Introduction to Digital Image Processing

Asim Banerjee

IEEE Workshop on Image Processing.

1st March 2009.

Objective

- To provide an introduction to basic concepts and methodologies of Digital Image Processing
- To familiarize one with the nuances of Digital Image Processing

Agenda

- Introduction
- Digital Image Fundamentals
- Image Transforms
- Image Enhancement Approaches
- Image Compression
- Image Processing Applications

NOTE: All the images used in this talk are from the book "*Digital Image Processing*" by R. C. Gonzalez and R. E. Woods

Introduction

- What is an image?
  - *Image* is a two dimensional light-intensity function, *f(x,y)*, where the value of *f* at a spatial location *(x,y)* is the intensity of the image at that point.
  - *Digital image* is obtained by sampling and quantizing the function *f(x,y)*

NOTE: The function *f(x,y)* can be a measure of the reflected light (photography), X-ray attenuation (X-Rays) or any other physical parameter.

Digital Image Processing

- Importance of Digital Image Processing stems from two principal application areas
  - Improvement of pictorial information for human interpretation
  - Processing of scene data for autonomous machine perception

Improvement of pictorial information for human interpretation

- Involved selection of printing procedures and distribution of brightness levels
- Improvements on processing methods for transmitted digital pictures
- Application areas include
  - Archeology
  - Astronomy
  - Biology
  - Industrial Applications
  - Law enforcements
  - Medical Imaging
  - Space program etc.

Processing of scene data for autonomous machine perception

- Focuses on procedures for extracting from an image information in a form suitable for computer processing

  NOTE : Often this information bears little resemblance to visual features that human beings use in interpreting the content of an image.
- Application areas include:
  - Automatic Optical Character Recognition
  - Machine vision for product assembly and inspection
  - Military recognizance
  - Automatic fingerprint matching etc.

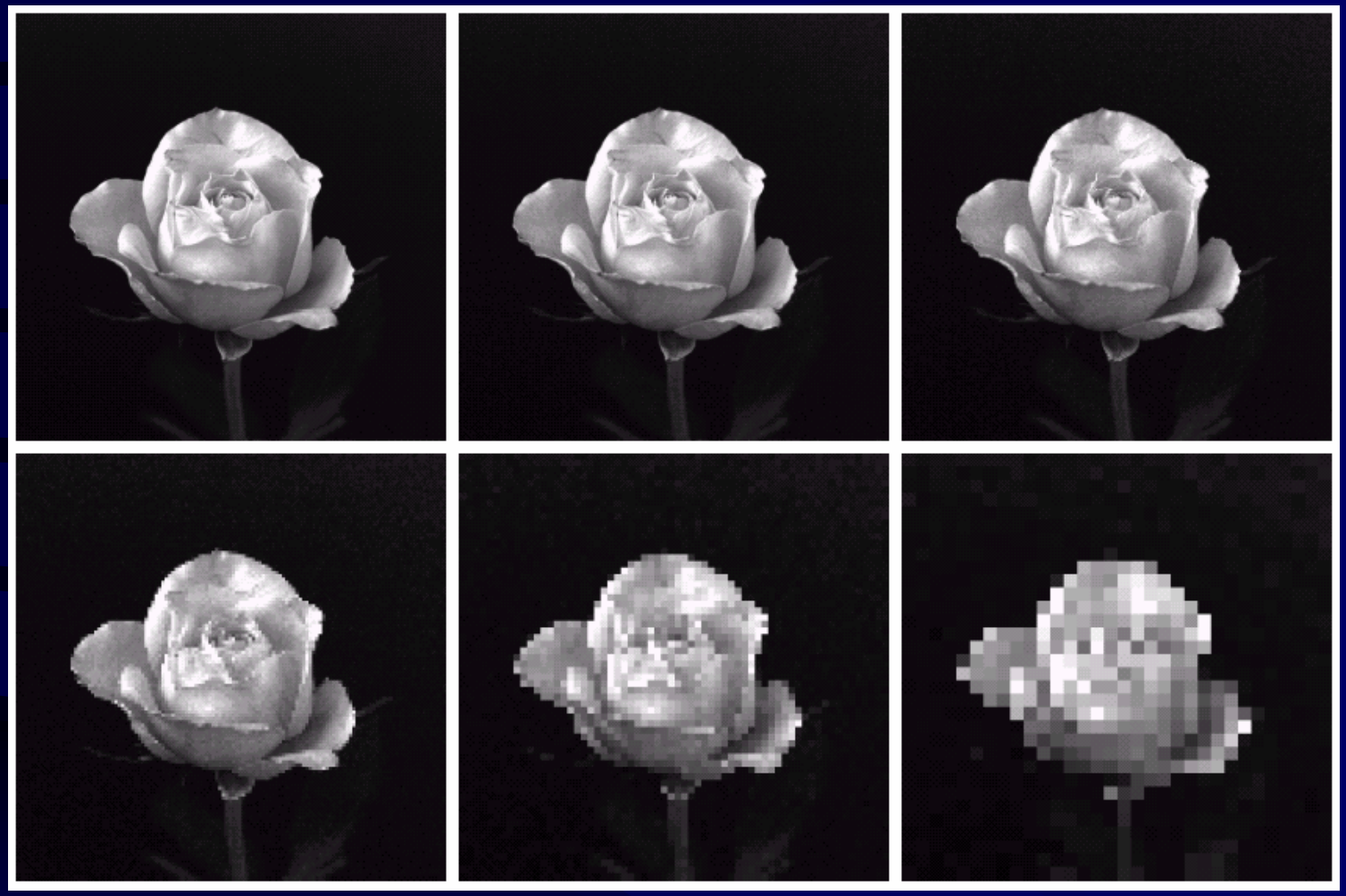
Digital Image Representation

- A digital Image is an image $f(x,y)$ that is discrete both in spatial coordinates (sampling) and brightness value (quantization).
- The elements of the digital array are called *image elements*, *picture elements*, *pixels* or *pels*

Image Resolution

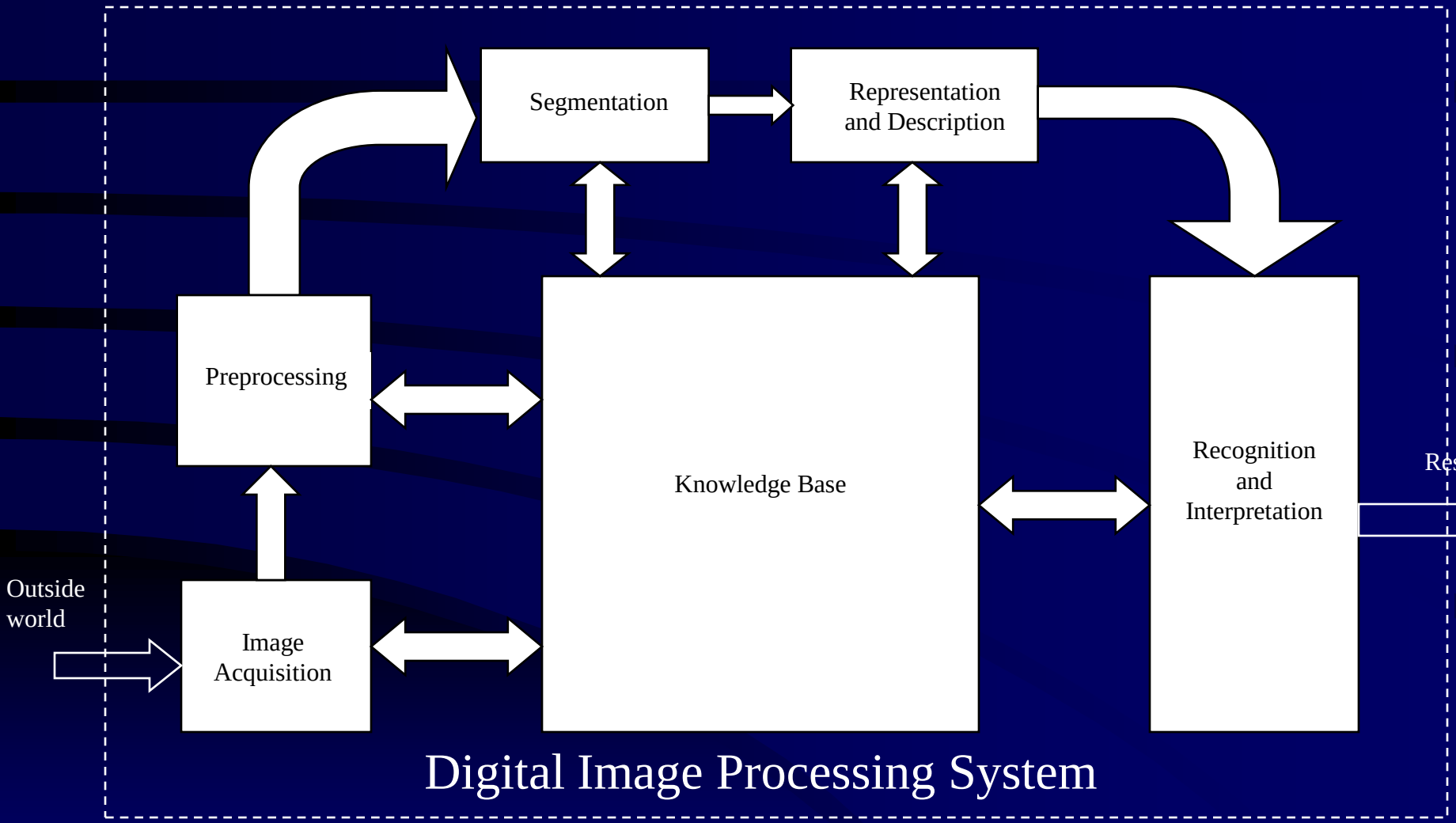
- Image resolution is the degree of discernible detail of an image
- It depends on
  - The number of samples in an image
  - The number of gray levels in an image

Effects Reducing Spatial Resolution



1024x1024 image progressively reduced in size by a factor of 2 in each dimension and then resampled to 1024x1024 by pixel replication

Steps in Digital Image Processing



Elements of Digital Image Processing System

- **Image acqusition**
  - Scanners, video camera, CCD cameras, digitizers, etc.
- **Storage**
  - Short term storage, on-line storage and archival storage
- **Processing**
  - Small personal computers to dedicated processing hardware.
- **Communication**
  - Local communication between the processing systems
  - Remote communication for transmission of images
- **Display**
  - Monochrome Monitors to sophisticated display devices

Visual Perception

- The ultimate goal in many techniques is to help an observer interpret the content of an image
- Hence basic understanding of the visual perception process is important.

