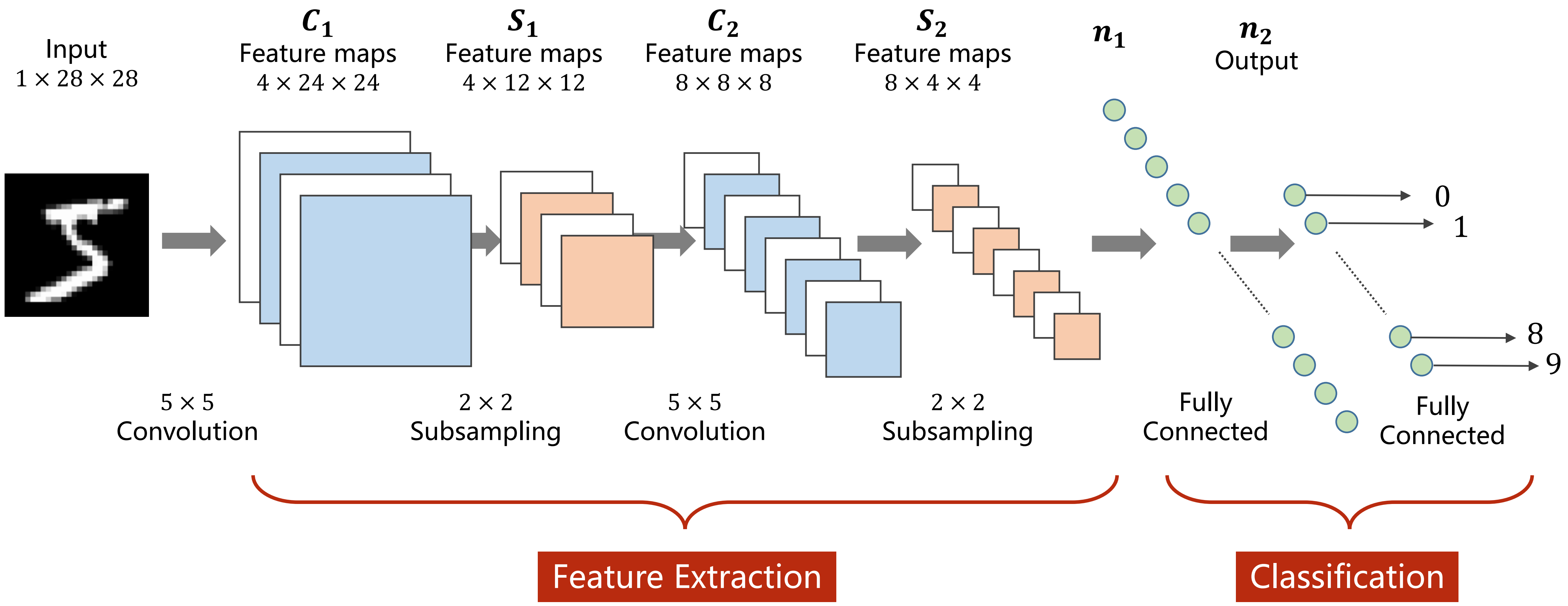
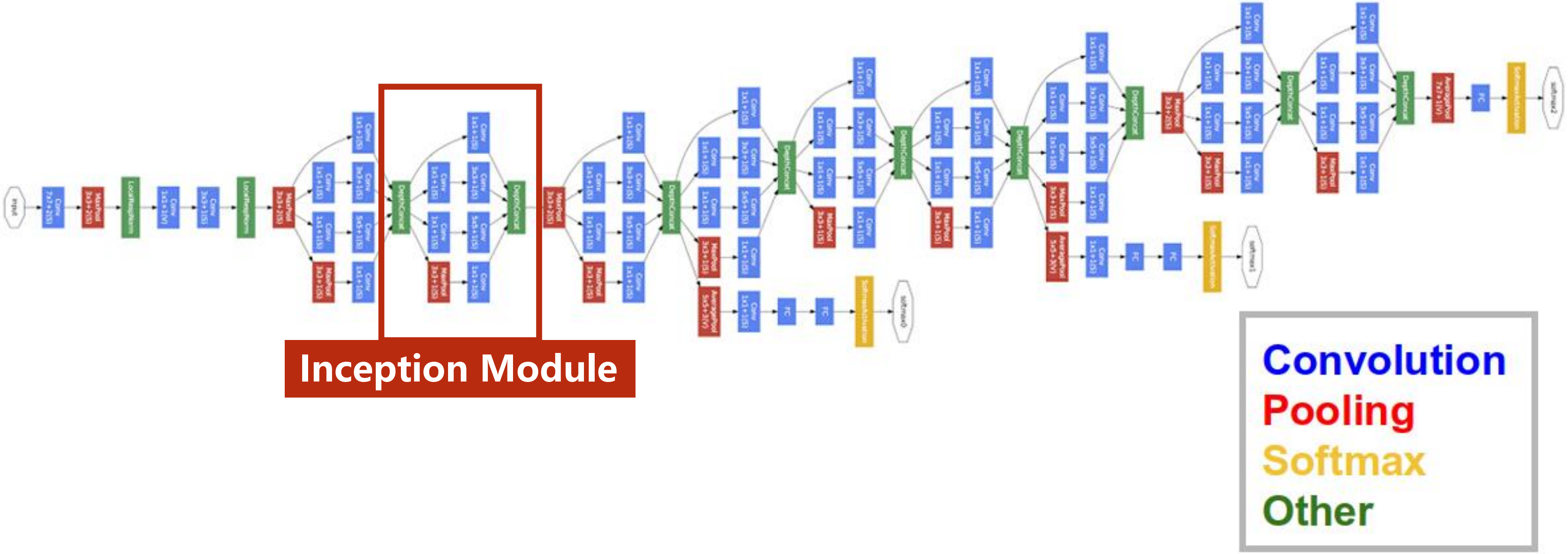
PyTorch Tutorial

11. Advanced CNN

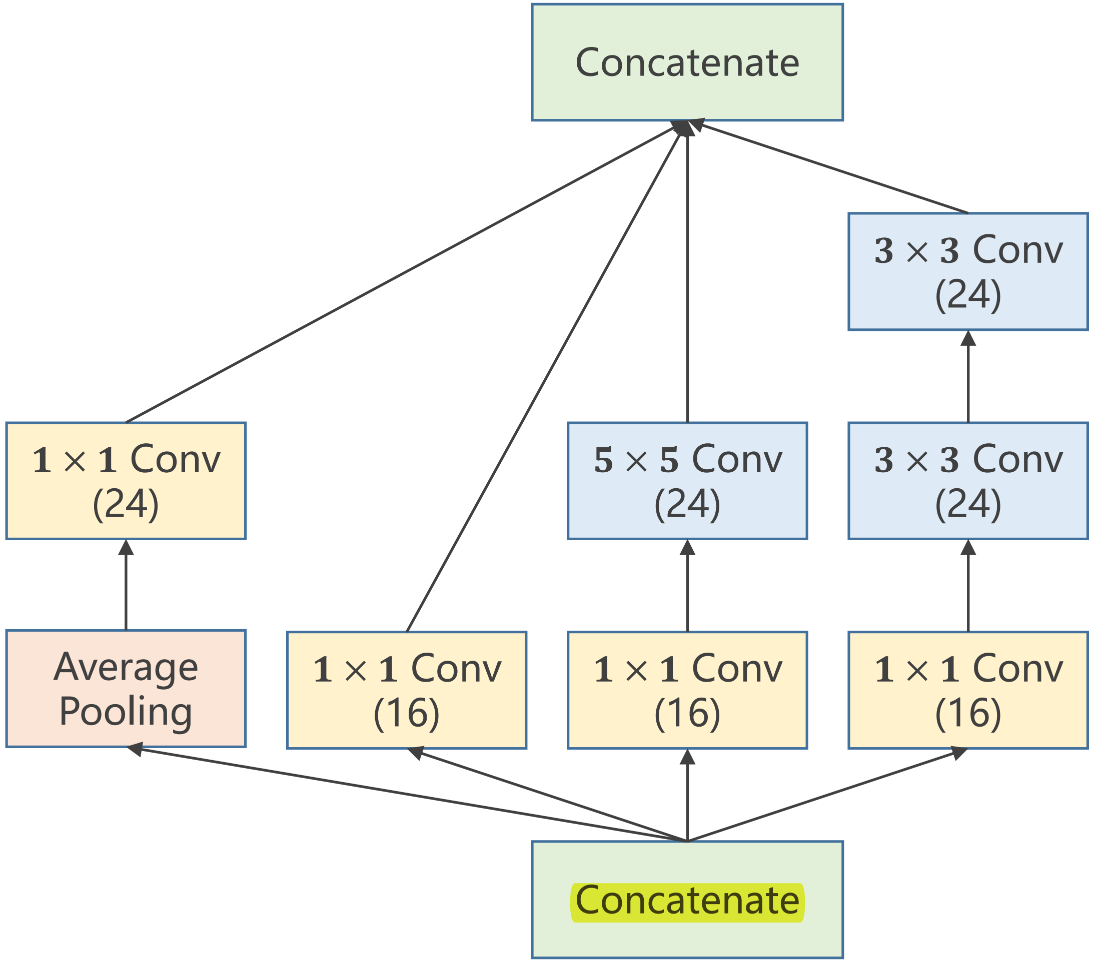
Revision

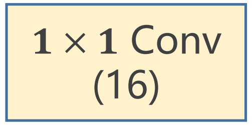


Input
$1 \times 28 \times 28$
C_1
Feature maps
$4 \times 24 \times 24$
S_1
Feature maps
$4 \times 12 \times 12$
C_2
Feature maps
$8 \times 8 \times 8$
S_2
Feature maps
$8 \times 4 \times 4$
n_1
n_2
Output
0
1
8
9
5×5
Convolution
2×2
Subsampling
5×5
Convolution
2×2
Subsampling
Fully
Connected
Fully
Connected
Feature Extraction
Classification


Inception Module
Convolution
Pooling
Softmax
Other

Inception Module





What is 1×1 convolution?

What is 1x1 convolution?

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix} \odot \begin{bmatrix} 0.5 \end{bmatrix} = \begin{bmatrix} 0.5 & 1.0 & 1.5 \\ 2.0 & 2.5 & 3.0 \\ 3.5 & 4.0 & 4.5 \end{bmatrix}$$

What is 1x1 convolution?

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix} \odot \begin{bmatrix} 0.5 \end{bmatrix} = \begin{bmatrix} 0.5 & 1.0 & 1.5 \\ 2.0 & 2.5 & 3.0 \\ 3.5 & 4.0 & 4.5 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 4 & 7 \\ 2 & 5 & 8 \\ 3 & 6 & 9 \end{bmatrix} \odot \begin{bmatrix} 0.3 \end{bmatrix} = \begin{bmatrix} 0.3 & 1.2 & 2.1 \\ 0.6 & 1.5 & 2.4 \\ 0.9 & 1.8 & 2.7 \end{bmatrix}$$

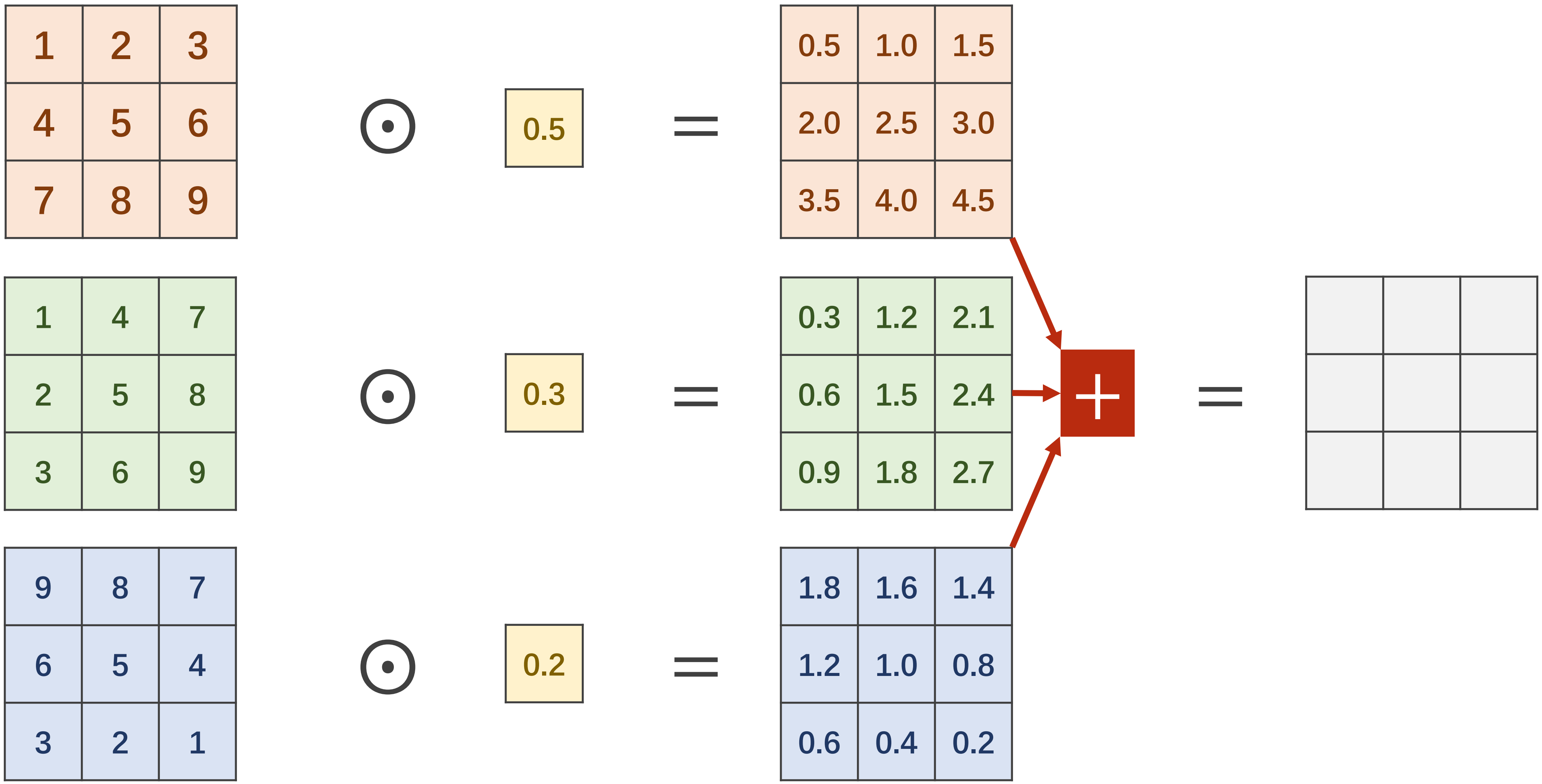
What is 1x1 convolution?

