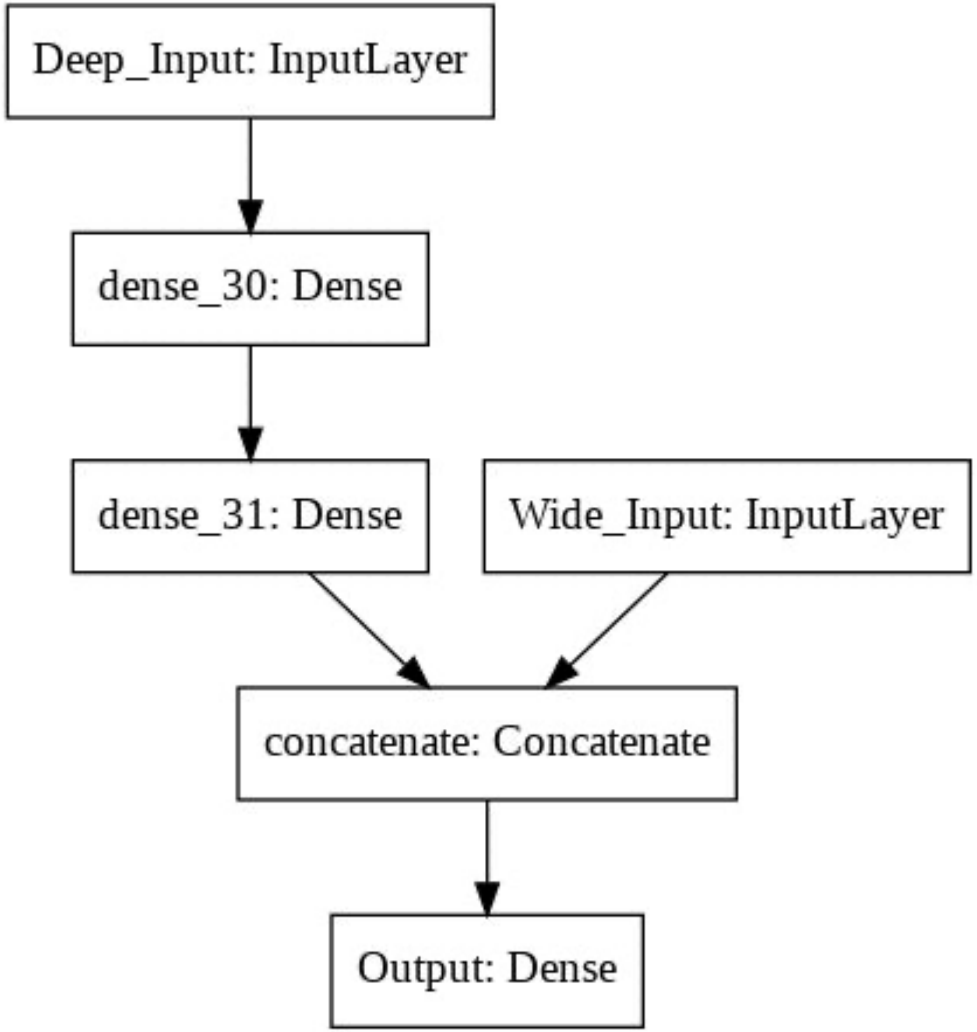
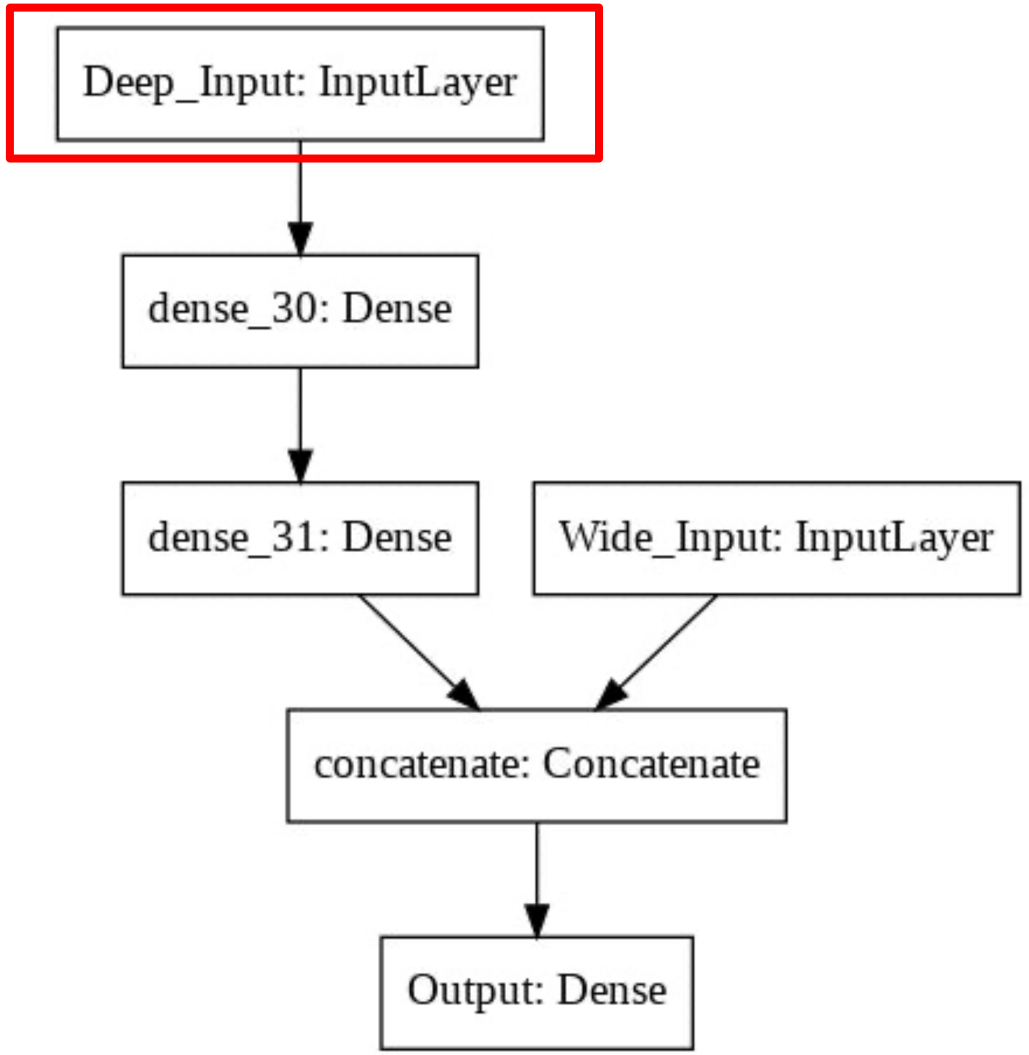

Deep_Input: InputLayer
dense_30: Dense
dense_31: Dense
Wide_Input: InputLayer
concatenate: Concatenate
Output: Dense


