

▼ Retinal Blood vessel segmentation using a CNN

Done in 02/2019

Modified on 09/2022 to be compatible with the latest version of tensorflow

Sadegh

▼ Setting up the google drive

```
1 from google.colab import drive
2 drive.mount('/content/gdrive')
```

Drive already mounted at /content/gdrive; to attempt to forcibly remount, call



```
1 Train = True #switch for training
```

▼ Loading and preparing data

```
1 import os
2 import numpy as np
3 from PIL import Image
4 from IPython.display import display
5 import matplotlib.pyplot as plt
6 from sklearn.model_selection import train_test_split
7
8 import tensorflow as tf
9 from tensorflow.keras.layers import *
10 from tensorflow.keras.activations import *
11 from tensorflow.keras.models import Model
12 from tensorflow.keras.optimizers import Adam
13 from tensorflow.keras.callbacks import EarlyStopping, ModelCheckpoint, ReduceLR
14 from tensorflow.keras.preprocessing.image import ImageDataGenerator
15
```

```
1 print(tf.__version__)
```

2.8.2

```
1 np.random.seed(70)
2 tf.random.set_seed(70)
```

```
1 data_path = '/content/gdrive/My Drive/Retinal/training/'
```

```

2
3 image_width = 565
4 image_height = 584

```

```

1 img_data_path = os.path.join(data_path, 'images')
2 seg_data_path = os.path.join(data_path, '1st_manual')
3 print(img_data_path)
4 print(seg_data_path)

```

```

/content/gdrive/My Drive/Retinal/training/images
/content/gdrive/My Drive/Retinal/training/1st_manual

```

```

1 def create_data_arr(img_data_path):
2     images = sorted(os.listdir(img_data_path))
3     num_images = len(images)
4     imgs_array = np.ndarray((num_images, image_width, image_height), dtype=np.uint8)
5
6     n = 0
7     good_imgs=[]
8     for image_name in images:
9         img = Image.open(os.path.join(img_data_path, image_name)).convert('L')
10        good_imgs.append(image_name)
11        img = np.array(img.resize((image_height, image_width)))
12        imgs_array[n] = img
13        n +=1
14    return imgs_array
15
16 print('Creating training images array...')
17 imgs_array = create_data_arr(img_data_path)
18 np.save('/content/gdrive/My Drive/Retinal/training/imgs_train.npy', imgs_array)
19 print(imgs_array.shape)
20
21 print('Creating training masks array...')
22 segs_array = create_data_arr(seg_data_path)
23 np.save('/content/gdrive/My Drive/Retinal/training/seg_train.npy', segs_array)
24 print(segs_array.shape)
25

```

```

Creating training images array...
(20, 565, 584)
Creating training masks array...
(20, 565, 584)

```

```

1 del imgs_array
2 del segs_array
3
4 imgs = np.load(data_path+'imgs_train.npy')
5 segs = np.load(data_path+'seg_train.npy')
6
7 hh = plt.hist(segs.flatten())
8 plt.title("Histogram of masks")
9
10 img_no=11

```

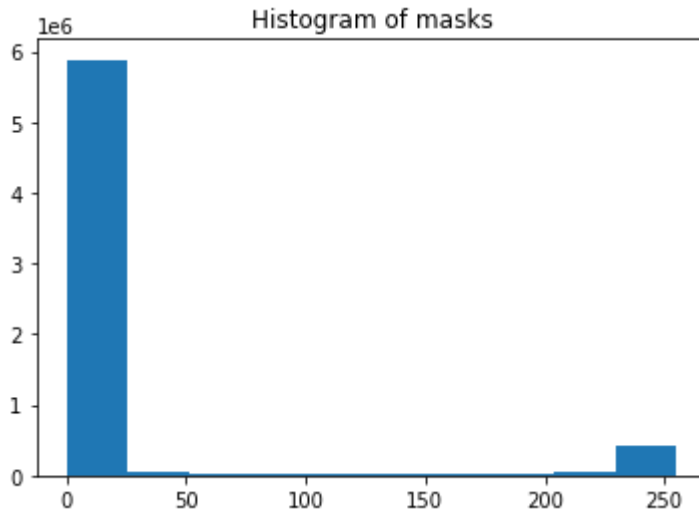
```

11 print(imgs.shape)
12 w=Image.fromarray(imgs[img_no].reshape(image_width,image_height))
13 #display(w)
14
15 print(segs.shape)
16 w=Image.fromarray(segs[img_no].reshape(image_width,image_height))
17 #display(w)

```

```
(20, 565, 584)
```

```
(20, 565, 584)
```



```

1 def create_patches(imgs,segs, patch_size=128, step_size=16):
2     #making patches of size patch_size*patch_size and stride=step_size
3     from skimage.util.shape import view_as_windows
4
5     imgs_patches = np.array([])
6     segs_patches = np.array([])
7     for i in range(imgs.shape[0]):
8         patches=view_as_windows(imgs[i], (patch_size, patch_size), step=step_size)
9         patches=patches.reshape(-1,patch_size,patch_size)
10        seg_pats=view_as_windows(segs[i], (patch_size, patch_size), step=step_size)
11        seg_pats=seg_pats.reshape(-1,patch_size,patch_size)
12
13        if i==0:
14            #first run
15            imgs_patches=patches
16            segs_patches=seg_pats
17        else:
18            imgs_patches=np.append(imgs_patches,patches,axis=0)
19            segs_patches=np.append(segs_patches,seg_pats,axis=0)
20
21    imgs_patches = imgs_patches[:, :, :, np.newaxis]
22    segs_patches = segs_patches[:, :, :, np.newaxis]
23
24    imgs_patches = imgs_patches.astype('float32')
25    imgs_patches /=255.0
26    segs_patches = segs_patches.astype('float32')
27    segs_patches /=255.0
28
29    return imgs_patches,segs_patches

