


[01:31](#)


Common Linear Operations



- **Correlation / Convolution**
 - **Correlation/convolution** is the **process** of moving a filter mask over the **image** and computing the sum of products at each location.
 - We use Correlation to check similarity between two images
- **difference between convolution and correlation** is that the **convolution process** rotates the matrix by 180 degrees.

[01:56](#)

Common Linear Operations



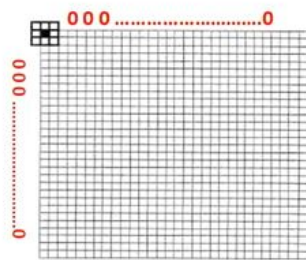
- **Correlation / Convolution**
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 - We use Correlation to check similarity between two images
- **difference between convolution and correlation** is that the **convolution process** rotates the matrix by 180 degrees.

[02:04](#)

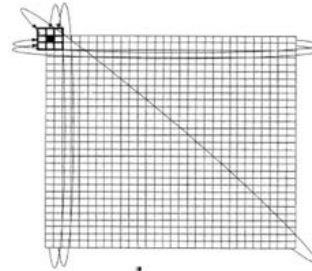
Handling Pixels Close to Boundaries



pad with zeroes



wrap around



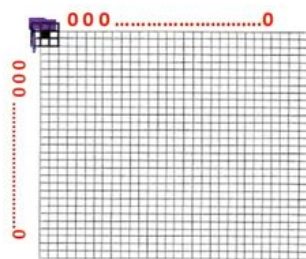
or

[02:27](#)

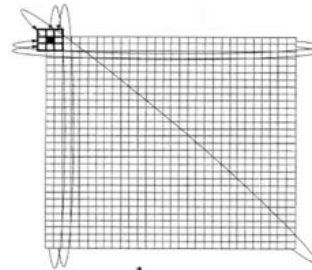
Handling Pixels Close to Boundaries



pad with zeroes



wrap around



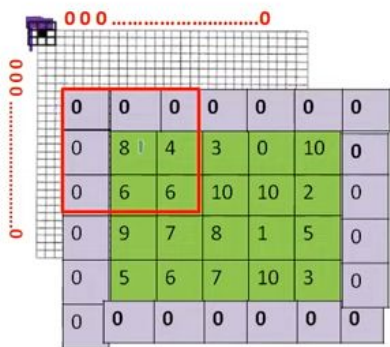
or

[02:51](#)

