Residual Networks With Examples

Anas BRITAL · Follow
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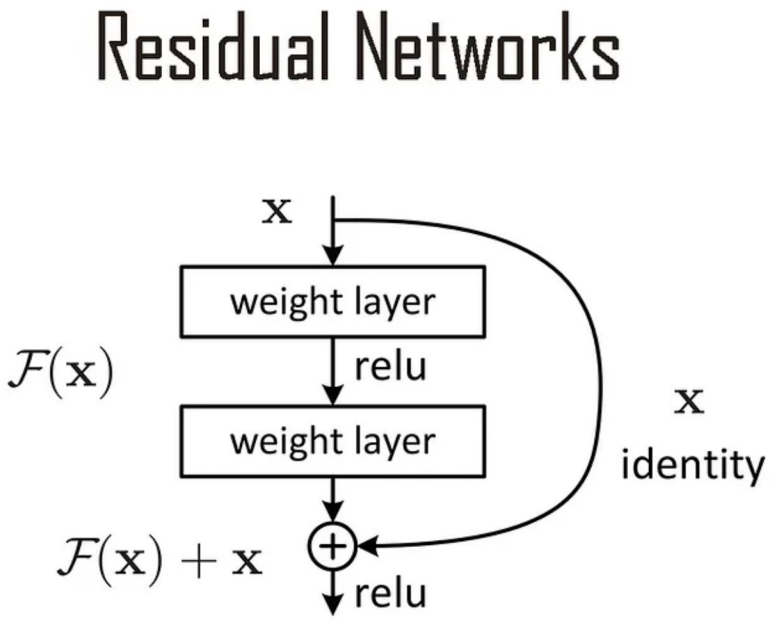
Residual Networks Explained and Implemented Using Keras and PyTorch .



In this article we will see what is a Residual network, and we will see two examples of this networks (ResNet 50 and ResNeXt 50), and how to implement them in both keras and PyTorch.

Residual Networks :

The first problem we encounter when we want to train deep neural networks is the gradient vanishing problem, the Residual networks (ResNet) come to solve this problem, ResNet networks are characterized

by skip connections, or shortcuts to jump over some layers, this trick gives the ability to train really deep networks without caring about The problem of gradient vanishing.

Feed Forward propagation in Residual Networks :

$$a^{\ell} := \mathbf{g}\left(Z^{\ell} + \sum_{k=2}^{K} W^{\ell-k,\ell} \cdot a^{\ell-k}\right)$$

a^{ℓ} : The Activation of layer L

$W^{\ell-k,\ell}$: The Weights Matrix between layer l-k and l.

g : is The Activation Function of Layer l

And z_l defined like this :

$$Z^{\ell} = W^{\ell-1,\ell} \cdot a^{\ell-1} + b^{\ell}$$

feed Forward in ResNet

Backward propagation in Residual Networks :

$$\Delta w^{\ell-k,\ell} := -\eta \frac{\partial E^{\ell}}{\partial w^{\ell-k,\ell}} = -\eta a^{\ell-k} \cdot \delta^{\ell}$$

a^{ℓ} : The Activation of layer L

$W^{\ell-k,\ell}$: The Weights Matrix between layer l-k and l.

n : is The Learning rate .

δ^{ℓ} : The Error in Layer l .

backward propagation in ResNet

Examples :

in this section we will see two examples of ResNet Networks , ResNet50 and ResNeXt50 , and we will see how to implement them in keras and PyTorch .

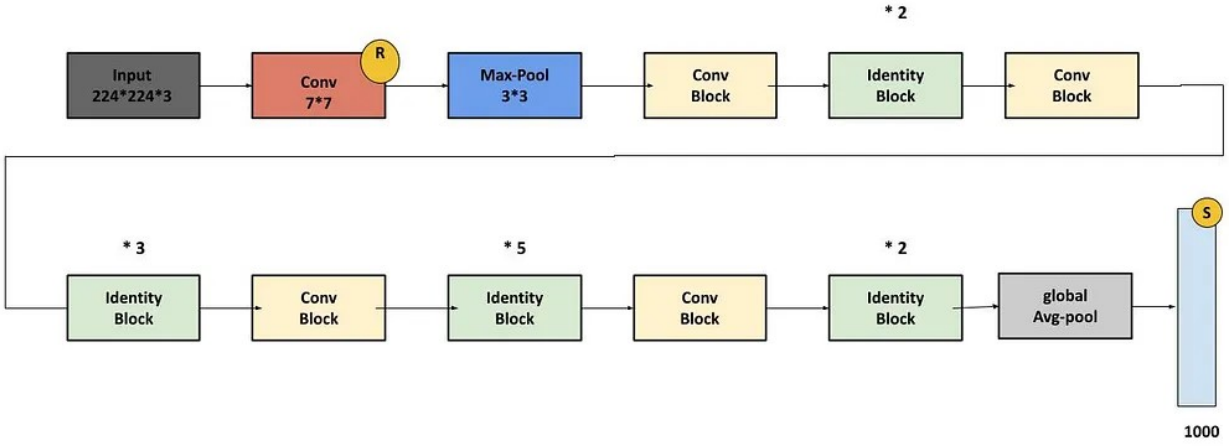
ResNet-50 :

Paper : Deep Residual Learning for Image Recognition.

Authors : Kaiming He, Xiangyu Zhang, Shaoqing Ren, Jian Sun. Microsoft .

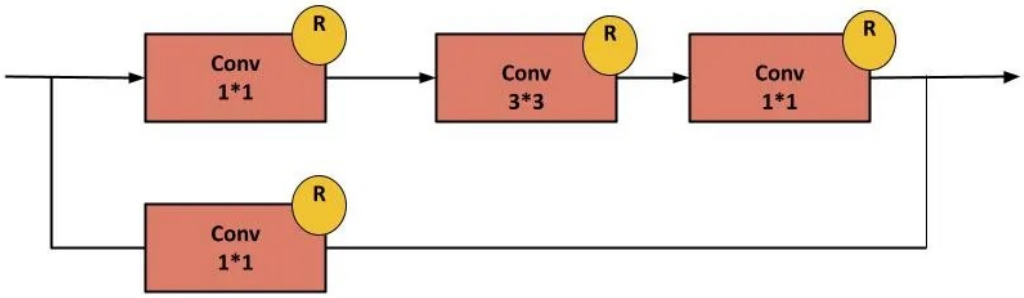
Published in : 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR).

