Lecture-2

EECE4810/EECE5810

Spring 2020

Lecture Summary:

1. Digital Images
2. Spatial Resolution
3. Intensity Resolution
4. Levels of Computations
    - Point
    - Local
    - Global
    - Object
5. Background
6. Look-up tables
7. Contrast Stretching

A SIMPLE IMAGE MODEL

- image - 2D light intensity function f(x,y), where the value of f at spatial coordinates (x,y) gives the intensity of the image at that point:

$$0 < f(x,y) < \infty$$

- the intensity of image f at coordinates (x,y) is the gray level (l) of the image

$$L_{min} \leq l \leq L_{max}$$

- the interval $[L_{min}, L_{max}]$ is called the gray scale;
typical scale for 8-bit images: [0,255], where 0 is considered black, 255 - white, and all intermediate values are shades of gray varying from black to white

- continuous image f(x) is approximated by equally spaced samples arranged in the form of an NxM array:

$$f(x) \approx \begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0,M-1) \\ f(1,0) & f(1,1) & \cdots & f(1,M-1) \\ \vdots & \vdots & \cdots & \vdots \\ f(N-1,0) & f(N-1,1) & \cdots & f(N-1,M-1) \end{bmatrix} \longleftarrow \text{digital image}$$

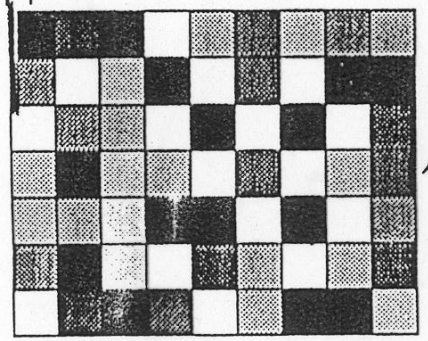
- usually N and M are integer powers of two: $N=2^n$, $M=2^k$; also - number of gray $G=2^m$; therefore number of bits required to store an image: b=N x M x m;
for example: 128 by 128 image with 256 gray levels requires 131,072 bits =16,0284 bytes =16KB of storage

The Digital Image

Spatial resolution is number of columns by number of lines.

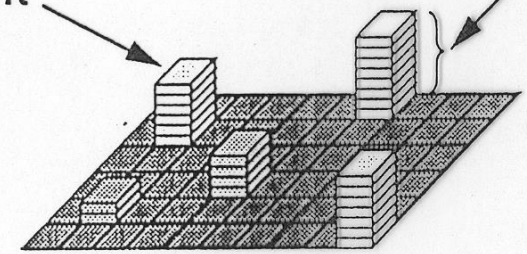
A column

A line or row



A "pixel" or picture element

Intensity resolution or "depth" is number of bits per pixel.



Examples

Spatial resolution

4 x 4
16 x 16
128 x 64
256 x 256
512 x 512
1024 x 1024
etc.

Intensity resolution

8 - bit unsigned
8 - bit signed
16 - bit unsigned
16 - bit signed
32 - bit unsigned
32 - bit signed
etc.

Signed and Unsigned Bytes

- **unsigned bytes**

Value	*Binary*
0	0000 0000
1	0000 0001
127	0111 1111
128	1000 0000
254	1111 1110
255	1111 1111

- **signed bytes**

Value	*Binary*
-128	0000 0000
-127	0000 0001
-1	0111 1111
0	1000 0000
1	1111 1110
127	1111 1111

- to change the sign of a stored number you 'flip' all of the bits (os to 1s and 1s to 0s), and then add 1 - this convention is called **twos-complement**
- you must know whether your image is signed or unsigned byte - there is no way to know by looking at the data!
- image transfer - always set the transfer mode to **binary**

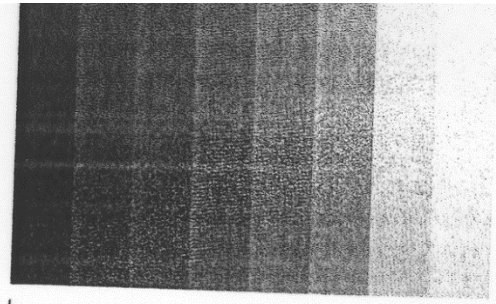
For Real Techies...

