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Introduction to Convolutional Neural Network

Code & Data

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Outline

- Neural Network: Review and Limitations
- Convolution Layer
- Pooling Layer
- Flatten Layer
- Practice
- Advanced Dicussion

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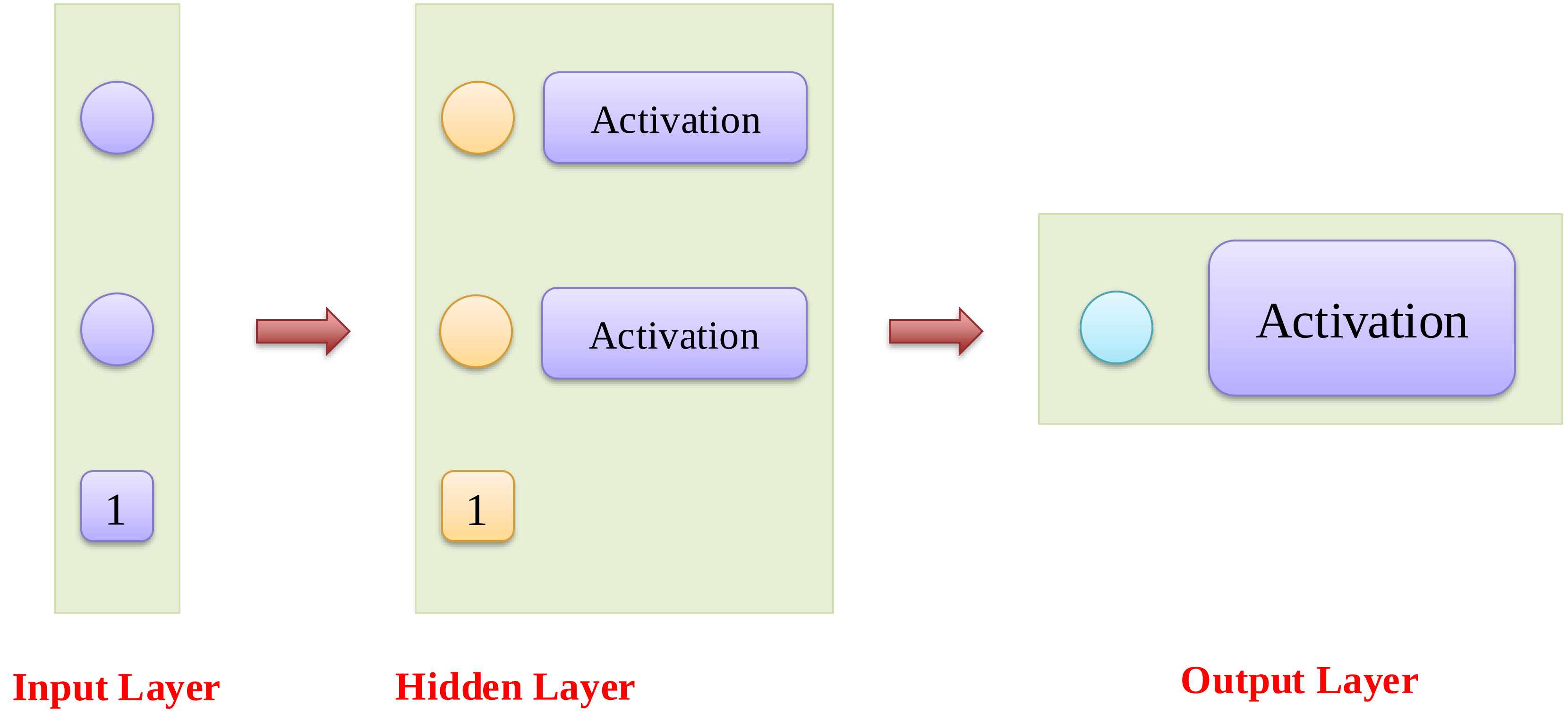
Neural Network