```

```

1 #Splitting the data
2 train_imgs, valid_test_imgs, train_segs, valid_test_segs = \
3     train_test_split(imgs, segs, test_size=0.5, random_state=54)
4
5 valid_imgs, test_imgs, valid_segs, test_segs = \
6     train_test_split(valid_test_imgs, valid_test_segs, test_size=0.5, random_state=54)
7
8 print(train_imgs.shape, train_segs.shape, valid_imgs.shape, valid_segs.shape, test_imgs.shape, test_segs.shape)
9
10 #Creating patches
11 TrainPatchImg, TrainPatchSeg = create_patches(train_imgs, train_segs, step_size=128)
12 ValidPatchImg, ValidPatchSeg = create_patches(valid_imgs, valid_segs, step_size=128)
13 TestPatchImg, TestPatchSeg = create_patches(test_imgs, test_segs, step_size=128)
14 TrainPatchImgEval, TrainPatchSegEval = create_patches(train_imgs, train_segs, step_size=128)
15 print(TrainPatchImg.shape, TrainPatchSeg.shape, ValidPatchImg.shape, ValidPatchSeg.shape, TestPatchImg.shape, TestPatchSeg.shape)

```

(10, 565, 584) (10, 565, 584) (5, 565, 584) (5, 565, 584) (5, 565, 584) (5, 565, 584)
 (31900, 128, 128, 1) (31900, 128, 128, 1) (80, 128, 128, 1) (80, 128, 128, 1) (80, 128, 128, 1) (80, 128, 128, 1)

```

1 '''
2 del imgs
3 del segs
4 del train_imgs
5 del valid_imgs
6 del test_imgs
7 import gc
8 gc.collect()
9 '''

```

'\ndel imgs\ndel segs\ndel train_imgs\ndel valid_imgs\ndel test_imgs\nimport gc\ngc.collect()\n'

▼ Training

Model architecture

```

1 def BN_ReLU(input_features):
2     output_features = BatchNormalization()(input_features)
3     output_features = relu(output_features)
4     return output_features
5
6 def Model_Architecture(input_layer):
7     initial_num_filters=16
8     input_layer = BatchNormalization()(input_layer) #sd
9     #in:128--out:64
10    conv1 = Conv2D(initial_num_filters * 1, (3, 3), padding="same")(input_layer)
11    out = BN_ReLU(conv1)
12    out = MaxPooling2D((2, 2))(out)
13    out = Dropout(0.2)(out)

```

```
14     #in:64--out:32
15     conv2 = Conv2D(initial_num_filters * 2, (3, 3), padding="same")(out)
16     out = BN_ReLU(conv2)
17     out = MaxPooling2D((2, 2))(out)
18     out = Dropout(0.2)(out)
19     #in:32--out:16
20     conv3 = Conv2D(initial_num_filters * 3, (3, 3), padding="same")(out)
21     out = BN_ReLU(conv3)
22     out = MaxPooling2D((2, 2))(out)
23     out = Dropout(0.2)(out)
24     #in:16--out:8
25     conv4 = Conv2D(initial_num_filters * 4, (3, 3), padding="same")(out)
26     out = BN_ReLU(conv4)
27     out = MaxPooling2D((2, 2))(out)
28     out = Dropout(0.2)(out)
29     #in:8--out:4
30     conv5 = Conv2D(initial_num_filters * 5, (3, 3), padding="same")(out)
31     out = BN_ReLU(conv5)
32     out = MaxPooling2D((2, 2))(out)
33     out = Dropout(0.2)(out)
34     #in:4--out:2
35     conv6 = Conv2D(initial_num_filters * 6, (3, 3), padding="same")(out)
36     out = BN_ReLU(conv6)
37     out = MaxPooling2D((2, 2))(out)
38     out = Dropout(0.2)(out)
39     #in:2--out:1
40     conv7 = Conv2D(initial_num_filters * 7, (3, 3), padding="same")(out)
41     out = BN_ReLU(conv7)
42     out = MaxPooling2D((2, 2))(out)
43     out = Dropout(0.2)(out)
44
45     #Decoding
46     convT7 = Conv2DTranspose(initial_num_filters * 7, (3, 3), strides=(2, 2), padding="same", output_shape=(1, 1, 1, 1))
47     convT7 = Conv2D(initial_num_filters * 7, (3, 3), padding="same")(convT7)
48     out = concatenate([convT7, conv7])
49     out = BN_ReLU(out)
50     out = Dropout(0.2)(out)
51
52     convT6 = Conv2DTranspose(initial_num_filters * 6, (3, 3), strides=(2, 2), padding="same", output_shape=(1, 1, 1, 1))
53     convT6 = Conv2D(initial_num_filters * 6, (3, 3), padding="same")(convT6)
54     out = concatenate([convT6, conv6])
55     out = BN_ReLU(out)
56     out = Dropout(0.2)(out)
57
58     convT5 = Conv2DTranspose(initial_num_filters * 5, (3, 3), strides=(2, 2), padding="same", output_shape=(1, 1, 1, 1))
59     convT5 = Conv2D(initial_num_filters * 5, (3, 3), padding="same")(convT5)
60     out = concatenate([convT5, conv5])
61     out = BN_ReLU(out)
62     out = Dropout(0.2)(out)
63
64     convT4 = Conv2DTranspose(initial_num_filters * 4, (3, 3), strides=(2, 2), padding="same", output_shape=(1, 1, 1, 1))
65     convT4 = Conv2D(initial_num_filters * 4, (3, 3), padding="same")(convT4)
66     out = concatenate([convT4, conv4])
67     out = BN_ReLU(out)
68     out = Dropout(0.2)(out)
```

```

69
70 convT3 = Conv2DTranspose(initial_num_filters * 3, (3, 3), strides=(2, 2), padding="same")
71 convT3 = Conv2D(initial_num_filters * 3, (3, 3), padding="same")(convT3)
72 out = concatenate([convT3, conv3])
73 out = BN_ReLU(out)
74 out = Dropout(0.2)(out)
75
76 convT2 = Conv2DTranspose(initial_num_filters * 2, (3, 3), strides=(2, 2), padding="same")
77 convT2 = Conv2D(initial_num_filters * 2, (3, 3), padding="same")(convT2)
78 out = concatenate([convT2, conv2])
79 out = BN_ReLU(out)
80 out = Dropout(0.2)(out)
81
82 convT1 = Conv2DTranspose(initial_num_filters * 1, (3, 3), strides=(2, 2), padding="same")
83 convT1 = Conv2D(initial_num_filters * 1, (3, 3), padding="same")(convT1)
84 out = concatenate([convT1, conv1])
85 out = BN_ReLU(out)
86 out = Dropout(0.2)(out)
87
88 output_layer = Conv2D(1, (1,1), padding="same", activation="sigmoid")(out)
89 return output_layer
90
91
92 input_layer=Input(shape=(128,128,1))
93 output_layer=Model_Architecture(input_layer)
94
95 model=Model(inputs=input_layer,outputs=output_layer)

