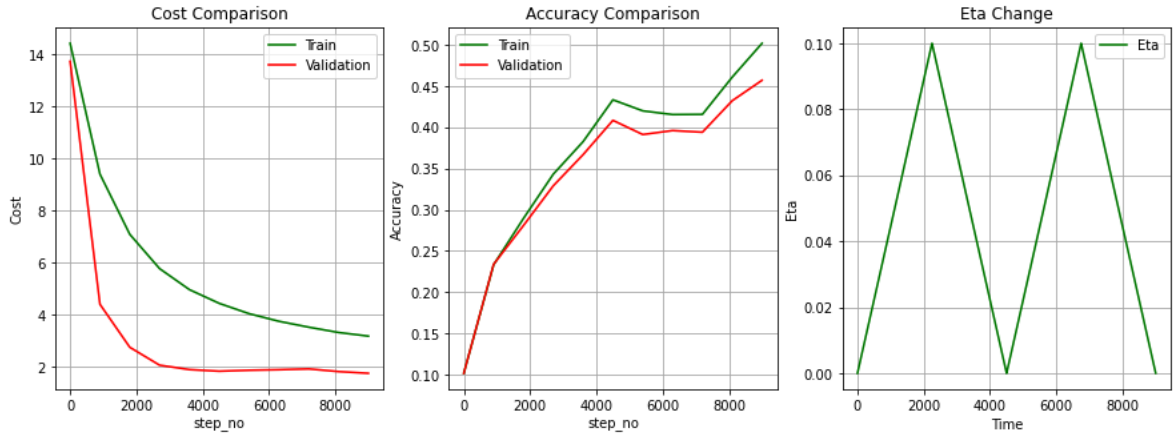
A3:

Parameter	Value
n_batch_size	100
n_cycles	2
lambda_cost	0.005
eta_min	1e-5
eta_max	1e-1
Hidden nodes	[50, 30, 20, 20, 10, 10, 10, 10]
k_cyckle	5 (n_s = 5 * 45000 / n_batch)
h	1e-5
init_type	'He'
alpha	0.9
plot_points	10
BN	False & True

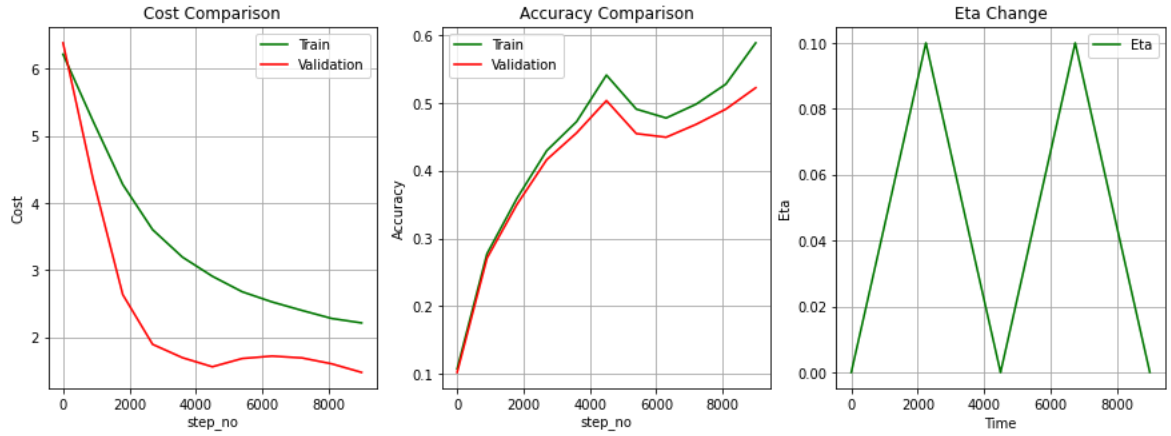
Table-7: Parameters used for 9-layer network accuracy computations

Network/Accuracy (%)	Training	Validation	Test
Without Batch Normalization	50.18	45.7	45.98
WITH Batch Normalization	58.91	52.28	52.02

Table-8: Accuracy results for 9-layer network



Picture-3: 9-layer Network – Without BN



Picture-4: 9-layer Network – WITH BN

NOTE: You can find the results for Xavier Initialization in the [App3: 9-layer network with Xavier Initialization.]

Q4: LAMBDA SEARCH

State the range of the values you searched for lambda when you tried to optimize the performance of the 3-layer network trained with batch normalization, and the lambda settings for your best performing 3-layer network. Also state the test accuracy achieved by this network.

A4:

Note: All above parameters are used as is, only Xavier initialization is used by mistake instead of He, b ut since it doesn't affect the results much, tests were not repeated with He.

Firstly, a coarse search was applied for values between 1e-5 and 1e-1 by picking 10 random values uni formly distributed in this range.

Secondly, another coarse search was applied by narrowing down the range between 1e-2.9612 and 1e -1.9586

Coarse Search-1	
Lambda	Accuracy
0.07551817375745834	0.4993
0.049722550077803684	0.5092
0.00031843718683816725	0.5186
4.084160858149218e-05	0.5193
4.879263419455391e-05	0.5194
0.024359159583172595	0.5202
1.3857911624979211e-05	0.5233
0.0009942565088993363	0.5242
0.0010933478237383542	0.5274
0.0035621657857409636	0.5347

Coarse Search-2	
Lambda	Accuracy
0.0016268068655851079	0.5259
0.00118663335141119	0.5262
0.0015558686373988403	0.5268
0.0034631634130629385	0.5291
0.010252590303797503	0.5298
0.0026033521015278852	0.5313
0.00923296327600833	0.5314
0.0035466209826920114	0.532
0.007720881832204912	0.5335
0.004768558843785876	**0.5395**

Table-9: Coarse search results

Then a Fine Search was applied for the lambda values between 0.0038 and .0.0081, some of the result are listed below:

Fine Search	
Lambda	Accuracy
0.0045960540264639435	0.5308
0.006158467929334429	0.5323
0.0057678644536168075	0.5329
0.0069396748807696714	0.5333
0.007330278356487293	0.5334
0.004986657502181565	0.5346
0.005499999999999998	0.5348
0.005699999999999998	0.5371
0.004205450550746322	0.5381
0.005099999999999999	0.5393

Table-10: Fine search results

Overall, the best result was observed when lambda equals to **0.004768558843785876** with the ac curacy of **53.95%.**

Q5: SENSITIVITY TO INITIALIZATION

Include the loss plots for the training with Batch Norm Vs no Batch Norm for the experiment related to Sensitivity to initialization and comment on your experimental findings.

