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Project 2: Deep Learning - Resnets

1. Experimental Results for cifar10 dataset

   The model summary for Resnet20 is given in Figure 1

```
 Layer (type)                   Output Shape         Param #     Connected to
==================================================================================================
 input_19 (InputLayer)          [(None, 32, 32, 3)]  0           []

 conv2d_118 (Conv2D)            (None, 32, 32, 16)   448         ['input_19[0][0]']

 batch_normalization_99 (BatchN  (None, 32, 32, 16)  64          ['conv2d_118[0][0]']
 ormalization)

 activation_86 (Activation)     (None, 32, 32, 16)   0           ['batch_normalization_99[0][0]']

 conv2d_119 (Conv2D)            (None, 32, 32, 16)   2320        ['activation_86[0][0]']

 batch_normalization_100 (Batch  (None, 32, 32, 16)  64          ['conv2d_119[0][0]']
 Normalization)

 activation_87 (Activation)     (None, 32, 32, 16)   0           ['batch_normalization_100[0][0]']

 conv2d_120 (Conv2D)            (None, 32, 32, 16)   2320        ['activation_87[0][0]']

 batch_normalization_101 (Batch  (None, 32, 32, 16)  64          ['conv2d_120[0][0]']
 Normalization)

 add_32 (Add)                   (None, 32, 32, 16)   0           ['activation_86[0][0]',
                                                                  'batch_normalization_101[0][0]']

 activation_88 (Activation)     (None, 32, 32, 16)   0           ['add_32[0][0]']

 conv2d_121 (Conv2D)            (None, 32, 32, 16)   2320        ['activation_88[0][0]']

 batch_normalization_102 (Batch  (None, 32, 32, 16)  64          ['conv2d_121[0][0]']
 Normalization)
```

```
 activation_89 (Activation)     (None, 32, 32, 16)   0           ['batch_normalization_102[0][0]']

 conv2d_122 (Conv2D)            (None, 32, 32, 16)   2320        ['activation_89[0][0]']

 batch_normalization_103 (Batch  (None, 32, 32, 16)  64          ['conv2d_122[0][0]']
 Normalization)

 add_33 (Add)                   (None, 32, 32, 16)   0           ['activation_88[0][0]',
                                                                  'batch_normalization_103[0][0]']

 activation_90 (Activation)     (None, 32, 32, 16)   0           ['add_33[0][0]']

 conv2d_123 (Conv2D)            (None, 32, 32, 16)   2320        ['activation_90[0][0]']

 batch_normalization_104 (Batch  (None, 32, 32, 16)  64          ['conv2d_123[0][0]']
 Normalization)

 activation_91 (Activation)     (None, 32, 32, 16)   0           ['batch_normalization_104[0][0]']

 conv2d_124 (Conv2D)            (None, 32, 32, 16)   2320        ['activation_91[0][0]']

 batch_normalization_105 (Batch  (None, 32, 32, 16)  64          ['conv2d_124[0][0]']
 Normalization)

 add_34 (Add)                   (None, 32, 32, 16)   0           ['activation_90[0][0]',
```

```
 activation_92 (Activation)     (None, 32, 32, 16)   0           ['add_34[0][0]']

 conv2d_125 (Conv2D)            (None, 16, 16, 32)   4640        ['activation_92[0][0]']

 batch_normalization_106 (Batch  (None, 16, 16, 32)  128         ['conv2d_125[0][0]']
 Normalization)

 activation_93 (Activation)     (None, 16, 16, 32)   0           ['batch_normalization_106[0][0]']

 conv2d_126 (Conv2D)            (None, 16, 16, 32)   9248        ['activation_93[0][0]']

 conv2d_127 (Conv2D)            (None, 16, 16, 32)   544         ['activation_92[0][0]']

 batch_normalization_107 (Batch  (None, 16, 16, 32)  128         ['conv2d_126[0][0]']
 Normalization)

 add_35 (Add)                   (None, 16, 16, 32)   0           ['conv2d_127[0][0]',
                                                                  'batch_normalization_107[0][0]']

 activation_94 (Activation)     (None, 16, 16, 32)   0           ['add_35[0][0]']

 conv2d_128 (Conv2D)            (None, 16, 16, 32)   9248        ['activation_94[0][0]']

 batch_normalization_108 (Batch  (None, 16, 16, 32)  128         ['conv2d_128[0][0]']
 Normalization)

 activation_95 (Activation)     (None, 16, 16, 32)   0           ['batch_normalization_108[0][0]']

 conv2d_129 (Conv2D)            (None, 16, 16, 32)   9248        ['activation_95[0][0]']

 batch_normalization_109 (Batch  (None, 16, 16, 32)  128         ['conv2d_129[0][0]']
 Normalization)

 add_36 (Add)                   (None, 16, 16, 32)   0           ['activation_94[0][0]',
                                                                  'batch_normalization_109[0][0]']
```

```
 activation_96 (Activation)     (None, 16, 16, 32)   0           ['add_36[0][0]']

 conv2d_130 (Conv2D)            (None, 16, 16, 32)   9248        ['activation_96[0][0]']

 batch_normalization_110 (Batch  (None, 16, 16, 32)  128         ['conv2d_130[0][0]']
 Normalization)

 activation_97 (Activation)     (None, 16, 16, 32)   0           ['batch_normalization_110[0][0]']

 conv2d_131 (Conv2D)            (None, 16, 16, 32)   9248        ['activation_97[0][0]']

 batch_normalization_111 (Batch  (None, 16, 16, 32)  128         ['conv2d_131[0][0]']
 Normalization)

 add_37 (Add)                   (None, 16, 16, 32)   0           ['activation_96[0][0]',
                                                                  'batch_normalization_111[0][0]']

 activation_98 (Activation)     (None, 16, 16, 32)   0           ['add_37[0][0]']

 conv2d_132 (Conv2D)            (None, 8, 8, 64)     18496       ['activation_98[0][0]']

 batch_normalization_112 (Batch  (None, 8, 8, 64)    256         ['conv2d_132[0][0]']
 Normalization)

 activation_99 (Activation)     (None, 8, 8, 64)     0           ['batch_normalization_112[0][0]']

 conv2d_133 (Conv2D)            (None, 8, 8, 64)     36928       ['activation_99[0][0]']

 conv2d_134 (Conv2D)            (None, 8, 8, 64)     2112        ['activation_98[0][0]']

 batch_normalization_113 (Batch  (None, 8, 8, 64)    256         ['conv2d_133[0][0]']
 Normalization)

 add_38 (Add)                   (None, 8, 8, 64)     0           ['conv2d_134[0][0]',
                                                                  'batch_normalization_113[0][0]']
```

```
activation_100 (Activation)    (None, 8, 8, 64)     0           ['add_38[0][0]']

conv2d_135 (Conv2D)            (None, 8, 8, 64)     36928       ['activation_100[0][0]']

batch_normalization_114 (Batch  (None, 8, 8, 64)    256         ['conv2d_135[0][0]']
Normalization)

activation_101 (Activation)    (None, 8, 8, 64)     0           ['batch_normalization_114[0][0]']

conv2d_136 (Conv2D)            (None, 8, 8, 64)     36928       ['activation_101[0][0]']

batch_normalization_115 (Batch  (None, 8, 8, 64)    256         ['conv2d_136[0][0]']
Normalization)

add_39 (Add)                   (None, 8, 8, 64)     0           ['activation_100[0][0]',
                                                                 'batch_normalization_115[0][0]']

activation_102 (Activation)    (None, 8, 8, 64)     0           ['add_39[0][0]']

conv2d_137 (Conv2D)            (None, 8, 8, 64)     36928       ['activation_102[0][0]']

batch_normalization_116 (Batch  (None, 8, 8, 64)    256         ['conv2d_137[0][0]']
Normalization)

activation_103 (Activation)    (None, 8, 8, 64)     0           ['batch_normalization_116[0][0]']

conv2d_138 (Conv2D)            (None, 8, 8, 64)     36928       ['activation_103[0][0]']

batch_normalization_117 (Batch  (None, 8, 8, 64)    256         ['conv2d_138[0][0]']
Normalization)

add_40 (Add)                   (None, 8, 8, 64)     0           ['activation_102[0][0]',
                                                                 'batch_normalization_117[0][0]']

activation_104 (Activation)    (None, 8, 8, 64)     0           ['add_40[0][0]']
```

```
 average_pooling2d_3 (AveragePo  (None, 1, 1, 64)    0           ['activation_104[0][0]']
 oling2D)

 flatten_3 (Flatten)            (None, 64)           0           ['average_pooling2d_3[0][0]']

 dense_3 (Dense)                (None, 10)           650         ['flatten_3[0][0]']

==================================================================================================
Total params: 274,442
Trainable params: 273,066
Non-trainable params: 1,376
__________________________________________________________________________________________________
```

