Chapter 4. Image Enhancement

- Processing of images to bring out specific features of an image
- Highlight certain characteristics of an image
- to process image so that the result is more suitable than the original image for a specific application (very much problem-oriented)

- Categories
  - spatial domain method
    : based on direct manipulation of pixels in image
    - point processing
    - mask processing
  - frequency domain method
    : based on modifying FT of image
  - combination two domain method

- Color image enhancement

4.1 Background

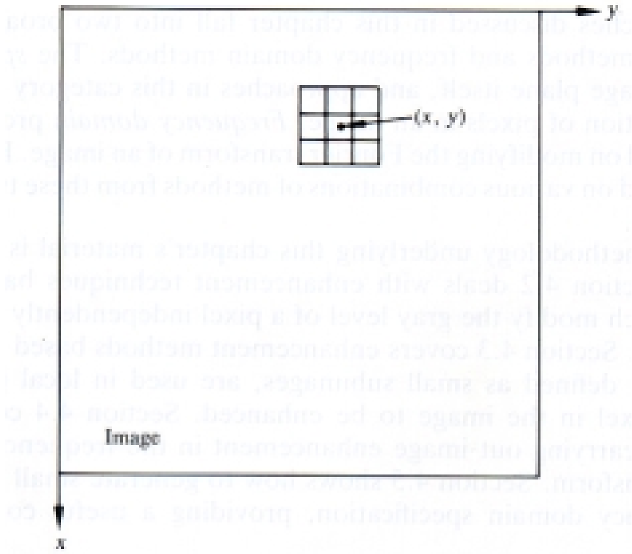
4.1.1 Spatial Domain Method

- **contrast and dynamic range modification**
- **noise reduction**
- **edge enhancement and detection**

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

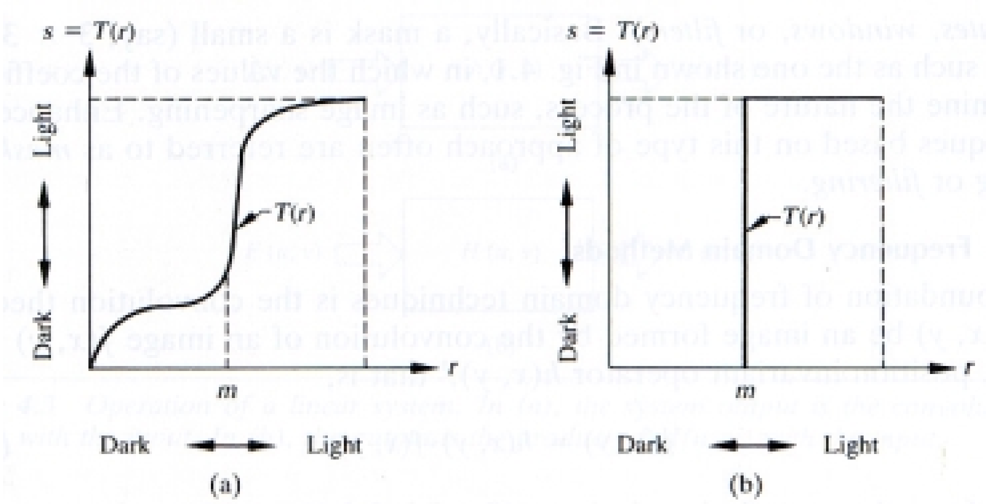
  T : operator on *f* defined over some neighborhood of *(x,y)*
  f: input, *g*: output (processed image)

- neighborhood :
  - pixel group processing
  - mask, template, window or filter
  - image is MRF !!



rectangular subimage area centered at (x,y).

- the simplest form of T :
  - neighborhood : 1×1
  - depends only on the value *f* at *(x,y)*
  - ex) T: gray-level transformation function $S = T(r)$



(a) to produce image of higher contrast (contrast stretching tech.)

(b) to produce two-level binary image (thresholding)

  - point processing technique.
  - Simple, powerful processing technique.

- mask approach :
  - larger neighborhood
  - 2D array; values of the arary determine the nature of process (ex. Image shapening)

4.1.2 Freq. Domain Method

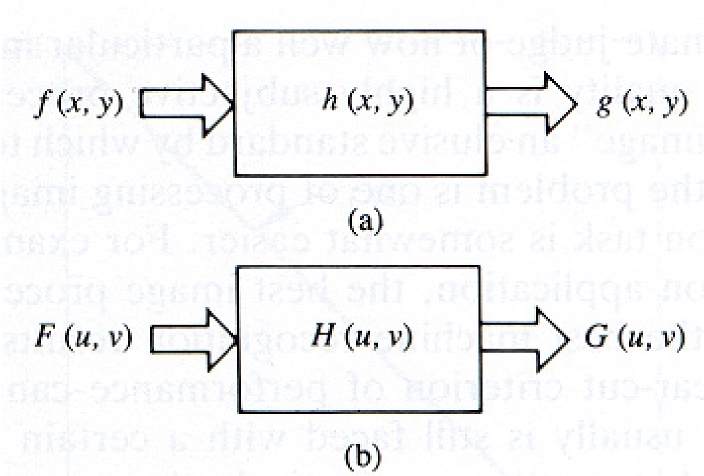
- convolution theorem :

$$g(x,y) = h(x,y) * f(x,y)$$

where *h(x,y)* : operator

$$G(u,v) = H(u,v)F(u,v)$$

H(u,v) : transfer function



- goal :

