

Digital Image Processing

Lecture # 1 **Introduction & Fundamentals**

Introduction

- Area of research: Analysis of medical images/signals using Image/signal processing and Machine Learning Techniques
- Current Research Areas:
 - Biomedical Image/Signal Analysis (Retina, Cardiac, Dental, EEG, Breath Sounds etc)
 - Biometrics (FP, Dental, Retina, Dorsal hand veins etc)



BIOMISA

BIOMetrics, Medical Image and Signal Analysis Research Group



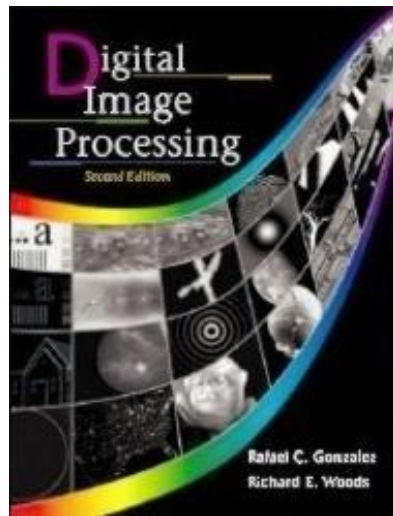
[*www.biomisa.org/usman](http://www.biomisa.org/usman)

[*www.biomisa.org](http://www.biomisa.org)

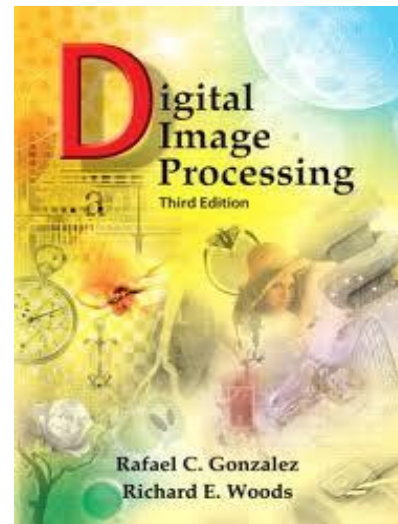
Course Information

◆ Books

- Digital Image Processing, Rafael C. Gonzalez & Richard E. Woods, Addison-Wesley



Second Edition



Third Edition

Other reference books are mentioned in course outline on the course web page.

Course Information

- **Course Material**

- Lectures slides, assignments (computer/written), solutions to problems, projects, and announcements will be uploaded on course web page.

<http://biomisa.org/usman/digital-image-processing-fall16>



Course Contents

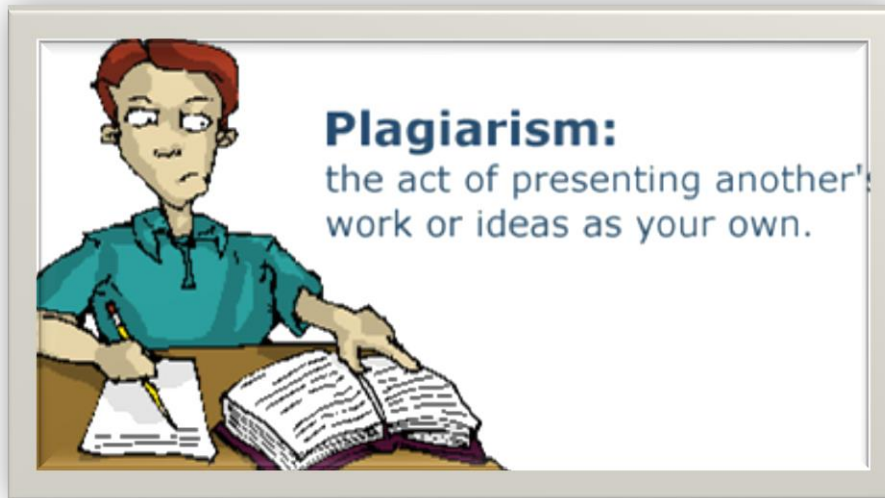
- Introduction to Image processing (Chapter – 1, 2)
- Image processing Fundamentals (Chapter-2)
- Image Enhancement & Restoration (Spatial & Frequency Domain) (Chapter – 3, 4, 5)
- Color Image Processing (Chapter – 6)
- Morphological operations (Chapter – 9)
- Segmentation (Chapter – 10)
- Feature extraction (edges, corners, local binary patterns, Histogram of Oriented gradients)
- Texture analysis (Chapter – 11)
- Image Registration/Matching
- Image Compression (Chapter – 08)
- Wavelets (Chapter – 07)
- Introduction to Machine Learning and basic types of classifiers, Performance parameters for evaluation (Chapter – 12)

Grading Policy

Mid:	20%
Quizzes (4-6):	10%
Computer assignments (3) :	10%
Project:	20%
Final Exam:	40%

Policies

- No extensions in assignment deadlines.
- Quizzes will be unannounced.
- Exams will be closed book.
- Never cheat.
 - “Better fail NOW or else will fail somewhere LATER in life”
- Plagiarism will also have strict penalties.



Courtesy Dr. Khawar

Adapted from *What is Plagiarism* PowerPoint
<http://mciu.org/~spjvweb/plagiarism.ppt>



Image Processing

Image Analysis

Pattern Recognition

Computer Vision

Machine Vision



Image Processing & Machine Vision

- ◆ From Image Processing to Machine Vision:
 - low, mid and high-level processes

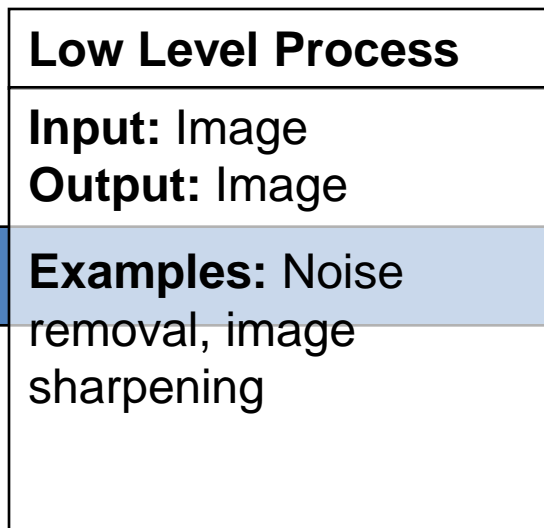


Image Processing



Example: Low Level Processing

Photo restoration



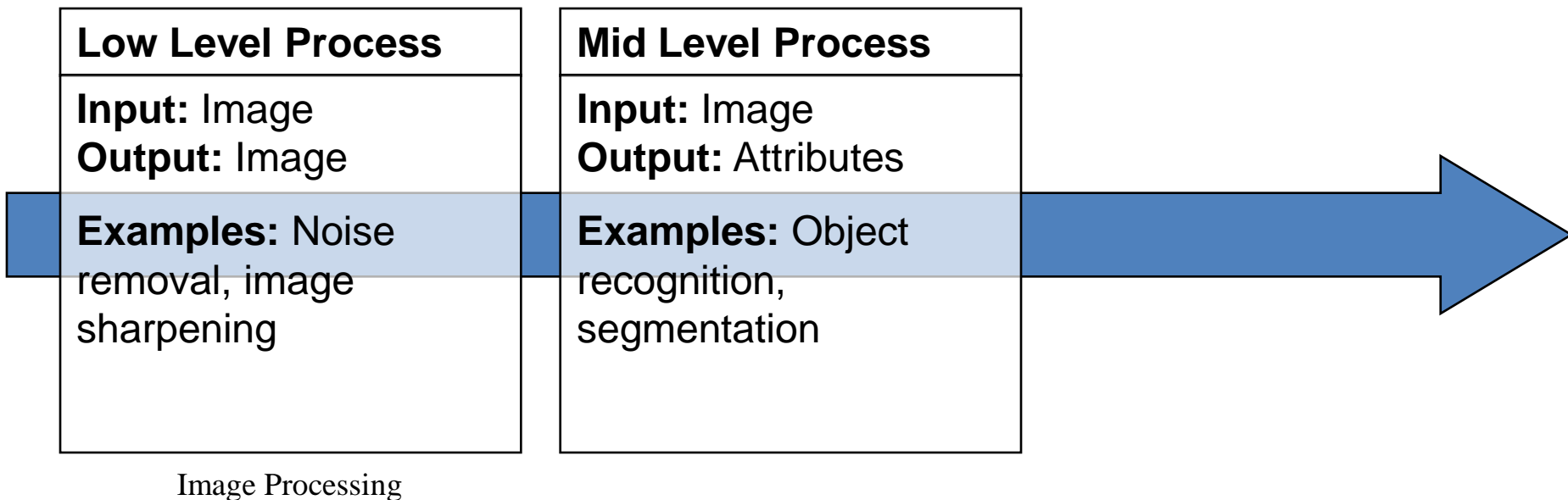
Damaged Image



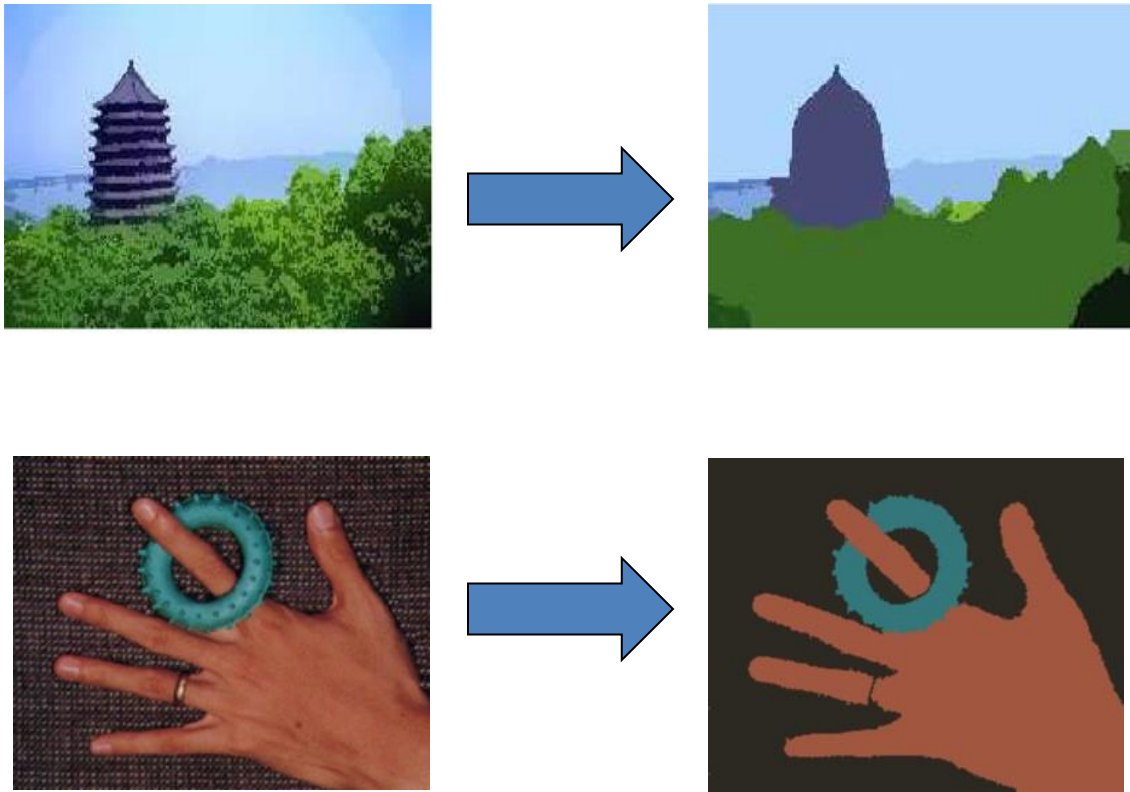
Restored Image

Image Processing & Machine Vision

- ◆ From Image Processing to Machine Vision:
 - low, mid and high-level processes



Example: Mid Level Processing

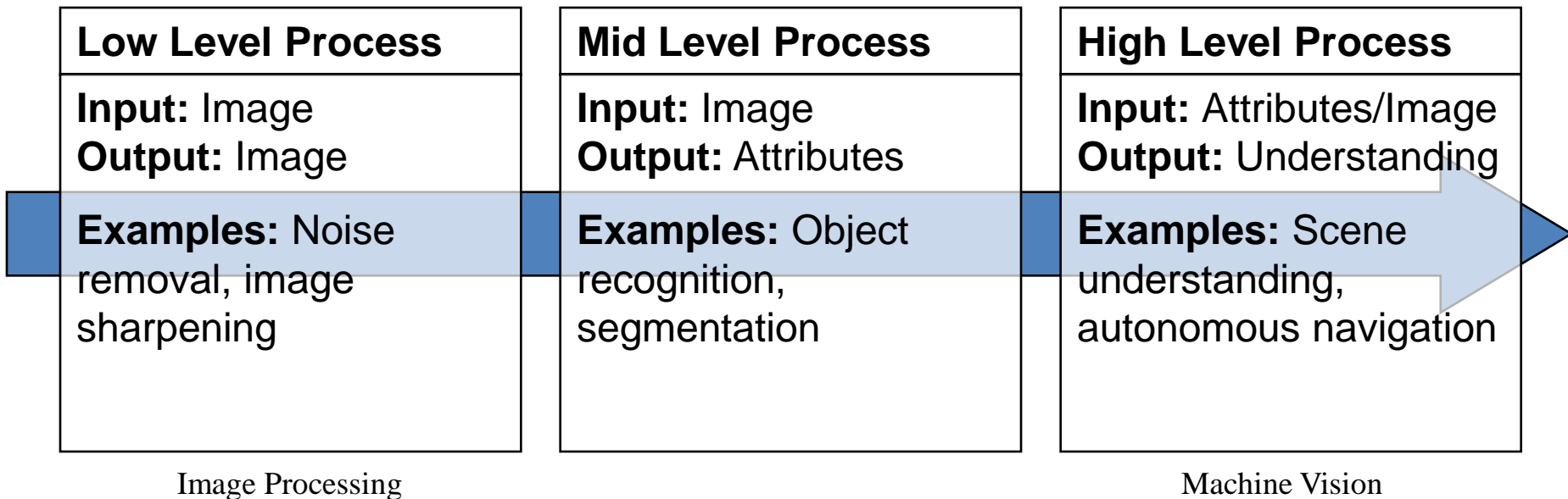


Segmentation of image into regions

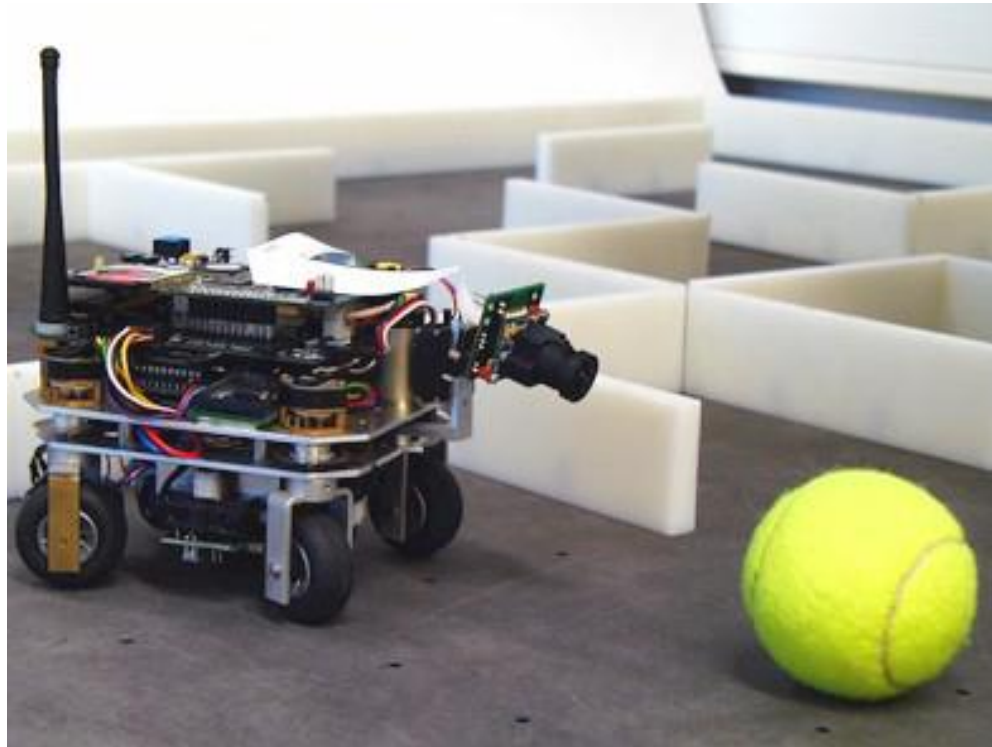
Image Processing & Machine Vision

◆ From Image Processing to Machine Vision:

- low, mid and high-level processes



Example: High Level Processing



Robot Navigation

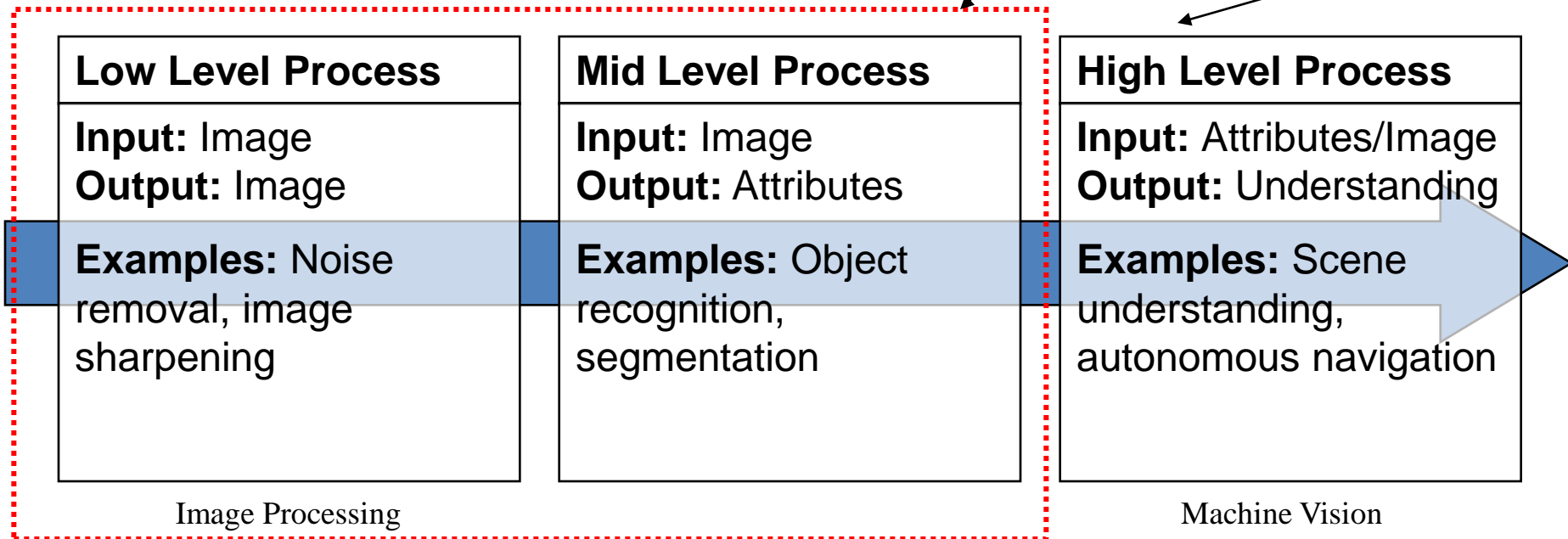
Image Processing & Machine Vision

◆ From Image Processing to Machine Vision:

- low, mid and high-level processes

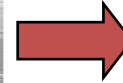
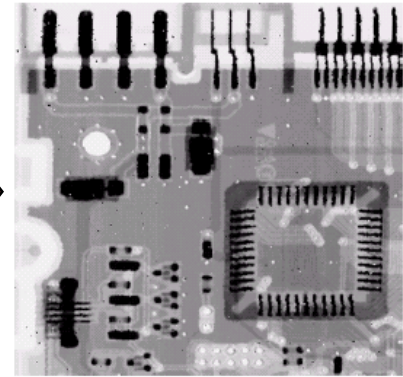
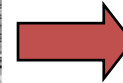
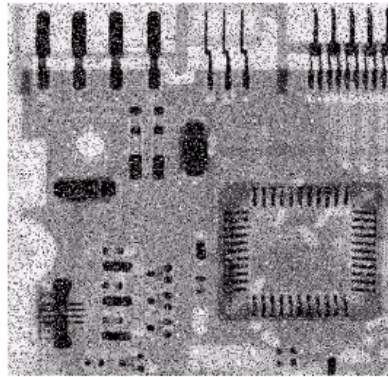
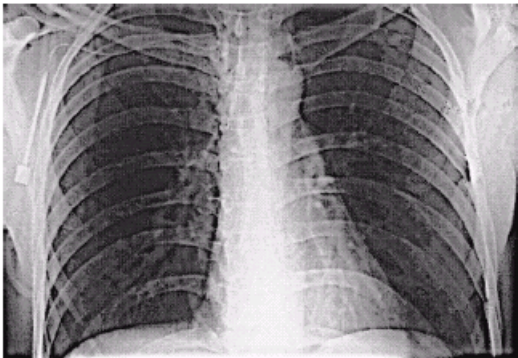
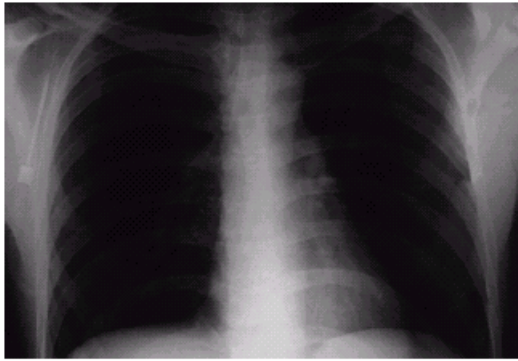
In this course

Some of this as well



Example Applications

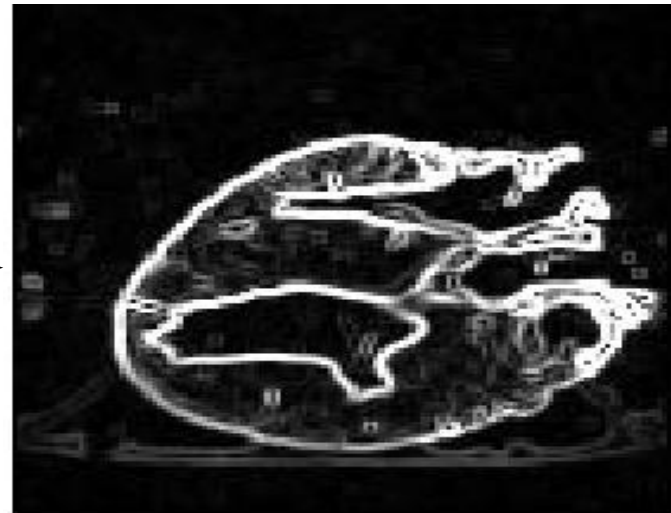
Examples: Image Enhancement



Examples: Medicine

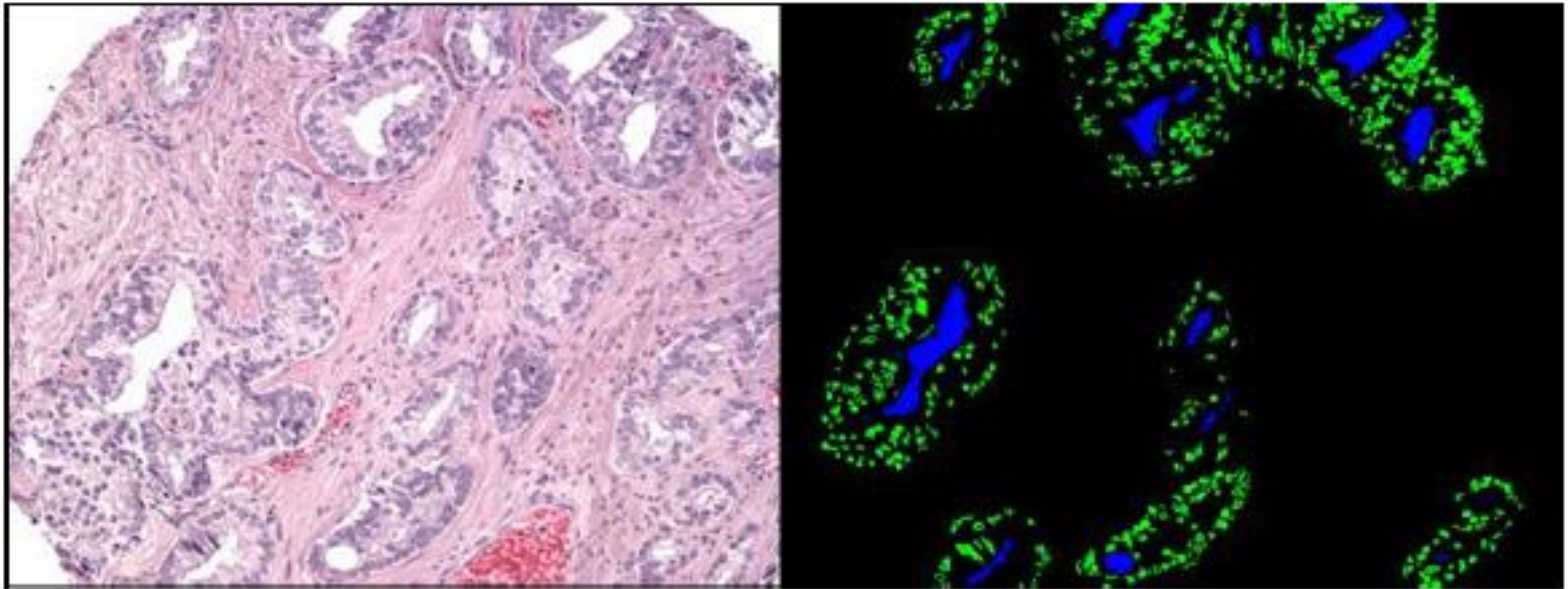


Original Image of a Dog Heart



Separation of tissues

Examples: Medicine

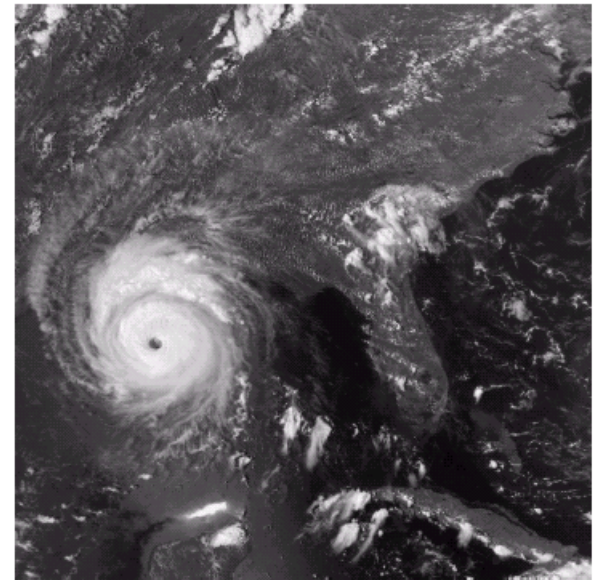
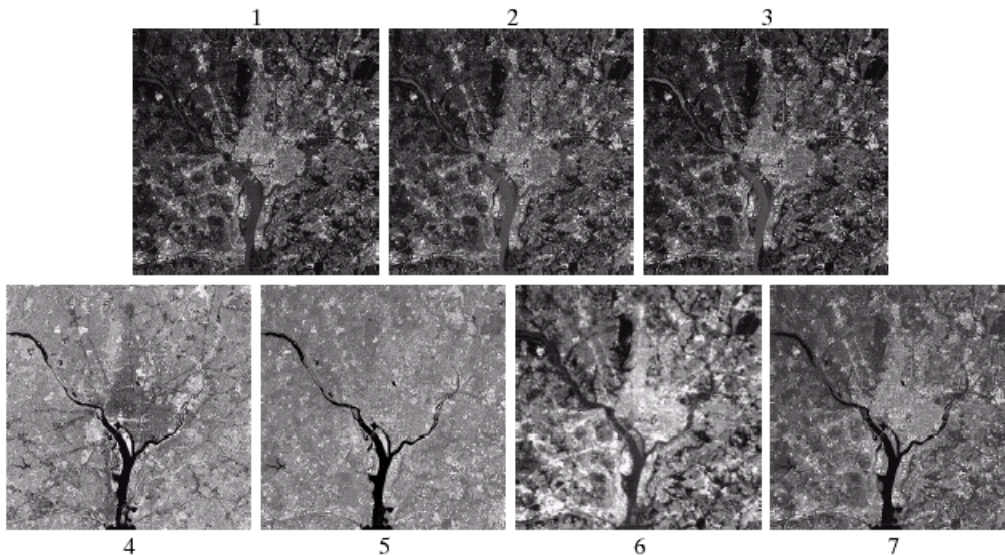