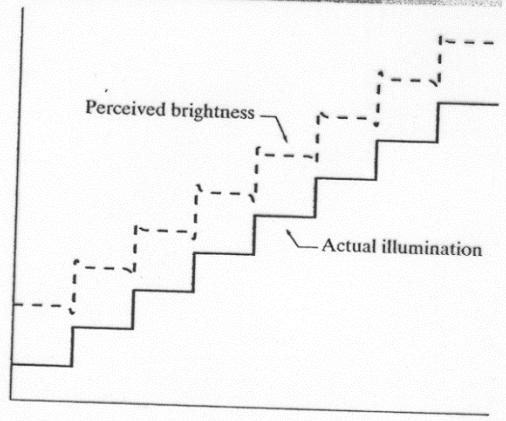
Twos-Complement vs. Ones-Complement

Most computers currently use twos-complement arithmetic as described above, but back in the computational stone ages, machines such as the Control Data Cybers used *ones-complement* arithmetic. In ones-complement, to change the sign of a stored number you just flip all of the bits. No 'add by 1.'

This was thought to be more efficient, but it created a problem— now there were two representations for zero: 00000000b and 11111111b. Programs had to check for 'positive' *zero and a* 'negative' zero (!).

Ask an old Cyber programmer about negative zero. Carefully.

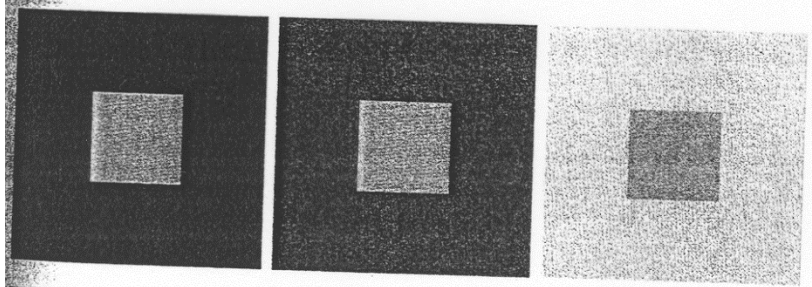




b

FIGURE 2.7
(a) An example showing that perceived brightness is not a simple function of intensity. The relative vertical positions between the two profiles in (b) have no special significance; they were chosen for clarity.

However, they appear to the eye to become darker as the background gets lighter. A more familiar example is a piece of paper that seems white when lying on a desk, but can appear totally black when used to shield the eyes while looking directly at a bright sky.



a b c

FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

Effect of Image size when the number of allowable gray levels is kept to constant

EXAMPLE 2.2: Typical effects of varying the number of samples in a digital image.