```

```
1 model.summary()
```

Model: "model"

Layer (type)	Output Shape	Param #	Connected to
input_1 (InputLayer)	(None, 128, 128, 1)	0	None
batch_normalization (Batch Normalization)	(None, 128, 128, 1)	4	input_1[0]
conv2d (Conv2D)	(None, 128, 128, 16)	160	batch_normalization[0]
batch_normalization_1 (Batch Normalization)	(None, 128, 128, 16)	64	conv2d[0]
tf.nn.relu (TFRelu)	(None, 128, 128, 16)	0	batch_normalization_1[0]
max_pooling2d (MaxPooling2D)	(None, 64, 64, 16)	0	tf.nn.relu[0]
dropout (Dropout)	(None, 64, 64, 16)	0	max_pooling2d[0]
conv2d_1 (Conv2D)	(None, 64, 64, 32)	4640	dropout[0]
batch_normalization_2 (Batch Normalization)	(None, 64, 64, 32)	128	conv2d_1[0]

rmalization)

tf.nn.relu_1 (TFOpLambda)	(None, 64, 64, 32)	0	['batch_no
max_pooling2d_1 (MaxPooling2D)	(None, 32, 32, 32)	0	['tf.nn.re
dropout_1 (Dropout)	(None, 32, 32, 32)	0	['max_pool
conv2d_2 (Conv2D)	(None, 32, 32, 48)	13872	['dropout_
batch_normalization_3 (BatchNo rmalization)	(None, 32, 32, 48)	192	['conv2d_2
tf.nn.relu_2 (TFOpLambda)	(None, 32, 32, 48)	0	['batch_no
max_pooling2d_2 (MaxPooling2D)	(None, 16, 16, 48)	0	['tf.nn.re
dropout_2 (Dropout)	(None, 16, 16, 48)	0	['max_pool
conv2d_3 (Conv2D)	(None, 16, 16, 64)	27712	['dropout_
batch_normalization_4 (BatchNo rmalization)	(None, 16, 16, 64)	256	['conv2d_3
tf.nn.relu_3 (TFOpLambda)	(None, 16, 16, 64)	0	['batch_no
max_pooling2d_3 (MaxPooling2D)	(None, 8, 8, 64)	0	['tf.nn.re
dropout_3 (Dropout)	(None, 8, 8, 64)	0	['max_pool
conv2d_4 (Conv2D)	(None, 8, 8, 80)	46160	['dropout_

```

1 import tensorflow as tf
2 from tensorflow.keras import backend as K
3 def focal_loss(gamma=2., alpha=.60):
4     def focal_loss_fixed(y_true, y_pred):
5         pt1 = tf.where(tf.equal(y_true, 1), y_pred, tf.ones_like(y_pred))
6         pt0 = tf.where(tf.equal(y_true, 0), y_pred, tf.zeros_like(y_pred))
7         # clip to prevent NaN's and Inf's
8         pt1 = K.clip(pt1, K.epsilon(), 1-K.epsilon())
9         pt0 = K.clip(pt0, K.epsilon(), 1-K.epsilon())
10        return -K.mean(alpha * K.pow(1. - pt1, gamma) * K.log(pt1), axis=-1) \
11                -K.mean((1-alpha) * K.pow( pt0, gamma) * K.log(1. - pt0) ,axis=-1)
12    return focal_loss_fixed
13
14 #loss =[focal_loss(gamma=0.0,alpha=0.60)], 'categorical_crossentropy'
```

```

1 model.compile(optimizer=Adam(lr=0.001), loss = [focal_loss(gamma=0.1,alpha=0.60
2
3 early_stopping = EarlyStopping(monitor='val_loss', min_delta=0, patience=8, ver
4 reduce_lr = ReduceLRonPlateau(monitor='val_loss', factor=0.1, patience=5, verbo
5 model_checkpoint = ModelCheckpoint(data_path+"checkpoint/keras.model", monitor=
```

```

/usr/local/lib/python3.7/dist-packages/keras/optimizer_v2/adam.py:105: UserWa
super(Adam, self).__init__(name, **kwargs)
```

```

1  batchsize=128
2
3  gen_args = dict(horizontal_flip=True,
4                  vertical_flip=True)
5  image_gen = ImageDataGenerator(**gen_args)
6  mask_gen = ImageDataGenerator(**gen_args)
7
8  seed = 854
9  image_generator = image_gen.flow(TrainPatchImg, batch_size=batchsize, shuffle=True)
10 mask_generator = mask_gen.flow(TrainPatchSeg, batch_size=batchsize, shuffle=True)
11
12 train_generator = zip(image_generator, mask_generator)
13 if Train:
14     model_history=model.fit(
15         train_generator,
16         steps_per_epoch=np.ceil(len(TrainPatchImg)/batchsize),
17         validation_data = (ValidPatchImg, ValidPatchSeg),
18         verbose=1,
19         callbacks=[early_stopping, model_checkpoint, reduce_lr],
20         initial_epoch=0,
21         epochs=30)

