Assignment-15: Try various CNN networks on MNIST dataset [M]

Three different architecture of CNN network on MNIST datasets.MNIST datasets contains handwritten images .

Objective:

1) 3_ConvNets with kernel 3x3
2) 5_ConvNets with kernel 5x5
3) 7_ConvnNets with kernel 2x2

In [0]:
```
# Credits: https://github.com/keras-team/keras/blob/master/examples/mnist_cnn.py

from datetime import datetime
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

from keras.initializers import he_normal
from keras.layers.normalization import BatchNormalization


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

In [0]:
```
#
(x_train, y_train), (x_test, y_test) = mnist.load_data()
```

In [12]:
```
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 [13]:
```
print(y_train.shape)
```

```
(60000, 10)
```

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):
  fig = plt.figure( facecolor='y', edgecolor='k')
  plt.plot(x, vy, 'b', label="Validation Loss")
  plt.plot(x, ty, 'r', label="Train Loss")
  plt.xlabel('Epochs')
  plt.ylabel('Categorical Crossentropy Loss')
  plt.legend()
  plt.grid()
  plt.show()
```

1 Model 1:CNN with 3 ConvNet & 3x3 kernel size

In [17]:
```
convnet3=Sequential() # Initializing the model

# First ConvNet
convnet3.add(Conv2D(32,kernel_size=(3,3),
                    activation='relu',
                    input_shape=input_shape))

convnet3.add(Conv2D(64,kernel_size=(3,3),
                    activation='relu'))

convnet3.add(Dropout(0.25))

convnet3.add(Conv2D(128,kernel_size=(3,3),
                   activation='relu'))
#maxpooling by (2,2 ) ,dropout,flattening
convnet3.add(MaxPooling2D(pool_size=(2,2)))
convnet3.add(Dropout(0.25))
convnet3.add(Flatten())

