

Hand Written Number Identification

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Abstract—

Index Terms—Computer Vision, SVM, Boost, CNN

I. INTRODUCTION

A. Background

Handwriting recognition (HWR), also known as Handwritten Text Recognition (HTR), is the ability of a computer to receive and interpret intelligible handwritten input from sources such as paper documents, photographs, touch-screens and other devices. The image of the written text may be sensed "offline" from a piece of paper by optical scanning (optical character recognition) or intelligent word recognition.

B. Problem Description

What's this problem?

- This is a supervised classification problem;
- And identification accuracy is the goals.

We decided to further investigate by following questions:

- 1) How to process image type data?
- 2) What is the best way to identifying hand written text?

II. DATA PREPARATION

A. Data Source

Identifying hand written text will be a hard task. To answer this question, we made use of MNIST data for Digits. [1].

B. Data Content

- The MNIST database (Modified National Institute of Standards and Technology database) of handwritten digits consists of a training set of 60,000 examples, and a test set of 10,000 examples;
- It is a subset of a larger set available from NIST;
- The records are 28 by 28 pixel black and white images, that is 784 variables;
- All variable are introduced grayscale levels, which is a number from 0 to 255;
- There are total 10 for Digits (i.e. 0 to 9).

Here's some example of data, Fig. 1

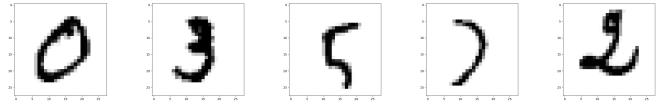


Fig. 1. Example of data

C. Data transformation

Besides, the data can't be normalized since there are some constant valued columns (some columns are always 0). Alternatively, We will map these values into an interval from [0.01, 1] by multiplying each pixel that values p with (1).

$$p^{new} = p * \frac{0.99}{255} + 0.01 \quad (1)$$

III. DATA VISUALIZATION

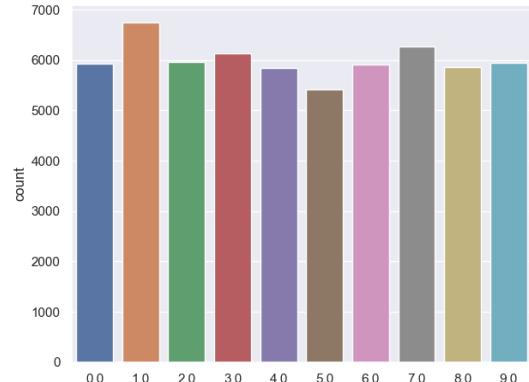


Fig. 2. Distribution of MNIST data

From Fig. 2, we can conclude that the data size of different class are basically equal, which means that our data is balanced.

IV. USED PROGRAMMING LANGUAGE

We are originally use R language as our tool to model, and by the limited computing ability, we only randomly pick 6,000 train and 1,000 test data from all numerate data from (0-9) to train our model, which is 1/10 of the MNIST data set. However, even if we reduced the data size, we still find the running time is extremely long when tuning model of Neural Network in VII.

Since Python is up to 8 times faster than R. Therefore, we only use R as our visualization programming language and Python as our model building language.

V. SUPPORT VECTOR MACHINES

In machine learning, support-vector machines (SVM) are supervised learning models with associated learning algorithms that analyze data used for classification and regression analysis.

A. Linear Kernel

1) Global optimization: First we use support vector machines of linear kernel.

$$K \langle x, x' \rangle = \langle x, x' \rangle$$

We added Elastic-Net regularization term (See (2) for the math formula of Elastic-Net) into our SVM model which linearly combines the L1 and L2 penalties of the lasso and ridge methods, and included two parameters:

- l_{1ratio} : weight of L_1 regularization term;
- α : overall penalization term.

$$R(w) := \alpha \left(\frac{1 - l_{1ratio}}{2} \sum_{i=1}^n w_i^2 + l_{1ratio} \sum_{i=1}^n |w_i| \right) \quad (2)$$

Applying this regularization term into SVM model, and tuning these 2 parameters, the results are as Fig. 3. From figure, we can easily see that a smaller α tend to be better, which means that there is barely improvement on test error by using regularization term. Therefore, we don't consider regularization term in the following SVM models.

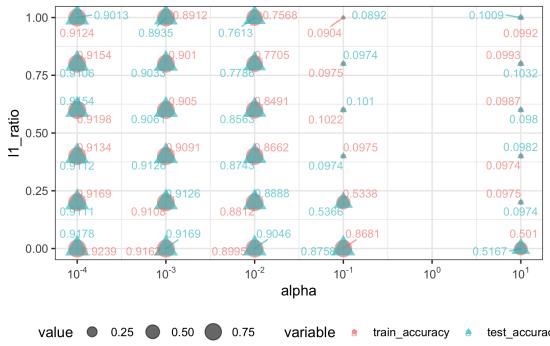


Fig. 3. SGD SVM Accuracy rate, alpha versus 11 ratio

We pick the model of best test accuracy, which is 0.9178, and the confusion table is as TABLE I.

B. RBF Kernel

In order to get a non-linear boundary, we use RBF kernel to train model.

$$K \langle x, x' \rangle = \exp \left(-\gamma \|x - x'\|^2 \right)$$

TABLE I
SVM CONFUSION TABLE

	0	1	2	3	4	5	6	7	8	9	
0	953	0	1	2	0	16	3	4	1	0	0.9724
1	0	1106	3	1	1	5	4	2	13	0	0.9744
2	7	3	899	19	9	20	15	17	39	4	0.8711
3	6	0	16	899	2	50	4	11	13	9	0.8901
4	1	1	7	0	926	0	7	4	32	0.9430	
5	6	1	0	22	12	814	14	4	14	5	0.9126
6	11	3	3	2	5	30	901	1	2	0	0.9405
7	1	5	19	4	4	4	1	969	2	19	0.9426
8	9	7	4	24	24	83	11	18	784	10	0.8049
9	8	4	0	10	47	22	1	38	9	870	0.8622
	0.9511	0.9788	0.9443	0.9145	0.8990	0.7797	0.9376	0.9073	0.8899	0.9168	0.9178

1) Tuning with 20% data set: Considering the computation complexity of RBF Kernel, we only use 20% data set to tune our model. The hyper-parameter field are as follows.

- $\gamma : 10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}$.

It takes total 2,263.077 seconds to train those 4 model with 4-core CPU. And we gain best model of $\gamma = 0.01$. We get a test accuracy of 0.9375.

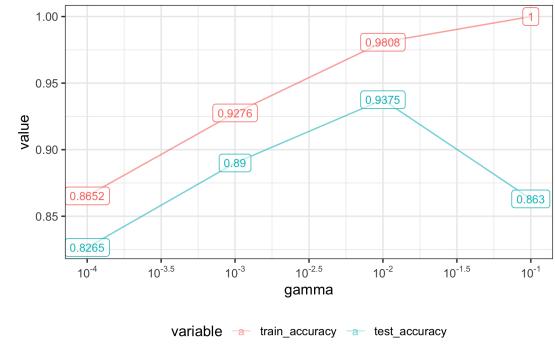


Fig. 4. RBF SVM Accuracy versus gamma

2) Train best model with whole data set: Applying best model of $\gamma = 0.01$ to whole data set. It takes total 2,749 seconds to train this model with 4-core CPU. We get a train accuracy of 0.9983 and test accuracy of 0.9852, and the confusion table is as TABLE II.

TABLE II
RBF SVM CONFUSION TABLE

	0	1	2	3	4	5	6	7	8	9	
0	1014	0	2	0	2	2	2	0	1	3	0.9902
1	0	1177	2	1	1	0	1	0	2	1	0.9932
2	2	2	1037	2	0	0	0	2	5	1	0.9867
3	0	0	3	1035	0	5	0	6	6	2	0.9792
4	0	0	1	0	957	0	1	2	0	3	0.9927
5	1	1	0	4	1	947	4	0	5	1	0.9824
6	2	0	1	0	2	0	1076	0	4	0	0.9917
7	1	1	8	1	1	0	0	1110	2	4	0.9840
8	0	4	2	4	1	6	0	1	1018	1	0.9817
9	3	1	0	7	5	2	0	4	9	974	0.9692
	0.9912	0.9924	0.9820	0.9820	0.9886	0.9844	0.9926	0.9867	0.9677	0.9838	0.9852

C. Polynomial Kernel

We now use Polynomial kernel to train model.

$$K \langle x, x' \rangle = (\gamma \langle x, x' \rangle)^d$$

1) Tuning with 20% data set: Considering the computation complexity of Polynomial Kernel, we only use 20% data set to tune our model. The hyper-parameter field are as follows.

- $\gamma : 10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}$;
- $d = 1, 2, 3, 4, 5$.

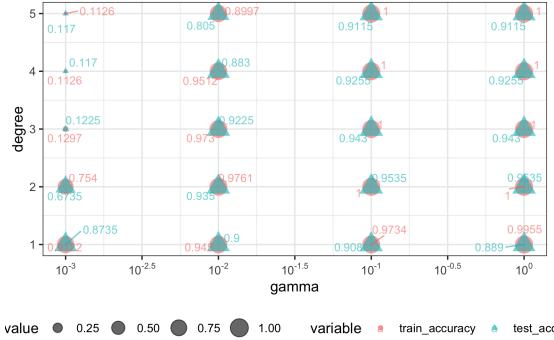


Fig. 5. Polynomial SVM Accuracy degree versus gamma

It takes total 4,916.98 seconds to tune the model with 4-core CPU. And we gain best model of $\gamma = 0.1, d = 2$. We get a test accuracy of 0.9535.

2) *Train best model with whole data set:* Applying best model of $\gamma = 0.1, d = 2$ to whole data set. It takes total 1,439.43 seconds to train this model with 4-core CPU. We get a train accuracy of 0.9989 and a test accuracy of 0.9806, and the confusion table is as TABLE III.

TABLE III
POLYNOMIAL SVM CONFUSION TABLE

	0	1	2	3	4	5	6	7	8	9	
0	973	0	1	2	0	1	1	0	2	0	0.9929
1	0	1128	2	1	0	1	1	1	0	0	0.9938
2	7	1	1008	1	1	0	4	6	4	0	0.9767
3	0	0	3	987	0	5	0	5	7	3	0.9772
4	1	0	4	0	966	0	2	0	0	9	0.9837
5	2	0	0	9	1	872	3	1	2	2	0.9776
6	5	2	2	0	2	5	940	0	2	0	0.9812
7	0	6	9	1	1	0	0	1002	1	8	0.9747
8	4	0	2	4	3	2	1	4	951	3	0.9764
9	2	4	0	4	9	4	0	4	3	979	0.9703
	0.9789	0.9886	0.9777	0.9782	0.9827	0.9798	0.9874	0.9795	0.9774	0.9751	0.9806

VI. BOOSTING

A. Ada Boosting

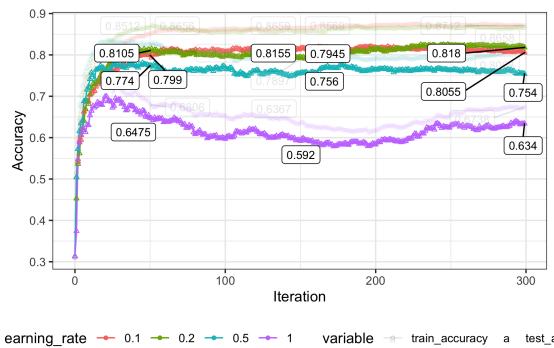


Fig. 6. Ada Boosting Accuracy By Iteration

1) *Tuning with 20% data set:* It takes total 1,044 seconds to tune the model with 4-core CPU. And we gain best model of learning rate = 0.1.

2) *Train best model with whole data set:* Now we apply the best model of learning rate = 0.1 into whole data, and it takes 1402 seconds to train the model. The test accuracy is 0.8902, train accuracy is 0.8911, and the confusion table is as TABLE IV. However from Fig. 7, we can see that there are barely differences between the test and train accuracy in each iteration, which means that our model is under-fitted. Try to increase the iteration number and decrease the learning rate might increase accuracy.