Elements of Visual Perception (1/2)

- Structure of the human eye
  - Comprises of the cornea and sclera outer cover, the choroid and the retina
- Image formation in the eye
  - The light from the object passes through the flexible lens
  - The image is formed on the retina of the eye
- Brightness adaptation
  - The range of intensity levels to which the system can adapt is enormous (~10^{10})
  - Subjective brightness is a logarithmic function of the light intensity incident on the eye

Elements of Visual Perception (2/2)

- Brightness discrimination
  - The total range of intensity levels the eye can discriminate simultaneously is rather small compared to the total adaptation range
  - Ability to discriminate between two intensity values is not a simple function of intensity
  - The visual system tends to undershoot or overshoot around boundary of regions of different intensities
  - A region's perceived brightness also depends on the intensity level of the surrounding region (simultaneous contrast)

Image Transforms (1/2)

- Why Transforms?
  - Transformation presents a different perspective of the same data
  - It facilitates extraction of desirable features that reflect the attribute(s) of interest from the data
  - It facilitates a different representation of the same data

Image Transforms (2/2)

- For images one mainly deals with two dimensional (2D) transforms like
  - Fourier Transform
  - Walsh Transform
  - Hadamard Transform
  - Discrete Cosine Transform

  NOTE: The 2D transforms are applied for Image enhancement, restoration, encoding and description

Image Enhancement

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

NOTE:

1. For visual interpretation of images, enhancement improves the subjective quality of the image.
2. In image enhancement for machine perception, the analyst is still faced with a certain trial and error before being able to settle on a particular enhancement approach.

Image Enhancement Approaches

- The approaches can be classified as
  - Spatial domain approaches
    - Involves direct manipulation of pixels in an image
  - Frequency domain approaches
    - Involves modifying the Fourier transform of an image

Spatial Domain Enhancement

- The approaches are further classified as
  - Point processing
    - Modify the gray level of a pixel independent of the nature of its neighbors e.g. thresholding, grav level transformation
  - Neighborhood Processing
    - Small sub-images (masks) are used in local processing to modify each pixel in the image to be enhanced e.g. image sharpening, edge detection

Intensity Transformations

- These techniques are also called gray level transformations
  - Image negative
  - Contrast stretching
  - Compressing dynamic range
  - Gray level slicing
  - Bit plane slicing

Gray Level Transformation Function

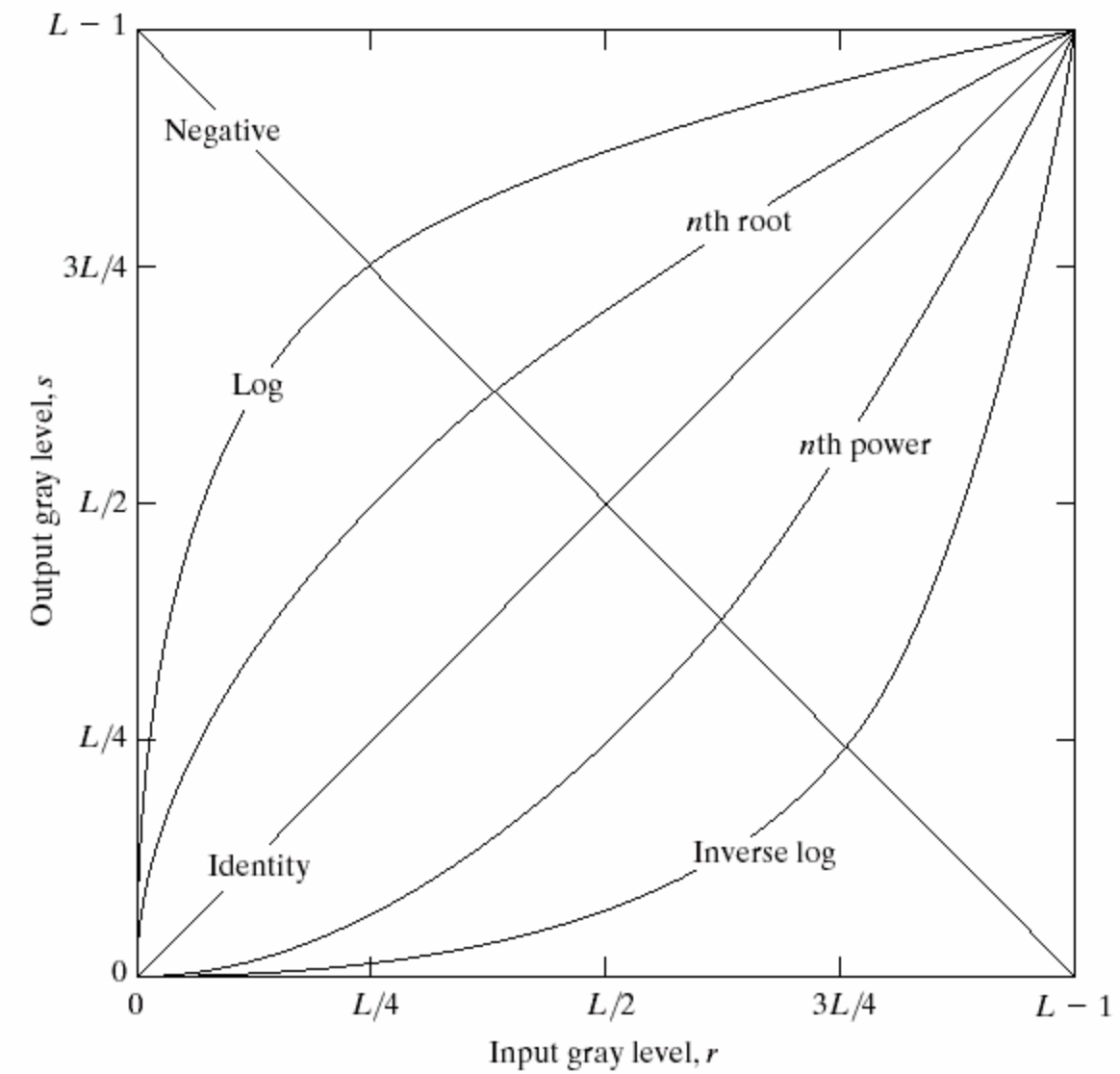
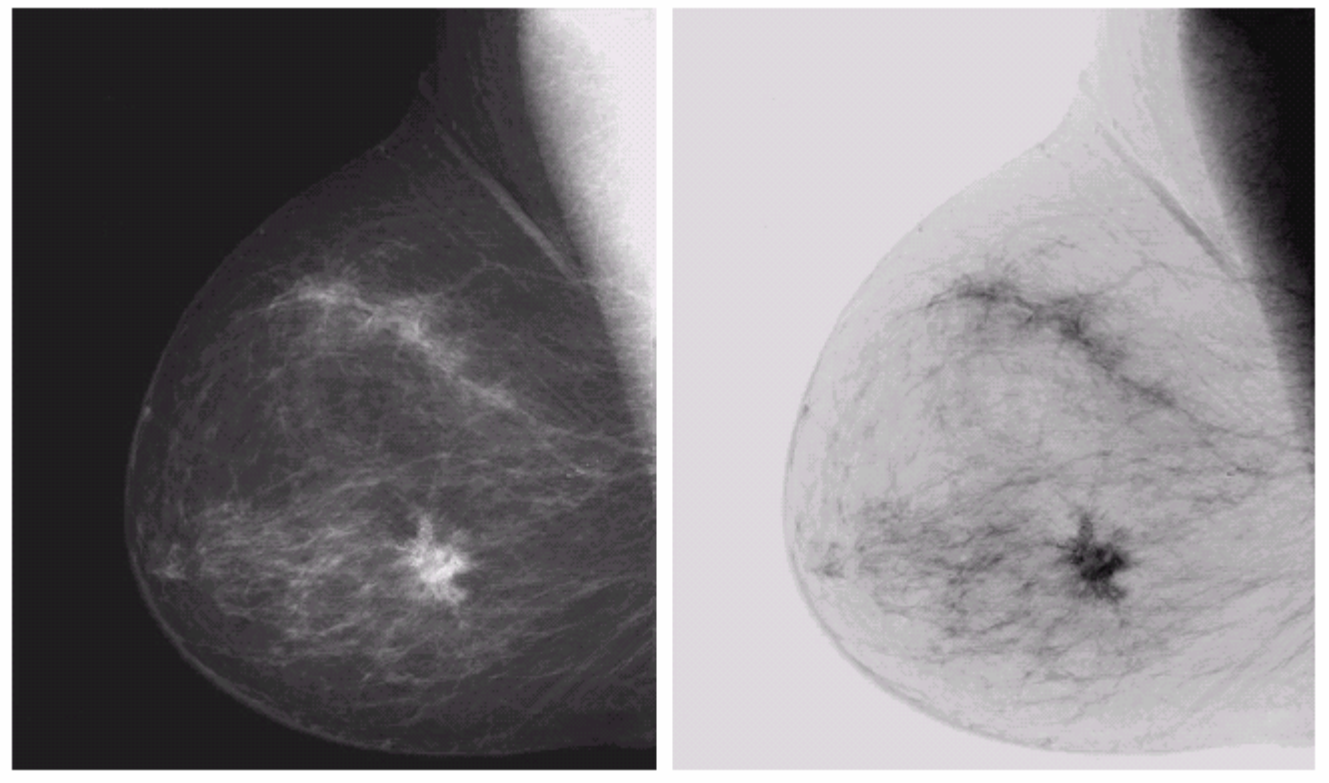
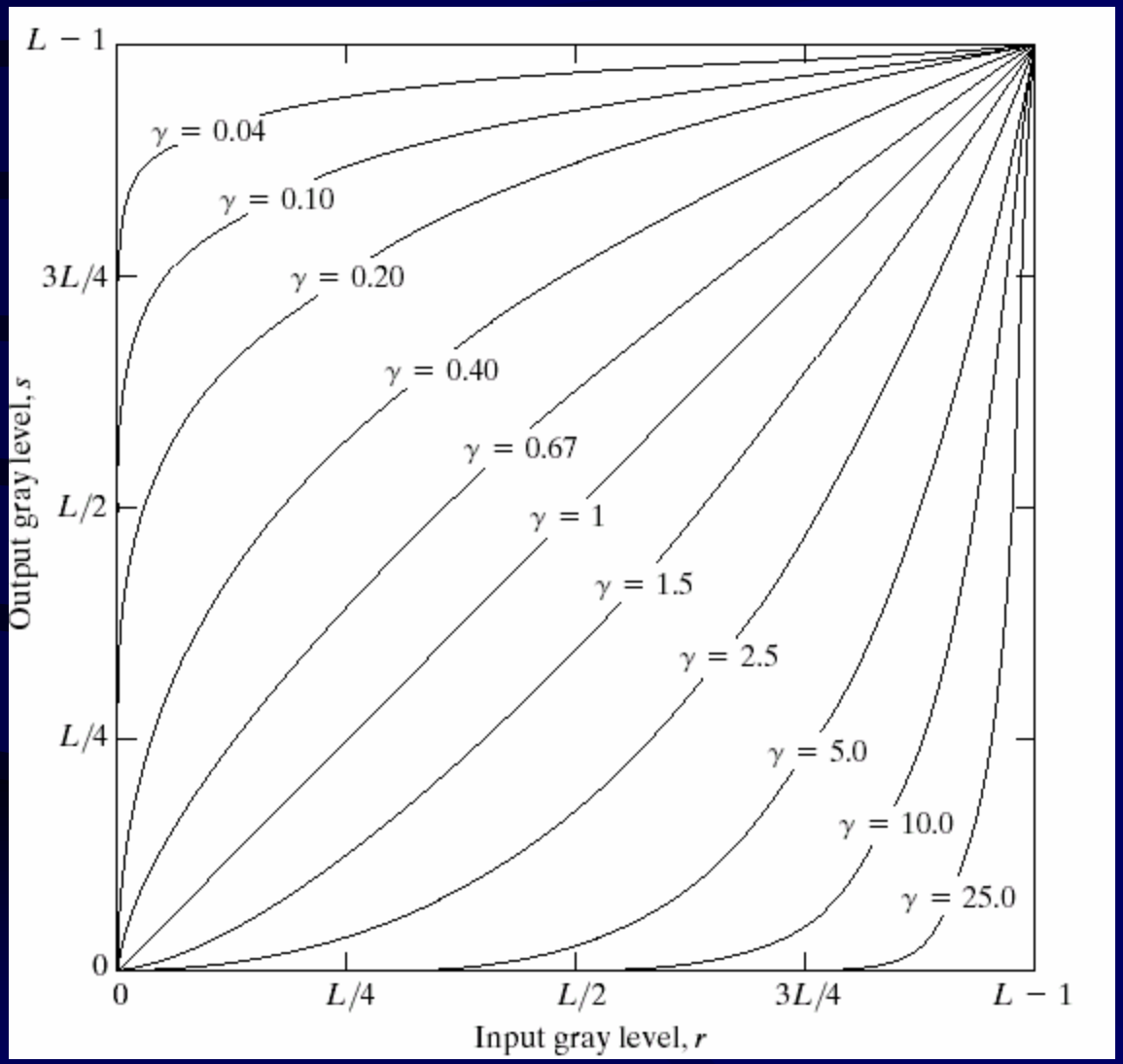


