Residual Networks

Welcome to the second assignment of this week! You will learn how to build very deep convolutional networks, using Residual Networks (ResNets). In theory, very deep networks can represent very complex functions; but in practice, they are hard to train. Residual Networks, introduced by He et al. (https://arxiv.org/pdf/1512.03385.pdf), allow you to train much deeper networks than were previously practically feasible.

In this assignment, you will:

- Implement the basic building blocks of ResNets.
- Put together these building blocks to implement and train a state-of-the-art neural network for image classification.

This assignment will be done in Keras.

Before jumping into the problem, let's run the cell below to load the required packages.

In [11]:
```
import numpy as np
from keras import layers
from keras.layers import Input, Add, Dense, Activation, ZeroPadding2D, BatchNo
rmalization, Flatten, Conv2D, AveragePooling2D, MaxPooling2D, GlobalMaxPooling
2D
from keras.models import Model, load_model
from keras.preprocessing import image
from keras.utils import layer_utils
from keras.utils.data_utils import get_file
from keras.applications.imagenet_utils import preprocess_input
import pydot
from IPython.display import SVG
from keras.utils.vis_utils import model_to_dot
from keras.utils import plot_model
from resnets_utils import *
from keras.initializers import glorot_uniform
import scipy.misc
from matplotlib.pyplot import imshow
%matplotlib inline

import keras.backend as K
K.set_image_data_format('channels_last')
K.set_learning_phase(1)
```

1 - The problem of very deep neural networks

Last week, you built your first convolutional neural network. In recent years, neural networks have become deeper, with state-of-the-art networks going from just a few layers (e.g., AlexNet) to over a hundred layers.

The main benefit of a very deep network is that it can represent very complex functions. It can also learn features at many different levels of abstraction, from edges (at the lower layers) to very complex features (at the deeper layers). However, using a deeper network doesn't always help. A huge barrier to training them is vanishing gradients: very deep networks often have a gradient signal that goes to zero quickly, thus making gradient descent unbearably slow. More specifically, during gradient descent, as you backprop from the final layer back to the first layer, you are multiplying by the weight matrix on each step, and thus the gradient can decrease exponentially quickly to zero (or, in rare cases, grow exponentially quickly and "explode" to take very large values).

During training, you might therefore see the magnitude (or norm) of the gradient for the earlier layers descrease to zero very rapidly as training proceeds:

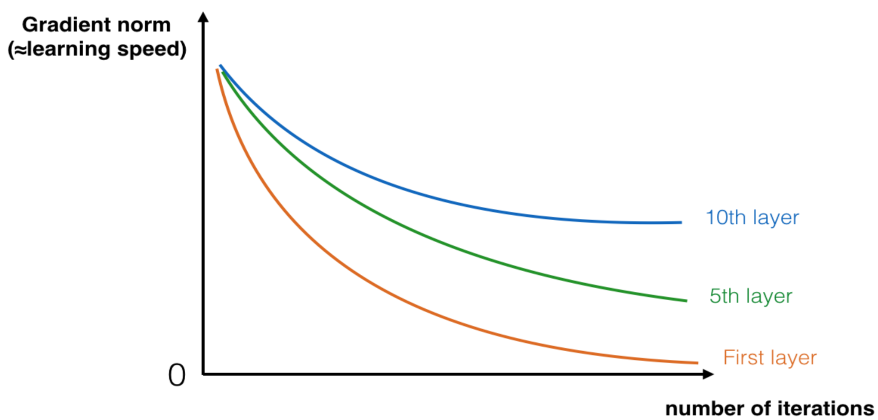


Figure 1 : **Vanishing gradient**
The speed of learning decreases very rapidly for the early layers as the network trains

You are now going to solve this problem by building a Residual Network!

2 - Building a Residual Network

In ResNets, a "shortcut" or a "skip connection" allows the gradient to be directly backpropagated to earlier layers:

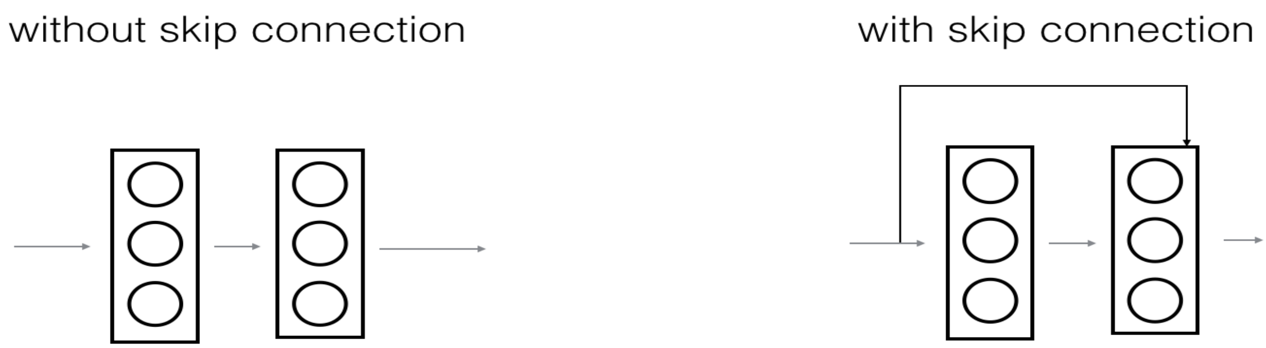


Figure 2 : A ResNet block showing a **skip-connection**

The image on the left shows the "main path" through the network. The image on the right adds a shortcut to the main path. By stacking these ResNet blocks on top of each other, you can form a very deep network.
We also saw in lecture that having ResNet blocks with the shortcut also makes it very easy for one of the blocks to learn an identity function. This means that you can stack on additional ResNet blocks with little risk of harming training set performance. (There is also some evidence that the ease of learning an identity function--even more than skip connections helping with vanishing gradients--accounts for ResNets' remarkable performance.)

Two main types of blocks are used in a ResNet, depending mainly on whether the input/output dimensions are same or different. You are going to implement both of them.

2.1 - The identity block

The identity block is the standard block used in ResNets, and corresponds to the case where the input activation (say $a^{[l]}$) has the same dimension as the output activation (say $a^{[l+2]}$). To flesh out the different steps of what happens in a ResNet's identity block, here is an alternative diagram showing the individual steps:

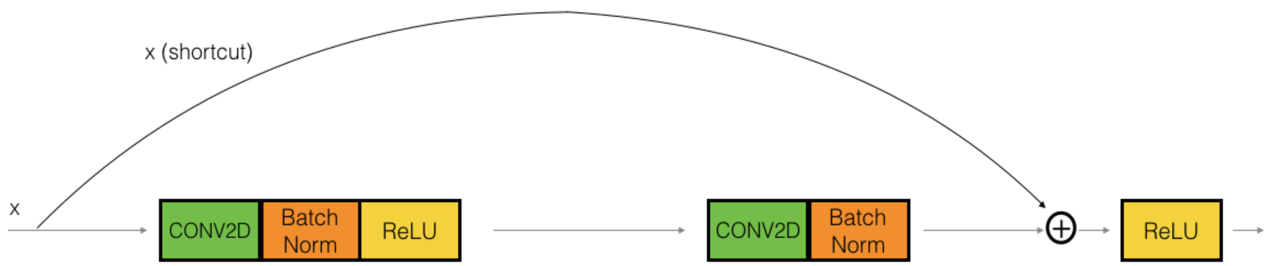


Figure 3 : **Identity block.** Skip connection "skips over" 2 layers.

The upper path is the "shortcut path." The lower path is the "main path." In this diagram, we have also made explicit the CONV2D and ReLU steps in each layer. To speed up training we have also added a BatchNorm step. Don't worry about this being complicated to implement--you'll see that BatchNorm is just one line of code in Keras!
In this exercise, you'll actually implement a slightly more powerful version of this identity block, in which the skip connection "skips over" 3 hidden layers rather than 2 layers. It looks like this:

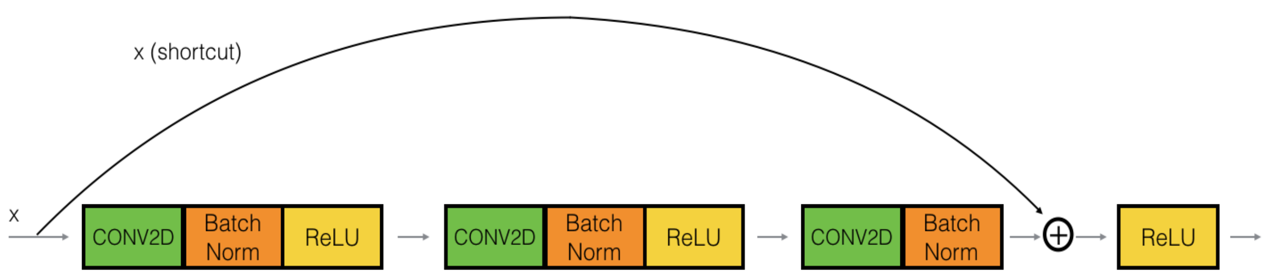


Figure 4 : **Identity block.** Skip connection "skips over" 3 layers.

Here're the individual steps.
First component of main path:

- The first CONV2D has F_1 filters of shape (1,1) and a stride of (1,1). Its padding is "valid" and its name should be `conv_name_base + '2a'`. Use 0 as the seed for the random initialization.
- The first BatchNorm is normalizing the channels axis. Its name should be `bn_name_base + '2a'`.
- Then apply the ReLU activation function. This has no name and no hyperparameters.

Second component of main path:

- The second CONV2D has F_2 filters of shape (f, f) and a stride of (1,1). Its padding is "same" and its name should be `conv_name_base + '2b'`. Use 0 as the seed for the random initialization.
- The second BatchNorm is normalizing the channels axis. Its name should be `bn_name_base + '2b'`.
- Then apply the ReLU activation function. This has no name and no hyperparameters.

Third component of main path:

- The third CONV2D has F_3 filters of shape (1,1) and a stride of (1,1). Its padding is "valid" and its name should be `conv_name_base + '2c'`. Use 0 as the seed for the random initialization.
- The third BatchNorm is normalizing the channels axis. Its name should be `bn_name_base + '2c'`. Note that there is no ReLU activation function in this component.

Final step:

- The shortcut and the input are added together.
- Then apply the ReLU activation function. This has no name and no hyperparameters.

Exercise: Implement the ResNet identity block. We have implemented the first component of the main path. Please read over this carefully to make sure you understand what it is doing. You should implement the rest.

- To implement the Conv2D step: See reference (https://keras.io/layers/convolutional/#conv2d)
- To implement BatchNorm: See reference (https://faroit.github.io/keras-docs/1.2.2/layers/normalization/) (axis: Integer, the axis that should be normalized (typically the channels axis))
- For the activation, use: `Activation('relu')(X)`
- To add the value passed forward by the shortcut: See reference (https://keras.io/layers/merge/#add)

In [14]:
```
# GRADED FUNCTION: identity_block

def identity_block(X, f, filters, stage, block):
    """
    Implementation of the identity block as defined in Figure 3

    Arguments:
    X -- input tensor of shape (m, n_H_prev, n_W_prev, n_C_prev)
    f -- integer, specifying the shape of the middle CONV's window for the
 main path
    filters -- python list of integers, defining the number of filters in t
he CONV layers of the main path
    stage -- integer, used to name the layers, depending on their position
 in the network
    block -- string/character, used to name the layers, depending on their
 position in the network

    Returns:
    X -- output of the identity block, tensor of shape (n_H, n_W, n_C)
    """

    # defining name basis
    conv_name_base = 'res' + str(stage) + block + '_branch'
    bn_name_base = 'bn' + str(stage) + block + '_branch'

    # Retrieve Filters
    F1, F2, F3 = filters

    # Save the input value. You'll need this later to add back to the main
 path.
    X_shortcut = X

    # First component of main path
    X = Conv2D(filters = F1, kernel_size = (1, 1), strides = (1,1), padding
 = 'valid', name = conv_name_base + '2a', kernel_initializer = glorot_unifo
rm(seed=0))(X)
    X = BatchNormalization(axis = 3, name = bn_name_base + '2a')(X)
    X = Activation('relu')(X)

    ### START CODE HERE ###

    # Second component of main path (≈3 lines)
    X = Conv2D(filters = F2, kernel_size = (f, f), strides = (1,1), padding
 = 'same', name = conv_name_base + '2b', kernel_initializer = glorot_unifor
m(seed=0))(X)
    X = BatchNormalization(axis = 3, name = bn_name_base + '2b')(X)
    X = Activation('relu')(X)

    # Third component of main path (≈2 lines)
    X = Conv2D(filters = F3, kernel_size = (1, 1), strides = (1,1), padding
 = 'valid', name = conv_name_base + '2c', kernel_initializer = glorot_unifo
rm(seed=0))(X)
    X = BatchNormalization(axis = 3, name = bn_name_base + '2c')(X)

    # Final step: Add shortcut value to main path, and pass it through a RE
LU activation (≈2 lines)
```

```
    X = layers.add([X, X_shortcut])
    X = Activation('relu')(X)

    ### END CODE HERE ###

    return X
```

In [15]:
```
tf.reset_default_graph()

with tf.Session() as test:
    np.random.seed(1)
    A_prev = tf.placeholder("float", [3, 4, 4, 6])
    X = np.random.randn(3, 4, 4, 6)
    A = identity_block(A_prev, f = 2, filters = [2, 4, 6], stage = 1, block =
'a')
    test.run(tf.global_variables_initializer())
    out = test.run([A], feed_dict={A_prev: X, K.learning_phase(): 0})
    print("out = " + str(out[0][1][1][0]))
```

```
out = [ 0.94822985  0.          1.16101444  2.747859    0.          1.3667700
3]
```

Expected Output:

out	[0.94822985 0. 1.16101444 2.747859 0. 1.36677003]

2.2 - The convolutional block

You've implemented the ResNet identity block. Next, the ResNet "convolutional block" is the other type of block. You can use this type of block when the input and output dimensions don't match up. The difference with the identity block is that there is a CONV2D layer in the shortcut path:

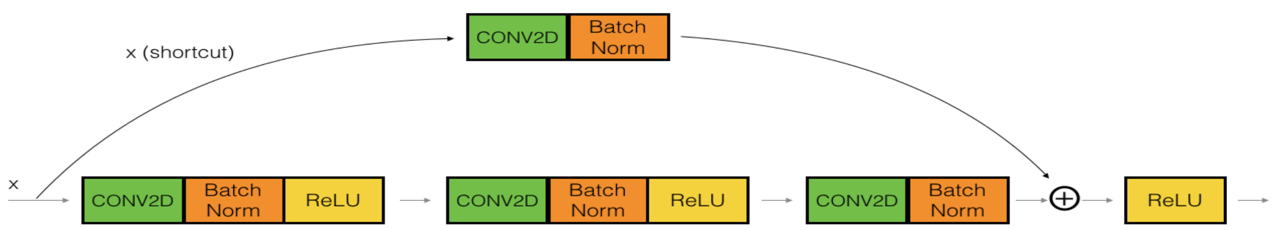


Figure 4 : **Convolutional block**

The CONV2D layer in the shortcut path is used to resize the input x to a different dimension, so that the dimensions match up in the final addition needed to add the shortcut value back to the main path. (This plays a similar role as the matrix W_s discussed in lecture.) For example, to reduce the activation dimensions's height and width by a factor of 2, you can use a 1x1 convolution with a stride of 2. The CONV2D layer on the shortcut path does not use any non-linear activation function. Its main role is to just apply a (learned) linear function that reduces the dimension of the input, so that the dimensions match up for the later addition step.
The details of the convolutional block are as follows.

