ECC419
IMAGE PROCESSING

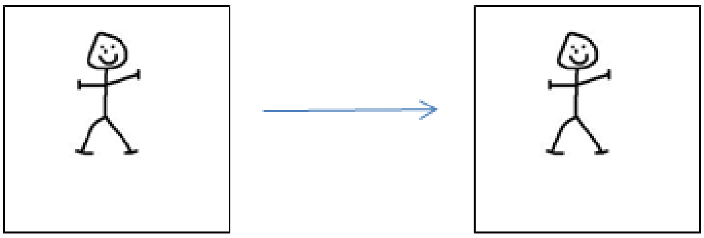
INTRODUCTION

Image Processing

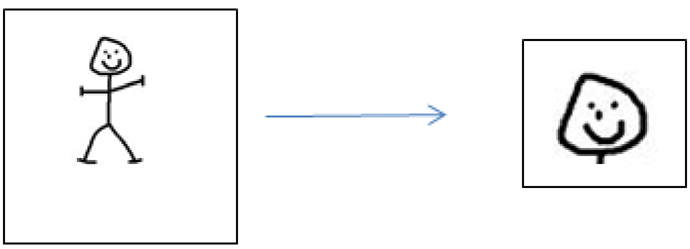
Image processing is a subclass of signal processing concerned specifically with pictures.

Digital Image Processing, process digital images by means of computer, it covers *low-*, *mid-* and *high-level* processes.

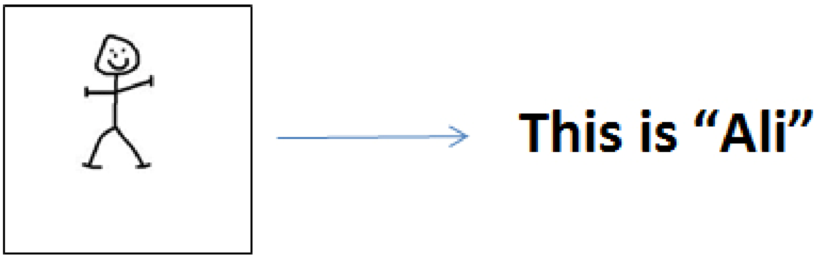
Low-level: Low level processes involve primitive operations, such as image preprocessing to reduce noise, contrast enhancement and image sharpening. A low-level process is characterized by the fact that both its inputs and outputs typically are images.



Mid-Level: Mid-level processes on images involve task such as segmentation (partitioning an image into regions or objects), description of those objects to reduce them to a form suitable for computer processing and classification (recognition) of individual objects. A mid-level process is characterized by the fact that its inputs generally are images, but its outputs are attributes extracted from those images (e.g. edges, contours, and the identity of individual objects).



High-Level: High-level processing involves "making sense" of an ensemble of recognized objects, as in image analysis, and at the far end of the continuum, performing the cognitive functions normally associated with human vision.



The aim of image processing:

- Improve image quality for human perception and/or computer interpretation.
- Processing of image data for storage, transmission and representation for autonomous machine perception.

There are other fields deal with images:

- Computer graphics: the creation of images.
- Computer vision: the analysis of image content

Digital Image

Digital image is a two-dimensional function *f(x,y)*, where x and y are spatial coordinates. The amplitude of *f* is called intensity or gray level at the point *(x,y)*.

Image Size = max*x* X max*y* e.g. 640x480, 512x512, 9x9

Pixel: **Pi**cture **El**ement: is a single point in a graphic image.

Grayscale Image: is an image in which the value of each pixel is a single sample, that is, it carries only intensity information. Pixel intensity value $f(x,y) \in [0,255]$ in 8-bit grayscale image.

Image Acquisition: The first stage of any vision system is the image acquisition stage. After the image has been obtained, various methods of processing can be applied to the image to perform the many different image processing.
However, if the image has not been acquired satisfactorily then the intended tasks may not be achievable, even with the aid of some form of image enhancement.

