Chapter 3 Image Enhancement in the Spatial Domain

It makes all the difference whether one sees darkness through the light or brightness through the shadows.

- David Lindsay

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Chapter 3 Image Enhancement in the Spatial Domain

point operators

local operators

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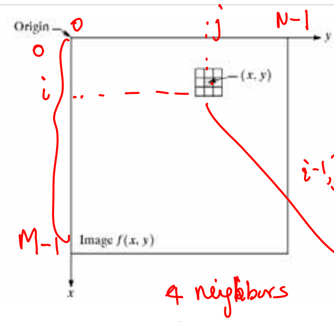
FIGURE 3.1 A 3 × 3 neighborhood about a point (x, y) in an image.



g[M][N]
unsigned char f[M][N];
for (int i=0; i<M; i++)
for (int j=0; j<N; j++)
g[i][j] = f[i][j] * 2;
O(MN)

f(x, y)
f[i][j]
f[i-1][j]
4 neighbors
8

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

g = T(f) = 2f = f+100
∈ [0, 255]   f ∈ [0, 255]

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Chapter 3
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Some Basic Gray Level Transformations

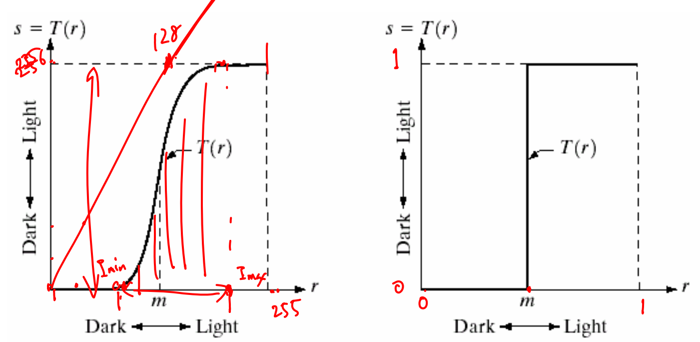

FIGURE 3.2 Gray-level transformation functions for contrast enhancement.

Contrast enhancement

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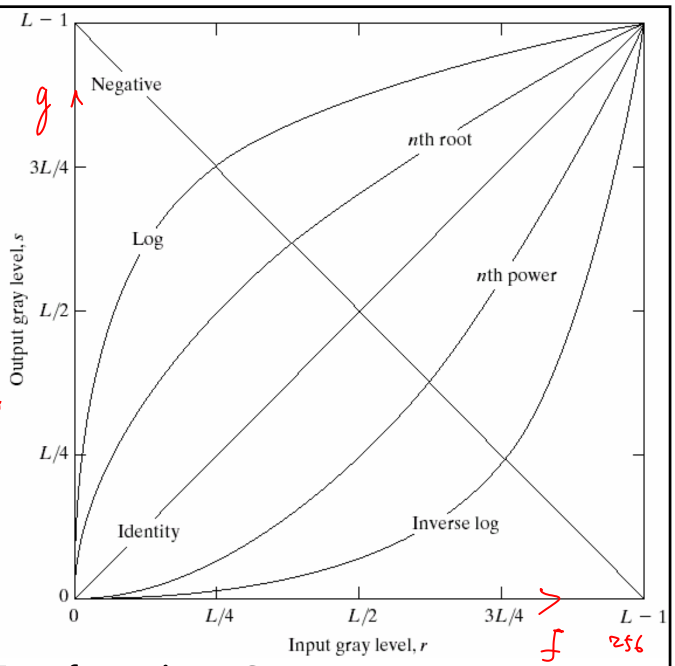
FIGURE 3.3 Some basic gray-level transformation functions used for image enhancement.



Basic Gray Level Transformations: Summary

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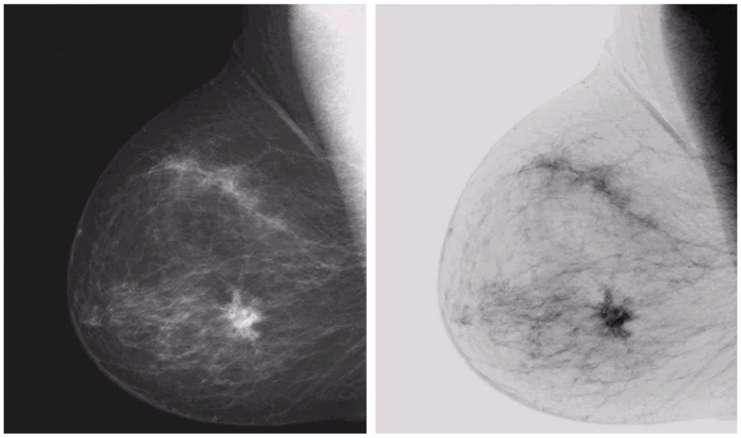
Image Enhancement in the Spatial Domain



a b

FIGURE 3.4 (a) Original digital mammogram. (b) Negative image obtained using the negative transformation in Eq. (3.2-1). (Courtesy of G.E. Medical Systems.)

Image Negatives

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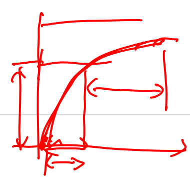
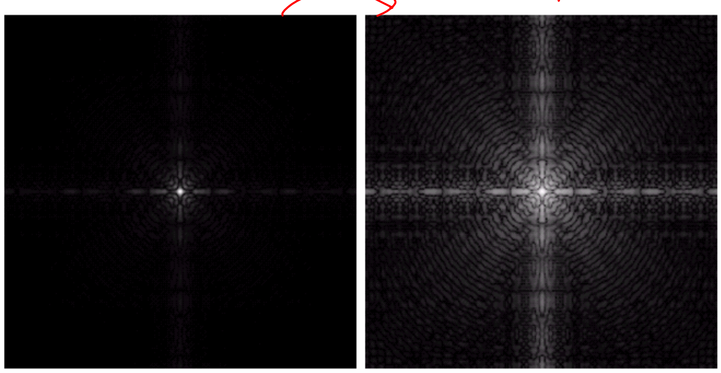


