1. CNN on MNIST data set.

1.1 Importing necessary Libraries

```
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
```

```
Using TensorFlow backend.
```

The default version of TensorFlow in Colab will soon switch to TensorFlow 2.x.
We recommend you upgrade now or ensure your notebook will continue to use TensorFlow 1.x via the `%tensorflow_version 1.x` magic: more info.

1.2 Setting required parameters and Reading MNIST data set

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

batch_size = 256
num_classes = 10
epochs = 10

# 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)

print('x_train shape:', x_train.shape)
print('x_test shape:', x_test.shape)
print(x_train.shape[0], 'train samples')
print(x_test.shape[0], 'test samples')
print(y_train.shape)
print(y_train)
```

```
Downloading data from https://s3.amazonaws.com/img-datasets/mnist.npz
11493376/11490434 [==============================] - 0s 0us/step
x_train shape: (60000, 28, 28, 1)
x_test shape: (10000, 28, 28, 1)
60000 train samples
10000 test samples
(60000,)
[5 0 4 ... 5 6 8]
```

1.3 Normalizing the data and converting output label into matrix for

```
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)
print(y_train)
```

```
x_train shape: (60000, 28, 28, 1)
60000 train samples
10000 test samples
[[0. 0. 0. ... 0. 0. 0.]
 [1. 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. 0.]]
```

1.4 Plot a dynamic graph

```
import matplotlib.pyplot as plt
%matplotlib inline
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()
```

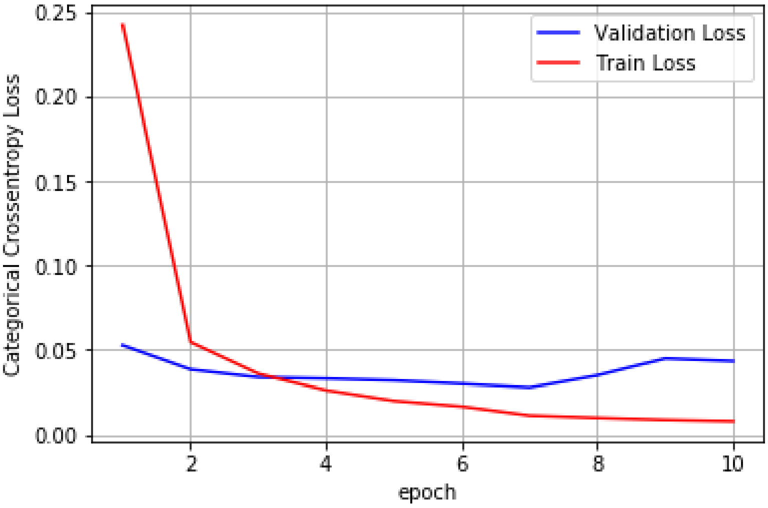
2. Training different models on MNIST data

2.1 Model A.1 : Three Convolution layers with 3X3 filter size(without Batch Normalization)

```
model = Sequential()
model.add(Conv2D(16, kernel_size=(3, 3),
                 activation='relu',
                 input_shape=input_shape))
model.summary()
print("------------------------------------------------")
model.add(Conv2D(32, (3, 3), activation='relu'))
model.summary()
print("------------------------------------------------")
model.add(Conv2D(64, (3, 3), activation='relu'))
model.summary()
print("------------------------------------------------")
model.add(MaxPooling2D(pool_size=(2, 2)))
model.summary()
print("------------------------------------------------")
model.add(Flatten())
model.summary()
print("------------------------------------------------")
model.add(Dense(64, activation='relu'))
model.summary()
print("------------------------------------------------")
model.add(Dense(num_classes, activation='softmax'))
model.summary()
print("------------------------------------------------")

