CSE 472
Convolutional Neural Networks

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1 Introduction

In this assignment, a convolutional neural network for an image classification task was implemented using the ***Numta Handwritten Bengali Digits*** dataset.

2 Model Architecture

For this assignment, Lenet architecture was used to train and predict the model. The learning rate was tuned as $0.001, 0.005$, and 0.01. Number of epochs was set to 25. Finally the best model was chosen to be the one which had maximum F1 score in validation data. The results for different learning rates are shown below.
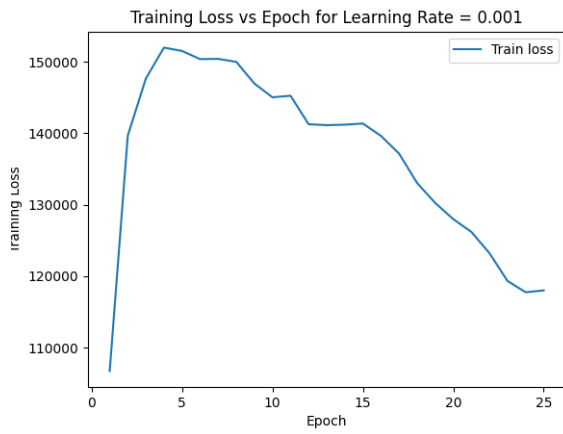
3 Learning rate 0.001

Train Loss, Training Accuracy, Training F1 Score, Validation Loss, Validation Accuracy, Validation F1 Score of all 25 epochs for learning rate 0.001 is shown in the table below.
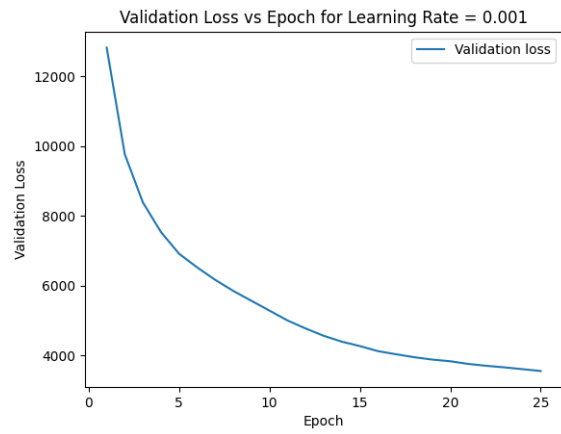
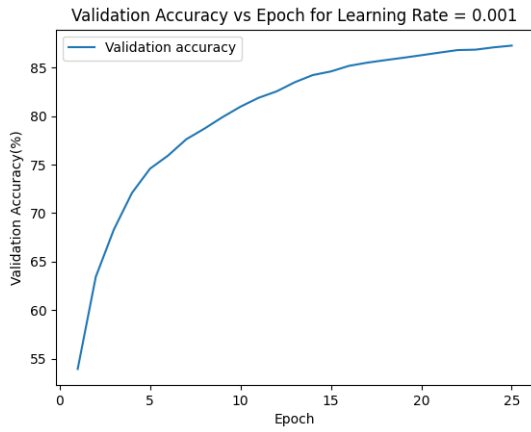| Epoch	Train Loss	Training Accuracy	Training F1 Score	Validation Loss	Validation Accuracy	Validation F1 Score
1	106720.23	31.74	0.33	12823.23	53.96	0.54
2	139670.31	36.97	0.39	9768.66	63.45	0.63
3	147662.78	38.91	0.42	8389.63	68.32	0.68
4	151989.67	39.41	0.43	7540.10	72.08	0.72
5	151520.42	40.81	0.45	6919.44	74.58	0.74
6	150376.44	41.93	0.46	6529.37	75.94	0.76
7	150415.36	42.86	0.47	6170.73	77.60	0.77
8	149994.53	43.82	0.48	5853.71	78.70	0.78
9	146960.12	44.23	0.48	5571.57	79.88	0.80
10	145034.71	44.84	0.49	5290.71	80.96	0.81
11	145253.99	45.04	0.49	5007.16	81.88	0.82
12	141265.08	45.68	0.50	4777.62	82.54	0.82
13	141133.73	45.79	0.50	4568.31	83.48	0.83
14	141202.43	45.99	0.51	4400.30	84.22	0.84
15	141364.50	46.17	0.51	4273.53	84.59	0.84
16	139633.65	46.55	0.52	4129.46	85.17	0.85
17	137159.49	46.91	0.52	4039.36	85.49	0.85
18	133032.84	47.36	0.52	3955.45	85.75	0.86
19	130241.55	47.87	0.53	3887.22	86.00	0.86
20	127977.04	48.43	0.53	3838.90	86.26	0.86
21	126191.84	48.86	0.54	3761.75	86.53	0.86
22	123215.26	49.43	0.54	3709.23	86.79	0.87
23	119320.45	50.25	0.55	3663.42	86.83	0.87
24	117745.94	50.65	0.55	3612.34	87.07	0.87
25	118001.48	50.87	0.56	3559.74	87.25	0.87

