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Image Enhancement in the Spatial Domain

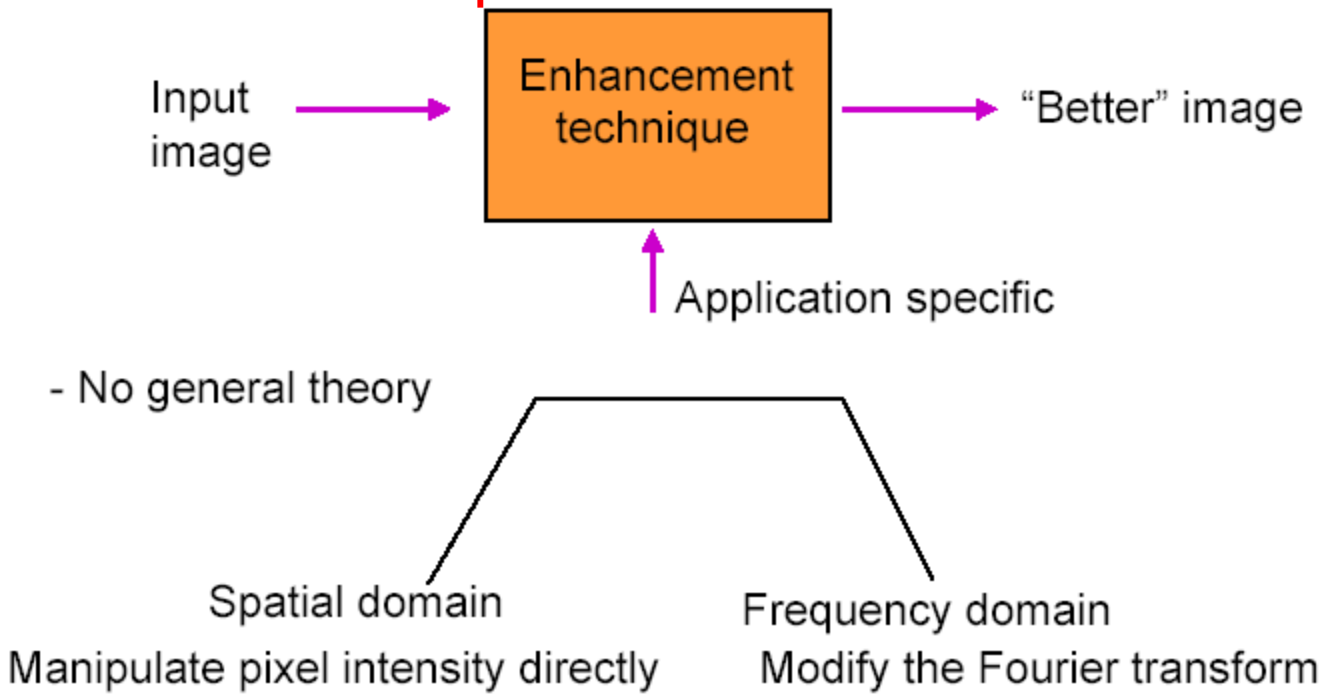
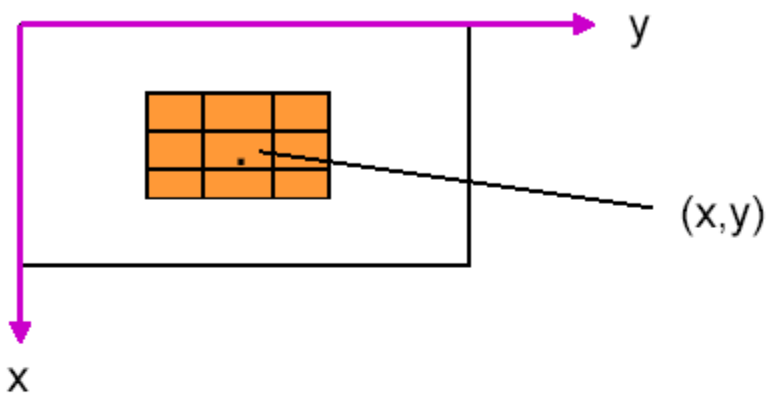


Image Enhancement in the Spatial Domain

$$g(x,y) = T[\,f\,(x,y)\,]$$

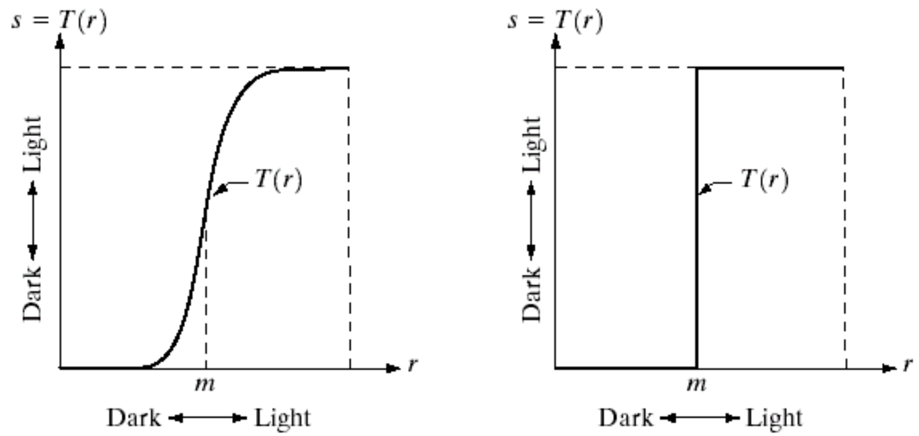


Simplest case: Neighbourhood is (x,y)

[g(.) depends only on the value of f at (x,y)]

Image Enhancement in the Spatial Domain

Gray Level Transformation Functions



a b

FIGURE 3.2 Gray-level transformation functions for contrast enhancement.

Image Enhancement in the Spatial Domain

Gray Level Transformation Functions

FIGURE 3.3 Some basic gray-level transformation functions used for image enhancement.

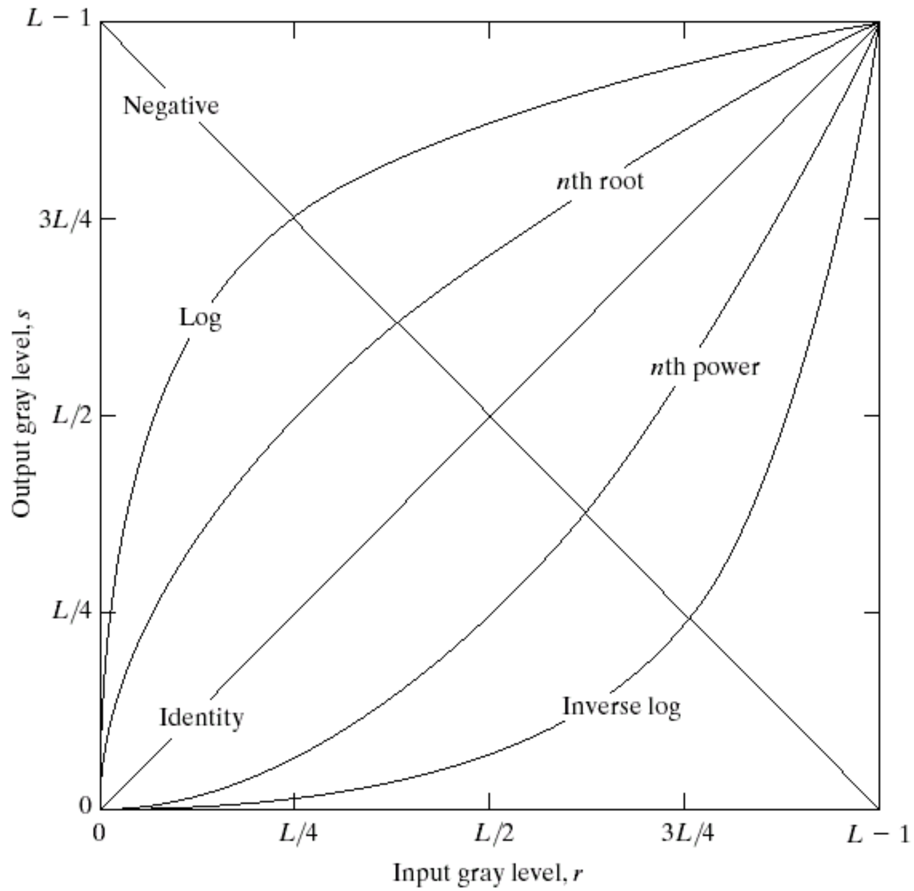
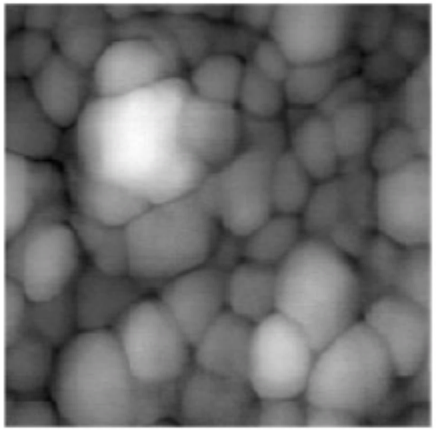


Image Enhancement in the Spatial Domain

(a) Negative image: Example: $g(x,y) = 255 - f(x,y)$



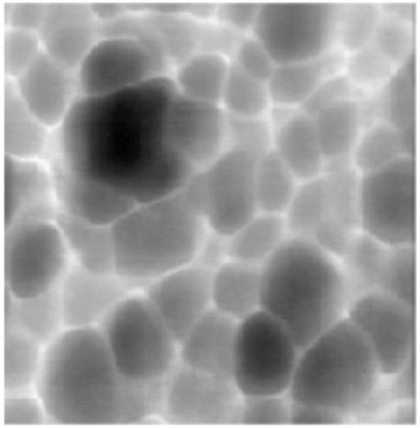


Image Enhancement in the Spatial Domain

(c) Compressing dynamic range

$s = c \log(1 + |r|)$ $\quad$ $c \longrightarrow$ Scaling factor

Example: Displaying the Fourier Spectrum

a b

FIGURE 3.5
(a) Fourier spectrum.
(b) Result of applying the log transformation given in Eq. (3.2-2) with $c = 1$.

