Digital Image Processing

Lecture # 1
Introduction & Fundamentals

My Introduction*

- Did PhD in 2012 from NUST
  - Area of research: Analysis of Fundus images using Image processing and Machine Learning Techniques
- Current Research Areas:
  - Biomedical Image/Signal Analysis (Retina, Cardiac, Dental, EEG, Breath Sounds etc)
  - Biometrics (Dental, Retina, Dorsal hand veins etc)
- Heading BIOMISA and ETL research lab

*www.biomisa.org/usman
*www.biomisa.org
*www.etechlab.pk

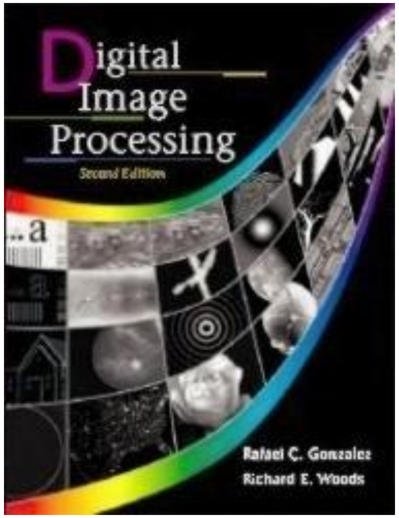
Course Information

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

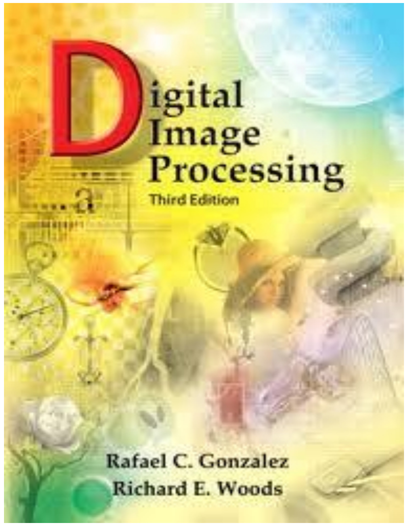
http://biomisa.org/usman/digital-image-processing-f14

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, local binary patterns)
- 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:	15%
Final Project:	10%
Final Exam:	40%

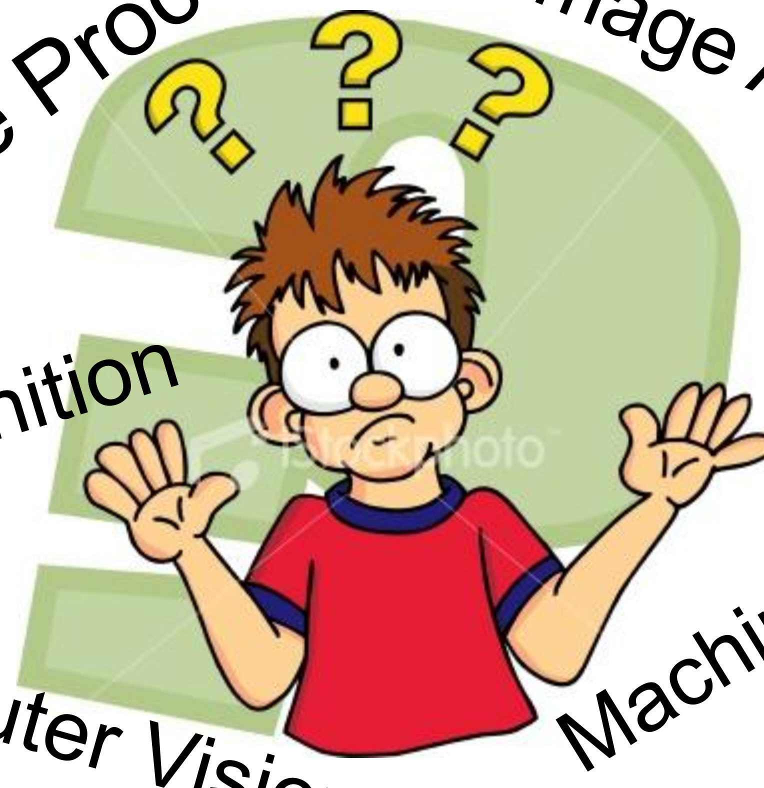
Before we start

How many of you are good in signal processing?

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

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

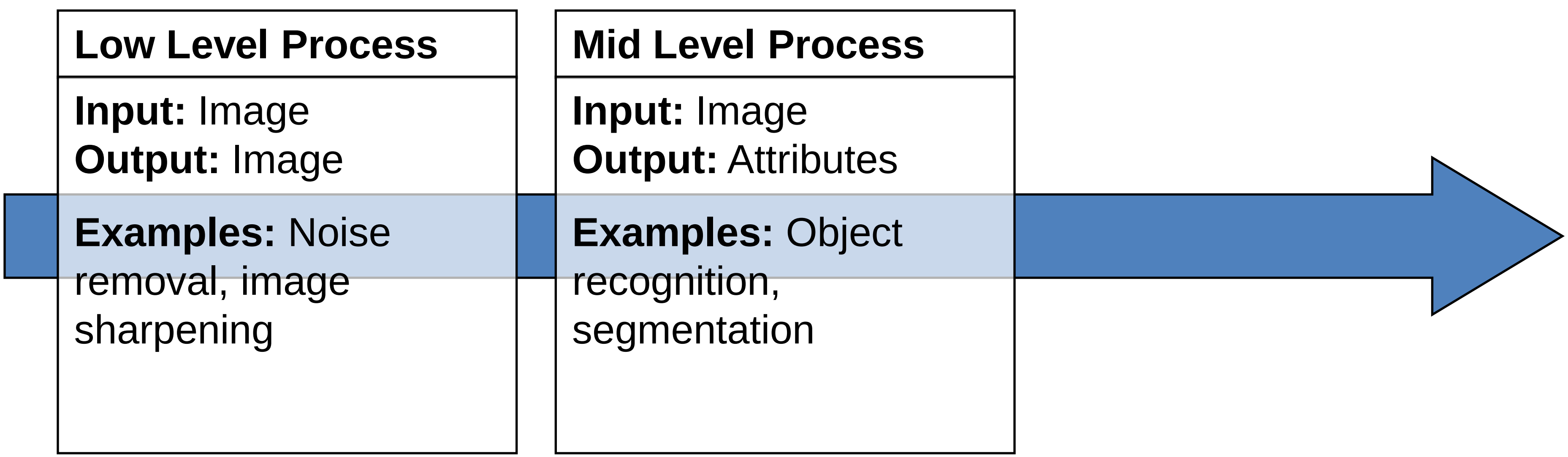
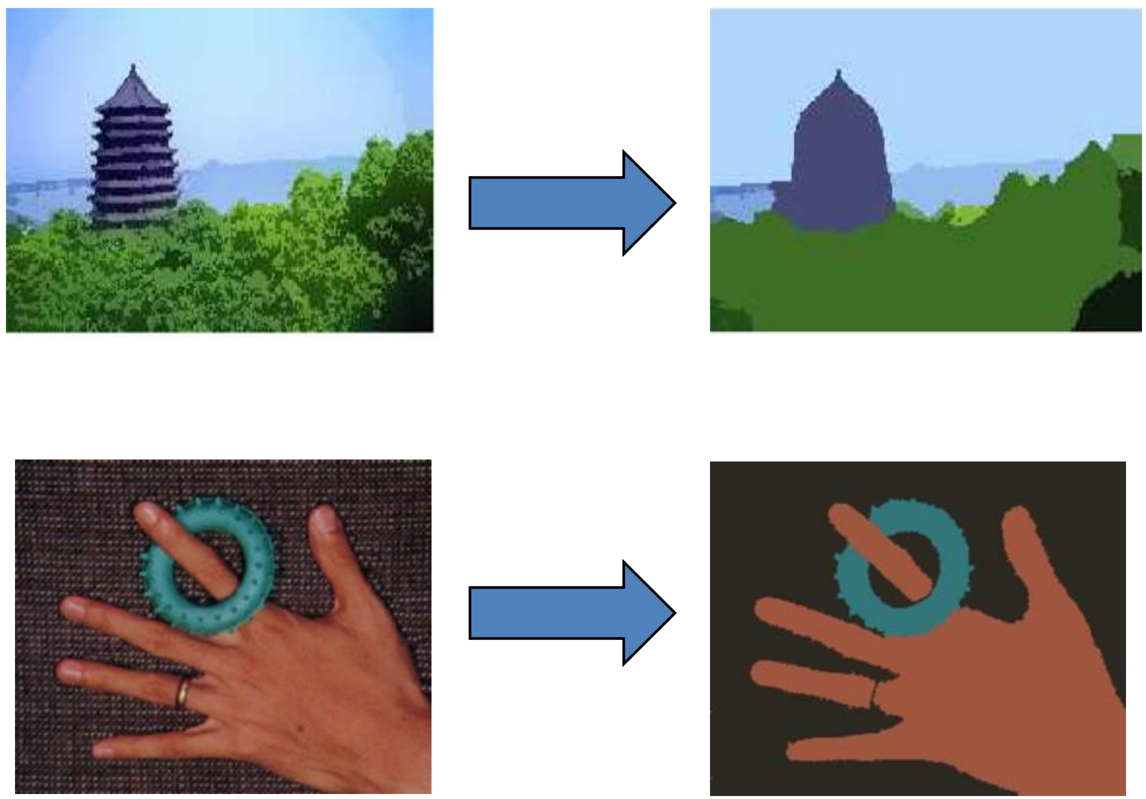


Image Processing

Example: Mid Level Processing



Segmentation of image into regions

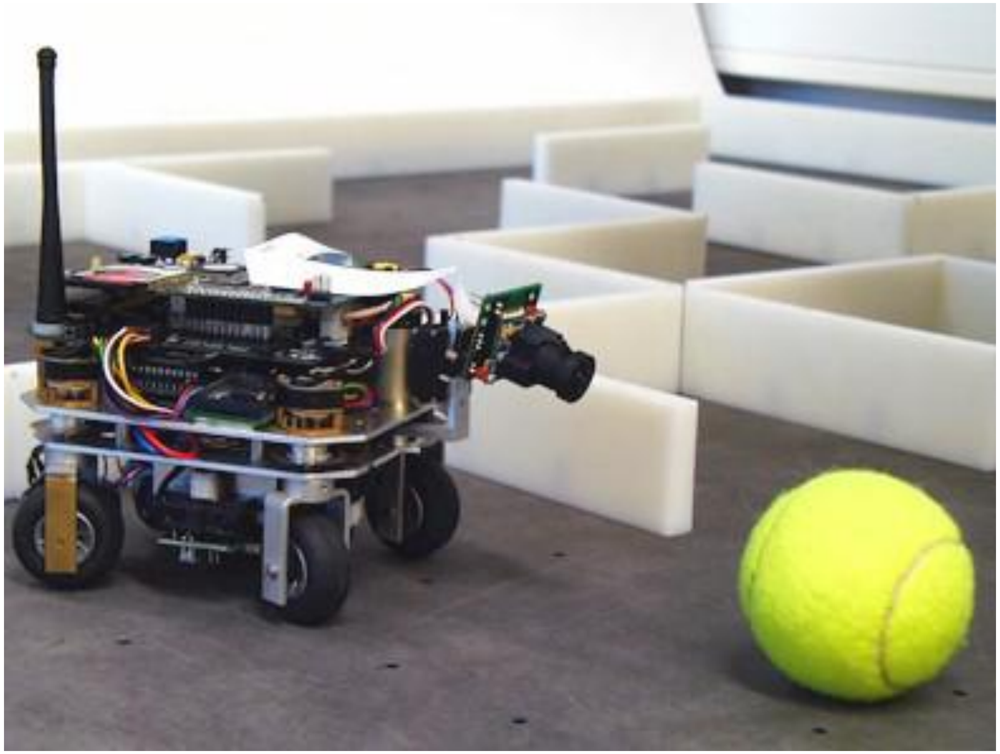
Image Processing & Machine Vision

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

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

Image Processing → Machine Vision

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

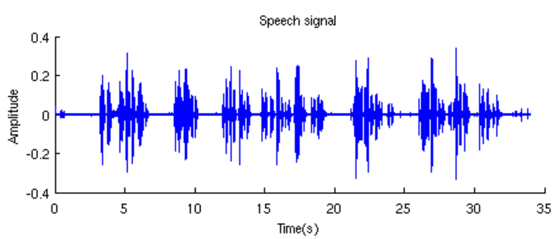
Low Level Process	Mid Level Process	High Level Process
Input: Image **Output:** Image	**Input:** Image **Output:** Attributes	**Input:** Attributes/Image **Output:** Understanding
Examples: Noise removal, image sharpening	**Examples:** Object recognition, segmentation	**Examples:** Scene understanding,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

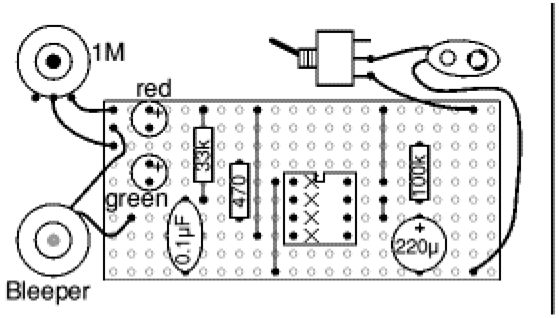
Image Processing

Machine Vision

Pattern

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

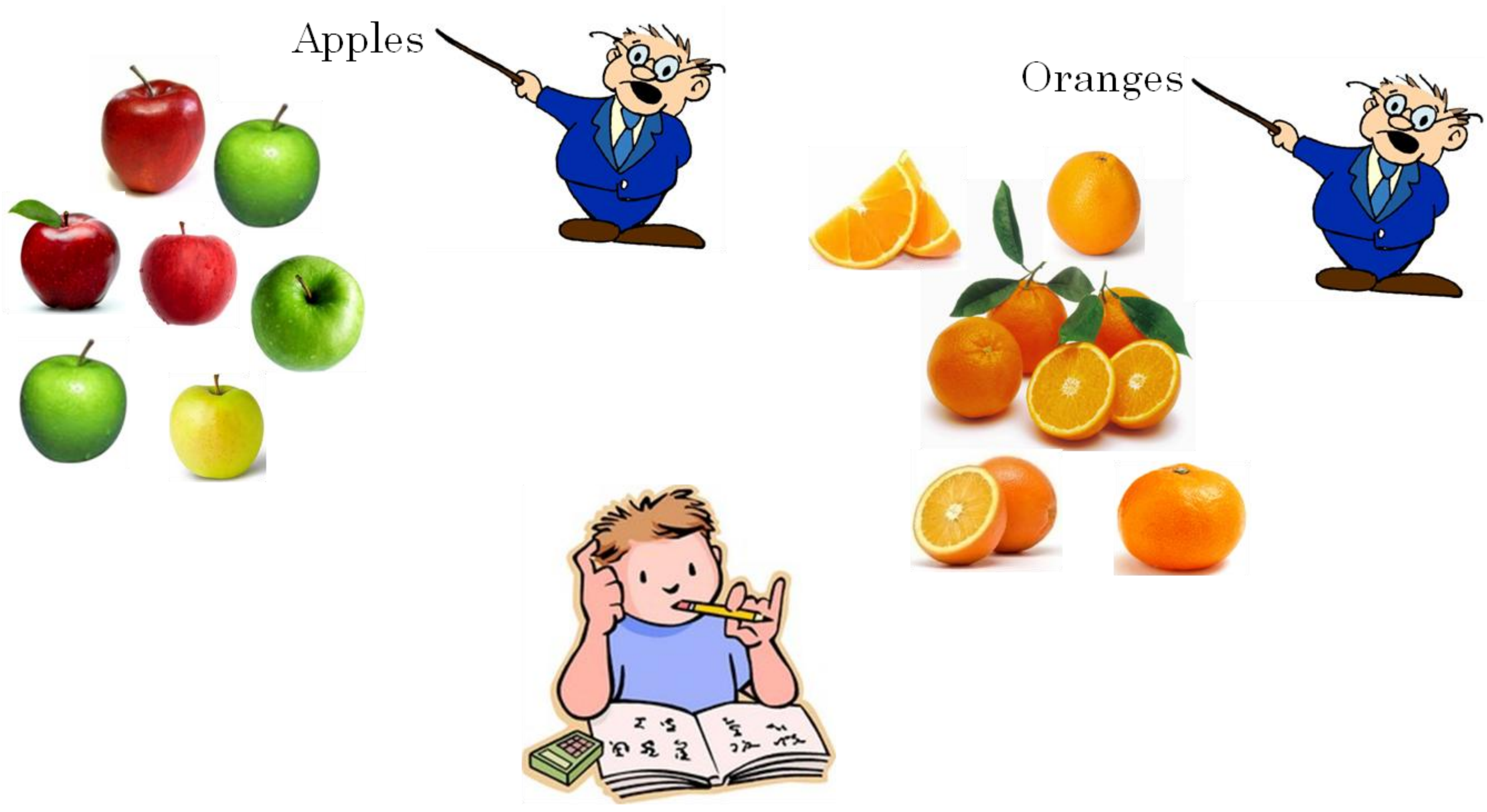




Recognition

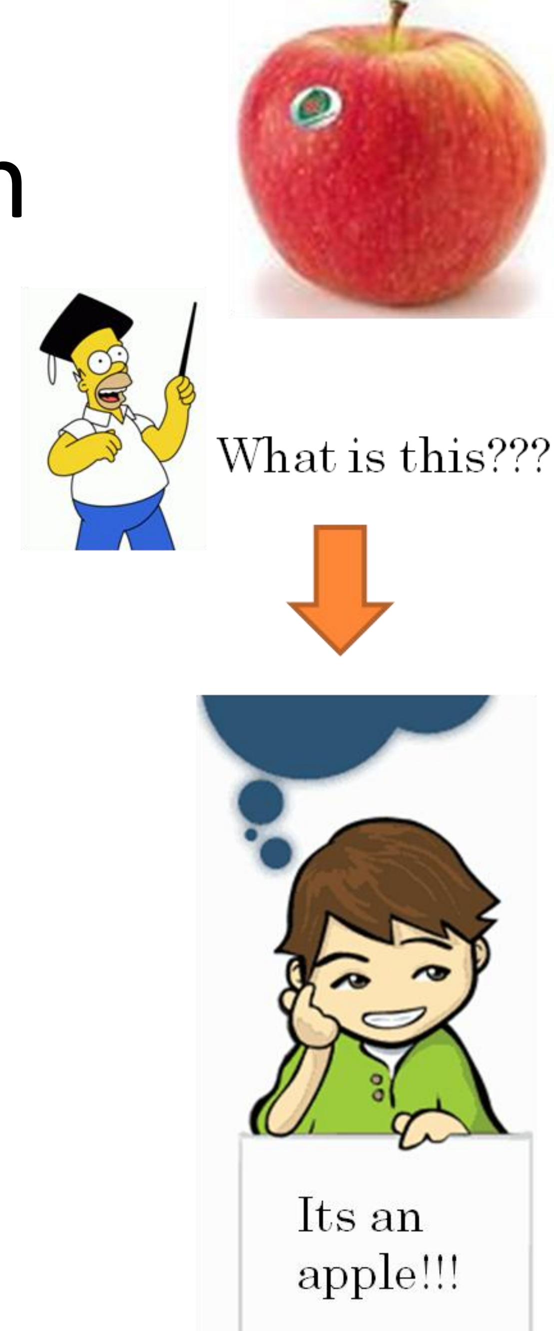
- Identification of a pattern as a member of a category

Classification



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



Classification

Given: training images and their categories

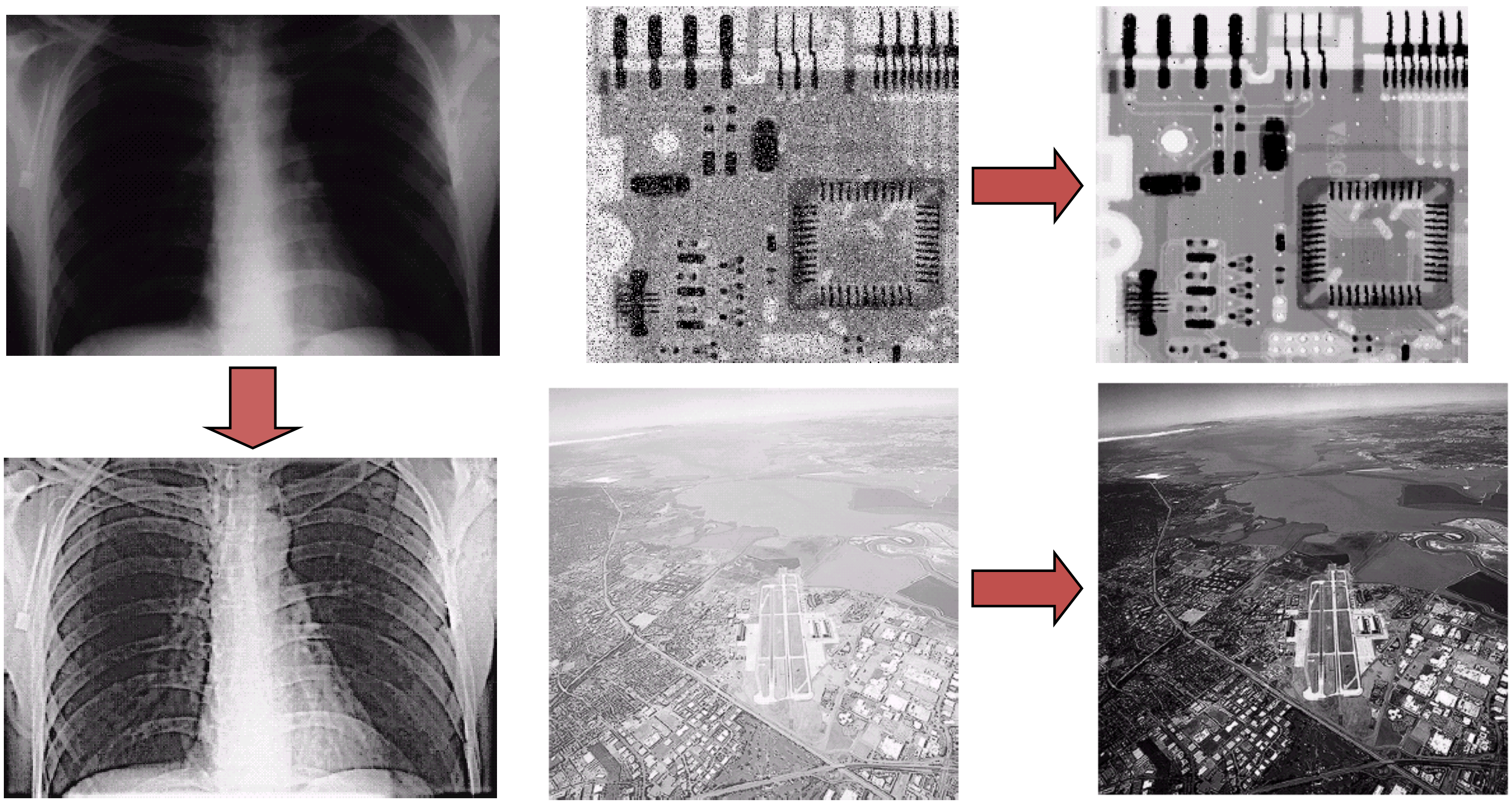
What are the categories of these test images?

Pattern Recognition

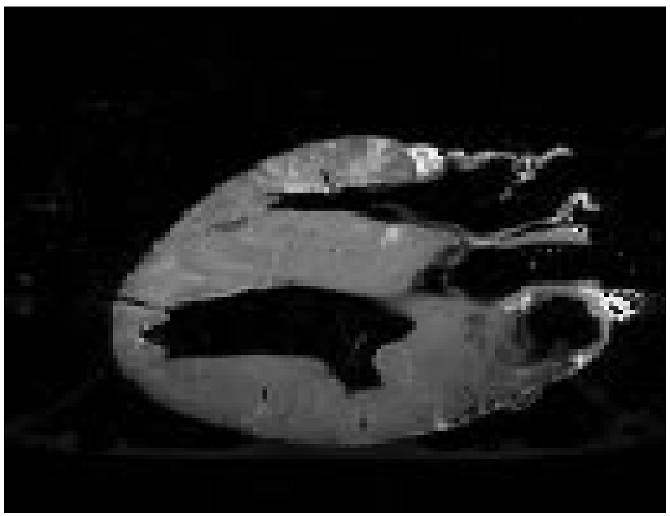
Given an input pattern, make a decision about the "category" or "class" of the pattern

Example Applications

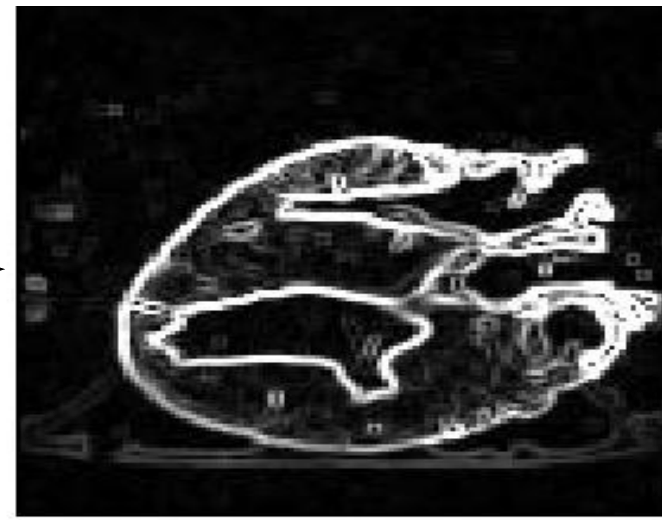
Examples: Image Enhancement



Examples: Medicine

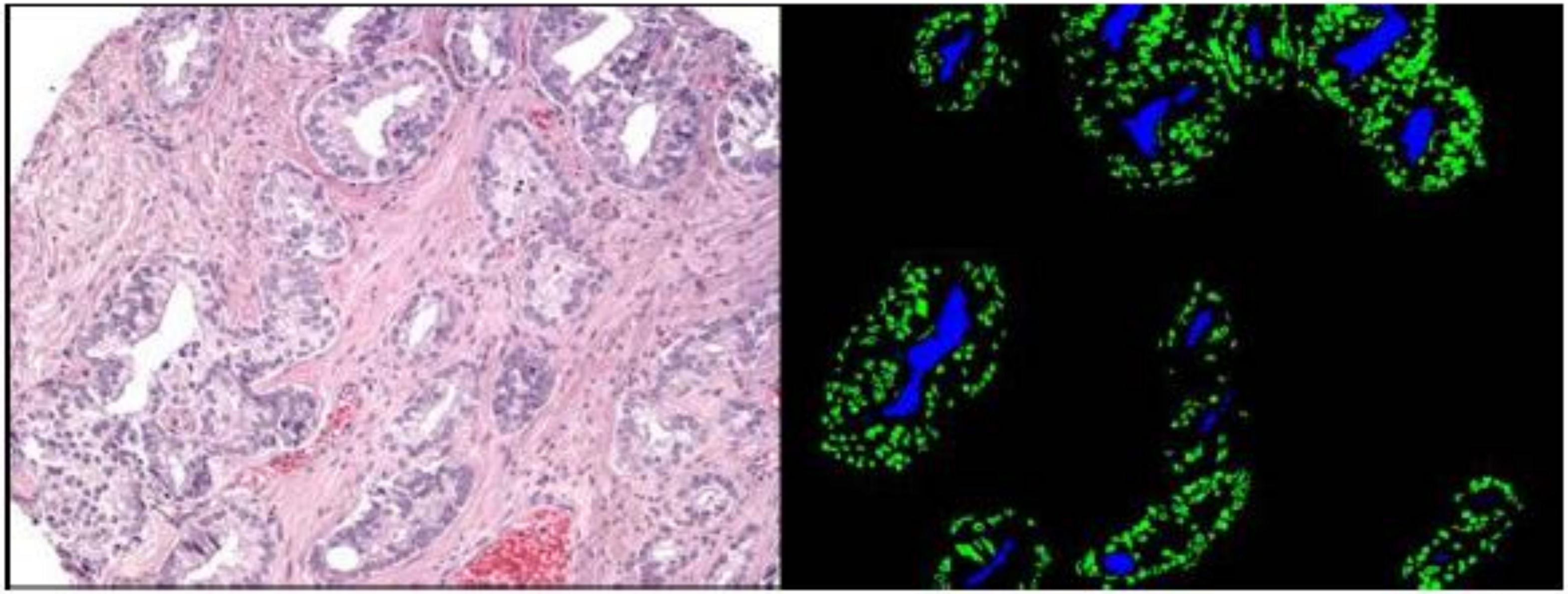


Original Image of a Dog Heart



Separation of tissues

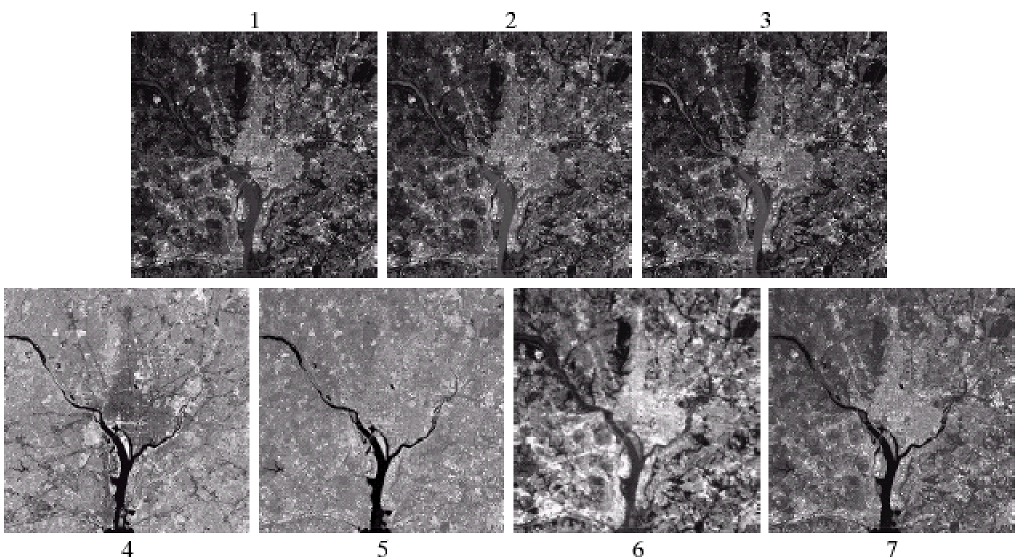
Examples: Medicine

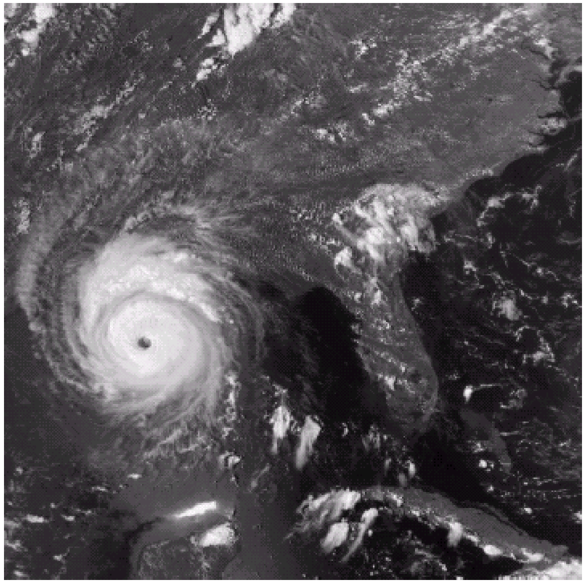


Microscopic tissue data - Cancer Detection

Examples: GIS

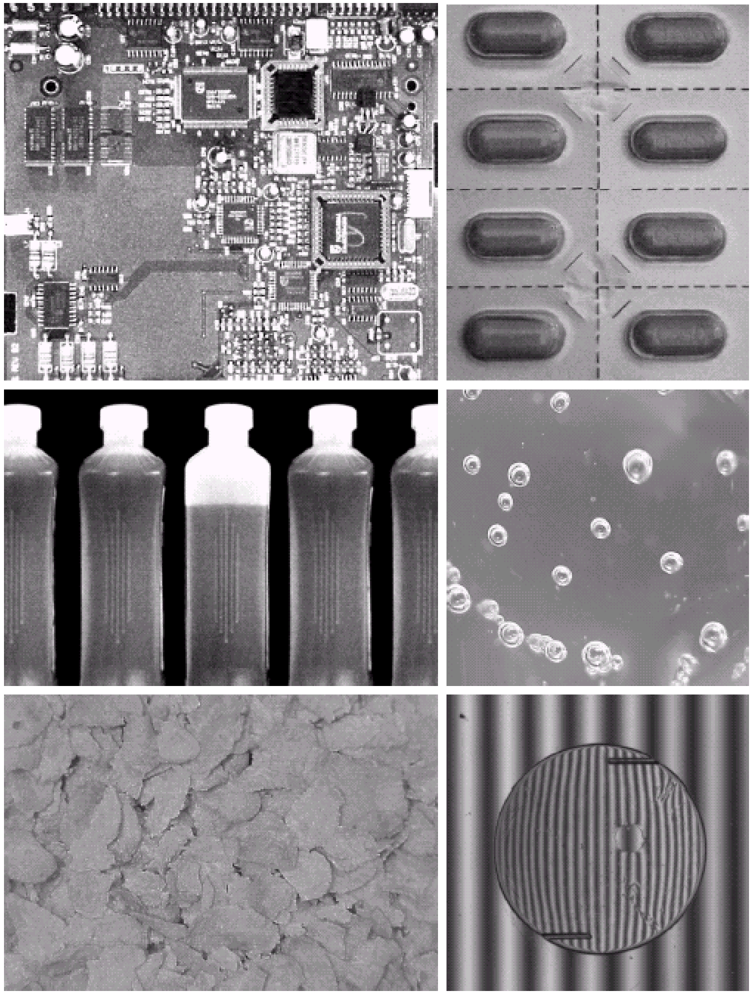
- Geographic Information Systems
  - Manipulation of Satellite Imagery
  - Terrain Classification, Meteorology