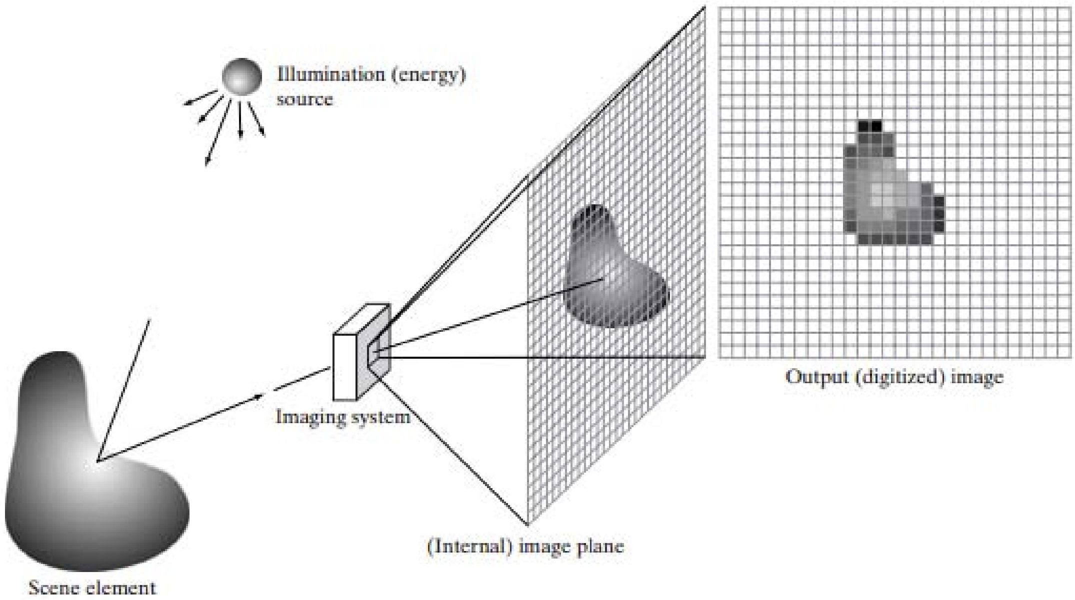


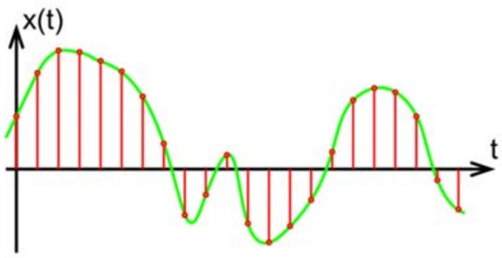
Image properties depend on:

- Image acquisition parameters
    - camera distance, viewpoint, motion
    - camera intrinsic parameters (e.g. lens aberration)
    - number of cameras
    - illumination
- Visual properties of the 3D world captured

Sampling

Sampling is the spacing of discrete values in the domain of a signal.

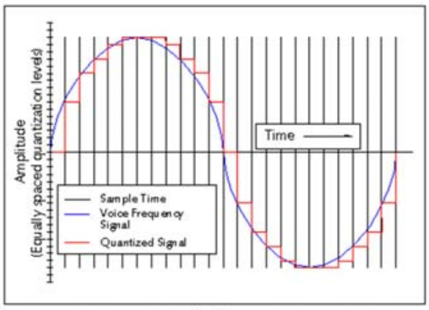
Sampling rate: how many samples are taken per unit of each dimension e.g.samples per second, frames per second, etc.



Quantization

Spacing of discrete values in the range of a signal.

Usually thought of as the number of bits per sample of the signal, e.g. 1 bit per pixel (b/w images), 16 bit audio, 24 bit color images, etc.



quantization

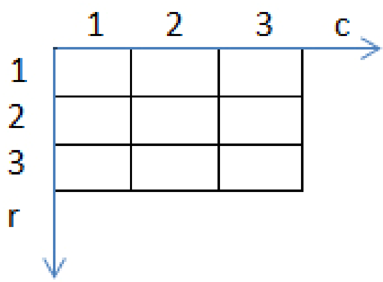
Resolution

Resolution (how much you can see the detail of the image) depends on sampling and gray levels.

- The bigger the sampling rate (n) and the grayscale (g), the better the approximation of the digitized image from the original.
- The more the quantization scale becomes, the bigger the size of the digitized image.