Neural Network



Loss: CrossEntropyLoss

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

Optimizer: SGD

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

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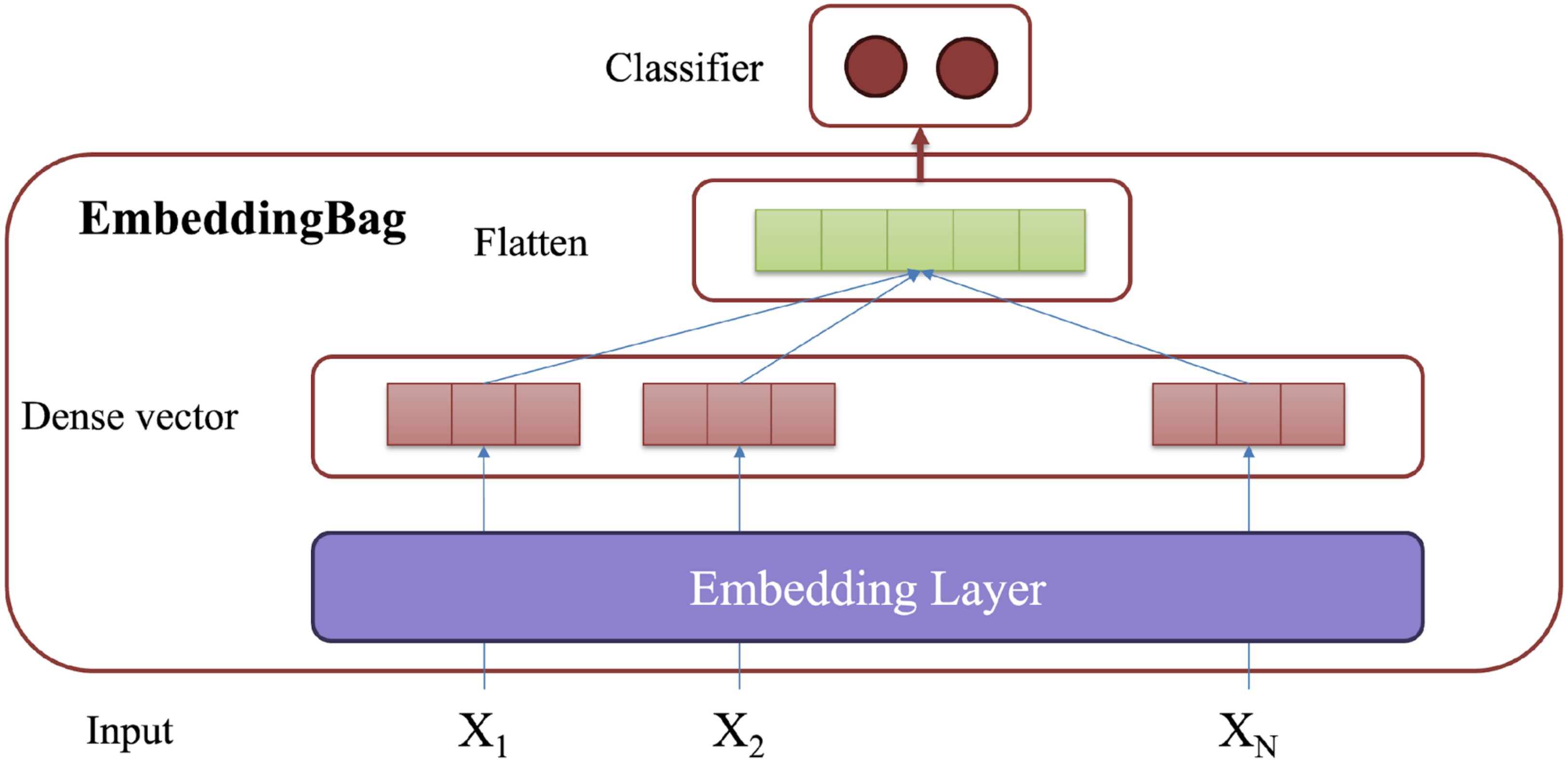
Neural Network

Neural Network for Text

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



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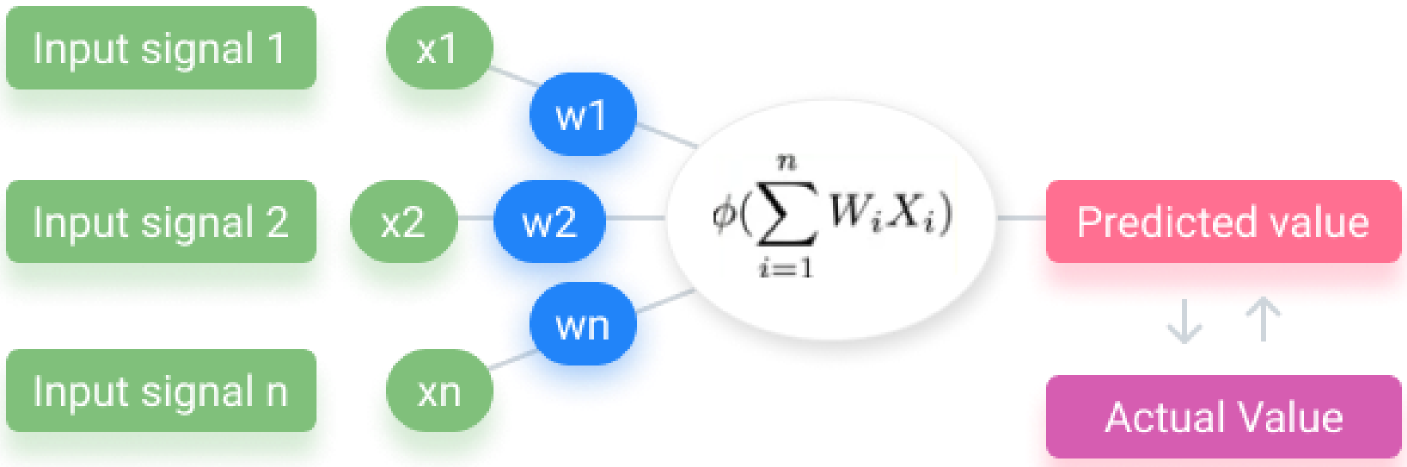
Neural Network

