Multi-class classification using pytorch

import library

In [1]:

```
import torch
import torch.nn as nn
import torch.nn.functional as F
import torchvision
from torch.utils.data import Dataset
from torchvision import datasets, transforms
import torchvision.transforms.functional as F
import numpy as np
import matplotlib.pyplot as plt
import math
from tqdm import tqdm
import random
import os
```

load data

In [2]:

```
directory_data  = './'
filename_data   = 'assignment_06_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']

num_data_train  = x_train.shape[0]
num_data_test   = x_test.shape[0]
```

In [3]:

```
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 : (20000, 32, 32)
size of y_train : (20000,)
**************************************************
size of x_test : (8000, 32, 32)
size of y_test : (8000,)
**************************************************
number of training image : 20000
height of training image : 32
width of training image : 32
**************************************************
number of testing image : 8000
height of testing image : 32
width of testing image : 32
**************************************************
```

number of classes

In [4]:

```
print('**************************************************')
print('number of classes :', len(set(y_train)))
print('**************************************************')
```

```
**************************************************
number of classes : 10
**************************************************
```

custom data loader for the PyTorch framework

In [5]:

```
class dataset(Dataset):

    def __init__(self, image, label):

        self.image  = image
        self.label  = label.astype(int)

    def __getitem__(self, index):

        image   = self.image[index, :, :]
        label   = self.label[index, ]

        image   = torch.FloatTensor(image).unsqueeze(dim=0)
        label   = torch.LongTensor([label])

        return image, label

    def __len__(self):

        return self.image.shape[0]

    def collate_fn(self, batch):
        images  = list()
        labels  = list()

        for b in batch:
            images.append(b[0])
            labels.append(b[1])

        images  = torch.stack(images, dim=0)
        labels  = torch.stack(labels, dim=0).squeeze()

        return images, labels
```

setting device (cpu or gpu)

In [6]:

```
device = torch.device('cuda' if torch.cuda.is_available() else
                      'mps' if torch.backends.mps.is_built() and torch.backends.
mps.is_available() else
                      'cpu')
```

In [7]:

```
print(device)
```

cuda

construct datasets and dataloaders for training and testing

In [93]:

```
# ==================================================
# determine the value of the following parameter
#
size_minibatch      = 32
#
# ==================================================

dataset_train       = dataset(x_train, y_train)
dataset_test        = dataset(x_test, y_test)

dataloader_train    = torch.utils.data.DataLoader(dataset_train, batch_size=size_minibatch, shuffle=True, drop_last=True, collate_fn=dataset_train.collate_fn)
dataloader_test     = torch.utils.data.DataLoader(dataset_test, batch_size=size_minibatch, shuffle=True, drop_last=True, collate_fn=dataset_test.collate_fn)
```

shape of the data when using the data loader

In [94]:

```
image, label    = next(iter(dataloader_train))
```

In [95]:

```
print('************************************************************')
print('size of mini-batch of the image:', image.shape)
print('************************************************************')
print('size of mini-batch of the label:', label.shape)
print('************************************************************')
```

```
************************************************************
size of mini-batch of the image: torch.Size([32, 1, 32, 32])
************************************************************
size of mini-batch of the label: torch.Size([32])
************************************************************
```

