Mahidol University *Wisdom of the Land*

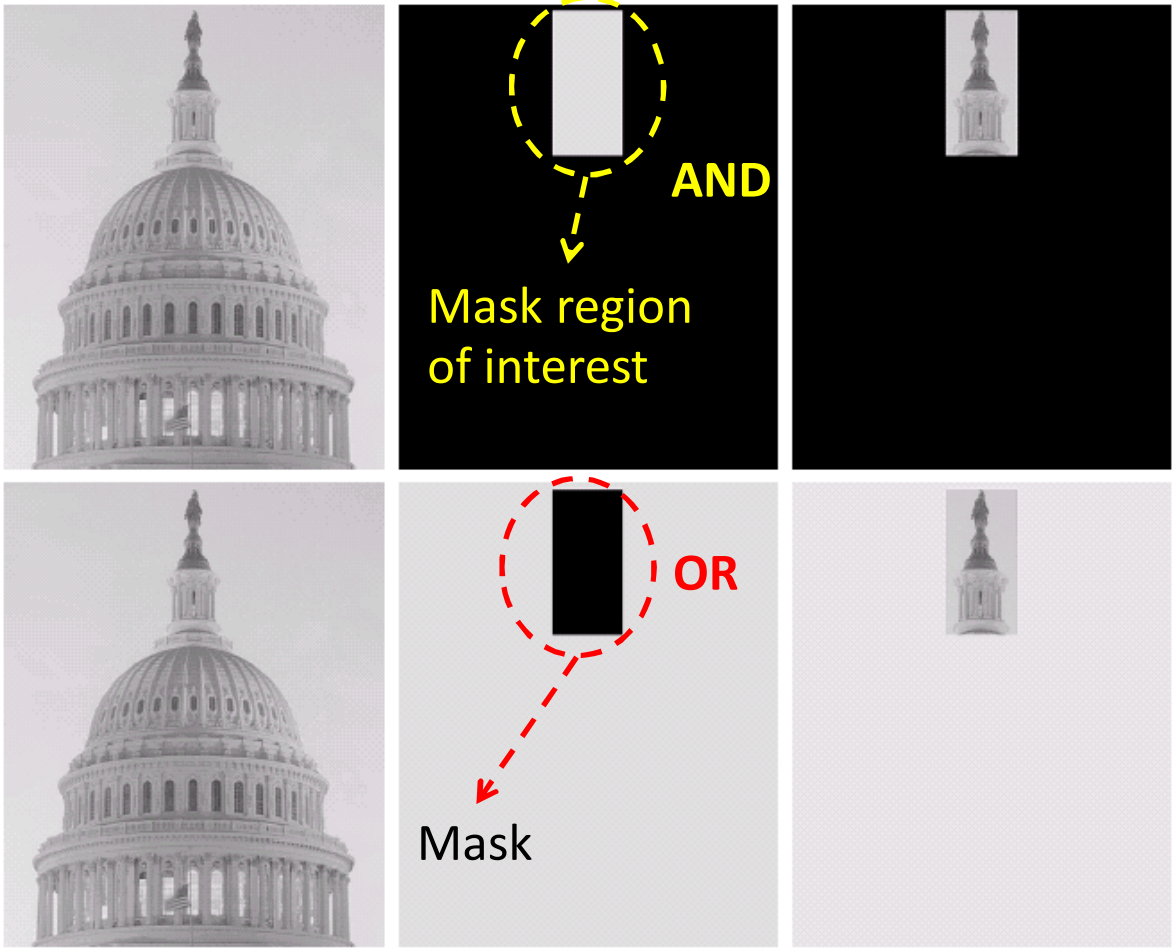
Chapter 3

Image Enhancement in the Spatial Domain

Enhancement Using Arithmetic/Logic Operations

- Arithmetic/logic operations involving images are performed on a pixel-by-pixel basis between two or more images.
- Logic operations are concerned with the ability to implement the AND, OR, and NOT logic operators because these three operators are functionally complete.
- Arithmetic operations are concerned about +,-,*, / and so on (arithmetic operators).

Logic Operations



Input image

The result is ROI:
Region of interest

- Application: for selecting sub-image in an image.
- Note: The images can be gray-level images. Each pixel is an 8-bit binary number. Bit by bit operation is used.

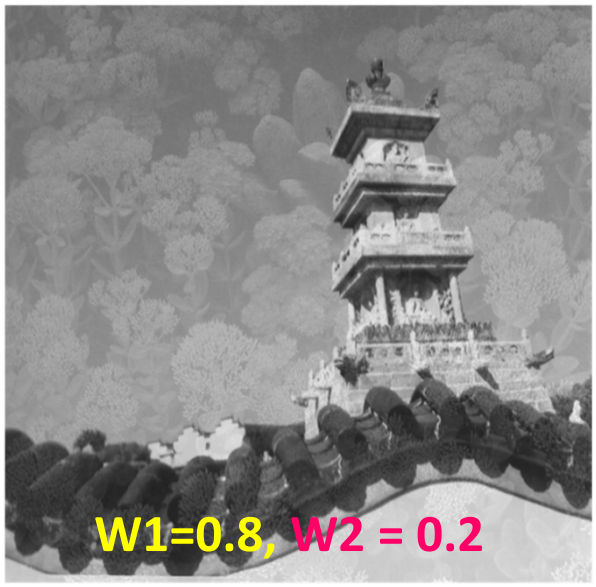
Image Addition

- The addition of two images $f_1(x,y)$ and $f_2(x,y)$ expressed as

$$g(x,y) = w_1 * f_1(x,y) + w_2 * f_2(x,y)$$

First image

Second image



The addition of two images

Image Subtraction

- The difference between two images $f_1(x, y)$ and $f_2(x, y)$ expressed as

$$g(x, y) = f_1(x, y) - f_2(x, y)$$

First image

Second image

The difference between two images

Image Averaging

- Consider a noisy image $g(x,y)$ formed by the addition of noise to original image $f(x,y)$

$$g(x,y) = f(x,y) + \eta(x,y)$$

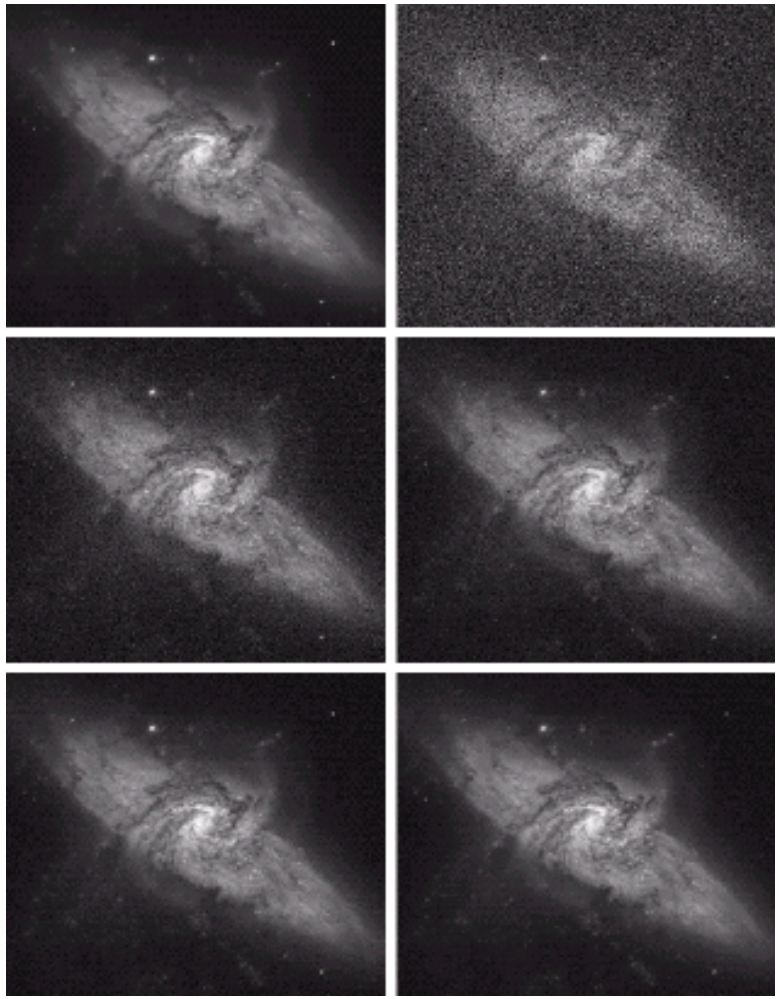
- Where the assumption is that at every pair of coordinates(x,y) the noise is uncorrelated and has zero average value.