First component of main path:

- The first CONV2D has F_1 filters of shape (1,1) and a stride of (s,s). Its padding is "valid" and its name should be `conv_name_base + '2a'`.
- The first BatchNorm is normalizing the channels axis. Its name should be `bn_name_base + '2a'`.
- Then apply the ReLU activation function. This has no name and no hyperparameters.

Second component of main path:

- The second CONV2D has F_2 filters of (f,f) and a stride of (1,1). Its padding is "same" and it's name should be `conv_name_base + '2b'`.
- The second BatchNorm is normalizing the channels axis. Its name should be `bn_name_base + '2b'`.
- Then apply the ReLU activation function. This has no name and no hyperparameters.

Third component of main path:

- The third CONV2D has F_3 filters of (1,1) and a stride of (1,1). Its padding is "valid" and it's name should be `conv_name_base + '2c'`.
- The third BatchNorm is normalizing the channels axis. Its name should be `bn_name_base + '2c'`. Note that there is no ReLU activation function in this component.

Shortcut path:

- The CONV2D has F_3 filters of shape (1,1) and a stride of (s,s). Its padding is "valid" and its name should be `conv_name_base + '1'`.
- The BatchNorm is normalizing the channels axis. Its name should be `bn_name_base + '1'`.

Final step:

- The shortcut and the main path values are added together.
- Then apply the ReLU activation function. This has no name and no hyperparameters.

Exercise: Implement the convolutional block. We have implemented the first component of the main path; you should implement the rest. As before, always use 0 as the seed for the random initialization, to ensure consistency with our grader.

- [Conv Hint (https://keras.io/layers/convolutional/#conv2d)](https://keras.io/layers/convolutional/#conv2d)
- [BatchNorm Hint (https://keras.io/layers/normalization/#batchnormalization)](https://keras.io/layers/normalization/#batchnormalization) (axis: Integer, the axis that should be normalized (typically the features axis))
- For the activation, use: `Activation('relu')(X)`
- [Addition Hint (https://keras.io/layers/merge/#add)](https://keras.io/layers/merge/#add)

In [18]:
```
# GRADED FUNCTION: convolutional_block

def convolutional_block(X, f, filters, stage, block, s = 2):
    """
    Implementation of the convolutional block as defined in Figure 4

    Arguments:
    X -- input tensor of shape (m, n_H_prev, n_W_prev, n_C_prev)
    f -- integer, specifying the shape of the middle CONV's window for the
 main path
    filters -- python list of integers, defining the number of filters in t
he CONV layers of the main path
    stage -- integer, used to name the layers, depending on their position
 in the network
    block -- string/character, used to name the layers, depending on their
 position in the network
    s -- Integer, specifying the stride to be used

    Returns:
    X -- output of the convolutional block, tensor of shape (n_H, n_W, n_C)
    """

    # defining name basis
    conv_name_base = 'res' + str(stage) + block + '_branch'
    bn_name_base = 'bn' + str(stage) + block + '_branch'

    # Retrieve Filters
    F1, F2, F3 = filters

    # Save the input value
    X_shortcut = X


    ##### MAIN PATH #####
    # First component of main path
    X = Conv2D(F1, (1, 1), strides = (s,s), name = conv_name_base + '2a',pa
dding = 'valid', kernel_initializer = glorot_uniform(seed=0))(X)
    X = BatchNormalization(axis = 3, name = bn_name_base + '2a')(X)
    X = Activation('relu')(X)

    ### START CODE HERE ###

    # Second component of main path (≈3 lines)
    X = Conv2D(F2, (f, f), strides = (1,1), name = conv_name_base + '2b',pa
dding = 'same', kernel_initializer = glorot_uniform(seed=0))(X)
    X = BatchNormalization(axis = 3, name = bn_name_base + '2b')(X)
    X = Activation('relu')(X)

    # Third component of main path (≈2 lines)
    X = Conv2D(F3, (1, 1), strides = (1,1), name = conv_name_base + '2c',pa
dding = 'valid', kernel_initializer = glorot_uniform(seed=0))(X)
    X = BatchNormalization(axis = 3, name = bn_name_base + '2c')(X)

    ##### SHORTCUT PATH #### (≈2 lines)
    X_shortcut = Conv2D(F3, (1, 1), strides = (s,s), name = conv_name_base
+ '1',padding = 'valid', kernel_initializer = glorot_uniform(seed=0))(X_sho
```

```
rtcut)
    X_shortcut = BatchNormalization(axis = 3, name = bn_name_base + '1')(X_
shortcut)

    # Final step: Add shortcut value to main path, and pass it through a RE
LU activation (≈2 lines)
    X = layers.add([X, X_shortcut])
    X = Activation('relu')(X)

    ### END CODE HERE ###

    return X
```

In [19]:

```
tf.reset_default_graph()

with tf.Session() as test:
    np.random.seed(1)
    A_prev = tf.placeholder("float", [3, 4, 4, 6])
    X = np.random.randn(3, 4, 4, 6)
    A = convolutional_block(A_prev, f = 2, filters = [2, 4, 6], stage = 1, blo
ck = 'a')
    test.run(tf.global_variables_initializer())
    out = test.run([A], feed_dict={A_prev: X, K.learning_phase(): 0})
    print("out = " + str(out[0][1][1][0]))
```

```
out = [ 0.09018463  1.23489773  0.46822017  0.0367176   0.          0.6551660
3]
```

Expected Output:

out	[0.09018463 1.23489773 0.46822017 0.0367176 0. 0.65516603]

3 - Building your first ResNet model (50 layers)

You now have the necessary blocks to build a very deep ResNet. The following figure describes in detail the architecture of this neural network. "ID BLOCK" in the diagram stands for "Identity block," and "ID BLOCK x3" means you should stack 3 identity blocks together.

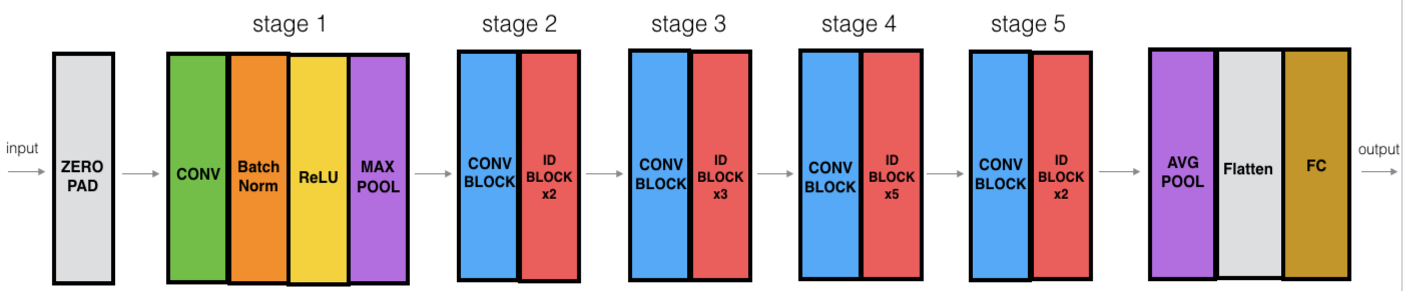


Figure 5 : **ResNet-50 model**

The details of this ResNet-50 model are:

- Zero-padding pads the input with a pad of (3,3)
- Stage 1:
  - The 2D Convolution has 64 filters of shape (7,7) and uses a stride of (2,2). Its name is "conv1".
  - BatchNorm is applied to the channels axis of the input.
  - MaxPooling uses a (3,3) window and a (2,2) stride.
- Stage 2:
  - The convolutional block uses three set of filters of size [64,64,256], "f" is 3, "s" is 1 and the block is "a".
  - The 2 identity blocks use three set of filters of size [64,64,256], "f" is 3 and the blocks are "b" and "c".
- Stage 3:
  - The convolutional block uses three set of filters of size [128,128,512], "f" is 3, "s" is 2 and the block is "a".
  - The 3 identity blocks use three set of filters of size [128,128,512], "f" is 3 and the blocks are "b", "c" and "d".
- Stage 4:
  - The convolutional block uses three set of filters of size [256, 256, 1024], "f" is 3, "s" is 2 and the block is "a".
  - The 5 identity blocks use three set of filters of size [256, 256, 1024], "f" is 3 and the blocks are "b", "c", "d", "e" and "f".
- Stage 5:
  - The convolutional block uses three set of filters of size [512, 512, 2048], "f" is 3, "s" is 2 and the block is "a".
  - The 2 identity blocks use three set of filters of size [512, 512, 2048], "f" is 3 and the blocks are "b" and "c".
- The 2D Average Pooling uses a window of shape (2,2) and its name is "avg_pool".
- The flatten doesn't have any hyperparameters or name.
- The Fully Connected (Dense) layer reduces its input to the number of classes using a softmax activation. Its name should be `'fc' + str(classes)`.

Exercise: Implement the ResNet with 50 layers described in the figure above. We have implemented Stages 1 and 2. Please implement the rest. (The syntax for implementing Stages 3-5 should be quite similar to that of Stage 2.) Make sure you follow the naming convention in the text above.

You'll need to use this function:

- Average pooling see reference (https://keras.io/layers/pooling/#averagepooling2d)

Here're some other functions we used in the code below:

- Conv2D: See reference (https://keras.io/layers/convolutional/#conv2d)
- BatchNorm: See reference (https://keras.io/layers/normalization/#batchnormalization) (axis: Integer, the axis that should be normalized (typically the features axis))
- Zero padding: See reference (https://keras.io/layers/convolutional/#zeropadding2d)
- Max pooling: See reference (https://keras.io/layers/pooling/#maxpooling2d)
- Fully conected layer: See reference (https://keras.io/layers/core/#dense)
- Addition: See reference (https://keras.io/layers/merge/#add)

In [25]:
```
# GRADED FUNCTION: ResNet50

def ResNet50(input_shape = (64, 64, 3), classes = 6):
    """
    Implementation of the popular ResNet50 the following architecture:
    CONV2D -> BATCHNORM -> RELU -> MAXPOOL -> CONVBLOCK -> IDBLOCK*2 -> CON
VBLOCK -> IDBLOCK*3
    -> CONVBLOCK -> IDBLOCK*5 -> CONVBLOCK -> IDBLOCK*2 -> AVGPOOL -> TOPLA
YER

    Arguments:
    input_shape -- shape of the images of the dataset
    classes -- integer, number of classes

    Returns:
    model -- a Model() instance in Keras
    """

    # Define the input as a tensor with shape input_shape
    X_input = Input(input_shape)


    # Zero-Padding
    X = ZeroPadding2D((3, 3))(X_input)

    # Stage 1
    X = Conv2D(64, (7, 7), strides = (2, 2), name = 'conv1', kernel_initial
izer = glorot_uniform(seed=0))(X)
    X = BatchNormalization(axis = 3, name = 'bn_conv1')(X)
    X = Activation('relu')(X)
    X = MaxPooling2D((3, 3), strides=(2, 2))(X)

    # Stage 2
    X = convolutional_block(X, f = 3, filters = [64, 64, 256], stage = 2, b
lock='a', s = 1)
    X = identity_block(X, 3, [64, 64, 256], stage=2, block='b')
    X = identity_block(X, 3, [64, 64, 256], stage=2, block='c')

    ### START CODE HERE ###

    # Stage 3 (≈4 lines)
    X = convolutional_block(X, f = 3, filters = [128,128,512], stage = 3, b
lock='a', s = 2)
    X = identity_block(X, 3, [128,128,512], stage = 3, block='b')
    X = identity_block(X, 3, [128,128,512], stage = 3, block='c')
    X = identity_block(X, 3, [128,128,512], stage = 3, block='d')

    # Stage 4 (≈6 lines)
    X = convolutional_block(X, f = 3, filters = [256,256,1024], stage = 4,
block='a', s = 2)
    X = identity_block(X, 3,[256,256,1024], stage = 4, block='b')
    X = identity_block(X, 3,[256,256,1024], stage = 4, block='c')
    X = identity_block(X, 3,[256,256,1024], stage = 4, block='d')
    X = identity_block(X, 3,[256,256,1024], stage = 4, block='e')
    X = identity_block(X, 3,[256,256,1024], stage = 4, block='f')
```

```
    # Stage 5 (≈3 lines)
    X = convolutional_block(X, f = 3, filters = [512,512,2048], stage = 5,
block='a', s = 2)
    X = identity_block(X, 3,[512,512,2048], stage = 5, block='b')
    X = identity_block(X, 3,[512,512,2048], stage = 5, block='c')

    # AVGPOOL (≈1 line). Use "X = AveragePooling2D(...)(X)"
    X = AveragePooling2D(pool_size=(2, 2), name='avg_pool')(X)

    ### END CODE HERE ###

    # output layer
    X = Flatten()(X)
    X = Dense(classes, activation='softmax', name='fc' + str(classes), kern
el_initializer = glorot_uniform(seed=0))(X)


    # Create model
    model = Model(inputs = X_input, outputs = X, name='ResNet50')

    return model
```

Run the following code to build the model's graph. If your implementation is not correct you will know it by checking your accuracy when running `model.fit(...)` below.

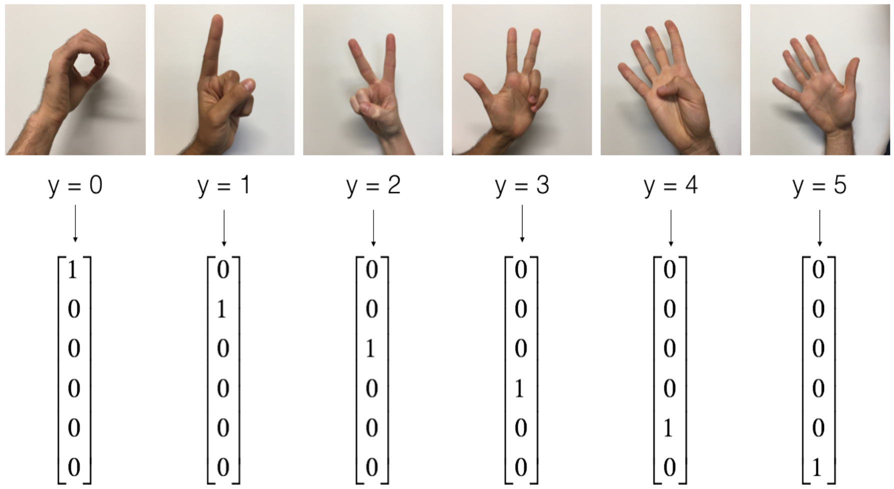
In [26]:
```
model = ResNet50(input_shape = (64, 64, 3), classes = 6)
```

As seen in the Keras Tutorial Notebook, prior training a model, you need to configure the learning process by compiling the model.

In [27]:
```
model.compile(optimizer='adam', loss='categorical_crossentropy', metrics=['acc
uracy'])
```

The model is now ready to be trained. The only thing you need is a dataset.