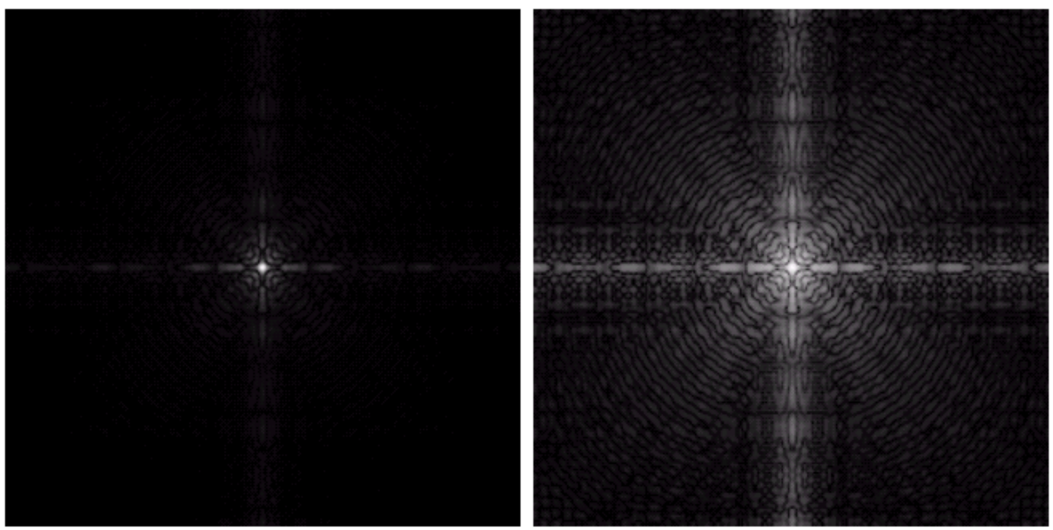


Image Enhancement in the Spatial Domain

Power Function

$$s = cr^{\gamma}$$

C and \gamma are positive constants.

Often referred to as "gamma correction".

CRT –intensity-to-voltage response follows a power function (typical value of gamma in the range 1.5-2.5.)

Image Enhancement in the Spatial Domain

Power Function

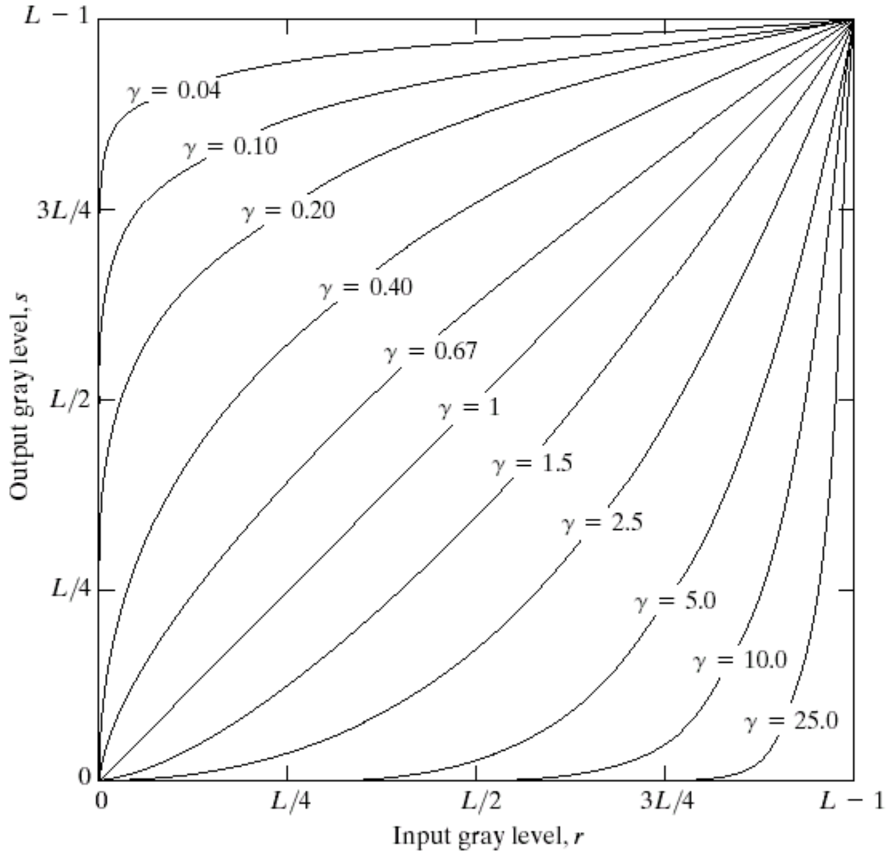


FIGURE 3.6 Plots of the equation $s = cr^{\gamma}$ for various values of γ ($c = 1$ in all cases).

Image Enhancement in the Spatial Domain

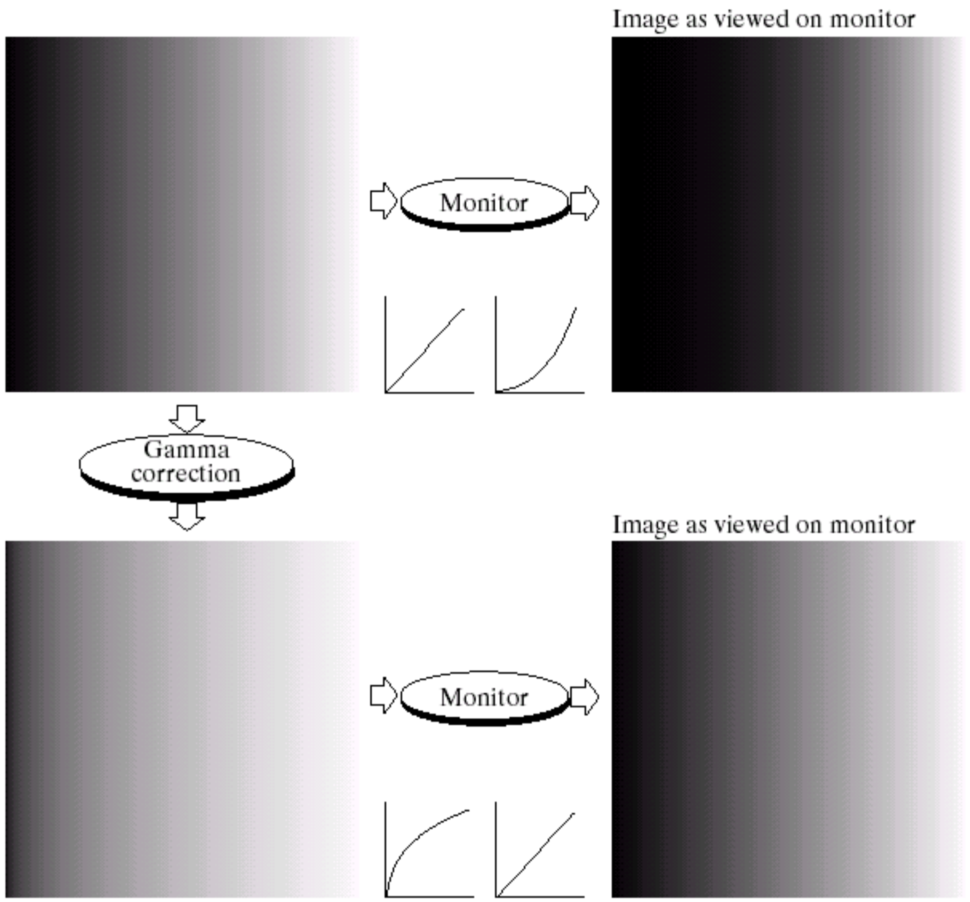
Power Function: Example

a	b
c	d

FIGURE 3.9 (a) Aerial image. (b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 3.0, 4.0,$ and 5.0, respectively. (Original image for this example courtesy of NASA.)