3.1 Plots

The train loss , validation loss, validation accuracy and validation F1 score over the epochs are shown below.
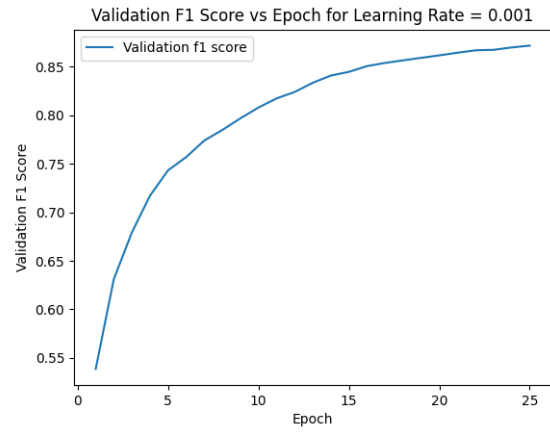

(a) Train loss vs Epoch

(b) Validation Loss vs Epoch

(c) Validation Accuracy vs Epoch

(d) Validation F1 Score vs Epoch

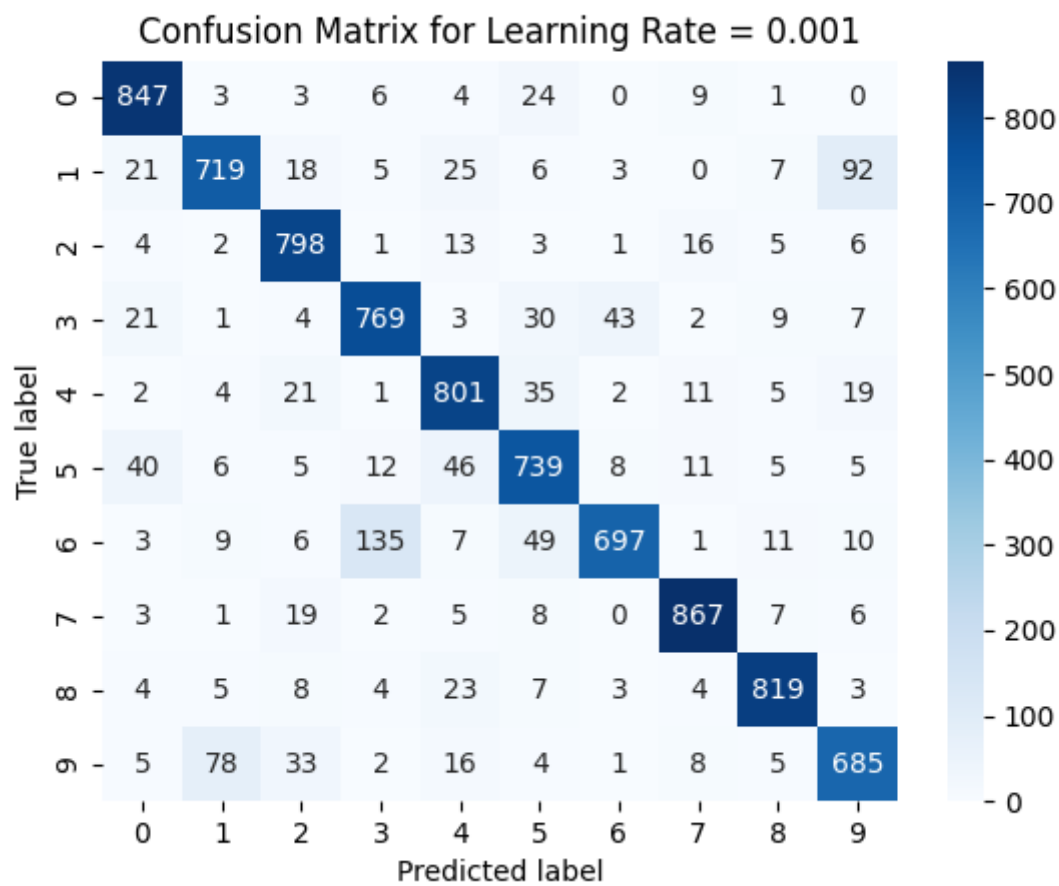## 3.2 Confusion Matrix

The confusion Matrix is shown below.

Figure 2: Confusion Matrix

4   Learning rate 0.005

Train Loss, Training Accuracy, Training F1 Score, Validation Loss, Validation Accuracy, Validation F1 Score of all 25 epochs for learning rate 0.005 is shown in the table below.
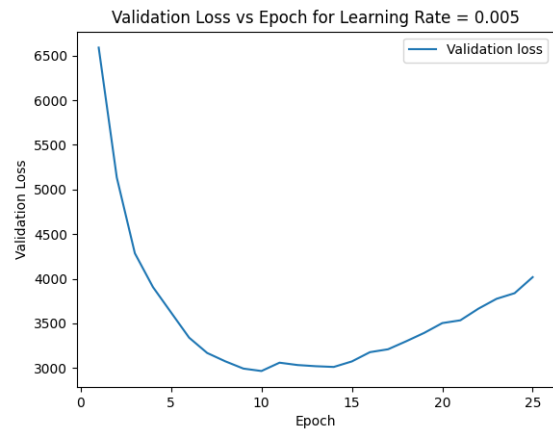
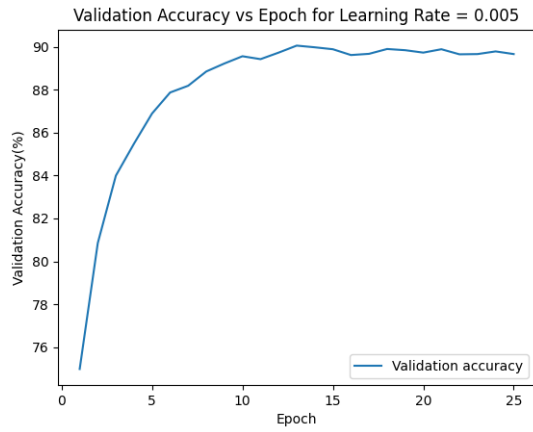| Epoch	Train Loss	Training Accuracy	Training F1 Score	Validation Loss	Validation Accuracy	Validation F1 Score
1	62427.55	47.87	0.51	6588.60	74.98	0.75
2	67051.87	48.62	0.52	5134.23	80.85	0.81
3	62603.98	50.96	0.55	4285.26	83.99	0.84
