



Microsoft Research
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Computer Vision Convolution

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Spatial Filtering

$w(-1,-1)$	$w(-1,0)$	$w(-1,1)$
$w(0,-1)$	$w(0,0)$	$w(0,1)$
$w(1,-1)$	$w(1,0)$	$w(1,1)$

Mask coefficients showing coordinate arrangement



Convolution

$$g(x, y) = \sum_{s=-a}^a \sum_{t=-b}^b \omega(s, t) f(x - s, y - t)$$

$$g = \omega * f$$



Convolution

Convolution kernel, ω

1	-1	-1
1	2	-1
1	1	1

Rotate $\downarrow 180^\circ$

1	1	1
-1	2	1
-1	-1	1

Input Image, f

2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2

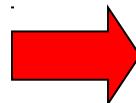


1	1	1
-1	2	1
-1	-1	1

Convolution

2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2

1	1	1		
-1	4	2	2	3
-1	-2	1	3	3
2	2	1	2	
1	3	2	2	



5			

Output
Image, g

UCERD Input Image, f



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1	1	1
-1	2	1
-1	-1	1

Convolution

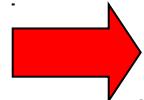
1	1	1
-2	4	2
-2	-1	3
2	2	1
1	3	2

Input Image, f

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www.ucerd.com

2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2

Output
Image, g



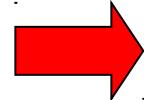
5	4		

1	1	1
-1	2	1
-1	-1	1

Convolution

Input Image, f

	1	1	1
2	-2	4	3
2	-1	-3	3
2	2	1	2
1	3	2	2



5	4	4

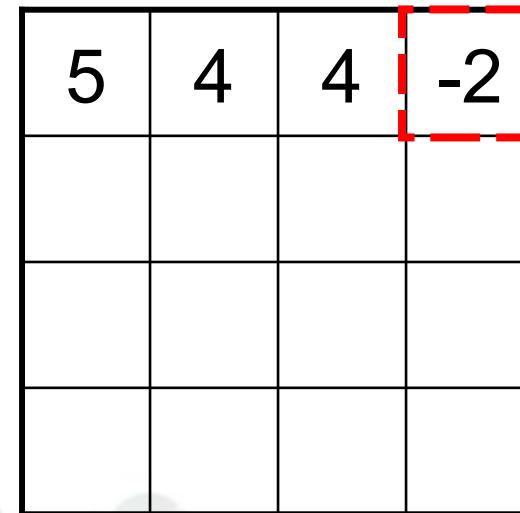
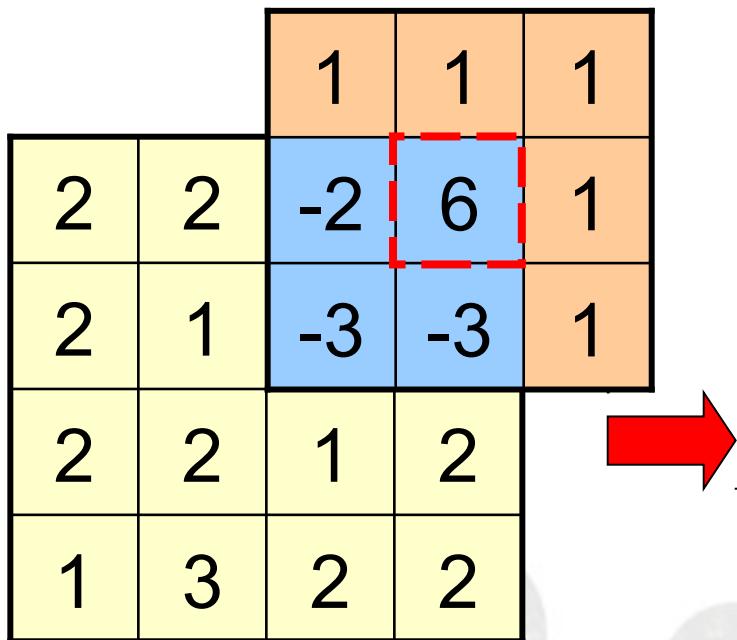
2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2