Image Enhancement in the Spatial Domain

Power Function: Gamma Correction

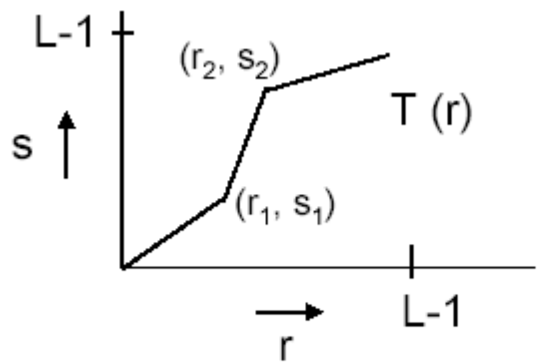


a b
c d

FIGURE 3.7 (a) Linear-wedge gray-scale image. (b) Response of monitor to linear wedge. (c) Gamma-corrected wedge. (d) Output of monitor.

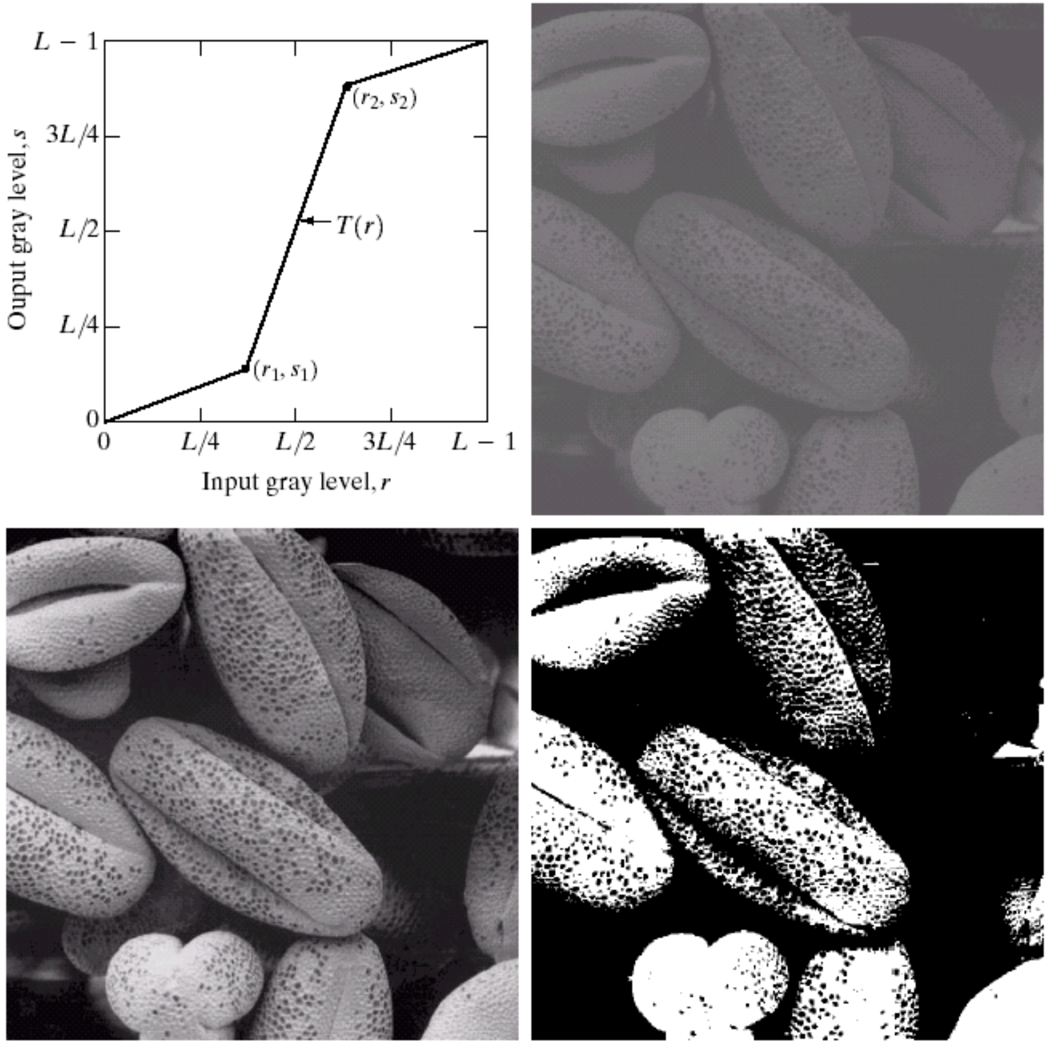
Image Enhancement in the Spatial Domain

(b) Contrast stretching



$r_1 = s_1$ $r_2 = s_2$	no change
$r_1 = r_2$ $s_1 = 0$ $s_2 = L-1$	Thresholding at r_1

Image Enhancement in the Spatial Domain

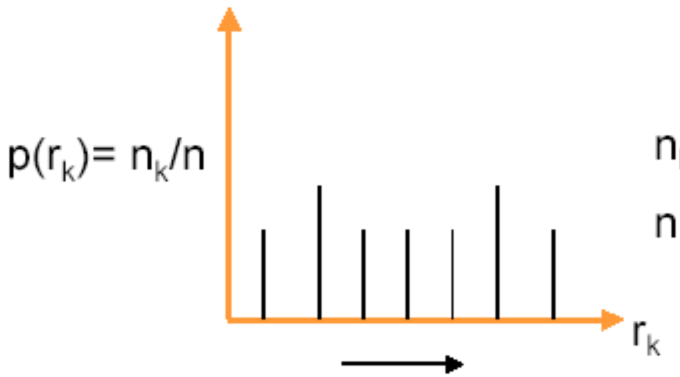


a b
c d

FIGURE 3.10 Contrast stretching. (a) Form of transformation function. (b) A low-contrast image. (c) Result of contrast stretching. (d) Result of thresholding. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)

Image Enhancement in the Spatial Domain

Histogram



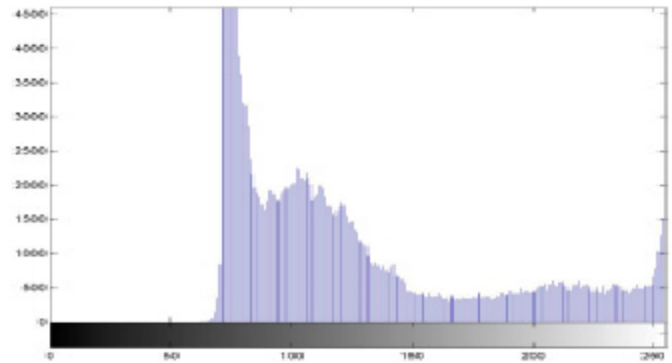
$r_k \in \{0, 1, 2, 3...., L-1\}$

n_k : # pixels with gray level r_k

n : # pixels in the image

Image Enhancement in the Spatial Domain

Histogram: Examples



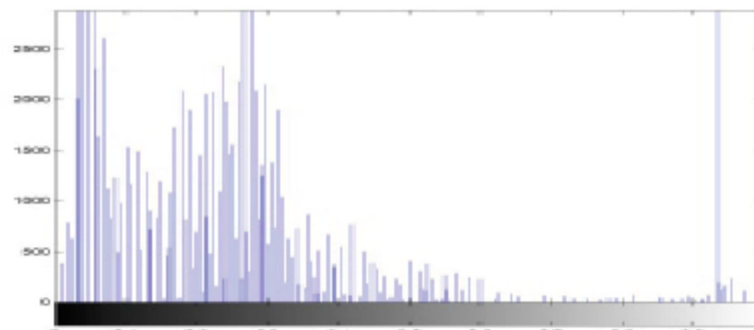
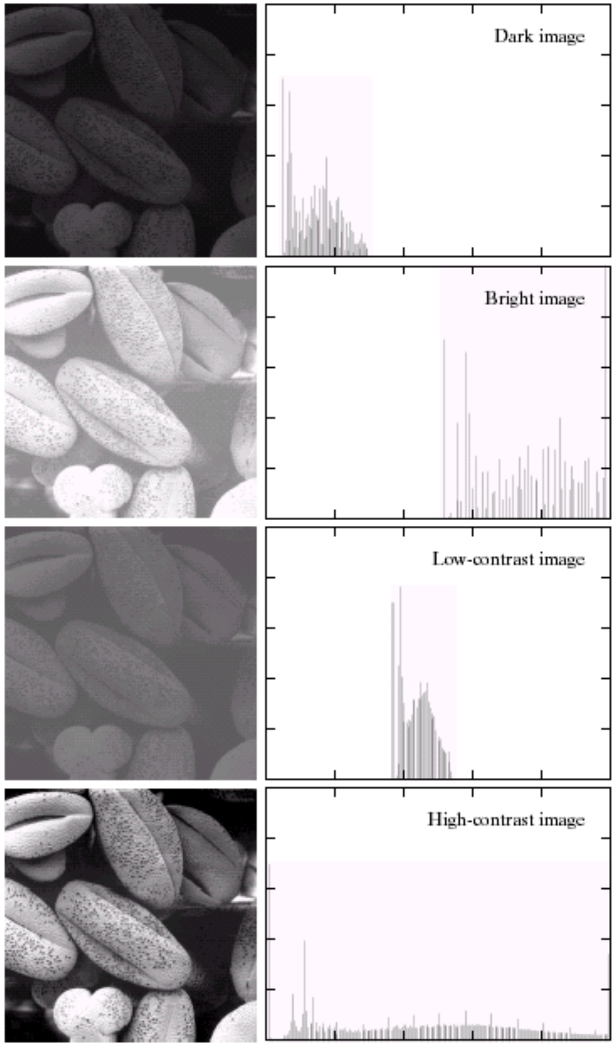


Image Enhancement in the Spatial Domain

Histogram: Examples



a b

FIGURE 3.15 Four basic image types: dark, light, low contrast, high contrast, and their corresponding histograms. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)

Image Enhancement in the Spatial Domain

Histogram Equalization

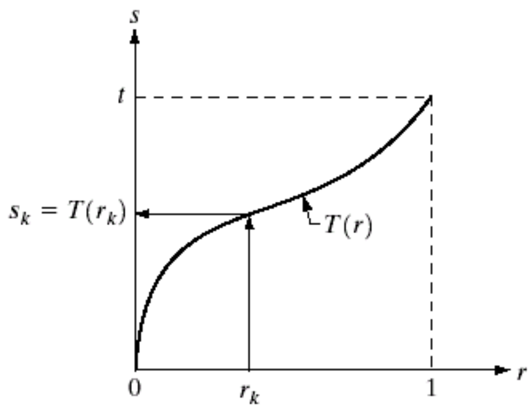


FIGURE 3.16 A gray-level transformation function that is both single valued and monotonically increasing.

