Spatial Filtering - Enhancement

References

1. Gonzalez and Woods, “ Digital Image Processing,” 2nd Edition, Prentice Hall, 2002.
2. Jain, “Fundamentals of Digital Image Processing,” Prentice Hall 1989

Filters – Powerful Imaging Tool

- Frequency domain is often used
  - Enhancement by accentuating the features of interest
- Spatial domain
  - Linear
  - Think of this as weighted average over a mask / filter region
  - Compare to convolution – imaging (Smoothing) filters are often symmetric

Spatial Filtering Computations

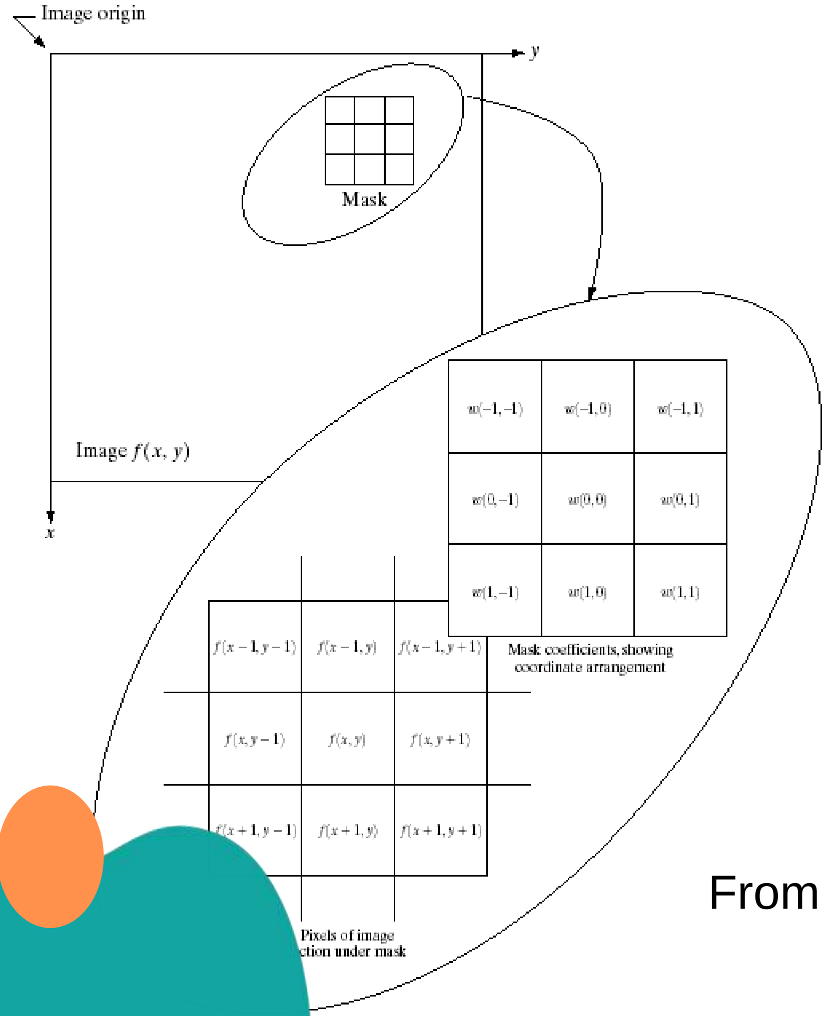


FIGURE 3.32 The mechanics of spatial filtering. The magnified drawing shows a 3 × 3 mask and the image section directly under it; the image section is shown displaced out from under the mask for ease of readability.

From [1]

Result for 3x3 mask

g(x,y) = w(-1,-1)f(x-1,y-1) + w(-1,0)f(x-1,y)
+ w(-1,1) f(x-1,y+1)
…….
+ w(1,1)f(x+1,y+1)

Result for mxn mask

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

a = (m-1)/2 b = (n-1)/2

If image size is MxN, then x=0,1,…M-1 and y=0,1,..N-1.