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix} \odot \begin{bmatrix} 0.5 \end{bmatrix} = \begin{bmatrix} 0.5 & 1.0 & 1.5 \\ 2.0 & 2.5 & 3.0 \\ 3.5 & 4.0 & 4.5 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 4 & 7 \\ 2 & 5 & 8 \\ 3 & 6 & 9 \end{bmatrix} \odot \begin{bmatrix} 0.3 \end{bmatrix} = \begin{bmatrix} 0.3 & 1.2 & 2.1 \\ 0.6 & 1.5 & 2.4 \\ 0.9 & 1.8 & 2.7 \end{bmatrix}$$

$$\begin{bmatrix} 9 & 8 & 7 \\ 6 & 5 & 4 \\ 3 & 2 & 1 \end{bmatrix} \odot \begin{bmatrix} 0.2 \end{bmatrix} = \begin{bmatrix} 1.8 & 1.6 & 1.4 \\ 1.2 & 1.0 & 0.8 \\ 0.6 & 0.4 & 0.2 \end{bmatrix}$$

What is 1x1 convolution?



What is 1x1 convolution?

$$\begin{bmatrix}1&2&3\\4&5&6\\7&8&9\end{bmatrix} \odot \begin{bmatrix}0.5\end{bmatrix} = \begin{bmatrix}0.5&1.0&1.5\\2.0&2.5&3.0\\3.5&4.0&4.5\end{bmatrix}$$

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$$\begin{bmatrix}9&8&7\\6&5&4\\3&2&1\end{bmatrix} \odot \begin{bmatrix}0.2\end{bmatrix} = \begin{bmatrix}1.8&1.6&1.4\\1.2&1.0&0.8\\0.6&0.4&0.2\end{bmatrix}$$

$$+ = \begin{bmatrix}2.6&3.8&5.0\\3.8&5.0&6.2\\5.0&6.2&7.4\end{bmatrix}$$

What is 1x1 convolution?

$$\begin{bmatrix}1&2&3\\4&5&6\\7&8&9\end{bmatrix} \odot \boxed{0.5} = \begin{bmatrix}0.5&1.0&1.5\\2.0&2.5&3.0\\3.5&4.0&4.5\end{bmatrix}$$

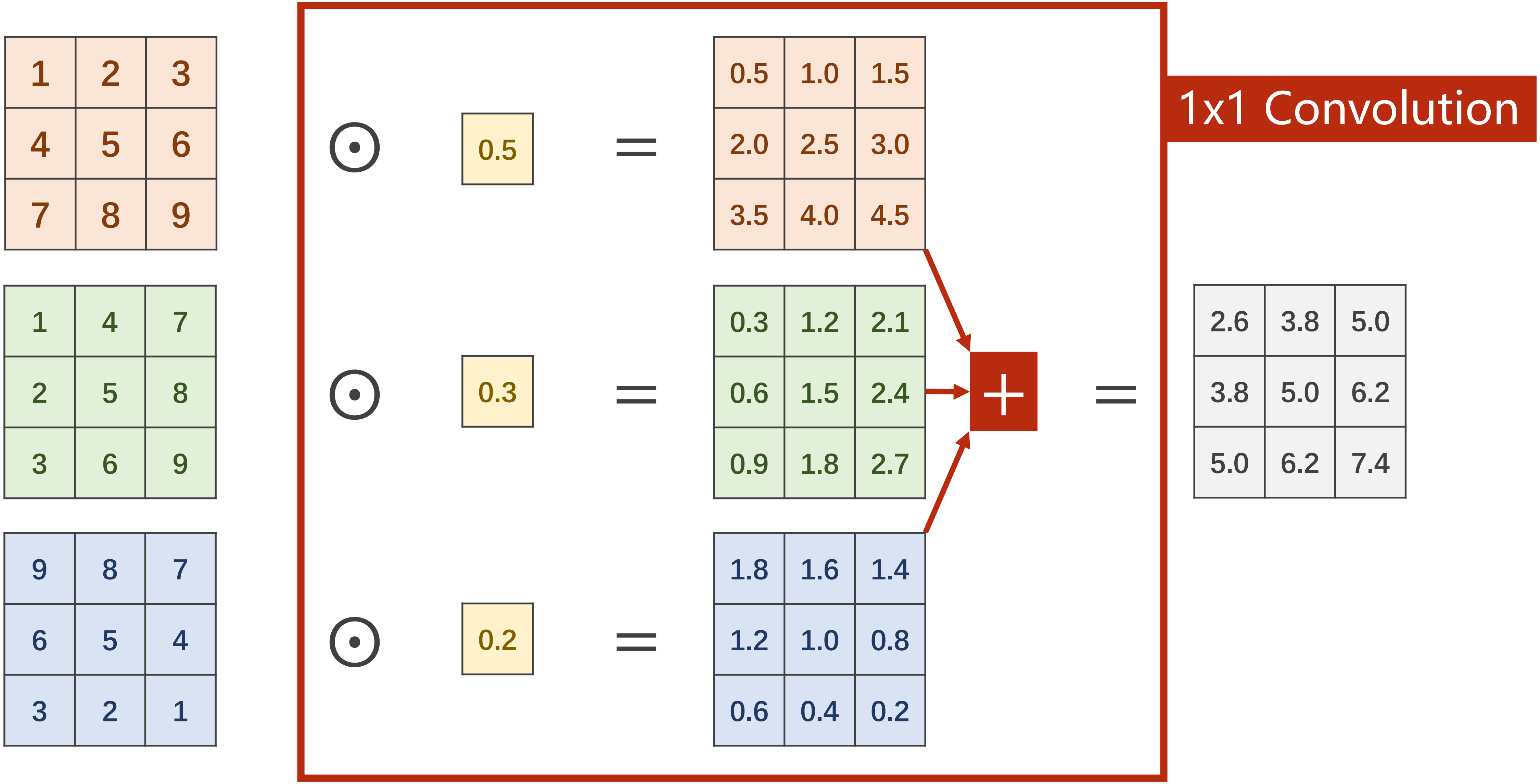
$$\begin{bmatrix}1&4&7\\2&5&8\\3&6&9\end{bmatrix} \odot \boxed{0.3} = \begin{bmatrix}0.3&1.2&2.1\\0.6&1.5&2.4\\0.9&1.8&2.7\end{bmatrix}$$

$$\begin{bmatrix}9&8&7\\6&5&4\\3&2&1\end{bmatrix} \odot \boxed{0.2} = \begin{bmatrix}1.8&1.6&1.4\\1.2&1.0&0.8\\0.6&0.4&0.2\end{bmatrix}$$

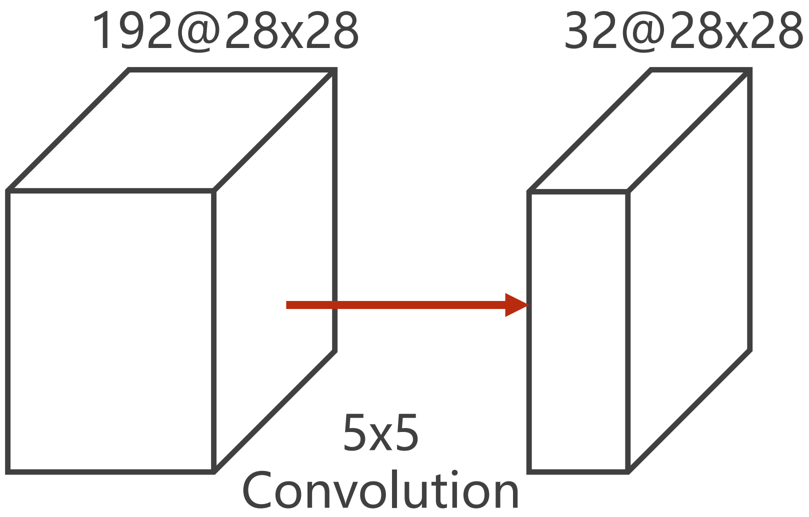
$$+ = \begin{bmatrix}2.6&3.8&5.0\\3.8&5.0&6.2\\5.0&6.2&7.4\end{bmatrix}$$

1x1 Convolution

What is 1x1 convolution?



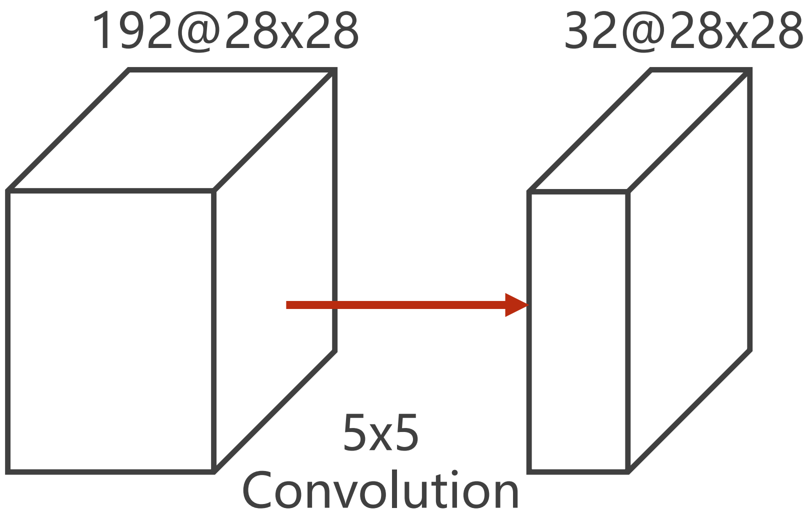
Why is 1x1 convolution?



Operations:

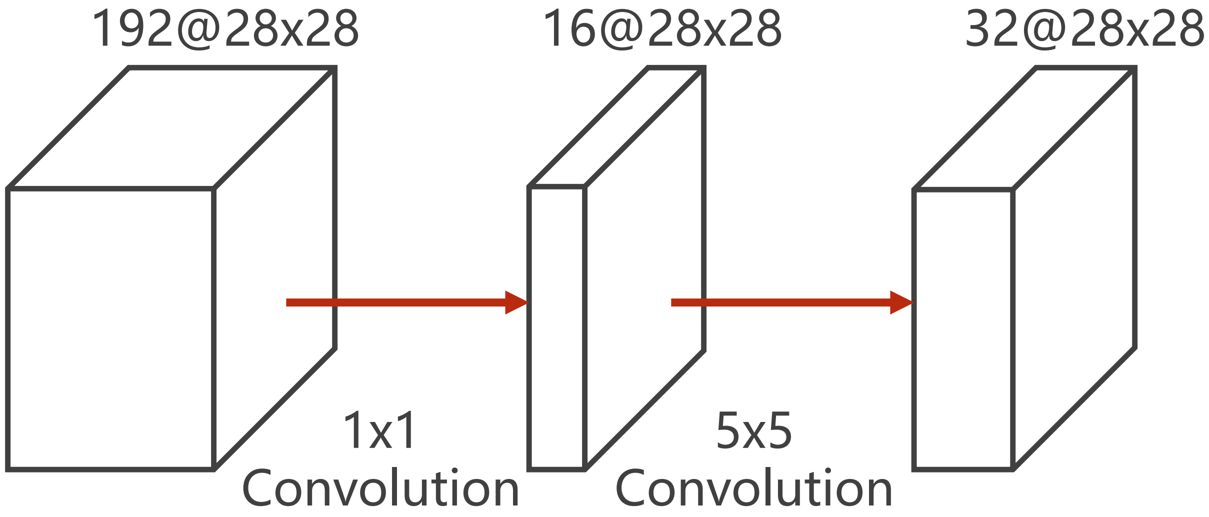
$5^2 \times 28^2 \times 192 \times 32 =$
$120{,}422{,}400$

Why is 1x1 convolution?



Operations:

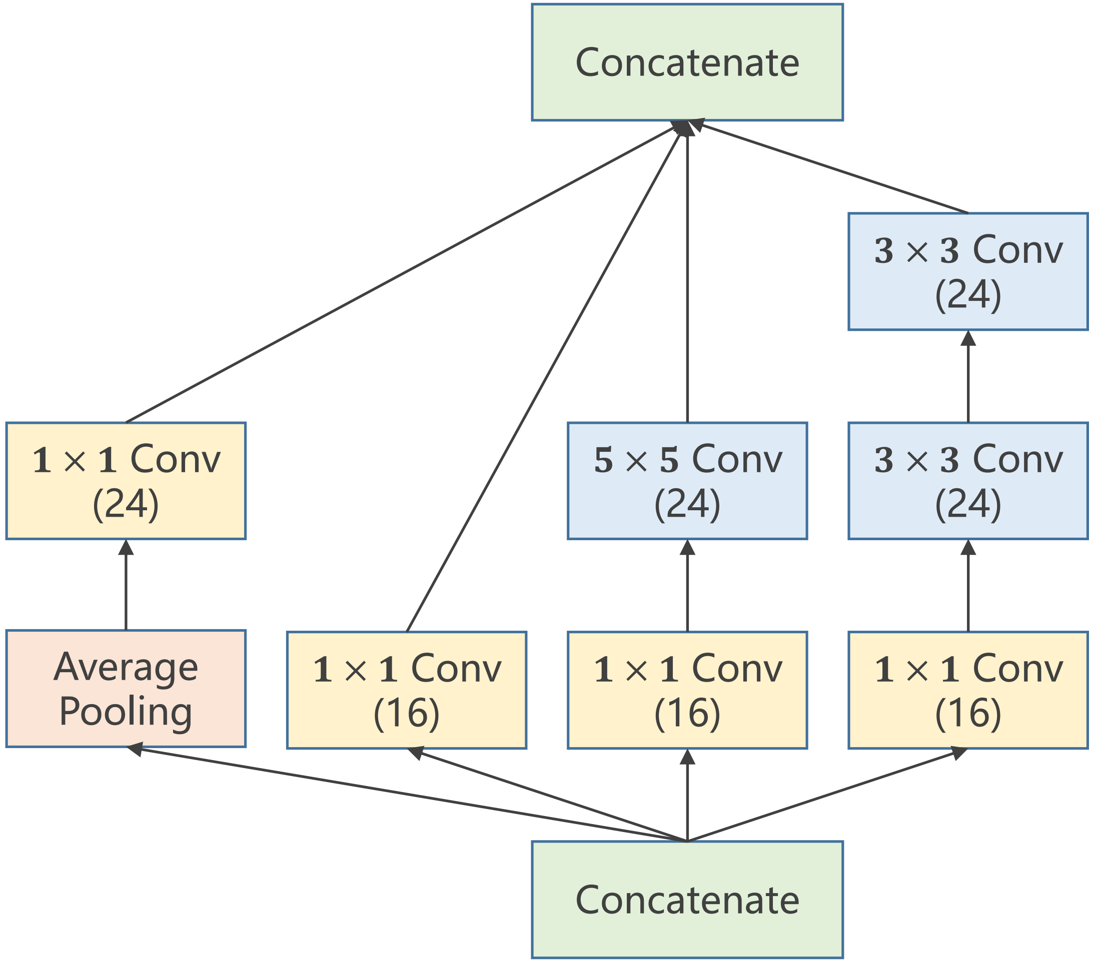
$$5^2 \times 28^2 \times 192 \times 32 = 120{,}422{,}400$$