```

Epoch 1/30

250/250 [=====] - ETA: 0s - loss: 0.0876 - accuracy:

Epoch 1: val_loss improved from inf to 0.13829, saving model to /content/gdri

250/250 [=====] - 99s 340ms/step - loss: 0.0876 - ac

Epoch 2/30

250/250 [=====] - ETA: 0s - loss: 0.0335 - accuracy:

Epoch 2: val_loss improved from 0.13829 to 0.09217, saving model to /content/

250/250 [=====] - 83s 330ms/step - loss: 0.0335 - ac

Epoch 3/30

250/250 [=====] - ETA: 0s - loss: 0.0262 - accuracy:

Epoch 3: val_loss improved from 0.09217 to 0.04062, saving model to /content/

250/250 [=====] - 83s 331ms/step - loss: 0.0262 - ac

Epoch 4/30

250/250 [=====] - ETA: 0s - loss: 0.0233 - accuracy:

Epoch 4: val_loss improved from 0.04062 to 0.03082, saving model to /content/

250/250 [=====] - 83s 331ms/step - loss: 0.0233 - ac

Epoch 5/30

250/250 [=====] - ETA: 0s - loss: 0.0215 - accuracy:

Epoch 5: val_loss improved from 0.03082 to 0.02945, saving model to /content/

250/250 [=====] - 83s 330ms/step - loss: 0.0215 - ac

Epoch 6/30

250/250 [=====] - ETA: 0s - loss: 0.0202 - accuracy:

Epoch 6: val_loss did not improve from 0.02945

250/250 [=====] - 75s 300ms/step - loss: 0.0202 - ac

Epoch 7/30

250/250 [=====] - ETA: 0s - loss: 0.0193 - accuracy:

Epoch 7: val_loss did not improve from 0.02945

250/250 [=====] - 75s 301ms/step - loss: 0.0193 - ac

Epoch 8/30

250/250 [=====] - ETA: 0s - loss: 0.0186 - accuracy:

Epoch 8: val_loss did not improve from 0.02945

250/250 [=====] - 75s 300ms/step - loss: 0.0186 - ac

Epoch 9/30


250/250 [=====] - ETA: 0s - loss: 0.0179 - accuracy:


```

Epoch 9: val_loss did not improve from 0.02945
250/250 [=====] - 75s 299ms/step - loss: 0.0179 - ac
Epoch 10/30
250/250 [=====] - ETA: 0s - loss: 0.0173 - accuracy:
Epoch 10: val_loss did not improve from 0.02945

Epoch 10: ReduceLROnPlateau reducing learning rate to 0.00010000000474974513.
250/250 [=====] - 75s 299ms/step - loss: 0.0173 - ac
Epoch 11/30
250/250 [=====] - ETA: 0s - loss: 0.0166 - accuracy:
Epoch 11: val_loss did not improve from 0.02945
250/250 [=====] - 75s 299ms/step - loss: 0.0166 - ac
Epoch 12/30
250/250 [=====] - ETA: 0s - loss: 0.0165 - accuracy:
Epoch 12: val_loss did not improve from 0.02945
250/250 [=====] - 75s 299ms/step - loss: 0.0165 - ac
Epoch 13/30
250/250 [=====] - ETA: 0s - loss: 0.0164 - accuracy:
Epoch 13: val_loss did not improve from 0.02945
250/250 [=====] - 75s 299ms/step - loss: 0.0164 - ac
Epoch 13: early stopping

```



```

1 if Train==True:
2     plt.figure(figsize=(8, 8))
3     plt.plot(model_history.history["loss"], label="Training loss")
4     plt.plot(model_history.history["val_loss"], label="Validation loss")
5     plt.plot( np.argmin(model_history.history["val_loss"]), np.min(model_history.l
6     plt.xlabel("Epochs")
7     plt.ylabel("Loss")
8     plt.legend()
9

