In [1]:

```
# 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
from keras.layers import Conv2D, MaxPooling2D
from keras import backend as K
import matplotlib


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)

model = Sequential()
model.add(Conv2D(32, kernel_size=(3, 3),
                 activation='relu',
                 input_shape=input_shape))
model.add(Conv2D(64, (3, 3), 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.compile(loss=keras.losses.categorical_crossentropy,
              optimizer=keras.optimizers.Adadelta(),
              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)
#histories.append(history)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
#print('Test loss:', score[0])
#print('Test accuracy:', score[1])
```

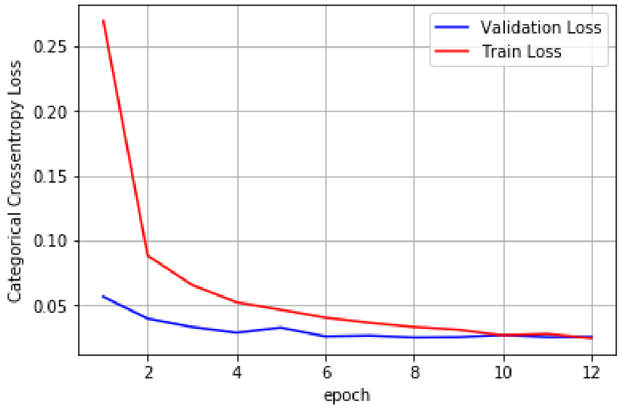
```
Using TensorFlow backend.
```

```
Downloading data from https://s3.amazonaws.com/img-datasets/mnist.npz
11493376/11490434 [==============================] - 1s 0us/step
x_train shape: (60000, 28, 28, 1)
60000 train samples
10000 test samples
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend.py:66:
The name tf.get_default_graph is deprecated. Please use tf.compat.v1.get_default_graph instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend.py:541:
The name tf.placeholder is deprecated. Please use tf.compat.v1.placeholder instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend.py:4432
: The name tf.random_uniform is deprecated. Please use tf.random.uniform instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend.py:4267
: The name tf.nn.max_pool is deprecated. Please use tf.nn.max_pool2d instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend.py:148:
The name tf.placeholder_with_default is deprecated. Please use tf.compat.v1.placeholder_with_default in
stead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend.py:3733
: calling dropout (from tensorflow.python.ops.nn_ops) with keep_prob is deprecated and will be removed
in a future version.
Instructions for updating:
Please use `rate` instead of `keep_prob`. Rate should be set to `rate = 1 - keep_prob`.
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/optimizers.py:793: The name tf.tra
in.Optimizer is deprecated. Please use tf.compat.v1.train.Optimizer instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend.py:3576
: The name tf.log is deprecated. Please use tf.math.log instead.

WARNING:tensorflow: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 [==============================] - 155s 3ms/step - loss: 0.2697 - acc: 0.9168 - val_loss: 0
.0568 - val_acc: 0.9810
Epoch 2/12
60000/60000 [==============================] - 154s 3ms/step - loss: 0.0886 - acc: 0.9737 - val_loss: 0
.0399 - val_acc: 0.9860
Epoch 3/12
60000/60000 [==============================] - 154s 3ms/step - loss: 0.0658 - acc: 0.9799 - val_loss: 0
.0334 - val_acc: 0.9896
Epoch 4/12
60000/60000 [==============================] - 151s 3ms/step - loss: 0.0526 - acc: 0.9844 - val_loss: 0
.0290 - val_acc: 0.9906
Epoch 5/12
60000/60000 [==============================] - 151s 3ms/step - loss: 0.0467 - acc: 0.9866 - val_loss: 0
.0329 - val_acc: 0.9893
Epoch 6/12
60000/60000 [==============================] - 152s 3ms/step - loss: 0.0407 - acc: 0.9873 - val_loss: 0
.0261 - val_acc: 0.9914
Epoch 7/12
60000/60000 [==============================] - 151s 3ms/step - loss: 0.0367 - acc: 0.9890 - val_loss: 0
.0267 - val_acc: 0.9911
Epoch 8/12
60000/60000 [==============================] - 152s 3ms/step - loss: 0.0334 - acc: 0.9899 - val_loss: 0
.0253 - val_acc: 0.9919
Epoch 9/12
60000/60000 [==============================] - 152s 3ms/step - loss: 0.0313 - acc: 0.9903 - val_loss: 0
.0256 - val_acc: 0.9913
Epoch 10/12
60000/60000 [==============================] - 155s 3ms/step - loss: 0.0270 - acc: 0.9918 - val_loss: 0
.0272 - val_acc: 0.9909
Epoch 11/12
60000/60000 [==============================] - 154s 3ms/step - loss: 0.0281 - acc: 0.9915 - val_loss: 0
.0257 - val_acc: 0.9913
Epoch 12/12
60000/60000 [==============================] - 154s 3ms/step - loss: 0.0247 - acc: 0.9921 - val_loss: 0
```

```
.0258 - val_acc: 0.9926

---------------------------------------------------------------------------
NameError                                 Traceback (most recent call last)
<ipython-input-1-ae70f27eee23> in <module>()
     64           validation_data=(x_test, y_test))
     65 score = model.evaluate(x_test, y_test, verbose=0)
---> 66 histories.append(history)
     67 print('Test loss:', score[0])
     68 print('Test accuracy:', score[1])

NameError: name 'histories' is not defined
```