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

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])
```

```
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 11, 11, 64)        0
_________________________________________________________________
flatten_2 (Flatten)          (None, 7744)              0
_________________________________________________________________
dense_3 (Dense)              (None, 64)                495680
=================================================================
Total params: 518,976
Trainable params: 518,976
Non-trainable params: 0
_________________________________________________________________
------------------------------------------------
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_4 (Conv2D)            (None, 26, 26, 16)        160
_________________________________________________________________
conv2d_5 (Conv2D)            (None, 24, 24, 32)        4640
_________________________________________________________________
conv2d_6 (Conv2D)            (None, 22, 22, 64)        18496
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 11, 11, 64)        0
_________________________________________________________________
flatten_2 (Flatten)          (None, 7744)              0
_________________________________________________________________
dense_3 (Dense)              (None, 64)                495680
_________________________________________________________________
dense_4 (Dense)              (None, 10)                650
=================================================================
Total params: 519,626
Trainable params: 519,626
Non-trainable params: 0
_________________________________________________________________
------------------------------------------------
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 139s 2ms/step - loss: 0.2423 -
Epoch 2/10
60000/60000 [==============================] - 138s 2ms/step - loss: 0.0545 -
Epoch 3/10
60000/60000 [==============================] - 136s 2ms/step - loss: 0.0359 -
Epoch 4/10
60000/60000 [==============================] - 137s 2ms/step - loss: 0.0261 -
Epoch 5/10
60000/60000 [==============================] - 137s 2ms/step - loss: 0.0198 -
Epoch 6/10
60000/60000 [==============================] - 136s 2ms/step - loss: 0.0165 -
Epoch 7/10
60000/60000 [==============================] - 136s 2ms/step - loss: 0.0112 -
Epoch 8/10
60000/60000 [==============================] - 136s 2ms/step - loss: 0.0098 -
Epoch 9/10
60000/60000 [==============================] - 136s 2ms/step - loss: 0.0086 -
Epoch 10/10
60000/60000 [==============================] - 135s 2ms/step - loss: 0.0078 -
Test loss: 0.04332130532190022
Test accuracy: 0.9894
```

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

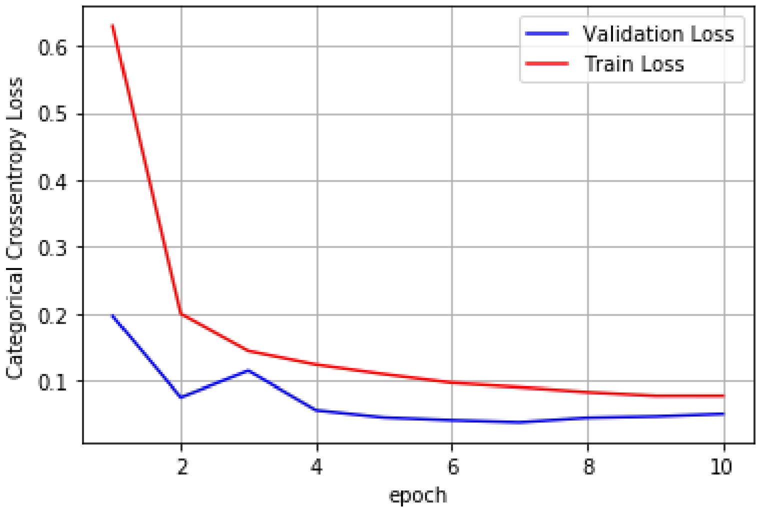


2.2 Model A.2 : Three Convolution layers with 3X3 filter size with drc

```
from keras.layers.normalization import BatchNormalization

model = Sequential()
model.add(Conv2D(32, kernel_size=(3, 3),
                 activation='relu',
                 input_shape=input_shape,padding = "same"))

model.add(Conv2D(16, (3, 3), activation='relu'))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.5))
model.add(Conv2D(32, (3, 3), activation='relu'))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(BatchNormalization())

model.add(Flatten())

model.add(Dense(64, activation='relu'))

model.add(Dropout(0.5))
model.add(BatchNormalization())
model.add(Dense(num_classes, activation='softmax'))
model.summary()
print("------------------------------------------------")

