# Deep Learning case Study - Retinal OCT(optical coherence tomography) Images classification

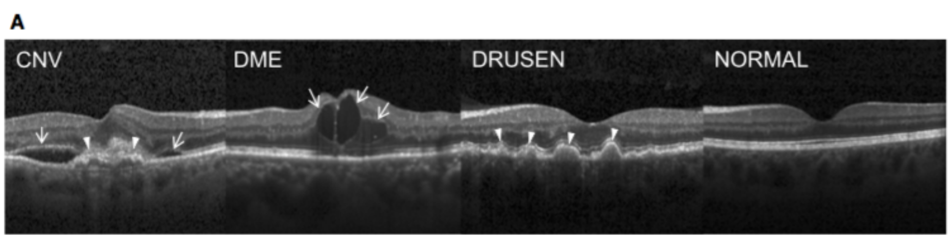
March 4, 2019

## 1 Deep Learning case Study: Retinal OCT Images classification.

Data Source: https://www.kaggle.com/paultimothymooney/kermany2018

### 1.1 Objective:

Given a new OCT image, determine whether the image belongs to which 4 class: CNV, DME, DRUSEN, and NORMAL. We are using CNN for the classification model.




### 1.2

Figure: Representative Optical Coherence Tomography Images and the Workflow Diagram 2. Reference: [Kermany et. al. 2018] http://www.cell.com/cell/fulltext/S0092-8674(18)30154-5

1. (Far left) choroidal neovascularization (CNV) with neovascular membrane (white arrowheads) and associated subretinal fluid (arrows).
2. (Middle left) Diabetic macular edema (DME) with retinal-thickening-associated intraretinal fluid (arrows).
3. (Middle right) Multiple drusen (arrowheads) present in early AMD.
4. (Far right) Normal retina with preserved foveal contour and absence of any retinal fluid/edema.

### 1.3 Context

http://www.cell.com/cell/fulltext/S0092-8674(18)30154-5

Retinal optical coherence tomography (OCT) is an imaging technique used to capture high-resolution cross sections of the retinas of living patients. Total **83,484** OCT images are there in the training dataset. Also **1000** OCT images are there in the test dataset.

It is an **imbalanced** dataset. Training dataset contains below number of images:

1. CNV = 26315
2. DME = 37205
3. DRUSEN = 11348
4. NORMAL = 8616

### 1.4 Content:

The dataset is organized into 2 folders (train, test) and contains subfolders for each image category (NORMAL,CNV,DME,DRUSEN). There are **84,495 X-Ray images (JPEG) and 4 categories (NORMAL,CNV,DME,DRUSEN).**

Images are labeled as (disease)-(randomized patient ID)-(image number by this patient) and split into 4 directories: CNV, DME, DRUSEN, and NORMAL.

Optical coherence tomography (OCT) images (Spectralis OCT, Heidelberg Engineering, Germany) were selected from retrospective cohorts of adult patients from the Shiley Eye Institute of the University of California San Diego, the California Retinal Research Foundation, Medical Center Ophthalmology Associates, the Shanghai First People's Hospital, and Beijing Tongren Eye Center between July 1, 2013 and March 1, 2017.

Before training, each image went through a tiered grading system consisting of multiple layers of trained graders of increasing exper- tise for verification and correction of image labels. Each image imported into the database started with a label matching the most recent diagnosis of the patient. The first tier of graders consisted of undergraduate and medical students who had taken and passed an OCT interpretation course review. This first tier of graders conducted initial quality control and excluded OCT images containing severe artifacts or significant image resolution reductions. The second tier of graders consisted of four ophthalmologists who independently graded each image that had passed the first tier. The presence or absence of choroidal neovascularization (active or in the form of subretinal fibrosis), macular edema, drusen, and other pathologies visible on the OCT scan were recorded. Finally, a third tier of two senior independent retinal specialists, each with over 20 years of clinical retina experience, verified the true labels for each image. To account for human error in grading, a validation subset of 993 scans was graded separately by two ophthalmologist graders, with disagreement in clinical labels arbitrated by a senior retinal specialist.

#### 1.4.1 Acknowledgements

1. Data: https://data.mendeley.com/datasets/rscbjbr9sj/2
2. Citation: http://www.cell.com/cell/fulltext/S0092-8674(18)30154-5

Dataset of validated OCT and Chest X-Ray images described and analyzed in "Deep learning-based classification and referral of treatable human diseases". The OCT Images are split into a training set and a testing set of independent patients. OCT Images are labeled as (disease)-(randomized patient ID)-(image number by this patient) and split into 4 directories: CNV, DME, DRUSEN, and NORMAL.

## 2 Overview of CNN Architecture:

1. Keras allows us to specify the number of filters we want and the size of the filters. So, in our **first layer** we specify the **shape of the input & Number of filters**.

2. The **second layer** is the Activation layer. We have used **ReLU (rectified linear unit) as our activation function. ReLU function is f(x) = max(0, x), where x is the input.** It sets all negative values in the matrix 'x' to 0 and keeps all the other values constant. It is the most used activation function since it reduces training time and prevents the problem of vanishing gradients.

3. The **third layer is the MaxPooling layer.** MaxPooling layer is used to down-sample the input to enable the model to make assumptions about the features so as to reduce over-fitting. It also reduces the number of parameters to learn, reducing the training time.

4. We can repeat the Activation layers if we want to create a Deep CNN.

5. It's a best practice to always do **BatchNormalization.** BatchNormalization normalizes the matrix after it is been through a convolution layer so that the scale of each dimension remains the same. It reduces the training time significantly.

6. **Dropout is the method used to reduce overfitting.** It forces the model to learn multiple independent representations of the same data by randomly disabling neurons in the learning phase. In our model, dropout will randomnly disable 20% of the neurons.

7. After creating all the convolutional layers, we need to flatten them, so that they can act as an input to the Dense layers. Dense layers are keras's alias for Fully connected layers. These layers give the ability to classify the features learned by the CNN.

8. The **last layer is the Softmax Activation layer.** Softmax activation enables us to calculate the output based on the probabilities. Each class is assigned a probability and the class with the maximum probability is the model's output for the input.

In [1]:
```
# Importing all the needed modules.
import os
from glob import glob
import matplotlib.pyplot as plt
import random
import cv2
import pandas as pd
import numpy as np
import matplotlib.gridspec as gridspec
import seaborn as sns
import zlib
import itertools
import sklearn
import itertools
import scipy
import skimage
from skimage.transform import resize
import csv
from tqdm import tqdm
import warnings
warnings.filterwarnings("ignore")
from sklearn import model_selection
```

```
from sklearn.model_selection import train_test_split, KFold, cross_val_score, Stratifie
from sklearn.utils import class_weight
from sklearn.metrics import confusion_matrix, make_scorer, accuracy_score, classificati
import keras
from keras.layers import Dense, Dropout, Activation, Flatten, Conv2D, MaxPooling2D, Lam
from keras.utils import np_utils
from keras.utils.np_utils import to_categorical
from keras.preprocessing.image import ImageDataGenerator
from keras import models, layers, optimizers
from sklearn.model_selection import train_test_split
from sklearn.metrics import confusion_matrix, accuracy_score
from sklearn.utils import class_weight
from keras.optimizers import SGD, RMSprop, Adam, Adagrad, Adadelta, RMSprop
from keras.models import Sequential, model_from_json
from keras.layers import Activation,Dense, Dropout, Flatten, Conv2D, MaxPool2D
from keras.layers import MaxPooling2D,AveragePooling2D, GlobalAveragePooling2D,BatchNor
from keras.preprocessing.image import array_to_img, img_to_array, load_img, ImageDataGe
from keras.callbacks import ReduceLROnPlateau, ModelCheckpoint
from keras import backend as K
from keras.applications.vgg16 import VGG16
from keras.models import Model
from keras.applications.mobilenet import MobileNet
from keras.applications.inception_v3 import InceptionV3
from imblearn.over_sampling import RandomOverSampler
from sklearn.metrics import roc_auc_score
from sklearn.metrics import roc_curve
from sklearn.metrics import auc
%matplotlib inline
```

```
Using TensorFlow backend.
```

## 2.1 Baseline Model: CNN with 3 Hidden Layers.

**Due to large size of dataset we have used ImageDataGenerator module from keras for Batch wise training of our CNN model.**

In [2]:
```
# Model parameters
image_size = 256
batch_size = 32
num_classes = 4
epochs = 10
```