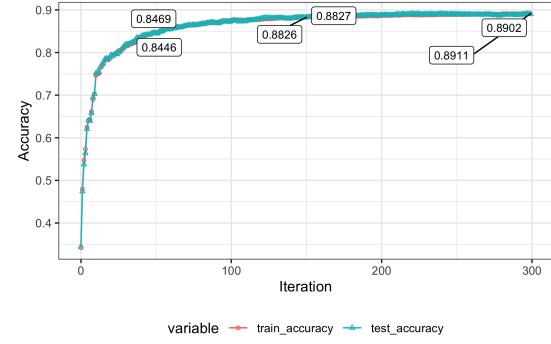


Fig. 7. Final Ada Boosting Accuracy By Iteration

TABLE IV
ADA BOOSTING CONFUSION TABLE

	0	1	2	3	4	5	6	7	8	9	
0	902	0	13	0	45	13	0	4	3	0.9204	
1	0	1114	5	3	0	1	1	8	2	0.9815	
2	12	14	852	16	8	5	38	9	76	2	0.8256
3	20	0	13	894	0	30	0	7	43	3	0.8851
4	1	0	6	0	902	1	2	1	8	61	0.9185
5	16	3	3	46	3	754	13	1	38	15	0.8453
6	10	3	44	0	31	29	833	0	8	0	0.8695
7	0	3	27	4	6	0	0	889	8	91	0.8648
8	12	10	3	18	8	11	4	3	891	14	0.9148
9	4	8	7	12	56	2	0	12	24	884	0.8761
	0.9232	0.9645	0.8756	0.9003	0.8895	0.8588	0.9215	0.9632	0.8042	0.8223	0.8911

B. Gradient Boosting

1) *Tuning with 20% data set:* Even though we only training model with 20% data, Gradient Boosting still need an average of 15 minutes to build one model, which is significantly slower than ada boosting method. We used 12,129 seconds in tuning parameters.

From Fig. 8, we can see that with the increasing of tree depth, the accuracies are going up. The best hyper parameters are learning rate = 0.2, tree depth = 4. ¹

2) *Train best model with whole data set:* Now we train the model of learning rate = 0.2, tree depth = 4 with whole data set. It takes 7,321 seconds to train the model, the test accuracy is 0.9674, train accuracy is 0.9981, and the confusion table is as TABLE V.

VII. NEUTRAL NETWORK

A neural network is a series of algorithms that endeavors to recognize underlying relationships in a set of data through

¹Since the size of tree depth we choose is the upper bound of our tuning field, therefore, we might gain a better result by using a tree depth that is more than 4.

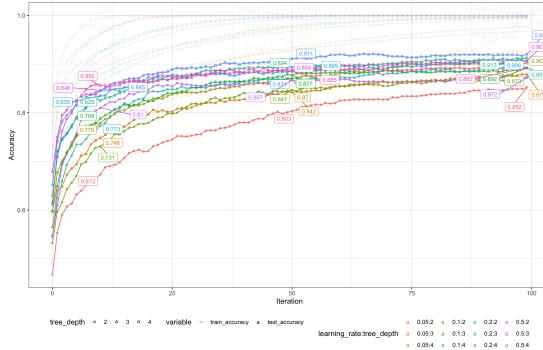


Fig. 8. Gradient Boosting Accuracy By Iteration

TABLE V
GRADIENT BOOSTING CONFUSION TABLE

	0	1	2	3	4	5	6	7	8	9	
0	962	0	0	2	0	7	4	2	3	0	0.9816
1	0	1121	2	1	1	1	4	1	4	0	0.9877
2	5	2	995	7	3	2	1	8	8	1	0.9641
3	1	1	6	960	1	18	0	8	9	6	0.9505
4	1	0	1	0	960	1	5	0	3	11	0.9776
5	2	1	0	1	2	871	5	1	6	3	0.9765
6	7	3	1	0	4	14	922	1	6	0	0.9624
7	1	7	10	5	3	1	0	985	1	15	0.9582
8	2	1	3	4	5	7	2	6	940	4	0.9651
9	3	7	1	7	10	8	1	7	8	957	0.9485
	0.9776	0.9808	0.9764	0.9726	0.9707	0.9366	0.9767	0.9666	0.9514	0.9599	0.9674

a process that mimics the way the human brain operates. We use batch² and epoch³ to update our parameters [2].

A. 1-layer Neutral Network

1) *Softmax activation function:* Softmax is a basic activation function because it not only maps our output to a [0,1] range but also maps each output in such a way that the total sum is 1.

$$\sigma(\mathbf{z})_j = \frac{e^{\mathbf{z}_j}}{\sum_{k=1}^K e^{\mathbf{z}_k}} \quad \text{for } j = 1, \dots, K$$

We trained 216 1-layer Neural Network models with different hidden nodes, learning rates and bias, for every type of model we trained 10 epochs. The hyper-parameter field are as follows.

- Bias: 1, None;
- Number of hidden nodes: 20, 50, 100, 150, 250, 500;
- batch size: 100, 200, 300;
- loss function: mean squared error, categorical cross entropy;
- Learning rate: 0.001, 0.01, 0.1.

Firstly, we need to know if all our model is converged. From Fig. 9, we get 9 models that are not converged. Therefore we need to add more epoch to those un converged model until them converged, and then use the converged model's test accuracy as their final accuracy.

²Batch: a set of N samples. The samples in a batch are processed independently, in parallel. If training, a batch results in only one update to the model. A batch generally approximates the distribution of the input data better than a single input.

³Epoch: an arbitrary cutoff, generally defined as "one pass over the entire dataset", used to separate training into distinct phases, which is useful for logging and periodic evaluation.

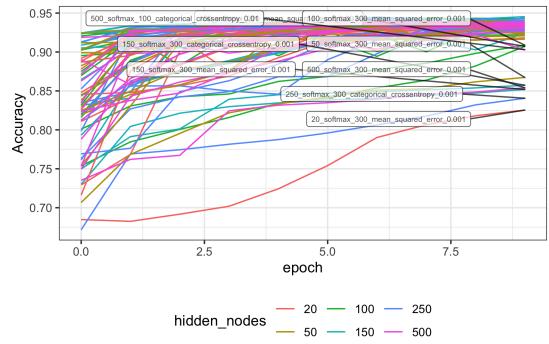


Fig. 9. 1-layer Neural Network Test Accuracy By Epoch

Next, we tune all the hyper-parameters. From Fig. 10, we

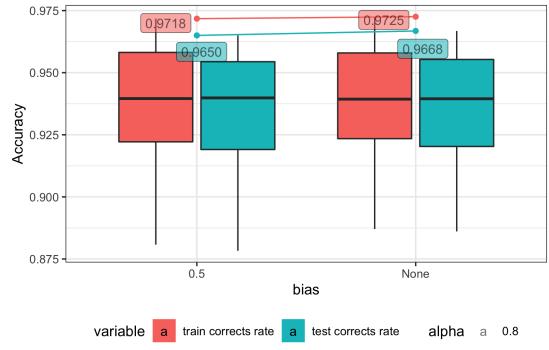


Fig. 10. 1-Hidden Layer NN Accuracy rate versus bias(Softmax)

can see that bias barely improves accuracy. From Fig. 11,

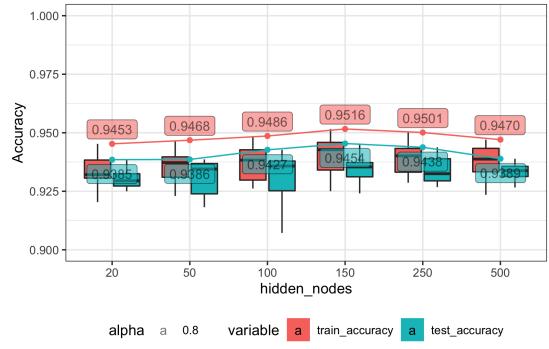


Fig. 11. 1-Hidden Layer NN Accuracy rate versus hidden nodes(Softmax)

we can see that a larger number of hidden nodes tends to have better accuracy. However, the best test accuracy is when number of hidden nodes equals 150. From Fig. 12, we can see that a learning rate of 0.01 tends to have better accuracy than 0.001. Besides, we also used a learning rate of 0.1. However, the accuracy of training result was trapped around 10%, which means that a learning rate of 0.1 skipped the best parameter. Therefore, we didn't show the box plot of 0.1 learning rate here. From Fig. 13, we can see that the use of different loss function don't impact the test accuracy a lot.

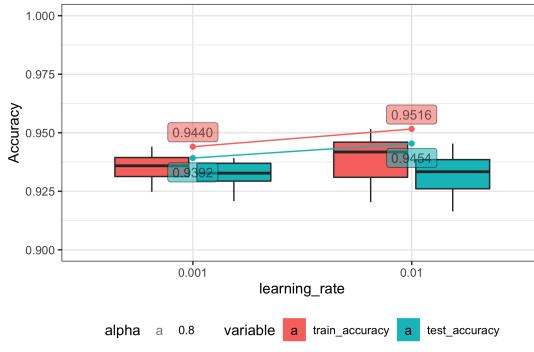


Fig. 12. 1-Hidden Layer NN Accuracy rate versus learning rate(Softmax)

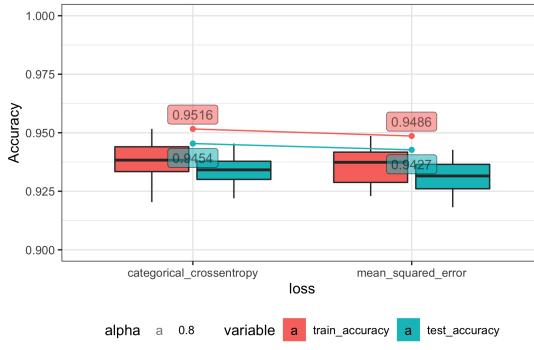


Fig. 13. 1-Hidden Layer NN Accuracy rate versus loss(Softmax)

We pick the model of best test accuracy, whose details are as in TABLE VI and the confusion table is as TABLE VII.

2) *ReLU activation function:* ReLU stands for rectified linear unit, and is a type of activation function:

$$\sigma(\mathbf{z})_j = \max(0, \mathbf{z}_j) \quad \text{for } j = 1, \dots, K$$

Since we conclude bias term nearly have no affects in improving test accuracy in VII-A1, we didn't consider bias term from now on. We trained 108 1-layer Neural Network models with different hidden nodes, learning rates and bias, for every type of model we trained 10 epochs. The hyper-parameter field are as follows, which are the same as the

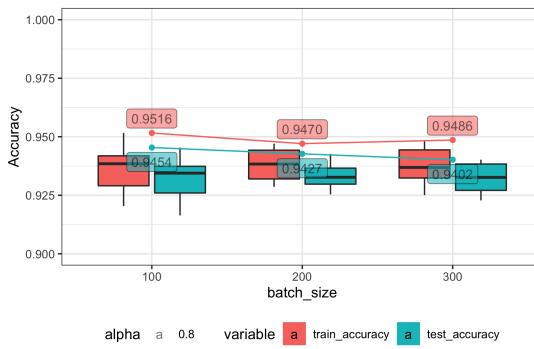


Fig. 14. 1-Hidden Layer NN Accuracy rate versus batch size(Softmax)

TABLE VI
1-LAYER NEURAL NETWORK BEST HYPER-PARAMETER(SOFTMAX)

hidden_nodes	activation	batch_size	loss
150	softmax	100	categorical_crossentropy
0.01	epoch	variable	test_accuracy

TABLE VII
1-LAYER NEURAL NETWORK CONFUSION TABLE(SOFTMAX)

	0	1	2	3	4	5	6	7	8	9	
0	965	0	9	0	2	5	6	1	5	2	0.9698
1	0	1126	4	0	0	1	4	8	4	6	0.9766
2	0	4	998	7	1	1	1	22	3	1	0.9615
3	1	1	5	977	0	10	0	10	23	9	0.9431
4	0	0	2	2	952	2	5	3	7	12	0.9665
5	3	1	0	10	0	853	13	0	7	1	0.9606
6	4	1	3	1	9	7	924	0	3	1	0.9696
7	1	1	7	4	0	2	0	966	5	5	0.9748
8	1	1	3	3	1	8	5	1	909	1	0.9743
9	5	0	1	6	17	3	0	17	8	971	0.9446
	0.9847	0.9921	0.9671	0.9673	0.9695	0.9563	0.9645	0.9397	0.9333	0.9623	0.9454

hyper-parameter field of 1-hidden layer neural networks with softmax activation function.

