# 15_CNN_MNIST

December 1, 2020

## 1 3,5,7 Layers CNN on MNIST dataset

```
In [1]: from __future__ import print_function
        import keras
        from keras.datasets import mnist
        from keras.models import Sequential
        from keras.layers import Dense, Dropout, Flatten,Activation
        from keras.layers import Conv2D, MaxPooling2D
        from keras import backend as K

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

        print("Number of X_train points :", X_train.shape)
        print("Number of y_train points :", y_train.shape)
        print("Number of X_test points :", X_test.shape)
        print("Number of y_test points :", y_test.shape)
```

```
Number of X_train points : (60000, 28, 28)
Number of y_train points : (60000,)
Number of X_test points : (10000, 28, 28)
Number of y_test points : (10000,)
```

```
In [3]: #Initialization
        batch_size = 128
        num_classes = 10
        epochs = 15

        # input image dimensions
        img_rows, img_cols = 28, 28

        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) # 1 here is eve
            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')
```

```
X_train shape: (60000, 28, 28, 1)
60000 train samples
10000 test samples
```

```
In [4]: # here we are having a class number for each image
        print("Class label of first image :", y_train[0])

        # lets convert this into a 10 dimensional vector
        # ex: consider an image is 5 convert it into 5 => [0, 0, 0, 0, 0, 1, 0, 0, 0, 0]
        # this conversion needed for MLPs

        Y_train = keras.utils.to_categorical(y_train, 10)
        Y_test = keras.utils.to_categorical(y_test, 10)

        print("After converting the output into a vector : ",Y_train[0])
```

```
Class label of first image : 5
After converting the output into a vector :  [0. 0. 0. 0. 0. 1. 0. 0. 0. 0.]
```