4	63359.66	51.64	0.56	3907.28	85.48	0.85
5	61188.51	53.55	0.58	3623.56	86.89	0.87
6	68111.04	53.04	0.58	3340.70	87.87	0.88
7	74843.08	52.91	0.58	3169.01	88.19	0.88
8	79143.52	52.65	0.58	3075.72	88.85	0.89
9	73048.44	55.61	0.60	2994.51	89.22	0.89
10	66016.31	58.62	0.63	2967.18	89.56	0.90
11	69393.20	58.13	0.63	3060.48	89.43	0.89
12	71934.23	59.13	0.63	3034.06	89.73	0.90
13	73306.11	59.83	0.64	3020.96	90.06	0.90
14	73894.00	60.92	0.65	3012.79	89.98	0.90
15	74915.45	60.89	0.65	3074.46	89.89	0.90
16	76621.09	61.27	0.65	3178.17	89.62	0.90
17	80657.21	61.40	0.65	3210.51	89.68	0.90
18	78366.32	62.50	0.66	3299.98	89.90	0.90
19	79222.14	62.52	0.66	3394.00	89.84	0.90
20	83669.83	62.84	0.66	3503.77	89.73	0.90
21	91716.78	61.71	0.65	3535.06	89.89	0.90
22	87925.53	63.31	0.67	3665.53	89.65	0.90
23	95067.85	62.49	0.66	3775.50	89.66	0.90
24	79829.24	65.42	0.69	3838.79	89.79	0.90
25	87110.27	64.39	0.68	4018.39	89.66	0.90

