Digital Image Processing and Pattern Recognition

E1528

Fall 2022-2023

Lecture 3

Intensity Transformations and Spatial Filtering

INSTRUCTOR

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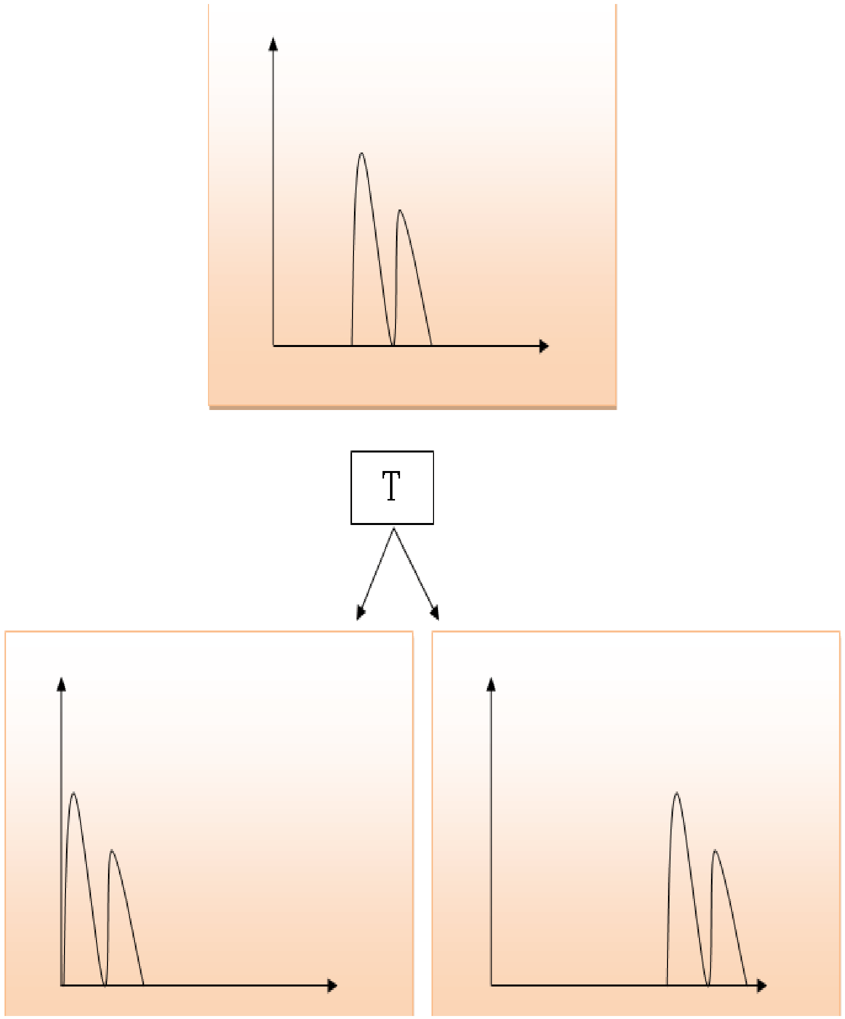
Histogram Processing Techniques

- Sliding
- Stretching
- Equalization

➢ Histogram Sliding

- In Histogram sliding, the complete histogram is shifted towards rightwards or leftwards.
- When a histogram is shifted towards the right or left, clear changes are seen in the brightness of the image.
- The brightness of the image is defined by the intensity of light which is emitted by a particular light source.



Histogram Sliding

- This technique consists of simply adding or subtracting a constant brightness value to all pixels in the image. The overall effect is an image with comparable contrast properties, but higher or lower average brightness, respectively. imadd and imsubtract functions can be used for histogram sliding.

- When implementing histogram sliding, you must make sure that pixel values do not go outside the greyscale boundaries. An example of histogram sliding is given below:

➢ Matlab code

```
A = imread('Penguins_grey.jpg');

imshow(A),title('Original Image');

B=im2double(A);

bright_add = 0.2;

imhist(A), title('Original Histogram');

C=B+bright_add;

imshow(C),title('New Bright Image');

imhist(C), title('New Histogram');
```

➢ Example

FIG 10

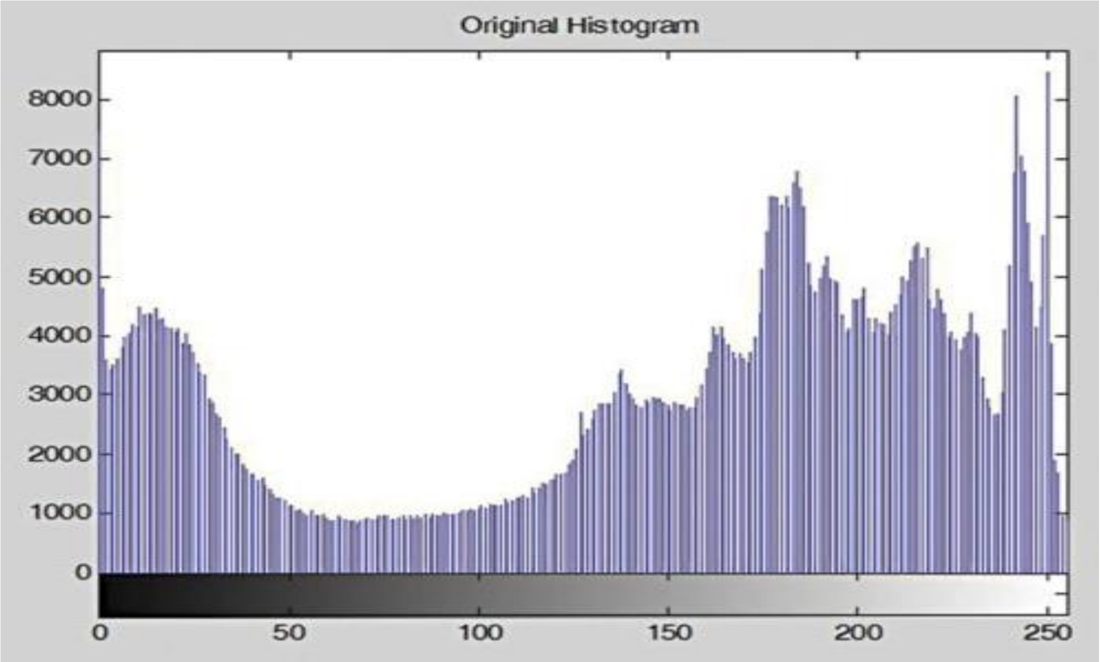


FIG 11

In the example, the image is brightened by adding 0.2 to its pixel values.