A5: COMMENTS

When the tests are done on a 3-layer network, it is observed that the network with Batch Normalization (BN) is not affected much from the initialization of the parameters, it is more stable. However, without BN, the network is more sensitive to the initialization of the parameters.

As an additional information, until 7-layer network, the accuracy drops gradually without BN and it is stuck at 10% when sigma 1e-1 is used. (e.g., 50, 50, 20]: 50.38%, [50, 50, 20, 20]: 48.28%, [50, 50, 20, 20, 10]: 39.45%, [50, 50, 20, 20, 10, 10]: 10.00). Yet, as you can see from the below results, even for a 3-layer network, having sigma as 1e-3 or 1e-4 results in a huge decrease in the accuracy.

When the same tests applied on a 9-layer network, this time the sensitivity of the network increased even with BN. On the other hand, if it is given enough cycles, the accuracy starts to increase, the network with BN starts to

recover by the time with the increasing number of training steps. At App4: Change for different cycles can be visited to see how cost and accuracy change once the number of cycles is increased from 2 to 3.

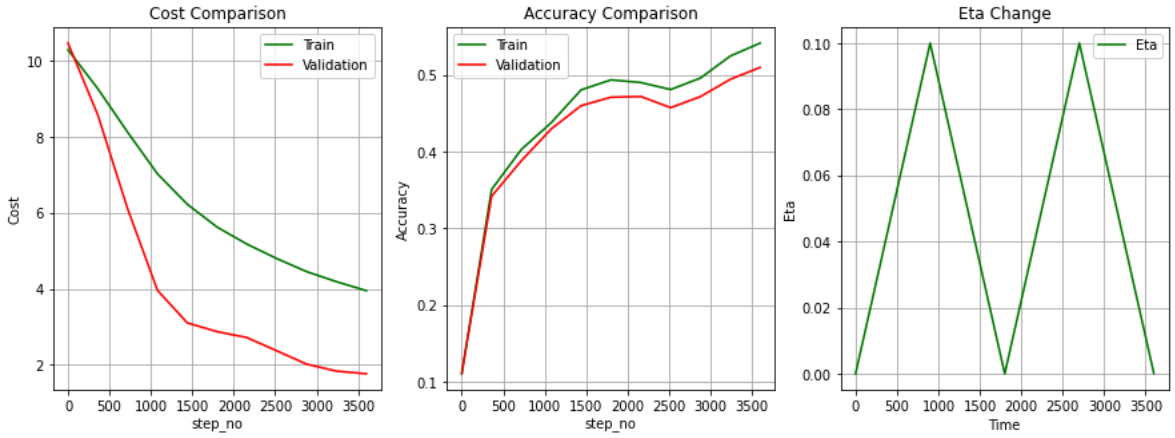
A5: FOR 3-LAYER NETWORK

Parameter	Value
n_batch_size	100
n_cycles	2
lambda_cost	0.005
eta_min	1e-5
eta_max	1e-1
Hidden nodes	[50, 50]
k_cyckle	5 (n_s = 5 * 45000 / n_batch)
h	1e-5
init_type	Fixed sigma values: 1e-1, 1e-3, 1e-4
alpha	0.9
plot_points	10
BN	False & True

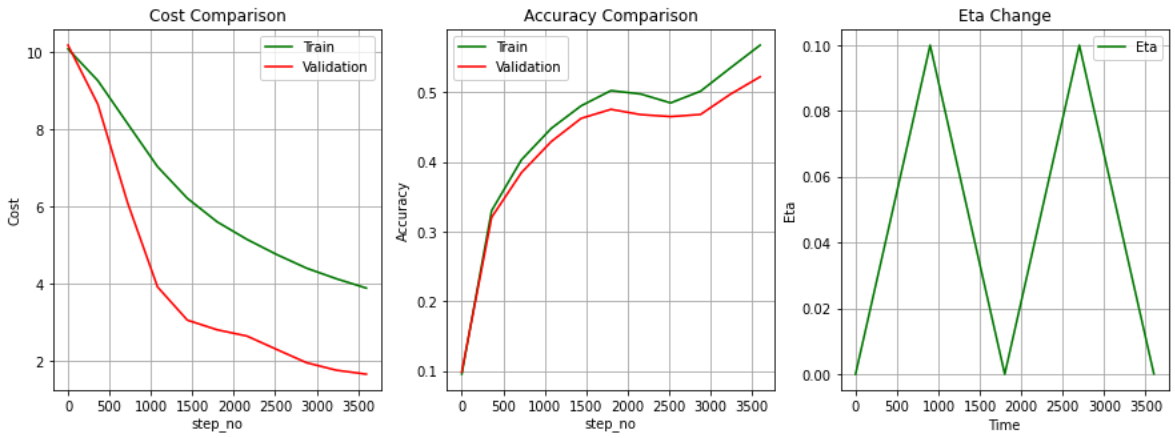
Table-11: Parameters used for Sensitivity Initialization network accuracy computations (3-layer Network)

Network/Sigma	1e-1	1e-3	1e-4
Without Batch Normalization	51.19	10.00	10.00
WITH Batch Normalization	51.4	55.26	55.32