Deep_Input: InputLayer
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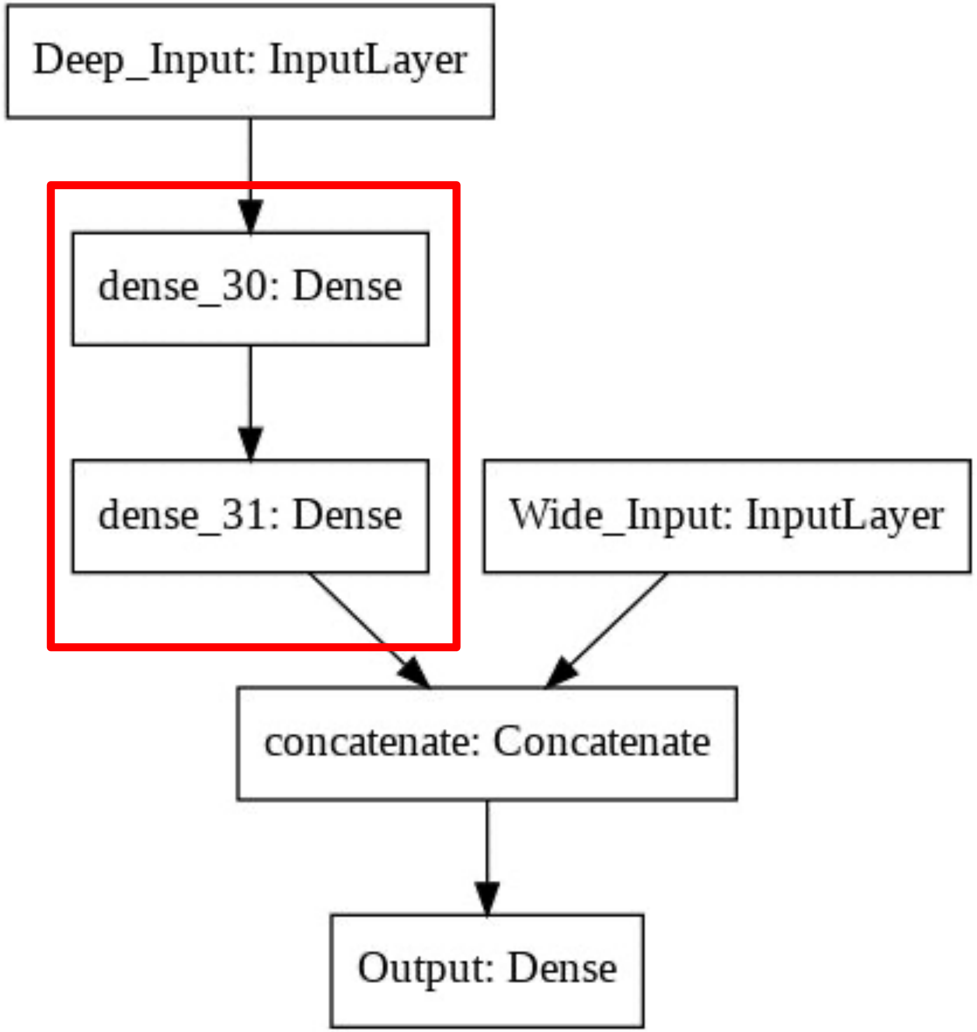
Deep_Input: InputLayer
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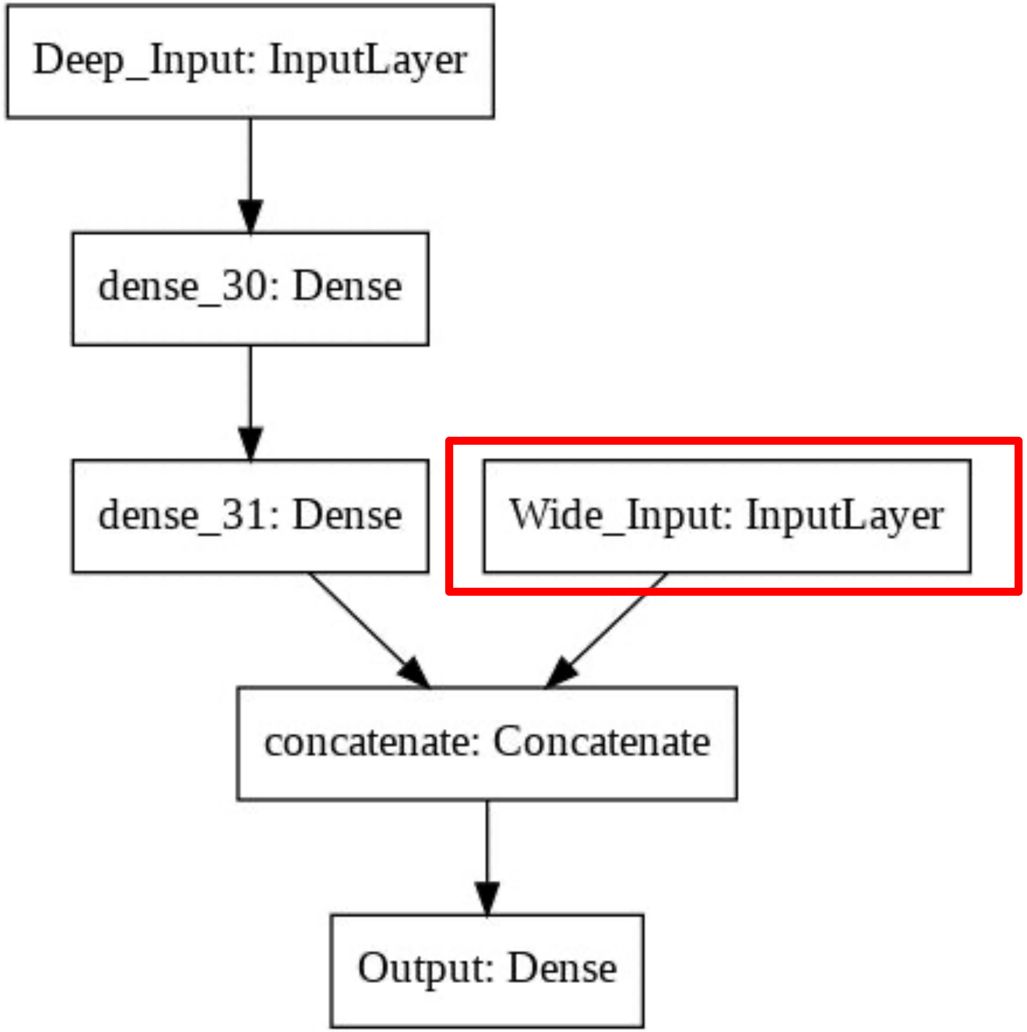
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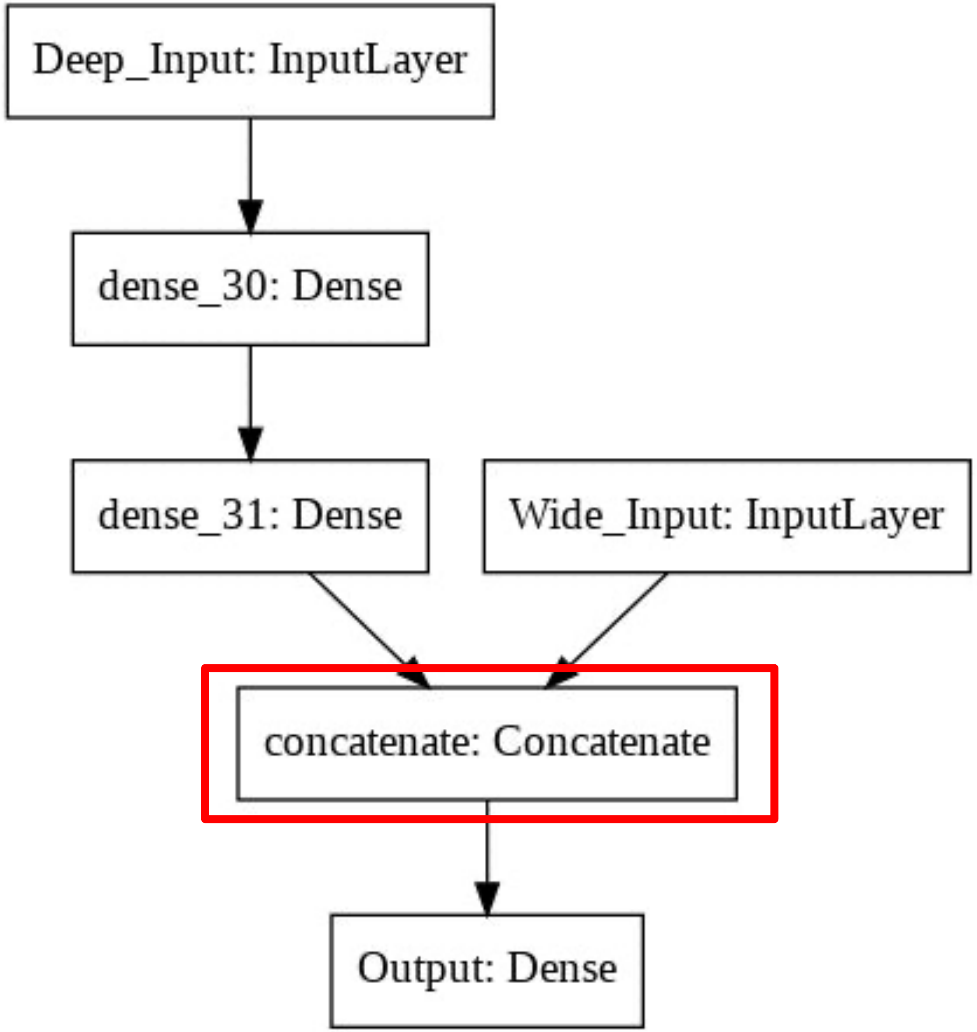
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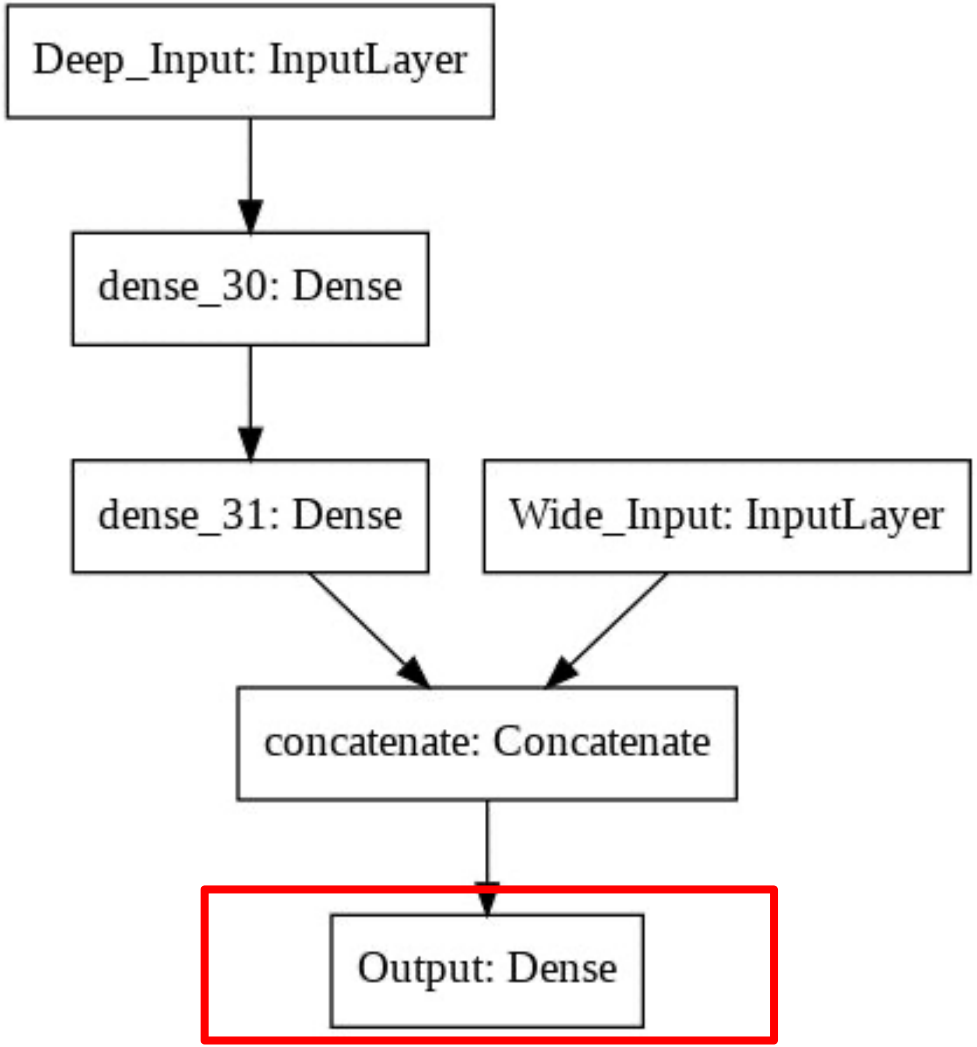
Deep_Input: InputLayer
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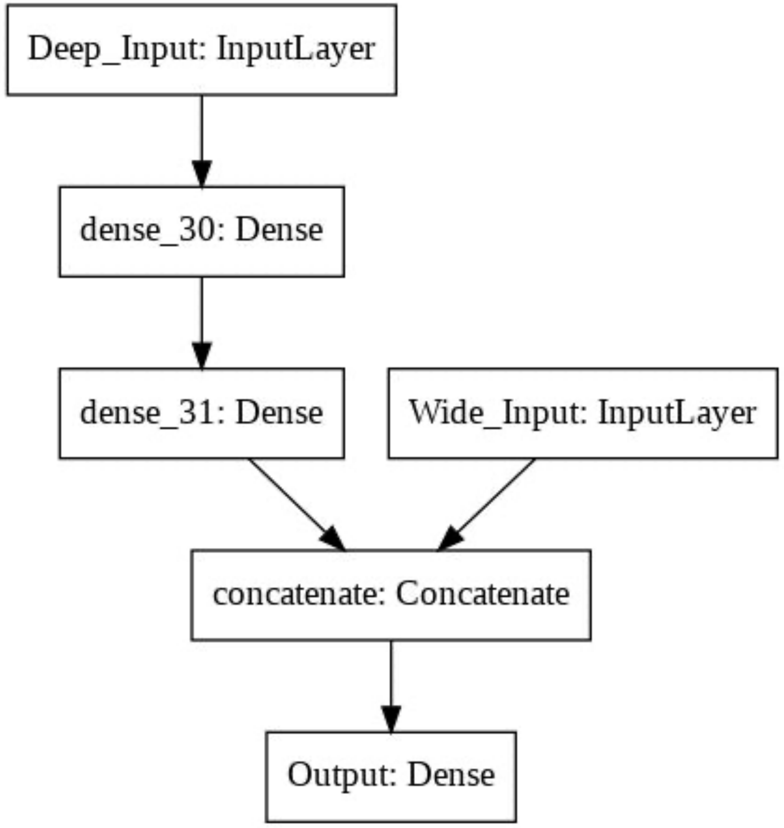
input_a = Input(shape=[1], name="Wide_Input")
input_b = Input(shape=[1], name="Deep_Input")
hidden_1 = Dense(30, activation="relu")(input_b)
hidden_2 = Dense(30, activation="relu")(hidden_1)
concat = concatenate([input_a, hidden_2])
output = Dense(1, name="Output")(concat)
model = Model(inputs=[input_a, input_b],
              outputs=[output])
```



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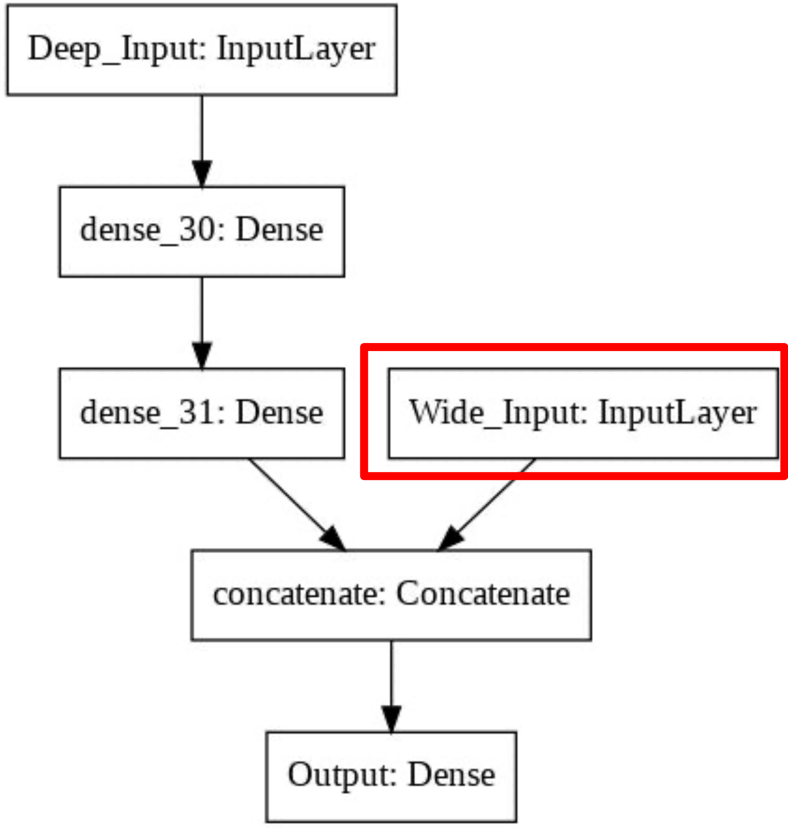

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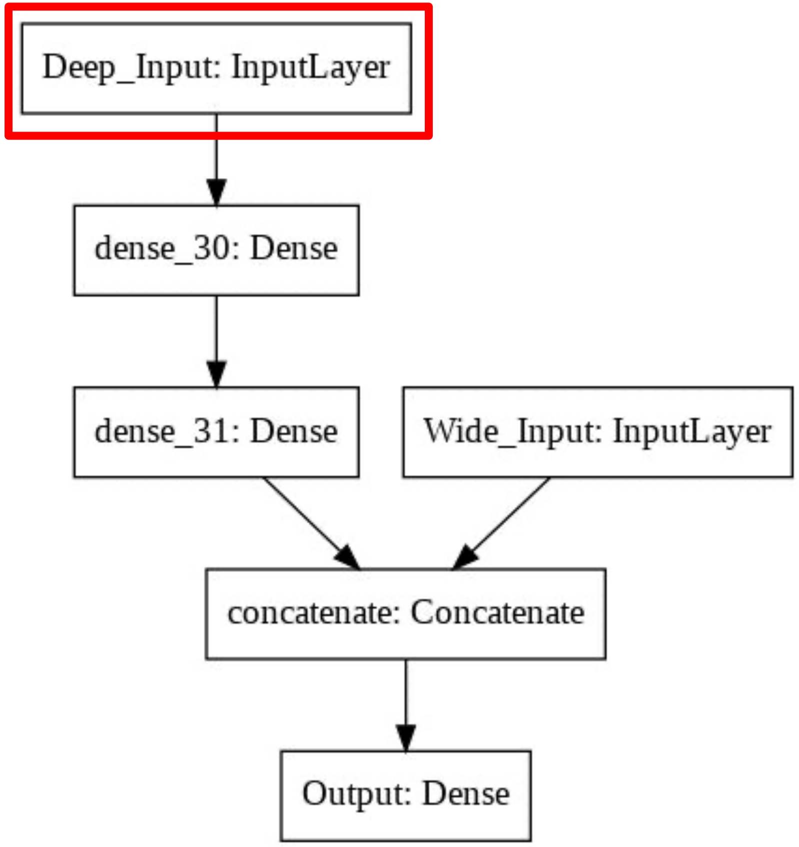

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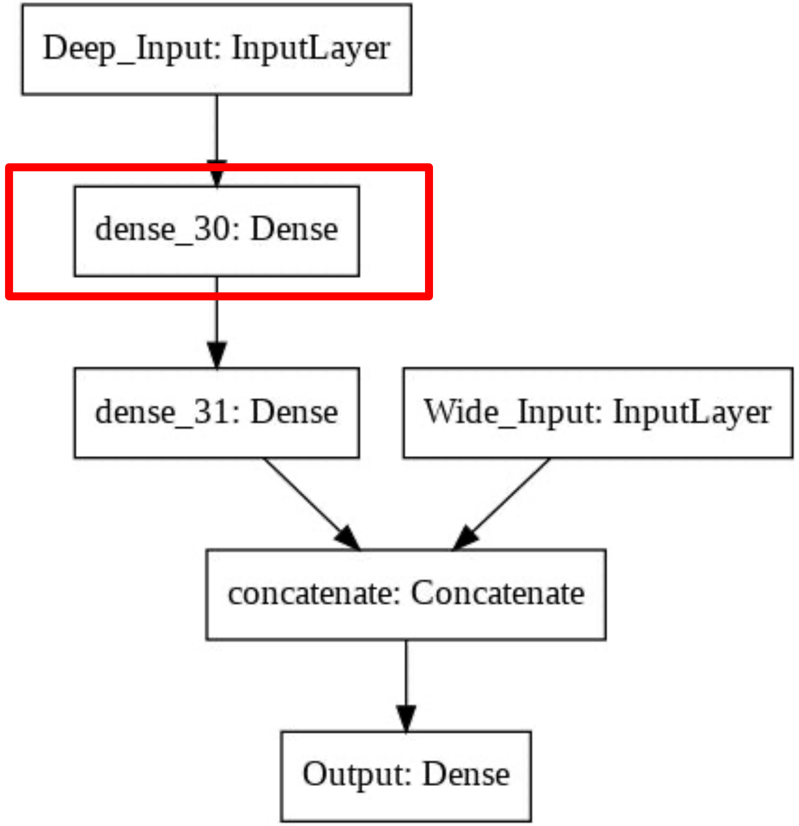

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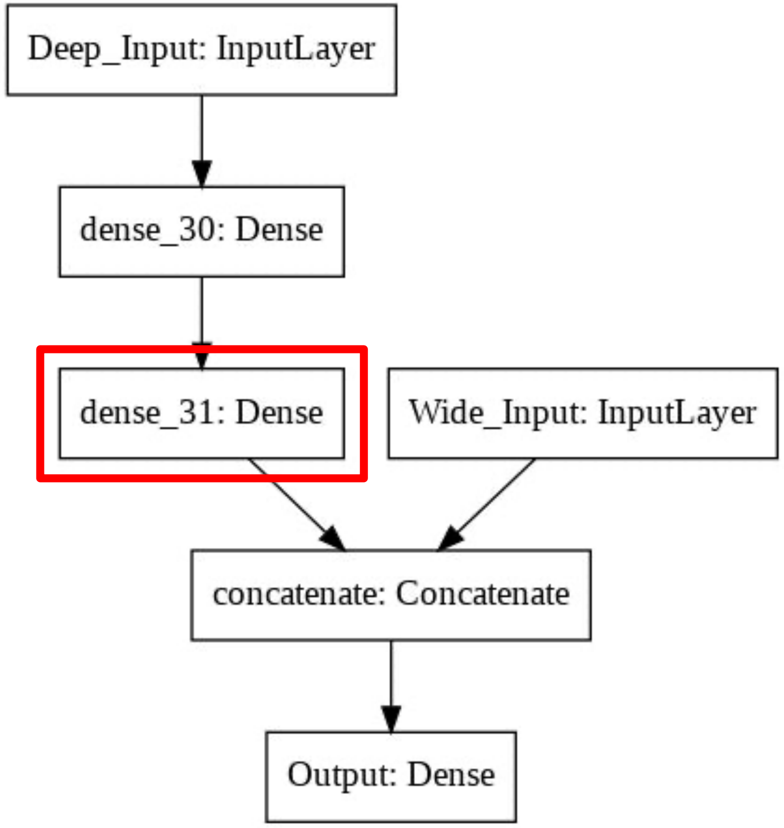

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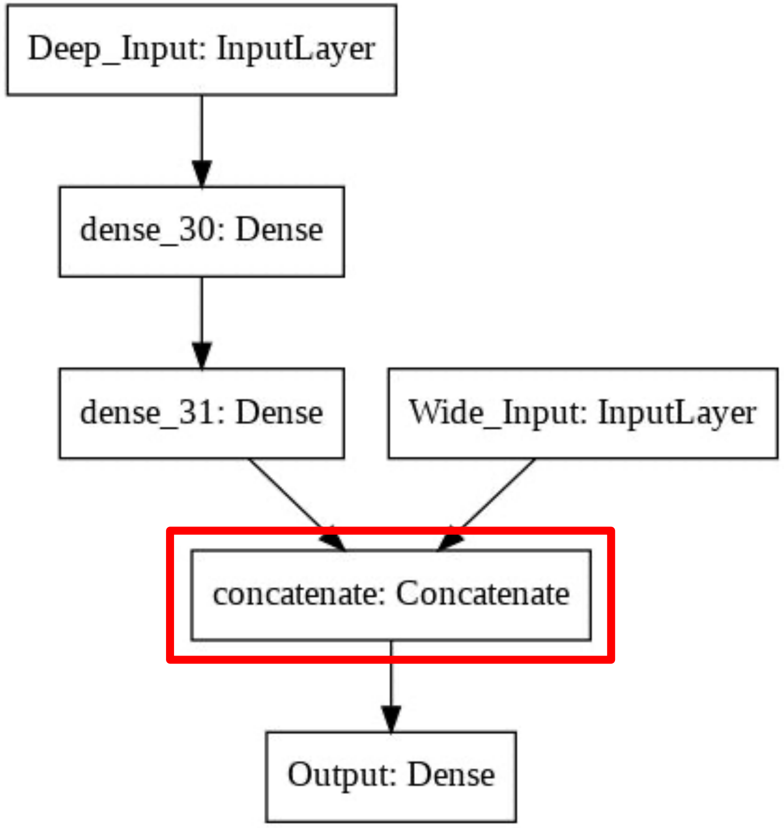

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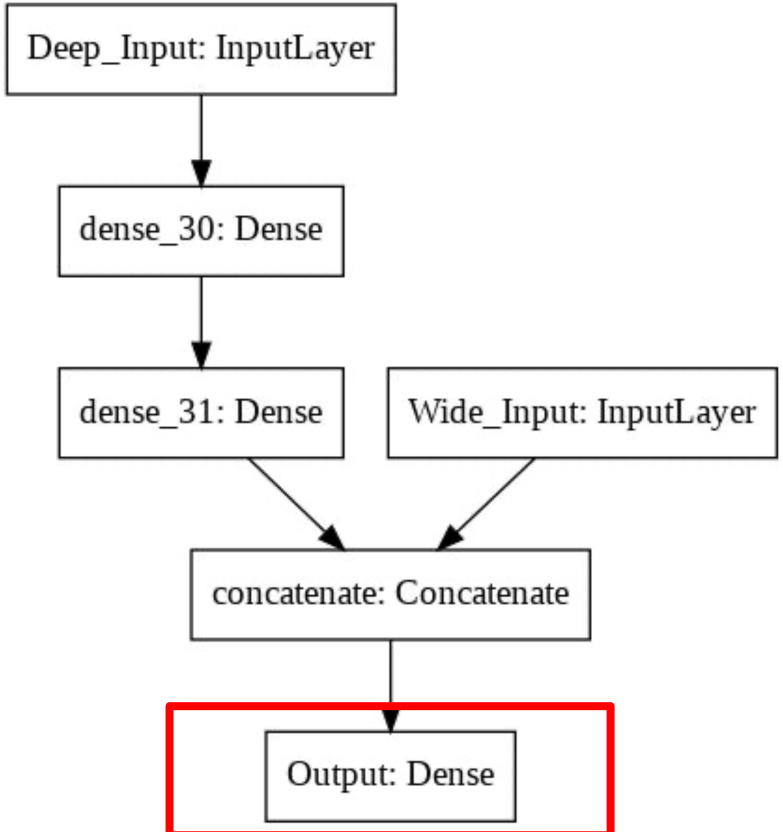

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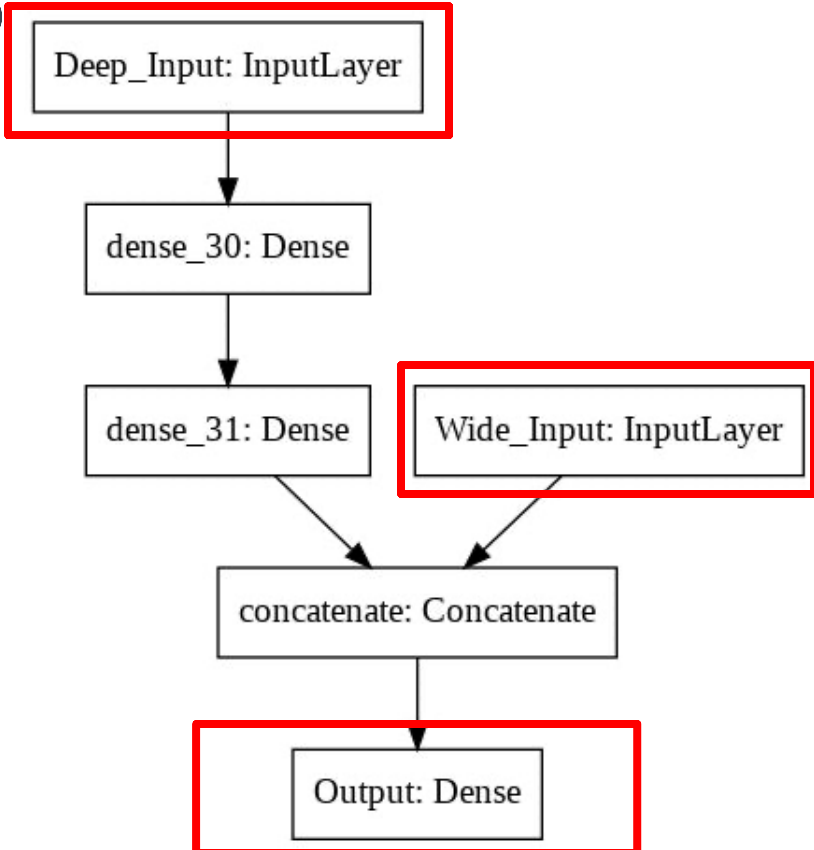

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aux_output = Dense(1,name="aux_Output")(hidden_2)
model = Model(inputs=[input_a, input_b],
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```

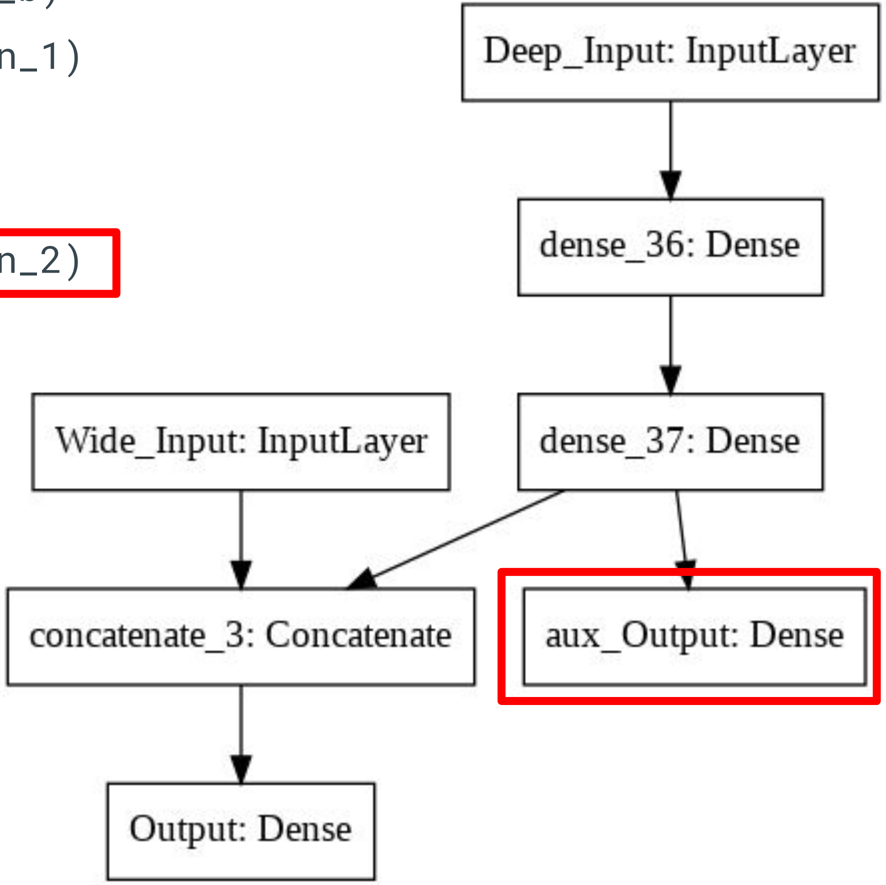

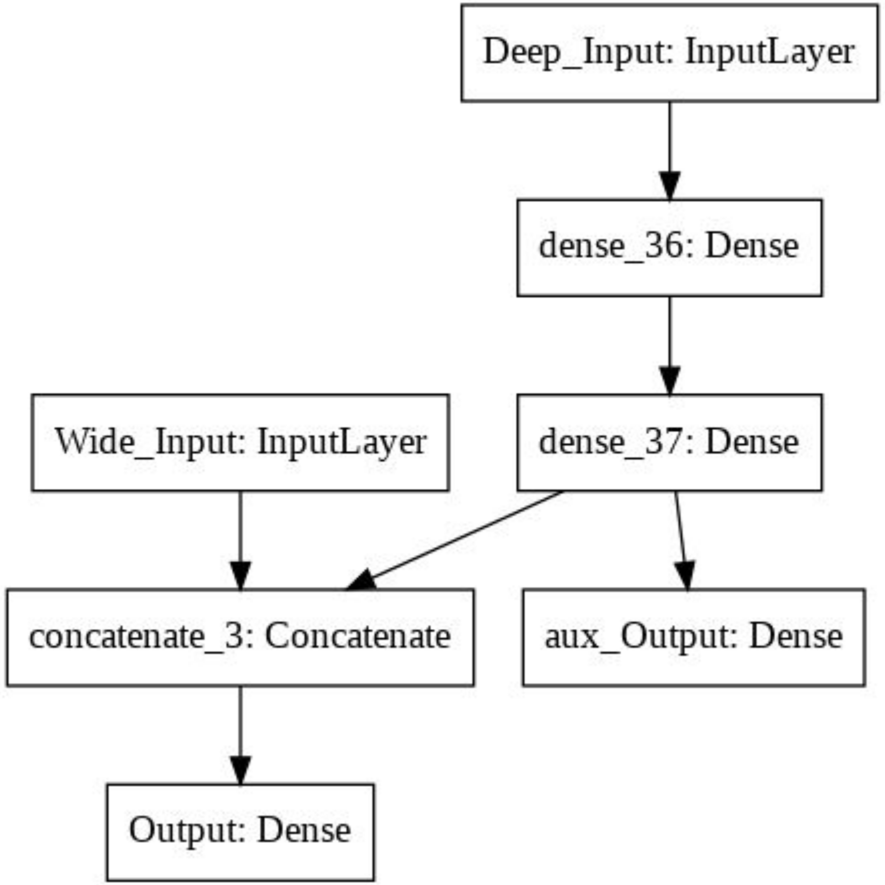
Deep_Input: InputLayer
dense_36: Dense
Wide_Input: InputLayer
dense_37: Dense
concatenate_3: Concatenate
aux_Output: Dense
Output: Dense