In [3]:

```
#score = model_relu.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))
#print(x)

# 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_epoch, verbose=1, validat
ion_data=(X_test, Y_test))

# 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 of epochs


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



In [0]:

```
%matplotlib inline
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")
    ax.plot(x, ty, 'r', label="Train Loss")
    plt.legend()
    plt.grid()
    fig.canvas.draw()
```

In [2]:

```
# 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
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_cols, img_rows, 1)
    x_test = x_test.reshape(x_test.shape[0], img_cols, img_rows, 1)
    input_shape = (img_cols, img_rows, 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, 10)
y_test = keras.utils.to_categorical(y_test, 10)
```

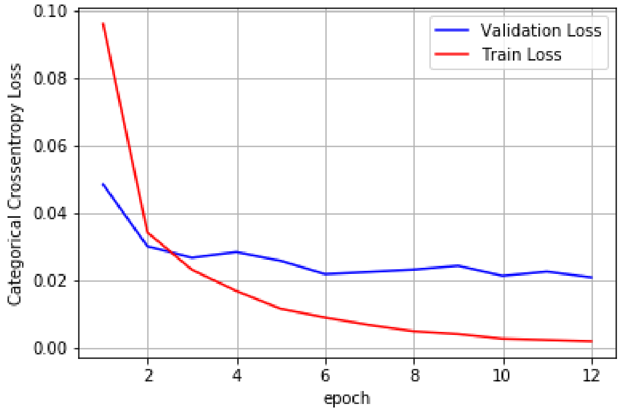
```
Downloading data from https://s3.amazonaws.com/img-datasets/mnist.npz
11493376/11490434 [==============================] - 1s 0us/step
x_train shape: (60000, 28, 28, 1)
60000 train samples
10000 test samples
```

3 layer CNN

In [4]:

```
#3 Convolution layer network with kernel size = (3,3)
from keras.layers.normalization import BatchNormalization
from keras.layers import Dense, Dropout, Activation, Flatten

model = Sequential()
model.add(Conv2D(32, (3, 3),input_shape=input_shape))
model.add(BatchNormalization(axis=-1))
model.add(Activation('relu'))
model.add(Conv2D(32, (3, 3)))
model.add(BatchNormalization(axis=-1))
model.add(Activation('relu'))
model.add(MaxPooling2D(pool_size=(2,2)))

model.add(Conv2D(64,(3, 3)))
model.add(BatchNormalization(axis=-1))
model.add(BatchNormalization(axis=-1))
model.add(Activation('relu'))
model.add(MaxPooling2D(pool_size=(2,2)))

model.add(Flatten())

# Fully connected layer
model.add(Dense(256))
model.add(BatchNormalization())
model.add(Activation('relu'))
model.add(Dropout(0.2))
model.add(Dense(num_classes, activation='softmax'))

model.compile(loss=keras.losses.categorical_crossentropy,
              optimizer=keras.optimizers.Adadelta(),
              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)
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(x)

