In [21]:

```
# 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,BatchNormalization
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)
```

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

In [10]:

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

1. CN-->Conv2d
2. MP-->max_pooling2d
3. DP-->Dropout
4. FL-->Flatten
5. DN-->Dense

1st Model CN(72,(7,7))->CN(38,(7,7))->CN(20,(7,7))->MP(2,2)->DP(0.25)->FL()->DN(10)

In [29]:

```
K.clear_session()
model = Sequential()
model.add(Conv2D(72, kernel_size=(7, 7),activation='relu',input_shape=input_shape))
model.add(Conv2D(38, (7, 7), activation='relu'))
model.add(Conv2D(20, (7, 7), 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.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_1 (Conv2D)            (None, 22, 22, 72)        3600
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 16, 16, 38)        134102
_________________________________________________________________
conv2d_3 (Conv2D)            (None, 10, 10, 20)        37260
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 5, 5, 20)          0
_________________________________________________________________
dropout_1 (Dropout)          (None, 5, 5, 20)          0
_________________________________________________________________
flatten_1 (Flatten)          (None, 500)               0
_________________________________________________________________
dense_1 (Dense)              (None, 128)               64128
_________________________________________________________________
dropout_2 (Dropout)          (None, 128)               0
_________________________________________________________________
dense_2 (Dense)              (None, 10)                1290
=================================================================
Total params: 240,380
Trainable params: 240,380
Non-trainable params: 0
_________________________________________________________________
```

In [14]:

```
model.compile(loss=keras.losses.categorical_crossentropy,optimizer='adam', metrics=['accuracy'])
history=model.fit(x_train, y_train,batch_size=batch_size,epochs=epochs,verbose=1,validation_data=(x_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 66s 1ms/step - loss: 0.2616 - acc: 0.9211 - val_loss: 0.0515 - val_acc: 0.9839
Epoch 2/12
60000/60000 [==============================] - 64s 1ms/step - loss: 0.0912 - acc: 0.9725 - val_loss: 0.0402 - val_acc: 0.9860
Epoch 3/12
60000/60000 [==============================] - 64s 1ms/step - loss: 0.0694 - acc: 0.9790 - val_loss: 0.0330 - val_acc: 0.9893
Epoch 4/12
60000/60000 [==============================] - 65s 1ms/step - loss: 0.0582 - acc: 0.9824 - val_loss: 0.0326 - val_acc: 0.9893
Epoch 5/12
60000/60000 [==============================] - 65s 1ms/step - loss: 0.0504 - acc: 0.9852 - val_loss: 0.0278 - val_acc: 0.9913
Epoch 6/12
60000/60000 [==============================] - 65s 1ms/step - loss: 0.0474 - acc: 0.9864 - val_loss: 0.0296 - val_acc: 0.9897
Epoch 7/12
60000/60000 [==============================] - 65s 1ms/step - loss: 0.0413 - acc: 0.9873 - val_loss:
```

```
s: 0.0260 - val_acc: 0.9910
Epoch 8/12
60000/60000 [==============================] - 65s 1ms/step - loss: 0.0362 - acc: 0.9888 - val_los
s: 0.0239 - val_acc: 0.9928
Epoch 9/12
60000/60000 [==============================] - 65s 1ms/step - loss: 0.0360 - acc: 0.9888 - val_los
s: 0.0258 - val_acc: 0.9920
Epoch 10/12
60000/60000 [==============================] - 65s 1ms/step - loss: 0.0333 - acc: 0.9898 - val_los
s: 0.0240 - val_acc: 0.9925
Epoch 11/12
60000/60000 [==============================] - 65s 1ms/step - loss: 0.0301 - acc: 0.9902 - val_los
s: 0.0217 - val_acc: 0.9930
Epoch 12/12
60000/60000 [==============================] - 65s 1ms/step - loss: 0.0283 - acc: 0.9910 - val_los
s: 0.0234 - val_acc: 0.9926
```