```python
class WideAndDeepModel(Model):
  def __init__(self, units=30, activation='relu', **kwargs):
    super().__init__(**kwargs)
    self.hidden1 = Dense(units, activation=activation)
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    self.main_output = Dense(1)
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  def call(self, inputs):
    input_A, input_B = inputs
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    main_output = self.main_output(concat)
    aux_output = self.aux_output(hidden2)
    return main_output, aux_output
```

```
model = WideAndDeepModel()
```

The Model class

- Built-in training, evaluation, and prediction loops

  e.g., `model.fit(), model.evaluate(), model.predict()`

- Saving and serialization APIs.

  e.g., `model.save(), model.save_weights()`

- Summarization and visualization APIs

  e.g., `model.summary(), tf.keras.utils.plot_model()`

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Limitations of Sequential/Functional APIs

- Only suited to models that are Directed Acyclic Graphs of layers

  e.g., `MobileNet, Inception, etc`

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Benefits of subclassing models

- Extends how you’ve been building models
- Continue to use functional and sequential code
- Modular architecture
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- Control flow in the network

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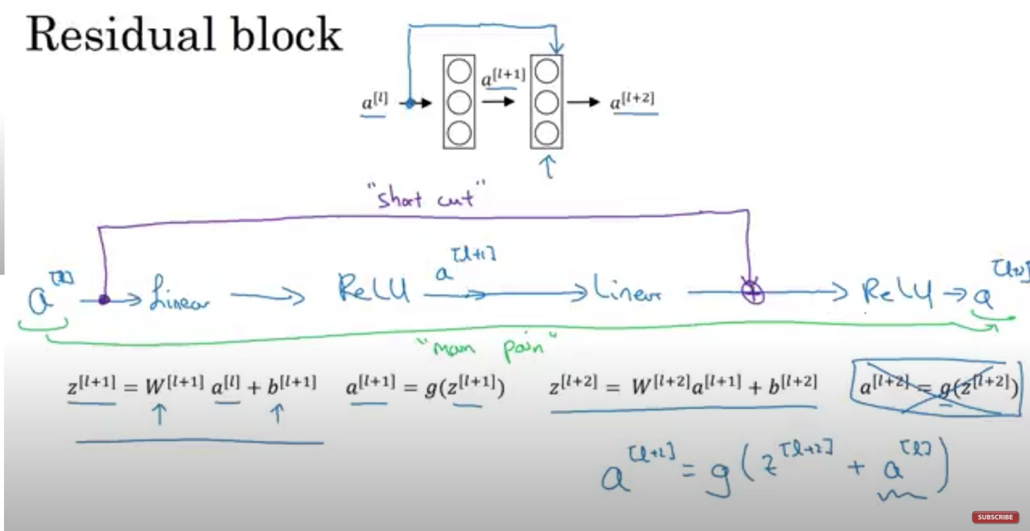
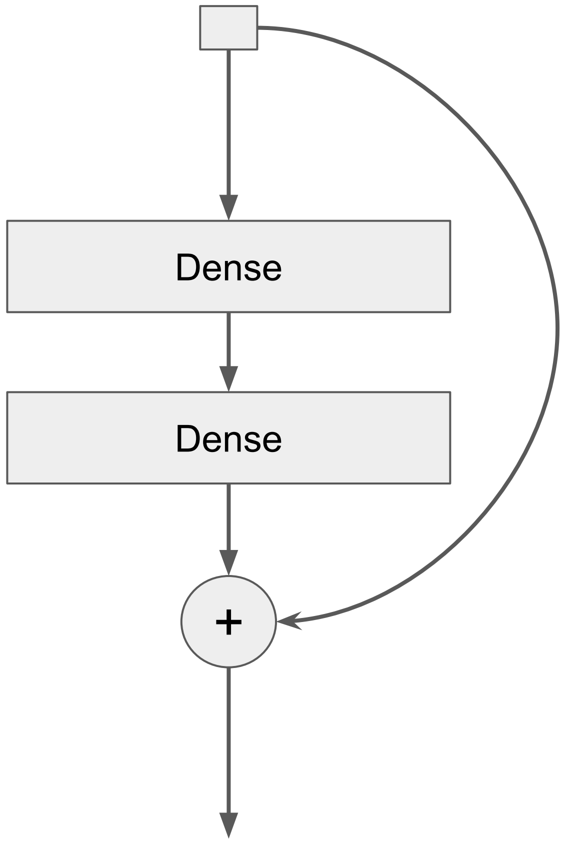
Residual Networks (ResNets)

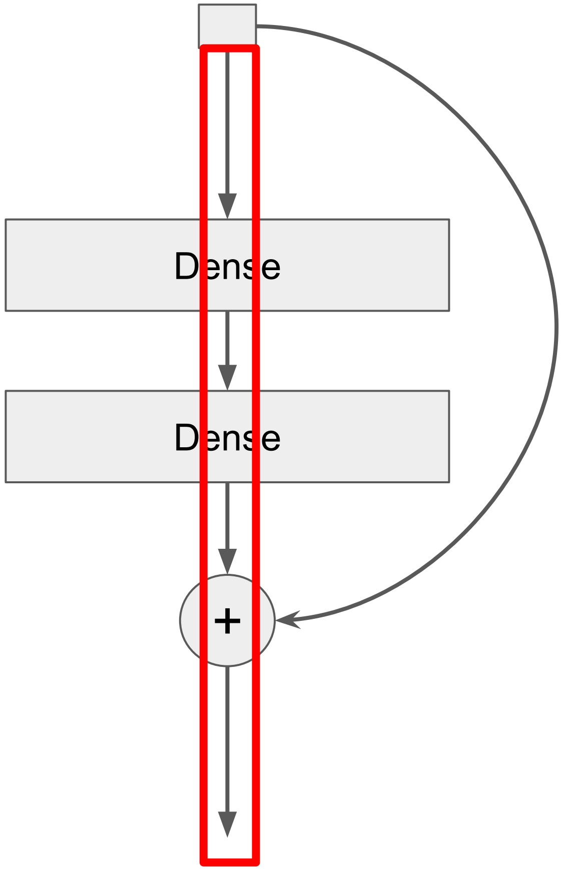
https://www.coursera.org/lecture/convolutional-neural-networks/resnets-HAhz9



$z^{[l+1]} = W^{[l+1]} a^{[l]} + b^{[l+1]}$ $a^{[l+1]} = g(z^{[l+1]})$ $z^{[l+2]} = W^{[l+2]} a^{[l+1]} + b^{[l+2]}$ $\boxed{\cancel{a^{[l+2]} = g(z^{[l+2]})}}$

$$a^{[l+2]} = g\left(z^{[l+2]} + a^{[l]}\right)$$


Dense
Dense
+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Dense
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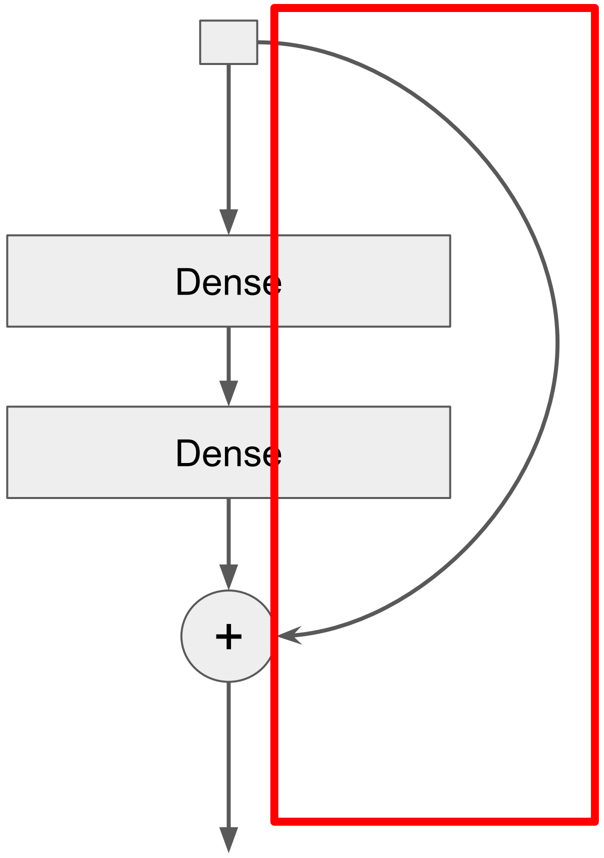
Dense
Dense
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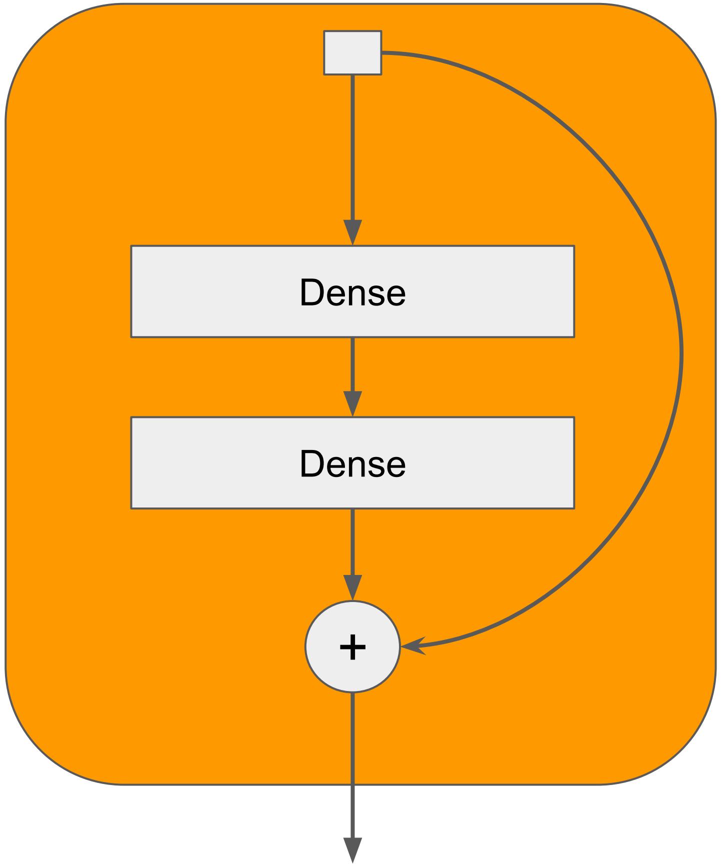
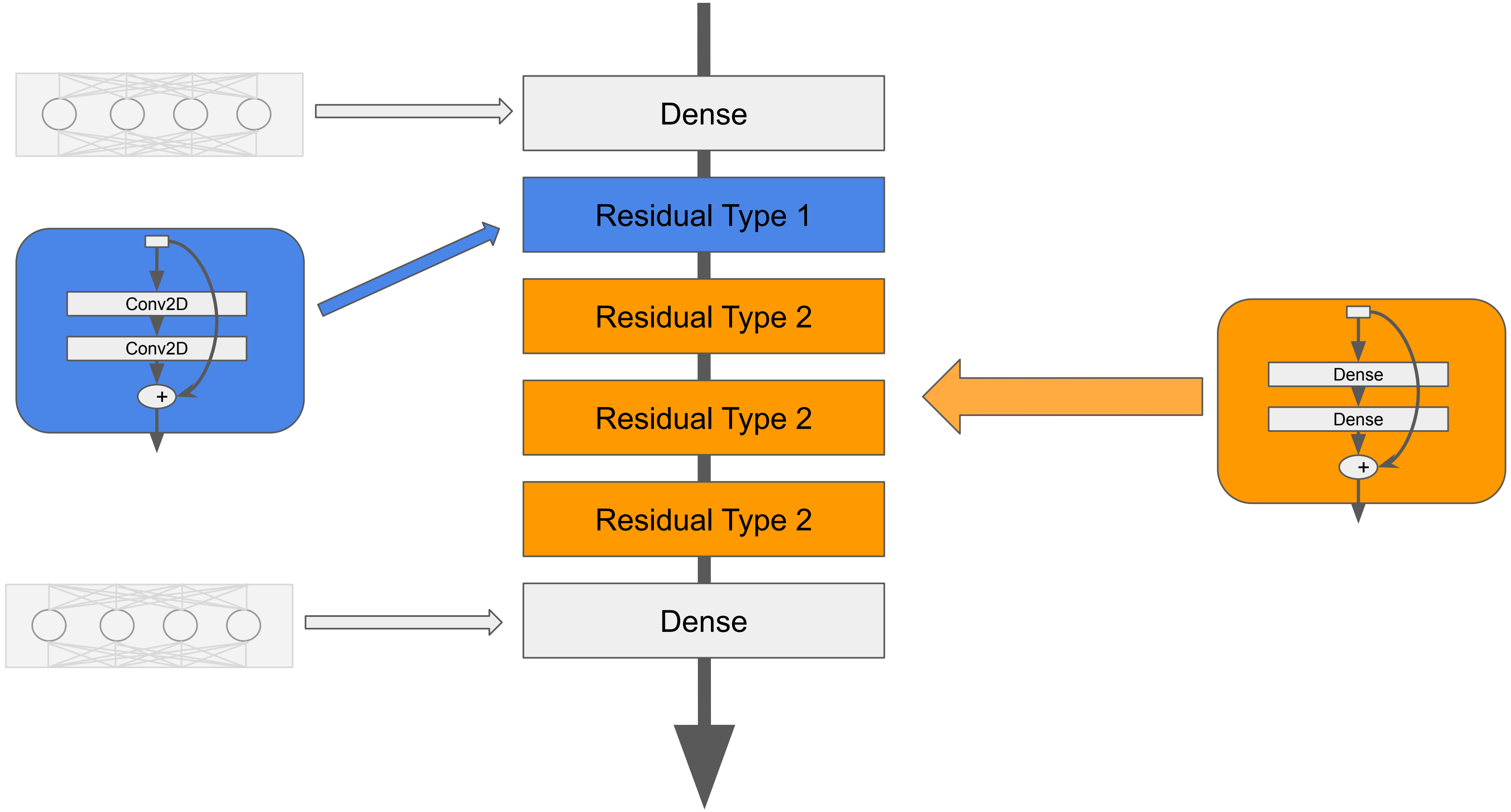
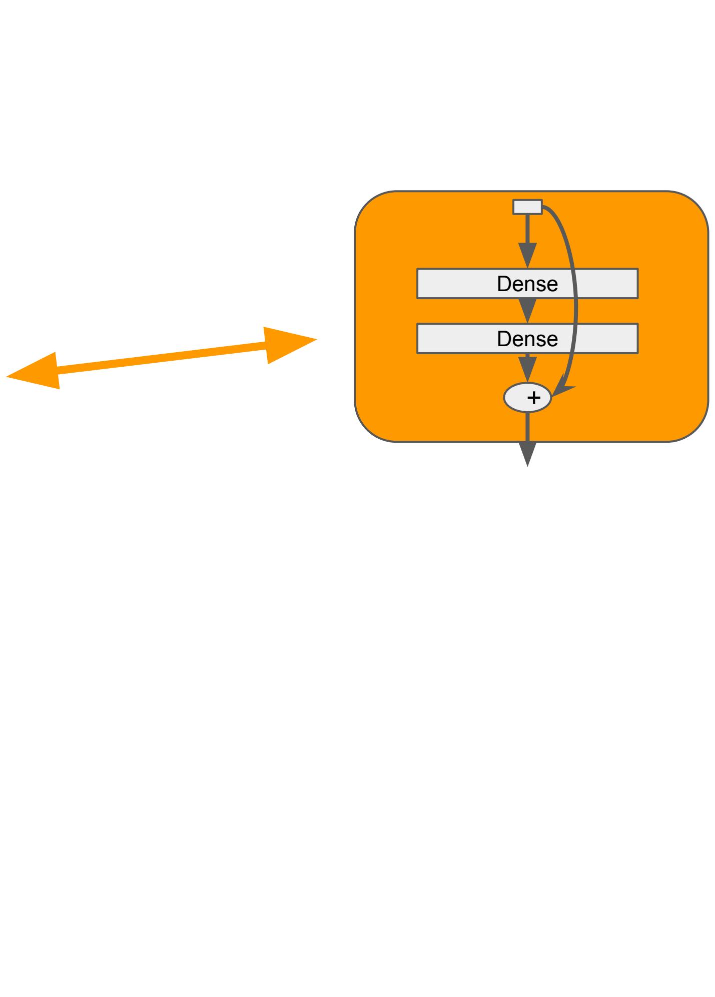
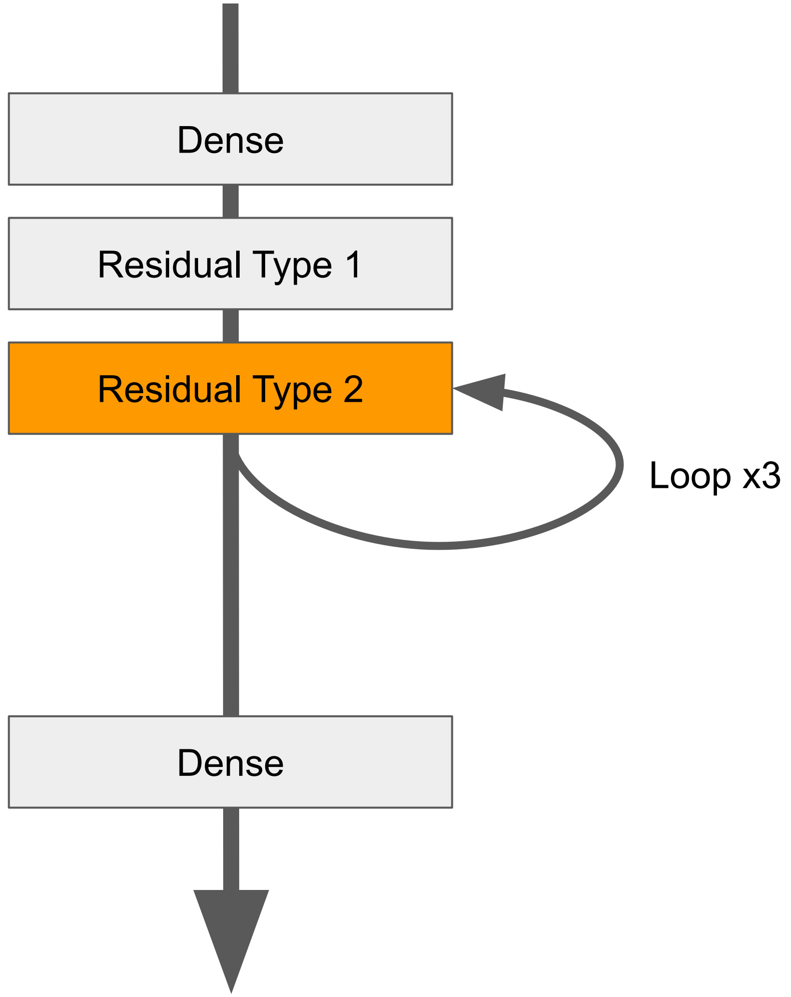

Dense
Dense
+

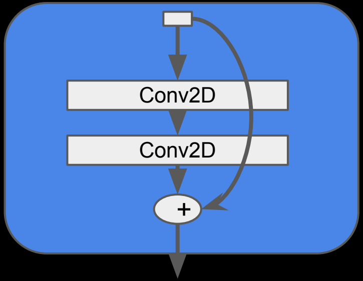

Dense
Residual Type 1
Residual Type 2
Residual Type 2
Residual Type 2
Dense
Conv2D
Conv2D
+
Dense
Dense
+


Dense
Residual Type 1
Residual Type 2
Residual Type 2
Residual Type 2
Dense
Dense
Dense
+


Dense
Residual Type 1
Residual Type 2
Loop x3
Dense