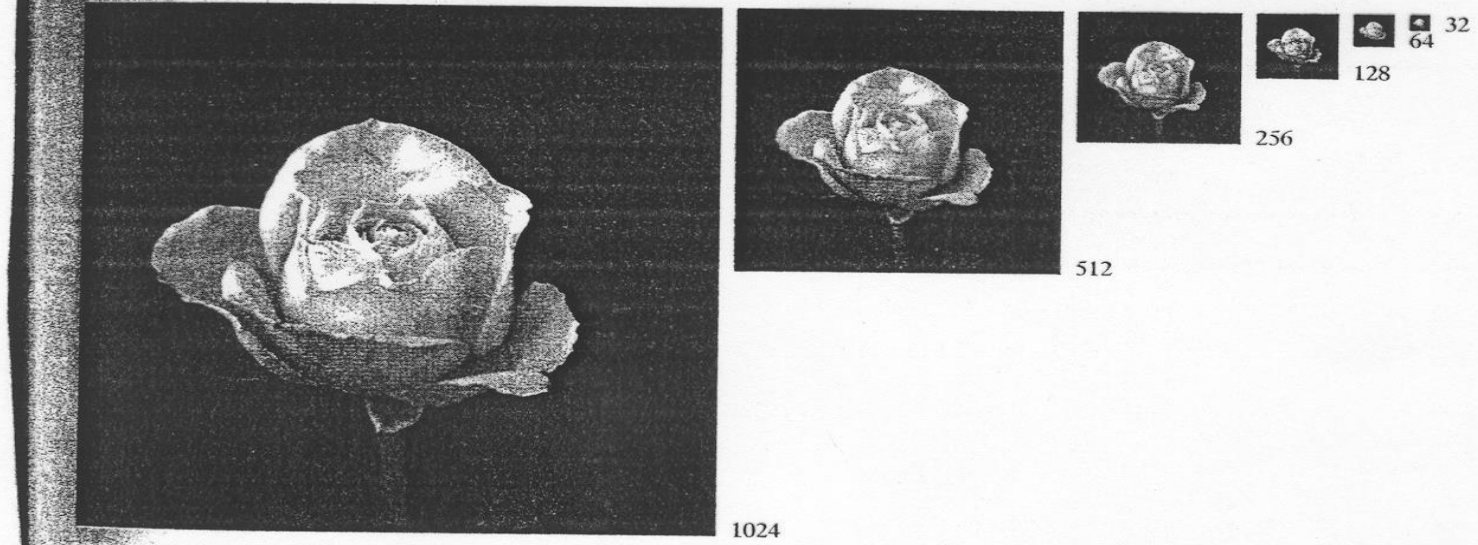
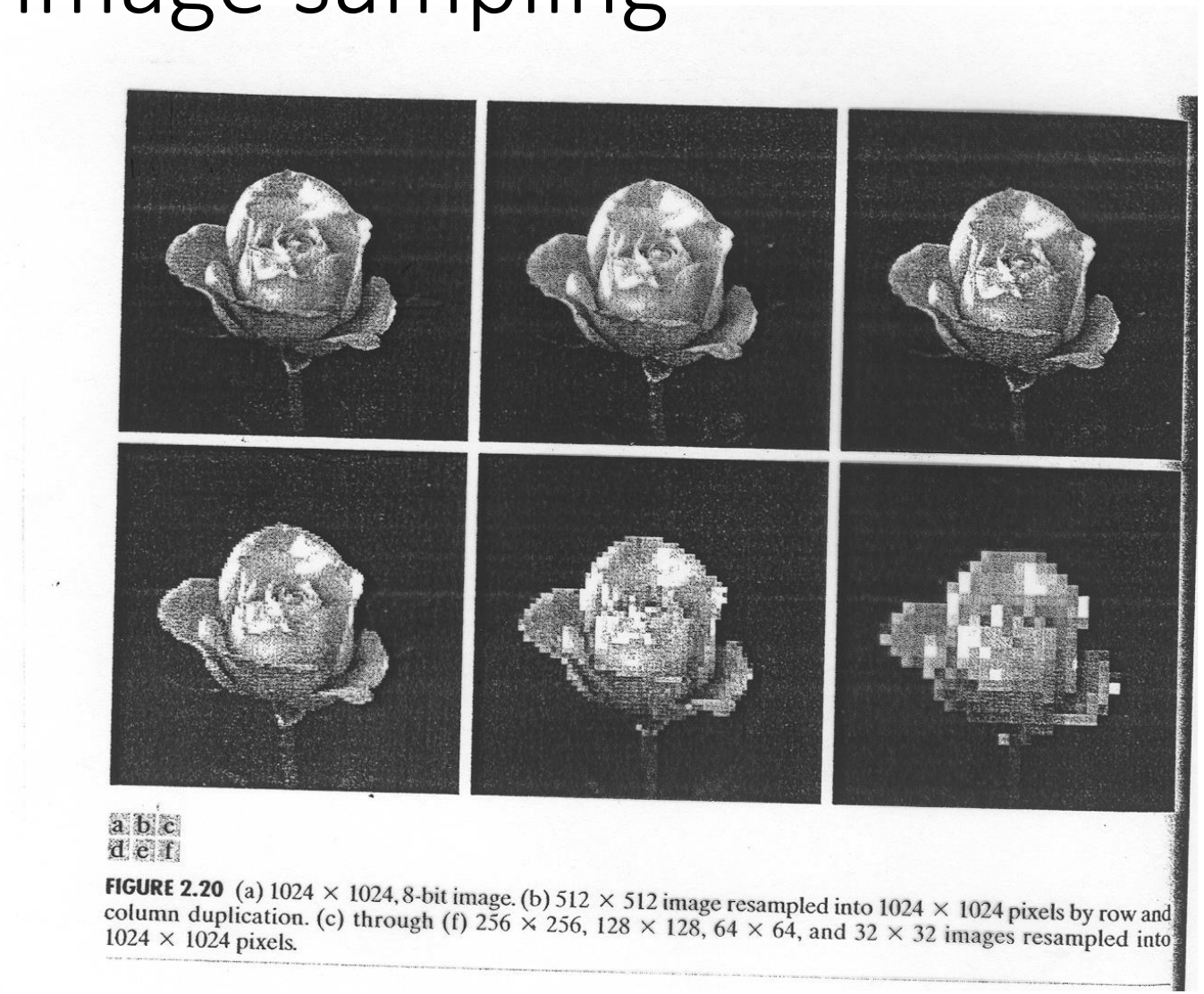


FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

Effect of image sampling



a b c
d e f

FIGURE 2.20 (a) 1024 × 1024, 8-bit image. (b) 512 × 512 image resampled into 1024 × 1024 pixels by row and column duplication. (c) through (f) 256 × 256, 128 × 128, 64 × 64, and 32 × 32 images resampled into 1024 × 1024 pixels.