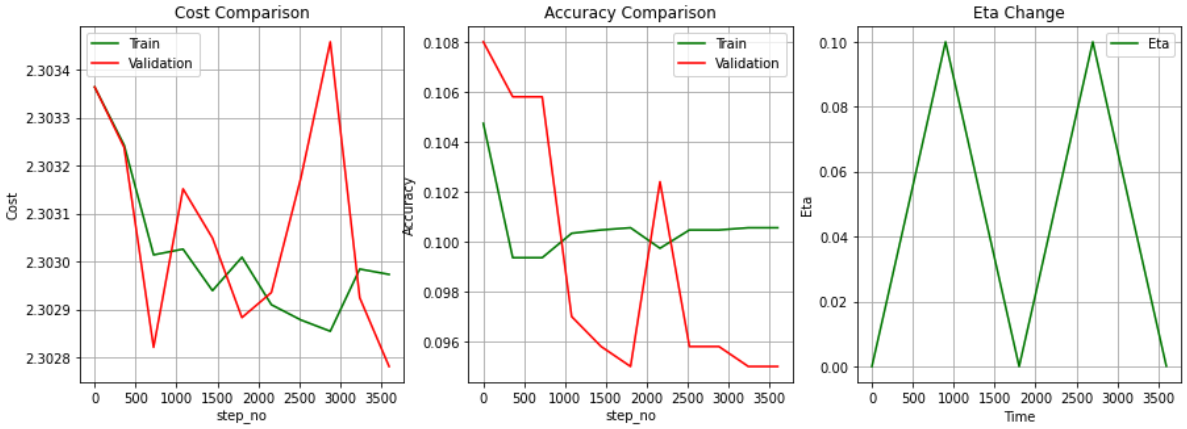
Table-12: Accuracy results for Sensitivity Initialization (3-layer Network)



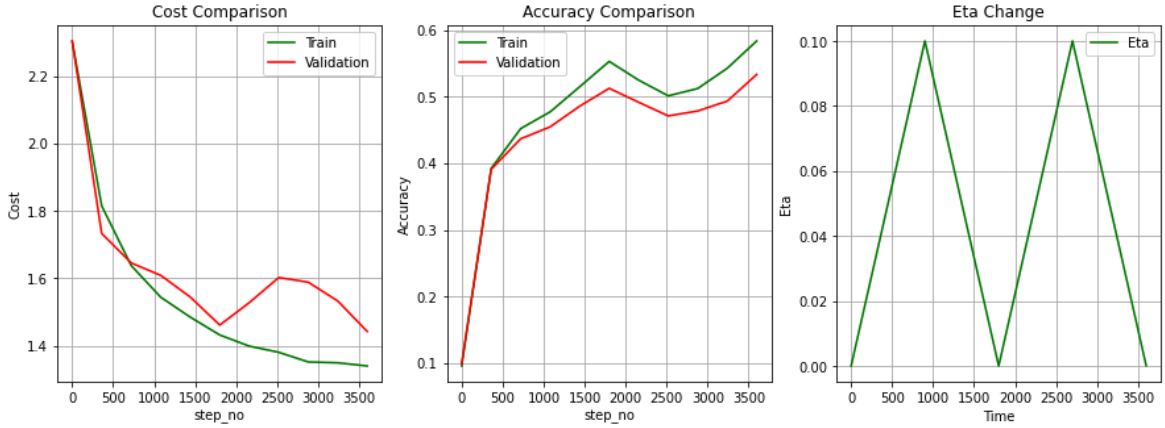
Picture-5: Sigma = 1e-1 – Without BN >> 3-layer



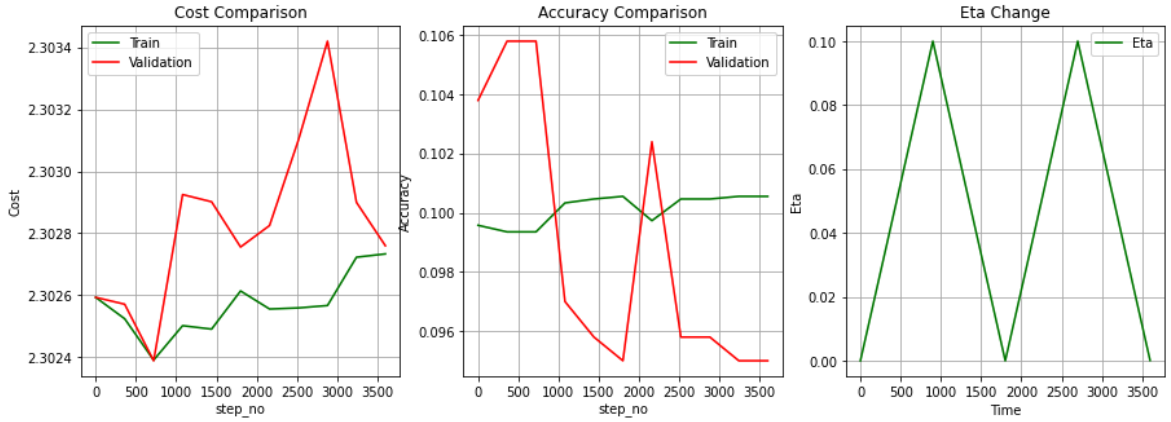
Picture-6: Sigma = 1e-1 – WITH BN >> 3-layer



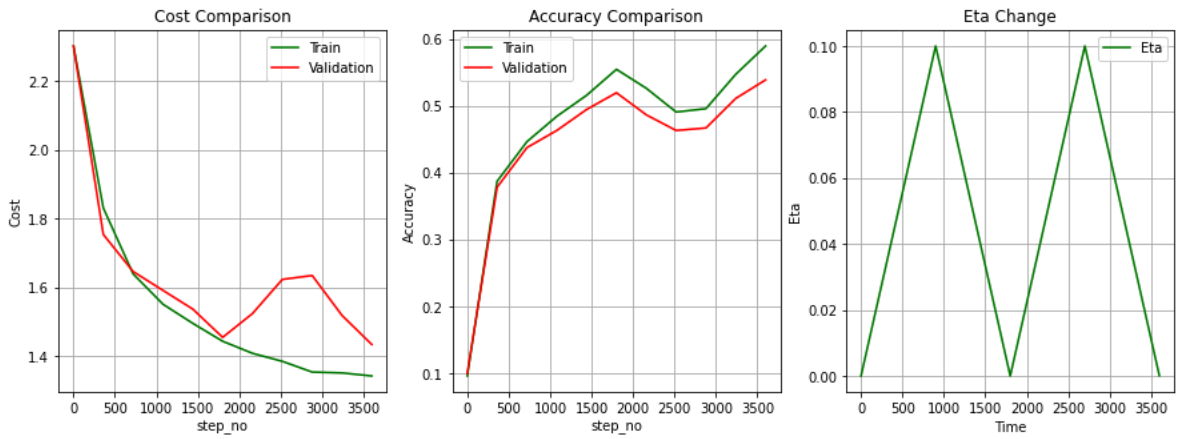
Picture-7: Sigma = 1e-3 – Without BN >> 3-layer