Smoothing Filters

- Weighted average
- Low pass filter
- Reduce the noise; remove small artifacts
- Blurring of edges
- Two masks: Note multiplication is by 2^n, divide once at end of process

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

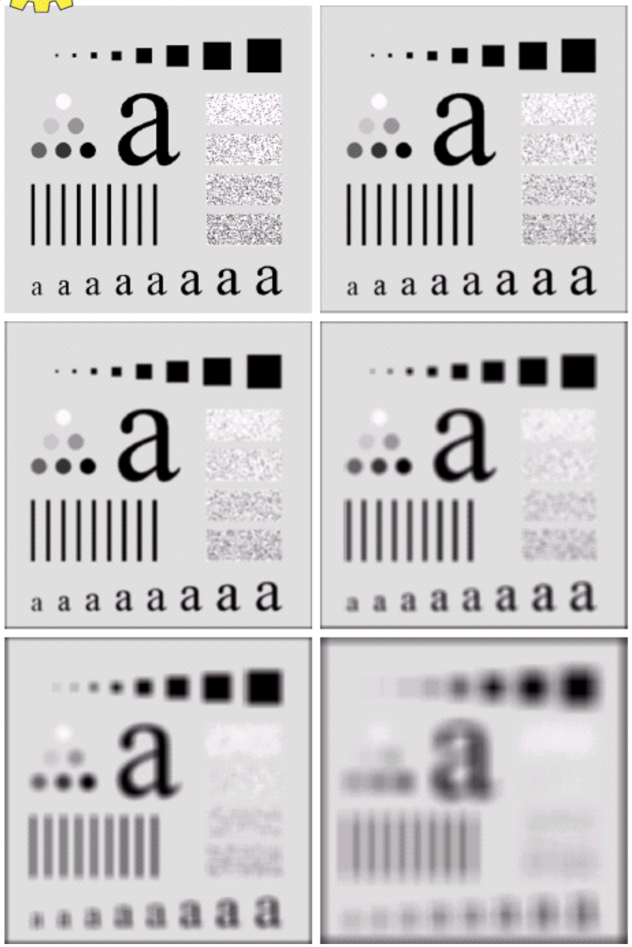
1	1	1
1	1	1
1	[illegible]	1

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

1	2	1
2	4	2
1	2	1

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

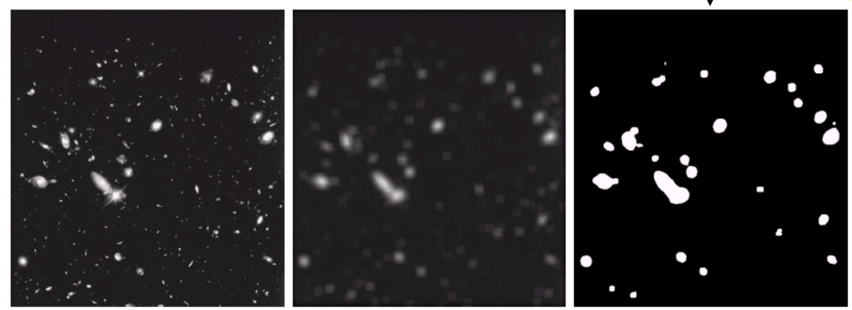
Smoothing - Examples



a b
d

FIGURE 3.35 (a) Original image, of size 500 × 500 pixels. (b)–(f) Results of smoothing with … averaging filter masks of sizes $n = 3, 5, 9, 15$, and 35, respectively. The black sq… e top are of sizes 3, 5, 9, 15, 25, 35, 45, and 55 pixels, respectively; their bor- d… letters at the bottom range in size from 10 to 24 points, in … letter at the top is 60 points. The vertical bars are 5 pix- … separation is 20 pixels. The diameter of the circles is … pixels apart; their gray levels range from 0% to 100% … ckground of the image is 10% black. The noisy rec-