Figure 1: First Model Summary for cifar 10 dataset

For cifar10 dataset:

parameters of training:
learning rate = 1e-3,
epoch = 20,
batch size = 32
x_train.shape = (50000,32,32,3)
loss function = categorical cross entropy, optimizer = Adam, metrics = accuracy

Training and validation accuracies in each epoch are given at Figure 2.

```
Epoch 1/20
1563/1563 [==============================] - 835s 531ms/step - loss: 1.5529 - accuracy: 0.4937 - val_loss: 3.1442 - val_accuracy: 0.2933
Epoch 2/20
1563/1563 [==============================] - 818s 523ms/step - loss: 1.1681 - accuracy: 0.6380 - val_loss: 1.4682 - val_accuracy: 0.5523
Epoch 3/20
1563/1563 [==============================] - 824s 527ms/step - loss: 1.0089 - accuracy: 0.7035 - val_loss: 1.2021 - val_accuracy: 0.6481
Epoch 4/20
1563/1563 [==============================] - 824s 527ms/step - loss: 0.9138 - accuracy: 0.7387 - val_loss: 1.0146 - val_accuracy: 0.7191
Epoch 5/20
1563/1563 [==============================] - 826s 528ms/step - loss: 0.8540 - accuracy: 0.7631 - val_loss: 0.9753 - val_accuracy: 0.7320
Epoch 6/20
1563/1563 [==============================] - 826s 529ms/step - loss: 0.8073 - accuracy: 0.7796 - val_loss: 0.8574 - val_accuracy: 0.7621
Epoch 7/20
1563/1563 [==============================] - 826s 528ms/step - loss: 0.7788 - accuracy: 0.7904 - val_loss: 0.9595 - val_accuracy: 0.7397
Epoch 8/20
1563/1563 [==============================] - 824s 527ms/step - loss: 0.7469 - accuracy: 0.8021 - val_loss: 0.8815 - val_accuracy: 0.7617
Epoch 9/20
1563/1563 [==============================] - 821s 525ms/step - loss: 0.7228 - accuracy: 0.8111 - val_loss: 0.8488 - val_accuracy: 0.7677
Epoch 10/20
1563/1563 [==============================] - 823s 526ms/step - loss: 0.7064 - accuracy: 0.8185 - val_loss: 0.9824 - val_accuracy: 0.7526
Epoch 11/20
1563/1563 [==============================] - 825s 528ms/step - loss: 0.6912 - accuracy: 0.8254 - val_loss: 0.8126 - val_accuracy: 0.7858
Epoch 12/20
1563/1563 [==============================] - 824s 527ms/step - loss: 0.6737 - accuracy: 0.8310 - val_loss: 1.0291 - val_accuracy: 0.7373
Epoch 13/20
1563/1563 [==============================] - 824s 527ms/step - loss: 0.6587 - accuracy: 0.8376 - val_loss: 0.8008 - val_accuracy: 0.7938
Epoch 14/20
1563/1563 [==============================] - 825s 528ms/step - loss: 0.6505 - accuracy: 0.8418 - val_loss: 0.8222 - val_accuracy: 0.7940
```

```
Epoch 15/20
1563/1563 [==============================] - 826s 528ms/step - loss: 0.6401 - accuracy: 0.8460 - val_loss: 0.7224 - val_accuracy: 0.8213
Epoch 16/20
1563/1563 [==============================] - 824s 527ms/step - loss: 0.6301 - accuracy: 0.8493 - val_loss: 0.9085 - val_accuracy: 0.7651
Epoch 17/20
1563/1563 [==============================] - 798s 510ms/step - loss: 0.6211 - accuracy: 0.8515 - val_loss: 0.7345 - val_accuracy: 0.8171
Epoch 18/20
1563/1563 [==============================] - 795s 508ms/step - loss: 0.6151 - accuracy: 0.8541 - val_loss: 0.8469 - val_accuracy: 0.7987
Epoch 19/20
1563/1563 [==============================] - 793s 507ms/step - loss: 0.6098 - accuracy: 0.8560 - val_loss: 0.8154 - val_accuracy: 0.7970
Epoch 20/20
1563/1563 [==============================] - 784s 502ms/step - loss: 0.6017 - accuracy: 0.8596 - val_loss: 0.7638 - val_accuracy: 0.8128
313/313 [==============================] - 34s 107ms/step - loss: 0.7638 - accuracy: 0.8128
```

Figure 2: Training and validation accuracies in each epoch

The test loss and test accuracy for this model are given in Figure 3:

```
Test loss: 0.9023741483688354
Test accuracy: 0.7856000065803528
```

Figure 3: test loss and accuracy of the model

The plot of validation and training accuracy for each epoch is given in Figure 4:

