In [1]:

```
#Import statements
from __future__ import print_function
import keras
import warnings
warnings.filterwarnings("ignore")
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.layers import Dropout, BatchNormalization
from keras import backend as K
from keras.optimizers import Adam, Adadelta
from keras.losses import categorical_crossentropy
from prettytable import PrettyTable
```

```
Using TensorFlow backend.
```

In [0]:

```
# Model parameters
batch_size = 128
num_classes = 10
epoch = 12
# input image dimensions
img_rows, img_cols = 28, 28
```

In [3]:

```
# loading and splitting the data
(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)
```

```
Downloading data from https://s3.amazonaws.com/img-datasets/mnist.npz
11493376/11490434 [==============================] - 1s 0us/step
```

In [4]:

```
#Normalization
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 [0]:

```
# 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)
```

In [0]:

```
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()
```

1. 1 CNN(3 layers)+ relu + adam +Batch normalization + Dropout with kernel size = (3*3)

In [0]:

```
model=Sequential()
# Adding first layer
model.add(Conv2D(64, kernel_size=(3, 3),activation='relu',input_shape=input_shape))
model.add(MaxPooling2D(pool_size=(2, 2)))

# Adding Second layer
model.add(Conv2D(32, kernel_size=(3, 3), activation='relu'))
model.add(BatchNormalization(axis=1))
model.add(MaxPooling2D(pool_size=(2,2)))

# Adding third layer
model.add(Conv2D(16, kernel_size=(3, 3), activation='relu'))
#axis=1 since we are using channels_first data format
model.add(BatchNormalization(axis=1))
model.add(MaxPooling2D(pool_size=(2,2)))

model.add(Flatten())
model.add(Dense(256, activation='relu'))
model.add(Dropout(0.5))

