Môn học: Machine Learning

Giảng viên: TS. Lê Thành Sách

Bài tập lớn số 1 : Bản hiện thực mạng CNN với numpy

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Mô tả bài tập lớn: Nhóm hiện thực một mạng CNN với nhiều layer khác nhau, dựa trên mô hình cấu trúc của thư viện Keras, gồm:

- **Model chính:** class Sequential quản lí việc forward dữ liệu và backward đạo hàm quua list các layers
- **Các layers:** Gồm các loại như Convolution2D, MaxPooling2D, Dropout, Flatten, Dense (Fully Connected)
- **Các hàm Activation:** Gồm hàm Relu, Sigmoid và Softmax (được chứa trong mỗi layer)
- **Hàm Loss :** Cross Entropy (được chứa trong class Sequential)

Install, import & setup

In [0]:

```
import numpy as np
import math
import numpy
import struct
import sys
import time
import keras
from sklearn.metrics import accuracy_score
import matplotlib.pyplot as plt
plt.style.use('seaborn-whitegrid')
eps = np.finfo(float).eps
from google.colab import drive
```

```
Using TensorFlow backend.
```

In [0]:

```
drive.mount('/content/drive')
sys.path.append('drive/My Drive/Colab Notebooks/')
```

```
Go to this URL in a browser: https://accounts.google.com/o/oauth2/au
th?client_id=947318989803-6bn6qk8qdgf4n4g3pfee6491hc0brc4i.apps.goog
leusercontent.com&redirect_uri=urn%3Aietf%3Awg%3Aoauth%3A2.0%3Aoob&s
cope=email%20https%3A%2F%2Fwww.googleapis.com%2Fauth%2Fdocs.test%20h
ttps%3A%2F%2Fwww.googleapis.com%2Fauth%2Fdrive%20https%3A%2F%2Fwww.g
oogleapis.com%2Fauth%2Fdrive.photos.readonly%20https%3A%2F%2Fwww.goo
gleapis.com%2Fauth%2Fpeopleapi.readonly&response_type=code

Enter your authorization code:
..........
Mounted at /content/drive
```

Load data, format & visualize

In [0]:

```
train_images_path = 'drive/My Drive/Colab Notebooks/Asgmt_ML_CNN/data/train-imag
es'
train_labels_path = 'drive/My Drive/Colab Notebooks/Asgmt_ML_CNN/data/train-labe
ls'
test_images_path = 'drive/My Drive/Colab Notebooks/Asgmt_ML_CNN/data/t10k-image
s'
test_label_path = 'drive/My Drive/Colab Notebooks/Asgmt_ML_CNN/data/t10k-labels'


def read_idx(filename):
    with open(filename, 'rb') as f:
        zero, data_type, dims = struct.unpack('>HBB', f.read(4))
        shape = tuple(struct.unpack('>I', f.read(4))[0] for d in range(dims))

        return numpy.fromstring(f.read(), dtype=np.uint8).reshape(shape)

def load_mnist_data():
  train_data = [read_idx(train_images_path), read_idx(train_labels_path)]
  test_data = [read_idx(test_images_path), read_idx(test_label_path)]
  return train_data, test_data
```

In [0]:

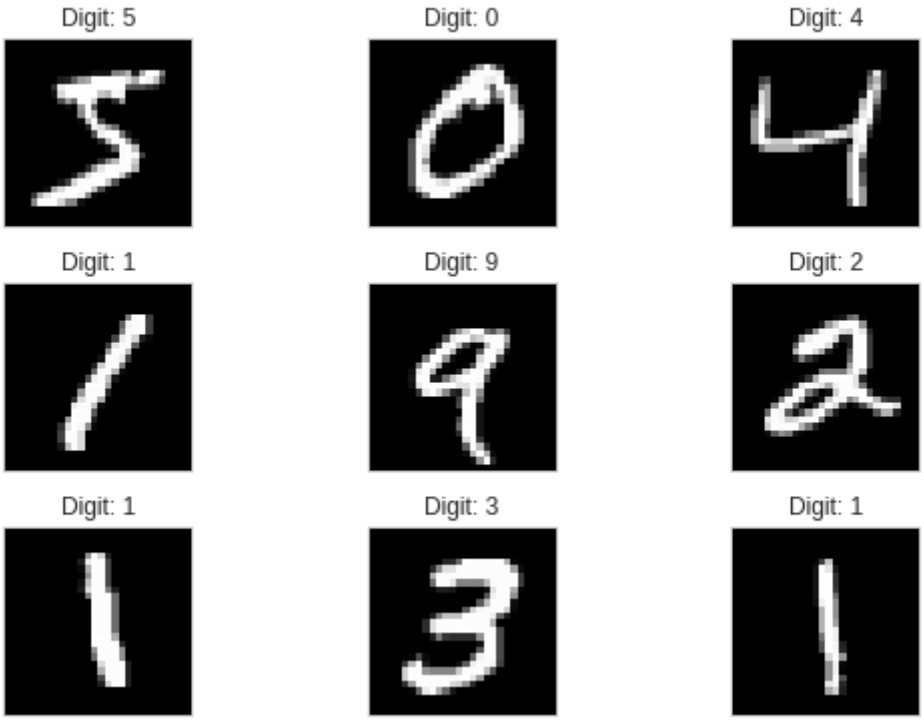
```
train_data, test_data = load_mnist_data()
X_train = train_data[0]
y_train = train_data[1]
X_test = test_data[0]
y_test = test_data[1]

X_train = np.array(X_train)
y_train = np.array(y_train)
X_test = np.array(X_test)
y_test = np.array(y_test)
```

```
/usr/local/lib/python3.6/dist-packages/ipykernel_launcher.py:11: Dep
recationWarning: The binary mode of fromstring is deprecated, as it
behaves surprisingly on unicode inputs. Use frombuffer instead
  # This is added back by InteractiveShellApp.init_path()
```