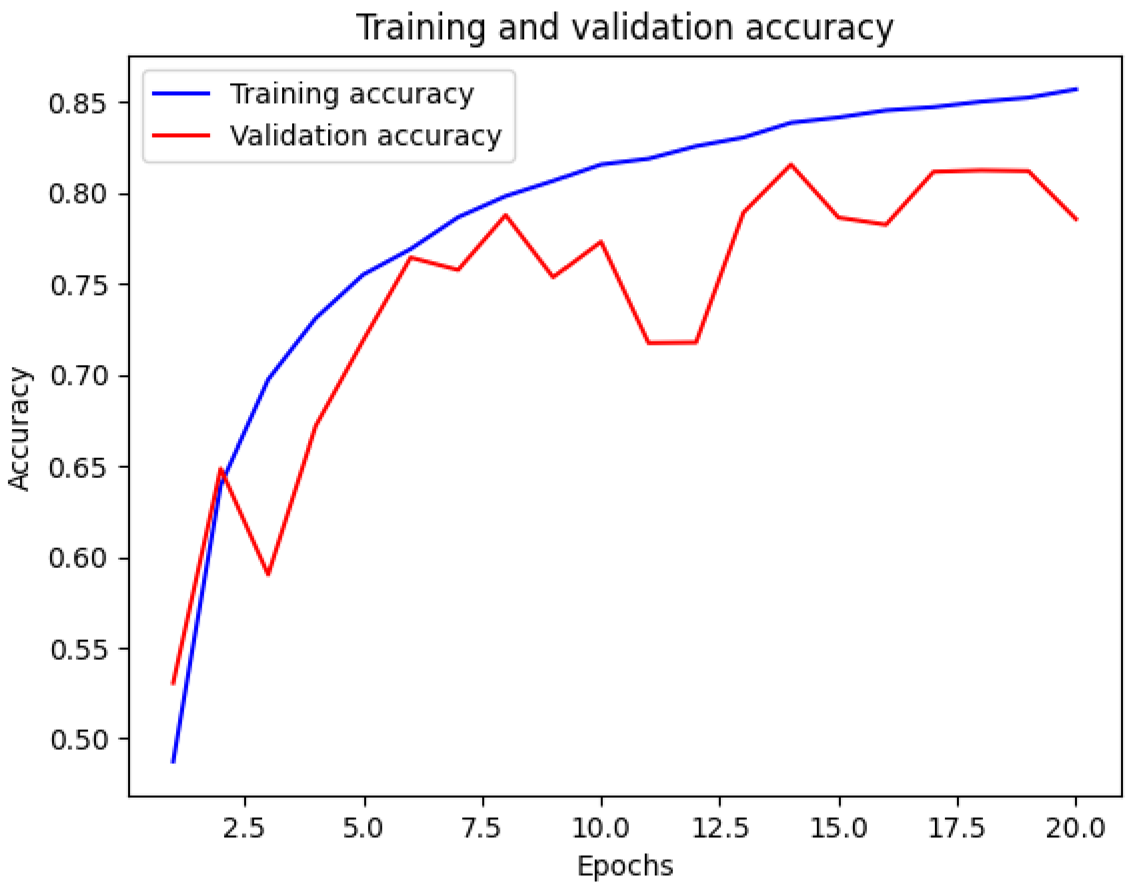

Figure 4: Validation and Training Accuracy

2. Discussion

   As it can be observed the model for cifar10, there is no overfitting observed and the training and test accurices are good. Trying the model with optimizer sgd instead of Adam gives the following results in Figure 5;

```
Epoch 1/20
<ipython-input-10-898cdac8ad22>:50: UserWarning: `Model.fit_generator` is deprecated and will be removed in a future version. Please use
  model2.fit_generator(datagen.flow(x_train, y_train, batch_size=batch_size),
1563/1563 [==============================] - 67s 33ms/step - loss: 1.8475 - accuracy: 0.3780 - val_loss: 1.7610 - val_accuracy: 0.4155
Epoch 2/20
1563/1563 [==============================] - 51s 33ms/step - loss: 1.5742 - accuracy: 0.4823 - val_loss: 1.5229 - val_accuracy: 0.5027
Epoch 3/20
1563/1563 [==============================] - 50s 32ms/step - loss: 1.4513 - accuracy: 0.5300 - val_loss: 1.6667 - val_accuracy: 0.4643
Epoch 4/20
1563/1563 [==============================] - 50s 32ms/step - loss: 1.3553 - accuracy: 0.5708 - val_loss: 1.4536 - val_accuracy: 0.5326
Epoch 5/20
1563/1563 [==============================] - 50s 32ms/step - loss: 1.2750 - accuracy: 0.5989 - val_loss: 1.2358 - val_accuracy: 0.6087
Epoch 6/20
1563/1563 [==============================] - 49s 31ms/step - loss: 1.2105 - accuracy: 0.6204 - val_loss: 1.3633 - val_accuracy: 0.5863
Epoch 7/20
1563/1563 [==============================] - 50s 32ms/step - loss: 1.1590 - accuracy: 0.6409 - val_loss: 1.2024 - val_accuracy: 0.6313
Epoch 8/20
1563/1563 [==============================] - 50s 32ms/step - loss: 1.1143 - accuracy: 0.6585 - val_loss: 1.4766 - val_accuracy: 0.5709
Epoch 9/20
1563/1563 [==============================] - 49s 31ms/step - loss: 1.0744 - accuracy: 0.6712 - val_loss: 1.1519 - val_accuracy: 0.6562
Epoch 10/20
1563/1563 [==============================] - 48s 31ms/step - loss: 1.0427 - accuracy: 0.6835 - val_loss: 1.2669 - val_accuracy: 0.6243
Epoch 11/20
1563/1563 [==============================] - 48s 31ms/step - loss: 1.0013 - accuracy: 0.6989 - val_loss: 1.3094 - val_accuracy: 0.6113
Epoch 12/20
1563/1563 [==============================] - 49s 31ms/step - loss: 0.9703 - accuracy: 0.7101 - val_loss: 1.1781 - val_accuracy: 0.6397
Epoch 13/20
1563/1563 [==============================] - 50s 32ms/step - loss: 0.9415 - accuracy: 0.7196 - val_loss: 1.0044 - val_accuracy: 0.6990
Epoch 14/20
1563/1563 [==============================] - 49s 31ms/step - loss: 0.9146 - accuracy: 0.7300 - val_loss: 1.1780 - val_accuracy: 0.6495
Epoch 15/20
1563/1563 [==============================] - 49s 31ms/step - loss: 0.8931 - accuracy: 0.7387 - val_loss: 1.2694 - val_accuracy: 0.6357
Epoch 16/20
```

```
Epoch 15/20
1563/1563 [==============================] - 49s 31ms/step - loss: 0.8931 - accuracy: 0.7387 - val_loss: 1.2694 - val_accuracy: 0.6357
Epoch 16/20
1563/1563 [==============================] - 49s 31ms/step - loss: 0.8692 - accuracy: 0.7455 - val_loss: 1.1327 - val_accuracy: 0.6811
Epoch 17/20
1563/1563 [==============================] - 49s 31ms/step - loss: 0.8471 - accuracy: 0.7550 - val_loss: 1.0730 - val_accuracy: 0.6982
Epoch 18/20
1563/1563 [==============================] - 56s 36ms/step - loss: 0.8252 - accuracy: 0.7606 - val_loss: 0.9042 - val_accuracy: 0.7297
Epoch 19/20
1563/1563 [==============================] - 57s 36ms/step - loss: 0.8083 - accuracy: 0.7677 - val_loss: 1.0221 - val_accuracy: 0.7159
Epoch 20/20
1563/1563 [==============================] - 55s 35ms/step - loss: 0.7867 - accuracy: 0.7763 - val_loss: 0.9325 - val_accuracy: 0.7354
313/313 [==============================] - 2s 5ms/step - loss: 0.9325 - accuracy: 0.7354
Test loss: 0.9325338006019592
Test accuracy: 0.7354000210762024
```