Let's load the SIGNS Dataset.



<u>**Figure 6** </u>: **SIGNS dataset**

In [28]:
```
X_train_orig, Y_train_orig, X_test_orig, Y_test_orig, classes = load_dataset()

# Normalize image vectors
X_train = X_train_orig/255.
X_test = X_test_orig/255.

# Convert training and test labels to one hot matrices
Y_train = convert_to_one_hot(Y_train_orig, 6).T
Y_test = convert_to_one_hot(Y_test_orig, 6).T

print ("number of training examples = " + str(X_train.shape[0]))
print ("number of test examples = " + str(X_test.shape[0]))
print ("X_train shape: " + str(X_train.shape))
print ("Y_train shape: " + str(Y_train.shape))
print ("X_test shape: " + str(X_test.shape))
print ("Y_test shape: " + str(Y_test.shape))
```

```
number of training examples = 1080
number of test examples = 120
X_train shape: (1080, 64, 64, 3)
Y_train shape: (1080, 6)
X_test shape: (120, 64, 64, 3)
Y_test shape: (120, 6)
```

Run the following cell to train your model on 2 epochs with a batch size of 32. On a CPU it should take you around 5min per epoch.

In [29]:
```
model.fit(X_train, Y_train, epochs = 2, batch_size = 32)
```

```
Epoch 1/2
1080/1080 [==============================] - 269s - loss: 3.0509 - acc: 0.199
1
Epoch 2/2
1080/1080 [==============================] - 254s - loss: 2.2270 - acc: 0.222
2
```

Out[29]: `<keras.callbacks.History at 0x7fb9f96c2dd8>`

Expected Output:

** Epoch 1/2**	loss: between 1 and 5, acc: between 0.2 and 0.5, although your results can be different from ours.
** Epoch 2/2**	loss: between 1 and 5, acc: between 0.2 and 0.5, you should see your loss decreasing and the accuracy increasing.

Let's see how this model (trained on only two epochs) performs on the test set.

In [30]:
```
preds = model.evaluate(X_test, Y_test)
print ("Loss = " + str(preds[0]))
print ("Test Accuracy = " + str(preds[1]))
```

```
120/120 [==============================] - 11s
Loss = 1.91680612564
Test Accuracy = 0.166666668653
```

Expected Output:

Test Accuracy	between 0.16 and 0.25

For the purpose of this assignment, we've asked you to train the model only for two epochs. You can see that it achieves poor performances. Please go ahead and submit your assignment; to check correctness, the online grader will run your code only for a small number of epochs as well.

After you have finished this official (graded) part of this assignment, you can also optionally train the ResNet for more iterations, if you want. We get a lot better performance when we train for ~20 epochs, but this will take more than an hour when training on a CPU.

Using a GPU, we've trained our own ResNet50 model's weights on the SIGNS dataset. You can load and run our trained model on the test set in the cells below. It may take ≈1min to load the model.

In [31]:
```
model = load_model('ResNet50.h5')
```

In [32]:
```
preds = model.evaluate(X_test, Y_test)
print ("Loss = " + str(preds[0]))
print ("Test Accuracy = " + str(preds[1]))
```

```
120/120 [==============================] - 12s
Loss = 0.530178320408
Test Accuracy = 0.866666662693
```

ResNet50 is a powerful model for image classification when it is trained for an adequate number of iterations. We hope you can use what you've learnt and apply it to your own classification problem to perform state-of-the-art accuracy.

Congratulations on finishing this assignment! You've now implemented a state-of-the-art image classification system!

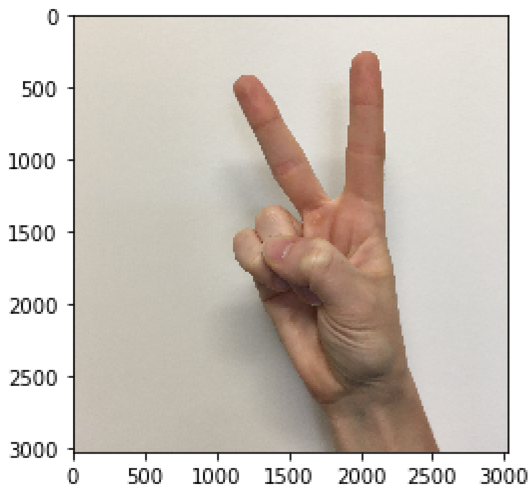
4 - Test on your own image (Optional/Ungraded)

If you wish, you can also take a picture of your own hand and see the output of the model. To do this:

```
1. Click on "File" in the upper bar of this notebook, then click "Open" to go on yo
ur Coursera Hub.
2. Add your image to this Jupyter Notebook's directory, in the "images" folder
3. Write your image's name in the following code
4. Run the code and check if the algorithm is right!
```

In [33]:
```
img_path = 'images/my_image.jpg'
img = image.load_img(img_path, target_size=(64, 64))
x = image.img_to_array(img)
x = np.expand_dims(x, axis=0)
x = preprocess_input(x)
print('Input image shape:', x.shape)
my_image = scipy.misc.imread(img_path)
imshow(my_image)
print("class prediction vector [p(0), p(1), p(2), p(3), p(4), p(5)] = ")
print(model.predict(x))
```

```
Input image shape: (1, 64, 64, 3)
class prediction vector [p(0), p(1), p(2), p(3), p(4), p(5)] =
[[ 1.  0.  0.  0.  0.  0.]]
```



You can also print a summary of your model by running the following code.