In [3]:
```
# Baseline Model.
model = Sequential()
model.add(Conv2D(256, kernel_size=(3, 3), activation='relu', input_shape=(image_size, i
model.add(BatchNormalization())
model.add(MaxPooling2D((2, 2)))
model.add(Dropout(0.25))
```

```
model.add(Conv2D(128, kernel_size=(3, 3), activation='relu'))
model.add(BatchNormalization())
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.25))

model.add(Conv2D(64, kernel_size=(3, 3), activation='relu'))
model.add(BatchNormalization())
model.add(Dropout(0.25))

model.add(Flatten())

model.add(Dense(64, activation='relu'))
model.add(BatchNormalization())
model.add(Dropout(0.5))

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

print(model.summary())

model.compile(loss=keras.losses.categorical_crossentropy, optimizer=keras.optimizers.Ac
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_1 (Conv2D)            (None, 254, 254, 256)     7168
_________________________________________________________________
batch_normalization_1 (Batch (None, 254, 254, 256)     1024
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 127, 127, 256)     0
_________________________________________________________________
dropout_1 (Dropout)          (None, 127, 127, 256)     0
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 125, 125, 128)     295040
_________________________________________________________________
batch_normalization_2 (Batch (None, 125, 125, 128)     512
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 62, 62, 128)       0
_________________________________________________________________
dropout_2 (Dropout)          (None, 62, 62, 128)       0
_________________________________________________________________
conv2d_3 (Conv2D)            (None, 60, 60, 64)        73792
_________________________________________________________________
batch_normalization_3 (Batch (None, 60, 60, 64)        256
_________________________________________________________________
dropout_3 (Dropout)          (None, 60, 60, 64)        0
_________________________________________________________________
flatten_1 (Flatten)          (None, 230400)            0
```

```
_________________________________________________________________
dense_1 (Dense)              (None, 64)                14745664
_________________________________________________________________
batch_normalization_4 (Batch (None, 64)                256
_________________________________________________________________
dropout_4 (Dropout)          (None, 64)                0
_________________________________________________________________
dense_2 (Dense)              (None, 4)                 260
=================================================================
Total params: 15,123,972
Trainable params: 15,122,948
Non-trainable params: 1,024
_________________________________________________________________
None
```

```
In [4]: filepath="weights_baseline.best.hdf5"
        checkpoint = ModelCheckpoint(filepath, monitor='val_acc', verbose=1, save_best_only=Tru
        callbacks_list = [checkpoint]
```

```
In [5]: train_datagen = ImageDataGenerator(validation_split=0.2) # set validation split

        train_generator = train_datagen.flow_from_directory('OCT2017/train',target_size=(image_
                                                            batch_size=batch_size,
                                                            class_mode='categorical',
                                                            subset='training') # set as traini

        validation_generator = train_datagen.flow_from_directory('OCT2017/train',target_size=(i
                                                                 batch_size=batch_size,
                                                                 class_mode='categorical',
                                                                 subset='validation') # set as


        test_datagen = ImageDataGenerator()

        test_generator = test_datagen.flow_from_directory("OCT2017/test",target_size=(image_siz
                                                          batch_size=batch_size,
                                                          class_mode='categorical')
```

```
Found 66788 images belonging to 4 classes.
Found 16696 images belonging to 4 classes.
Found 1000 images belonging to 4 classes.
```

```
In [6]: # Train the network
        history = model.fit_generator(train_generator,
                                      steps_per_epoch = train_generator.samples // batch_size,
                                      validation_data = validation_generator,
                                      validation_steps = validation_generator.samples // batch_
```

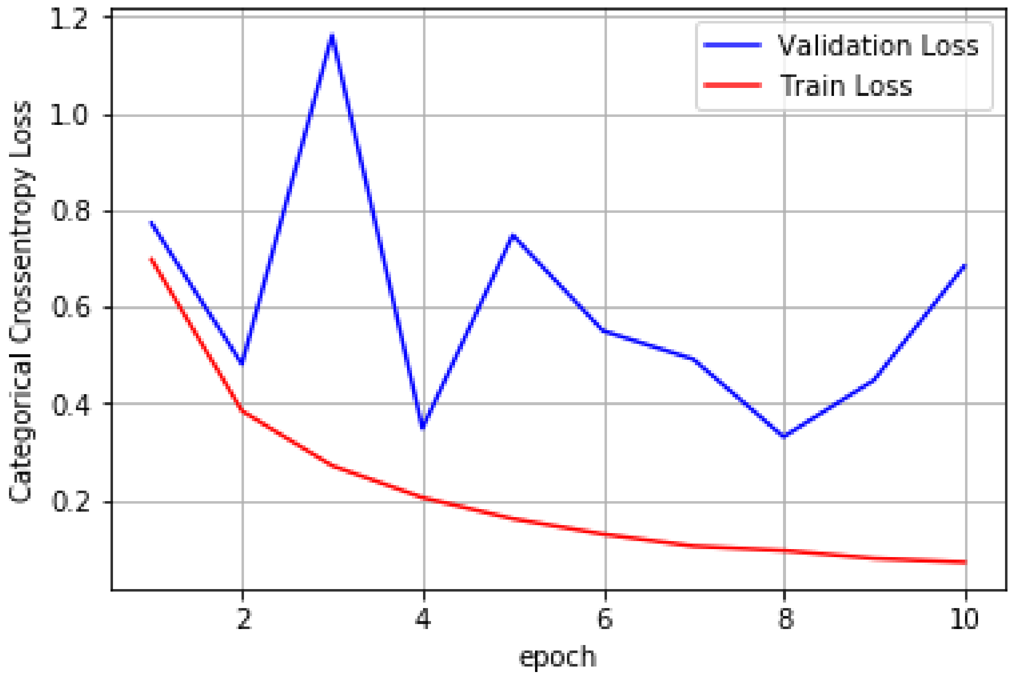
```
                                    epochs = epochs,
                                    callbacks=callbacks_list)
```

```
Epoch 1/10
2087/2087 [==============================] - 2770s 1s/step - loss: 0.6977 - acc: 0.7462 - val_l

Epoch 00001: val_acc improved from -inf to 0.71557, saving model to weights_baseline.best.hdf5
Epoch 2/10
2087/2087 [==============================] - 655s 314ms/step - loss: 0.3858 - acc: 0.8623 - val

Epoch 00002: val_acc improved from 0.71557 to 0.82615, saving model to weights_baseline.best.hd
Epoch 3/10
2087/2087 [==============================] - 654s 313ms/step - loss: 0.2716 - acc: 0.9067 - val

Epoch 00003: val_acc did not improve from 0.82615
Epoch 4/10
2087/2087 [==============================] - 655s 314ms/step - loss: 0.2056 - acc: 0.9298 - val

Epoch 00004: val_acc improved from 0.82615 to 0.87494, saving model to weights_baseline.best.hd
Epoch 5/10
2087/2087 [==============================] - 658s 315ms/step - loss: 0.1618 - acc: 0.9439 - val

Epoch 00005: val_acc did not improve from 0.87494
Epoch 6/10
2087/2087 [==============================] - 655s 314ms/step - loss: 0.1303 - acc: 0.9553 - val

Epoch 00006: val_acc did not improve from 0.87494
Epoch 7/10
2087/2087 [==============================] - 655s 314ms/step - loss: 0.1052 - acc: 0.9638 - val

Epoch 00007: val_acc improved from 0.87494 to 0.88832, saving model to weights_baseline.best.hd
Epoch 8/10
2087/2087 [==============================] - 654s 314ms/step - loss: 0.0961 - acc: 0.9678 - val

Epoch 00008: val_acc improved from 0.88832 to 0.91053, saving model to weights_baseline.best.hd
Epoch 9/10
2087/2087 [==============================] - 659s 316ms/step - loss: 0.0799 - acc: 0.9733 - val

Epoch 00009: val_acc did not improve from 0.91053
Epoch 10/10
2087/2087 [==============================] - 655s 314ms/step - loss: 0.0720 - acc: 0.9761 - val

Epoch 00010: val_acc did not improve from 0.91053
```

In [7]:
```
# serialize model to JSON
model_json = model.to_json()
with open("model_baseline.json", "w") as json_file:
    json_file.write(model_json)
```

In [12]:
```
score = model.evaluate_generator(test_generator,steps = test_generator.samples // batc
print("\n\n")
print('Test Loss:', score[0])
print('Test accuracy:', score[1])

# 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()

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 Loss: 0.6890423384087145
Test accuracy: 0.8543388429752066
```




```
In [3]: def load_test_data(folder):
            """
            Function to load the images and labels.
            """
            Image = []
            Label = []

            for folder_name in os.listdir(folder):
                # Reading the labels.
                if not folder_name.startswith('.'):
                    if folder_name in ['CNV']:
                        label = 0
                    elif folder_name in ['DME']:
                        label = 1
                    elif folder_name in ['DRUSEN']:
                        label = 2
                    elif folder_name in ['NORMAL']:
                        label = 3
                    else:
                        label = 4
                    for image_file_name in tqdm(os.listdir(folder + folder_name)):
                        # Reading the images.
                        image_file = cv2.imread(folder + folder_name + '/' + image_file_name)
                        if image_file is not None:
```

```
                    # Converting images into array.
                    image_file = skimage.transform.resize(image_file, (image_size, imag
                    image_array = np.asarray(image_file)
                    Image.append(image_array)
                    Label.append(label)
            Image = np.asarray(Image)
            Label = np.asarray(Label)
            return Image,Label
        #Reference: https://stackoverflow.com/questions/49220111/read-own-multiple-images-from
        #Reference: https://stackoverflow.com/questions/30230592/loading-all-images-using-imre
```

```
In [4]: # Load the Test labels.
        X_test,Y_test= load_test_data("OCT2017/test/")
```

```
100%|| 250/250 [00:04<00:00, 56.78it/s]
100%|| 250/250 [00:04<00:00, 59.67it/s]
100%|| 250/250 [00:04<00:00, 55.48it/s]
100%|| 250/250 [00:03<00:00, 65.00it/s]
```

```
In [5]: from keras.models import load_model
        model = load_model('weights_baseline.best.hdf5')
```

```
In [6]: pred_datagen = ImageDataGenerator()

        pred_generator = pred_datagen.flow_from_directory("OCT2017/test",target_size=(image_siz
                                                          batch_size=1,
                                                          class_mode='categorical',
                                                          shuffle = False)
```

```
Found 1000 images belonging to 4 classes.
```

```
In [7]: pred_generator.reset()
        y_pred = model.predict_generator(pred_generator,steps = 1000)
        Y_test = pred_generator.classes[pred_generator.index_array]
        Y_pred = np.argmax(y_pred, axis=-1)
```

```
In [8]: Y_pred = np.argmax(y_pred,axis = 1)
```