```
class CNNResidual(Layer):
  def __init__(self, layers, filters, **kwargs):
    super().__init__(**kwargs)
    self.hidden = [Conv2D(filters, (3, 3), activation="relu")
                   for _ in range(layers)]

  def call(self, inputs):
    x = inputs
    for layer in self.hidden:
      x = layer(x)
    return inputs + x
```



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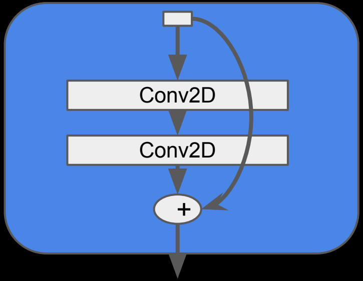

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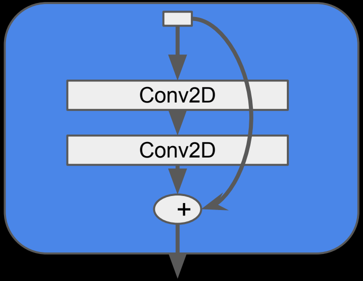

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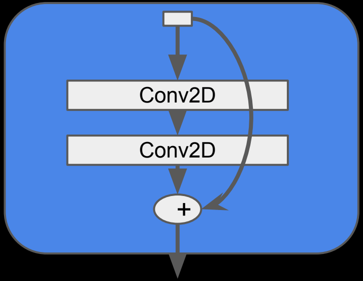

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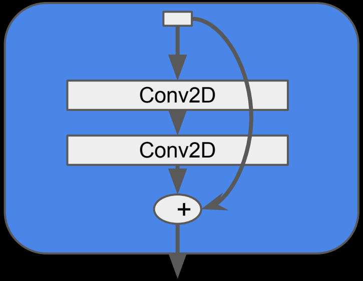

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class CNNResidual(Layer):
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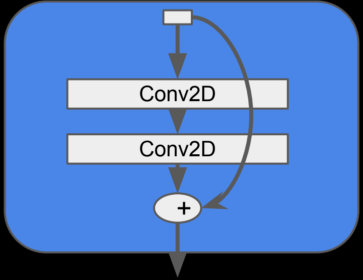
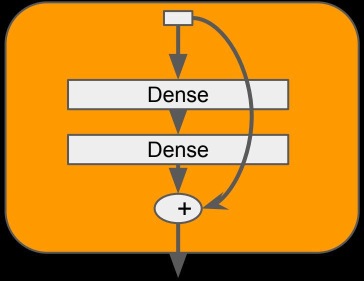
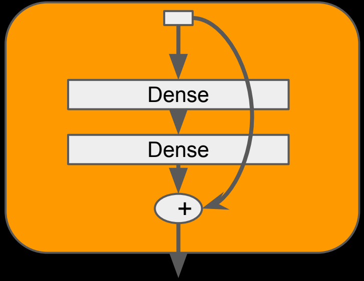


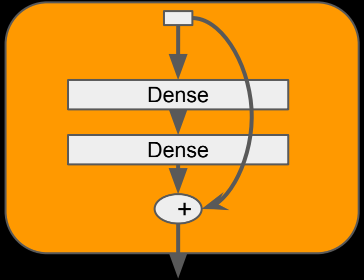
```python
class DNNResidual(Layer):
  def __init__(self, layers, neurons, **kwargs):
    super().__init__(**kwargs)
    self.hidden = [Dense(neurons, activation="relu")
                   for _ in range(layers)]

  def call(self, inputs):
    x = inputs
    for layer in self.hidden:
      x = layer(x)
    return inputs + x
```

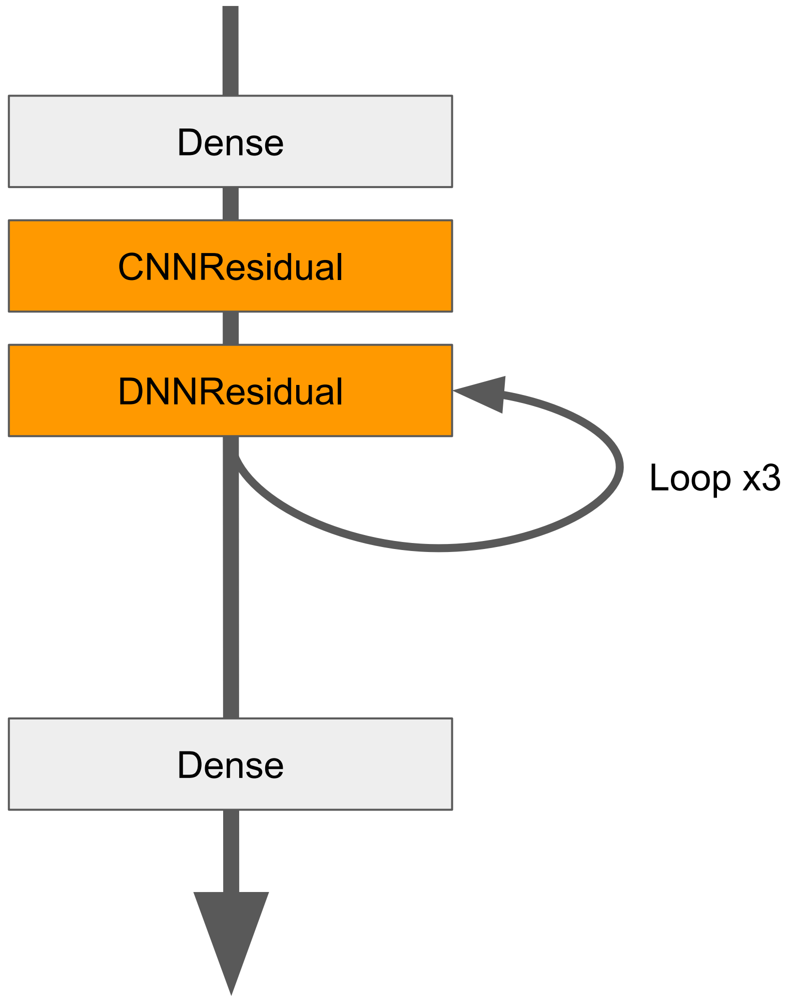


```
class DNNResidual(Layer):
  def __init__(self, layers, neurons, **kwargs):
    super().__init__(**kwargs)
    self.hidden = [Dense(neurons, activation="relu")
                      for _ in range(layers)]

  def call(self, inputs):
    x = inputs
    for layer in self.hidden:
      x = layer(x)
    return inputs + x
```

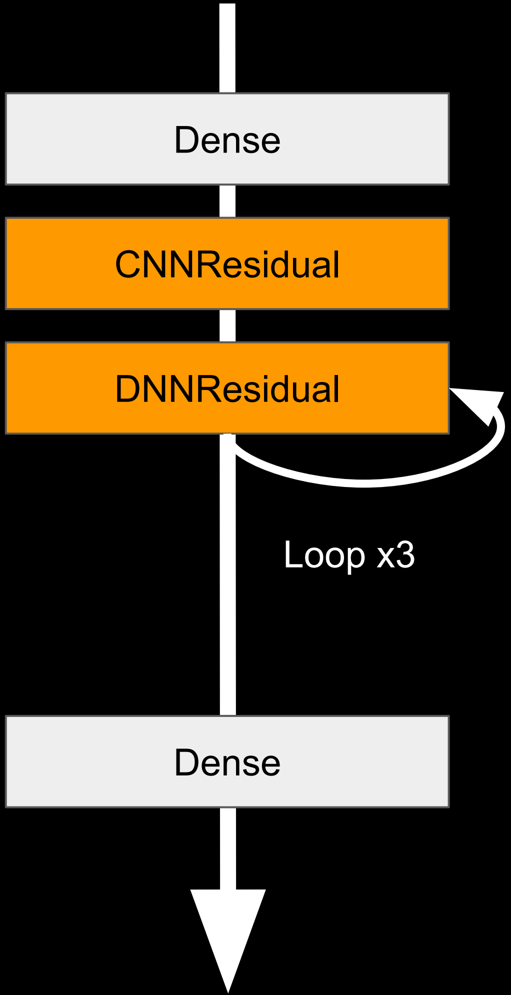


```
class DNNResidual(Layer):
  def __init__(self, layers, neurons, **kwargs):
    super().__init__(**kwargs)
    self.hidden = [Dense(neurons, activation="relu")
                   for _ in range(layers)]

  def call(self, inputs):
    x = inputs
    for layer in self.hidden:
      x = layer(x)
    return inputs + x
```




Dense
CNNResidual
DNNResidual
Loop x3
Dense

```
class MyResidual(Model):
  def __init__(self, **kwargs):
    self.hidden1 = Dense(30, activation="relu")
    self.block1 = CNNResidual(2, 32)
    self.block2 = DNNResidual(2, 64)
    self.out = Dense(1)

  def call(self, inputs):
    x = self.hidden1(inputs)
    x = self.block1(x)
    for _ in range(1, 4):#this will run 3 times
      x = self.block2(x)
    return self.out(x)
```



```
class MyResidual(Model):
  def __init__(self, **kwargs):
    self.hidden1 = Dense(30, activation="relu")
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    x = self.block1(x)
    for _ in range(1, 4):#this will run 3 times
      x = self.block2(x)
    return self.out(x)
```

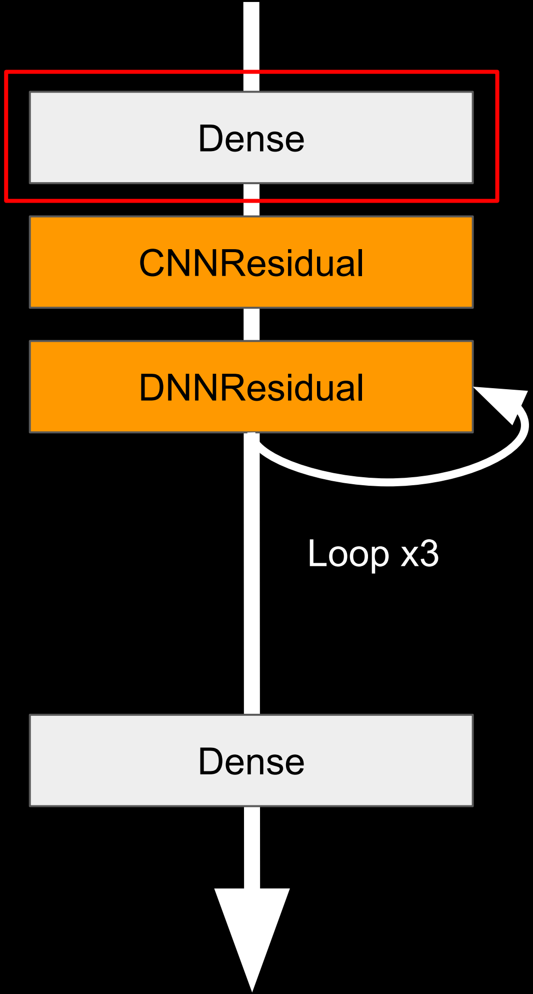

```
class MyResidual(Model):
  def __init__(self, **kwargs):
    self.hidden1 = Dense(30, activation="relu")
    self.block1 = CNNResidual(2, 32)
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  def call(self, inputs):
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    for _ in range(1, 4):#this will run 3 times
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```

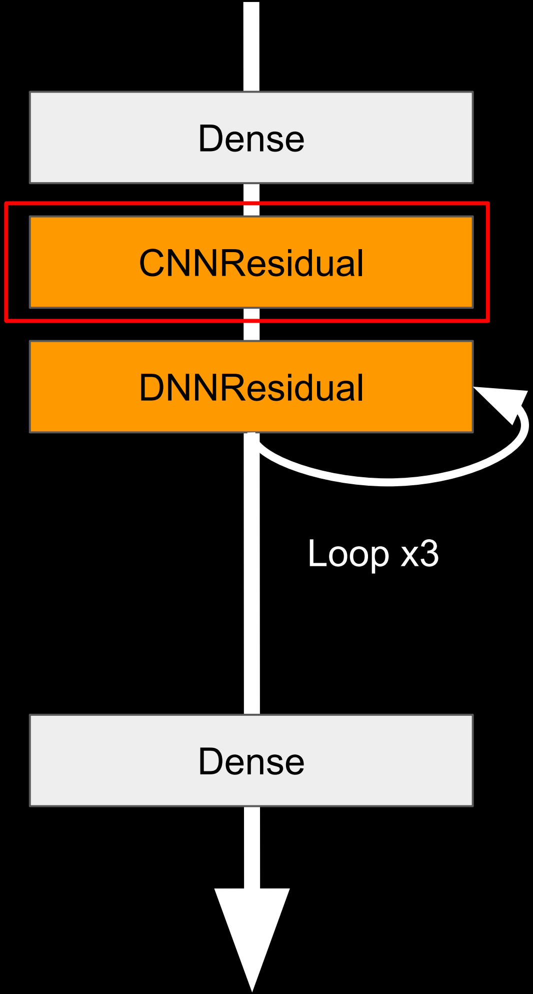

```
class MyResidual(Model):
  def __init__(self, **kwargs):
    self.hidden1 = Dense(30, activation="relu")
    self.block1 = CNNResidual(2, 32)
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    self.out = Dense(1)

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    x = self.hidden1(inputs)
    x = self.block1(x)
    for _ in range(1, 4):#this will run 3 times
      x = self.block2(x)
    return self.out(x)
```