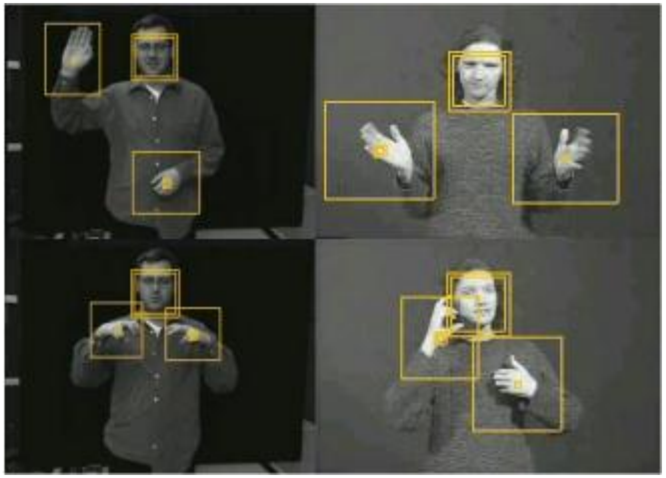
Examples: Industrial Inspection

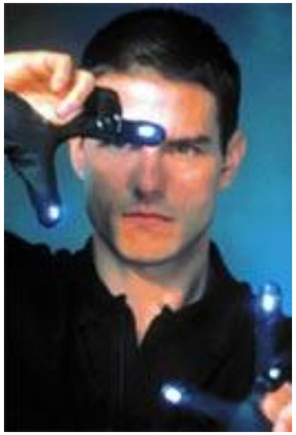
- Human operators are expensive, slow and unreliable
- Make machines do the job instead

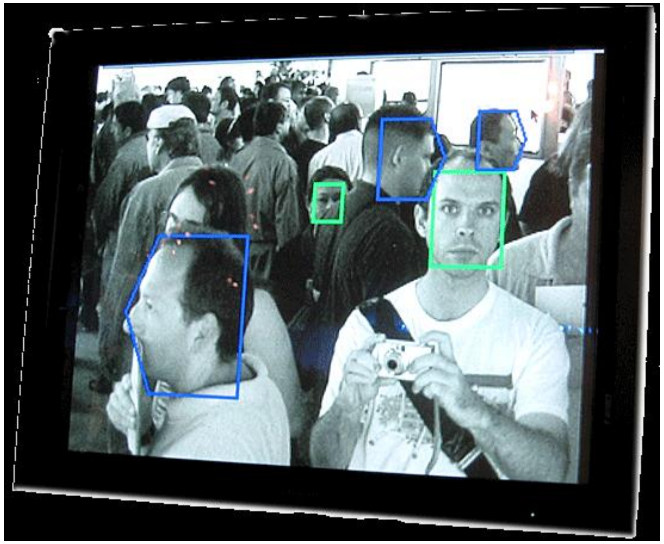


Examples: HCI

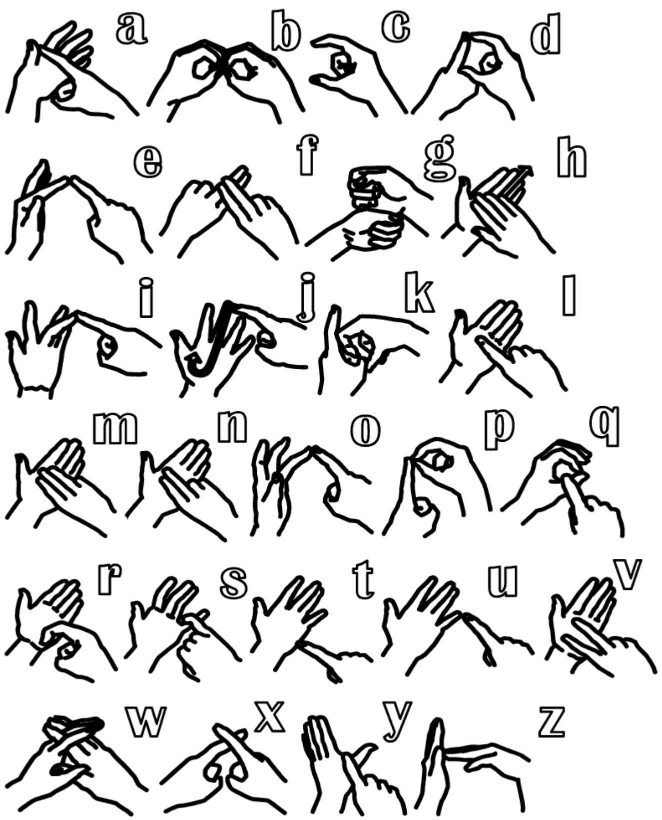
- Try to make human computer interfaces more natural
  - Gesture recognition
  - Facial Expression Recognition
  - Lip reading



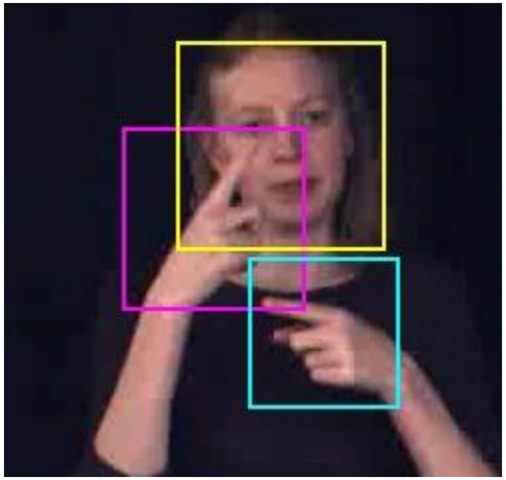




Examples: Sign Language/Gesture Recognition



British Sign Language Alphabet



Examples: Lip Reading

Can you guess? ee oo sh

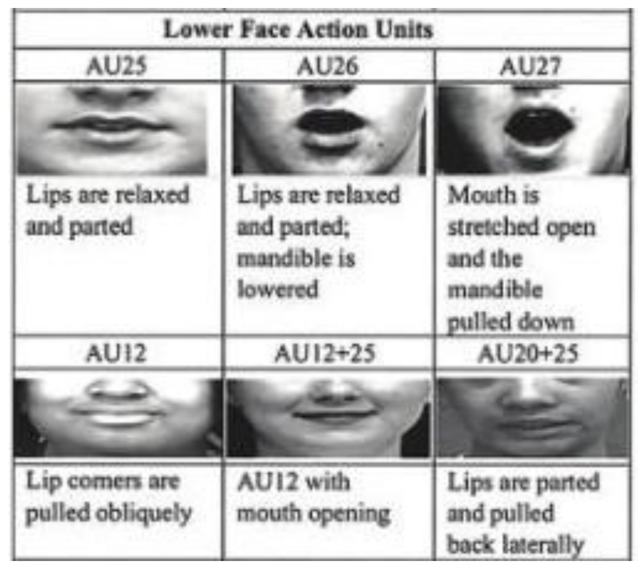
Examples: Lip Reading

Examples: Facial Expression Recognition

- Implicit customer feedback

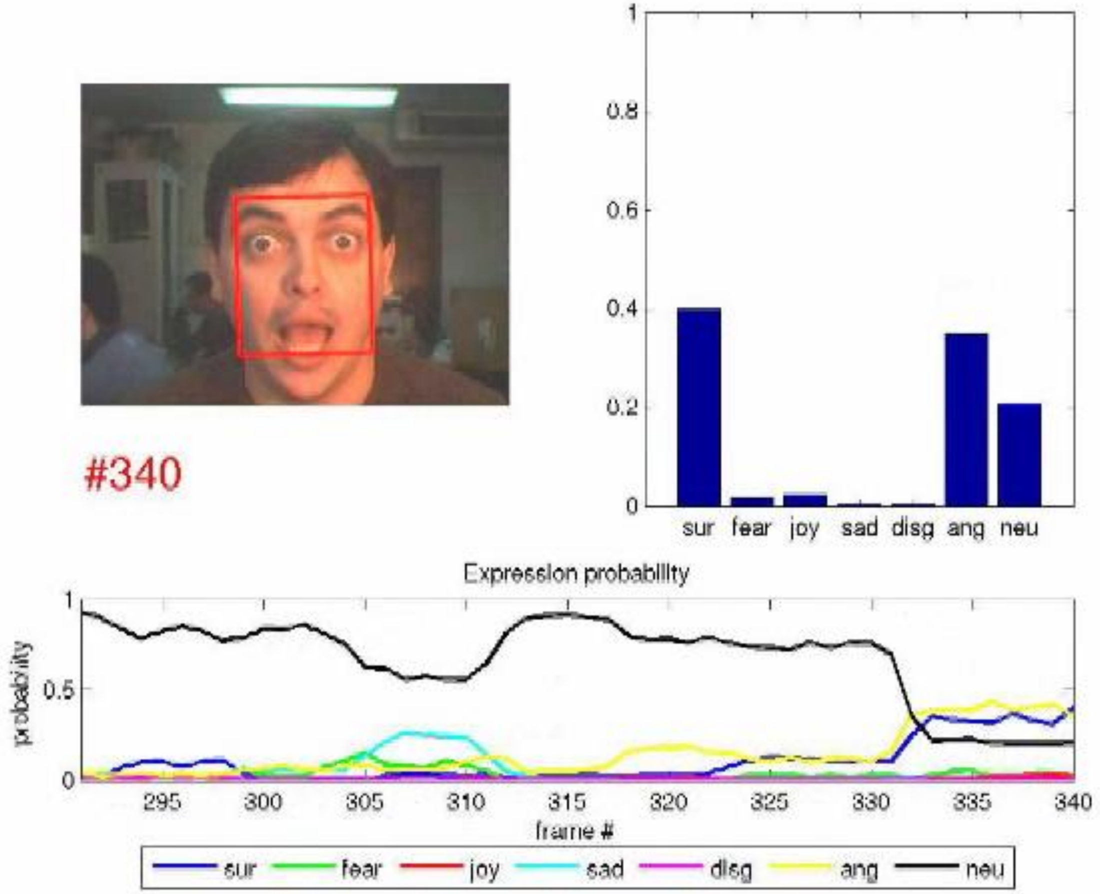
Examples: Facial Expression Recognition

- Implicit customer feedback



Examples: Facial Expression Recognition

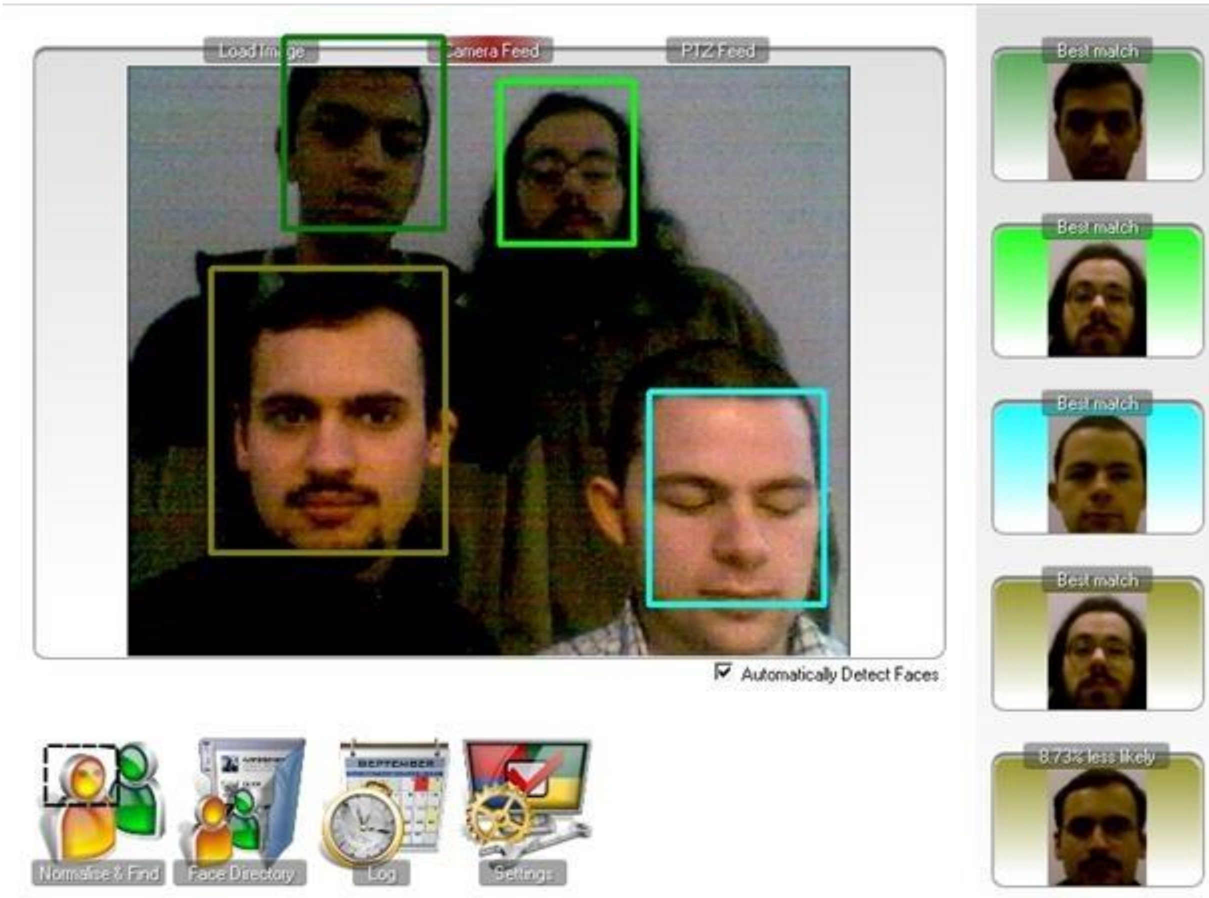
- Implicit customer feedback



Examples: Biometrics

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

Examples: Biometrics – Face Recognition



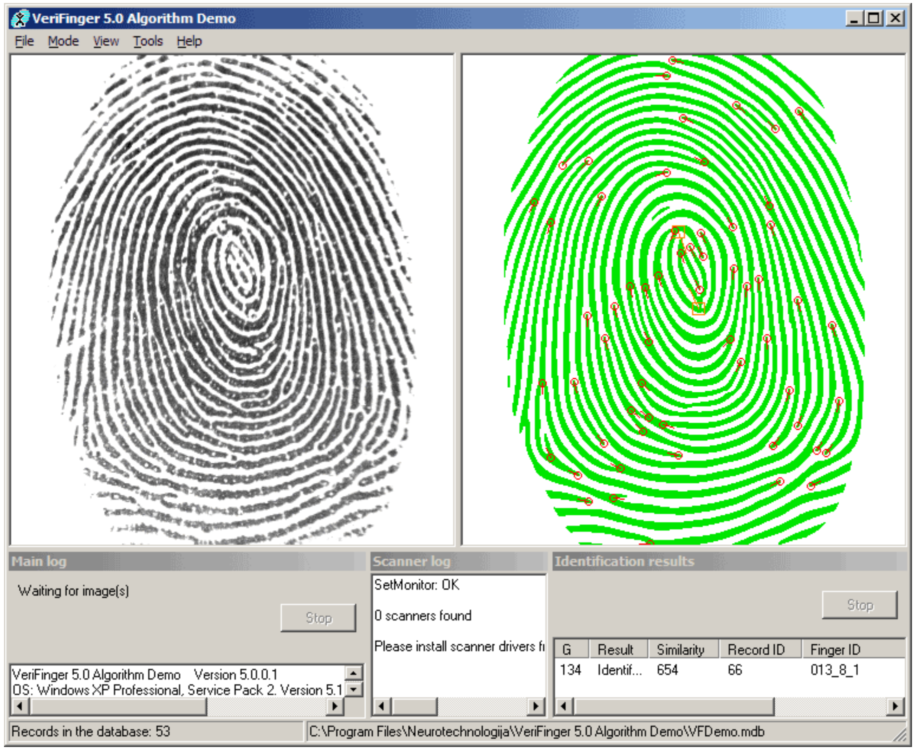
Faces and Digital Cameras

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

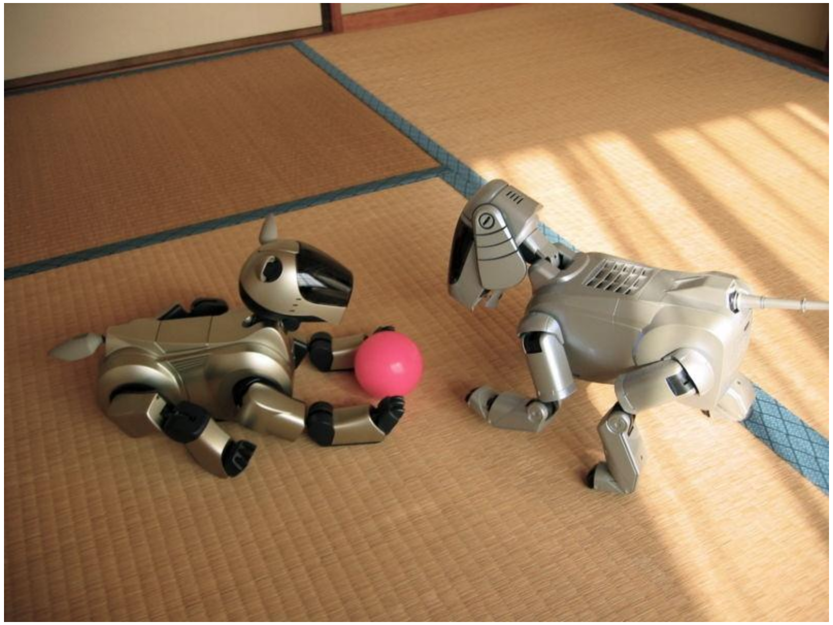


Examples: Biometrics – Signature Verification

Examples: Robotics

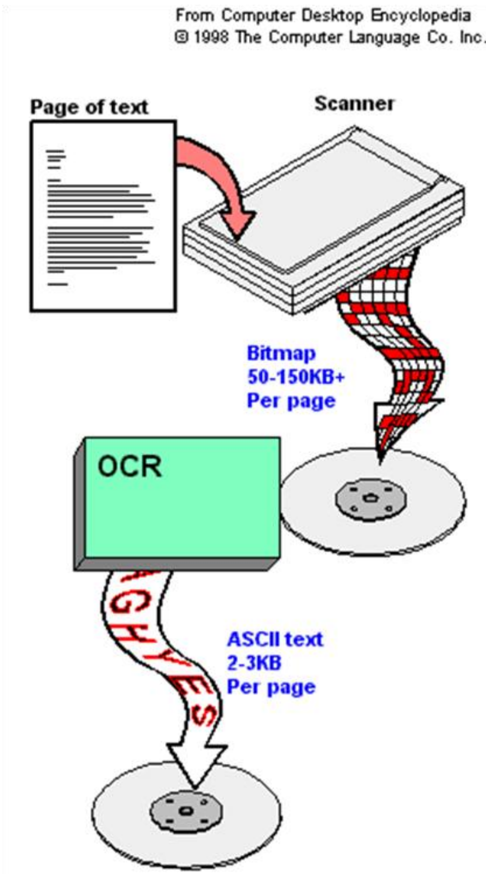
Examples: Robotics

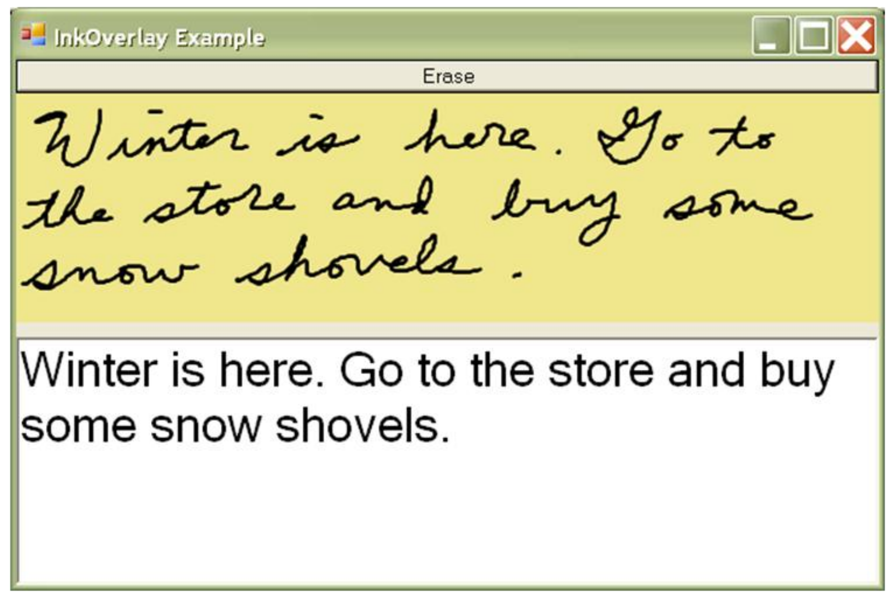
- AIBO



Examples: Optical Character Recognition

- Convert document image into text





Examples: Optical Character Recognition

- Indexing and Retrieval

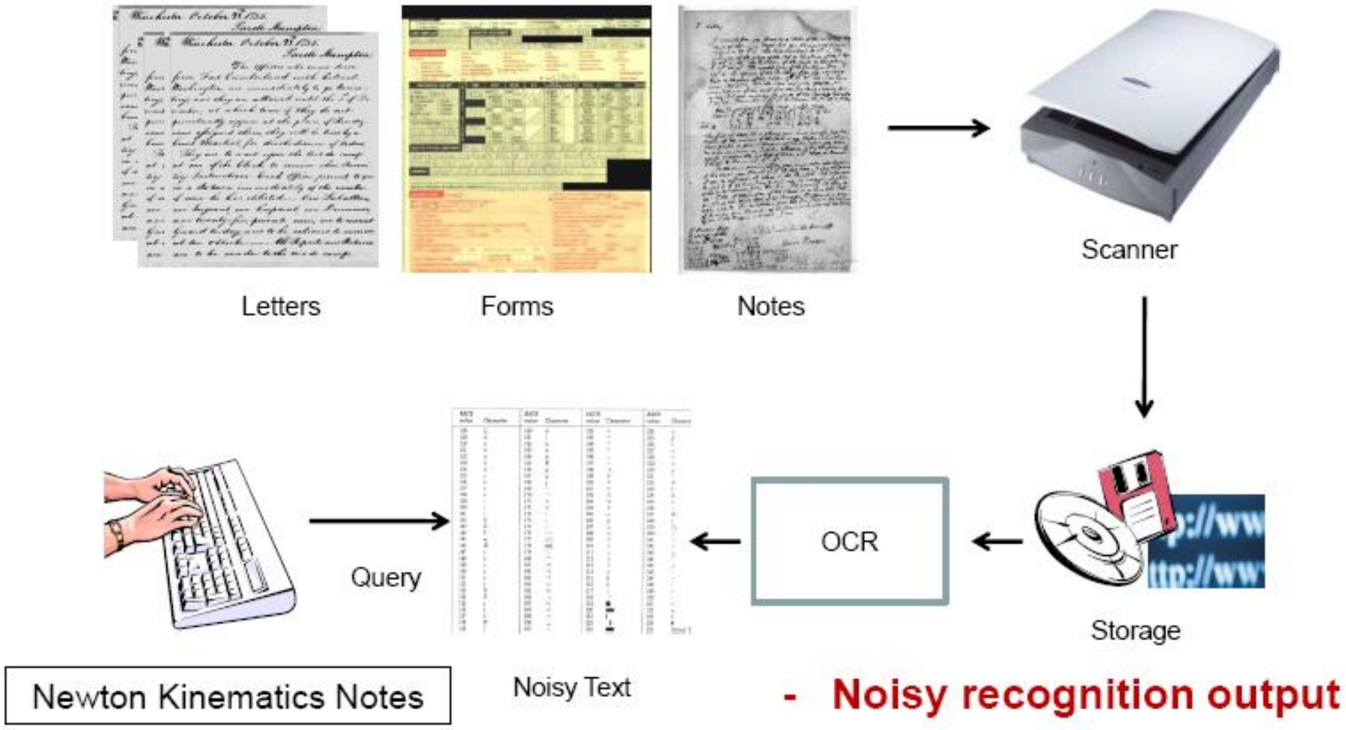


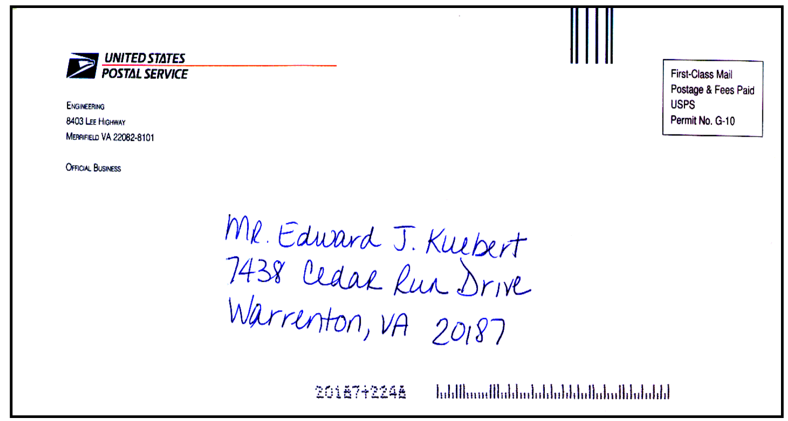
Image Source: CEDAR

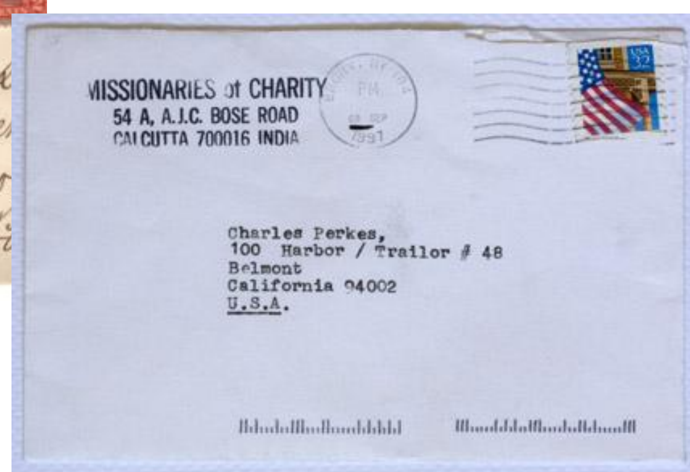
Examples: Optical Character Recognition

- License Plate Recognition

Examples: Optical Character Recognition

- Automatic Mail Sorting

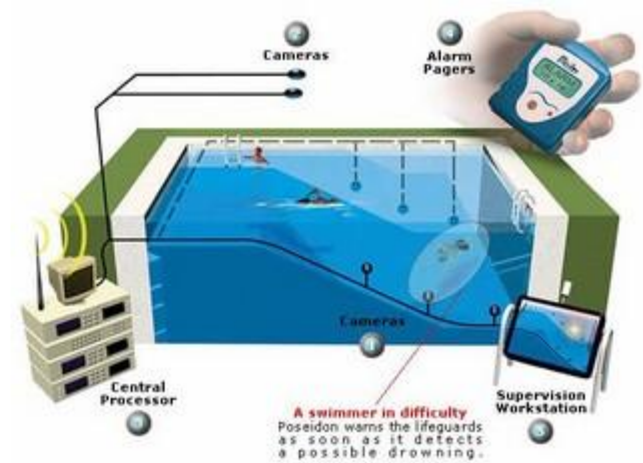




Safety and Security

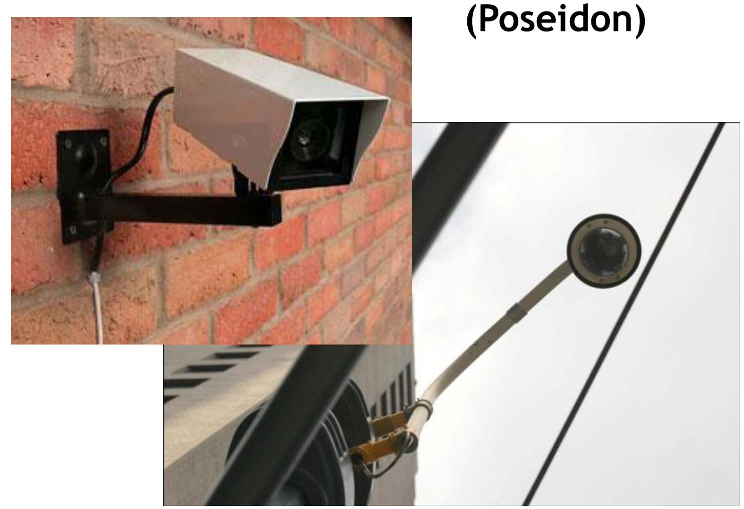
Autonomous robots

Driver assistance

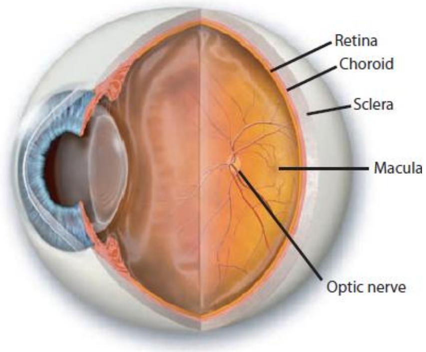


Monitoring pools
(Poseidon)

Pedestrian detection
[MERL, Viola et al.]