### 1.1 3 layer CNN

```
In [5]: from keras.layers.normalization import BatchNormalization
        #Activation=ReLU
        #Optimizer=Adam
        #Architecture= conv2d,maxpool,conv2d,maxpool,conv2d,bn,maxpool,fc,dropout,sm

        model_3l = Sequential()
        # first layer
        model_3l.add(Conv2D(32, kernel_size=(3, 3),activation='relu',input_shape=input_shape))
        model_3l.add(MaxPooling2D(pool_size=(2, 2)))
        # second layer
        model_3l.add(Conv2D(64, kernel_size=(3, 3), activation='relu'))
        model_3l.add(MaxPooling2D(pool_size=(2, 2)))
        # third layer
        model_3l.add(Conv2D(64, kernel_size=(3, 3), activation='relu'))
        model_3l.add(BatchNormalization(axis=1))
```

```
model_31.add(MaxPooling2D(pool_size=(2, 2)))
# flattening,dropout
model_31.add(Flatten())
model_31.add(Dense(128, activation='relu'))
model_31.add(Dropout(0.5))
# softmax
model_31.add(Dense(num_classes, activation='softmax'))
model_31.summary()
```

```
Model: "sequential"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d (Conv2D)              (None, 26, 26, 32)        320       
_________________________________________________________________
max_pooling2d (MaxPooling2D) (None, 13, 13, 32)        0         
_________________________________________________________________
conv2d_1 (Conv2D)            (None, 11, 11, 64)        18496     
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 5, 5, 64)          0         
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 3, 3, 64)          36928     
_________________________________________________________________
batch_normalization (BatchNo (None, 3, 3, 64)          12        
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 1, 1, 64)          0         
_________________________________________________________________
flatten (Flatten)            (None, 64)                0         
_________________________________________________________________
dense (Dense)                (None, 128)               8320      
_________________________________________________________________
dropout (Dropout)            (None, 128)               0         
_________________________________________________________________
dense_1 (Dense)              (None, 10)                1290      
=================================================================
Total params: 65,366
Trainable params: 65,360
Non-trainable params: 6
_________________________________________________________________
```

```
In [6]: model_31.compile(loss=keras.losses.categorical_crossentropy,optimizer=keras.optimizers
        history=model_31.fit(X_train, Y_train,batch_size=batch_size,epochs=epochs,verbose=1,val
```

```
Epoch 1/15
469/469 [==============================] - 3s 6ms/step - loss: 0.3624 - accuracy: 0.8861 - val
Epoch 2/15
469/469 [==============================] - 2s 5ms/step - loss: 0.0907 - accuracy: 0.9735 - val
```

```
Epoch 3/15
469/469 [==============================] - 2s 5ms/step - loss: 0.0657 - accuracy: 0.9811 - val_
Epoch 4/15
469/469 [==============================] - 2s 5ms/step - loss: 0.0529 - accuracy: 0.9848 - val_
Epoch 5/15
469/469 [==============================] - 2s 5ms/step - loss: 0.0452 - accuracy: 0.9861 - val_
Epoch 6/15
469/469 [==============================] - 2s 5ms/step - loss: 0.0367 - accuracy: 0.9892 - val_
Epoch 7/15
469/469 [==============================] - 2s 5ms/step - loss: 0.0339 - accuracy: 0.9896 - val_
Epoch 8/15
469/469 [==============================] - 2s 5ms/step - loss: 0.0283 - accuracy: 0.9916 - val_
Epoch 9/15
469/469 [==============================] - 2s 5ms/step - loss: 0.0255 - accuracy: 0.9918 - val_
Epoch 10/15
469/469 [==============================] - 2s 5ms/step - loss: 0.0225 - accuracy: 0.9930 - val_
Epoch 11/15
469/469 [==============================] - 2s 5ms/step - loss: 0.0224 - accuracy: 0.9931 - val_
Epoch 12/15
469/469 [==============================] - 2s 5ms/step - loss: 0.0174 - accuracy: 0.9944 - val_
Epoch 13/15
469/469 [==============================] - 2s 5ms/step - loss: 0.0164 - accuracy: 0.9949 - val_
Epoch 14/15
469/469 [==============================] - 2s 5ms/step - loss: 0.0160 - accuracy: 0.9949 - val_
Epoch 15/15
469/469 [==============================] - 2s 5ms/step - loss: 0.0142 - accuracy: 0.9954 - val_
```

```
In [7]: #plotting function
        %matplotlib notebook
        import matplotlib.pyplot as plt
        %matplotlib inline
        import numpy as np

        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()
```

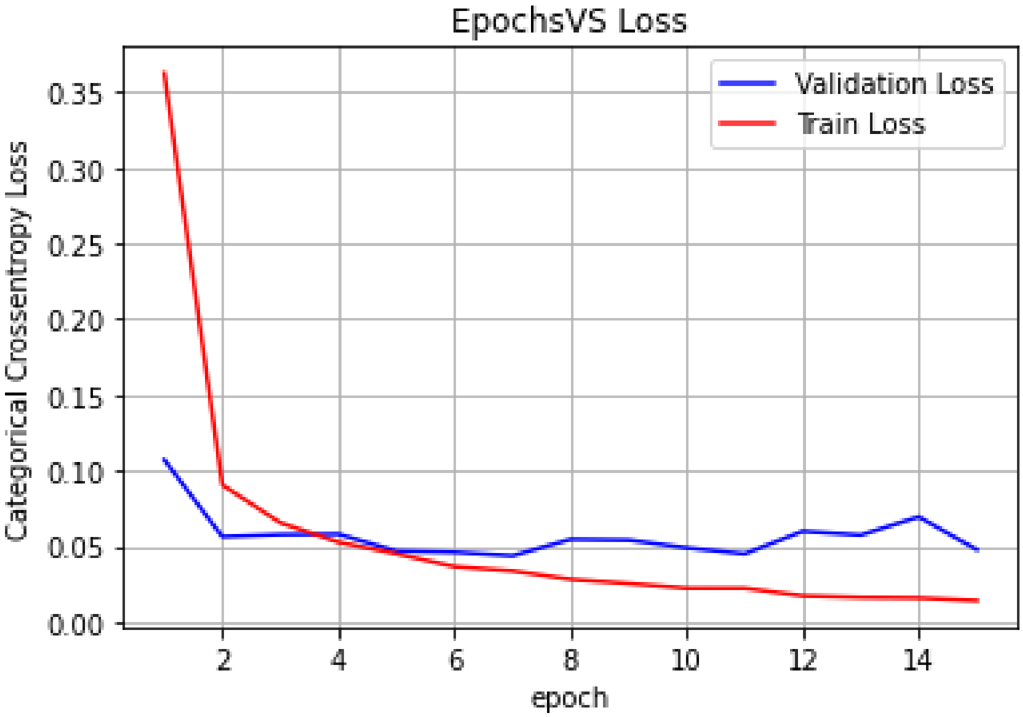
```
In [8]: score = model_31.evaluate(X_test, Y_test, verbose=0)
        print('Test score:', score[0])
        print('Test accuracy:', score[1])


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

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


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