Effect of variation of the number of pixels used

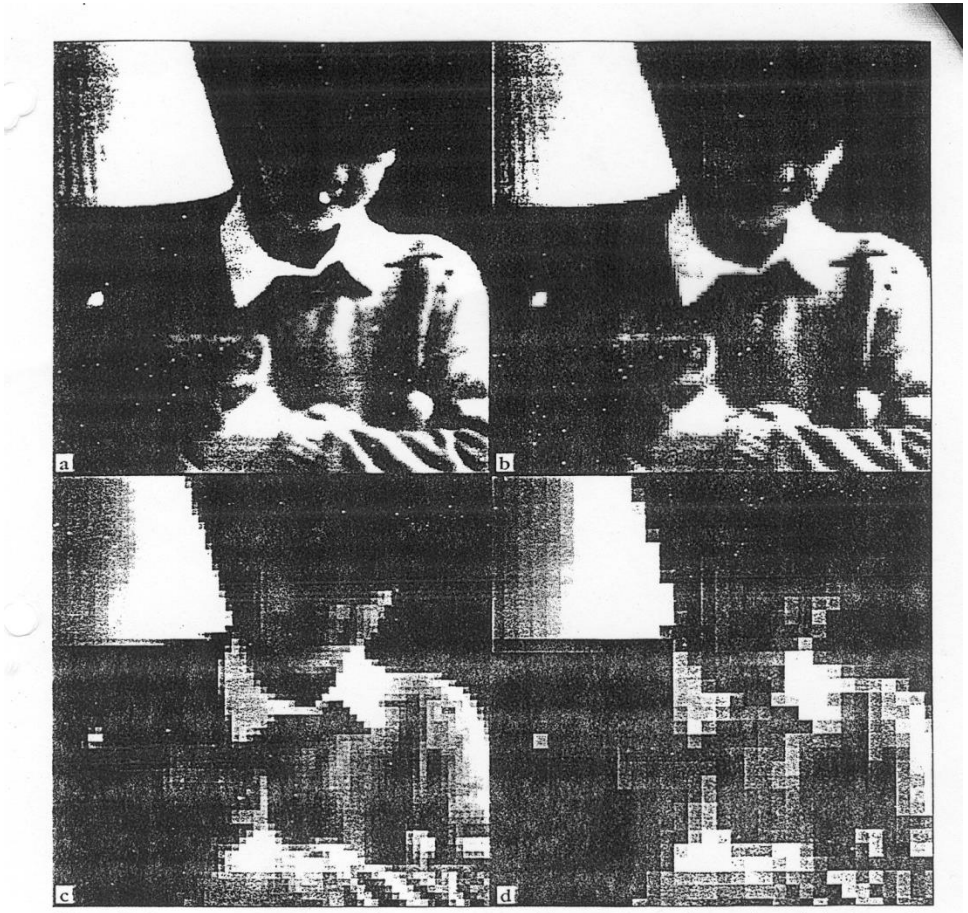


Figure 25. Four representations of the same image, with variation in the number of pixels used:
a) 256×256: b) 128×128: c) 64×64: d) 32×32.
In all cases, a full 256 grey values are retained. Each step in coarsening of the image is accomplished by averaging the brightness of the region covered by the larger pixels.

