Copy_of_CNN_MNIST

March 6, 2020

In [1]:
```
# Credits: https://github.com/keras-team/keras/blob/master/examples/mnist_cnn.py


from __future__ import print_function
import keras
from keras.datasets import mnist
from keras.models import Sequential
from keras.layers import Dense, Dropout, Flatten
from keras.layers import Conv2D, MaxPooling2D
from keras import backend as K

batch_size = 128
num_classes = 10
epochs = 12

# input image dimensions
img_rows, img_cols = 28, 28

# the data, split between train and test sets
(x_train, y_train), (x_test, y_test) = mnist.load_data()

if K.image_data_format() == 'channels_first':
    x_train = x_train.reshape(x_train.shape[0], 1, img_rows, img_cols)
    x_test = x_test.reshape(x_test.shape[0], 1, img_rows, img_cols)
    input_shape = (1, img_rows, img_cols)
else:
    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 = x_train.astype('float32')
x_test = x_test.astype('float32')
x_train /= 255
x_test /= 255
print('x_train shape:', x_train.shape)
print(x_train.shape[0], 'train samples')
print(x_test.shape[0], 'test samples')
```

```
        # convert class vectors to binary class matrices
        y_train = keras.utils.to_categorical(y_train, num_classes)
        y_test = keras.utils.to_categorical(y_test, num_classes)

        model = Sequential()
        model.add(Conv2D(32, kernel_size=(3, 3),
                         activation='relu',
                         input_shape=input_shape))
        model.add(Conv2D(64, (3, 3), activation='relu'))
        model.add(MaxPooling2D(pool_size=(2, 2)))
        model.add(Dropout(0.25))
        model.add(Flatten())
        model.add(Dense(128, activation='relu'))
        model.add(Dropout(0.5))
        model.add(Dense(num_classes, activation='softmax'))

        model.compile(loss=keras.losses.categorical_crossentropy,
                      optimizer=keras.optimizers.Adadelta(),
                      metrics=['accuracy'])

        model.fit(x_train, y_train,
                  batch_size=batch_size,
                  epochs=epochs,
                  verbose=1,
                  validation_data=(x_test, y_test))
        score = model.evaluate(x_test, y_test, verbose=0)
        print('Test loss:', score[0])
        print('Test accuracy:', score[1])
```

```
Using TensorFlow backend.
```

```
<IPython.core.display.HTML object>
```

```
Downloading data from https://s3.amazonaws.com/img-datasets/mnist.npz
11493376/11490434 [==============================] - 0s 0us/step
x_train shape: (60000, 28, 28, 1)
60000 train samples
10000 test samples
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend
```

```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend
Instructions for updating:
Please use `rate` instead of `keep_prob`. Rate should be set to `rate = 1 - keep_prob`.
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/optimizers.py:793: The nam

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend

WARNING:tensorflow:From /tensorflow-1.15.0/python3.6/tensorflow_core/python/ops/math_grad.py:14
Instructions for updating:
Use tf.where in 2.0, which has the same broadcast rule as np.where
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend

Train on 60000 samples, validate on 10000 samples
Epoch 1/12
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend

60000/60000 [==============================] - 156s 3ms/step - loss: 0.2588 - acc: 0.9201 - val
Epoch 2/12
60000/60000 [==============================] - 156s 3ms/step - loss: 0.0877 - acc: 0.9737 - val
Epoch 3/12
60000/60000 [==============================] - 156s 3ms/step - loss: 0.0662 - acc: 0.9799 - val
Epoch 4/12
60000/60000 [==============================] - 156s 3ms/step - loss: 0.0552 - acc: 0.9834 - val