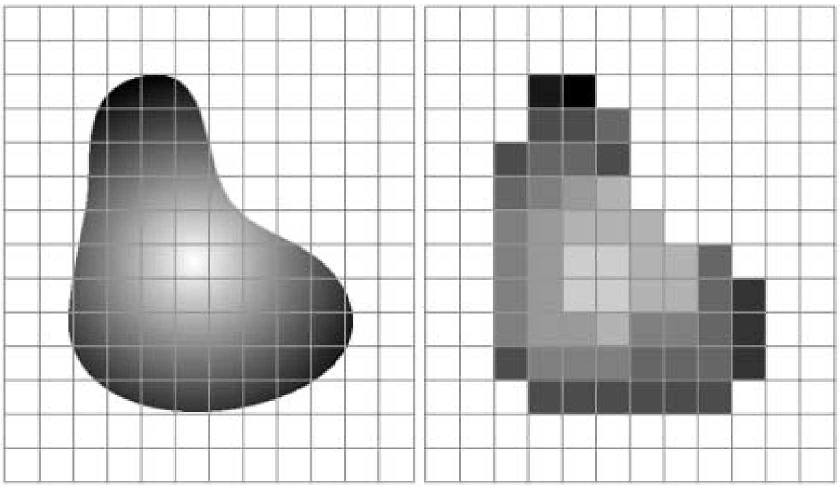
The Pixel Coordinate System:

For pixel coordinates, the first component *r* (the row) increases downward, while the second component *c* (the column) increases to the right. Pixel coordinates are integer values and range between 1 and the length of the row or column.

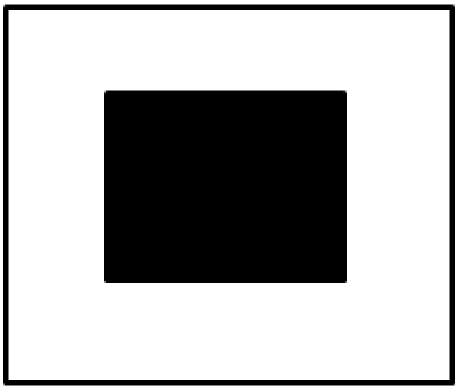


Digital Image Representation

A digital image can be considered as a matrix whose row and column indices identify a point in the image and the corresponding matrix element value identifies the gray level at the point.



Example 9x9 8-bit grayscale image:

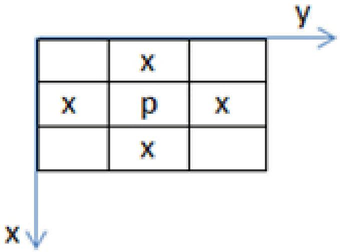


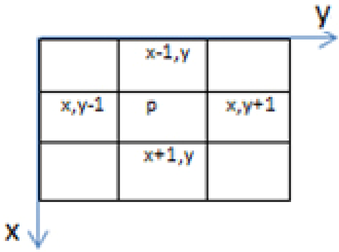
255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255
255	255	0	0	0	0	0	255	255
255	255	0	0	0	0	0	255	255
255	255	0	0	0	0	0	255	255
255	255	0	0	0	0	0	255	255
255	255	0	0	0	0	0	255	255
255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255

Neighbors of a Pixel:

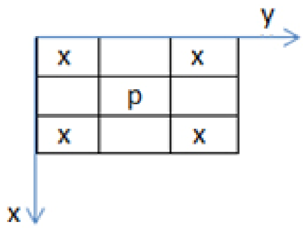
A pixel *p* at coordinate *(x,y)* has:

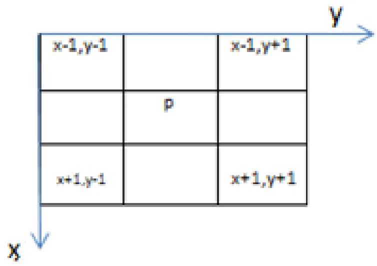
- $N_4(p)$ = 4 neighbors of *p*:
(x+1,y), (x-1,y), (x,y+1), (x,y-1)