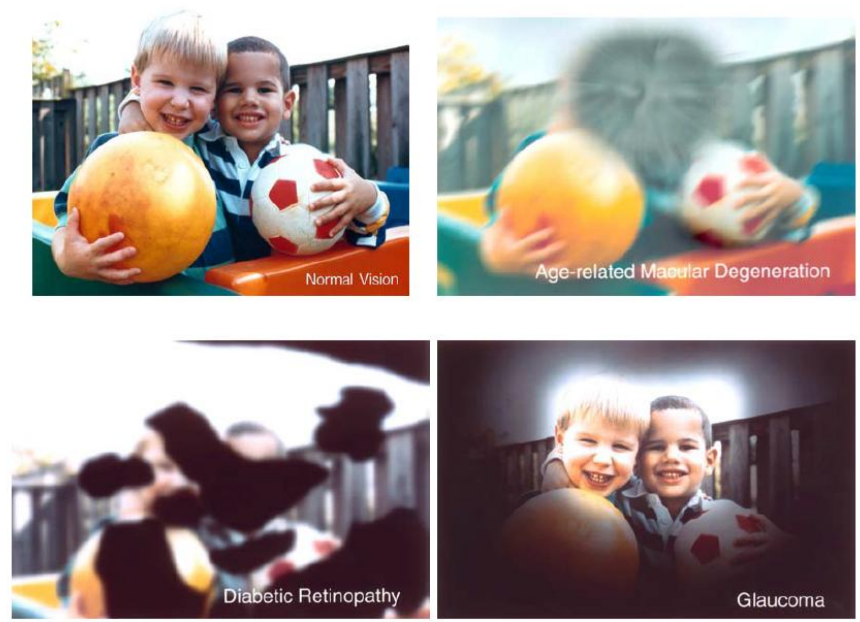


Surveillance

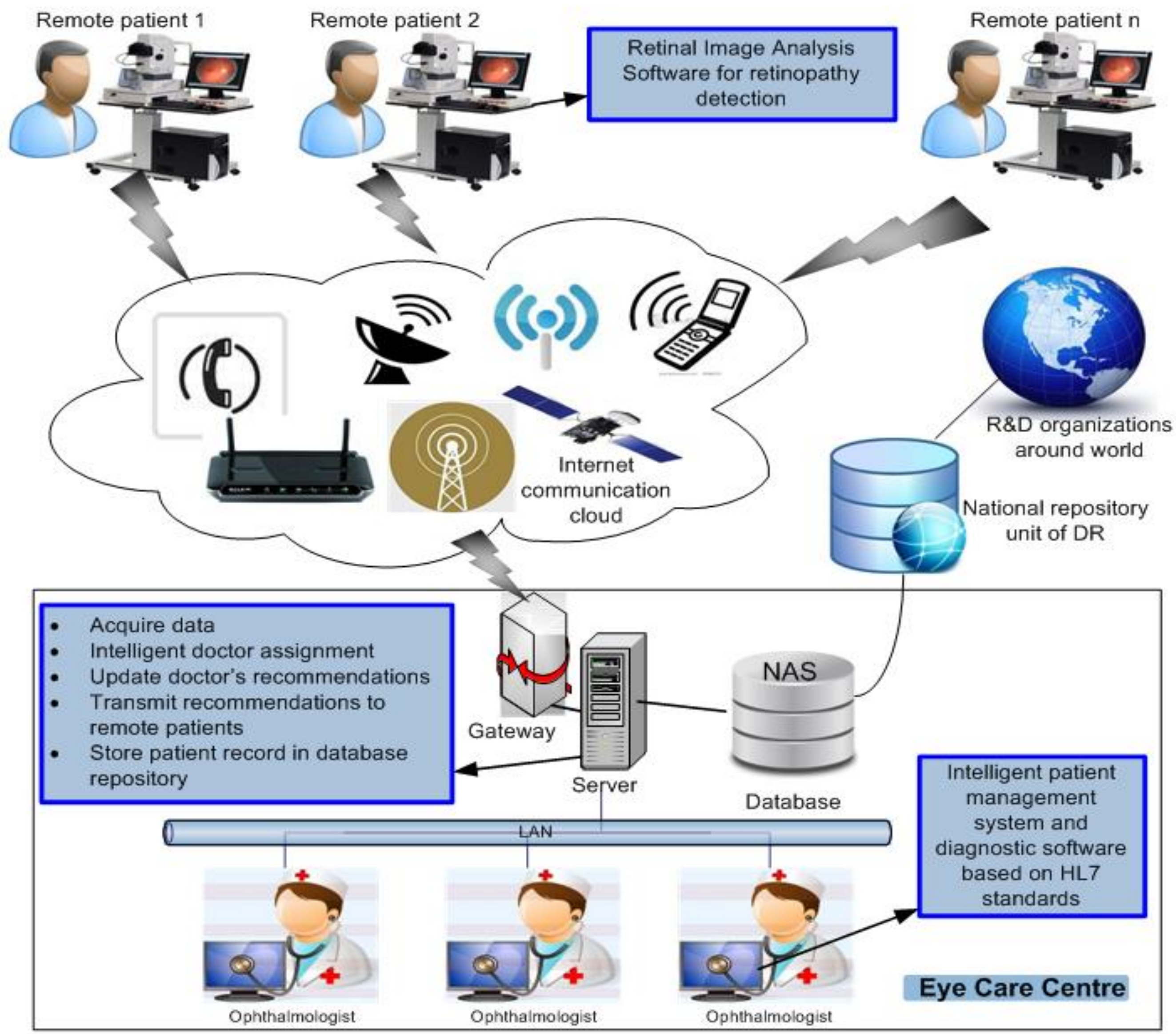


Eye Care

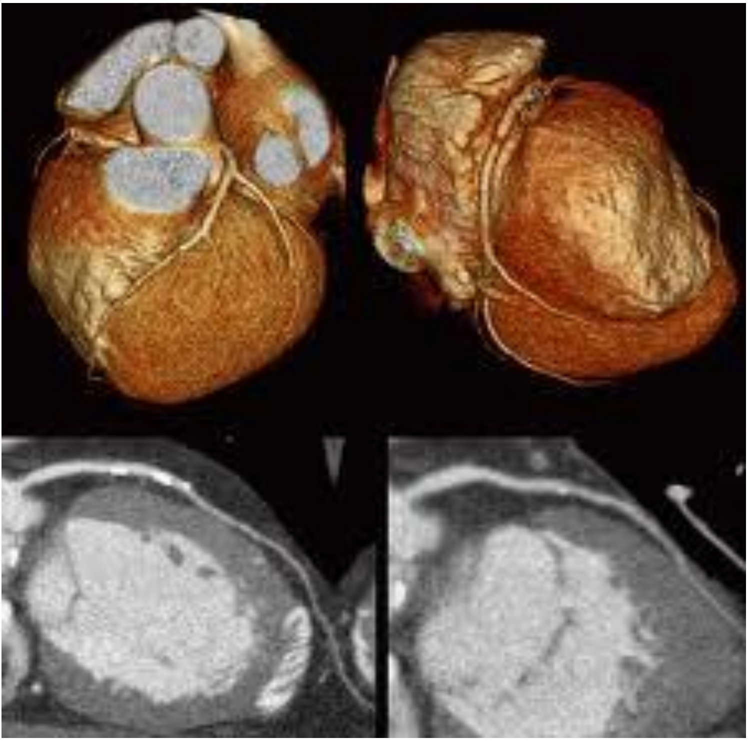
- Diabetic Retinopathy (DR) using Fundus Images
- Diabetic Maculopathy (DM) using Fundus Images
- Optical Coherence Tomography (OCT) analysis for detection of AMD
- Glaucoma Detection using Fundus Image
- Analysis of Fundus Images for detection of AMD

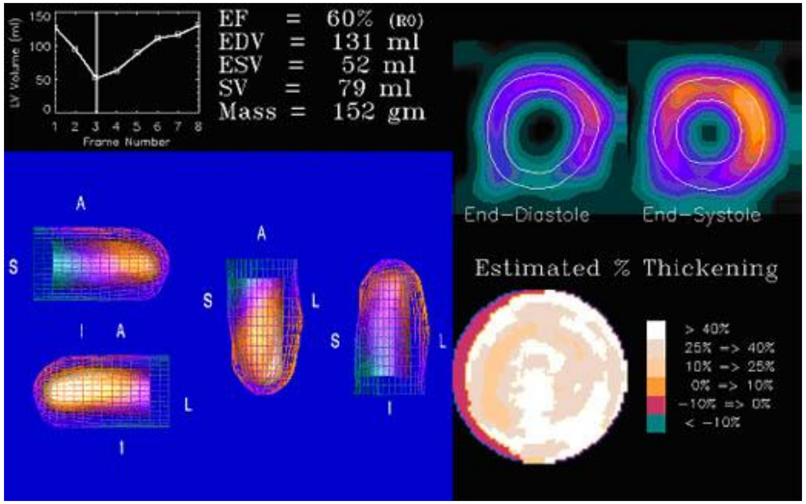


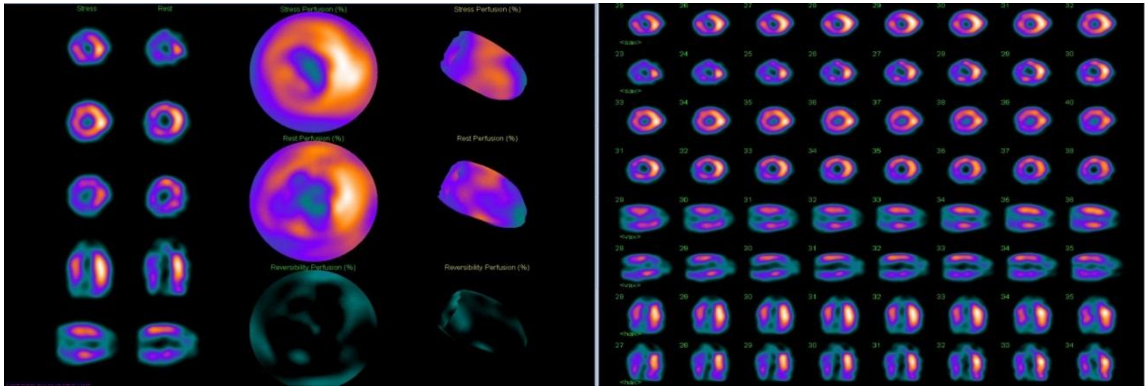
Telescreening System (National ICT R&D Funded Project)

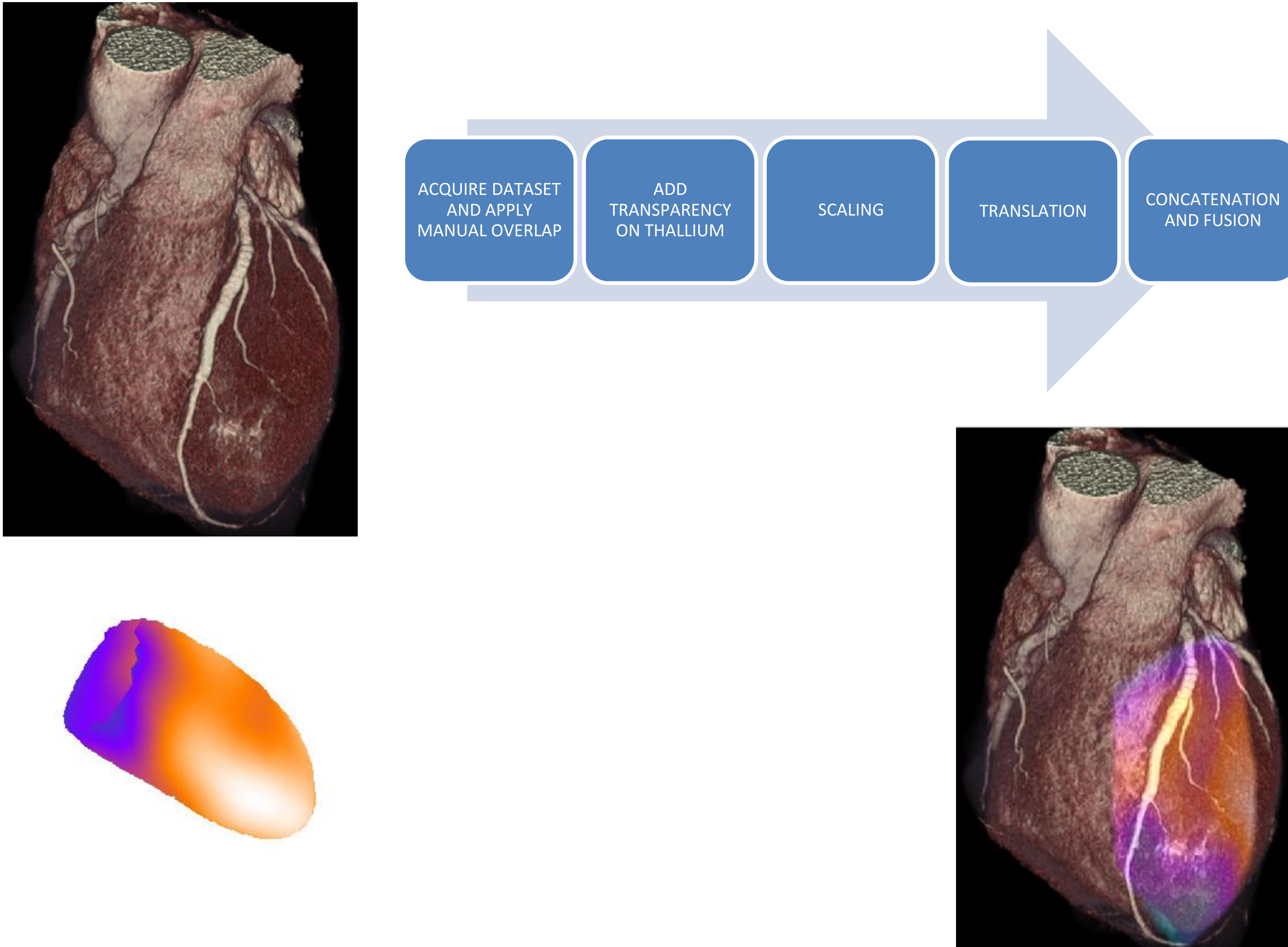


CT Angiography and Thallium Scan Images

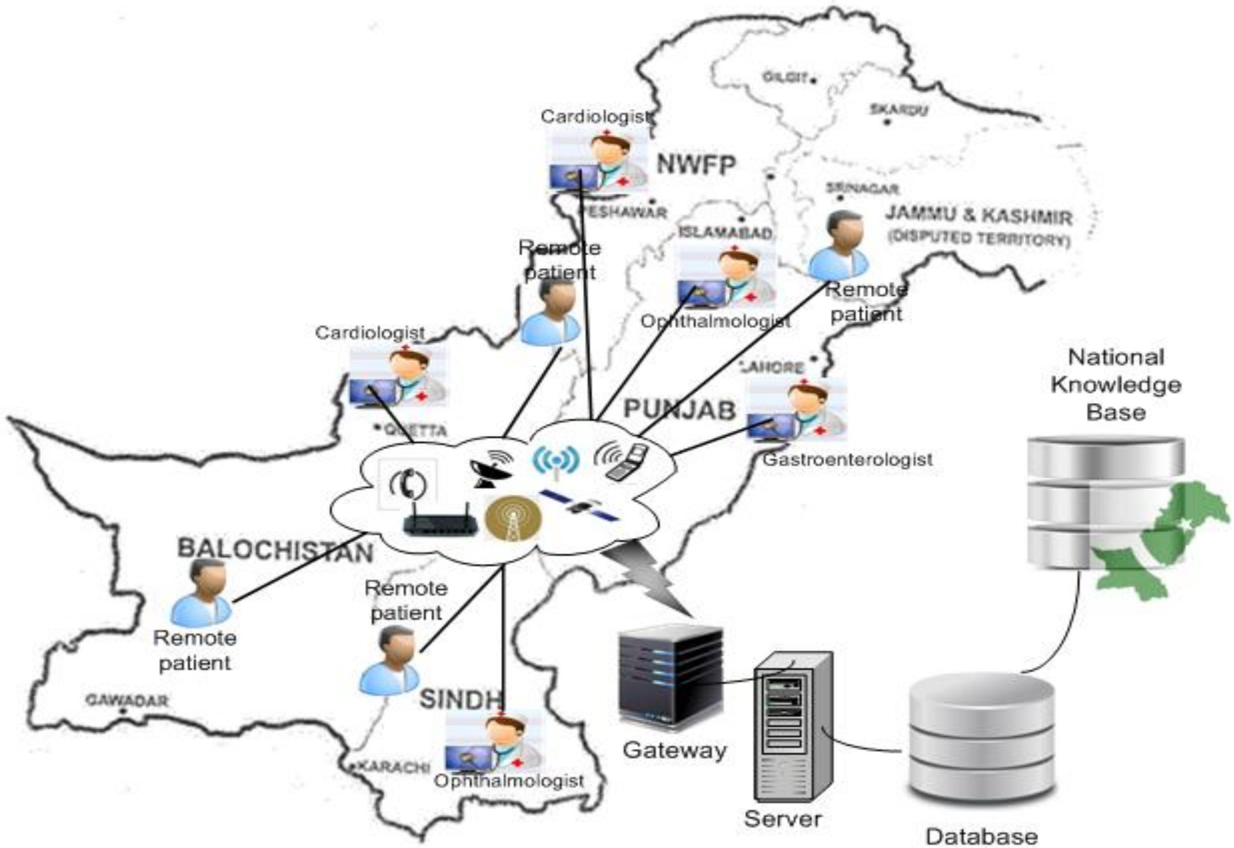







ACQUIRE DATASET AND APPLY MANUAL OVERLAP
ADD TRANSPARENCY ON THALLIUM
SCALING
TRANSLATION
CONCATENATION AND FUSION

i-Hospital



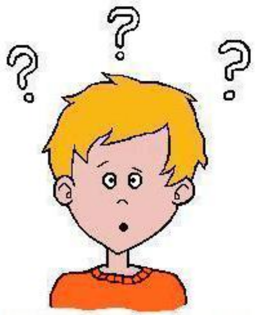
Cardiologist
NWFP
PESHAWAR
GILGIT
SKARDU
SRINAGAR
JAMMU & KASHMIR
(DISPUTED TERRITORY)
ISLAMABAD
Remote patient
Ophthalmologist
Remote patient
Cardiologist
QUETTA
LAHORE
PUNJAB
Gastroenterologist
National Knowledge Base
BALOCHISTAN
Remote patient
Remote patient
GAWADAR
SINDH
KARACHI
Ophthalmologist
Gateway
Server
Database

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)

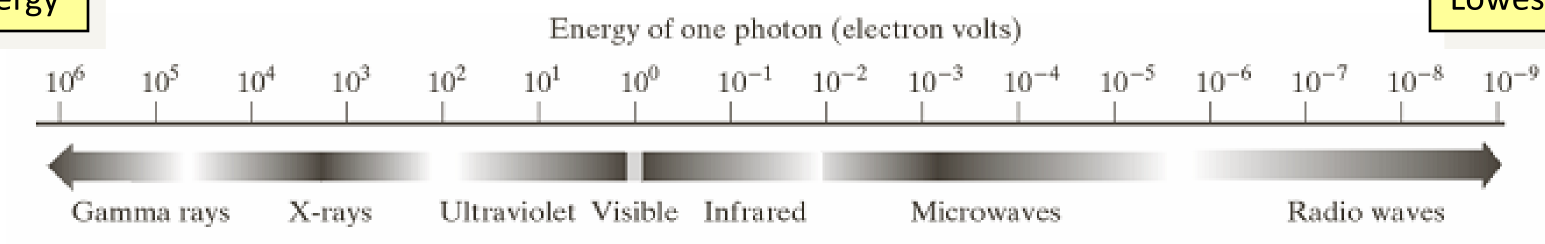


Light & EM Spectrum

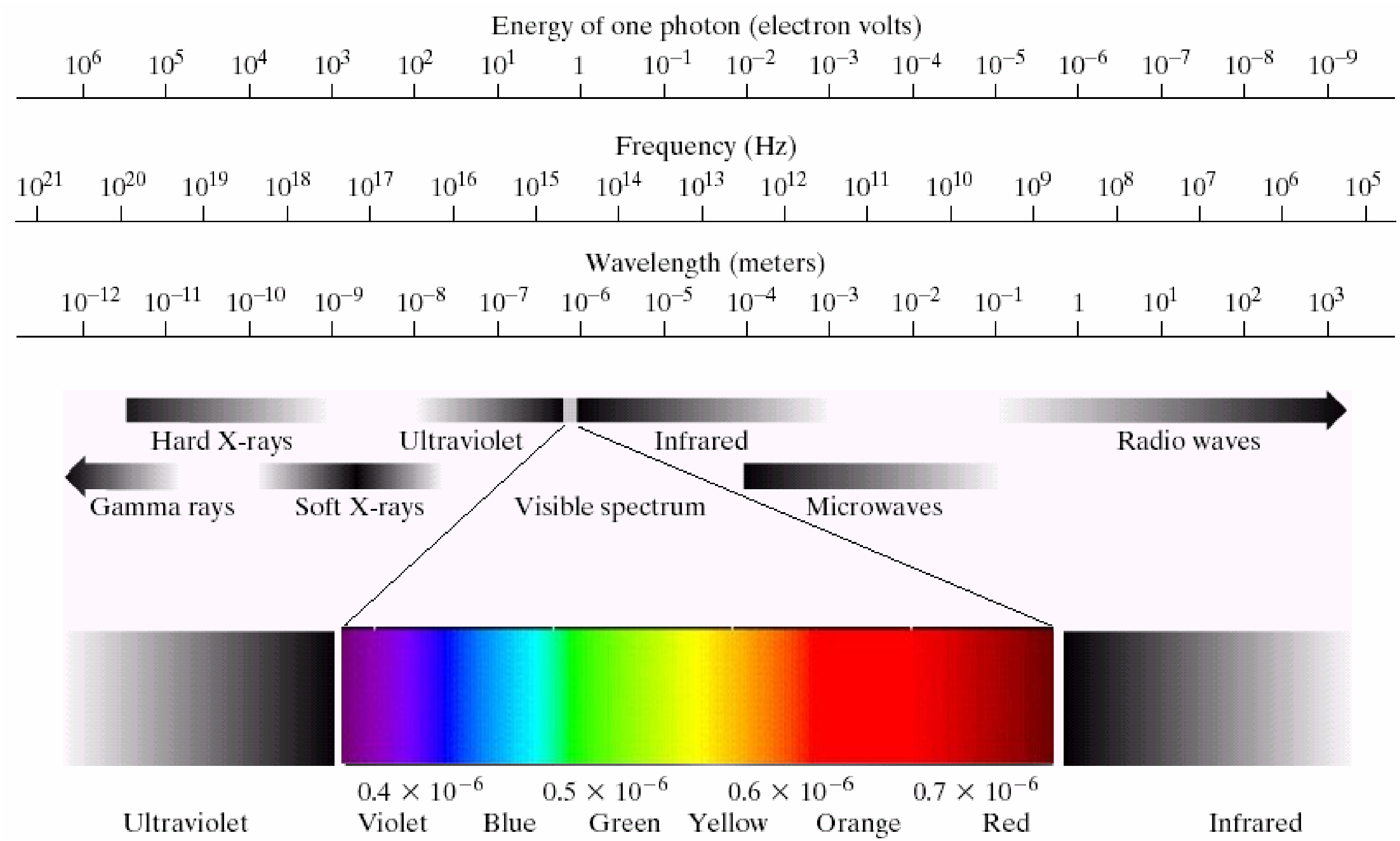
- EM Waves
  - A stream of mass less particles each travelling in a wave like pattern, moving at the speed of light and contains a certain bundle of energy
  - The electromagnetic spectrum is split up in to bands according to the energy per photon

Highest Energy

Lowest Energy



Light & EM Spectrum



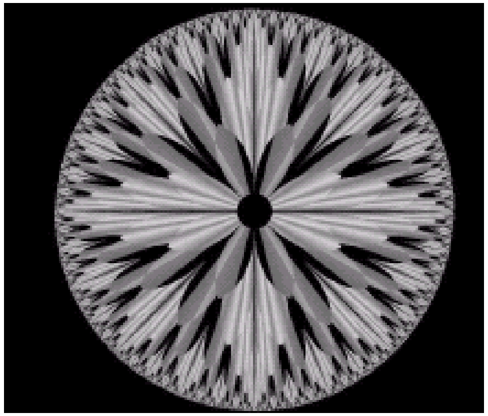
Visible light is just a particular part of the electromagnetic spectrum that can be sensed by the human eye

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

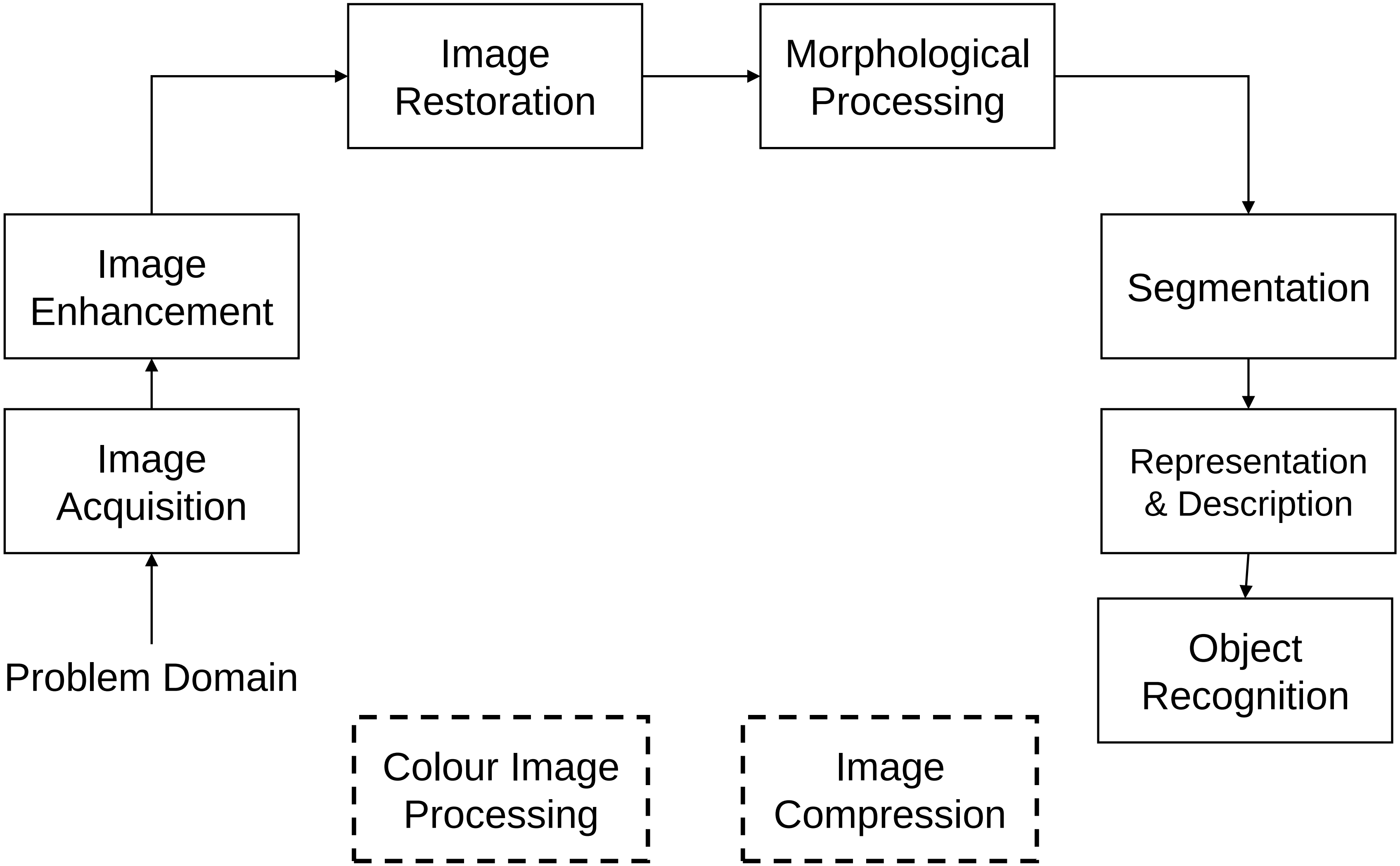
Examples: Imaging other Modalities

- 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

Image Restoration

Morphological Processing

Image Enhancement

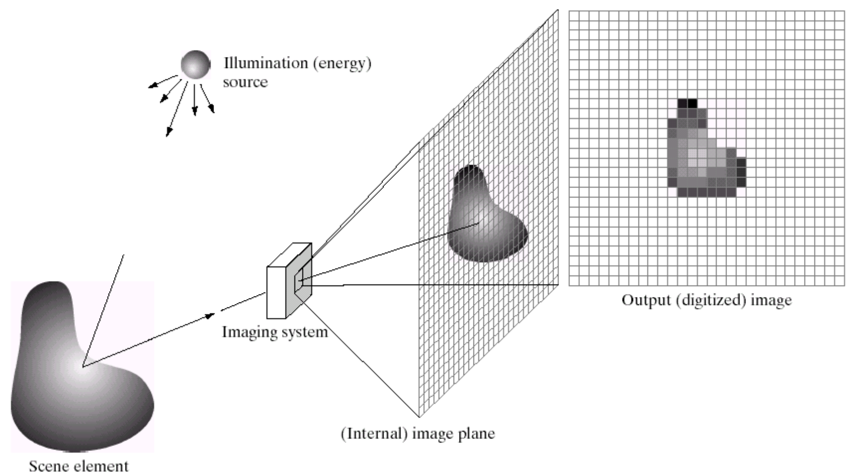
Segmentation

Image Acquisition

Representation & Description

Object Recognition

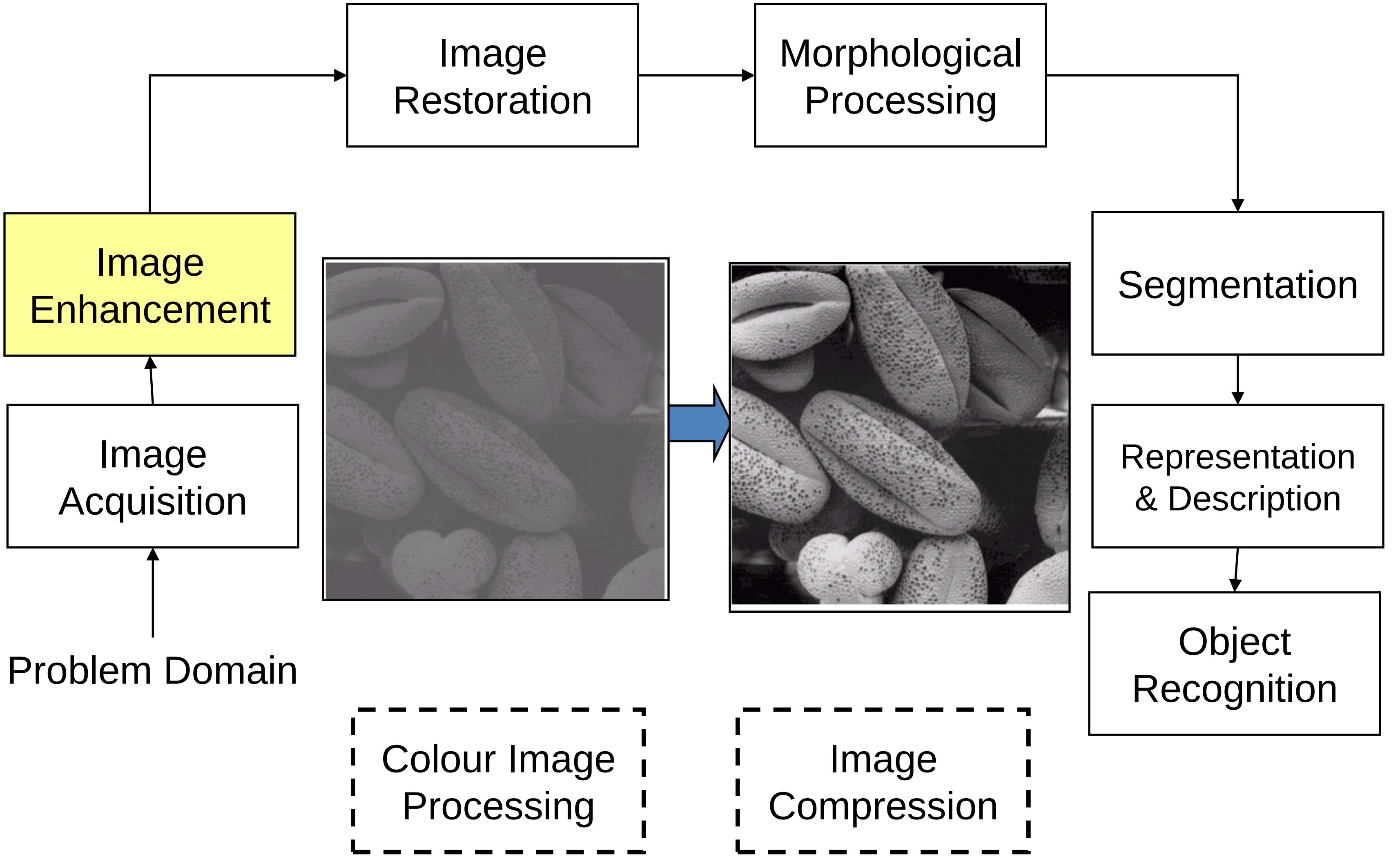
Problem Domain



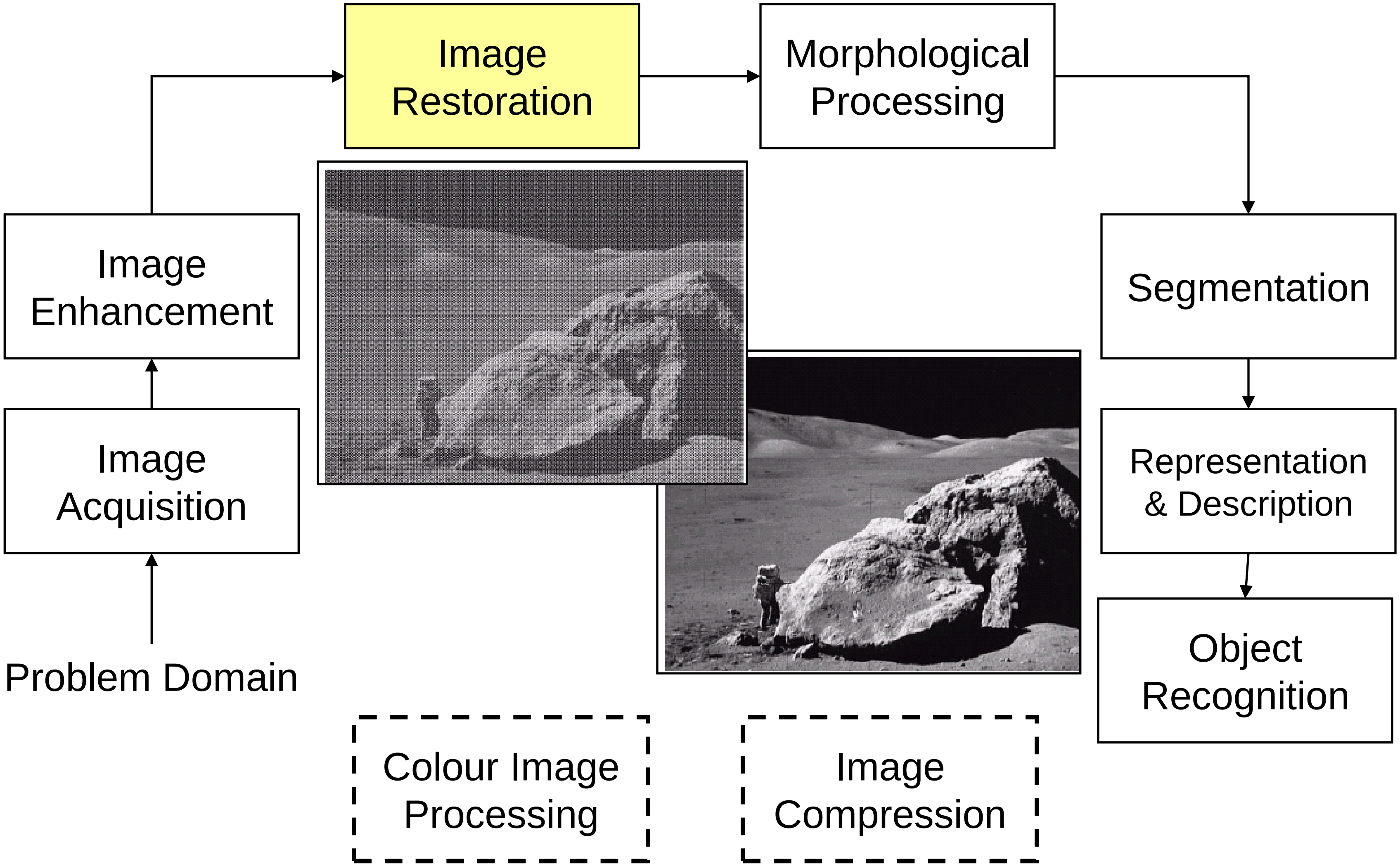
Colour Image Processing

Image Compression

Key Stages in DIP



Key Stages in DIP



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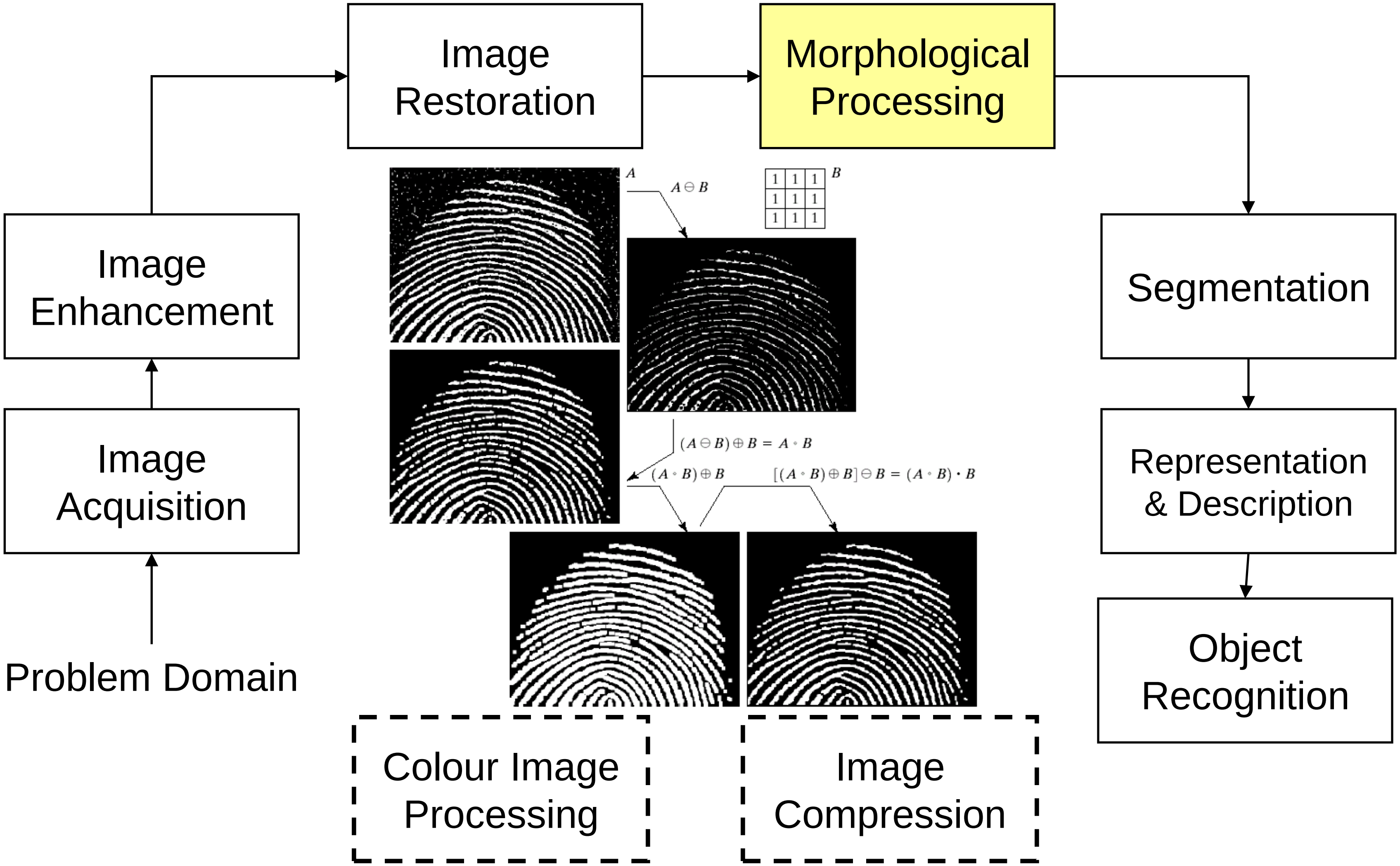