Epoch 5/12
60000/60000 [==============================] - 155s 3ms/step - loss: 0.0482 - acc: 0.9853 - val
Epoch 6/12
60000/60000 [==============================] - 156s 3ms/step - loss: 0.0414 - acc: 0.9875 - val
Epoch 7/12
60000/60000 [==============================] - 155s 3ms/step - loss: 0.0367 - acc: 0.9888 - val
Epoch 8/12
60000/60000 [==============================] - 156s 3ms/step - loss: 0.0335 - acc: 0.9896 - val
Epoch 9/12
60000/60000 [==============================] - 155s 3ms/step - loss: 0.0303 - acc: 0.9905 - val
```

```
Epoch 10/12
60000/60000 [==============================] - 157s 3ms/step - loss: 0.0289 - acc: 0.9918 - val
Epoch 11/12
60000/60000 [==============================] - 156s 3ms/step - loss: 0.0275 - acc: 0.9917 - val
Epoch 12/12
60000/60000 [==============================] - 156s 3ms/step - loss: 0.0268 - acc: 0.9915 - val
Test loss: 0.03266163398709341
Test accuracy: 0.9899
```

Using the Errorplot code from the Keras assignment

```
In [0]: # if you keras is not using tensorflow as backend set "KERAS_BACKEND=tensorflow" use ti
        from keras.utils import np_utils
        from keras.datasets import mnist
        import seaborn as sns
        from keras.initializers import RandomNormal
```

```
In [0]: %matplotlib notebook
        import matplotlib.pyplot as plt
        import numpy as np
        import time
        # https://gist.github.com/greydanus/f6eee59eaf1d90fcb3b534a25362cea4
        # https://stackoverflow.com/a/14434334
        # this function is used to update the plots for each epoch and error
        def plt_dynamic(x, vy, ty, ax, colors=['b']):
            ax.plot(x, vy, 'b', label="Validation Loss")
            ax.plot(x, ty, 'r', label="Train Loss")
            plt.legend()
            plt.grid()
            fig.canvas.draw()
```

```
In [0]: %matplotlib inline
```

Model 1 : 2 conv + 2 maxpool + dropout + 2 dense layer + adam optimizer

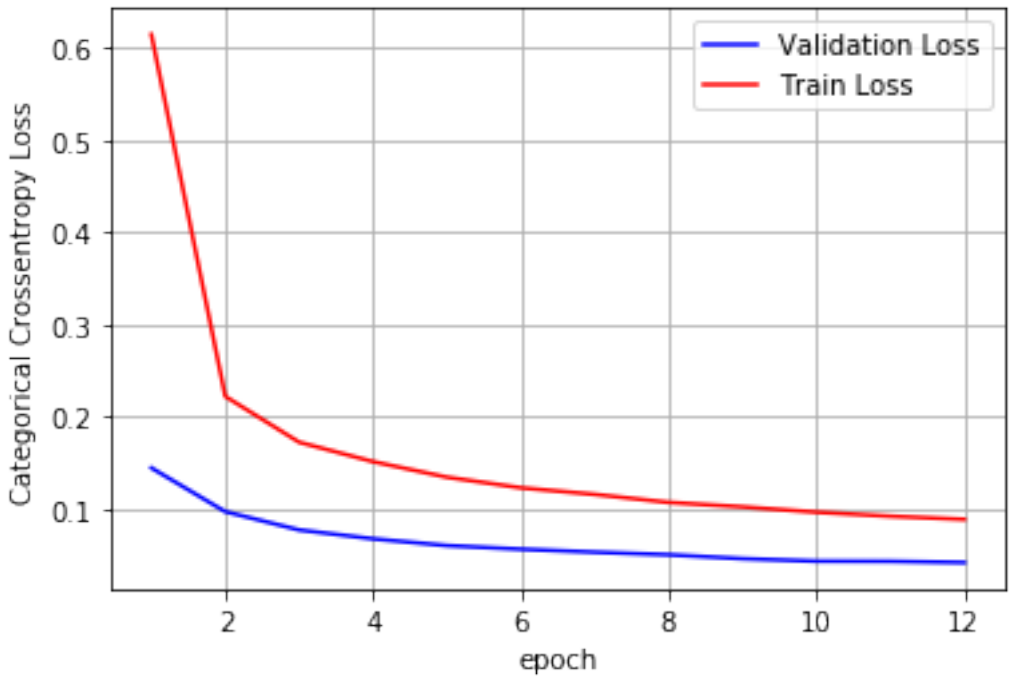
```
In [5]: model = Sequential()
        model.add(Conv2D(4, kernel_size=(3, 3),activation='relu',padding='same',input_shape=inp
        model.add(MaxPooling2D(pool_size=(2, 2),strides=2))
        model.add(Conv2D(8, (3, 3), activation='relu'))
        model.add(MaxPooling2D(pool_size=(2, 2),strides=2))
        model.add(Flatten())
        model.add(Dense(84, activation='relu'))
        model.add(Dropout(0.5))
        model.add(Dense(num_classes, activation='softmax'))
        model.compile(loss=keras.losses.categorical_crossentropy,
                      optimizer=keras.optimizers.adam(),
                      metrics=['accuracy'])
        # this will train the model and validate the model in this fit function
        model.summary()
```

```
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_3 (Conv2D)            (None, 28, 28, 4)         40
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 14, 14, 4)         0
_________________________________________________________________
conv2d_4 (Conv2D)            (None, 12, 12, 8)         296
_________________________________________________________________
max_pooling2d_3 (MaxPooling2 (None, 6, 6, 8)           0
_________________________________________________________________
flatten_2 (Flatten)          (None, 288)               0
_________________________________________________________________
dense_3 (Dense)              (None, 84)                24276
_________________________________________________________________
dropout_3 (Dropout)          (None, 84)                0
_________________________________________________________________
dense_4 (Dense)              (None, 10)                850
=================================================================