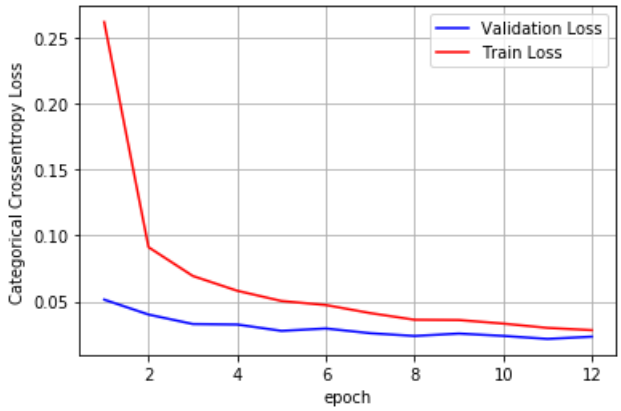
In [15]:

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

```
Test score: 0.023416508061222523
Test accuracy: 0.9926
```



2nd Model CN(20,(5,5))->BN()->CN(20)->BN()->CN(40)->BN()->CN(10)->BN()->CN(10)->MP(2,2)->DP(0.25)->FL()->DN(128)

In [22]:

```
K.clear_session()
model_1 = Sequential()
model_1.add(Conv2D(20, kernel_size=(5, 5),activation='relu',input_shape=input_shape))
model_1.add(BatchNormalization())
model_1.add(Conv2D(20, (5, 5), activation='relu'))
model_1.add(BatchNormalization())
model_1.add(Conv2D(40, (5, 5), activation='relu'))
model_1.add(BatchNormalization())
model_1.add(Conv2D(10, (5, 5), activation='relu'))
model_1.add(BatchNormalization())
model_1.add(Conv2D(10, (5, 5), activation='relu'))
model_1.add(MaxPooling2D(pool_size=(2, 2)))
model_1.add(Dropout(0.25))
model_1.add(Flatten())
model_1.add(Dense(128, activation='relu'))
model_1.add(Dropout(0.5))
```

```
model_1.add(Dense(num_classes, activation='softmax'))
model_1.summary()
```

```
WARNING:tensorflow:From C:\Users\nnagari\AppData\Local\Continuum\anaconda3\envs\tf_gpu\lib\site-pa
ckages\keras\backend\tensorflow_backend.py:1834: The name tf.nn.fused_batch_norm is deprecated. Pl
ease use tf.compat.v1.nn.fused_batch_norm instead.
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_1 (Conv2D)            (None, 24, 24, 20)        520
_________________________________________________________________
batch_normalization_1 (Batch (None, 24, 24, 20)        80
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 20, 20, 20)        10020
_________________________________________________________________
batch_normalization_2 (Batch (None, 20, 20, 20)        80
_________________________________________________________________
conv2d_3 (Conv2D)            (None, 16, 16, 40)        20040
_________________________________________________________________
batch_normalization_3 (Batch (None, 16, 16, 40)        160
_________________________________________________________________
conv2d_4 (Conv2D)            (None, 12, 12, 10)        10010
_________________________________________________________________
batch_normalization_4 (Batch (None, 12, 12, 10)        40
_________________________________________________________________
conv2d_5 (Conv2D)            (None, 8, 8, 10)          2510
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 4, 4, 10)          0
_________________________________________________________________
dropout_1 (Dropout)          (None, 4, 4, 10)          0
_________________________________________________________________
flatten_1 (Flatten)          (None, 160)               0
_________________________________________________________________
dense_1 (Dense)              (None, 128)               20608
_________________________________________________________________
dropout_2 (Dropout)          (None, 128)               0
_________________________________________________________________
dense_2 (Dense)              (None, 10)                1290
=================================================================
Total params: 65,358
Trainable params: 65,178
Non-trainable params: 180
_________________________________________________________________
```