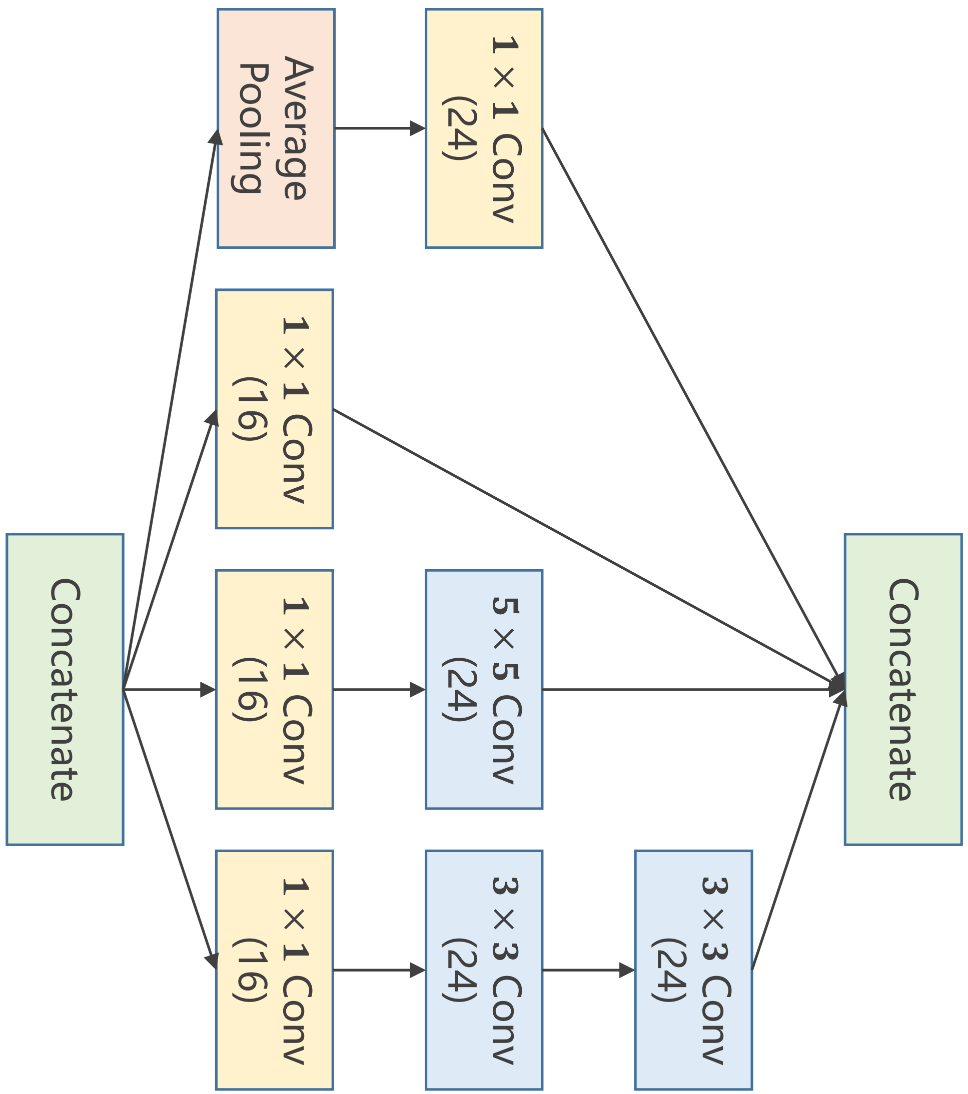
Operations:

$$1^2 \times 28^2 \times 192 \times 16 + 5^2 \times 28^2 \times 16 \times 32 = 12{,}433{,}648$$

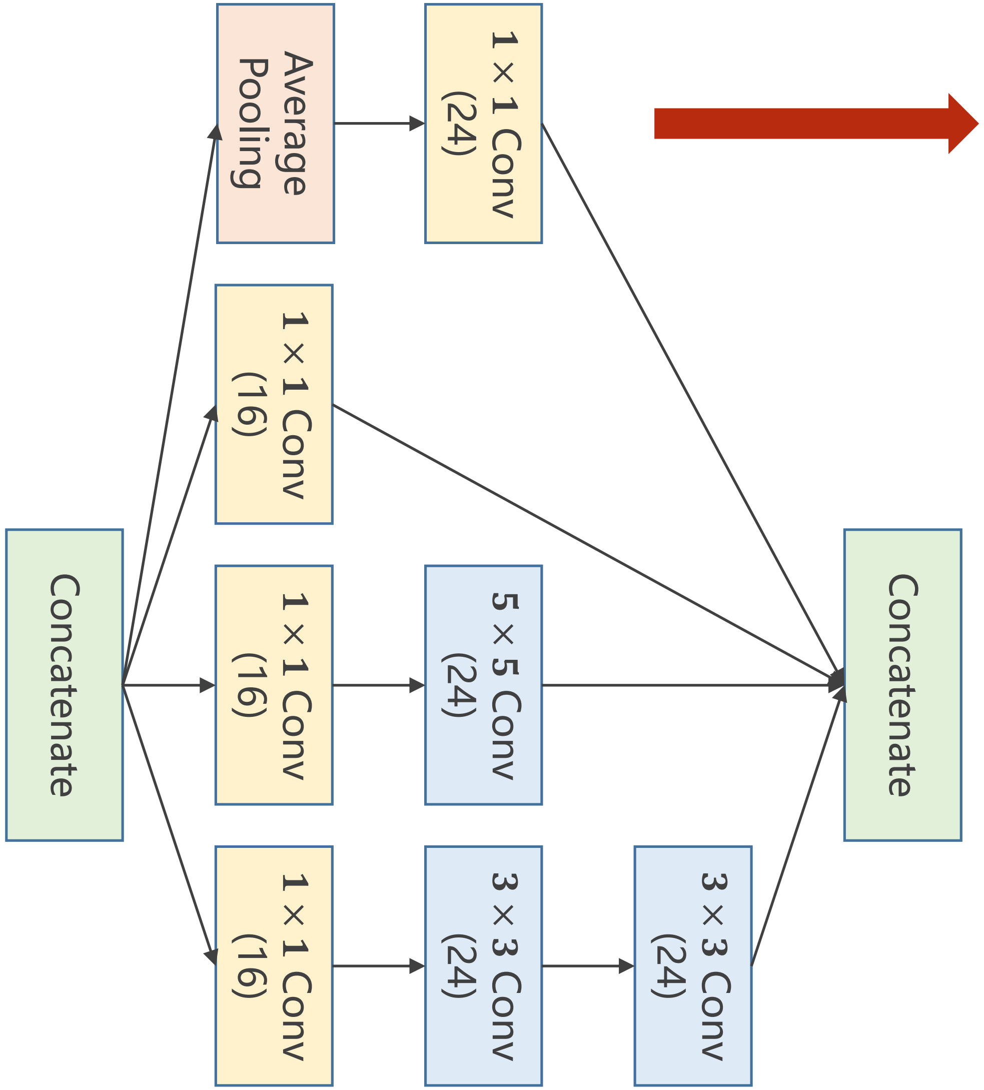
Implementation of Inception Module



Implementation of Inception Module



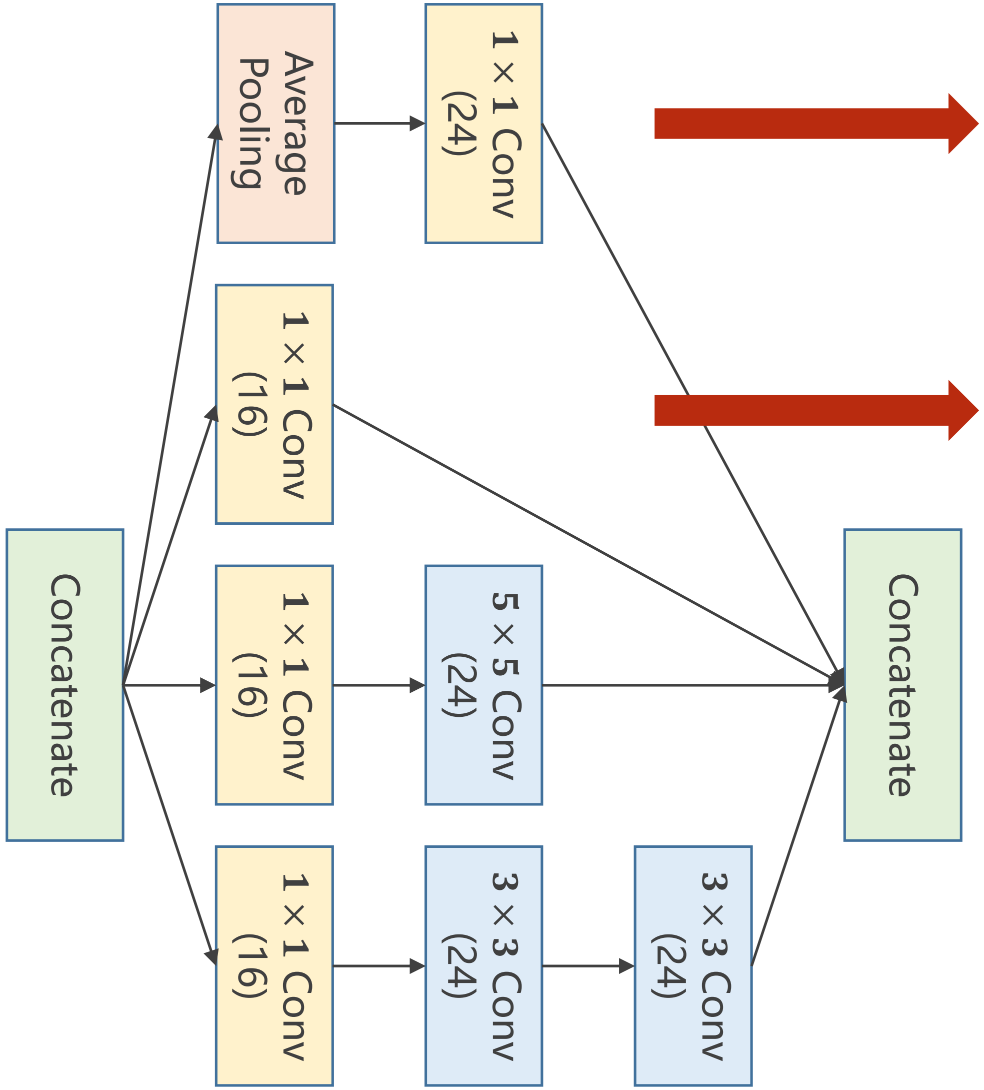
Implementation of Inception Module




```python
self.branch_pool = nn.Conv2d(in_channels, 24, kernel_size=1)

branch_pool = F.avg_pool2d(x, kernel_size=3, stride=1, padding=1)
branch_pool = self.branch_pool(branch_pool)
```

Implementation of Inception Module



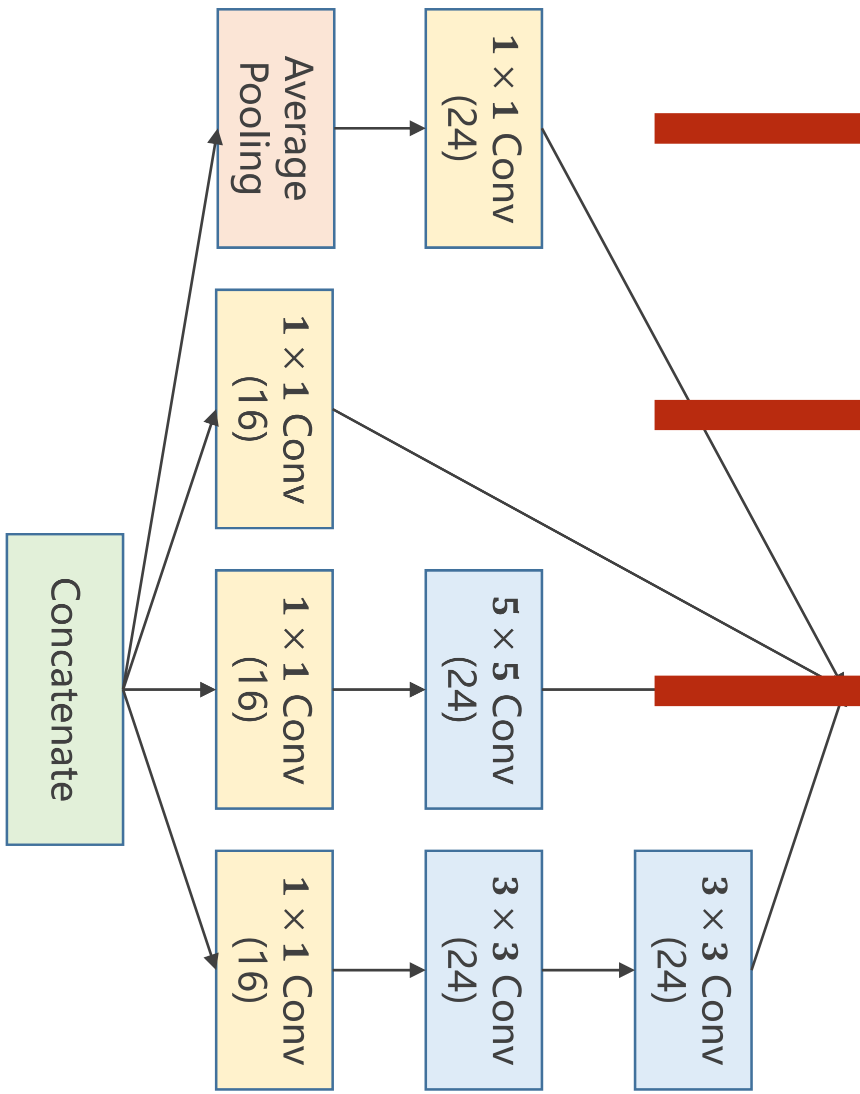

```
self.branch_pool = nn.Conv2d(in_channels, 24, kernel_size=1)

branch_pool = F.avg_pool2d(x, kernel_size=3, stride=1, padding=1)
branch_pool = self.branch_pool(branch_pool)
```

```
self.branch1x1 = nn.Conv2d(in_channels, 16, kernel_size=1)

branch1x1 = self.branch1x1(x)
```

