HW5_Task3

April 30, 2019

1 Applied Machine Learning Homework 5

1.0.1 Po-Chieh Liu (pl2441), Peter Grantcharov (pdg2116)

2 Task 3

In [1]:
```
# base packages
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
from keras import utils
```

```
Using TensorFlow backend.
```

Import Data

In [0]:
```
# import packages for import zip files
import zipfile
import imageio
from skimage import io
```

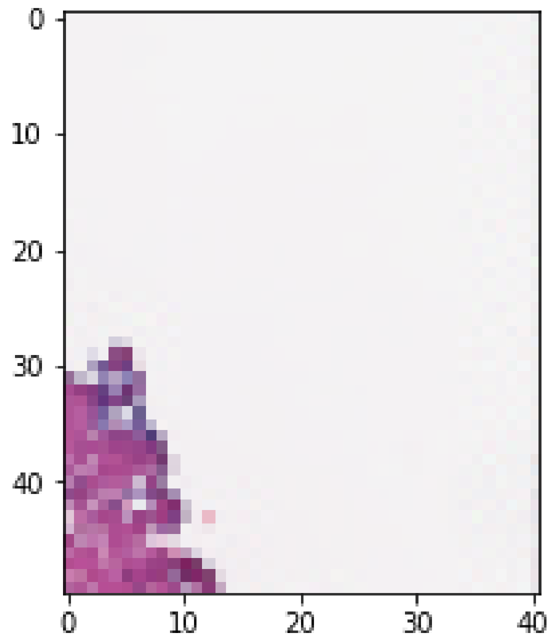
In [3]:
```
# package for load data from google drive
from google.colab import drive
drive.mount('/gdrive')
```

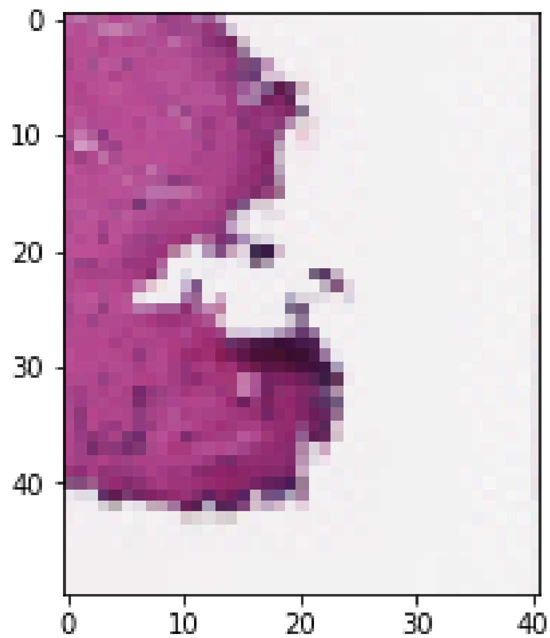
```
Drive already mounted at /gdrive; to attempt to forcibly remount, call drive.mount("/gdrive", :
```

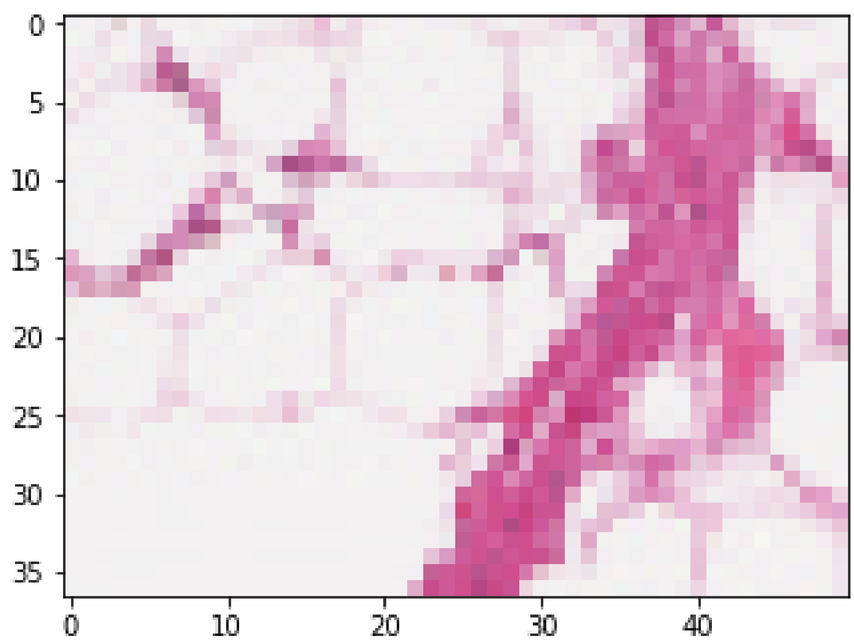
In [0]:
```
# get images
file_dir = '/gdrive/My Drive/Colab Notebooks/Data/IDC_regular_ps50_idx5.zip'

# zipfile
archive = zipfile.ZipFile(file_dir)

# due to memory limit, only extract first 75,000 pictures for this task
images = [f.filename for f in archive.filelist if f.is_dir() == False][:75000]
ic = io.ImageCollection(images, load_func = (lambda x: imageio.imread(archive.read(x)))
```

Drop irregular shape images

```
In [5]: # There are some irregular shape images
        # just show the first 3 images
        count = 0
        for idx, image in enumerate(ic):
            if image.shape != (50, 50, 3):
                count += 1
                plt.figure()
                plt.imshow(image)
            if count == 3:
                break
```