  - to select *H(u,v)* so that the desired image

  $$g(x,y) = \mathcal{F}^{-1}[H(u,v)F(u,v)]$$

  exhibits some highlighted feature of *f(x,y)*

  ex) edge enhancement

  : use a function H(u,v) that emphasize the high-frequency components of *F(u,v)*

- *H(u,v), h(x,y)*
  - impulse response

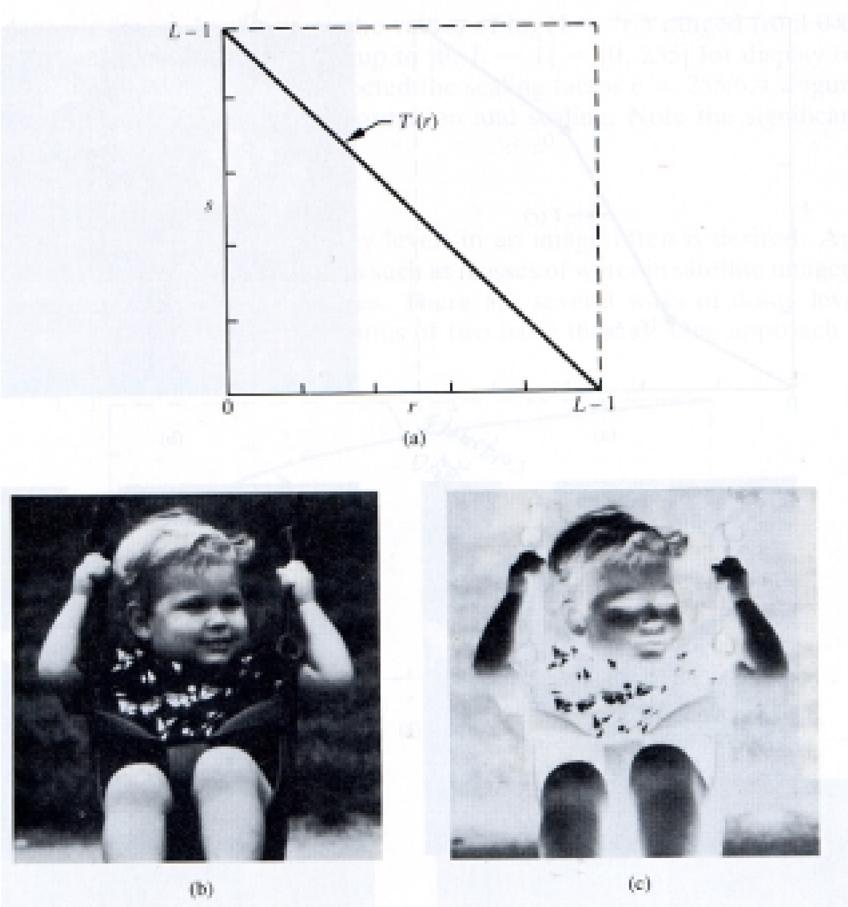
- in optics
  h(x,y) : point spread function (blurring (spreading) the point)
- spatial convolution mask

4.2 Enhancement by Point Processing

: the simplest method

4.2.1 Some simple intensity transformations

1)image negatives; (complements)



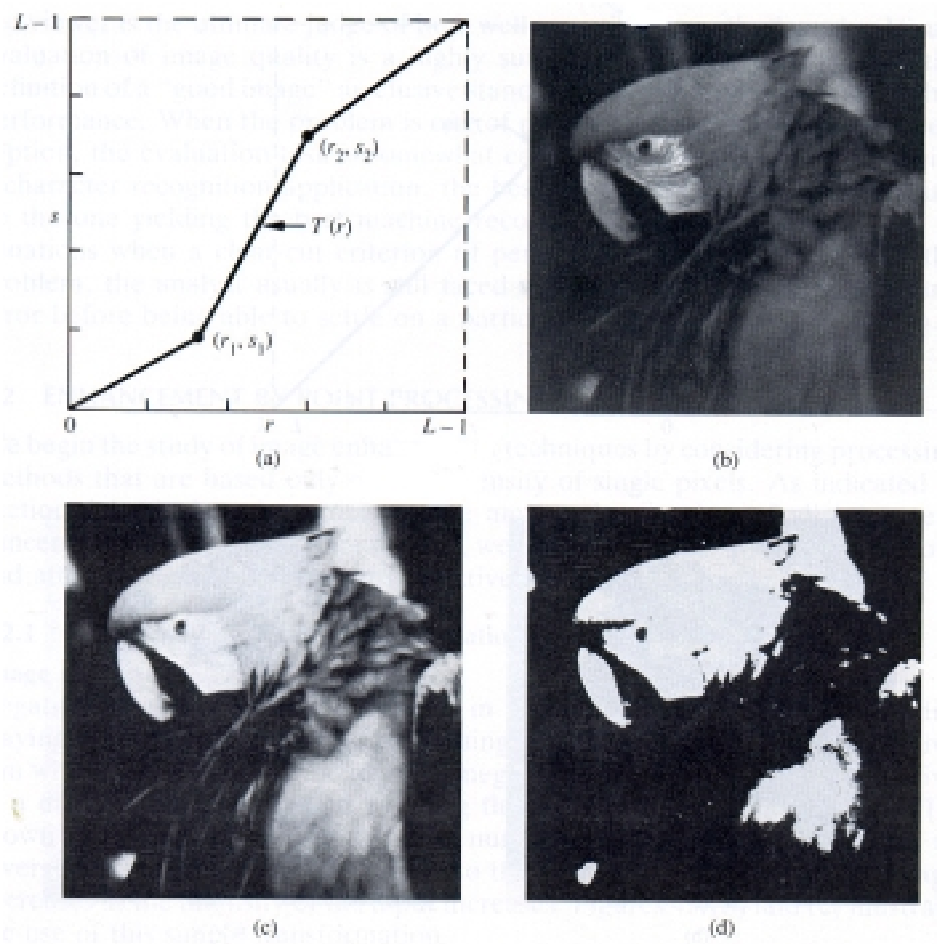
(a) $s = T(r)$, r : intensity of pixels before processing, s : intensity of pixels after processing
(b) image ,(c) its negative

2) contrast stretching :

- low contrast image :
  - poor illumination

- lack of dynamic range in imaging sensor
- wrong setting of lens aperture

- basic idea :
  - increase the dynamic range of gray level

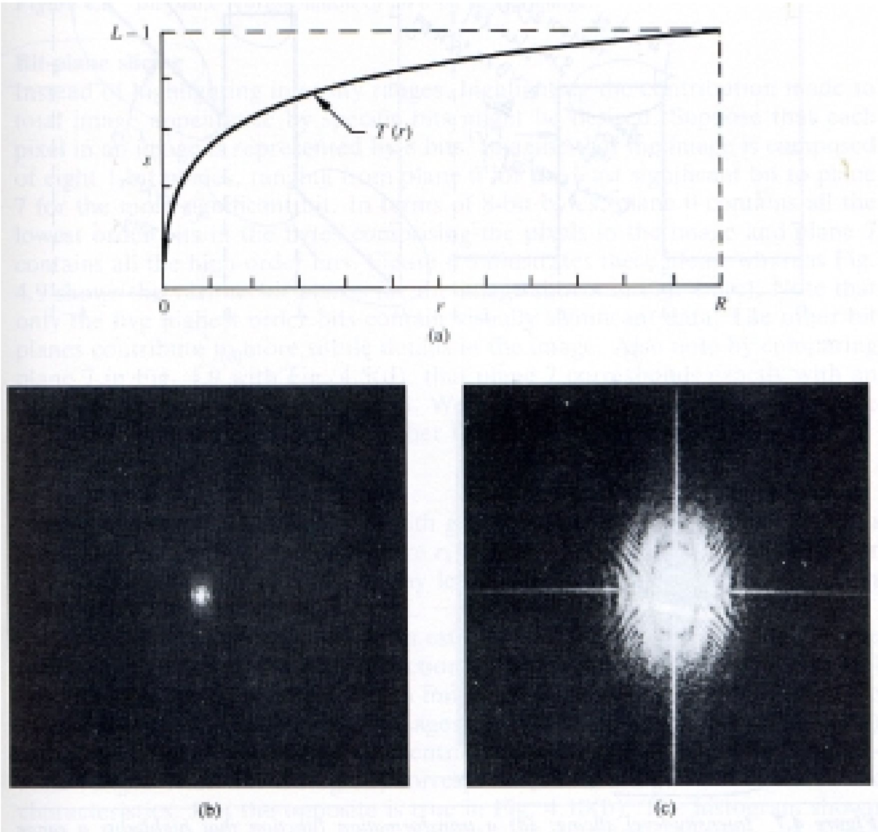


(a) transformation function location (b) low-contrast image
(c) contrast stretched image (d) binary image $(r_1 = r_2, s_1 = 0, s_2 = L-1)$
in general $r_1 \le r_2, \quad s_1 \le s_2$

