新冠肺炎CT图像识别

案例目标：通过迁移学习识别感染和未感染新冠的CT图像

教学目的：（1）学习使用数据生成器进行训练集和测试集的生成；（2）掌握迁移学习模型的使用（3）对感染了新冠肺炎和未感染新冠肺炎的CT进行自动识别；（4）尝试使用不同的迁移学习模型进行训练并对比不同模型的效果

相关知识点：（1）ImageDataGenerator的使用；（2）数据增强处理的基本技巧；（3）迁移学习Inception V3模型；（4）对给定的CT图像进行预测，判断其感染新冠肺炎的概率

一、背景介绍

新冠肺炎疫情自爆发以来迅速在全球蔓延，毒株的变异更是增强了新冠肺炎病毒的传播能力，欧美地区感染人数仍在飞速增加，中国部分地区也出现多轮疫情反复，新冠肺炎疫情仍然影响着人们的正常生活，威胁着人们的生命健康。本案例使用SARS-CoV-2 CT-scan公开数据集（https://www.kaggle.com/datasets/plameneduardo/sarscov2-ctscan-dataset (https://www.kaggle.com/datasets/plameneduardo/sarscov2-ctscan-dataset)），通过构建迁移学习模型（Inception V3）对CT图像进行分类，尝试高效区分感染和未感染新冠肺炎的CT图像。

二、数据准备

SARS-CoV-2 CT-scan数据集是收集自巴西圣保罗医院真实患者的公开数据集，该数据集的图片以.png格式存储，共包含感染新冠肺炎的CT图片1252张，未感染新冠肺炎的CT图片1229张。所有数据存储在data文件夹下，首先展示目录存储结构，之所以这样进行数据存储，是为了后续构建数据生成器。

In [1]:
```
import os
print(os.listdir('./data'))                      #展示data文件夹
print(os.listdir('./data/train'))                #展示train文件夹
print(os.listdir('./data/validation'))           #展示validation
文件夹
```

```
['train', 'validation']
['COVID-negative', 'COVID-positive']
['COVID-negative', 'COVID-positive']
```

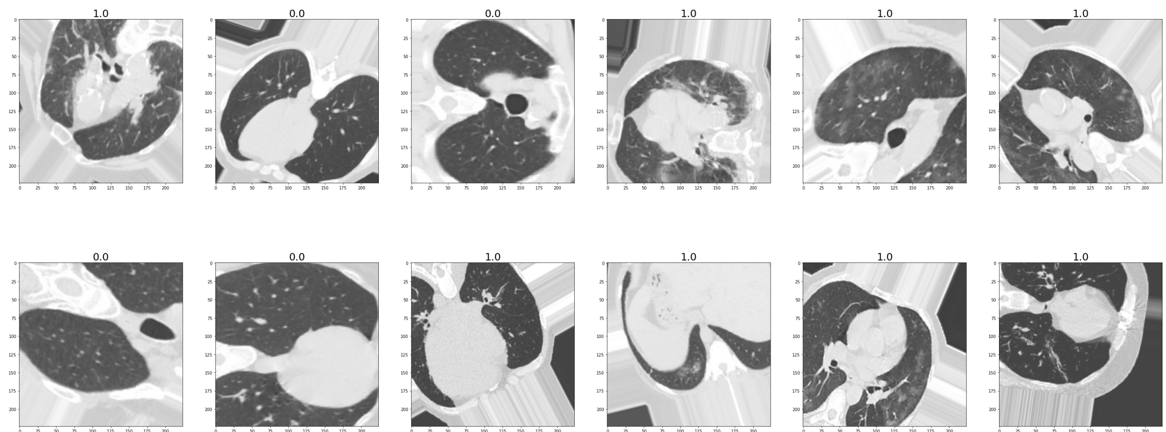
由于数据量太大，无法一次性读入显存，因此需要建立一个数据生成器，其中训练数据集的生成器需要做数据增强操作，而校验集的数据生成器不需要。

```
In [2]: from keras.preprocessing.image import ImageDataGenerator

IMAGE_SIZE = 224                                                  #设置图片大小

train_generator = ImageDataGenerator(                             #训练集数据生成器（需要进行数据增强）
                        rescale=1./255,                           #将图片像素取值转换至0-1之间
                        rotation_range=360,                       #图片旋转
                        width_shift_range=0.2,                    #水平方向平移
                        height_shift_range=0.2,                   #竖直方向平移
                        zoom_range=0.2,                           #图片缩放
                        horizontal_flip=True,                     #随机水平翻转
                        vertical_flip=True).flow_from_directory(  #随机数值翻转
                        './data/train',                           #设置读取路径
                        target_size=(IMAGE_SIZE,IMAGE_SIZE),      #将图片调整至统一大小
                        batch_size=64,                            #每批次的样本量设置为256
                        class_mode='categorical',                 #声明分类问题
                        shuffle = True)                           #随机打乱

validation_generator=ImageDataGenerator(                          #校验集数据生成器（无需数据增强）
                        rescale=1./255).flow_from_directory(      #将图片像素取值转换至0-1之间
                        './data/validation',                      #设置读取路径
                        target_size=(IMAGE_SIZE,IMAGE_SIZE),      #将图片调整至统一大小
                        batch_size=64,                            #每批次的样本量设置为256
                        class_mode='categorical',                 #声明为分类问题
                        shuffle=False)                            #不在每个epoch之前打乱排序（方便后续预测）
```

```
Found 1737 images belonging to 2 classes.
Found 744 images belonging to 2 classes.
```

深度学习代码实践中经常涉及到非常复杂的数据处理。疏漏错误实在难免。因此，所有的数据读取过程，最好都需要一个可视化肉眼核实确认的环节。为此，我们选取一个批次的部分训练集数据进行展示。其中1为感染新冠，0为未感染新冠。

In [3]:
```python
from matplotlib import pyplot as plt

X,Y=next(train_generator)                          #取出一批训练数据
fig,ax=plt.subplots(2,6)                           #生成画布并切分
fig.set_figheight(20)                              #设置高度
fig.set_figwidth(50)                               #设置宽度
ax=ax.flatten()                                    #拉直画布
for i in range(12):                                #依次展示图片
    ax[i].imshow(X[i])                             #展示训练图像
    ax[i].set_title(Y[i,1],fontsize=25)            #将其Y值作为标题展示
```



三、模型训练：迁移学习Inception V3

“迁移学习”是指将某个领域或任务上学习到的知识或模式运用到不同、但相关的领域或问题中。我们可以使用Keras中的迁移学习模型，站在前人的肩膀上，将别人的模型结构和参数训练结果应用在自己的模型中，从而快速且相对准确地得到预测结果。本案例中，我们迁移Inception V3作为基础模型，将基础模型的输出继续输入全局池化层、BN层、Dropout层和全连接层进行相应操作后，得到模型的最终输出。