Figure 5: Training and validation accuracy at each epoch for optimizer sgd

As it can be seen the adam optimizer works better than sgd for this model. This might be due the the deep nature of this neural network. Now in the following I have tried the optimizer adam and increased the depth of the network by using n = 4 instead n = 3. It resulted as follows;

```
 input_2 (InputLayer)           [(None, 32, 32, 3)]  0           []

 conv2d_21 (Conv2D)             (None, 32, 32, 16)   448         ['input_2[0][0]']

 batch_normalization_19 (BatchN  (None, 32, 32, 16)  64          ['conv2d_21[0][0]']
 ormalization)

 activation_19 (Activation)     (None, 32, 32, 16)   0           ['batch_normalization_19[0][0]']

 conv2d_22 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_19[0][0]']

 batch_normalization_20 (BatchN  (None, 32, 32, 16)  64          ['conv2d_22[0][0]']
 ormalization)

 activation_20 (Activation)     (None, 32, 32, 16)   0           ['batch_normalization_20[0][0]']

 conv2d_23 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_20[0][0]']

 batch_normalization_21 (BatchN  (None, 32, 32, 16)  64          ['conv2d_23[0][0]']
 ormalization)

 add_9 (Add)                    (None, 32, 32, 16)   0           ['activation_19[0][0]',
                                                                  'batch_normalization_21[0][0]']

 activation_21 (Activation)     (None, 32, 32, 16)   0           ['add_9[0][0]']

 conv2d_24 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_21[0][0]']

 batch_normalization_22 (BatchN  (None, 32, 32, 16)  64          ['conv2d_24[0][0]']
```

```
conv2d_24 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_21[0][0]']

batch_normalization_22 (BatchN  (None, 32, 32, 16)  64          ['conv2d_24[0][0]']
ormalization)

activation_22 (Activation)     (None, 32, 32, 16)   0           ['batch_normalization_22[0][0]']

conv2d_25 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_22[0][0]']

batch_normalization_23 (BatchN  (None, 32, 32, 16)  64          ['conv2d_25[0][0]']
ormalization)

add_10 (Add)                   (None, 32, 32, 16)   0           ['activation_21[0][0]',
                                                                 'batch_normalization_23[0][0]']

activation_23 (Activation)     (None, 32, 32, 16)   0           ['add_10[0][0]']

conv2d_26 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_23[0][0]']

batch_normalization_24 (BatchN  (None, 32, 32, 16)  64          ['conv2d_26[0][0]']
ormalization)

activation_24 (Activation)     (None, 32, 32, 16)   0           ['batch_normalization_24[0][0]']

conv2d_27 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_24[0][0]']

batch_normalization_25 (BatchN  (None, 32, 32, 16)  64          ['conv2d_27[0][0]']
ormalization)
```

```
add_11 (Add)                   (None, 32, 32, 16)   0           ['activation_23[0][0]',
                                                                 'batch_normalization_25[0][0]']

activation_25 (Activation)     (None, 32, 32, 16)   0           ['add_11[0][0]']

conv2d_28 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_25[0][0]']

batch_normalization_26 (BatchN  (None, 32, 32, 16)  64          ['conv2d_28[0][0]']
ormalization)

activation_26 (Activation)     (None, 32, 32, 16)   0           ['batch_normalization_26[0][0]']

conv2d_29 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_26[0][0]']

batch_normalization_27 (BatchN  (None, 32, 32, 16)  64          ['conv2d_29[0][0]']
ormalization)

add_12 (Add)                   (None, 32, 32, 16)   0           ['activation_25[0][0]',
                                                                 'batch_normalization_27[0][0]']

activation_27 (Activation)     (None, 32, 32, 16)   0           ['add_12[0][0]']

conv2d_30 (Conv2D)             (None, 16, 16, 32)   4640        ['activation_27[0][0]']

batch_normalization_28 (BatchN  (None, 16, 16, 32)  128         ['conv2d_30[0][0]']
ormalization)

activation_28 (Activation)     (None, 16, 16, 32)   0           ['batch_normalization_28[0][0]']
```

```
conv2d_31 (Conv2D)             (None, 16, 16, 32)   9248        ['activation_28[0][0]']

conv2d_32 (Conv2D)             (None, 16, 16, 32)   544         ['activation_27[0][0]']

batch_normalization_29 (BatchN  (None, 16, 16, 32)  128         ['conv2d_31[0][0]']
ormalization)

add_13 (Add)                   (None, 16, 16, 32)   0           ['conv2d_32[0][0]',
                                                                 'batch_normalization_29[0][0]']

activation_29 (Activation)     (None, 16, 16, 32)   0           ['add_13[0][0]']

conv2d_33 (Conv2D)             (None, 16, 16, 32)   9248        ['activation_29[0][0]']

batch_normalization_30 (BatchN  (None, 16, 16, 32)  128         ['conv2d_33[0][0]']
ormalization)

activation_30 (Activation)     (None, 16, 16, 32)   0           ['batch_normalization_30[0][0]']

conv2d_34 (Conv2D)             (None, 16, 16, 32)   9248        ['activation_30[0][0]']

batch_normalization_31 (BatchN  (None, 16, 16, 32)  128         ['conv2d_34[0][0]']
ormalization)

add_14 (Add)                   (None, 16, 16, 32)   0           ['activation_29[0][0]',
                                                                 'batch_normalization_31[0][0]']

activation_31 (Activation)     (None, 16, 16, 32)   0           ['add_14[0][0]']
```

```
conv2d_35 (Conv2D)             (None, 16, 16, 32)   9248        ['activation_31[0][0]']

batch_normalization_32 (BatchN  (None, 16, 16, 32)  128         ['conv2d_35[0][0]']
ormalization)

activation_32 (Activation)     (None, 16, 16, 32)   0           ['batch_normalization_32[0][0]']

conv2d_36 (Conv2D)             (None, 16, 16, 32)   9248        ['activation_32[0][0]']

batch_normalization_33 (BatchN  (None, 16, 16, 32)  128         ['conv2d_36[0][0]']
ormalization)

add_15 (Add)                   (None, 16, 16, 32)   0           ['activation_31[0][0]',
                                                                 'batch_normalization_33[0][0]']

activation_33 (Activation)     (None, 16, 16, 32)   0           ['add_15[0][0]']

conv2d_37 (Conv2D)             (None, 16, 16, 32)   9248        ['activation_33[0][0]']

batch_normalization_34 (BatchN  (None, 16, 16, 32)  128         ['conv2d_37[0][0]']
ormalization)

activation_34 (Activation)     (None, 16, 16, 32)   0           ['batch_normalization_34[0][0]']

conv2d_38 (Conv2D)             (None, 16, 16, 32)   9248        ['activation_34[0][0]']

batch_normalization_35 (BatchN  (None, 16, 16, 32)  128         ['conv2d_38[0][0]']
ormalization)
```

```
 add_16 (Add)                   (None, 16, 16, 32)   0           ['activation_33[0][0]',
                                                                  'batch_normalization_35[0][0]']

 activation_35 (Activation)     (None, 16, 16, 32)   0           ['add_16[0][0]']

 conv2d_39 (Conv2D)             (None, 8, 8, 64)     18496       ['activation_35[0][0]']

 batch_normalization_36 (BatchN  (None, 8, 8, 64)    256         ['conv2d_39[0][0]']
 ormalization)

 activation_36 (Activation)     (None, 8, 8, 64)     0           ['batch_normalization_36[0][0]']

 conv2d_40 (Conv2D)             (None, 8, 8, 64)     36928       ['activation_36[0][0]']

 conv2d_41 (Conv2D)             (None, 8, 8, 64)     2112        ['activation_35[0][0]']

 batch_normalization_37 (BatchN  (None, 8, 8, 64)    256         ['conv2d_40[0][0]']
 ormalization)

 add_17 (Add)                   (None, 8, 8, 64)     0           ['conv2d_41[0][0]',
                                                                  'batch_normalization_37[0][0]']

 activation_37 (Activation)     (None, 8, 8, 64)     0           ['add_17[0][0]']

 conv2d_42 (Conv2D)             (None, 8, 8, 64)     36928       ['activation_37[0][0]']

 batch_normalization_38 (BatchN  (None, 8, 8, 64)    256         ['conv2d_42[0][0]']
 ormalization)

 activation_38 (Activation)     (None, 8, 8, 64)     0           ['batch_normalization_38[0][0]']

 conv2d_43 (Conv2D)             (None, 8, 8, 64)     36928       ['activation_38[0][0]']
```

```
batch_normalization_39 (BatchN  (None, 8, 8, 64)    256         ['conv2d_43[0][0]']
ormalization)

add_18 (Add)                   (None, 8, 8, 64)     0           ['activation_37[0][0]',
                                                                 'batch_normalization_39[0][0]']

activation_39 (Activation)     (None, 8, 8, 64)     0           ['add_18[0][0]']

conv2d_44 (Conv2D)             (None, 8, 8, 64)     36928       ['activation_39[0][0]']

batch_normalization_40 (BatchN  (None, 8, 8, 64)    256         ['conv2d_44[0][0]']
ormalization)

activation_40 (Activation)     (None, 8, 8, 64)     0           ['batch_normalization_40[0][0]']

conv2d_45 (Conv2D)             (None, 8, 8, 64)     36928       ['activation_40[0][0]']

batch_normalization_41 (BatchN  (None, 8, 8, 64)    256         ['conv2d_45[0][0]']
ormalization)

add_19 (Add)                   (None, 8, 8, 64)     0           ['activation_39[0][0]',
                                                                 'batch_normalization_41[0][0]']

activation_41 (Activation)     (None, 8, 8, 64)     0           ['add_19[0][0]']

conv2d_46 (Conv2D)             (None, 8, 8, 64)     36928       ['activation_41[0][0]']

batch_normalization_42 (BatchN  (None, 8, 8, 64)    256         ['conv2d_46[0][0]']
ormalization)

activation_42 (Activation)     (None, 8, 8, 64)     0           ['batch_normalization_42[0][0]']
```

```
 activation_42 (Activation)      (None, 8, 8, 64)     0           ['batch_normalization_42[0][0]']

 conv2d_47 (Conv2D)              (None, 8, 8, 64)     36928       ['activation_42[0][0]']

 batch_normalization_43 (BatchN  (None, 8, 8, 64)     256         ['conv2d_47[0][0]']
 ormalization)

 add_20 (Add)                    (None, 8, 8, 64)     0           ['activation_41[0][0]',
                                                                   'batch_normalization_43[0][0]']

 activation_43 (Activation)      (None, 8, 8, 64)     0           ['add_20[0][0]']

 average_pooling2d_1 (AveragePo  (None, 1, 1, 64)     0           ['activation_43[0][0]']
 oling2D)

 flatten_1 (Flatten)             (None, 64)           0           ['average_pooling2d_1[0][0]']

 dense_1 (Dense)                 (None, 10)           650         ['flatten_1[0][0]']

==================================================================================================
Total params: 372,330
Trainable params: 370,506
Non-trainable params: 1,824
__________________________________________________________________________________________________
```

Figure 6: Model summary with n = 4

This model gave the accuracy plots as such:

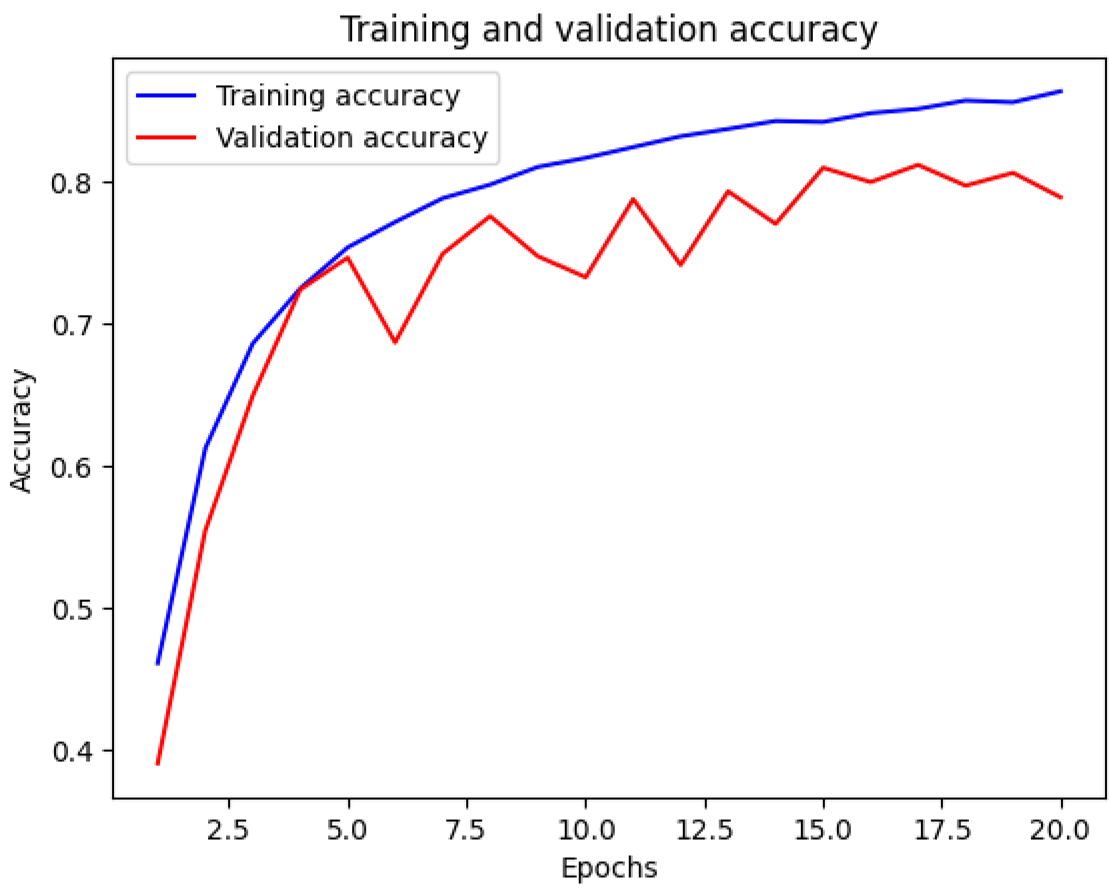

Figure 7: Training and validation accuracy

Test accuracy for this model is 0.7888000011444092

As it can be observed that the model with n = 4, the model with more depth has better accuracy. The optimizer used for this model is adam and the other parameters are the same. Since resnet models have shortcuts the training is fast and lets deeper models train and outcome overall good accuracies.