Microscopic tissue data - Cancer Detection

Examples: GIS

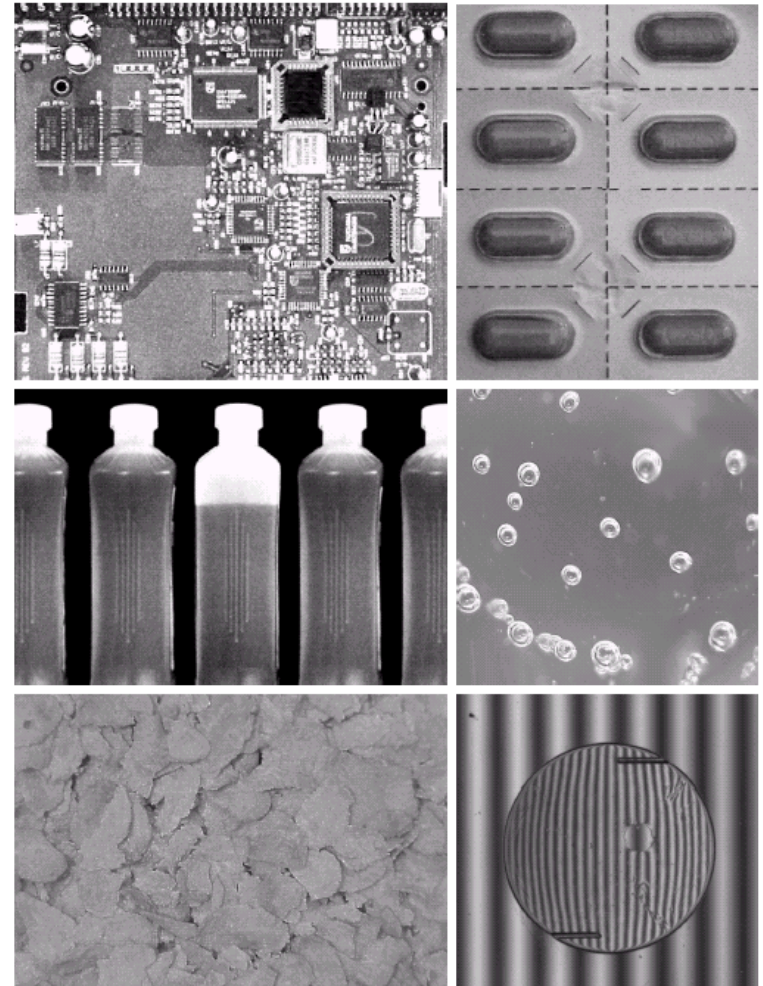
◆ Geographic Information Systems

- Manipulation of Satellite Imagery
- Terrain Classification, Meteorology



Examples: Industrial Inspection

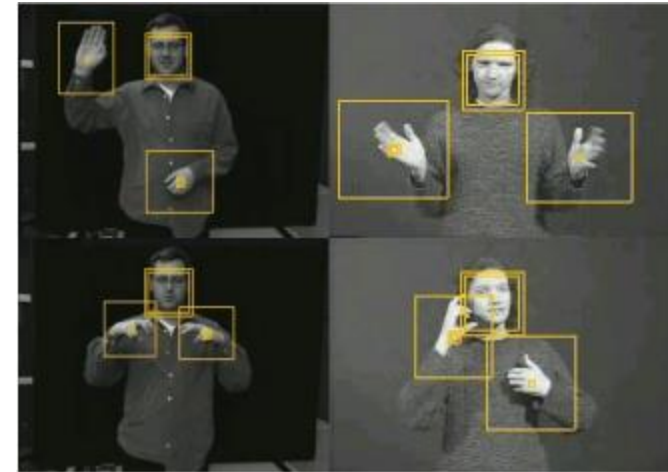
- ◆ Human operators are expensive, slow and unreliable
- ◆ Make machines do the job instead



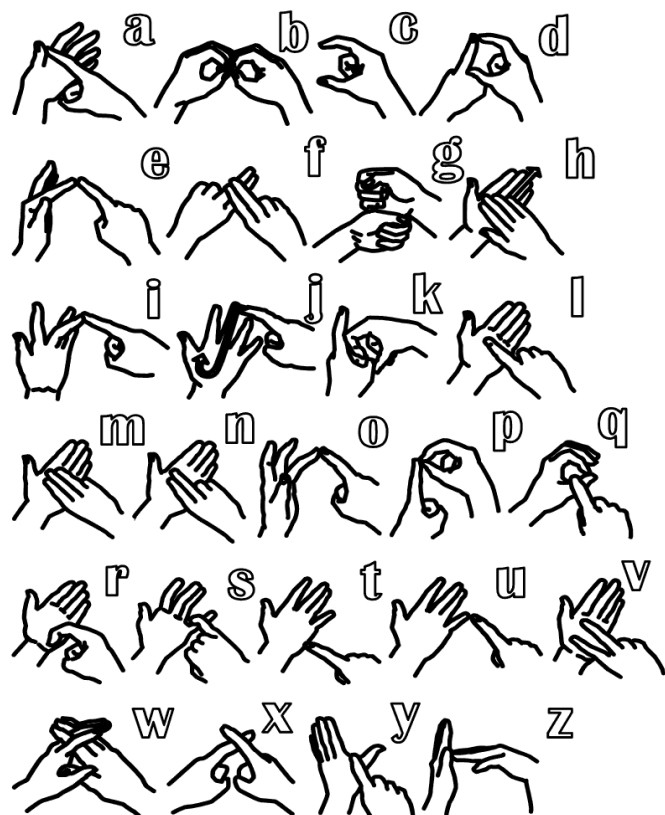
Examples: HCI

◆ Try to make human computer interfaces more natural

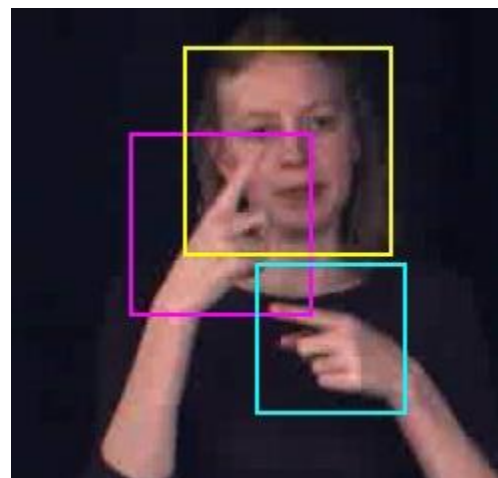
- Gesture recognition
- Facial Expression Recognition
- Lip reading



Examples: Sign Language/Gesture Recognition



British Sign Language Alphabet



Examples: Lip Reading



Can you guess? ee oo sh















Examples: Lip Reading



Examples: Facial Expression Recognition

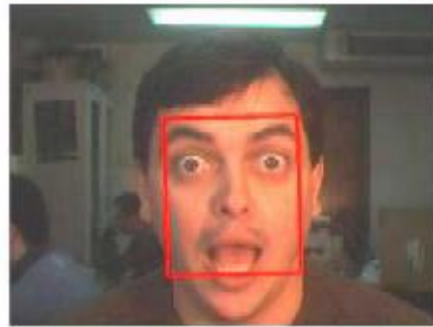
- Implicit customer feedback

Upper Face Action Units		
AU4	AU1+4	AU1+2
		
Brows lowered and drawn together	Medial portion of the brows is raised and pulled together	Inner and outer portions of the brows are raised
AU5	AU6	AU7
		
Upper eyelids are raised	Cheeks are raised and eye opening is narrowed	Lower eyelids are raised

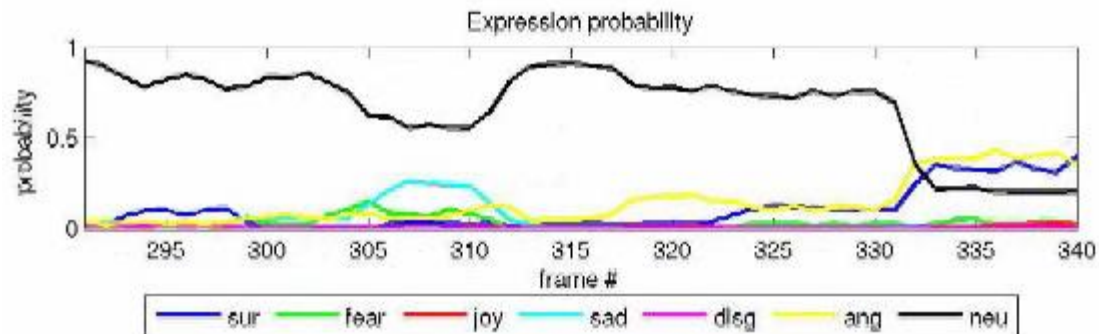
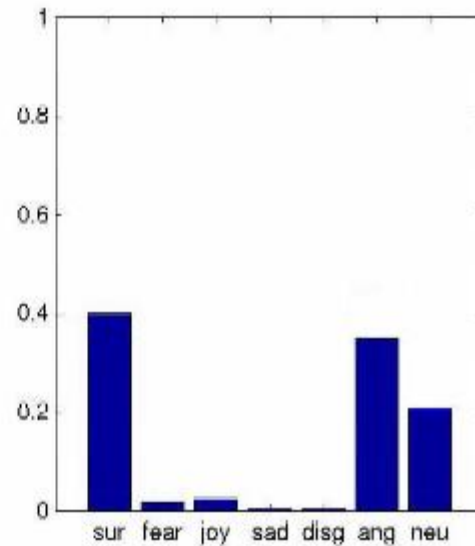
Lower Face Action Units		
AU25	AU26	AU27
		
Lips are relaxed and parted	Lips are relaxed and parted; mandible is lowered	Mouth is stretched open and the mandible pulled down
AU12	AU12+25	AU20+25
		
Lip corners are pulled obliquely	AU12 with mouth opening	Lips are parted and pulled back laterally

Examples: Facial Expression Recognition

- Implicit customer feedback

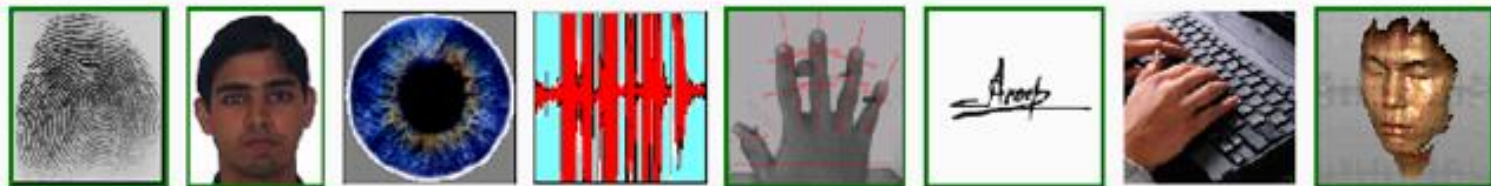


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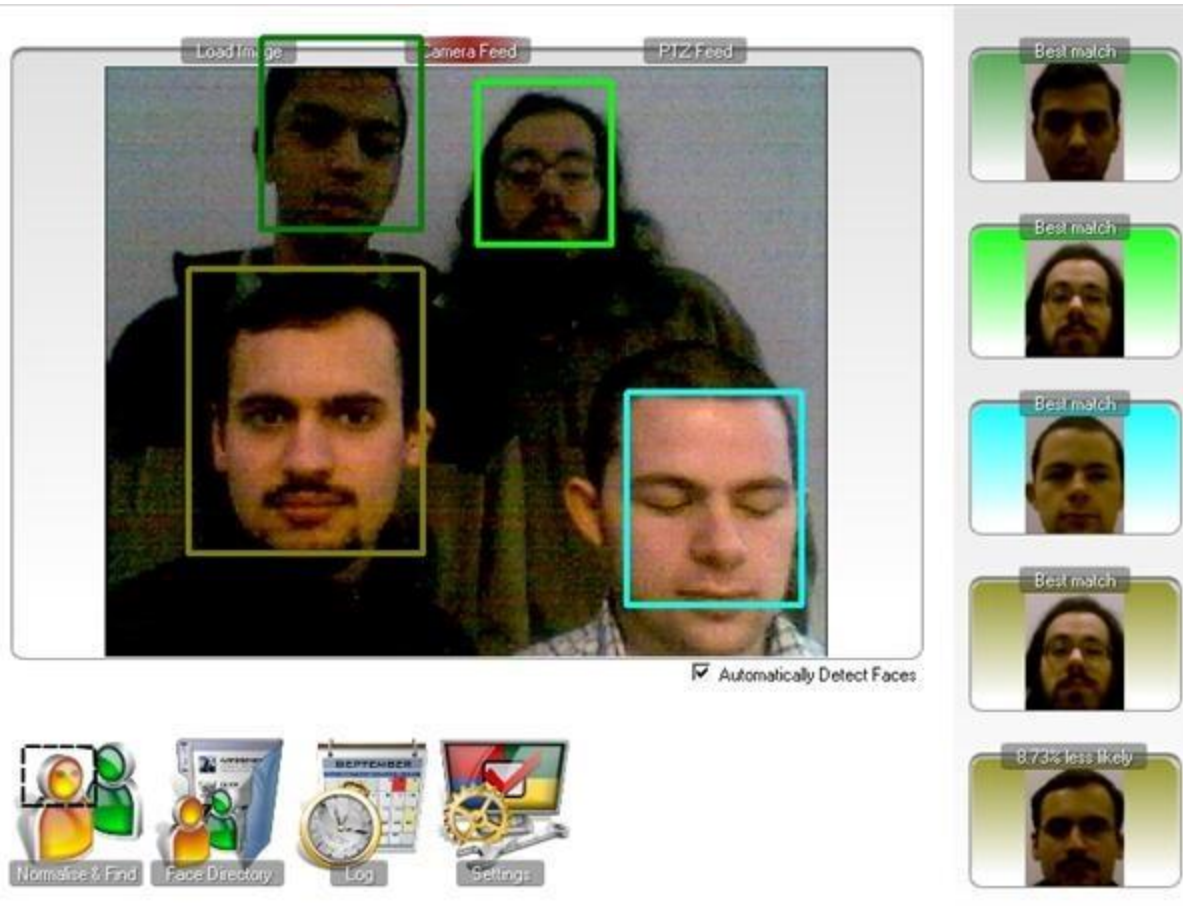


Examples: Biometrics

- ◆ Biometrics - Authentication techniques
- ◆ Physiological Biometrics
 - Face, IRIS, DNA, Finger Prints
- ◆ Behavioral Biometrics
 - Typing Rhythm, Handwriting, Gait



Examples: Biometrics – Face Recognition



Faces and Digital Cameras



Setting camera focus via face detection

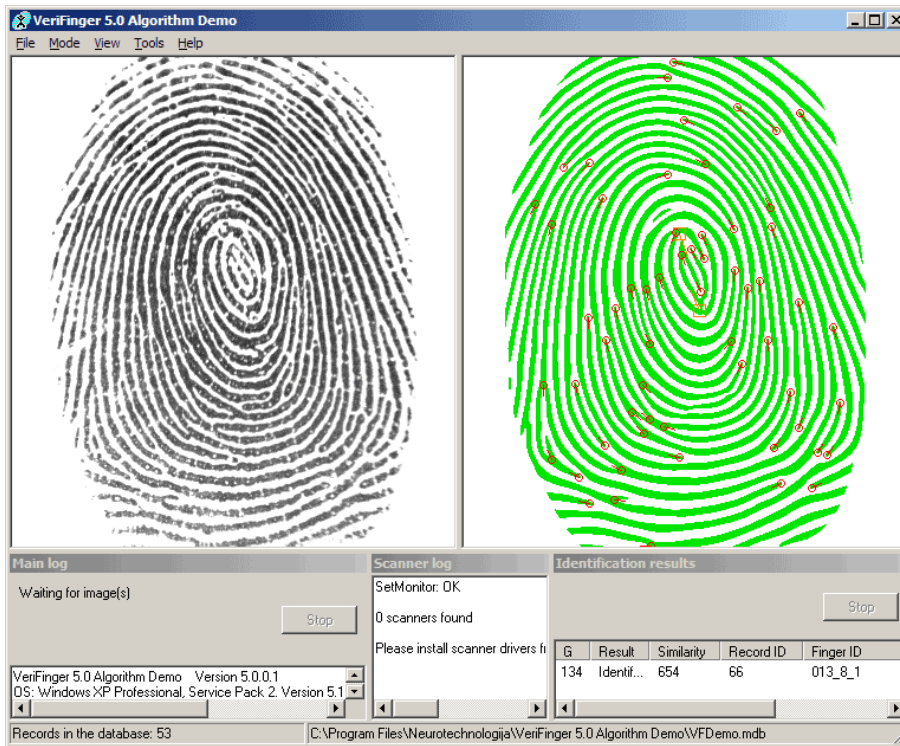


Camera waits for everyone to smile to take a photo [Canon]

Automatic lighting correction based on face detection



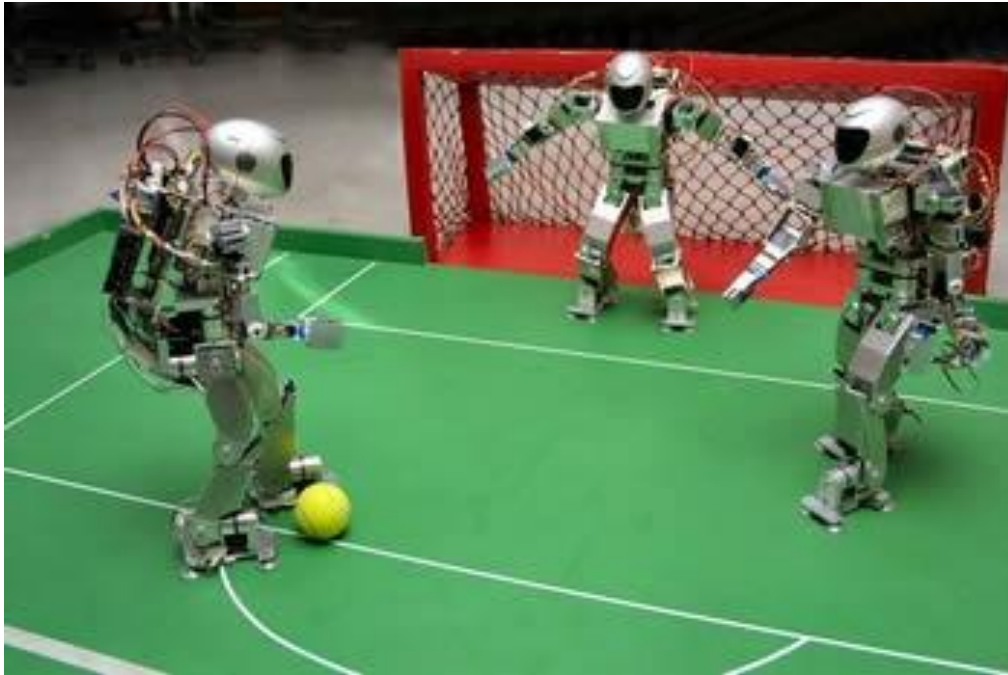
Examples: Biometrics – Finger Print Recognition



Examples: Biometrics – Signature Verification



Examples: Robotics



Examples: Robotics

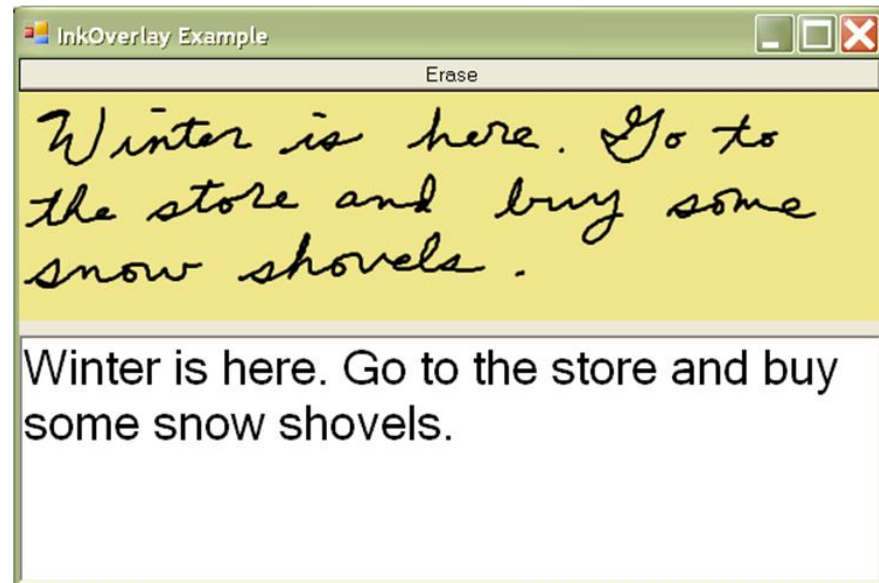
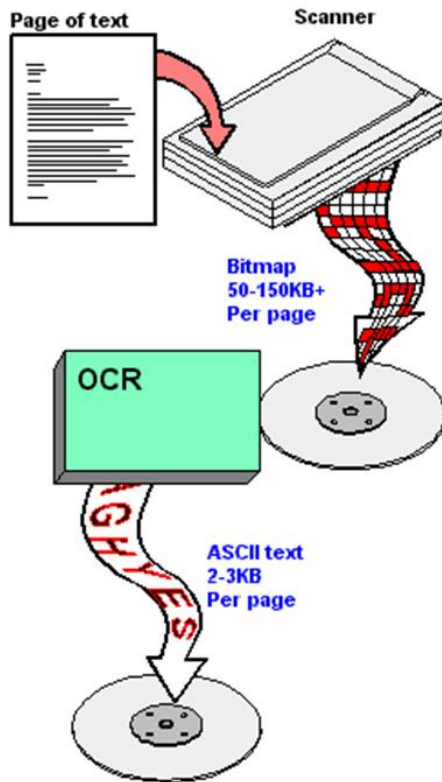
◆ AIBO



Examples: Optical Character Recognition

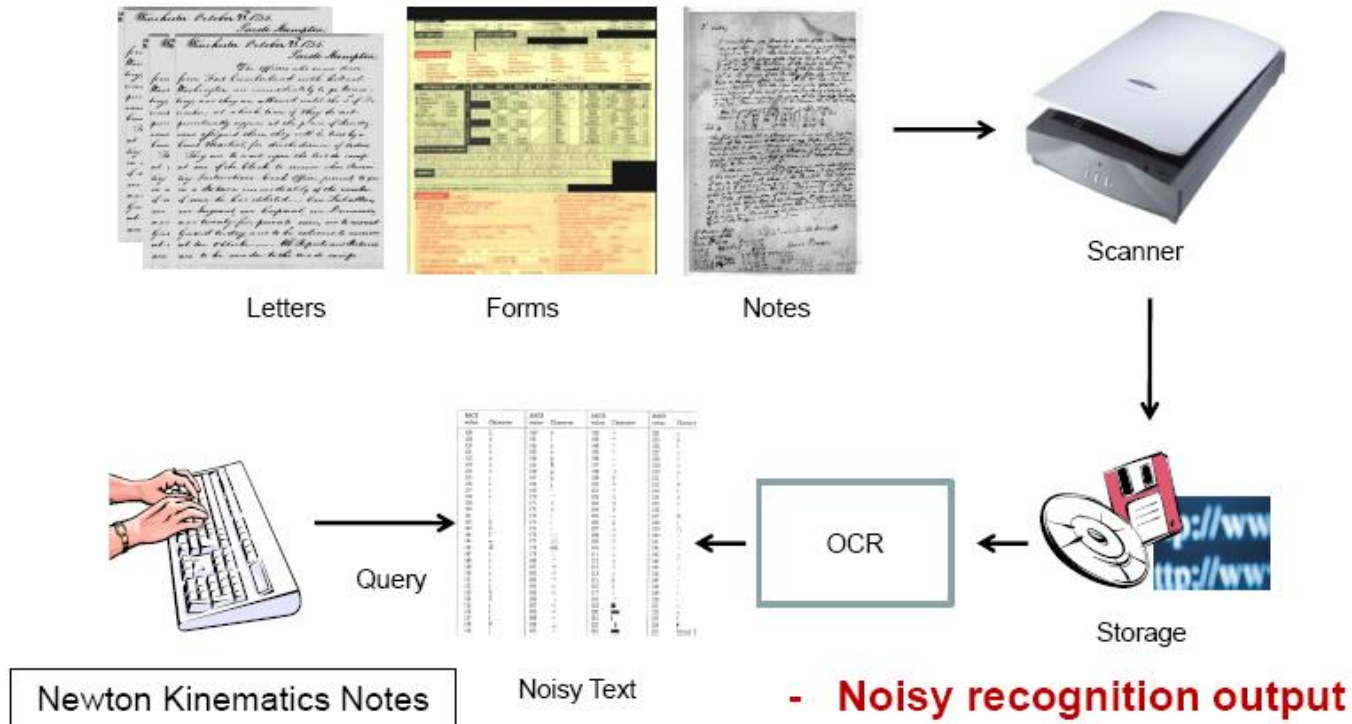
◆ Convert document image into text

From Computer Desktop Encyclopedia
© 1998 The Computer Language Co. Inc.