Suppressed small objects in the scene

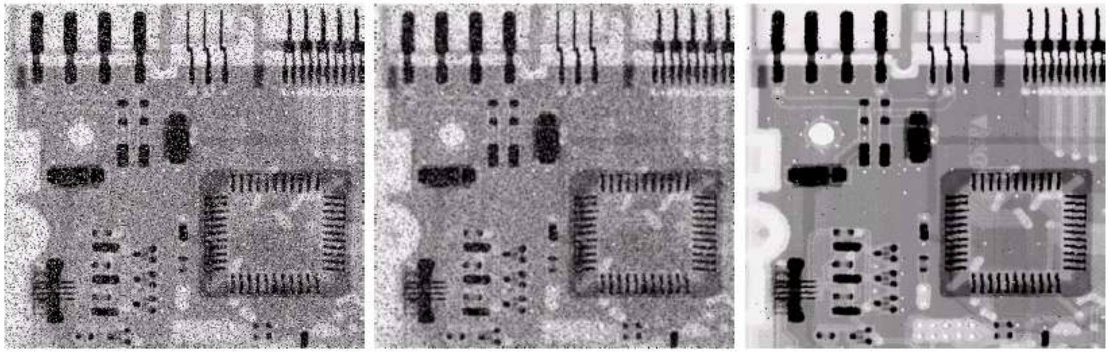


a b c

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.)

Median Filter

- Example of Order Statistics Filter.
  - Other examples – max filter or min filter
- Effective for impulse noise (salt and pepper noise)
- Median – half the values <= the median value
  - NxN neighborhood, where N is odd
  - Replace center of mask with the median value
  - Stray values are eliminated; uniform neighborhoods not affected



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.)

Sharpening Filters

- Smoothing ⇨ Blurring ⇨ “Averaging”
- Sharpening is the reverse process
  - Smoothing is the result of integration
  - Sharpening involves differentiation
    - Enhances discontinuities
      - Noise
      - Edges
    - De-emphasizes uniform parts of the image

Differentiation – Numeric Techniques

- Derivatives are defined in terms of differences
  - First – order derivative

    $f'(x) = (f(x) - f(x - \Delta)) / \Delta$
  - Second – order derivative

    $f''(x) = (f'(x+\Delta) - f'(x)) / \Delta$

    $= (\{f(x+\Delta) - f(x)\} - \{f(x) - f(x - \Delta)\}) / \Delta^2$

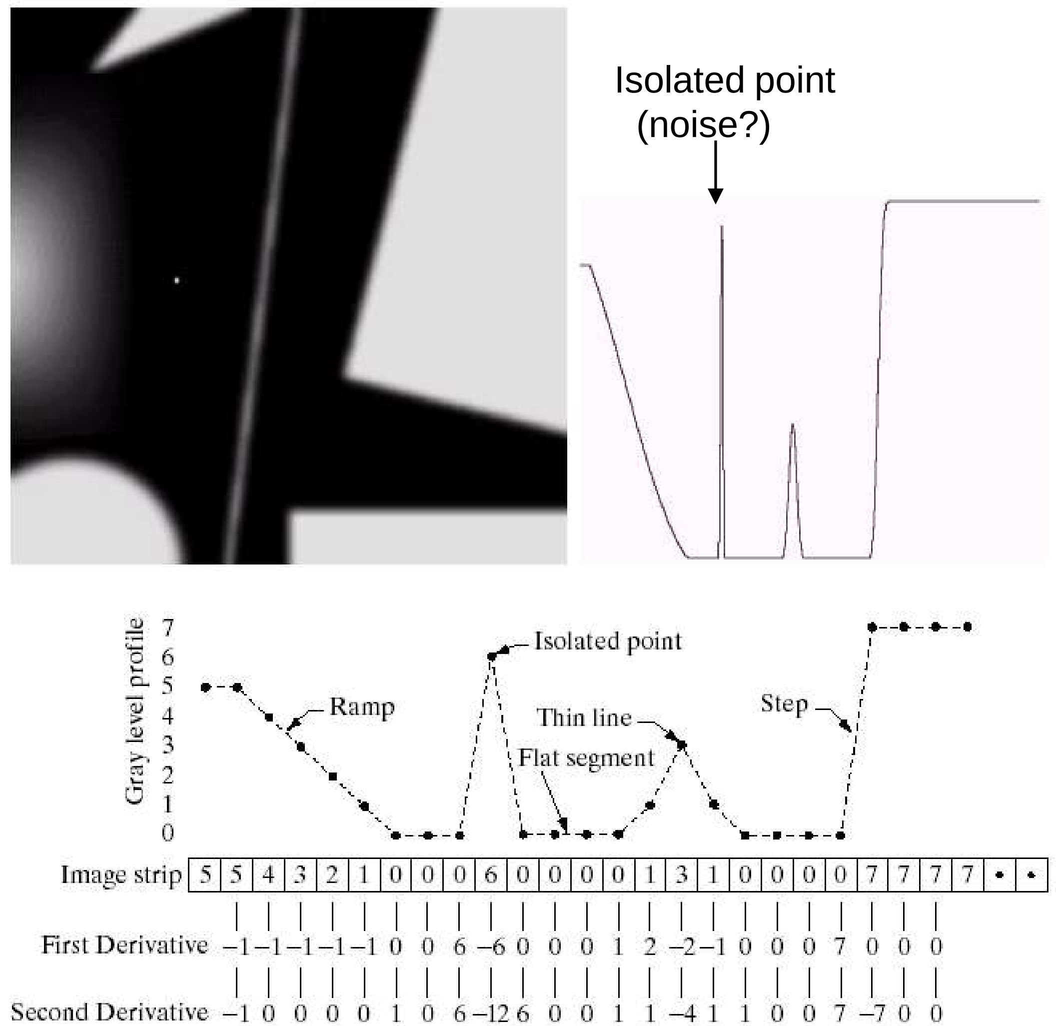
    $= (\{f(x+\Delta) - 2f(x) - f(x - \Delta)\}) / \Delta^2$