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

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])
```

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

Model: "sequential_4"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_8 (Conv2D)            (None, 28, 28, 32)        320
_________________________________________________________________
conv2d_9 (Conv2D)            (None, 26, 26, 16)        4624
_________________________________________________________________
max_pooling2d_3 (MaxPooling2 (None, 13, 13, 16)        0
_________________________________________________________________
dropout_1 (Dropout)          (None, 13, 13, 16)        0
_________________________________________________________________
conv2d_10 (Conv2D)           (None, 11, 11, 32)        4640
_________________________________________________________________
max_pooling2d_4 (MaxPooling2 (None, 5, 5, 32)          0
_________________________________________________________________
batch_normalization_1 (Batch (None, 5, 5, 32)          128
_________________________________________________________________
flatten_3 (Flatten)          (None, 800)               0
_________________________________________________________________
dense_5 (Dense)              (None, 64)                51264
_________________________________________________________________
dropout_2 (Dropout)          (None, 64)                0
_________________________________________________________________
batch_normalization_2 (Batch (None, 64)                256
_________________________________________________________________
dense_6 (Dense)              (None, 10)                650
=================================================================
Total params: 61,882
Trainable params: 61,690
Non-trainable params: 192
_________________________________________________________________
------------------------------------------------
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 110s 2ms/step - loss: 0.6297 -
Epoch 2/10
60000/60000 [==============================] - 109s 2ms/step - loss: 0.2002 -
Epoch 3/10
60000/60000 [==============================] - 108s 2ms/step - loss: 0.1446 -
Epoch 4/10
60000/60000 [==============================] - 108s 2ms/step - loss: 0.1242 -
Epoch 5/10
60000/60000 [==============================] - 108s 2ms/step - loss: 0.1099 -
Epoch 6/10
60000/60000 [==============================] - 107s 2ms/step - loss: 0.0972 -
Epoch 7/10
60000/60000 [==============================] - 107s 2ms/step - loss: 0.0907 -
Epoch 8/10
60000/60000 [==============================] - 108s 2ms/step - loss: 0.0836 -
Epoch 9/10
60000/60000 [==============================] - 107s 2ms/step - loss: 0.0783 -
Epoch 10/10
60000/60000 [==============================] - 108s 2ms/step - loss: 0.0782 -
Test loss: 0.051169814010197295
Test accuracy: 0.9853
```