Figs 10 and 11 show the original image and its histogram

➢ Example

FIG 12

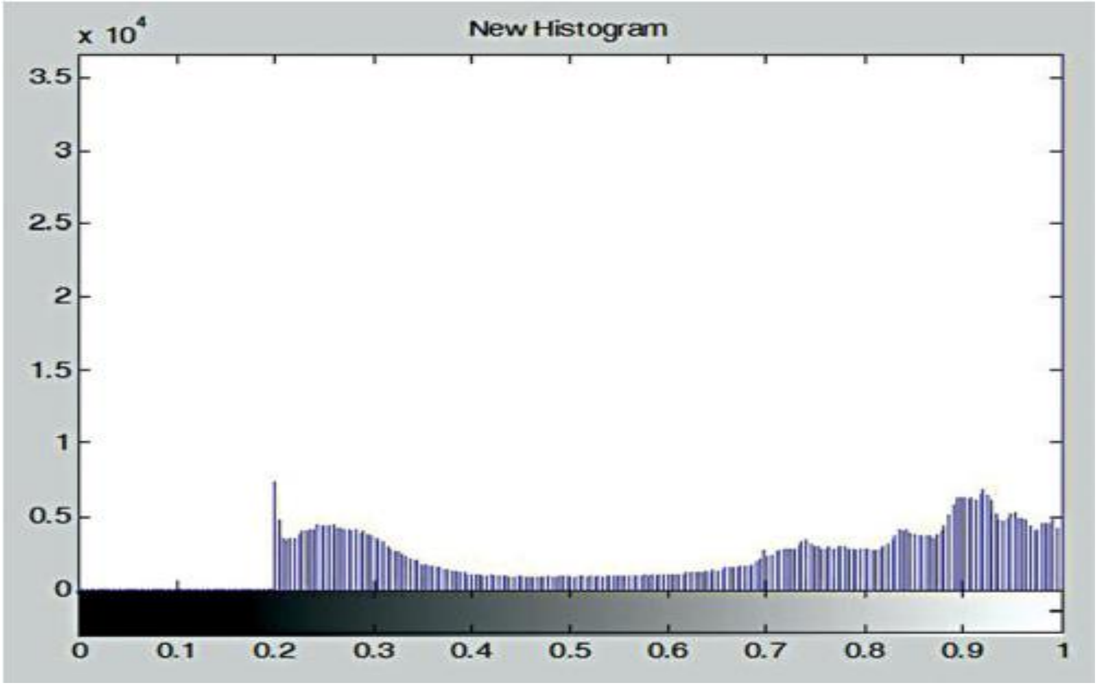
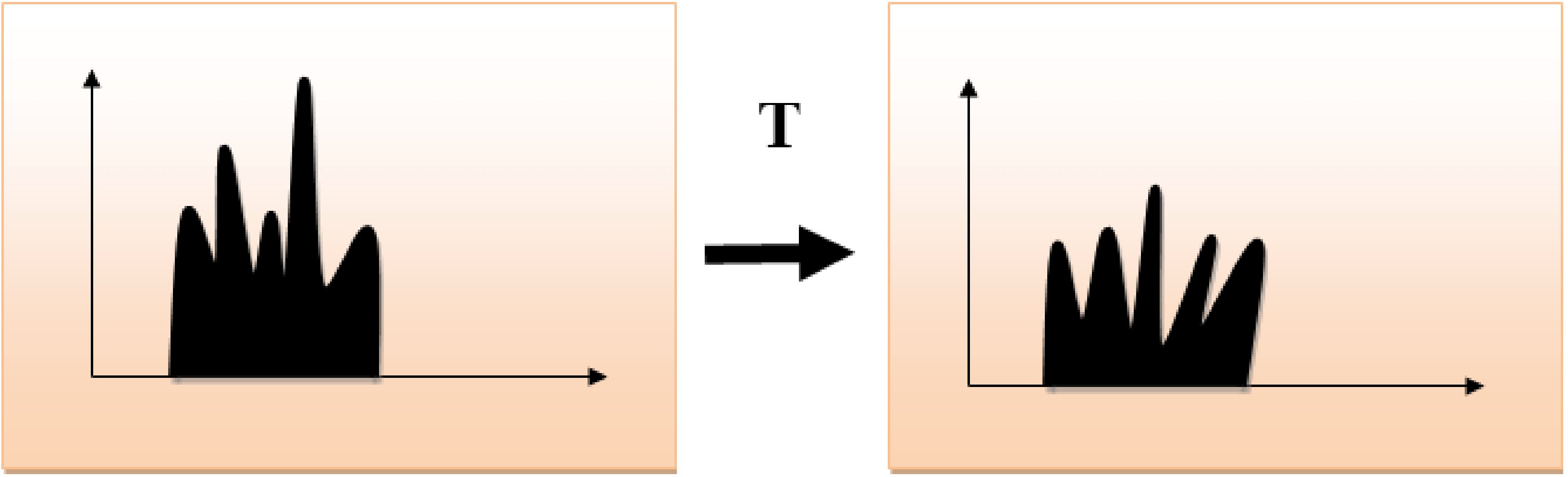


FIG 13

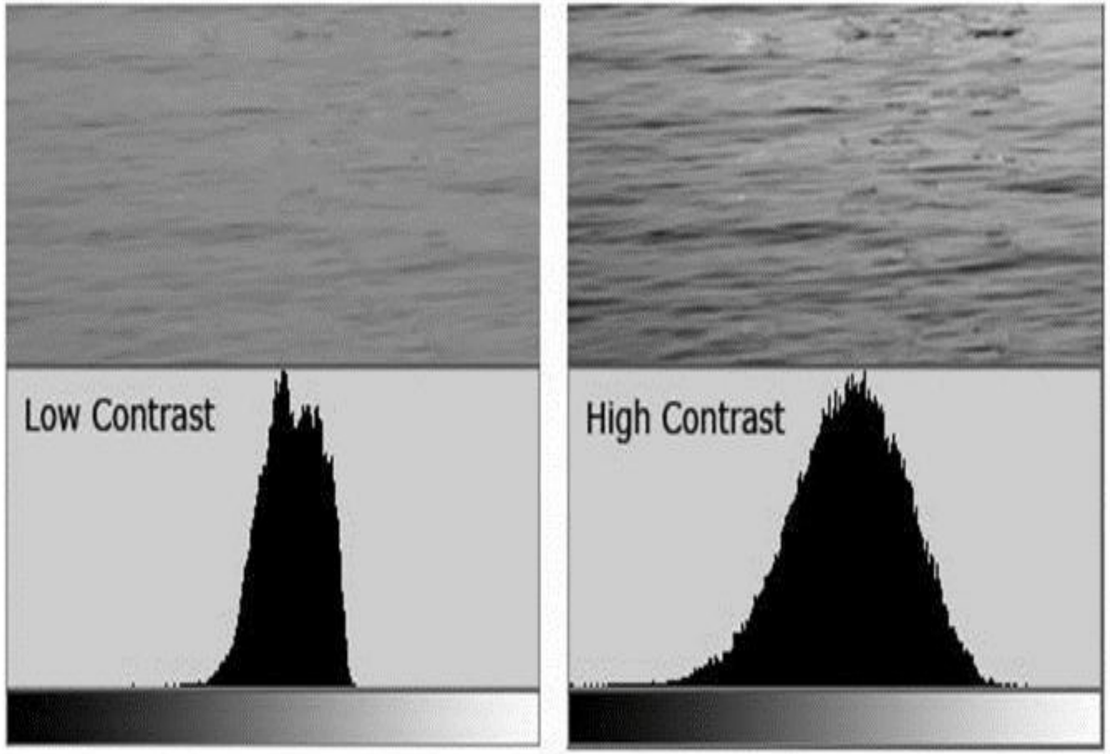
Figs 12 and 13 show the modified image and its histogram, respectively.

