CSL 461 / CSL617
Digital Image Analysis

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"One picture is worth more than ten thousand words"

Course Info

Reference Books:

- Rafael C. Gonzalez, Richard E. Woods, "Digital Image Processing" , 3Ed, Pearson
- Anil K. Jain, "Fundamentals of Digital Image Processing" , Prentice Hall India
- W. Burger, M. J. Burge, "Principles of Digital Image Processing: Core Algorithms", Springer

Prerequisites :

- CSL 201 Data Structures

Anti-requisites :

- EEL 484

Evaluation Criteria

Evaluation Criteria :

- **Exams – ≈65%:**
  - **Midterm – ≈20%**
  - **EndTerm – ≈30%**
  - **Quizzes – ≈15%**
- **HWs/Lab-Assignments/Projects – ≈35%**
- **Attendance (beyond 75%) – ≈1% bonus**

- Min 70% in Exams and 80% in Total for "A" grade
- Min 25% in Exams and 30% in Total for passing grade
- N Quizzes (N >= 5 likely). Best N-1 marks would be chosen.
- Programming Language:
  - Matlab for CBME students
  - OpenCV with C++ for other students
- Academic dishonesty/ Plagiarism of any kind (even identified later after assignment evaluation) will attract strict penalty

Course Content

Tentatively

Digital Image Fundamentals;

Image Enhancement in Spatial Domain; Gray Level Transformation, Histogram Processing, Spatial Filters;

Image Transforms; Fourier Transform and their properties, Fast Fourier Transform, Other Transforms; Image Enhancement in Frequency Domain;

Morphological operators;

Image Segmentation; edge detection,

Hough transform, region based segmentation;

Image Compression;

Image restoration;

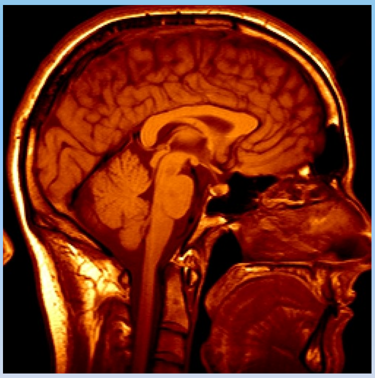
Colour Image Processing, and/or Other recent topics and applications r related to Image Processing

Credits/Acknowledgments

- Rich Course content from Open sources
  - Reference books and corresponding online content
  - Stanford , MIT, NUS and other Universities (incl. IITs) lecture/tutorial notes
  - Brian Mac Namee, School of Computing at the Dublin Institute of Technology
  - Online resources

Intent : To provide enriching learning experience

Medical imaging



3D imaging
MRI, CT

Image guided surgery
Grimson et al., MIT

Credits: I. Nwogu, CSE 473/573 Lecture notes, University at Buffalo

Vision-based interaction (and games)

Digimask: put your face on a 3D avatar.

Nintendo Wii has camera-based IR tracking built in. See Lee's work at CMU on clever tricks on using it to create a multi-touch display!

"Game turns moviegoers into Human Joysticks", CNET
Camera tracking a crowd, based on this work.

Credits: I. Nwogu, CSE 473/573 Lecture notes, University at Buffalo

Smart cars

Mobileye

- Vision systems currently in high-end BMW, GM, Volvo models
- Back-up camera requirement for all new cars and light trucks
- Video demo

Credits: I. Nwogu, CSE 473/573 Lecture notes, University at Buffalo

Earthquake Analysis from Space

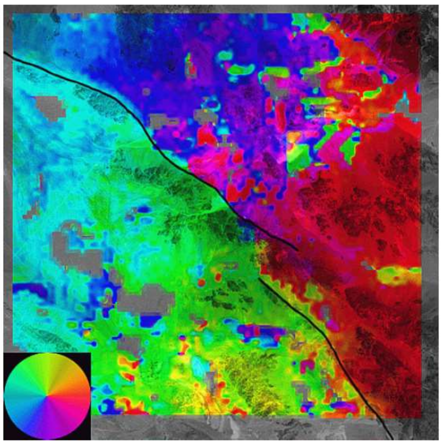
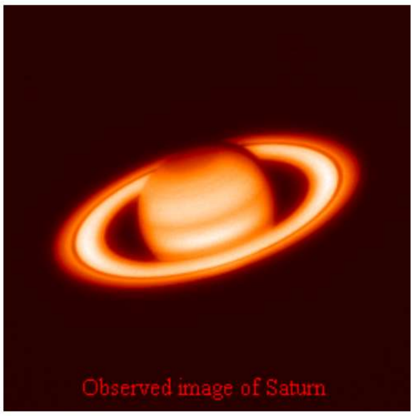
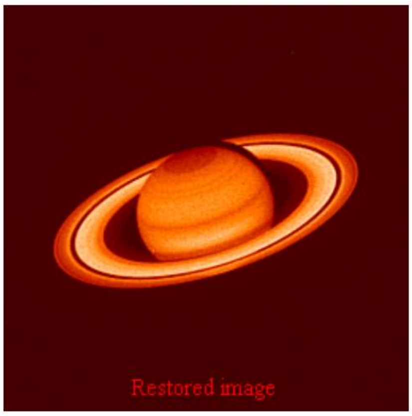


Image shows the ground displacement due to Landers earthquake in CA, 1992

Source: JPL, Pasadena, QUAKEFINDER project

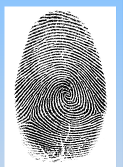
Restoration of image from Hubble Space Telescope





Source: IVPL Northwestern University, Chicago

Login without a password…



Fingerprint scanners on many new laptops, other devices

Face recognition systems now beginning to appear more widely
http://www.sensiblevision.com/

Credits: I. Nwogu, CSE 473/573 Lecture notes, University at Buffalo

Object recognition (in mobile phones)

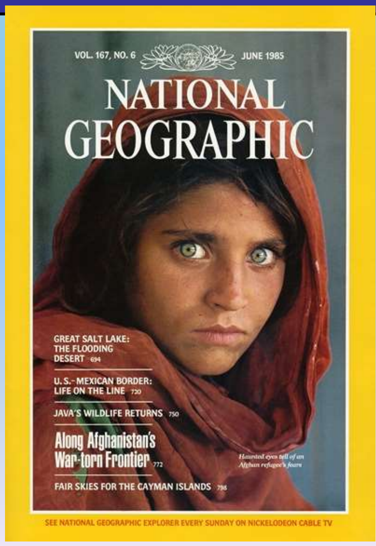
– Microsoft Research

Lincoln

– Point & Find, Nokia
– SnapTell.com (now amazon)

Credits: I. Nwogu, CSE 473/573 Lecture notes, University at Buffalo

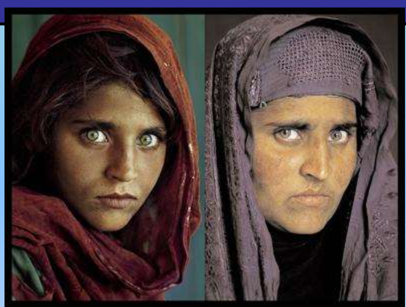
Face recognition



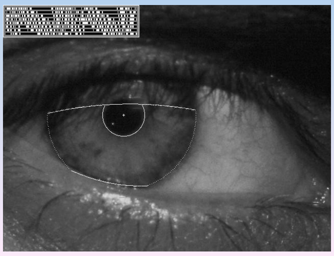
Who is she?

Credits: I. Nwogu, CSE 473/573 Lecture notes, University at Buffalo

Vision-based biometrics



"*How the Afghan Girl was Identified by Her Iris Patterns*" Read the story

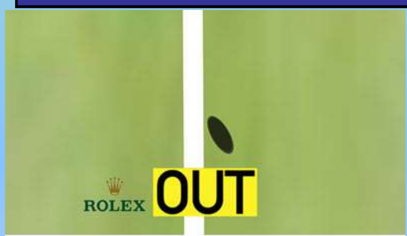


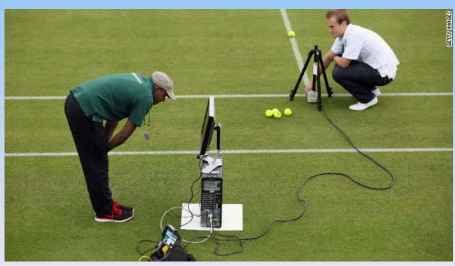
Credits: I. Nwogu, CSE 473/573 Lecture notes, University at Buffalo

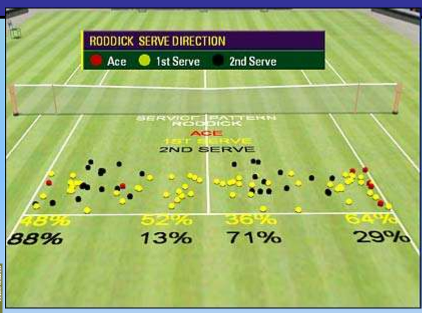
Sports

Sportvision first down line
Nice explanation on www.howstuffworks.com

Sports







Brief explanation on how hawk-eye works can be found here

Digital Halftoning

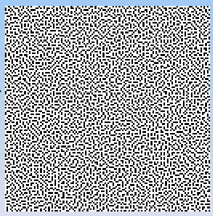
➢ Digital Halftoning: The process of rendering a continuous-tone image on devices, such as printers, that can only produce a small set of tone levels.

➢ Halftoning works because *human visual system* (HVS), to a first degree of approximation, acts as a *spatial low-pass filter* that blurs the rendered pixel pattern, so that it is perceived as a continuous-tone image.

Three important types of halftones

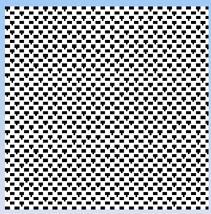
Continuous tone image

Aperiodic dispersed-dot (Blue Noise)



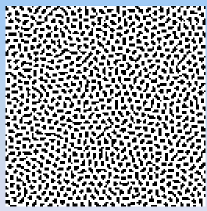
- Good detail rendition
- Less stable

Periodic clustered-dot



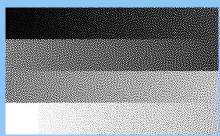
- Smooth appearance
- Stable
- Visible periodic moiré

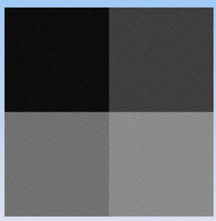
Aperiodic clustered-dot (Green Noise)

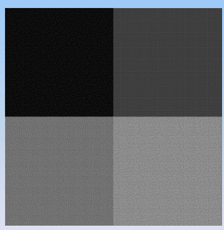


- Stable (Less printer-induced artifacts)
- No periodic moiré

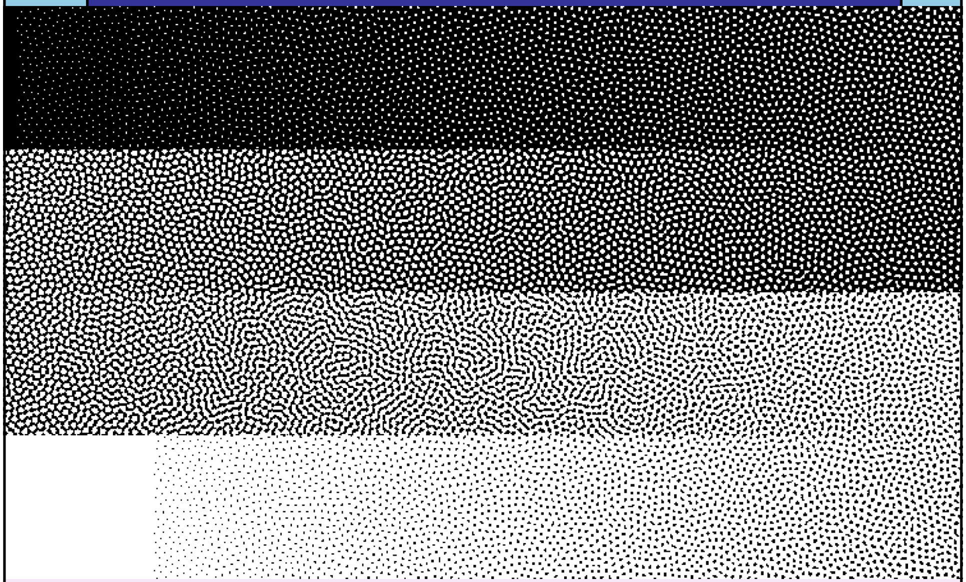
Some Halftone Images







Ramp – Halftone Image



Special Effects

Photo

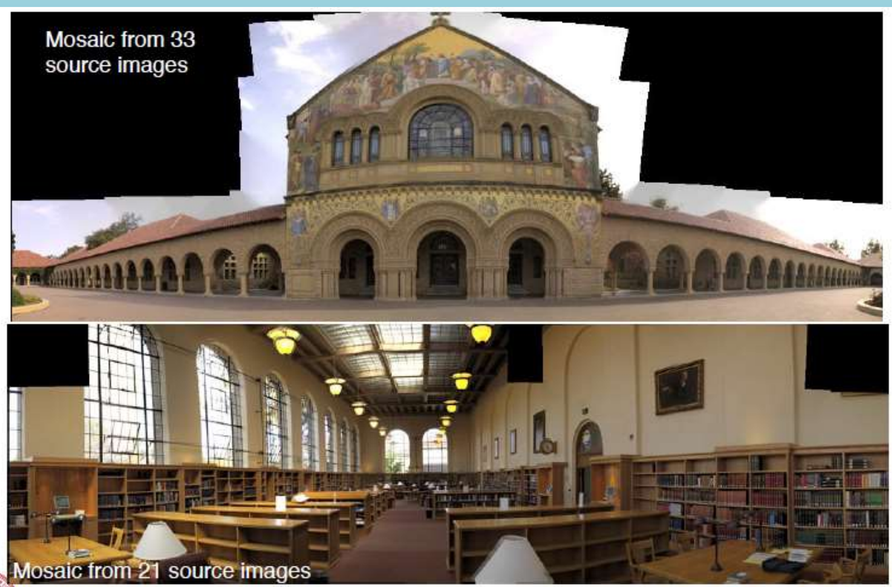
Simulated
color pencils

Simulated
oil painting

source: Feng Xiao, EE368 class project, spring 2000.