In [0]:

```
fig = plt.figure()
for i in range(9):
  plt.subplot(3,3,i+1)
  plt.tight_layout()
  plt.imshow(X_train[i], cmap='gray', interpolation='none')
  plt.title("Digit: {}".format(y_train[i]))
  plt.xticks([])
  plt.yticks([])
```



In [0]:

```
img_rows = 28
img_cols = 28
#Chuyển ảnh về format channel first
X_train_norm = X_train.reshape(X_train.shape[0], 1, img_rows, img_cols)
X_test_norm = X_test.reshape(X_test.shape[0], 1, img_rows, img_cols)
input_shape = (1, img_rows, img_cols)

#Chuyển ảnh về dạng channel last
# X_train = X_train.reshape(X_train.shape[0], img_rows, img_cols, 1)
# X_test = X_test.reshape(X_test.shape[0], img_rows, img_cols, 1)
# input_shape = (img_rows, img_cols, 1)

X_train_norm = X_train_norm.astype('float32')
X_test_norm = X_test_norm.astype('float32')
X_train_norm /= 255
X_test_norm /= 255

# X_train_crop = np.array([x[0, 12:16, 12:16] for x in X_train_norm])
# X_test_crop = np.array([x[0, 12:16, 12:16] for x in X_test_norm])
# X_train_crop = X_train_crop.reshape(60000, 1, 4, 4)
#X_test_crop = X_test_crop.reshape(X_test.shape[0], 1, img_rows, img_cols)

print('X_train shape:', X_train.shape)
```

```
X_train shape: (60000, 28, 28)
```

In [0]:

```
#Chuyển tập target về dạng one-hot
def get_one_hot(targets, nb_classes):
    res = np.eye(nb_classes)[np.array(targets).reshape(-1)]
    return res.reshape(list(targets.shape)+[nb_classes])

num_category = 10 #ứng với 10 label từ 0->9
y_train_norm = get_one_hot(y_train, num_category)
y_test_norm = get_one_hot(y_test, num_category)
print('y_train shape:', y_train_norm.shape)
```

```
y_train shape: (60000, 10)
```