Image Negative



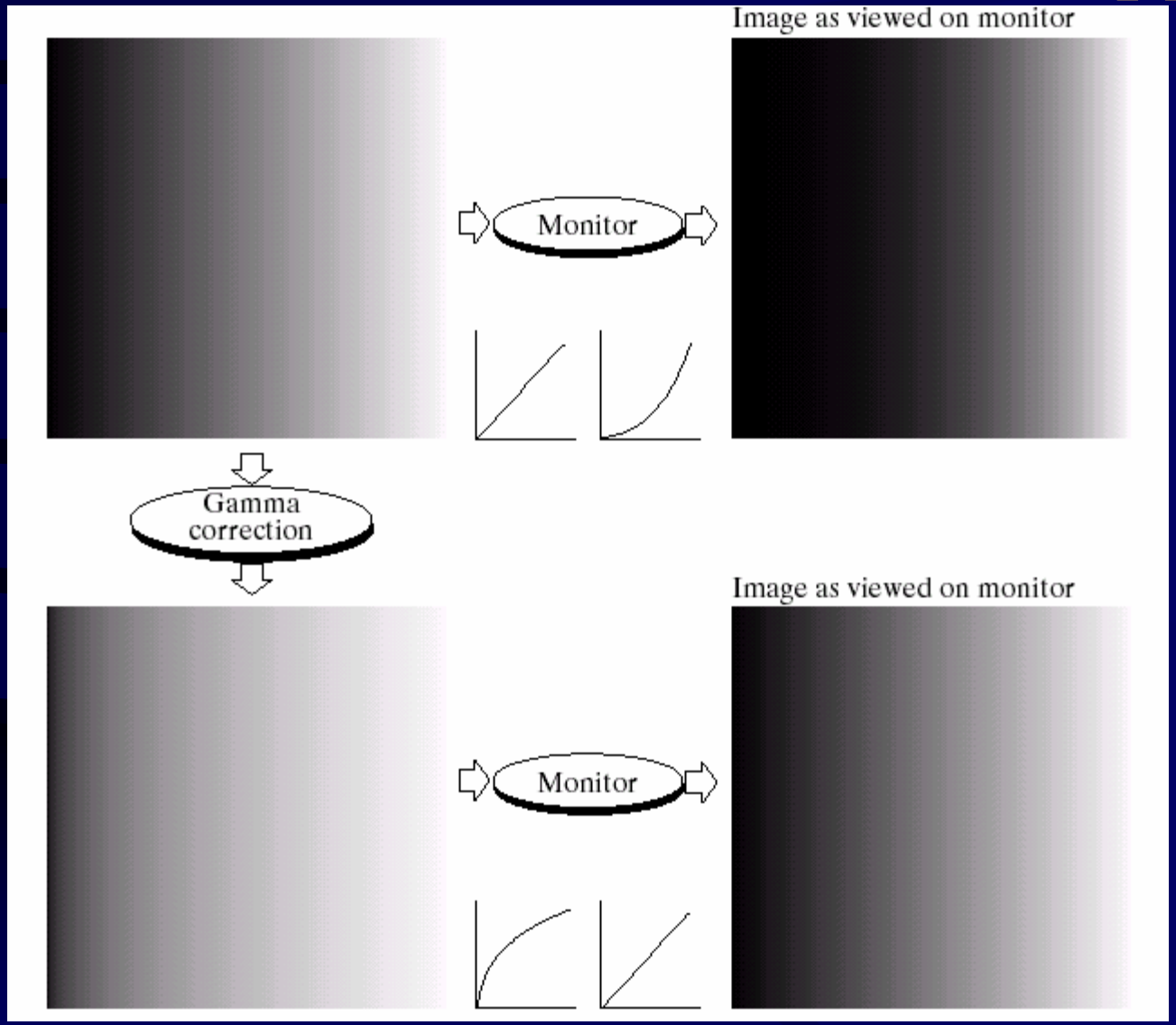
Digital Mammogram and its negative image