construct a neural network

In [107]:

```
# ==================================================
# define the neural network architecture
#
class Classifier(nn.Module):
    def __init__(self):
        super(Classifier, self).__init__()

        self.feature    = nn.Sequential(
            # 98.675
            nn.Conv2d(in_channels=1, out_channels=64, kernel_size=3, stride=1, p
adding=1),
            nn.ReLU(),
            nn.Conv2d(in_channels=64, out_channels=64, kernel_size=3, stride=1,
padding=1),
            nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),

            nn.Conv2d(in_channels=64, out_channels=128, kernel_size=3, stride=1,
padding=0),
            nn.ReLU(),
            nn.Conv2d(in_channels=128, out_channels=128, kernel_size=3, stride=1
, padding=0),
            nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),

            nn.Conv2d(in_channels=128, out_channels=256, kernel_size=3, stride=1
, padding=0),
            nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
        )

        self.classifier = nn.Sequential(
            # 98.675
            nn.Linear(1024, 512),
            nn.ReLU(),
            nn.Linear(512, 10)
        )

        self.network    = nn.Sequential(
            self.feature,
            nn.Flatten(),
            self.classifier,
        )

        self.initialize()


    def initialize(self):

        for m in self.network.modules():

            if isinstance(m, nn.Conv2d):
                #nn.init.constant_(m.weight, 0.01)
                nn.init.xavier_uniform_(m.weight)
                nn.init.constant_(m.bias, 1)

            elif isinstance(m, nn.Linear):
```

```
                #nn.init.constant_(m.weight, 0.01)
                nn.init.xavier_uniform_(m.weight)
                nn.init.constant_(m.bias, 1)


    def forward(self, input):

        output = self.network(input)

        return output
#
# ==================================================
```

build network

In [109]:

```
# ==================================================
# determine the value of the following parameter
#
learning_rate   = 0.01
weight_decay    = 0.0001
#
# ==================================================

classifier      = Classifier().to(device)
optimizer       = torch.optim.SGD(classifier.parameters(), lr=learning_rate, wei
ght_decay=weight_decay)
```

In [110]:

```
print(classifier)
```

```
Classifier(
  (feature): Sequential(
    (0): Conv2d(1, 64, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1))
    (1): ReLU()
    (2): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1))
    (3): ReLU()
    (4): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, c
eil_mode=False)
    (5): Conv2d(64, 128, kernel_size=(3, 3), stride=(1, 1))
    (6): ReLU()
    (7): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1))
    (8): ReLU()
    (9): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, c
eil_mode=False)
    (10): Conv2d(128, 256, kernel_size=(3, 3), stride=(1, 1))
    (11): ReLU()
    (12): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=1024, out_features=512, bias=True)
    (1): ReLU()
    (2): Linear(in_features=512, out_features=10, bias=True)
  )
  (network): Sequential(
    (0): Sequential(
      (0): Conv2d(1, 64, kernel_size=(3, 3), stride=(1, 1), padding=
(1, 1))
      (1): ReLU()
      (2): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding
=(1, 1))
      (3): ReLU()
      (4): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
      (5): Conv2d(64, 128, kernel_size=(3, 3), stride=(1, 1))
      (6): ReLU()
      (7): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1))
      (8): ReLU()
      (9): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
      (10): Conv2d(128, 256, kernel_size=(3, 3), stride=(1, 1))
      (11): ReLU()
      (12): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=
1, ceil_mode=False)
    )
    (1): Flatten(start_dim=1, end_dim=-1)
    (2): Sequential(
      (0): Linear(in_features=1024, out_features=512, bias=True)
      (1): ReLU()
      (2): Linear(in_features=512, out_features=10, bias=True)
    )
  )
)
```

compute the prediction

In [45]:

```
def compute_prediction(model, input):

# ==================================================
# fill up the blank
#
    prediction = model(input)
#
# ==================================================

    return prediction
```

compute the loss

- use `CrossEntropyLoss`
- compute loss and its value (`loss.item()`)

In [46]:

```
def compute_loss(prediction, label):

# ==================================================
# fill up the blank
#

    loss_fn     = nn.CrossEntropyLoss()
    loss        = loss_fn(prediction, label)

#
# ==================================================

    return loss
```

compute the loss value

In [47]:

```
def compute_loss_value(loss):

    loss_value = loss.item()

    return loss_value
```

compute the accuracy

- accuracy in percentile : 0 - 100 (%)