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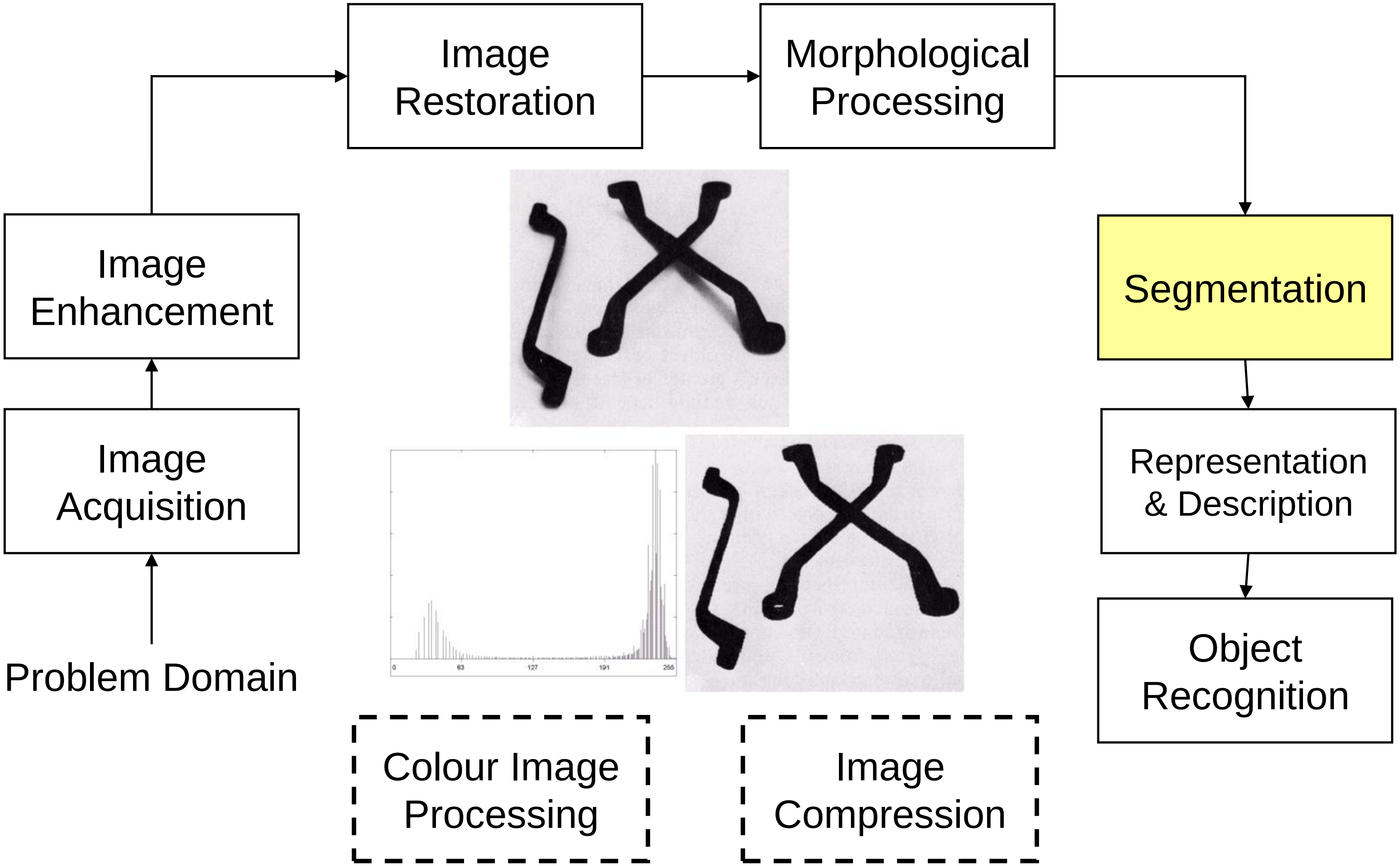

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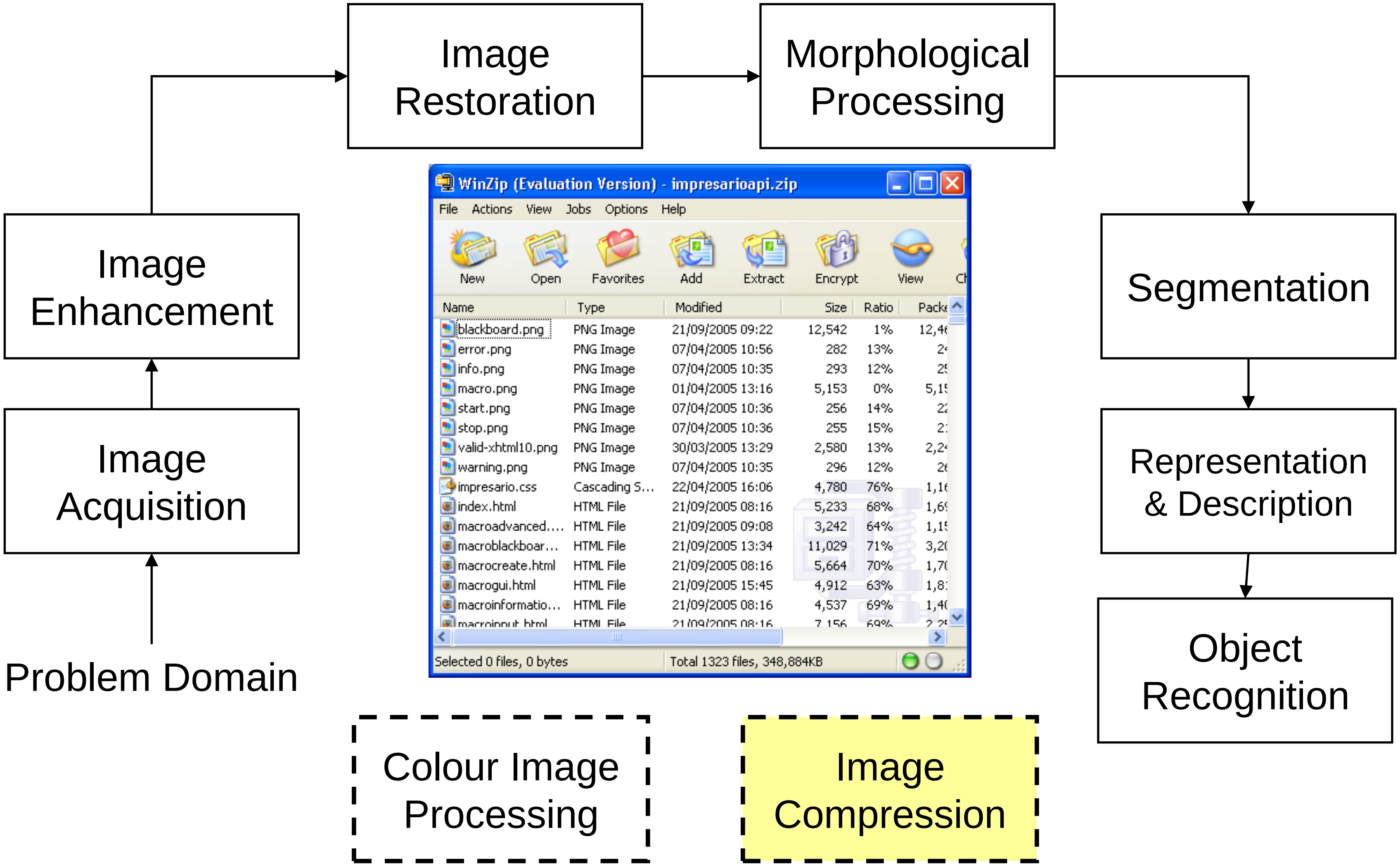

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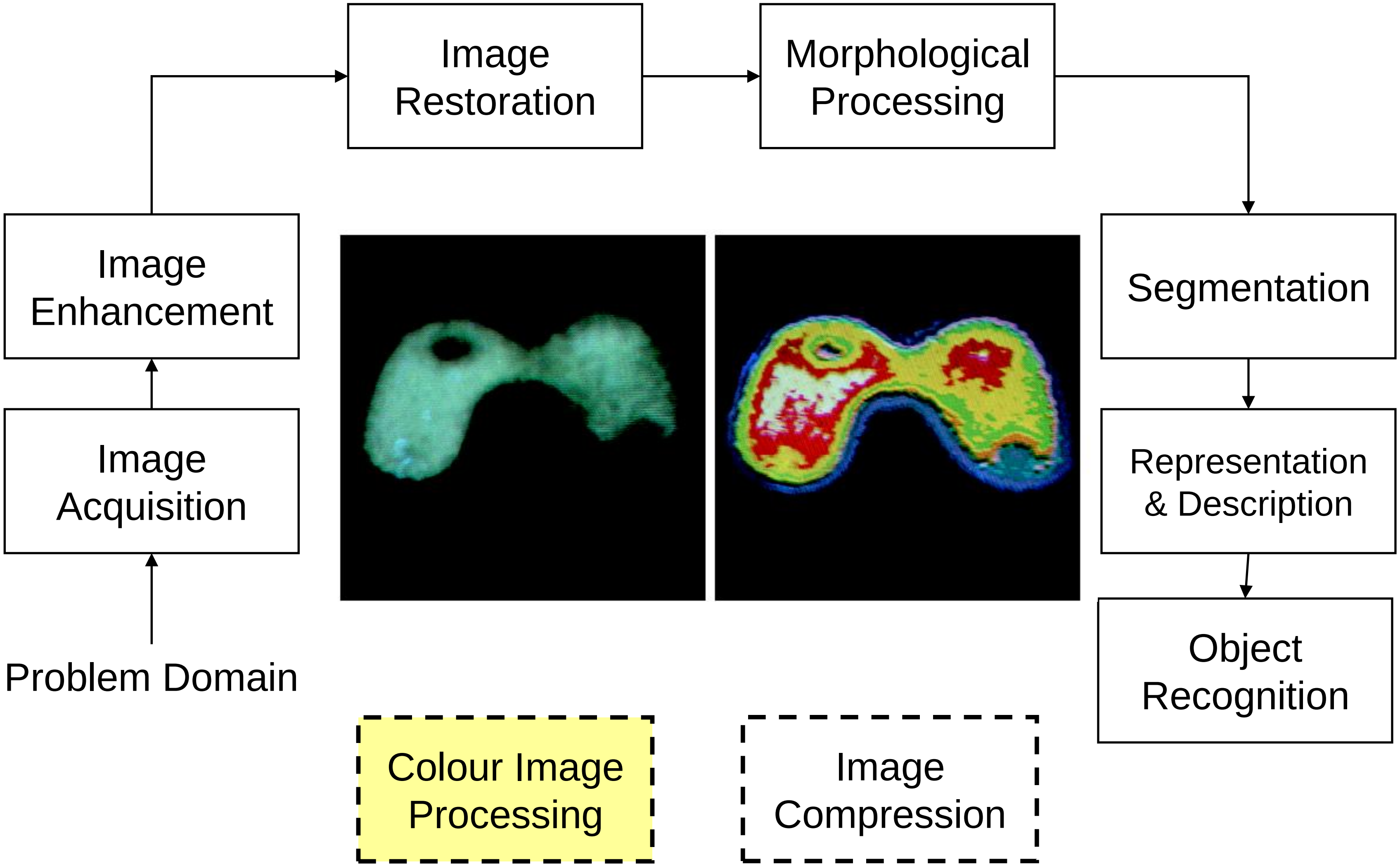
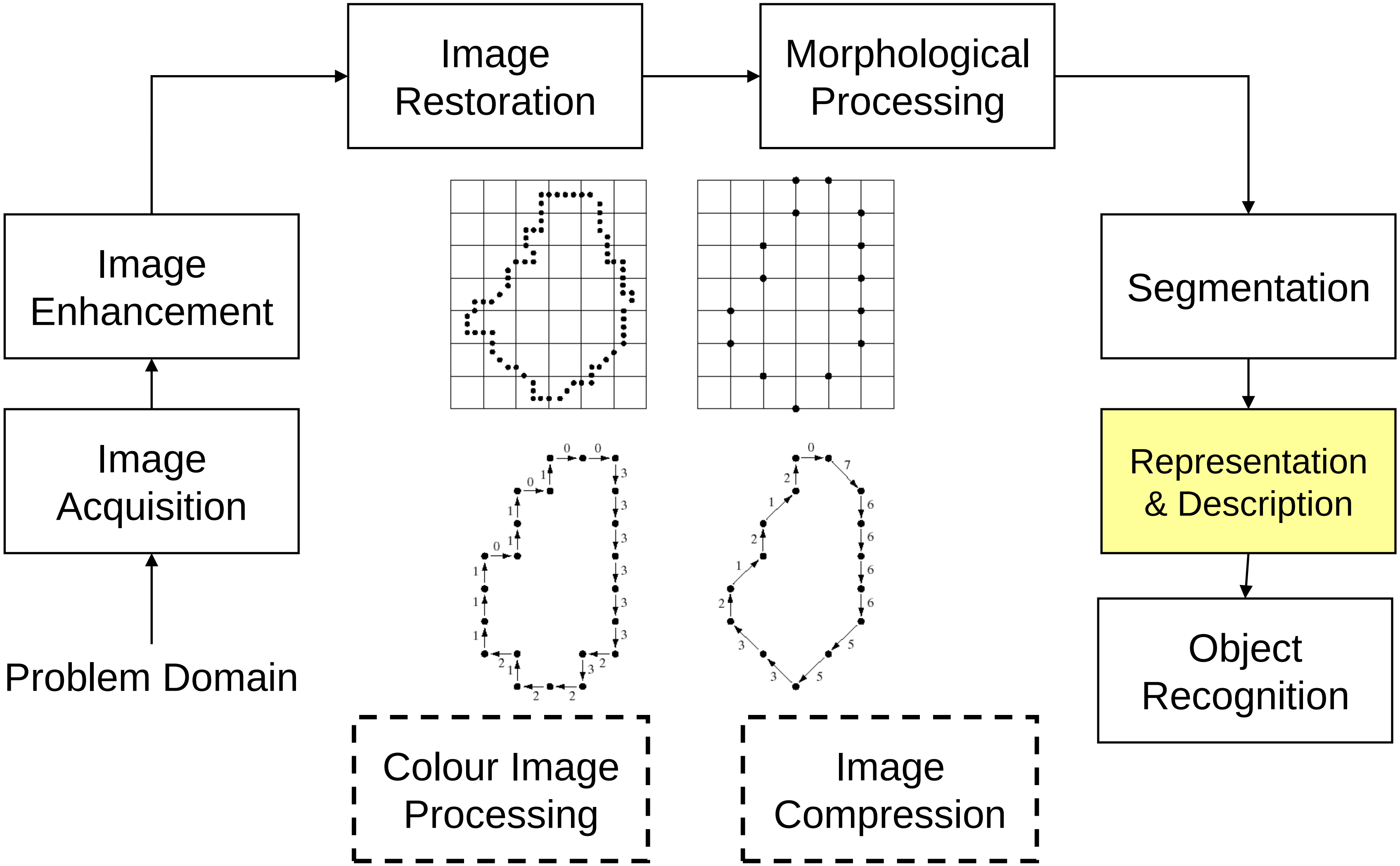
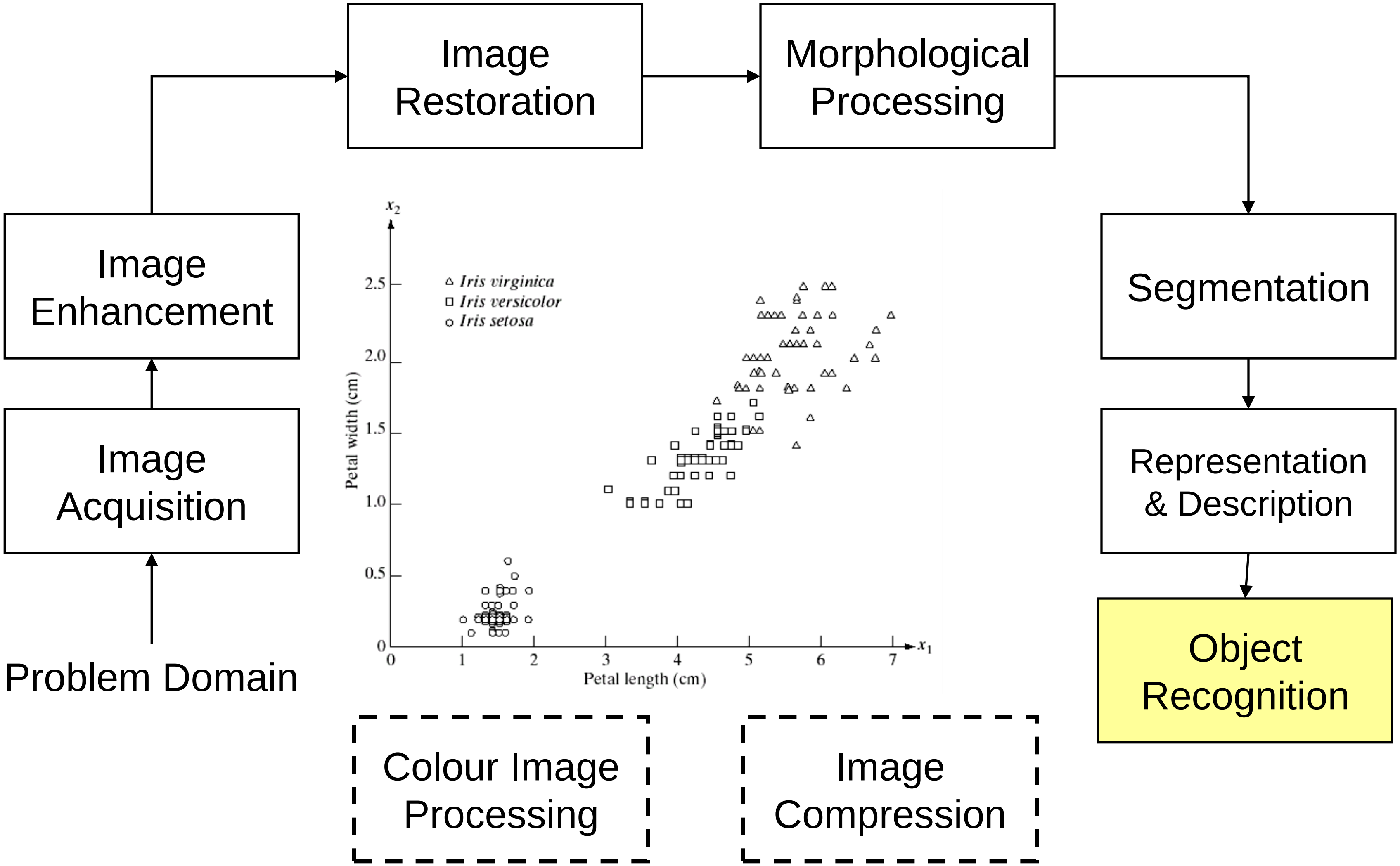


Key Stages in DIP



Key Stages in DIP

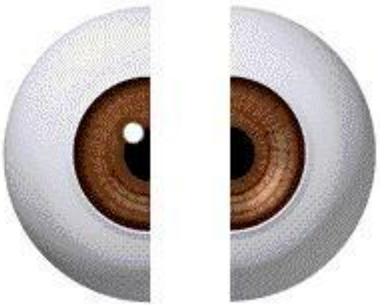


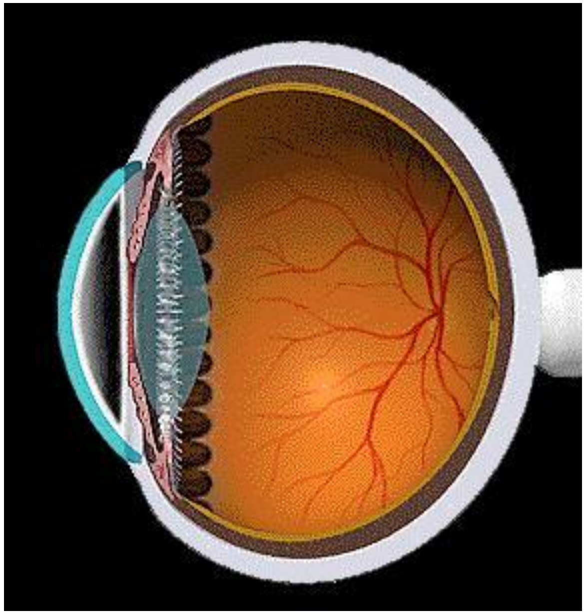
Human and Image Perception

- 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

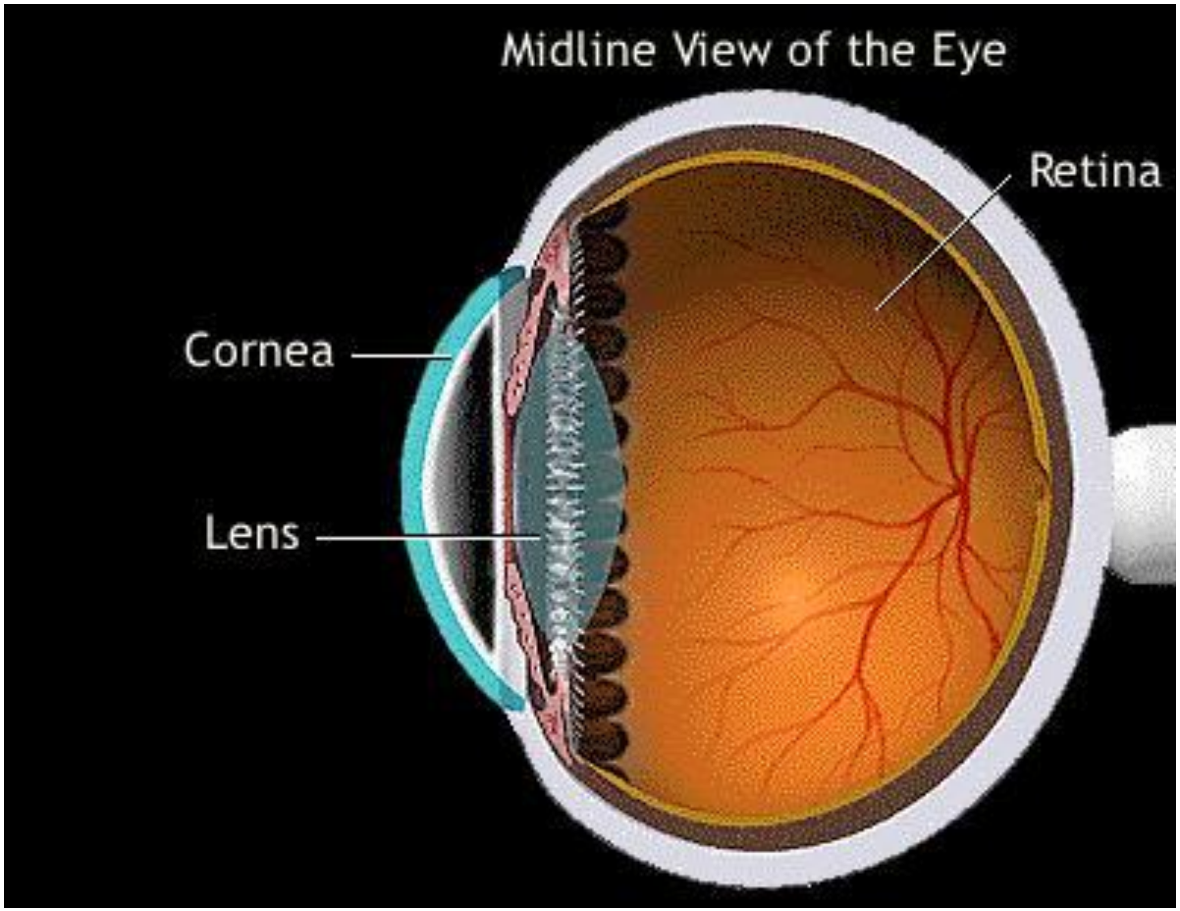
Eye Basic Anatomy: Eye can be “extracted” and “disassembled” (for study)

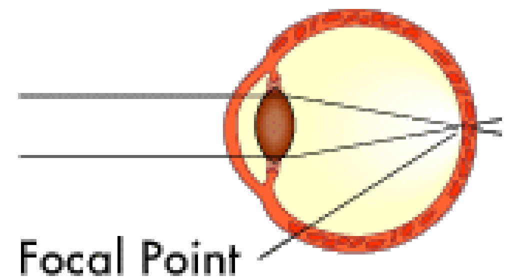




Human and Image Perception

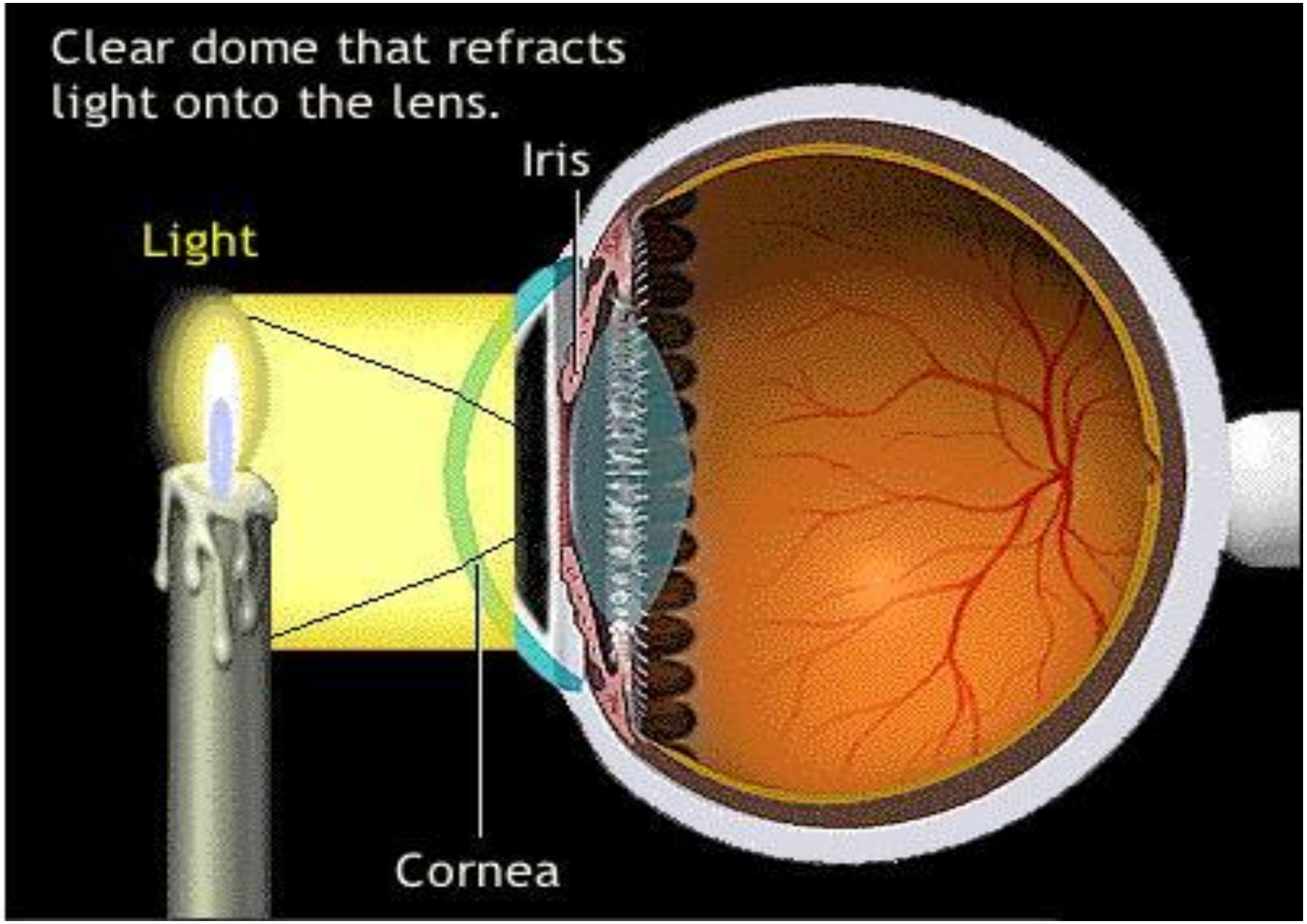
Simplified Midline View of the Eye (To explain how eye focuses)



