Spatial Domain Image Processing

Image Enhancement

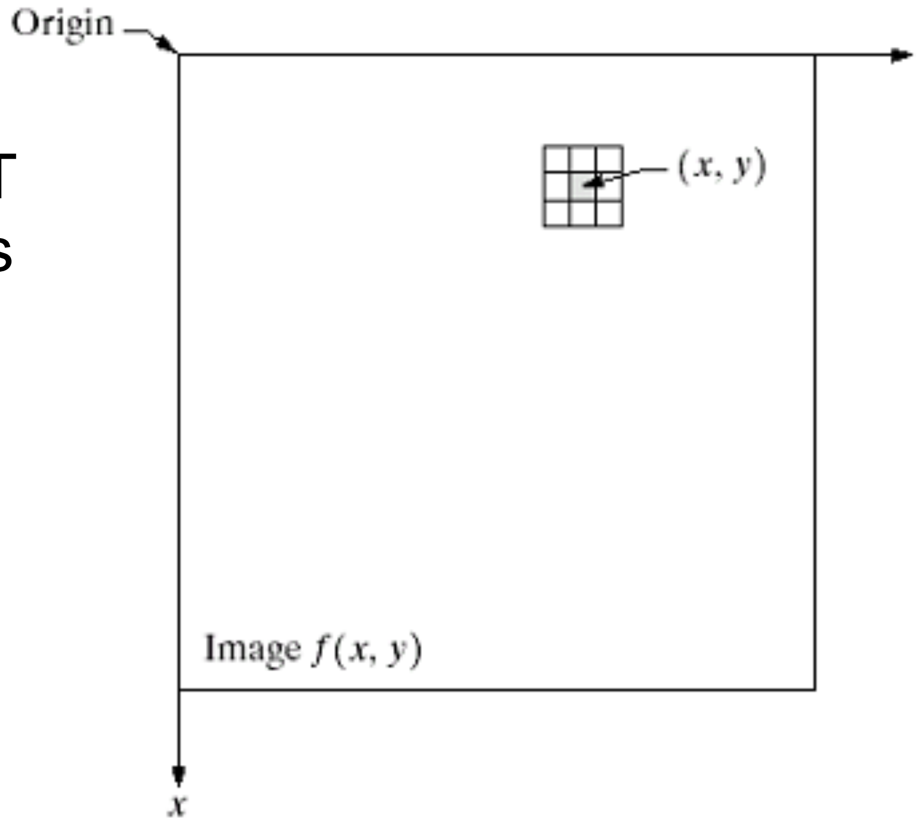
Image Enhancement means improvement of images to be suitable for specific applications.

Example:

Note: each image enhancement technique that is suitable for one application may not be suitable for other applications.

Neighbourhood

- For example, an operator T utilizes only the pixels in the area of the image spanned by the neighborhood, e.g., a 3x3 neighborhood.