Power Law Transformation



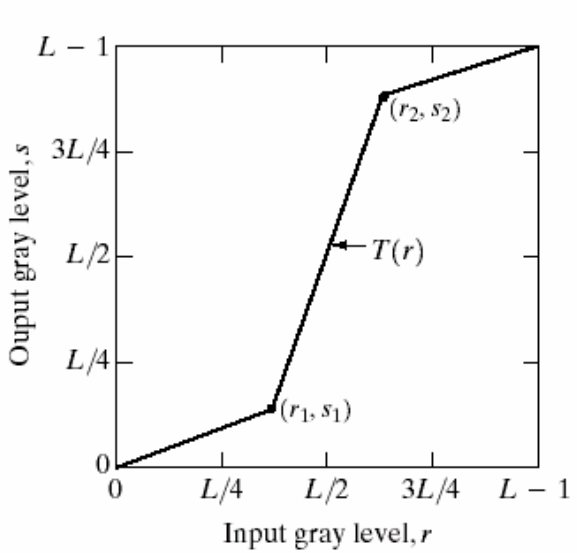
$$s = r^{\gamma}$$

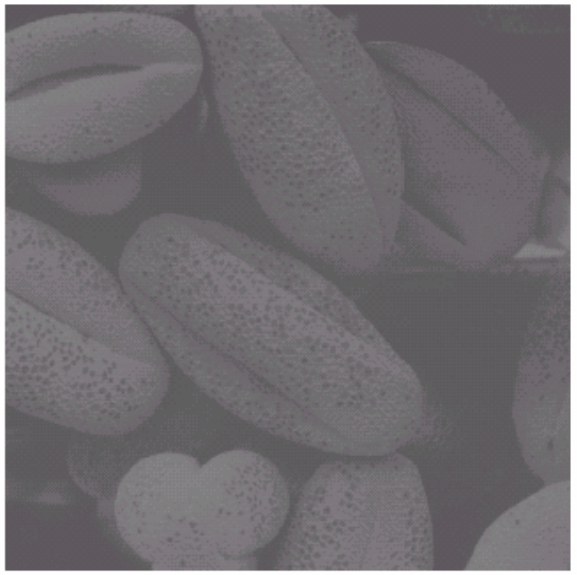
Power Law Transformation - Application

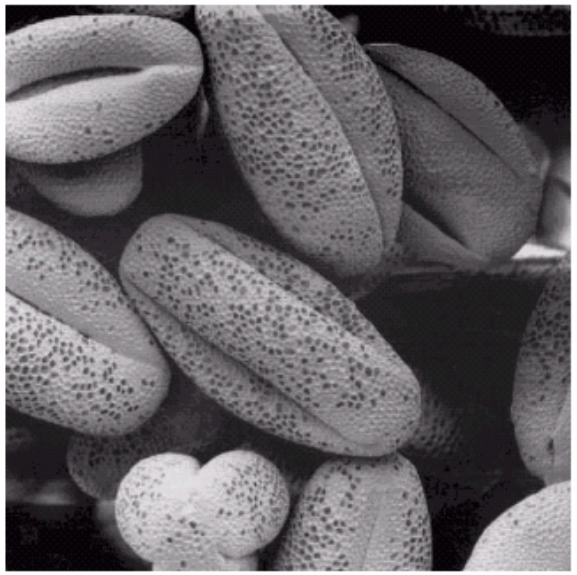


$\gamma > 1$

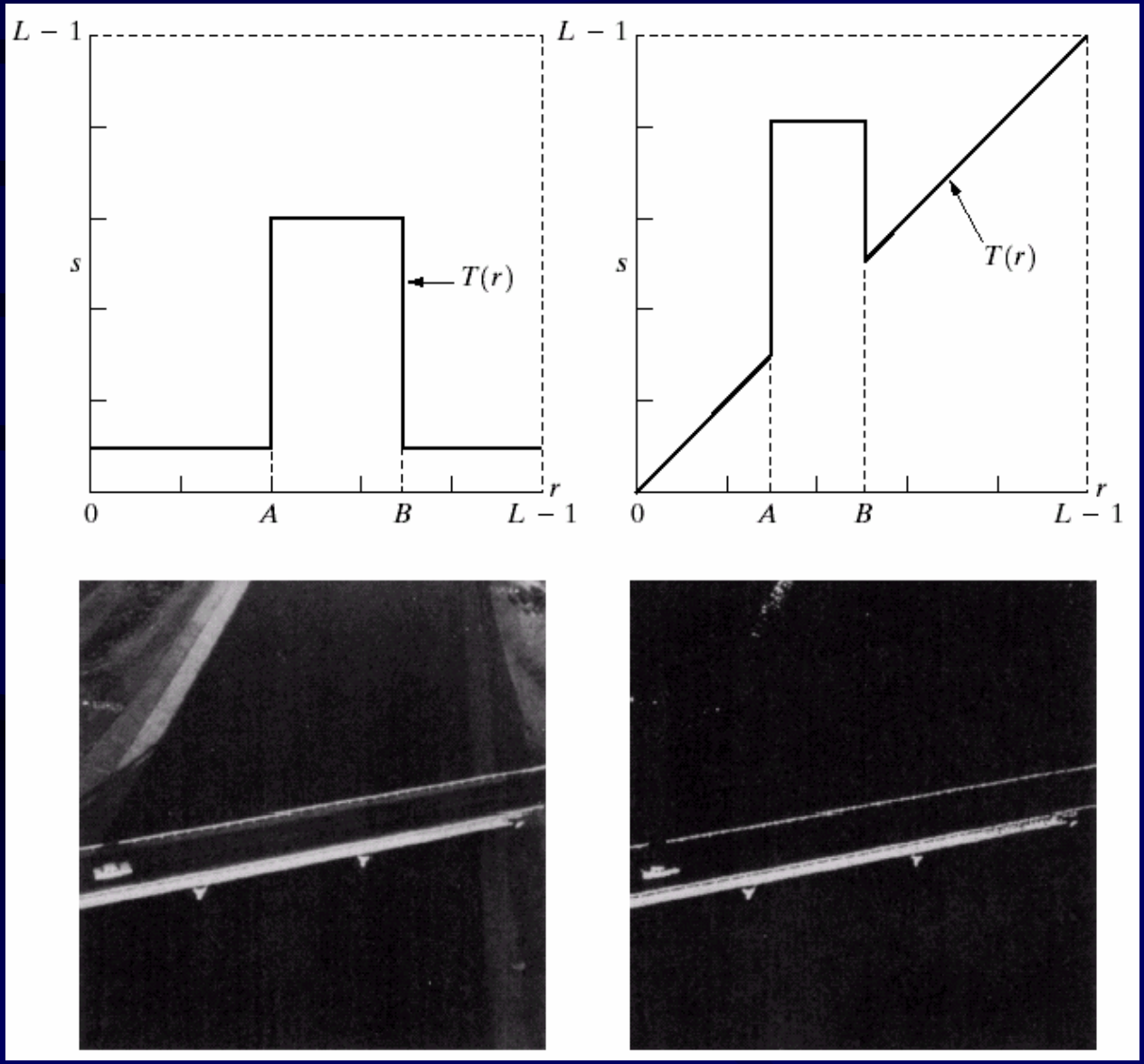
Contrast Stretching



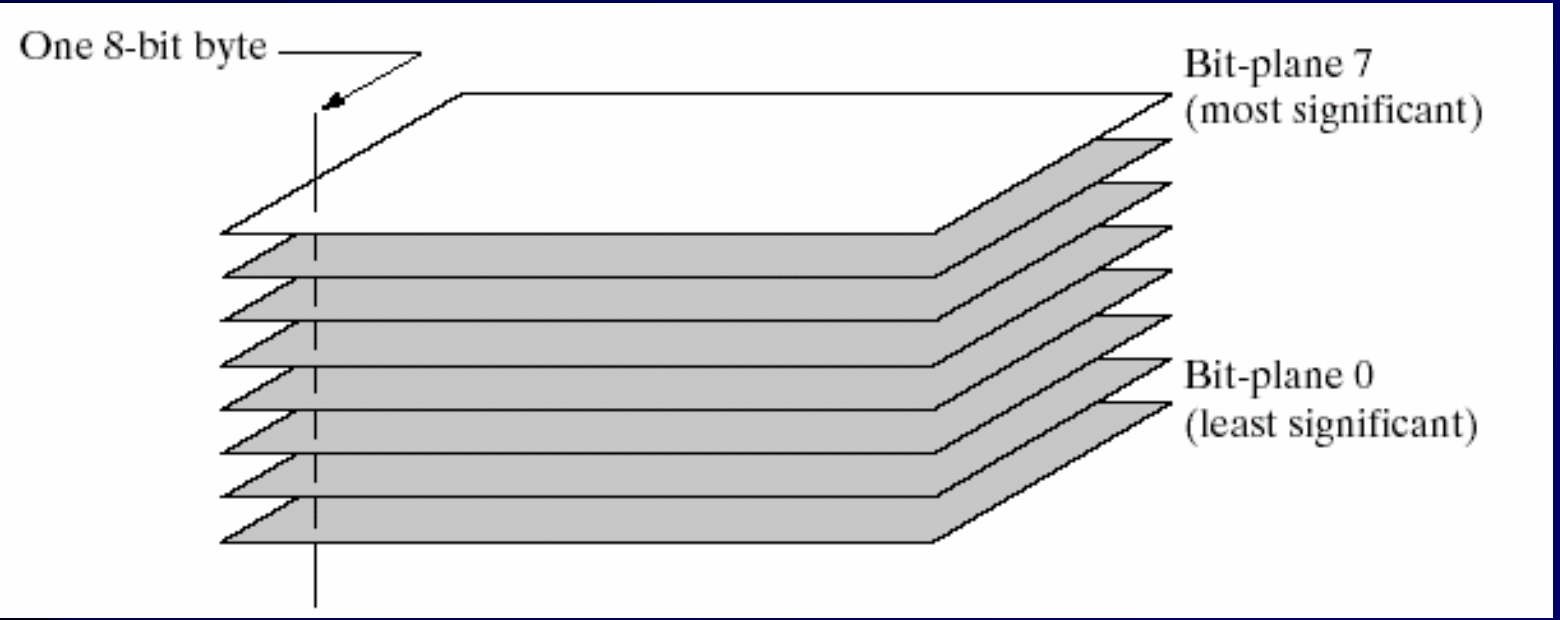




Gray Level Slicing



Bit Plane Slicing (1/2)



Bit Plane Slicing (2/2)