In [8]:
```
from tensorflow.keras.applications.inception_v3 import InceptionV3
from tensorflow.keras import Model
from tensorflow.keras.layers import Dense, Dropout, Flatten, Conv2D, MaxPoo
l2D, BatchNormalization, AveragePooling2D, GlobalAveragePooling2D, Activati
on
from tensorflow.keras.optimizers import Adam,SGD

base_model = InceptionV3(weights='imagenet', include_top=False)  #基础模型In
ception V3，设置迁移的模型不包含全连接层
x = base_model.output                                             #取基础模型
的输出
x = GlobalAveragePooling2D()(x)                                   #全局池化
x = BatchNormalization()(x)                                       #BN层
x = Dropout(0.7)(x)                                               #Dropout避
免过拟合，修改为0.7
x = Dense(256, activation='relu')(x)                              #第一个全连
接层
x = BatchNormalization()(x)                                       #再次进行BN
操作
x = Dropout(0.7)(x)                                                #修改为0.7
predictions = Dense(2, activation = 'softmax')(x)                 #第二个全连
接层，得到输出
model = Model(inputs = base_model.input, outputs = predictions)  #建立模型，
声明输入、输出
for layer in base_model.layers:
    layer.trainable = False                                       #直接迁移训
练好的Inception V3模型，设置基础模型每一层的参数都不需要训练
model.summary()                                                   #打印模型概
要表
```

```
Model: "model_2"
__________________________________________________________________________________________________
Layer (type)                    Output Shape         Param #     Connected to
==================================================================================================
input_3 (InputLayer)            [(None, None, None,  0
__________________________________________________________________________________________________
conv2d_188 (Conv2D)             (None, None, None, 3 864         input_3[0][0]
__________________________________________________________________________________________________
batch_normalization_193 (BatchN (None, None, None, 3 96          conv2d_188[0][0]
__________________________________________________________________________________________________
activation_188 (Activation)     (None, None, None, 3 0           batch_normalization_193[0][0]
__________________________________________________________________________________________________
conv2d_189 (Conv2D)             (None, None, None, 3 9216        activation_188[0][0]
__________________________________________________________________________________________________
batch_normalization_194 (BatchN (None, None, None, 3 96          conv2d_189[0][0]
__________________________________________________________________________________________________
activation_189 (Activation)     (None, None, None, 3 0           batch_normalization_194[0][0]
__________________________________________________________________________________________________
conv2d_190 (Conv2D)             (None, None, None, 6 18432       activation_189[0][0]
__________________________________________________________________________________________________
batch_normalization_195 (BatchN (None, None, None, 6 192         conv2d_190[0][0]
__________________________________________________________________________________________________
activation_190 (Activation)     (None, None, None, 6 0           batch_normalization_195[0][0]
__________________________________________________________________________________________________
max_pooling2d_8 (MaxPooling2D)  (None, None, None, 6 0           activation_190[0][0]
__________________________________________________________________________________________________
conv2d_191 (Conv2D)             (None, None, None, 8 5120        max_pooling2d_8[0][0]
__________________________________________________________________________________________________
batch_normalization_196 (BatchN (None, None, None, 8 240         conv2d_191[0][0]
```

```
__________________________________________________________________________________________________
activation_191 (Activation)     (None, None, None, 8 0           batch_normalization_196[0][0]
__________________________________________________________________________________________________
conv2d_192 (Conv2D)             (None, None, None, 1 138240      activation_191[0][0]
__________________________________________________________________________________________________
batch_normalization_197 (BatchN (None, None, None, 1 576         conv2d_192[0][0]
__________________________________________________________________________________________________
activation_192 (Activation)     (None, None, None, 1 0           batch_normalization_197[0][0]
__________________________________________________________________________________________________
max_pooling2d_9 (MaxPooling2D)  (None, None, None, 1 0           activation_192[0][0]
__________________________________________________________________________________________________
conv2d_196 (Conv2D)             (None, None, None, 6 12288       max_pooling2d_9[0][0]
__________________________________________________________________________________________________
batch_normalization_201 (BatchN (None, None, None, 6 192         conv2d_196[0][0]
__________________________________________________________________________________________________
activation_196 (Activation)     (None, None, None, 6 0           batch_normalization_201[0][0]
__________________________________________________________________________________________________
conv2d_194 (Conv2D)             (None, None, None, 4 9216        max_pooling2d_9[0][0]
__________________________________________________________________________________________________
conv2d_197 (Conv2D)             (None, None, None, 9 55296       activation_196[0][0]
__________________________________________________________________________________________________
batch_normalization_199 (BatchN (None, None, None, 4 144         conv2d_194[0][0]
__________________________________________________________________________________________________
batch_normalization_202 (BatchN (None, None, None, 9 288         conv2d_197[0][0]
__________________________________________________________________________________________________
activation_194 (Activation)     (None, None, None, 4 0           batch_normalization_199[0][0]
__________________________________________________________________________________________________
activation_197 (Activation)     (None, None, None, 9 0           batch_normalization_202[0][0]
```

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__________________________________________________________________________________________________
average_pooling2d_18 (AveragePo (None, None, None, 1 0           max_poolin
g2d_9[0][0]
__________________________________________________________________________________________________
conv2d_193 (Conv2D)             (None, None, None, 6 12288       max_poolin
g2d_9[0][0]
__________________________________________________________________________________________________
conv2d_195 (Conv2D)             (None, None, None, 6 76800       activation
_194[0][0]
__________________________________________________________________________________________________
conv2d_198 (Conv2D)             (None, None, None, 9 82944       activation
_197[0][0]
__________________________________________________________________________________________________
conv2d_199 (Conv2D)             (None, None, None, 3 6144        average_po
oling2d_18[0][0]
__________________________________________________________________________________________________
batch_normalization_198 (BatchN (None, None, None, 6 192         conv2d_193
[0][0]
__________________________________________________________________________________________________
batch_normalization_200 (BatchN (None, None, None, 6 192         conv2d_195
[0][0]
__________________________________________________________________________________________________
batch_normalization_203 (BatchN (None, None, None, 9 288         conv2d_198
[0][0]
__________________________________________________________________________________________________
batch_normalization_204 (BatchN (None, None, None, 3 96          conv2d_199
[0][0]
__________________________________________________________________________________________________
activation_193 (Activation)     (None, None, None, 6 0           batch_norm
alization_198[0][0]
__________________________________________________________________________________________________
activation_195 (Activation)     (None, None, None, 6 0           batch_norm
alization_200[0][0]
__________________________________________________________________________________________________
activation_198 (Activation)     (None, None, None, 9 0           batch_norm
alization_203[0][0]
__________________________________________________________________________________________________
activation_199 (Activation)     (None, None, None, 3 0           batch_norm
alization_204[0][0]
__________________________________________________________________________________________________
mixed0 (Concatenate)            (None, None, None, 2 0           activation
_193[0][0]
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                                                                          activation
_195[0][0]
                                                                          activation
_198[0][0]
                                                                          activation
_199[0][0]
__________________________________________________________________________________________________
conv2d_203 (Conv2D)             (None, None, None, 6 16384       mixed0
[0][0]
__________________________________________________________________________________________________
batch_normalization_208 (BatchN (None, None, None, 6 192         conv2d_203
[0][0]
__________________________________________________________________________________________________
activation_203 (Activation)     (None, None, None, 6 0           batch_norm
alization_208[0][0]
__________________________________________________________________________________________________
conv2d_201 (Conv2D)             (None, None, None, 4 12288       mixed0
[0][0]
__________________________________________________________________________________________________
conv2d_204 (Conv2D)             (None, None, None, 9 55296       activation
_203[0][0]
__________________________________________________________________________________________________
batch_normalization_206 (BatchN (None, None, None, 4 144         conv2d_201
[0][0]
__________________________________________________________________________________________________
batch_normalization_209 (BatchN (None, None, None, 9 288         conv2d_204
[0][0]
__________________________________________________________________________________________________
activation_201 (Activation)     (None, None, None, 4 0           batch_norm
alization_206[0][0]
__________________________________________________________________________________________________
activation_204 (Activation)     (None, None, None, 9 0           batch_norm
alization_209[0][0]
__________________________________________________________________________________________________
average_pooling2d_19 (AveragePo (None, None, None, 2 0           mixed0
[0][0]
__________________________________________________________________________________________________
conv2d_200 (Conv2D)             (None, None, None, 6 16384       mixed0
[0][0]
__________________________________________________________________________________________________
conv2d_202 (Conv2D)             (None, None, None, 6 76800       activation
_201[0][0]
__________________________________________________________________________________________________
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conv2d_205 (Conv2D)            (None, None, None, 9 82944       activation
_204[0][0]
__________________________________________________________________________________________________
conv2d_206 (Conv2D)            (None, None, None, 6 16384       average_po
oling2d_19[0][0]
__________________________________________________________________________________________________
batch_normalization_205 (BatchN (None, None, None, 6 192         conv2d_200
[0][0]
__________________________________________________________________________________________________
batch_normalization_207 (BatchN (None, None, None, 6 192         conv2d_202
[0][0]
__________________________________________________________________________________________________
batch_normalization_210 (BatchN (None, None, None, 9 288         conv2d_205
[0][0]
__________________________________________________________________________________________________
batch_normalization_211 (BatchN (None, None, None, 6 192         conv2d_206
[0][0]
__________________________________________________________________________________________________
activation_200 (Activation)    (None, None, None, 6 0           batch_norm
alization_205[0][0]
__________________________________________________________________________________________________
activation_202 (Activation)    (None, None, None, 6 0           batch_norm
alization_207[0][0]
__________________________________________________________________________________________________
activation_205 (Activation)    (None, None, None, 9 0           batch_norm
alization_210[0][0]
__________________________________________________________________________________________________
activation_206 (Activation)    (None, None, None, 6 0           batch_norm
alization_211[0][0]
__________________________________________________________________________________________________
mixed1 (Concatenate)           (None, None, None, 2 0           activation
_200[0][0]
                                                                 activation
_202[0][0]
                                                                 activation
_205[0][0]
                                                                 activation
_206[0][0]
__________________________________________________________________________________________________
conv2d_210 (Conv2D)            (None, None, None, 6 18432       mixed1
[0][0]
__________________________________________________________________________________________________
batch_normalization_215 (BatchN (None, None, None, 6 192         conv2d_210
[0][0]
```