Examples: Optical Character Recognition

◆ Indexing and Retrieval



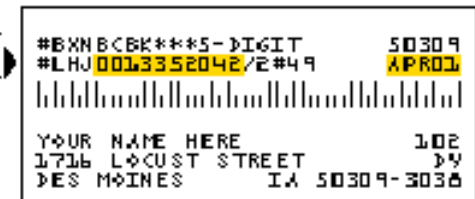
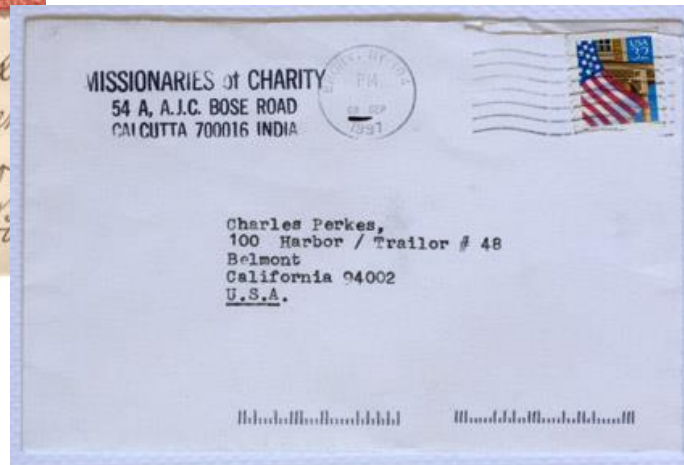
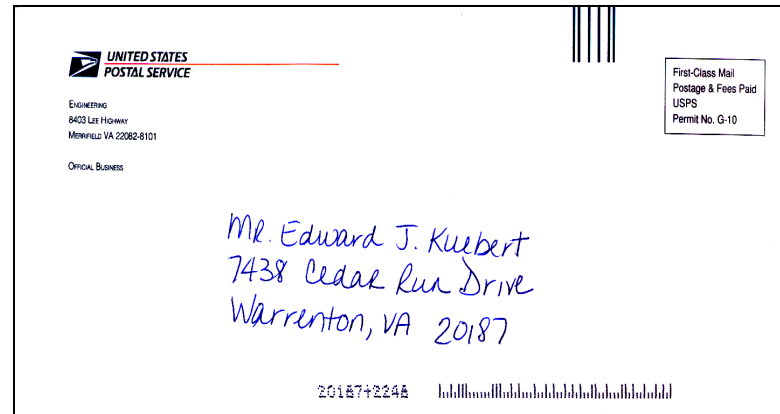
Examples: Optical Character Recognition

- ◆ License Plate Recognition



Examples: Optical Character Recognition

- Automatic Mail Sorting



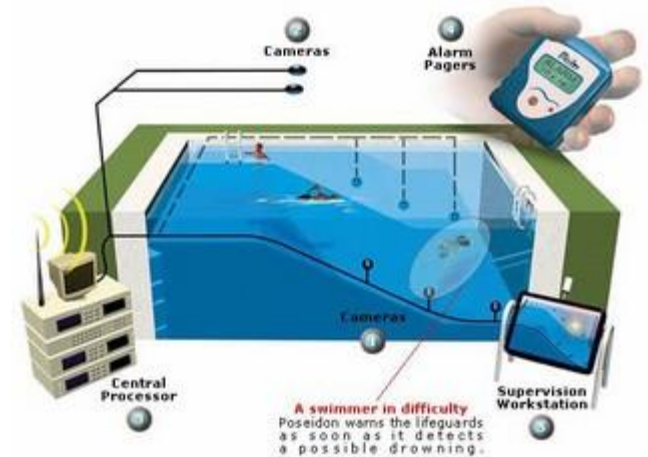
Safety and Security



Autonomous robots



Driver assistance



Monitoring pools
(Poseidon)



Pedestrian detection
[MERL, Viola et al.]



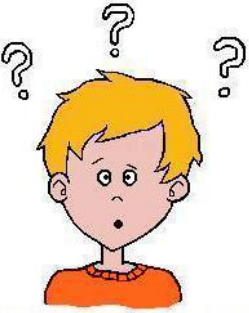
Surveillance

Summary of Applications

Problem Domain	Application	Input Pattern	Output Class
Document Image Analysis	Optical Character Recognition	Document Image	Characters/words
Document Classification	Internet search	Text Document	Semantic categories
Document Classification	Junk mail filtering	Email	Junk/Non-Junk
Multimedia retrieval	Internet search	Video clip	Video genres
Speech Recognition	Telephone directory assistance	Speech waveform	Spoken words
Natural Language Processing	Information extraction	Sentence	Parts of Speech
Biometric Recognition	Personal identification	Face, finger print, Iris	Authorized users for access control
Medical	Computer aided diagnosis	Microscopic Image	Healthy/cancerous cell
Military	Automatic target recognition	Infrared image	Target type
Industrial automation	Fruit sorting	Images taken on conveyor belt	Grade of quality
Bioinformatics	Sequence analysis	DNA sequence	Known types of genes

Image Sources

- **Electromagnetic (EM) band imaging**
 - Gamma ray band images
 - X-ray band images
 - Ultra violet band images
 - Visual light and infra-red images
 - Images based on micro waves or radio
- **Non-EM band imaging**
 - Acoustic and ultrasonic images
 - Electron microscopy
 - Computer generated images (synthetic)



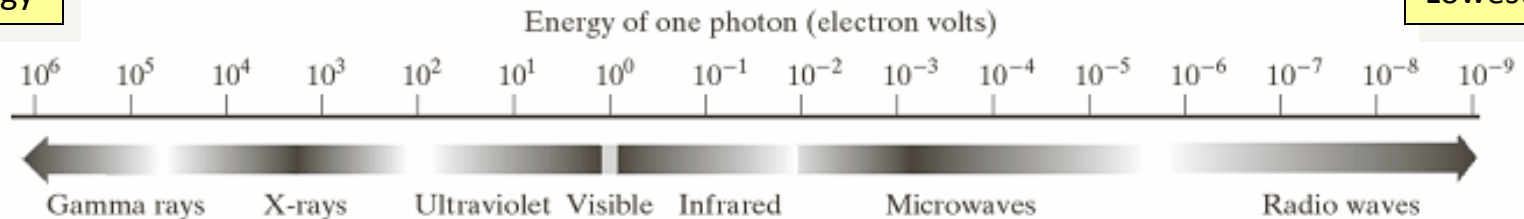
Light & EM Spectrum

- EM Waves

- A stream of mass less particles each travelling in a wave like pattern, moving at the speed of light and contains a certain bundle of energy
- The electromagnetic spectrum is split up in to bands according to the energy per photon

Highest Energy

Lowest Energy



Visible light is just a particular part of the electromagnetic spectrum that can be sensed by the human eye

Light & EM Spectrum

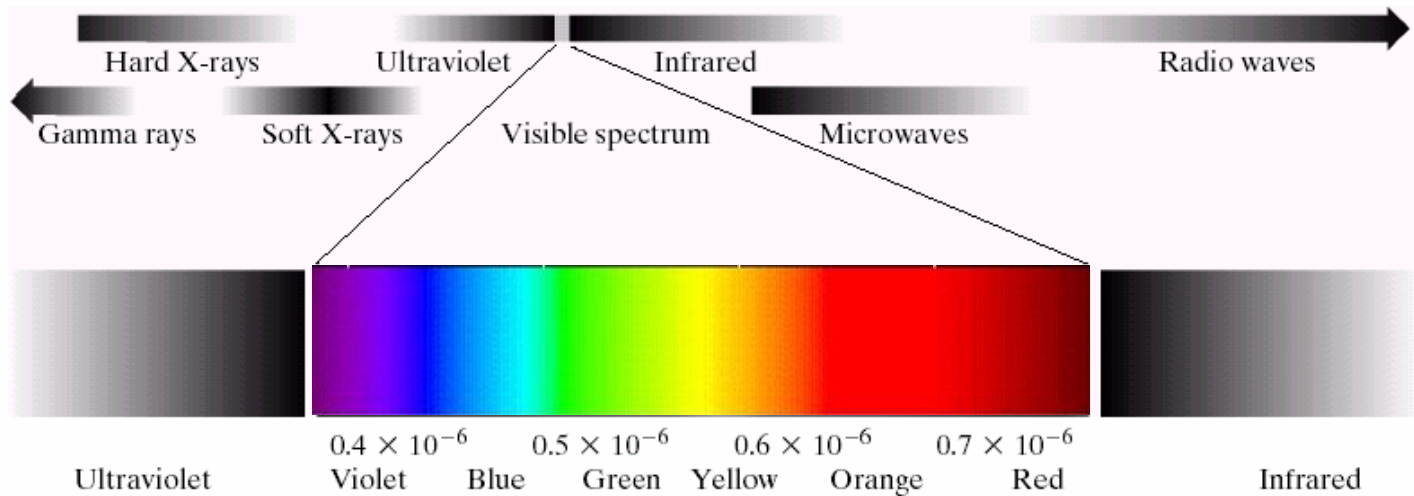
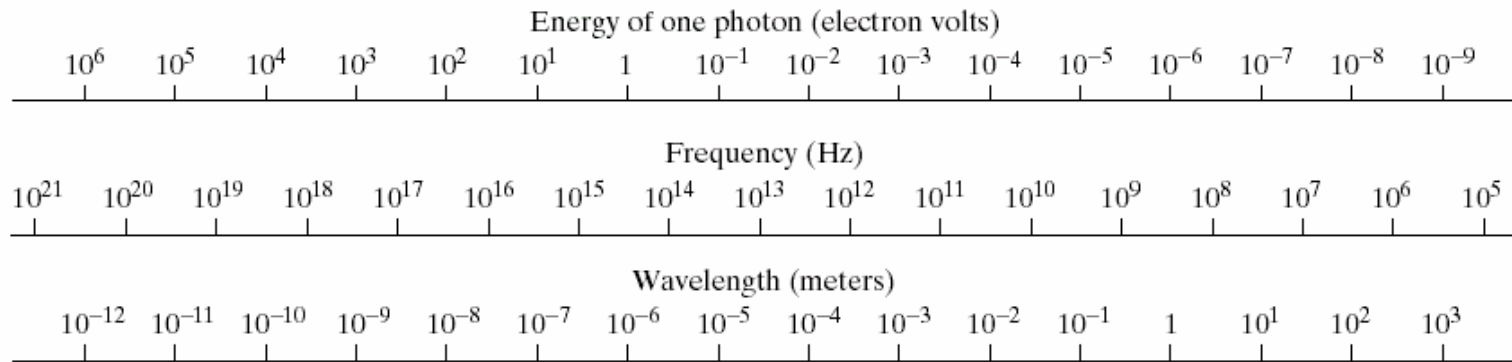
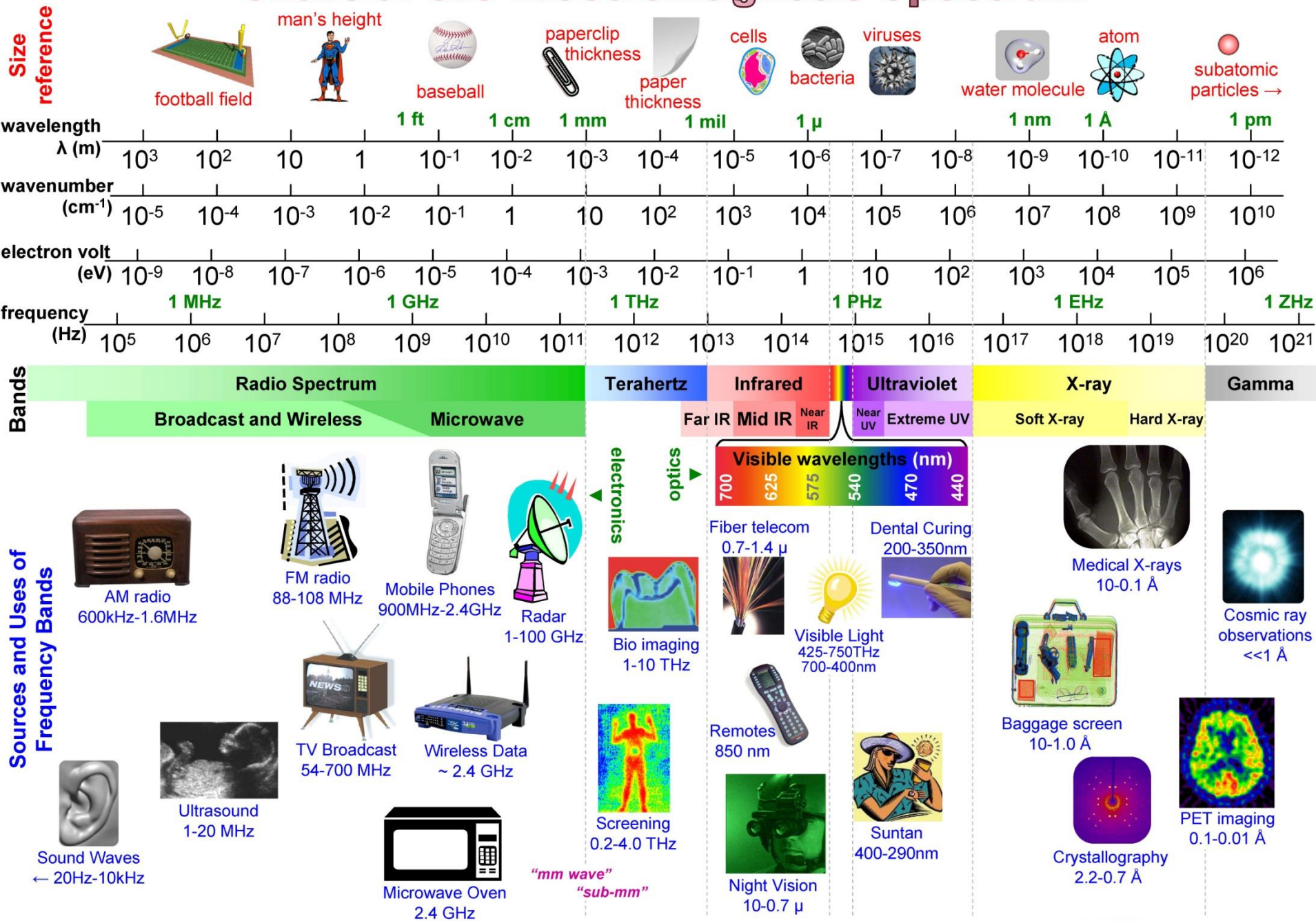


Chart of the Electromagnetic Spectrum



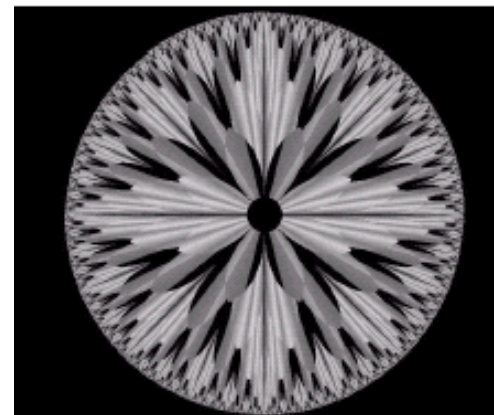
$$\lambda = 3 \times 10^8 / \text{freq} = 1 / (\text{wn} * 100) = 1.24 \times 10^{-6} / \text{eV}$$

Examples: Imaging in EM bands

Spectral Band	Example
Gamma-Rays	Nuclear Medicine (Radioactive isotope injected in the patient)
X-Rays	Medical Diagnostic
Ultraviolet	Fluorescence microscopy
Visible & Infrared	Remote sensing, industrial inspection, ...
Microwave	Radar
Radio	Medicine – MRI

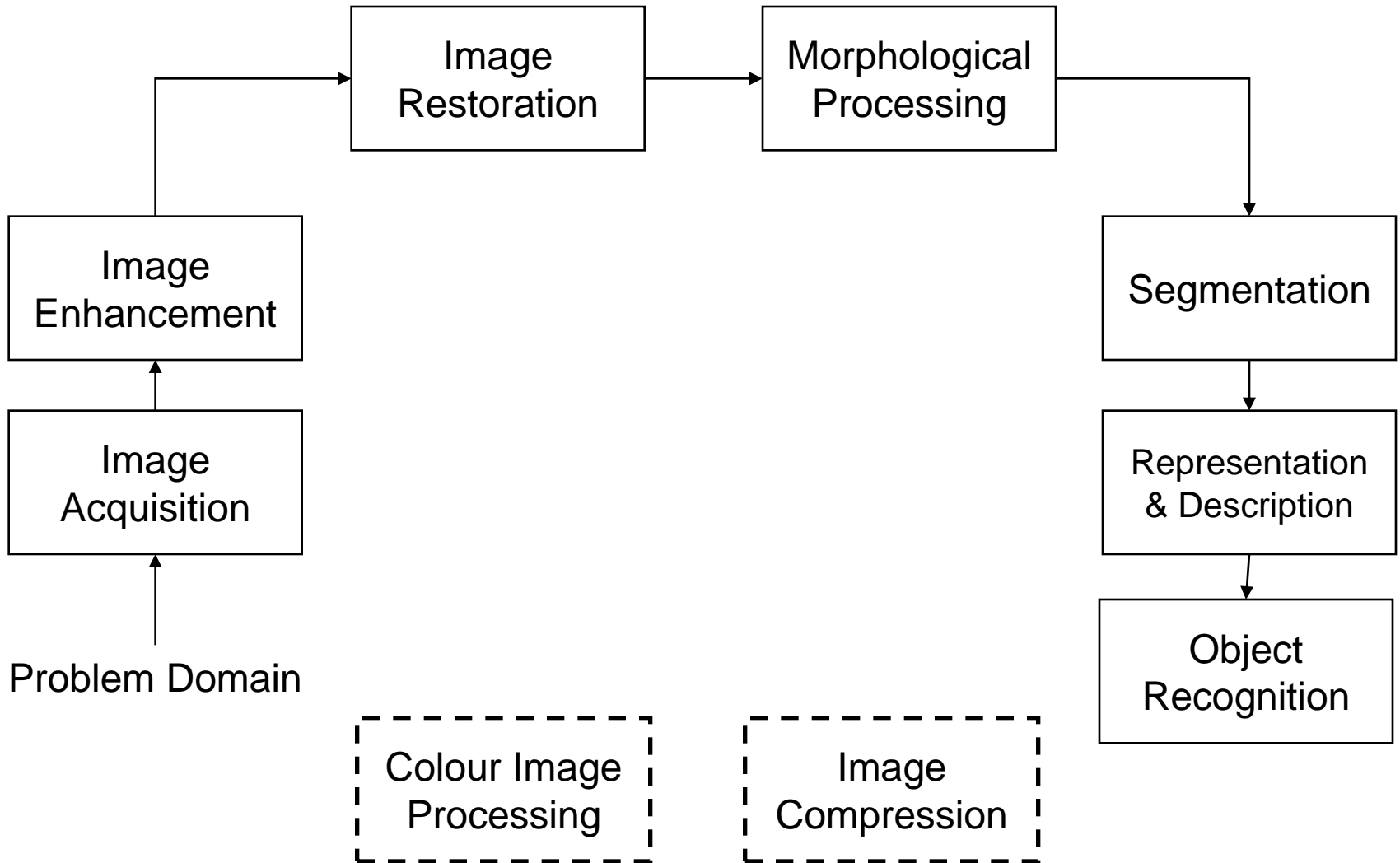
Examples: Imaging other Modalities

- Sound
 - Geological Applications – Oil and Gas Exploration
 - Medicine – Ultrasound Imaging
- Synthetic Images
 - Computer generated