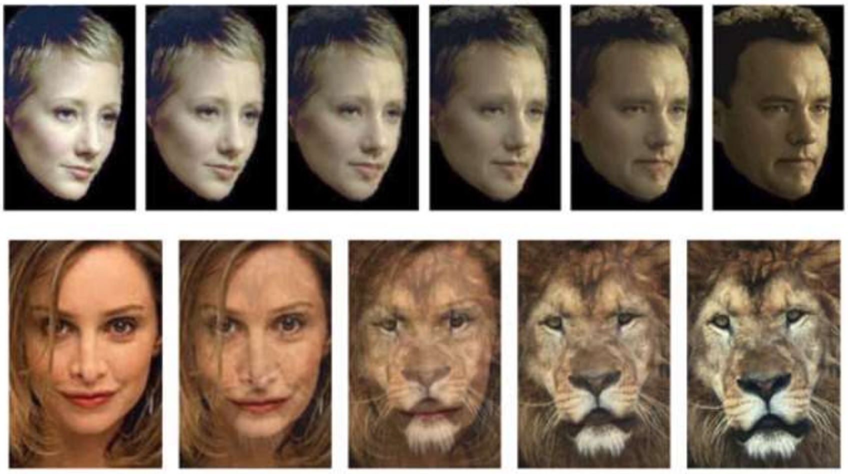
Face Detection

source: Henry Chang, Ulises Robles, EE368 class project, spring 2000.



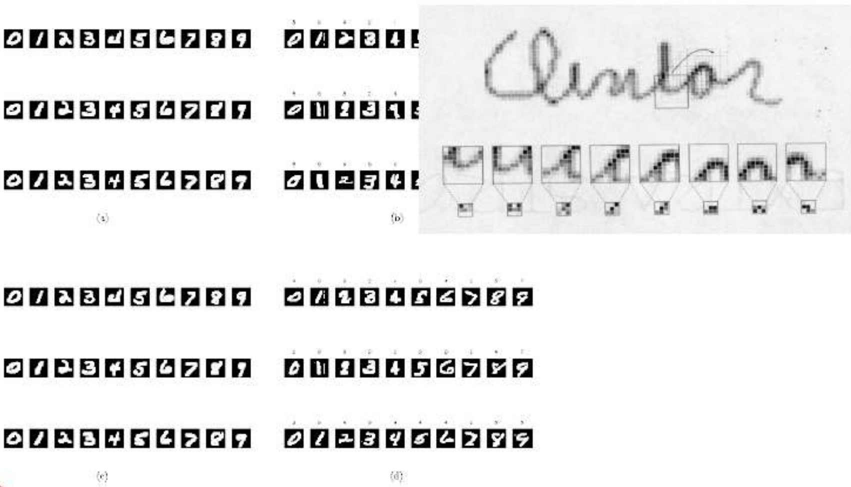
source: M. Borgmann, L. Meunier, EE368 class project, spring 2000.

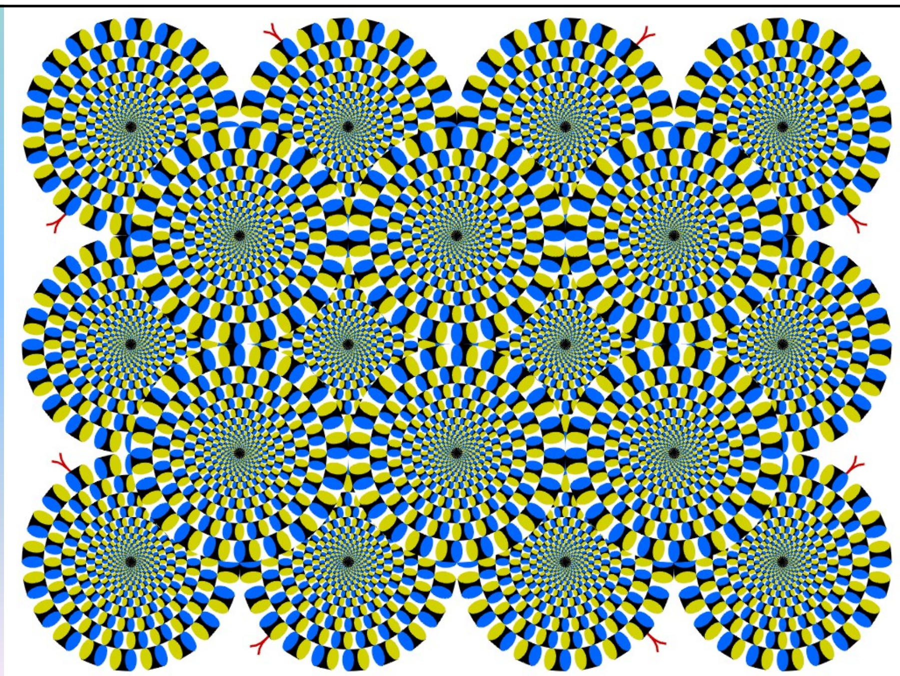
Face morphing



Source: Yi-Wen Liu and Yu-Li Hsueh, EE368 class project, spring 2000

Handwriting recognition





a b
c
d

FIGURE 1.15 Some additional examples of imaging in the visual spectrum. (a) Thumb print. (b) Paper currency. (c) and (d) Automated license plate reading. (Figure (a) courtesy of the National Institute of Standards and Technology. Figures (c) and (d) courtesy of Dr. Juan Herrera, Perceptics Corporation.)

FIGURE 1.1 A digital picture produced in 1921 from a coded tape by a telegraph printer with special type faces. (McFarlane.[†])

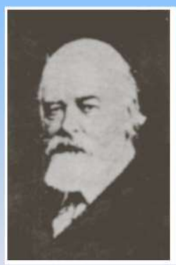
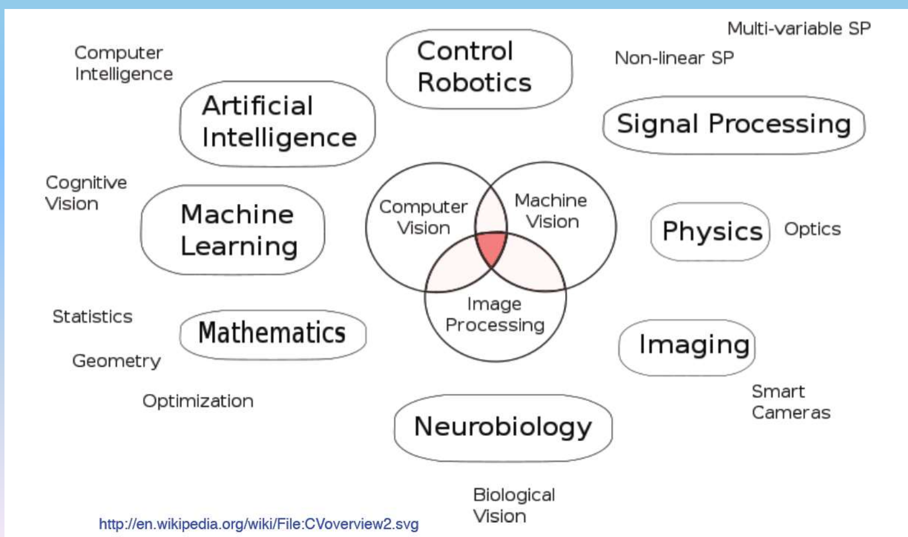


FIGURE 1.2 A digital picture made in 1922 from a tape punched after the signals had crossed the Atlantic twice. (McFarlane.)

Image Processing and Related Fields



Image

Two dimensional light intensity function

f (x,y) where x and y are spatial coordinates and f at (x,y) is related to brightness or color of the image at that point

Energy

✓To capture an image a camera requires some sort of measurable energy.

✓Light or *electromagnetic* waves (*Photon*). It is massless entity.

✓**Electromagnitic wave:** electric and magnetic fields vary sinusoidally

1. A photon can be described by its energy E, which is measured in [eV]
2. A photon can be described by its frequency f , which is measured in Hertz [Hz]. A frequency is the number of cycles or wave-tops in one second.
3. A photon can be described by its wavelength λ, which is measured in meters [m]. A wavelength is the distance between two wave-tops.

$$\lambda = \frac{c}{f}, \qquad E = h \cdot f \quad \Rightarrow \quad E = \frac{h \cdot c}{\lambda}$$

c= 2.998 x 10^8 m/s

h=6.626176 x 10^{-34} joule-seconds

Credits: S. Murala, EEL484 Lecture notes/slides, IIT Ropar

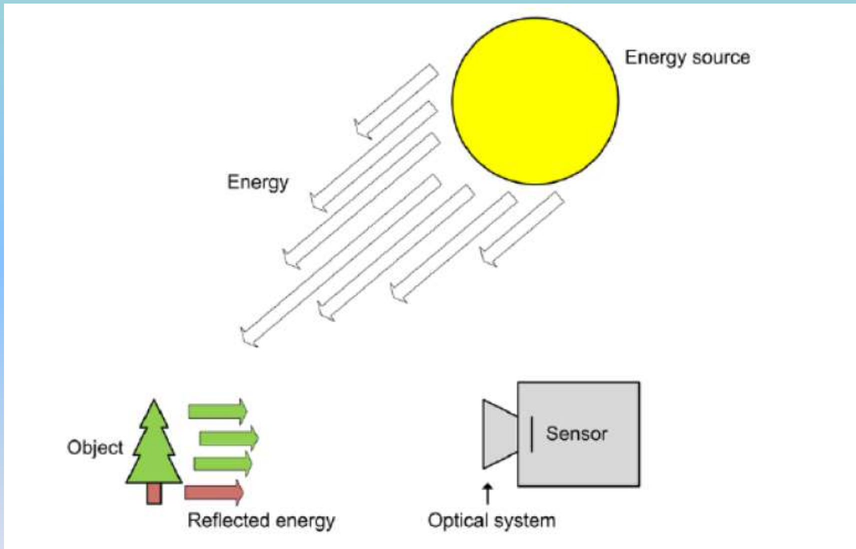


Fig. Overview of the typical image acquisition process.

Credits: S. Murala, EEL484 Lecture notes/slides, IIT Ropar

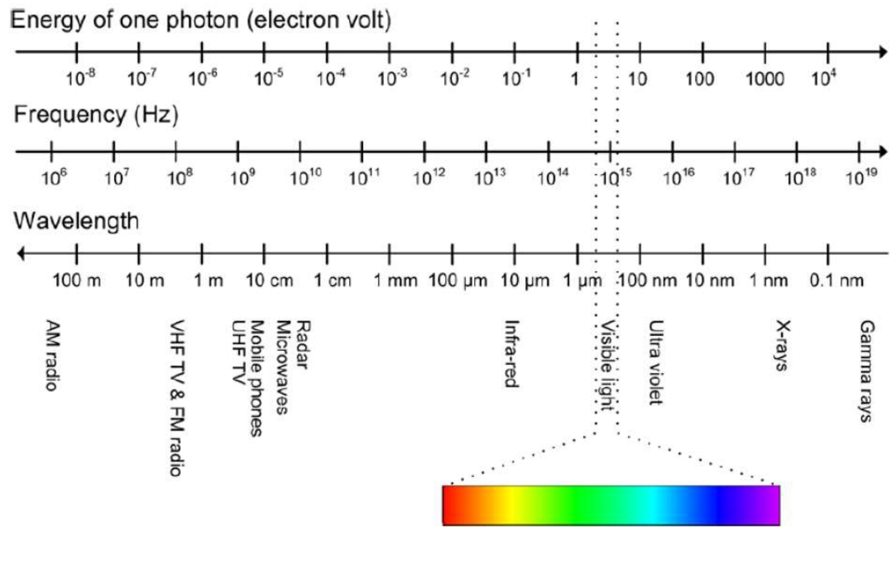


Fig. The electromagnetic spectrum

Credits: S. Murala, EEL484 Lecture notes/slides, IIT Ropar

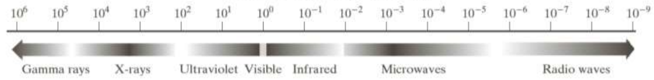


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content of soil and vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Middle infrared	2.08–2.35	Mineral mapping

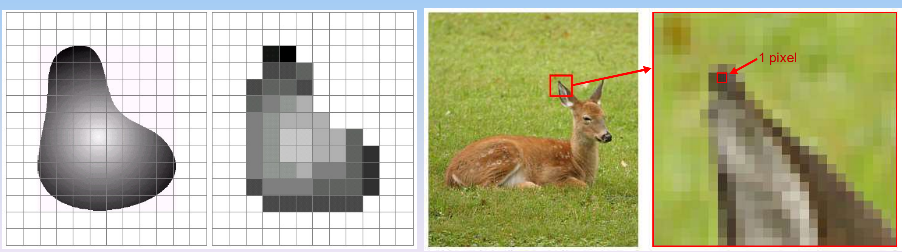
TABLE 1.1 Thematic bands in NASA's LANDSAT satellite.