g = log f

a b

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



Log Transformations

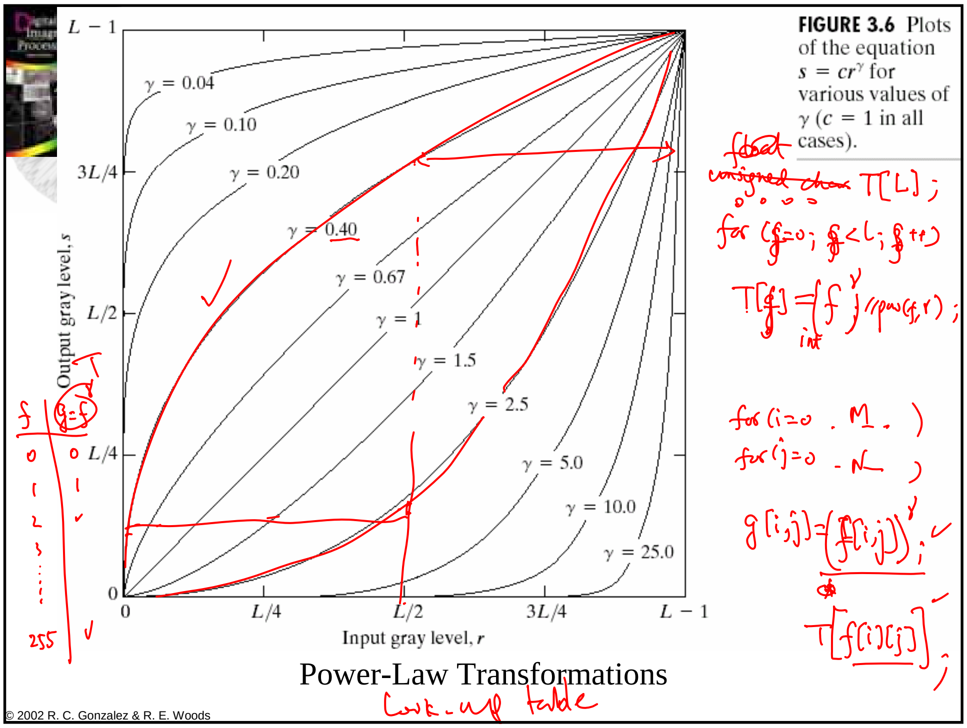


FIGURE 3.6 Plots of the equation $s = cr^{\gamma}$ for various values of γ ($c = 1$ in all cases).
L − 1
3L/4
L/2
L/4
0
Output gray level, s
Input gray level, r
γ = 0.04
γ = 0.10
γ = 0.20
γ = 0.40
γ = 0.67
γ = 1
γ = 1.5
γ = 2.5
γ = 5.0
γ = 10.0
γ = 25.0
Power-Law Transformations
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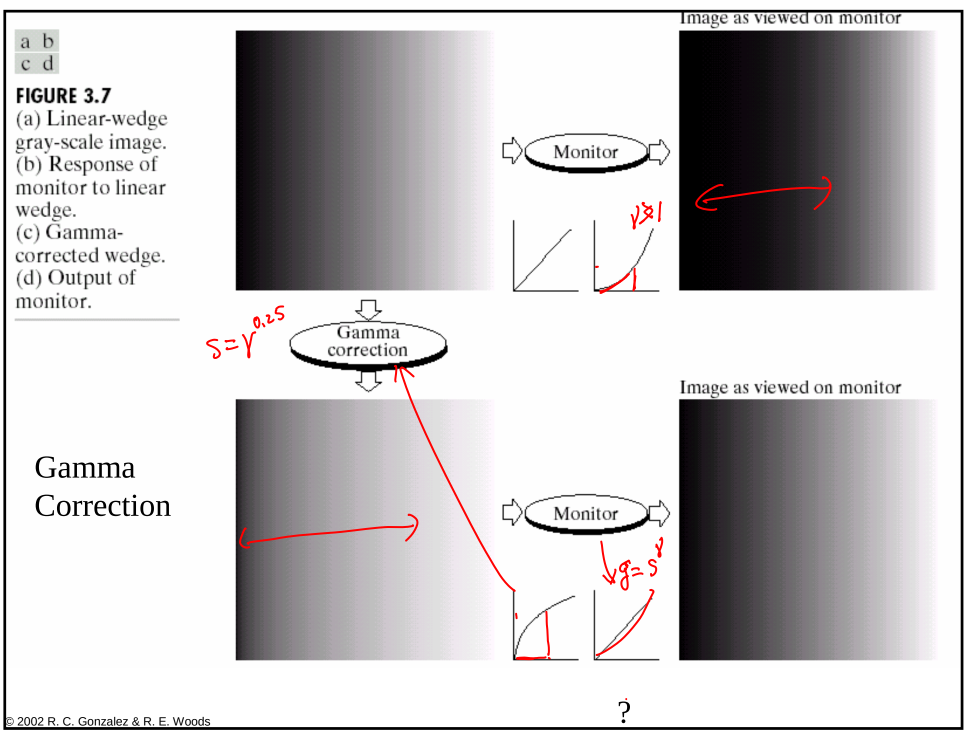
a b
c d
FIGURE 3.7
(a) Linear-wedge gray-scale image.
(b) Response of monitor to linear wedge.
(c) Gamma-corrected wedge.
(d) Output of monitor.
Image as viewed on monitor
Monitor
Gamma correction
Monitor
Image as viewed on monitor
Gamma Correction
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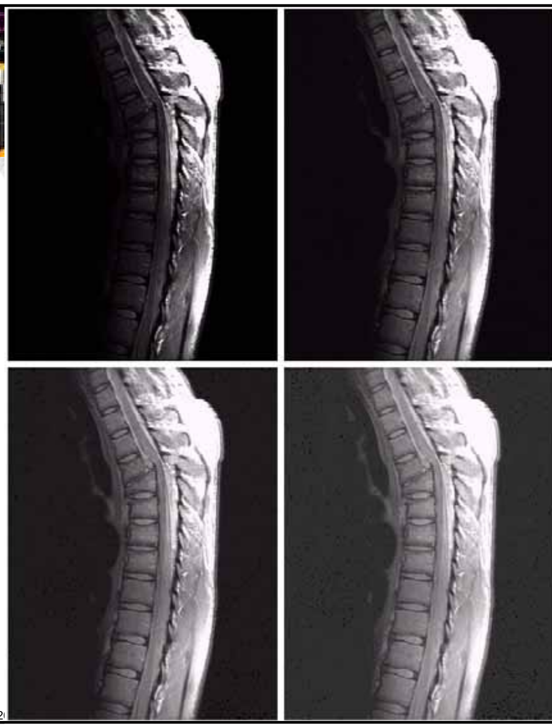

a b
c d

FIGURE 3.8 (a) Magnetic resonance (MR) image of a fractured human spine. (b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 0.6, 0.4,$ and 0.3, respectively. (Original image for this example courtesy of Dr. David R. Pickens, Department of Radiology and Radiological Sciences, Vanderbilt University Medical Center.)