In [66]:

```
def compute_accuracy(prediction, label):

# ==================================================
# fill up the blank
#

    accuracy = torch.argmax(prediction, dim=1) == label
    accuracy = accuracy.to(torch.float).mean().item()
    accuracy = accuracy * 100

#
# ==================================================

    return accuracy
```

variables for the learning curve

In [482]:

```
# ==================================================
# determine the value of the following parameter
#
number_epoch        = 1230
#
# ==================================================

loss_train_mean     = np.zeros(number_epoch)
loss_train_std      = np.zeros(number_epoch)
accuracy_train_mean = np.zeros(number_epoch)
accuracy_train_std  = np.zeros(number_epoch)

loss_test_mean      = np.zeros(number_epoch)
loss_test_std       = np.zeros(number_epoch)
accuracy_test_mean  = np.zeros(number_epoch)
accuracy_test_std   = np.zeros(number_epoch)
```

train and test

In [483]:

```
# ==============================================================================
==
#
# iterations for epochs
#
# ==============================================================================
==
for i in tqdm(range(number_epoch)):

    # ==========================================================================
======
    #
    # training
    #
    # ==========================================================================
======
    loss_train_epoch        = []
    accuracy_train_epoch    = []

    classifier.train()

    for index_batch, (image_train, label_train) in enumerate(dataloader_train):

        image_train = image_train.to(device)
        label_train = label_train.to(device)

# ==================================================
# fill up the blank
#

        prediction_train        = compute_prediction(classifier, image_train)
        loss_train              = compute_loss(prediction_train, label_train)
        loss_value_train        = compute_loss_value(loss_train)
        accuracy_train          = compute_accuracy(prediction_train, label_train
)

#
# ==================================================

        loss_train_epoch.append(loss_value_train)
        accuracy_train_epoch.append(accuracy_train)

# ==================================================
# fill up the blank (update model parameters using a mini-batch)
#
        optimizer.zero_grad()
        loss_train.backward()
        optimizer.step()
#
# ==================================================


    loss_train_mean[i]      = np.mean(loss_train_epoch)
    loss_train_std[i]       = np.std(loss_train_epoch)

    accuracy_train_mean[i]  = np.mean(accuracy_train_epoch)
    accuracy_train_std[i]   = np.std(accuracy_train_epoch)
```

```
    # for continuous learning
#     loss_train_mean = np.append(loss_train_mean, np.mean(loss_train_epoch))
#     loss_train_std = np.append(loss_train_std, np.mean(loss_train_epoch))
#     accuracy_train_mean = np.append(accuracy_train_mean, np.mean(accuracy_trai
n_epoch))
#     accuracy_train_std = np.append(accuracy_train_std, np.std(accuracy_train_e
poch))

    # ================================================================================
======
    #
    # testing
    #
    # ================================================================================
======
    loss_test_epoch        = []
    accuracy_test_epoch    = []

    classifier.eval()

    for index_batch, (image_test, label_test) in enumerate(dataloader_test):

        image_test = image_test.to(device)
        label_test = label_test.to(device)

# ==================================================
# fill up the blank
#

        prediction_test = compute_prediction(classifier, image_test)
        loss_test       = compute_loss(prediction_test, label_test)
        loss_value_test = compute_loss_value(loss_test)
        accuracy_test   = compute_accuracy(prediction_test, label_test)

#
# ==================================================

        loss_test_epoch.append(loss_value_test)
        accuracy_test_epoch.append(accuracy_test)

    loss_test_mean[i]       = np.mean(loss_test_epoch)
    loss_test_std[i]        = np.std(loss_test_epoch)

    accuracy_test_mean[i]   = np.mean(accuracy_test_epoch)
    accuracy_test_std[i]    = np.std(accuracy_test_epoch)

    # for continuous learning
#     loss_test_mean = np.append(loss_test_mean, np.mean(loss_test_epoch))
#     loss_test_std = np.append(loss_test_std, np.std(loss_test_epoch))
#     accuracy_test_mean = np.append(accuracy_test_mean, np.mean(accuracy_test_e
poch))
#     accuracy_test_std = np.append(accuracy_test_std, np.std(accuracy_test_epoc
h))
```

```
100%|████████████████████████████████████████████████████████████
█████████████████| 1230/1230 [1:31:39<00:00,  4.47s/it]
```

functions for presenting the results

In [24]:

```
def function_result_01():

    title           = 'loss (training)'
    label_axis_x    = 'epoch'
    label_axis_y    = 'loss'
    color_mean      = 'red'
    color_std       = 'blue'
    alpha           = 0.3

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

    plt.plot(range(len(loss_train_mean)), loss_train_mean, '-', color = color_me
an)
    plt.fill_between(range(len(loss_train_mean)), loss_train_mean - loss_train_s
td, loss_train_mean + loss_train_std, facecolor = color_std, alpha = alpha)

    plt.xlabel(label_axis_x)
    plt.ylabel(label_axis_y)

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

In [25]:

```
def function_result_02():

    title           = 'loss (testing)'
    label_axis_x    = 'epoch'
    label_axis_y    = 'loss'
    color_mean      = 'red'
    color_std       = 'blue'
    alpha           = 0.3

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

    plt.plot(range(len(loss_test_mean)), loss_test_mean, '-', color = color_mean
)
    plt.fill_between(range(len(loss_test_mean)), loss_test_mean - loss_test_std,
loss_test_mean + loss_test_std, facecolor = color_std, alpha = alpha)

    plt.xlabel(label_axis_x)
    plt.ylabel(label_axis_y)

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

In [26]:

```
def function_result_03():

    title           = 'accuracy (training)'
    label_axis_x    = 'epoch'
    label_axis_y    = 'accuracy'
    color_mean      = 'red'
    color_std       = 'blue'
    alpha           = 0.3

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

    plt.plot(range(len(accuracy_train_mean)), accuracy_train_mean, '-', color =
color_mean)
    plt.fill_between(range(len(accuracy_train_mean)), accuracy_train_mean - accu
racy_train_std, accuracy_train_mean + accuracy_train_std, facecolor = color_std,
alpha = alpha)

    plt.xlabel(label_axis_x)
    plt.ylabel(label_axis_y)

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

In [27]:

```
def function_result_04():

    title           = 'accuracy (testing)'
    label_axis_x    = 'epoch'
    label_axis_y    = 'accuracy'
    color_mean      = 'red'
    color_std       = 'blue'
    alpha           = 0.3

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

    plt.plot(range(len(accuracy_test_mean)), accuracy_test_mean, '-', color = co
lor_mean)
    plt.fill_between(range(len(accuracy_test_mean)), accuracy_test_mean - accura
cy_test_std, accuracy_test_mean + accuracy_test_std, facecolor = color_std, alph
a = alpha)

    plt.xlabel(label_axis_x)
    plt.ylabel(label_axis_y)

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

In [28]:

```
def function_result_05():

    print('final training accuracy = %9.8f' % (accuracy_train_mean[-1]))
```

In [29]:

```
def function_result_06():

    print('final testing accuracy = %9.8f' % (accuracy_test_mean[-1]))
```