```
Test score: 0.047884970903396606
Test accuracy: 0.9900000095367432
```



### 1.2 5 layer CNN

```
In [9]: #Architecture = Conv2d,pool,conv2d,d,pool,conv2d,bn,pool,conv2d,bn,pool,conv2d,pool
        model_5l = Sequential()
        # first layer
        model_5l.add(Conv2D(64, kernel_size=(2, 2),activation='relu',input_shape=input_shape))
        model_5l.add(MaxPooling2D(pool_size=(1, 1)))
        # second layer
        model_5l.add(Conv2D(64, kernel_size=(2, 2), activation='relu'))
        model_5l.add(Dropout(0.25))
```

```
model_51.add(MaxPooling2D(pool_size=(2, 2)))
# third layer
model_51.add(Conv2D(32, kernel_size=(3, 3), activation='relu'))
model_51.add(BatchNormalization(axis=1))
model_51.add(MaxPooling2D(pool_size=(1, 1)))
# fourth layer
model_51.add(Conv2D(32, kernel_size=(2, 2), activation='relu'))
model_51.add(BatchNormalization(axis=1))
model_51.add(MaxPooling2D(pool_size=(2, 2)))
# fifth layer
model_51.add(Conv2D(16, kernel_size=(2, 2), activation='relu'))
model_51.add(MaxPooling2D(pool_size=(2, 2)))
# flattening,dropout
model_51.add(Flatten())
model_51.add(Dense(128, activation='relu'))
model_51.add(Dropout(0.5))
# softmax
model_51.add(Dense(num_classes, activation='softmax'))
model_51.summary()
```

```
Model: "sequential_1"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_3 (Conv2D)            (None, 27, 27, 64)        320       
_________________________________________________________________
max_pooling2d_3 (MaxPooling2 (None, 27, 27, 64)        0         
_________________________________________________________________
conv2d_4 (Conv2D)            (None, 26, 26, 64)        16448     
_________________________________________________________________
dropout_1 (Dropout)          (None, 26, 26, 64)        0         
_________________________________________________________________
max_pooling2d_4 (MaxPooling2 (None, 13, 13, 64)        0         
_________________________________________________________________
conv2d_5 (Conv2D)            (None, 11, 11, 32)        18464     
_________________________________________________________________
batch_normalization_1 (Batch (None, 11, 11, 32)        44        
_________________________________________________________________
max_pooling2d_5 (MaxPooling2 (None, 11, 11, 32)        0         
_________________________________________________________________
conv2d_6 (Conv2D)            (None, 10, 10, 32)        4128      
_________________________________________________________________
batch_normalization_2 (Batch (None, 10, 10, 32)        40        
_________________________________________________________________
max_pooling2d_6 (MaxPooling2 (None, 5, 5, 32)          0         
_________________________________________________________________
conv2d_7 (Conv2D)            (None, 4, 4, 16)          2064      
_________________________________________________________________
```