3. Experimental Results for cifar100 dataset

The model summary for Resnet20 is given in the figure below; the only difference with the model used for cifar 10 dataset is the output layer having 100 nodes instead of 10.

```
Model: "model_1"
__________________________________________________________________________________________________
 Layer (type)                   Output Shape         Param #     Connected to
==================================================================================================
 input_2 (InputLayer)           [(None, 32, 32, 3)]  0           []

 conv2d_21 (Conv2D)             (None, 32, 32, 16)   448         ['input_2[0][0]']

 batch_normalization_19 (BatchN  (None, 32, 32, 16)  64          ['conv2d_21[0][0]']
 ormalization)

 activation_19 (Activation)     (None, 32, 32, 16)   0           ['batch_normalization_19[0][0]']

 conv2d_22 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_19[0][0]']

 batch_normalization_20 (BatchN  (None, 32, 32, 16)  64          ['conv2d_22[0][0]']
 ormalization)

 activation_20 (Activation)     (None, 32, 32, 16)   0           ['batch_normalization_20[0][0]']

 conv2d_23 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_20[0][0]']

 batch_normalization_21 (BatchN  (None, 32, 32, 16)  64          ['conv2d_23[0][0]']
 ormalization)

 add_9 (Add)                    (None, 32, 32, 16)   0           ['activation_19[0][0]',
                                                                  'batch_normalization_21[0][0]']

 activation_21 (Activation)     (None, 32, 32, 16)   0           ['add_9[0][0]']

 conv2d_24 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_21[0][0]']
```

```
batch_normalization_22 (BatchN  (None, 32, 32, 16)  64          ['conv2d_24[0][0]']
ormalization)

activation_22 (Activation)     (None, 32, 32, 16)   0           ['batch_normalization_22[0][0]']

conv2d_25 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_22[0][0]']

batch_normalization_23 (BatchN  (None, 32, 32, 16)  64          ['conv2d_25[0][0]']
ormalization)

add_10 (Add)                   (None, 32, 32, 16)   0           ['activation_21[0][0]',
                                                                 'batch_normalization_23[0][0]']

activation_23 (Activation)     (None, 32, 32, 16)   0           ['add_10[0][0]']

conv2d_26 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_23[0][0]']

batch_normalization_24 (BatchN  (None, 32, 32, 16)  64          ['conv2d_26[0][0]']
ormalization)

activation_24 (Activation)     (None, 32, 32, 16)   0           ['batch_normalization_24[0][0]']

conv2d_27 (Conv2D)             (None, 32, 32, 16)   2320        ['activation_24[0][0]']

batch_normalization_25 (BatchN  (None, 32, 32, 16)  64          ['conv2d_27[0][0]']
ormalization)

add_11 (Add)                   (None, 32, 32, 16)   0           ['activation_23[0][0]',
                                                                 'batch_normalization_25[0][0]']

activation_25 (Activation)     (None, 32, 32, 16)   0           ['add_11[0][0]']
```

```
conv2d_28 (Conv2D)             (None, 16, 16, 32)   4640        ['activation_25[0][0]']

batch_normalization_26 (BatchN  (None, 16, 16, 32)  128         ['conv2d_28[0][0]']
ormalization)

activation_26 (Activation)     (None, 16, 16, 32)   0           ['batch_normalization_26[0][0]']

conv2d_29 (Conv2D)             (None, 16, 16, 32)   9248        ['activation_26[0][0]']

conv2d_30 (Conv2D)             (None, 16, 16, 32)   544         ['activation_25[0][0]']

batch_normalization_27 (BatchN  (None, 16, 16, 32)  128         ['conv2d_29[0][0]']
ormalization)

add_12 (Add)                   (None, 16, 16, 32)   0           ['conv2d_30[0][0]',
                                                                 'batch_normalization_27[0][0]']

activation_27 (Activation)     (None, 16, 16, 32)   0           ['add_12[0][0]']

conv2d_31 (Conv2D)             (None, 16, 16, 32)   9248        ['activation_27[0][0]']

batch_normalization_28 (BatchN  (None, 16, 16, 32)  128         ['conv2d_31[0][0]']
ormalization)

activation_28 (Activation)     (None, 16, 16, 32)   0           ['batch_normalization_28[0][0]']

conv2d_32 (Conv2D)             (None, 16, 16, 32)   9248        ['activation_28[0][0]']

batch_normalization_29 (BatchN  (None, 16, 16, 32)  128         ['conv2d_32[0][0]']
ormalization)
```

```
 add_13 (Add)                   (None, 16, 16, 32)   0           ['activation_27[0][0]',
                                                                  'batch_normalization_29[0][0]']

 activation_29 (Activation)     (None, 16, 16, 32)   0           ['add_13[0][0]']

 conv2d_33 (Conv2D)             (None, 16, 16, 32)   9248        ['activation_29[0][0]']

 batch_normalization_30 (BatchN  (None, 16, 16, 32)  128         ['conv2d_33[0][0]']
 ormalization)

 activation_30 (Activation)     (None, 16, 16, 32)   0           ['batch_normalization_30[0][0]']

 conv2d_34 (Conv2D)             (None, 16, 16, 32)   9248        ['activation_30[0][0]']

 batch_normalization_31 (BatchN  (None, 16, 16, 32)  128         ['conv2d_34[0][0]']
 ormalization)

 add_14 (Add)                   (None, 16, 16, 32)   0           ['activation_29[0][0]',
                                                                  'batch_normalization_31[0][0]']

 activation_31 (Activation)     (None, 16, 16, 32)   0           ['add_14[0][0]']

 conv2d_35 (Conv2D)             (None, 8, 8, 64)     18496       ['activation_31[0][0]']

 batch_normalization_32 (BatchN  (None, 8, 8, 64)    256         ['conv2d_35[0][0]']
 ormalization)

 activation_32 (Activation)     (None, 8, 8, 64)     0           ['batch_normalization_32[0][0]']

 conv2d_36 (Conv2D)             (None, 8, 8, 64)     36928       ['activation_32[0][0]']

 conv2d_37 (Conv2D)             (None, 8, 8, 64)     2112        ['activation_31[0][0]']

 batch_normalization_33 (BatchN  (None, 8, 8, 64)    256         ['conv2d_36[0][0]']
 ormalization)

 add_15 (Add)                   (None, 8, 8, 64)     0           ['conv2d_37[0][0]',
                                                                  'batch_normalization_33[0][0]']

 activation_33 (Activation)     (None, 8, 8, 64)     0           ['add_15[0][0]']

 conv2d_38 (Conv2D)             (None, 8, 8, 64)     36928       ['activation_33[0][0]']

 batch_normalization_34 (BatchN  (None, 8, 8, 64)    256         ['conv2d_38[0][0]']
 ormalization)

 activation_34 (Activation)     (None, 8, 8, 64)     0           ['batch_normalization_34[0][0]']

 conv2d_39 (Conv2D)             (None, 8, 8, 64)     36928       ['activation_34[0][0]']

 batch_normalization_35 (BatchN  (None, 8, 8, 64)    256         ['conv2d_39[0][0]']
 ormalization)

 add_16 (Add)                   (None, 8, 8, 64)     0           ['activation_33[0][0]',
                                                                  'batch_normalization_35[0][0]']

 activation_35 (Activation)     (None, 8, 8, 64)     0           ['add_16[0][0]']

 conv2d_40 (Conv2D)             (None, 8, 8, 64)     36928       ['activation_35[0][0]']

 batch_normalization_36 (BatchN  (None, 8, 8, 64)    256         ['conv2d_40[0][0]']
 ormalization)

 activation_36 (Activation)     (None, 8, 8, 64)     0           ['batch_normalization_36[0][0]']
```

```
 conv2d_41 (Conv2D)             (None, 8, 8, 64)     36928       ['activation_36[0][0]']

 batch_normalization_37 (BatchN  (None, 8, 8, 64)    256         ['conv2d_41[0][0]']
 ormalization)

 add_17 (Add)                   (None, 8, 8, 64)     0           ['activation_35[0][0]',
                                                                  'batch_normalization_37[0][0]']

 activation_37 (Activation)     (None, 8, 8, 64)     0           ['add_17[0][0]']

 average_pooling2d_1 (AveragePo  (None, 1, 1, 64)    0           ['activation_37[0][0]']
 oling2D)

 flatten_1 (Flatten)            (None, 64)           0           ['average_pooling2d_1[0][0]']

 dense_1 (Dense)                (None, 100)          6500        ['flatten_1[0][0]']

==================================================================================================
Total params: 280,292
Trainable params: 278,916
Non-trainable params: 1,376
__________________________________________________________________________________________________
```

Figure 8: Model summary for cifar 100 dataset

The training parameters of this model is:
parameters of training:
learning rate = 1e-3,
epoch = 20,
batch size = 32
x_train.shape = (50000,32,32,3)
loss function = categorical cross entropy, optimizer = Adam, metrics = accuracy

Training and validation accuracy plot in each epoch are given at Figure 9.