Histogram Stretching

- In histogram stretching, contrast of an image is increased. The contrast of an image is defined between the maximum and minimum value of pixel intensity.
- If we want to increase the contrast of an image, histogram of that image will be fully stretched and covered the dynamic range of the histogram.
- From histogram of an image, we can check that the image has low or high contrast.

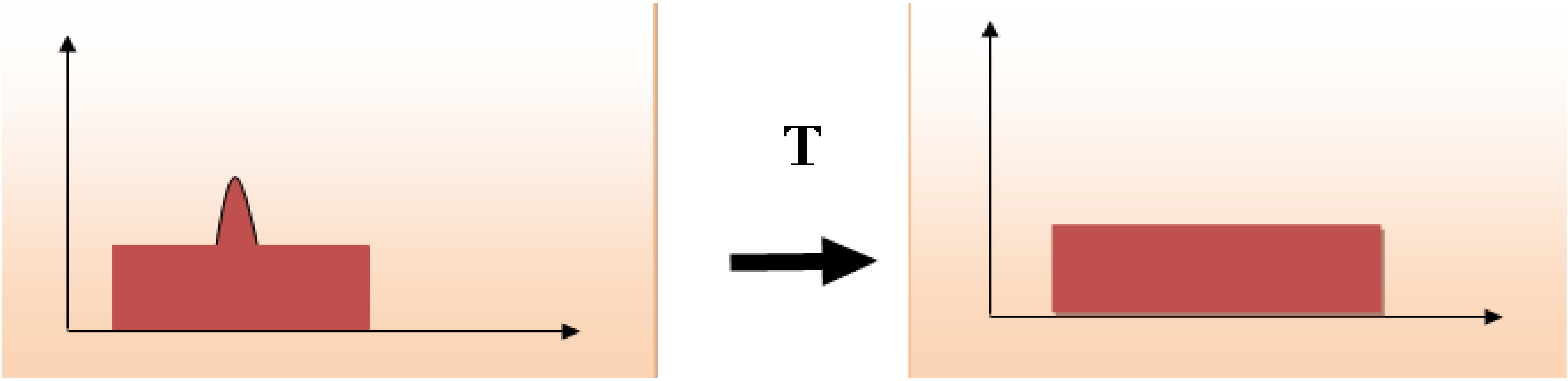


➢ Histogram Stretching

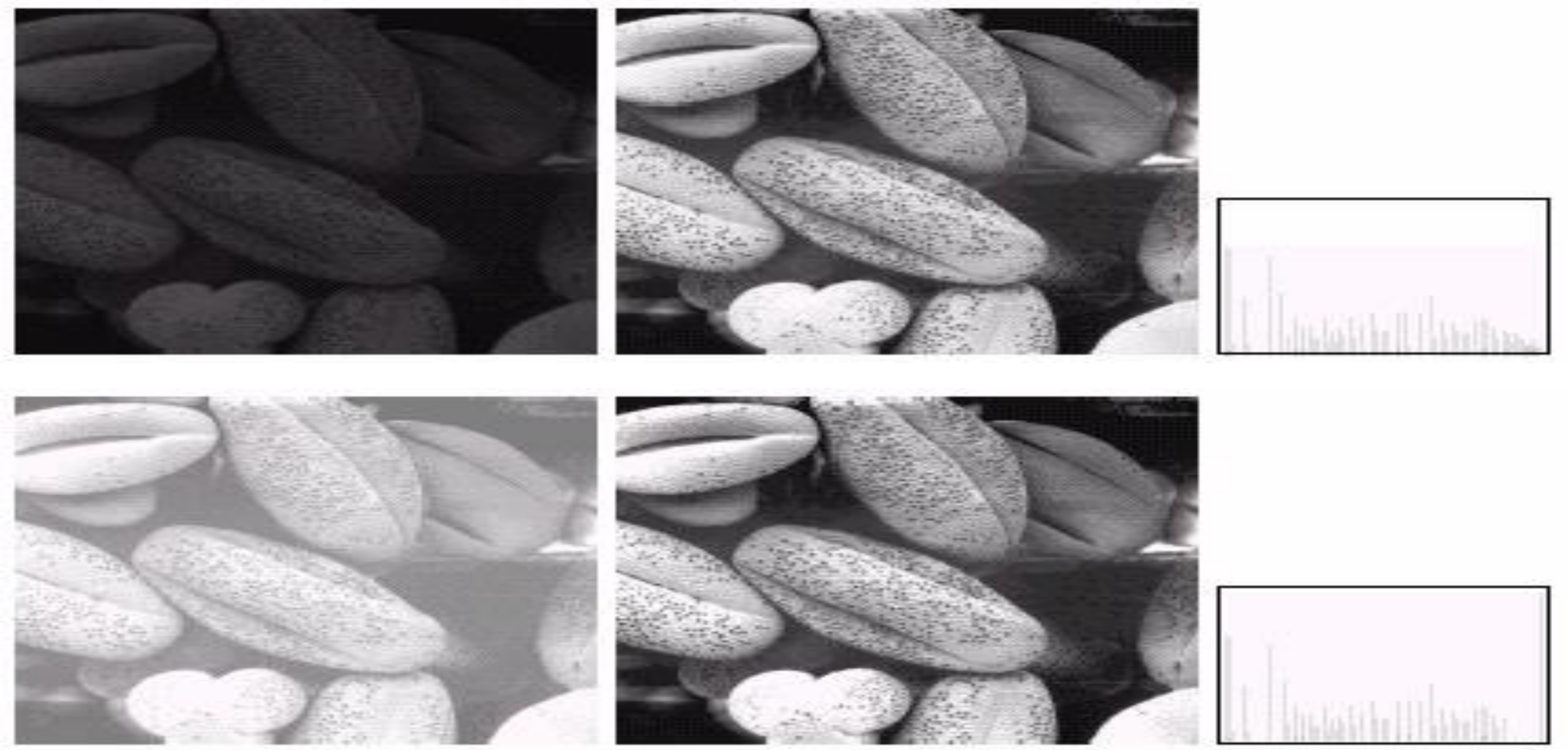


Histogram Equalization

- Histogram equalization is used for equalizing all the pixel values of an image. Transformation is done in such a way that uniform flattened histogram is produced.
- Histogram equalization increases the dynamic range of pixel values and makes an equal count of pixels at each level which produces a flat histogram with high contrast image.
- While stretching histogram, the shape of histogram remains the same whereas in Histogram equalization, the shape of histogram changes and it generates only one image.