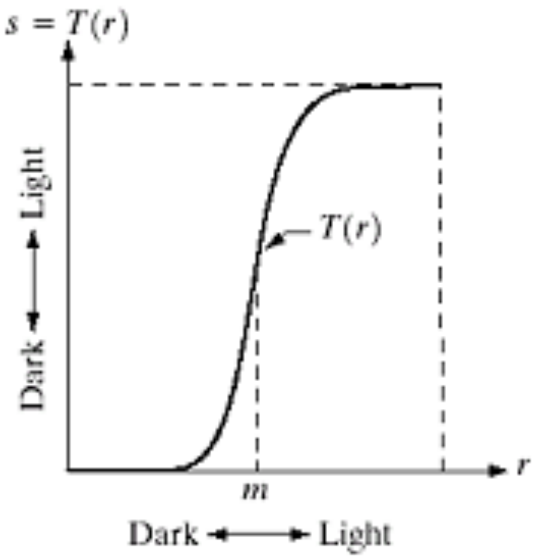


Point processing - 1x1 neighborhood

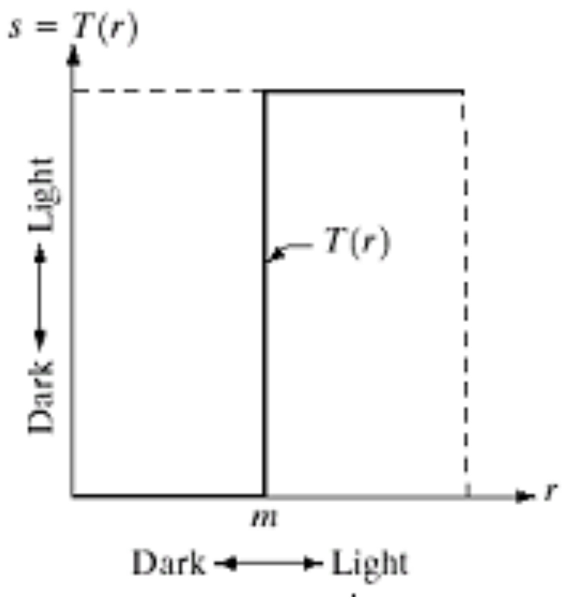
- Gray-level Transformation Function

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

Contrast Stretching



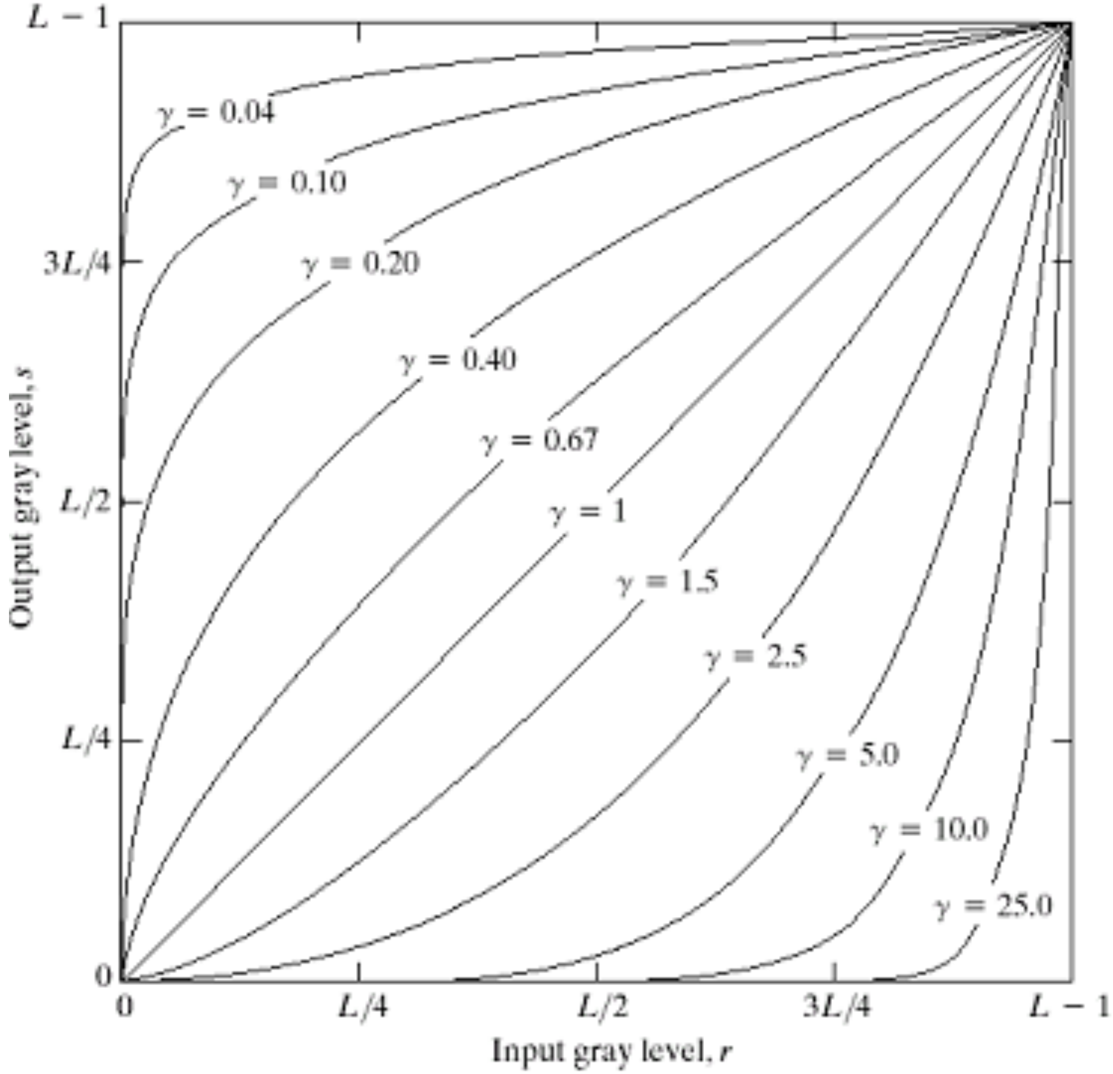
Thresholding



Gamma Correction

gamma

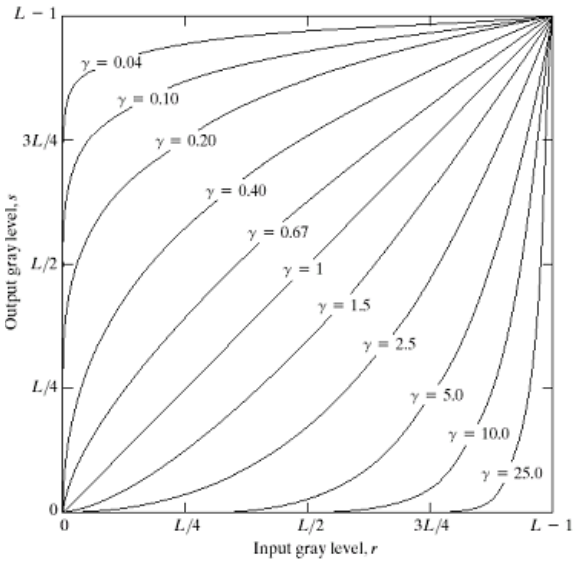
$s = c\, r^{\gamma}$

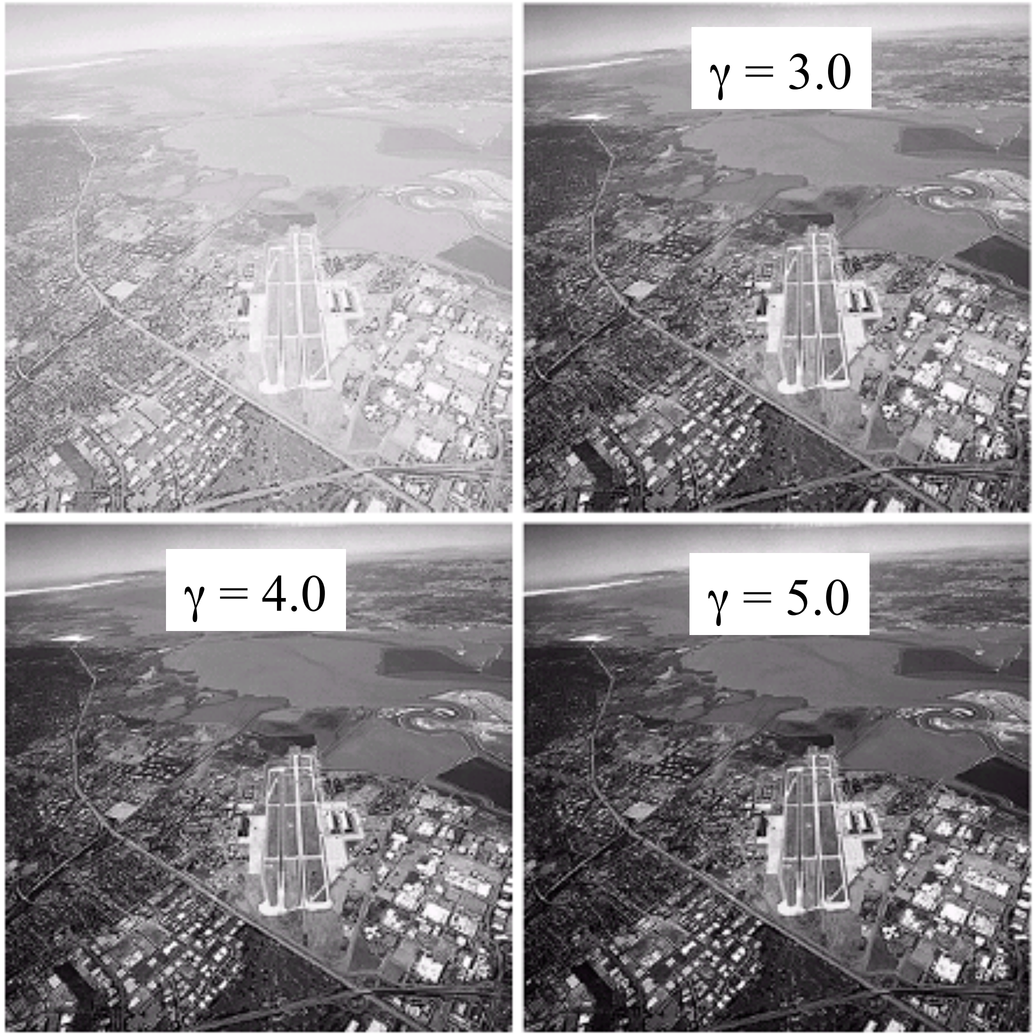


Gamma Correction

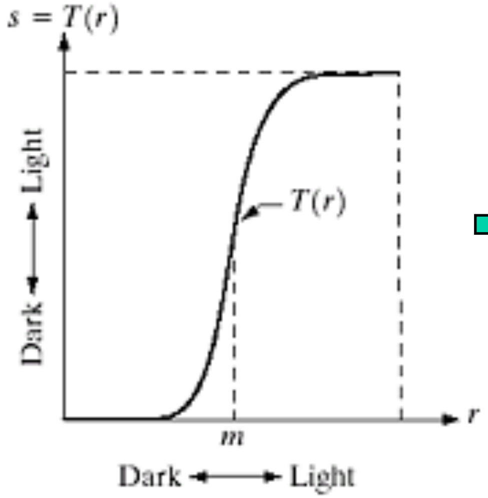
gamma

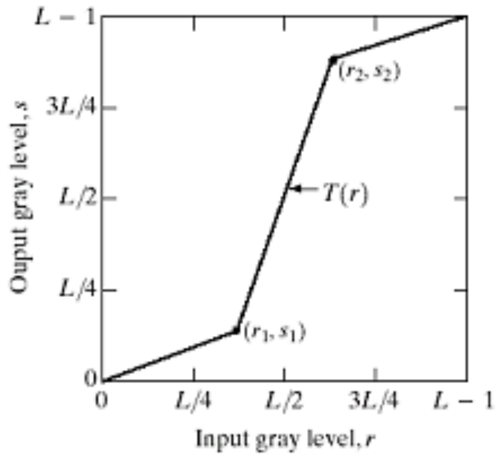
$$s = c\, r^{\gamma}$$

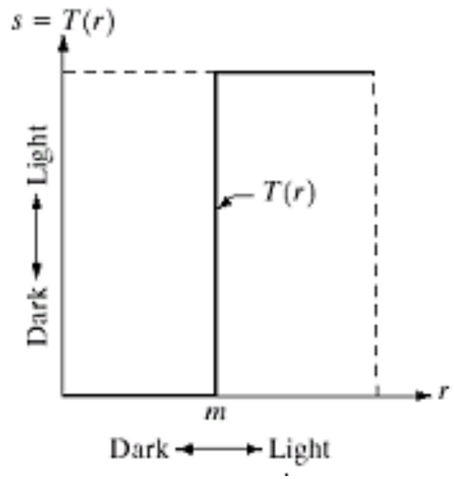


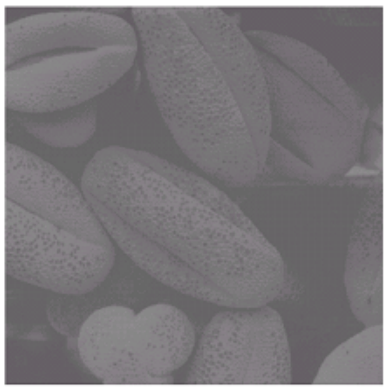


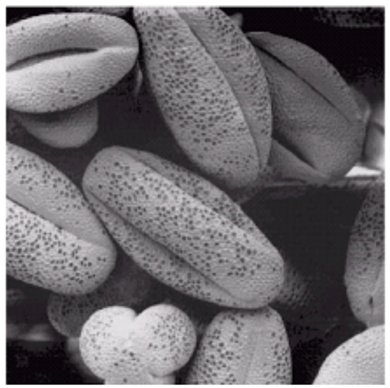
Contrast Stretching











Full-Scale Histogram Stretch

$(r_1, s_1) = (r_{min}, 0)$

$(r_2, s_2) = (r_{max}, L\text{-}1)$

Thresholding

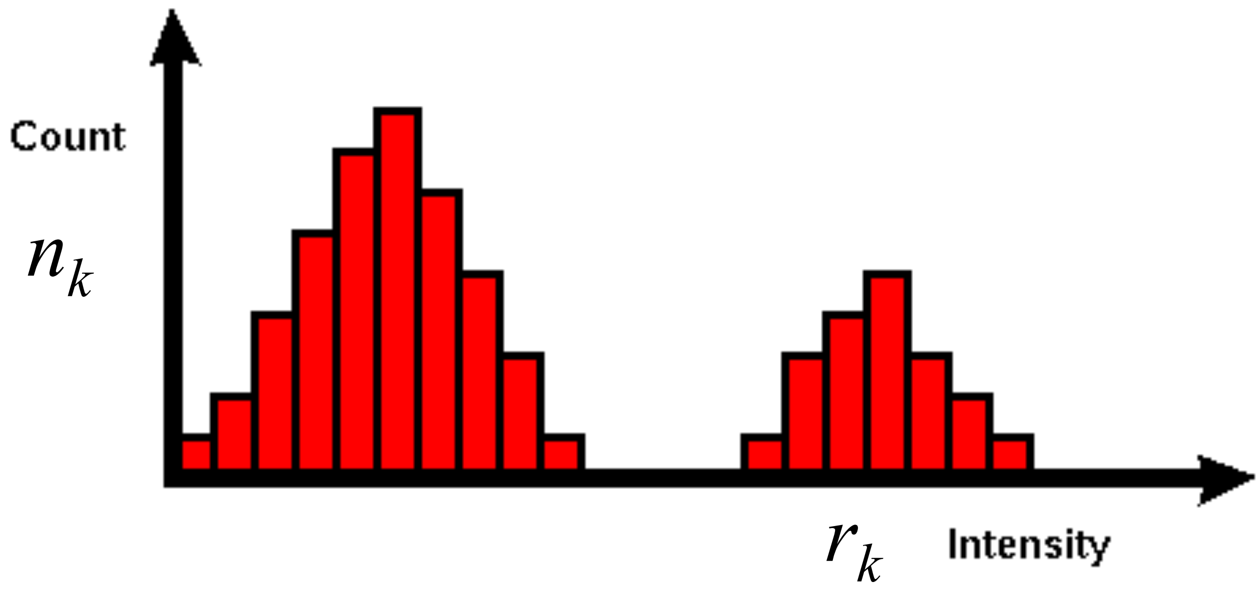
Histogram

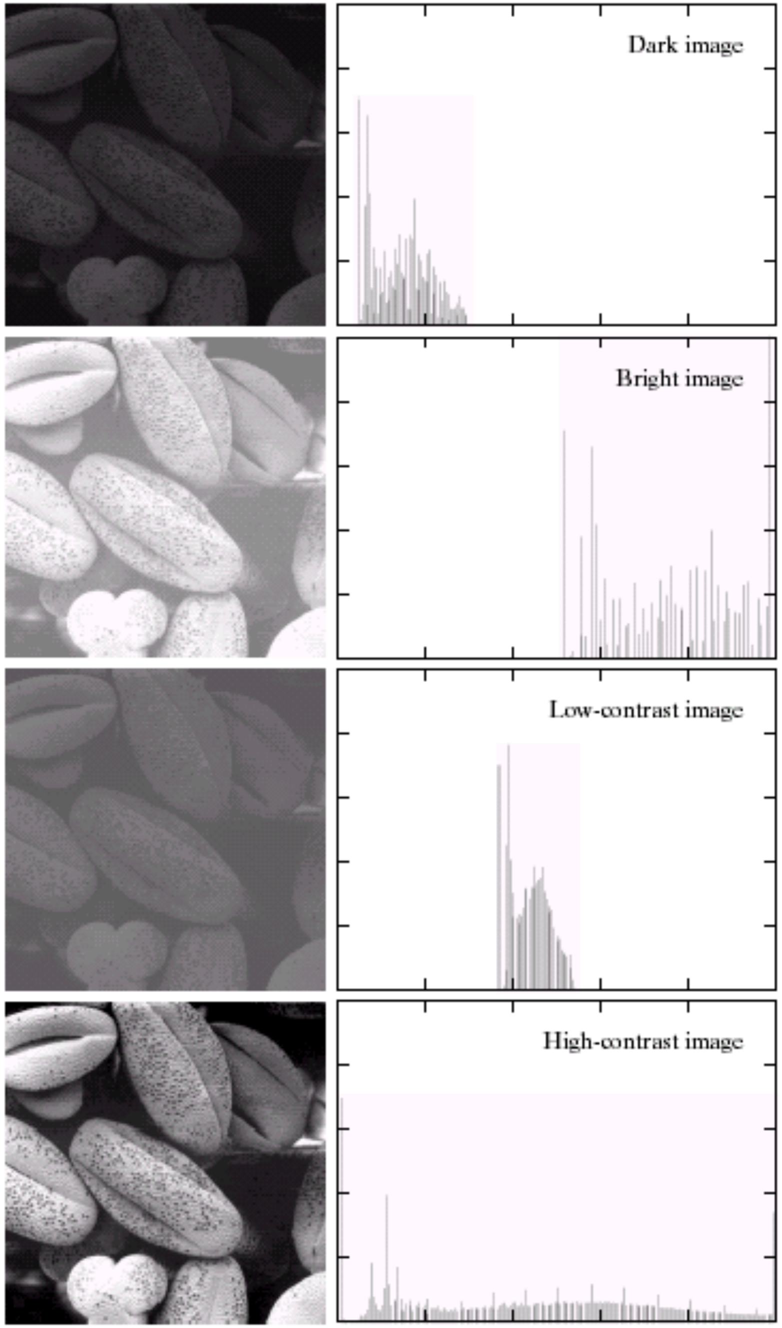
- Histogram of a digital image is a distribution function

$$h(r_k) = n_k$$

– where r_k is the kth gray level

and n_k is the number of pixels having gray level r_k





Different types of histograms:

- Normalized histogram

$$p(r_k) = n_k / n \ , \quad k = 1, \ ..., L$$

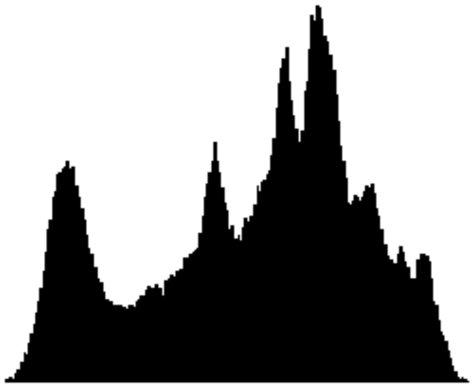
- Histogram is useful for
  -- image enhancement
  -- image compression
  -- image segmentation
  -- etc.