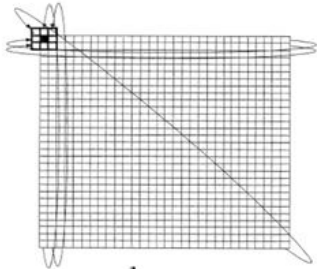
Handling Pixels Close to Boundaries



pad with zeroes



wrap around

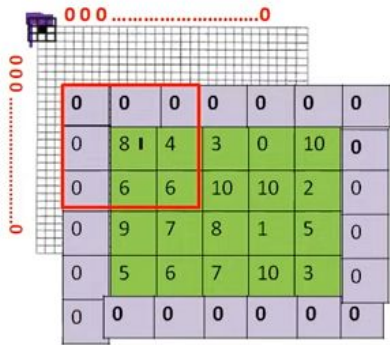


03:11

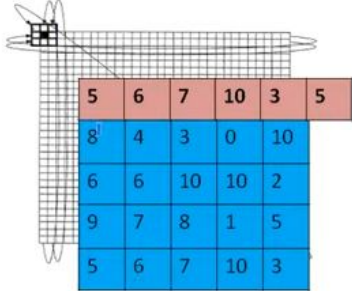
Handling Pixels Close to Boundaries



pad with zeroes



wrap around

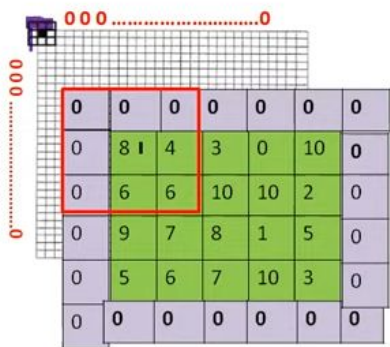


03:20

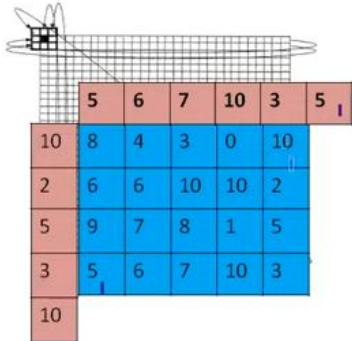
Handling Pixels Close to Boundaries



pad with zeroes

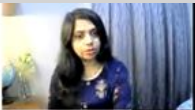


wrap around

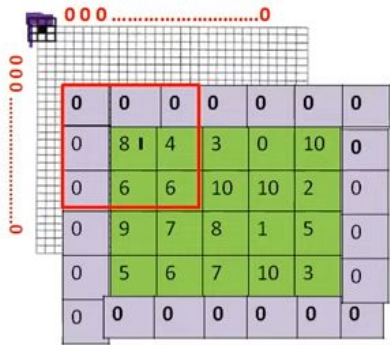


03:37

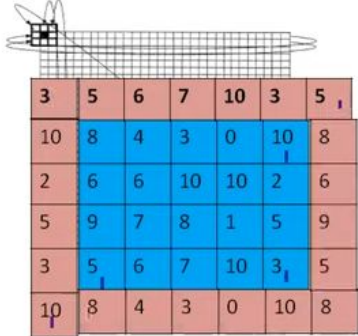
Handling Pixels Close to Boundaries



pad with zeroes



wrap around



04:11

Example

$$F(x,y) = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 & 0 \end{bmatrix} \quad \text{mask} = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}$$

04:35

Example

$$F(x,y) = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 & 0 \end{bmatrix} \quad \text{mask} = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}$$

Hand-drawn purple lines connect the top row of the mask to the first three columns of the matrix, and the bottom row of the mask to the last three columns of the matrix, illustrating the sliding window operation.