In [35]:
```
model.summary()
```

```
____________________________________________________________________________________________________
Layer (type)                     Output Shape          Param #     Connecte
d to
====================================================================================================
input_1 (InputLayer)             (None, 64, 64, 3)     0


____________________________________________________________________________________________________
zero_padding2d_1 (ZeroPadding2D) (None, 70, 70, 3)     0           input_1
[0][0]
____________________________________________________________________________________________________
conv1 (Conv2D)                   (None, 32, 32, 64)    9472        zero_pad
ding2d_1[0][0]
____________________________________________________________________________________________________
bn_conv1 (BatchNormalization)    (None, 32, 32, 64)    256         conv1[0]
[0]
____________________________________________________________________________________________________
activation_4 (Activation)        (None, 32, 32, 64)    0           bn_conv1
[0][0]
____________________________________________________________________________________________________
max_pooling2d_1 (MaxPooling2D)   (None, 15, 15, 64)    0           activati
on_4[0][0]
____________________________________________________________________________________________________
res2a_branch2a (Conv2D)          (None, 15, 15, 64)    4160        max_pool
ing2d_1[0][0]
____________________________________________________________________________________________________
bn2a_branch2a (BatchNormalizatio (None, 15, 15, 64)    256         res2a_br
anch2a[0][0]
____________________________________________________________________________________________________
activation_5 (Activation)        (None, 15, 15, 64)    0           bn2a_bra
nch2a[0][0]
____________________________________________________________________________________________________
res2a_branch2b (Conv2D)          (None, 15, 15, 64)    36928       activati
on_5[0][0]
____________________________________________________________________________________________________
bn2a_branch2b (BatchNormalizatio (None, 15, 15, 64)    256         res2a_br
anch2b[0][0]
____________________________________________________________________________________________________
activation_6 (Activation)        (None, 15, 15, 64)    0           bn2a_bra
nch2b[0][0]
____________________________________________________________________________________________________
res2a_branch2c (Conv2D)          (None, 15, 15, 256)   16640       activati
on_6[0][0]
____________________________________________________________________________________________________
```

```
_________________________
res2a_branch1 (Conv2D)          (None, 15, 15, 256)   16640       max_pool
ing2d_1[0][0]
__________________________________________________________________________
_________________________
bn2a_branch2c (BatchNormalizatio (None, 15, 15, 256)   1024        res2a_br
anch2c[0][0]
__________________________________________________________________________
_________________________
bn2a_branch1 (BatchNormalization (None, 15, 15, 256)   1024        res2a_br
anch1[0][0]
__________________________________________________________________________
_________________________
add_2 (Add)                     (None, 15, 15, 256)   0           bn2a_bra
nch2c[0][0]
                                                                  bn2a_bra
nch1[0][0]
__________________________________________________________________________
_________________________
activation_7 (Activation)       (None, 15, 15, 256)   0           add_2[0]
[0]
__________________________________________________________________________
_________________________
res2b_branch2a (Conv2D)         (None, 15, 15, 64)    16448       activati
on_7[0][0]
__________________________________________________________________________
_________________________
bn2b_branch2a (BatchNormalizatio (None, 15, 15, 64)    256         res2b_br
anch2a[0][0]
__________________________________________________________________________
_________________________
activation_8 (Activation)       (None, 15, 15, 64)    0           bn2b_bra
nch2a[0][0]
__________________________________________________________________________
_________________________
res2b_branch2b (Conv2D)         (None, 15, 15, 64)    36928       activati
on_8[0][0]
__________________________________________________________________________
_________________________
bn2b_branch2b (BatchNormalizatio (None, 15, 15, 64)    256         res2b_br
anch2b[0][0]
__________________________________________________________________________
_________________________
activation_9 (Activation)       (None, 15, 15, 64)    0           bn2b_bra
nch2b[0][0]
__________________________________________________________________________
_________________________
res2b_branch2c (Conv2D)         (None, 15, 15, 256)   16640       activati
on_9[0][0]
__________________________________________________________________________
_________________________
bn2b_branch2c (BatchNormalizatio (None, 15, 15, 256)   1024        res2b_br
anch2c[0][0]
__________________________________________________________________________
_________________________
add_3 (Add)                     (None, 15, 15, 256)   0           bn2b_bra
nch2c[0][0]
```

```
                                                                        activati
on_7[0][0]
__________________________________________________________________________________________________
activation_10 (Activation)      (None, 15, 15, 256)  0           add_3[0]
[0]
__________________________________________________________________________________________________
res2c_branch2a (Conv2D)         (None, 15, 15, 64)   16448       activati
on_10[0][0]
__________________________________________________________________________________________________
bn2c_branch2a (BatchNormalizatio (None, 15, 15, 64)  256         res2c_br
anch2a[0][0]
__________________________________________________________________________________________________
activation_11 (Activation)      (None, 15, 15, 64)   0           bn2c_bra
nch2a[0][0]
__________________________________________________________________________________________________
res2c_branch2b (Conv2D)         (None, 15, 15, 64)   36928       activati
on_11[0][0]
__________________________________________________________________________________________________
bn2c_branch2b (BatchNormalizatio (None, 15, 15, 64)  256         res2c_br
anch2b[0][0]
__________________________________________________________________________________________________
activation_12 (Activation)      (None, 15, 15, 64)   0           bn2c_bra
nch2b[0][0]
__________________________________________________________________________________________________
res2c_branch2c (Conv2D)         (None, 15, 15, 256)  16640       activati
on_12[0][0]
__________________________________________________________________________________________________
bn2c_branch2c (BatchNormalizatio (None, 15, 15, 256) 1024        res2c_br
anch2c[0][0]
__________________________________________________________________________________________________
add_4 (Add)                     (None, 15, 15, 256)  0           bn2c_bra
nch2c[0][0]
                                                                 activati
on_10[0][0]
__________________________________________________________________________________________________
activation_13 (Activation)      (None, 15, 15, 256)  0           add_4[0]
[0]
__________________________________________________________________________________________________
res3a_branch2a (Conv2D)         (None, 8, 8, 128)    32896       activati
on_13[0][0]
__________________________________________________________________________________________________
bn3a_branch2a (BatchNormalizatio (None, 8, 8, 128)   512         res3a_br
anch2a[0][0]
__________________________________________________________________________________________________
```

```
________________________________________________________________________________
activation_14 (Activation)       (None, 8, 8, 128)     0           bn3a_bra
nch2a[0][0]
__________________________________________________________________________________
________________________________________________________________________________
res3a_branch2b (Conv2D)          (None, 8, 8, 128)     147584      activati
on_14[0][0]
__________________________________________________________________________________
________________________________________________________________________________
bn3a_branch2b (BatchNormalizatio (None, 8, 8, 128)     512         res3a_br
anch2b[0][0]
__________________________________________________________________________________
________________________________________________________________________________
activation_15 (Activation)       (None, 8, 8, 128)     0           bn3a_bra
nch2b[0][0]
__________________________________________________________________________________
________________________________________________________________________________
res3a_branch2c (Conv2D)          (None, 8, 8, 512)     66048       activati
on_15[0][0]
__________________________________________________________________________________
________________________________________________________________________________
res3a_branch1 (Conv2D)           (None, 8, 8, 512)     131584      activati
on_13[0][0]
__________________________________________________________________________________
________________________________________________________________________________
bn3a_branch2c (BatchNormalizatio (None, 8, 8, 512)     2048        res3a_br
anch2c[0][0]
__________________________________________________________________________________
________________________________________________________________________________
bn3a_branch1 (BatchNormalization (None, 8, 8, 512)     2048        res3a_br
anch1[0][0]
__________________________________________________________________________________
________________________________________________________________________________
add_5 (Add)                      (None, 8, 8, 512)     0           bn3a_bra
nch2c[0][0]
                                                                   bn3a_bra
nch1[0][0]
__________________________________________________________________________________
________________________________________________________________________________
activation_16 (Activation)       (None, 8, 8, 512)     0           add_5[0]
[0]
__________________________________________________________________________________
________________________________________________________________________________
res3b_branch2a (Conv2D)          (None, 8, 8, 128)     65664       activati
on_16[0][0]
__________________________________________________________________________________
________________________________________________________________________________
bn3b_branch2a (BatchNormalizatio (None, 8, 8, 128)     512         res3b_br
anch2a[0][0]
__________________________________________________________________________________
________________________________________________________________________________
activation_17 (Activation)       (None, 8, 8, 128)     0           bn3b_bra
nch2a[0][0]
__________________________________________________________________________________
________________________________________________________________________________
res3b_branch2b (Conv2D)          (None, 8, 8, 128)     147584      activati
on_17[0][0]
```

```
________________________________________________________________________________
__________________________
bn3b_branch2b (BatchNormalizatio (None, 8, 8, 128)    512         res3b_br
anch2b[0][0]
________________________________________________________________________________
__________________________
activation_18 (Activation)       (None, 8, 8, 128)    0           bn3b_bra
nch2b[0][0]
________________________________________________________________________________
__________________________
res3b_branch2c (Conv2D)          (None, 8, 8, 512)    66048       activati
on_18[0][0]
________________________________________________________________________________
__________________________
bn3b_branch2c (BatchNormalizatio (None, 8, 8, 512)    2048        res3b_br
anch2c[0][0]
________________________________________________________________________________
__________________________
add_6 (Add)                      (None, 8, 8, 512)    0           bn3b_bra
nch2c[0][0]
                                                                  activati
on_16[0][0]
________________________________________________________________________________
__________________________
activation_19 (Activation)       (None, 8, 8, 512)    0           add_6[0]
[0]
________________________________________________________________________________
__________________________
res3c_branch2a (Conv2D)          (None, 8, 8, 128)    65664       activati
on_19[0][0]
________________________________________________________________________________
__________________________
bn3c_branch2a (BatchNormalizatio (None, 8, 8, 128)    512         res3c_br
anch2a[0][0]
________________________________________________________________________________
__________________________
activation_20 (Activation)       (None, 8, 8, 128)    0           bn3c_bra
nch2a[0][0]
________________________________________________________________________________
__________________________
res3c_branch2b (Conv2D)          (None, 8, 8, 128)    147584      activati
on_20[0][0]
________________________________________________________________________________
__________________________
bn3c_branch2b (BatchNormalizatio (None, 8, 8, 128)    512         res3c_br
anch2b[0][0]
________________________________________________________________________________
__________________________
activation_21 (Activation)       (None, 8, 8, 128)    0           bn3c_bra
nch2b[0][0]
________________________________________________________________________________
__________________________
res3c_branch2c (Conv2D)          (None, 8, 8, 512)    66048       activati
on_21[0][0]
________________________________________________________________________________
__________________________
bn3c_branch2c (BatchNormalizatio (None, 8, 8, 512)    2048        res3c_br
```

```
anch2c[0][0]
____________________________________________________________________________________________________
add_7 (Add)                      (None, 8, 8, 512)     0           bn3c_bra
nch2c[0][0]
                                                                   activati
on_19[0][0]
____________________________________________________________________________________________________
activation_22 (Activation)       (None, 8, 8, 512)     0           add_7[0]
[0]
____________________________________________________________________________________________________
res3d_branch2a (Conv2D)          (None, 8, 8, 128)     65664       activati
on_22[0][0]
____________________________________________________________________________________________________
bn3d_branch2a (BatchNormalizatio (None, 8, 8, 128)     512         res3d_br
anch2a[0][0]
____________________________________________________________________________________________________
activation_23 (Activation)       (None, 8, 8, 128)     0           bn3d_bra
nch2a[0][0]
____________________________________________________________________________________________________
res3d_branch2b (Conv2D)          (None, 8, 8, 128)     147584      activati
on_23[0][0]
____________________________________________________________________________________________________
bn3d_branch2b (BatchNormalizatio (None, 8, 8, 128)     512         res3d_br
anch2b[0][0]
____________________________________________________________________________________________________
activation_24 (Activation)       (None, 8, 8, 128)     0           bn3d_bra
nch2b[0][0]
____________________________________________________________________________________________________
res3d_branch2c (Conv2D)          (None, 8, 8, 512)     66048       activati
on_24[0][0]
____________________________________________________________________________________________________
bn3d_branch2c (BatchNormalizatio (None, 8, 8, 512)     2048        res3d_br
anch2c[0][0]
____________________________________________________________________________________________________
add_8 (Add)                      (None, 8, 8, 512)     0           bn3d_bra
nch2c[0][0]
                                                                   activati
on_22[0][0]
____________________________________________________________________________________________________
activation_25 (Activation)       (None, 8, 8, 512)     0           add_8[0]
[0]
____________________________________________________________________________________________________
res4a_branch2a (Conv2D)          (None, 4, 4, 256)     131328      activati
on_25[0][0]
```

```
________________________________________________________________________________
______________________________
bn4a_branch2a (BatchNormalizatio (None, 4, 4, 256)    1024        res4a_br
anch2a[0][0]
________________________________________________________________________________
______________________________
activation_26 (Activation)       (None, 4, 4, 256)    0           bn4a_bra
nch2a[0][0]
________________________________________________________________________________
______________________________
res4a_branch2b (Conv2D)          (None, 4, 4, 256)    590080      activati
on_26[0][0]
________________________________________________________________________________
______________________________
bn4a_branch2b (BatchNormalizatio (None, 4, 4, 256)    1024        res4a_br
anch2b[0][0]
________________________________________________________________________________
______________________________
activation_27 (Activation)       (None, 4, 4, 256)    0           bn4a_bra
nch2b[0][0]
________________________________________________________________________________
______________________________
res4a_branch2c (Conv2D)          (None, 4, 4, 1024)   263168      activati
on_27[0][0]
________________________________________________________________________________
______________________________
res4a_branch1 (Conv2D)           (None, 4, 4, 1024)   525312      activati
on_25[0][0]
________________________________________________________________________________
______________________________
bn4a_branch2c (BatchNormalizatio (None, 4, 4, 1024)   4096        res4a_br
anch2c[0][0]
________________________________________________________________________________
______________________________
bn4a_branch1 (BatchNormalization (None, 4, 4, 1024)   4096        res4a_br
anch1[0][0]
________________________________________________________________________________
______________________________
add_9 (Add)                      (None, 4, 4, 1024)   0           bn4a_bra
nch2c[0][0]
                                                                  bn4a_bra
nch1[0][0]
________________________________________________________________________________
______________________________
activation_28 (Activation)       (None, 4, 4, 1024)   0           add_9[0]
[0]
________________________________________________________________________________
______________________________
res4b_branch2a (Conv2D)          (None, 4, 4, 256)    262400      activati
on_28[0][0]
________________________________________________________________________________
______________________________
bn4b_branch2a (BatchNormalizatio (None, 4, 4, 256)    1024        res4b_br
anch2a[0][0]
________________________________________________________________________________
______________________________
activation_29 (Activation)       (None, 4, 4, 256)    0           bn4b_bra
```

```
nch2a[0][0]
________________________________________________________________________________
_________________________
res4b_branch2b (Conv2D)         (None, 4, 4, 256)    590080      activati
on_29[0][0]
________________________________________________________________________________
_________________________
bn4b_branch2b (BatchNormalizatio (None, 4, 4, 256)    1024        res4b_br
anch2b[0][0]
________________________________________________________________________________
_________________________
activation_30 (Activation)      (None, 4, 4, 256)    0           bn4b_bra
nch2b[0][0]
________________________________________________________________________________
_________________________
res4b_branch2c (Conv2D)         (None, 4, 4, 1024)   263168      activati
on_30[0][0]
________________________________________________________________________________
_________________________
bn4b_branch2c (BatchNormalizatio (None, 4, 4, 1024)   4096        res4b_br
anch2c[0][0]
________________________________________________________________________________
_________________________
add_10 (Add)                    (None, 4, 4, 1024)   0           bn4b_bra
nch2c[0][0]
                                                                 activati
on_28[0][0]
________________________________________________________________________________
_________________________
activation_31 (Activation)      (None, 4, 4, 1024)   0           add_10
[0][0]
________________________________________________________________________________
_________________________
res4c_branch2a (Conv2D)         (None, 4, 4, 256)    262400      activati
on_31[0][0]
________________________________________________________________________________
_________________________
bn4c_branch2a (BatchNormalizatio (None, 4, 4, 256)    1024        res4c_br
anch2a[0][0]
________________________________________________________________________________
_________________________
activation_32 (Activation)      (None, 4, 4, 256)    0           bn4c_bra
nch2a[0][0]
________________________________________________________________________________
_________________________
res4c_branch2b (Conv2D)         (None, 4, 4, 256)    590080      activati
on_32[0][0]
________________________________________________________________________________
_________________________
bn4c_branch2b (BatchNormalizatio (None, 4, 4, 256)    1024        res4c_br
anch2b[0][0]
________________________________________________________________________________
_________________________
activation_33 (Activation)      (None, 4, 4, 256)    0           bn4c_bra
nch2b[0][0]
________________________________________________________________________________
_________________________
```

```
res4c_branch2c (Conv2D)          (None, 4, 4, 1024)   263168      activati
on_33[0][0]
__________________________________________________________________________
______________________________
bn4c_branch2c (BatchNormalizatio (None, 4, 4, 1024)   4096        res4c_br
anch2c[0][0]
__________________________________________________________________________
______________________________
add_11 (Add)                     (None, 4, 4, 1024)   0           bn4c_bra
nch2c[0][0]
                                                                  activati
on_31[0][0]
__________________________________________________________________________
______________________________
activation_34 (Activation)       (None, 4, 4, 1024)   0           add_11
[0][0]
__________________________________________________________________________
______________________________
res4d_branch2a (Conv2D)          (None, 4, 4, 256)    262400      activati
on_34[0][0]
__________________________________________________________________________
______________________________
bn4d_branch2a (BatchNormalizatio (None, 4, 4, 256)    1024        res4d_br
anch2a[0][0]
__________________________________________________________________________
______________________________
activation_35 (Activation)       (None, 4, 4, 256)    0           bn4d_bra
nch2a[0][0]
__________________________________________________________________________
______________________________
res4d_branch2b (Conv2D)          (None, 4, 4, 256)    590080      activati
on_35[0][0]
__________________________________________________________________________
______________________________
bn4d_branch2b (BatchNormalizatio (None, 4, 4, 256)    1024        res4d_br
anch2b[0][0]
__________________________________________________________________________
______________________________
activation_36 (Activation)       (None, 4, 4, 256)    0           bn4d_bra
nch2b[0][0]
__________________________________________________________________________
______________________________
res4d_branch2c (Conv2D)          (None, 4, 4, 1024)   263168      activati
on_36[0][0]
__________________________________________________________________________
______________________________
bn4d_branch2c (BatchNormalizatio (None, 4, 4, 1024)   4096        res4d_br
anch2c[0][0]
__________________________________________________________________________
______________________________
add_12 (Add)                     (None, 4, 4, 1024)   0           bn4d_bra
nch2c[0][0]
                                                                  activati
on_34[0][0]
__________________________________________________________________________
______________________________
activation_37 (Activation)       (None, 4, 4, 1024)   0           add_12
```

```
[0][0]
__________________________________________________________________________________________________
res4e_branch2a (Conv2D)         (None, 4, 4, 256)    262400      activati
on_37[0][0]
__________________________________________________________________________________________________
bn4e_branch2a (BatchNormalizatio (None, 4, 4, 256)    1024        res4e_br
anch2a[0][0]
__________________________________________________________________________________________________
activation_38 (Activation)      (None, 4, 4, 256)    0           bn4e_bra
nch2a[0][0]
__________________________________________________________________________________________________
res4e_branch2b (Conv2D)         (None, 4, 4, 256)    590080      activati
on_38[0][0]
__________________________________________________________________________________________________
bn4e_branch2b (BatchNormalizatio (None, 4, 4, 256)    1024        res4e_br
anch2b[0][0]
__________________________________________________________________________________________________
activation_39 (Activation)      (None, 4, 4, 256)    0           bn4e_bra
nch2b[0][0]
__________________________________________________________________________________________________
res4e_branch2c (Conv2D)         (None, 4, 4, 1024)   263168      activati
on_39[0][0]
__________________________________________________________________________________________________
bn4e_branch2c (BatchNormalizatio (None, 4, 4, 1024)   4096        res4e_br
anch2c[0][0]
__________________________________________________________________________________________________
add_13 (Add)                    (None, 4, 4, 1024)   0           bn4e_bra
nch2c[0][0]
                                                                 activati
on_37[0][0]
__________________________________________________________________________________________________
activation_40 (Activation)      (None, 4, 4, 1024)   0           add_13
[0][0]
__________________________________________________________________________________________________
res4f_branch2a (Conv2D)         (None, 4, 4, 256)    262400      activati
on_40[0][0]
__________________________________________________________________________________________________
bn4f_branch2a (BatchNormalizatio (None, 4, 4, 256)    1024        res4f_br
anch2a[0][0]
__________________________________________________________________________________________________
activation_41 (Activation)      (None, 4, 4, 256)    0           bn4f_bra
nch2a[0][0]
__________________________________________________________________________________________________
```

```
res4f_branch2b (Conv2D)          (None, 4, 4, 256)     590080      activati
on_41[0][0]
__________________________________________________________________________
_________________________
bn4f_branch2b (BatchNormalizatio (None, 4, 4, 256)     1024        res4f_br
anch2b[0][0]
__________________________________________________________________________
_________________________
activation_42 (Activation)       (None, 4, 4, 256)     0           bn4f_bra
nch2b[0][0]
__________________________________________________________________________
_________________________
res4f_branch2c (Conv2D)          (None, 4, 4, 1024)    263168      activati
on_42[0][0]
__________________________________________________________________________
_________________________
bn4f_branch2c (BatchNormalizatio (None, 4, 4, 1024)    4096        res4f_br
anch2c[0][0]
__________________________________________________________________________
_________________________
add_14 (Add)                     (None, 4, 4, 1024)    0           bn4f_bra
nch2c[0][0]
                                                                   activati
on_40[0][0]
__________________________________________________________________________
_________________________
activation_43 (Activation)       (None, 4, 4, 1024)    0           add_14
[0][0]
__________________________________________________________________________
_________________________
res5a_branch2a (Conv2D)          (None, 2, 2, 512)     524800      activati
on_43[0][0]
__________________________________________________________________________
_________________________
bn5a_branch2a (BatchNormalizatio (None, 2, 2, 512)     2048        res5a_br
anch2a[0][0]
__________________________________________________________________________
_________________________
activation_44 (Activation)       (None, 2, 2, 512)     0           bn5a_bra
nch2a[0][0]
__________________________________________________________________________
_________________________
res5a_branch2b (Conv2D)          (None, 2, 2, 512)     2359808     activati
on_44[0][0]
__________________________________________________________________________
_________________________
bn5a_branch2b (BatchNormalizatio (None, 2, 2, 512)     2048        res5a_br
anch2b[0][0]
__________________________________________________________________________
_________________________
activation_45 (Activation)       (None, 2, 2, 512)     0           bn5a_bra
nch2b[0][0]
__________________________________________________________________________
_________________________
res5a_branch2c (Conv2D)          (None, 2, 2, 2048)    1050624     activati
on_45[0][0]
__________________________________________________________________________
```

```
____________________________________________________________________________________________
res5a_branch1 (Conv2D)          (None, 2, 2, 2048)   2099200     activati
on_43[0][0]
____________________________________________________________________________________________
bn5a_branch2c (BatchNormalizatio (None, 2, 2, 2048)  8192        res5a_br
anch2c[0][0]
____________________________________________________________________________________________
bn5a_branch1 (BatchNormalization (None, 2, 2, 2048)  8192        res5a_br
anch1[0][0]
____________________________________________________________________________________________
add_15 (Add)                    (None, 2, 2, 2048)   0           bn5a_bra
nch2c[0][0]
                                                                 bn5a_bra
nch1[0][0]
____________________________________________________________________________________________
activation_46 (Activation)      (None, 2, 2, 2048)   0           add_15
[0][0]
____________________________________________________________________________________________
res5b_branch2a (Conv2D)         (None, 2, 2, 512)    1049088     activati
on_46[0][0]
____________________________________________________________________________________________
bn5b_branch2a (BatchNormalizatio (None, 2, 2, 512)   2048        res5b_br
anch2a[0][0]
____________________________________________________________________________________________
activation_47 (Activation)      (None, 2, 2, 512)    0           bn5b_bra
nch2a[0][0]
____________________________________________________________________________________________
res5b_branch2b (Conv2D)         (None, 2, 2, 512)    2359808     activati
on_47[0][0]
____________________________________________________________________________________________
bn5b_branch2b (BatchNormalizatio (None, 2, 2, 512)   2048        res5b_br
anch2b[0][0]
____________________________________________________________________________________________
activation_48 (Activation)      (None, 2, 2, 512)    0           bn5b_bra
nch2b[0][0]
____________________________________________________________________________________________
res5b_branch2c (Conv2D)         (None, 2, 2, 2048)   1050624     activati
on_48[0][0]
____________________________________________________________________________________________
bn5b_branch2c (BatchNormalizatio (None, 2, 2, 2048)  8192        res5b_br
anch2c[0][0]
____________________________________________________________________________________________
add_16 (Add)                    (None, 2, 2, 2048)   0           bn5b_bra
nch2c[0][0]
```