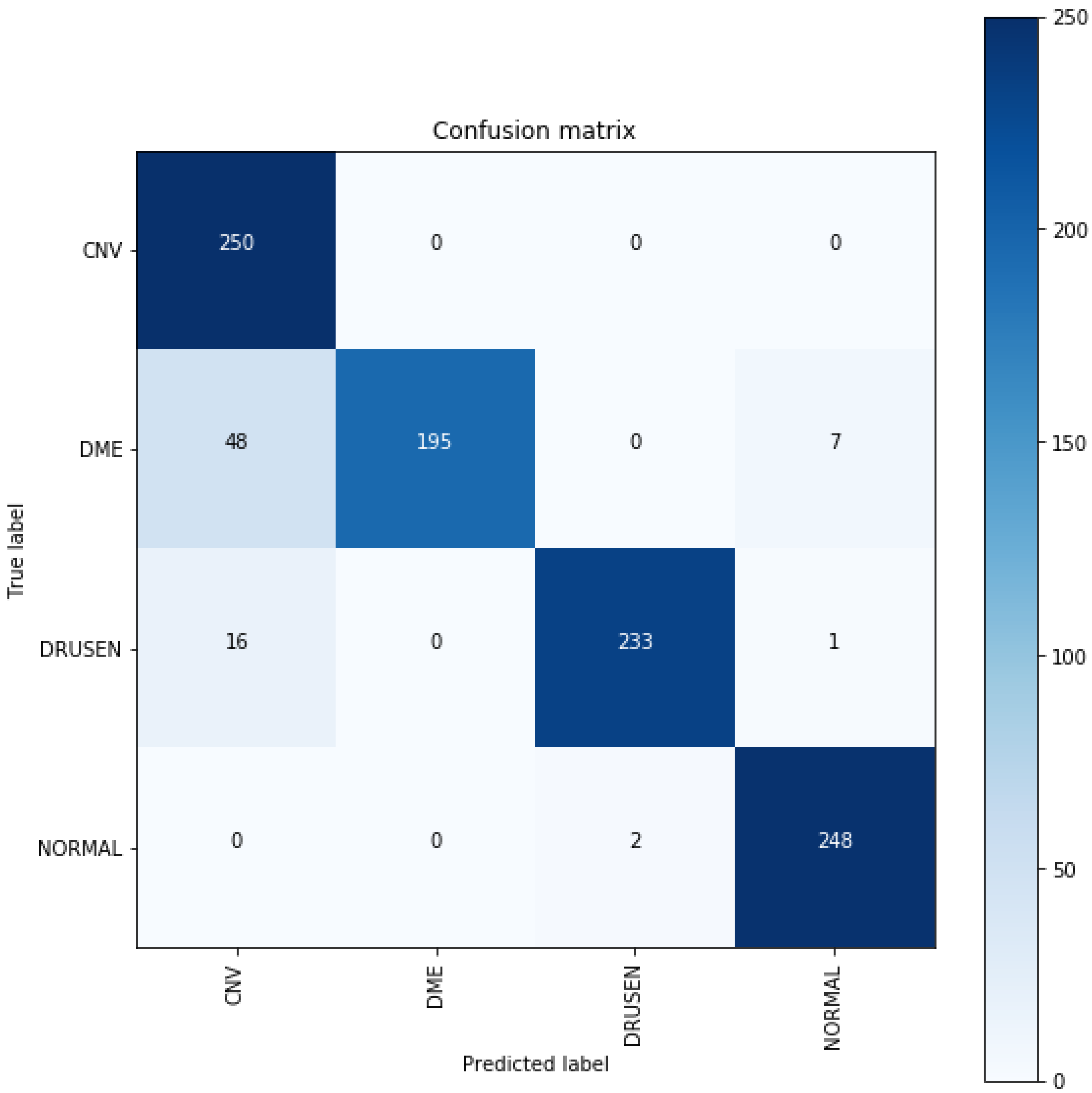
```
In [9]: import pickle
        with open('y_pred_baseline_model.pkl','wb') as f:
            pickle.dump(y_pred, f)
```

```
In [10]: def plot_confusion_matrix(cm, classes,
                                   normalize=False,
                                   title='Confusion matrix',
                                   cmap=plt.cm.Blues):
             if normalize:
```

```
            cm = cm.astype('float') / cm.sum(axis=1)[:, np.newaxis]

        plt.imshow(cm, interpolation='nearest', cmap=cmap)
        plt.title(title)
        plt.colorbar()
        tick_marks = np.arange(len(classes))
        plt.xticks(tick_marks, classes, rotation=90)
        plt.yticks(tick_marks, classes)

        fmt = '.2f' if normalize else 'd'
        thresh = cm.max() / 2.
        for i, j in itertools.product(range(cm.shape[0]), range(cm.shape[1])):
            plt.text(j, i, format(cm[i, j], fmt),
                     horizontalalignment="center",
                     color="white" if cm[i, j] > thresh else "black")

        plt.tight_layout()
        plt.ylabel('True label')
        plt.xlabel('Predicted label')
```

```
In [11]: # confusion matrix
         cm = confusion_matrix(Y_test, Y_pred)

         print('--------------------')
         print('| Confusion Matrix |')
         print('--------------------')
         print('\n {}'.format(cm))

         # plot confusin matrix
         plt.figure(figsize=(8,8))
         plt.grid(b=False)
         plot_confusion_matrix(cm, classes=['CNV','DME','DRUSEN','NORMAL'], normalize=False,
                               title='Confusion matrix', cmap = plt.cm.Blues)
         plt.show()
```

```
--------------------
| Confusion Matrix |
--------------------

 [[250   0   0   0]
 [ 48 195   0   7]
 [ 16   0 233   1]
 [  0   0   2 248]]
```




```
In [13]: from sklearn.metrics import classification_report
         print(classification_report(Y_test,Y_pred,target_names=['CNV','DME','DRUSEN','Normal']
```

```
              precision    recall  f1-score   support

         CNV       0.80      1.00      0.89       250
         DME       1.00      0.78      0.88       250
      DRUSEN       0.99      0.93      0.96       250
      Normal       0.97      0.99      0.98       250

   micro avg       0.93      0.93      0.93      1000
   macro avg       0.94      0.93      0.93      1000
weighted avg       0.94      0.93      0.93      1000
```

### 2.1.1 Observations:

1. We have 3 hidden layers in this CNN model.
2. **Test Loss: 0.689**
3. **Test accuracy: 0.854**
4. **precision = 0.94 | | recall = 0.93 | | f1-score = 0.93**
5. Dataset imbalance causes low Train & Test accuracy:

## 2.2 CNN Model with 3 Hidden Layers & Class_weights balancing.

```
In [2]: # Model parameters
        image_size = 256
        batch_size = 32
        num_classes = 4
        epochs = 10
```

```
In [3]: # Baseline Model.
        model = Sequential()
        model.add(Conv2D(256, kernel_size=(3, 3), activation='relu', input_shape=(image_size, i
        model.add(BatchNormalization())
        model.add(MaxPooling2D((2, 2)))
        model.add(Dropout(0.25))

        model.add(Conv2D(128, kernel_size=(3, 3), activation='relu'))
        model.add(BatchNormalization())
        model.add(MaxPooling2D(pool_size=(2, 2)))
        model.add(Dropout(0.25))

        model.add(Conv2D(64, kernel_size=(3, 3), activation='relu'))
        model.add(BatchNormalization())
        model.add(Dropout(0.25))

        model.add(Flatten())

        model.add(Dense(64, activation='relu'))
        model.add(BatchNormalization())
        model.add(Dropout(0.5))

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

        print(model.summary())

        model.compile(loss=keras.losses.categorical_crossentropy, optimizer=keras.optimizers.Ad
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
```

```
=================================================================
conv2d_1 (Conv2D)            (None, 254, 254, 256)     7168
_________________________________________________________________
batch_normalization_1 (Batch (None, 254, 254, 256)     1024
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 127, 127, 256)     0
_________________________________________________________________
dropout_1 (Dropout)          (None, 127, 127, 256)     0
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 125, 125, 128)     295040
_________________________________________________________________
batch_normalization_2 (Batch (None, 125, 125, 128)     512
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 62, 62, 128)       0
_________________________________________________________________
dropout_2 (Dropout)          (None, 62, 62, 128)       0
_________________________________________________________________
conv2d_3 (Conv2D)            (None, 60, 60, 64)        73792
_________________________________________________________________
batch_normalization_3 (Batch (None, 60, 60, 64)        256
_________________________________________________________________
dropout_3 (Dropout)          (None, 60, 60, 64)        0
_________________________________________________________________
flatten_1 (Flatten)          (None, 230400)            0
_________________________________________________________________
dense_1 (Dense)              (None, 64)                14745664
_________________________________________________________________
batch_normalization_4 (Batch (None, 64)                256
_________________________________________________________________
dropout_4 (Dropout)          (None, 64)                0
_________________________________________________________________
dense_2 (Dense)              (None, 4)                 260
=================================================================
Total params: 15,123,972
Trainable params: 15,122,948
Non-trainable params: 1,024
_________________________________________________________________
None
```

```
In [5]: train_datagen = ImageDataGenerator(validation_split=0.2) # set validation split

        train_generator = train_datagen.flow_from_directory('OCT2017/train',target_size=(image_
                                                            batch_size=batch_size,
                                                            class_mode='categorical',
                                                            subset='training') # set as traini

        validation_generator = train_datagen.flow_from_directory('OCT2017/train',target_size=(i
```

```
                                                                    batch_size=batch_size,
                                                                    class_mode='categorical',
                                                                    subset='validation') # set as


        test_datagen = ImageDataGenerator()

        test_generator = test_datagen.flow_from_directory("OCT2017/test",target_size=(image_si
                                                          batch_size=batch_size,
                                                          class_mode='categorical')
```

```
Found 66788 images belonging to 4 classes.
Found 16696 images belonging to 4 classes.
Found 1000 images belonging to 4 classes.
```