- The objective of this procedure is to reduce the noise content.
- Let there are K different noisy images
- If an image $\overline{g}(x,y)$ is formed by averaging K different noisy images

$$\overline{g}(x,y) = \frac{1}{K}\sum_{i=1}^{K} g_i(x,y)$$

Example : Image Averaging

- Image of Galaxy Pair NGC 3314



Input image

One of the noisy images

Average of K = 8 noisy images

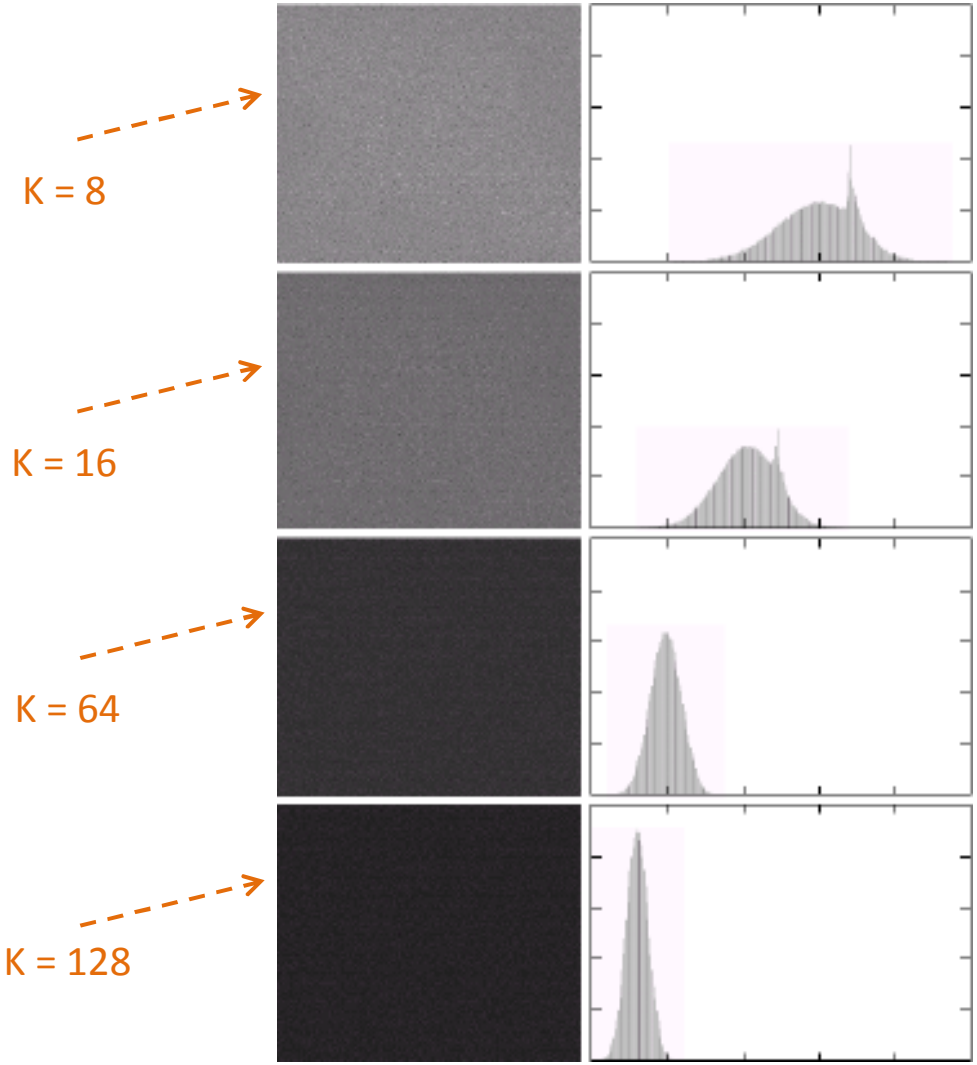
Average of K = 16 noisy images

Average of K = 64 noisy images

Average of K = 128 noisy images

Application : Noise reduction

Example : Image Averaging

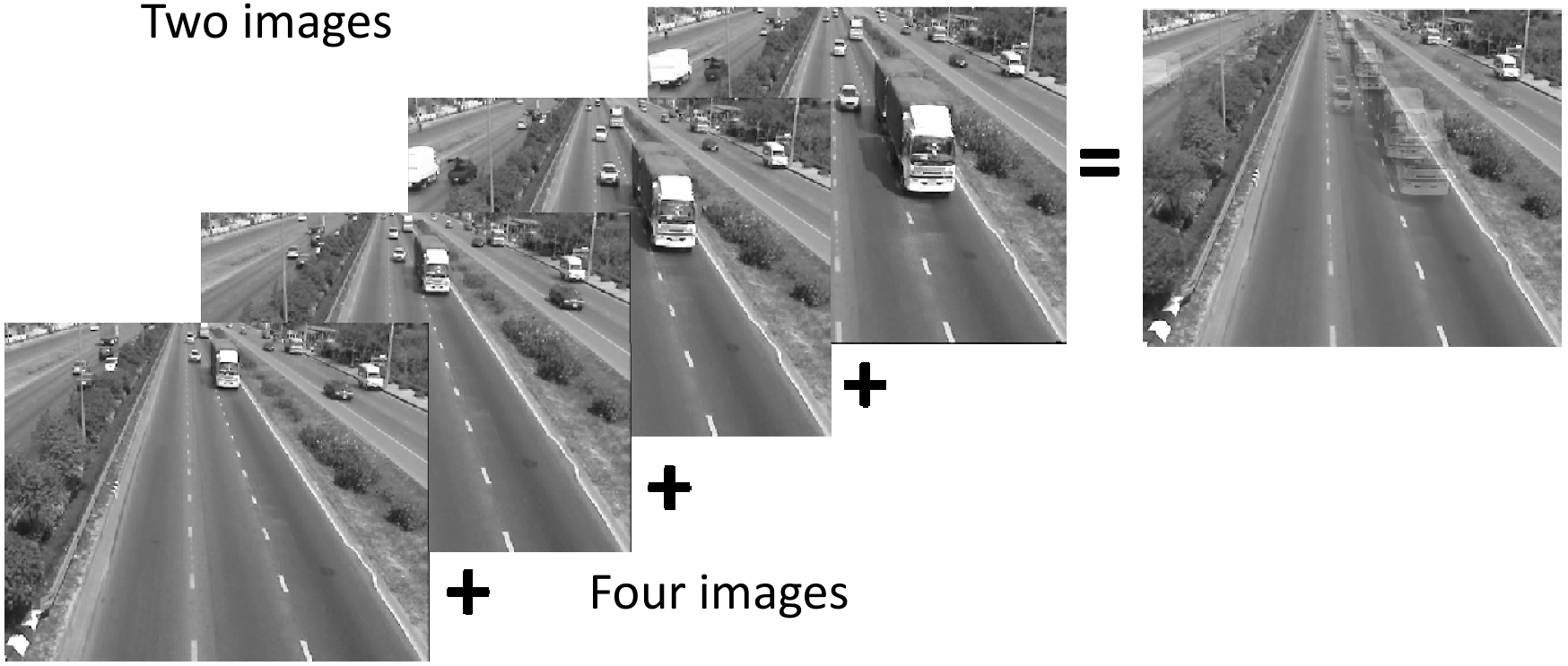


- Difference = Input - Averaged

$$d(x,y) = f(x,y) - \overline{g}(x,y)$$

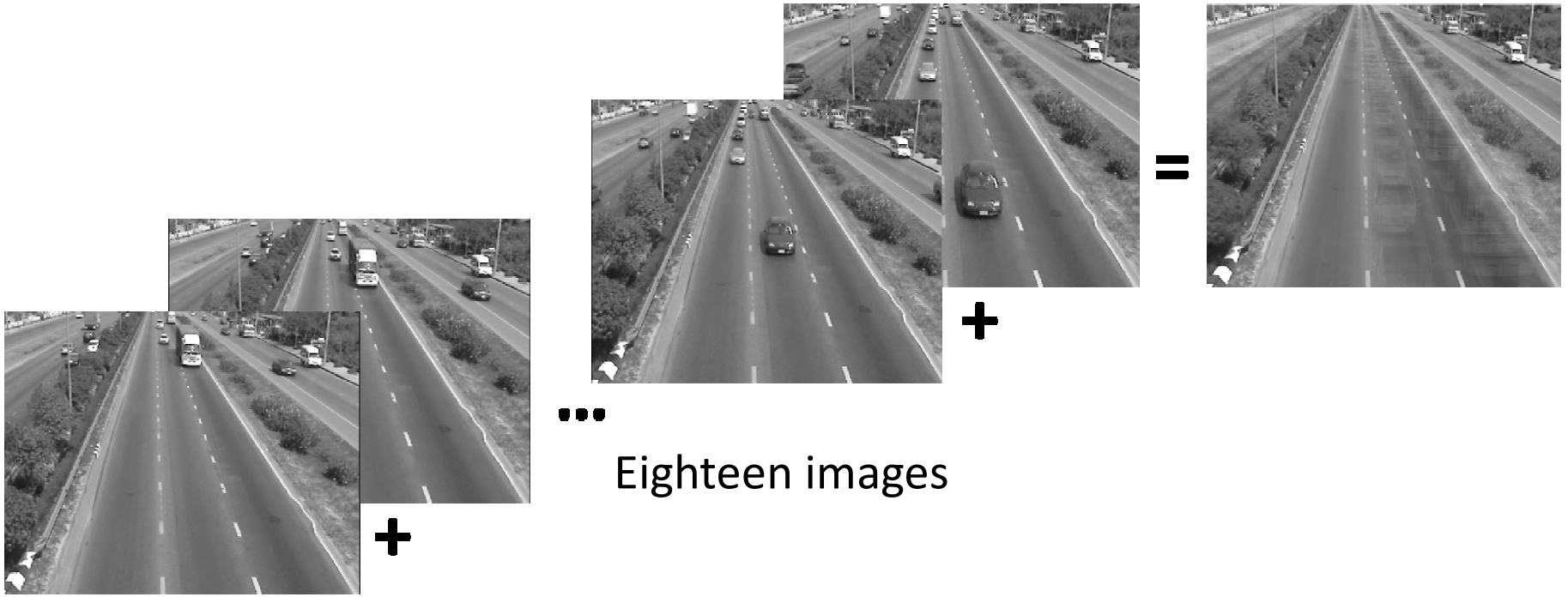