#Softmax
model.add(Dense(num_classes, activation='softmax'))
model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_7 (Conv2D)            (None, 26, 26, 64)        640       
_________________________________________________________________
max_pooling2d_7 (MaxPooling2 (None, 13, 13, 64)        0         
_________________________________________________________________
conv2d_8 (Conv2D)            (None, 11, 11, 32)        18464     
_________________________________________________________________
batch_normalization_5 (Batch (None, 11, 11, 32)        44        
_________________________________________________________________
max_pooling2d_8 (MaxPooling2 (None, 5, 5, 32)          0         
_________________________________________________________________
conv2d_9 (Conv2D)            (None, 3, 3, 16)          4624      
_________________________________________________________________
batch_normalization_6 (Batch (None, 3, 3, 16)          12        
_________________________________________________________________
max_pooling2d_9 (MaxPooling2 (None, 1, 1, 16)          0         
_________________________________________________________________
flatten_3 (Flatten)          (None, 16)                0         
_________________________________________________________________
dense_5 (Dense)              (None, 256)               4352      
_________________________________________________________________
dropout_3 (Dropout)          (None, 256)               0         
_________________________________________________________________
dense_6 (Dense)              (None, 10)                2570      
=================================================================
Total params: 30,706
Trainable params: 30,678
Non-trainable params: 28
_________________________________________________________________
```

In [0]:

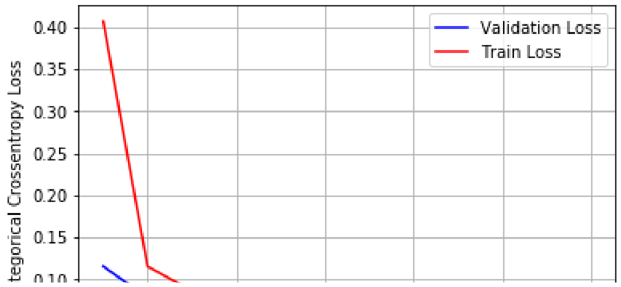
```
model.compile(loss='categorical_crossentropy', optimizer=Adam(), metrics=['accuracy'])
history=model.fit(x_train, y_train,batch_size=batch_size,epochs=epoch,verbose=1,validation_data=(x_
test, y_test))
```

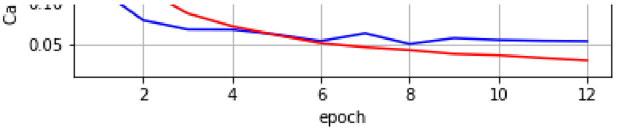
```
Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 70s 1ms/step - loss: 0.4069 - acc: 0.8740 - val_los
s: 0.1157 - val_acc: 0.9648
Epoch 2/12
60000/60000 [==============================] - 69s 1ms/step - loss: 0.1156 - acc: 0.9662 - val_los
s: 0.0784 - val_acc: 0.9768
Epoch 3/12
60000/60000 [==============================] - 69s 1ms/step - loss: 0.0866 - acc: 0.9737 - val_los
s: 0.0675 - val_acc: 0.9792
Epoch 4/12
60000/60000 [==============================] - 69s 1ms/step - loss: 0.0712 - acc: 0.9782 - val_los
s: 0.0672 - val_acc: 0.9803
Epoch 5/12
60000/60000 [==============================] - 69s 1ms/step - loss: 0.0608 - acc: 0.9812 - val_los
s: 0.0615 - val_acc: 0.9817
Epoch 6/12
60000/60000 [==============================] - 69s 1ms/step - loss: 0.0511 - acc: 0.9842 - val_los
s: 0.0536 - val_acc: 0.9837
Epoch 7/12
60000/60000 [==============================] - 69s 1ms/step - loss: 0.0462 - acc: 0.9862 - val_los
s: 0.0629 - val_acc: 0.9820
Epoch 8/12
60000/60000 [==============================] - 69s 1ms/step - loss: 0.0429 - acc: 0.9868 - val_los
s: 0.0501 - val_acc: 0.9849
Epoch 9/12
60000/60000 [==============================] - 69s 1ms/step - loss: 0.0383 - acc: 0.9879 - val_los
s: 0.0571 - val_acc: 0.9829
Epoch 10/12
60000/60000 [==============================] - 68s 1ms/step - loss: 0.0367 - acc: 0.9884 - val_los
s: 0.0549 - val_acc: 0.9828
Epoch 11/12
60000/60000 [==============================] - 69s 1ms/step - loss: 0.0334 - acc: 0.9890 - val_los
s: 0.0539 - val_acc: 0.9836
Epoch 12/12
60000/60000 [==============================] - 68s 1ms/step - loss: 0.0305 - acc: 0.9898 - val_los
s: 0.0534 - val_acc: 0.9860
```

In [0]:

```
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,epoch+1))

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

```
Test score: 0.05342528630345478
Test accuracy: 0.986
```





1. 2 CNN(5 layers)+ relu + adam +Batch normalization + Dropout with kernel size = (5*5)