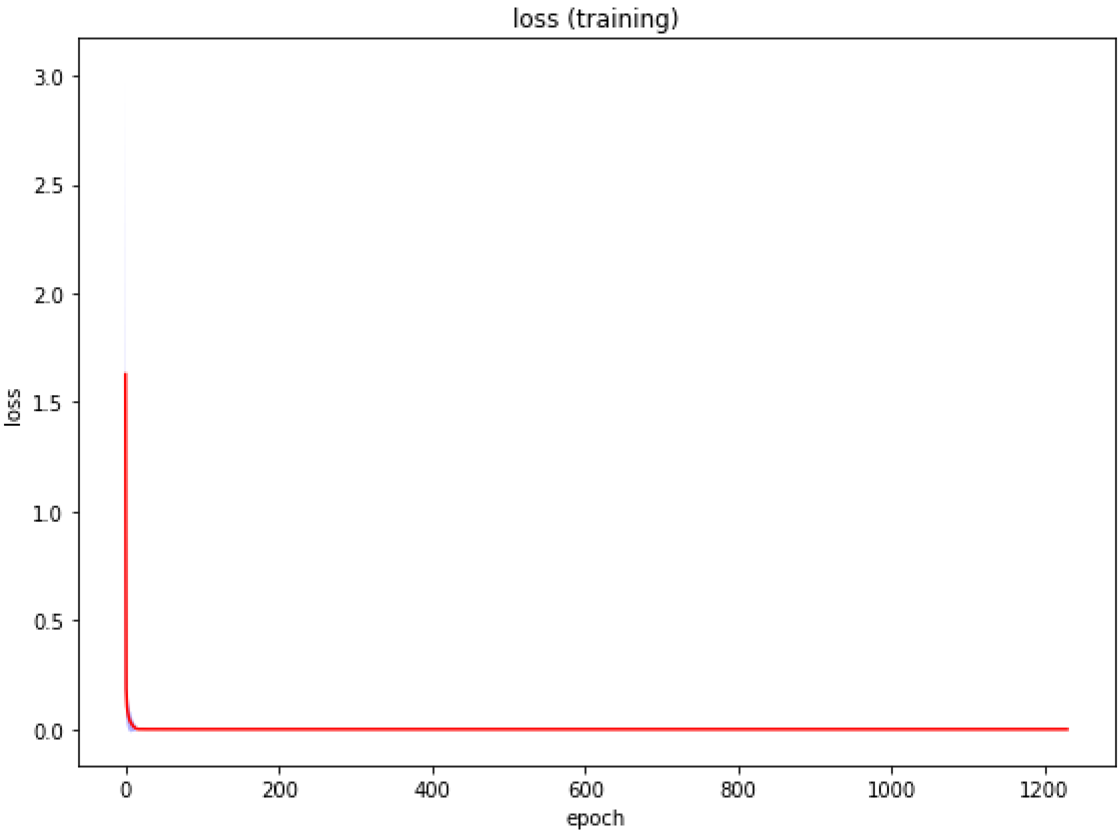
---

results

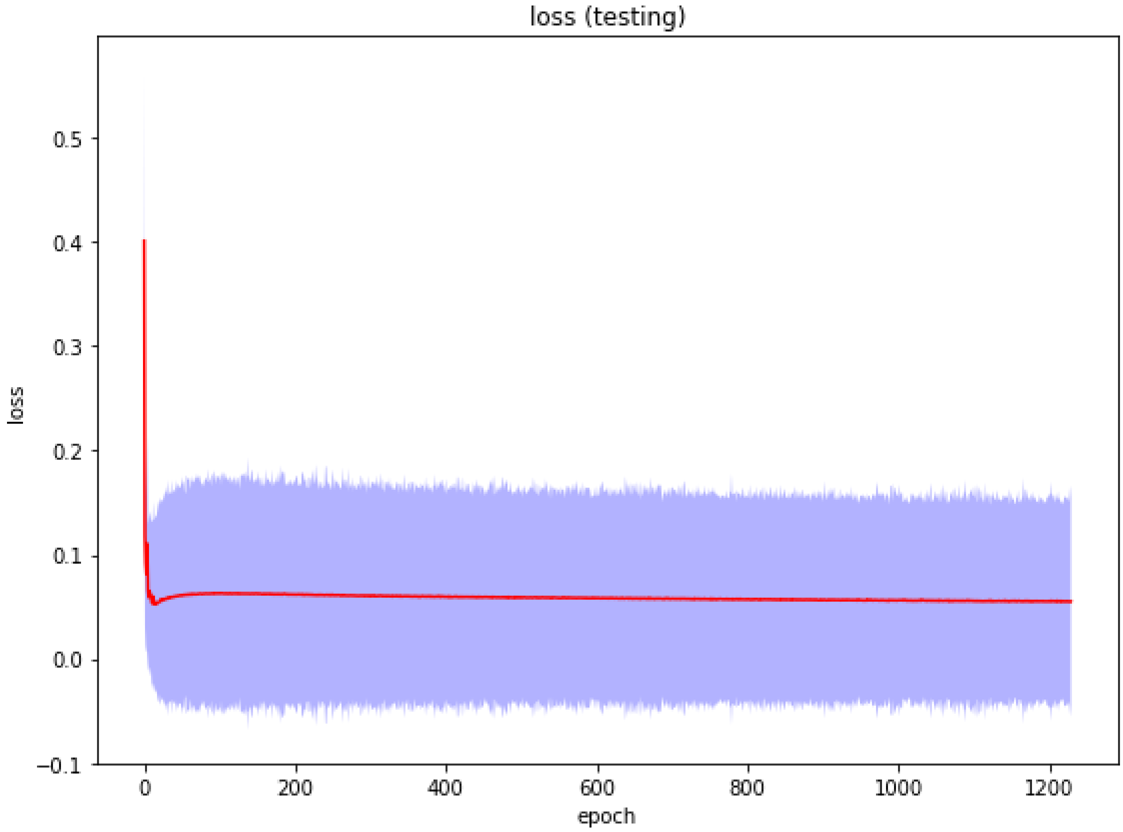
In [484]:

```
number_result = 6

for i in range(number_result):

    title           = '# RESULT # {:02d}'.format(i+1)
    name_function   = 'function_result_{:02d}()'.format(i+1)

    print('')
    print('################################################################################')
    print('#')
    print(title)
    print('#')
    print('################################################################################')
    print('')

    eval(name_function)
```