```
__________________________________________________________________________________________________
activation_210 (Activation)     (None, None, None, 6 0           batch_normalization_215[0][0]
__________________________________________________________________________________________________
conv2d_208 (Conv2D)             (None, None, None, 4 13824       mixed1[0][0]
__________________________________________________________________________________________________
conv2d_211 (Conv2D)             (None, None, None, 9 55296       activation_210[0][0]
__________________________________________________________________________________________________
batch_normalization_213 (BatchN (None, None, None, 4 144         conv2d_208[0][0]
__________________________________________________________________________________________________
batch_normalization_216 (BatchN (None, None, None, 9 288         conv2d_211[0][0]
__________________________________________________________________________________________________
activation_208 (Activation)     (None, None, None, 4 0           batch_normalization_213[0][0]
__________________________________________________________________________________________________
activation_211 (Activation)     (None, None, None, 9 0           batch_normalization_216[0][0]
__________________________________________________________________________________________________
average_pooling2d_20 (AveragePo (None, None, None, 2 0           mixed1[0][0]
__________________________________________________________________________________________________
conv2d_207 (Conv2D)             (None, None, None, 6 18432       mixed1[0][0]
__________________________________________________________________________________________________
conv2d_209 (Conv2D)             (None, None, None, 6 76800       activation_208[0][0]
__________________________________________________________________________________________________
conv2d_212 (Conv2D)             (None, None, None, 9 82944       activation_211[0][0]
__________________________________________________________________________________________________
conv2d_213 (Conv2D)             (None, None, None, 6 18432       average_pooling2d_20[0][0]
__________________________________________________________________________________________________
batch_normalization_212 (BatchN (None, None, None, 6 192         conv2d_207[0][0]
__________________________________________________________________________________________________
batch_normalization_214 (BatchN (None, None, None, 6 192         conv2d_209[0][0]
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__________________________________________________________________________________________________
batch_normalization_217 (BatchN (None, None, None, 9 288         conv2d_212[0][0]
__________________________________________________________________________________________________
batch_normalization_218 (BatchN (None, None, None, 6 192         conv2d_213[0][0]
__________________________________________________________________________________________________
activation_207 (Activation)     (None, None, None, 6 0           batch_normalization_212[0][0]
__________________________________________________________________________________________________
activation_209 (Activation)     (None, None, None, 6 0           batch_normalization_214[0][0]
__________________________________________________________________________________________________
activation_212 (Activation)     (None, None, None, 9 0           batch_normalization_217[0][0]
__________________________________________________________________________________________________
activation_213 (Activation)     (None, None, None, 6 0           batch_normalization_218[0][0]
__________________________________________________________________________________________________
mixed2 (Concatenate)            (None, None, None, 2 0           activation_207[0][0]
                                                                 activation_209[0][0]
                                                                 activation_212[0][0]
                                                                 activation_213[0][0]
__________________________________________________________________________________________________
conv2d_215 (Conv2D)             (None, None, None, 6 18432       mixed2[0][0]
__________________________________________________________________________________________________
batch_normalization_220 (BatchN (None, None, None, 6 192         conv2d_215[0][0]
__________________________________________________________________________________________________
activation_215 (Activation)     (None, None, None, 6 0           batch_normalization_220[0][0]
__________________________________________________________________________________________________
conv2d_216 (Conv2D)             (None, None, None, 9 55296       activation_215[0][0]
__________________________________________________________________________________________________
batch_normalization_221 (BatchN (None, None, None, 9 288         conv2d_216[0][0]
__________________________________________________________________________________________________
```

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activation_216 (Activation)     (None, None, None, 9 0           batch_norm
alization_221[0][0]
__________________________________________________________________________
______________________
conv2d_214 (Conv2D)             (None, None, None, 3 995328      mixed2
[0][0]
__________________________________________________________________________
______________________
conv2d_217 (Conv2D)             (None, None, None, 9 82944       activation
_216[0][0]
__________________________________________________________________________
______________________
batch_normalization_219 (BatchN (None, None, None, 3 1152        conv2d_214
[0][0]
__________________________________________________________________________
______________________
batch_normalization_222 (BatchN (None, None, None, 9 288         conv2d_217
[0][0]
__________________________________________________________________________
______________________
activation_214 (Activation)     (None, None, None, 3 0           batch_norm
alization_219[0][0]
__________________________________________________________________________
______________________
activation_217 (Activation)     (None, None, None, 9 0           batch_norm
alization_222[0][0]
__________________________________________________________________________
______________________
max_pooling2d_10 (MaxPooling2D) (None, None, None, 2 0           mixed2
[0][0]
__________________________________________________________________________
______________________
mixed3 (Concatenate)            (None, None, None, 7 0           activation
_214[0][0]
                                                                 activation
_217[0][0]
                                                                 max_poolin
g2d_10[0][0]
__________________________________________________________________________
______________________
conv2d_222 (Conv2D)             (None, None, None, 1 98304       mixed3
[0][0]
__________________________________________________________________________
______________________
batch_normalization_227 (BatchN (None, None, None, 1 384         conv2d_222
[0][0]
__________________________________________________________________________
______________________
activation_222 (Activation)     (None, None, None, 1 0           batch_norm
alization_227[0][0]
__________________________________________________________________________
______________________
conv2d_223 (Conv2D)             (None, None, None, 1 114688      activation
_222[0][0]
__________________________________________________________________________
______________________
```

```
batch_normalization_228 (BatchN (None, None, None, 1 384         conv2d_223
[0][0]
__________________________________________________________________________________________________
activation_223 (Activation)     (None, None, None, 1 0           batch_norm
alization_228[0][0]
__________________________________________________________________________________________________
conv2d_219 (Conv2D)             (None, None, None, 1 98304       mixed3
[0][0]
__________________________________________________________________________________________________
conv2d_224 (Conv2D)             (None, None, None, 1 114688      activation
_223[0][0]
__________________________________________________________________________________________________
batch_normalization_224 (BatchN (None, None, None, 1 384         conv2d_219
[0][0]
__________________________________________________________________________________________________
batch_normalization_229 (BatchN (None, None, None, 1 384         conv2d_224
[0][0]
__________________________________________________________________________________________________
activation_219 (Activation)     (None, None, None, 1 0           batch_norm
alization_224[0][0]
__________________________________________________________________________________________________
activation_224 (Activation)     (None, None, None, 1 0           batch_norm
alization_229[0][0]
__________________________________________________________________________________________________
conv2d_220 (Conv2D)             (None, None, None, 1 114688      activation
_219[0][0]
__________________________________________________________________________________________________
conv2d_225 (Conv2D)             (None, None, None, 1 114688      activation
_224[0][0]
__________________________________________________________________________________________________
batch_normalization_225 (BatchN (None, None, None, 1 384         conv2d_220
[0][0]
__________________________________________________________________________________________________
batch_normalization_230 (BatchN (None, None, None, 1 384         conv2d_225
[0][0]
__________________________________________________________________________________________________
activation_220 (Activation)     (None, None, None, 1 0           batch_norm
alization_225[0][0]
__________________________________________________________________________________________________
activation_225 (Activation)     (None, None, None, 1 0           batch_norm
alization_230[0][0]
__________________________________________________________________________________________________
```

```
average_pooling2d_21 (AveragePo (None, None, None, 7 0           mixed3
[0][0]
__________________________________________________________________________
______________________
conv2d_218 (Conv2D)             (None, None, None, 1 147456      mixed3
[0][0]
__________________________________________________________________________
______________________
conv2d_221 (Conv2D)             (None, None, None, 1 172032      activation
_220[0][0]
__________________________________________________________________________
______________________
conv2d_226 (Conv2D)             (None, None, None, 1 172032      activation
_225[0][0]
__________________________________________________________________________
______________________
conv2d_227 (Conv2D)             (None, None, None, 1 147456      average_po
oling2d_21[0][0]
__________________________________________________________________________
______________________
batch_normalization_223 (BatchN (None, None, None, 1 576         conv2d_218
[0][0]
__________________________________________________________________________
______________________
batch_normalization_226 (BatchN (None, None, None, 1 576         conv2d_221
[0][0]
__________________________________________________________________________
______________________
batch_normalization_231 (BatchN (None, None, None, 1 576         conv2d_226
[0][0]
__________________________________________________________________________
______________________
batch_normalization_232 (BatchN (None, None, None, 1 576         conv2d_227
[0][0]
__________________________________________________________________________
______________________
activation_218 (Activation)     (None, None, None, 1 0           batch_norm
alization_223[0][0]
__________________________________________________________________________
______________________
activation_221 (Activation)     (None, None, None, 1 0           batch_norm
alization_226[0][0]
__________________________________________________________________________
______________________
activation_226 (Activation)     (None, None, None, 1 0           batch_norm
alization_231[0][0]
__________________________________________________________________________
______________________
activation_227 (Activation)     (None, None, None, 1 0           batch_norm
alization_232[0][0]
__________________________________________________________________________
______________________
mixed4 (Concatenate)            (None, None, None, 7 0           activation
_218[0][0]
                                                                 activation
_221[0][0]
```