#hidden_layer
convnet3.add(Dense(256,
                   activation='relu',
                   kernel_initializer=he_normal(seed=None)))
convnet3.add(Dropout(0.5))
convnet3.add(Dense(num_classes,activation='softmax'))
print(convnet3.summary())
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_7 (Conv2D)            (None, 26, 26, 32)        320
_________________________________________________________________
conv2d_8 (Conv2D)            (None, 24, 24, 64)        18496
_________________________________________________________________
dropout_6 (Dropout)          (None, 24, 24, 64)        0
_________________________________________________________________
conv2d_9 (Conv2D)            (None, 22, 22, 128)       73856
_________________________________________________________________
max_pooling2d_3 (MaxPooling2 (None, 11, 11, 128)       0
_________________________________________________________________
dropout_7 (Dropout)          (None, 11, 11, 128)       0
_________________________________________________________________
flatten_3 (Flatten)          (None, 15488)             0
_________________________________________________________________
dense_3 (Dense)              (None, 256)               3965184
_________________________________________________________________
dropout_8 (Dropout)          (None, 256)               0
_________________________________________________________________
dense_4 (Dense)              (None, 10)                2570
=================================================================
Total params: 4,060,426
Trainable params: 4,060,426
Non-trainable params: 0
_________________________________________________________________
None
```

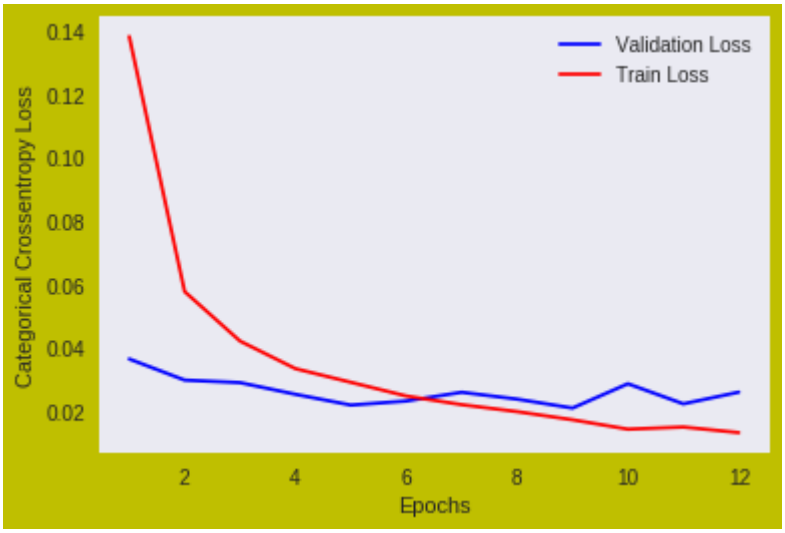
In [24]:
```
#Model compilation
convnet3.compile(optimizer=keras.optimizers.Adam(),
                 loss=keras.losses.categorical_crossentropy,
                 metrics=['accuracy'])
convnet3_history=convnet3.fit(x_train,y_train,batch_size=batch_size,
                              epochs=epochs,
                              verbose=1,
                              validation_data=(x_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 555s 9ms/step - loss: 0.1380 -
acc: 0.9585 - val_loss: 0.0364 - val_acc: 0.9878
Epoch 2/12
60000/60000 [==============================] - 555s 9ms/step - loss: 0.0576 -
acc: 0.9823 - val_loss: 0.0297 - val_acc: 0.9906
Epoch 3/12
60000/60000 [==============================] - 555s 9ms/step - loss: 0.0420 -
acc: 0.9872 - val_loss: 0.0289 - val_acc: 0.9908
Epoch 4/12
60000/60000 [==============================] - 553s 9ms/step - loss: 0.0333 -
acc: 0.9898 - val_loss: 0.0252 - val_acc: 0.9923
Epoch 5/12
60000/60000 [==============================] - 557s 9ms/step - loss: 0.0290 -
acc: 0.9909 - val_loss: 0.0218 - val_acc: 0.9931
Epoch 6/12
60000/60000 [==============================] - 555s 9ms/step - loss: 0.0247 -
acc: 0.9919 - val_loss: 0.0231 - val_acc: 0.9930
Epoch 7/12
60000/60000 [==============================] - 557s 9ms/step - loss: 0.0219 -
acc: 0.9929 - val_loss: 0.0259 - val_acc: 0.9920
Epoch 8/12
60000/60000 [==============================] - 555s 9ms/step - loss: 0.0197 -
acc: 0.9937 - val_loss: 0.0237 - val_acc: 0.9929
Epoch 9/12
60000/60000 [==============================] - 563s 9ms/step - loss: 0.0172 -
acc: 0.9943 - val_loss: 0.0209 - val_acc: 0.9938
Epoch 10/12
60000/60000 [==============================] - 561s 9ms/step - loss: 0.0142 -
acc: 0.9953 - val_loss: 0.0285 - val_acc: 0.9916
Epoch 11/12
60000/60000 [==============================] - 564s 9ms/step - loss: 0.0149 -
acc: 0.9956 - val_loss: 0.0222 - val_acc: 0.9940
Epoch 12/12
60000/60000 [==============================] - 562s 9ms/step - loss: 0.0131 -
acc: 0.9957 - val_loss: 0.0259 - val_acc: 0.9938
```

In [32]:
```
#evaluating model

score=convnet3.evaluate(x_test,y_test,verbose=0)
test_score3=score[0]
test_accuracy3=score[1]
train_accuracy3=max(convnet3_history.history['acc'])
print('test score :',test_score3)
print('test sccuracy :',test_accuracy3)
# error plot
x=list(range(1,epochs+1))
vy=convnet3_history.history['val_loss'] #validation loss
ty=convnet3_history.history['loss'] # train loss
plt_dynamic(x, vy, ty)
```

