

Digital Image Processing

Lecture # 1 **Introduction & Fundamentals**

Course Information

- **Course Material**

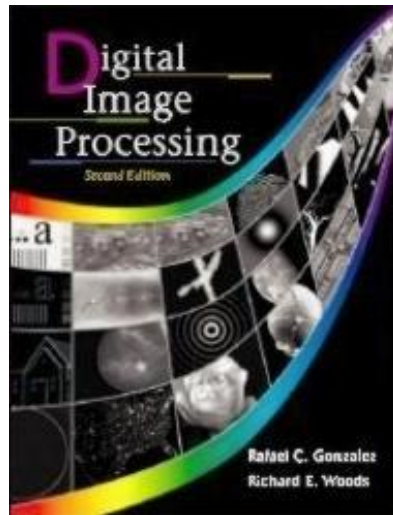
- Lectures slides, assignments (computer/written), solutions to problems, projects, and announcements will be uploaded on course web page.

<http://biomisa.org/usman/digital-image-processing-2>

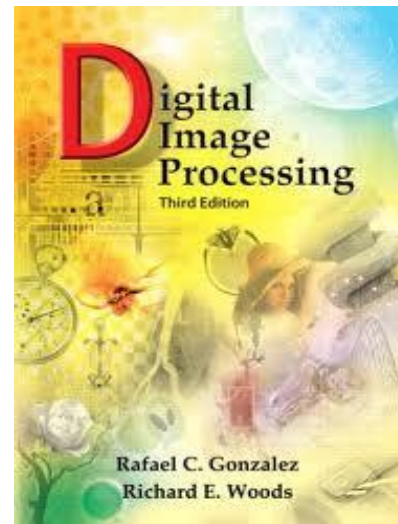
Course Information

◆ 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 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)
- 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

| | |
|-------------------------------------|-----|
| Sessional Exams: | 25% |
| Quizzes (4-6): | 10% |
| Computer and numerical assignments: | 07% |
| Final Project: | 08% |
| Lab | 10% |
| Final Exam: | 40% |

Before we start

How many of you
are good in signal &
systems?

How many of you
are familiar with
MATLAB?

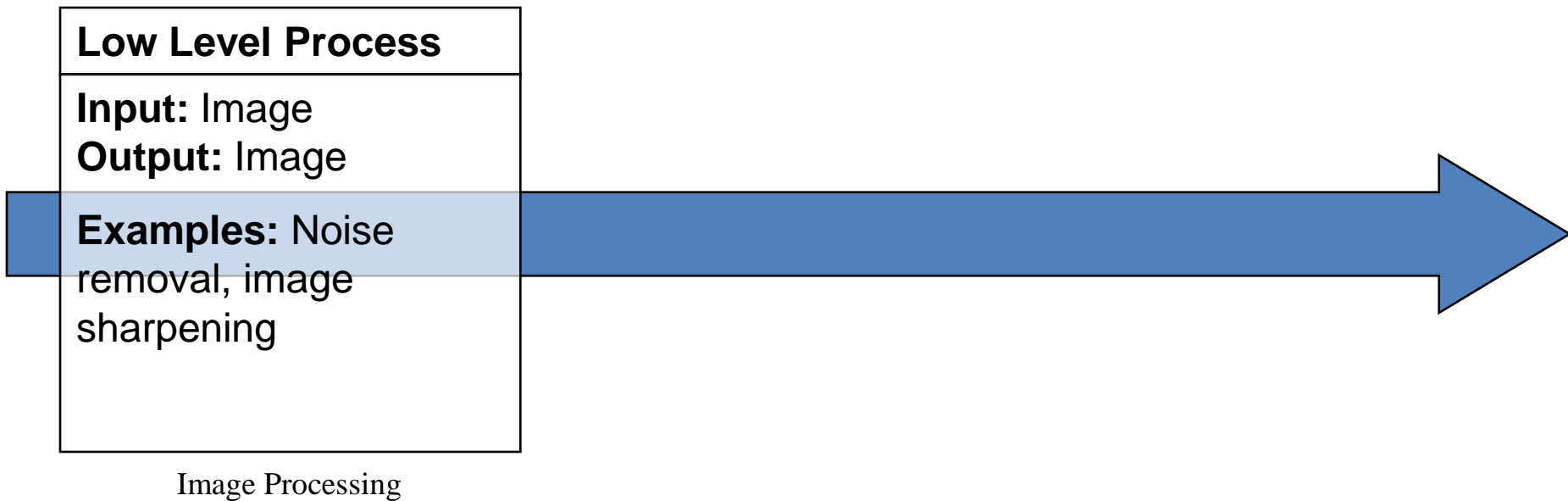


Image Processing
Image Analysis
Pattern Recognition
Machine Vision
Computer Vision



Image Processing & Machine Vision

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



Example: Low Level Processing

Photo restoration



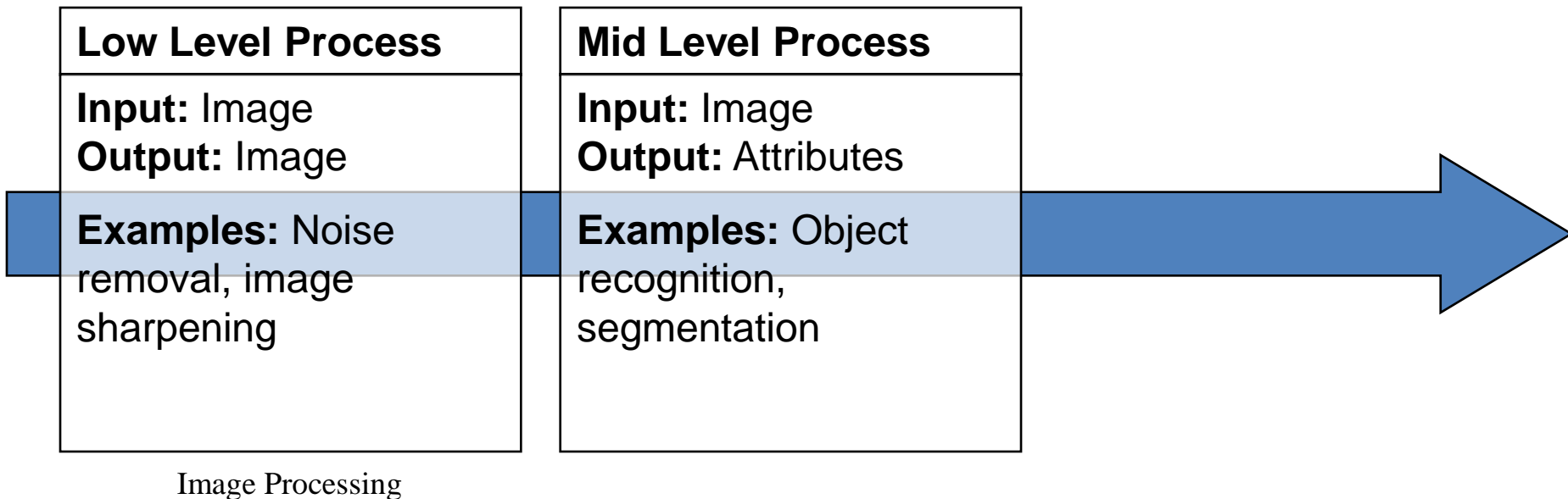
Damaged Image



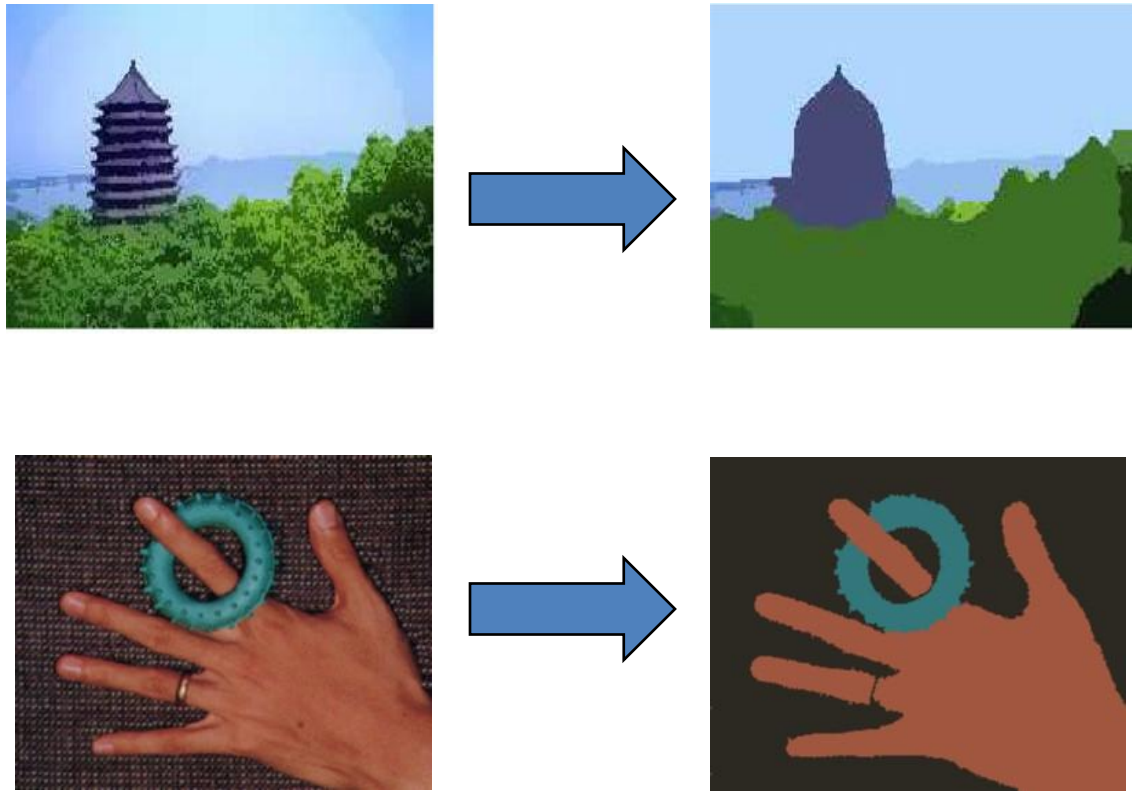
Restored Image

Image Processing & Machine Vision

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



Example: Mid Level Processing

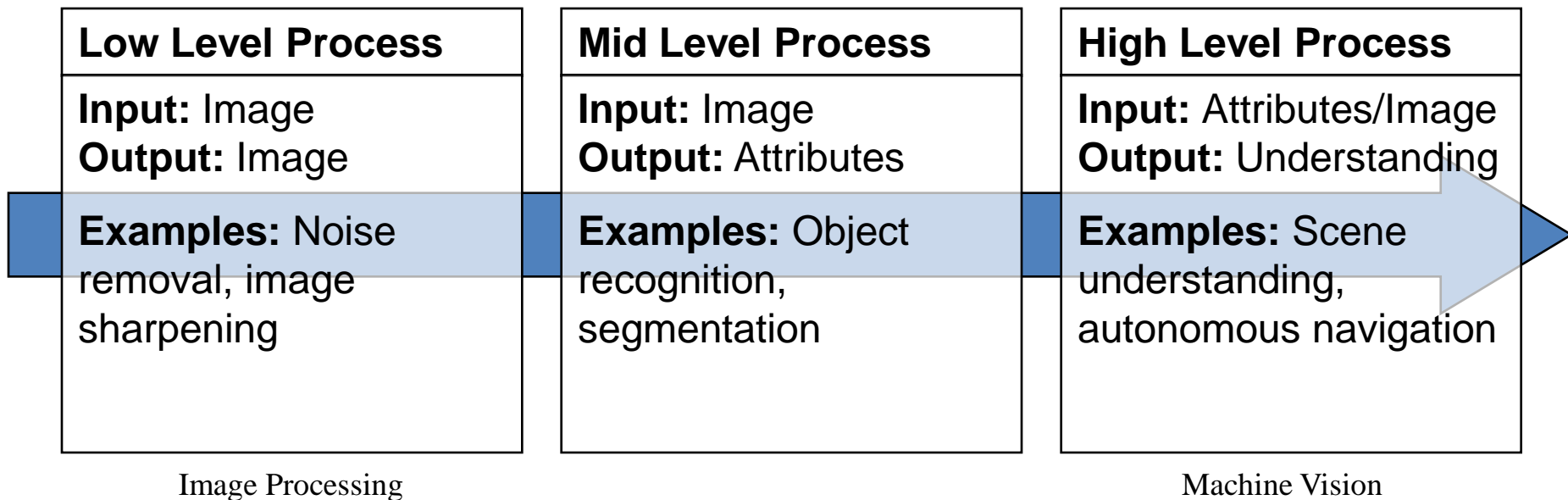


Segmentation of image into regions

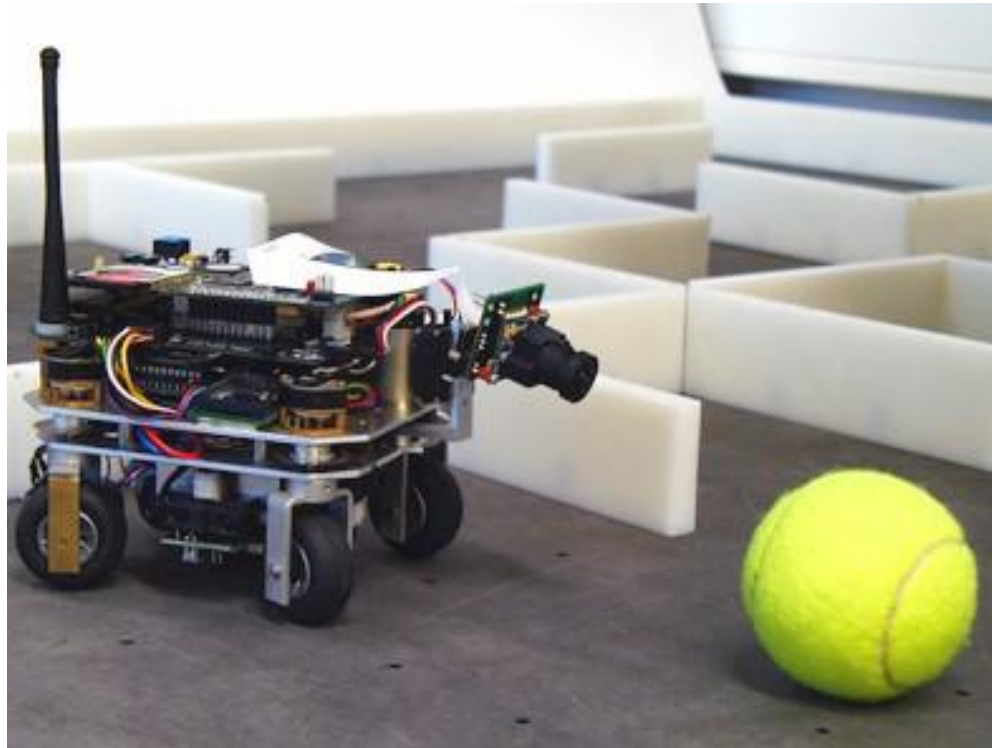
Image Processing & Machine Vision

◆ 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

Low Level Process

Input: Image
Output: Image

Examples: Noise removal, image sharpening

Image Processing

Mid Level Process

Input: Image
Output: Attributes

Examples: Object recognition, segmentation

High Level Process

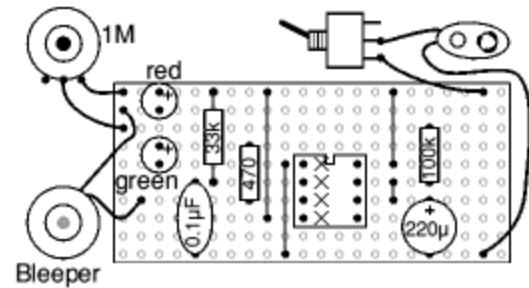
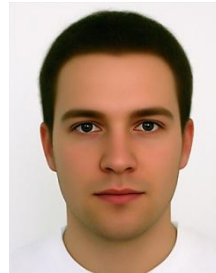
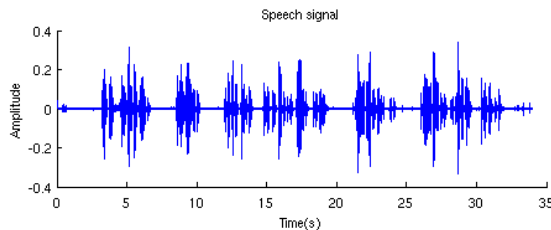
Input: Attributes/Image
Output: Understanding

Examples: Scene understanding, autonomous navigation

Machine Vision

Pattern

A pattern is the **opposite of a chaos**, it is an entity that can be given a name



Recognition

- Identification of a pattern as a member of a category

Classification

Apples



Oranges

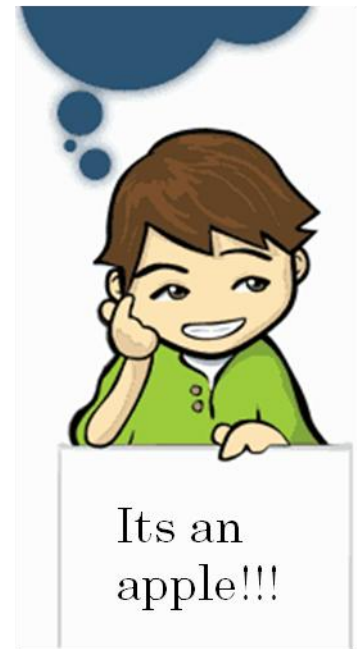


Classification

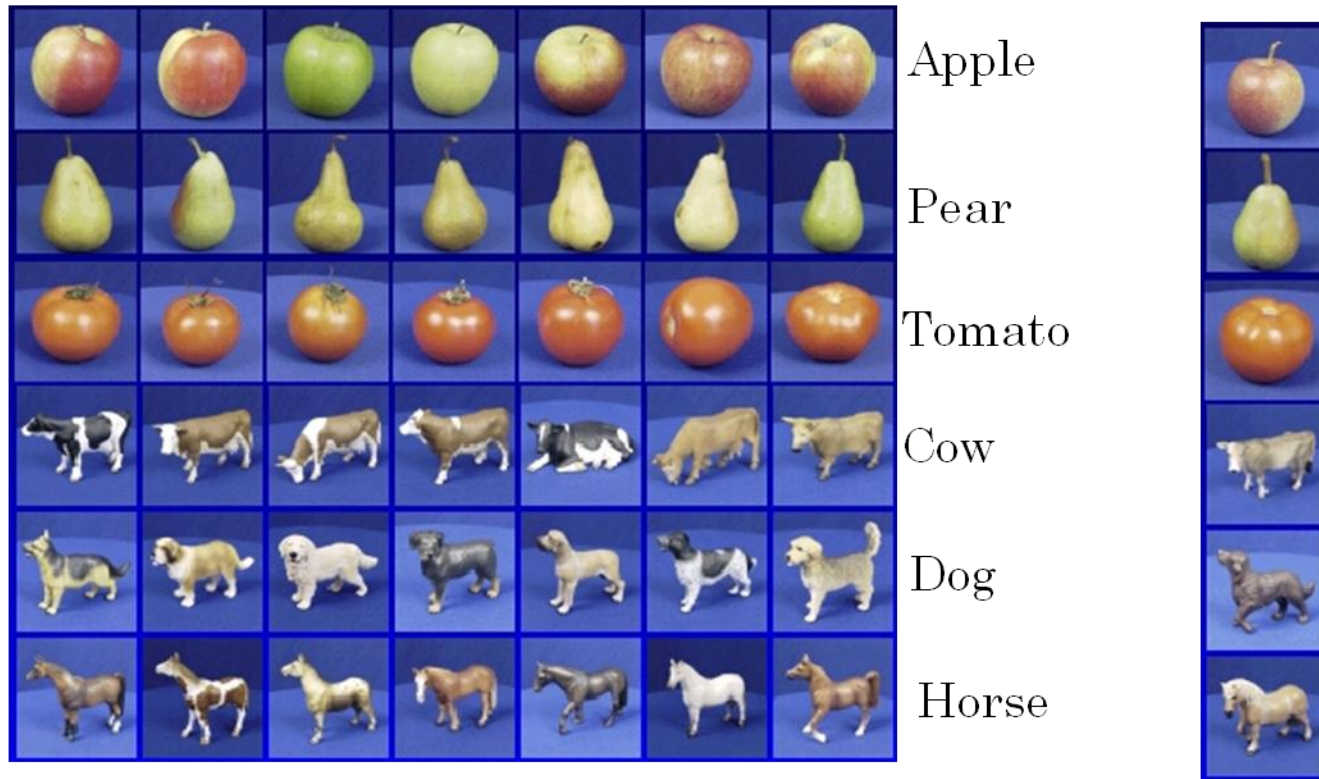
- You had some training example or '*training data*'
- The examples were '*labeled*'
- You used those examples to make the kid '*learn*' the difference between an apple and an orange



What is this???



Classification



Given: training images and their categories

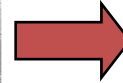
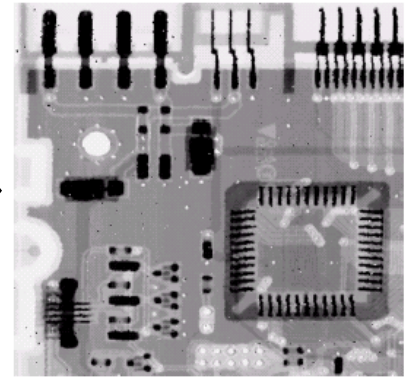
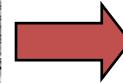
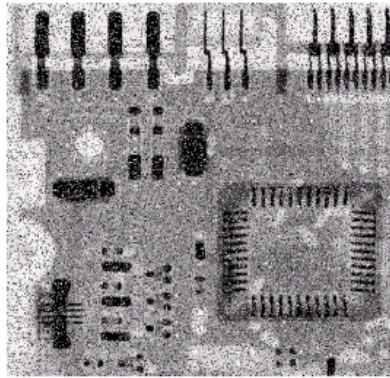
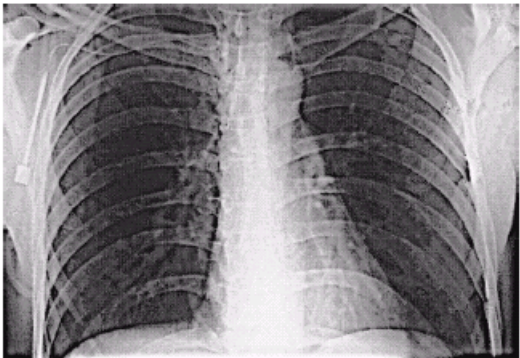
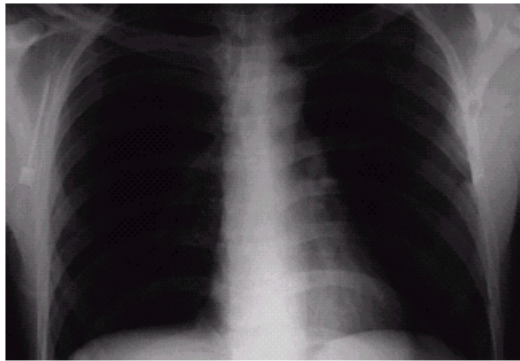
What are the categories of these test images?

