assignment_04

September 30, 2021

1 Classification for multiple classes based on softmax and cross entropy

1.1 import libraries

[ ]:
```
import numpy as np
import matplotlib.pyplot as plt
import os
from tqdm import tqdm
```

1.2 load data

[ ]:
```
directory_data  = '/Users/lyuwan-u/Desktop/2021-2/
 ↪assignment-machine-learning-project/assignment04'
filename_data   = 'assignment_04_data.npz'
data            = np.load(os.path.join(directory_data, filename_data))

x_train = data['x_train']
y_train = data['y_train']

x_test  = data['x_test']
y_test  = data['y_test']

print('*************************************************')
print('size of x_train :', x_train.shape)
print('size of y_train :', y_train.shape)
print('*************************************************')
print('size of x_test :', x_test.shape)
print('size of y_test :', y_test.shape)
print('*************************************************')
print('number of training image :', x_train.shape[0])
print('height of training image :', x_train.shape[1])
print('width of training image :', x_train.shape[2])
print('*************************************************')
print('number of testing image :', x_test.shape[0])
print('height of testing image :', x_test.shape[1])
print('width of testing image :', x_test.shape[2])
```

```
print('************************************************')
```

```
************************************************
size of x_train : (10000, 28, 28)
size of y_train : (10000, 5)
************************************************
size of x_test : (4500, 28, 28)
size of y_test : (4500, 5)
************************************************
number of training image : 10000
height of training image : 28
width of training image : 28
************************************************
number of testing image : 4500
height of testing image : 28
width of testing image : 28
************************************************
```

1.3 number of classes

[ ]:
```
nClass = y_train.shape[1]
print('number of classes: ', nClass)
```

```
number of classes:  5
```

1.4 label data

[ ]:
```
print('label data for training image 0: ', y_train[0])
print('label data for training image 1: ', y_train[2000])
print('label data for training image 2: ', y_train[4000])
print('label data for training image 3: ', y_train[6000])
print('label data for training image 4: ', y_train[8000])
```

```
label data for training image 0:  [1. 0. 0. 0. 0.]
label data for training image 1:  [0. 1. 0. 0. 0.]
label data for training image 2:  [0. 0. 1. 0. 0.]
label data for training image 3:  [0. 0. 0. 1. 0.]
label data for training image 4:  [0. 0. 0. 0. 1.]
```

1.5 vectorize image data

[ ]:
```
vector_x_train  = x_train.reshape(x_train.shape[0], x_train.shape[1] * x_train.
 ↪shape[2])
vector_x_test   = x_test.reshape(x_test.shape[0], x_test.shape[1] * x_test.
 ↪shape[2])

print('dimension of the training data matrix: ', vector_x_train.shape)
print('dimension of the testing data matrix: ', vector_x_test.shape)
```

```
print('dimension of the trainin label data: ', y_train.shape)
print('dimension of the testing label data: ', y_test.shape)
```

```
dimension of the training data matrix:  (10000, 784)
dimension of the testing data matrix:  (4500, 784)
dimension of the trainin label data:  (10000, 5)
dimension of the testing label data:  (4500, 5)
```

1.6 index for each class

[ ]:
```
index_train = [[0] for i in range(nClass)]
index_test  = [[0] for i in range(nClass)]

number_index_train  = np.zeros(nClass)
number_index_test   = np.zeros(nClass)

for i in range(nClass):

    index_train[i]  = [[j for j in range(len(y_train)) if y_train[j][i] == 1]]
    index_test[i]   = [[j for j in range(len(y_test)) if y_test[j][i] == 1]]

    number_index_train[i]   = len(index_train[i][0])
    number_index_test[i]    = len(index_test[i][0])

print('number of training images for each class: ', number_index_train)
print('number of testing images for each class: ', number_index_test)
```

```
number of training images for each class:  [2000. 2000. 2000. 2000. 2000.]
number of testing images for each class:  [900. 900. 900. 900. 900.]
```

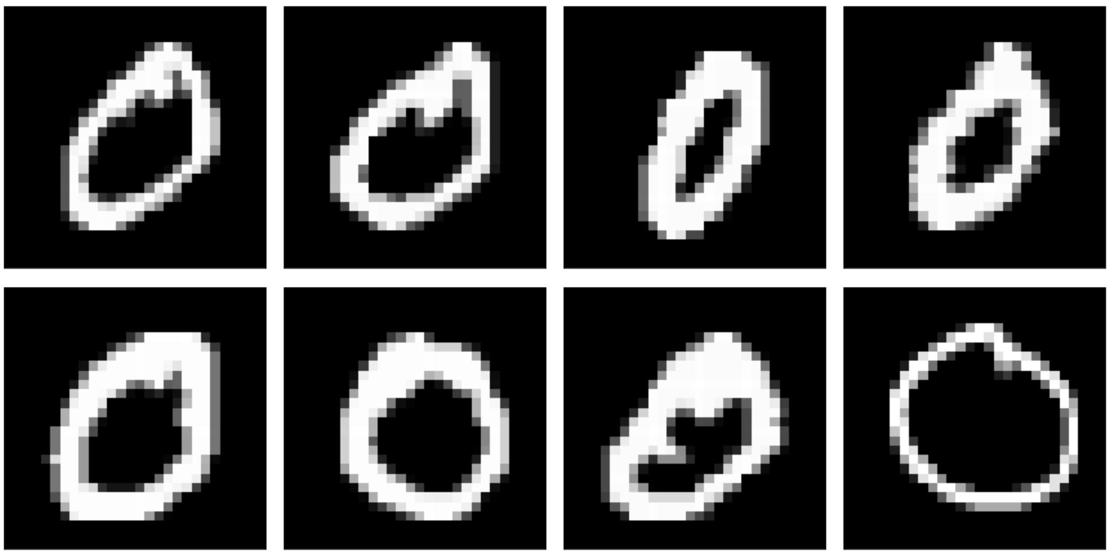
1.7 plot data

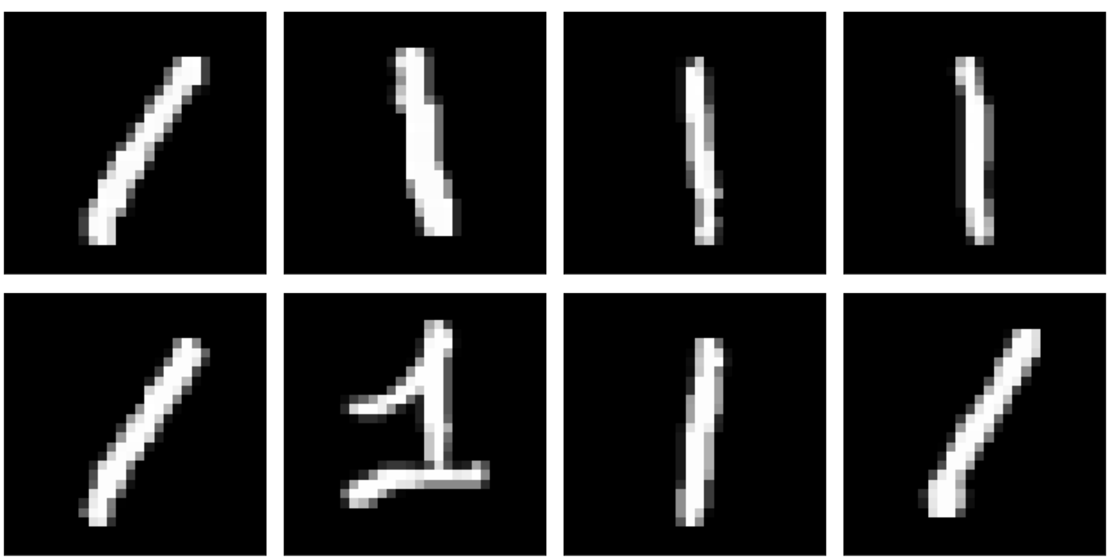
[ ]:
```
def plot_data_grid(data, index_data, nRow, nCol):

    fig, axes = plt.subplots(nRow, nCol, constrained_layout=True, figsize=(nCol␣
 ↪* 3, nRow * 3))

    for i in range(nRow):
        for j in range(nCol):

            k       = i * nCol + j
            index   = index_data[k]

            axes[i, j].imshow(data[index], cmap='gray', vmin=0, vmax=1)
            axes[i, j].xaxis.set_visible(False)
            axes[i, j].yaxis.set_visible(False)
```

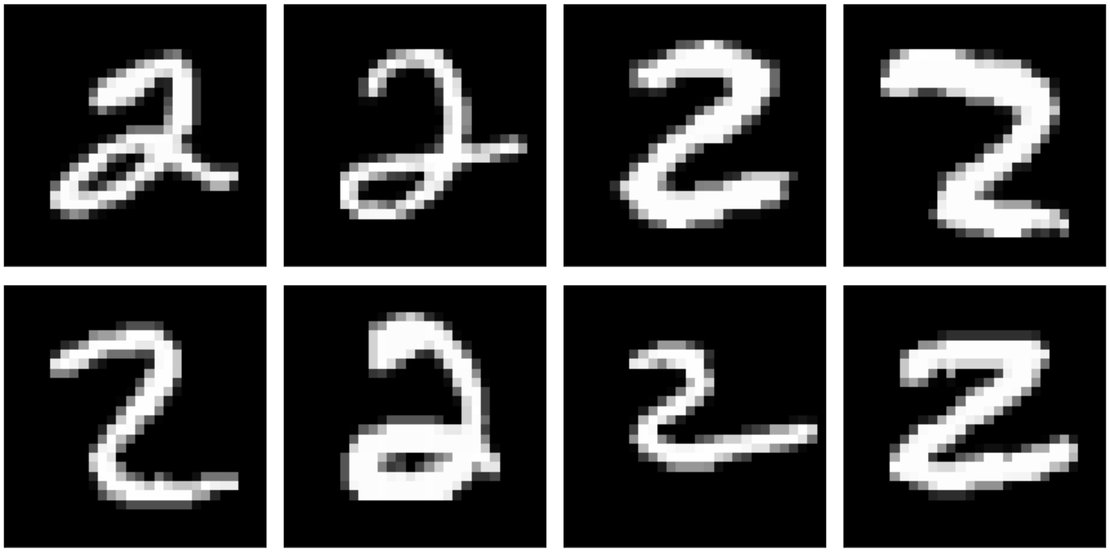
```
    plt.show()
```

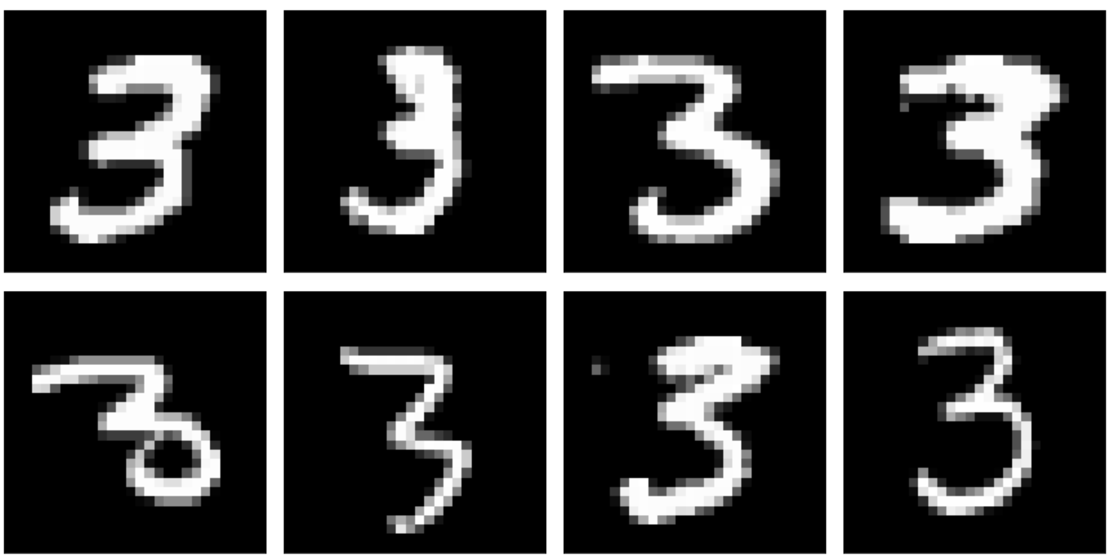
[ ]:
```
nRow    = 2
nCol    = 4
nPlot   = nRow * nCol
```

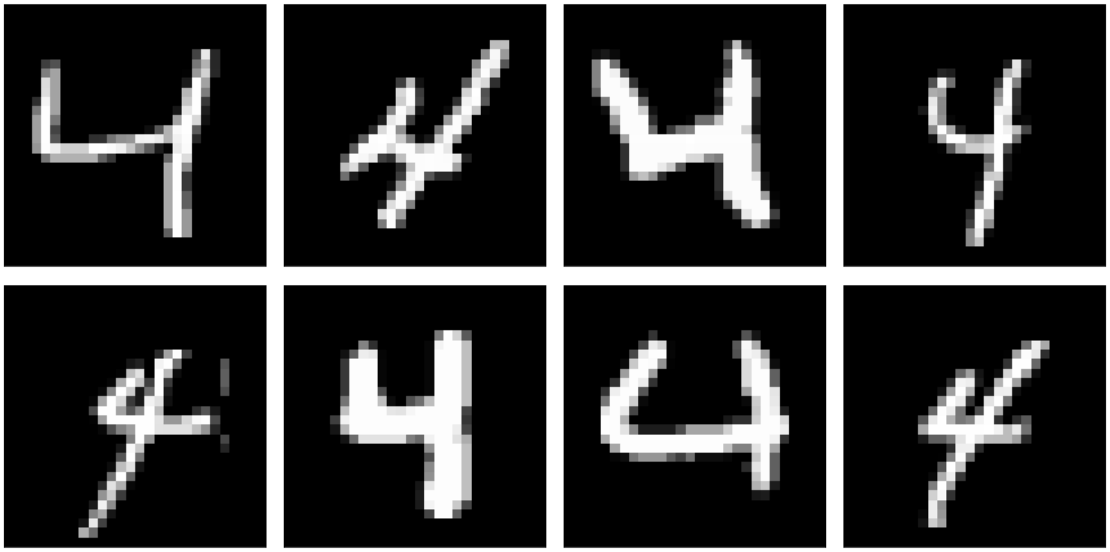
[ ]:
```
for i in range(nClass):

    index_class_plot = index_train[i][0][0:nPlot]
    plot_data_grid(x_train, index_class_plot, nRow, nCol)
```











1.8 linear layer

[ ]:
```
dim_input    = vector_x_train.shape[1]
dim_output   = nClass
weight       = np.ones((dim_output, dim_input))
weight       = weight * 0.001

print('size of weights: ', weight.shape)
```

```
size of weights:  (5, 784)
```

[ ]:
```
def layer_linear(input, weight):

    output = np.dot(input,weight.T)

    return output
```

1.9 Softmax function

[ ]:
```
def activation_softmax(input):

    input_exp = np.exp(input)
    partition = input_exp.sum(axis=1,keepdims=True)
    output = input_exp / partition

    return output
```