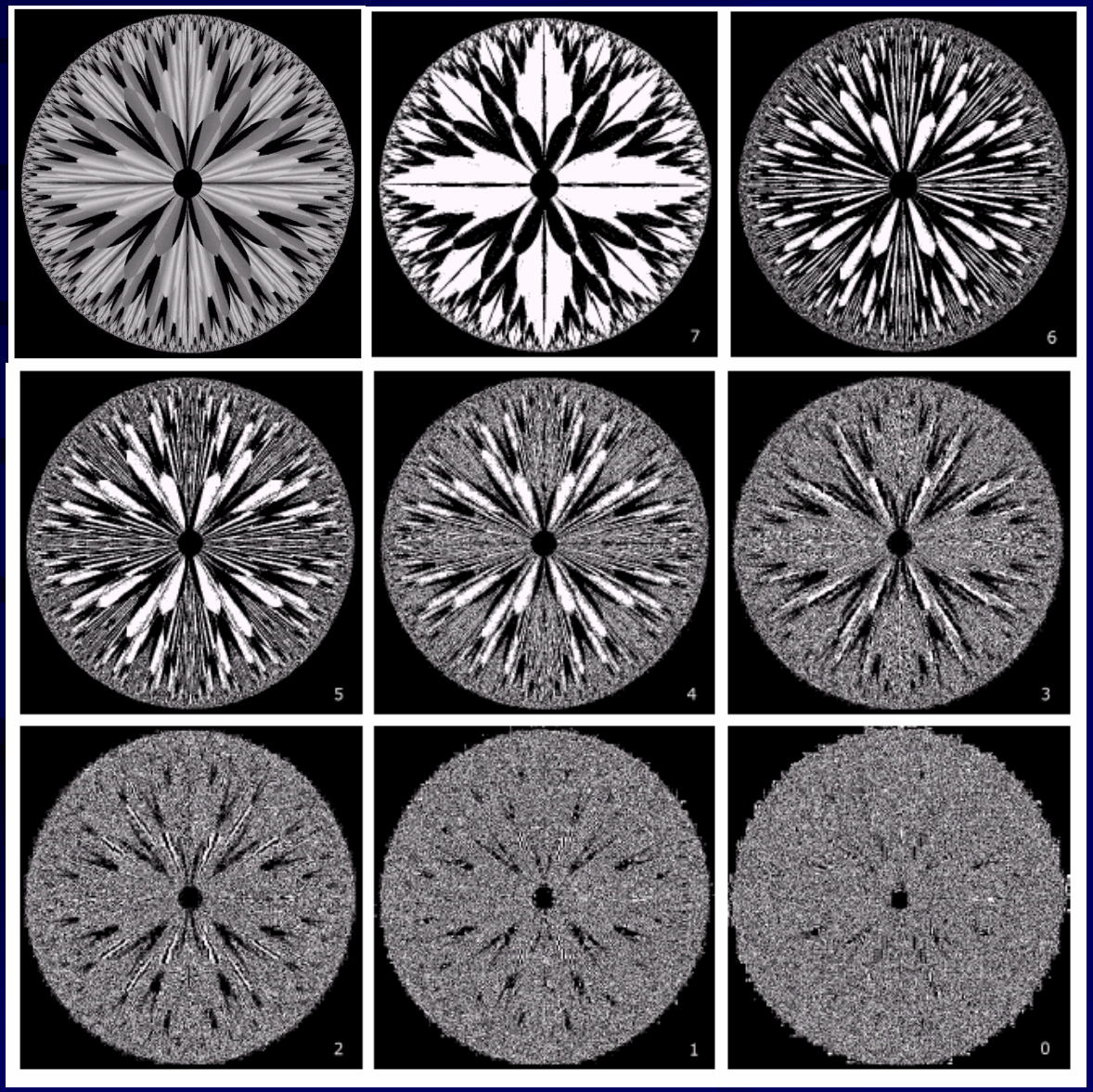
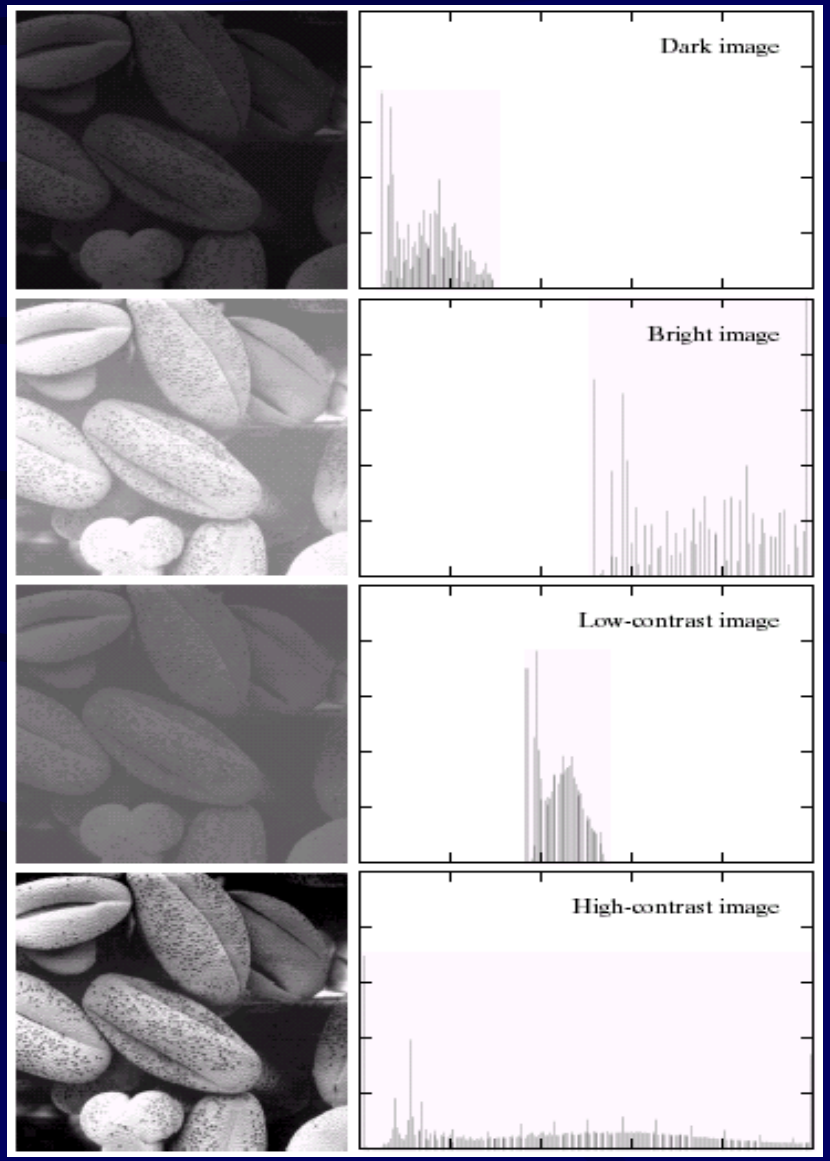


Image Histogram

- Histogram of an image '*h*' is a function that gives the number of occurrences of the gray levels in an image '*f*' *i.e. h(k)* is the number of occurrence of the gray *'k'* in the image '*f*'

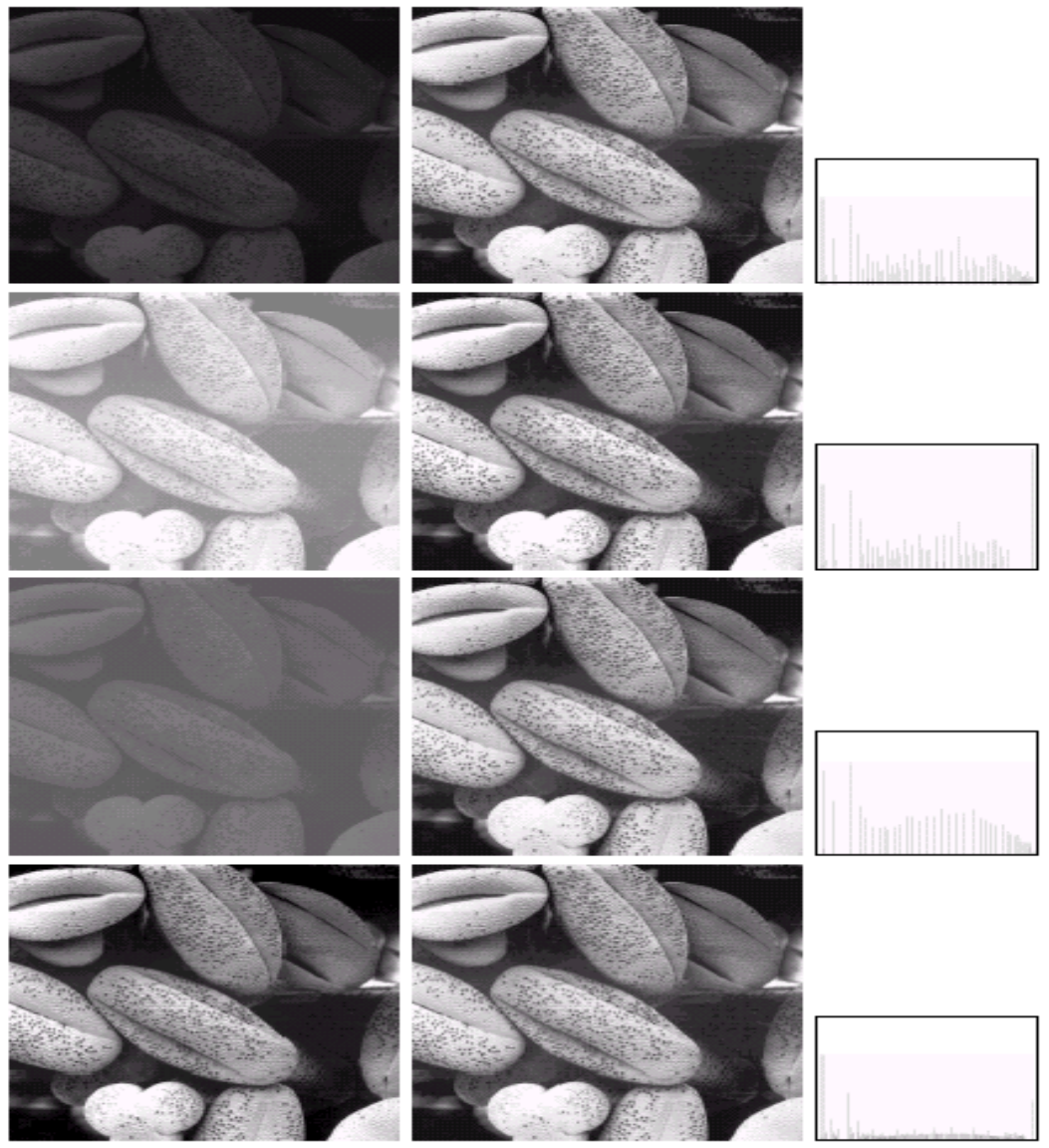
Image Histogram - Examples



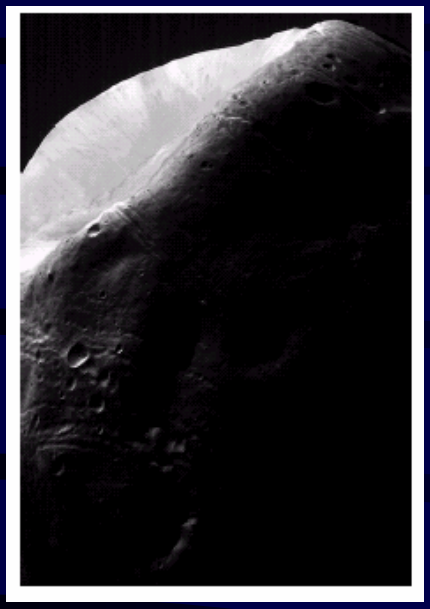
Histogram Processing

- Histogram processing includes
  - Histogram equalization
  - Histogram specification