Picture-8: Sigma = 1e-3 – WITH BN >> 3-layer



Picture-9: Sigma = 1e-4 – Without BN >> 3-layer



Picture-10: Sigma = 1e-4 – WITH BN >> 3-layer

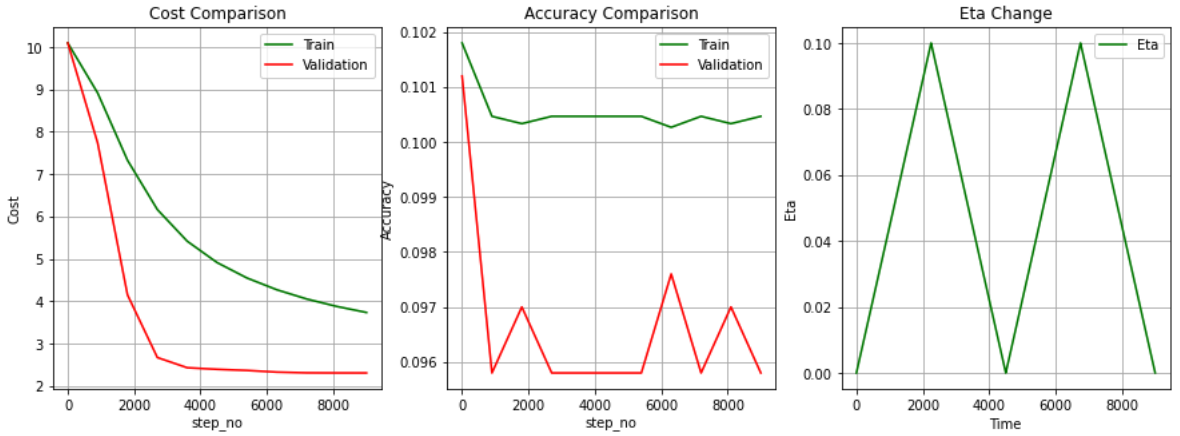
A5: FOR 9-LAYER NETWORK

Parameter	Value
n_batch_size	100
n_cycles	2
lambda_cost	0.005
eta_min	1e-5
eta_max	1e-1
Hidden nodes	[50, 30, 20, 20, 10, 10, 10, 10]
k_cyckle	5 (n_s = 5 * 45000 / n_batch)
h	1e-5
init_type	Fixed sigma values: 1e-1, 1e-3, 1e-4
alpha	0.9
plot_points	10
BN	False & True

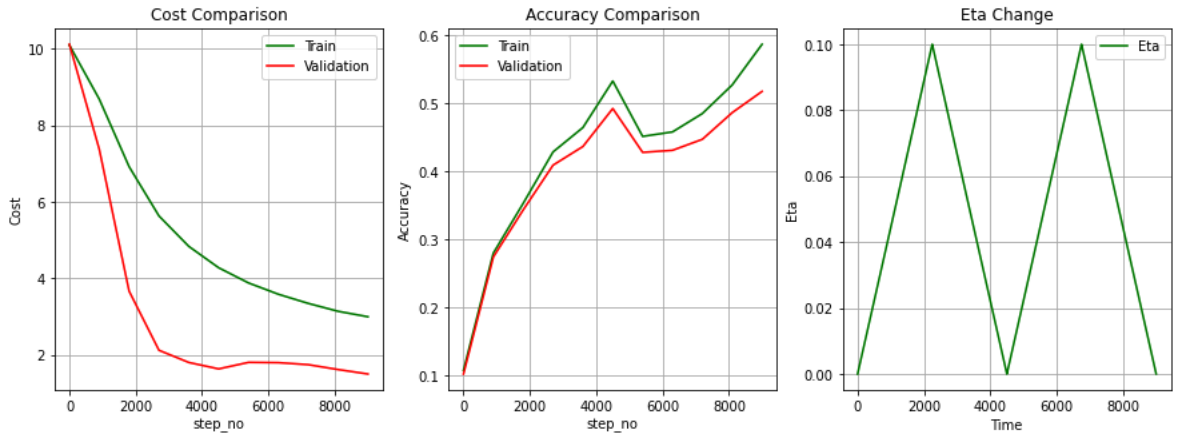
Table-13: Parameters used for Sensitivity Initialization network accuracy computations (9-layer Network)

Network/Sigma	1e-1	1e-3	1e-4
Without Batch Normalization	10.00	10.00	10.00
WITH Batch Normalization	51.98	17.37	33.75