1.10 compute prediction by the forward propagation of the neural network

[ ]:
```
def compute_prediction(input, weight):

    output      = layer_linear(input,weight)
    prediction  = activation_softmax(output)

    return prediction
```

1.11 compute loss function

[ ]:
```
def compute_loss(prediction, label):

    pred = np.log(prediction)
    loss = -(np.sum(np.sum(label*pred,axis=1)))/label.shape[0]
    return loss
```

[ ]:
```
compute_loss(compute_prediction(vector_x_train,weight),y_train)
```

[ ]:
```
1.6094379124340998
```

[ ]:
```
t = np.dot((compute_prediction(vector_x_train,weight)-y_train).T,vector_x_train)
print(t.shape)
```

```
(5, 784)
```

1.12 compute gradient

[ ]:
```
def compute_gradient(input, prediction, label):

    gradient = np.dot((prediction-label).T,input)
    gradient = gradient / len(label)

    return gradient
```

[ ]:
```
compute_gradient(vector_x_train,compute_prediction(vector_x_train,weight),y_train)
```

[ ]:
```
array([[0., 0., 0., …, 0., 0., 0.],
       [0., 0., 0., …, 0., 0., 0.],
       [0., 0., 0., …, 0., 0., 0.],
       [0., 0., 0., …, 0., 0., 0.],
       [0., 0., 0., …, 0., 0., 0.]])
```

1.13 compute accuracy

[ ]:
```
temp = compute_prediction(vector_x_train,weight)
print(temp)
print(max(temp[0]))
print(np.where(temp[0]==max(temp[0])))
```

```
[[0.2 0.2 0.2 0.2 0.2]
 [0.2 0.2 0.2 0.2 0.2]
 [0.2 0.2 0.2 0.2 0.2]
 …
 [0.2 0.2 0.2 0.2 0.2]
 [0.2 0.2 0.2 0.2 0.2]
 [0.2 0.2 0.2 0.2 0.2]]
0.2
(array([0, 1, 2, 3, 4]),)
```

[ ]:
```
def compute_accuracy(prediction, label):

    bCorrect    = [True if list(prediction[i]).
 ↪index(max(prediction[i]))==list(label[i]).index(1) else False for i in␣
 ↪range(len(label))]
    accuracy    = np.sum(bCorrect) / len(label)

    return accuracy
```

[ ]:
```
compute_accuracy(compute_prediction(vector_x_train,weight),y_train)
```

[ ]:
```
0.2
```

1.14 initialize weight

[ ]:
```
dim_input   = vector_x_train.shape[1]
dim_output  = nClass
weight      = np.ones((dim_output, dim_input))
weight      = weight * 0.001

print('size of weights: ', weight.shape)
```

```
size of weights:  (5, 784)
```

1.15 hyper-parameters

[ ]:
```
number_iteration    = 2000
learning_rate       = 0.5
```

1.16 variables for optimization information

[ ]:
```
loss_train_iteration        = np.zeros(number_iteration)
loss_test_iteration         = np.zeros(number_iteration)

accuracy_train_iteration    = np.zeros(number_iteration)
accuracy_test_iteration     = np.zeros(number_iteration)

pred_train_mean_iteration   = np.zeros((nClass, number_iteration))
pred_train_std_iteration    = np.zeros((nClass, number_iteration))
pred_test_mean_iteration    = np.zeros((nClass, number_iteration))
pred_test_std_iteration     = np.zeros((nClass, number_iteration))
```

1.17 gradient descent iterations

[ ]:
```
for i in tqdm(range(number_iteration)):

    prediction_train    = compute_prediction(vector_x_train,weight)
    prediction_test     = compute_prediction(vector_x_test,weight)

    gradient_train      =␣
 ↪compute_gradient(vector_x_train,prediction_train,y_train)
    weight              = weight - learning_rate * gradient_train

    prediction_train    = compute_prediction(vector_x_train,weight)
    prediction_test     = compute_prediction(vector_x_test,weight)

    loss_train          = compute_loss(prediction_train,y_train)
    loss_test           = compute_loss(prediction_test,y_test)

    accuracy_train      = compute_accuracy(prediction_train,y_train)
    accuracy_test       = compute_accuracy(prediction_test, y_test)

    for j in range(nClass):

        pred_train    = prediction_train[index_train[j][0]][:, j]
        pred_test     = prediction_test[index_test[j][0]][:, j]

        pred_train_mean_iteration[j, i]  = np.mean(pred_train)
        pred_train_std_iteration[j, i]   = np.std(pred_train)

        pred_test_mean_iteration[j, i]   = np.mean(pred_test)
        pred_test_std_iteration[j, i]    = np.std(pred_test)

    loss_train_iteration[i]         = loss_train
    loss_test_iteration[i]          = loss_test
```

```
    accuracy_train_iteration[i]     = accuracy_train
    accuracy_test_iteration[i]      = accuracy_test
```

```
100%|      | 2000/2000 [05:34<00:00,  5.97it/s]
```

1.18 plot curve

```
[ ]: def plot_curve(data, x_label, y_label, title):

         plt.figure(figsize=(8, 6))
         plt.title(title)

         plt.plot(range(len(data)), data, '-', color='red')

         plt.xlabel(x_label)
         plt.ylabel(y_label)

         plt.tight_layout()
         plt.show()
```

```
[ ]: def plot_curve2(data1, label_data1, data2, label_data2, x_label, y_label,␣
      ↪title):

         plt.figure(figsize=(8, 6))
         plt.title(title)

         plt.plot(range(len(data1)), data1, '-', color = 'blue', label = label_data1)
         plt.plot(range(len(data2)), data2, '-', color = 'red', label = label_data2)

         plt.xlabel(x_label)
         plt.ylabel(y_label)

         plt.tight_layout()
         plt.show()
```

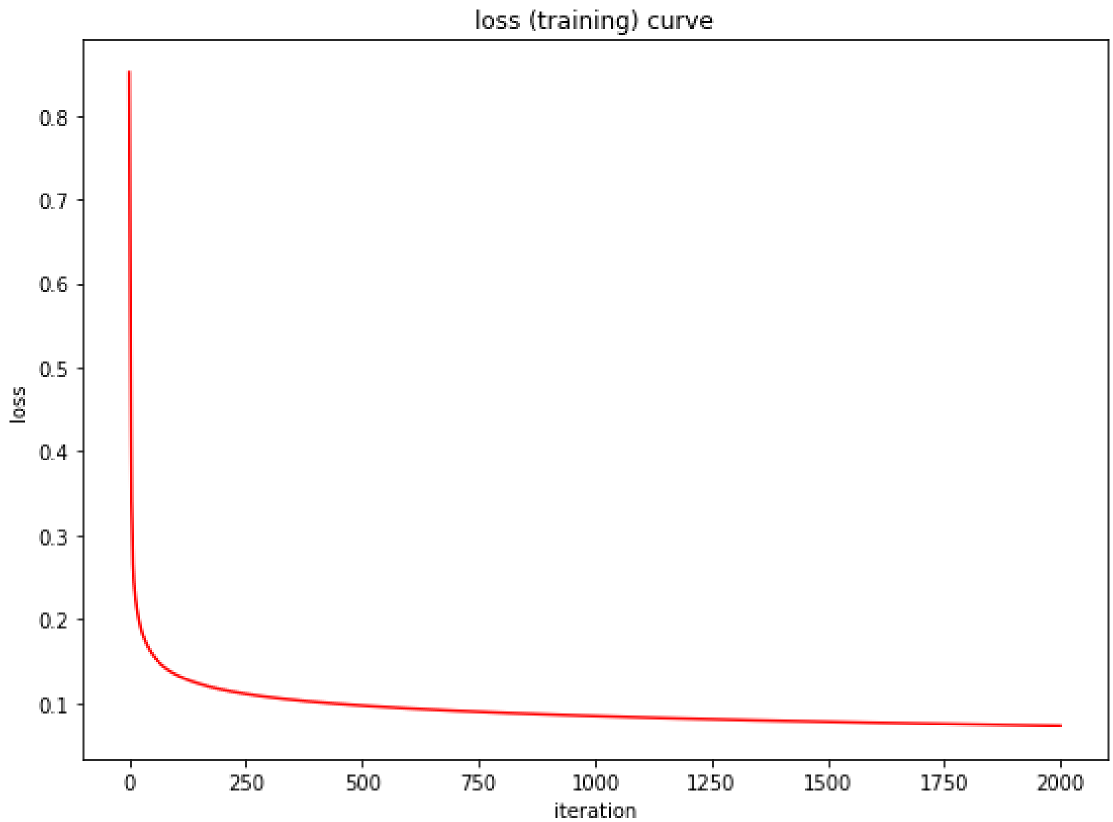
```
[ ]: def plot_curve_error(data_mean, data_std, x_label, y_label, title):

         plt.figure(figsize=(8, 6))
         plt.title(title)

         alpha = 0.3

         plt.plot(range(len(data_mean)), data_mean, '-', color = 'red')
         plt.fill_between(range(len(data_mean)), data_mean - data_std, data_mean +␣
      ↪data_std, facecolor = 'blue', alpha = alpha)

         plt.xlabel(x_label)
```

```
    plt.ylabel(y_label)

    plt.tight_layout()
    plt.show()
```

[ ]:
```
def plot_curve_error2(data1_mean, data1_std, data1_label, data2_mean,␣
↪data2_std, data2_label, x_label, y_label, title):

    plt.figure(figsize=(8, 6))
    plt.title(title)

    alpha = 0.3

    plt.plot(range(len(data1_mean)), data1_mean, '-', color = 'blue', label =␣
↪data1_label)
    plt.fill_between(range(len(data1_mean)), data1_mean - data1_std, data1_mean␣
↪+ data1_std, facecolor = 'blue', alpha = alpha)

    plt.plot(range(len(data2_mean)), data2_mean, '-', color = 'red', label =␣
↪data2_label)
    plt.fill_between(range(len(data2_mean)), data2_mean - data2_std, data2_mean␣
↪+ data2_std, facecolor = 'red', alpha = alpha)

    plt.xlabel(x_label)
    plt.ylabel(y_label)

    plt.tight_layout()
    plt.show()
```

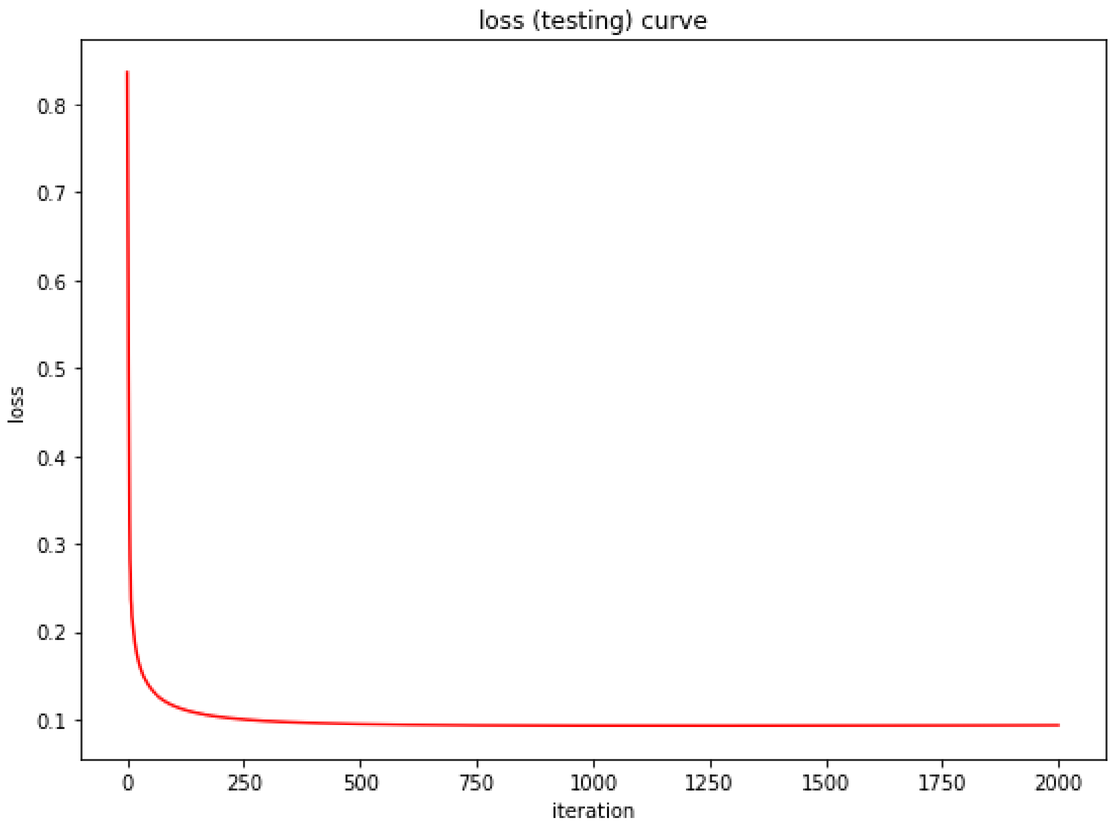
1.19 loss (training) curve

[ ]:
```
plot_curve(loss_train_iteration, 'iteration', 'loss', 'loss (training) curve')
```



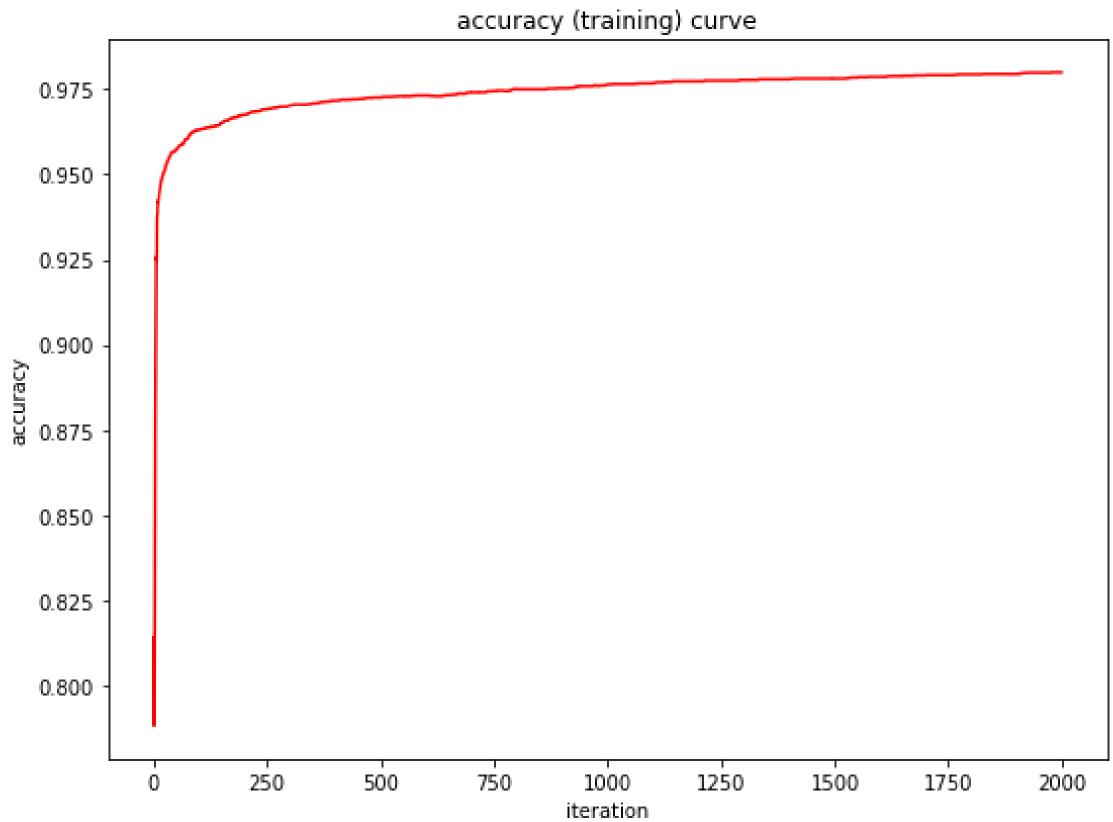
1.20 loss (testing) curve

[ ]:
```
plot_curve(loss_test_iteration, 'iteration', 'loss', 'loss (testing) curve')
```