Credits: Gonzalez, Woods, Book slides

What is a Digital Image?

Pixel values typically represent gray levels, colours, heights, opacities etc

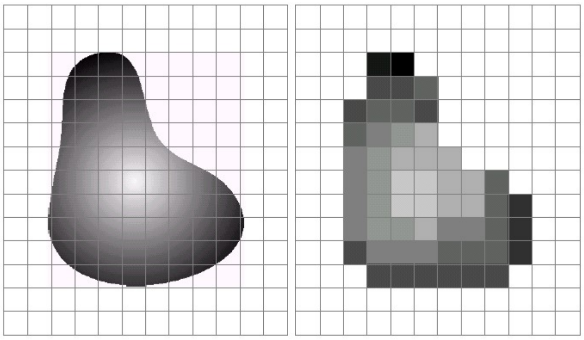
Remember *digitization* implies that a digital image is an *approximation* of a real scene



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Sampling and Quantization

- Sampling: digitizing the 2-dimensional spatial coordinate values
- Quantization: digitizing the amplitude values (brightness level)



a b

FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

Representing Digital Images

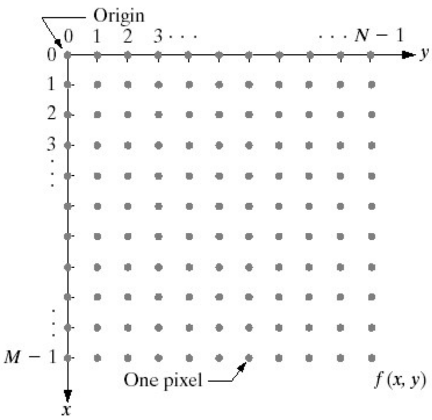


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

Spatial Resolution

The spatial resolution of an image is determined by how sampling was carried out

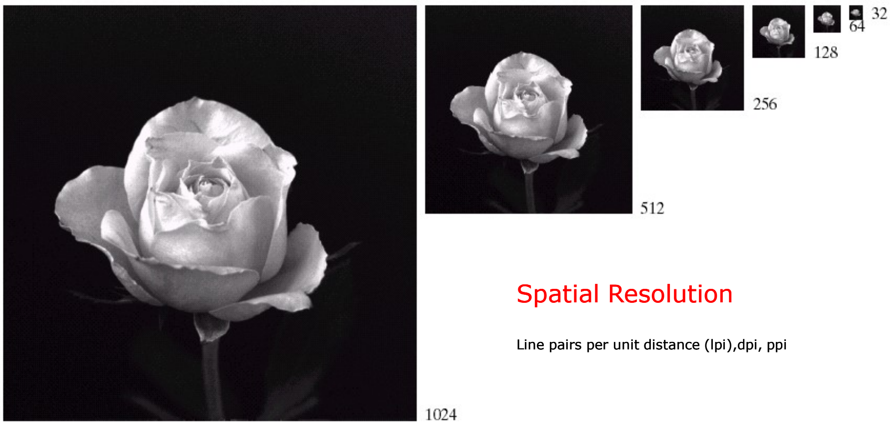
Spatial resolution simply refers to the smallest discernable detail in an image

- Vision specialists will often talk about pixel size
- Graphic designers will talk about *dots per inch* (DPI)

Digital Image Processing, 2nd ed.

www.imageprocessingbook.com

Spatial and Gray-Level Resolution



Spatial Resolution

Line pairs per unit distance (lpi),dpi, ppi

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.

Spatial Resolution (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Spatial Resolution (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Spatial Resolution (cont…)

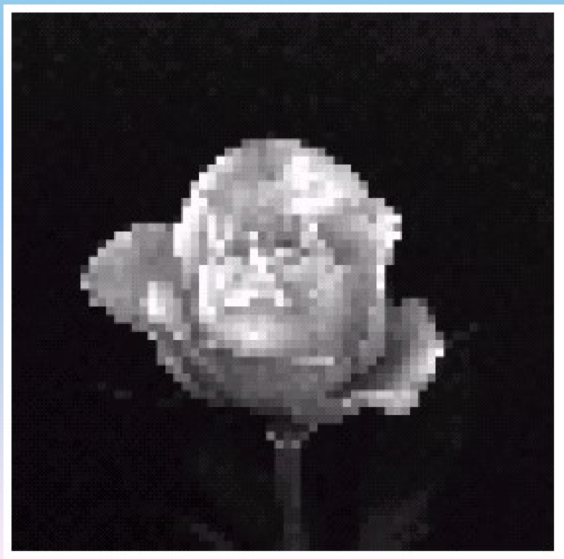
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Spatial Resolution (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

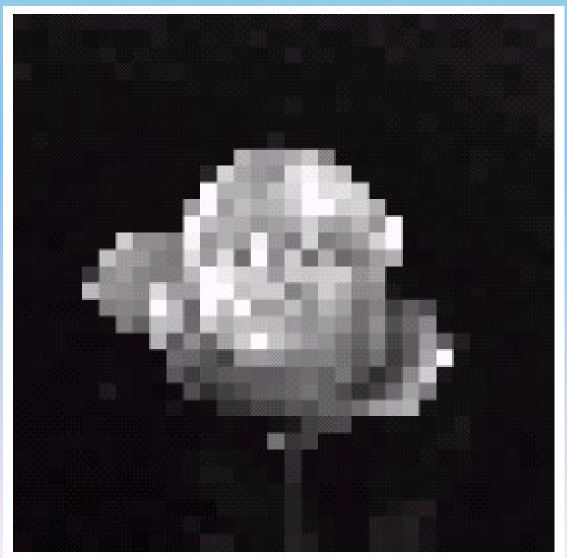
Spatial Resolution (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)



Spatial Resolution (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)



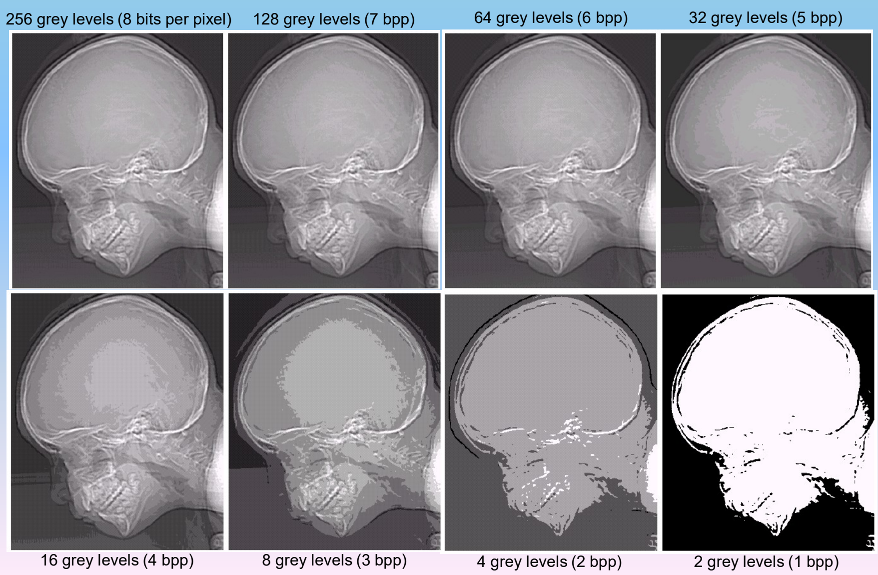
Intensity Level Resolution

Intensity level resolution refers to the number of intensity levels used to represent the image

- The more intensity levels used, the finer the level of detail discernable in an image
- Intensity level resolution is usually given in terms of the number of bits used to store each intensity level

Number of Bits	Number of Intensity Levels	Examples
1	2	0, 1
2	4	00, 01, 10, 11
4	16	0000, 0101, 1111
8	256	00110011, 01010101
16	65,536	1010101010101010

Intensity Level Resolution (cont…)



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Intensity Level Resolution (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Intensity Level Resolution (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Intensity Level Resolution (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Intensity Level Resolution (cont…)

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Intensity Level Resolution (cont…)

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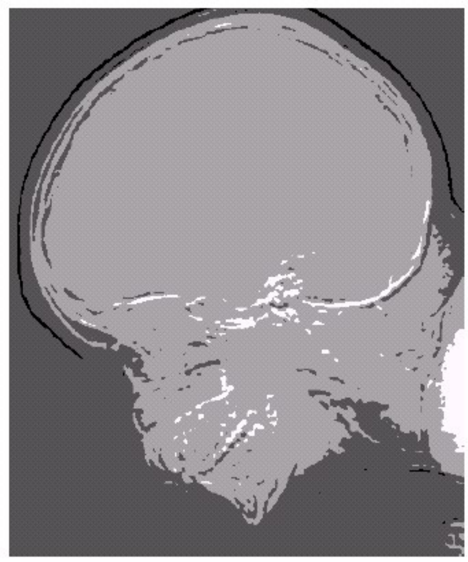
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Intensity Level Resolution (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)



Intensity Level Resolution (cont…)

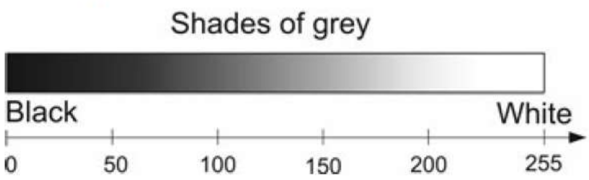
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

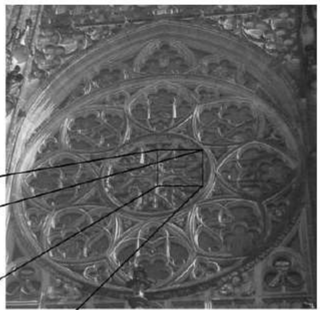
What is a Digital Image?

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)

The Digital Image

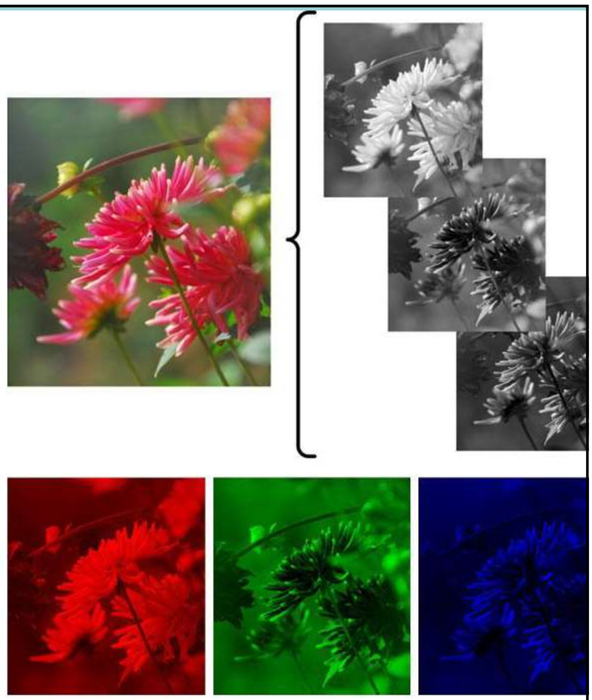




202	134	112	122	...	112
209	133	112	126	...	102
223	151	94	108	...	106
233	166	109	115	...	126
...	...	...	...	...	...
132	138	147	131	...	95

Credits: S. Murala, EEL484 Lecture notes/slides, IIT Ropar

Fig.: A color image



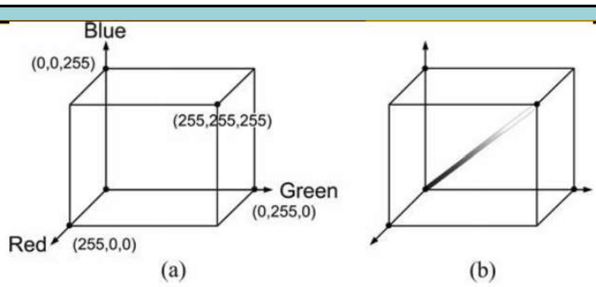
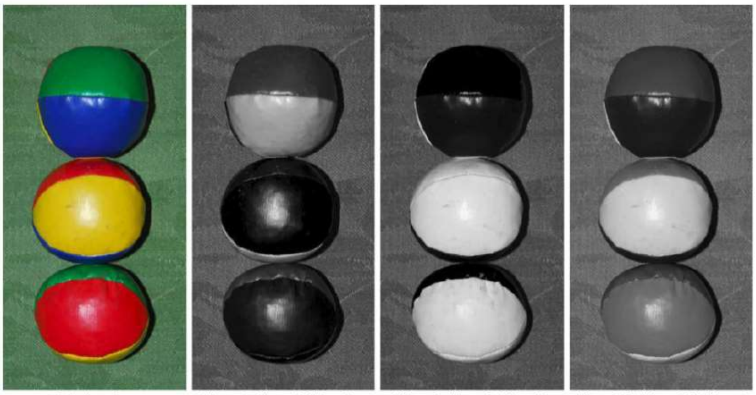


Fig. : (a) The RGB color cube. (b) The gray-vector in the RGB color cube

Corner	Color
(0, 0, 0)	Black
(255, 0, 0)	Red
(0, 255, 0)	Green
(0, 0, 255)	Blue
(255, 255, 0)	Yellow
(255, 0, 255)	Magenta
(0, 255, 255)	Cyan
(255, 255, 255)	White