Pattern Recognition

Given an input pattern, **make a decision** about the “category” or “class” of the pattern

Example Applications

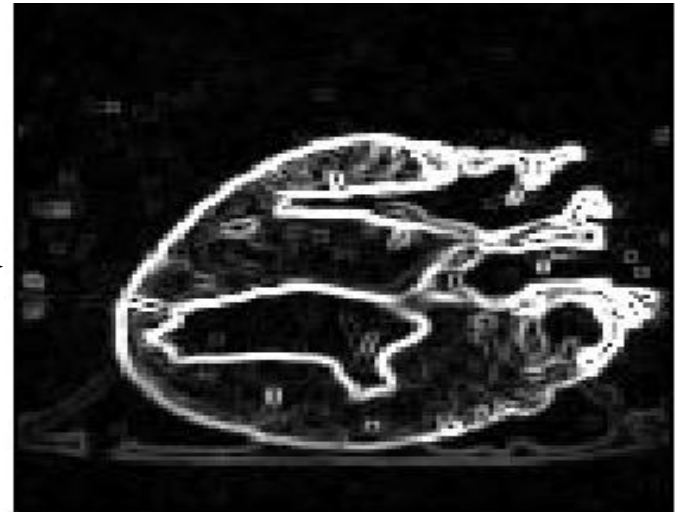
Examples: Image Enhancement



Examples: Medicine

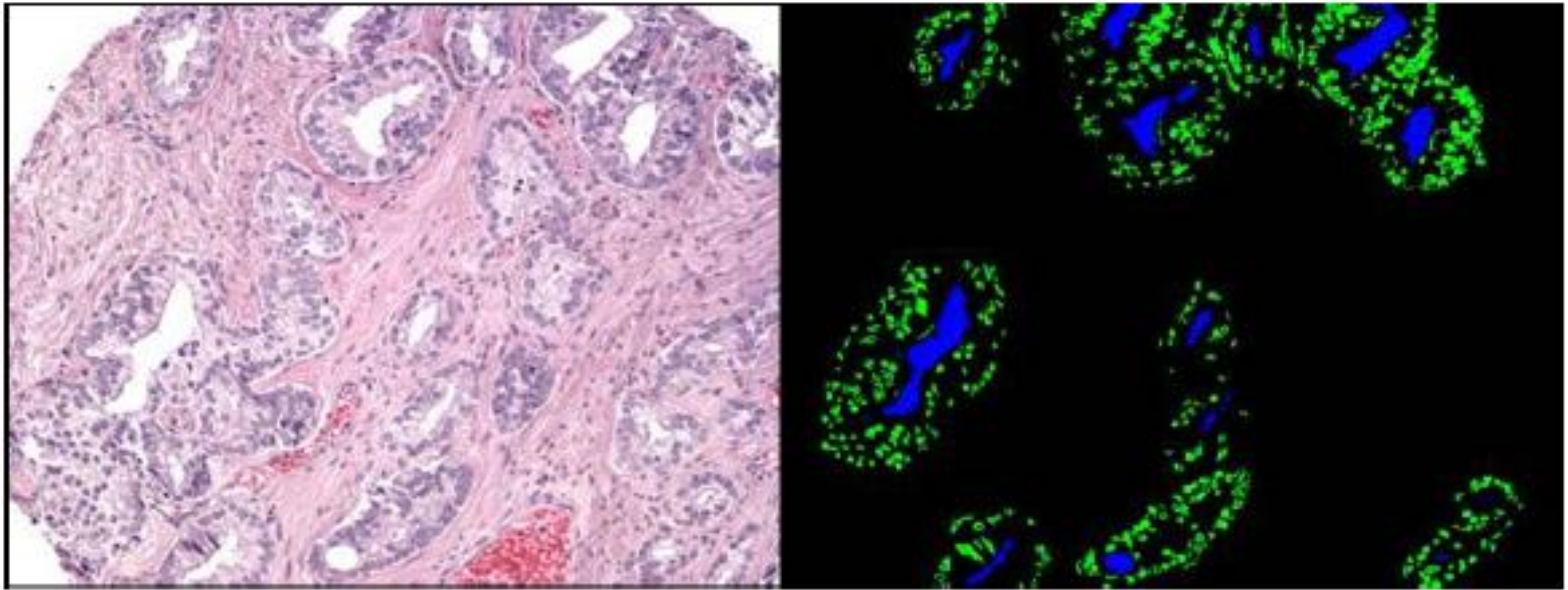


Original Image of a Dog Heart



Separation of tissues

Examples: Medicine

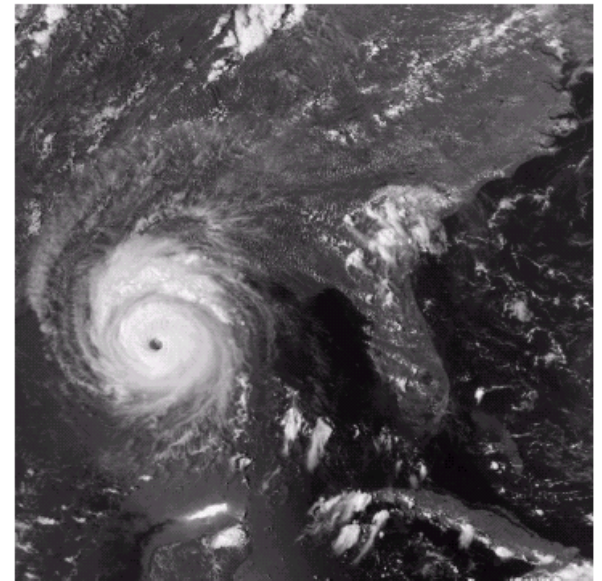
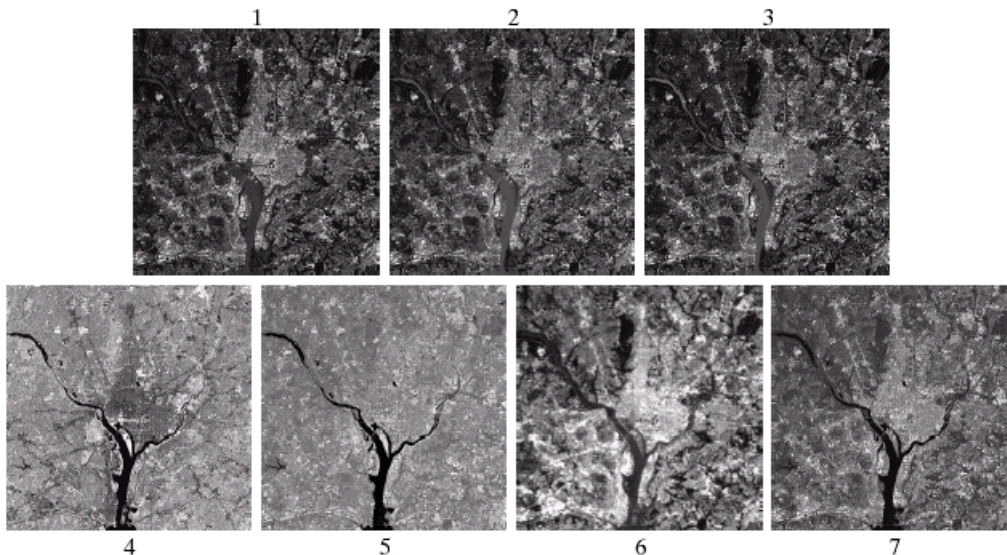


Microscopic tissue data - Cancer Detection

Examples: GIS

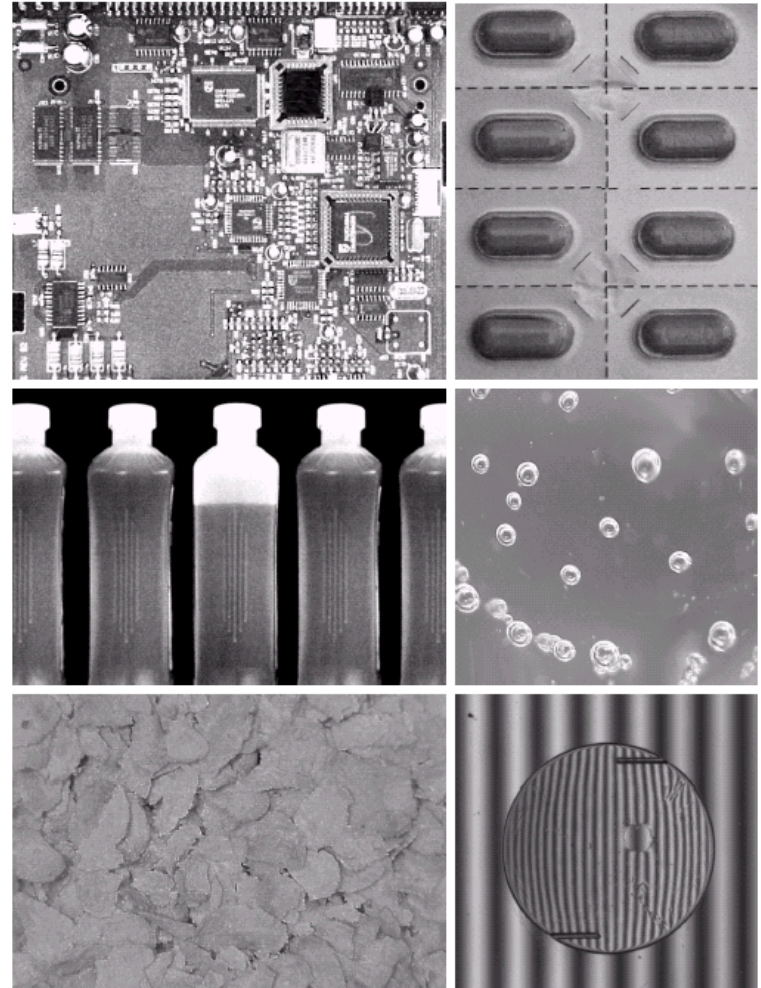
◆ Geographic Information Systems

- Manipulation of Satellite Imagery
- Terrain Classification, Meteorology



Examples: Industrial Inspection

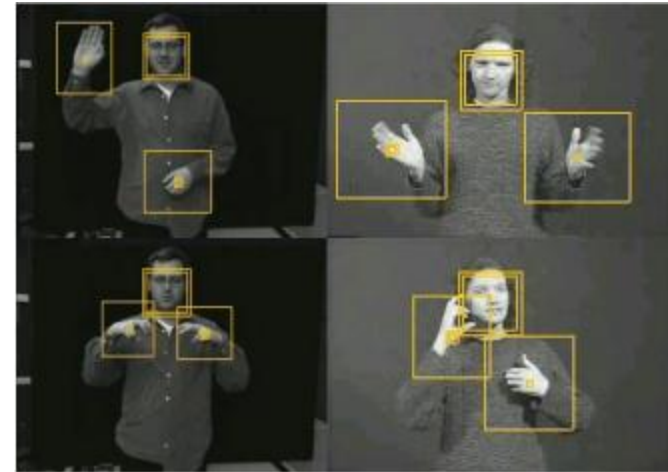
- ◆ Human operators are expensive, slow and unreliable
- ◆ Make machines do the job instead



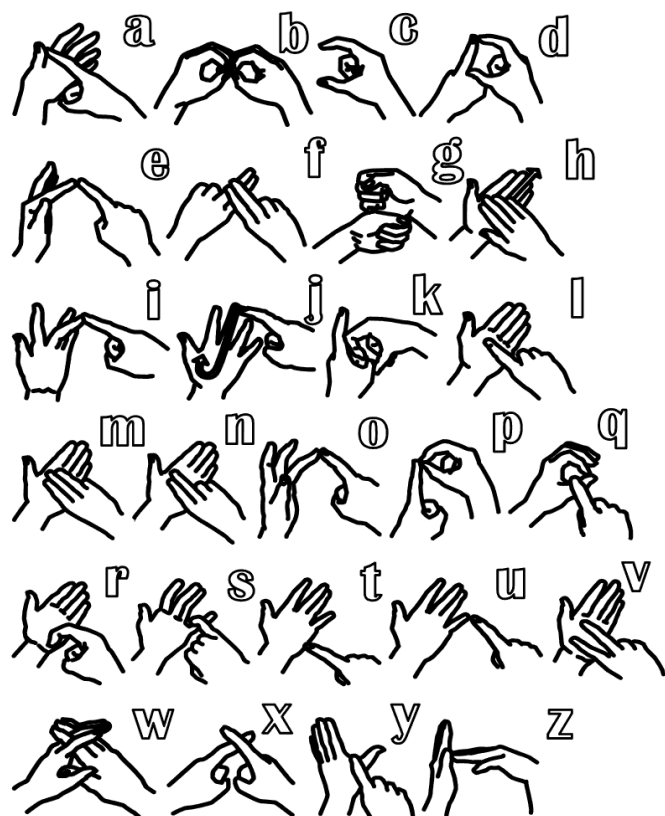
Examples: HCI

◆ Try to make human computer interfaces more natural

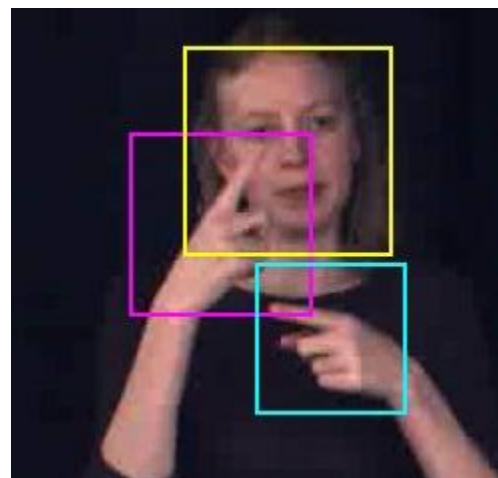
- Gesture recognition
- Facial Expression Recognition
- Lip reading



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



Normal



Happy








Sad









Surprised

Examples: Facial Expression Recognition

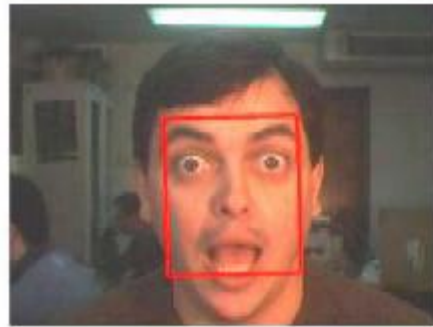
- Implicit customer feedback

| 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 |

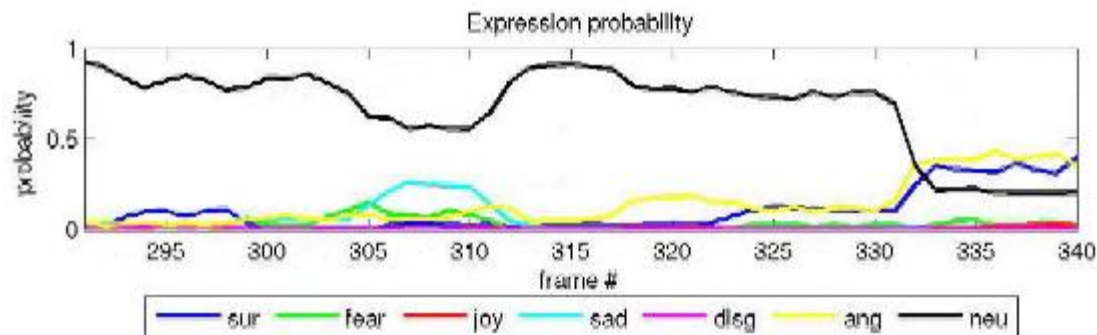
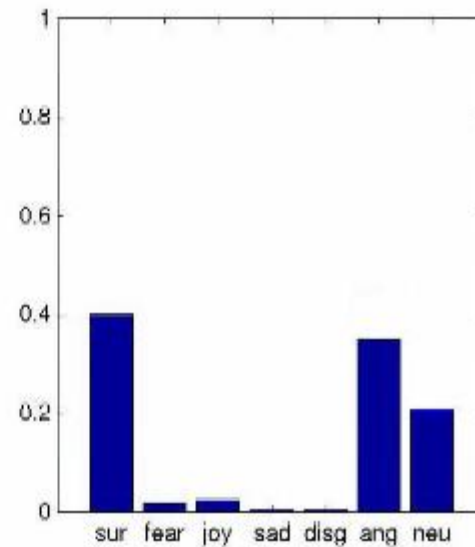
| Lower Face Action Units | | |
|---|---|---|
| AU25 | AU26 | AU27 |
|  |  |  |
| Lips are relaxed and parted | Lips are relaxed and parted; mandible is lowered | Mouth is stretched open and the mandible pulled down |
| AU12 | AU12+25 | AU20+25 |
|  |  |  |
| Lip corners are pulled obliquely | AU12 with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

Examples: Facial Expression Recognition

- Implicit customer feedback

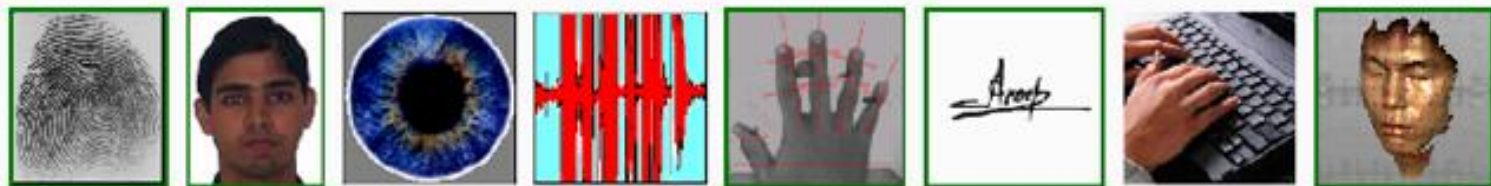


#340

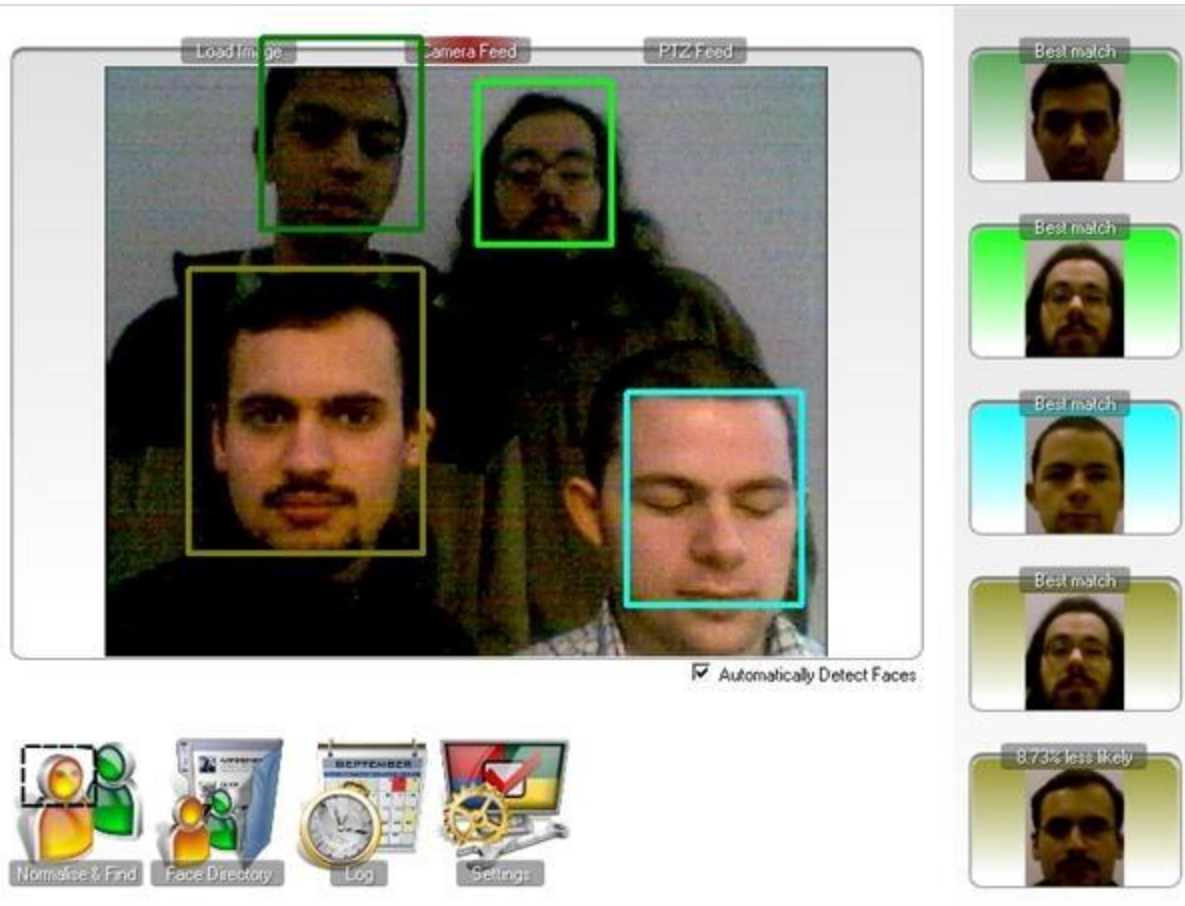


Examples: Biometrics

- ◆ 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

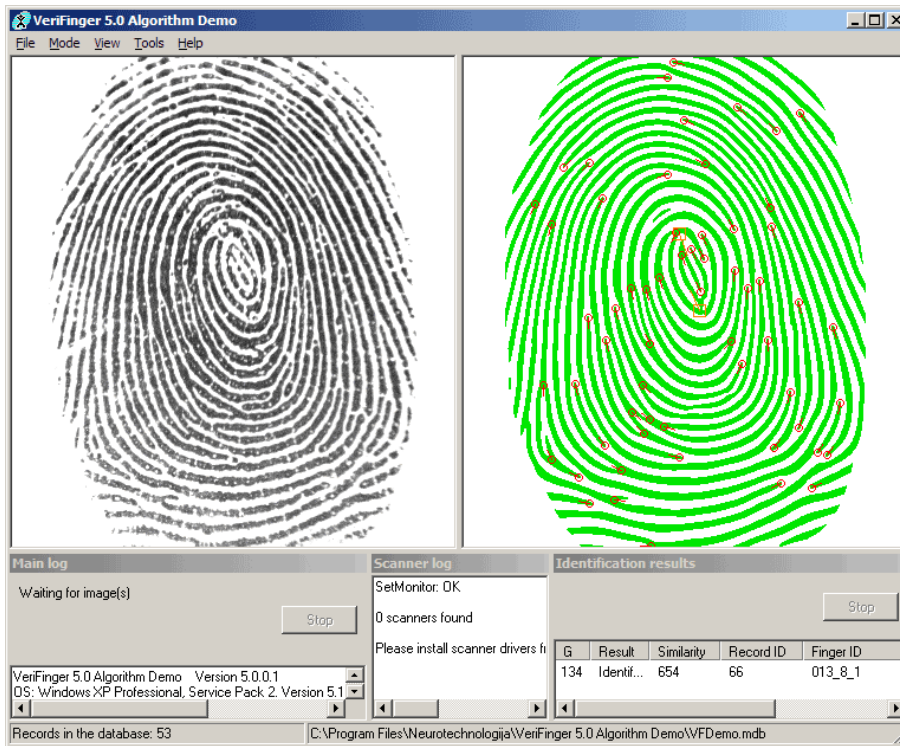


Camera waits for everyone to
smile to take a photo [Canon]

Automatic lighting
correction based
on face detection



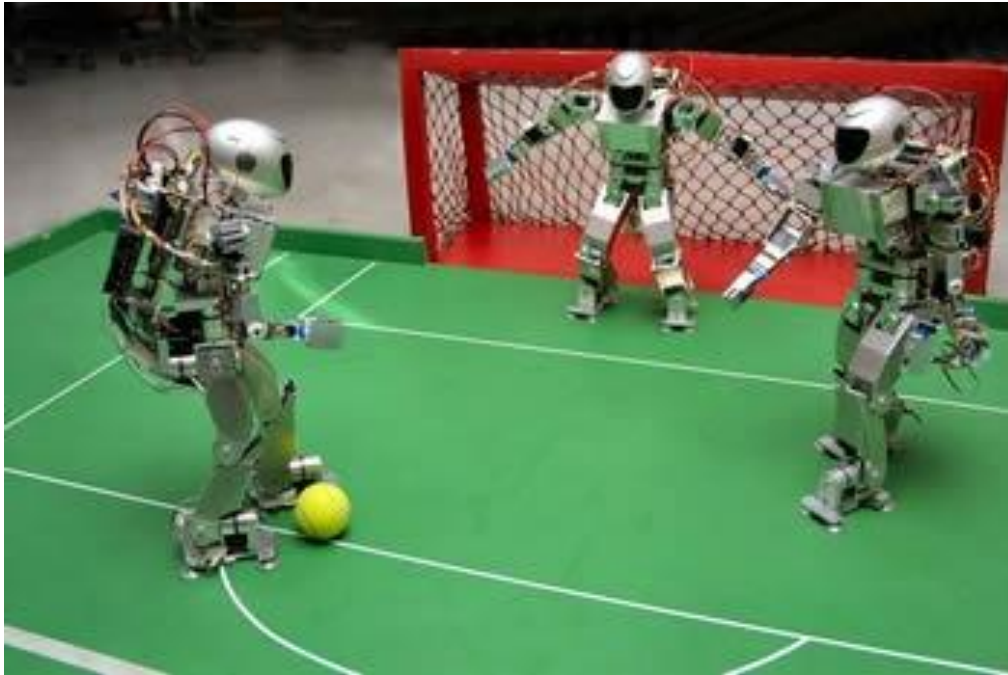
Examples: Biometrics – Finger Print Recognition