4.1 Plots

The train loss , validation loss, validation accuracy and validation F1 score over the epochs are shown below.
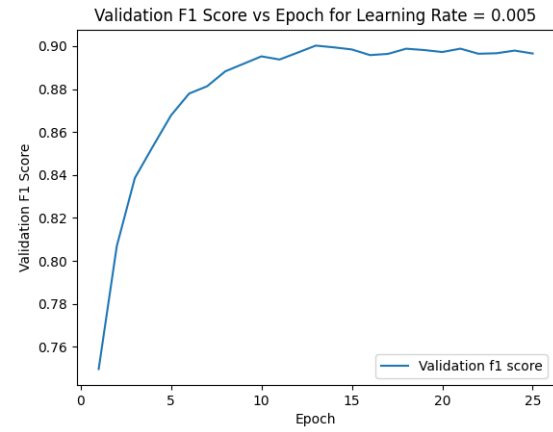

(a) Train loss vs Epoch

(b) Validation Loss vs Epoch

(c) Validation Accuracy vs Epoch

(d) Validation F1 Score vs Epoch

4.2 Confusion Matrix
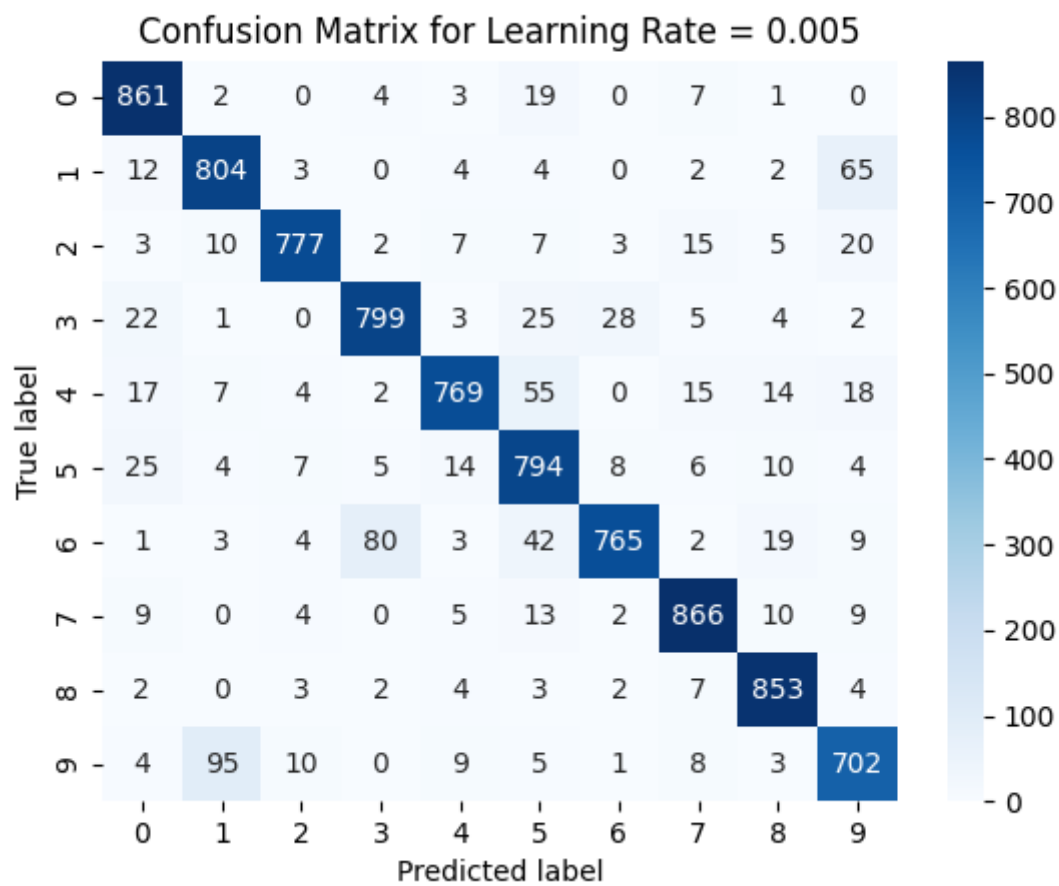
The confusion Matrix is shown below.

Confusion Matrix for Learning Rate = 0.005

	0	1	2	3	4	5	6	7	8	9
0	861	2	0	4	3	19	0	7	1	0
1	12	804	3	0	4	4	0	2	2	65
2	3	10	777	2	7	7	3	15	5	20
3	22	1	0	799	3	25	28	5	4	2
4	17	7	4	2	769	55	0	15	14	18
5	25	4	7	5	14	794	8	6	10	4
6	1	3	4	80	3	42	765	2	19	9
7	9	0	4	0	5	13	2	866	10	9
8	2	0	3	2	4	3	2	7	853	4
9	4	95	10	0	9	5	1	8	3	702

True label (vertical axis) / Predicted label (horizontal axis)

Figure 4: Confusion Matrix

5 Learning rate 0.01

Train Loss, Training Accuracy, Training F1 Score, Validation Loss, Validation Accuracy, Validation F1 Score of all 25 epochs for learning rate 0.01 is shown in the table below.

| Epoch	Train Loss	Training Accuracy	Training F1 Score	Validation Loss	Validation Accuracy	Validation F1 Score