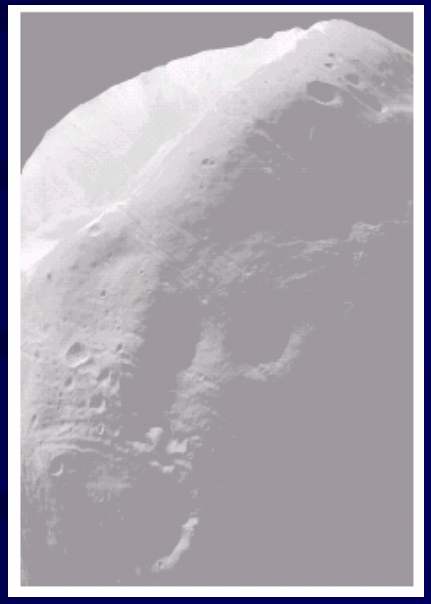
Histogram Equalization - Examples



Histogram Specification - Example

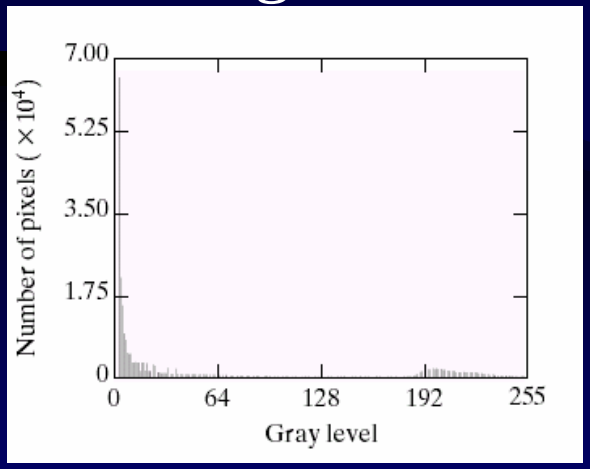


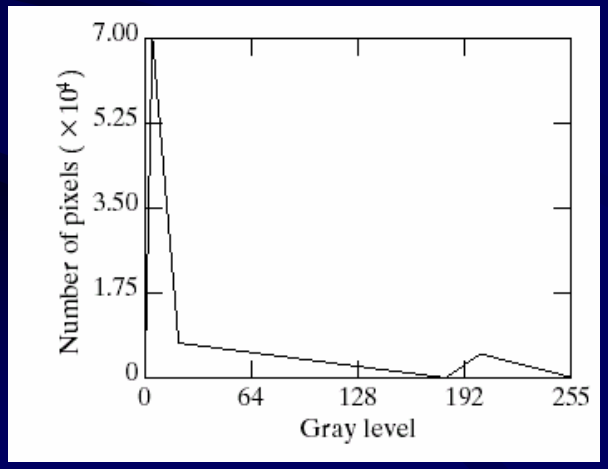
Original

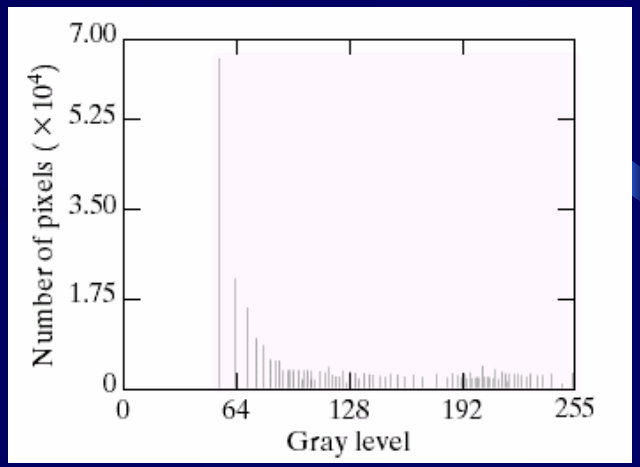


Histogram Equalized

Histogram Specified



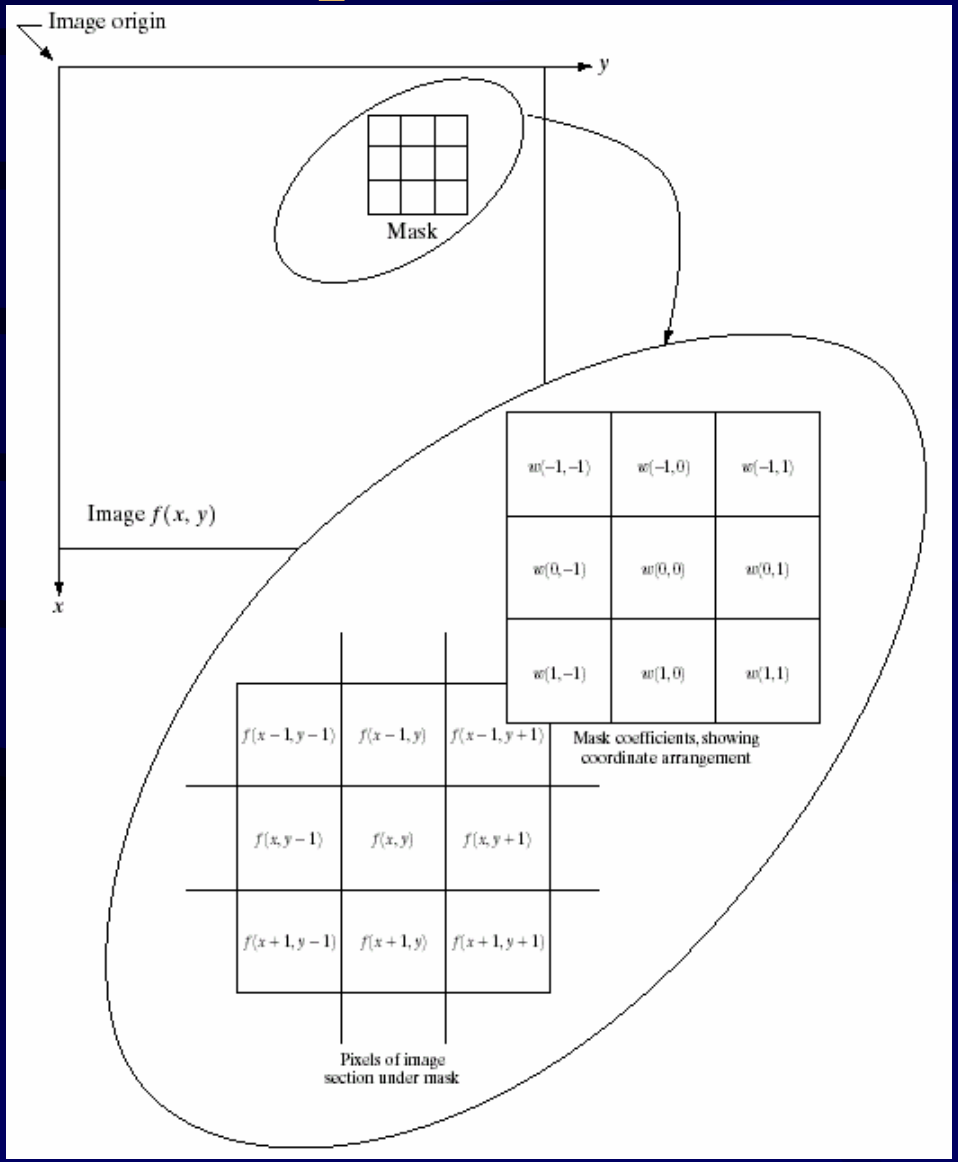




Spatial Filtering (1/2)

- The use of spatial masks for image processing is usually called spatial filtering.
- Examples
  - Low pass filtering (averaging)
  - Median filtering
  - High pass filtering

Spatial Filtering (2/2)