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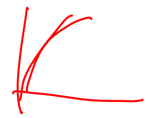
$s = r^{\gamma}$

too dark

$\Rightarrow \gamma < 1$



Power-Law Transformations To MRI of a fractured human spine

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.)

too bright

$\Rightarrow \gamma > 1$

Power-Law Transformations To Aerial Image

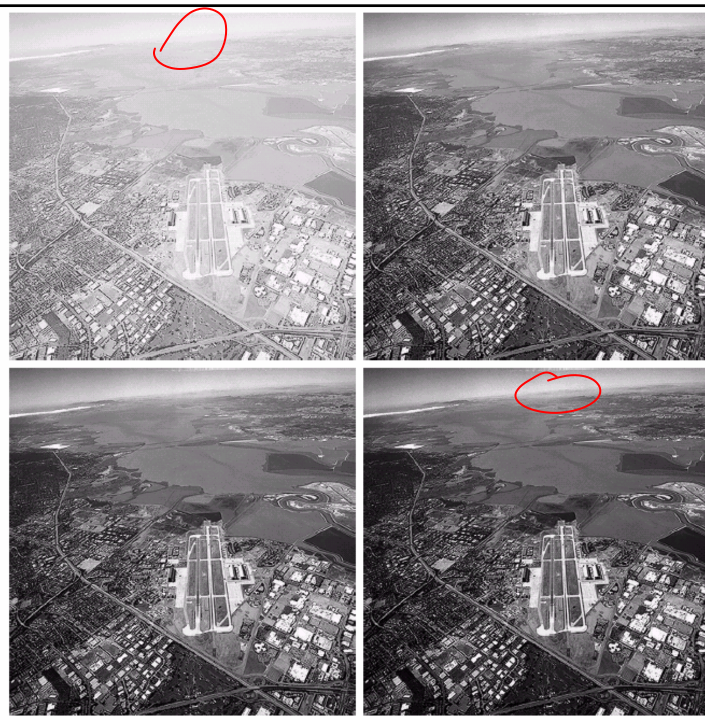


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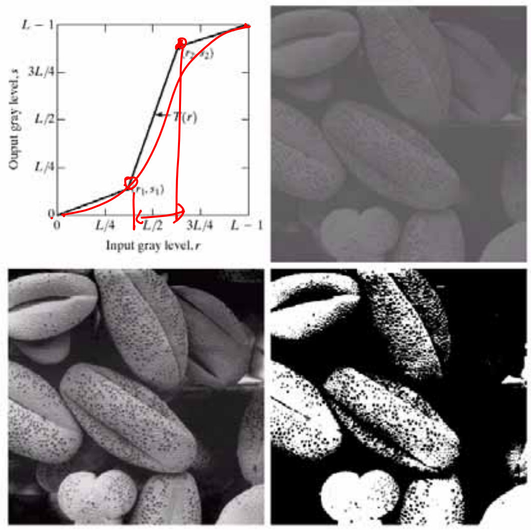
Image Enhancement in the Spatial Domain

Piecewise-Linear Transformation Functions for **contrast stretching**



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.)

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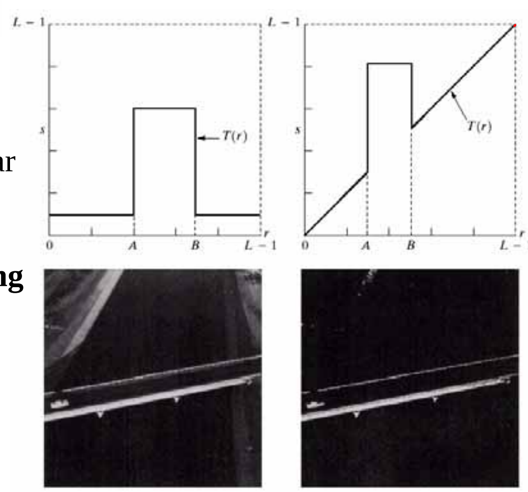
Image Enhancement in the Spatial Domain

Piecewise-Linear Transformation Functions for **gray-level slicing**



a b
c d

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).

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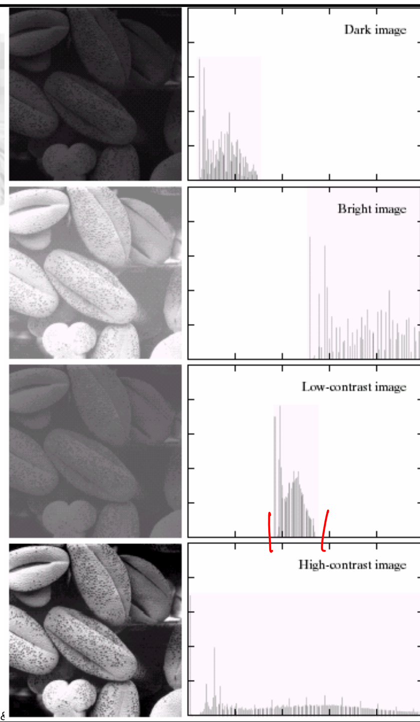
- The image shows the spatial distribution of gray values.
- The image **histogram** discards the spatial information and shows the relative frequency of occurrence of the gray values.

Image

0	3	3	2	5	5
1	1	0	3	4	5
2	2	2	4	4	4
3	3	4	4	5	5
3	4	5	5	6	6
7	6	6	6	6	5

Gray Value	Count	Rel. Freq.
0	2	.05
1	2	.05
2	4	.11
3	6	.17
4	7	.20
5	8	.22
6	6	.17
7	1	.03
Sum=	36	1.00

nt in the
ain



Histogram Processing

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.)