product

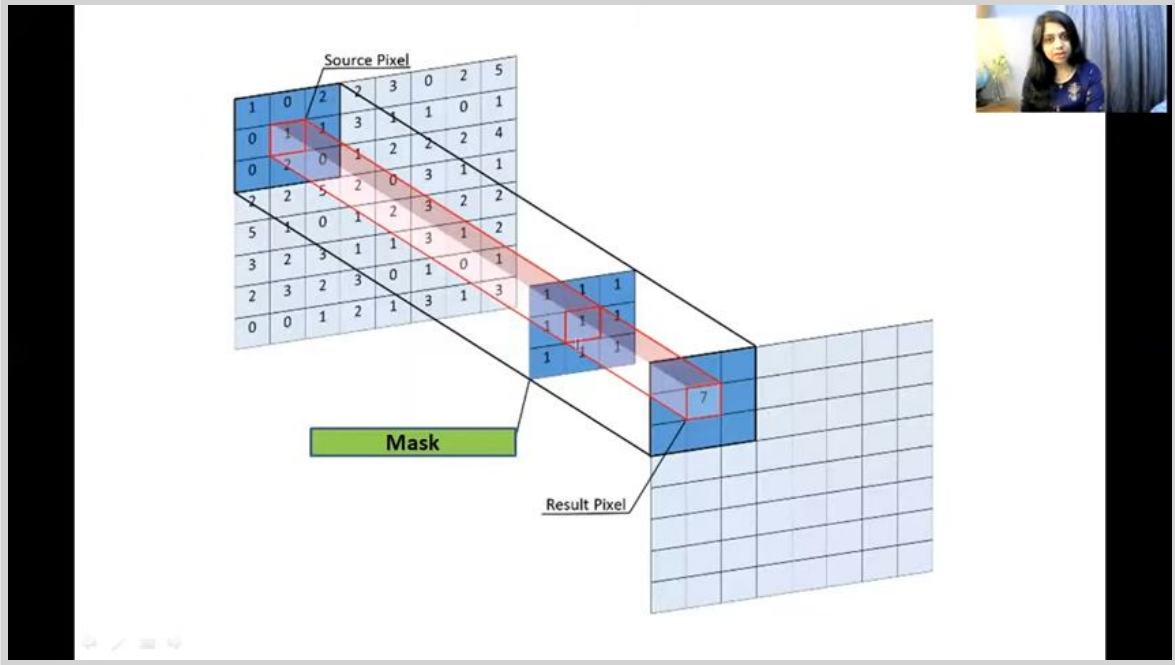
04:43

Example

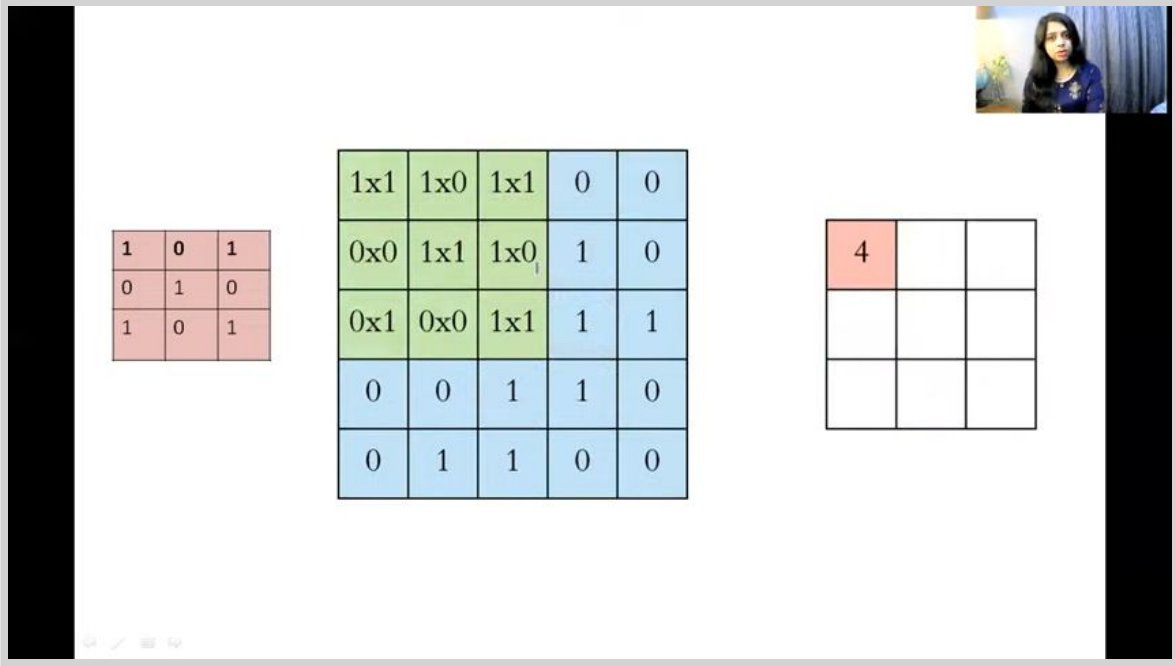
05:06

Example

05:10



05:33



05:34

1	0	1
0	1	0
1	0	1

1	1x1	1x0	0x1	0
0	1x0	1x1	1x0	0
0	0x1	1x0	1x1	1
0	0	1	1	0
0	1	1	0	0

4	3	

05:39

1	0	1
0	1	0
1	0	1

1	1	1	0	0
0	1	1	1	0
0x1	0x0	1x1	1	1
0x0	0x1	1x0	1	0
0x1	1x0	1x1	0	0

4	3	4
2	4	3
2		

05:42



1	0	1
0	1	0
1	0	1

1x1	1x0	1x1	0	0
0x0	1x1	1x0	1	0
0x1	0x0	1x1	1	1
0	0	1	1	0
0	1	1	0	0

4		

05:43



1	0	1
0	1	0
1	0	1

1	1x1	1x0	0x1	0
0	1x0	1x1	1x0	0
0	0x1	1x0	1x1	1
0	0	1	1	0
0	1	1	0	0

4	3	

05:44

05:46

1	0	1
0	1	0
1	0	1

1	1	1	0	0
0x1	1x0	1x1	1	0
0x0	0x1	1x0	1	1
0x1	0x0	1x1	1	0
0	1	1	0	0

4	3	4
2		

05:47

1	0	1
0	1	0
1	0	1

1	1	1	0	0
0	1	1x1	1x0	0x1
0	0	1x0	1x1	1x0
0	0	1x1	1x0	0x1
0	1	1	0	0

4	3	4
2	4	3

05:51



1	0	1
0	1	0
1	0	1

1	1	1	0	0
0	1	1	1	0
0	0	1x1	1x0	1x1
0	0	1x0	1x1	0x0
0	1	1x1	0x0	0x1

4	3	4
2	4	3
2	3	4

06:19

8	4	3	0	1	2	3	6
6	6	0	0	2	5	7	8
9	7	8	1	5	6	0	3
5	6	7	1	3	8	6	0
3	8	4	6	5	4	3	8
6	0	7	0	7	9	8	8
0		3	0	6	6	4	1
3	8	6	7	1	4	0	4

8	1	5
7	1	3
4	6	5

Correlation =
 $8 \times 0 + 1 \times 0 + 5 \times 0 + 7 \times 0 + 1 \times 8 + 3 \times 4 + 4 \times 0 + 6 \times 6 + 5 \times 6$