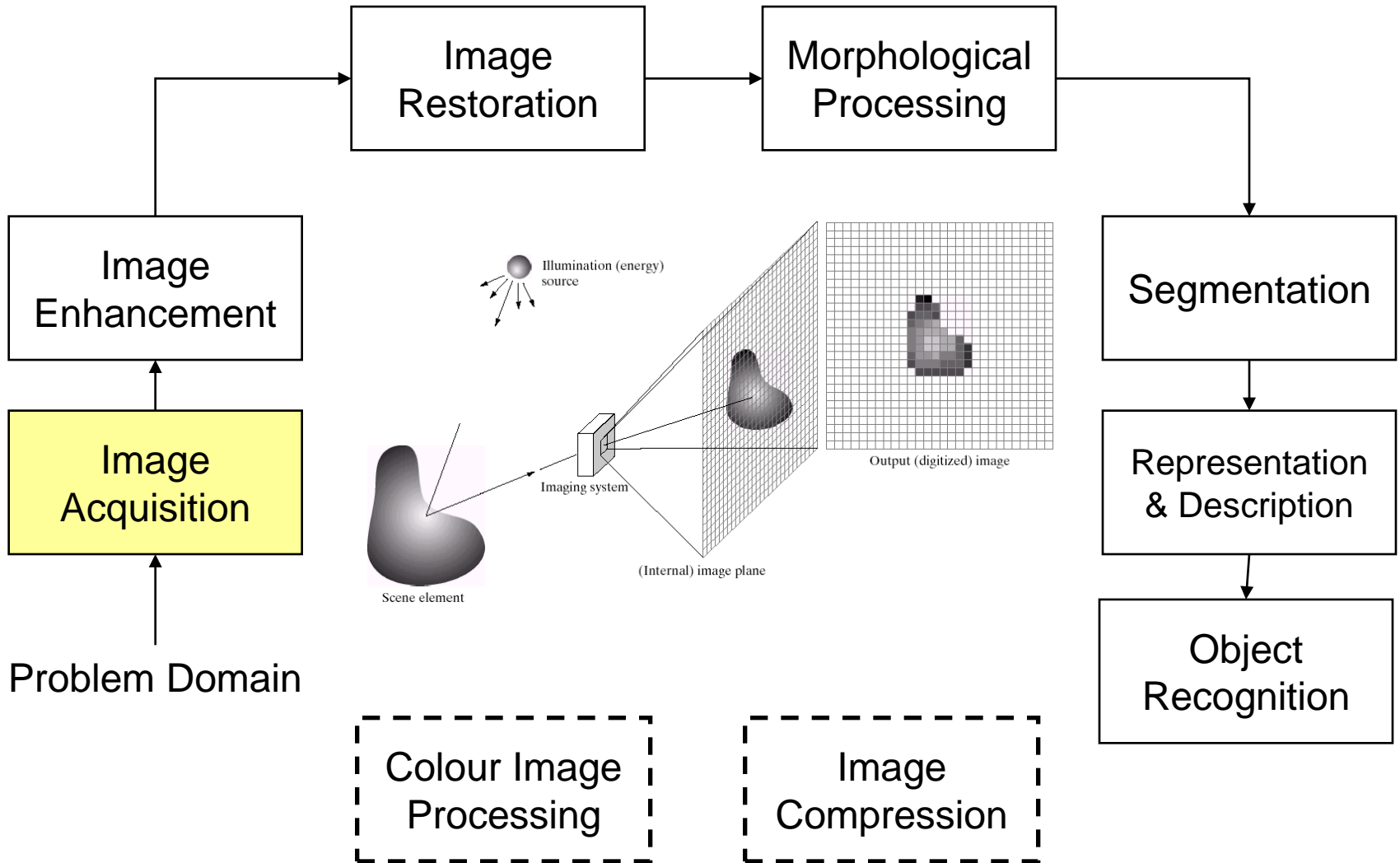


A synthetic image

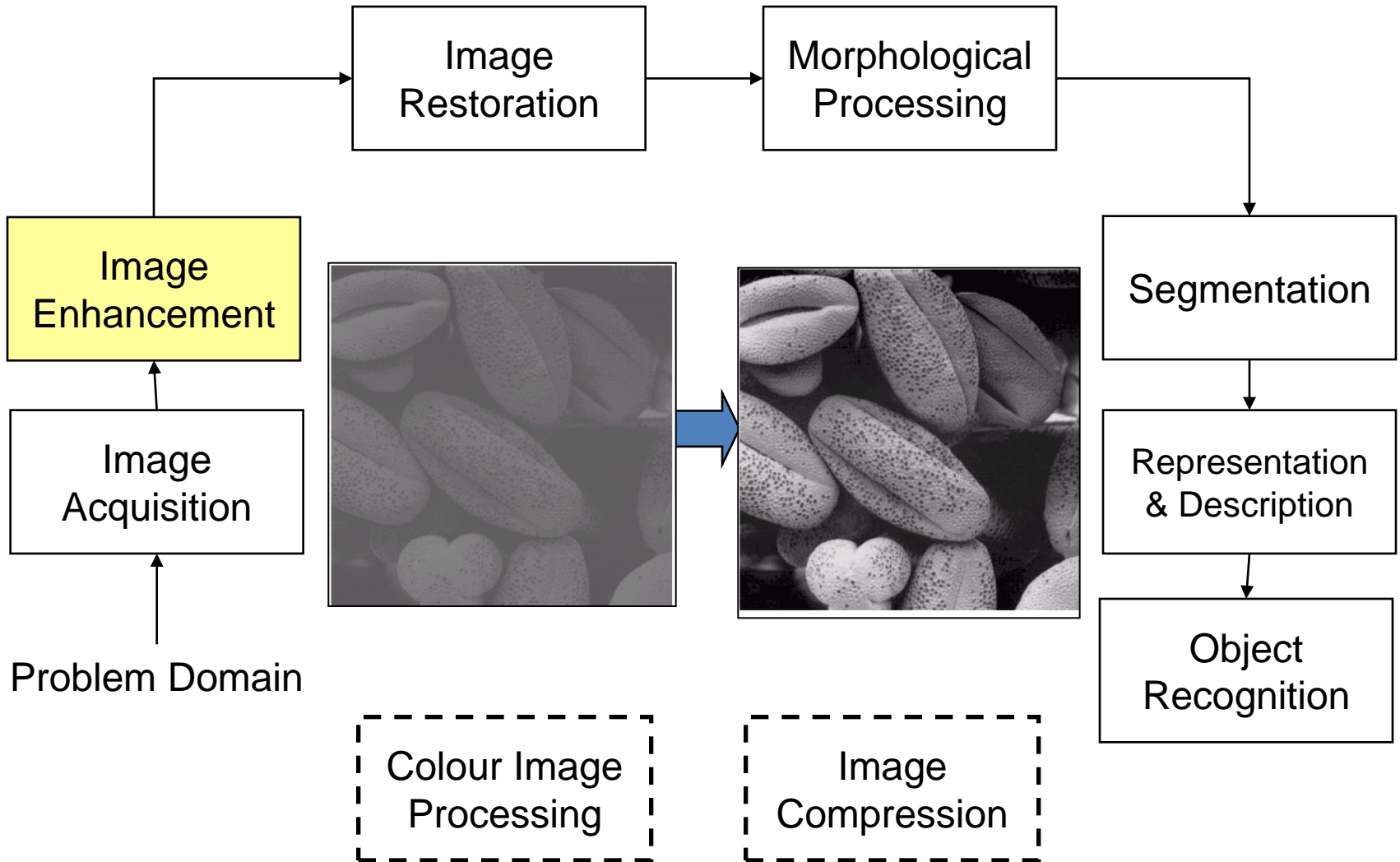
Key Stages in DIP



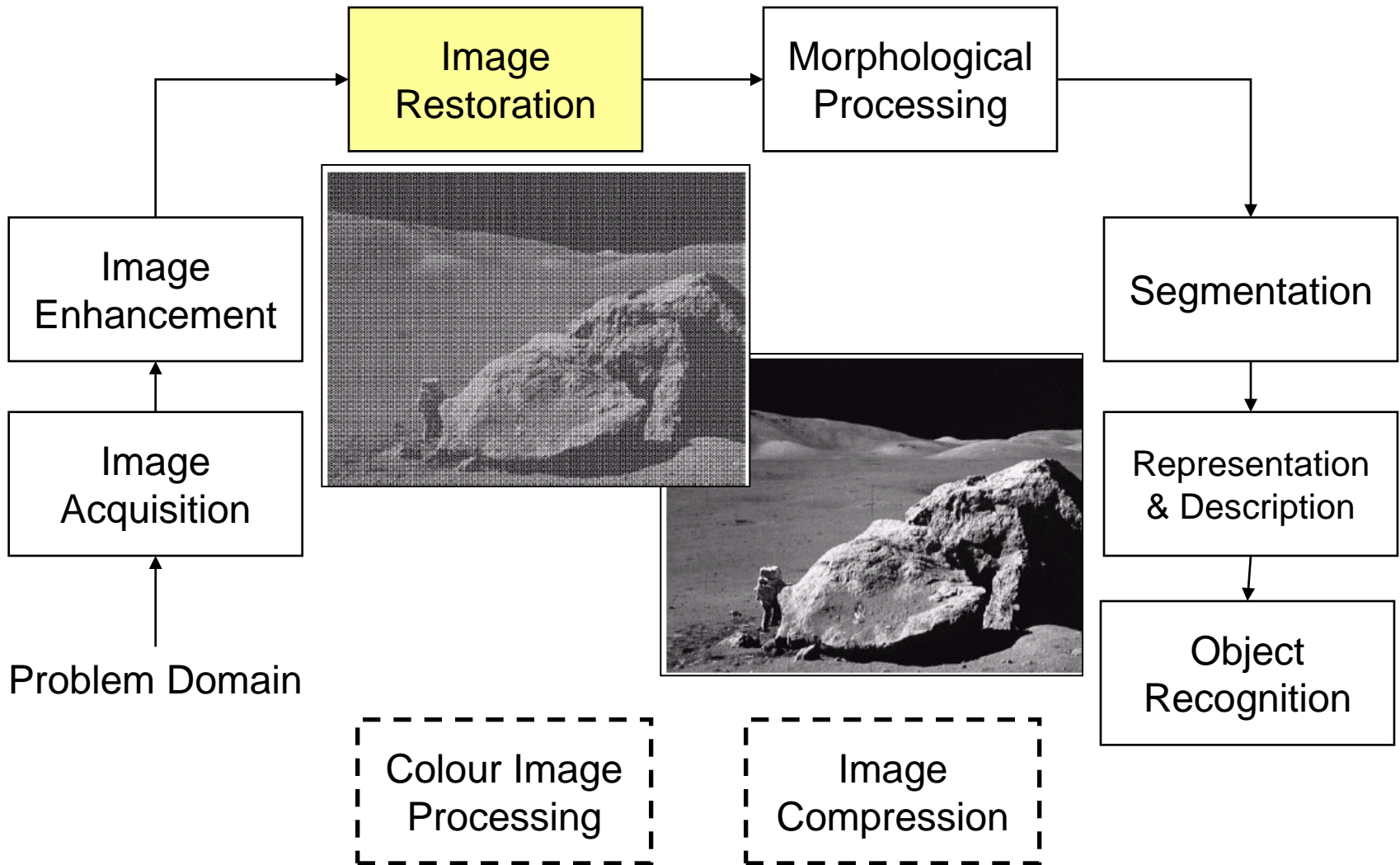
Key Stages in DIP



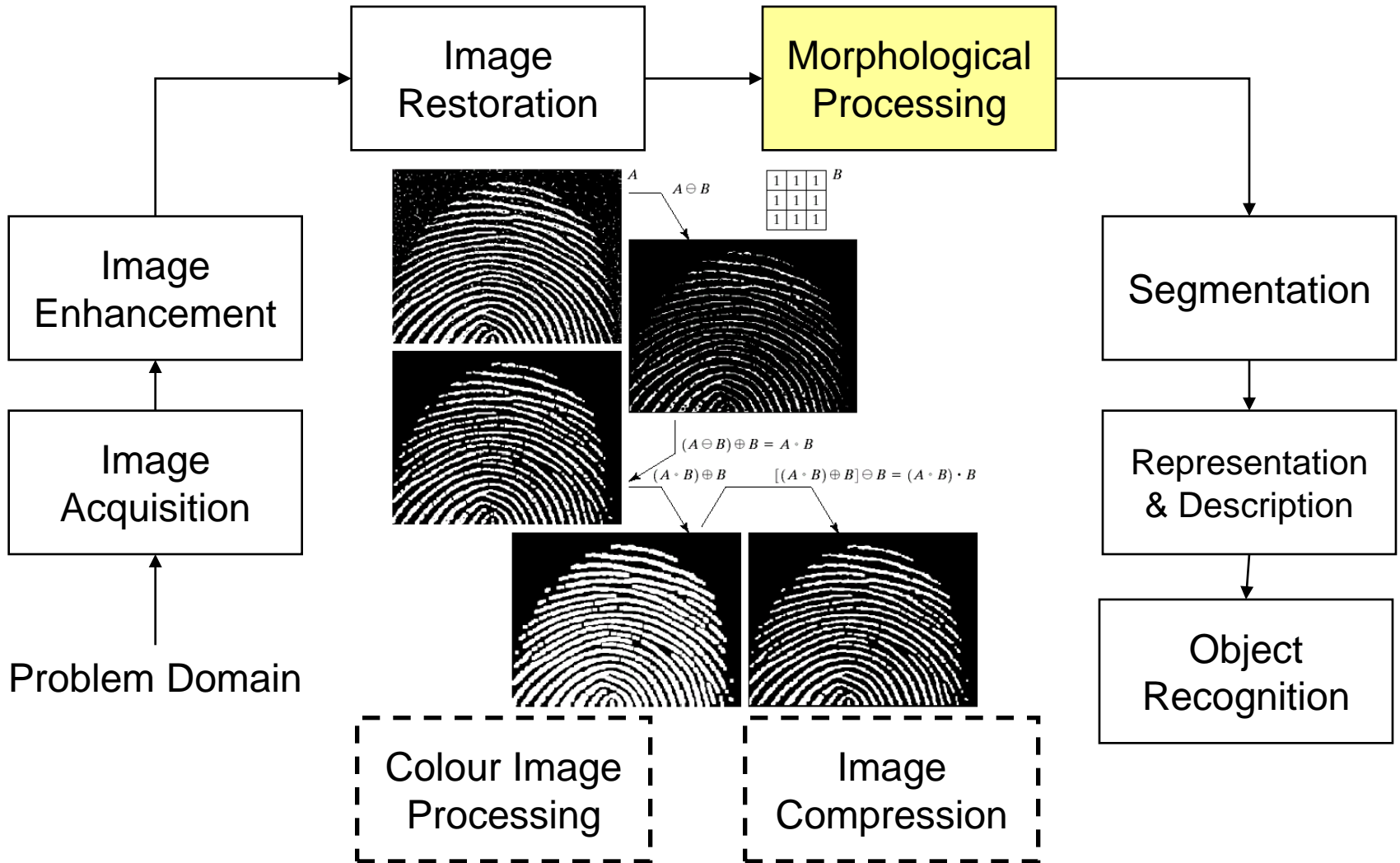
Key Stages in DIP



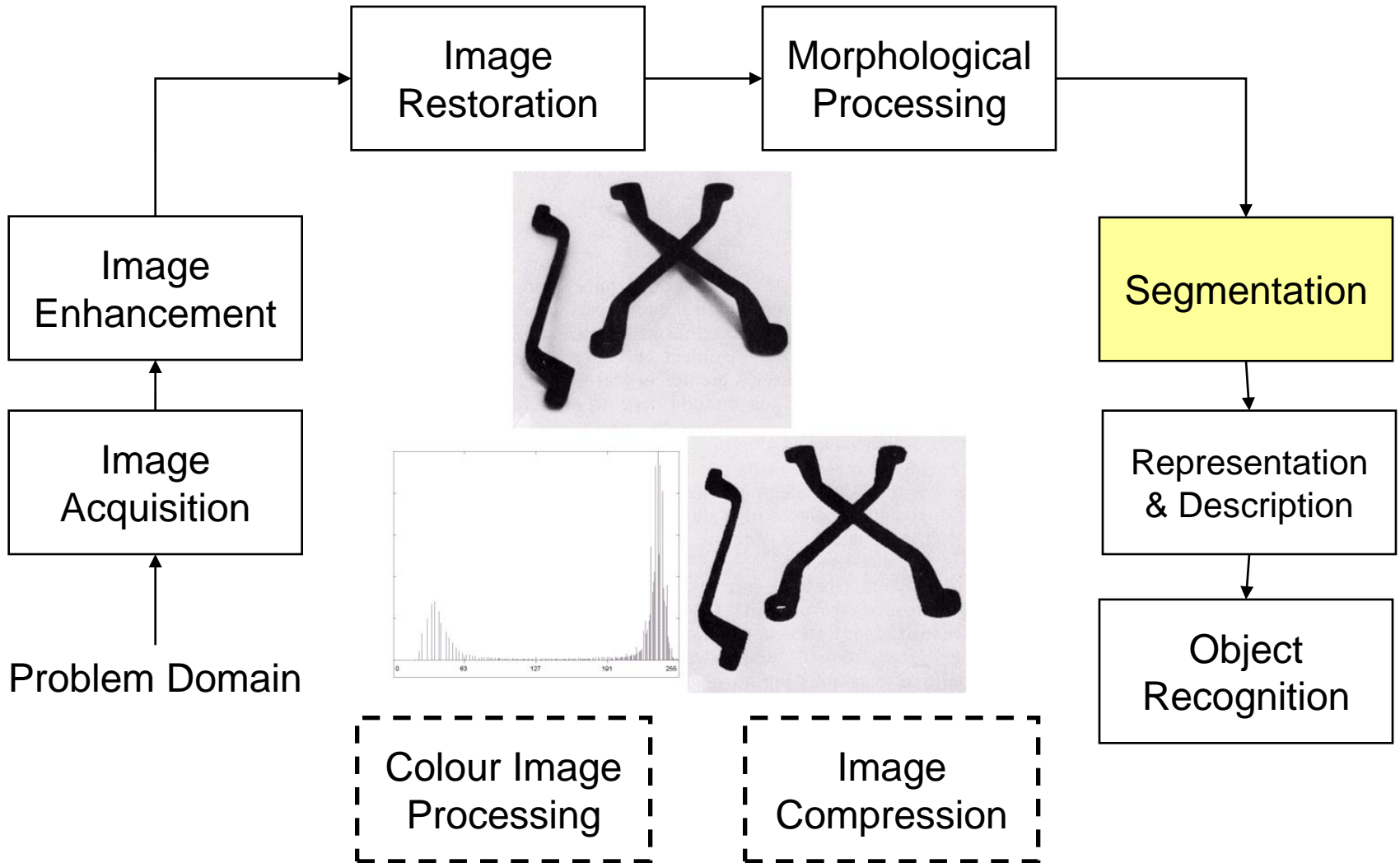
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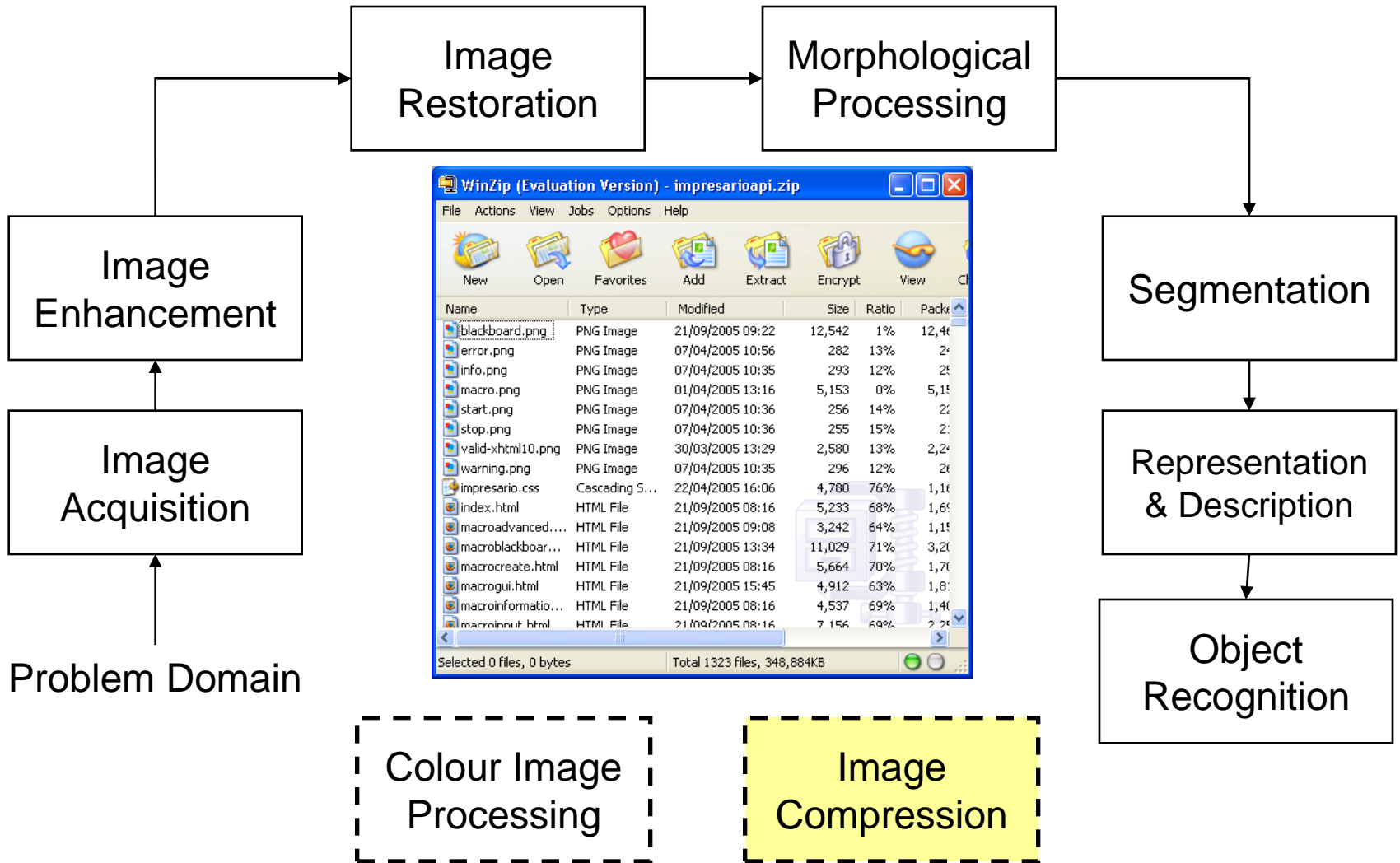
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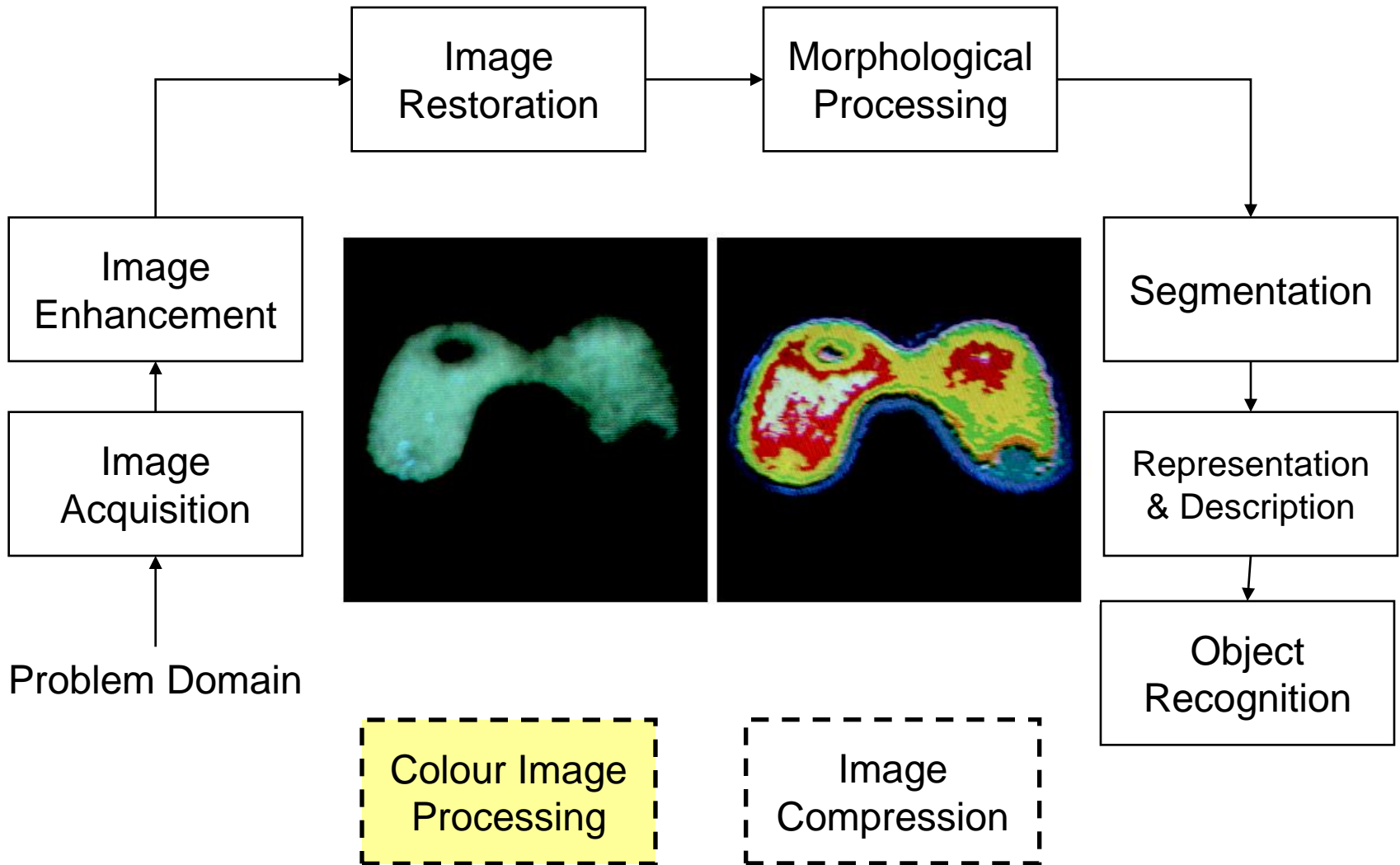
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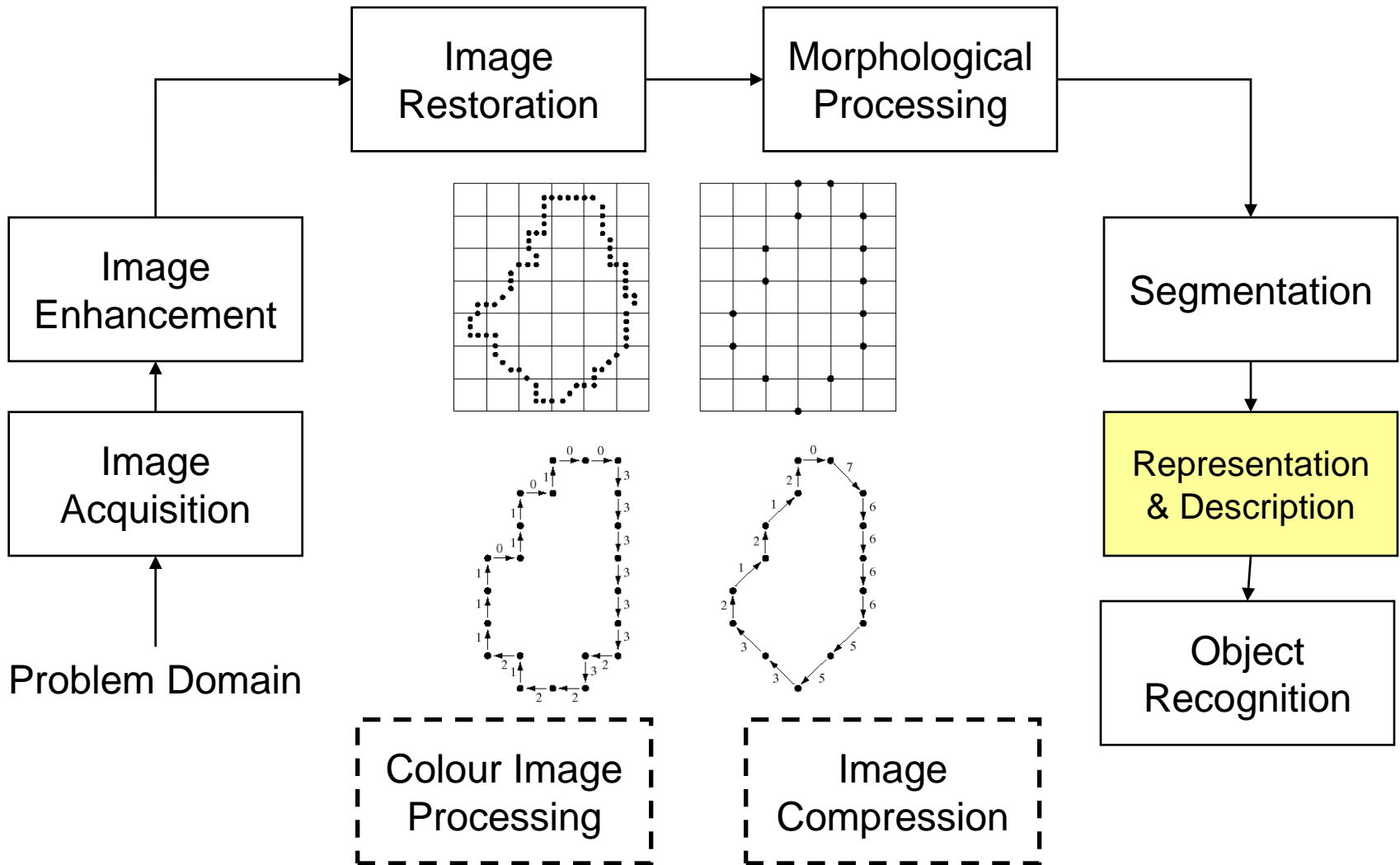
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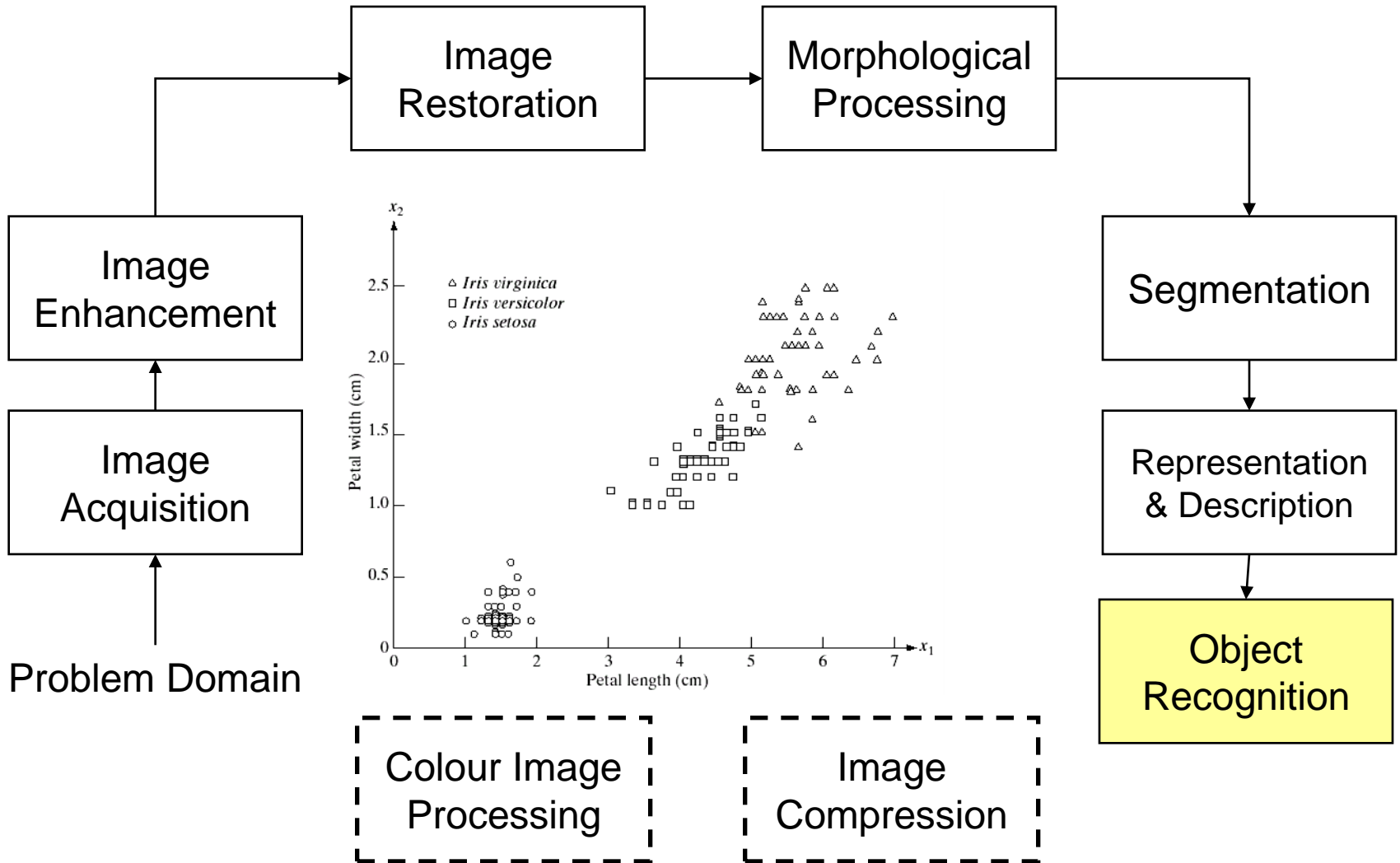
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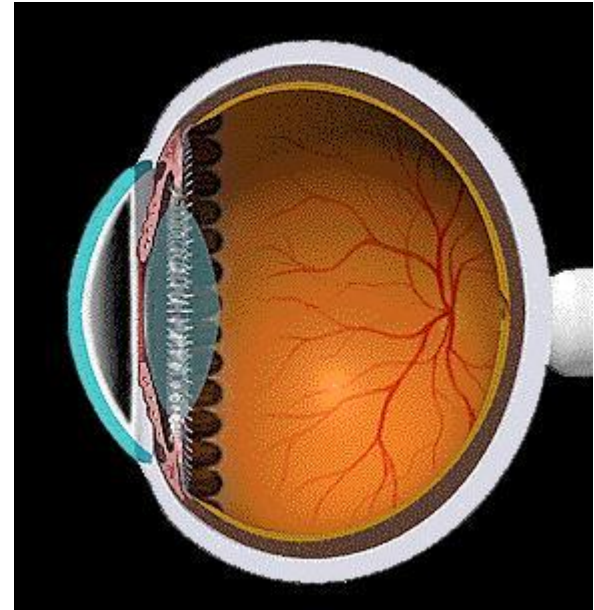
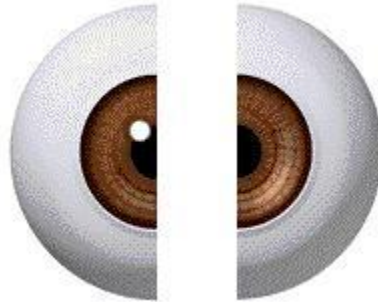


Human and Image Perception

- We can't think of image processing without human vision system.
- We observe and evaluate the images that we process with our visual system.
- Without taking this elementary fact into consideration, we may be much misled in the interpretation of images.