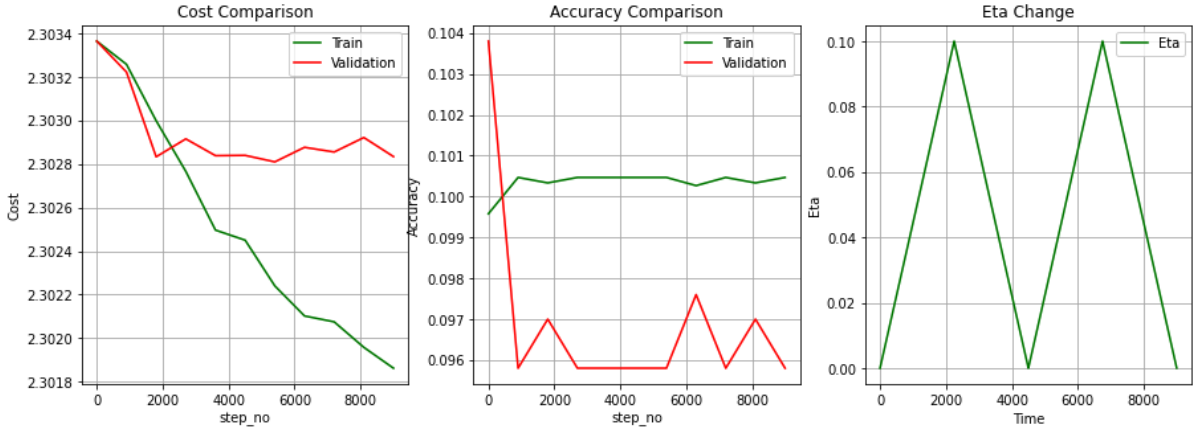
Table-14: Accuracy results for Sensitivity Initialization (9-layer Network)



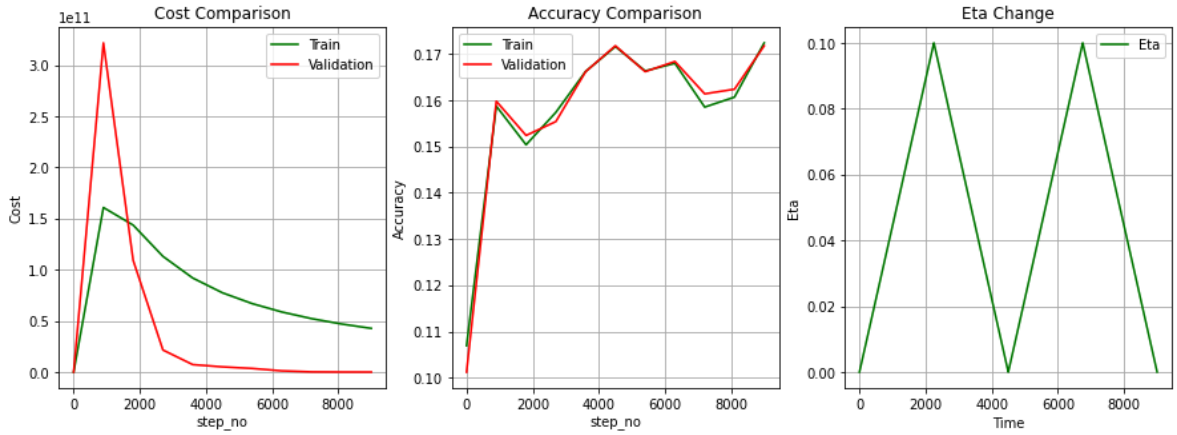
Picture-11: Sigma = 1e-1 – Without BN >> 9-layer



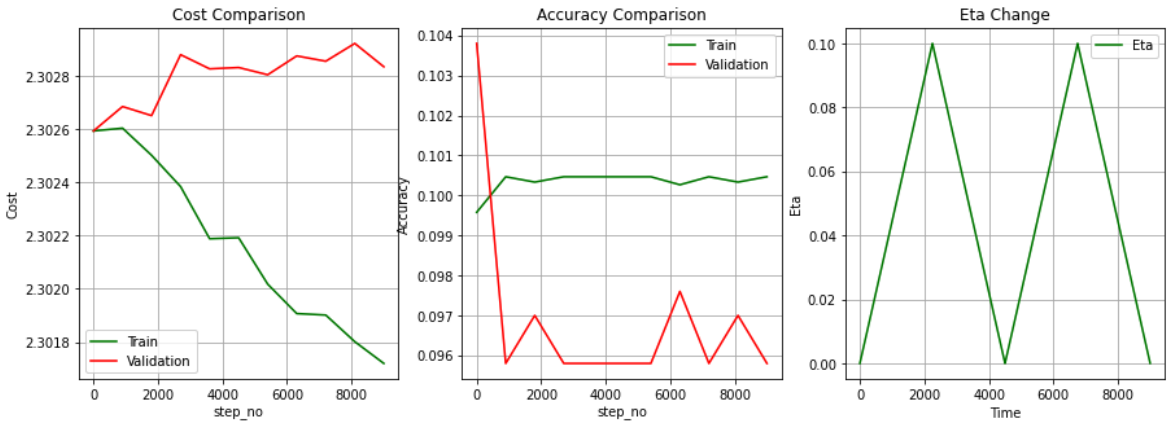
Picture-12: Sigma = 1e-1 – WITH BN >> 9-layer



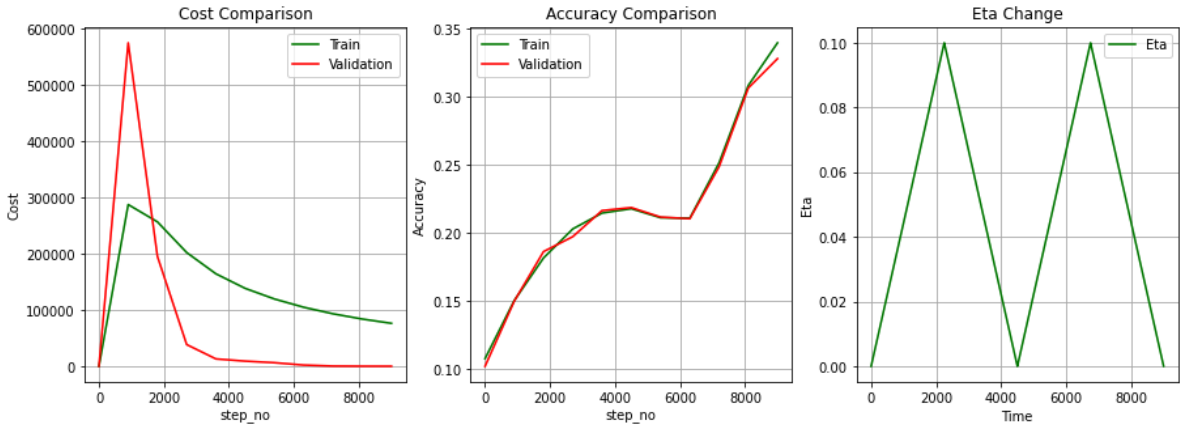
Picture-13: Sigma = 1e-3 – Without BN >> 9-layer



Picture-14: Sigma = 1e-3 – WITH BN >> 9-layer



Picture-15: Sigma = 1e-4 – Without BN >> 9-layer



Picture-16: Sigma = 1e-4 – WITH BN >> 9-layer

APPENDIX

APP1: PARAMETER DESCRIPTIONS

Below, you can find the parameter descriptions which are used for the assignment.

