A Glimpse of Digital Image Processing

"One picture is worth more than thousands words"

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Outline

- First part: Brief overview of fundamental steps in digital image processing.
- Second part: Image restoration.

Part: I

Overview of digital image processing

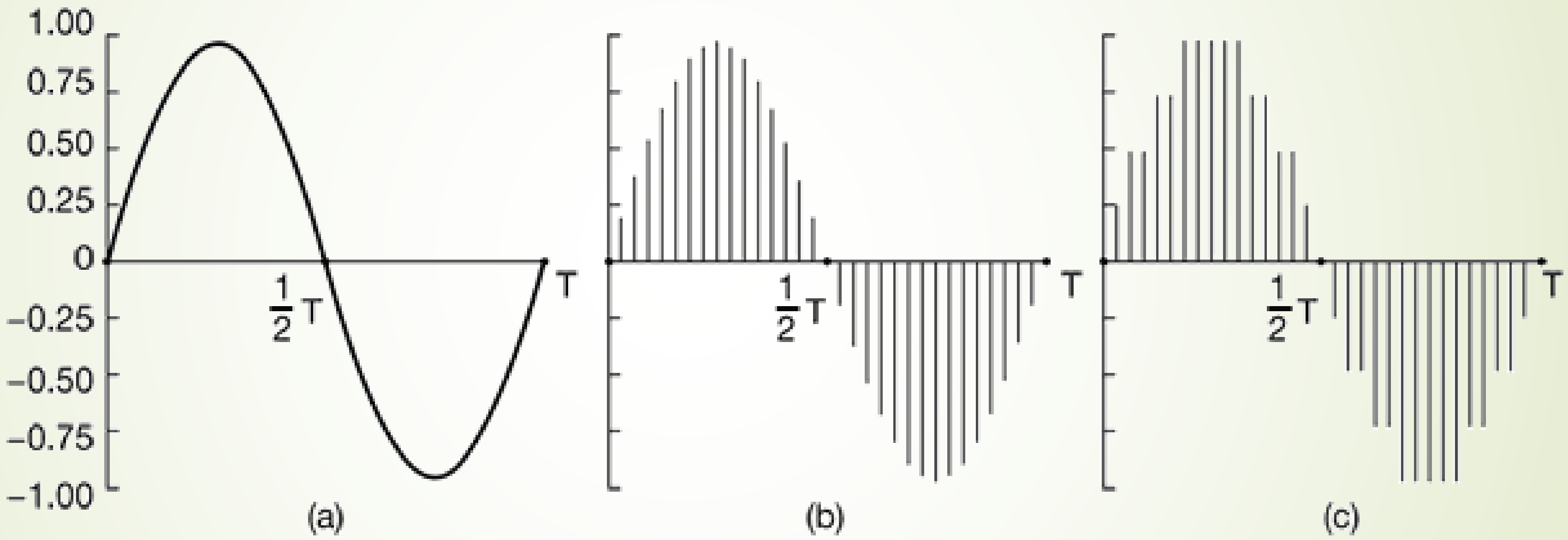
What is digital image processing (DIP)?

- Lets know the meaning of the string "***Digital Image Processing***".
- The word '***Digital***' is more meaningful when it is associated with other words such as clock, signal, electronics, signature, camera, etc.
- Here signal is our interest.

What is a signal?

- Signal is something which carries some information.
- It may be of different types:
  - Continuous time
  - Discrete time
  - Digital

Digital from continuous



(a) Continuous, (b) Discrete time and (c) Digital signal.

Image – A signal?

- No need to mention that image contains significant information.

- So image is a signal and thus “digital image” is valid.

What is an image?

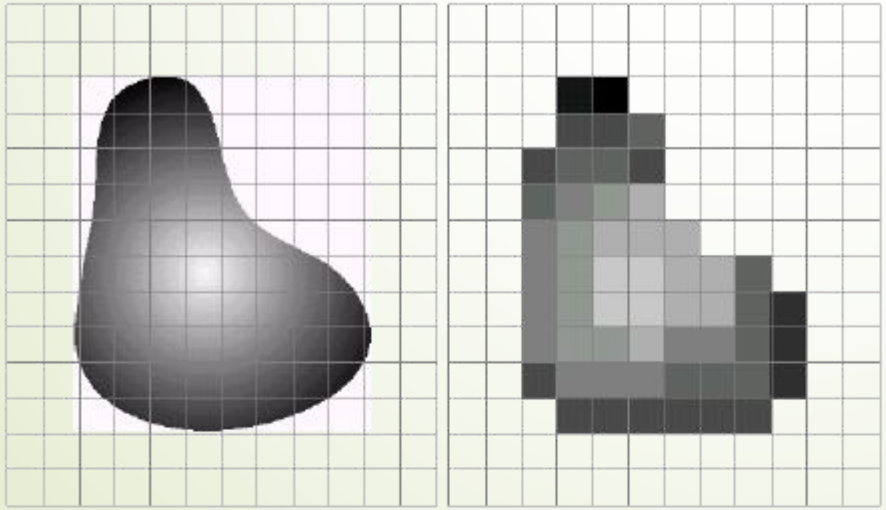
- Generally it can be defined as a pictorial representation of a scene.
- A 2-D function f(x,y).
- x and y are *spatial* (plane) coordinates.
- The amplitude of *f* at any pair of coordinates (*x*, *y*) is called the *intensity* or *gray level* of the image at that point.

What is digital image?

- When x, y, and the intensity values of f are all finite, discrete quantities, we call the image a *digital image*.
- Representation of a two-dimensional image as a finite set of digital values, called picture elements or pixels.
- The field of *digital image processing* refers to processing digital images by means of a digital computer.

More on pixels

- Pixel values typically represent gray levels, colors, heights, opacities etc.
- **Remember** *digitization* implies that a digital image is an *approximation* of a real scene.



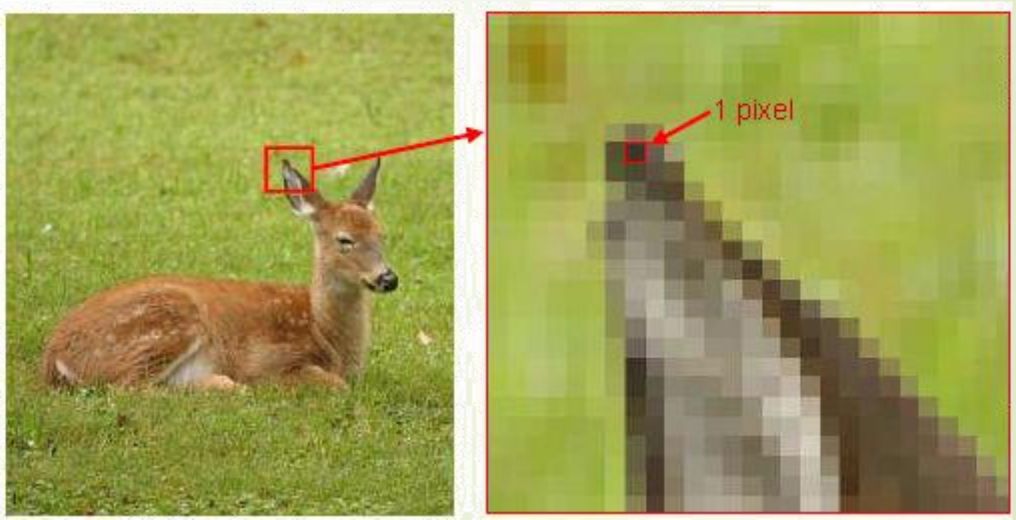
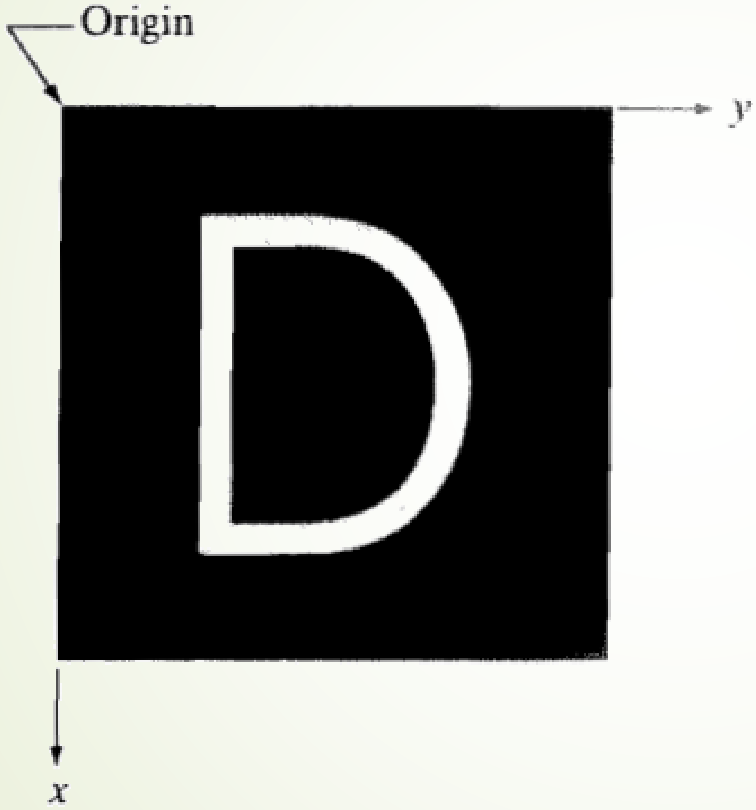


Image Representation



Contd..

- Common image formats include:
  - 1 sample per point (B&W or Grayscale)
  - 3 samples per point (Red, Green, and Blue)
  - 4 samples per point (Red, Green, Blue, and “Alpha”, a.k.a. Opacity)



Memory space requirement of image

- For k-bit image of dimension M*N the space requirement is

$$b = M \times N \times k$$

Image Processing and related fields

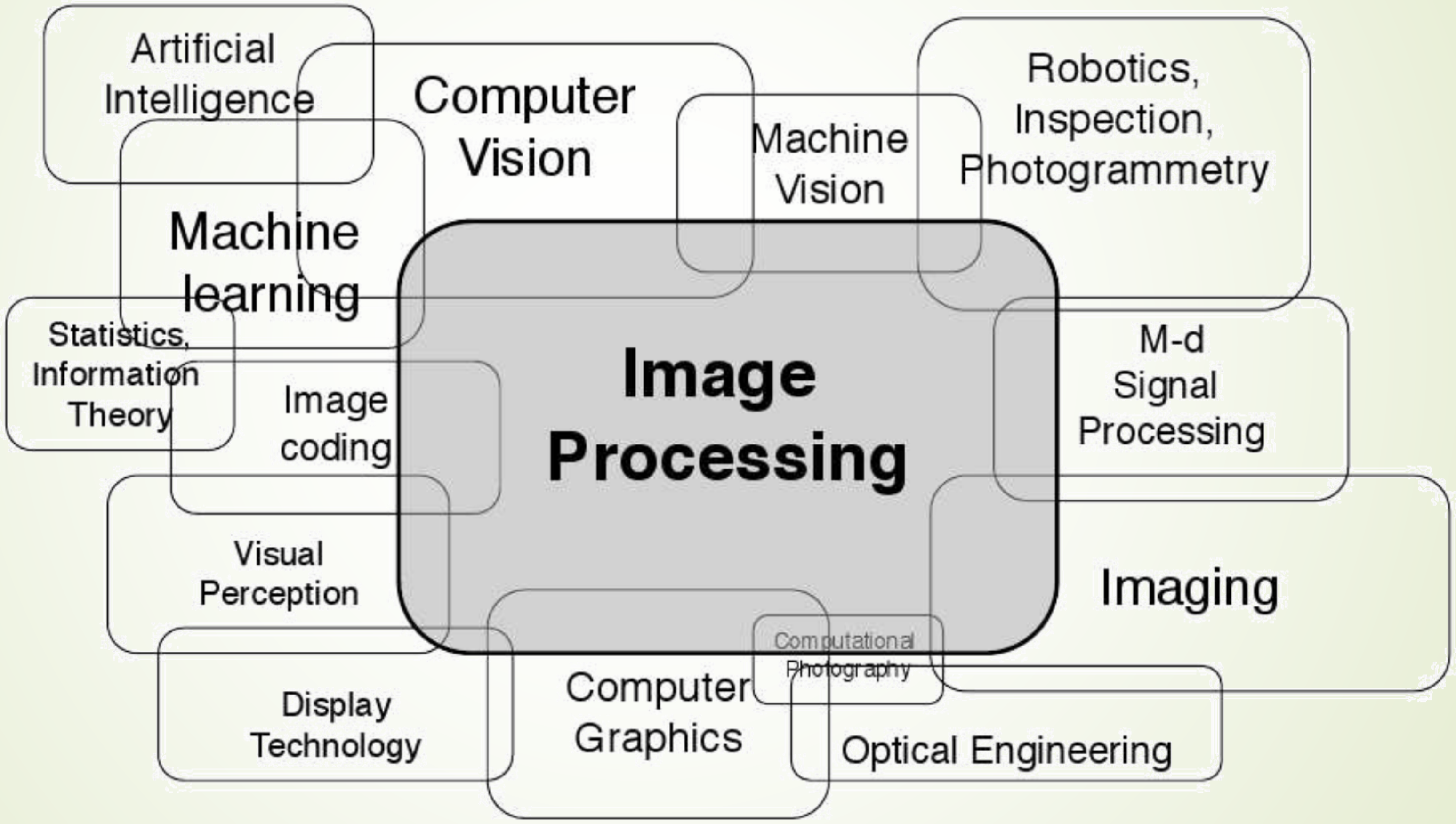


Image Processing to Computer Vision

- The continuum from image processing to computer vision can be broken up into low-, mid- and high-level processes.

Low Level Process	Mid Level Process	High Level Process
Input: Image **Output:** Image	**Input:** Image **Output:** Attributes	**Input:** Attributes **Output:** Understanding
Examples: Noise removal, image sharpening	**Examples:** Object recognition, segmentation	**Examples:** Scene understanding, autonomous navigation

History of DIP

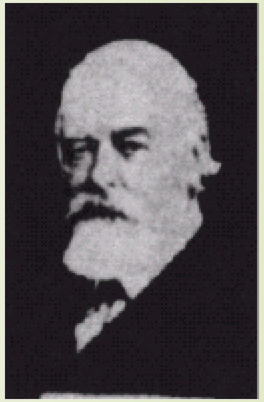
- **Early 1920s:** One of the first applications of digital imaging was in the news-paper industry.

Early digital image

- Images were transferred by submarine cable between London and New York
- The Bartlane cable picture transmission service
- Pictures were coded for cable transfer and reconstructed at the receiving end on a telegraph printer

History contd..

- **Mid to late 1920s:** Improvements to the Bartlane system resulted in higher quality images
- New reproduction processes based on photographic techniques
- Increased number of tones in reproduced images



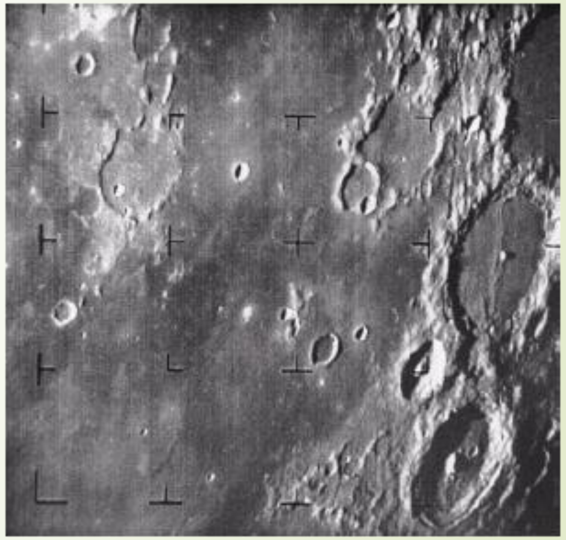
Improved digital image

History contd..

- **1960s:** Improvements in computing technology and the onset of the space race led to a surge of work in digital image processing.

- **1964:** Computers used to improve the quality of images of the moon taken by the *Ranger 7* probe

- Such techniques were used in other space missions including the Apollo landings

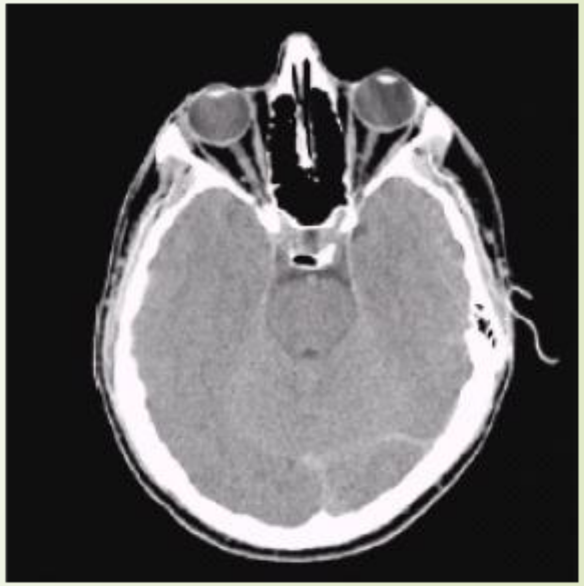


A picture of the moon taken by the Ranger 7 probe minutes before landing

History contd..