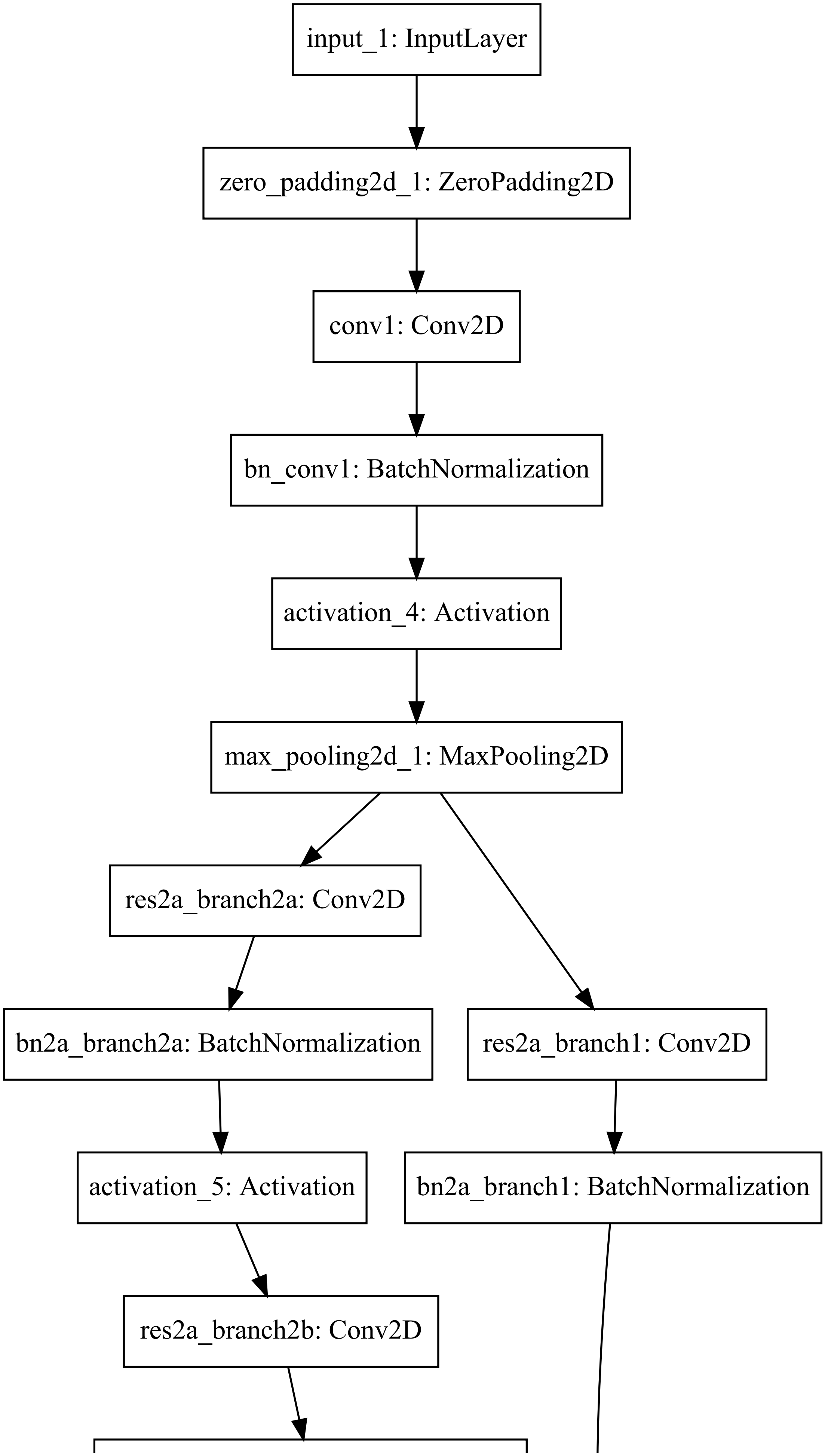
```
                                                                 activati
on_46[0][0]
__________________________________________________________________________
activation_49 (Activation)      (None, 2, 2, 2048)   0           add_16
[0][0]
__________________________________________________________________________
res5c_branch2a (Conv2D)         (None, 2, 2, 512)    1049088     activati
on_49[0][0]
__________________________________________________________________________
bn5c_branch2a (BatchNormalizatio (None, 2, 2, 512)   2048        res5c_br
anch2a[0][0]
__________________________________________________________________________
activation_50 (Activation)      (None, 2, 2, 512)    0           bn5c_bra
nch2a[0][0]
__________________________________________________________________________
res5c_branch2b (Conv2D)         (None, 2, 2, 512)    2359808     activati
on_50[0][0]
__________________________________________________________________________
bn5c_branch2b (BatchNormalizatio (None, 2, 2, 512)   2048        res5c_br
anch2b[0][0]
__________________________________________________________________________
activation_51 (Activation)      (None, 2, 2, 512)    0           bn5c_bra
nch2b[0][0]
__________________________________________________________________________
res5c_branch2c (Conv2D)         (None, 2, 2, 2048)   1050624     activati
on_51[0][0]
__________________________________________________________________________
bn5c_branch2c (BatchNormalizatio (None, 2, 2, 2048)  8192        res5c_br
anch2c[0][0]
__________________________________________________________________________
add_17 (Add)                    (None, 2, 2, 2048)   0           bn5c_bra
nch2c[0][0]
                                                                 activati
on_49[0][0]
__________________________________________________________________________
activation_52 (Activation)      (None, 2, 2, 2048)   0           add_17
[0][0]
__________________________________________________________________________
avg_pool (AveragePooling2D)     (None, 1, 1, 2048)   0           activati
on_52[0][0]
__________________________________________________________________________
flatten_1 (Flatten)             (None, 2048)         0           avg_pool
[0][0]
__________________________________________________________________________
```

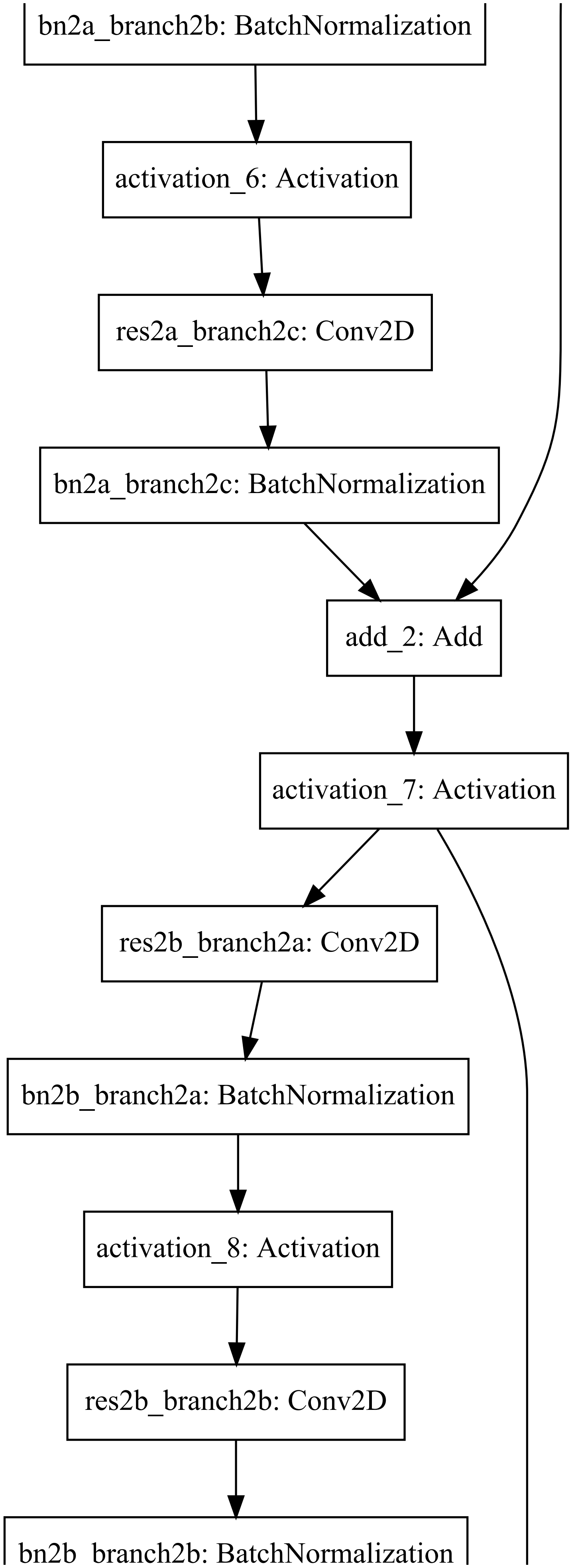
```
_________________________
fc6 (Dense)                      (None, 6)             12294       flatten_
1[0][0]
===========================================================================
=========================
Total params: 23,600,006
Trainable params: 23,546,886
Non-trainable params: 53,120
___________________________________________________________________________
_________________________
```

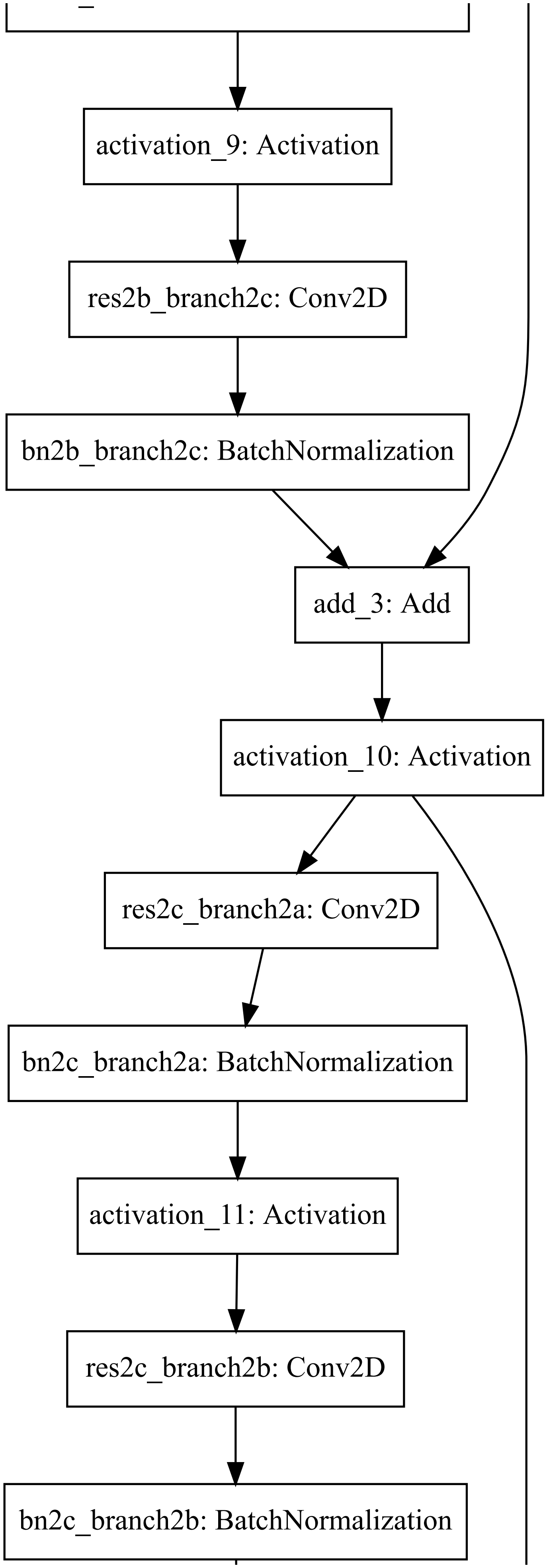
Finally, run the code below to visualize your ResNet50. You can also download a .png picture of your model by going to "File -> Open...-> model.png".

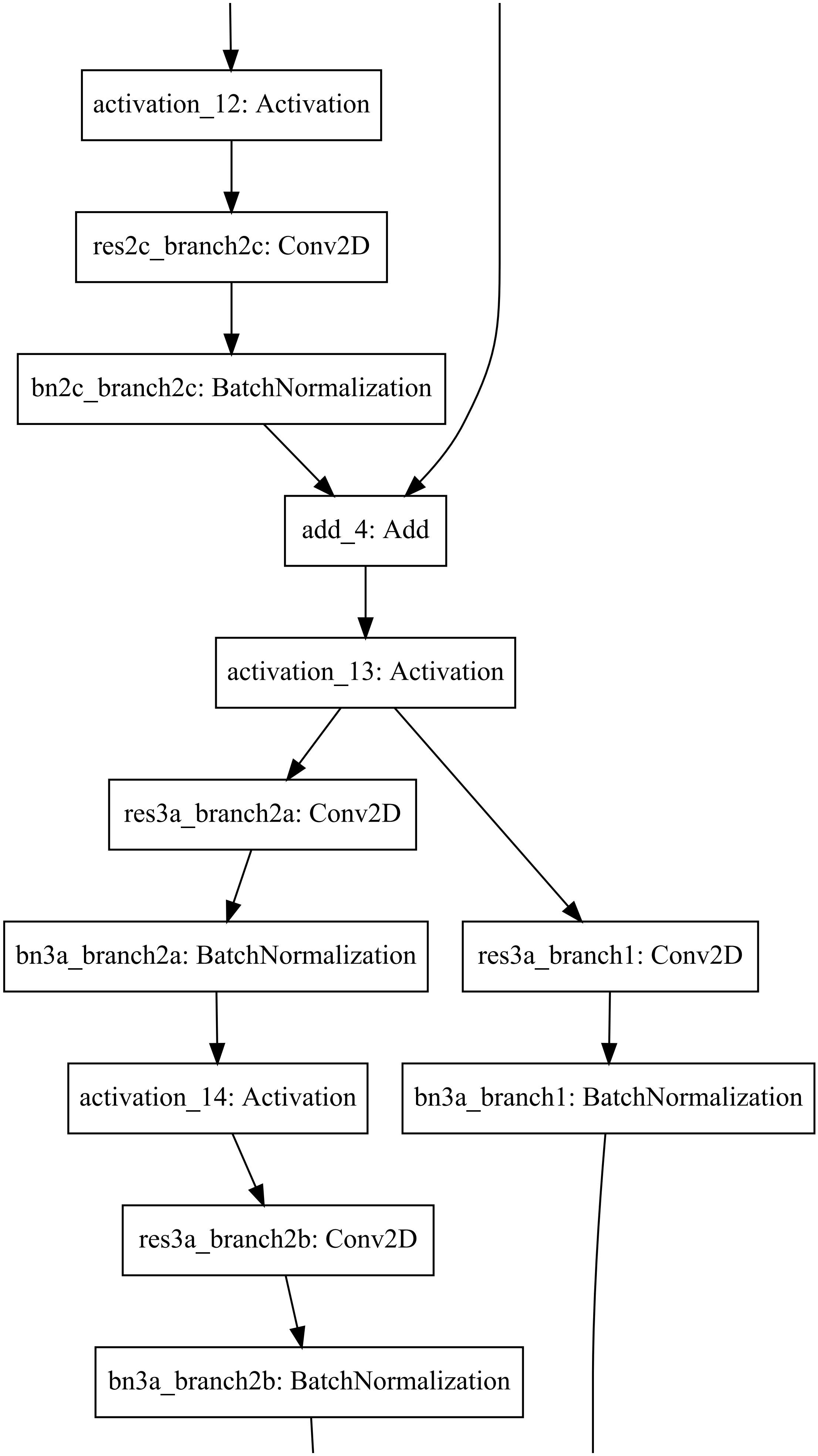
In [36]:
```
plot_model(model, to_file='model.png')
SVG(model_to_dot(model).create(prog='dot', format='svg'))
```

