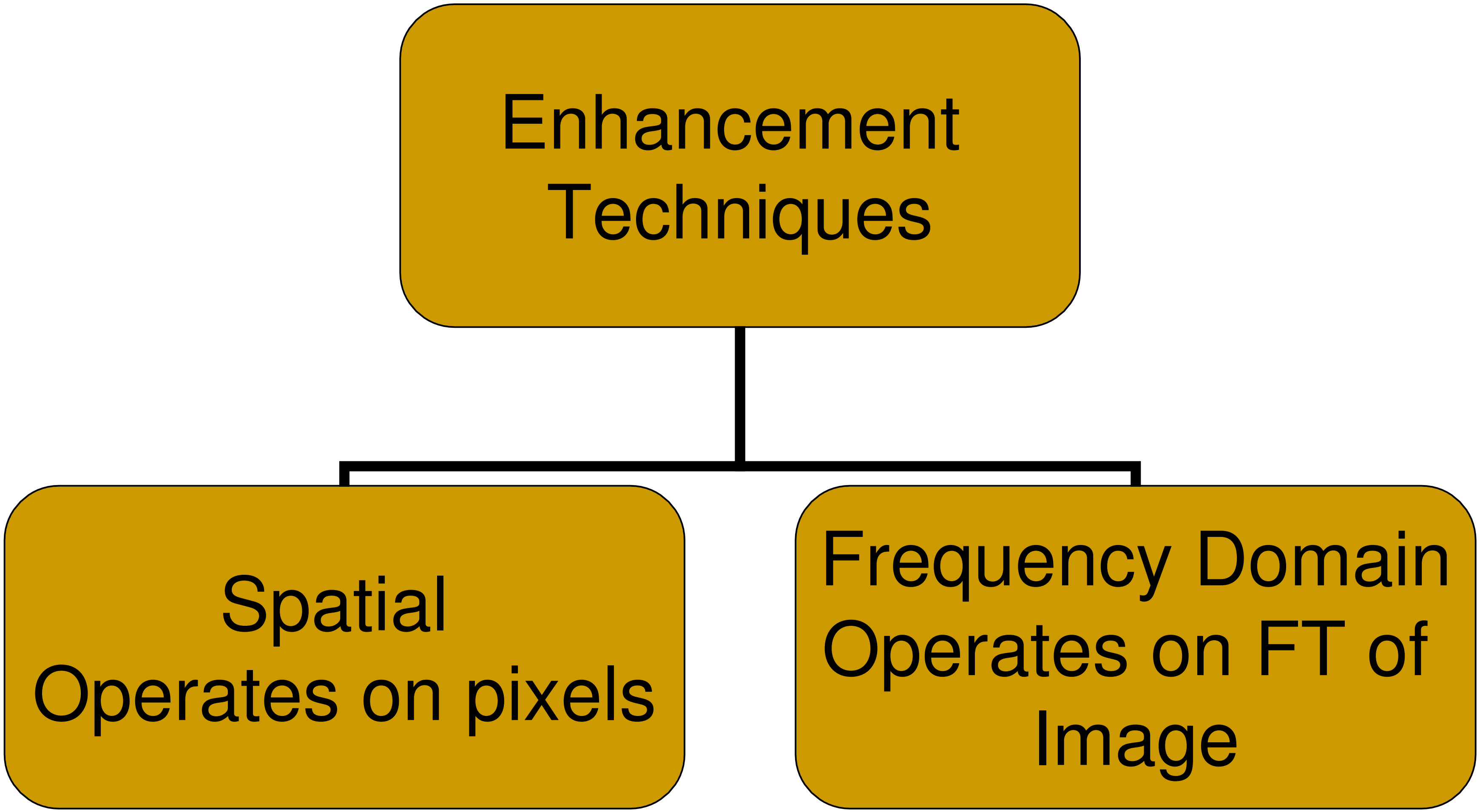
Image Enhancement In Spatial Domain

Today

- Image Enhancement Techniques
- Spatial Domain Method
- Histogram Methods
- Frequency Domain Methods


Enhancement Techniques
Spatial
Operates on pixels
Frequency Domain
Operates on FT of Image

Spatial Domain Methods

- In these methods a operation (linear or non-linear) is performed on the pixels in the neighborhood of coordinate (x,y) in the input image F, giving enhanced image F'
- Neighborhood can be any shape but generally it is rectangular (3x3, 5x5, 9x9 etc)

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

Grey Scale Manipulation

- Simplest form of window (1x1)
- Assume input gray scale values are in range [0, L-1] (in 8 bit images L = 256)
- N^{th} root Transformation

$$s = c\,(r)^n$$

contd…

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

- Linear: Negative, Identity
- Logarithmic: Log, Inverse Log
- Power-Law: *n*th power, *n*th root