The Main Architecture :



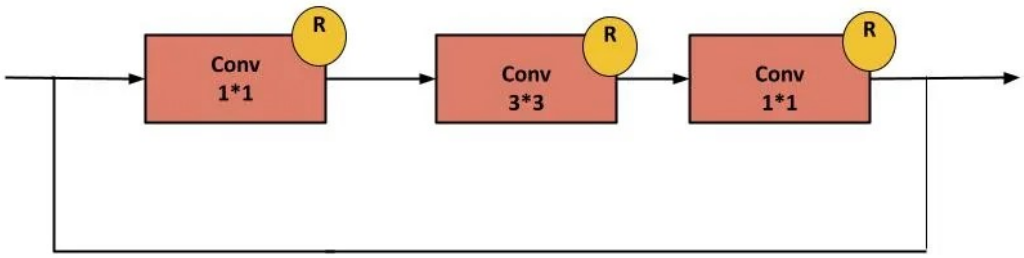
ResNet 50

Conv Block :



Conv Block

Identity Block :



identity Block

Implementation :

1. keras :

```
from keras.models import Model
from keras.layers.merge import concatenate
from keras.layers import Conv2D , MaxPool2D , Input ,AveragePooling2D, Dense , Dropout ,Activat



def IdentityBlock(prev_Layer , filters):
    f1 , f2 , f3 = filters

    x = Conv2D(filters=f1, kernel_size = (1,1) , strides=(1,1), padding='valid')(prev_Layer)
    x = BatchNormalization(axis=3)(x)
    x = Activation(activation='relu')(x)

    x = Conv2D(filters=f2, kernel_size = (3,3) , strides=(1,1), padding='same')(x)
    x = BatchNormalization(axis=3)(x)
    x = Activation(activation='relu')(x)

    x = Conv2D(filters=f3, kernel_size = (1,1) , strides=(1,1), padding='valid')(x)
    x = BatchNormalization(axis=3)(x)
    x = Activation(activation='relu')(x)

    x = concatenate([ x, prev_Layer ], axis=-1)
    x = Activation(activation='relu')(x)
    return x

def ConvBlock(prev_Layer , filters , strides):
    f1 , f2 , f3 = filters

    #Path 1
    x = Conv2D(filters=f1, kernel_size = (1,1) ,padding='valid', strides=strides)(prev_Layer)
    x = BatchNormalization(axis=3)(x)
    x = Activation(activation='relu')(x)

    x = Conv2D(filters=f2, kernel_size = (3,3) , padding='same' , strides=(1 ,1))(x)
    x = BatchNormalization(axis=3)(x)
    x = Activation(activation='relu')(x)

    x = Conv2D(filters=f3, kernel_size = (1,1), padding='valid' , strides=(1 ,1))(x)
    x = BatchNormalization(axis=3)(x)
    x = Activation(activation='relu')(x)

    #Path 2

    x2 = Conv2D(filters=f3, kernel_size=(1,1), padding='valid' , strides=strides)(prev_Layer)
    x2 = BatchNormalization(axis=3)(x2)

    x = concatenate([x , x2], axis=-1)
    x = Activation(activation='relu')(x)
    return x

def ResNet50():
    input_layer = Input(shape = (224, 224, 3))
    #Stage 1
```

```
    #Stage 1
    x = ZeroPadding2D((3, 3))(input_layer)
    x = Conv2D(filters = 64, kernel_size = (7,7), strides=(2,2)) (x)
    x = BatchNormalization(axis=3)(x)
    x = Activation(activation='relu')(x)
    x = MaxPool2D(pool_size=(3,3) , strides=(2,2))(x)

    #Stage 2
    x = ConvBlock(prev_Layer=x, filters = [64 , 64 , 256], strides = 1)
    x = IdentityBlock(prev_Layer=x, filters = [64,64,256])
    x = IdentityBlock(prev_Layer=x, filters = [64,64,256])

    #Stage 3
    x = ConvBlock(prev_Layer=x, filters = [128 , 128 , 512], strides = 2)
    x = IdentityBlock(prev_Layer=x, filters = [128 , 128 , 512])
    x = IdentityBlock(prev_Layer=x, filters = [128 , 128 , 512])
    x = IdentityBlock(prev_Layer=x, filters = [128 , 128 , 512])

    #Stage 4
    x = ConvBlock(prev_Layer=x, filters = [256 , 256 , 1024], strides = 2)
    x = IdentityBlock(prev_Layer=x, filters = [256 , 265 , 1024])
    x = IdentityBlock(prev_Layer=x, filters = [256 , 265 , 1024])
    x = IdentityBlock(prev_Layer=x, filters = [256 , 265 , 1024])
    x = IdentityBlock(prev_Layer=x, filters = [256 , 265 , 1024])
    x = IdentityBlock(prev_Layer=x, filters = [256 , 265 , 1024])

    #Stage 5
    x = ConvBlock(prev_Layer=x, filters = [512 , 512 , 2048], strides = 2)
    x = IdentityBlock(prev_Layer=x, filters = [512 , 512 , 2048])
    x = IdentityBlock(prev_Layer=x, filters = [512 , 512 , 2048])

    #Stage 6
    x = AveragePooling2D(pool_size=(7,7)) (x)

    x = Flatten()(x)
    x = Dense(units=1000, activation='softmax')(x)

    model = Model(inputs=input_layer , outputs = x , name='ResNet50')
    return model
```