Total params: 25,462
Trainable params: 25,462
Non-trainable params: 0
_________________________________________________________________
```

```
In [6]: history=model.fit(x_train, y_train,
                         batch_size=batch_size,
                         epochs=epochs,
                         verbose=1,
                         validation_data=(x_test, y_test))
        score = model.evaluate(x_test, y_test, verbose=0)
        print('Test loss:', score[0])
        print('Test accuracy:', score[1])

Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 23s 377us/step - loss: 0.6148 - acc: 0.8085 - va
Epoch 2/12
60000/60000 [==============================] - 22s 368us/step - loss: 0.2220 - acc: 0.9327 - va
Epoch 3/12
60000/60000 [==============================] - 22s 366us/step - loss: 0.1722 - acc: 0.9489 - va
Epoch 4/12
60000/60000 [==============================] - 22s 367us/step - loss: 0.1511 - acc: 0.9554 - va
Epoch 5/12
60000/60000 [==============================] - 22s 366us/step - loss: 0.1342 - acc: 0.9598 - va
Epoch 6/12
60000/60000 [==============================] - 22s 365us/step - loss: 0.1228 - acc: 0.9632 - va
```

```
Epoch 7/12
60000/60000 [==============================] - 22s 368us/step - loss: 0.1156 - acc: 0.9656 - va
Epoch 8/12
60000/60000 [==============================] - 22s 363us/step - loss: 0.1069 - acc: 0.9682 - va
Epoch 9/12
60000/60000 [==============================] - 22s 367us/step - loss: 0.1021 - acc: 0.9698 - va
Epoch 10/12
60000/60000 [==============================] - 22s 364us/step - loss: 0.0963 - acc: 0.9705 - va
Epoch 11/12
60000/60000 [==============================] - 22s 364us/step - loss: 0.0919 - acc: 0.9714 - va
Epoch 12/12
60000/60000 [==============================] - 22s 369us/step - loss: 0.0885 - acc: 0.9730 - va
Test loss: 0.041687695559760325
Test accuracy: 0.9866
```

```
In [10]: score = model.evaluate(x_test, y_test, verbose=0)
         print('Test score:', score[0])
         print('Test accuracy:', score[1])

         fig,ax = plt.subplots(1,1)
         ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

         # list of epoch numbers
         x = list(range(1,epochs+1))

         # print(history.history.keys())
         # dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
         # history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epochs=nb_epoch,

         # we will get val_loss and val_acc only when you pass the paramter validation_data
         # val_loss : validation loss
         # val_acc : validation accuracy

         # loss : training loss
         # acc : train accuracy
         # for each key in histrory.histrory we will have a list of length equal to number of

         vy = history.history['val_loss']
         ty = history.history['loss']
         plt_dynamic(x, vy, ty, ax)

Test score: 0.041687695559760325
Test accuracy: 0.9866
```



Model 2 : 3 conv + 2 maxpool + BN + dropout + 3 dense layer + adam optimizer

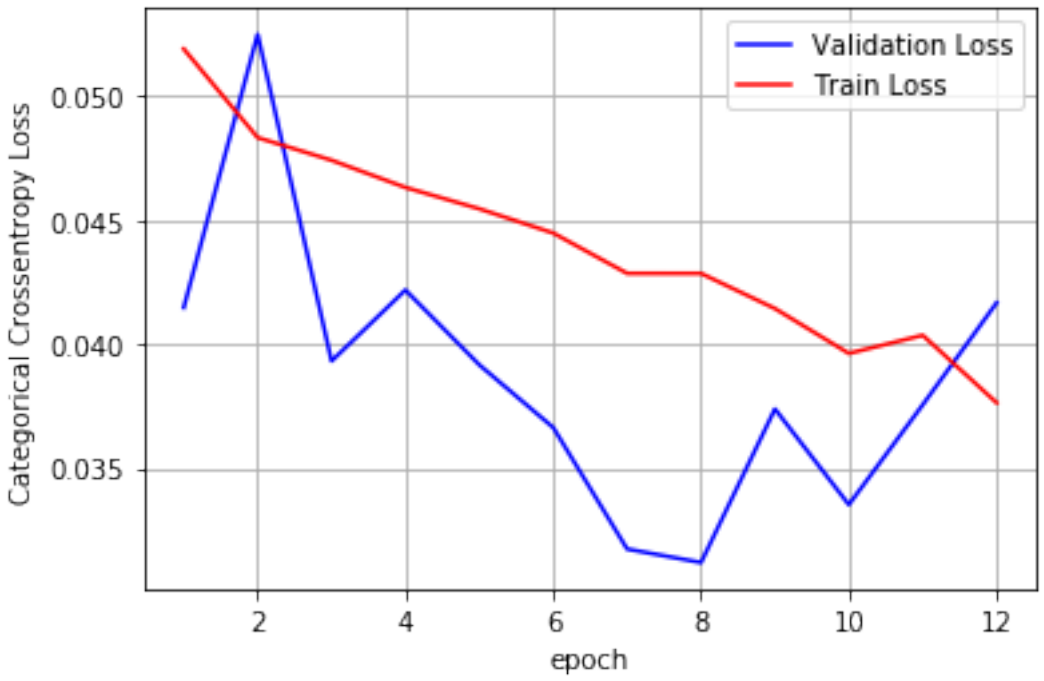
```
In [12]: from keras.layers.normalization import BatchNormalization
         model_1 = Sequential()
         model_1.add(Conv2D(4, kernel_size=(3, 3),activation='relu',padding='same',input_shape=
         model_1.add(MaxPooling2D(pool_size=(2, 2),strides=2))
         model_1.add(Conv2D(8, (3, 3), activation='relu'))
         model_1.add(MaxPooling2D(pool_size=(2, 2),strides=2))
         model_1.add(Conv2D(12, (3, 3), activation='relu'))
         model_1.add(Flatten())
         model_1.add(Dense(84, activation='relu'))
         model_1.add(BatchNormalization())
         model_1.add(Dropout(0.5))
         model_1.add(Dense(120, activation='relu'))