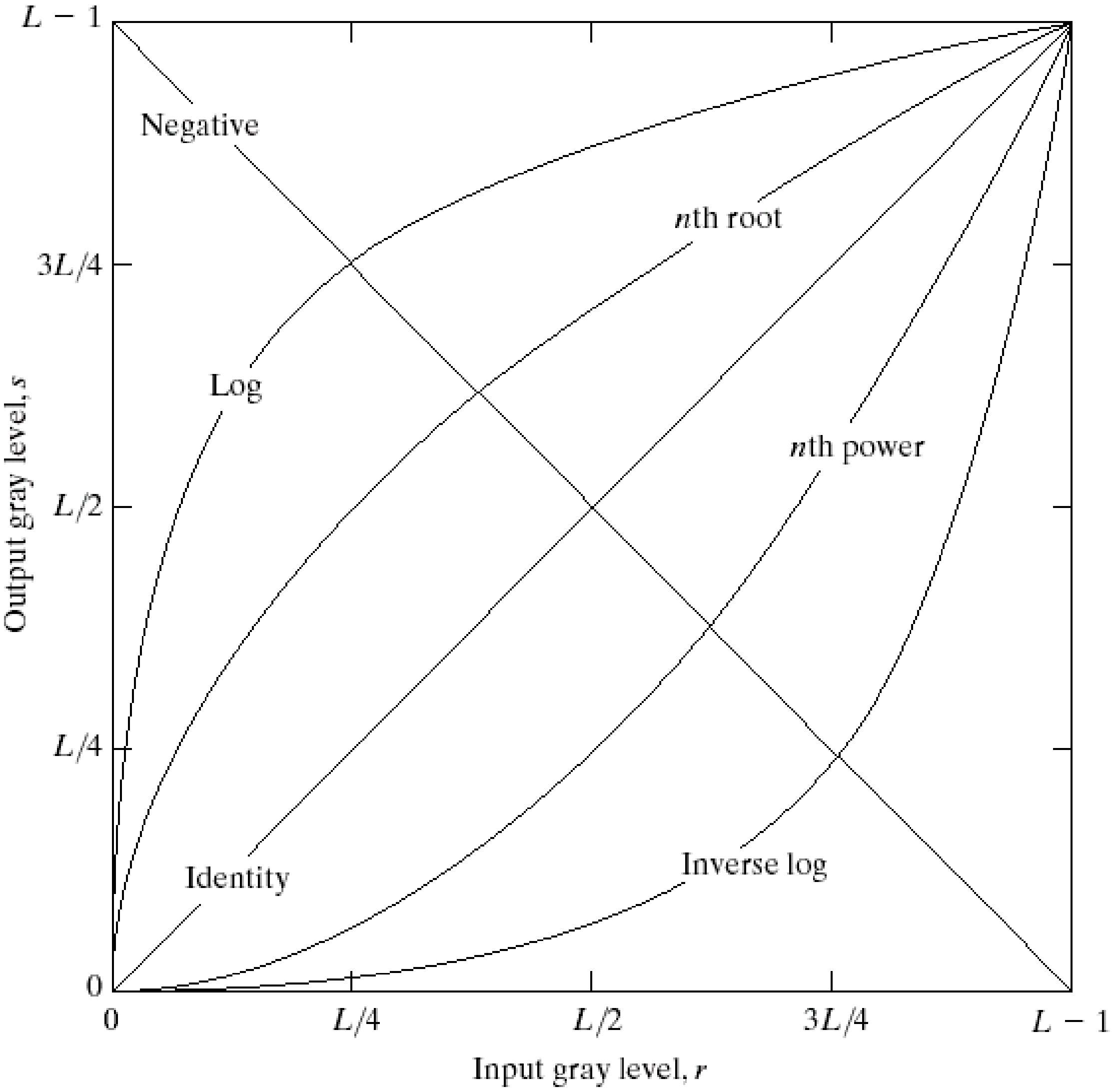
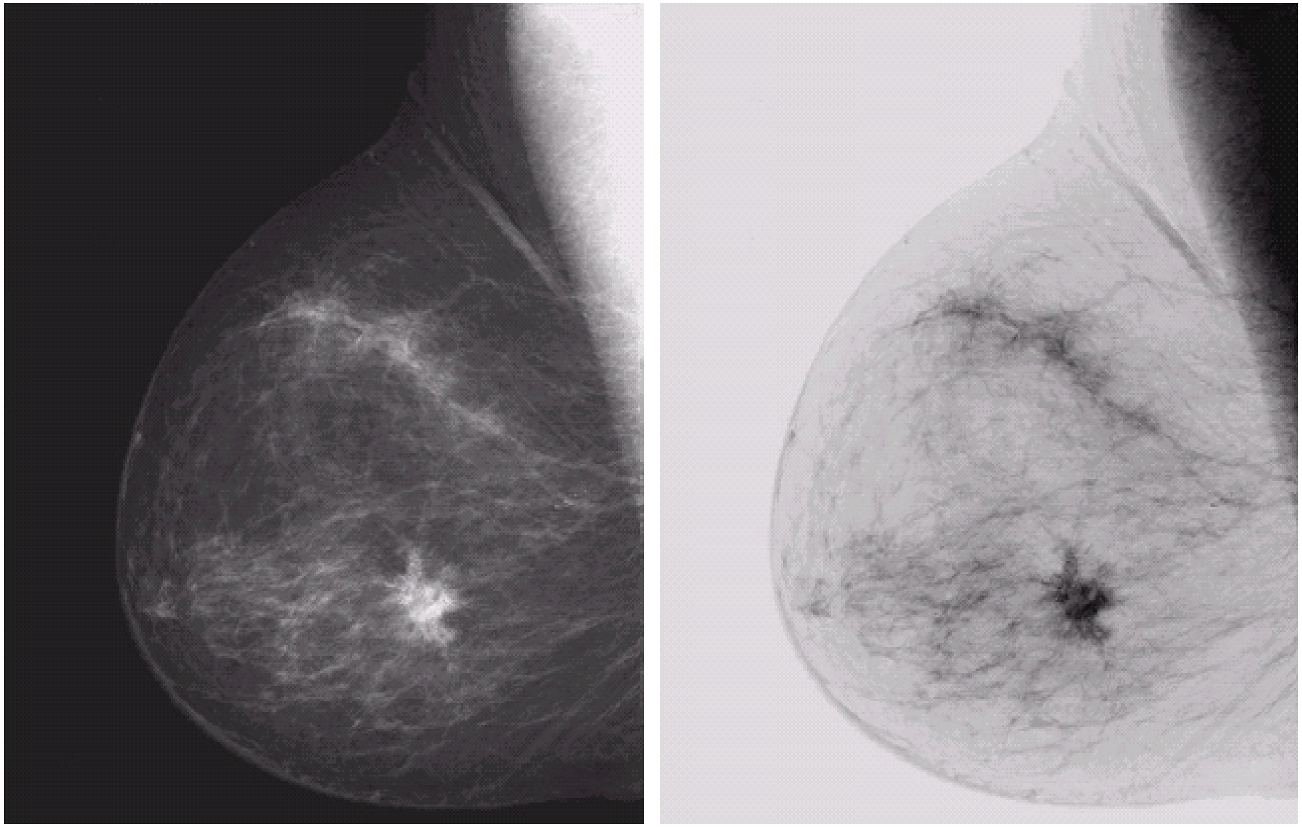