Neural Network for Time Series

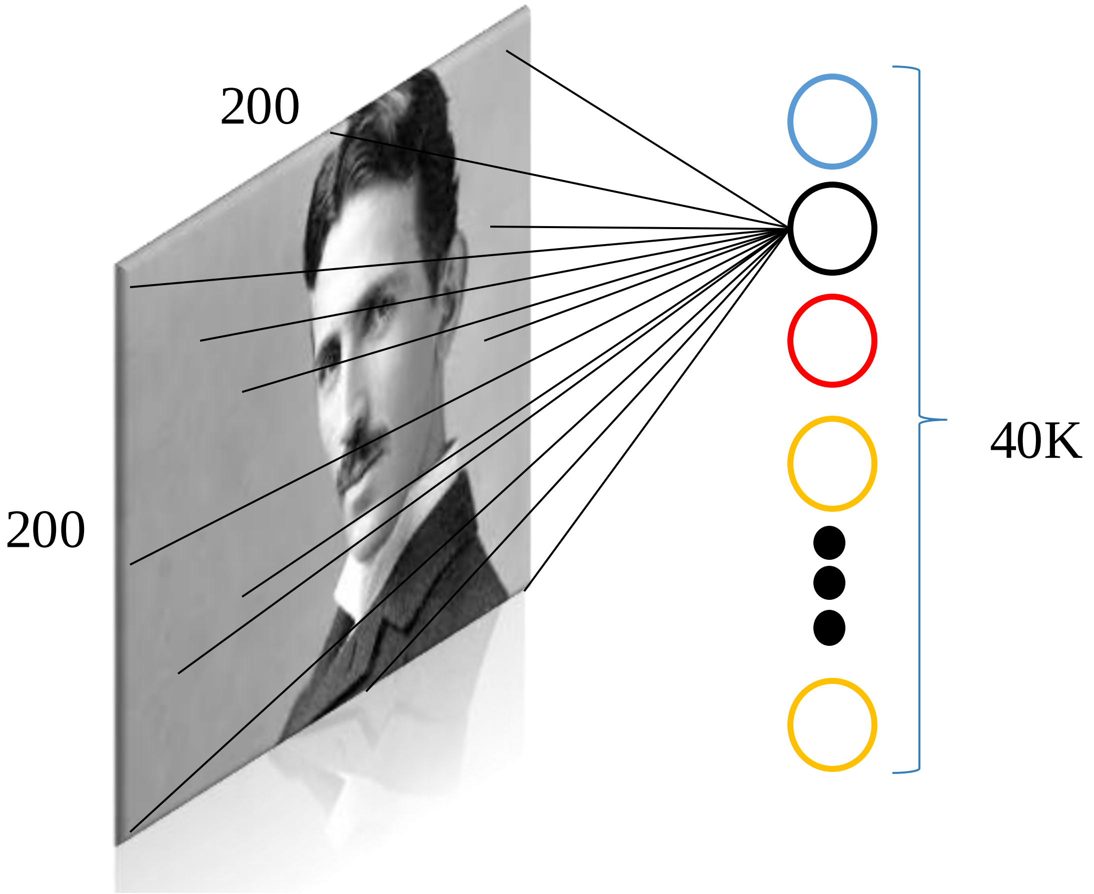
❖ Cannot deal with the problem of having different amount of input values