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

```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend.py:2041
: The name tf.nn.fused_batch_norm is deprecated. Please use tf.compat.v1.nn.fused_batch_norm instead.

Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 188s 3ms/step - loss: 0.0958 - acc: 0.9725 - val_loss: 0
.0483 - val_acc: 0.9832
Epoch 2/12
60000/60000 [==============================] - 187s 3ms/step - loss: 0.0340 - acc: 0.9901 - val_loss: 0
.0299 - val_acc: 0.9898
Epoch 3/12
60000/60000 [==============================] - 192s 3ms/step - loss: 0.0230 - acc: 0.9931 - val_loss: 0
.0266 - val_acc: 0.9910
Epoch 4/12
60000/60000 [==============================] - 190s 3ms/step - loss: 0.0167 - acc: 0.9948 - val_loss: 0
.0282 - val_acc: 0.9907
Epoch 5/12
60000/60000 [==============================] - 188s 3ms/step - loss: 0.0114 - acc: 0.9968 - val_loss: 0
.0256 - val_acc: 0.9923
Epoch 6/12
60000/60000 [==============================] - 187s 3ms/step - loss: 0.0088 - acc: 0.9974 - val_loss: 0
.0217 - val_acc: 0.9929
Epoch 7/12
60000/60000 [==============================] - 186s 3ms/step - loss: 0.0066 - acc: 0.9983 - val_loss: 0
.0223 - val_acc: 0.9934
Epoch 8/12
60000/60000 [==============================] - 189s 3ms/step - loss: 0.0047 - acc: 0.9988 - val_loss: 0
.0230 - val_acc: 0.9925
Epoch 9/12
60000/60000 [==============================] - 190s 3ms/step - loss: 0.0039 - acc: 0.9990 - val_loss: 0
.0242 - val_acc: 0.9937
Epoch 10/12
60000/60000 [==============================] - 190s 3ms/step - loss: 0.0025 - acc: 0.9995 - val_loss: 0
.0212 - val_acc: 0.9946
Epoch 11/12
60000/60000 [==============================] - 187s 3ms/step - loss: 0.0021 - acc: 0.9997 - val_loss: 0
.0225 - val_acc: 0.9932
Epoch 12/12
60000/60000 [==============================] - 188s 3ms/step - loss: 0.0018 - acc: 0.9997 - val_loss: 0
.0207 - val_acc: 0.9945
```