    Δ = smallest unit; for images $\Delta = 1$.

Example of Derivative Computation

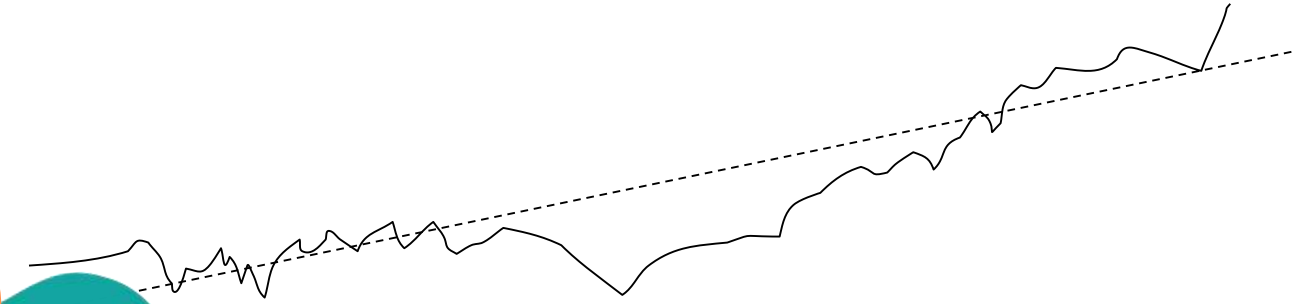
a b
c

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).



Use Derivatives with care

- What is the gradient?
- Slope at a local point, may be quite different than the overall trend
- Often use a smoothing filter to reduce impact of noise
- Higher the order of the derivative, higher is the impact of local discontinuities



Laplacian for Enhancement

- Second order derivatives are better at highlighting finer details
- Imaging requires derivatives in 2D
- Laplacian $\nabla^2 f = f_{xx} + f_{yy}$, where
- $f_{xx} = f(x+1,y) + f(x-1,y) - 2\,f(x,y)$
- $f_{yy} = f(x,y+1) + f(x, y-1) - 2\,f(x,y)$

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

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 implementatio of the Laplaci