Image Negative



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 Negative: $s = L - 1 - r$

Log Transformation

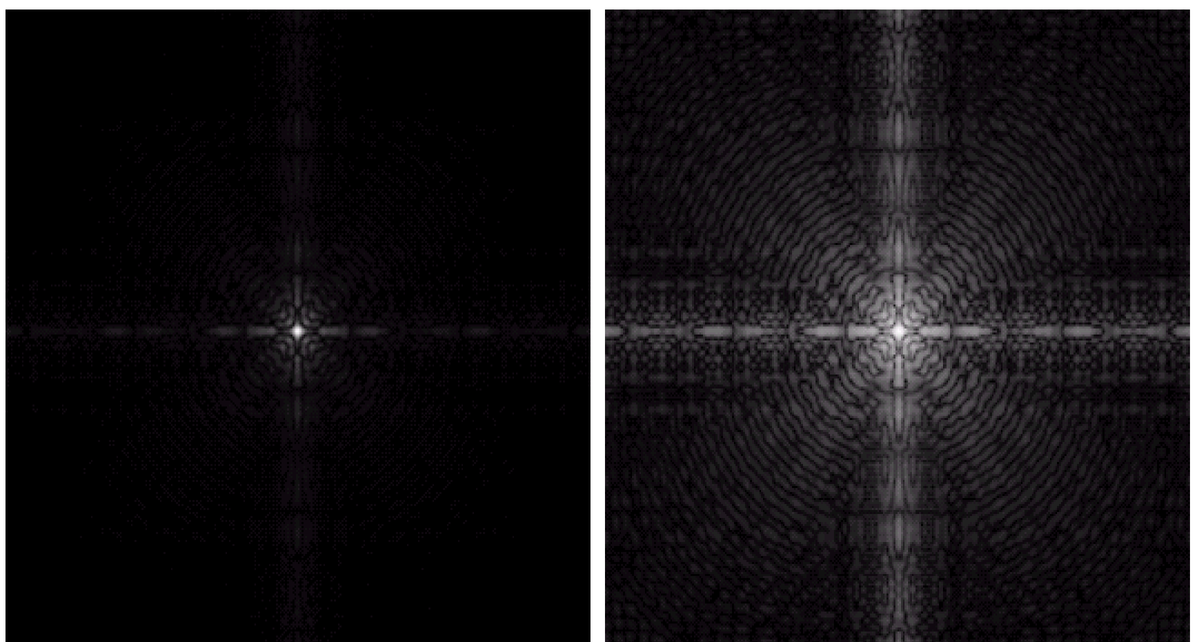
$$s = c \log(1+r)$$

c: constant

- Compresses the dynamic range of images with large variations in pixel values

a b

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



Power Law Transformation

- $s = cr^{\gamma}$
- C, γ : positive constants
- Gamma correction

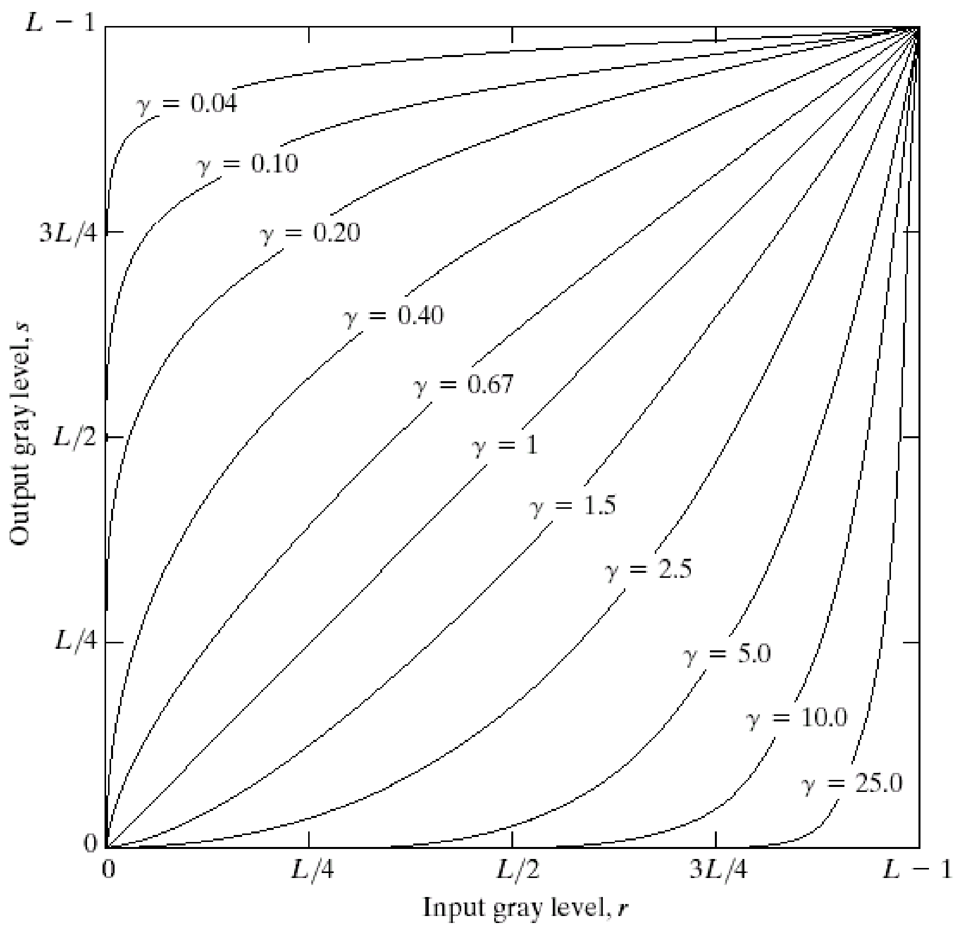
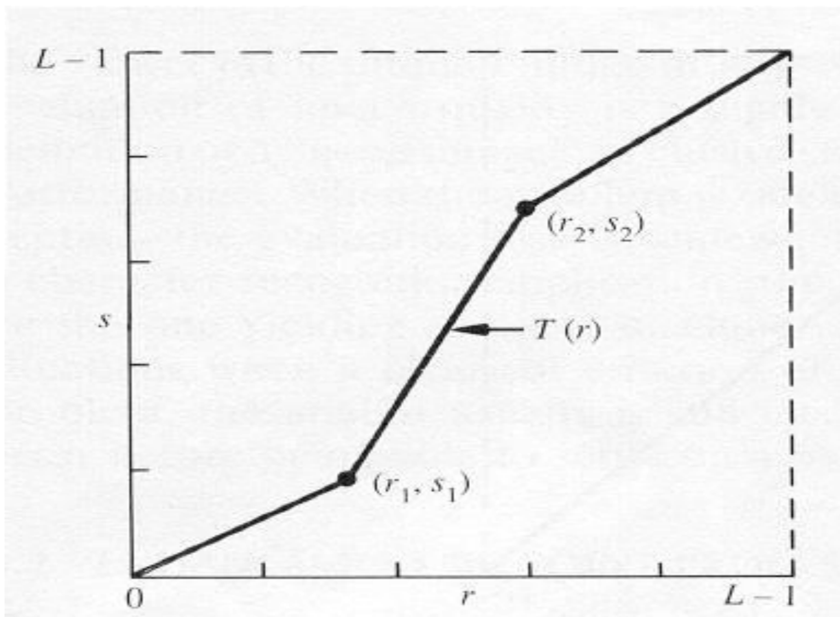