The process of Spatial Filtering

Spatial Low Pass Filtering

Original

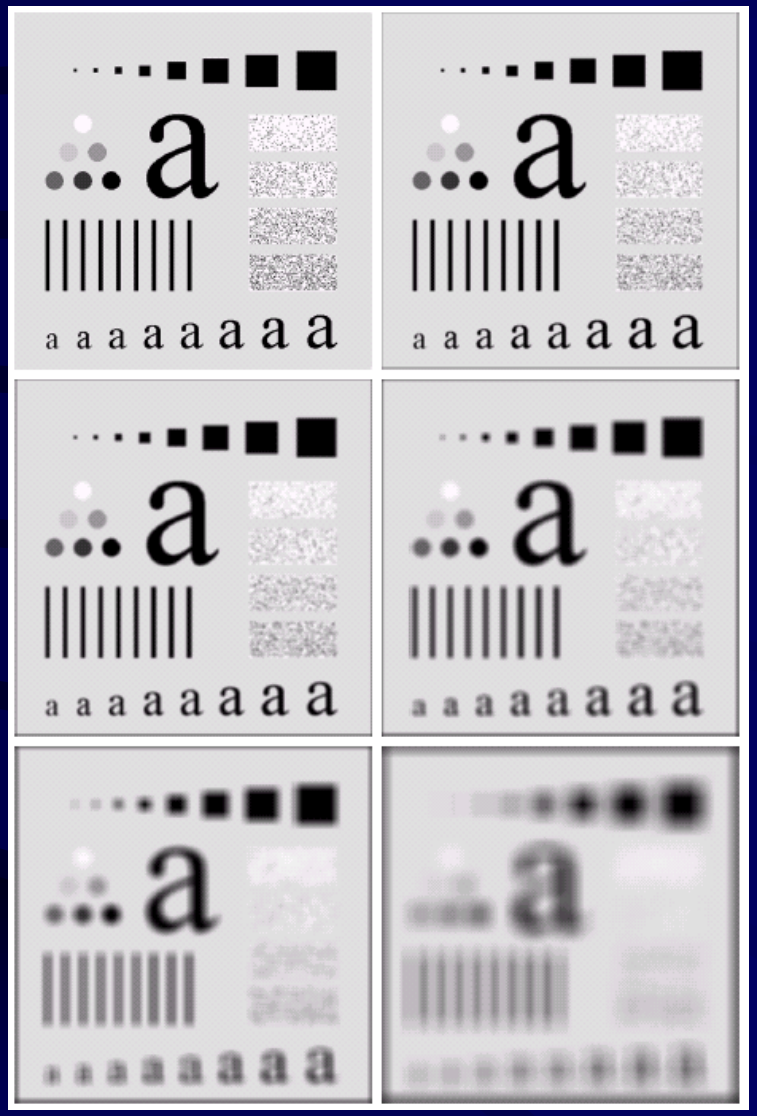
3x3

5x5

9x9

15x15

35x35



Averaging with different mask sizes

Spatial Median Filtering

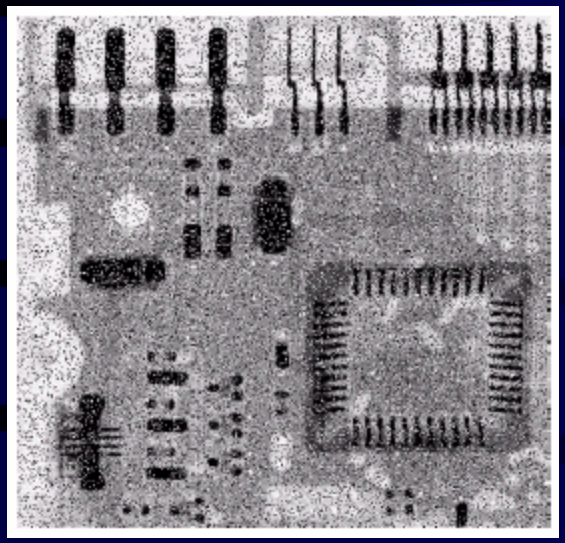
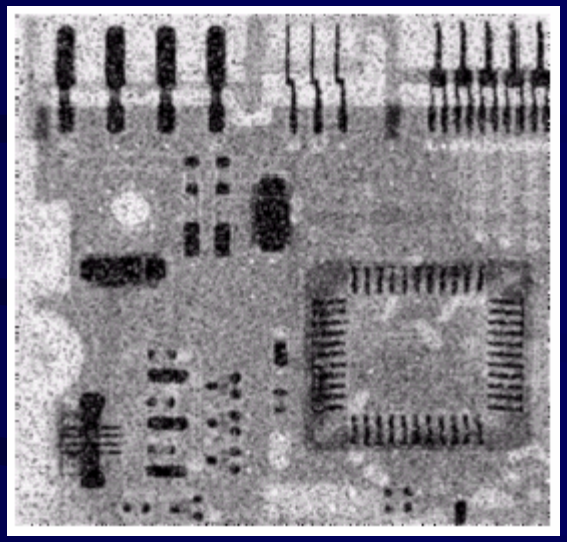
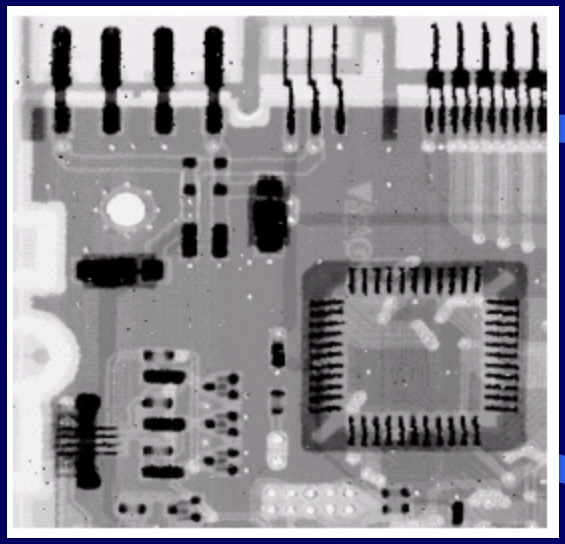