- **1970s:** Digital image processing begins to be used in medical applications

- **1979:** Sir Godfrey N. Hounsfield & Prof. Allan M. Cormack share the Nobel Prize in medicine for the invention of tomography, the technology behind Computerized Axial Tomography (CAT) scans



Typical head slice CAT image

History contd..

- **1980s - Today:** The use of digital image processing techniques has exploded and they are now used for all kinds of tasks in all kinds of areas
  - Image enhancement & restoration
  - Artistic effects
  - Medical visualization
  - Industrial inspection
  - Law enforcement
  - Human computer interfaces

Why do we process image?

- Acquire an image
  - Correct aperture and color balance
  - Reconstruct image from projections: Panoramic view
- Facilitate picture storage and transmission
  - Send an image from space
  - Efficiently store an image in a digital camera
- Enhance and restore images
  - Touch up personal photos
  - Visibility of images in navigation
- Extract information from images
  - Object/Character recognition

Applications

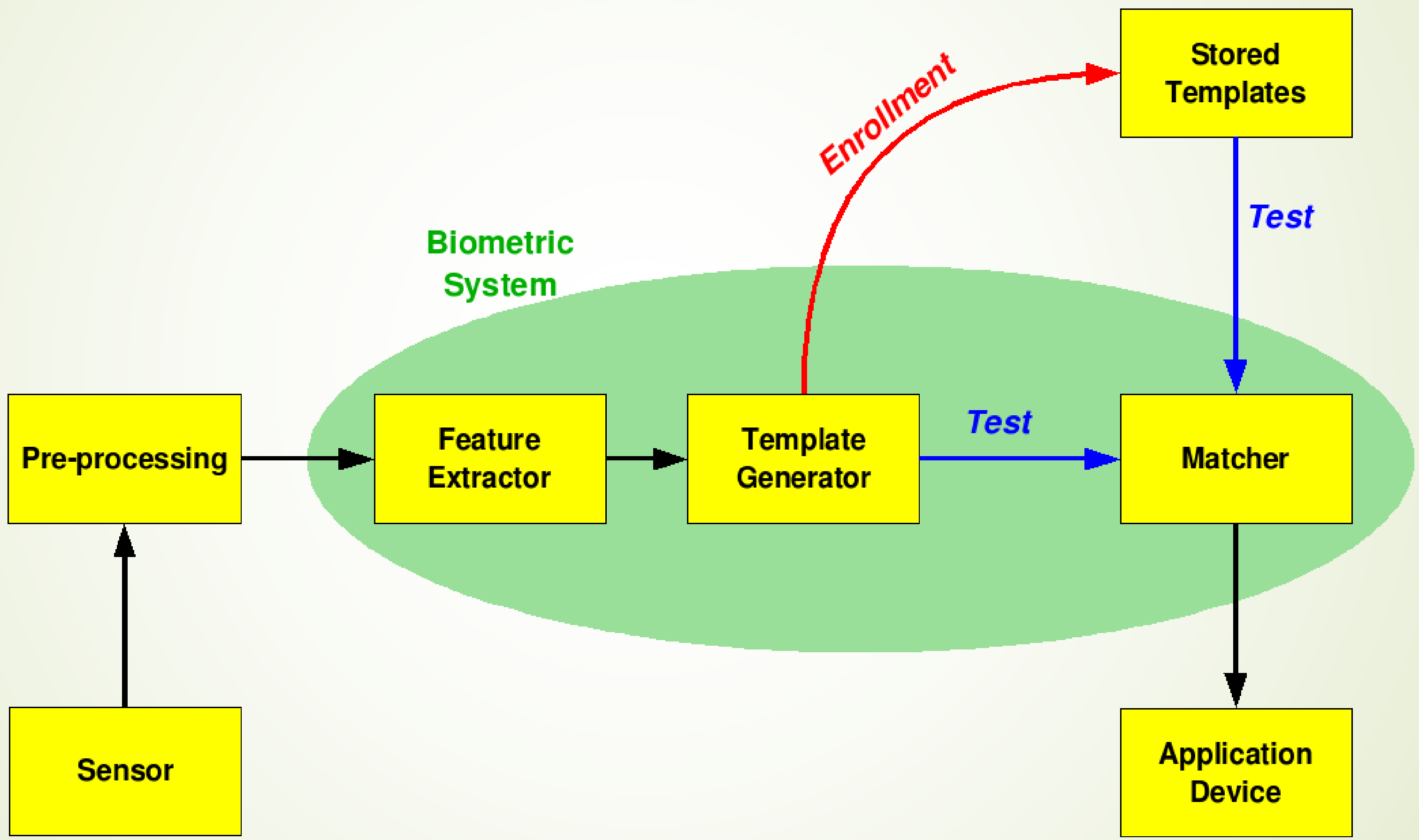
- Biometric:








Generalized biometric system



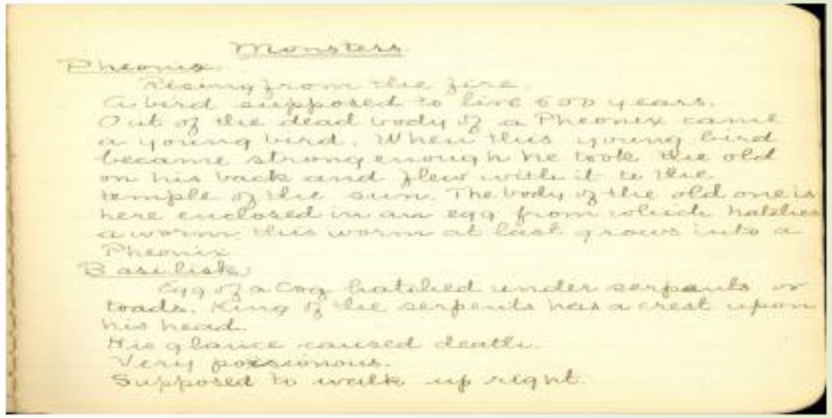
Applications

- Text analysis: Archiving the data

ΜΑΚΕΔΟΝΙΑ

ΕΦΗΜΕΡΙΣ ΤΟΥ ΛΑΟΥ

ΑΓΓΕΛΙΑ



Monsters

Pheonix:

Rising from the fire.
A bird supposed to live 600 years.
Out of the dead body of a Pheonix came
a young bird. When this young bird
became strong enough he took the old
on his back and flew with it to the
temple of the sun. The body of the old one is
here enclosed in an egg from which hatches
a worm, this worm at last grows into a
Pheonix

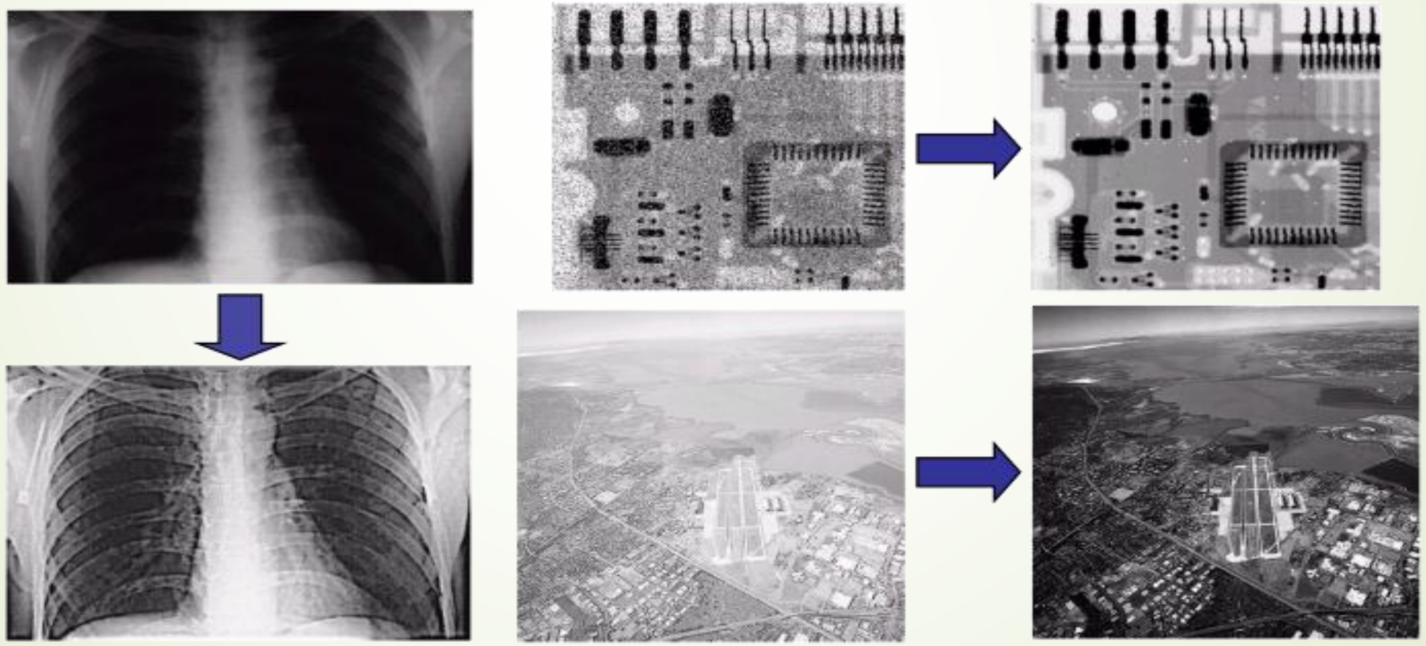
Basilisk:

Egg of a Cog hatched under serpents or
toads. King of the serpents has a crest upon
his head.
His glance caused death.
Very poisonous.
Supposed to walk up right.

- Satellite image
  - Forest management: Forest stock
  - Weather forecasting
  - Road map detection
- Forensic applications and many more.

Examples: Image Enhancement

One of the most common uses of DIP techniques: improve quality, remove noise etc

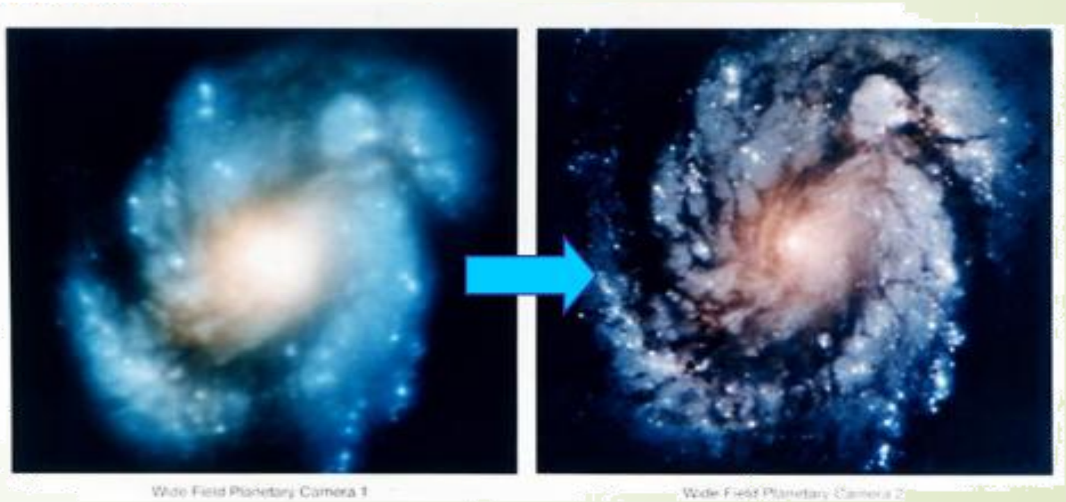


Examples: The Hubble Telescope

Launched in 1990 the Hubble telescope can take images of very distant objects

However, an incorrect mirror made many of Hubble's images useless

Image processing techniques were used to fix this



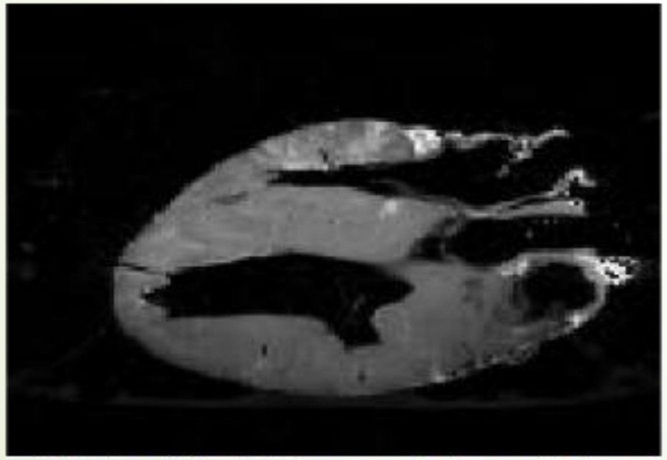
Examples: Artistic Effects

Artistic effects are used to make images more visually appealing, to add special effects and to make composite images

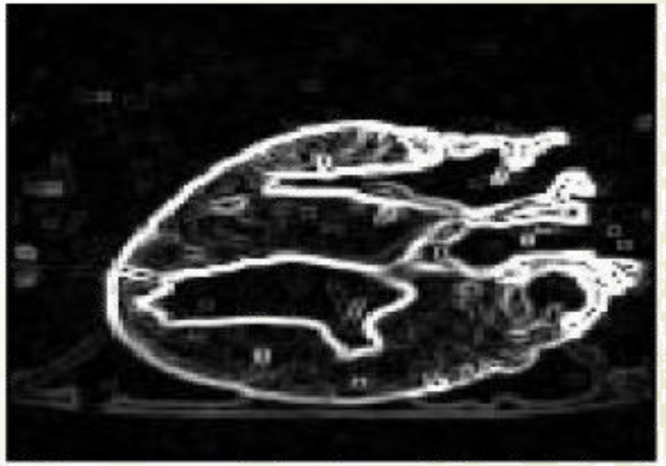
Examples: Medicine

Take slice from MRI scan of canine heart, and find boundaries between types of tissue

- Image with gray levels representing tissue density
- Use a suitable filter to highlight edges



Original MRI Image of a Dog Heart

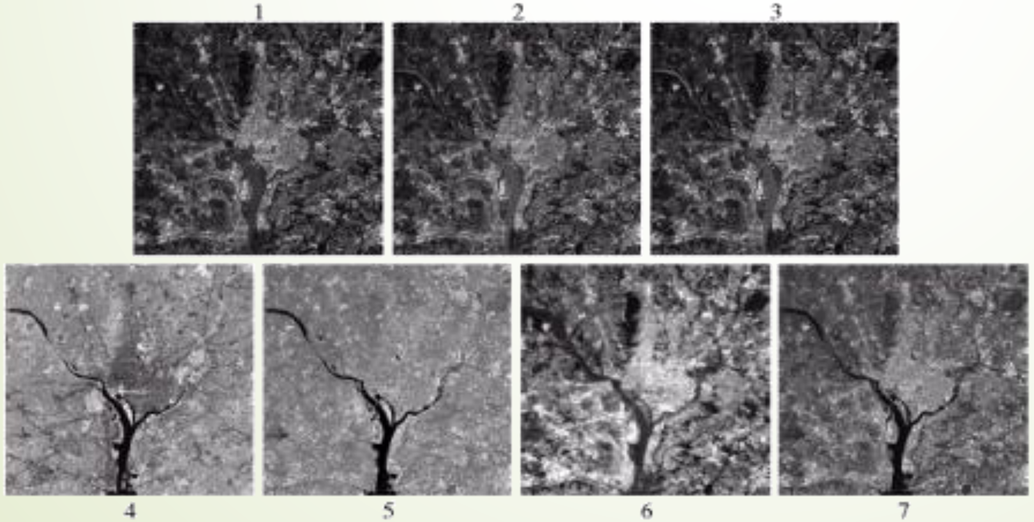


Edge Detection Image

Example: GIS

Geographic Information Systems

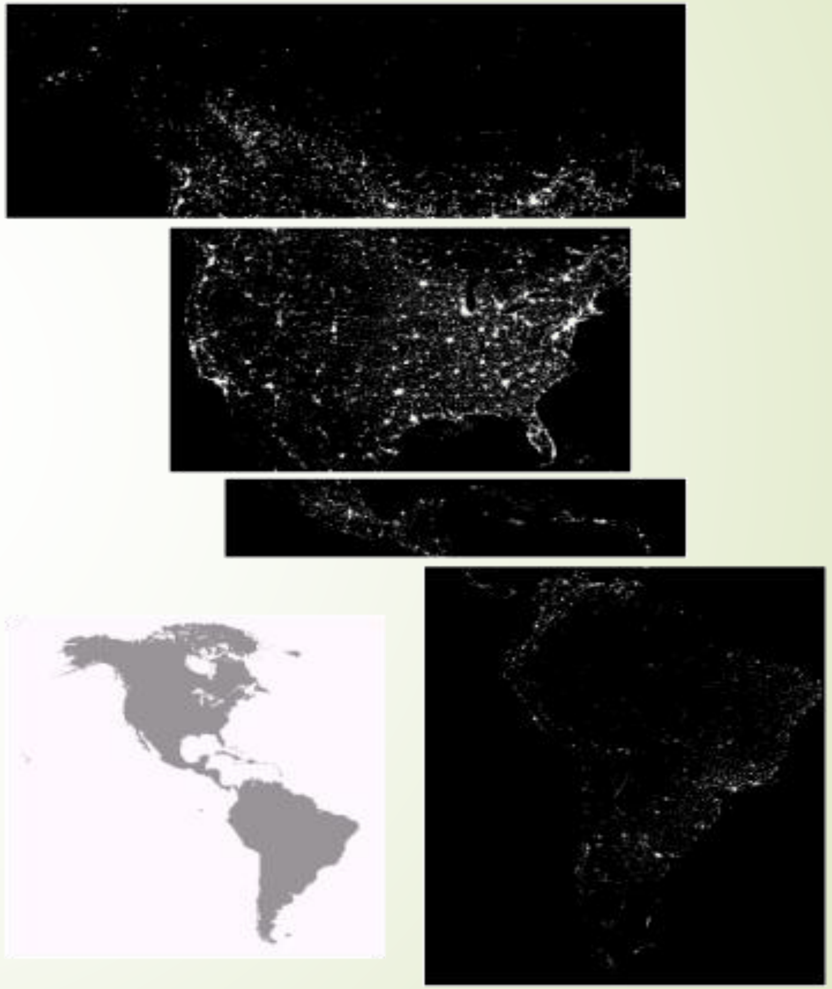
- Digital image processing techniques are used extensively to manipulate satellite imagery
- Terrain classification
- Meteorology



GIS: contd.

