Introduction to CNN

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Year 2023

CONTENT

(1) – Neural Network

(2) – Convolutional Layer

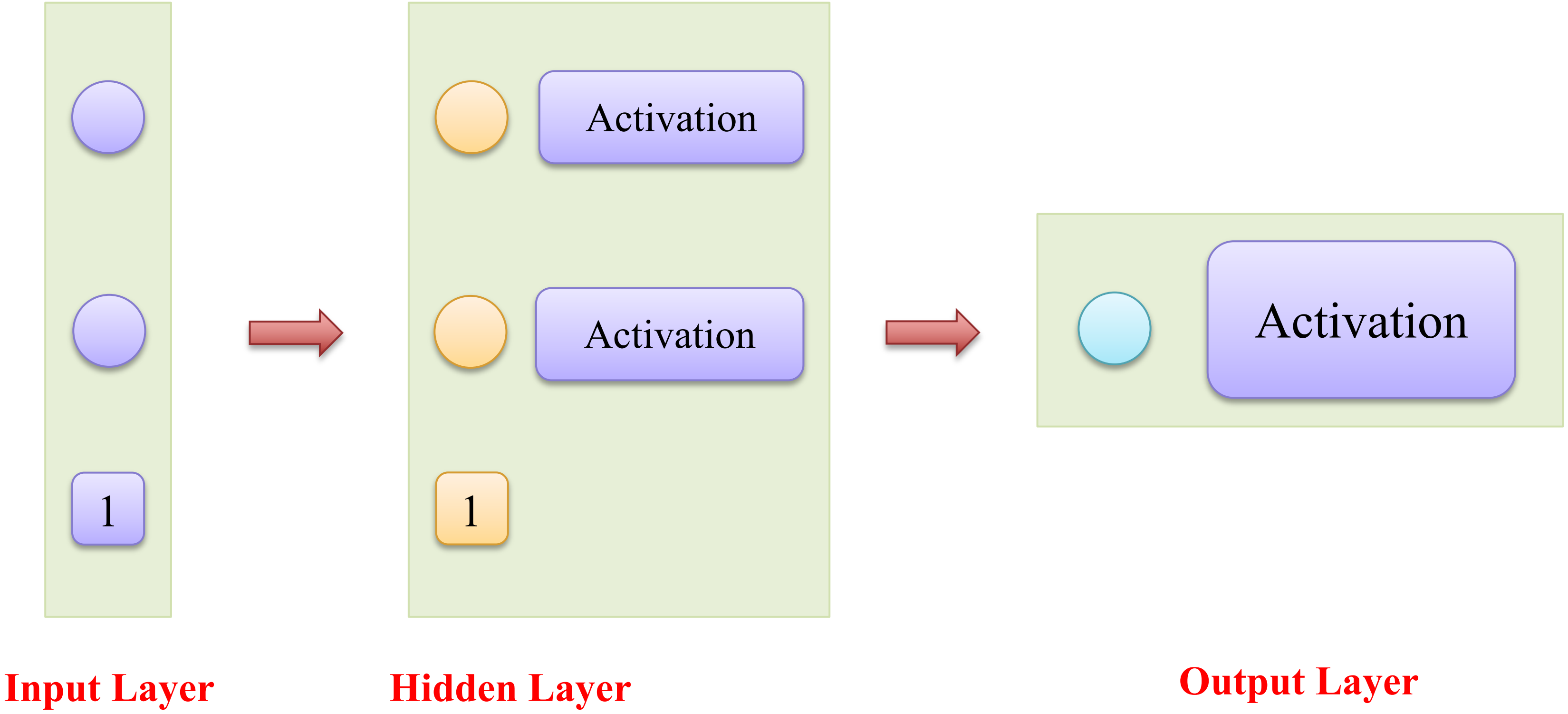
(3) – Pooling Layer

(4) – Flatten

(5) – Practice

1 – Neural Network

Neural Network



Loss: CrossEntropyLoss

$$L(\boldsymbol{\theta}) = -\sum_{i} y_i \log(\hat{y}_i)$$

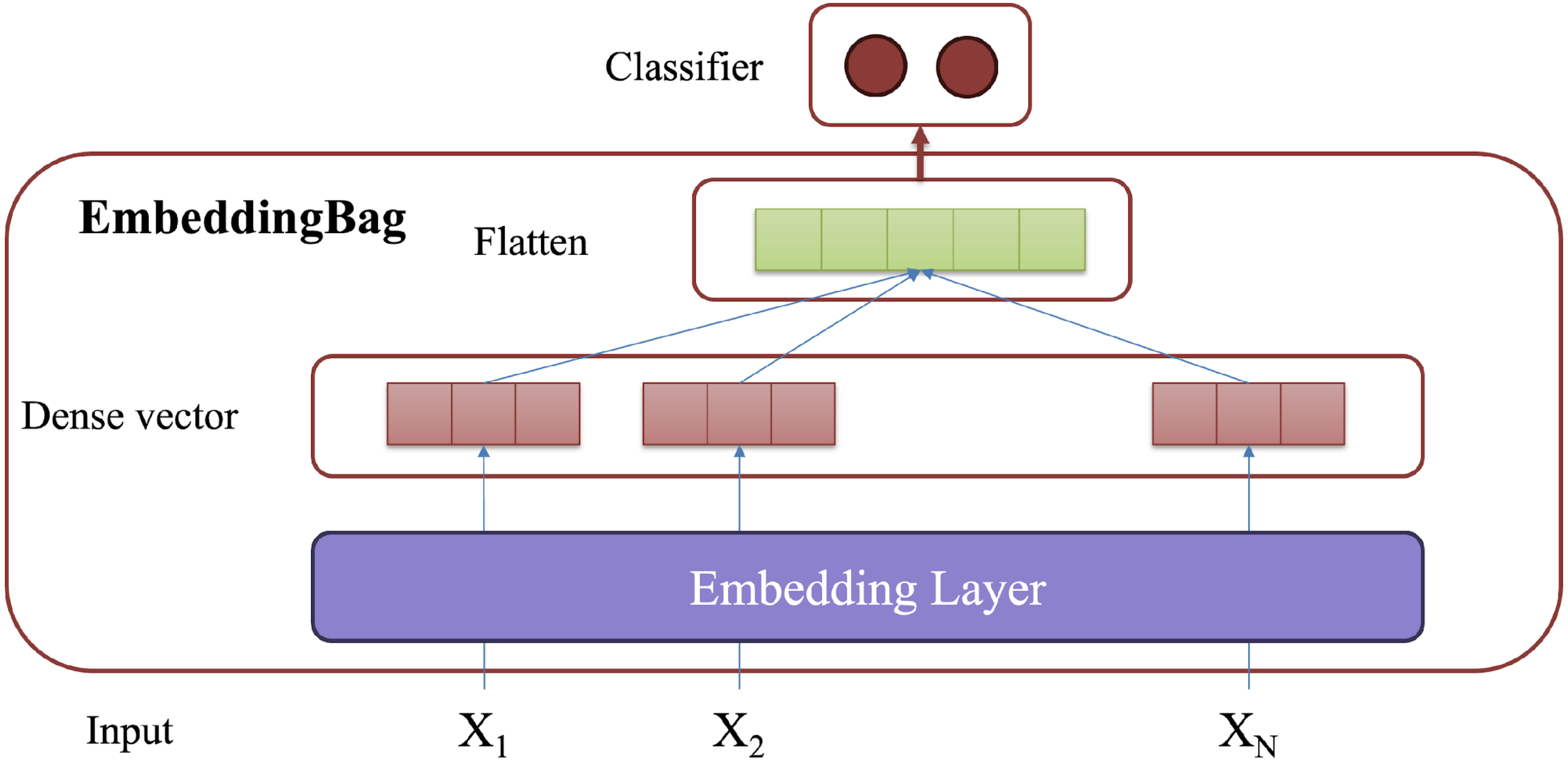
Optimizer: SGD

$$x = x - \eta * f'(x)$$

1 – Neural Network

Neural Network for Text (Time Series)

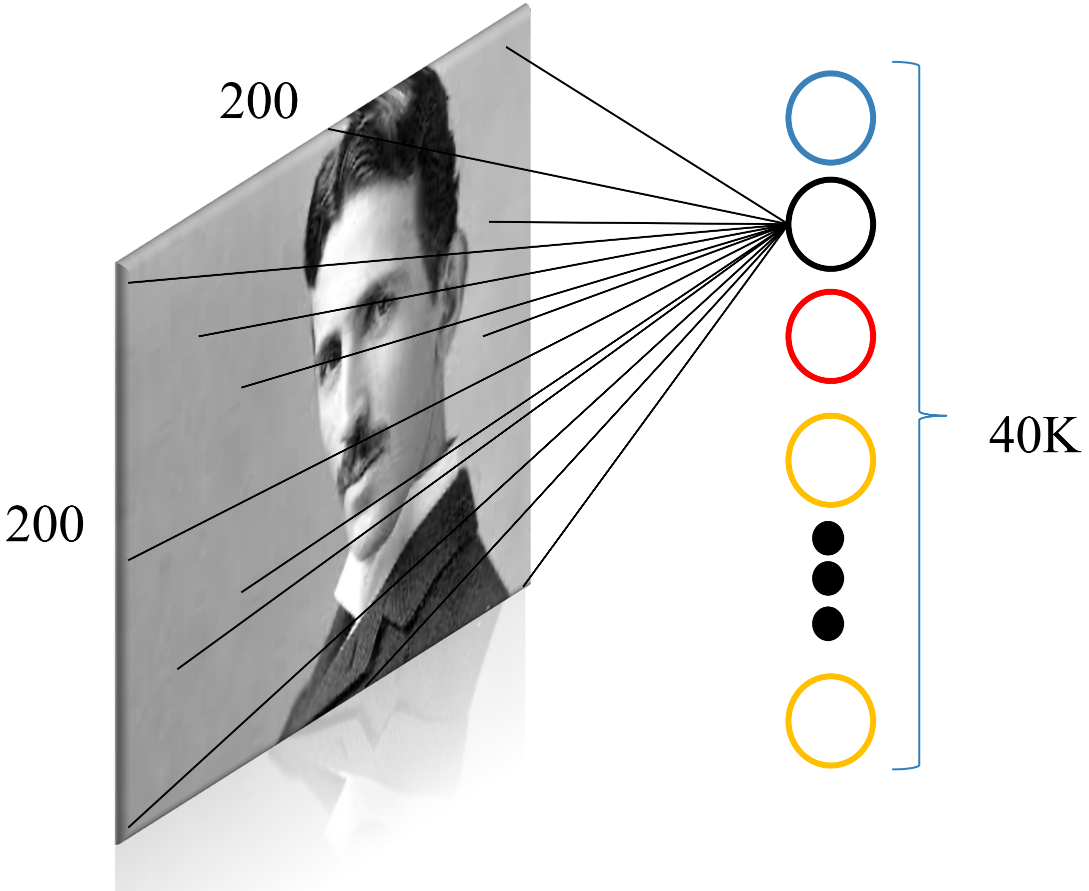
- No capture the order and importance of words in a sentence

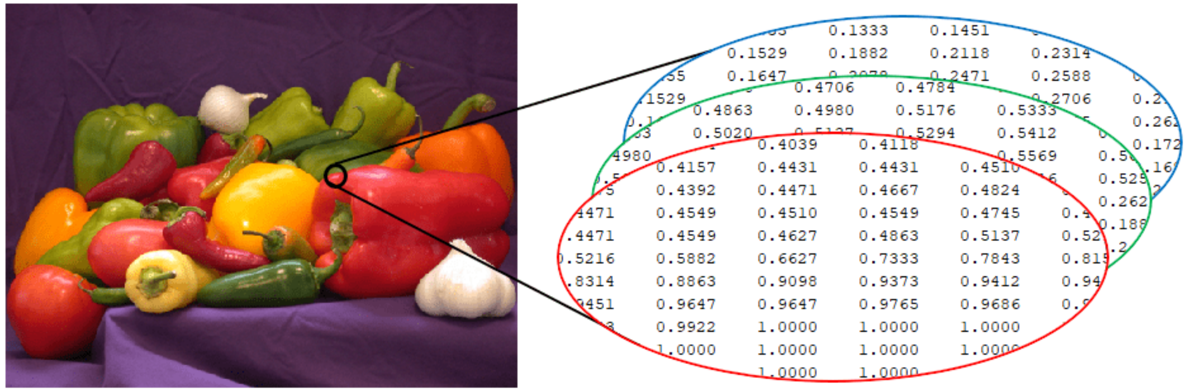


1 – Neural Network

Neural Network for Image

- Each hidden node connects to all the other nodes





1 – Neural Network

Neural Network

- **Need better network architectures…**

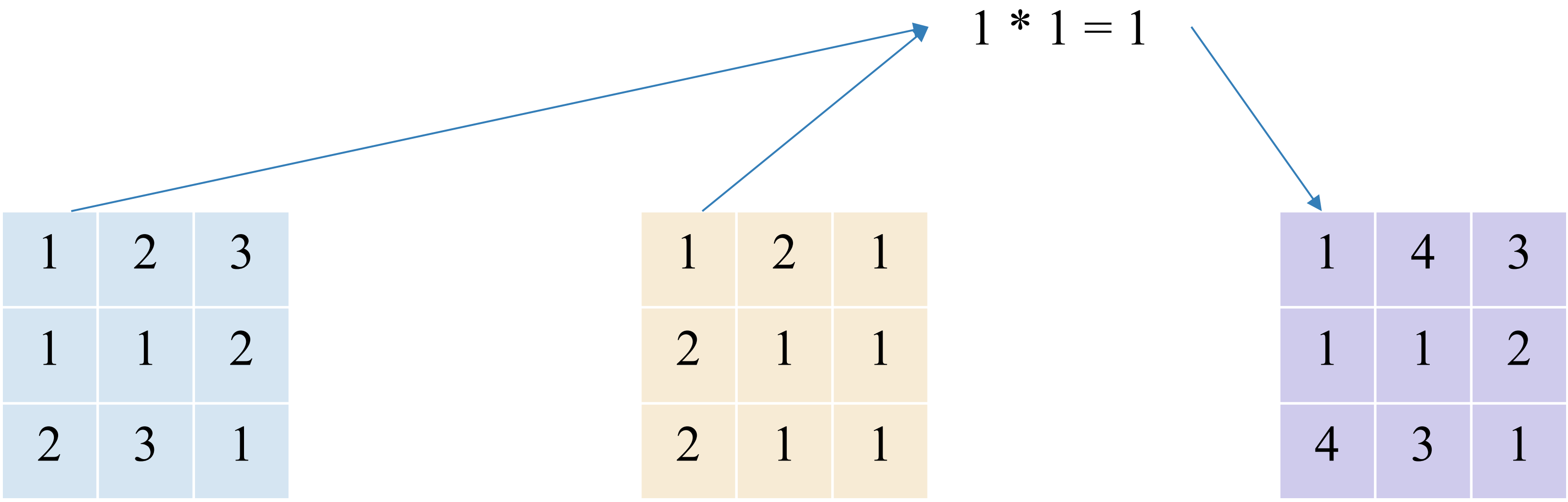
RNNs for Sequence

CNNs for Image

2 – Convolutional Layer

Convolutional Operation

- **Element-wise Multiplication Matrix**
  - A (MxN) B (MxN) => C (MxN)