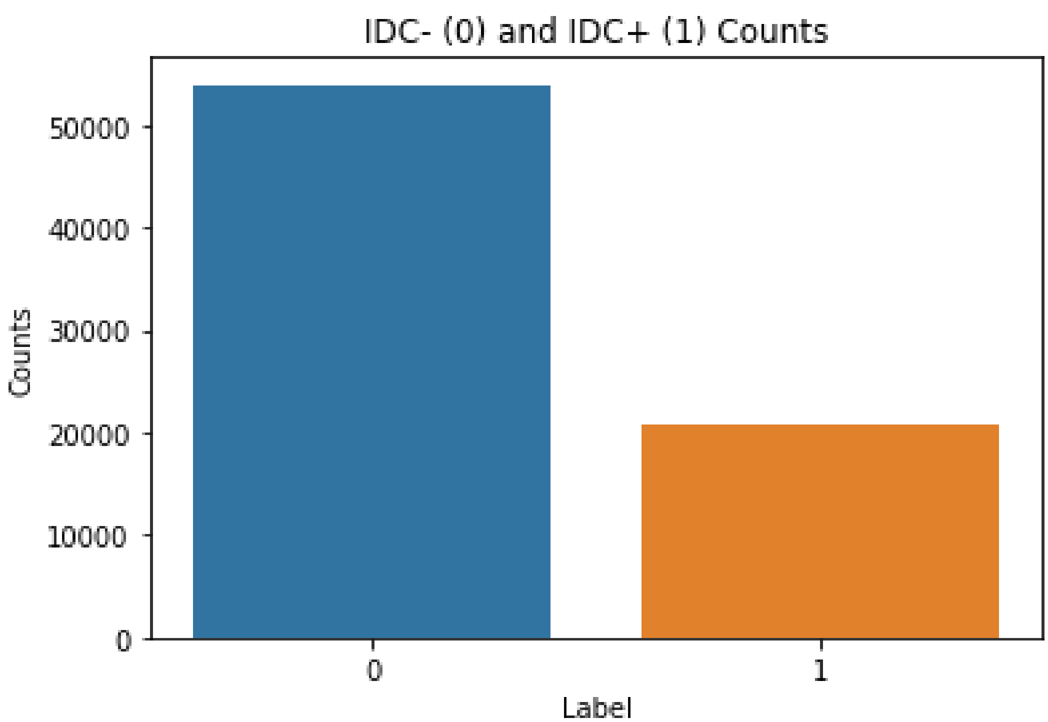


These irregular shapes are incompatible with our neural networks, so we will simply exclude them from our sample.

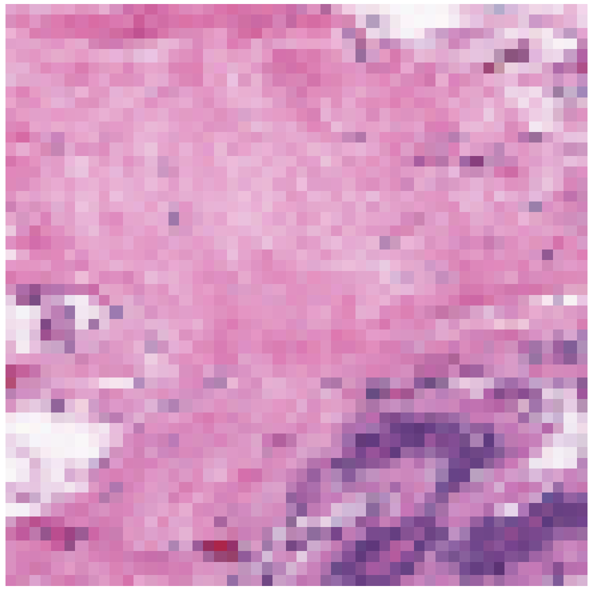
```
In [0]: # get all images with proper shape
        X, y = [], []
```

```
for idx, image in enumerate(ic):
    if image.shape == (50, 50, 3):
        X.append(image)
        y.append(images[idx][-5])

# scale features to be between 0 and 1
X = np.array(X) / 255.0
y = utils.to_categorical(np.array(y))

# free memory
del ic, images, archive
```

In [7]:
```
# visualize imbalance
_ = sns.countplot(y[:, 1].astype(int))
_ = plt.xlabel('Label')
_ = plt.ylabel('Counts')
_ = plt.title('IDC- (0) and IDC+ (1) Counts')
```



In [8]:
```
# sample
_ = plt.imshow((X[0] * 255).astype(int))
_ = plt.axis('off')
```



2.1 Task 3.1

Start with a model without residual connections (using batch normalization is likely to be helpful and you should try it, whether you use dropout is your choice).

In [0]:
```
# 80%-20% split data for training and testing
from sklearn.model_selection import train_test_split
X_train, X_test, y_train, y_test = train_test_split(
    X, y, stratify = y, test_size = 0.2)

del X, y

# 80% 20% training data split for training and validating
X_train, X_val, y_train, y_val = train_test_split(
    X_train, y_train, stratify = y_train, test_size = 0.2)
```

In [10]:
```
from sklearn.utils import class_weight
class_weights = class_weight.compute_class_weight('balanced',
                                                  [0, 1],
                                                  y_train[:,1])
class_weights
```