= 86

**Use of Correlation for
template matching**

0	0	0	0	0	0	0	0	0	0
0	8	4	3	0	1	2	3	6	0
0	6	6	0	0	2	5	7	8	0
0	9	7	8	1	5	6	0	3	0
0	5	6	7	1	3	8	6	0	0
0	3	8	4	6	5	4	3	8	0
0	6	0	7	0	7	9	8	8	0
0	0		3	0	6	6	4	1	0
0	3	8	6	7	1	4	0	4	0
0	0	0	0	0	0	0	0	0	0

image 8 x 8

07:31

8	1	5
7	1	3
4	6	5

Correlation =
8x0+1x0+5x0+7x8+1x4+3x3+4x6+6x6+5x0
=129

0	0	0	0	0	0	0	0	0	0
0	8	4	3	0	1	2	3	6	0
0	6	6	0	0	2	5	7	8	0
0	9	7	8	1	5	6	0	3	0
0	5	6	7	1	3	8	6	0	0
0	3	8	4	6	5	4	3	8	0
0	6	0	7	0	7	9	8	8	0
0	0		3	0	6	6	4	1	0
0	3	8	6	7	1	4	0	4	0
0	0	0	0	0	0	0	0	0	0

07:38

8	1	5
7	1	3
4	6	5

Correlation = 7x1+1x3+4x6= 34

0	0	0	0	0	0	0	0	0	0
0	8	4	3	0	1	2	3	6	0
0	6	6	0	0	2	5	7	8	0
0	9	7	8	1	5	6	0	3	0
0	5	6	7	1	3	8	6	0	0
0	3	8	4	6	5	4	3	8	0
0	6	0	7	0	7	9	8	8	0
0	0		3	0	6	6	4	1	0
0	3	8	6	7	1	4	0	4	0
0	0	0	0	0	0	0	0	0	0

07:57

8	1	5
7	1	3
4	6	5

Correlation = $7 \times 1 + 1 \times 3 + 4 \times 6 = 34$

Correlation = $7 \times 3 + 3 \times 1 + 5 \times 2 = 34$

0	0	0	0	0	0	0	0	0	0
0	8	4	3	0	1	2	3	6	0
0	6	6	0	0	2	5	7	8	0
0	9	7	8	1	5	6	0	3	0
0	5	6	7	1	3	8	6	0	0
0	3	8	4	6	5	4	3	8	0
0	6	0	7	0	7	9	8	8	0
0	0		3	0	6	6	4	1	0
0	3	8	6	7	1	4	0	4	0
0	0	0	0	0	0	0	0	0	0