Example : Image Averaging

Two images



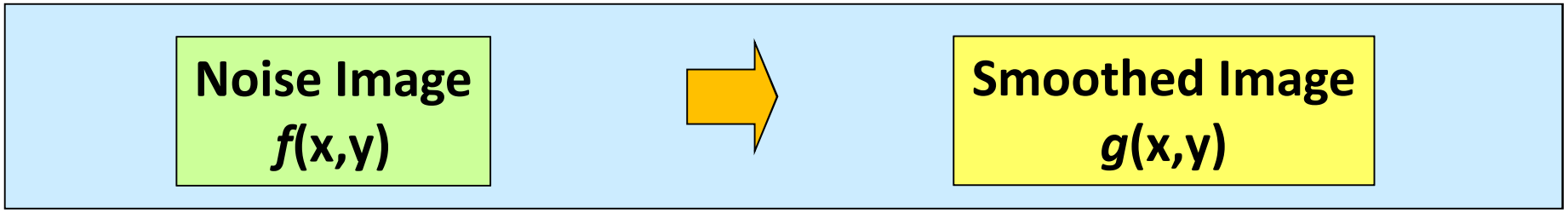
Four images

Example : Image Averaging



Eighteen images

Basics of Spatial Filtering



Cause :

a) Environment while taking images

b) Sensor malfunction

Smoothing spatial filters :

a) Smoothing nonlinear filters (Order-statistics nonlinear filters)

b) Smoothing linear filters (Averaging linear filters)

Basics of Spatial Filtering

- When the image has noise happens in the image. Removing noise from images is difficult due to the uncertainty of the position and the amount of noise.
- Reducing noise from images is can not eliminate all noise, but help to achieve the improved quality to be processed further.