FIGURE 3.6 Plots of the equation $s = cr^{\gamma}$ for various values of γ ($c = 1$ in all cases).

Contrast Stretching

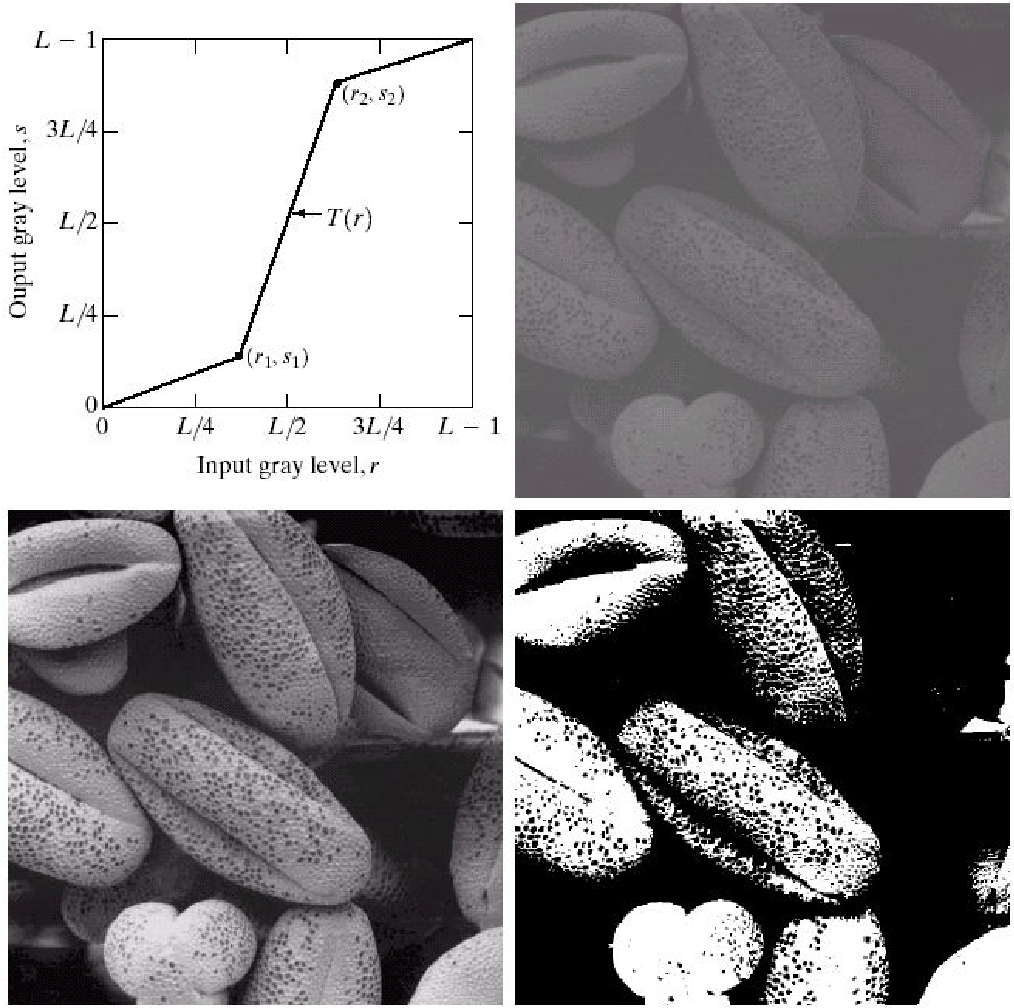
- To increase the dynamic range of the gray levels in the image being processed.



contd…

- The locations of (r_1,s_1) and (r_2,s_2) control the shape of the transformation function.
  - If $r_1= s_1$ and $r_2= s_2$ the transformation is a linear function and produces no changes.
  - If $r_1=r_2$, $s_1=0$ and $s_2=L-1$, the transformation becomes a thresholding function that creates a binary image.
  - Intermediate values of (r_1,s_1) and (r_2,s_2) produce various degrees of spread in the gray levels of the output image, thus affecting its contrast.
  - Generally, $r_1 \le r_2$ and $s_1 \le s_2$ is assumed.

Example



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.)

Bit-Plane Slicing

- To highlight the contribution made to the total image appearance by specific bits.
  - i.e. Assuming that each pixel is represented by 8 bits, the image is composed of 8 1-bit planes.
  - Plane 0 contains the least significant bit and plane 7 contains the most significant bit.
  - Only the higher order bits (top four) contain visually significant data. The other bit planes contribute the more subtle details.