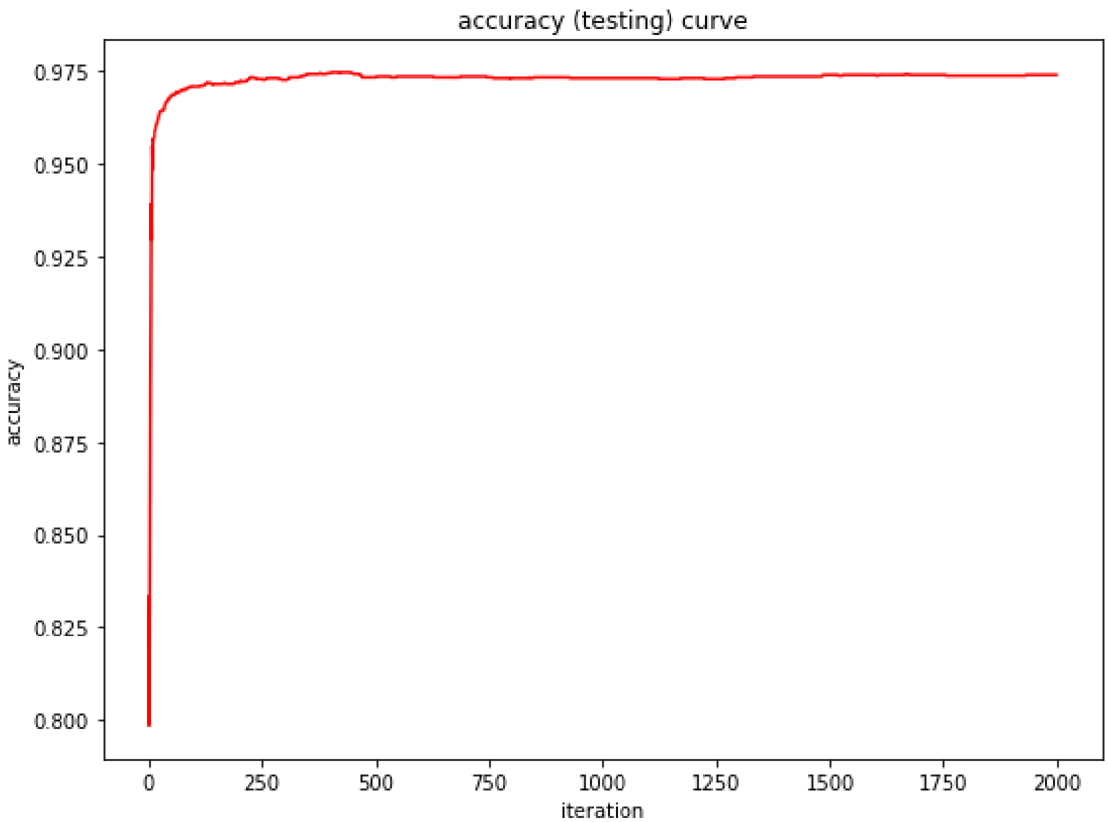
1.21 accuracy (training) curve

[ ]:
```
plot_curve(accuracy_train_iteration, 'iteration', 'accuracy', 'accuracy␣
↪(training) curve')
```



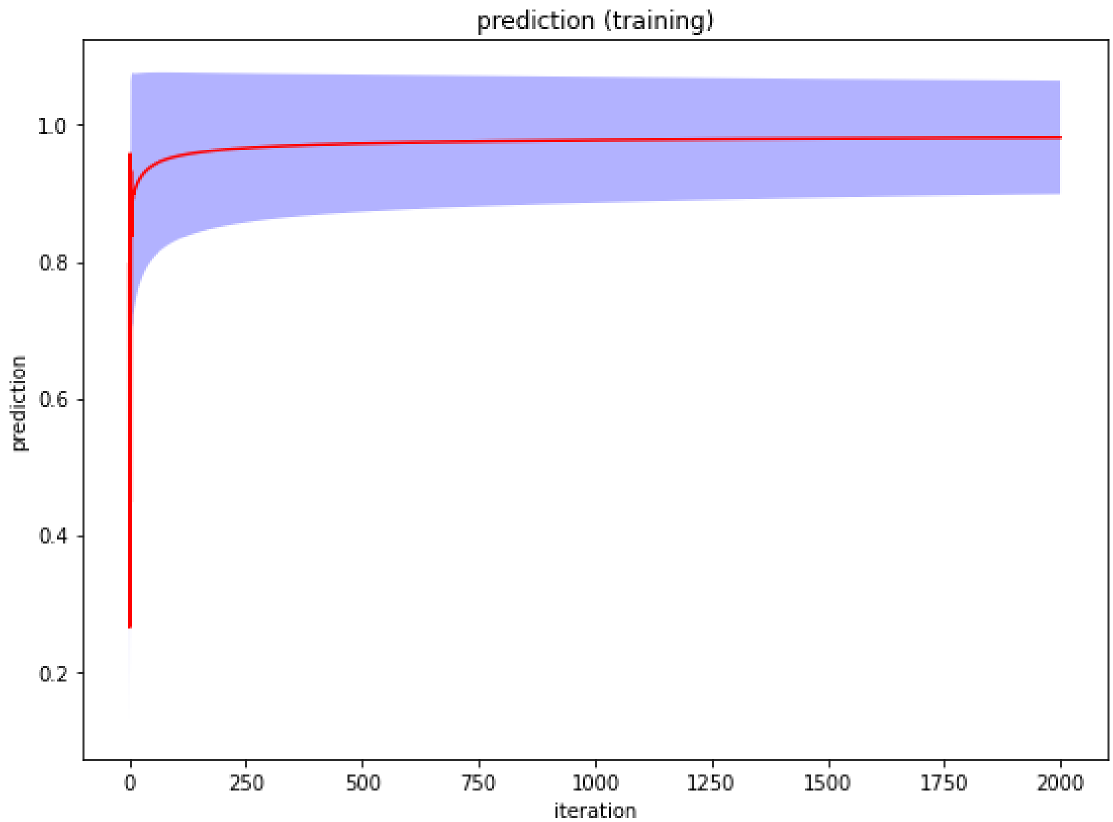
1.22 accuracy (testing) curve

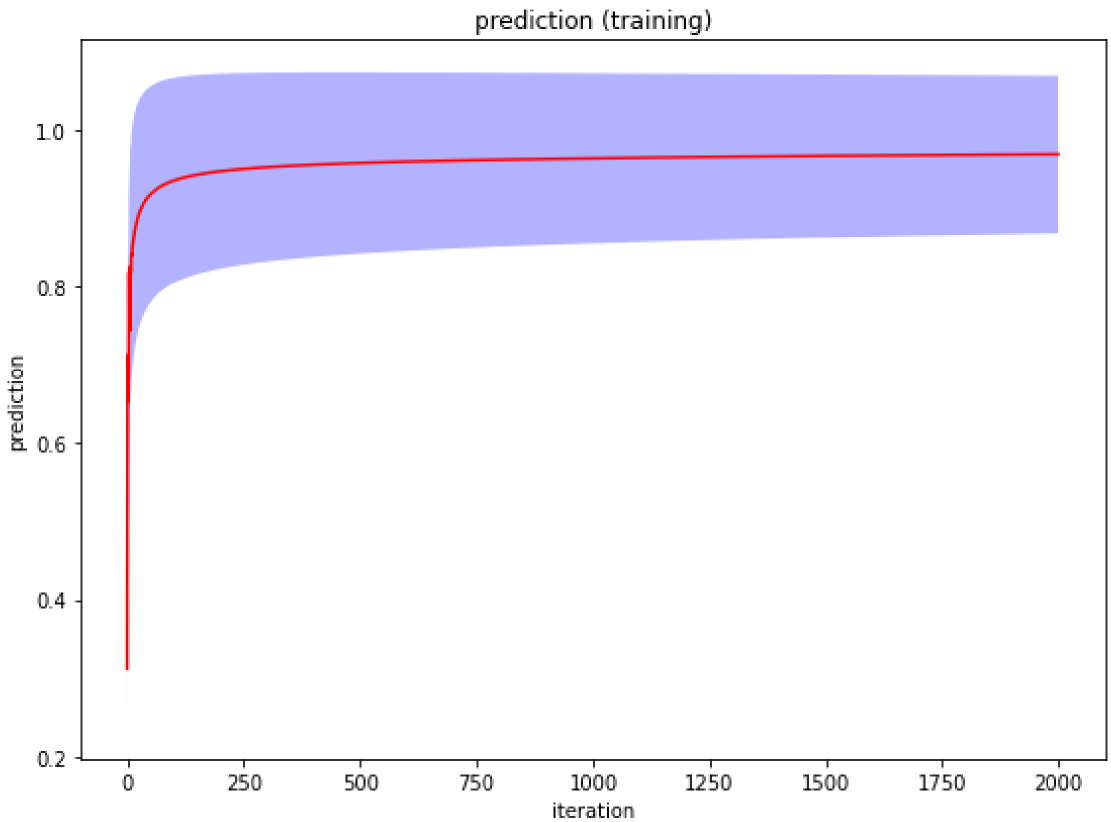
[ ]:
```
plot_curve(accuracy_test_iteration, 'iteration', 'accuracy', 'accuracy␣
↪(testing) curve')
```

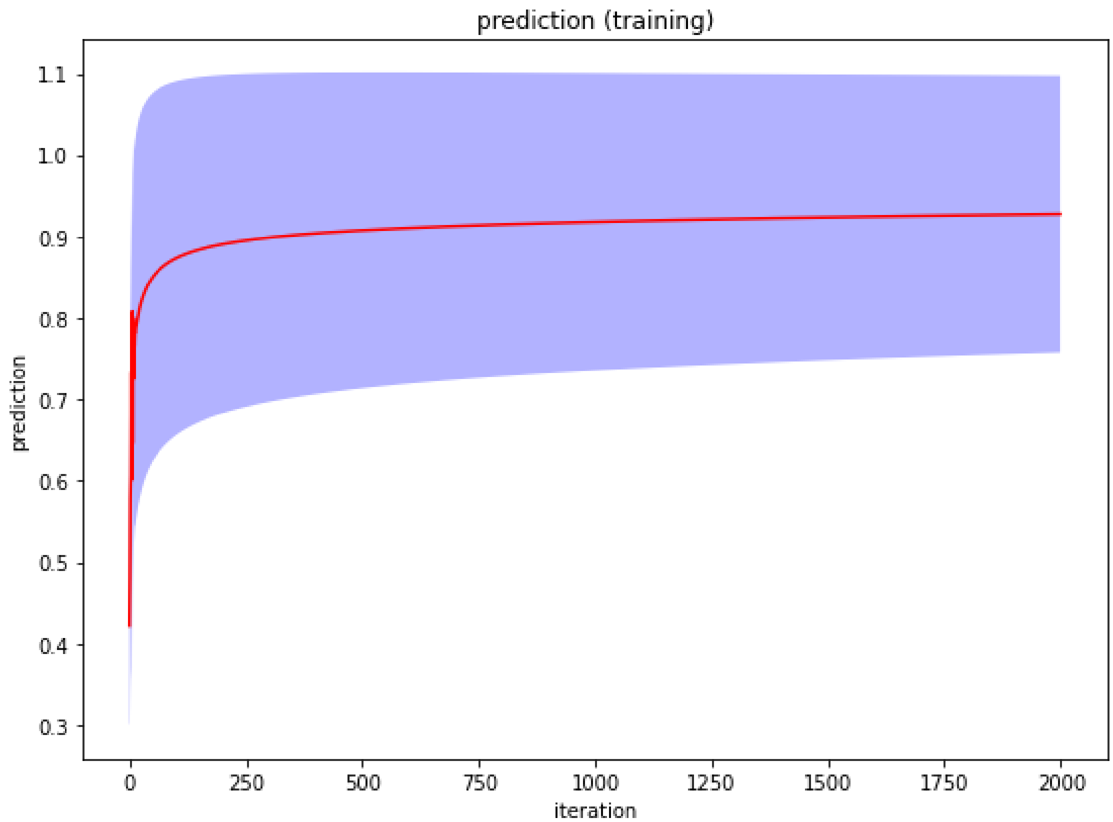


1.23 plot prediction values

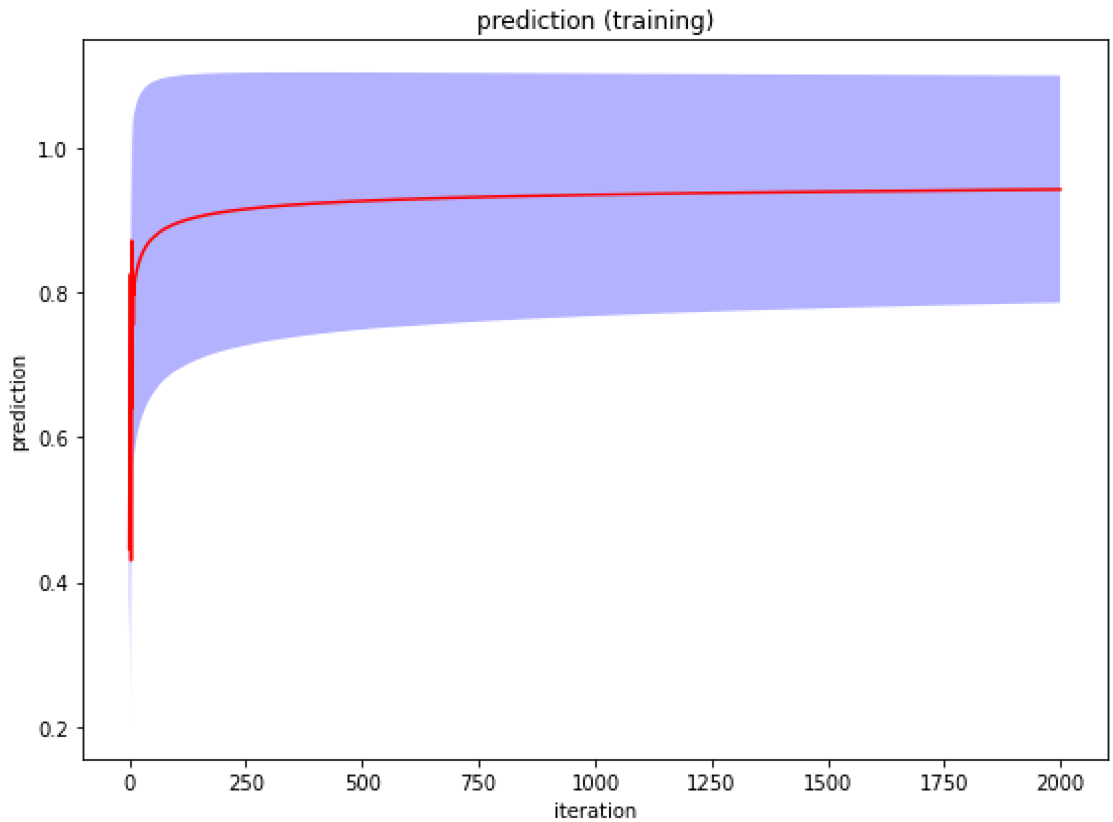
```
[ ]: for i in range(nClass):

        plot_curve_error(pred_train_mean_iteration[i], pred_train_std_iteration[i],␣
      ↪'iteration', 'prediction', 'prediction (training)')
```