Image Enhancement in the Spatial Domain

Histogram Equalization

(i) $T(r)$ is single valued valued and monotonically increasing in

$0 \le r \le 1$

(ii) $0 \le T(r) \le 1 \quad$ for $\quad 0 \le r \le 1$

$$[0,\ 1] \xrightarrow{T} [0, 1]$$

Inverse transformation : $T^{-1}(s) = r \qquad 0 \le s \le 1$

$T^{-1}(s)$ also satisfies (i) and (ii)

The gray levels in the image can be viewed as random variables taking values in the range [0,1].

Let $p_r(r)$: p.d.f. of input level r and let $p_s(s)$: p.d.f. of s

Image Enhancement in the Spatial Domain

Histogram Equalization

r : Input gray level $\in$ [0, 1]
s : Transformed gray level $\in$ [0, 1]

$s = T(r)$ T : Transformation function

We are interested in obtaining a transformation function T( ) which transforms an arbitrary p.d.f. to an uniform distribution

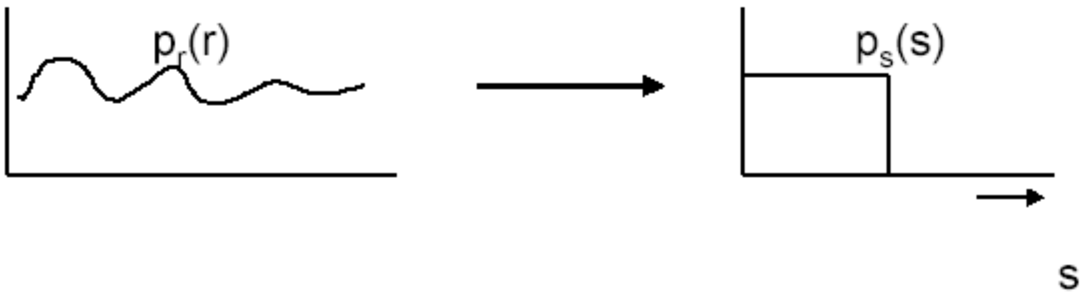


Image Enhancement in the Spatial Domain

Histogram Equalization

$$\text{Consider } s = T(r) = \int_0^r p_r(w)\,dw \quad 0 \le r \le 1$$

(Cumulative distribution function of r)

$$p_s(s) = p_r(r) \left. {}^{dr}\!\!/_{ds} \right|_{r=T^{-1}(s)} \;;$$

$$\frac{ds}{dr} = \frac{d}{dr}\left[\int_r^0 p_r(w)dw\right] = p_r(r)$$

$$\therefore p_s(s) = p_r(r) \left. \frac{1}{p_r(r)} \right|_{r=T^{-1}(s)} \equiv 1 \qquad 0 \le s \le 1$$

Image Enhancement in the Spatial Domain

Histogram Equalization

$$p_r(r_k) = \frac{n_k}{n} \qquad 0 \le r_k \le 1 \quad ; \quad k = 0,1,\dots,L-1$$

$L \rightarrow$ Number of levels

$$s_k = T(r_k) \quad = \sum_{j=0}^{k} p_r(r_j) \quad = \quad \sum_{j=0}^{k} n_j \Big/ n$$

Image Enhancement in the Spatial Domain

Histogram Equalization

$$\begin{bmatrix} 52 & 55 & 61 & 66 & 70 & 61 & 64 & 73 \\ 63 & 59 & 55 & 90 & 109 & 85 & 69 & 72 \\ 62 & 59 & 68 & 113 & 144 & 104 & 66 & 73 \\ 63 & 58 & 71 & 122 & 154 & 106 & 70 & 69 \\ 67 & 61 & 68 & 104 & 126 & 88 & 68 & 70 \\ 79 & 65 & 60 & 70 & 77 & 68 & 58 & 75 \\ 85 & 71 & 64 & 59 & 55 & 61 & 65 & 83 \\ 87 & 79 & 69 & 68 & 65 & 76 & 78 & 94 \end{bmatrix}$$

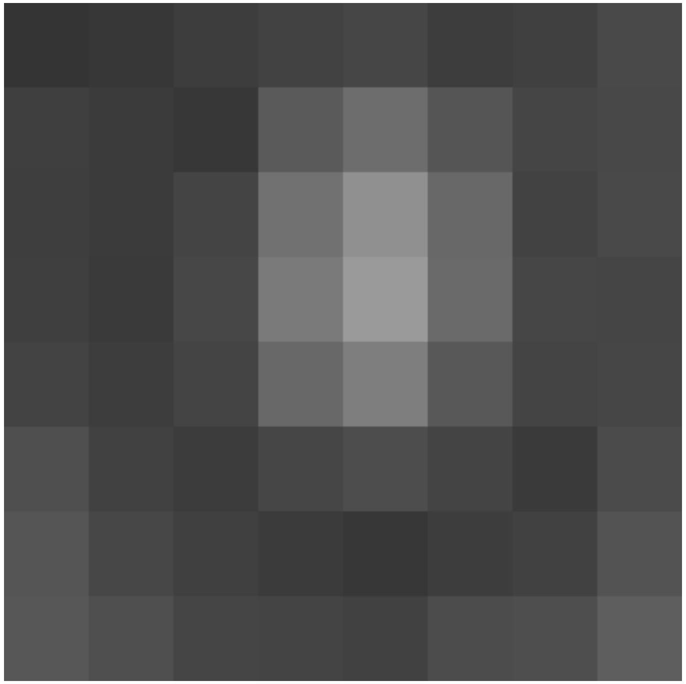


Image Enhancement in the Spatial Domain

Histogram Equalization

52	1		52	1
55	3		55	4
58	2		58	6
59	3		59	9
60	1		60	10
61	4		61	14
.				
.				
.				
144	1		144	63
154	1		154	64

Image Enhancement in the Spatial Domain

Histogram Equalization

$$h(v) = \mathrm{round}\left(\frac{cdf(v) - cdf_{min}}{(M \times N) - cdf_{min}} \times (L-1)\right)$$

$$h(v) = \mathrm{round}\left(\frac{cdf(v) - 1}{63} \times 255\right)$$

Image Enhancement in the Spatial Domain

Histogram Equalization

$$\begin{bmatrix} 0 & 12 & 53 & 93 & 146 & 53 & 73 & 166 \\ 65 & 32 & 12 & 215 & 235 & 202 & 130 & 158 \\ 57 & 32 & 117 & 239 & 251 & 227 & 93 & 166 \\ 65 & 20 & 154 & 243 & 255 & 231 & 146 & 130 \\ 97 & 53 & 117 & 227 & 247 & 210 & 117 & 146 \\ 190 & 85 & 36 & 146 & 178 & 117 & 20 & 170 \\ 202 & 154 & 73 & 32 & 12 & 53 & 85 & 194 \\ 206 & 190 & 130 & 117 & 85 & 174 & 182 & 219 \end{bmatrix}$$