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

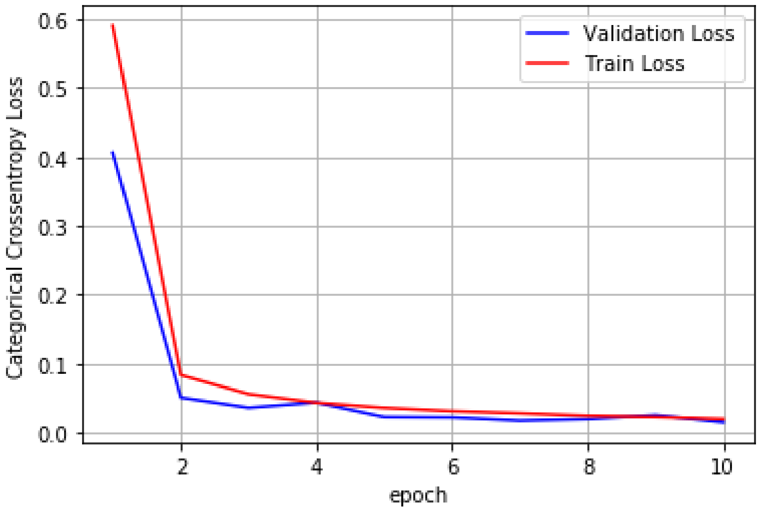


2.3 Model B : Five Convolution layers with 5X5 filter size + Dropout + Normalization + Max Pooling

```
from keras.layers.normalization import BatchNormalization

model = Sequential()
model.add(Conv2D(32, kernel_size=(5, 5),
                 activation='relu',
                 input_shape=input_shape,padding = "same"))
model.add(Conv2D(128, (5, 5), activation='relu',padding = "same"))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.25))
model.add(Conv2D(64, (5, 5), activation='relu',padding = "same"))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.25))
model.add(Conv2D(64, (5, 5), activation='relu',padding = "same"))
model.add(BatchNormalization())
model.add(Conv2D(32, (5, 5), activation='relu',padding = "same"))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.25))
model.add(Flatten())
model.add(Dense(128, activation='relu'))
model.add(BatchNormalization())
model.add(Dropout(0.5))
model.add(Dense(num_classes, activation='softmax'))
model.summary()


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

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])
```

```
_________________________________________________________________
max_pooling2d_11 (MaxPooling (None, 14, 14, 128)       0
_________________________________________________________________
dropout_9 (Dropout)          (None, 14, 14, 128)       0
_________________________________________________________________
conv2d_26 (Conv2D)           (None, 14, 14, 64)        204864
_________________________________________________________________
max_pooling2d_12 (MaxPooling (None, 7, 7, 64)          0
_________________________________________________________________
dropout_10 (Dropout)         (None, 7, 7, 64)          0
_________________________________________________________________
conv2d_27 (Conv2D)           (None, 7, 7, 64)          102464
_________________________________________________________________
batch_normalization_4 (Batch (None, 7, 7, 64)          256
_________________________________________________________________
conv2d_28 (Conv2D)           (None, 7, 7, 32)          51232
_________________________________________________________________
max_pooling2d_13 (MaxPooling (None, 3, 3, 32)          0
_________________________________________________________________
dropout_11 (Dropout)         (None, 3, 3, 32)          0
_________________________________________________________________
flatten_4 (Flatten)          (None, 288)               0
_________________________________________________________________
dense_7 (Dense)              (None, 128)               36992
_________________________________________________________________
batch_normalization_5 (Batch (None, 128)               512
_________________________________________________________________
dropout_12 (Dropout)         (None, 128)               0
_________________________________________________________________
dense_8 (Dense)              (None, 10)                1290
=================================================================
Total params: 500,970
Trainable params: 500,586
Non-trainable params: 384
_________________________________________________________________
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 1013s 17ms/step - loss: 0.5902
Epoch 2/10
60000/60000 [==============================] - 1000s 17ms/step - loss: 0.0836
Epoch 3/10
60000/60000 [==============================] - 992s 17ms/step - loss: 0.0560
Epoch 4/10
60000/60000 [==============================] - 1005s 17ms/step - loss: 0.0436
Epoch 5/10
60000/60000 [==============================] - 1006s 17ms/step - loss: 0.0362
Epoch 6/10
60000/60000 [==============================] - 1011s 17ms/step - loss: 0.0314
Epoch 7/10
60000/60000 [==============================] - 1004s 17ms/step - loss: 0.0284
Epoch 8/10
60000/60000 [==============================] - 1001s 17ms/step - loss: 0.0248
Epoch 9/10
60000/60000 [==============================] - 1004s 17ms/step - loss: 0.0231
Epoch 10/10
60000/60000 [==============================] - 1001s 17ms/step - loss: 0.0202
Test loss: 0.015447779501778496
Test accuracy: 0.9951
```