3) compression of dynamic range :

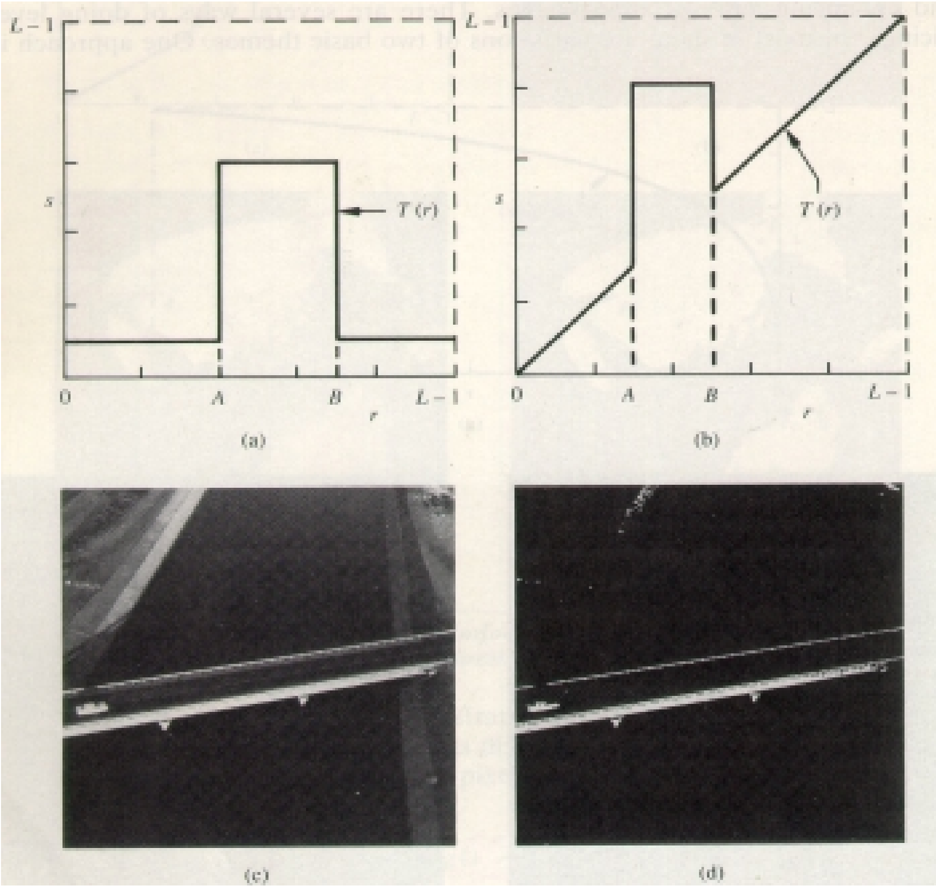
- image with large dynamic range that exceeds the capability of the display device :
  $\rightarrow$ only the brightest parts of image : visible on screen
  (ex. Display of FT spectrum of image)

- intensity transform :
  $s = c \log(1 + |r|)$



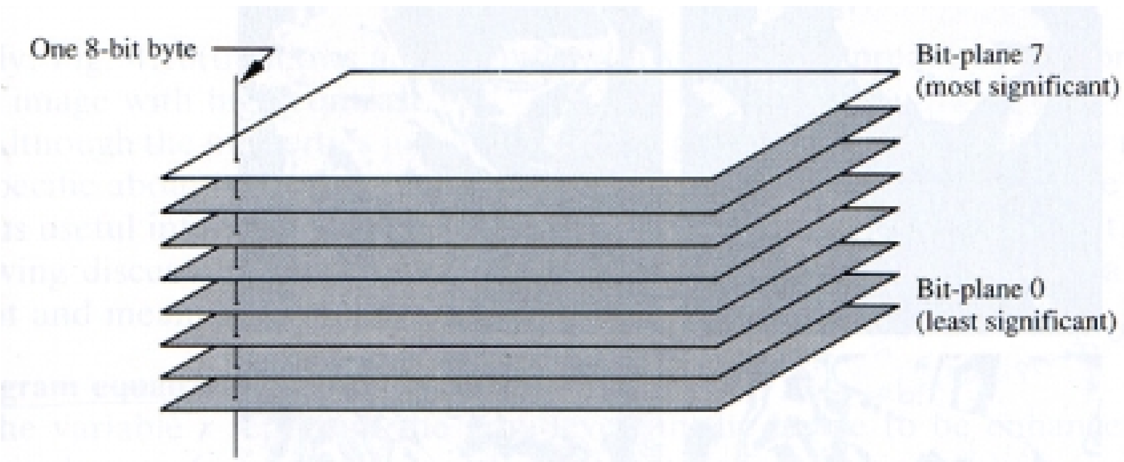
4) gray-level slicing :

- highlighting a specific range of gray level :