2. PyTorch :

```python
import torch
import torch.nn as nn

class convolution2D(nn.Module):
  def __init__(self , in_channels , out_channels , kernel_size , stride , padding , activation
    super(convolution2D , self).__init__()
    self.conv = nn.Conv2d(in_channels , out_channels , kernel_size , stride , padding)
    self.batchNornalization = nn.BatchNorm2d(num_features=out_channels)
    self.activation = nn.ReLU()
    self.act = activation

  def forward(self , x):
    out = self.conv(x)
    out = self.batchNornalization(out)
    if self.act :
      out = self.activation(out)
    return out

class conv_Block(nn.Module):
  def __init__(self , in_channels , filters , stride):
    super(conv_Block , self).__init__()
    f1 , f2 , f3 = filters

    self.branch1 = nn.Sequential(
        convolution2D(in_channels , f1 , 1 , stride , 0 , True),
        convolution2D(f1 , f2 , 3 , 1 , 1, True),
        convolution2D(f2 , f3 , 1 , 1 , 0, False)
    )

    self.branch2 = convolution2D(in_channels , f3 , 1 , stride , 0, False)

    self.activation = nn.ReLU()

  def forward(self , x):

    branch1 = self.branch1(x)

    branch2 = self.branch2(x)

    out = torch.cat([branch1 , branch2] , 1)

    return self.activation(out)

class identity_Block(nn.Module):
  def __init__(self , in_channels , filters ):
    super(identity_Block , self).__init__()

    f1 , f2 , f3 = filters
    self.branch1 = nn.Sequential(
        convolution2D(in_channels , f1 , 1 , 1 , 0 , True),
        convolution2D(f1 , f2 , 3 , 1 , 1, True),
        convolution2D(f2 , f3 , 1 , 1 , 0, False)
```

```
        )

        self.activation = nn.ReLU()

    def forward(self , x):

        branch1 = self.branch1(x)

        branch2 = x

        out = torch.cat([branch1 , branch2] , 1)

        return self.activation(out)

class ResNet_50(nn.Module):
    def __init__(self):
        super(ResNet_50 , self).__init__()

        self.conv1 = convolution2D(in_channels = 3 , out_channels = 64, kernel_size = 7 , stride =
        self.MaxPooling1 = nn.MaxPool2d(kernel_size=3 , stride = 2)

        self.ConvBlock1 = conv_Block(64 , [64, 64,256] , 1)
        self.IdentityBlock1 = identity_Block(512 , [64,64,256])
        self.IdentityBlock2 = identity_Block(768 , [64,64,256])
        self.ConvBlock2 = conv_Block(1024 , [128, 128,512] , 2)
        self.IdentityBlock3 = identity_Block(1024 , [128,128,512])
        self.IdentityBlock4 = identity_Block(1536 , [128,128,512])
        self.IdentityBlock5 = identity_Block(2048 , [128,128,512])
        self.ConvBlock3 = conv_Block(2560 , [256, 256,1024] , 2)
        self.IdentityBlock6 = identity_Block(2048 , [256, 256,1024])
        self.IdentityBlock7 = identity_Block(3072 , [256, 256,1024])
        self.IdentityBlock8 = identity_Block(4096 , [256, 256,1024])
        self.IdentityBlock9 = identity_Block(5120 , [256, 256,1024])
        self.IdentityBlock10 = identity_Block(6144 , [256, 256,1024])
        self.ConvBlock4 = conv_Block(7168 , [512, 512,2048] , 2)
        self.IdentityBlock11 = identity_Block(4096 , [512, 512,2048])
        self.IdentityBlock12 = identity_Block(6144 , [512, 512,2048])
        self.globalAvgPooling = nn.Conv2d(in_channels=8192 , out_channels=8192 , kernel_size=7)
        self.fc = nn.Linear(in_features=8192 , out_features=1000)
        self.activation = nn.Softmax()

    def forward(self , x):

        out = self.conv1(x)
        out = self.MaxPooling1(out)

        out = self.ConvBlock1(out)

        out = self.IdentityBlock1(out)
        out = self.IdentityBlock2(out)

        out = self.ConvBlock2(out)

        out = self.IdentityBlock3(out)
        out = self.IdentityBlock4(out)
```

```
        out = self.IdentityBlock5(out)

        out = self.ConvBlock3(out)

        out = self.IdentityBlock6(out)
        out = self.IdentityBlock7(out)
        out = self.IdentityBlock8(out)
        out = self.IdentityBlock9(out)
        out = self.IdentityBlock10(out)

        out = self.ConvBlock4(out)

        out = self.IdentityBlock11(out)
        out = self.IdentityBlock12(out)

        out = self.globalAvgPooling(out)

        out = out.reshape(out.shape[0] , -1)

        out = self.fc(out)
        out = self.activation(out)

        return out
```

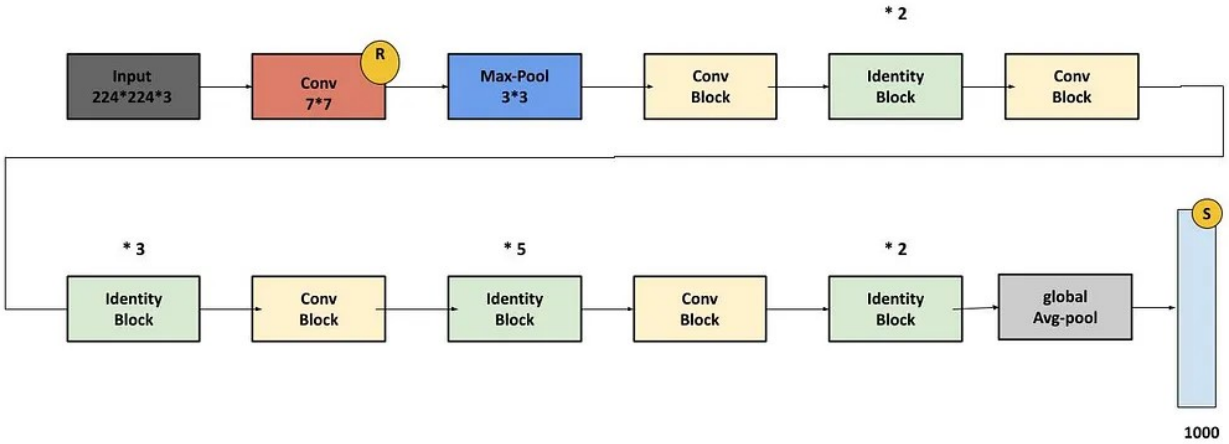
ResNeXt-50 :

Paper : Aggregated Residual Transformations for Deep Neural Networks.

Authors : Saining Xie, Ross Girshick, Piotr Dollár, Zhuowen Tu, Kaiming He. University of California San Diego, Facebook Research .

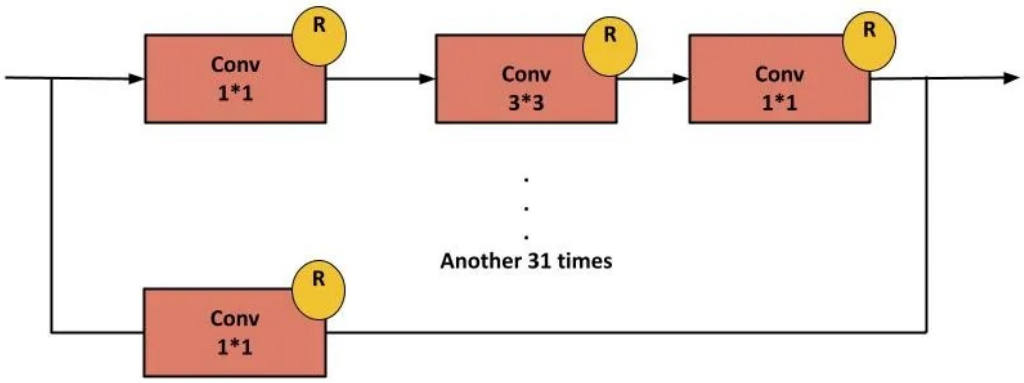
Published in : 2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR) .