Effect on the image of the number of gray levels used

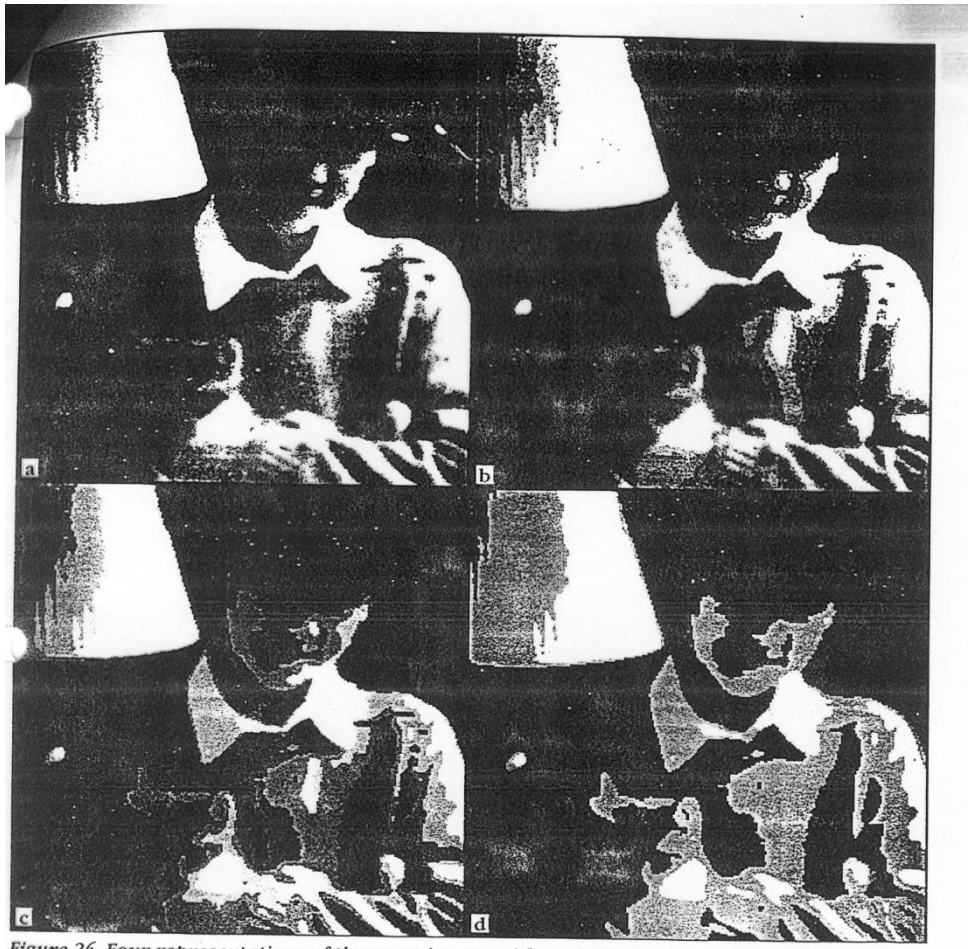


Figure 26. Four representations of the same image, with variation in the number of grey levels used: a) 32; b) 16; c) 8; d) 4.
In all cases, a full 256×256 array of pixels are retained. Each step in the coarsening of the image is accomplished by rounding the brightness of the original pixel value.

Levels of Computation

an image usually consists of several objects; a vision application usually involves computing certain properties of an object, not the image as a whole

first, the individual objects must be identified - using algorithms for connectivity and segmentation

point level processing - operations that produce an output based on only a **point** in an image

local level processing - operations that produce an output image in which the intensity at a point depends on the **neighborhood** of the corresponding point in the input image

global level processing - operations that produce an output (not necessary an output image) which depends on the whole input image

object level processing - operations that produce object characteristics, such as size, average intensity, shape. etc.

Point Level Processing

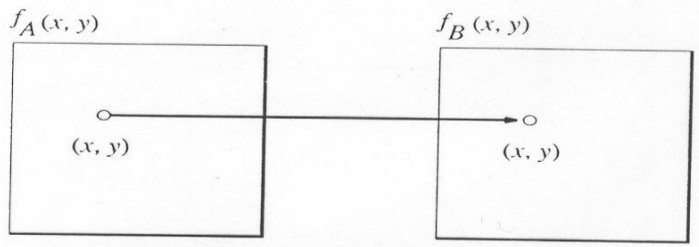
Point processes are the simplest of basic image processing operations. A point operation takes a single input image into a single output image in such a way that each output pixel's gray level depends only upon the gray level of the corresponding input pixel. Thus, a point operation cannot modify the spatial relationships within an image.

$$f_B[i,j] = O_{point}\{f_A[i,j]\}$$

where f_A - input image and f_B - output image

- **point operations transform the gray scale of an image**
- **linear and nonlinear point operations**
- **they are useful in photometric calibration, display calibration, enhancement and histogram modification**
- **examples:**