```
test score : 0.025890892835492695
test sccuracy : 0.9938
```



2 Model2:CNN with 5 ConvNet & kernel_size=(5x5)

5 convNet followed by maxpooling(2,2) and dropout

In [39]:
```
convnet5=Sequential() # Initializing the model

# First ConvNet
convnet5.add(Conv2D(32,kernel_size=(5,5),
                    activation='relu',
                    padding='same',
                    input_shape=input_shape))

convnet5.add(Conv2D(64,kernel_size=(5,5),
                    padding='same',
                    activation='relu'))#Second Convnet
convnet5.add(MaxPooling2D(pool_size=(2,2)))
convnet5.add(Dropout(0.25))

convnet5.add(Conv2D(96,kernel_size=(5,5),
                    padding='same',
                   activation='relu'))  # 3rd ConvNet
#maxpooling by (2,2 ) ,dropout,flattening
convnet5.add(MaxPooling2D(pool_size=(2,2)))
convnet5.add(Dropout(0.25))

convnet5.add(Conv2D(128,kernel_size=(5,5),
                    padding='same',
                    activation='relu'))#fourth Convnet
convnet5.add(MaxPooling2D(pool_size=(2,2)))
convnet5.add(Dropout(0.25))
convnet5.add(Conv2D(164,kernel_size=(5,5),
                    padding='same',
                    activation='relu'))#fifth Convnet
convnet5.add(MaxPooling2D(pool_size=(2,2)))
convnet5.add(Dropout(0.25))
convnet5.add(Flatten())