Examples: Biometrics – Signature Verification



Examples: Robotics



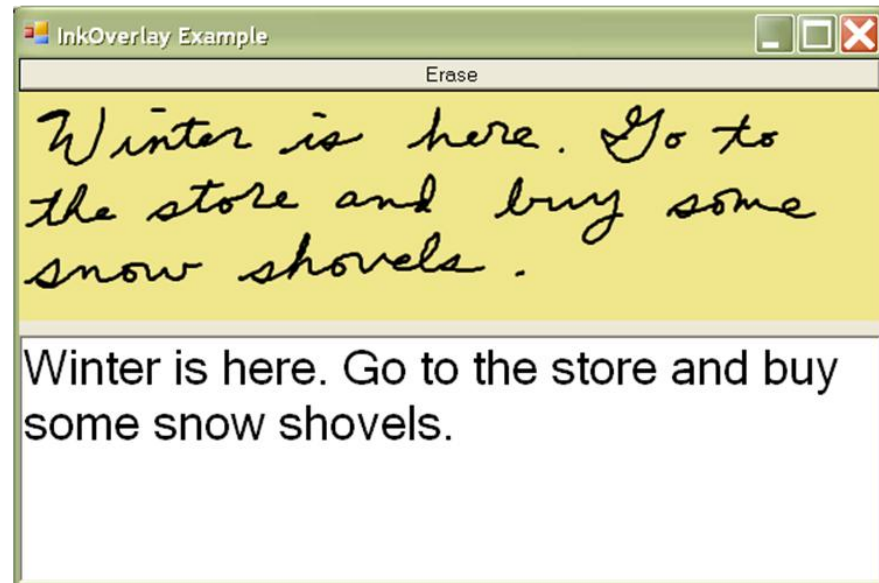
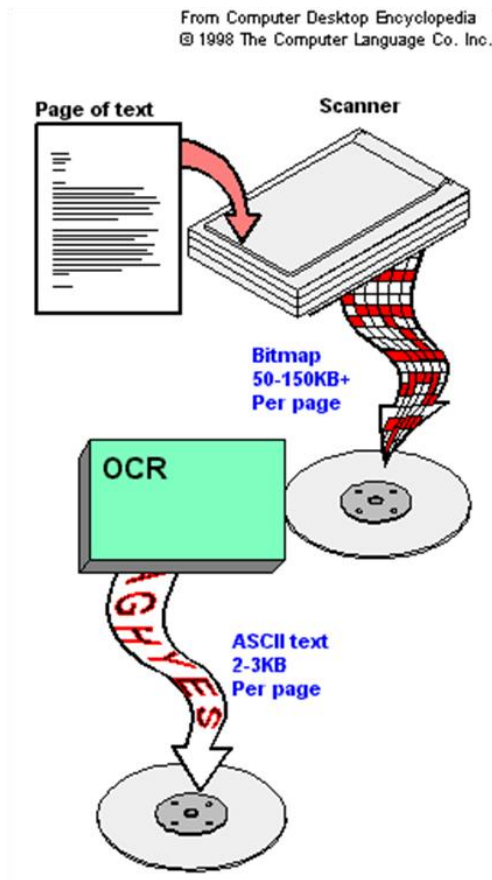
Examples: Robotics

◆ AIBO



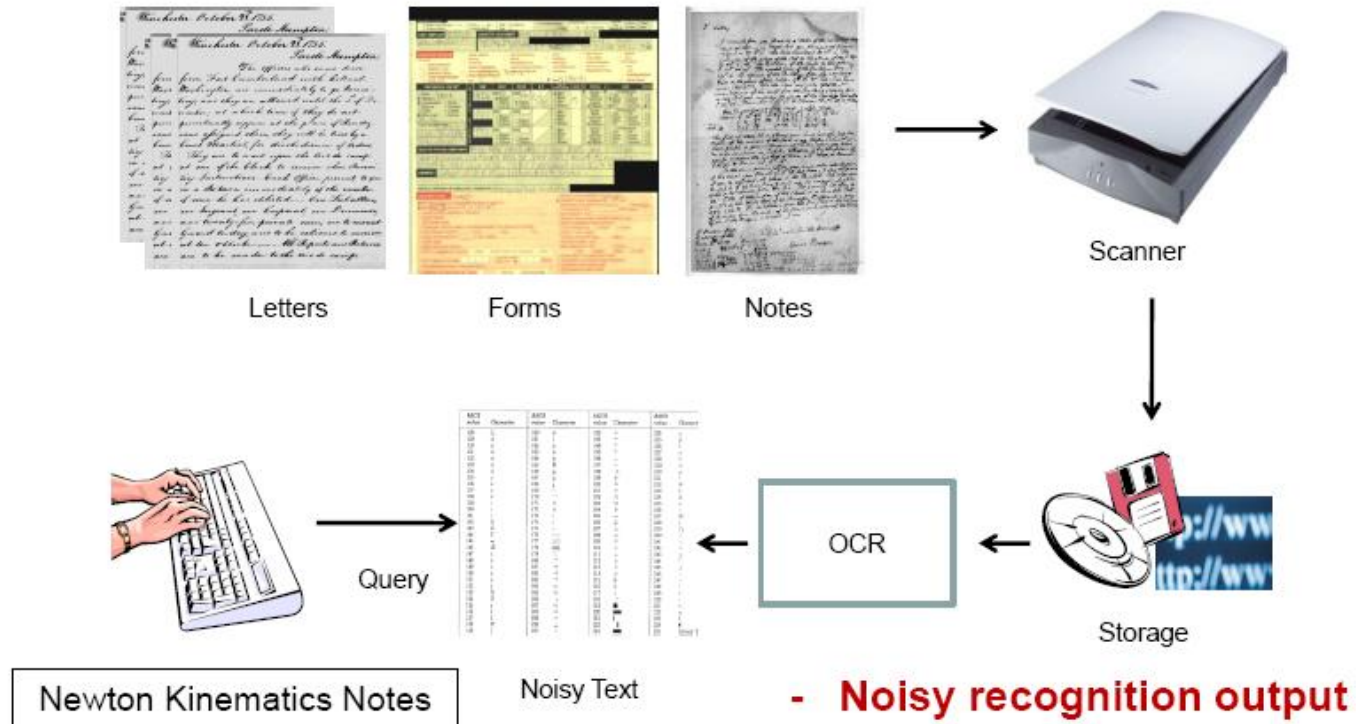
Examples: Optical Character Recognition

◆ Convert document image into text



Examples: Optical Character Recognition

◆ Indexing and Retrieval



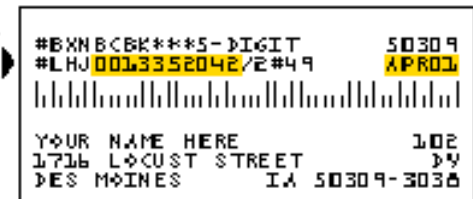
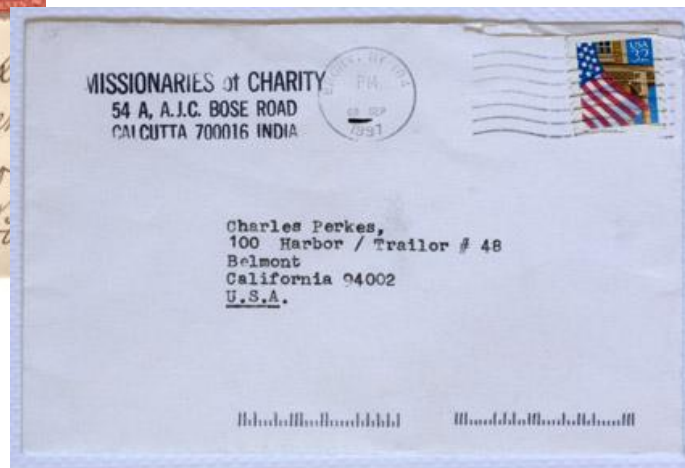
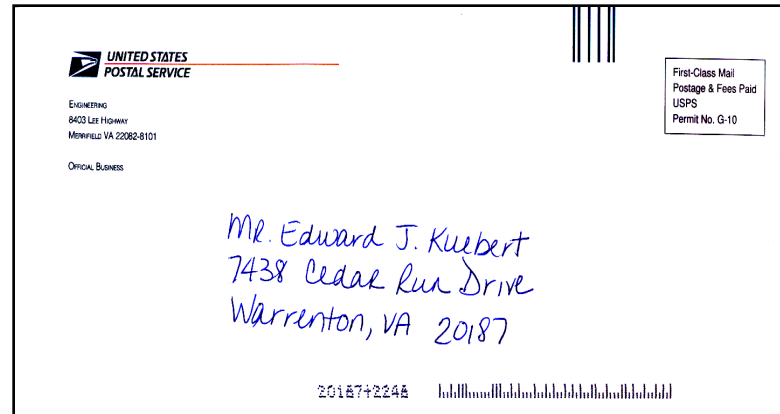
Examples: Optical Character Recognition

- ◆ License Plate Recognition



Examples: Optical Character Recognition

- Automatic Mail Sorting



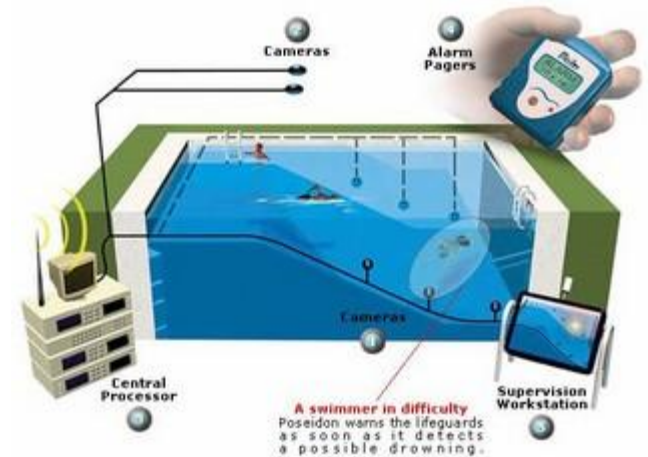
Safety and Security



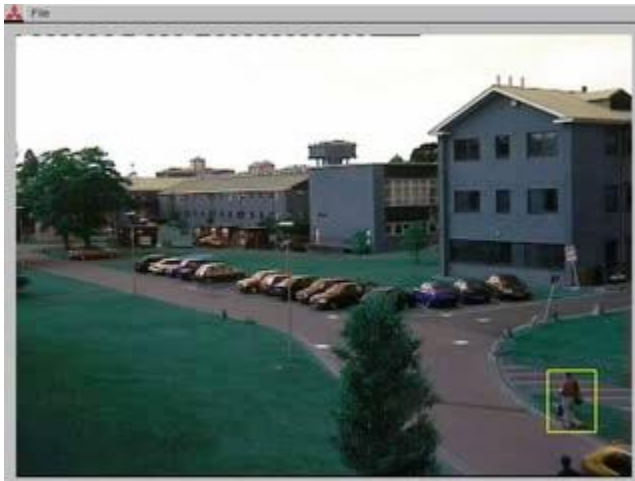
Autonomous robots



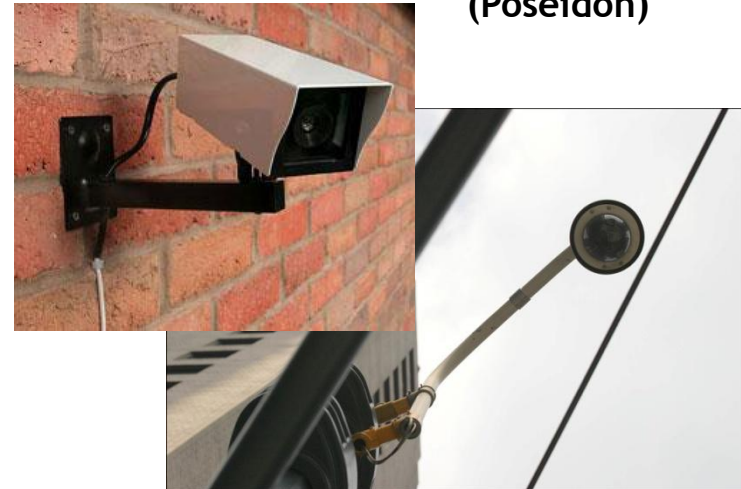
Driver assistance



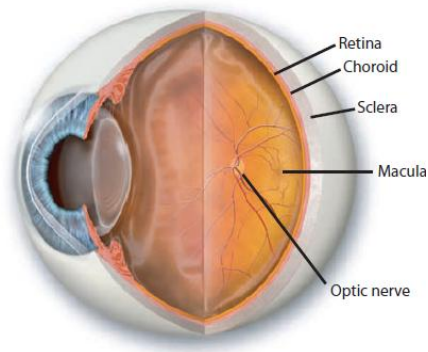
Monitoring pools
(Poseidon)



Pedestrian detection
[MERL, Viola et al.]



Surveillance

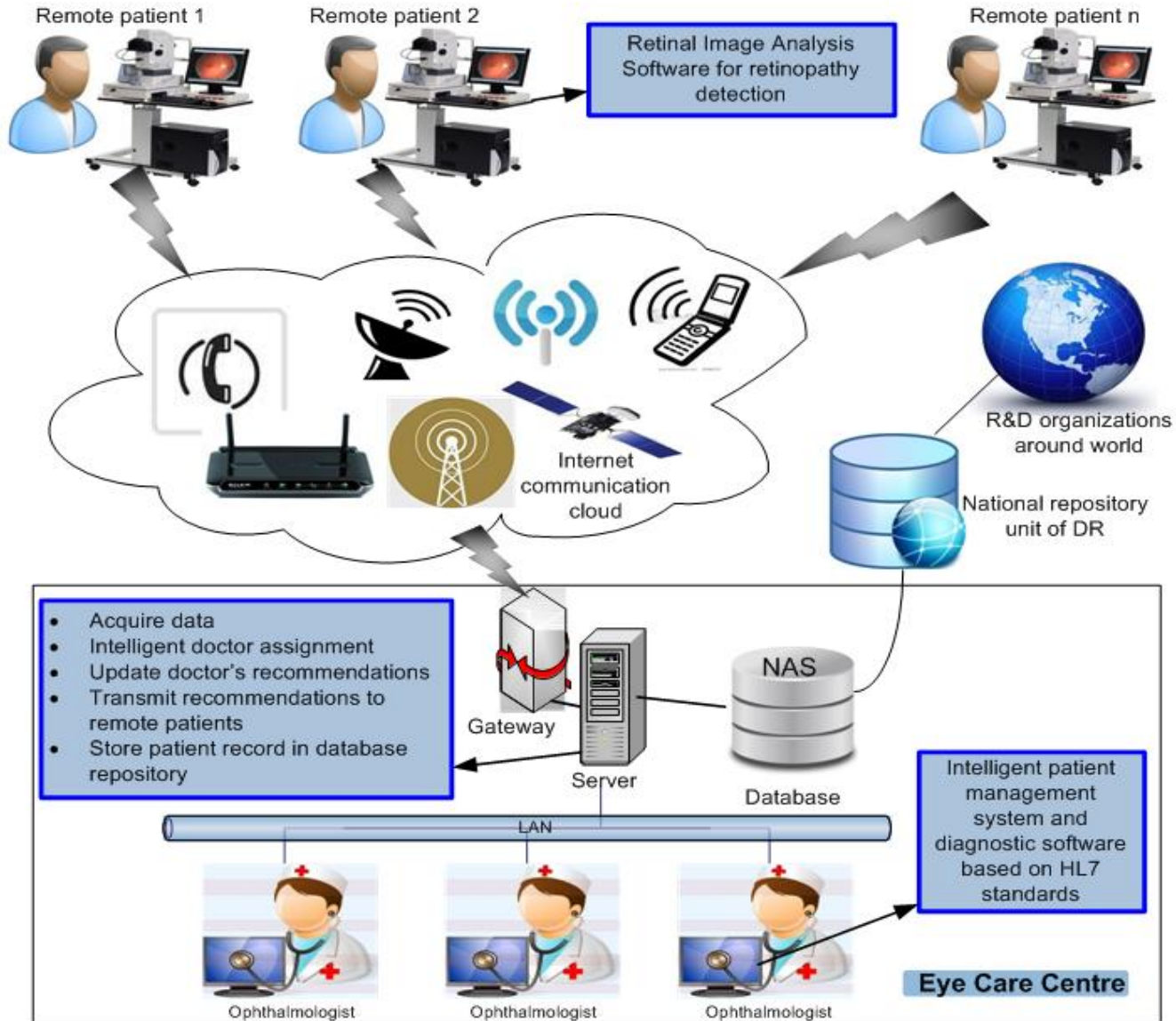


Eye Care

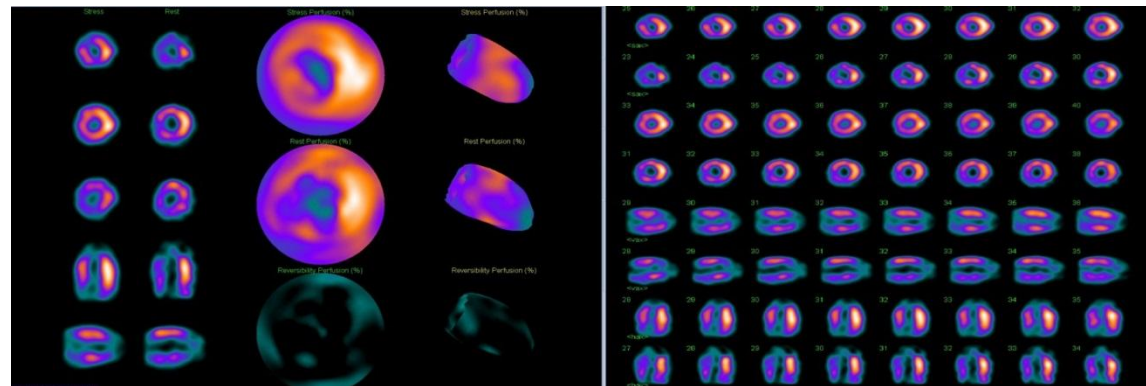
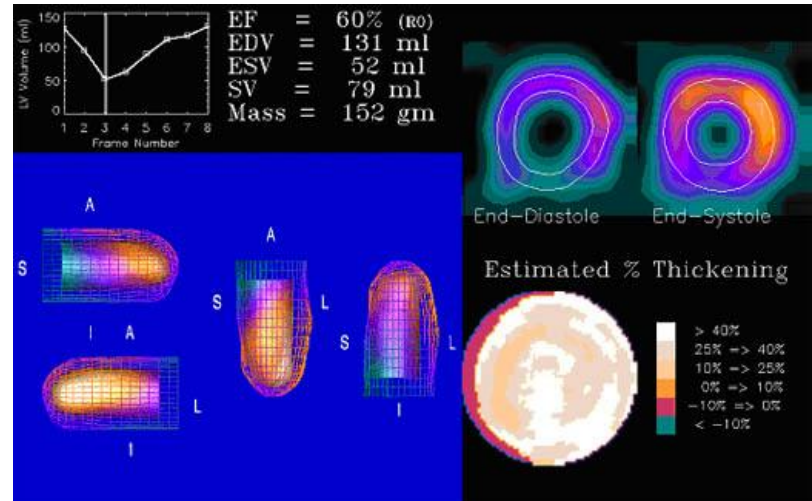
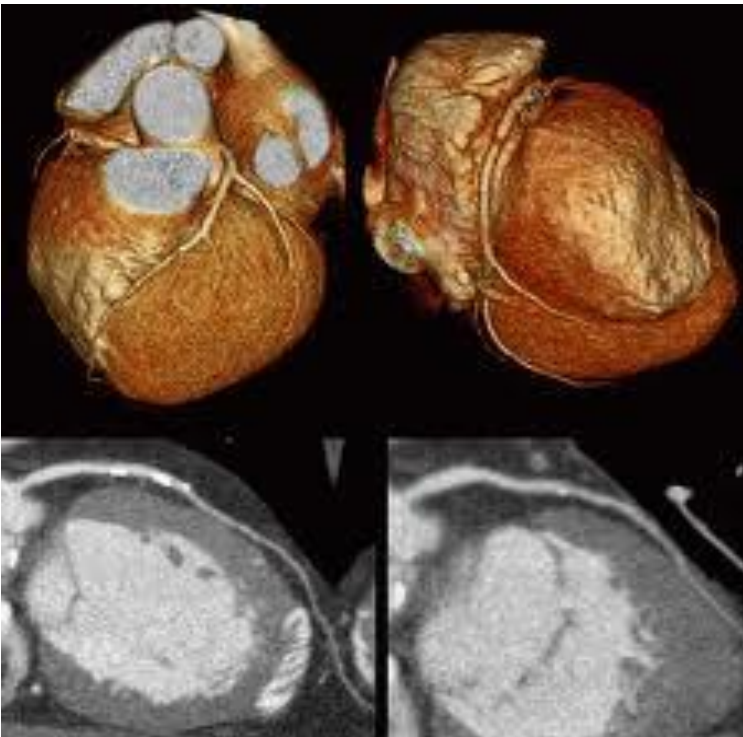
- Diabetic Retinopathy (DR) using Fundus Images
- Diabetic Maculopathy (DM) using Fundus Images
- Optical Coherence Tomography (OCT) analysis for detection of AMD
- Glaucoma Detection using Fundus Image
- Analysis of Fundus Images for detection of AMD



Telescreening System (National ICT R&D Funded Project)



CT Angiography and Thallium Scan Images





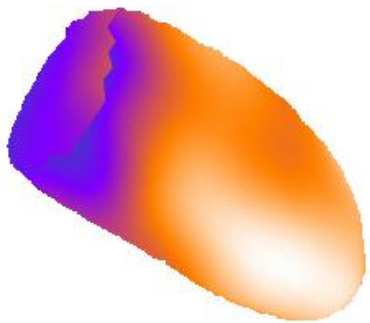
ACQUIRE DATASET
AND APPLY
MANUAL OVERLAP