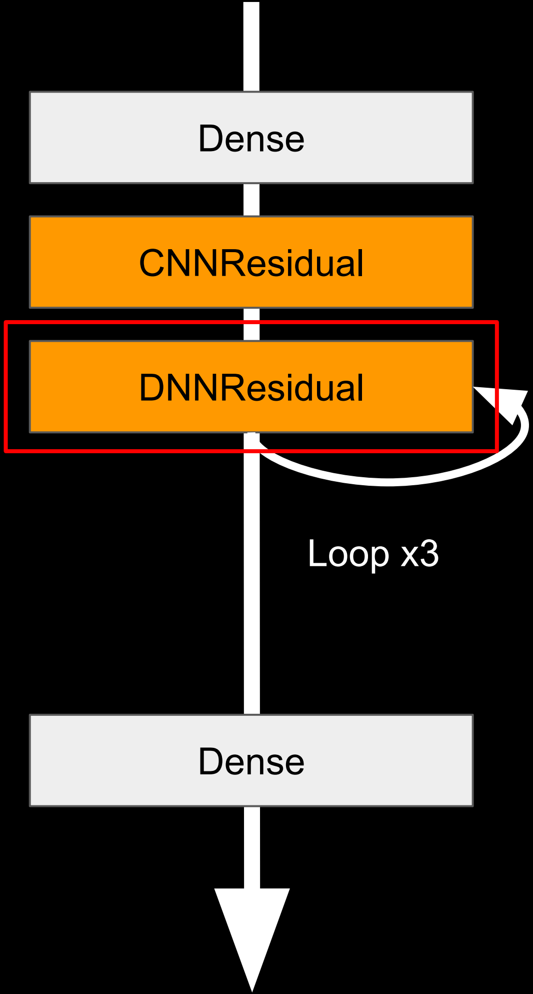

```
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  def __init__(self, **kwargs):
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```

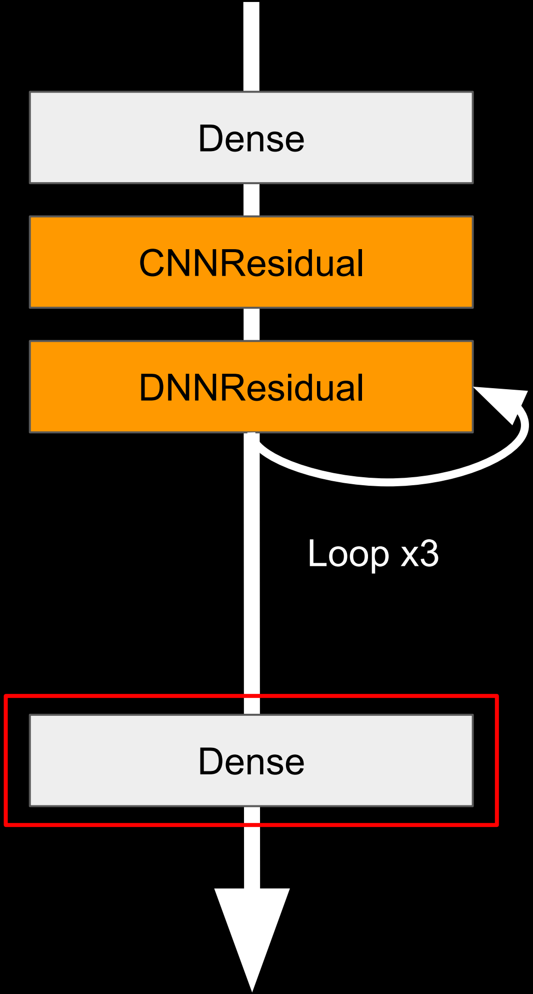

```
class MyResidual(Model):
  def __init__(self, **kwargs):
    self.hidden1 = Dense(30, activation="relu")
    self.block1 = CNNResidual(2, 32)
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      x = self.block2(x)
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```
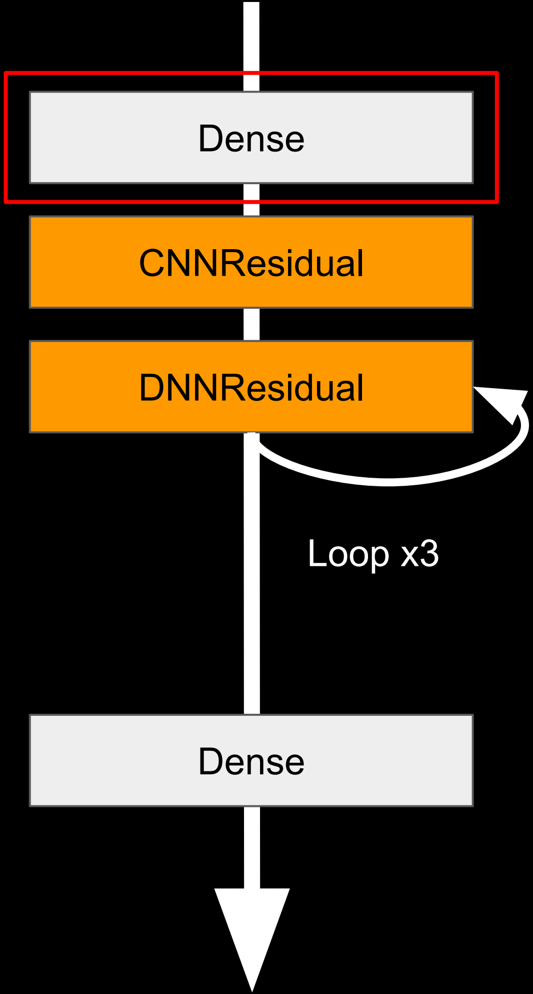
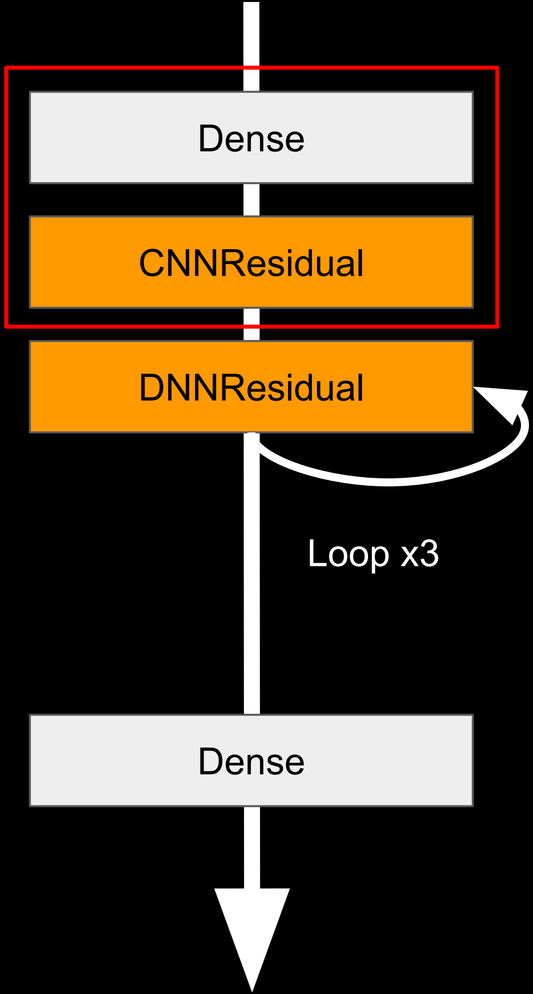



```python
class MyResidual(Model):
  def __init__(self, **kwargs):
    self.hidden1 = Dense(30, activation="relu")
    self.block1 = CNNResidual(2, 32)
    self.block2 = DNNResidual(2, 64)
    self.out = Dense(1)

  def call(self, inputs):
    x = self.hidden1(inputs)
    x = self.block1(x)
    for _ in range(1, 4):#this will run 3 times
      x = self.block2(x)
    return self.out(x)
```



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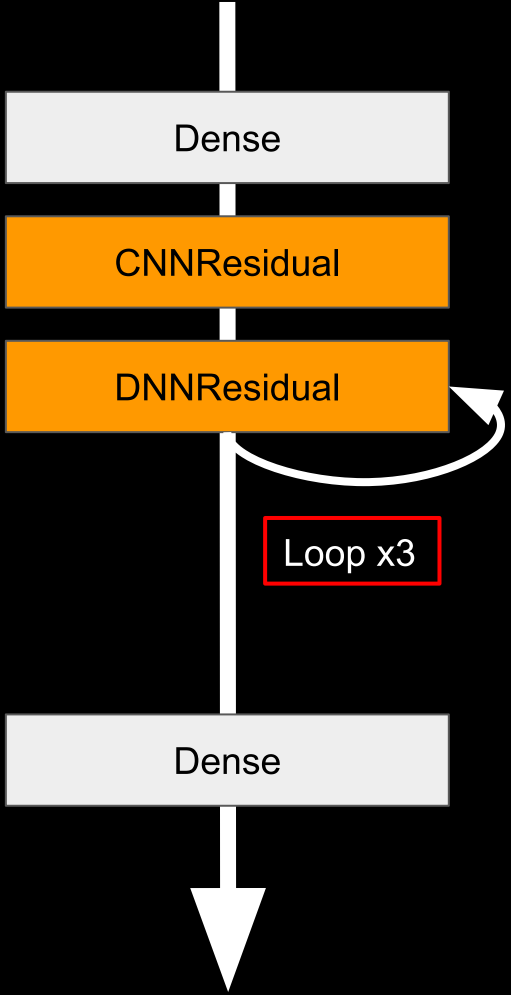
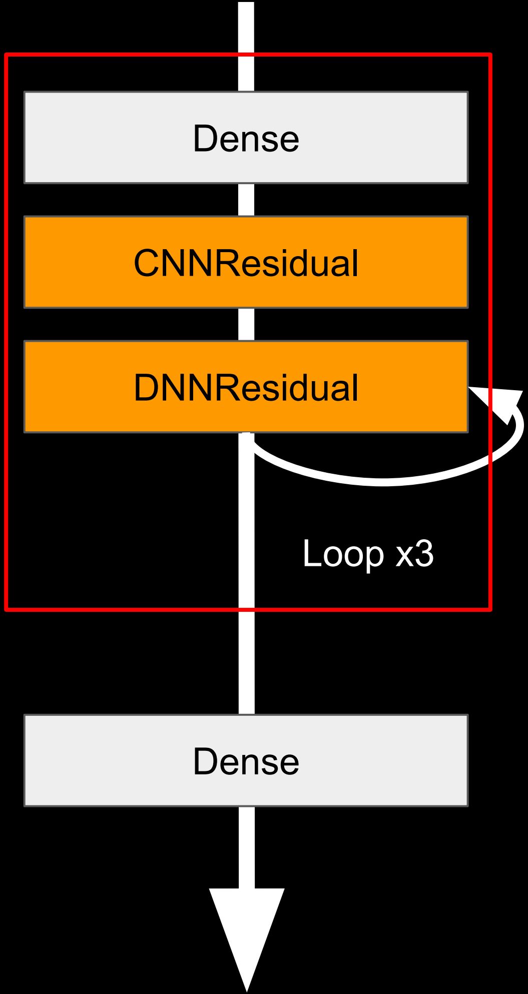
class MyResidual(Model):
  def __init__(self, **kwargs):
    self.hidden1 = Dense(30, activation="relu")
    self.block1 = CNNResidual(2, 32)
    self.block2 = DNNResidual(2, 64)
    self.out = Dense(1)

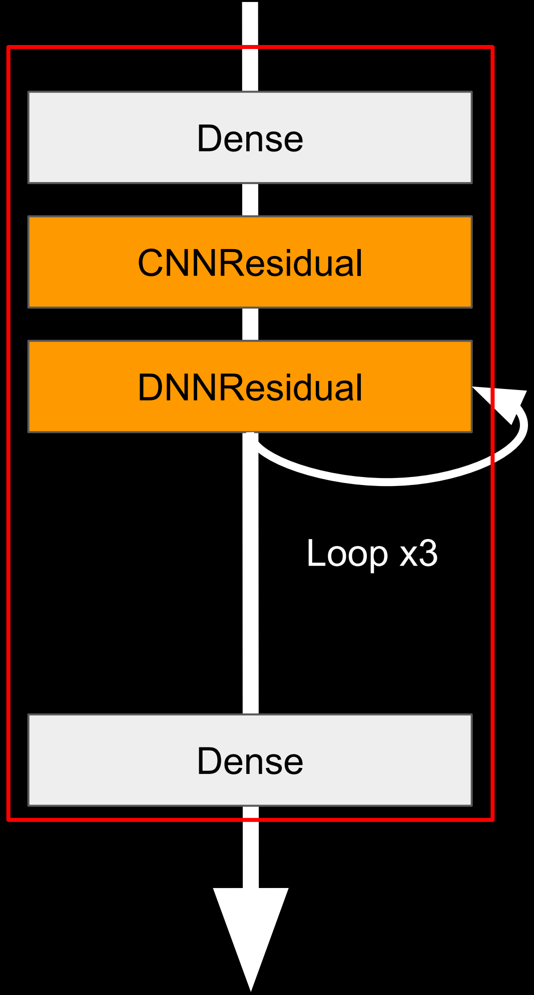
  def call(self, inputs):
    x = self.hidden1(inputs)
    x = self.block1(x)
    for _ in range(1, 4):#this will run 3 times
      x = self.block2(x)
    return self.out(x)
```



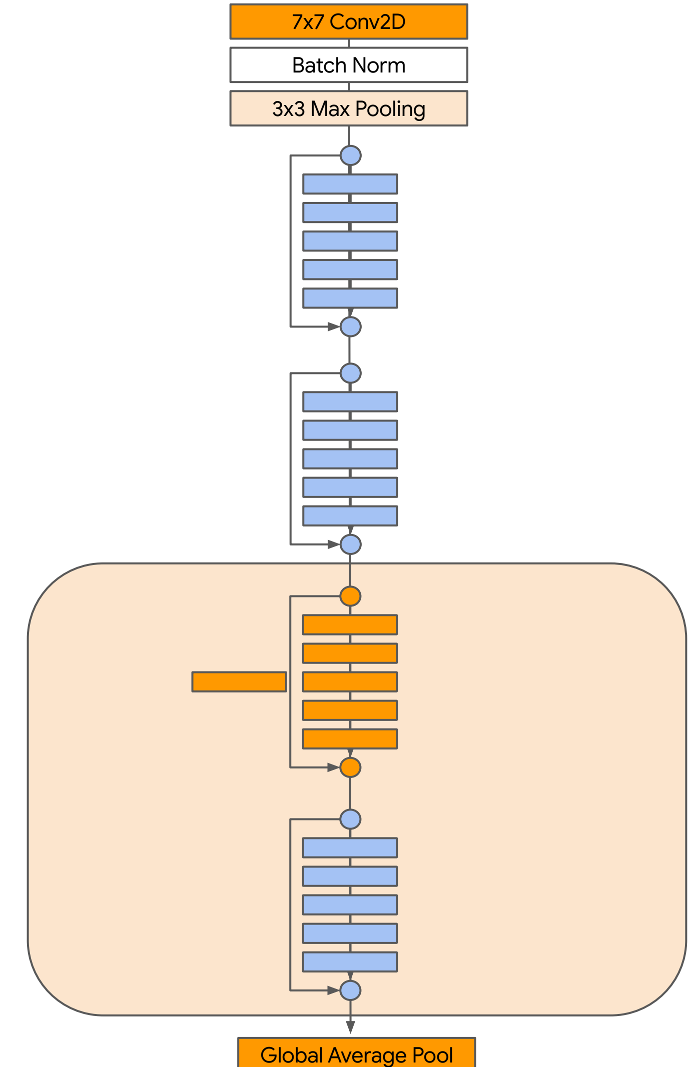
```python
class MyResidual(Model):
  def __init__(self, **kwargs):
    self.hidden1 = Dense(30, activation="relu")
    self.block1 = CNNResidual(2, 32)
    self.block2 = DNNResidual(2, 64)
    self.out = Dense(1)

  def call(self, inputs):
    x = self.hidden1(inputs)
    x = self.block1(x)
    for _ in range(1, 4):#this will run 3 times
      x = self.block2(x)
    return self.out(x)
```



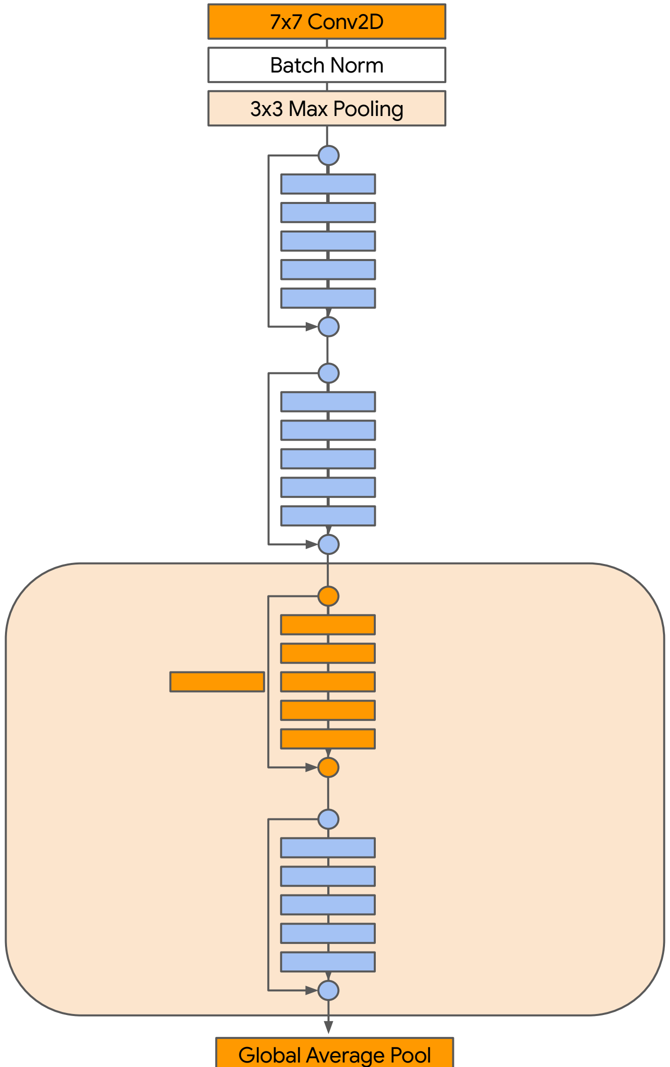
```
class MyResidual(Model):
  def __init__(self, **kwargs):
    self.hidden1 = Dense(30, activation="relu")
    self.block1 = CNNResidual(2, 32)
    self.block2 = DNNResidual(2, 64)
    self.out = Dense(1)