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                                                                  activation
_226[0][0]
                                                                  activation
_227[0][0]
__________________________________________________________________________________
______________________
conv2d_232 (Conv2D)             (None, None, None, 1 122880      mixed4
[0][0]
__________________________________________________________________________________
______________________
batch_normalization_237 (BatchN (None, None, None, 1 480         conv2d_232
[0][0]
__________________________________________________________________________________
______________________
activation_232 (Activation)     (None, None, None, 1 0           batch_norm
alization_237[0][0]
__________________________________________________________________________________
______________________
conv2d_233 (Conv2D)             (None, None, None, 1 179200      activation
_232[0][0]
__________________________________________________________________________________
______________________
batch_normalization_238 (BatchN (None, None, None, 1 480         conv2d_233
[0][0]
__________________________________________________________________________________
______________________
activation_233 (Activation)     (None, None, None, 1 0           batch_norm
alization_238[0][0]
__________________________________________________________________________________
______________________
conv2d_229 (Conv2D)             (None, None, None, 1 122880      mixed4
[0][0]
__________________________________________________________________________________
______________________
conv2d_234 (Conv2D)             (None, None, None, 1 179200      activation
_233[0][0]
__________________________________________________________________________________
______________________
batch_normalization_234 (BatchN (None, None, None, 1 480         conv2d_229
[0][0]
__________________________________________________________________________________
______________________
batch_normalization_239 (BatchN (None, None, None, 1 480         conv2d_234
[0][0]
__________________________________________________________________________________
______________________
activation_229 (Activation)     (None, None, None, 1 0           batch_norm
alization_234[0][0]
__________________________________________________________________________________
______________________
activation_234 (Activation)     (None, None, None, 1 0           batch_norm
alization_239[0][0]
__________________________________________________________________________________
______________________
conv2d_230 (Conv2D)             (None, None, None, 1 179200      activation
_229[0][0]
```

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__________________________________________________________________________________________________
conv2d_235 (Conv2D)             (None, None, None, 1 179200      activation
_234[0][0]
__________________________________________________________________________________________________
batch_normalization_235 (BatchN (None, None, None, 1 480         conv2d_230
[0][0]
__________________________________________________________________________________________________
batch_normalization_240 (BatchN (None, None, None, 1 480         conv2d_235
[0][0]
__________________________________________________________________________________________________
activation_230 (Activation)     (None, None, None, 1 0           batch_norm
alization_235[0][0]
__________________________________________________________________________________________________
activation_235 (Activation)     (None, None, None, 1 0           batch_norm
alization_240[0][0]
__________________________________________________________________________________________________
average_pooling2d_22 (AveragePo (None, None, None, 7 0           mixed4
[0][0]
__________________________________________________________________________________________________
conv2d_228 (Conv2D)             (None, None, None, 1 147456      mixed4
[0][0]
__________________________________________________________________________________________________
conv2d_231 (Conv2D)             (None, None, None, 1 215040      activation
_230[0][0]
__________________________________________________________________________________________________
conv2d_236 (Conv2D)             (None, None, None, 1 215040      activation
_235[0][0]
__________________________________________________________________________________________________
conv2d_237 (Conv2D)             (None, None, None, 1 147456      average_po
oling2d_22[0][0]
__________________________________________________________________________________________________
batch_normalization_233 (BatchN (None, None, None, 1 576         conv2d_228
[0][0]
__________________________________________________________________________________________________
batch_normalization_236 (BatchN (None, None, None, 1 576         conv2d_231
[0][0]
__________________________________________________________________________________________________
batch_normalization_241 (BatchN (None, None, None, 1 576         conv2d_236
[0][0]
__________________________________________________________________________________________________
batch_normalization_242 (BatchN (None, None, None, 1 576         conv2d_237
[0][0]
```

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__________________________________________________________________________________________________
activation_228 (Activation)     (None, None, None, 1 0           batch_norm
alization_233[0][0]
__________________________________________________________________________________________________
activation_231 (Activation)     (None, None, None, 1 0           batch_norm
alization_236[0][0]
__________________________________________________________________________________________________
activation_236 (Activation)     (None, None, None, 1 0           batch_norm
alization_241[0][0]
__________________________________________________________________________________________________
activation_237 (Activation)     (None, None, None, 1 0           batch_norm
alization_242[0][0]
__________________________________________________________________________________________________
mixed5 (Concatenate)            (None, None, None, 7 0           activation
_228[0][0]
                                                                 activation
_231[0][0]
                                                                 activation
_236[0][0]
                                                                 activation
_237[0][0]
__________________________________________________________________________________________________
conv2d_242 (Conv2D)             (None, None, None, 1 122880      mixed5
[0][0]
__________________________________________________________________________________________________
batch_normalization_247 (BatchN (None, None, None, 1 480         conv2d_242
[0][0]
__________________________________________________________________________________________________
activation_242 (Activation)     (None, None, None, 1 0           batch_norm
alization_247[0][0]
__________________________________________________________________________________________________
conv2d_243 (Conv2D)             (None, None, None, 1 179200      activation
_242[0][0]
__________________________________________________________________________________________________
batch_normalization_248 (BatchN (None, None, None, 1 480         conv2d_243
[0][0]
__________________________________________________________________________________________________
activation_243 (Activation)     (None, None, None, 1 0           batch_norm
alization_248[0][0]
__________________________________________________________________________________________________
conv2d_239 (Conv2D)             (None, None, None, 1 122880      mixed5
[0][0]
__________________________________________________________________________________________________
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```
conv2d_244 (Conv2D)            (None, None, None, 1 179200      activation
_243[0][0]
__________________________________________________________________________
______________________
batch_normalization_244 (BatchN (None, None, None, 1 480         conv2d_239
[0][0]
__________________________________________________________________________
______________________
batch_normalization_249 (BatchN (None, None, None, 1 480         conv2d_244
[0][0]
__________________________________________________________________________
______________________
activation_239 (Activation)     (None, None, None, 1 0           batch_norm
alization_244[0][0]
__________________________________________________________________________
______________________
activation_244 (Activation)     (None, None, None, 1 0           batch_norm
alization_249[0][0]
__________________________________________________________________________
______________________
conv2d_240 (Conv2D)             (None, None, None, 1 179200      activation
_239[0][0]
__________________________________________________________________________
______________________
conv2d_245 (Conv2D)             (None, None, None, 1 179200      activation
_244[0][0]
__________________________________________________________________________
______________________
batch_normalization_245 (BatchN (None, None, None, 1 480         conv2d_240
[0][0]
__________________________________________________________________________
______________________
batch_normalization_250 (BatchN (None, None, None, 1 480         conv2d_245
[0][0]
__________________________________________________________________________
______________________
activation_240 (Activation)     (None, None, None, 1 0           batch_norm
alization_245[0][0]
__________________________________________________________________________
______________________
activation_245 (Activation)     (None, None, None, 1 0           batch_norm
alization_250[0][0]
__________________________________________________________________________
______________________
average_pooling2d_23 (AveragePo (None, None, None, 7 0           mixed5
[0][0]
__________________________________________________________________________
______________________
conv2d_238 (Conv2D)             (None, None, None, 1 147456      mixed5
[0][0]
__________________________________________________________________________
______________________
conv2d_241 (Conv2D)             (None, None, None, 1 215040      activation
_240[0][0]
__________________________________________________________________________
______________________
```

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conv2d_246 (Conv2D)             (None, None, None, 1 215040      activation
_245[0][0]
__________________________________________________________________________________________________
conv2d_247 (Conv2D)             (None, None, None, 1 147456      average_po
oling2d_23[0][0]
__________________________________________________________________________________________________
batch_normalization_243 (BatchN (None, None, None, 1 576         conv2d_238
[0][0]
__________________________________________________________________________________________________
batch_normalization_246 (BatchN (None, None, None, 1 576         conv2d_241
[0][0]
__________________________________________________________________________________________________
batch_normalization_251 (BatchN (None, None, None, 1 576         conv2d_246
[0][0]
__________________________________________________________________________________________________
batch_normalization_252 (BatchN (None, None, None, 1 576         conv2d_247
[0][0]
__________________________________________________________________________________________________
activation_238 (Activation)     (None, None, None, 1 0           batch_norm
alization_243[0][0]
__________________________________________________________________________________________________
activation_241 (Activation)     (None, None, None, 1 0           batch_norm
alization_246[0][0]
__________________________________________________________________________________________________
activation_246 (Activation)     (None, None, None, 1 0           batch_norm
alization_251[0][0]
__________________________________________________________________________________________________
activation_247 (Activation)     (None, None, None, 1 0           batch_norm
alization_252[0][0]
__________________________________________________________________________________________________
mixed6 (Concatenate)            (None, None, None, 7 0           activation
_238[0][0]
                                                                 activation
_241[0][0]
                                                                 activation
_246[0][0]
                                                                 activation
_247[0][0]
__________________________________________________________________________________________________
conv2d_252 (Conv2D)             (None, None, None, 1 147456      mixed6
[0][0]
__________________________________________________________________________________________________
batch_normalization_257 (BatchN (None, None, None, 1 576         conv2d_252
[0][0]
```