In [23]:

```
model = Sequential()

# Adding first layer
model.add(Conv2D(40, kernel_size = (5, 5), activation = "relu", input_shape = input_shape))
model.add(Dropout(0.25))

# Adding second layer
model.add(Conv2D(60, kernel_size = (5, 5), activation = "relu"))
model.add(Dropout(0.25))
model.add(MaxPooling2D(pool_size = (1, 1)))


# Adding third layer
model.add(Conv2D(70, kernel_size = (5, 5), activation = "relu"))
model.add(Dropout(0.25))
model.add(BatchNormalization(axis=1))

# Adding fourth layer
model.add(Conv2D(90, kernel_size = (5, 5), activation = "relu"))
model.add(MaxPooling2D(pool_size = (2, 2)))
model.add(BatchNormalization(axis=1))

# Adding fifth layer
model.add(Conv2D(100, kernel_size = (5, 5), activation = "relu"))
model.add(MaxPooling2D(pool_size = (1, 1)))

model.add(Flatten())
model.add(Dense(512, activation = "relu"))
model.add(Dropout(0.5))

#Softmax
model.add(Dense(num_classes, activation = "softmax"))
model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_71 (Conv2D)           (None, 24, 24, 40)        1040      
_________________________________________________________________
dropout_43 (Dropout)         (None, 24, 24, 40)        0         
_________________________________________________________________
conv2d_72 (Conv2D)           (None, 20, 20, 60)        60060     
_________________________________________________________________
dropout_44 (Dropout)         (None, 20, 20, 60)        0         
_________________________________________________________________
max_pooling2d_40 (MaxPooling (None, 20, 20, 60)        0         
_________________________________________________________________
conv2d_73 (Conv2D)           (None, 16, 16, 70)        105070    
_________________________________________________________________
dropout_45 (Dropout)         (None, 16, 16, 70)        0         
_________________________________________________________________
batch_normalization_26 (Batc (None, 16, 16, 70)        64        
_________________________________________________________________
conv2d_74 (Conv2D)           (None, 12, 12, 90)        157590    
_________________________________________________________________
max_pooling2d_41 (MaxPooling (None, 6, 6, 90)          0         
_________________________________________________________________
batch_normalization_27 (Batc (None, 6, 6, 90)          24        
_________________________________________________________________
conv2d_75 (Conv2D)           (None, 2, 2, 100)         225100    
_________________________________________________________________
max_pooling2d_42 (MaxPooling (None, 2, 2, 100)         0         
_________________________________________________________________
flatten_15 (Flatten)         (None, 400)               0         
```

```
_________________________________________________________________
dense_29 (Dense)             (None, 512)               205312    
_________________________________________________________________
dropout_46 (Dropout)         (None, 512)               0         
_________________________________________________________________
dense_30 (Dense)             (None, 10)                5130      
=================================================================
Total params: 759,390
Trainable params: 759,346
Non-trainable params: 44
_________________________________________________________________
```

In [24]:

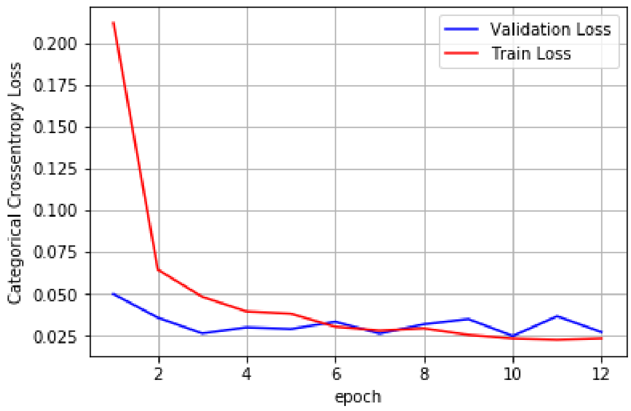
```
model.compile(loss='categorical_crossentropy', optimizer=Adam(), metrics=['accuracy'])
history=model.fit(x_train, y_train,batch_size=batch_size,epochs=epoch,verbose=1,validation_data=(x_
test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 960s 16ms/step - loss: 0.2118 - acc: 0.9349 - val_l
oss: 0.0499 - val_acc: 0.9849
Epoch 2/12
60000/60000 [==============================] - 958s 16ms/step - loss: 0.0645 - acc: 0.9819 - val_l
oss: 0.0358 - val_acc: 0.9900
Epoch 3/12
60000/60000 [==============================] - 959s 16ms/step - loss: 0.0483 - acc: 0.9863 - val_l
oss: 0.0264 - val_acc: 0.9925
Epoch 4/12
60000/60000 [==============================] - 961s 16ms/step - loss: 0.0395 - acc: 0.9888 - val_l
oss: 0.0300 - val_acc: 0.9913
Epoch 5/12
60000/60000 [==============================] - 960s 16ms/step - loss: 0.0382 - acc: 0.9895 - val_l
oss: 0.0290 - val_acc: 0.9913
Epoch 6/12
60000/60000 [==============================] - 961s 16ms/step - loss: 0.0304 - acc: 0.9919 - val_l
oss: 0.0334 - val_acc: 0.9909
Epoch 7/12
60000/60000 [==============================] - 968s 16ms/step - loss: 0.0281 - acc: 0.9918 - val_l
oss: 0.0263 - val_acc: 0.9928
Epoch 8/12
60000/60000 [==============================] - 950s 16ms/step - loss: 0.0294 - acc: 0.9921 - val_l
oss: 0.0319 - val_acc: 0.9917
Epoch 9/12
60000/60000 [==============================] - 946s 16ms/step - loss: 0.0255 - acc: 0.9931 - val_l
oss: 0.0350 - val_acc: 0.9928
Epoch 10/12
60000/60000 [==============================] - 952s 16ms/step - loss: 0.0233 - acc: 0.9936 - val_l
oss: 0.0249 - val_acc: 0.9923
Epoch 11/12
60000/60000 [==============================] - 948s 16ms/step - loss: 0.0225 - acc: 0.9940 - val_l
oss: 0.0367 - val_acc: 0.9905
Epoch 12/12
60000/60000 [==============================] - 950s 16ms/step - loss: 0.0234 - acc: 0.9935 - val_l
oss: 0.0272 - val_acc: 0.9932
```