➢ Histogram Equalization



(a) Images (b) Results of histogram equalization. (c) Corresponding histograms.

➢ Example: Fixed Intensity Transformation

- A 4x4, 4bits/pixel image

1	8	6	6
6	3	11	8
8	8	9	10
9	10	10	7

passes through an intensity transformation $s = T(r) = round\left(\frac{1}{15}r^2\right)$

1 → round(0.0667) = 0;

3 → round(0.6) = 1;

6 → round(2.4) = 2;

7 → round(3.2667) = 3;

8 → round(4.2667) = 4;

9 → round(5.4) =5;

10 → round(6.6667) = 7;

11 → round(8.0667) = 8;

The resulting image is:

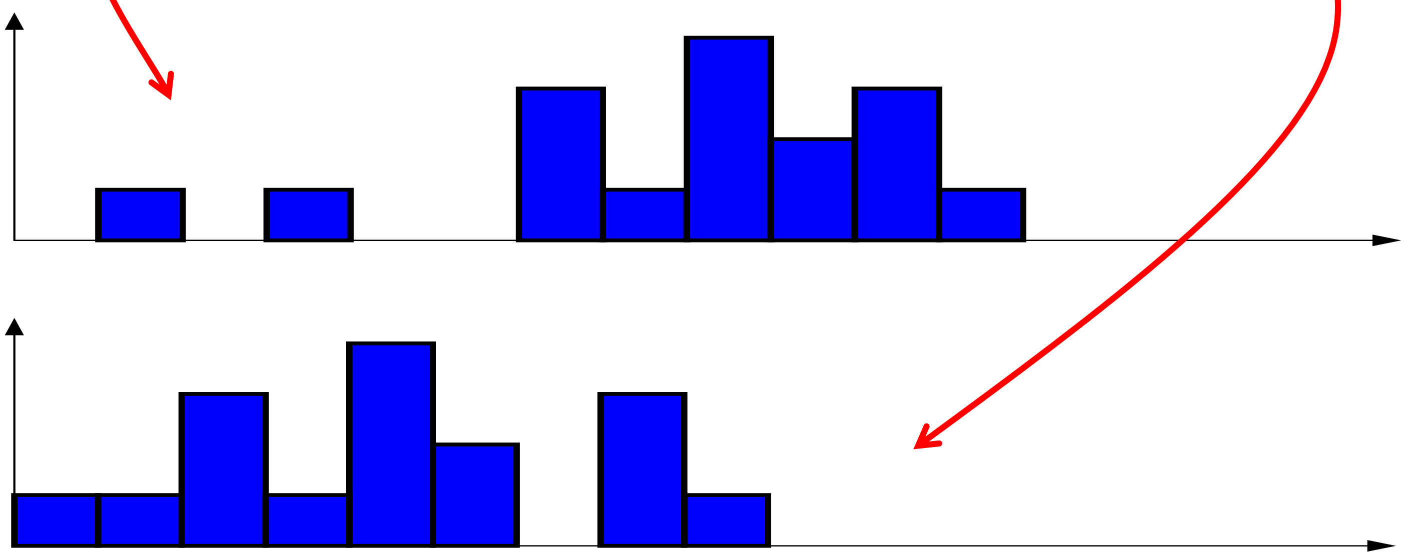
0	4	2	2
2	1	8	4
4	4	5	7
5	7	7	3

➢ Example: Histogram Change

1	8	6	6
6	3	11	8
8	8	9	10
9	10	10	7

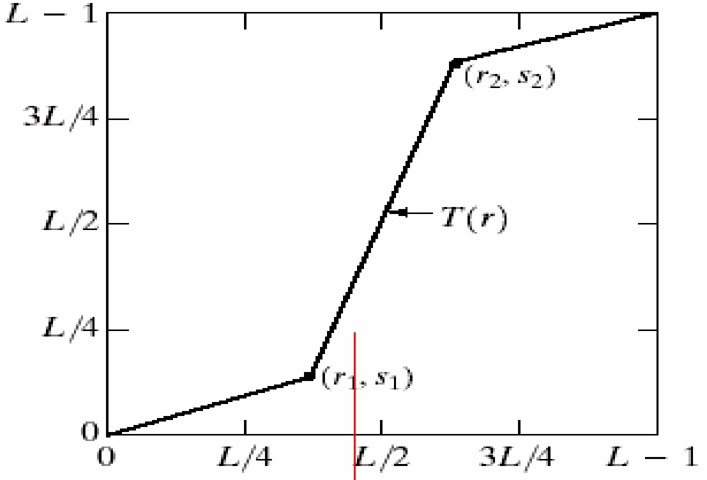
→

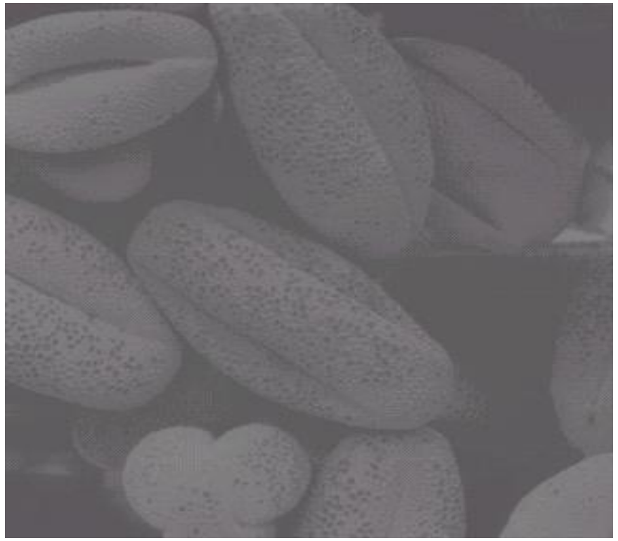
0	4	2	2
2	1	8	4
4	4	5	7
5	7	7	3



Contrast Stretch

➢ General Idea: Make Best Use of the Dynamic Range





➢ Contrast Stretch

General form:

$$s = \begin{cases} \dfrac{s_1}{r_1} \cdot r & 0 \le r < r_1 \\ \dfrac{s_2 - s_1}{r_2 - r_1} \cdot r + \dfrac{s_1 r_2 - s_2 r_1}{r_2 - r_1} & r_1 \le r \le r_2 \\ \dfrac{2^B - 1 - s_2}{2^B - 1 - r_2} \cdot r + (2^B - 1) \cdot \dfrac{s_2 - r_2}{2^B - 1 - r_2} & r_2 < r \le 2^B - 1 \end{cases}$$