#hidden_layer
convnet5.add(Dense(256,
                   activation='relu',
                   kernel_initializer=he_normal(seed=None)))
convnet5.add(BatchNormalization())
convnet5.add(Dropout(0.5))
convnet5.add(Dense(num_classes,activation='softmax'))
print(convnet5.summary())
```

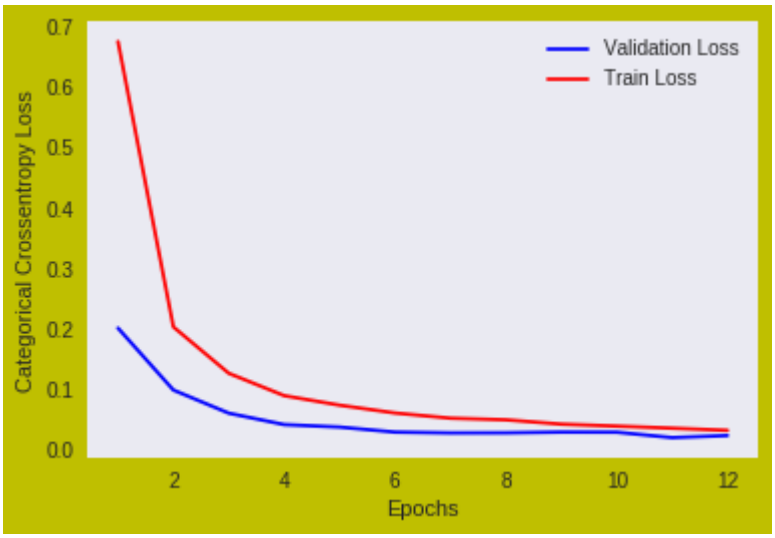
```
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_20 (Conv2D)           (None, 28, 28, 32)        832       
_________________________________________________________________
conv2d_21 (Conv2D)           (None, 28, 28, 64)        51264     
_________________________________________________________________
max_pooling2d_14 (MaxPooling (None, 14, 14, 64)        0         
_________________________________________________________________
dropout_17 (Dropout)         (None, 14, 14, 64)        0         
_________________________________________________________________
conv2d_22 (Conv2D)           (None, 14, 14, 96)        153696    
_________________________________________________________________
max_pooling2d_15 (MaxPooling (None, 7, 7, 96)          0         
_________________________________________________________________
dropout_18 (Dropout)         (None, 7, 7, 96)          0         
_________________________________________________________________
conv2d_23 (Conv2D)           (None, 7, 7, 128)         307328    
_________________________________________________________________
max_pooling2d_16 (MaxPooling (None, 3, 3, 128)         0         
_________________________________________________________________
dropout_19 (Dropout)         (None, 3, 3, 128)         0         
_________________________________________________________________
conv2d_24 (Conv2D)           (None, 3, 3, 164)         524964    
_________________________________________________________________
max_pooling2d_17 (MaxPooling (None, 1, 1, 164)         0         
_________________________________________________________________
dropout_20 (Dropout)         (None, 1, 1, 164)         0         
_________________________________________________________________
flatten_4 (Flatten)          (None, 164)               0         
_________________________________________________________________
dense_5 (Dense)              (None, 256)               42240     
_________________________________________________________________
batch_normalization_1 (Batch (None, 256)               1024      
_________________________________________________________________
dropout_21 (Dropout)         (None, 256)               0         
_________________________________________________________________
dense_6 (Dense)              (None, 10)                2570      
=================================================================
Total params: 1,083,918
Trainable params: 1,083,406
Non-trainable params: 512
_________________________________________________________________
None
```

In [42]:
```
#Model compilation
start = datetime.now()
convnet5.compile(optimizer=keras.optimizers.Adam(),
                 loss=keras.losses.categorical_crossentropy,
                 metrics=['accuracy'])
convnet5_history=convnet5.fit(x_train,y_train,batch_size=batch_size,
                              epochs=epochs,
                              verbose=1,
                              validation_data=(x_test, y_test))
print("Time taken to run this cell :", datetime.now() - start)
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 983s 16ms/step - loss: 0.6764
- acc: 0.7753 - val_loss: 0.2016 - val_acc: 0.9378
Epoch 2/12
60000/60000 [==============================] - 981s 16ms/step - loss: 0.2034
- acc: 0.9396 - val_loss: 0.0988 - val_acc: 0.9679
Epoch 3/12
60000/60000 [==============================] - 989s 16ms/step - loss: 0.1265
- acc: 0.9634 - val_loss: 0.0604 - val_acc: 0.9821
Epoch 4/12
60000/60000 [==============================] - 985s 16ms/step - loss: 0.0895
- acc: 0.9740 - val_loss: 0.0415 - val_acc: 0.9863
Epoch 5/12
60000/60000 [==============================] - 977s 16ms/step - loss: 0.0737
- acc: 0.9792 - val_loss: 0.0374 - val_acc: 0.9872
Epoch 6/12
60000/60000 [==============================] - 970s 16ms/step - loss: 0.0607
- acc: 0.9823 - val_loss: 0.0290 - val_acc: 0.9909
Epoch 7/12
60000/60000 [==============================] - 970s 16ms/step - loss: 0.0521
- acc: 0.9851 - val_loss: 0.0277 - val_acc: 0.9921
Epoch 8/12
60000/60000 [==============================] - 972s 16ms/step - loss: 0.0494
- acc: 0.9860 - val_loss: 0.0279 - val_acc: 0.9917
Epoch 9/12
60000/60000 [==============================] - 972s 16ms/step - loss: 0.0423
- acc: 0.9872 - val_loss: 0.0291 - val_acc: 0.9910
Epoch 10/12
60000/60000 [==============================] - 985s 16ms/step - loss: 0.0390
- acc: 0.9885 - val_loss: 0.0289 - val_acc: 0.9921
Epoch 11/12
60000/60000 [==============================] - 982s 16ms/step - loss: 0.0356
- acc: 0.9902 - val_loss: 0.0199 - val_acc: 0.9938
Epoch 12/12
60000/60000 [==============================] - 981s 16ms/step - loss: 0.0320
- acc: 0.9905 - val_loss: 0.0234 - val_acc: 0.9930
Time taken to run this cell : 3:15:47.690485
```

In [43]:
```
#evaluating model
score=convnet5.evaluate(x_test,y_test,verbose=0)
test_score5=score[0]
test_accuracy5=score[1]
train_accuracy5=max(convnet5_history.history['acc'])
print('test score :',test_score5)
print('test Accuracy :',test_accuracy5)
# error plot
x=list(range(1,epochs+1))
vy=convnet5_history.history['val_loss'] #validation loss
ty=convnet5_history.history['loss'] # train loss
plt_dynamic(x, vy, ty)
```