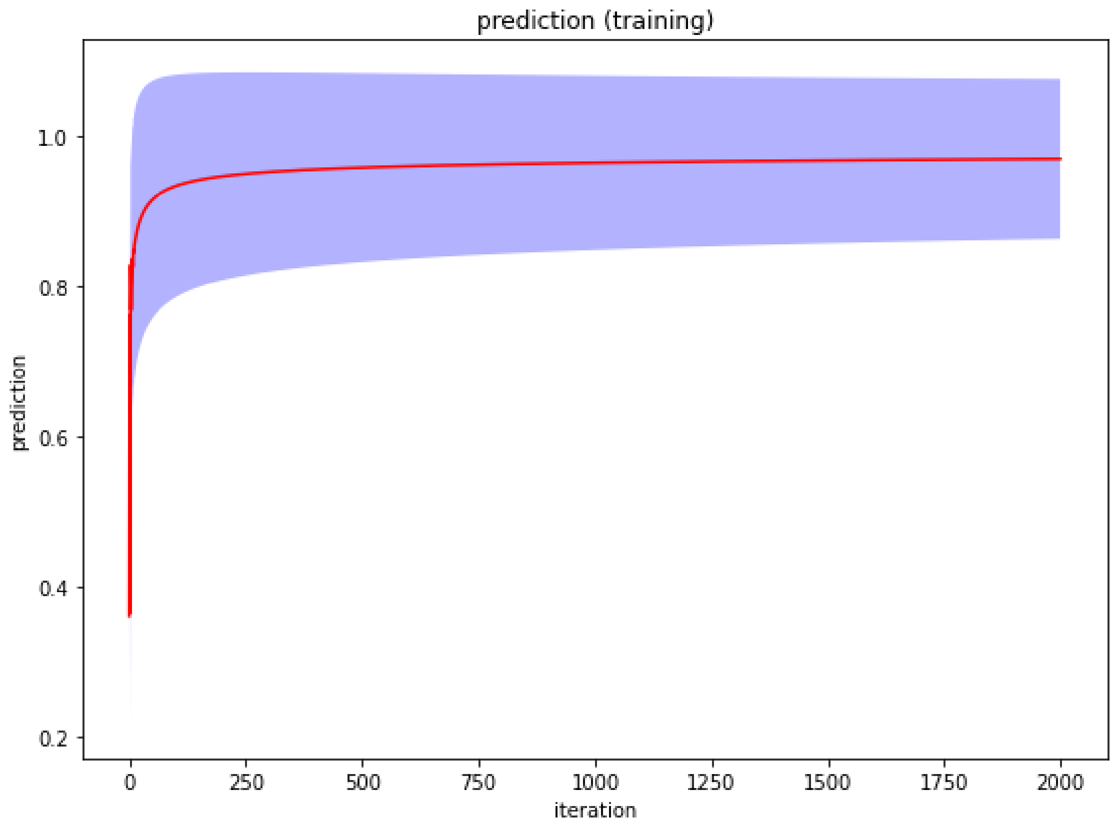

prediction (training)
1.0
0.8
0.6
0.4
0.2
prediction
0
250
500
750
1000
1250
1500
1750
2000
iteration


prediction (training)
prediction
iteration
0.2
0.4
0.6
0.8
1.0
0
250
500
750
1000
1250
1500
1750
2000

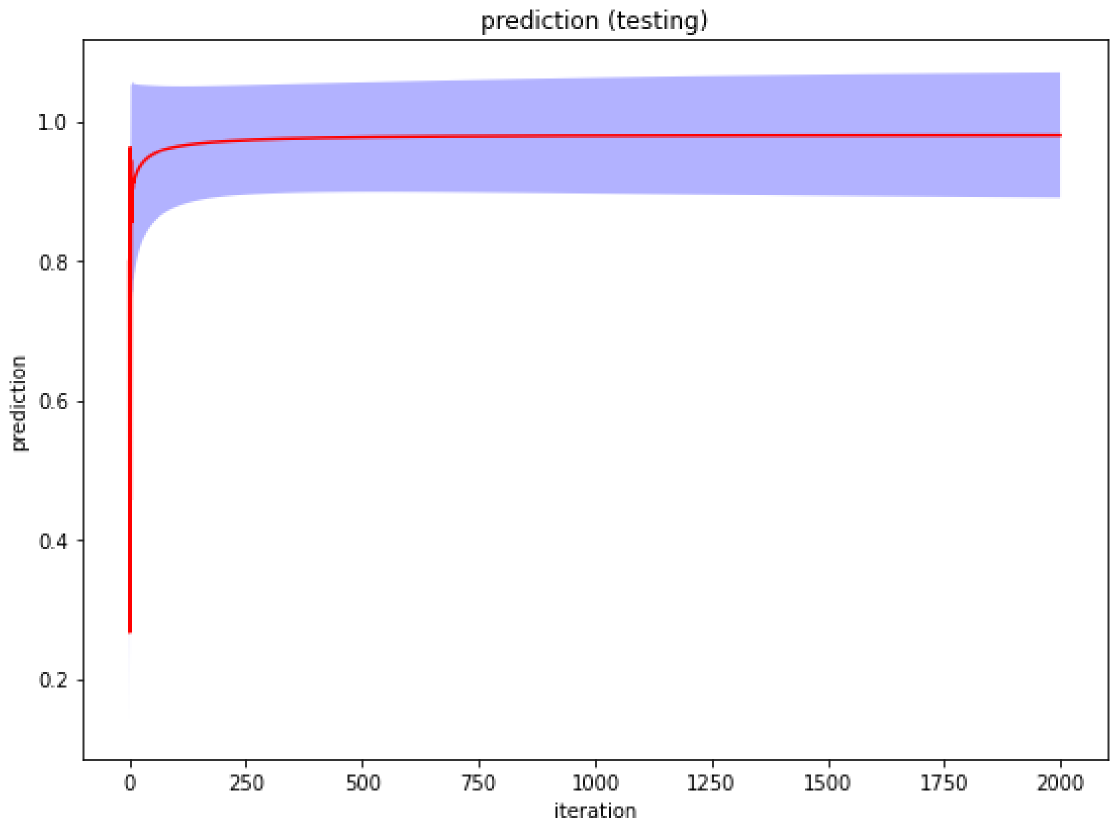


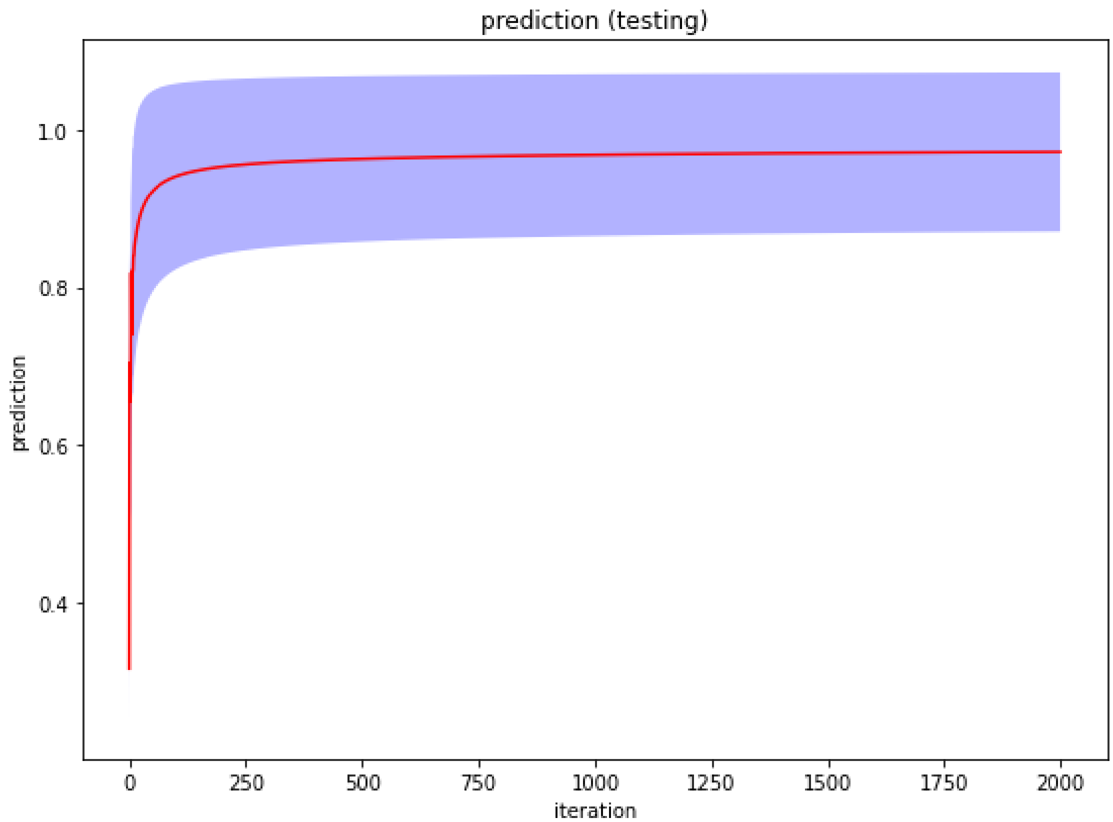
prediction (training)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
prediction
0
250
500
750
1000
1250
1500
1750
2000
iteration

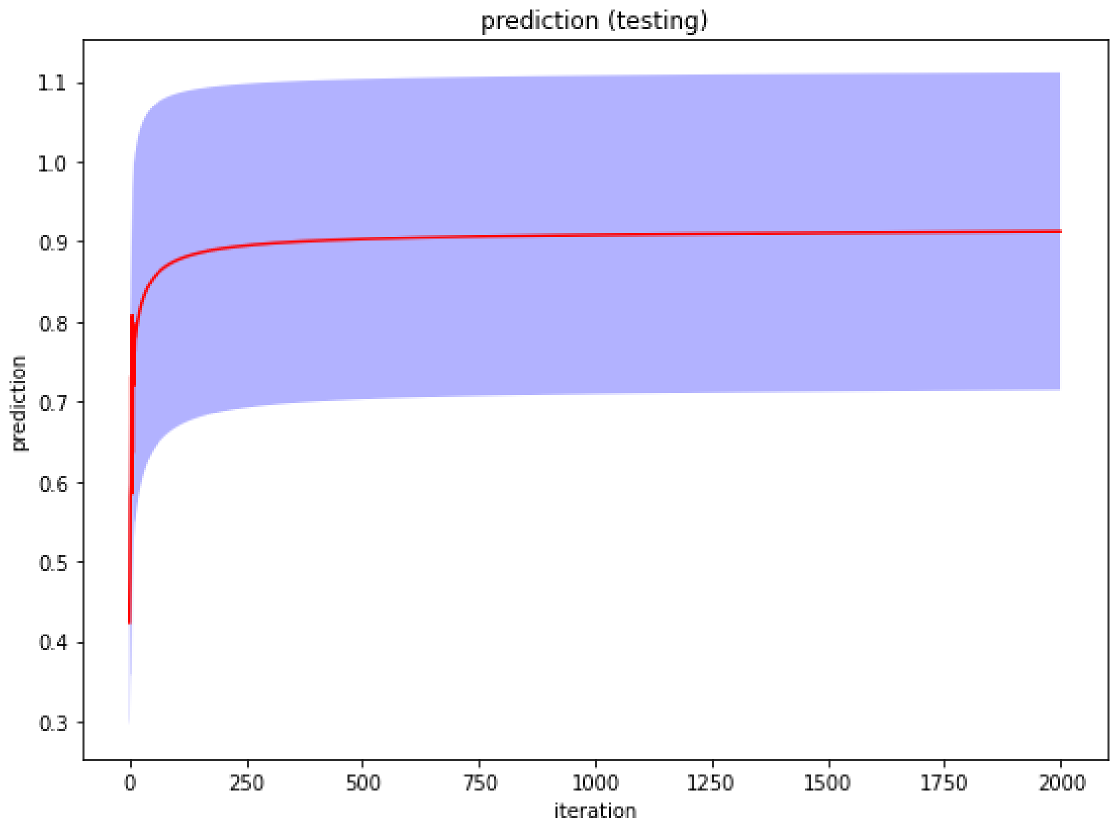

prediction (training)
prediction
1.0
0.8
0.6
0.4
0.2
0
250
500
750
1000
1250
1500
1750
2000
iteration