- Number of hidden nodes: 20, 50, 100, 150, 250, 500;
- batch size: 100, 200, 300;
- loss function: mean squared error, categorical cross-entropy;
- Learning rate: 0.001, 0.01, 0.1.

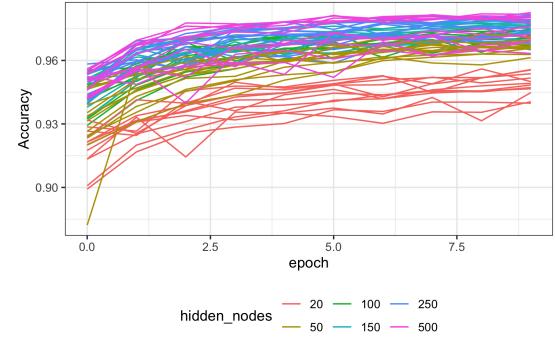


Fig. 15. 1-layer Neural Network Test Accuracy By Epoch(ReLU)

First, we need to know if all our model is converged. From Fig. 15, we can see that all of our models are converged. Besides, we can also see that those different group of model's iteration lines are approximately parallel, which implies that ReLU activation function can update the parameter more correctly, compared to Fig. 9.

Next, we tune all the hyper-parameters. From Fig. 16, we can see that the more hidden nodes, the better the maximum test accuracy is. From Fig. 17, we can see that a learning rate of 0.001 is better than 0.01. Besides, we also used a learning rate of 0.1. However, the accuracy of training result was trapped around 10%, which means that a learning rate of 0.1 skipped the best parameter. Therefore, we didn't show the box plot of 0.1 learning rate here. From Fig. 18, we conclude loss function barely impact accuracy. From Fig. 19, we conclude batch size barely impact accuracy.

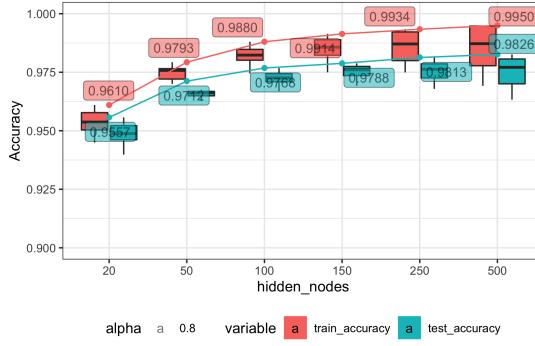


Fig. 16. 1-Hidden Layer NN Accuracy rate versus hidden nodes(ReLU)

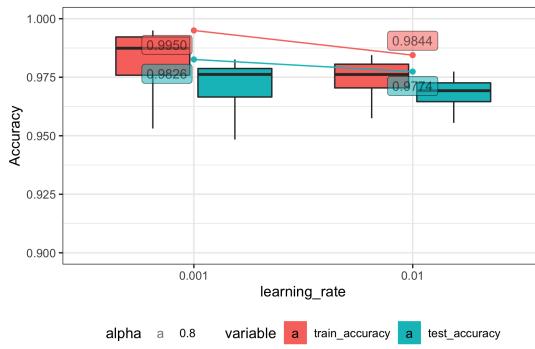


Fig. 17. 1-Hidden Layer Neural Network Accuracy rate versus learning rate(ReLU)

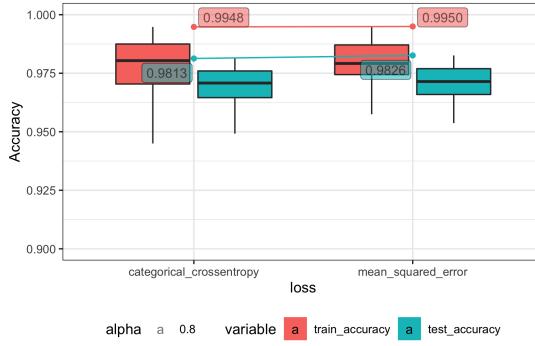


Fig. 18. 1-Hidden Layer NN Accuracy rate versus loss(ReLU)

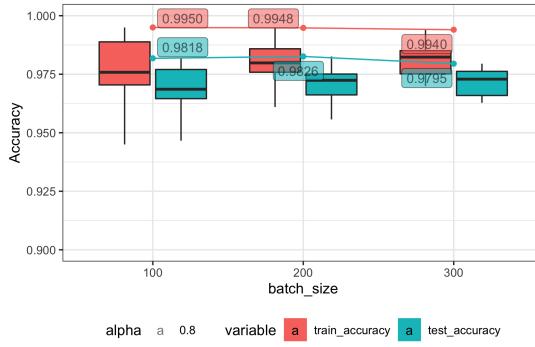


Fig. 19. 1-Hidden Layer NN Accuracy rate versus batch size(ReLU)

We pick the model of best test accuracy, whose details are as in TABLE VIII and the confusion table is as TABLE IX.

TABLE VIII
1-LAYER NEUTRAL NETWORK BEST HYPER-PARAMETER(RELU)

hidden_nodes	activation	batch_size	loss
500	ReLU	200	mean_squared_error
0.001	epoch	variable	test_accuracy

TABLE IX
1-LAYER NEUTRAL NETWORK CONFUSION TABLE(RELU)

	0	1	2	3	4	5	6	7	8	9	
0	971	0	0	1	0	5	0	1	2	0	0.9908
1	0	1126	3	2	0	0	2	1	1	0	0.9921
2	1	1	1018	4	0	0	1	4	3	0	0.9864
3	0	0	2	996	0	5	0	3	1	3	0.9861
4	0	0	5	1	960	2	5	1	0	8	0.9776
5	1	0	0	4	0	885	1	0	1	0	0.9922
6	4	2	1	1	2	10	937	0	1	0	0.9781
7	1	2	8	3	0	1	0	1005	3	5	0.9776
8	2	0	6	6	3	8	3	5	939	2	0.9641
9	1	2	2	12	7	10	0	4	3	968	0.9594
	0.9898	0.9938	0.9742	0.9670	0.9877	0.9557	0.9874	0.9814	0.9843	0.9817	0.9826

3) Comparison: Now we compare the result of softmax activation function and ReLU activation function.

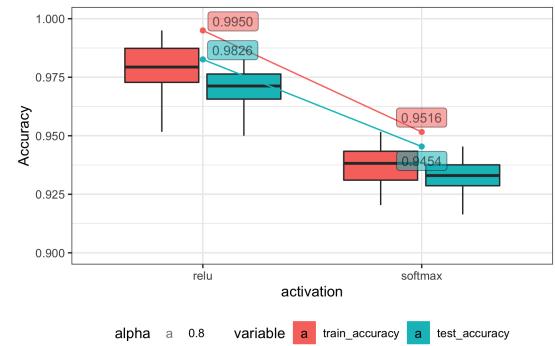


Fig. 20. 1-Hidden Layer Neural Network Accuracy rate versus activation

From Fig. 20, we can see that ReLU activation greatly improved the overall accuracy. From Fig. 21, we can see that

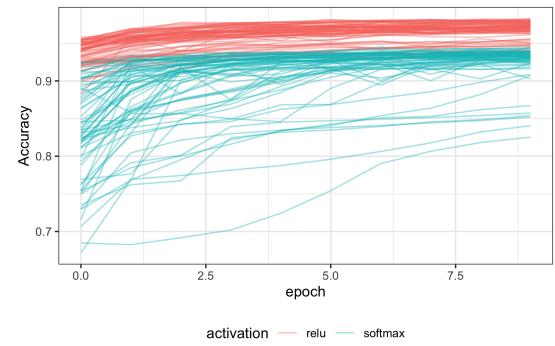


Fig. 21. 1-Hidden layer Neural Network Accuracy rate By Epoch

ReLU activation greatly shortened the converge time of neural network.

B. 2-layer Neutral Network

We didn't introduce bias term in this section and skipped the learning rate of 0.1 when tuning hyper-parameters and only uses ReLU activation function. We trained 648 2-layer Neutral Network models with different hidden nodes, learning rates and bias, and for every type of model we trained 10 epochs. The hyper-parameter field are as follows:

- Number of hidden nodes of 1st layer: 20, 50, 100, 150, 250, 500;
- Number of hidden nodes of 2nd layer: 20, 50, 100, 150, 250, 500;
- batch size: 100, 200, 300;
- loss function: mean squared error, categorical cross-entropy;
- Learning rate: 0.001, 0.01.

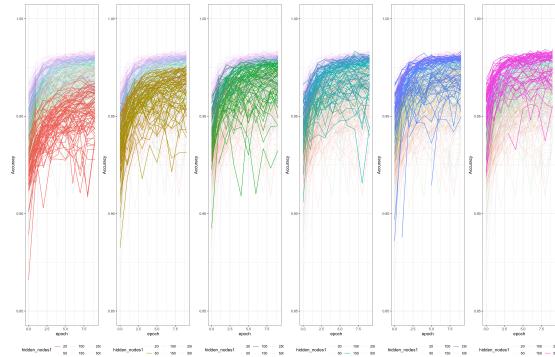


Fig. 22. 2-layer Neural Network Test Accuracy By Epoch(ReLU)-1

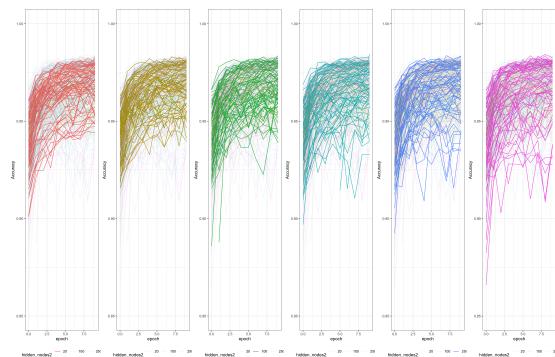


Fig. 23. 2-layer Neural Network Test Accuracy By Epoch(ReLU)-2

First, we need to know if all our model is converged. From Fig. 22 and Fig. 23, we can see that all of our models are converged. And from Fig. 22, we can see that with the number of 1st hidden layer nodes going up, the test accuracy going up.

Next, we tune all the hyper-parameters. From Fig. 24 and Fig. 25, we can see that the more 1st layer hidden nodes, the better the maximum test accuracy is, the more 2nd layer hidden nodes, the larger the variance of test accuracy is. From Fig. 26, we can see that a learning rate of 0.001 is better than 0.01. From Fig. 27, we conclude loss function barely impact

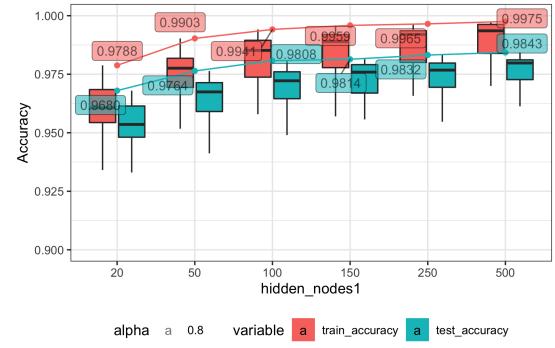


Fig. 24. 2-Hidden Layer NN Accuracy rate versus hidden nodes of 1st layer(ReLU)

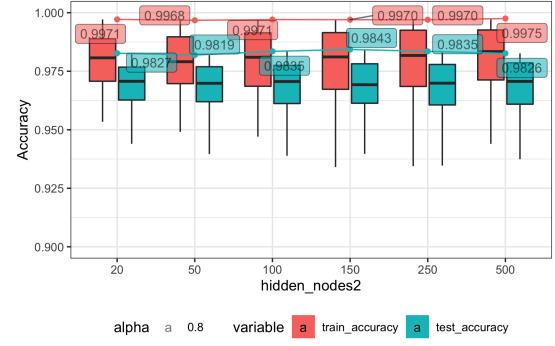


Fig. 25. 2-Hidden Layer NN Accuracy rate versus hidden nodes of 2nd layer(ReLU)

accuracy. From Fig. 28, we conclude batch size barely impact accuracy.