In [25]:

```
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,epoch+1))

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

```
Test score: 0.027181752927140496
Test accuracy: 0.9932
```



1. 3 CNN(7 layers)+ relu + adam +Batch normalization + Dropout with various kernel sizes

In [26]:

```
model=Sequential()
#Adding first layer
model.add(Conv2D(128, kernel_size=(7, 7),activation='relu',input_shape=input_shape))
model.add(Dropout(0.25))
model.add(MaxPooling2D(pool_size=(1, 1)))


#Adding Second Layer
model.add(Conv2D(64,kernel_size=(3,3),activation='relu'))
model.add(BatchNormalization(axis=1))

#Adding Third Layer
model.add(Conv2D(32,kernel_size=(5,5),activation='relu'))
model.add(Dropout(0.5))
model.add(MaxPooling2D(pool_size=(1,1)))

#Fourth layer
model.add(Conv2D(32, kernel_size=(3, 3), activation='relu'))
model.add(Dropout(0.25))
model.add(MaxPooling2D(pool_size=(1,1)))
model.add(BatchNormalization(axis=1))

#Fifth layer
model.add(Conv2D(16, kernel_size=(2, 2), activation='relu'))
model.add(BatchNormalization(axis=1))
model.add(MaxPooling2D(pool_size=(1,1)))

#Sixth Layer
model.add(Conv2D(16,kernel_size=(2,2),activation='relu'))
model.add(BatchNormalization(axis=1))
model.add(Dropout(0.5))
model.add(MaxPooling2D(pool_size=(2,2)))

#Seventh Layer
model.add(Conv2D(8,kernel_size=(3,3),activation='relu'))
model.add(MaxPooling2D(pool_size=(2,2)))

#Fully Connected layer
#Flattening
model.add(Flatten())
model.add(Dense(256, activation = "relu"))
model.add(Dropout(0.25))

#Softmax
model.add(Dense(num_classes, activation='softmax'))
model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_76 (Conv2D)           (None, 22, 22, 128)       6400      
_________________________________________________________________
dropout_47 (Dropout)         (None, 22, 22, 128)       0         
```