RGB to GRAY

$$I = W_R \cdot \mathrm{R} + W_G \cdot \mathrm{G} + W_B \cdot \mathrm{B}$$

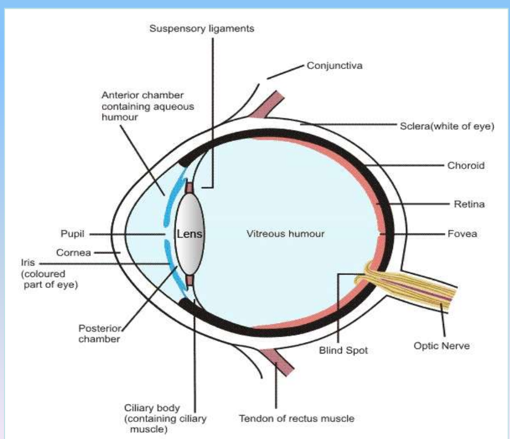


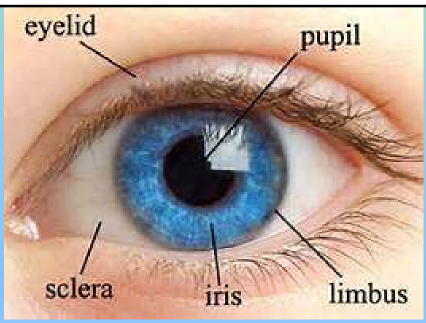
Color input | $W_R = 0, W_G = 0, W_B = 1$ | $W_R = 1, W_G = 0, W_B = 0$ | $W_R = 0.5, W_G = 0.5, W_B = 0$

Fig.: A color image and how it can be mapped to different gray-scale images depending on the weights

How do human perceive images ? Human Visual System

- The exact process by which the humans interpret visual scene content is still not fully understood.
- The human visual system, though powerful enough, still has certain physical limitations
- Consider a brief overview of the anatomical structure of the human eye





Credit: fstoppers.com

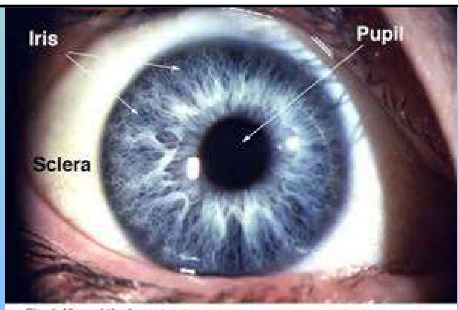


Fig. 1. View of the human eye

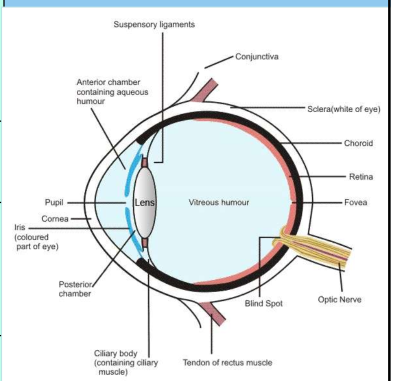
Credit: webvision.med.utah.edu

Behind the cornea is the iris, the colored part of the eye. The iris acts as a diaphragm, like a shutter on a camera, regulating the amount of light that enters through the pupil. The pupil appears as a black hole at the center of the iris. It is the opening through which light enters the eye. Some iris muscles contract to enlarge the pupil when more light is needed; others reduce it when there is too much light, to protect the inside of the eye. The pupil dilates and constricts in response to changes in lighting but excitement, attractive sights and some drugs also have this effect.

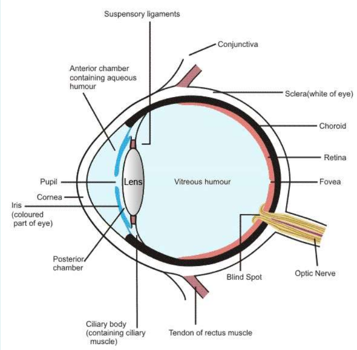
The iris contracts and expands, adjusting the size of the pupil and amount of light that enters the eye.

The amount of pigment in the iris determines the color of the eye. Blue eyes have the least amount of pigment, while brown eyes have the most. The random patterns on the iris are unique to each individual. Each person has a distinct pattern of filaments, pits and striations. Infants' eyes often change color as they become toddlers but from this age forward, the iris color and pattern is stable throughout life. Credits: https://www.visionweb.com/content/consumers/dev_consumerarticles.jsp?RID=30

The eye ball	The eye ball is approximately spherical. The vertical measure of an eye ball is approximately 24 mm and is slightly less than the horizontal width. The eye offers a field of view covering 160°(width) × 135° height area. The anterior of the eye has the outer coating cornea while the posterior has the outer layer of sclera.
Cornea	The cornea is a transparent, curved, refractive window through which the light enters the eye. The corneal segment (typically 8 mm in radius) is linked to the larger unit, the sclera, which extends and covers the posterior portion of the optic globe. The cornea and sclera are connected by a ring called the limbus.
Iris	The light entering the cornea is blocked by the visible colored and opaque surface of the iris. The back of the iris is coated with a black pigment.
Pupil	The pupil is the opening at the center of the iris. The pupil controls the amount of light entering the eye ball. Its diameter varies from 1 to 8 mm in response to illumination changes. In low light conditions it dilates to increase the amount of light reaching the retina. Behind the pupil is the lens of the eye.
Lens	The lens is suspended to the ciliary body by the suspensory ligament (Zonule of Zinn), made up of fine transparent fibers. The lens is transparent (has 70% water) and absorbs approximately 8% of the visible light spectrum. The protein in the lens absorbs the harmful infrared and ultraviolet light and prevents damage to the eye.



Choroid	Beneath the sclera is a membrane called choroid. It contains blood vessels to nourish the cells in the eye. Like the iris, it is pigmented to prevent light from entering the eye from any other direction other than the pupil.
Retina	Beneath the choroid lies the retina, the innermost membrane of the eye where the light entering the eye is sensed by the receptor cells. The retina has 2 types of photoreceptor cells – rods and cones. These receptor cells respond to light in the 330 to 730 nm wavelength range.
Fovea	The central portion of the retina at the posterior part is the fovea. It is about 1.5 mm in diameter.
Rods	There about 100 million rods in the eye. The rods help in the dim-light (scotopic) vision. Their spatial distribution is radially symmetric about the fovea, but varies across the retina. They are distributed over a larger area in the retina. The rods are extremely sensitive and can respond even to a single photon. However they are not involved in color vision. They cannot resolve fine spatial detail despite high number because many rods are connected to a single nerve.
Cones	There are about 6 million cones in the eye. The cones help in the bright-light (photopic) vision. These are highly sensitive to color. They are located primarily in the fovea where the image is focused by the lens. Each cone cell is connected to its separate nerve ending. Hence they have the ability to resolve fine details.
	Though the photo-receptors are distributed in radially symmetric manner about the fovea, there is a region near the fovea where



Color Images

Photoreceptor cell	Wavelength in nanometers (nm)	Peak response in nanometer (nm)	Interpretation by the human brain
Cones (type L)	[400–680]	564	Red
Cones (type M)	[400–650]	534	Green
Cones (type S)	[370–530]	420	Blue
Rods	[400–600]	498	Shade of gray

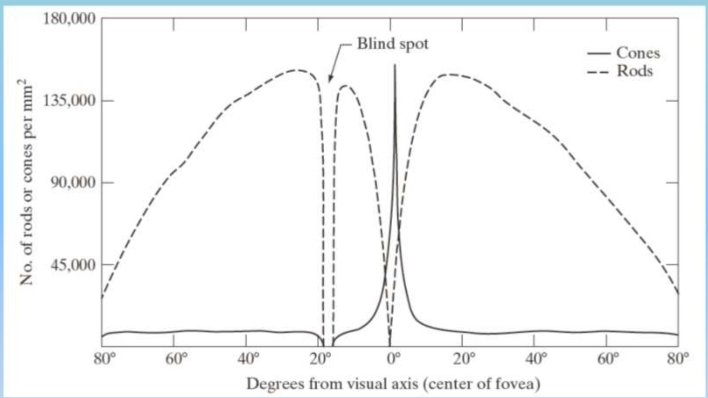


FIGURE 2.2 Distribution of rods and cones in the retina.

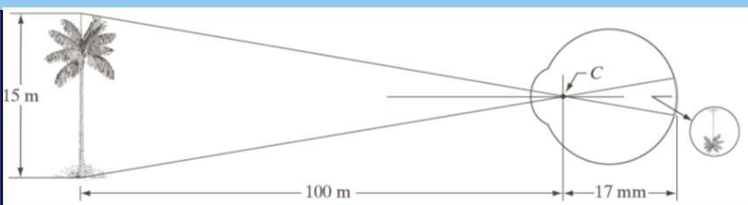


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point C is the optical center of the lens.

Light and the Electromagnetic Spectrum

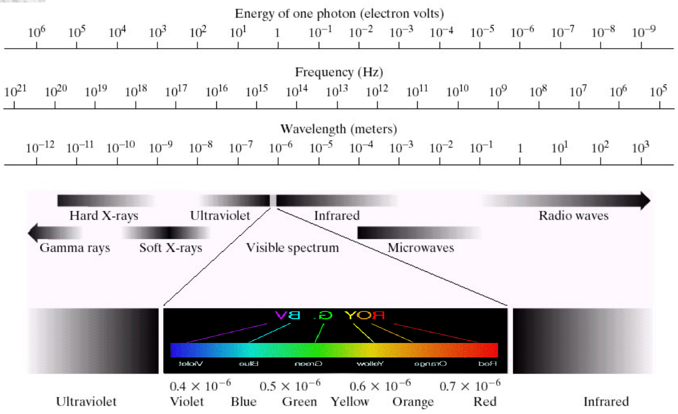


FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

Digital Image Processing, 2nd ed.
www.imageprocessingbook.com

Light and the Electromagnetic Spectrum

- Light that is void of color is called monochromatic or achromatic light.
  - Attribute : Intensity
- Three basic quantities described the quality of a chromatic (color) light source:
  - Radiance: the total amount energy that flow from the light source (can be measured)
  - Luminance: the amount of energy an observer perceives from a light source (can be measured)
  - Brightness: a subjective descriptor of light perception; perceived quantity of light emitted (cannot be measured)
- The wavelength of an electromagnetic wave that is required to see an object must be of the same size as or smaller than the object
- EM waves predominant source, but there are also other major sources of digital images (sound reflected from object, electron beams, synthetic images etc.)

Image Sensing and Acquisition

- Nowadays most visible and near IR electromagnetic imaging is done with 2-dimensional charged-coupled devices (CCDs).

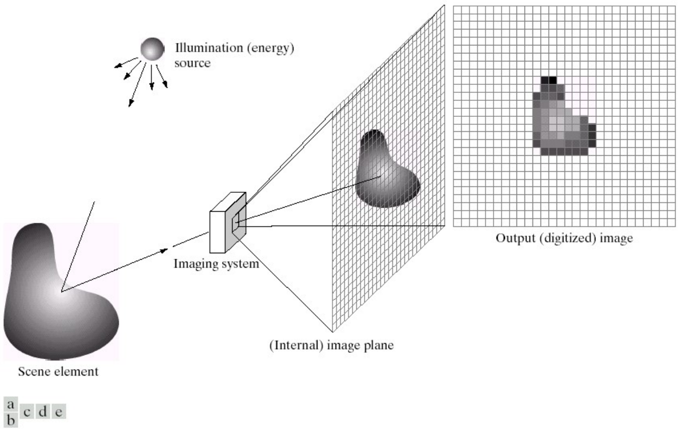


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

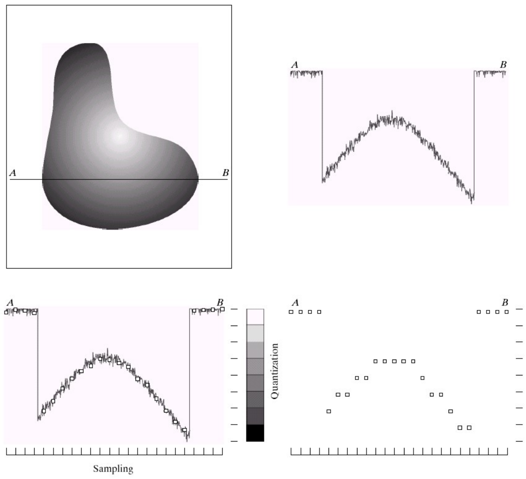
A Simple Image Formation Model

- Binary images: images having only two possible brightness levels (black and white)
- Gray scale images : "black and white" images
- Color images: can be described mathematically as three gray scale images

- Let $f(x,y)$ be an image function, then
  $f(x,y) = i(x,y)\, r(x,y)$,
  where $i(x,y)$: the illumination function
  $r(x,y)$: the reflection function
  Note: $0 < i(x,y) < \infty$ and $0 < r(x,y) < 1$.

- For digital images the minimum gray level is usually 0, but the maximum depends on number of quantization levels used to digitize an image. The most common is 256 levels, so that the maximum level is 255.