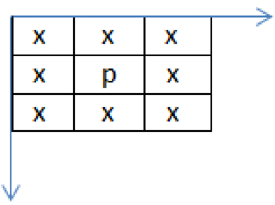


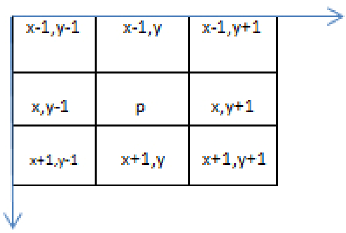
- $N_D(p)$ = 4 diagonal neighbors of *p*:
(x+1,y+1), (x-1,y-1), (x-1,y+1), (x+1,y-1)





- $N_8(p)$ = 8 neighbors of *p*:





Types of operations:

The types of operations that can be applied to digital images to transform an input image *a[m,n]* into an output image *b[m,n]* (or another representation) can be classified into three categories:

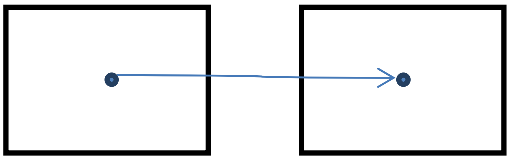
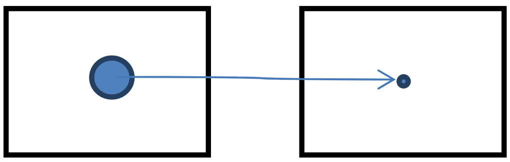
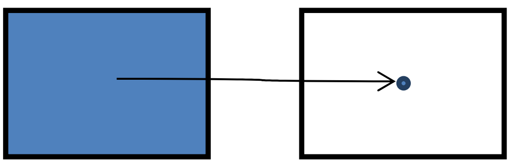
Operation	Characterization
Point	The output value at a specific coordinate is dependent only on the input value at that same coordinate. 
Local	The output value at a specific coordinate is dependent on the input values in the neighborhood of that same coordinate. 
Global	The output value at a specific coordinate is dependent on all the values in the input image. 

IMAGE INTERPOLATION

Interpolation works by using known data to estimate values at unknown points. Common interpolation algorithms can be grouped into 2 categories: adaptive and non-adaptive. Adaptive methods change depending on what they are interpolating whereas non-adaptive methods treat all pixels equally.

Non-adaptive algorithms include nearest neighbor, bilinear, bicubic etc. Depending on their complexity, these use anywhere from 0 to 256 (or more) adjacent pixels when interpolating. The more adjacent pixels they include, the more accurate they can become, but this comes at the expense of much longer processing time. These algorithms can be used to both distort and resize a photo.

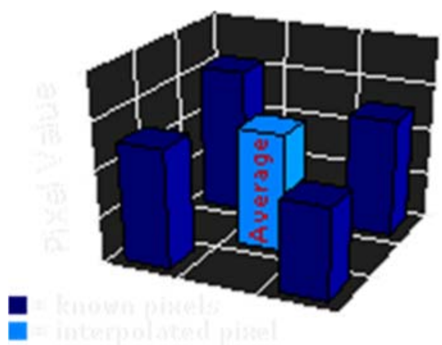
Adaptive algorithms include many proprietary algorithms in licensed software such as Qimage, PhotoZoom Pro etc. These algorithms are primarily designed to maximize artfact-free detail in enlarged photos, so some cannot be used to distort or rotate an image.

NEAREST NEIGHBOR INTERPOLATION

Nearest neighbor is the most basic and requires the least processing time of all the interpolation algorithms because it only considers one pixel – the closest one to the interpolated point.

BILINEAR INTERPOLATION

Bilinear interpolation considers the closest 2x2 neighborhood of known pixel values surrounding the unknown pixel. It then takes a weighted average of these 4 pixels to arrive at its final interpolated value. This results in much smoother looking images than nearest neighbor.



BICUBIC INTERPOLATION

Bicubic goes one step beyond bilinear by considering the closest 4x4 neighborhood of known pixels- for a total of 16 pixels. Since these are at various distances from the unknown pixel, closer pixels are given a higher weighting in the calculation. Bicubic produces noticeably sharper images than the previous two methods, and is perhaps the ideal combination of processing time and output quality. For this reason it is a standard in many image editing programs (including Adobe Photoshop), printer drivers and in-camera interpolation.