```



▼ Loading the trained model

```
1 from tensorflow.keras.models import load_model
2 model = load_model(data_path+'checkpoint/keras.model', custom_objects={'focal_loss'})

1 '''
2 c=0 #0 or 1
3
4 imageNo=23 #40 80
5 #image
6 w=Image.fromarray(255*PatchImg[imageNo,:,:,c]).convert('L')
7 display(w)
8
9 #real seg
10 w=Image.fromarray(255*PatchSeg[imageNo,:,:,c]).convert('L')
11 display(w)
12
13 #predicted seg
14 w=Image.fromarray(255*predicted_[imageNo,:,:,c]).convert('L')
15 display(w)
16
17 #predicted seg -- rounded with threshold
18 thresh=0.5
19 preds_valid_rounded = np.round(predicted_>thresh)
20 preds_valid_rounded=preds_valid_rounded.astype(np.float32)
21
22 w=Image.fromarray(255*preds_valid_rounded[imageNo,:,:,c].astype('uint8')).convert('L')
23 display(w)
24 '''

'\nc=0 #0 or 1\n\nimageNo=23 #40 80\n#image\nw=Image.fromarray(255*PatchImg[imageNo,:,:,c]).convert('L')\ndisplay(w)\n\n#real seg\nw=Image.fromarray(255*PatchSeg[imageNo,:,:,c]).convert('L')\ndisplay(w)\n\n#predicted seg\nw=Image.fromarray(255*predicted_[imageNo,:,:,c]).convert('L')\ndisplay(w)\n\n#predicted seg -- rounded with threshold\nthresh=0.5\npreds_valid_rounded = np.round(predicted_>thresh)\npreds_valid_rounded=preds_valid_rounded.astype(np.float32)
```

▼ Evaluation of the trained model

```
1 #defining dice metric
2 smooth = 1
3 def dice_coef(y_true, y_pred):
4     y_true_f = K.flatten(y_true)
5     y_pred_f = K.flatten(y_pred)
6     intersection = K.sum(y_true_f * y_pred_f)
7     return (2. * intersection + smooth) / (K.sum(y_true_f) + K.sum(y_pred_f) + smooth)
```

```

8
9 def dice_coef_loss(y_true, y_pred):
10     return 1-dice_coef(y_true, y_pred)
11
12
13 #Confusion Matrix
14 import itertools
15 def plot_confusion_matrix(cm, classes,
16                           normalize=False,
17                           title='Confusion matrix',
18                           cmap=plt.cm.Blues):
19     """
20     This function prints and plots the confusion matrix.
21     Normalization can be applied by setting `normalize=True`.
22     """
23     if normalize:
24         cm = cm.astype('float') / cm.sum(axis=1)[:, np.newaxis]
25         #print("Normalized confusion matrix")
26     else:
27         #print('Confusion matrix, without normalization')
28         pass
29
30     plt.imshow(cm, interpolation='nearest', cmap=cmap)
31     plt.title(title)
32     plt.colorbar()
33     tick_marks = np.arange(len(classes))
34     plt.xticks(tick_marks, classes, rotation=45)
35     plt.yticks(tick_marks, classes)
36
37     fmt = '.2f' if normalize else 'd'
38     thresh = cm.max() / 2.
39     for i, j in itertools.product(range(cm.shape[0]), range(cm.shape[1])):
40         plt.text(j, i, format(cm[i, j], fmt),
41                  horizontalalignment="center",
42                  color="white" if cm[i, j] > thresh else "black")
43
44     plt.ylabel('True label')
45     plt.xlabel('Predicted label')
46     plt.tight_layout()
47
48
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```

1 def generate_report(true_seg,predicted_):
2     thresh=0.5
3     preds_rounded = np.round(predicted_>thresh)
4     preds_rounded=preds_rounded.astype(np.float32)
5
6     c=0 #0 or 1
7     y_true = true_seg[:,:::,c].flatten().astype(int)
8     y_pred = preds_rounded[:,:::,c].flatten() #with a specific thresh
9     y_pred_prob = predicted_[:,:::,c].flatten()
10
11     from sklearn import metrics
12     acc=metrics.accuracy_score(y_true, y_pred, normalize=True)
13     print('Accuracy = '+str(acc))