→ Want to have a more flat histogram !

=> Histogram Equalization

Histogram Equalization

Image
Enhancement



Histogram
Equalization

To make histogram distributed uniformly

Aogirithm of Histogram Equalization

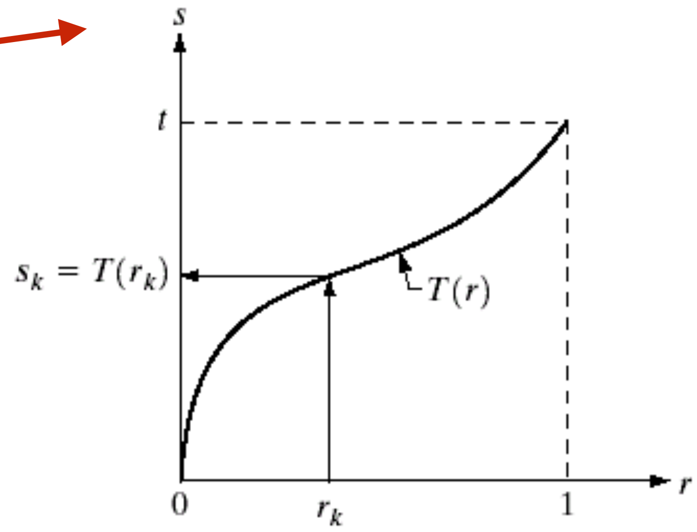
1. Compute the histogram of the input image:

$h(k) = \#\{(x,y)|f(x,y)=k\}$, where $k = 0$ *to* 255.

2. Compute the transformation function:

$$T(k) = 255 * \sum_{j=0}^{k} \frac{h(j)}{n}$$

Cumulative normalized histogram



3. Transform the value of each pixel by

$$g(x,y)=T(f(x,y))$$

Histogram Equalization Example

Intensity	# pixels
0	20
1	5
2	25
3	10
4	15
5	5
6	10
7	10
Total	100

Accumulative Sum of P_r
20/100 = 0.2
(20+5)/100 = 0.25
(20+5+25)/100 = 0.5
(20+5+25+10)/100 = 0.6
(20+5+25+10+15)/100 = 0.75
(20+5+25+10+15+5)/100 = 0.8
(20+5+25+10+15+5+10)/100 = 0.9
(20+5+25+10+15+5+10+10)/100 = 1.0
1.0

Histogram Equalization Example

Intensity (r)	No. of Pixels (n_j)	Acc Sum of P_r	Output value	Quantized Output (s)
0	20	0.2	0.2x7 = 1.4	1
1	5	0.25	0.25*7 = 1.75	1
2	25	0.5	0.5*7 = 3.5	3
3	10	0.6	0.6*7 = 4.2	4
4	15	0.75	0.75*7 = 5.25	5
5	5	0.8	0.8*7 = 5.6	5
6	10	0.9	0.9*7 = 6.3	6
7	10	1.0	1.0x7 = 7	7
Total	100			

Mask Processing

Mask processing - Spatial Filtering

- Filter, Mask, Kernel,
  Template, Window
- Coefficients
- Linear Filtering *vs*
  Nonlinear Filtering
  (e.g., median filtering)