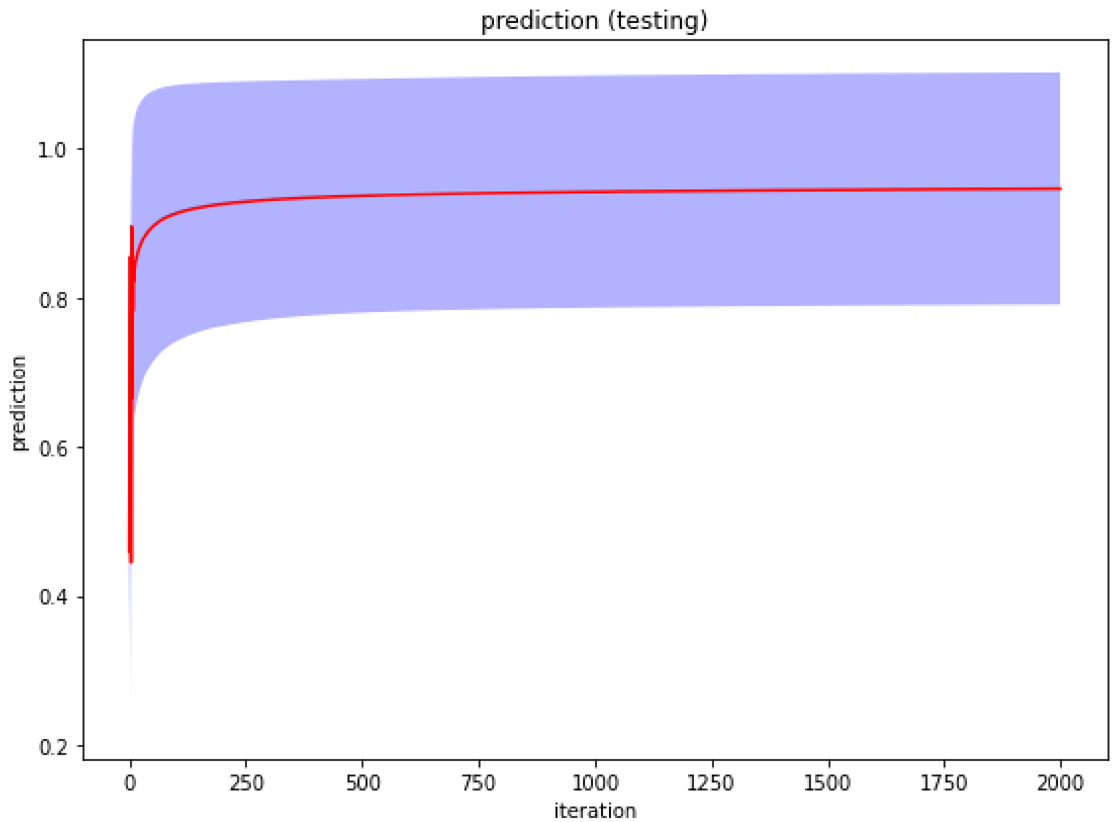


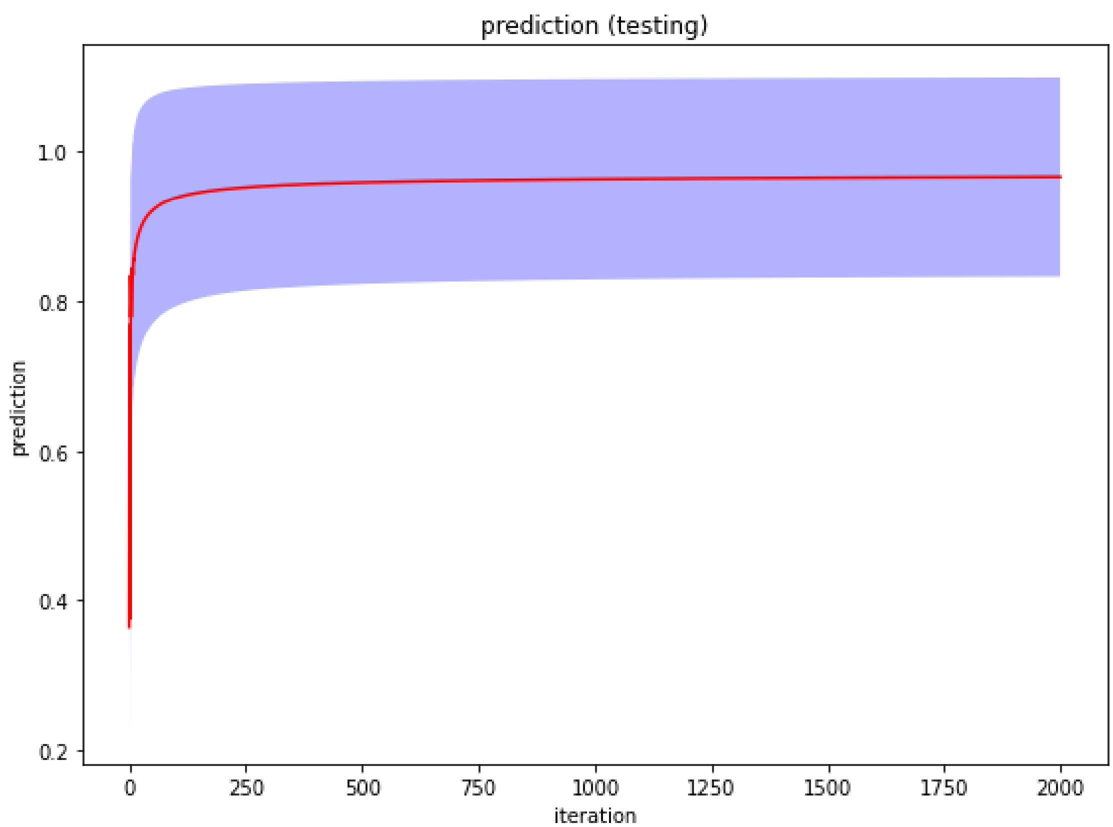
[ ]:
```
for i in range(nClass):

    plot_curve_error(pred_test_mean_iteration[i], pred_test_std_iteration[i],␣
 ↪'iteration', 'prediction', 'prediction (testing)')
```


prediction (testing)
prediction
iteration
1.0
0.8
0.6
0.4
0.2
0
250
500
750
1000
1250
1500
1750
2000


prediction (testing)
prediction
iteration
1.0
0.8
0.6
0.4
0
250
500
750
1000
1250
1500
1750
2000


prediction (testing)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
prediction
0
250
500
750
1000
1250
1500
1750
2000
iteration


prediction (testing)
prediction
iteration
0.2
0.4
0.6
0.8
1.0
0
250
500
750
1000
1250
1500
1750
2000



1.24 print values

```
[ ]: def print_curve(data, index):

         for i in range(len(index)):

             idx = index[i]
             val = data[idx]

             print('index = %4d, value = %12.10f' % (idx, val))
```

1.25 given iterations at which the values are presented

```
[ ]: index = np.array([0, 100, 200, 300, 400, 500, 600, 700, 800, 900])
```

1.26 training loss

```
[ ]: print_curve(loss_train_iteration, index)
```

```
index =    0, value = 0.8516388787
```

```
index =  100, value = 0.1339429389
index =  200, value = 0.1157748007
index =  300, value = 0.1069166127
index =  400, value = 0.1011699953
index =  500, value = 0.0969356204
index =  600, value = 0.0935861772
index =  700, value = 0.0908157813
index =  800, value = 0.0884532877
index =  900, value = 0.0863934761
```

1.27 testing loss

[ ]:
```
print_curve(loss_test_iteration, index)
```

```
index =    0, value = 0.8360542535
index =  100, value = 0.1155831250
index =  200, value = 0.1030645859
index =  300, value = 0.0984429816
index =  400, value = 0.0961438411
index =  500, value = 0.0948397523
index =  600, value = 0.0940481203
index =  700, value = 0.0935513893
index =  800, value = 0.0932376237
index =  900, value = 0.0930438257
```

1.28 training accuracy

[ ]:
```
print_curve(accuracy_train_iteration, index)
```

```
index =    0, value = 0.8142000000
index =  100, value = 0.9630000000
index =  200, value = 0.9674000000
index =  300, value = 0.9701000000
index =  400, value = 0.9716000000
index =  500, value = 0.9725000000
index =  600, value = 0.9731000000
index =  700, value = 0.9739000000
index =  800, value = 0.9749000000
index =  900, value = 0.9752000000
```

1.29 testing accuracy

[ ]:
```
print_curve(accuracy_test_iteration, index)
```

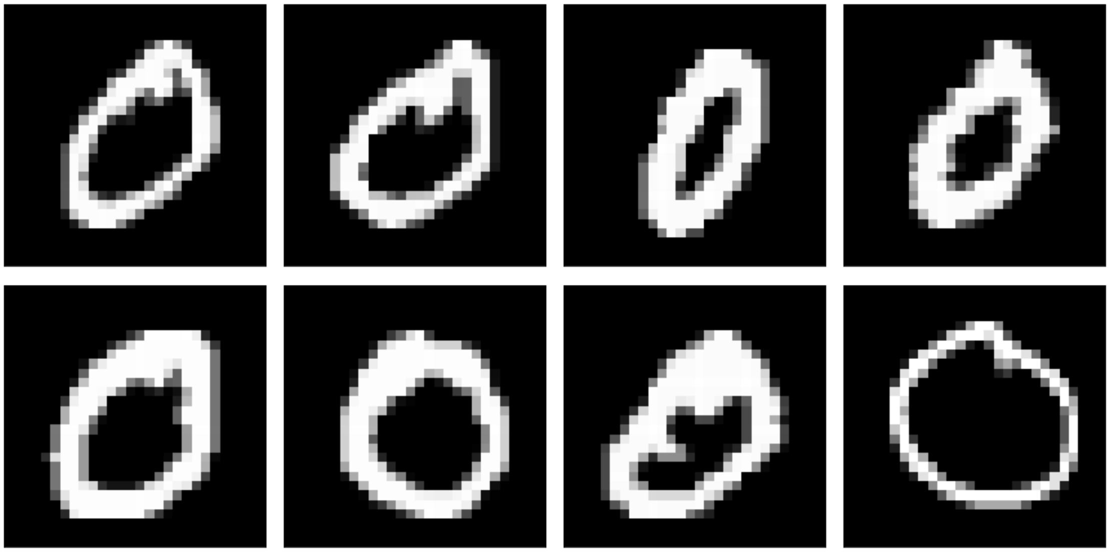
```
index =    0, value = 0.8331111111
index =  100, value = 0.9708888889
index =  200, value = 0.9720000000
index =  300, value = 0.9726666667
```

```
index =  400, value = 0.9744444444
index =  500, value = 0.9733333333
index =  600, value = 0.9735555556
index =  700, value = 0.9735555556
index =  800, value = 0.9731111111
index =  900, value = 0.9733333333
```

1.30 functions for presenting the results

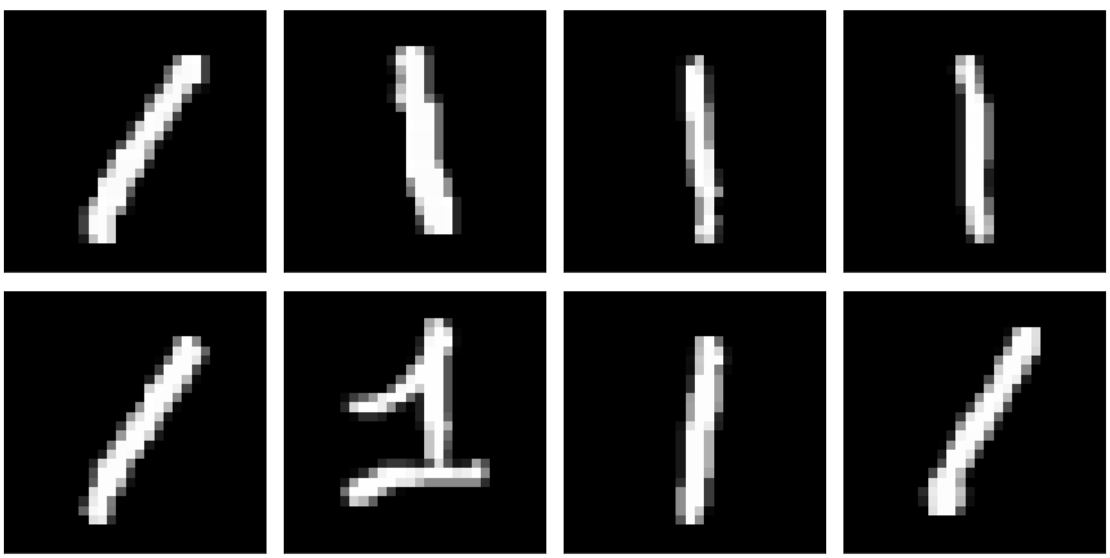
[ ]:
```
def function_results_01(data,nRow,nCol):
    fig, axes = plt.subplots(nRow, nCol, constrained_layout=True, figsize=(nCol␣
↪* 3, nRow * 3))
    nPlot      = nRow * nCol

    index_data = index_train[0][0][0:nPlot]

    for i in range(nRow):
        for j in range(nCol):

            k       = i * nCol + j
            index   = index_data[k]

            axes[i, j].imshow(data[index], cmap='gray', vmin=0, vmax=1)
            axes[i, j].xaxis.set_visible(False)
            axes[i, j].yaxis.set_visible(False)

    plt.show()
```

[ ]:
```
function_results_01(x_train,2,4)
```



```
[ ]: def function_results_02(data,nRow,nCol):
         fig, axes = plt.subplots(nRow, nCol, constrained_layout=True, figsize=(nCol␣
      ↪* 3, nRow * 3))
         nPlot      = nRow * nCol

         index_data = index_train[1][0][0:nPlot]

         for i in range(nRow):
             for j in range(nCol):

                 k       = i * nCol + j
                 index   = index_data[k]

                 axes[i, j].imshow(data[index], cmap='gray', vmin=0, vmax=1)
                 axes[i, j].xaxis.set_visible(False)
                 axes[i, j].yaxis.set_visible(False)

         plt.show()
```

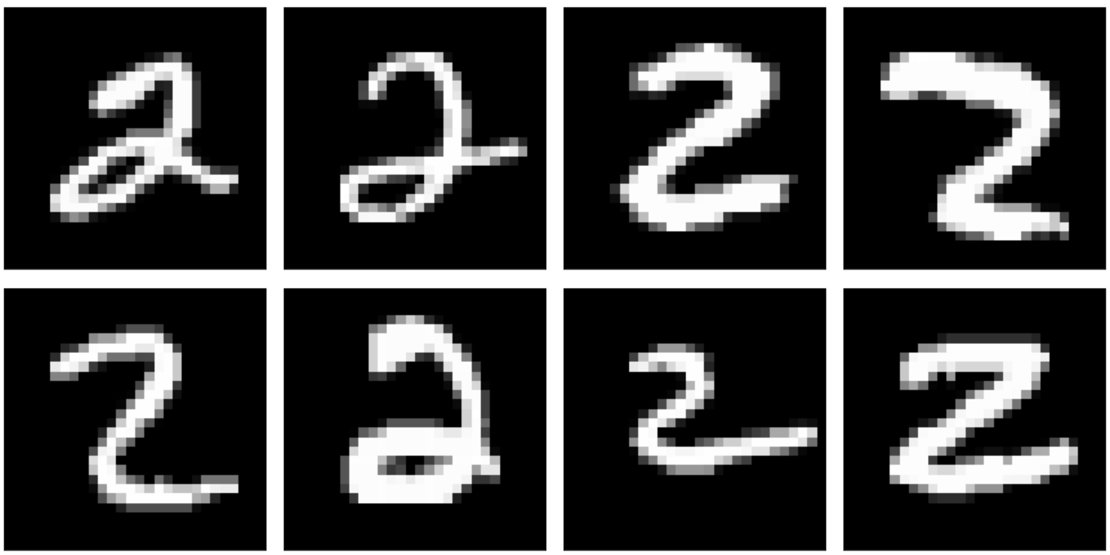
```
[ ]: function_results_02(x_train,2,4)
```



```
[ ]: def function_results_03(data,nRow,nCol):
         fig, axes = plt.subplots(nRow, nCol, constrained_layout=True, figsize=(nCol␣
      ↪* 3, nRow * 3))
         nPlot      = nRow * nCol

         index_data = index_train[2][0][0:nPlot]
```

```
    for i in range(nRow):
        for j in range(nCol):

            k       = i * nCol + j
            index   = index_data[k]

            axes[i, j].imshow(data[index], cmap='gray', vmin=0, vmax=1)
            axes[i, j].xaxis.set_visible(False)
            axes[i, j].yaxis.set_visible(False)

    plt.show()
```