ADD
TRANSPARENCY
ON THALLIUM

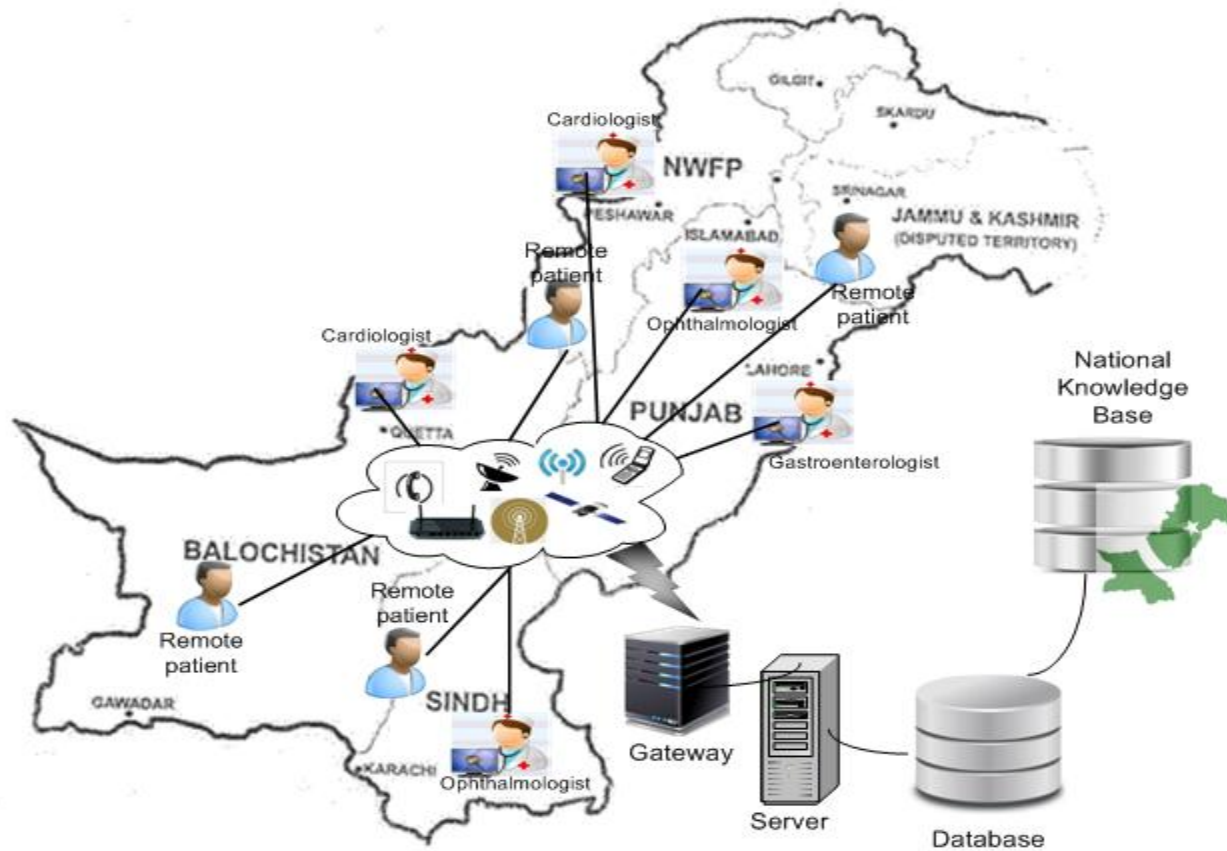
SCALING

TRANSLATION

CONCATENATION
AND FUSION



i-Hospital

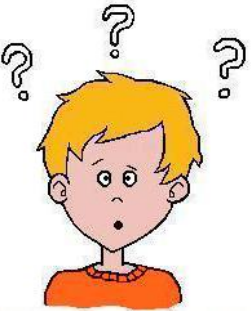


Summary of Applications

| 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)



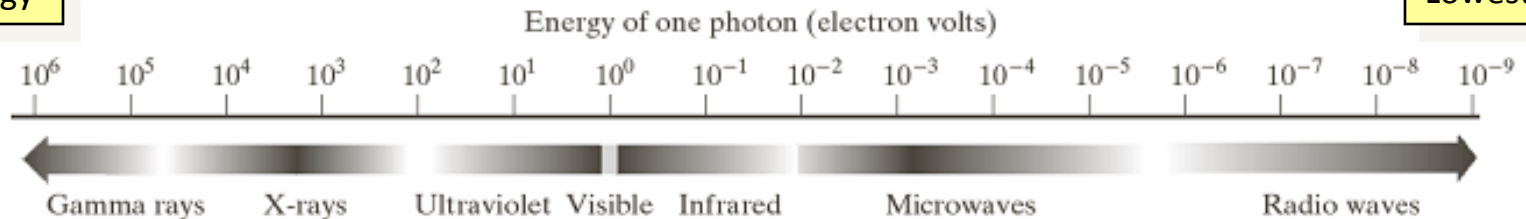
Light & EM Spectrum

- 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

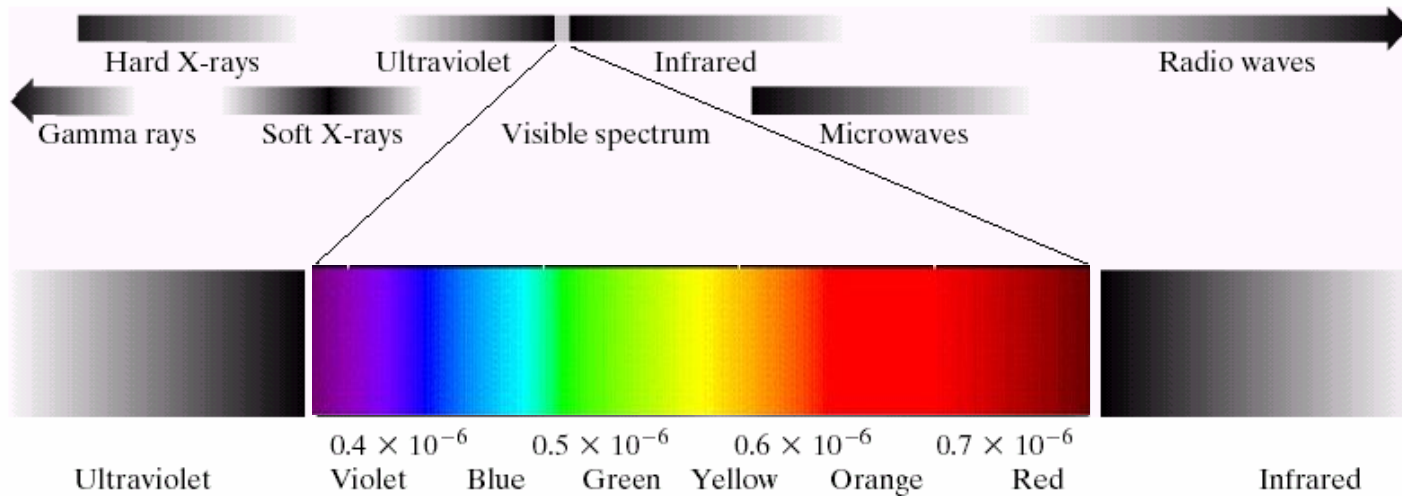
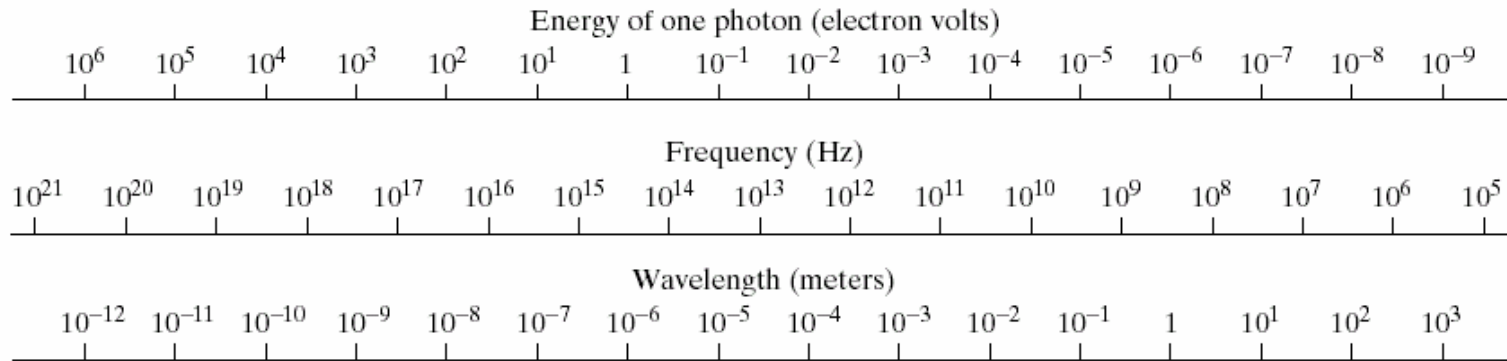
Highest Energy