Image with Salt and Pepper Noise



Low Pass Filtered Output



Median Filtered Output

Ability of the median filter to handle impulse noise

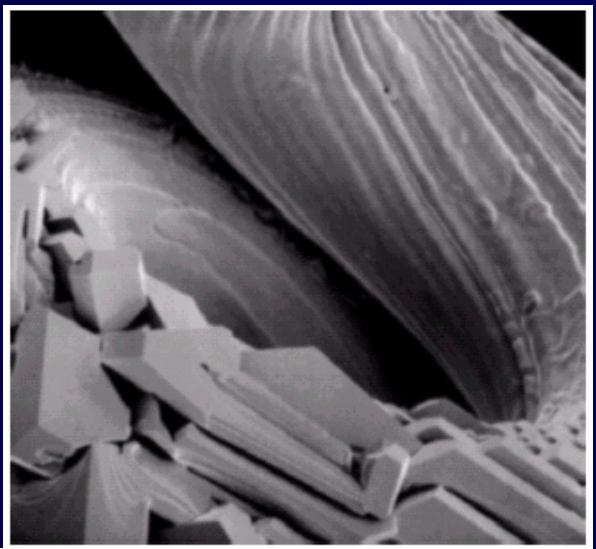
High Boost Filtering

2 Masks

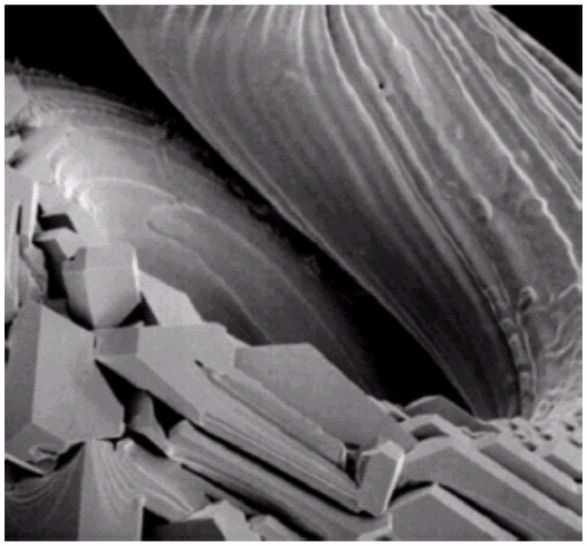
0	−1	0
−1	5	−1
0	−1	0

−1	−1	−1
−1	9	−1
−1	−1	−1

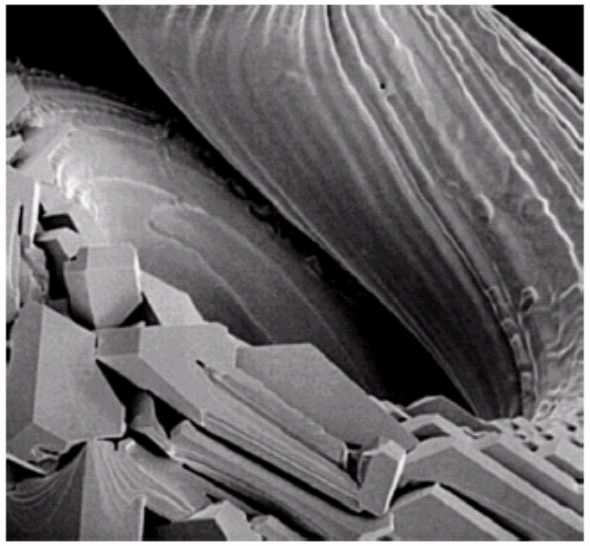
Original Image



1st Mask Output



2nd Mask Output



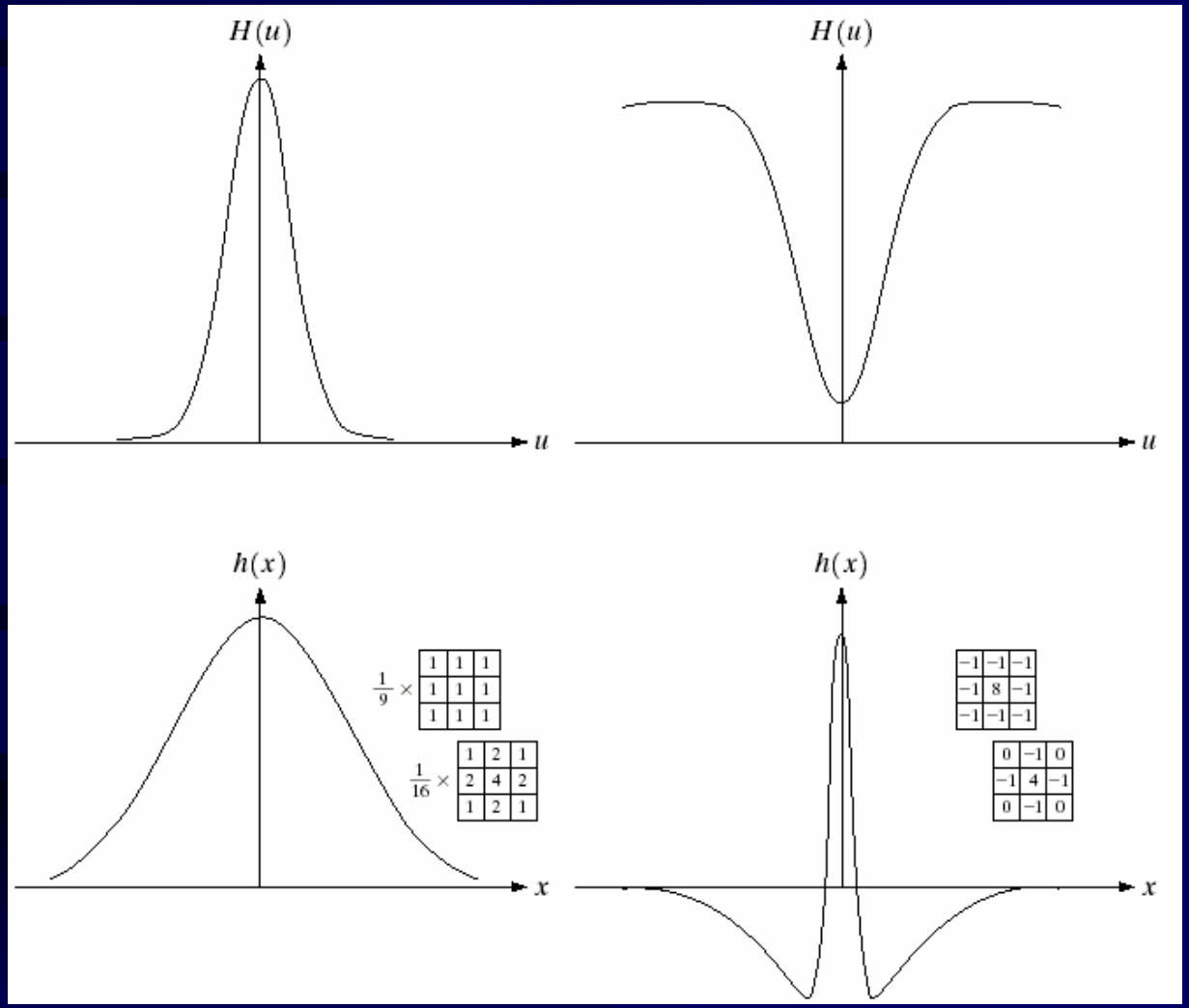
Frequency Domain Enhancement

- It is based on the convolution theorem, which states that an enhanced image *g(x,y)* can be produced by convolving the image *f(x,y)* with an operator *h(x,y)*.
- Depending on the choice of *h(x,y)* different enhancement operations are possible for example low pass filtering, high pass filtering, etc.

Spatial & Frequency Domain

Frequency Domain

Spatial Domain



Low Pass Filter High Pass Filter

Image Compression

- To efficiently store, process and communicate the enormous amount of data is produced when a 2D intensity function is quantized to create a digital image.
- It addresses the problem of reducing the amount of data required to represent a digital image by removing redundant information

Need for Image Compression

- It is crucial for the growth of multimedia computing (use of computers for printing & publishing and video production & dissemination.
- Required to handle the increased resolutions of the present day sensors.
- Application areas include remote sensing, videoconferencing, document & medical imaging, facsimile transmission (FAX) etc.

Image Compression Models

- Source encoder and decoder
  - Reduces or eliminates any coding, interpixel and/or psychovisual redundancies in the input image.
- Channel encoder and decoder
  - Plays an important role when the channel is noisy or prone to error by inserting “controlled redundancy”.

Types of Compression

- Lossless compression
  - Huffman coding
  - Bit-plane coding
  - Run length coding
- Lossy compression
  - Lossy predictive coding
  - Transform coding
  - JPEG

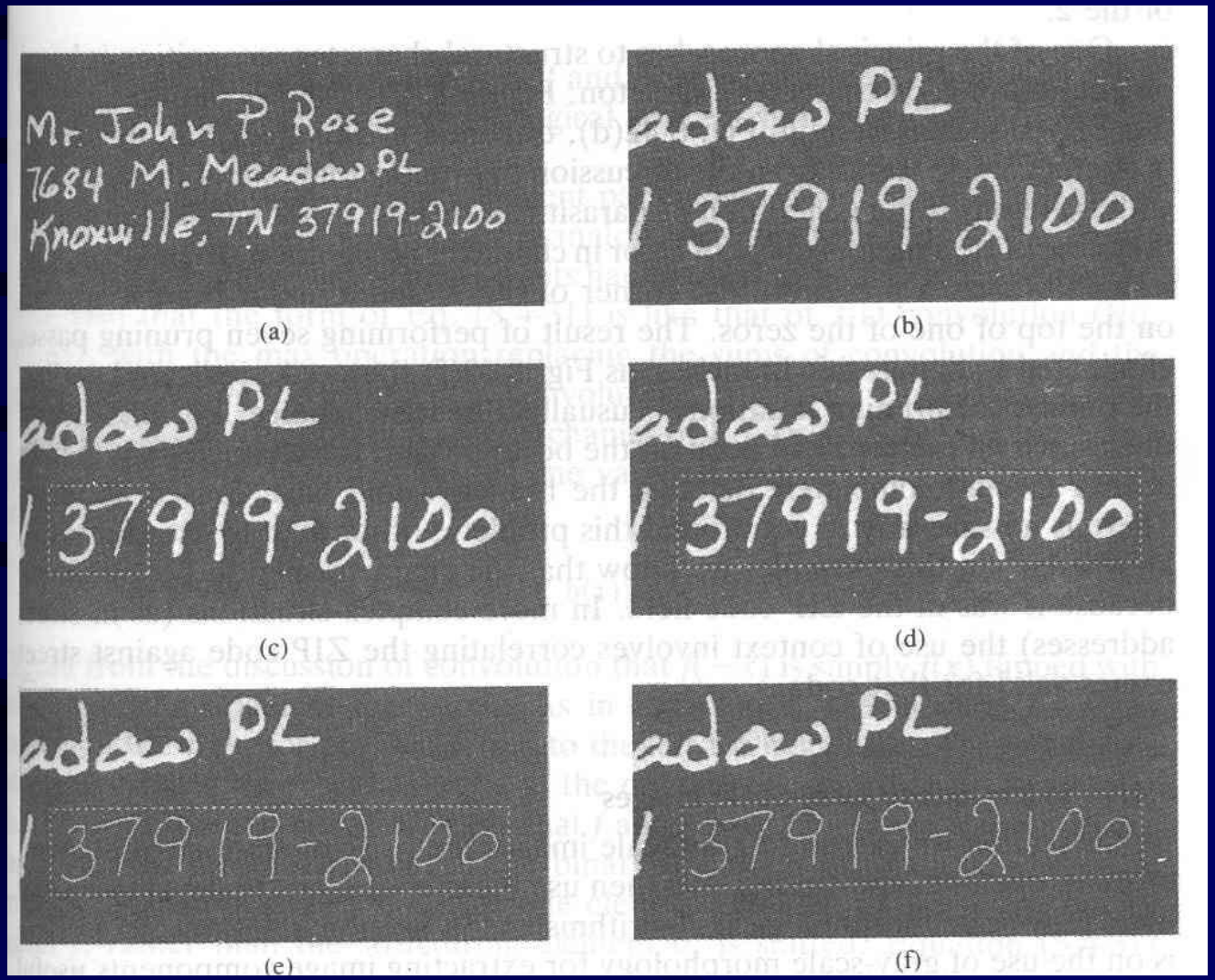
Compression Standards

- Jointly developed and sanctioned by
  - International Standardization Organization (ISO)
  - Consultative Committee of the International Telephone and Telegraph (CCITT)
- Examples
  - JPEG standard
  - MPEG standard (MPEG 1, MPEG 2, MPEG 4, MPEG 7 and MPEG 21)

Image Processing Applications

- Script Recognition
- Optical Character Recognition
- Handwritten Signature Verification
- Remote sensing
- Medical Imaging
- Non-destructive testing
- Multimedia
  - Education
  - Entertainment
  - Telemedicine

Optical Character Recognition



Recap: Digital Image Processing

- Digital Image Fundamentals
- DIP System
- Image Transforms
- Image Enhancement Approaches
- Image Compression
- Image Processing Applications

Reading Material - Books

- R. C. Gonzalez and R. E. Woods "*Digital Image Processing*" Pearson Education.
- A. K. Jain: "*Fundamentals of digital image processing"*, Prentice Hall.
- W. K. Pratt: "*Digital image processing"*, Prentice Hall.
- A. Rosenfeld and A.C. Kak: "*Digital image processing"*, Academic Press.
- A. Rosenfeld and A. C. Kak: "*Digital image processing*", Vols 1 and 2, Prentice Hall.
- H. C. Andrew and B. R. Hunt, "*Digital image restoration*", Prentice Hall.
- K. R. Castleman: "*Digital image processing*", Prentice Hall.

Reading Material - Journals

- IEEE Transactions on Image Processing
- IEEE Transactions on Pattern Analysis & Machine Intelligence.
- IEEE Transactions on Medical Imaging
- Pattern Recognition Letters
- IEEE Transactions on Biomedical Engineering.

Any Questions?

THANK YOU