```
_________________________________________________________________
max_pooling2d_43 (MaxPooling (None, 22, 22, 128)       0         
_________________________________________________________________
conv2d_77 (Conv2D)           (None, 20, 20, 64)        73792     
_________________________________________________________________
batch_normalization_28 (Batc (None, 20, 20, 64)        80        
_________________________________________________________________
conv2d_78 (Conv2D)           (None, 16, 16, 32)        51232     
_________________________________________________________________
dropout_48 (Dropout)         (None, 16, 16, 32)        0         
_________________________________________________________________
max_pooling2d_44 (MaxPooling (None, 16, 16, 32)        0         
_________________________________________________________________
conv2d_79 (Conv2D)           (None, 14, 14, 32)        9248      
_________________________________________________________________
dropout_49 (Dropout)         (None, 14, 14, 32)        0         
_________________________________________________________________
max_pooling2d_45 (MaxPooling (None, 14, 14, 32)        0         
_________________________________________________________________
batch_normalization_29 (Batc (None, 14, 14, 32)        56        
_________________________________________________________________
conv2d_80 (Conv2D)           (None, 13, 13, 16)        2064      
_________________________________________________________________
batch_normalization_30 (Batc (None, 13, 13, 16)        52        
_________________________________________________________________
max_pooling2d_46 (MaxPooling (None, 13, 13, 16)        0         
_________________________________________________________________
conv2d_81 (Conv2D)           (None, 12, 12, 16)        1040      
_________________________________________________________________
batch_normalization_31 (Batc (None, 12, 12, 16)        48        
_________________________________________________________________
dropout_50 (Dropout)         (None, 12, 12, 16)        0         
_________________________________________________________________
max_pooling2d_47 (MaxPooling (None, 6, 6, 16)          0         
_________________________________________________________________
conv2d_82 (Conv2D)           (None, 4, 4, 8)           1160      
_________________________________________________________________
max_pooling2d_48 (MaxPooling (None, 2, 2, 8)           0         
_________________________________________________________________
flatten_16 (Flatten)         (None, 32)                0         
_________________________________________________________________
dense_31 (Dense)             (None, 256)               8448      
_________________________________________________________________
dropout_51 (Dropout)         (None, 256)               0         
_________________________________________________________________
dense_32 (Dense)             (None, 10)                2570      
=================================================================
Total params: 156,190
Trainable params: 156,072
Non-trainable params: 118

_________________________________________________________________
```

In [0]:

```
model.compile(loss='categorical_crossentropy', optimizer=Adam(), metrics=['accuracy'])
history=model.fit(x_train, y_train,batch_size=batch_size,epochs=epoch,verbose=1,validation_data=(x_
test, y_test))
```

```
W0819 12:30:20.541568 140130769213312 deprecation_wrapper.py:119] From
/usr/local/lib/python3.6/dist-packages/keras/optimizers.py:790: The name tf.train.Optimizer is dep
recated. Please use tf.compat.v1.train.Optimizer instead.

W0819 12:30:20.669526 140130769213312 deprecation.py:323] From /usr/local/lib/python3.6/dist-
packages/tensorflow/python/ops/math_grad.py:1250: add_dispatch_support.<locals>.wrapper (from
tensorflow.python.ops.array_ops) is deprecated and will be removed in a future version.
Instructions for updating:
Use tf.where in 2.0, which has the same broadcast rule as np.where
```

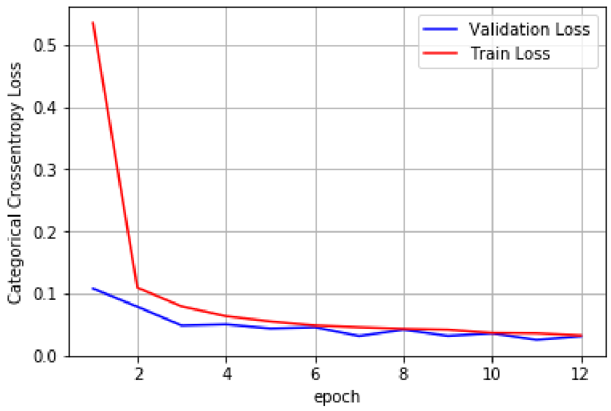
```
Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 697s 12ms/step - loss: 0.5350 - acc: 0.8237 - val_l
oss: 0.1080 - val_acc: 0.9736
Epoch 2/12
60000/60000 [==============================] - 689s 11ms/step - loss: 0.1094 - acc: 0.9667 - val_l
oss: 0.0787 - val_acc: 0.9799
```