Lowest Energy



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

Light & EM Spectrum

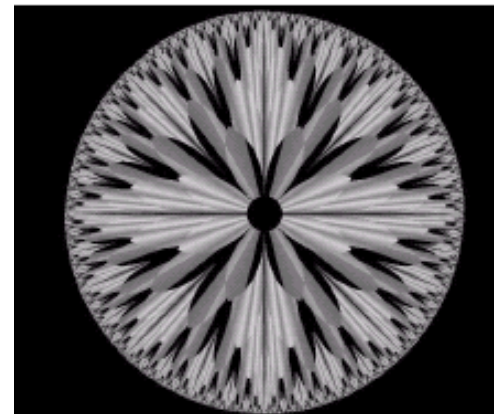


Examples: Imaging in EM bands

| 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 |

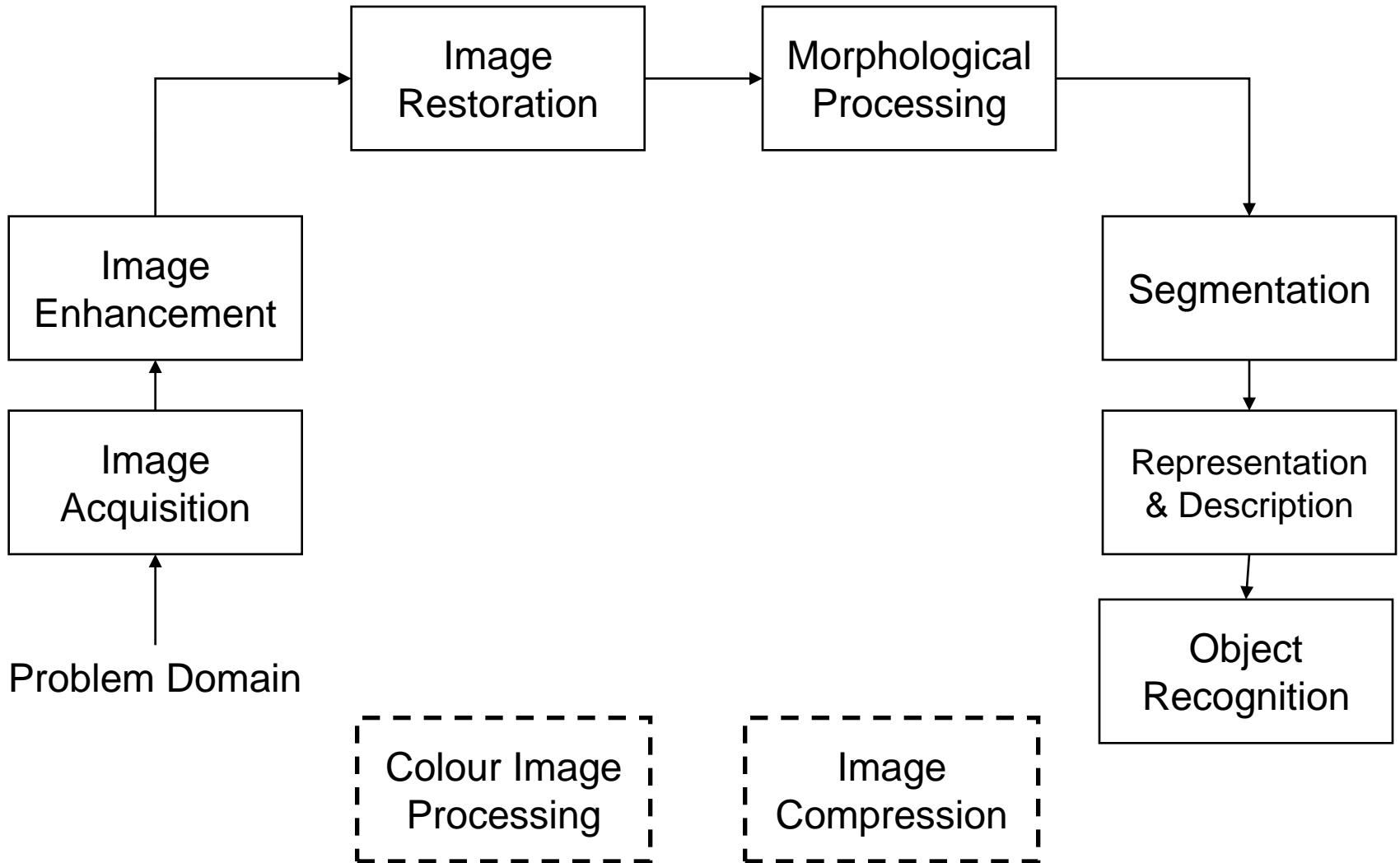
Examples: Imaging other Modalities

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

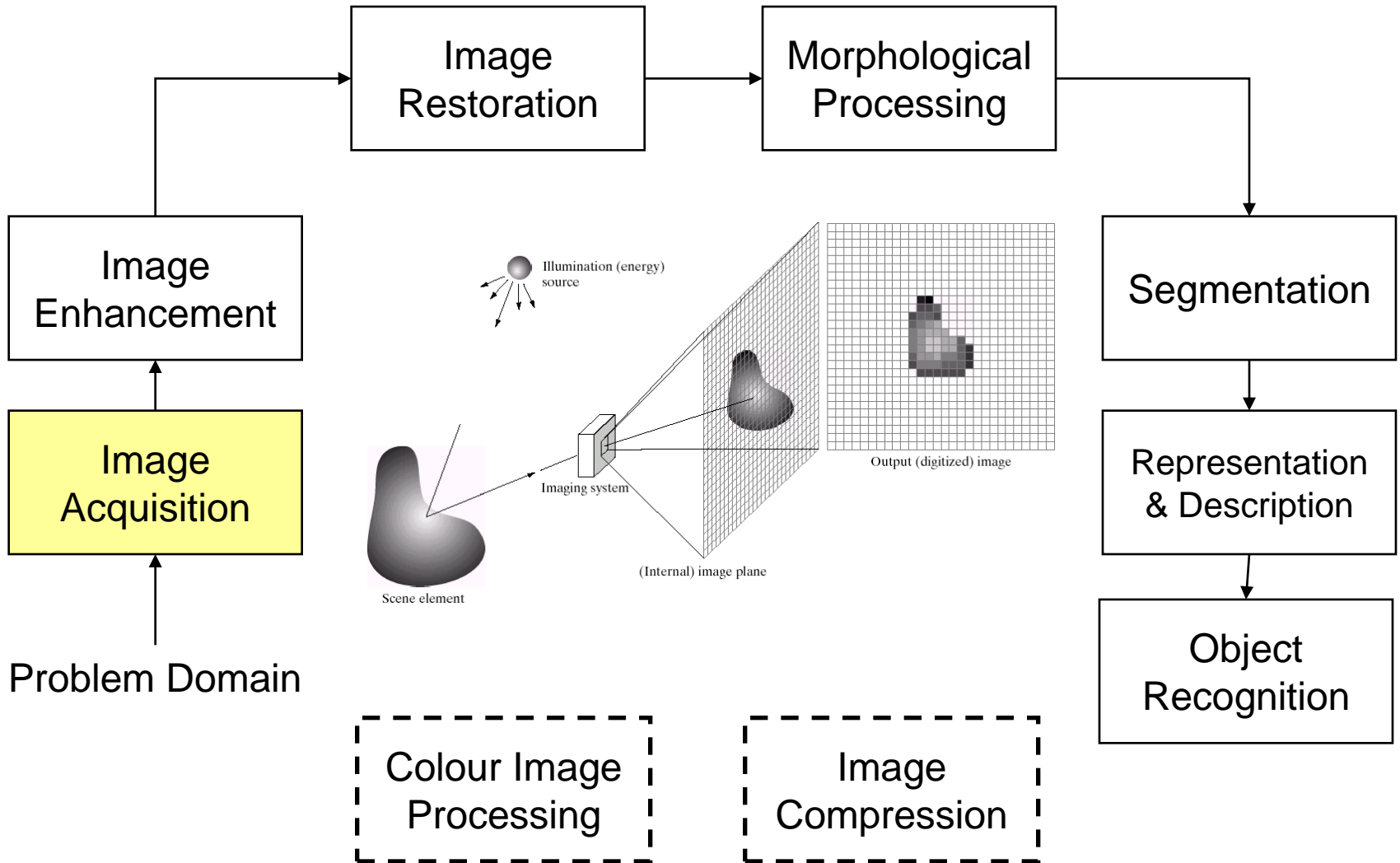


A synthetic image

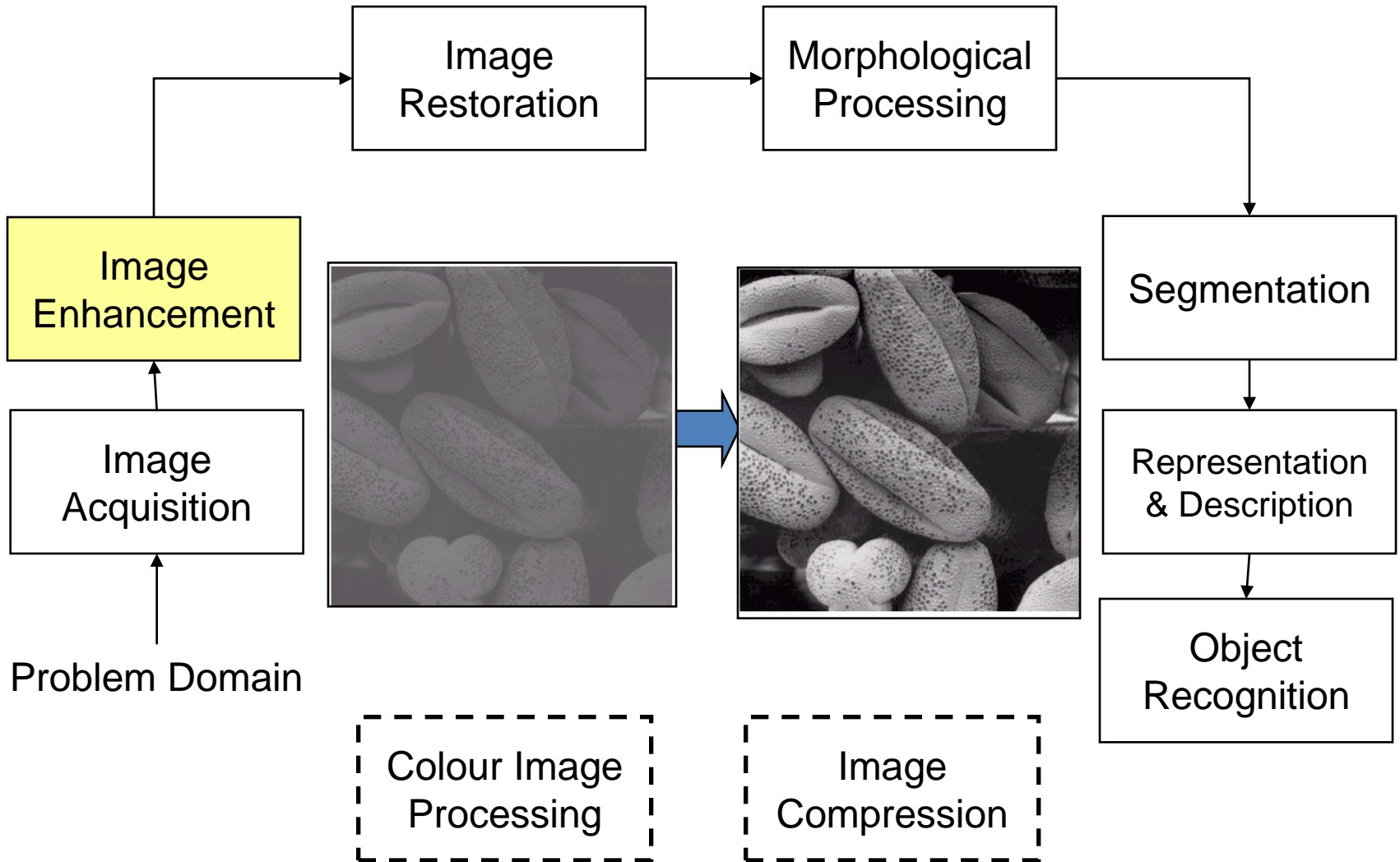
Key Stages in DIP



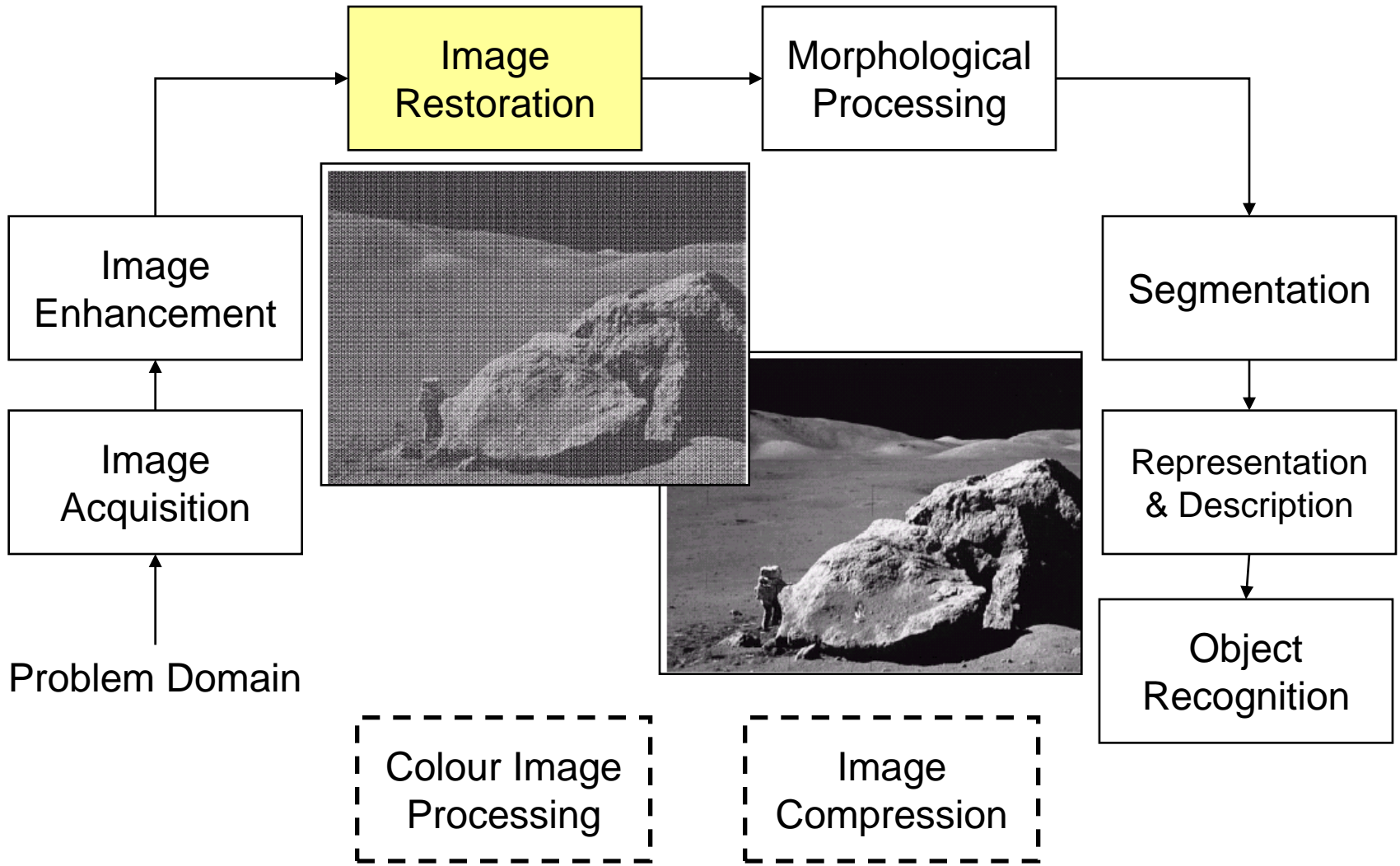
Key Stages in DIP



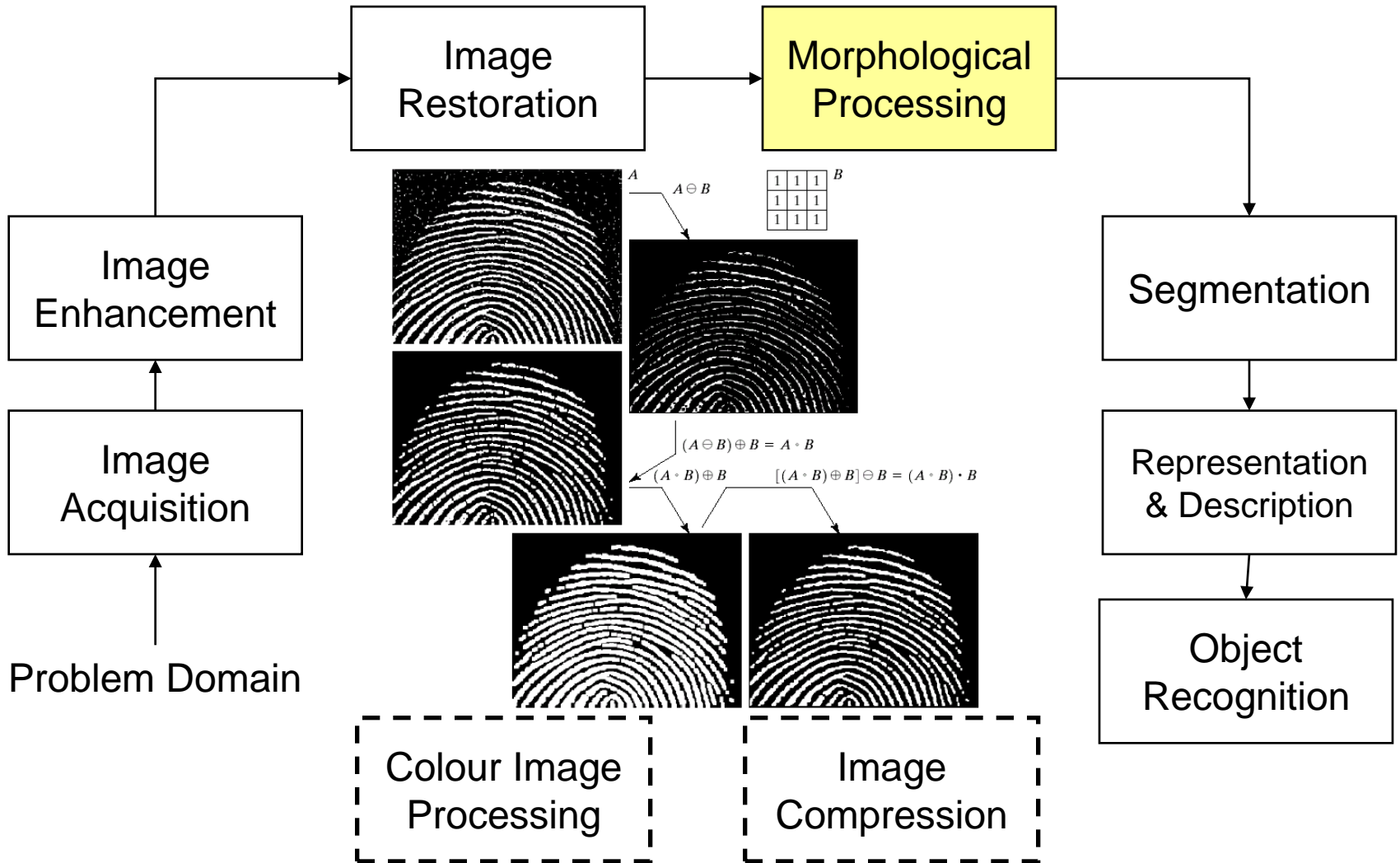
Key Stages in DIP



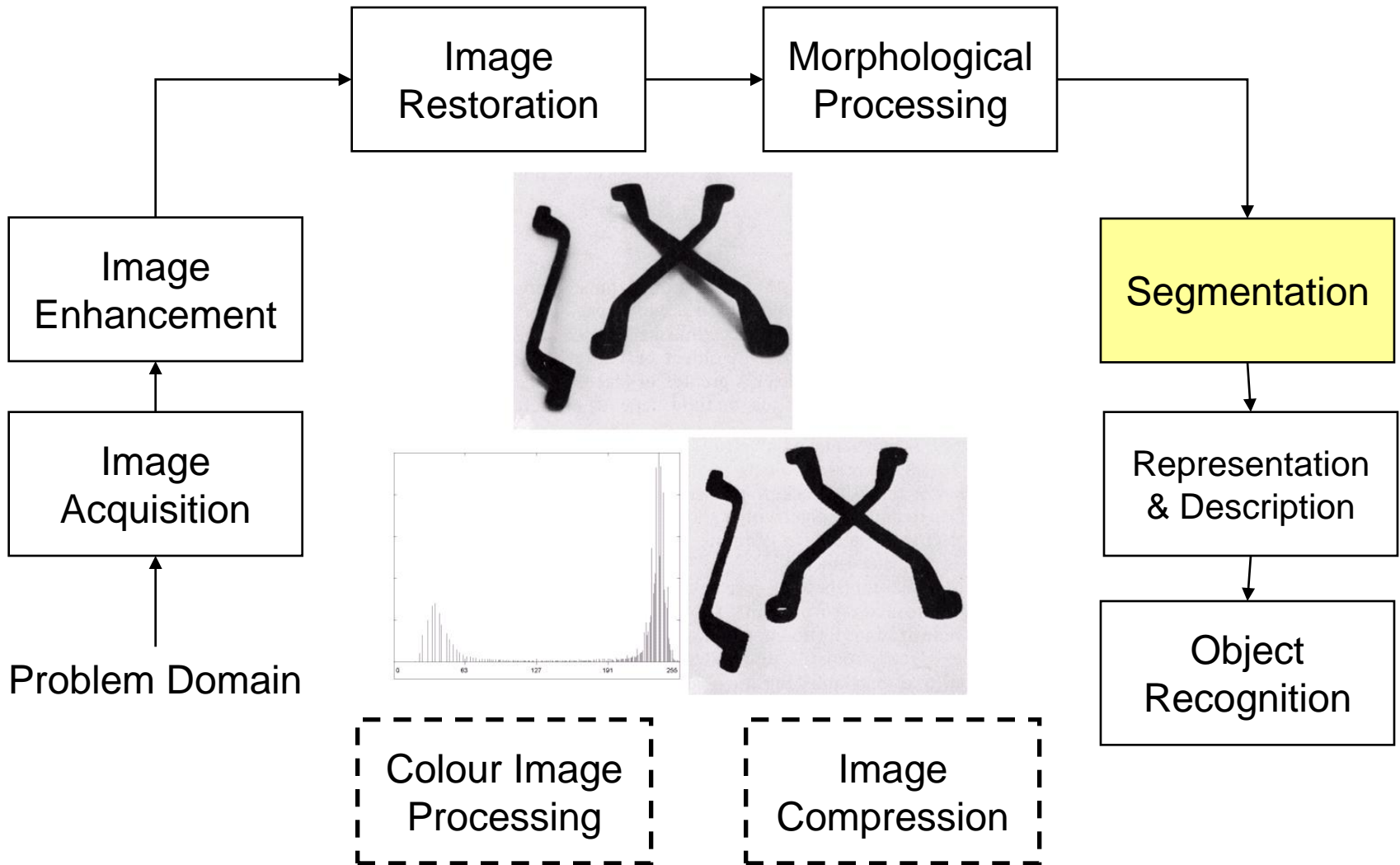
Key Stages in DIP



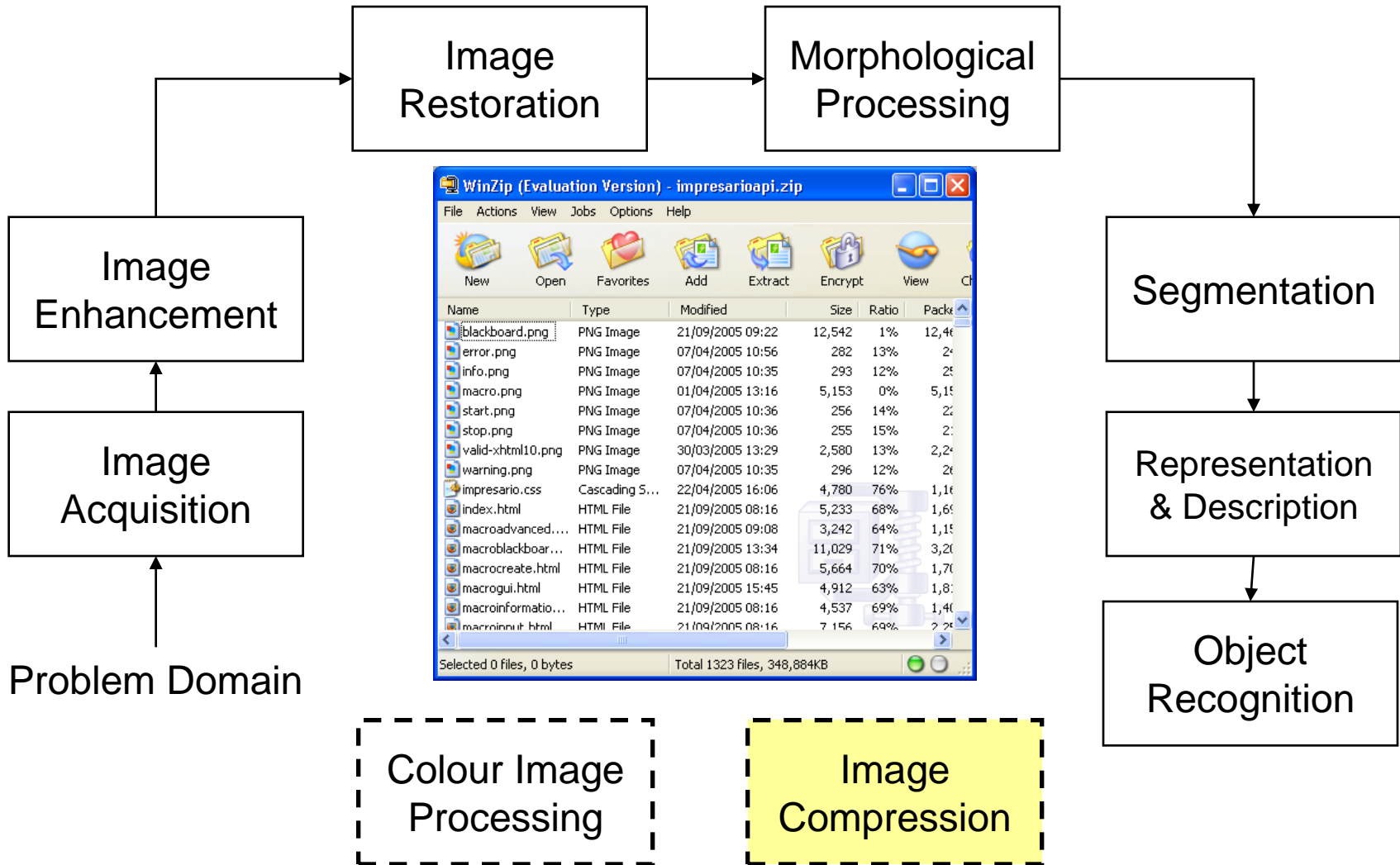
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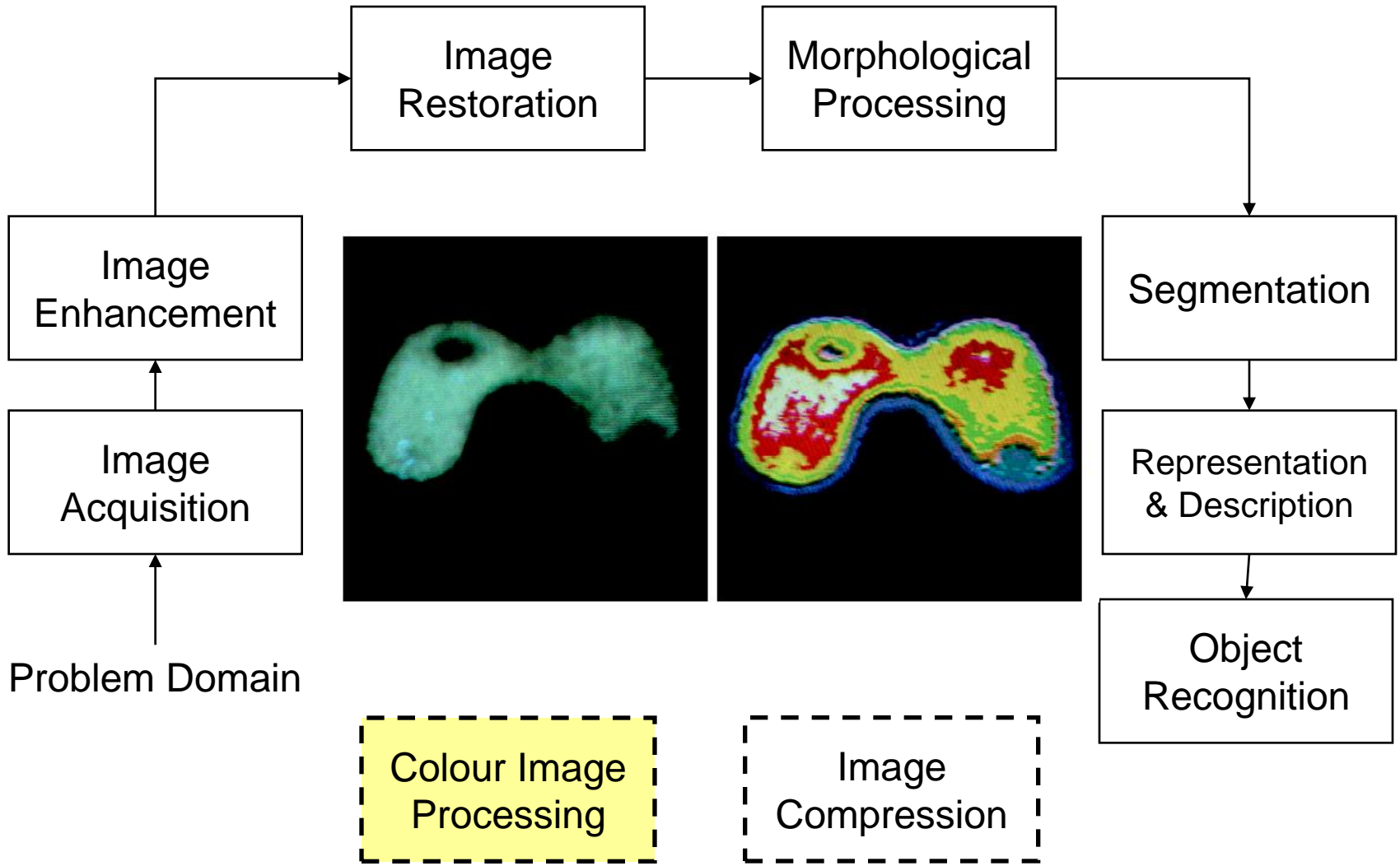
Key Stages in DIP



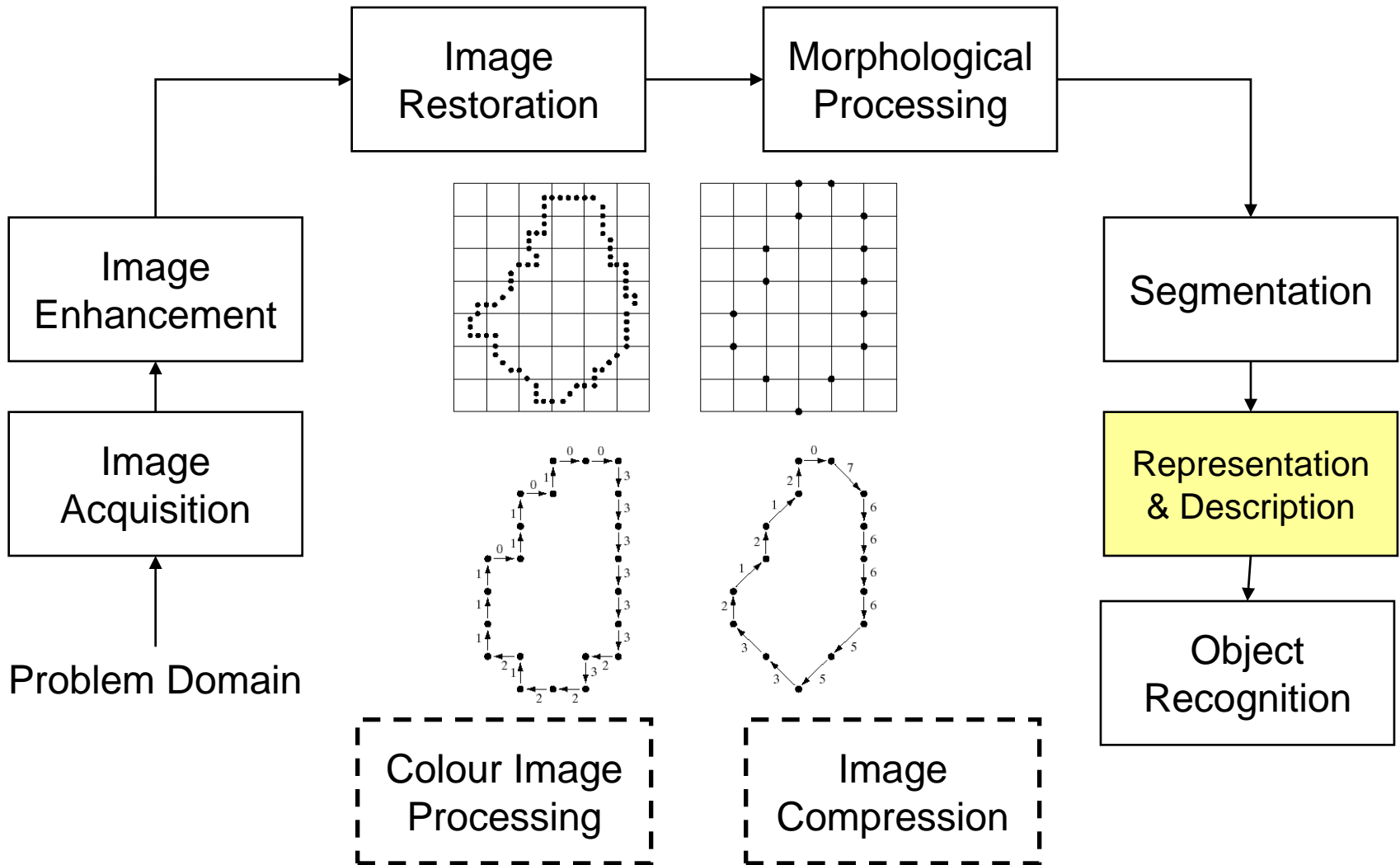
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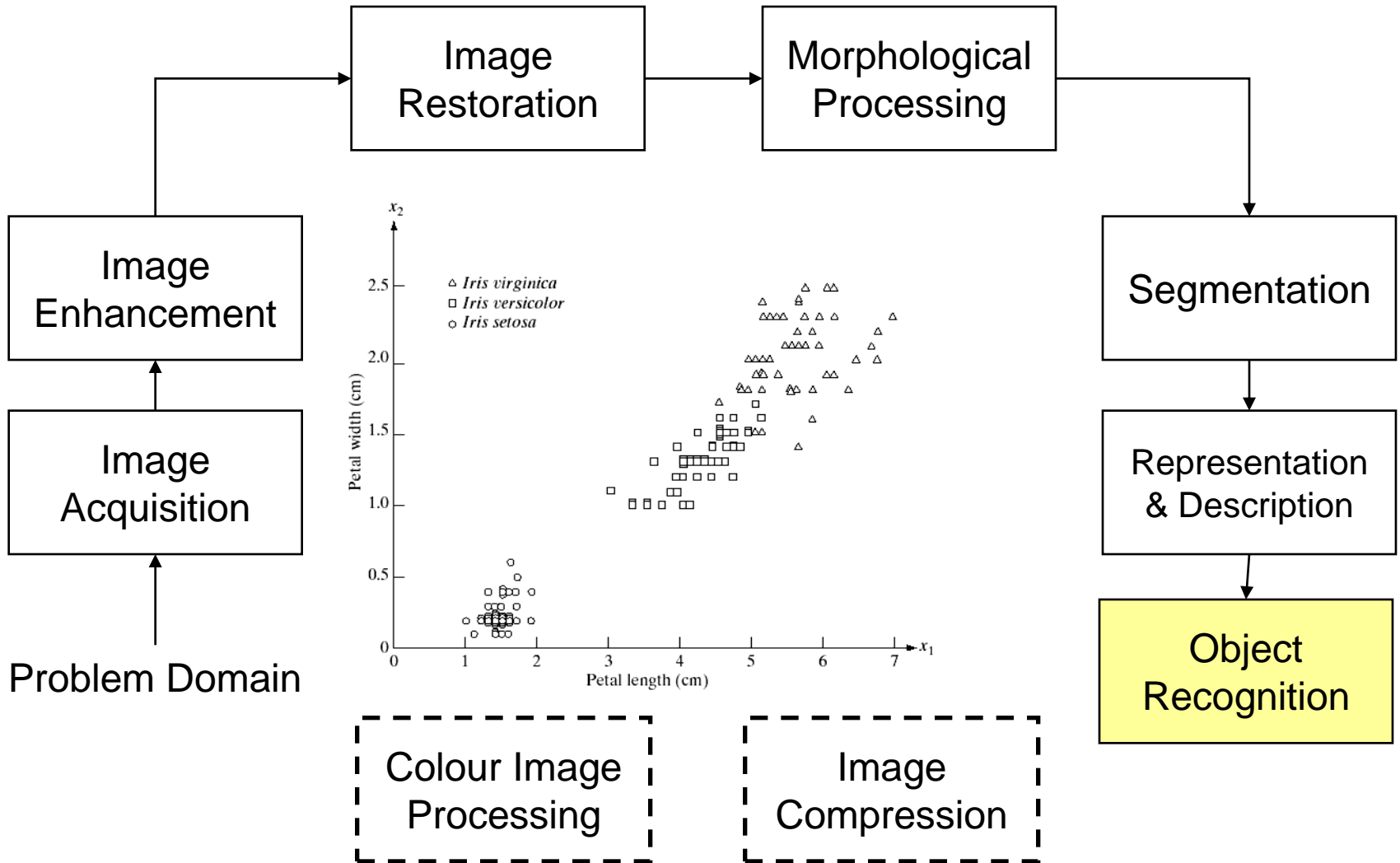
Key Stages in DIP



Key Stages in DIP



Key Stages in DIP

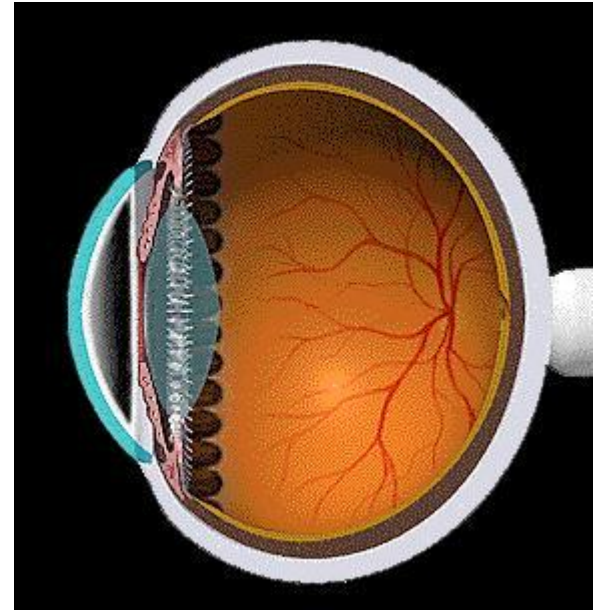
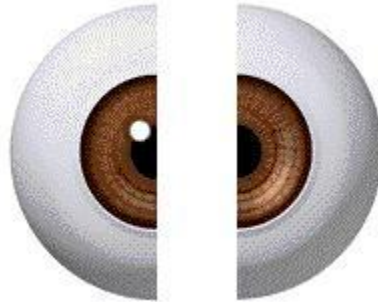


Human and Image Perception

- 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.