Out[10]:
```
array([0.69380777, 1.78993795])
```

In [0]:
```
# model parameter
batch_size = 50
```

```
num_classes = 2
epochs = 10

# input image dimensions
img_rows, img_cols = 50, 50
input_shape = (img_rows, img_cols, 3)
```

```
In [0]: # user defined f1 metric
        import tensorflow as tf
        import keras.backend as K

        def f1(y_true, y_pred):
            y_pred = K.round(y_pred)
            tp = K.sum(K.cast(y_true*y_pred, 'float'), axis=0)
            tn = K.sum(K.cast((1-y_true)*(1-y_pred), 'float'), axis=0)
            fp = K.sum(K.cast((1-y_true)*y_pred, 'float'), axis=0)
            fn = K.sum(K.cast(y_true*(1-y_pred), 'float'), axis=0)

            p = tp / (tp + fp + K.epsilon())
            r = tp / (tp + fn + K.epsilon())

            f1 = 2*p*r / (p+r+K.epsilon())
            f1 = tf.where(tf.is_nan(f1), tf.zeros_like(f1), f1)
            return K.mean(f1)
```

```
In [13]: from keras import Sequential
         from keras.layers import Conv2D, MaxPooling2D, Flatten, Dense, BatchNormalization

         cnn = Sequential()

         ####### cluster1
         cnn.add(Conv2D(32, kernel_size=(3, 3), activation='relu',
                          input_shape=input_shape))
         cnn.add(BatchNormalization())
         cnn.add(MaxPooling2D(pool_size=(2, 2)))

         ###### cluster2
         cnn.add(Conv2D(64, (3, 3), activation='relu'))
         cnn.add(BatchNormalization())
         cnn.add(MaxPooling2D(pool_size=(2, 2)))

         ###### cluster 3
         cnn.add(Conv2D(128, (3, 3), activation='relu'))
         cnn.add(BatchNormalization())
         cnn.add(MaxPooling2D(pool_size=(2, 2)))

         ##### flat for dense
         cnn.add(Flatten())
```

```python
cnn.add(Dense(128, activation='relu'))
cnn.add(Dense(64, activation='relu'))
cnn.add(Dense(32, activation='relu'))
cnn.add(Dense(2, activation='softmax'))

cnn.compile(optimizer='adam', loss="binary_crossentropy", metrics=['acc', f1])

cnn.summary()
```

```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/tensorflow/python/framework/op_d
Instructions for updating:
Colocations handled automatically by placer.
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_1 (Conv2D)            (None, 48, 48, 32)        896
_________________________________________________________________
batch_normalization_1 (Batch (None, 48, 48, 32)        128
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 24, 24, 32)        0
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 22, 22, 64)        18496
_________________________________________________________________
batch_normalization_2 (Batch (None, 22, 22, 64)        256
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 11, 11, 64)        0
_________________________________________________________________
conv2d_3 (Conv2D)            (None, 9, 9, 128)         73856
_________________________________________________________________
batch_normalization_3 (Batch (None, 9, 9, 128)         512
_________________________________________________________________
max_pooling2d_3 (MaxPooling2 (None, 4, 4, 128)         0
_________________________________________________________________
flatten_1 (Flatten)          (None, 2048)              0
_________________________________________________________________
dense_1 (Dense)              (None, 128)               262272
_________________________________________________________________
dense_2 (Dense)              (None, 64)                8256
_________________________________________________________________
dense_3 (Dense)              (None, 32)                2080
_________________________________________________________________
dense_4 (Dense)              (None, 2)                 66
=================================================================
Total params: 366,818
Trainable params: 366,370
Non-trainable params: 448
_________________________________________________________________
```

```
In [14]: hist_cnn = cnn.fit(X_train,
                            y_train,
                            batch_size=batch_size,
                            epochs=epochs,
                            verbose=1,
                            validation_data=(X_val,y_val),
                            class_weight = class_weights)
```

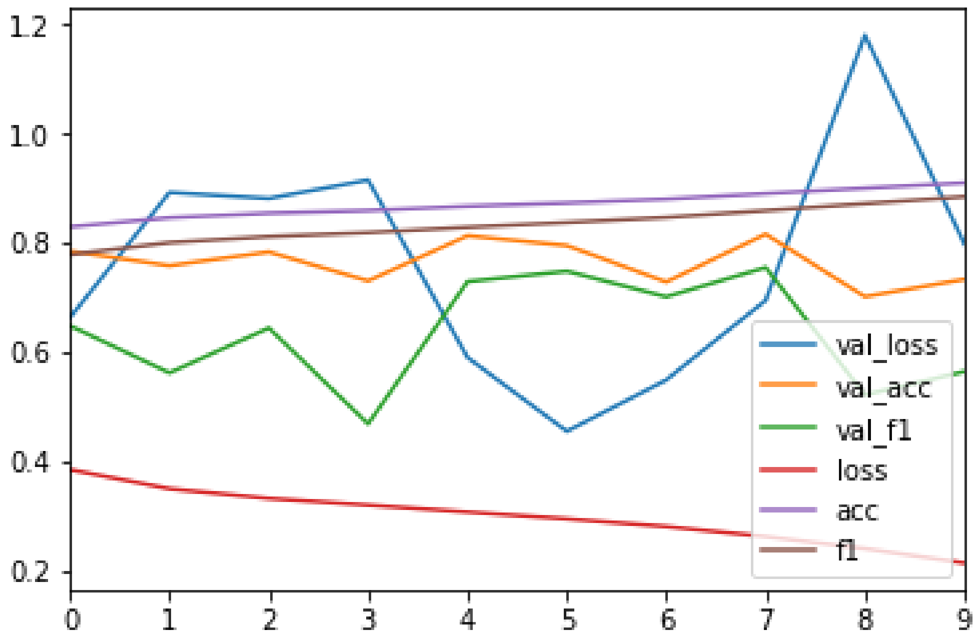
```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/tensorflow/python/ops/math_ops.p
Instructions for updating:
Use tf.cast instead.
Train on 47888 samples, validate on 11973 samples
Epoch 1/10
47888/47888 [==============================] - 17s 346us/step - loss: 0.3855 - acc: 0.8297 - f1
Epoch 2/10
47888/47888 [==============================] - 12s 247us/step - loss: 0.3507 - acc: 0.8463 - f1
Epoch 3/10
47888/47888 [==============================] - 12s 240us/step - loss: 0.3333 - acc: 0.8545 - f1
Epoch 4/10
47888/47888 [==============================] - 12s 241us/step - loss: 0.3211 - acc: 0.8594 - f1
Epoch 5/10
47888/47888 [==============================] - 11s 240us/step - loss: 0.3083 - acc: 0.8673 - f1
Epoch 6/10
47888/47888 [==============================] - 11s 240us/step - loss: 0.2958 - acc: 0.8734 - f1
Epoch 7/10
47888/47888 [==============================] - 11s 240us/step - loss: 0.2817 - acc: 0.8804 - f1
Epoch 8/10
47888/47888 [==============================] - 12s 251us/step - loss: 0.2634 - acc: 0.8905 - f1
Epoch 9/10
47888/47888 [==============================] - 12s 244us/step - loss: 0.2413 - acc: 0.9004 - f1
Epoch 10/10
47888/47888 [==============================] - 12s 240us/step - loss: 0.2151 - acc: 0.9101 - f1
```

```
In [15]: # check test set score
         cnn.evaluate(X_test, y_test)
```

```
14966/14966 [==============================] - 2s 123us/step
```

```
Out[15]: [0.7865344994243064, 0.7386075103408781, 0.5704361179901543]
```

```
In [16]: # visulize
         _ = pd.DataFrame(hist_cnn.history).plot()
```



3 Summary

In this section, we constructed a relatively simple network comprised of some max pooling, convolutional, and bach normalization layers. We trained the model for 10 epochs, and achieved a test set accuracy score of 0.74. Since the classes are somewhat imbalanced, we also developed an F1 scoring metric, which was 0.57 for the test set. These metrics will act as our baseline from here on out.