Implementation of Inception Module




```
self.branch_pool = nn.Conv2d(in_channels, 24, kernel_size=1)

branch_pool = F.avg_pool2d(x, kernel_size=3, stride=1, padding=1)
branch_pool = self.branch_pool(branch_pool)
```

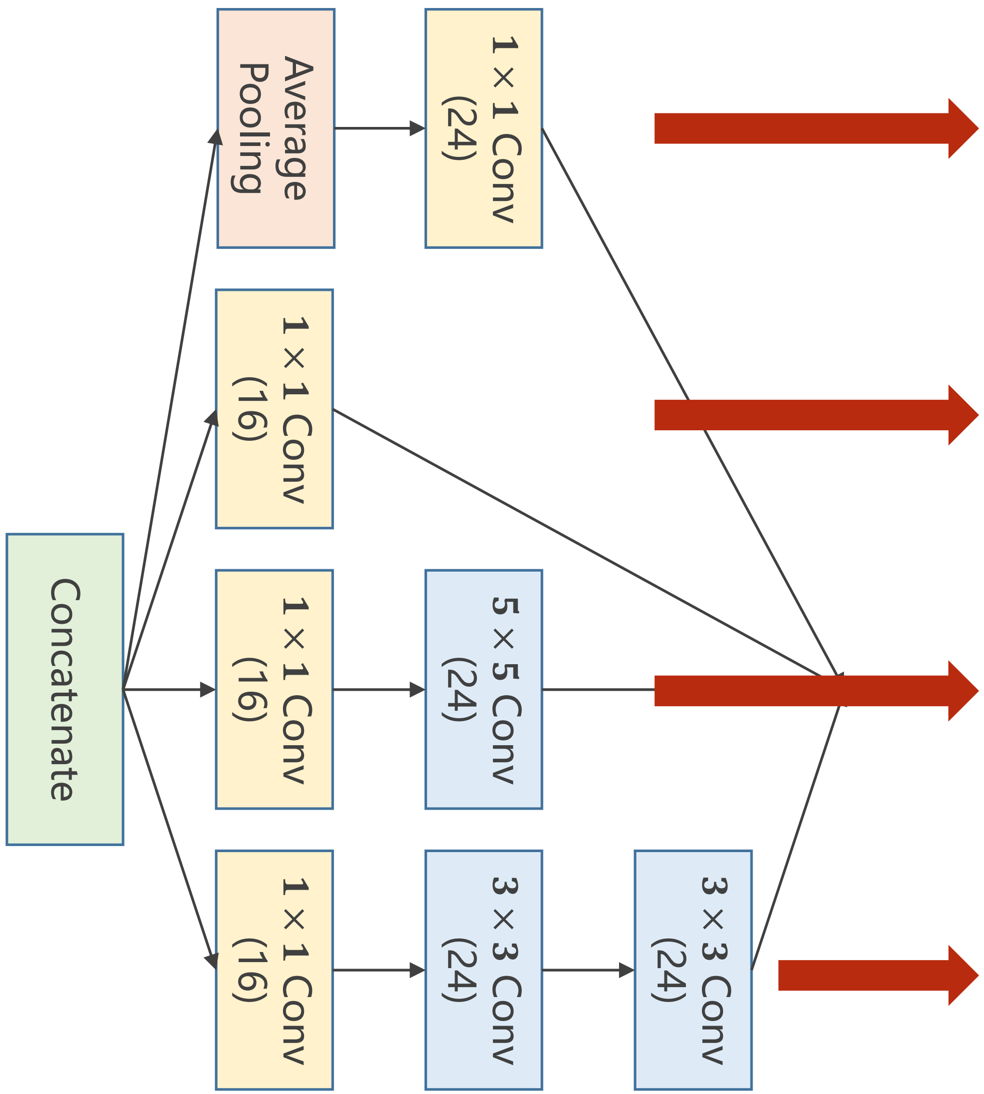
```
self.branch1x1 = nn.Conv2d(in_channels, 16, kernel_size=1)

branch1x1 = self.branch1x1(x)
```

```
self.branch5x5_1 = nn.Conv2d(in_channels,16, kernel_size=1)
self.branch5x5_2 = nn.Conv2d(16, 24, kernel_size=5, padding=2)

branch5x5 = self.branch5x5_1(x)
branch5x5 = self.branch5x5_2(branch5x5)
```

Implementation of Inception Module

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self.branch_pool = nn.Conv2d(in_channels, 24, kernel_size=1)

branch_pool = F.avg_pool2d(x, kernel_size=3, stride=1, padding=1)
branch_pool = self.branch_pool(branch_pool)
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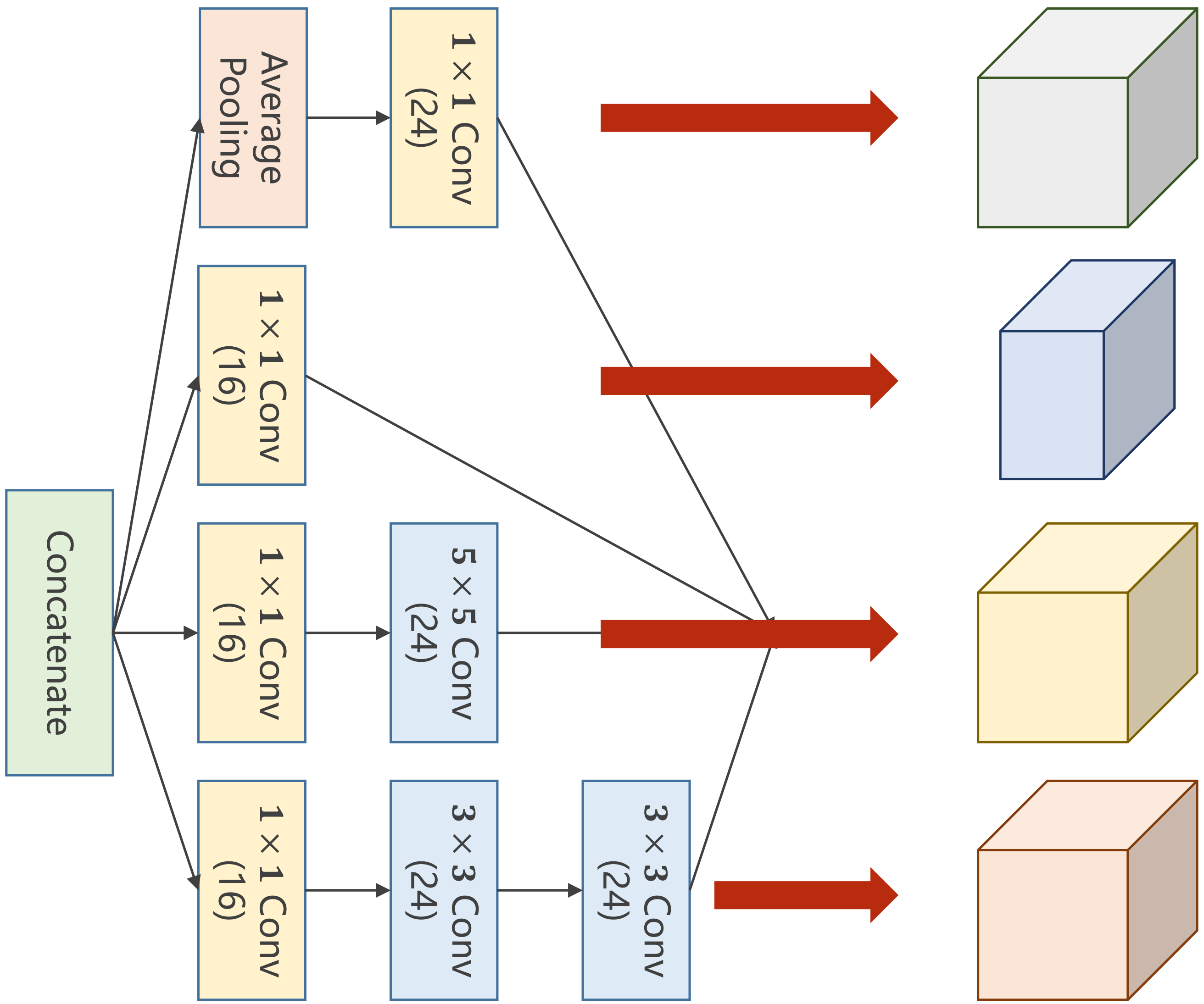
```
self.branch1x1 = nn.Conv2d(in_channels, 16, kernel_size=1)

branch1x1 = self.branch1x1(x)
```

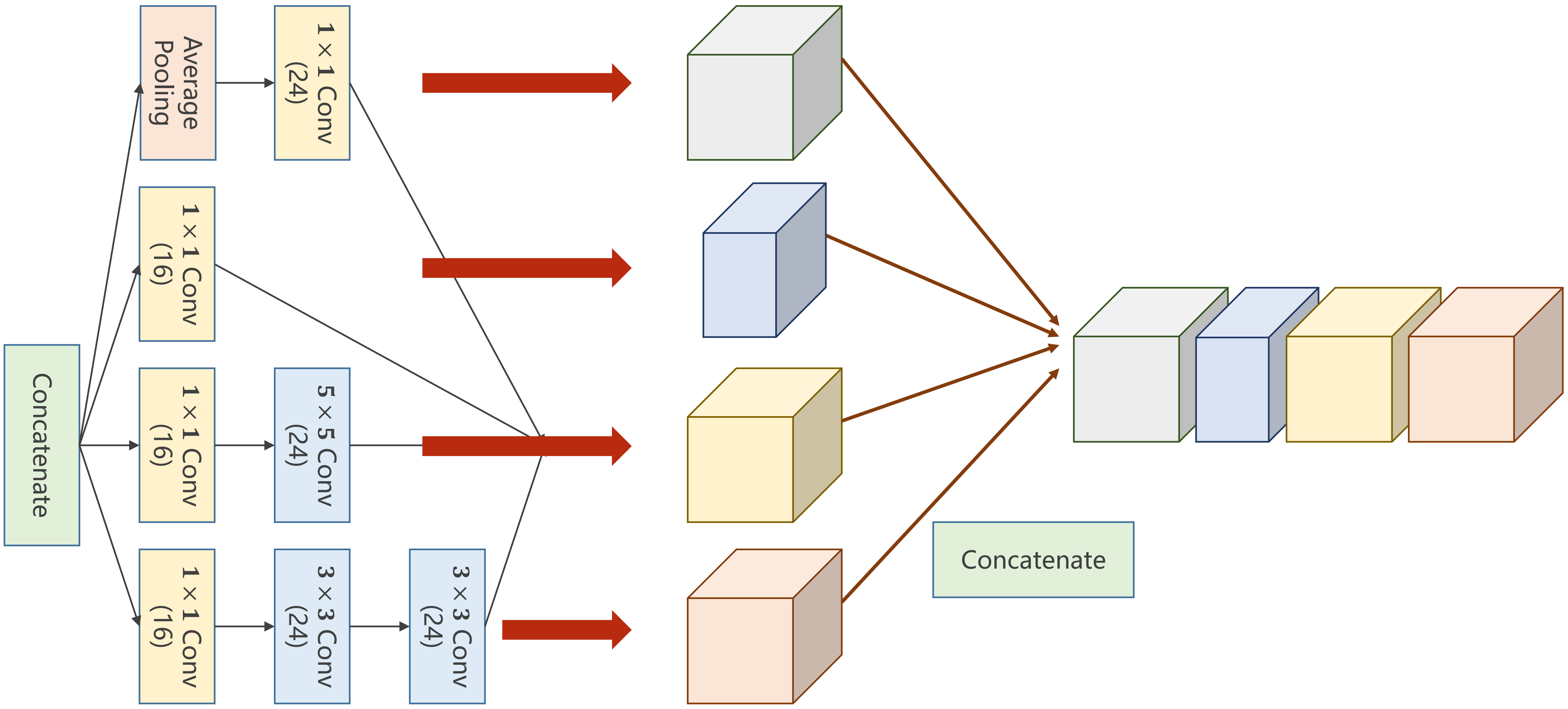
```
self.branch5x5_1 = nn.Conv2d(in_channels,16, kernel_size=1)
self.branch5x5_2 = nn.Conv2d(16, 24, kernel_size=5, padding=2)

branch5x5 = self.branch5x5_1(x)
branch5x5 = self.branch5x5_2(branch5x5)
```

```
self.branch3x3_1 = nn.Conv2d(in_channels, 16, kernel_size=1)
self.branch3x3_2 = nn.Conv2d(16, 24, kernel_size=3, padding=1)
self.branch3x3_3 = nn.Conv2d(24, 24, kernel_size=3, padding=1)

branch3x3 = self.branch3x3_1(x)
branch3x3 = self.branch3x3_2(branch3x3)
```