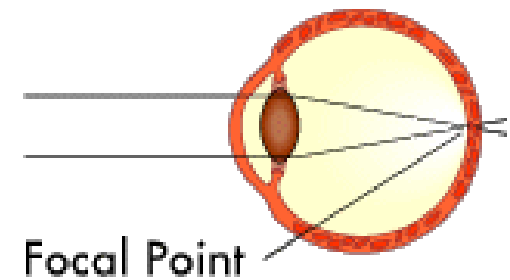
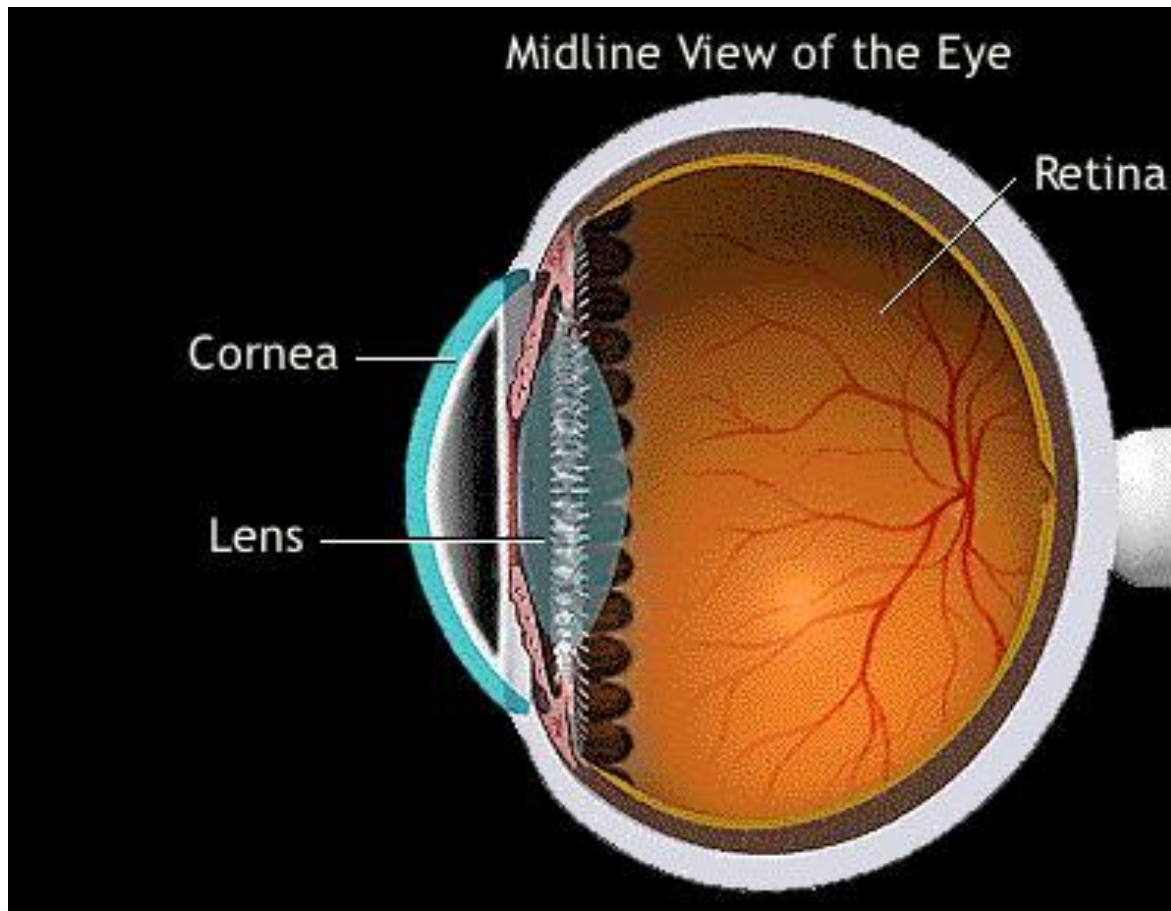
Human and Image Perception

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



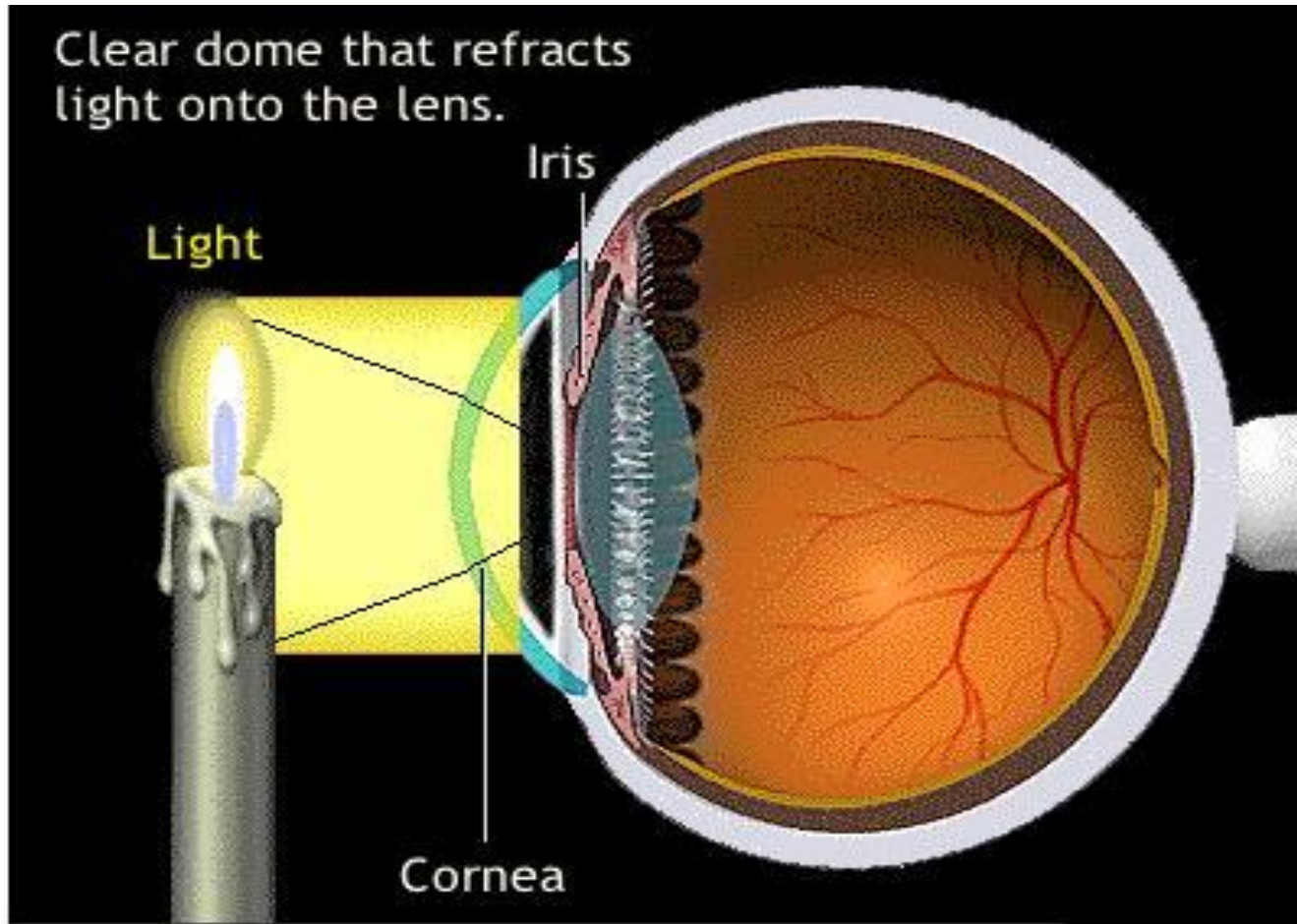
Human and Image Perception

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

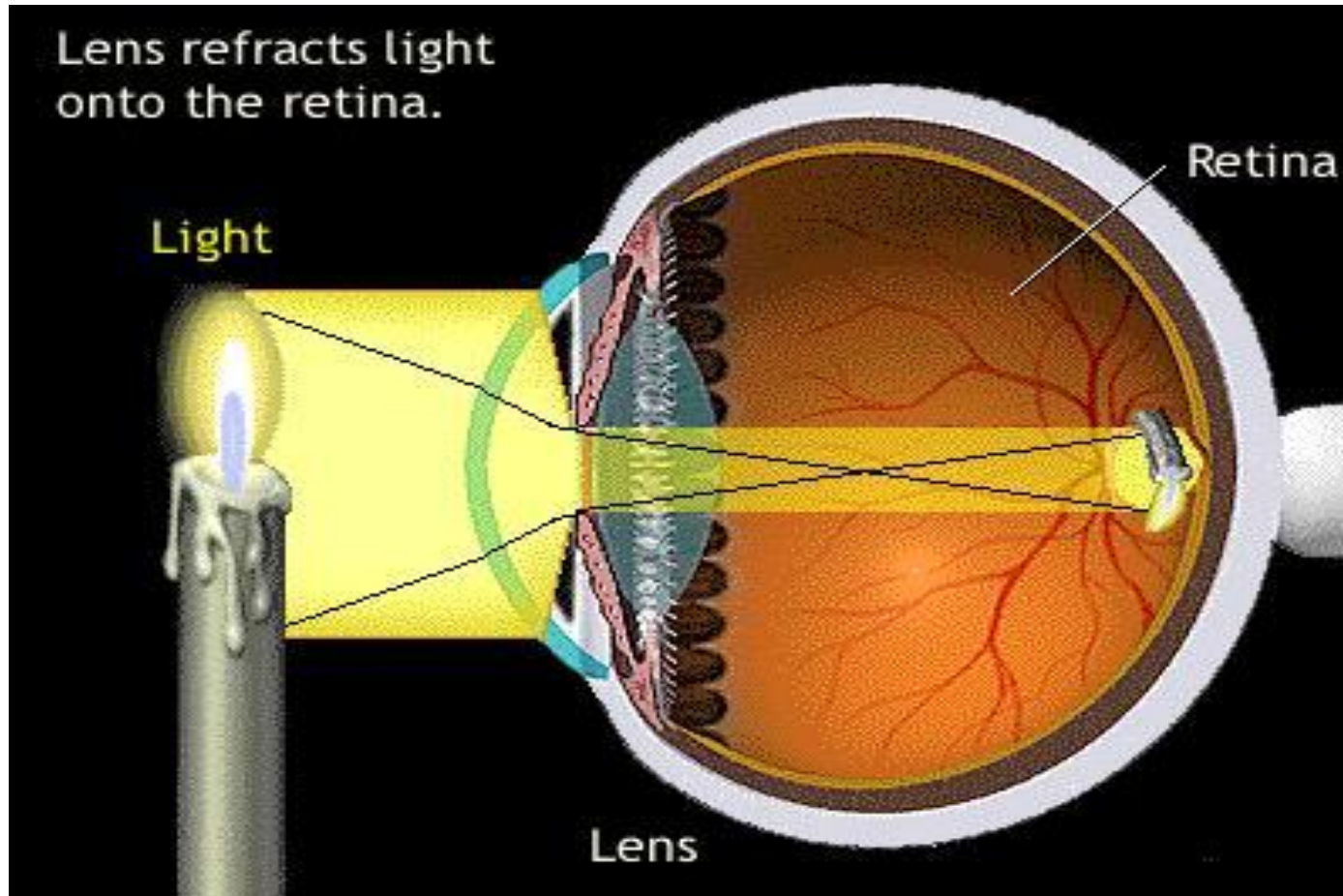


Human and Image Perception

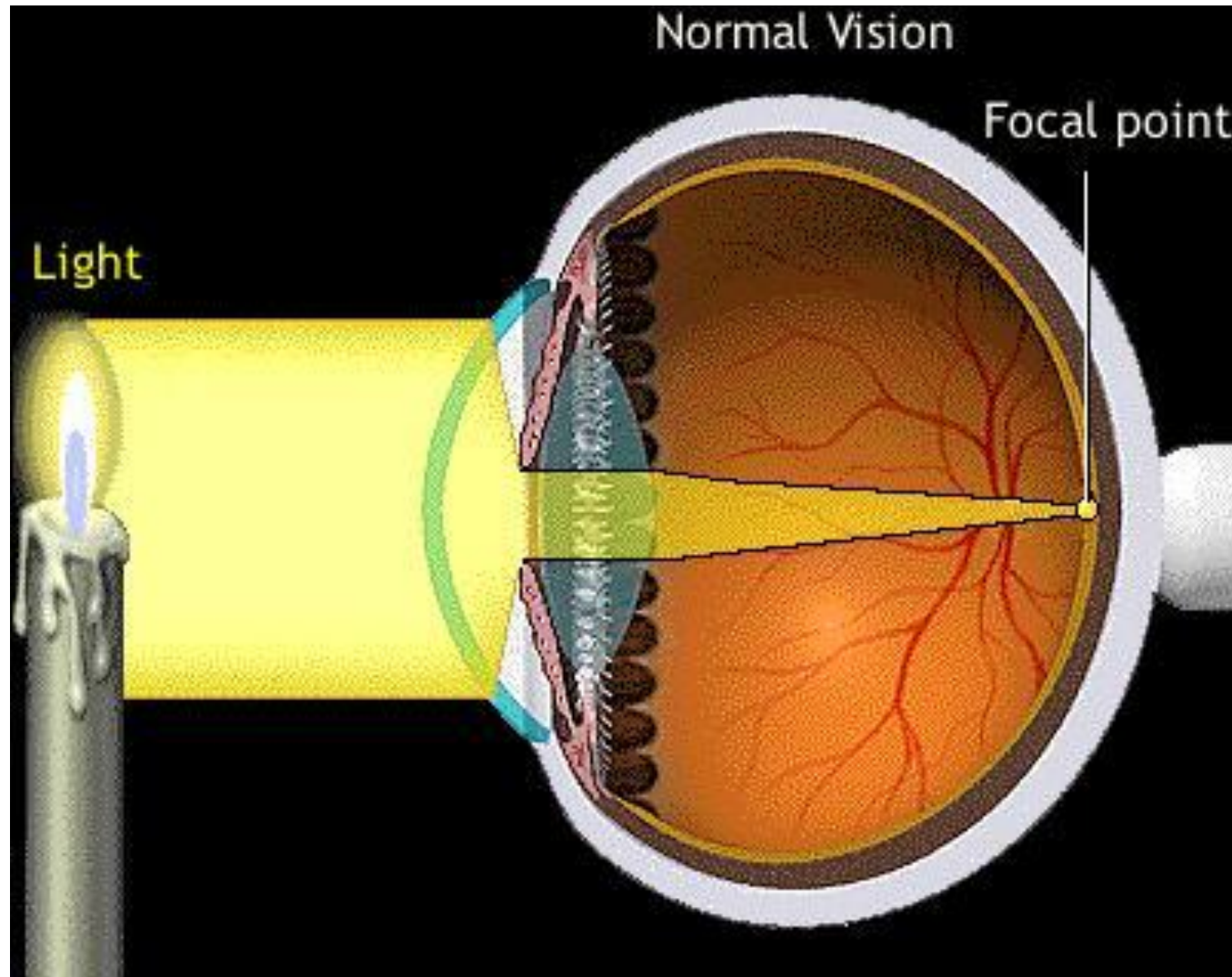
How eye focuses



Human and Image Perception



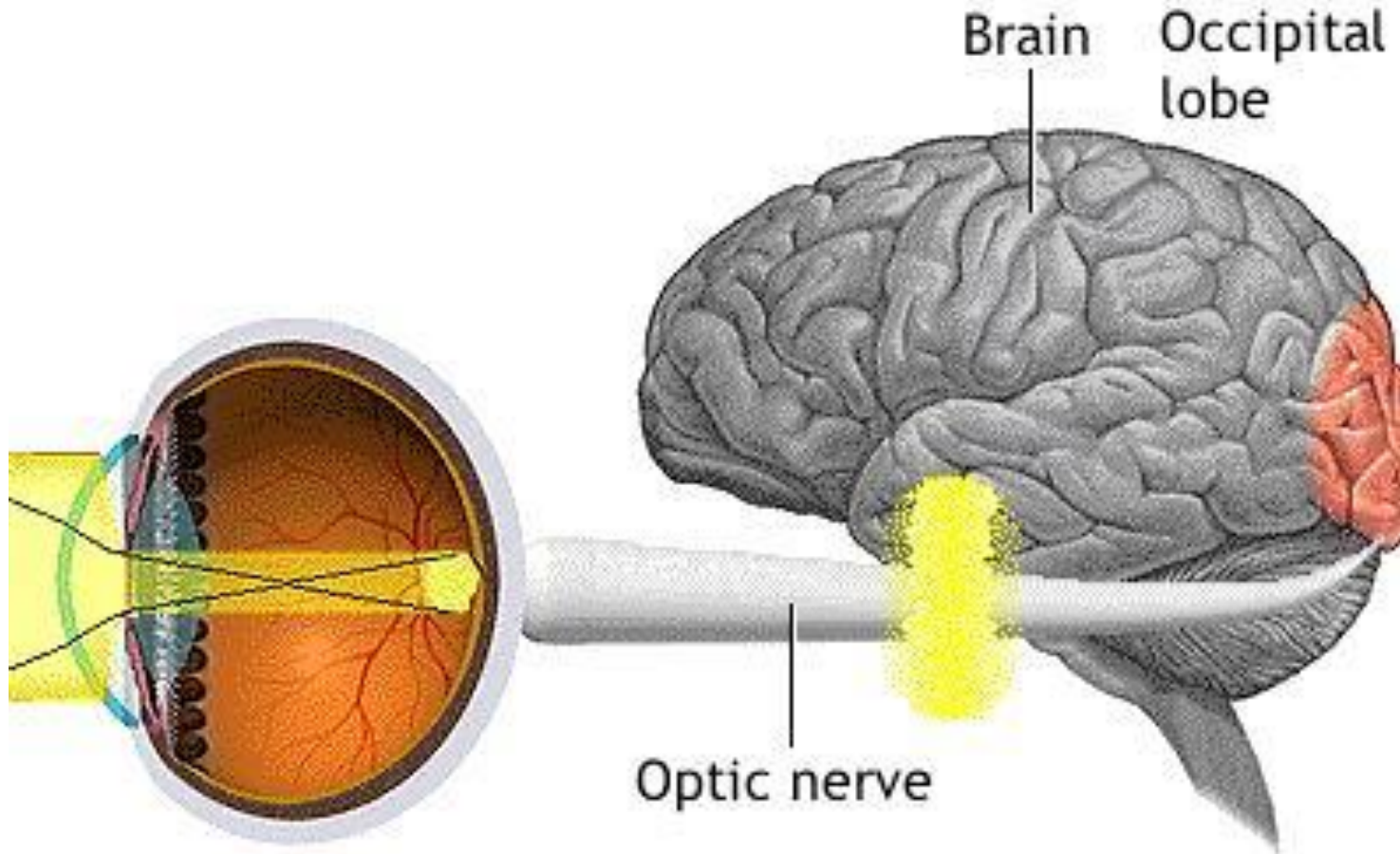
How eye focuses: Normal Vision-Focusing on the Retina



From Eye to the Brain

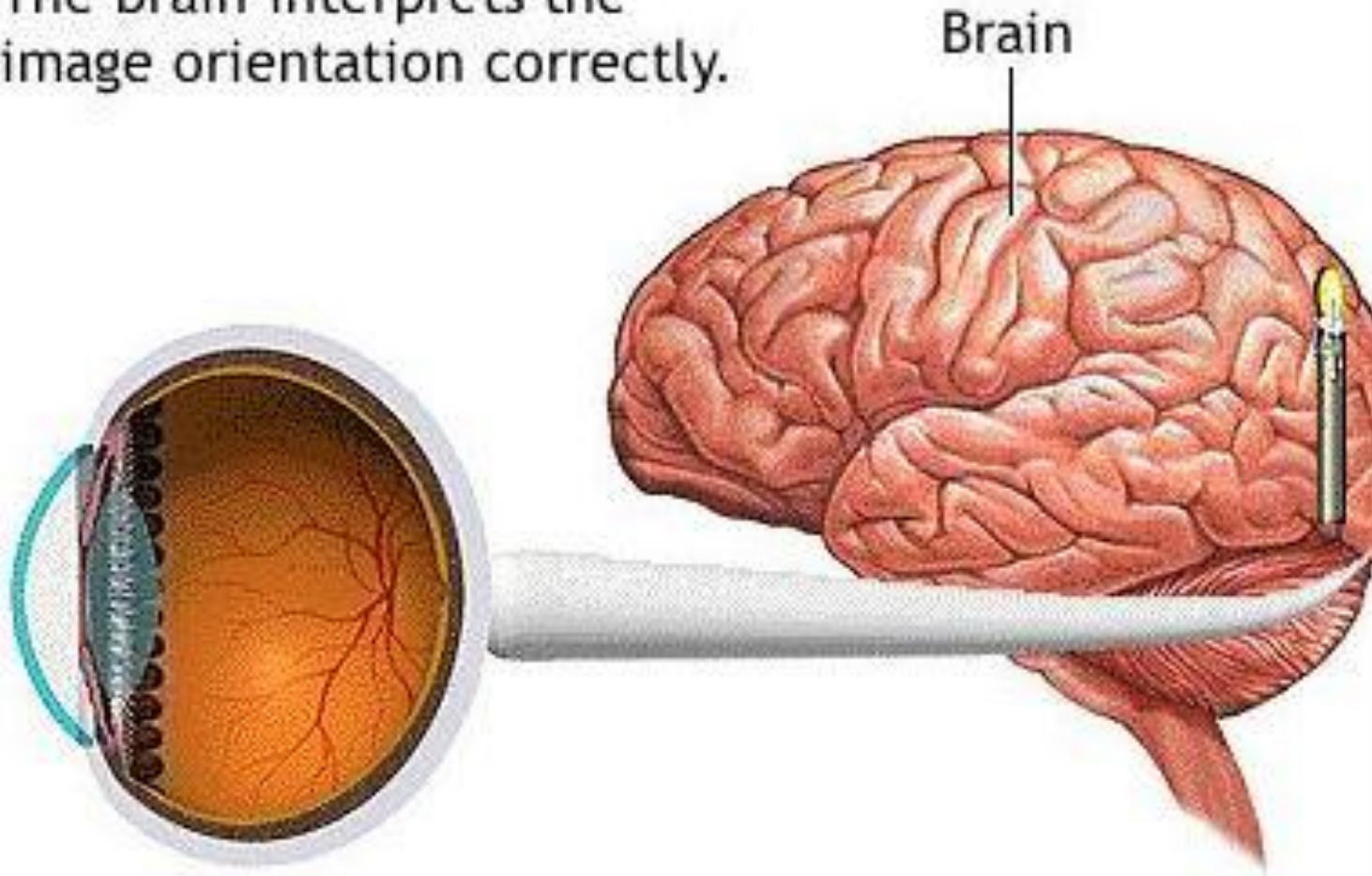
How does our brain receive this information?