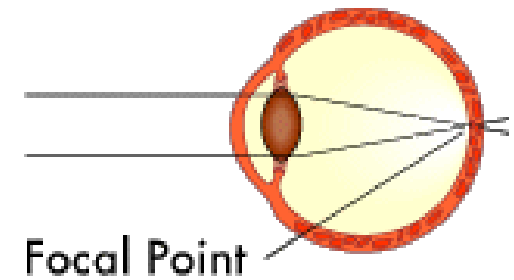
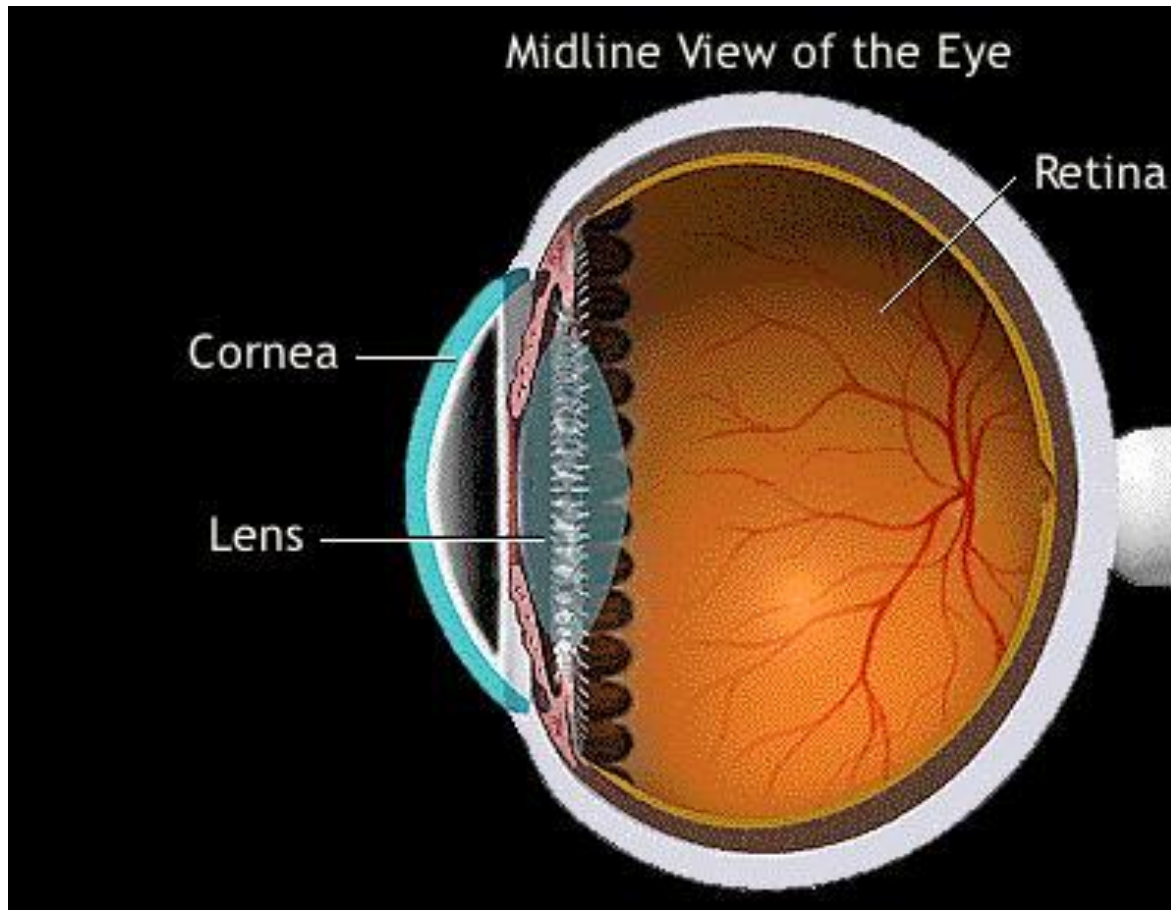
Human and Image Perception

Eye Basic Anatomy: Eye can be “extracted” and “disassembled” (for study)



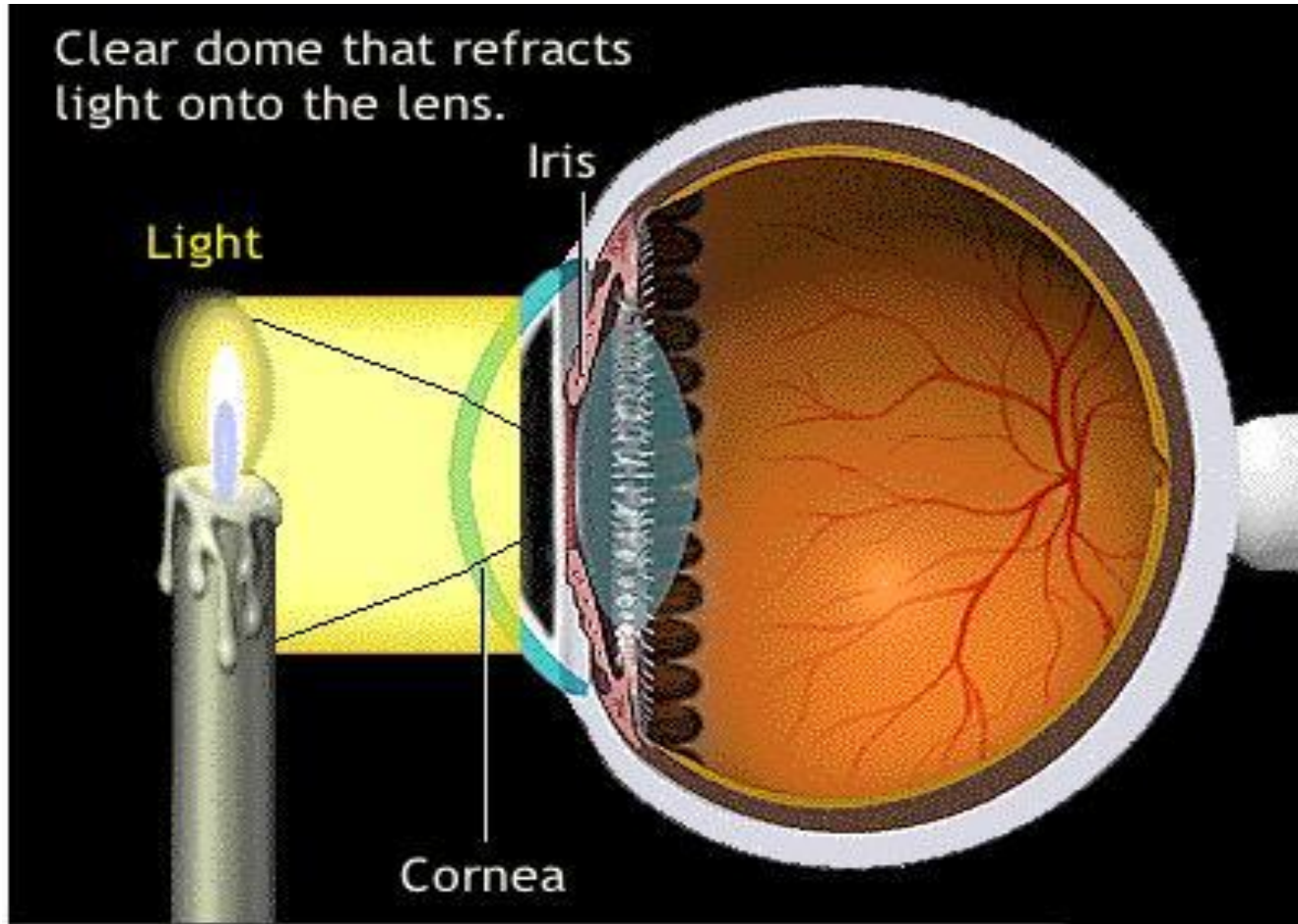
Human and Image Perception

Simplified Midline View of the Eye (To explain how eye focuses)

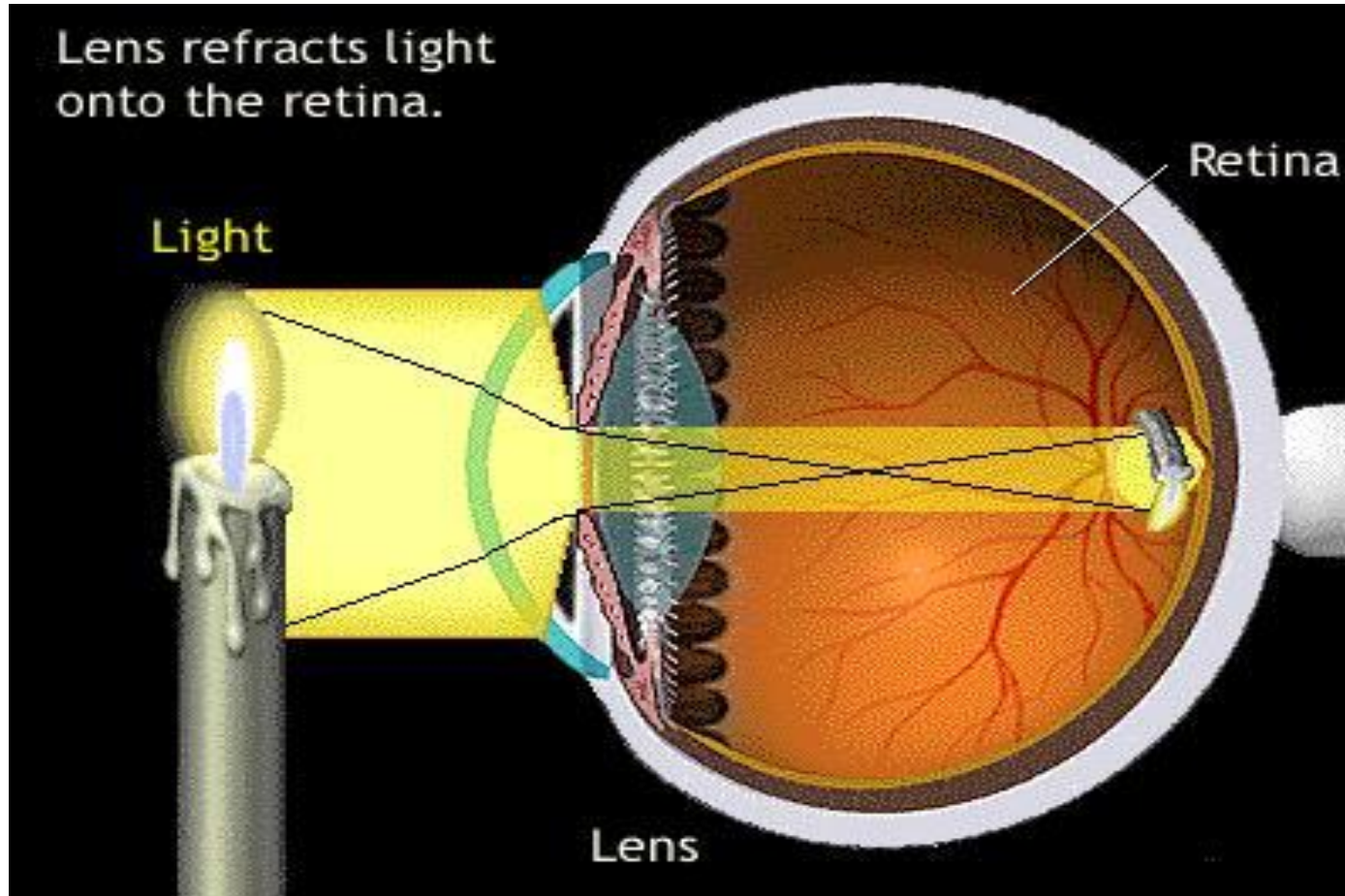


Human and Image Perception

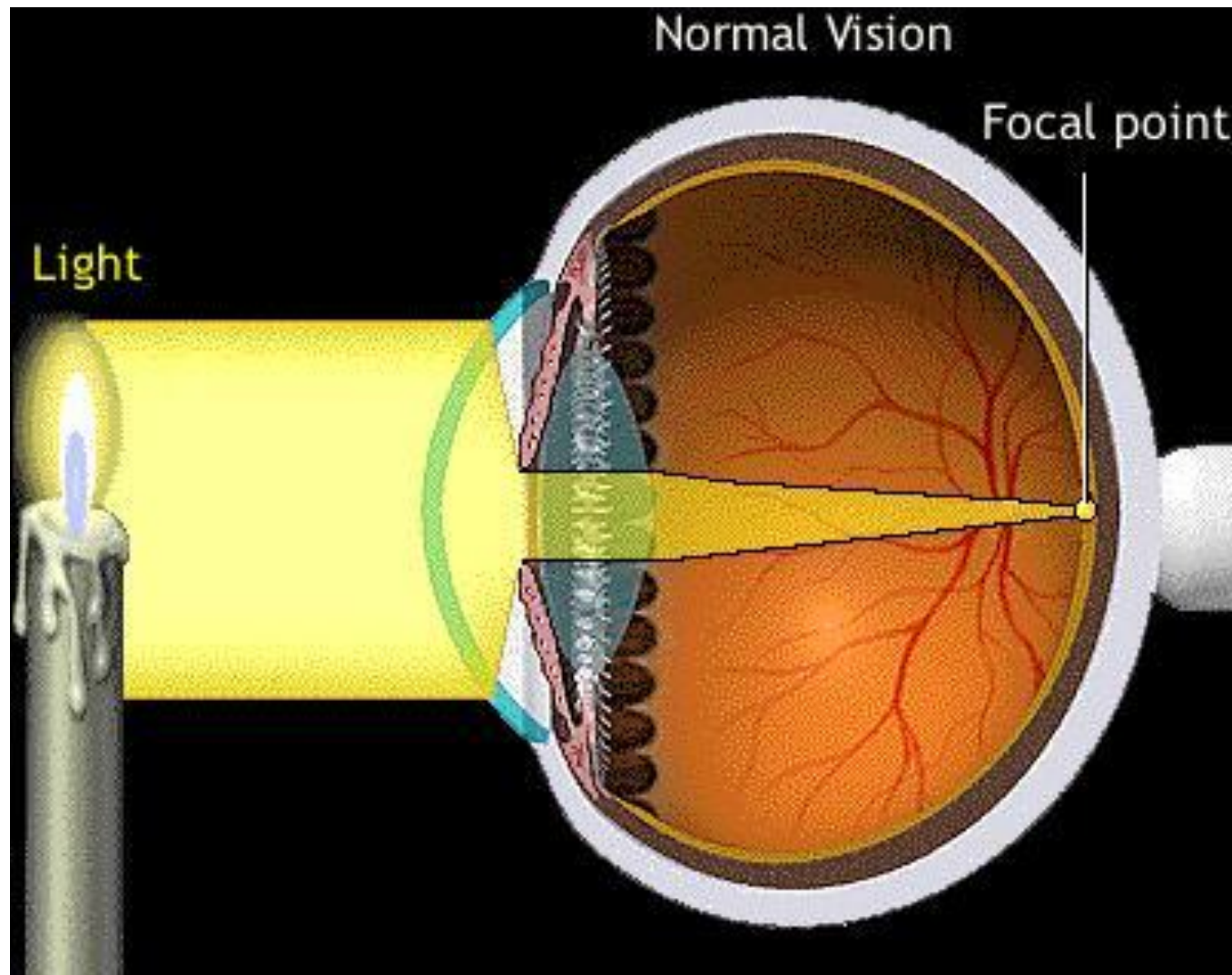
How eye focuses



Human and Image Perception



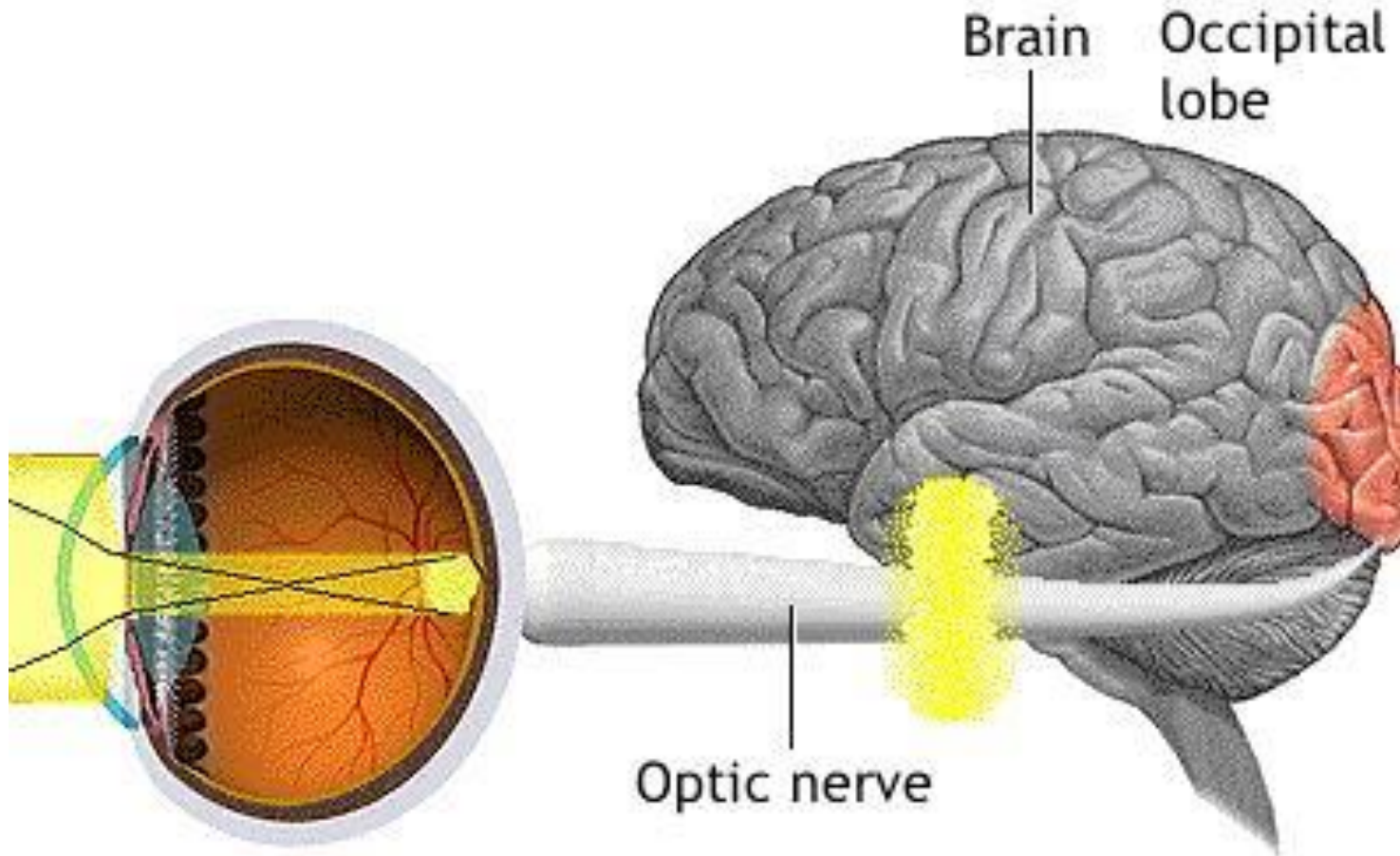
How eye focuses: Normal Vision-Focusing on the Retina



From Eye to the Brain

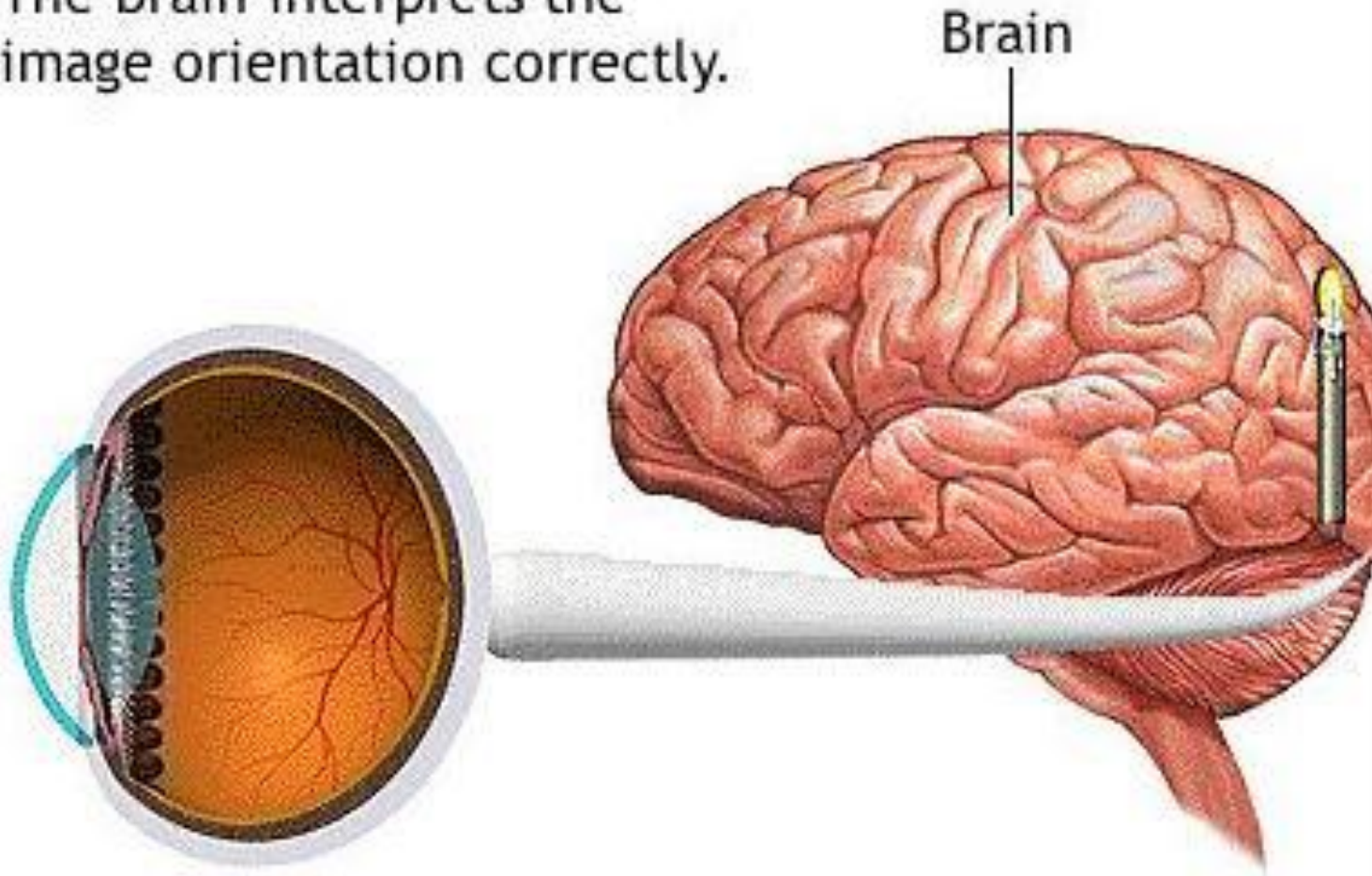
How does our brain receive this information?