The Main Architecture :



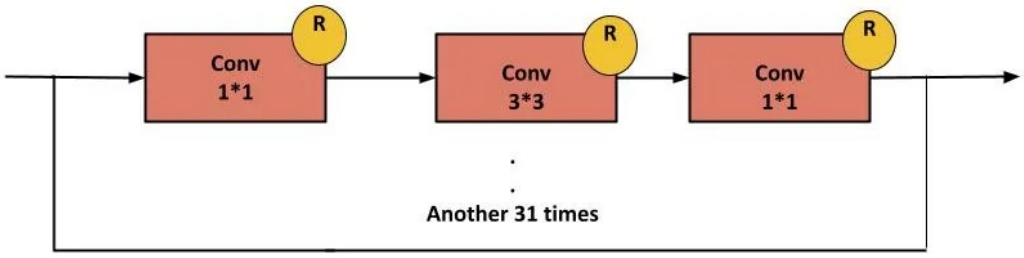
ResNeXt-50

Conv Block :



Conv Block

Identity Block :



identity Block

Implementation :

1. Keras :

```
from keras.models import Model
from keras.layers import Conv2D , MaxPool2D , ZeroPadding2D, Input ,AveragePooling2D, Dense , D
from keras.layers import Add

def IdentityBlock(prev_Layer , filters):

    f1 , f2 ,f3 = filters
    block = []

    for i in range(32):
        x = Conv2D(filters=f1, kernel_size = (1,1) , strides=(1,1), padding='valid')(prev_Layer
        x = BatchNormalization(axis=3)(x)
        x = Activation(activation='relu')(x)

        x = Conv2D(filters=f2, kernel_size = (3,3) , strides=(1,1), padding='same')(x)
        x = BatchNormalization(axis=3)(x)
        x = Activation(activation='relu')(x)

        x = Conv2D(filters=f3, kernel_size = (1,1) , strides=(1,1), padding='valid')(x)
        x = BatchNormalization(axis=3)(x)
        x = Activation(activation='relu')(x)
        block.append(x)

    block.append(prev_Layer)
    x = Add()(block)
    x = Activation(activation='relu')(x)

    return x


def ConvBlock(prev_Layer , filters , strides):
    f1 , f2 , f3 = filters

    block = []

    for i in range(32):
        x = Conv2D(filters=f1, kernel_size = (1,1) ,padding='valid', strides=strides)(prev_Laye
        x = BatchNormalization(axis=3)(x)
        x = Activation(activation='relu')(x)

        x = Conv2D(filters=f2, kernel_size = (3,3) , padding='same' , strides=(1 ,1))(x)
        x = BatchNormalization(axis=3)(x)
        x = Activation(activation='relu')(x)

        x = Conv2D(filters=f3, kernel_size = (1,1), padding='valid' , strides=(1 ,1))(x)
        x = BatchNormalization(axis=3)(x)
        x = Activation(activation='relu')(x)
        block.append(x)

    x2 = Conv2D(filters=f3, kernel_size=(1,1), padding='valid' , strides=strides)(prev_Layer)
    x2 = BatchNormalization(axis=3)(x2)

    block.append(x2)
```

```
    block.append(x2)
    x = Add()(block)
    x = Activation(activation='relu')(x)
    return x


def ResNext():
    input_layer = Input(shape = (224, 224, 3))
    #Stage 1
    x = ZeroPadding2D((3, 3))(input_layer)
    x = Conv2D(filters = 64, kernel_size = (7,7), strides=(2,2)) (x)
    x = BatchNormalization(axis=3)(x)
    x = Activation(activation='relu')(x)
    x = MaxPool2D(pool_size=(3,3) , strides=(2,2))(x)

    #Stage 2
    x = ConvBlock(prev_Layer=x, filters = [128 , 128 , 256], strides = 1)
    x = IdentityBlock(prev_Layer=x, filters = [128 , 128 , 256])
    x = IdentityBlock(prev_Layer=x, filters = [128 , 128 , 256])

    #Stage 3
    x = ConvBlock(prev_Layer=x, filters = [256 , 256 , 512], strides = 2)
    x = IdentityBlock(prev_Layer=x, filters = [256 , 256 , 512])
    x = IdentityBlock(prev_Layer=x, filters = [256 , 256 , 512])
    x = IdentityBlock(prev_Layer=x, filters = [256 , 256 , 512])

    #Stage 4
    x = ConvBlock(prev_Layer=x, filters = [512 , 512 , 1024], strides = 2)
    x = IdentityBlock(prev_Layer=x, filters = [512 , 512 , 1024])
    x = IdentityBlock(prev_Layer=x, filters = [512 , 512 , 1024])
    x = IdentityBlock(prev_Layer=x, filters = [512 , 512 , 1024])
    x = IdentityBlock(prev_Layer=x, filters = [512 , 512 , 1024])
    x = IdentityBlock(prev_Layer=x, filters = [512 , 512 , 1024])

    #Stage 5
    x = ConvBlock(prev_Layer=x, filters = [1024 , 1024 , 2048], strides = 2)
    x = IdentityBlock(prev_Layer=x, filters = [1024 , 1024 , 2048])
    x = IdentityBlock(prev_Layer=x, filters = [1024 , 1024 , 2048])

    #Stage 6
    x = AveragePooling2D(pool_size=(7,7)) (x)

    x = Flatten()(x)
    x = Dense(units=1000, activation='softmax')(x)

    model = Model(inputs=input_layer , outputs = x , name='ResNet50')
    return model
```