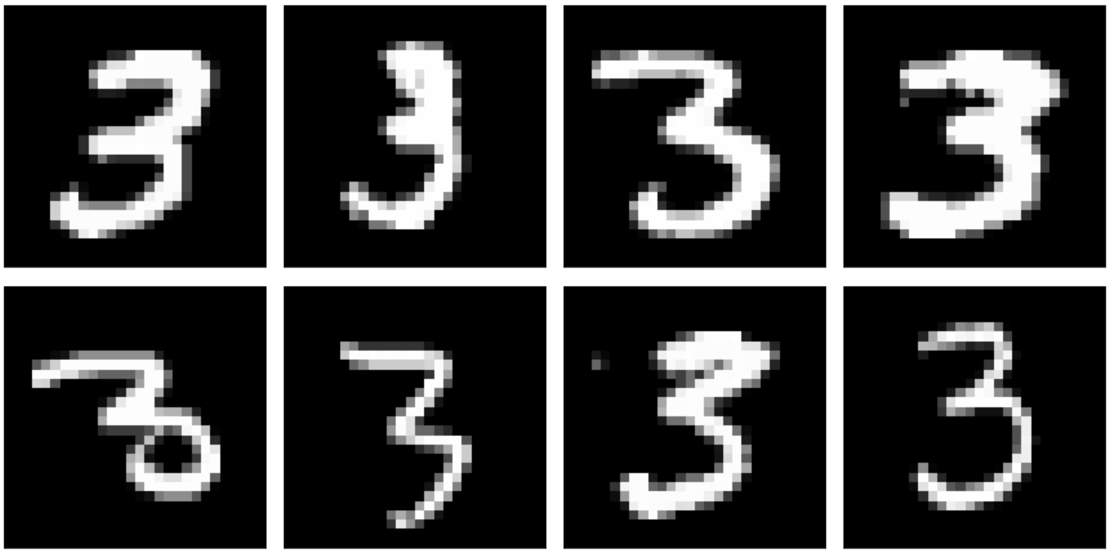
[ ]:
```
function_results_03(x_train,2,4)
```



[ ]:
```
def function_results_04(data,nRow,nCol):
    fig, axes = plt.subplots(nRow, nCol, constrained_layout=True, figsize=(nCol␣
↪* 3, nRow * 3))
    nPlot      = nRow * nCol

    index_data = index_train[3][0][0:nPlot]

    for i in range(nRow):
        for j in range(nCol):

            k       = i * nCol + j
            index   = index_data[k]
```

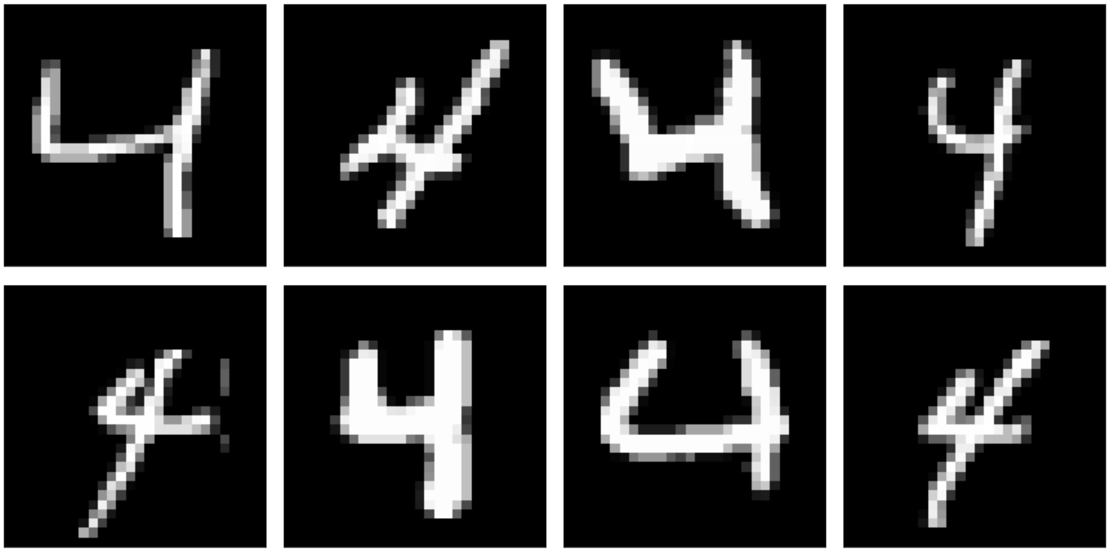
```
            axes[i, j].imshow(data[index], cmap='gray', vmin=0, vmax=1)
            axes[i, j].xaxis.set_visible(False)
            axes[i, j].yaxis.set_visible(False)

    plt.show()
```

[ ]:
```
function_results_04(x_train,2,4)
```



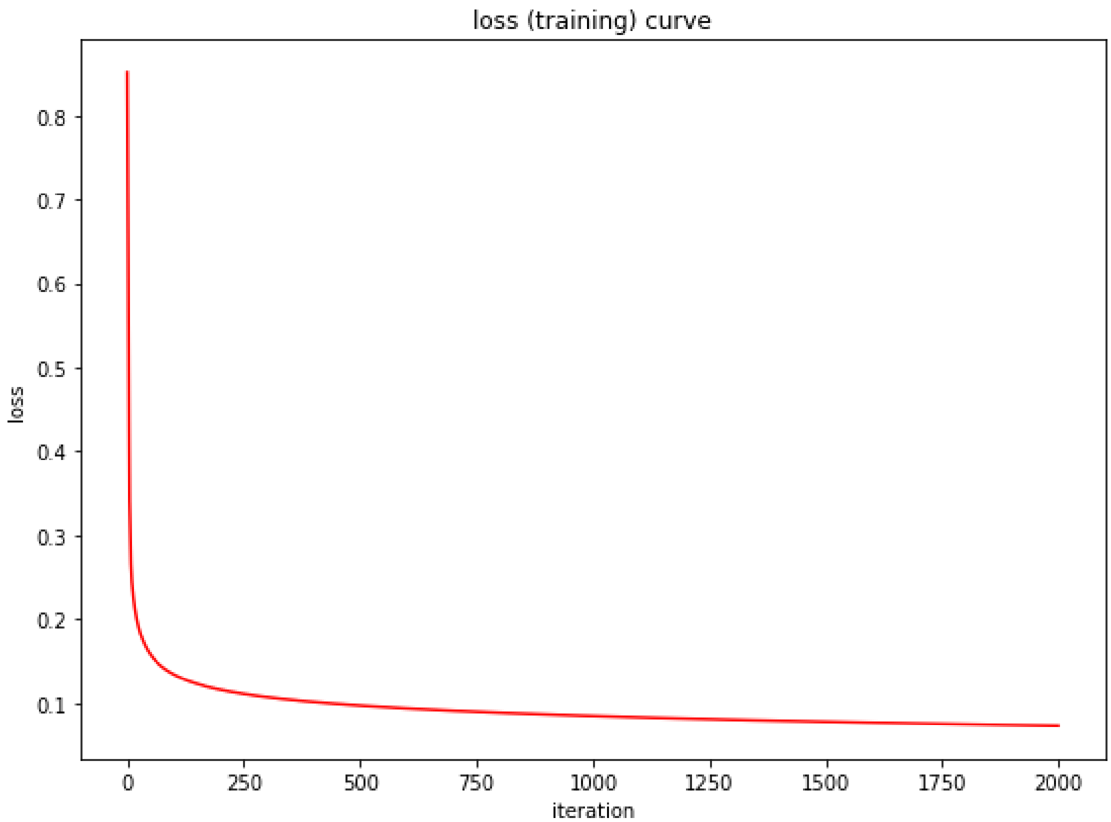
[ ]:
```
def function_results_05(data,nRow,nCol):
    fig, axes = plt.subplots(nRow, nCol, constrained_layout=True, figsize=(nCol␣
↪* 3, nRow * 3))
    nPlot      = nRow * nCol

    index_data = index_train[4][0][0:nPlot]

    for i in range(nRow):
        for j in range(nCol):

            k       = i * nCol + j
            index   = index_data[k]

            axes[i, j].imshow(data[index], cmap='gray', vmin=0, vmax=1)
            axes[i, j].xaxis.set_visible(False)
            axes[i, j].yaxis.set_visible(False)

    plt.show()
```

[ ]:
```
function_results_05(x_train,2,4)
```



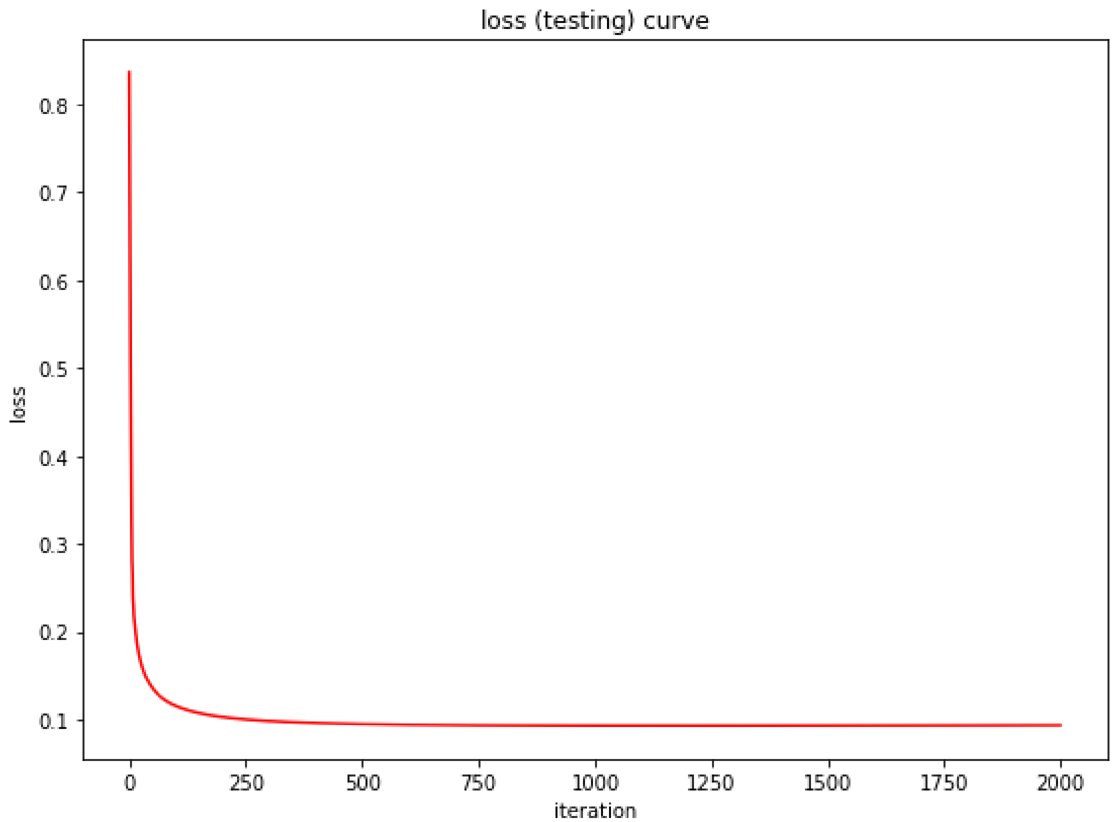
```
[ ]: def function_results_06():
         plot_curve(loss_train_iteration, 'iteration', 'loss', 'loss (training)␣
      ↪curve')
```

```
[ ]: function_results_06()
```



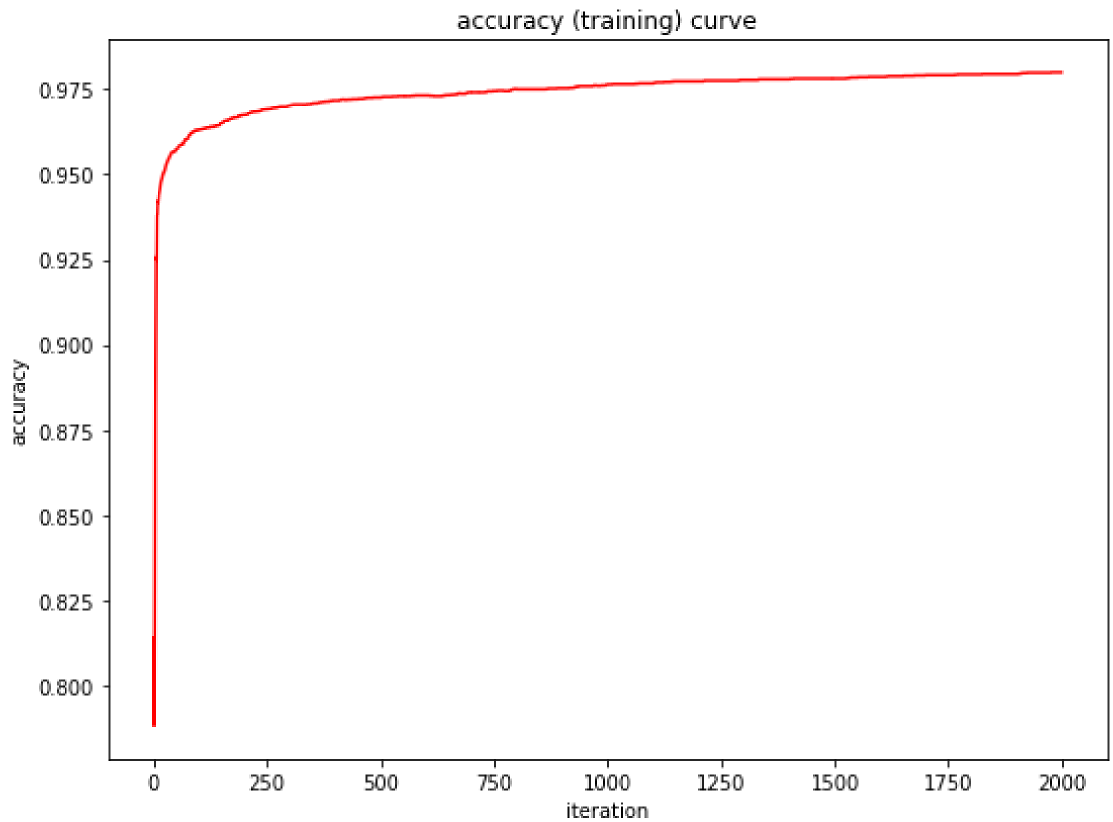
[ ]:
```
def function_results_07():
    plot_curve(loss_test_iteration, 'iteration', 'loss', 'loss (testing) curve')
```