Once the image is clearly focused on the sensitive part of the retina, energy in the light that makes up that image creates an electrical signal. Nerve impulses can then carry information about that image to the brain through the optic nerve.



What we really “see” (after a number of days after the birth)

The brain interprets the image orientation correctly.



Human Eye

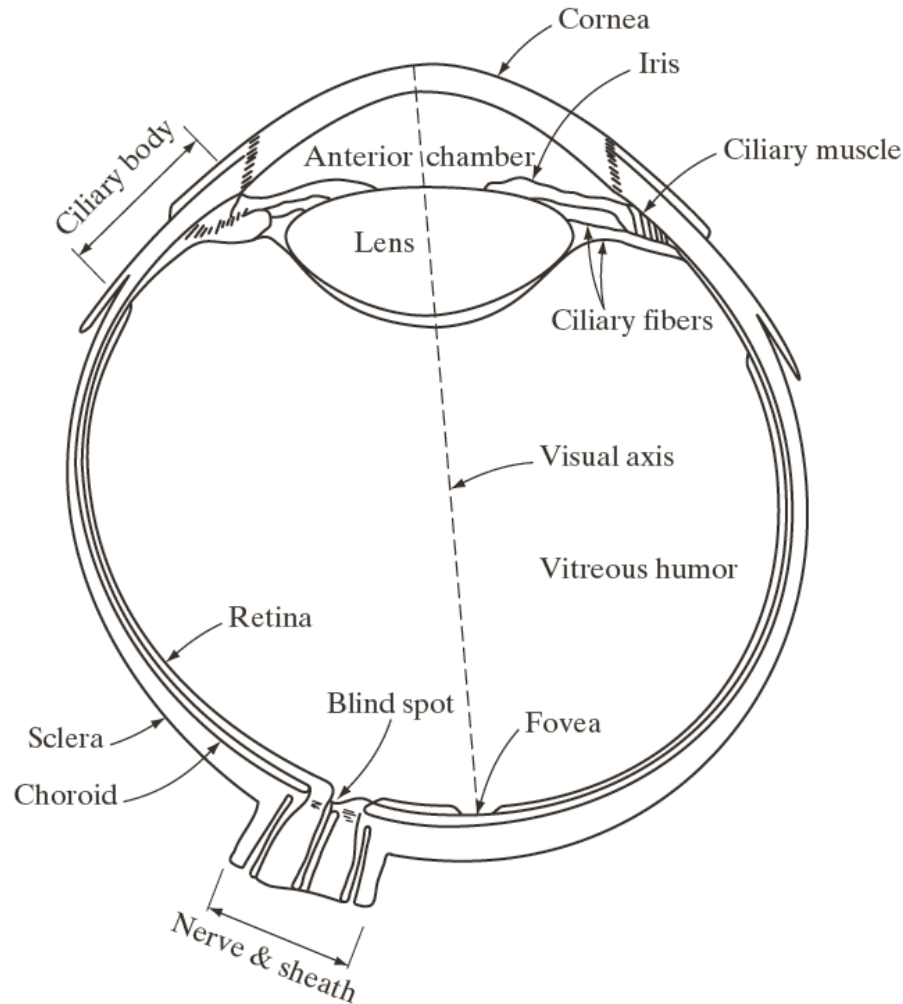
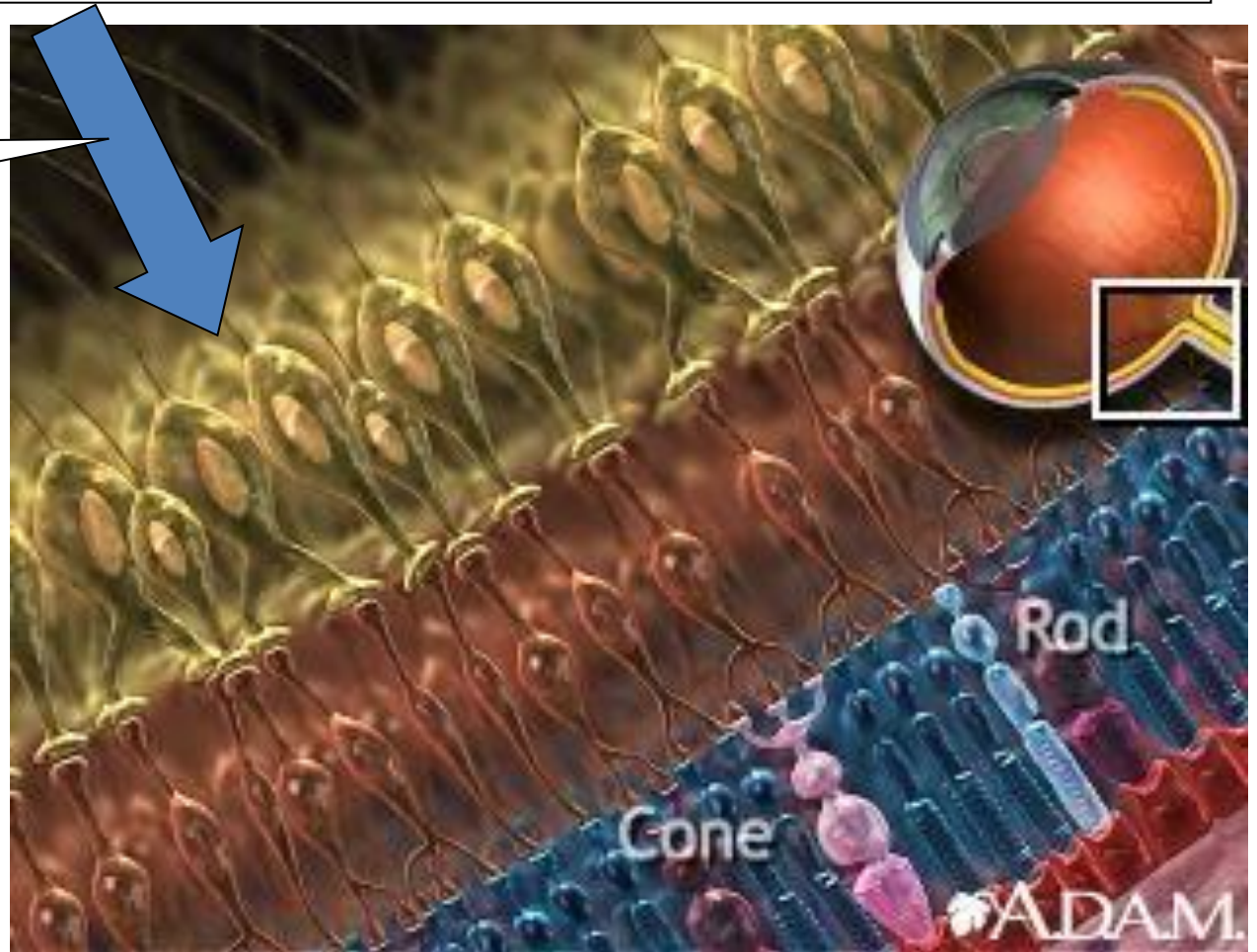


FIGURE 2.1
Simplified
diagram of a cross
section of the
human eye.

Retina: Contains specialized cells: (photo) receptors *{converts light into electrical signals}*
Rods – Black & White (Gray) images in low light (night)
Cones – Color Vision in bright light (day)

Direction of
Light

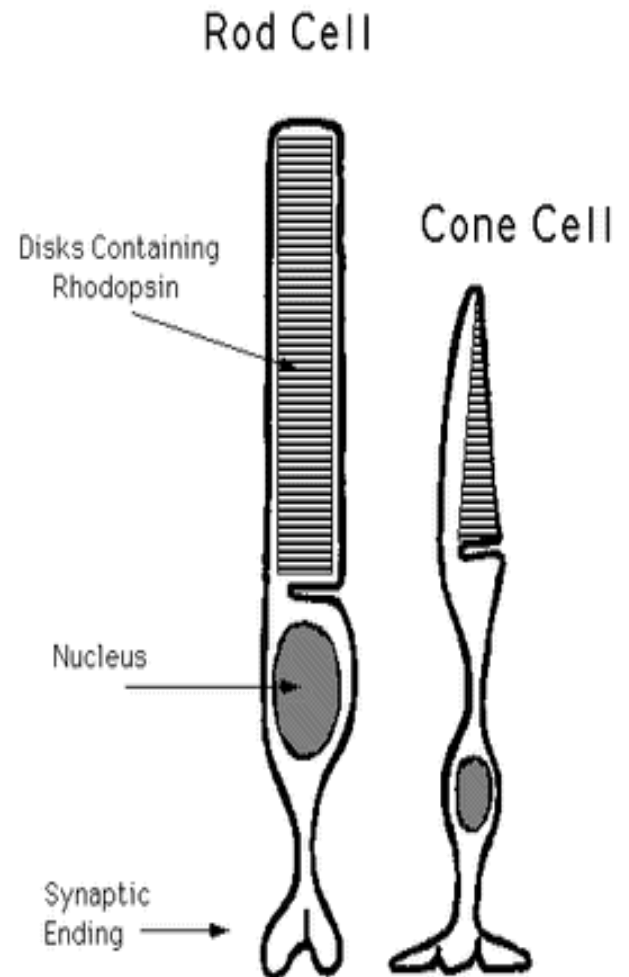


What happens when light reaches the retina?

It is packed with photosensitive cells called rods and cones.

- Cones are the cells responsible for daylight vision there are three different kinds – each responding to a different wavelength of light
- One responds to red light, one to green light and one to blue light.
- It is these cones which allow us to see in colour and detail
- Rods, on the other hand, are responsible for night vision.
- They are sensitive to light but not to wavelength information (colour)

In darkness, the cones do not function at all– so we need rods in order to see things even if it is only in shades of grey



Rods and Cones

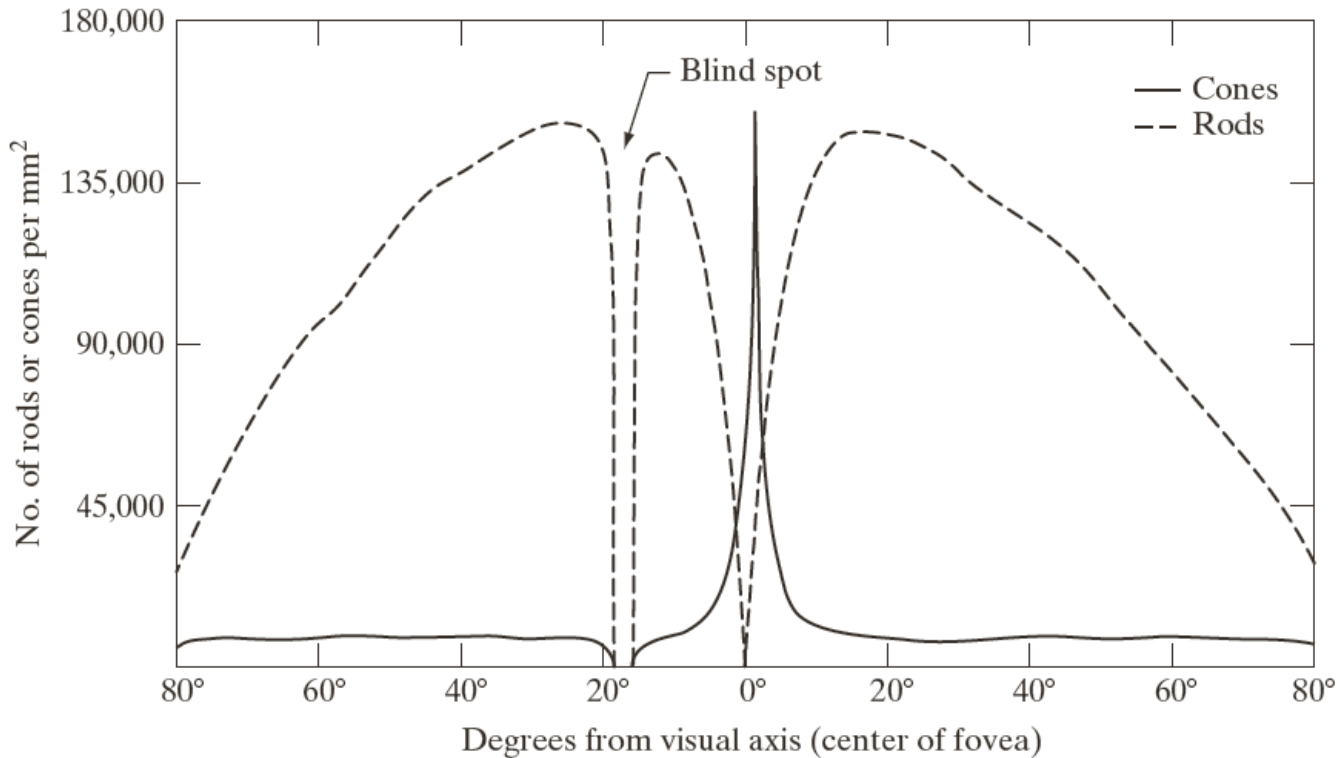


FIGURE 2.2
Distribution of rods and cones in the retina.

BRIGHTNESS ADAPTATION AND DISCRIMINATION

- The human visual system can perceive approximately 10^{10} different light intensity levels
- However, at any one time we can only discriminate between a much smaller number – *brightness adaptation*

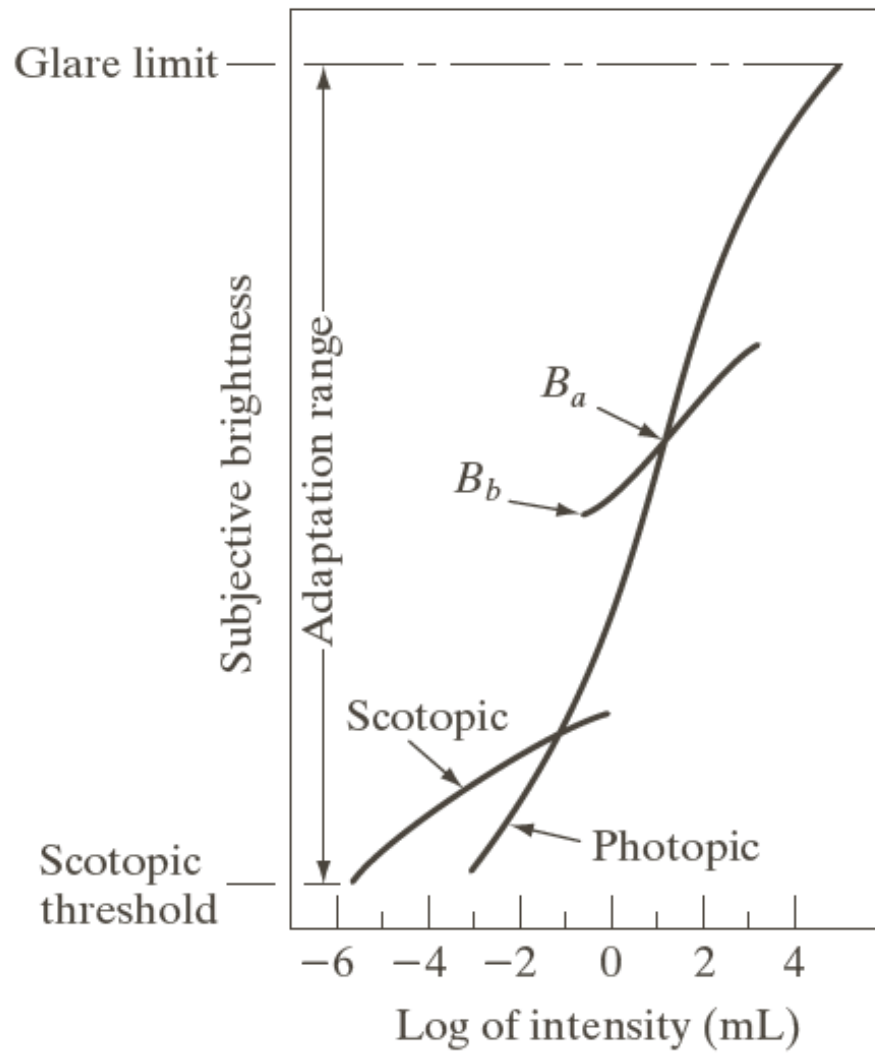
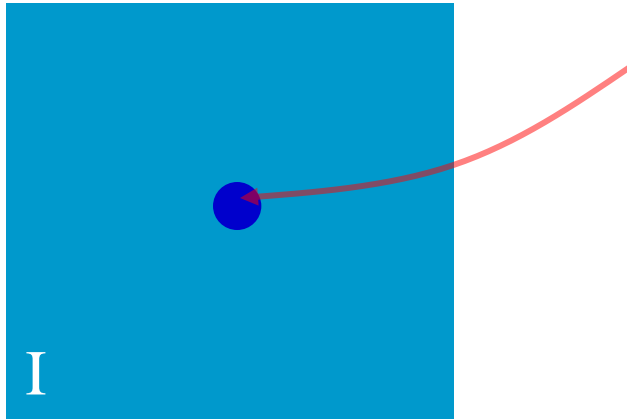


FIGURE 2.4
Range of subjective
brightness
sensations
showing a
particular
adaptation level.

CONTRAST SENSITIVITY



Weber's ratio: $\Delta I_c / I$

Good brightness discrimination

$\Rightarrow \Delta I_c / I$ is small.

Bad brightness discrimination

$\Rightarrow \Delta I_c / I$ is large.

- The ability of the eye to discrimination b/w changes in brightness at any specific adaptation level is of considerable interest.
- I is uniformly illuminated on a flat area large enough to occupy the entire field of view.
- ΔI_c is the change in the object brightness required to just distinguish the object from the background

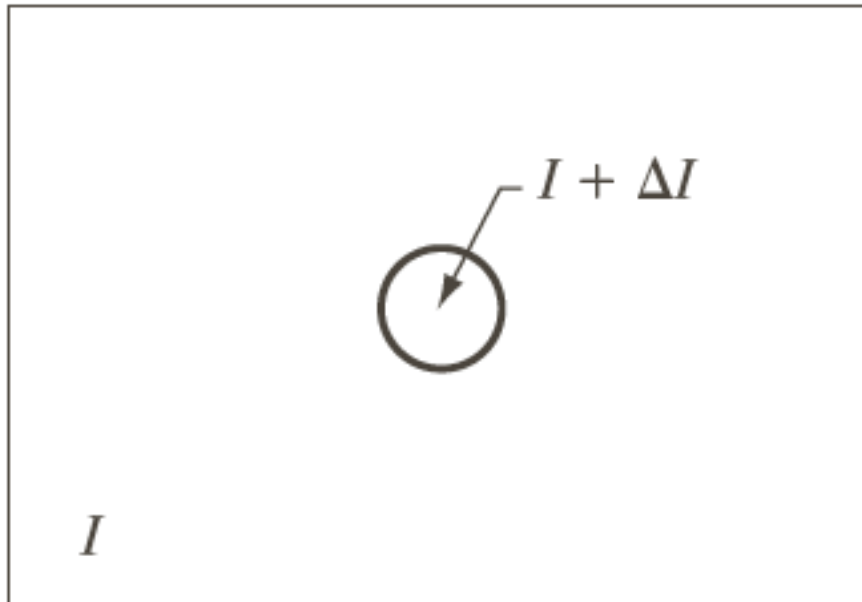


FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

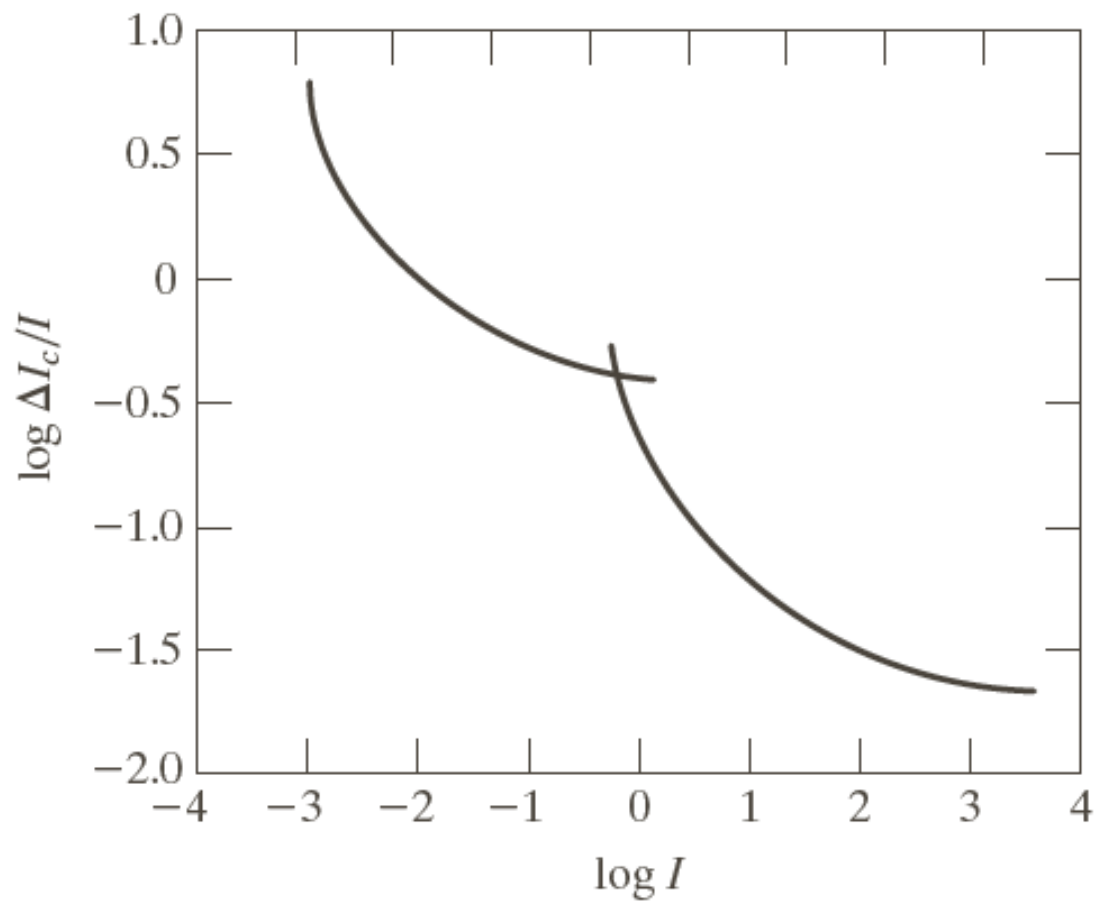
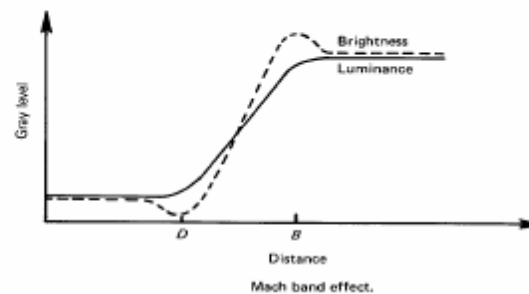
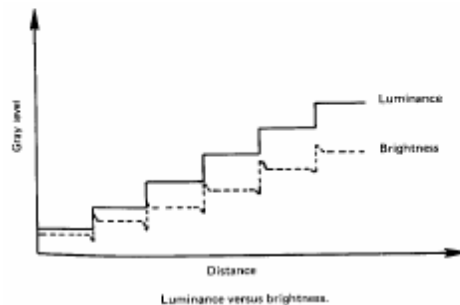
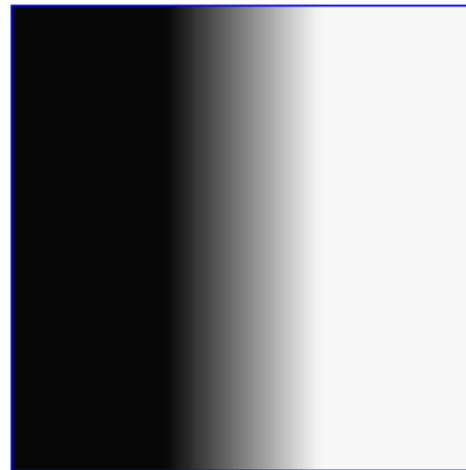
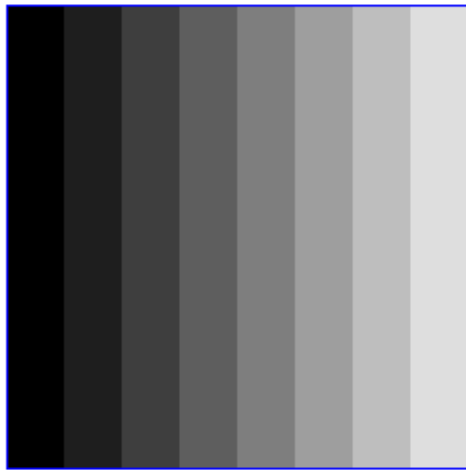


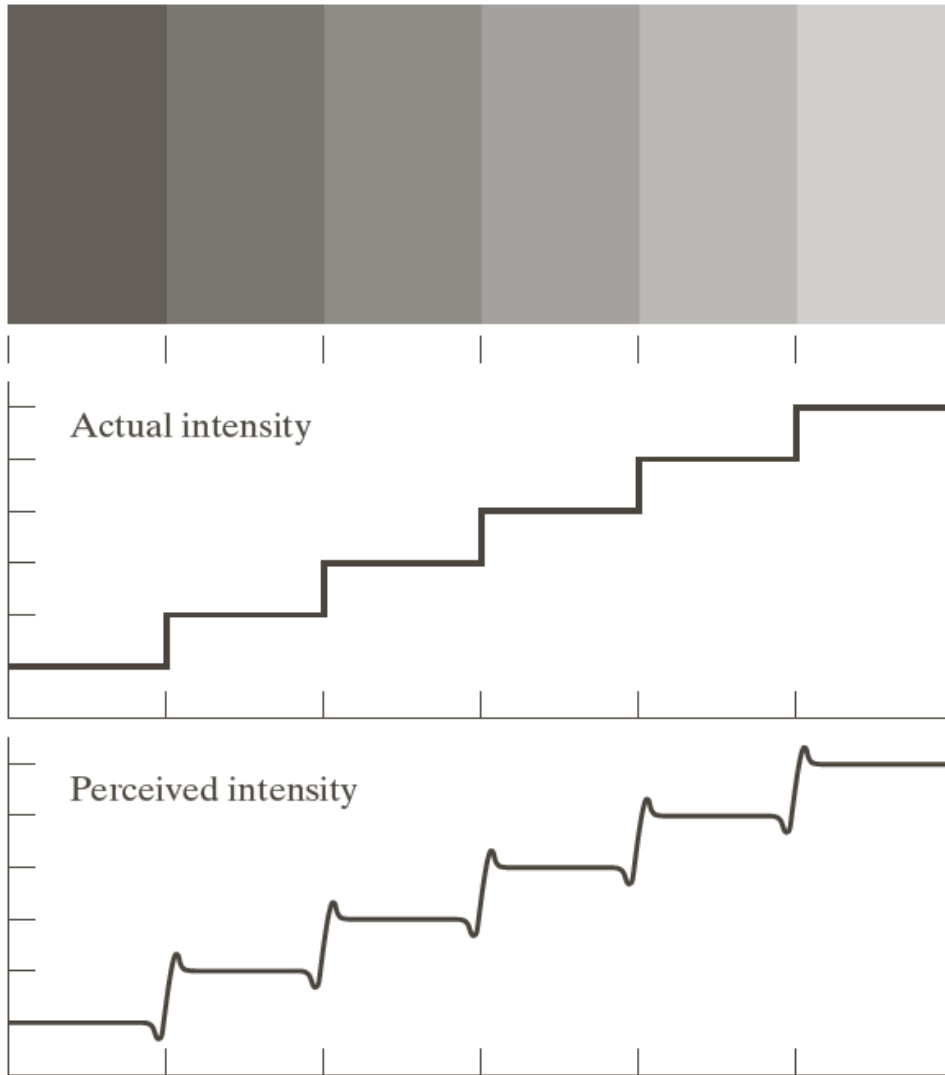
FIGURE 2.6
Typical Weber
ratio as a function
of intensity.