Special case → Full-scale contrast stretch:

$r_1 = r_{\min}$ $\quad s_1 = 0$

$r_2 = r_{\max}$ $\quad s_2 = 2^B - 1$

$\longrightarrow$

$$s = (2^B - 1) \cdot \frac{r - r_{\min}}{r_{\max} - r_{\min}}$$

Typically used: $s = round\left((2^B - 1) \cdot \dfrac{r - r_{\min}}{r_{\max} - r_{\min}}\right)$

➢ Example: Full-Scale Contrast Stretch

- Full-scale contrast stretch of a 4x4, 4bits/pixel image

4	8	6	6
6	4	11	8
8	8	9	10
8	11	10	7

- Find when $r_{\min}$=4 $r_{\max}$=11 $2^B - 1 = 15$

$$s = round\left((2^B - 1)\cdot\frac{r - r_{\min}}{r_{\max} - r_{\min}}\right) = round\left(15\cdot\frac{r-4}{11-4}\right) = round\left(\frac{15}{7}(r-4)\right)$$

4 → round(0) = 0;
6 → round(4.29) = 4;
7 → round(6.43) = 6;
8 → round(8.57) = 9;
9 → round(10.71) = 11;
10 → round(12.86) = 13;
11 → round(15) = 15;

The resulting image is:

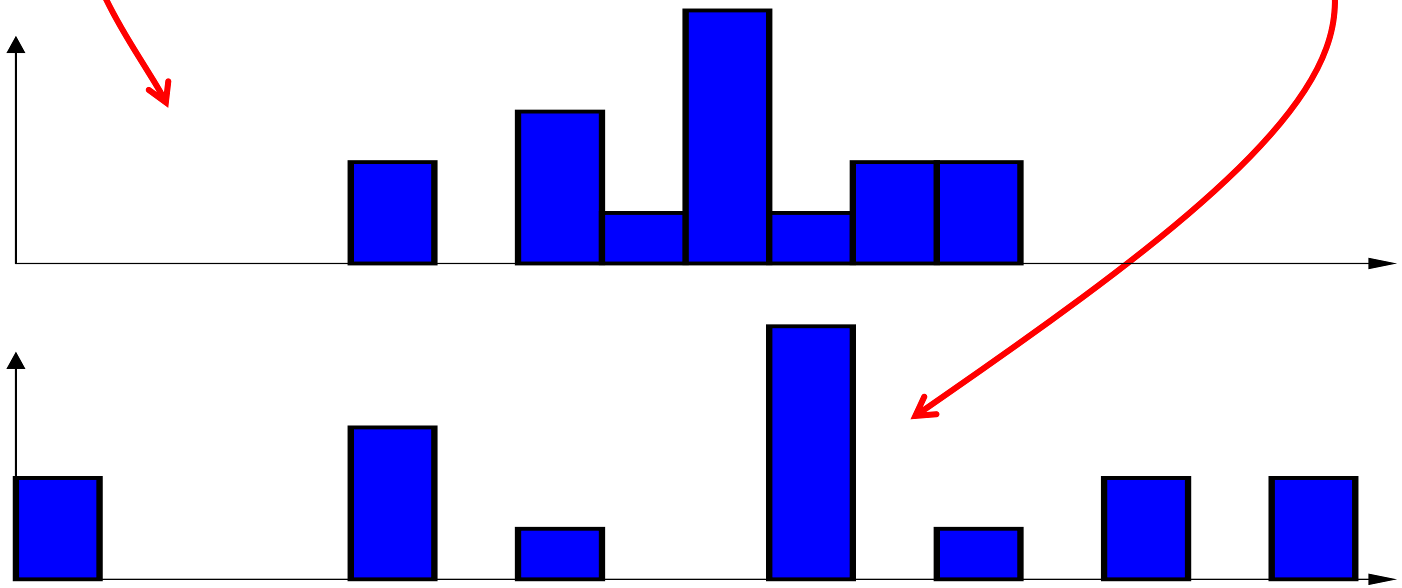
0	9	4	4
4	0	15	9
9	9	11	13
9	15	13	6

➢ Example: Histogram Change

4	8	6	6
6	4	11	8
8	8	9	10
8	11	10	7

→

0	9	4	4
4	0	15	9
9	9	11	13
9	15	13	6



Histogram Equalization

➢ Example

- A 4x4, 4bits/pixel image

2	8	9	9
2	3	10	9
8	3	3	11
8	3	10	11

- First try full-scale contrast stretch $r_{min}=2$ $r_{max}=11$

$$s = round\left((2^B - 1) \cdot \frac{r - r_{min}}{r_{max} - r_{min}}\right) = round\left(15 \cdot \frac{r-2}{11-2}\right) = round\left(\frac{15}{9}(r-2)\right)$$

2 → round(0) = 0;
3 → round(1.67) = 2;
8 → round(10.00) = 10;
9 → round(11.67) = 12;
10 → round(13.33) = 13;
11 → round(15) = 15;

The resulting image is:

0	10	12	12
0	2	13	12
10	2	2	15
10	2	13	15

➢ Example: Histogram Change

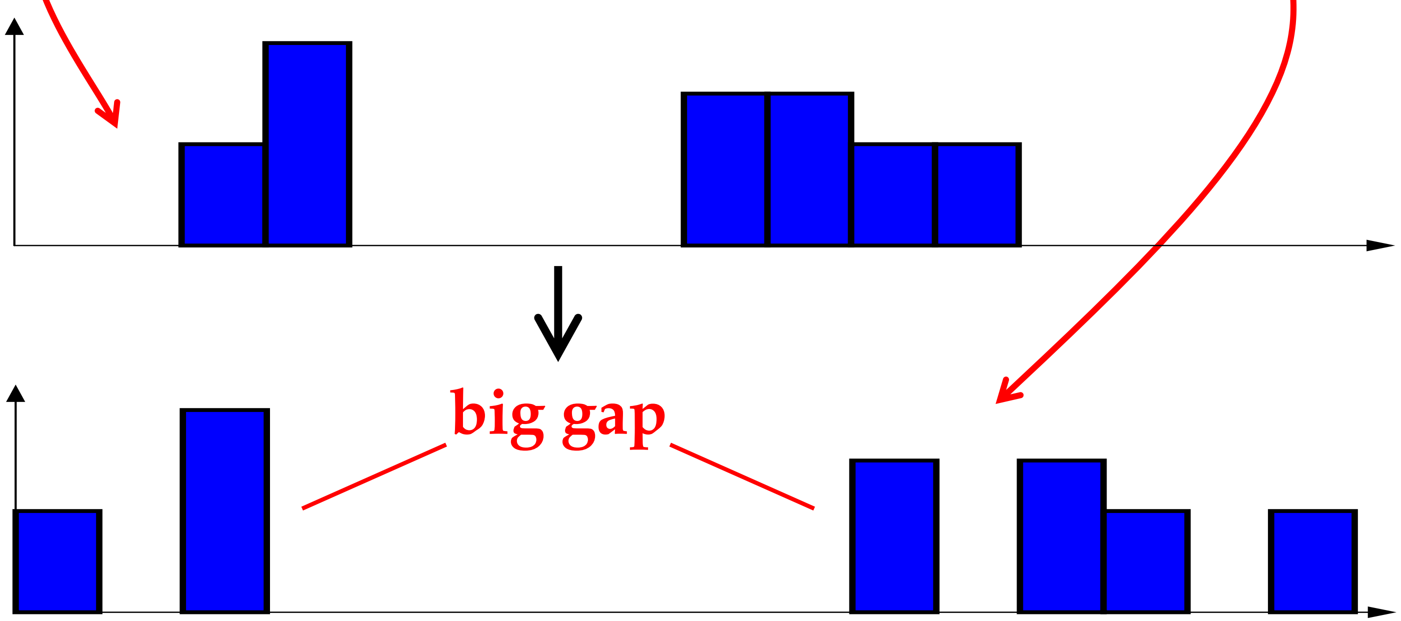
original

2	8	9	9
2	3	10	9
8	3	3	11
8	3	10	11

→

0	10	12	12
0	2	13	12
10	2	2	15
10	2	13	15

full-scale contrast stretch

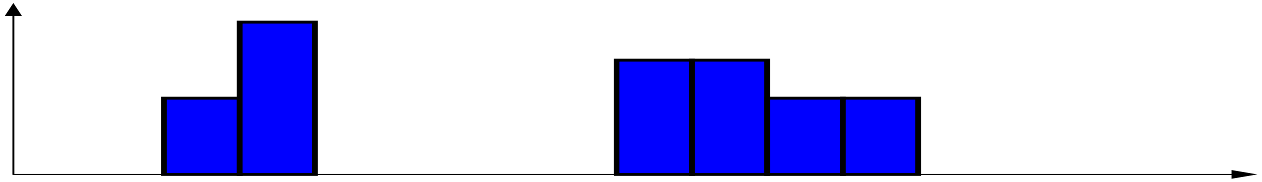


➢ Cumulative Histogram

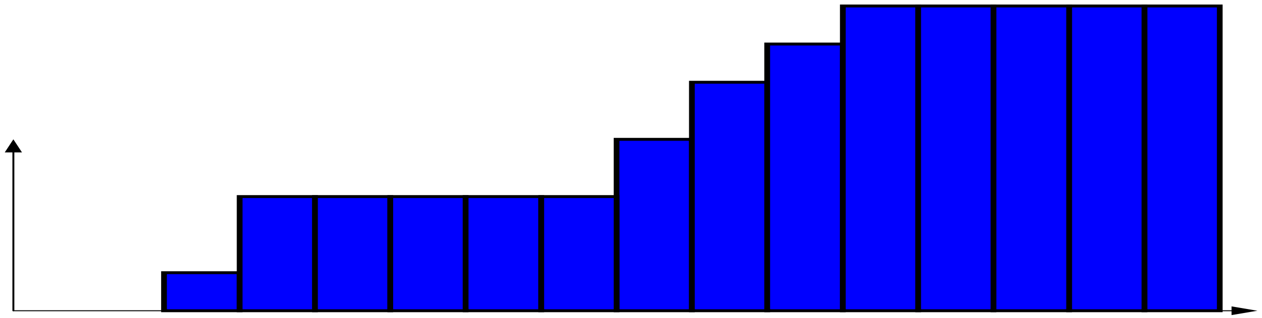
2	8	9	9
2	3	10	9
8	3	3	11
8	3	10	11

k	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
H(k)	0	0	2	4	0	0	0	0	3	3	2	2	0	0	0	0
Q(k)	0	0	2	6	6	6	6	6	9	12	14	16	16	16	16	16

H(k)



Q(k)



➢ Intermediate Image

k	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
H(k)	0	0	2	4	0	0	0	0	3	3	2	2	0	0	0	0
Q(k)	0	0	2	6	6	6	6	6	9	12	14	16	16	16	16	16

original

2	8	9	9
2	3	10	9
8	3	3	11
8	3	10	11

→

2	9	12	12
2	6	14	12
9	6	6	16
9	6	14	16

intermediate image

➢ Full-Scale Contrast Stretch of Intermediate Image

intermediate image

2	9	12	12
2	6	14	12
9	6	6	16
9	6	14	16

$r_{\min}$=2 $r_{\max}$=16

$$s = round\left((2^B - 1)\cdot\frac{r - r_{\min}}{r_{\max} - r_{\min}}\right) = round\left(15\cdot\frac{r-2}{16-2}\right) = round\left(\frac{15}{14}(r-2)\right)$$

2 → round(0) = 0;
6 → round(4.29) = 4;
9 → round(7.50) = 8;
12 → round(10.71) = 11;
14 → round(12.86) = 13;
16 → round(15) = 15;