```
test score : 0.023384571030837107
test Accuracy : 0.993
```



3 Model3:CNN with 7 ConvNet & kernel_size=(2x2)

5 convNet followed by maxpooling(2,2) and dropout

In [49]:
```
convnet7=Sequential() # Initializing the model

# First ConvNet
convnet7.add(Conv2D(16,kernel_size=(2,2),
                    activation='relu',
                    padding='same',strides=(1,1),
                    input_shape=input_shape))


convnet7.add(Conv2D(32,kernel_size=(2,2),
                    padding='same',strides=(2,2),
                    activation='relu'))#Second Convnet
#convnet7.add(MaxPooling2D(pool_size=(2,2)))
#convnet7.add(Dropout(0.25))

convnet7.add(Conv2D(64,kernel_size=(2,2),
                    padding='same',
                   activation='relu'))  # 3rd ConvNet
#maxpooling by (2,2 ) ,dropout,flattening
#convnet7.add(MaxPooling2D(pool_size=(2,2)))
convnet7.add(Dropout(0.15))

convnet7.add(Conv2D(96,kernel_size=(2,2),
                    padding='same',
                    activation='relu'))#fourth Convnet
convnet7.add(MaxPooling2D(pool_size=(2,2)))
convnet7.add(Dropout(0.39))
convnet7.add(Conv2D(128,kernel_size=(2,2),
                    padding='same',
                    activation='relu'))#fifth Convnet
convnet7.add(MaxPooling2D(pool_size=(2,2)))
convnet7.add(Dropout(0.3))
convnet7.add(Conv2D(164,kernel_size=(2,2),
                    padding='same',
                    activation='relu'))#sixth Convnet
convnet7.add(Conv2D(164,kernel_size=(2,2),
                    padding='same',strides=(1,1),
                    activation='relu'))#seventh Convnet

convnet7.add(MaxPooling2D(pool_size=(2,2)))
convnet7.add(Dropout(0.4))
convnet7.add(Flatten())

#hidden_layer
convnet7.add(Dense(256,
                   activation='relu',
                   kernel_initializer=he_normal(seed=None)))#1 hidden layer
convnet7.add(BatchNormalization())
convnet7.add(Dropout(0.5))
convnet7.add(Dense(148,
                   activation='relu',
                   kernel_initializer=he_normal(seed=None)))#2 hidden layer
convnet7.add(BatchNormalization())
convnet7.add(Dropout(0.5))
convnet7.add(Dense(128,
                   activation='relu',
```