The hyper-parameter of best model is as TABLE X, the test accuracy is 0.9843, train accuracy is 0.9971, and the confusion table is as TABLE XI. Here, we made a slight improvement than the 1 hidden layer neural network.

VIII. CONCLUSION

From TABLE XII, we can see that SVM with RBF kernel have the best test accuracy, but it takes a lot of time to train.

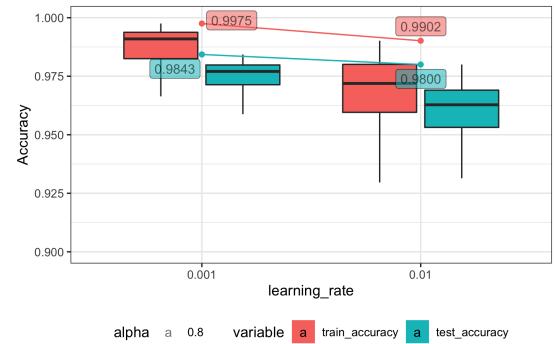


Fig. 26. 2-Hidden Layer Neural Network Accuracy rate versus learning rate(ReLU)

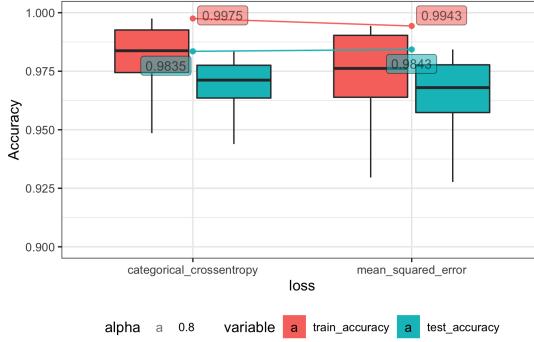


Fig. 27. 2-Hidden Layer NN Accuracy rate versus loss(ReLU)

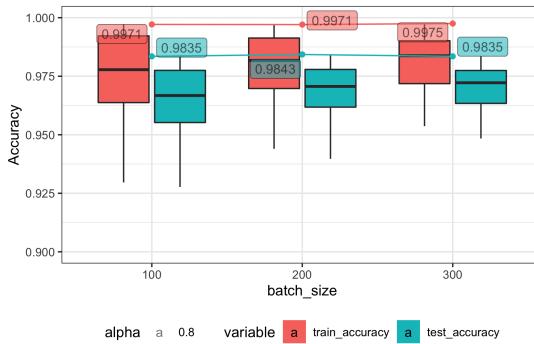


Fig. 28. 2-Hidden Layer NN Accuracy rate versus batch size(ReLU)

TABLE X
2-LAYER NEUTRAL NETWORK BEST HYPER-PARAMETER(RELU)

hidden_nodes1 500	hidden_nodes2 150	activation ReLU	batch_size 200
learning_rate 0.001	epoch 10	variable test_accuracy	value 0.9843
loss mean_squared_error			

TABLE XI
2-LAYER NEUTRAL NETWORK CONFUSION TABLE

	0	1	2	3	4	5	6	7	8	9	
0	975	1	0	0	1	1	1	1	1	0	0.9939
1	0	1129	1	2	0	1	2	0	0	0	0.9947
2	4	3	1002	3	5	0	4	6	4	0	0.9719
3	0	1	1	1000	0	4	0	4	4	1	0.9852
4	0	2	3	0	968	0	2	0	0	7	0.9857
5	3	1	0	5	1	867	7	0	2	1	0.9775
6	2	2	0	1	8	4	941	0	0	0	0.9823
7	1	5	4	2	0	0	0	1007	4	5	0.9796
8	2	1	2	3	3	1	4	3	953	2	0.9784
9	3	4	0	4	8	9	1	4	4	972	0.9633
	0.9848	0.9826	0.9891	0.9804	0.9738	0.9775	0.9782	0.9824	0.9805	0.9838	0.9843

TABLE XII
COMPARISON

Method	Train Accuracy	Test Accuracy	Yann LeCun	Time(Second)
SVM Linear Kernel	0.9239	0.9178	NA	344
SVM RBF Kernel	0.9983	0.9852	0.9860	2.749
SVM Polynomial Kernel	0.9989	0.9806	0.9890	1.439
Gradient Boosting	0.9981	0.9673	0.9874	7.321
Ada Boosting	0.8911	0.8902	0.923	1.402
1-layer NN 150 (Softmax)	0.9516	0.9454	0.953	30
1-layer NN 500 (ReLU)	0.9950	0.9826	0.984	40
2-Layer NN 500-150 (ReLU,ReLU)	0.9971	0.9843	0.9705	57

The second best model is 2-layer neural network with 500 hidden nodes and ReLU activation function, and it only takes 40 seconds to train the model. The test accuracy difference of these 2 model is only 0.0026, but the time difference is nearly 3,000 seconds. Therefore, we conclude that for MNIST data, the best model, considering test accuracy and training time, is 2-layer neural network with 500 hidden nodes and ReLU activation function.

ACKNOWLEDGMENT

I would like to express my special thanks of gratitude to my teacher who gave me the golden opportunity to do this wonderful project on the topic of this, which also helped me in doing a lot of Research and I came to know about so many new things I am really thankful to him.

REFERENCES

- [1] Y. LeCun and C. Cortes, “MNIST handwritten digit database,” 2010. [Online]. Available: <http://yann.lecun.com/exdb/mnist/>
- [2] F. Chollet *et al.*, “Keras,” <https://github.com/fchollet/keras>, 2015.

APPENDIX A

PYTHON SOURCE CODE

```

1 import matplotlib.pyplot as plt
2 import numpy as np
3
4
5 image_size = 28 # width and length
6 no_of_different_labels = 10 # i.e. 0, 1, 2, 3, ..., 9
7 image_pixels = image_size * image_size
8 data_path = "data/CSV/"
9 train_data = np.loadtxt(data_path + "mnist_train.csv",
10                         delimiter=",")
11 test_data = np.loadtxt(data_path + "mnist_test.csv",
12                         delimiter=",")
13
14 img = train_data[190,1:785].reshape((28,28))
15 plt.imshow(img, cmap="Greys")
16 plt.show()
17
18
19 fac = 0.99 / 255
20 train_imgs = np.asarray(train_data[:, 1:]) * fac + 0.01
21 test_imgs = np.asarray(test_data[:, 1:]) * fac + 0.01
22
23 train_labels = np.asarray(train_data[:, :1])
24 test_labels = np.asarray(test_data[:, :1])
25
26
27 # lr = np.arange(10)
28 #
29 # for label in range(10):
30 #     one_hot = (lr==label).astype(np.int)
31 #     print("label: ", label, " in one-hot representation: ", one_hot)
32
33 lr = np.arange(no_of_different_labels)
34
35 # transform labels into one hot representation
36 train_labels_one_hot = (lr==train_labels).astype(np.float)
37 test_labels_one_hot = (lr==test_labels).astype(np.float)
38
39 # we don't want zeroes and ones in the labels neither:
40 train_labels_one_hot[train_labels_one_hot==0] = 0.01
41 train_labels_one_hot[train_labels_one_hot==1] = 0.99
42 test_labels_one_hot[test_labels_one_hot==0] = 0.01
43 test_labels_one_hot[test_labels_one_hot==1] = 0.99
44
45 # Before we start using the MNIST data sets with our neural network,
46 # → we will have a look at some images
47 for i in range(10):
48     img = train_imgs[i].reshape((28,28))
49     plt.imshow(img, cmap="Greys")
50     plt.show()
51
52 import pickle
53
54 with open("data/pkl/pickled_mnist.pkl", "bw") as fh:
55     data = (train_imgs,
56             test_imgs,
57             train_labels,
58             test_labels,
59             train_labels_one_hot,
60             test_labels_one_hot)
61     pickle.dump(data, fh)

```

```

6 import seaborn as sns
7 import numpy as np
8 import time
9 import pickle
10
11 sns.set()
12
13 (x_train, y_train), (x_test, y_test) = mnist.load_data()
14 num_classes = 10
15 x_train = x_train.reshape(60000, 784)
16 x_test = x_test.reshape(10000, 784)
17 x_train = x_train.astype('float32')
18 x_test = x_test.astype('float32')
19 x_train /= 255
20 x_test /= 255
21
22 # n=0.2
23 # x_train=x_train[1:int(60000*n)+1,]
24 # x_test=x_test[1:int(10000*n)+1,]
25 # y_train=y_train[1:int(60000*n)+1,]
26 # y_test=y_test[1:int(10000*n)+1,]
27
28
29
30 print('Train size:', x_train.shape[0])
31 print('Test size:', x_test.shape[0])
32
33 # Following code is too slow consider SGD
34 # clf = svm.LinearSVC()
35
36 # with open("Result/nist_tests_SVM.csv", "w") as fh_out:
37 # for alpha in [0.001,0.001,0.01,0.1,10]:
38 # for l1_ratio in [0.0,0.2,0.4,0.6,0.8,1]:
39 # print("*", end="")
40 # clf = linear_model.SGDClassifier(max_iter=1000, tol=1e-3, alpha=
41 #                                   ↪ alpha, penalty='elasticnet', l1_ratio=l1_ratio, learning_rate='
42 #                                   ↪ optimal')
43 # clf_fit=clf.fit(train_imgs, np.ravel(train_labels))
44 # train_score = clf_fit.score(train_imgs, np.ravel(train_labels))
45 # test_score = clf_fit.score(test_imgs, np.ravel(test_labels))
46 #
47 # outstr = str(alpha) + " " + str(l1_ratio) + " "
48 # outstr += str(train_score) + " " + str(test_score)
49 #
50 # fh_out.write(outstr + "\n")
51 # fh_out.flush()
52
53 # clf = linear_model.SGDClassifier(max_iter=1000, tol=1e-3)
54 # start_time = time.time()
55 # clf_fit=clf.fit(x_train, y_train)
56 # print("---- %s seconds ----" % (time.time() - start_time))
57 #
58 # train_score=clf_fit.score(x_train,y_train)
59 # test_score=clf_fit.score(x_test,y_test)
60 # cm=confusion_matrix(np.ravel(y_test),clf_fit.predict(x_test))
61 # print('Train Accuracy=',train_score)
62 # print('Test Accuracy=',test_score)
63 # print(cm)
64
65
66 # clf = svm.SVC(kernel='linear')
67 # start_time = time.time()
68 # clf_fit=clf.fit(x_train, y_train)
69 # print("---- %s seconds ----" % (time.time() - start_time))
70 #
71 # train_score=clf_fit.score(x_train,y_train)
72 # test_score=clf_fit.score(x_test,y_test)
73 # cm=confusion_matrix(np.ravel(y_test),clf_fit.predict(x_test))
74 # print('Train Accuracy=',train_score)
75 # print('Test Accuracy=',test_score)
76 # print(cm)
77

```

Listing 1. Data Process

```

1 import matplotlib.pyplot as plt
2 from sklearn import linear_model
3 from sklearn import svm
4 from sklearn.metrics import confusion_matrix
5 from keras.datasets import mnist