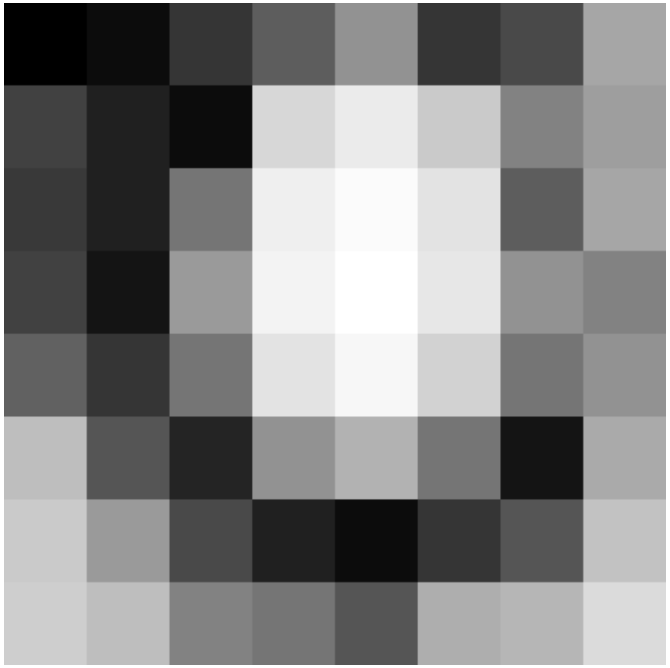
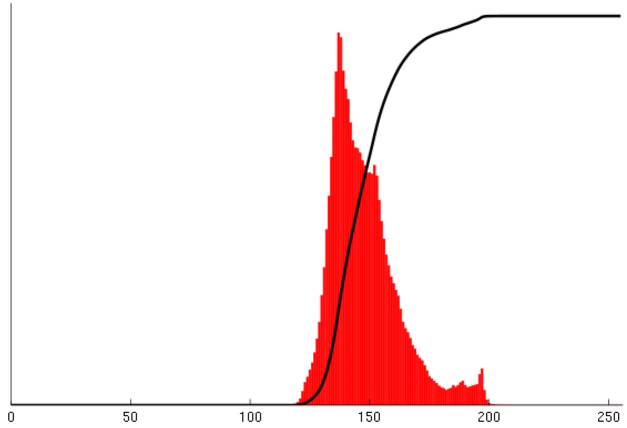


Image Enhancement in the Spatial Domain



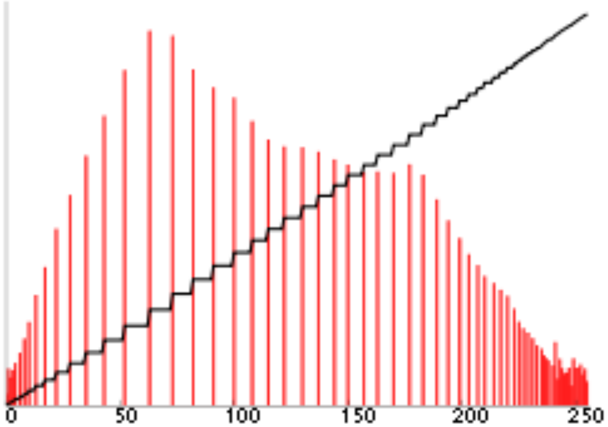
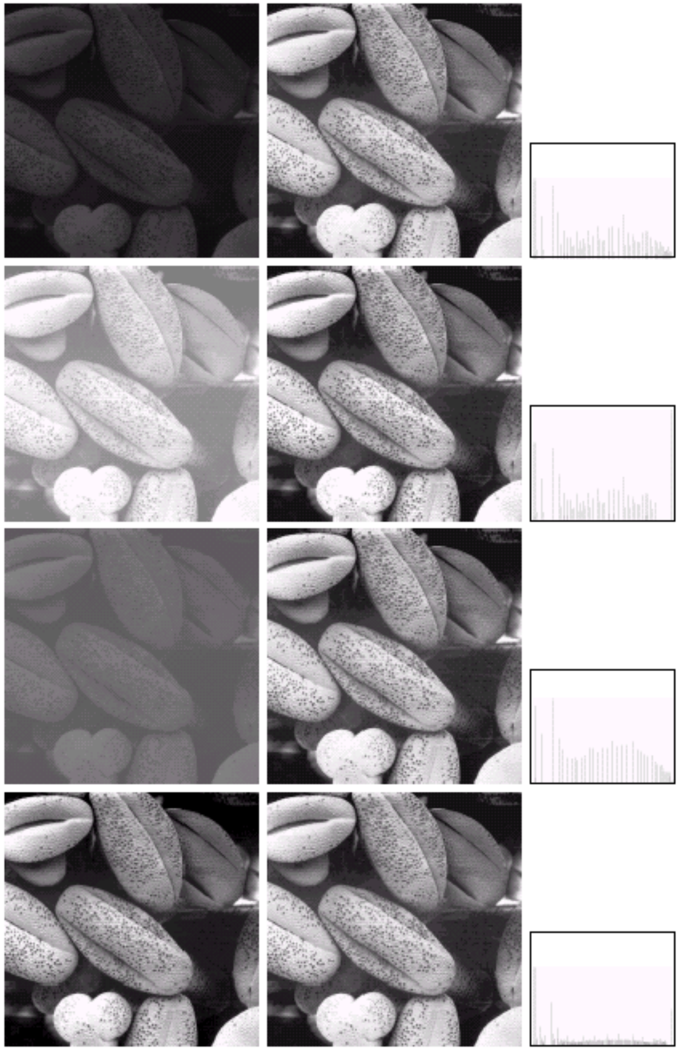


Image Enhancement in the Spatial Domain



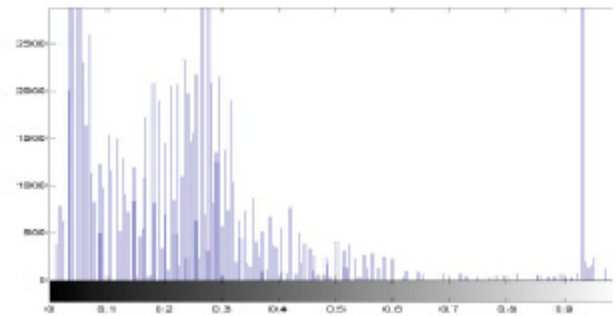
a b c

FIGURE 3.17 (a) Images from Fig. 3.15. (b) Results of histogram equalization. (c) Corresponding histograms.

Histogram Equalization
: Examples

Image Enhancement in the Spatial Domain

Histogram Equalization: Examples



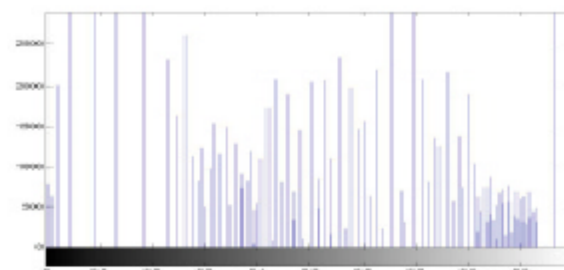


Image Enhancement in the Spatial Domain

Histogram Specification

Suppose $s = T(r) = \int_0^r p_r(w)\,dw$

$p_r(r) \rightarrow$ Original histogram ; $p_z(z) \rightarrow$ Desired histogram

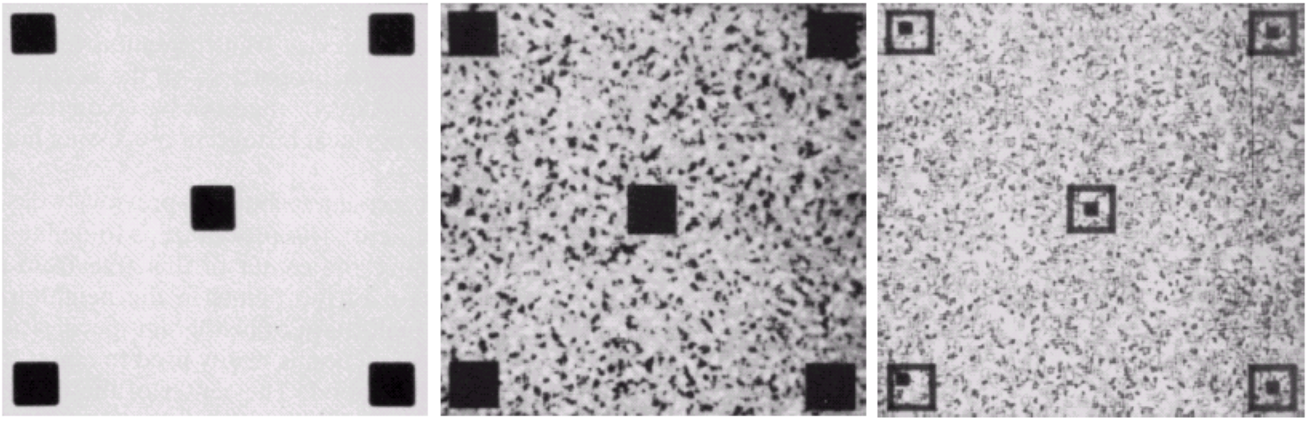
Let $v = G(z) = \int_0^z p_z(w)\,dw$ and $z = G^{-1}(v)$

But s and v are identical p.d.f.

$\therefore z = G^{-1}(v) = G^{-1}(s) = G^{-1}(T(r))$

Image Enhancement in the Spatial Domain

Histogram Equalization: Local Enhancement



a b c

FIGURE 3.23 (a) Original image. (b) Result of global histogram equalization. (c) Result of local histogram equalization using a 7×7 neighborhood about each pixel.