Night-Time Lights of the World data set

- Global inventory of human settlement
- Not hard to imagine the kind of analysis that might be done using this data



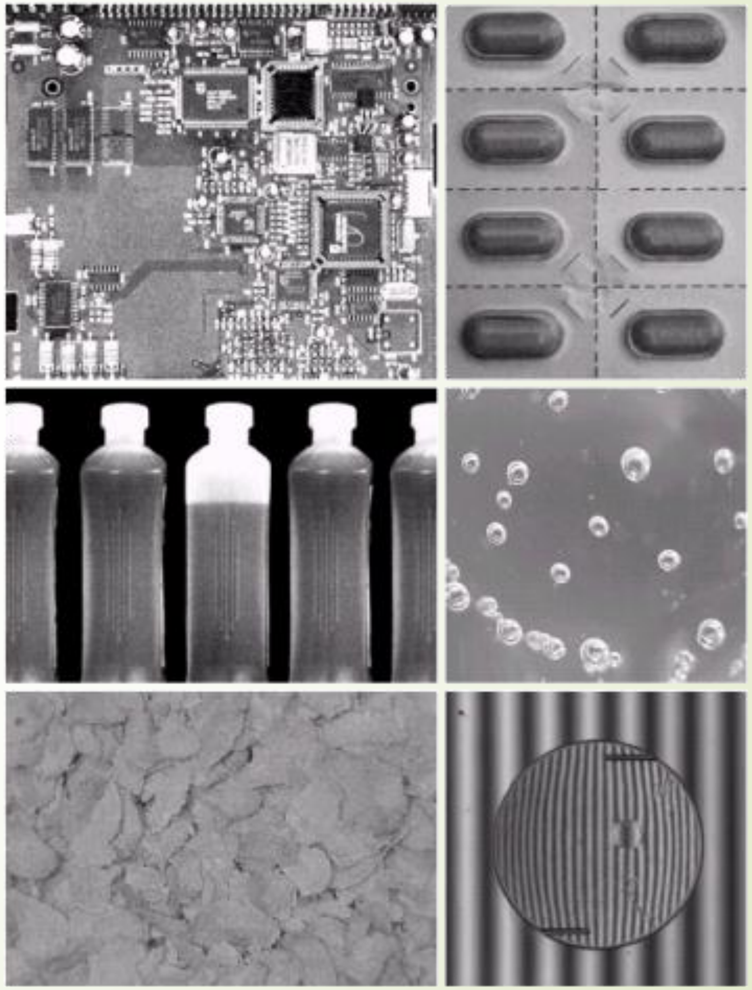
Industrial Inspection

Human operators are expensive, slow and unreliable

Make machines do the job instead

Industrial vision systems are used in all kinds of industries

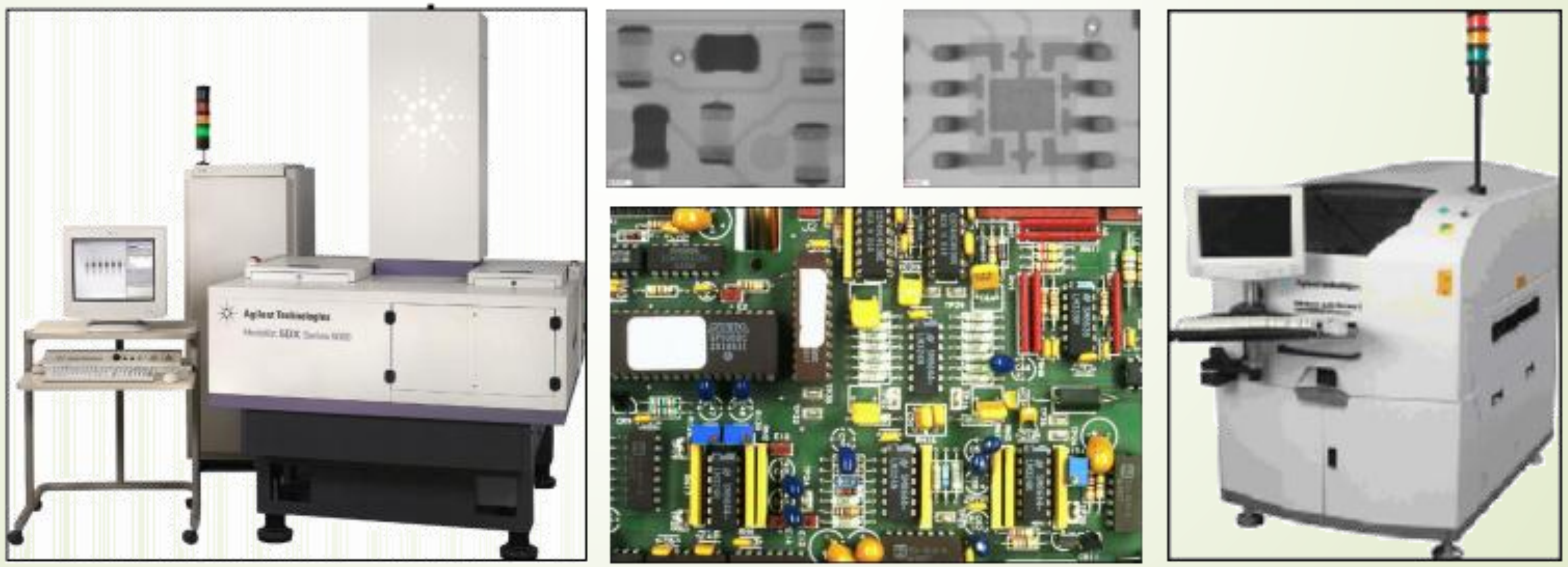
Can we trust them?



Examples: PCB Inspection

Printed Circuit Board (PCB) inspection

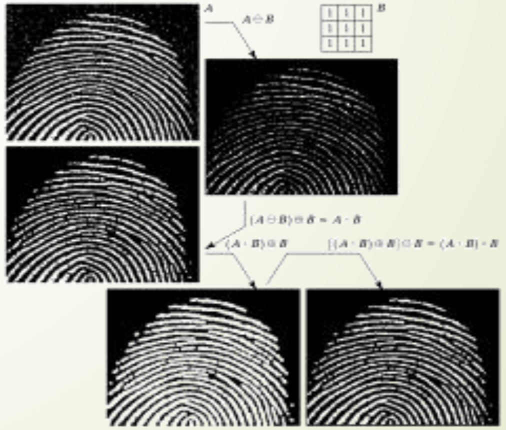
- Machine inspection is used to determine that all components are present and that all solder joints are acceptable
- Both conventional imaging and x-ray imaging



Examples: Law Enforcement

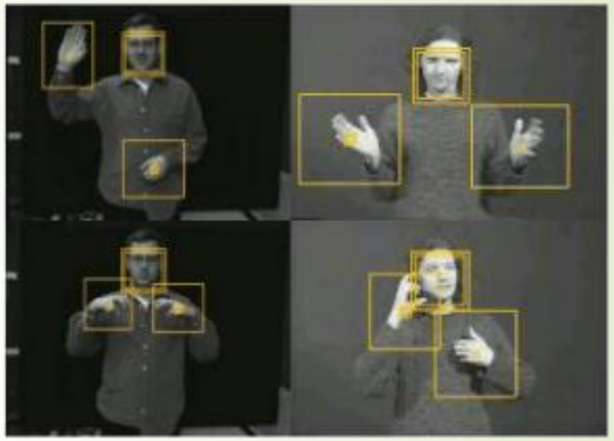
Image processing techniques are used extensively by law enforcers

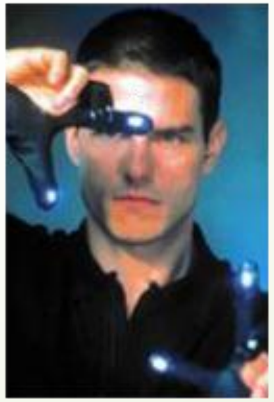
- Number plate recognition for speed cameras/automated toll systems
- Fingerprint recognition
- Enhancement of CCTV images



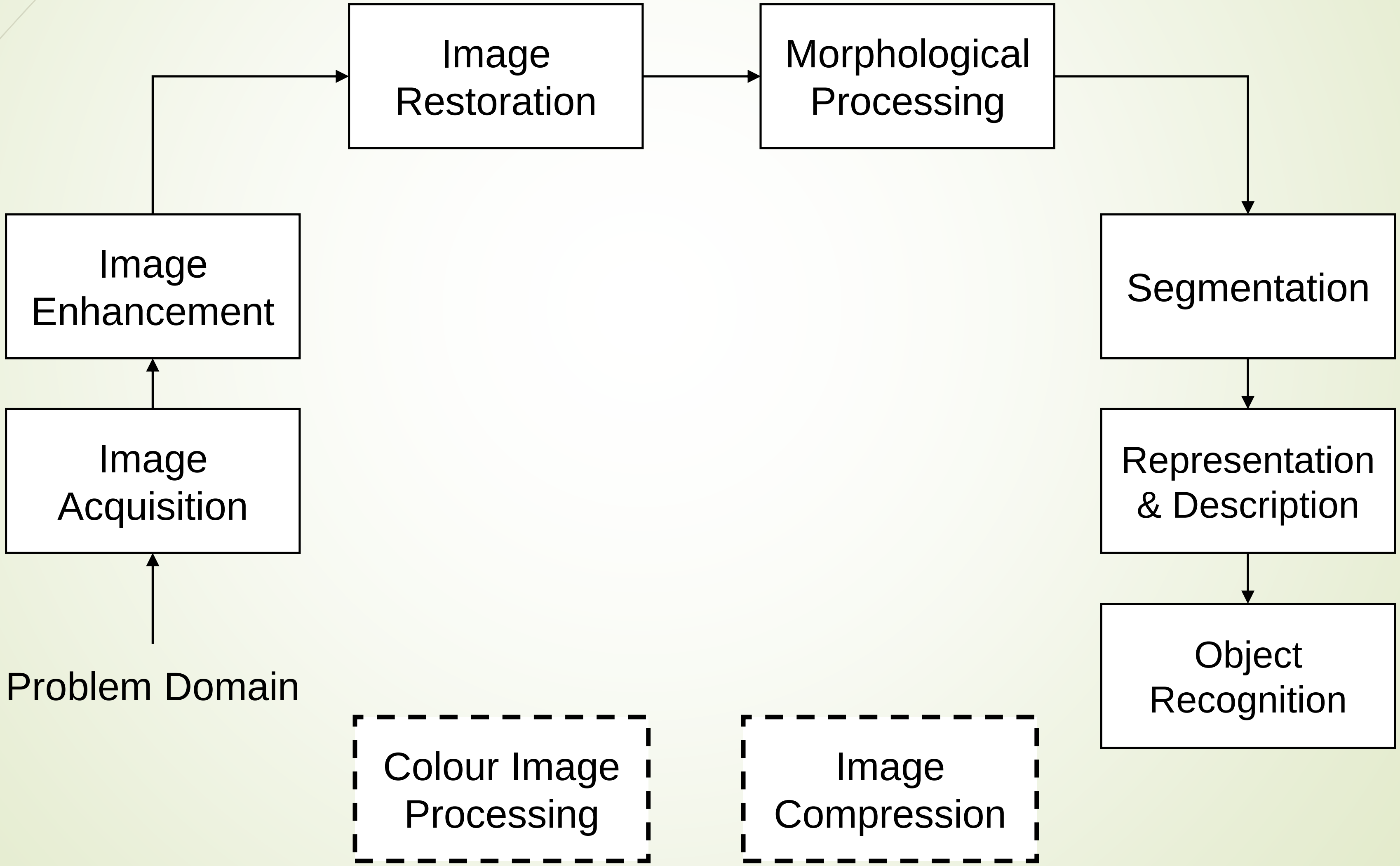
Examples: HCI

- Try to make human computer interfaces more natural
  - Face recognition
  - Gesture recognition
- Does anyone remember the user interface from “Minority Report”?
- These tasks can be extremely difficult