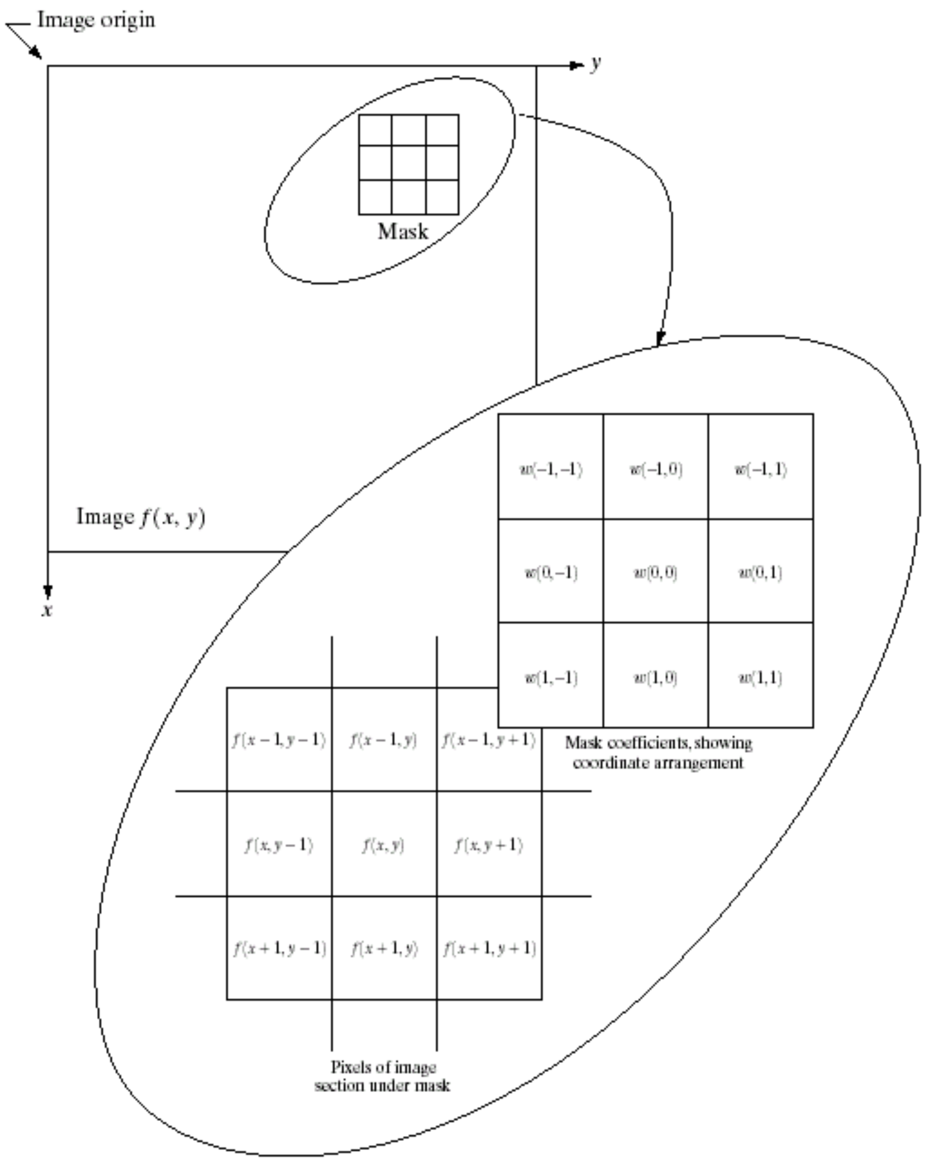


FIGURE 3.32 The mechanics of spatial filtering. The magnified drawing shows a 3×3 mask and the image section directly under it; the image section is shown displaced out from under the mask for ease of readability.

Linear Smoothing Filters – averaging filters

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

1	1	1
1	1	1
1	1	1

Box Filter

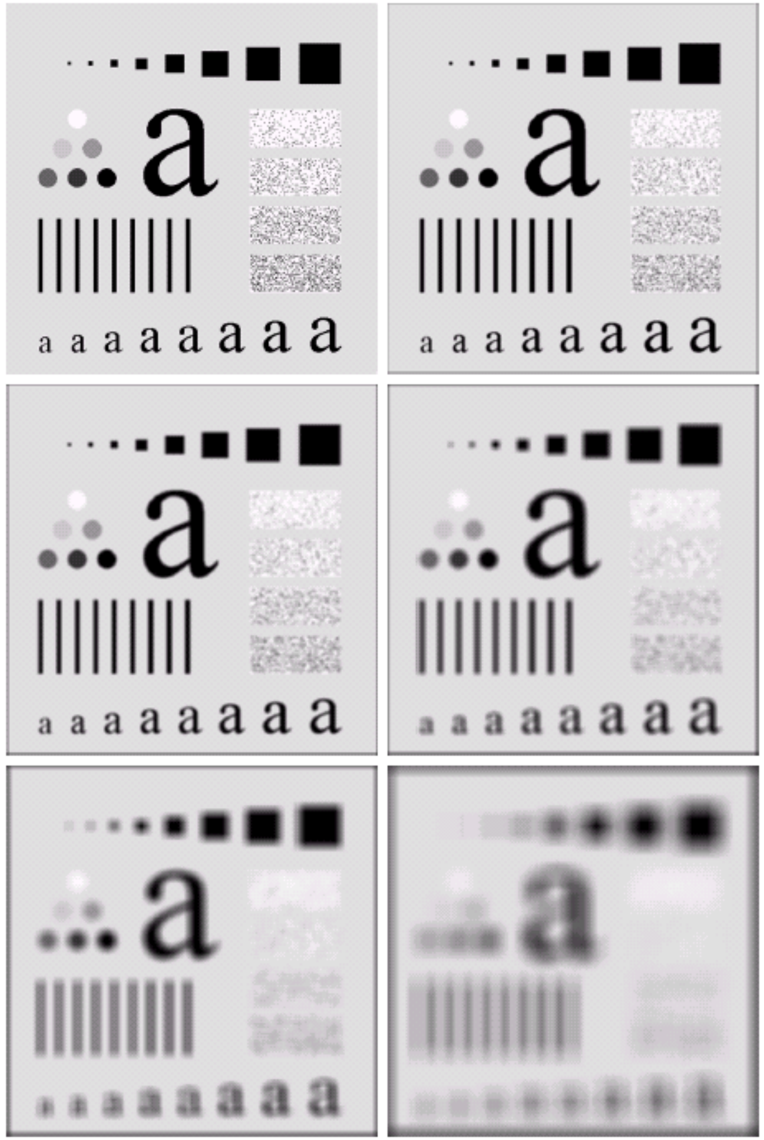
$\frac{1}{16} \times$

1	2	1
2	4	2
1	2	1

Weighted Average

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

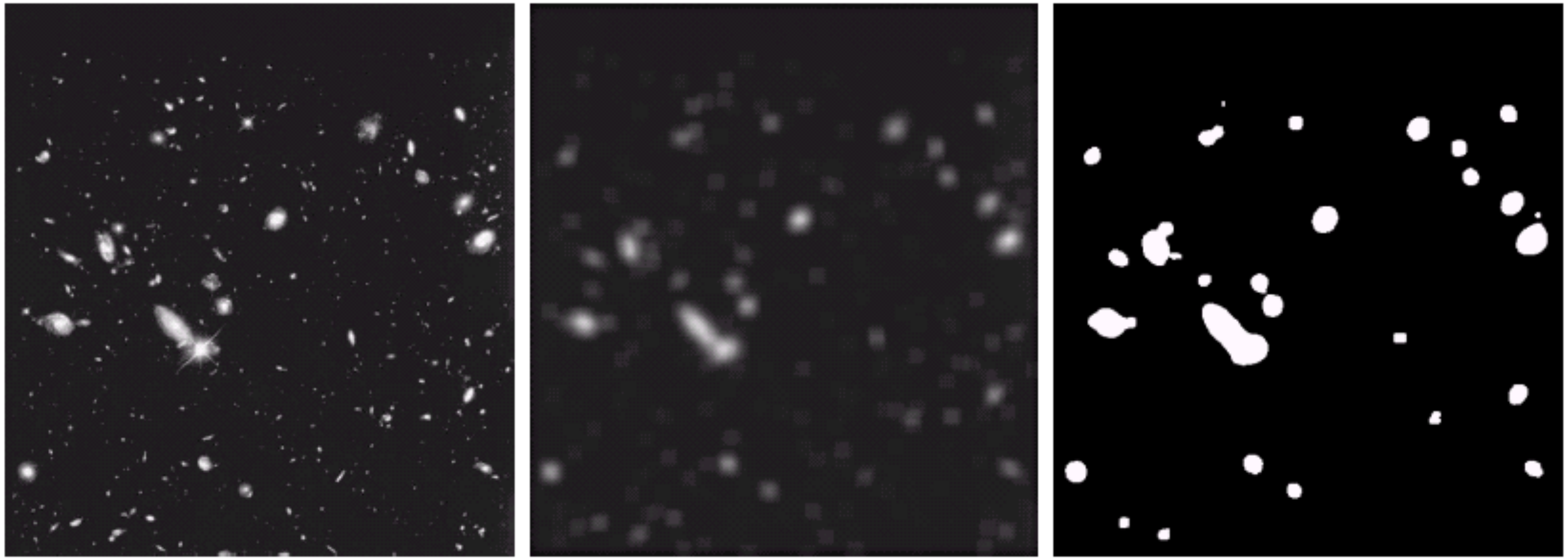
Linear Smoothing Filters – averaging filters



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.