$1 * 1 = 1$

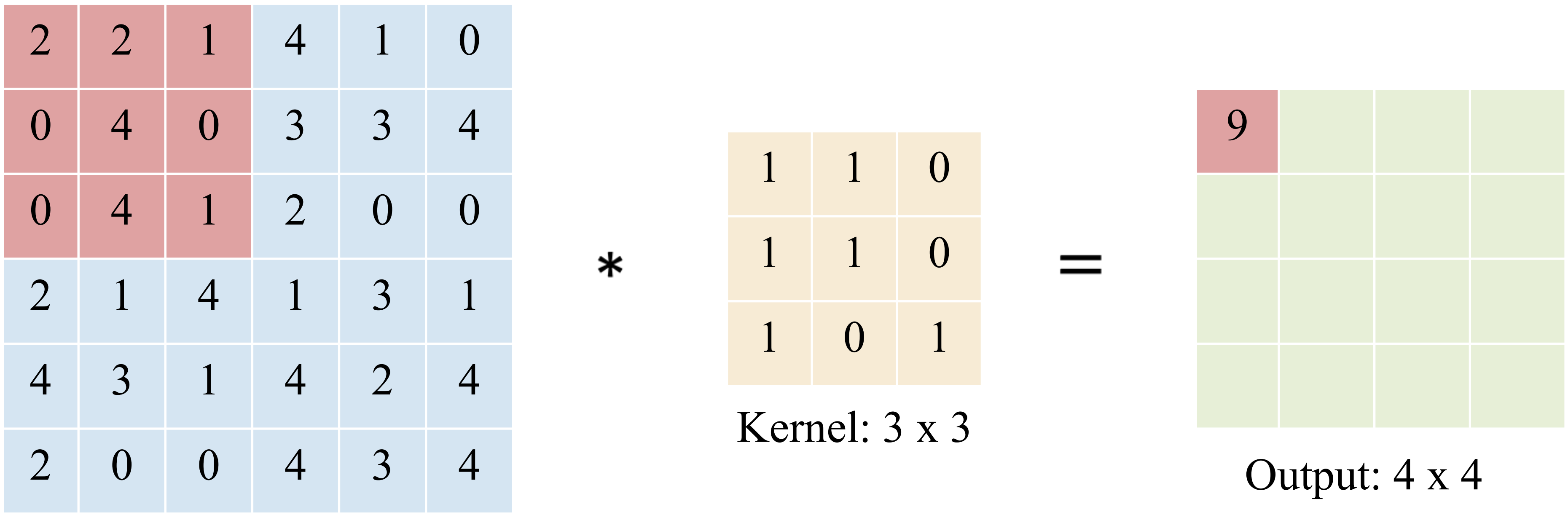
1	2	3
1	1	2
2	3	1

1	2	1
2	1	1
2	1	1

1	4	3
1	1	2
4	3	1

2 – Convolutional Layer

Convolutional Operation



2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1
4	3	1	4	2	4
2	0	0	4	3	4

Input: 6 x 6

1	1	0
1	1	0
1	0	1

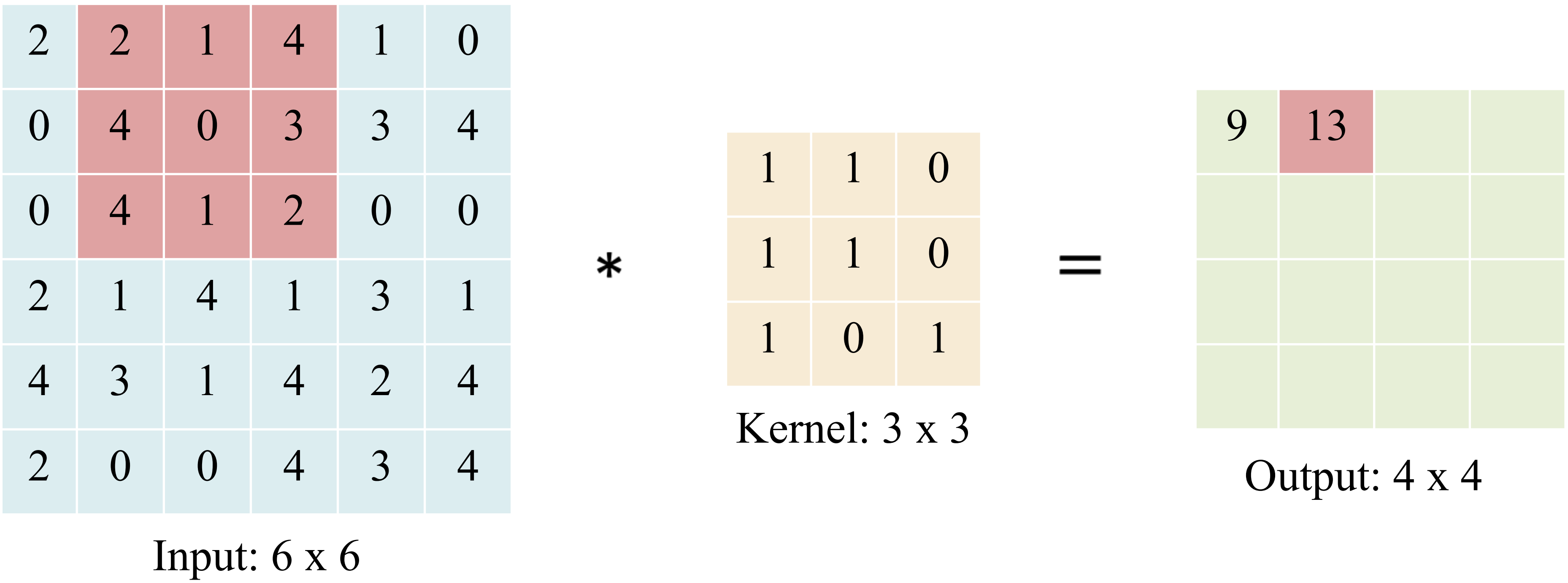
Kernel: 3 x 3

9			

Output: 4 x 4

2 – Convolutional Layer

Convolutional Operation



2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1
4	3	1	4	2	4
2	0	0	4	3	4

Input: 6 x 6

*

1	1	0
1	1	0
1	0	1

Kernel: 3 x 3

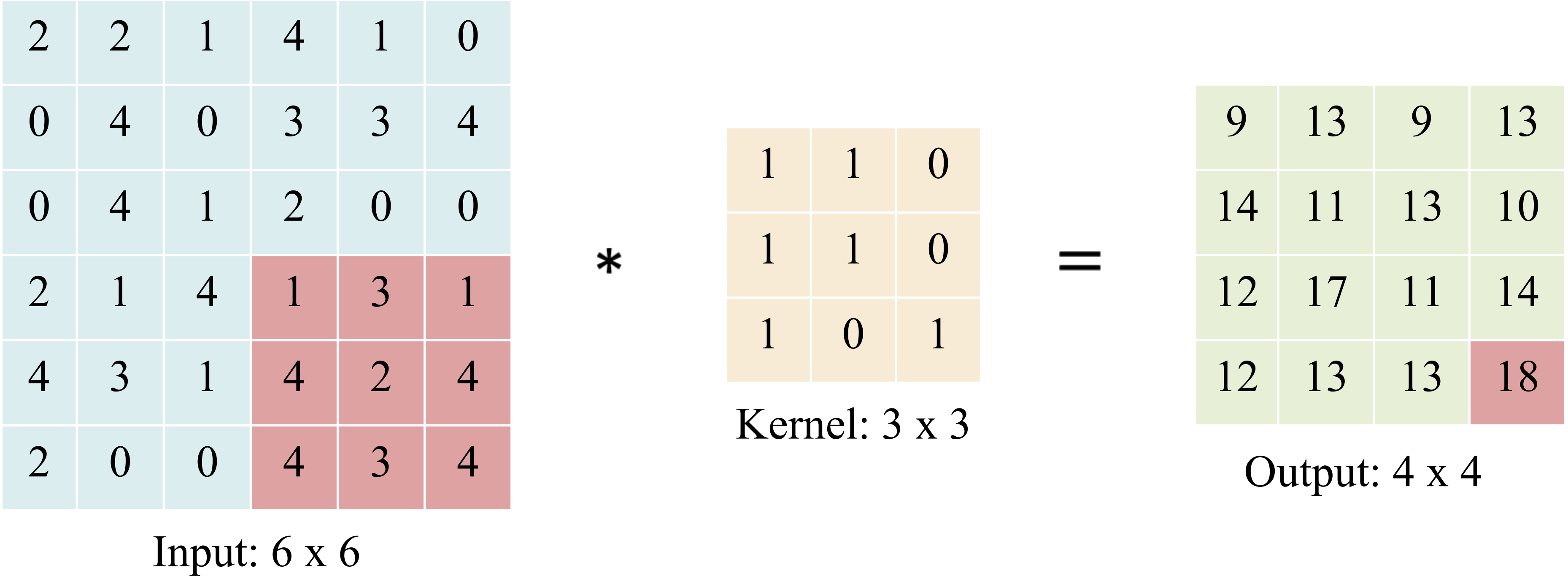
=

9	13		

Output: 4 x 4

2 – Convolutional Layer

Convolutional Operation



2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1
4	3	1	4	2	4
2	0	0	4	3	4

Input: 6 x 6

*

1	1	0
1	1	0
1	0	1

Kernel: 3 x 3

=

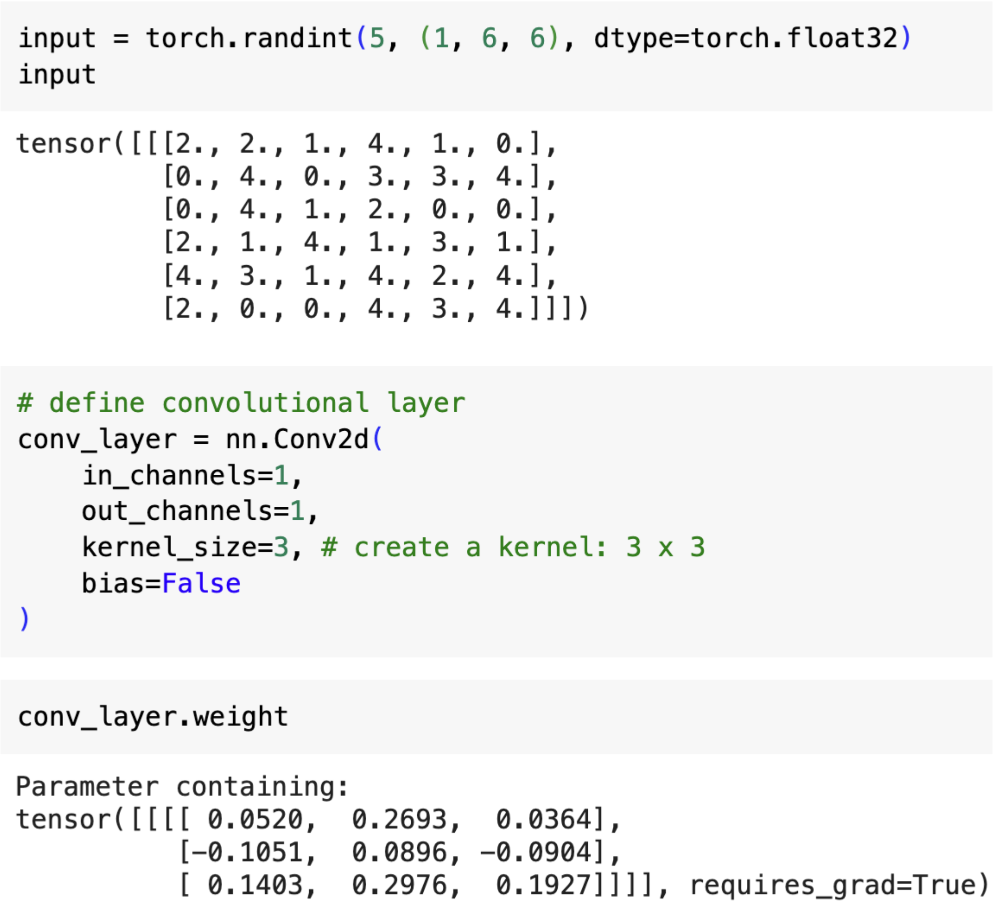
9	13	9	13
14	11	13	10
12	17	11	14
12	13	13	18

Output: 4 x 4

2 – Convolutional Layer

Convolutional Operation

❖ Pytorch



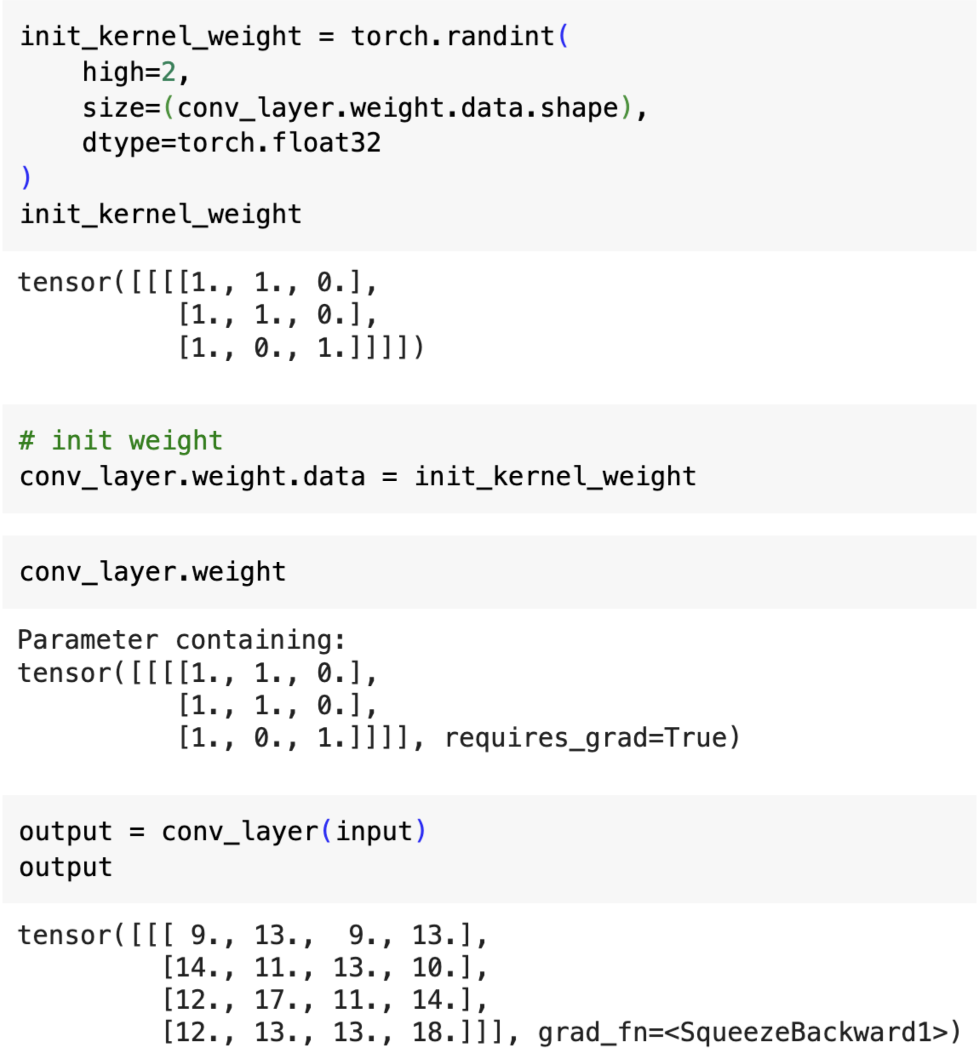
```
input = torch.randint(5, (1, 6, 6), dtype=torch.float32)
input
```

```
tensor([[[2., 2., 1., 4., 1., 0.],
         [0., 4., 0., 3., 3., 4.],
         [0., 4., 1., 2., 0., 0.],
         [2., 1., 4., 1., 3., 1.],
         [4., 3., 1., 4., 2., 4.],
         [2., 0., 0., 4., 3., 4.]]])
```

```
# define convolutional layer
conv_layer = nn.Conv2d(
    in_channels=1,
    out_channels=1,
    kernel_size=3, # create a kernel: 3 x 3
    bias=False
)
```

```
conv_layer.weight
```

```
Parameter containing:
tensor([[[[ 0.0520,  0.2693,  0.0364],
          [-0.1051,  0.0896, -0.0904],
          [ 0.1403,  0.2976,  0.1927]]]], requires_grad=True)
```



```
init_kernel_weight = torch.randint(
    high=2,
    size=(conv_layer.weight.data.shape),
    dtype=torch.float32
)
init_kernel_weight
```

```
tensor([[[[1., 1., 0.],
          [1., 1., 0.],
          [1., 0., 1.]]]])
```

```
# init weight
conv_layer.weight.data = init_kernel_weight
```

```
conv_layer.weight
```

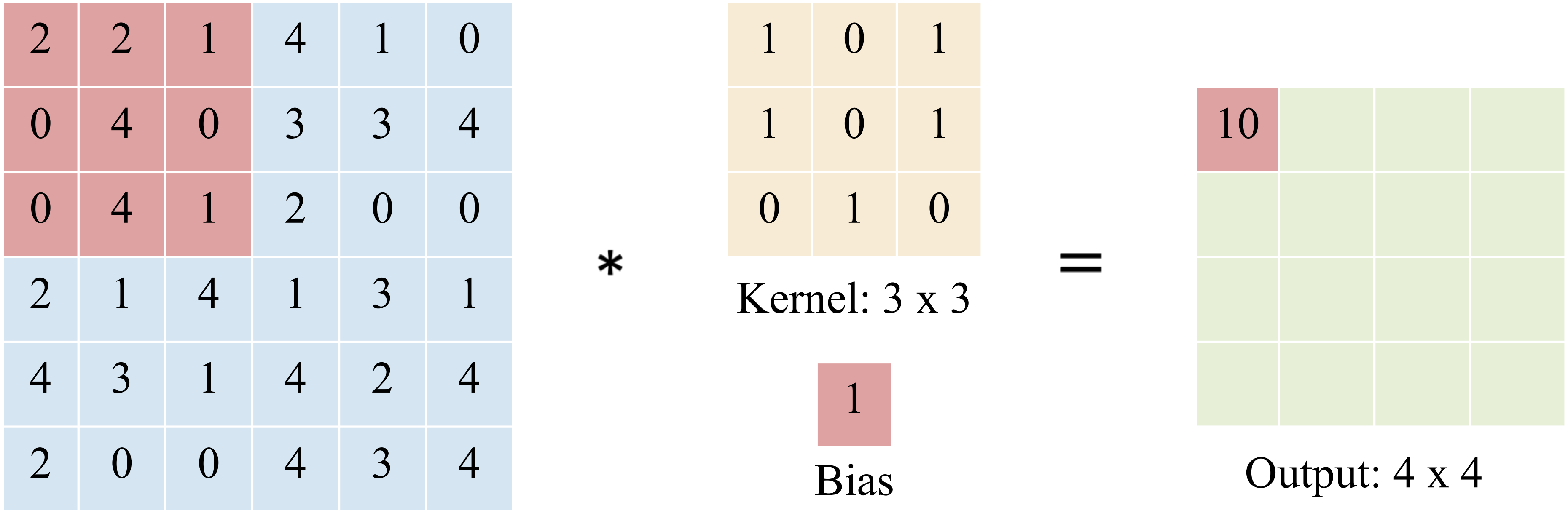
```
Parameter containing:
tensor([[[[1., 1., 0.],
          [1., 1., 0.],
          [1., 0., 1.]]]], requires_grad=True)
```

```
output = conv_layer(input)
output
```

```
tensor([[[ 9., 13.,  9., 13.],
         [14., 11., 13., 10.],
         [12., 17., 11., 14.],
         [12., 13., 13., 18.]]], grad_fn=<SqueezeBackward1>)
```

2 – Convolutional Layer

Convolutional Operation



2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1
4	3	1	4	2	4
2	0	0	4	3	4

Input: 6 x 6

*

1	0	1
1	0	1
0	1	0

Kernel: 3 x 3

1

Bias

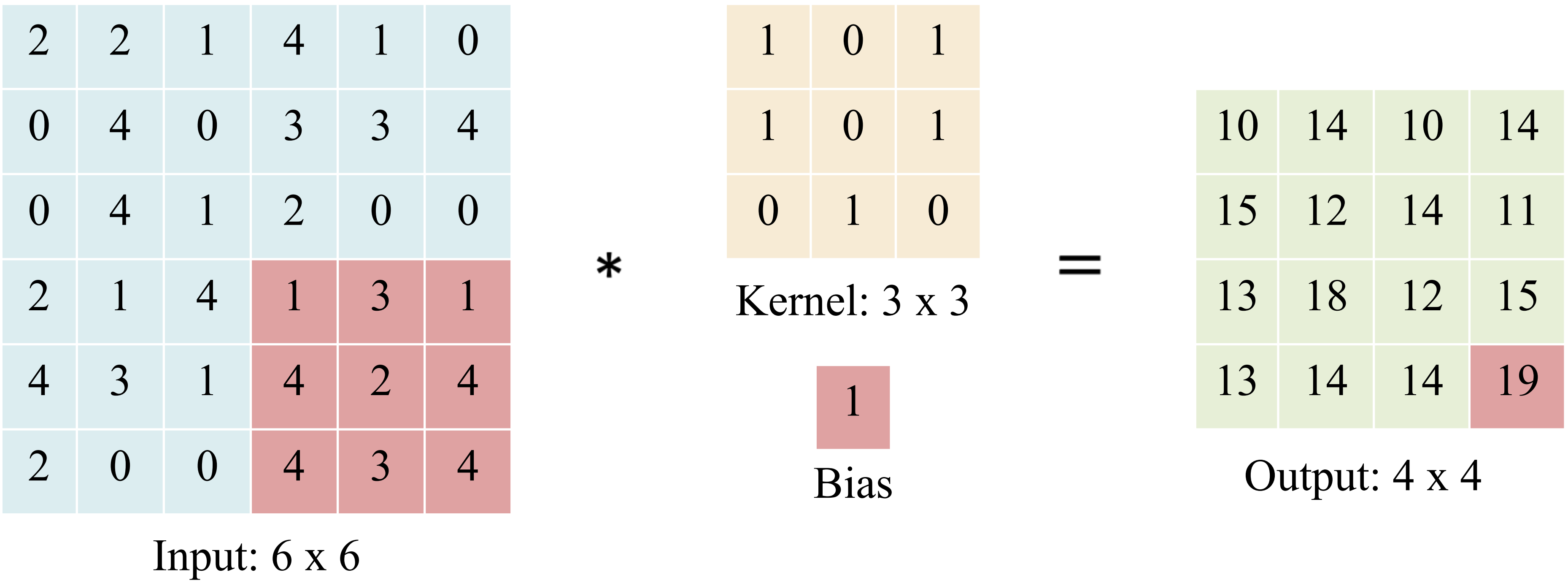
=

10			

Output: 4 x 4

2 – Convolutional Layer

Convolutional Operation



2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1
4	3	1	4	2	4
2	0	0	4	3	4

Input: 6 x 6

1	0	1
1	0	1
0	1	0

Kernel: 3 x 3

1

Bias

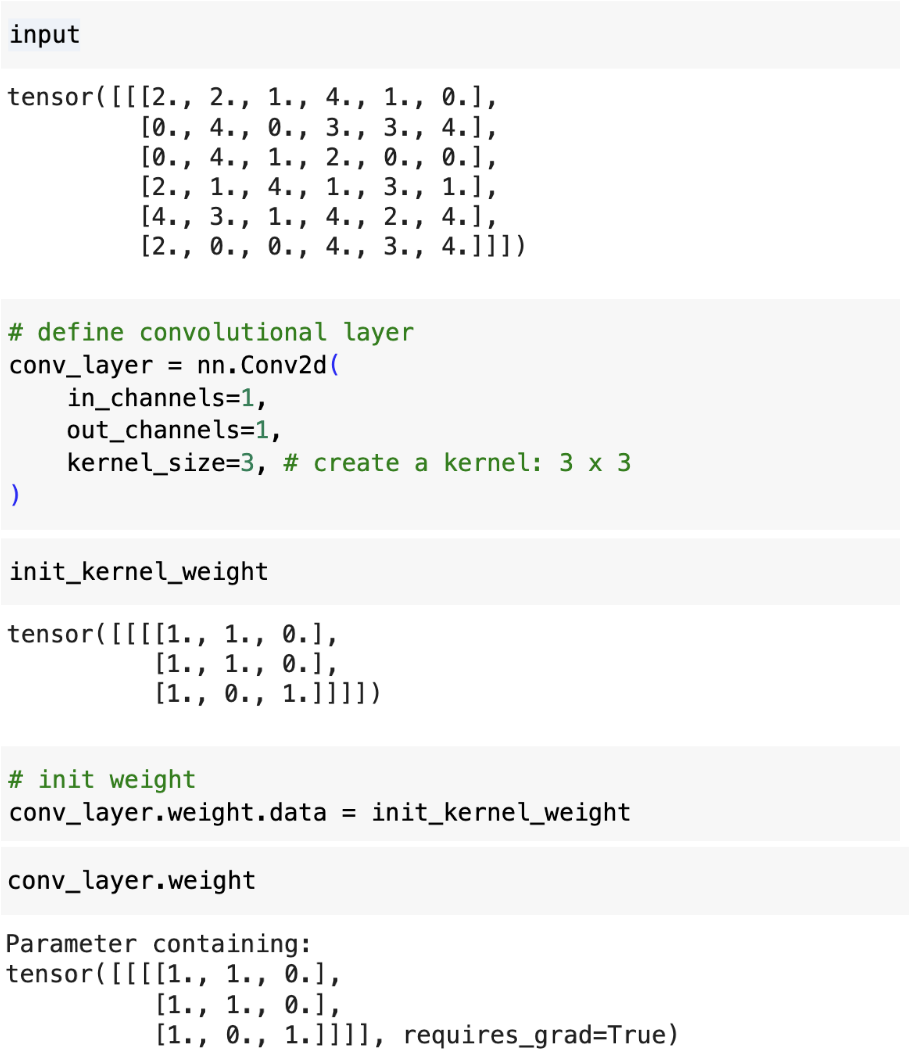
10	14	10	14
15	12	14	11
13	18	12	15
13	14	14	19

Output: 4 x 4

2 – Convolutional Layer

Convolutional Operation

❖ **Pytorch**



```
input
```

```
tensor([[[2., 2., 1., 4., 1., 0.],
         [0., 4., 0., 3., 3., 4.],
         [0., 4., 1., 2., 0., 0.],
         [2., 1., 4., 1., 3., 1.],
         [4., 3., 1., 4., 2., 4.],
         [2., 0., 0., 4., 3., 4.]]])
```

```
# define convolutional layer
conv_layer = nn.Conv2d(
    in_channels=1,
    out_channels=1,
    kernel_size=3, # create a kernel: 3 x 3
)
```

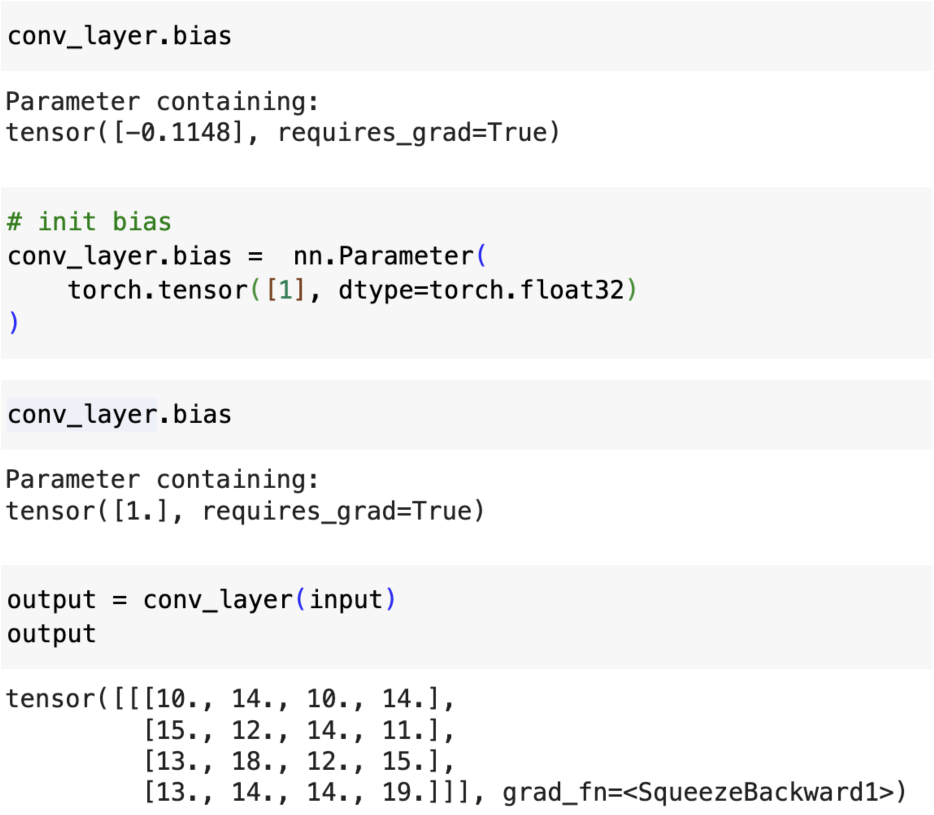
```
init_kernel_weight
```

```
tensor([[[[1., 1., 0.],
          [1., 1., 0.],
          [1., 0., 1.]]]])
```

```
# init weight
conv_layer.weight.data = init_kernel_weight
```

```
conv_layer.weight
```

```
Parameter containing:
tensor([[[[1., 1., 0.],
          [1., 1., 0.],
          [1., 0., 1.]]]], requires_grad=True)
```



```
conv_layer.bias
```

```
Parameter containing:
tensor([-0.1148], requires_grad=True)
```

```
# init bias
conv_layer.bias =  nn.Parameter(
    torch.tensor([1], dtype=torch.float32)
)
```

```
conv_layer.bias
```