Image Enhancement in the Spatial Domain

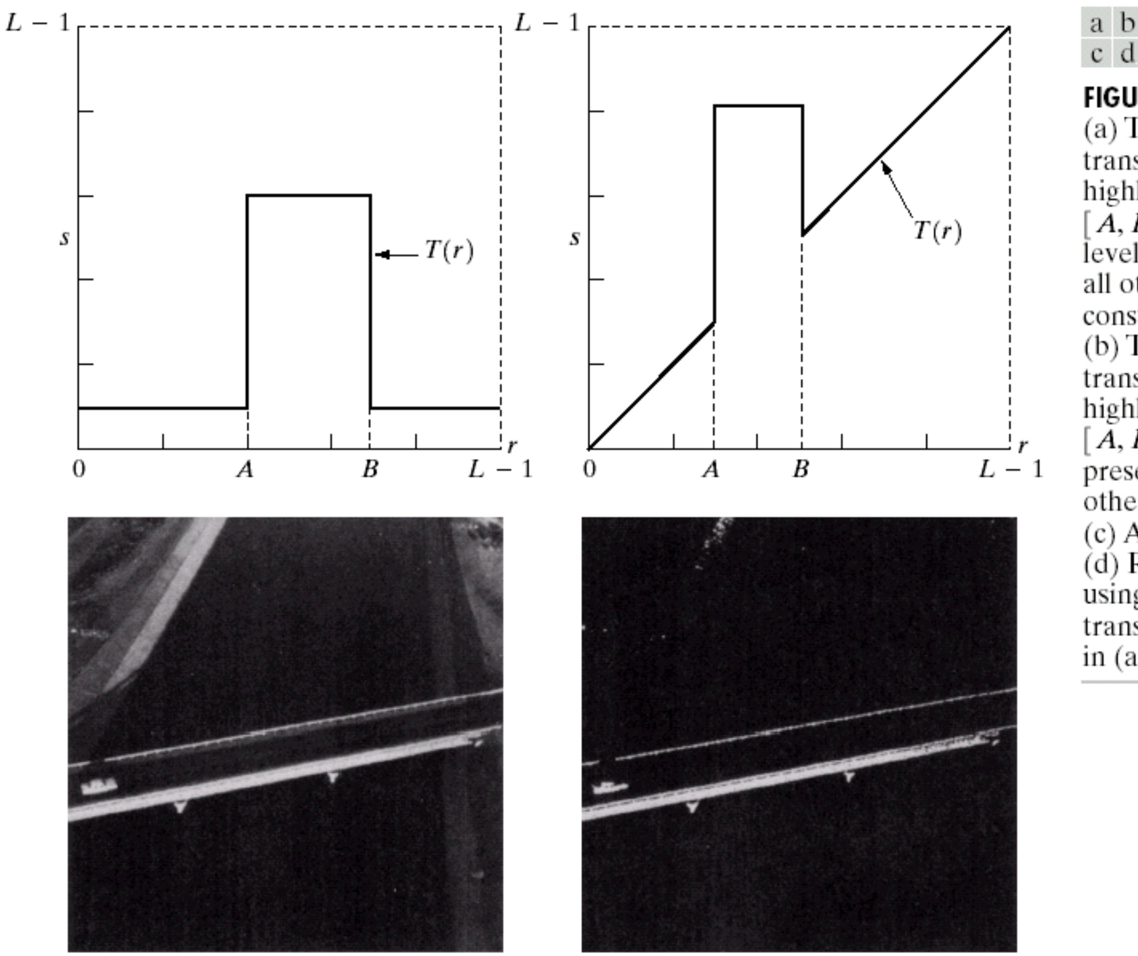


FIGURE 3.11 (a) This transformation highlights range $[A, B]$ of gray levels and reduces all others to a constant level. (b) This transformation highlights range $[A, B]$ but preserves all other levels. (c) An image. (d) Result of using the transformation in (a).

Image Enhancement in the Spatial Domain

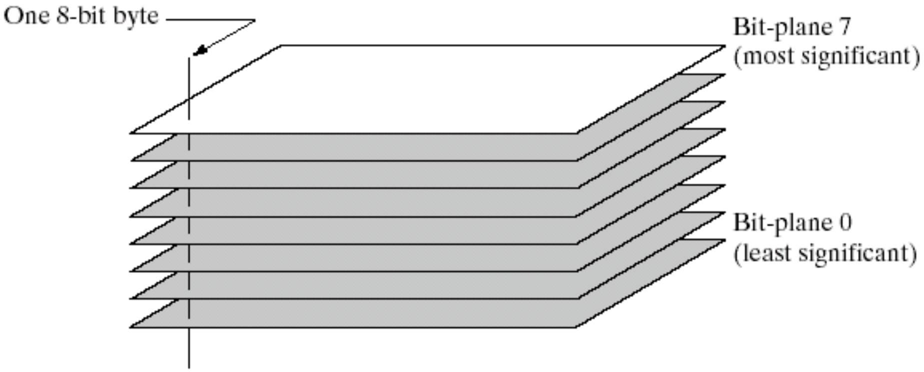


FIGURE 3.12 Bit-plane representation of an 8-bit image.

Image Enhancement in the Spatial Domain

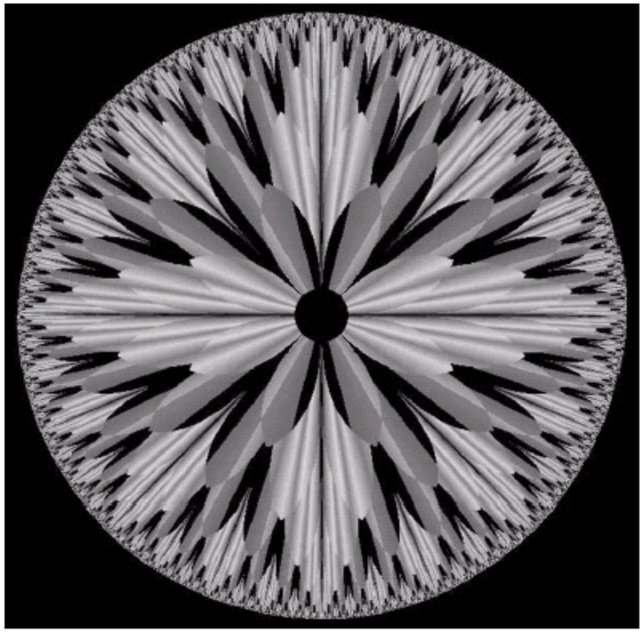


FIGURE 3.13 An 8-bit fractal image. (A fractal is an image generated from mathematical expressions). (Courtesy of Ms. Melissa D. Binde, Swarthmore College, Swarthmore, PA.)

Image Enhancement in the Spatial Domain

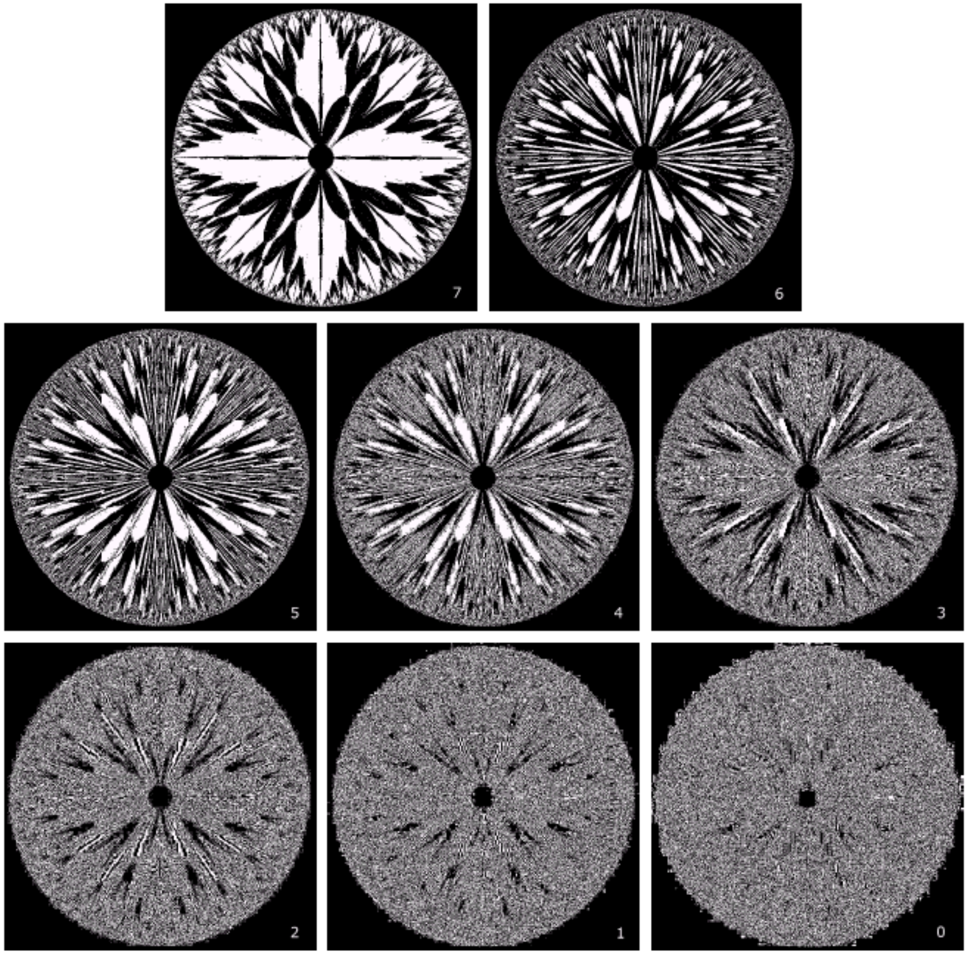


FIGURE 3.14 The eight bit planes of the image in Fig. 3.13. The number at the bottom, right of each image identifies the bit plane.