3.1 3.2 Augment the data using rotations, mirroring and possibly other transformations. How much can you improve your original model by data augmentation?

```
In [0]: # apply ImageDataGenerator to augment data
        from keras.preprocessing.image import ImageDataGenerator

        # apply rotation, shift, zoom and flip
        train_datagen = ImageDataGenerator(
            rotation_range=90,
            width_shift_range=0.2,
            height_shift_range=0.2,
            zoom_range=0.2,
            horizontal_flip=True,
            vertical_flip=True,
            fill_mode='nearest')

        train_datagen.fit(X_train)
```

In [18]:
```python
cnn2 = Sequential()

####### cluster1
cnn2.add(Conv2D(32, kernel_size=(3, 3), activation='relu',
                 input_shape=input_shape))
cnn2.add(BatchNormalization())
cnn2.add(MaxPooling2D(pool_size=(2, 2)))

###### cluster2
cnn2.add(Conv2D(64, (3, 3), activation='relu'))
cnn2.add(BatchNormalization())
cnn2.add(MaxPooling2D(pool_size=(2, 2)))

###### cluster 3
cnn2.add(Conv2D(128, (3, 3), activation='relu'))
cnn2.add(BatchNormalization())
cnn2.add(MaxPooling2D(pool_size=(2, 2)))

##### flat for dense
cnn2.add(Flatten())
cnn2.add(Dense(128, activation='relu'))
cnn2.add(Dense(64, activation='relu'))
cnn2.add(Dense(32, activation='relu'))
cnn2.add(Dense(2, activation='softmax'))

cnn2.compile(optimizer='adam', loss="binary_crossentropy", metrics=['acc', f1])

cnn2.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_4 (Conv2D)            (None, 48, 48, 32)        896
_________________________________________________________________
batch_normalization_4 (Batch (None, 48, 48, 32)        128
_________________________________________________________________
max_pooling2d_4 (MaxPooling2 (None, 24, 24, 32)        0
_________________________________________________________________
conv2d_5 (Conv2D)            (None, 22, 22, 64)        18496
_________________________________________________________________
batch_normalization_5 (Batch (None, 22, 22, 64)        256
_________________________________________________________________
max_pooling2d_5 (MaxPooling2 (None, 11, 11, 64)        0
_________________________________________________________________
conv2d_6 (Conv2D)            (None, 9, 9, 128)         73856
_________________________________________________________________
batch_normalization_6 (Batch (None, 9, 9, 128)         512
_________________________________________________________________
```

```
max_pooling2d_6 (MaxPooling2 (None, 4, 4, 128)         0
_________________________________________________________________
flatten_2 (Flatten)          (None, 2048)              0
_________________________________________________________________
dense_5 (Dense)              (None, 128)               262272
_________________________________________________________________
dense_6 (Dense)              (None, 64)                8256
_________________________________________________________________
dense_7 (Dense)              (None, 32)                2080
_________________________________________________________________
dense_8 (Dense)              (None, 2)                 66
=================================================================
Total params: 366,818
Trainable params: 366,370
Non-trainable params: 448
_________________________________________________________________
```

In [19]:
```
hist_cnn2 = cnn2.fit_generator(
          train_datagen.flow(X_train,y_train, batch_size=batch_size),
          steps_per_epoch = len(X_train) / batch_size,
          epochs = epochs,
          validation_data = (X_val,y_val),
          verbose=1,
          class_weight = class_weights)
```

```
Epoch 1/10
958/957 [==============================] - 40s 42ms/step - loss: 0.3924 - acc: 0.8282 - f1: 0.7
Epoch 2/10
958/957 [==============================] - 40s 41ms/step - loss: 0.3619 - acc: 0.8415 - f1: 0.7
Epoch 3/10
958/957 [==============================] - 38s 40ms/step - loss: 0.3523 - acc: 0.8456 - f1: 0.8
Epoch 4/10
958/957 [==============================] - 39s 41ms/step - loss: 0.3447 - acc: 0.8491 - f1: 0.8
Epoch 5/10
958/957 [==============================] - 38s 39ms/step - loss: 0.3362 - acc: 0.8541 - f1: 0.8
Epoch 6/10
958/957 [==============================] - 39s 41ms/step - loss: 0.3296 - acc: 0.8581 - f1: 0.8
Epoch 7/10
958/957 [==============================] - 38s 39ms/step - loss: 0.3230 - acc: 0.8602 - f1: 0.8
Epoch 8/10
958/957 [==============================] - 39s 41ms/step - loss: 0.3198 - acc: 0.8614 - f1: 0.8
Epoch 9/10
958/957 [==============================] - 38s 40ms/step - loss: 0.3152 - acc: 0.8652 - f1: 0.8
Epoch 10/10
958/957 [==============================] - 40s 42ms/step - loss: 0.3110 - acc: 0.8656 - f1: 0.8
```