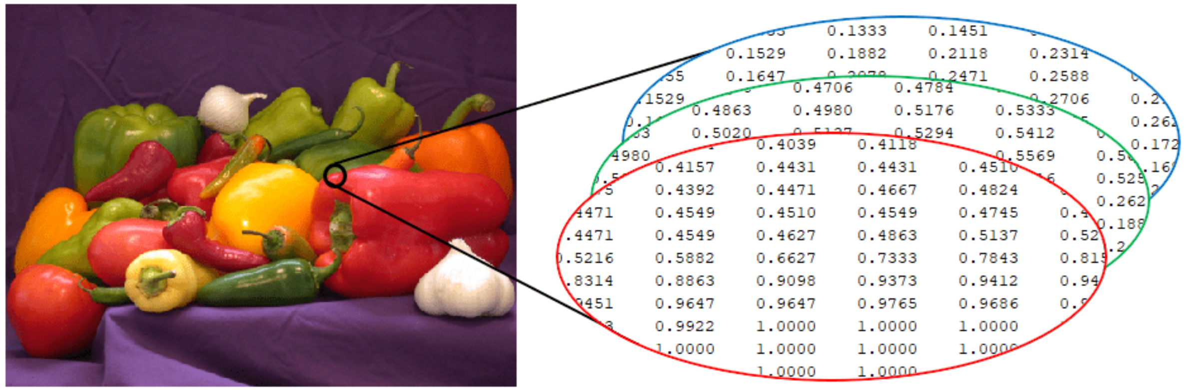


Neural Network

Neural Network for Image

- Each hidden node connects to all the other nodes





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Neural Network

Neural Network

- **Need better network architectures…**

RNNs for Sequence

CNNs for Image

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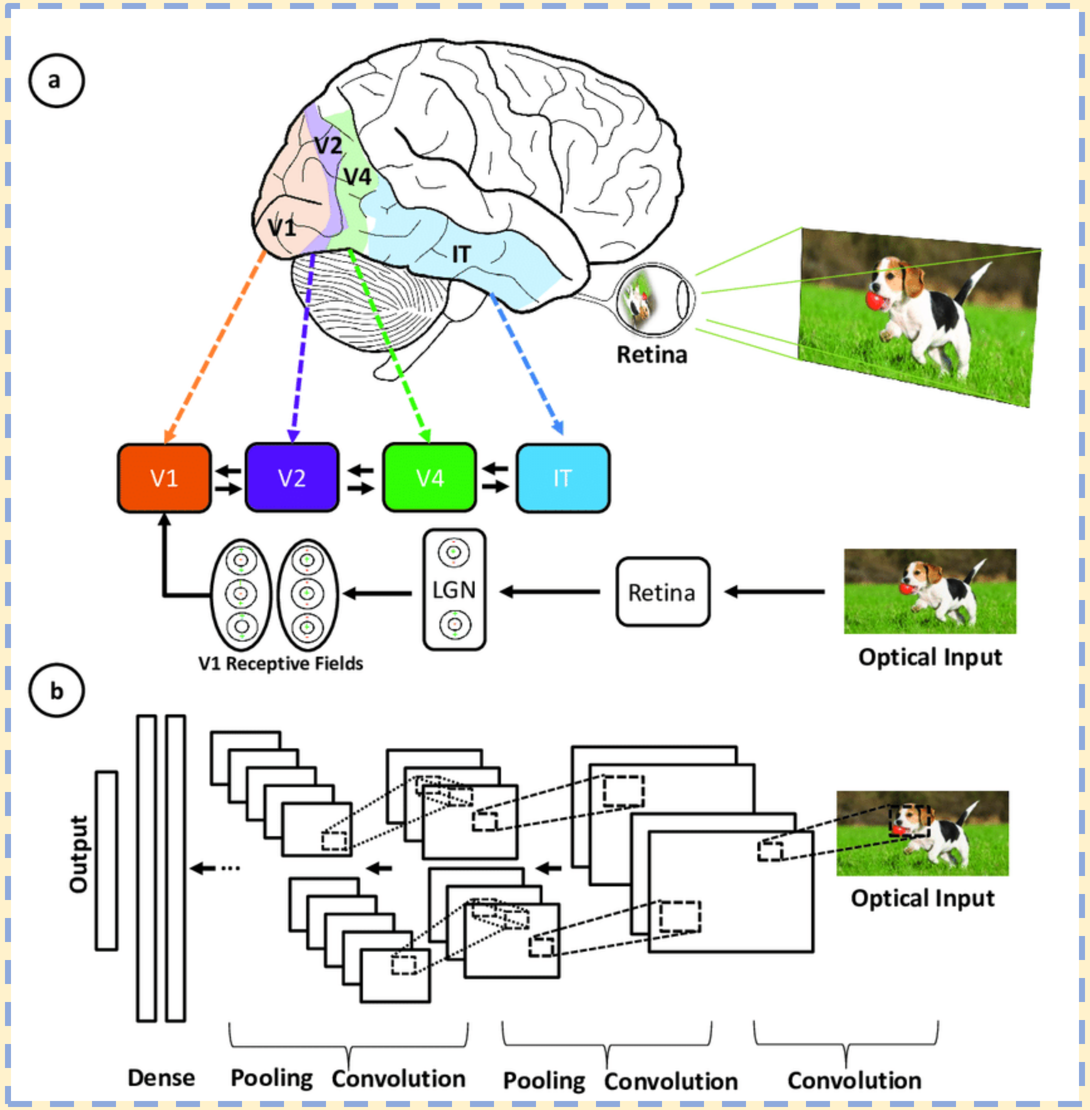
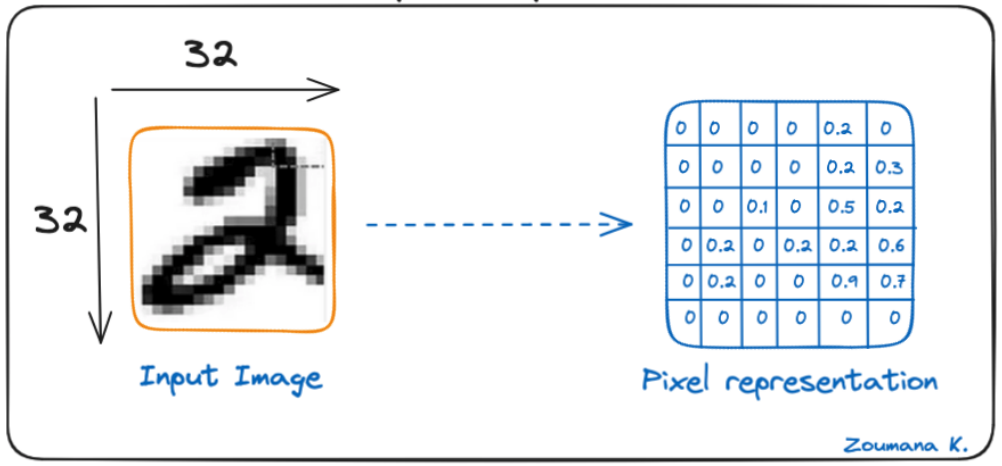
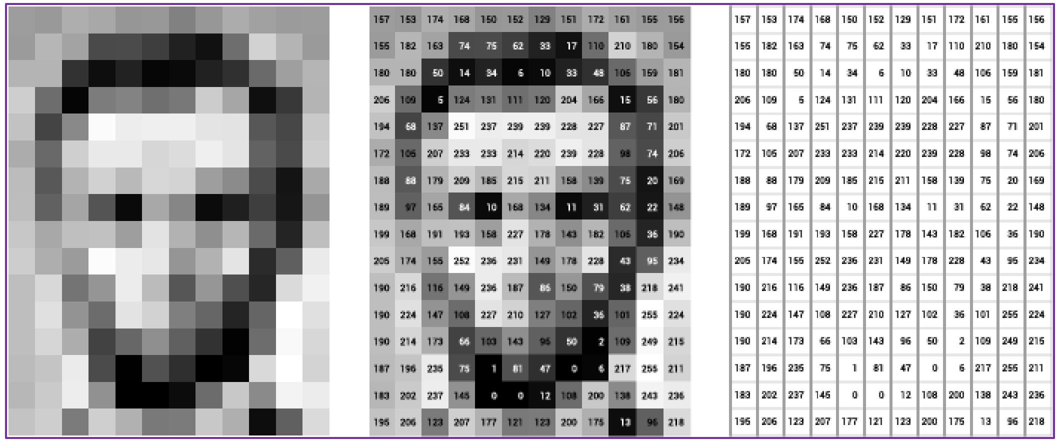
CNN Motivation