In [6]:
```
# https://stackoverflow.com/questions/41815354/keras-flow-from-directory-over-or-under
class_weights = class_weight.compute_class_weight('balanced',
                                                  np.unique(train_generator.classes),
                                                  train_generator.classes)
```

In [7]:
```
filepath="weights_balanced_cnn_best.hdf5"
checkpoint = ModelCheckpoint(filepath, monitor='val_acc', verbose=1, save_best_only=Tr
callbacks_list = [checkpoint]
```

In [8]:
```
# Train the network
history = model.fit_generator(train_generator,
                              steps_per_epoch = train_generator.samples // batch_size,
                              validation_data = validation_generator,
                              validation_steps = validation_generator.samples // batch
                              epochs = epochs,
                              callbacks=callbacks_list,
                              class_weight=class_weights)
```

```
Epoch 1/10
2087/2087 [==============================] - 662s 317ms/step - loss: 0.7140 - acc: 0.7462 - va

Epoch 00001: val_acc improved from -inf to 0.81520, saving model to weights_balanced_cnn_best.
Epoch 2/10
2087/2087 [==============================] - 656s 314ms/step - loss: 0.4119 - acc: 0.8531 - va

Epoch 00002: val_acc did not improve from 0.81520
Epoch 3/10
2087/2087 [==============================] - 655s 314ms/step - loss: 0.2796 - acc: 0.9035 - va

Epoch 00003: val_acc improved from 0.81520 to 0.88058, saving model to weights_balanced_cnn_be
Epoch 4/10
2087/2087 [==============================] - 654s 314ms/step - loss: 0.2185 - acc: 0.9247 - va
```

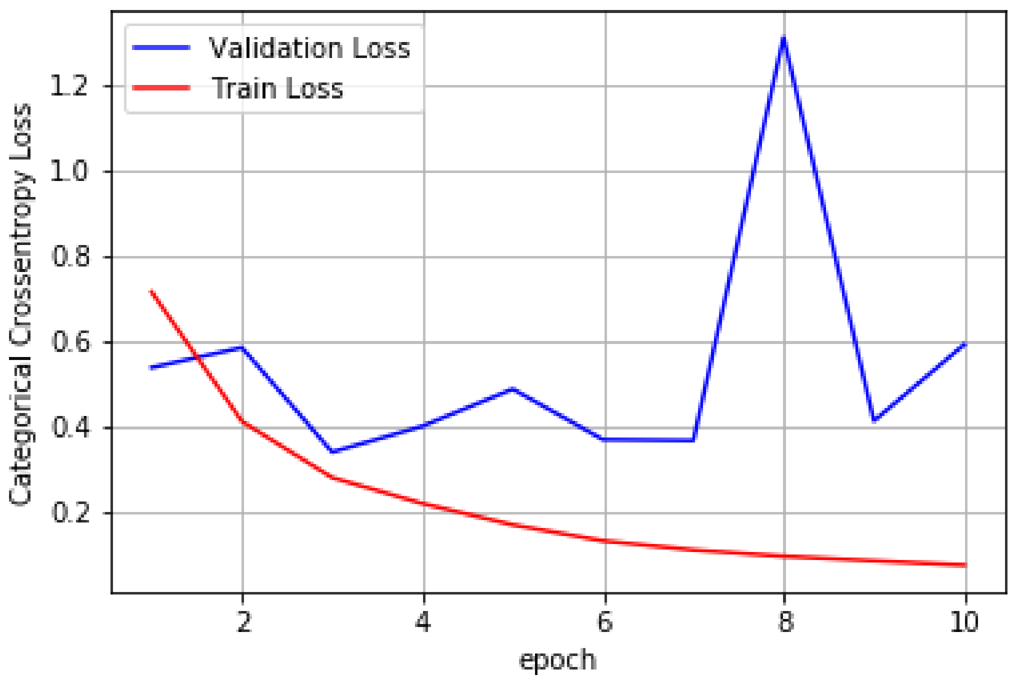
```
Epoch 00004: val_acc did not improve from 0.88058
Epoch 5/10
2087/2087 [==============================] - 656s 314ms/step - loss: 0.1701 - acc: 0.9413 - val

Epoch 00005: val_acc did not improve from 0.88058
Epoch 6/10
2087/2087 [==============================] - 655s 314ms/step - loss: 0.1310 - acc: 0.9554 - val

Epoch 00006: val_acc improved from 0.88058 to 0.88598, saving model to weights_balanced_cnn_bes
Epoch 7/10
2087/2087 [==============================] - 654s 314ms/step - loss: 0.1097 - acc: 0.9617 - val

Epoch 00007: val_acc improved from 0.88598 to 0.89222, saving model to weights_balanced_cnn_bes
Epoch 8/10
2087/2087 [==============================] - 656s 314ms/step - loss: 0.0949 - acc: 0.9674 - val

Epoch 00008: val_acc did not improve from 0.89222
Epoch 9/10
2087/2087 [==============================] - 656s 314ms/step - loss: 0.0843 - acc: 0.9719 - val

Epoch 00009: val_acc improved from 0.89222 to 0.89450, saving model to weights_balanced_cnn_bes
Epoch 10/10
2087/2087 [==============================] - 656s 314ms/step - loss: 0.0743 - acc: 0.9743 - val

Epoch 00010: val_acc did not improve from 0.89450
```

```
In [9]: # serialize model to JSON
        model_json = model.to_json()
        with open("model_balanced_cnn.json", "w") as json_file:
            json_file.write(model_json)
```

```
In [10]: score = model.evaluate_generator(test_generator,steps = test_generator.samples // batc
         print("\n\n")
         print('Test Loss:', score[0])
         print('Test accuracy:', score[1])

         # 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()

         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 Loss: 0.23170399683858117
Test accuracy: 0.9405241935483871
```

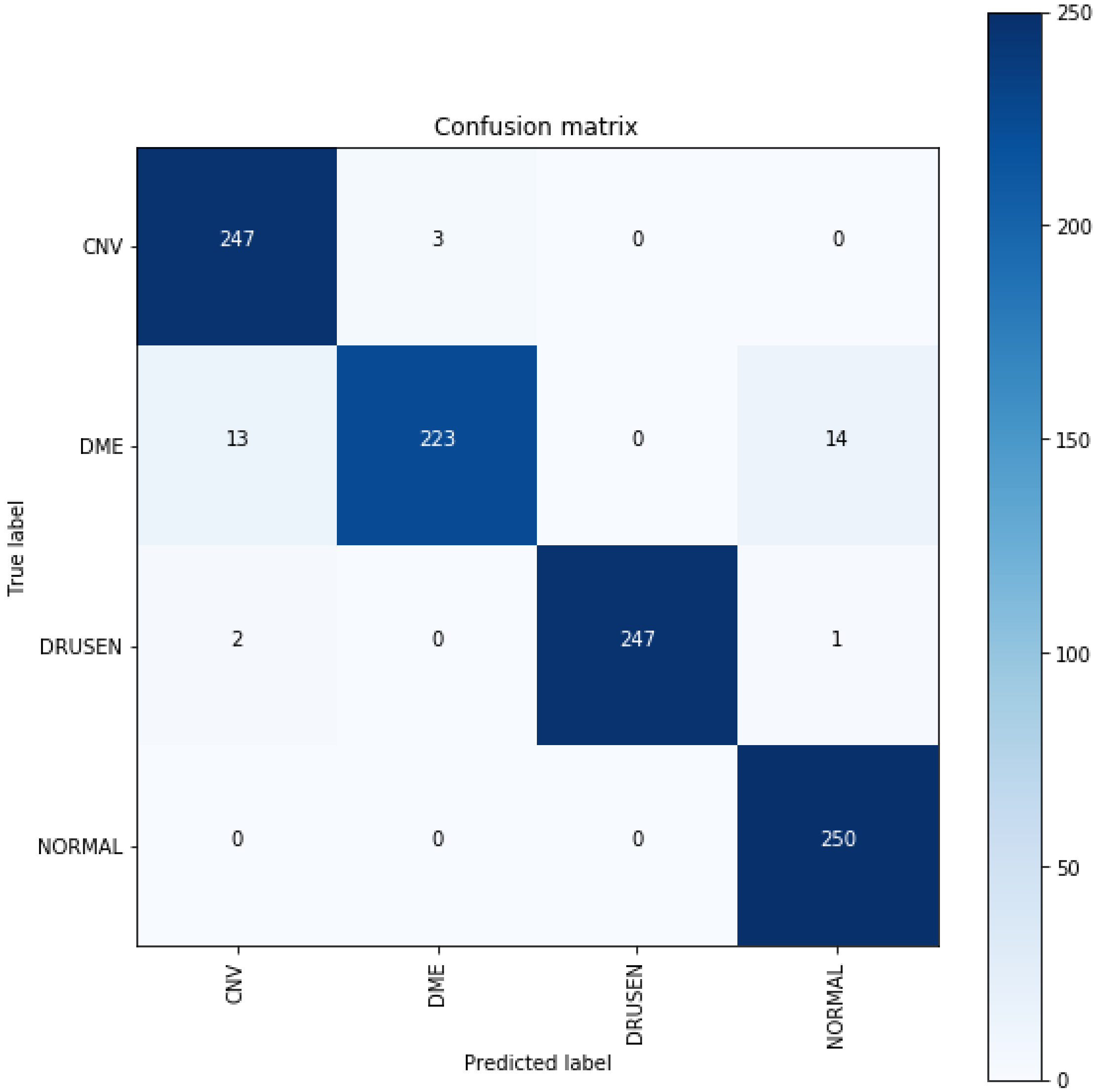



```
In [28]: from keras.models import load_model
         model = load_model('weights_balanced_cnn_best.hdf5')

In [29]: pred_datagen = ImageDataGenerator()

         pred_generator = pred_datagen.flow_from_directory("OCT2017/test",target_size=(image_s
                                                           batch_size=1,
                                                           class_mode='categorical',
                                                           shuffle = False)
```

```
Found 1000 images belonging to 4 classes.
```

```
In [30]: pred_generator.reset()
         y_pred = model.predict_generator(pred_generator,steps = 1000)
         Y_test = pred_generator.classes[pred_generator.index_array]
         Y_pred = np.argmax(y_pred, axis=-1)

In [31]: Y_pred = np.argmax(y_pred,axis = 1)

In [32]: import pickle
         with open('y_pred_balanced_cnn_best.pkl','wb') as f:
             pickle.dump(y_pred, f)

In [33]: # confusion matrix
         cm = confusion_matrix(Y_test, Y_pred)

         print('--------------------')
         print('| Confusion Matrix |')
         print('--------------------')
         print('\n {}'.format(cm))

         # plot confusin matrix
         plt.figure(figsize=(8,8))
         plt.grid(b=False)
         plot_confusion_matrix(cm, classes=['CNV','DME','DRUSEN','NORMAL'], normalize=False,
                               title='Confusion matrix', cmap = plt.cm.Blues)
         plt.show()
```

```
--------------------
| Confusion Matrix |
--------------------

 [[247   3   0   0]
 [ 13 223   0  14]
 [  2   0 247   1]
 [  0   0   0 250]]
```




```
In [34]: from sklearn.metrics import classification_report
         print(classification_report(Y_test,Y_pred,target_names=['CNV','DME','DRUSEN','Normal']

              precision    recall  f1-score   support

         CNV       0.94      0.99      0.96       250
         DME       0.99      0.89      0.94       250
      DRUSEN       1.00      0.99      0.99       250
      Normal       0.94      1.00      0.97       250

   micro avg       0.97      0.97      0.97      1000
   macro avg       0.97      0.97      0.97      1000
weighted avg       0.97      0.97      0.97      1000
```