In [20]:
```
# check test set score
```

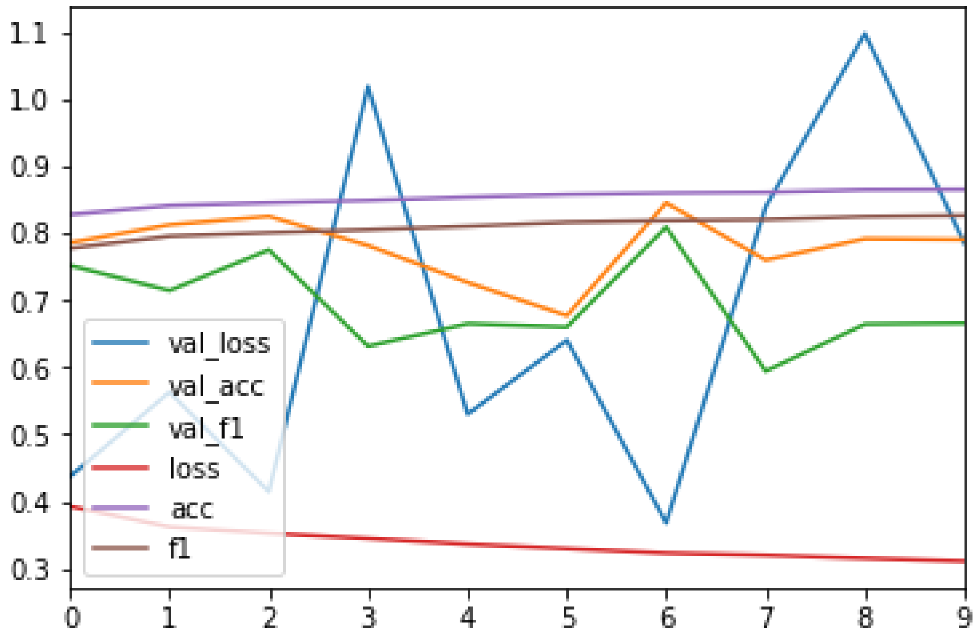
```
cnn2.evaluate(X_test, y_test)
```

```
14966/14966 [==============================] - 2s 126us/step
```

Out[20]: [0.7662685723144167, 0.7940665508167287, 0.6709475991847951]

```
In [21]: # visualize?
         pd.DataFrame(hist_cnn2.history).plot()
```

Out[21]: <matplotlib.axes._subplots.AxesSubplot at 0x7f0b401d7fd0>



4 Summary

In this section, we introduced several transformations to our data, in order to hopefully construct a more robust model. Specifically, we used the ImageGenerator class in Keras to perform rotations of up to 90 degrees, as well as several types of flips, zooms, and shifts.

By training on this transformed data used the same network as in task 3.1, we were able to noticably improve both our test set accuracy and F1 score 0.79 and 0.67, respectively. It should also be noted that the difference between the training and validation set scores were not nearly as large as they were for task 3.1.

5 Taks 3.3

Build a deeper model using residual connections. Show that you can build a deep model that would not be able to learn if you remove the residual connections (i.e. compare a deep model with and without residual connections while the rest of the architecture is constant).

Deep net

```
In [22]: cnn3 = Sequential()

         ####### cluster1
         cnn3.add(Conv2D(4, kernel_size=(3, 3), activation='relu',
                          input_shape=input_shape, padding = 'same'))
         cnn3.add(BatchNormalization())

         # create additional 51 layers
         for i in range(51):
           cnn3.add(Conv2D(4, (3, 3), activation='relu', padding = 'same'))
           cnn3.add(BatchNormalization())

         ##### flat for dense
         cnn3.add(Flatten())
         cnn3.add(Dense(32, activation='relu'))
         cnn3.add(Dense(16, activation='relu'))
         cnn3.add(Dense(2, activation='softmax'))

         cnn3.compile(optimizer='adam', loss="binary_crossentropy", metrics=['acc', f1])

         cnn3.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_7 (Conv2D)            (None, 50, 50, 4)         112
_________________________________________________________________
batch_normalization_7 (Batch (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_8 (Conv2D)            (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_8 (Batch (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_9 (Conv2D)            (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_9 (Batch (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_10 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_10 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_11 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_11 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_12 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
```

```
batch_normalization_12 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_13 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_13 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_14 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_14 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_15 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_15 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_16 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_16 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_17 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_17 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_18 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_18 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_19 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_19 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_20 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_20 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_21 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_21 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_22 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_22 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_23 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_23 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_24 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
```

```
batch_normalization_24 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_25 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_25 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_26 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_26 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_27 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_27 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_28 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_28 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_29 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_29 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_30 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_30 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_31 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_31 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_32 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_32 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_33 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_33 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_34 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_34 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_35 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_35 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_36 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
```

```
batch_normalization_36 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_37 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_37 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_38 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_38 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_39 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_39 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_40 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_40 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_41 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_41 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_42 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_42 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_43 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_43 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_44 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_44 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_45 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_45 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_46 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_46 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_47 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
batch_normalization_47 (Batc (None, 50, 50, 4)        16
_________________________________________________________________
conv2d_48 (Conv2D)           (None, 50, 50, 4)        148
_________________________________________________________________
```

```
batch_normalization_48 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_49 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_49 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_50 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_50 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_51 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_51 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_52 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_52 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_53 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_53 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_54 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_54 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_55 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_55 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_56 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_56 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_57 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_57 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
conv2d_58 (Conv2D)           (None, 50, 50, 4)         148
_________________________________________________________________
batch_normalization_58 (Batc (None, 50, 50, 4)         16
_________________________________________________________________
flatten_3 (Flatten)          (None, 10000)             0
_________________________________________________________________
dense_9 (Dense)              (None, 32)                320032
_________________________________________________________________
dense_10 (Dense)             (None, 16)                528
_________________________________________________________________
```

```
dense_11 (Dense)             (None, 2)                 34
=================================================================
Total params: 329,086
Trainable params: 328,670
Non-trainable params: 416
_________________________________________________________________
```

```
In [23]: hist_cnn3 = cnn3.fit(X_train,
                              y_train,
                              batch_size=batch_size,
                              epochs=epochs,
                              verbose=1,
                              validation_data=(X_val,y_val),
                              class_weight = class_weights)
```