result:
histogram equalized image

0	8	11	11
0	4	13	11
8	4	4	15
8	4	13	15

➢ Histogram Comparison

4	8	6	6
6	4	11	8
8	8	9	10
8	11	10	7

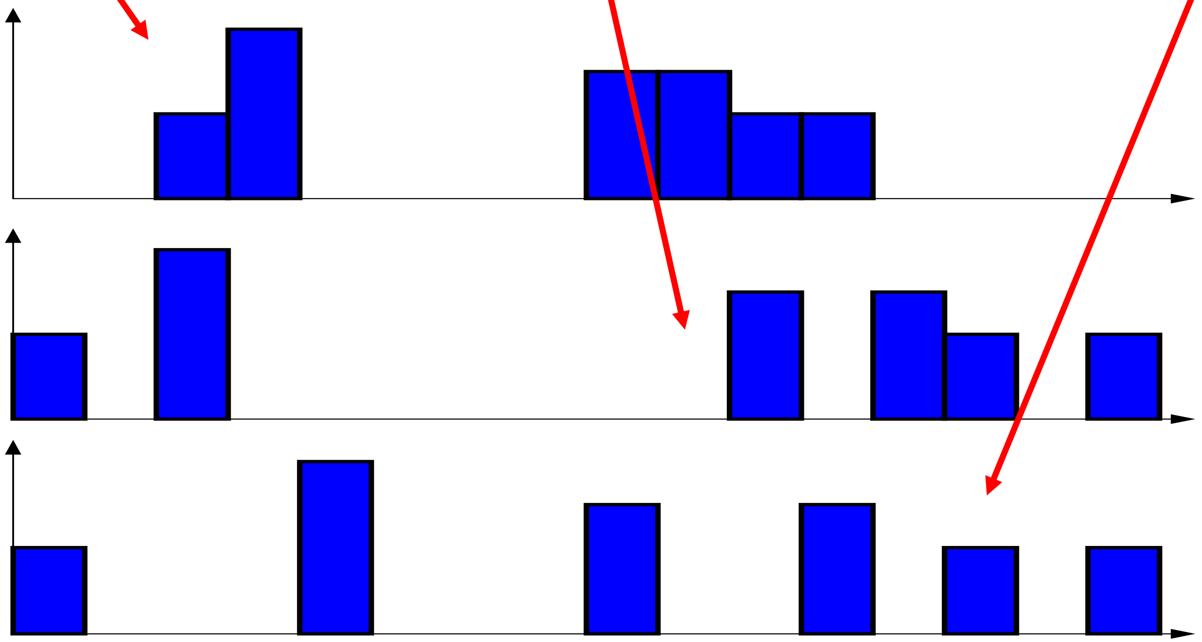
original

0	10	12	12
0	2	13	12
10	2	2	15
10	2	13	15

direct full-scale contrast stretch

0	8	11	11
0	4	13	11
8	4	4	15
8	4	13	15

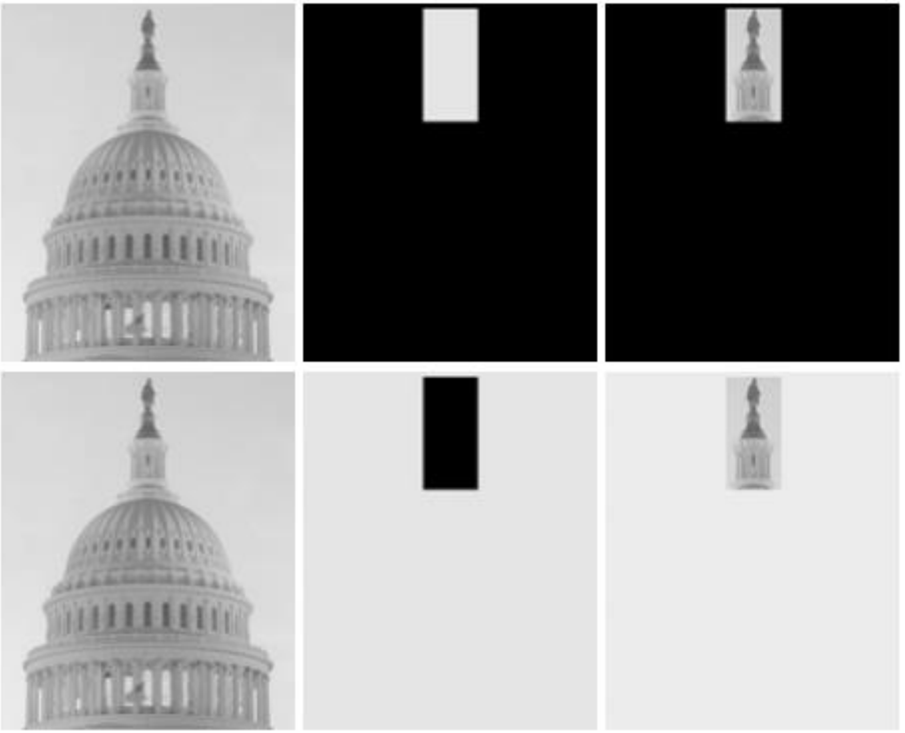
histogram-equalized



more equalized

➢ Enhancement Using Arithmetic/Logic Operations

- Arithmetic/logic operations involving images are performed on a pixel-by-pixel basis between two or more images (this excludes the logic operation NOT, which is performed on a single image).



a b c
d e f

(a) Original image. (b) AND image mask. (c) Result of the AND operation on images (a) and (b). (d) Original image. (e) OR image mask. (f) Result of operation OR on images (d) and (e).

Basics of Spatial Filtering

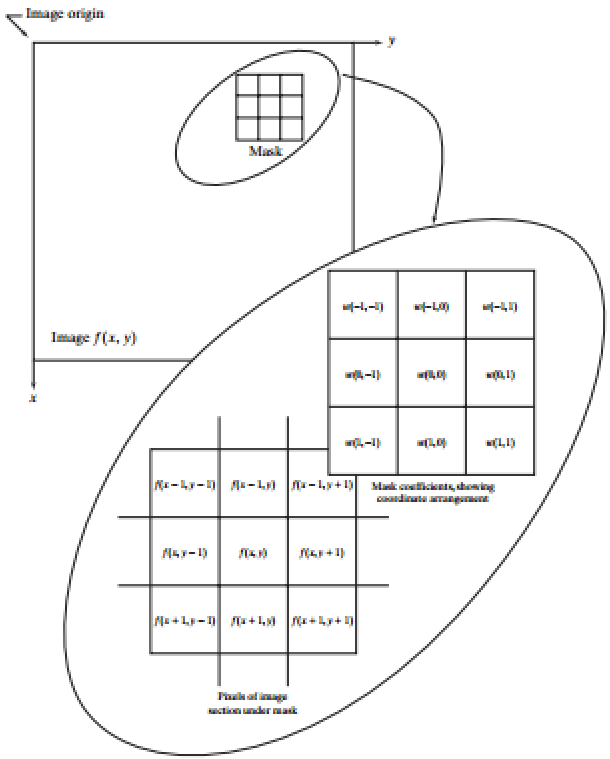
- As mentioned, some neighborhood operations work with the values of the image pixels in the neighborhood and the corresponding values of a sub-image that has the same dimensions as the neighborhood.

- The sub-image is called a filter, mask, kernel, template, or window, with the first three terms being the most prevalent terminology.

- The values in a filter sub-image are referred to as coefficients, rather than pixels.

➢ Mechanics of spatial filtering

- ➢ The process consists simply of moving the filter mask from point to point in an image. At each point (x, y), the response of the filter at that point is calculated using a predefined relationship.



- ➢ For linear spatial filtering, the response is given by a sum of products of the filter coefficients and the corresponding image pixels in the area spanned by the filter mask.

Smoothing Spatial Filters

- Smoothing filters are used for blurring and for noise reduction.

- Blurring is used in preprocessing steps, such as removal of small details from an image prior to (large) object extraction and bridging of small gaps in lines or curves.

- Noise reduction can be accomplished by blurring with a linear filter and by nonlinear filtering.

➢ 1. Smoothing Linear Filters

- The output (response) of a smoothing, linear spatial filter is simply the average of the pixels contained in the neighborhood of the filter mask.

- These filters sometimes are called averaging filters.