```
max_pooling2d_7 (MaxPooling2 (None, 2, 2, 16)          0
_________________________________________________________________
flatten_1 (Flatten)          (None, 64)                0
_________________________________________________________________
dense_2 (Dense)              (None, 128)               8320
_________________________________________________________________
dropout_2 (Dropout)          (None, 128)               0
_________________________________________________________________
dense_3 (Dense)              (None, 10)                1290
=================================================================
Total params: 51,118
Trainable params: 51,076
Non-trainable params: 42
_________________________________________________________________
```

```
In [10]: model_51.compile(loss=keras.losses.categorical_crossentropy,optimizer=keras.optimizers
         history=model_51.fit(X_train, Y_train,batch_size=batch_size,epochs=epochs,verbose=1,v
```

```
Epoch 1/15
469/469 [==============================] - 5s 11ms/step - loss: 0.4308 - accuracy: 0.8625 - val
Epoch 2/15
469/469 [==============================] - 5s 11ms/step - loss: 0.1072 - accuracy: 0.9684 - val
Epoch 3/15
469/469 [==============================] - 5s 11ms/step - loss: 0.0763 - accuracy: 0.9771 - val
Epoch 4/15
469/469 [==============================] - 5s 11ms/step - loss: 0.0623 - accuracy: 0.9813 - val
Epoch 5/15
469/469 [==============================] - 5s 11ms/step - loss: 0.0537 - accuracy: 0.9845 - val
Epoch 6/15
469/469 [==============================] - 5s 11ms/step - loss: 0.0483 - accuracy: 0.9857 - val
Epoch 7/15
469/469 [==============================] - 5s 11ms/step - loss: 0.0427 - accuracy: 0.9871 - val
Epoch 8/15
469/469 [==============================] - 5s 11ms/step - loss: 0.0396 - accuracy: 0.9873 - val
Epoch 9/15
469/469 [==============================] - 5s 11ms/step - loss: 0.0376 - accuracy: 0.9887 - val
Epoch 10/15
469/469 [==============================] - 5s 11ms/step - loss: 0.0330 - accuracy: 0.9900 - val
Epoch 11/15
469/469 [==============================] - 5s 11ms/step - loss: 0.0323 - accuracy: 0.9904 - val
Epoch 12/15
469/469 [==============================] - 5s 11ms/step - loss: 0.0303 - accuracy: 0.9909 - val
Epoch 13/15
469/469 [==============================] - 5s 11ms/step - loss: 0.0280 - accuracy: 0.9912 - val
Epoch 14/15
469/469 [==============================] - 5s 11ms/step - loss: 0.0272 - accuracy: 0.9919 - val
Epoch 15/15
```