  def call(self, inputs):
    x = self.hidden1(inputs)
    x = self.block1(x)
    for _ in range(1, 4):#this will run 3 times
      x = self.block2(x)
    return self.out(x)
```



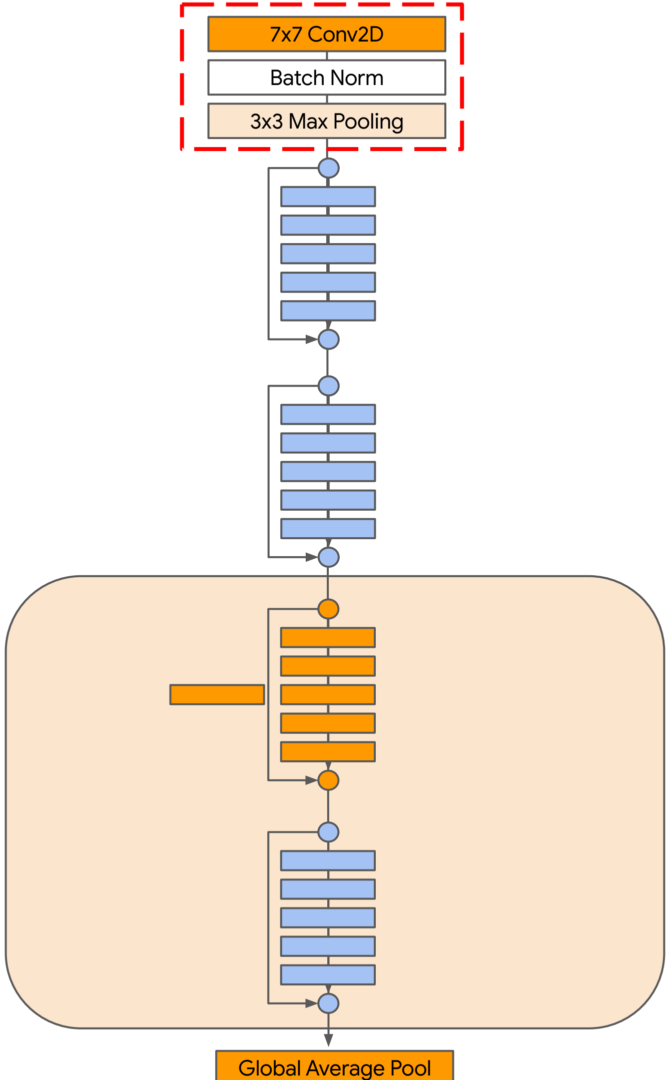
ResNet18



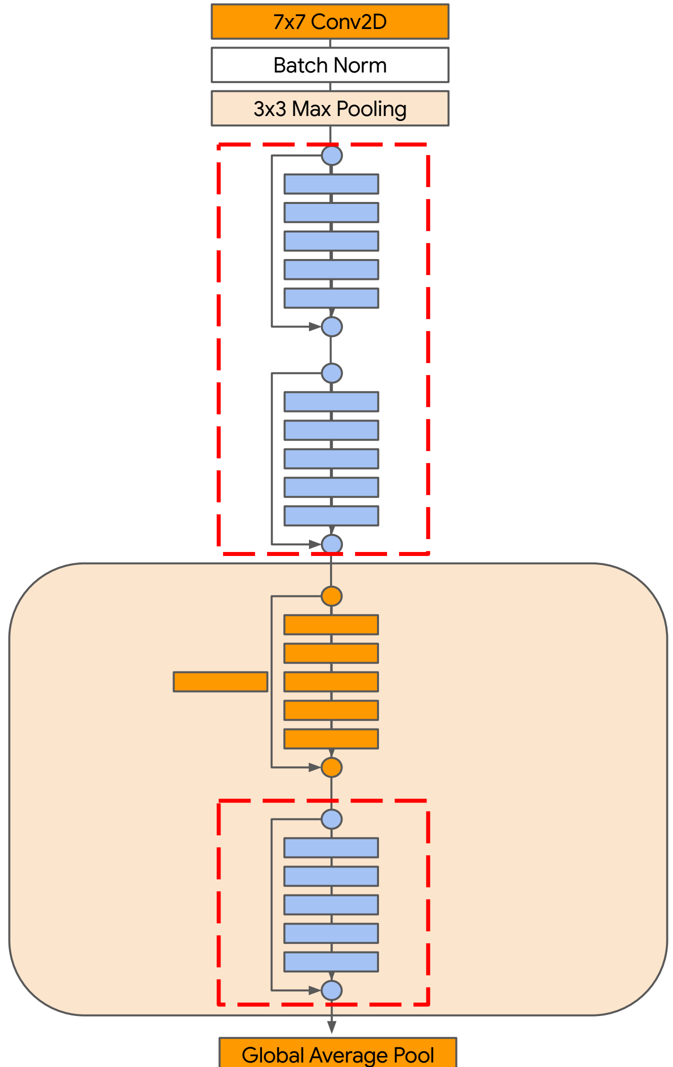
ResNet18

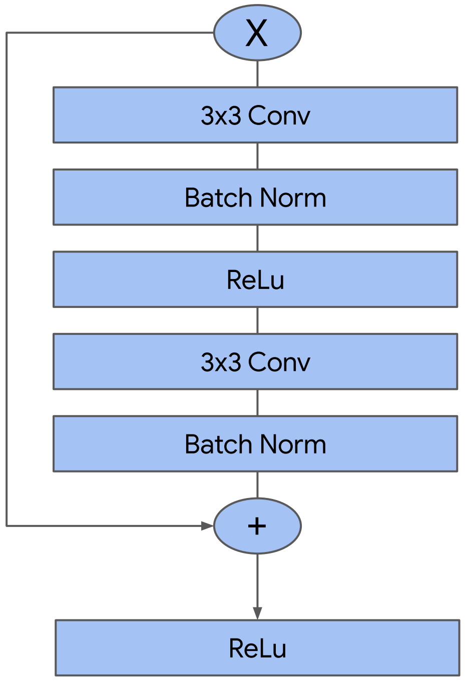


ResNet18



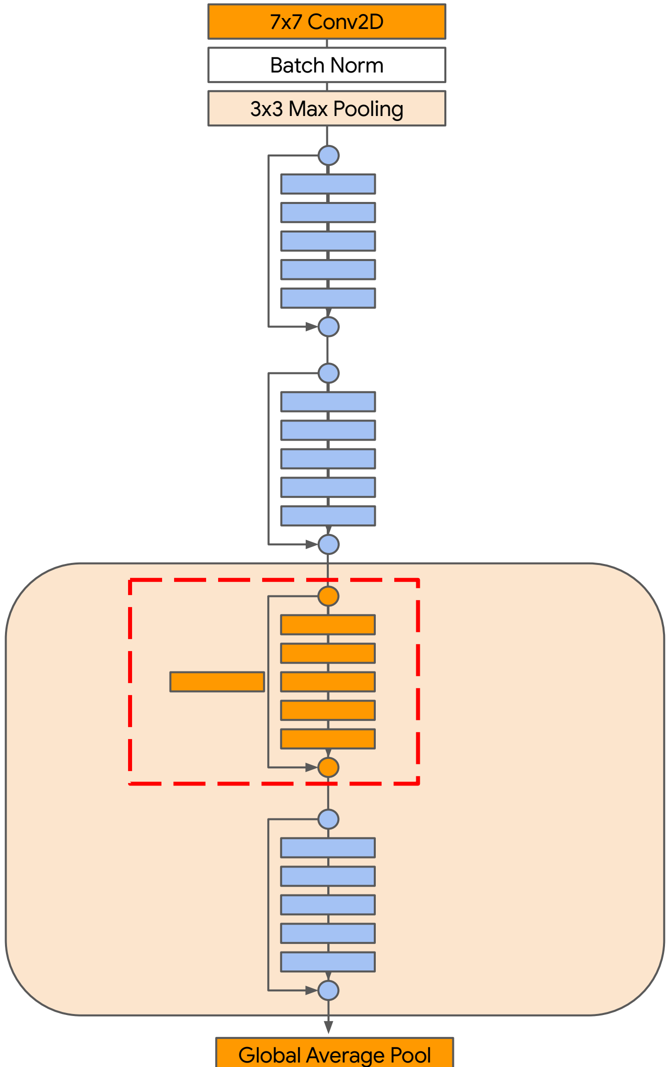
ResNet18

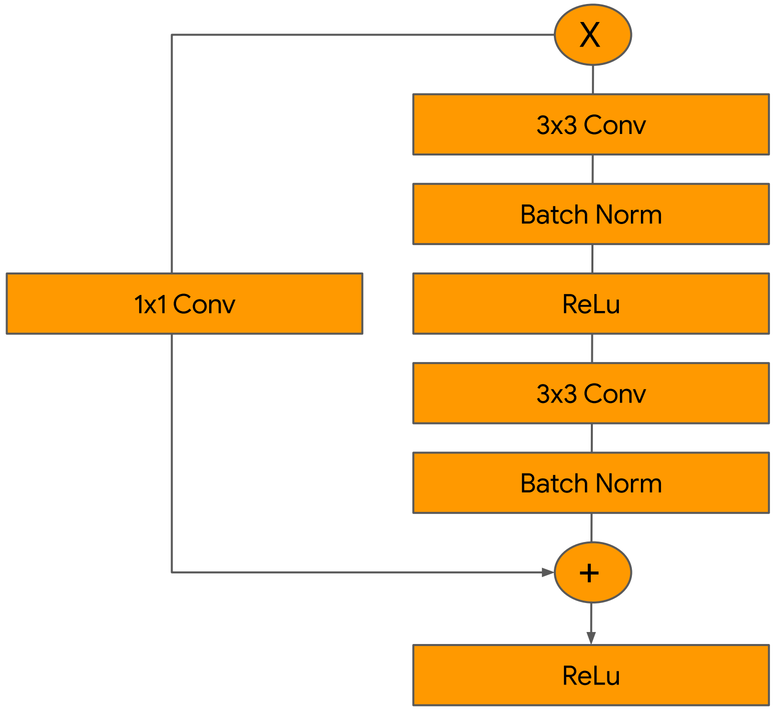




"Identity ResNet Block"

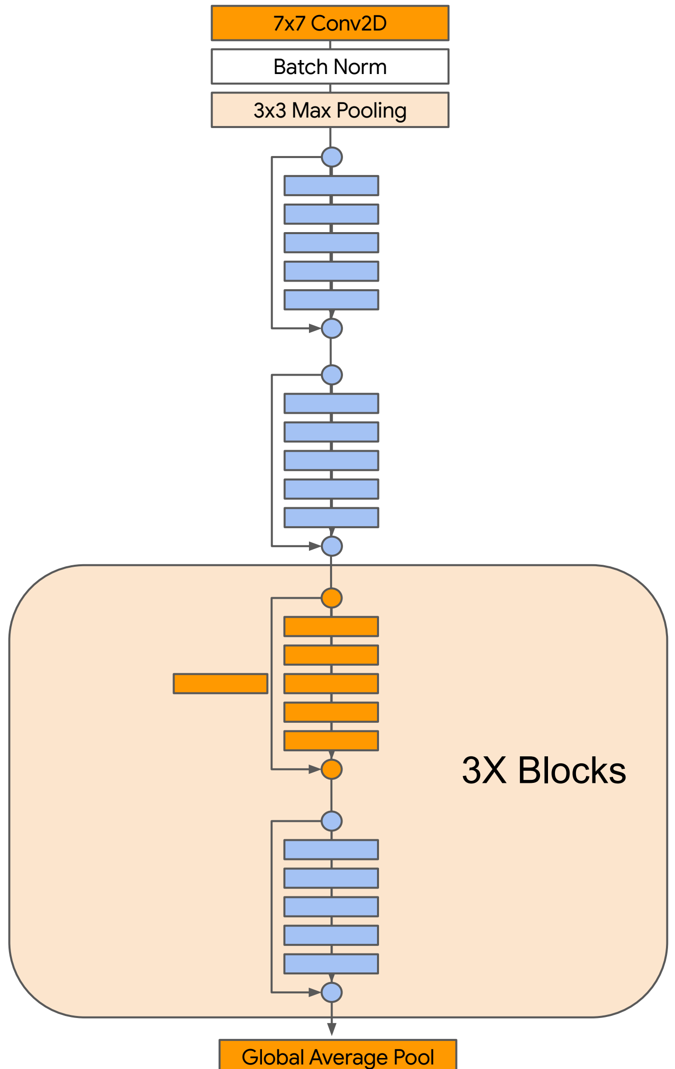
ResNet18

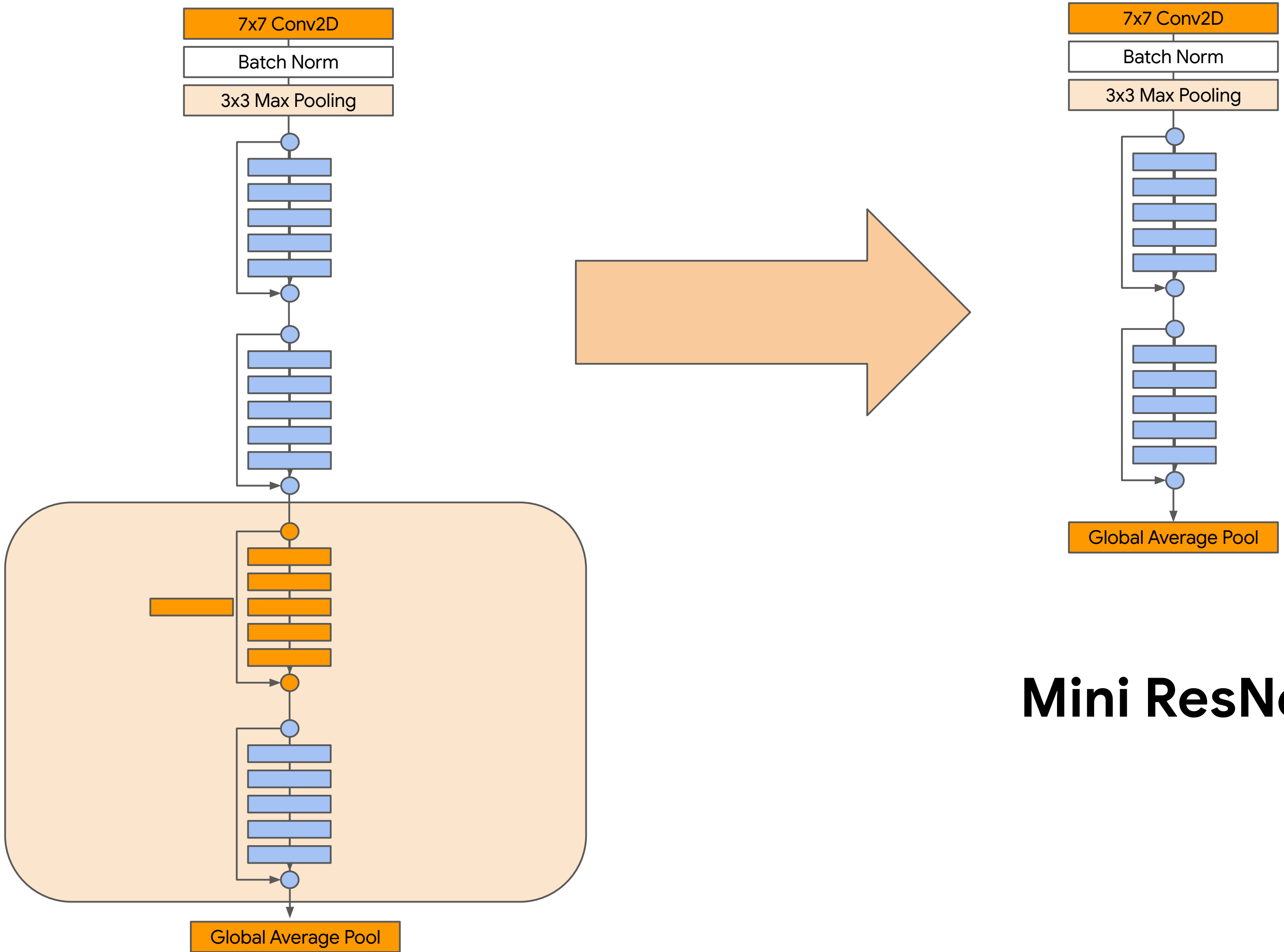




"Identity ResNet Block with 1x1 Convolution"

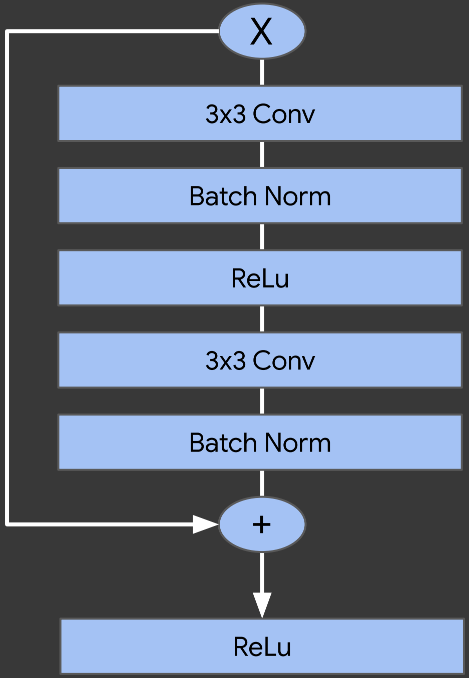
ResNet18


7x7 Conv2D
Batch Norm
3x3 Max Pooling
3X Blocks
Global Average Pool

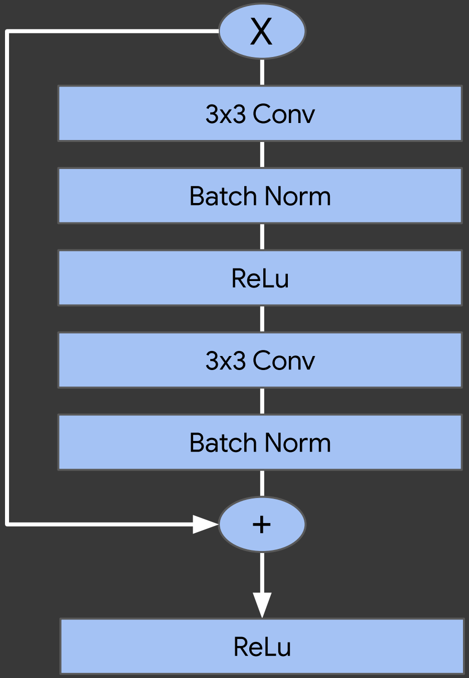

7x7 Conv2D
Batch Norm
3x3 Max Pooling
Global Average Pool
7x7 Conv2D
Batch Norm
3x3 Max Pooling
Global Average Pool

Mini ResNet

```
class IdentityBlock(tf.keras.Model):
  def __init__(self, filters, kernel_size):
    super(IdentityBlock, self).__init__(name='')

    self.conv1 = tf.keras.layers.Conv2D(filters, kernel_size, padding='same')
    self.bn1 = tf.keras.layers.BatchNormalization()

    self.conv2 = tf.keras.layers.Conv2D(filters, kernel_size, padding='same')
    self.bn2 = tf.keras.layers.BatchNormalization()

    self.act = tf.keras.layers.Activation('relu')
    self.add = tf.keras.layers.Add()

  def call(self, input_tensor):
    x = self.conv1(input_tensor)
    x = self.bn1(x)
    x = self.act(x)

    x = self.conv2(x)
    x = self.bn2(x)
    x = self.act(x)

    x = self.add([x, input_tensor])
    x = self.act(x)
    return x
```



```
class IdentityBlock(tf.keras.Model):
  def __init__(self, filters, kernel_size):
    super(IdentityBlock, self).__init__(name='')

    self.conv1 = tf.keras.layers.Conv2D(filters, kernel_size, padding='same')
    self.bn1 = tf.keras.layers.BatchNormalization()

    self.conv2 = tf.keras.layers.Conv2D(filters, kernel_size, padding='same')
    self.bn2 = tf.keras.layers.BatchNormalization()

    self.act = tf.keras.layers.Activation('relu')
    self.add = tf.keras.layers.Add()

  def call(self, input_tensor):
    x = self.conv1(input_tensor)
    x = self.bn1(x)
    x = self.act(x)

    x = self.conv2(x)
    x = self.bn2(x)
    x = self.act(x)

    x = self.add([x, input_tensor])
    x = self.act(x)
    return x
```



```python
class IdentityBlock(tf.keras.Model):
  def __init__(self, filters, kernel_size):
    super(IdentityBlock, self).__init__(name='')

    self.conv1 = tf.keras.layers.Conv2D(filters, kernel_size, padding='same')
    self.bn1 = tf.keras.layers.BatchNormalization()