Image Enhancement in the Spatial Domain

Image Subtraction

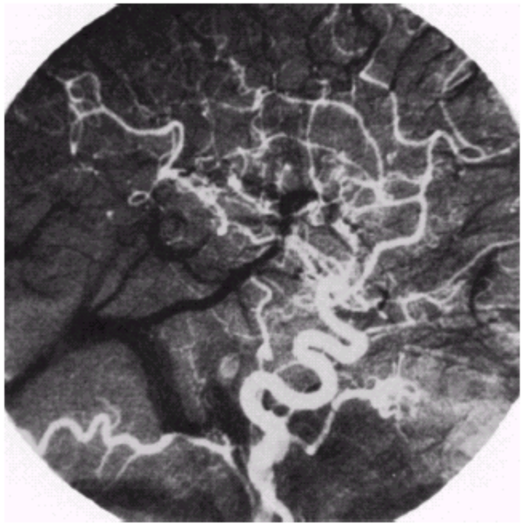
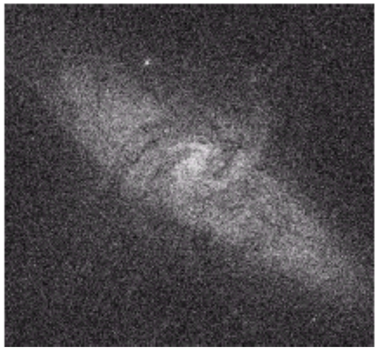


Image Addition



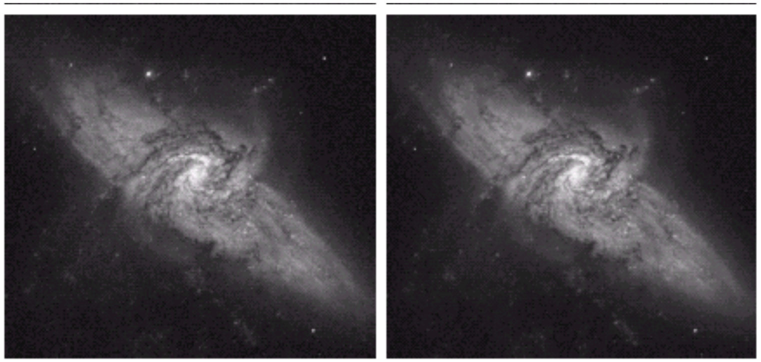


Image Enhancement in the Spatial Domain

Spatial Filtering

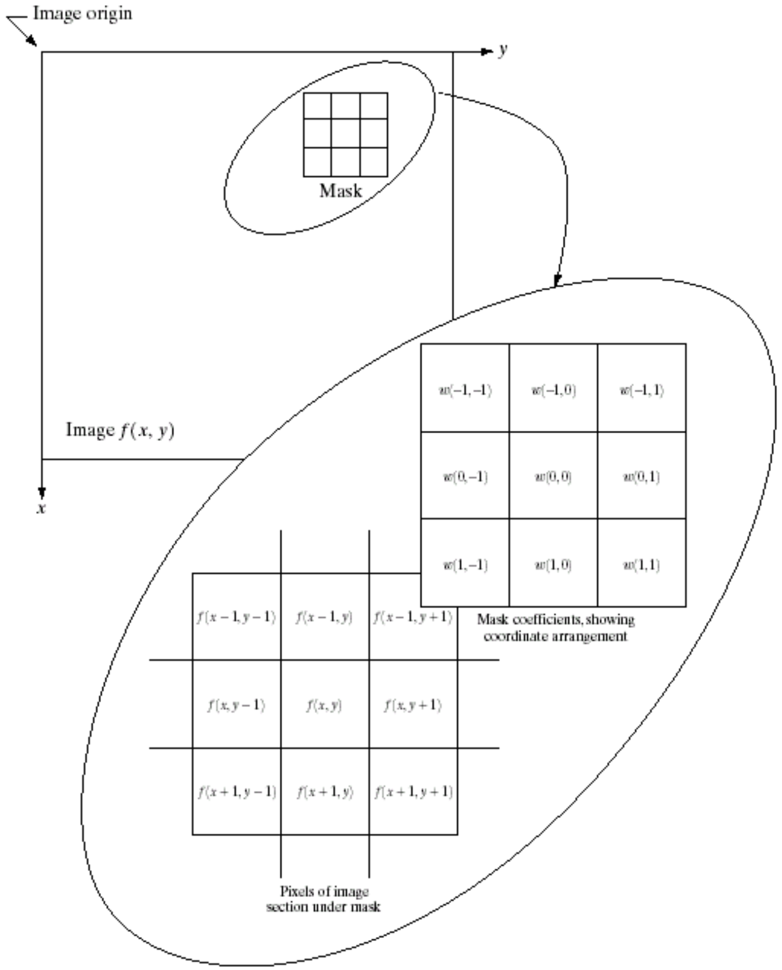
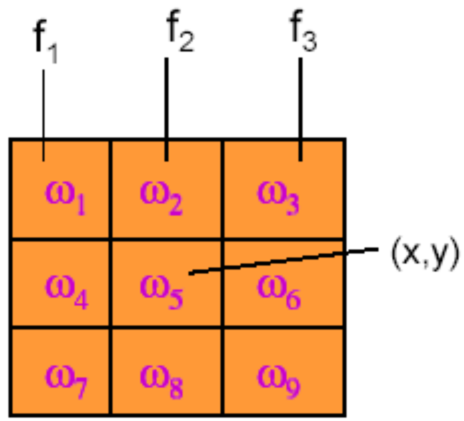


FIGURE 3.32 The mechanics of spatial filtering. The magnified drawing shows a 3×3 mask and the image section directly under it; the image section is shown displaced out from under the mask for ease of readability.

Image Enhancement in the Spatial Domain

Spatial Filtering



Replace f (x,y) with

$$\hat{f}(x,y) = \sum_{i} \omega_i f_i$$

Linear filter

LPF: reduces additive noise → blurs the image
→ sharpness details are lost
(Example: Local averaging)

Image Enhancement in the Spatial Domain

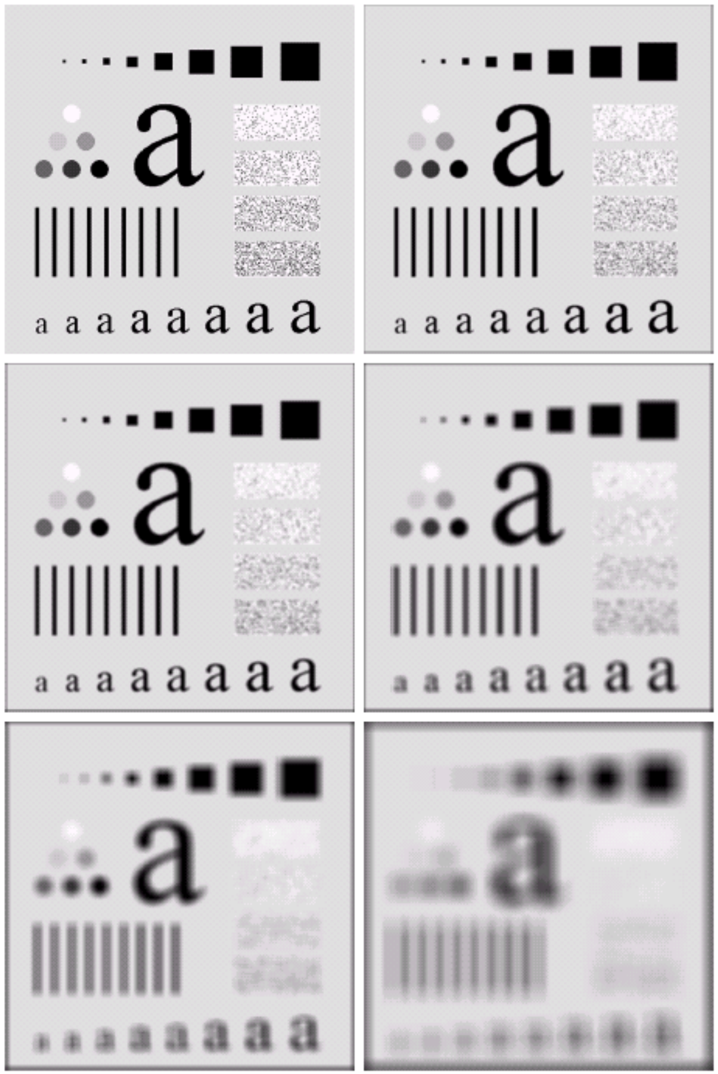
Spatial Filtering: Neighborhood Averaging

$$\frac{1}{9} \times \begin{array}{|c|c|c|} \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array} \qquad \frac{1}{16} \times \begin{array}{|c|c|c|} \hline 1 & 2 & 1 \\ \hline 2 & 4 & 2 \\ \hline 1 & 2 & 1 \\ \hline \end{array}$$

a b

FIGURE 3.34 Two 3×3 smoothing (averaging) filter masks. The constant multipli er in front of each mask is equal to the sum of the values of its coefficients, as is required to compute an average.