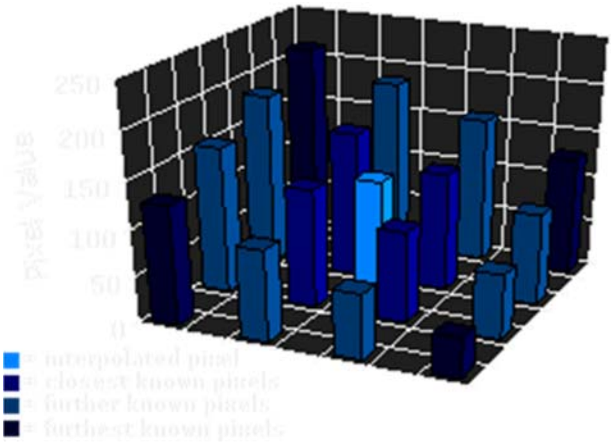


IMAGE ENHANCEMENT

Preview
The principal objective of enhancement is to process an image so that the result is more suitable than the original image for a specific application.

Why for a specific application?
Image enhancement techniques are application dependent because a method that is useful for enhancing x-ray images may not be suitable for images of space transmitted by a space probe.

Image Enhancement techniques fall into broad categories:

- Spatial Domain Methods
  It refers to the image itself, and approaches in this category are based on direct manipulation of pixels in an image.

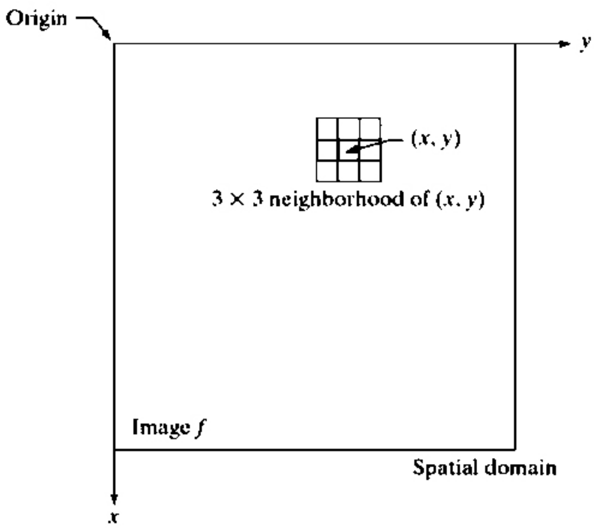
- Frequency Domain Methods
  Frequency Domain techniques are based on modifying Fourier Transform of an image.

Spatial Domain Image Enhancement

Spatial Domain processes will be denoted by the expression:

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

where*g(x,y)* is the output image, *T* is an operator over some neighborhood of *(x,y)* and *f(x,y)* is the input image.



If we use T by a neighborhood size 1x1, it becomes a gray-level (also called intensity or mapping) transformation function and can be rewritten as:

$$s = T(r)$$

where *s* is the gray level of *g(x,y)* at *(x,y)* and *r* is the gray level of *f(x,y)* at *(x,y)*.

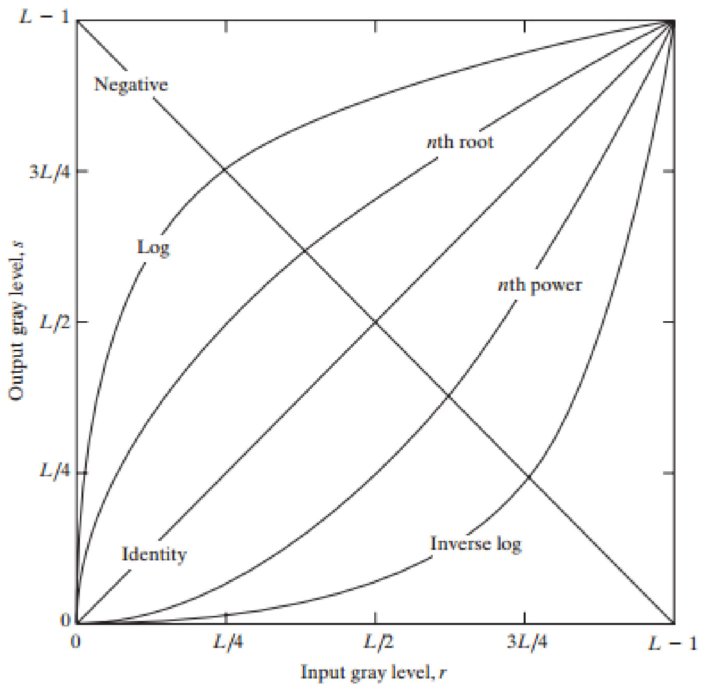
Basic Grey Level Transformations in Spatial Domain:

- Image Negatives
- Logarithmic Transformations
- Power-Law Transformations
- Piecewise Linear Transformation Functions

Image Negatives: are used to obtain photographic negative of an image by applying the negative transformation function.

$$s = L - 1 - r$$

wheres is the output pixel, *L* is the gray level range of image (256) and *r* is the input pixel.



Ex:

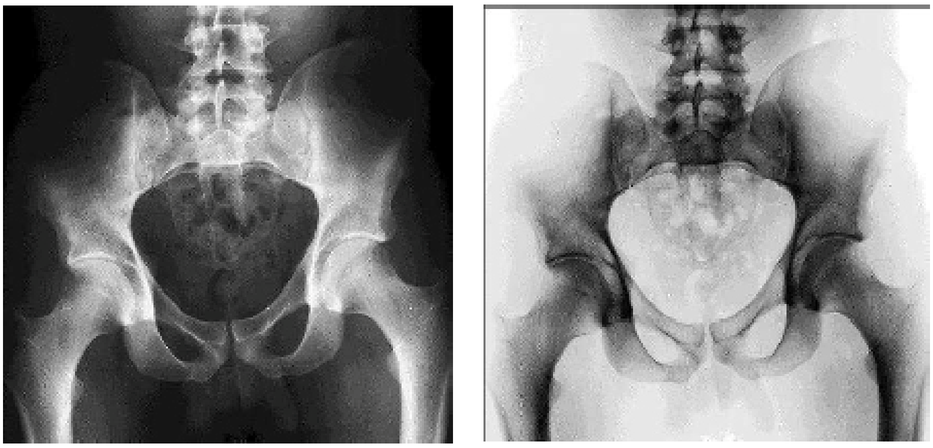
Original 2x2 image

15	130
200	0

f(1,1) = 256-1-15= 240
f(1,2) = 256-1-130 = 125
f(2,1) = 256-1-200 = 55
f(2,2) = 256-1-0= 255

output image

240	125
55	255

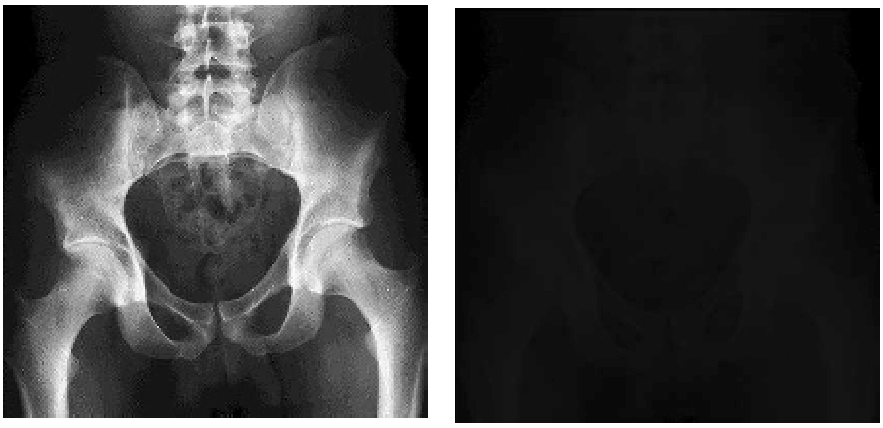


Example of Image Negatives

Logarithmic Transformations: are used to expand the spectrum of dark pixels while compressing the spectrum of higher value pixels in an image.
General form of Logarithmic Transformations:

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

where *s* is the output pixel, *c* is the constant and *r* is the input pixel.



Example of Logarithmic Transformation (c=1)

Power-Law Transformation: provides more flexible transformation curve than Logarithmic Transformation, according to the value of *c* and *γ* (gamma).

$$s = cr^{\gamma}$$

where$s$ is the output pixel, c is the constant and r is the input pixel.