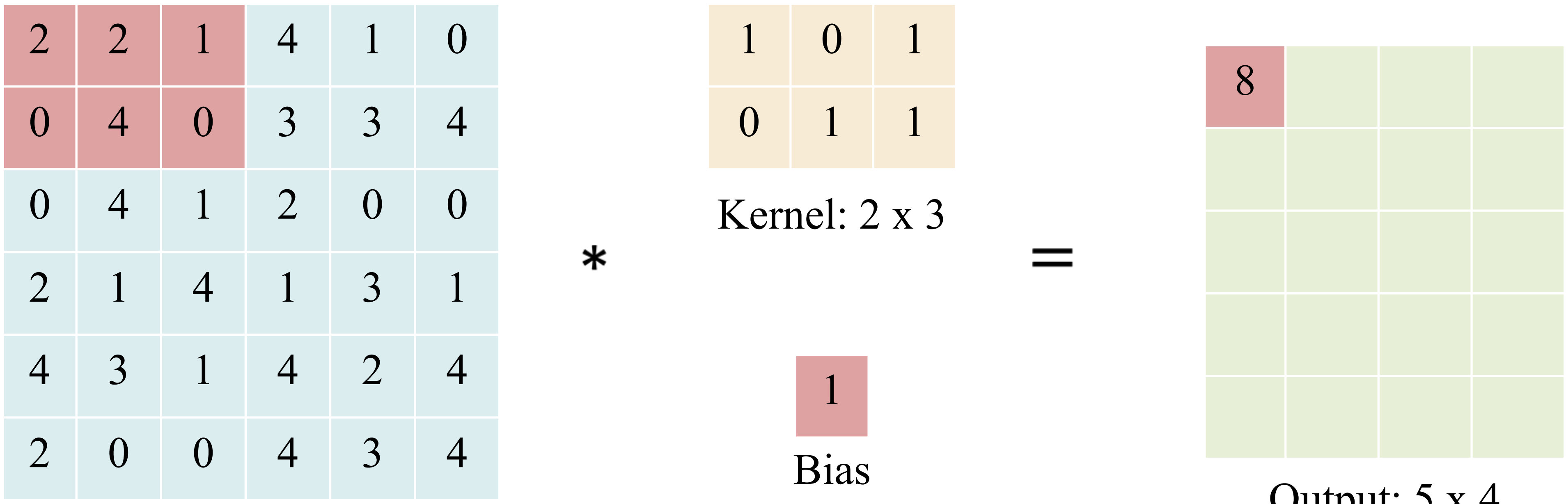
```
Parameter containing:
tensor([1.], requires_grad=True)
```

```
output = conv_layer(input)
output
```

```
tensor([[[10., 14., 10., 14.],
         [15., 12., 14., 11.],
         [13., 18., 12., 15.],
         [13., 14., 14., 19.]]], grad_fn=<SqueezeBackward1>)
```

2 – Convolutional Layer

Convolutional Operation



2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1
4	3	1	4	2	4
2	0	0	4	3	4

Input: 6 x 6

*

1	0	1
0	1	1

Kernel: 2 x 3

1

Bias

=

8			

Output: 5 x 4

2 – Convolutional Layer

Convolutional Operation

2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1
4	3	1	4	2	4
2	0	0	4	3	4

Input: 6 x 6

*

1	0	1
0	1	1

Kernel: 2 x 3

1

Bias

=

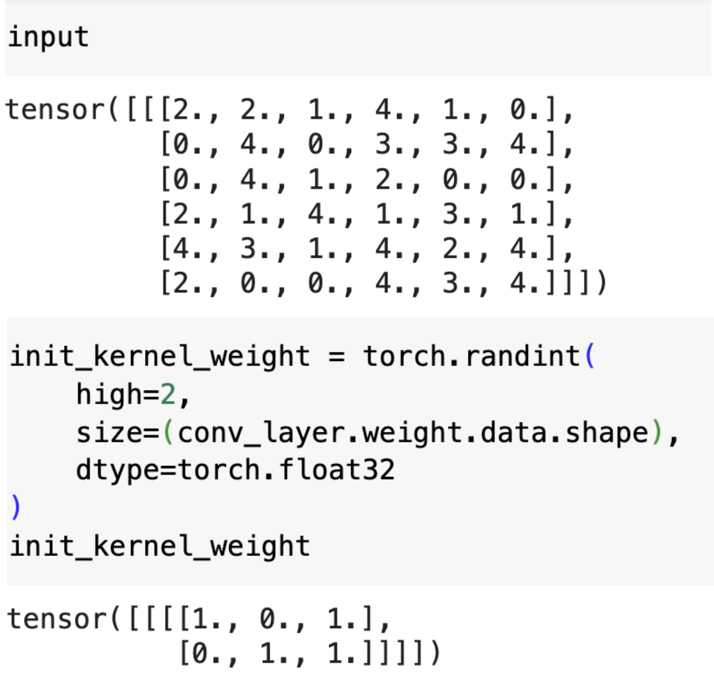
8	10	9	12
6	11	6	8
7	12	6	7
11	8	14	9
6	12	11	16

Output: 5 x 4

2 – Convolutional Layer

Convolutional Operation

Pytorch

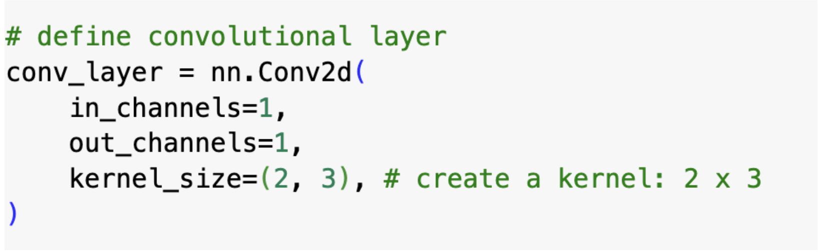


```
input
```

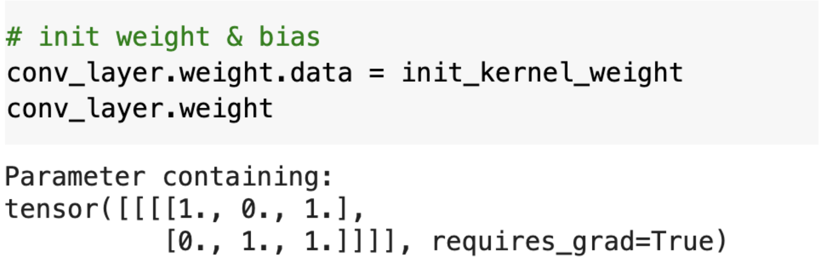
```
tensor([[[2., 2., 1., 4., 1., 0.],
         [0., 4., 0., 3., 3., 4.],
         [0., 4., 1., 2., 0., 0.],
         [2., 1., 4., 1., 3., 1.],
         [4., 3., 1., 4., 2., 4.],
         [2., 0., 0., 4., 3., 4.]]])
```

```
init_kernel_weight = torch.randint(
    high=2,
    size=(conv_layer.weight.data.shape),
    dtype=torch.float32
)
init_kernel_weight
```

```
tensor([[[[1., 0., 1.],
          [0., 1., 1.]]]])
```

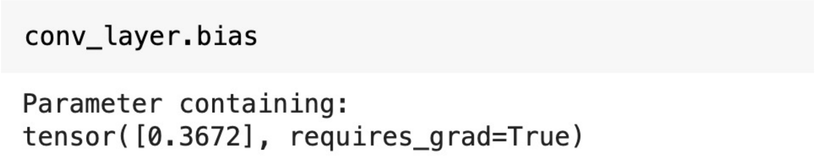


```
# define convolutional layer
conv_layer = nn.Conv2d(
    in_channels=1,
    out_channels=1,
    kernel_size=(2, 3), # create a kernel: 2 x 3
)
```



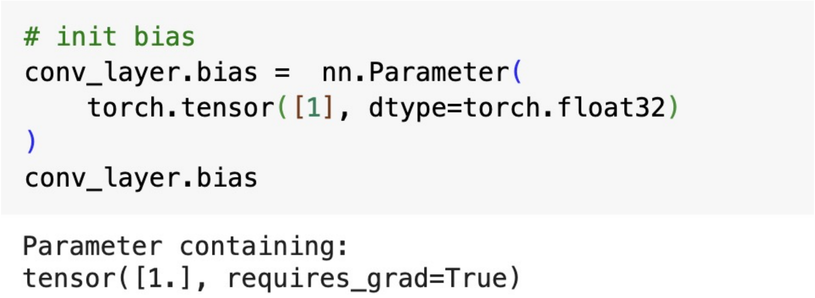
```
# init weight & bias
conv_layer.weight.data = init_kernel_weight
conv_layer.weight
```

```
Parameter containing:
tensor([[[[1., 0., 1.],
          [0., 1., 1.]]]], requires_grad=True)
```



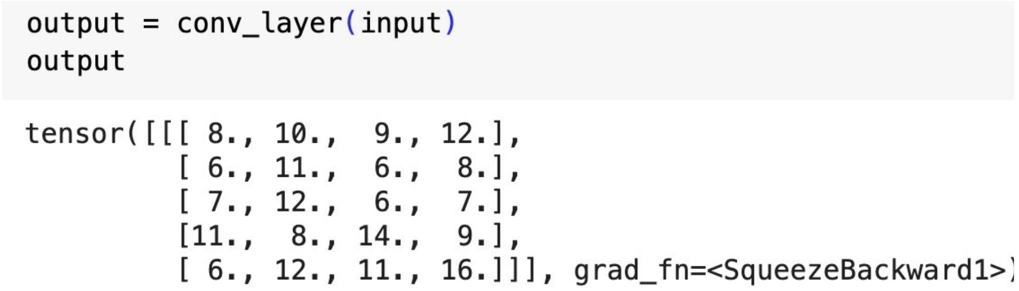
```
conv_layer.bias
```

```
Parameter containing:
tensor([0.3672], requires_grad=True)
```



```
# init bias
conv_layer.bias =  nn.Parameter(
    torch.tensor([1], dtype=torch.float32)
)
conv_layer.bias
```

```
Parameter containing:
tensor([1.], requires_grad=True)
```

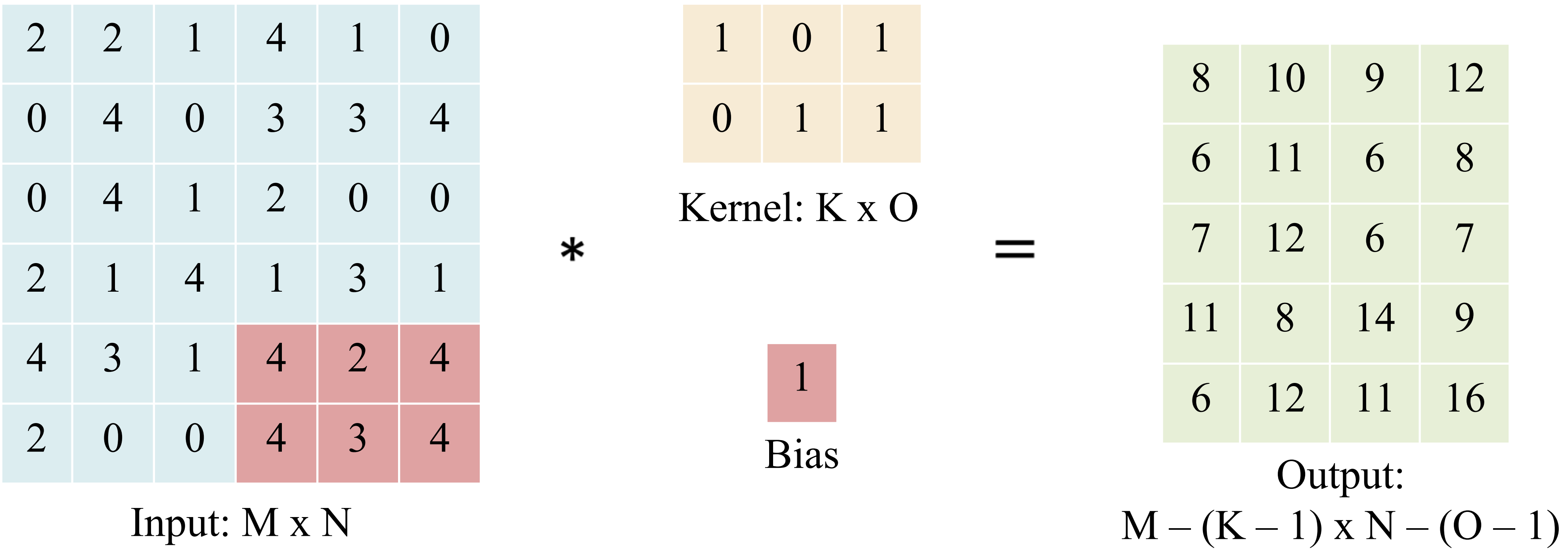


```
output = conv_layer(input)
output
```

```
tensor([[[ 8., 10.,  9., 12.],
         [ 6., 11.,  6.,  8.],
         [ 7., 12.,  6.,  7.],
         [11.,  8., 14.,  9.],
         [ 6., 12., 11., 16.]]], grad_fn=<SqueezeBackward1>)
```

2 – Convolutional Layer

Convolutional Operation



2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1
4	3	1	4	2	4
2	0	0	4	3	4

Input: M x N

*

1	0	1
0	1	1

Kernel: K x O

1

Bias

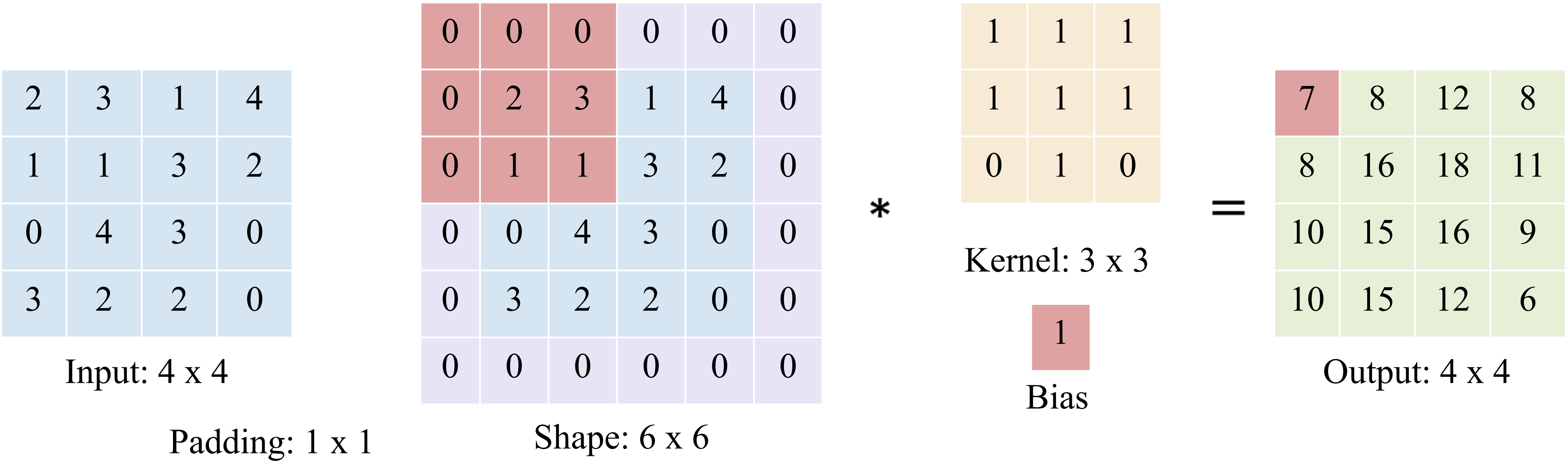
=

8	10	9	12
6	11	6	8
7	12	6	7
11	8	14	9
6	12	11	16

Output:
M – (K – 1) x N – (O – 1)

2 – Convolutional Layer

Padding



2	3	1	4
1	1	3	2
0	4	3	0
3	2	2	0

Input: 4 x 4

Padding: 1 x 1

0	0	0	0	0	0
0	2	3	1	4	0
0	1	1	3	2	0
0	0	4	3	0	0
0	3	2	2	0	0
0	0	0	0	0	0

Shape: 6 x 6

*

1	1	1
1	1	1
0	1	0

Kernel: 3 x 3

1

Bias

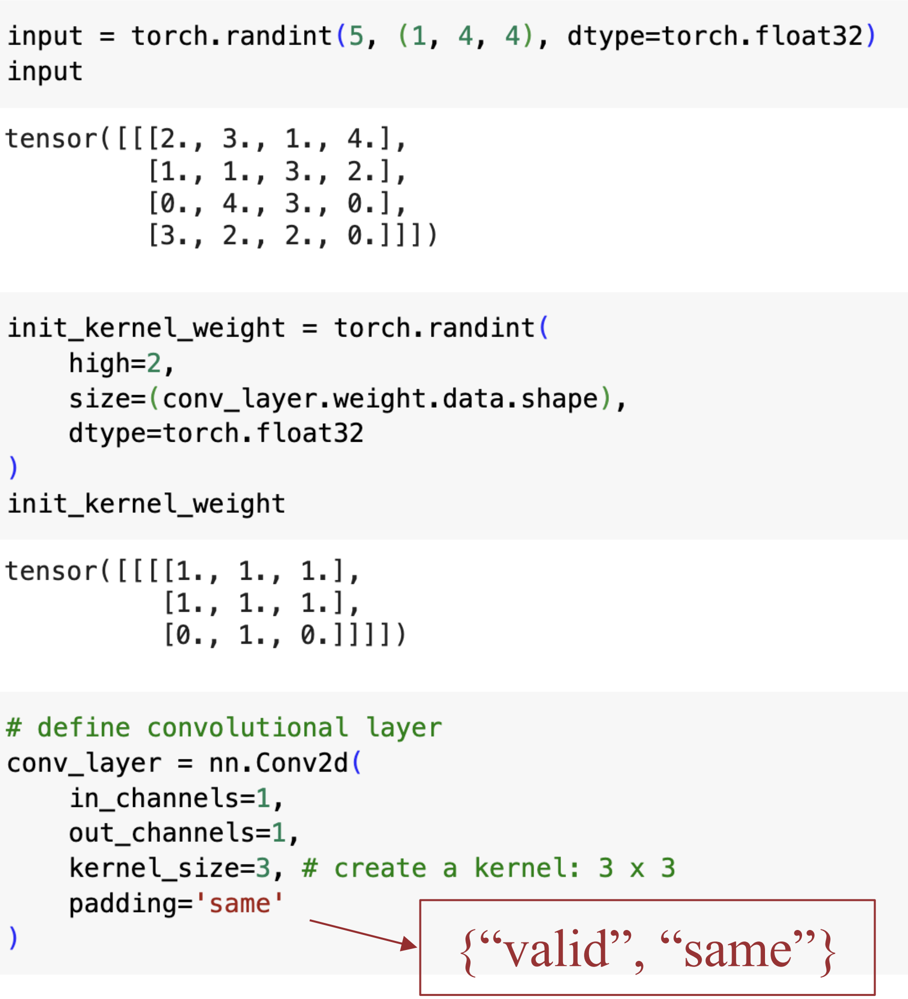
=

7	8	12	8
8	16	18	11
10	15	16	9
10	15	12	6

Output: 4 x 4

2 – Convolutional Layer

Padding



```
input = torch.randint(5, (1, 4, 4), dtype=torch.float32)
input
```

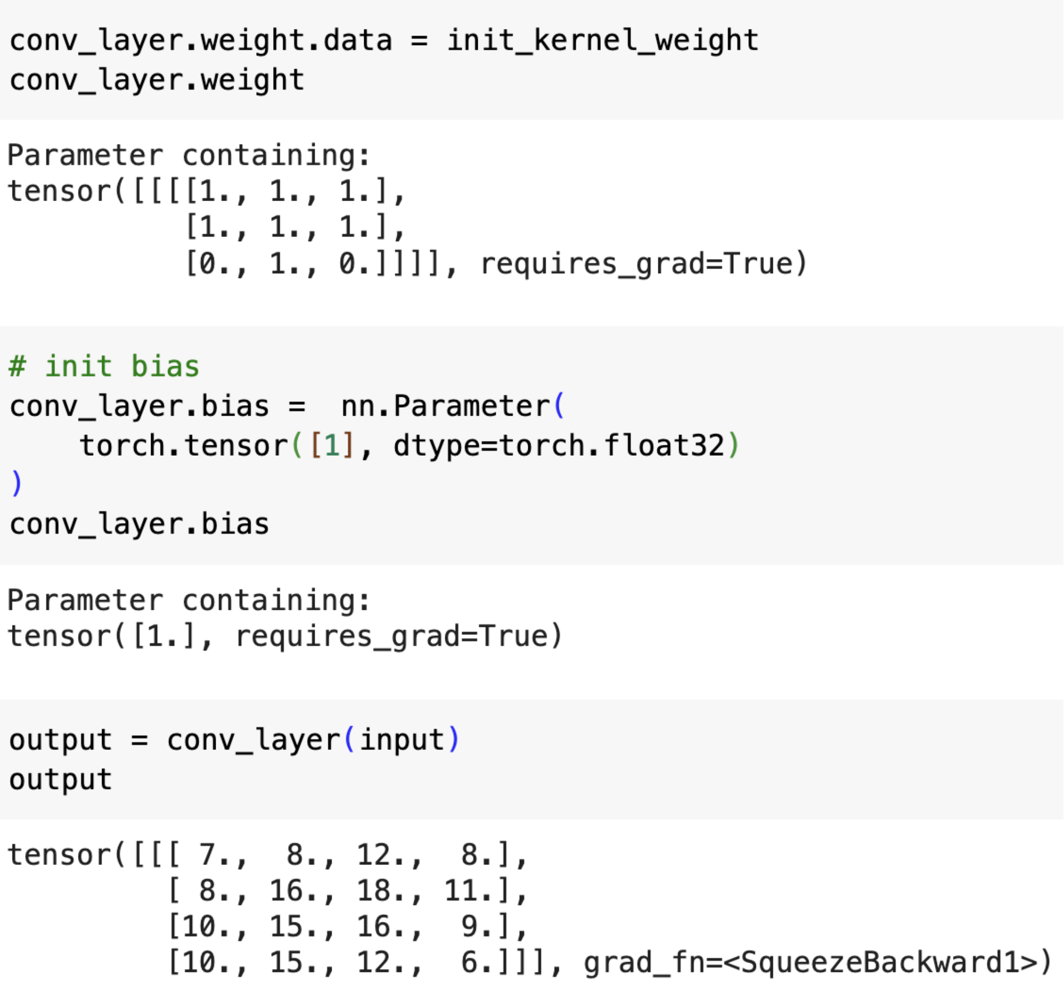
```
tensor([[[2., 3., 1., 4.],
         [1., 1., 3., 2.],
         [0., 4., 3., 0.],
         [3., 2., 2., 0.]]])
```

```
init_kernel_weight = torch.randint(
    high=2,
    size=(conv_layer.weight.data.shape),
    dtype=torch.float32
)
init_kernel_weight
```

```
tensor([[[[1., 1., 1.],
          [1., 1., 1.],
          [0., 1., 0.]]]])
```

```
# define convolutional layer
conv_layer = nn.Conv2d(
    in_channels=1,
    out_channels=1,
    kernel_size=3, # create a kernel: 3 x 3
    padding='same'
)
```