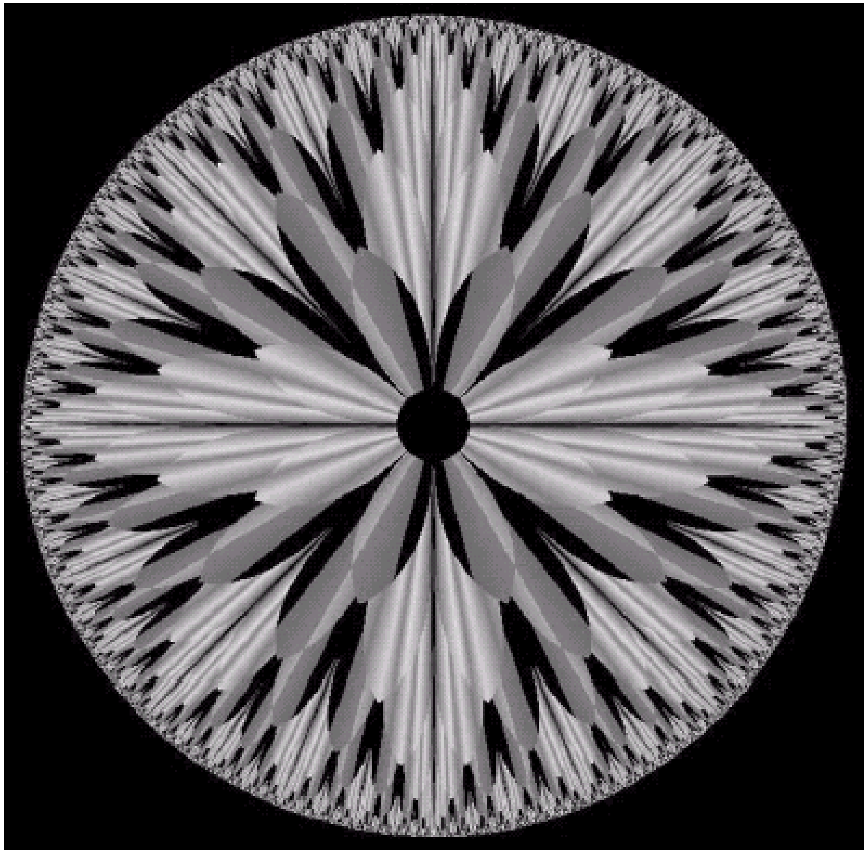


FIGURE 3.13 An 8-bit fractal image. (A fractal is an image generated from mathematical expressions). (Courtesy of Ms. Melissa D. Binde, Swarthmore College, Swarthmore, PA.)

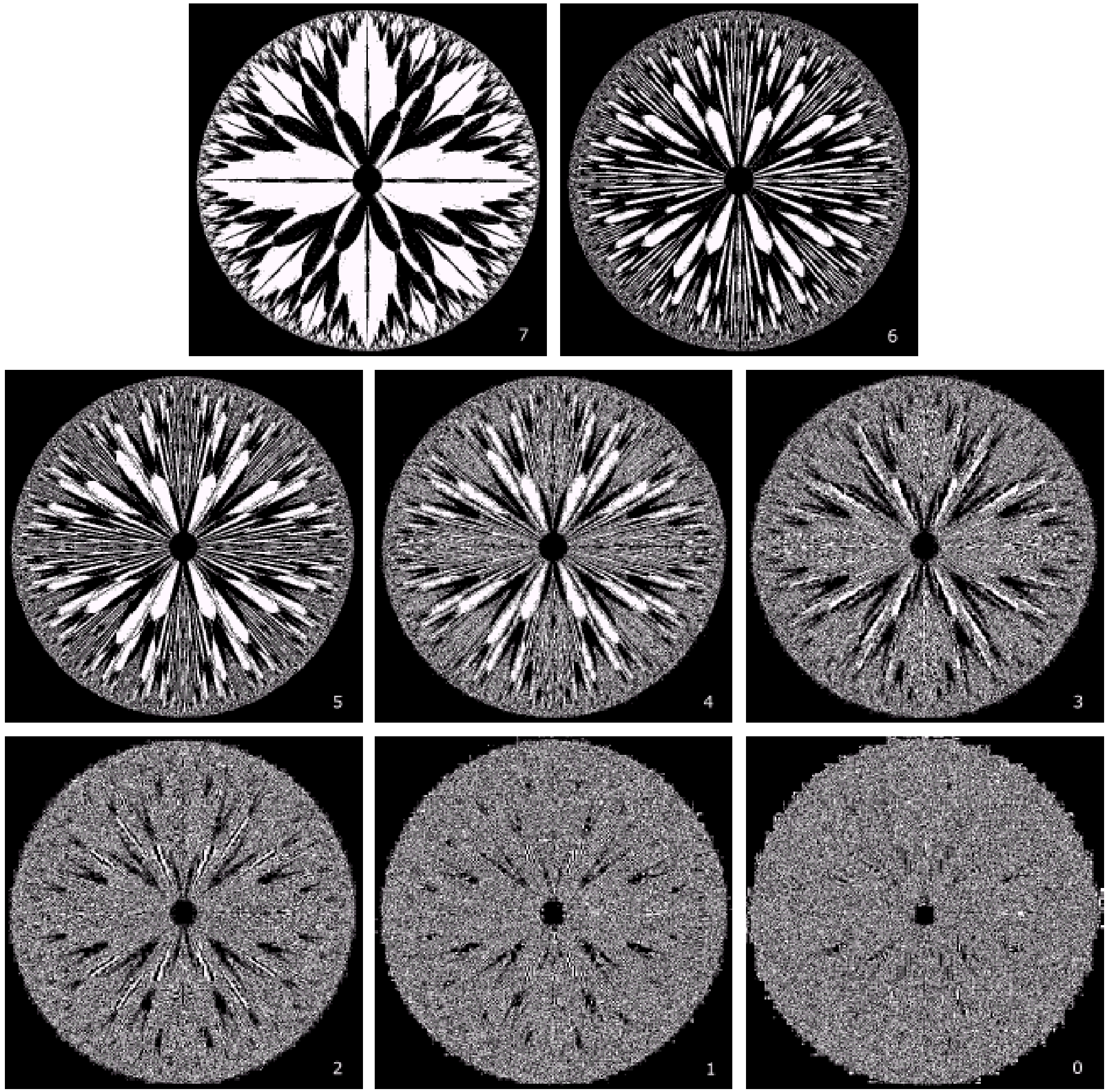


FIGURE 3.14 The eight bit planes of the image in Fig. 3.13. The number at the bottom, right of each image identifies the bit plane.