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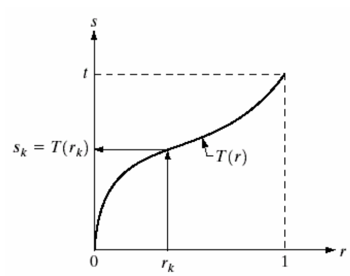
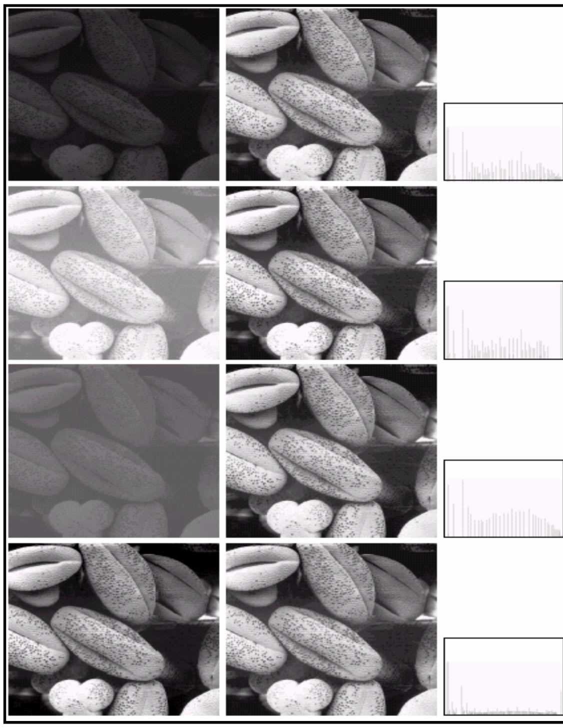


FIGURE 3.16 A gray-level transformation function that is both single valued and monotonically increasing.

Histogram Equalization

Transformation both single valued and monotonic



a b c

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

Histogram Equalization

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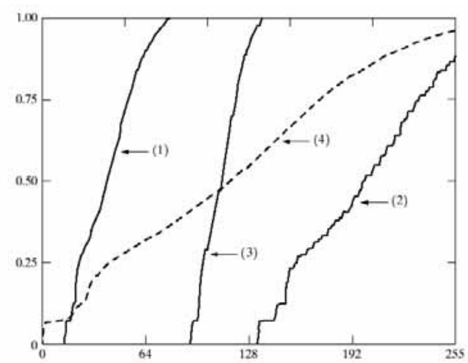
FIGURE 3.18 Transformation functions (1) through (4) were obtained from the histograms of the images in Fig.3.17(a), using Eq. (3.3-8).



Histogram Equalization

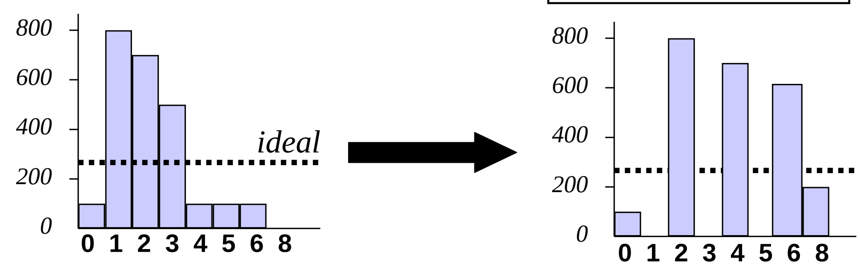
How It Works

(Homework 1)

G=8
MxN=2400
$N_p=300$

$$CH(j) = \sum_{i=0}^{j} H(i)$$

j	H(j)	CH(j)	i
0	100	100	0
1	800	900	2
2	700	1600	4
3	500	2100	6
4	100	2200	6
5	100	2300	7
6	100	2400	7
7	0	2400	7



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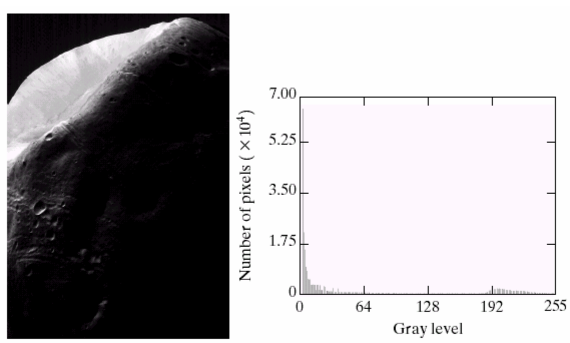

a b

FIGURE 3.20 (a) Image of the Mars moon Photos taken by NASA's *Mars Global Surveyor.* (b) Histogram. (Original image courtesy of NASA.)

Improvement 1: Histogram Matching

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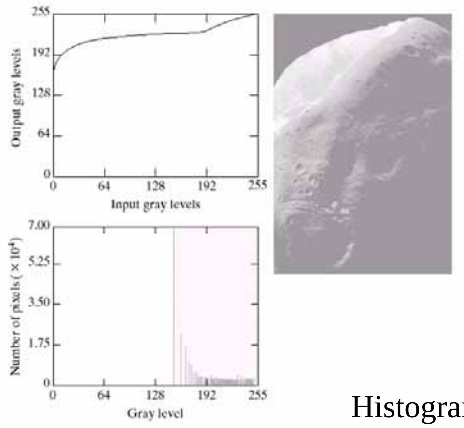


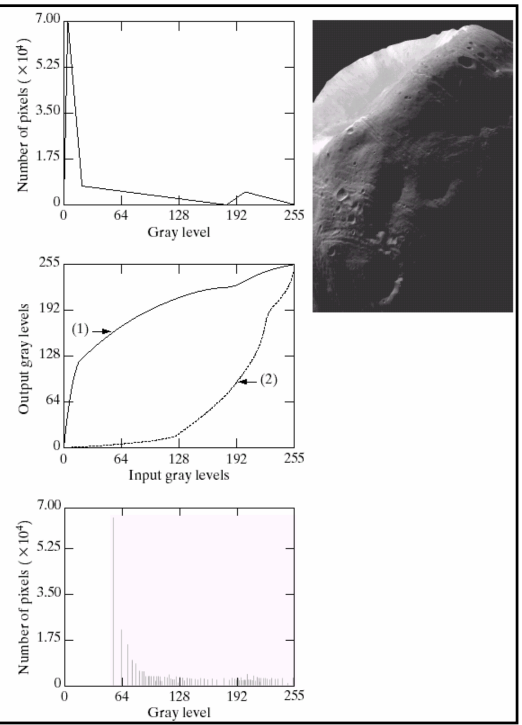
a b
c

FIGURE 3.21 (a) Transformation function for histogram equalization. (b) Histogram-equalized image (note the washed-out appearance). (c) Histogram of (b).

Histogram Equalization

a c
b
d

FIGURE 3.22 (a) Specified histogram. (b) Curve (1) is from Eq. (3.3-14), using the histogram in (a); curve (2) was obtained using the iterative procedure in Eq. (3.3-17). (c) Enhanced image using mappings from curve (2). (d) Histogram of (c).