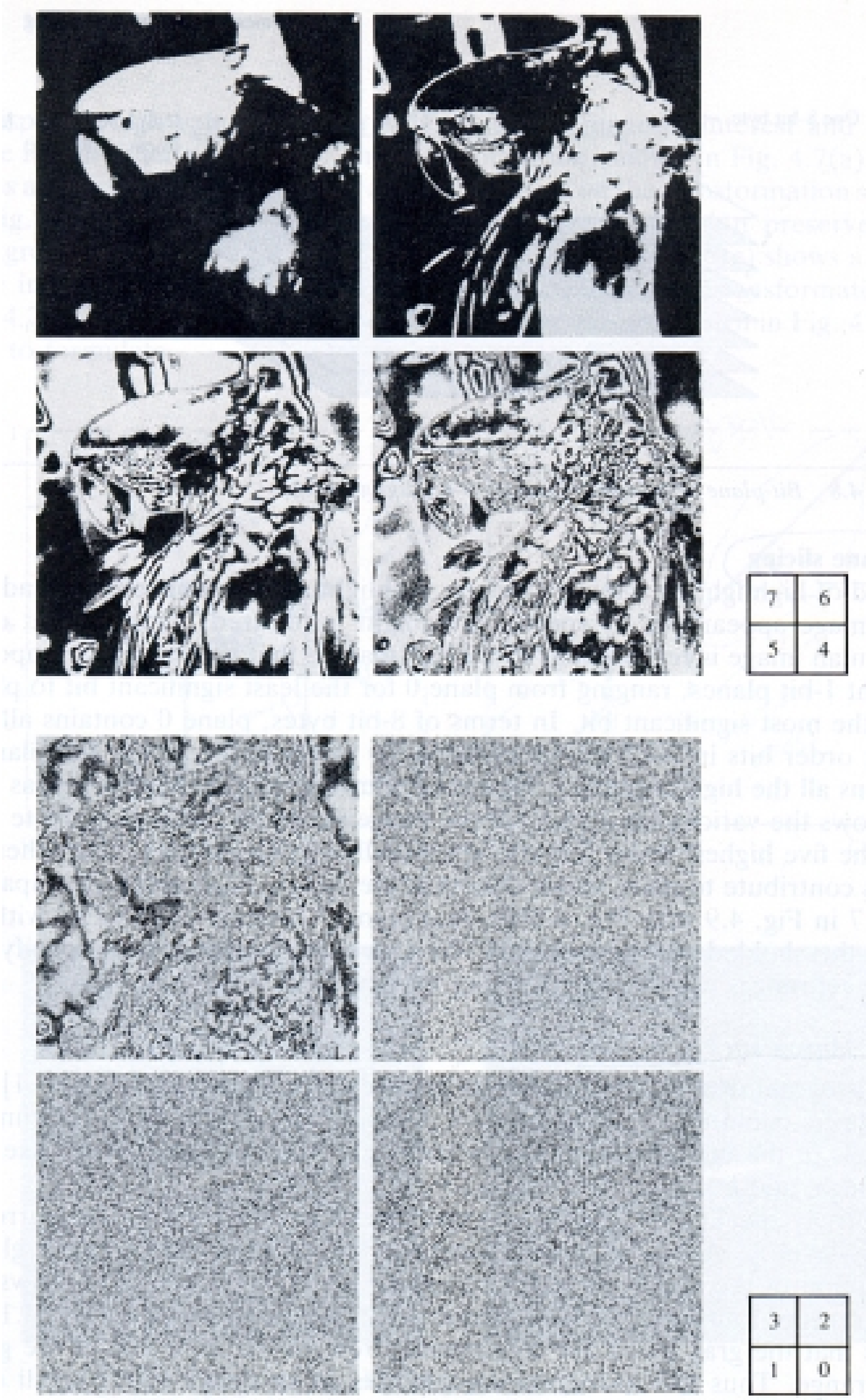


(a) the range of interest : high gray level, all other : low gray level
(b) the range of interest : high gray level, all other : preserve

5) bit-plane slicing :



1-bit planes : from MSB to LSB



→ only 5 highest order bits contain visually significant data

4.2.2 Histogram Processing (Modeling)

→ modify an image so that its histogram has a desired shape

- histogram :
  - discrete function

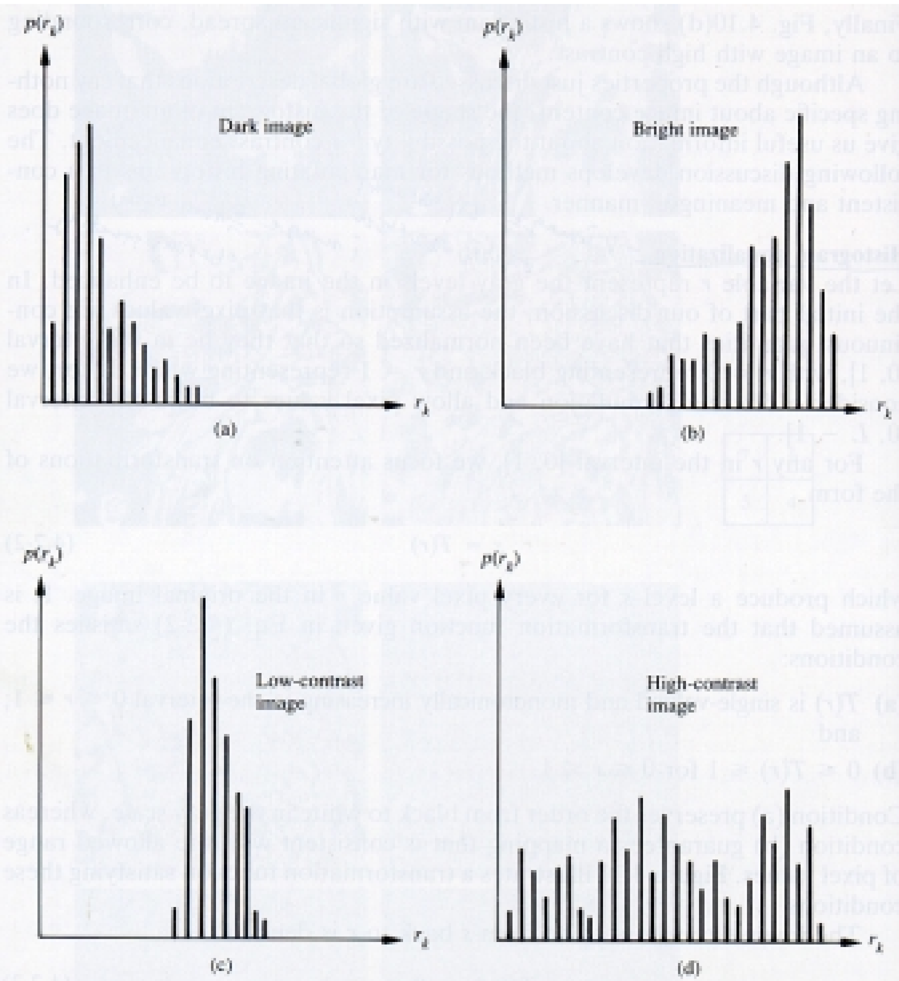
    $p(r_k) = n_k / n$

    where r_k : k-th gray level

    n_k : number of pixels with k-th gray level in image

    n : total number of pixels in image

    k : 0,1,2,…,L-1
  - $p(r_k)$: probability of occurrence of gray level r_k



(a) dark (b) bright (c) little dynamic range (low contrast)
(d) large dynamic range (high contrast, well-balanced)