```
                    kernel_initializer=he_normal(seed=None)))#3 hidden layer
convnet7.add(BatchNormalization())
convnet7.add(Dropout(0.5))
convnet7.add(Dense(num_classes,activation='softmax'))
print(convnet7.summary())
```

Layer (type)	Output Shape	Param #
conv2d_56 (Conv2D)	(None, 28, 28, 16)	80
conv2d_57 (Conv2D)	(None, 14, 14, 32)	2080
conv2d_58 (Conv2D)	(None, 14, 14, 64)	8256
dropout_41 (Dropout)	(None, 14, 14, 64)	0
conv2d_59 (Conv2D)	(None, 14, 14, 96)	24672
max_pooling2d_37 (MaxPooling	(None, 7, 7, 96)	0
dropout_42 (Dropout)	(None, 7, 7, 96)	0
conv2d_60 (Conv2D)	(None, 7, 7, 128)	49280
max_pooling2d_38 (MaxPooling	(None, 3, 3, 128)	0
dropout_43 (Dropout)	(None, 3, 3, 128)	0
conv2d_61 (Conv2D)	(None, 3, 3, 164)	84132
conv2d_62 (Conv2D)	(None, 3, 3, 164)	107748
max_pooling2d_39 (MaxPooling	(None, 1, 1, 164)	0
dropout_44 (Dropout)	(None, 1, 1, 164)	0
flatten_6 (Flatten)	(None, 164)	0
dense_11 (Dense)	(None, 256)	42240
batch_normalization_5 (Batch	(None, 256)	1024
dropout_45 (Dropout)	(None, 256)	0
dense_12 (Dense)	(None, 148)	38036
batch_normalization_6 (Batch	(None, 148)	592
dropout_46 (Dropout)	(None, 148)	0
dense_13 (Dense)	(None, 128)	19072
batch_normalization_7 (Batch	(None, 128)	512
dropout_47 (Dropout)	(None, 128)	0
dense_14 (Dense)	(None, 10)	1290

Total params: 379,014
Trainable params: 377,950
Non-trainable params: 1,064

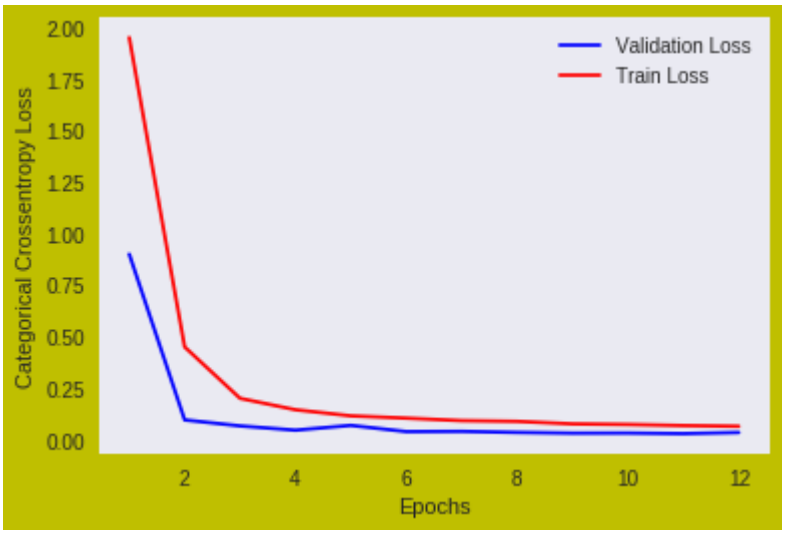
None

In [50]:
```
#Model compilation
start=datetime.now()
convnet7.compile(optimizer=keras.optimizers.Adam(),
                 loss=keras.losses.categorical_crossentropy,
                 metrics=['accuracy'])
convnet7_history=convnet7.fit(x_train,y_train,batch_size=batch_size,
                              epochs=epochs,
                              verbose=1,
                              validation_data=(x_test, y_test))
print("Time taken to run this cell :", datetime.now() - start)
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/12
60000/60000 [==============================] - 168s 3ms/step - loss: 1.9486 -
acc: 0.3600 - val_loss: 0.8981 - val_acc: 0.6529
Epoch 2/12
60000/60000 [==============================] - 162s 3ms/step - loss: 0.4479 -
acc: 0.8694 - val_loss: 0.0940 - val_acc: 0.9737
Epoch 3/12
60000/60000 [==============================] - 163s 3ms/step - loss: 0.1987 -
acc: 0.9485 - val_loss: 0.0649 - val_acc: 0.9835
Epoch 4/12
60000/60000 [==============================] - 164s 3ms/step - loss: 0.1433 -
acc: 0.9640 - val_loss: 0.0442 - val_acc: 0.9873
Epoch 5/12
60000/60000 [==============================] - 163s 3ms/step - loss: 0.1137 -
acc: 0.9715 - val_loss: 0.0675 - val_acc: 0.9833
Epoch 6/12
60000/60000 [==============================] - 163s 3ms/step - loss: 0.1026 -
acc: 0.9748 - val_loss: 0.0373 - val_acc: 0.9905
Epoch 7/12
60000/60000 [==============================] - 164s 3ms/step - loss: 0.0904 -
acc: 0.9783 - val_loss: 0.0384 - val_acc: 0.9900
Epoch 8/12
60000/60000 [==============================] - 165s 3ms/step - loss: 0.0869 -
acc: 0.9790 - val_loss: 0.0333 - val_acc: 0.9918
Epoch 9/12
60000/60000 [==============================] - 165s 3ms/step - loss: 0.0747 -
acc: 0.9818 - val_loss: 0.0298 - val_acc: 0.9928
Epoch 10/12
60000/60000 [==============================] - 162s 3ms/step - loss: 0.0719 -
acc: 0.9820 - val_loss: 0.0302 - val_acc: 0.9931
Epoch 11/12
60000/60000 [==============================] - 163s 3ms/step - loss: 0.0666 -
acc: 0.9830 - val_loss: 0.0275 - val_acc: 0.9932
Epoch 12/12
60000/60000 [==============================] - 163s 3ms/step - loss: 0.0633 -
acc: 0.9844 - val_loss: 0.0330 - val_acc: 0.9926
Time taken to run this cell : 0:32:47.172971
```

In [51]:
```
#evaluating model
score=convnet7.evaluate(x_test,y_test,verbose=0)
test_score7=score[0]
test_accuracy7=score[1]
train_accuracy7=max(convnet7_history.history['acc'])
print('test score :',test_score7)
print('test Accuracy :',test_accuracy7)
# error plot
x=list(range(1,epochs+1))
vy=convnet7_history.history['val_loss'] #validation loss
ty=convnet7_history.history['loss'] # train loss
plt_dynamic(x, vy, ty)
```