Linear Smoothing Filters – averaging filters



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.)

Application: Averaging before Thresholding

Nonlinear Smoothing Filters – Order-Statistics Filters

Median Filter

-- the 50^{th} percentile of a ranked set of numbers

-- effective for reducing *impulse noise,* or *salt-and-pepper noise*

Max Filter

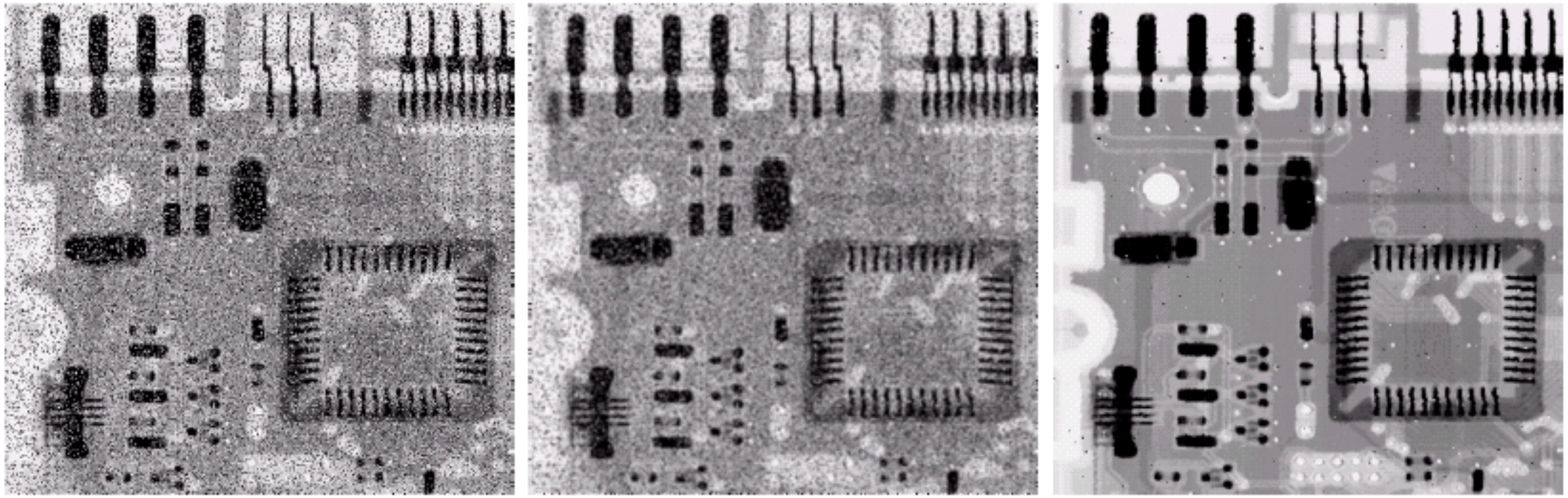
-- the 100^{th} percentile filter

Min Filter

-- the 0^{th} percentile filter

Nonlinear Smoothing Filters – Order-Statistics Filters

Salt-and-pepper noise image | 3x3 averaging filter | 3x3 median filter



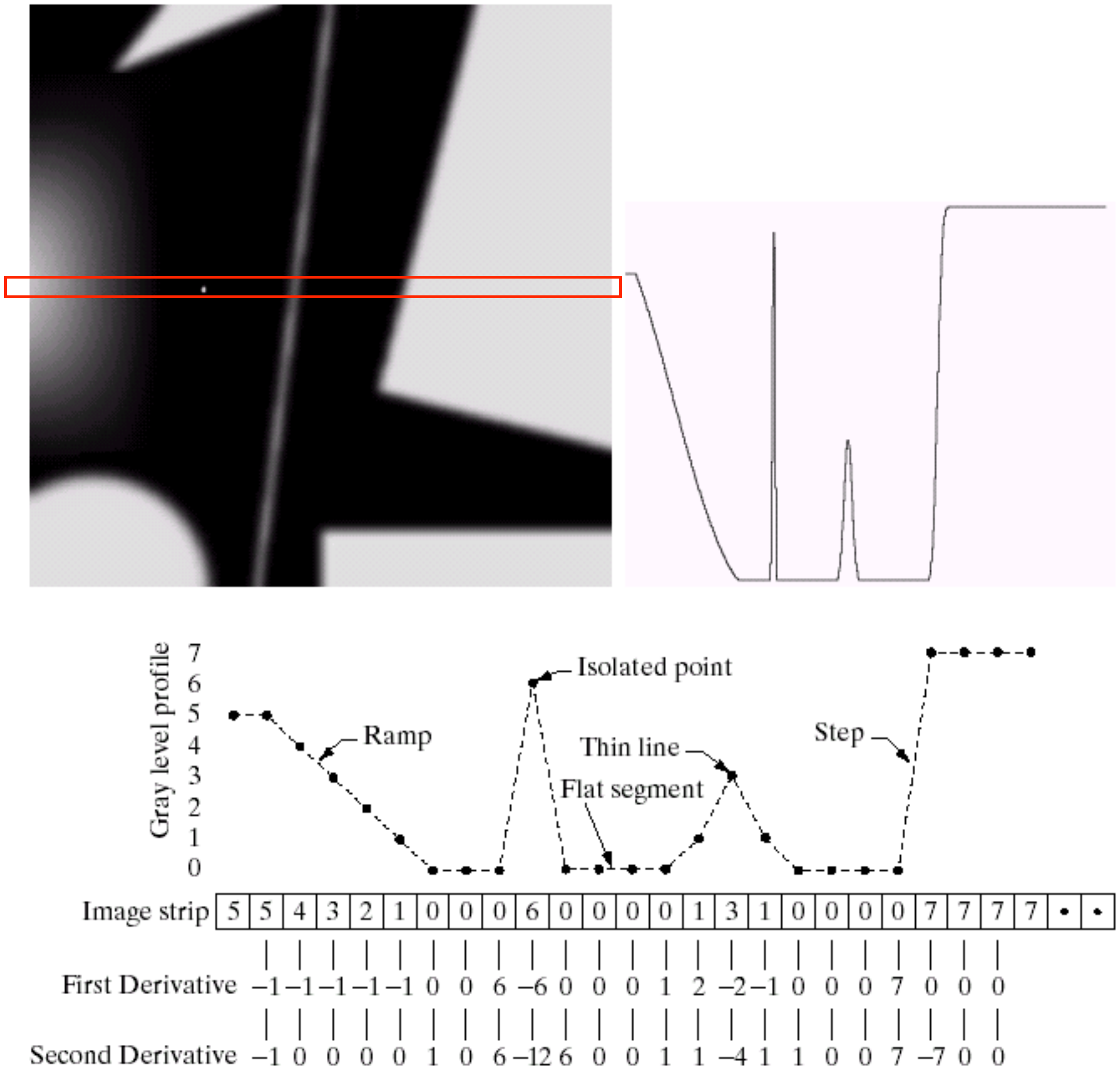
a b c

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.)

Edge detection and sharpening

a b
c

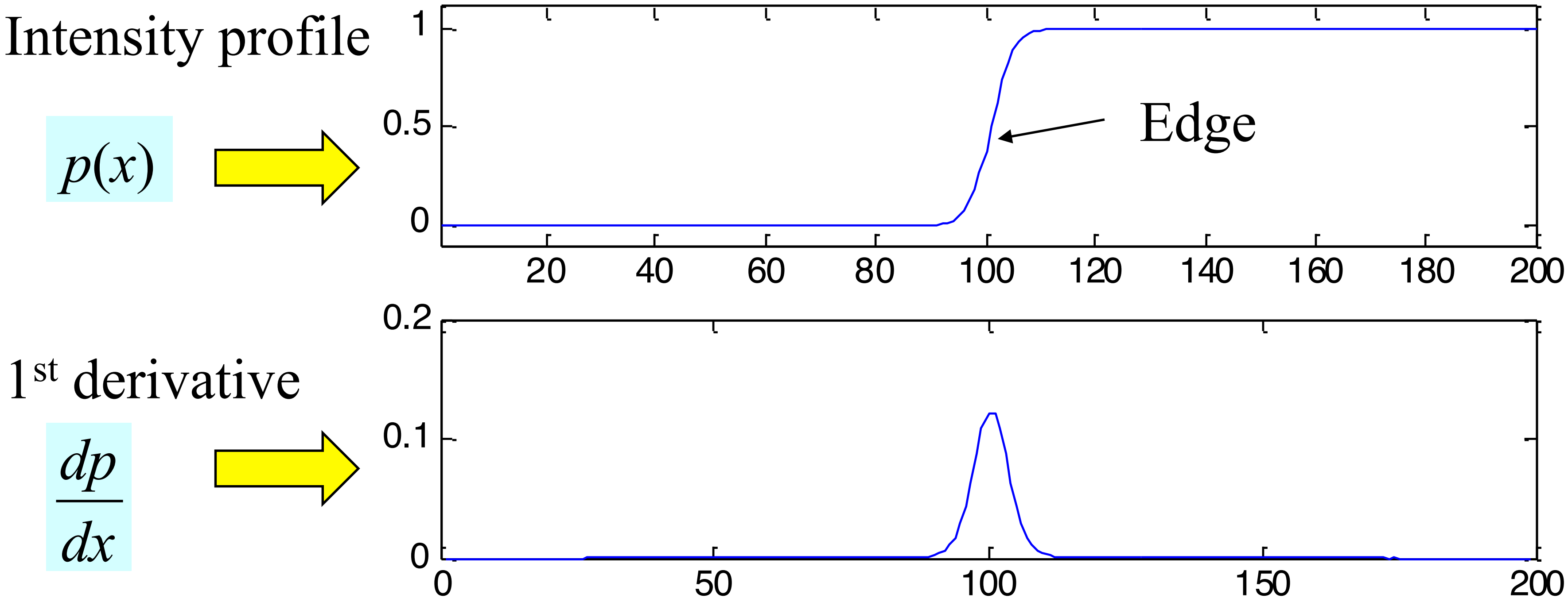
FIGURE 3.38 (a) A simple image. (b) 1-D horizontal gray-level profile along the center of the image and including the isolated noise point. (c) Simplified profile (the points are joined by dashed lines to simplify interpretation).