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________________________________________________________________________________
__________________________
activation_252 (Activation)     (None, None, None, 1 0           batch_norm
alization_257[0][0]
________________________________________________________________________________
__________________________
conv2d_253 (Conv2D)             (None, None, None, 1 258048      activation
_252[0][0]
________________________________________________________________________________
__________________________
batch_normalization_258 (BatchN (None, None, None, 1 576         conv2d_253
[0][0]
________________________________________________________________________________
__________________________
activation_253 (Activation)     (None, None, None, 1 0           batch_norm
alization_258[0][0]
________________________________________________________________________________
__________________________
conv2d_249 (Conv2D)             (None, None, None, 1 147456      mixed6
[0][0]
________________________________________________________________________________
__________________________
conv2d_254 (Conv2D)             (None, None, None, 1 258048      activation
_253[0][0]
________________________________________________________________________________
__________________________
batch_normalization_254 (BatchN (None, None, None, 1 576         conv2d_249
[0][0]
________________________________________________________________________________
__________________________
batch_normalization_259 (BatchN (None, None, None, 1 576         conv2d_254
[0][0]
________________________________________________________________________________
__________________________
activation_249 (Activation)     (None, None, None, 1 0           batch_norm
alization_254[0][0]
________________________________________________________________________________
__________________________
activation_254 (Activation)     (None, None, None, 1 0           batch_norm
alization_259[0][0]
________________________________________________________________________________
__________________________
conv2d_250 (Conv2D)             (None, None, None, 1 258048      activation
_249[0][0]
________________________________________________________________________________
__________________________
conv2d_255 (Conv2D)             (None, None, None, 1 258048      activation
_254[0][0]
________________________________________________________________________________
__________________________
batch_normalization_255 (BatchN (None, None, None, 1 576         conv2d_250
[0][0]
________________________________________________________________________________
__________________________
batch_normalization_260 (BatchN (None, None, None, 1 576         conv2d_255
[0][0]
```

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________________________________________________________________________________
__________________________
activation_250 (Activation)     (None, None, None, 1 0          batch_norm
alization_255[0][0]
________________________________________________________________________________
__________________________
activation_255 (Activation)     (None, None, None, 1 0          batch_norm
alization_260[0][0]
________________________________________________________________________________
__________________________
average_pooling2d_24 (AveragePo (None, None, None, 7 0          mixed6
[0][0]
________________________________________________________________________________
__________________________
conv2d_248 (Conv2D)             (None, None, None, 1 147456     mixed6
[0][0]
________________________________________________________________________________
__________________________
conv2d_251 (Conv2D)             (None, None, None, 1 258048     activation
_250[0][0]
________________________________________________________________________________
__________________________
conv2d_256 (Conv2D)             (None, None, None, 1 258048     activation
_255[0][0]
________________________________________________________________________________
__________________________
conv2d_257 (Conv2D)             (None, None, None, 1 147456     average_po
oling2d_24[0][0]
________________________________________________________________________________
__________________________
batch_normalization_253 (BatchN (None, None, None, 1 576        conv2d_248
[0][0]
________________________________________________________________________________
__________________________
batch_normalization_256 (BatchN (None, None, None, 1 576        conv2d_251
[0][0]
________________________________________________________________________________
__________________________
batch_normalization_261 (BatchN (None, None, None, 1 576        conv2d_256
[0][0]
________________________________________________________________________________
__________________________
batch_normalization_262 (BatchN (None, None, None, 1 576        conv2d_257
[0][0]
________________________________________________________________________________
__________________________
activation_248 (Activation)     (None, None, None, 1 0          batch_norm
alization_253[0][0]
________________________________________________________________________________
__________________________
activation_251 (Activation)     (None, None, None, 1 0          batch_norm
alization_256[0][0]
________________________________________________________________________________
__________________________
activation_256 (Activation)     (None, None, None, 1 0          batch_norm
alization_261[0][0]
```