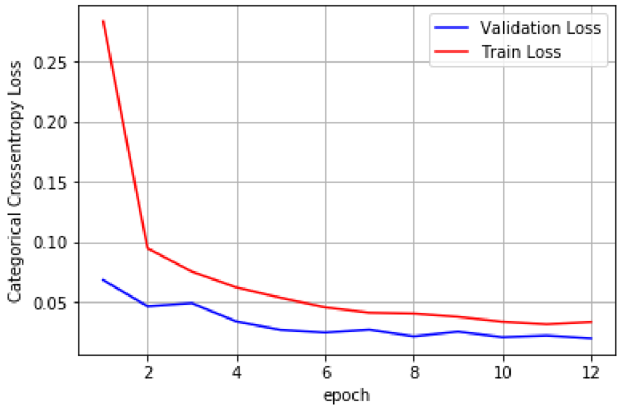


5 Layer CNN

In [5]:

```
model = Sequential()

model.add(Conv2D(32, kernel_size=5, activation = 'relu'))
model.add(Conv2D(32, kernel_size=5, activation = 'relu'))
model.add(MaxPooling2D(2,2))
model.add(BatchNormalization())
model.add(Dropout(0.4))

model.add(Conv2D(64, kernel_size=3,activation = 'relu'))
model.add(Conv2D(64, kernel_size=3,activation = 'relu'))
model.add(MaxPooling2D(2,2))
model.add(BatchNormalization())
model.add(Dropout(0.4))

model.add(Conv2D(128, kernel_size=3, activation = 'relu'))
model.add(BatchNormalization())

model.add(Flatten())
model.add(Dense(256, activation = "relu"))
model.add(Dropout(0.4))
model.add(Dense(128, activation = "relu"))
model.add(Dropout(0.4))
model.add(Dense(10, activation = "softmax"))


model.compile(loss=keras.losses.categorical_crossentropy,
              optimizer=keras.optimizers.Adadelta(),
              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])
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(x)

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

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 192s 3ms/step - loss: 0.2834 - acc: 0.9137 - val_loss: 0
.0682 - val_acc: 0.9813
Epoch 2/12
60000/60000 [==============================] - 188s 3ms/step - loss: 0.0946 - acc: 0.9738 - val_loss: 0
.0464 - val_acc: 0.9882
Epoch 3/12
60000/60000 [==============================] - 186s 3ms/step - loss: 0.0752 - acc: 0.9789 - val_loss: 0
.0490 - val_acc: 0.9870
Epoch 4/12
60000/60000 [==============================] - 188s 3ms/step - loss: 0.0621 - acc: 0.9830 - val_loss: 0
.0338 - val_acc: 0.9903
Epoch 5/12
60000/60000 [==============================] - 190s 3ms/step - loss: 0.0535 - acc: 0.9856 - val_loss: 0
.0267 - val_acc: 0.9917
Epoch 6/12
60000/60000 [==============================] - 191s 3ms/step - loss: 0.0456 - acc: 0.9877 - val_loss: 0
.0245 - val_acc: 0.9928
Epoch 7/12
60000/60000 [==============================] - 190s 3ms/step - loss: 0.0411 - acc: 0.9885 - val_loss: 0
.0269 - val_acc: 0.9920
Epoch 8/12
60000/60000 [==============================] - 188s 3ms/step - loss: 0.0404 - acc: 0.9892 - val_loss: 0
.0213 - val_acc: 0.9940
Epoch 9/12
60000/60000 [==============================] - 189s 3ms/step - loss: 0.0376 - acc: 0.9891 - val_loss: 0
.0253 - val_acc: 0.9933
Epoch 10/12
60000/60000 [==============================] - 186s 3ms/step - loss: 0.0335 - acc: 0.9907 - val_loss: 0
.0206 - val_acc: 0.9944
Epoch 11/12
60000/60000 [==============================] - 188s 3ms/step - loss: 0.0314 - acc: 0.9917 - val_loss: 0
.0220 - val_acc: 0.9941
Epoch 12/12
60000/60000 [==============================] - 187s 3ms/step - loss: 0.0333 - acc: 0.9908 - val_loss: 0
.0197 - val_acc: 0.9948
Test loss: 0.019651852898731 34
Test accuracy: 0.9948
```