Outline

- Neural Network: Review and Limitations
- Convolution Layer
- Pooling Layer
- Flatten Layer
- Practice
- Advanced Dicussion

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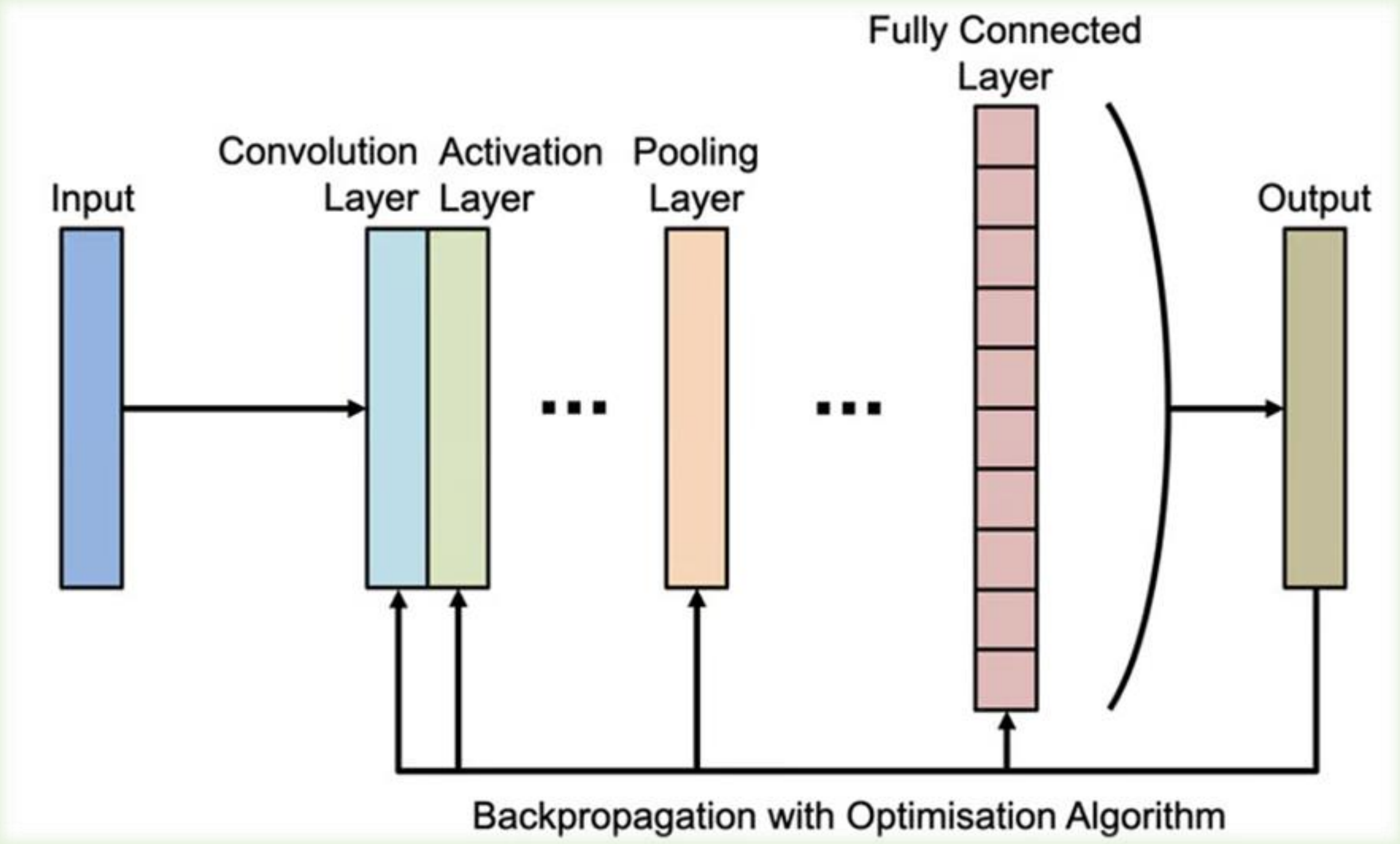
The Building Blocks of a CNN



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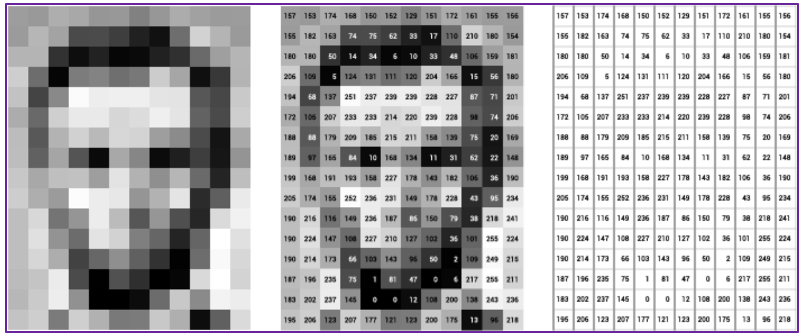
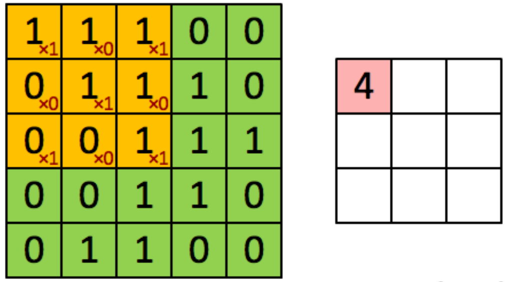
Convolution Layer: Quick Look