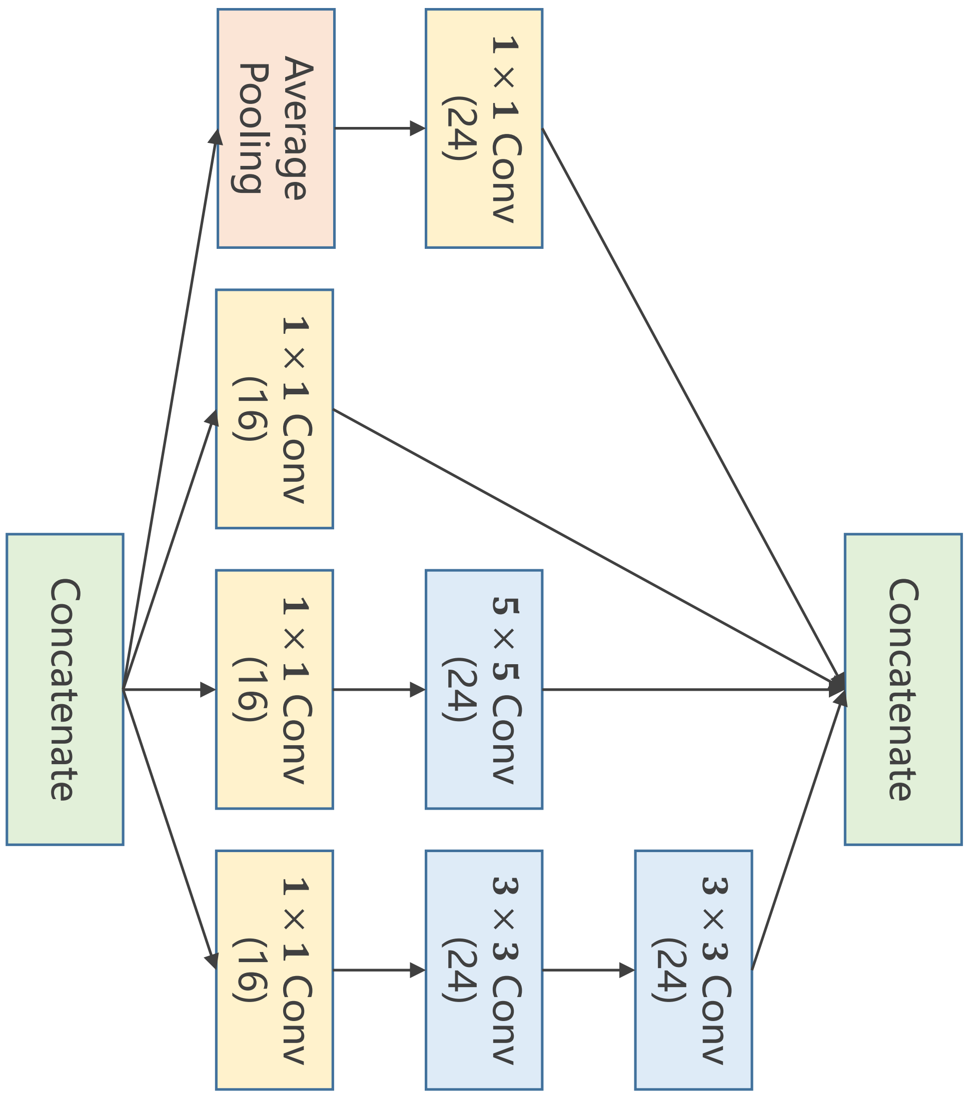
Implementation of Inception Module



Implementation of Inception Module



Implementation of Inception Module




```python
outputs = [branch1x1, branch5x5, branch3x3, branch_pool]
return torch.cat(outputs, dim=1)
```

Implementation of Inception Module

```
class InceptionA(nn.Module):
    def __init__(self, in_channels):
        super(InceptionA, self).__init__()
        self.branch1x1 = nn.Conv2d(in_channels, 16, kernel_size=1)

        self.branch5x5_1 = nn.Conv2d(in_channels,16, kernel_size=1)
        self.branch5x5_2 = nn.Conv2d(16, 24, kernel_size=5, padding=2)

        self.branch3x3_1 = nn.Conv2d(in_channels, 16, kernel_size=1)
        self.branch3x3_2 = nn.Conv2d(16, 24, kernel_size=3, padding=1)
        self.branch3x3_3 = nn.Conv2d(24, 24, kernel_size=3, padding=1)

        self.branch_pool = nn.Conv2d(in_channels, 24, kernel_size=1)

    def forward(self, x):
        branch1x1 = self.branch1x1(x)

        branch5x5 = self.branch5x5_1(x)
        branch5x5 = self.branch5x5_2(branch5x5)

        branch3x3 = self.branch3x3_1(x)
        branch3x3 = self.branch3x3_2(branch3x3)
        branch3x3 = self.branch3x3_3(branch3x3)

        branch_pool = F.avg_pool2d(x, kernel_size=3, stride=1, padding=1)
        branch_pool = self.branch_pool(branch_pool)

        outputs = [branch1x1, branch5x5, branch3x3, branch_pool]
        return torch.cat(outputs, dim=1)
```

Using Inception Module

```python
class InceptionA(nn.Module):
    def __init__(self, in_channels):
        super(InceptionA, self).__init__()
        self.branch1x1 = nn.Conv2d(in_channels, 16, kernel_size=1)

        self.branch5x5_1 = nn.Conv2d(in_channels,16, kernel_size=1)
        self.branch5x5_2 = nn.Conv2d(16, 24, kernel_size=5, padding=2)

        self.branch3x3_1 = nn.Conv2d(in_channels, 16, kernel_size=1)
        self.branch3x3_2 = nn.Conv2d(16, 24, kernel_size=3, padding=1)
        self.branch3x3_3 = nn.Conv2d(24, 24, kernel_size=3, padding=1)

        self.branch_pool = nn.Conv2d(in_channels, 24, kernel_size=1)

    def forward(self, x):
        branch1x1 = self.branch1x1(x)

        branch5x5 = self.branch5x5_1(x)
        branch5x5 = self.branch5x5_2(branch5x5)

        branch3x3 = self.branch3x3_1(x)
        branch3x3 = self.branch3x3_2(branch3x3)
        branch3x3 = self.branch3x3_3(branch3x3)

        branch_pool = F.avg_pool2d(x, kernel_size=3, stride=1, padding=1)
        branch_pool = self.branch_pool(branch_pool)

        outputs = [branch1x1, branch5x5, branch3x3, branch_pool]
        return torch.cat(outputs, dim=1)
```

```python
class Net(nn.Module):
    def __init__(self):
        super(Net, self).__init__()
        self.conv1 = nn.Conv2d(1, 10, kernel_size=5)
        self.conv2 = nn.Conv2d(88, 20, kernel_size=5)

        self.incep1 = InceptionA(in_channels=10)
        self.incep2 = InceptionA(in_channels=20)

        self.mp = nn.MaxPool2d(2)
        self.fc = nn.Linear(1408, 10)

    def forward(self, x):
        in_size = x.size(0)
        x = F.relu(self.mp(self.conv1(x)))
        x = self.incep1(x)
        x = F.relu(self.mp(self.conv2(x)))
        x = self.incep2(x)
        x = x.view(in_size, -1)
        x = self.fc(x)
        return x
```

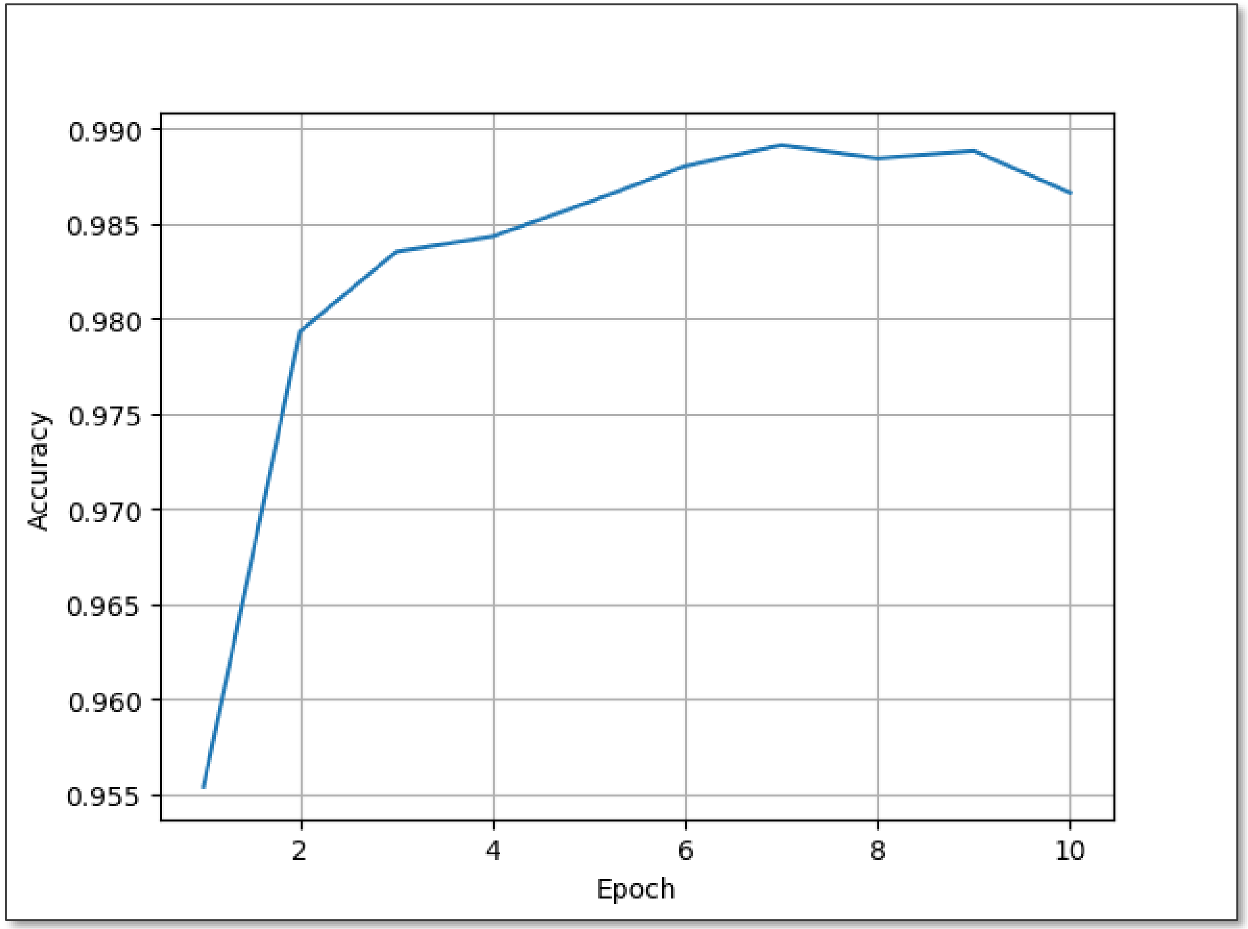
Using Inception Module

```python
class InceptionA(nn.Module):
    def __init__(self, in_channels):
        super(InceptionA, self).__init__()
        self.branch1x1 = nn.Conv2d(in_channels, 16, kernel_size=1)

        self.branch5x5_1 = nn.Conv2d(in_channels,16, kernel_size=1)
        self.branch5x5_2 = nn.Conv2d(16, 24, kernel_size=5, padding=2)

        self.branch3x3_1 = nn.Conv2d(in_channels, 16, kernel_size=1)
        self.branch3x3_2 = nn.Conv2d(16, 24, kernel_size=3, padding=1)
        self.branch3x3_3 = nn.Conv2d(24, 24, kernel_size=3, padding=1)

        self.branch_pool = nn.Conv2d(in_channels, 24, kernel_size=1)

    def forward(self, x):
        branch1x1 = self.branch1x1(x)

        branch5x5 = self.branch5x5_1(x)
        branch5x5 = self.branch5x5_2(branch5x5)

        branch3x3 = self.branch3x3_1(x)
        branch3x3 = self.branch3x3_2(branch3x3)
        branch3x3 = self.branch3x3_3(branch3x3)

        branch_pool = F.avg_pool2d(x, kernel_size=3, stride=1, padding=1)
        branch_pool = self.branch_pool(branch_pool)

        outputs = [branch1x1, branch5x5, branch3x3, branch_pool]
        return torch.cat(outputs, dim=1)
```

```python
class Net(nn.Module):
    def __init__(self):
        super(Net, self).__init__()
        self.conv1 = nn.Conv2d(1, 10, kernel_size=5)
        self.conv2 = nn.Conv2d(88, 20, kernel_size=5)

        self.incep1 = InceptionA(in_channels=10)
        self.incep2 = InceptionA(in_channels=20)

        self.mp = nn.MaxPool2d(2)
        self.fc = nn.Linear(1408, 10)

    def forward(self, x):
        in_size = x.size(0)
        x = F.relu(self.mp(self.conv1(x)))
        x = self.incep1(x)
        x = F.relu(self.mp(self.conv2(x)))
        x = self.incep2(x)
        x = x.view(in_size, -1)
        x = self.fc(x)
        return x
```

Results of using Inception Module

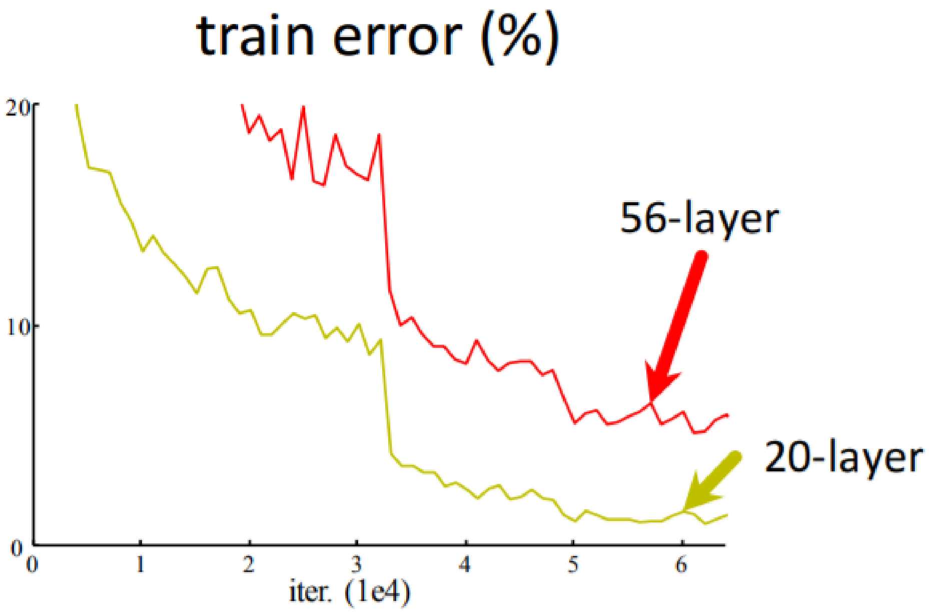
Accuracy on test set: 9 % [982/10000]
[1, 300] loss: 0.141
[1, 600] loss: 0.031
[1, 900] loss: 0.020
Accuracy on test set: 95 % [9554/10000]
[2, 300] loss: 0.015
[2, 600] loss: 0.014
[2, 900] loss: 0.012
Accuracy on test set: 97 % [9793/10000]
……
[9, 300] loss: 0.005
[9, 600] loss: 0.005
[9, 900] loss: 0.005
Accuracy on test set: 98 % [9888/10000]
[10, 300] loss: 0.005
[10, 600] loss: 0.005
[10, 900] loss: 0.005
Accuracy on test set: 98 % [9866/10000]

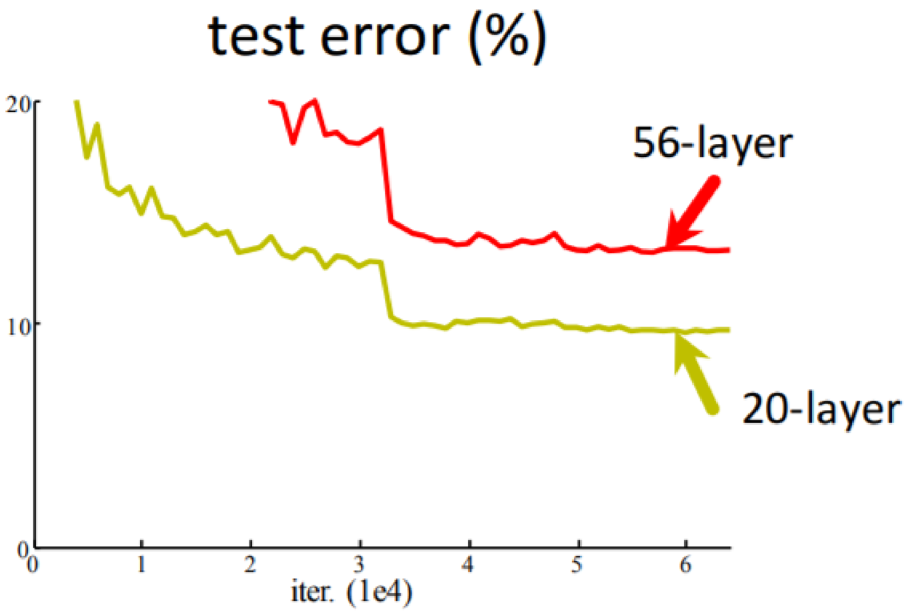


Go Deeper

Can we stack layers to go deeper?