The main stages of DIP



Key Stages in Digital Image Processing: Image Acquisition

Image Restoration

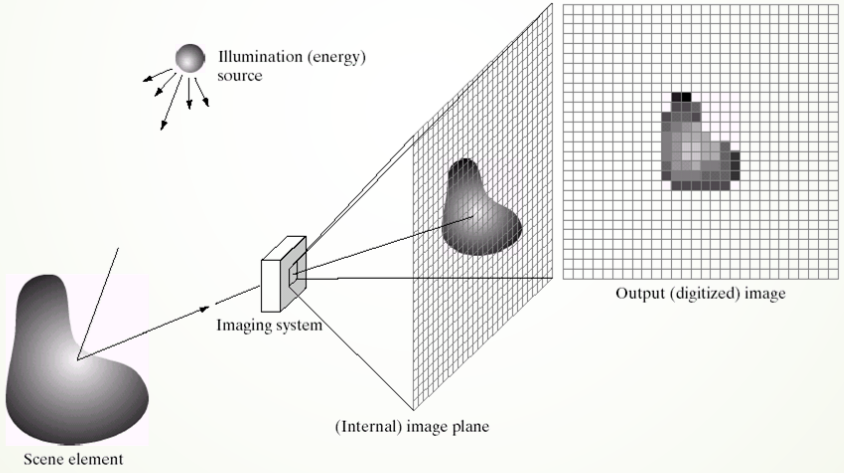
Morphological Processing

Image Enhancement

Segmentation

Image Acquisition

Representation & Description



Problem Domain

Object Recognition

Colour Image Processing

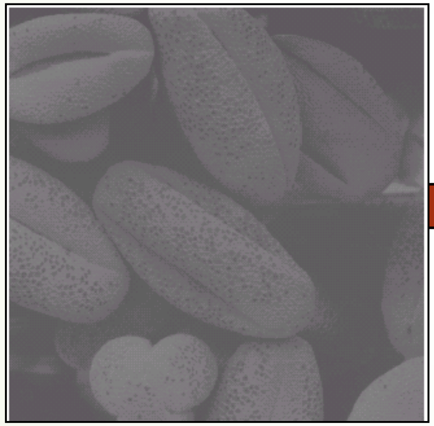
Image Compression

Key Stages in Digital Image Processing: Image Enhancement

Image Restoration

Morphological Processing

Image Enhancement



Segmentation

Image Acquisition

Representation & Description

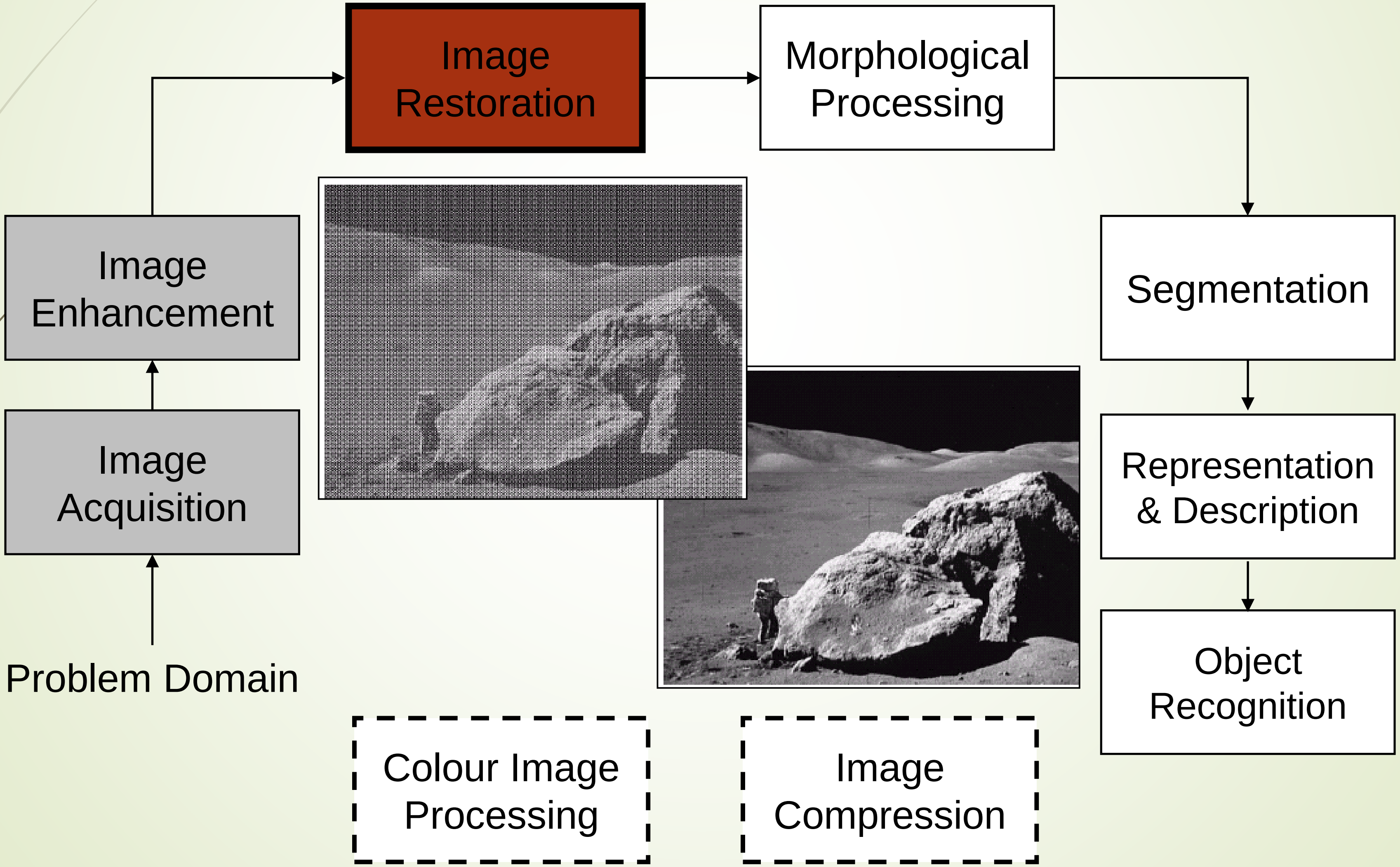
Problem Domain

Object Recognition

Colour Image Processing

Image Compression

Key Stages in Digital Image Processing: Image Restoration



Key Stages in Digital Image Processing: Morphological Processing

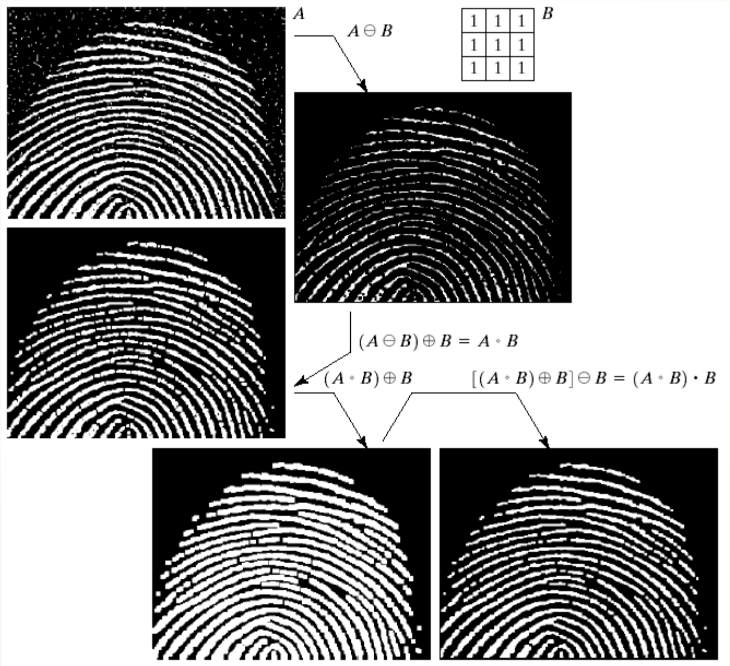
Image Enhancement

Image Acquisition

Problem Domain

Image Restoration

Morphological Processing



Colour Image Processing

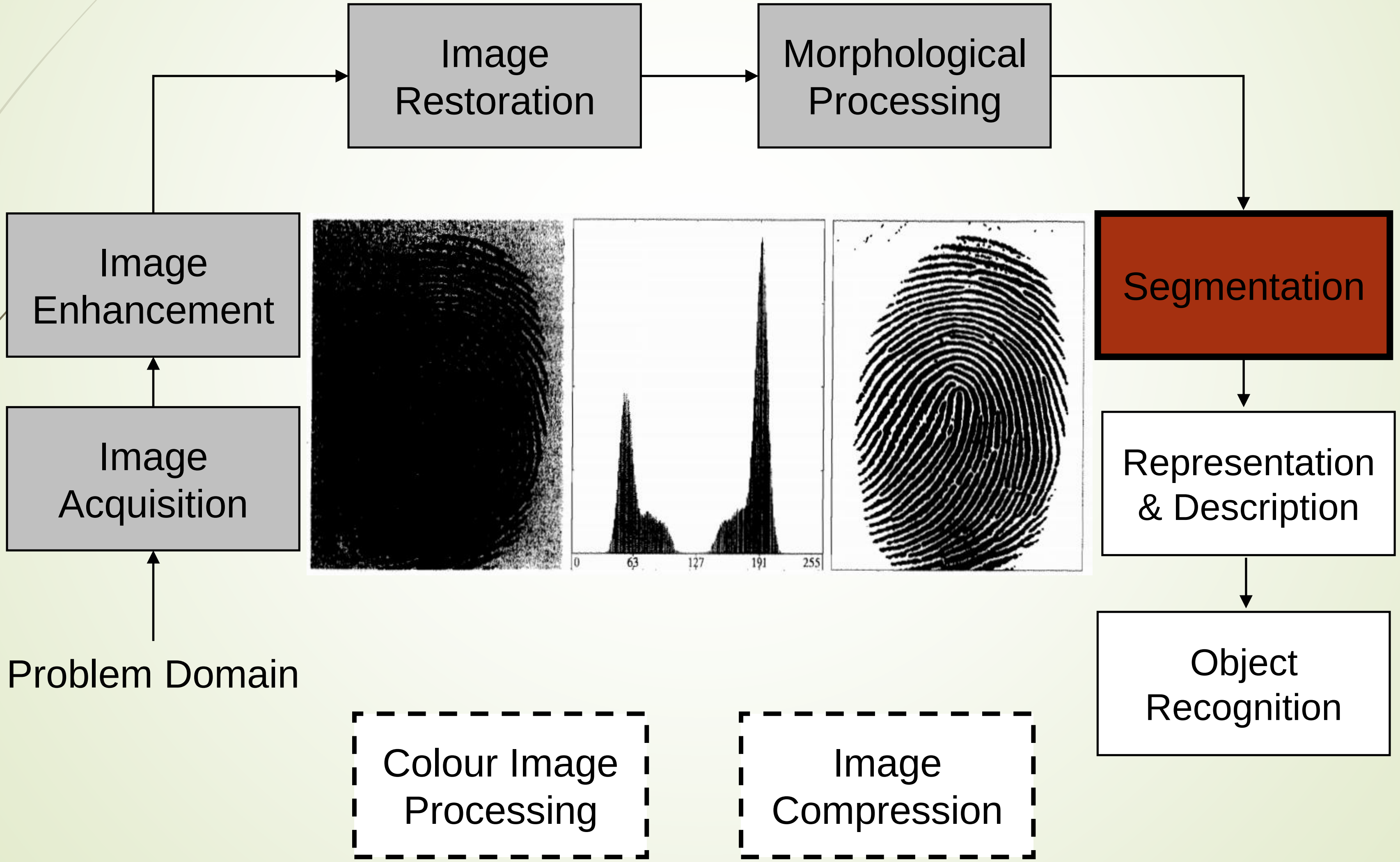
Image Compression

Segmentation

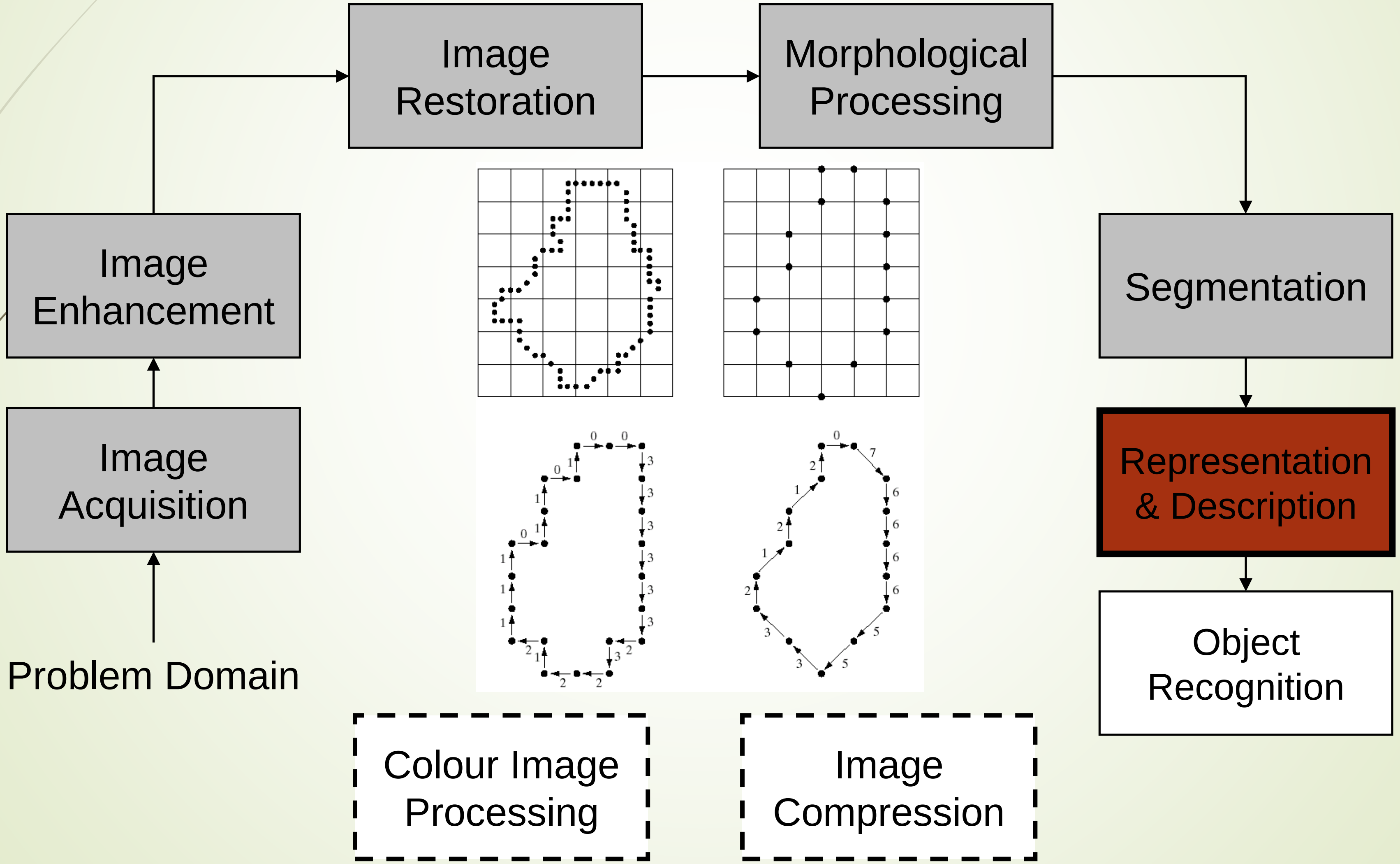
Representation & Description

Object Recognition

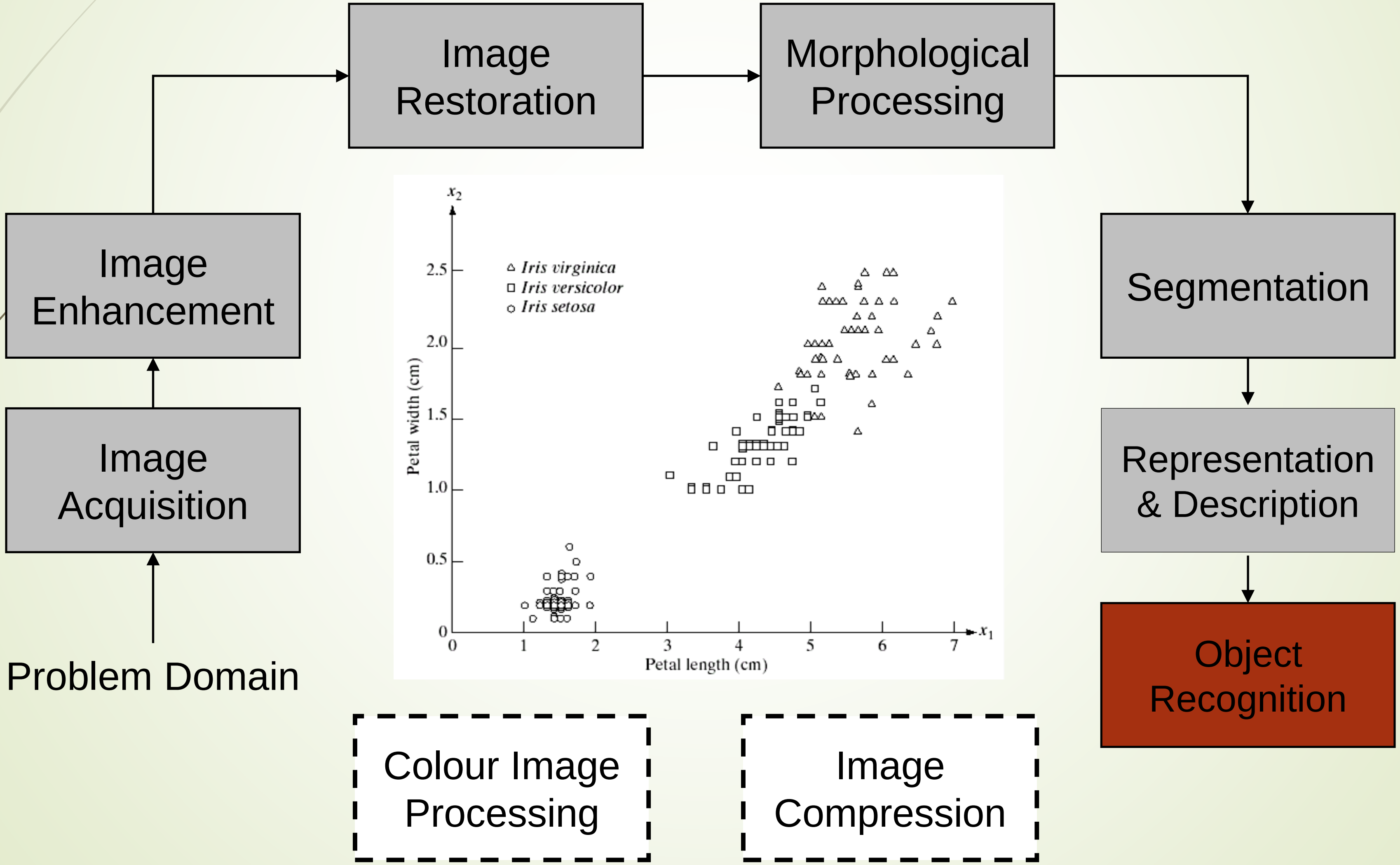
Key Stages in Digital Image Processing: Segmentation



Key Stages in Digital Image Processing: Representation & Description



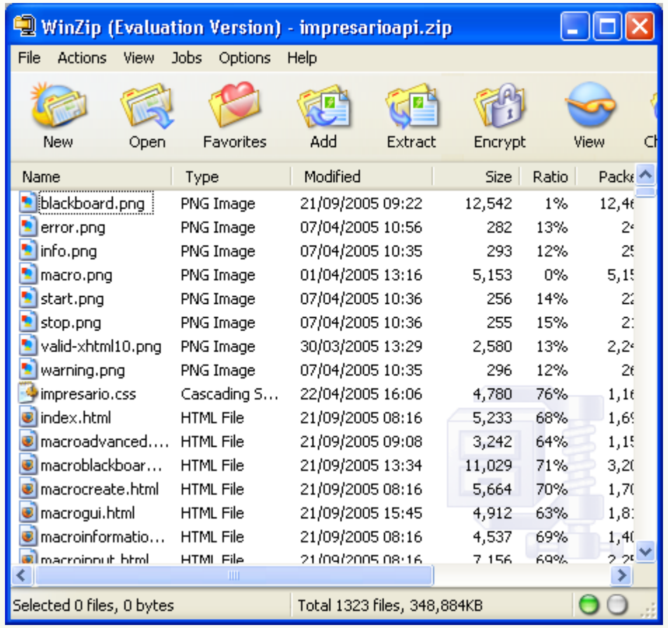
Key Stages in Digital Image Processing: Object Recognition