```
469/469 [==============================] - 5s 11ms/step - loss: 0.0235 - accuracy: 0.9923 - val
```

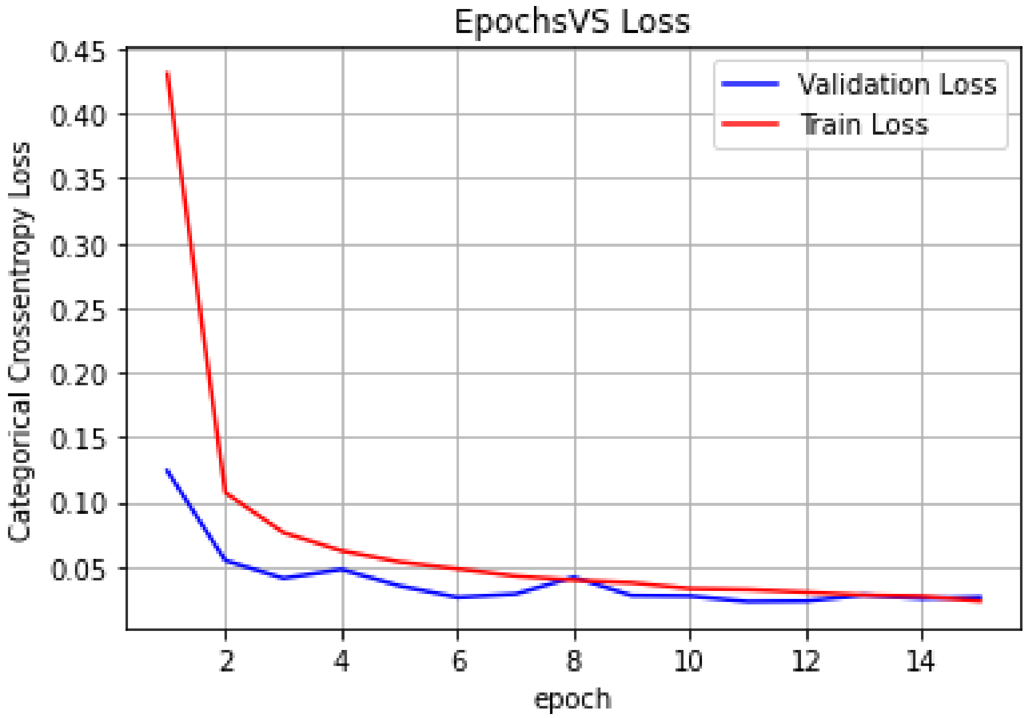
```
In [11]: score = model_51.evaluate(X_test, Y_test, verbose=0)
         print('Test score:', score[0])
         print('Test accuracy:', score[1])


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

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


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

```
Test score: 0.026484984904527664
Test accuracy: 0.9919999837875366
```