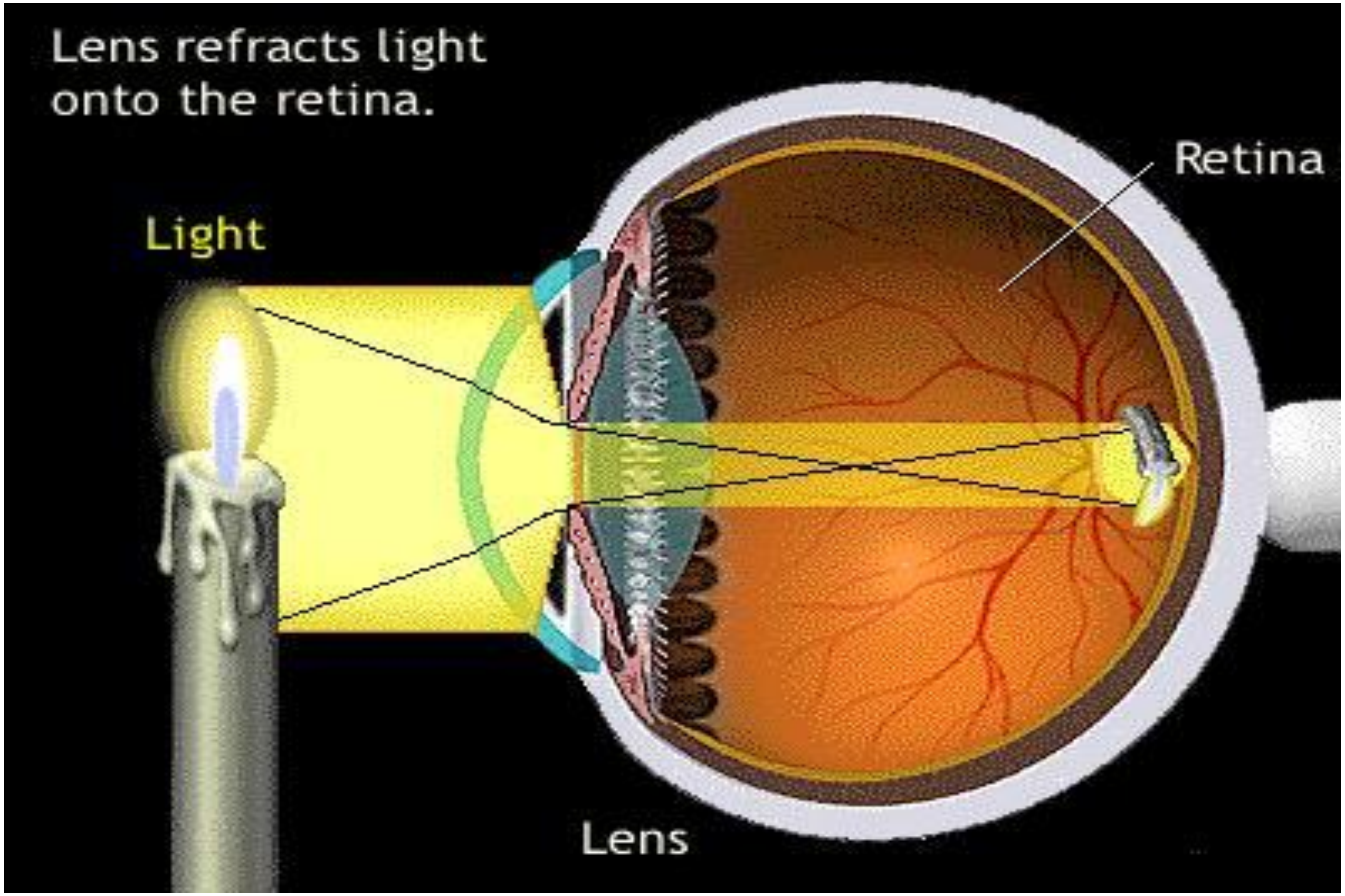


Human and Image Perception

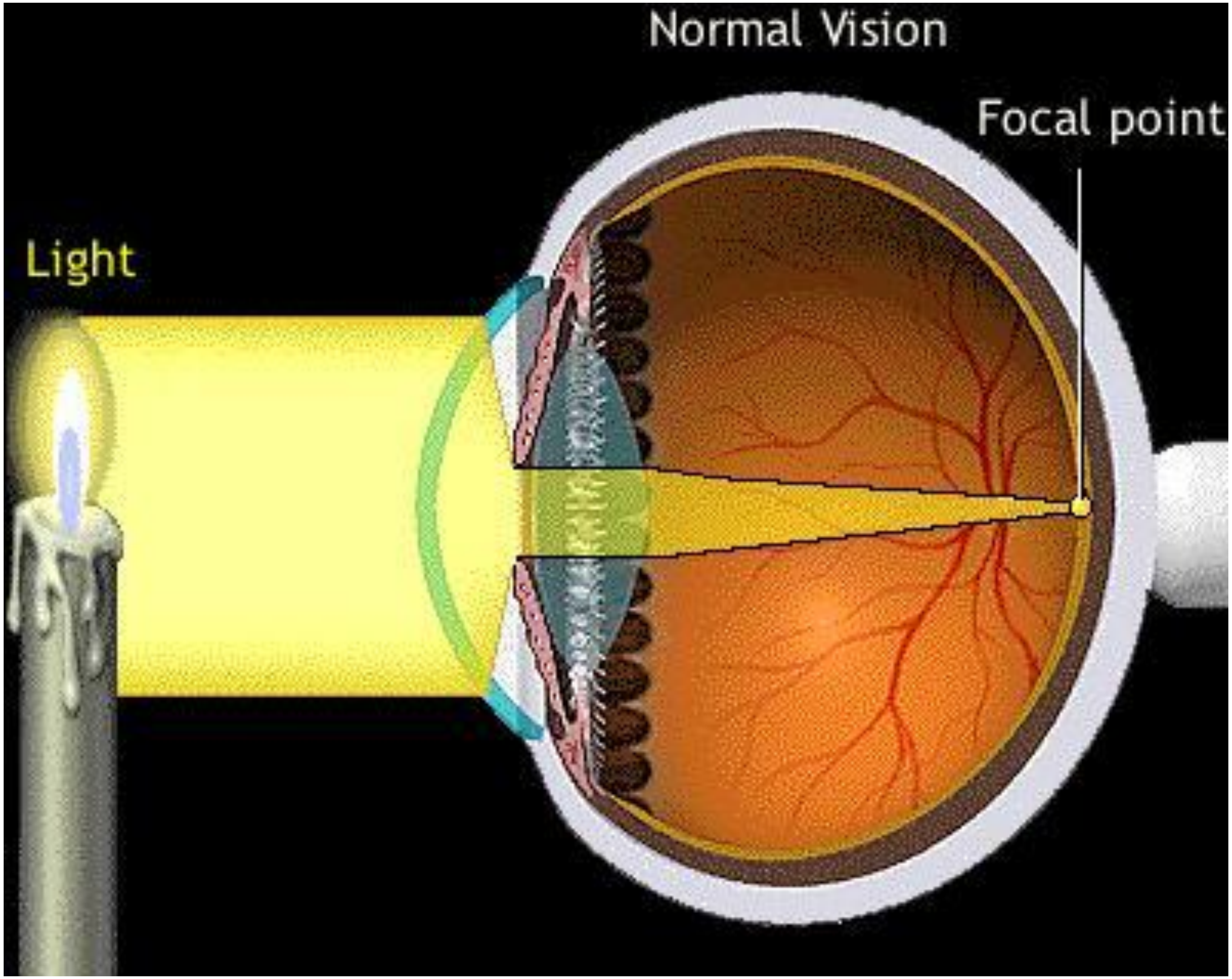
How eye focuses



Human and Image Perception

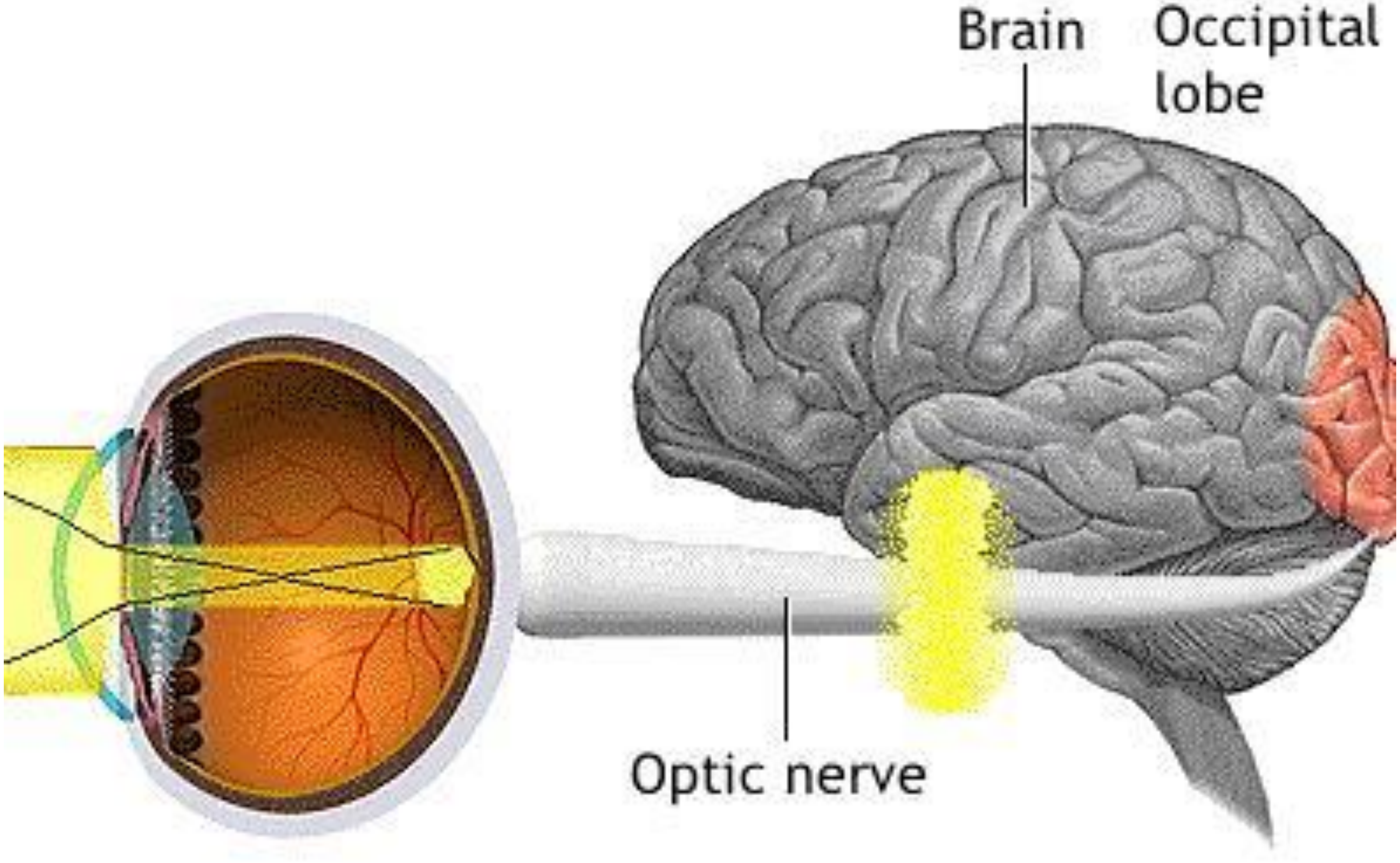


How eye focuses: Normal Vision-Focusing on the Retina

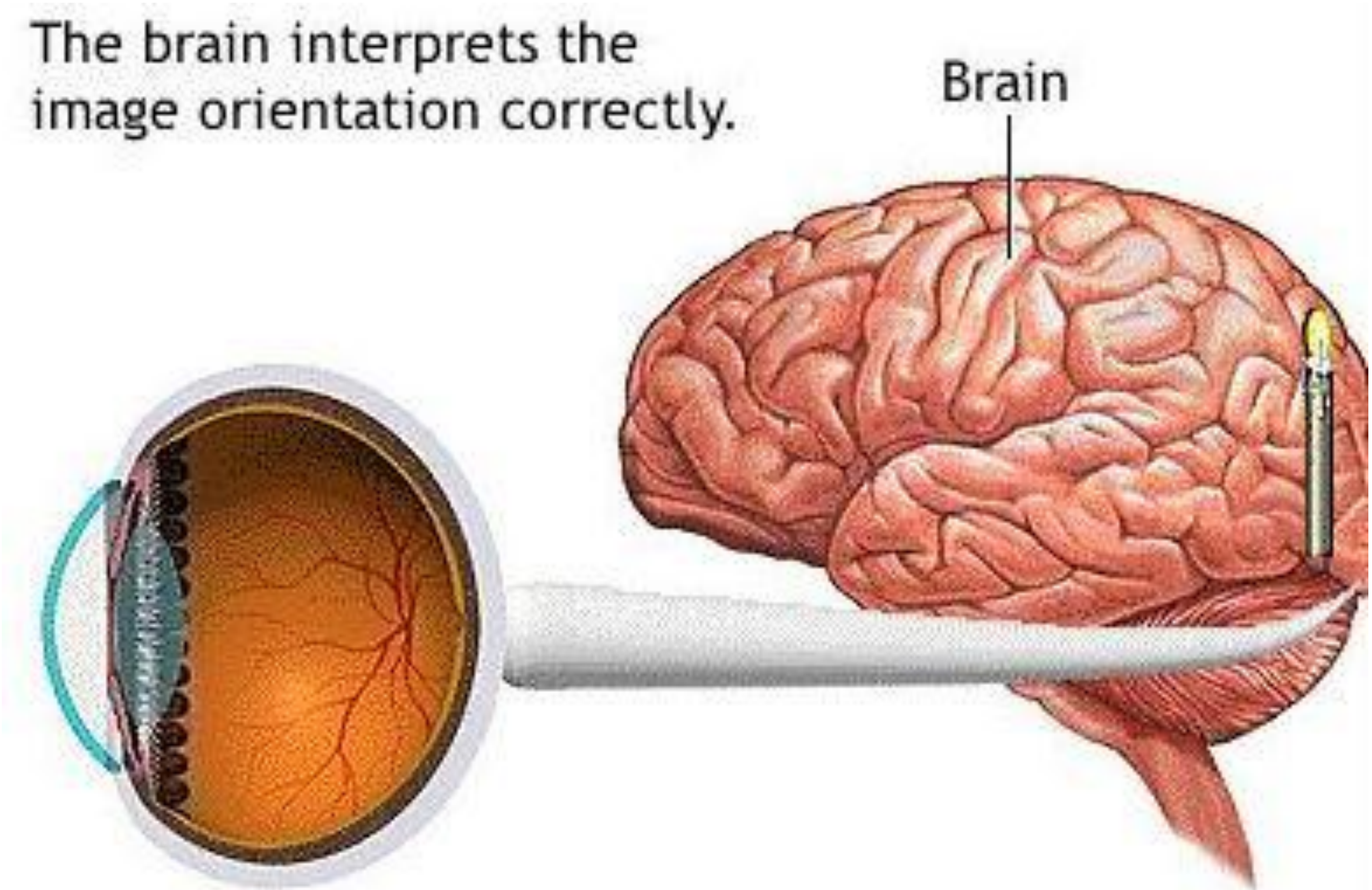


From Eye to the Brain

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)



Human Eye

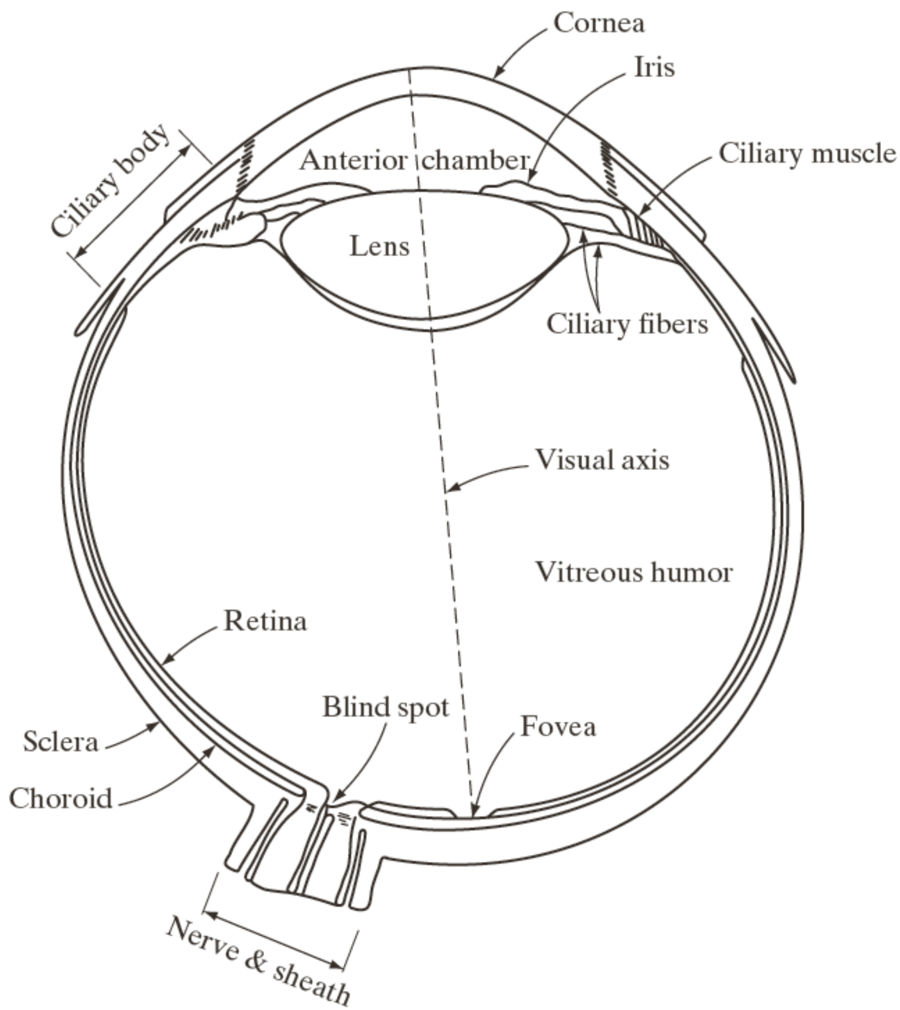
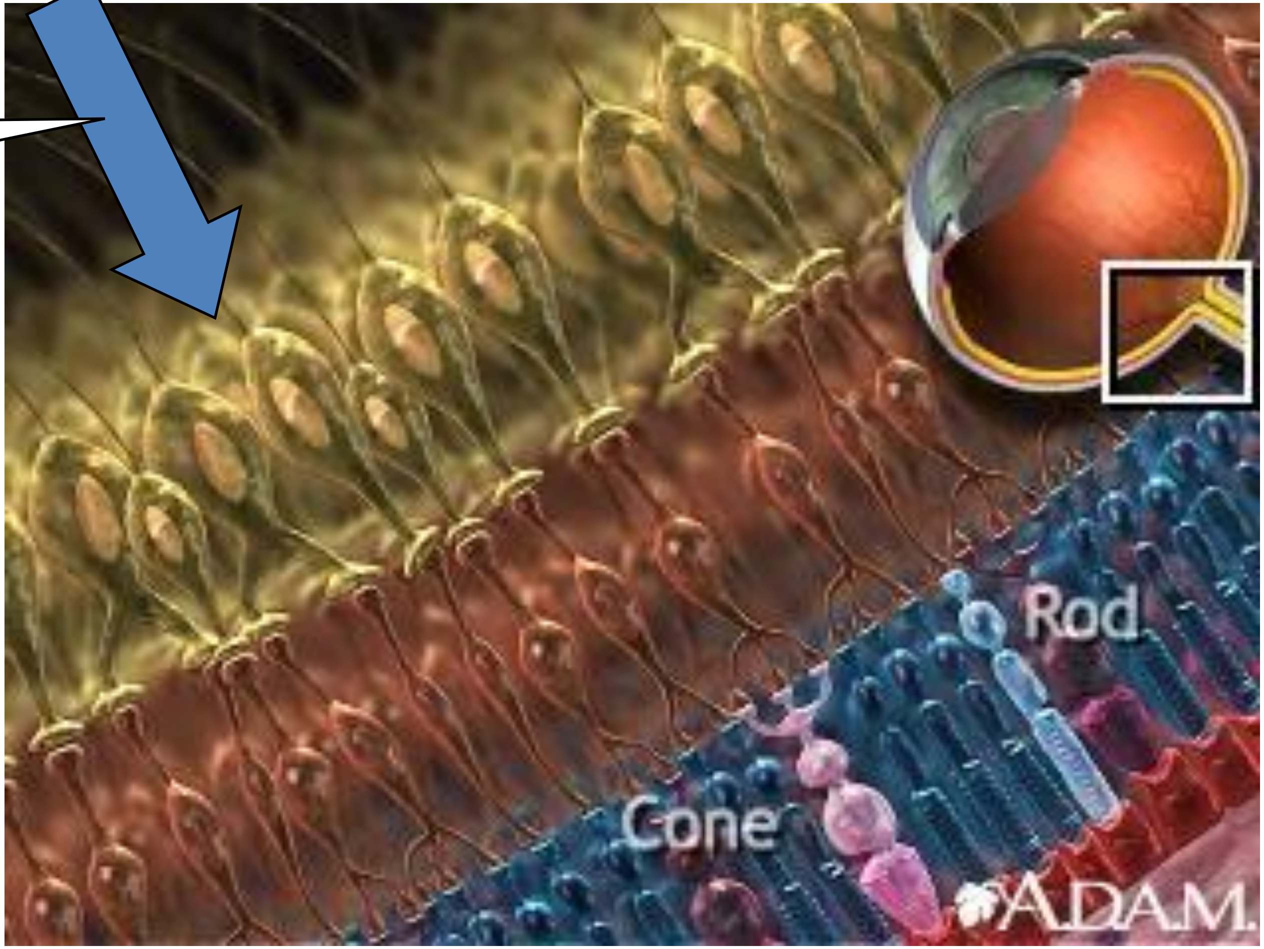


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

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

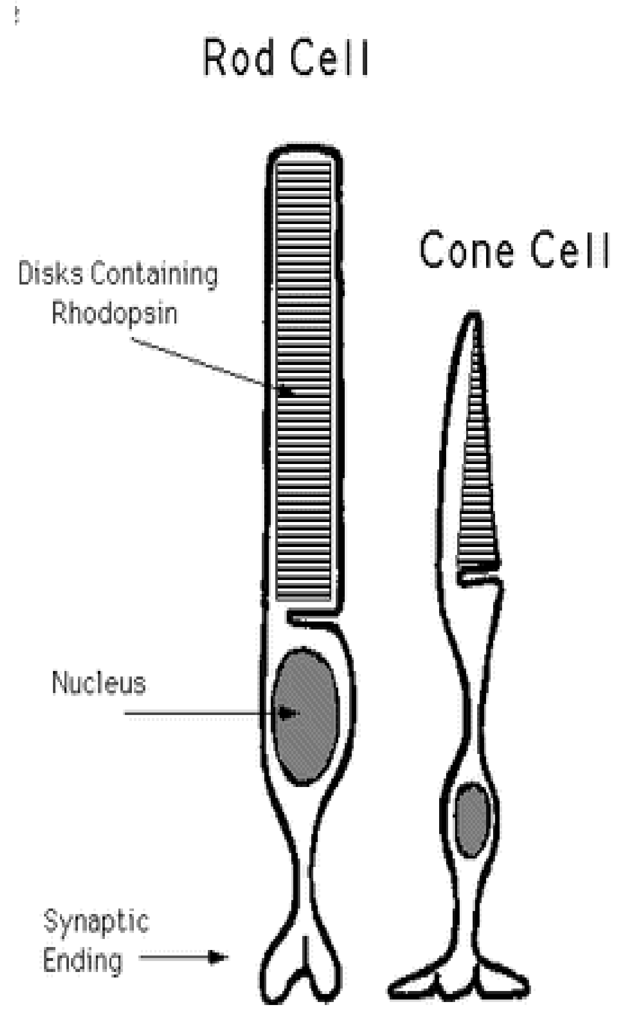


What happens when light reaches the retina?

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 thingseven if it is only in shades of grey



Rods and Cones

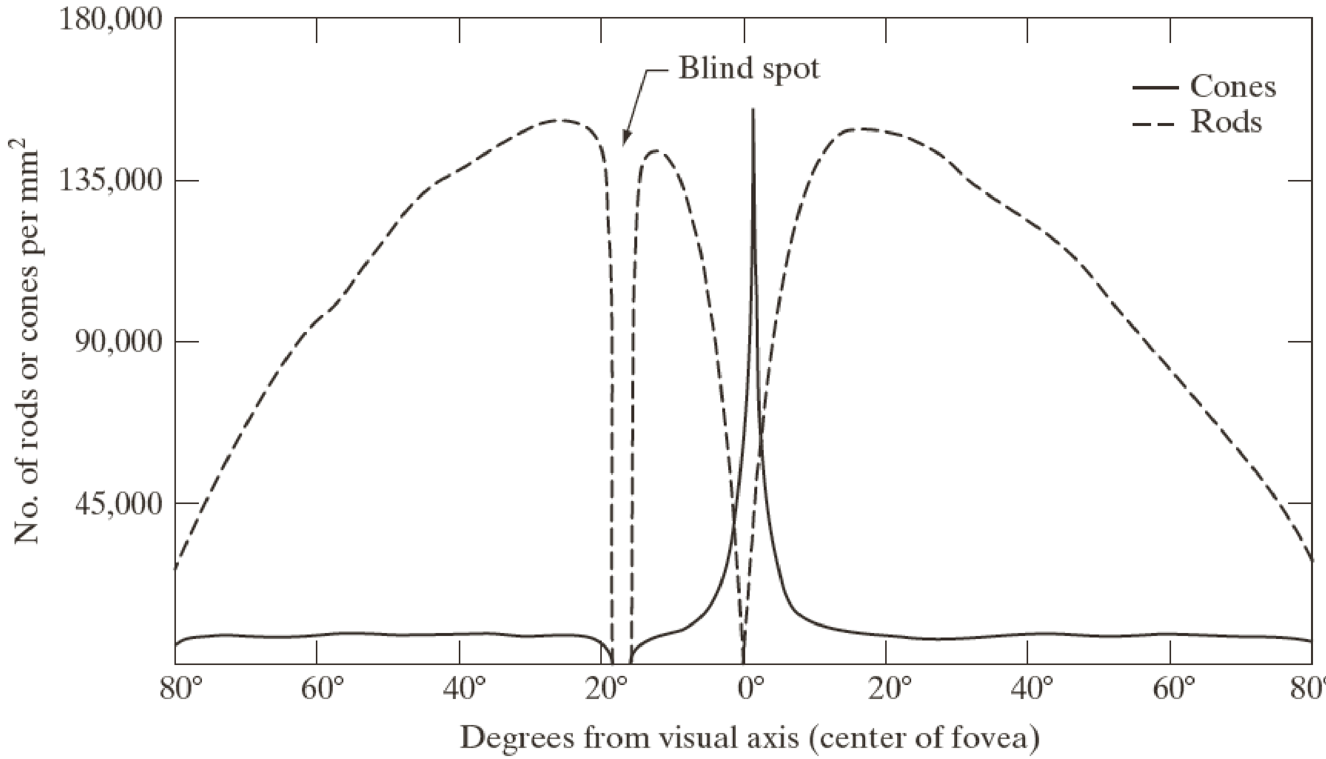


FIGURE 2.2
Distribution of rods and cones in the retina.

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*

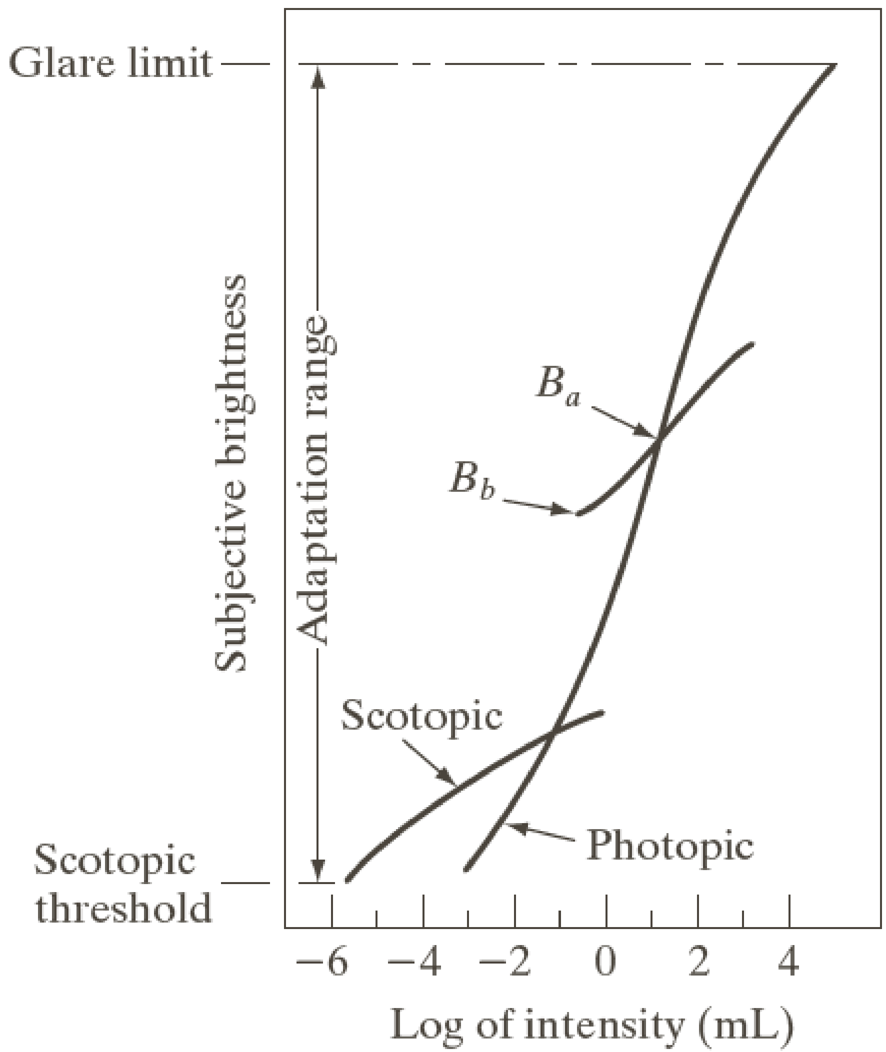
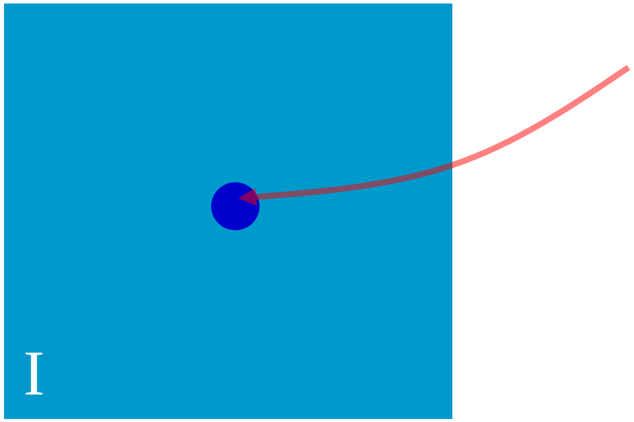


FIGURE 2.4 Range of subjective brightness sensations showing a particular adaptation level.

CONTRAST SENSITIVITY



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

Good brightness discrimination

⇨ $\Delta I_c/I$ is small.

Bad brightness discrimination

⇨ $\Delta I_c/I$ 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

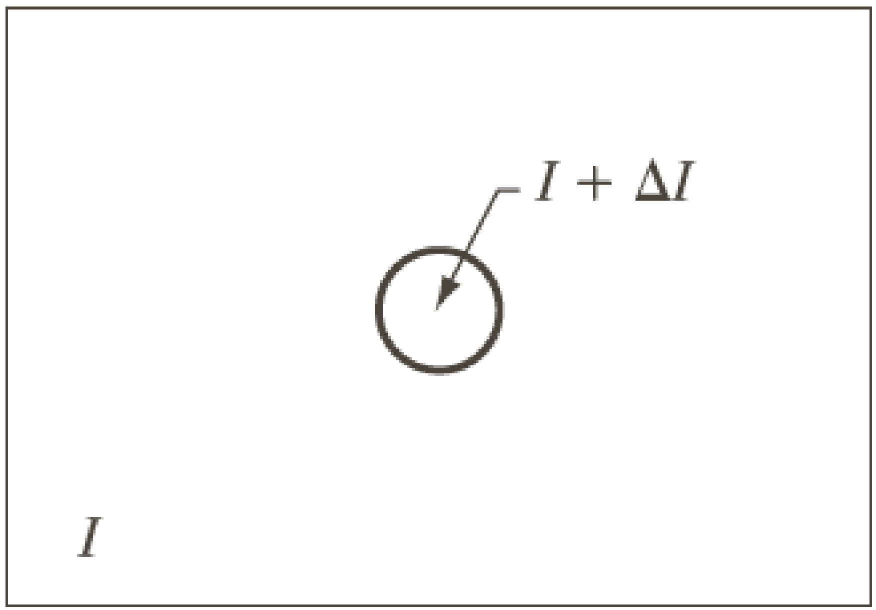


FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

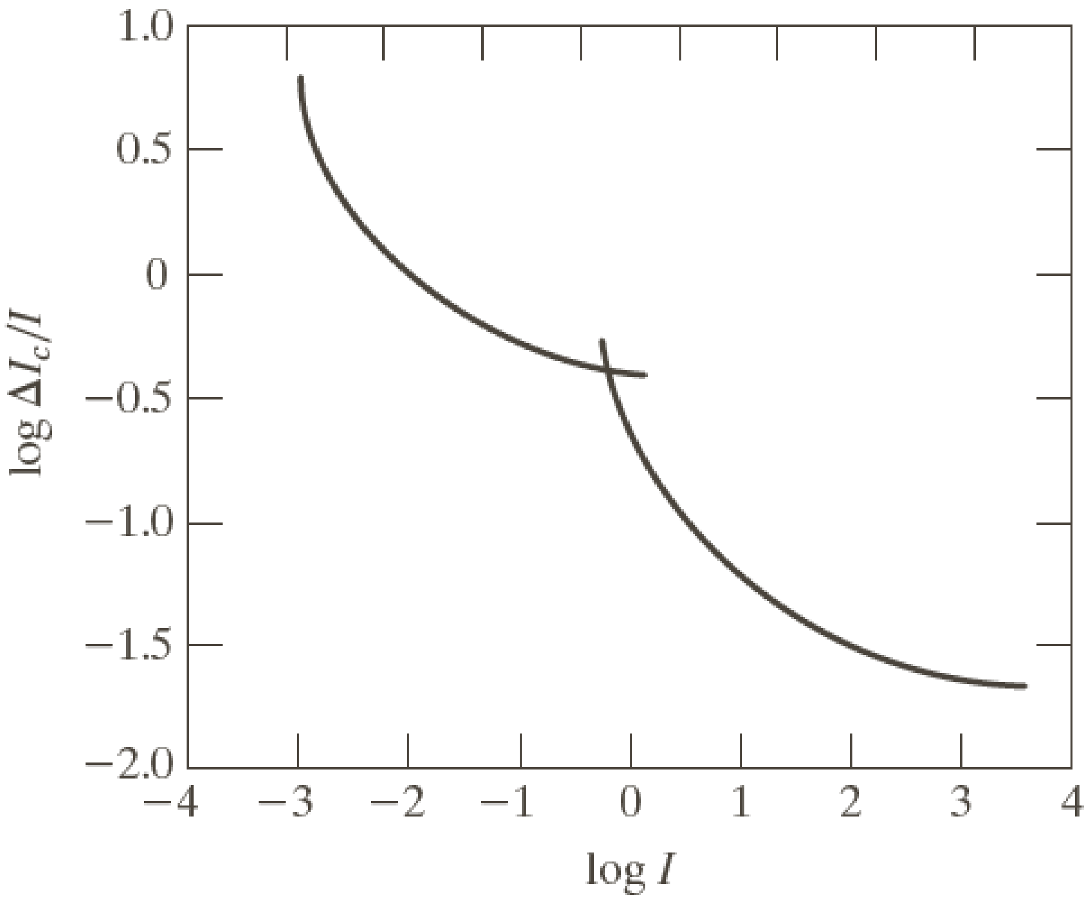
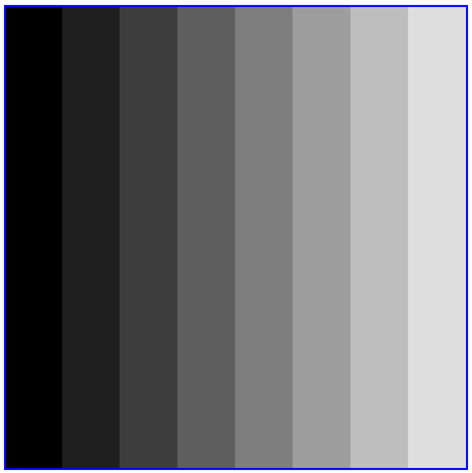
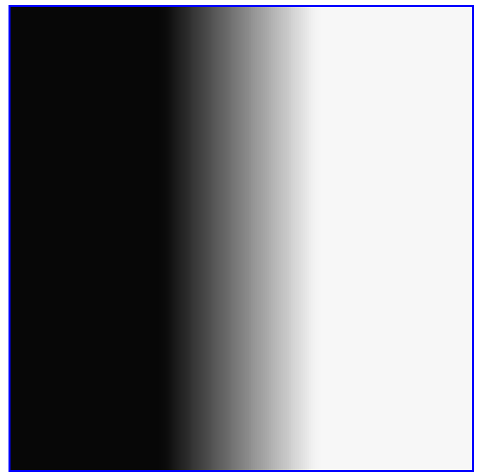


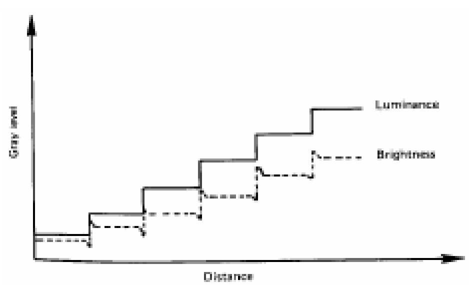
FIGURE 2.6 Typical Weber ratio as a function of intensity.