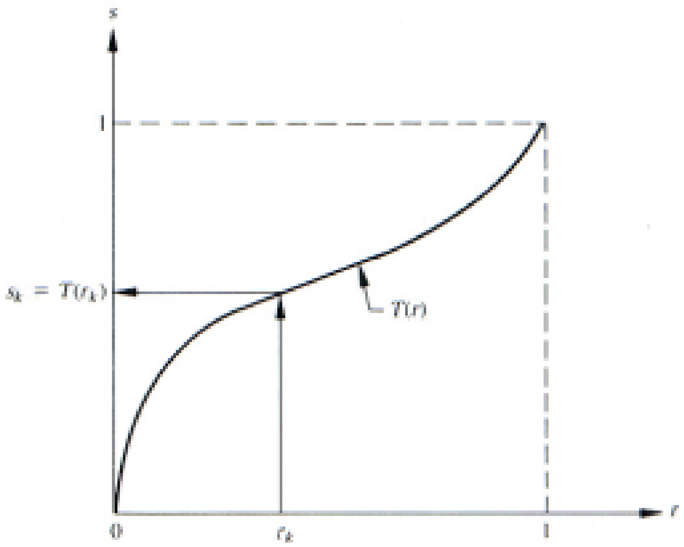
1) histogram equalization (linearization) : global processing

- r : continuos gray level with interval [0,1]
- transformation

  s = T(r)

  (a) T(r) : single-valued, monotonically increasing (the order from black to white in gray scale); preserve the order from black to white

  (b) $0 \le T(r) \le 1$ for $0 \le r \le 1$; 지정된 범위내의 값 갖는 것을 보장



- inverse transformation :

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

  : satisfied two conditions
- s, r : random variables :
  - $P_s(s)$, $P_r(r)$: prob. density function
  - from prob. theory

  $$P_s(s) = \left[P_r(r) \frac{dr}{ds} \right]_{r=T^{-1}(s)}$$
- transformation function :

$$s = T(r) = \int_0^r P_r(w)dw \qquad 0 \le r \le 1$$

: cumulative distribution function (CDF) of r

$$\frac{ds}{dr} = P_r(r)$$

$$P_s(s) = \left[P_r(r) \frac{1}{P_r(r)} \right]_{r=T^{-1}(s)}$$

$$= 1 \qquad 0 \le s \le 1$$

: uniform density !

independent of the inverse transformation function

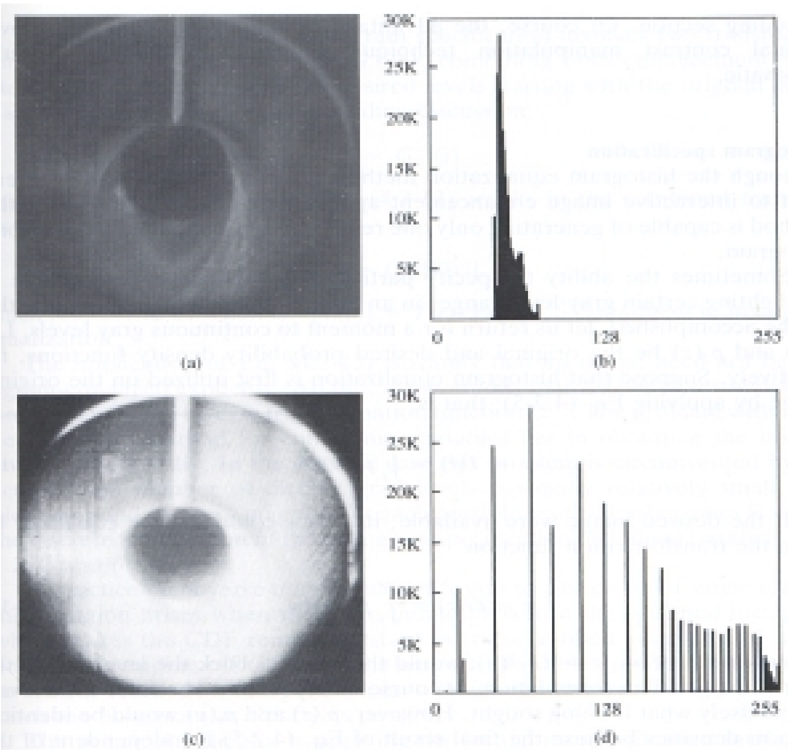
increase in the dynamic range of pixels

considerable effect in appearance of image

- discrete form :
  - prob. of k-th gray level
  - plot of $P_r(r_k)$ versus r_k : called histogram
  - histogram equalization (or linearization)
  - $S_k = T(r_k) = \sum_{j=0}^{k} \frac{n_i}{n}$

    $= \sum_{j=0}^{k} P_r(r_j) \qquad 0 \le r_k \le 1$ and k=0,1,2,…,L-1
  - inverse transformation

    $r_k = T^{-1}(s_k) \qquad 0 \le s_k \le 1$



(a) 512×512 8-bit image (b) histogram of image

(c) the result of histogram equalization (d) its histogram

- increase in dynamic range
- similar enhancement

: can be achieved by using the contrast stretching

: manual manipulation

: histogram equalization →fully automatic

2) histogram specification :

- histogram equalization :
  - only one result : uniform histogram
  - not lend itself to interactive image enhancement application

- procedure to specify particular histogram shape :

i. $s = T(r) = \int_0^r P_r(w)dw$; histogram equalization

ii. $v = G(z) = \int_0^z P_z(w)dw$; specify desired density function and obtain xform function

$P_z(z)$: pdf of desired image

$G(z)$: transformation function

→ specifies

iii. apply inverse transformation function $x = G^{-1}(s)$ to the levels obtained in step i
  - the new gray level : characterized by the specified density $P_z(z)$

- combined transformation function :

  $z = G^{-1}(s) = G^{-1}[T(r)]$

  if $G^{-1}[T(r)] = T(r) \rightarrow$ histogram equalization

- methods to construct a meaningful histogram :

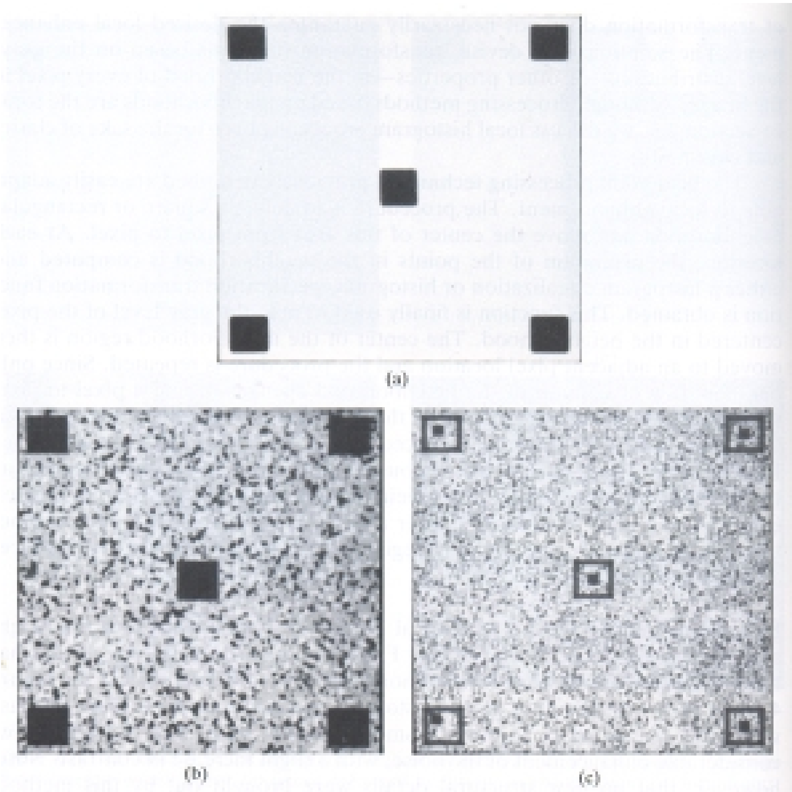
i. to specify a particular pdf (ex. Gaussian function) and then form a histogram by digitizing the given function