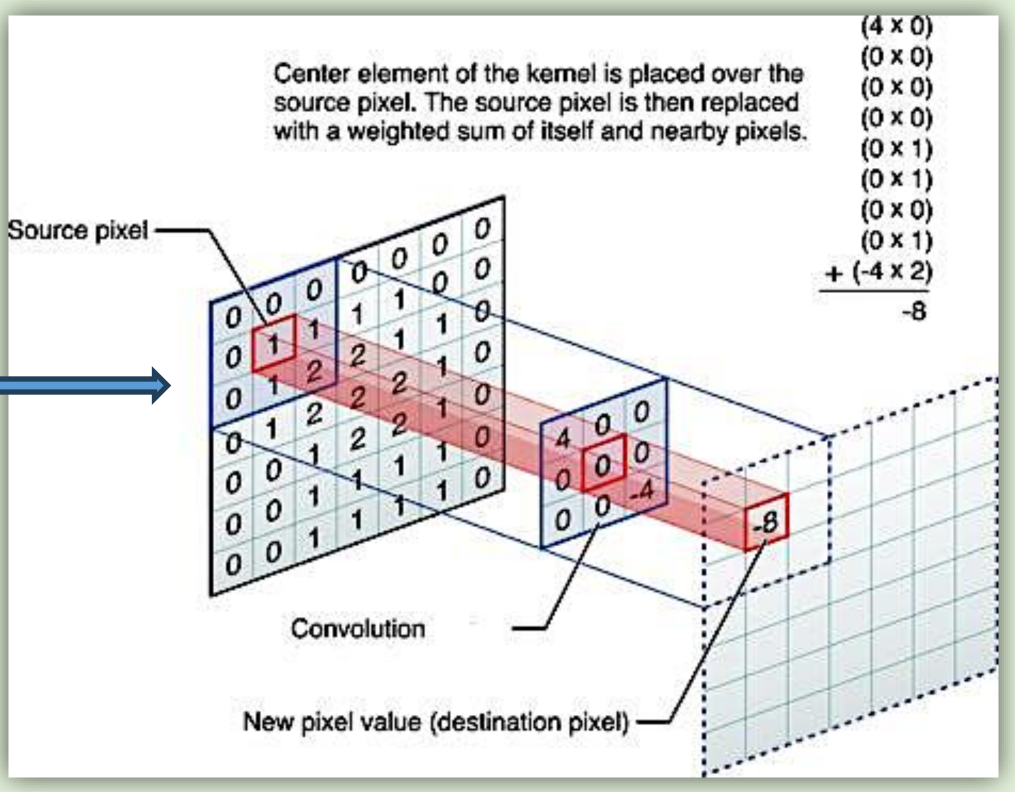
Input image	Convolution Kernel	Feature map
	$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$	





Image

Convolved Feature



Applying filters to an image highlights its edges, creating a new image (in CNN terms, **a feature map**)

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
2	1	2
4	3	1

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Convolutional Layer

Convolutional Operation

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

=

2x1 + 2x1 + 1x0 +
0x1 + 4x1 + 0x0 +
0x1 + 4x0 + 1x1 = 9

9			

Output: 4 x 4

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

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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

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>)
```

Convolutional Layer

Convolutional Operation

$$
\begin{bmatrix} 2 & 2 & 1 & 4 & 1 & 0 \\ 0 & 4 & 0 & 3 & 3 & 4 \\ 0 & 4 & 1 & 2 & 0 & 0 \\ 2 & 1 & 4 & 1 & 3 & 1 \\ 4 & 3 & 1 & 4 & 2 & 4 \\ 2 & 0 & 0 & 4 & 3 & 4 \end{bmatrix}
*
\begin{bmatrix} 1 & 1 & 0 \\ 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}
=
\begin{bmatrix} 10 & & & \\ & & & \\ & & & \\ & & & \end{bmatrix}
$$

Input: 6 x 6

Kernel: 3 x 3

Bias: 1

Output: 4 x 4

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

1

Bias

=

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

Output: 4 x 4

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>)
```

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

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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

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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>)
```

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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)

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

Convolutional Layer

Padding

```python
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.]]])
```

```python
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.]]]])
```

```python
# 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"}

```python
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)
```

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

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

```python
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>)
```

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

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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>)
```

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)

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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

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

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

Convolutional Layer

Stride

Skip Skip

Stride: 2 (2x2)

Skip

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

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

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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>)
```