for edge detection

for sharpening

Edge detection



Edge detection

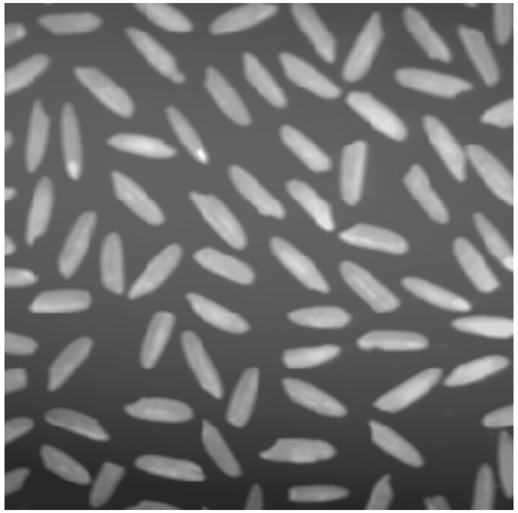
Sobel operators

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

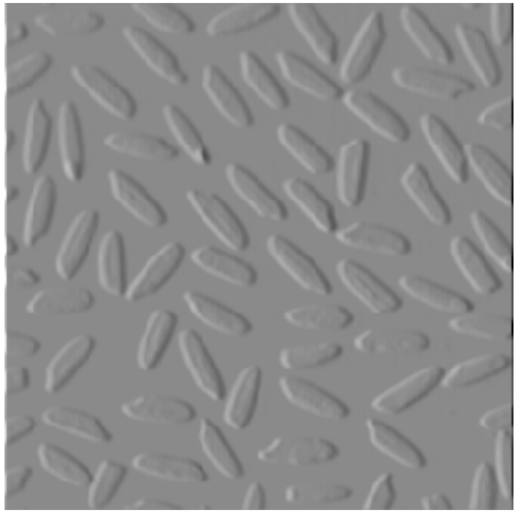
to compute $\frac{\partial P}{\partial x}$

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

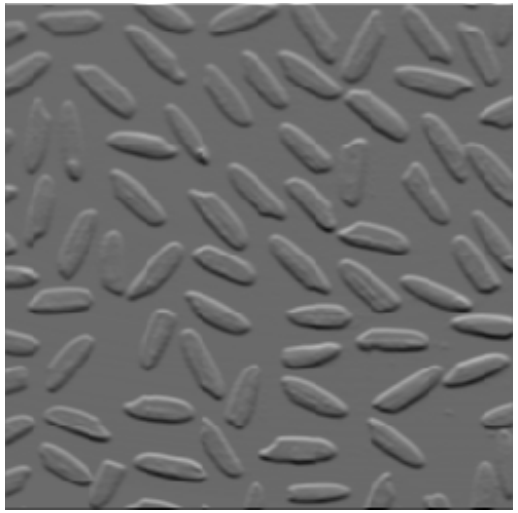
to compute $\frac{\partial P}{\partial y}$



P



$\frac{\partial P}{\partial x}$

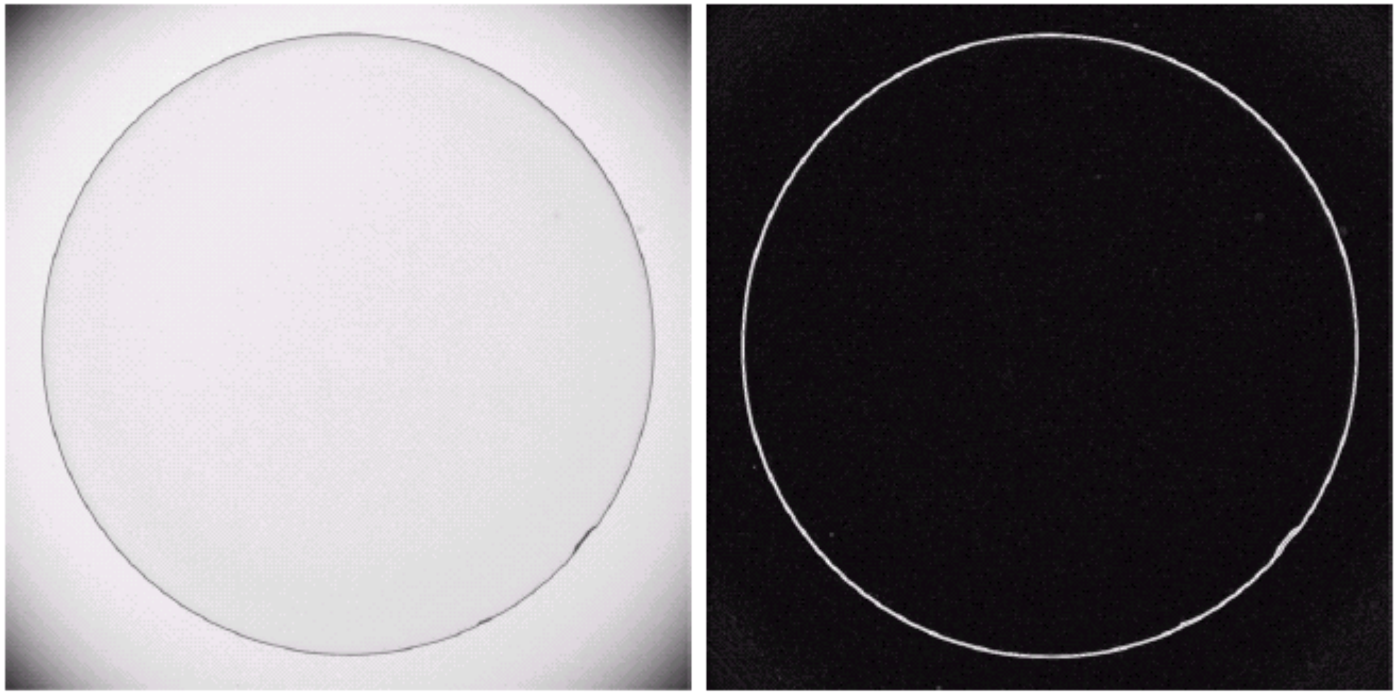


$\frac{\partial P}{\partial y}$

Edge detection

Gradient magnitude

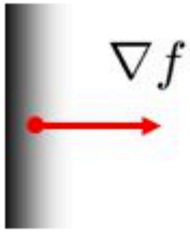
$$|\nabla P| = \sqrt{\left(\frac{\partial P}{\partial x}\right)^2 + \left(\frac{\partial P}{\partial y}\right)^2}$$



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.)

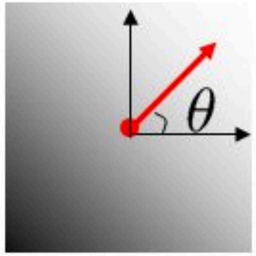
Gradient direction



$$\nabla f = \left[\frac{\partial f}{\partial x}, 0\right]$$

$$\nabla f = \left[0, \frac{\partial f}{\partial y}\right]$$

$$\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$$



$$\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$$

The gradient direction is given by:

$$\theta = \tan^{-1}\left(\frac{\partial f}{\partial y} / \frac{\partial f}{\partial x}\right)$$