Key Stages in Digital Image Processing: Image Compression

Image Restoration → Morphological Processing → Segmentation → Representation & Description → Object Recognition

Problem Domain → Image Acquisition → Image Enhancement → Image Restoration



Colour Image Processing

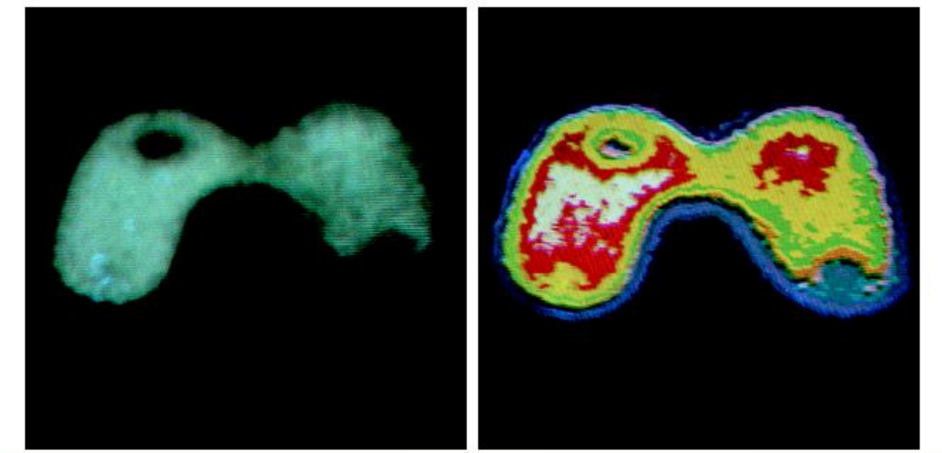
Image Compression

Key Stages in Digital Image Processing: Colour Image Processing

Image Restoration

Morphological Processing

Image Enhancement



Segmentation

Image Acquisition

Representation & Description

Problem Domain

Object Recognition

Colour Image Processing

Image Compression

Part: II

Image Restoration

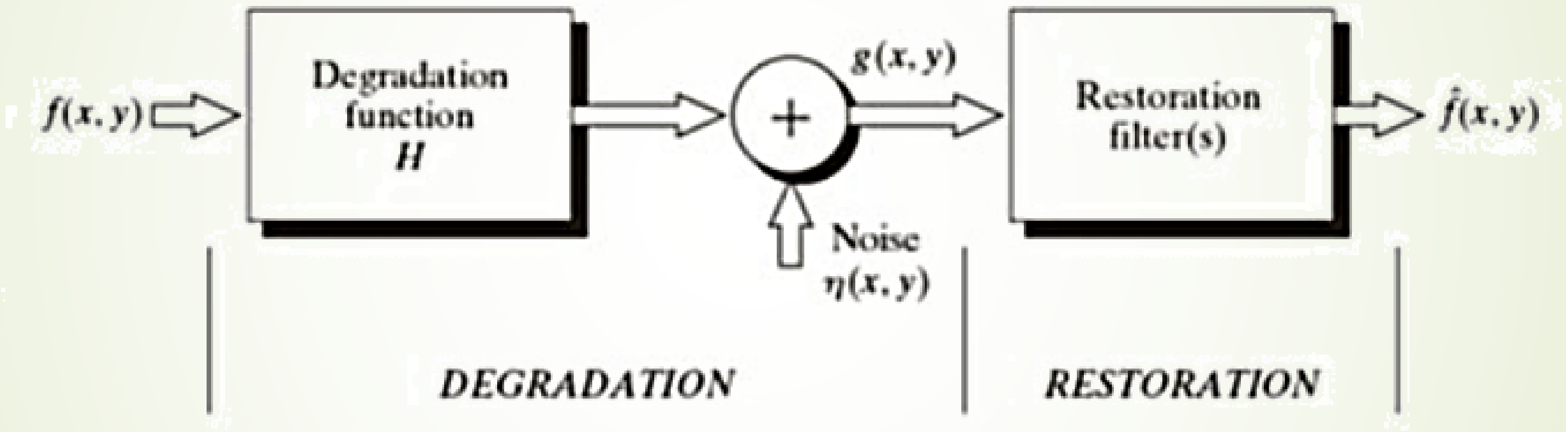
Image restoration vs. Image enhancement

- Image restoration: Objective is restore the original image from the degraded image.

- Image enhancement: Objective is to manipulate an image to take advantage of psychophysical aspect of human visual system.

An illustration of image restoration

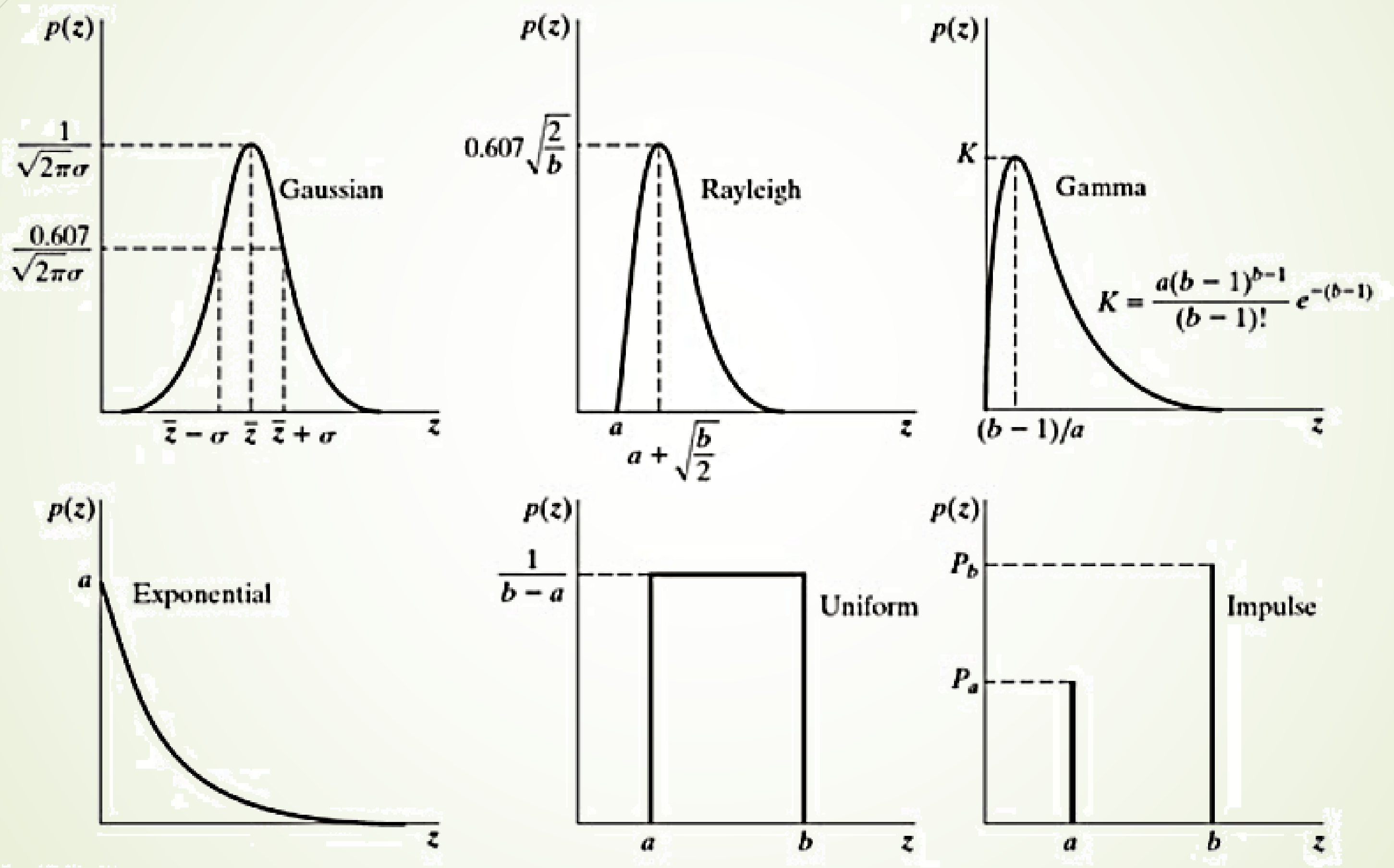
The modeling of the problem



The applications of image restoration

- Processing of astronomy images
- Processing of images degraded due to bad weather
- Medical image processing
- Processing surveillance video tape

Noise model

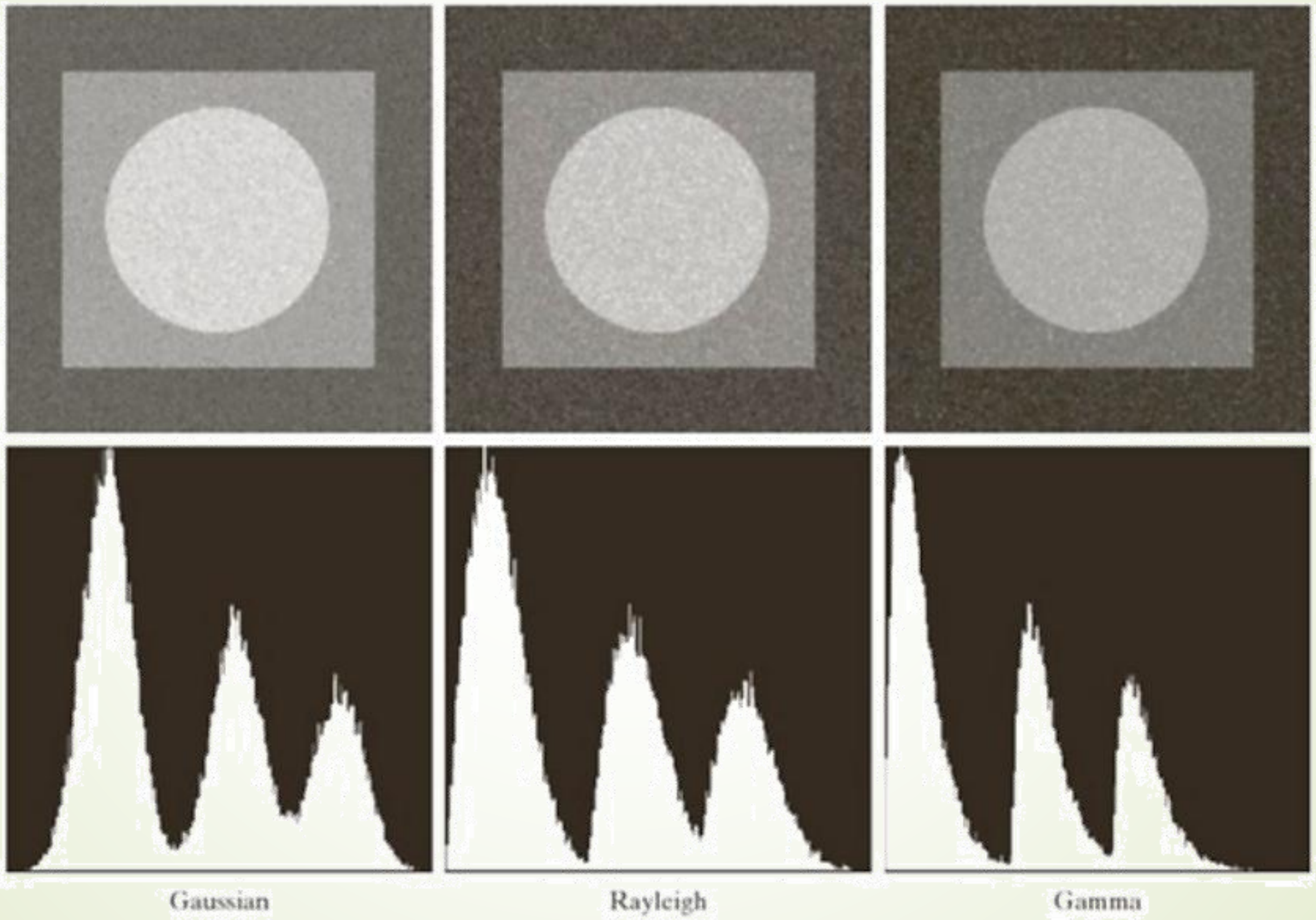


$p(z)$
$\frac{1}{\sqrt{2\pi}\sigma}$
$\frac{0.607}{\sqrt{2\pi}\sigma}$
Gaussian
$\bar{z}-\sigma$ $\bar{z}$ $\bar{z}+\sigma$
z
$p(z)$
$0.607\sqrt{\frac{2}{b}}$
Rayleigh
a
$a+\sqrt{\frac{b}{2}}$
z
$p(z)$
K
Gamma
$K = \frac{a(b-1)^{b-1}}{(b-1)!}e^{-(b-1)}$
$(b-1)/a$
z
$p(z)$
a
Exponential
z
$p(z)$
$\frac{1}{b-a}$
Uniform
a b z
$p(z)$
P_b
P_a
Impulse
a b z

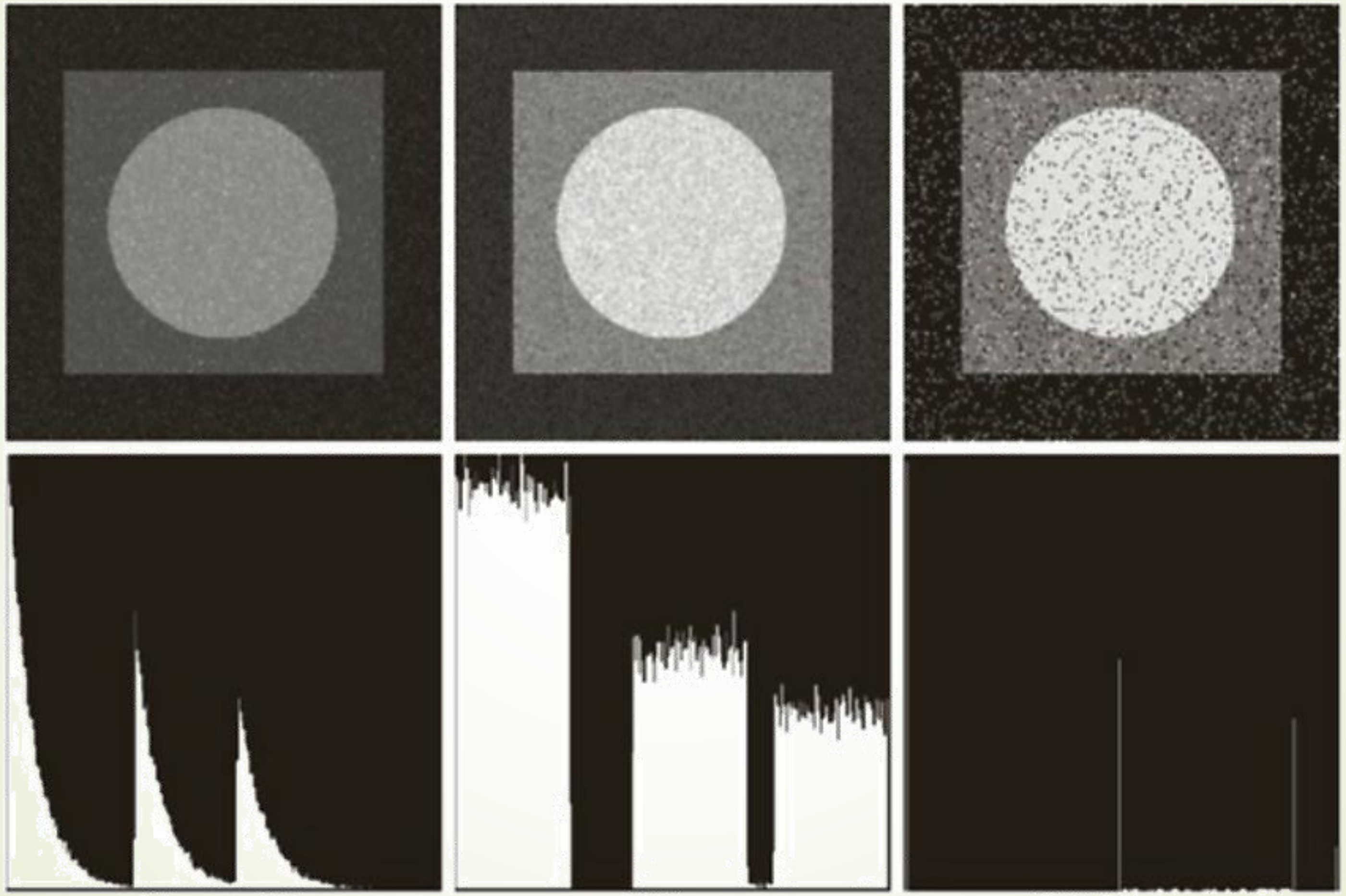
Noise model: Visualization

- Lets construct a test pattern to illustrate different noise models

Noise Model Contd..



Noise Model Contd..