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

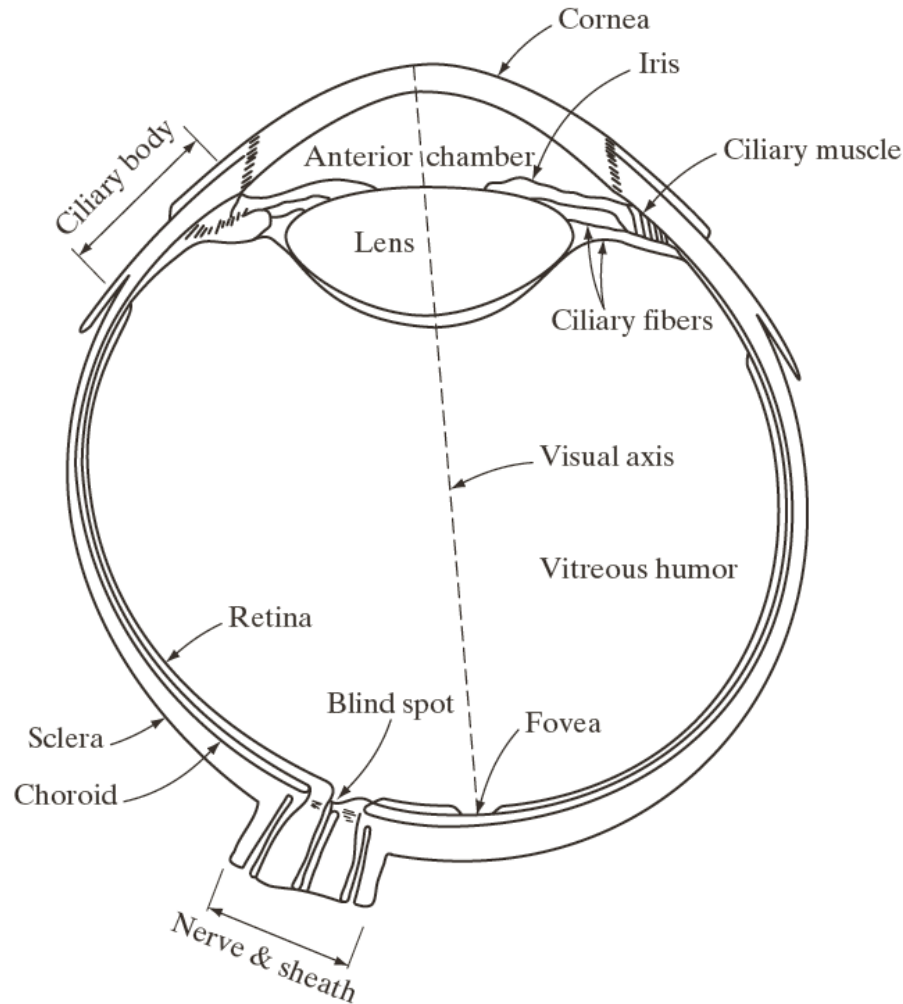
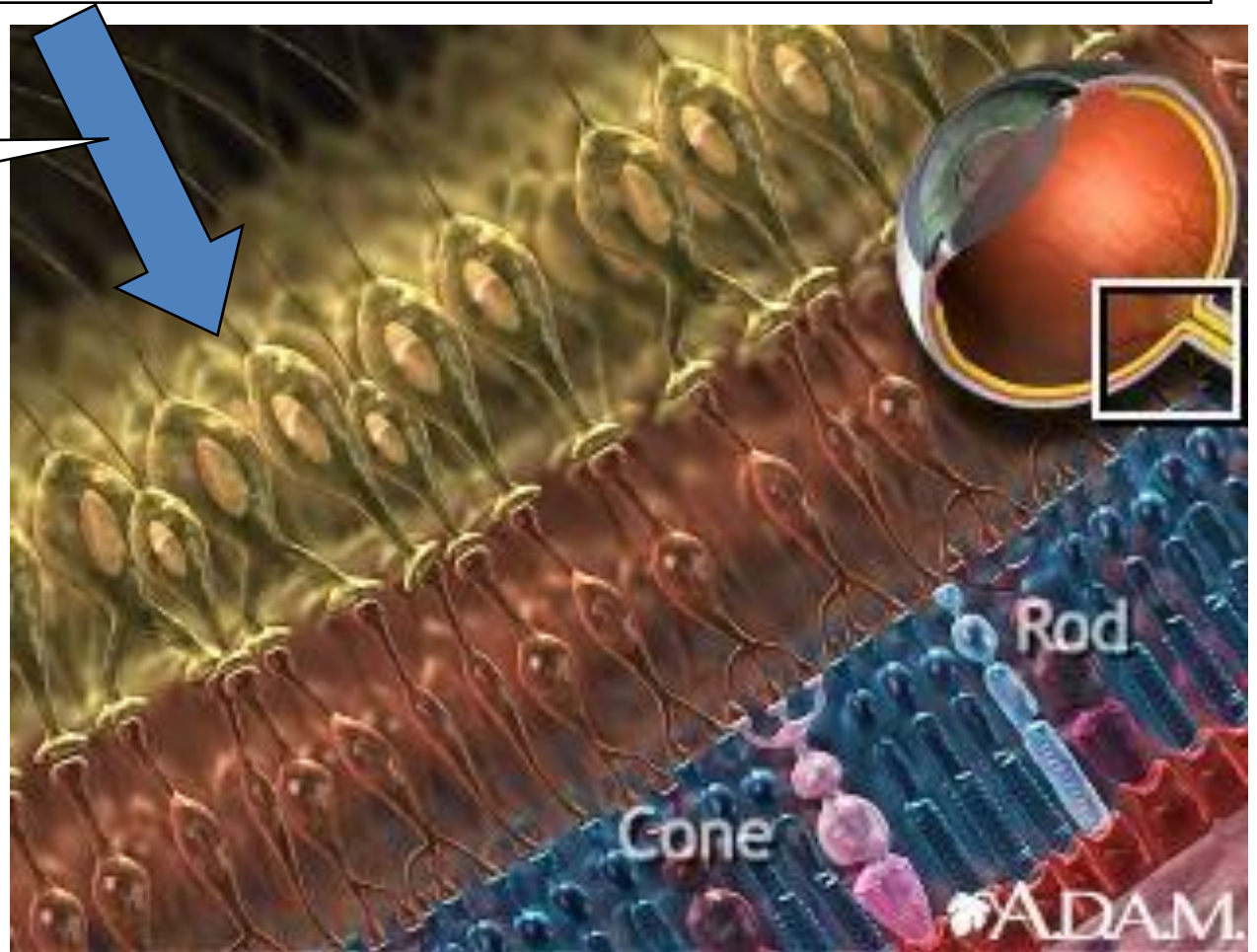


FIGURE 2.1
Simplified
diagram of a cross
section of the
human eye.

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

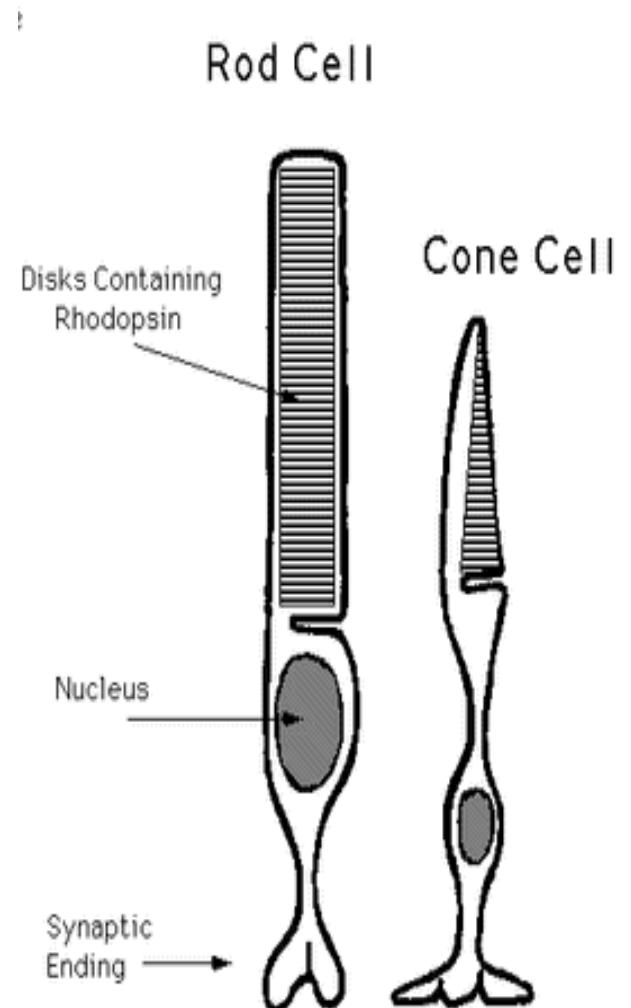


What happens when light reaches the retina?

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

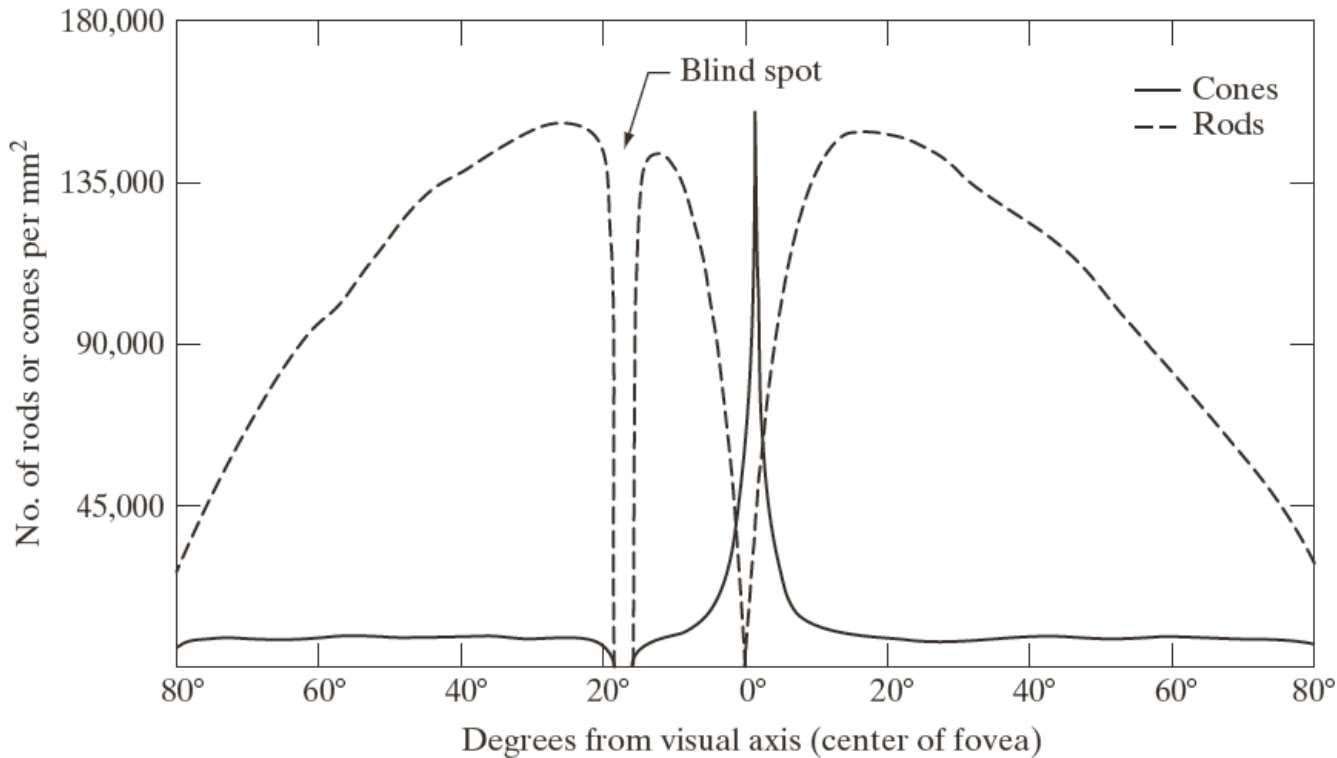
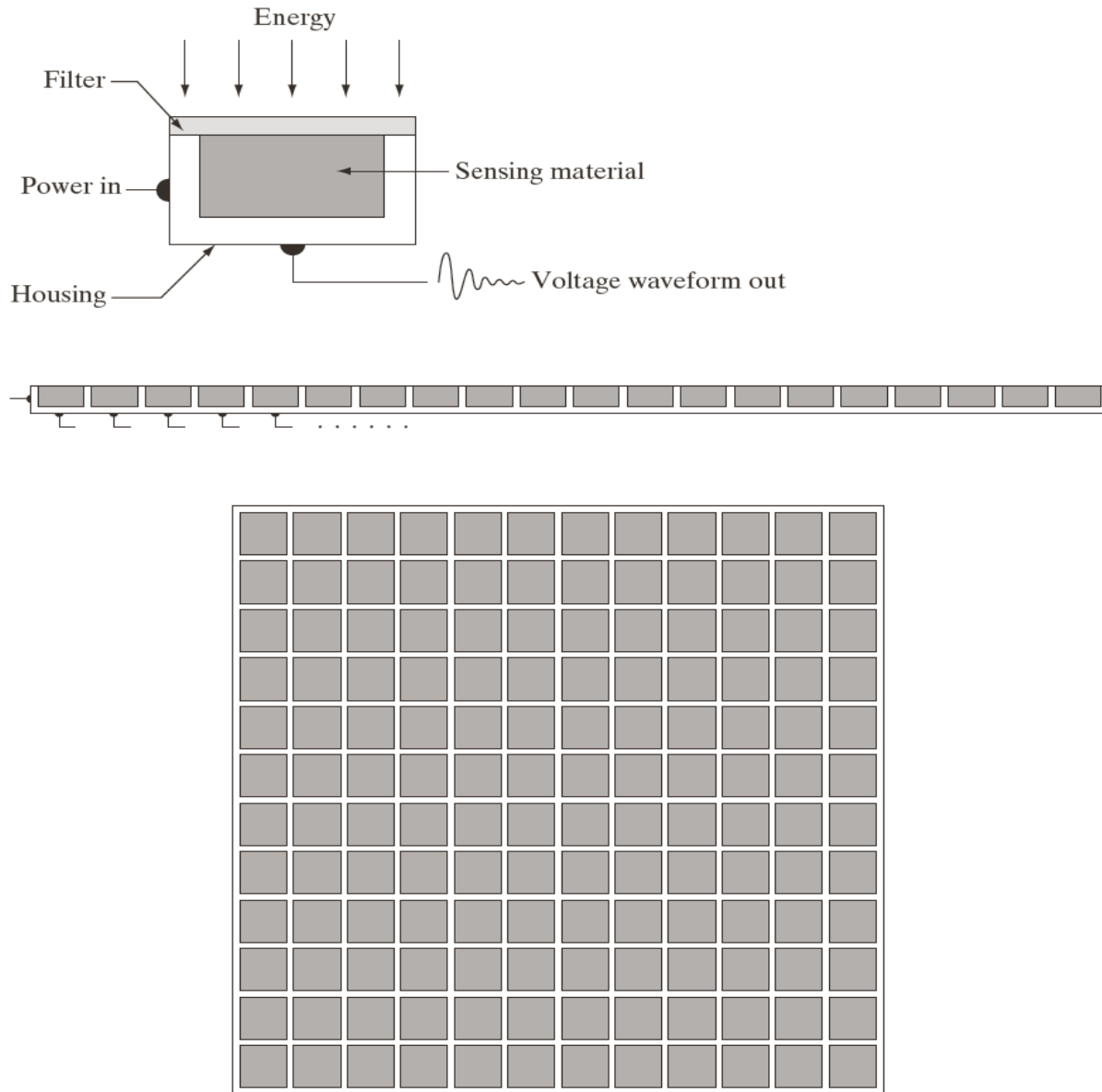


FIGURE 2.2
Distribution of rods and cones in the retina.

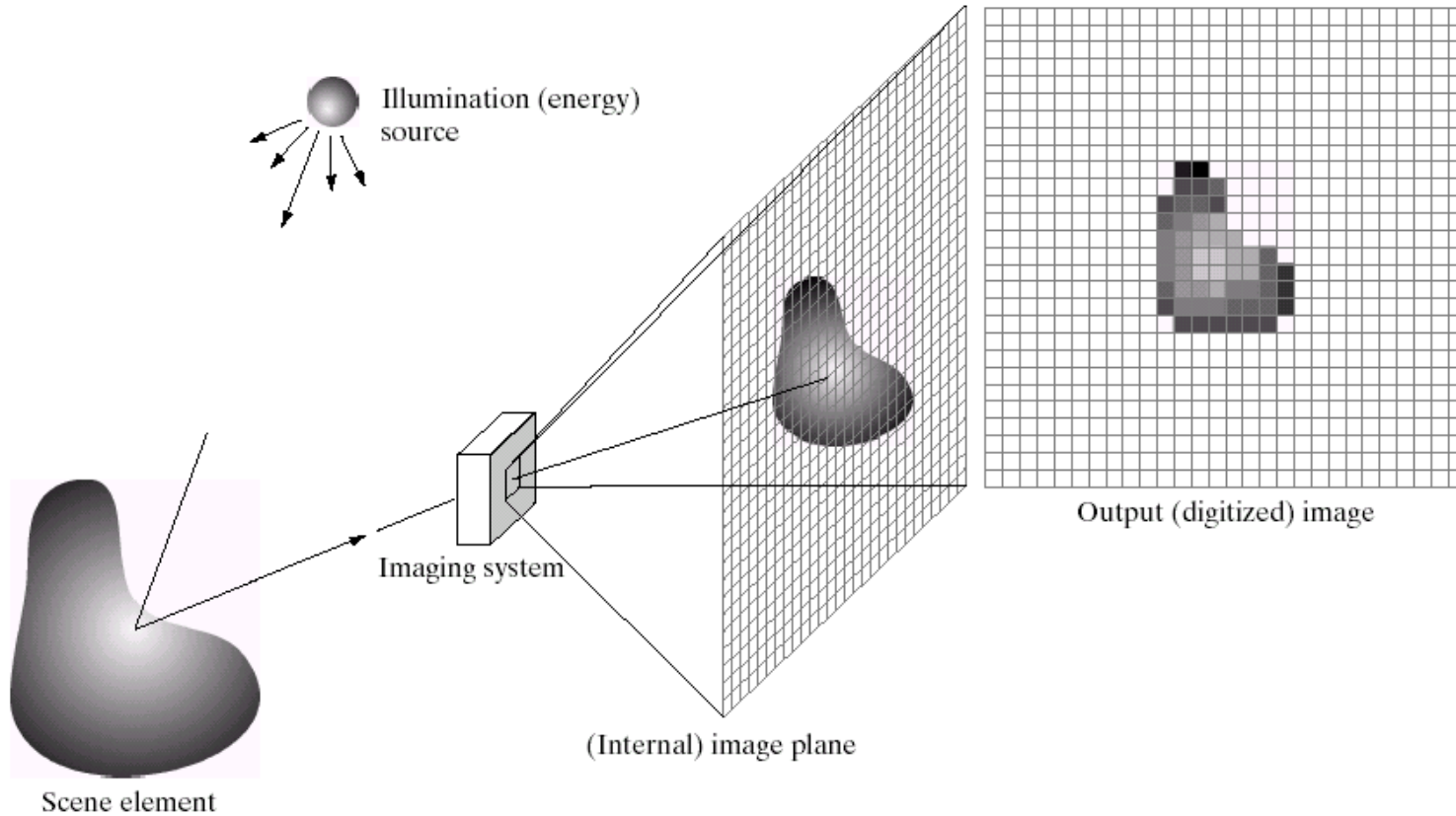
Image Acquisition



a
b
c

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

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

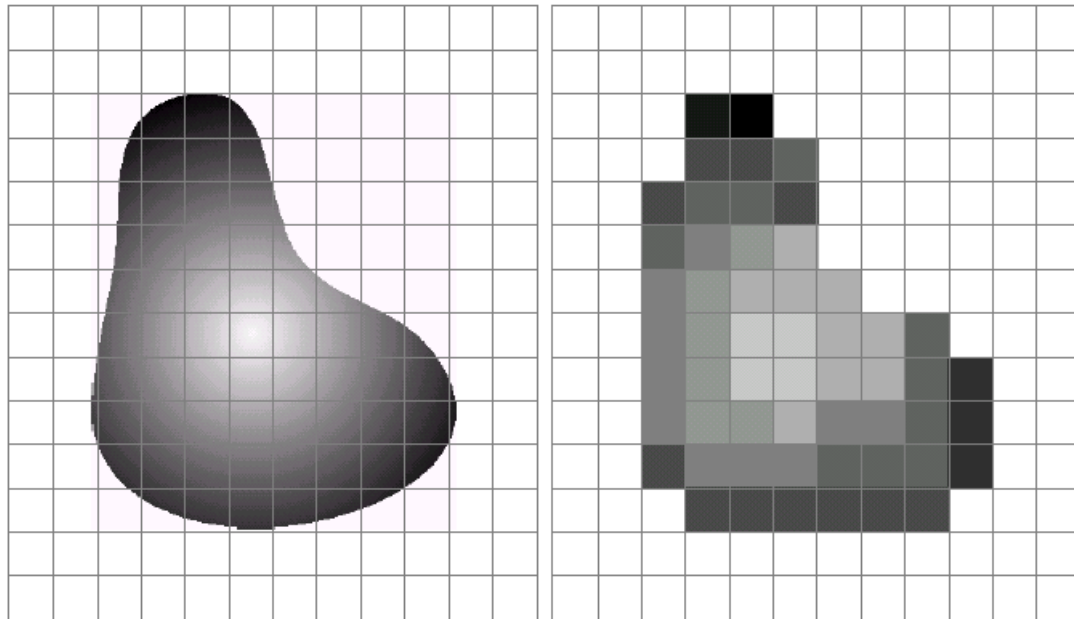
- 8 bit quantization: $2^8 = 256$ gray levels (0: black, 255: white)
- 1 bit quantization: 2 gray levels (0: black, 1: white) – binary

◆ Sampling

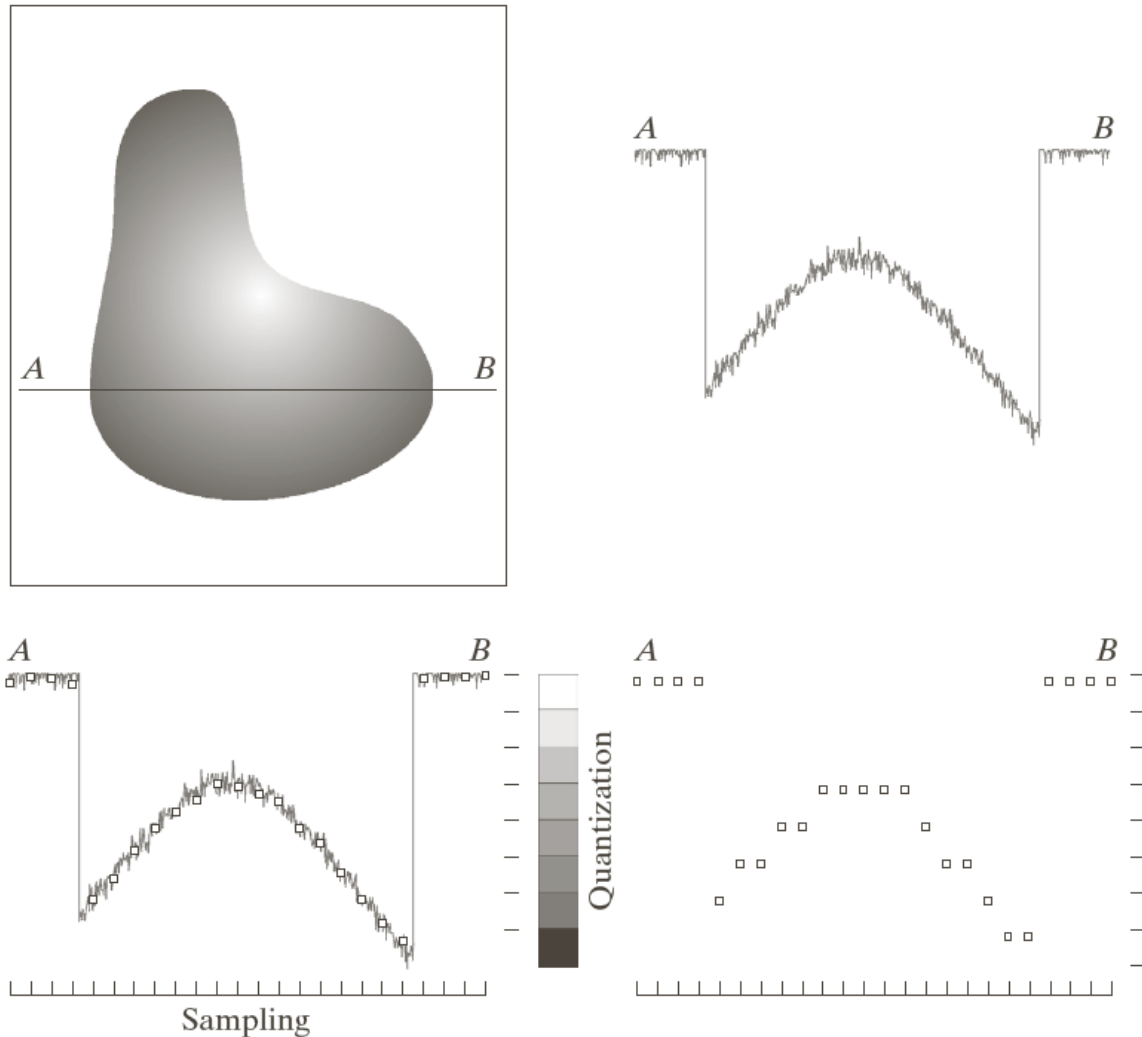
- Commonly used number of samples (resolution)
 - Digital still cameras: 640x480, 1024x1024, 4064 x 2704
 - Digital video cameras: 640x480 at 30 frames/second (fps)