CIFAR-10

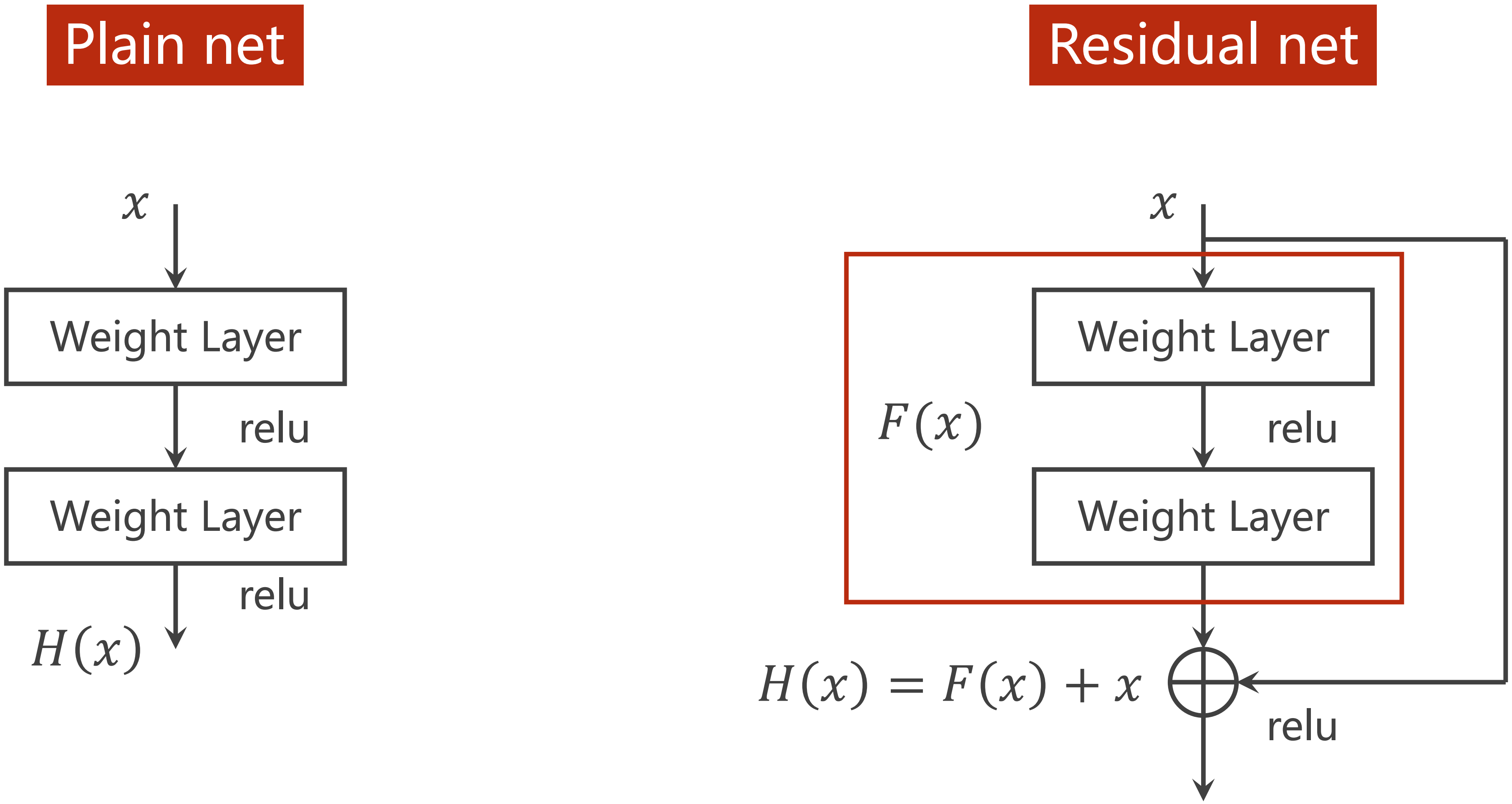




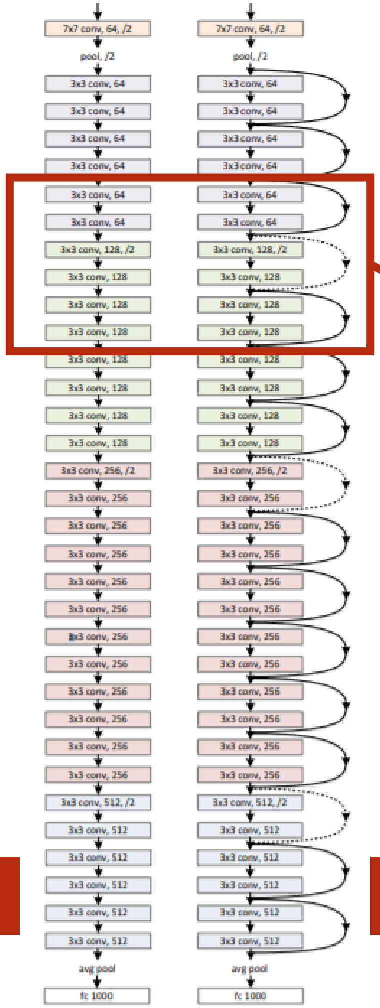
Plain nets: stacking 3x3 conv layers

He K, Zhang X, Ren S, et al. Deep Residual Learning for Image Recognition[C]// IEEE Conference on Computer Vision and Pattern Recognition. IEEE Computer Society, 2016:770-778.

Deep Residual Learning

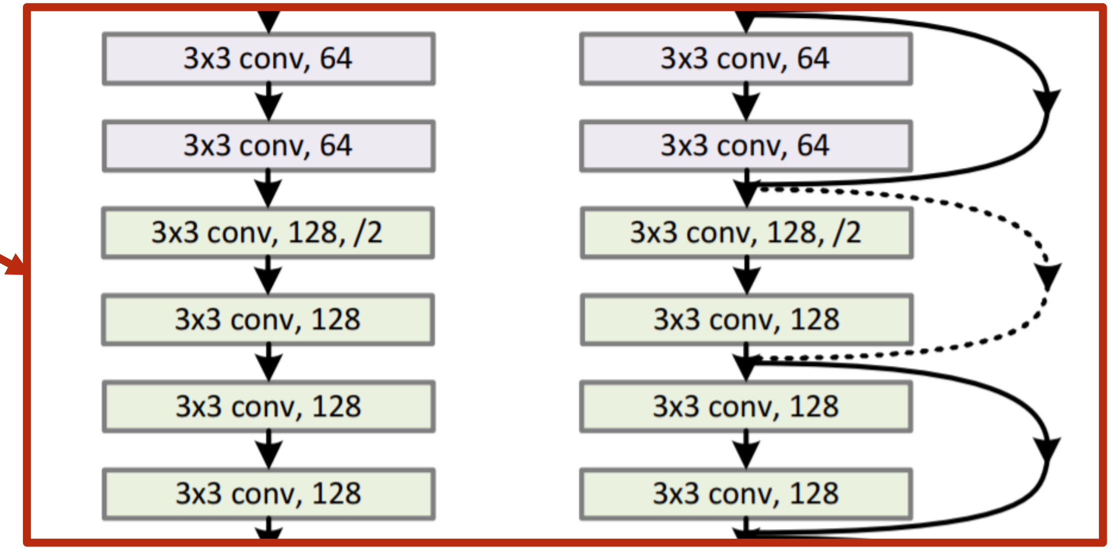


Residual Network

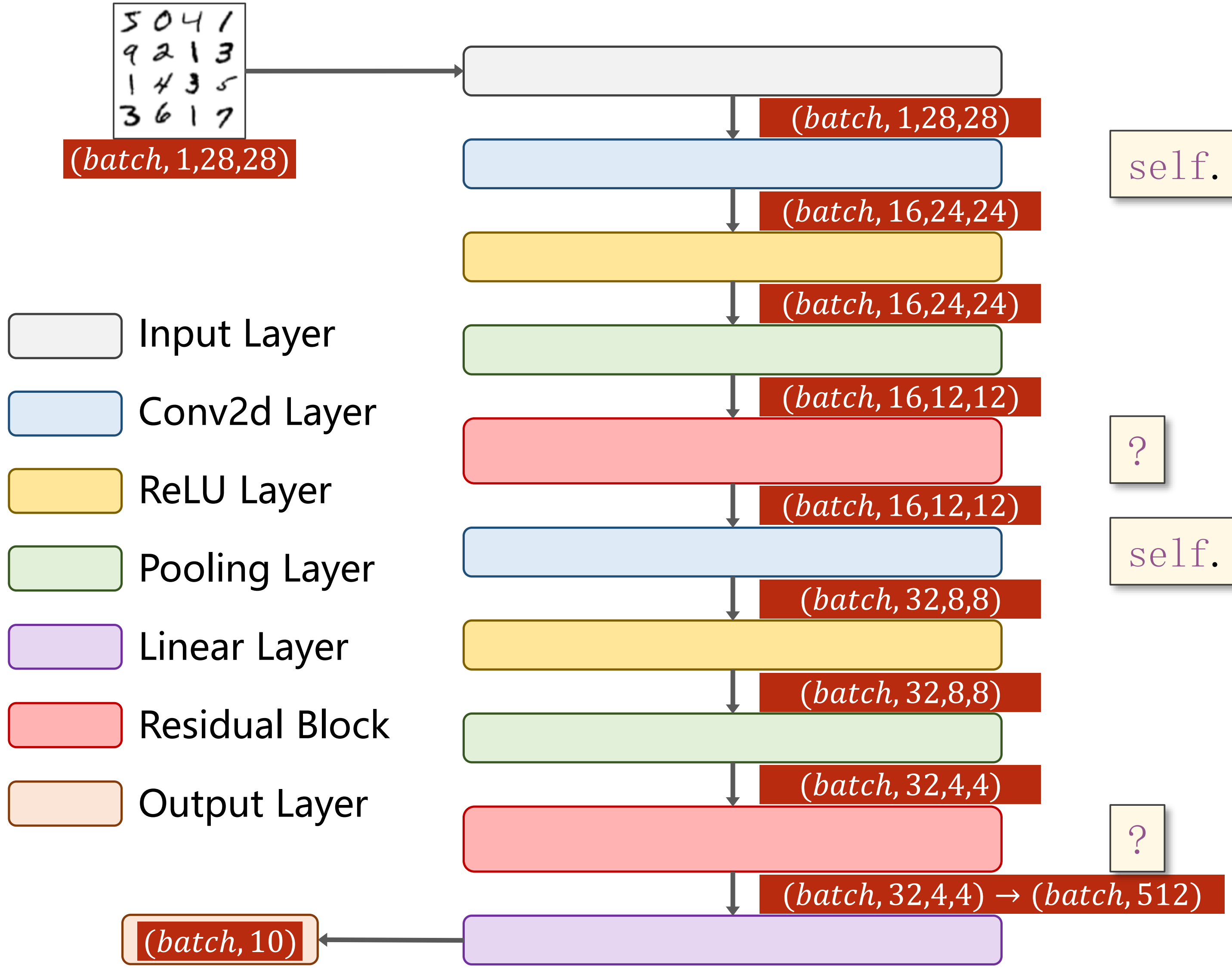


Plain net

Residual net



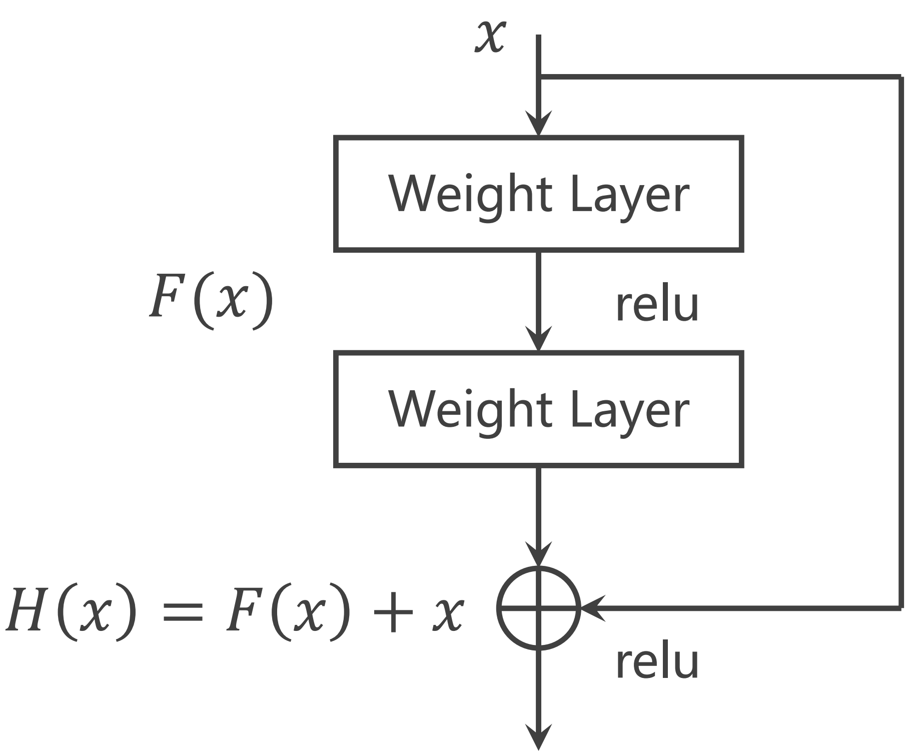
Implementation of Simple Residual Network




```
self.conv1 = nn.Conv2d(1, 16, kernel_size=5)
```