MACH BANDS

- Perceived brightness depends on **surroundings** as well as luminance



The intensity of the stripes is constant but we actually perceive a brightness pattern which is strongly scalloped near the boundaries.



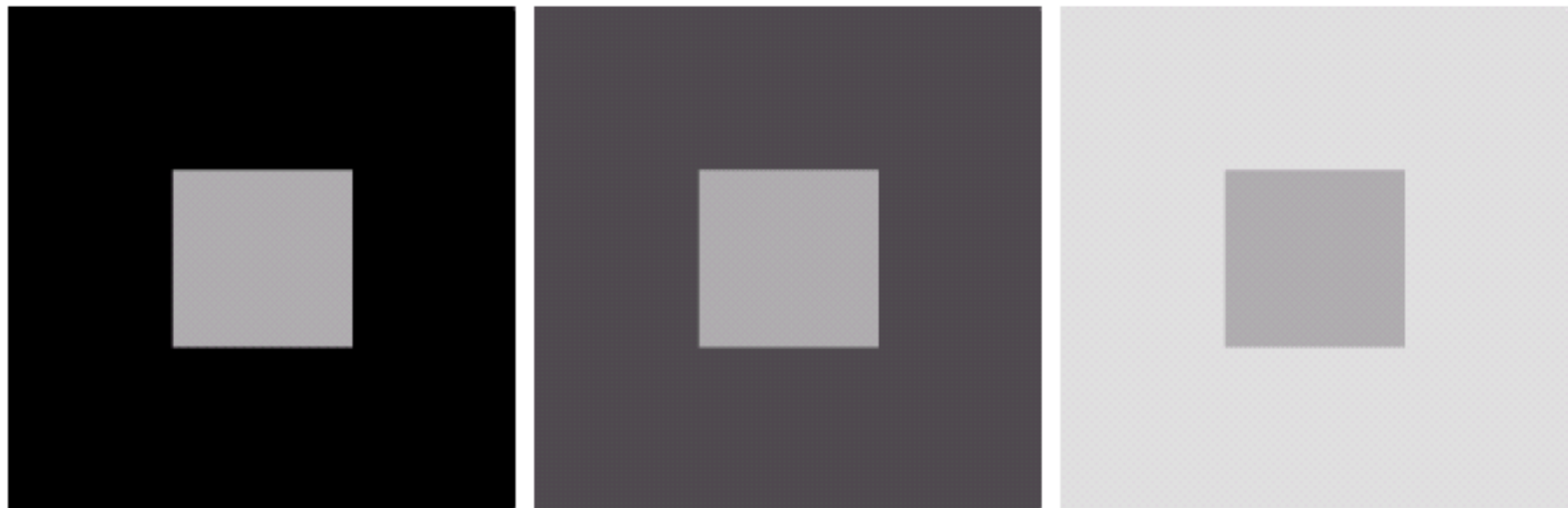
a
b
c

FIGURE 2.7

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

Simultaneous Contrast

- Perceived brightness depends on **surroundings** as well as luminance

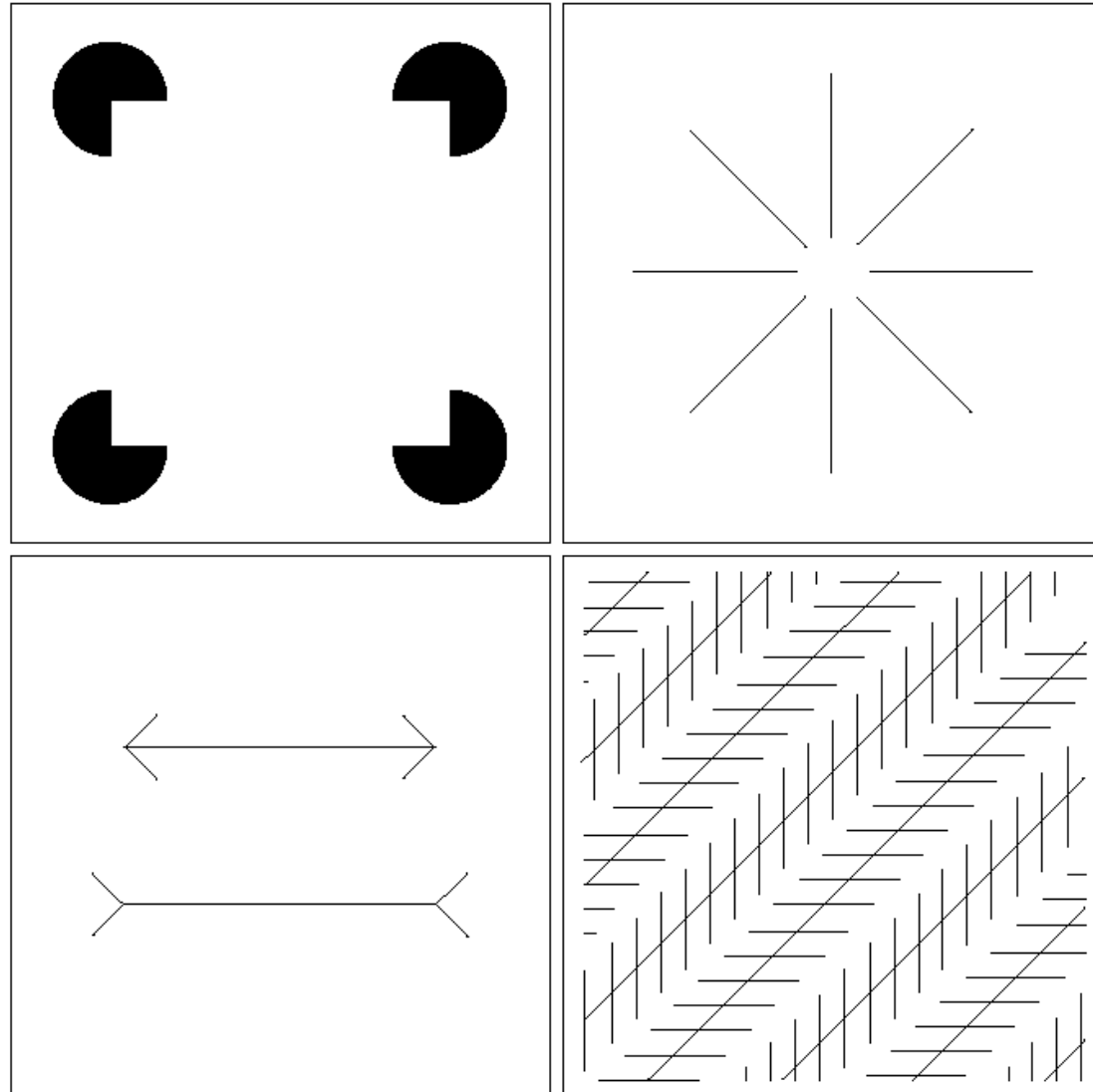


a b c

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

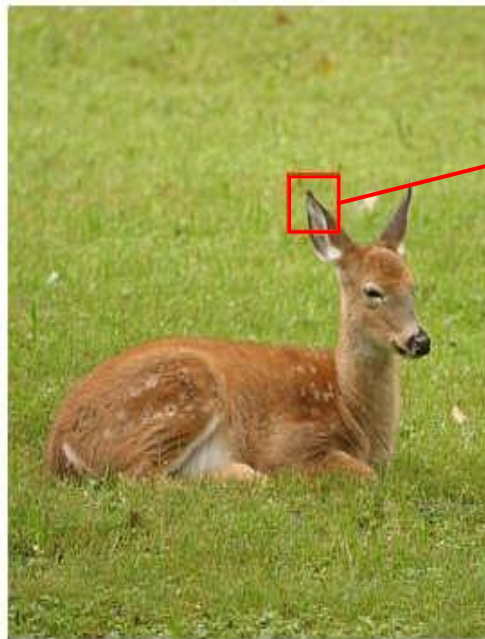
FIGURE 2.9 Some well-known optical illusions.



Digital Image

a grid of squares,
each of which
contains a single
color

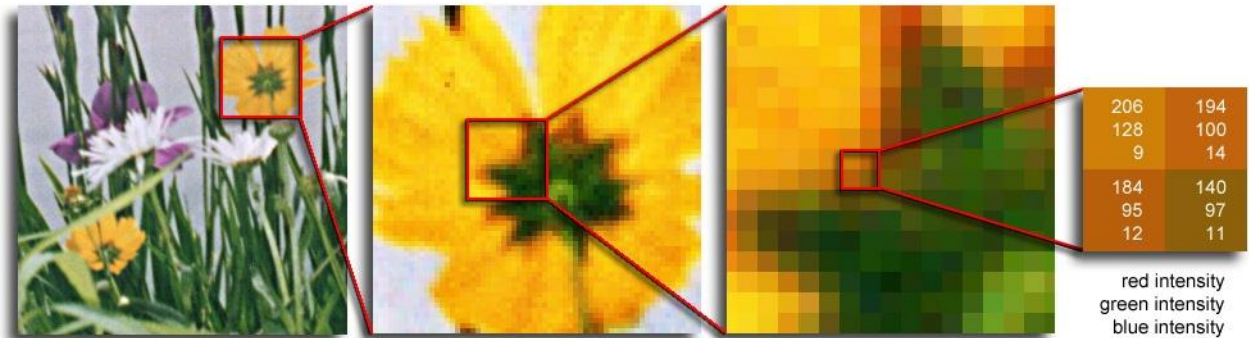
each square is
called a pixel (for
picture element)



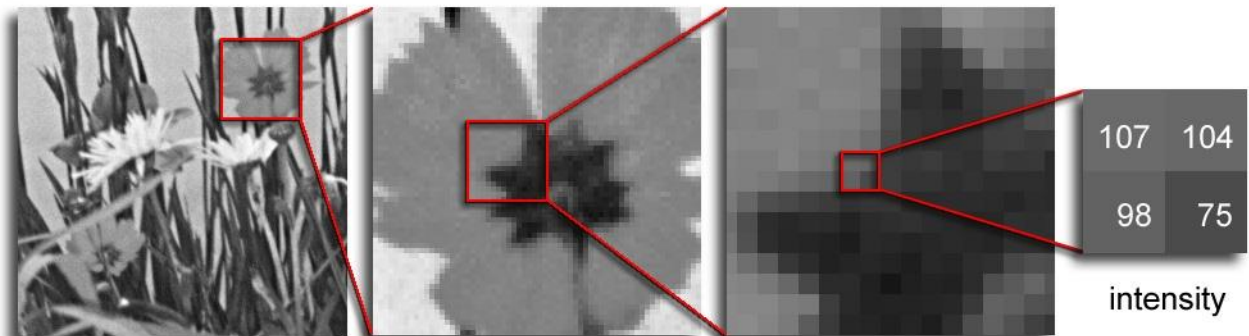
Digital Image

Color images have 3 values per pixel; monochrome images have 1 value per pixel.

a grid of squares, each of which contains a single color



each square is called a pixel (for *picture element*)

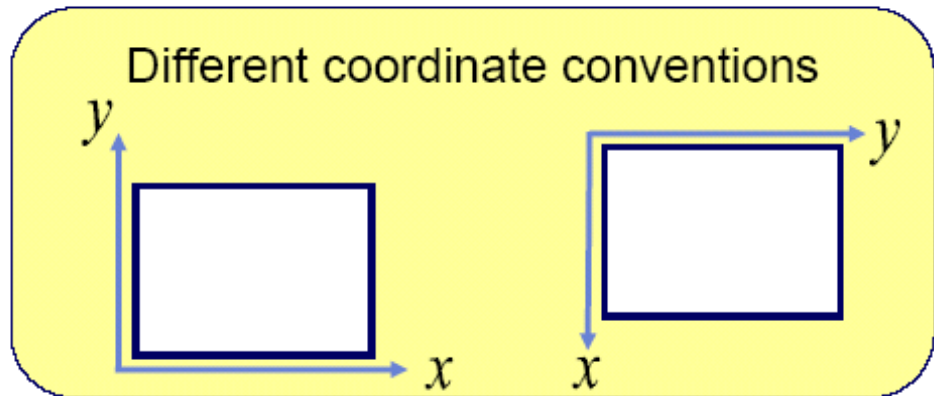
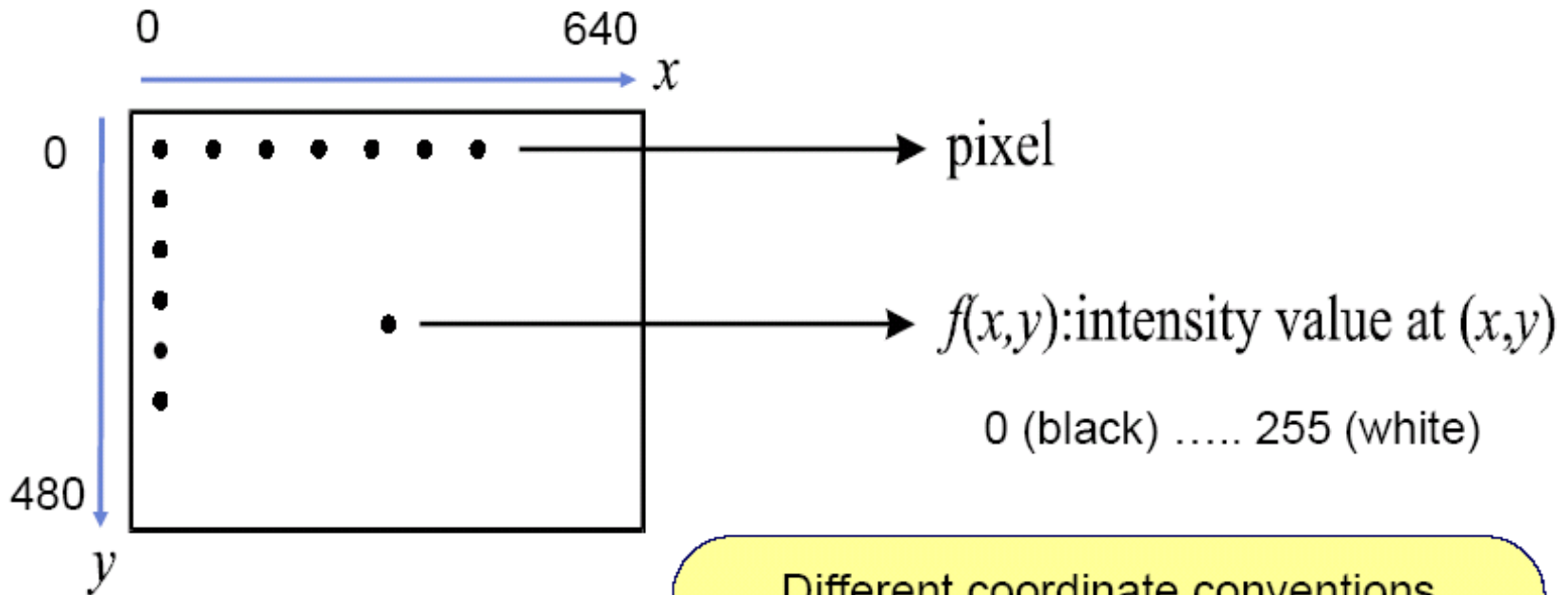


Digital Image

- A set of pixels (picture elements, pels)
- Pixel means
 - pixel coordinate
 - pixel value
 - or both
- Both coordinates and value are discrete

Example

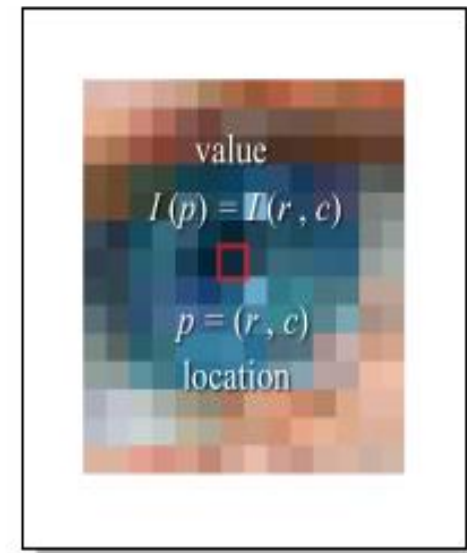
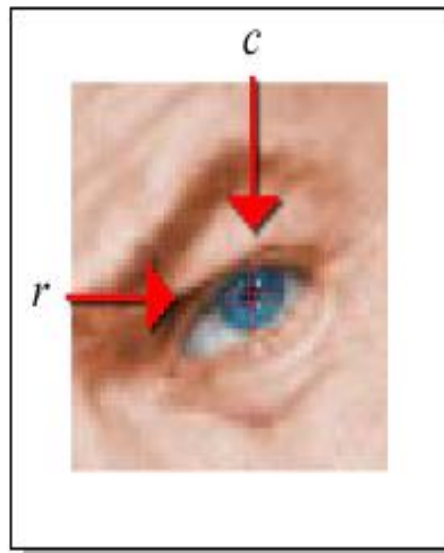
640 x 480 8-bit image



Pixels

- $p = (r, c)$ is the pixel location indexed by row, r , and column, c .
- $I(p) = I(r, c)$ is the value of the pixel at location p .
- If $I(p)$ is a single number then I is monochrome.
- If $I(p)$ is a vector (ordered list of numbers) then I has multiple bands (*e.g.*, a color image).

Pixels



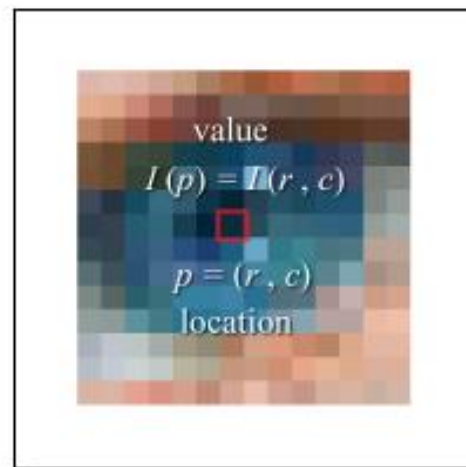
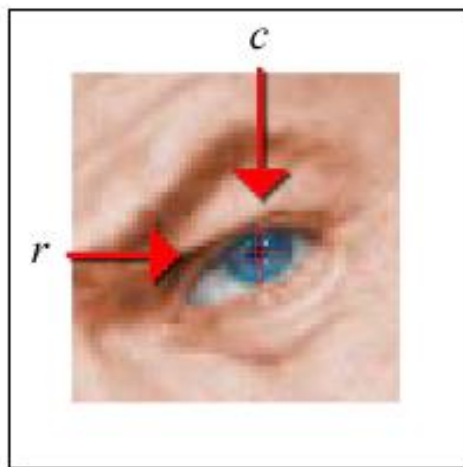
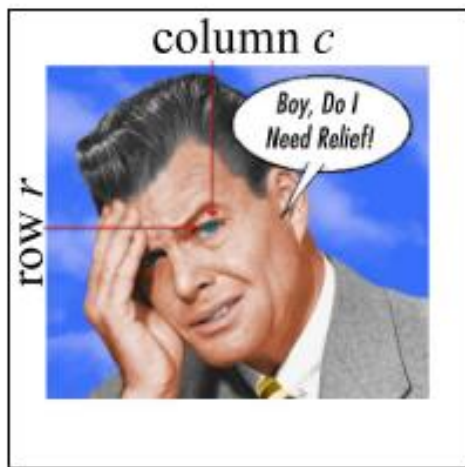
Pixel Location: $p = (r, c)$

Pixel Value: $I(p) = I(r, c)$

Pixel : $[p, I(p)]$

Pixels

Pixel : $[p, I(p)]$



$$\begin{aligned} p &= (r, c) \\ &= (\text{row \#, col \#}) \\ &= (272, 277) \end{aligned}$$

$$I(p) = \begin{bmatrix} \text{red} \\ \text{green} \\ \text{blue} \end{bmatrix} = \begin{bmatrix} 12 \\ 43 \\ 61 \end{bmatrix}$$

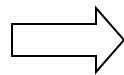
DIGITAL IMAGE REPRESENTATION



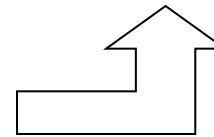
PIXEL VALUES IN HIGHLIGHTED REGION

99	71	61	51	49	40	35	53	86	99
93	74	53	56	48	46	48	72	85	102
101	69	57	53	54	52	64	82	88	101
107	82	64	63	59	60	81	90	93	100
114	93	76	69	72	85	94	99	95	99
117	108	94	92	97	101	100	108	105	99
116	114	109	106	105	108	108	102	107	110
115	113	109	114	111	111	113	108	111	115
110	113	111	109	106	108	110	115	120	122
103	107	106	108	109	114	120	124	124	132

CAMERA



DIGITIZER



**A set of number
in 2D grid**

Samples the analog data and digitizes it.

What is a Digital Image? (cont...)

- Common image formats include:
 - 1 sample per point (B&W or Grayscale)
 - 3 samples per point (Red, Green, and Blue)



- For most of this course we will focus on grey-scale images

IMAGE FORMATION MODEL

- Image refers to a 2d light-intensity function, $f(x, y)$
- The amplitude of f at spatial coordinates (x, y) gives the intensity (brightness) of the image at that point.
- Light is a form of energy thus $f(x, y)$ must be nonzero and finite.