Output
Image, g

Convolution

1	1	1
-1	2	1
-1	-1	1

2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2



Output
Image, g

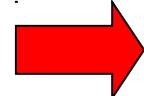
Input Image, f

Convolution

1	1	1
-1	2	1
-1	-1	1

2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2

1	2	2	2	3
-1	4	1	3	3
-1	-2	2	1	2
1	3	2	2	



5	4	4	-2
9			

Output
Image, g

Input Image, f

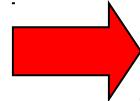
Convolution

1	1	1
-1	2	1
-1	-1	1

2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2

2	2	2	3
-2	2	3	3
-2	-2	1	2
1	3	2	2

Input Image, f



5	4	4	-2
9	6		

Output
Image, g



Convolution

5	4	4	-2
9	6	14	5
11	7	6	5
9	12	8	5

Final output Image, g



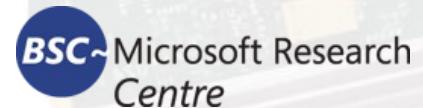
Correlation

$$g(x, y) = \sum_{s=-a}^a \sum_{t=-b}^b \omega(s, t) f(x + s, y + t)$$

$$g = \omega \circ f$$



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Correlation

correlation kernel, ω

1	-1	-1
1	2	-1
1	1	1

Don't rotate use it directly

Input Image f

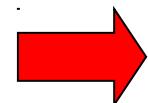
2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2