{“valid”, “same”}



```
conv_layer.weight.data = init_kernel_weight
conv_layer.weight
```

```
Parameter containing:
tensor([[[[1., 1., 1.],
          [1., 1., 1.],
          [0., 1., 0.]]]], requires_grad=True)
```

```
# init bias
conv_layer.bias =  nn.Parameter(
    torch.tensor([1], dtype=torch.float32)
)
conv_layer.bias
```

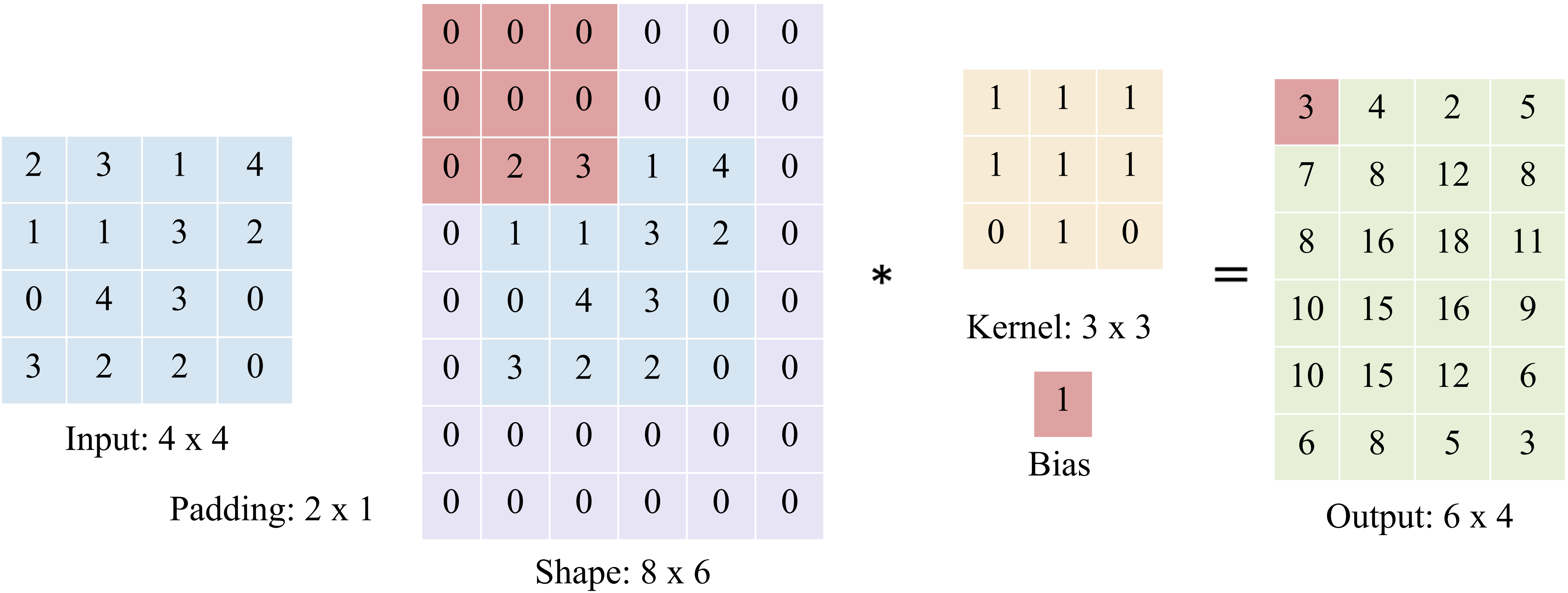
```
Parameter containing:
tensor([1.], requires_grad=True)
```

```
output = conv_layer(input)
output
```

```
tensor([[[ 7.,  8., 12.,  8.],
         [ 8., 16., 18., 11.],
         [10., 15., 16.,  9.],
         [10., 15., 12.,  6.]]], grad_fn=<SqueezeBackward1>)
```

2 – Convolutional Layer

Padding



2	3	1	4
1	1	3	2
0	4	3	0
3	2	2	0

Input: 4 x 4

Padding: 2 x 1

0	0	0	0	0	0
0	0	0	0	0	0
0	2	3	1	4	0
0	1	1	3	2	0
0	0	4	3	0	0
0	3	2	2	0	0
0	0	0	0	0	0
0	0	0	0	0	0

Shape: 8 x 6

*

1	1	1
1	1	1
0	1	0

Kernel: 3 x 3

1

Bias

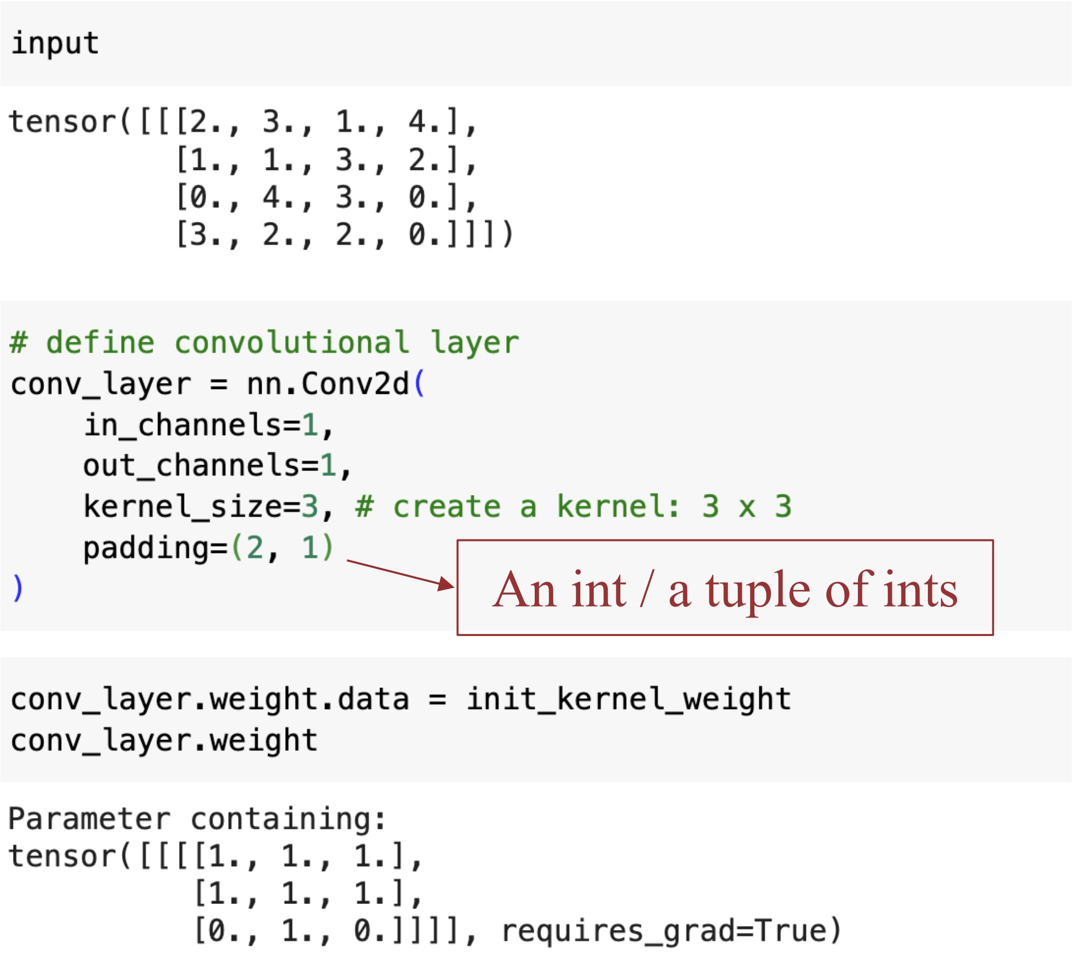
=

3	4	2	5
7	8	12	8
8	16	18	11
10	15	16	9
10	15	12	6
6	8	5	3

Output: 6 x 4

2 – Convolutional Layer

Padding



```
input
```

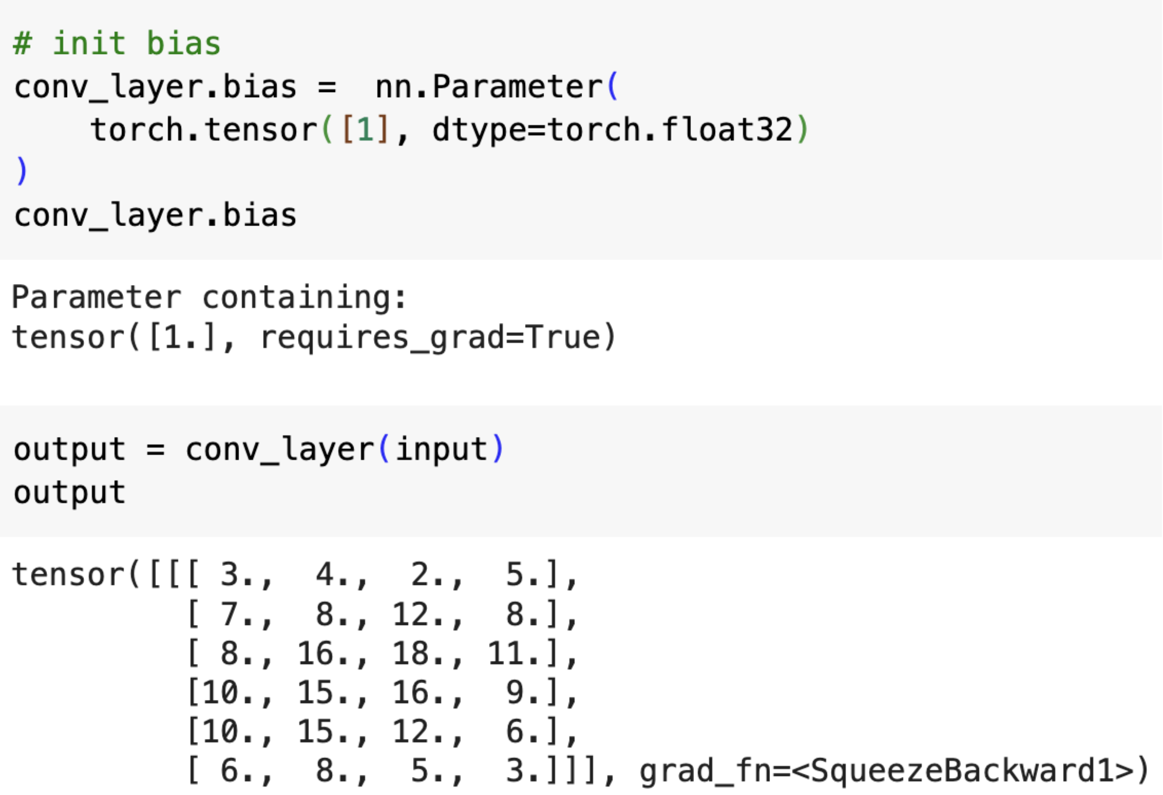
```
tensor([[[2., 3., 1., 4.],
         [1., 1., 3., 2.],
         [0., 4., 3., 0.],
         [3., 2., 2., 0.]]])
```

```
# define convolutional layer
conv_layer = nn.Conv2d(
    in_channels=1,
    out_channels=1,
    kernel_size=3, # create a kernel: 3 x 3
    padding=(2, 1)
)
```

An int / a tuple of ints

```
conv_layer.weight.data = init_kernel_weight
conv_layer.weight
```

```
Parameter containing:
tensor([[[[1., 1., 1.],
          [1., 1., 1.],
          [0., 1., 0.]]]], requires_grad=True)
```



```
# init bias
conv_layer.bias =  nn.Parameter(
    torch.tensor([1], dtype=torch.float32)
)
conv_layer.bias
```

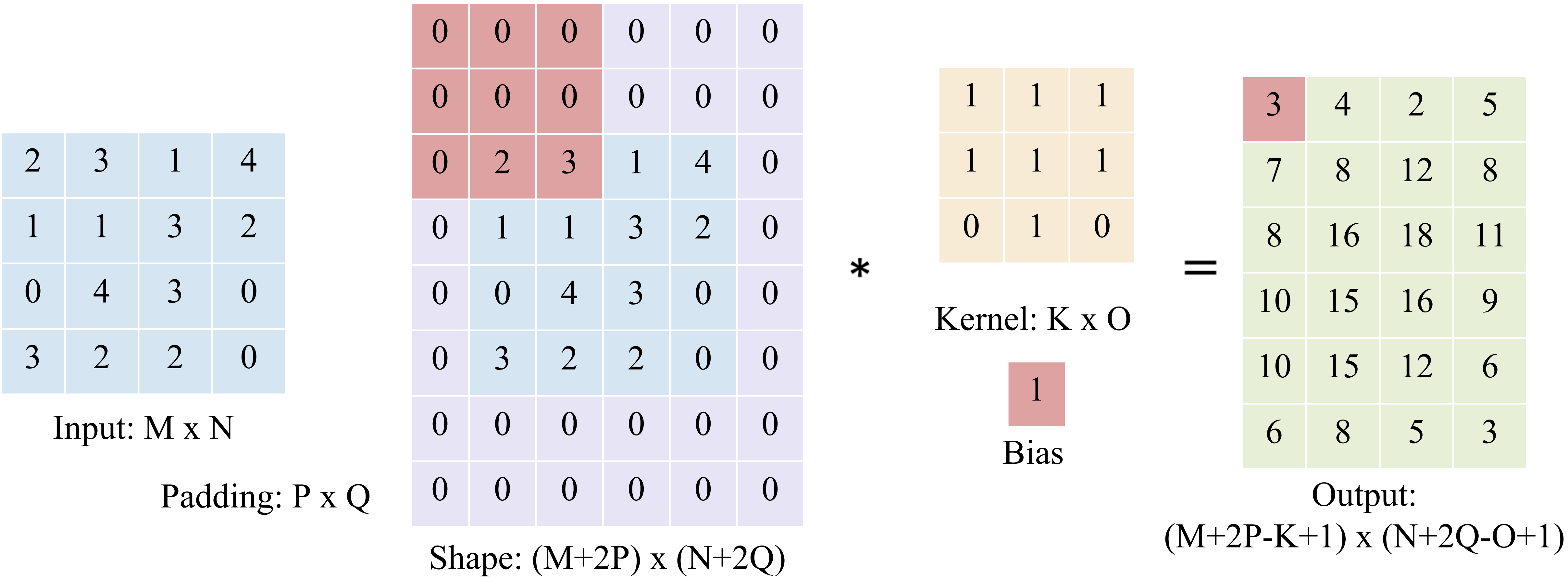
```
Parameter containing:
tensor([1.], requires_grad=True)
```

```
output = conv_layer(input)
output
```

```
tensor([[[ 3.,  4.,  2.,  5.],
         [ 7.,  8., 12.,  8.],
         [ 8., 16., 18., 11.],
         [10., 15., 16.,  9.],
         [10., 15., 12.,  6.],
         [ 6.,  8.,  5.,  3.]]], grad_fn=<SqueezeBackward1>)
```

2 – Convolutional Layer

Padding



2	3	1	4
1	1	3	2
0	4	3	0
3	2	2	0

Input: M x N

Padding: P x Q

0	0	0	0	0	0
0	0	0	0	0	0
0	2	3	1	4	0
0	1	1	3	2	0
0	0	4	3	0	0
0	3	2	2	0	0
0	0	0	0	0	0
0	0	0	0	0	0

Shape: (M+2P) x (N+2Q)

*

1	1	1
1	1	1
0	1	0

Kernel: K x O

1

Bias

=

3	4	2	5
7	8	12	8
8	16	18	11
10	15	16	9
10	15	12	6
6	8	5	3

Output:
(M+2P-K+1) x (N+2Q-O+1)

2 – Convolutional Layer

Stride

Stride: 1 (1x1)

1	0	1	3	1	3
0	1	4	0	0	4
0	2	0	3	3	2
2	2	1	3	2	2
1	3	0	3	1	0
3	2	3	3	4	3

Input: 6 x 6

*

1	1	1
1	1	1
0	1	0

Kernel: 3 x 3

1

Bias

=

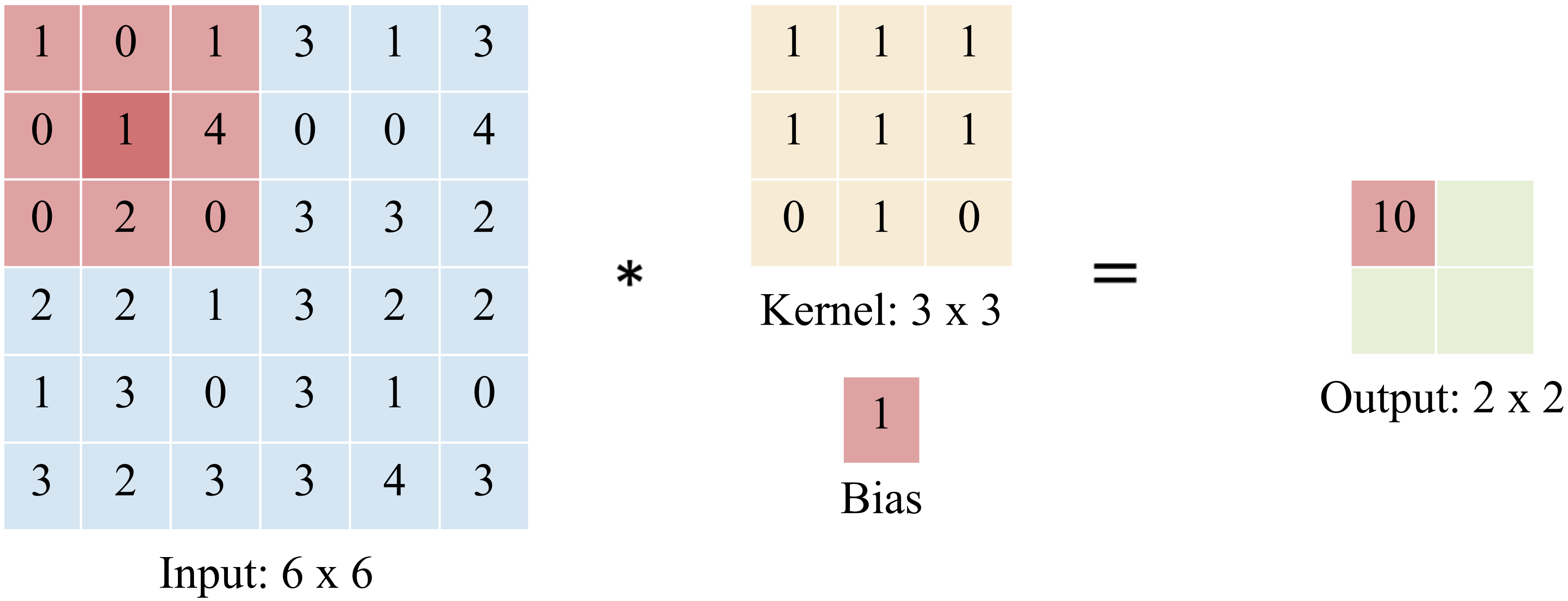
10	10	13	15
10	12	14	15
11	12	16	17
12	16	14	16

Output: 4 x 4

2 – Convolutional Layer

Stride

Stride: 2 (2x2)