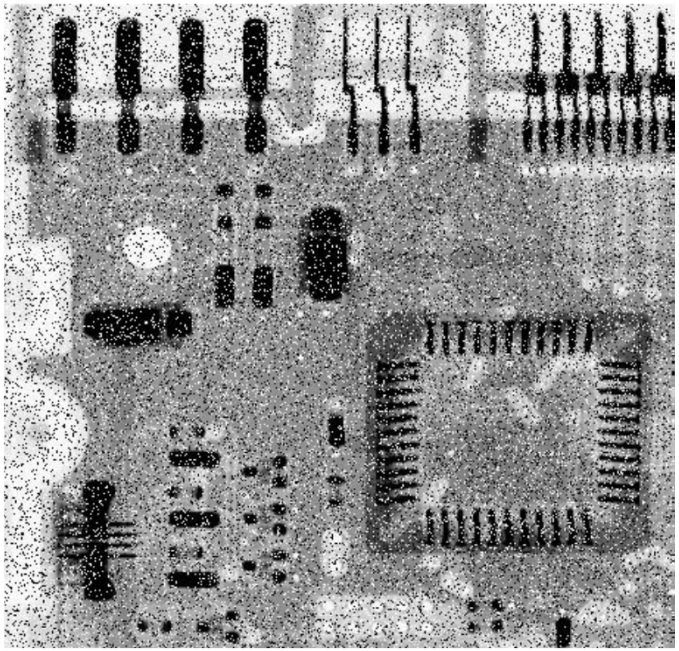
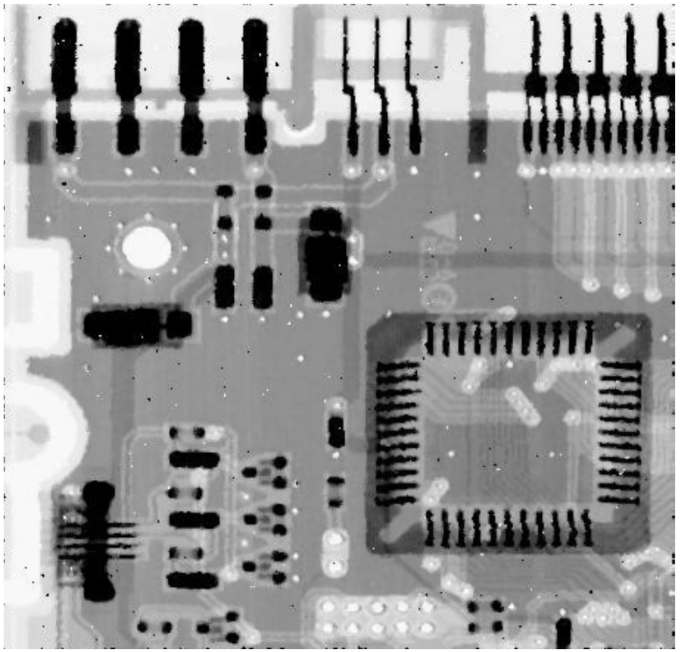
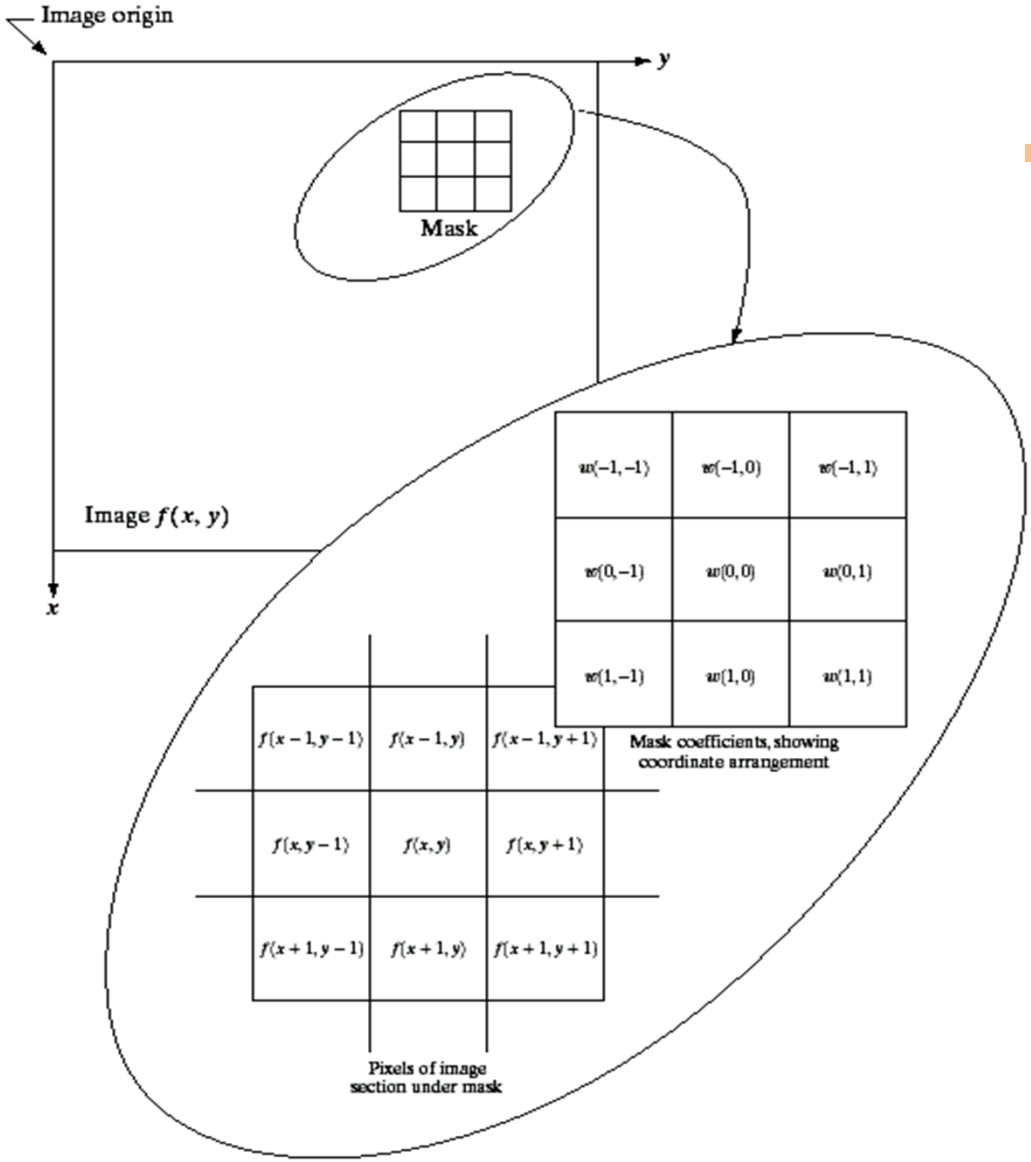


Image corrupted by noise



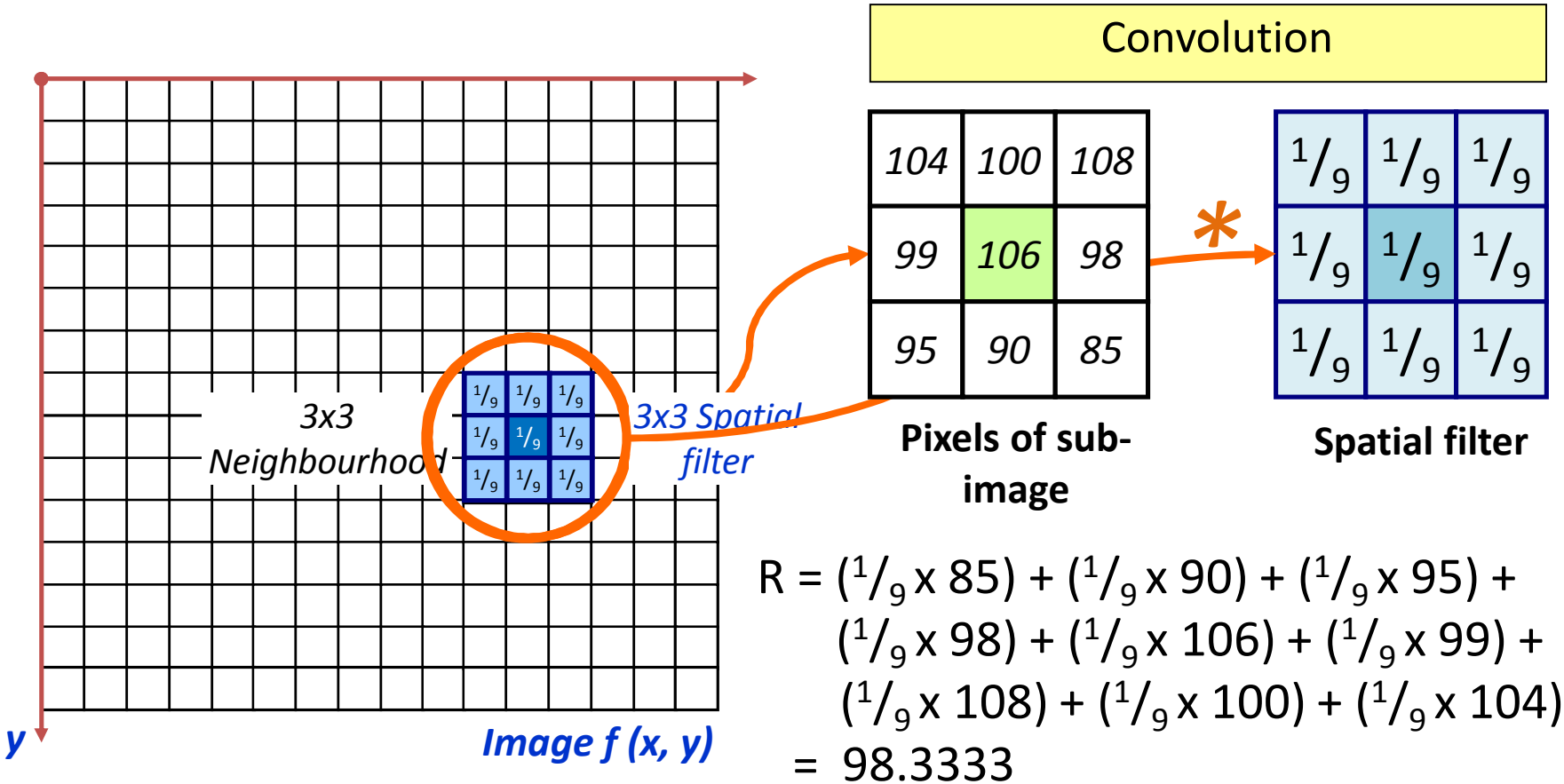
Result of applying a 3×3 mask filter

Mechanics of spatial filtering



- The magnified drawing shows a 3x3 mask and the sub-image directly under it; the image section is shown displaced out from under the mask for ease of readability.