1	53737.73	49.07	0.51	8258.28	69.65	0.70
2	62766.89	51.92	0.55	4405.11	83.56	0.83
3	76671.71	51.33	0.55	4372.17	83.90	0.84
4	70314.22	53.97	0.57	4304.16	84.36	0.84
5	65373.15	58.32	0.60	4731.72	83.76	0.84
6	62941.16	58.98	0.60	5334.87	83.04	0.83
7	60176.96	62.36	0.63	4082.34	86.41	0.86
8	59576.75	62.78	0.63	3329.11	88.67	0.89
9	59757.36	64.19	0.65	3527.94	88.62	0.89
10	56663.99	65.51	0.66	3453.14	89.04	0.89
11	51126.51	65.27	0.66	4147.98	87.35	0.87
12	46695.65	68.79	0.69	3362.33	89.96	0.90
13	51503.58	68.59	0.70	3769.86	89.06	0.89
14	39459.60	72.11	0.73	3665.60	89.69	0.90
15	40034.03	72.73	0.74	3882.05	89.37	0.89
16	52508.97	69.37	0.71	3460.25	90.68	0.91
17	51292.86	69.49	0.72	3823.54	90.25	0.90
18	67379.57	66.44	0.70	3539.25	91.17	0.91
19	74302.41	65.69	0.69	3659.84	91.16	0.91
20	65427.25	67.73	0.70	3889.37	90.86	0.91
21	47848.21	73.45	0.75	4018.15	90.75	0.91
22	74665.80	66.63	0.70	3667.40	91.31	0.91
23	50356.62	74.30	0.76	4237.97	90.45	0.90
24	49987.50	74.19	0.76	4671.04	90.00	0.90
25	58748.39	73.09	0.75	4035.46	91.16	0.91