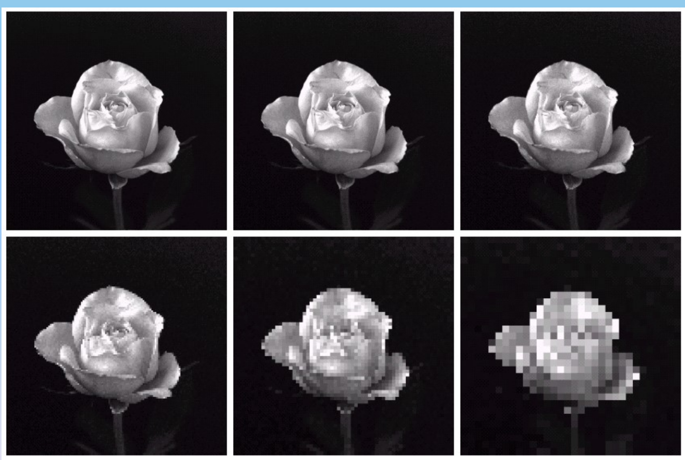
Image Sampling and Quantization



a b
c d

FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

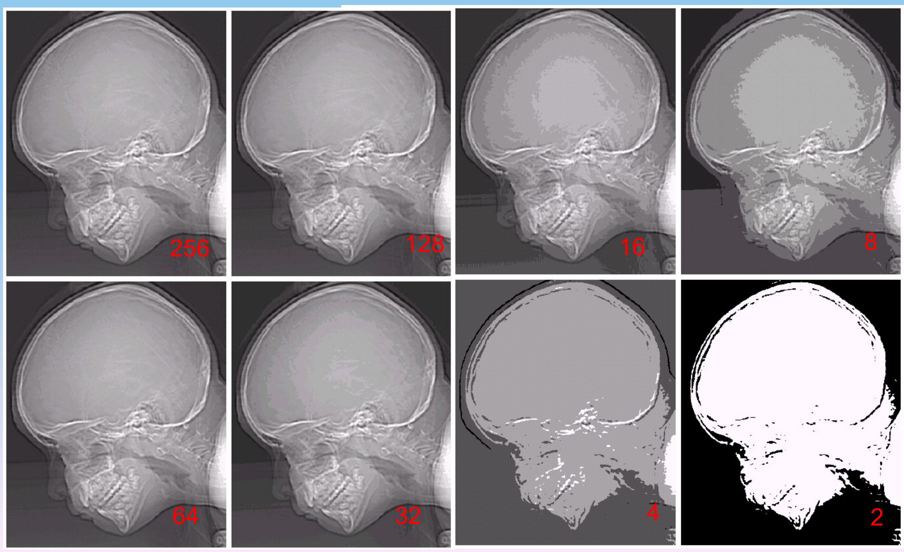
Spatial Resolution by Re-sampling



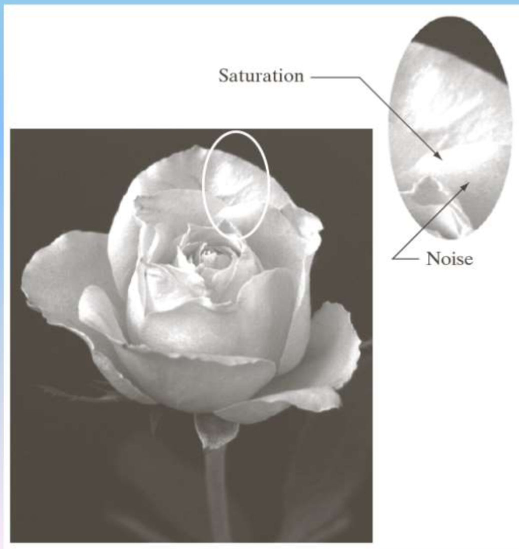
a b c
d e f

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.

Gray-Level Resolution



Saturation & Noise



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Resolution: How Much Is Enough?

The big question with resolution is always *how much is enough*?

- This all depends on what is in the image and what you would like to do with it
- Key questions include
  - Does the image look aesthetically pleasing?
  - Can you see what you need to see within the image?

Resolution: How Much Is Enough? (cont…)

The picture on the right is fine for counting the number of cars, but not for reading the number plate

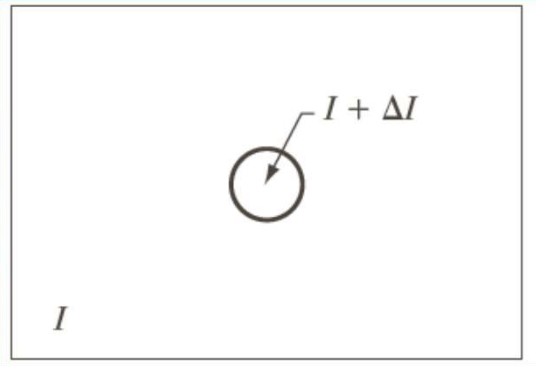
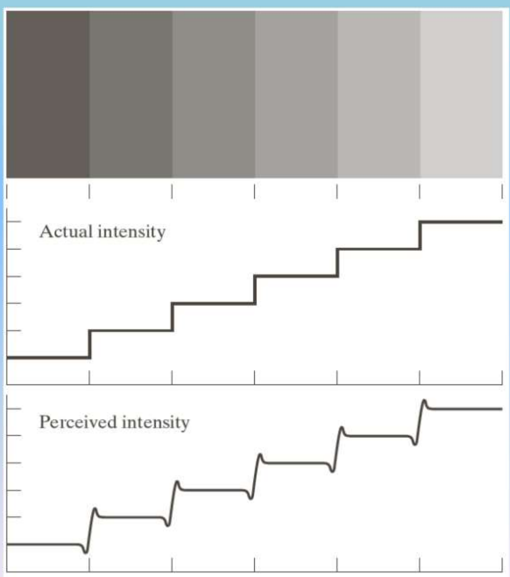


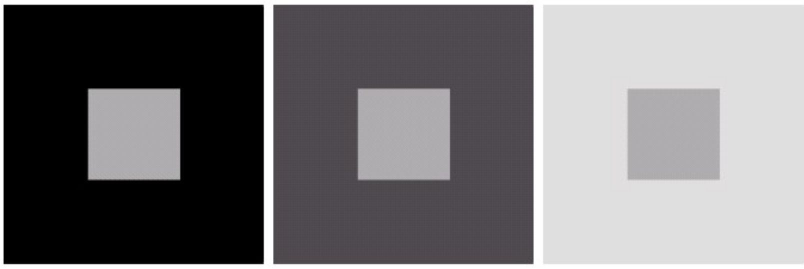
FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

Images taken from Gonzalez & Woods, Digital Image Processing (2002)



a
b
c

FIGURE 2.7 Illustration of the Mach band effect. Perceived intensity is not a simple function of actual intensity.

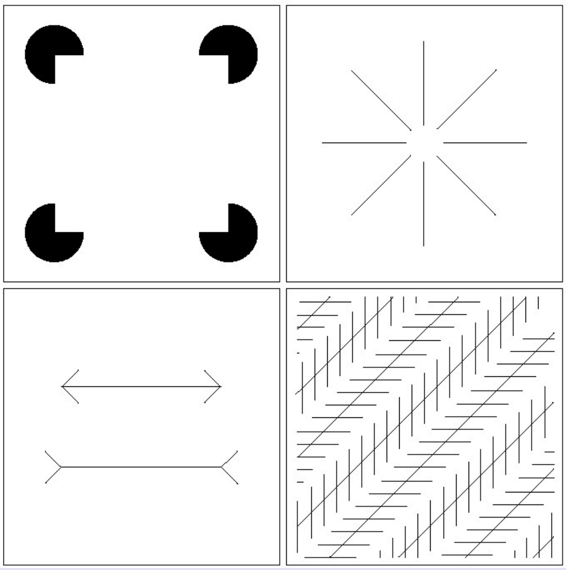


a b c

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.

a b
c d

FIGURE 2.9 Some well-known optical illusions.



What is Digital Image Processing?

Digital image processing focuses on two major tasks

- Improvement of pictorial information for human interpretation
- Processing of image data for storage, transmission and representation for autonomous machine perception

Some argument about where image processing ends and fields such as computer vision start

DIP and 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

Credits: Brian Mac, Dublin Institute of Technology

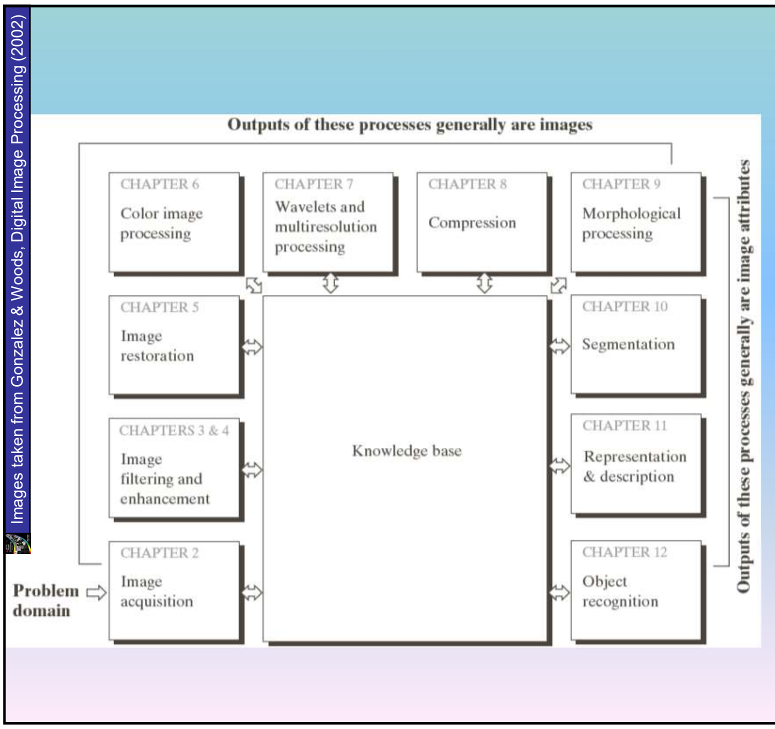
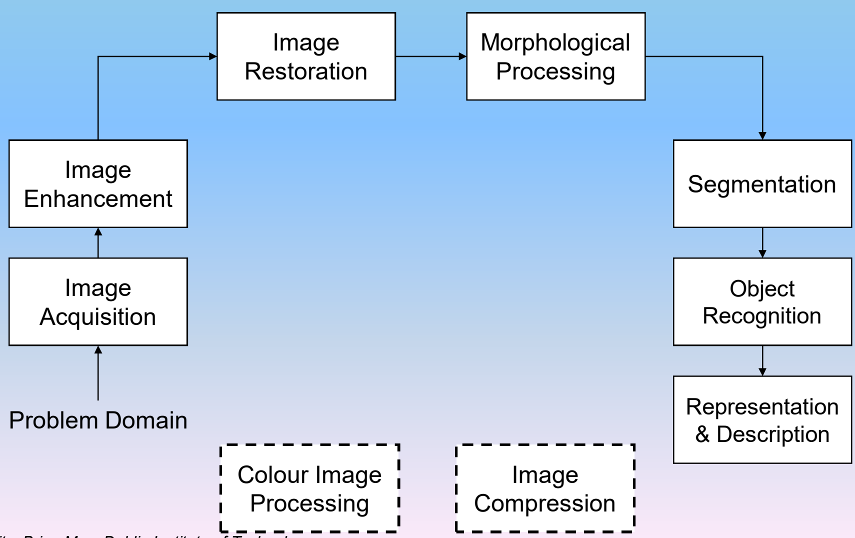


FIGURE 1.23 Fundamental steps in digital image processing. The chapter(s) indicated in the boxes is where the material described in the box is discussed.

Key Stages in Digital Image Processing



Credits: Brian Mac, Dublin Institute of Technology

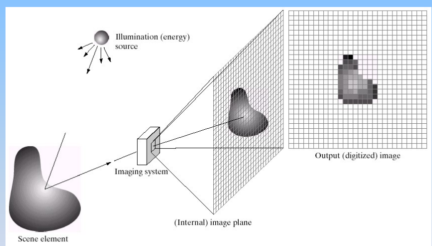
Key Stages in Digital Image Processing: Image Aquisition

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

Problem Domain → **Image Acquisition** → Image Enhancement → Image Restoration

Colour Image Processing

Image Compression



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Credits: Brian Mac, Dublin Institute of Technology

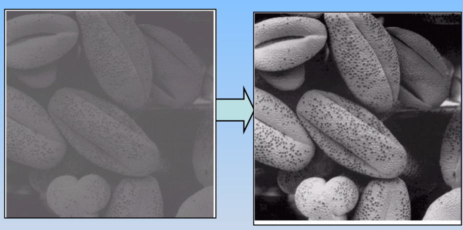
Key Stages in Digital Image Processing: Image Enhancement

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

Problem Domain → Image Acquisition → **Image Enhancement** → Image Restoration

Colour Image Processing

Image Compression



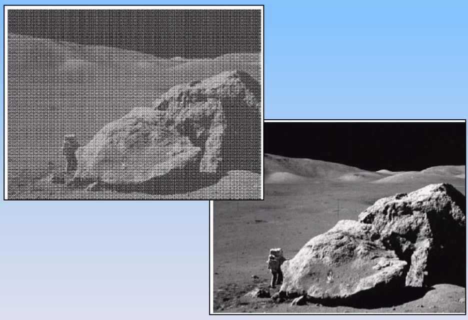
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Credits: Brian Mac, Dublin Institute of Technology

Key Stages in Digital Image Processing: Image Restoration

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

- Problem Domain
- Image Acquisition
- Image Enhancement
- Image Restoration
- Morphological Processing
- Segmentation
- Object Recognition
- Representation & Description
- Colour Image Processing
- Image Compression