Laplacian sharpening

Intensity profile

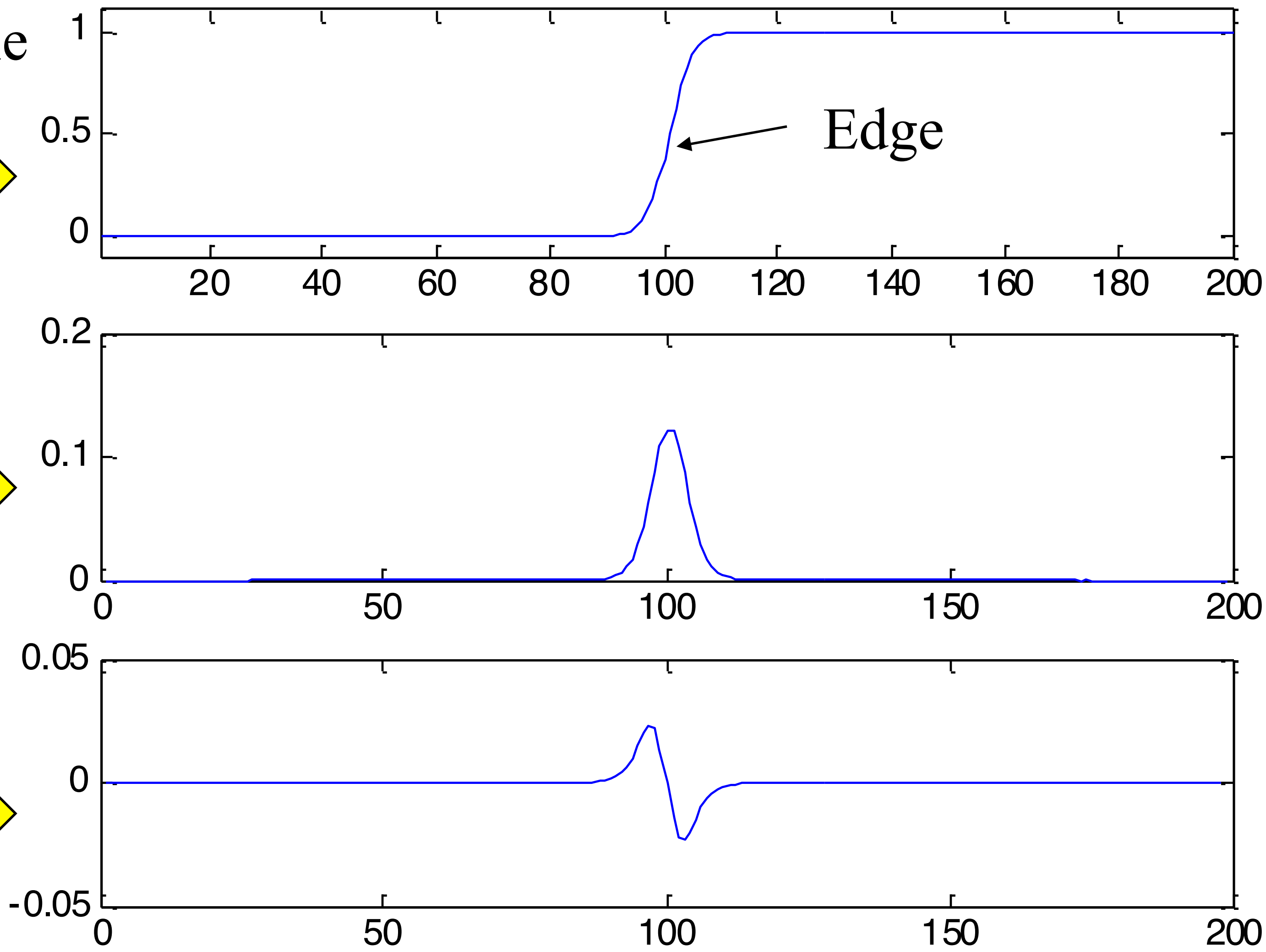
$p(x)$

1st derivative

$$\frac{dp}{dx}$$

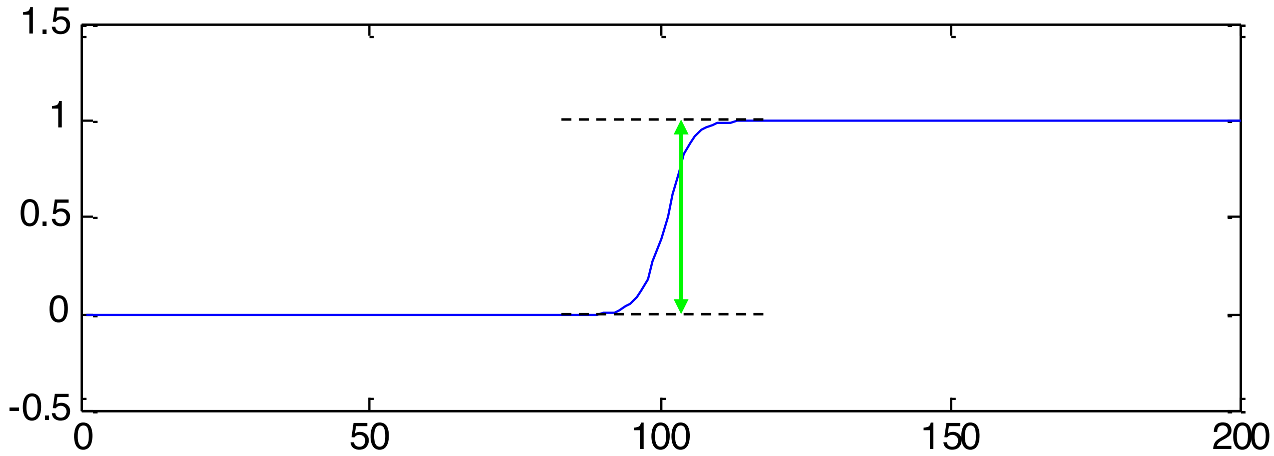
2nd derivative

$$\frac{d^2 p}{dx^2}$$

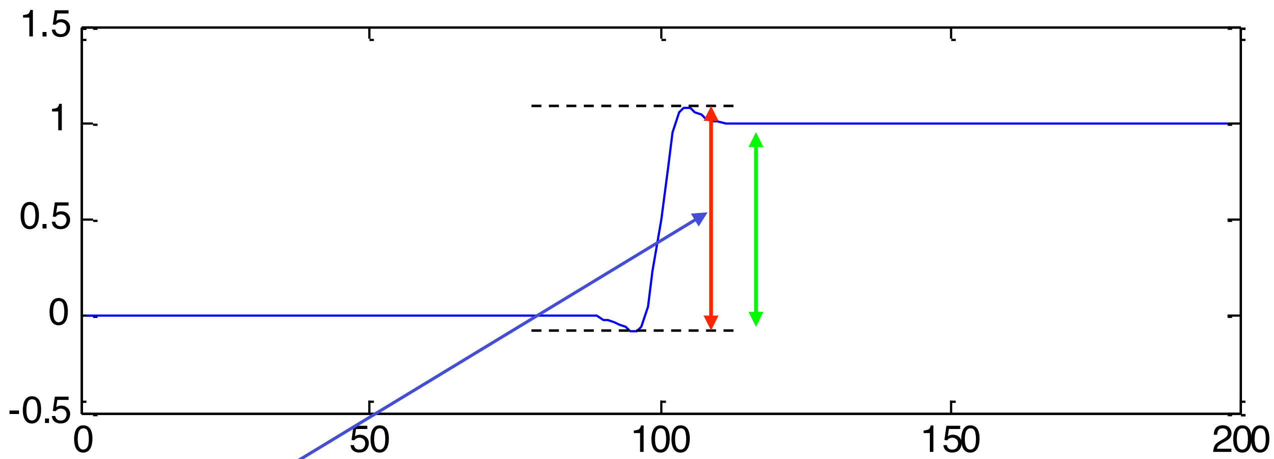


Laplacian sharpening

$p(x)$

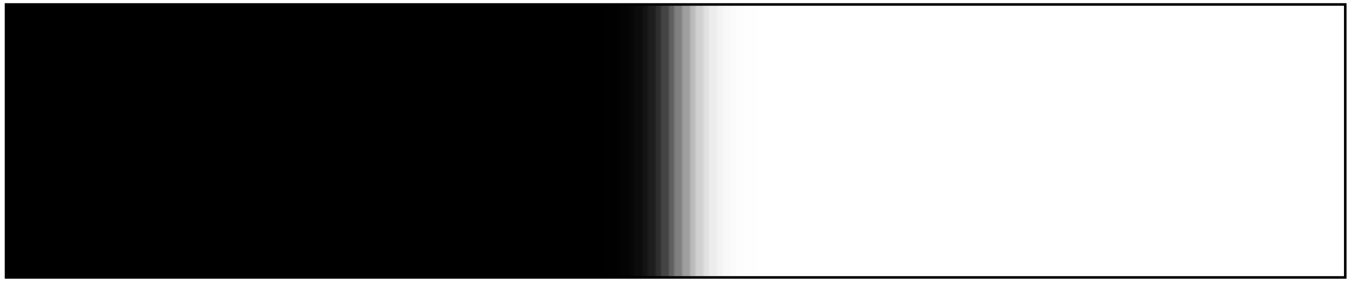


$$p(x) - 10\frac{d^2 p}{dx^2}$$



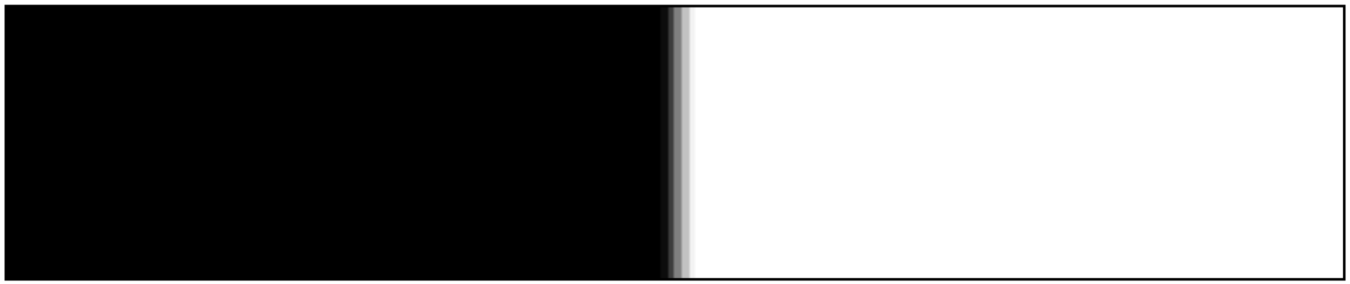
Laplacian sharpening results in larger intensity discontinuity near the edge.