ii. to specify a histogram shape by mean of a graphic device (ex. Interactive screen, drawing tablet) whose output is fed into processor executing the histogram specification algorithm

ex.) p. 181

3) local enhancement :

- enhancement in details over small areas :
  - transformation functions based on the gray -level distribution in the neighborhood of every pixel in the image
  - procedure
    - ✓ define a square of rectangular neighborhood
    - ✓ move the center of the area from pixel to pixel
    - ✓ each location, histogram transformation is obtained
    - ✓ map the gray level of pixel centered in the neighborhood
    - ✓ window : moved to adjacent pixel location
    - ✓ the procedure : repeated
    - ✓ only one new row or column of neighborhood : changed
    - ✓ updating the histogram (recursive)



(a): image slightly blurred to reduce its noise center, (b): result of global histogram equalization, considerable enhancement of noise, slight increase in contrast, no new structural details, (c): local histogram equalization with 7× 7 window, reveal small square, finer noise texture

- local enhancement using pixel intensities :
  - intensity mean
    - ✓ measure of average brightness
  - variance
    - ✓ measure of contrast
  - transformation at each location (x,y)

$$g(x,y) = A(x,y) \cdot [f(x,y) - m(x,y)] + m(x,y)$$

$$A(x,y) = kM / \sigma(x,y) \qquad 0 \le k \le 1$$

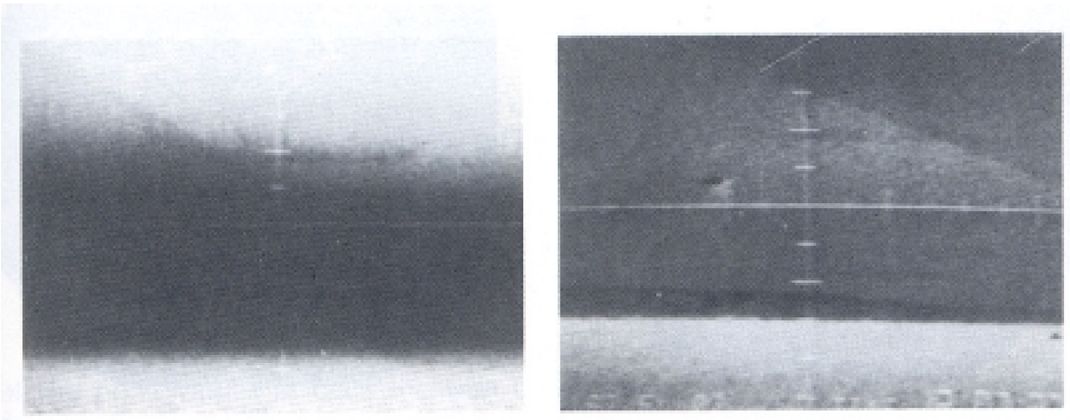
where f(x,y) : input image

g(x,y) : output

m(x,y) : gray level mean computed in a neighborhood centered at (x,y)

σ (x,y) : gray level standard deviation

M : global mean of f(x,y)



(a) (b)

4.2.3 Image Subtraction

- **application areas :**
  - **digital subtraction angiography**
  - **motion detection and tracking**
  - **background elimination**

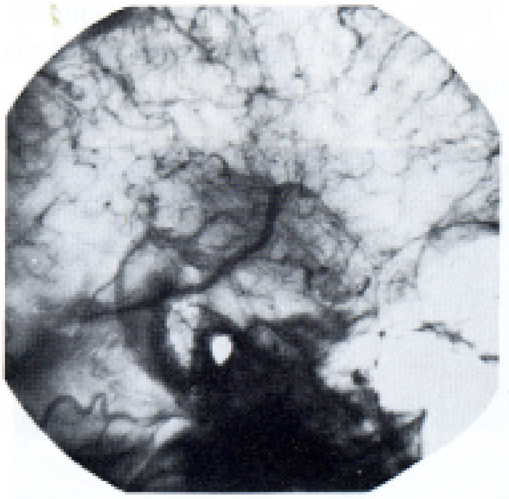
- difference between two images f(x,y) and h(x,y)

  $g(x,y) = f(x,y) - h(x,y)$

- mask mode radiography
  - $h(x,y)$: mask, image

    : image captured by intensifier located opposite as x-ray source
  - $f(x,y)$: image

    : image acquired after injection of a dye
  - $g(x,y) = f(x,y) - h(x,y)$



(a)

(b)

4.2.4 Image Averaging

- noisy image :
  - $g(x,y) = f(x,y) + \eta(x,y)$
  - noise : uncorrelated, zero mean value (assumption)
  - by averaging M different noisy images