----------CNN - numpy inplementation----------

Model - Sequential

Class Sequential đóng vai trò nắm giữ các layers, quản lí việc forward, backward

Có hiện thực các hàm evaluate, hỗ trợ predict và predict_class

In [0]:

```
#Class đóng vai trò là model, quản lí việc forward và backward cho các layers
class Sequential:
  def __init__(self):
    self.layer_list = list()

  def add(self, new_layer):
    self.layer_list.append(new_layer)

  def compile(self, loss = 'cross_entropy'):
    if loss == 'cross_entropy':
      self.loss = CrossEntropy()
    else:
      pass #Có thể hiện thực thêm nhiều hàm lỗi khác

  def fit(self, X_train, y_train, batch_size = 128, num_epoch = 10, validation_d
ata = None):
    self.X_train = X_train
    self.y_train = y_train

    train_loss_list = list()
    val_loss_list = list()
    epoch_time_list = list()

    for epoch in range(num_epoch):
      epoch_loss = list()
      for num_batch in range(X_train.shape[0] // batch_size):
        current_index = num_batch*batch_size
        image_batch = X_train[current_index : current_index + batch_size] #Lấy
 các ảnh ứng với epoch
        target_batch = y_train[current_index : current_index + batch_size] #Lấy
 các target ứng với các ảnh

        for index, image in enumerate(image_batch):
          output = self.feed_forward(image) #Feed từng ảnh qua mạng
          self.loss.feed_forward(output, target_batch[index]) #Add ouput của la
yer cuối cùng vào hàm loss

        batch_avg_loss = self.loss.get_avg_loss(batch_size)
        epoch_loss.append(batch_avg_loss)
#           avg_grad = self.loss.backward(batch_size)
        avg_grad = target_batch[index]
        self.backward(avg_grad)
        self.loss.reset()

      epoch_avg_loss = sum(epoch_loss) / len(epoch_loss)

      train_loss_list.append(epoch_avg_loss)
      epoch_time_list.append(epoch)

      if validation_data is not None:
        val_loss = self.evaluate(validation_data[0], validation_data[1])
        val_loss_list.append(val_loss)
        print("Epoch ", epoch,"- Training loss: ", np.round(epoch_avg_loss, 14),
 " - Validating loss: ", val_loss)
      else:
        print("Epoch ", epoch,"- Training Loss: ", epoch_avg_loss)

    plt.plot(epoch_time_list, train_loss_list)
    plt.plot(epoch_time_list, val_loss_list)
```

```
    plt.legend(('Train', 'Val'))
    plt.xlabel('Epoch:')
    plt.ylabel('Loss: ')
    plt.show(block=False)


  def feed_forward(self, data, isTrain = True):
    layer_input = data
    for layer in self.layer_list:
#       print('Feedforward through layer: ',type(layer)) ##
      if not isTrain and type(layer) is Dropout: #Biế´n isTrain đê̂ bypass layer
 Dropout
        continue
      layer_input = layer.feed_forward(layer_input)
#       print("Output :", np.around(layer_input, decimals = 4), layer_input.shap
e) ##

    #Sau khi feed qua tâ´t ca̛ layer thì biế´n layer_input chứa output cưa laye
r cuô´i cùng
    return layer_input

  def backward(self, dY, isTrain = True):
    layer_grad = dY
    for layer in reversed(self.layer_list):
#       print('Back-forward through layer: ', type(layer)) ##
      if isTrain == False and type(layer) is Dropout:
        continue
      layer_grad = layer.backward(layer_grad)
#       print ("Output: ", np.around(layer_grad, decimals = 4), layer_grad.shap
e) ##


  def evaluate(self, X_test, y_test):
    output_list = list()
    for index, image in enumerate(X_test):
      output = self.feed_forward(image, isTrain = False)
      output_list.append(output)
      self.loss.feed_forward(output, y_test[index])
    avg_loss = self.loss.get_avg_loss(len(y_test))
    self.loss.reset()
    return avg_loss

  def predict(self, X_test):
    output_list = list()
    for index, image in enumerate(X_test):
      output = self.feed_forward(image, isTrain = False)
      output_onehot = np.zeros_like(output)
      output_onehot[output.argmax()] = 1
      output_list.append(output_onehot)
    return output_list

  def predict_class(self, X_test):
    output_list = self.predict(X_test)
    output_list_class = list()
    for one_hot in output_list:
      num_class,  = np.where(one_hot== 1)[0]
      output_list_class.append(num_class)
    return output_list_class
```

Các hàm Activation

ReLu

In [0]:

```
class ReLU:
  def __init__(self):
    self.data = None

  def feed_forward(self, data):
    data[data<0] = 0
    data = data/ (np.amax(data) + eps)
    self.data = data
    return data

  def backward(self, dY):
    max_data = np.amax(self.data)
    self.data[self.data>0] = 1
    return np.multiply(self.data, dY)*max_data
```

Sigmoid

In [0]:

```
class Sigmoid:
  def __init__(self):
    self.data = None

  def sigmoid(x):
    return 1 / (1 + math.exp(-x))

  def feed_forward(self, data):
    self.data = self.sigmoid(data)
    return data

  def backward(self, dY):
    return np.multiply(np.multiply(self.data, 1- self.data), dY)
```

Softmax

In [0]:

```
class Softmax():
  def __init__(self):
    self.cache = None

  def feed_forward(self, X):
    self.cache = np.exp(X) / np.sum(np.exp(X), axis = 0)
    return self.cache

  def backward(self, dY):
    return self.cache - dY
```