2. PyTorch :

```python
import torch
import torch.nn as nn
from torchsummary import summary

class convolution2D(nn.Module):
  def __init__(self , in_channels , out_channels , kernel_size , stride , padding , activation
    super(convolution2D , self).__init__()
    self.conv = nn.Conv2d(in_channels , out_channels , kernel_size , stride , padding)
    self.batchNornalization = nn.BatchNorm2d(num_features=out_channels)
    self.activation = nn.ReLU()
    self.act = activation

  def forward(self , x):
    out = self.conv(x)
    out = self.batchNornalization(out)
    if self.act :
      out = self.activation(out)
    return out

class Conv_Block(nn.Module):

  def __init__(self , in_channels , filters , stride):
    super(Conv_Block , self).__init__()
    f1 , f2 , f3 = filters

    self.branch1 = nn.Sequential(
        convolution2D(in_channels , f1 , 1 , stride , 0 , True),
        convolution2D(f1 , f2 , 3 , 1 , 1, True),
        convolution2D(f2 , f3 , 1 , 1 , 0, False)
    )

    self.branch2 = convolution2D(in_channels , f3 , 1 , 1 , 0, False)
    self.activation = nn.ReLU()

  def forward(self,x):

    paths = [self.branch1(x) for i in range(32)]
    paths.append(self.branch2(x))

    out = torch.cat(paths , 1)
    return self.activation(out)

class Identity_Block(nn.Module):

  def __init__(self , in_channels , filters):
    super(Identity_Block , self).__init__()
    f1 , f2 , f3 = filters

    self.branch1 = nn.Sequential(
        convolution2D(in_channels , f1 , 1 , 1 , 0 , True),
        convolution2D(f1 , f2 , 3 , 1 , 1, True),
        convolution2D(f2 , f3 , 1 , 1 , 0, False)
```

```
        )
        self.activation = nn.ReLU()
    def forward(self , x):
        paths = [self.branch1(x) for i in range(32)]
        paths.append(x)

        out = torch.cat(paths , 1)
        return self.activation(out)

class ResNext_50(nn.Module):

    def __init__(self):
        super(ResNext_50,self).__init__()
        self.conv1 = convolution2D(in_channels = 3 , out_channels = 64, kernel_size = 7 , stride =
        self.MaxPooling1 = nn.MaxPool2d(kernel_size=3 , stride = 2)

        self.convBlock1 = Conv_Block(64 , [128 , 128 , 256] , 1)
        self.IdentityBlock1 = Identity_Block(8448 , [128 , 128 , 256])
        self.IdentityBlock2 = Identity_Block(16640 , [128 , 128 , 256])
        self.convBlock2 = Conv_Block(16896 , [256 , 256 , 512] , 2)
        self.IdentityBlock3 = Identity_Block(33280 , [256 , 256 , 512])
        self.IdentityBlock4 = Identity_Block(49664 , [256 , 256 , 512])
        self.IdentityBlock5 = Identity_Block(66048 , [256 , 256 , 512])
        self.convBlock3 = Conv_Block(33792 , [512 , 512 , 1024] , 2)
        self.IdentityBlock6 = Identity_Block(66560 , [512 , 512 , 1024])
        self.IdentityBlock7 = Identity_Block(99328 , [512 , 512 , 1024])
        self.IdentityBlock8 = Identity_Block(132096 , [512 , 512 , 1024])
        self.IdentityBlock9 = Identity_Block(164864, [512 , 512 , 1024])
        self.IdentityBlock10 = Identity_Block(197632 , [512 , 512 , 1024])
        self.convBlock4 = Conv_Block(67584 , [1024 , 1024 , 2048] , 2)
        self.IdentityBlock11 = Identity_Block(133120, [1024 , 1024 , 2048])
        self.IdentityBlock12 = Identity_Block(192656, [1024 , 1024 , 2048])
        self.globalAvgPooling = nn.Conv2d(in_channels=8192 , out_channels=8192 , kernel_size=7)
        self.fc = nn.Linear(in_features=192656 , out_features=1000)
        self.activation = nn.Softmax()
    def forward(self , x):
        out = self.conv1(x)
        out = self.MaxPooling1(out)

        out = self.convBlock1(out)

        out = self.IdentityBlock1(out)
        out = self.IdentityBlock2(out)

        out = self.convBlock2(out)

        out = self.IdentityBlock3(out)
        out = self.IdentityBlock4(out)
        out = self.IdentityBlock5(out)

        out = self.convBlock3(out)

        out = self.IdentityBlock6(out)
        out = self.IdentityBlock7(out)
        out = self.IdentityBlock8(out)
```

```
        out = self.IdentityBlock9(out)
        out = self.IdentityBlock10(out)

        out = self.convBlock4(out)

        out = self.IdentityBlock11(out)
        out = self.IdentityBlock12(out)

        out = self.globalAvgPooling(out)

        out = out.reshape(out.shape[0] , -1)

        out = self.fc(out)
        out = self.activation(out)
        return out
```

References :

- If you want to see other Architectures implemented in both PyTorch and Keras you can check this repo and you can also find high quality images (svg format) of the above illustrations.

- Residual neural network by wikipedia .
- PyTorch documentation .
- Keras documentation .

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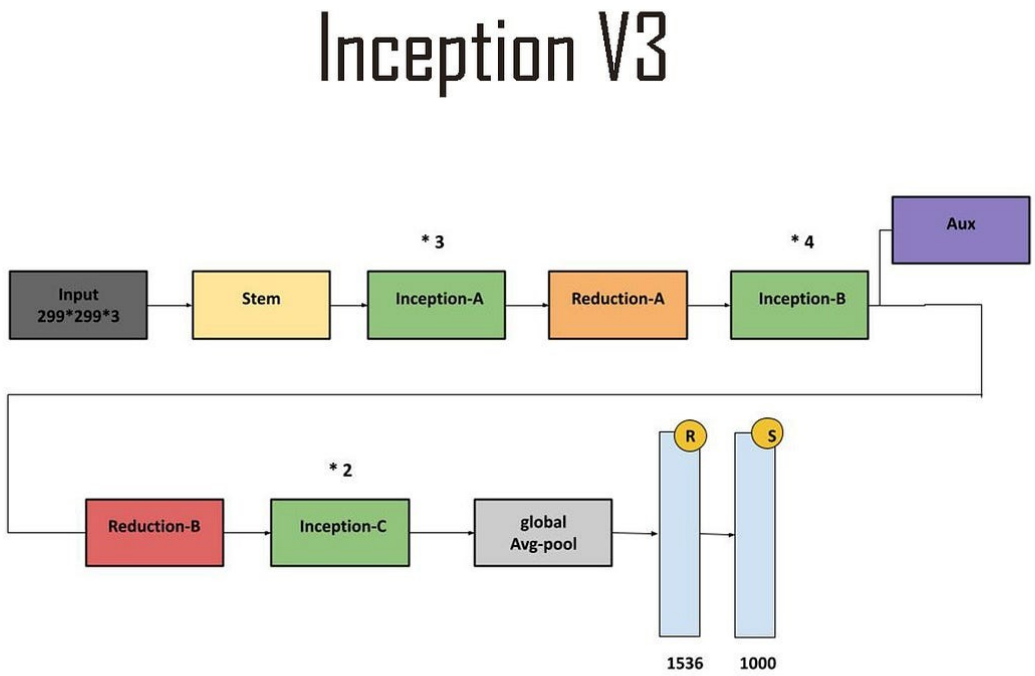

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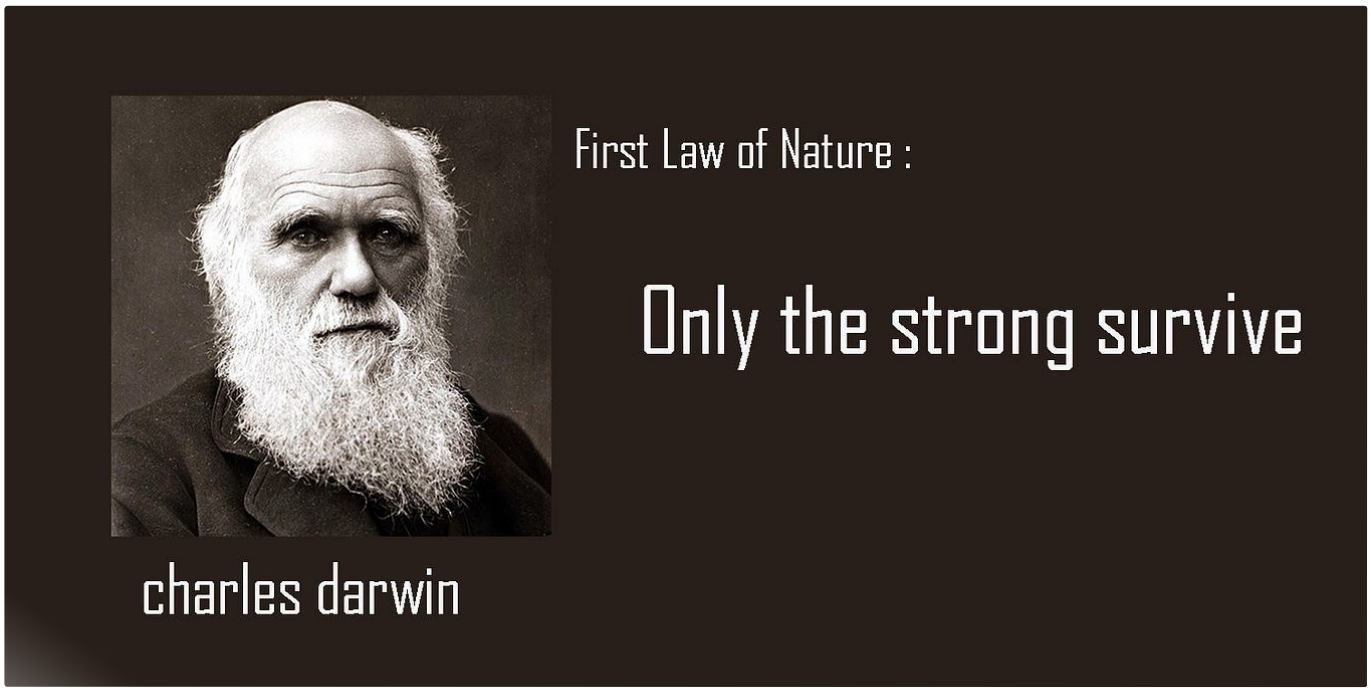