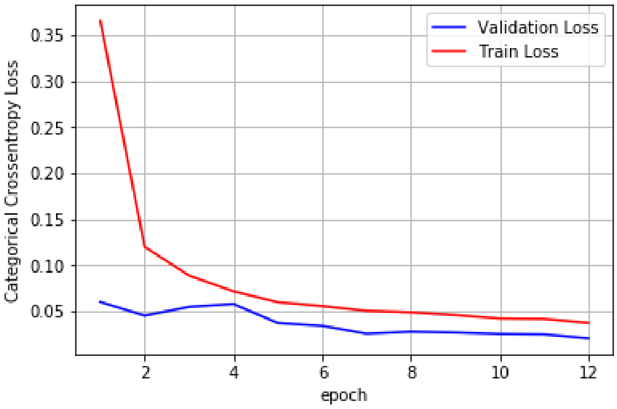
7 Layer CNN

In [5]:

```
from keras.layers.normalization import BatchNormalization
from keras.layers import Dense, Dropout, Activation, Flatten
model = Sequential()

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

model.add(Conv2D(32, kernel_size=3, activation = 'relu',padding='same'))
model.add(MaxPooling2D(2,2))
model.add(BatchNormalization())
model.add(Dropout(0.4))

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


model.add(Conv2D(64, kernel_size=3,activation = 'relu',padding='same'))
model.add(MaxPooling2D(2,2))
model.add(BatchNormalization())
model.add(Dropout(0.4))

model.add(Conv2D(64, kernel_size=3,activation = 'relu',padding='same'))
model.add(MaxPooling2D(2,2))
model.add(BatchNormalization())
model.add(Dropout(0.4))


model.add(Conv2D(128, kernel_size=3, activation = 'relu',padding='same'))
model.add(BatchNormalization())


model.add(Flatten())
model.add(Dense(256, activation = "relu"))

model.add(Dropout(0.4))
model.add(Dense(128, activation = "relu"))

model.add(Dropout(0.4))
model.add(Dense(10, activation = "softmax"))



model.compile(loss=keras.losses.categorical_crossentropy,
              optimizer=keras.optimizers.Adadelta(),
              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])
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(x)

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

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 332s 6ms/step - loss: 0.3652 - acc: 0.8895 - val_loss: 0
.0601 - val_acc: 0.9824
Epoch 2/12
60000/60000 [==============================] - 330s 5ms/step - loss: 0.1199 - acc: 0.9676 - val_loss: 0
.0453 - val_acc: 0.9880
Epoch 3/12
60000/60000 [==============================] - 333s 6ms/step - loss: 0.0888 - acc: 0.9768 - val_loss: 0
.0548 - val_acc: 0.9842
Epoch 4/12
60000/60000 [==============================] - 333s 6ms/step - loss: 0.0716 - acc: 0.9809 - val_loss: 0
.0579 - val_acc: 0.9867
Epoch 5/12
60000/60000 [==============================] - 331s 6ms/step - loss: 0.0599 - acc: 0.9838 - val_loss: 0
.0373 - val_acc: 0.9907
Epoch 6/12
60000/60000 [==============================] - 331s 6ms/step - loss: 0.0556 - acc: 0.9853 - val_loss: 0
.0342 - val_acc: 0.9907
Epoch 7/12
60000/60000 [==============================] - 333s 6ms/step - loss: 0.0506 - acc: 0.9863 - val_loss: 0
.0257 - val_acc: 0.9931
Epoch 8/12
```

```
60000/60000 [==============================] - 334s 6ms/step - loss: 0.0489 - acc: 0.9869 - val_loss: 0
.0278 - val_acc: 0.9932
Epoch 9/12
60000/60000 [==============================] - 330s 6ms/step - loss: 0.0459 - acc: 0.9887 - val_loss: 0
.0269 - val_acc: 0.9927
Epoch 10/12
60000/60000 [==============================] - 317s 5ms/step - loss: 0.0422 - acc: 0.9892 - val_loss: 0
.0253 - val_acc: 0.9942
Epoch 11/12
60000/60000 [==============================] - 314s 5ms/step - loss: 0.0417 - acc: 0.9894 - val_loss: 0
.0249 - val_acc: 0.9935
Epoch 12/12
60000/60000 [==============================] - 313s 5ms/step - loss: 0.0374 - acc: 0.9901 - val_loss: 0
.0206 - val_acc: 0.9944
Test loss: 0.020643120348520644
Test accuracy: 0.9944
```



3 Layer CNN with data augmentation

In [0]:

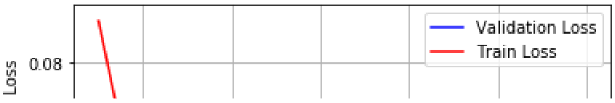
```python
from keras.preprocessing.image import ImageDataGenerator
datagen = ImageDataGenerator(
    featurewise_center=False,  # set input mean to 0 over the dataset
    samplewise_center=False,  # set each sample mean to 0
    featurewise_std_normalization=False,  # divide inputs by std of the dataset
    samplewise_std_normalization=False,  # divide each input by its std
    zca_whitening=False,  # apply ZCA whitening
    rotation_range=25,  # randomly rotate images in the range (degrees, 0 to 180)
    width_shift_range=0.1,  # randomly shift images horizontally (fraction of total width)
    height_shift_range=0.1,  # randomly shift images vertically (fraction of total height)
    horizontal_flip=False,  # randomly flip images
    vertical_flip=False)  # randomly flip images

datagen.fit(x_train)
```