```

```
14
15 dice_result=dice_coef(true_seg[:,:,:,:0],preds_rounded[:,:,:,:0])
16 print('Dice='+str(K.eval(dice_result)))
17
18 report=metrics.classification_report(y_true, y_pred, digits=4)
19 print(report)
20
21
22 #Plot ROC curve
23 fpr, tpr, thresholds = metrics.roc_curve(y_true, y_pred_prob, pos_label=1)
24 roc_auc = metrics.auc(fpr, tpr)
25 plt.figure()
26 lw = 2
27 plt.plot(fpr, tpr, color='darkorange',
28          lw=lw, label='ROC curve (area = %0.4f)' % roc_auc)
29 plt.plot([0, 1], [0, 1], color='navy', lw=lw, linestyle='--')
30 plt.xlim([0.0, 1.0])
31 plt.ylim([0.0, 1.05])
32 plt.xlabel('False Positive Rate')
33 plt.ylabel('True Positive Rate')
34 plt.title('ROC Curve')
35 plt.legend(loc="lower right")
36 plt.show()
37
38
39 from sklearn.metrics import confusion_matrix
40 cnf_matrix = confusion_matrix(y_true, y_pred, labels=[1,0])
41 #positive:vessel:1:mask:white
42 #negative:backgrnd:0:black
43
44 np.set_printoptions(precision=2)
45 class_names=['mask','background']
46
47 # Plot non-normalized confusion matrix
48 plt.figure()
49 plot_confusion_matrix(cnf_matrix, classes=class_names,
50                       title='Confusion matrix, without normalization');
51
52 # Plot normalized confusion matrix
53 plt.figure()
54 plot_confusion_matrix(cnf_matrix, classes=class_names, normalize=True,
55                       title='Normalized confusion matrix');
56
57 plt.show()

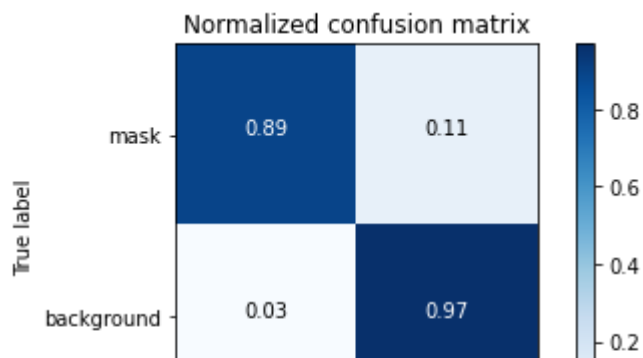
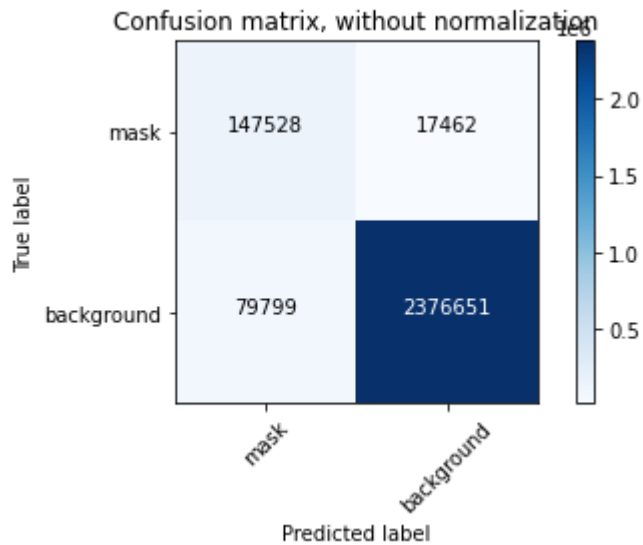
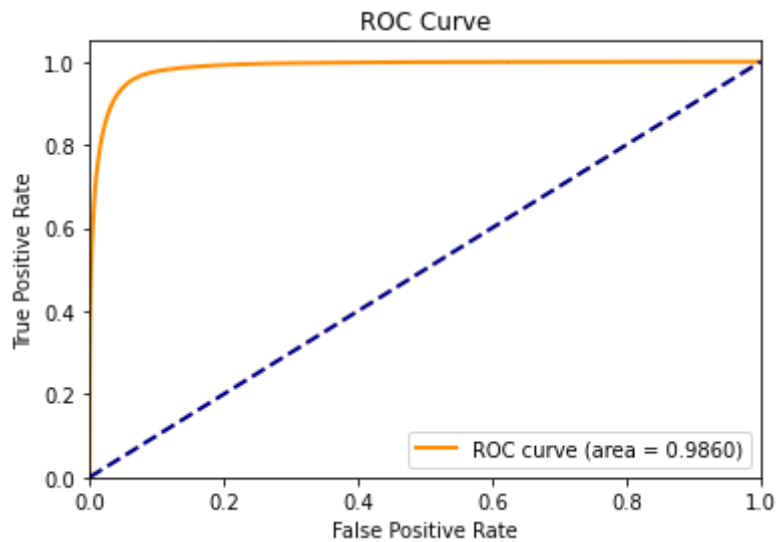
1 print('Evaluation on the TRAINING set')
2 predicted_ = model.predict(TrainPatchImgEval)
3 generate_report(TrainPatchSegEval,predicted_)
```