```

```

78 with open("Result/nist_tests_SVM_rbf.csv", "w") as fh_out:
79     for gamma in range(4):
80         gamma = 10 ** -(gamma + 1)
81         print("gamma=", gamma)
82         clf = svm.SVC(kernel='rbf', gamma=gamma)
83         start_time = time.time()
84         clf_fit = clf.fit(x_train, y_train)
85         training_time = time.time() - start_time
86         print("---- %s seconds ----" % (training_time))
87
88         outfile = 'SVMrbfmodel/' + str(gamma)
89         with open(outfile, 'wb') as pickle_file:
90             pickle.dump(clf, pickle_file)
91
92         train_score = clf_fit.score(x_train, y_train)
93         test_score = clf_fit.score(x_test, y_test)
94         cm = confusion_matrix(np.ravel(y_test), clf_fit.predict(x_test))
95         print('Train Accuracy=', train_score)
96         print('Test Accuracy=', test_score)
97         print(cm)
98
99         outstr = str(gamma) + " " + str(train_score) + " " + str(test_
100             ↪ score) + " " + str(training_time)
101        fh_out.write(outstr + "\n")
102        fh_out.flush()
103
104 with open("Result/nist_tests_SVM_poly.csv", "w") as fh_out:
105     for degree in range(5):
106         degree=degree+1
107         for gamma in range(4):
108             gamma=10**-(gamma)
109             print("degree=",degree,"gamma=",gamma)
110             clf = svm.SVC(kernel='poly', degree=degree,gamma=
111                 ↪ gamma)
112             start_time = time.time()
113             clf_fit = clf.fit(x_train, y_train)
114             training_time=time.time() - start_time
115             print("---- %s seconds ----" % (training_time))
116
117             outfile = 'SVMpolymodel/' + str(degree) + '_' +str(gamma)
118             with open(outfile, 'wb') as pickle_file:
119                 pickle.dump(clf, pickle_file)
120
121             train_score = clf_fit.score(x_train, y_train)
122             test_score = clf_fit.score(x_test, y_test)
123             cm = confusion_matrix(np.ravel(y_test), clf_fit.predict(x_test
124                 ↪ ))
125             print('Train Accuracy=', train_score)
126             print('Test Accuracy=', test_score)
127             print(cm)
128
129             outstr = str(degree) + " " + str(gamma) + " " + str(train_
130                 ↪ score) + " " + str(test_score)+" "+str(training_time
131                 ↪ )
132             fh_out.write(outstr + "\n")
133             fh_out.flush()

```

Listing 2. SVM

```

1 import matplotlib.pyplot as plt
2 from sklearn import linear_model
3 from sklearn import svm
4 from sklearn.metrics import confusion_matrix
5 from keras.datasets import mnist
6 import seaborn as sns
7 import numpy as np
8 import time
9 import pickle
10
11 sns.set()
12
13 (x_train, y_train), (x_test, y_test) = mnist.load_data()
14 num_classes = 10
15 x_train = x_train.reshape(60000, 784)

```

```

16 x_test = x_test.reshape(10000, 784)
17 x_train = x_train.astype('float32')
18 x_test = x_test.astype('float32')
19 x_train /= 255
20 x_test /= 255
21
22 # n=0.2
23 # x_train=x_train[1:int(60000*n)+1,:]
24 # x_test=x_test[1:int(10000*n)+1,:]
25 # y_train=y_train[1:int(60000*n)+1,:]
26 # y_test=y_test[1:int(10000*n)+1,:]
27
28
29
30 print('Train size:', x_train.shape[0])
31 print('Test size:', x_test.shape[0])
32
33 # Following code is too slow consider SGD
34 # clf = svm.LinearSVC()
35
36 # with open("Result/nist_tests_SVM.csv", "w") as fh_out:
37 # for alpha in [0.0001,0.001,0.01,0.1,10]:
38 # for l1_ratio in [0.0,2.0,4.0,6.0,8.1]:
39 # print("*", end="")
40 # clf = linear_model.SGDClassifier(max_iter=1000, tol=1e-3,alpha=
41 #     ↪ alpha,penalty='elasticnet',l1_ratio=l1_ratio,learning_rate='
42 #     ↪ optimal')
43 # clf_fit=clf.fit(train_imgs, np.ravel(train_labels))
44 # train_score = clf_fit.score(train_imgs, np.ravel(train_labels))
45 # test_score = clf_fit.score(test_imgs, np.ravel(test_labels))
46 #
47 # outstr = str(alpha) + " " + str(l1_ratio) + " "
48 # outstr += str(train_score) + " " + str(test_score)
49 #
50 # fh_out.write(outstr + "\n")
51 # fh_out.flush()
52
53 # clf = linear_model.SGDClassifier(max_iter=1000, tol=1e-3)
54 # start_time = time.time()
55 # clf_fit=clf.fit(x_train, y_train)
56 # print("---- %s seconds ----" % (time.time() - start_time))
57 #
58 # train_score=clf_fit.score(x_train,y_train)
59 # test_score=clf_fit.score(x_test,y_test)
60 # cm=confusion_matrix(np.ravel(y_test),clf_fit.predict(x_test))
61 # print('Train Accuracy=',train_score)
62 # print('Test Accuracy=',test_score)
63 # print(cm)
64
65 # clf = svm.SVC(kernel='linear')
66 # start_time = time.time()
67 # clf_fit=clf.fit(x_train, y_train)
68 # print("---- %s seconds ----" % (time.time() - start_time))
69 #
70 # train_score=clf_fit.score(x_train,y_train)
71 # test_score=clf_fit.score(x_test,y_test)
72 # cm=confusion_matrix(np.ravel(y_test),clf_fit.predict(x_test))
73 # print('Train Accuracy=',train_score)
74 # print('Test Accuracy=',test_score)
75 # print(cm)
76
77
78 with open("Result/nist_tests_SVM_rbf.csv", "w") as fh_out:
79     for gamma in range(4):
80         gamma = 10 ** -(gamma + 1)
81         print("gamma=",gamma)
82         clf = svm.SVC(kernel='rbf',gamma=gamma)
83         start_time = time.time()
84         clf_fit = clf.fit(x_train, y_train)
85         training_time = time.time() - start_time
86         print("---- %s seconds ----" % (training_time))

```

```

88 outfile = 'SVMrbfmodel/' + str(gamma)
89 with open(outfile, 'wb') as pickle_file:
90     pickle.dump(clf, pickle_file)
91
92 train_score = clf_fit.score(x_train, y_train)
93 test_score = clf_fit.score(x_test, y_test)
94 cm = confusion_matrix(np.ravel(y_test), clf_fit.predict(x_test))
95 print('Train Accuracy= ', train_score)
96 print('Test Accuracy= ', test_score)
97 print(cm)
98
99 outstr = str(gamma) + " " + str(train_score) + " " + str(test_
100     ↪ score) + ' ' + str(training_time)
101 fh_out.write(outstr + "\n")
102 fh_out.flush()
103
104 with open('Result/nist_tests_SVM_poly.csv', 'w') as fh_out:
105     for degree in range(5):
106         degree=degree+1
107         for gamma in range(4):
108             gamma=10**-(gamma)
109             print("degree=",degree,"gamma=",gamma)
110             clf = svm.SVC(kernel='poly', degree=degree,gamma=
111                 ↪ gamma)
112             start_time = time.time()
113             clf_fit = clf.fit(x_train, y_train)
114             training_time=time.time() - start_time
115             print("---- %s seconds ----" % (training_time))
116
117             outfile = 'SVMpolymodel/' + str(degree) + ' ' +str(gamma)
118             with open(outfile, 'wb') as pickle_file:
119                 pickle.dump(clf, pickle_file)
120
121             train_score = clf_fit.score(x_train, y_train)
122             test_score = clf_fit.score(x_test, y_test)
123             cm = confusion_matrix(np.ravel(y_test), clf_fit.predict(x_test)
124                 ↪ )
125             print('Train Accuracy= ', train_score)
126             print('Test Accuracy= ', test_score)
127             print(cm)
128
129             outstr = str(degree) + " " + str(gamma) + " " + str(train_
130                 ↪ score) + " " + str(test_score)+ ' ' +str(training_time
131                 ↪ )
132             fh_out.write(outstr + "\n")
133             fh_out.flush()
134
135             # y_test=y_test[1:int(10000*n)+1,]
136
137             print('Train size:', x_train.shape[0])
138             print('Test size:', x_test.shape[0])
139
140             # Following code is too slow consider SGD
141             # clf = svm.LinearSVC()
142
143             # with open("Result/nist_tests_SVM.csv", "w") as fh_out:
144             # for alpha in [0.0001,0.001,0.01,0.1,10]:
145             # for l1_ratio in [0.0,0.2,0.4,0.6,0.8,1]:
146             # print("*", end="")
147             # clf = linear_model.SGDClassifier(max_iter=1000, tol=1e-3,alpha=
148                 ↪ alpha,penalty='elasticnet',l1_ratio=l1_ratio,learning_rate='
149                 ↪ optimal')
150             # clf_fit =clf.fit(train_imgs, np.ravel(train_labels))
151             # train_score = clf_fit.score(train_imgs, np.ravel(train_labels))
152             # test_score = clf_fit.score(test_imgs, np.ravel(test_labels))
153
154             #
155             # outstr = str(alpha) + " " + str(l1_ratio) + " "
156             # outstr += str(train_score) + " " + str(test_score)
157             #
158             # fh_out.write(outstr + "\n")
159             # fh_out.flush()
160
161             # clf = linear_model.SGDClassifier(max_iter=1000, tol=1e-3)
162             # start_time = time.time()
163             # clf_fit=clf.fit(x_train, y_train)
164             # print("---- %s seconds ----" % (time.time() - start_time))
165
166             #
167             # train_score=clf_fit.score(x_train,y_train)
168             # test_score=clf_fit.score(x_test,y_test)
169             # cm=confusion_matrix(np.ravel(y_test),clf_fit.predict(x_test))
170             # print('Train Accuracy= ',train_score)
171             # print('Test Accuracy= ',test_score)
172             # print(cm)
173
174             #
175             # clf = svm.SVC(kernel='linear')
176             # start_time = time.time()
177             # clf_fit=clf.fit(x_train, y_train)
178             # print("---- %s seconds ----" % (time.time() - start_time))
179
180             #
181             # train_score=clf_fit.score(x_train,y_train)
182             # test_score=clf_fit.score(x_test,y_test)
183             # cm=confusion_matrix(np.ravel(y_test),clf_fit.predict(x_test))
184             # print('Train Accuracy= ',train_score)
185             # print('Test Accuracy= ',test_score)
186             # print(cm)
187
188             #
189             # with open("Result/nist_tests_SVM_rbf.csv", "w") as fh_out:
190             for gamma in range(4):
191                 gamma = 10 ** -(gamma + 1)
192                 print("gamma=",gamma)
193                 clf = svm.SVC(kernel='rbf',gamma=gamma)
194                 start_time = time.time()
195                 clf_fit = clf.fit(x_train, y_train)
196                 training_time = time.time() - start_time
197                 print("---- %s seconds ----" % (training_time))
198
199                 outfile = 'SVMrbfmodel/' + str(gamma)
200                 with open(outfile, 'wb') as pickle_file:
201                     pickle.dump(clf, pickle_file)
202
203                     train_score = clf_fit.score(x_train, y_train)
204                     test_score = clf_fit.score(x_test, y_test)
205                     cm = confusion_matrix(np.ravel(y_test), clf_fit.predict(x_test))
206                     print('Train Accuracy= ', train_score)
207                     print('Test Accuracy= ', test_score)
208                     print(cm)