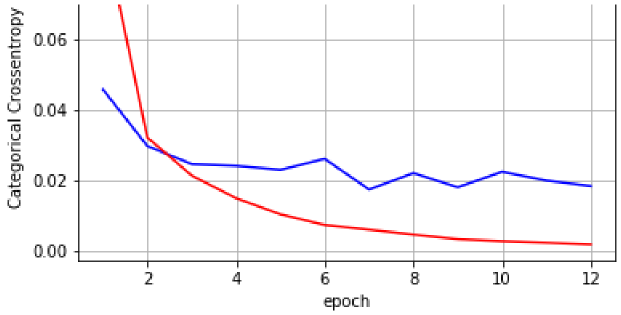
In [7]:

```python
from keras.layers.normalization import BatchNormalization
from keras.layers import Dense, Dropout, Activation, Flatten
model = Sequential()
model.add(Conv2D(32, (3, 3),input_shape=input_shape))
model.add(BatchNormalization(axis=-1))
model.add(Activation('relu'))
model.add(Conv2D(32, (3, 3)))
model.add(BatchNormalization(axis=-1))
model.add(Activation('relu'))
model.add(MaxPooling2D(pool_size=(2,2)))

model.add(Conv2D(64,(3, 3)))
model.add(BatchNormalization(axis=-1))
model.add(Activation('relu'))
model.add(MaxPooling2D(pool_size=(2,2)))

model.add(Flatten())
```

```
# Fully connected layer
model.add(Dense(256))
model.add(BatchNormalization())
model.add(Activation('relu'))
model.add(Dropout(0.2))
model.add(Dense(num_classes, activation='softmax'))

model.compile(loss=keras.losses.categorical_crossentropy,
              optimizer=keras.optimizers.Adadelta(),
              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])
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(x)

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

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 189s 3ms/step - loss: 0.0919 - acc: 0.9732 - val_loss: 0
.0458 - val_acc: 0.9847
Epoch 2/12
60000/60000 [==============================] - 203s 3ms/step - loss: 0.0321 - acc: 0.9907 - val_loss: 0
.0297 - val_acc: 0.9906
Epoch 3/12
60000/60000 [==============================] - 202s 3ms/step - loss: 0.0213 - acc: 0.9938 - val_loss: 0
.0246 - val_acc: 0.9915
Epoch 4/12
60000/60000 [==============================] - 201s 3ms/step - loss: 0.0148 - acc: 0.9954 - val_loss: 0
.0241 - val_acc: 0.9922
Epoch 5/12
60000/60000 [==============================] - 201s 3ms/step - loss: 0.0103 - acc: 0.9970 - val_loss: 0
.0229 - val_acc: 0.9919
Epoch 6/12
60000/60000 [==============================] - 202s 3ms/step - loss: 0.0072 - acc: 0.9980 - val_loss: 0
.0261 - val_acc: 0.9916
Epoch 7/12
60000/60000 [==============================] - 202s 3ms/step - loss: 0.0059 - acc: 0.9984 - val_loss: 0
.0173 - val_acc: 0.9941
Epoch 8/12
60000/60000 [==============================] - 200s 3ms/step - loss: 0.0045 - acc: 0.9987 - val_loss: 0
.0220 - val_acc: 0.9931
Epoch 9/12
60000/60000 [==============================] - 200s 3ms/step - loss: 0.0032 - acc: 0.9992 - val_loss: 0
.0180 - val_acc: 0.9942
Epoch 10/12
60000/60000 [==============================] - 198s 3ms/step - loss: 0.0026 - acc: 0.9994 - val_loss: 0
.0224 - val_acc: 0.9928
Epoch 11/12
60000/60000 [==============================] - 193s 3ms/step - loss: 0.0021 - acc: 0.9995 - val_loss: 0
.0199 - val_acc: 0.9947
Epoch 12/12
60000/60000 [==============================] - 206s 3ms/step - loss: 0.0016 - acc: 0.9997 - val_loss: 0
.0183 - val_acc: 0.9941
Test loss: 0.018317274589365024
Test accuracy: 0.9941
```