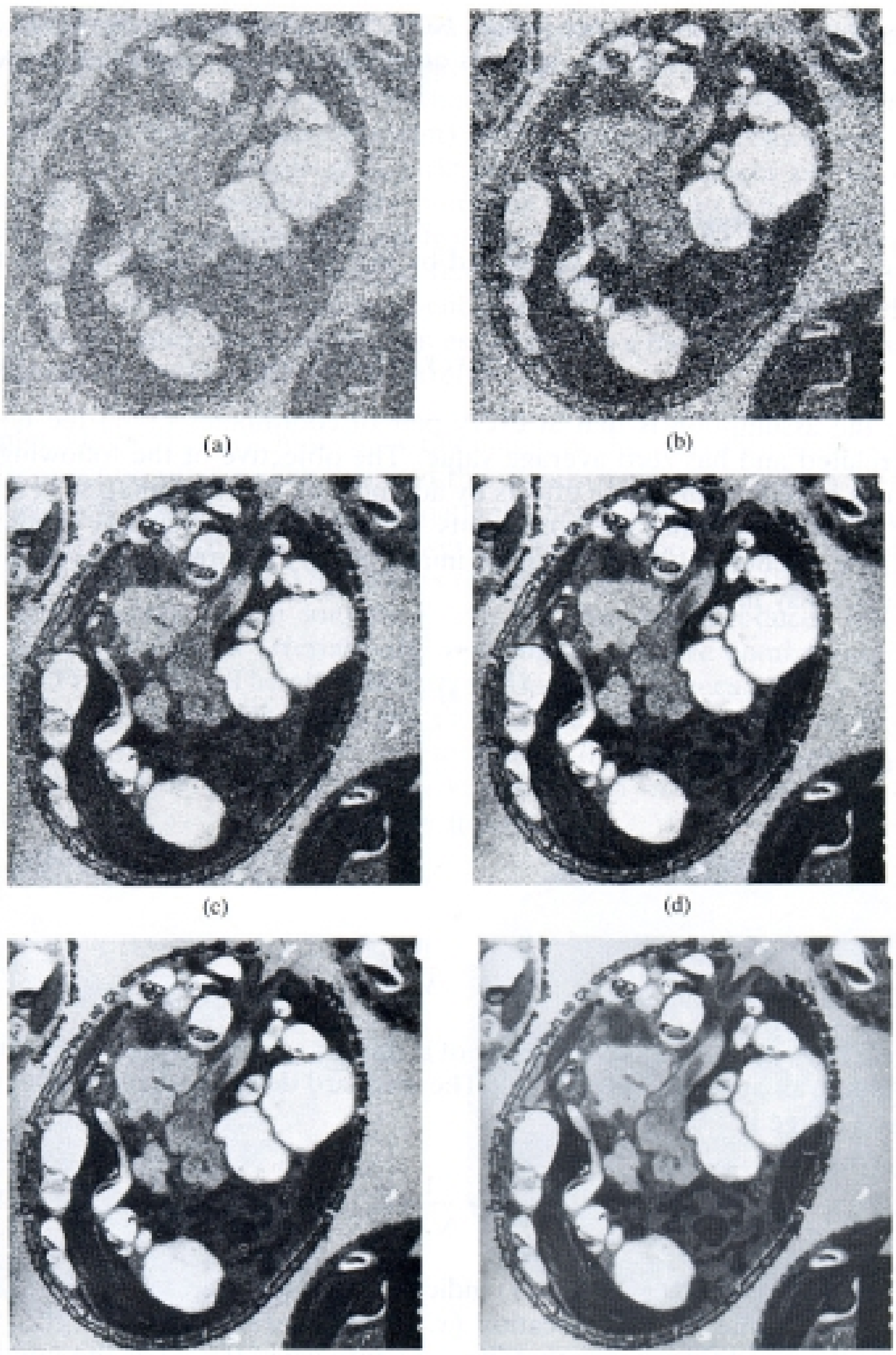
if $\hat{g}(x,y) = \frac{1}{M}\sum_{i=0}^{M} g_i(x,y)$

$\rightarrow$ $E\{\hat{g}(x,y)\} = f(x,y)$

$$\sigma^2_{\hat{g}(x,y)} = \frac{1}{M}\sigma^2_{\eta(x,y)}$$

- standard deviation at any point in average image

$$\sigma_{\hat{g}(x,y)} = \frac{1}{\sqrt{M}}\sigma_{\eta(x,y)}$$

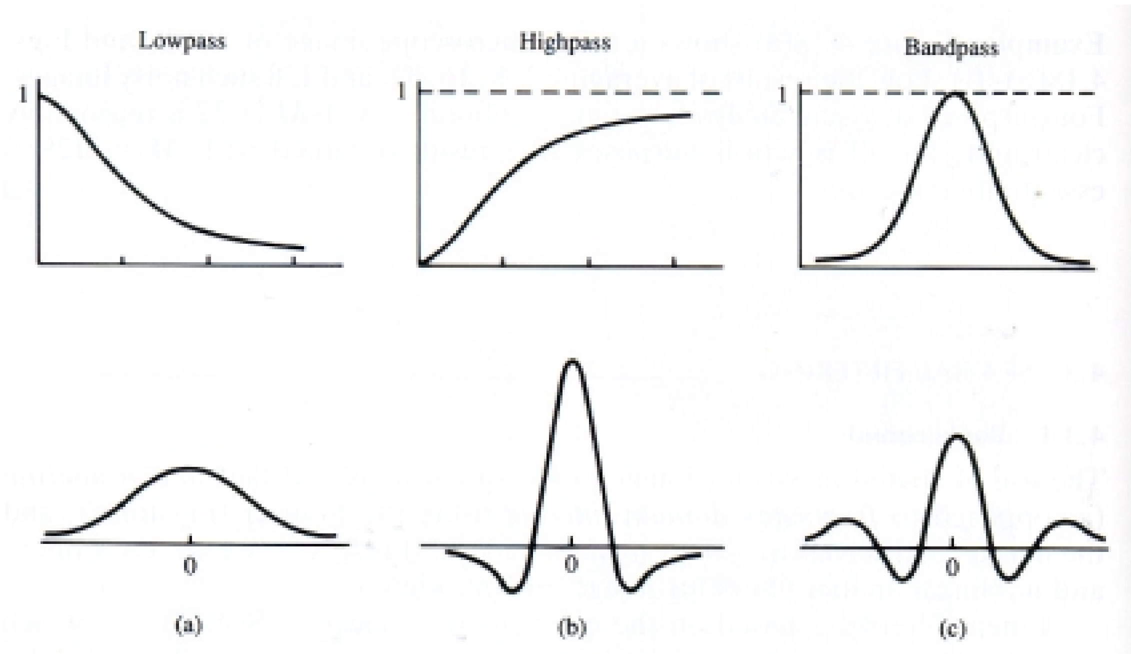

(a)
(b)
(c)
(d)
(e)
(f)

4.3 Spatial Filtering

- **use of spatial masks for image processing**
- **linear and non-linear spatial filters fro image enhancement**
- **high-frequency components: edges and sharp details or noises**
- **low-frequency components: slowly varying characteristics**

4.3.1 Background

- LPF : image blurring
- HPF :
  - eliminate low freq. Components (overall contrast, average intensity)
  - sharpening of edges
- BPF :
  - used for image restoration
  - seldom of interest in image enhancement



- filter in freq. Domain
- corresponding spatial filter

- spatial filtering :
  - to sum products between the mask coefficients. And the intensities of the pixels under mask at a specific location in the image

3×3 mask

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

  - $R = \sum_{i=1}^{9} w_i z_i$

    where w_i : mask coeffs.