### 1.3 7 layer CNN

```
In [12]: #Architecture=conv2d,pool,conv2d,bn,pool,conv2d,d,pool,conv2d,d,pool,conv2d,bn,pool,c
         model_7l = Sequential()
         # first layer
         model_7l.add(Conv2D(64, kernel_size=(5, 5),activation='relu',input_shape=input_shape)
         model_7l.add(MaxPooling2D(pool_size=(1, 1)))
         # second layer
         model_7l.add(Conv2D(64, kernel_size=(3, 3), activation='relu'))
         model_7l.add(BatchNormalization(axis=1))
         model_7l.add(MaxPooling2D(pool_size=(2, 2)))
         # third layer
         model_7l.add(Conv2D(32, kernel_size=(3, 3), activation='relu'))
         model_7l.add(Dropout(0.5))
         model_7l.add(MaxPooling2D(pool_size=(1, 1)))
         # fourth layer
         model_7l.add(Conv2D(32, kernel_size=(3, 3), activation='relu'))
         model_7l.add(Dropout(0.25))
         model_7l.add(MaxPooling2D(pool_size=(1, 1)))
         # fifth layer
         model_7l.add(Conv2D(16, kernel_size=(2, 2), activation='relu'))
         model_7l.add(BatchNormalization(axis=1))
         model_7l.add(MaxPooling2D(pool_size=(1, 1)))
         # sixth layer
         model_7l.add(Conv2D(16, kernel_size=(2, 2), activation='relu'))
         model_7l.add(BatchNormalization(axis=1))
         model_7l.add(MaxPooling2D(pool_size=(1, 1)))
         # seventh layer
         model_7l.add(Conv2D(8, kernel_size=(3, 3), activation='relu'))
         model_7l.add(MaxPooling2D(pool_size=(1, 1)))
         # flattening,dropout
         model_7l.add(Flatten())
         model_7l.add(Dense(128, activation='relu'))
         model_7l.add(Dropout(0.5))
         # softmax
         model_7l.add(Dense(num_classes, activation='softmax'))
         model_7l.summary()
```

```
Model: "sequential_2"

_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_8 (Conv2D)            (None, 24, 24, 64)        1664

_________________________________________________________________
max_pooling2d_8 (MaxPooling2 (None, 24, 24, 64)        0

_________________________________________________________________
conv2d_9 (Conv2D)            (None, 22, 22, 64)        36928

_________________________________________________________________
batch_normalization_3 (Batch (None, 22, 22, 64)        88
_________________________________________________________________
max_pooling2d_9 (MaxPooling2 (None, 11, 11, 64)        0
_________________________________________________________________
conv2d_10 (Conv2D)           (None, 9, 9, 32)          18464
_________________________________________________________________
dropout_3 (Dropout)          (None, 9, 9, 32)          0
_________________________________________________________________
max_pooling2d_10 (MaxPooling (None, 9, 9, 32)          0
_________________________________________________________________
conv2d_11 (Conv2D)           (None, 7, 7, 32)          9248
_________________________________________________________________
dropout_4 (Dropout)          (None, 7, 7, 32)          0
_________________________________________________________________
max_pooling2d_11 (MaxPooling (None, 7, 7, 32)          0
_________________________________________________________________
conv2d_12 (Conv2D)           (None, 6, 6, 16)          2064
_________________________________________________________________
batch_normalization_4 (Batch (None, 6, 6, 16)          24
_________________________________________________________________
max_pooling2d_12 (MaxPooling (None, 6, 6, 16)          0
_________________________________________________________________
conv2d_13 (Conv2D)           (None, 5, 5, 16)          1040
_________________________________________________________________
batch_normalization_5 (Batch (None, 5, 5, 16)          20
_________________________________________________________________
max_pooling2d_13 (MaxPooling (None, 5, 5, 16)          0
_________________________________________________________________
conv2d_14 (Conv2D)           (None, 3, 3, 8)           1160
_________________________________________________________________
max_pooling2d_14 (MaxPooling (None, 3, 3, 8)           0
_________________________________________________________________
flatten_2 (Flatten)          (None, 72)                0
_________________________________________________________________
dense_4 (Dense)              (None, 128)               9344
_________________________________________________________________
dropout_5 (Dropout)          (None, 128)               0
_________________________________________________________________
dense_5 (Dense)              (None, 10)                1290
=================================================================
Total params: 81,334
Trainable params: 81,268
Non-trainable params: 66
_________________________________________________________________
```

```
In [13]: model_71.compile(loss=keras.losses.categorical_crossentropy,optimizer=keras.optimizers
         history=model_71.fit(X_train, Y_train,batch_size=batch_size,epochs=epochs,verbose=1,va
```

```
Epoch 1/15
```

```
469/469 [==============================] - 6s 12ms/step - loss: 0.5877 - accuracy: 0.8027 - va
Epoch 2/15
469/469 [==============================] - 5s 12ms/step - loss: 0.1203 - accuracy: 0.9651 - val
Epoch 3/15
469/469 [==============================] - 5s 12ms/step - loss: 0.0888 - accuracy: 0.9741 - val
Epoch 4/15
469/469 [==============================] - 6s 12ms/step - loss: 0.0748 - accuracy: 0.9788 - val
Epoch 5/15
469/469 [==============================] - 5s 12ms/step - loss: 0.0676 - accuracy: 0.9810 - val
Epoch 6/15
469/469 [==============================] - 6s 12ms/step - loss: 0.0589 - accuracy: 0.9826 - val
Epoch 7/15
469/469 [==============================] - 5s 12ms/step - loss: 0.0583 - accuracy: 0.9834 - val
Epoch 8/15
469/469 [==============================] - 5s 12ms/step - loss: 0.0532 - accuracy: 0.9855 - val
Epoch 9/15
469/469 [==============================] - 5s 12ms/step - loss: 0.0496 - accuracy: 0.9857 - val
Epoch 10/15
469/469 [==============================] - 6s 12ms/step - loss: 0.0451 - accuracy: 0.9868 - val
Epoch 11/15
469/469 [==============================] - 5s 12ms/step - loss: 0.0434 - accuracy: 0.9869 - val
Epoch 12/15
469/469 [==============================] - 5s 12ms/step - loss: 0.0416 - accuracy: 0.9886 - val
Epoch 13/15
469/469 [==============================] - 5s 12ms/step - loss: 0.0386 - accuracy: 0.9889 - val
Epoch 14/15
469/469 [==============================] - 5s 12ms/step - loss: 0.0374 - accuracy: 0.9891 - val
Epoch 15/15
469/469 [==============================] - 5s 12ms/step - loss: 0.0372 - accuracy: 0.9891 - val
```