Composite Laplacian for Enhancement

- Laplacian highlights discontinuities (b and c)
- The “uniform” regions are suppressed
- To restore the balance, for image enhancement the original image is added to the Laplacian

$$g(x,y)=f(x,y) - \nabla^2 f(x,y) \quad \text{if } \nabla^2 f(x,y) < 0$$

$$g(x,y)=f(x,y) + \nabla^2 f(x,y) \quad \text{if } \nabla^2 f(x,y) >= 0$$

- In difference form

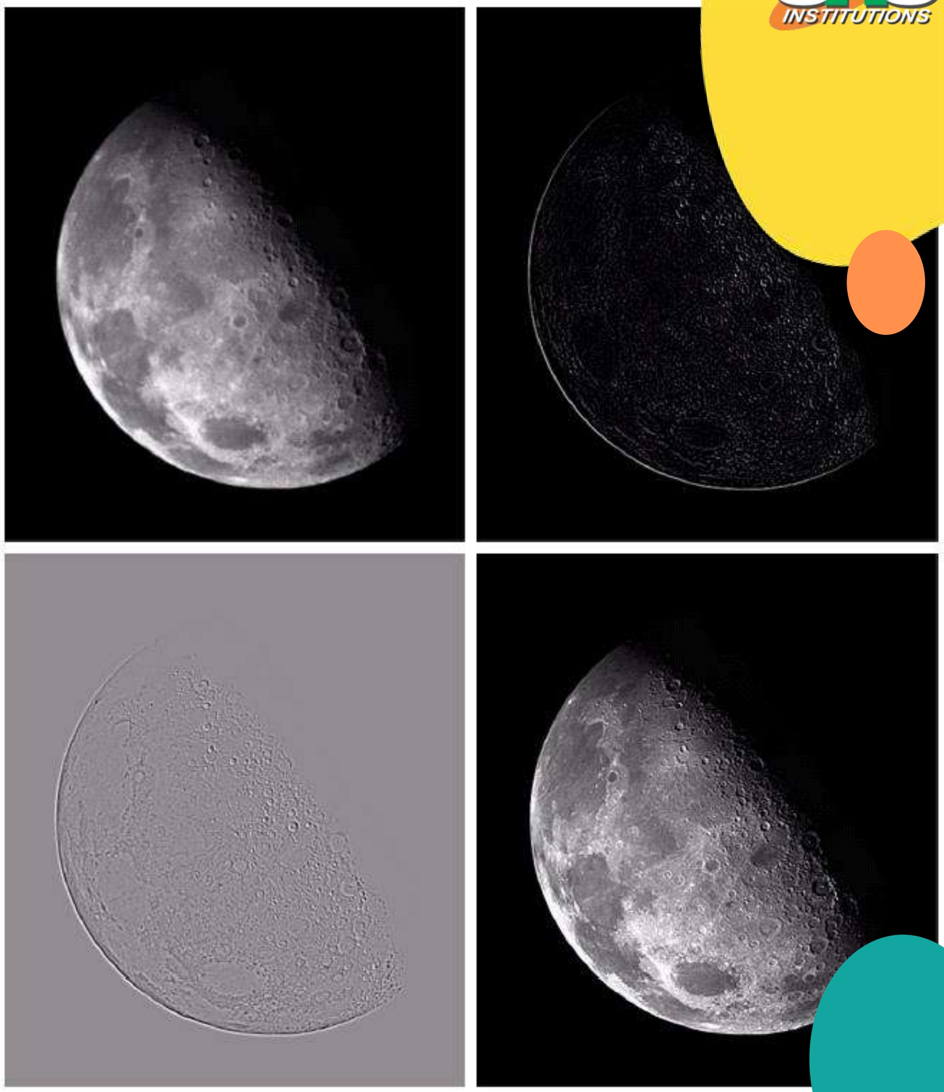
$$g(x,y)=5f(x,y)-\{f(x+1,y)+f(x-1,y)+f(x,y+1)+f(x,y-1)\}$$

- Leads to new mask

Next slide

a b
c d

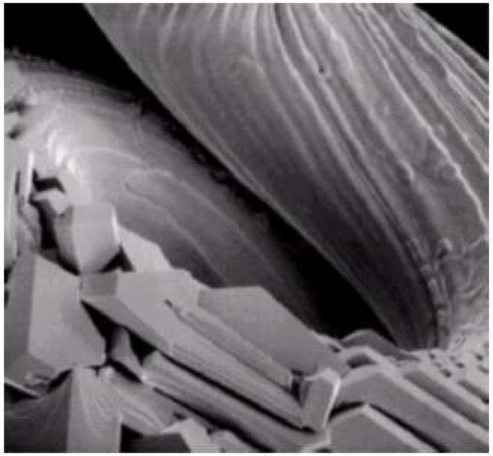
FIGURE 3.40 (a) Image of the North Pole of the moon. (b) Laplacian-filtered image. (c) Laplacian image scaled for display purposes. (d) Image enhanced by using Eq. (3.7-5). (Original image courtesy of NASA.)

