CNN networks on MNIST dataset

```
import matplotlib.pyplot as plt
from keras.utils import np_utils
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.normalization import BatchNormalization
from keras.initializers import he_normal

import seaborn as sns
import numpy as np
import keras
```

```
Using TensorFlow backend.
```

The default version of TensorFlow in Colab will soon switch to TensorFlow 2.x.
We recommend you upgrade now or ensure your notebook will continue to use TensorFlow 1.x via the `%tensorflow_version 1.x` magic: more info.

```
(X_train, y_train), (X_test, y_test) = mnist.load_data()

img_rows, img_cols = 28, 28
```

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

```
print("Training data shape: ", X_train.shape)
print("Test data shape", X_test.shape)

print("Training label shape: ", y_train.shape)
print("First 5 training labels: ", y_train[:5])
```

```
Training data shape:  (60000, 28, 28)
Test data shape (10000, 28, 28)
Training label shape:  (60000,)
First 5 training labels:  [5 0 4 1 9]
```

```
num_classes = 10
batch_size = 128
epochs = 10

from keras import backend as K

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')
```

```
x_train shape: (60000, 28, 28, 1)
60000 train samples
10000 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 1:CNN with 3 ConvNet & 3x3 kernel size

```
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())
```

```
#Model compilation
convnet3.compile(optimizer=keras.optimizers.Adam(),
                loss=keras.losses.categorical_crossentropy,
                metrics=['accuracy'])
convnet_3=convnet3.fit(X_train,y_train,batch_size=batch_size,
                           epochs=epochs,
                           verbose=1,
                           validation_data=(X_test, y_test))
score = convnet3.evaluate(X_test, y_test, verbose=0)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 499s 8ms/step - loss: 0.1778 - acc: 0.945
Epoch 2/10
60000/60000 [==============================] - 496s 8ms/step - loss: 0.0620 - acc: 0.981
Epoch 3/10
60000/60000 [==============================] - 494s 8ms/step - loss: 0.0439 - acc: 0.986
Epoch 4/10
60000/60000 [==============================] - 492s 8ms/step - loss: 0.0376 - acc: 0.988
Epoch 5/10
60000/60000 [==============================] - 493s 8ms/step - loss: 0.0291 - acc: 0.991
Epoch 6/10
60000/60000 [==============================] - 492s 8ms/step - loss: 0.0259 - acc: 0.992
Epoch 7/10
60000/60000 [==============================] - 495s 8ms/step - loss: 0.0212 - acc: 0.993
Epoch 8/10
60000/60000 [==============================] - 497s 8ms/step - loss: 0.0202 - acc: 0.993
Epoch 9/10
60000/60000 [==============================] - 499s 8ms/step - loss: 0.0199 - acc: 0.993
Epoch 10/10
60000/60000 [==============================] - 500s 8ms/step - loss: 0.0162 - acc: 0.995
Test loss: 0.027885543293261435
Test accuracy: 0.9917
```

```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,epochs+1))

train_loss = convnet_3.history['loss']
val_loss = convnet_3.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show();
```

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

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