MACH BANDS

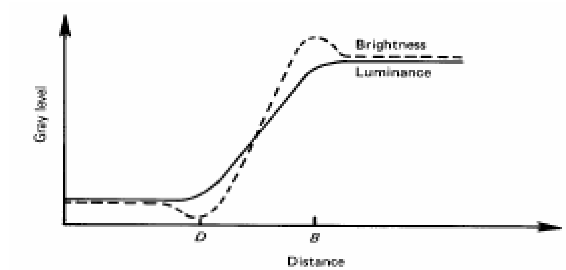
- Perceived brightness depends on **surroundings** as well as luminance





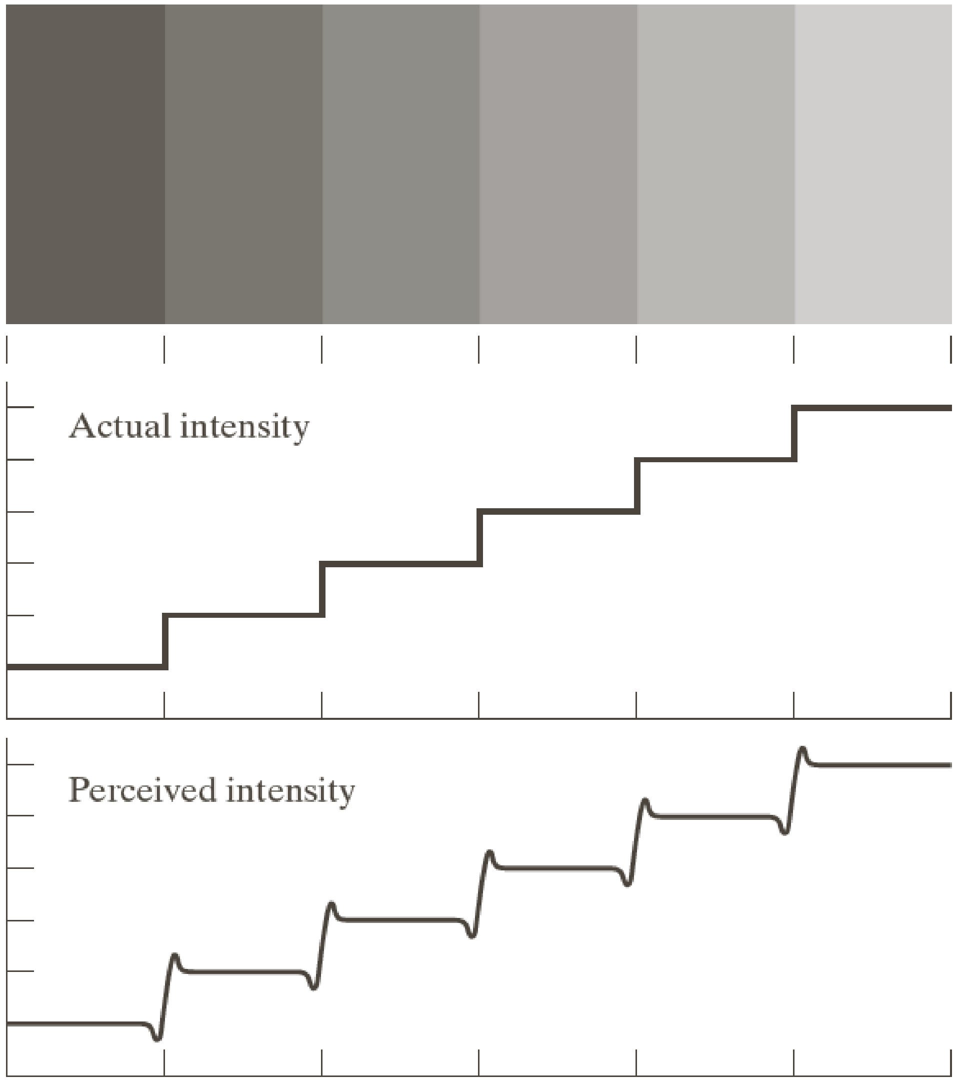


Luminance versus brightness.



Mach band effect.

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

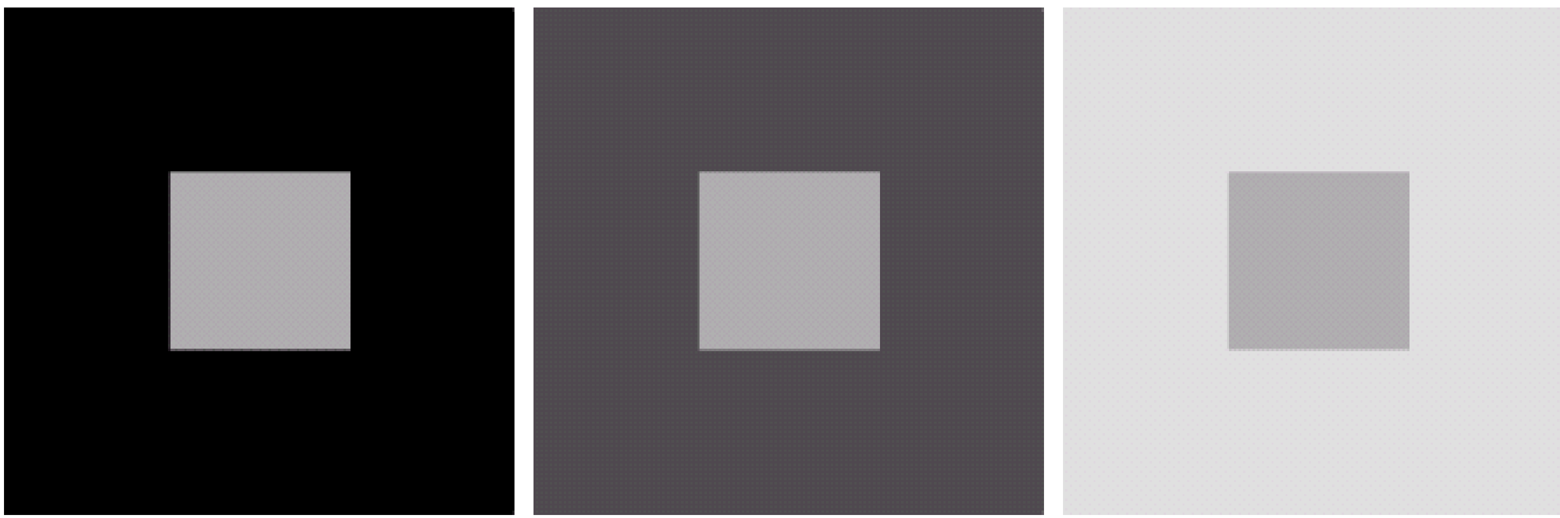
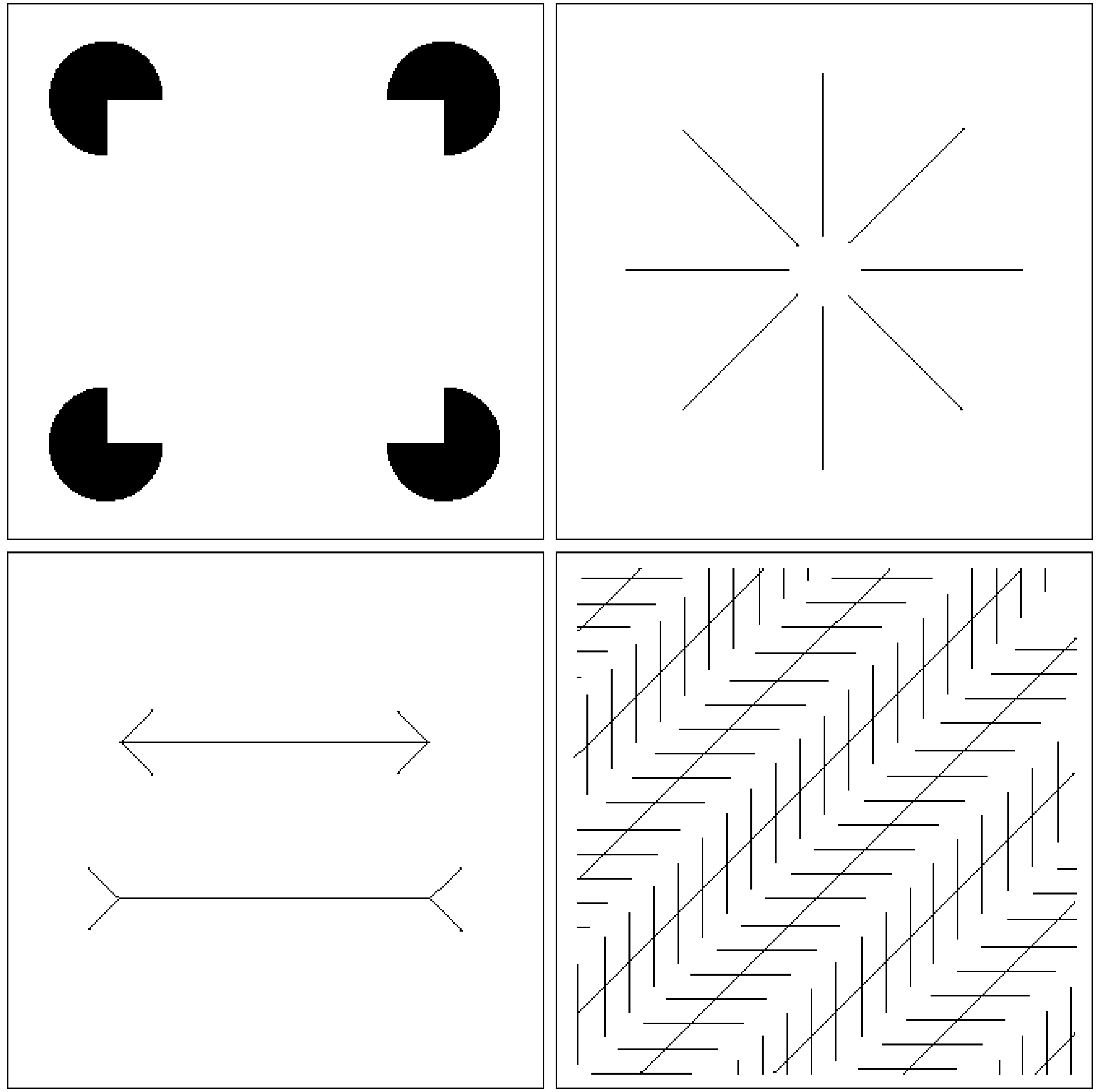


FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.



a b
c d

FIGURE 2.9 Some well-known optical illusions.

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

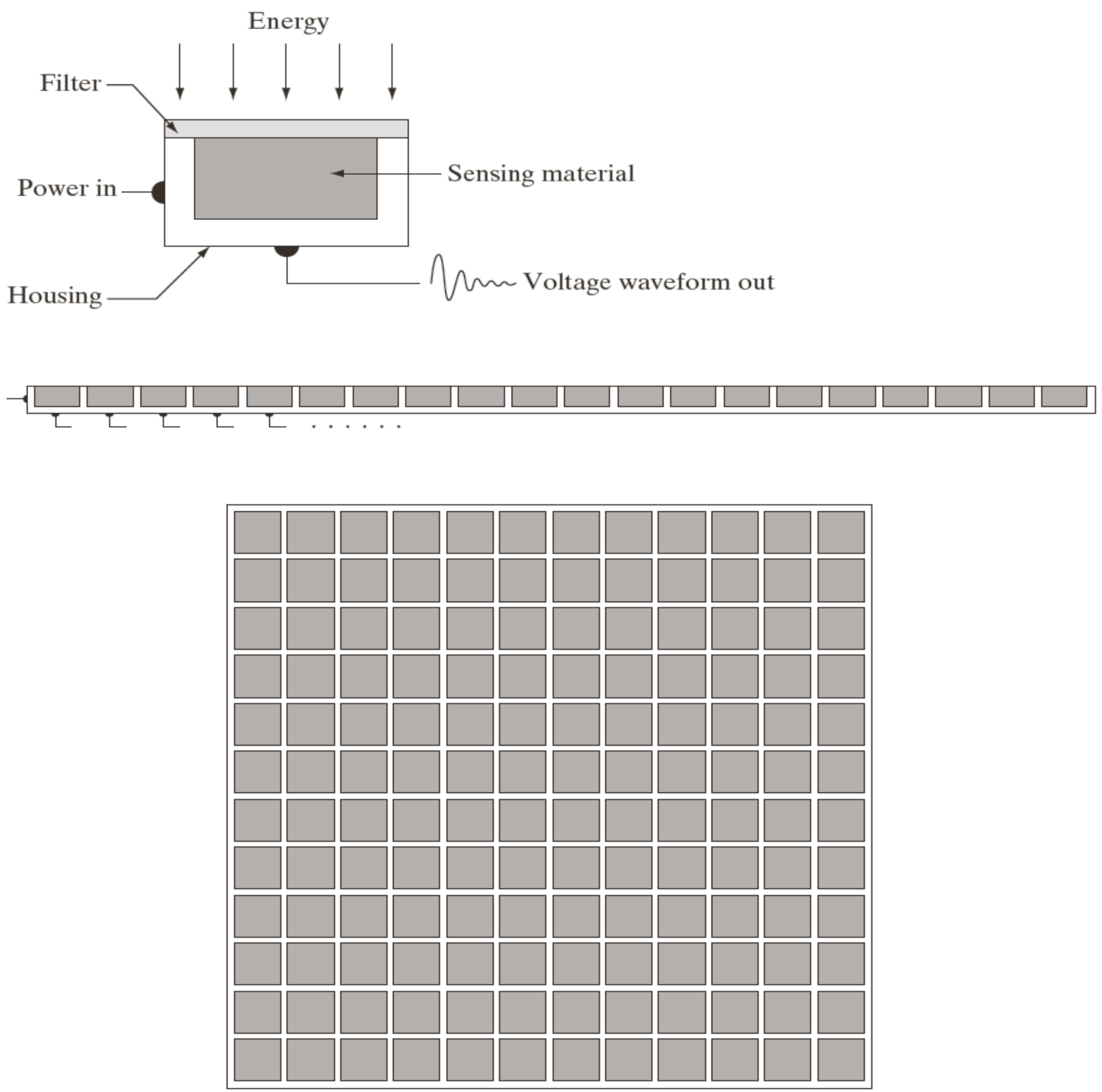
- The function f(x, y) may be characterized by two components:
  - The amount of source light incident on the scene being viewed ⇨ illumination.
  - The amount of light reflected by the objects in the scene ⇨ reflectance.

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

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

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

Image Acquisition



a
b
c

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

Image Acquisition

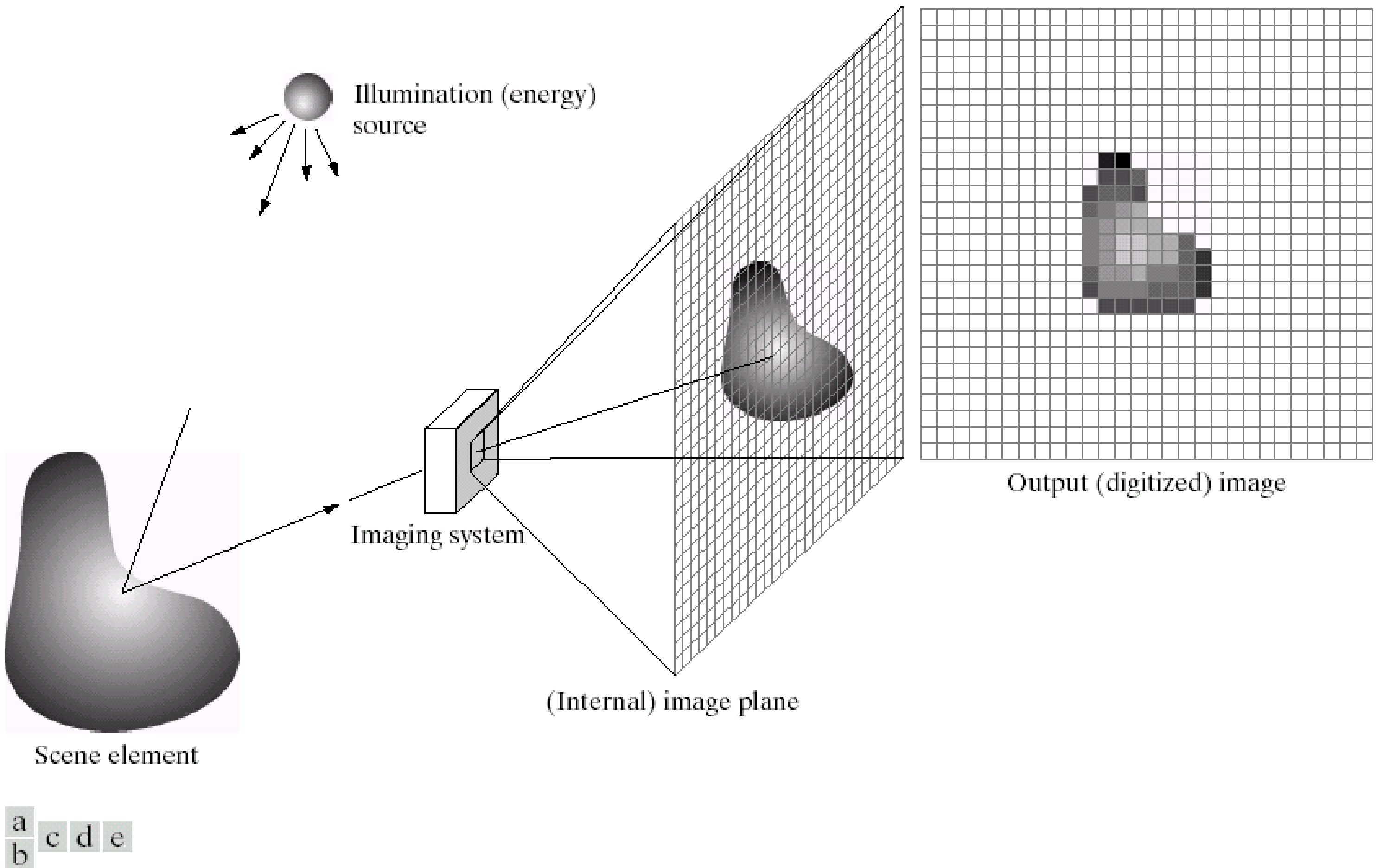


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Sampling and Quantization

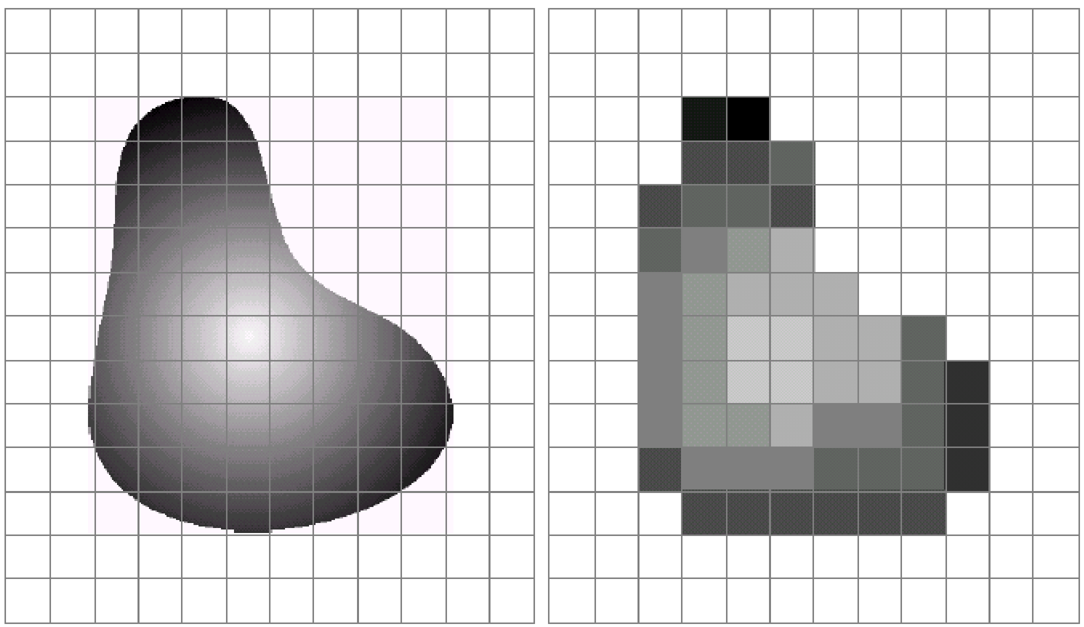
- Sampling:
  - Digitization of the spatial coordinates (x,y)
- Quantization:
  - Digitization in amplitude (also known as gray level quantization)

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

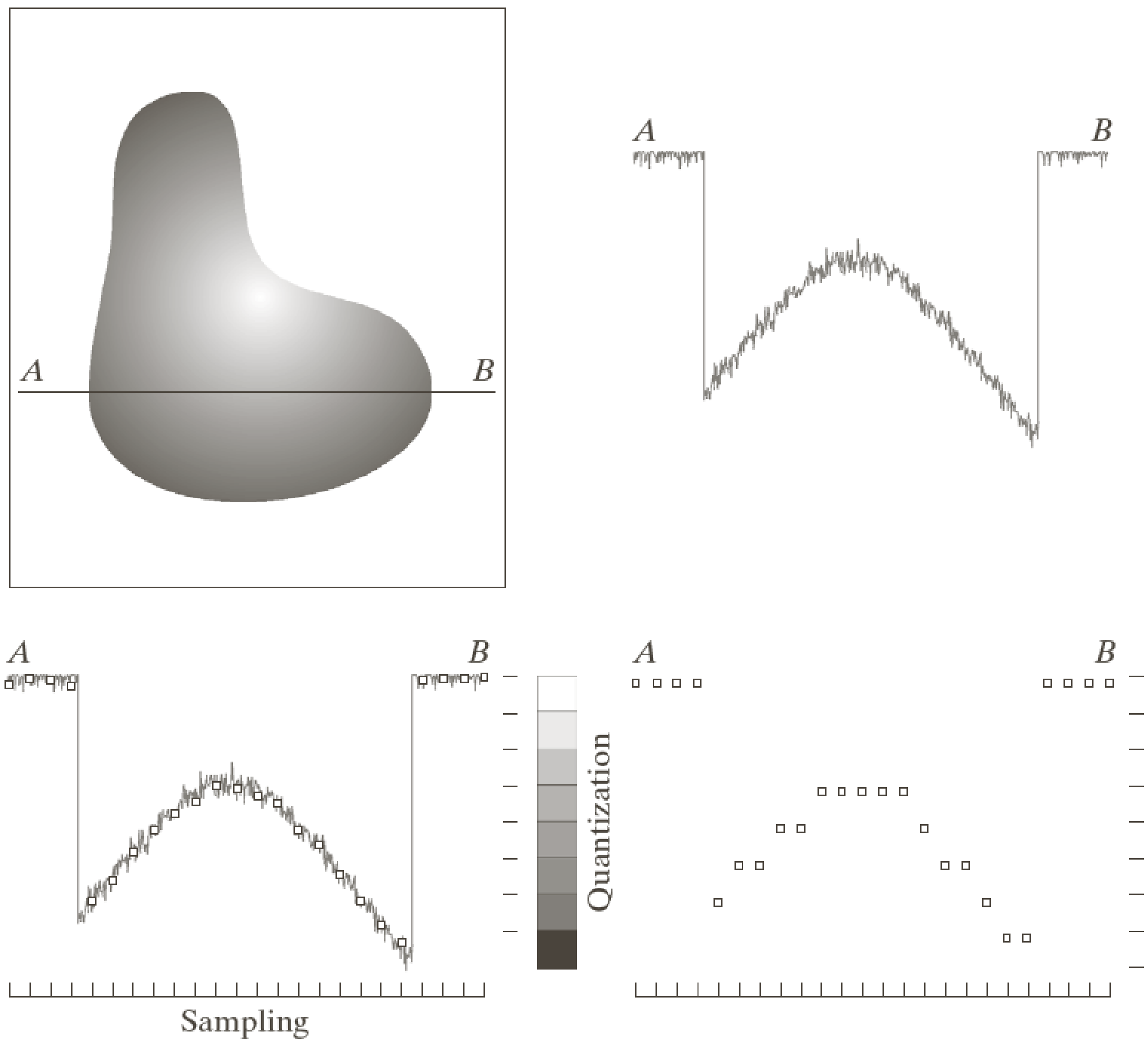
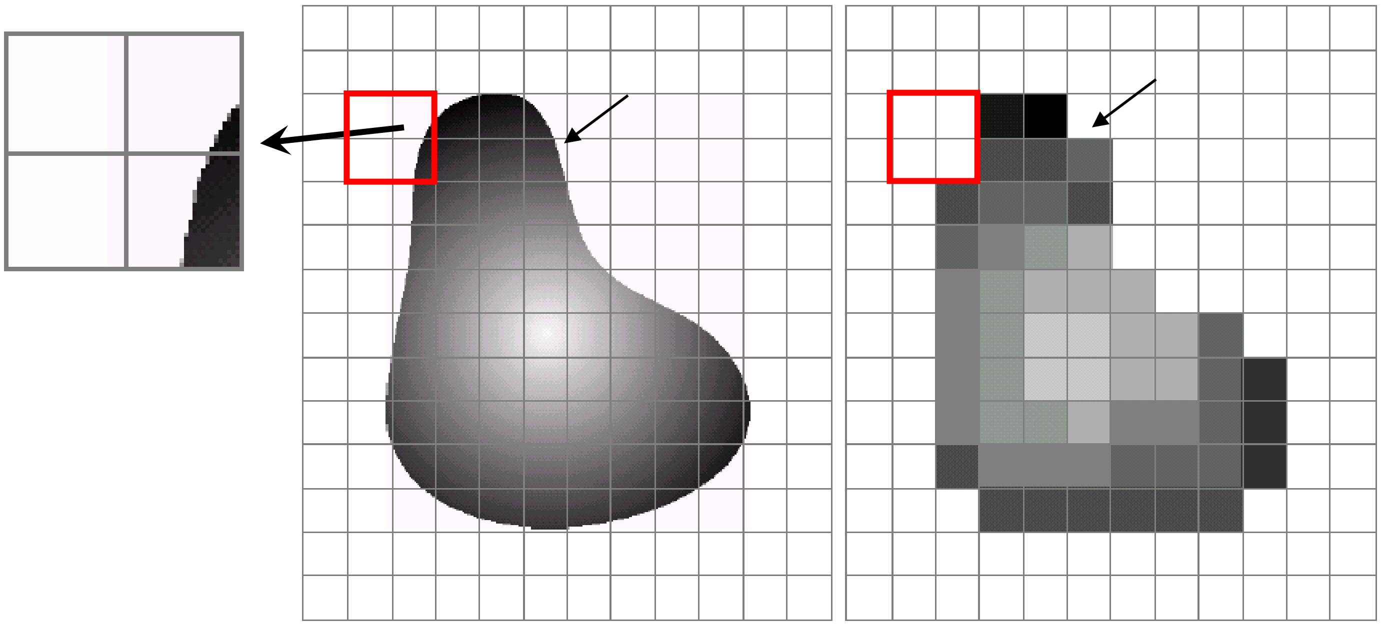


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from *A* to *B* in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Image Formation

- Digital Image is an approximation of a real world scene



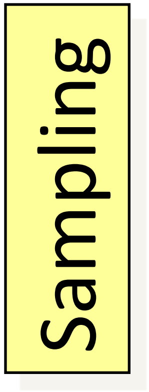
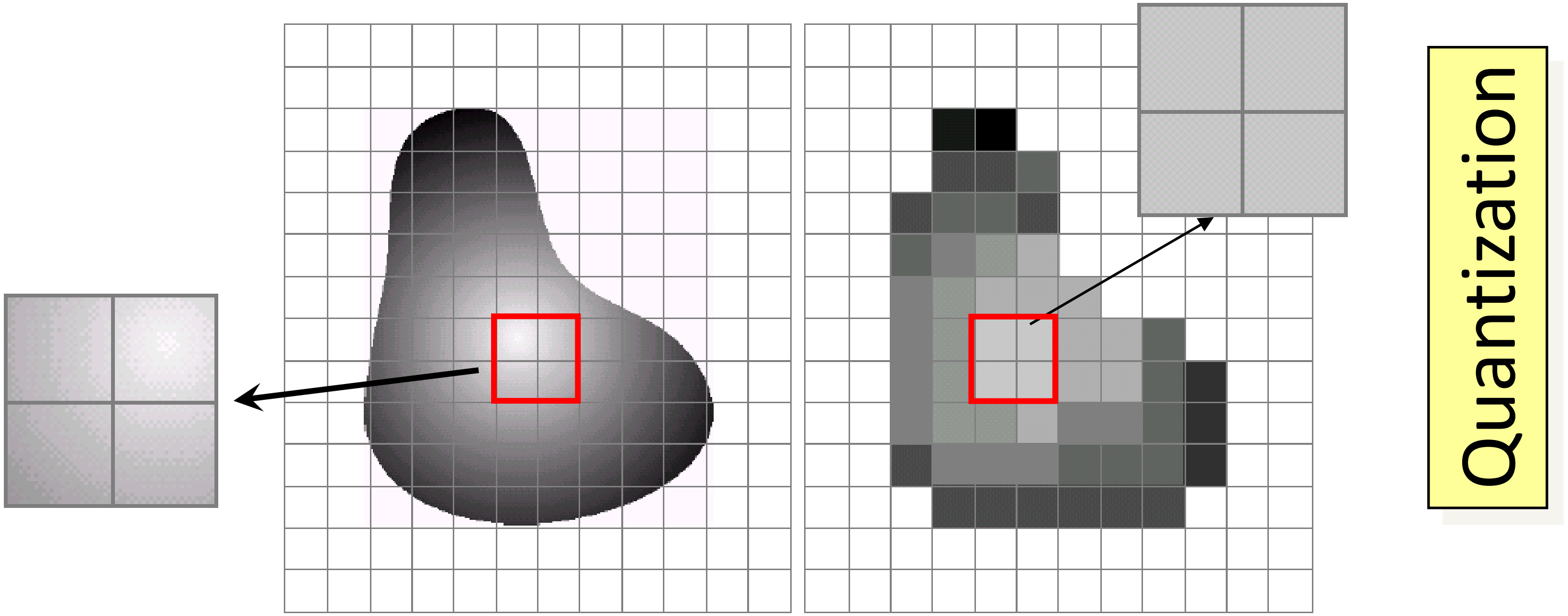
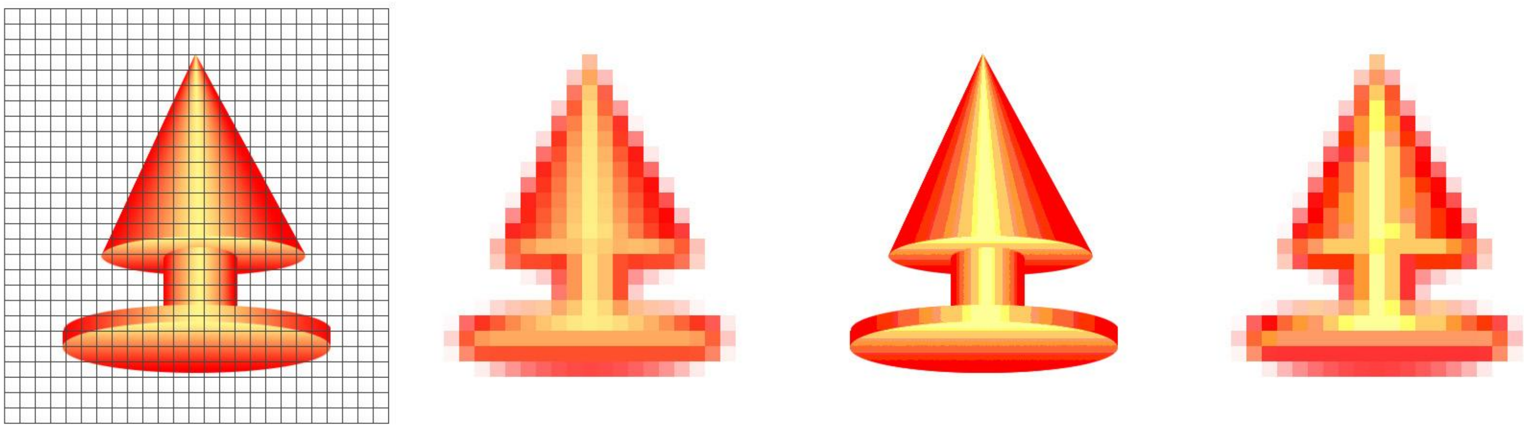


