

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

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

$$g = \omega \star f$$

Convolution

Convolution kernel, ω

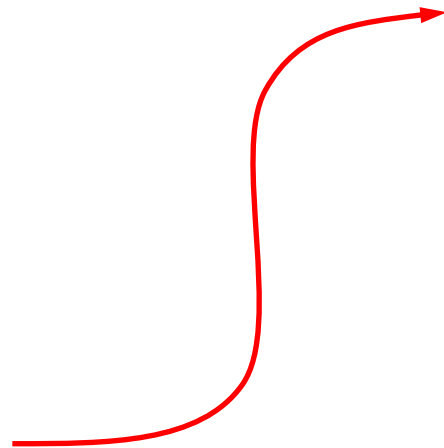
| | | |
|---|----|----|
| 1 | -1 | -1 |
| 1 | 2 | -1 |
| 1 | 1 | 1 |

Rotate \downarrow 180°

| | | |
|----|----|---|
| 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 |

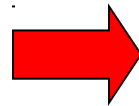


Convolution

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



| | | | |
|---|--|--|--|
| 5 | | | |
| | | | |
| | | | |
| | | | |

Output Image, g

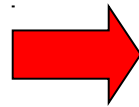
UCERD Input Image, f

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



| | | | |
|---|---|--|--|
| 5 | 4 | | |
| | | | |
| | | | |
| | | | |

**Output
Image, g**

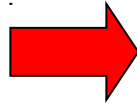
Input Image, f

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



| | | | |
|---|---|---|--|
| 5 | 4 | 4 | |
| | | | |
| | | | |
| | | | |

Output Image, g

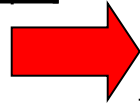
Input Image, f

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 | 1 | 1 |
| 2 | 2 | -2 | 6 | 1 |
| 2 | 1 | -3 | -3 | 1 |
| 2 | 2 | 1 | 2 | |
| 1 | 3 | 2 | 2 | |



| | | | |
|---|---|---|----|
| 5 | 4 | 4 | -2 |
| | | | |
| | | | |
| | | | |

Output Image, g

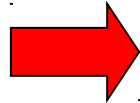
Input Image, f

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

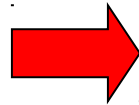
Convolution

| | | |
|----|----|---|
| 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

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

$$g = \omega \circ f$$

Correlation

correlation kernel, ω

| | | |
|---|----|----|
| 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 |

Don't rotate use it directly

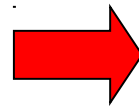


Correlation

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



| | | | |
|---|--|--|--|
| 5 | | | |
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**output
Image, g**

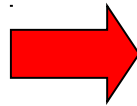
Input Image, f

Correlation

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



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output
Image, g

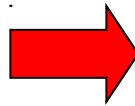
Input Image, f

Correlation

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



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output
Image, g

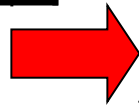
Input Image, f

Correlation

| | | |
|---|----|----|
| 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 | -1 | -1 |
| 2 | 2 | 2 | 6 | -1 |
| 2 | 1 | 3 | 3 | 1 |
| 2 | 2 | 1 | 2 | |
| 1 | 3 | 2 | 2 | |



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output
Image, g

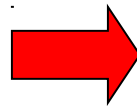
Input Image, f

Correlation

| | | |
|---|----|----|
| 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 |



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| | | | |

output
Image, g

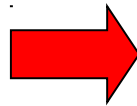
Input Image, f

Correlation

| | | |
|---|----|----|
| 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 |