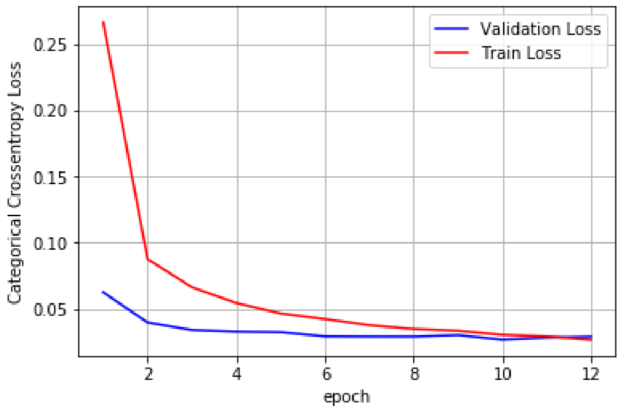
In [8]:

```
from keras.layers.normalization import BatchNormalization
from keras.layers import Dense, Dropout, Activation, Flatten
model = Sequential()
model.add(Conv2D(32, kernel_size=(3, 3),
                 activation='relu',
                 input_shape=input_shape))
model.add(Conv2D(64, (3, 3), activation='relu'))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.25))
model.add(Flatten())
model.add(Dense(128, activation='relu',init='glorot_normal'))
model.add(Dropout(0.5))
model.add(Dense(num_classes, activation='softmax',init='glorot_normal'))


model.compile(loss=keras.losses.categorical_crossentropy,
              optimizer=keras.optimizers.Adadelta(),
              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])
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(x)

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

#model.compile(loss='categorical_crossentropy', optimizer=RMSprop())
#model.fit(X_train, Y_train, batch_size=32, nb_epoch=25,
          #verbose=1, show_accuracy=True, validation_data=(X_test, Y_test))
```

```
/usr/local/lib/python3.6/dist-packages/ipykernel_launcher.py:11: UserWarning: Update your `Dense` call
to the Keras 2 API: `Dense(128, activation="relu", kernel_initializer="glorot_normal")`
  # This is added back by InteractiveShellApp.init_path()
/usr/local/lib/python3.6/dist-packages/ipykernel_launcher.py:13: UserWarning: Update your `Dense` call
to the Keras 2 API: `Dense(10, activation="softmax", kernel_initializer="glorot_normal")`
  del sys.path[0]
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 136s 2ms/step - loss: 0.2667 - acc: 0.9176 - val_loss: 0
.0624 - val_acc: 0.9804
Epoch 2/12
60000/60000 [==============================] - 134s 2ms/step - loss: 0.0876 - acc: 0.9741 - val_loss: 0
.0396 - val_acc: 0.9869
Epoch 3/12
60000/60000 [==============================] - 135s 2ms/step - loss: 0.0662 - acc: 0.9797 - val_loss: 0
.0339 - val_acc: 0.9886
```

```
Epoch 4/12
60000/60000 [==============================] - 134s 2ms/step - loss: 0.0544 - acc: 0.9837 - val_loss: 0
.0327 - val_acc: 0.9891
Epoch 5/12
60000/60000 [==============================] - 135s 2ms/step - loss: 0.0464 - acc: 0.9857 - val_loss: 0
.0323 - val_acc: 0.9888
Epoch 6/12
60000/60000 [==============================] - 138s 2ms/step - loss: 0.0422 - acc: 0.9873 - val_loss: 0
.0291 - val_acc: 0.9903
Epoch 7/12
60000/60000 [==============================] - 134s 2ms/step - loss: 0.0376 - acc: 0.9887 - val_loss: 0
.0289 - val_acc: 0.9911
Epoch 8/12
60000/60000 [==============================] - 133s 2ms/step - loss: 0.0347 - acc: 0.9892 - val_loss: 0
.0289 - val_acc: 0.9906
Epoch 9/12
60000/60000 [==============================] - 131s 2ms/step - loss: 0.0333 - acc: 0.9900 - val_loss: 0
.0300 - val_acc: 0.9900
Epoch 10/12
60000/60000 [==============================] - 132s 2ms/step - loss: 0.0303 - acc: 0.9911 - val_loss: 0
.0266 - val_acc: 0.9911
Epoch 11/12
60000/60000 [==============================] - 132s 2ms/step - loss: 0.0291 - acc: 0.9909 - val_loss: 0
.0281 - val_acc: 0.9908
Epoch 12/12
60000/60000 [==============================] - 135s 2ms/step - loss: 0.0265 - acc: 0.9915 - val_loss: 0
.0288 - val_acc: 0.9922
Test loss: 0.02883751948070858
Test accuracy: 0.9922
```



In [9]:

```
from prettytable import PrettyTable

x = PrettyTable()

x.field_names = ["Model", "Test accuracy"]

x.add_row(["Conv 2 Layer",99.26])
x.add_row(["Conv 3 Layer",99.45])
x.add_row(["Conv 5 Layer",99.48])
x.add_row(["Conv 7 Layer",99.44])
x.add_row(["Conv 3 Layer with (32,32,64) filters (data augmentation)",99.41])
x.add_row(["Conv 3 Layer with (32,64,128) filters(data augmentation)",99.2])


print(x)
```

```
+----------------------------------------------------------+---------------+
|                          Model                           | Test accuracy |
+----------------------------------------------------------+---------------+
|                       Conv 2 Layer                       |     99.26     |
|                       Conv 3 Layer                       |     99.45     |
|                       Conv 5 Layer                       |     99.48     |
|                       Conv 7 Layer                       |     99.44     |
| Conv 3 Layer with (32,32,64) filters (data augmentation) |     99.41     |
| Conv 3 Layer with (32,64,128) filters(data augmentation) |      99.2     |
+----------------------------------------------------------+---------------+
```

Observation:

1. Various CNN architecture is implemented on MNIST dataset and the test accuracy has been calculated.
2. Maximum accuracy achieved, using 5 convolution layer architecture is 99.5. From the error plot, it is found that the validation and train loss converges, when the model is trained for 12 epochs.
3. The model performs well for data augmented x_train data with accuracy of 99.2.
4. Based on the number of convolution filters, some of the architectures overfits.(3 Conv layer,Conv 3 Layer with (32,32,64) filters (data augmentation))