```
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())
```

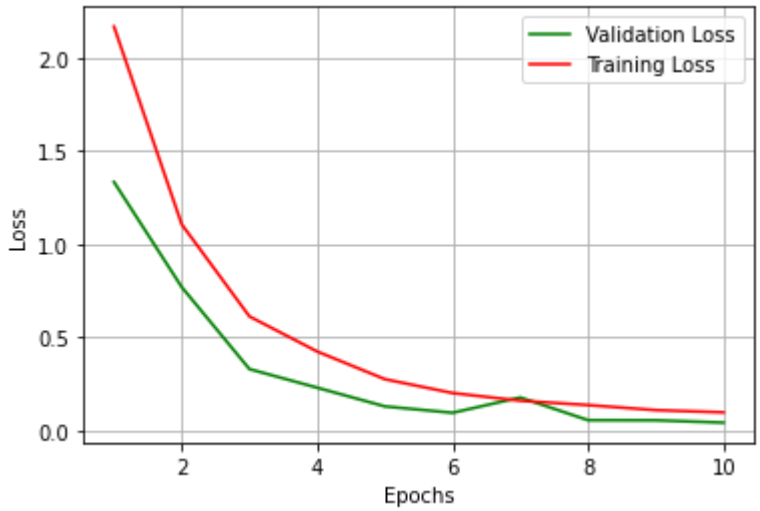
```
Model: "sequential_4"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_10 (Conv2D)           (None, 28, 28, 32)        832
_________________________________________________________________
conv2d_11 (Conv2D)           (None, 28, 28, 64)        51264
_________________________________________________________________
max_pooling2d_4 (MaxPooling2 (None, 14, 14, 64)        0
_________________________________________________________________
dropout_9 (Dropout)          (None, 14, 14, 64)        0
_________________________________________________________________
conv2d_12 (Conv2D)           (None, 14, 14, 96)        153696
_________________________________________________________________
max_pooling2d_5 (MaxPooling2 (None, 7, 7, 96)          0
_________________________________________________________________
dropout_10 (Dropout)         (None, 7, 7, 96)          0
_________________________________________________________________
conv2d_13 (Conv2D)           (None, 7, 7, 128)         307328
_________________________________________________________________
max_pooling2d_6 (MaxPooling2 (None, 3, 3, 128)         0
_________________________________________________________________
dropout_11 (Dropout)         (None, 3, 3, 128)         0
_________________________________________________________________
conv2d_14 (Conv2D)           (None, 3, 3, 164)         524964
_________________________________________________________________
max_pooling2d_7 (MaxPooling2 (None, 1, 1, 164)         0
_________________________________________________________________
dropout_12 (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_13 (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
```

```
#Model compilation
from datetime import datetime
start = datetime.now()
convnet5.compile(optimizer=keras.optimizers.Adam(),
                 loss=keras.losses.categorical_crossentropy,
                 metrics=['accuracy'])
convnet_5=convnet5.fit(X_train,y_train,batch_size=batch_size,
                           epochs=epochs,
```

```
                                  verbose=1,
                                  validation_data=(X_test, y_test))
score = convnet5.evaluate(X_test, y_test, verbose=0)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
print("Time taken to run this cell :", datetime.now() - start)
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 909s 15ms/step - loss: 2.1667 - acc: 0.28
Epoch 2/10
60000/60000 [==============================] - 909s 15ms/step - loss: 1.1052 - acc: 0.61
Epoch 3/10
60000/60000 [==============================] - 914s 15ms/step - loss: 0.6110 - acc: 0.79
Epoch 4/10
60000/60000 [==============================] - 912s 15ms/step - loss: 0.4228 - acc: 0.86
Epoch 5/10
60000/60000 [==============================] - 921s 15ms/step - loss: 0.2741 - acc: 0.91
Epoch 6/10
60000/60000 [==============================] - 924s 15ms/step - loss: 0.1998 - acc: 0.94
Epoch 7/10
60000/60000 [==============================] - 924s 15ms/step - loss: 0.1586 - acc: 0.95
Epoch 8/10
60000/60000 [==============================] - 920s 15ms/step - loss: 0.1352 - acc: 0.96
Epoch 9/10
60000/60000 [==============================] - 924s 15ms/step - loss: 0.1081 - acc: 0.96
Epoch 10/10
60000/60000 [==============================] - 917s 15ms/step - loss: 0.0960 - acc: 0.97
Test loss: 0.040991343469824644
Test accuracy: 0.9869
Time taken to run this cell : 2:33:29.157051
```

```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,epochs+1))

train_loss = convnet_5.history['loss']
val_loss = convnet_5.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show();
```



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

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