Image Formation

- Digital Image is an approximation of a real world scene

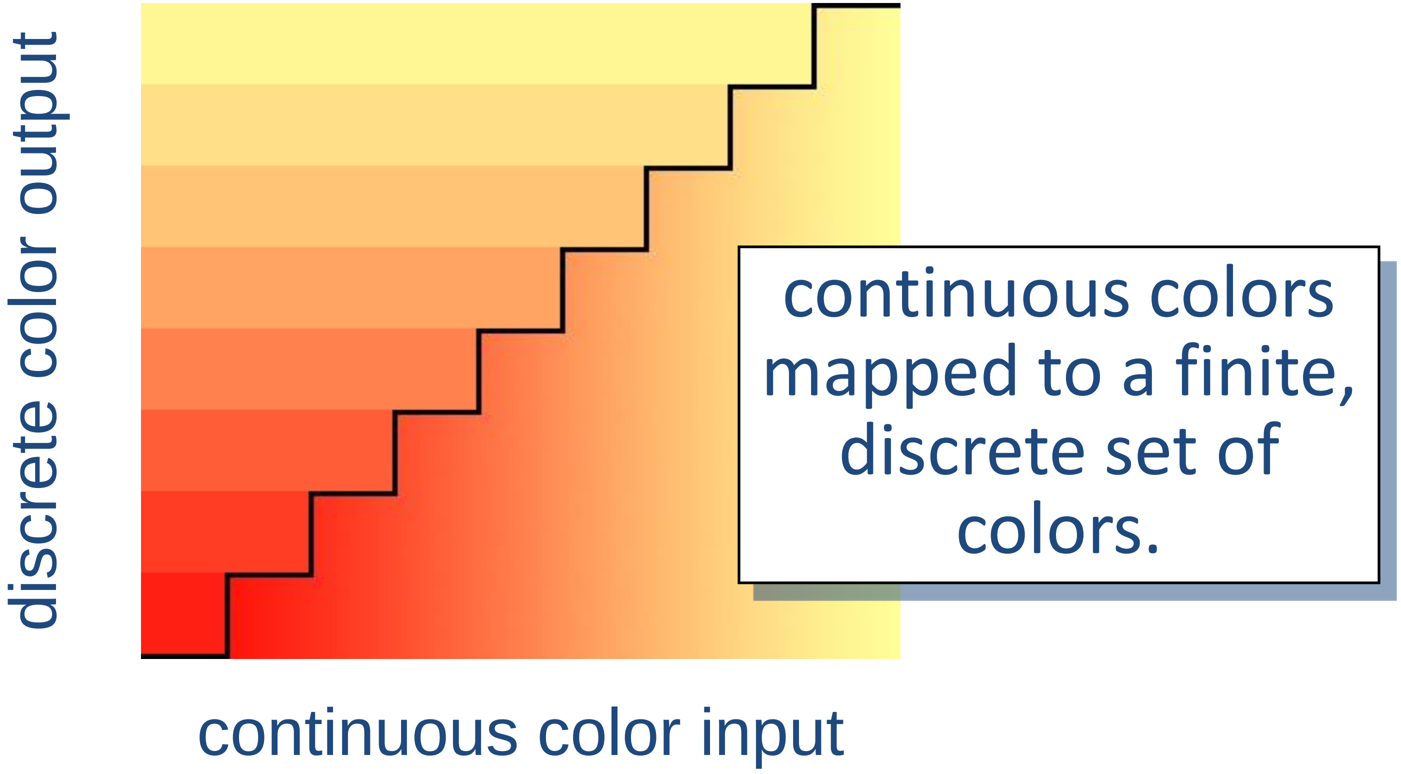


Sampling and Quantization



real image | sampled | quantized | sampled & quantized

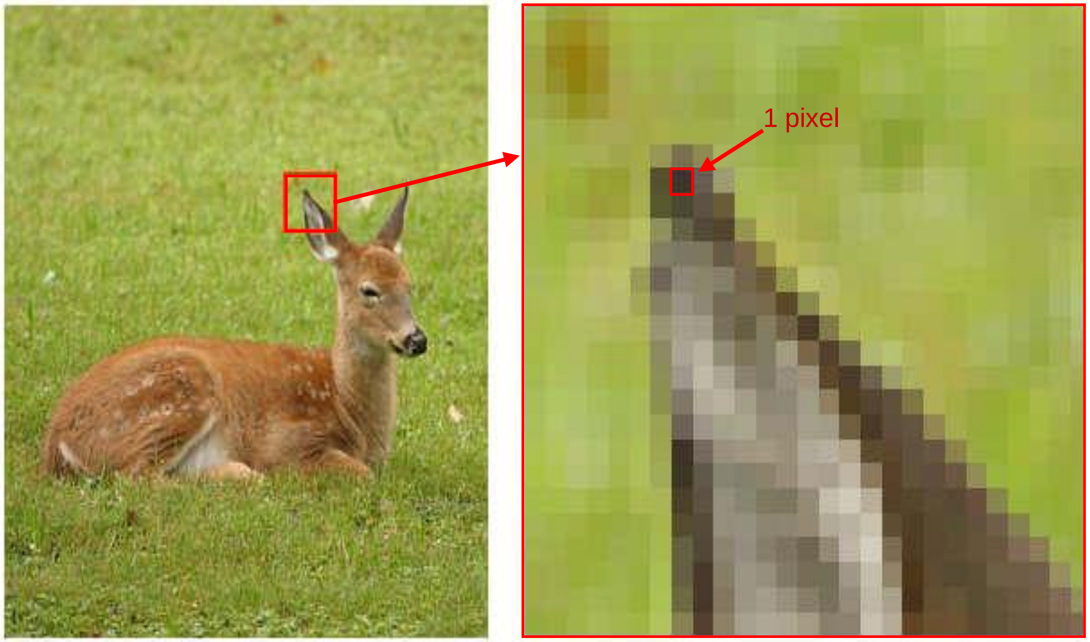
Image Formation - Quantization



Digital Image

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

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

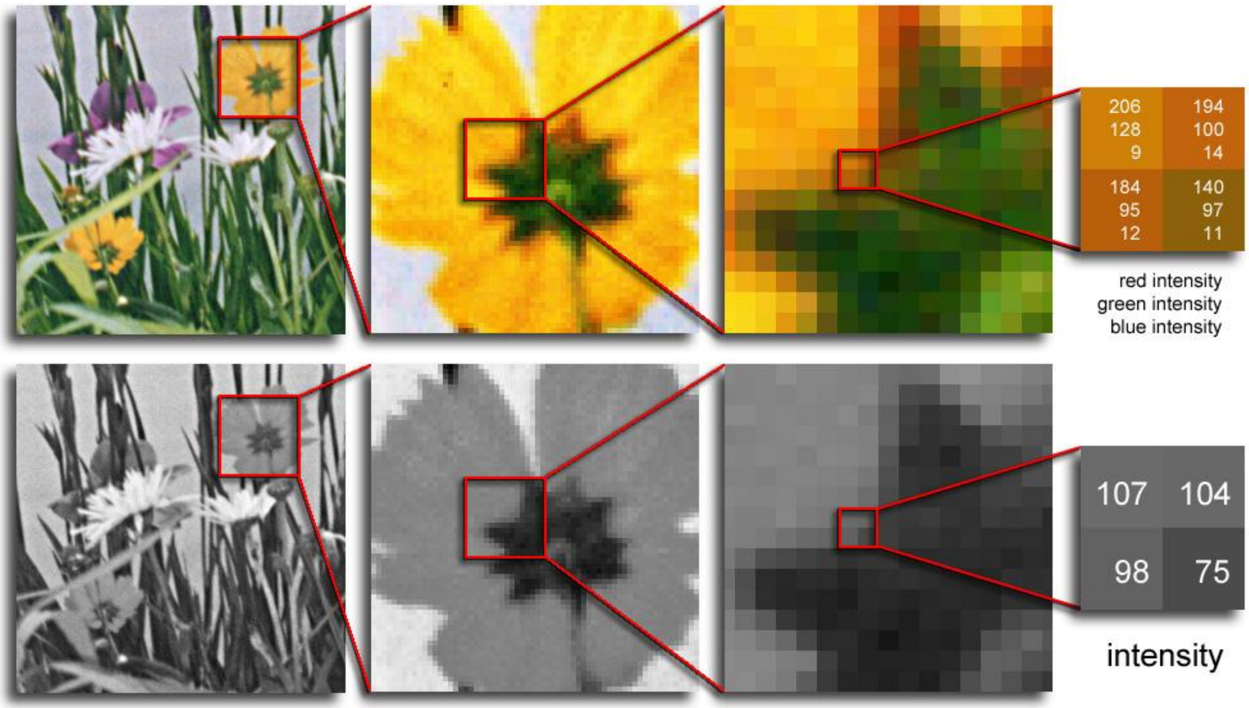


Digital Image

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*)

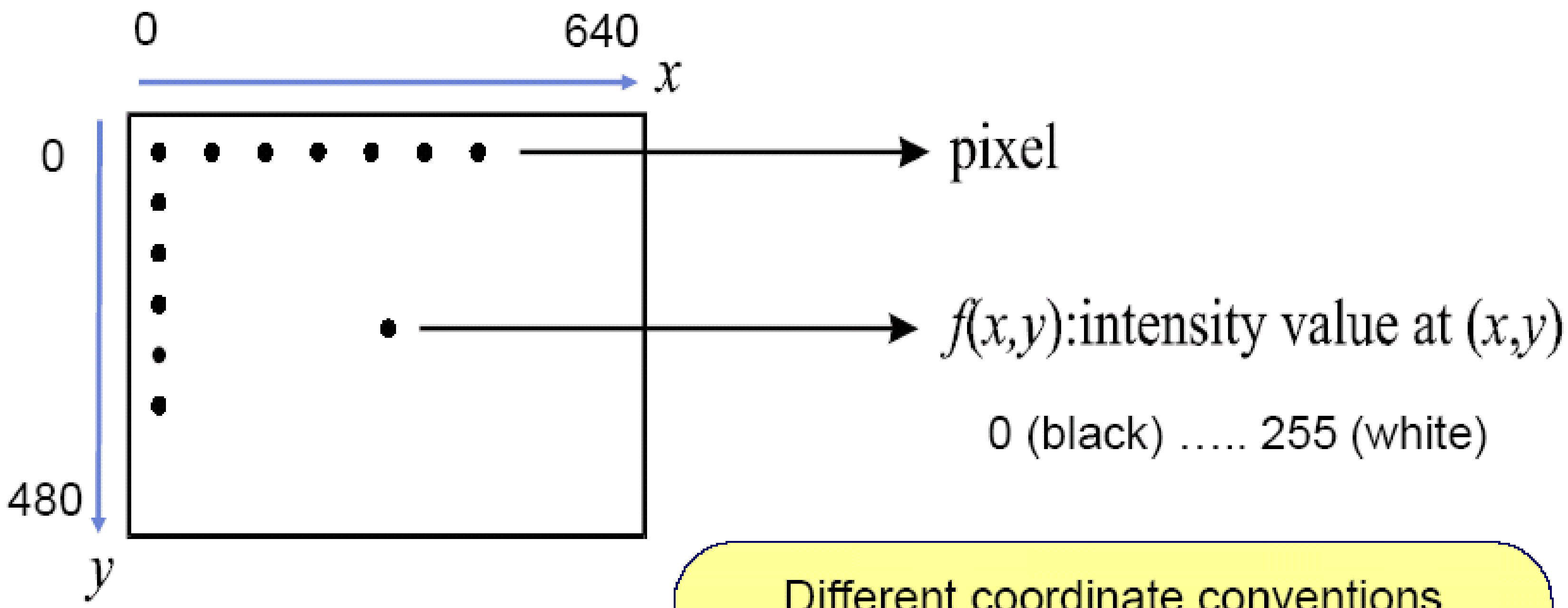


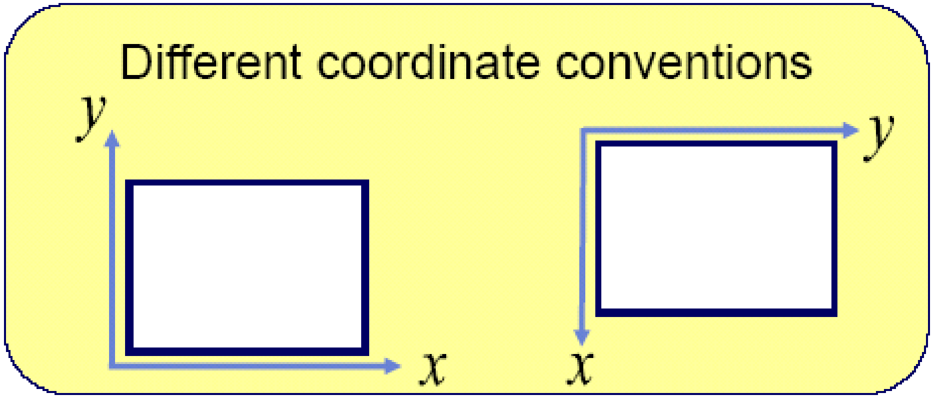
Digital Image

- 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

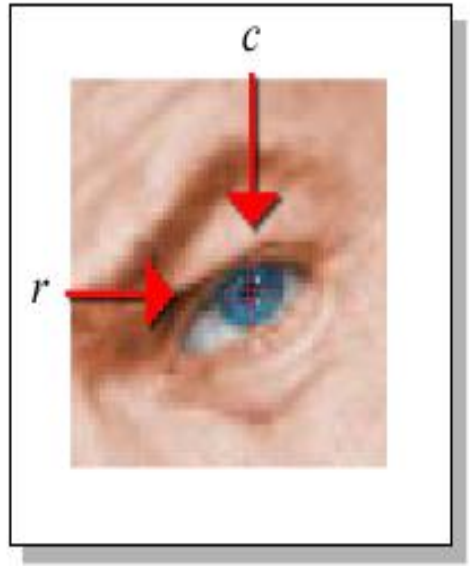


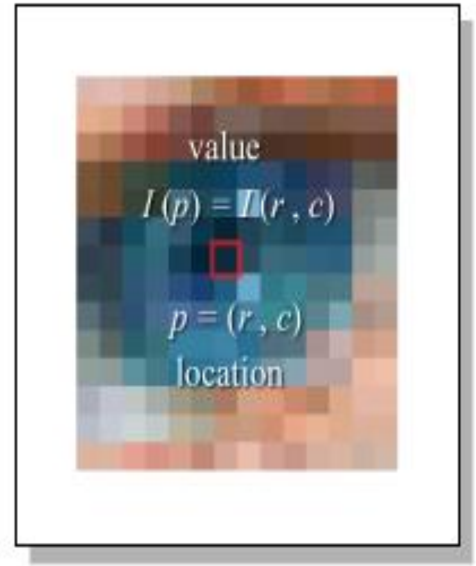


Pixels

- $p = (r,c)$ 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





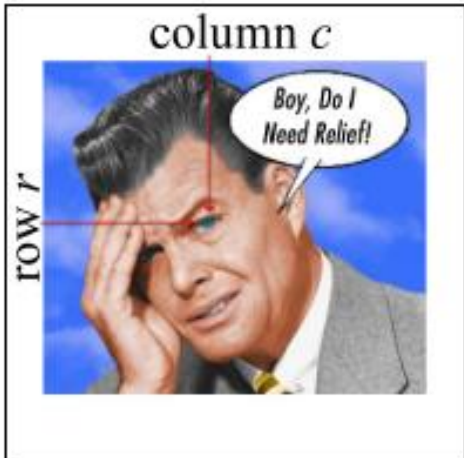
Pixel Location: $p = (r\ ,\ c)$

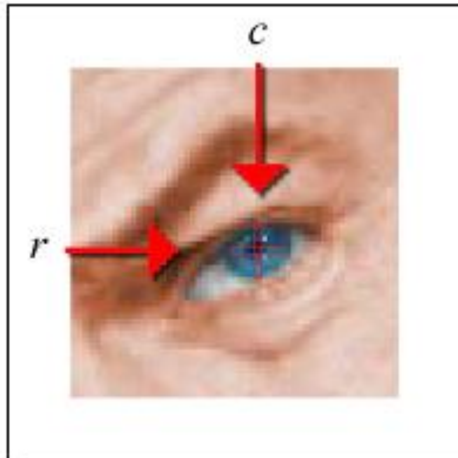
Pixel Value: $I(p) = I(r\ ,\ c)$

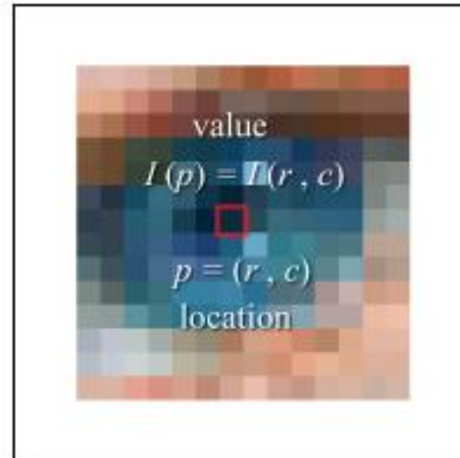
Pixel : $[\ p, I(p)]$

Pixels

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



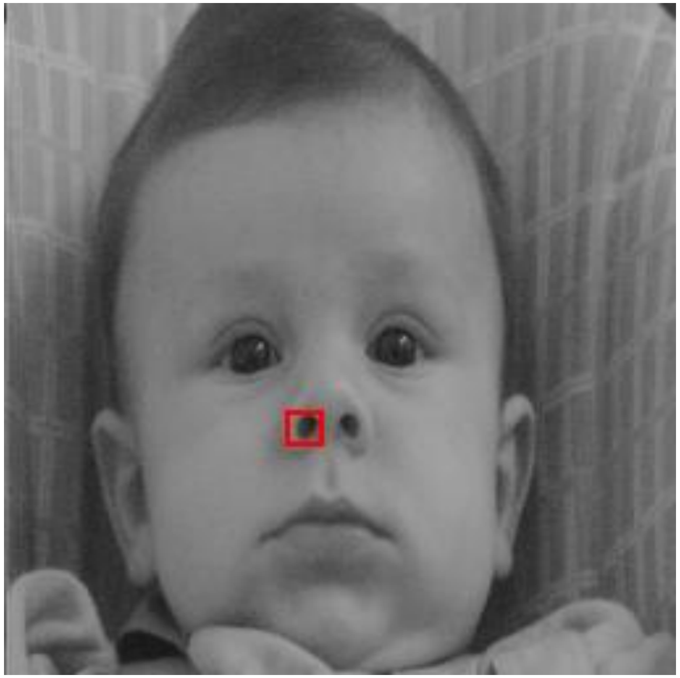




$$
\begin{aligned}
p &= (r, c) \\
&= (\text{row \#},\ \text{col \#}) \\
&= (272,\ 277)
\end{aligned}
$$

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

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

A set of number in 2D grid

CAMERA → **DIGITIZER**

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

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

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

- 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

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

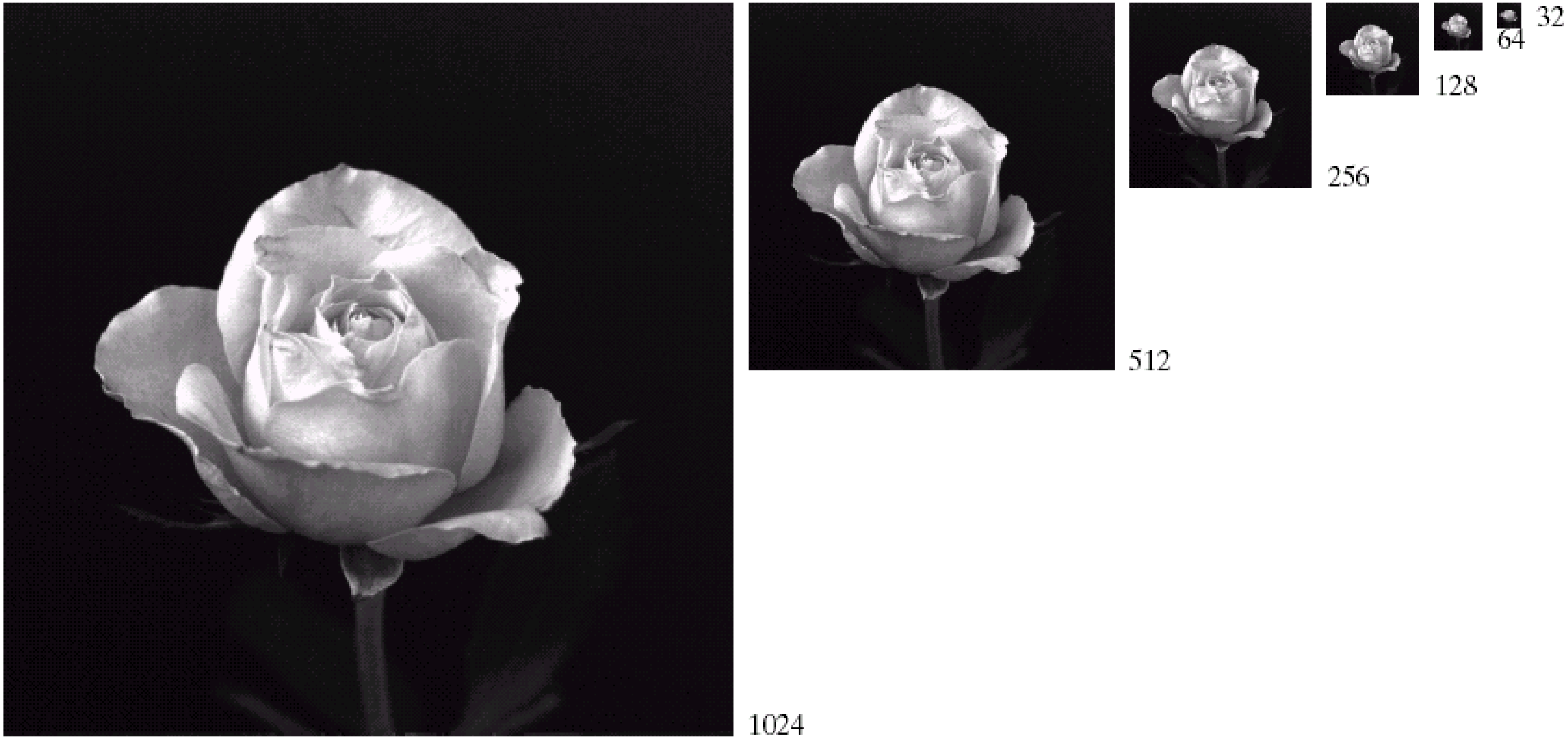
  - Image having 2^k intensity levels
    - k – bit image
    - 256 intensity levels – 8 bit image

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

Spatial Resolution



Spatial Resolution

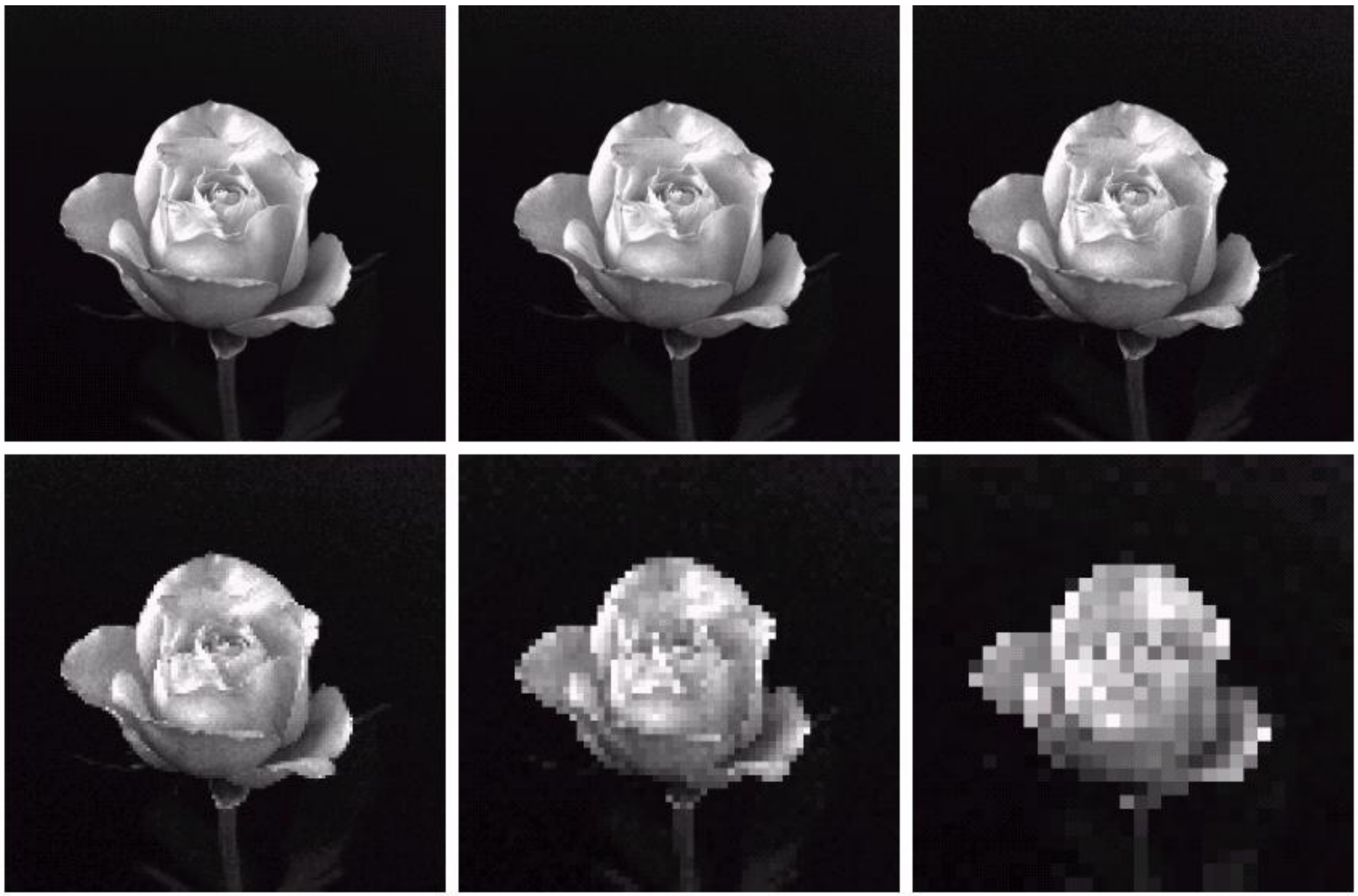


FIGURE 2.20 Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.

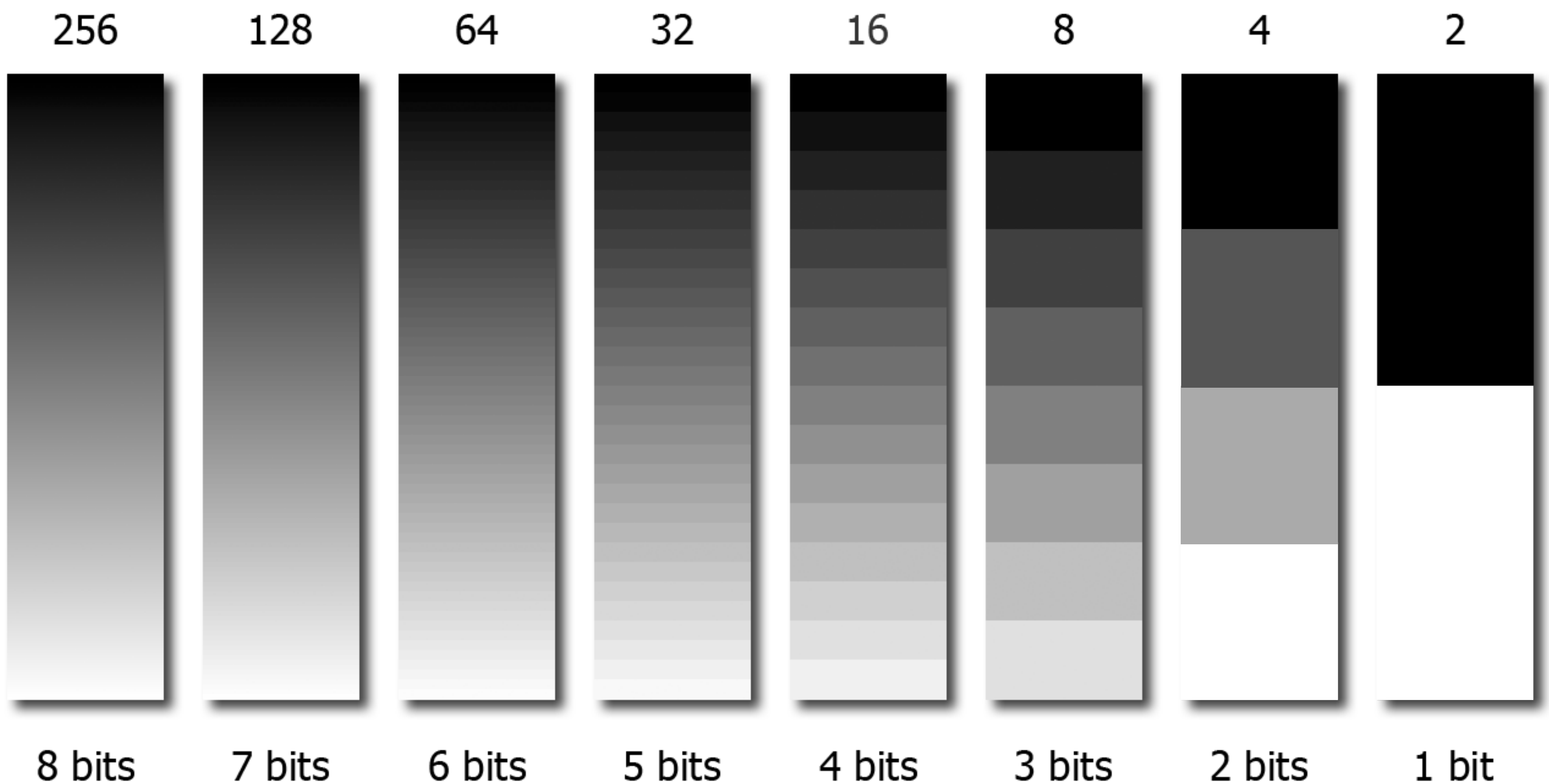
Intensity Level Resolution

- *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 in an image
  - Intensity level resolution is usually given in terms of the number of bits used to store each intensity level

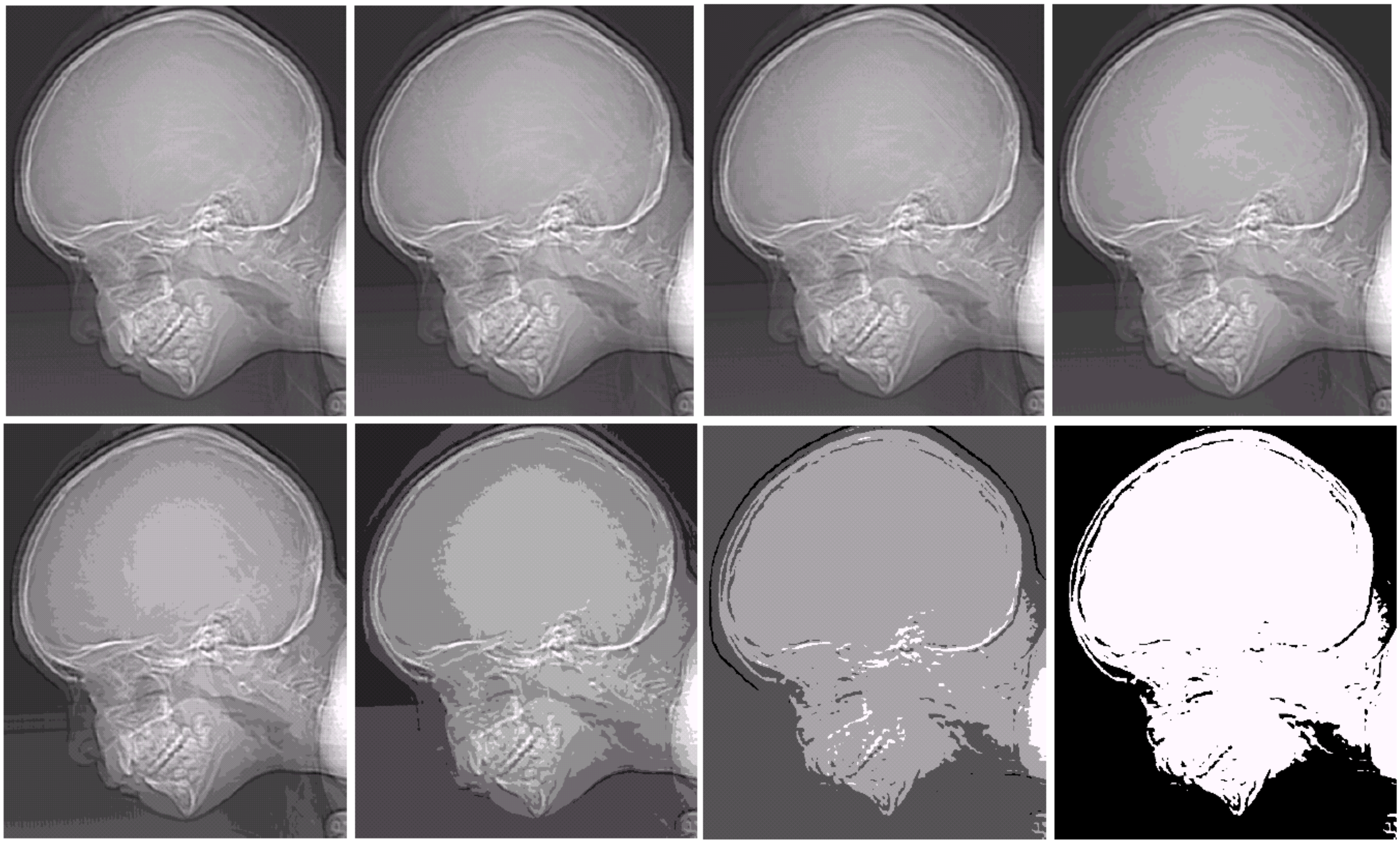
Intensity Level Resolution

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



Intensity Level Resolution



256 grey levels (8 bits per pixel) | 128 grey levels (7 bpp) | 64 grey levels (6 bpp) | 32 grey levels (5 bpp)

16 grey levels (4 bpp) | 8 grey levels (3 bpp) | 4 grey levels (2 bpp) | 2 grey levels (1 bpp)

Resolution: How much is enough?