- **If γ<1:**
  - Expands the spectrum of dark pixels.
  - Compresses the spectrum of higher value pixels.

- **If γ>1:**
  - Compresses the spectrum of dark pixels.
  - Expands the spectrum of higher value pixels.

- **If γ=1:**
  - Identity transformation.

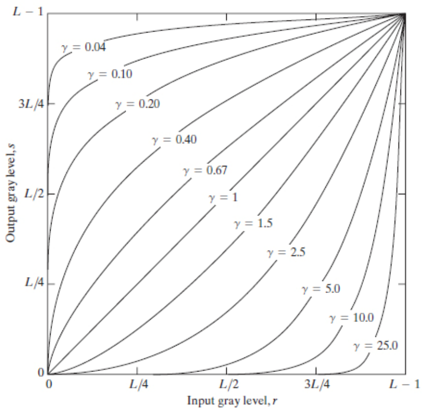


Image after power-law transformation with $\gamma = 0.8$

Image after power-law transformation with $\gamma = 1.2, c = 1$

Piecewise Linear Transformation Functions: consists of several functions such as contrast stretching, gray-level slicing and bit-plane slicing which are used for image enhancement.

Contrast Stretching is one of the simplest and most important approaches for Piecewise Linear Transformation Functions. During image acquisition, images may become low-contrast because of poor illumination. The idea of contrast stretching is to increase the dynamic range of the gray levels in the image being processed and typical formula is:

$$s = (r - c)\left(\frac{b - a}{d - c}\right) + a$$

where*s* is output pixel, *r* is the input pixel, *a* and *b* is the lower and upper limits respectively and *c* and *d* is the lowest and the highest pixel value in an image respectively.

Original low-contrast image

Enhanced image after contrast stretching

Histogram Processing in Spatial Domain

It is an important approach for image enhancement and it is basis for numerous techniques. Histogram is the discrete function of digital image in *k* as *[0, L-1]* and it is defined as:

$$h(r_k) = n_k$$

where $r_k = k^{th}$ gray level and n_k is the number of pixels in the image having gray level r_k.

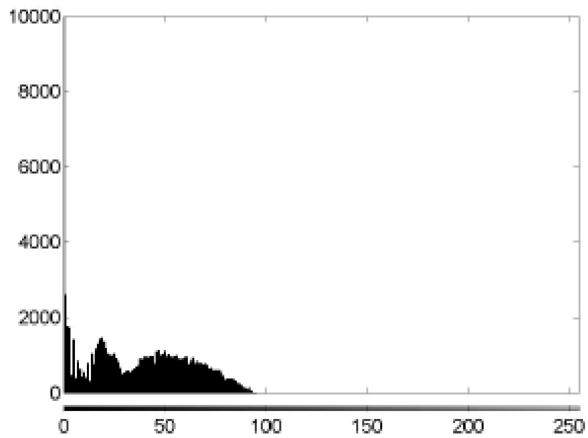
Normalization of Histogram:
Probability of occurrence of gray level $r_k(p(r_k))$ is estimated by dividing its values by total number of pixels in the image:

$$p(r_k) = \frac{n_k}{n}$$

Determination of Contrast Level

Dark Image: can be defined as the collection of image pixels in the range [0, n] without having pixels in the range [n, L-1].

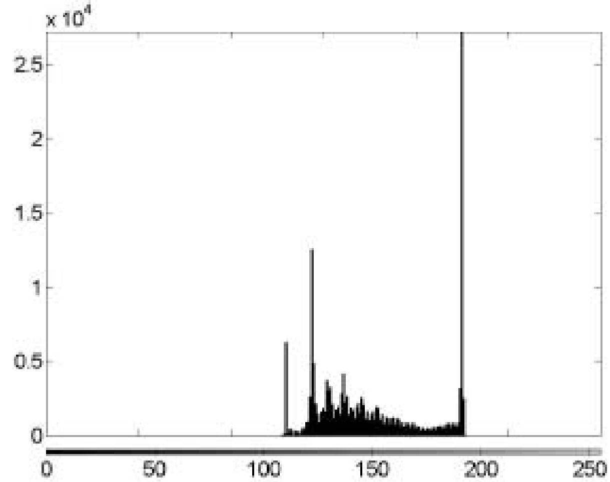
Dark image



Histogram

Bright Image: can be defined as the collection of image pixels in the range [n, L-1] without having pixel values in the range [0, n].