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

IMAGE FORMATION MODEL

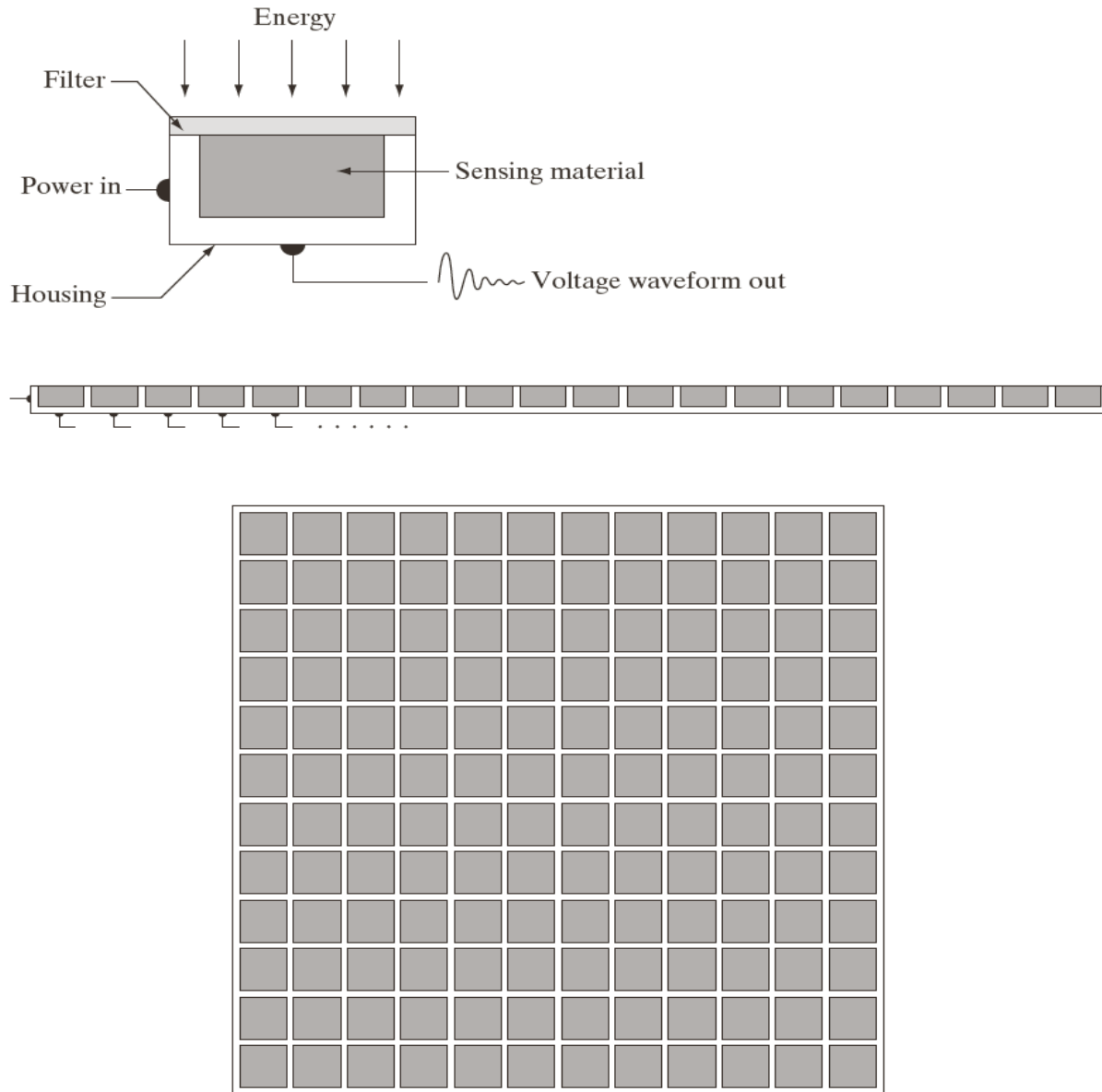
- The function $f(x, y)$ may be characterized by two components:
 - The amount of source light incident on the scene being viewed \Rightarrow illumination.
 - The amount of light reflected by the objects in the scene \Rightarrow reflectance.

$$f(x, y) = i(x, y)r(x, y)$$

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

$$0 < r(x, y) < 1.$$

Image Acquisition



a
b
c

FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

Bayer Color Filter

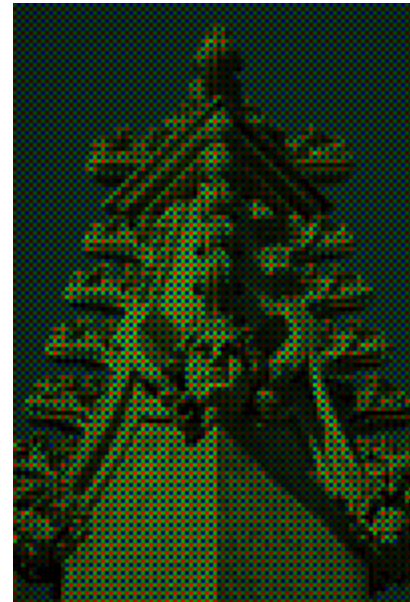
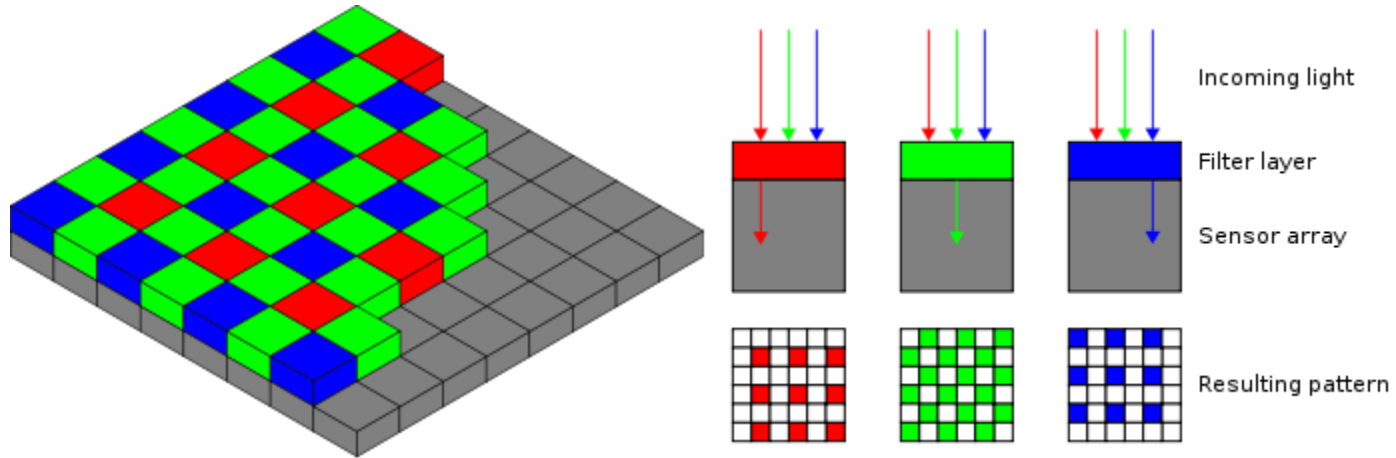
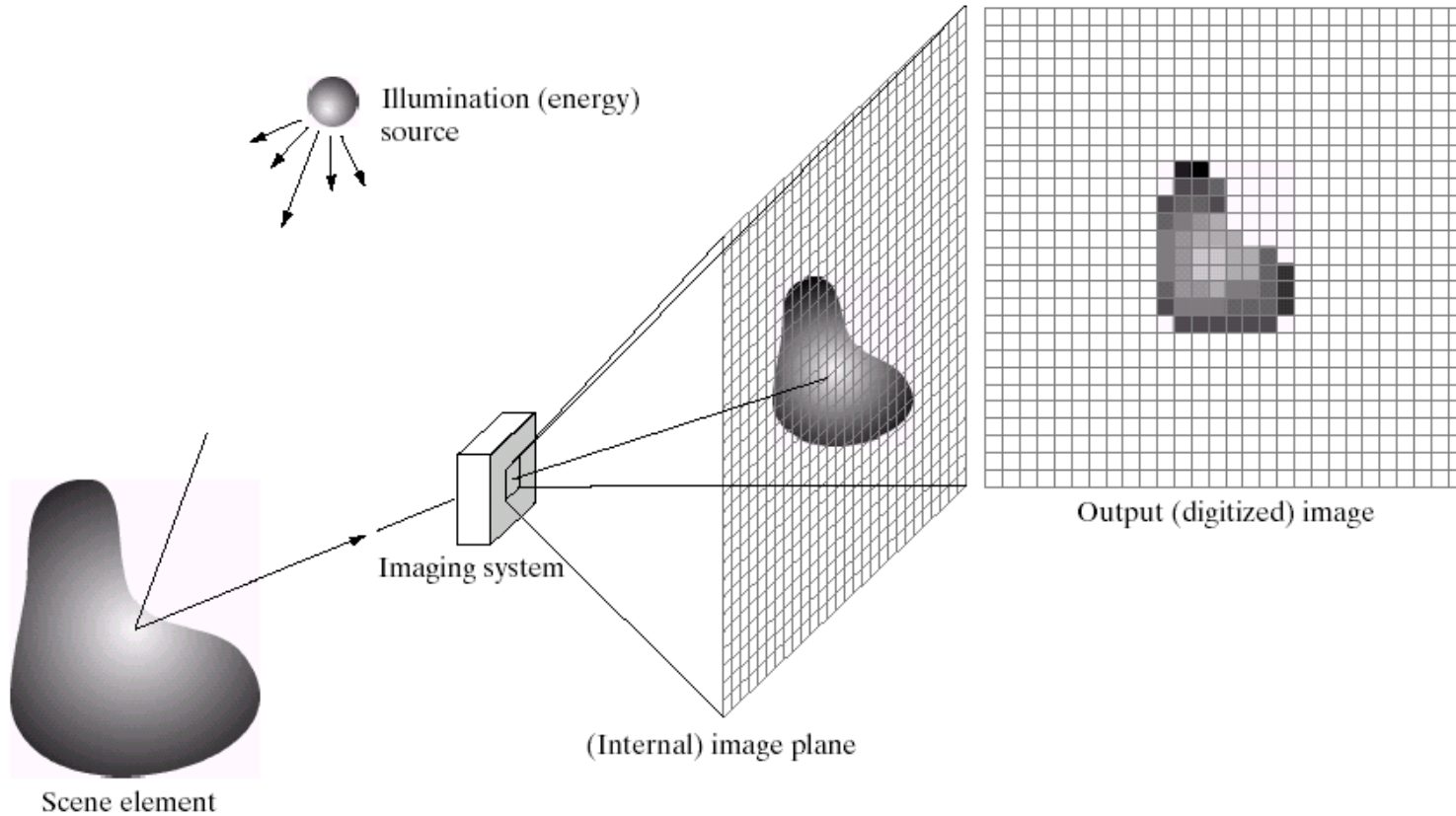


Image Acquisition



a
b c d e

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.

Sampling and Quantization

- ◆ **Sampling:**

- Digitization of the spatial coordinates (x,y)

- ◆ **Quantization:**

- Digitization in amplitude (also known as gray level quantization)

Sampling and Quantization

◆ Quantization

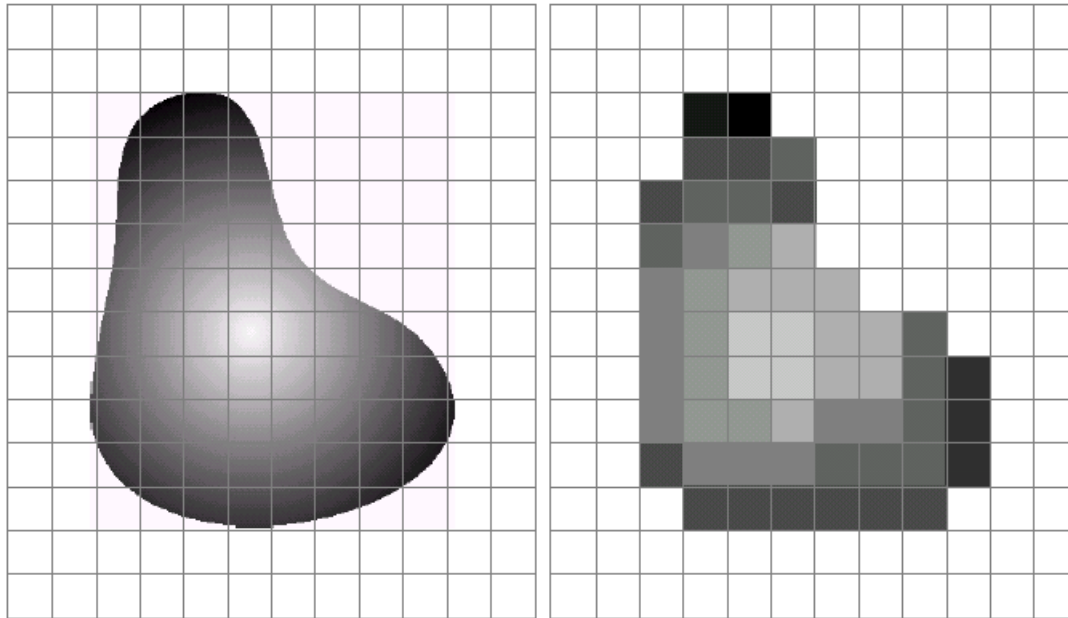
- 8 bit quantization: $2^8 = 256$ gray levels (0: black, 255: white)
- 1 bit quantization: 2 gray levels (0: black, 1: white) – binary

◆ Sampling

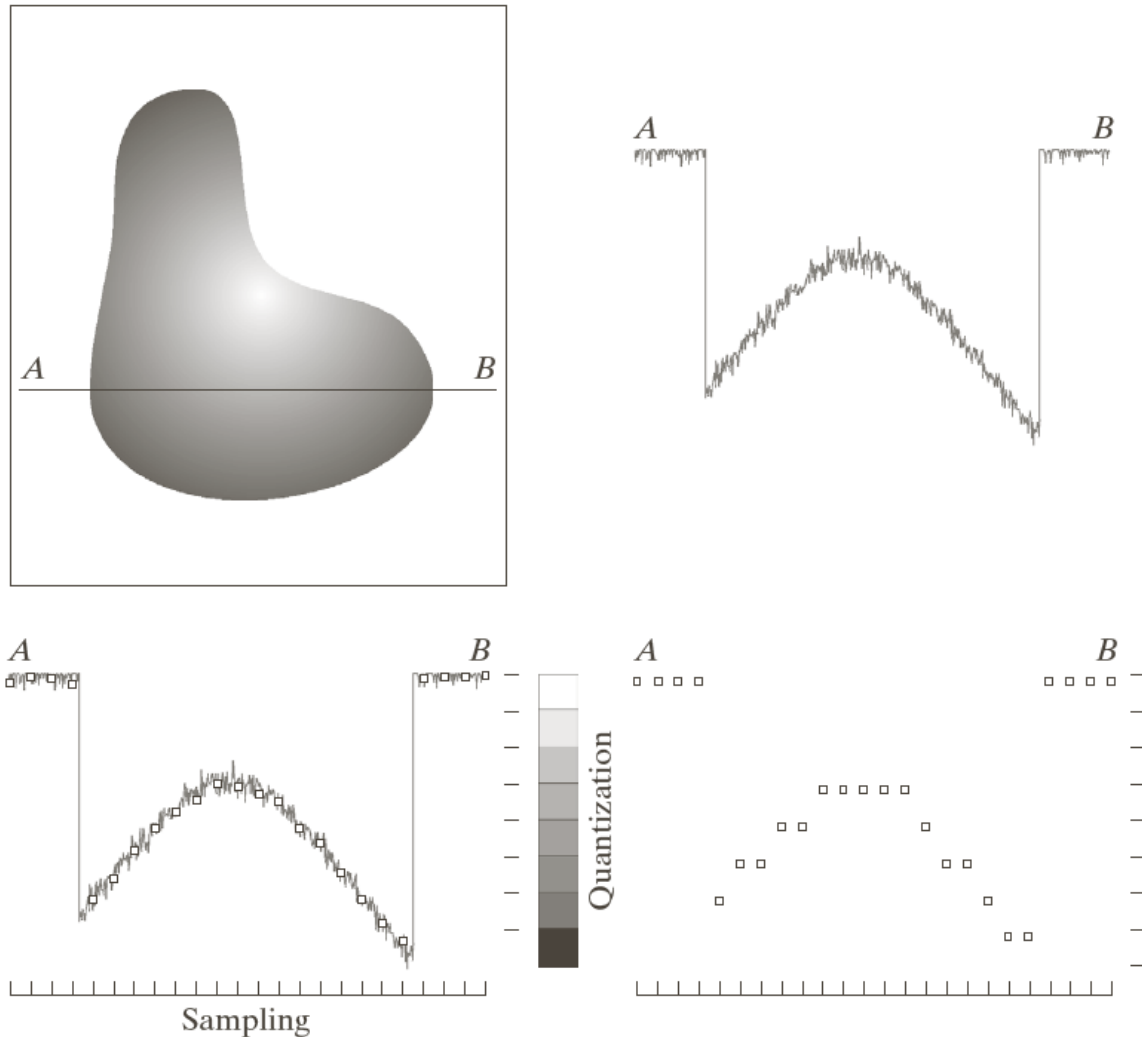
- Commonly used number of samples (resolution)
 - Digital still cameras: 640x480, 1024x1024, 4064 x 2704
 - Digital video cameras: 640x480 at 30 frames/second (fps)

Sampling and Quantization

- ◆ Digital Image is an approximation of a real world scene



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.

Image Formation

- ◆ Digital Image is an approximation of a real world scene

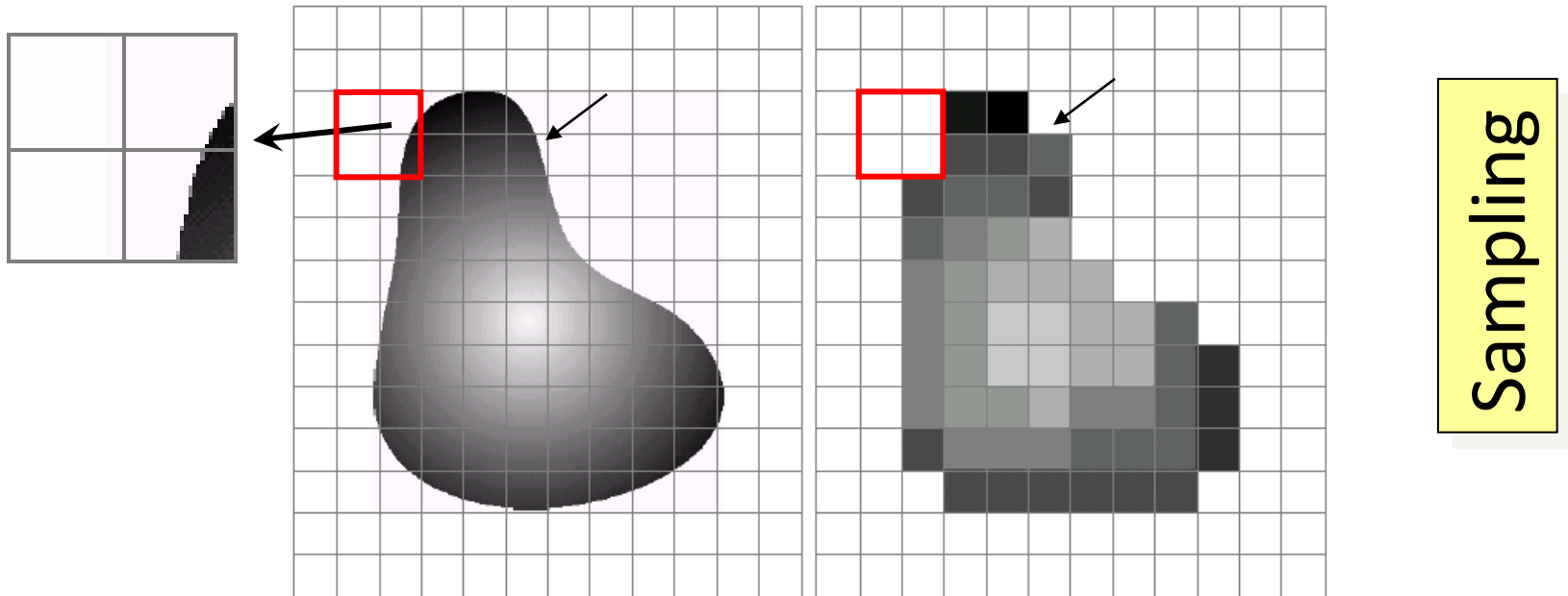
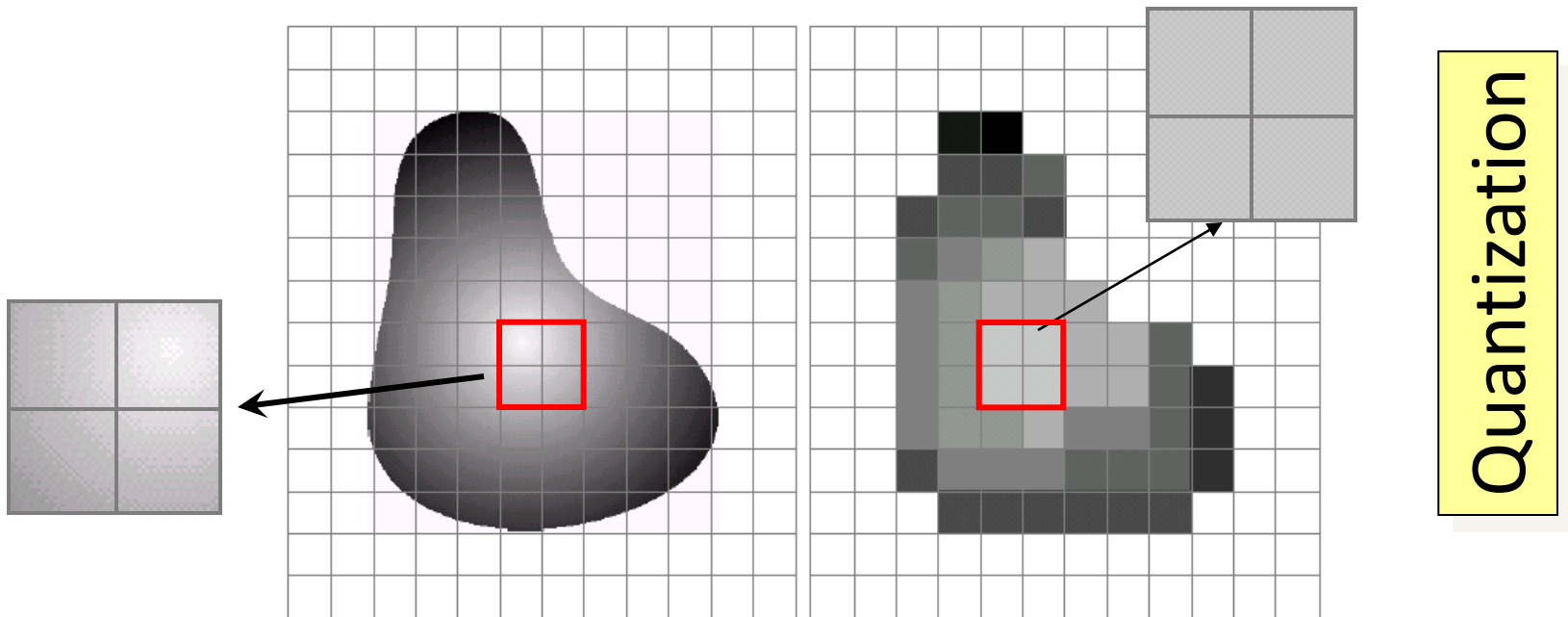
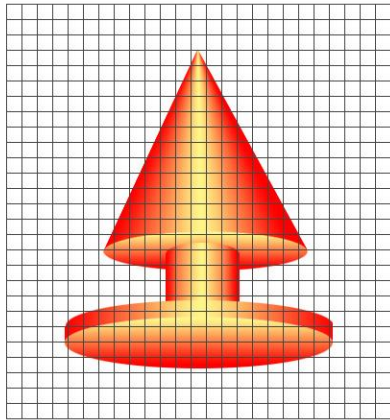


Image Formation

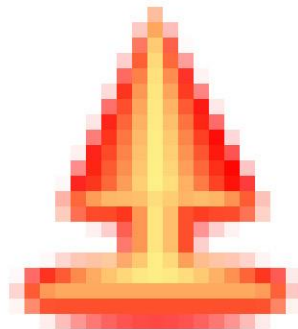
- ◆ Digital Image is an approximation of a real world scene



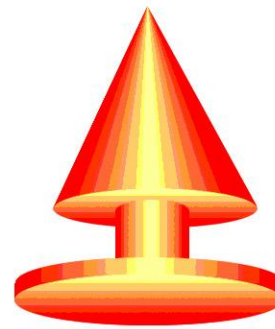
Sampling and Quantization



real image



sampled

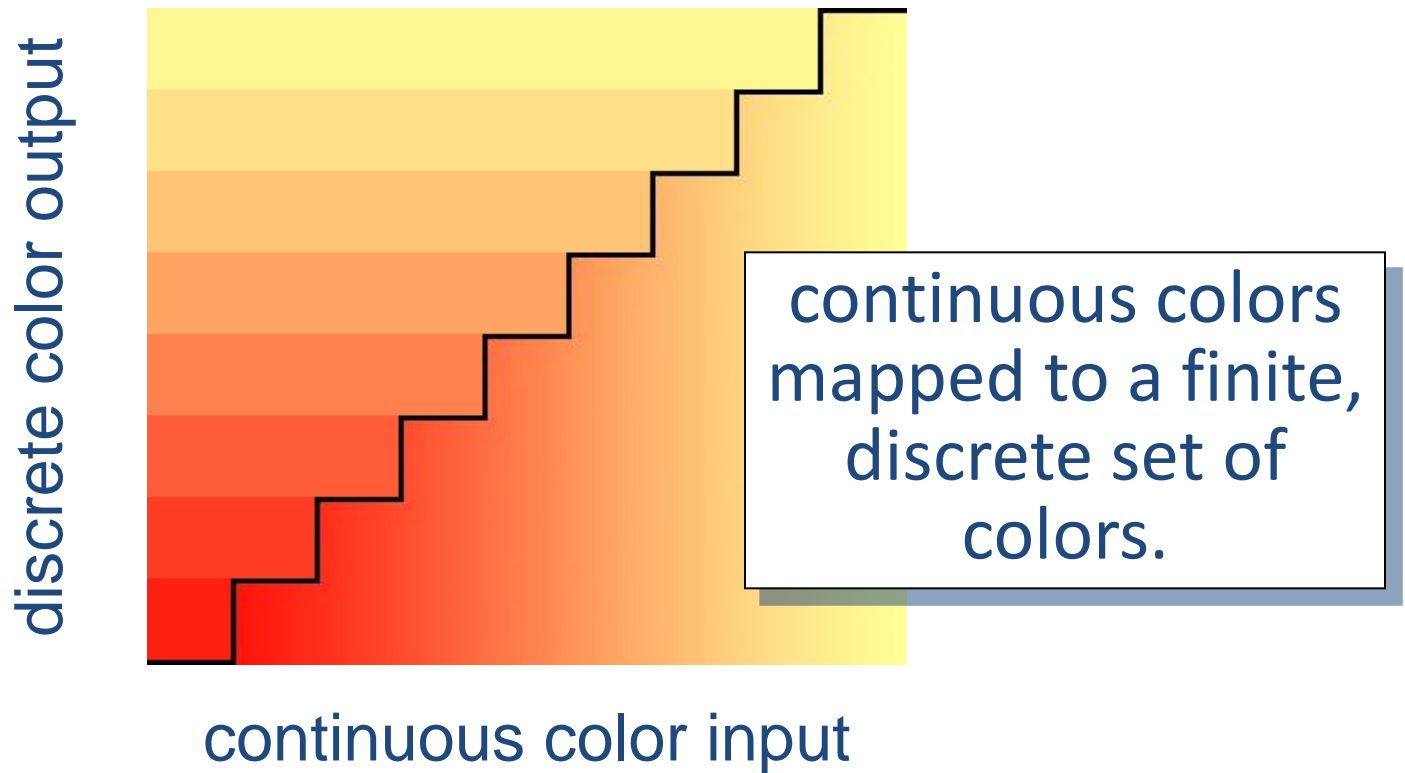


quantized



sampled &
quantized

Image Formation - Quantization



GRAY LEVEL

- WE CALL THE INTENSITY OF A MONOCHROME IMAGE f AT COORDINATE (x, y) THE GRAY LEVEL (L) OF THE IMAGE AT THAT POINT.
- Thus, l lies in the range

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

- L_{\min} is positive and L_{\max} is finite.
- Gray scale = $[L_{\min}, L_{\max}]$
- Common practice, shift the interval to $[0, L]$: 0 = black, $L-1$ = white

Digital Image Representation

- ◆ Image Size

- Number of bits required to store an image

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

- Image having 2^k intensity levels
 - k – bit image
 - 256 intensity levels – 8 bit image

Image Size

TABLE 2.1

Number of storage bits for various values of N and k .

N/k	1 ($L = 2$)	2 ($L = 4$)	3 ($L = 8$)	4 ($L = 16$)	5 ($L = 32$)	6 ($L = 64$)	7 ($L = 128$)	8 ($L = 256$)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

Readings from Book (3rd Edn.)

- Chapter - 1
- 2.1 Elements of Visual Perception
- 2.2 Light and EM Spectrum



Acknowledgements

- ◆ Statistical Pattern Recognition: A Review – A.K Jain et al., PAMI (22) 2000
- ◆ Pattern Recognition and Analysis Course – A.K. Jain, MSU
- ◆ *Pattern Classification*” by Duda et al., John Wiley & Sons.
- ◆ Digital Image Processing”, Rafael C. Gonzalez & Richard E. Woods, Addison-Wesley, 2002
- ◆ Machine Vision: Automated Visual Inspection and Robot Vision”, David Vernon, Prentice Hall, 1991
- ◆ www.eu.aibo.com/
- ◆ Advances in Human Computer Interaction, Shane Pinder, InTech, Austria, October 2008