Laplacian sharpening



Before sharpening

$p(x)$



After sharpening

$$p(x) - 10\frac{d^2 p}{dx^2}$$

Laplacian sharpening

Used for estimating image Laplacian $\nabla^2 P = \frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2}$

-1	-1	-1
-1	8	-1
-1	-1	-1

0	-1	0
-1	4	-1
0	-1	0

The center of the mask is positive

or

1	1	1
1	-8	1
1	1	1

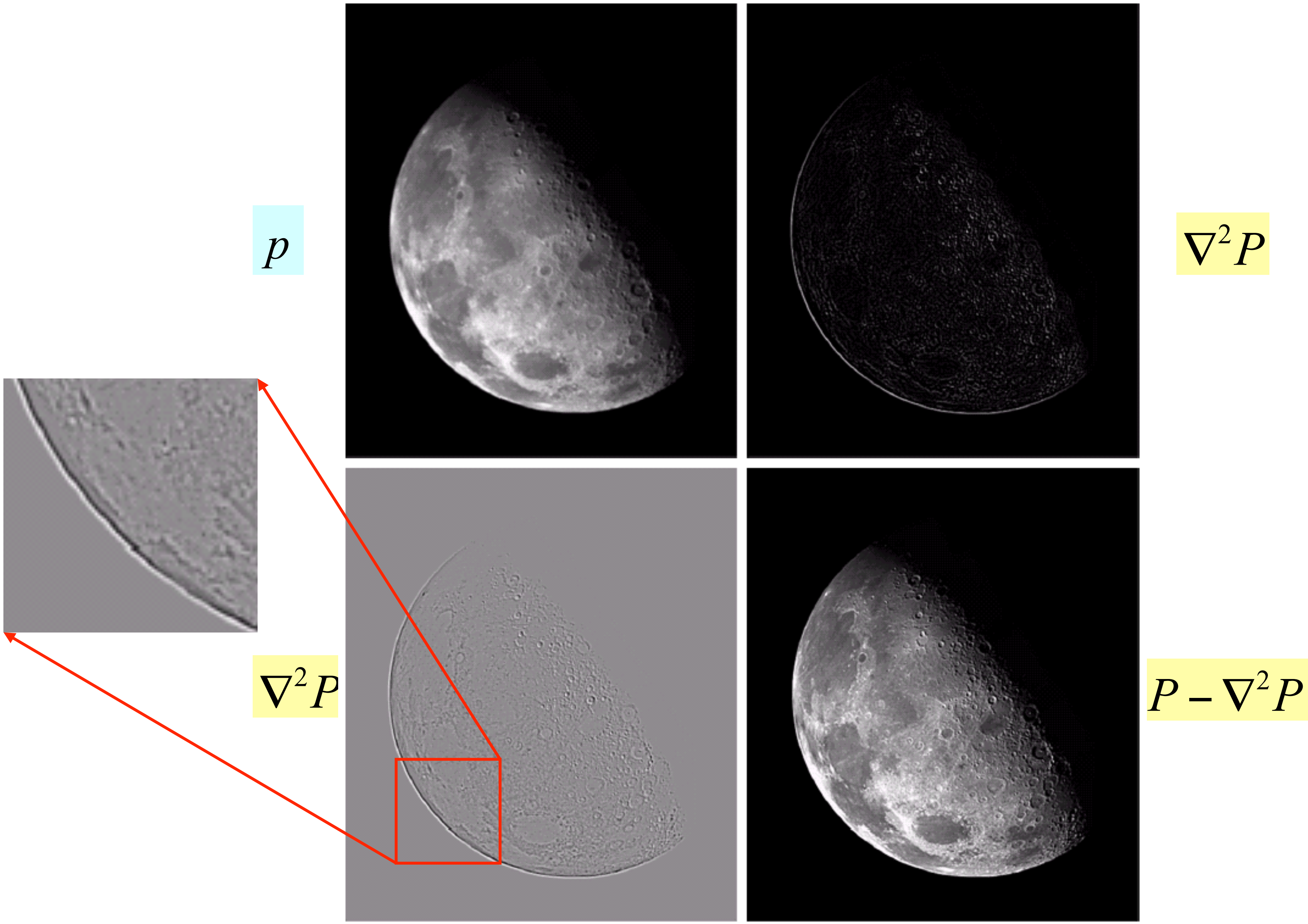
0	1	0
1	-4	1
0	1	0

The center of the mask is negative

Application: Enhance edge, line, point

Disadvantage: Enhance noise

Laplacian sharpening



Laplacian sharpening

Mask for $P - \nabla^2 P$

0	-1	0
-1	5	-1
0	-1	0

or

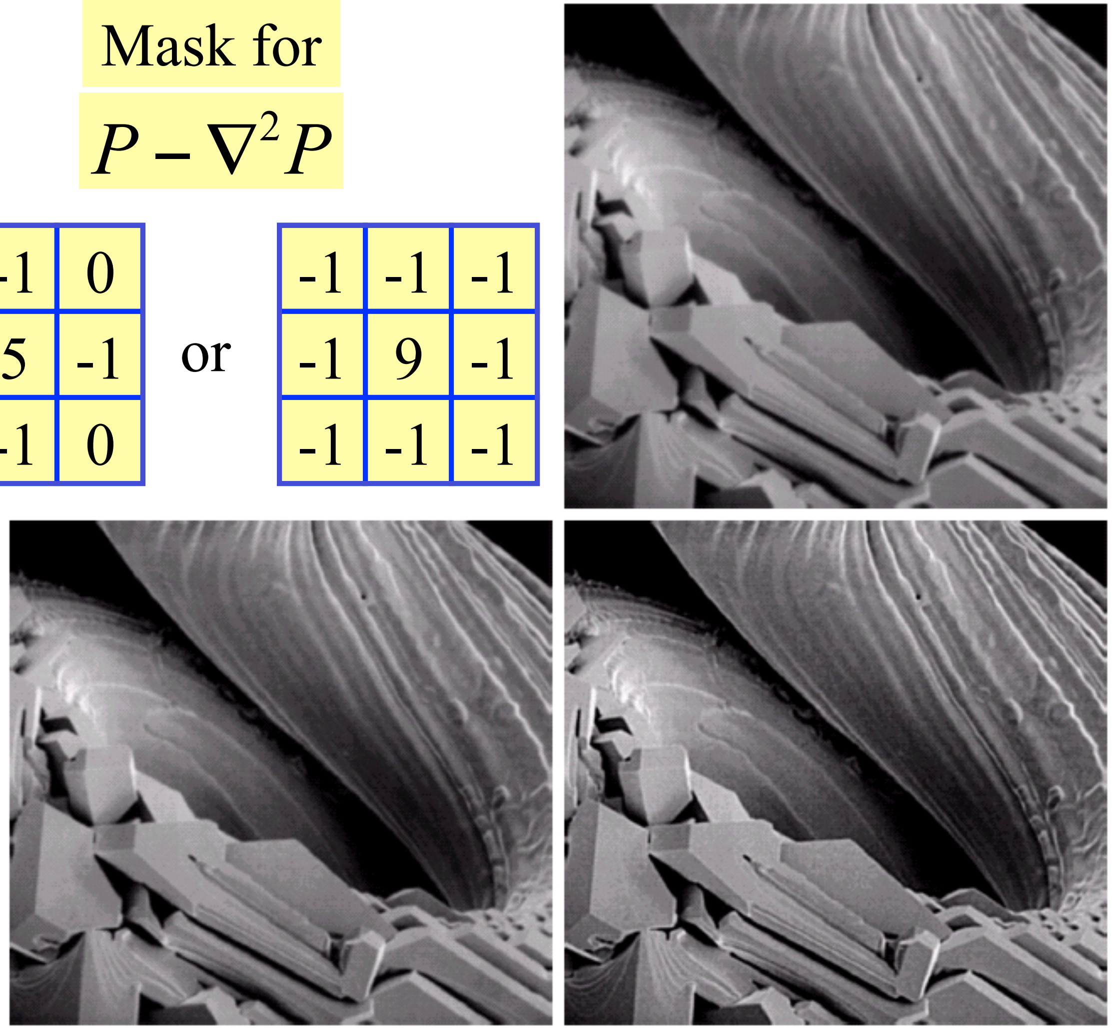
-1	-1	-1
-1	9	-1
-1	-1	-1

Mask for $\nabla^2 P$

1	1	1
1	-8	1
1	1	1

or

0	1	0
1	-4	1
0	1	0



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.)

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Digital Image Processing

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2018/3/8