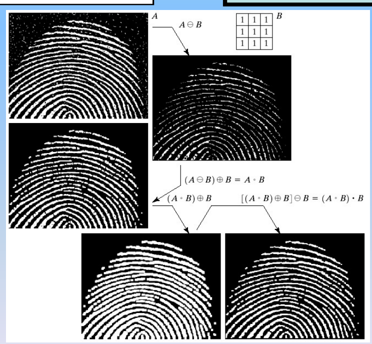


Credits: Brian Mac, Dublin Institute of Technology

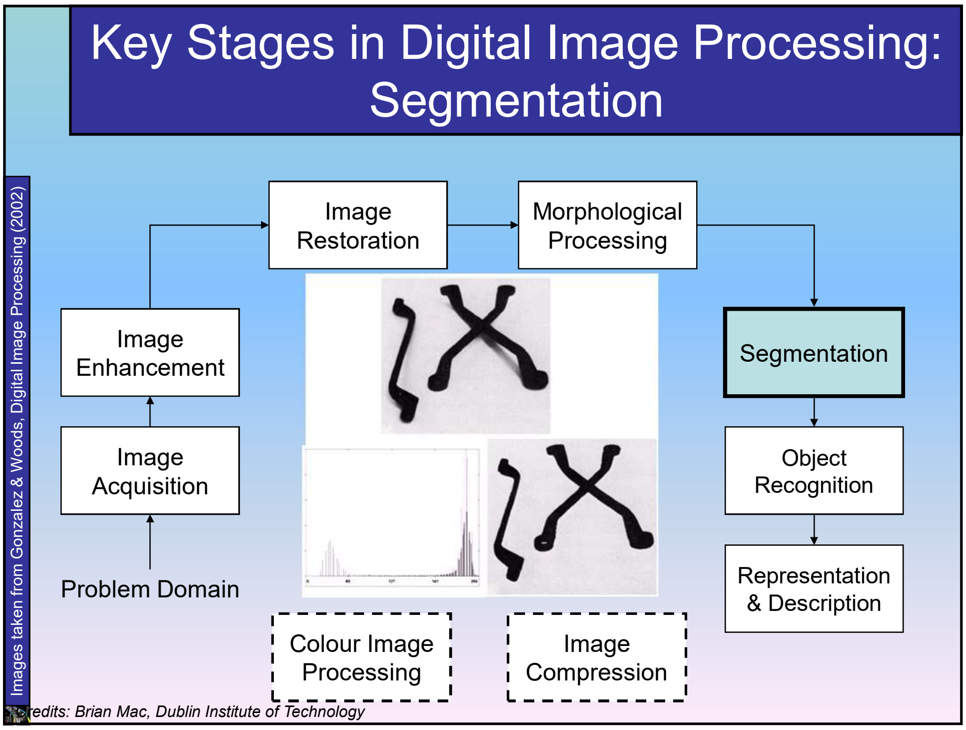
Key Stages in Digital Image Processing: Morphological Processing

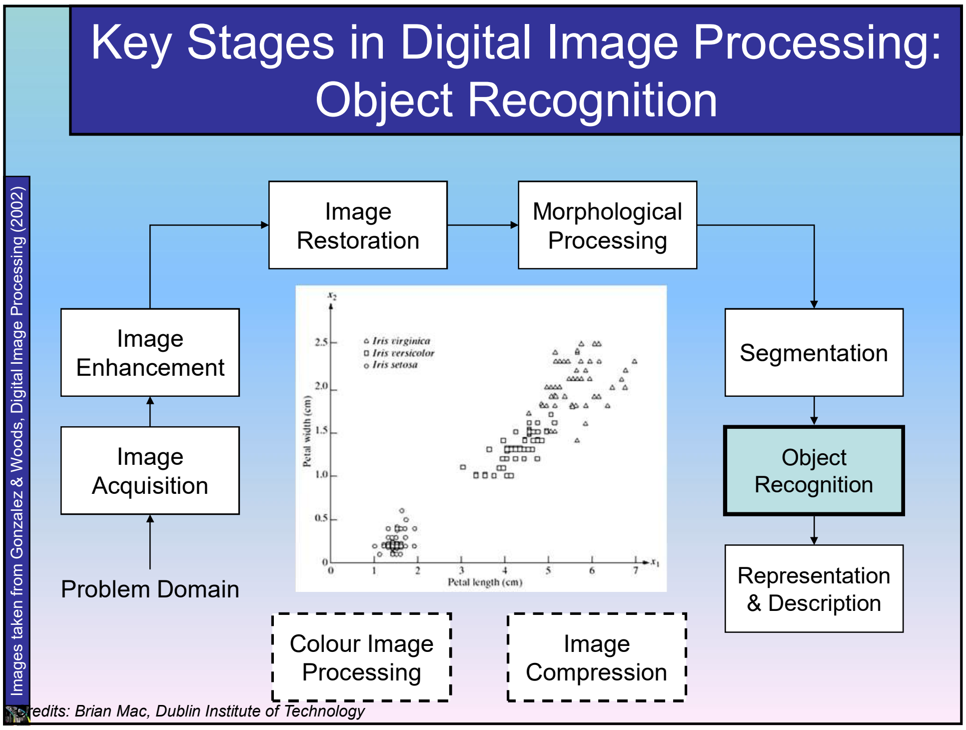
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

- Problem Domain
- Image Acquisition
- Image Enhancement
- Image Restoration
- Morphological Processing
- Segmentation
- Object Recognition
- Representation & Description
- Colour Image Processing
- Image Compression



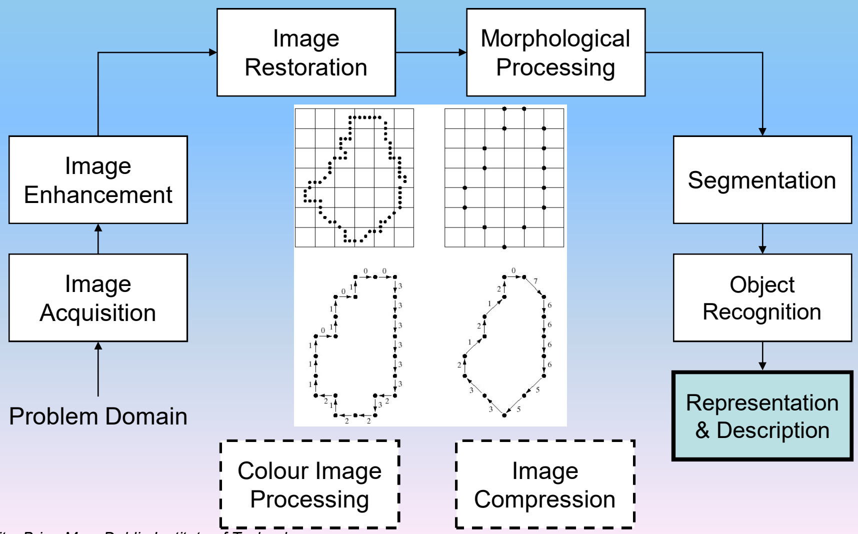
Credits: Brian Mac, Dublin Institute of Technology


Key Stages in Digital Image Processing: Segmentation
Images taken from Gonzalez & Woods, Digital Image Processing (2002)
Image Restoration
Morphological Processing
Image Enhancement
Segmentation
Image Acquisition
Object Recognition
Representation & Description
Problem Domain
Colour Image Processing
Image Compression
Credits: Brian Mac, Dublin Institute of Technology


Key Stages in Digital Image Processing: Object Recognition
Images taken from Gonzalez & Woods, Digital Image Processing (2002)
Image Restoration
Morphological Processing
Image Enhancement
Segmentation
Image Acquisition
Object Recognition
Representation & Description
Problem Domain
Colour Image Processing
Image Compression
Iris virginica
Iris versicolor
Iris setosa
Petal width (cm)
Petal length (cm)
Credits: Brian Mac, Dublin Institute of Technology

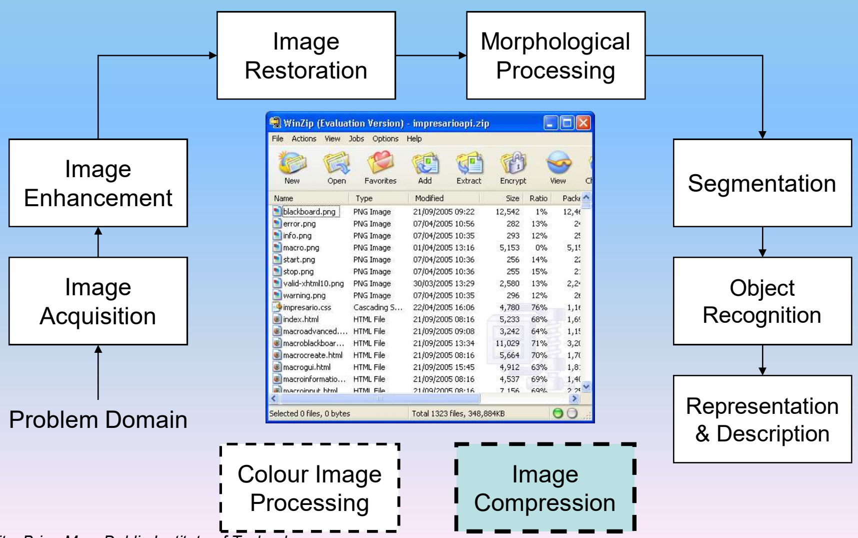
Key Stages in Digital Image Processing: Representation & Description

Images taken from Gonzalez & Woods, Digital Image Processing (2002)



Credits: Brian Mac, Dublin Institute of Technology

Key Stages in Digital Image Processing: Image Compression

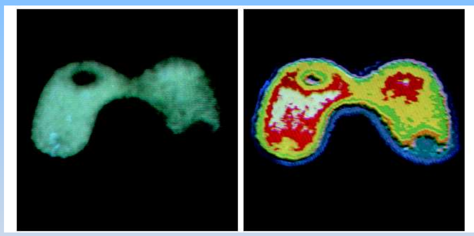


Credits: Brian Mac, Dublin Institute of Technology

Key Stages in Digital Image Processing: Colour Image Processing

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

Problem Domain → Image Acquisition → Image Enhancement → Image Restoration



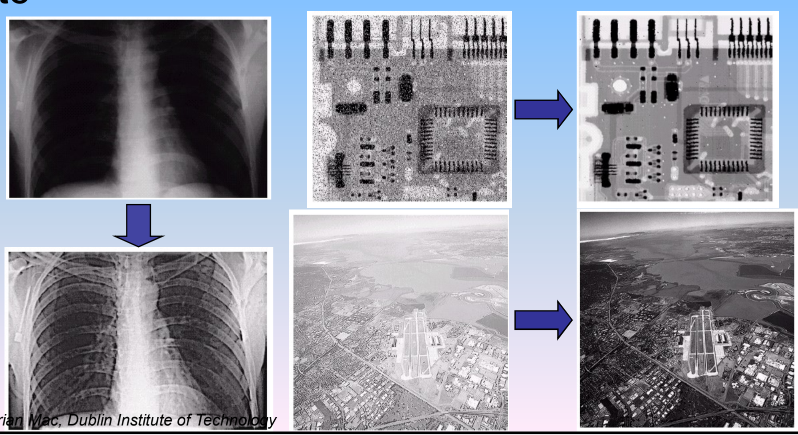
Colour Image Processing

Image Compression

Credits: Brian Mac, Dublin Institute of Technology

Examples: Image Enhancement

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



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Credits: Brian Mac, Dublin Institute of Technology

How to Decide Spatial and Gray-Level Resolution?

FIGURE 2.22 (a) Image with a low level of detail. (b) Image with a medium level of detail. (c) Image with a relatively large amount of detail. (Image (b) courtesy of the Massachusetts Institute of Technology.)

- Figure 2.22 (a): The woman’s face; Image with low level of detail.
- Figure 2.22 (b): The cameraman; Image with medium level of detail.
- Figure 2.22 (c): The crowd picture; Image with a relatively large amount of detail.

Zooming and Shrinking Digital Images

- Zooming: increasing the number of pixels in an image so that the image appears larger
  - Nearest neighbor interpolation
    - For example: pixel replication--to repeat rows and columns of an image
  - Bilinear interpolation
    - Smoother
  - Higher order interpolation
- Image shrinking: subsampling

Zooming and Shrinking Digital Images

Nearest neighbor Interpolation (Pixel replication)

Bilinear interpolation

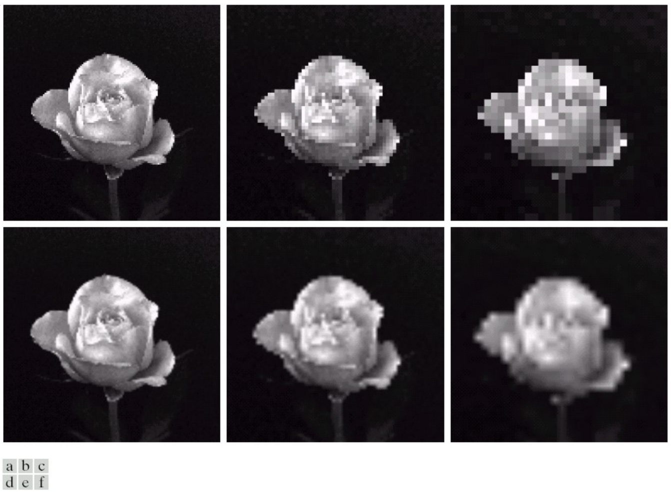


FIGURE 2.25 Top row: images zoomed from 128 × 128, 64 × 64, and 32 × 32 pixels to 1024 × 1024 pixels, using nearest neighbor gray-level interpolation. Bottom row: same sequence, but using bilinear interpolation.