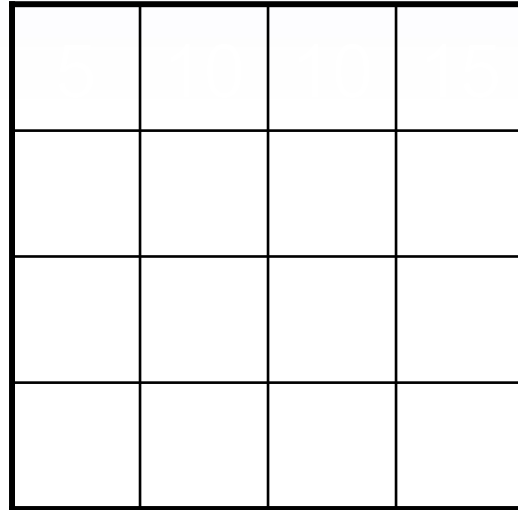


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| | | | |
| | | | |

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

$$\frac{1}{9} \times$$

| | | |
|---|---|---|
| 1 | 1 | 1 |
| 1 | 1 | 1 |
| 1 | 1 | 1 |

Box filter

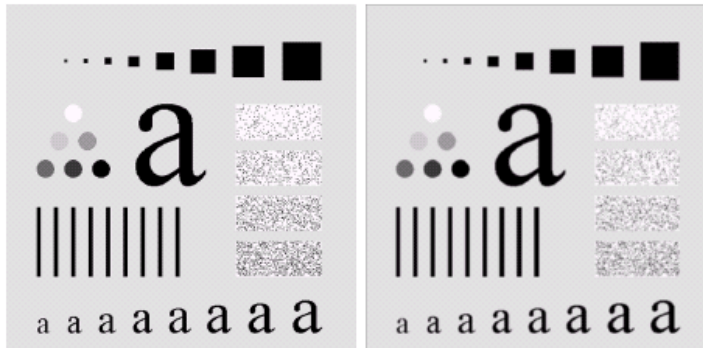
$$\frac{1}{16} \times$$

| | | |
|---|---|---|
| 1 | 2 | 1 |
| 2 | 4 | 2 |
| 1 | 2 | 1 |

Weighted average filter

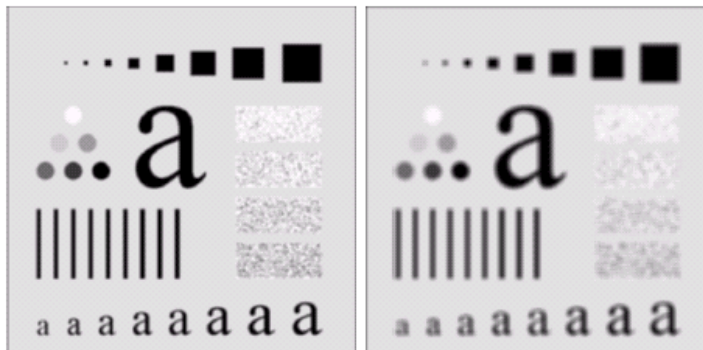
Smoothing Linear Filters

Original



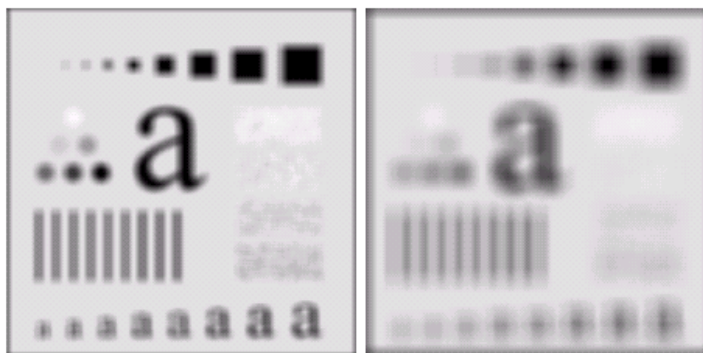
3x3

5x5



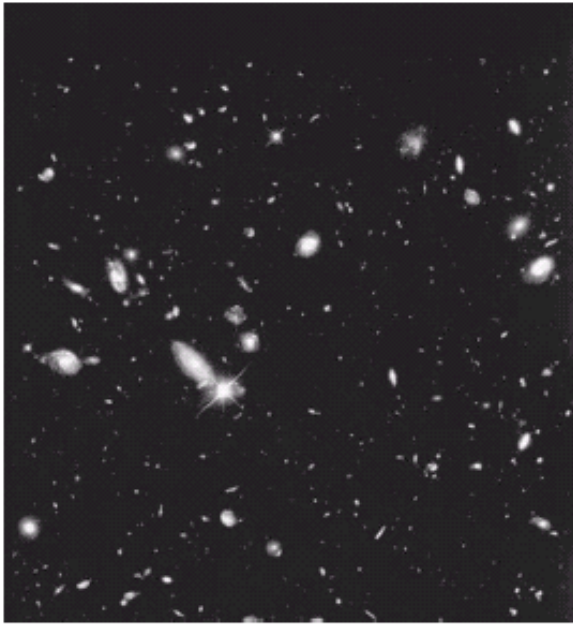
9x9

15x15

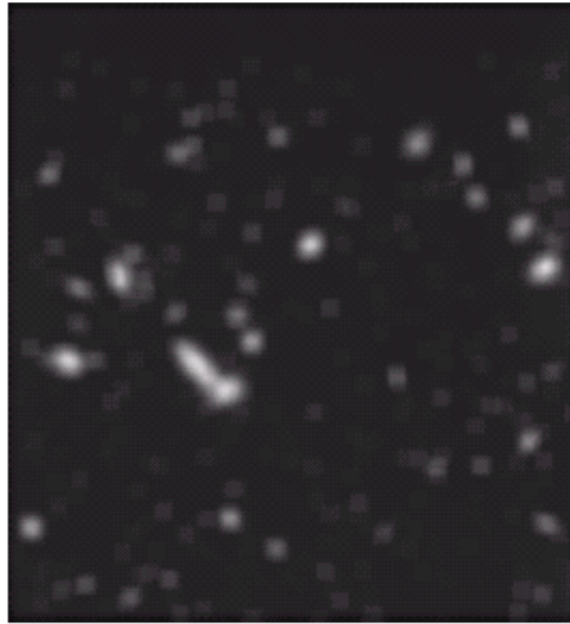


35x35

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