Contrast Stretching
Image Negatives
Intensity-level Slicing
Bit-plane Slicing
Histogram Equalization



called binary image

←Thresholding is done using Point operation

There is a difference between image1 and image3:

image1

-

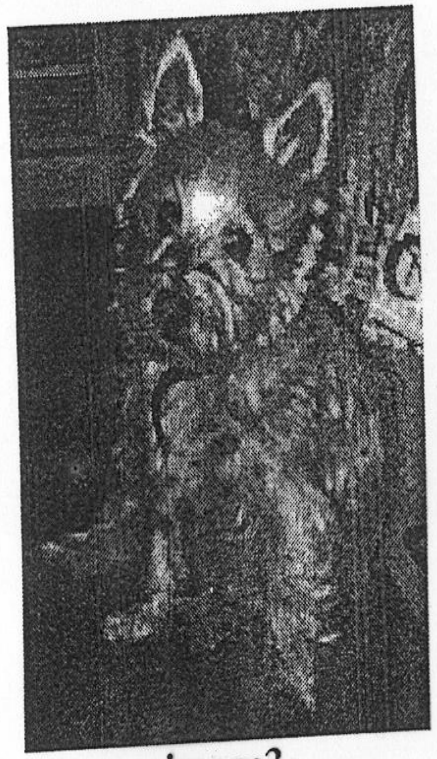


image3

=

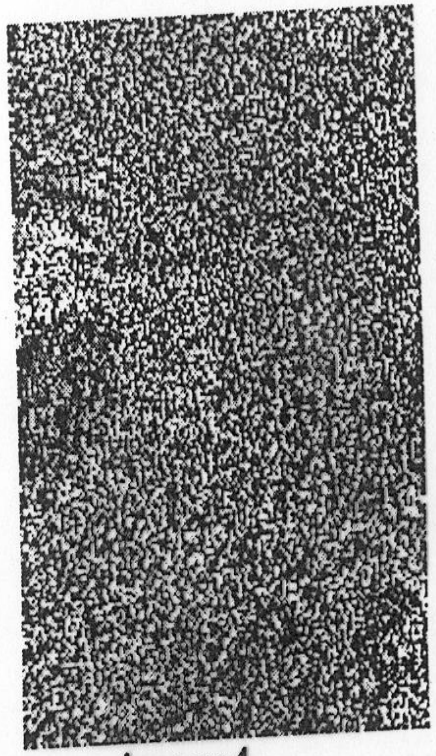


image4

Local Level Processing

A local operation takes a single input image into a single output image in such a way that each output pixel's gray level depends upon the gray levels of the pixels in the neighborhood of the corresponding input pixel.

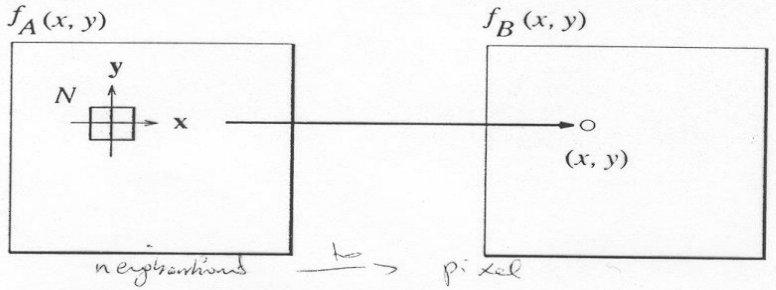
$$f_B[i,j] = O_{local}\{f_A[i_k, j_l];\ [i_k, j_l] \in N[i,j]\}$$

where f_A - input image and f_B - output image $N[i,j]$ - neighborhood of [i,j]

area processing typically is formulated in the context of so-called **mask** operations (the terms **template, kernel, window, filter,** and **convolution mask** are also used to denote a mask); mask is an array of numbers (typically 3x3 or 5x5, etc.); mask is usually very small with respect to the processed image; mask values are called coefficients; values of coefficients determine the nature of the process

examples:

smoothing
sharpening
median
max and min



←smoothing

GLOBAL LEVEL PROCESSING

A global operation takes a single input image into a single output image (or a single symbolic output) in such a way that the output depends on the whole input image