1	0	1	3	1	3
0	1	4	0	0	4
0	2	0	3	3	2
2	2	1	3	2	2
1	3	0	3	1	0
3	2	3	3	4	3

Input: 6 x 6

1	1	1
1	1	1
0	1	0

Kernel: 3 x 3

1

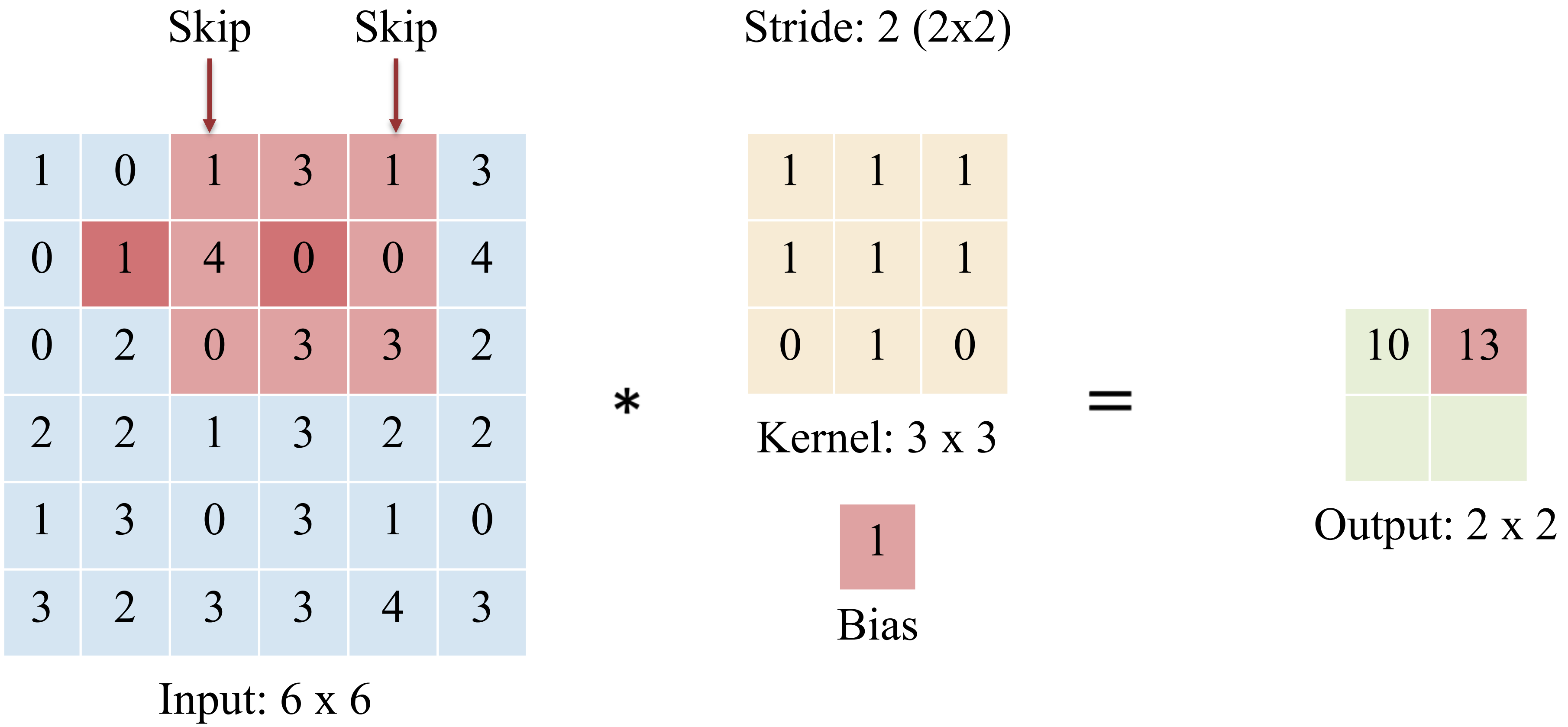
Bias

10	

Output: 2 x 2

2 – Convolutional Layer

Stride



Skip

Skip

Stride: 2 (2x2)

1	0	1	3	1	3
0	1	4	0	0	4
0	2	0	3	3	2
2	2	1	3	2	2
1	3	0	3	1	0
3	2	3	3	4	3

Input: 6 x 6

*

1	1	1
1	1	1
0	1	0

Kernel: 3 x 3

1

Bias

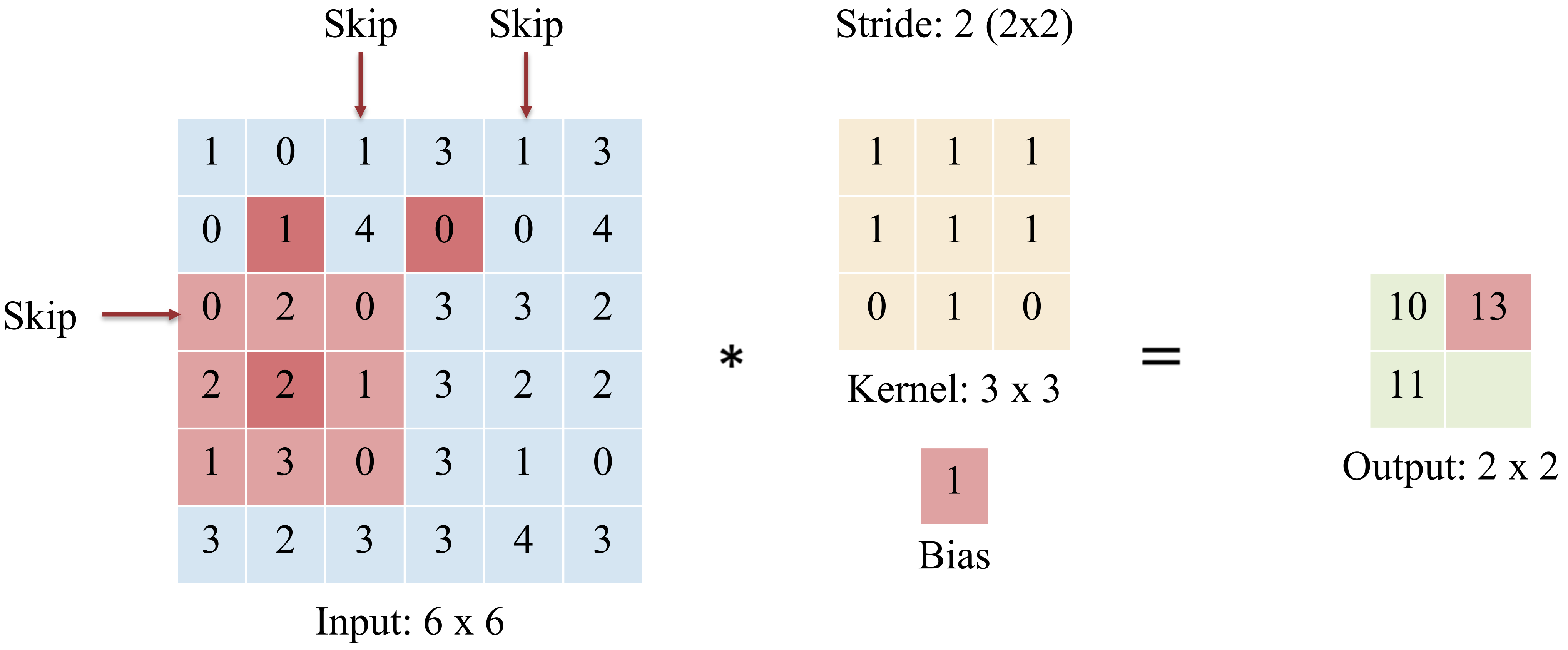
=

10	13

Output: 2 x 2

2 – Convolutional Layer

Stride



Stride: 2 (2x2)

1	0	1	3	1	3
0	1	4	0	0	4
0	2	0	3	3	2
2	2	1	3	2	2
1	3	0	3	1	0
3	2	3	3	4	3

Input: 6 x 6

1	1	1
1	1	1
0	1	0

Kernel: 3 x 3

1

Bias

10	13
11	

Output: 2 x 2

2 – Convolutional Layer

Stride

Stride: 2 (2x2)

1	0	1	3	1	3
0	1	4	0	0	4
0	2	0	3	3	2
2	2	1	3	2	2
1	3	0	3	1	0
3	2	3	3	4	3

Input: 6 x 6

*

1	1	1
1	1	1
0	1	0

Kernel: 3 x 3

1

Bias

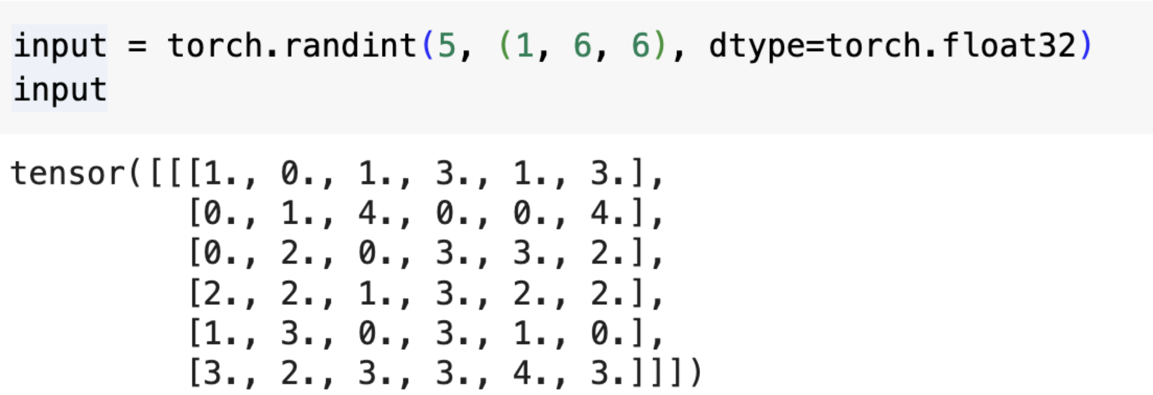
=

10	13
11	16

Output: 2 x 2

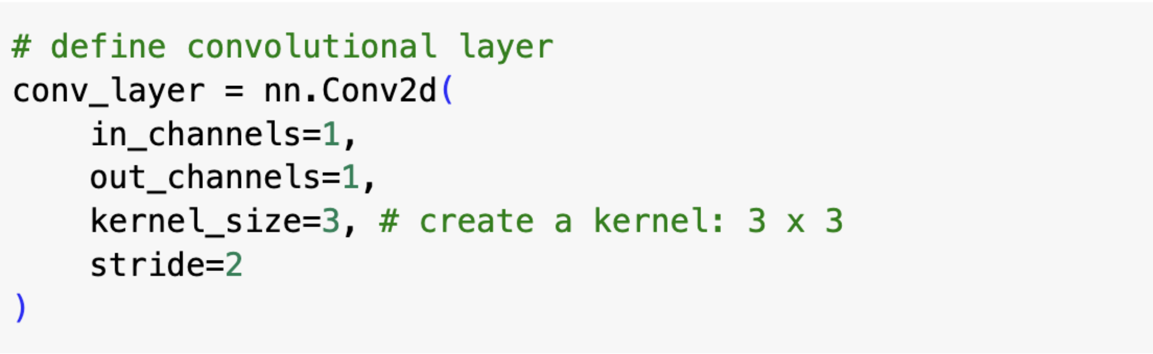
2 – Convolutional Layer

Stride

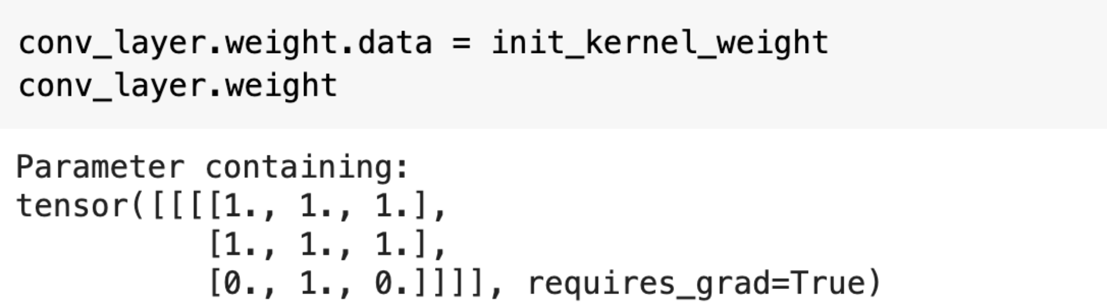


```
input = torch.randint(5, (1, 6, 6), dtype=torch.float32)
input
```

```
tensor([[[1., 0., 1., 3., 1., 3.],
         [0., 1., 4., 0., 0., 4.],
         [0., 2., 0., 3., 3., 2.],
         [2., 2., 1., 3., 2., 2.],
         [1., 3., 0., 3., 1., 0.],
         [3., 2., 3., 3., 4., 3.]]])
```

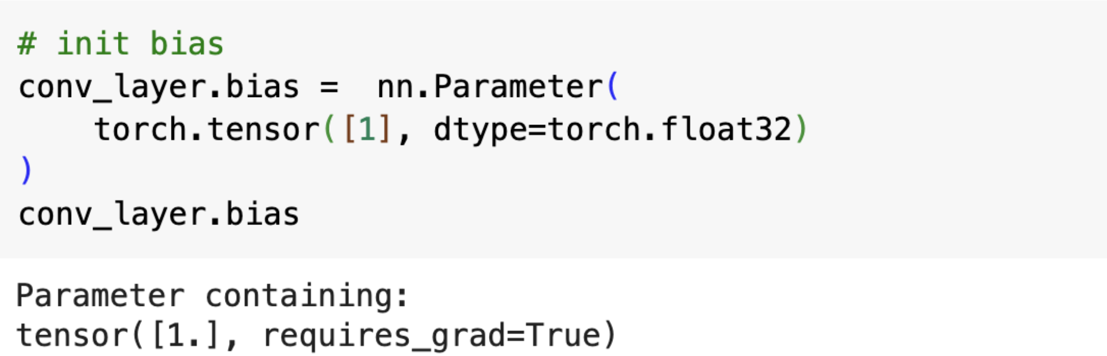


```
# define convolutional layer
conv_layer = nn.Conv2d(
    in_channels=1,
    out_channels=1,
    kernel_size=3, # create a kernel: 3 x 3
    stride=2
)
```



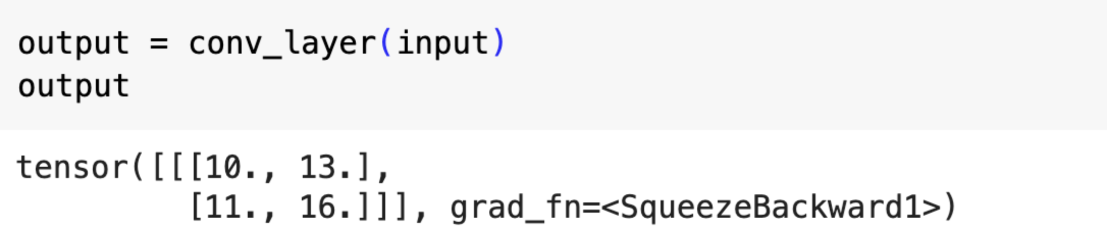
```
conv_layer.weight.data = init_kernel_weight
conv_layer.weight
```

```
Parameter containing:
tensor([[[[1., 1., 1.],
          [1., 1., 1.],
          [0., 1., 0.]]]], requires_grad=True)
```



```
# init bias
conv_layer.bias =  nn.Parameter(
    torch.tensor([1], dtype=torch.float32)
)
conv_layer.bias
```

```
Parameter containing:
tensor([1.], requires_grad=True)
```

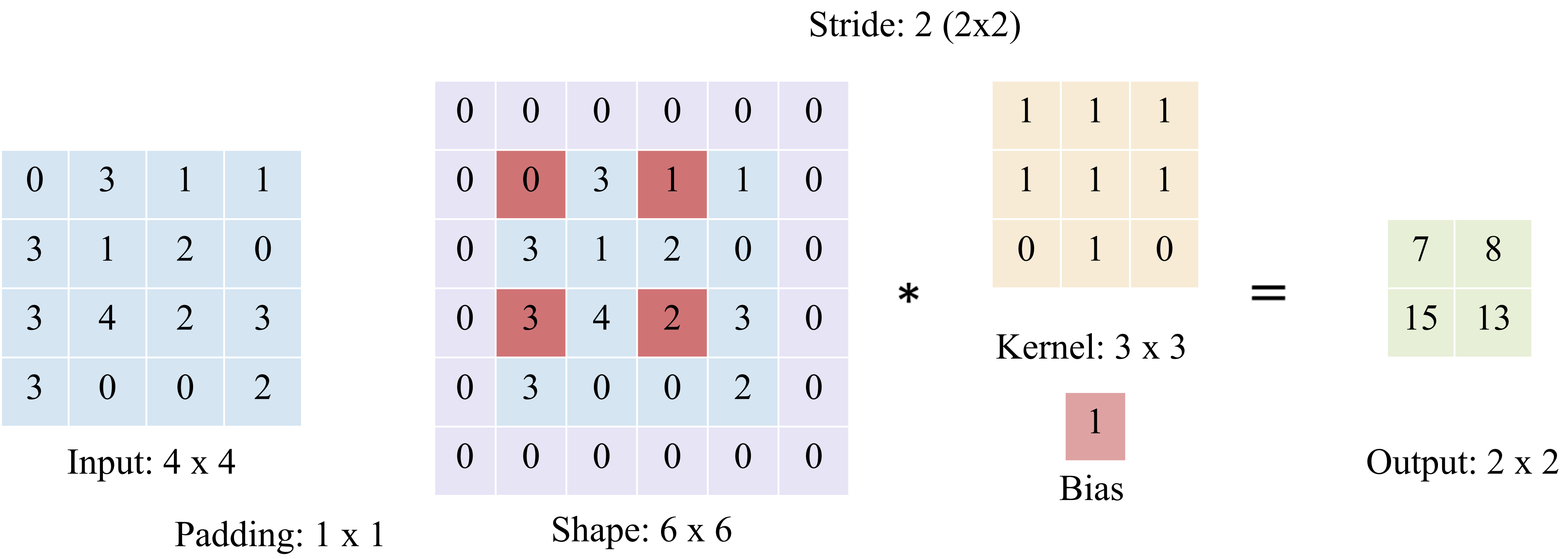


```
output = conv_layer(input)
output
```

```
tensor([[[10., 13.],
         [11., 16.]]], grad_fn=<SqueezeBackward1>)
```

2 – Convolutional Layer

Stride



Stride: 2 (2x2)

0	3	1	1
3	1	2	0
3	4	2	3
3	0	0	2

Input: 4 x 4

Padding: 1 x 1

0	0	0	0	0	0
0	0	3	1	1	0
0	3	1	2	0	0
0	3	4	2	3	0
0	3	0	0	2	0
0	0	0	0	0	0

Shape: 6 x 6

*

1	1	1
1	1	1
0	1	0

Kernel: 3 x 3

1

Bias

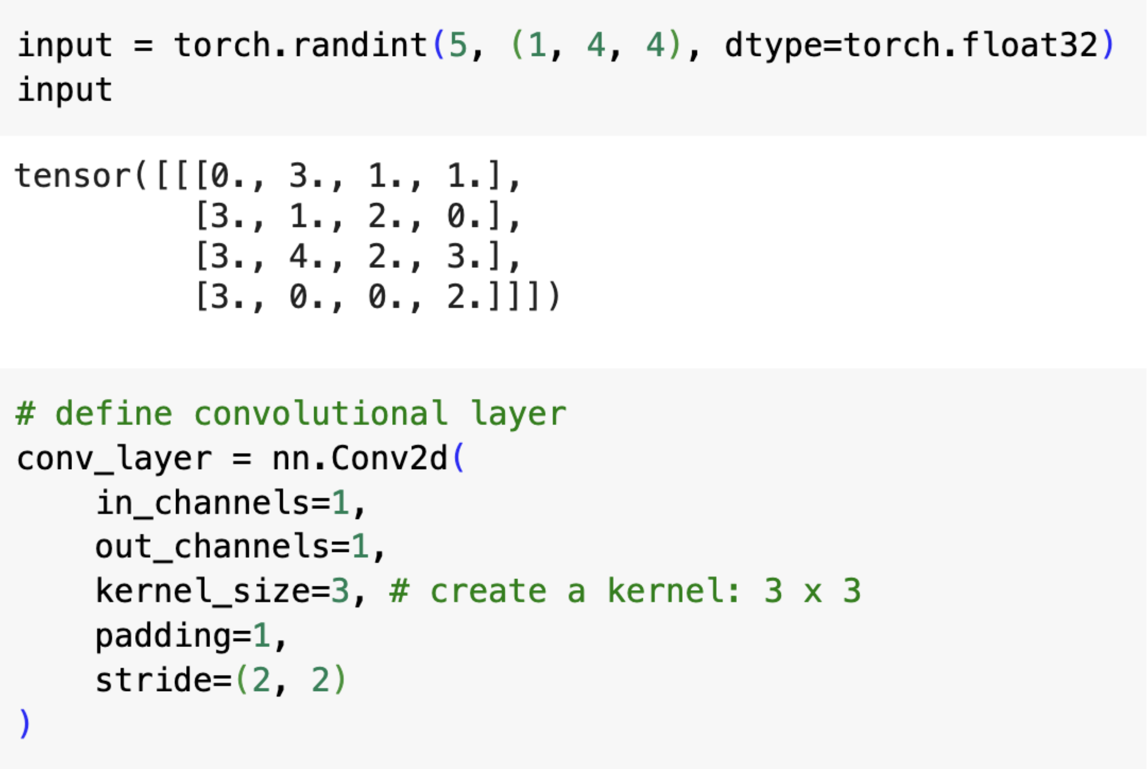
=

7	8
15	13

Output: 2 x 2

2 – Convolutional Layer

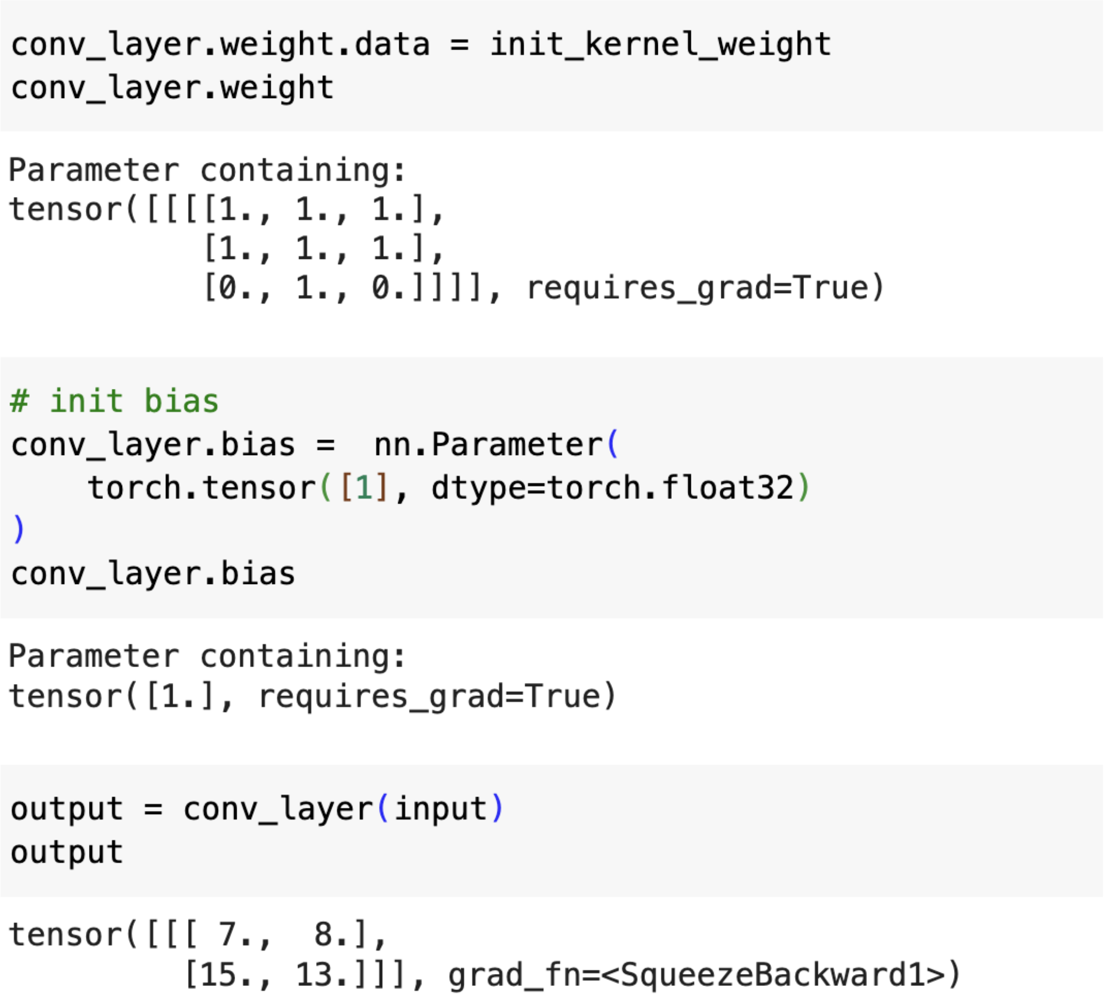
Stride



```
input = torch.randint(5, (1, 4, 4), dtype=torch.float32)
input
```

```
tensor([[[0., 3., 1., 1.],
         [3., 1., 2., 0.],
         [3., 4., 2., 3.],
         [3., 0., 0., 2.]]])
```

```
# define convolutional layer
conv_layer = nn.Conv2d(
    in_channels=1,
    out_channels=1,
    kernel_size=3, # create a kernel: 3 x 3
    padding=1,
    stride=(2, 2)
)
```



```
conv_layer.weight.data = init_kernel_weight
conv_layer.weight
```

```
Parameter containing:
tensor([[[[1., 1., 1.],
          [1., 1., 1.],
          [0., 1., 0.]]]], requires_grad=True)
```

```
# init bias
conv_layer.bias =  nn.Parameter(
    torch.tensor([1], dtype=torch.float32)
)
conv_layer.bias
```