Out[36]:

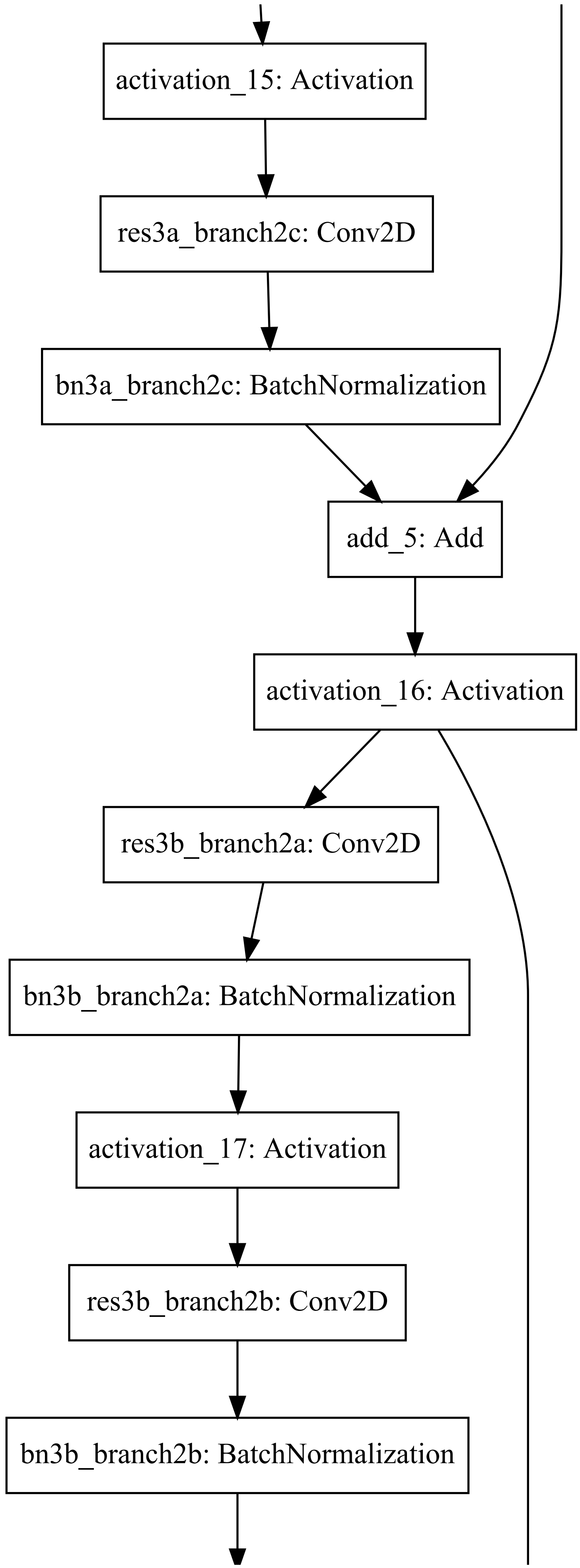

input_1: InputLayer
zero_padding2d_1: ZeroPadding2D
conv1: Conv2D
bn_conv1: BatchNormalization
activation_4: Activation
max_pooling2d_1: MaxPooling2D
res2a_branch2a: Conv2D
bn2a_branch2a: BatchNormalization
res2a_branch1: Conv2D
activation_5: Activation
bn2a_branch1: BatchNormalization
res2a_branch2b: Conv2D

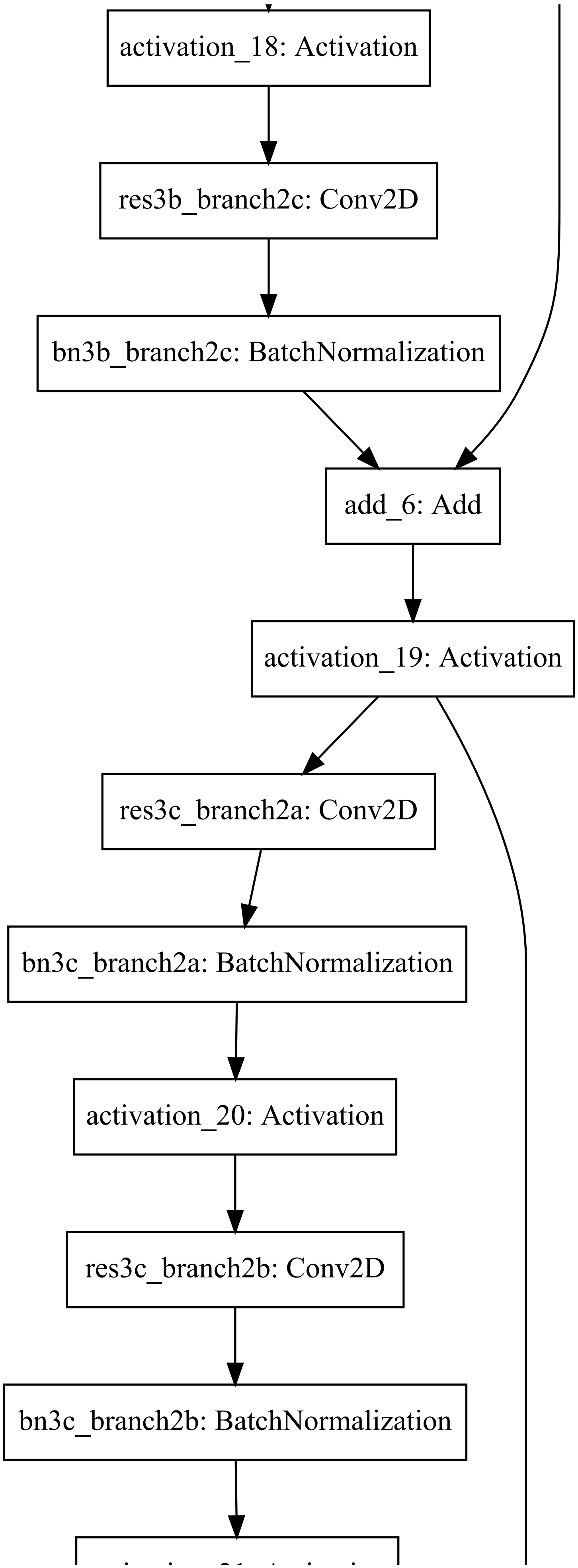

bn2a_branch2b: BatchNormalization
activation_6: Activation
res2a_branch2c: Conv2D
bn2a_branch2c: BatchNormalization
add_2: Add
activation_7: Activation
res2b_branch2a: Conv2D
bn2b_branch2a: BatchNormalization
activation_8: Activation
res2b_branch2b: Conv2D
bn2b_branch2b: BatchNormalization

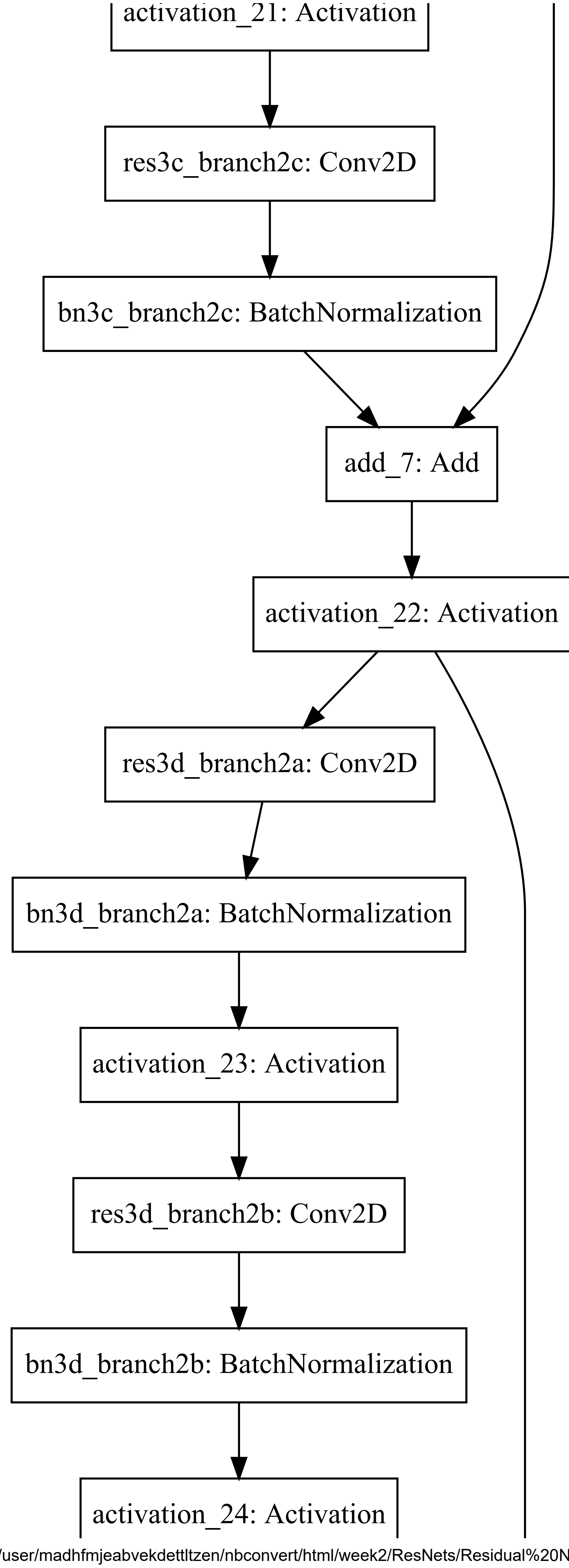

activation_9: Activation
res2b_branch2c: Conv2D
bn2b_branch2c: BatchNormalization
add_3: Add
activation_10: Activation
res2c_branch2a: Conv2D
bn2c_branch2a: BatchNormalization
activation_11: Activation
res2c_branch2b: Conv2D
bn2c_branch2b: BatchNormalization