Exponential Uniform Salt & Pepper

Restoration by spatial filtering

- Mean filters
  - Arithmetic mean filter
  - Geometric mean filter
  - Contraharmonic mean filter
- Order statistic filters
  - Median Filter
  - Max and Min filter
  - Mid point Filter
- Noise removal by frequency domain filters

Arithmetic Mean Filter

- This is the simplest of the mean filters

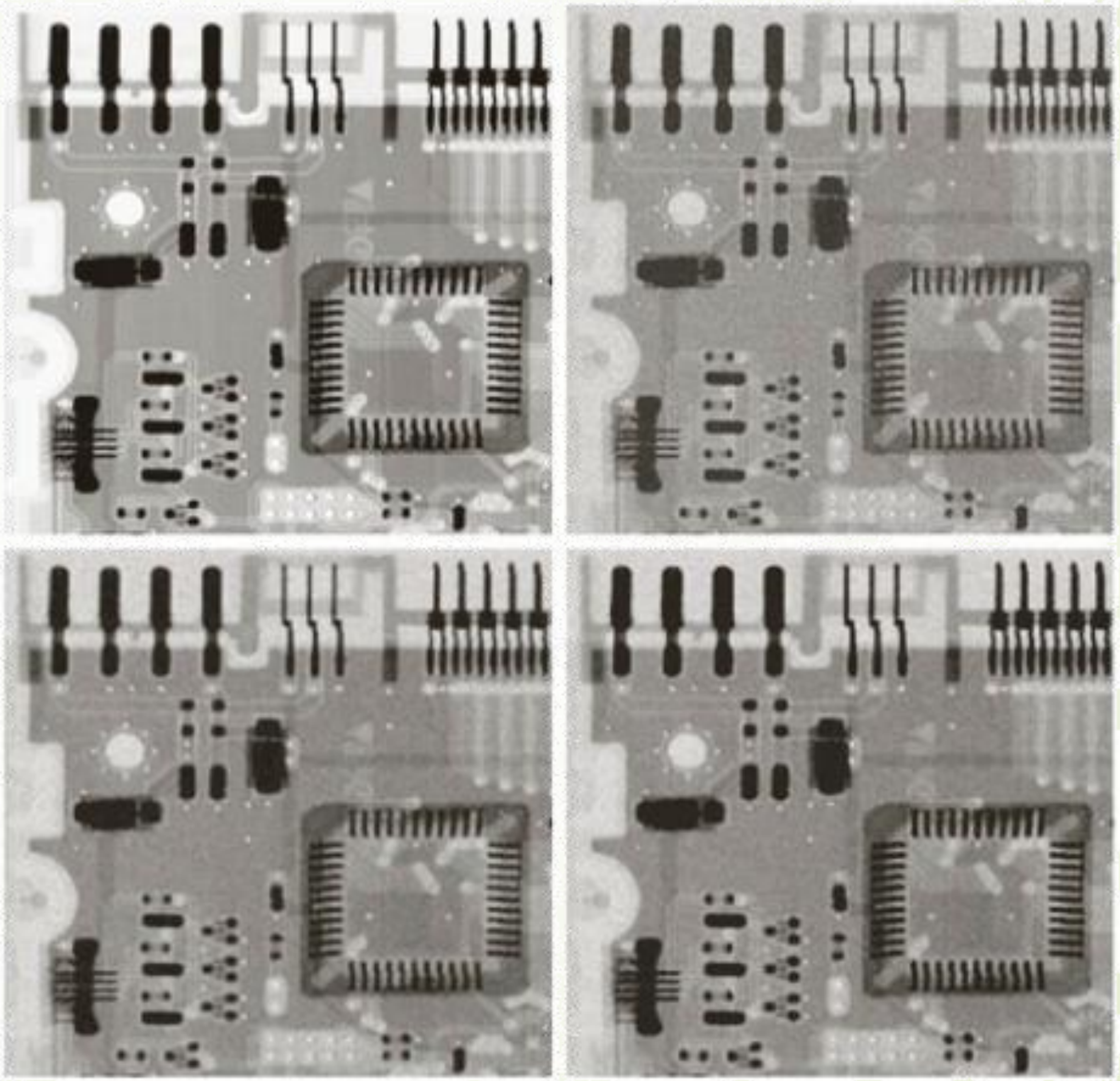
$$\hat{f}(x, y) = \frac{1}{mn} \sum_{(s,t) \in S_{xy}} g(s, t)$$

Geometric Mean Filter

- It performs better than the AM filter.

$$\hat{f}(x, y) = \left[\prod_{(s,t) \in S_{xy}} g(s, t) \right]^{\frac{1}{mn}}$$

Results



a b
c d

FIGURE
(a) X-ray image. (b) Image corrupted by additive Gaussian noise. (c) Result of filtering with an arithmetic mean filter of size 3 × 3. (d) Result of filtering with a geometric mean filter of the same size. (Original image courtesy of Mr. Joseph E. Pascente, Lixi, Inc.)

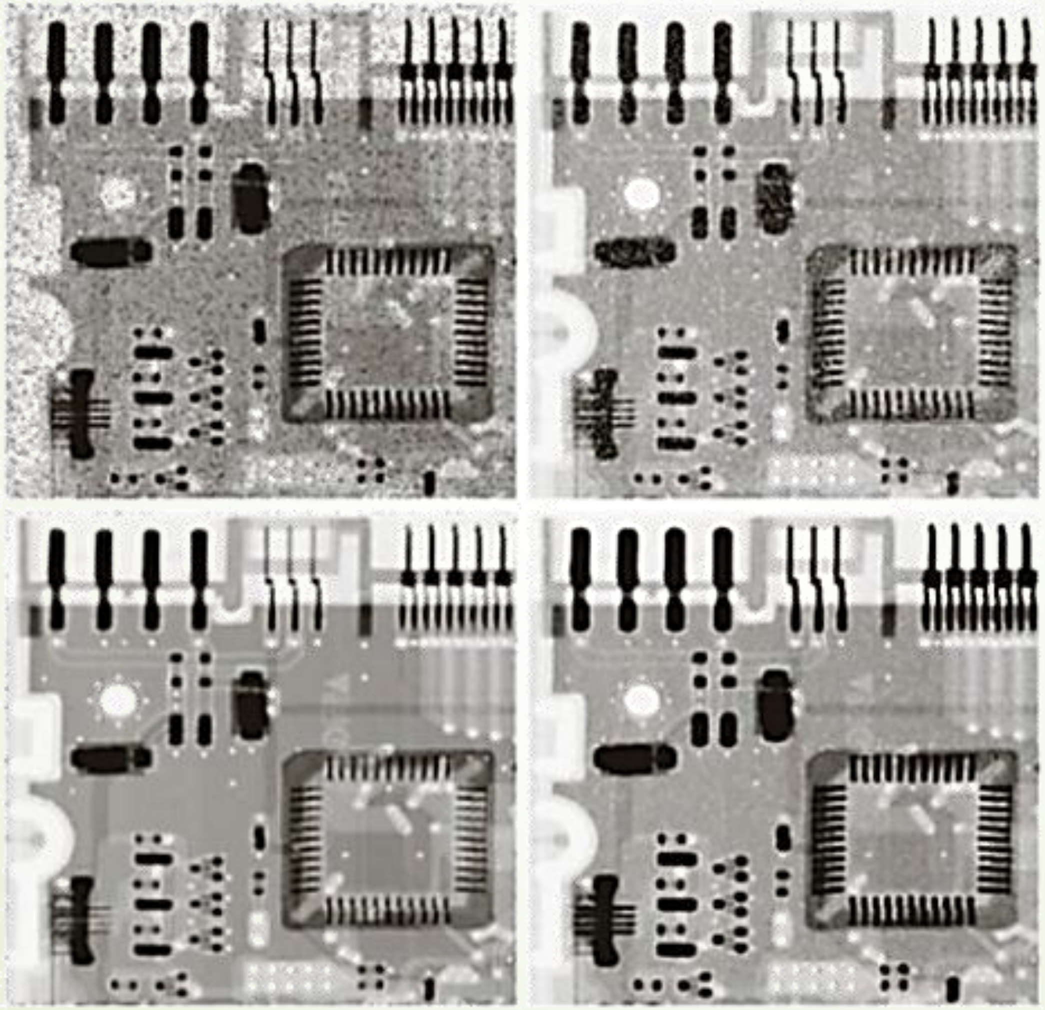
Contraharmonic mean filter

- It restores image based on the expression

$$\hat{f}(x, y) = \frac{\sum_{(s,t)\in S_{xy}} g(s,t)^{Q+1}}{\sum_{(s,t)\in S_{xy}} g(s,t)^{Q}}$$

- For Q>0, it eliminates pepper noise
- For Q<0, it eliminates salt noise
- For Q=0, it becomes arithmetic mean filter

Results



a b
c d

FIGURE
(a) Image corrupted by pepper noise with a probability of 0.1. (b) Image corrupted by salt noise with the same probability. (c) Result of filtering (a) with a 3×3 contra-harmonic filter of order 1.5. (d) Result of filtering (b) with $Q = -1.5$.

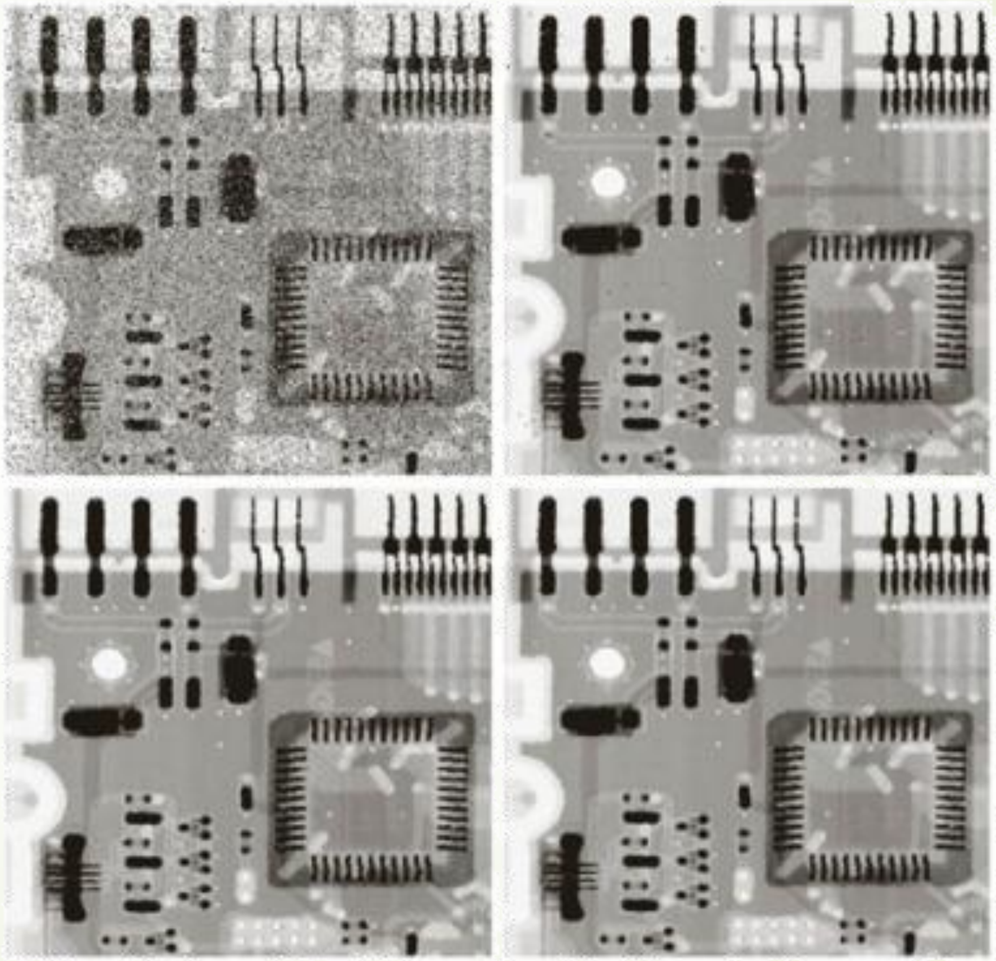
Median Filter

- Replaces the value of a pixel by the median of the intensity levels in the neighborhood of that pixel

$$\hat{f}(x, y) = \underset{(s,t) \in S_{xy}}{\text{median}} \{g(s, t)\}$$

- Median filters are practically effective in the presence of both bi-polar and unipolar impulse noise.

Results



a b
c d

FIGURE
(a) Image corrupted by salt-and-pepper noise with probabilities $P_a = P_b = 0.1$.
(b) Result of one pass with a median filter of size 3×3.
(c) Result of processing (b) with this filter.
(d) Result of processing (c) with the same filter.

Max, Min and Midpoint Filters

- Pepper noise can be reduced by max filter

$$\hat{f}(x, y) = \max_{(s,t)\in S_{xy}} \{g(s, t)\}$$

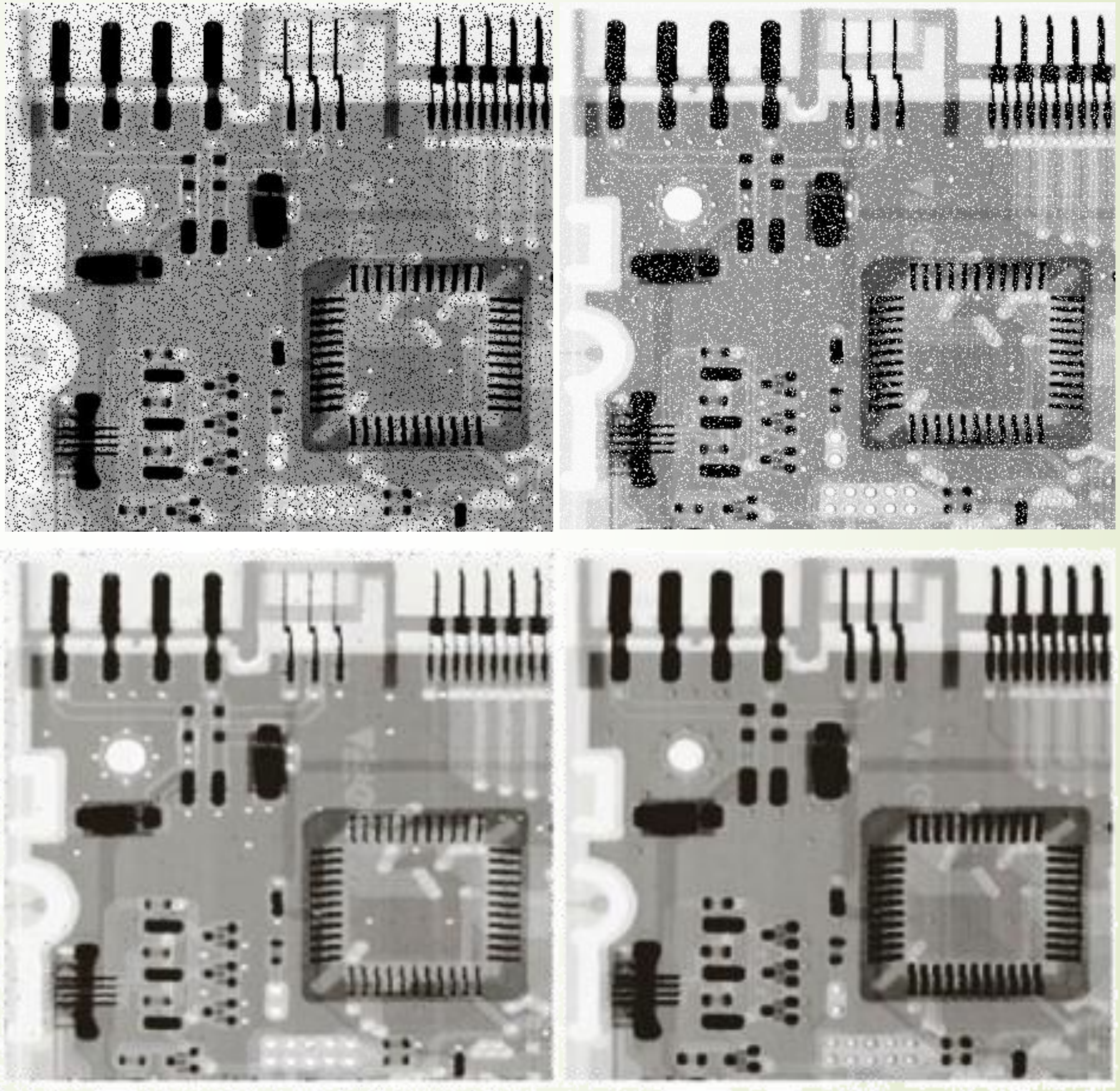
- Salt noise can be reduced by min filter

$$\hat{f}(x, y) = \min_{(s,t)\in S_{xy}} \{g(s, t)\}$$

- Midpoint filter computes the midpoint between max and in values in the area encompasses by the filter:

$$\hat{f}(x, y) = \frac{1}{2}\left[\max_{(s,t)\in S_{xy}} \{g(s, t)\} + \min_{(s,t)\in S_{xy}} \{g(s, t)\}\right]$$

Results

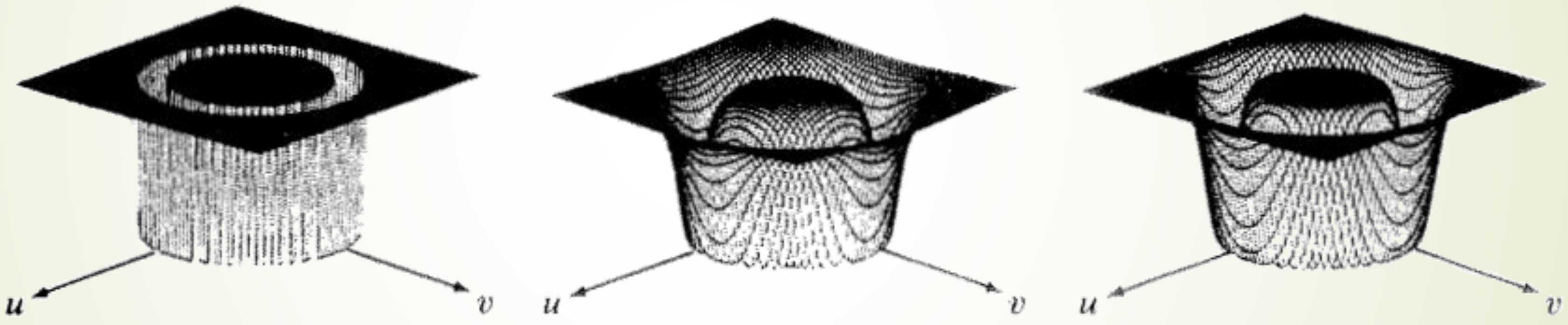


a b

FIGURE
(a) Result of filtering Fig. 5.8(a) with a max filter of size 3 × 3. (b) Result of filtering 5.8(b) with a min filter of the same size.