5.1 Plots

The train loss , validation loss, validation accuracy and validation F1 score over the epochs are shown below.
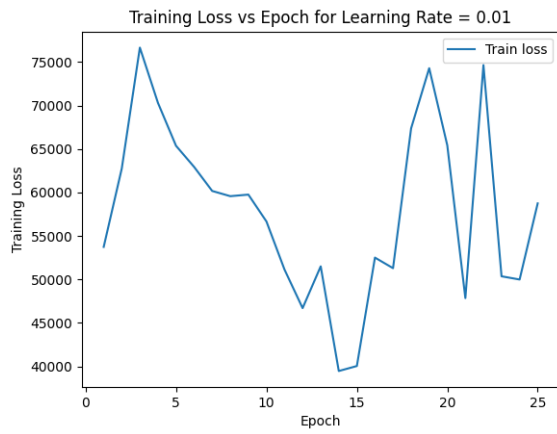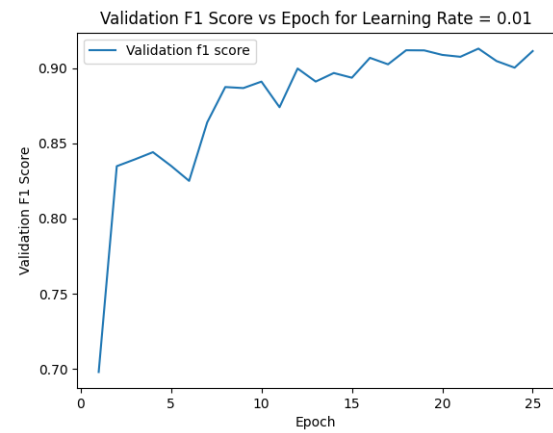

(a) Train loss vs Epoch
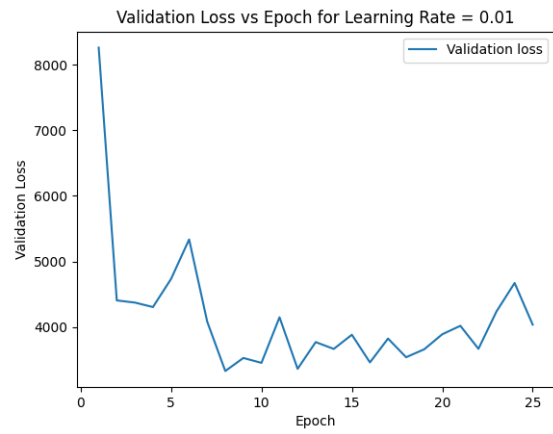
(b) Validation Loss vs Epoch
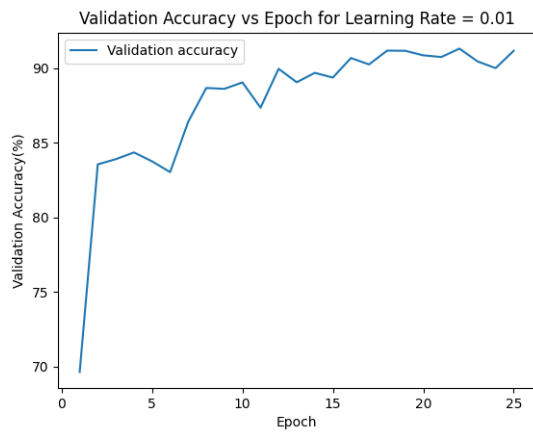
(c) Validation Accuracy vs Epoch