Histogram Processing

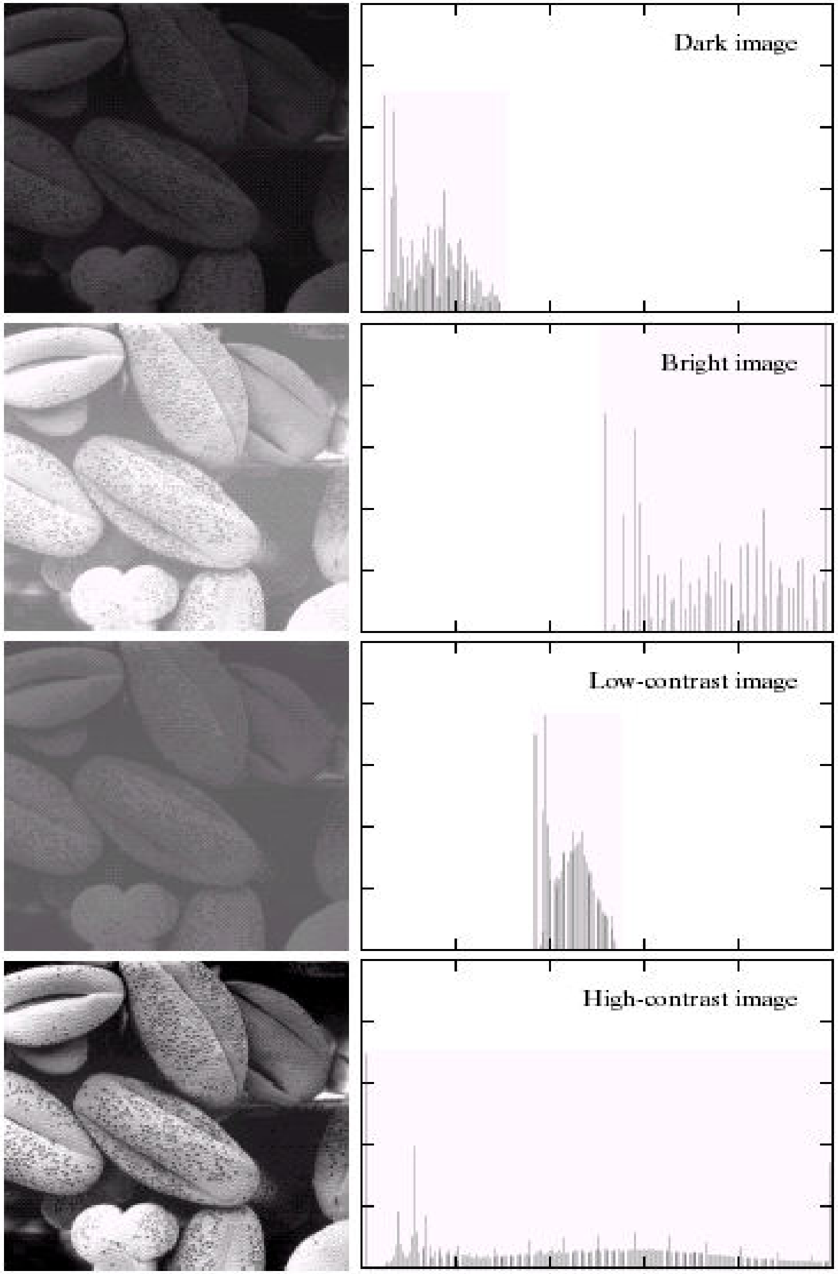
- The histogram of a digital image with gray levels from 0 to L-1 is a discrete function $h(r_k)=n_k$, where:
  - r_k is the kth gray level
  - n_k is the # pixels in the image with that gray level
  - n is the total number of pixels in the image
  - $k = 0, 1, 2, \ldots, L-1$
- Normalized histogram: $p(r_k)=n_k/n$
  - sum of all components = 1

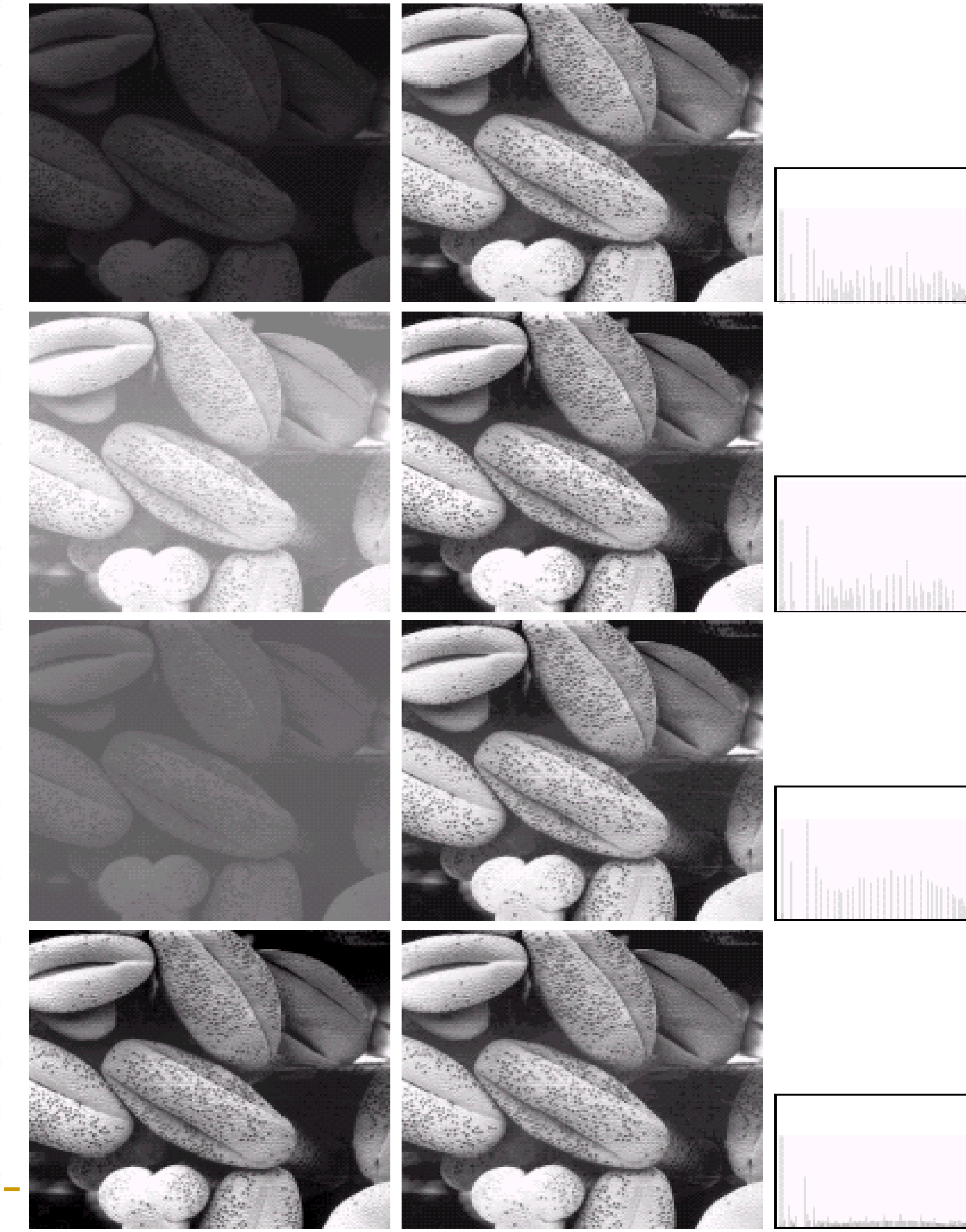
- Types of processing:
  - Histogram equalization
  - Histogram matching (specification)
  - Local enhancement