Histogram Matching (Specification)

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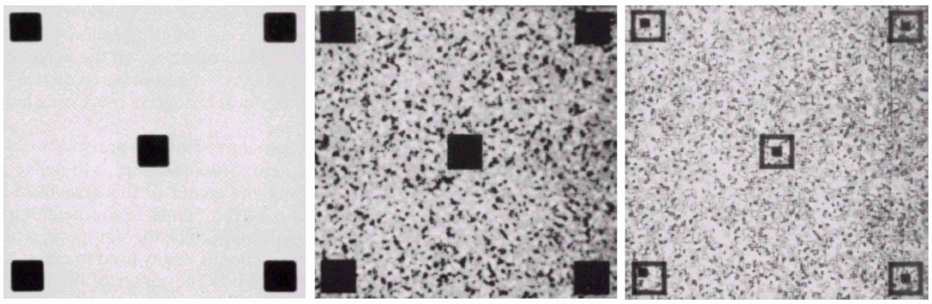

a b c

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.

Improvement 2: Global vs. Local Enhancement

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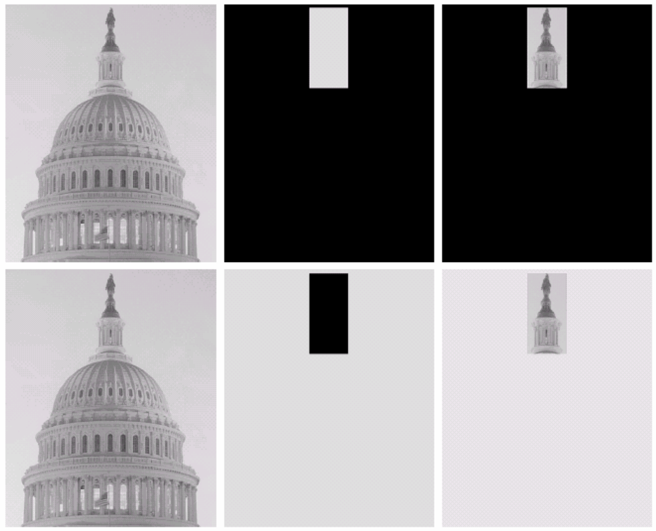
Image AND/OR operators



a b c
d e f

FIGURE 3.27 (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).

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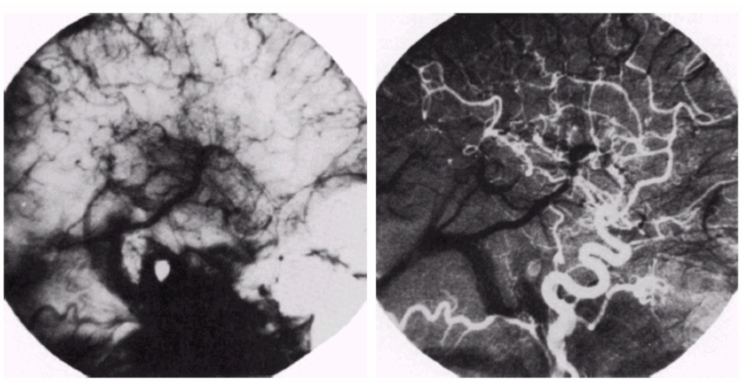

a b

FIGURE 3.29 Enhancement by image subtraction. (a) Mask image. (b) An image (taken after injection of a contrast medium into the bloodstream) with mask subtracted out.

Image Subtraction in medical application

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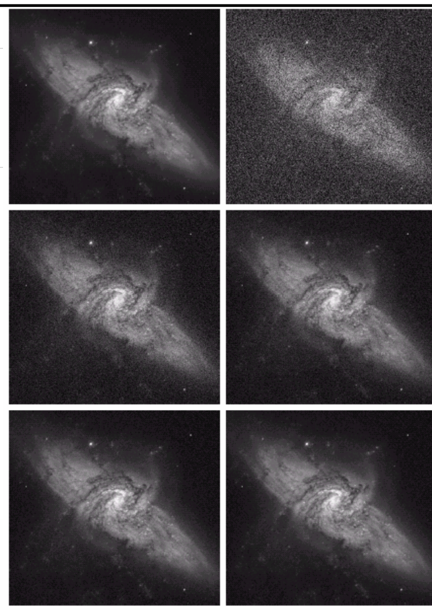
Image Averaging



a b
c d
e f

FIGURE 3.30 (a) Image of Galaxy Pair NGC 3314. (b) Image corrupted by additive Gaussian noise with zero mean and a standard deviation of 64 gray levels. (c)–(f) Results of averaging $K = 8, 16, 64$, and 128 noisy images. (Original image courtesy of NASA.)

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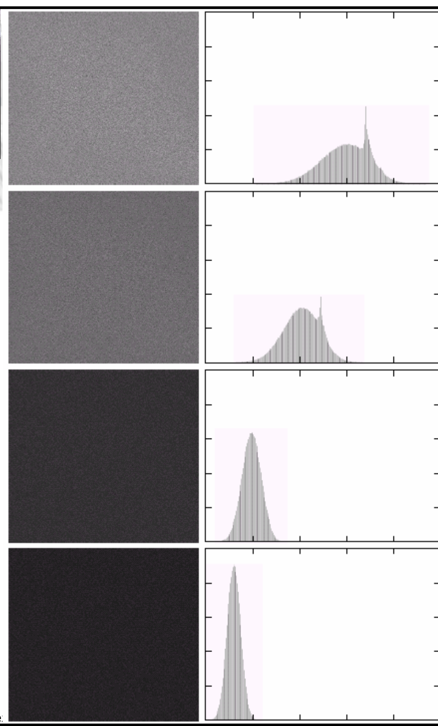

a b

FIGURE 3.31 (a) From top to bottom: Difference images between Fig. 3.30(a) and the four images in Figs. 3.30(c) through (f), respectively. (b) Corresponding histograms.