$$P = O_{global}\{f_A[i,j]\}$$

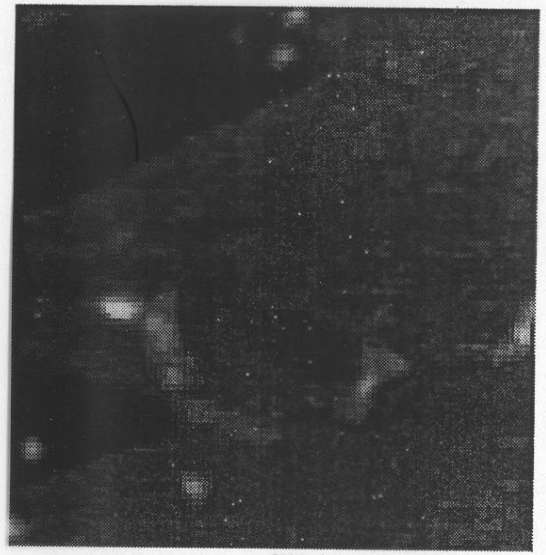
where f_A - input image and **P** - output image or symbolic output

- **examples:**

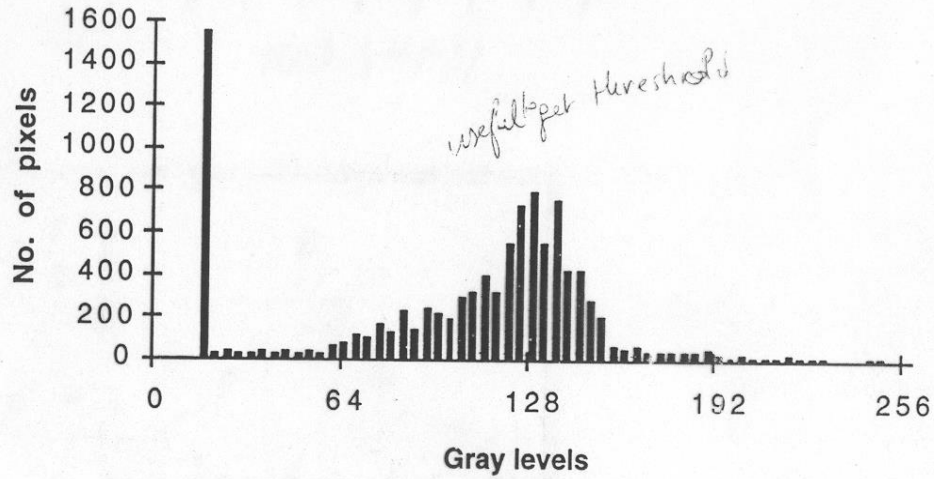
histogram
Fourier transform
image subtraction
averaging
logical operations

Histogram

- gray level **histogram** of an image - a function showing for each gray level the number of pixels in the image that have that gray level; it is simply a bar graph of the pixel intensities



CT image



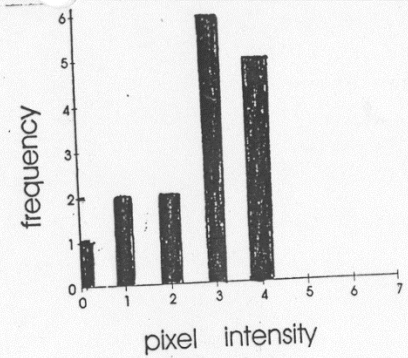
Histogram of the CT image

- histogram gives us a convenient, easy-to-read representation of concentration of pixels versus intensity in an image
- dynamic range - an range of intensity values that occur in an image
- contrast stretching - if image has low-dynamic range; low-dynamic range can result from poor illumination, lack of dynamic range in imaging sensor, wrong setting of the sensor parameters, etc.
- compression of dynamic range - if the dynamic range of the image far exceeds the capability of the display device