### 2.2.1 Observations:

1. We have 3 hidden layers in this CNN model.
2. **Test Loss: 0.231**
3. **Test accuracy: 0.94**
4. **precision = 0.97 || recall = 0.97 || f1-score = 0.97**
5. **Class weights balancing has dtastically improved Test Loss & Test accuracy**

## 2.3 CNN Model with 5 Hidden Layers.

In [15]:
```
# Model parameters
image_size = 256
batch_size = 32
num_classes = 4
epochs = 10
```

In [16]:
```
# Baseline Model.
model = Sequential()
model.add(Conv2D(256, kernel_size=(3, 3), activation='relu', input_shape=(image_size,
model.add(BatchNormalization())
model.add(MaxPooling2D((2, 2)))
model.add(Dropout(0.4))

model.add(Conv2D(256, kernel_size=(3, 3), activation='relu'))
model.add(BatchNormalization())
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.4))

model.add(Conv2D(128, kernel_size=(3, 3), activation='relu'))
model.add(BatchNormalization())
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.4))

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

model.add(Conv2D(32, kernel_size=(3, 3), activation='relu'))
model.add(BatchNormalization())
model.add(Dropout(0.5))

model.add(Flatten())

model.add(Dense(32, activation='relu'))
model.add(BatchNormalization())
```

```
model.add(Dropout(0.5))

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

print(model.summary())

model.compile(loss=keras.losses.categorical_crossentropy, optimizer=keras.optimizers.A
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_11 (Conv2D)           (None, 254, 254, 256)     7168
_________________________________________________________________
batch_normalization_13 (Batc (None, 254, 254, 256)     1024
_________________________________________________________________
max_pooling2d_7 (MaxPooling2 (None, 127, 127, 256)     0
_________________________________________________________________
dropout_13 (Dropout)         (None, 127, 127, 256)     0
_________________________________________________________________
conv2d_12 (Conv2D)           (None, 125, 125, 256)     590080
_________________________________________________________________
batch_normalization_14 (Batc (None, 125, 125, 256)     1024
_________________________________________________________________
max_pooling2d_8 (MaxPooling2 (None, 62, 62, 256)       0
_________________________________________________________________
dropout_14 (Dropout)         (None, 62, 62, 256)       0
_________________________________________________________________
conv2d_13 (Conv2D)           (None, 60, 60, 128)       295040
_________________________________________________________________
batch_normalization_15 (Batc (None, 60, 60, 128)       512
_________________________________________________________________
max_pooling2d_9 (MaxPooling2 (None, 30, 30, 128)       0
_________________________________________________________________
dropout_15 (Dropout)         (None, 30, 30, 128)       0
_________________________________________________________________
conv2d_14 (Conv2D)           (None, 28, 28, 64)        73792
_________________________________________________________________
batch_normalization_16 (Batc (None, 28, 28, 64)        256
_________________________________________________________________
dropout_16 (Dropout)         (None, 28, 28, 64)        0
_________________________________________________________________
conv2d_15 (Conv2D)           (None, 26, 26, 32)        18464
_________________________________________________________________
batch_normalization_17 (Batc (None, 26, 26, 32)        128
_________________________________________________________________
dropout_17 (Dropout)         (None, 26, 26, 32)        0
_________________________________________________________________
flatten_3 (Flatten)          (None, 21632)             0
```

```
_________________________________________________________________
dense_5 (Dense)              (None, 32)                692256
_________________________________________________________________
batch_normalization_18 (Batc (None, 32)                128
_________________________________________________________________
dropout_18 (Dropout)         (None, 32)                0
_________________________________________________________________
dense_6 (Dense)              (None, 4)                 132
=================================================================
Total params: 1,680,004
Trainable params: 1,678,468
Non-trainable params: 1,536
_________________________________________________________________
None
```

In [17]:
```
train_datagen = ImageDataGenerator(validation_split=0.2) # set validation split

train_generator = train_datagen.flow_from_directory('OCT2017/train',target_size=(image
                                                    batch_size=batch_size,
                                                    class_mode='categorical',
                                                    subset='training') # set as train

validation_generator = train_datagen.flow_from_directory('OCT2017/train',target_size=
                                                         batch_size=batch_size,
                                                         class_mode='categorical',
                                                         subset='validation') # set a


test_datagen = ImageDataGenerator()

test_generator = test_datagen.flow_from_directory("OCT2017/test",target_size=(image_si
                                                  batch_size=batch_size,
                                                  class_mode='categorical')
```

```
Found 66788 images belonging to 4 classes.
Found 16696 images belonging to 4 classes.
Found 1000 images belonging to 4 classes.
```

In [18]:
```
# https://stackoverflow.com/questions/41815354/keras-flow-from-directory-over-or-unde
class_weights = class_weight.compute_class_weight('balanced',
                                                  np.unique(train_generator.classes),
                                                  train_generator.classes)
```

In [19]:
```
filepath="weights_balanced_cnn_5layered_best.hdf5"
checkpoint = ModelCheckpoint(filepath, monitor='val_acc', verbose=1, save_best_only=T
callbacks_list = [checkpoint]
```

```
In [20]: # Train the network
         history = model.fit_generator(train_generator,
                                       steps_per_epoch = train_generator.samples // batch_size
                                       validation_data = validation_generator,
                                       validation_steps = validation_generator.samples // batcl
                                       epochs = epochs,
                                       callbacks=callbacks_list,
                                       class_weight=class_weights)
```