         model_1.add(Dense(num_classes, activation='softmax'))
         model_1.compile(loss=keras.losses.categorical_crossentropy,
                         optimizer=keras.optimizers.adam(),
                         metrics=['accuracy'])
         # this will train the model and validate the model in this fit function
         model_1.summary()

Model: "sequential_4"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_8 (Conv2D)            (None, 28, 28, 4)         40
```

```
_________________________________________________________________
max_pooling2d_6 (MaxPooling2 (None, 14, 14, 4)         0
_________________________________________________________________
conv2d_9 (Conv2D)            (None, 12, 12, 8)         296
_________________________________________________________________
max_pooling2d_7 (MaxPooling2 (None, 6, 6, 8)           0
_________________________________________________________________
conv2d_10 (Conv2D)           (None, 4, 4, 12)          876
_________________________________________________________________
flatten_4 (Flatten)          (None, 192)               0
_________________________________________________________________
dense_6 (Dense)              (None, 84)                16212
_________________________________________________________________
batch_normalization_1 (Batch (None, 84)                336
_________________________________________________________________
dropout_4 (Dropout)          (None, 84)                0
_________________________________________________________________
dense_7 (Dense)              (None, 120)               10200
_________________________________________________________________
dense_8 (Dense)              (None, 10)                1210
=================================================================
Total params: 29,170
Trainable params: 29,002
Non-trainable params: 168
_________________________________________________________________
```

```
In [17]: history=model_1.fit(x_train, y_train,
                             batch_size=batch_size,
                             epochs=epochs,
                             verbose=1,
                             validation_data=(x_test, y_test))
         score_1 = model_1.evaluate(x_test, y_test, verbose=0)
         print('Test loss:', score_1[0])
         print('Test accuracy:', score_1[1])

Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 23s 392us/step - loss: 0.0519 - acc: 0.9840 - va
Epoch 2/12
60000/60000 [==============================] - 23s 390us/step - loss: 0.0483 - acc: 0.9849 - va
Epoch 3/12
60000/60000 [==============================] - 23s 375us/step - loss: 0.0474 - acc: 0.9854 - va
Epoch 4/12
60000/60000 [==============================] - 23s 382us/step - loss: 0.0463 - acc: 0.9856 - va
Epoch 5/12
60000/60000 [==============================] - 23s 379us/step - loss: 0.0455 - acc: 0.9859 - va
Epoch 6/12
```

```
60000/60000 [==============================] - 22s 370us/step - loss: 0.0445 - acc: 0.9863 - va
Epoch 7/12
60000/60000 [==============================] - 23s 379us/step - loss: 0.0429 - acc: 0.9863 - va
Epoch 8/12
60000/60000 [==============================] - 23s 392us/step - loss: 0.0429 - acc: 0.9865 - va
Epoch 9/12
60000/60000 [==============================] - 23s 383us/step - loss: 0.0414 - acc: 0.9873 - va
Epoch 10/12
60000/60000 [==============================] - 22s 369us/step - loss: 0.0396 - acc: 0.9870 - va
Epoch 11/12
60000/60000 [==============================] - 22s 375us/step - loss: 0.0404 - acc: 0.9875 - va
Epoch 12/12
60000/60000 [==============================] - 23s 376us/step - loss: 0.0376 - acc: 0.9877 - va
Test loss: 0.04166760154593212
Test accuracy: 0.9879
```

```