1	-1	-1
1	2	-1
1	1	1

Correlation

1	-1	-1		
1	4	-2	2	3
1	2	1	3	3
2	2	1	2	
1	3	2	2	



5			

output
Image, g

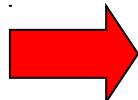
Input Image, f

1	-1	-1
1	2	-1
1	1	1

Correlation

1	-1	-1	
2	4	-2	3
2	1	3	3
2	2	1	2
1	3	2	2

Input Image, f

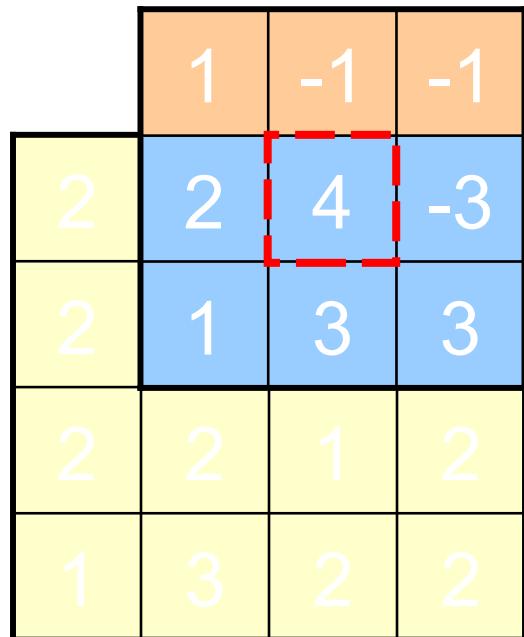


2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2

output
Image, g

1	-1	-1
1	2	-1
1	1	1

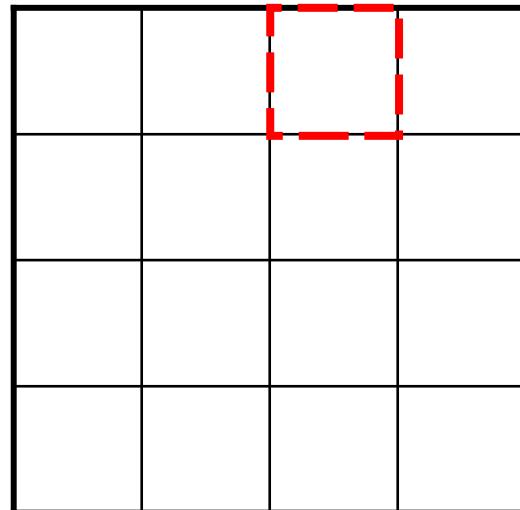
Correlation



Input Image, f

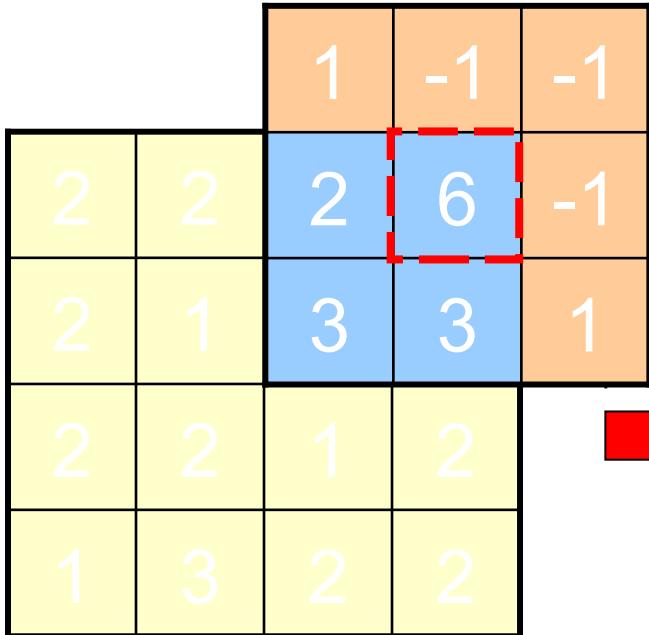
The input image f is a 5x4 grid of values. A 3x3 kernel is highlighted with a red dashed border, centered on the value 4.

1	-1	-1	
2	2	4	-3
2	1	3	3
2	2	1	2
1	3	2	2

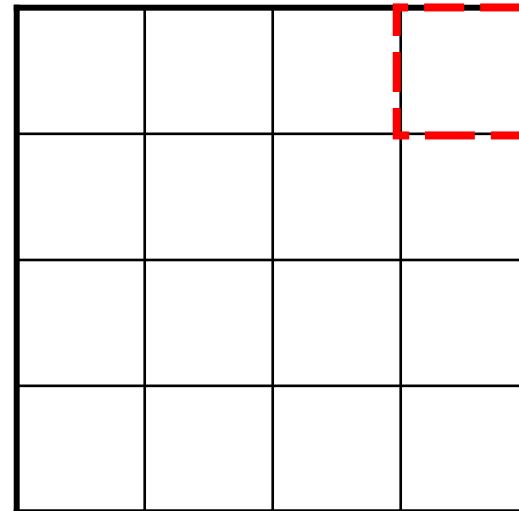


1	-1	-1
1	2	-1
1	1	1

Correlation



Input Image, f



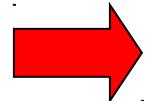
output
Image, g

1	-1	-1
1	2	-1
1	1	1

Correlation

2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2

1	-2	-2	2	3
1	4	-1	3	3
1	2	2	1	2
1	3	2	2	



output
Image, g

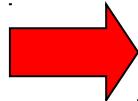
Input Image, f

1	-1	-1
1	2	-1
1	1	1

Correlation

2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2

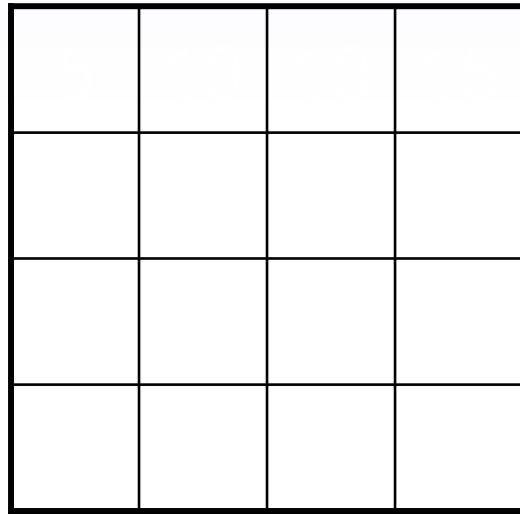
2	-2	-2	3
2	2	-3	3
2	2	1	2
1	3	2	2



output
Image, g

Input Image, f

Correlation



Final output Image, g



Linear Spatial Filtering

$$R = \omega(-1, -1)f(x-1, y-1) + \omega(-1, 0)f(x-1, y) + \dots \\ + \omega(0, 0)f(x, y) + \dots + \omega(1, 0)f(x+1, y) + \omega(1, 1)f(x+1, y+1)$$

Smoothing Spatial Filters

Types of Smoothing Filters :

Smoothing Linear Filters :

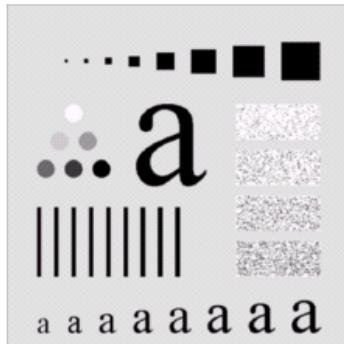
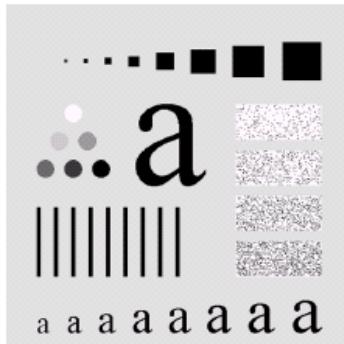