Histogram Equalization

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

- Histogram equalization (HE) results are similar to contrast stretching but offer the advantage of full automation, since HE automatically determines a transformation function to produce a new image with a uniform histogram.


Dark image
Bright image
Low-contrast image
High-contrast image



Histogram Matching (or Specification)

- Histogram equalization does not allow interactive image enhancement and generates only one result: an approximation to a uniform histogram.
- Sometimes though, we need to be able to specify particular histogram shapes capable of highlighting certain gray-level ranges.

Method

- Specify the desired density function and obtain the transformation function G(z):

$$v = G(z) = \sum_{0}^{z} p_z(w) \approx \sum_{i=0}^{z} \frac{n_i}{n}$$

p_z: specified desirable PDF for output

– Apply the inverse transformation function $z=G^{-1}(s)$ to the levels obtained in step 1.

Image Smoothing or Averaging

- A noisy image:

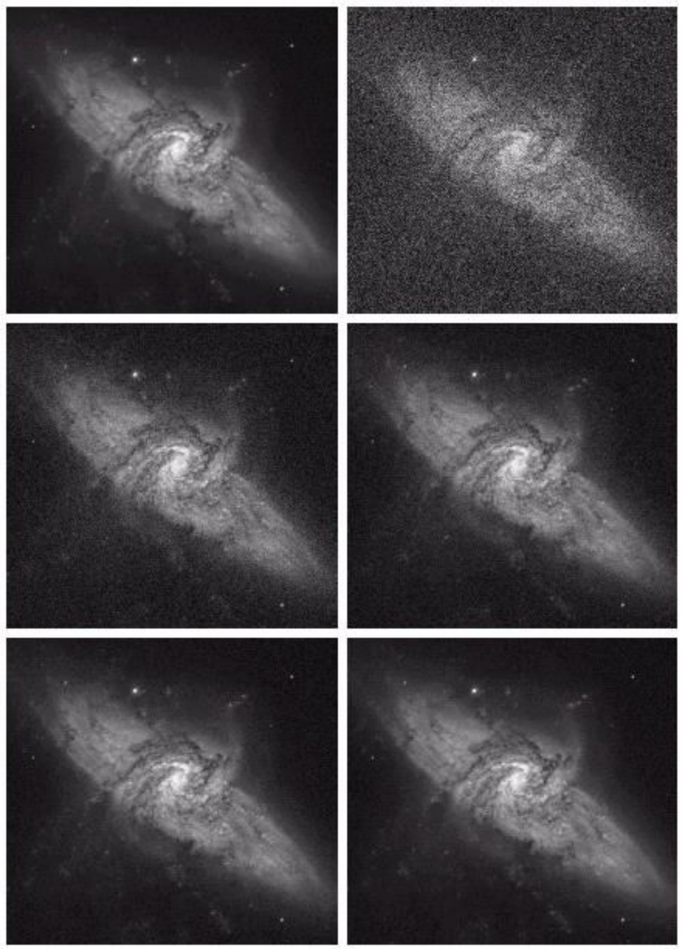
$$g(x, y) = f(x, y) + n(x, y)$$

- Averaging M different noisy images:

$$\overline{g}(x, y) = \frac{1}{M}\sum_{i=1}^{M} g_i(x, y)$$

- As M increases, the variability of the pixel values at each location decreases.
  - This means that g(x,y) approaches f(x,y) as the number of noisy images used in the averaging process increases.

Example



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.)

Spatial Filtering

- Use of spatial masks for image processing (spatial filters)
- Linear and nonlinear filters
- Low-pass filters eliminate or attenuate high frequency components in the frequency domain (sharp image details), and result in image blurring.

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

a=(m-1)/2 and *b=(n-1)/2*,
m x *n* (odd numbers)

For *x*=0,1,…,M-1 and *y*=0,1,…,N-1

The basic approach is to sum products between the mask coefficients and the intensities of the pixels under the mask at a specific location in the image:

$$R = w_1 z_1 + w_2 z_2 + \ldots + w_9 z_9$$ (for a 3 x 3 filter)

Neighborhood Averaging

Each point in the smoothed image, $\hat{F}(x, y)$ is obtained from the average pixel value in a neighbourhood of (x, y) in the input image.

For example, if we use a 3×3 neighbourhood around each pixel we would use the mask

$$\begin{array}{ccc} 1/9 & 1/9 & 1/9 \\ 1/9 & 1/9 & 1/9 \\ 1/9 & 1/9 & 1/9 \end{array}$$

General Spatial Filter

FIGURE 3.33 Another representation of a general 3×3 spatial filter mask.