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__________________________________________________________________________________________________
activation_257 (Activation)     (None, None, None, 1 0           batch_norm
alization_262[0][0]
__________________________________________________________________________________________________
mixed7 (Concatenate)            (None, None, None, 7 0           activation
_248[0][0]
                                                                 activation
_251[0][0]
                                                                 activation
_256[0][0]
                                                                 activation
_257[0][0]
__________________________________________________________________________________________________
conv2d_260 (Conv2D)             (None, None, None, 1 147456      mixed7
[0][0]
__________________________________________________________________________________________________
batch_normalization_265 (BatchN (None, None, None, 1 576         conv2d_260
[0][0]
__________________________________________________________________________________________________
activation_260 (Activation)     (None, None, None, 1 0           batch_norm
alization_265[0][0]
__________________________________________________________________________________________________
conv2d_261 (Conv2D)             (None, None, None, 1 258048      activation
_260[0][0]
__________________________________________________________________________________________________
batch_normalization_266 (BatchN (None, None, None, 1 576         conv2d_261
[0][0]
__________________________________________________________________________________________________
activation_261 (Activation)     (None, None, None, 1 0           batch_norm
alization_266[0][0]
__________________________________________________________________________________________________
conv2d_258 (Conv2D)             (None, None, None, 1 147456      mixed7
[0][0]
__________________________________________________________________________________________________
conv2d_262 (Conv2D)             (None, None, None, 1 258048      activation
_261[0][0]
__________________________________________________________________________________________________
batch_normalization_263 (BatchN (None, None, None, 1 576         conv2d_258
[0][0]
__________________________________________________________________________________________________
batch_normalization_267 (BatchN (None, None, None, 1 576         conv2d_262
[0][0]
__________________________________________________________________________________________________
```

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activation_258 (Activation)     (None, None, None, 1 0           batch_norm
alization_263[0][0]
__________________________________________________________________________________________________
activation_262 (Activation)     (None, None, None, 1 0           batch_norm
alization_267[0][0]
__________________________________________________________________________________________________
conv2d_259 (Conv2D)             (None, None, None, 3 552960      activation
_258[0][0]
__________________________________________________________________________________________________
conv2d_263 (Conv2D)             (None, None, None, 1 331776      activation
_262[0][0]
__________________________________________________________________________________________________
batch_normalization_264 (BatchN (None, None, None, 3 960         conv2d_259
[0][0]
__________________________________________________________________________________________________
batch_normalization_268 (BatchN (None, None, None, 1 576         conv2d_263
[0][0]
__________________________________________________________________________________________________
activation_259 (Activation)     (None, None, None, 3 0           batch_norm
alization_264[0][0]
__________________________________________________________________________________________________
activation_263 (Activation)     (None, None, None, 1 0           batch_norm
alization_268[0][0]
__________________________________________________________________________________________________
max_pooling2d_11 (MaxPooling2D) (None, None, None, 7 0           mixed7
[0][0]
__________________________________________________________________________________________________
mixed8 (Concatenate)            (None, None, None, 1 0           activation
_259[0][0]
                                                                 activation
_263[0][0]
                                                                 max_poolin
g2d_11[0][0]
__________________________________________________________________________________________________
conv2d_268 (Conv2D)             (None, None, None, 4 573440      mixed8
[0][0]
__________________________________________________________________________________________________
batch_normalization_273 (BatchN (None, None, None, 4 1344        conv2d_268
[0][0]
__________________________________________________________________________________________________
activation_268 (Activation)     (None, None, None, 4 0           batch_norm
alization_273[0][0]
__________________________________________________________________________________________________
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conv2d_265 (Conv2D)            (None, None, None, 3 491520      mixed8
[0][0]
__________________________________________________________________________________________________
conv2d_269 (Conv2D)            (None, None, None, 3 1548288     activation
_268[0][0]
__________________________________________________________________________________________________
batch_normalization_270 (BatchN (None, None, None, 3 1152        conv2d_265
[0][0]
__________________________________________________________________________________________________
batch_normalization_274 (BatchN (None, None, None, 3 1152        conv2d_269
[0][0]
__________________________________________________________________________________________________
activation_265 (Activation)    (None, None, None, 3 0           batch_norm
alization_270[0][0]
__________________________________________________________________________________________________
activation_269 (Activation)    (None, None, None, 3 0           batch_norm
alization_274[0][0]
__________________________________________________________________________________________________
conv2d_266 (Conv2D)            (None, None, None, 3 442368      activation
_265[0][0]
__________________________________________________________________________________________________
conv2d_267 (Conv2D)            (None, None, None, 3 442368      activation
_265[0][0]
__________________________________________________________________________________________________
conv2d_270 (Conv2D)            (None, None, None, 3 442368      activation
_269[0][0]
__________________________________________________________________________________________________
conv2d_271 (Conv2D)            (None, None, None, 3 442368      activation
_269[0][0]
__________________________________________________________________________________________________
average_pooling2d_25 (AveragePo (None, None, None, 1 0           mixed8
[0][0]
__________________________________________________________________________________________________
conv2d_264 (Conv2D)            (None, None, None, 3 409600      mixed8
[0][0]
__________________________________________________________________________________________________
batch_normalization_271 (BatchN (None, None, None, 3 1152        conv2d_266
[0][0]
__________________________________________________________________________________________________
batch_normalization_272 (BatchN (None, None, None, 3 1152        conv2d_267
[0][0]
__________________________________________________________________________________________________
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batch_normalization_275 (BatchN (None, None, None, 3 1152        conv2d_270
[0][0]
__________________________________________________________________________
__________________________
batch_normalization_276 (BatchN (None, None, None, 3 1152        conv2d_271
[0][0]
__________________________________________________________________________
__________________________
conv2d_272 (Conv2D)             (None, None, None, 1 245760      average_po
oling2d_25[0][0]
__________________________________________________________________________
__________________________
batch_normalization_269 (BatchN (None, None, None, 3 960         conv2d_264
[0][0]
__________________________________________________________________________
__________________________
activation_266 (Activation)     (None, None, None, 3 0           batch_norm
alization_271[0][0]
__________________________________________________________________________
__________________________
activation_267 (Activation)     (None, None, None, 3 0           batch_norm
alization_272[0][0]
__________________________________________________________________________
__________________________
activation_270 (Activation)     (None, None, None, 3 0           batch_norm
alization_275[0][0]
__________________________________________________________________________
__________________________
activation_271 (Activation)     (None, None, None, 3 0           batch_norm
alization_276[0][0]
__________________________________________________________________________
__________________________
batch_normalization_277 (BatchN (None, None, None, 1 576         conv2d_272
[0][0]
__________________________________________________________________________
__________________________
activation_264 (Activation)     (None, None, None, 3 0           batch_norm
alization_269[0][0]
__________________________________________________________________________
__________________________
mixed9_0 (Concatenate)          (None, None, None, 7 0           activation
_266[0][0]
                                                                 activation
_267[0][0]
__________________________________________________________________________
__________________________
concatenate_4 (Concatenate)     (None, None, None, 7 0           activation
_270[0][0]
                                                                 activation
_271[0][0]
__________________________________________________________________________
__________________________
activation_272 (Activation)     (None, None, None, 1 0           batch_norm
alization_277[0][0]
__________________________________________________________________________
__________________________
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mixed9 (Concatenate)            (None, None, None, 2 0           activation
_264[0][0]
                                                                 mixed9_0
[0][0]
                                                                 concatenat
e_4[0][0]
                                                                 activation
_272[0][0]
__________________________________________________________________________________________________
conv2d_277 (Conv2D)             (None, None, None, 4 917504      mixed9
[0][0]
__________________________________________________________________________________________________
batch_normalization_282 (BatchN (None, None, None, 4 1344        conv2d_277
[0][0]
__________________________________________________________________________________________________
activation_277 (Activation)     (None, None, None, 4 0           batch_norm
alization_282[0][0]
__________________________________________________________________________________________________
conv2d_274 (Conv2D)             (None, None, None, 3 786432      mixed9
[0][0]
__________________________________________________________________________________________________
conv2d_278 (Conv2D)             (None, None, None, 3 1548288     activation
_277[0][0]
__________________________________________________________________________________________________
batch_normalization_279 (BatchN (None, None, None, 3 1152        conv2d_274
[0][0]
__________________________________________________________________________________________________
batch_normalization_283 (BatchN (None, None, None, 3 1152        conv2d_278
[0][0]
__________________________________________________________________________________________________
activation_274 (Activation)     (None, None, None, 3 0           batch_norm
alization_279[0][0]
__________________________________________________________________________________________________
activation_278 (Activation)     (None, None, None, 3 0           batch_norm
alization_283[0][0]
__________________________________________________________________________________________________
conv2d_275 (Conv2D)             (None, None, None, 3 442368      activation
_274[0][0]
__________________________________________________________________________________________________
conv2d_276 (Conv2D)             (None, None, None, 3 442368      activation
_274[0][0]
__________________________________________________________________________________________________
conv2d_279 (Conv2D)             (None, None, None, 3 442368      activation
_278[0][0]
```

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__________________________________________________________________________________________________
conv2d_280 (Conv2D)             (None, None, None, 3 442368      activation
_278[0][0]
__________________________________________________________________________________________________
average_pooling2d_26 (AveragePo (None, None, None, 2 0           mixed9
[0][0]
__________________________________________________________________________________________________
conv2d_273 (Conv2D)             (None, None, None, 3 655360      mixed9
[0][0]
__________________________________________________________________________________________________
batch_normalization_280 (BatchN (None, None, None, 3 1152        conv2d_275
[0][0]
__________________________________________________________________________________________________
batch_normalization_281 (BatchN (None, None, None, 3 1152        conv2d_276
[0][0]
__________________________________________________________________________________________________
batch_normalization_284 (BatchN (None, None, None, 3 1152        conv2d_279
[0][0]
__________________________________________________________________________________________________
batch_normalization_285 (BatchN (None, None, None, 3 1152        conv2d_280
[0][0]
__________________________________________________________________________________________________
conv2d_281 (Conv2D)             (None, None, None, 1 393216      average_po
oling2d_26[0][0]
__________________________________________________________________________________________________
batch_normalization_278 (BatchN (None, None, None, 3 960         conv2d_273
[0][0]
__________________________________________________________________________________________________
activation_275 (Activation)     (None, None, None, 3 0           batch_norm
alization_280[0][0]
__________________________________________________________________________________________________
activation_276 (Activation)     (None, None, None, 3 0           batch_norm
alization_281[0][0]
__________________________________________________________________________________________________
activation_279 (Activation)     (None, None, None, 3 0           batch_norm
alization_284[0][0]
__________________________________________________________________________________________________
activation_280 (Activation)     (None, None, None, 3 0           batch_norm
alization_285[0][0]
__________________________________________________________________________________________________
batch_normalization_286 (BatchN (None, None, None, 1 576         conv2d_281
[0][0]
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__________________________________________________________________________________________________
activation_273 (Activation)     (None, None, None, 3 0           batch_normalization_278[0][0]
__________________________________________________________________________________________________
mixed9_1 (Concatenate)          (None, None, None, 7 0           activation_275[0][0]
                                                                 activation_276[0][0]
__________________________________________________________________________________________________
concatenate_5 (Concatenate)     (None, None, None, 7 0           activation_279[0][0]
                                                                 activation_280[0][0]
__________________________________________________________________________________________________
activation_281 (Activation)     (None, None, None, 1 0           batch_normalization_286[0][0]
__________________________________________________________________________________________________
mixed10 (Concatenate)           (None, None, None, 2 0           activation_273[0][0]
                                                                 mixed9_1[0][0]
                                                                 concatenate_5[0][0]
                                                                 activation_281[0][0]
__________________________________________________________________________________________________
global_average_pooling2d_2 (Glo (None, 2048)         0           mixed10[0][0]
__________________________________________________________________________________________________
batch_normalization_287 (BatchN (None, 2048)         8192        global_average_pooling2d_2[0][0]
__________________________________________________________________________________________________
dropout_5 (Dropout)             (None, 2048)         0           batch_normalization_287[0][0]
__________________________________________________________________________________________________
dense_5 (Dense)                 (None, 256)          524544      dropout_5[0][0]
__________________________________________________________________________________________________
batch_normalization_288 (BatchN (None, 256)          1024        dense_5[0][0]
__________________________________________________________________________________________________
dropout_6 (Dropout)             (None, 256)          0           batch_normalization_288[0][0]
__________________________________________________________________________________________________
```

接下来做模型训练，可以模型看到在15个epoch循环后，达到70%左右的精度。

In [11]:
```
#模型编译，采用交叉熵损失函数和SGD优化器，打印训练的精度和损失，Adam修改为SGD
model.compile(loss='categorical_crossentropy', optimizer=SGD(learning_rate=
0.002,momentum=0.9), metrics=['accuracy'])
model.fit(train_generator,
#指定训练集
          epochs=30,
#设置轮次为30
          validation_data=validation_generator,workers = 12)
#设置校验集并开启多线程运算
```