```

Listing 3. Ada Boosting

```

1 import matplotlib.pyplot as plt
2 from sklearn import linear_model
3 from sklearn import svm
4 from sklearn.metrics import confusion_matrix
5 from keras.datasets import mnist
6 import seaborn as sns
7 import numpy as np
8 import time
9 import pickle
10
11 sns.set()
12
13 (x_train, y_train), (x_test, y_test) = mnist.load_data()
14 num_classes = 10
15 x_train = x_train.reshape(60000, 784)
16 x_test = x_test.reshape(10000, 784)
17 x_train = x_train.astype('float32')
18 x_test = x_test.astype('float32')
19 x_train /= 255
20 x_test /= 255
21
22 # n=0.2
23 # x_train=x_train[1:int(60000*n)+1,]
24 # x_test=x_test[1:int(10000*n)+1,]
25 # y_train=y_train[1:int(60000*n)+1,]
26
27
28
29
30 print('Train size:', x_train.shape[0])
31 print('Test size:', x_test.shape[0])
32
33 # Following code is too slow consider SGD
34 # clf = svm.LinearSVC()
35
36 # with open("Result/nist_tests_SVM.csv", "w") as fh_out:
37 # for alpha in [0.0001,0.001,0.01,0.1,10]:
38 # for l1_ratio in [0.0,0.2,0.4,0.6,0.8,1]:
39 # print("*", end="")
40 # clf = linear_model.SGDClassifier(max_iter=1000, tol=1e-3,alpha=
41 #     ↪ alpha,penalty='elasticnet',l1_ratio=l1_ratio,learning_rate='
42 #     ↪ optimal')
43 # clf_fit =clf.fit(train_imgs, np.ravel(train_labels))
44 # train_score = clf_fit.score(train_imgs, np.ravel(train_labels))
45 # test_score = clf_fit.score(test_imgs, np.ravel(test_labels))
46
47 #
48 # outstr = str(alpha) + " " + str(l1_ratio) + " "
49 # outstr += str(train_score) + " " + str(test_score)
50 #
51 # fh_out.write(outstr + "\n")
52 # fh_out.flush()
53
54 #
55 # train_score=clf_fit.score(x_train,y_train)
56 # test_score=clf_fit.score(x_test,y_test)
57 # cm=confusion_matrix(np.ravel(y_test),clf_fit.predict(x_test))
58 # print('Train Accuracy= ',train_score)
59 # print('Test Accuracy= ',test_score)
60 # print(cm)
61
62
63
64 # clf = svm.SVC(kernel='linear')
65 # start_time = time.time()
66 # clf_fit=clf.fit(x_train, y_train)
67 # print("---- %s seconds ----" % (time.time() - start_time))
68
69 #
70 # train_score=clf_fit.score(x_train,y_train)
71 # test_score=clf_fit.score(x_test,y_test)
72 # cm=confusion_matrix(np.ravel(y_test),clf_fit.predict(x_test))
73 # print('Train Accuracy= ',train_score)
74 # print('Test Accuracy= ',test_score)
75 # print(cm)
76
77
78 with open("Result/nist_tests_SVM_rbf.csv", "w") as fh_out:
79     for gamma in range(4):
80         gamma = 10 ** -(gamma + 1)
81         print("gamma=",gamma)
82         clf = svm.SVC(kernel='rbf',gamma=gamma)
83         start_time = time.time()
84         clf_fit = clf.fit(x_train, y_train)
85         training_time = time.time() - start_time
86         print("---- %s seconds ----" % (training_time))
87
88         outfile = 'SVMrbfmodel/' + str(gamma)
89         with open(outfile, 'wb') as pickle_file:
90             pickle.dump(clf, pickle_file)
91
92             train_score = clf_fit.score(x_train, y_train)
93             test_score = clf_fit.score(x_test, y_test)
94             cm = confusion_matrix(np.ravel(y_test), clf_fit.predict(x_test))
95             print('Train Accuracy= ', train_score)
96             print('Test Accuracy= ', test_score)
97             print(cm)

```

```

98
99     outstr = str(gamma) + " " + str(train_score) + " " + str(test_
100        ↪ score) + " " + str(training_time)
101    fh_out.write(outstr + "\n")
102    fh_out.flush()
103
104 with open("Result/nist_tests_SVM_poly.csv", "w") as fh_out:
105     for degree in range(5):
106         degree=degree+1
107         for gamma in range(4):
108             gamma=10**-(gamma)
109             print("degree=" ,degree, "gamma=",gamma)
110             clf = svm.SVC(kernel='poly', degree=degree,gamma=
111                ↪ gamma)
112             start_time = time.time()
113             clf_fit = clf.fit(x_train, y_train)
114             training_time=time.time() - start_time
115             print("---- %s seconds ----" % (training_time))
116
117             outfile = 'SVMpolymodel/' + str(degree) + '_' +str(gamma)
118             with open(outfile, 'wb') as pickle_file:
119                 pickle_file = pickle.dump(clf, pickle_file)
120
121             train_score = clf_fit.score(x_train, y_train)
122             test_score = clf_fit.score(x_test, y_test)
123             cm = confusion_matrix(np.ravel(y_test), clf_fit.predict(x_test
124                ↪ ))
125             print('Train Accuracy=', train_score)
126             print('Test Accuracy=', test_score)
127             print(cm)
128
129             outstr = str(degree) + " " + str(gamma) + " " + str(train_
130                ↪ score) + " " + str(test_score)+" "+str(training_time
131                ↪ )
132             fh_out.write(outstr + "\n")
133             fh_out.flush()

```

Listing 4. Gradient Boosting

```

1 import numpy as np
2 import time
3 import keras
4 from keras.datasets import mnist
5 from keras.models import Sequential
6 from keras.layers import Dense, Activation
7 from keras.optimizers import RMSprop,SGD
8 from sklearn.metrics import confusion_matrix
9 import os
10 os.environ['KMP_DUPLICATE_LIB_OK']=True'
11
12
13 (x_train, y_train), (x_test, y_test) = mnist.load_data()
14
15 num_classes = 10
16 x_train = x_train.reshape(60000, 784)
17 x_test = x_test.reshape(10000, 784)
18 x_train = x_train.astype('float32')
19 x_test = x_test.astype('float32')
20 x_train /= 255
21 x_test /= 255
22 y_train = keras.utils.to_categorical(y_train, num_classes)
23 y_test = keras.utils.to_categorical(y_test, num_classes)
24
25 print('Train size:', x_train.shape[0])
26 print('Test size:', x_test.shape[0])
27
28 # model = Sequential()
29 # model.add(Dense(120, input_shape=(784,)))
30 # model.add(Activation('relu'))
31 # model.add(Dense(num_classes))
32 # model.add(Activation('softmax'))
33 #
34 # for l in model.layers:
35
36 # print(l.output.name, l.input_shape, '==>', l.output_shape)
37 # print(model.summary())
38 #
39 # batch_size = 200
40 # epochs = 1
41 #
42 # model.compile(loss='mean_squared_error',
43 # optimizer=RMSprop(),
44 # metrics=['accuracy'])
45 #
46 # history = model.fit(x_train, y_train,
47 # batch_size=batch_size,
48 # epochs=epochs,
49 # verbose=1,
50 # validation_data=(x_test, y_test))
51 #
52 # score = model.evaluate(x_test, y_test, verbose=100)
53 #
54 # print('Test loss:', round(score[0], 3))
55 # print('Test accuracy:', round(score[1], 3))
56 #
57 # plt.plot(history.history['accuracy'])
58 # plt.plot(history.history['val_accuracy'])
59 # plt.title('model loss')
60 # plt.ylabel('loss')
61 # plt.xlabel('epoch')
62 # plt.legend(['train', 'test'], loc='upper left')
63 # plt.show()
64 #
65 epochs=10
66 # with open("Result/nist_tests_keras.csv", "w") as fh_out:
67 # for hidden_nodes in [20, 50, 100, 150, 250, 500]:
68 # for activation in ['softmax', 'relu']:
69 # for batch_size in [100, 200, 300]:
70 # for loss in ['mean_squared_error', 'categorical_crossentropy']:
71 # for learning_rate in [0.001,0.01]:
72 # model = Sequential()
73 # model.add(Dense(hidden_nodes, activation=activation, input_shape
74    ↪ =(784,)))
75 # model.add(Dense(num_classes, activation='softmax'))
76 # model.compile(loss=loss,
77 # optimizer=RMSprop(learning_rate=learning_rate),
78 # metrics=['accuracy'])
79 #
80 # for l in model.layers:
81 # print(l.name, l.input_shape, '==>', l.output_shape, 'Activation=',
82    ↪ activation)
83 # print('Loss=', loss)
84 # print('batch size=', batch_size)
85 # print(model.summary())
86 #
87 # history = model.fit(x_train, y_train,
88 # batch_size=batch_size,
89 # epochs=epochs,
90 # verbose=2,
91 # validation_data=(x_test, y_test))
92 #
93 # score = model.evaluate(x_test, y_test, verbose=100)
94 # print(history.history['accuracy'])
95 #
96 # for epoch in range(epochs):
97 # outstr = str(hidden_nodes) + " " + str(activation) + " " + str(batch_size
98    ↪ )+ " " + str(loss)+ " " + str(learning_rate)
99 # outstr += " " + str(epoch) + " " + str(history.history['accuracy'][epoch
100   ↪ ]) + " " + str(history.history['val_accuracy'][epoch])
101 # outstr += " " + str(history.history['loss'][epoch]) + " " + str(history.
102   ↪ history['val_loss'][epoch])
103 # fh_out.write(outstr + "\n")
104 # fh_out.flush()

```

```

105 loss='mean_squared_error'
106 batch_size=200
107 learning_rate=0.001
108 model = Sequential()
109 model.add(Dense(hidden_nodes1, activation=activation, input_shape
110     ↪ =(784,)))
111 model.add(Dense(num_classes, activation='softmax'))
112 model.compile(loss='mean_squared_error',
113     optimizer=RMSprop(learning_rate=learning_rate),
114     metrics=['accuracy'])
115
116 for l in model.layers:
117     print(l.name, l.input_shape, '==>', l.output_shape, 'Activation=',
118           ↪ activation)
119     print('Loss=', loss)
120     print('batch size=', batch_size)
121     print(model.summary())
122
123 start_time = time.time()
124 history = model.fit(x_train, y_train,
125     batch_size=batch_size,
126     epochs=epochs,
127     verbose=2,
128     validation_data=(x_test, y_test))
129 training_time=time.time() - start_time
130 print("— %s seconds ——" % (training_time))
131
132 def hot_to_cat(y_test):
133     decoded_datum = np.zeros(len(y_test), 1), int
134     for i in range(len(y_test)):
135         decoded_datum[i] = np.argmax(y_test[i])
136     return decoded_datum
137
138 cm=confusion_matrix(hot_to_cat(y_test), model.predict_classes(x_test))
139 print(cm)

```

Listing 5. 1-layer Neural Network

```

1 import numpy as np
2 import time
3 import keras
4 from keras.datasets import mnist
5 from keras.models import Sequential
6 from keras.layers import Dense, Activation
7 from keras.optimizers import RMSprop, SGD
8 from sklearn.metrics import confusion_matrix
9 import os
10 os.environ['KMP_DUPLICATE_LIB_OK']=True
11
12
13 (x_train, y_train), (x_test, y_test) = mnist.load_data()
14
15 num_classes = 10
16 x_train = x_train.reshape(60000, 784)
17 x_test = x_test.reshape(10000, 784)
18 x_train = x_train.astype('float32')
19 x_test = x_test.astype('float32')
20 x_train /= 255
21 x_test /= 255
22 y_train = keras.utils.to_categorical(y_train, num_classes)
23 y_test = keras.utils.to_categorical(y_test, num_classes)
24
25 print('Train size:', x_train.shape[0])
26 print('Test size:', x_test.shape[0])
27
28 # model = Sequential()
29 # model.add(Dense(120, input_shape=(784,)))
30 # model.add(Activation('relu'))
31 # model.add(Dense(num_classes))
32 # model.add(Activation('softmax'))
33
34 # for l in model.layers:
35
36 # print(l.output.name, l.input_shape, '==>', l.output_shape)
37 # print(model.summary())
38 #
39 # batch_size = 200
40 # epochs = 1
41 #
42 # model.compile(loss='mean_squared_error',
43 # optimizer=RMSprop(),
44 # metrics=['accuracy'])
45 #
46 # history = model.fit(x_train, y_train,
47 # batch_size=batch_size,
48 # epochs=epochs,
49 # verbose=1,
50 # validation_data=(x_test, y_test))
51 #
52 # score = model.evaluate(x_test, y_test, verbose=100)
53 #
54 # print('Test loss:', round(score[0], 3))
55 # print('Test accuracy:', round(score[1], 3))
56 #
57 # plt.plot(history.history['accuracy'])
58 # plt.plot(history.history['val_accuracy'])
59 # plt.title('model loss')
60 # plt.ylabel('loss')
61 # plt.xlabel('epoch')
62 # plt.legend(['train', 'test'], loc='upper left')
63 # plt.show()
64 #
65 # epochs=10
66 # activation='relu'
67 # with open("Result/nist_tests_keras_2.csv", "a") as fh_out:
68 # for hidden_nodes1 in [20, 50, 100, 150, 250, 500]:
69 # for hidden_nodes2 in [20, 50, 100, 150, 250, 500]:
70 # for batch_size in [100, 200, 300]:
71 # for loss in ['mean_squared_error', 'categorical_crossentropy']:
72 # for learning_rate in [0.001, 0.01]:
73 # model = Sequential()
74 # model.add(Dense(hidden_nodes1, activation=activation, input_shape
75     ↪ =(784,)))
76 # model.add(Dense(hidden_nodes2, activation=activation))
77 # model.add(Dense(num_classes, activation='softmax'))
78 # model.compile(loss=loss,
79 # optimizer=RMSprop(learning_rate=learning_rate),
80 # metrics=['accuracy'])
81 #
82 # for l in model.layers:
83 # print(l.name, l.input_shape, '==>', l.output_shape, 'Activation=',
84     ↪ activation)
85 # print('Loss=', loss, 'batch size=', batch_size)
86 # print(model.summary())
87 #
88 # history = model.fit(x_train, y_train,
89 # batch_size=batch_size,
90 # epochs=epochs,
91 # verbose=2,
92 # validation_data=(x_test, y_test))
93 #
94 # score = model.evaluate(x_test, y_test, verbose=100)
95 # print(history.history['accuracy'])
96 #
97 # for epoch in range(epochs):
98 # outstr = str(hidden_nodes1) + " " + str(hidden_nodes2) + " " + str(
99     ↪ activation) + " " + str(batch_size) + " " + str(loss) + " " + str(
100    ↪ learning_rate)
101 # outstr += " " + str(epoch) + " " + str(history.history['accuracy'][epoch])
102 # outstr += " " + str(history.history['val_accuracy'][epoch])
103 # outstr += " " + str(history.history['loss'][epoch]) + " " + str(history.
104     ↪ history['val_loss'][epoch])
105 # fh_out.write(outstr + "\n")
106 # fh_out.flush()
107
108 epochs=10