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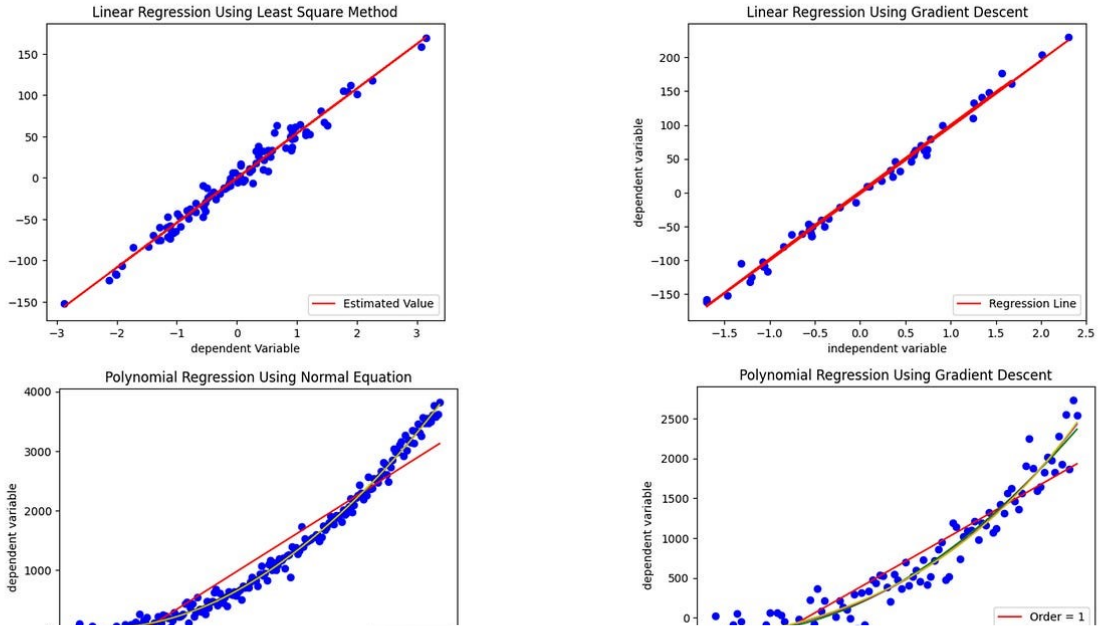

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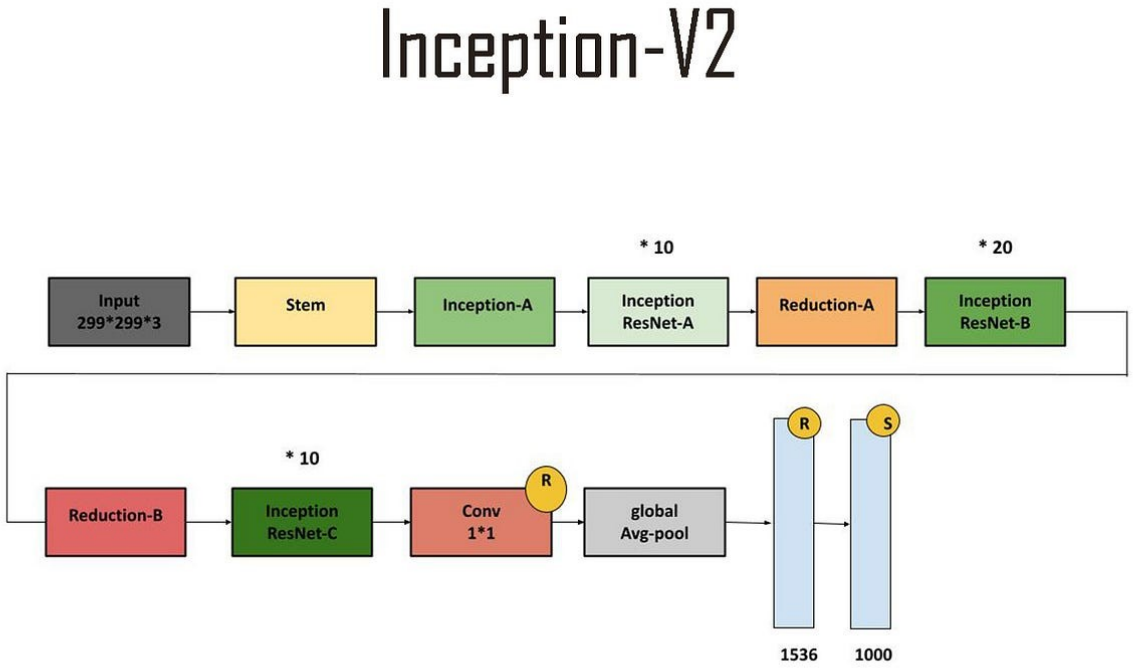