```
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
```

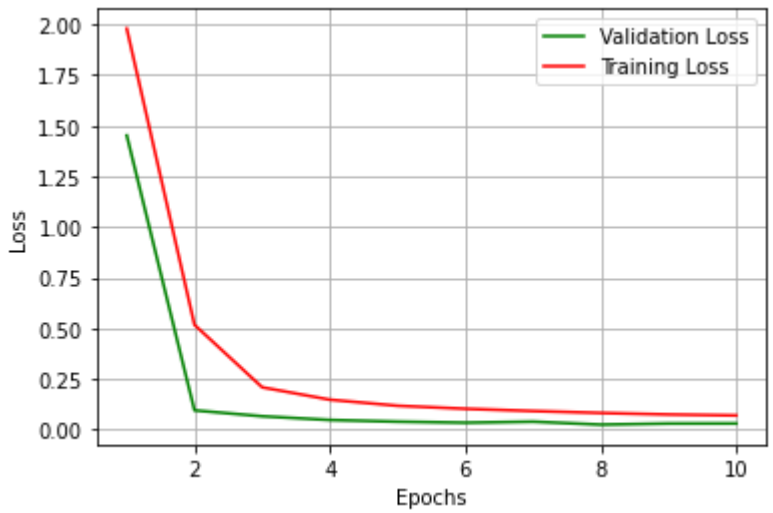
```
                     activation='relu'))#fifth Convnet
convnet7.add(MaxPooling2D(pool_size=(2,2)))
convnet7.add(Dropout(0.3))
convnet7.add(Conv2D(164,kernel_size=(2,2),
                    padding='same',
                    activation='relu'))#sixth Convnet
convnet7.add(Conv2D(164,kernel_size=(2,2),
                    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())
```

```
#Model compilation
from datetime import datetime
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))
score = convnet7.evaluate(X_test, y_test, verbose=0)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
print("Time taken to run this cell :", datetime.now() - start)
```

```
WARNING:tensorflow:From /tensorflow-1.15.0/python3.6/tensorflow_core/python/ops/math_gra
Instructions for updating:
Use tf.where in 2.0, which has the same broadcast rule as np.where
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_

Train on 60000 samples, validate on 10000 samples
Epoch 1/10
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_

60000/60000 [==============================] - 139s 2ms/step - loss: 1.9793 - acc: 0.345
Epoch 2/10
60000/60000 [==============================] - 135s 2ms/step - loss: 0.5178 - acc: 0.841
Epoch 3/10
60000/60000 [==============================] - 135s 2ms/step - loss: 0.2094 - acc: 0.944
Epoch 4/10
60000/60000 [==============================] - 134s 2ms/step - loss: 0.1483 - acc: 0.962
Epoch 5/10
60000/60000 [==============================] - 135s 2ms/step - loss: 0.1184 - acc: 0.971
Epoch 6/10
60000/60000 [==============================] - 134s 2ms/step - loss: 0.1035 - acc: 0.974
Epoch 7/10
60000/60000 [==============================] - 134s 2ms/step - loss: 0.0924 - acc: 0.976
Epoch 8/10
60000/60000 [==============================] - 134s 2ms/step - loss: 0.0829 - acc: 0.979
Epoch 9/10
60000/60000 [==============================] - 134s 2ms/step - loss: 0.0753 - acc: 0.981
Epoch 10/10
60000/60000 [==============================] - 134s 2ms/step - loss: 0.0707 - acc: 0.983
Test loss: 0.030946802491589914
Test accuracy: 0.9924
Time taken to run this cell : 0:22:34.258270
```

```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,epochs+1))

train_loss = convnet7_history.history['loss']
val_loss = convnet7_history.history['val_loss']
```

```
ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show();
```



Summary

```
from prettytable import PrettyTable
x = PrettyTable()
x.field_names = ["MODEL_NAME","TRAINING ACCURACY","TESTING ACCURACY"]
x.add_row(["Cnn with 3 convnet & 3x3 kernel size", 0.9950, 0.9917])
x.add_row(["Cnn with 5 convnet & 5x5 kernel size", 0.9718, 9869])
x.add_row(["Cnn with 7 convnet & 2x2 Kernel size",0.9834, 0.9924])

print(x)
```

```
+--------------------------------------+-------------------+------------------+
|              MODEL_NAME              | TRAINING ACCURACY | TESTING ACCURACY |
+--------------------------------------+-------------------+------------------+
| Cnn with 3 convnet & 3x3 kernel size |       0.995       |      0.9917      |
| Cnn with 5 convnet & 5x5 kernel size |       0.9718      |       9869       |
| Cnn with 7 convnet & 2x2 Kernel size |       0.9834      |      0.9924      |
+--------------------------------------+-------------------+------------------+
```