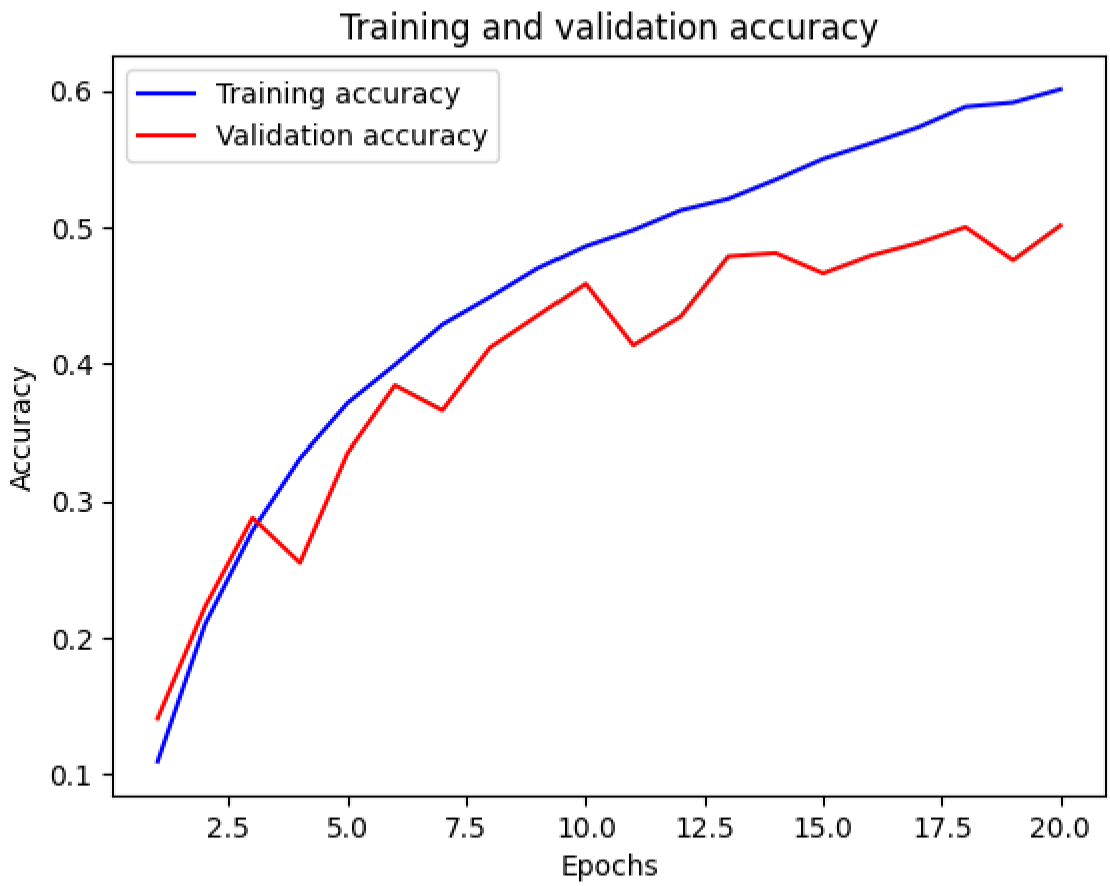

Figure 9 : The plot of train and test accuracy

4. Discussion for cifar-100 dataset
   As it can be observed from the plot there is no over fitting observed in these 20 epochs.
   The training time was significantly longer since there is 100 classes instead of 10.
   Comparing with the CNN modules used in the previous assignments resnets give much better results with not very significant training time differences.