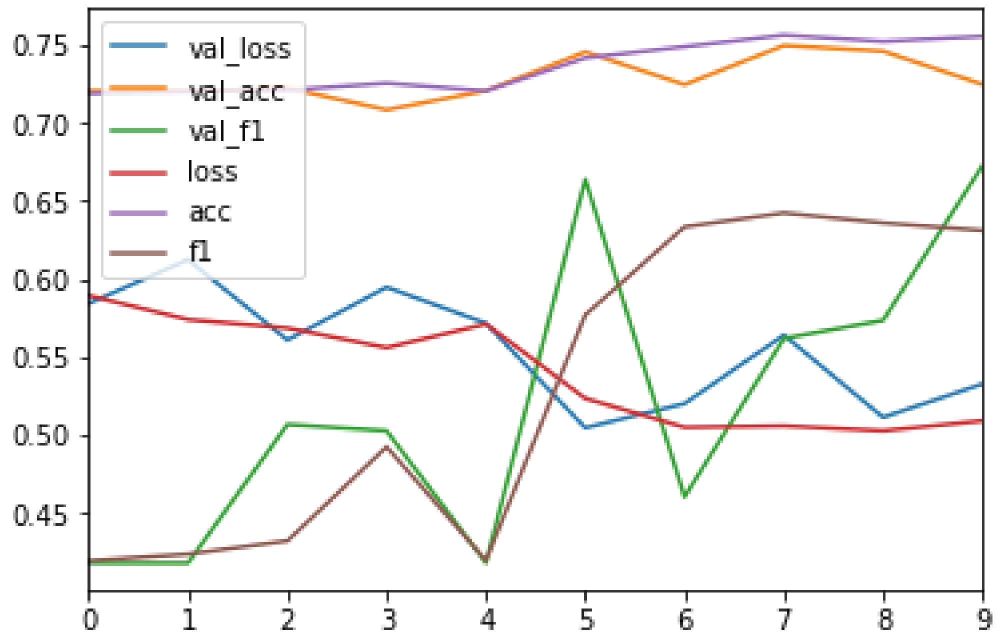
```
Train on 47888 samples, validate on 11973 samples
Epoch 1/10
47888/47888 [==============================] - 81s 2ms/step - loss: 0.5894 - acc: 0.7191 - f1:
Epoch 2/10
47888/47888 [==============================] - 71s 1ms/step - loss: 0.5740 - acc: 0.7202 - f1:
Epoch 3/10
47888/47888 [==============================] - 71s 1ms/step - loss: 0.5686 - acc: 0.7211 - f1:
Epoch 4/10
47888/47888 [==============================] - 72s 1ms/step - loss: 0.5560 - acc: 0.7256 - f1:
Epoch 5/10
47888/47888 [==============================] - 71s 1ms/step - loss: 0.5712 - acc: 0.7206 - f1:
Epoch 6/10
47888/47888 [==============================] - 71s 1ms/step - loss: 0.5235 - acc: 0.7418 - f1:
Epoch 7/10
47888/47888 [==============================] - 71s 1ms/step - loss: 0.5050 - acc: 0.7490 - f1:
Epoch 8/10
47888/47888 [==============================] - 72s 1ms/step - loss: 0.5059 - acc: 0.7564 - f1:
Epoch 9/10
47888/47888 [==============================] - 71s 1ms/step - loss: 0.5028 - acc: 0.7524 - f1:
Epoch 10/10
47888/47888 [==============================] - 71s 1ms/step - loss: 0.5091 - acc: 0.7556 - f1:
```

```
In [24]: # check test set score
         cnn3.evaluate(X_test, y_test)
```

```
14966/14966 [==============================] - 4s 290us/step
```

```
Out[24]: [0.5279028024103781, 0.7272484297661894, 0.6746583132442427]
```

```
In [25]: # visualization
         _ = pd.DataFrame(hist_cnn3.history).plot()
```