Mechanics of Spatial Filtering



$$R = (1/9 \times 85) + (1/9 \times 90) + (1/9 \times 95) + (1/9 \times 98) + (1/9 \times 106) + (1/9 \times 99) + (1/9 \times 108) + (1/9 \times 100) + (1/9 \times 104)$$
$$= 98.3333$$

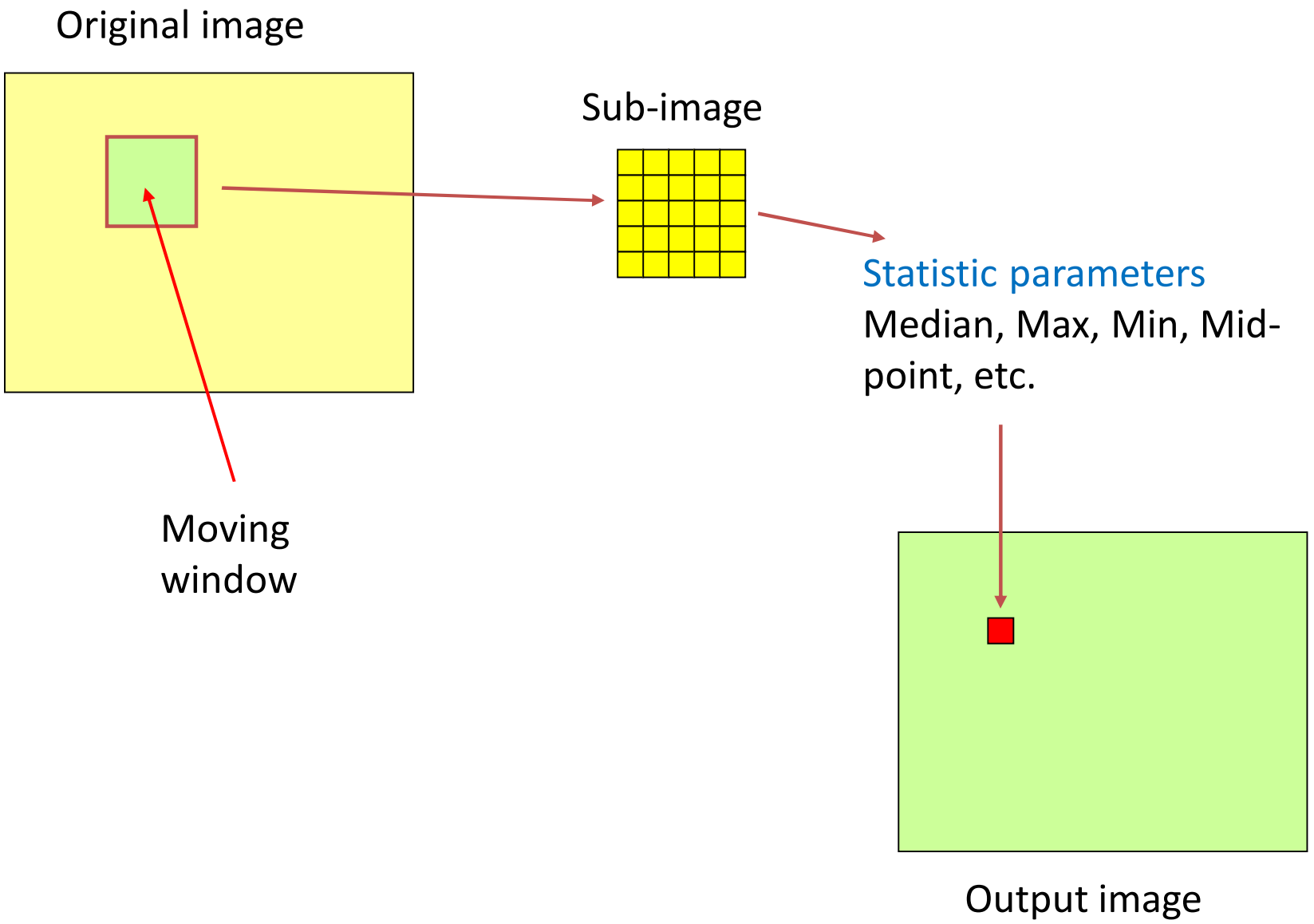
- The above is repeated for every pixel in the input image to generate the smoothed image.

Smoothing Spatial Filters

- Smoothing spatial filters are used for blurring and for noise reduction.
- Blurring can be used as a pre-processing steps to :
  - remove small details from an image prior to (large) object extraction
  - bridge small gaps in lines or curves.
- Noise reduction can be accomplished by blurring with a linear filter and also by nonlinear filtering.

- There are two main types of smoothing spatial filters :
  - Smoothing nonlinear filters (Order-statistics nonlinear filters)
  - Smoothing linear filters (Averaging linear filters)

Order-statistics Nonlinear Filters



Example : Median Filter

- The best known order-statistics filter is the median filter.
- The median filter is excellent for random noise reduction with considerably less blurring than the linear smoothing filters.

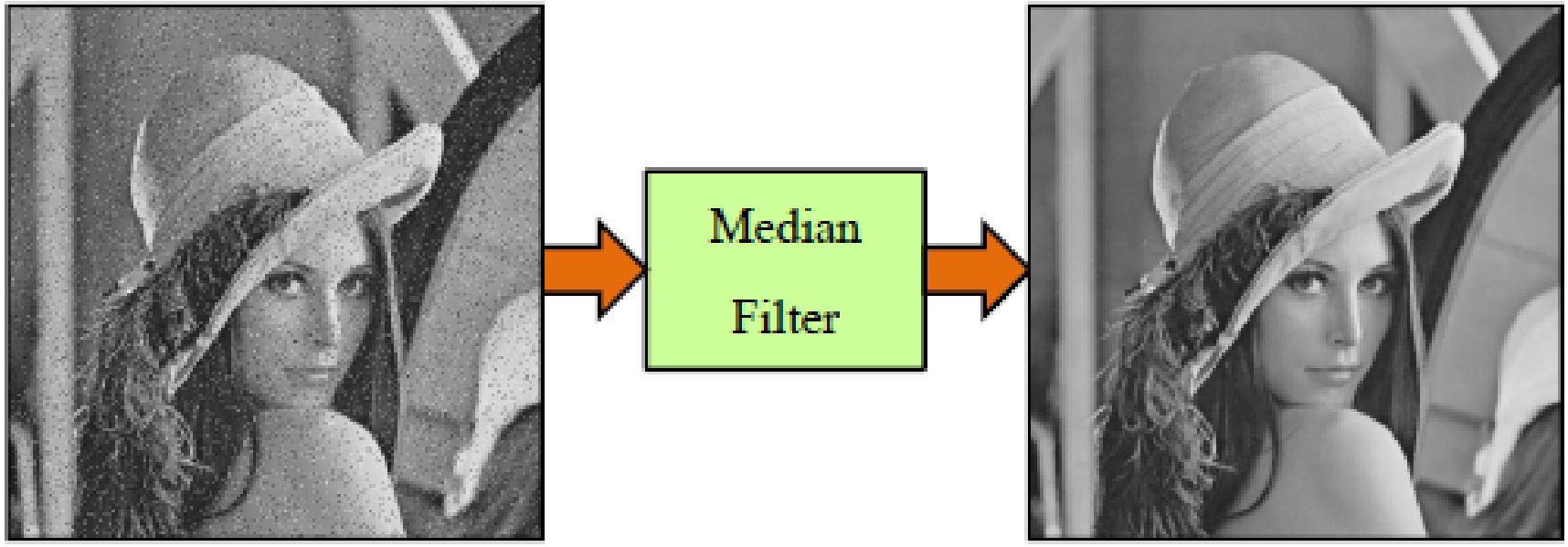


Image with salt and pepper noise

Image after median filter

Example : Median Filter

Padding

0	0	0	0	0	0	0
0	16	8	34	12	255	0
0	120	255	2	0	15	0
0	3	4	5	60	70	0
0	255	14	120	255	0	0
0	9	55	0	47	36	0
0	0	0	0	0	0	0