In [18]: score_1 = model_1.evaluate(x_test, y_test, verbose=0)
         print('Test score:', score_1[0])
         print('Test accuracy:', score_1[1])

         fig,ax = plt.subplots(1,1)
         ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

         # list of epoch numbers
         x = list(range(1,epochs+1))

         # print(history.history.keys())
         # dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
         # history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epochs=nb_epoch,

         # we will get val_loss and val_acc only when you pass the paramter validation_data
         # val_loss : validation loss
         # val_acc : validation accuracy

         # loss : training loss
         # acc : train accuracy
         # for each key in histrory.histrory we will have a list of length equal to number of

         vy = history.history['val_loss']
         ty = history.history['loss']
         plt_dynamic(x, vy, ty, ax)

Test score: 0.04166760154593212
Test accuracy: 0.9879
```



Model 3 : 5 conv + 3 maxpool + 2 BN + 2 dropout + 3 dense layer + adam optimizer

```
In [29]: model_2 = Sequential()
         model_2.add(Conv2D(4, kernel_size=(3, 3),activation='relu',padding='same',input_shape=
         model_2.add(MaxPooling2D(pool_size=(2, 2),strides=2))
         model_2.add(Conv2D(8, (3, 3), activation='relu', padding='same'))
         model_2.add(MaxPooling2D(pool_size=(2, 2),strides=2))
         model_2.add(Conv2D(12, (3, 3), activation='relu', padding='same'))
         model_2.add(MaxPooling2D(pool_size=(2, 2),strides=2))
         model_2.add(Conv2D(48, (3, 3), activation='relu', padding='same'))
         model_2.add(BatchNormalization())
         model_2.add(Dropout(0.5))
         model_2.add(Conv2D(120, (3, 3), activation='relu', padding='same'))
         model_2.add(BatchNormalization())
         model_2.add(Dropout(0.5))
         model_2.add(Flatten())
         model_2.add(Dense(84, activation='relu'))
         model_2.add(Dense(120, activation='relu'))
         model_2.add(Dense(num_classes, activation='softmax'))
         model_2.compile(loss=keras.losses.categorical_crossentropy,
                         optimizer=keras.optimizers.adam(),
                         metrics=['accuracy'])
         # this will train the model and validate the model in this fit function
         model_2.summary()

Model: "sequential_9"
_________________________________________________________________
```

```
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_28 (Conv2D)           (None, 28, 28, 4)         40
_________________________________________________________________
max_pooling2d_20 (MaxPooling (None, 14, 14, 4)         0
_________________________________________________________________
conv2d_29 (Conv2D)           (None, 14, 14, 8)         296
_________________________________________________________________
max_pooling2d_21 (MaxPooling (None, 7, 7, 8)           0
_________________________________________________________________
conv2d_30 (Conv2D)           (None, 7, 7, 12)          876
_________________________________________________________________
max_pooling2d_22 (MaxPooling (None, 3, 3, 12)          0
_________________________________________________________________
conv2d_31 (Conv2D)           (None, 3, 3, 48)          5232
_________________________________________________________________
batch_normalization_3 (Batch (None, 3, 3, 48)          192
_________________________________________________________________
dropout_6 (Dropout)          (None, 3, 3, 48)          0
_________________________________________________________________
conv2d_32 (Conv2D)           (None, 3, 3, 120)         51960