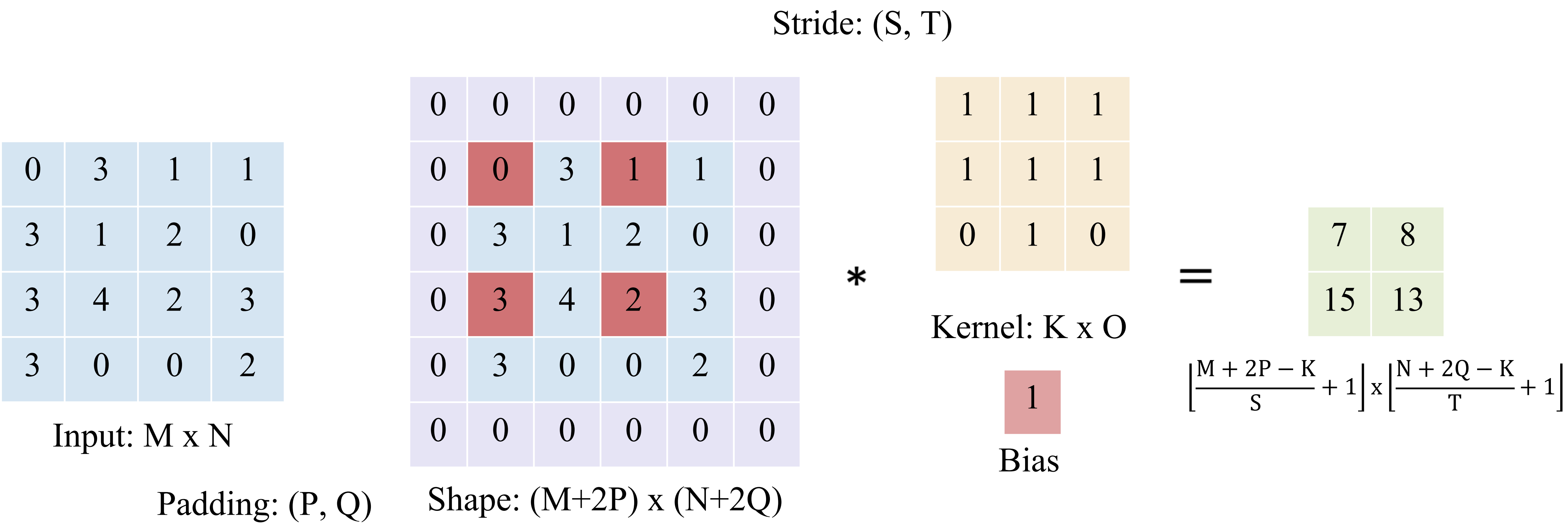
```
Parameter containing:
tensor([1.], requires_grad=True)
```

```
output = conv_layer(input)
output
```

```
tensor([[[ 7.,  8.],
         [15., 13.]]], grad_fn=<SqueezeBackward1>)
```

2 – Convolutional Layer

Stride



Stride: (S, T)

0	3	1	1
3	1	2	0
3	4	2	3
3	0	0	2

Input: M x N

Padding: (P, Q)

0	0	0	0	0	0
0	0	3	1	1	0
0	3	1	2	0	0
0	3	4	2	3	0
0	3	0	0	2	0
0	0	0	0	0	0

Shape: (M+2P) x (N+2Q)

*

1	1	1
1	1	1
0	1	0

Kernel: K x O

1

Bias

=

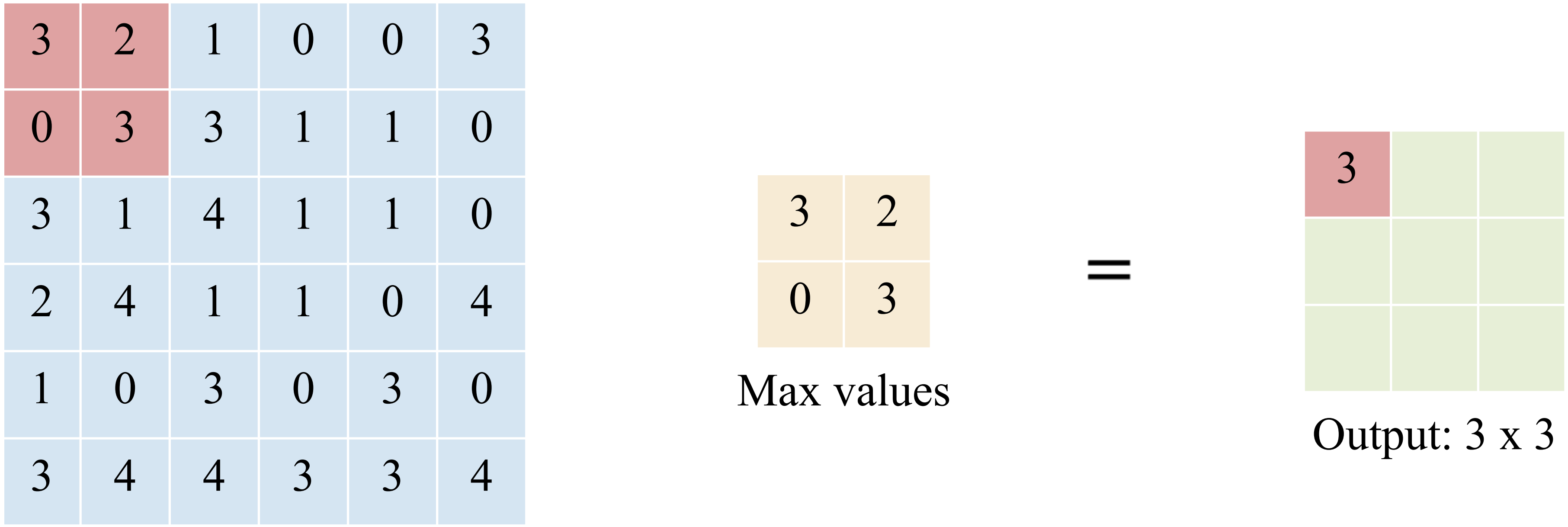
7	8
15	13

$$\left\lfloor \frac{M+2P-K}{S} + 1 \right\rfloor \text{x} \left\lfloor \frac{N+2Q-K}{T} + 1 \right\rfloor$$

3 – Pooling Layer

Max Pooling

Kernel Size: 2
Stride: 2



3	2	1	0	0	3
0	3	3	1	1	0
3	1	4	1	1	0
2	4	1	1	0	4
1	0	3	0	3	0
3	4	4	3	3	4

Input: 6 x 6

3	2
0	3

Max values

=

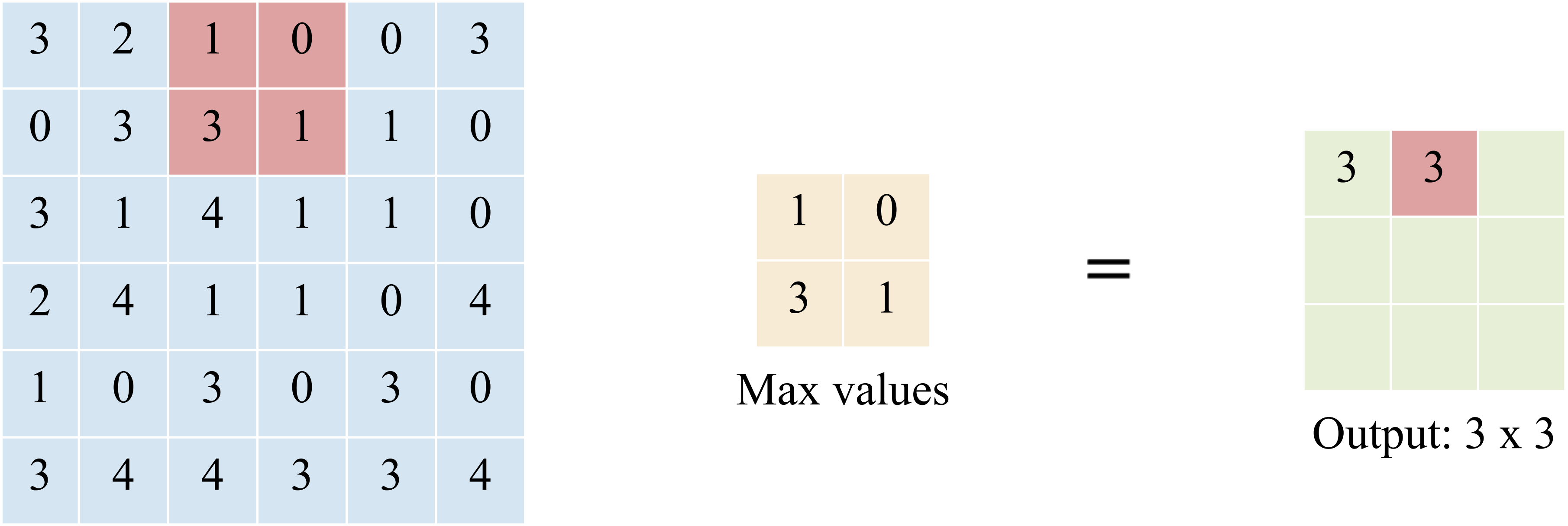
3		

Output: 3 x 3

3 – Pooling Layer

Max Pooling

Kernel Size: 2
Stride: 2



3	2	1	0	0	3
0	3	3	1	1	0
3	1	4	1	1	0
2	4	1	1	0	4
1	0	3	0	3	0
3	4	4	3	3	4

Input: 6 x 6

1	0
3	1

Max values

=

3	3	

Output: 3 x 3

3 – Pooling Layer

Max Pooling

Kernel Size: 2
Stride: 2

3	2	1	0	0	3
0	3	3	1	1	0
3	1	4	1	1	0
2	4	1	1	0	4
1	0	3	0	3	0
3	4	4	3	3	4

Input: 6 x 6

1	0
3	1

Max values

=

3	3	3
4	4	4
4	4	4

Output: 3 x 3

3 – Pooling Layer

Max Pooling

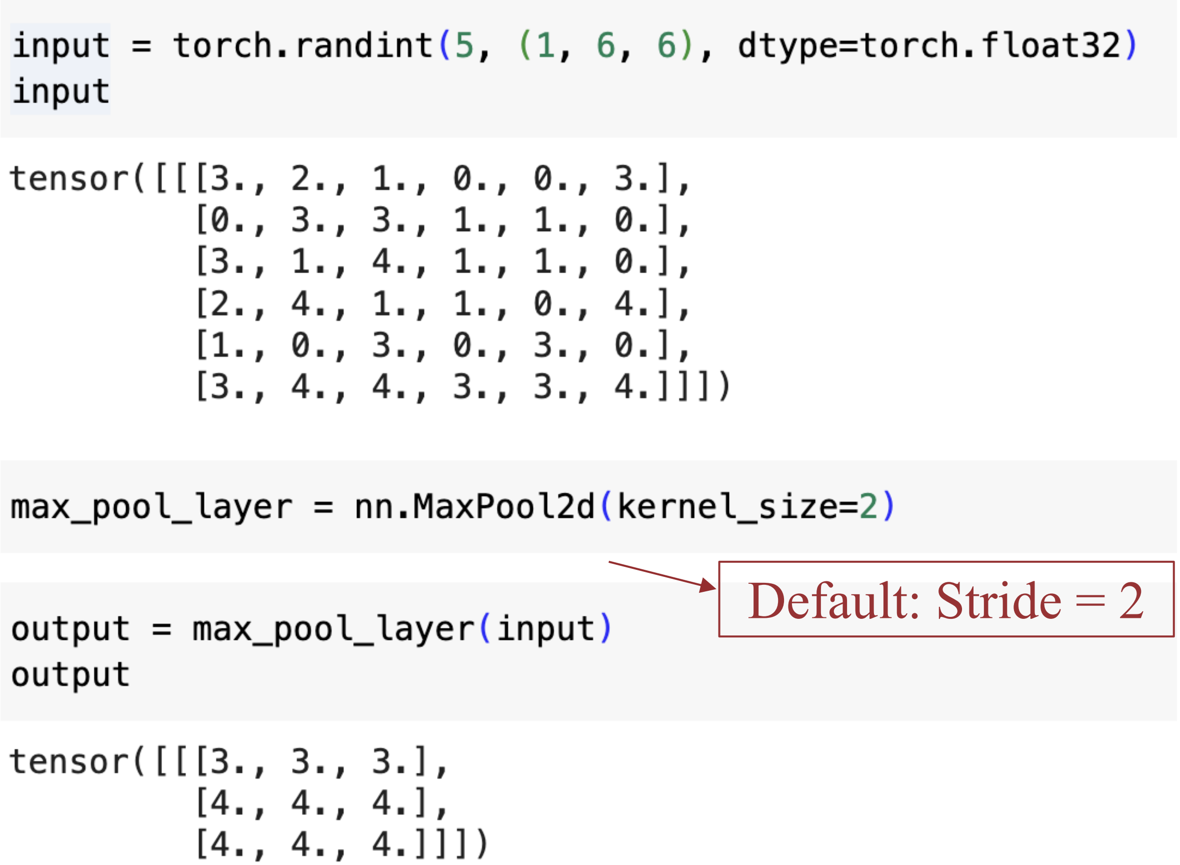
3	2	1	0	0	3
0	3	3	1	1	0
3	1	4	1	1	0
2	4	1	1	0	4
1	0	3	0	3	0
3	4	4	3	3	4

Input: 6 x 6

Kernel Size: 2
Stride: 2

3	3	3
4	4	4
4	4	4

Output: 3 x 3



```
input = torch.randint(5, (1, 6, 6), dtype=torch.float32)
input
```

```
tensor([[[3., 2., 1., 0., 0., 3.],
         [0., 3., 3., 1., 1., 0.],
         [3., 1., 4., 1., 1., 0.],
         [2., 4., 1., 1., 0., 4.],
         [1., 0., 3., 0., 3., 0.],
         [3., 4., 4., 3., 3., 4.]]])
```

```
max_pool_layer = nn.MaxPool2d(kernel_size=2)
```

Default: Stride = 2

```
output = max_pool_layer(input)
output
```

```
tensor([[[3., 3., 3.],
         [4., 4., 4.],
         [4., 4., 4.]]])
```

3 – Pooling Layer

Max Pooling

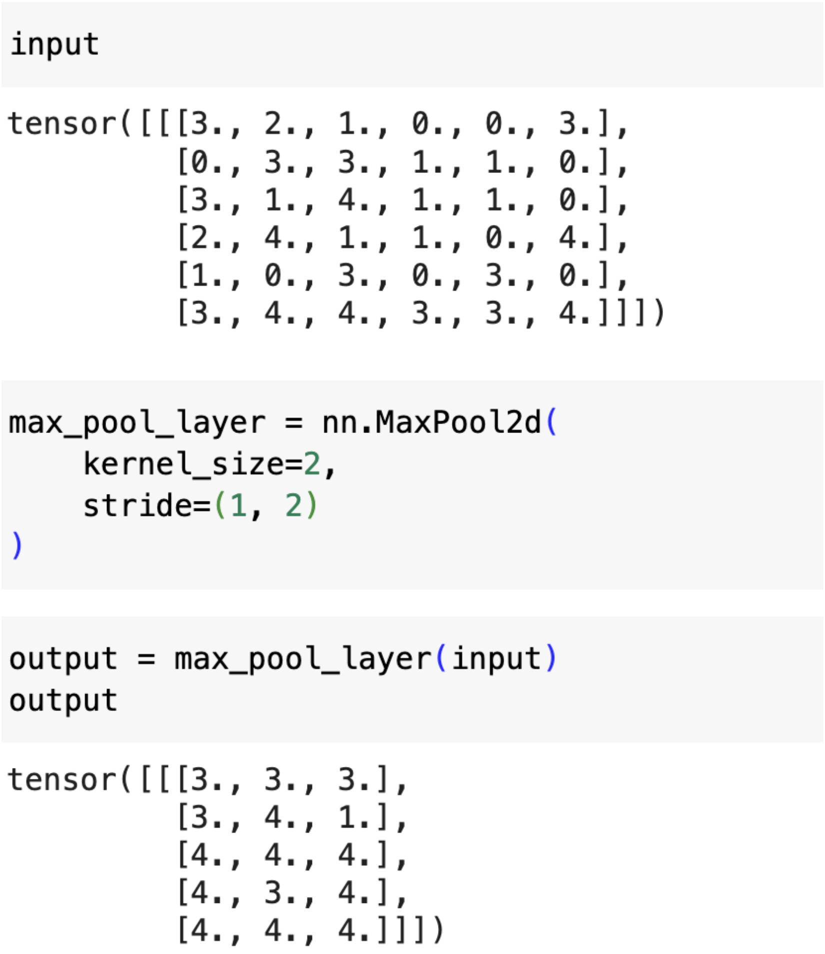
Kernel Size: 2
Stride: (1, 2)

3	2	1	0	0	3
0	3	3	1	1	0
3	1	4	1	1	0
2	4	1	1	0	4
1	0	3	0	3	0
3	4	4	3	3	4

Input: 6 x 6

3	3	4
3	4	1
4	4	4
4	3	4
4	4	4

Output: 5 x 3



```
input
```

```
tensor([[[3., 2., 1., 0., 0., 3.],
         [0., 3., 3., 1., 1., 0.],
         [3., 1., 4., 1., 1., 0.],
         [2., 4., 1., 1., 0., 4.],
         [1., 0., 3., 0., 3., 0.],
         [3., 4., 4., 3., 3., 4.]]])
```

```
max_pool_layer = nn.MaxPool2d(
    kernel_size=2,
    stride=(1, 2)
)
```

```
output = max_pool_layer(input)
output
```

```
tensor([[[3., 3., 3.],
         [3., 4., 1.],
         [4., 4., 4.],
         [4., 3., 4.],
         [4., 4., 4.]]])
```

3 – Pooling Layer

Max Pooling

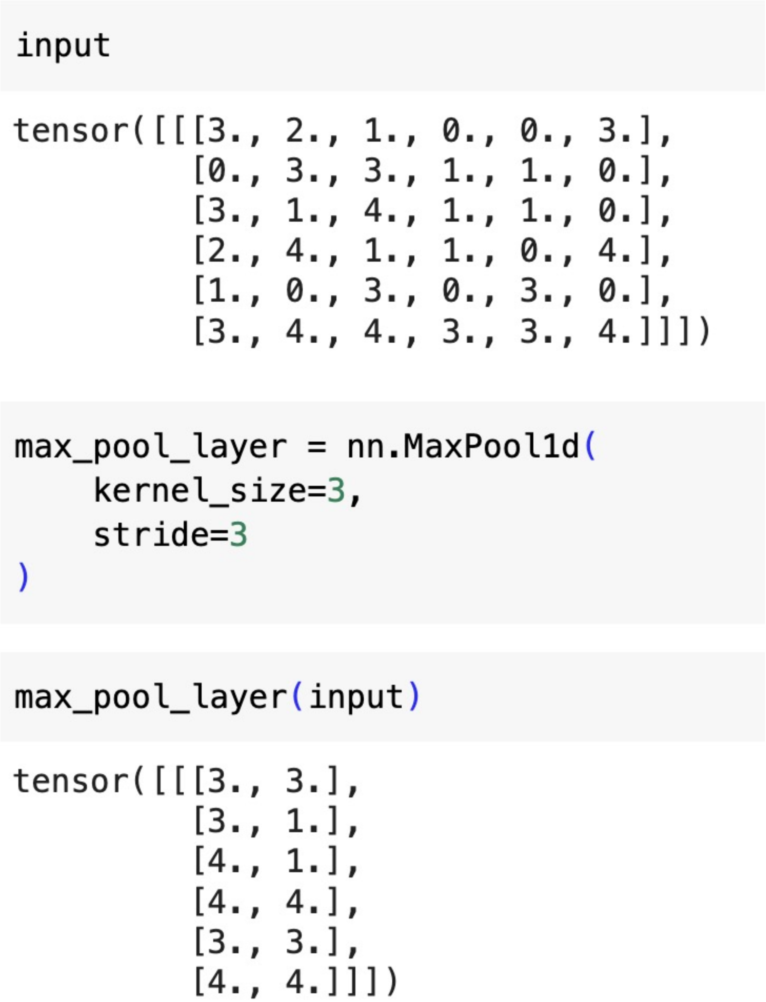
MaxPool1d
Kernel Size: 3
Stride: 3

3	2	1	0	0	3
0	3	3	1	1	0
3	1	4	1	1	0
2	4	1	1	0	4
1	0	3	0	3	0
3	4	4	3	3	4

Input: 6 x 6

3	3
3	1
4	1
4	4
3	3
4	4

Output: 4 x 3



```
input
```

```
tensor([[[3., 2., 1., 0., 0., 3.],
         [0., 3., 3., 1., 1., 0.],
         [3., 1., 4., 1., 1., 0.],
         [2., 4., 1., 1., 0., 4.],
         [1., 0., 3., 0., 3., 0.],
         [3., 4., 4., 3., 3., 4.]]])
```

```
max_pool_layer = nn.MaxPool1d(
    kernel_size=3,
    stride=3
)
```