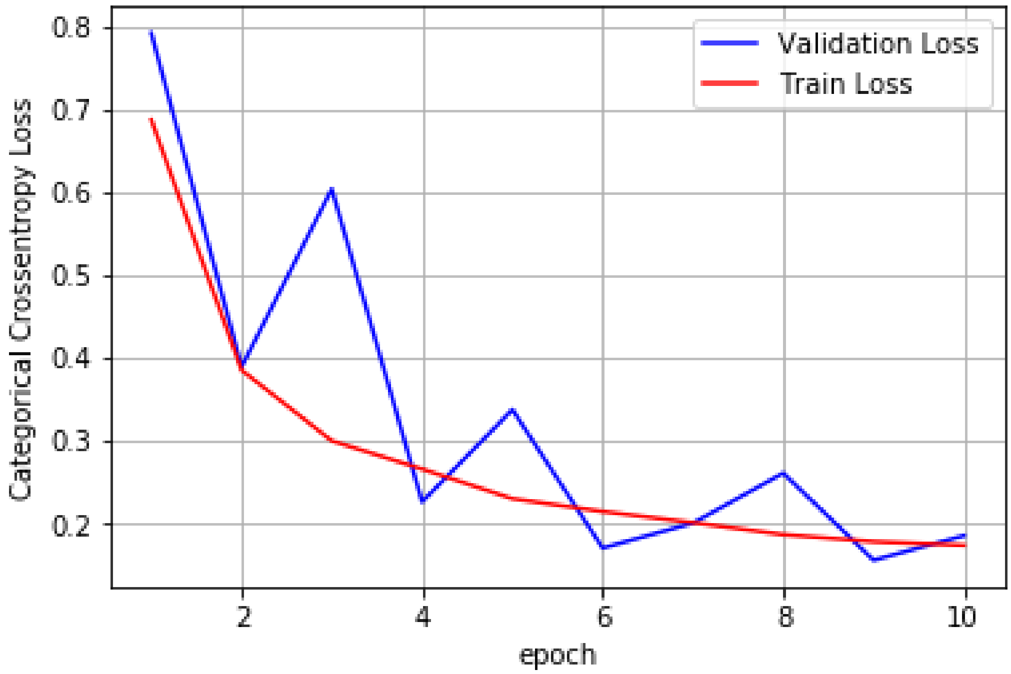
```
Epoch 1/10
2087/2087 [==============================] - 792s 379ms/step - loss: 0.6870 - acc: 0.7516 - val

Epoch 00001: val_acc improved from -inf to 0.65349, saving model to weights_balanced_cnn_5laye
Epoch 2/10
2087/2087 [==============================] - 792s 380ms/step - loss: 0.3850 - acc: 0.8665 - val

Epoch 00002: val_acc improved from 0.65349 to 0.87128, saving model to weights_balanced_cnn_5la
Epoch 3/10
2087/2087 [==============================] - 788s 378ms/step - loss: 0.3001 - acc: 0.9015 - val

Epoch 00003: val_acc did not improve from 0.87128
Epoch 4/10
2087/2087 [==============================] - 788s 378ms/step - loss: 0.2667 - acc: 0.9131 - val

Epoch 00004: val_acc improved from 0.87128 to 0.92469, saving model to weights_balanced_cnn_5la
Epoch 5/10
2087/2087 [==============================] - 789s 378ms/step - loss: 0.2301 - acc: 0.9257 - val

Epoch 00005: val_acc did not improve from 0.92469
Epoch 6/10
2087/2087 [==============================] - 788s 378ms/step - loss: 0.2154 - acc: 0.9308 - val

Epoch 00006: val_acc improved from 0.92469 to 0.94395, saving model to weights_balanced_cnn_5la
Epoch 7/10
2087/2087 [==============================] - 792s 379ms/step - loss: 0.2022 - acc: 0.9352 - val

Epoch 00007: val_acc did not improve from 0.94395
Epoch 8/10
2087/2087 [==============================] - 789s 378ms/step - loss: 0.1868 - acc: 0.9405 - val

Epoch 00008: val_acc did not improve from 0.94395
Epoch 9/10
2087/2087 [==============================] - 788s 378ms/step - loss: 0.1786 - acc: 0.9427 - val

Epoch 00009: val_acc improved from 0.94395 to 0.94869, saving model to weights_balanced_cnn_5la
Epoch 10/10
2087/2087 [==============================] - 788s 378ms/step - loss: 0.1752 - acc: 0.9433 - val
```

```
Epoch 00010: val_acc did not improve from 0.94869
```

```
In [21]: # serialize model to JSON
         model_json = model.to_json()
         with open("model_balanced_cnn5layered.json", "w") as json_file:
             json_file.write(model_json)
```

```
In [22]: score = model.evaluate_generator(test_generator,steps = test_generator.samples // batc
         print("\n\n")
         print('Test Loss:', score[0])
         print('Test accuracy:', score[1])

         # 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()

         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)
```

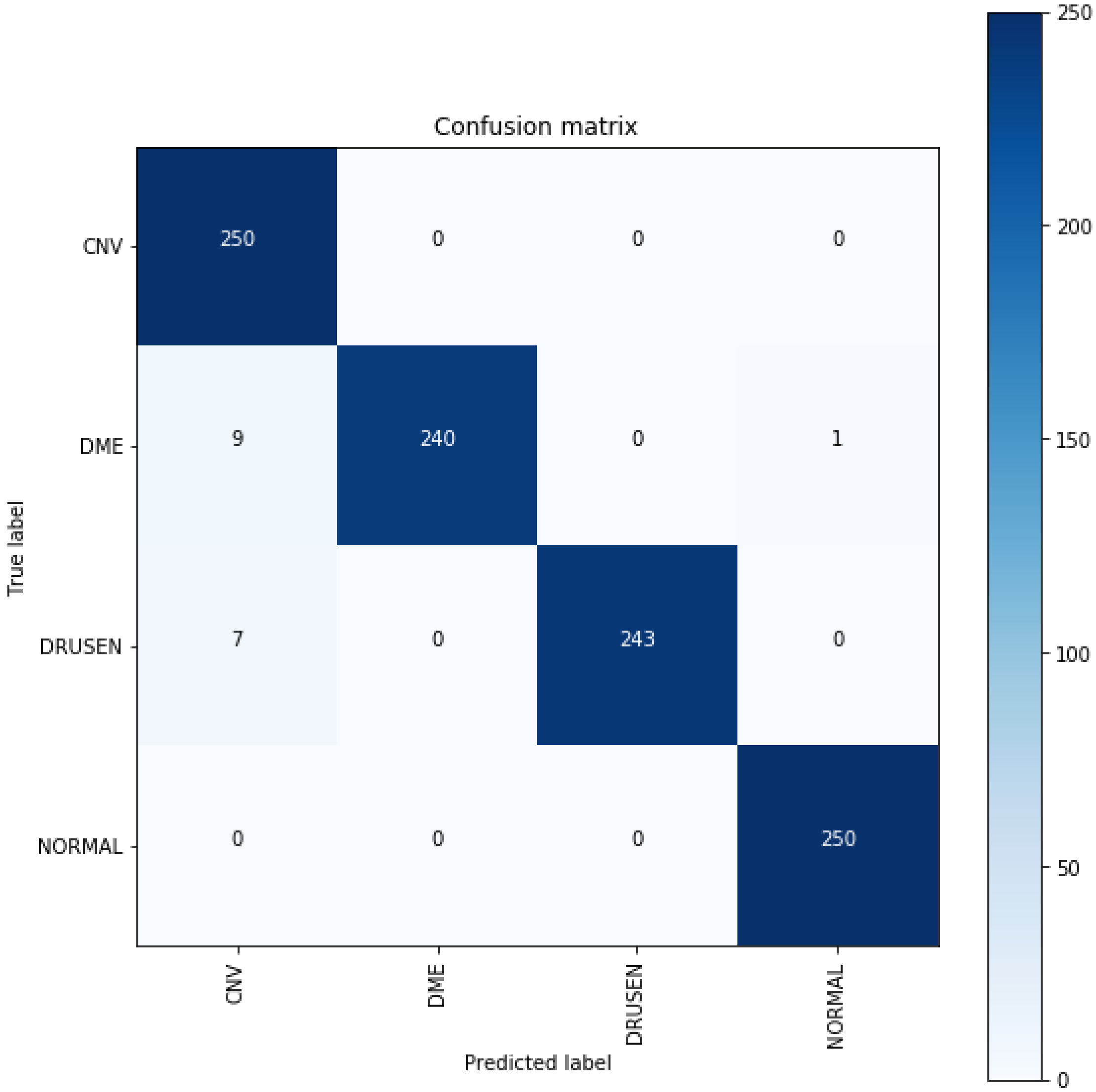
```
Test Loss: 0.04069264918085067
Test accuracy: 0.9899193548387096
```




```
In [35]: from keras.models import load_model
         model = load_model('weights_balanced_cnn_5layered_best.hdf5')

In [36]: pred_datagen = ImageDataGenerator()

         pred_generator = pred_datagen.flow_from_directory("OCT2017/test",target_size=(image_si
                                                           batch_size=1,
                                                           class_mode='categorical',
                                                           shuffle = False)

Found 1000 images belonging to 4 classes.


In [37]: pred_generator.reset()
         y_pred = model.predict_generator(pred_generator,steps = 1000)
         Y_test = pred_generator.classes[pred_generator.index_array]
         Y_pred = np.argmax(y_pred, axis=-1)

In [38]: import pickle
         with open('y_pred_balanced_cnn_5layered_best.pkl','wb') as f:
             pickle.dump(y_pred, f)

In [39]: # confusion matrix
         cm = confusion_matrix(Y_test, Y_pred)
```

```
    print('--------------------')
    print('| Confusion Matrix |')
    print('--------------------')
    print('\n {}'.format(cm))

    # plot confusin matrix
    plt.figure(figsize=(8,8))
    plt.grid(b=False)
    plot_confusion_matrix(cm, classes=['CNV','DME','DRUSEN','NORMAL'], normalize=False,
                          title='Confusion matrix', cmap = plt.cm.Blues)
    plt.show()
```

```
--------------------
| Confusion Matrix |
--------------------

 [[250   0   0   0]
 [  9 240   0   1]
 [  7   0 243   0]
 [  0   0   0 250]]
```




```
In [40]: from sklearn.metrics import classification_report
         print(classification_report(Y_test,Y_pred,target_names=['CNV','DME','DRUSEN','Normal']

              precision    recall  f1-score   support

         CNV       0.94      1.00      0.97       250
         DME       1.00      0.96      0.98       250
      DRUSEN       1.00      0.97      0.99       250
      Normal       1.00      1.00      1.00       250

   micro avg       0.98      0.98      0.98      1000
   macro avg       0.98      0.98      0.98      1000
weighted avg       0.98      0.98      0.98      1000
```