Hàm Loss

In [0]:

```
class CrossEntropy():
  def __init__(self):
    self.reset()

  def reset(self): #Gọi sau mỗi batch
    self.gradient = None #Chứa tổng gradient để backward cho mỗi batch
    self.total_loss = None #Chứa tổng loss của mỗi batch

  def feed_forward(self, output, target):
    temp = -target*(1/(np.log(2)*output))
    if self.gradient is None:
      self.gradient = temp
    else:
      self.gradient += temp

    loss = np.sum(-1*target * np.log2(output + eps))
    if self.total_loss is None:
      self.total_loss = loss
    else:
      self.total_loss += loss

  def get_avg_loss(self, batch_size):
    return self.total_loss / batch_size

  def backward(self, batch_size):
    return self.gradient/batch_size
```

Các Layer

Convolution2D

Class Convolution2D có khả năng nhận input nhiều channel, torng nội bộ class có chứa nhiều filter và hỗ trợ padding, stride

Có hiện thực cơ chế im2col và kernel2row để forward và backward dữ liệu

Có hỗ trợ lưu các trọng số thành file và có thể load để tiếp tục sử dụng

Input: width W, height H, Channels C, Stride S, Padding P

Filters: F_width, F_height, k filter

= > Output:

- (W - F_width - 2*P1) / S1
- (H - F_height - 2*P2) / S2
- Channel = k

In [0]:

```
class Convolution2D:
  def __init__(self, num_filter, filter_size, input_shape, padding = 0, stride =
 1, init_weights = None, init_bias = None, activation = 'relu', learning_rate =
0.01):
    self.num_filter = num_filter
    self.filter_size = filter_size
    self.input_shape = input_shape
    self.weights = init_weights
#     self.bias = init_bias
    self.padding = padding
    self.stride = stride
    if activation == 'relu':
      self.activation = ReLU()
    else:
      pass #Có thể hiện thực nhiều hàm activation khác
    self.lrn_rate = learning_rate

    if self.weights is None:
      rand_number = math.sqrt(6/(input_shape[0]+num_filter))
      self.weights = np.random.uniform(low = -rand_number, high = rand_number, s
ize = (num_filter, input_shape[0] ,filter_size[0], filter_size[1]))#Channel firs
t format: param 2 -> số channel input
#     if self.bias is None:
#       self.bias = np.zeros(num_filter)


  def set_input(self, data): #Padding ảnh input với 0
    self.input = np.zeros((self.input_shape[0], self.input_shape[1] + self.paddi
ng*2, self.input_shape[2] + self.padding*2))
    for channel in range(self.input_shape[0]):
      self.input[channel] = np.pad(data[channel], pad_width = self.padding, mode
 = 'constant', constant_values = 0)

  def feed_forward(self, data):
    self.set_input(data)
    self.convert_X_conv()
    self.convert_W_conv()
    self.convert_W_flat()
    self.output = list()
#     print ("Weights of Convolution forward", self.weights, self.weights.shape)
 ##
    for filter in range(self.num_filter):
      test = np.matmul(self.W_flat_list[filter], self.X_conv)
      self.output.append(test.reshape(self.o1, self.o2))
    return self.activation.feed_forward(np.array(self.output))

  def backward(self, dY_flat):
    dY_flat = self.activation.backward(dY_flat)
    dX = np.zeros((self.input_shape[0], self.input.shape[1], self.input.shape[2
]))
    for filter in range(self.num_filter):
      dY_flatten = dY_flat[filter, :, :].flatten()
      #print(dY_flatten.shape)
      dW = np.matmul(self.X_conv, dY_flatten).reshape(self.input_shape[0], self.
filter_size[0], self.filter_size[1])
      dX += np.matmul(dY_flatten.reshape(1, dY_flatten.shape[0]) ,self.W_conv_li
st[filter]).reshape((self.input_shape[0], self.input.shape[1], self.input.shape[
2]))
      self.weights[filter] -= dW*self.lrn_rate
```

```
#     print ("Weights of Convolution backward", self.weights, self.weights.shape)##
    return dX


  def convert_W_flat(self):
    self.W_flat_list = list()
    for filter in range(self.num_filter):
      W_flat = None
      for channel in range(self.input_shape[0]):
        temp = self.weights[filter, channel, :, :].flatten()
        if W_flat is None:
          W_flat = temp
        else:
          W_flat = np.concatenate((W_flat, temp), axis = 0)
      self.W_flat_list.append(W_flat)


  def convert_X_conv(self):
    #im2col cho các channel cuả input
    self.X_conv = None
    for channel in range(self.input_shape[0]):
      temp = self.im2col(self.input[channel])
      if self.X_conv is None:
        self.X_conv = temp
      else:
        self.X_conv = np.concatenate((self.X_conv, temp), axis=0) #Mơ rộng chiều rows


  def convert_W_conv(self):
    self.W_conv_list = list()
    #kernel2col cho tất cả các kernel (tất cả channel)
    for filter in range(self.num_filter):
      W_conv = None
      for channel in range(self.input_shape[0]):
        temp = self.kernel2row(self.weights[filter, channel,:,:])
        if W_conv is None:
          W_conv = temp
        else:
          W_conv =  np.concatenate((W_conv, temp), axis=1) #Ghép theo cột
      self.W_conv_list.append( W_conv)


  def im2col(self, image): #Chuyển một ma trận 2 chiều (1 channel) về dạng X_conv
    self.o1 = int((self.input.shape[1] - self.filter_size[0])/self.stride) + 1 # Số step dịch kernel theo row
    self.o2 = int((self.input.shape[2] - self.filter_size[1])/self.stride) + 1 # Số step dịch kernel theo column
    list_conv = list()
    for row in range(self.o1):
      row_start = row * self.stride
      row_end = row_start + self.filter_size[0]
      for col in range(self.o2):
        col_start = col*self.stride
        col_end = col_start + self.filter_size[1]
        temp = image[row_start:row_end, col_start:col_end]
        list_conv.append(np.flip(temp.flatten(),0))
    X_conv = np.transpose(np.array(list_conv))
    return X_conv
```

```
  def kernel2row(self, kernel): #Chuyển một kernel về dạng W_conv
    rot_kernel = np.flip(kernel, 0)
    rot_kernel = np.flip(rot_kernel, 1)
    list_w_conv = list()
    for row in range(self.o1):
      row_start = row * self.stride
      row_end = row_start + self.filter_size[0]
      for col in range(self.o2):
        col_start = col*self.stride
        col_end = col_start + self.filter_size[1]
        temp = np.zeros((self.input.shape[1], self.input.shape[2]))
        temp[row_start:row_end, col_start:col_end] = rot_kernel
        list_w_conv.append(temp.flatten())
    W_conv = np.array(list_w_conv)
    return W_conv

  def save_weights(self, filename):
    np.save('drive/My Drive/Colab Notebooks/Asgmt_ML_CNN/saved_model/' + filenam
e + '.npy', self.weights)

  def load_weights(self, filename):
    self.weights = np.load('drive/My Drive/Colab Notebooks/Asgmt_ML_CNN/saved_mo
del/' + filename + '.npy')
```