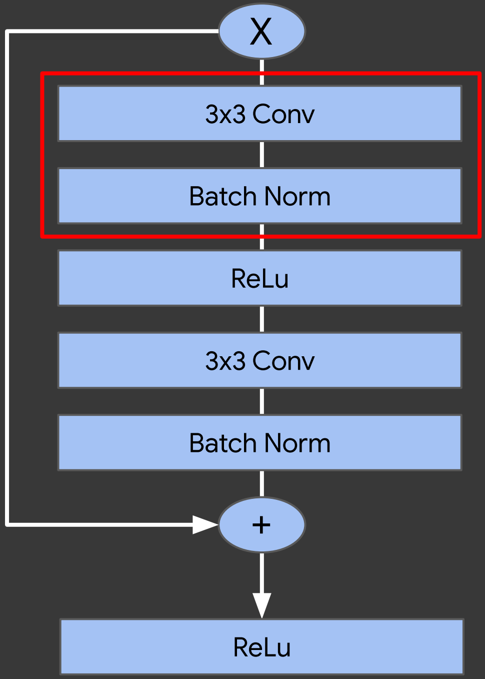
    self.conv2 = tf.keras.layers.Conv2D(filters, kernel_size, padding='same')
    self.bn2 = tf.keras.layers.BatchNormalization()

    self.act = tf.keras.layers.Activation('relu')
    self.add = tf.keras.layers.Add()

  def call(self, input_tensor):
    x = self.conv1(input_tensor)
    x = self.bn1(x)
    x = self.act(x)

    x = self.conv2(x)
    x = self.bn2(x)
    x = self.act(x)

    x = self.add([x, input_tensor])
    x = self.act(x)
    return x
```



```
class IdentityBlock(tf.keras.Model):
  def __init__(self, filters, kernel_size):
    super(IdentityBlock, self).__init__(name='')

    self.conv1 = tf.keras.layers.Conv2D(filters, kernel_size, padding='same')
    self.bn1 = tf.keras.layers.BatchNormalization()

    self.conv2 = tf.keras.layers.Conv2D(filters, kernel_size, padding='same')
    self.bn2 = tf.keras.layers.BatchNormalization()

    self.act = tf.keras.layers.Activation('relu')
    self.add = tf.keras.layers.Add()

  def call(self, input_tensor):
    x = self.conv1(input_tensor)
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    x = self.bn2(x)
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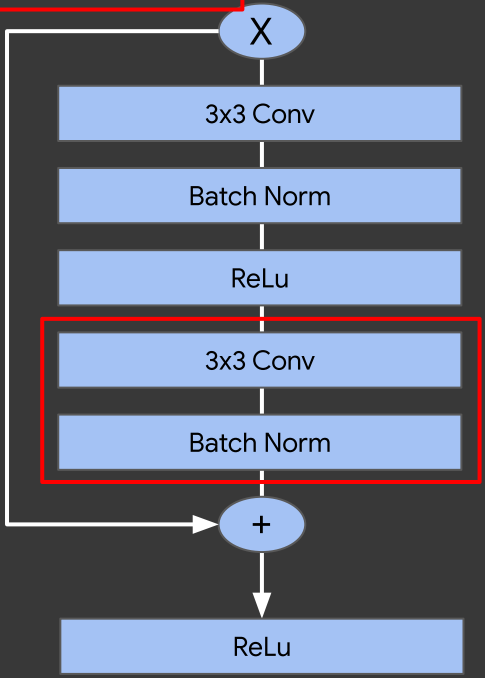
    x = self.add([x, input_tensor])
    x = self.act(x)
    return x
```



```
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  def __init__(self, filters, kernel_size):
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    self.conv1 = tf.keras.layers.Conv2D(filters, kernel_size, padding='same')
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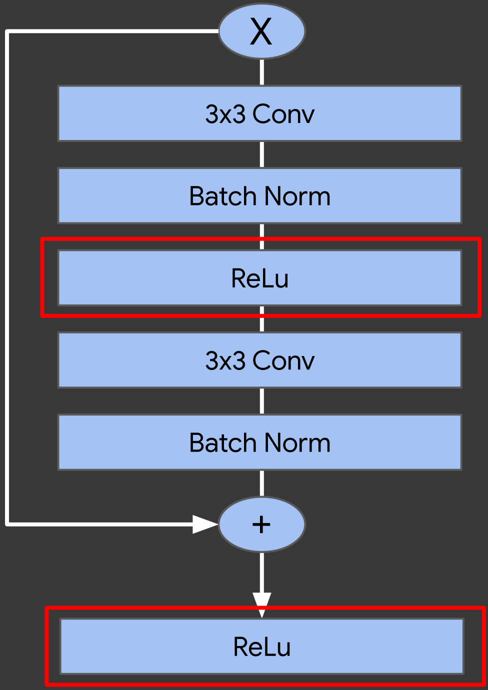
    x = self.act(x)

    x = self.conv2(x)
    x = self.bn2(x)
    x = self.act(x)

    x = self.add([x, input_tensor])
    x = self.act(x)
    return x
```



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    super(IdentityBlock, self).__init__(name='')

    self.conv1 = tf.keras.layers.Conv2D(filters, kernel_size, padding='same')
    self.bn1 = tf.keras.layers.BatchNormalization()

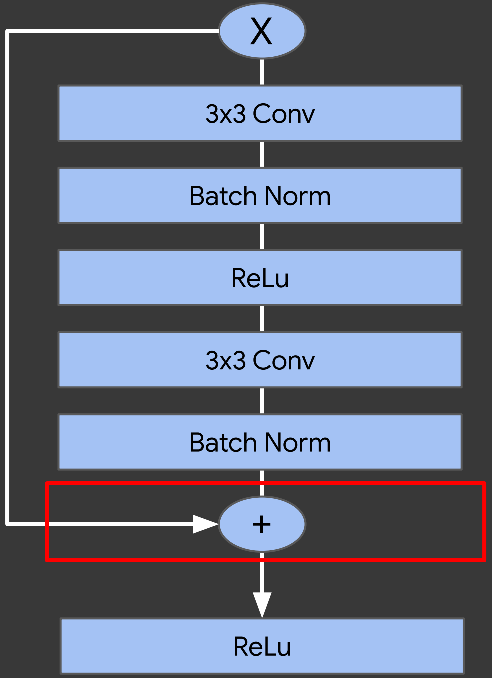
    self.conv2 = tf.keras.layers.Conv2D(filters, kernel_size, padding='same')
    self.bn2 = tf.keras.layers.BatchNormalization()

    self.act = tf.keras.layers.Activation('relu')
    self.add = tf.keras.layers.Add()

  def call(self, input_tensor):
    x = self.conv1(input_tensor)
    x = self.bn1(x)
    x = self.act(x)

    x = self.conv2(x)
    x = self.bn2(x)
    x = self.act(x)

    x = self.add([x, input_tensor])
    x = self.act(x)
    return x
```



```
class IdentityBlock(tf.keras.Model):
  def __init__(self, filters, kernel_size):
    super(IdentityBlock, self).__init__(name='')

    self.conv1 = tf.keras.layers.Conv2D(filters, kernel_size, padding='same')
    self.bn1 = tf.keras.layers.BatchNormalization()

    self.conv2 = tf.keras.layers.Conv2D(filters, kernel_size, padding='same')
    self.bn2 = tf.keras.layers.BatchNormalization()

    self.act = tf.keras.layers.Activation('relu')
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  def call(self, input_tensor):
    x = self.conv1(input_tensor)
    x = self.bn1(x)
    x = self.act(x)

    x = self.conv2(x)
    x = self.bn2(x)
    x = self.act(x)

    x = self.add([x, input_tensor])
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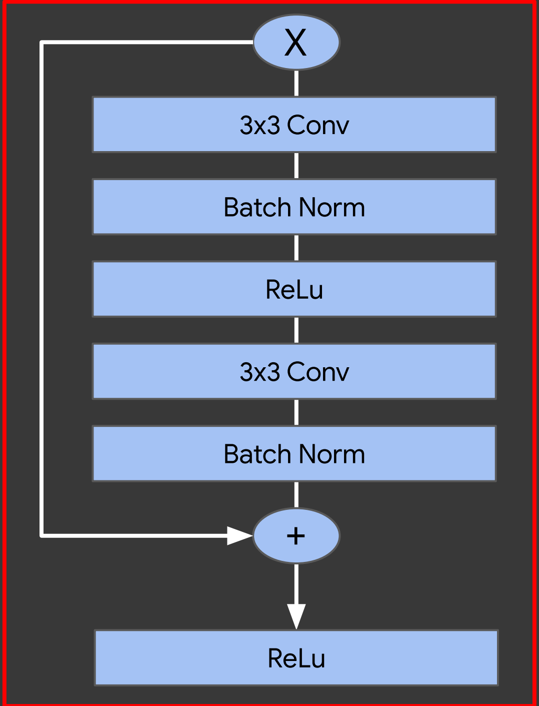
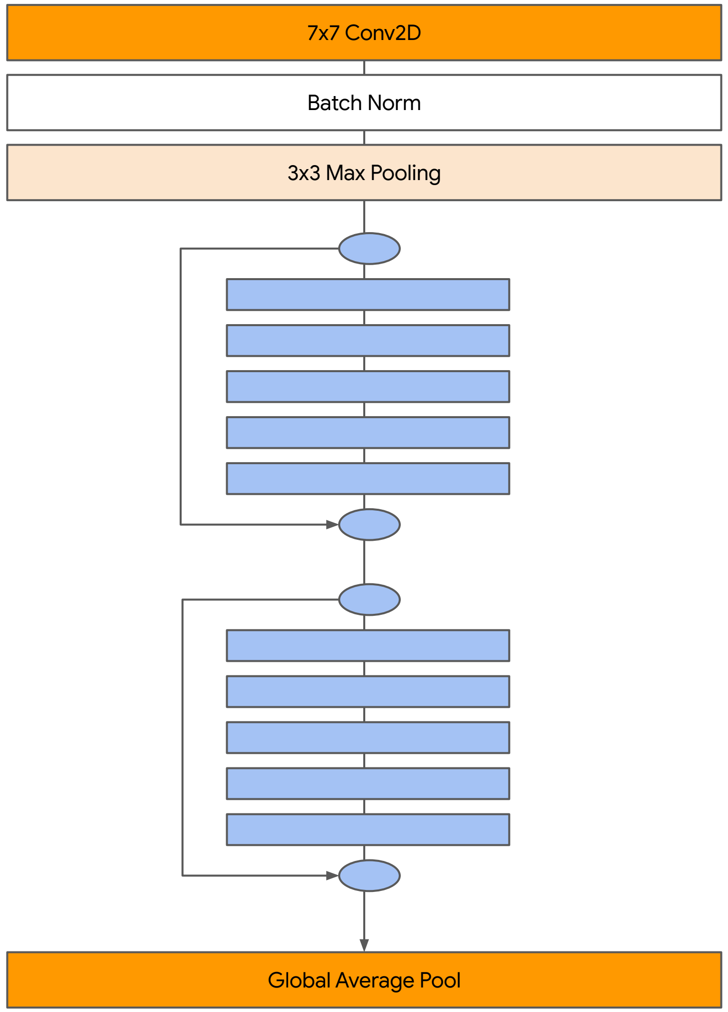
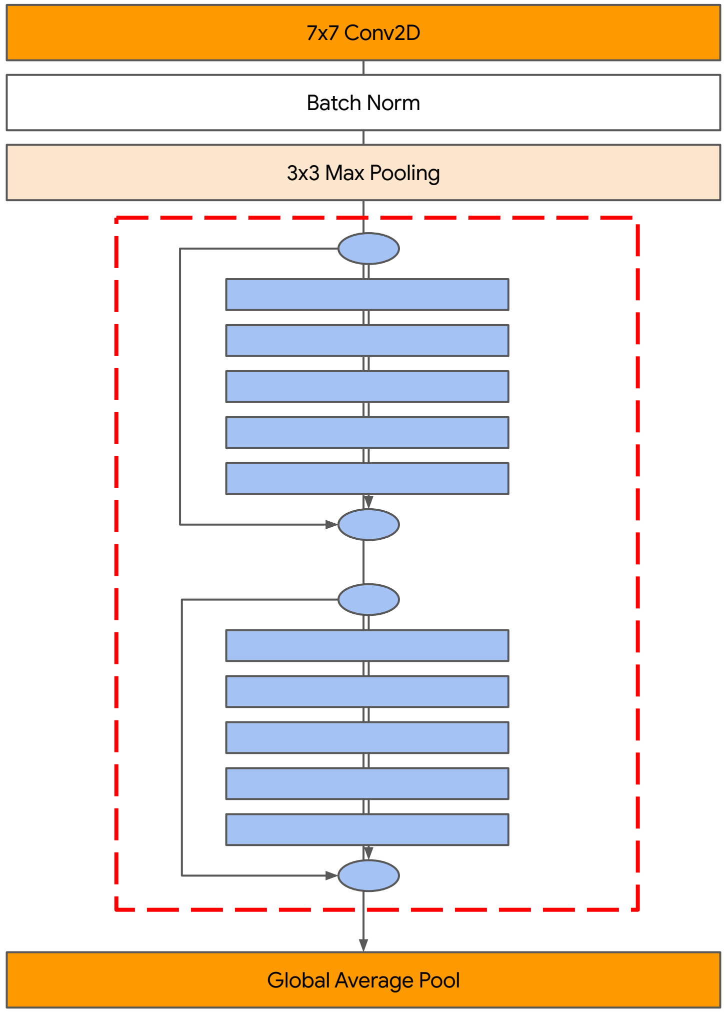
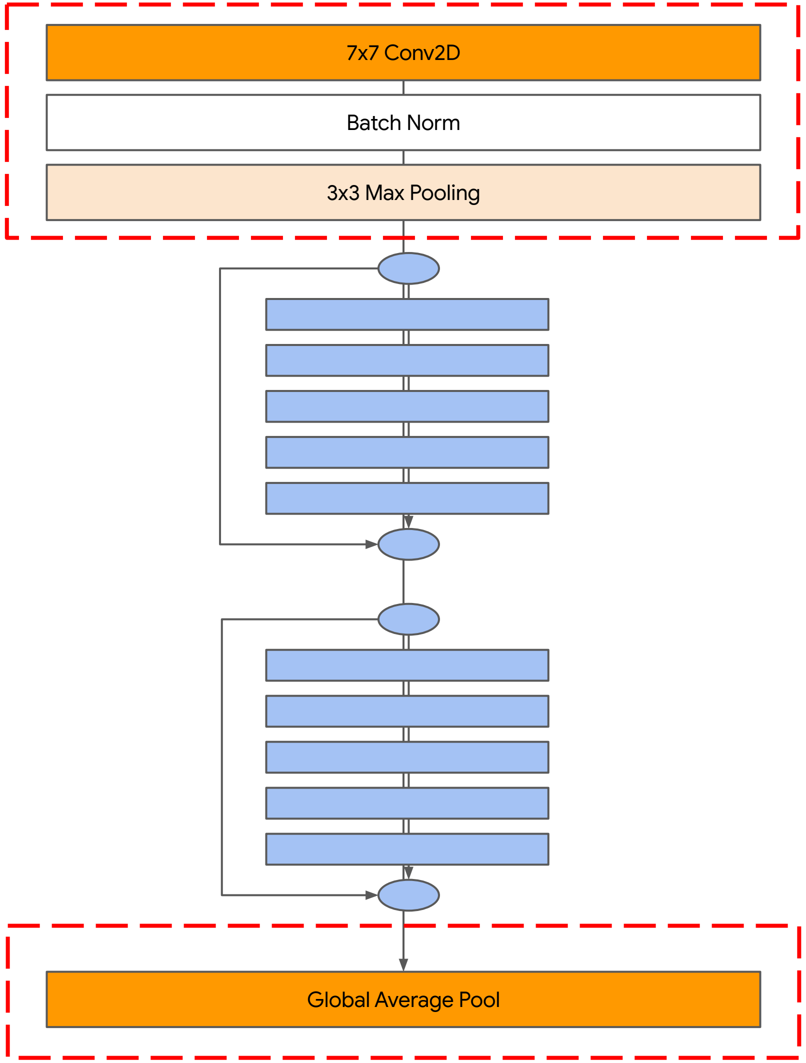
    return x
```

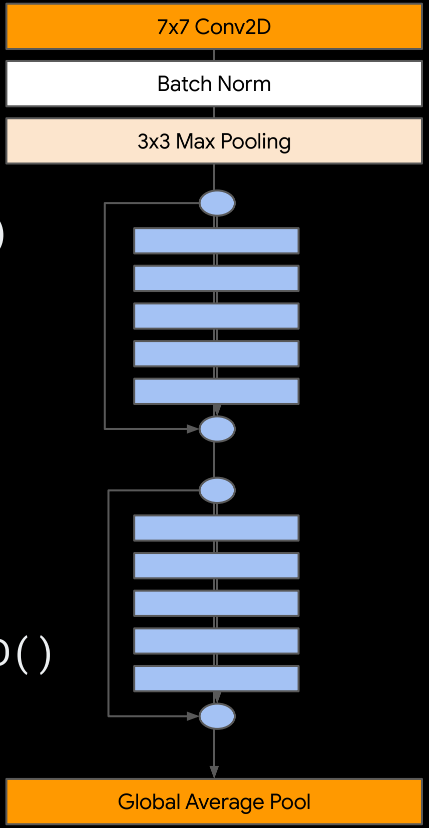



7x7 Conv2D
Batch Norm
3x3 Max Pooling
Global Average Pool

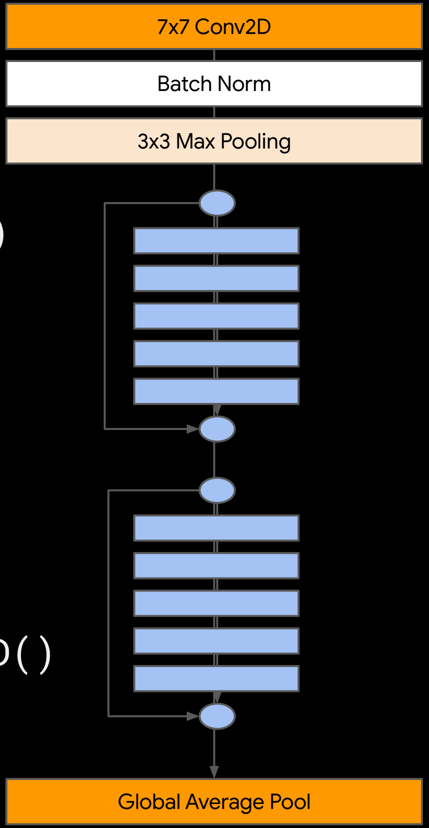

7x7 Conv2D
Batch Norm
3x3 Max Pooling
Global Average Pool


7x7 Conv2D
Batch Norm
3x3 Max Pooling
Global Average Pool

```
class ResNet(tf.keras.Model):
  def __init__(self, num_classes):
    super(ResNet, self).__init__()
    self.conv = tf.keras.layers.Conv2D(64, 7, padding='same')
    self.bn = tf.keras.layers.BatchNormalization()
    self.act = tf.keras.layers.Activation('relu')
    self.max_pool = tf.keras.layers.MaxPool2D((3, 3))
    self.id1a = IdentityBlock(64, 3)
    self.id1b = IdentityBlock(64, 3)
    self.global_pool = tf.keras.layers.GlobalAveragePooling2D()
    self.classifier = tf.keras.layers.Dense(num_classes,
                                   activation='softmax')
```



```python
class ResNet(tf.keras.Model):
  def __init__(self, num_classes):
    super(ResNet, self).__init__()
    self.conv = tf.keras.layers.Conv2D(64, 7, padding='same')
    self.bn = tf.keras.layers.BatchNormalization()
    self.act = tf.keras.layers.Activation('relu')
    self.max_pool = tf.keras.layers.MaxPool2D((3, 3))
    self.id1a = IdentityBlock(64, 3)
    self.id1b = IdentityBlock(64, 3)
    self.global_pool = tf.keras.layers.GlobalAveragePooling2D()
    self.classifier = tf.keras.layers.Dense(num_classes,
                           activation='softmax')
```