Deep ResNet

```
In [26]: from keras.layers import (Dense, Flatten, Conv2D,
                                   BatchNormalization, Input,
                                   add, MaxPooling2D)
         from keras import Model

         num_classes = 2

         inputs = Input(shape=(50,50,3))


         lst = [None] * int(5*13)
         # total 13 * 4 = 52 conv layers
         for i in range(13):
           # 1
           if i == 0:
             lst[0+i*5] = Conv2D(4, (3, 3), activation = 'relu',
                           padding = 'same')(inputs)
           else:
             lst[0+i*5] = Conv2D(4, (3, 3), activation = 'relu',
                           padding = 'same')(lst[4+(i-1)*5])
           # 2
           lst[1+i*5] = Conv2D(4, (3, 3), activation = 'relu',
                           padding = 'same')(lst[0+i*5])
```

```python
        # 3
        lst[2+i*5] = Conv2D(4, (3, 3), activation = 'relu',
                            padding = 'same')(lst[1+i*5])
        # 4
        lst[3+i*5] = Conv2D(4, (3, 3), activation = 'relu',
                            padding = 'same')(lst[2+i*5])
        # skip
        lst[4+i*5] = add([lst[0+i*5], lst[3+i*5]])


    flat = Flatten()(lst[-1])
    dense1 = Dense(32, activation='relu')(flat)
    dense2 = Dense(16, activation='relu')(dense1)
    prediction = Dense(2, activation='softmax')(dense2)

    model = Model(inputs = inputs, outputs = prediction)

    model.compile(optimizer='adam', loss="binary_crossentropy", metrics=['acc', f1])

    model.summary()
```

```
____________________________________________________________________________________________
Layer (type)                    Output Shape         Param #     Connected to
============================================================================================
input_1 (InputLayer)            (None, 50, 50, 3)    0

____________________________________________________________________________________________
conv2d_59 (Conv2D)              (None, 50, 50, 4)    112         input_1[0][0]
____________________________________________________________________________________________
conv2d_60 (Conv2D)              (None, 50, 50, 4)    148         conv2d_59[0][0]
____________________________________________________________________________________________
conv2d_61 (Conv2D)              (None, 50, 50, 4)    148         conv2d_60[0][0]
____________________________________________________________________________________________
conv2d_62 (Conv2D)              (None, 50, 50, 4)    148         conv2d_61[0][0]
____________________________________________________________________________________________
add_1 (Add)                     (None, 50, 50, 4)    0           conv2d_59[0][0]
                                                                 conv2d_62[0][0]
____________________________________________________________________________________________
conv2d_63 (Conv2D)              (None, 50, 50, 4)    148         add_1[0][0]
____________________________________________________________________________________________
conv2d_64 (Conv2D)              (None, 50, 50, 4)    148         conv2d_63[0][0]
____________________________________________________________________________________________
conv2d_65 (Conv2D)              (None, 50, 50, 4)    148         conv2d_64[0][0]
____________________________________________________________________________________________
conv2d_66 (Conv2D)              (None, 50, 50, 4)    148         conv2d_65[0][0]
____________________________________________________________________________________________
add_2 (Add)                     (None, 50, 50, 4)    0           conv2d_63[0][0]
                                                                 conv2d_66[0][0]
____________________________________________________________________________________________
```

```
conv2d_67 (Conv2D)              (None, 50, 50, 4)    148         add_2[0][0]
____________________________________________________________________________________________________
conv2d_68 (Conv2D)              (None, 50, 50, 4)    148         conv2d_67[0][0]
____________________________________________________________________________________________________
conv2d_69 (Conv2D)              (None, 50, 50, 4)    148         conv2d_68[0][0]
____________________________________________________________________________________________________
conv2d_70 (Conv2D)              (None, 50, 50, 4)    148         conv2d_69[0][0]
____________________________________________________________________________________________________
add_3 (Add)                     (None, 50, 50, 4)    0           conv2d_67[0][0]
                                                                 conv2d_70[0][0]
____________________________________________________________________________________________________
conv2d_71 (Conv2D)              (None, 50, 50, 4)    148         add_3[0][0]
____________________________________________________________________________________________________
conv2d_72 (Conv2D)              (None, 50, 50, 4)    148         conv2d_71[0][0]
____________________________________________________________________________________________________
conv2d_73 (Conv2D)              (None, 50, 50, 4)    148         conv2d_72[0][0]
____________________________________________________________________________________________________
conv2d_74 (Conv2D)              (None, 50, 50, 4)    148         conv2d_73[0][0]
____________________________________________________________________________________________________
add_4 (Add)                     (None, 50, 50, 4)    0           conv2d_71[0][0]
                                                                 conv2d_74[0][0]
____________________________________________________________________________________________________
conv2d_75 (Conv2D)              (None, 50, 50, 4)    148         add_4[0][0]
____________________________________________________________________________________________________
conv2d_76 (Conv2D)              (None, 50, 50, 4)    148         conv2d_75[0][0]
____________________________________________________________________________________________________
conv2d_77 (Conv2D)              (None, 50, 50, 4)    148         conv2d_76[0][0]
____________________________________________________________________________________________________
conv2d_78 (Conv2D)              (None, 50, 50, 4)    148         conv2d_77[0][0]
____________________________________________________________________________________________________
add_5 (Add)                     (None, 50, 50, 4)    0           conv2d_75[0][0]
                                                                 conv2d_78[0][0]
____________________________________________________________________________________________________
conv2d_79 (Conv2D)              (None, 50, 50, 4)    148         add_5[0][0]
____________________________________________________________________________________________________
conv2d_80 (Conv2D)              (None, 50, 50, 4)    148         conv2d_79[0][0]
____________________________________________________________________________________________________
conv2d_81 (Conv2D)              (None, 50, 50, 4)    148         conv2d_80[0][0]
____________________________________________________________________________________________________
conv2d_82 (Conv2D)              (None, 50, 50, 4)    148         conv2d_81[0][0]
____________________________________________________________________________________________________
add_6 (Add)                     (None, 50, 50, 4)    0           conv2d_79[0][0]
                                                                 conv2d_82[0][0]
____________________________________________________________________________________________________
conv2d_83 (Conv2D)              (None, 50, 50, 4)    148         add_6[0][0]
____________________________________________________________________________________________________
conv2d_84 (Conv2D)              (None, 50, 50, 4)    148         conv2d_83[0][0]
____________________________________________________________________________________________________
```

conv2d_85 (Conv2D)	(None, 50, 50, 4)	148	conv2d_84[0][0]
conv2d_86 (Conv2D)	(None, 50, 50, 4)	148	conv2d_85[0][0]
add_7 (Add)	(None, 50, 50, 4)	0	conv2d_83[0][0] conv2d_86[0][0]
conv2d_87 (Conv2D)	(None, 50, 50, 4)	148	add_7[0][0]
conv2d_88 (Conv2D)	(None, 50, 50, 4)	148	conv2d_87[0][0]
conv2d_89 (Conv2D)	(None, 50, 50, 4)	148	conv2d_88[0][0]
conv2d_90 (Conv2D)	(None, 50, 50, 4)	148	conv2d_89[0][0]
add_8 (Add)	(None, 50, 50, 4)	0	conv2d_87[0][0] conv2d_90[0][0]
conv2d_91 (Conv2D)	(None, 50, 50, 4)	148	add_8[0][0]
conv2d_92 (Conv2D)	(None, 50, 50, 4)	148	conv2d_91[0][0]
conv2d_93 (Conv2D)	(None, 50, 50, 4)	148	conv2d_92[0][0]
conv2d_94 (Conv2D)	(None, 50, 50, 4)	148	conv2d_93[0][0]
add_9 (Add)	(None, 50, 50, 4)	0	conv2d_91[0][0] conv2d_94[0][0]
conv2d_95 (Conv2D)	(None, 50, 50, 4)	148	add_9[0][0]
conv2d_96 (Conv2D)	(None, 50, 50, 4)	148	conv2d_95[0][0]
conv2d_97 (Conv2D)	(None, 50, 50, 4)	148	conv2d_96[0][0]
conv2d_98 (Conv2D)	(None, 50, 50, 4)	148	conv2d_97[0][0]
add_10 (Add)	(None, 50, 50, 4)	0	conv2d_95[0][0] conv2d_98[0][0]
conv2d_99 (Conv2D)	(None, 50, 50, 4)	148	add_10[0][0]
conv2d_100 (Conv2D)	(None, 50, 50, 4)	148	conv2d_99[0][0]
conv2d_101 (Conv2D)	(None, 50, 50, 4)	148	conv2d_100[0][0]
conv2d_102 (Conv2D)	(None, 50, 50, 4)	148	conv2d_101[0][0]

```
add_11 (Add)                    (None, 50, 50, 4)    0            conv2d_99[0][0]
                                                                  conv2d_102[0][0]
__________________________________________________________________________________________________
conv2d_103 (Conv2D)             (None, 50, 50, 4)    148          add_11[0][0]
__________________________________________________________________________________________________
conv2d_104 (Conv2D)             (None, 50, 50, 4)    148          conv2d_103[0][0]
__________________________________________________________________________________________________
conv2d_105 (Conv2D)             (None, 50, 50, 4)    148          conv2d_104[0][0]
__________________________________________________________________________________________________
conv2d_106 (Conv2D)             (None, 50, 50, 4)    148          conv2d_105[0][0]
__________________________________________________________________________________________________
add_12 (Add)                    (None, 50, 50, 4)    0            conv2d_103[0][0]
                                                                  conv2d_106[0][0]
__________________________________________________________________________________________________
conv2d_107 (Conv2D)             (None, 50, 50, 4)    148          add_12[0][0]
__________________________________________________________________________________________________
conv2d_108 (Conv2D)             (None, 50, 50, 4)    148          conv2d_107[0][0]
__________________________________________________________________________________________________
conv2d_109 (Conv2D)             (None, 50, 50, 4)    148          conv2d_108[0][0]
__________________________________________________________________________________________________
conv2d_110 (Conv2D)             (None, 50, 50, 4)    148          conv2d_109[0][0]
__________________________________________________________________________________________________
add_13 (Add)                    (None, 50, 50, 4)    0            conv2d_107[0][0]
                                                                  conv2d_110[0][0]
__________________________________________________________________________________________________
flatten_4 (Flatten)             (None, 10000)        0            add_13[0][0]
__________________________________________________________________________________________________
dense_12 (Dense)                (None, 32)           320032       flatten_4[0][0]
__________________________________________________________________________________________________
dense_13 (Dense)                (None, 16)           528          dense_12[0][0]
__________________________________________________________________________________________________
dense_14 (Dense)                (None, 2)            34           dense_13[0][0]
==================================================================================================
Total params: 328,254
Trainable params: 328,254
Non-trainable params: 0
__________________________________________________________________________________________________
```