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

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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>)
```

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

=

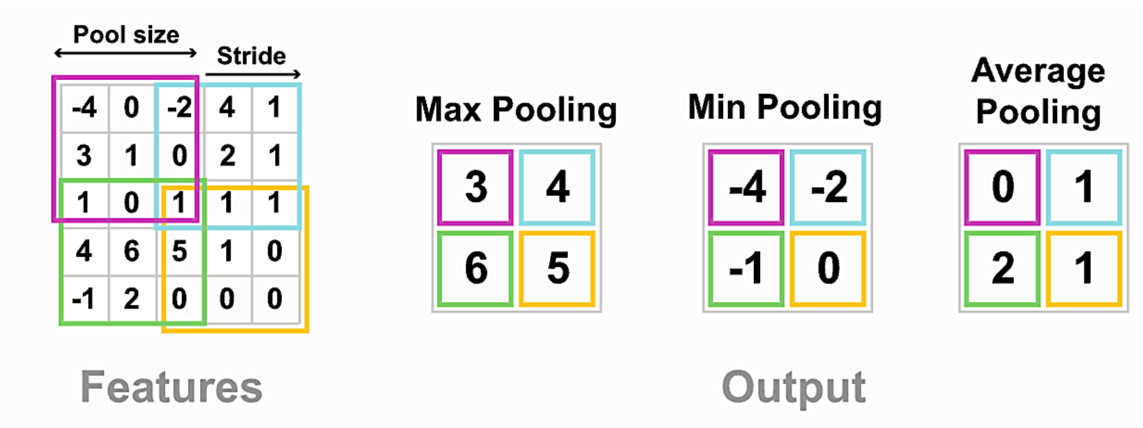
7	8
15	13

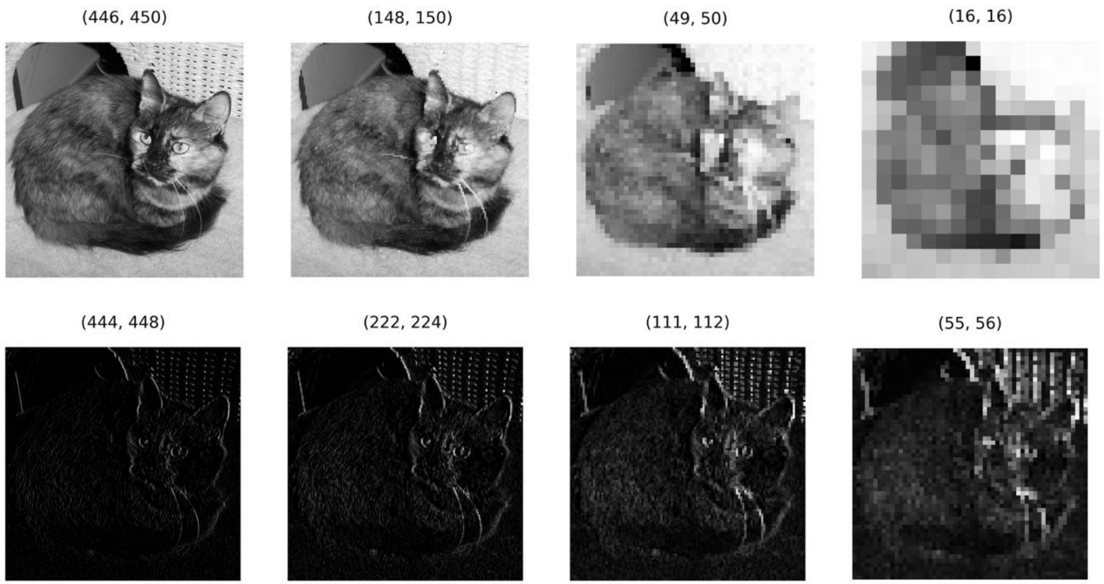
$$\left\lfloor \frac{M + 2P - K}{S} + 1 \right\rfloor \text{x} \left\lfloor \frac{N + 2Q - K}{T} + 1 \right\rfloor$$

Outline

- Neural Network: Review and Limitations
- Convolution Layer
- Pooling Layer
- Flatten Layer
- Practice
- Advanced Dicussion

Pooling Layer: Quick Look





This layer helps to make the CNN more computationally efficient by reducing the number of parameters and ensuring that the model focuses on the most important features.

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

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

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

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.]]])
```

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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	3
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.]]])
```

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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: 6 x 2

```
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.]]])
```

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: 2 x 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

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

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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: 2 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]]])
```

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: 6 x 2

```
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]]])
```

Outline

- Neural Network: Review and Limitations
- Convolution Layer
- Pooling Layer
- Flatten Layer
- Practice
- Advanced Dicussion

Flatten Layer

!

