In [1]:
```
### Importing libraries
import keras
from keras.datasets import mnist
from keras.layers import Dense,Dropout,Flatten,BatchNormalization
from keras.models import Sequential
from keras.layers import Conv2D,MaxPooling2D
from keras import backend as K
```

In [2]:
```
## Loading dataset
(x_train,y_train),(x_test,y_test) = mnist.load_data()

## network parameters
img_rows,img_cols = 28,28
batch_size = 128
n_epoch = 15
classes = 10

##
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)

##Converting x_train,x_test to float
x_train = x_train.astype('float32')
x_test = x_test.astype('float32')

## normalize it between 0-1
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')

## one hot encode the target labels
y_train = keras.utils.to_categorical(y_train,classes)
y_test = keras.utils.to_categorical(y_test,classes)
```

```
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datasets/mnist.npz (https://storage.googleapis.com/tensorflow/tf-keras-datasets/mnist.npz)
11493376/11490434 [==============================] - 0s 0us/step
x_train shape: (60000, 28, 28, 1)
60000 train samples
10000 test samples
```

Model 1 :

```
Architecture
Kernels : 3x3,5x5,2x2
Number of convnet layers : 3
Optimizer :Adam
Activation : Relu
Maxpooling layers : 3
Regularizations : Dropout,Batch Normalization after every two layers
```

In [3]:

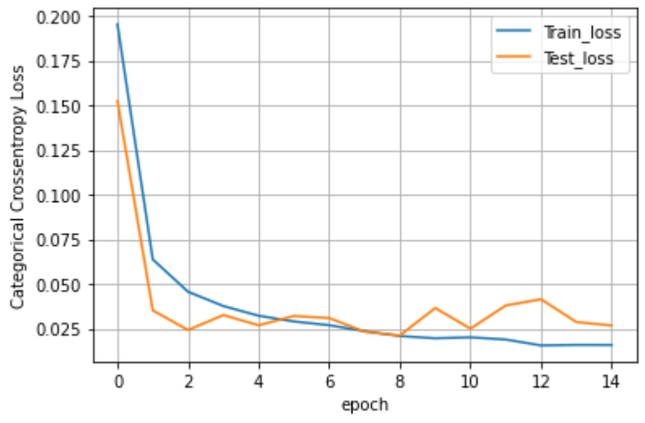
```
model = Sequential()
## create the architecture
model.add(Conv2D(32,activation='relu', kernel_size=(3, 3),input_shape = input_shape))
model.add(MaxPooling2D(pool_size=(2, 2),padding='same'))
model.add(Conv2D(64, (5, 5), activation='relu',padding='same'))
model.add(MaxPooling2D(pool_size=(2, 2),padding='same'))

model.add(BatchNormalization())
model.add(Dropout(0.35))

model.add(Conv2D(128, (2, 2), activation='relu',padding='same'))
model.add(MaxPooling2D(pool_size=(2, 2),padding='same'))

model.add(BatchNormalization())
model.add(Dropout(0.35))

model.add(Flatten())
model.add(Dense(256, activation='relu'))
model.add(Dense(classes, activation='softmax'))

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

## train the model
history = model.fit(x_train,y_train,batch_size=batch_size,
          epochs=n_epoch,
          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])
```

```
Epoch 1/15
469/469 [==============================] - 3s 7ms/step - loss: 0.1953 - accuracy: 0.9401 - val_loss: 0.1523 - val_accuracy: 0.9509
Epoch 2/15
469/469 [==============================] - 3s 6ms/step - loss: 0.0637 - accuracy: 0.9801 - val_loss: 0.0351 - val_accuracy: 0.9887
Epoch 3/15
469/469 [==============================] - 3s 7ms/step - loss: 0.0456 - accuracy: 0.9853 - val_loss: 0.0242 - val_accuracy: 0.9928
Epoch 4/15
469/469 [==============================] - 3s 7ms/step - loss: 0.0376 - accuracy: 0.9881 - val_loss: 0.0326 - val_accuracy: 0.9895
Epoch 5/15
469/469 [==============================] - 3s 7ms/step - loss: 0.0322 - accuracy: 0.9898 - val_loss: 0.0269 - val_accuracy: 0.9916
Epoch 6/15
469/469 [==============================] - 3s 6ms/step - loss: 0.0290 - accuracy: 0.9909 - val_loss: 0.0320 - val_accuracy: 0.9897
Epoch 7/15
469/469 [==============================] - 3s 7ms/step - loss: 0.0269 - accuracy: 0.9918 - val_loss: 0.0309 - val_accuracy: 0.9914
Epoch 8/15
469/469 [==============================] - 3s 7ms/step - loss: 0.0235 - accuracy: 0.9923 - val_loss: 0.0233 - val_accuracy: 0.9928
Epoch 9/15
469/469 [==============================] - 3s 7ms/step - loss: 0.0208 - accuracy: 0.9935 - val_loss: 0.0211 - val_accuracy: 0.9931
Epoch 10/15
469/469 [==============================] - 3s 7ms/step - loss: 0.0196 - accuracy: 0.9939 - val_loss: 0.0365 - val_accuracy: 0.9890
Epoch 11/15
469/469 [==============================] - 3s 7ms/step - loss: 0.0201 - accuracy: 0.9934 - val_loss: 0.0250 - val_accuracy: 0.9921
Epoch 12/15
469/469 [==============================] - 3s 7ms/step - loss: 0.0189 - accuracy: 0.9938 - val_loss: 0.0379 - val_accuracy: 0.9910
Epoch 13/15
469/469 [==============================] - 3s 6ms/step - loss: 0.0156 - accuracy: 0.9950 - val_loss: 0.0414 - val_accuracy: 0.9896
```

```
Epoch 14/15
469/469 [==============================] - 3s 7ms/step - loss: 0.0159 - accuracy: 0.9951 - val_loss: 0.0286 - val_accuracy: 0.9927
Epoch 15/15
469/469 [==============================] - 3s 6ms/step - loss: 0.0158 - accuracy: 0.9949 - val_loss: 0.0267 - val_accuracy: 0.9927
Test loss: 0.026714051142334938
Test accuracy: 0.9926999807357788
```