In [23]:

```
model_1.compile(loss=keras.losses.categorical_crossentropy,optimizer='adam', metrics=['accuracy'])
history=model_1.fit(x_train, y_train,batch_size=batch_size,epochs=epochs,verbose=1,validation_data=
(x_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 52s 870us/step - loss: 0.4221 - acc: 0.8676 - val_l
oss: 0.0828 - val_acc: 0.9767
Epoch 2/12
60000/60000 [==============================] - 50s 833us/step - loss: 0.1077 - acc: 0.9700 - val_l
oss: 0.0470 - val_acc: 0.9852
Epoch 3/12
60000/60000 [==============================] - 50s 831us/step - loss: 0.0775 - acc: 0.9775 - val_l
oss: 0.0450 - val_acc: 0.9863
Epoch 4/12
60000/60000 [==============================] - 50s 832us/step - loss: 0.0664 - acc: 0.9813 - val_l
oss: 0.0429 - val_acc: 0.9867
Epoch 5/12
60000/60000 [==============================] - 50s 834us/step - loss: 0.0562 - acc: 0.9835 - val_l
oss: 0.0338 - val_acc: 0.9903
Epoch 6/12
60000/60000 [==============================] - 50s 832us/step - loss: 0.0494 - acc: 0.9858 - val_l
oss: 0.0301 - val_acc: 0.9908
Epoch 7/12
60000/60000 [==============================] - 50s 834us/step - loss: 0.0482 - acc: 0.9861 - val_l
oss: 0.0300 - val_acc: 0.9922
Epoch 8/12
60000/60000 [==============================] - 50s 834us/step - loss: 0.0462 - acc: 0.9865 - val_l
```

```
oss: 0.0337 - val_acc: 0.9898
Epoch 9/12
60000/60000 [==============================] - 50s 834us/step - loss: 0.0414 - acc: 0.9883 - val_l
oss: 0.0320 - val_acc: 0.9913
Epoch 10/12
60000/60000 [==============================] - 50s 832us/step - loss: 0.0372 - acc: 0.9891 - val_l
oss: 0.0348 - val_acc: 0.9903
Epoch 11/12
60000/60000 [==============================] - 50s 836us/step - loss: 0.0373 - acc: 0.9891 - val_l
oss: 0.0279 - val_acc: 0.9918
Epoch 12/12
60000/60000 [==============================] - 50s 838us/step - loss: 0.0337 - acc: 0.9898 - val_l
oss: 0.0293 - val_acc: 0.9914
```

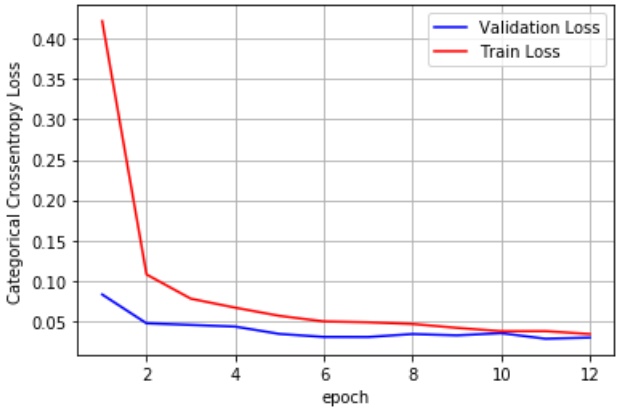
In [25]:

```
score = model_1.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))
vy = history.history['val_loss']
ty = history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.029317251708592812
Test accuracy: 0.9914
```



3rd Model CN(30,(5,5))->BN()->CN(30)->BN()->CN(50)->BN()->CN(50)->BN()->CN(100)->BN()->CN(100)->MP(2,2)->BN()->CN(150)->MP(2,2)->DP(0.25)->FL()->DN(120)