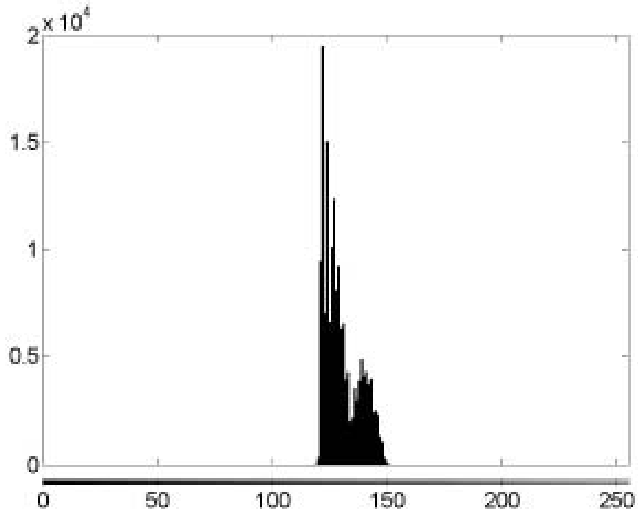
Bright image



Histogram

Low-contrast Image: have more complex relationship in the upper and lower limits of gray level values. An image can be classified as a low contrast image if the image pixels are collected in the range [n-z, n+z].

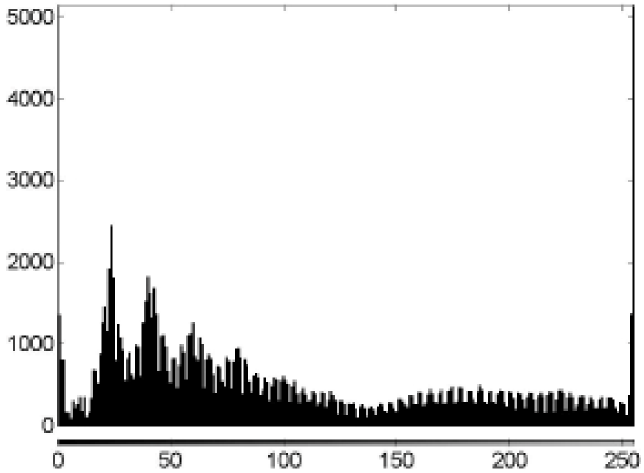
Low-contrast image



Histogram

High-contrast Image: can be defined as the equal distribution of image pixels in the range [0, L-1].

(g) High-contrast image



(h) Histogram of (g)

Histogram Equalization

$$s_k = T(r_k) = \sum_{j=0}^{k} P_r(r_j)$$

where $s_k$is resultant image, T is transformation function for Histogram Equalization, r_k is k^{th} gray level and $P_r(r_j)$ is probability of occurrence.

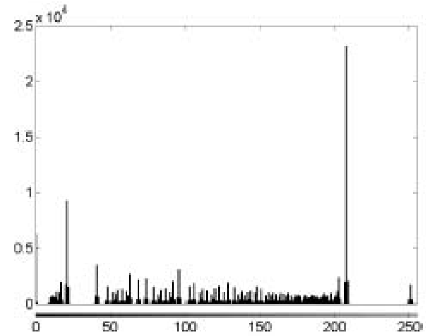
$$s_k = \sum_{j=0}^{k} \frac{n_j}{n}$$

where n_j is the number of pixels that have same gray level r_k.

Ex.

(a) Bright image

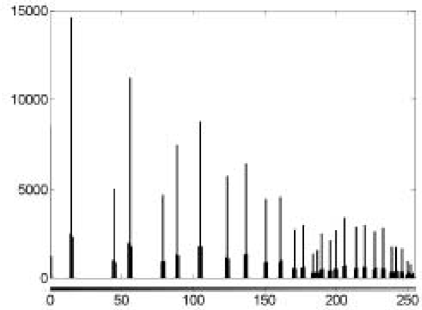
(b) Enhanced image of (a) after histogram equalization



(c) Histogram of (b)

(d) Low-contrast image

(e) Enhanced image of (d) after histogram equalization



(f) Histogram of (e)