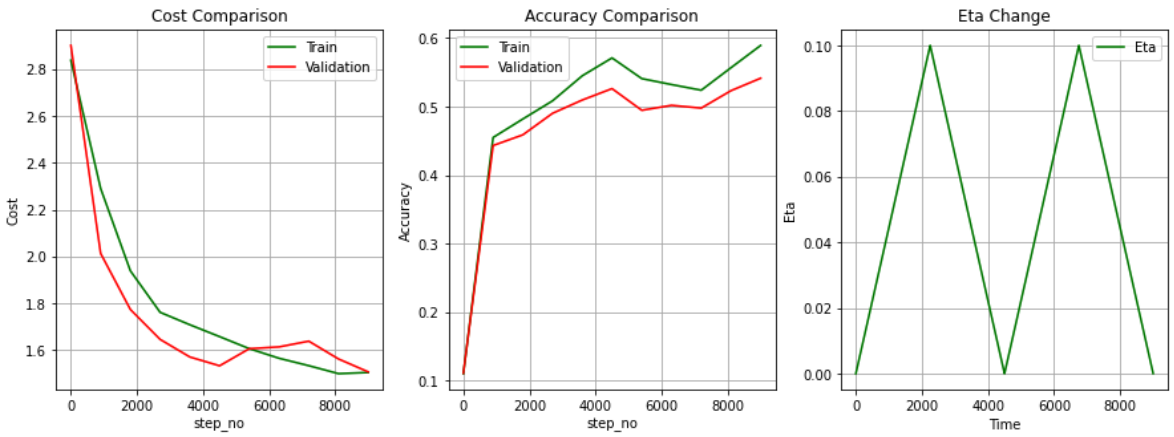
Parameter	Value (Sample)	Description
n_batch_size	100	Size of the mini batch. In other words, the number of images in 1 mini-batch.
n_cycles	2	learning rate (step-size)
lambda_cost	0.005	regularization coefficient (punishment)
eta	Min: 1e-5 Max: 1e-1	learning rate (step-size)
Hidden nodes	[50, 50]	Hidden nodes used (hidden_nodes)
k_cyckle	5 (n_s = 5 * 45000 / n_batch)	coefficient used in cycling learning calculations
h	1e-5	Precision value
init_type	'He', 'Xavier', 1e-2	Parameter initialization for W
alpha	0.9	Exponential moving average coefficient
plot_points	10	Number of samples to plot the graph
BN	False or True	With or without Batch Normalization

Table-15: Parameters used for Gradient Computations

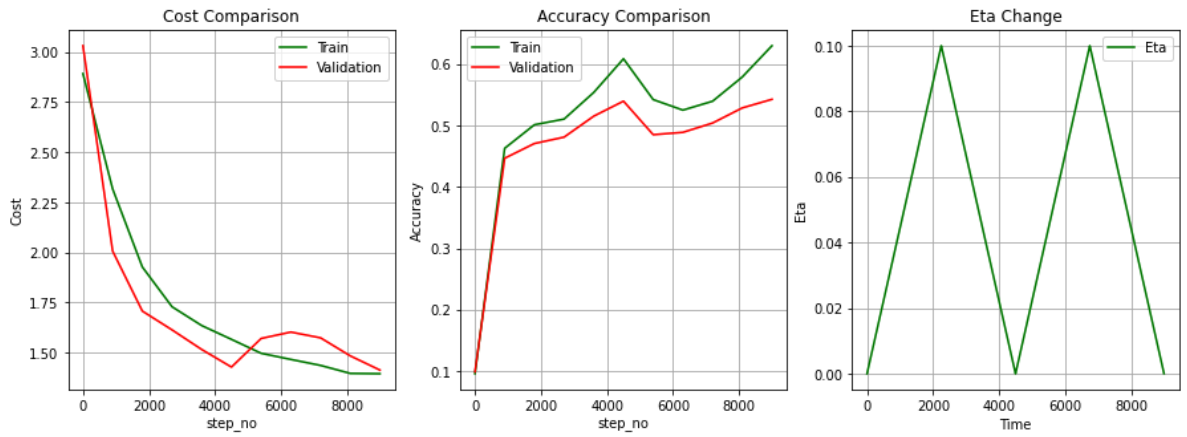
APP2: 3-LAYER NETWORK WITH XAVIER INITIALIZATION

Network/Accuracy (%)	Training	Validation	Test
Without Batch Normalization	58.92	54.14	53.24
WITH Batch Normalization	62.99	54.26	53.43

Table-16: Accuracy results for 3-layer network (Xavier)



Picture-17: 3-layer Network – Without BN (Xavier)