```
oss: 0.0787 - val_acc: 0.9799
Epoch 3/12
60000/60000 [==============================] - 684s 11ms/step - loss: 0.0792 - acc: 0.9766 - val_l
oss: 0.0484 - val_acc: 0.9869
Epoch 4/12
60000/60000 [==============================] - 685s 11ms/step - loss: 0.0635 - acc: 0.9808 - val_l
oss: 0.0502 - val_acc: 0.9867
Epoch 5/12
60000/60000 [==============================] - 684s 11ms/step - loss: 0.0550 - acc: 0.9833 - val_l
oss: 0.0436 - val_acc: 0.9878
Epoch 6/12
60000/60000 [==============================] - 688s 11ms/step - loss: 0.0486 - acc: 0.9851 - val_l
oss: 0.0456 - val_acc: 0.9861
Epoch 7/12
60000/60000 [==============================] - 690s 11ms/step - loss: 0.0455 - acc: 0.9862 - val_l
oss: 0.0316 - val_acc: 0.9923
Epoch 8/12
60000/60000 [==============================] - 690s 11ms/step - loss: 0.0431 - acc: 0.9870 - val_l
oss: 0.0417 - val_acc: 0.9878
Epoch 9/12
60000/60000 [==============================] - 688s 11ms/step - loss: 0.0417 - acc: 0.9874 - val_l
oss: 0.0317 - val_acc: 0.9916
Epoch 10/12
60000/60000 [==============================] - 687s 11ms/step - loss: 0.0366 - acc: 0.9888 - val_l
oss: 0.0359 - val_acc: 0.9903
Epoch 11/12
60000/60000 [==============================] - 690s 11ms/step - loss: 0.0359 - acc: 0.9888 - val_l
oss: 0.0253 - val_acc: 0.9932
Epoch 12/12
60000/60000 [==============================] - 692s 12ms/step - loss: 0.0324 - acc: 0.9900 - val_l
oss: 0.0311 - val_acc: 0.9911
```

In [0]:

```
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,epoch+1))

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

```
Test score: 0.031061326131038368
Test accuracy: 0.9911
```



Observations

In [4]:

```
x = PrettyTable()
x.field_names = ["Architecture", "Accuracy-%"]
```

```
x.add_row(["3 layer CNN,kernel size=(3*3)","98.6"])
x.add_row(["5 layer CNN,kernel size=(5*5)","99.3"])
x.add_row(["7 layer CNN,different kernel sizes","99.1"])
print(x)
```

```
+------------------------------------+------------+
|            Architecture            | Accuracy-% |
+------------------------------------+------------+
|   3 layer CNN,kernel size=(3*3)    |    98.6    |
|   5 layer CNN,kernel size=(5*5)    |    99.3    |
| 7 layer CNN,different kernel sizes |    99.1    |
+------------------------------------+------------+
```

3 layer architecture

Conv2d-->Maxpooling-->Conv2d-->BN-->Conv2d-->Maxpooling-->Conv2d-->BN-->Conv2d-->Maxpooling-->Flatten,dense-->Dropout-->softmax

5 layer architecture

Conv2d-->drouput-->Conv2d-->dropout-->Maxpooling-->Conv2d-->dropout-->BN-->Conv2d-->Maxpooling-->BN-->#Conv2d-->drouput-->Conv2d-->-->dropout-->Maxpooling-->Conv2d-->dropout-->BN-->Conv2d-->Maxpooling-->Flatten,dense-->Dropout-->Softmax

7 layer architecture

Conv2d-->drouput-->Maxpooling-->Conv2d-->dropout-->BN-->Conv2d-->dropout-->Maxpooling-->Conv2d-->dropout-->Maxpooling-->BN-->Conv2d-->BN-->Maxpooling-->Conv2d-->BN-->Dropout-->Maxpooling-->Conv2d-->Maxpooling-->Flatten,dense-->Dropout-->softmax

Accuracy got increased while increasing the number of layers,but it slightly reduced on using different kernel sizes with 7 layers compared to 5 layer CNN.