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

1	1	1
1	1	1
1	1	1

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

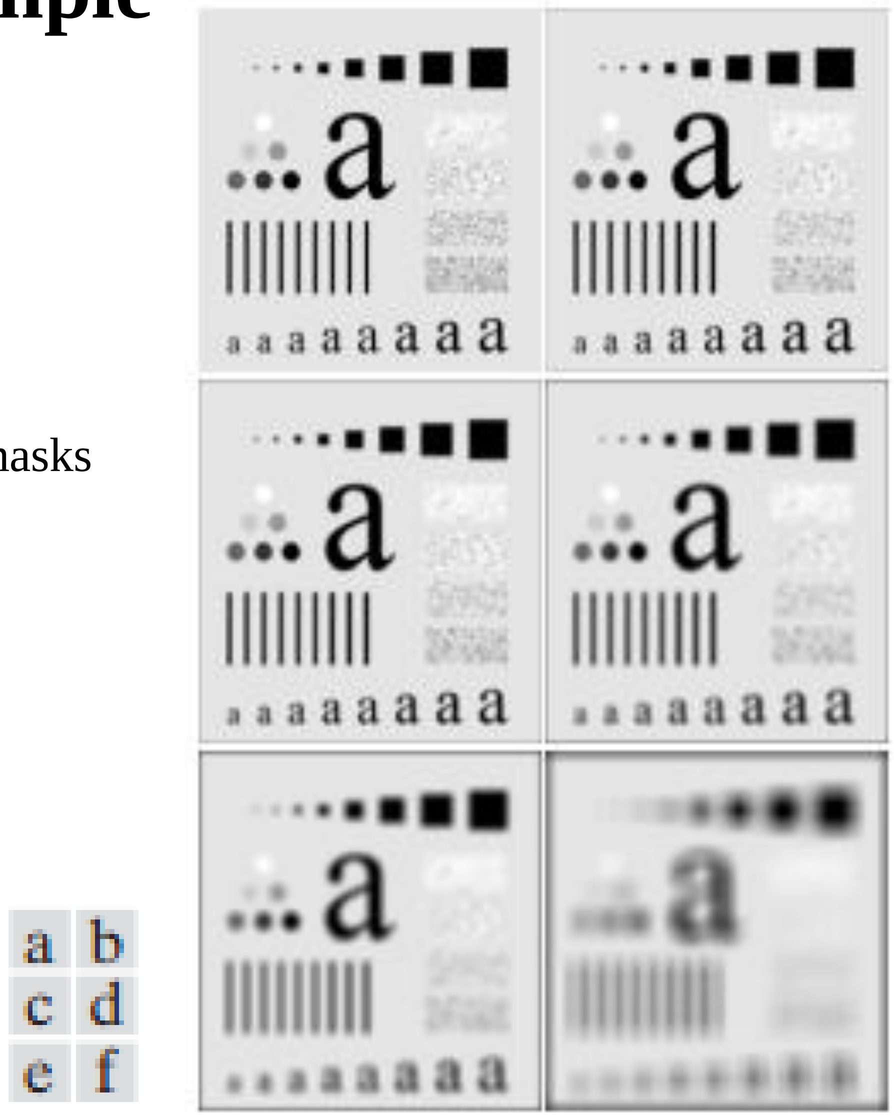
1	2	1
2	4	2
1	2	1

$$R = \frac{1}{\sum} \sum_{i=1}^{n} z_i$$

➢ 1. Smoothing Linear Filters Example

(a) Original image, of size 500*500 pixels.

(b) → (f) Results of smoothing with square averaging filter masks of sizes n=3, 5, 9, 15, and 35, respectively.



2. Order-Statistics Filters

- Order-statistics filters are nonlinear spatial filters whose response is based on ordering (ranking) the pixels contained in the image area encompassed by the filter, and then replacing the value of the center pixel with the value determined by the ranking result.

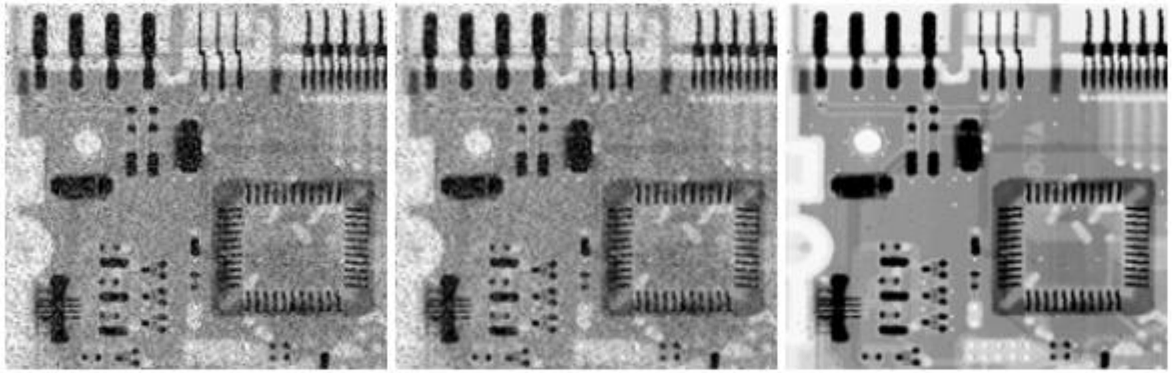
- The best-known example in this category is the median filter, which, as its name implies, replaces the value of a pixel by the median of the gray levels in the neighborhood of that pixel.

- Median filters are quite popular because, for certain types of random noise, they provide excellent noise-reduction capabilities, with considerably less blurring than linear smoothing filters of similar size.

2. Order-Statistics Filters - Median filter

- In order to perform median filtering at a point in an image, we first sort the values of the pixel in question and its neighbors, determine their median, and assign this value to that pixel.

- For example, suppose that a 3*3 neighborhood has values (10, 20, 20, 20, 15, 20, 20, 25, 100). These values are sorted as (10, 15, 20, 20, 20, 20, 20, 25, 100), which results in a median of 20.



- Example:-

- (a) X-ray image of circuit board corrupted by salt-and-pepper noise. (b) Noise reduction with a 3*3 averaging mask. (c) Noise reduction with a 3*3 median filter.

Sharpening Spatial Filters

- The principal objective of sharpening is to highlight fine detail in an image or to enhance detail that has been blurred, either in error or as a natural effect of a particular method of image acquisition.

- Uses of image sharpening vary and include applications ranging from electronic printing and medical imaging to industrial inspection and autonomous guidance in military systems.

➢ 1. Use of Second Derivatives for Enhancement–The Laplacian

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}.$$

$$\frac{\partial^2 f}{\partial^2 x^2} = f(x+1, y) + f(x-1, y) - 2f(x, y)$$

$$\frac{\partial^2 f}{\partial^2 y^2} = f(x, y+1) + f(x, y-1) - 2f(x, y)$$

$$\nabla^2 f = [f(x+1, y) + f(x-1, y) + f(x, y+1) + f(x, y-1)] - 4f(x, y).$$ (

0	1	0
1	−4	1
0	1	0

1	1	1
1	−8	1
1	1	1

0	−1	0
−1	4	−1
0	−1	0

−1	−1	−1
−1	8	−1
−1	−1	−1


Thank you