Zero padding

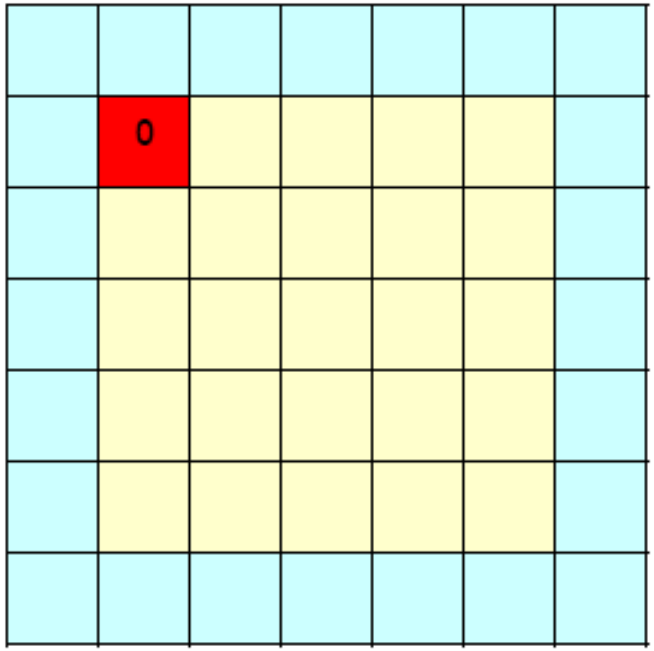
16	16	8	34	12	255	255
16	16	8	34	12	255	255
120	120	255	2	0	15	15
3	3	4	5	60	70	70
255	255	14	120	255	0	0
9	9	55	0	47	36	36
9	9	55	0	47	36	36

Reflect padding

Example : Median Filter

Zero padding Median filter

0	0	0	0	0	0	0
0	16	8	34	12	255	0
0	120	255	2	0	15	0
0	3	4	5	60	70	0
0	255	14	120	255	0	0
0	9	55	0	47	36	0
0	0	0	0	0	0	0



An unordered number

0	0	0	0	16	8	0	120	255

Arrange in ascending order

0	0	0	0	0	8	16	120	255

Example : Median Filter

Zero padding Median filter

0	0	0	0	0	0	0
0	16	8	34	12	255	0
0	120	255	2	0	15	0
0	3	4	5	60	70	0
0	255	14	120	255	0	0
0	9	55	0	47	36	0
0	0	0	0	0	0	0

	0	8				

An unordered number

0	0	0	16	8	34	120	255	2

Arrange in ascending order

0	0	0	2	8	16	34	120	255

Example : Median Filter

Zero padding Median filter

0	0	0	0	0	0	0
0	16	8	34	12	255	0
0	120	255	2	0	15	0
0	3	4	5	60	70	0
0	255	14	120	255	0	0
0	9	55	0	47	36	0
0	0	0	0	0	0	0

Output image with zero padding

	0	8	2	2	0	
	4	8	8	15	12	
	4	14	14	15	0	
	4	9	47	47	36	
	0	9	14	0	0	

Output image

Example : Median Filter

Zero padding Median filter

16	8	34	12	255
120	255	2	0	15
3	4	5	60	70
255	14	120	255	0
9	55	0	47	36

Input image

0	8	2	2	0
4	8	8	15	12
4	14	14	15	0
4	9	47	47	36
0	9	14	0	0

Output image

Example : Median Filter

Reflect padding Median filter

16	16	8	34	12	255	255
16	16	8	34	12	255	255
120	120	255	2	0	15	15
3	3	4	5	60	70	70
255	255	14	120	255	0	0
9	9	55	0	47	36	36
9	9	55	0	47	36	36

	16							

An unordered number

16	16	8	16	16	8	120	120	255

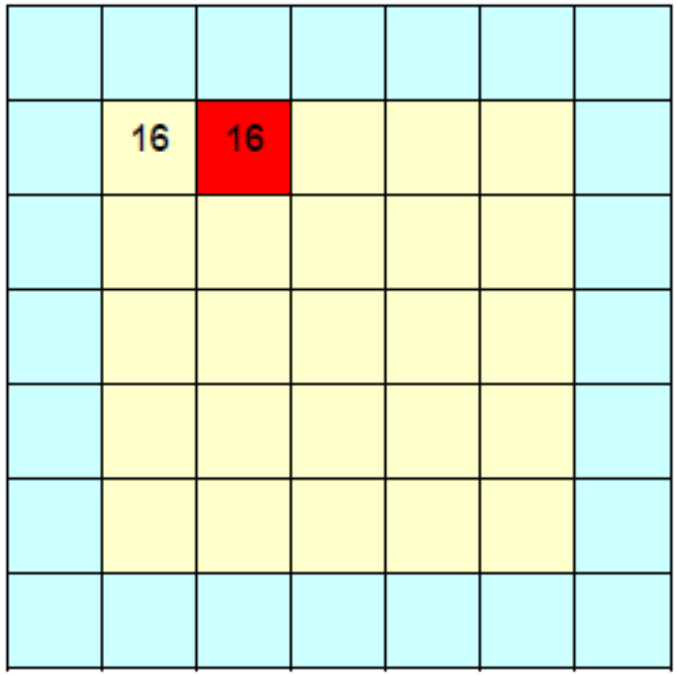
Arrange in ascending order

8	8	16	16	16	16	120	120	255

Example : Median Filter

Reflect padding Median filter

16	16	8	34	12	255	255
16	16	8	34	12	255	255
120	120	255	2	0	15	15
3	3	4	5	60	70	70
255	255	14	120	255	0	0
9	9	55	0	47	36	36
9	9	55	0	47	36	36



An unordered number

Arrange in ascending order

16	8	34	16	8	34	120	255	2
2	8	8	16	16	34	34	120	255

Example : Median Filter

Reflect padding Median filter

16	16	8	34	12	255	255
16	16	8	34	12	255	255
120	120	255	2	0	15	15
3	3	4	5	60	70	70
255	255	14	120	255	0	0
9	9	55	0	47	36	36
9	9	55	0	47	36	36