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.]])
```

Outline

- Neural Network: Review and Limitations
- Convolution Layer
- Pooling Layer
- Flatten Layer
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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

=

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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			

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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		

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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	

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

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
4	8	4	8

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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

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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

=

6	9	7	10
6	10	6	10

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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

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Practice

2 Exercise – Padding

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

Input: 5 x 3

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: 7 x 5

*

Stride: 1 (1x1)

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

2

Bias

=

11	13	12

Practice

2 Exercise – Padding

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

Input: 5 x 3

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: 7 x 5

*

Stride: 1 (1x1)

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

2

Bias

=

11	13	12
15	18	13

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Practice

2 Exercise – Padding

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

Input: 5 x 3

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: 7 x 5

*

Stride: 1 (1x1)

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

2

Bias

=

11	13	12
15	18	13
14	14	11

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Practice

2 Exercise – Padding

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

Input: 5 x 3

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: 7 x 5

*

Stride: 1 (1x1)

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

2

Bias

=

11	13	12
15	18	13
14	14	11
9	17	8

Practice

2 Exercise – Padding

Input: 5 x 3

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

Padding: 1 x 1

Input: 7 x 5

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

*

Stride: 1 (1x1)

Kernel: 3 x 3

1	0	1
1	1	1
0	1	0

Bias: 2

=

11	13	12
15	18	13
14	14	11
9	17	8
7	15	6

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Practice

2 Exercise – Padding

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

Input: 5 x 3

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: 7 x 5

*

Stride: 2 (2x2)

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

=

2

Bias

Practice

2 Exercise – Padding

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

Input: 5 x 3

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: 7 x 5

*

Stride: 2 (2x2)

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

2

Bias

=

11	12

Practice

2 Exercise – Padding

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

Input: 5 x 3

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: 7 x 5

Stride: 2 (2x2)

*

1	0	1
1	1	1
0	1	0

Kernel: 3 x 3

2

Bias

=

11	12
14	11

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Practice

2 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

=

Practice

2 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)

Practice

2 Exercise – Convolutional Layer + Pooling

Input: 5 x 3

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

*

Stride: 1 (1x1)

Kernel: 3 x 2

1	1
1	0
0	0

Bias

1

=

8	10
8	8
6	4

Max Pooling
Kernel Size: (1x2)

10
8
6

Practice

2 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

MaxPooling
2x2

=

Output: 3 x 3

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Practice

2 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

MaxPooling
2x2

=

0	43	43
191	250	251
241	198	250

Output: 3 x 3

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Practice

2 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

*

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

Kernel: 3 x 3

=

Output: 5 x 5

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Practice

2 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

*

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

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Practice

2 Exercise – Pooling 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

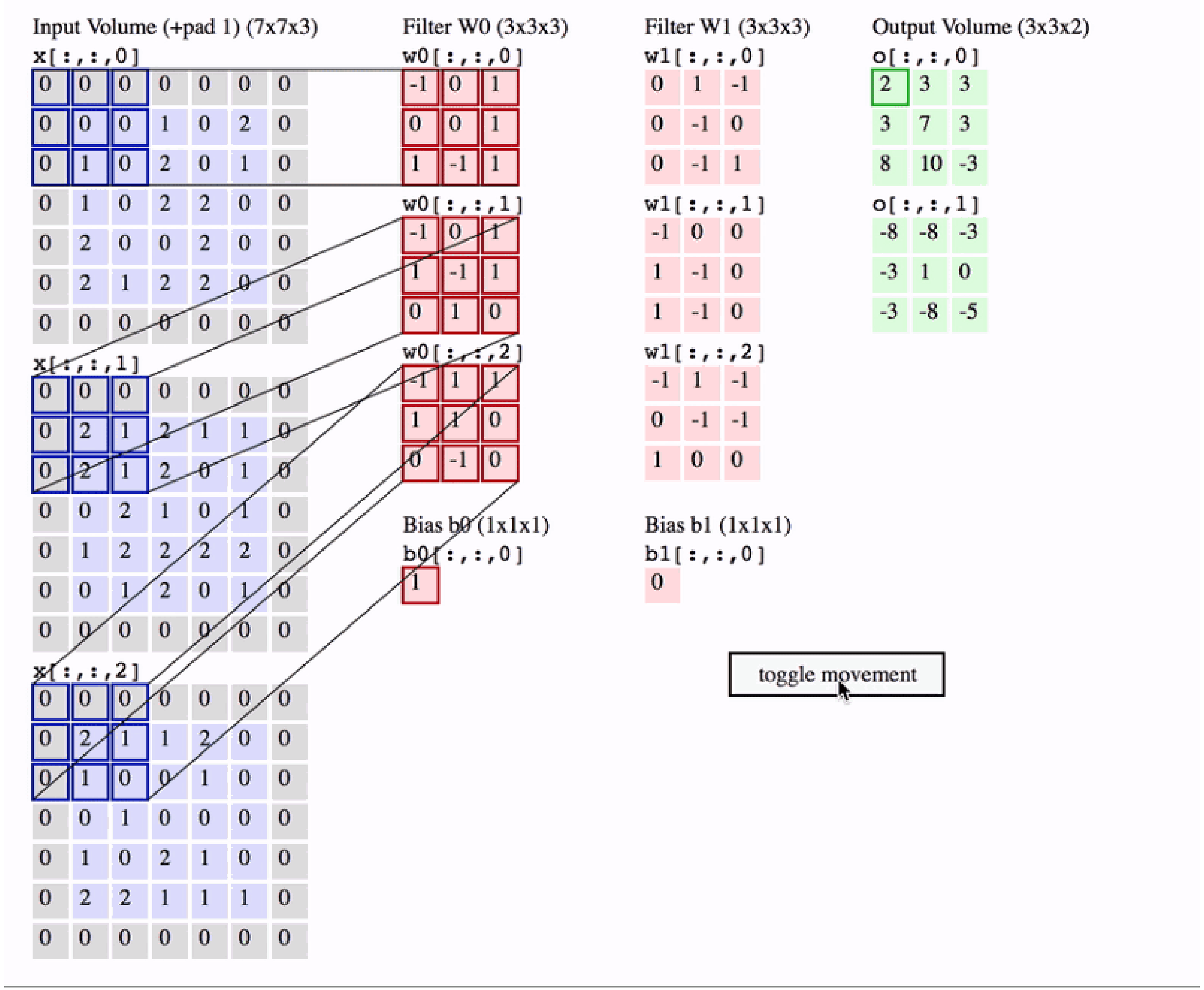
MaxPooling
Kernel: 2

34	206
657	297

Outline

- Neural Network: Review and Limitations
- Convolution Layer
- Pooling Layer
- Flatten Layer
- Practice
- Advanced Dicussion

Feature Map: Discussion



Feature Map: Discussion

SL.No		Activation Shape	Activation Size	# Parameters
1.	Input Layer:	(32, 32, 3)	3072	
2.	CONV1 (f=5, s=1)	(28, 28, 8)	6272	
3.	POOL1	(14, 14, 8)	1568	
4.	CONV2 (f=5, s=1)	(10, 10, 16)	1600	
5.	POOL2	(5, 5, 16)	400	
6.	FC3	(120, 1)	120	
7.	FC4	(84, 1)	84	
8.	Softmax	(10, 1)	10	

Feature Map: Discussion

Feature Map: Discussion