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class ResNet(tf.keras.Model):
  def __init__(self, num_classes):
    super(ResNet, self).__init__()
    self.conv = tf.keras.layers.Conv2D(64, 7, padding='same')
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    self.act = tf.keras.layers.Activation('relu')
    self.max_pool = tf.keras.layers.MaxPool2D((3, 3))
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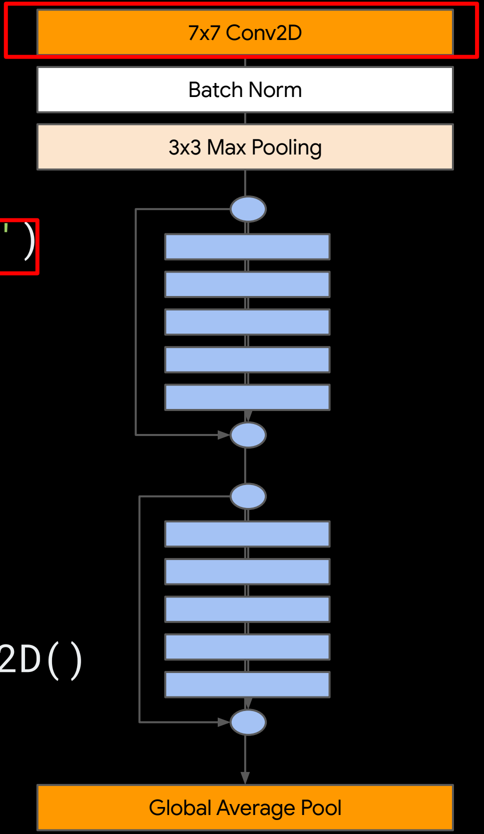

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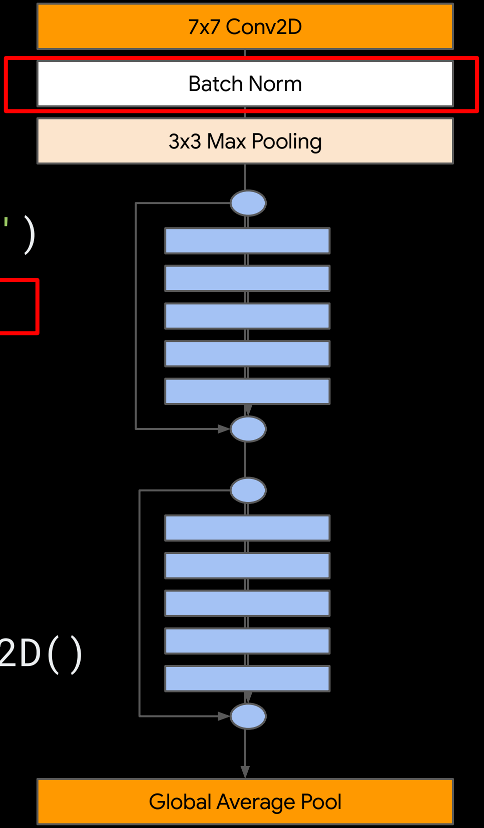

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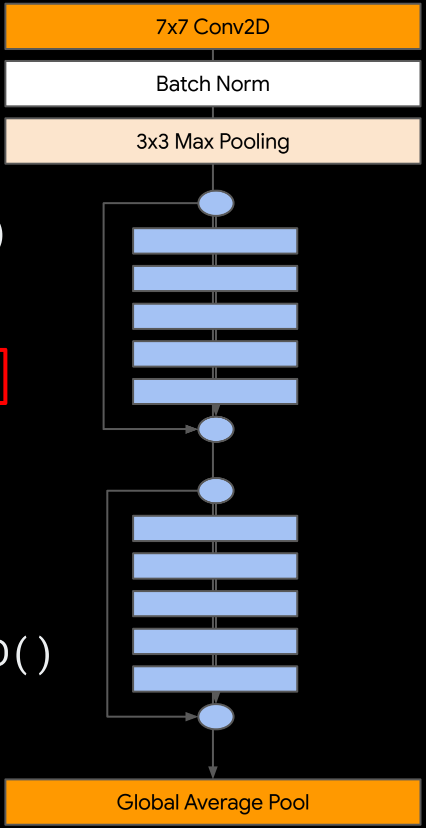

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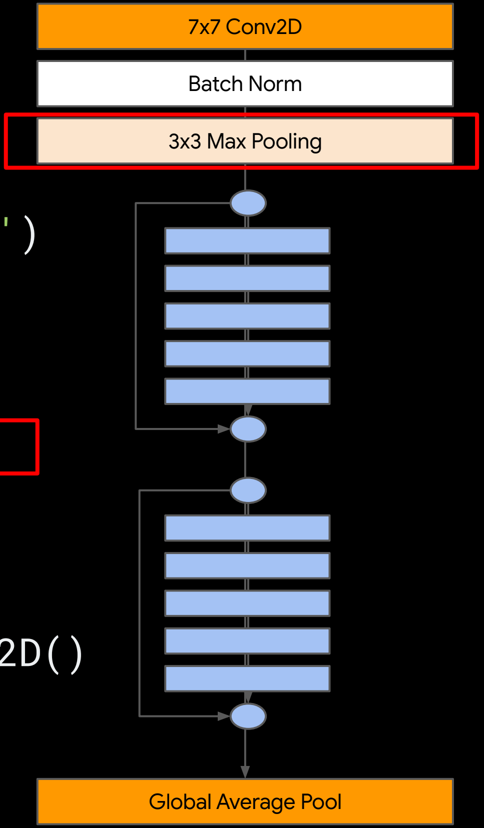

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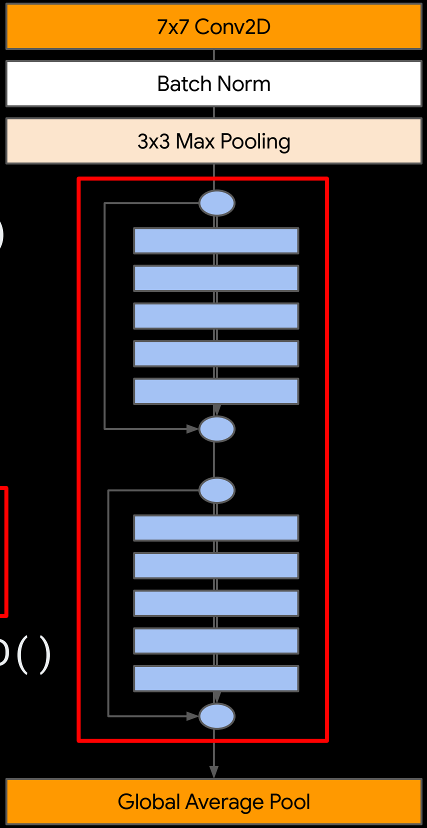

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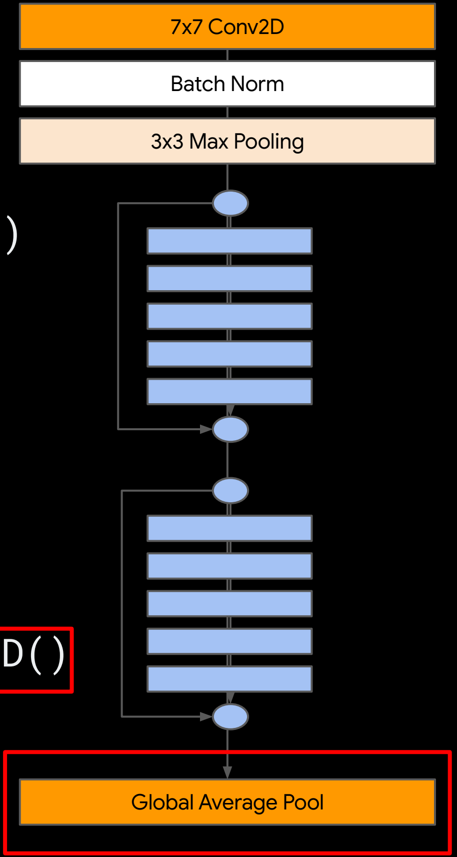

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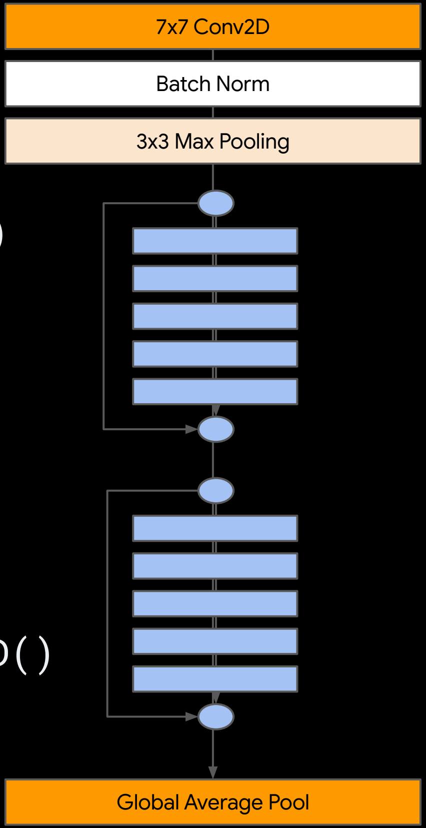

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def call(self, inputs):
  x = self.conv(inputs)
  x = self.bn(x)
  x = self.act(x)
  x = self.max_pool(x)

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  x = self.id1b(x)

  x = self.global_pool(x)
  return self.classifier(x)
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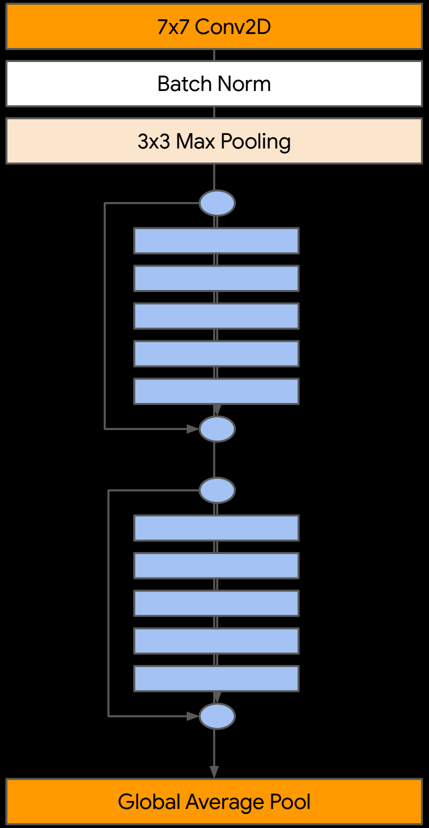

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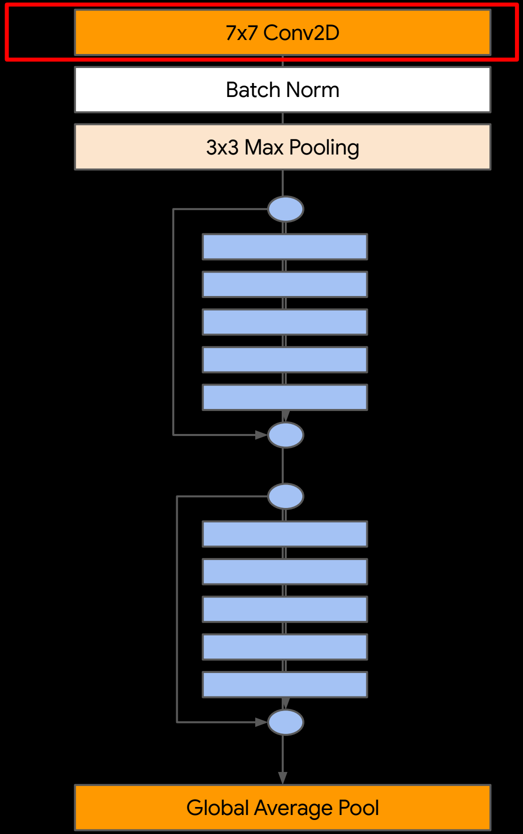

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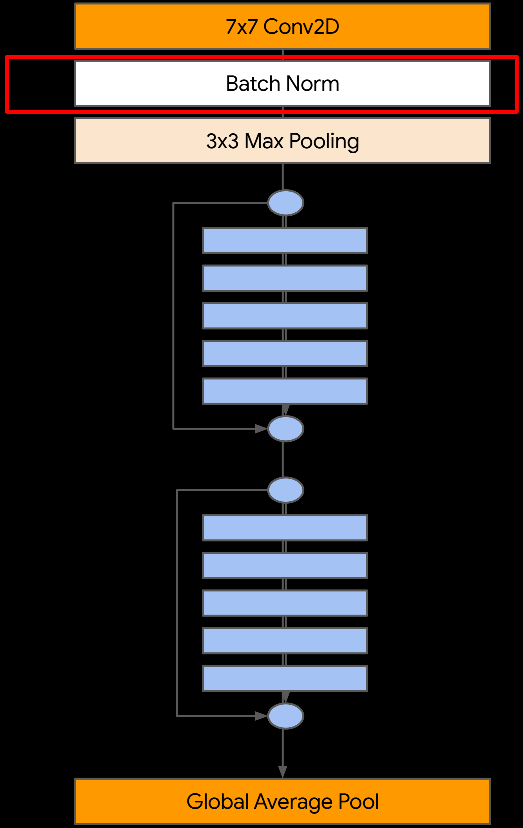

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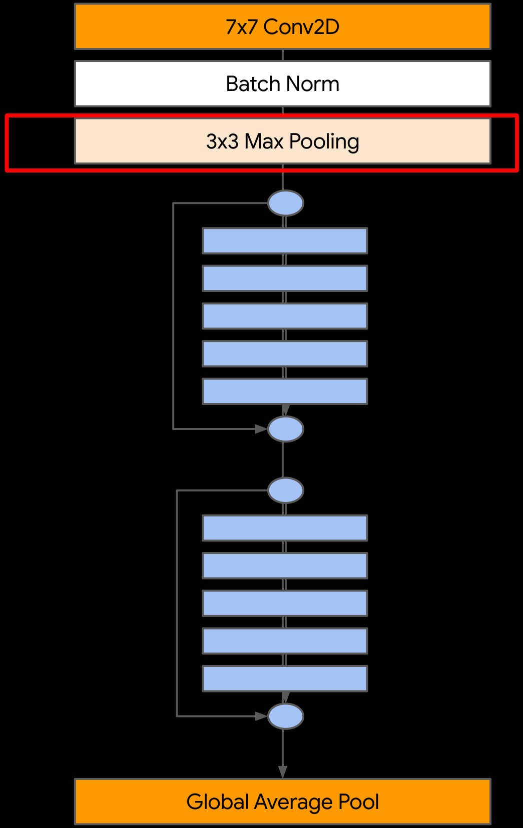

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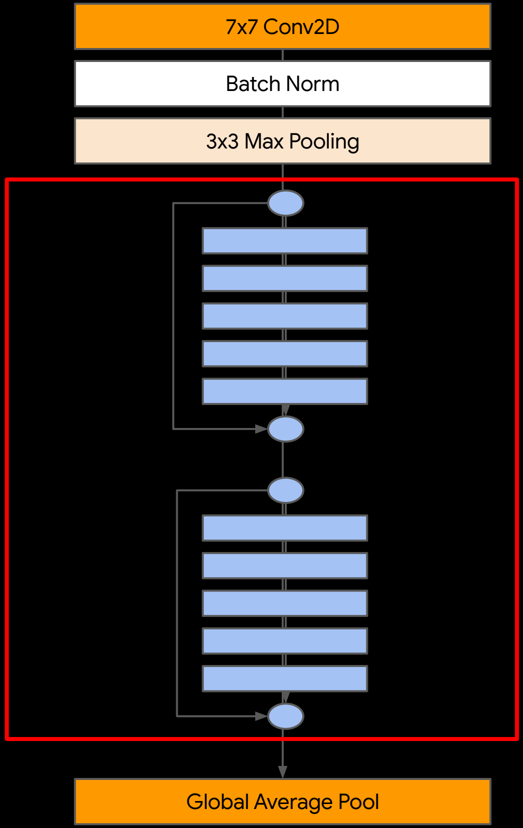

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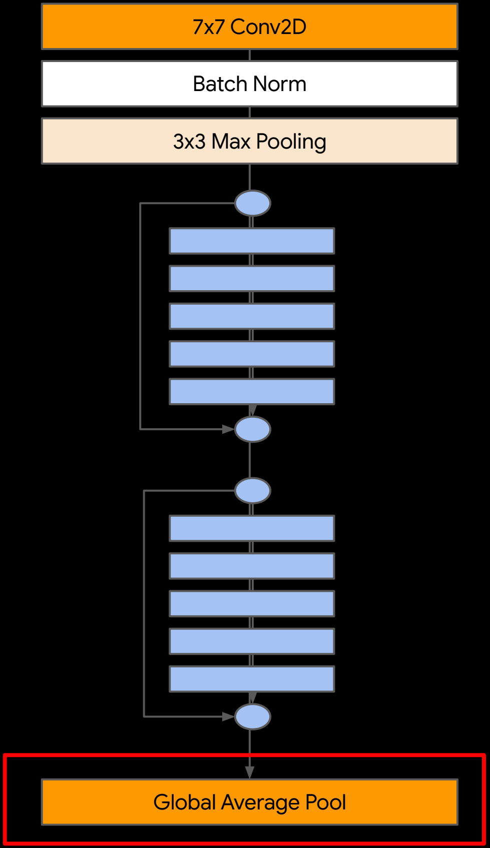

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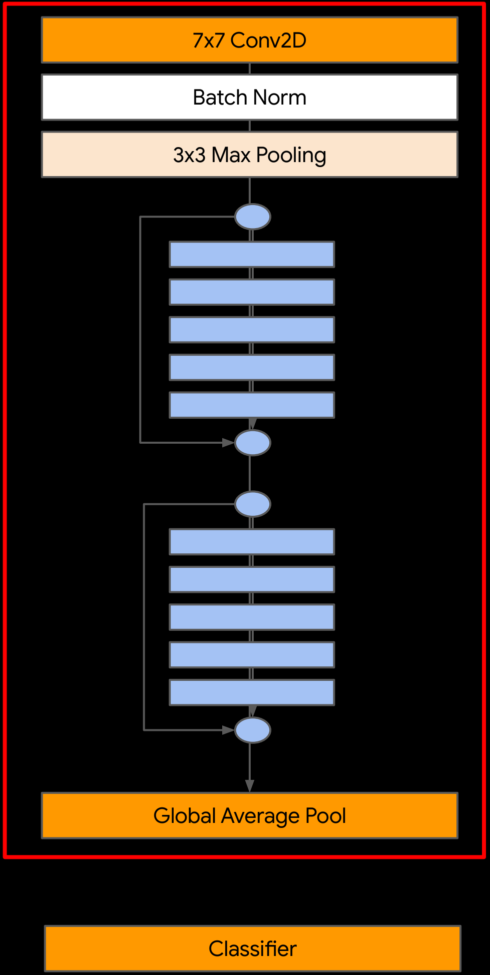

```python
resnet = ResNet(10)
resnet.compile(optimizer='adam', loss='sparse_categorical_crossentropy',
               metrics=['accuracy'])
dataset = tfds.load('mnist', split=tfds.Split.TRAIN)
dataset = dataset.map(preprocess).batch(32)
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