Smoothing Linear Filters

$\frac{1}{9} \times$	<table border="1"><tr><td>1</td><td>1</td><td>1</td></tr><tr><td>1</td><td>1</td><td>1</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>	1	1	1	1	1	1	1	1	1	$\frac{1}{16} \times$	<table border="1"><tr><td>1</td><td>2</td><td>1</td></tr><tr><td>2</td><td>4</td><td>2</td></tr><tr><td>1</td><td>2</td><td>1</td></tr></table>	1	2	1	2	4	2	1	2	1
1	1	1																			
1	1	1																			
1	1	1																			
1	2	1																			
2	4	2																			
1	2	1																			
<i>Box filter</i>			<i>Weighted average filter</i>																		

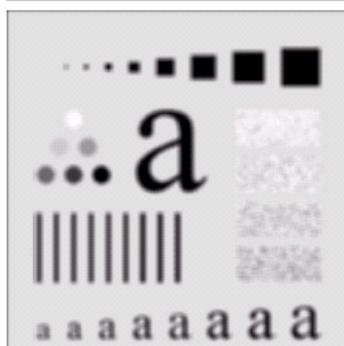
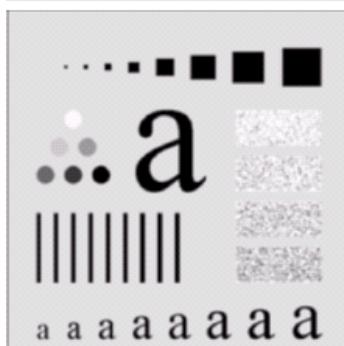
Smoothing Linear Filters

Original



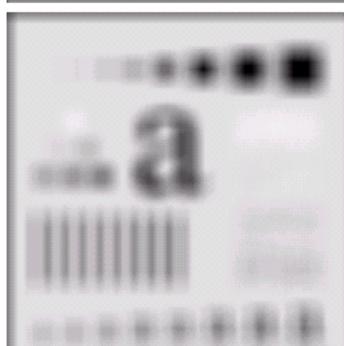
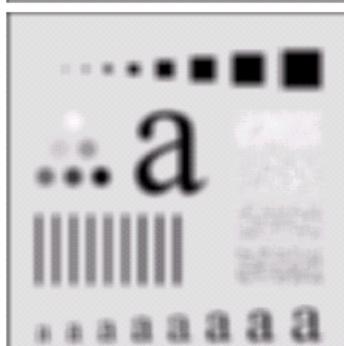
3x3

5x5



9x9

15x15

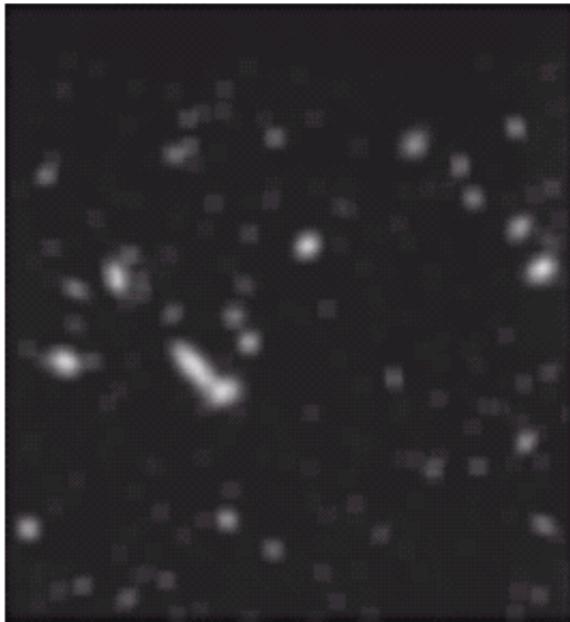


35x35

Smoothing Linear Filters



original



blurred



thresholded

Summary

- We have looked at:
 - What are spatial domain operations.
 - What are convolution and correlation.
 - What is smoothing linear filter
- Next time we will continue our talk about image enhancement in spatial domain by focusing on statistical terminology