(d) Validation F1 Score vs Epoch

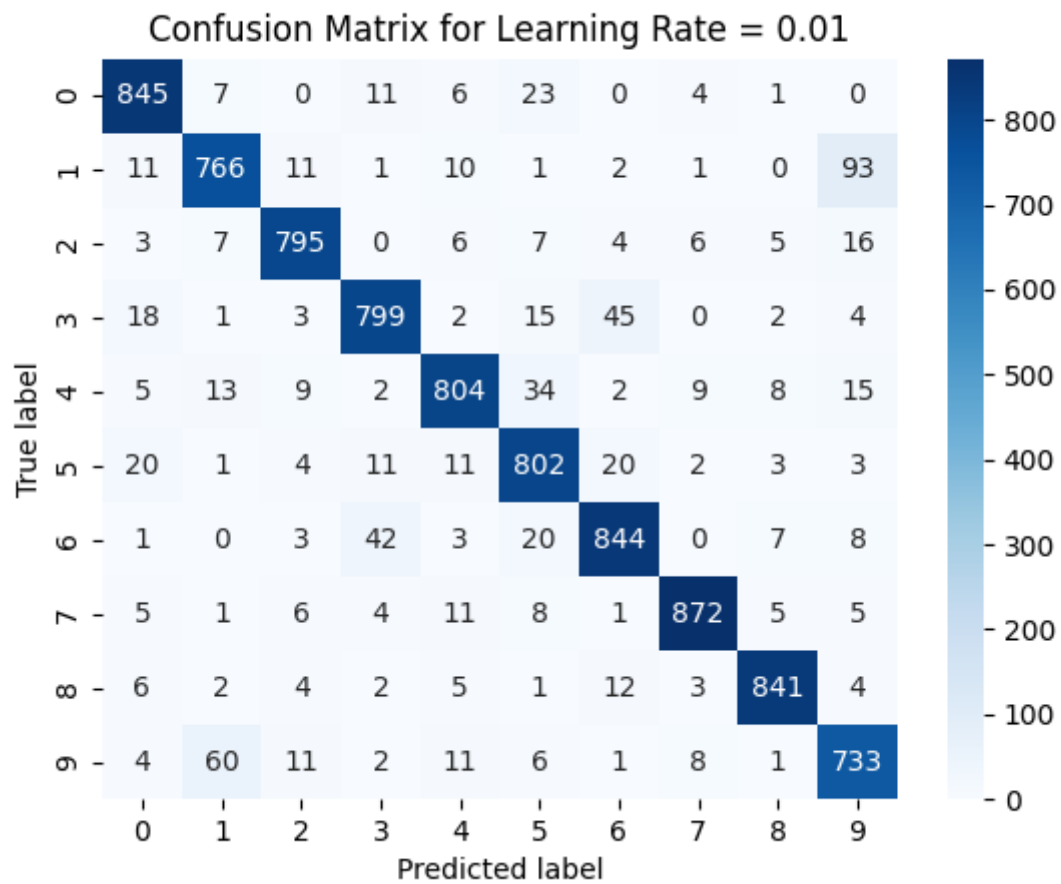## 5.2 Confusion Matrix

The confusion Matrix is shown below.

Figure 6: Confusion Matrix

6   Result

As we can see from the data, using 0.01 as learning rate the model achieves highest Training Accuracy 74%, highest validation accuracy 91% and highest validation F1 score 0.91. So this was selected as the best model and was used to predict the test-set. This model achieves 78% accuracy and 0.79 F1 score in the test-set.