5. Resnet50 vs model constructed for cifar 10 dataset
   In this section the accuracy results for pre-trained Resnet50 and the 2 models with n = 3 and n = 4 are compared for cifar10 dataset.
   Due to training time and since the network is deeper I set epoch to 5, the rest of the training parameters are the same.
   The model summary for Resnet50 is given in the below figure;

```
Model: "model_1"
__________________________________________________________________________________________________
 Layer (type)                   Output Shape         Param #     Connected to
==================================================================================================
 input_1 (InputLayer)           [(None, 32, 32, 3)]  0           []

 conv1_pad (ZeroPadding2D)      (None, 38, 38, 3)    0           ['input_1[0][0]']

 conv1_conv (Conv2D)            (None, 16, 16, 64)   9472        ['conv1_pad[0][0]']

 conv1_bn (BatchNormalization)  (None, 16, 16, 64)   256         ['conv1_conv[0][0]']

 conv1_relu (Activation)        (None, 16, 16, 64)   0           ['conv1_bn[0][0]']

 pool1_pad (ZeroPadding2D)      (None, 18, 18, 64)   0           ['conv1_relu[0][0]']

 pool1_pool (MaxPooling2D)      (None, 8, 8, 64)     0           ['pool1_pad[0][0]']

 conv2_block1_1_conv (Conv2D)   (None, 8, 8, 64)     4160        ['pool1_pool[0][0]']

 conv2_block1_1_bn (BatchNormal  (None, 8, 8, 64)    256         ['conv2_block1_1_conv[0][0]']
 ization)

 conv2_block1_1_relu (Activatio  (None, 8, 8, 64)    0           ['conv2_block1_1_bn[0][0]']
 n)

 conv2_block1_2_conv (Conv2D)   (None, 8, 8, 64)     36928       ['conv2_block1_1_relu[0][0]']

 conv2_block1_2_bn (BatchNormal  (None, 8, 8, 64)    256         ['conv2_block1_2_conv[0][0]']
 ization)

 conv2_block1_2_relu (Activatio  (None, 8, 8, 64)    0           ['conv2_block1_2_bn[0][0]']
 n)
```

```
 conv2_block1_0_conv (Conv2D)   (None, 8, 8, 256)    16640       ['pool1_pool[0][0]']

 conv2_block1_3_conv (Conv2D)   (None, 8, 8, 256)    16640       ['conv2_block1_2_relu[0][0]']

 conv2_block1_0_bn (BatchNormal  (None, 8, 8, 256)   1024        ['conv2_block1_0_conv[0][0]']
 ization)

 conv2_block1_3_bn (BatchNormal  (None, 8, 8, 256)   1024        ['conv2_block1_3_conv[0][0]']
 ization)

 conv2_block1_add (Add)         (None, 8, 8, 256)    0           ['conv2_block1_0_bn[0][0]',
                                                                  'conv2_block1_3_bn[0][0]']

 conv2_block1_out (Activation)  (None, 8, 8, 256)    0           ['conv2_block1_add[0][0]']

 conv2_block2_1_conv (Conv2D)   (None, 8, 8, 64)     16448       ['conv2_block1_out[0][0]']

 conv2_block2_1_bn (BatchNormal  (None, 8, 8, 64)    256         ['conv2_block2_1_conv[0][0]']
 ization)

 conv2_block2_1_relu (Activatio  (None, 8, 8, 64)    0           ['conv2_block2_1_bn[0][0]']
 n)

 conv2_block2_2_conv (Conv2D)   (None, 8, 8, 64)     36928       ['conv2_block2_1_relu[0][0]']

 conv2_block2_2_bn (BatchNormal  (None, 8, 8, 64)    256         ['conv2_block2_2_conv[0][0]']
 ization)

 conv2_block2_2_relu (Activatio  (None, 8, 8, 64)    0           ['conv2_block2_2_bn[0][0]']
 n)

 conv2_block2_3_conv (Conv2D)   (None, 8, 8, 256)    16640       ['conv2_block2_2_relu[0][0]']
```

```
conv2_block2_3_bn (BatchNormal  (None, 8, 8, 256)   1024        ['conv2_block2_3_conv[0][0]']
ization)

conv2_block2_add (Add)         (None, 8, 8, 256)    0           ['conv2_block1_out[0][0]',
                                                                 'conv2_block2_3_bn[0][0]']

conv2_block2_out (Activation)  (None, 8, 8, 256)    0           ['conv2_block2_add[0][0]']

conv2_block3_1_conv (Conv2D)   (None, 8, 8, 64)     16448       ['conv2_block2_out[0][0]']

conv2_block3_1_bn (BatchNormal  (None, 8, 8, 64)    256         ['conv2_block3_1_conv[0][0]']
ization)

conv2_block3_1_relu (Activatio  (None, 8, 8, 64)    0           ['conv2_block3_1_bn[0][0]']
n)

conv2_block3_2_conv (Conv2D)   (None, 8, 8, 64)     36928       ['conv2_block3_1_relu[0][0]']

conv2_block3_2_bn (BatchNormal  (None, 8, 8, 64)    256         ['conv2_block3_2_conv[0][0]']
ization)

conv2_block3_2_relu (Activatio  (None, 8, 8, 64)    0           ['conv2_block3_2_bn[0][0]']
n)

conv2_block3_3_conv (Conv2D)   (None, 8, 8, 256)    16640       ['conv2_block3_2_relu[0][0]']

conv2_block3_3_bn (BatchNormal  (None, 8, 8, 256)   1024        ['conv2_block3_3_conv[0][0]']
ization)

conv2_block3_add (Add)         (None, 8, 8, 256)    0           ['conv2_block2_out[0][0]',
                                                                 'conv2_block3_3_bn[0][0]']
```

```
conv2_block3_out (Activation)  (None, 8, 8, 256)    0           ['conv2_block3_add[0][0]']

conv3_block1_1_conv (Conv2D)   (None, 4, 4, 128)    32896       ['conv2_block3_out[0][0]']

conv3_block1_1_bn (BatchNormal  (None, 4, 4, 128)   512         ['conv3_block1_1_conv[0][0]']
ization)

conv3_block1_1_relu (Activatio  (None, 4, 4, 128)   0           ['conv3_block1_1_bn[0][0]']
n)

conv3_block1_2_conv (Conv2D)   (None, 4, 4, 128)    147584      ['conv3_block1_1_relu[0][0]']

conv3_block1_2_bn (BatchNormal  (None, 4, 4, 128)   512         ['conv3_block1_2_conv[0][0]']
ization)

conv3_block1_2_relu (Activatio  (None, 4, 4, 128)   0           ['conv3_block1_2_bn[0][0]']
n)

conv3_block1_0_conv (Conv2D)   (None, 4, 4, 512)    131584      ['conv2_block3_out[0][0]']

conv3_block1_3_conv (Conv2D)   (None, 4, 4, 512)    66048       ['conv3_block1_2_relu[0][0]']

conv3_block1_0_bn (BatchNormal  (None, 4, 4, 512)   2048        ['conv3_block1_0_conv[0][0]']
ization)

conv3_block1_3_bn (BatchNormal  (None, 4, 4, 512)   2048        ['conv3_block1_3_conv[0][0]']
ization)

conv3_block1_add (Add)         (None, 4, 4, 512)    0           ['conv3_block1_0_bn[0][0]',
                                                                 'conv3_block1_3_bn[0][0]']

conv3_block1_out (Activation)  (None, 4, 4, 512)    0           ['conv3_block1_add[0][0]']
```

```
conv3_block2_1_conv (Conv2D)   (None, 4, 4, 128)    65664       ['conv3_block1_out[0][0]']

conv3_block2_1_bn (BatchNormal  (None, 4, 4, 128)   512         ['conv3_block2_1_conv[0][0]']
ization)

conv3_block2_1_relu (Activatio  (None, 4, 4, 128)   0           ['conv3_block2_1_bn[0][0]']
n)

conv3_block2_2_conv (Conv2D)   (None, 4, 4, 128)    147584      ['conv3_block2_1_relu[0][0]']

conv3_block2_2_bn (BatchNormal  (None, 4, 4, 128)   512         ['conv3_block2_2_conv[0][0]']
ization)

conv3_block2_2_relu (Activatio  (None, 4, 4, 128)   0           ['conv3_block2_2_bn[0][0]']
n)

conv3_block2_3_conv (Conv2D)   (None, 4, 4, 512)    66048       ['conv3_block2_2_relu[0][0]']

conv3_block2_3_bn (BatchNormal  (None, 4, 4, 512)   2048        ['conv3_block2_3_conv[0][0]']
ization)

conv3_block2_add (Add)         (None, 4, 4, 512)    0           ['conv3_block1_out[0][0]',
                                                                 'conv3_block2_3_bn[0][0]']

conv3_block2_out (Activation)  (None, 4, 4, 512)    0           ['conv3_block2_add[0][0]']

conv3_block3_1_conv (Conv2D)   (None, 4, 4, 128)    65664       ['conv3_block2_out[0][0]']

conv3_block3_1_bn (BatchNormal  (None, 4, 4, 128)   512         ['conv3_block3_1_conv[0][0]']
ization)

conv3_block3_1_relu (Activatio  (None, 4, 4, 128)   0           ['conv3_block3_1_bn[0][0]']
```

```
conv3_block3_2_conv (Conv2D)   (None, 4, 4, 128)    147584      ['conv3_block3_1_relu[0][0]']

conv3_block3_2_bn (BatchNormal  (None, 4, 4, 128)   512         ['conv3_block3_2_conv[0][0]']
ization)

conv3_block3_2_relu (Activatio  (None, 4, 4, 128)   0           ['conv3_block3_2_bn[0][0]']
n)

conv3_block3_3_conv (Conv2D)   (None, 4, 4, 512)    66048       ['conv3_block3_2_relu[0][0]']

conv3_block3_3_bn (BatchNormal  (None, 4, 4, 512)   2048        ['conv3_block3_3_conv[0][0]']
ization)

conv3_block3_add (Add)         (None, 4, 4, 512)    0           ['conv3_block2_out[0][0]',
                                                                 'conv3_block3_3_bn[0][0]']

conv3_block3_out (Activation)  (None, 4, 4, 512)    0           ['conv3_block3_add[0][0]']

conv3_block4_1_conv (Conv2D)   (None, 4, 4, 128)    65664       ['conv3_block3_out[0][0]']

conv3_block4_1_bn (BatchNormal  (None, 4, 4, 128)   512         ['conv3_block4_1_conv[0][0]']
ization)

conv3_block4_1_relu (Activatio  (None, 4, 4, 128)   0           ['conv3_block4_1_bn[0][0]']
n)

conv3_block4_2_conv (Conv2D)   (None, 4, 4, 128)    147584      ['conv3_block4_1_relu[0][0]']

conv3_block4_2_bn (BatchNormal  (None, 4, 4, 128)   512         ['conv3_block4_2_conv[0][0]']
ization)

conv3_block4_2_relu (Activatio  (None, 4, 4, 128)   0           ['conv3_block4_2_bn[0][0]']
```

```
conv3_block4_3_conv (Conv2D)   (None, 4, 4, 512)    66048       ['conv3_block4_2_relu[0][0]']

conv3_block4_3_bn (BatchNormal  (None, 4, 4, 512)   2048        ['conv3_block4_3_conv[0][0]']
ization)

conv3_block4_add (Add)         (None, 4, 4, 512)    0           ['conv3_block3_out[0][0]',
                                                                 'conv3_block4_3_bn[0][0]']

conv3_block4_out (Activation)  (None, 4, 4, 512)    0           ['conv3_block4_add[0][0]']

conv4_block1_1_conv (Conv2D)   (None, 2, 2, 256)    131328      ['conv3_block4_out[0][0]']

conv4_block1_1_bn (BatchNormal  (None, 2, 2, 256)   1024        ['conv4_block1_1_conv[0][0]']
ization)

conv4_block1_1_relu (Activatio  (None, 2, 2, 256)   0           ['conv4_block1_1_bn[0][0]']
n)

conv4_block1_2_conv (Conv2D)   (None, 2, 2, 256)    590080      ['conv4_block1_1_relu[0][0]']

conv4_block1_2_bn (BatchNormal  (None, 2, 2, 256)   1024        ['conv4_block1_2_conv[0][0]']
ization)

conv4_block1_2_relu (Activatio  (None, 2, 2, 256)   0           ['conv4_block1_2_bn[0][0]']
n)

conv4_block1_0_conv (Conv2D)   (None, 2, 2, 1024)   525312      ['conv3_block4_out[0][0]']

conv4_block1_3_conv (Conv2D)   (None, 2, 2, 1024)   263168      ['conv4_block1_2_relu[0][0]']

conv4_block1_0_bn (BatchNormal  (None, 2, 2, 1024)  4096        ['conv4_block1_0_conv[0][0]']
```

```
conv4_block1_3_bn (BatchNormal  (None, 2, 2, 1024)  4096        ['conv4_block1_3_conv[0][0]'
ization)

conv4_block1_add (Add)         (None, 2, 2, 1024)   0           ['conv4_block1_0_bn[0][0]',
                                                                 'conv4_block1_3_bn[0][0]']

conv4_block1_out (Activation)  (None, 2, 2, 1024)   0           ['conv4_block1_add[0][0]']

conv4_block2_1_conv (Conv2D)   (None, 2, 2, 256)    262400      ['conv4_block1_out[0][0]']

conv4_block2_1_bn (BatchNormal  (None, 2, 2, 256)   1024        ['conv4_block2_1_conv[0][0]'
ization)

conv4_block2_1_relu (Activatio  (None, 2, 2, 256)   0           ['conv4_block2_1_bn[0][0]']
n)

conv4_block2_2_conv (Conv2D)   (None, 2, 2, 256)    590080      ['conv4_block2_1_relu[0][0]'

conv4_block2_2_bn (BatchNormal  (None, 2, 2, 256)   1024        ['conv4_block2_2_conv[0][0]'
ization)

conv4_block2_2_relu (Activatio  (None, 2, 2, 256)   0           ['conv4_block2_2_bn[0][0]']
n)

conv4_block2_3_conv (Conv2D)   (None, 2, 2, 1024)   263168      ['conv4_block2_2_relu[0][0]'

conv4_block2_3_bn (BatchNormal  (None, 2, 2, 1024)  4096        ['conv4_block2_3_conv[0][0]'
ization)

conv4_block2_add (Add)         (None, 2, 2, 1024)   0           ['conv4_block1_out[0][0]',
                                                                 'conv4_block2_3_bn[0][0]']

conv4_block2_out (Activation)  (None, 2, 2, 1024)   0           ['conv4_block2_add[0][0]']
```

```
conv4_block3_1_conv (Conv2D)   (None, 2, 2, 256)    262400      ['conv4_block2_out[0][0]']

conv4_block3_1_bn (BatchNormal  (None, 2, 2, 256)   1024        ['conv4_block3_1_conv[0][0]']
ization)

conv4_block3_1_relu (Activatio  (None, 2, 2, 256)   0           ['conv4_block3_1_bn[0][0]']
n)

conv4_block3_2_conv (Conv2D)   (None, 2, 2, 256)    590080      ['conv4_block3_1_relu[0][0]']

conv4_block3_2_bn (BatchNormal  (None, 2, 2, 256)   1024        ['conv4_block3_2_conv[0][0]']
ization)

conv4_block3_2_relu (Activatio  (None, 2, 2, 256)   0           ['conv4_block3_2_bn[0][0]']
n)

conv4_block3_3_conv (Conv2D)   (None, 2, 2, 1024)   263168      ['conv4_block3_2_relu[0][0]']

conv4_block3_3_bn (BatchNormal  (None, 2, 2, 1024)  4096        ['conv4_block3_3_conv[0][0]']
ization)

conv4_block3_add (Add)         (None, 2, 2, 1024)   0           ['conv4_block2_out[0][0]',
                                                                 'conv4_block3_3_bn[0][0]']

conv4_block3_out (Activation)  (None, 2, 2, 1024)   0           ['conv4_block3_add[0][0]']

conv4_block4_1_conv (Conv2D)   (None, 2, 2, 256)    262400      ['conv4_block3_out[0][0]']

conv4_block4_1_bn (BatchNormal  (None, 2, 2, 256)   1024        ['conv4_block4_1_conv[0][0]']
ization)

conv4_block4_1_relu (Activatio  (None, 2, 2, 256)   0           ['conv4_block4_1_bn[0][0]']
n)

conv4_block4_2_conv (Conv2D)   (None, 2, 2, 256)    590080      ['conv4_block4_1_relu[0][0]']

conv4_block4_2_bn (BatchNormal  (None, 2, 2, 256)   1024        ['conv4_block4_2_conv[0][0]']
```

```
conv4_block4_2_bn (BatchNormal  (None, 2, 2, 256)   1024        ['conv4_block4_2_conv[0][0]']
ization)

conv4_block4_2_relu (Activatio  (None, 2, 2, 256)   0           ['conv4_block4_2_bn[0][0]']
n)

conv4_block4_3_conv (Conv2D)   (None, 2, 2, 1024)   263168      ['conv4_block4_2_relu[0][0]']

conv4_block4_3_bn (BatchNormal  (None, 2, 2, 1024)  4096        ['conv4_block4_3_conv[0][0]']
ization)

conv4_block4_add (Add)         (None, 2, 2, 1024)   0           ['conv4_block3_out[0][0]',
                                                                 'conv4_block4_3_bn[0][0]']

conv4_block4_out (Activation)  (None, 2, 2, 1024)   0           ['conv4_block4_add[0][0]']

conv4_block5_1_conv (Conv2D)   (None, 2, 2, 256)    262400      ['conv4_block4_out[0][0]']

conv4_block5_1_bn (BatchNormal  (None, 2, 2, 256)   1024        ['conv4_block5_1_conv[0][0]']
ization)

conv4_block5_1_relu (Activatio  (None, 2, 2, 256)   0           ['conv4_block5_1_bn[0][0]']
```