Evaluation on the TRAINING set

Accuracy = 0.9628978729248047

Dice=0.78898644

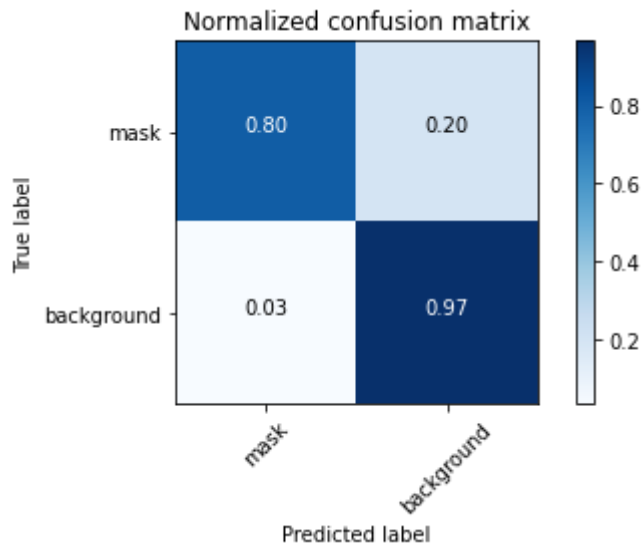
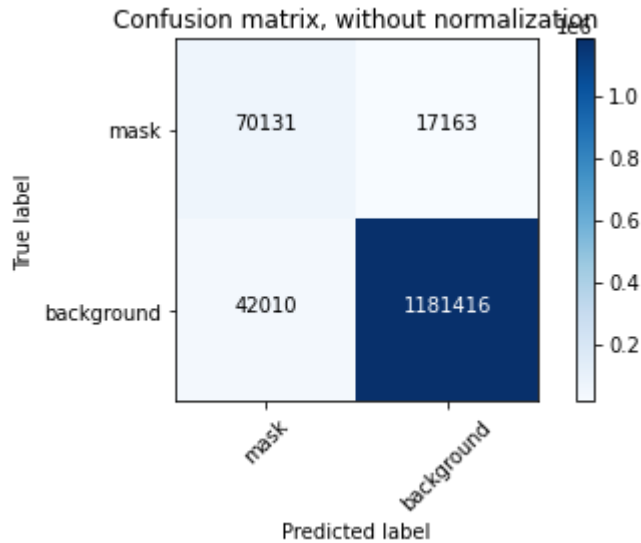
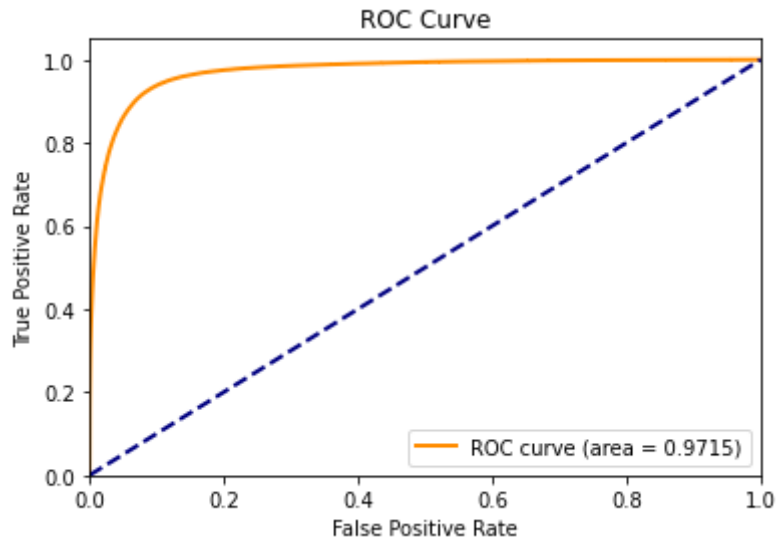
	precision	recall	f1-score	support
0	0.9927	0.9675	0.9799	2456450
1	0.6490	0.8942	0.7521	164990
accuracy			0.9629	2621440
macro avg	0.8208	0.9308	0.8660	2621440
weighted avg	0.9711	0.9629	0.9656	2621440



```
1 print('Evaluation on the VALIDATION set')
2 predicted_ = model.predict(ValidPatchImg)
3 generate_report(ValidPatchSeg,predicted_)
```

Evaluation on the VALIDATION set
Accuracy = 0.9548545837402344
Dice=0.73072815

	precision	recall	f1-score	support
0	0.9857	0.9657	0.9756	1223426
1	0.6254	0.8034	0.7033	87294
accuracy			0.9549	1310720
macro avg	0.8055	0.8845	0.8394	1310720
weighted avg	0.9617	0.9549	0.9574	1310720



```
1 print('Evaluation on the TEST set')  
2 predicted_ = model.predict(TestPatchImg)  
3 generate_report(TestPatchSeg,predicted_)
```

Evaluation on the TEST set
 Accuracy = 0.9619827270507812
 Dice=0.7477367

	precision	recall	f1-score	support
0	0.9899	0.9694	0.9795	1230579
1	0.6435	0.8482	0.7318	80141