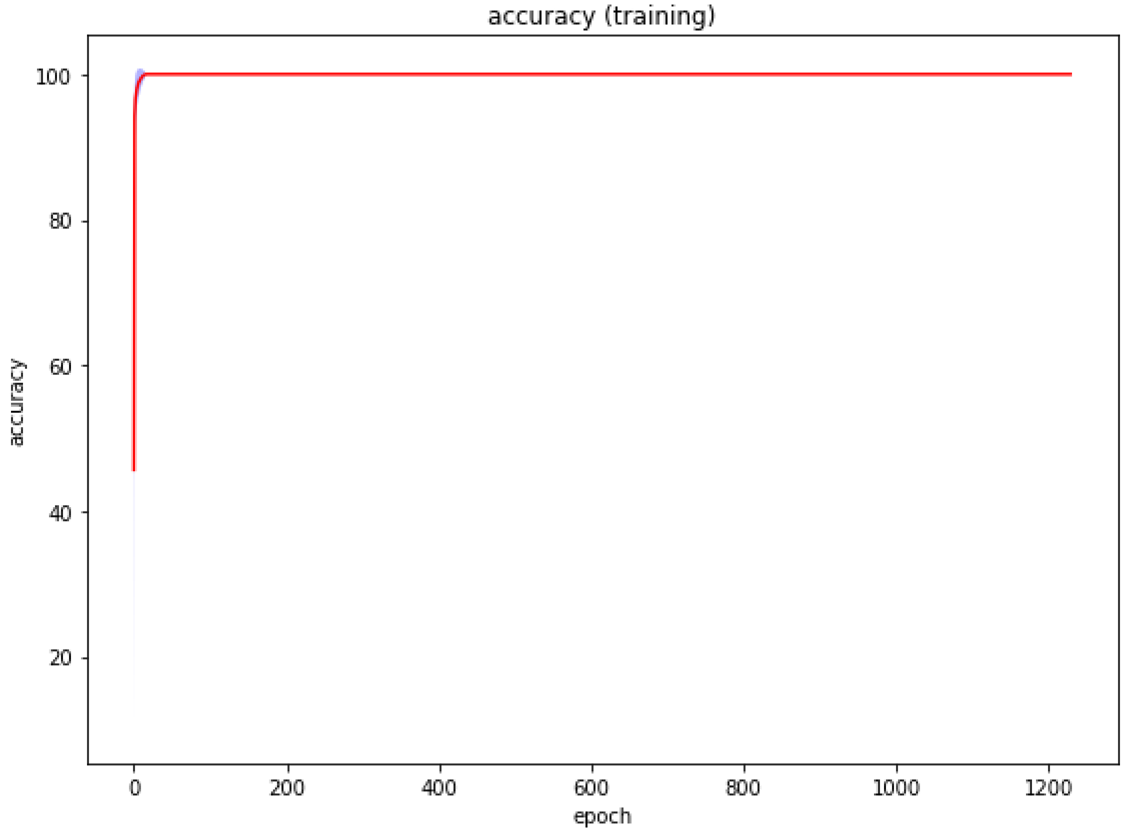
```
################################################################################
#
# RESULT # 01
#
################################################################################
```