Frequency domain filtering

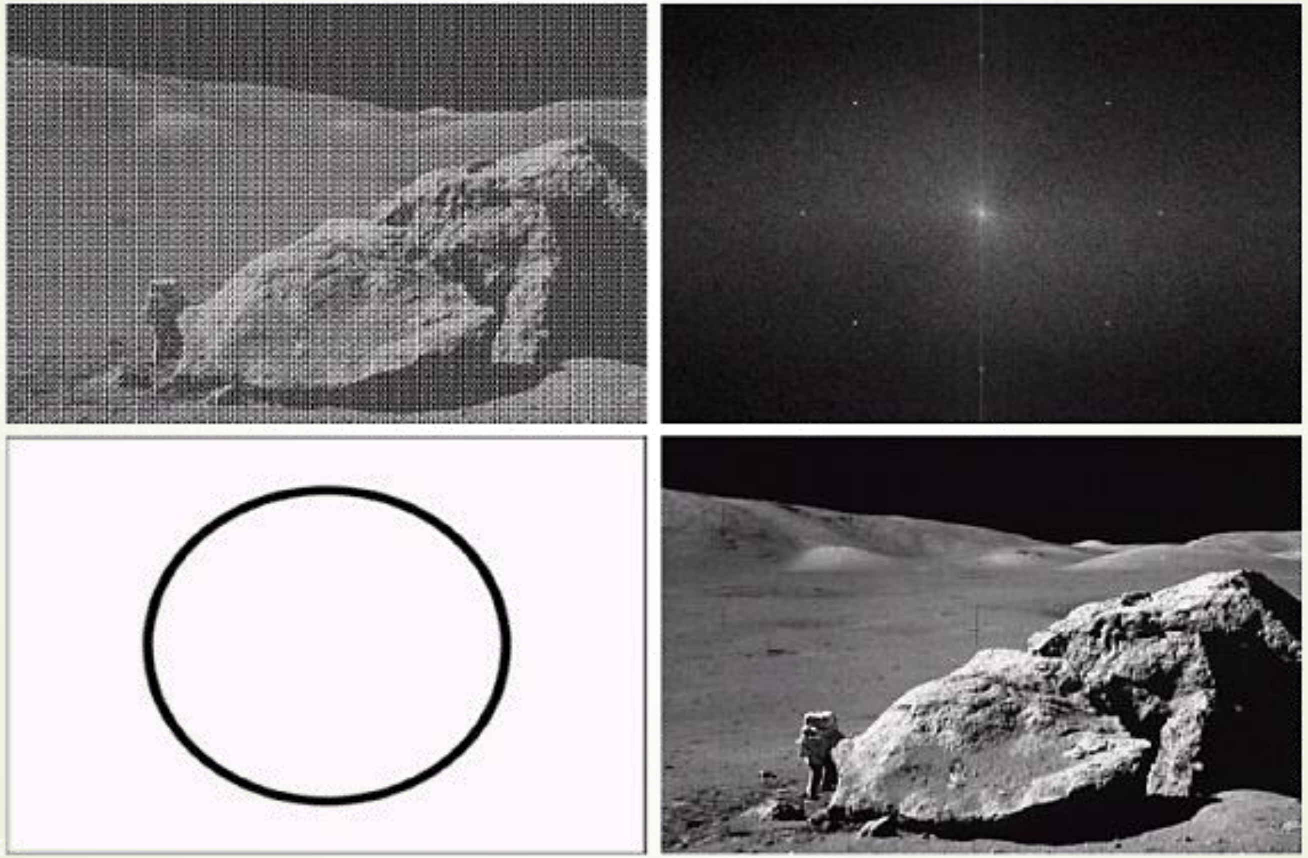
- Band Reject filters



a b c

From left to right, perspective plots of ideal, Butterworth (of order 1), and Gaussian bandreject filters.

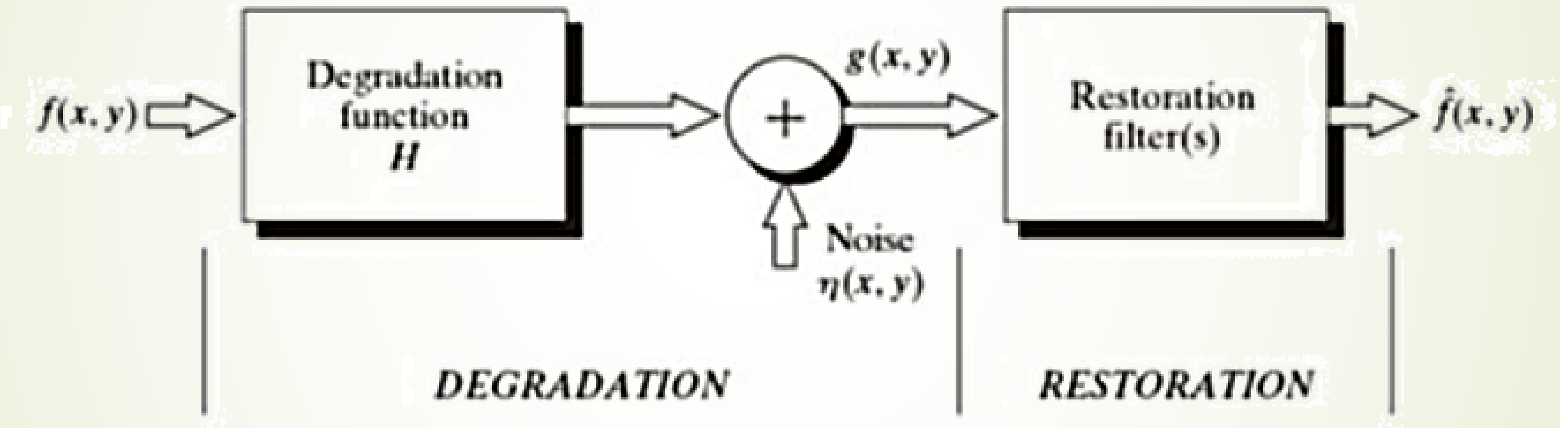
Results:



a b
c d

(a) Image corrupted by sinusoidal noise. (b) Spectrum of (a). (c) Butterworth bandreject filter (white represents 1). (d) Result of filtering. (Original image courtesy of NASA.)

The degradation-restoration model



Estimation of Degradation Function

- Estimation by image observation
- Estimation by experimentation
- Estimation by modeling

Estimation by image observation

- Looking for an area, in which signal content is strong.
- Process that area to make it as clean as possible.
- Let the observed part is g_s (x,y) and let the processed part is f*_s(x,y).

$$H_s(u, v) = \frac{G_s(u, v)}{\hat{F}_s(u, v)}$$

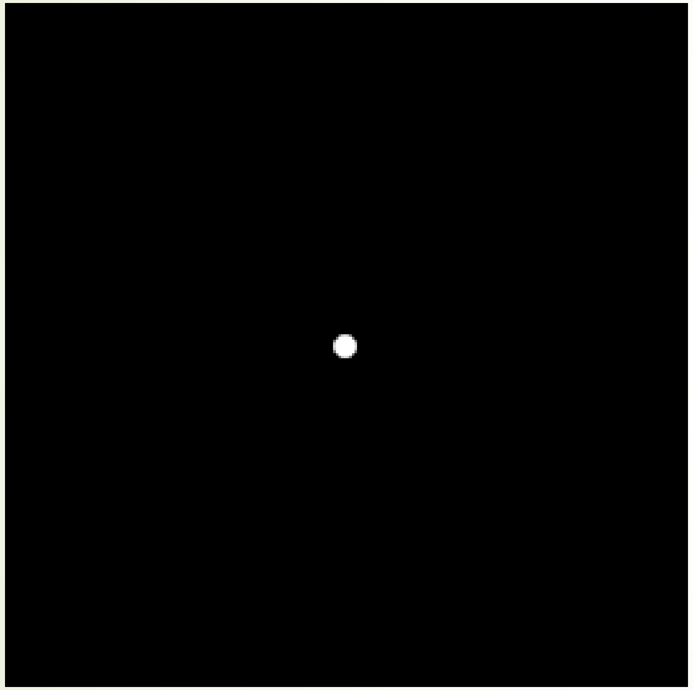
- Complete degradation function H(u,v) can be deduced.

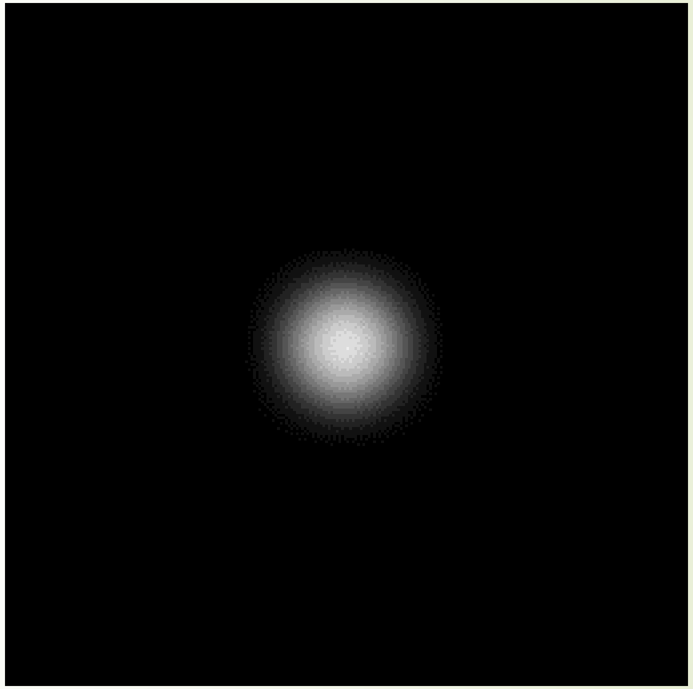
Estimation by experimentation

- If equipment similar to the equipment used to capture the degraded image, it is possible to estimate the degradation function.
- Manipulate some of the settings of your image capturing device to capture an image, which is degraded as the observed one.
- Using same system settings capture the impulse response, which will be constant value A in frequency domain.

$$H(u, v) = \frac{G(u, v)}{A}$$

Contd..





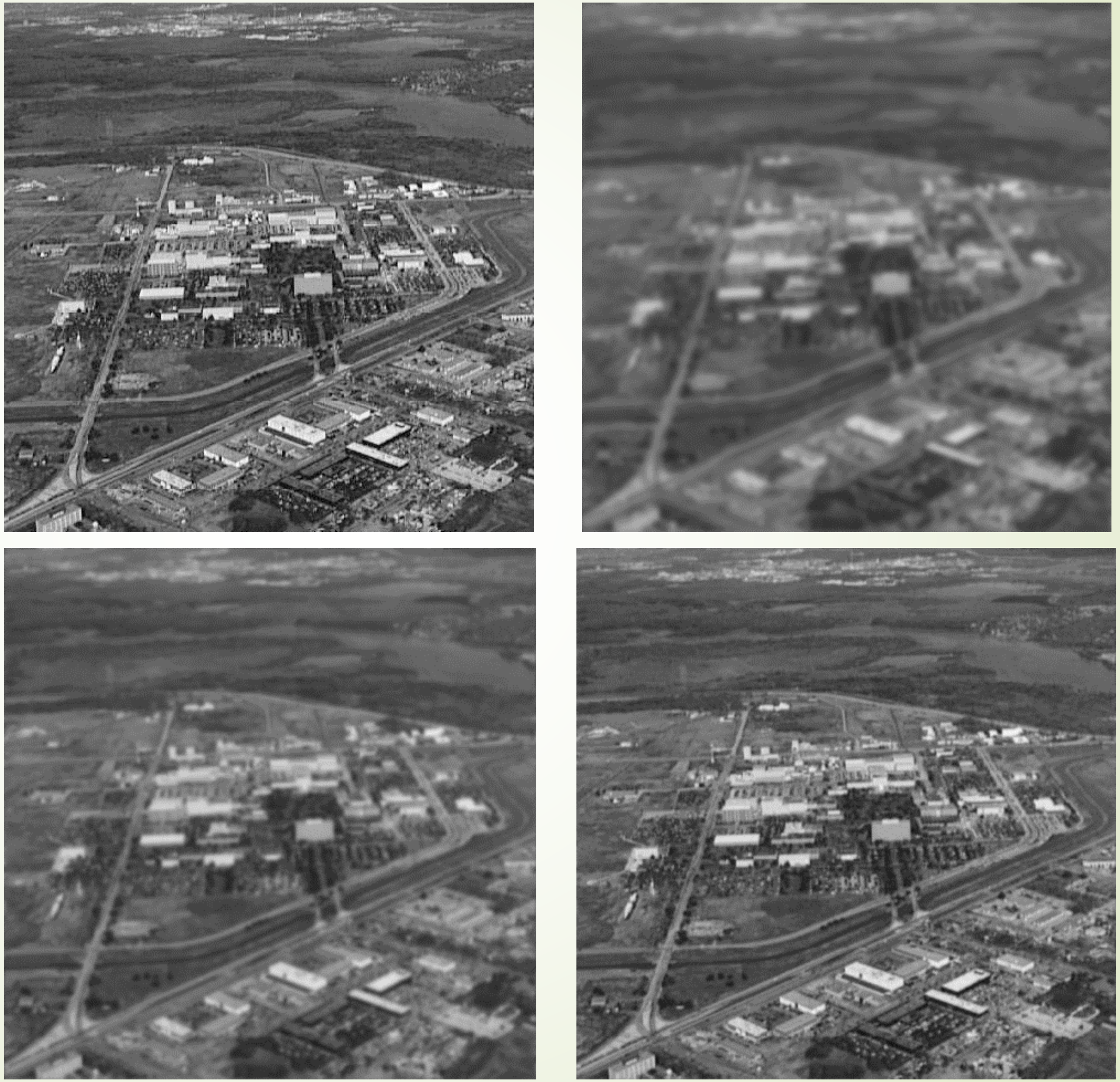
Estimation by modeling

- Model can take into account environmental conditions that cause degradations.
- Hufnagel and Stanley [1964] proposed a degradation model based on the physical characteristics of atmospheric turbulence. This model has the form:

$$H(u, v) = e^{-k(u^2+v^2)^{5/6}}$$

Contd..

Illustration of the atmospheric turbulence model. (a) Negligible turbulence. (b) Severe turbulence, $k = 0.0025$. (c) Mild turbulence, $k = 0.001$. (d) Low turbulence, $k = 0.00025$. (Original image courtesy of NASA.)



Approaches to remove degradation

- Inverse filtering
- Wiener filtering
- Least square error filtering and many more…

Inverse filtering

- Once we have the degradation function H(u,v), we can restore the image by

$$\hat{F}(u,v) = \frac{G(u,v)}{H(u,v)}$$

$$\hat{F}(u,v) = F(u,v) + \frac{N(u,v)}{H(u,v)}$$

- It will be a problem when H(u,v) is very small.

Results

a b
c d

FIGURE Restoring Fig. 5.25(b) with Eq. (5.7-1). (a) Result of using the full filter. (b) Result with H cut off outside a radius of 40; (c) outside a radius of 70; and (d) outside a radius of 85.