Some Basic Relationships Between Pixels

- Neighbors of a pixel
  - There are three kinds of neighbors of a pixel:
    - $N_4(p)$ 4-neighbors: the set of horizontal and vertical neighbors
    - $N_D(p)$ diagonal neighbors: the set of 4 diagonal neighbors
    - $N_8(p)$ 8-neighbors: union of 4-neighbors and diagonal neighbors

	O	
O	X	O
	O	

O		O
	X	
O		O

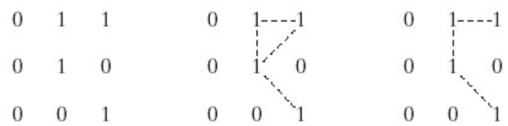
O	O	O
O	X	O
O	O	O

Some Basic Relationships Between Pixels

- Adjacency:
  - Two pixels that are neighbors and have the same grey-level (or some other specified similarity criterion) are adjacent
  - Pixels can be 4-adjacent, diagonally adjacent, 8-adjacent, or m-adjacent.
- *m*-adjacency (mixed adjacency):
  - Two pixels *p* and *q* of the same value (or specified similarity) are *m*-adjacent if either
    - (i) *q* and *p* are 4-adjacent, or
    - (ii) *p* and *q* are diagonally adjacent and do not have any common 4-adjacent neighbors.
    - They cannot be both (i) and (ii).

Some Basic Relationships Between Pixels

- An example of adjacency:



a b c

FIGURE 2.26 (a) Arrangement of pixels; (b) pixels that are 8-adjacent (shown dashed) to the center pixel; (c) *m*-adjacency.

Some Basic Relationships Between Pixels

- Path:
  - The length of the path
  - Closed path
- Connectivity in a subset *S* of an image
  - Two pixels are connected if there is a path between them that lies completely within *S*.
- Connected component of *S*:
  - The set of all pixels in *S* that are connected to a given pixel in *S*.
- Region of an image
- Boundary, border or contour of a region R
  - The set of points that are adjacent to points in the complement of R.
- Edge: a path of one or more pixels that separate two regions of significantly different gray levels.

Some Basic Relationships Between Pixels

Distance measures

- Distance function: a function of two points, *p* and *q*, in space that satisfies three criteria

$$(a)\ D(p,q) \geq 0$$
$$(b)\ D(p,q) = D(q,p), \text{ and}$$
$$(c)\ D(p,z) \leq D(p,q) + D(q,z)$$

- The Euclidean distance $D_e(p, q)$

$$D_e(p,q) = \sqrt{(x-s)^2 + (y-t)^2}$$

- The city-block (Manhattan) distance $D_4(p, q)$

$$D_4(p,q) = |x-s| + |y-t|$$

- The chessboard distance $D_8(p, q)$

$$D_8(p,q) = \max(|x-s|, |y-t|)$$

- $D_m(p,q)$ = Shortest m-path between p and q.
  In this case, distance depends also on the value of pixels along the path and their neighbours

A Note About Grey Levels

So far when we have spoken about image grey level values we have said they are in the range [0, 255]

- Where 0 is black and 255 is white

There is no reason why we have to use this range

- The range [0,255] stems from display technologoes

For many of the image processing operations in this lecture grey levels are assumed to be given in the range [0.0, 1.0]

What Is Image Enhancement?

Image enhancement is the process of making images more useful

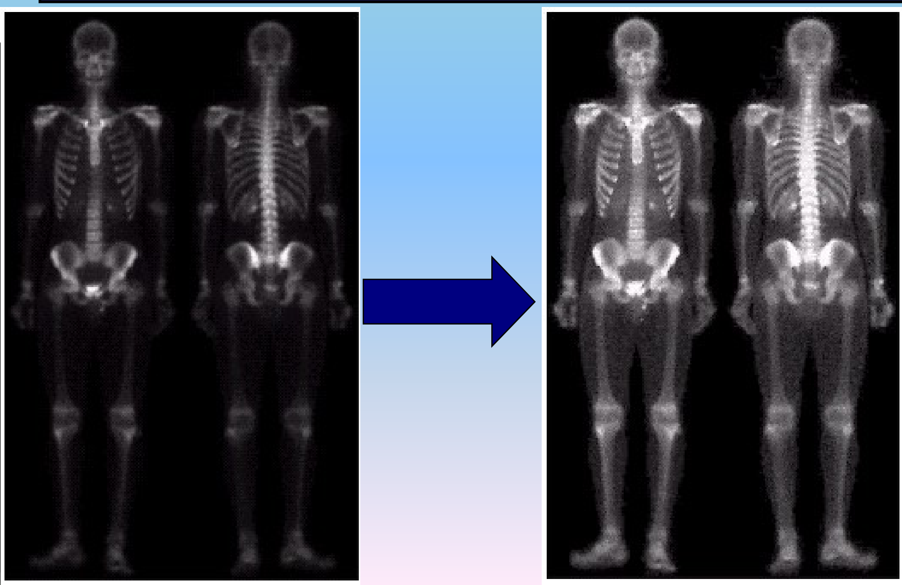
The reasons for doing this include:

- Highlighting interesting detail in images
- Removing noise from images
- Making images more visually appealing

Image Enhancement Examples

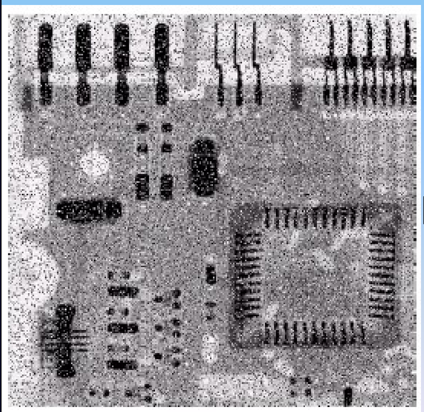
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Enhancement Examples (cont…)



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Enhancement Examples (cont…)



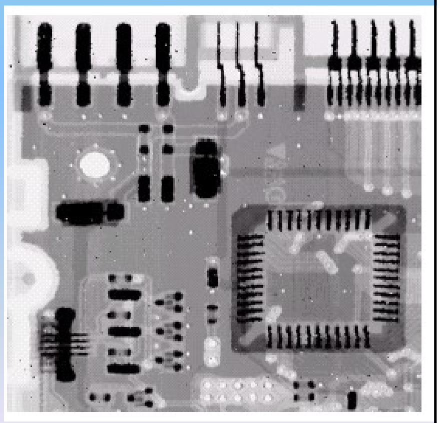


Image Enhancement Examples (cont…)

Spatial & Frequency Domains

There are two broad categories of image enhancement techniques

- Spatial domain techniques
  - Direct manipulation of image pixels
- Frequency domain techniques
  - Manipulation of Fourier transform or wavelet transform of an image

For the moment we will concentrate on techniques that operate in the spatial domain

Image Enhancement in the Spatial Domain

- **The spatial domain:**
  - The image plane
  - For a digital image is a Cartesian coordinate system of discrete rows and columns. At the intersection of each row and column is a pixel. Each pixel has a value, which we will call intensity.
- **The frequency domain :**
  - A (2-dimensional) discrete Fourier transform of the spatial domain
  - We will discuss it later (Book chapter 4)
- **Enhancement** :
  - To "improve" the usefulness of an image by using some transformation on the image.
  - Often the improvement is to help make the image "better" looking, such as increasing the intensity or contrast.

Background

- A mathematical representation of spatial domain enhancement:

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

where $f(x, y)$: the input image

$g(x, y)$: the processed image

T: an operator on f, defined over some neighborhood of (x, y)

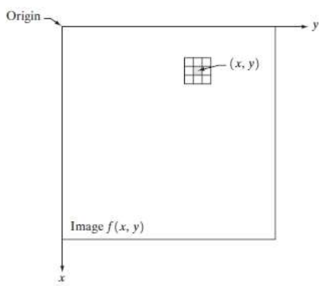


FIGURE 3.1 A 3 × 3 neighborhood about a point (x, y) in an image.

- The simplest form of ***T***, is when the neighborhood of size 1X1 (that is a single pixel). In this case, g depends only on the value of f at (x,y), and ***T*** becomes a *grey-level* (also called *intensity* or *mapping*) *transformation function* of the form:

$$s = T(r)$$

Where, for simplicity in notation, r and s are variables denoting, respectively, the grey level of f(x,y) and g(x,y) at any point (x,y)

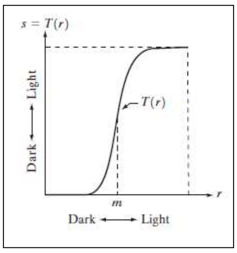
Examples of Enhancement Techniques

- **Contrast Stretching**:

If T(r) has the form as shown in the figure below, the effect of applying the transformation to every pixel of f to generate the corresponding pixels in g would:

Produce higher contrast than the original image, by:

- Darkening the levels below m in the original image
- Brightening the levels above m in the original image

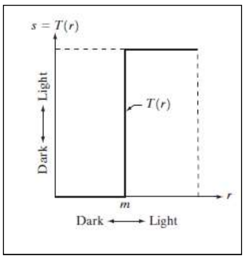


So, Contrast Stretching: is a simple image enhancement technique that improves the contrast in an image by 'stretching' the range of intensity values it contains to span a desired range of values. Typically, it uses a linear function

Examples of Enhancement Techniques

- **Thresholding**

Is a limited case of contrast stretching, it produces a two-level (binary) image.



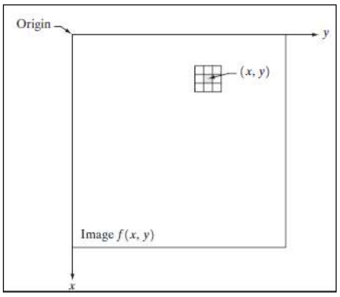
Some fairly simple, yet powerful, processing approaches can be formulated with grey-level transformations. Because enhancement at any point in an image depends only on the gray level at that point, techniques in this category often are referred to as *point processing*.

Examples of Enhancement Techniques

Larger neighborhoods allow considerable more flexibility. The general approach is to use a function of the values of *f* in a predefined neighborhood of (x,y) to determine the value of *g* at (x,y).

One of the principal approaches in this formulation is based on the use of so-called *masks* (also referred to as *filters)*

So, a mask/filter: is a small (say 3X3) 2-D array, such as the one shown in the figure, in which the values of the mask coefficients determine the nature of the process, such as *image sharpening*. Enhancement techniques based on this type of approach often are referred to as *mask processing* or *filtering*.



Some Basic Intensity (Gray-level) Transformation Functions

- Grey-level transformation functions (also called, intensity functions), are considered the simplest of all image enhancement techniques.
- The value of pixels, before an after processing, will be denoted by *r* and *s*, respectively. These values are related by the expression of the form:

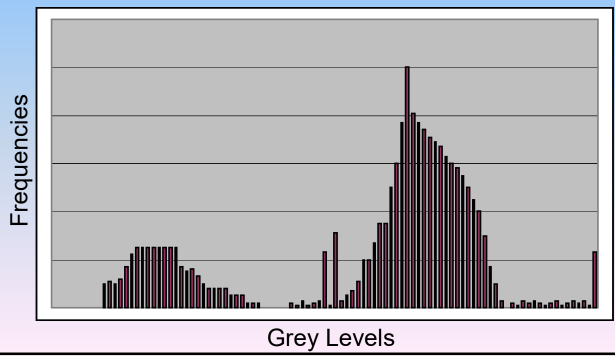
  s = *T* (r)

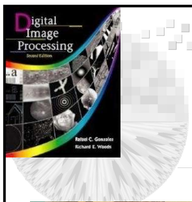
  where T is a transformation that maps a pixel value r into a pixel value s.

Image Histograms

The histogram of an image shows us the distribution of grey levels in the image

Massively useful in image processing, especially in segmentation





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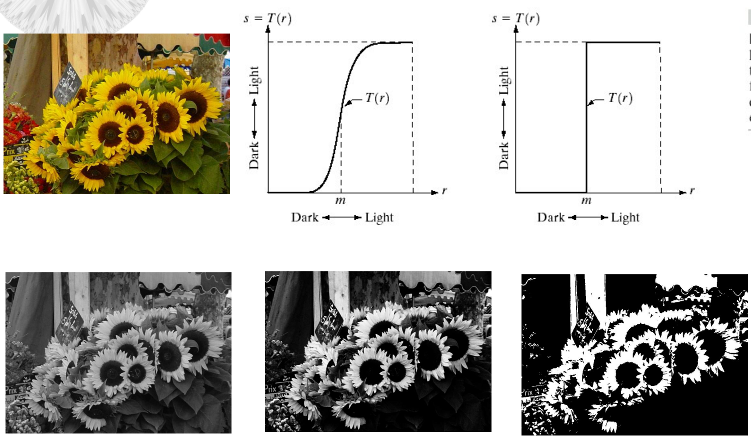
www.imageprocessingbook.com

Gray-level Transformation



a b

FIGURE 3.2 Gray-level transformation functions for contrast enhancement.

Some Basic Gray Level Transformations

FIGURE 3.3 Some basic gray-level transformation functions used for image enhancement.