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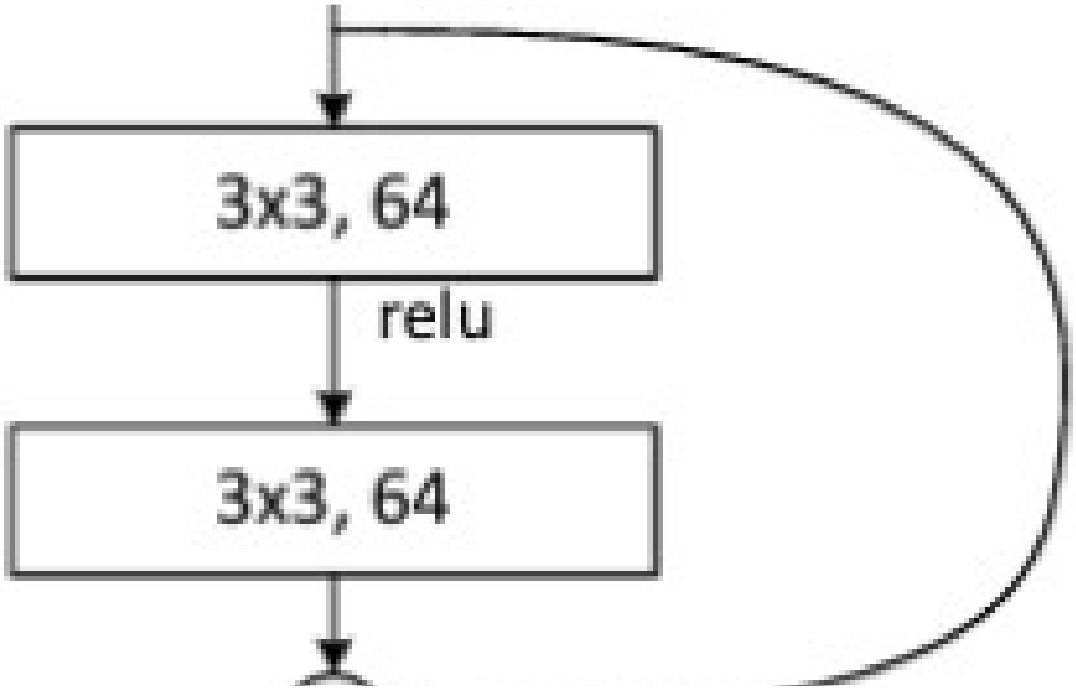

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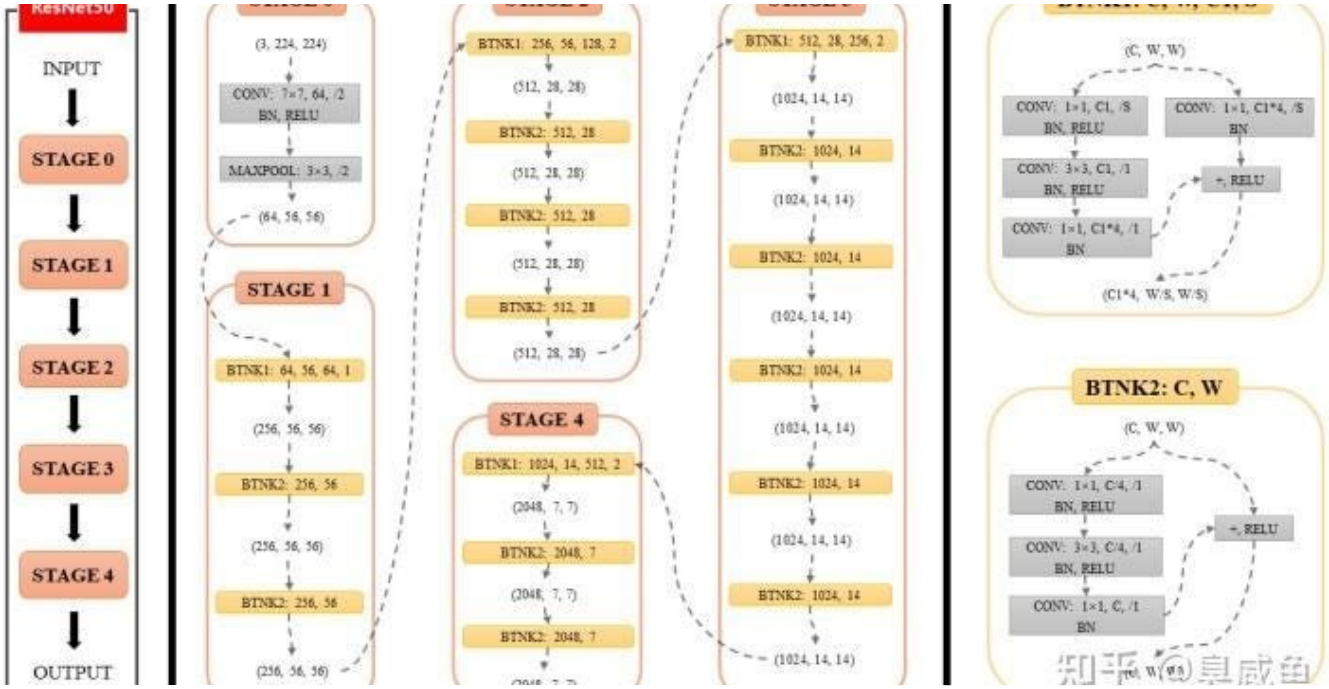

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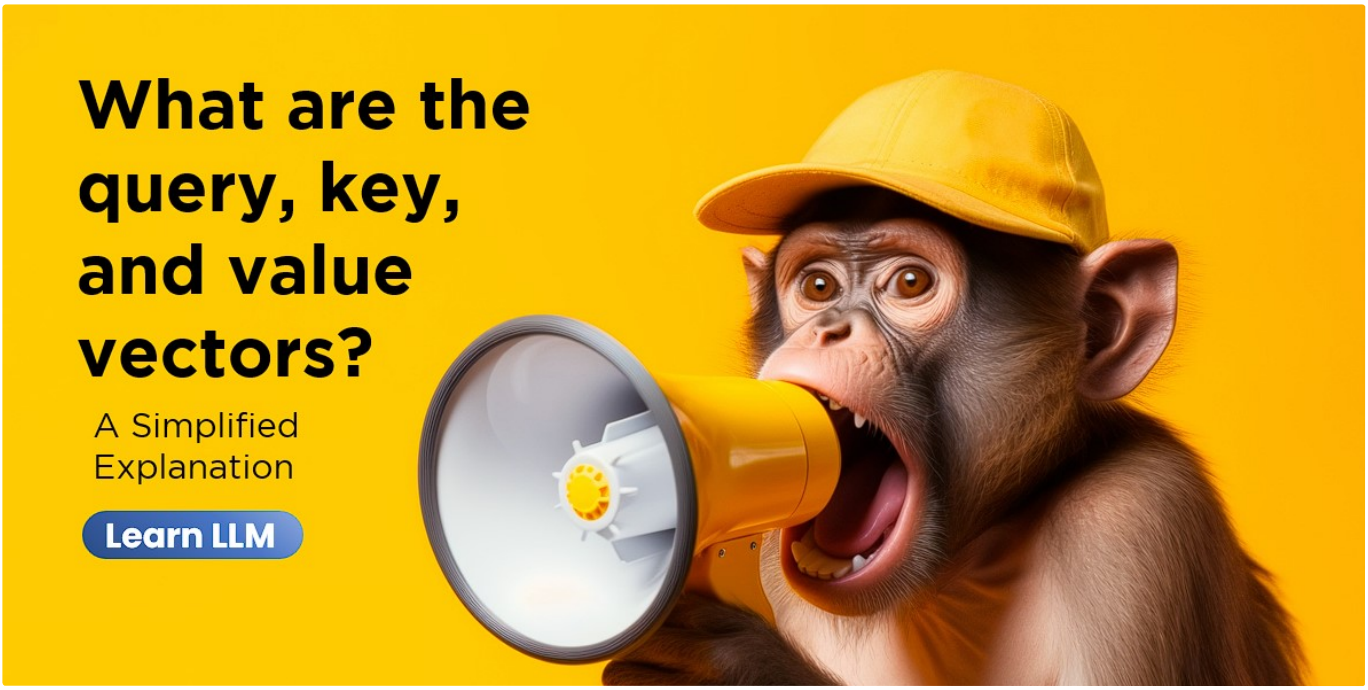