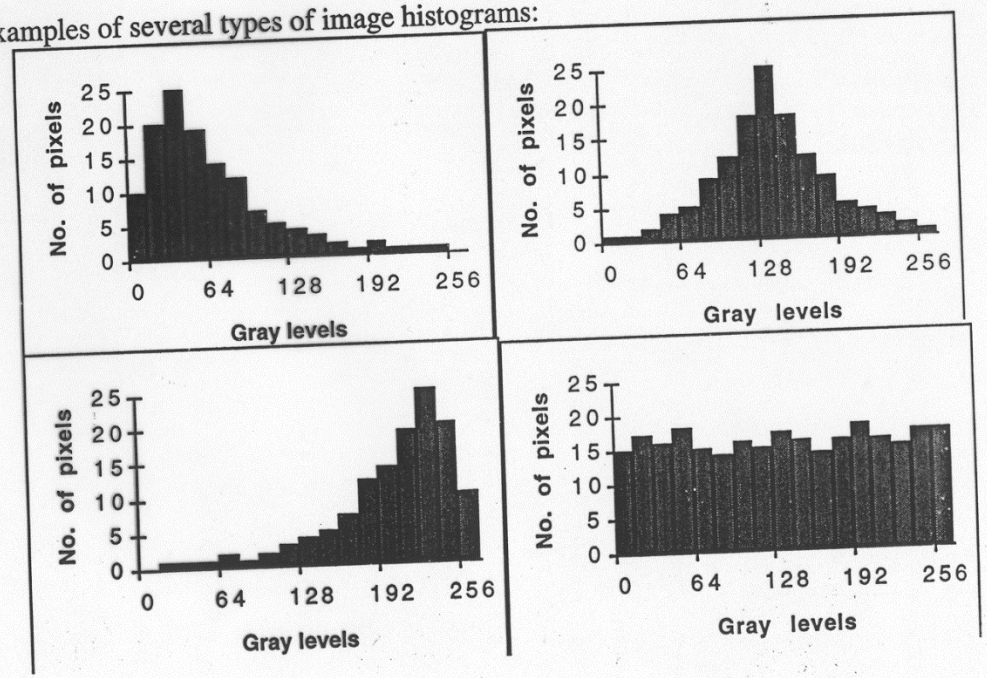
Histogram calculation:

4	4	3	3
4	4	3	3
4	1	2	3
0	1	2	3

image

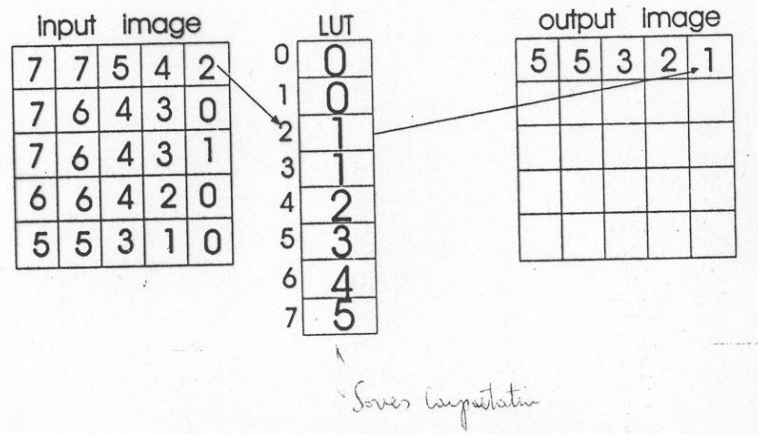


Examples of several types of image histograms:



Lookup Tables (LUTs)

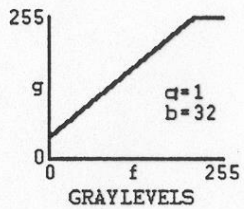
- LUTs are arrays that use the current pixel value as the array index; the new value is the array element pointed by this index:



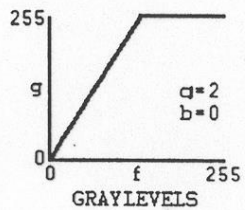
- computational savings - using LUTs avoids needless repeated computations for each pixel; for example, if you were to add some value to every pixel in a 512 x 512 image, it would require 262,144 operations without LUT, and 256 operations with LUT

Examples

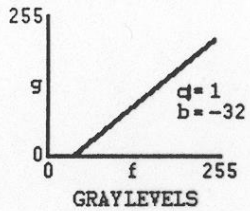
linear LUTs



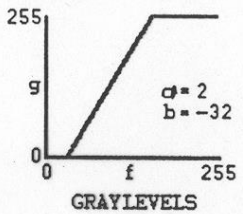
(a)



(b)



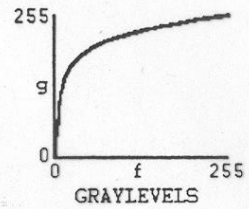
(c)



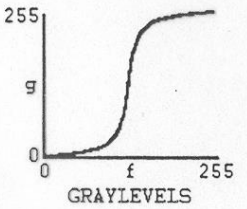
(d)

$g = a * f + b$

nonlinear LUTs



(a)



(b)

$g = 31.9 * \log_2(f+1)$

Contrast Stretching