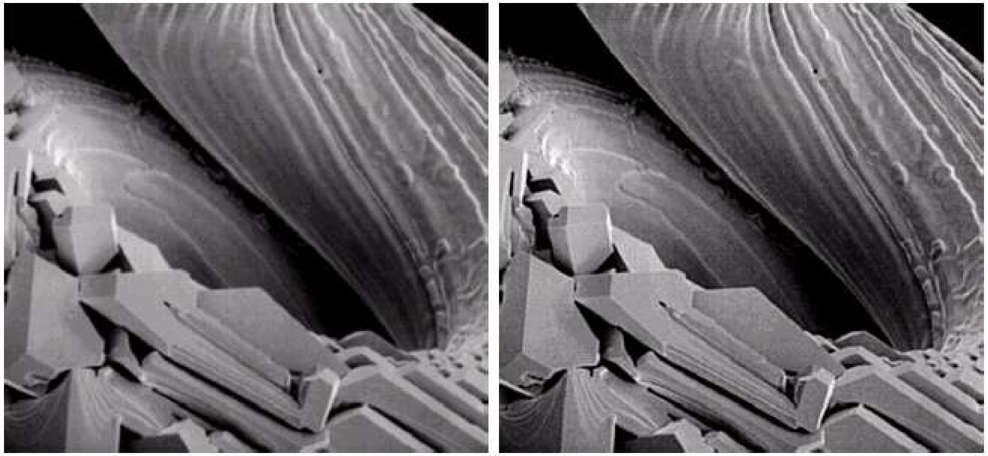


Application of Composite Masks

0	–1	0
–1	5	–1
0	–1	0

–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.)