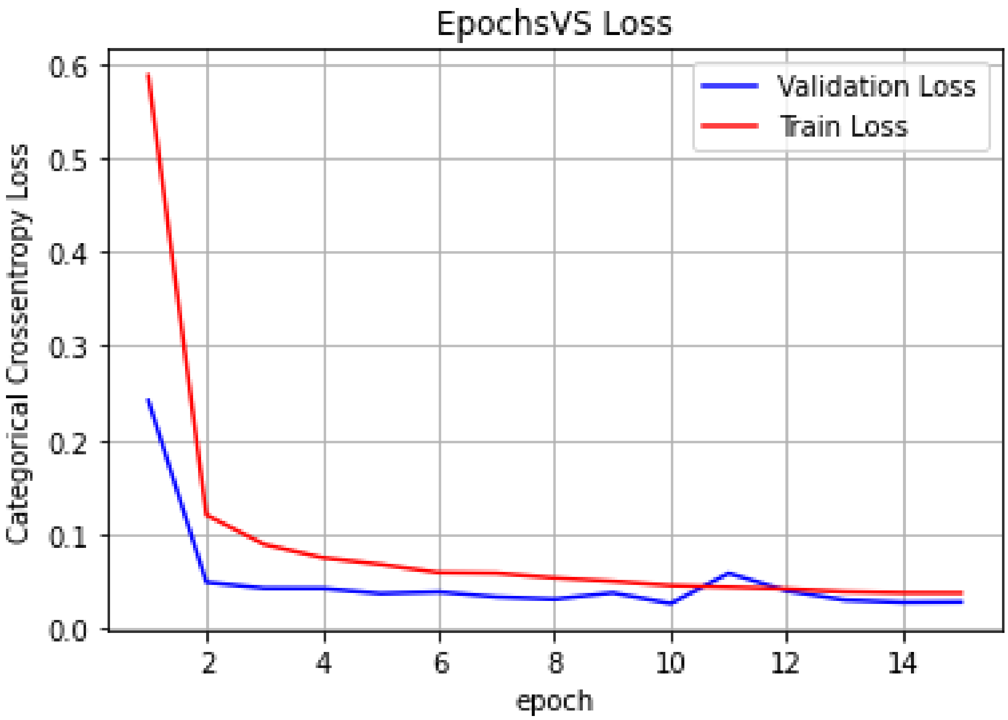
```
In [14]: score = model_71.evaluate(X_test, Y_test, verbose=0)
         print('Test score:', score[0])
         print('Test accuracy:', score[1])


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

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


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

```
Test score: 0.027606463059782982
Test accuracy: 0.9926999807357788
```



```
In [16]: from prettytable import PrettyTable
         x = PrettyTable()
         x.field_names = ["No. of layer", "Accuracy %"]

         x.add_row(["3","99.00"])
         x.add_row(["5","99.19"])
         x.add_row(["7","99.26"])
         print(x)
```

```
+--------------+------------+
| No. of layer | Accuracy % |
+--------------+------------+
|      3       |   99.00    |
|      5       |   99.19    |
|      7       |   99.26    |
+--------------+------------+
```

## 2 Summary

1 created 3,5,7 layered cnn using batch normalization
2 observed that as layer increases accuracy also increased