In [44]:

```
K.clear_session()
model_2 = Sequential()
model_2.add(Conv2D(30, kernel_size=(3, 3),activation='relu',input_shape=input_shape))
model_2.add(BatchNormalization())
model_2.add(Conv2D(30, (3, 3), activation='relu'))
model_2.add(BatchNormalization())
model_2.add(Conv2D(50, (3, 3), activation='relu'))
model_2.add(BatchNormalization())
model_2.add(Conv2D(50, (3, 3), activation='relu'))
model_2.add(BatchNormalization())
model_2.add(Conv2D(100, (3, 3), activation='relu'))
model_2.add(BatchNormalization())
model_2.add(Conv2D(100, (3, 3), activation='relu'))
model_2.add(MaxPooling2D(pool_size=(2, 2)))
model_2.add(BatchNormalization())
model_2.add(Conv2D(150, (3, 3), activation='relu'))
model_2.add(MaxPooling2D(pool_size=(2, 2)))
model_2.add(Dropout(0.25))
model_2.add(Flatten())
```

```
model_2.add(Dense(120, activation='relu'))
model_2.add(Dropout(0.5))
model_2.add(Dense(num_classes, activation='softmax'))
model_2.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_1 (Conv2D)            (None, 26, 26, 30)        300
_________________________________________________________________
batch_normalization_1 (Batch (None, 26, 26, 30)        120
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 24, 24, 30)        8130
_________________________________________________________________
batch_normalization_2 (Batch (None, 24, 24, 30)        120
_________________________________________________________________
conv2d_3 (Conv2D)            (None, 22, 22, 50)        13550
_________________________________________________________________
batch_normalization_3 (Batch (None, 22, 22, 50)        200
_________________________________________________________________
conv2d_4 (Conv2D)            (None, 20, 20, 50)        22550
_________________________________________________________________
batch_normalization_4 (Batch (None, 20, 20, 50)        200
_________________________________________________________________
conv2d_5 (Conv2D)            (None, 18, 18, 100)       45100
_________________________________________________________________
batch_normalization_5 (Batch (None, 18, 18, 100)       400
_________________________________________________________________
conv2d_6 (Conv2D)            (None, 16, 16, 100)       90100
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 8, 8, 100)         0
_________________________________________________________________
batch_normalization_6 (Batch (None, 8, 8, 100)         400
_________________________________________________________________
conv2d_7 (Conv2D)            (None, 6, 6, 150)         135150
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 3, 3, 150)         0
_________________________________________________________________
dropout_1 (Dropout)          (None, 3, 3, 150)         0
_________________________________________________________________
flatten_1 (Flatten)          (None, 1350)              0
_________________________________________________________________
dense_1 (Dense)              (None, 120)               162120
_________________________________________________________________
dropout_2 (Dropout)          (None, 120)               0
_________________________________________________________________
dense_2 (Dense)              (None, 10)                1210
=================================================================
Total params: 479,650
Trainable params: 478,930
Non-trainable params: 720
_________________________________________________________________
```

In [45]:

```
model_2.compile(loss=keras.losses.categorical_crossentropy,optimizer='adam', metrics=['accuracy'])
history=model_2.fit(x_train, y_train,batch_size=batch_size,epochs=epochs,verbose=1,validation_data=
(x_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 195s 3ms/step - loss: 0.2658 - acc: 0.9202 - val_lo
ss: 0.0506 - val_acc: 0.9843
Epoch 2/12
60000/60000 [==============================] - 198s 3ms/step - loss: 0.1011 - acc: 0.9720 - val_lo
ss: 0.0383 - val_acc: 0.9891
Epoch 3/12
60000/60000 [==============================] - 198s 3ms/step - loss: 0.0750 - acc: 0.9799 - val_lo
ss: 0.0309 - val_acc: 0.9903
Epoch 4/12
60000/60000 [==============================] - 197s 3ms/step - loss: 0.0681 - acc: 0.9812 - val_lo
ss: 0.0270 - val_acc: 0.9915
Epoch 5/12
60000/60000 [==============================] - 198s 3ms/step - loss: 0.0546 - acc: 0.9852 - val_lo
ss: 0.0338 - val acc: 0.9901
```

```
Epoch 6/12
60000/60000 [==============================] - 198s 3ms/step - loss: 0.0450 - acc: 0.9872 - val_lo
ss: 0.0300 - val_acc: 0.9924
Epoch 7/12
60000/60000 [==============================] - 198s 3ms/step - loss: 0.0428 - acc: 0.9878 - val_lo
ss: 0.0251 - val_acc: 0.9911
Epoch 8/12
60000/60000 [==============================] - 198s 3ms/step - loss: 0.0402 - acc: 0.9886 - val_lo
ss: 0.0353 - val_acc: 0.9898
Epoch 9/12
60000/60000 [==============================] - 198s 3ms/step - loss: 0.0386 - acc: 0.9893 - val_lo
ss: 0.0234 - val_acc: 0.9940
Epoch 10/12
60000/60000 [==============================] - 199s 3ms/step - loss: 0.0361 - acc: 0.9902 - val_lo
ss: 0.0260 - val_acc: 0.9925
Epoch 11/12
60000/60000 [==============================] - 198s 3ms/step - loss: 0.0347 - acc: 0.9906 - val_lo
ss: 0.0278 - val_acc: 0.9916
Epoch 12/12
60000/60000 [==============================] - 197s 3ms/step - loss: 0.0295 - acc: 0.9917 - val_lo
ss: 0.0343 - val_acc: 0.9923
```