High Boost Filters

- For image enhancement the augmented original image is added to the Laplacian

$$g(x,y) = Af(x,y) - \nabla^2 f(x,y) \quad \text{if } \nabla^2 f(x,y) < 0$$

$$g(x,y) = Af(x,y) + \nabla^2 f(x,y) \quad \text{if } \nabla^2 f(x,y) >= 0$$

- In difference form

$$g(x,y)=(A+4)f(x,y)-\{f(x+1,y)+f(x-1,y)+f(x,y+1)+f(x,y-1)\}$$

a

0	−1	0
−1	$A+4$	−1
0	−1	0

b

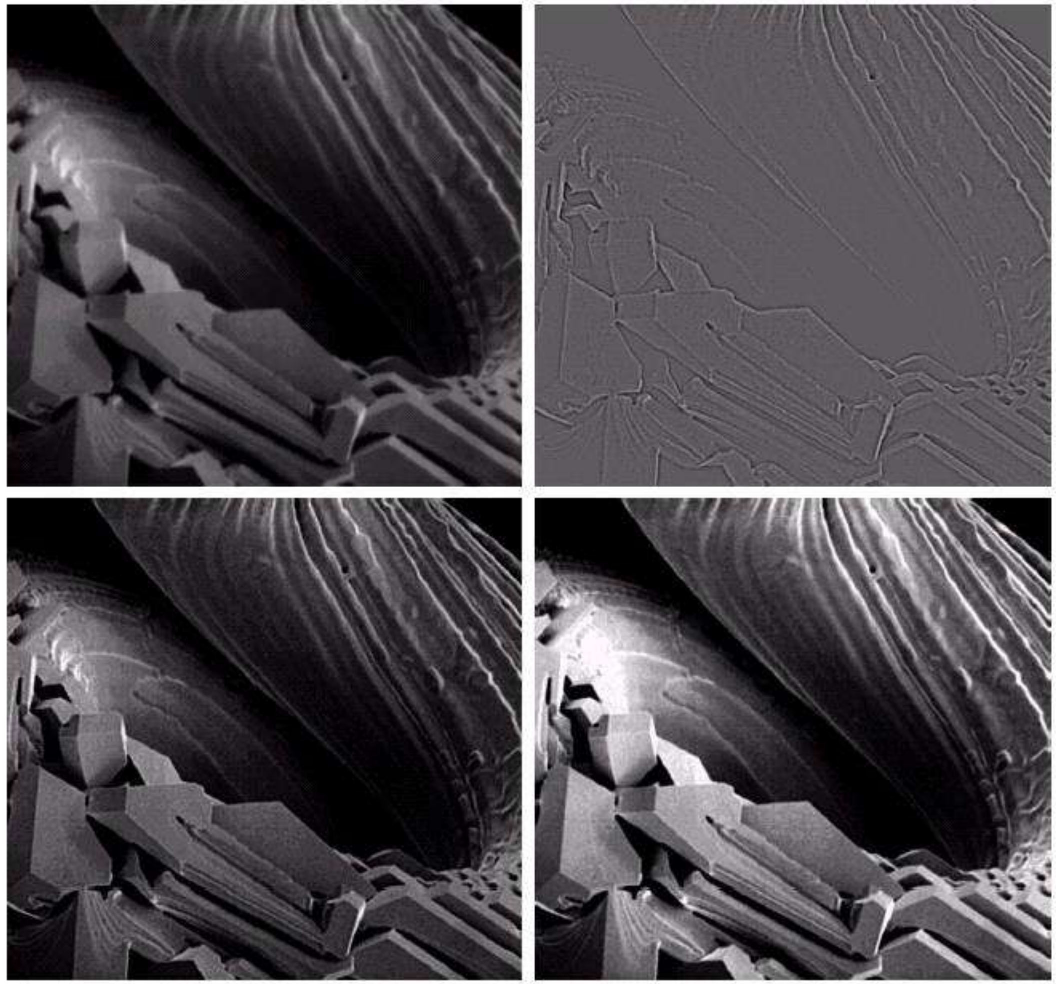
−1	−1	−1
−1	$A+8$	−1
−1	−1	−1

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

High Boost Filter with Different A – values

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 $A = 1.7$.



Roberts and Sobel Gradient Based Masks

a

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

b

−1	0
0	1

c

0	−1
1	0

d

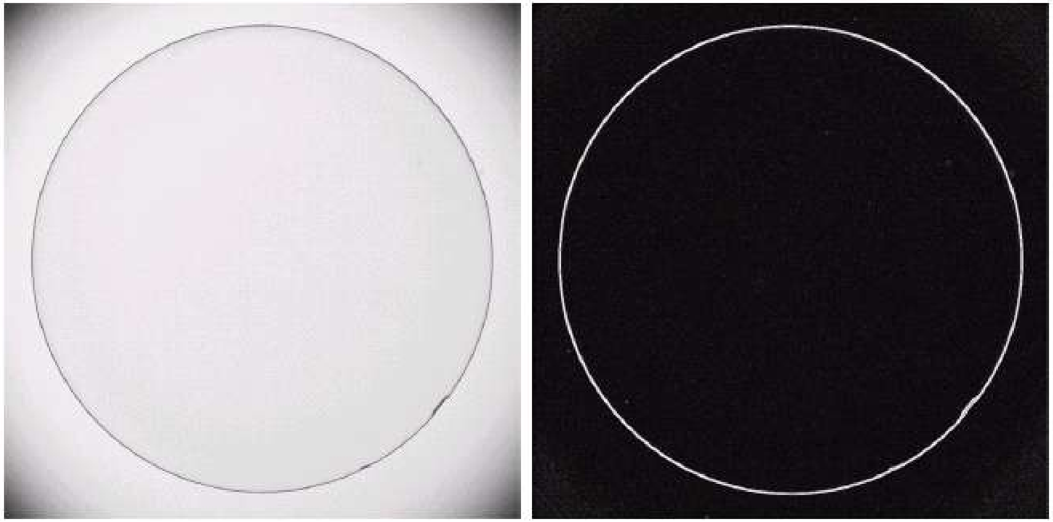
−1	−2	−1
0	0	0
1	2	1

e

−1	0	1
−2	0	2
−1	0	1

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.