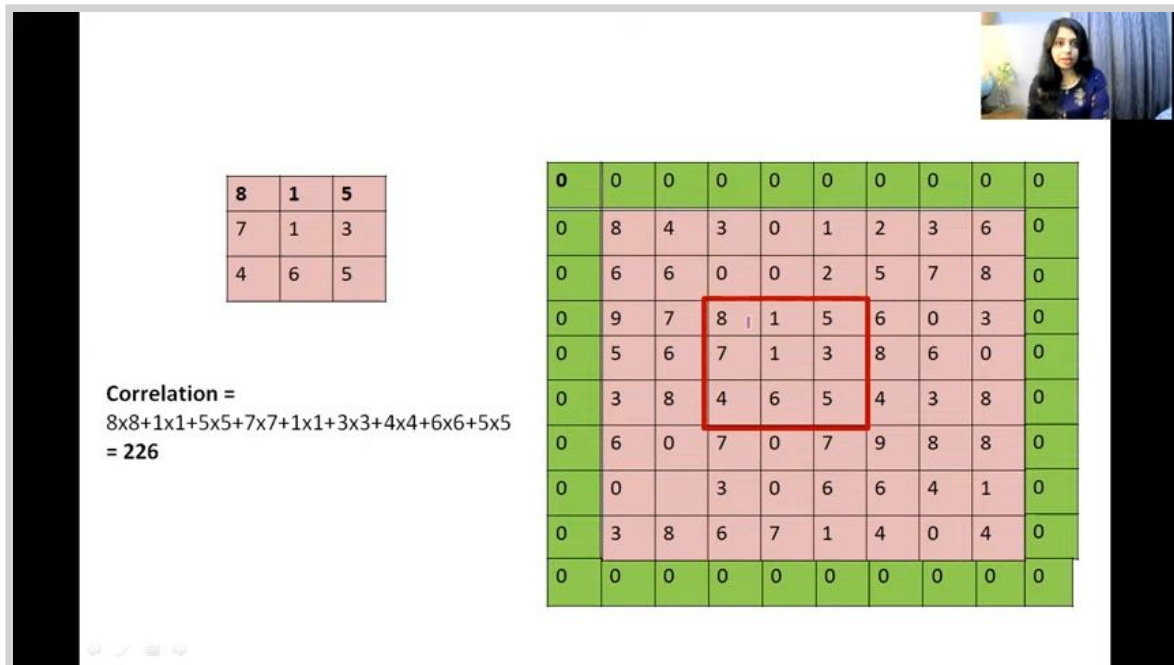
08:02

8	1	5
7	1	3
4	6	5

Correlation = $8 \times 8 + 1 \times 1 + 5 \times 5 + 7 \times 7 + 1 \times 1 + 3 \times 3 + 4 \times 4 + 6 \times 6 + 5 \times 5 = 226$

0	0	0	0	0	0	0	0	0	0
0	8	4	3	0	1	2	3	6	0
0	6	6	0	0	2	5	7	8	0
0	9	7	8	1	5	6	0	3	0
0	5	6	7	1	3	8	6	0	0
0	3	8	4	6	5	4	3	8	0
0	6	0	7	0	7	9	8	8	0
0	0		3	0	6	6	4	1	0
0	3	8	6	7	1	4	0	4	0
0	0	0	0	0	0	0	0	0	0