Output image with reflect padding

	16	16	12	15	15	
	16	8	8	15	60	
	120	14	14	15	15	
	9	9	47	47	47	
	14	14	47	36	36	

Output image

Example : Median Filter

Reflect padding Median filter

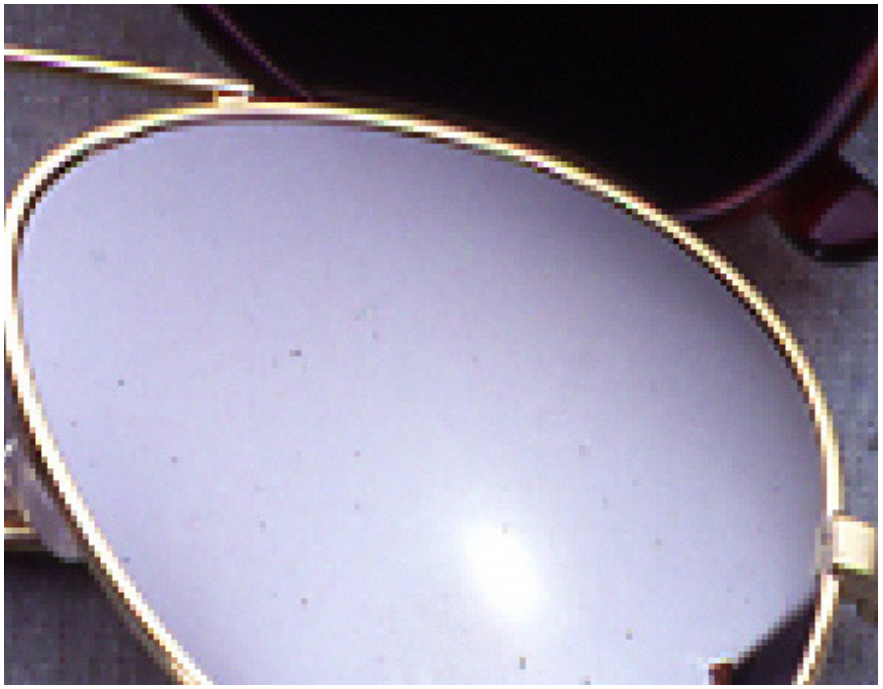
16	8	34	12	255
120	255	2	0	15
3	4	5	60	70
255	14	120	255	0
9	55	0	47	36

Input image

16	16	12	15	15
16	8	8	15	60
120	14	14	15	15
9	9	47	47	47
14	14	47	36	36

Output image

Example : Median Filter



Noise from Glass effect

Remove noise by median filter

Examples : Average Filter

- Smoothing linear filter is simply the average of the pixels contained in the neighborhood of the filter mask.
- The undesirable effects of the averaging filters is the blurring of edges.

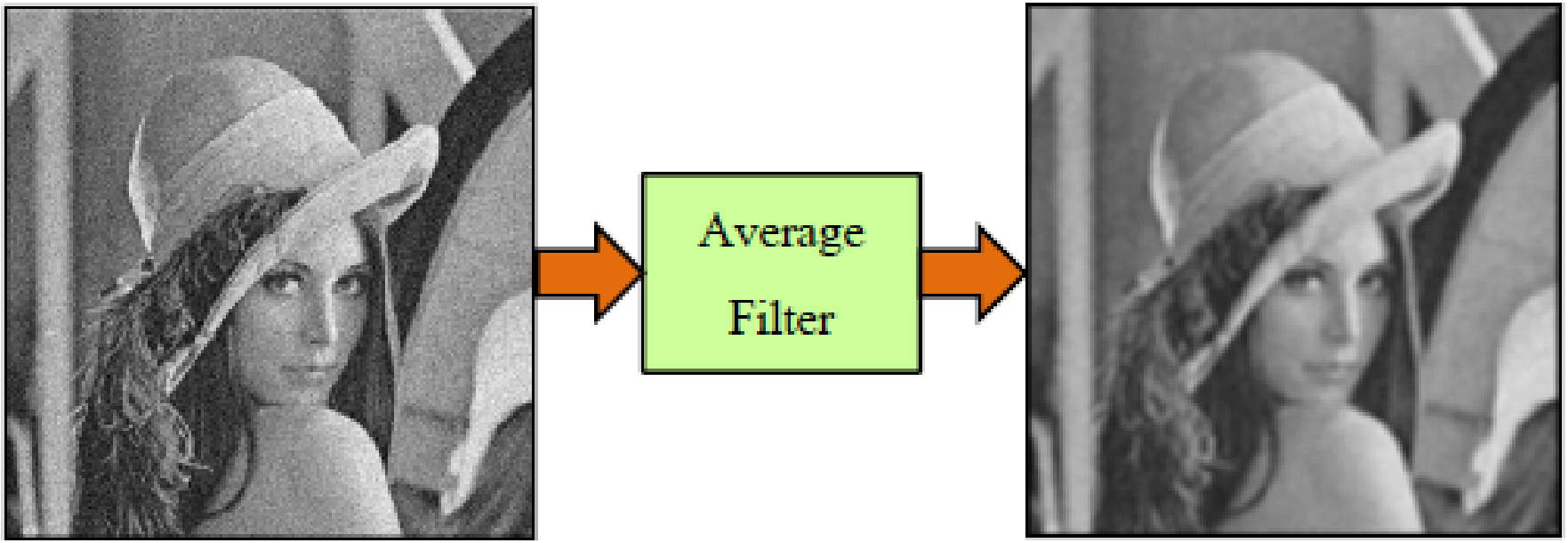


Image with Gaussian noise

Image after average filter

Average filter masks

$$\frac{1}{9}\times\begin{bmatrix}1&1&1\\1&1&1\\1&1&1\end{bmatrix}$$

Average filters

$$\frac{1}{16}\times\begin{bmatrix}1&2&1\\2&4&2\\1&2&1\end{bmatrix}$$

Weighted average filters

- The constant multiplier in front of each mask is equal to the sum of the values of its coefficients, as is required to compute an average.

Mechanics of Spatial Linear Filtering

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

Convolution

$$g = h * f$$

$$w(s,t) = \begin{bmatrix} w(-1,-1) & w(-1,0) & w(-1,1) \\ w(0,-1) & w(0,0) & w(0,1) \\ w(1,-1) & w(1,0) & w(1,1) \end{bmatrix}$$

$$f(x,y) = \begin{bmatrix} f(x-1,y-1) & f(x-1,y) & f(x-1,y+1) \\ f(x,y-1) & f(x,y) & f(x,y+1) \\ f(x+1,y-1) & f(x+1,y) & f(x+1,y+1) \end{bmatrix}$$

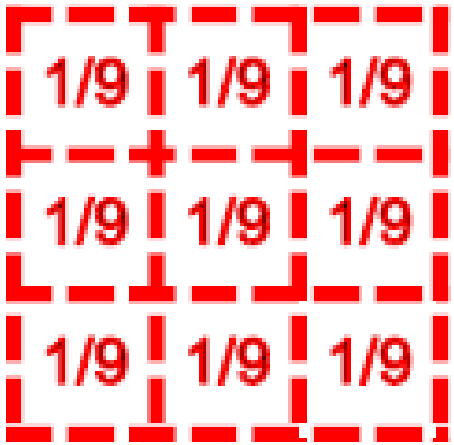
$$g(x,y) = \begin{bmatrix} w(-1,-1) f(x+1,y+1) & w(-1,0) f(x+1,y) & w(-1,1) f(x+1,y-1) \\ w(0,-1) f(x,y+1) & w(0,0) f(x,y) & w(0,1) f(x,y-1) \\ w(1,-1) f(x-1,y+1) & w(1,0) f(x-1,y) & w(1,1) f(x-1,y-1) \end{bmatrix}$$

Examples : Average Filter

Average filter

18	20	12	120	255
9	84	26	36	255
12	150	6	78	99
140	18	16	25	12
220	254	32	64	41

Input image



Mask size 3 x 3

Example : Average Filter

Zero padding Average filter

0	0	0	0	0	0	0
0	18	20	12	120	255	0
0	9	84	26	36	255	0
0	12	150	6	78	99	0
0	140	18	16	25	12	0
0	220	254	32	64	41	0
0	0	0	0	0	0	0