[ ]:
```
function_results_07()
```



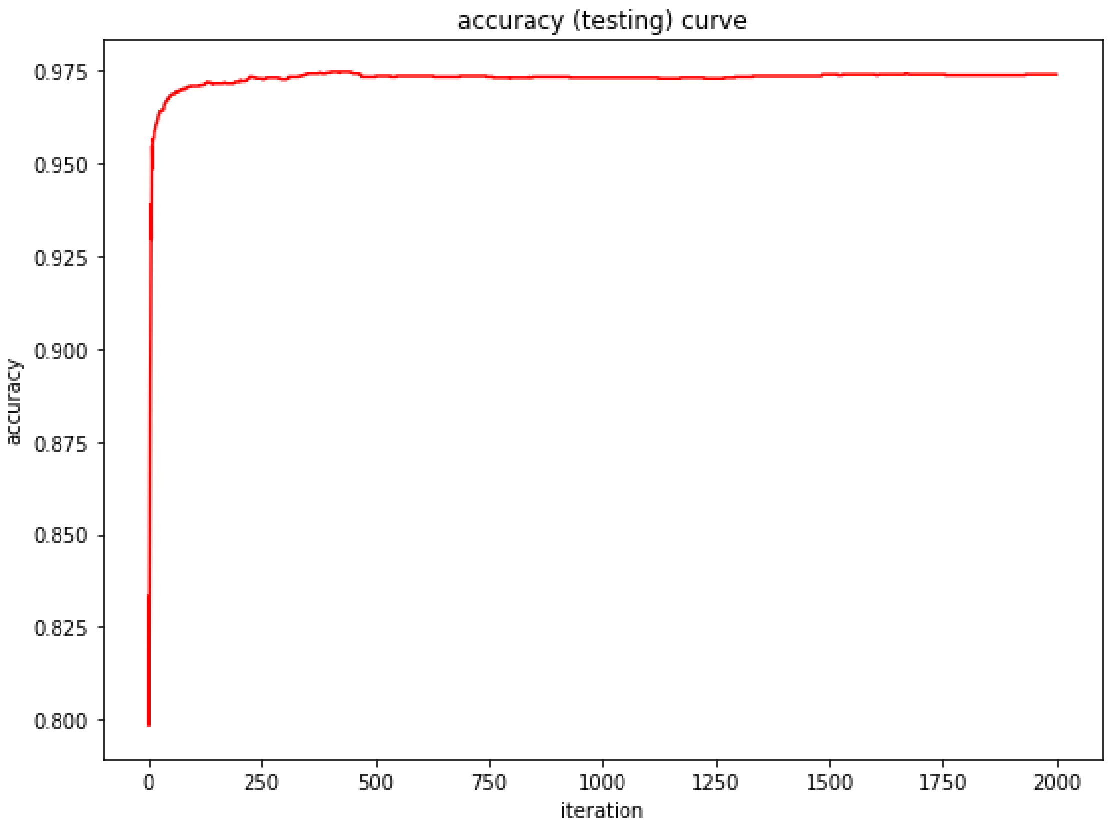

```
[ ]: def function_results_08():
         plot_curve(accuracy_train_iteration, 'iteration', 'accuracy', 'accuracy␣
      ↪(training) curve')
```

```
[ ]: function_results_08()
```



[ ]:
```
def function_results_09():
    plot_curve(accuracy_test_iteration, 'iteration', 'accuracy', 'accuracy␣
↪(testing) curve')
```

[ ]:
```
function_results_09()
```



[ ]:
```
def function_results_10(data):
    index = np.array([0, 100, 200, 300, 400, 500, 600, 700, 800, 900])
    for i in range(len(index)):

        idx = index[i]
        val = data[idx]

        print('index = %4d, value = %12.10f' % (idx, val))
```

[ ]:
```
function_results_10(loss_train_iteration)
```

```
index =    0, value = 0.8516388787
index =  100, value = 0.1339429389
index =  200, value = 0.1157748007
index =  300, value = 0.1069166127
index =  400, value = 0.1011699953
index =  500, value = 0.0969356204
index =  600, value = 0.0935861772
index =  700, value = 0.0908157813
index =  800, value = 0.0884532877
```

```
index =  900, value = 0.0863934761
```

[ ]:
```python
def function_results_11(data):
    index = np.array([0, 100, 200, 300, 400, 500, 600, 700, 800, 900])
    for i in range(len(index)):

        idx = index[i]
        val = data[idx]

        print('index = %4d, value = %12.10f' % (idx, val))
```

[ ]:
```python
function_results_11(loss_test_iteration)
```

```
index =    0, value = 0.8360542535
index =  100, value = 0.1155831250
index =  200, value = 0.1030645859
index =  300, value = 0.0984429816
index =  400, value = 0.0961438411
index =  500, value = 0.0948397523
index =  600, value = 0.0940481203
index =  700, value = 0.0935513893
index =  800, value = 0.0932376237
index =  900, value = 0.0930438257
```

[ ]:
```python
def function_results_12(data):
    index = np.array([0, 100, 200, 300, 400, 500, 600, 700, 800, 900])
    for i in range(len(index)):

        idx = index[i]
        val = data[idx]

        print('index = %4d, value = %12.10f' % (idx, val))
```

[ ]:
```python
function_results_12(accuracy_train_iteration)
```

```
index =    0, value = 0.8142000000
index =  100, value = 0.9630000000
index =  200, value = 0.9674000000
index =  300, value = 0.9701000000
index =  400, value = 0.9716000000
index =  500, value = 0.9725000000
index =  600, value = 0.9731000000
index =  700, value = 0.9739000000
index =  800, value = 0.9749000000
index =  900, value = 0.9752000000
```

[ ]:
```
def function_results_13(data):
    index = np.array([0, 100, 200, 300, 400, 500, 600, 700, 800, 900])
    for i in range(len(index)):

        idx = index[i]
        val = data[idx]

        print('index = %4d, value = %12.10f' % (idx, val))
```

[ ]:
```
function_results_13(accuracy_test_iteration)
```

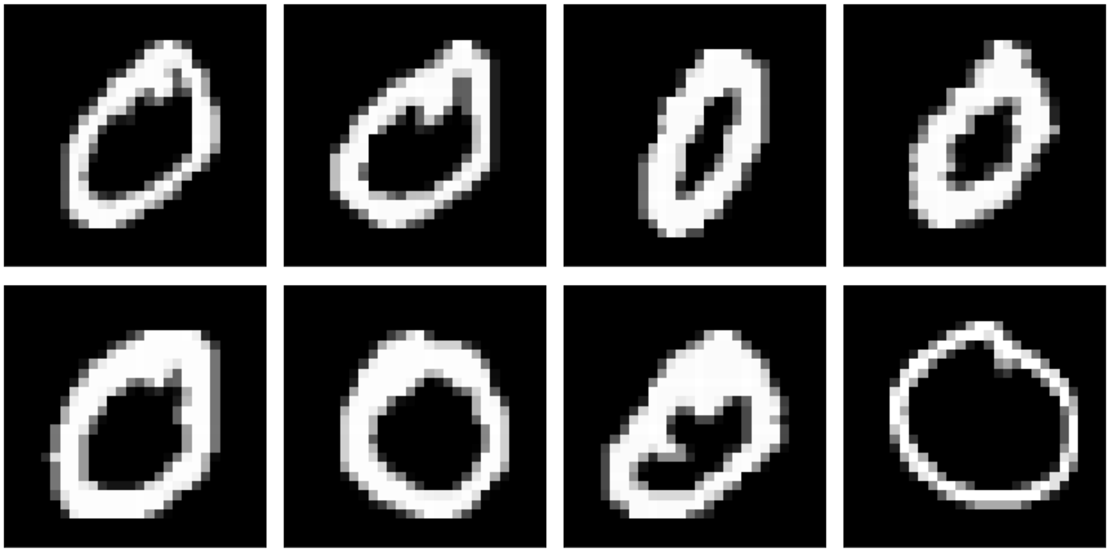
```
index =    0, value = 0.8331111111
index =  100, value = 0.9708888889
index =  200, value = 0.9720000000
index =  300, value = 0.9726666667
index =  400, value = 0.9744444444
index =  500, value = 0.9733333333
index =  600, value = 0.9735555556
index =  700, value = 0.9735555556
index =  800, value = 0.9731111111
index =  900, value = 0.9733333333
```

---

2 RESULTS

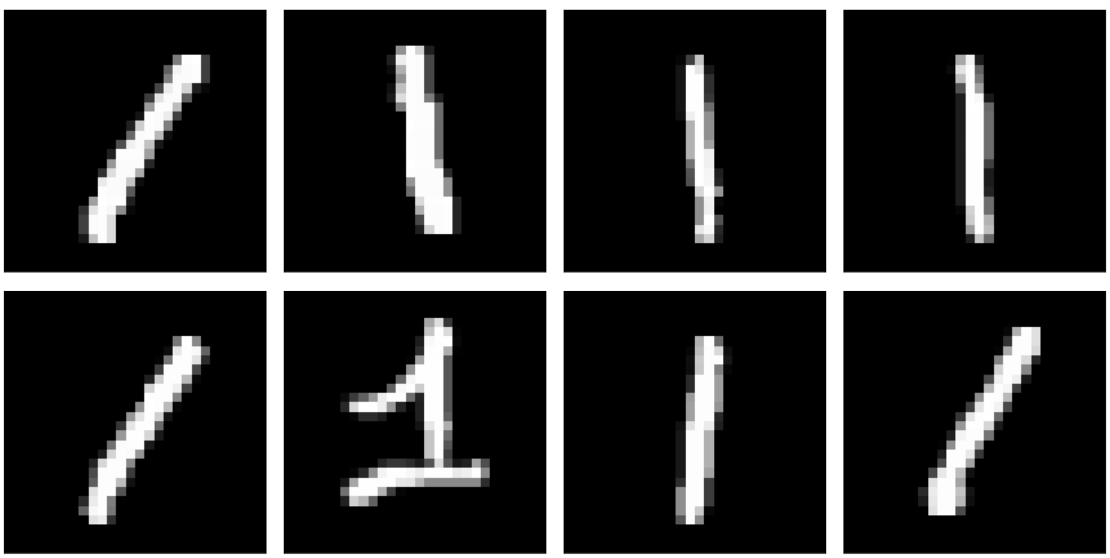
2.1 # 01. plot the input images for '0'

[ ]:
```
function_results_01(x_train,2,4)
```



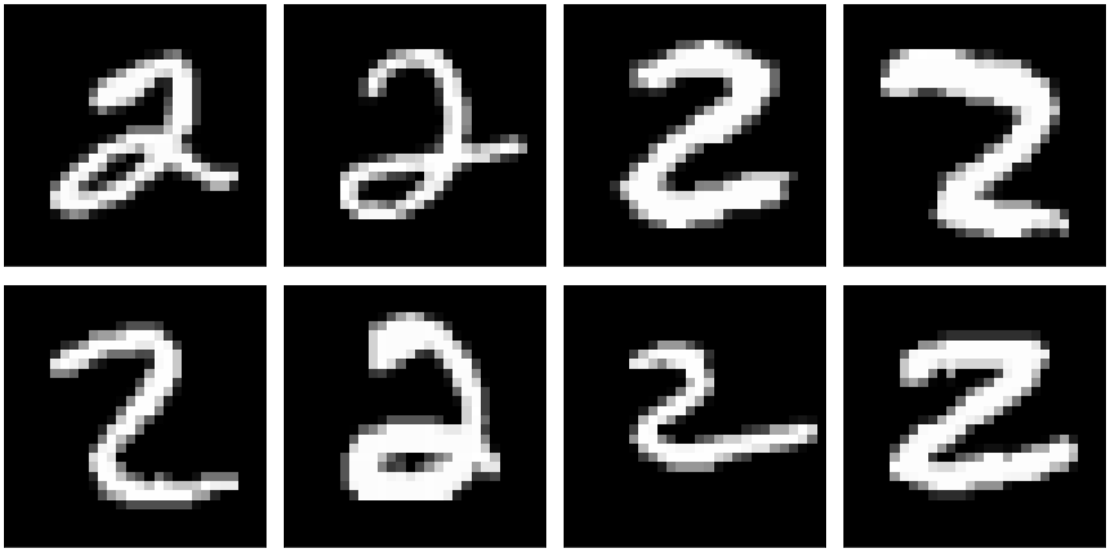
2.2 # 02. plot the input images for '1'

[ ]:
```
function_results_02(x_train,2,4)
```



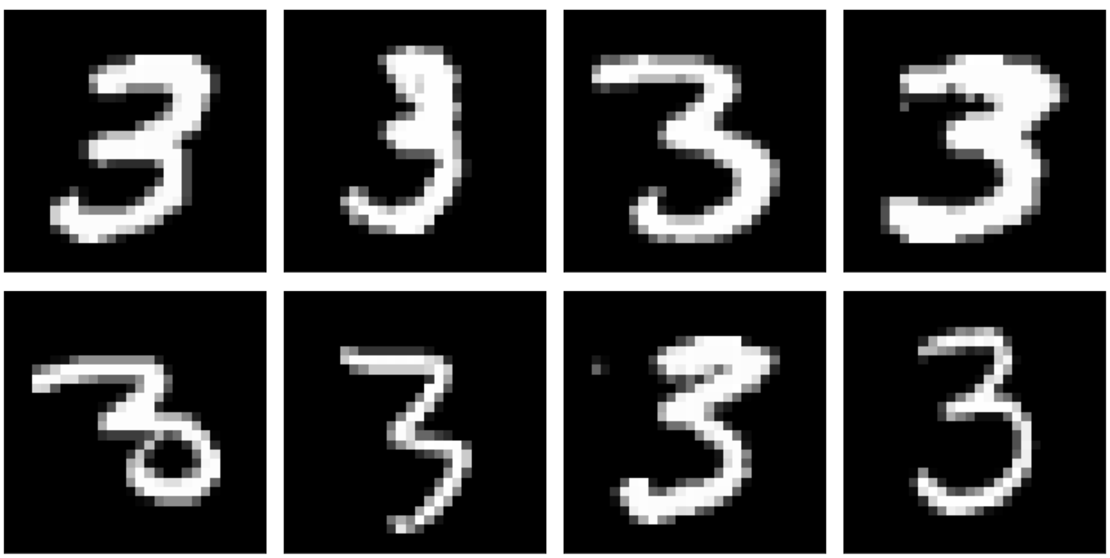
2.3 # 03. plot the input images for '2'

[ ]:
```
function_results_03(x_train,2,4)
```



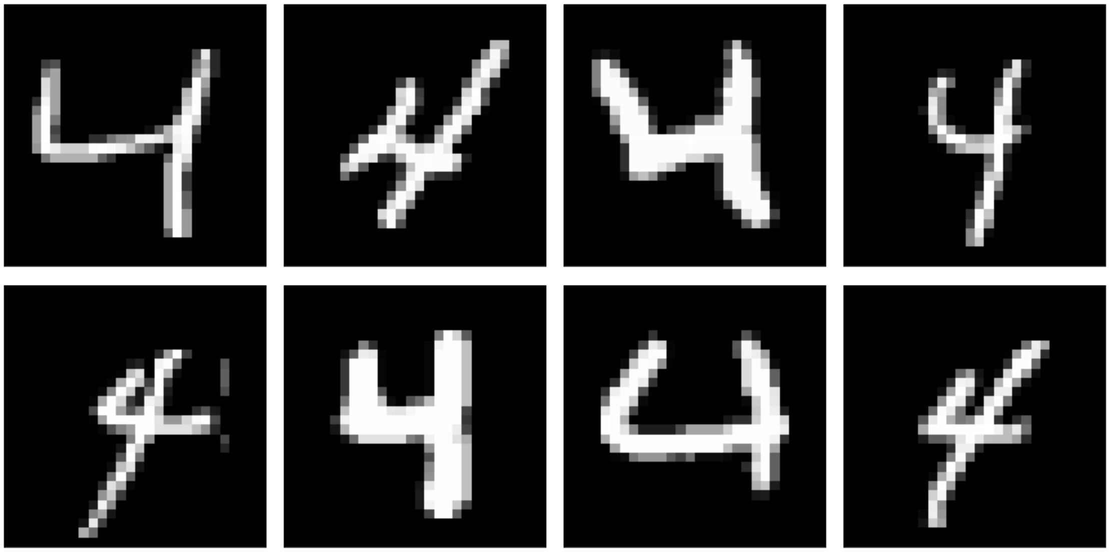
2.4 # 04. plot the input images for '3'