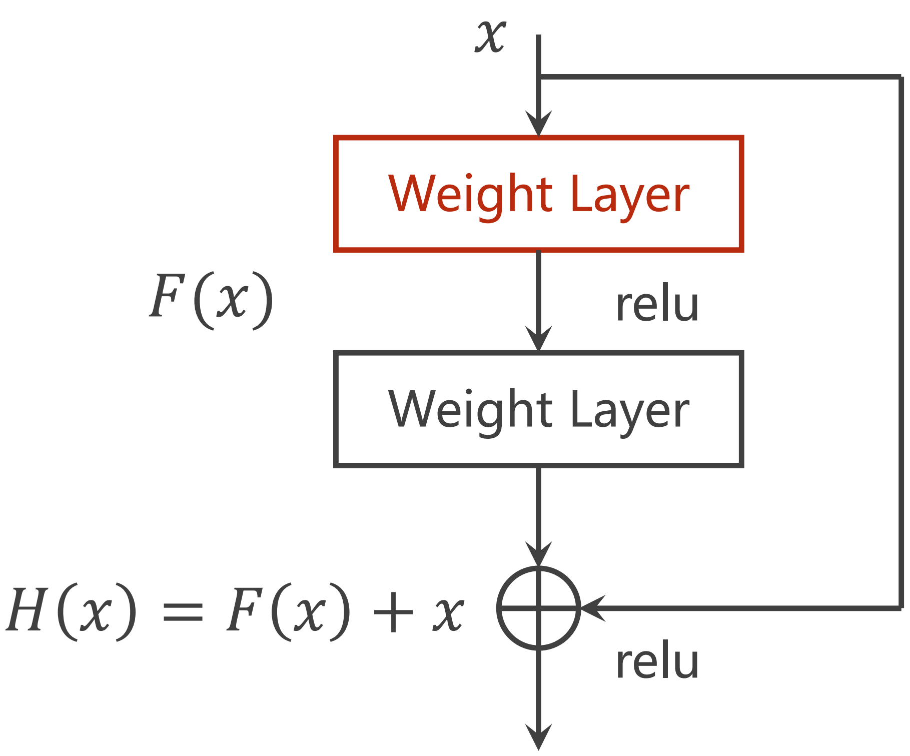
```
self.conv2 = nn.Conv2d(16, 32, kernel_size=5)
```

Implementation of Residual Block




```python
class ResidualBlock(nn.Module):
    def __init__(self, channels):
        super(ResidualBlock, self).__init__()
        self.channels = channels
        self.conv1 = nn.Conv2d(channels, channels,
                               kernel_size=3, padding=1)
        self.conv2 = nn.Conv2d(channels, channels,
                               kernel_size=3, padding=1)

    def forward(self, x):
        y = F.relu(self.conv1(x))
        y = self.conv2(y)
        return F.relu(x + y)
```

Implementation of Residual Block




```python
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    def __init__(self, channels):
        super(ResidualBlock, self).__init__()
        self.channels = channels
        self.conv1 = nn.Conv2d(channels, channels,
                               kernel_size=3, padding=1)
        self.conv2 = nn.Conv2d(channels, channels,
                               kernel_size=3, padding=1)

    def forward(self, x):
        y = F.relu(self.conv1(x))
        y = self.conv2(y)
        return F.relu(x + y)
```
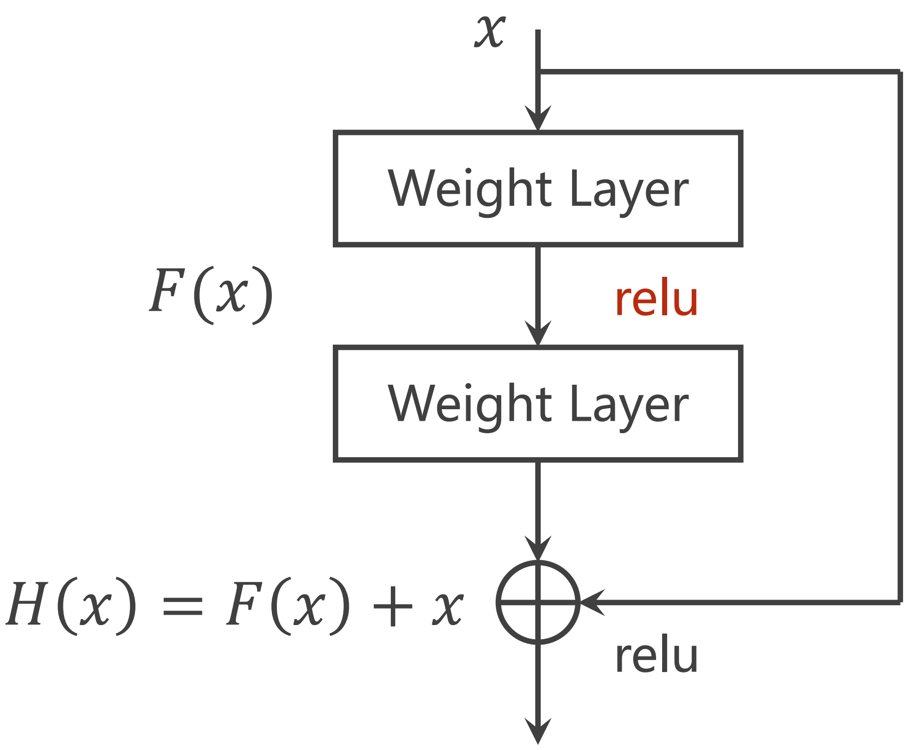
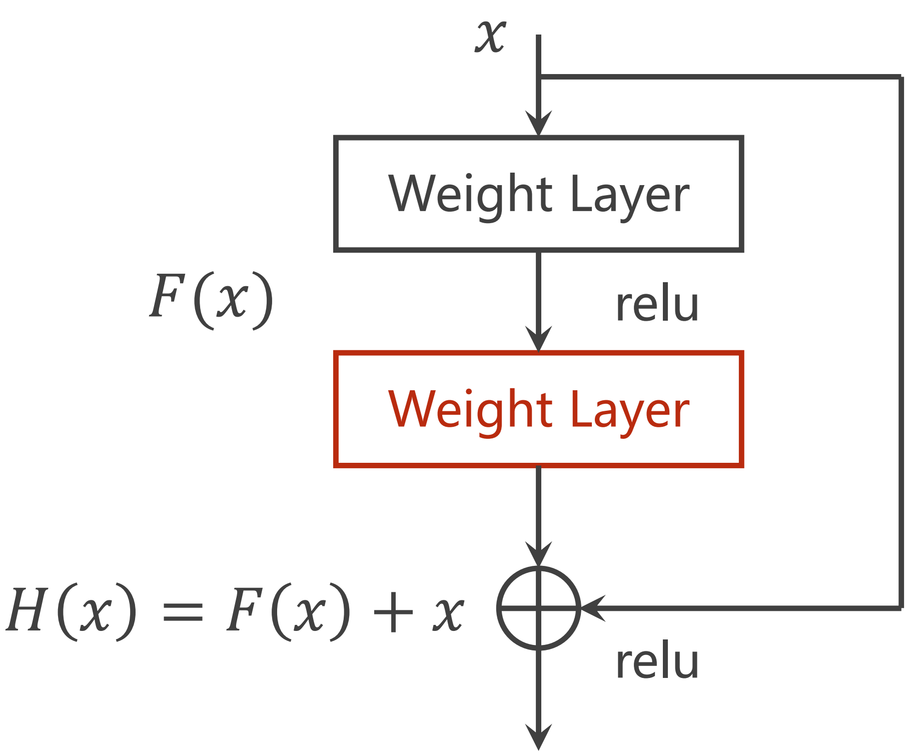

Implementation of Residual Block



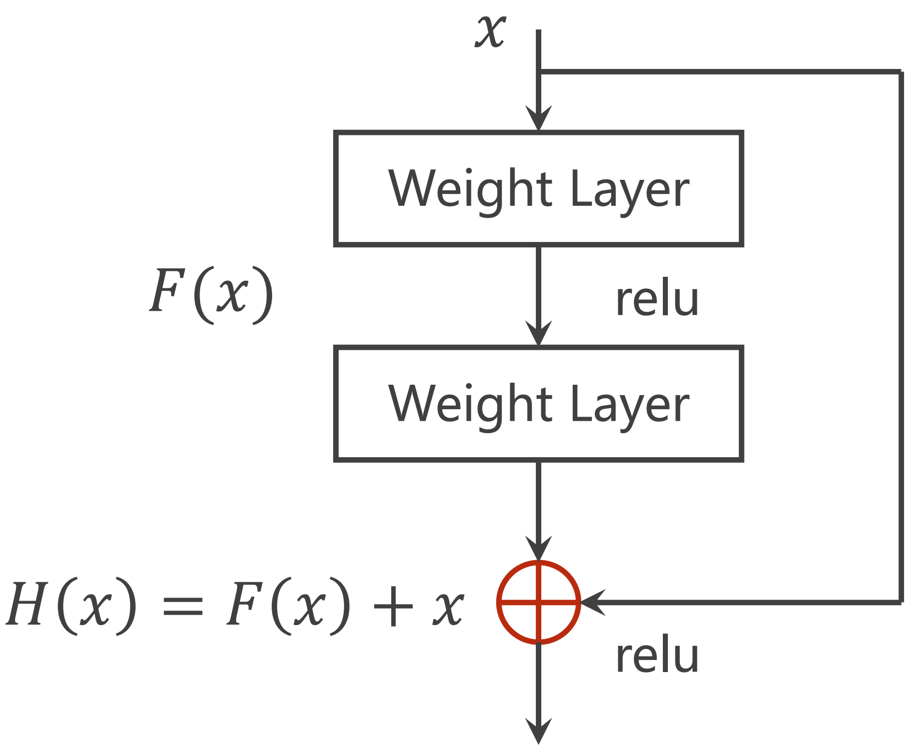

```python
class ResidualBlock(nn.Module):
    def __init__(self, channels):
        super(ResidualBlock, self).__init__()
        self.channels = channels
        self.conv1 = nn.Conv2d(channels, channels,
                               kernel_size=3, padding=1)
        self.conv2 = nn.Conv2d(channels, channels,
                               kernel_size=3, padding=1)

    def forward(self, x):
        y = F.relu(self.conv1(x))
        y = self.conv2(y)
        return F.relu(x + y)
```

Implementation of Residual Block



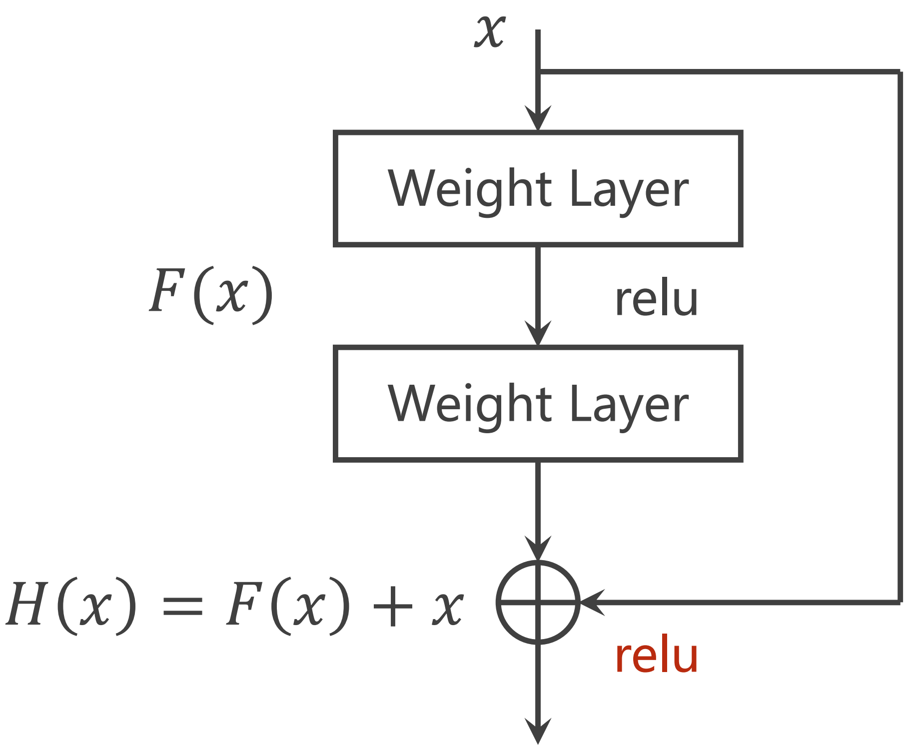

```python
class ResidualBlock(nn.Module):
    def __init__(self, channels):
        super(ResidualBlock, self).__init__()
        self.channels = channels
        self.conv1 = nn.Conv2d(channels, channels,
                               kernel_size=3, padding=1)
        self.conv2 = nn.Conv2d(channels, channels,
                               kernel_size=3, padding=1)

    def forward(self, x):
        y = F.relu(self.conv1(x))
        y = self.conv2(y)
        return F.relu(x + y)
```