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

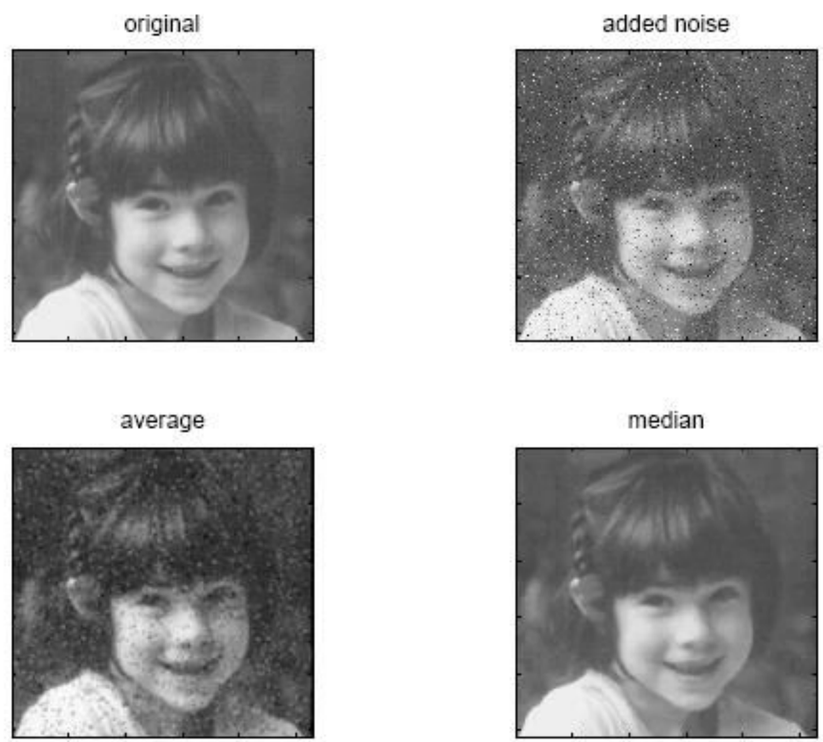
$$\frac{1}{9} \times \begin{array}{|c|c|c|} \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array} \qquad \frac{1}{16} \times \begin{array}{|c|c|c|} \hline 1 & 2 & 1 \\ \hline 2 & 4 & 2 \\ \hline 1 & 2 & 1 \\ \hline \end{array}$$

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.

Non-linear Filter

- Median filtering (nonlinear)
  - Used primarily for noise reduction (eliminates isolated spikes)
  - The gray level of each pixel is replaced by the median of the gray levels in the neighborhood of that pixel (instead of by the average as before).


original
added noise
average
median

Sharpening Filters

- The main aim in image sharpening is to highlight fine detail in the image
- With image sharpening, we want to enhance the high-frequency components; this implies a spatial lter shape that has a high positive component at the centre

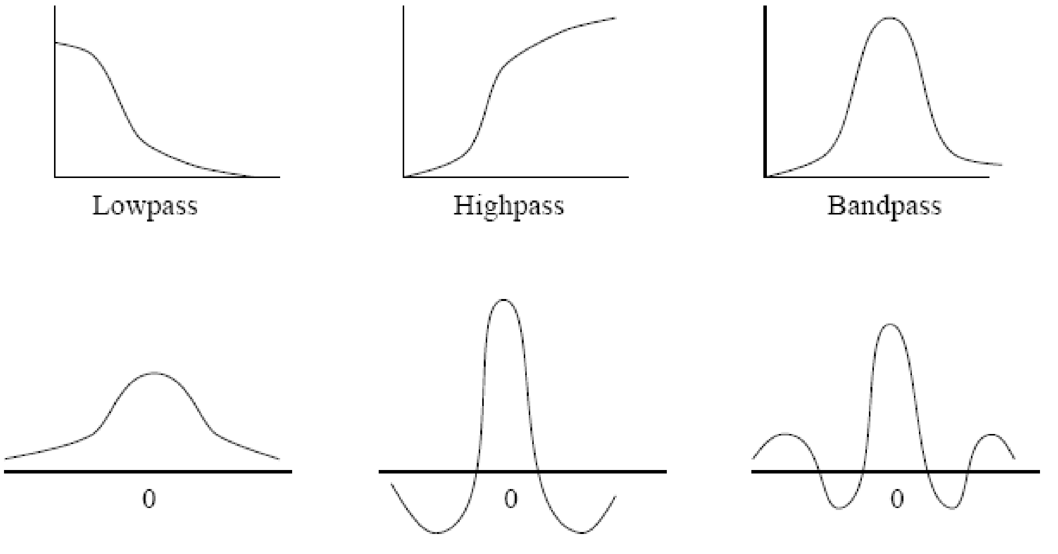


Figure 4: Frequency domain filters (top) and their corresponding spatial domain counterparts (bottom).

Derivatives

- First derivative

$$\frac{\partial f}{\partial x} = f(x+1) - f(x)$$

- Second derivative

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

Observations

- 1st order derivatives produce thicker edges in an image
- 2nd order derivatives have stronger response to fine detail
- 1st order derivatives have stronger response to a gray lever step
- 2nd order derivatives produce a double response at step changes in gray level

A simple spatial filter that achieves image sharpening is given by

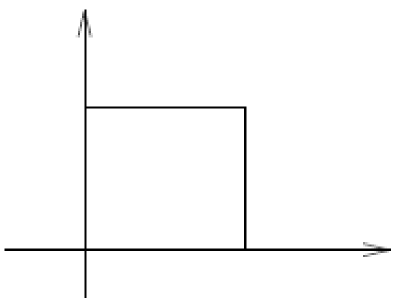
$$\begin{matrix} -1/9 & -1/9 & -1/9 \\ -1/9 & 8/9 & -1/9 \\ -1/9 & -1/9 & -1/9 \end{matrix}$$

- Since the sum of all the weights is zero, the resulting signal will have a zero DC value

Frequency Domain Methods

- We simply compute the Fourier transform of the image to be enhanced, multiply the result by a filter (rather than convolve in the spatial domain), and take the inverse transform to produce the enhanced image.
- Low pass filtering involves the elimination of the high frequency components in the image. It results in blurring of the image

Frequency Domain Methods



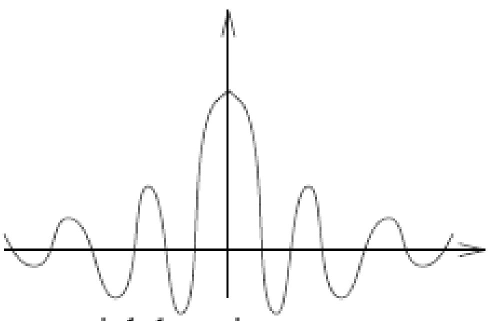


Figure 5: Transfer function for an ideal low pass filter.