In [4]:

```
## Lets plot the accuracy
import matplotlib.pyplot as plt
def plot_dynamic(x,y,y_,ax):
    ax.plot(x,y,label='Train_loss')
    ax.plot(x,y_,label='Test_loss')
    plt.legend()
    plt.grid()
    fig.canvas.draw()

x = list(range(n_epoch))

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')
vy = history.history['loss']
ty = history.history['val_loss']
plot_dynamic(x, vy, ty, ax)
```



Model 2 :

Architecture
Kernels : 3x3,5x5,2x2
Number of convnet layers : 5
Optimizer :Adam
Activation : Relu
Maxpooling layers : 5
Regularizations : Dropout,Batch Normalization

In [5]:

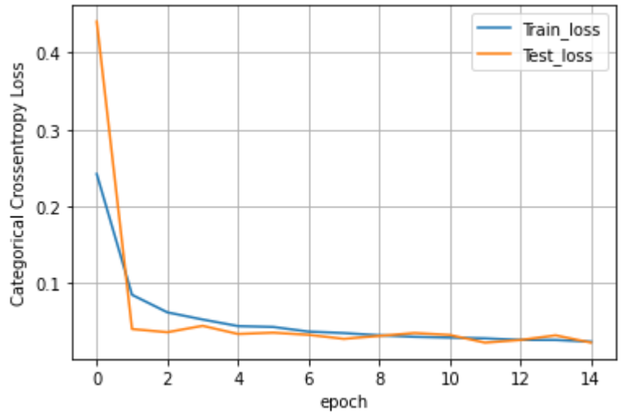
```
# from keras import backend as K
# K.common.set_image_dim_ordering('tf')

model = Sequential()
## create the architecture
model.add(Conv2D(16,activation='relu', kernel_size=(3, 3),input_shape = input_shape,padding='same'))
model.add(MaxPooling2D(pool_size=(2, 2),padding='same'))
model.add(Conv2D(32, (5, 5), activation='relu',padding='same'))
model.add(MaxPooling2D(pool_size=(2, 2),padding='same'))


model.add(BatchNormalization())
model.add(Dropout(0.35))


model.add(Conv2D(64, (2, 2), activation='relu',padding='same'))
model.add(MaxPooling2D(pool_size=(2, 2),padding='same'))
model.add(Conv2D(128,(3, 3),activation='relu',padding='same'))
model.add(MaxPooling2D(pool_size=(2, 2),padding='same'))

model.add(BatchNormalization())
model.add(Dropout(0.35))

model.add(Conv2D(256, (5, 5), activation='relu',padding='same'))
model.add(MaxPooling2D(pool_size=(2, 2),padding='same'))

model.add(Flatten())
model.add(Dense(512, activation='relu'))

model.add(BatchNormalization())
model.add(Dropout(0.35))

model.add(Dense(classes, activation='softmax'))

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

## train the model
history = model.fit(x_train,y_train,batch_size=batch_size,\
          epochs=n_epoch,\
          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])
```

```
Epoch 1/15
469/469 [==============================] - 4s 9ms/step - loss: 0.2421 - accuracy: 0.9243 - val_loss: 0.4402 - val_accuracy: 0.8528
Epoch 2/15
469/469 [==============================] - 4s 8ms/step - loss: 0.0852 - accuracy: 0.9725 - val_loss: 0.0407 - val_accuracy: 0.9857
Epoch 3/15