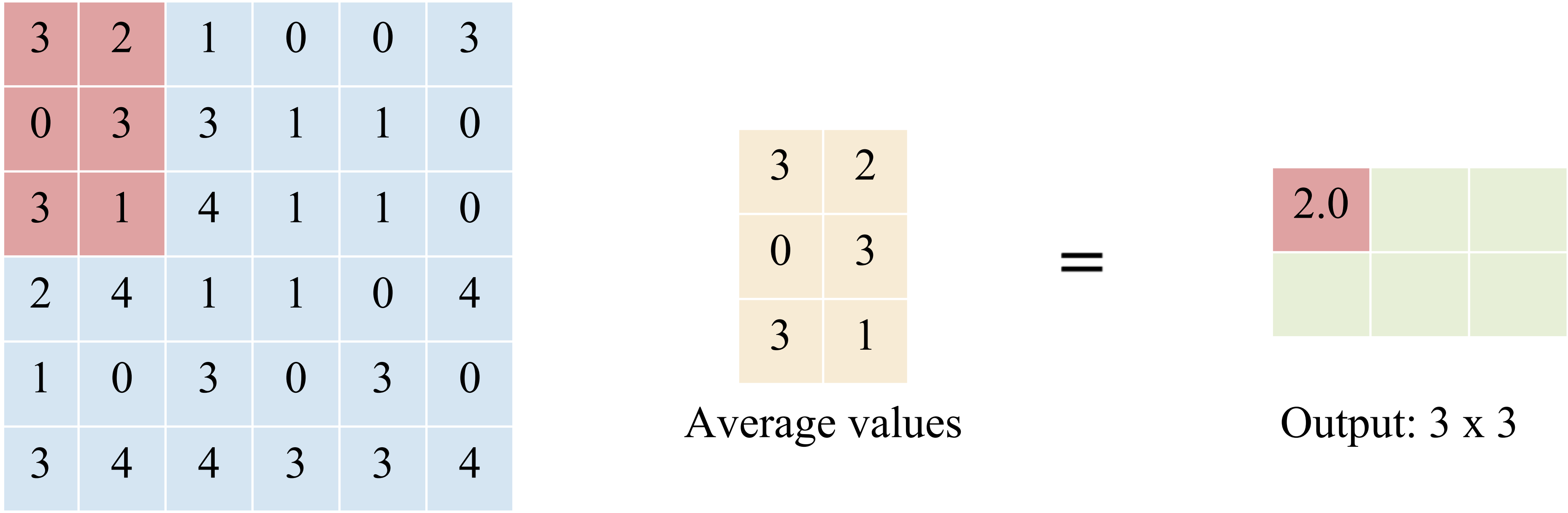
```
max_pool_layer(input)
```

```
tensor([[[3., 3.],
         [3., 1.],
         [4., 1.],
         [4., 4.],
         [3., 3.],
         [4., 4.]]])
```

3 – Pooling Layer

Average Pooling

Kernel Size: (3, 2)
Stride: 2



3	2	1	0	0	3
0	3	3	1	1	0
3	1	4	1	1	0
2	4	1	1	0	4
1	0	3	0	3	0
3	4	4	3	3	4

Input: 6 x 6

3	2
0	3
3	1

Average values

=

2.0		

Output: 3 x 3

3 – Pooling Layer

Average Pooling

Kernel Size: (3, 2)
Stride: 2

3	2	1	0	0	3
0	3	3	1	1	0
3	1	4	1	1	0
2	4	1	1	0	4
1	0	3	0	3	0
3	4	4	3	3	4

Input: 6 x 6

1	0
3	1
4	1

Average values

=

2	1.7	

Output: 2 x 3

3 – Pooling Layer

Average Pooling

Kernel Size: (3, 2)
Stride: 2

3	2	1	0	0	3
0	3	3	1	1	0
3	1	4	1	1	0
2	4	1	1	0	4
1	0	3	0	3	0
3	4	4	3	3	4

Input: 6 x 6

3	1
2	4
1	0

Average values

=

2	1.7	0.8
1.8		

Output: 2 x 3

3 – Pooling Layer

Average Pooling

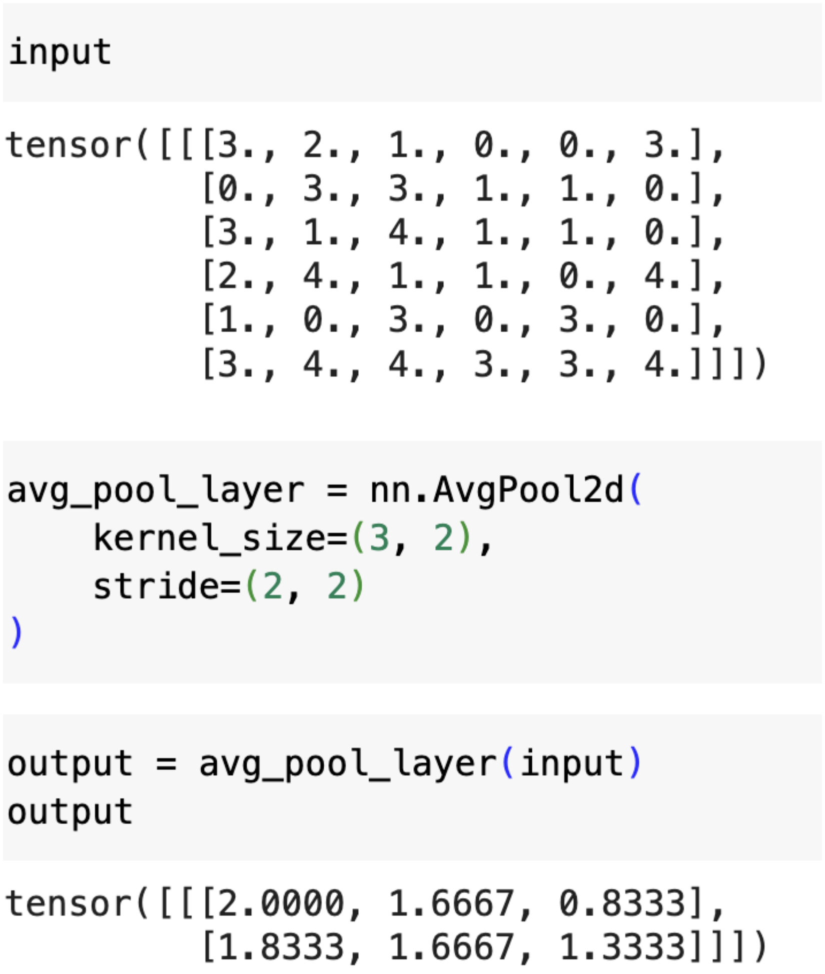
3	2	1	0	0	3
0	3	3	1	1	0
3	1	4	1	1	0
2	4	1	1	0	4
1	0	3	0	3	0
3	4	4	3	3	4

Input: 6 x 6

Kernel Size: (3, 2)
Stride: 2

2	1.7	0.8
1.8	1.6	1.3

Output: 3 x 3



```
input
```

```
tensor([[[3., 2., 1., 0., 0., 3.],
         [0., 3., 3., 1., 1., 0.],
         [3., 1., 4., 1., 1., 0.],
         [2., 4., 1., 1., 0., 4.],
         [1., 0., 3., 0., 3., 0.],
         [3., 4., 4., 3., 3., 4.]]])
```

```
avg_pool_layer = nn.AvgPool2d(
    kernel_size=(3, 2),
    stride=(2, 2)
)
```

```
output = avg_pool_layer(input)
output
```

```
tensor([[[2.0000, 1.6667, 0.8333],
         [1.8333, 1.6667, 1.3333]]])
```

3 – Pooling Layer

Average Pooling

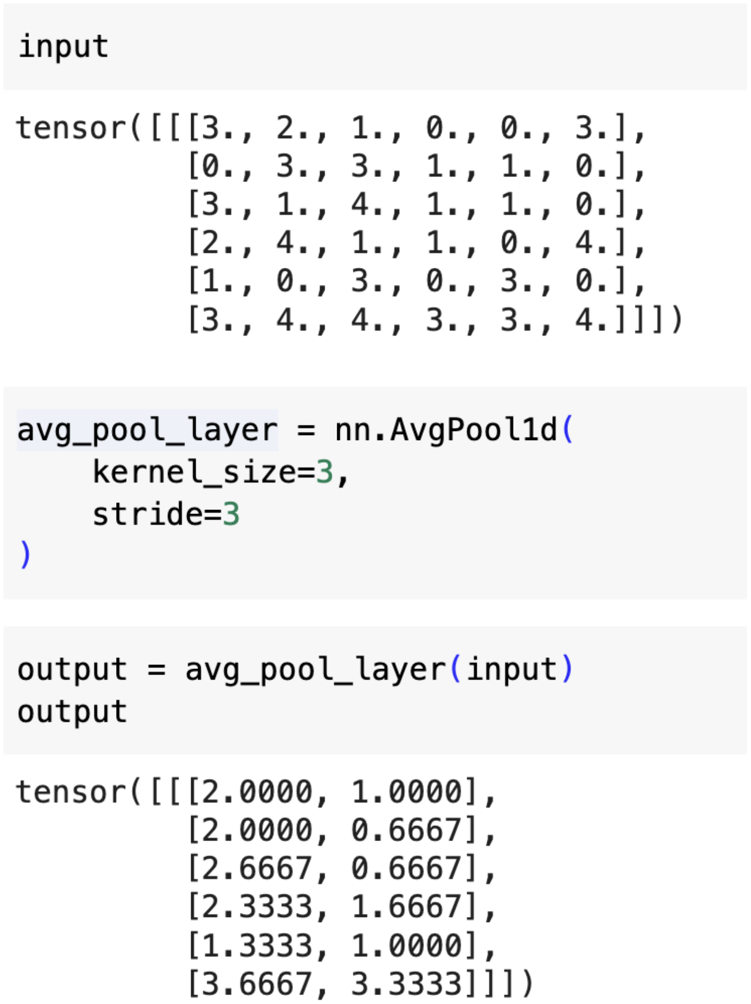
AvgPool1d
Kernel Size: 3
Stride: 3

3	2	1	0	0	3
0	3	3	1	1	0
3	1	4	1	1	0
2	4	1	1	0	4
1	0	3	0	3	0
3	4	4	3	3	4

Input: 6 x 6

2.0	1.0
2.0	0.7
2.7	0.7
2.3	1.7
1.3	1.0
3.7	3.3

Output: 4 x 3



```
input
```

```
tensor([[[3., 2., 1., 0., 0., 3.],
         [0., 3., 3., 1., 1., 0.],
         [3., 1., 4., 1., 1., 0.],
         [2., 4., 1., 1., 0., 4.],
         [1., 0., 3., 0., 3., 0.],
         [3., 4., 4., 3., 3., 4.]]])
```

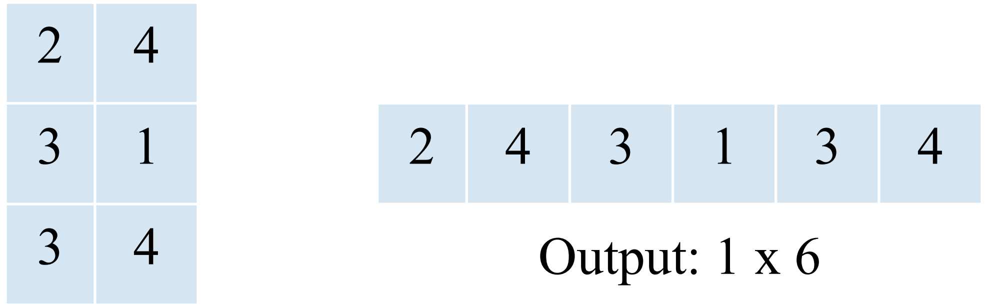
```
avg_pool_layer = nn.AvgPool1d(
    kernel_size=3,
    stride=3
)
```

```
output = avg_pool_layer(input)
output
```

```
tensor([[[2.0000, 1.0000],
         [2.0000, 0.6667],
         [2.6667, 0.6667],
         [2.3333, 1.6667],
         [1.3333, 1.0000],
         [3.6667, 3.3333]]])
```

4 - Flatten

Flattens a contiguous range of dims into a tensor

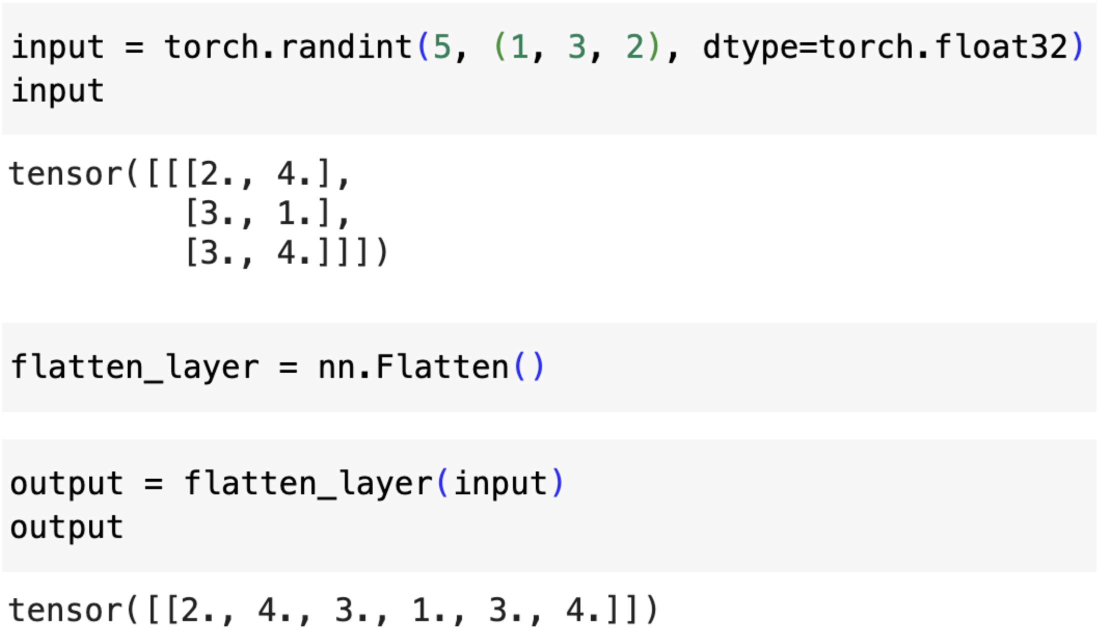


2	4
3	1
3	4

Input: 3 x 2

2	4	3	1	3	4

Output: 1 x 6



```
input = torch.randint(5, (1, 3, 2), dtype=torch.float32)
input
```

```
tensor([[[2., 4.],
         [3., 1.],
         [3., 4.]]])
```

```
flatten_layer = nn.Flatten()
```

```
output = flatten_layer(input)
output
```

```
tensor([[2., 4., 3., 1., 3., 4.]])
```

1 Exercise – Convolutional Layer

2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1

Input: 4 x 6

*

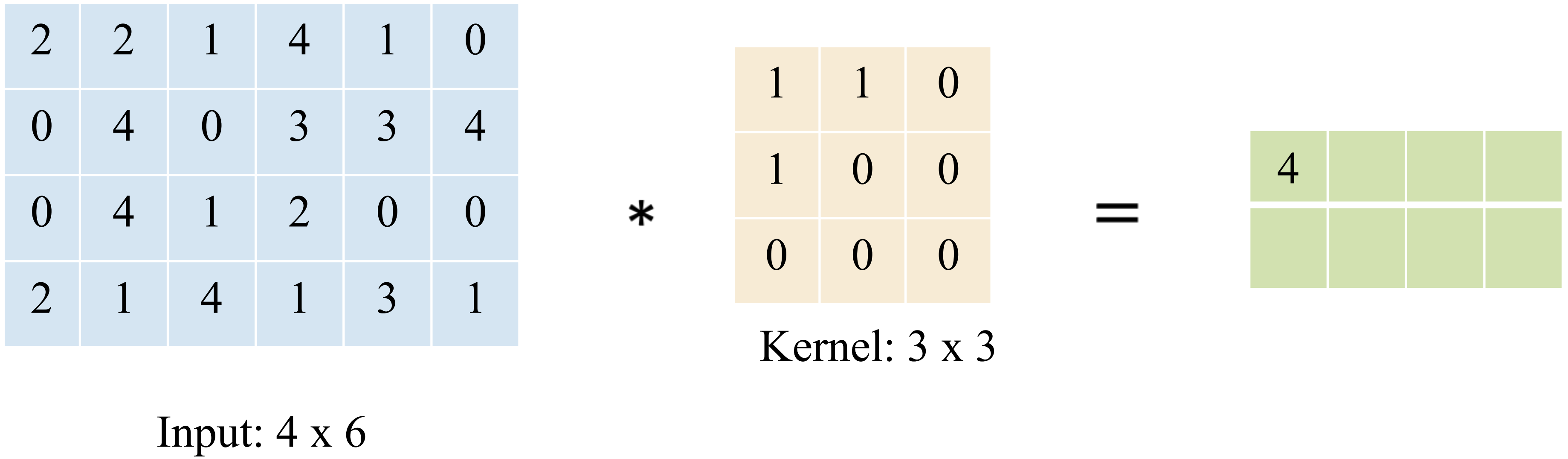
1	1	0
1	0	0
0	0	0

Kernel: 3 x 3

=

5 - Practice

1 Exercise – Convolutional Layer



2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1

Input: 4 x 6

*

1	1	0
1	0	0
0	0	0

Kernel: 3 x 3

=

4			

5 - Practice

1 Exercise – Convolutional Layer

2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1

Input: 4 x 6

*

1	1	0
1	0	0
0	0	0

Kernel: 3 x 3

=

4	7		

1 Exercise – Convolutional Layer

2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1

Input: 4 x 6

*

1	1	0
1	0	0
0	0	0

Kernel: 3 x 3

=

4	7	5	

5 - Practice

1 Exercise – Convolutional Layer

2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1

Input: 4 x 6

*

1	1	0
1	0	0
0	0	0

Kernel: 3 x 3

=

4	7	5	8

1 Exercise – Convolutional Layer

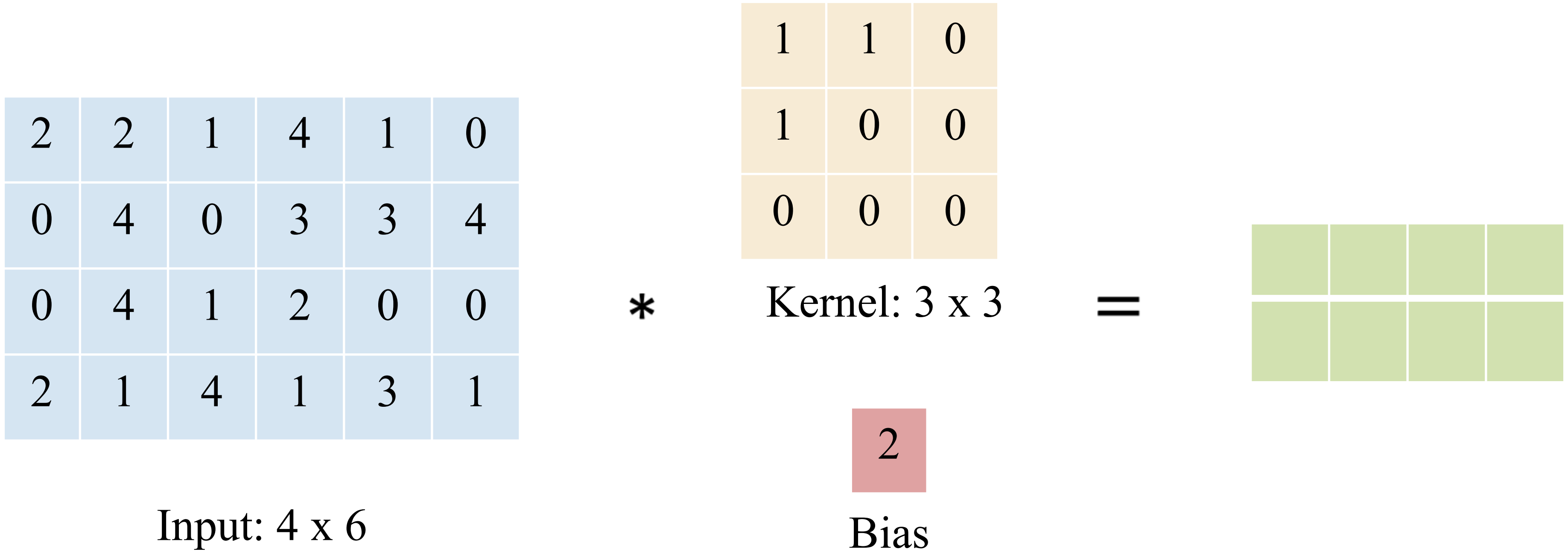
$$\begin{bmatrix} 2 & 2 & 1 & 4 & 1 & 0 \\ 0 & 4 & 0 & 3 & 3 & 4 \\ 0 & 4 & 1 & 2 & 0 & 0 \\ 2 & 1 & 4 & 1 & 3 & 1 \end{bmatrix} * \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 4 & 7 & 5 & 8 \\ 4 & 8 & 4 & 8 \end{bmatrix}$$

Kernel: 3 x 3

Input: 4 x 6

5 - Practice

1 Exercise – Convolutional Layer



2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1

Input: 4 x 6

*

1	1	0
1	0	0
0	0	0

Kernel: 3 x 3

2

Bias

=

2 Exercise – Convolutional Layer

Stride: 1 (1x1)