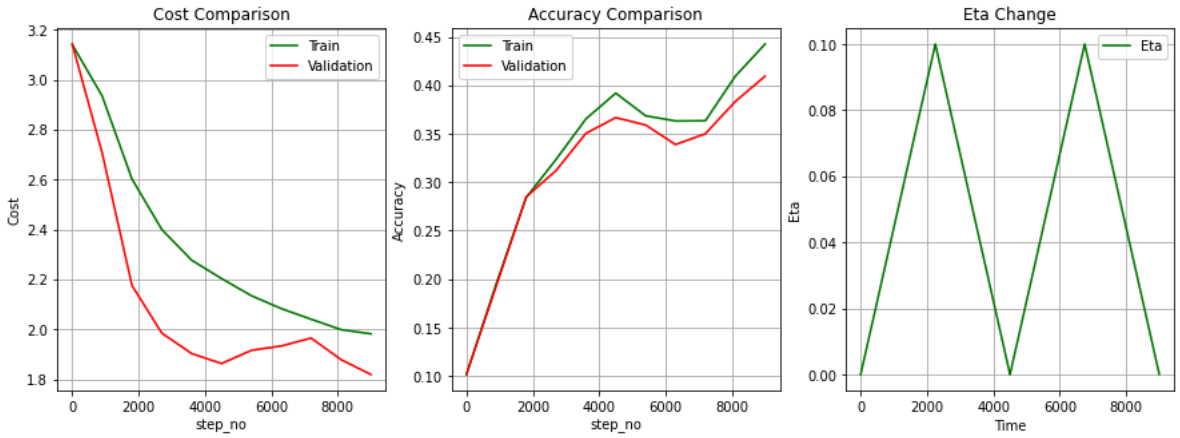


Picture-18: 3-layer Network – WITH BN (Xavier)

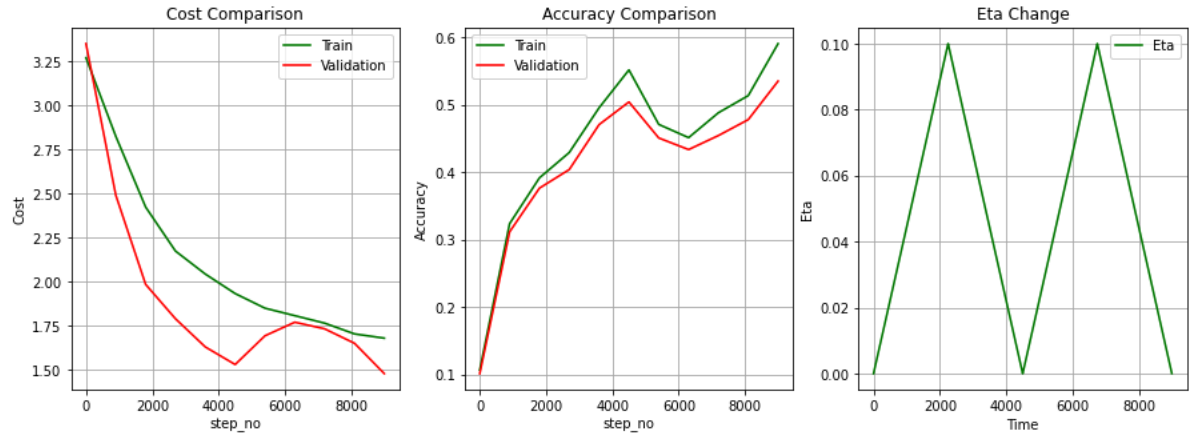
APP3: 9-LAYER NETWORK WITH XAVIER INITIALIZATION

Network/Accuracy (%)	Training	Validation	Test
Without Batch Normalization	44.25	40.94	40.71
WITH Batch Normalization	59.06	53.5	51.79

Table-17: Accuracy results for 9-layer network (Xavier)



Picture-19: 9-layer Network – Without BN (Xavier)

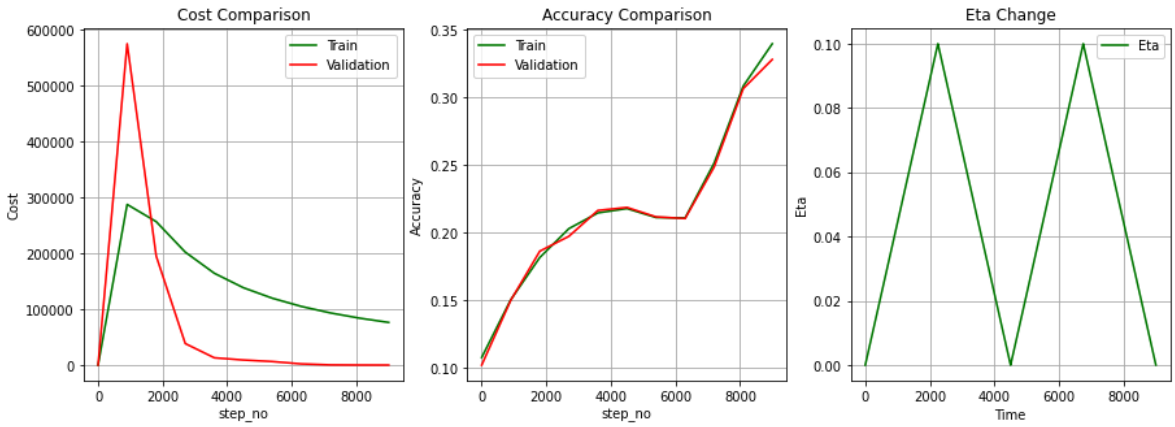


Picture-20: 9-layer Network – WITH BN (Xavier)

9-layer Network with BN, alpha=1e-4, using:

2-cycles (9000 training steps)