### 2.3.1 Observations:

1. We have 5 hidden layers in this CNN model.
2. **Test Loss: 0.040**
3. **Test accuracy: 0.989**
4. **precision = 0.98 || recall = 0.98 || f1-score = 0.98**
5. **CNN model with 5 hidden layers perform brilliantly.**

## 2.4 CNN Model with 7 Hidden Layers.

In [2]:
```
# Model parameters
image_size = 256
batch_size = 32
num_classes = 4
epochs = 10
```

In [3]:
```
# Baseline Model.
model = Sequential()
model.add(Conv2D(256, kernel_size=(3, 3), activation='relu', input_shape=(image_size, i
model.add(BatchNormalization())
model.add(MaxPooling2D((2, 2)))
model.add(Dropout(0.5))

model.add(Conv2D(256, kernel_size=(3, 3), activation='relu'))
model.add(BatchNormalization())
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.5))

model.add(Conv2D(128, kernel_size=(3, 3), activation='relu'))
model.add(BatchNormalization())
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.5))

model.add(Conv2D(64, kernel_size=(3, 3), activation='relu'))
model.add(BatchNormalization())
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.5))

model.add(Conv2D(64, kernel_size=(3, 3), activation='relu'))
model.add(BatchNormalization())
model.add(Dropout(0.5))

model.add(Conv2D(32, kernel_size=(3, 3), activation='relu'))
model.add(BatchNormalization())
model.add(Dropout(0.5))
```

```
model.add(Conv2D(32, kernel_size=(3, 3), activation='relu'))
model.add(BatchNormalization())
model.add(Dropout(0.5))

model.add(Flatten())

model.add(Dense(32, activation='relu'))
model.add(BatchNormalization())
model.add(Dropout(0.5))

model.add(Dense(32, activation='relu'))
model.add(BatchNormalization())
model.add(Dropout(0.5))

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

print(model.summary())

model.compile(loss=keras.losses.categorical_crossentropy, optimizer=keras.optimizers.Ad
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_1 (Conv2D)            (None, 254, 254, 256)     7168
_________________________________________________________________
batch_normalization_1 (Batch (None, 254, 254, 256)     1024
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 127, 127, 256)     0
_________________________________________________________________
dropout_1 (Dropout)          (None, 127, 127, 256)     0
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 125, 125, 256)     590080
_________________________________________________________________
batch_normalization_2 (Batch (None, 125, 125, 256)     1024
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 62, 62, 256)       0
_________________________________________________________________
dropout_2 (Dropout)          (None, 62, 62, 256)       0
_________________________________________________________________
conv2d_3 (Conv2D)            (None, 60, 60, 128)       295040
_________________________________________________________________
batch_normalization_3 (Batch (None, 60, 60, 128)       512
_________________________________________________________________
max_pooling2d_3 (MaxPooling2 (None, 30, 30, 128)       0
_________________________________________________________________
dropout_3 (Dropout)          (None, 30, 30, 128)       0
_________________________________________________________________
```

```
conv2d_4 (Conv2D)            (None, 28, 28, 64)        73792
_________________________________________________________________
batch_normalization_4 (Batch (None, 28, 28, 64)        256
_________________________________________________________________
max_pooling2d_4 (MaxPooling2 (None, 14, 14, 64)        0
_________________________________________________________________
dropout_4 (Dropout)          (None, 14, 14, 64)        0
_________________________________________________________________
conv2d_5 (Conv2D)            (None, 12, 12, 64)        36928
_________________________________________________________________
batch_normalization_5 (Batch (None, 12, 12, 64)        256
_________________________________________________________________
dropout_5 (Dropout)          (None, 12, 12, 64)        0
_________________________________________________________________
conv2d_6 (Conv2D)            (None, 10, 10, 32)        18464
_________________________________________________________________
batch_normalization_6 (Batch (None, 10, 10, 32)        128
_________________________________________________________________
dropout_6 (Dropout)          (None, 10, 10, 32)        0
_________________________________________________________________
conv2d_7 (Conv2D)            (None, 8, 8, 32)          9248
_________________________________________________________________
batch_normalization_7 (Batch (None, 8, 8, 32)          128
_________________________________________________________________
dropout_7 (Dropout)          (None, 8, 8, 32)          0
_________________________________________________________________
flatten_1 (Flatten)          (None, 2048)              0
_________________________________________________________________
dense_1 (Dense)              (None, 32)                65568
_________________________________________________________________
batch_normalization_8 (Batch (None, 32)                128
_________________________________________________________________
dropout_8 (Dropout)          (None, 32)                0
_________________________________________________________________
dense_2 (Dense)              (None, 32)                1056
_________________________________________________________________
batch_normalization_9 (Batch (None, 32)                128
_________________________________________________________________
dropout_9 (Dropout)          (None, 32)                0
_________________________________________________________________
dense_3 (Dense)              (None, 4)                 132
=================================================================
Total params: 1,101,060
Trainable params: 1,099,268
Non-trainable params: 1,792
_________________________________________________________________
None
```

```
In [4]: train_datagen = ImageDataGenerator(validation_split=0.2) # set validation split

        train_generator = train_datagen.flow_from_directory('OCT2017/train',target_size=(image_
                                                            batch_size=batch_size,
                                                            class_mode='categorical',
                                                            subset='training') # set as traini

        validation_generator = train_datagen.flow_from_directory('OCT2017/train',target_size=(i
                                                                 batch_size=batch_size,
                                                                 class_mode='categorical',
                                                                 subset='validation') # set as


        test_datagen = ImageDataGenerator()

        test_generator = test_datagen.flow_from_directory("OCT2017/test",target_size=(image_siz
                                                          batch_size=batch_size,
                                                          class_mode='categorical')
```

```
Found 66788 images belonging to 4 classes.
Found 16696 images belonging to 4 classes.
Found 1000 images belonging to 4 classes.
```

```
In [5]: # https://stackoverflow.com/questions/41815354/keras-flow-from-directory-over-or-under
        class_weights = class_weight.compute_class_weight('balanced',
                                                          np.unique(train_generator.classes),
                                                          train_generator.classes)

In [6]: filepath="weights_balanced_cnn_7layered_best.hdf5"
        checkpoint = ModelCheckpoint(filepath, monitor='val_acc', verbose=1, save_best_only=Tru
        callbacks_list = [checkpoint]

In [7]: # Train the network
        history = model.fit_generator(train_generator,
                                      steps_per_epoch = train_generator.samples // batch_size,
                                      validation_data = validation_generator,
                                      validation_steps = validation_generator.samples // batch_
                                      epochs = epochs,
                                      callbacks=callbacks_list,
                                      class_weight=class_weights)
```

```
Epoch 1/10
2087/2087 [==============================] - 804s 385ms/step - loss: 0.9618 - acc: 0.6413 - va

Epoch 00001: val_acc improved from -inf to 0.77417, saving model to weights_balanced_cnn_7laye
Epoch 2/10
2087/2087 [==============================] - 796s 382ms/step - loss: 0.6232 - acc: 0.7831 - va
```

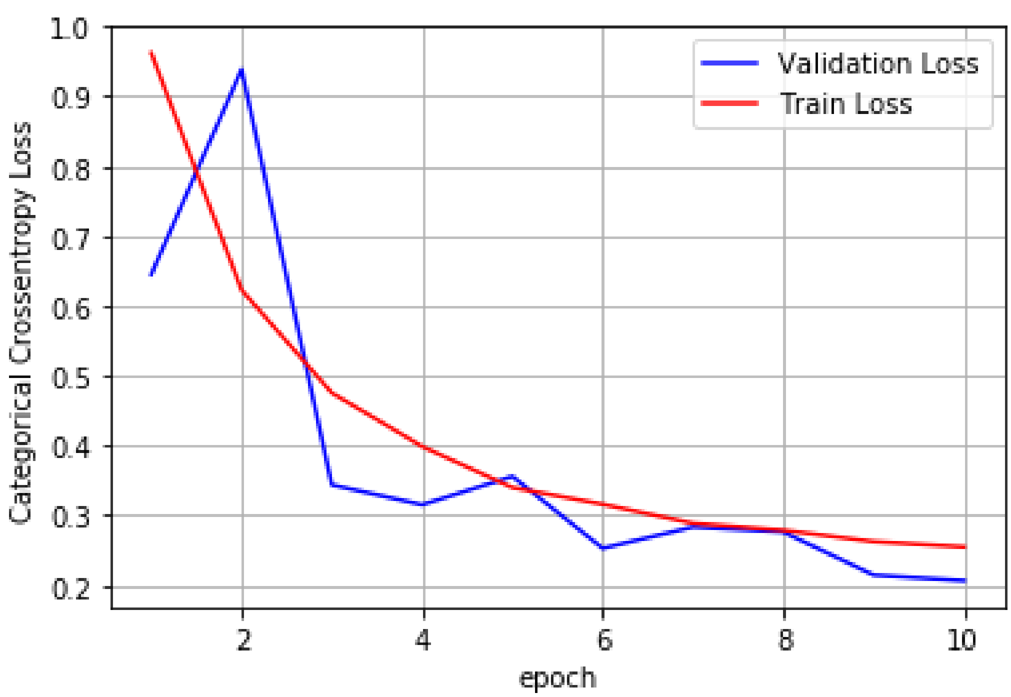
```
Epoch 00002: val_acc did not improve from 0.77417
Epoch 3/10
2087/2087 [==============================] - 798s 382ms/step - loss: 0.4749 - acc: 0.8392 - val

Epoch 00003: val_acc improved from 0.77417 to 0.88754, saving model to weights_balanced_cnn_7la
Epoch 4/10
2087/2087 [==============================] - 796s 381ms/step - loss: 0.3983 - acc: 0.8727 - val

Epoch 00004: val_acc improved from 0.88754 to 0.90134, saving model to weights_balanced_cnn_7la
Epoch 5/10
2087/2087 [==============================] - 796s 381ms/step - loss: 0.3405 - acc: 0.8948 - val

Epoch 00005: val_acc did not improve from 0.90134
Epoch 6/10
2087/2087 [==============================] - 794s 381ms/step - loss: 0.3174 - acc: 0.9029 - val

Epoch 00006: val_acc improved from 0.90134 to 0.92349, saving model to weights_balanced_cnn_7la
Epoch 7/10
2087/2087 [==============================] - 798s 383ms/step - loss: 0.2883 - acc: 0.9120 - val

Epoch 00007: val_acc did not improve from 0.92349
Epoch 8/10
2087/2087 [==============================] - 798s 383ms/step - loss: 0.2783 - acc: 0.9153 - val

Epoch 00008: val_acc did not improve from 0.92349
Epoch 9/10
2087/2087 [==============================] - 795s 381ms/step - loss: 0.2621 - acc: 0.9220 - val

Epoch 00009: val_acc improved from 0.92349 to 0.92931, saving model to weights_balanced_cnn_7la
Epoch 10/10
2087/2087 [==============================] - 796s 381ms/step - loss: 0.2545 - acc: 0.9246 - val

Epoch 00010: val_acc improved from 0.92931 to 0.93483, saving model to weights_balanced_cnn_7la
```