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

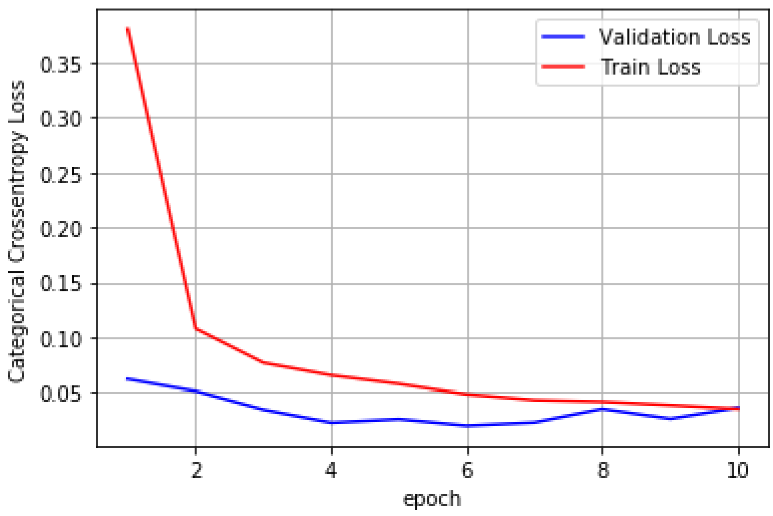


2.4 Model C : Seven Convolution layers with 7X7 filter size + Dropou Normalization + Max Pooling

```
from keras.layers.normalization import BatchNormalization
epochs = 10
model = Sequential()
model.add(Conv2D(64, kernel_size=(2, 2),
                 activation='relu',
                 input_shape=input_shape,padding = "same"))
model.add(Conv2D(128, (2, 2), activation='relu',padding = "same"))
model.add(Conv2D(64, (2, 2), activation='relu',padding = "same"))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.25))
model.add(Conv2D(64, (3, 3), activation='relu',padding = "same"))
model.add(Conv2D(32, (2, 2), activation='relu',padding = "same"))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Conv2D(32, (3, 3), activation='relu',padding = "same"))
model.add(Conv2D(32, (2, 2), activation='relu',padding = "same"))
model.add(Dropout(0.25))
model.add(BatchNormalization())
model.add(Flatten())
model.add(Dense(64, activation='relu'))
model.add(Dropout(0.5))
model.add(Dense(num_classes, activation='softmax'))
model.summary()


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

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])
```

```
_________________________________________________________________
conv2d_16 (Conv2D)           (None, 28, 28, 128)       32896     
_________________________________________________________________
conv2d_17 (Conv2D)           (None, 28, 28, 64)        32832     
_________________________________________________________________
max_pooling2d_5 (MaxPooling2 (None, 14, 14, 64)        0         
_________________________________________________________________
dropout_7 (Dropout)          (None, 14, 14, 64)        0         
_________________________________________________________________
conv2d_18 (Conv2D)           (None, 14, 14, 64)        36928     
_________________________________________________________________
conv2d_19 (Conv2D)           (None, 14, 14, 32)        8224      
_________________________________________________________________
max_pooling2d_6 (MaxPooling2 (None, 7, 7, 32)          0         
_________________________________________________________________
conv2d_20 (Conv2D)           (None, 7, 7, 32)          9248      
_________________________________________________________________
conv2d_21 (Conv2D)           (None, 7, 7, 32)          4128      
_________________________________________________________________
dropout_8 (Dropout)          (None, 7, 7, 32)          0         
_________________________________________________________________
batch_normalization_3 (Batch (None, 7, 7, 32)          128       
_________________________________________________________________
flatten_3 (Flatten)          (None, 1568)              0         
_________________________________________________________________
dense_5 (Dense)              (None, 64)                100416    
_________________________________________________________________
dropout_9 (Dropout)          (None, 64)                0         
_________________________________________________________________
dense_6 (Dense)              (None, 10)                650       
=================================================================
Total params: 228,650
Trainable params: 228,586
Non-trainable params: 64
_________________________________________________________________
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 651s 11ms/step - loss: 0.3806
Epoch 2/10
60000/60000 [==============================] - 650s 11ms/step - loss: 0.1078
Epoch 3/10
60000/60000 [==============================] - 649s 11ms/step - loss: 0.0768
Epoch 4/10
60000/60000 [==============================] - 651s 11ms/step - loss: 0.0655
Epoch 5/10
60000/60000 [==============================] - 650s 11ms/step - loss: 0.0577
Epoch 6/10
60000/60000 [==============================] - 648s 11ms/step - loss: 0.0481
Epoch 7/10
60000/60000 [==============================] - 648s 11ms/step - loss: 0.0430
Epoch 8/10
60000/60000 [==============================] - 652s 11ms/step - loss: 0.0415
Epoch 9/10
60000/60000 [==============================] - 652s 11ms/step - loss: 0.0384
Epoch 10/10
60000/60000 [==============================] - 651s 11ms/step - loss: 0.0351
Test loss: 0.03611384315206651
Test accuracy: 0.9907
```

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



3. Summary

```
# To summarize the results:
# summary table in jupyter notebook
# http://zetcode.com/python/prettytable/
# https://stackoverflow.com/questions/35160256/how-do-i-output-lists-as-a-table-in

from prettytable import PrettyTable
print("Epoch : 10 and Batch Size : 256")
x = PrettyTable()

x.field_names = ["Model","Convolution Layers","Kernel Size","Max pool","Padding","

x.add_row(["CNN", "3","3X3 for all","Yes","No","No","No",0.043,98.94])
x.add_row(["CNN", "3","3X3 for all","Yes","Yes","Yes","Yes",0.051,98.53])
x.add_row(["CNN", "5","5X5 for all","Yes","Yes","Yes","Yes",0.0154,99.51])
x.add_row(["CNN", "7","3X3 for 4th and 6th layer,2X2 for rest","Yes","Yes","Yes","
```