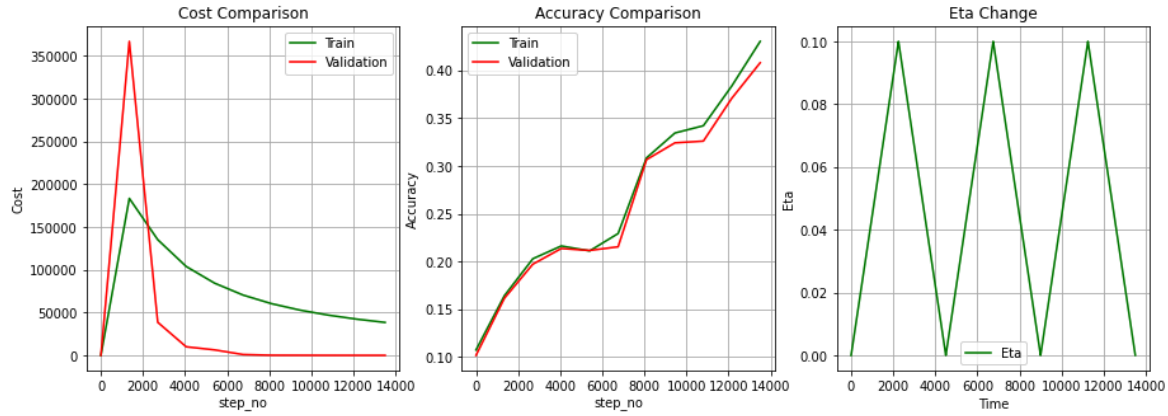
```
e: 0 ... step_no: 0 .. cost_record: 0 ... time: 2021-01-17 21:52:06.428683
J_train: 2.302546201964557 ... smooth_cost : 2.302546201964557 ... J_validation: 2.3025940893610573
e: 2 ... step_no: 900 .. cost_record: 1 ... time: 2021-01-17 21:52:09.515477
J_train: 575395.4017029937 ... smooth_cost : 287698.8521245978 ... J_validation: 575395.4224756308
e: 4 ... step_no: 1800 .. cost_record: 2 ... time: 2021-01-17 21:52:12.639743
J_train: 195245.00080398182 ... smooth_cost : 256880.90168439248 ... J_validation: 195245.18507171495
e: 6 ... step_no: 2700 .. cost_record: 3 ... time: 2021-01-17 21:52:15.706827
J_train: 38611.458639609235 ... smooth_cost : 202313.54092319668 ... J_validation: 38611.504383570915
e: 8 ... step_no: 3600 .. cost_record: 4 ... time: 2021-01-17 21:52:18.884753
J_train: 13113.571964440514 ... smooth_cost : 164473.54713144543 ... J_validation: 13113.58783160317
e: 10 ... step_no: 4500 .. cost_record: 5 ... time: 2021-01-17 21:52:21.952814
J_train: 9151.510838921717 ... smooth_cost : 138586.5410826915 ... J_validation: 9151.570949883402
e: 12 ... step_no: 5400 .. cost_record: 6 ... time: 2021-01-17 21:52:25.021931
J_train: 6381.676122397203 ... smooth_cost : 119700.13180264946 ... J_validation: 6381.723499307219
e: 14 ... step_no: 6300 .. cost_record: 7 ... time: 2021-01-17 21:52:28.128475
J_train: 2166.837663031489 ... smooth_cost : 105008.47003519721 ... J_validation: 2166.862033772152
e: 16 ... step_no: 7200 .. cost_record: 8 ... time: 2021-01-17 21:52:31.292801
J_train: 430.0581343309276 ... smooth_cost : 93388.64649065651 ... J_validation: 430.160326030615
e: 18 ... step_no: 8100 .. cost_record: 9 ... time: 2021-01-17 21:52:34.313339
J_train: 147.14792906695808 ... smooth_cost : 84064.49663449755 ... J_validation: 147.31177503662215
e: 19 ... step_no: 8999 .. cost_record: 10 ... time: 2021-01-17 21:52:37.372185
J_train: 103.26144476397707 ... smooth_cost : 76431.6570717945 ... J_validation: 103.31536142866396
A_train:        0.3398
A_validation:   0.3282
A_test:         0.3375
```



Picture-21: 9-layer Network – WITH BN, alpha=1e-4, 2-cycle training

3-cycles (13500 training steps)

```
e: 0 ... step_no: 0 .. cost_record: 0 ... time: 2021-01-17 21:53:40.527512
J_train: 2.302546201964557 ... smooth_cost : 2.302546201964557 ... J_validation: 2.3025940893610573
e: 3 ... step_no: 1350 .. cost_record: 1 ... time: 2021-01-17 21:53:45.211093
J_train: 366757.2218719709 ... smooth_cost : 183379.76220908645 ... J_validation: 366757.3143200195
e: 6 ... step_no: 2700 .. cost_record: 2 ... time: 2021-01-17 21:53:49.741279
J_train: 38611.458639609235 ... smooth_cost : 135123.6610192607 ... J_validation: 38611.504383570915
e: 9 ... step_no: 4050 .. cost_record: 3 ... time: 2021-01-17 21:53:54.242885
J_train: 10011.991336242865 ... smooth_cost : 103845.74359850625 ... J_validation: 10012.085530480752
e: 12 ... step_no: 5400 .. cost_record: 4 ... time: 2021-01-17 21:53:58.652246
J_train: 6381.676122397203 ... smooth_cost : 84352.93010328444 ... J_validation: 6381.723499307219
e: 15 ... step_no: 6750 .. cost_record: 5 ... time: 2021-01-17 21:54:03.012359
J_train: 964.5630677376071 ... smooth_cost : 70454.8689306933 ... J_validation: 964.5595120909976
e: 18 ... step_no: 8100 .. cost_record: 6 ... time: 2021-01-17 21:54:07.341741
J_train: 147.14792906695808 ... smooth_cost : 60410.908787603825 ... J_validation: 147.31177503662215
e: 21 ... step_no: 9450 .. cost_record: 7 ... time: 2021-01-17 21:54:11.670836
J_train: 94.40627810414304 ... smooth_cost : 52871.345973916366 ... J_validation: 94.57375086809238
e: 24 ... step_no: 10800 .. cost_record: 8 ... time: 2021-01-17 21:54:15.979905
J_train: 25.723201658158807 ... smooth_cost : 46999.61011033212 ... J_validation: 25.91268285060501
e: 27 ... step_no: 12150 .. cost_record: 9 ... time: 2021-01-17 21:54:20.402499
J_train: 4.023488549415476 ... smooth_cost : 42300.05144815385 ... J_validation: 4.350329369047781
e: 29 ... step_no: 13499 .. cost_record: 10 ... time: 2021-01-17 21:54:24.719489
J_train: 3.051233495981685 ... smooth_cost : 38454.86961045768 ... J_validation: 2.841446109851982
A_train:        0.4304
A_validation:   0.408
A_test:         0.4133
```



Picture-22: 9-layer Network – WITH BN, alpha=1e-4, 3-cycle training