```
test score : 0.032985285274824125
test Accuracy : 0.9926
```



Observation

In [53]:
```
from prettytable import PrettyTable
models=['3ConvNet with kernel 3x3',
        '5ConvNet with kernel 5x5',
        '7ConvNet with kernel 2x2']
training_accuracy=[train_accuracy3,train_accuracy5,train_accuracy7]
test_accuracy=[test_accuracy3,test_accuracy5,test_accuracy7]
INDEX = [1,2,3]
# Initializing prettytable
Model_Performance = PrettyTable()
# Adding columns
Model_Performance.add_column("INDEX.",INDEX)
Model_Performance.add_column("MODEL_NAME",models)
Model_Performance.add_column("TRAINING ACCURACY",training_accuracy)
Model_Performance.add_column("TESTING ACCURACY",test_accuracy)
#Model_Performance.add_column("TEST SCORE",test_score)

# Printing the Model_Performance
print(Model_Performance)
```

```
+--------+--------------------------+--------------------+------------------+
| INDEX. |        MODEL_NAME        | TRAINING ACCURACY  | TESTING ACCURACY |
+--------+--------------------------+--------------------+------------------+
|   1    | 3ConvNet with kernel 3x3 | 0.9957166666666667 |      0.9938      |
|   2    | 5ConvNet with kernel 5x5 | 0.9905000000317892 |      0.993       |
|   3    | 7ConvNet with kernel 2x2 | 0.9844166666348775 |      0.9926      |
+--------+--------------------------+--------------------+------------------+
```

- from graphs in model1,model2 and model 3 model3 gives best plot amongst other model.
- Non_trainable params:

  Model1=0
  Model2=512
  Model3=1064

- The Training time for model2 and model1 is very high comapratively model3.
- Model performance with three different CNN model is shown in above table.