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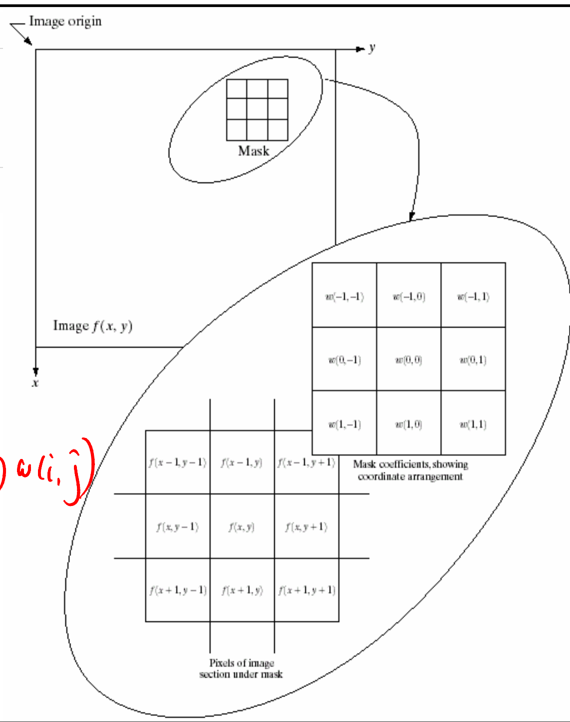
Image Enhancement in the Spatial Domain



$$g(x,y) = \sum_{i,j=-1}^{1} f(x-i, y-j)\, w(i,j)$$

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.

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

1	1	1
1	1	1
1	1	1

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

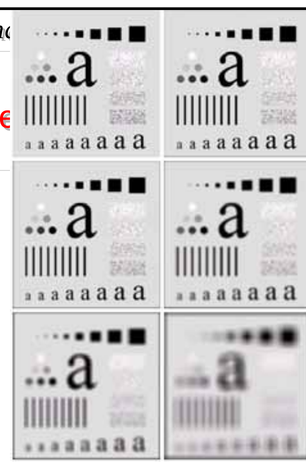
1	2	1
2	4	2
1	2	1

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.

Smoothing Spatial Filters

- Smoothing Linear Filters



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.

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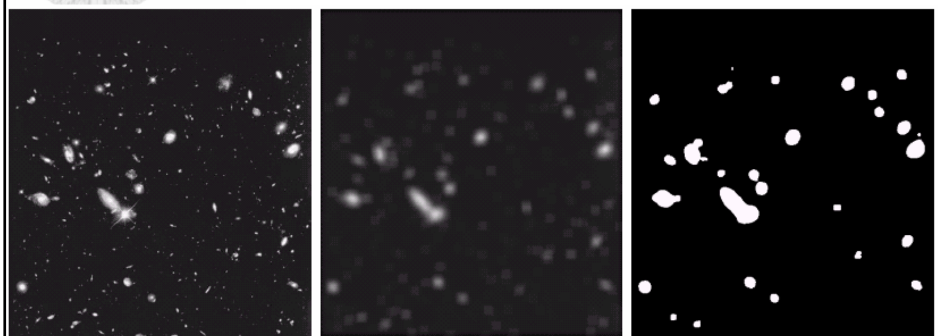

a b c

FIGURE 3.36 (a) Image from the Hubble Space Telescope. (b) Image processed by a 15 × 15 averaging mask. (c) Result of thresholding (b). (Original image courtesy of NASA.)

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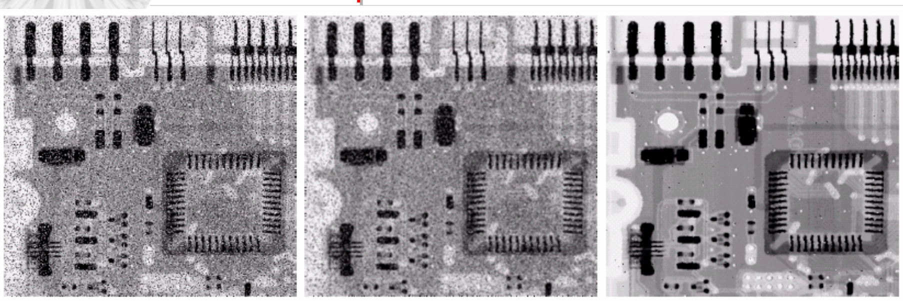


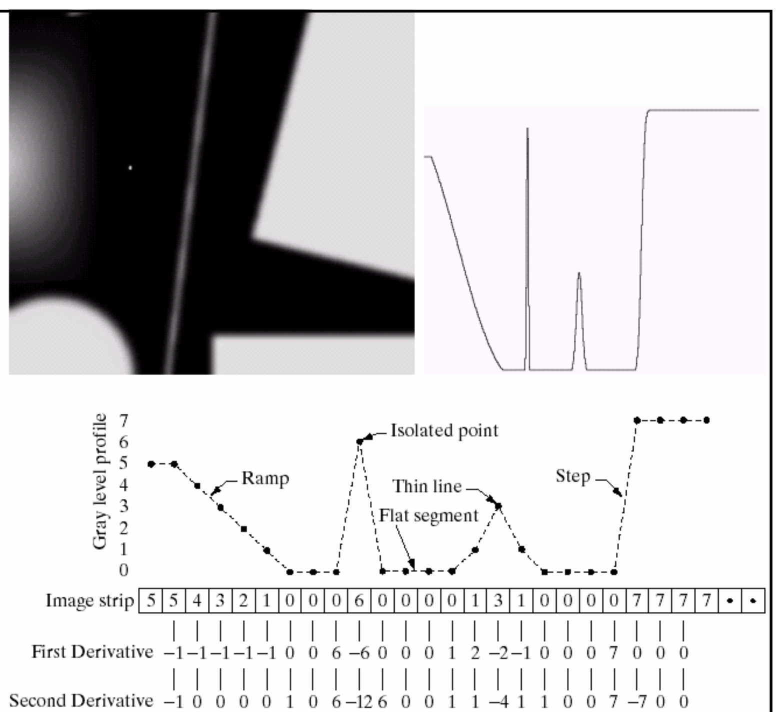
a b c

FIGURE 3.37 (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. (Original image courtesy of Mr. Joseph E. Pascente, Lixi, Inc.)

Order-Statistics Filters – Median filter

3.7 Sharpening Spatial Filters 125

FIGURE 3.38 (a) A simple image. (b) 1-D horizontal gray-level profile along the center of the image and including the isolated noise point. (c) Simplified profile (the points are joined by dashed lines to simplify interpretation).