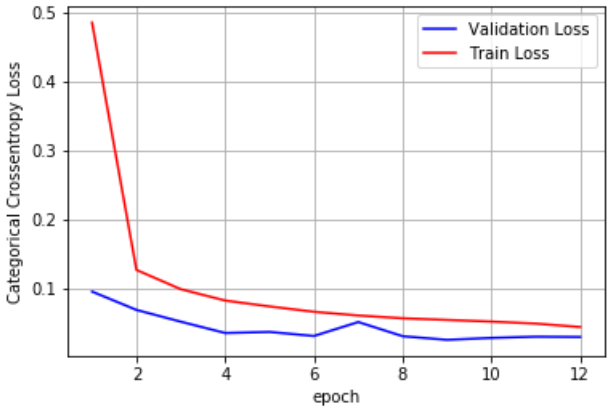
In [41]:

```
score = model_2.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))
vy = history.history['val_loss']
ty = history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.029114628794253077
Test accuracy: 0.9915
```



Observation

We have 28X28 size image if we add max pooling layer multiple times in Network demission of the image will reduce and we will get following error “Negative dimension size caused by subtracting 3 from 2 for 'conv2d_7/convolution' (op: 'Conv2D') with input shapes: [?,2,2,20], [3,3,20,20]. ”

In [59]:

```
print("(Model 1st:-",  "CN(72,(7,7))->CN(38,(7,7))->CN(20,(7,7))->MP(2,2)->DP(0.25)->FL()->DN(10)\
n")
print("(Model 2nd:-CN(20,(5,5))->BN()->CN(20)->BN()->CN(40)->BN()->CN(10)->BN()->CN(10)->MP(2,2)->
DP(0.25)->FL()->DN(128)\n")
print("(Model 3rd:-",  "CN(30,(5,5))->BN()->CN(30)->BN()->CN(50)->BN()->CN(50)->BN()->CN(100)-
>BN()->CN(100)->MP(2,2)->BN()->CN(150)->MP(2,2)->DP(0.25)->FL()->DN(120)")
```

(Model 1st:- CN(72,(7,7))->CN(38,(7,7))->CN(20,(7,7))->MP(2,2)->DP(0.25)->FL()->DN(10)

(Model 2nd:-CN(20,(5,5))->BN()->CN(20)->BN()->CN(40)->BN()->CN(10)->BN()->CN(10)->MP(2,2)->DP(0.25)->FL()->DN(128)

(Model 3rd:- CN(30,(5,5))->BN()->CN(30)->BN()->CN(50)->BN()->CN(50)->BN()->CN(100)->BN()->CN(100)->MP(2,2)->BN()->CN(150)->MP(2,2)->DP(0.25)->FL()->DN(120)

In [62]:

```
from prettytable import PrettyTable
table = PrettyTable()

table.field_names = ["Model","Accuracy"]

table.add_row(["Model 1st","0.9926" ])
table.add_row(["Model 2nd","0.9914" ])
table.add_row(["Model 3nd","0.9915" ])
print(table)
```

```
+-----------+----------+
|   Model   | Accuracy |
+-----------+----------+
| Model 1st |  0.9926  |
| Model 2nd |  0.9914  |
| Model 3nd |  0.9915  |
+-----------+----------+
```