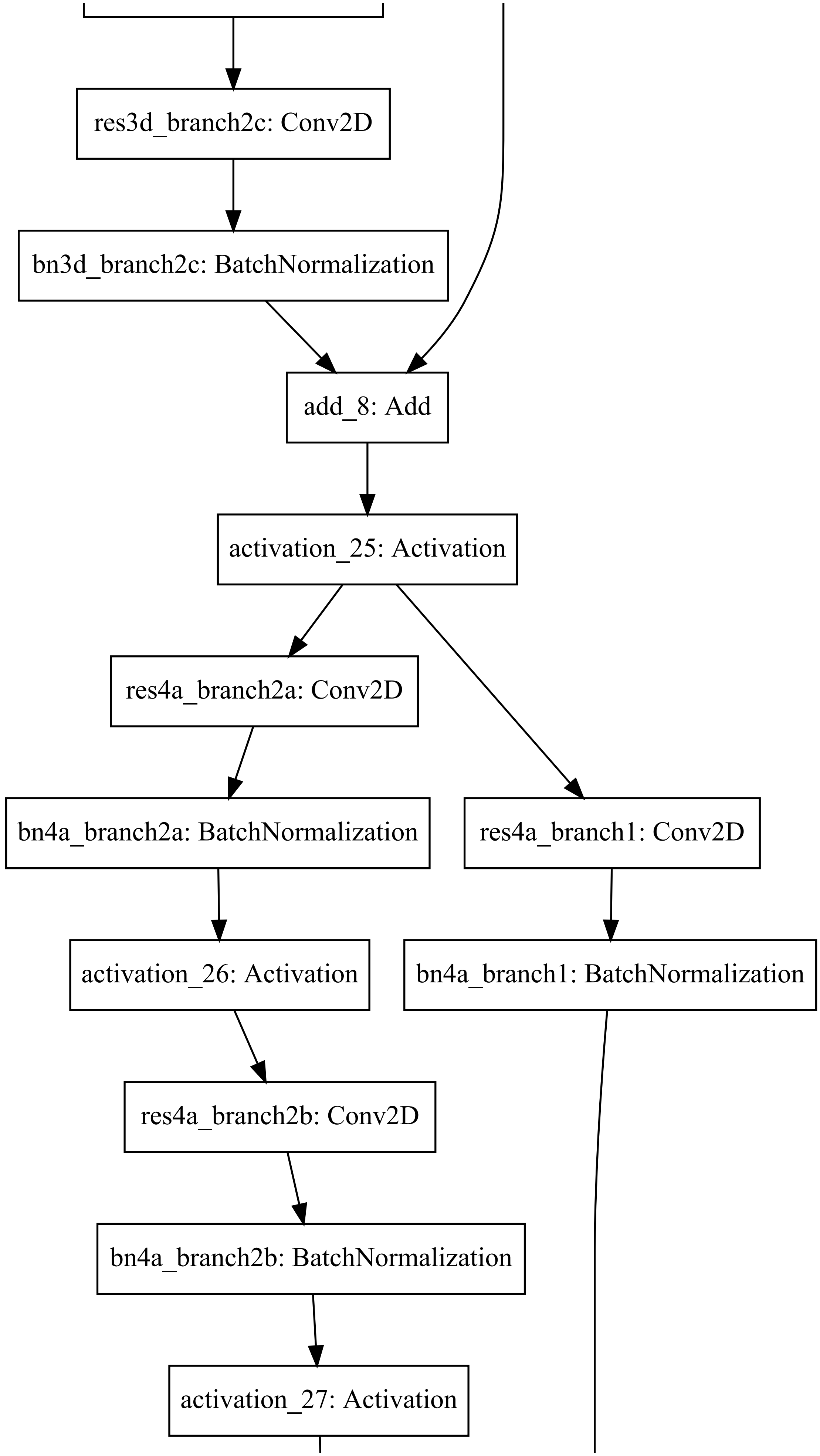


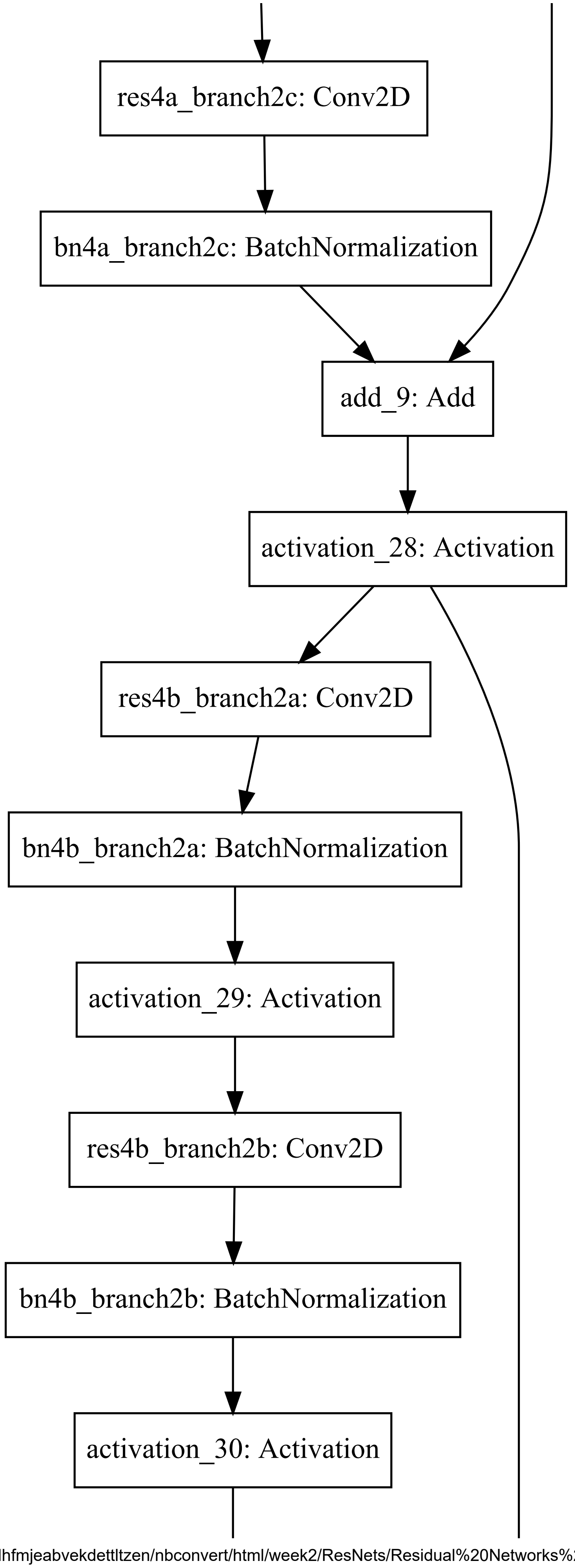
activation_12: Activation
res2c_branch2c: Conv2D
bn2c_branch2c: BatchNormalization
add_4: Add
activation_13: Activation
res3a_branch2a: Conv2D
bn3a_branch2a: BatchNormalization
res3a_branch1: Conv2D
activation_14: Activation
bn3a_branch1: BatchNormalization
res3a_branch2b: Conv2D
bn3a_branch2b: BatchNormalization

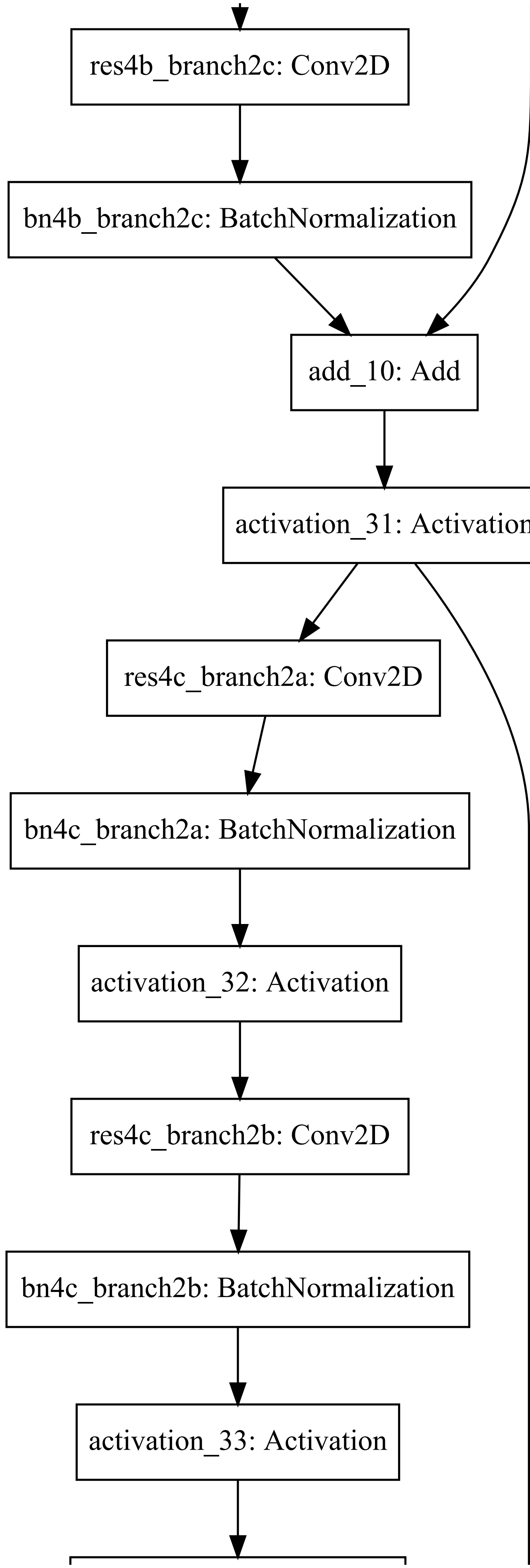

activation_15: Activation
res3a_branch2c: Conv2D
bn3a_branch2c: BatchNormalization
add_5: Add
activation_16: Activation
res3b_branch2a: Conv2D
bn3b_branch2a: BatchNormalization
activation_17: Activation
res3b_branch2b: Conv2D
bn3b_branch2b: BatchNormalization

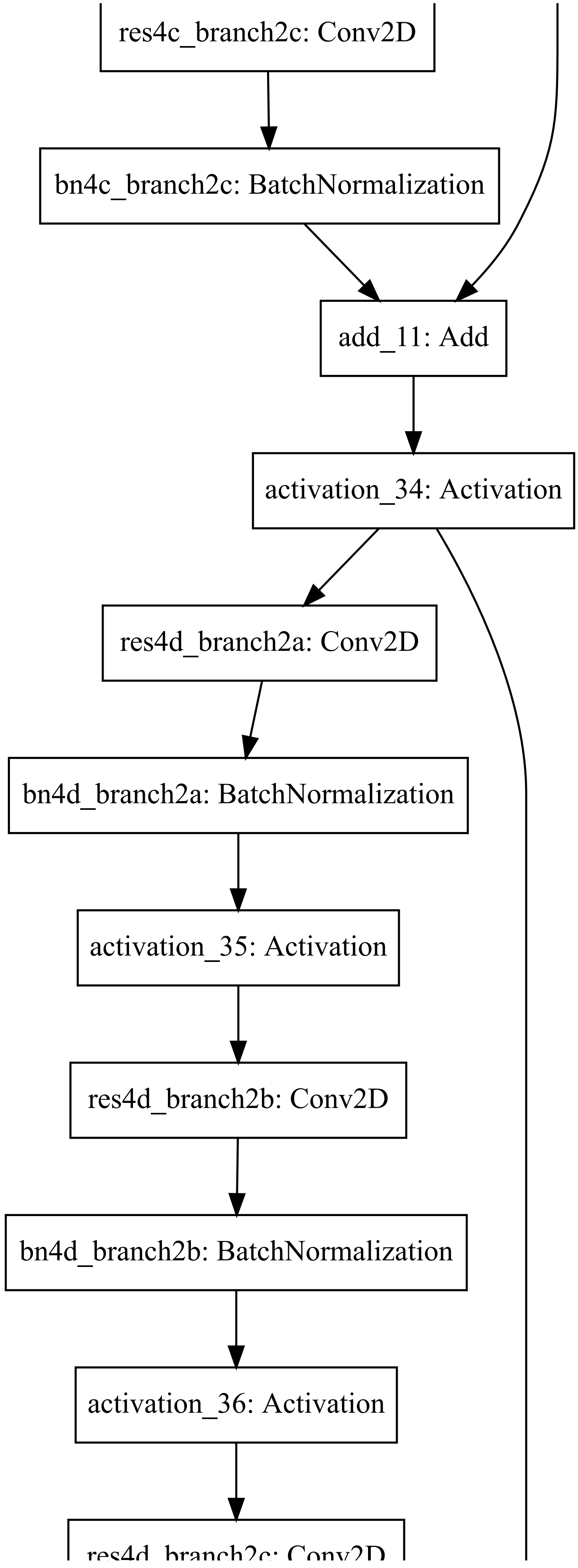

activation_18: Activation
res3b_branch2c: Conv2D
bn3b_branch2c: BatchNormalization
add_6: Add
activation_19: Activation
res3c_branch2a: Conv2D
bn3c_branch2a: BatchNormalization
activation_20: Activation
res3c_branch2b: Conv2D
bn3c_branch2b: BatchNormalization

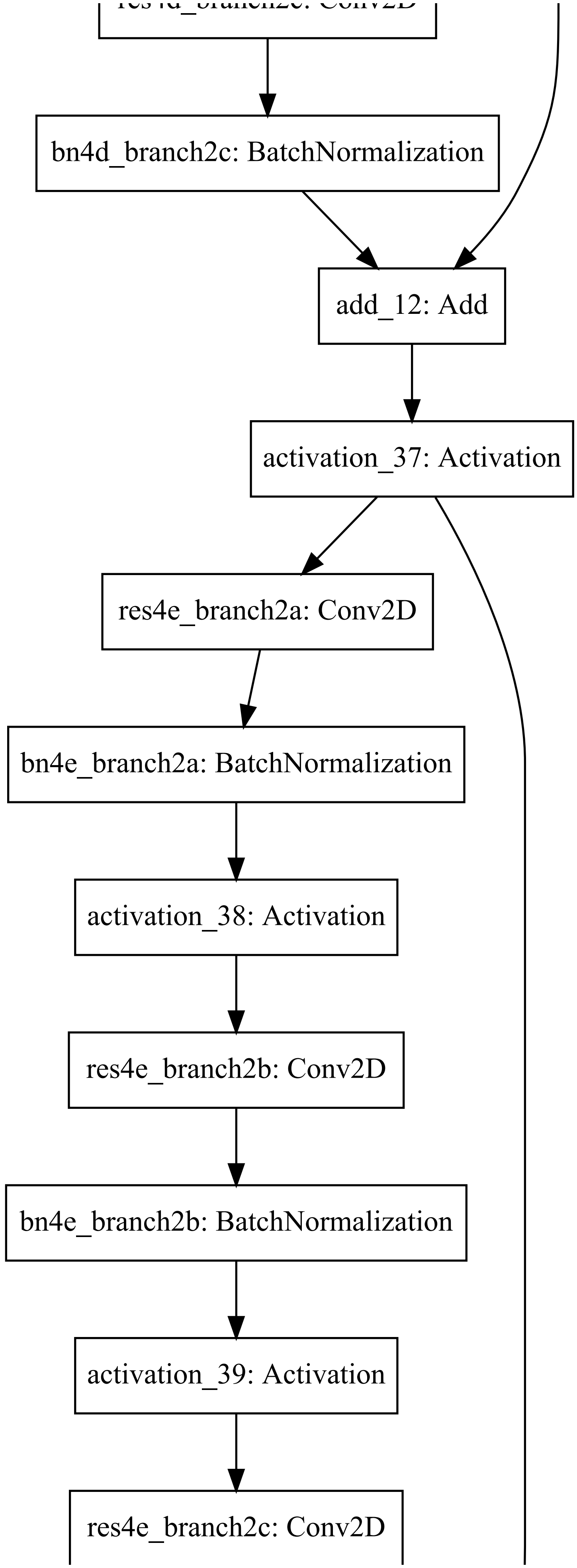

activation_21: Activation
res3c_branch2c: Conv2D
bn3c_branch2c: BatchNormalization
add_7: Add
activation_22: Activation
res3d_branch2a: Conv2D
bn3d_branch2a: BatchNormalization
activation_23: Activation
res3d_branch2b: Conv2D
bn3d_branch2b: BatchNormalization
activation_24: Activation

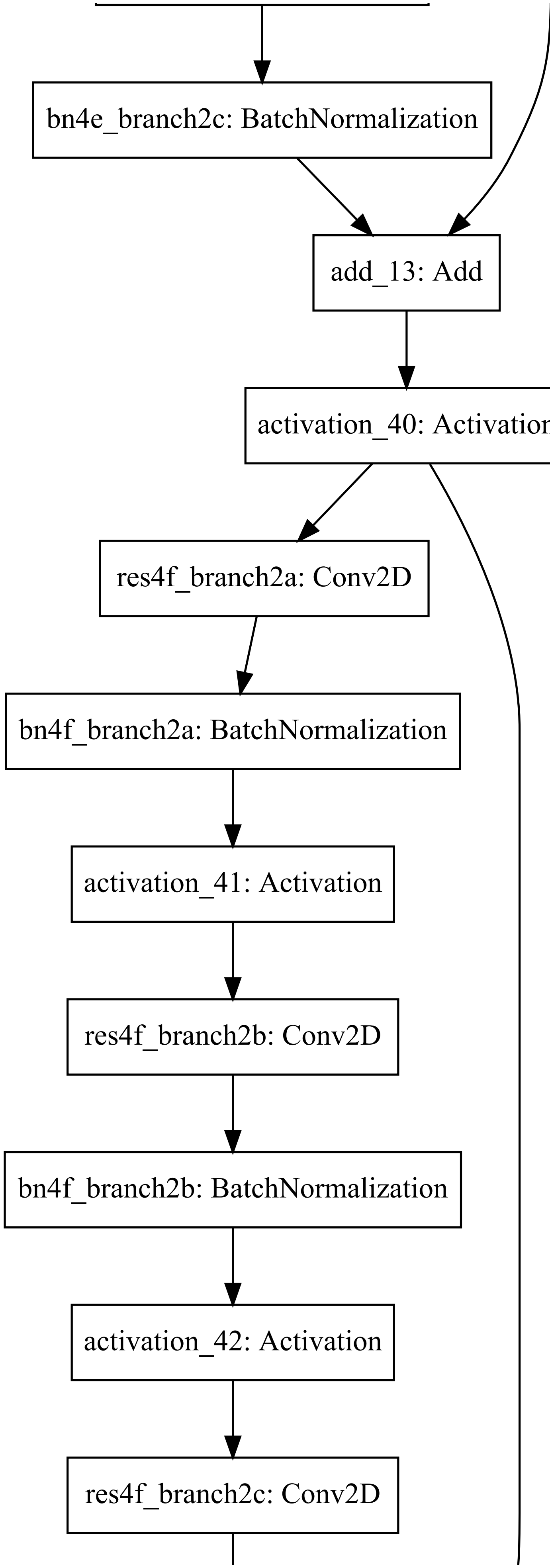

res3d_branch2c: Conv2D
bn3d_branch2c: BatchNormalization
add_8: Add
activation_25: Activation
res4a_branch2a: Conv2D
bn4a_branch2a: BatchNormalization
res4a_branch1: Conv2D
activation_26: Activation
bn4a_branch1: BatchNormalization
res4a_branch2b: Conv2D
bn4a_branch2b: BatchNormalization
activation_27: Activation