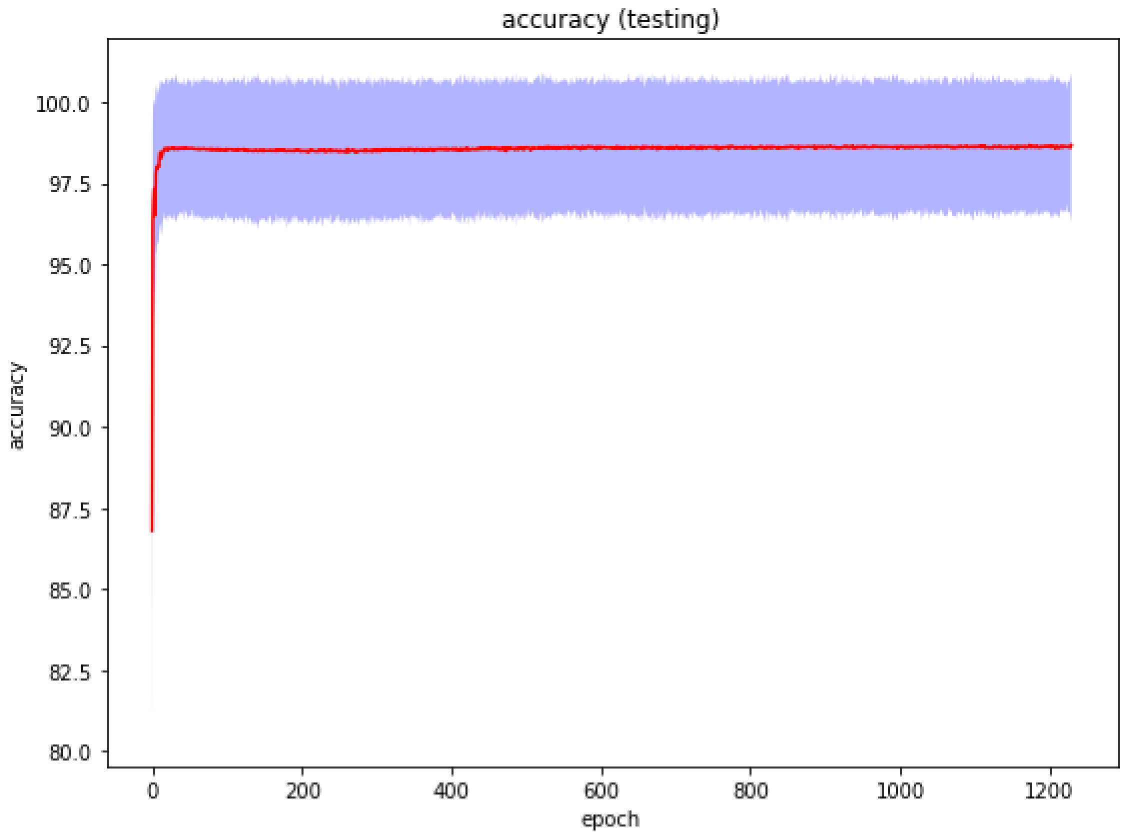

```
################################################################################
#
# RESULT # 02
#
################################################################################
```


loss (testing)
loss
epoch
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
0
200
400
600
800
1000
1200

```
########################################################################
#
# RESULT # 03
#
########################################################################
```


accuracy (training)
accuracy
epoch
100
80
60
40
20
0
200
400
600
800
1000
1200

```
####################################################################
############
#
# RESULT # 04
#
####################################################################
############
```




```
################################################################################
#
# RESULT # 05
#
################################################################################

final training accuracy = 100.00000000

################################################################################
#
# RESULT # 06
#
################################################################################

final testing accuracy = 98.67500305
```