```

```
hidden_nodes1=500
hidden_nodes2=150
activation='relu'

loss='mean_squared_error'
batch_size=200
learning_rate=0.001
model = Sequential()
model.add(Dense(hidden_nodes1, activation=activation, input_shape
    ↪ =(784,)))
model.add(Dense(hidden_nodes2, activation=activation))
model.add(Dense(num_classes, activation='softmax'))
model.compile(loss='mean_squared_error',
    optimizer=RMSprop(learning_rate=learning_rate),
    metrics=['accuracy'])

for l in model.layers:
    print(l.name, l.input_shape, '==>', l.output_shape, 'Activation=',
        ↪ activation)
print('Loss=', loss)
print('batch size=', batch_size)
print(model.summary())

start_time = time.time()
history = model.fit(x_train, y_train,
    batch_size=batch_size,
    epochs=epochs,
    verbose=2,
    validation_data=(x_test, y_test))
training_time=time.time() - start_time
print("---- %s seconds ----" % (training_time))

def hot_to_cat(y_test):
    decoded_datum = np.zeros((len(y_test), 1), int)
    for i in range(len(y_test)):
        decoded_datum[i] = np.argmax(y_test[i])
    return decoded_datum

cm=confusion_matrix(hot_to_cat(y_test), model.predict_classes(x_test))
print(cm)
```

```

19 ggsave(paste('1-Hidden Layer Neural Network Accuracy rate versus',
20   ↪ ,x,'.png',sep = ''), path ='..Report/figure', scale = 0.6)
21
22
23
24
25 # accuracies = read.csv('Result/nist_tests_Multiple.csv', sep = ' ', header =
26   ↪ = FALSE)
27 # colnames(accuracies) = c('layer_one_nodes','layer_two_nodes','train
28   ↪ corrects rate','train wrongs rate','test corrects rate','test wrongs
29   ↪ rate')
30 # accuracies = accuracies[, -c(4, 6)]
31 # accuracies = reshape2::melt(accuracies, id.vars = c('layer_one_nodes',
32   ↪ 'layer_two_nodes'))
33 #
34 # ggplot(accuracies, aes(layer_one_nodes, layer_two_nodes,color=
35   ↪ variable, shape = variable,size=value,label=round(value,4))) +
36 # geom_point(alpha=0.6)+
37 # ggrepel::geom_text_repel(size = 3,alpha=0.6,box.padding=3,segment.
38   ↪ alpha=0.6)+
39 # ylab('Accuracy')+
40 # theme_bw() + theme(legend.position="bottom")
41 # ggsave(paste('2-Hidden Layer Neural Network Accuracy rate, layer_-
42   ↪ one_nodes versus layer_two_nodes.png',sep = ''), path ='../
43   ↪ Report/figure', scale = 0.6)
44
45
46
47 accuracies = read.csv('Result/nist_tests_keras.csv', sep = ' ', header =
48   ↪ FALSE)
49 colnames(accuracies) = c('hidden_nodes','activation','batch_size','loss',
50   ↪ 'learning_rate','epoch','train_accuracy','test_accuracy','train_
51   ↪ loss','test_loss')
52 accuracies = reshape2::melt(accuracies,measure.vars = c('train_accuracy',
53   ↪ 'test_accuracy','train_loss','test_loss'), id.vars = c('hidden_
54   ↪ nodes','activation','batch_size','loss','learning_rate','epoch'))
55 accuracies=tidyrr::unite(accuracies, col , 'hidden_nodes':'learning_rate',
56   ↪ sep = '_', remove = FALSE, na.rm = FALSE)
57 accuracies[c('hidden_nodes','activation','batch_size','loss','learning_rate',
58   ↪ )]=lapply(accuracies[c('hidden_nodes','activation','batch_size',
59   ↪ 'loss','learning_rate')], factor)
60 accuracies=subset(accuracies,learning_rate!=0.1)
61
62 dt=subset(accuracies, variable %in% c('test_accuracy')&activation=='-
63   ↪ softmax')
64 ggplot(dt, aes(epoch, value, group=col,color=hidden_nodes)) +
65   geom_line()+
66   xlim(0,9)+
67   ggrepel::geom_label_repel(data=subset(dt, value<0.91&epoch==9),aes(
68     ↪ epoch, value,label=col),color='black',force = 10,alpha=0.7,
69     ↪ xlim=c(0, 8),size=2)+
70   ylab('Accuracy')+theme_bw() + theme(legend.position="bottom")
71 ggsave(paste('1-layer Neural Network Test Accuracy By Epoch.png',sep
72   ↪ = ''), path ='..Report/figure', scale = 0.6)
73
74 dt=subset(accuracies, variable %in% c('test_accuracy')&activation=='relu
75   ↪ ')
76 ggplot(dt, aes(epoch, value, group=col,color=hidden_nodes)) +
77   geom_line()+
78   xlim(0,9)+
79   ggrepel::geom_label_repel(data=subset(dt, value<0.91&epoch==9),aes(
80     ↪ epoch, value,label=col),color='black',force = 10,alpha=0.7,
81     ↪ xlim=c(0, 8),size=2)+
82   ylab('Accuracy')+theme_bw() + theme(legend.position="bottom")

```

Listing 6. 2-layer Neural Network

APPENDIX B R SOURCE CODE

```

1 accuracies = read.csv('Result/nist_tests.csv', sep = ' ', header = FALSE)
2 colnames(accuracies) = c('hidden_nodes', 'learning_rate', 'bias', 'epoch',
3   ↪ 'train corrects rate', 'train wrongs rate', 'test corrects rate', '
4   ↪ test wrongs rate')
5 accuracies = accuracies[, -c(6, 8)]
6 accuracies = reshape2::melt(accuracies, id.vars = c('hidden_nodes', '
7   ↪ learning_rate', 'bias', 'epoch'))
8 accuracies[c('hidden_nodes', 'learning_rate', 'bias')] = lapply(accuracies[c(
9   ↪ 'hidden_nodes', 'learning_rate', 'bias')], factor)
10
11 library(ggplot2)
12 library(ggrepel)
13 dt=accuracies
14 for (x in c('bias')) {
15   ggplot(dt,aes(dt[[x]],value,fill=variable))+  

16     geom_boxplot() +  

17     xlab(x)+  

18     stat_summary(fun.y=max, geom="line", aes(group=variable,color=
19       ↪ variable))+  

20     stat_summary(fun.y=max, geom="point", aes(group=variable,color=
21       ↪ variable))+  

22     stat_summary(geom="label_repel", fun.y=max,aes(group=variable,
23       ↪ label=sprintf("%1.4f", ..y..),alpha=0.8, size=3.5)+  

24     theme_bw()+ theme(legend.position="bottom")+ylab('Accuracy')
25   # title('hidden_nodes=20, 50, 100, 120, 150\n learning_rate=0.01,
26     ↪ 0.05, 0.1, 0.2\n bias=None, 0.5\n epoch=1,2,3')