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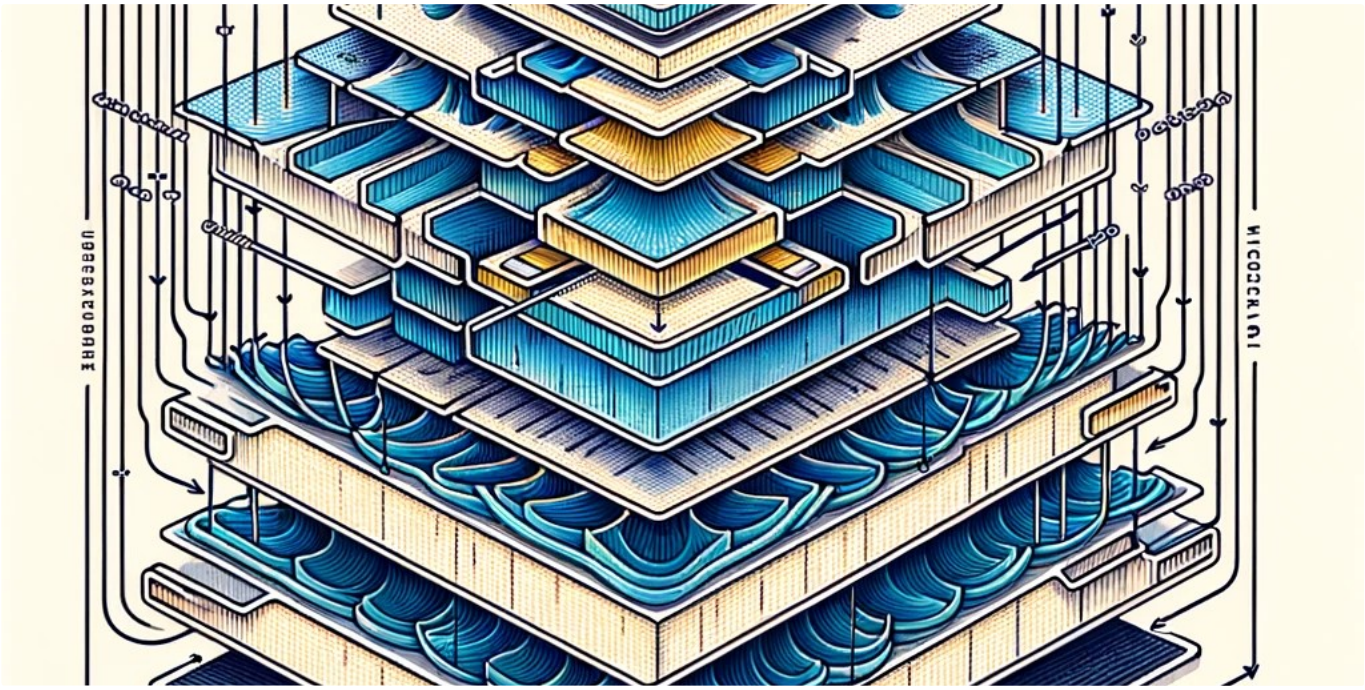

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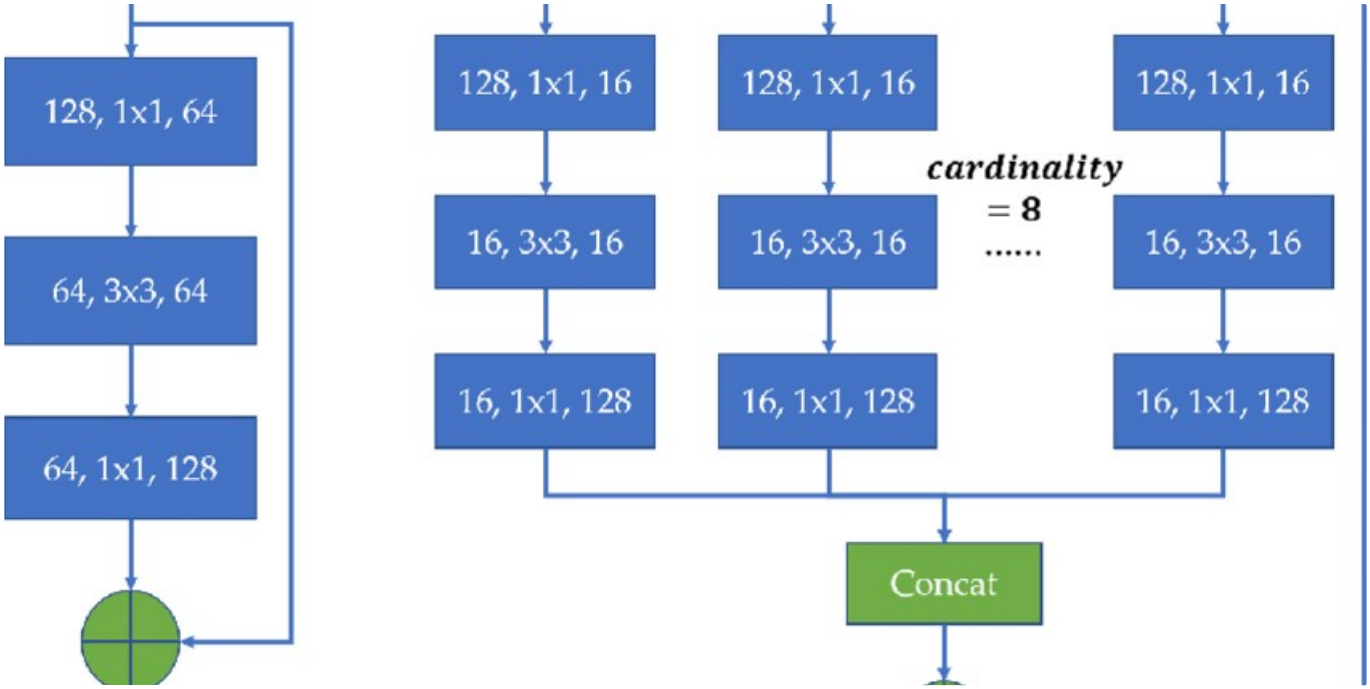

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