Chapter 3 Image Enhancement in the Spatial Domain

Use of Second Derivatives for Enhancement– The Laplacian

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

$\nabla^2 f$

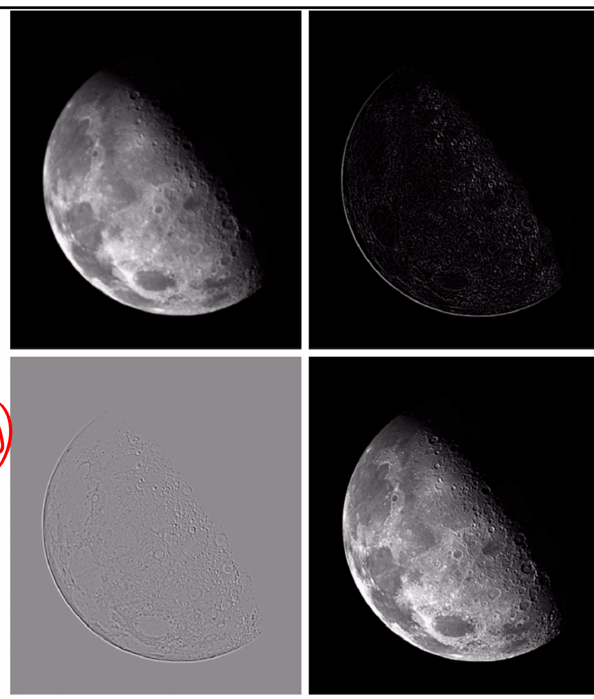
0	1	0	1	1	1
1	−4	1	1	−8	1
0	1	0	1	1	1

$-\nabla^2 f$

0	−1	0	−1	−1	−1
−1	4	−1	−1	8	−1
0	−1	0	−1	−1	−1

a b
c d

FIGURE 3.39 (a) Filter mask used to implement the digital Laplacian, as defined in Eq. (3.7-4). (b) Mask used to implement an extension of this equation that includes the diagonal neighbors. (c) and (d) Two other implementations of the Laplacian.



a b
c d

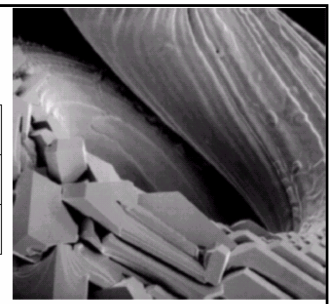
FIGURE 3.40 (a) Image of the North Pole of the moon. (b) Laplacian-filtered image. (c) Laplacian image scaled for display purposes. (d) Image enhanced by using Eq. (3.7-5). (Original image courtesy of NASA.)

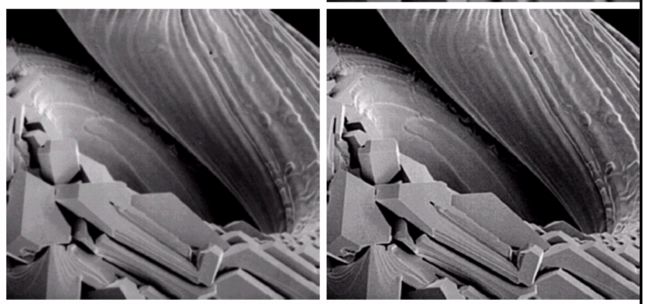
$$g(x,y) = f(x,y) - \nabla^2 f(x,y)$$

0	−1	0
−1	5	−1
0	−1	0

$f - \nabla^2 f$

−1	−1	−1
−1	9	−1
−1	−1	−1





a b c
d e

FIGURE 3.41 (a) Composite Laplacian mask. (b) A second composite mask. (c) Scanning electron microscope image. (d) and (e) Results of filtering with the masks in (a) and (b), respectively. Note how much sharper (e) is than (d). (Original image courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene.)

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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 $A \geq 1$.

Use of Second Derivatives for Enhancement–
Unsharp masking and high- boost filtering

$$f_{hb}(x,y) = Af(x,y) - \nabla^2 f(x,y)$$

a b
c d

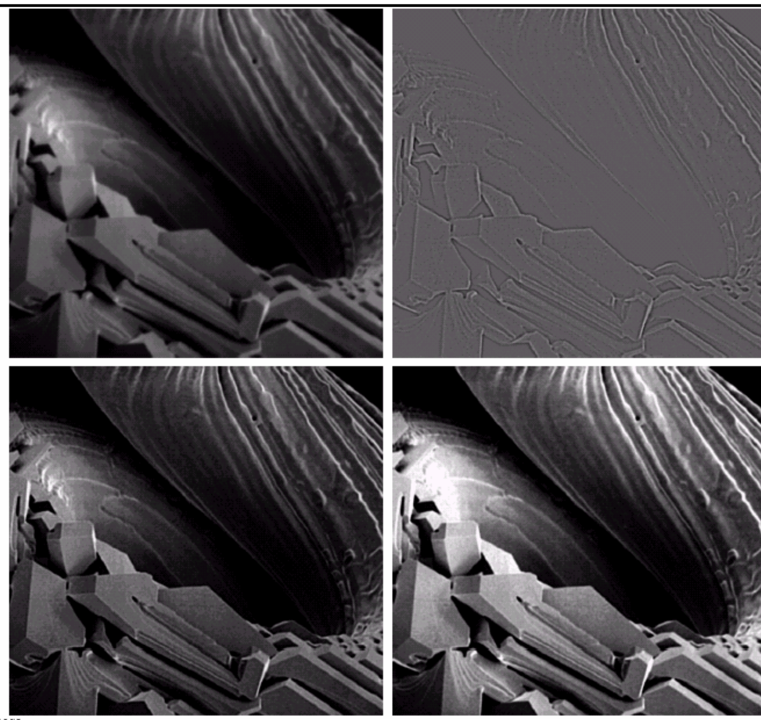

FIGURE 3.43
(a) Same as Fig. 3.41(c), but darker.
(a) Laplacian of (a) computed with the mask in Fig. 3.42(b) using $A = 0$.
(c) Laplacian enhanced image using the mask in Fig. 3.42(b) with $A = 1$. (d) Same as (c), but using $A = 1.7$.

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Use of First Derivatives for Enhancement—**The Gradient**

$$\nabla f = \begin{pmatrix} G_x \\ G_y \end{pmatrix} = \begin{pmatrix} \partial f / \partial x \\ \partial f / \partial y \end{pmatrix}$$

a
b c
d e

FIGURE 3.44
A 3×3 region of an image (the z's are gray-level values) and masks used to compute the gradient at point labeled z_5. All masks coefficients sum to zero, as expected of a derivative operator.