In [27]:
```
hist_cnn4 = model.fit(X_train,
                      y_train,
                      batch_size=batch_size,
                      epochs=epochs,
                      verbose=1,
                      validation_data=(X_val,y_val),
                      class_weight = class_weights
                     )
```

```
Train on 47888 samples, validate on 11973 samples
```

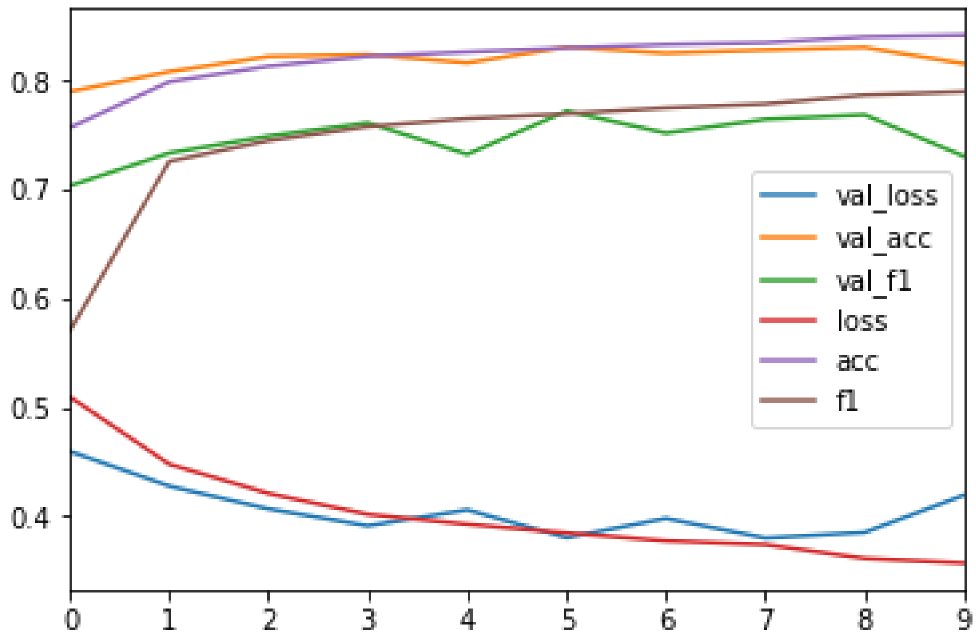
```
Epoch 1/10
47888/47888 [==============================] - 45s 930us/step - loss: 0.5096 - acc: 0.7569 - f1
Epoch 2/10
47888/47888 [==============================] - 39s 823us/step - loss: 0.4476 - acc: 0.7992 - f1
Epoch 3/10
47888/47888 [==============================] - 40s 826us/step - loss: 0.4209 - acc: 0.8135 - f1
Epoch 4/10
47888/47888 [==============================] - 40s 838us/step - loss: 0.4016 - acc: 0.8226 - f1
Epoch 5/10
47888/47888 [==============================] - 40s 834us/step - loss: 0.3925 - acc: 0.8266 - f1
Epoch 6/10
47888/47888 [==============================] - 39s 825us/step - loss: 0.3845 - acc: 0.8302 - f1
Epoch 7/10
47888/47888 [==============================] - 40s 827us/step - loss: 0.3772 - acc: 0.8335 - f1
Epoch 8/10
47888/47888 [==============================] - 40s 826us/step - loss: 0.3738 - acc: 0.8352 - f1
Epoch 9/10
47888/47888 [==============================] - 40s 828us/step - loss: 0.3610 - acc: 0.8405 - f1
Epoch 10/10
47888/47888 [==============================] - 40s 827us/step - loss: 0.3569 - acc: 0.8421 - f1
```

In [28]:
```
model.evaluate(X_test, y_test)
```

```
14966/14966 [==============================] - 3s 224us/step
```

Out[28]:
```
[0.4136357147330733, 0.8196578912599256, 0.7326452597153309]
```

In [29]:
```
# visualize
_ = pd.DataFrame(hist_cnn4.history).plot()
```



6 Summary

In this final section, we began by building a very deep model with 52 convolutional layers and no residual connections. This ultimately proved to be very ineffective, as the model was too deep to properly learn the data, as evidenced by the training set accuracy and F1 scores of 0.73 and 0.67, respectively. This was almost below our very basic network that we constructed in task 3.1.

For the second part of the task, we added residual connections between every 4 convolutional layers, which turned out to be very effective. The test set performance increased to our best model yet, with accuracy and F1 scores of 0.82 and 0.73, respectively.