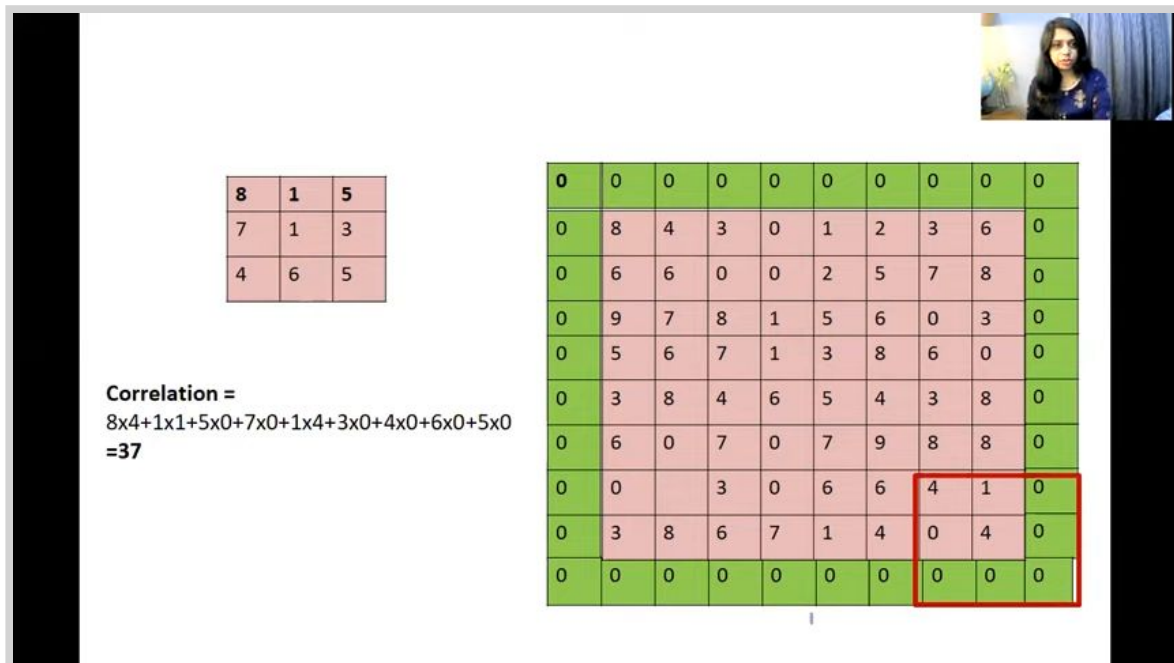
08:16



Correlation =
 $8 \times 8 + 1 \times 1 + 5 \times 5 + 7 \times 7 + 1 \times 1 + 3 \times 3 + 4 \times 4 + 6 \times 6 + 5 \times 5$
= 226

when mask and image value same :
 you get the highest value like above..

[09:03](#)



Correlation =
 $8 \times 4 + 1 \times 1 + 5 \times 0 + 7 \times 0 + 1 \times 4 + 3 \times 0 + 4 \times 0 + 6 \times 0 + 5 \times 0$
= 37

[09:29](#)


8	1	5
7	1	3
4	6	5

Correlation
={ 86,129,34,-----,226,-----37}



0	0	0	0	0	0	0	0	0	0
0	8	4	3	0	1	2	3	6	0
0	6	6	0	0	2	5	7	8	0
0	9	7	8	1	5	6	0	3	0
0	5	6	7	1	3	8	6	0	0
0	3	8	4	6	5	4	3	8	0
0	6	0	7	0	7	9	8	8	0
0	0		3	0	6	6	4	1	0
0	3	8	6	7	1	4	0	4	0
0	0	0	0	0	0	0	0	0	0

09:48

•Correlation measure the similarity between images or parts of images.



mask



10:18

Convolution



- Same as correlation except that the mask is **flipped**, both horizontally and vertically.

For symmetric masks (i.e., $h(i,j)=h(-i,-j)$), convolution is equivalent to correlation!

Notation:

$$h * f = f * h$$

[10:35](#)

Convolution



- Same as correlation except that the mask is **flipped**, both horizontally and vertically.



1	2	3
4	5	6
7	8	9

For symmetric masks (i.e., $h(i,j)=h(-i,-j)$), convolution is equivalent to correlation!

Notation:

$$h * f = f * h$$

[11:04](#)

[11:16](#)

Convolution

1	1	1	0	0
0	1	1	1	0
0	0	1	1	1
0	0	1	1	0
0	1	1	0	0

Image

4		

Convolved Feature

11:18

Convolution

1	1	1	0	0
0	1	1	1	0
0	0	1	1	1
0	0	1	1	0
0	1	1	0	0

Image

4	3	

Convolved Feature

11:18

Convolution



1	1	1	0	0
0	1	1	1	0
0	0	1	1	1
0	0	1	1	0
0	1	1	0	0

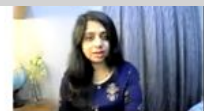
Image

4	3	4
2		

Convolved
Feature

11:22

Convolution



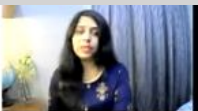
1	1	1	0	0
0	1	1	1	0
0	0	1	1	1
0	0	1	1	0
0	1	1	0	0