Weiner filtering

- Here we try to minimize the square error

$$e^2 = E\{(f - \hat{f})^2\}$$

- The solution is

$$\begin{aligned}\hat{F}(u, v) &= \left[\frac{H^*(u, v)S_f(u, v)}{S_f(u, v)|H(u, v)|^2 + S_\eta(u, v)}\right]G(u, v)\\ &= \left[\frac{H^*(u, v)}{|H(u, v)|^2 + S_\eta(u, v)/S_f(u, v)}\right]G(u, v)\\ &= \left[\frac{1}{H(u, v)}\frac{|H(u, v)|^2}{|H(u, v)|^2 + S_\eta(u, v)/S_f(u, v)}\right]G(u, v)\end{aligned}$$

Results

a b c

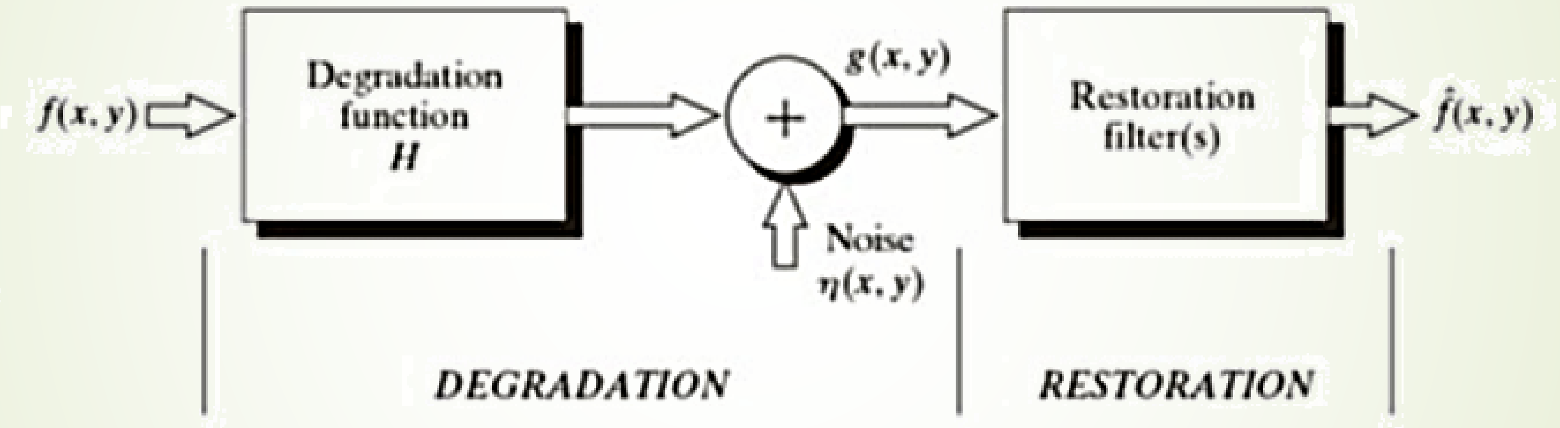
FIGURE Comparison of inverse and Wiener filtering. (a) Result of full inverse filtering of Fig. 5.25(b). (b) Radially limited inverse filter result. (c) Wiener filter result.

Results contd..

FIGURE (a) 8-bit image corrupted by motion blur and additive noise. (b) Result of inverse filtering. (c) Result of Wiener filtering. (d)–(f) Same sequence, but with noise variance one order of magnitude less. (g)–(i) Same sequence, but noise variance reduced by five orders of magnitude from (a). Note in (h) how the deblurred image is quite visible through a "curtain" of noise.

Towards super-resolution

Observe the model again



The word “Resolution”

Researchers in digital image processing and computer vision use the term resolution in three different ways:

- *Spatial resolution*
- *Brightness resolution*
- *Temporal resolution*

Illustration of resolution

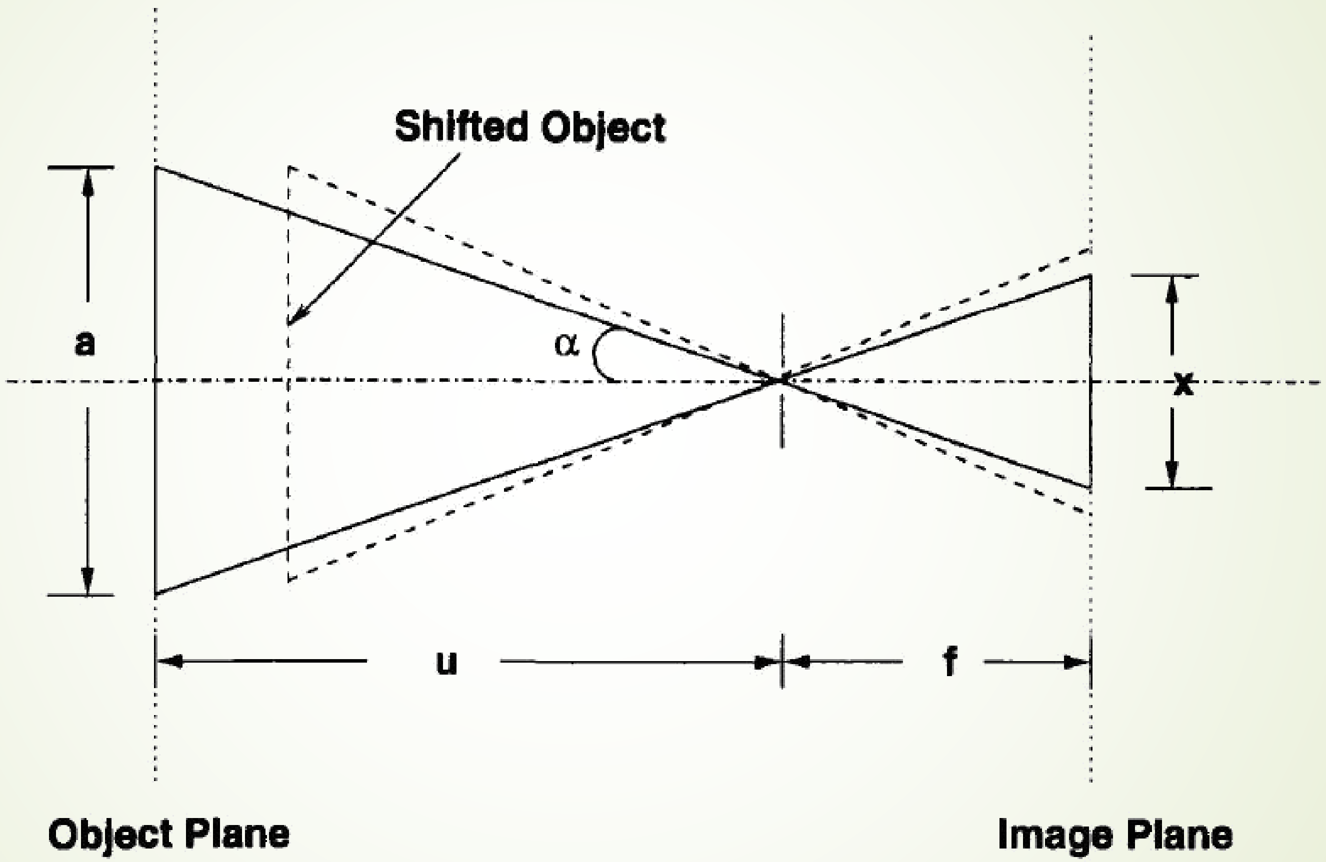


Fig. The concept of *spatial resolution* illustrated for a pin-hole camera.

How to get high resolution image?

- Pay extra amount of money and buy HR camera – *which is of course not a feasible solution*.
- The storage requirement will be increased – we don't want that.
- Increase the number of pixels per unit area that means reduce pixel size. Reducing pixel size less than 40µm^2 incorporates shot noise in the image – *do we need noisy image??*
- Increase the chip size of the camera, so that number of pixels can be increased. But increasing chip size means increase in capacitance and this will slow down the image acquisition process – *so this approach is not considered effective.*

Super-Resolution Imaging

- The problem is shown pictorially:

Conversion

LR Image

HR Image

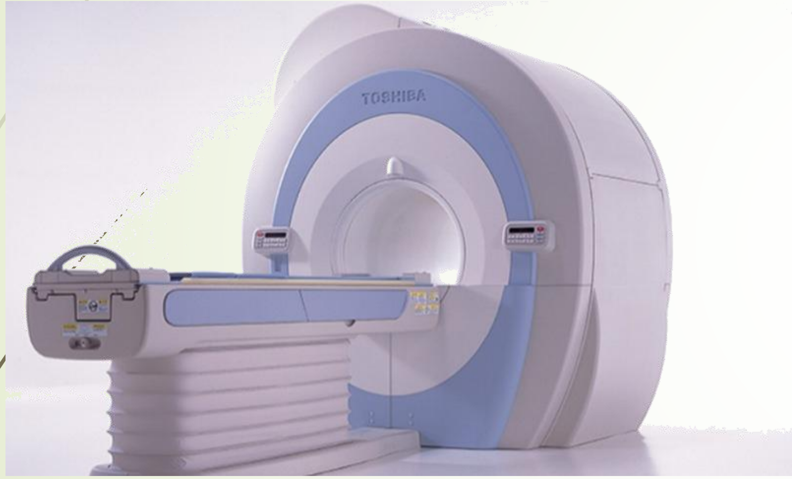
LR - Low Resolution

HR - High Resolution

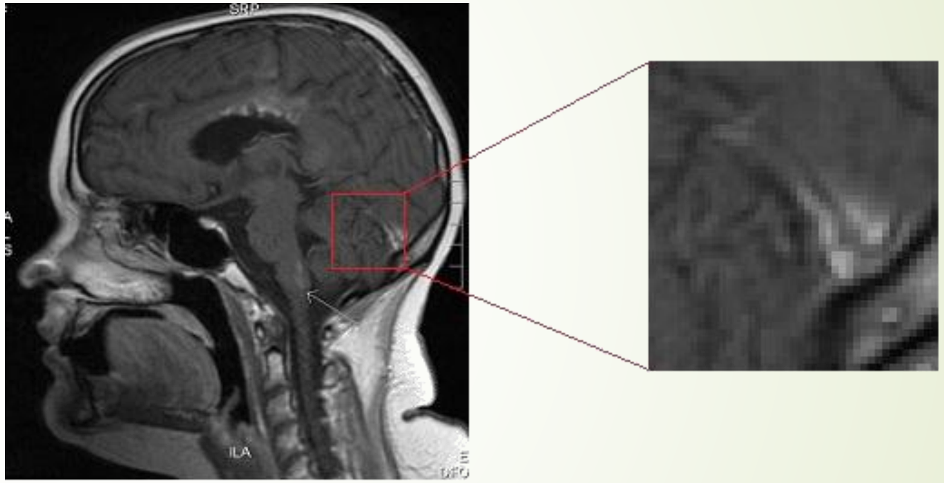
i.e. the method of **obtaining a HR image from the degraded LR image(s)** is called SR.

When do we need SR?

- Medical Imaging:



Magnetic Resonance Imaging Scanner



Brain Image

Magnified region of interest (ROI) part of the image

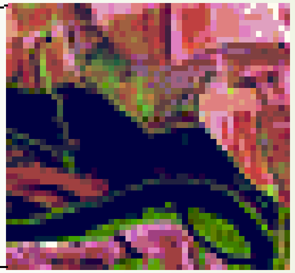
When do we need SR? (contd.)

- Remote sensing:

Satellite dedicated for RS

This Landsat image of the Missouri River links to a remote-sensing activity for the Event-Based Science *Flood!* unit. Image shows flood waters as they recede (October 4, 1993).

(From: NASA/Goddard Space Flight Center)



Magnified ROI part

When do we need SR? (contd.)

- Surveillance applications:

Surveillance camera

Corridor

Magnified ROI

(here face region)

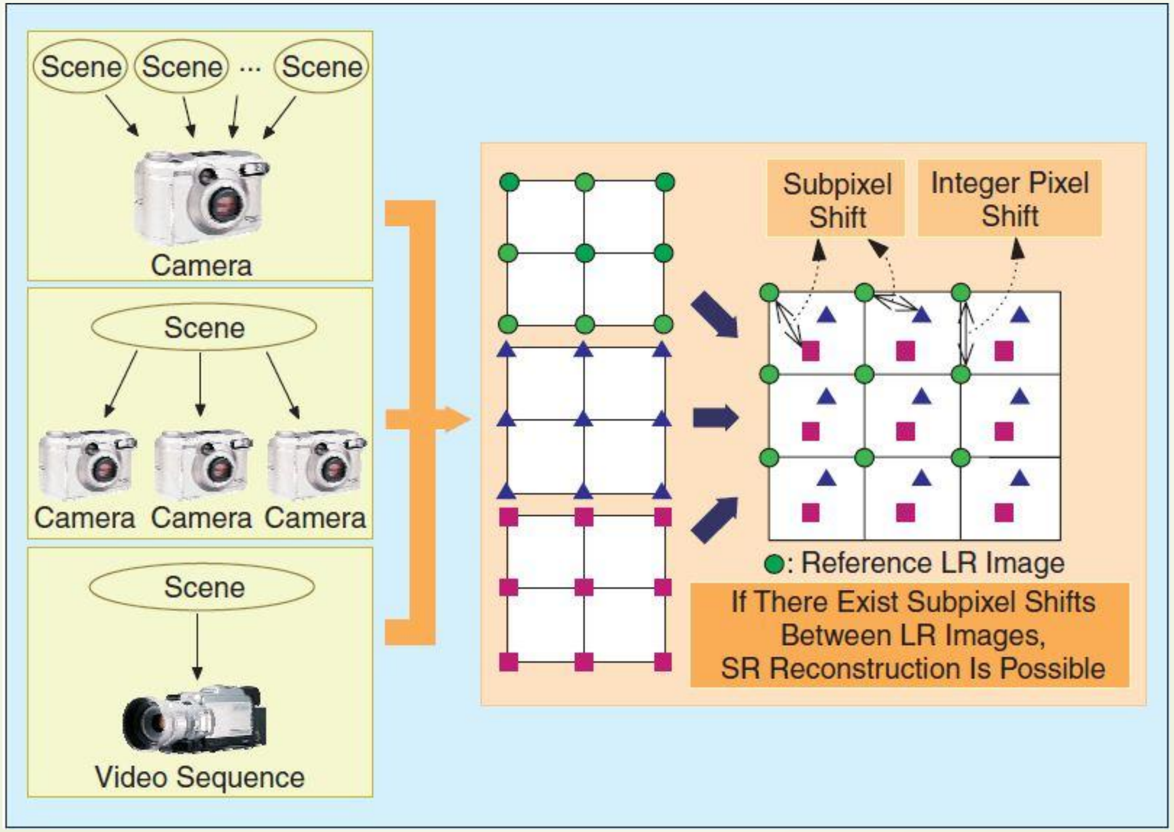
and many more...

SR classification

- Based on the number of LR images required to perform SR, it can be classified into two classes:
  - Multiple image SR,
  - Single image SR.

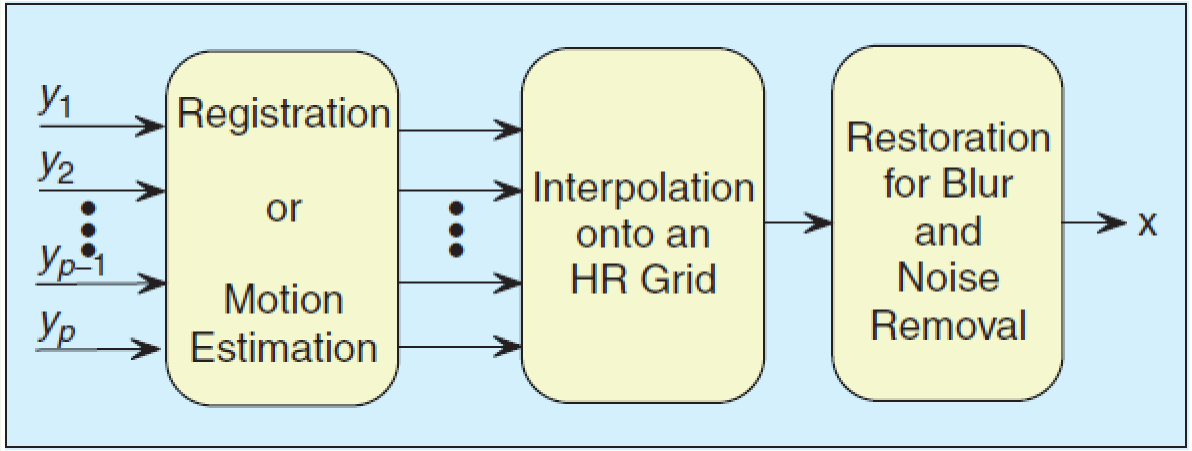
Multiple image SR

- Multiple sub-pixel shifted LR images are required to perform SR.



Scheme of SR for multiple images

- Most of the multiple images SR follow the following scheme:



Single image SR

- When multiple LR images of the same scene are not available, the only available option is single image SR, that is the major advantage over multiple image SR.
- In single image SR, information are adopted from other HR (random) images.

Results

a) LR Image b) Reconstructed HR image

Results contd..

Input LR video (180×256) – Resized

Results contd..

Output HR video (540×768) – Resized

References

- R. C. Gonzalez and R. E. Woods, " Digital Image Processing" Third edition, Pearson Education, 2009
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- Srimanta Mandal and Anil Kumar Sao, "Edge Preserving Single Image Super Resolution in Sparse Environment," in *Proceedings of the 20th IEEE International Conference on Image Processing (ICIP'13), Sept.2013, pp. 967-971*
- S. Chaudhuri (Editor), "Super-Resolution Imaging", Kluwer Academic Press, Boston, 2001.

Questions??

Thank You!!

For more information regarding my work please visit

http://www.students.iitmandi.ac.in/~srimanta_mandal/