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

Roberts

−1	0
0	1

0	−1
1	0

Sobel

−1	−2	−1
0	0	0
1	2	1

−1	0	1
−2	0	2
−1	0	1

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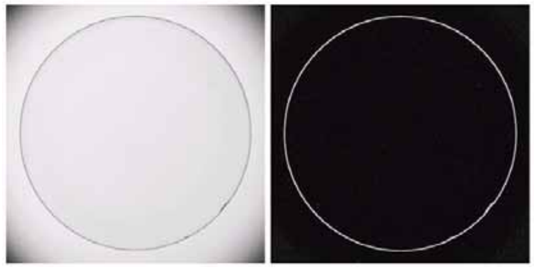


a b

FIGURE 3.45 Optical image of contact lens (note defects on the boundary at 4 and 5 o'clock). (b) Sobel gradient. (Original image courtesy of Mr. Pete Sites, Perceptics Corporation.)

Sobel gradient

MATLAB/Image Processing Toolbox

LINEAR SPATIAL FILTERING

```
>> f=imread(fig3.15(a).jpg');          %load in checkerboard figure
% g=imfilter(f,w,filtering_mode, boundary_options,size_options)
% f is the input image
% w is the filter mask
% Filtering mode:
%      'corr' filtering is done using correlation
%      'conv' filtering is done using convolution -- flips mask 180 degrees
% Boundary options
%     P without quotes (default) - pad image with zeros
%    'replicate' - extend image by replicating border pixels
%    'symmetric' - extend image by mirroring it across its border
%    'circular' - extend image byrepeating it (one period of a periodic function)
% Size options
%    'full' - output is the same size as the padded image
%    'same' - output is the same size as the input

>> w=ones(9);                         % create a 9x9 filter (not normalized)
>> gd=imfilter(f,w);                   % filter using default values
>> imshow( gd, [ ])                   % [ ] causes MATLAB to display using low and high
                                     % gray levels of input image.
                                      %Good for low dynamic range
>> gr=imfilter(f,w,'replicate');       % pad using replication
>> figure, imshow(gr, [ ])             %
>> gs=imfilter(f,w,'symmetric');    % pad using symmetry
>> figure, imshow(gs, [ ])            % show this figure in a new window
```

SEE GWE, Section 3.4.1Linear Spatial Filtering

MATLAB/Image Processing Toolbox

LINEAR SPATIAL FILTERING

```
>> f=imread(fig3.15(a).jpg');        %load in checkerboard figure
>> w=ones(9);                        % create a 9x9 filter (not normalized)

% f is of type double in [0,1] by default
>> f8=im2uint8(f);                   % converts image to uint8, i.e., integers in range [0,255]

>> g8r=imfilter(f8,w,'replicate');   % pad using replication
% imfilter creates an output of same data class as input, i.e., uint(8)
>> imshow( g8r, [ ])                 % clipping caused data loss since filter was not
                                     % normalized
```

SEE GWE, Section 3.4.1Linear Spatial Filtering

MATLAB/Image Processing Toolbox

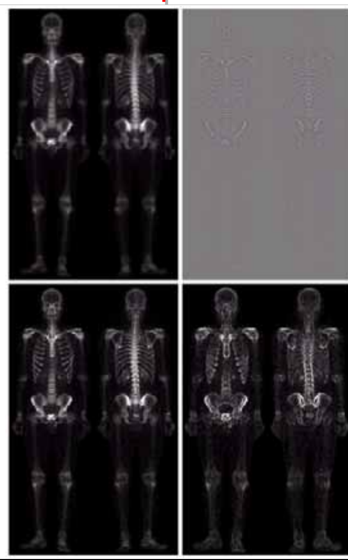
MATLAB's built-in filters

```
>> f=imread('fig3.15(a).jpg');        %load in checkerboard figure
>> w=fspecial('type', parameters); % create filter mask

% filter types:
%   'average', default is 3x3
%   'gaussian', default is 3x3 and sigma=0.5
%   'laplacian, default alpha=0.5
%   'prewitt', vertical gradient, default is 3x3.  Get horizontal by wh=w'
%   'sobel', vertical gradient, default is 3x3
%  'unsharp', default is 3x3 with alpha=0.2
```

SEE GWE, Section 3.5 Image processing Toolbox Standard Spatial Filters

Chapter 3
Image Enhancement in the Spatial Domain

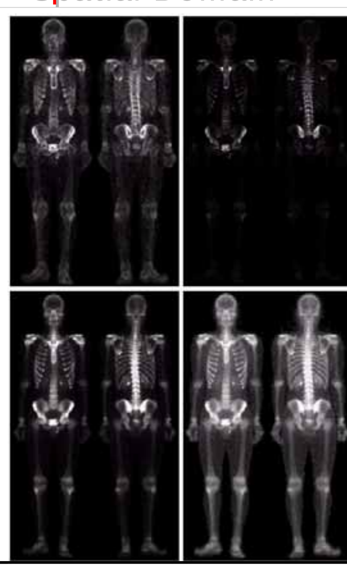


a b
c d

FIGURE 3.46
(a) Image of whole body bone scan. (b) Laplacian of (a). (c) Sharpened image obtained by adding (a) and (b). (d) Sobel of (a).

Digital Image Processing, 2nd ed.

Chapter 3
Image Enhancement in the Spatial Domain



e f
g h

FIGURE 3.46
(Continued)
(e) Sobel image smoothed with a 5 × 5 averaging filter. (f) Mask image formed by the product of (c) and (e). (g) Sharpened image obtained by the sum of (a) and (f). (h) Final result obtained by applying a power-law transformation to (g). Compare (g) and (h) with (a). (Original image courtesy of G.E. Medical Systems.)

MATLAB/Image Processing Toolbox

PRODUCING FIGURE 3.40

```
>> f=imread('Fig_Moon.jpg');      %load in lunar north pole image
>> w4=fspecial('laplacian',0)      % creates 3x3 laplacian, alpha=0 [0:1]
>> w8=[1 1 1;1 -8 1;1 1 1]         % create a Laplacian that fspecial can't
>>f=im2double(f);                  % output same as input unit8 so
                                   % negative values are truncated.
                                   % Convert to double to keep negative values.
>> g4=f-imfilter(f,w4,'replicate');  % filter using default values
>> g8=f-imfilter(f,w8,'replicate');  % filter using default values
>> imshow(f)                       % display original image
>> imshow(g4)                      % display g4 processed image
>> imshow(g8)                      % display g8 processed image
```

SEE GWE, Section 3.5.1Linear Spatial Filters