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

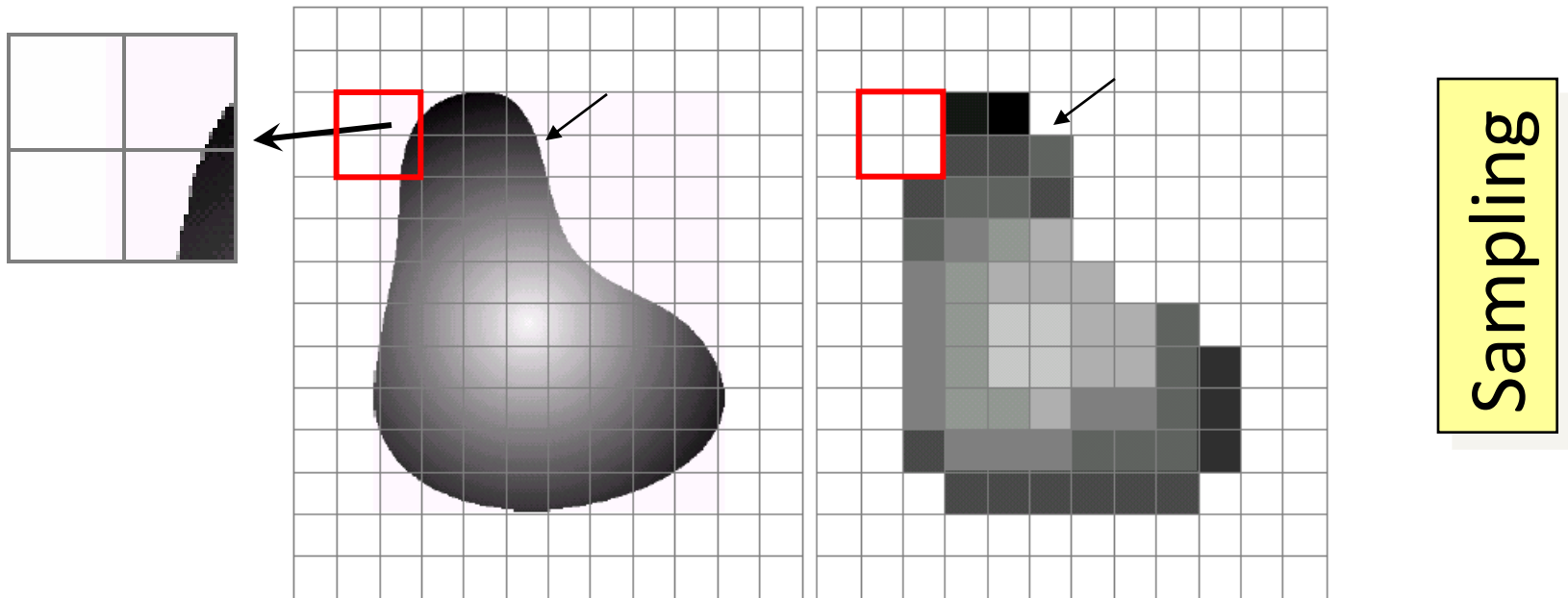
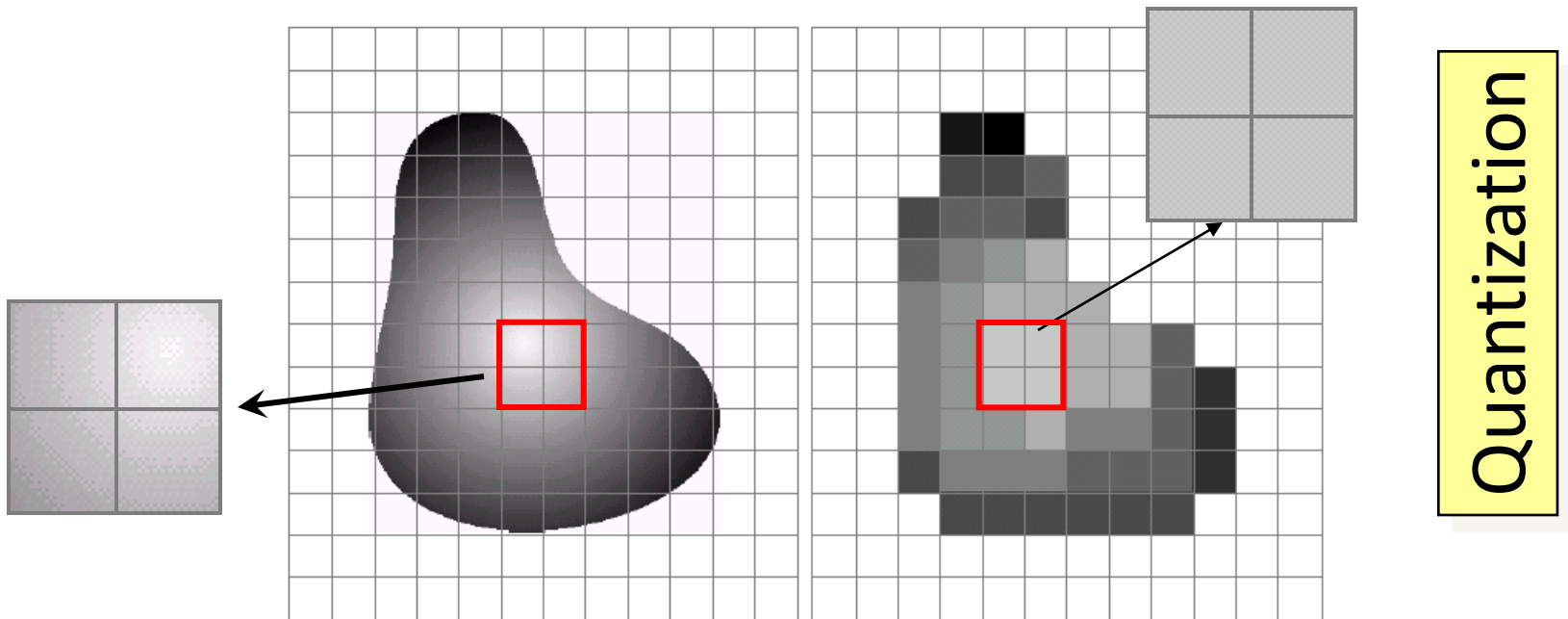
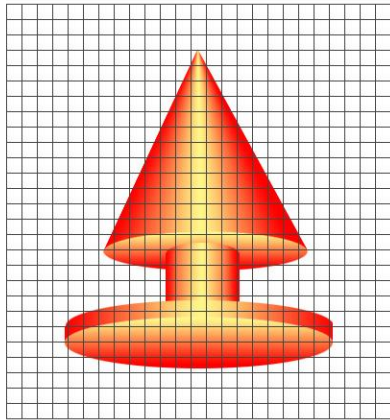


Image Formation

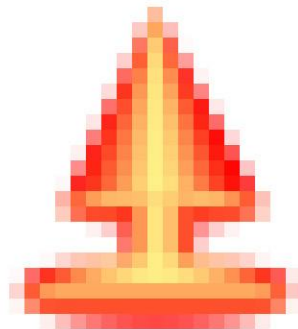
- ◆ Digital Image is an approximation of a real world scene



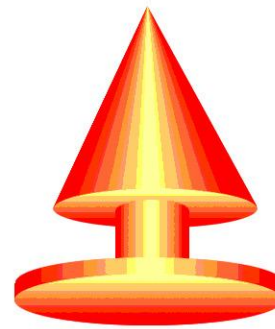
Sampling and Quantization



real image



sampled

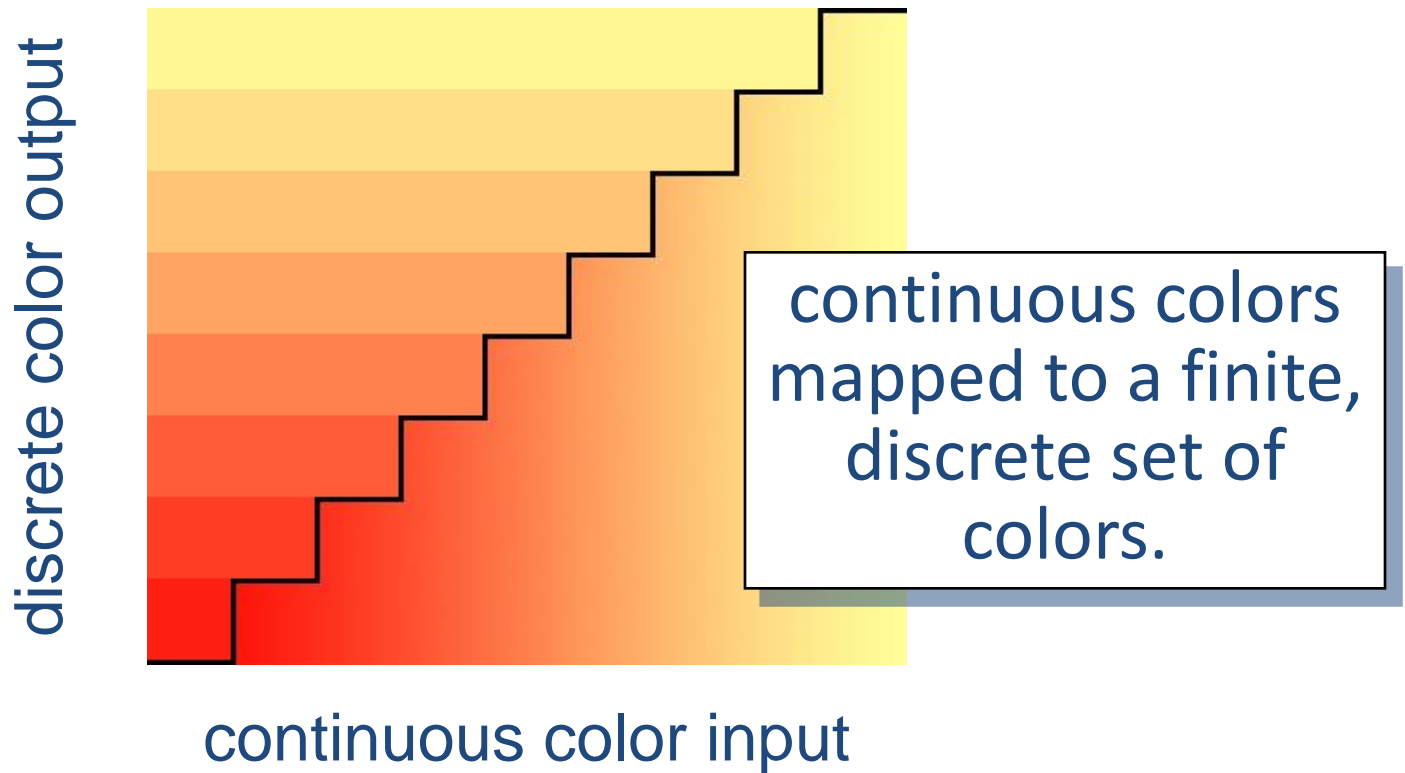


quantized



sampled &
quantized

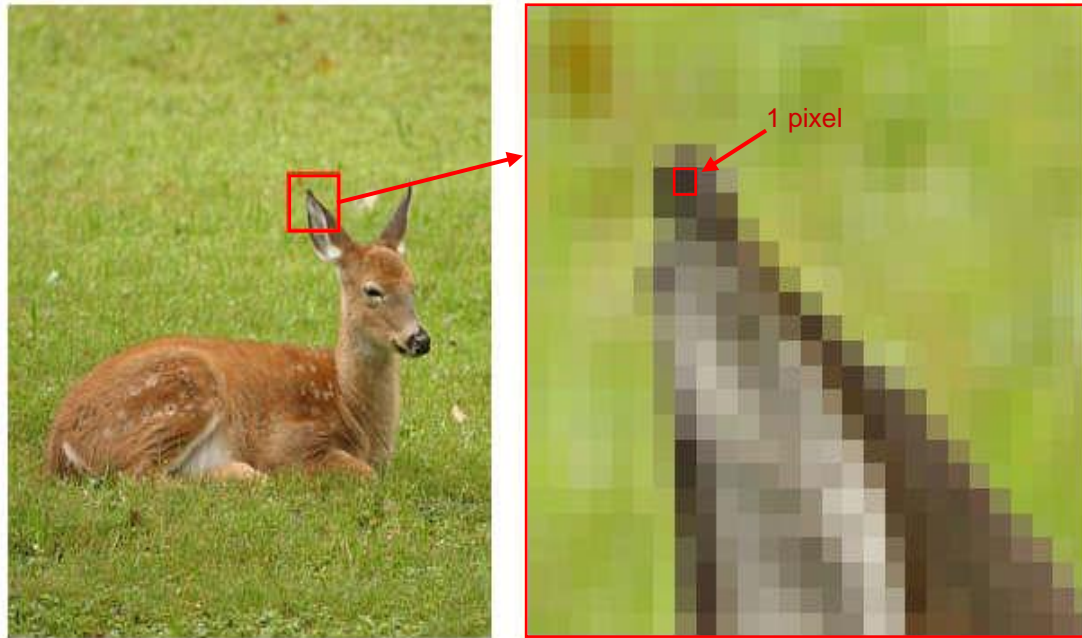
Image Formation - Quantization



Digital Image

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

each square is
called a pixel (for
picture element)



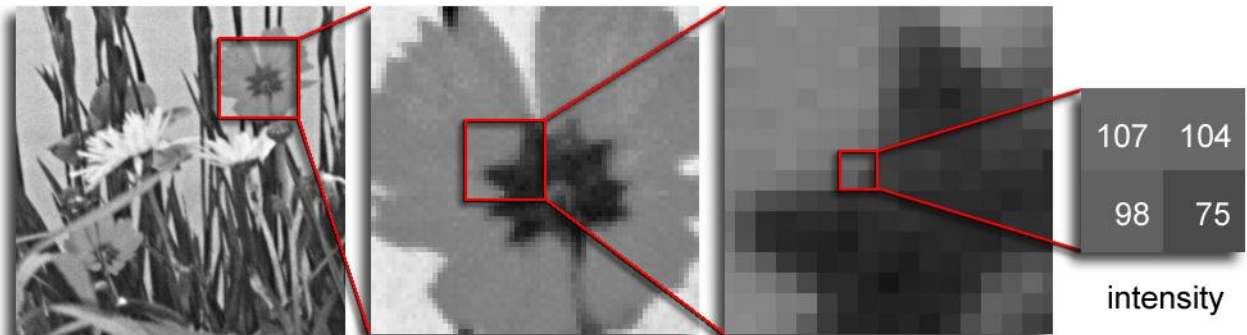
Digital Image

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*)

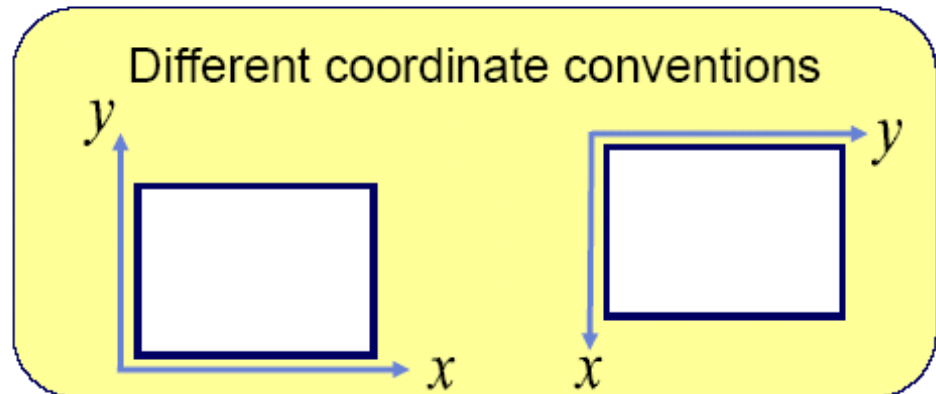
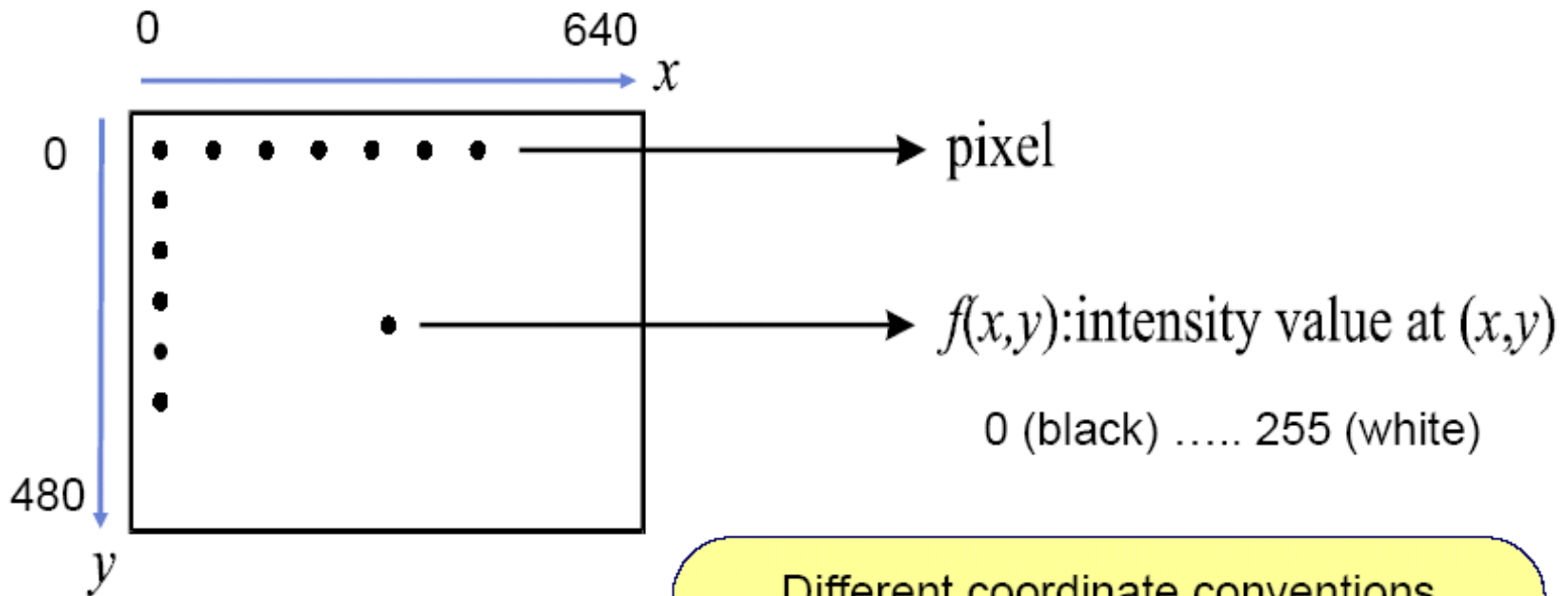


Digital Image

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

Example

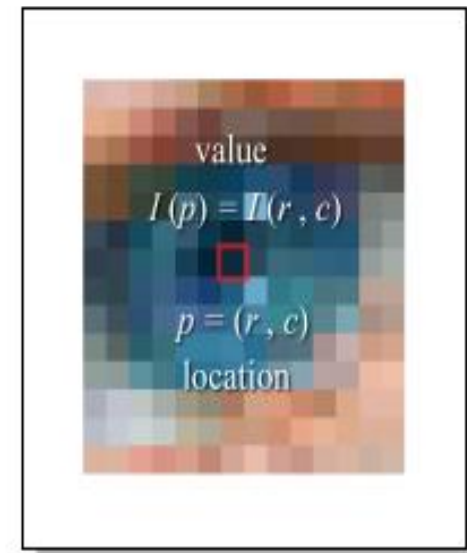
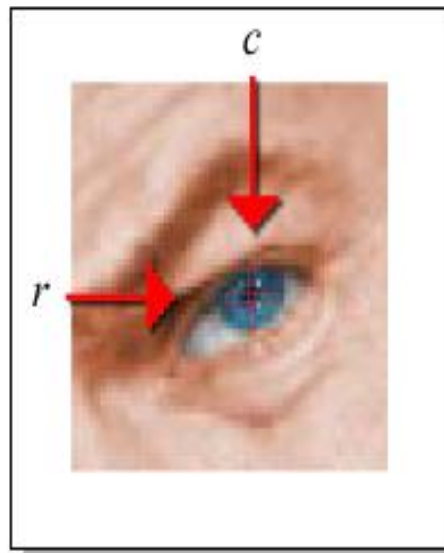
640 x 480 8-bit image



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



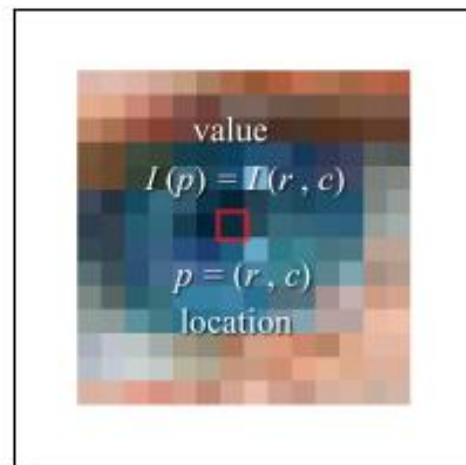
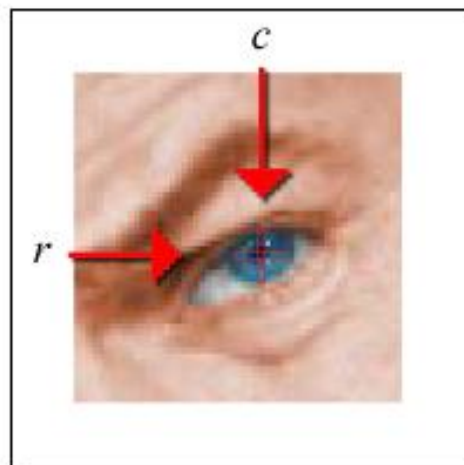
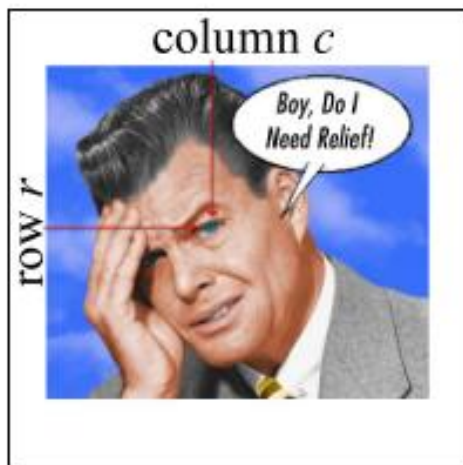
Pixel Location: $p = (r, c)$

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

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

Pixels

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



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

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

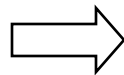
DIGITAL IMAGE REPRESENTATION



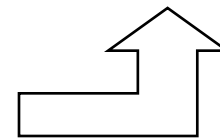
PIXEL VALUES IN HIGHLIGHTED REGION

| | | | | | | | | | |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 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

Readings from Book (3rd Edn.)

- Chapter - 1
- 2.1 Elements of Visual Perception
- 2.2 Light and EM Spectrum
- 2.3 Image Sensing and Acquisition
- 2.4 Image Sampling & Quantization
- 2.5 Basic Relationships between Pixels



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