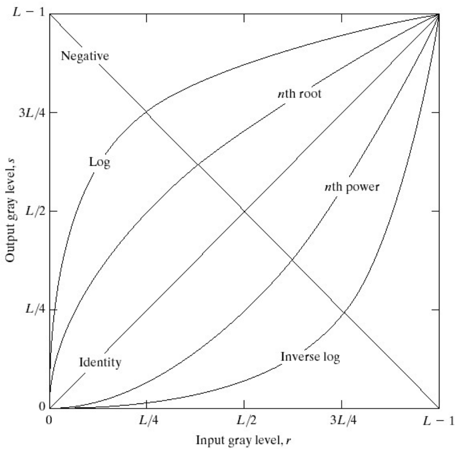
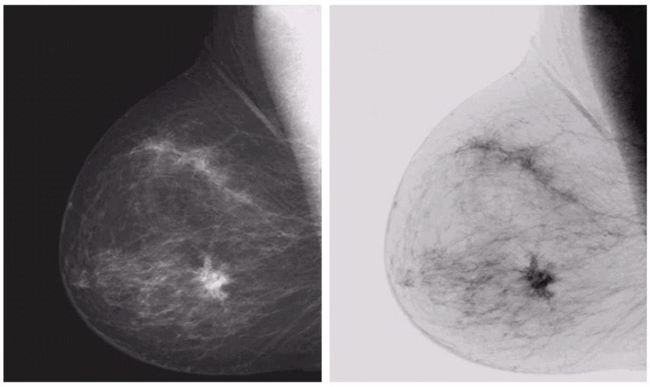


Image Negatives

- Let the range of gray level be [0, L-1], then

$$s = L - 1 - r$$



a b

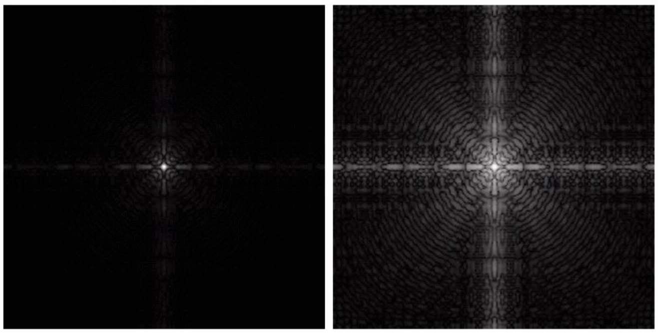
FIGURE 3.4 (a) Original digital mammogram. (b) Negative image obtained using the negative transformation in Eq. (3.2-1). (Courtesy of G.E. Medical Systems.)

Log Transformations

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

where *c* : constant

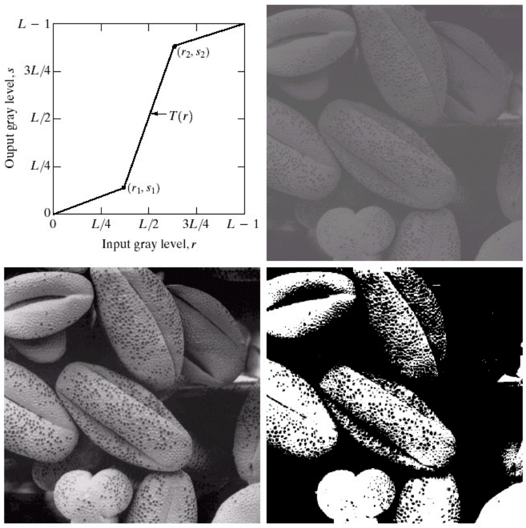
$$r \geq 0$$



a b

FIGURE 3.5 (a) Fourier spectrum. (b) Result of applying the log transformation given in Eq. (3.2-2) with $c = 1$.

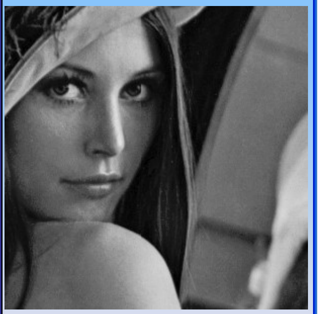
Piecewise-Linear Transformation Functions
Contrast Stretching

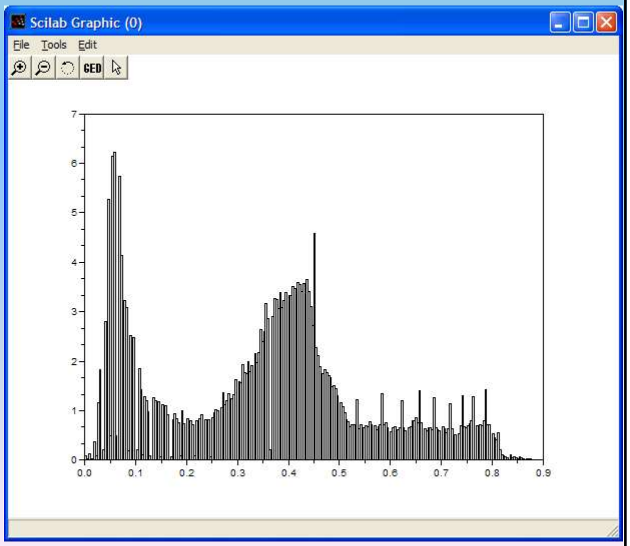


a b
c d

FIGURE 3.10 Contrast stretching. (a) Form of transformation function. (b) A low-contrast image. (c) Result of contrast stretching. (d) Result of thresholding. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)

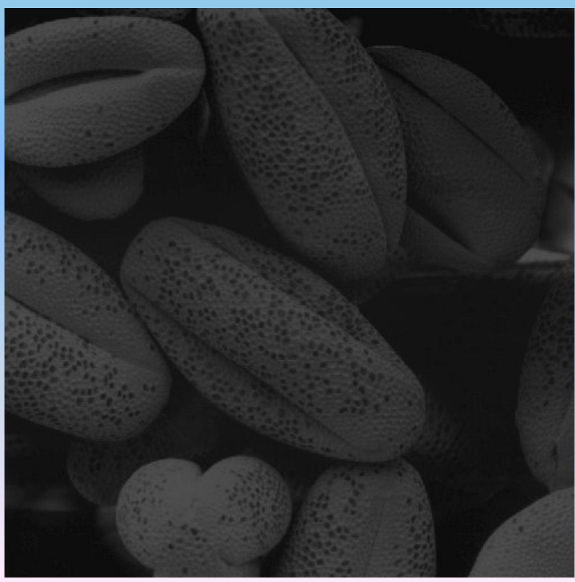
Histogram Examples





Images taken from Gonzalez & Woods, Digital Image Processing (2002)

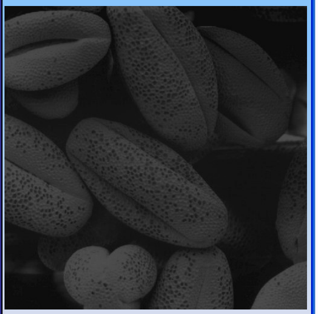
Histogram Examples (cont…)

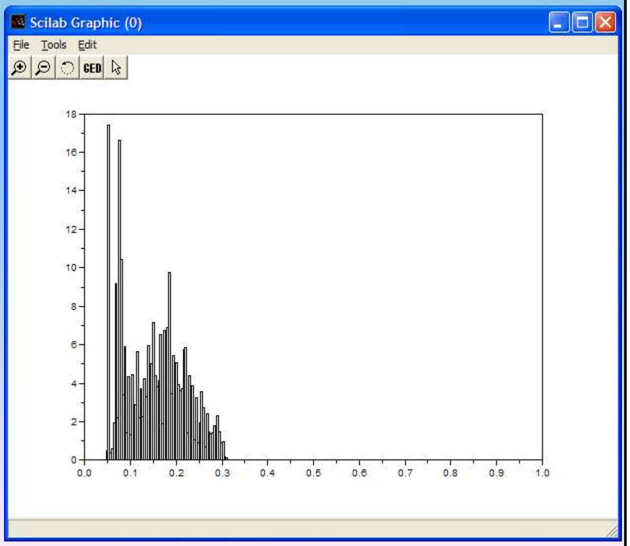


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Histogram Examples (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)



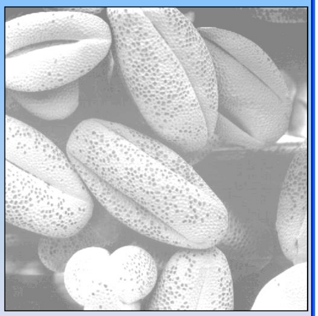


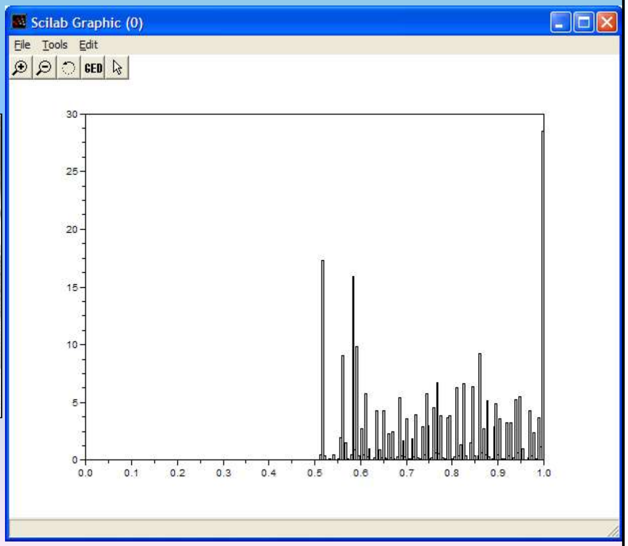
Histogram Examples (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Histogram Examples (cont…)

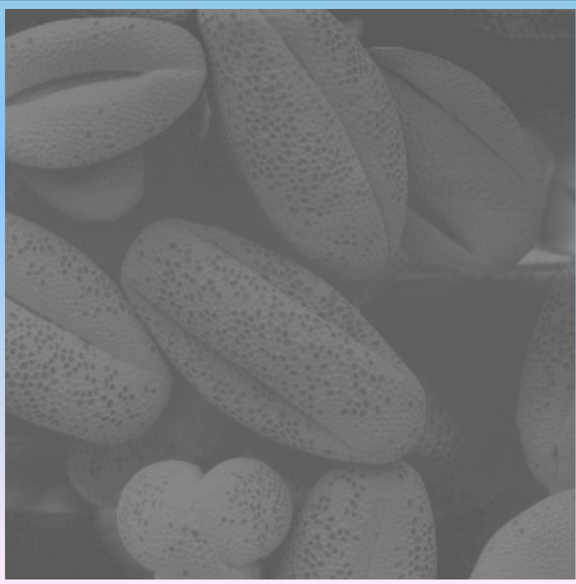
Images taken from Gonzalez & Woods, Digital Image Processing (2002)



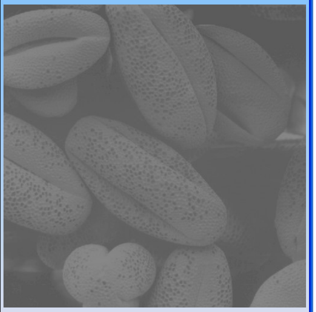


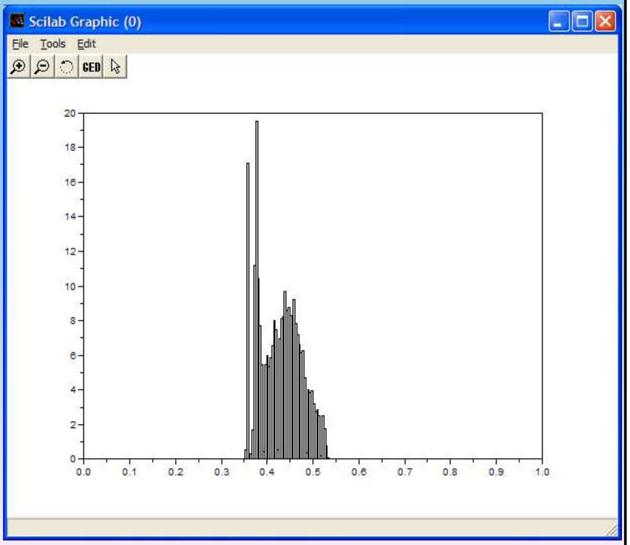
Histogram Examples (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)



Histogram Examples (cont…)





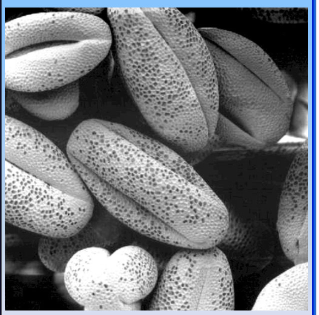
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

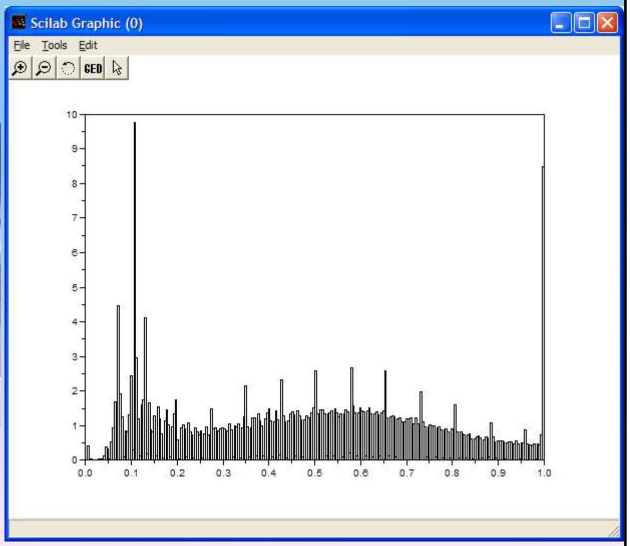
Histogram Examples (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Histogram Examples (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)





Histogram Examples (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

- A selection of images and their histograms
- Notice the relationships between the images and their histograms
- Note that the high contrast image has the most evenly spaced histogram