▼ Display on the test set

```

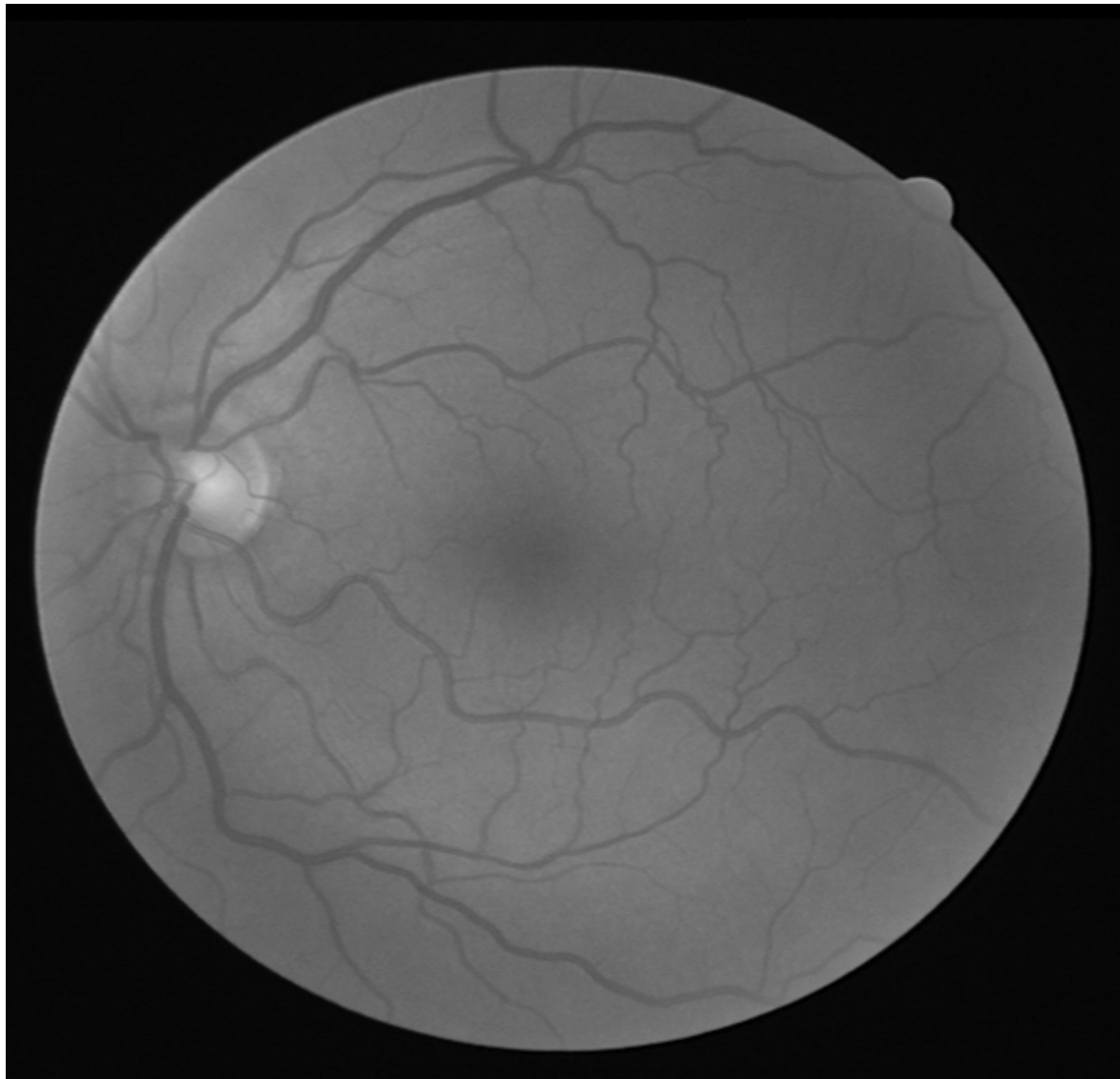
1 imgs = test_imgs
2 #resize to 640*640
3 imgs_resized = np.ndarray((imgs.shape[0], 640, 640), dtype=np.uint8)
4 n=0
5 import cv2
6 for img in imgs:
7     res = cv2.resize(img, dsize=(640, 640), interpolation=cv2.INTER_CUBIC)
8     imgs_resized[n]=res
9     n=n+1
10
11 #making patches of size 128*128
12 patch_size=128
13 step_size=128
14
15 from skimage.util.shape import view_as_windows
16 '''
17 imgs_patches = np.array([])
18 for i in range(imgs_resized.shape[0]):
19     patches=view_as_windows(imgs_resized[i], (patch_size, patch_size), step=step_
20     patches=patches.reshape(-1,patch_size,patch_size, order='A')
21     if i==0:
22         imgs_patches=patches
23     else:
24         imgs_patches=np.append(imgs_patches,patches,axis=0)
25 '''
26
27 imgs_patches = np.ndarray((500, patch_size, patch_size), dtype=np.uint8)
28 p=0
29 for i in range(imgs_resized.shape[0]):
30     #patches=view_as_windows(imgs_resized[i], (patch_size, patch_size), step=step_
31     for r in range(5):
32         for c in range(5):
33             imgs_patches[p]=imgs_resized[i,r*128:(r+1)*128,c*128:(c+1)*128]
34             p=p+1
35
36 imgs_patches = imgs_patches[:,:,:,:,np.newaxis]
37 imgs_patches = imgs_patches.astype('float32')
38 imgs_patches /=255.0
39
40
41
42 predicted_test = model.predict(imgs_patches)
43
44

```



```
45 #join patches together
46 full_segs = np.ndarray((20, 640, 640), dtype=np.float32)
47 p=0
48 num_tests=5
49 for i in range(num_tests):
50     for r in range(5):
51         for c in range(5):
52             full_segs[i, r*128:(r+1)*128, c*128:(c+1)*128]=predicted_test[p,:,:,0]
53             p=p+1
54
55 #resize back to 565*584
56 full_segs_resized = np.ndarray((full_segs.shape[0], 584, 565), dtype=np.float32)
57 n=0
58 for img in full_segs:
59     res = cv2.resize(img, dsize=(565, 584), interpolation=cv2.INTER_CUBIC)
60     full_segs_resized[n]=res
61     n=n+1
62
63 #predicted seg -- rounded
64 thresh=0.5
65 full_segs_rounded = np.round(full_segs_resized>thresh)
66 w=Image.fromarray(255*full_segs_rounded[0].astype('uint8')).convert('L')
67 display(w)
```

```
1 w=Image.fromarray(test_imgs[0])  
2 display(w)  
3  
4
```



```
1 w=Image.fromarray(test_segs[0]).convert('L')  
2 display(w)  
3
```



1



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