```

```

68 ggsave(paste('91-layer Neural Network Test Accuracy By Epoch.png',
69   ↪ sep = ''), path ='./Report/figure', scale = 0.6)
70
71 dt=subset(accuracies, variable %in% c('train_accuracy','test_accuracy')&
72   ↪ epoch==9&activation=='softmax')
73 for (x in c('hidden_nodes','batch_size','loss','learning_rate')) {
74   ggplot(dt,aes(dt[[x]],value,fill=variable))+
75     geom_boxplot(outlier.shape = NA) +
76     xlab(x)+
77     stat_summary(fun.y=max, geom="line", aes(group=variable,color=
78       ↪ variable))++
79     stat_summary(fun.y=max, geom="point", aes(group=variable,color=
80       ↪ variable))++
81     stat_summary(geom="label_repel", fun.y=max,aes(group=variable,
82       ↪ label=sprintf("%1.4f", ..y..),alpha=0.8), size=3.5)+
83     ylim(0.9,1)+
84     theme_bw() + theme(legend.position="bottom") + ylab('Accuracy')
85   ggsave(paste('1-Hidden Layer Neural Network Accuracy rate versus',
86     ↪ ,x,'.png',sep = ''), path ='./Report/figure', scale = 0.6)
87 }
88
89 dt=subset(accuracies, variable %in% c('train_accuracy','test_accuracy')&
90   ↪ epoch==9&activation=='relu')
91 for (x in c('hidden_nodes','batch_size','loss','learning_rate')) {
92   ggplot(dt,aes(dt[[x]],value,fill=variable))+
93     geom_boxplot(outlier.shape = NA) +
94     xlab(x)+
95     stat_summary(fun.y=max, geom="line", aes(group=variable,color=
96       ↪ variable))++
97     stat_summary(fun.y=max, geom="point", aes(group=variable,color=
98       ↪ variable))++
99     stat_summary(geom="label_repel", fun.y=max,aes(group=variable,
100       ↪ label=sprintf("%1.4f", ..y..),alpha=0.8), size=3.5)+
101     ylim(0.9,1)+
102     theme_bw() + theme(legend.position="bottom") + ylab('Accuracy')
103   ggsave(paste('91-Hidden Layer Neural Network Accuracy rate versus',
104     ↪ ,x,'.png',sep = ''), path ='./Report/figure', scale = 0.6)
105 }
106 ######Acti Comparison#####
107
108 dt=subset(accuracies, variable %in% c('train_accuracy','test_accuracy')&
109   ↪ epoch==9)
110 x='activation'
111 ggplot(dt,aes(dt[[x]],value,fill=variable))+
112   geom_boxplot(outlier.shape = NA) +
113   xlab(x)+
114   stat_summary(fun.y=max, geom="line", aes(group=variable,color=
115     ↪ variable))++
116   stat_summary(fun.y=max, geom="point", aes(group=variable,color=
117     ↪ variable))++
118   stat_summary(geom="label_repel", fun.y=max,aes(group=variable,label
119     ↪ =sprintf("%1.4f", ..y..),alpha=0.8), size=3.5)+
120   ylim(0.9,1)+
121   theme_bw() + theme(legend.position="bottom") + ylab('Accuracy')
122   ggsave(paste('1-Hidden Layer Neural Network Accuracy rate versus ',x,
123     ↪ '.png',sep = ''), path ='./Report/figure', scale = 0.6)
124
125 dt=subset(accuracies, variable %in% c('test_accuracy'))
126 ggplot(dt, aes(epoch, value, group=col,color=activation)) +
127   geom_line(alpha=0.4)+
128   xlim(0,9)+
129   # ggrepel::geom_label_repel(data=subset(dt, value<0.91&epoch==9),
130     ↪ aes(epoch, value,label=col),color='black',force = 10,alpha
131     ↪ =0.7,xlim=c(0, 8),size=3)+
132   ylab('Accuracy')+theme_bw() + theme(legend.position="bottom")
133   ggsave(paste('1-Hidden layer Neural Network Accuracy rate By Epoch.
134     ↪ png',sep = ''), path ='./Report/figure', scale = 0.6)
135
136
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147
148 accuracies = read.csv('Result/nist_tests_keras_2.csv', sep = ' ', header =
149   ↪ FALSE)
150 colnames(accuracies) = c('hidden_nodes1','hidden_nodes2','activation',
151   ↪ 'batch_size','loss','learning_rate','epoch','train_accuracy','test_
152   ↪ accuracy','train_loss','test_loss')
153 accuracies = reshape2::melt(accuracies,measure.vars = c('train_accuracy',
154   ↪ 'test_accuracy','train_loss','test_loss'), id.vars = c('hidden_
155   ↪ nodes1','hidden_nodes2','activation','batch_size','loss',
156   ↪ 'learning_rate','epoch'))
157 accuracies=tidyr::unite(accuracies, col, 'hidden_nodes1','hidden_nodes2':
158   ↪ 'learning_rate', sep = "_", remove = FALSE, na.rm = FALSE)
159 accuracies[c('hidden_nodes1','hidden_nodes2','activation','batch_size',
160   ↪ 'loss','learning_rate')]=lapply(accuracies[c('hidden_nodes1',
161   ↪ 'hidden_nodes2','activation','batch_size','loss','learning_rate')], ↪
162   ↪ factor)
163 accuracies=subset(accuracies,learning_rate!=0.1)
164
165 # library(plotly)
166 # plot_ly(x=temp, y=pressure, z=dtime, type="scatter3d", mode="
167   ↪ markers", color=temp)
168 library(gridExtra)
169
170 dt=subset(accuracies, variable %in% c('test_accuracy')&activation=='relu
171   ↪ ')
172 p <- list()
173 for(i in 1:6){
174   values = c(0.1,0.1,0.1,0.1,0.1,0.1)
175   values[i] = 1
176   p[i]=ggplot(dt, aes(epoch, value, group=col,color=hidden_nodes1,
177     ↪ alpha=hidden_nodes1)) +
178     geom_line()+
179     xlim(0,9)+
180     # stat_summary(geom="label_repel", fun.y=max,aes(group=variable,
181       ↪ label=sprintf("%1.4f", ..y..),alpha=0.8), size=3.5)+
182     ylab('Accuracy')+theme_bw() + theme(legend.position="bottom")+
183     ↪ ylim(0.85,1)+scale_alpha_manual(values = values)
184 }
185 ggsave(paste('2-layer Neural Network Test Accuracy By Epoch.png',sep
186   ↪ = ''), plot=ggarrange(plotlist=p,ncol=6),path ='./Report/figure',
187   ↪ , scale = 2)
188
189 p <- list()
190 for(i in 1:6){
191   values = c(0.1,0.1,0.1,0.1,0.1,0.1)
192   values[i] = 1
193   p[i]=ggplot(dt, aes(epoch, value, group=col,color=hidden_nodes2,
194     ↪ alpha=hidden_nodes2)) +
195     geom_line()+
196     xlim(0,9)+
```

```

179 # stat_summary(geom="label_repel", fun.y=max,aes(group=variable,
180   ↪ label=sprintf("%1.4f", .y.),alpha=0.8), size=3.5)+  

181 ylab('Accuracy')+theme_bw() + theme(legend.position="bottom")+ylim  

182   ↪ (0.85,1)+scale_alpha_manual(values = values)  

183 }  

184 ggsave(paste('2-layer Neural Network Test Accuracy By Epoch2.png',  

185   ↪ sep = ''), plot=ggarrange(plotlist=p,ncol=6),path = './Report/  

186   ↪ figure', scale = 2)  

187  

188 dt=subset(accuracies, variable %in% c('train_accuracy','test_accuracy')&  

189   ↪ epoch==9&activation=='relu')  

190 for (x in c('hidden_nodes1','hidden_nodes2','batch_size','loss','learning_  

191   ↪ rate')) {  

192 ggplot(dt,aes(dt[[x]],value,fill=variable))+  

193   geom_boxplot(outlier.shape = NA) +  

194   xlab(x)+  

195   stat_summary(fun.y=max, geom="line", aes(group=variable,color=  

196     ↪ variable))+  

197   stat_summary(fun.y=max, geom="point", aes(group=variable,color=  

198     ↪ variable))+  

199   stat_summary(geom="label_repel", fun.y=max,aes(group=variable,  

200     ↪ label=sprintf("%1.4f", .y.),alpha=0.8), size=3.5)+  

201   ylim(0.9,1)+  

202   theme_bw() + theme(legend.position="bottom")+ylab('Accuracy')  

203 ggsave(paste('2-Hidden Layer Neural Network Accuracy rate versus ',  

204   ↪ ,x,'.png',sep = ''), path ='./Report/figure', scale = 0.6)  

205 }  

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215 #####SVM#####  

216 accuracies = read.csv('Result/nist_tests_SVM.csv', sep = ' ', header =  

217   ↪ FALSE)  

218 colnames(accuracies) = c('alpha','ll_ratio','train_accuracy','test_accuracy'  

219   ↪ )  

220 accuracies = reshape2::melt(accuracies, id.vars = c('alpha', 'll_ratio'))  

221  

222 ggplot(accuracies, aes(alpha, ll_ratio, color = variable, shape = variable,  

223   ↪ size=value,label=round(value,4))) +  

224   geom_point(alpha=0.6)+  

225   ggrepel::geom_text_repel(size = 3,alpha=0.6)+  

226   scale_x_log10(  

227     breaks = scales::trans_breaks("log10", function(x) 10^x),  

228     labels = scales::trans_format("log10", scales::math_format(10^.x))  

229   )+  

230   theme_bw() + theme(legend.position="bottom")  

231 ggsave(paste('SGD SVM Accuracy rate, alpha versus ll_ratio.png',sep =  

232   ↪ ''), path ='./Report/figure', scale = 0.6)  

233  

234  

235 accuracies = read.csv('Result/nist_tests_SVM_rbf.csv', sep = ' ', header =  

236   ↪ FALSE)  

237 colnames(accuracies) = c('gamma','train_accuracy','test_accuracy','time'  

238   ↪ )  

239  

240 accuracies = reshape2::melt(accuracies, id.vars = c('gamma','time'))  

241  

242 ggplot(accuracies, aes(gamma, value, color = variable,label=round(value  

243   ↪ ,4))) +  

244   geom_line(alpha=0.6)+  

245   geom_label(size = 3,alpha=0.6)+  

246   scale_x_log10(  

247     breaks = scales::trans_breaks("log10", function(x) 10^x),  

248     labels = scales::trans_format("log10", scales::math_format(10^.x))  

249   )+  

250   theme_bw() + theme(legend.position="bottom")  

251 ggsave(paste('RBF SVM Accuracy versus gamma.png',sep = ''), path =  

252   ↪ './Report/figure', scale = 0.6)  

253  

254  

255 accuracies = read.csv('Result/nist_tests_SVM_poly.csv', sep = ' ', header =  

256   ↪ FALSE)  

257 colnames(accuracies) = c('degree','gamma','train_accuracy','test_  

258   ↪ accuracy','time')  

259 accuracies = reshape2::melt(accuracies, id.vars = c('degree','gamma',  

260   ↪ time))  

261  

262 ggplot(accuracies, aes(gamma, degree, color = variable, shape = variable,  

263   ↪ size=value,label=round(value,4))) +  

264   geom_point(alpha=0.6)+  

265   ggrepel::geom_text_repel(size = 3,alpha=0.6)+  

266   scale_x_log10(  

267     breaks = scales::trans_breaks("log10", function(x) 10^x),  

268     labels = scales::trans_format("log10", scales::math_format(10^.x))  

269   )+  

270   theme_bw() + theme(legend.position="bottom")  

271 ggsave(paste('Polynomial SVM Accuracy degree versus gamma.png',sep =  

272   ↪ ''), path ='./Report/figure', scale = 0.6)  

273  

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284  

285 #####boost#####  

286 accuracies = read.csv('Result/nist_tests_ada.csv', sep = ' ', header =  

287   ↪ FALSE)  

288 colnames(accuracies) = c('n_estimators','learning_rate','Iteration','train_  

289   ↪ accuracy','test_accuracy','time')  

290 accuracies = reshape2::melt(accuracies, id.vars = c('n_estimators',  

291   ↪ learning_rate','Iteration','time'))  

292  

293 dt=subset(accuracies,n_estimators==300,c('learning_rate','Iteration',  

294   ↪ value','variable'))  

295 dt$learning_rate=factor(dt$learning_rate)  

296 p=ggplot(dt, aes(Iteration,value , alpha= variable,shape = variable,color=  

297   ↪ learning_rate ))+  

298   geom_line()  

299   geom_point(size=1)+  

300   ggrepel::geom_label_repel(data=subset(dt, value<0.91&Iteration%in%  

301   ↪ (50,150,299)),aes(Iteration, value,label=round(value,4)),color  

302   ↪ ='black',size=3)+
```

```

297   ylab('Accuracy')+theme_bw() + theme(legend.position="bottom")+
298     ↪ scale_shape( solid = FALSE)
299 ggsave(paste('Ada Boosting Accuracy By Iteration.png',sep = ''),p,
300   ↪ path ='./Report/figure', scale = 0.6)
301
300 accuracies = read.csv('Result/nist_tests_ada_final.csv', sep = ' ', header
301   ↪ = FALSE)
301 colnames(accuracies) = c('n_estimators','learning_rate','Iteration','train_
302   ↪ accuracy','test_accuracy','time')
302 accuracies = reshape2::melt(accuracies, id.vars = c('n_estimators',
302   ↪ 'learning_rate','Iteration','time'))
303
304 dt=subset(accuracies,n_estimators==300,c('learning_rate','Iteration',
304   ↪ 'value','variable'))
305 dt$learning_rate=factor(dt$learning_rate)
306 p=ggplot(dt, aes(Iteration,value ,shape = variable,color=variable ))+
307   geom_line()+
308   geom_point(size=1)+
309   ggrepel::geom_label_repel(data=subset(dt, Iteration%in%c(50,150,299))
309     ↪ ,aes(Iteration, value,label=round(value,4)),color='black',size
309     ↪ =3)+

310 ylab('Accuracy')+theme_bw() + theme(legend.position="bottom")+
310   ↪ scale_shape( solid = FALSE)
311 ggsave(paste('Final Ada Boosting Accuracy By Iteration.png',sep = ''),p,
311   ↪ path ='./Report/figure', scale = 0.6)
312
313
314
315
316 accuracies = read.csv('Result/nist_tests_gra.csv', sep = ' ', header =
316   ↪ FALSE)
317 colnames(accuracies) = c('n_estimators','learning_rate','tree_depth',
317   ↪ 'Iteration','train_accuracy','test_accuracy','time')
318 accuracies = reshape2::melt(accuracies, id.vars = c('n_estimators',
318   ↪ 'learning_rate','Iteration','tree_depth','time'))
319
320 dt=subset(accuracies,n_estimators==100,c('tree_depth','learning_rate',
320   ↪ 'Iteration','value','variable'))
321 dt$learning_rate=factor(dt$learning_rate)
322 dt$tree_depth=factor(dt$tree_depth)
323 p=ggplot(dt, aes(Iteration,value , alpha= variable, shape = tree_depth,
323   ↪ color=learning_rate:tree_depth ))+
324   geom_line()+
325   geom_point(size=1)+
326   ggrepel::geom_label_repel(data=subset(dt,Iteration%in%c(10,50,99)),
326     ↪ aes(Iteration, value,label=round(value,4)),size=3)+
327   # ggrepel::geom_text_repel(size = 3,alpha=0.6)+

328 ylab('Accuracy')+theme_bw() + theme(legend.position="bottom")+
328   ↪ scale_shape( solid = FALSE)
329 ggsave(paste('Gradient Boosting Accuracy By Iteration.png',sep = ''), p,
329   ↪ path ='./Report/figure', scale = 1.2)

```

Listing 7. Result Visualization