[ ]:
```
function_results_04(x_train,2,4)
```



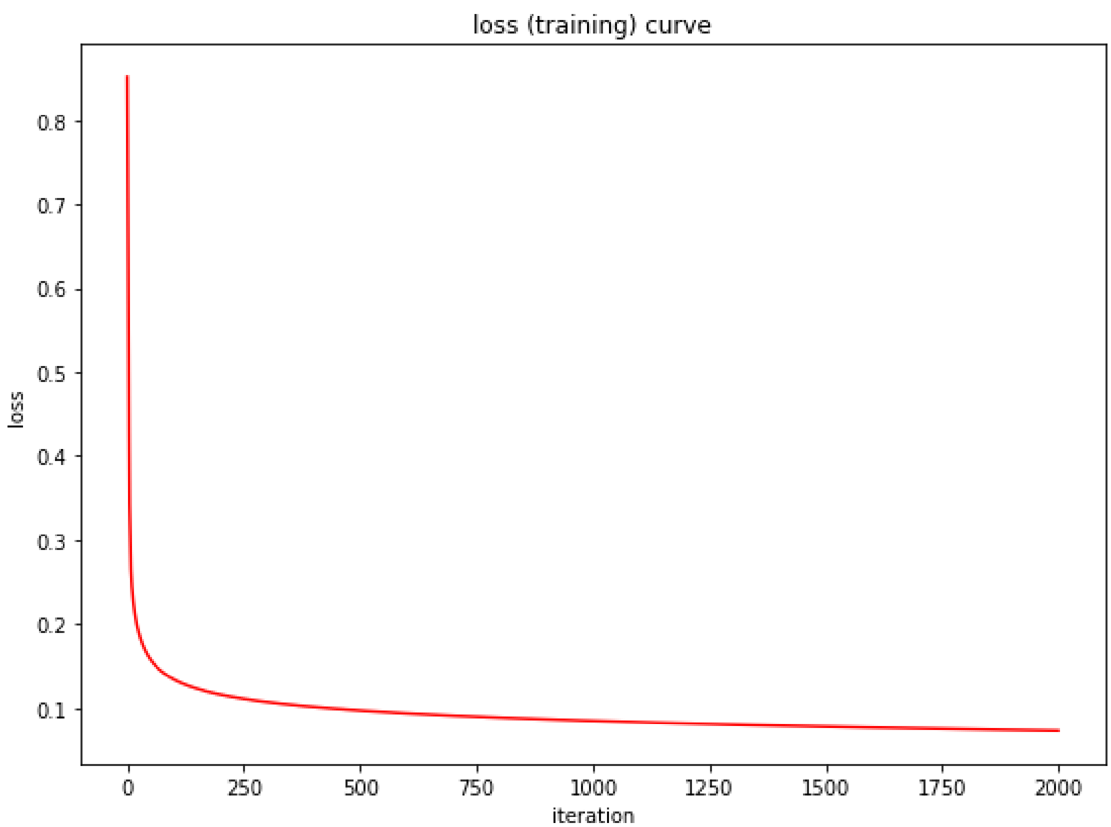
2.5 # 05. plot the input images for '4'

[ ]:
```
function_results_05(x_train,2,4)
```



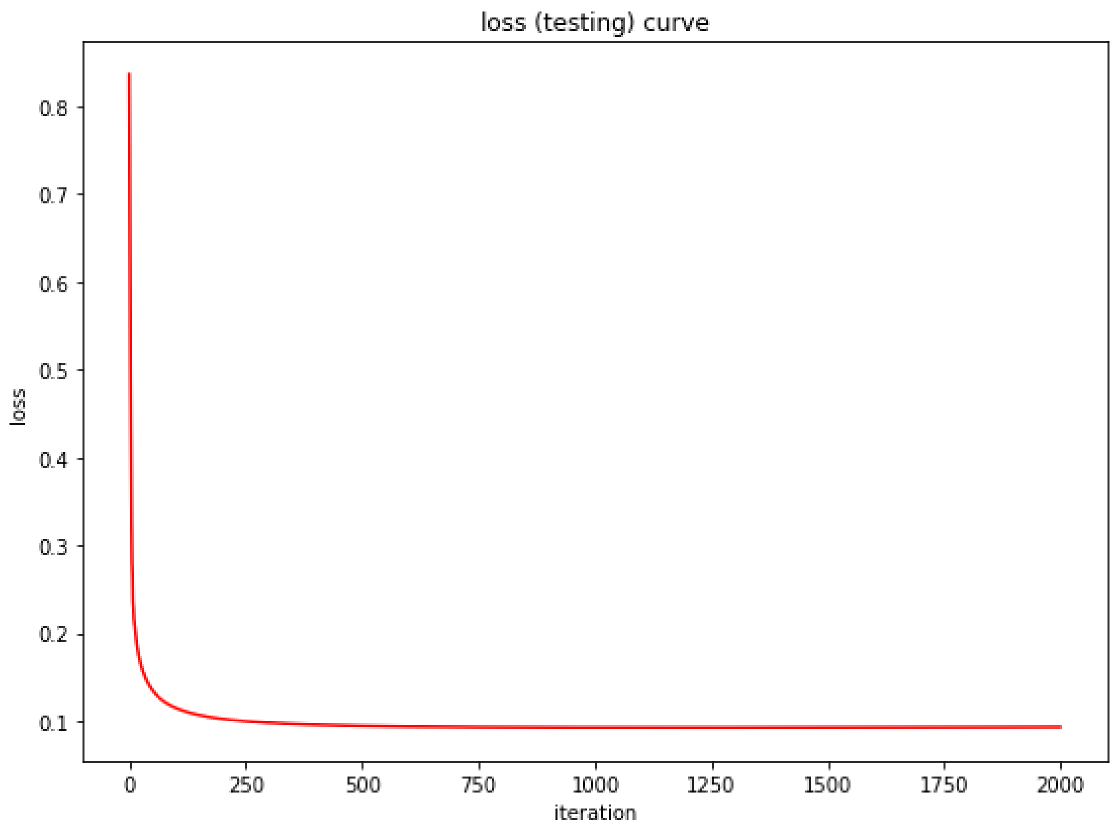
2.6 # 06. plot the training loss curve (x-axis: iteration, y-axis: loss)

[ ]:
```
function_results_06()
```



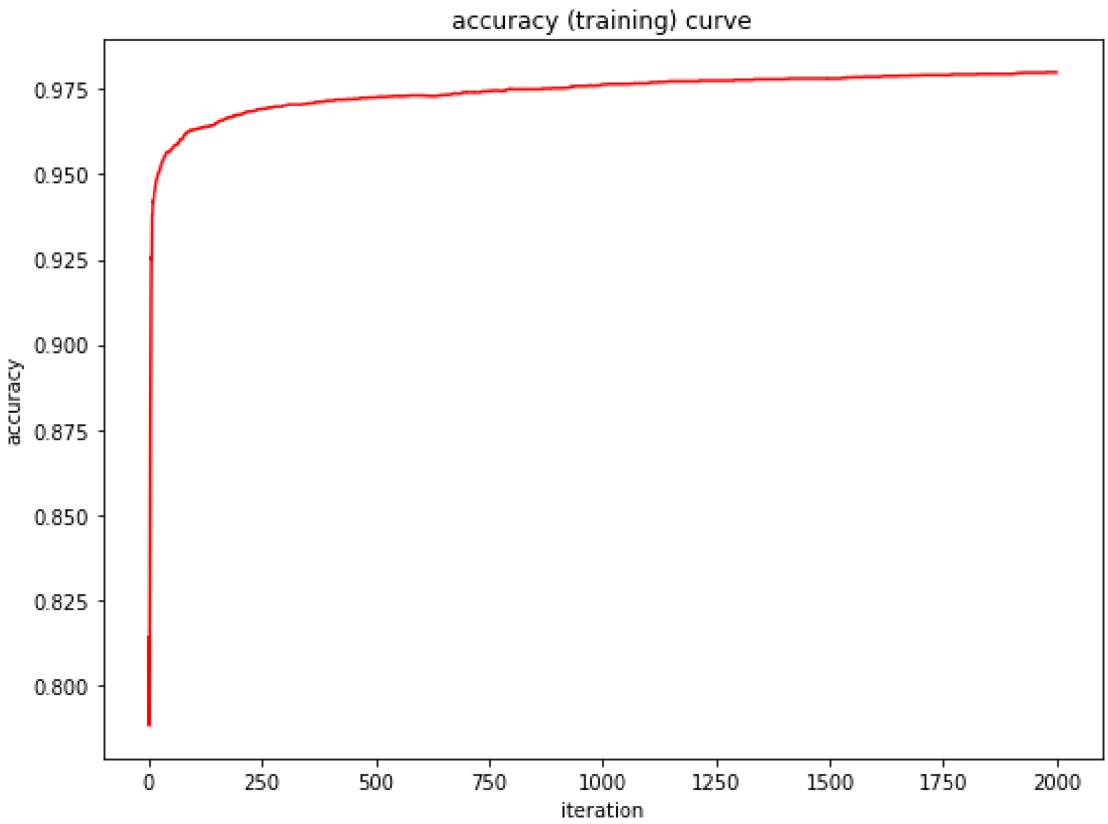
2.7 # 07. plot the testing loss curve (x-axis: iteration, y-axis: loss)

[ ]:
```
function_results_07()
```



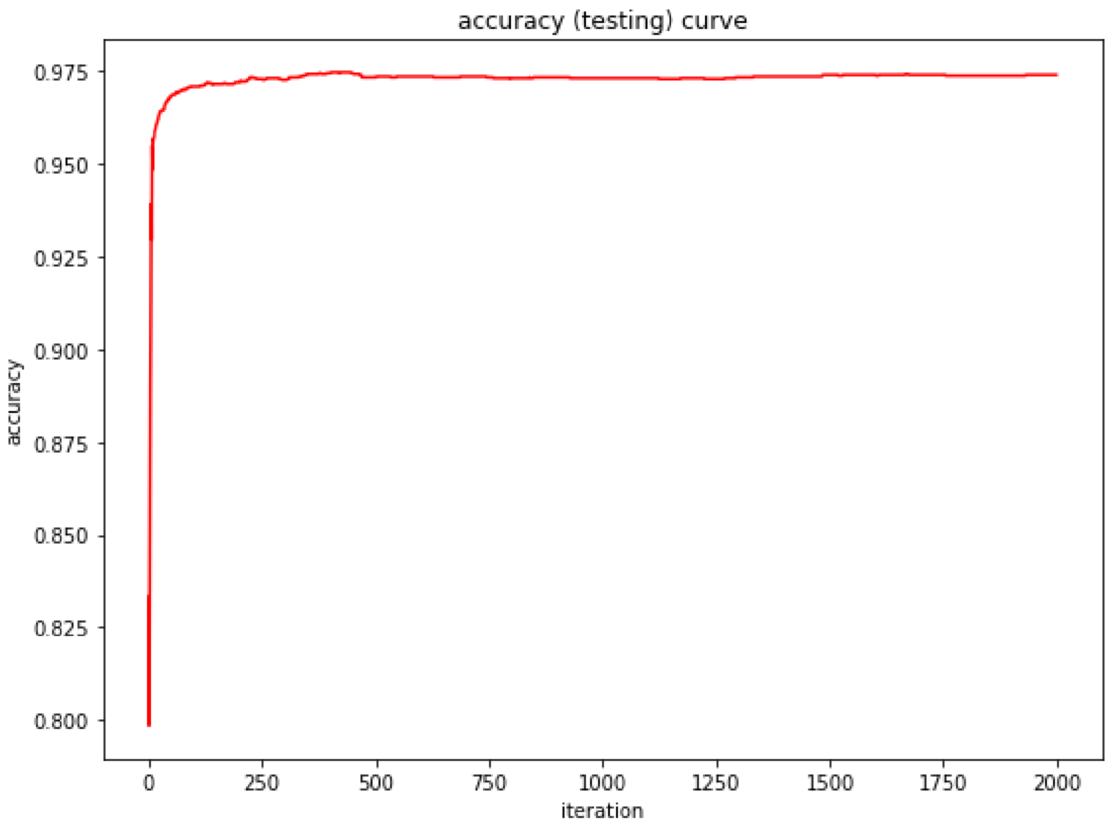
2.8 # 08. plot the training accuracy curve (x-axis: iteration, y-axis: accuracy)

[ ]:
```
function_results_08()
```



2.9 # 09. plot the testing accuracy curve (x-axis: iteration, y-axis: accuracy)

[ ]:
```
function_results_09()
```



2.10 # 10. print the training loss at iterations 0, 100, 200, 300, 400, 500, 600, 700, 800, 900

[ ]:
```
function_results_10(loss_train_iteration)
```

```
index =    0, value = 0.8516388787
index =  100, value = 0.1339429389
index =  200, value = 0.1157748007
index =  300, value = 0.1069166127
index =  400, value = 0.1011699953
index =  500, value = 0.0969356204
index =  600, value = 0.0935861772
index =  700, value = 0.0908157813
index =  800, value = 0.0884532877
index =  900, value = 0.0863934761
```

2.11 # 11. print the testing loss at iterations 0, 100, 200, 300, 400, 500, 600, 700, 800, 900

[ ]:
```
function_results_11(loss_test_iteration)
```

```
index =    0, value = 0.8360542535
index =  100, value = 0.1155831250
index =  200, value = 0.1030645859
index =  300, value = 0.0984429816
index =  400, value = 0.0961438411
index =  500, value = 0.0948397523
index =  600, value = 0.0940481203
index =  700, value = 0.0935513893
index =  800, value = 0.0932376237
index =  900, value = 0.0930438257
```

2.12 # 12. print the training accuracy at iterations 0, 100, 200, 300, 400, 500, 600, 700, 800, 900

[ ]:
```
function_results_12(accuracy_train_iteration)
```

```
index =    0, value = 0.8142000000
index =  100, value = 0.9630000000
index =  200, value = 0.9674000000
index =  300, value = 0.9701000000
index =  400, value = 0.9716000000
index =  500, value = 0.9725000000
index =  600, value = 0.9731000000
index =  700, value = 0.9739000000
index =  800, value = 0.9749000000
index =  900, value = 0.9752000000
```

2.13 # 13. print the testing accuracy at iterations 0, 100, 200, 300, 400, 500, 600, 700, 800, 900

[ ]:
```
function_results_13(accuracy_test_iteration)
```

```
index =    0, value = 0.8331111111
index =  100, value = 0.9708888889
index =  200, value = 0.9720000000
index =  300, value = 0.9726666667
index =  400, value = 0.9744444444
index =  500, value = 0.9733333333
index =  600, value = 0.9735555556
index =  700, value = 0.9735555556
index =  800, value = 0.9731111111
index =  900, value = 0.9733333333
```

[ ]:

```

```