MaxPooling2D

In [0]:

```
class MaxPooling2D():
  def __init__(self, pool_size=(2, 2), stride=None):
    self.X = None
    self.pool_indices = list()
    self.pool_size = pool_size
    if stride is None:
      self.stride = pool_size
    else:
      self.stride = stride

  def feed_forward(self, X):
    D, W, H = X.shape
    W_pool = self.pool_size[0]
    H_pool = self.pool_size[1]
    W_S = self.stride[0]
    H_S = self.stride[1]
    WW = 1 + (W - W_pool)//W_S
    HH = 1 + (H - H_pool)//H_S
    DD = D
    out = np.zeros((DD, HH, WW))
    for depth in range(D):
      for row in range(HH):
        for col in range(WW):
          out[depth, row, col] = np.max(X[depth, row*H_S:row*H_S+H_pool, col*W_S
:col*W_S+W_pool])
    self.cache = X
    return np.array(out)

  def backward(self, out):
    D, W, H = self.cache.shape
    DD, WW, HH = out.shape
    W_pool = self.pool_size[0]
    H_pool = self.pool_size[1]
    W_S = self.stride[0]
    H_S = self.stride[1]
    dX = np.zeros(self.cache.shape)

    for depth in range(D):
      for row in range(0, HH):
        for col in range(0, WW):
          x_pool = self.cache[depth, row*H_S:row*H_S+H_pool, col*W_S:col*W_S+W_p
ool]
          mask = (x_pool == np.max(x_pool))
          dX[depth, row*H_S:row*H_S+H_pool, col*W_S:col*W_S+W_pool] = mask* out[
depth, row, col]
    return dX
```

Dropout

In [0]:

```
class Dropout():
  def __init__(self, drop_rate = 0.25):
    self.drop_rate = drop_rate
    self.data = None

  def drop(self, element): #Mỗi phần tử bị set 0 với xác suất là drop_rate
    rand = np.random.ranf(1)
    if rand < self.drop_rate:
      return 0
    else:
      return element/(1-self.drop_rate)

#   def feed_forward(self, data):
#     vec = np.vectorize(self.drop) #Map tất cả các phần tử với hàm drop
#     self.data = vec(data)
#     return self.data

  def feed_forward(self, data):
    shape = data.shape
    flat = data.flatten()
    for i in range(len(flat)):
      flat[i] = self.drop(flat[i])
    self.data = flat.reshape(shape)
    return self.data

  def backward(self, dY):
    self.data[self.data != 0] = 1
    return np.multiply(self.data, dY)
```