- How many samples and gray levels are required for a good approximation?
  - Quality of an image depends on number of pixels and gray-level number
  - The more these parameters are increased, the closer the digitized array approximates the original image
  - But: Storage & processing requirements increase rapidly as a function of N, M, and k

Resolution: How much is enough?

- Depends on what is in the image and what you would like to do with it

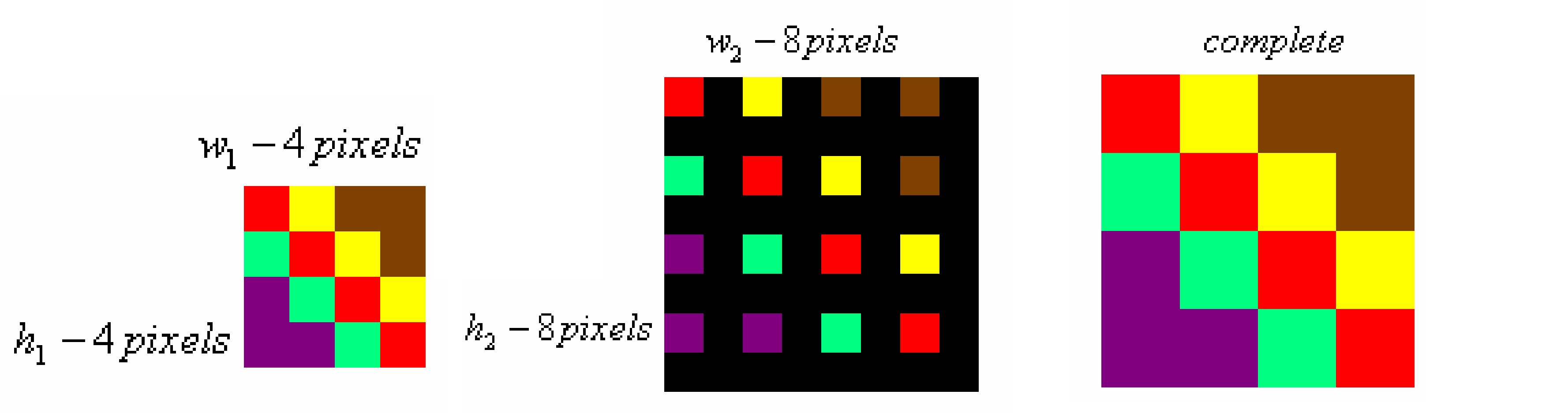
Enlarging an Image

- Pixel replication

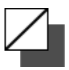
[1 2 3 4 5]

[1 1 2 2 3 3 4 4 5 5]   (One step)

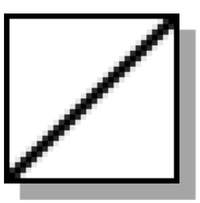
[1 1 1 2 2 2 3 3 3 4 4 4 5 5 5] (Two step)



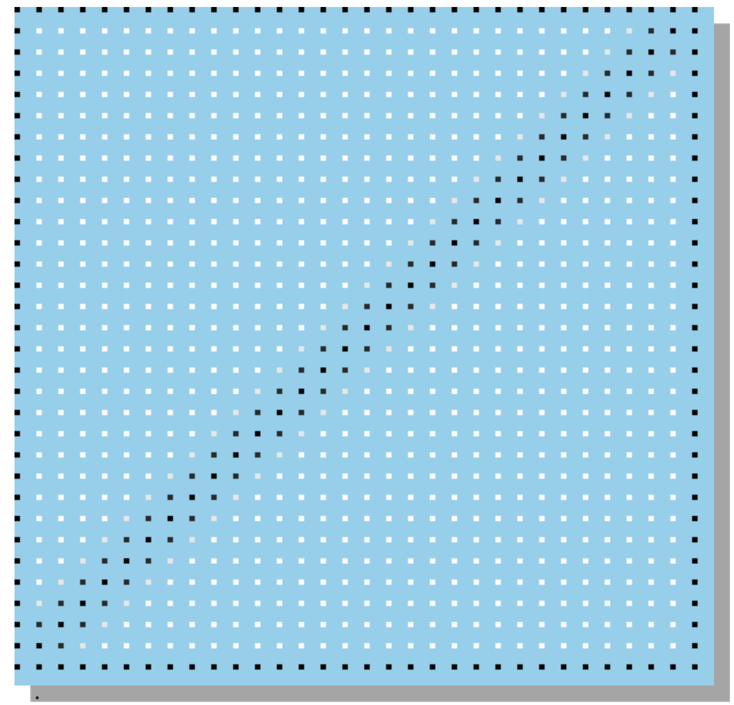
Enlarging an Image



Example: zoom this image 4x to get this image.

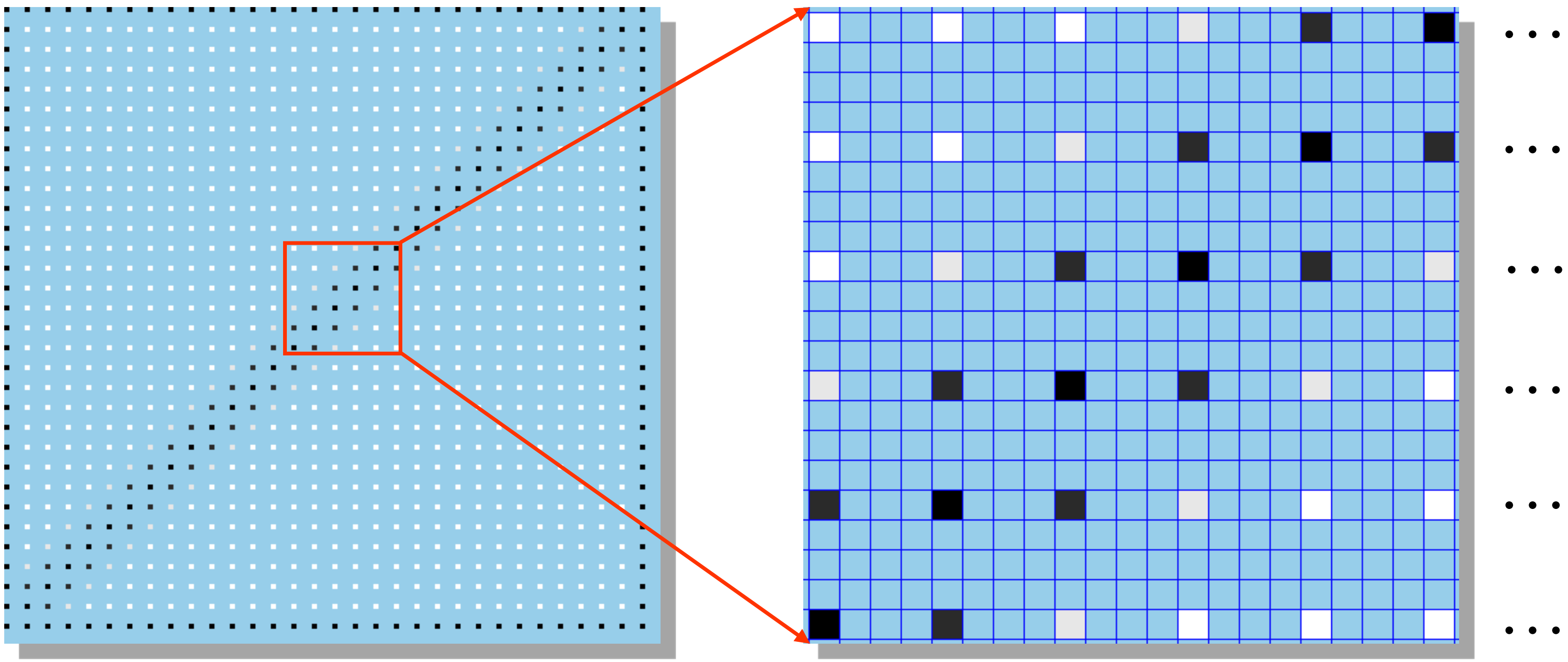


Start with a blank image 4 times the linear dimensions of the original.



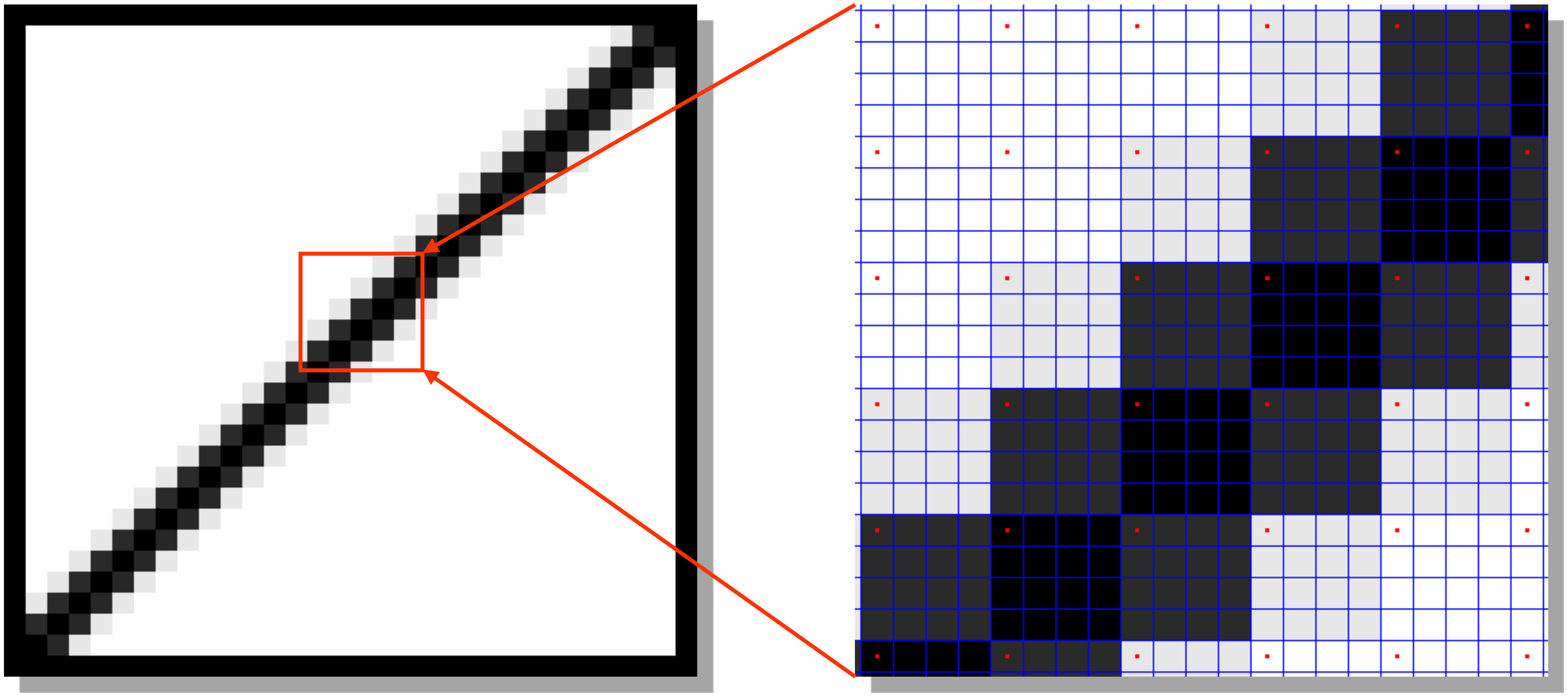
Fill in every 4th pixel in every 4th row with the original pixel values.

Enlarging an Image



Detail showing every 4th pixel in every 4th row with the original pixel values.

Enlarging an Image



Replicate the values

Image Interpolation

- Nearest neighbour interpolation
  - Simple but produces undesired artefacts
- Bilinear Interpolation
  - Contribution from 4 neighbors
- Bicubic Interpolation
  - Contribution from 16 neighbors

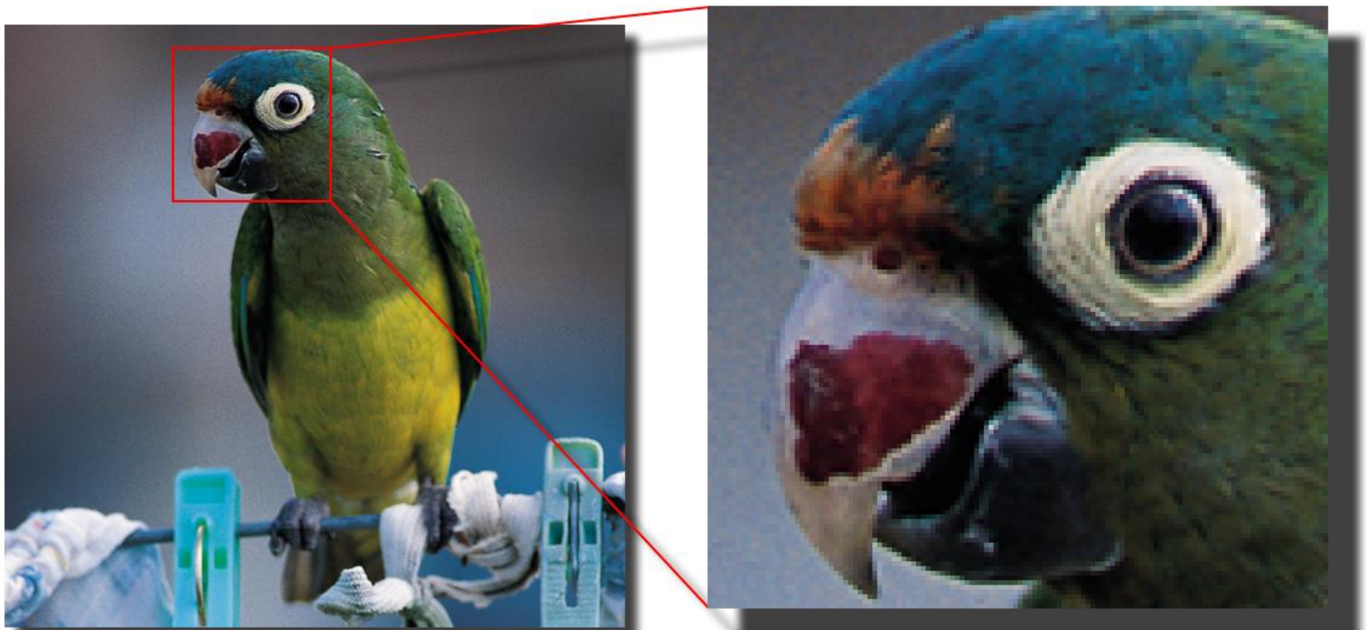
Interpolation: Comparison

We'll enlarge this image by a factor of 4 …

… via bilinear interpolation and compare it to a nearest neighbor enlargement.

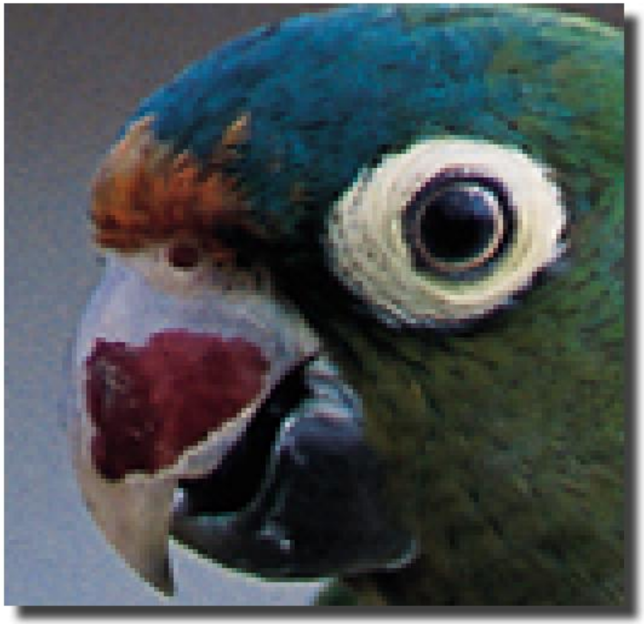
Interpolation: Comparison

Original Image



To better see what happens, we'll look at the parrot's eye.

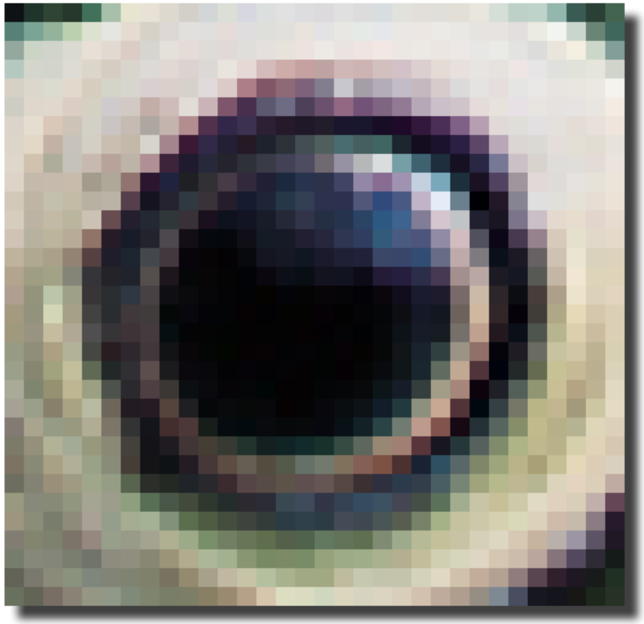
Interpolation: Comparison



Pixel replication

Bilinear interpolation

Interpolation: Comparison

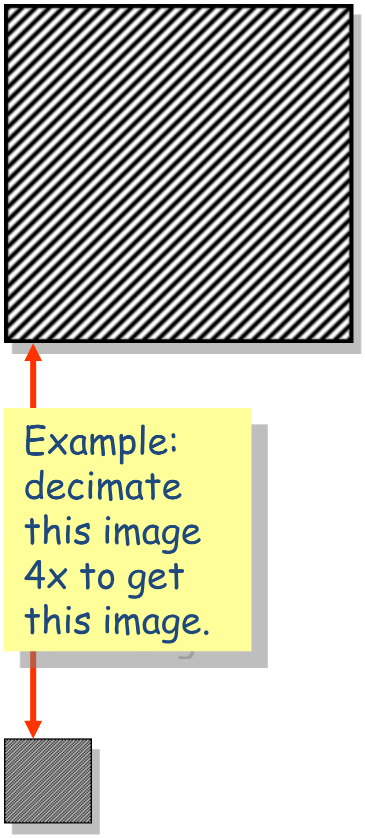


Pixel replication

Bilinear interpolation

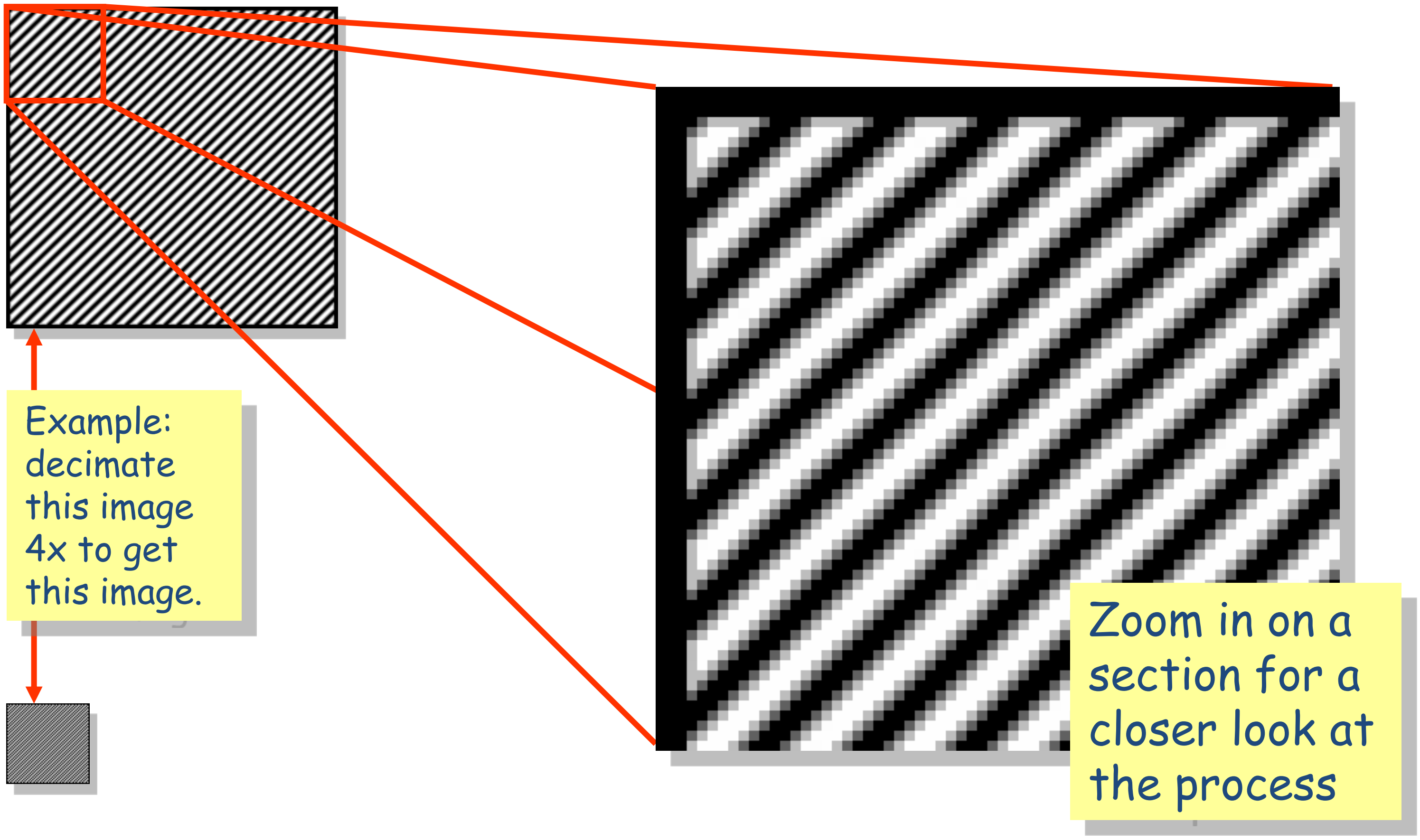
Reducing an Image

- Pixel Decimation

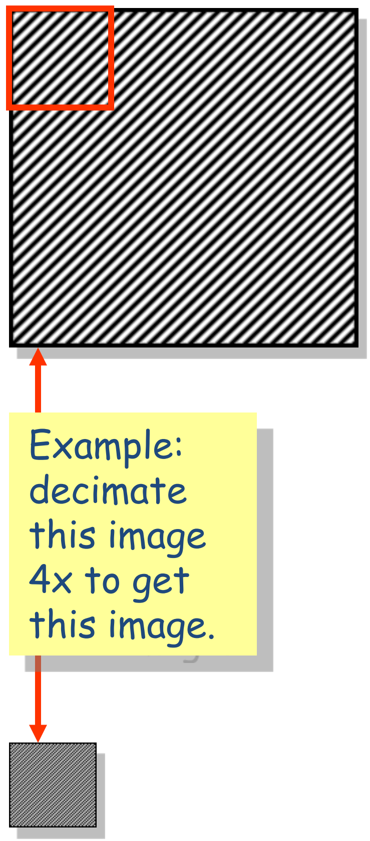


Decimation by a factor of *n*: take every *n*th pixel in every *n*th row

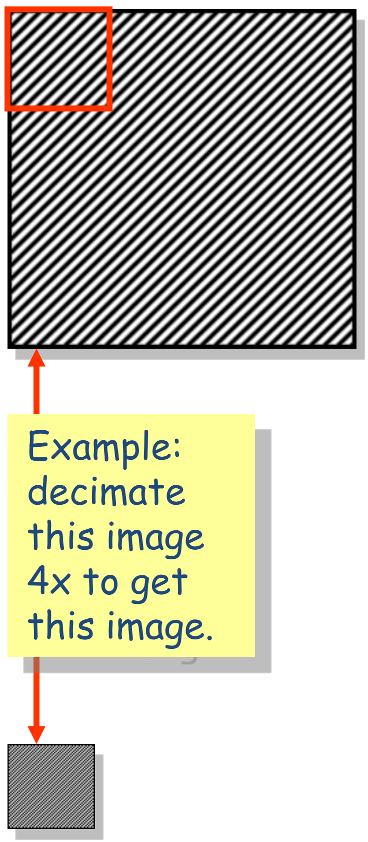
Reducing an Image

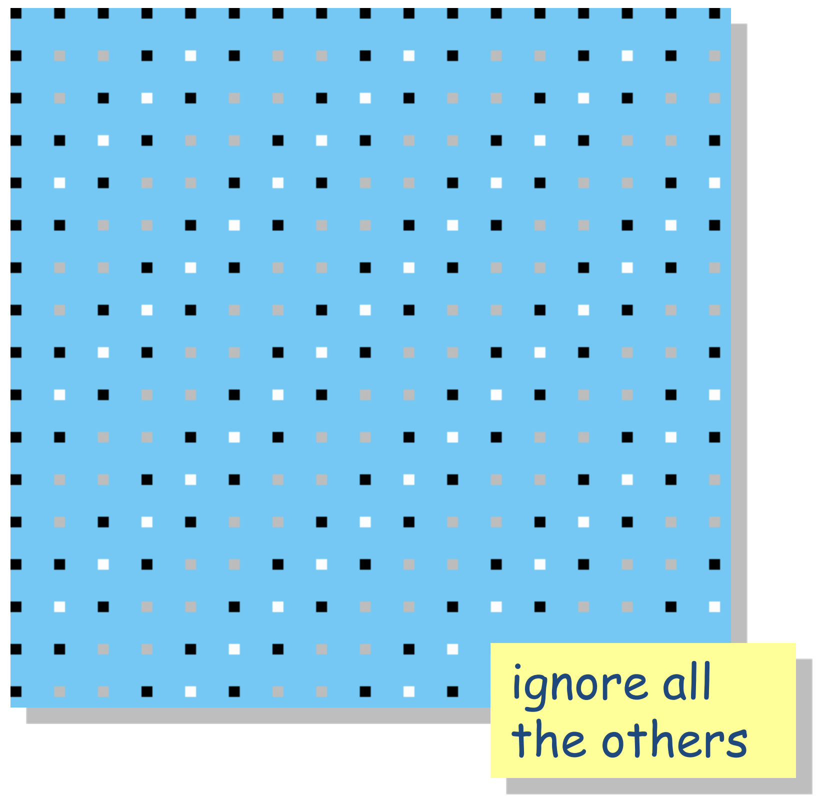


Reducing an Image

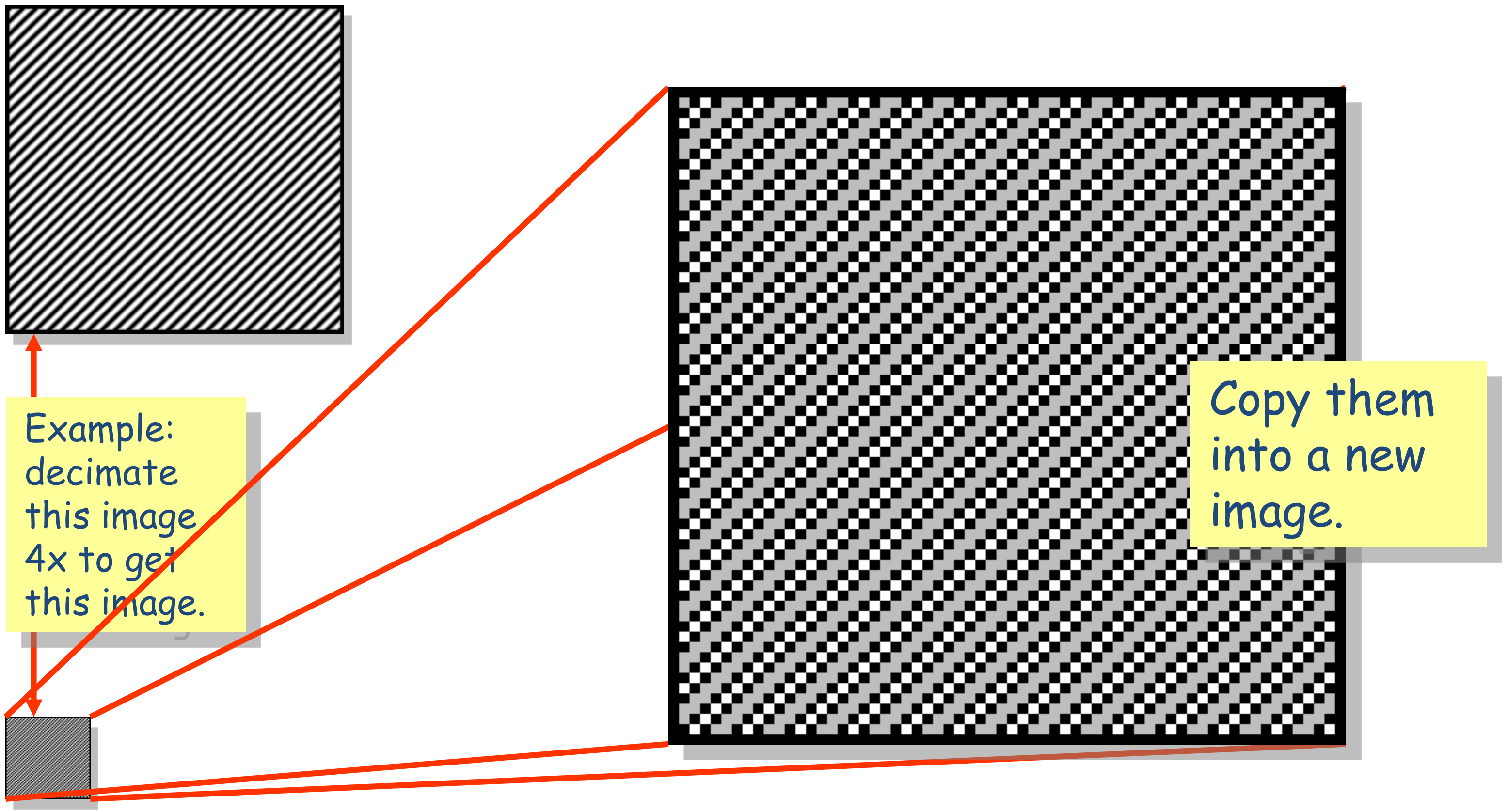


Reducing an Image





Reducing an Image



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

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

Material in these slides has been taken from, the following resources