469/469 [==============================] - 4s 8ms/step - loss: 0.0625 - accuracy: 0.9798 - val_loss: 0.0366 - val_accuracy: 0.9892
Epoch 4/15
469/469 [==============================] - 4s 8ms/step - loss: 0.0532 - accuracy: 0.9833 - val_loss: 0.0450 - val_accuracy: 0.9856
Epoch 5/15
469/469 [==============================] - 4s 8ms/step - loss: 0.0446 - accuracy: 0.9860 - val_loss: 0.0344 - val_accuracy: 0.9897
Epoch 6/15
469/469 [==============================] - 4s 8ms/step - loss: 0.0435 - accuracy: 0.9863 - val_loss: 0.0361 - val_accuracy: 0.9890
```

```
Epoch 7/15
469/469 [==============================] - 4s 8ms/step - loss: 0.0375 - accuracy: 0.9881 - val_loss: 0.0333 - val_accuracy: 0.9902
Epoch 8/15
469/469 [==============================] - 4s 8ms/step - loss: 0.0355 - accuracy: 0.9887 - val_loss: 0.0280 - val_accuracy: 0.9919
Epoch 9/15
469/469 [==============================] - 4s 8ms/step - loss: 0.0327 - accuracy: 0.9896 - val_loss: 0.0319 - val_accuracy: 0.9916
Epoch 10/15
469/469 [==============================] - 4s 8ms/step - loss: 0.0307 - accuracy: 0.9904 - val_loss: 0.0356 - val_accuracy: 0.9889
Epoch 11/15
469/469 [==============================] - 4s 8ms/step - loss: 0.0296 - accuracy: 0.9905 - val_loss: 0.0331 - val_accuracy: 0.9910
Epoch 12/15
469/469 [==============================] - 4s 8ms/step - loss: 0.0287 - accuracy: 0.9908 - val_loss: 0.0231 - val_accuracy: 0.9938
Epoch 13/15
469/469 [==============================] - 4s 8ms/step - loss: 0.0266 - accuracy: 0.9913 - val_loss: 0.0266 - val_accuracy: 0.9921
Epoch 14/15
469/469 [==============================] - 4s 8ms/step - loss: 0.0265 - accuracy: 0.9913 - val_loss: 0.0326 - val_accuracy: 0.9902
Epoch 15/15
469/469 [==============================] - 4s 8ms/step - loss: 0.0244 - accuracy: 0.9923 - val_loss: 0.0232 - val_accuracy: 0.9930
Test loss: 0.02315954491496086
Test accuracy: 0.9929999709129333
```

In [6]:

```
x = list(range(n_epoch))
fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')
vy = history.history['loss']
ty = history.history['val_loss']
plot_dynamic(x, vy, ty, ax)
```



Model 3 :

```
Architecture
Kernels : 3x3,5x5,2x2,7x7
Number of convnet layers : 7
Optimizer :Adam
Activation : Relu
Maxpooling layers : 7
Regularizations : Dropout,Batch Normalization after every two layers
```

In [7]:

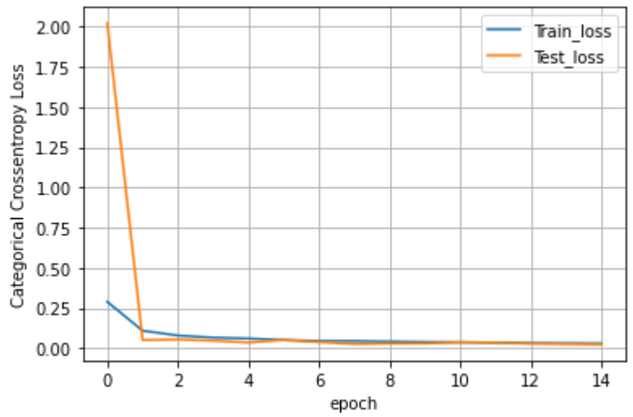
```
model = Sequential()
## create the architecture
model.add(Conv2D(16,activation='relu', kernel_size=(3, 3),input_shape = input_shape))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Conv2D(32, (5, 5), activation='relu',padding='same'))
model.add(MaxPooling2D(pool_size=(2, 2),padding='same'))

model.add(BatchNormalization())
model.add(Dropout(0.35))

model.add(Conv2D(64, (2, 2), activation='relu',padding='same'))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Conv2D(128,activation='relu', kernel_size=(3, 3),padding='same'))
model.add(MaxPooling2D(pool_size=(2, 2),padding='same'))

model.add(BatchNormalization())
model.add(Dropout(0.35))

model.add(Conv2D(256, (5, 5), activation='relu',padding='same'))
model.add(MaxPooling2D(pool_size=(2, 2),padding='same'))
model.add(Conv2D(384, (7, 7), activation='relu',padding='same'))
model.add(MaxPooling2D(pool_size=(2, 2),padding='same'))

model.add(BatchNormalization())
model.add(Dropout(0.35))

model.add(Conv2D(474, (5,5), activation='relu',padding='same'))
model.add(MaxPooling2D(pool_size=(2, 2),padding='same'))

model.add(Flatten())
model.add(Dense(512, activation='relu'))

model.add(BatchNormalization())
model.add(Dropout(0.35))
model.add(Dense(classes, activation='softmax'))

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

## train the model
history = model.fit(x_train,y_train,batch_size=batch_size,
          epochs=n_epoch,
          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])
```

```
Epoch 1/15
469/469 [==============================] - 10s 21ms/step - loss: 0.2895 - accuracy: 0.9096 - val_loss: 2.0209 - val_accuracy: 0.5539
Epoch 2/15
469/469 [==============================] - 9s 20ms/step - loss: 0.1095 - accuracy: 0.9672 - val_loss: 0.0518 - val_accuracy: 0.9841
Epoch 3/15
469/469 [==============================] - 9s 20ms/step - loss: 0.0797 - accuracy: 0.9761 - val_loss: 0.0550 - val_accuracy: 0.9844
Epoch 4/15
469/469 [==============================] - 9s 20ms/step - loss: 0.0665 - accuracy: 0.9797 - val_loss: 0.0477 - val_accuracy: 0.9858
Epoch 5/15
469/469 [==============================] - 9s 20ms/step - loss: 0.0611 - accuracy: 0.9820 - val_loss: 0.0362 - val_accuracy: 0.9887
```

```
Epoch 6/15
469/469 [==============================] - 9s 20ms/step - loss: 0.0517 - accuracy: 0.9844 - val_loss: 0.0517 - val_accuracy: 0.9856
Epoch 7/15
469/469 [==============================] - 10s 21ms/step - loss: 0.0454 - accuracy: 0.9869 - val_loss: 0.0388 - val_accuracy: 0.9892
Epoch 8/15
469/469 [==============================] - 9s 20ms/step - loss: 0.0454 - accuracy: 0.9864 - val_loss: 0.0265 - val_accuracy: 0.9920
Epoch 9/15
469/469 [==============================] - 9s 20ms/step - loss: 0.0422 - accuracy: 0.9875 - val_loss: 0.0300 - val_accuracy: 0.9910
Epoch 10/15
469/469 [==============================] - 9s 20ms/step - loss: 0.0395 - accuracy: 0.9880 - val_loss: 0.0307 - val_accuracy: 0.9903
Epoch 11/15
469/469 [==============================] - 9s 20ms/step - loss: 0.0385 - accuracy: 0.9884 - val_loss: 0.0377 - val_accuracy: 0.9901
Epoch 12/15
469/469 [==============================] - 9s 20ms/step - loss: 0.0356 - accuracy: 0.9894 - val_loss: 0.0360 - val_accuracy: 0.9904
Epoch 13/15
469/469 [==============================] - 9s 20ms/step - loss: 0.0324 - accuracy: 0.9902 - val_loss: 0.0285 - val_accuracy: 0.9915
Epoch 14/15
469/469 [==============================] - 9s 20ms/step - loss: 0.0317 - accuracy: 0.9901 - val_loss: 0.0261 - val_accuracy: 0.9922
Epoch 15/15
469/469 [==============================] - 9s 20ms/step - loss: 0.0306 - accuracy: 0.9911 - val_loss: 0.0248 - val_accuracy: 0.9921
Test loss: 0.024801477789878845
Test accuracy: 0.9921000003814697
```

In [8]:

```
x = list(range(n_epoch))
fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch')
ax.set_ylabel('Categorical Crossentropy Loss')
vy = history.history['loss']
ty = history.history['val_loss']
plot_dynamic(x, vy, ty, ax)
```



Observations:

* As the number of convolution layer increases accuracy increases and loss reduces
* As the number of convolution layers increases loss is reduces sharply at very early epochs.
* Dropout and Batch normalization acts as regulaizers and avoids overfitting