2	2	1	4	1	0
0	4	0	3	3	4
0	4	1	2	0	0
2	1	4	1	3	1

Input: 4 x 6

*

1	1	0
1	0	0
0	0	0

Kernel: 3 x 3

2

Bias

=

6	9	7	10
6	10	6	10

2 Exercise – Padding

2	4	2
3	3	4
3	2	0
4	0	4
1	4	0

Input: 4 x 6

Padding: 1 x 1

0	0	0	0	0
0	2	4	2	0
0	3	3	4	0
0	3	2	0	0
0	4	0	4	0
0	1	4	0	0
0	0	0	0	0

Input: 6 x 8

Stride: 1 (1x1)

*

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

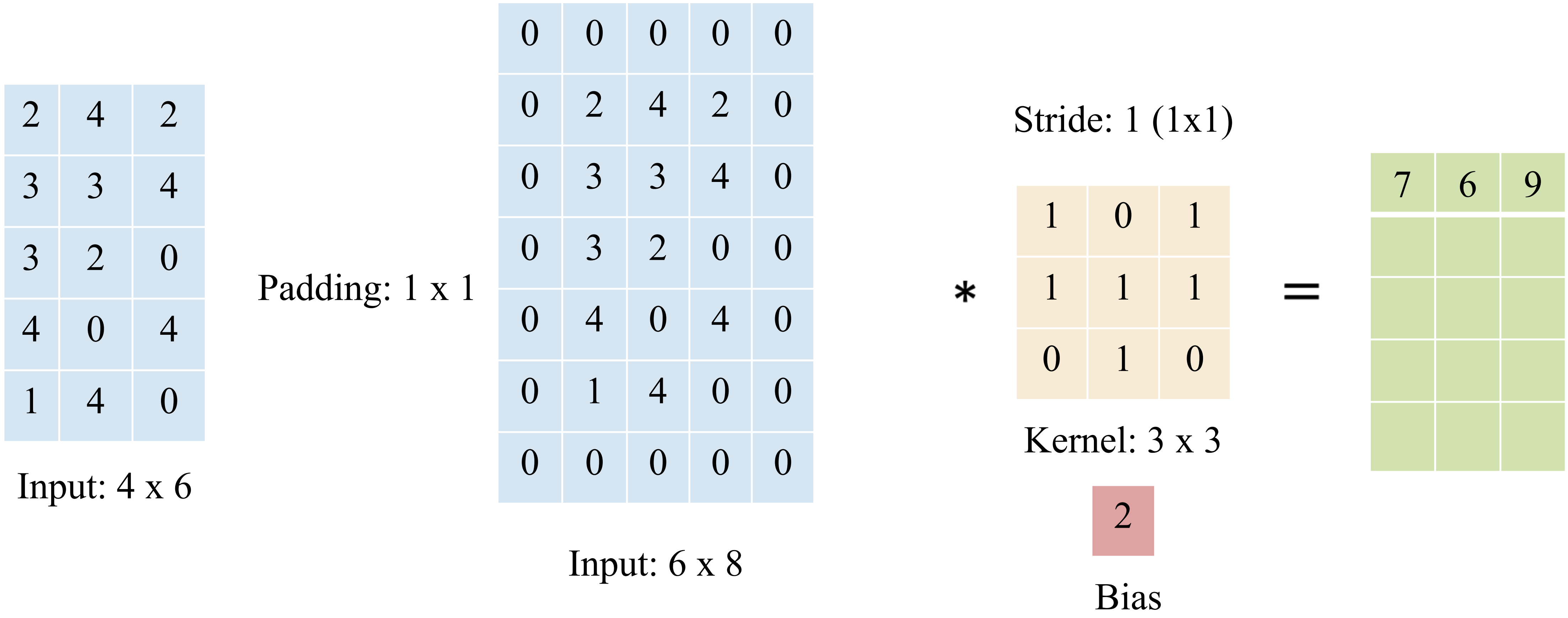
2

Bias

=

5 - Practice

2 Exercise – Padding



2	4	2
3	3	4
3	2	0
4	0	4
1	4	0

Input: 4 x 6

Padding: 1 x 1

0	0	0	0	0
0	2	4	2	0
0	3	3	4	0
0	3	2	0	0
0	4	0	4	0
0	1	4	0	0
0	0	0	0	0

Input: 6 x 8

Stride: 1 (1x1)

*

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

2

Bias

=

7	6	9

2 Exercise – Padding

2	4	2
3	3	4
3	2	0
4	0	4
1	4	0

Input: 4 x 6

Padding: 1 x 1

0	0	0	0	0
0	2	4	2	0
0	3	3	4	0
0	3	2	0	0
0	4	0	4	0
0	1	4	0	0
0	0	0	0	0

Input: 6 x 8

Stride: 1 (1x1)

*

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

2

Bias

=

7	6	9
7	13	5

2 Exercise – Padding

2	4	2
3	3	4
3	2	0
4	0	4
1	4	0

Input: 4 x 6

Padding: 1 x 1

0	0	0	0	0
0	2	4	2	0
0	3	3	4	0
0	3	2	0	0
0	4	0	4	0
0	1	4	0	0
0	0	0	0	0

Input: 6 x 8

Stride: 1 (1x1)

*

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

2

Bias

=

7	6	9
7	13	5
10	11	2

5 - Practice

2 Exercise – Padding

2	4	2
3	3	4
3	2	0
4	0	4
1	4	0

Input: 4 x 6

Padding: 1 x 1

0	0	0	0	0
0	2	4	2	0
0	3	3	4	0
0	3	2	0	0
0	4	0	4	0
0	1	4	0	0
0	0	0	0	0

Input: 6 x 8

*

Stride: 1 (1x1)

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

2

Bias

=

7	6	9
7	13	5
10	11	2
10	9	5

5 - Practice

2 Exercise – Padding

2	4	2
3	3	4
3	2	0
4	0	4
1	4	0

Input: 4 x 6

Padding: 1 x 1

0	0	0	0	0
0	2	4	2	0
0	3	3	4	0
0	3	2	0	0
0	4	0	4	0
0	1	4	0	0
0	0	0	0	0

Input: 6 x 8

*

Stride: 1 (1x1)

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

2

Bias

=

7	6	9
7	13	5
10	11	2
10	9	5
8	11	4

2 Exercise – Padding

2	4	2
3	3	4
3	2	0
4	0	4
1	4	0

Input: 4 x 6

Padding: 1 x 1

0	0	0	0	0
0	2	4	2	0
0	3	3	4	0
0	3	2	0	0
0	4	0	4	0
0	1	4	0	0
0	0	0	0	0

Input: 6 x 8

Stride: 2 (2x2)

*

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

2

Bias

=

2 Exercise – Padding

2	4	2
3	3	4
3	2	0
4	0	4
1	4	0

Input: 4 x 6

Padding: 1 x 1

0	0	0	0	0
0	2	4	2	0
0	3	3	4	0
0	3	2	0	0
0	4	0	4	0
0	1	4	0	0
0	0	0	0	0

Input: 6 x 8

Stride: 2 (2x2)

*

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

2

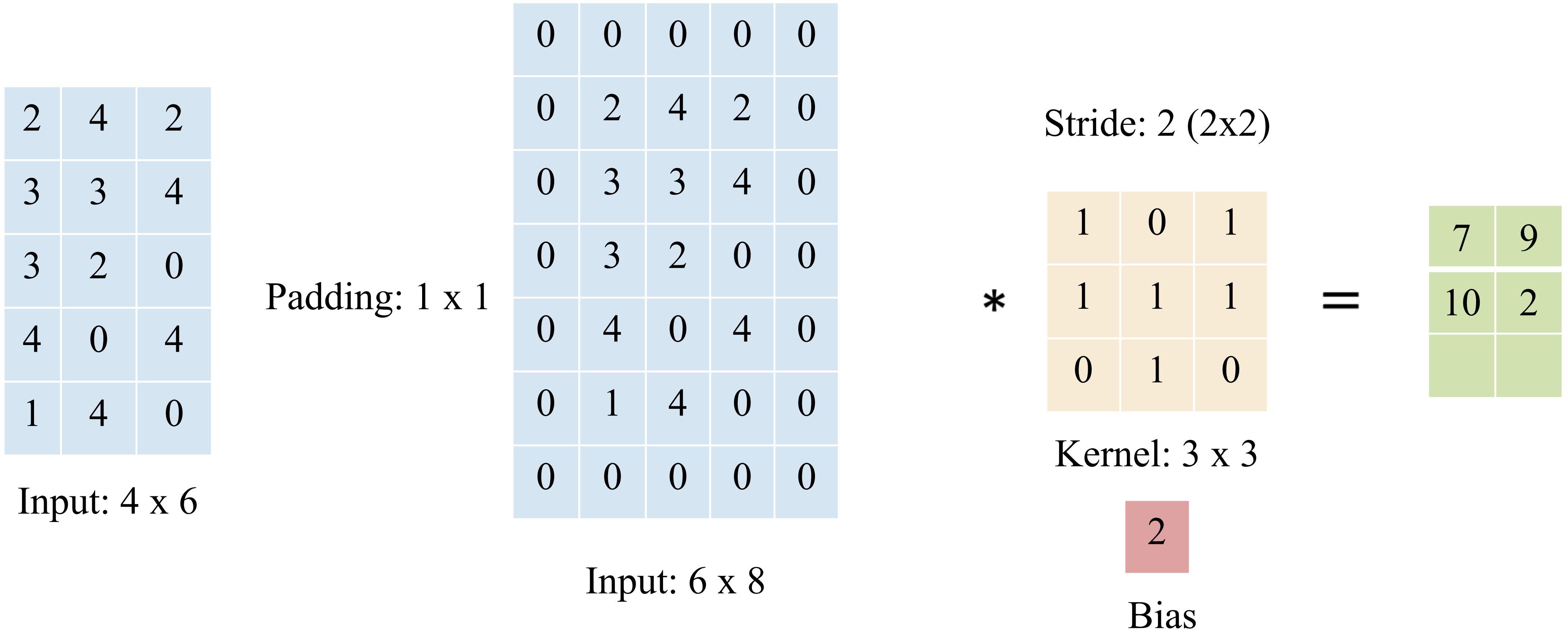
Bias

=

7	9

5 - Practice

2 Exercise – Padding



2	4	2
3	3	4
3	2	0
4	0	4
1	4	0

Input: 4 x 6

Padding: 1 x 1

0	0	0	0	0
0	2	4	2	0
0	3	3	4	0
0	3	2	0	0
0	4	0	4	0
0	1	4	0	0
0	0	0	0	0

Input: 6 x 8

Stride: 2 (2x2)

*

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

2

Bias

=

7	9
10	2

5 - Practice

2 Exercise – Padding

2	4	2
3	3	4
3	2	0
4	0	4
1	4	0

Input: 4 x 6

Padding: 1 x 1

0	0	0	0	0
0	2	4	2	0
0	3	3	4	0
0	3	2	0	0
0	4	0	4	0
0	1	4	0	0
0	0	0	0	0

Input: 6 x 8

Stride: 2 (2x2)

*

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

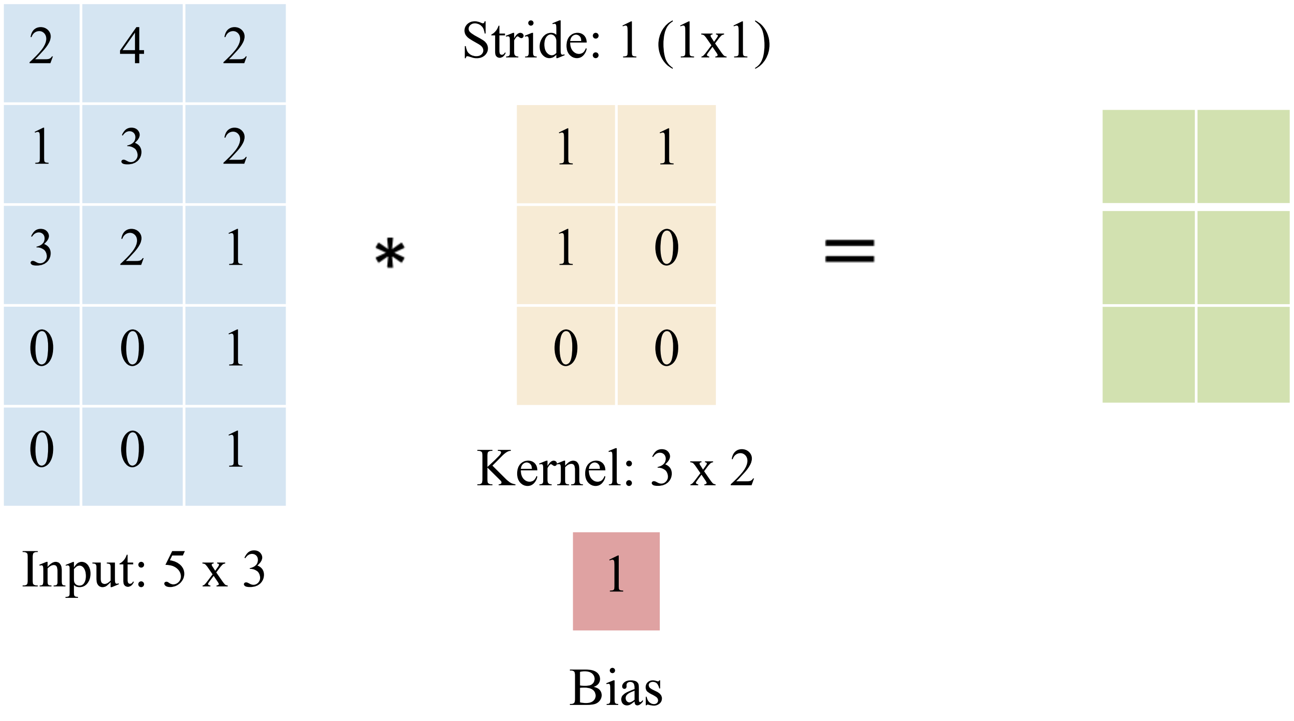
2

Bias

=

7	9
10	2
8	4

3 Exercise – Convolutional Layer + Pooling



2	4	2
1	3	2
3	2	1
0	0	1
0	0	1

Input: 5 x 3

*

Stride: 1 (1x1)

1	1
1	0
0	0

Kernel: 3 x 2

1

Bias

=

3 Exercise – Convolutional Layer + Pooling

2	4	2
1	3	2
3	2	1
0	0	1
0	0	1

Input: 5 x 3

*

Stride: 1 (1x1)

1	1
1	0
0	0

Kernel: 3 x 2

1

Bias

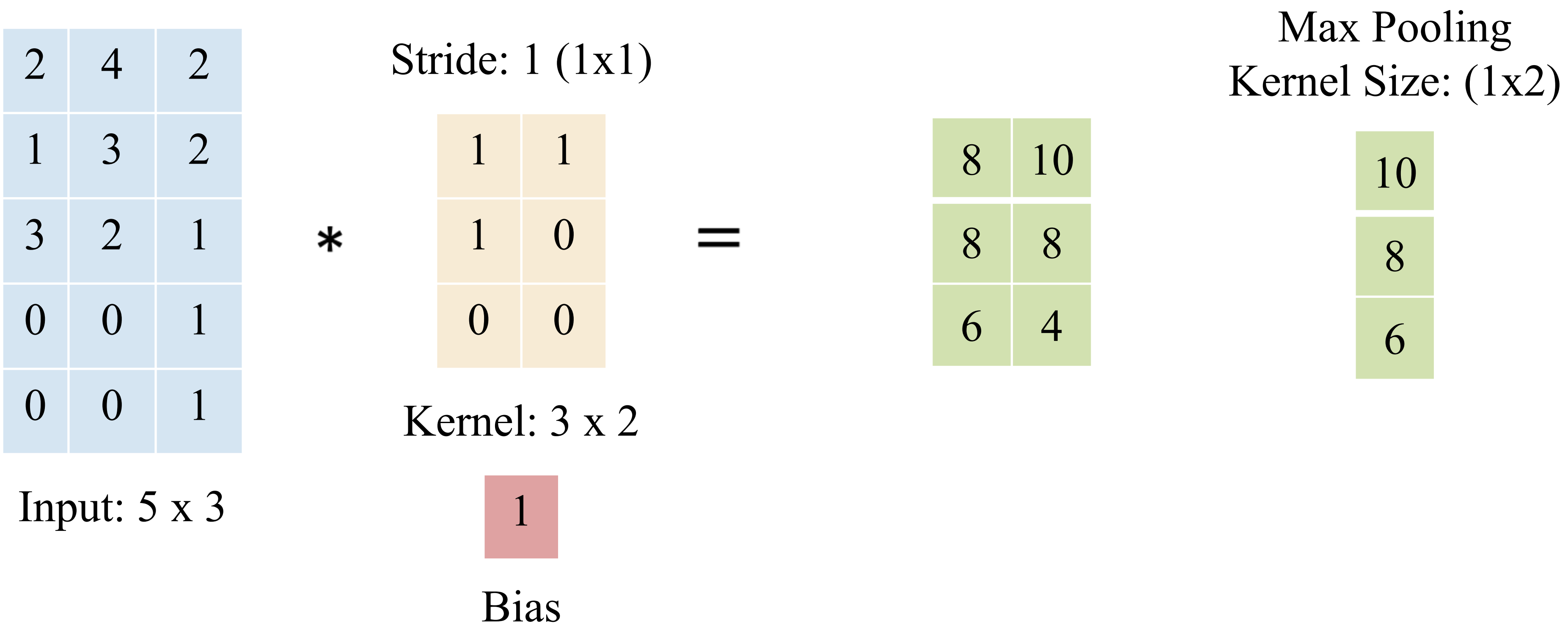
=

8	10
8	8
6	4

Max Pooling
Kernel Size: (1x2)

5 - Practice

3 Exercise – Convolutional Layer + Pooling



2	4	2
1	3	2
3	2	1
0	0	1
0	0	1

Input: 5 x 3

*

Stride: 1 (1x1)

1	1
1	0
0	0

Kernel: 3 x 2

1

Bias

=

8	10
8	8
6	4

Max Pooling
Kernel Size: (1x2)

10
8
6

4 Exercise – Pooling For Grayscale Image

0	0	0	0	0	0	0
0	0	0	43	43	0	0
0	30	250	230	125	251	0
0	191	38	0	0	81	0
0	241	0	35	119	250	0
0	49	193	198	83	0	0
0	0	0	0	0	0	0

Input: 7 x 7

*

0	0
0	0

MaxPooling
2x2

=

Output: 3 x 3

4 Exercise – Pooling For Grayscale Image

0	0	0	0	0	0	0
0	0	0	43	43	0	0
0	30	250	230	125	251	0
0	191	38	0	0	81	0
0	241	0	35	119	250	0
0	49	193	198	83	0	0
0	0	0	0	0	0	0

Input: 7 x 7

*

0	0
0	0

MaxPooling
2x2

=

0	43	43
191	250	251
241	198	250

Output: 3 x 3

4 Exercise – Convolutional For Grayscale Image

0	0	0	0	0	0	0
0	0	0	43	43	0	0
0	30	250	230	125	251	0
0	191	38	0	0	81	0
0	241	0	35	119	250	0
0	49	193	198	83	0	0
0	0	0	0	0	0	0

Input: 7 x 7

*

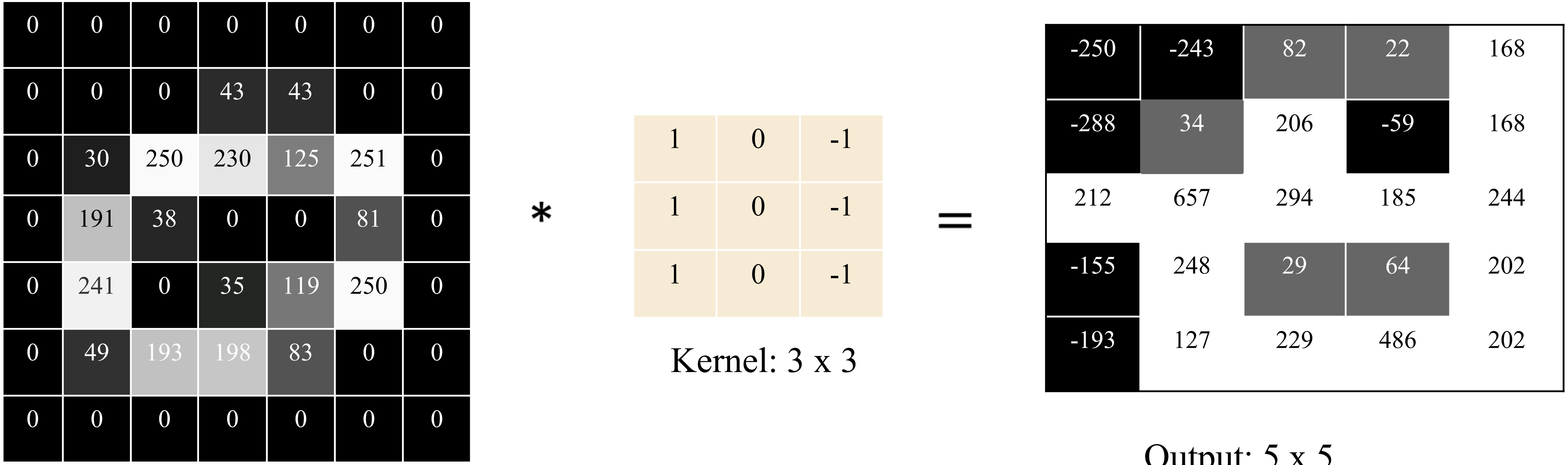
1	0	-1
1	0	-1
1	0	-1

Kernel: 3 x 3

=

Output: 5 x 5

4 Exercise – Convolutional For Grayscale Image



0	0	0	0	0	0	0
0	0	0	43	43	0	0
0	30	250	230	125	251	0
0	191	38	0	0	81	0
0	241	0	35	119	250	0
0	49	193	198	83	0	0
0	0	0	0	0	0	0

Input: 7 x 7

*

1	0	-1
1	0	-1
1	0	-1

Kernel: 3 x 3

=

-250	-243	82	22	168
-288	34	206	-59	168
212	657	294	185	244
-155	248	29	64	202
-193	127	229	486	202

Output: 5 x 5

4 Exercise – Convolutional For Grayscale Image

-250	-243	82	22	168
-288	34	206	-59	168
212	657	294	185	244
-155	248	29	64	202
-193	127	229	486	202

Input: 5 x 5

MaxPooling
Kernel: 2

34	206
657	297

Thanks!

Any questions?