Figure 10: Resnet50 model summary for cifar-10 dataset

The resulting accuracy plot it gives is in the following figure.

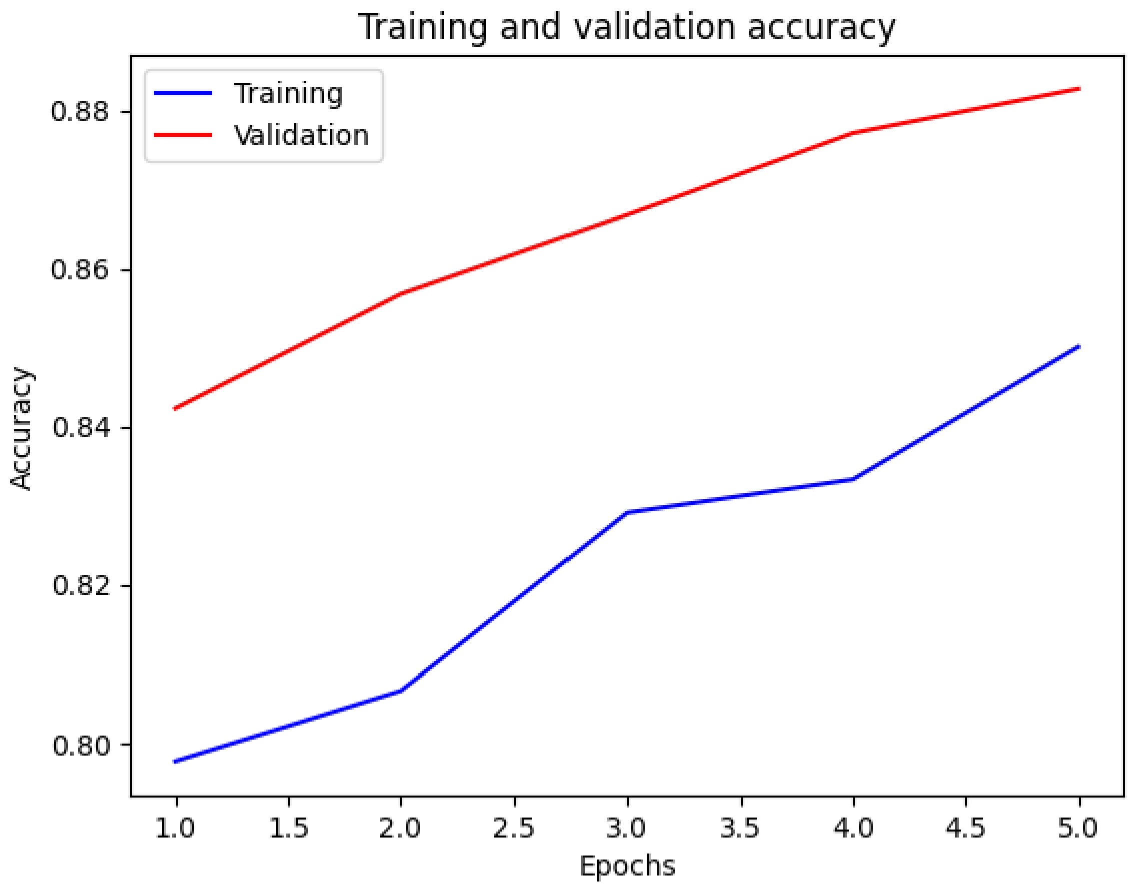

Figure 11: Resnet50 accuracy plot for cifar 10 dataset

The table shows the difference in accuracies for each model.

	Resnet50	Resnet20, n = 3	Resnet with n = 4
test accuracies	0.88276483483333449	0.7354000210762024	0.7888000011444092

The best accuracy is acquired from Resnet50, which has the most depth among the Resnets trained. hence allows more complex features to be learned and represented.