

CONVOLUTION

Input

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

Kernal

$$\begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix}$$

Output

$$\begin{bmatrix} 3 \end{bmatrix}$$

$$\begin{aligned} \text{Output}(1,2) &= (2 \times 1) + (0 \times 0) + (1 \times -1) + (1 \times 1) + (0 \times 0) + (2 \times -1) + (3 \times 1) + (1 \times 0) + (0 \times -1) \\ &= 2 + 0 - 1 + 1 + 0 - 2 + 3 + 0 - 0 \\ &= 3 \end{aligned}$$

CONVOLUTION

5×5
Input

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

Kernal

$$\begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix}$$

3×3
Output

$$\begin{bmatrix} & & \\ & 3 & \\ & & \end{bmatrix}$$

$$\begin{aligned} \text{Output}(1,2) &= (2 \times 1) + (0 \times 0) + (1 \times -1) + (1 \times 1) + (0 \times 0) + (2 \times -1) + (3 \times 1) + (1 \times 0) + (0 \times -1) \\ &= 2 + 0 - 1 + 1 + 0 - 2 + 3 + 0 - 0 \\ &= 3 \end{aligned}$$

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3×3
Kernal

$$\begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix}$$

3×3
Output

$$\begin{bmatrix} & & \\ & 3 & \\ & & \end{bmatrix}$$

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$\text{input} - \text{kernel} + 1$

3×3
Kernel

$$\begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix}$$

3×3
Output

$$\begin{bmatrix} & & \\ & 3 & \\ & & \end{bmatrix}$$

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3×3
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3×3
Output

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input - kernel + 1

3x3
Kernel

$$\begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix}$$

3x3
Output

$$\begin{bmatrix} 3 \end{bmatrix}$$

$$\begin{aligned} \text{Output}(1,2) &= (2 \times 1) + (0 \times 0) + (1 \times -1) + (1 \times 1) + (0 \times 0) + (2 \times -1) + (3 \times 1) + (1 \times 0) + (0 \times -1) \\ &= 2 + 0 - 1 + 1 + 0 - 2 + 3 + 0 - 0 \\ &= 3 \end{aligned}$$

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input - kernel + 1

3x3

Kernal

$$\begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix}$$

3x3

Output

$$\begin{bmatrix} & & \\ & \underline{3} & \\ & & \end{bmatrix}$$

$$\underline{\text{Output}(1,2)} = (2 \times 1) + (0 \times 0) + (1 \times -1) + (1 \times 1) + (0 \times 0) + (2 \times -1) + (3 \times 1) + (1 \times 0) + (0 \times -1)$$

$$= 2 + 0 - 1 + 1 + 0 - 2 + 3 + 0 - 0$$

$$= 3$$

CONVOLUTION

5x5

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input - kernel + 1

3x3

Kernel

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3x3

Output

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$$\text{Output}(1,2) = (2 \times 1) + (0 \times 0) + (1 \times -1) + (1 \times 1) + (0 \times 0) + (2 \times -1) + (3 \times 1) + (1 \times 0) + (0 \times -1)$$

$$= 2 + 0 - 1 + 1 + 0 - 2 + 3 + 0 - 0$$

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5x5

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input - kernel + 1

3x3

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3x3

Output

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input - kernel + 1

3x3

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3x3

Output

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Kernal

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Output

$$\begin{bmatrix} \underline{2} & 3 \\ & \end{bmatrix}$$

$$\begin{aligned} \text{Output}(1,2) &= (2 \times 1) + (0 \times 0) + (1 \times -1) + (1 \times 1) + (0 \times 0) + (2 \times -1) + (3 \times 1) + (1 \times 0) + (0 \times -1) \\ &= 2 + 0 - 1 + 1 + 0 - 2 + 3 + 0 - 0 \\ &= 3 \end{aligned}$$

CONVOLUTION

Input

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

Kernal

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

Output

<u>2</u>	<u>3</u>	<u>2</u>

$$\begin{aligned}\text{Output}(1,2) &= (2 \times 1) + (0 \times 0) + (1 \times -1) + (1 \times 1) + (0 \times 0) + (2 \times -1) + (3 \times 1) + (1 \times 0) + (0 \times -1) \\ &= 2 + 0 - 1 + 1 + 0 - 2 + 3 + 0 - 0 \\ &= 3\end{aligned}$$

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Input

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

Kernal

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

Output

<u>2</u>	<u>3</u>	<u>2</u>
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$$\begin{aligned}\text{Output}(1,2) &= (2 \times 1) + (0 \times 0) + (1 \times -1) + (1 \times 1) + (0 \times 0) + (2 \times -1) + (3 \times 1) + (1 \times 0) + (0 \times -1) \\ &= 2 + 0 - 1 + 1 + 0 - 2 + 3 + 0 - 0 \\ &= 3\end{aligned}$$

CONVOLUTION

5 x 5
Input

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

$$5 - 3 + 1 =$$

3 x 3
Kernal

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

3 x 3
Output

<u>2</u>	<u>3</u>	<u>2</u>

$$\begin{aligned}\text{Output}(1,2) &= (2 \times 1) + (0 \times 0) + (1 \times -1) + (1 \times 1) + (0 \times 0) + (2 \times -1) + (3 \times 1) + (1 \times 0) + (0 \times -1) \\ &= 2 + 0 - 1 + 1 + 0 - 2 + 3 + 0 - 0 \\ &= 3\end{aligned}$$

CONVOLUTION

5 x 5
Input

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

$$\underline{5} - \underline{3} + \underline{1} = 3$$

3 x 3
Kernal

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

3 x 3
Output

<u>2</u>	<u>3</u>	<u>2</u>

$$\begin{aligned}\text{Output}(1,2) &= (2 \times 1) + (0 \times 0) + (1 \times -1) + (1 \times 1) + (0 \times 0) + (2 \times -1) + (3 \times 1) + (1 \times 0) + (0 \times -1) \\ &= 2 + 0 - 1 + 1 + 0 - 2 + 3 + 0 - 0 \\ &= 3\end{aligned}$$

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5 x 5
Input

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

3 x 3
Kernal

$$\begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix}$$

3 x 3
Output

$$\begin{bmatrix} 2 & 3 & 2 \\ - & - & - \\ - & - & - \end{bmatrix}$$

$$\begin{aligned} \text{Output}(1,2) &= (2 \times 1) + (0 \times 0) + (1 \times -1) + (1 \times 1) + (0 \times 0) + (2 \times -1) + (3 \times 1) + (1 \times 0) + (0 \times -1) \\ &= 2 + 0 - 1 + 1 + 0 - 2 + 3 + 0 - 0 \\ &= 3 \end{aligned}$$