    z_i : gray levels of pixels under mask

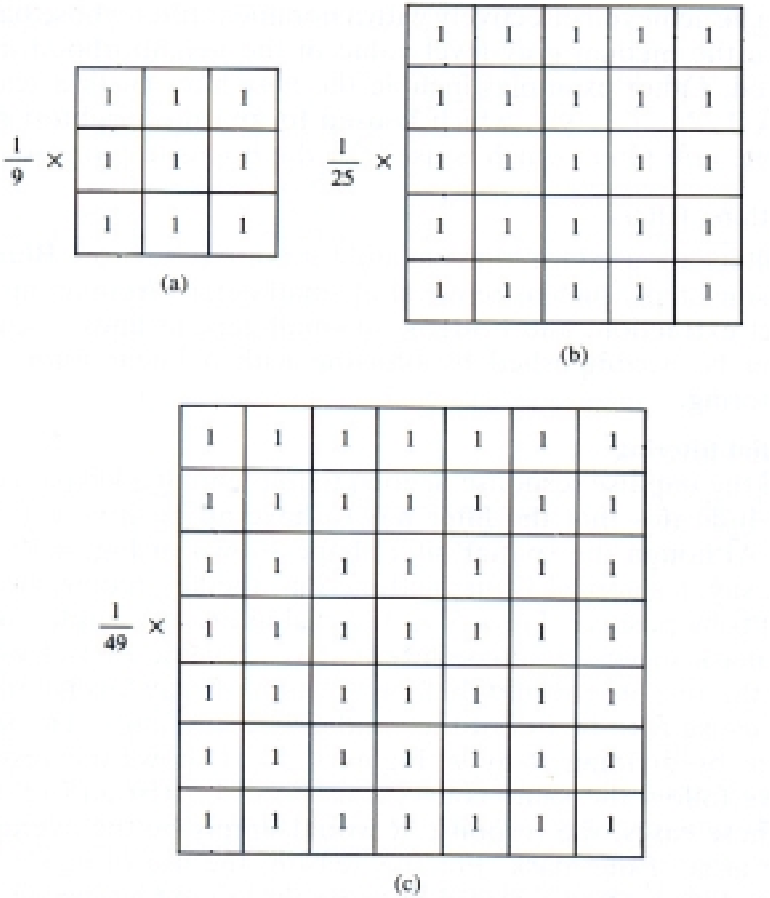
- nonlinear filters :
  - median, max, min filters

4.3.2 Smoothing filters

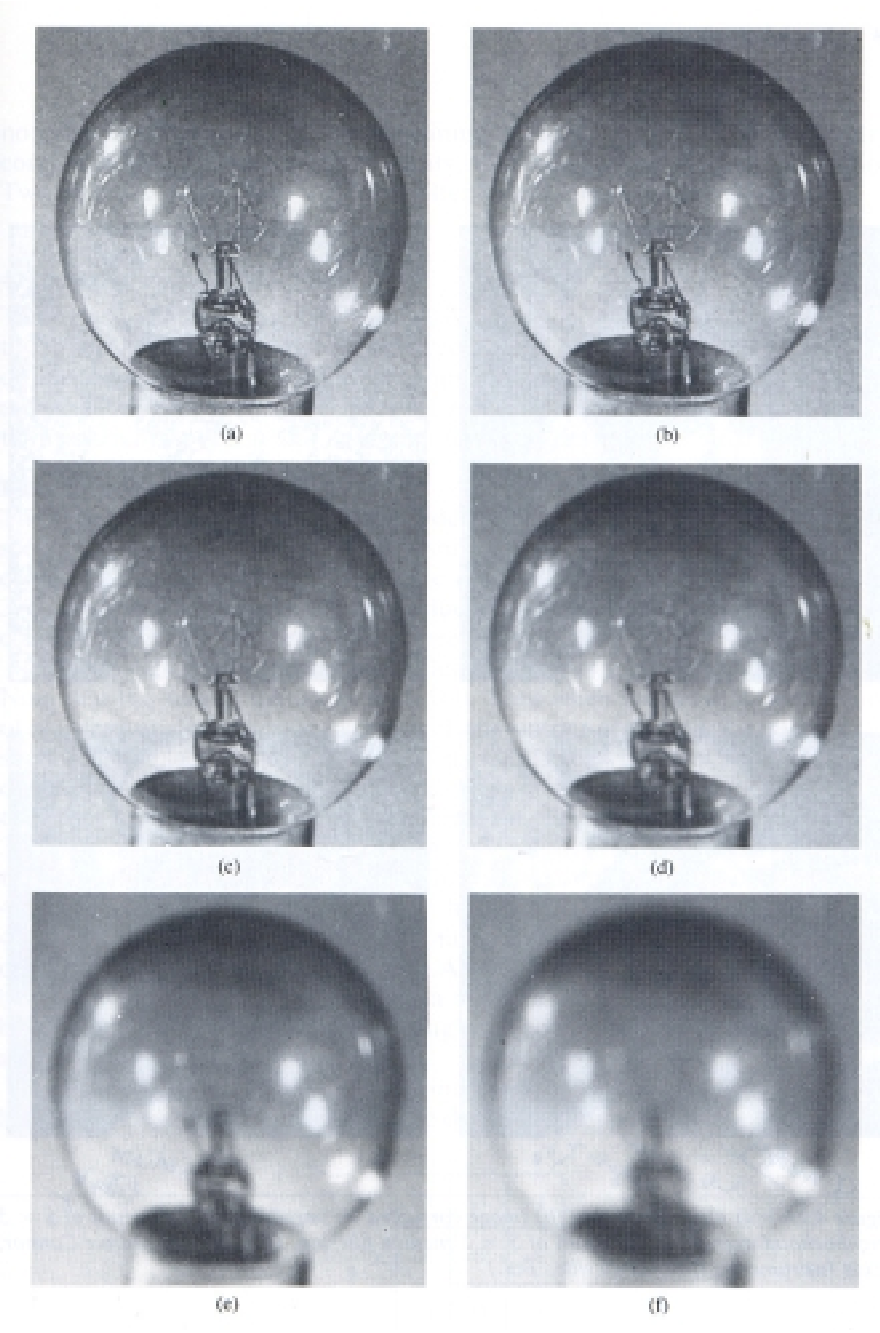
- purpose :
  - blurring, noise reduction
  - blurring
    - ✓ removal of small details from image prior to object extraction
    - ✓ bridging of small gap in lines of curves

1)Lowpass spatial filtering

- All coeffs. : positive
  - modeled by sampled Gaussian function



: neighborhood averaging



2)Median filtering

- Objective :
  - noise reduction rather than blurring
  -
- Gray level of each pixel :
  - replaced by median of gray level in mask

- Effective in reduction of strong, spikelike noise

- 3×3 mask :
  - median value : 5^{th} largest value

- equal value :
  ex) (10, 20, 20, 20, 15, 20, 20, 25, 100)
  $\xrightarrow{sorting}$ (10, 15, 20, 20, 20, 20, 20, 25, 100)
  median value : 20

- principal function of median filter :
  - force points with distinct intensities to be more like their neighbors

  ex.)