Image

4	3	4
2	4	3
2		

Convolved
Feature

11:24



Convolution

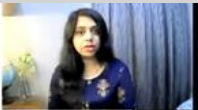
1	1	1	0	0
0	1	1	1	0
0	0	1 _{x1}	1 _{x0}	1 _{x1}
0	0	1 _{x0}	1 _{x1}	0 _{x0}
0	1	1 _{x1}	0 _{x0}	0 _{x1}

Image

4	3	4
2	4	3
2	3	4

Convolved Feature

11:41



Correlation/Convolution Examples

1	1	1x1	0x0	0x1
0	1	1x0	1x1	0x0
0	0	1x1	1x0	1x1
0	0	1	1	0
0	1	1	0	0

4	3	4

Image Matrix				
1	0	0=0x1	0=1x0	0=1x0
1	0	1=1x1	0=1x0	0=1x0
0	1	0=1x0	0=0x1	1=1x1
0	1	0	1	0
1	1	1	0	1

Convolved Matrix		
4	1	2

11:43

Correlation/Convolution Examples

1	1	1	0	0
0	1	1x1	1x0	0x1
0	0	1x0	1x1	1x0
0	0	1x1	1x0	0x1
0	1	1	0	0

4	3	4
2	4	3

Image Matrix

1	0	0	1	1
1	0=0x1	0=1x0	0=1x0	1
0	1=1x1	0=1x0	0=0x0	1
0	0=1x0	0=0x1	1=1x1	0
1	1	1	0	1

Convolved Matrix

4	1	2
2	2	

11:44

Correlation/Convolution Examples

1	1	1	0	0
0	1	1x1	1x0	0x1
0	0	1x0	1x1	1x0
0	0	1x1	1x0	0x1
0	1	1	0	0

4	3	4
2	4	3

Image Matrix

1	0	0	1	1
1	0=0x1	0=1x0	0=1x0	1
0	1=1x1	0=1x0	0=0x0	1
0	0=1x0	0=0x1	1=1x1	0
1	1	1	0	1

Convolved Matrix

4	1	2
2	2	

11:47

https://askify.video/view/youtube?_source=youtube_extension&_action=download_pdf&_id=rM91VLA6n2Lx78bxhKsv

20/23

Correlation/Convolution Examples



1x1	1x0	1x1	0	0
0x0	1x1	1x0	1	0
0x1	0x0	1x1	1	1
0	0	1	1	0
0	1	1	0	0

4		

Image Matrix

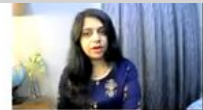
1	0	0	1	1
1	0	1	1	1
0	1=1x1	0=1x0	0=0x0	1
0	1=1x1	0=0x0	0=1x0	0
1	0=1x0	1=1x1	0=0x1	1

Convolved Matrix

4	1	2
2	2	3
2	3	

11:51

Correlation/Convolution Examples



1	1	1	0	0
0x1	1x0	1x1	1	0
0x0	0x1	1x0	1	1
0x1	0x0	1x1	1	0
0	1	1	0	0

4	3	4
2		

Image Matrix

1	0=0x1	0=0x0	0=1x0	1
1	0=0x1	0=1x0	0=1x0	1
0	0=1x0	1=1x1	0=0x1	1
0	1	0	1	0
1	1	1	0	1

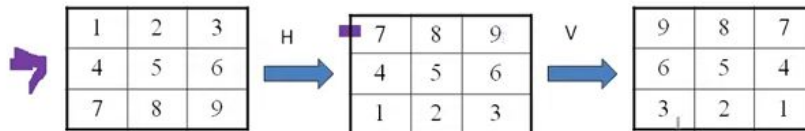
Convolved Matrix

4	1	

Convolution



- Same as correlation except that the mask is **flipped**, both horizontally and vertically.



For symmetric masks (i.e., $h(i,j)=h(-i,-j)$), convolution is equivalent to correlation!

Notation:

$$h * f = f * h$$



1	0	1
0	1	0
1	0	1

1	1	1x1	0x0	0x1
0	1	1x0	1x1	0x0
0	0	1x1	1x0	1x1
0	0	1	1	0
0	1	1	0	0

4	3	4