Flatten

In [0]:

```
class Flatten():
  def __init__(self):
    self.shape = None

  def feed_forward(self, data):
    self.shape = data.shape
    return data.flatten()

  def backward(self, dY):
    return dY.reshape(self.shape)
```

Dense

Lớp fully connected có hỗ trợ lưu và load lại trọng số từ file

In [0]:

```
class Dense():
  def __init__(self, num_units, init_weights = None, init_bias = None, activatio
n = 'relu', learning_rate = 0.01):
    self.num_units = num_units
    self.weights = init_weights
    self.bias = init_bias
    if activation == 'relu':
      self.activation = ReLU()
    elif activation == 'softmax':
      self.activation = Softmax()
    self.lrn_rate = learning_rate

  def feed_forward(self, data):
    self.input = data
    if self.weights is None:
      rand_number = math.sqrt(6/(self.num_units+data.shape[0]))
      self.weights = np.random.uniform( low = -rand_number, high = rand_number,
size = (self.num_units, data.shape[0]))
    if self.bias is None:
      rand_number = math.sqrt(6/(self.num_units+data.shape[0]))
      self.bias  = np.random.uniform(low = -rand_number, high = rand_number, siz
e = self.num_units)
    A = np.matmul(self.weights, data) + self.bias
    return self.activation.feed_forward(A)

  def backward(self, dY):
    dY = self.activation.backward(dY)
    dW = np.matmul(dY.reshape(dY.shape[0], 1), self.input.reshape(1, self.input.
shape[0]))
    dX =  np.matmul(self.weights.T, dY)
    self.weights -= dW*self.lrn_rate
    self.bias -= dY*self.lrn_rate
    return dX

  def save_weights(self, filename):
    np.save('drive/My Drive/Colab Notebooks/Asgmt_ML_CNN/saved_model/' + filenam
e + '.npy', self.weights)
    np.save('drive/My Drive/Colab Notebooks/Asgmt_ML_CNN/saved_model/' + filenam
e + '_bias.npy', self.bias)

  def load_weights(self, filename):
    self.weights = np.load('drive/My Drive/Colab Notebooks/Asgmt_ML_CNN/saved_mo
del/' + filename + '.npy')
    self.bias = np.load('drive/My Drive/Colab Notebooks/Asgmt_ML_CNN/saved_mode
l/' + filename + '_bias.npy')
```

----------Testing----------

Xây dựng model theo cấu trúc Conv2D - Conv2D - MaxPooling2D - Dropout - Flatten - Dropout - Dense - Dense

Train trên 10000 ảnh, qua 20 epochs với batch_size = 20

In [0]:

```
num_class = 10

convol2D_1  = Convolution2D(2, (3, 3), input_shape=(1,28,28), learning_rate = 0.
05)
convol2D_2  = Convolution2D(4, (4, 4), input_shape=(2,26,26), learning_rate = 0.
05)
max_pooling = MaxPooling2D(pool_size=(2, 2))
dropout_1   = Dropout(0.1)
flatten     = Flatten()
dropout_2   = Dropout(0.25)
dense_1     = Dense(24, activation='relu',learning_rate = 0.05)
dense_2     = Dense(num_class, activation='softmax', learning_rate = 0.05)
```

In [0]:

```
# convol2D_1.load_weights('convol2D_1')
# convol2D_2.load_weights('convol2D_2')
# dense_1.load_weights('dense_1')
# dense_2.load_weights('dense_2')
```

In [0]:

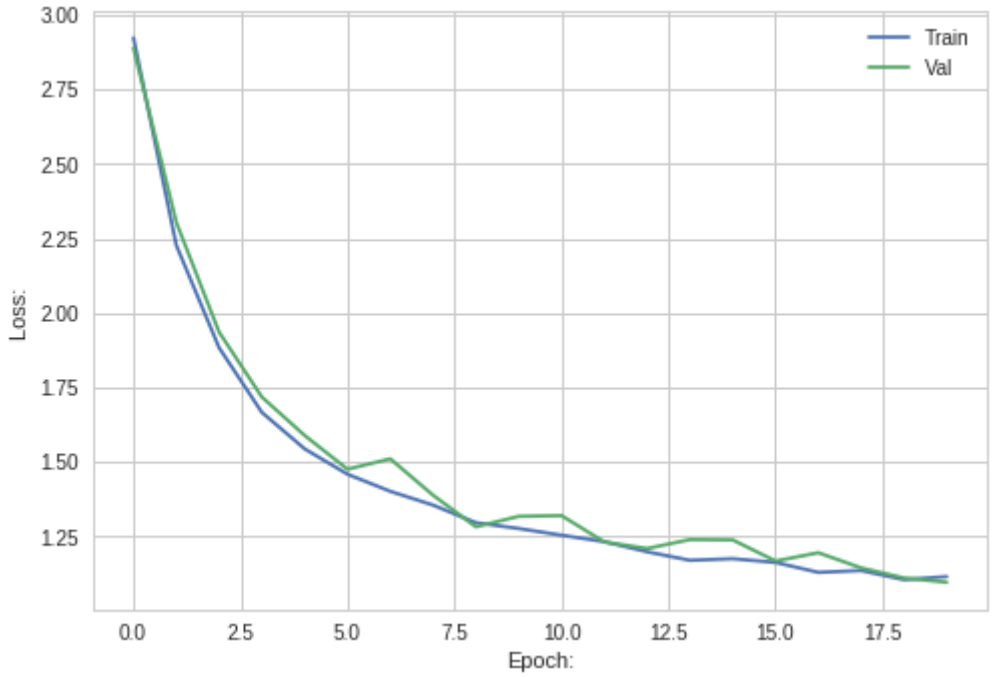
```
model = Sequential()
model.add(convol2D_1)
model.add(convol2D_2)
model.add(max_pooling)
model.add(dropout_1)
model.add(flatten)
model.add(dropout_2)
model.add(dense_1)
model.add(dense_2)

model.compile(loss = 'cross_entropy')

batch_size = 20
epochs = 20

model.fit(
      X_train_norm[0:10000],
      y_train_norm[0:10000],
      batch_size = batch_size,
      num_epoch = epochs,
      validation_data = (X_test_norm[0:20], y_test_norm[0:20])
)
```

```
Epoch  0 - Training loss:  2.92365631378023  - Validating loss:  2.8
89496777805659
Epoch  1 - Training loss:  2.22761676848523  - Validating loss:  2.3
044589611493778
Epoch  2 - Training loss:  1.88353669942595  - Validating loss:  1.9
360579906544593
Epoch  3 - Training loss:  1.66652325945595  - Validating loss:  1.7
180017805268606
Epoch  4 - Training loss:  1.54414263431477  - Validating loss:  1.5
891256835366783
Epoch  5 - Training loss:  1.45903993536859  - Validating loss:  1.4
759077819632918
Epoch  6 - Training loss:  1.40161767819103  - Validating loss:  1.5
107993065396212
Epoch  7 - Training loss:  1.35543781867044  - Validating loss:  1.3
885984613429794
Epoch  8 - Training loss:  1.29635936266021  - Validating loss:  1.2
825559801767707
Epoch  9 - Training loss:  1.27687882133079  - Validating loss:  1.3
177467516887087
Epoch  10 - Training loss:  1.25443171495781  - Validating loss:  1.
3202330311432977
Epoch  11 - Training loss:  1.23273109407053  - Validating loss:  1.
2317145807732657
Epoch  12 - Training loss:  1.1987292532765  - Validating loss:  1.2
09769903076661
Epoch  13 - Training loss:  1.17013863824366  - Validating loss:  1.
2396785448516332
Epoch  14 - Training loss:  1.17553892552322  - Validating loss:  1.
238631098268376
Epoch  15 - Training loss:  1.16294906888189  - Validating loss:  1.
1677090361705007
Epoch  16 - Training loss:  1.12969124166967  - Validating loss:  1.
195619758834148
Epoch  17 - Training loss:  1.13579455284543  - Validating loss:  1.
1446844309632866
Epoch  18 - Training loss:  1.10504974330452  - Validating loss:  1.
1108574746635018
Epoch  19 - Training loss:  1.11541749400538  - Validating loss:  1.
0964983492651066
```



In [0]:

```
convol2D_1.save_weights('convol2D_1')
convol2D_2.save_weights('convol2D_2')
dense_1.save_weights('dense_1')
dense_2.save_weights('dense_2')
```

In [0]:

```
predicted = model.predict_class(X_test_norm[0:200])
target =  y_test[0:200]
```

In [0]:

```
print("Accuracy: ",accuracy_score(predicted, target))
from sklearn import metrics
print(metrics.classification_report(target, predicted))
```

```
Accuracy:  0.75
             precision    recall  f1-score   support

          0       0.94      1.00      0.97        17
          1       0.92      0.79      0.85        28
          2       0.67      0.62      0.65        16
          3       0.65      0.81      0.72        16
          4       0.79      0.82      0.81        28
          5       0.81      0.65      0.72        20
          6       0.79      0.75      0.77        20
          7       0.89      0.67      0.76        24
          8       0.40      1.00      0.57        10
          9       0.69      0.52      0.59        21

avg / total       0.78      0.75      0.75       200
```