In [8]:
```
# serialize model to JSON
model_json = model.to_json()
with open("model_balanced_cnn_7layered.json", "w") as json_file:
    json_file.write(model_json)
```

In [9]:
```
score = model.evaluate_generator(test_generator,steps = test_generator.samples // batch
print("\n\n")
print('Test Loss:', score[0])
print('Test accuracy:', score[1])

# 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()

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 Loss: 0.08890247164714721
Test accuracy: 0.9707661290322581
```

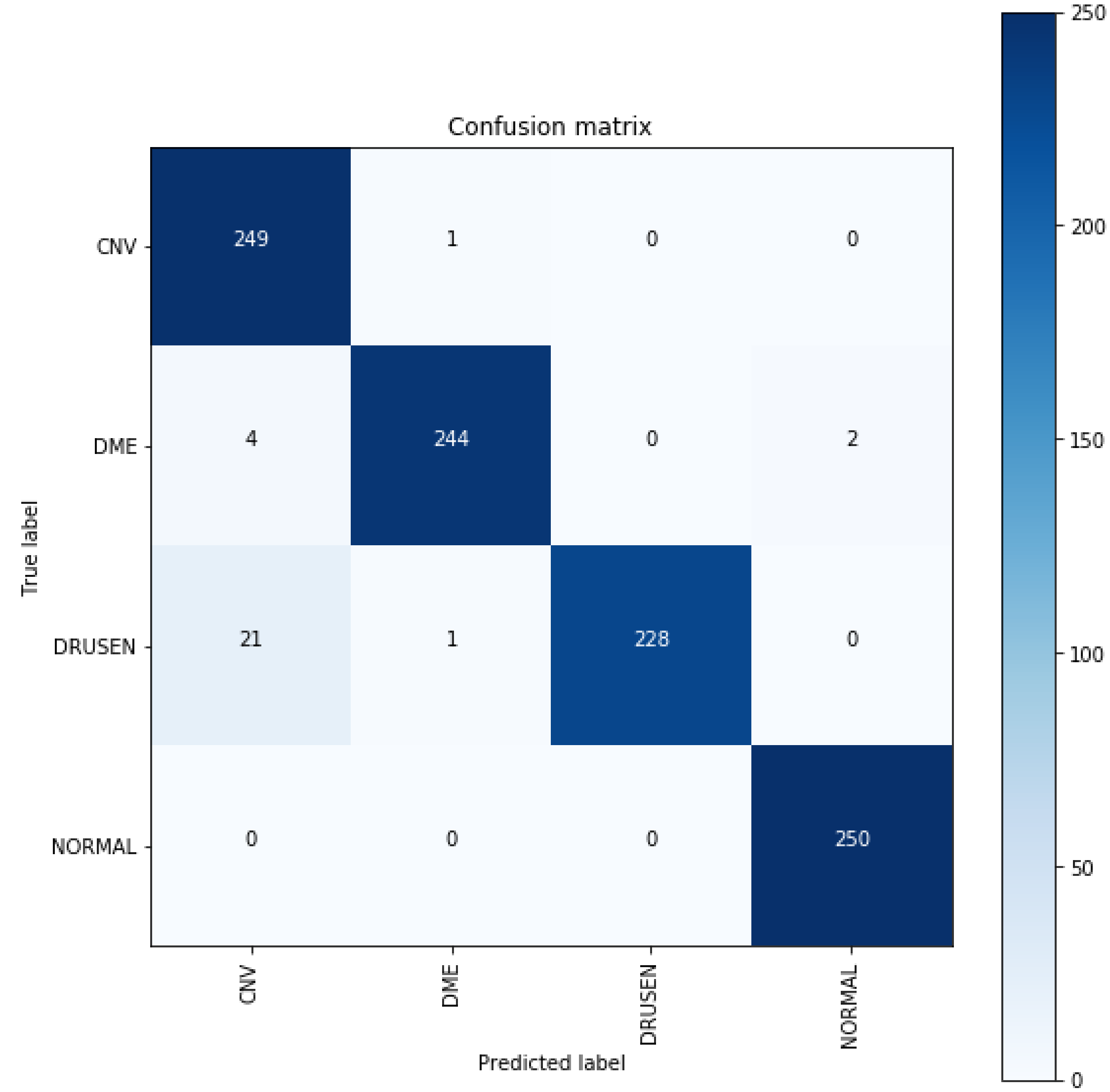


```
In [44]: from keras.models import load_model
         model = load_model('weights_balanced_cnn_7layered_best.hdf5')

In [45]: pred_datagen = ImageDataGenerator()

         pred_generator = pred_datagen.flow_from_directory("OCT2017/test",target_size=(image_s
                                                           batch_size=1,
                                                           class_mode='categorical',
                                                           shuffle = False)
```

```
Found 1000 images belonging to 4 classes.
```

```
In [46]: pred_generator.reset()
         y_pred = model.predict_generator(pred_generator,steps = 1000)
         Y_test = pred_generator.classes[pred_generator.index_array]
         Y_pred = np.argmax(y_pred, axis=-1)

In [47]: import pickle
         with open('y_pred_balanced_cnn_7layered_best.pkl','wb') as f:
             pickle.dump(y_pred, f)

In [48]: # confusion matrix
         cm = confusion_matrix(Y_test, Y_pred)

         print('--------------------')
         print('| Confusion Matrix |')
         print('--------------------')
         print('\n {}'.format(cm))

         # plot confusin matrix
         plt.figure(figsize=(8,8))
         plt.grid(b=False)
         plot_confusion_matrix(cm, classes=['CNV','DME','DRUSEN','NORMAL'], normalize=False,
                               title='Confusion matrix', cmap = plt.cm.Blues)
         plt.show()
```

```
--------------------
| Confusion Matrix |
--------------------

 [[249   1   0   0]
 [  4 244   0   2]
 [ 21   1 228   0]
 [  0   0   0 250]]
```




```
In [49]: from sklearn.metrics import classification_report
         print(classification_report(Y_test,Y_pred,target_names=['CNV','DME','DRUSEN','Normal']

              precision    recall  f1-score   support

         CNV       0.91      1.00      0.95       250
         DME       0.99      0.98      0.98       250
      DRUSEN       1.00      0.91      0.95       250
      Normal       0.99      1.00      1.00       250

   micro avg       0.97      0.97      0.97      1000
   macro avg       0.97      0.97      0.97      1000
weighted avg       0.97      0.97      0.97      1000
```

### 2.4.1 Observations:

1. We have 7 hidden layers in this CNN model.
2. **Test Loss: 0.088**
3. **Test accuracy: 0.971**
4. **precision = 0.97 | | recall = 0.97 | | f1-score = 0.97**
5. **CNN model with 5 hidden layers perform brilliantly.**

# 3 Models Performance Table

### 3.1

| Retinal OCT Images classification Using CNN | | | | | |
|---|---|---|---|---|---|
| **Sr. No.** | **Architecture (Number of Convolution Layer's)** | **Kernel Size** | **Test Accuracy %** | **Test Error/Loss** | **Test F1-score** |
| 1 | 3 Layer's | 3*3 | 85.40 | 0.689 | 0.93 |
| 2 | 3 Layer's + Class Weights Balanced | 3*3 | 94.05 | 0.231 | 0.97 |
| 3 | 5 Layer's | 3*3 | 98.99 | 0.040 | 0.98 |
| 4 | 7 Layer's | 3*3 | 97.07 | 0.088 | 0.97 |

# 4 Conclusion:

1. **We have Deep learning CNN for classification model.**
2. **Due to large size of dataset we have used ImageDataGenerator module from keras for Batch wise training of our CNN model.**
3. **CNN model with 5 Hdden Layers gives best results:**

   1. **Test Loss: 0.040**
   2. **Test accuracy: 0.989**