_________________________________________________________________
batch_normalization_4 (Batch (None, 3, 3, 120)         480
_________________________________________________________________
dropout_7 (Dropout)          (None, 3, 3, 120)         0
_________________________________________________________________
flatten_6 (Flatten)          (None, 1080)              0
_________________________________________________________________
dense_12 (Dense)             (None, 84)                90804
_________________________________________________________________
dense_13 (Dense)             (None, 120)               10200
_________________________________________________________________
dense_14 (Dense)             (None, 10)                1210
=================================================================
Total params: 161,290
Trainable params: 160,954
Non-trainable params: 336
_________________________________________________________________
```

```
In [30]: history=model_2.fit(x_train, y_train,
                            batch_size=batch_size,
                            epochs=epochs,
                            verbose=1,
                            validation_data=(x_test, y_test))
         score_2 = model_2.evaluate(x_test, y_test, verbose=0)
         print('Test loss:', score_2[0])
         print('Test accuracy:', score_2[1])
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 40s 668us/step - loss: 0.4384 - acc: 0.8562 - va
Epoch 2/12
60000/60000 [==============================] - 38s 636us/step - loss: 0.1624 - acc: 0.9484 - va
Epoch 3/12
60000/60000 [==============================] - 38s 640us/step - loss: 0.1184 - acc: 0.9618 - va
Epoch 4/12
60000/60000 [==============================] - 38s 628us/step - loss: 0.1005 - acc: 0.9685 - va
Epoch 5/12
60000/60000 [==============================] - 37s 623us/step - loss: 0.0869 - acc: 0.9728 - va
Epoch 6/12
60000/60000 [==============================] - 38s 632us/step - loss: 0.0783 - acc: 0.9748 - va
Epoch 7/12
60000/60000 [==============================] - 38s 633us/step - loss: 0.0714 - acc: 0.9773 - va
Epoch 8/12
60000/60000 [==============================] - 38s 631us/step - loss: 0.0656 - acc: 0.9792 - va
Epoch 9/12
60000/60000 [==============================] - 38s 638us/step - loss: 0.0620 - acc: 0.9801 - va
Epoch 10/12
60000/60000 [==============================] - 38s 635us/step - loss: 0.0581 - acc: 0.9815 - va
Epoch 11/12
60000/60000 [==============================] - 39s 645us/step - loss: 0.0566 - acc: 0.9818 - va
Epoch 12/12
60000/60000 [==============================] - 38s 633us/step - loss: 0.0527 - acc: 0.9835 - va
Test loss: 0.04472449148670421
Test accuracy: 0.9878
```

```
In [31]: score_2 = model_2.evaluate(x_test, y_test, verbose=0)
         print('Test score:', score_2[0])
         print('Test accuracy:', score_2[1])

         fig,ax = plt.subplots(1,1)
         ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

         # list of epoch numbers
         x = list(range(1,epochs+1))

         # print(history.history.keys())
         # dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
         # history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epochs=nb_epoch,

         # we will get val_loss and val_acc only when you pass the paramter validation_data
         # val_loss : validation loss
         # val_acc : validation accuracy

         # loss : training loss
```

```
        # acc : train accuracy
        # for each key in histrory.histrory we will have a list of length equal to number of
        vy = history.history['val_loss']
        ty = history.history['loss']
        plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.04472449148670421
Test accuracy: 0.9878
```