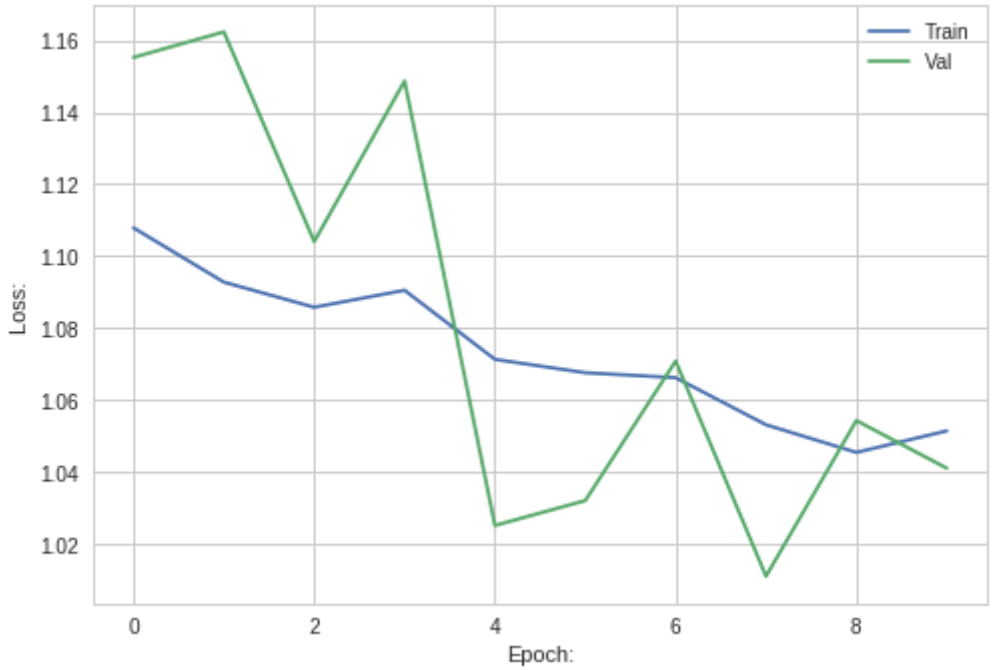
Tiếp tục train thêm 10 epoch

In [0]:

```
batch_size = 20
epochs = 10

model.fit(
      X_train_norm[0:10000],
      y_train_norm[0:10000],
      batch_size = batch_size,
      num_epoch = epochs,
      validation_data = (X_test_norm[0:20], y_test_norm[0:20])
)
```

```
Epoch  0 - Training loss:  1.10790770405805  - Validating loss:  1.1
55222209115932
Epoch  1 - Training loss:  1.09282723283647  - Validating loss:  1.1
62309162119335
Epoch  2 - Training loss:  1.08585056518316  - Validating loss:  1.1
040841597355642
Epoch  3 - Training loss:  1.09057195790592  - Validating loss:  1.1
486624710842532
Epoch  4 - Training loss:  1.07138561907188  - Validating loss:  1.0
252644052066695
Epoch  5 - Training loss:  1.06766938472369  - Validating loss:  1.0
321799405416445
Epoch  6 - Training loss:  1.06629894387216  - Validating loss:  1.0
709090977270928
Epoch  7 - Training loss:  1.0532231673278  - Validating loss:  1.01
11623533597647
Epoch  8 - Training loss:  1.04554922811798  - Validating loss:  1.0
543915088628302
Epoch  9 - Training loss:  1.05152575009738  - Validating loss:  1.0
411727615378026
```



In [0]:

```
convol2D_1.save_weights('convol2D_1')
convol2D_2.save_weights('convol2D_2')
dense_1.save_weights('dense_1')
dense_2.save_weights('dense_2')
```

In [0]:

```
predicted = model.predict_class(X_test_norm[200:400])
target =  y_test[200:400]
print("Accuracy: ",accuracy_score(predicted, target))
from sklearn import metrics
print(metrics.classification_report(target, predicted))
```

```
Accuracy:  0.77
             precision    recall  f1-score   support

          0       0.89      1.00      0.94        16
          1       0.82      0.93      0.87        29
          2       0.92      0.79      0.85        28
          3       0.68      0.79      0.73        19
          4       0.72      0.72      0.72        18
          5       0.67      0.55      0.60        22
          6       0.82      0.64      0.72        14
          7       0.77      0.59      0.67        17
          8       0.65      0.88      0.75        17
          9       0.75      0.75      0.75        20

avg / total       0.77      0.77      0.77       200
```