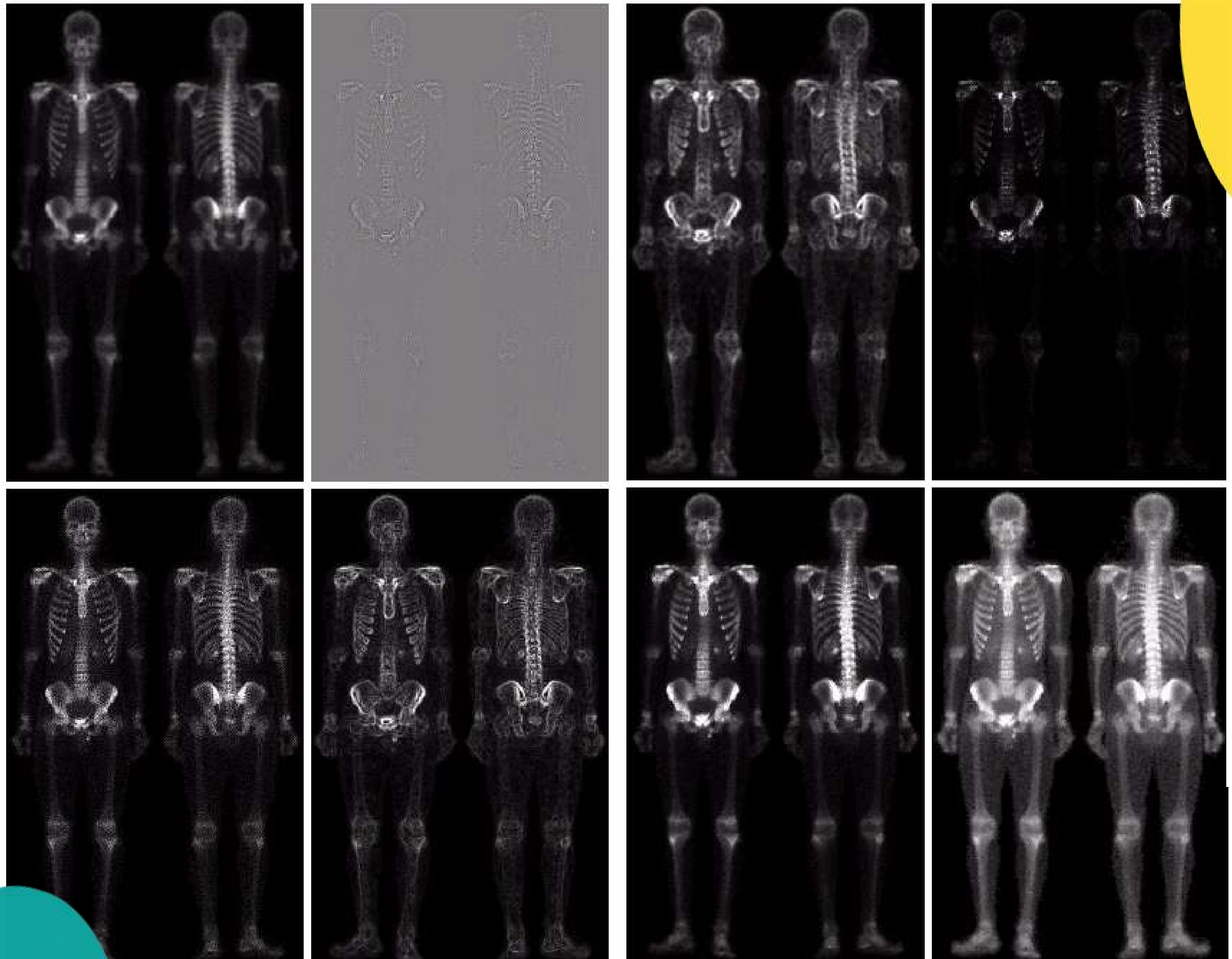
Sobel Mask – Detects Edges



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.)

Multiple Step Spatial Enhancement



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).

(e) Sob... ge smooth... h a 5 × 5 ave...ging 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.)

Thank You