	15					

$$\text{Pixel}_{out} = \left(0\times\frac{1}{9}\right)+\left(0\times\frac{1}{9}\right)+\left(0\times\frac{1}{9}\right)+\left(0\times\frac{1}{9}\right)+\left(18\times\frac{1}{9}\right)+\left(20\times\frac{1}{9}\right)+\left(0\times\frac{1}{9}\right)+\left(9\times\frac{1}{9}\right)+\left(84\times\frac{1}{9}\right)$$

$$= 14.55 \cong 15$$

Or $\text{Pixel}_{out} = (0+0+0+0+16+8+0+120+255)/9 = 14.55 \cong 15$

Example : Average Filter

Zero padding Average filter

0	0	0	0	0	0	0
0	18	20	12	120	255	0
0	9	84	26	36	255	0
0	12	150	6	78	99	0
0	140	18	16	25	12	0
0	220	254	32	64	41	0
0	0	0	0	0	0	0

Output image with zero padding

	15	19	33	78	74	
	33	37	59	99	94	
	46	51	49	61	56	
	86	92	71	41	35	
	68	73	45	21	16	

Output image

Example : Average Filter

Zero padding Average filter

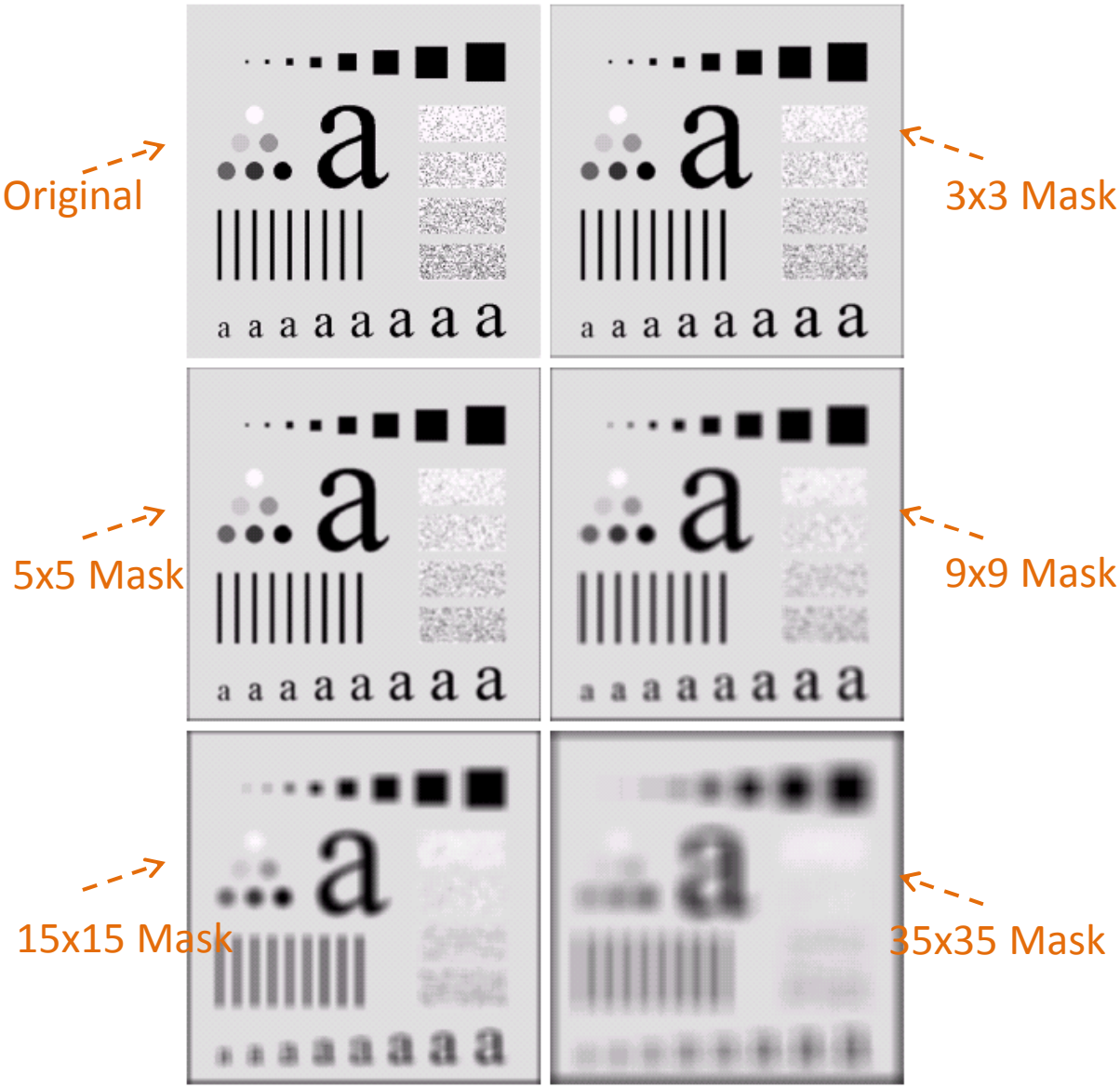
18	20	12	120	255
9	84	26	36	255
12	150	6	78	99
140	18	16	25	12
220	254	32	64	41

Input image

15	19	33	78	74
33	37	59	99	94
46	51	49	61	56
86	92	71	41	35
68	73	45	21	16

Output image

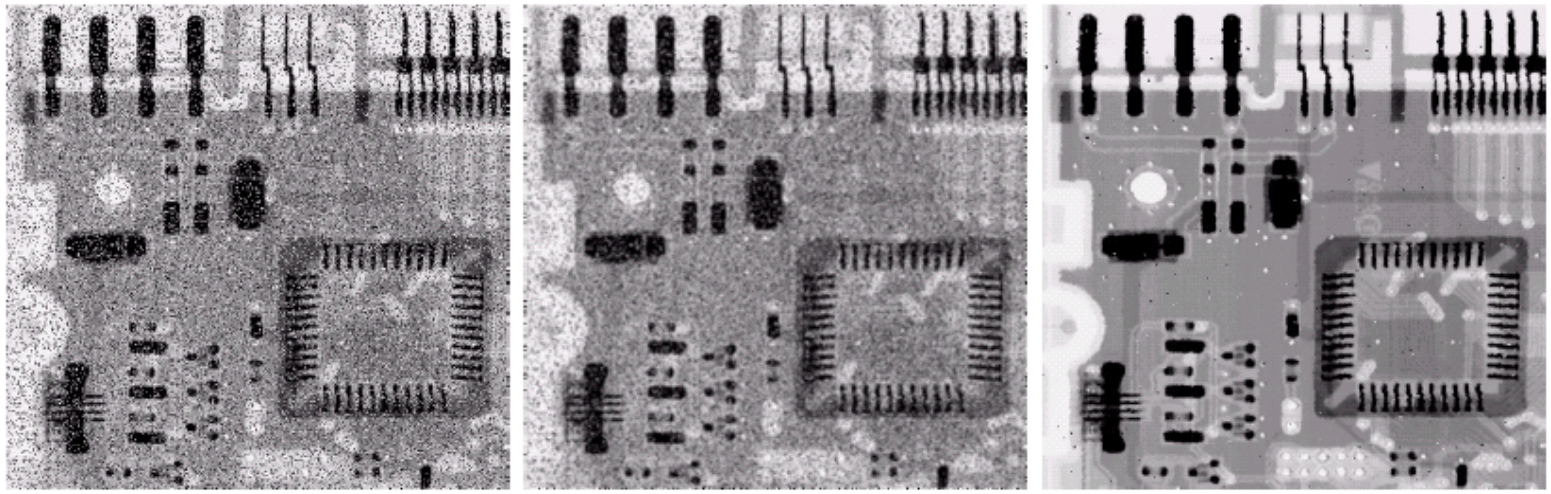
Example : Average Filter



Example : Average Filter

- Filtering is often used to remove noise from images. Sometimes a median filter works better than an averaging filter.

Corrupted by salt and pepper noise



Original Image With Noise

Image After Averaging Filter

Image After Median Filter

Thanks for your attention