Implementation of Residual Block



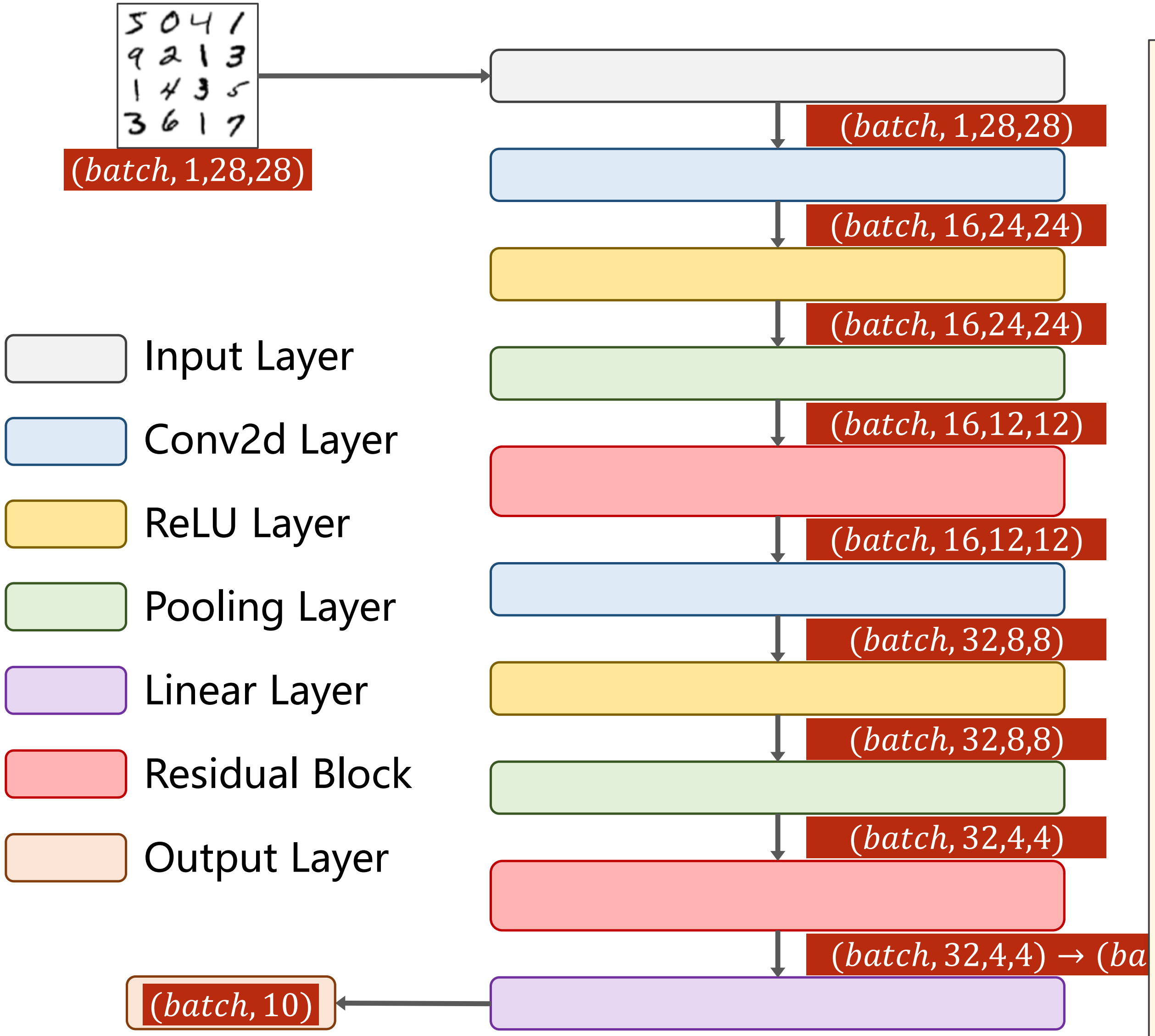

```python
class ResidualBlock(nn.Module):
    def __init__(self, channels):
        super(ResidualBlock, self).__init__()
        self.channels = channels
        self.conv1 = nn.Conv2d(channels, channels,
                               kernel_size=3, padding=1)
        self.conv2 = nn.Conv2d(channels, channels,
                               kernel_size=3, padding=1)

    def forward(self, x):
        y = F.relu(self.conv1(x))
        y = self.conv2(y)
        return F.relu(x + y)
```

Implementation of Residual Block



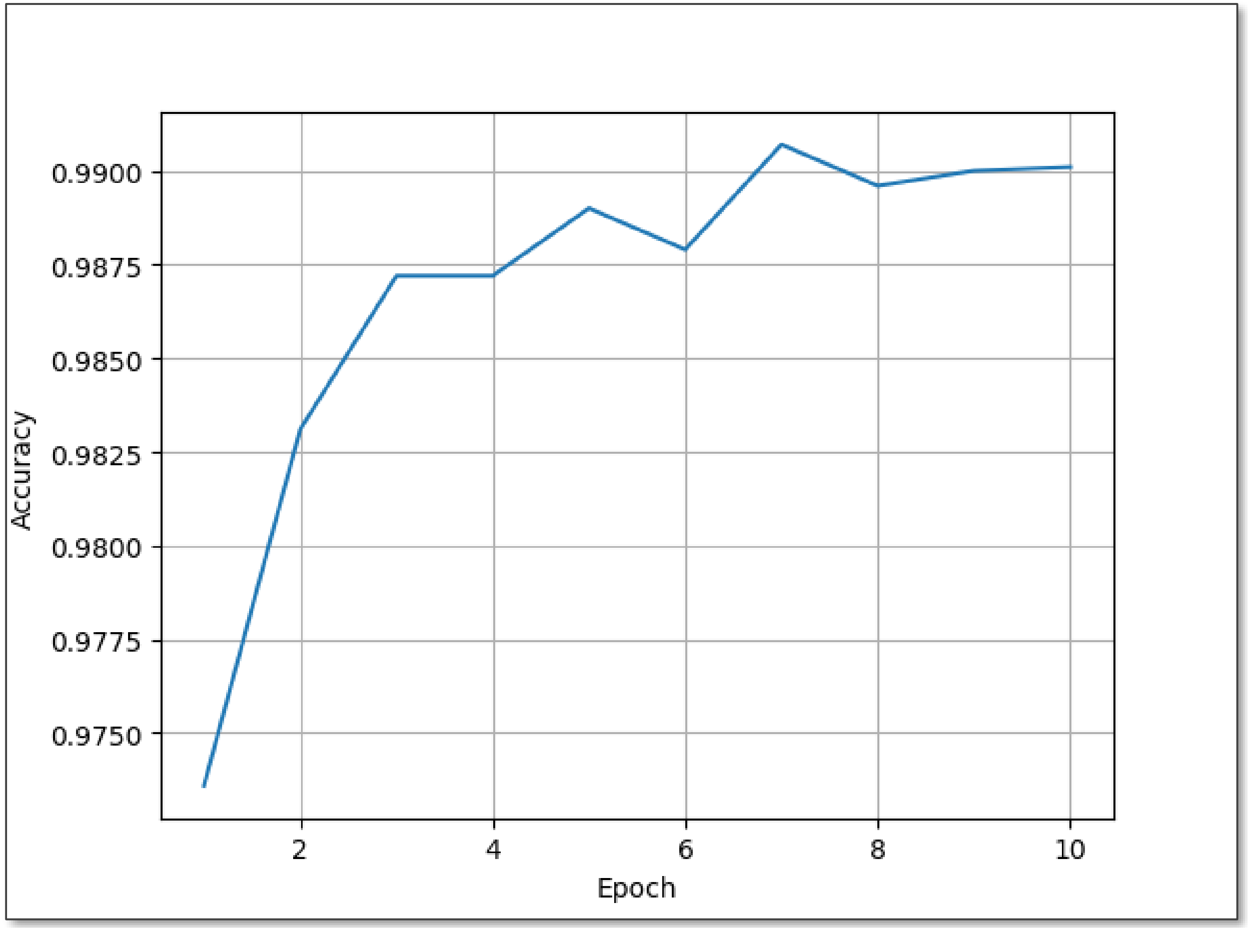

```
class ResidualBlock(nn.Module):
    def __init__(self, channels):
        super(ResidualBlock, self).__init__()
        self.channels = channels
        self.conv1 = nn.Conv2d(channels, channels,
                               kernel_size=3, padding=1)
        self.conv2 = nn.Conv2d(channels, channels,
                               kernel_size=3, padding=1)

    def forward(self, x):
        y = F.relu(self.conv1(x))
        y = self.conv2(y)
        return F.relu(x + y)
```

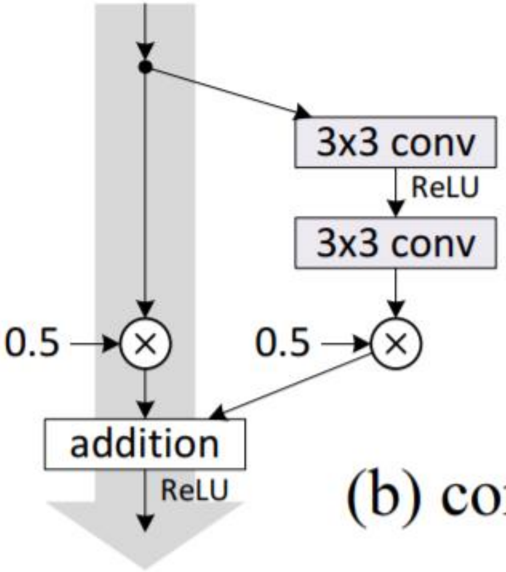
Implementation of Simple Residual Network



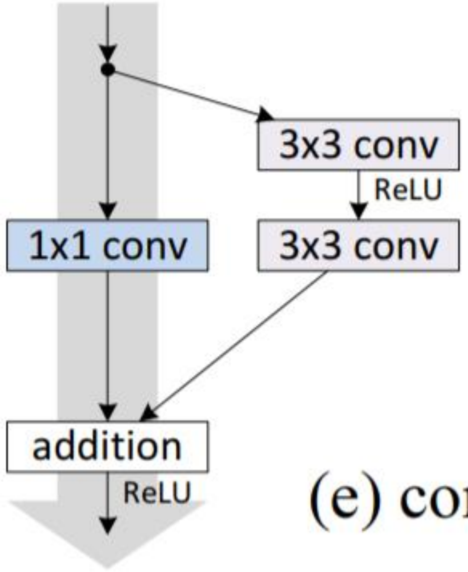

```python
class Net(nn.Module):
    def __init__(self):
        super(Net, self).__init__()
        self.conv1 = nn.Conv2d(1, 16, kernel_size=5)
        self.conv2 = nn.Conv2d(16, 32, kernel_size=5)
        self.mp = nn.MaxPool2d(2)

        self.rblock1 = ResidualBlock(16)
        self.rblock2 = ResidualBlock(32)

        self.fc = nn.Linear(512, 10)

    def forward(self, x):
        in_size = x.size(0)
        x = self.mp(F.relu(self.conv1(x)))
        x = self.rblock1(x)
        x = self.mp(F.relu(self.conv2(x)))
        x = self.rblock2(x)
        x = x.view(in_size, -1)
        x = self.fc(x)
        return x
```

Accuracy on test set: 9 % [916/10000]
[1, 300] loss: 0.074
[1, 600] loss: 0.021
[1, 900] loss: 0.017
Accuracy on test set: 97 % [9736/10000]
[2, 300] loss: 0.013
[2, 600] loss: 0.011
[2, 900] loss: 0.011
Accuracy on test set: 98 % [9831/10000]
……
[9, 300] loss: 0.003
[9, 600] loss: 0.004
[9, 900] loss: 0.004
Accuracy on test set: 99 % [9900/10000]
[10, 300] loss: 0.003
[10, 600] loss: 0.003
[10, 900] loss: 0.004
Accuracy on test set: 99 % [9901/10000]





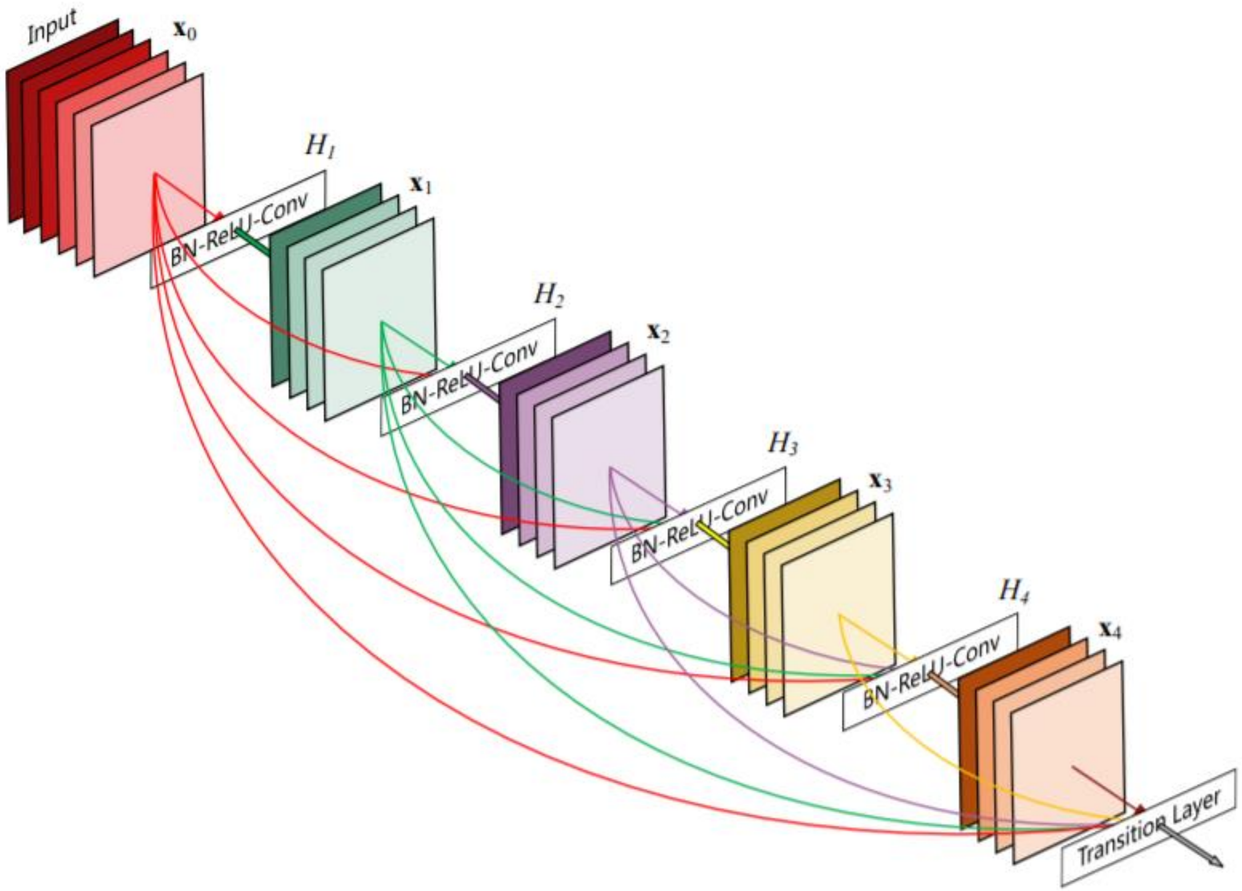
(b) constant scaling



(e) conv shortcut

He K, Zhang X, Ren S, et al. Identity Mappings in Deep Residual Networks[C]

Exercise 11-2: Reading and Implementing DenseNet



Huang G, Liu Z, Laurens V D M, et al. Densely Connected Convolutional Networks[J]. 2016:2261-2269.

PyTorch Tutorial

11. Advanced CNN