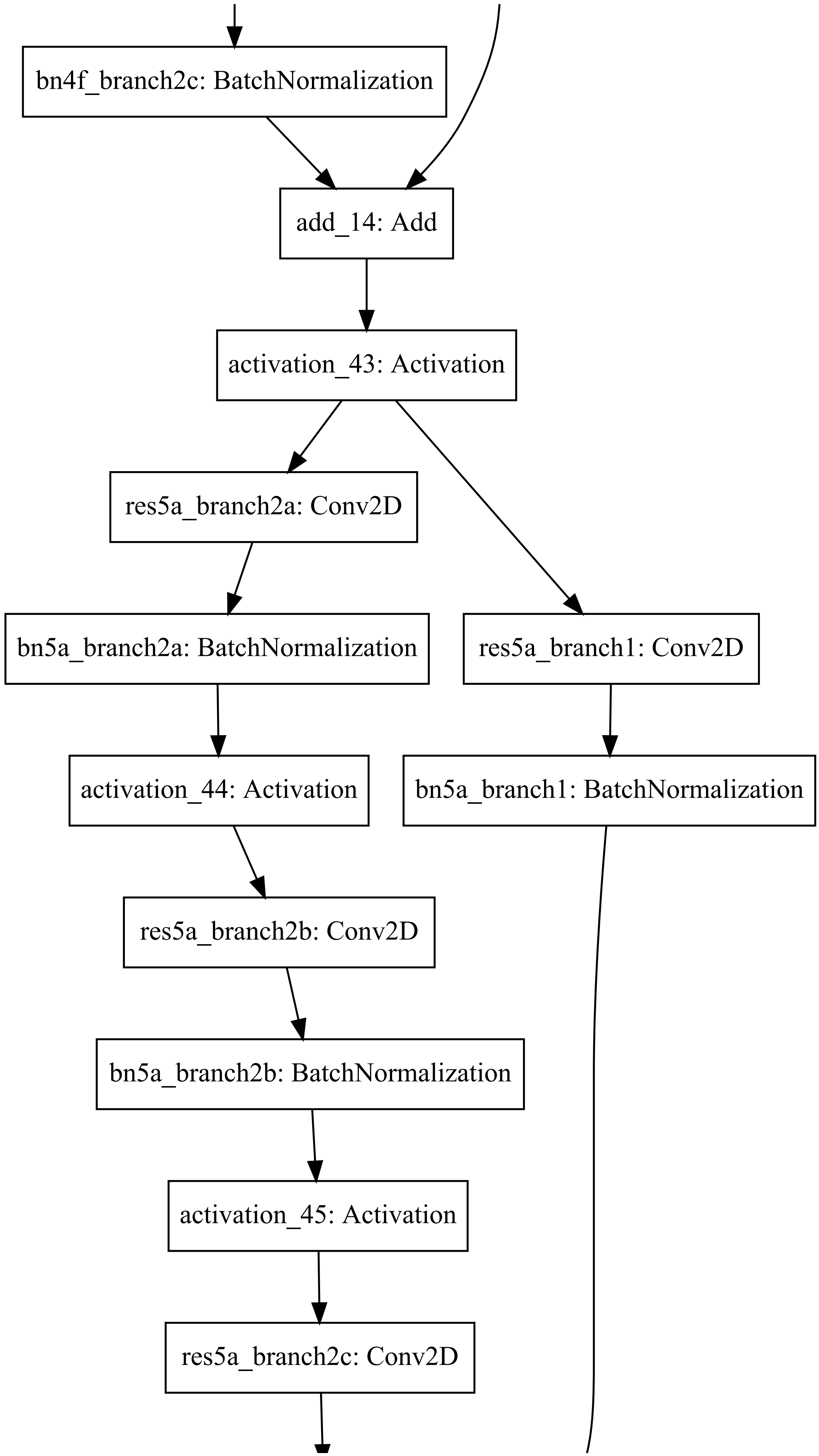

res4a_branch2c: Conv2D
bn4a_branch2c: BatchNormalization
add_9: Add
activation_28: Activation
res4b_branch2a: Conv2D
bn4b_branch2a: BatchNormalization
activation_29: Activation
res4b_branch2b: Conv2D
bn4b_branch2b: BatchNormalization
activation_30: Activation

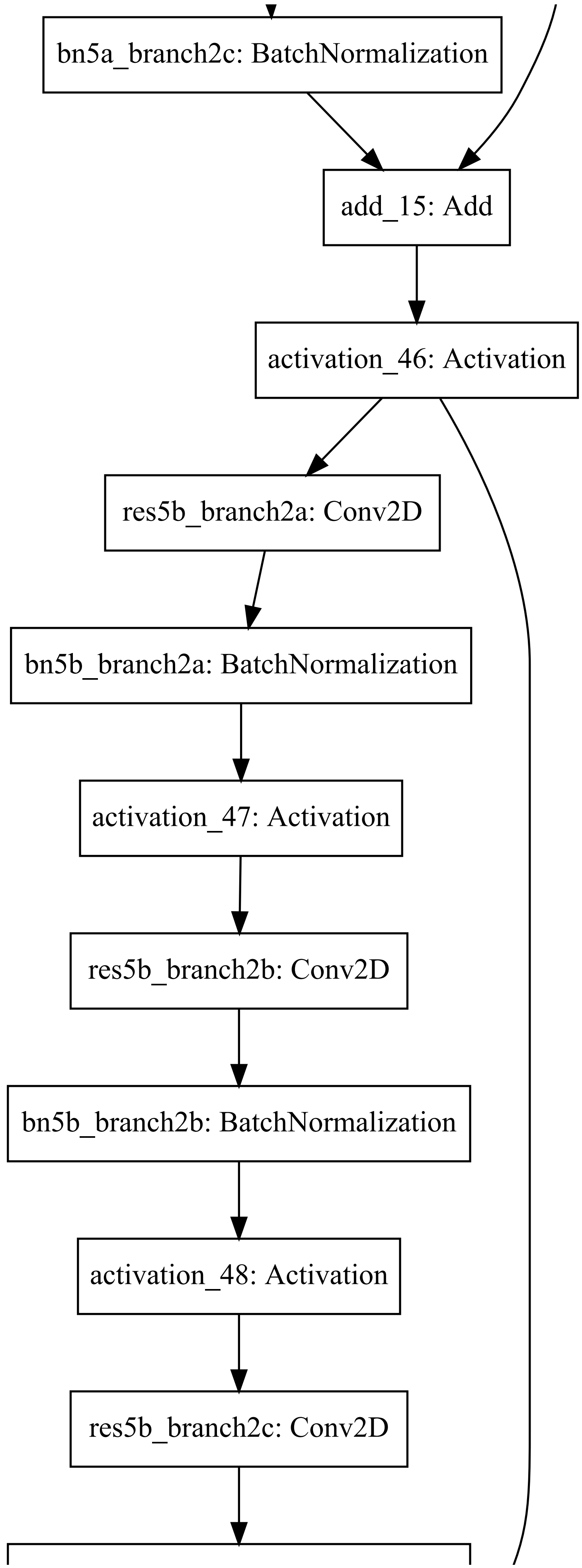

res4b_branch2c: Conv2D
bn4b_branch2c: BatchNormalization
add_10: Add
activation_31: Activation
res4c_branch2a: Conv2D
bn4c_branch2a: BatchNormalization
activation_32: Activation
res4c_branch2b: Conv2D
bn4c_branch2b: BatchNormalization
activation_33: Activation

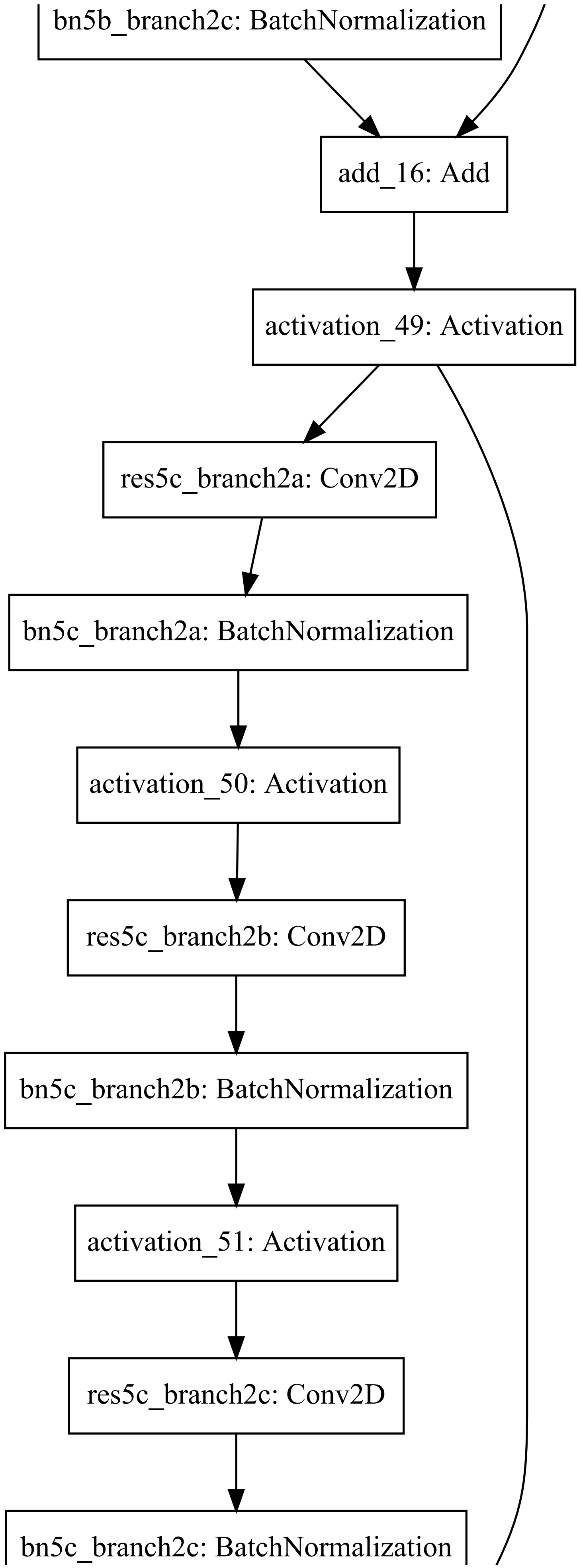

res4c_branch2c: Conv2D
bn4c_branch2c: BatchNormalization
add_11: Add
activation_34: Activation
res4d_branch2a: Conv2D
bn4d_branch2a: BatchNormalization
activation_35: Activation
res4d_branch2b: Conv2D
bn4d_branch2b: BatchNormalization
activation_36: Activation

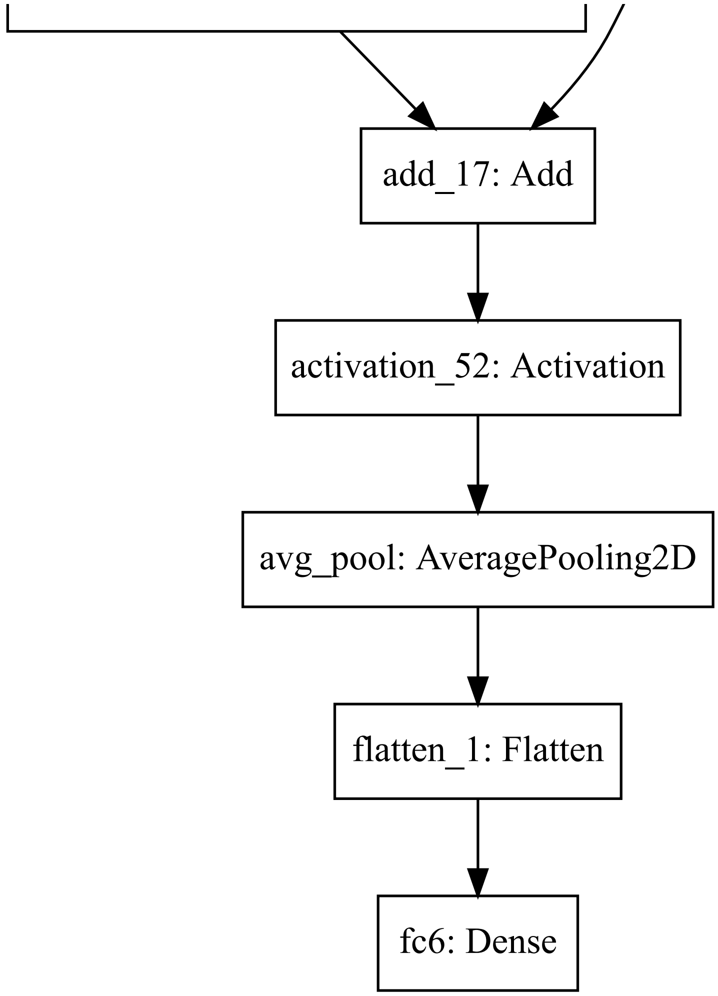

bn4d_branch2c: BatchNormalization
add_12: Add
activation_37: Activation
res4e_branch2a: Conv2D
bn4e_branch2a: BatchNormalization
activation_38: Activation
res4e_branch2b: Conv2D
bn4e_branch2b: BatchNormalization
activation_39: Activation
res4e_branch2c: Conv2D


bn4e_branch2c: BatchNormalization
add_13: Add
activation_40: Activation
res4f_branch2a: Conv2D
bn4f_branch2a: BatchNormalization
activation_41: Activation
res4f_branch2b: Conv2D
bn4f_branch2b: BatchNormalization
activation_42: Activation
res4f_branch2c: Conv2D


bn4f_branch2c: BatchNormalization
add_14: Add
activation_43: Activation
res5a_branch2a: Conv2D
bn5a_branch2a: BatchNormalization
res5a_branch1: Conv2D
activation_44: Activation
bn5a_branch1: BatchNormalization
res5a_branch2b: Conv2D
bn5a_branch2b: BatchNormalization
activation_45: Activation
res5a_branch2c: Conv2D


bn5a_branch2c: BatchNormalization
add_15: Add
activation_46: Activation
res5b_branch2a: Conv2D
bn5b_branch2a: BatchNormalization
activation_47: Activation
res5b_branch2b: Conv2D
bn5b_branch2b: BatchNormalization
activation_48: Activation
res5b_branch2c: Conv2D


bn5b_branch2c: BatchNormalization
add_16: Add
activation_49: Activation
res5c_branch2a: Conv2D
bn5c_branch2a: BatchNormalization
activation_50: Activation
res5c_branch2b: Conv2D
bn5c_branch2b: BatchNormalization
activation_51: Activation
res5c_branch2c: Conv2D
bn5c_branch2c: BatchNormalization



What you should remember:

- Very deep "plain" networks don't work in practice because they are hard to train due to vanishing gradients.
- The skip-connections help to address the Vanishing Gradient problem. They also make it easy for a ResNet block to learn an identity function.
- There are two main type of blocks: The identity block and the convolutional block.
- Very deep Residual Networks are built by stacking these blocks together.

References

This notebook presents the ResNet algorithm due to He et al. (2015). The implementation here also took significant inspiration and follows the structure given in the github repository of Francois Chollet:

- Kaiming He, Xiangyu Zhang, Shaoqing Ren, Jian Sun - Deep Residual Learning for Image Recognition (2015) (https://arxiv.org/abs/1512.03385)
- Francois Chollet's github repository: https://github.com/fchollet/deep-learning-models/blob/master/resnet50.py (https://github.com/fchollet/deep-learning-models/blob/master/resnet50.py)