Image Enhancement in the Spatial Domain



Spatial Filtering:
Neighborhood Averaging

a b
c d
e f

FIGURE 3.35 (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. The black squares at the top are of sizes 3, 5, 9, 15, 25, 35, 45, and 55 pixels, respectively; their borders are 25 pixels apart. The letters at the bottom range in size from 10 to 24 points, in increments of 2 points; the large letter at the top is 60 points. The vertical bars are 5 pixels wide and 100 pixels high; their separation is 20 pixels. The diameter of the circles is 25 pixels, and their borders are 15 pixels apart; their gray levels range from 0% to 100% black in increments of 20%. The background of the image is 10% black. The noisy rectangles are of size 50 × 120 pixels.

Image Enhancement in the Spatial Domain

Median Filter

Replace f (x,y) with median [f (x' , y')]

(x' , y') ε neighbourhood

- Useful in eliminating intensity spikes. (salt & pepper noise)
- Better at preserving edges.

Example:

10	20	20
20	15	20
25	20	100

→ (10,15,20,20,20,20,20,25,100)

Median=20

So replace (15) with (20)

Image Enhancement in the Spatial Domain

Median Filter: Example

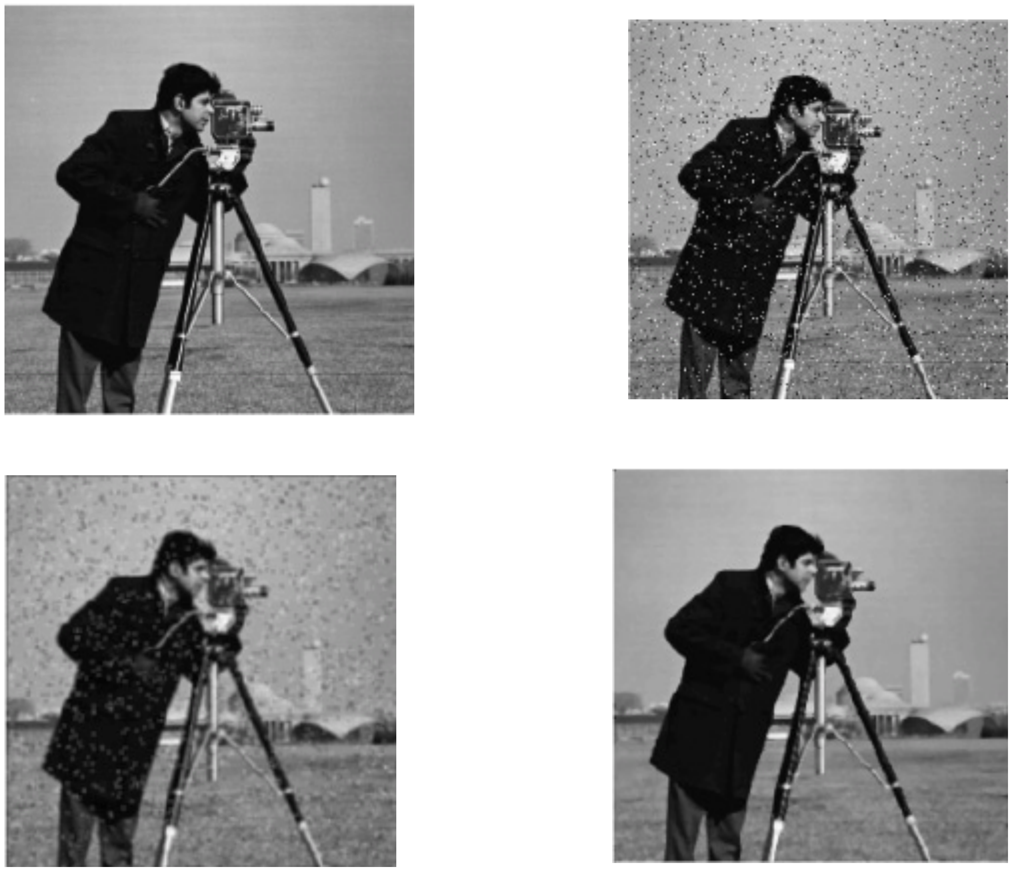


Image Enhancement in the Spatial Domain

Sharpening Filter

- Enhance finer image details (such as edges)
- Detect region /object boundaries.

Example:

−1	−1	−1
−1	8	−1
−1	−1	−1

Image Enhancement in the Spatial Domain

Highboost Filter

0	−1	0
−1	$A+4$	−1
0	−1	0

−1	−1	−1
−1	$A+8$	−1
−1	−1	−1

a b

FIGURE 3.42 The high-boost filtering technique can be implemented with either one of these masks, with $A \geq 1$.

Image Enhancement in the Spatial Domain

Highboost Filter: Example

a b
c d

FIGURE 3.43
(a) Same as Fig. 3.41(c), but darker.
(a) Laplacian of (a) computed with the mask in Fig. 3.42(b) using $A = 0$.
(c) Laplacian enhanced image using the mask in Fig. 3.42(b) with $A = 1$. (d) Same as (c), but using $A = 1.7$.

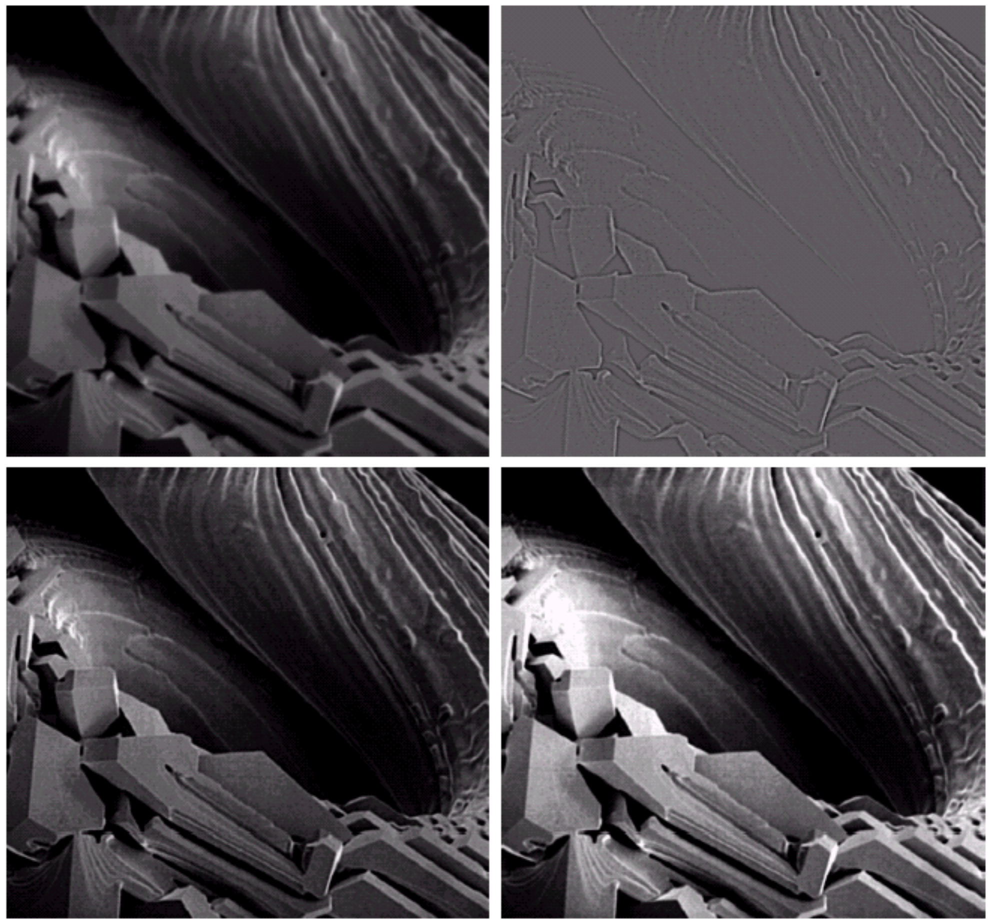


Image Enhancement in the Spatial Domain

Gradient Filter

Gradient

$$\nabla f = \left[\frac{\partial f}{\partial x} \quad \frac{\partial f}{\partial y} \right]^T$$

$$\|\nabla f\| = \left[\left(\frac{\partial f}{\partial x} \right)^2 + \left(\frac{\partial f}{\partial y} \right)^2 \right]^{1/2}$$

Image Enhancement in the Spatial Domain

Gradient Filter

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

$$|\nabla f| \approx \left[(z_5 - z_8)^2 + (z_5 - z_6)^2\right]^{1/2}$$

$$|\nabla f| \approx |z_5 - z_8| + |z_5 - z_6|$$

Robert's operator

1	0
0	-1

$| z_5 - z_9 |$

0	1
-1	0

$| z_6 - z_8 |$

prewitt

-1	-1	-1
0	0	0
1	1	1

-1	0	1
-1	0	1
-1	0	1

Sobel's

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	0	1