```
Epoch 1/30
28/28 [==============================] - 23s 567ms/step - loss: 0.5519 - ac
curacy: 0.7265 - val_loss: 0.5038 - val_accuracy: 0.7460
Epoch 2/30
28/28 [==============================] - 17s 429ms/step - loss: 0.5437 - ac
curacy: 0.7427 - val_loss: 0.5116 - val_accuracy: 0.7487
Epoch 3/30
28/28 [==============================] - 15s 400ms/step - loss: 0.5055 - ac
curacy: 0.7524 - val_loss: 0.5148 - val_accuracy: 0.7446
Epoch 4/30
28/28 [==============================] - 16s 428ms/step - loss: 0.5015 - ac
curacy: 0.7565 - val_loss: 0.5084 - val_accuracy: 0.7527
Epoch 5/30
28/28 [==============================] - 16s 425ms/step - loss: 0.5100 - ac
curacy: 0.7478 - val_loss: 0.5129 - val_accuracy: 0.7379
Epoch 6/30
28/28 [==============================] - 16s 417ms/step - loss: 0.5116 - ac
curacy: 0.7455 - val_loss: 0.5133 - val_accuracy: 0.7500
Epoch 7/30
28/28 [==============================] - 16s 416ms/step - loss: 0.5014 - ac
curacy: 0.7559 - val_loss: 0.5171 - val_accuracy: 0.7352
Epoch 8/30
28/28 [==============================] - 15s 437ms/step - loss: 0.5083 - ac
curacy: 0.7582 - val_loss: 0.5129 - val_accuracy: 0.7460
Epoch 9/30
28/28 [==============================] - 15s 411ms/step - loss: 0.5015 - ac
curacy: 0.7599 - val_loss: 0.5056 - val_accuracy: 0.7567
Epoch 10/30
28/28 [==============================] - 16s 422ms/step - loss: 0.5098 - ac
curacy: 0.7547 - val_loss: 0.5047 - val_accuracy: 0.7648
Epoch 11/30
28/28 [==============================] - 16s 430ms/step - loss: 0.5089 - ac
curacy: 0.7547 - val_loss: 0.5035 - val_accuracy: 0.7527
Epoch 12/30
28/28 [==============================] - 16s 438ms/step - loss: 0.4882 - ac
curacy: 0.7605 - val_loss: 0.5030 - val_accuracy: 0.7513
Epoch 13/30
28/28 [==============================] - 16s 432ms/step - loss: 0.5080 - ac
curacy: 0.7651 - val_loss: 0.5140 - val_accuracy: 0.7352
Epoch 14/30
28/28 [==============================] - 16s 433ms/step - loss: 0.4842 - ac
curacy: 0.7841 - val_loss: 0.5165 - val_accuracy: 0.7406
Epoch 15/30
28/28 [==============================] - 15s 426ms/step - loss: 0.4924 - ac
curacy: 0.7668 - val_loss: 0.5167 - val_accuracy: 0.7473
Epoch 16/30
28/28 [==============================] - 16s 428ms/step - loss: 0.5161 - ac
curacy: 0.7444 - val_loss: 0.5293 - val_accuracy: 0.7218
Epoch 17/30
28/28 [==============================] - 16s 428ms/step - loss: 0.4877 - ac
curacy: 0.7686 - val_loss: 0.5259 - val_accuracy: 0.7164
Epoch 18/30
28/28 [==============================] - 16s 427ms/step - loss: 0.4984 - ac
curacy: 0.7530 - val_loss: 0.5188 - val_accuracy: 0.7406
Epoch 19/30
28/28 [==============================] - 15s 539ms/step - loss: 0.4974 - ac
```

```
curacy: 0.7542 - val_loss: 0.5267 - val_accuracy: 0.7272
Epoch 20/30
28/28 [==============================] - 16s 434ms/step - loss: 0.5078 - ac
curacy: 0.7617 - val_loss: 0.5080 - val_accuracy: 0.7446
Epoch 21/30
28/28 [==============================] - 16s 443ms/step - loss: 0.5148 - ac
curacy: 0.7513 - val_loss: 0.5140 - val_accuracy: 0.7339
Epoch 22/30
28/28 [==============================] - 15s 404ms/step - loss: 0.5004 - ac
curacy: 0.7691 - val_loss: 0.5136 - val_accuracy: 0.7446
Epoch 23/30
28/28 [==============================] - 16s 407ms/step - loss: 0.5148 - ac
curacy: 0.7478 - val_loss: 0.5082 - val_accuracy: 0.7500
Epoch 24/30
28/28 [==============================] - 15s 403ms/step - loss: 0.4930 - ac
curacy: 0.7559 - val_loss: 0.5071 - val_accuracy: 0.7513
Epoch 25/30
28/28 [==============================] - 16s 431ms/step - loss: 0.4853 - ac
curacy: 0.7680 - val_loss: 0.5098 - val_accuracy: 0.7513
Epoch 26/30
28/28 [==============================] - 16s 423ms/step - loss: 0.4963 - ac
curacy: 0.7634 - val_loss: 0.5173 - val_accuracy: 0.7392
Epoch 27/30
28/28 [==============================] - 16s 408ms/step - loss: 0.4907 - ac
curacy: 0.7622 - val_loss: 0.5066 - val_accuracy: 0.7567
Epoch 28/30
28/28 [==============================] - 15s 377ms/step - loss: 0.4822 - ac
curacy: 0.7761 - val_loss: 0.4978 - val_accuracy: 0.7581
Epoch 29/30
28/28 [==============================] - 16s 413ms/step - loss: 0.4837 - ac
curacy: 0.7714 - val_loss: 0.4997 - val_accuracy: 0.7554
Epoch 30/30
28/28 [==============================] - 16s 440ms/step - loss: 0.4825 - ac
curacy: 0.7645 - val_loss: 0.5032 - val_accuracy: 0.7594
```

Out[11]:
```
<keras.callbacks.History at 0x7f6964f29280>
```

四、模型评估

绘制ROC曲线并计算AUC取值。

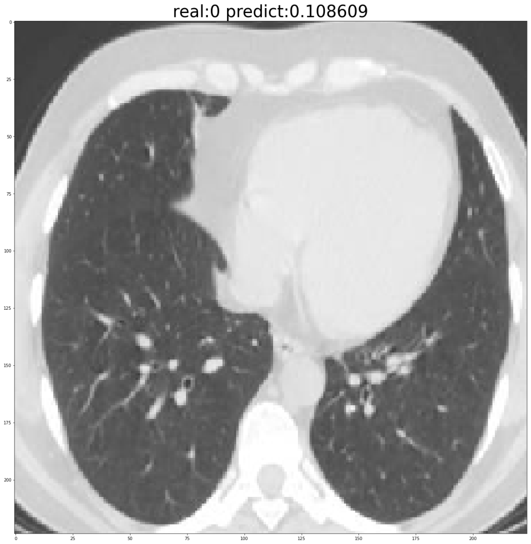
首先将测试集图片并带入模型进行预测。

In [18]:
```
Yscore = model.predict(validation_generator)[:,1]          #带入模型进行预测得输出概率
Ytrue=validation_generator.classes                          #数据的真实标签
```

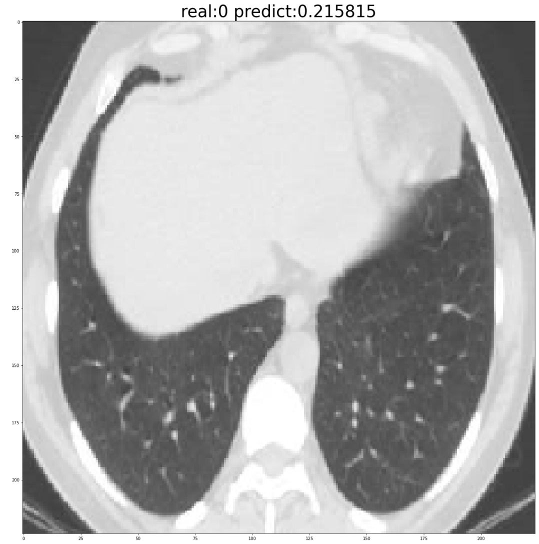
In [39]:

```
import numpy as np
X,Y=next(validation_generator)                                    #取出
一批训练数据
fig,ax=plt.subplots(2,2)                                       #生成画布
并切分
fig.set_figheight(50)                                          #设置高度
fig.set_figwidth(50)                                           #设置宽度
ax=ax.flatten()                                                #拉直画布
ax[0].imshow(X[0])                                             #展示图像
ax[0].set_title("real:%d predict:%f"%(Y[0,1],model.predict(X[:1])[:,1]),fon
tsize=40)
ax[1].imshow(X[1])                                             #展示图像
ax[1].set_title("real:%d predict:%f"%(Y[1,1],model.predict(X[1:2])[:,1]),fo
ntsize=40)
ax[2].imshow(X[-1])                                             #展示图像
ax[2].set_title("real:%d predict:%f"%(Y[-1,1],model.predict(X[-1:])[:,1]),f
ontsize=40)
ax[3].imshow(X[-2])                                             #展示图像
ax[3].set_title("real:%d predict:%f"%(Y[i,1],model.predict(X[-2:-1])[:,1]),
fontsize=40)
print()
```

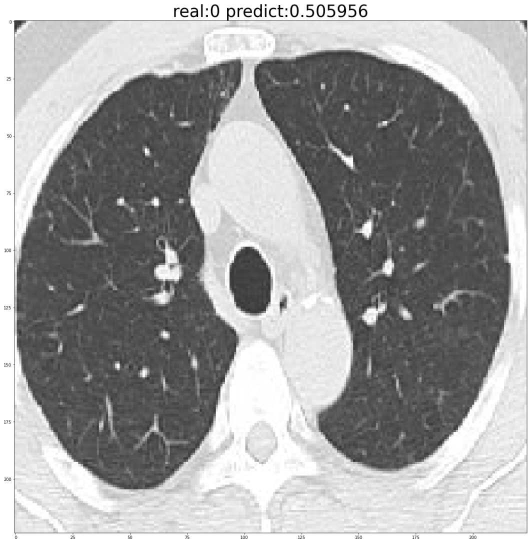
real:0 predict:0.108609



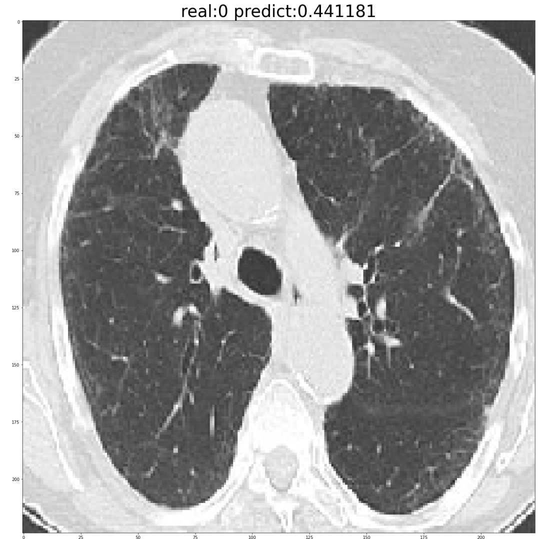
real:0 predict:0.215815



real:0 predict:0.505956



real:0 predict:0.441181



针对二分类的问题，通常会将样本分为以下四种情况：

（1）真阳(TP)：实例是阳性，被预测为阳性；

（2）假阴(FN)：实例是阳性，被预测为阴性；

（3）假阳(FP)：实例是阴性，被预测为阳性；

（4）真阴(TN)：实例是阴性，被预测为阴性。

基于此，模型评估时，常考虑以下几个指标：

True Positive Rate真阳率TPR=TP/(TP+FN)

False Positive Rate假阳率FPR=FP/(FP+TN)

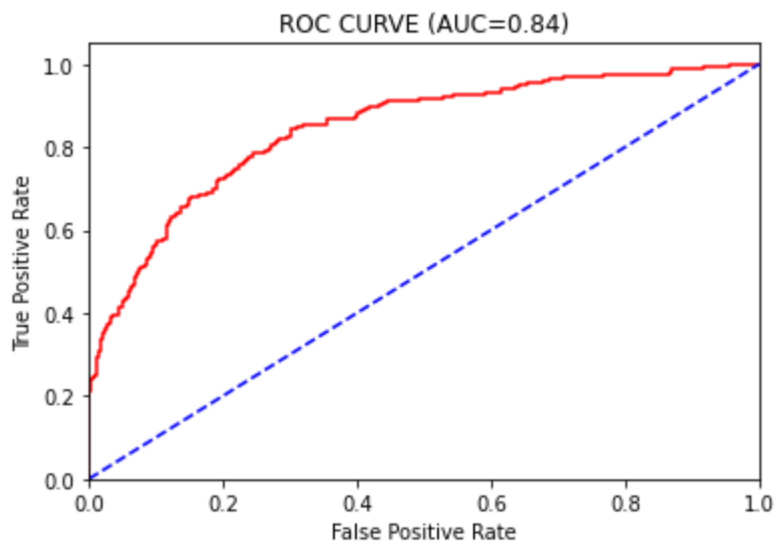
Precision精度PRE=TP/(TP+FP)

下面，我们首先基于TPR和FPR绘制ROC曲线，随后计算最佳阈值，最后再给出各评估指标的数值。

In [19]:
```
import pandas as pd
import matplotlib.pyplot as plt
from sklearn.metrics import roc_curve,auc

fpr, tpr, threshold = roc_curve(Ytrue, Yscore)          #利用内置函数计算用于绘制曲线的fpr和tpr坐标
roc_auc = auc(fpr, tpr)                                 #计算auc的值

#ROC曲线绘制
plt.figure()
plt.title('ROC CURVE (AUC={:.2f})'.format(roc_auc))     #设置图表标题
plt.xlabel('False Positive Rate')                       #横纵坐标轴标签
plt.ylabel('True Positive Rate')
plt.xlim([0.0,1.0])                                     #横纵坐标轴取值范围
plt.ylim([0.0,1.05])
plt.plot(fpr,tpr,color='r')                             #绘制ROC曲线
plt.plot([0, 1], [0, 1], color='b', linestyle='--')
plt.show()
```



理想的最佳阈值，应使TPR尽量大且FPR尽量小，即二者差值最大；因此，我们选取ROC图像中TPR与FPR之差最大的点对应的阈值为最佳阈值。

In [20]:
```
import numpy as np

optimal_threshold = threshold[np.argmax(tpr-fpr)]          #求出最佳阈值
print('最佳阈值: ',round(optimal_threshold,4))              #打印最佳阈值

Yhat=1.0*(Yscore>optimal_threshold)                        #利用最佳阈值给出新
的预测标签
TPR=np.sum(Yhat*Ytrue)/np.sum(Ytrue)                       #计算True Positive
Rate
FPR=np.sum(Yhat*(1-Ytrue))/np.sum(1-Ytrue)                 #计算False Positiv
e Rate
PRE=np.sum(Yhat*Ytrue)/np.sum(Yhat)                        #计算Precision
print('TPR',round(TPR,4))                                  #打印
print('FPR',round(FPR,4))
print('PRE',round(PRE,4))
```

```
最佳阈值:  0.3573
TPR 0.84
FPR 0.3008
PRE 0.7394
```

task2: sensitivity:真阳性人数/（真阳性人数+假阴性人数）*100% 即TPR=TP/ (TP+ FN)

specificity:真阴性人数/（真阴性人数+假阳性人数））*100% 即TNR= TN / (FP + TN)

PPV=TP / (TP + FP)

NPV=TN / (FN + TN)

In [22]:
```
sensitivity=np.sum(Yhat*Ytrue)/np.sum(Ytrue)
specificity=np.sum((1-Yhat)*(1-Ytrue))/np.sum(1-Ytrue)
PPV=np.sum(Yhat*Ytrue)/np.sum(Yhat)
NPV=np.sum((1-Yhat)*(1-Ytrue))/np.sum(1-Yhat)
print("sensitivity",round(sensitivity,4))
print("specificity",round(specificity,4))
print("PPV",round(PPV,4))
print("NPV",round(NPV,4))
```

```
sensitivity 0.84
specificity 0.6992
PPV 0.7394
NPV 0.8113
```

思考：你还可以把模型的精度训练的更高么？

In [ ]: