Digital Image Processing

Lecture # 1
Introduction & Fundamentals

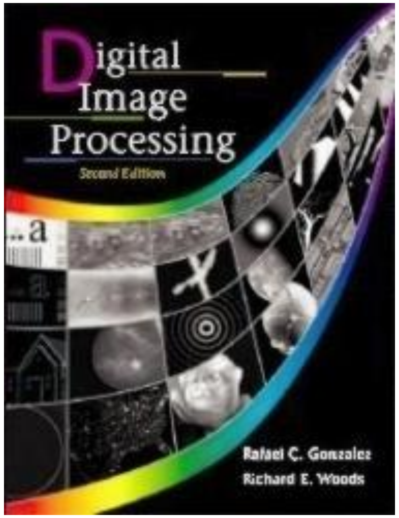
Course Information

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

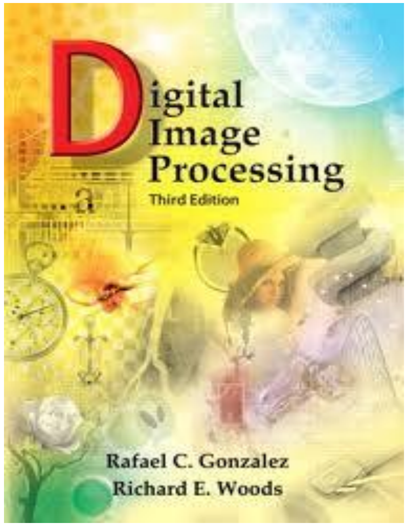
http://biomisa.org/usman/digital-image-processing

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
- Image processing Fundamentals
- Image Enhancement & Restoration
- Morphological operations
- Feature extraction (edges, corners)
- Segmentation
- Texture analysis
- Wavelets
- Introduction to Machine Learning and basic types of classifiers, Performance parameters for evaluation

Grading Policy

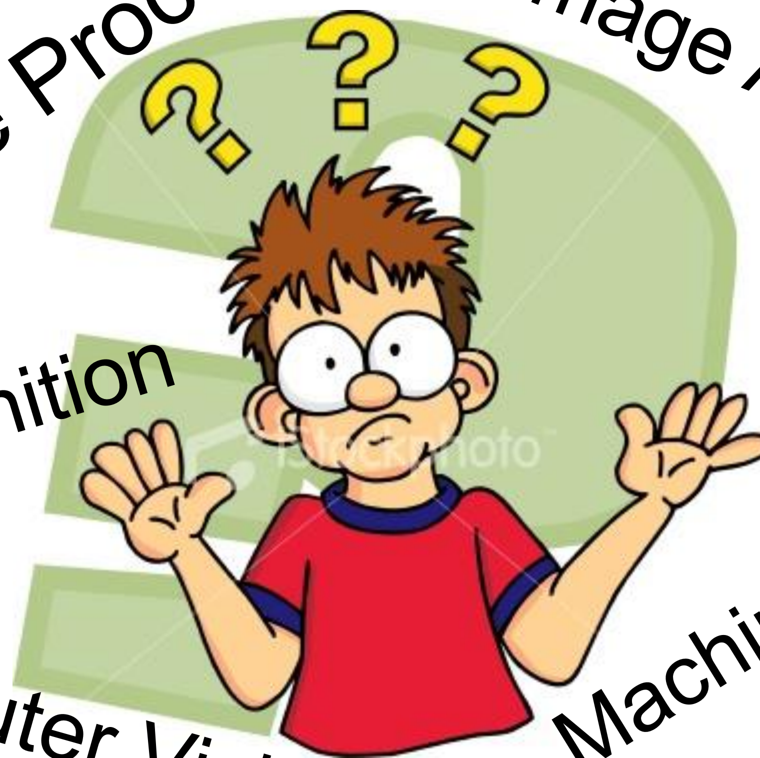
Sessional Exams:	25%
Quizzes (4-6):	10%
Computer and numerical assignments:	10%
Final Project:	15%
Final Exam:	40%

Before we start

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

Low Level Process

Input: Image
Output: Image

Examples: Noise removal, image sharpening

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

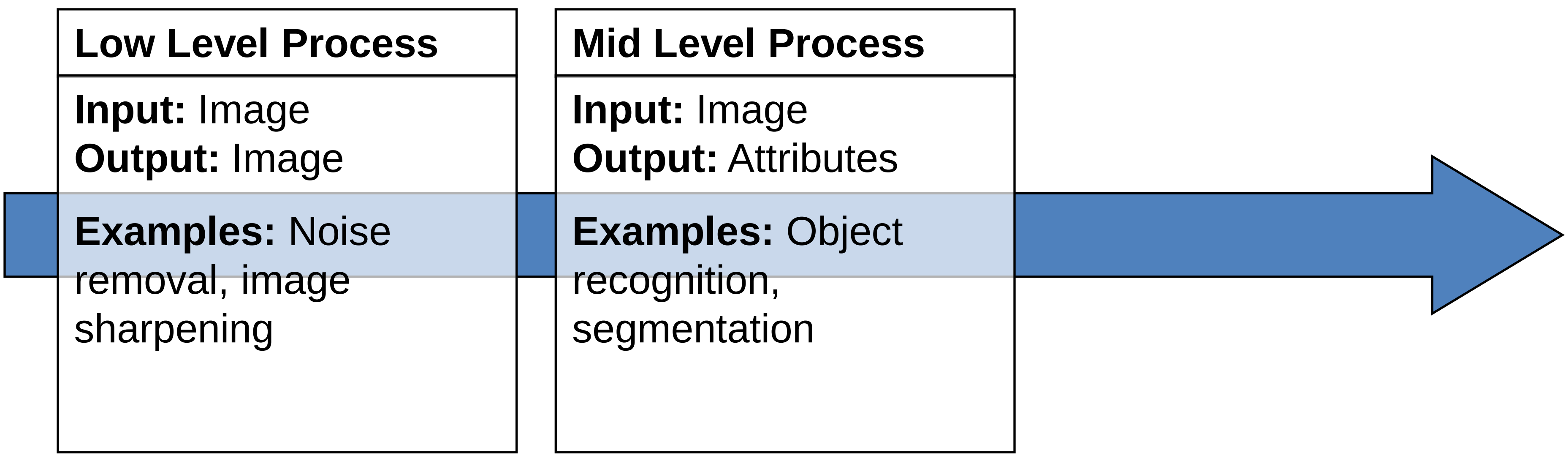
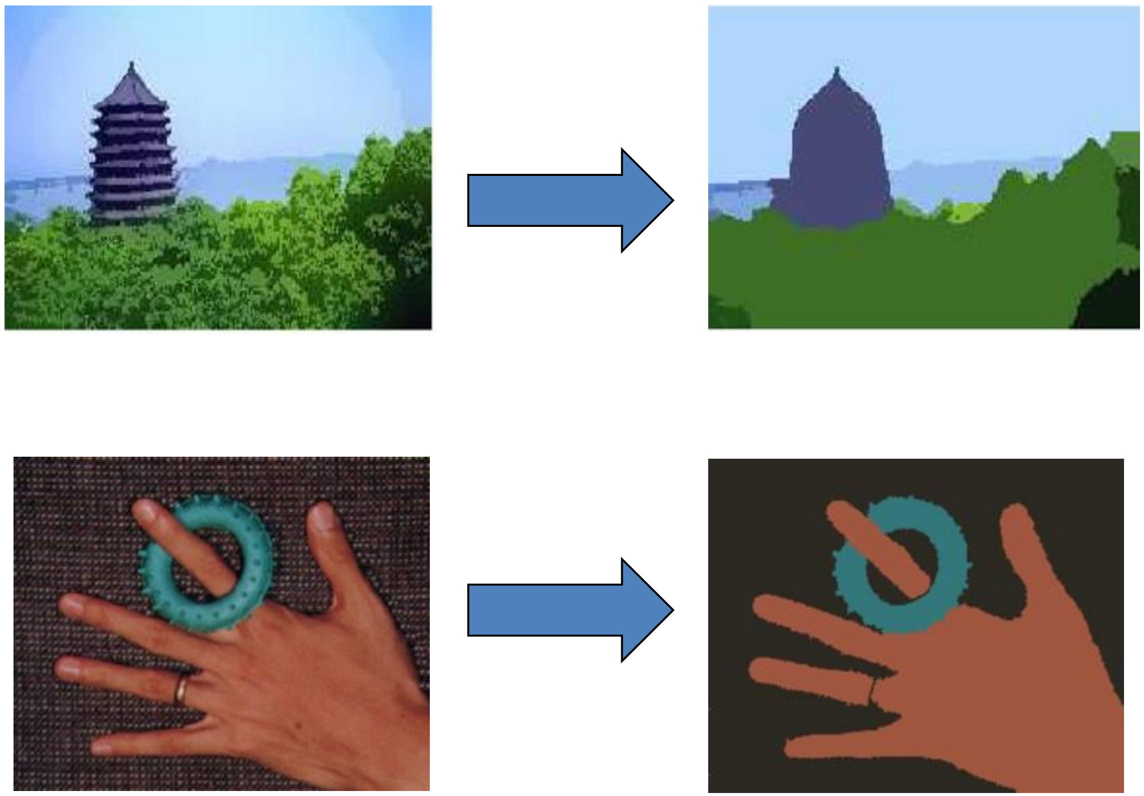


Image Processing

Example: Mid Level Processing



Segmentation of image into regions

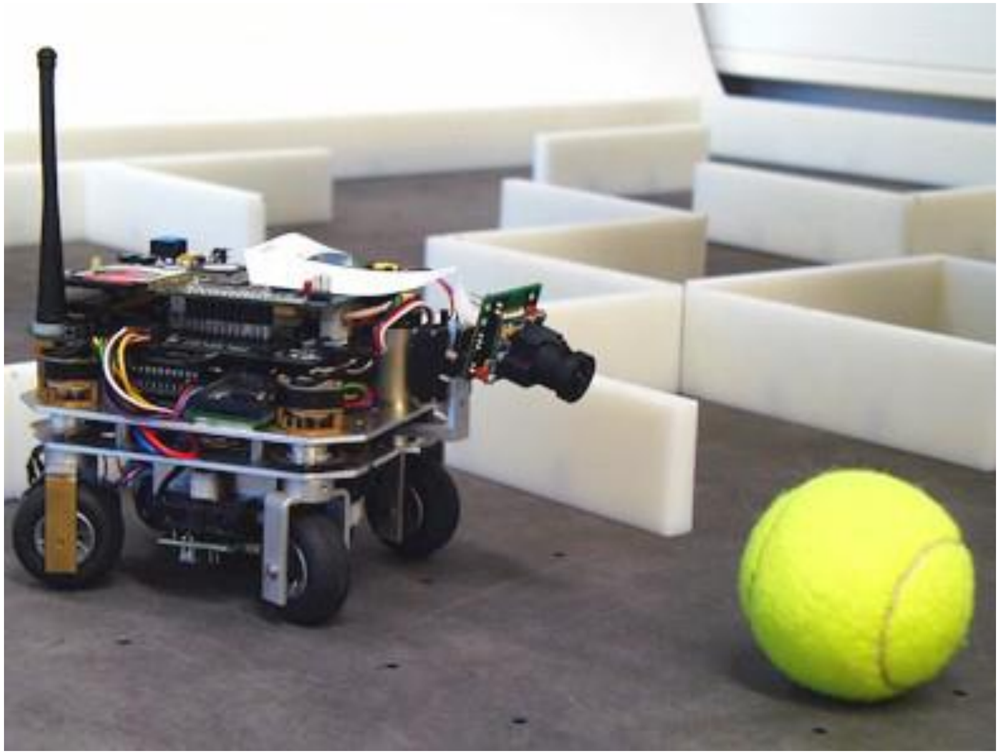
Image Processing & Machine Vision

- 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

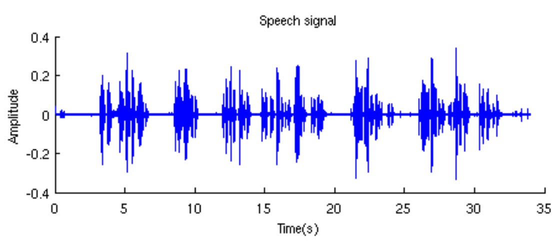
Low Level Process	Mid Level Process	High Level Process
Input: Image **Output:** Image	**Input:** Image **Output:** Attributes	**Input:** Attributes/Image **Output:** Understanding
Examples: Noise removal, image sharpening	**Examples:** Object recognition, segmentation	**Examples:** Scene understanding,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

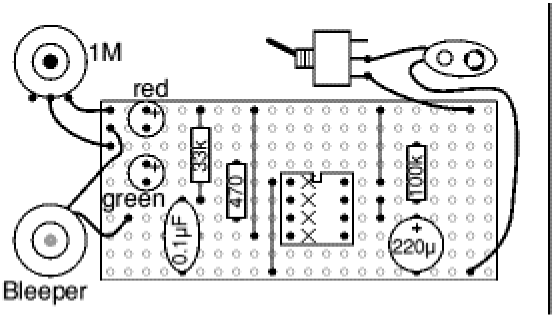
Image Processing

Machine Vision

Pattern

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

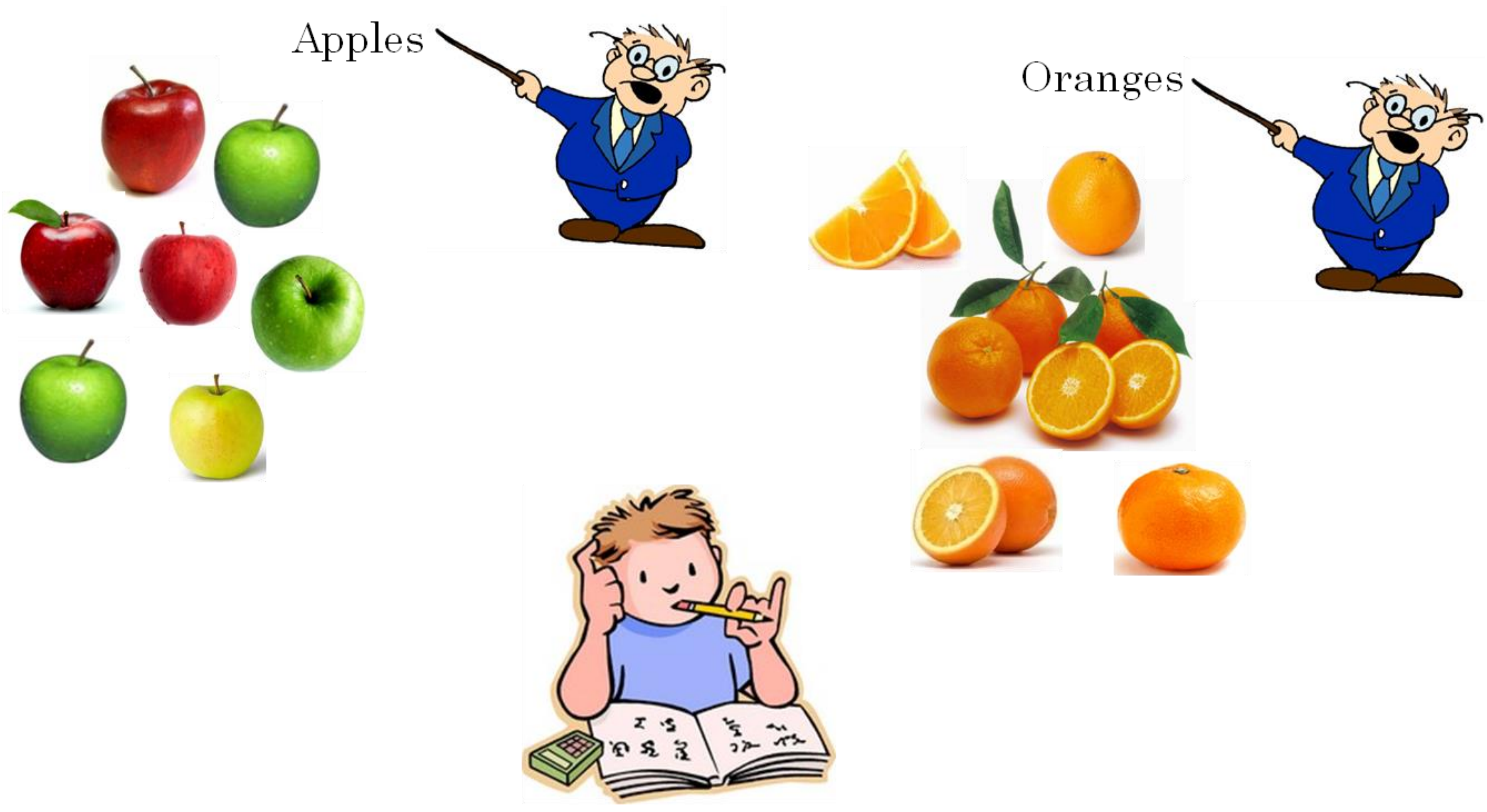




Recognition

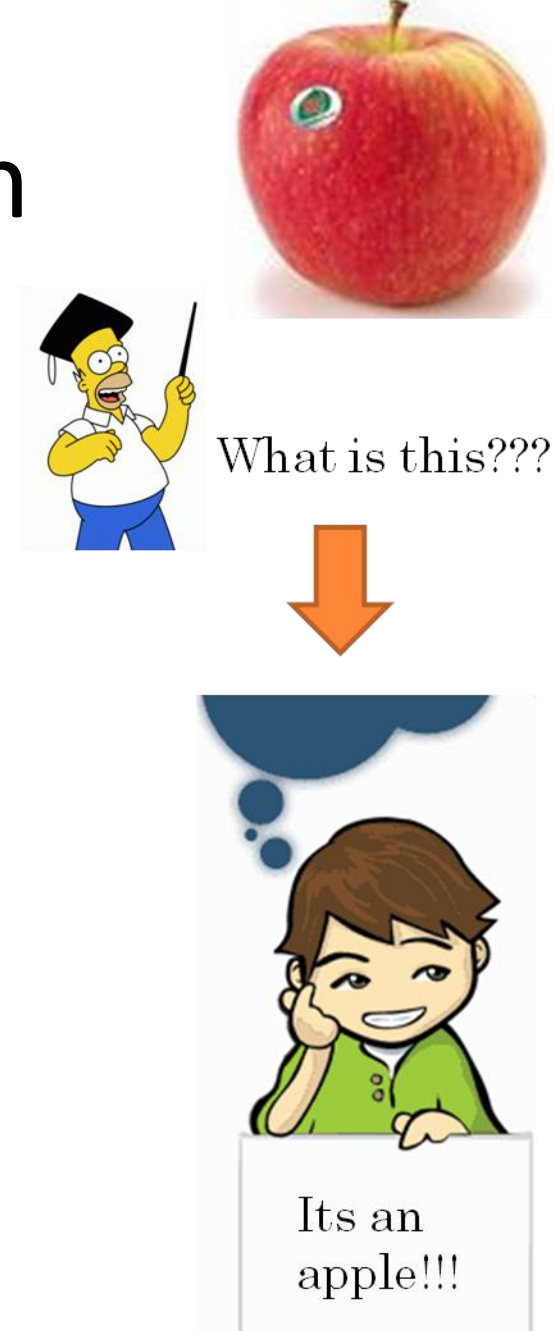
- Identification of a pattern as a member of a category

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?

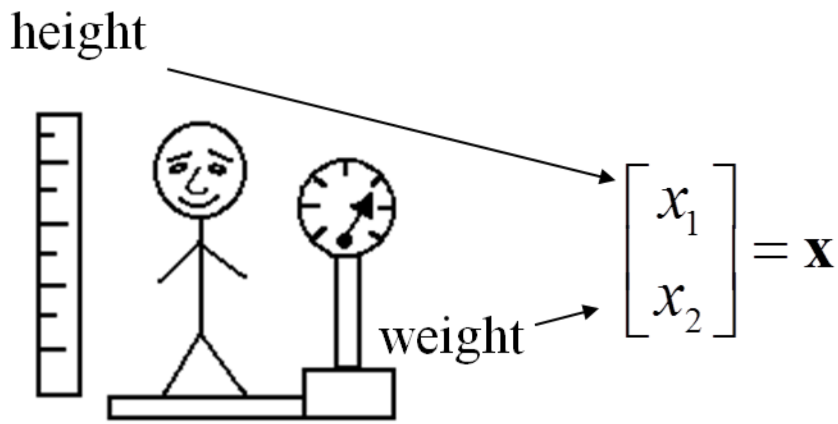
Pattern Recognition

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

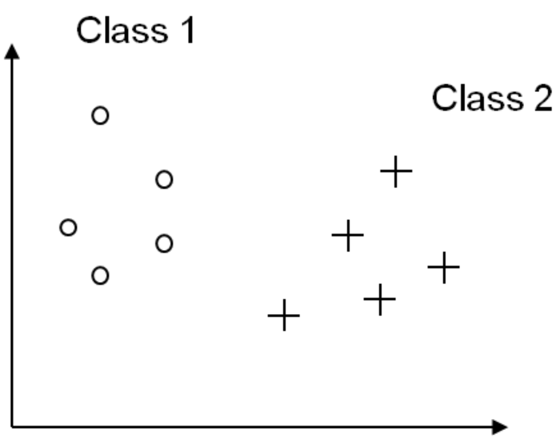
Features

- Features are the individual measurable properties of the signal being observed.
- The set of features used for learning/recognition is called feature vector.
- The number of used features is the dimensionality of the feature vector.
- n-dimensional feature vectors can be represented as points in n-dimensional feature space

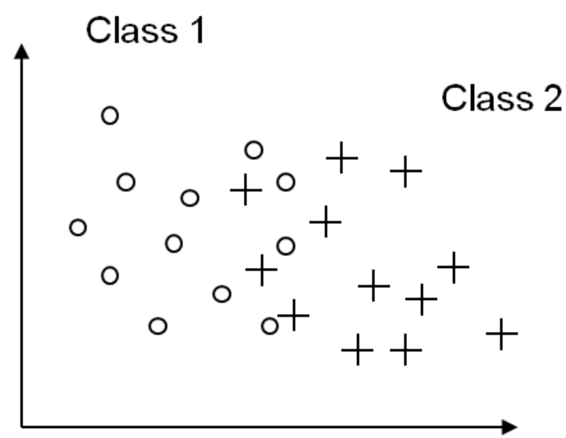
Features



height
$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \mathbf{x}$
weight



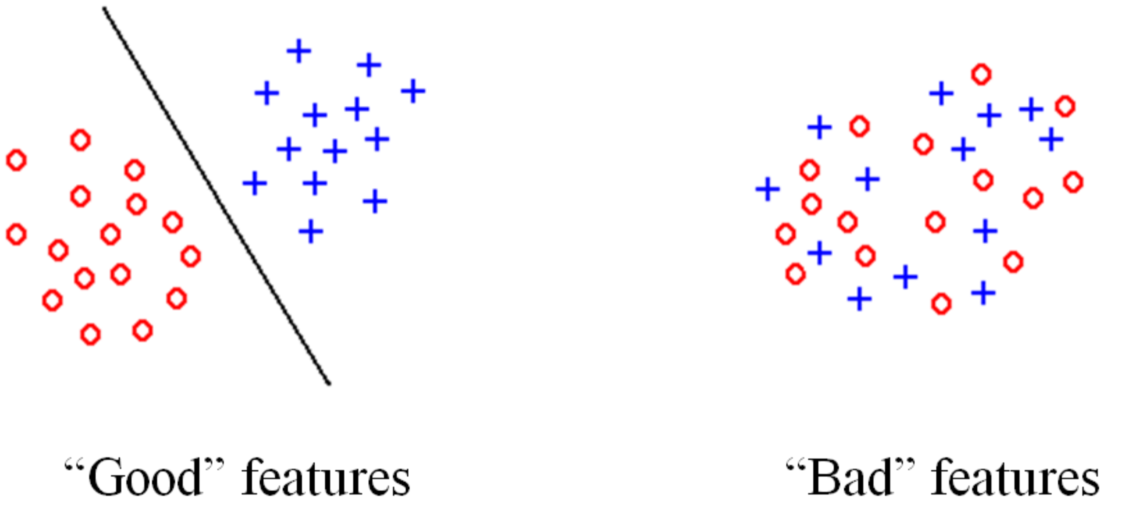
Class 1
Class 2



Class 1
Class 2

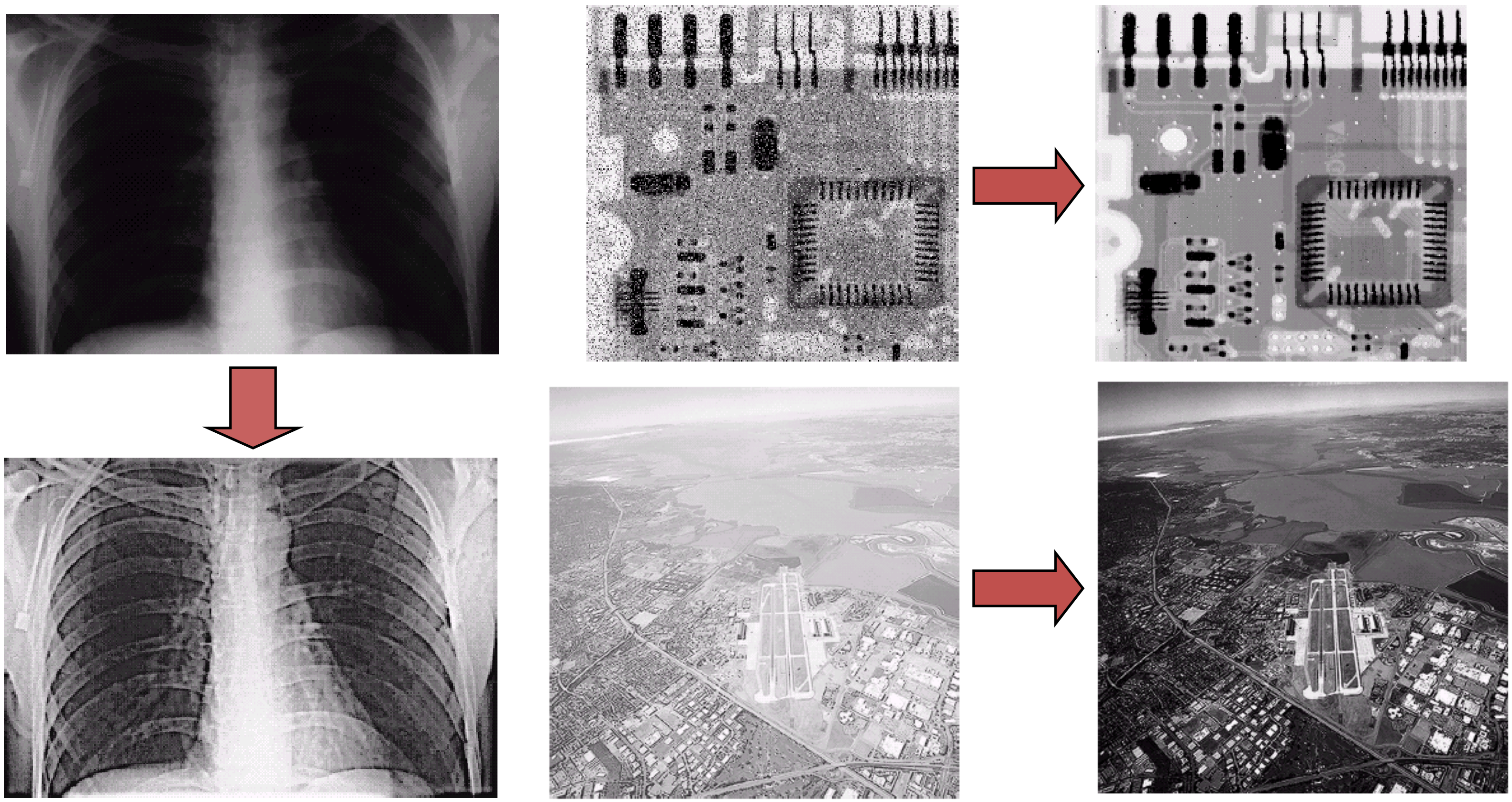
Feature Extraction

- Feature extraction aims to create discriminative features good for learning
  - Good Features
    - Objects from the same class have similar feature values.
    - Objects from different classes have different values.



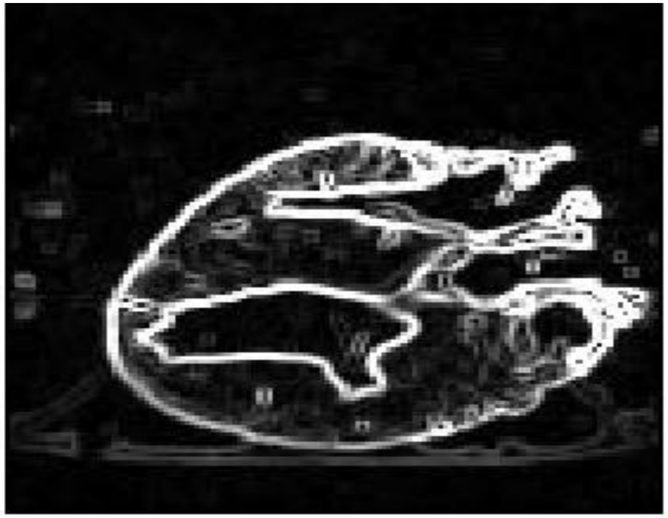
Example Applications

Examples: Image Enhancement



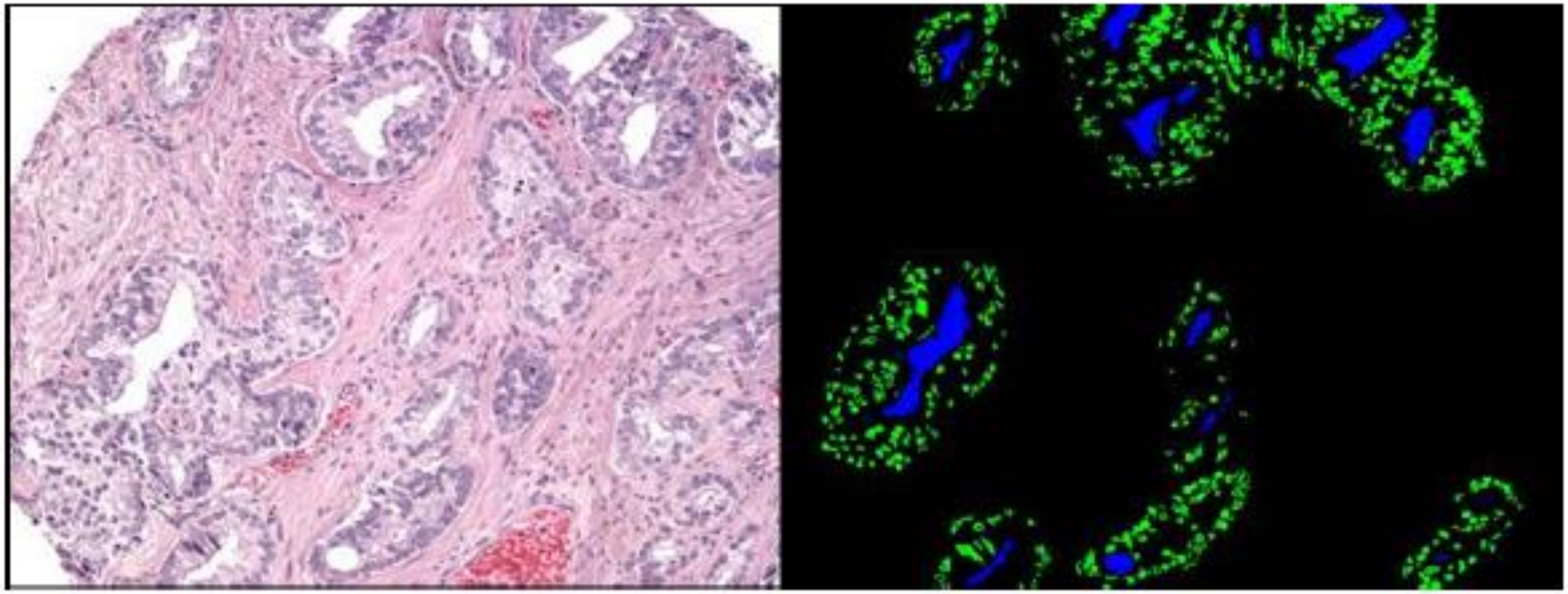
Examples: Medicine

Original Image of a Dog Heart



Separation of tissues

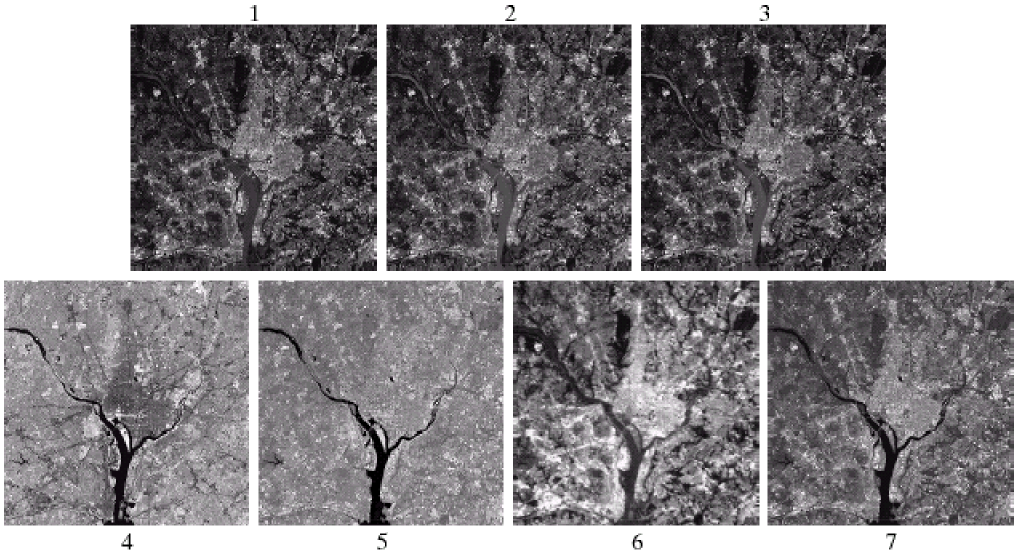
Examples: Medicine

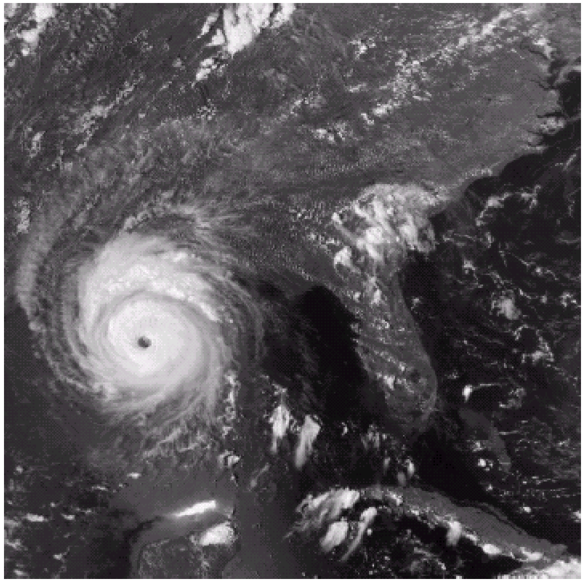


Microscopic tissue data - Cancer Detection

Examples: GIS

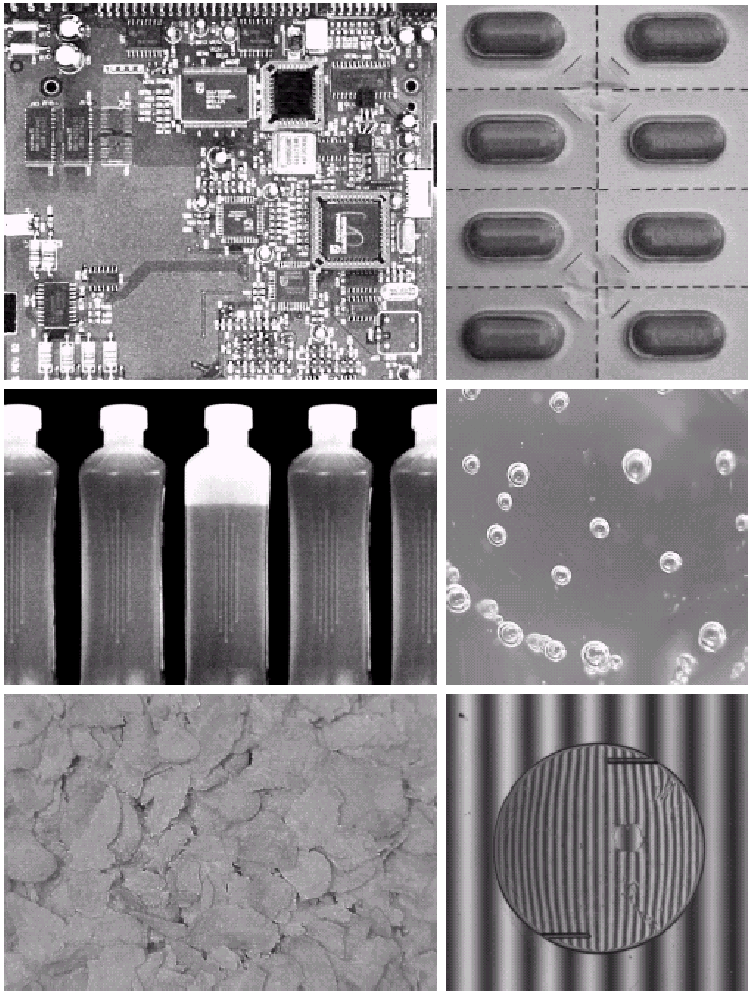
- Geographic Information Systems
  - Manipulation of Satellite Imagery
  - Terrain Classification, Meteorology





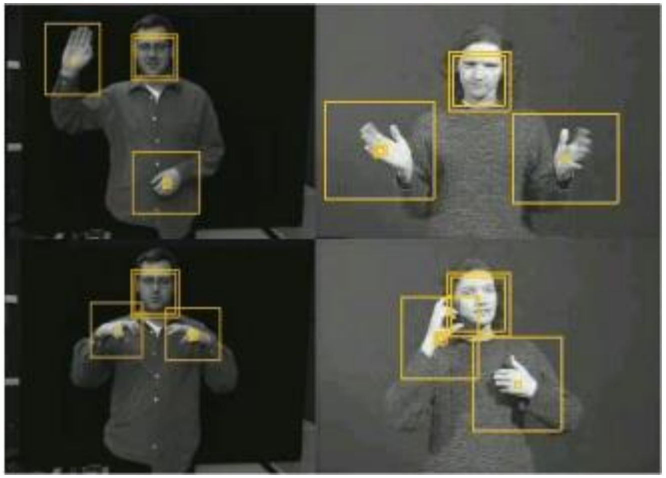
Examples: Industrial Inspection

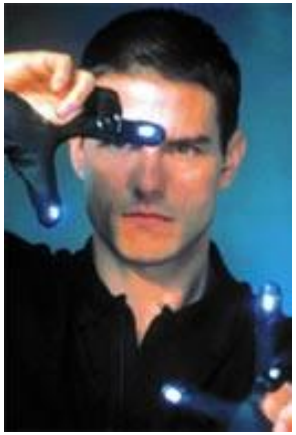
- Human operators are expensive, slow and unreliable
- Make machines do the job instead

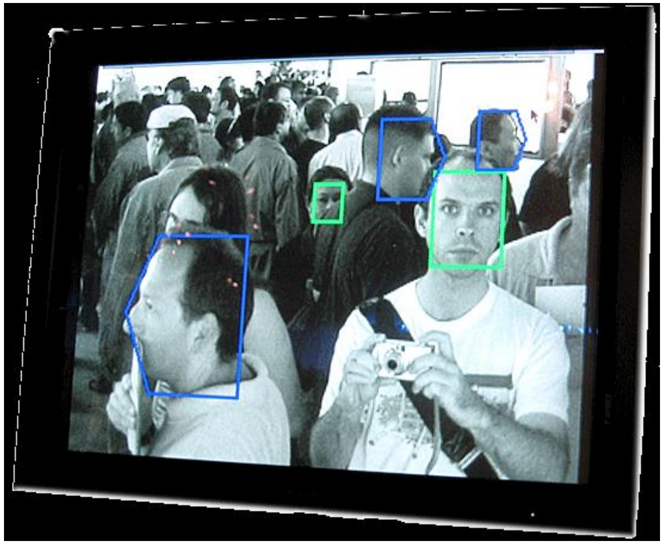


Examples: HCI

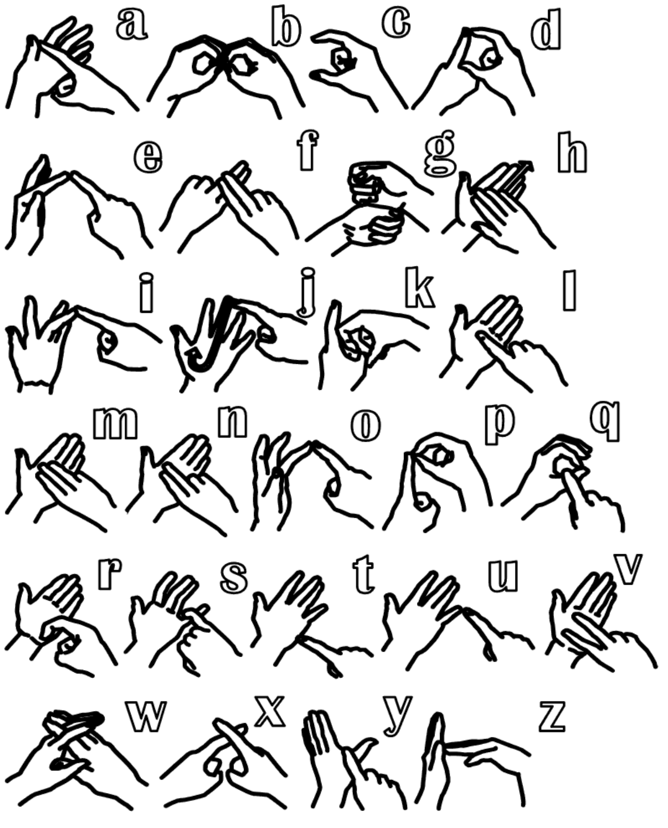
- Try to make human computer interfaces more natural
  - Gesture recognition
  - Facial Expression Recognition
  - Lip reading



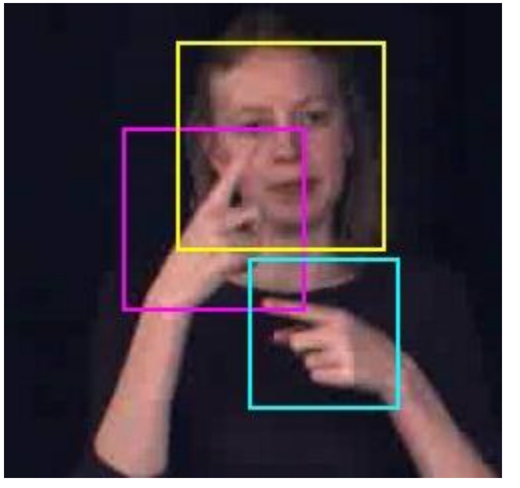




Examples: Sign Language/Gesture Recognition



British Sign Language Alphabet



Examples: Lip Reading

Can you guess? ee oo sh

Examples: Lip Reading

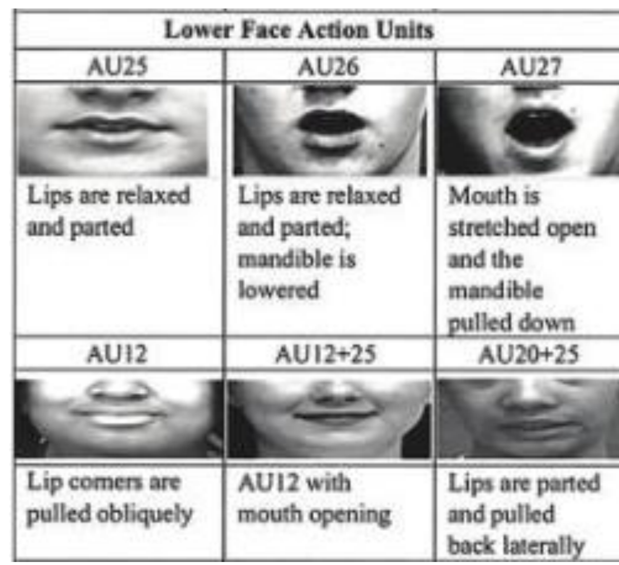
Examples: Facial Expression Recognition

- Implicit customer feedback

Examples: Facial Expression Recognition

- Implicit customer feedback

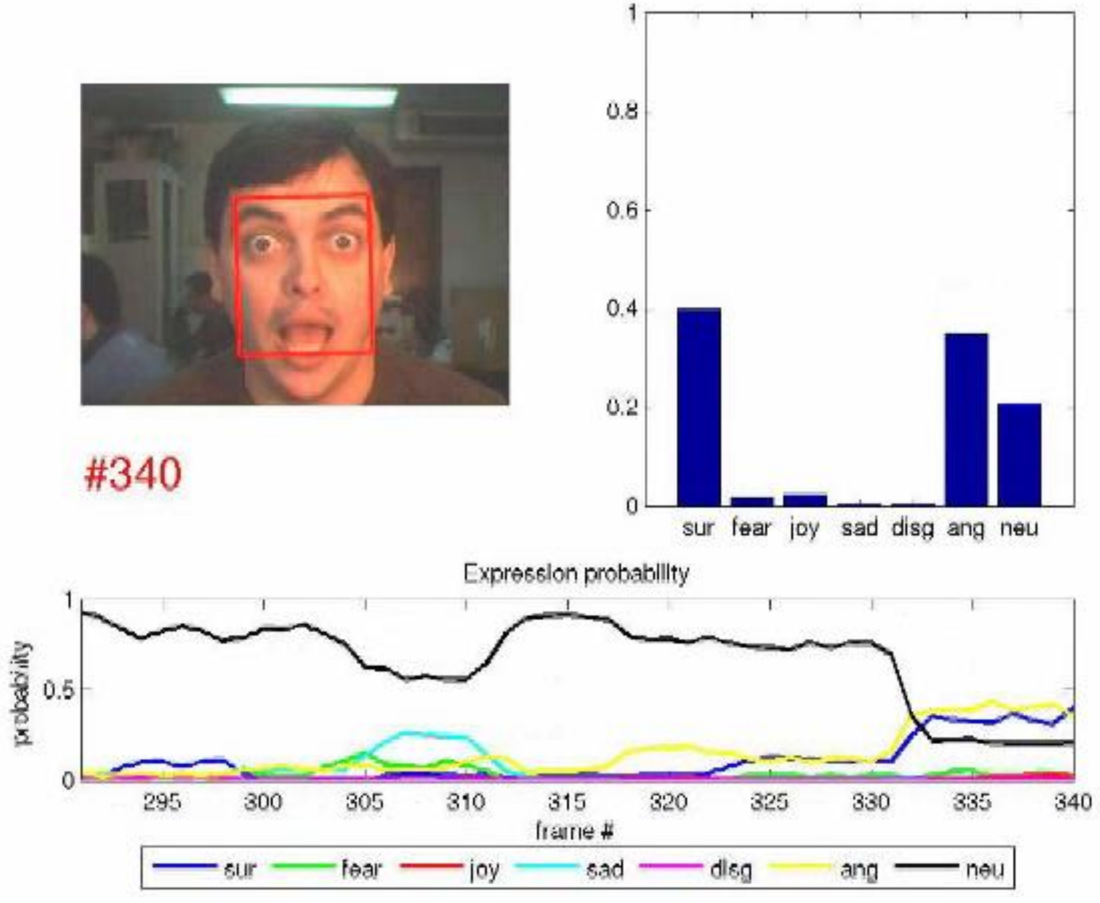
Upper Face Action Units		
AU4	AU1+4	AU1+2
Brows lowered and drawn together	Medial portion of the brows is raised and pulled together	Inner and outer portions of the brows are raised
AU5	AU6	AU7
Upper eyelids are raised	Cheeks are raised and eye opening is narrowed	Lower eyelids are raised



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

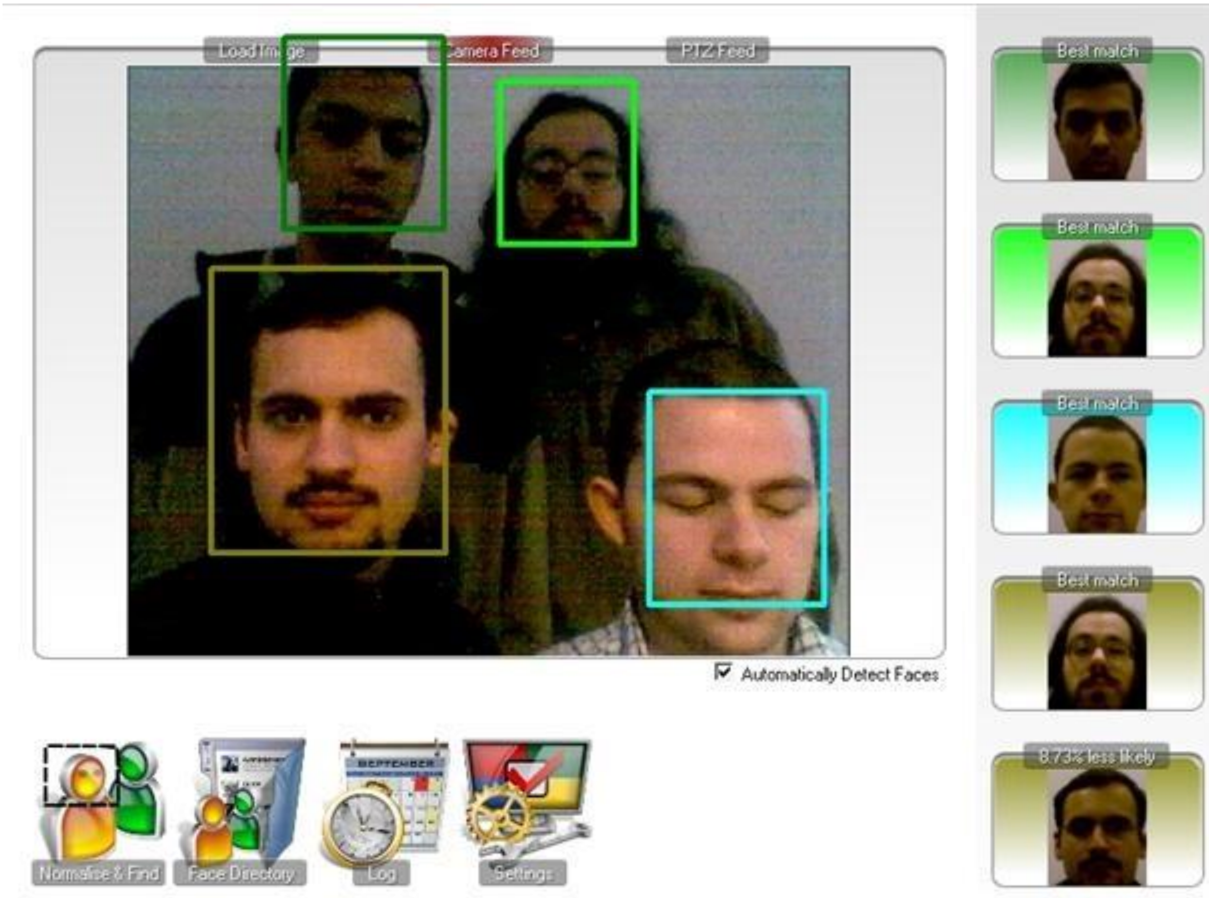
- Implicit customer feedback



Examples: Biometrics

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

Examples: Biometrics – Face Recognition



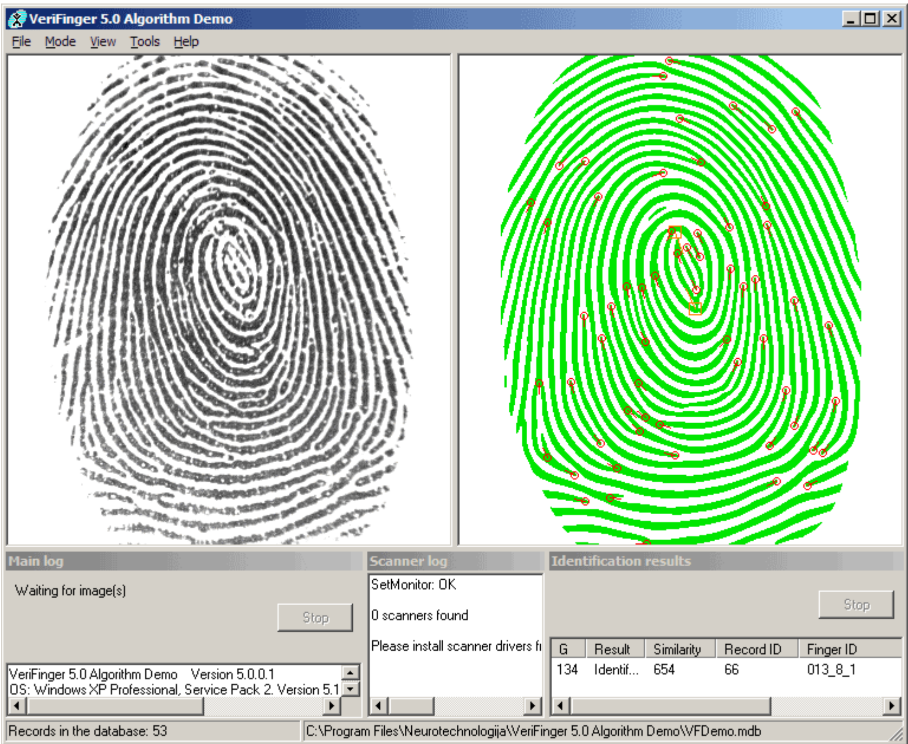
Faces and Digital Cameras

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

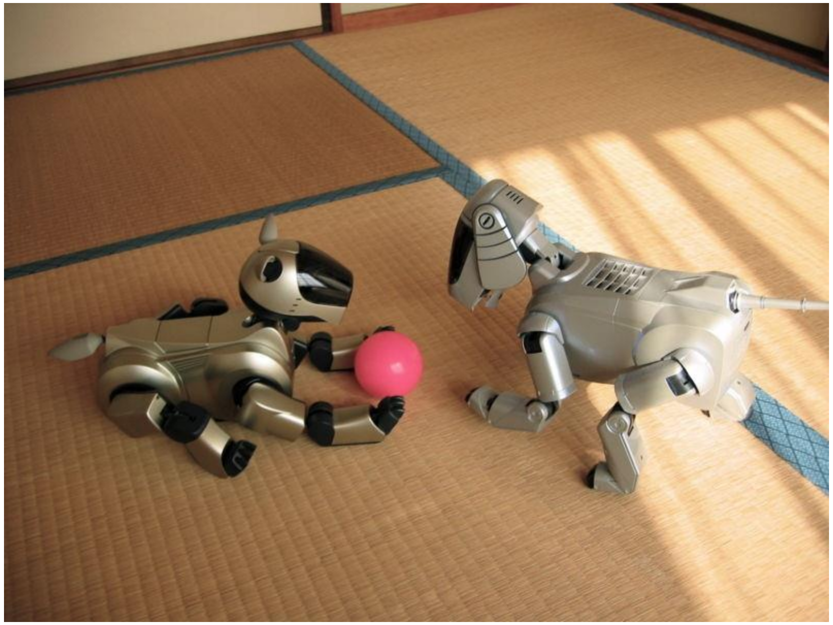


Examples: Biometrics – Signature Verification

Examples: Robotics

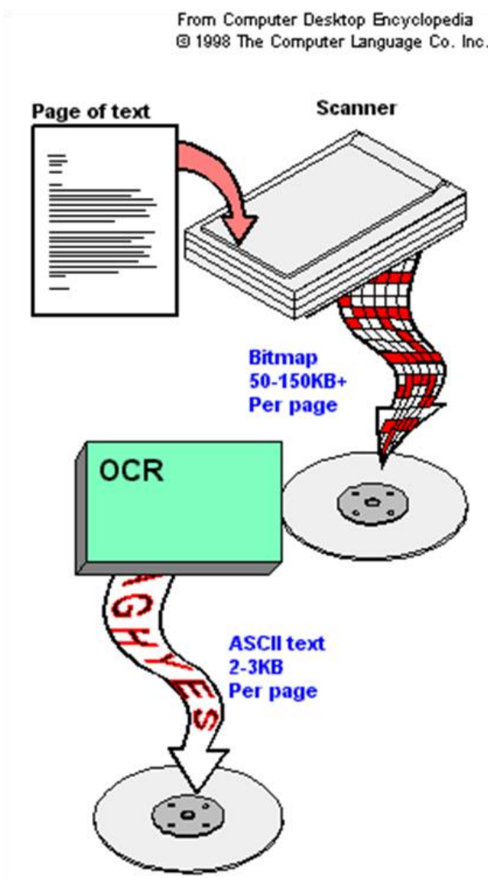
Examples: Robotics

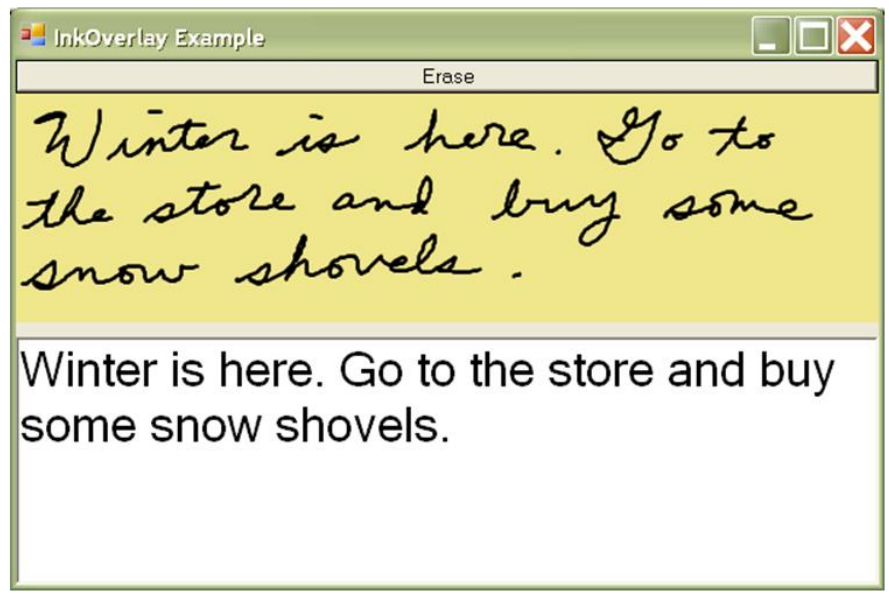
- AIBO



Examples: Optical Character Recognition

- Convert document image into text





Examples: Optical Character Recognition

- Indexing and Retrieval

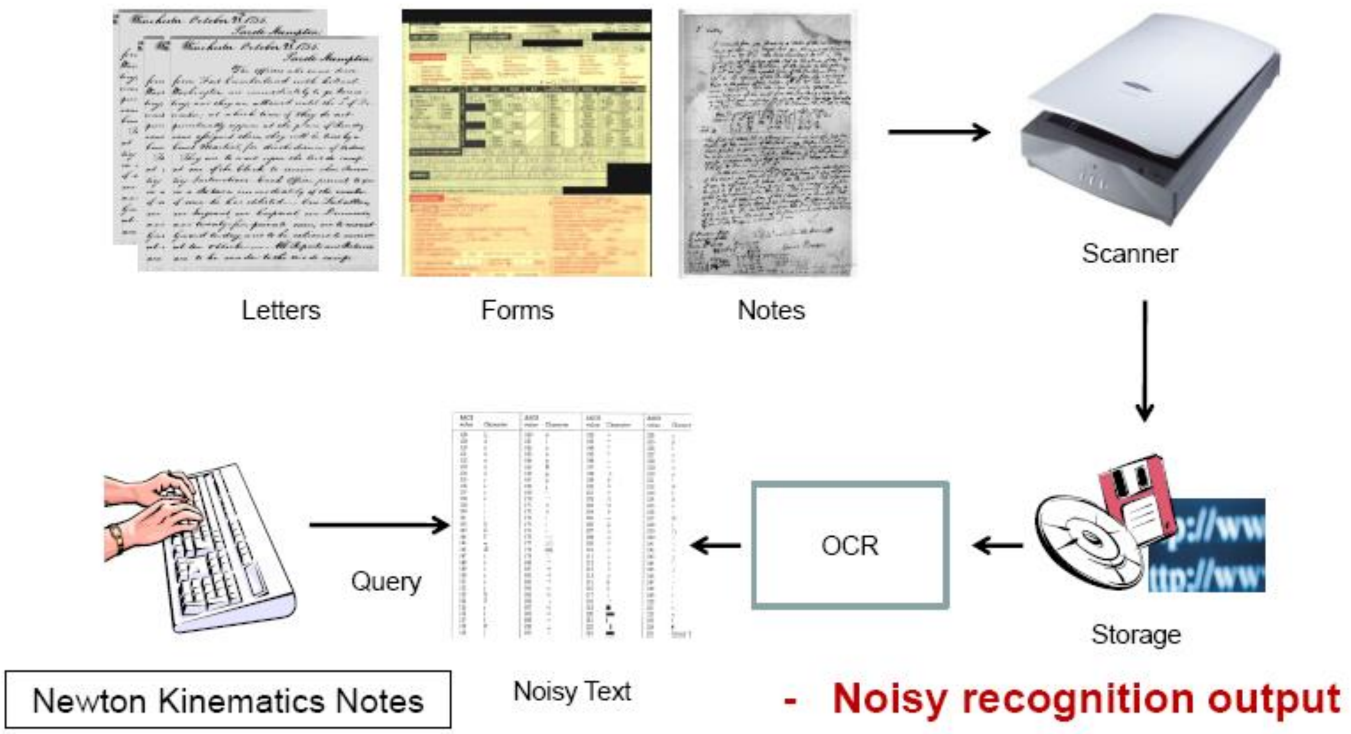


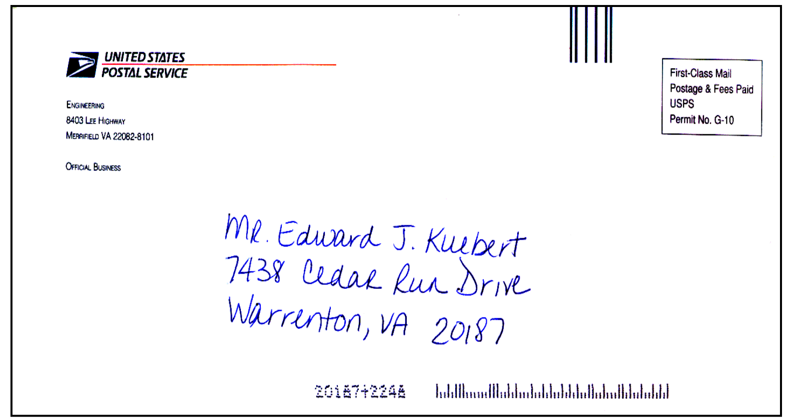
Image Source: CEDAR

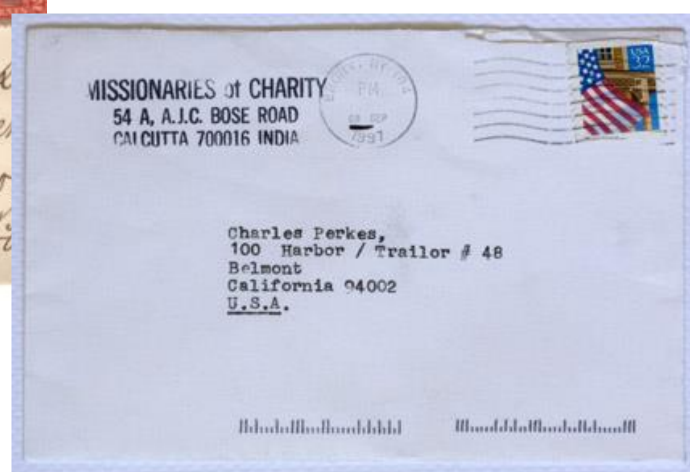
Examples: Optical Character Recognition

- License Plate Recognition

Examples: Optical Character Recognition

- Automatic Mail Sorting

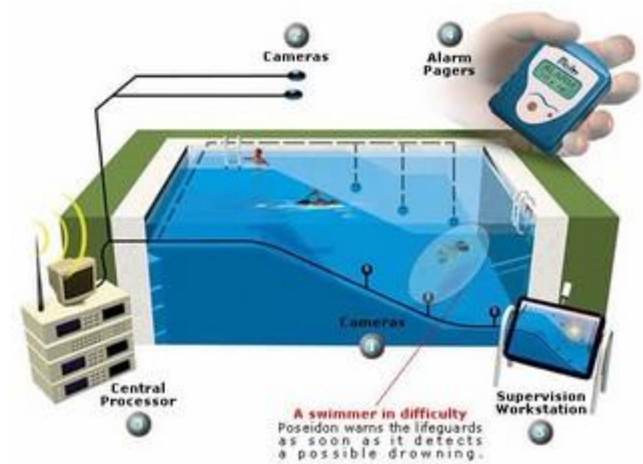




Safety and Security

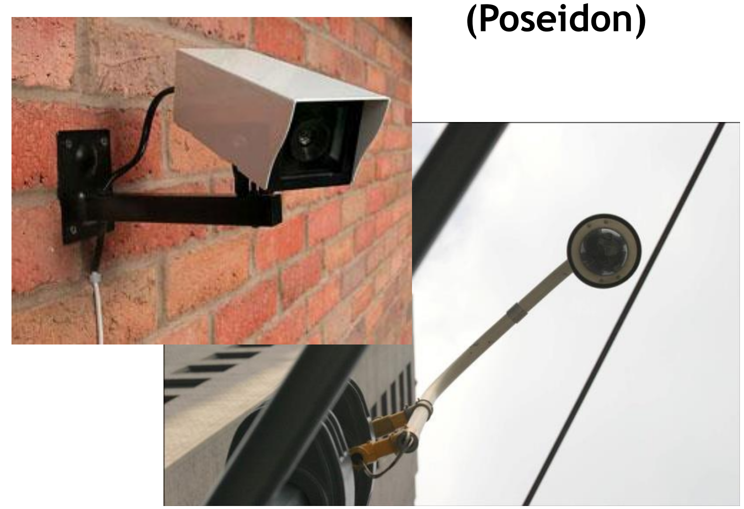
Autonomous robots

Driver assistance

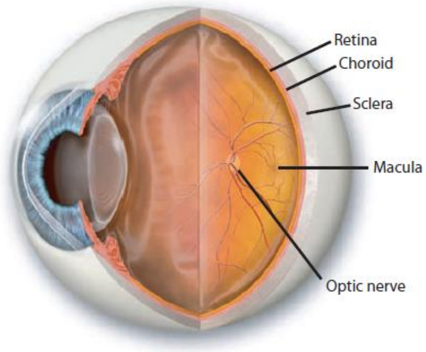


Monitoring pools
(Poseidon)

Pedestrian detection
[MERL, Viola et al.]

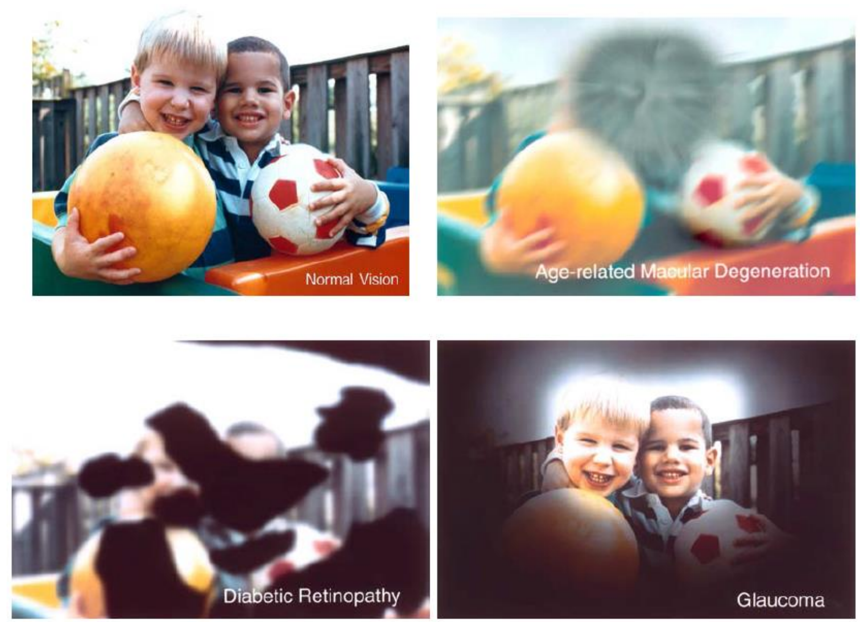


Surveillance

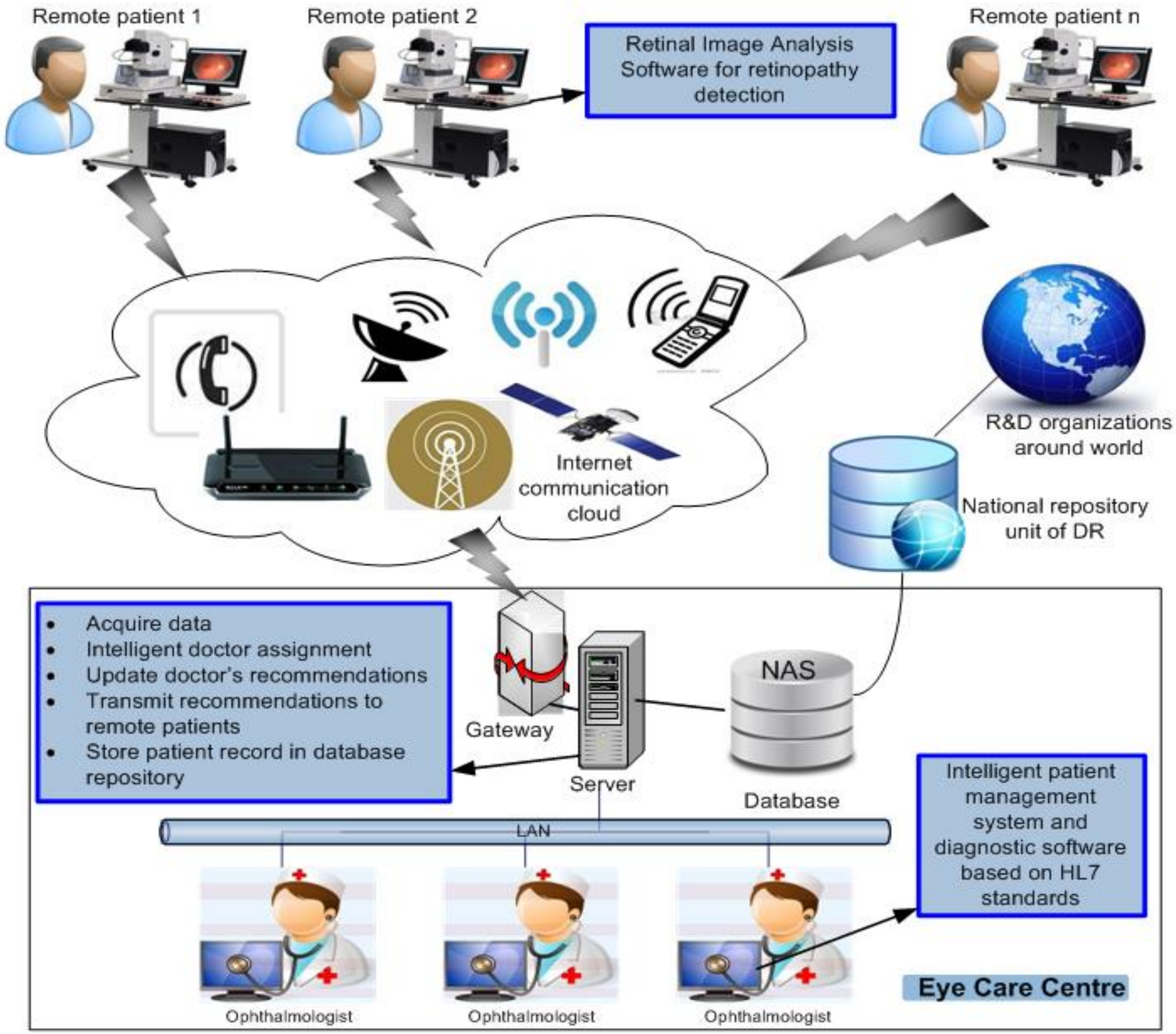


Eye Care

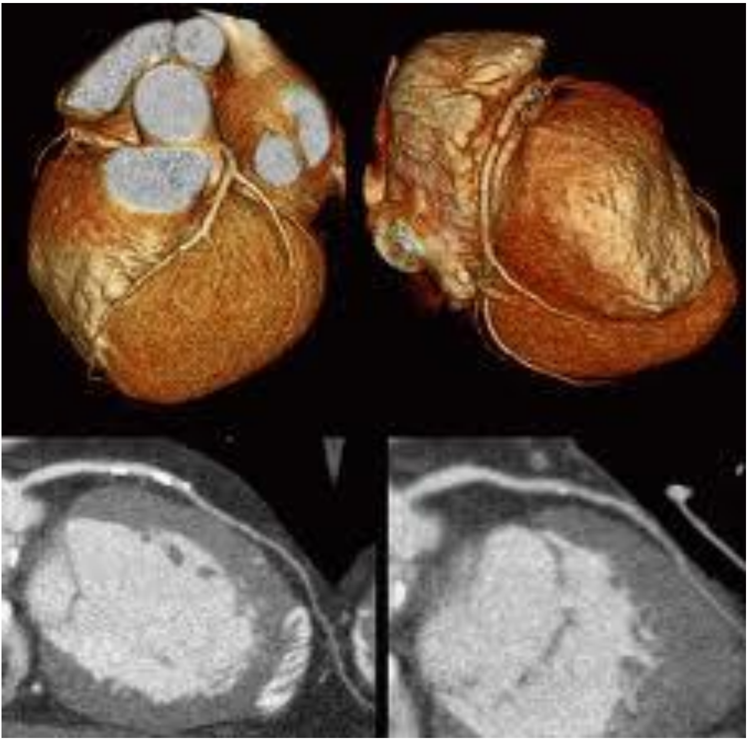
- Diabetic Retinopathy (DR) using Fundus Images
- Diabetic Maculopathy (DM) using Fundus Images
- Optical Coherence Tomography (OCT) analysis for detection of AMD
- Glaucoma Detection using Fundus Image
- Analysis of Fundus Images for detection of AMD

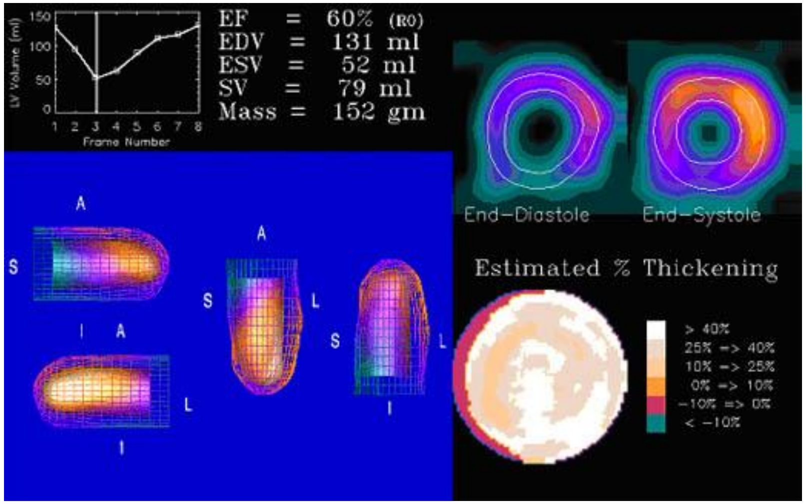


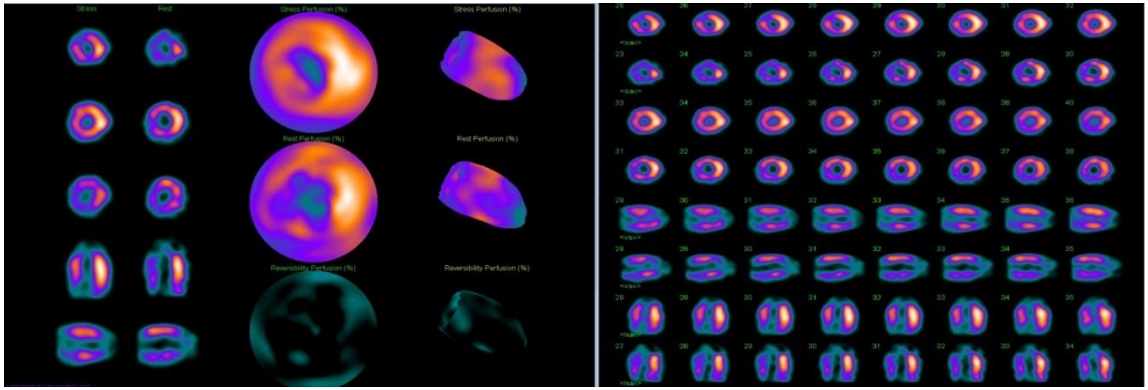
Telescreening System (National ICT R&D Funded Project)

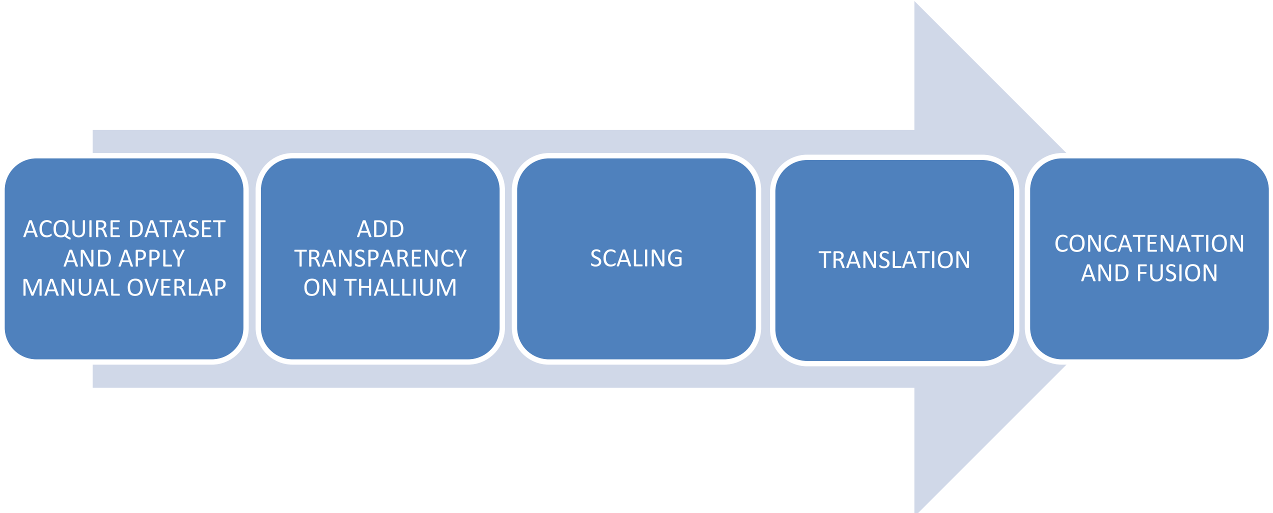


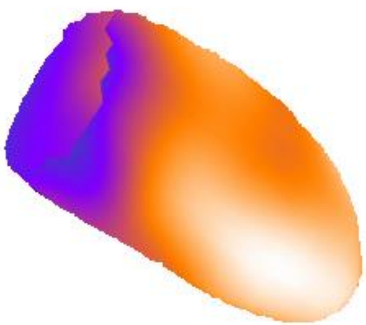
CT Angiography and Thallium Scan Images



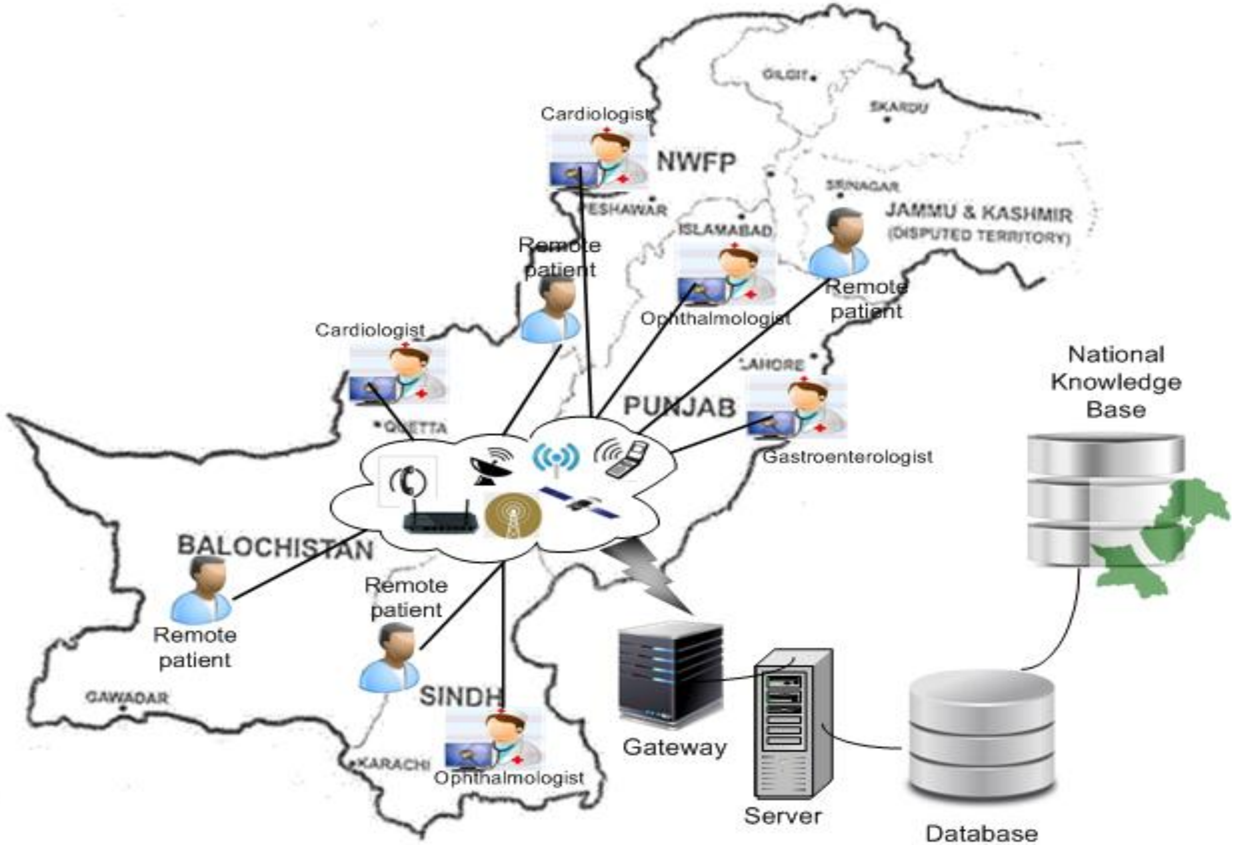





ACQUIRE DATASET AND APPLY MANUAL OVERLAP
ADD TRANSPARENCY ON THALLIUM
SCALING
TRANSLATION
CONCATENATION AND FUSION



i-Hospital



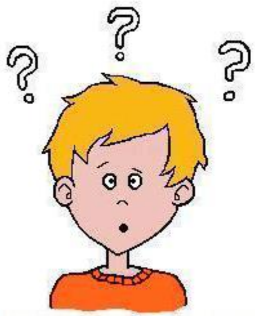
Cardiologist
NWFP
PESHAWAR
GILGIT
SKARDU
SRINAGAR
JAMMU & KASHMIR
(DISPUTED TERRITORY)
ISLAMABAD
Remote patient
Ophthalmologist
Remote patient
Cardiologist
QUETTA
LAHORE
PUNJAB
Gastroenterologist
National Knowledge Base
BALOCHISTAN
Remote patient
Remote patient
SINDH
GAWADAR
KARACHI
Ophthalmologist
Gateway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

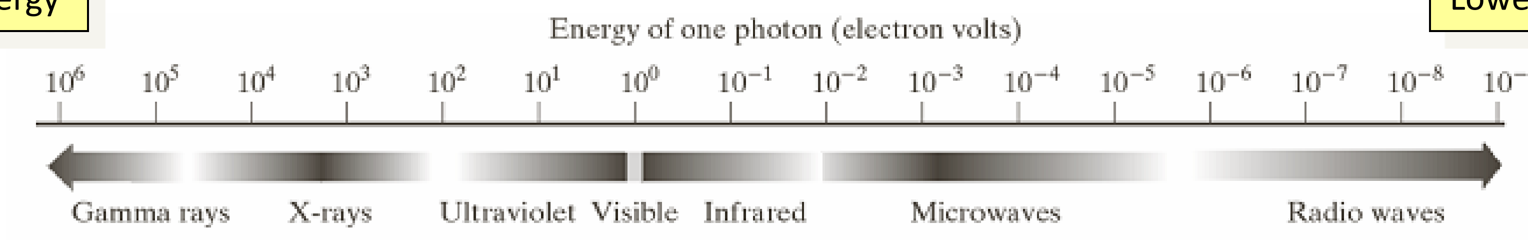


Light & EM Spectrum

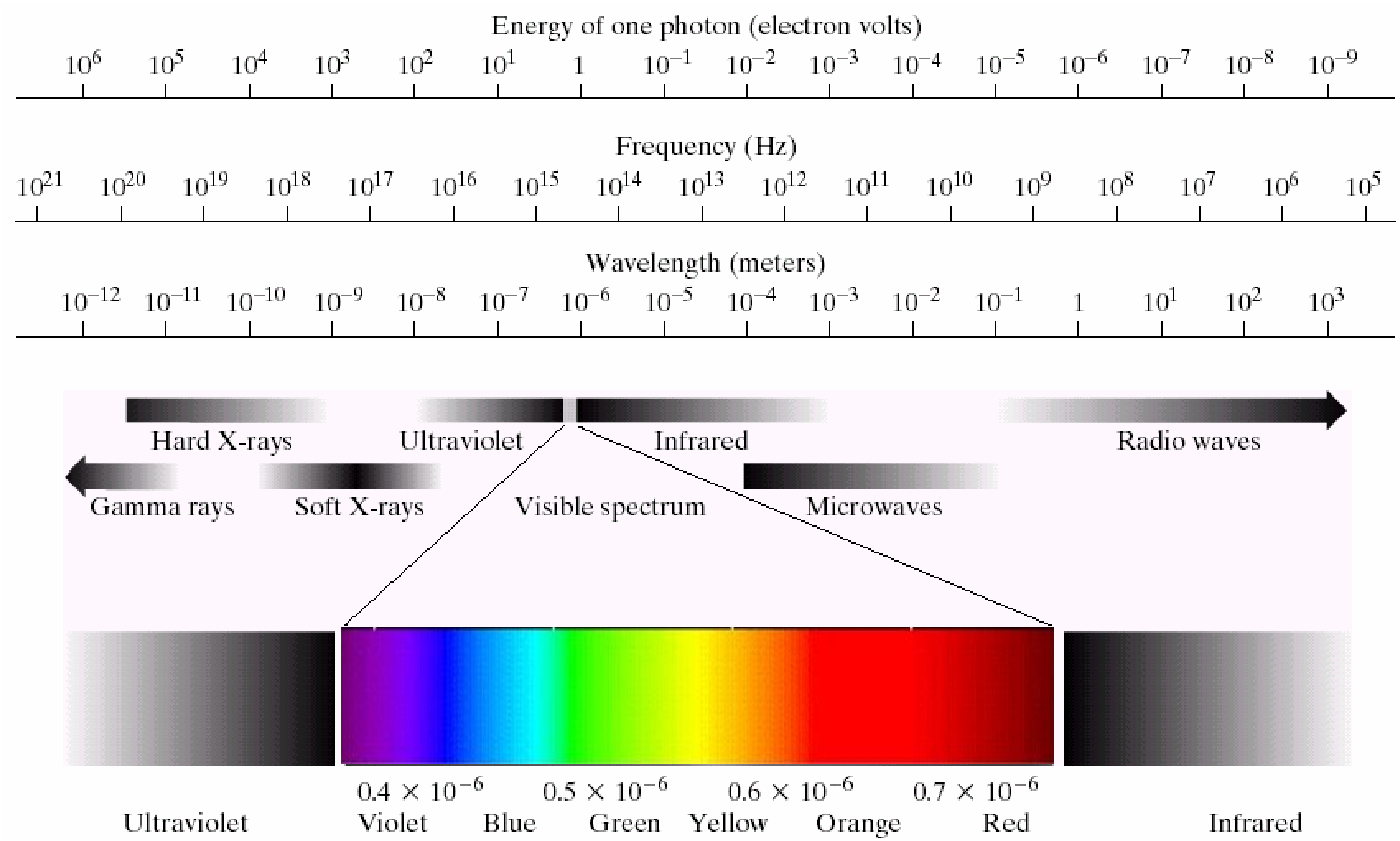
- EM Waves
  - A stream of mass less particles each travelling in a wave like pattern, moving at the speed of light and contains a certain bundle of energy
  - The electromagnetic spectrum is split up in to bands according to the energy per photon

Highest Energy

Lowest Energy



Light & EM Spectrum



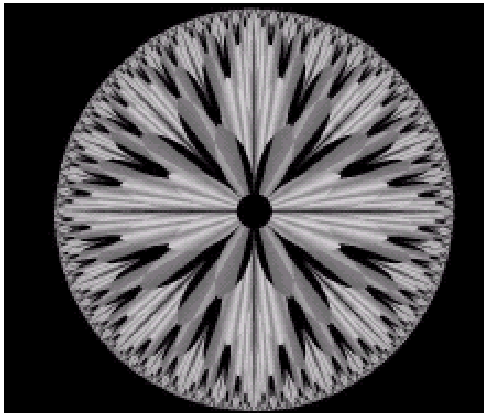
Visible light is just a particular part of the electromagnetic spectrum that can be sensed by the human eye

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

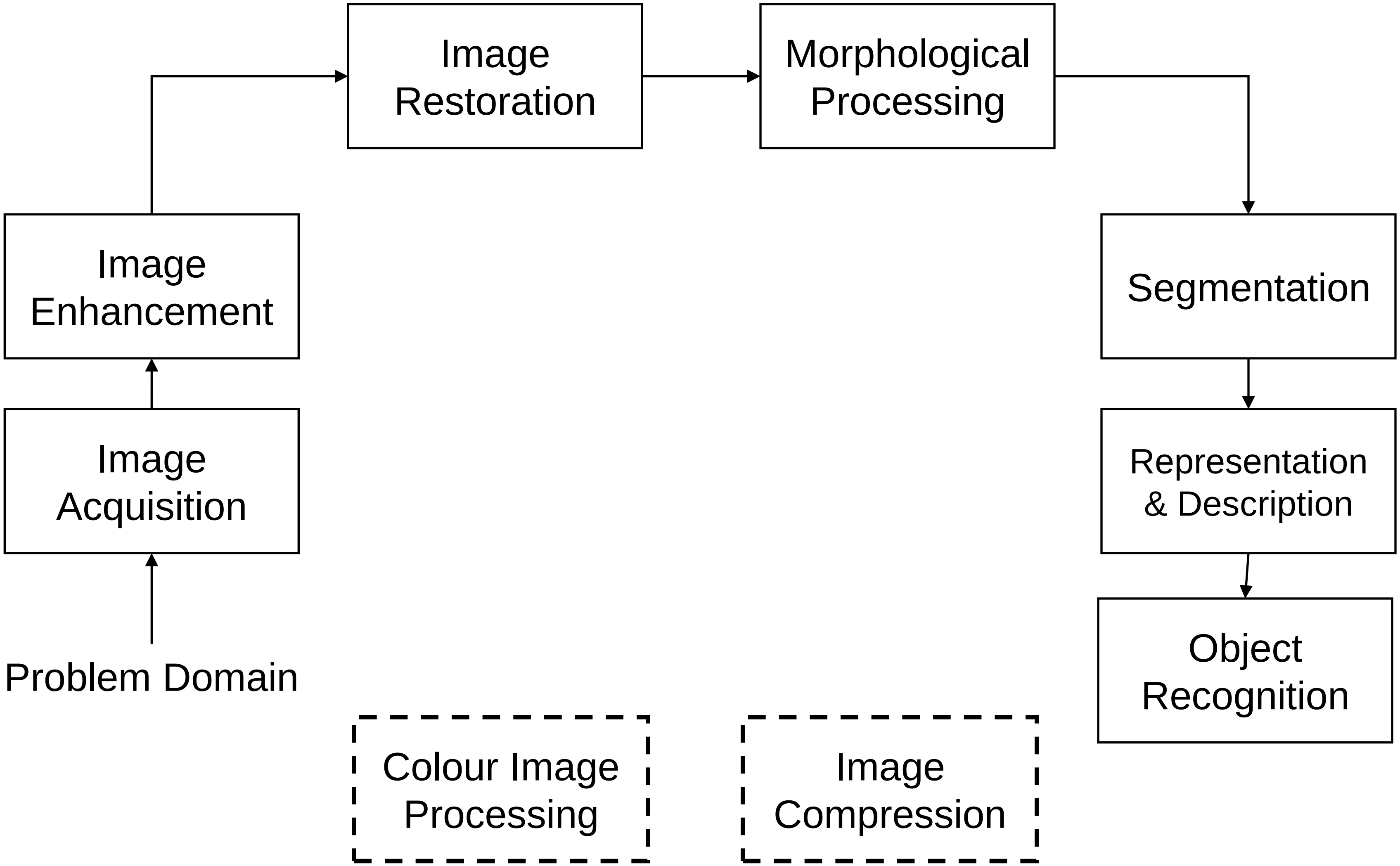
Examples: Imaging other Modalities

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

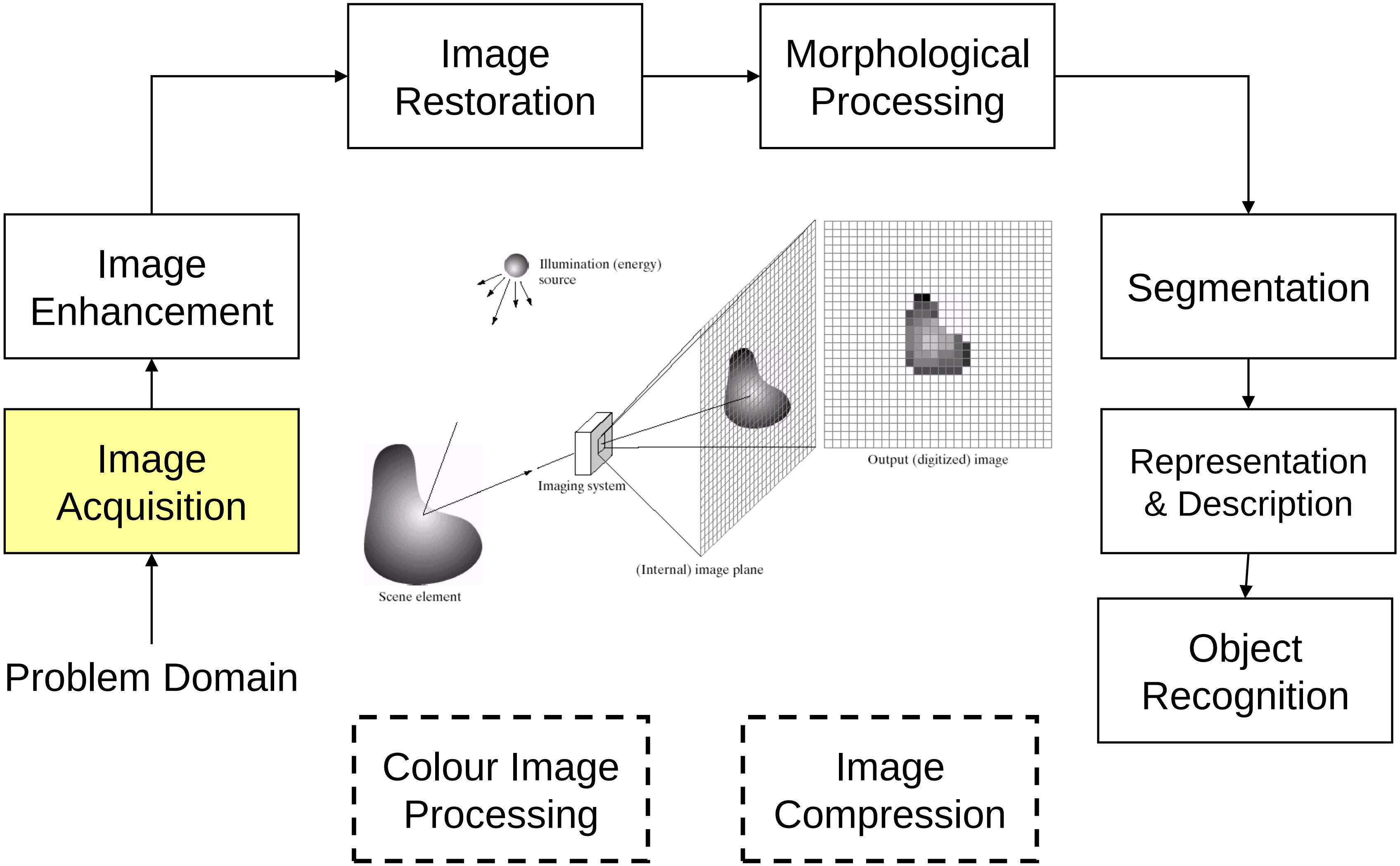


A synthetic image

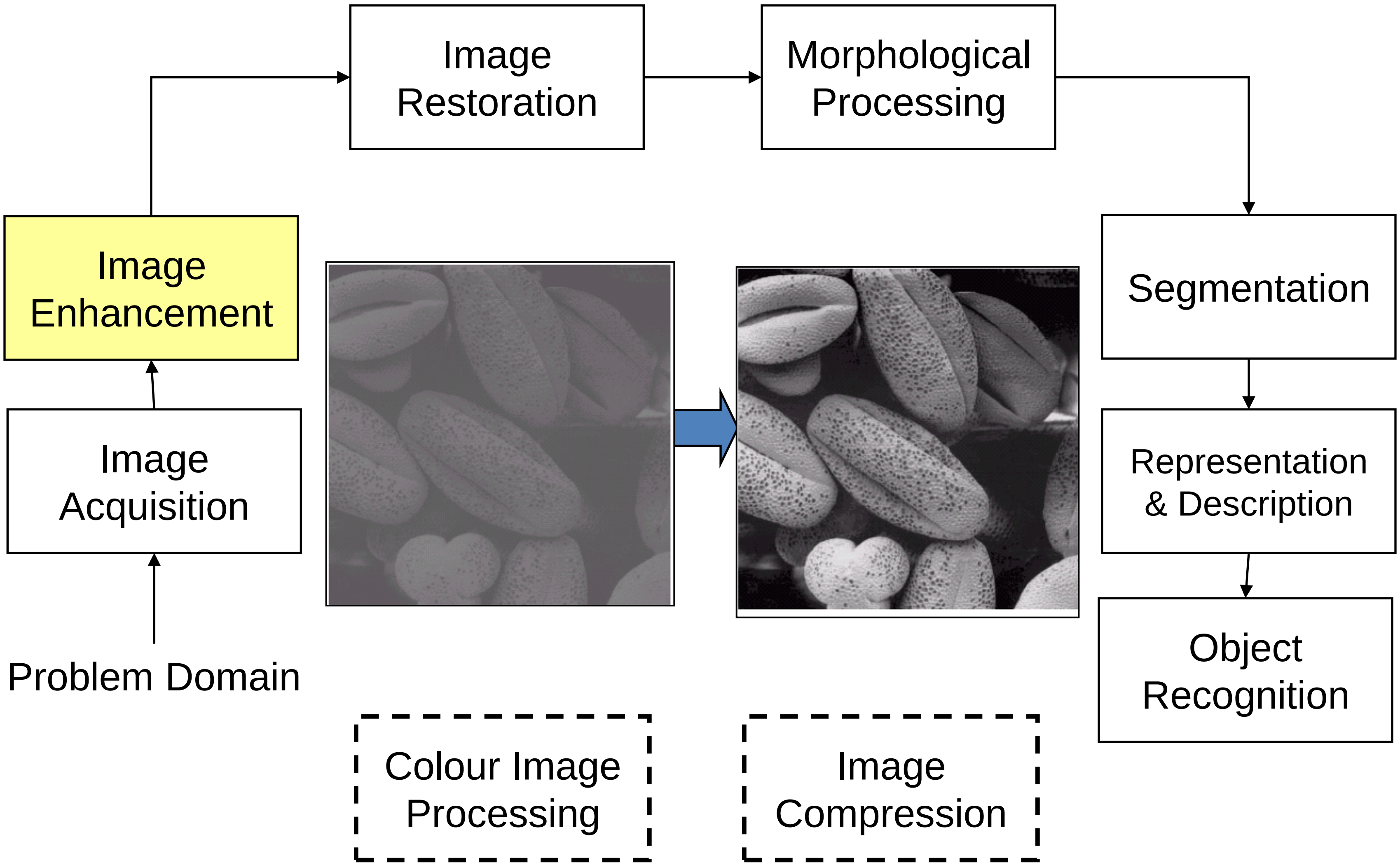
Key Stages in DIP



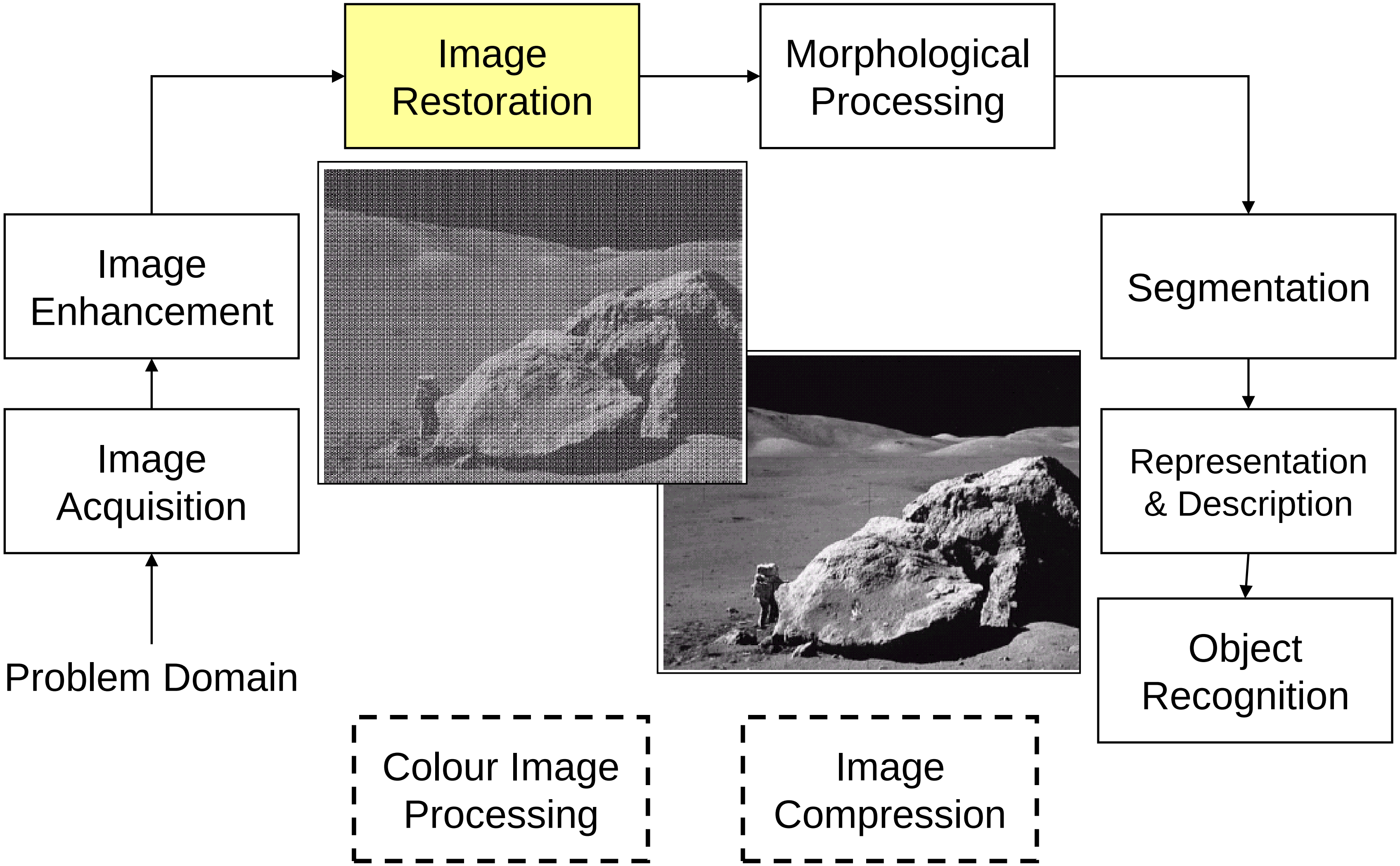
Key Stages in DIP



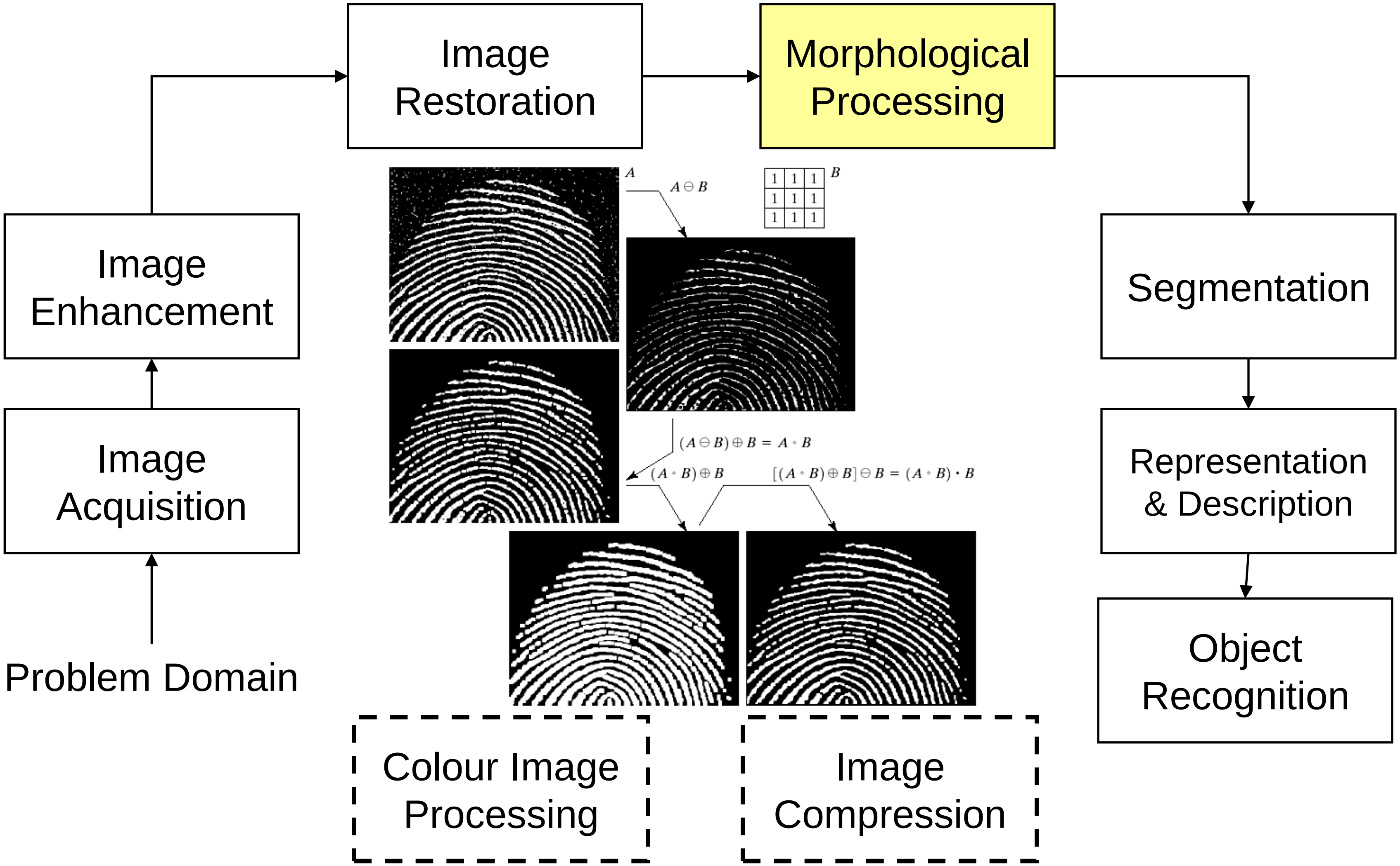
Key Stages in DIP



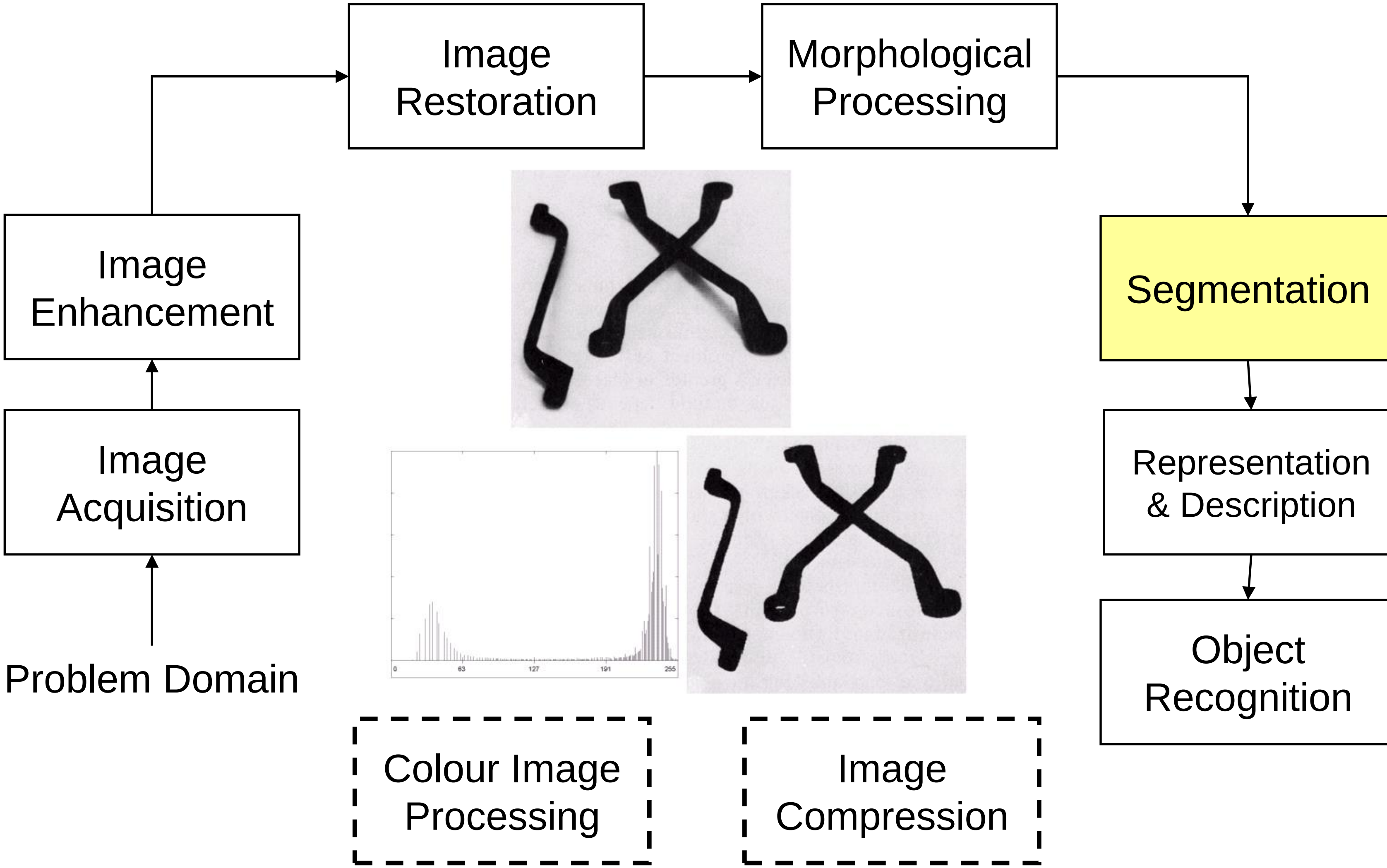
Key Stages in DIP



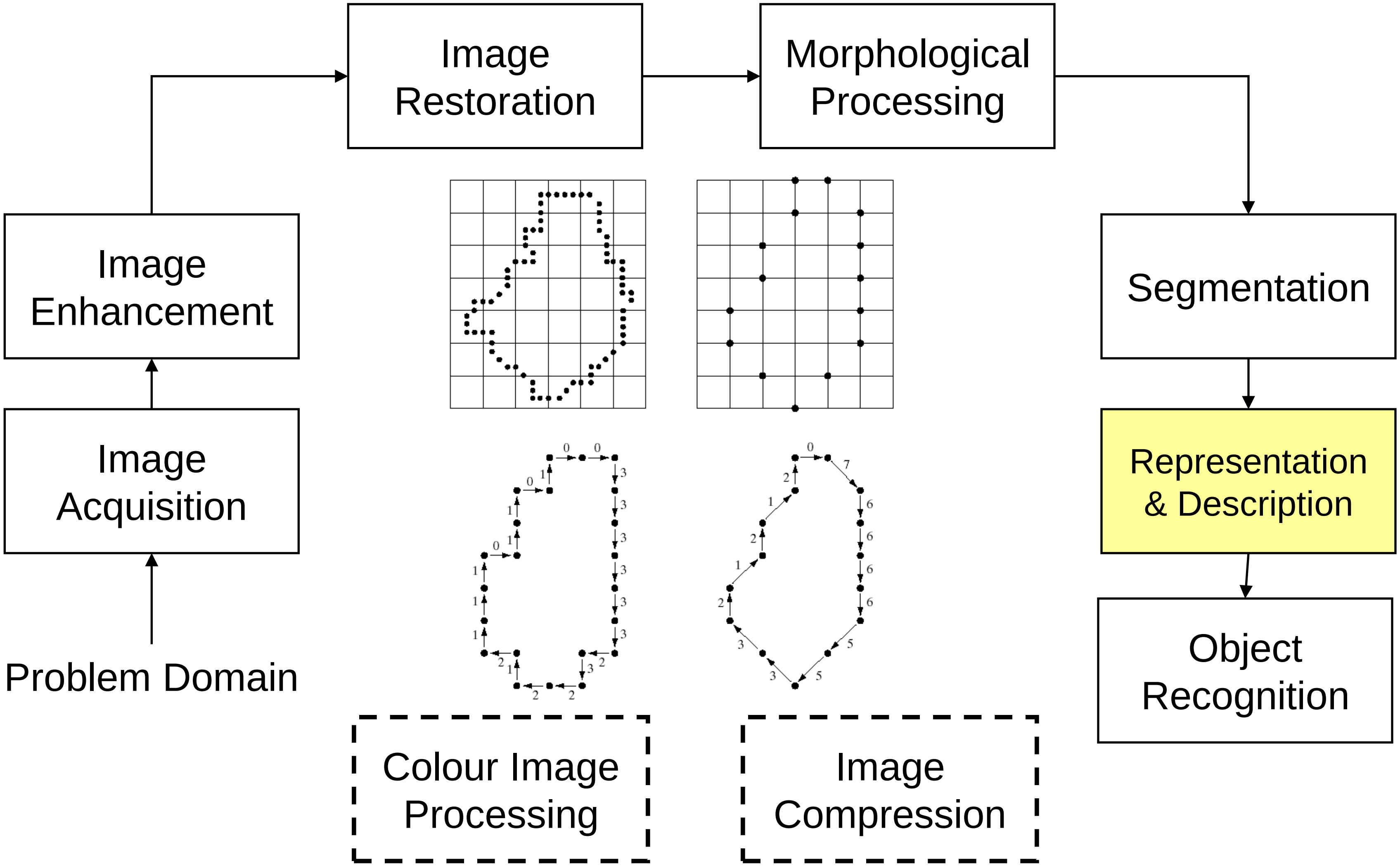
Key Stages in DIP



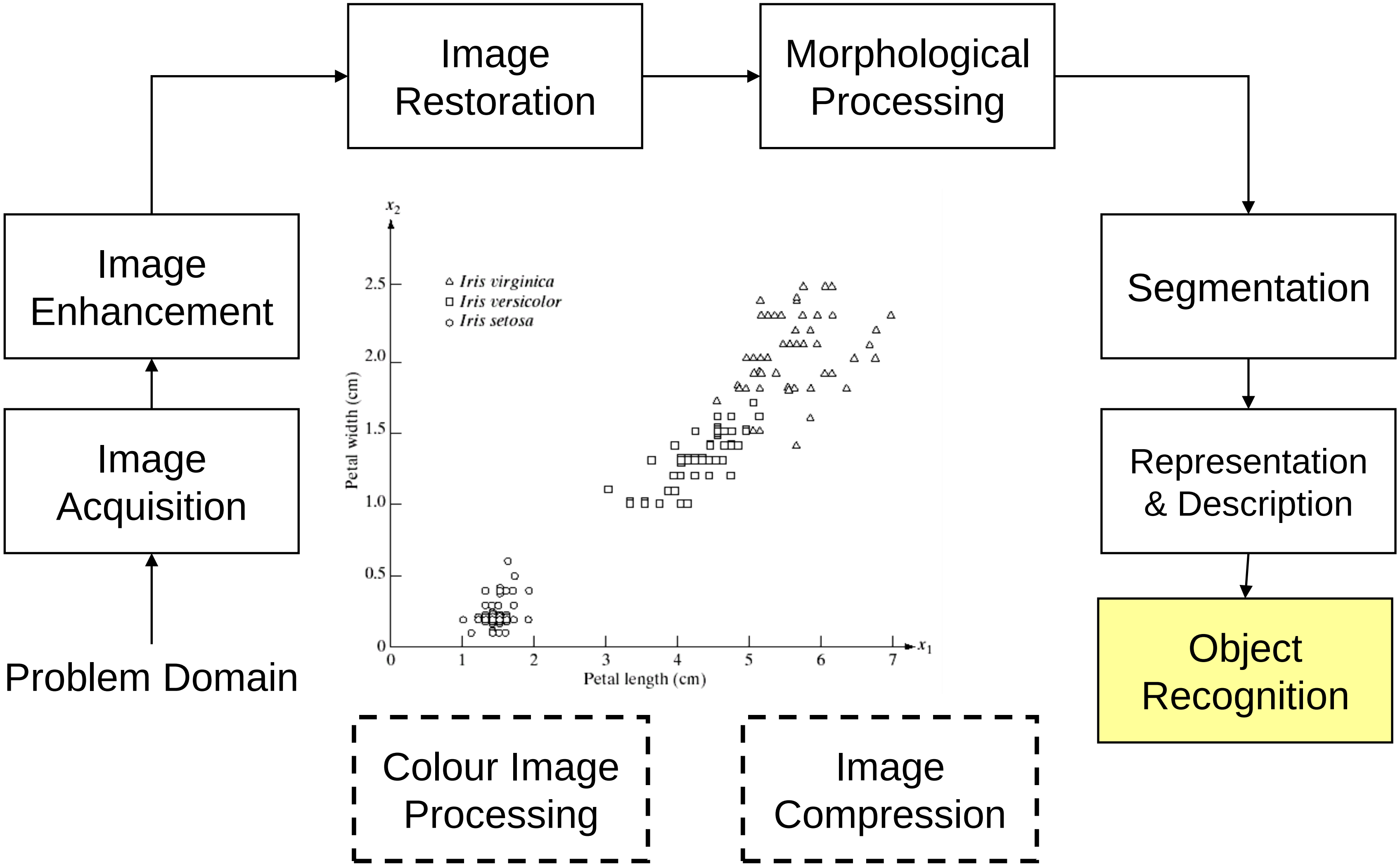
Key Stages in DIP



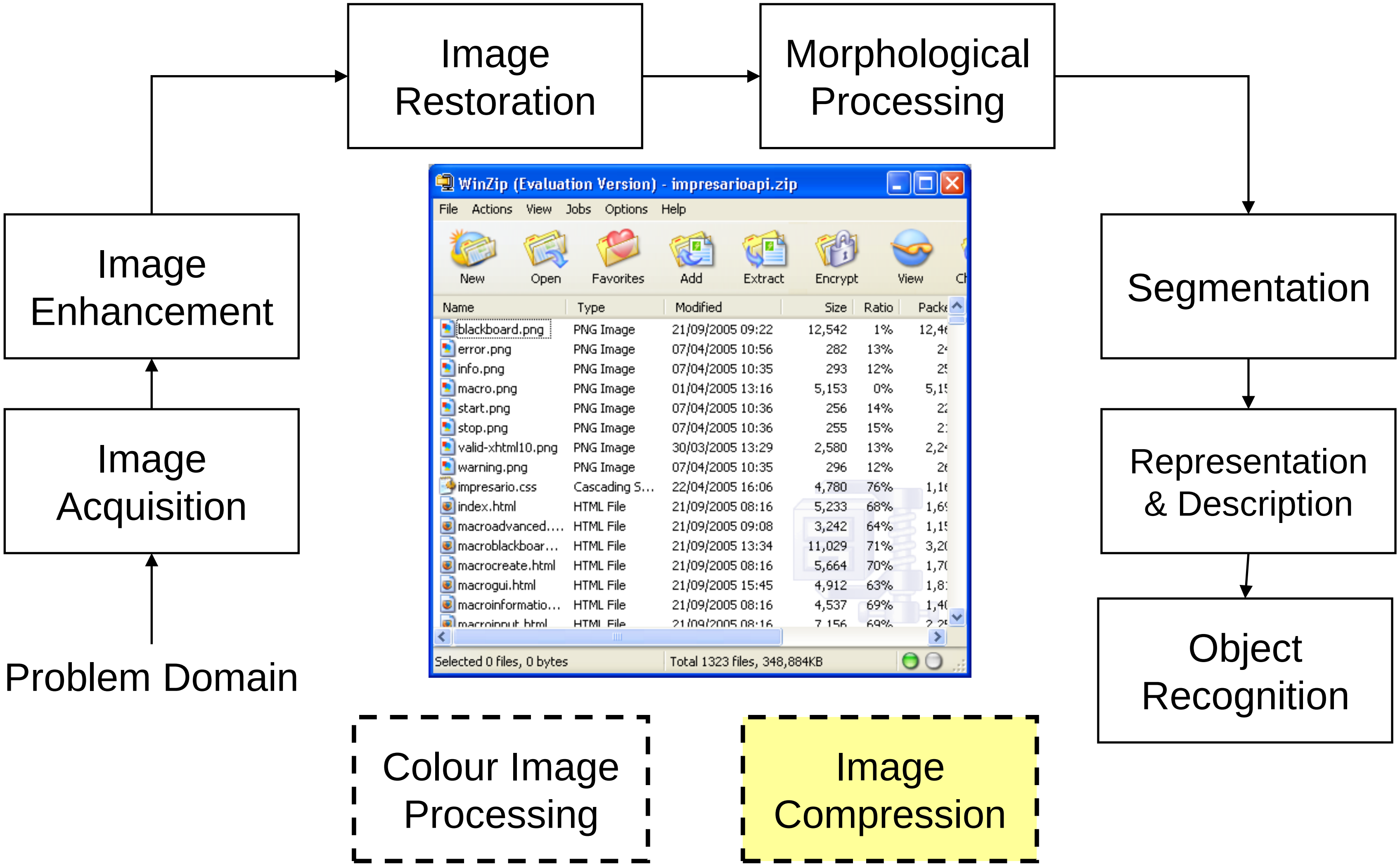
Key Stages in DIP



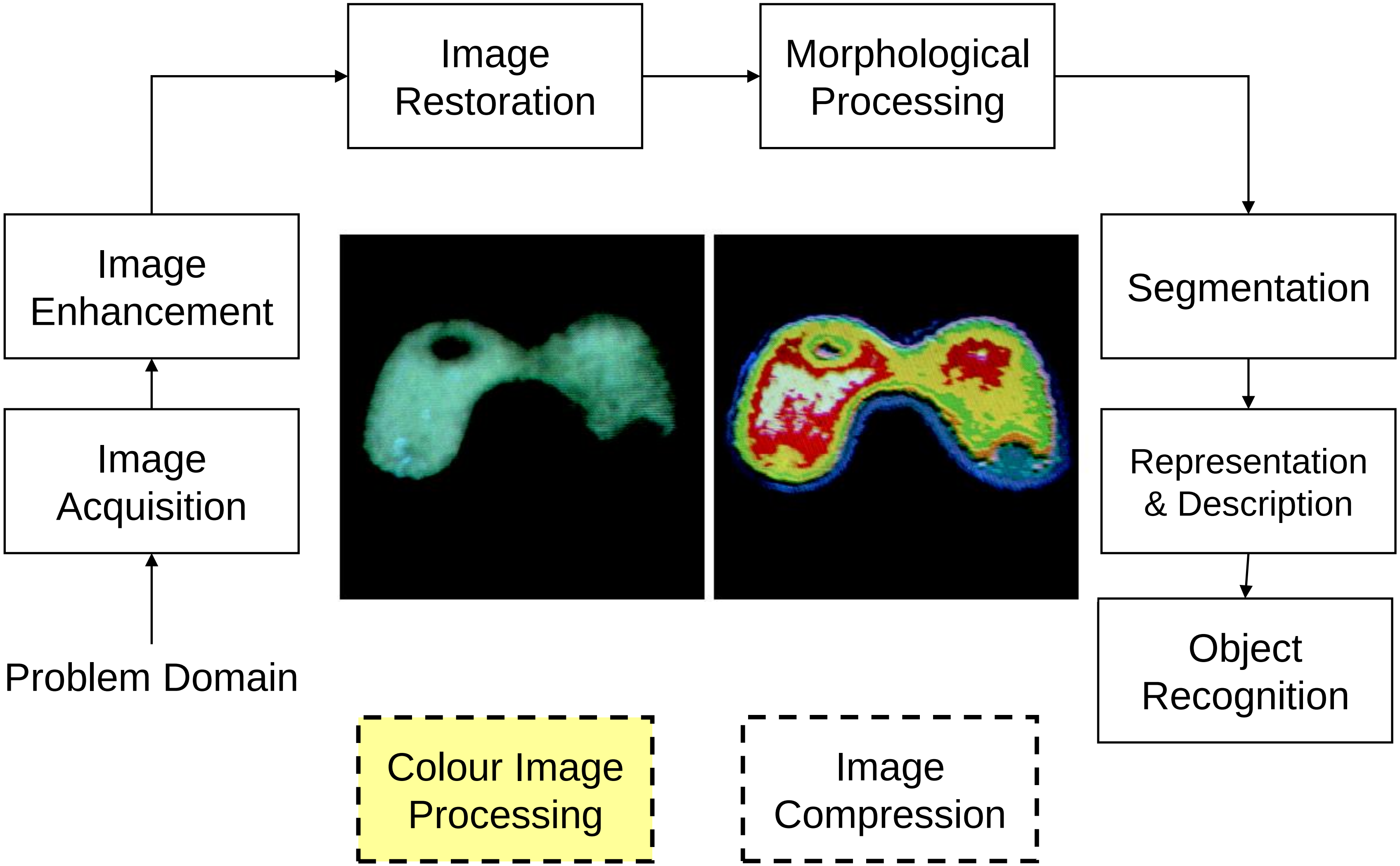
Key Stages in DIP



Key Stages in DIP



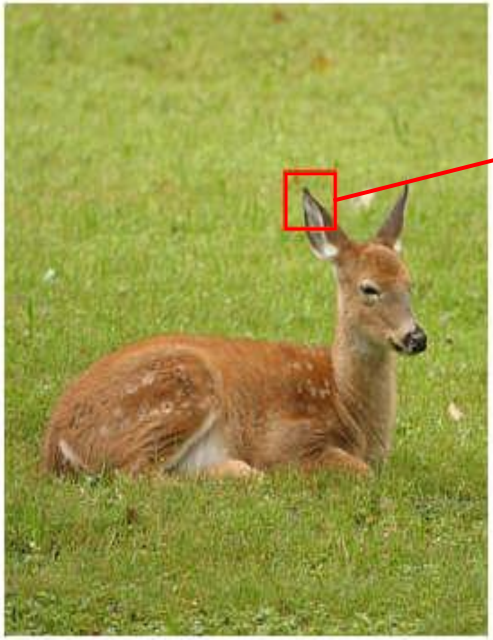
Key Stages in DIP

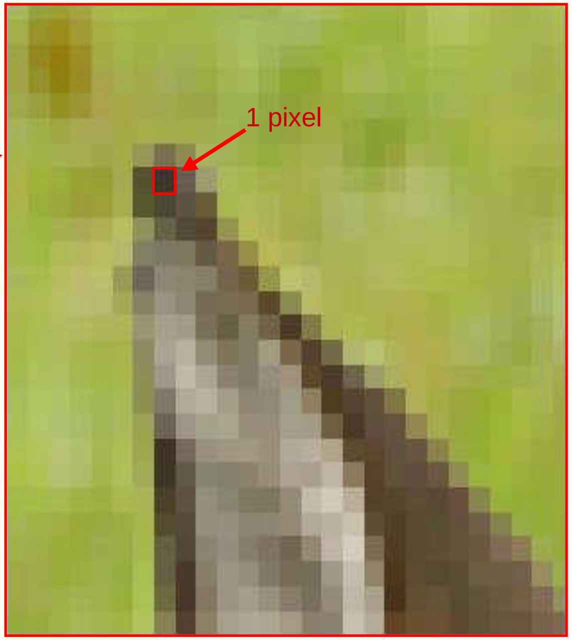


Digital Image

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*)

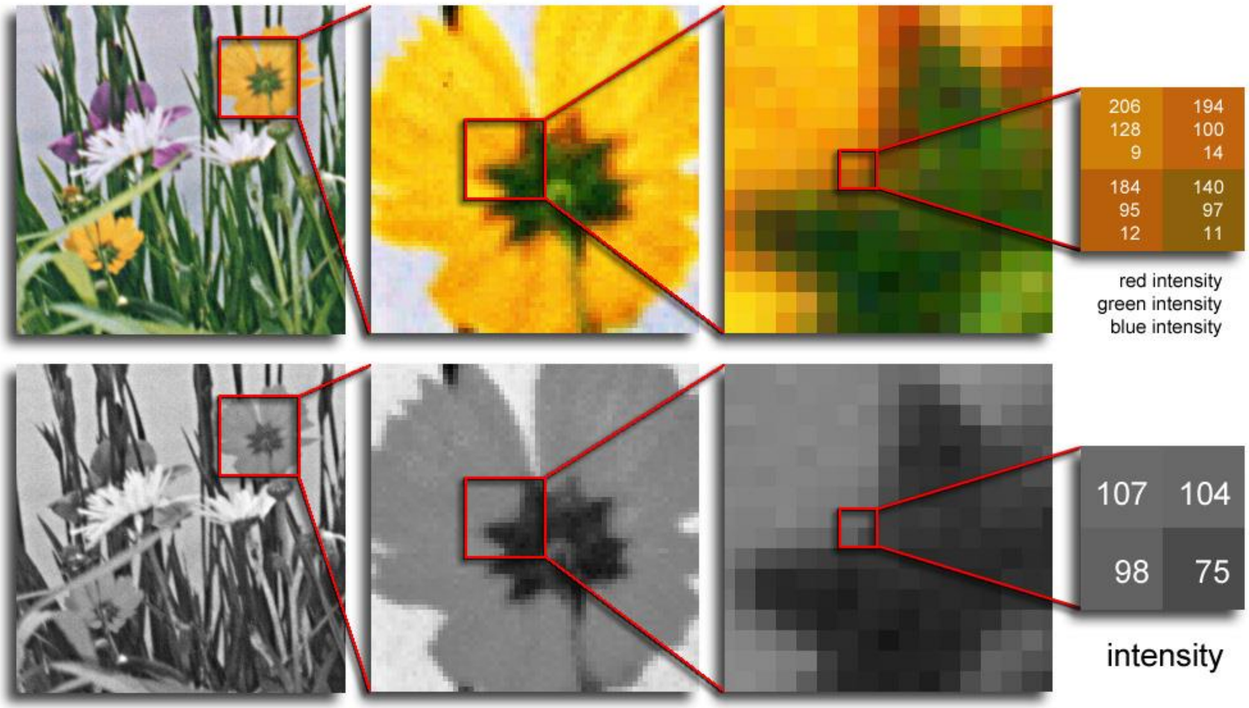


Image Formation

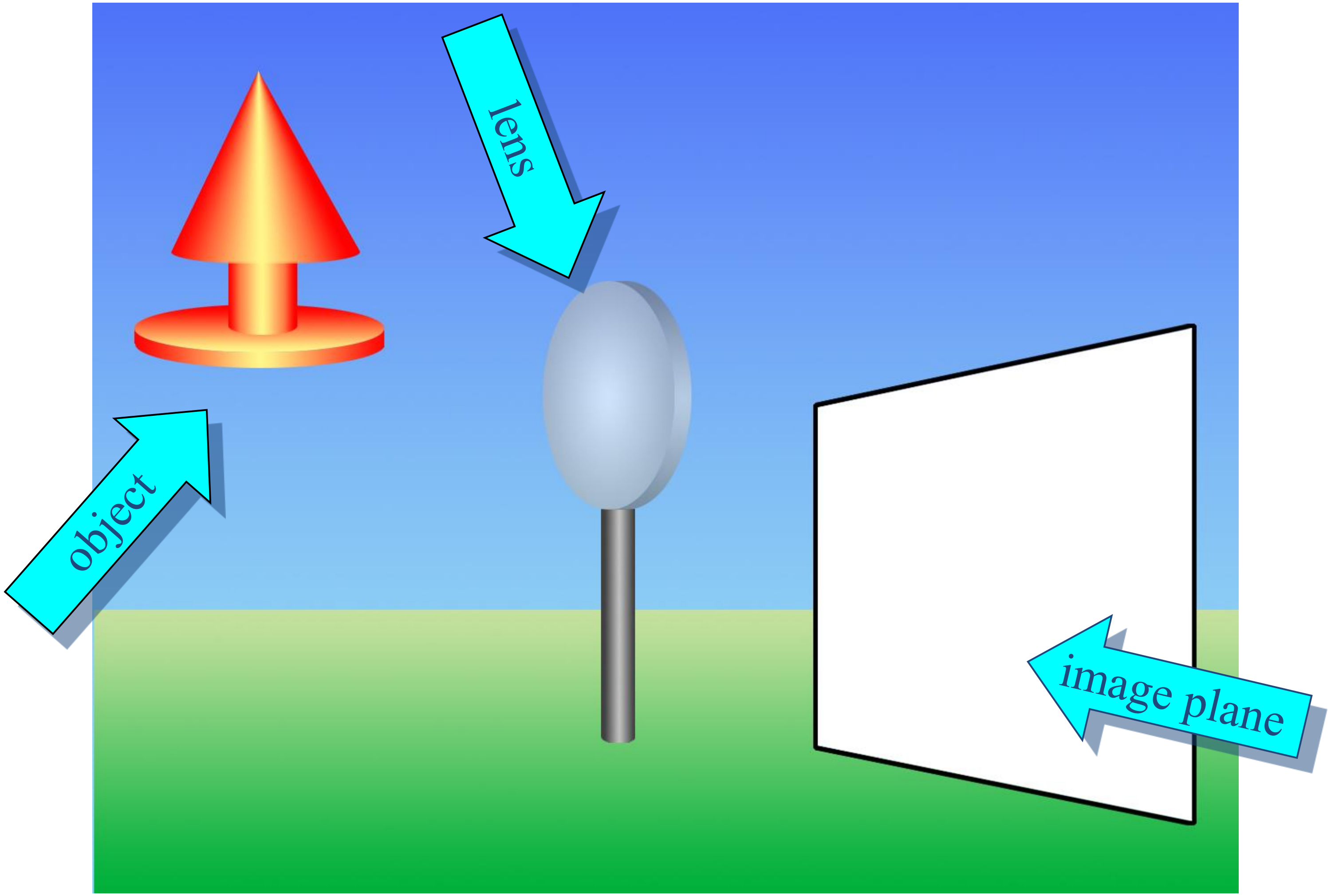


Image Formation

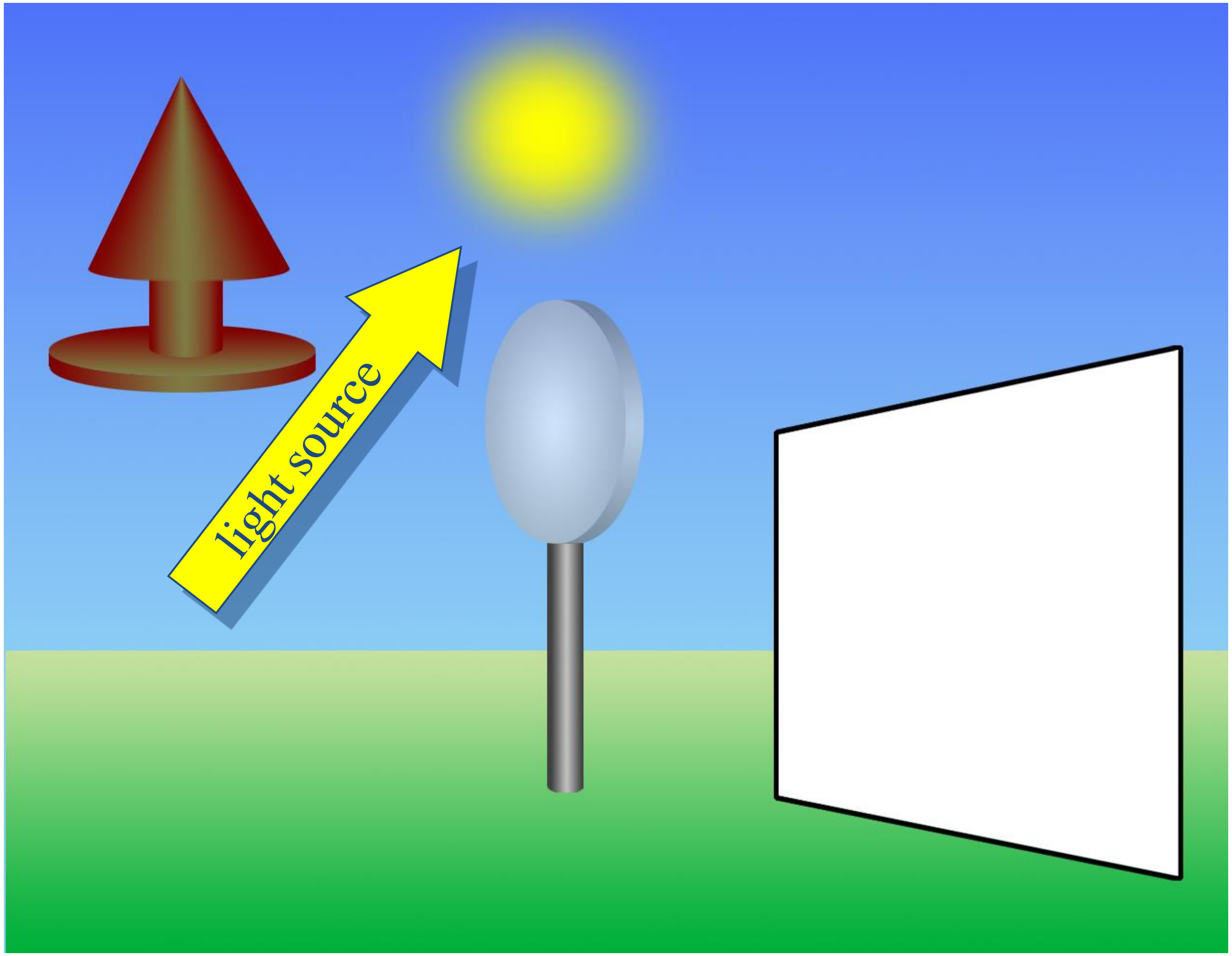


Image Formation

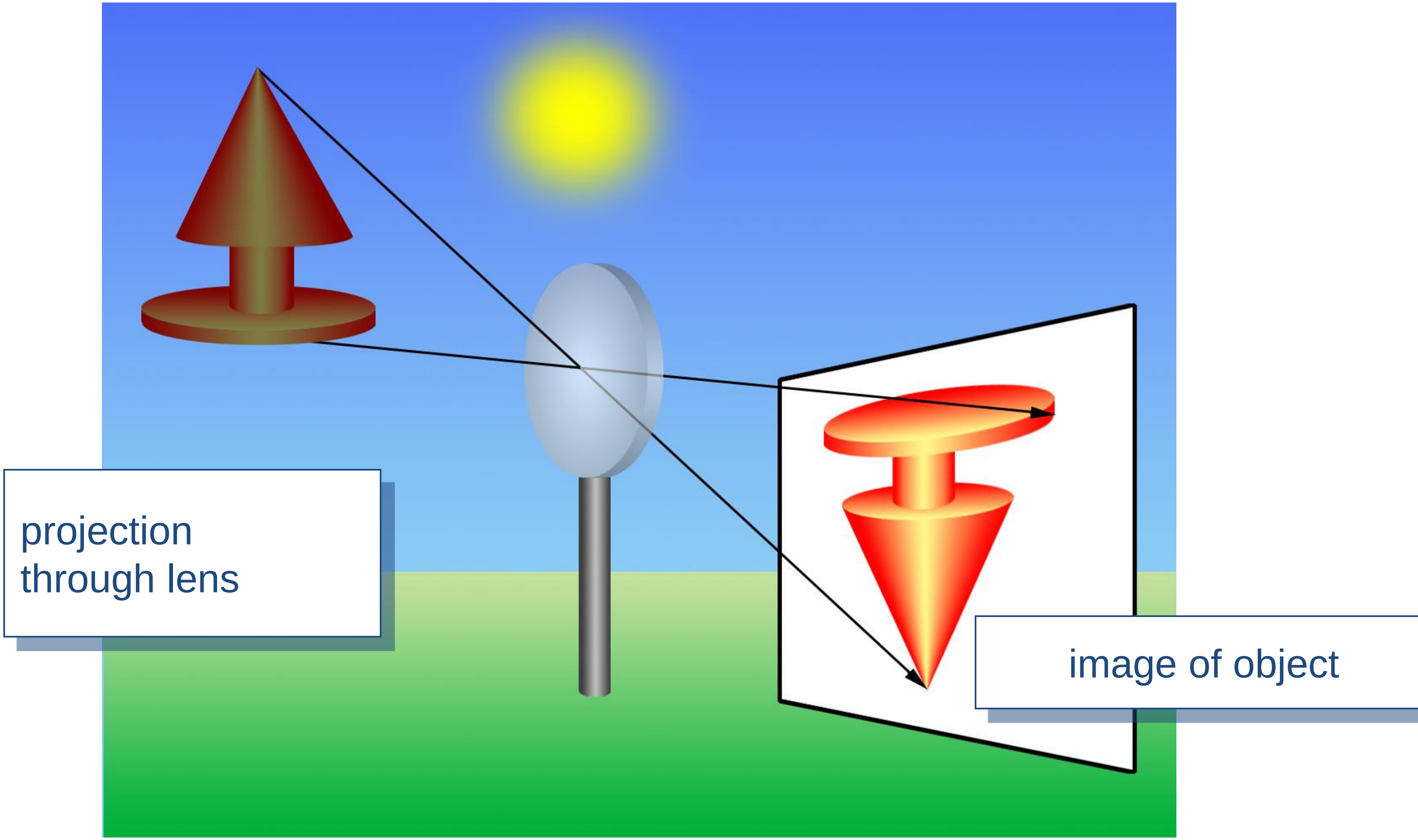


Image Formation

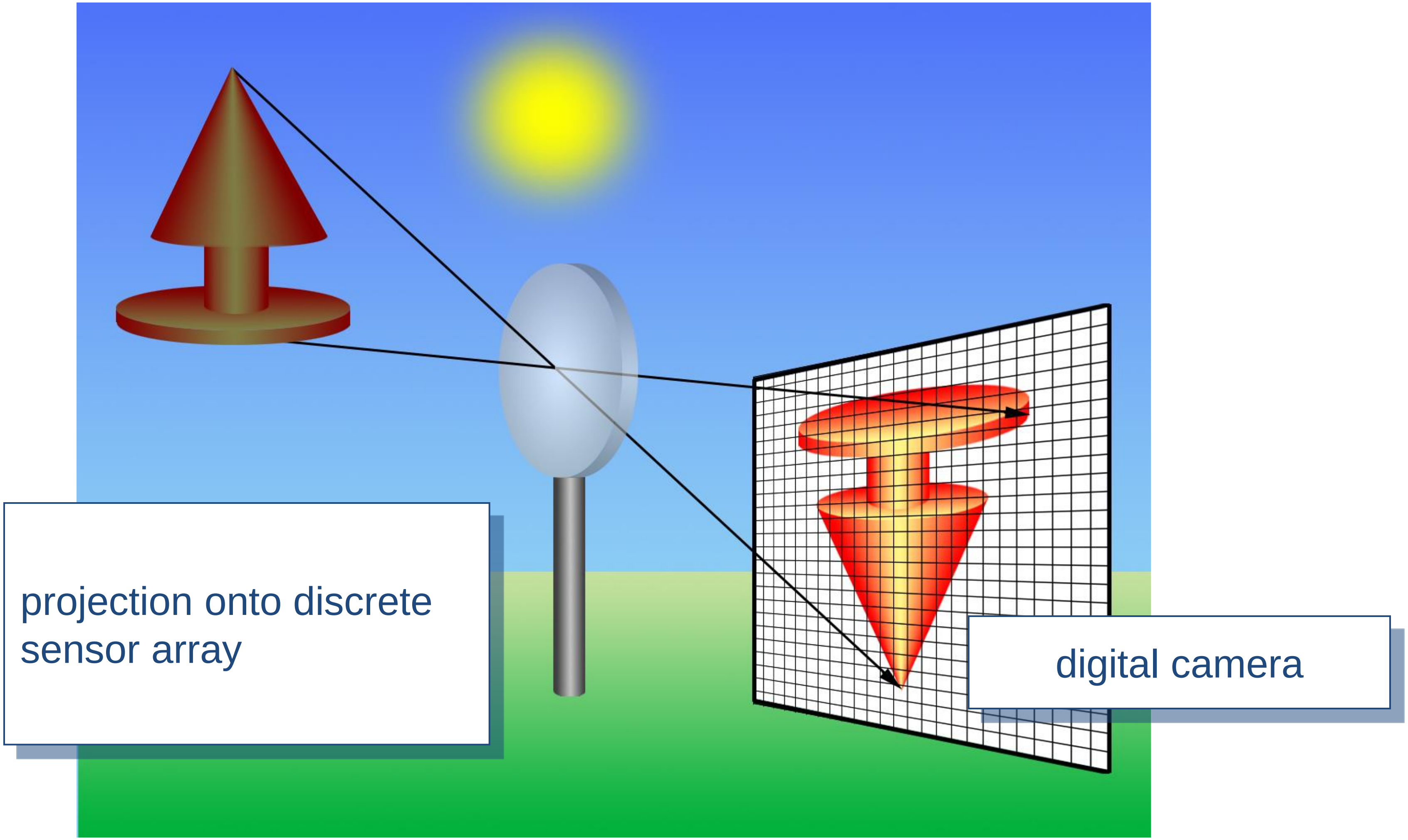


Image Formation

- Digital Image is an approximation of a real world scene

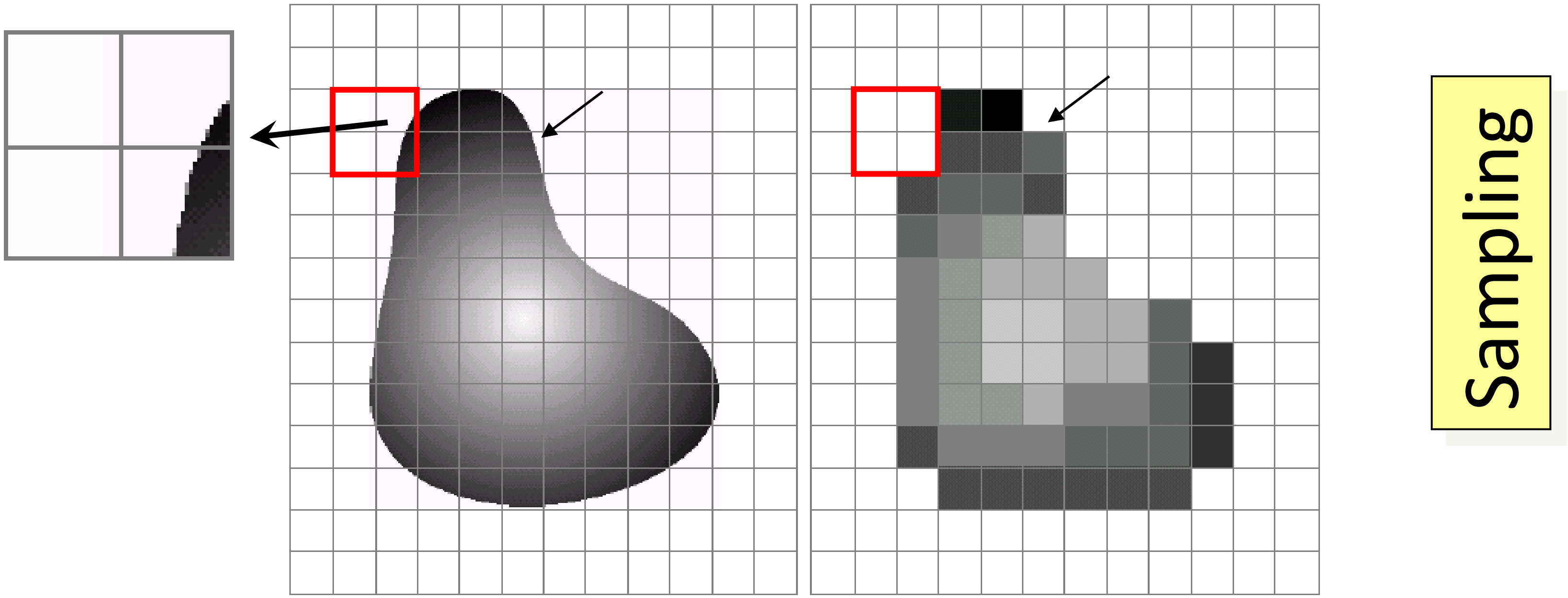


Image Formation

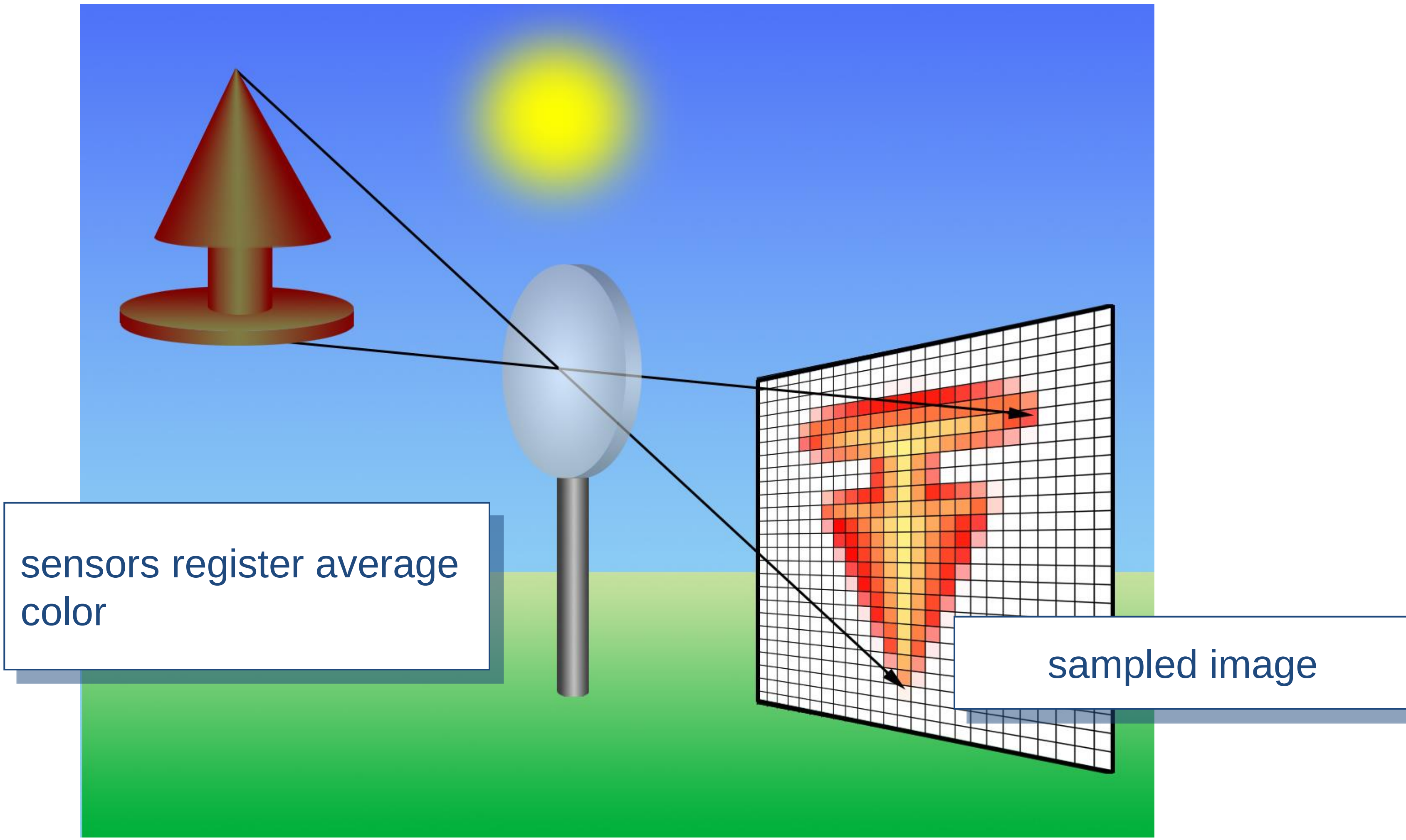


Image Formation

- Digital Image is an approximation of a real world scene

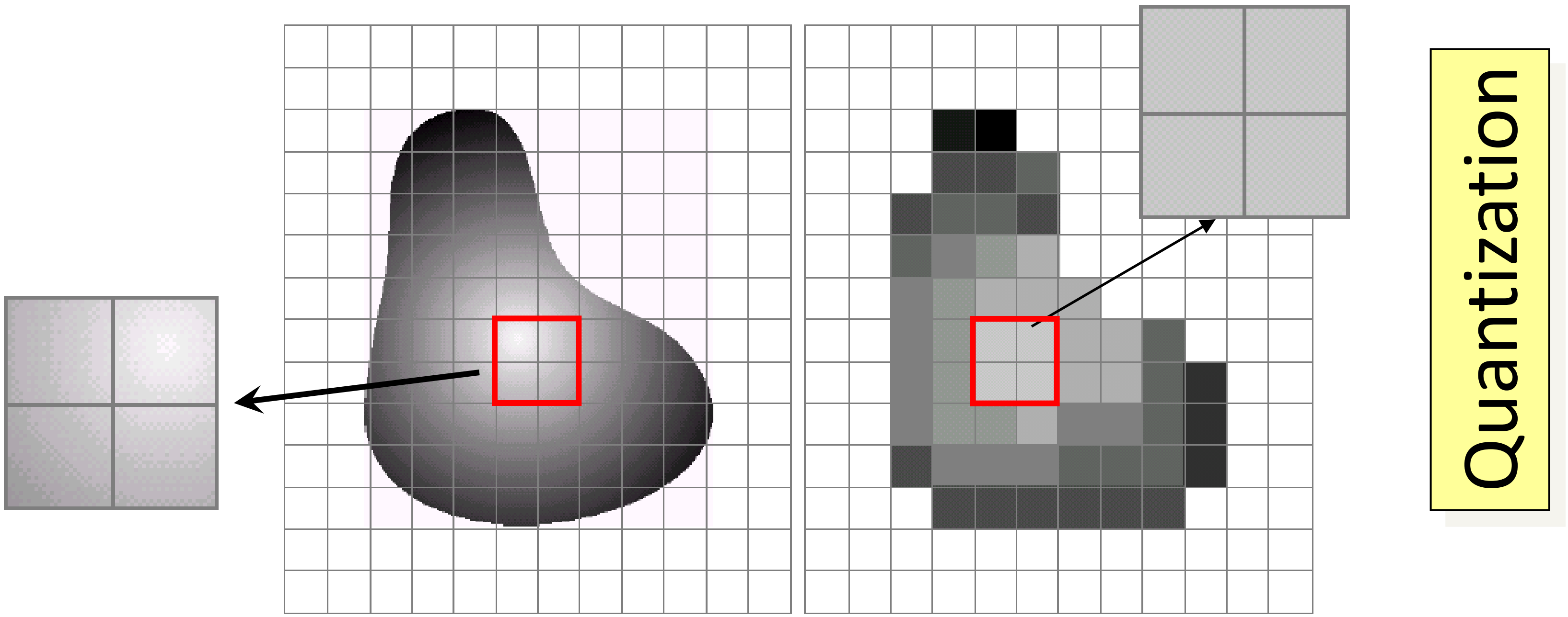
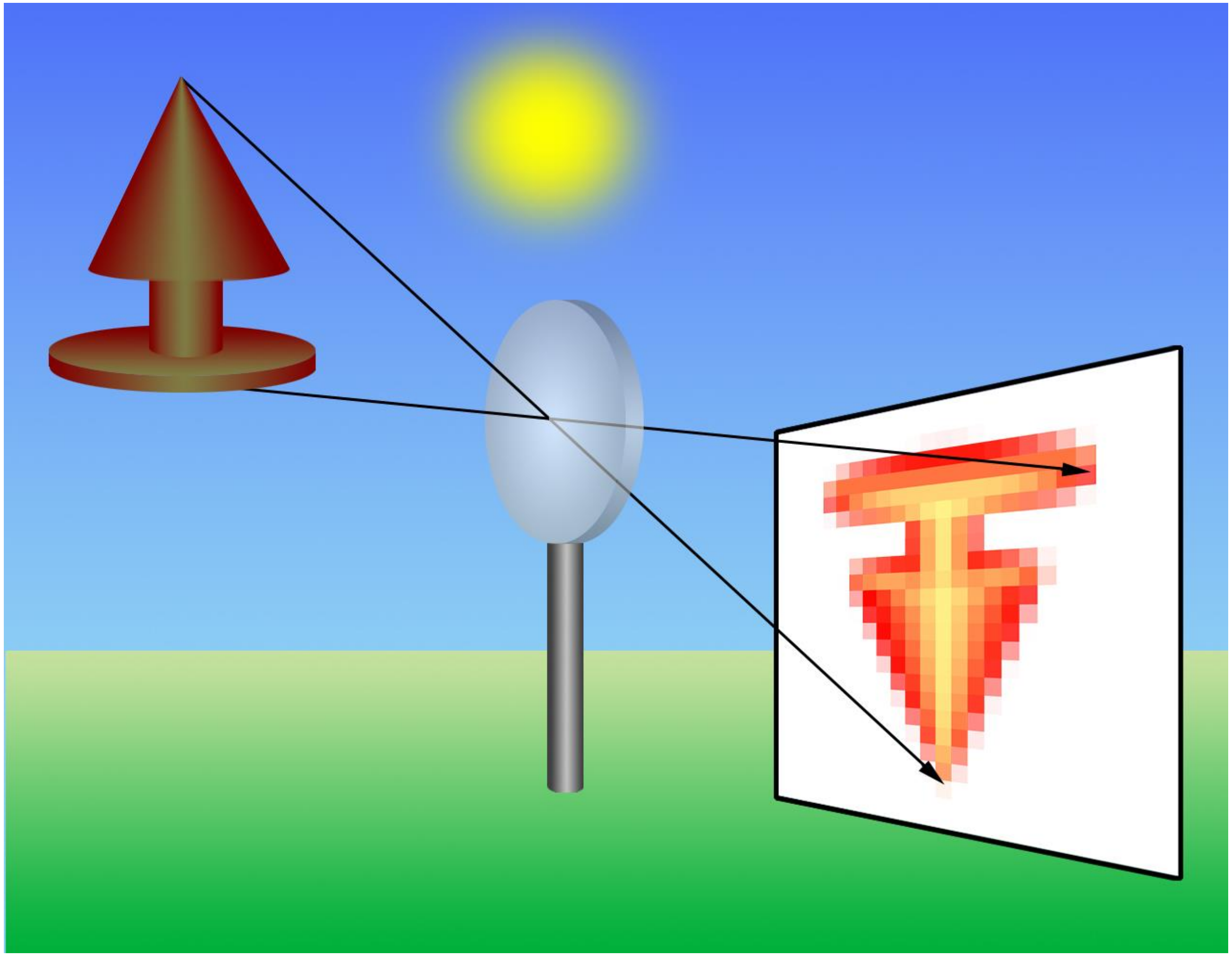
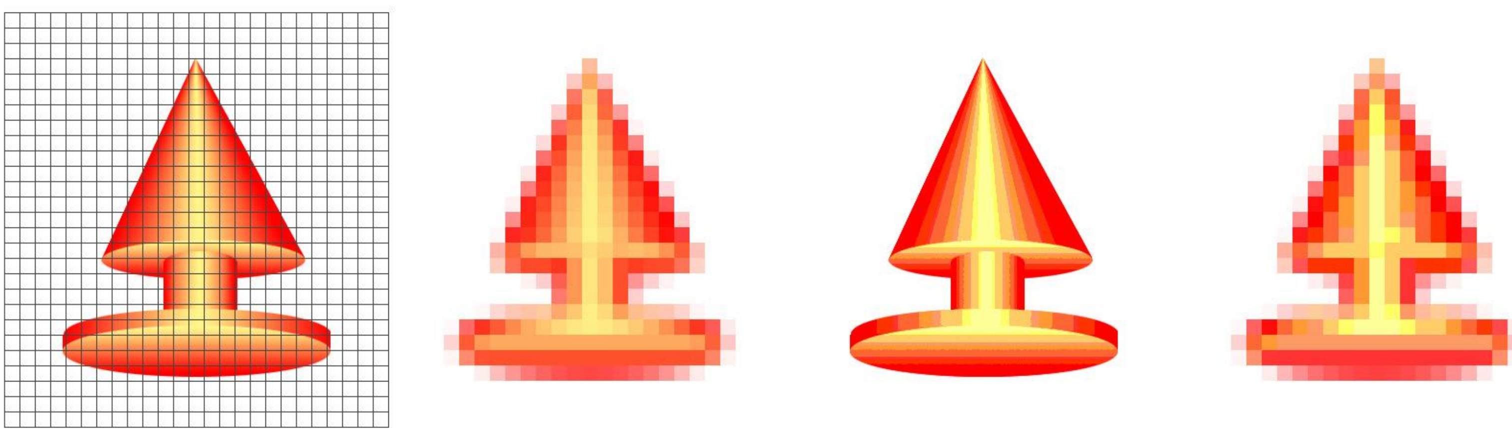


Image Formation



Sampling and Quantization



real image | sampled | quantized | sampled & quantized

Quantization: Example

Return change using only these

Quantization: Example

For Rs. 2	Return 5
For Rs. 7	Return 5
For Rs. 9	Return 10
For Rs. 12	Return 10
For Rs. 23	Return 25
….	….

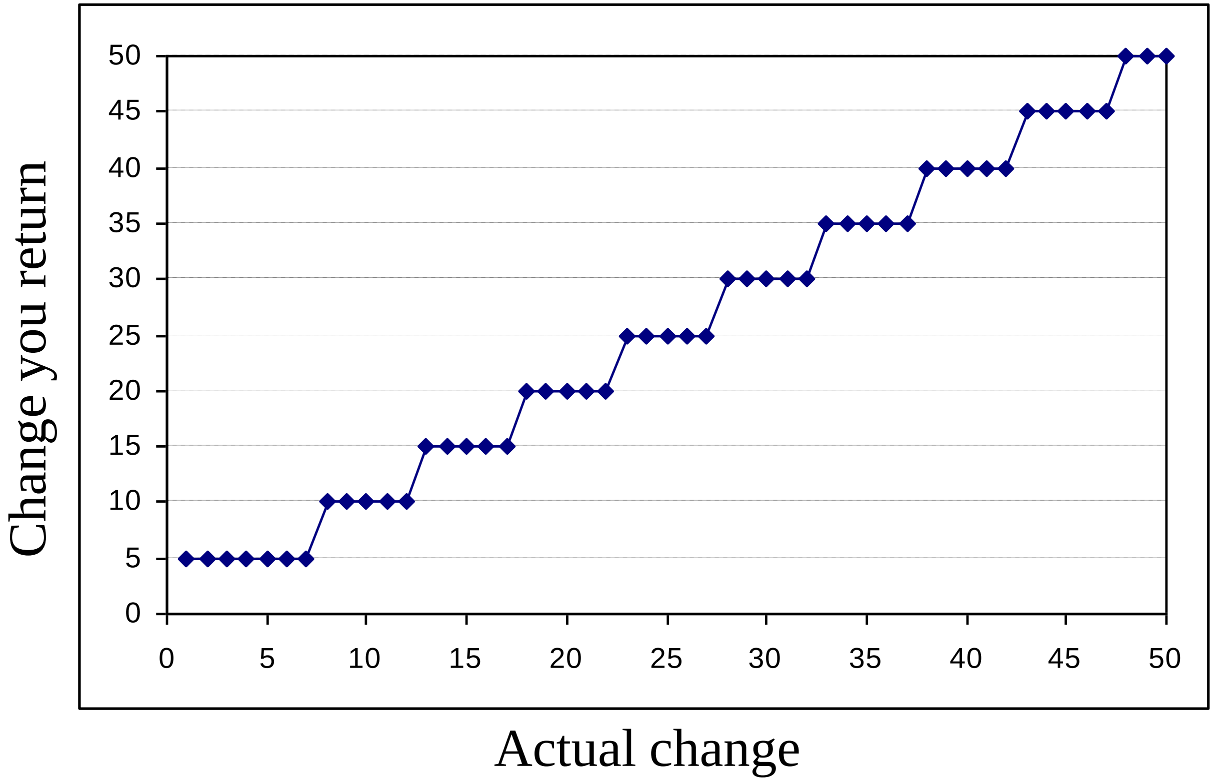
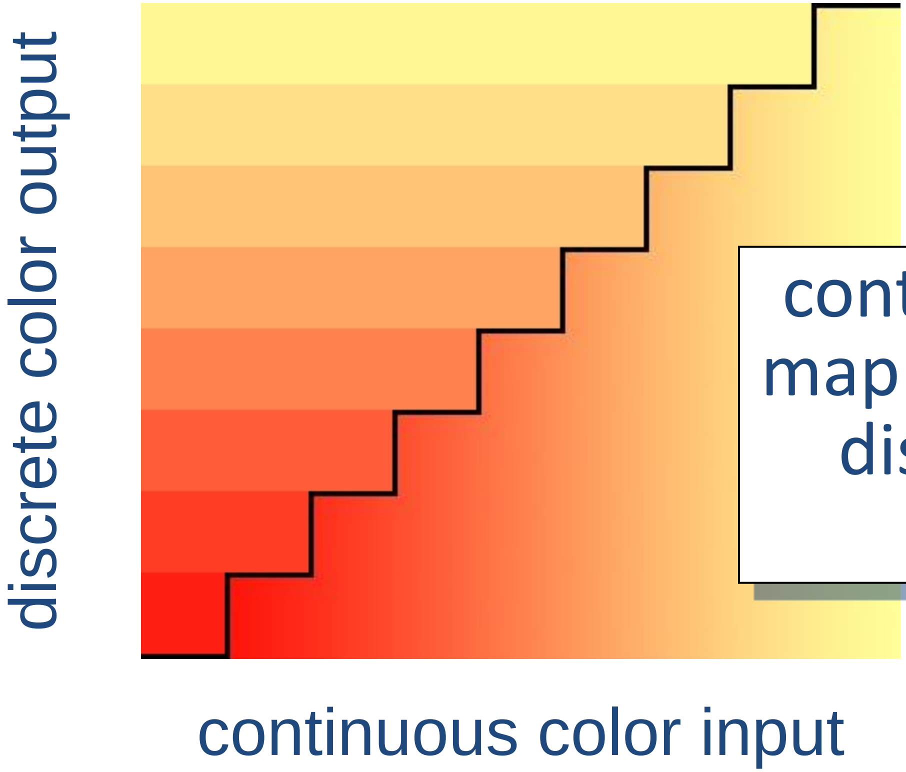
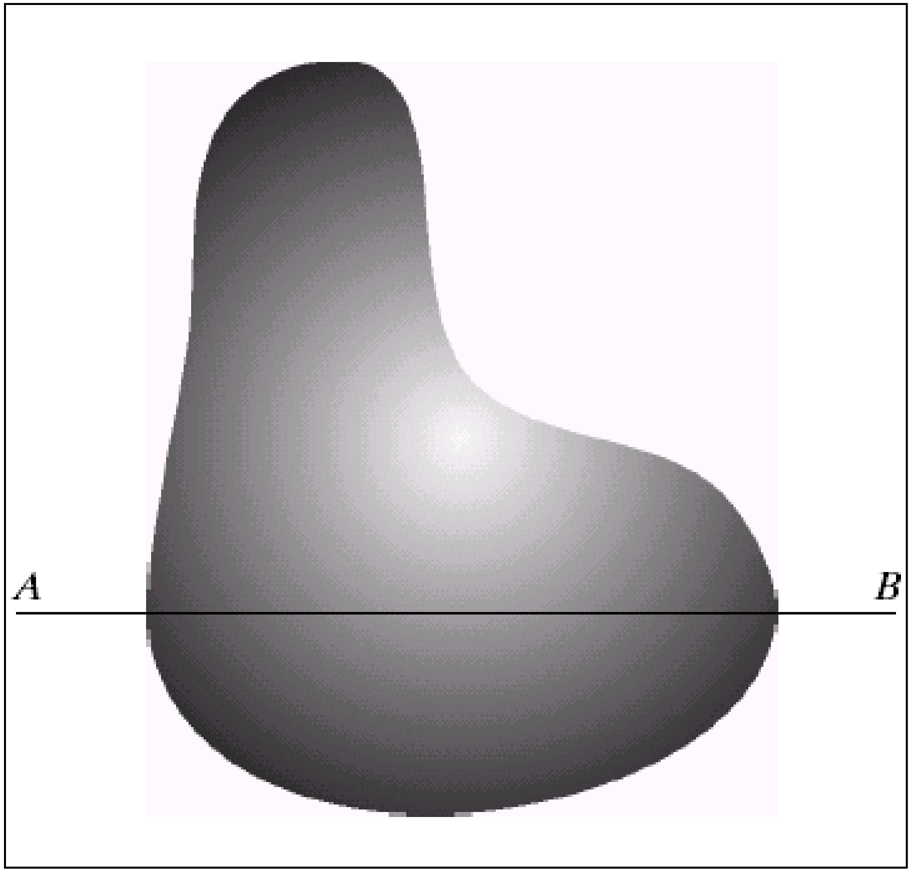


Image Formation - Quantization

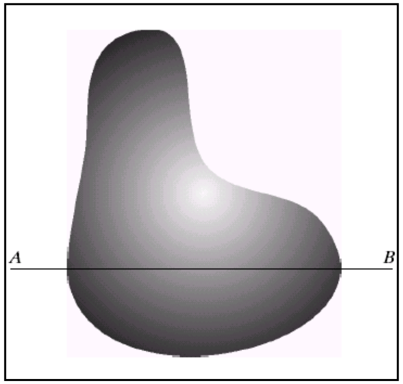


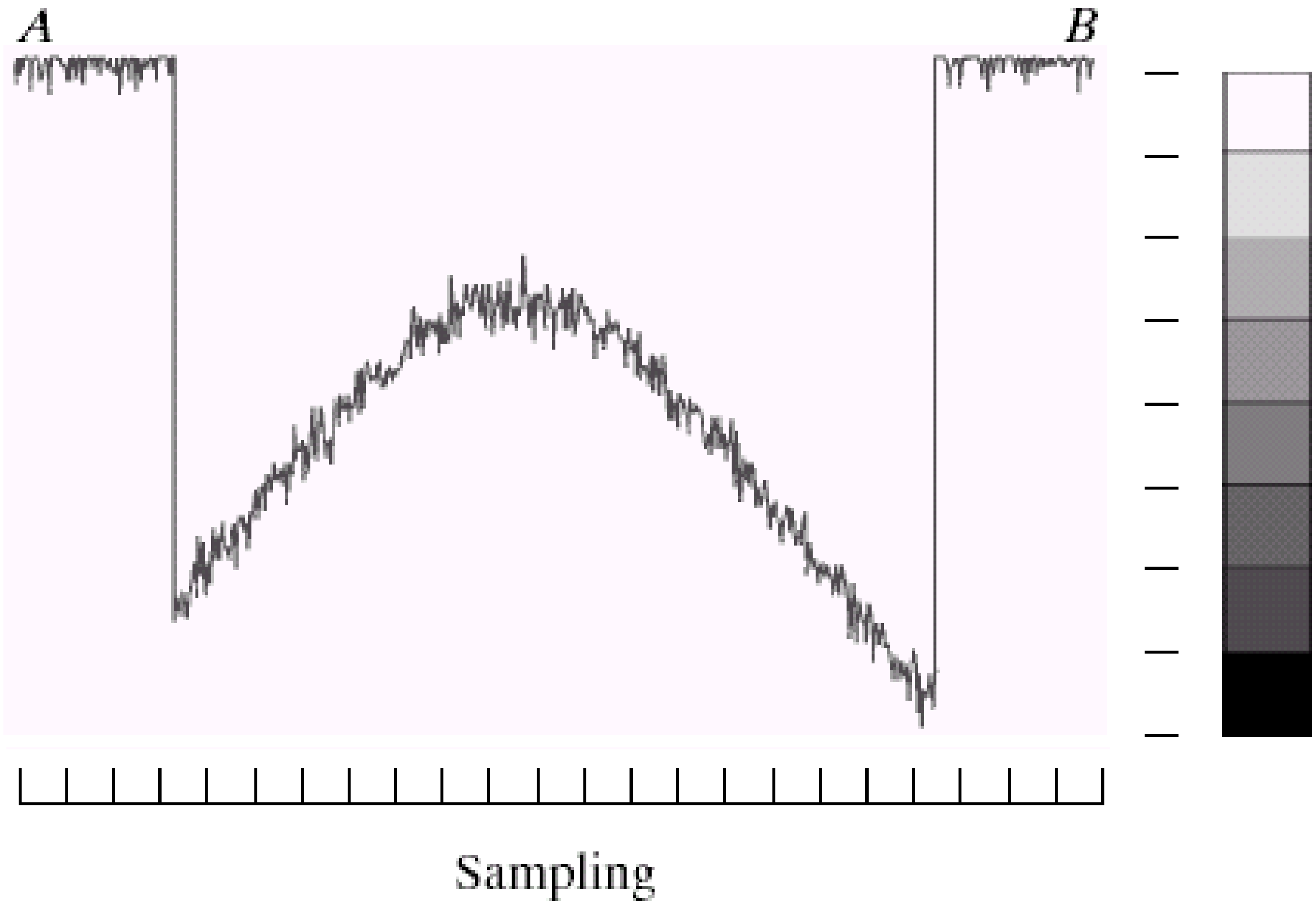
continuous colors mapped to a finite, discrete set of colors.

Sampling and Quantization

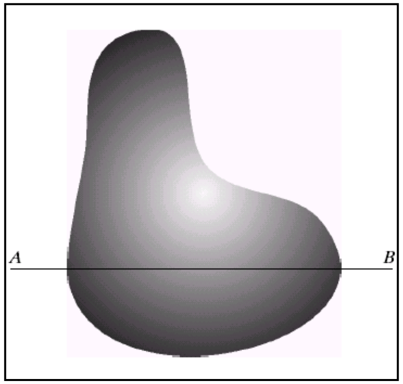


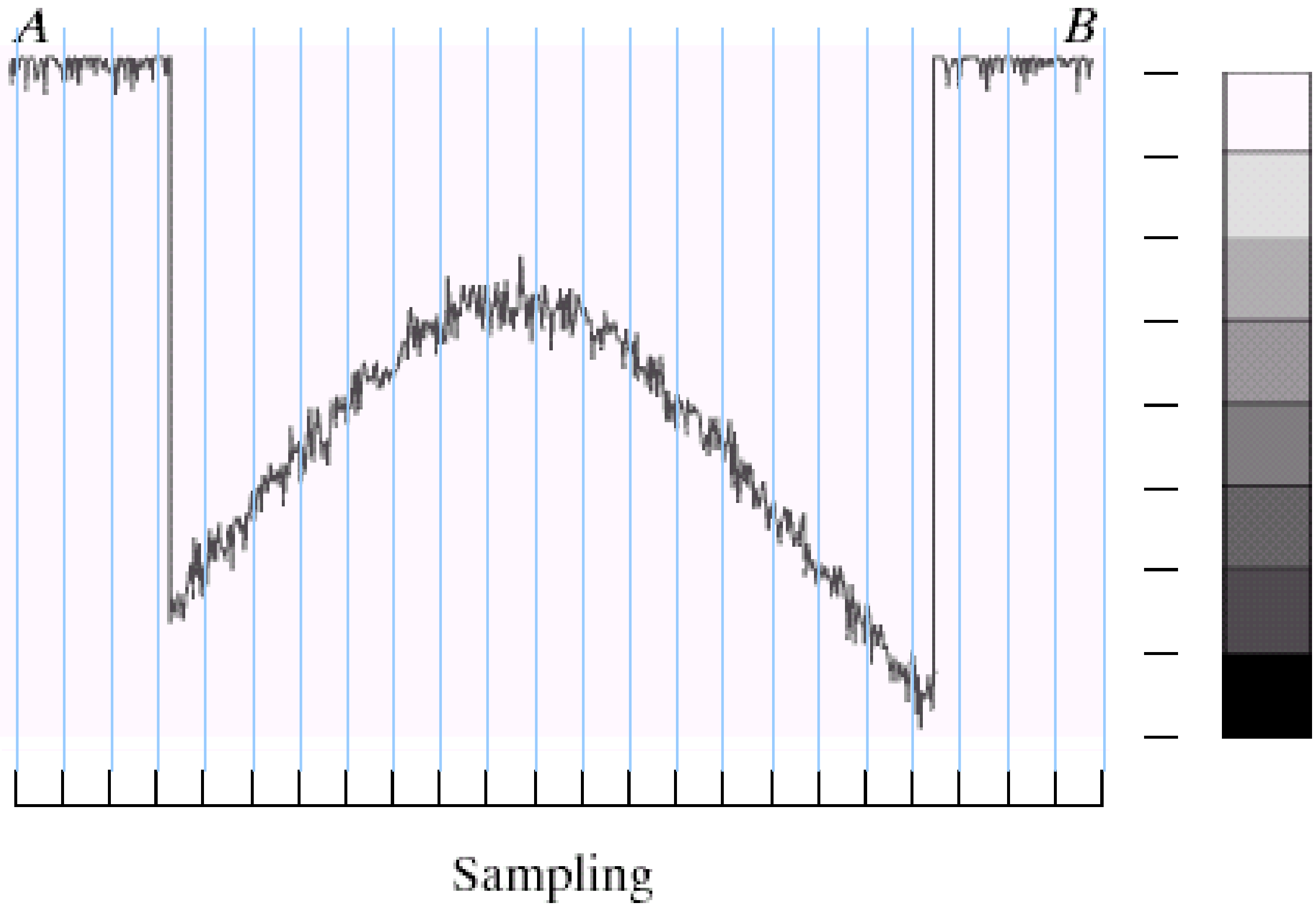
Sampling and Quantization





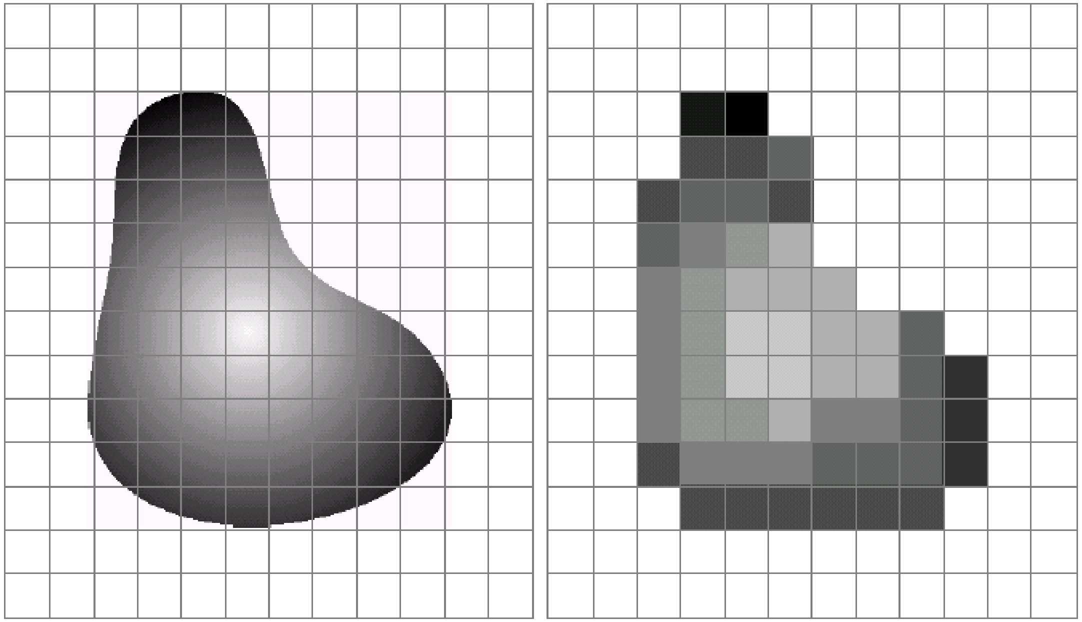
Sampling and Quantization





Sampling and Quantization

- Digital Image is an approximation of a real world scene



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, up to 4064 x 2704
    - Digital video cameras: 640x480 at 30 frames/second (fps)

Digital Image Representation

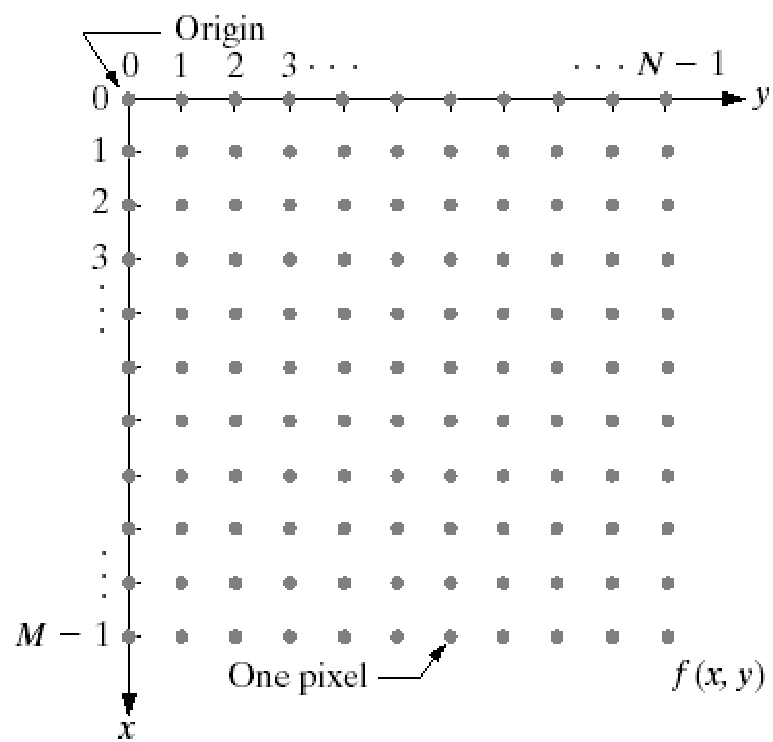
Columns →

Rows ↓

$$f(x,y)=\begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & \cdots & f(1,N-1) \\ \vdots & \vdots & & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1,N-1) \end{bmatrix}$$

N : No of Columns

M : No of Rows



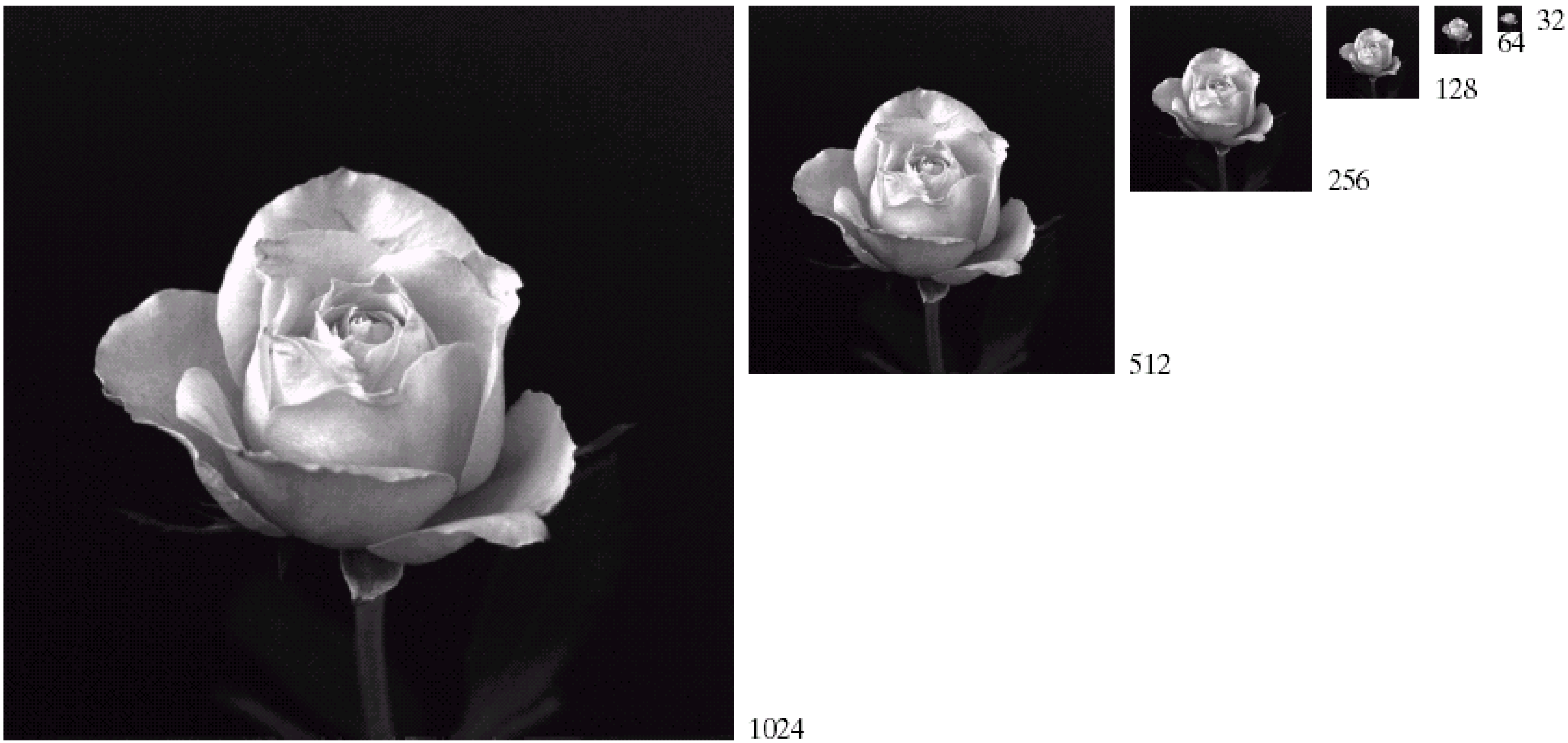
Digital Image Representation

- Image Size
  - Number of bits required to store an image

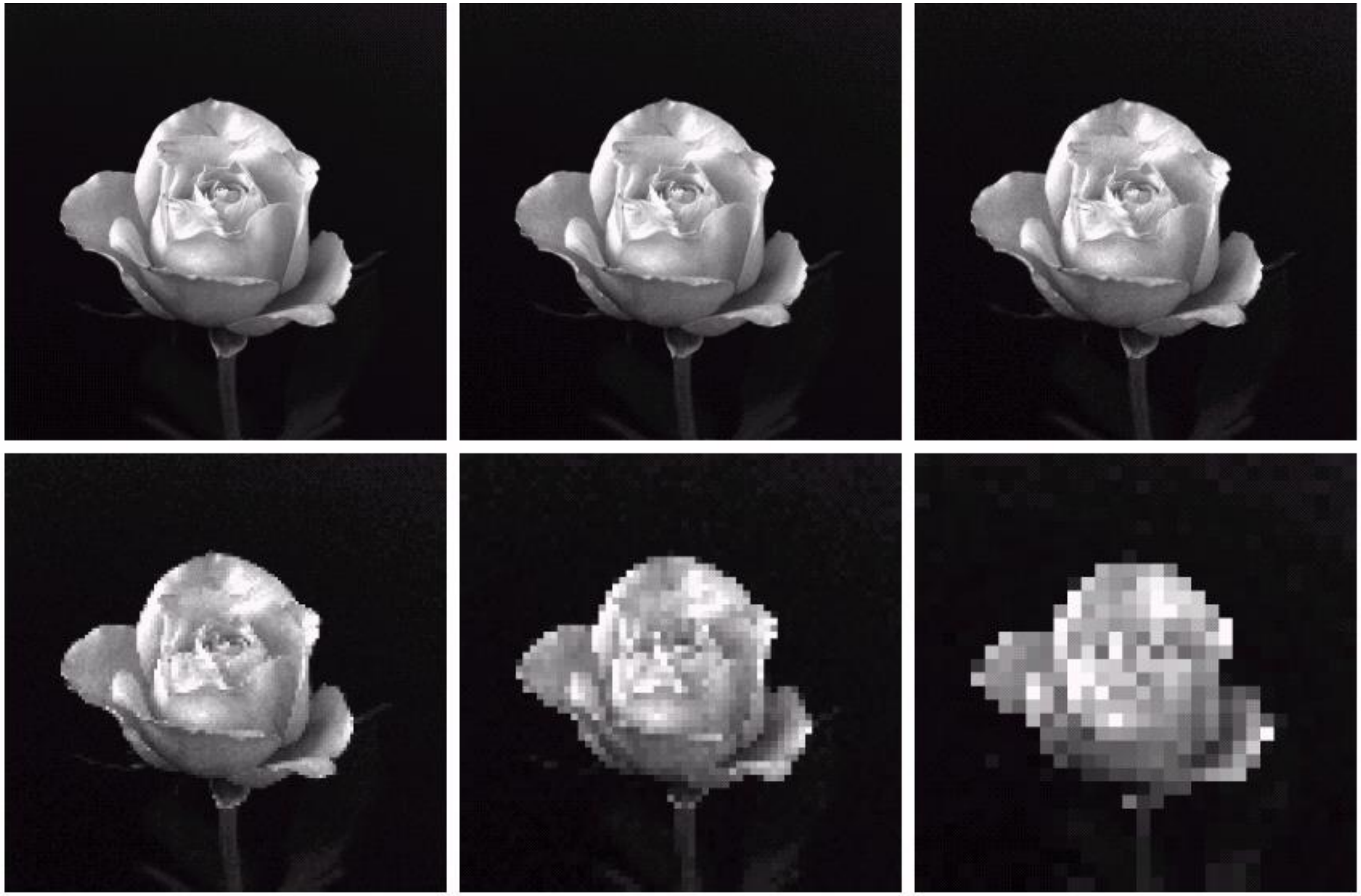
$$b = M \times N \times k$$

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

Spatial Resolution



Spatial Resolution



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

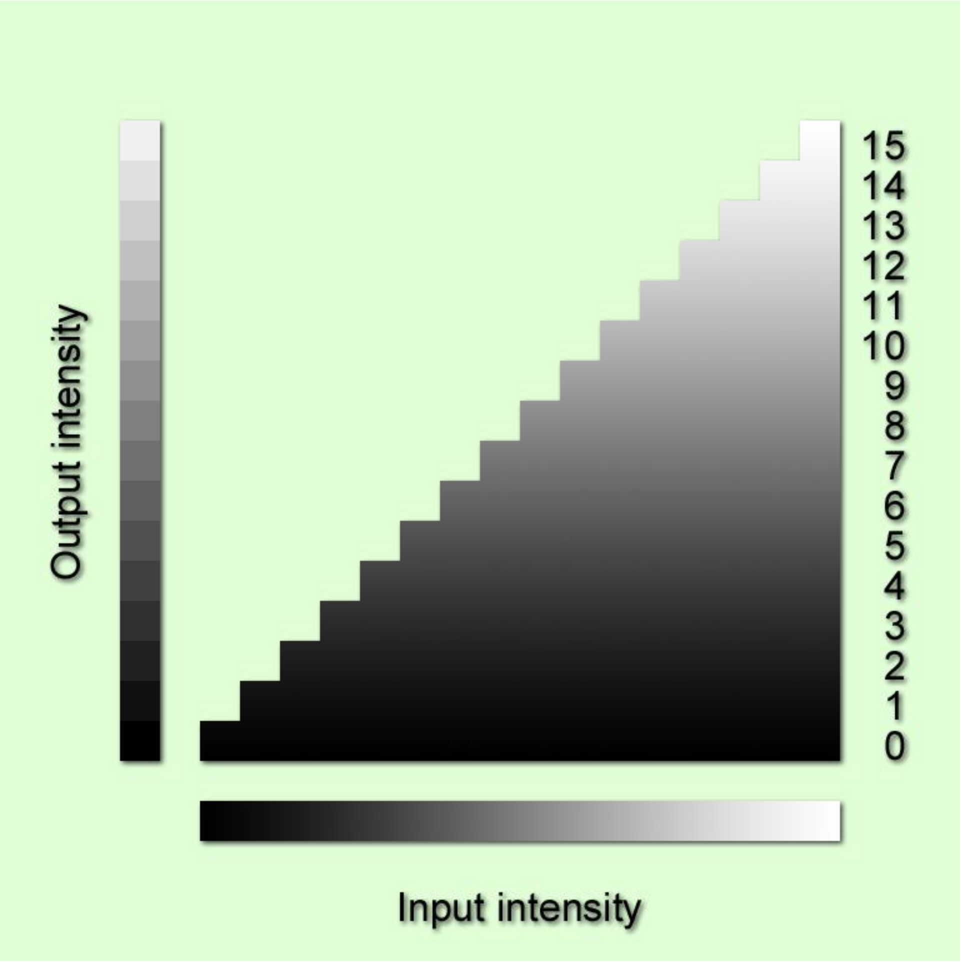
Intensity Level Resolution

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

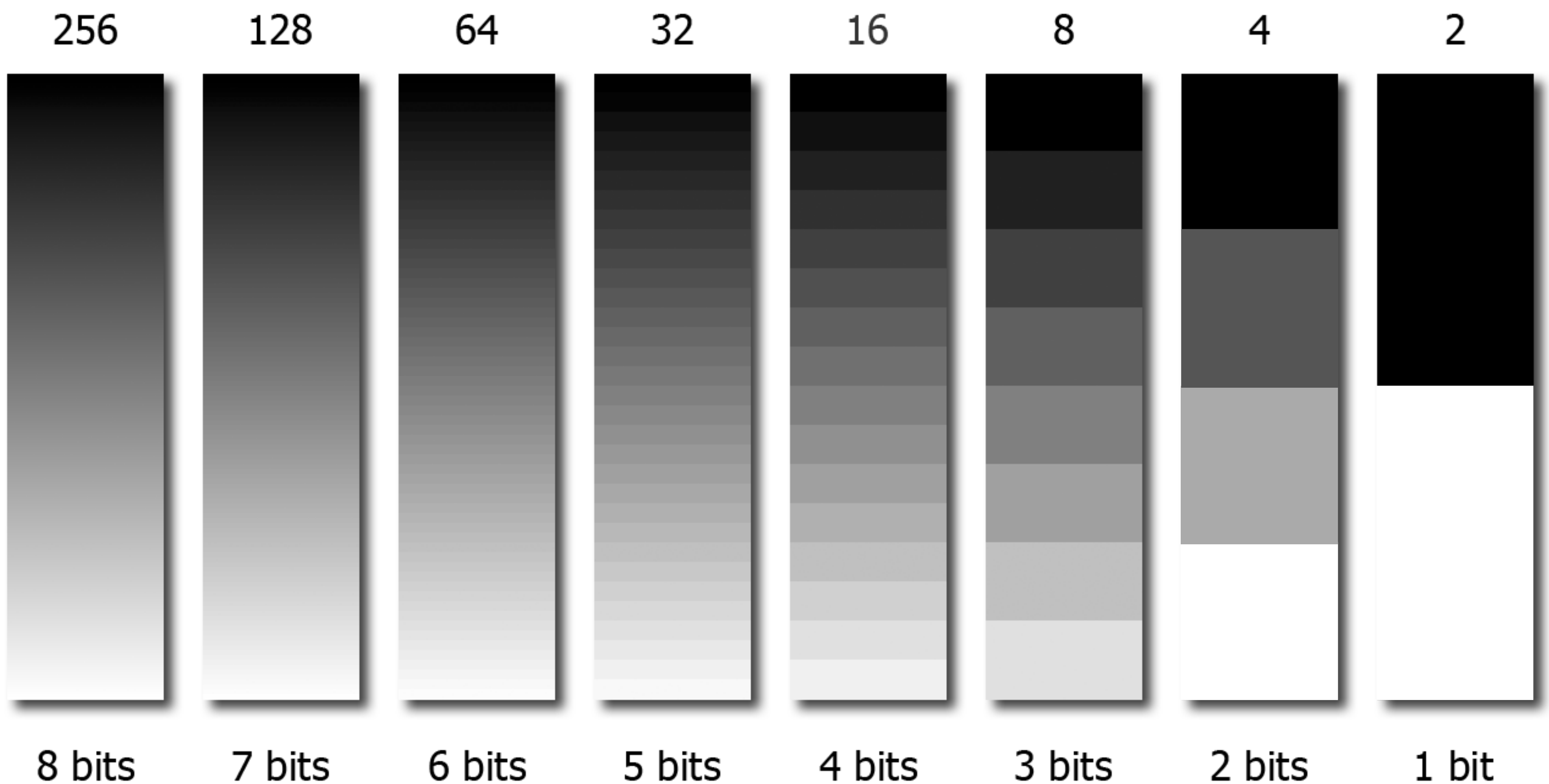
Intensity Level Resolution

16 million colors

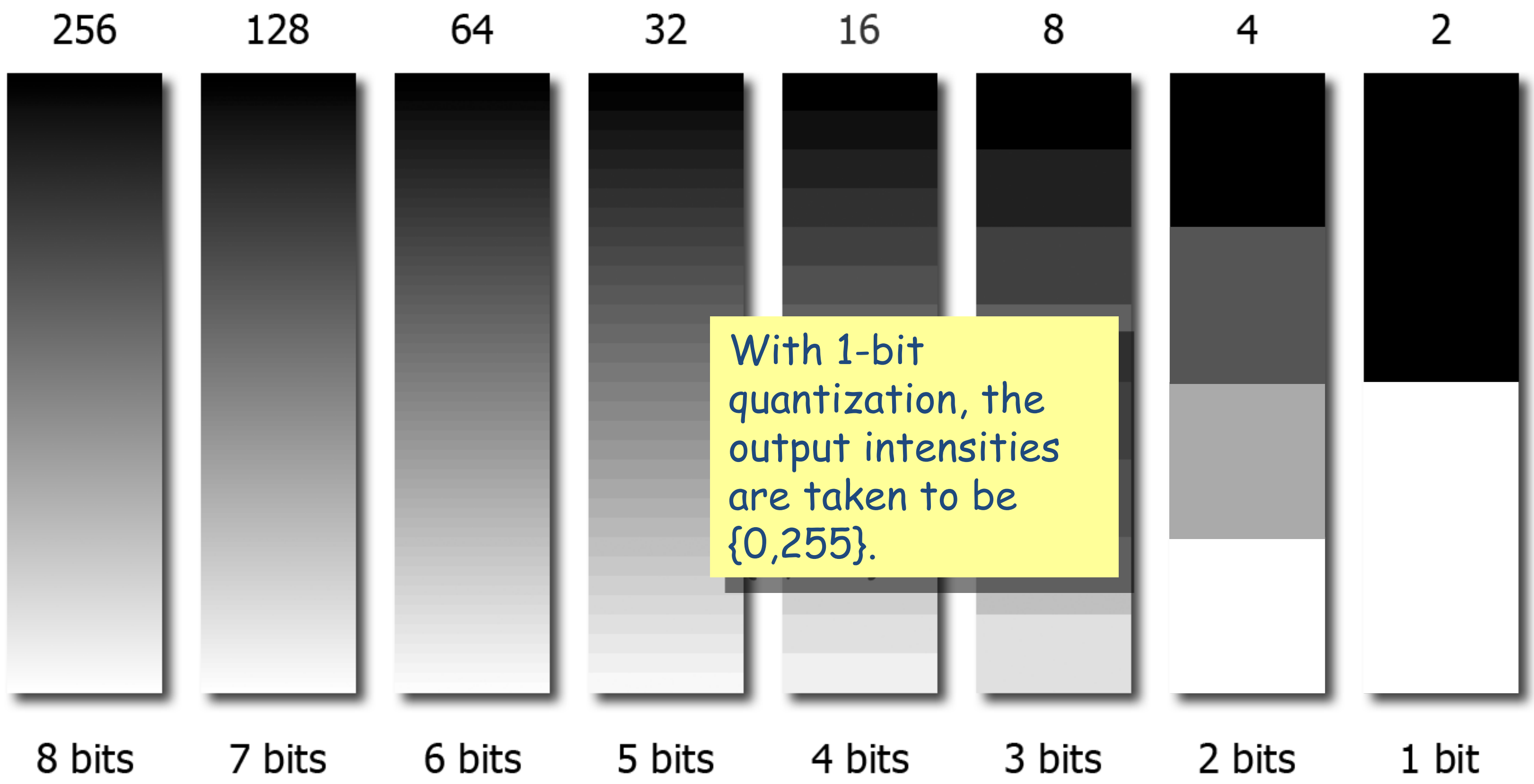
16 colors



Intensity Level Resolution



Intensity Level Resolution



Intensity Level Resolution

256 grey levels (8 bits per pixel)

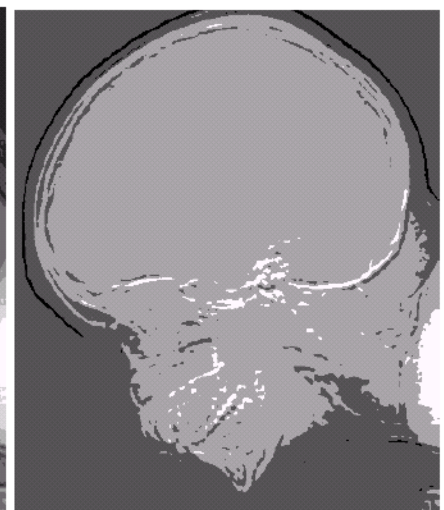
128 grey levels (7 bpp)

64 grey levels (6 bpp)

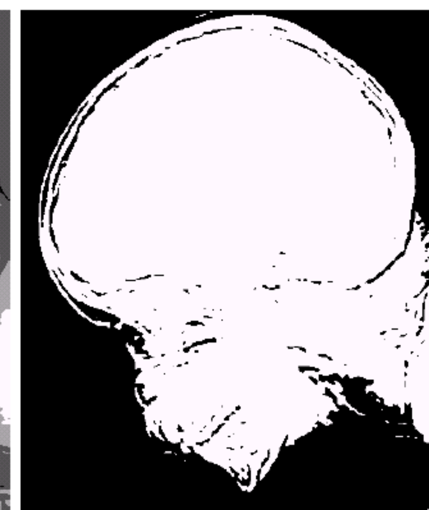
32 grey levels (5 bpp)

16 grey levels (4 bpp)

8 grey levels (3 bpp)



4 grey levels (2 bpp)



2 grey levels (1 bpp)

Intensity Level Resolution

8 bits 256 levels

7 bits 128 levels

6 bits 64 levels

5 bits 32 levels

4 bits 16 levels

3 bits 8 levels

2 bits 4 levels

1 bit 2 levels

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

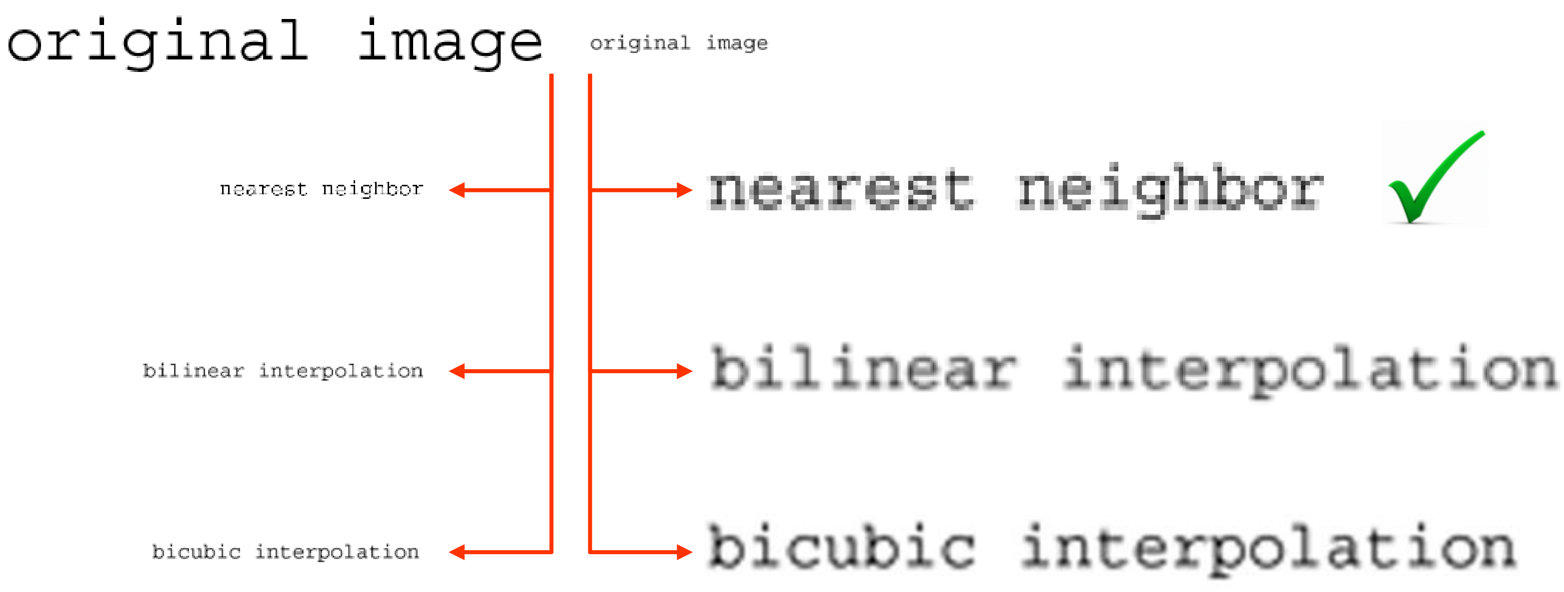
Resolution: How much is enough?

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

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

Image Interpolation

- Image resizing
- Three methods



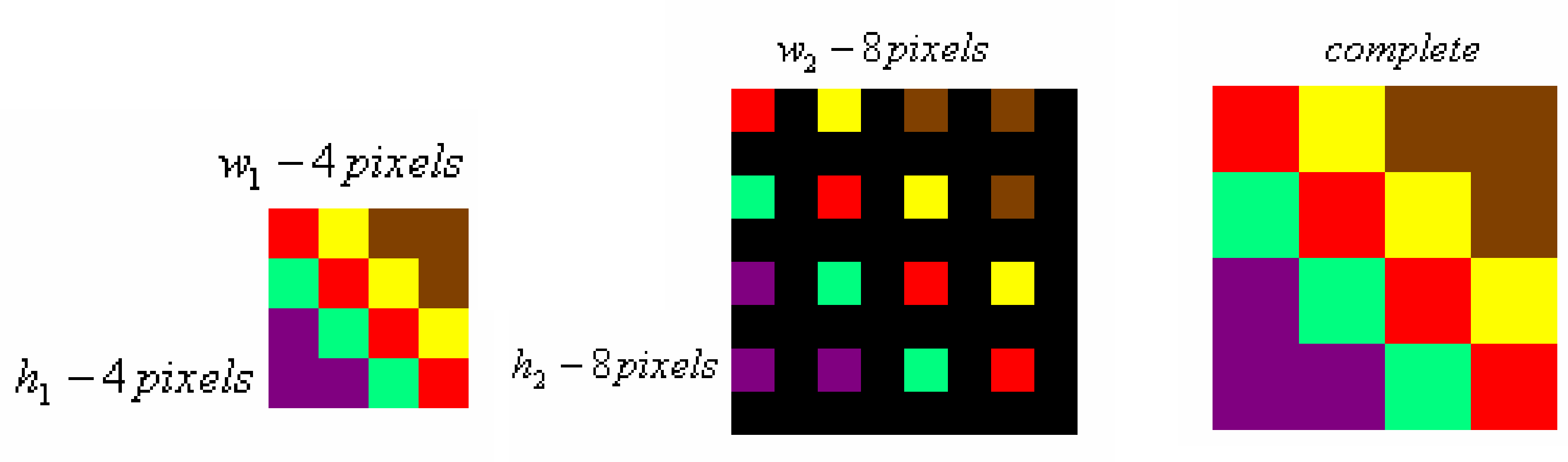
Enlarging an Image

- Pixel replication

[1 2 3 4 5]

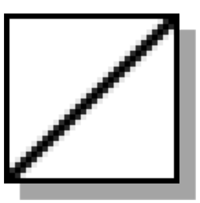
[1 1 2 2 3 3 4 4 5 5]   (One step)

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

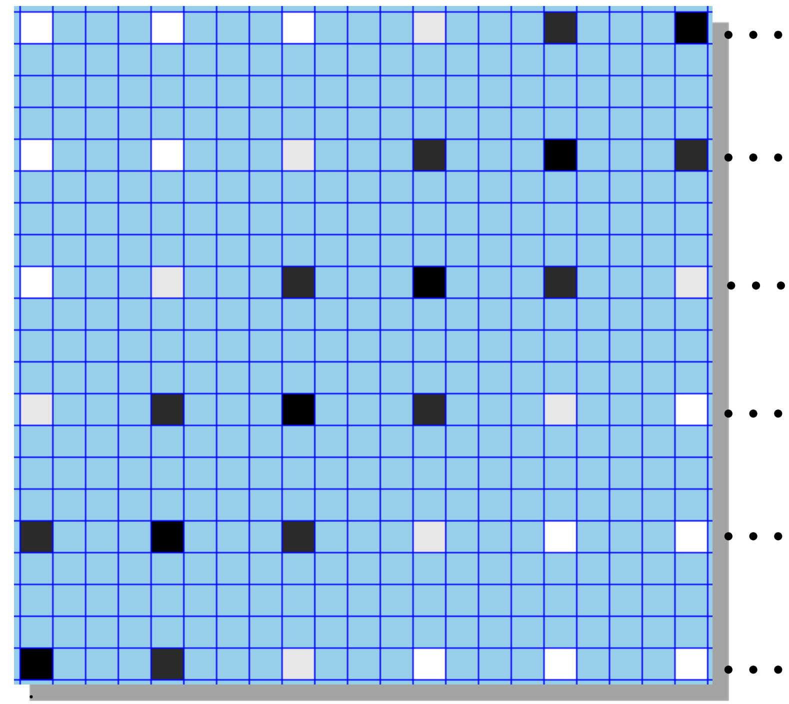


Enlarging an Image

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

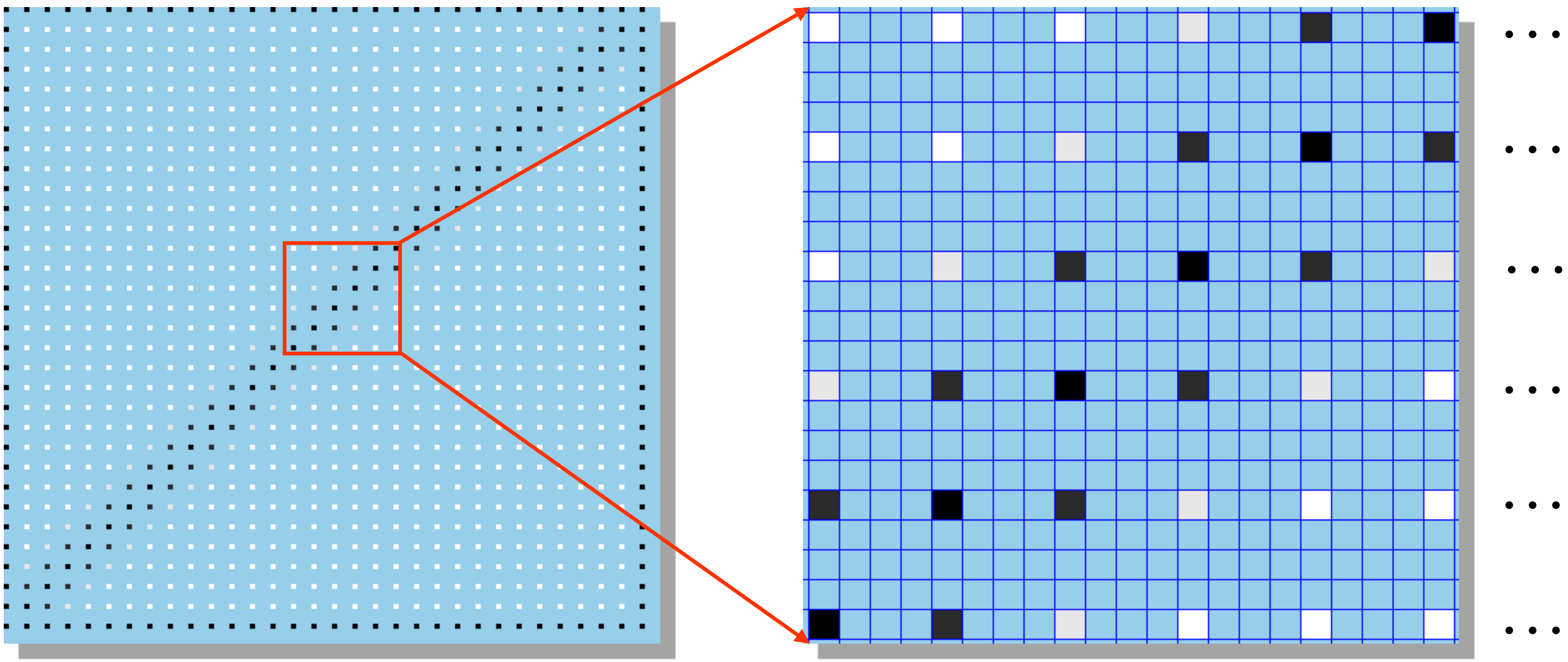


Start with a blank image 4 times the linear dimensions of the original.



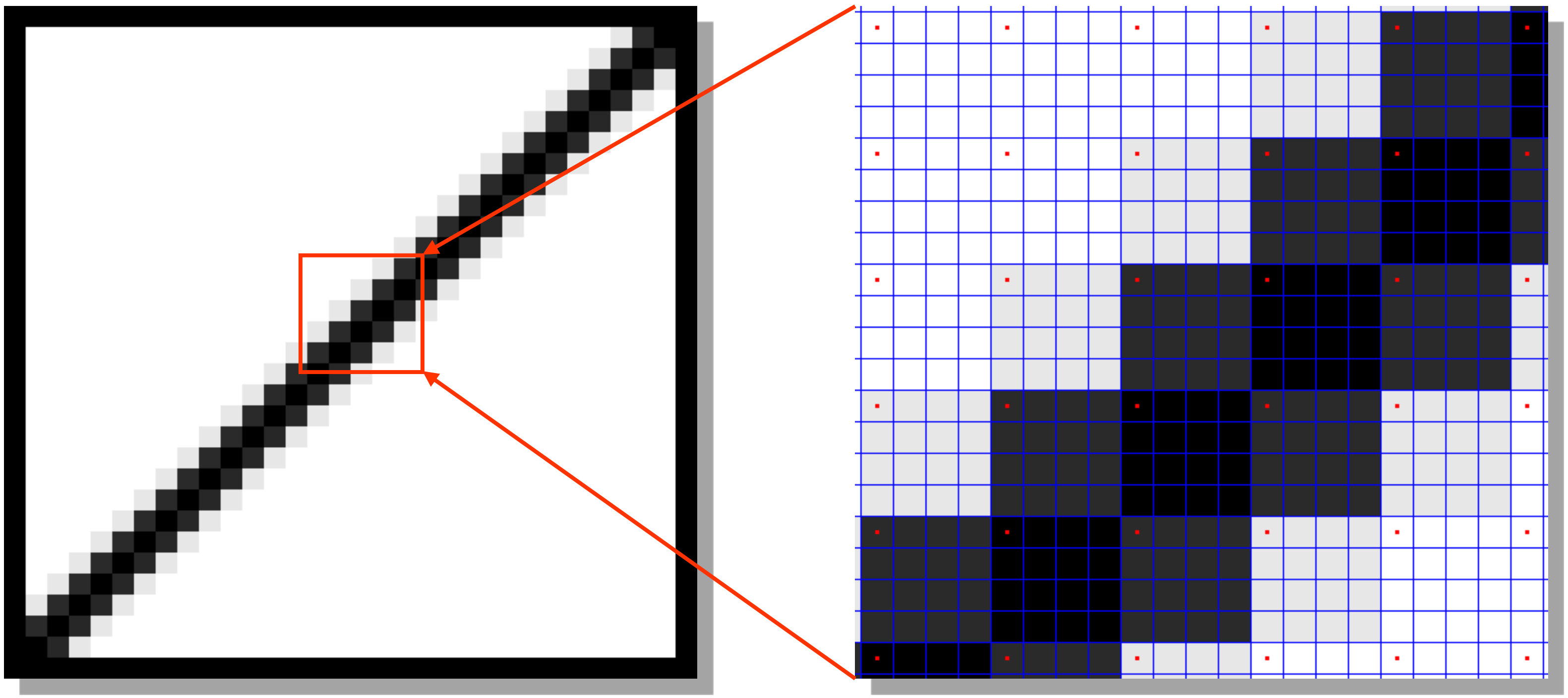
Fill in every 4th pixel in every 4th row with the original pixel values.

Enlarging an Image



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

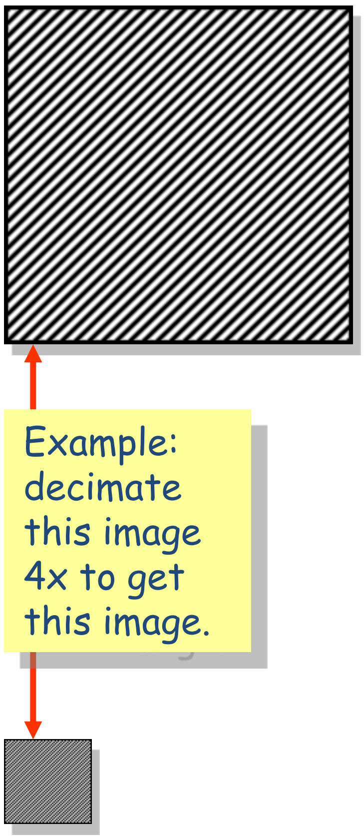
Enlarging an Image



Replicate the values

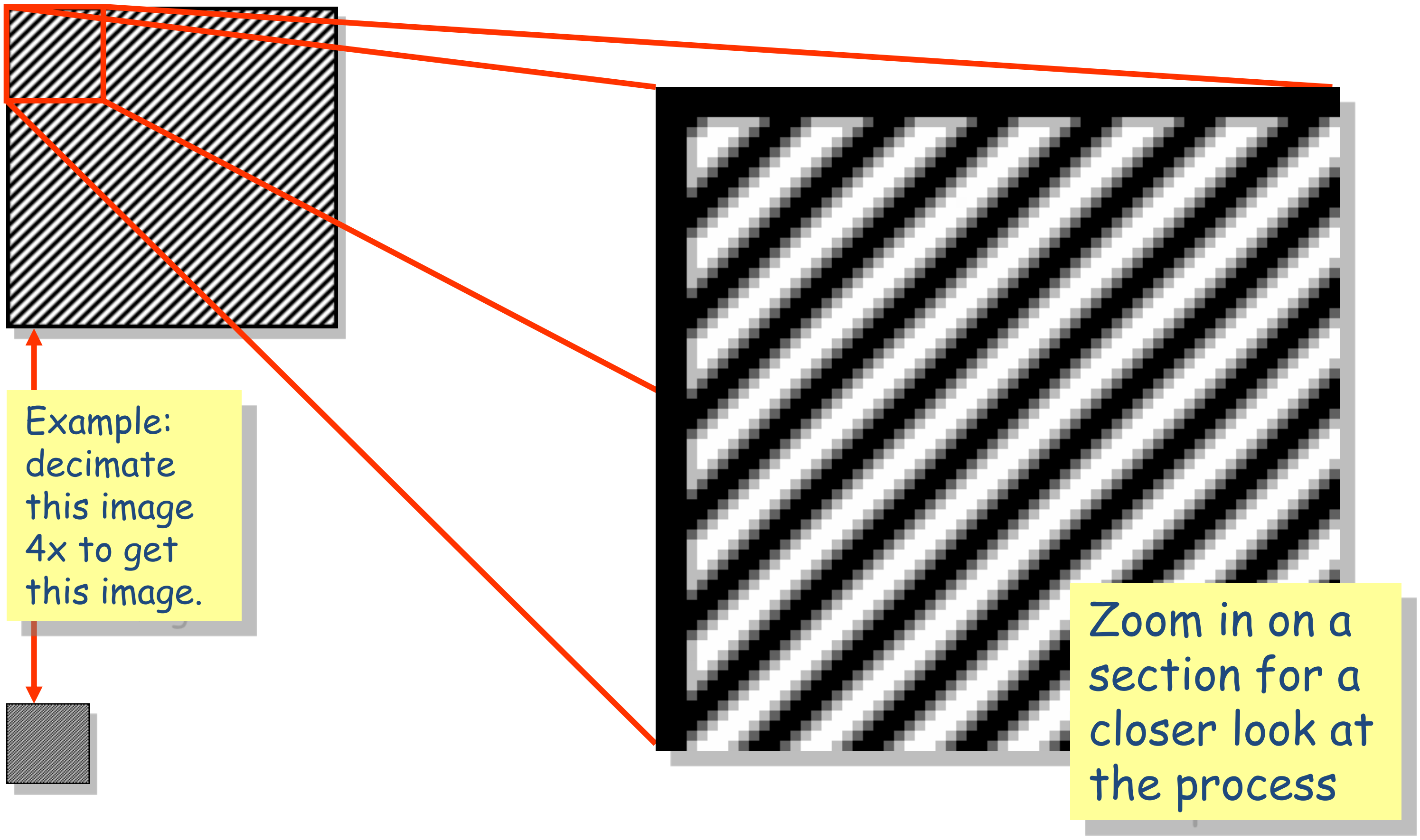
Reducing an Image

- Pixel Decimation

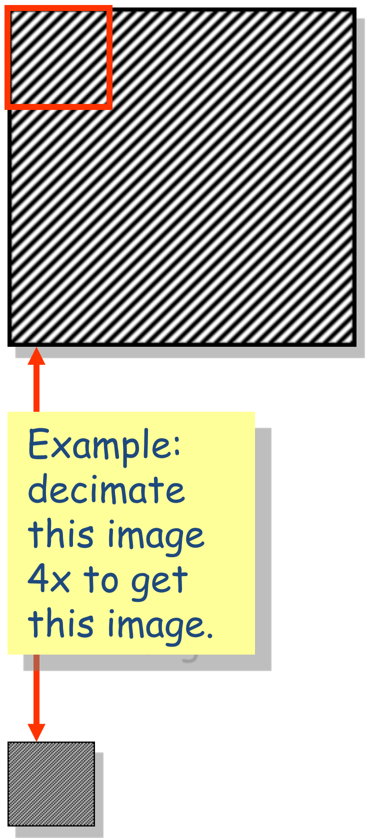


Decimation by a factor of *n*: take every *n*th pixel in every *n*th row

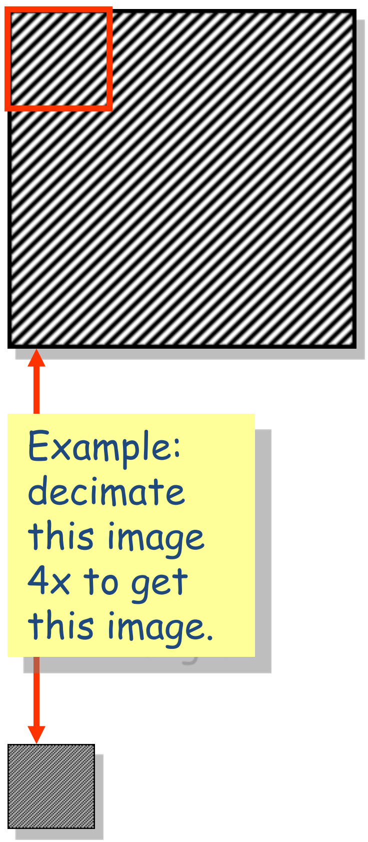
Reducing an Image

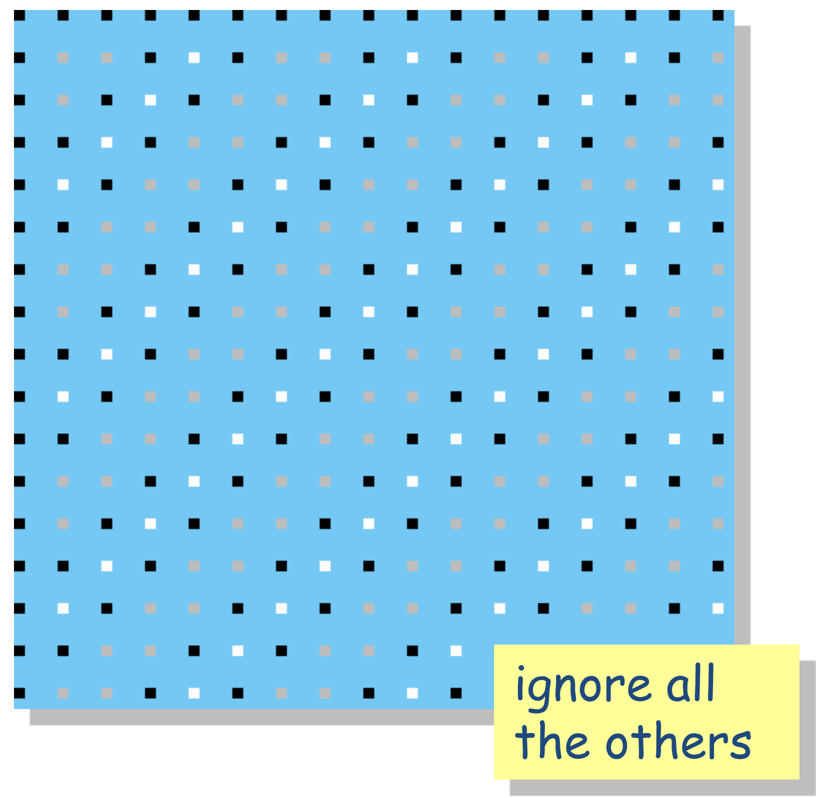


Reducing an Image

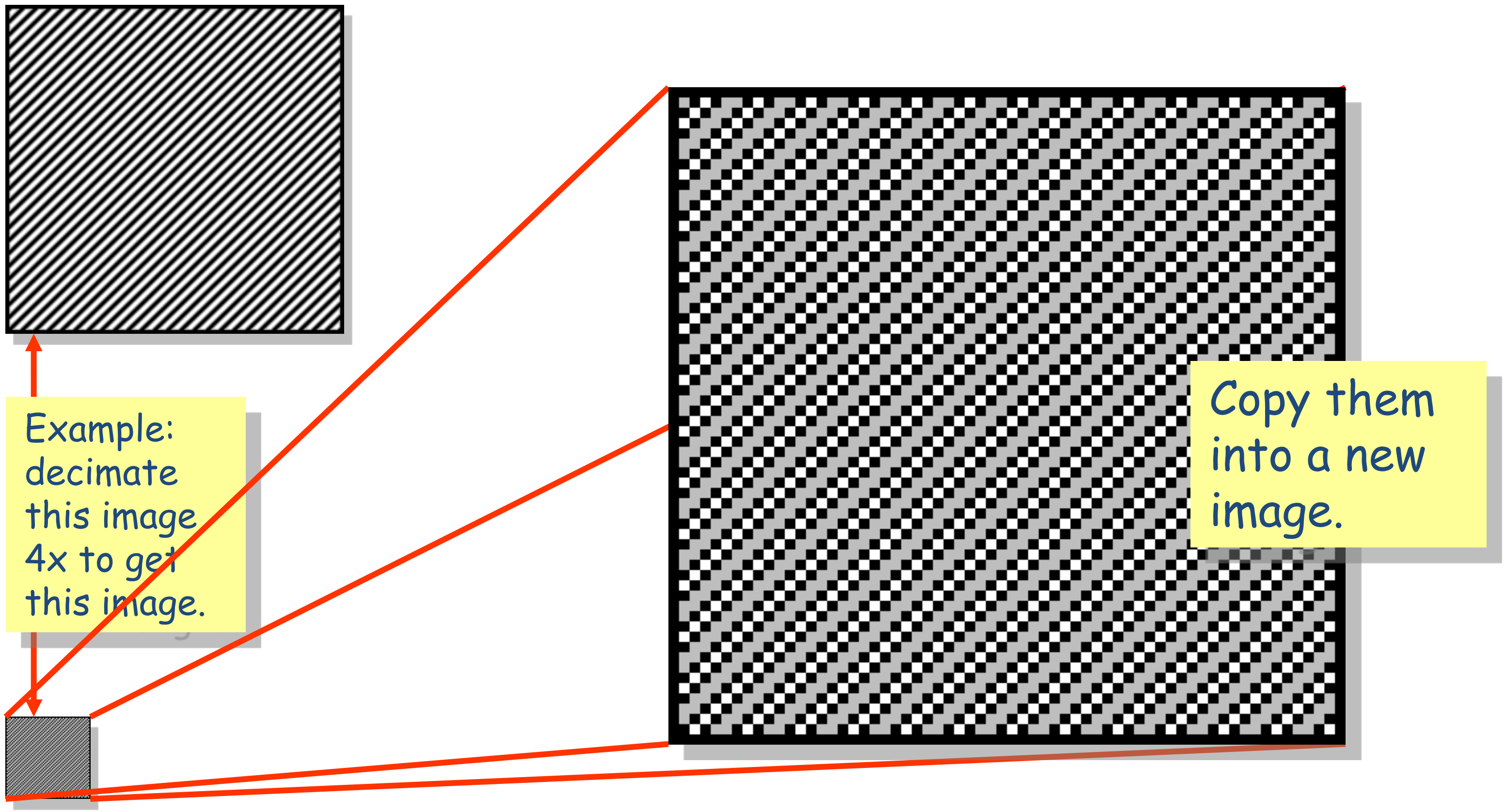


Reducing an Image





Reducing an Image



Nearest Neighbor Interpolation

The "Nearest Neighbor" algorithm is a generalization of pixel replication and decimation.

It also includes fractional resizing, *i.e.* resizing an image so that it has p/q of the pixels per row and p/q of the rows in the original. (p and q are both integers.)

Image Interpolation

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

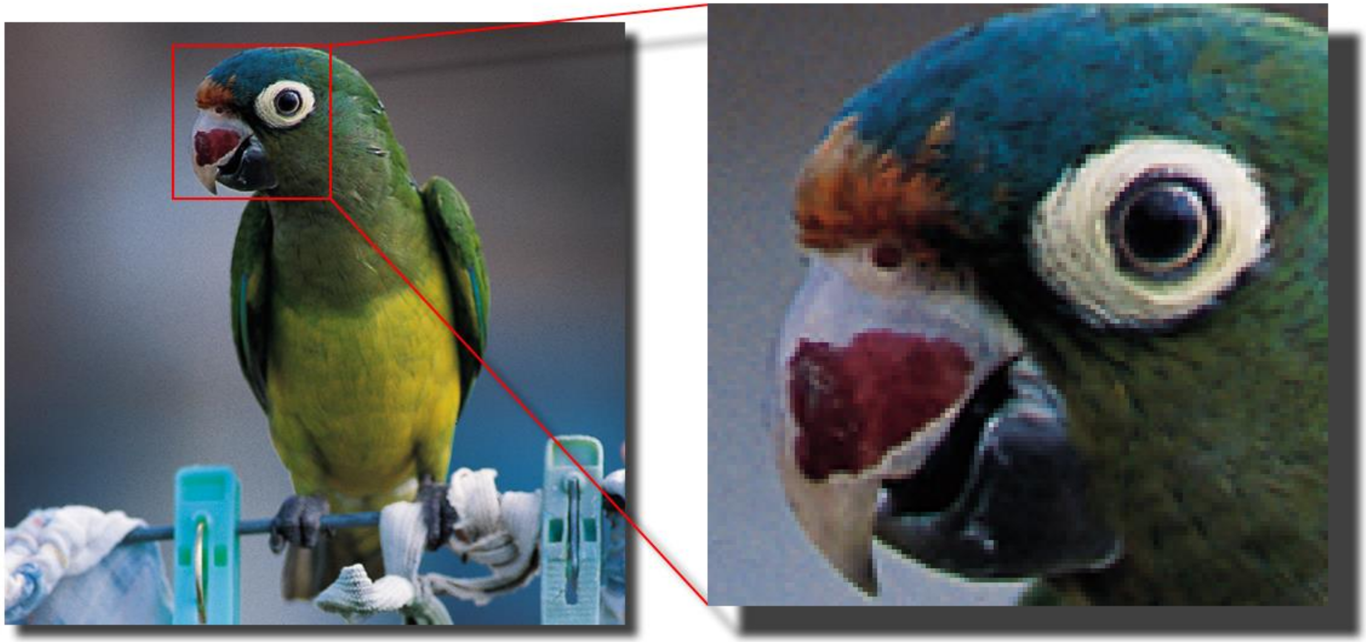
Interpolation: Comparison

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

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

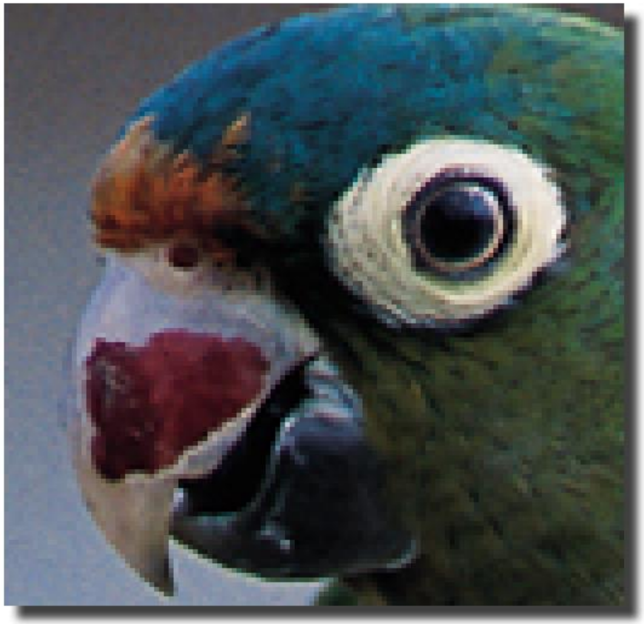
Interpolation: Comparison

Original Image



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

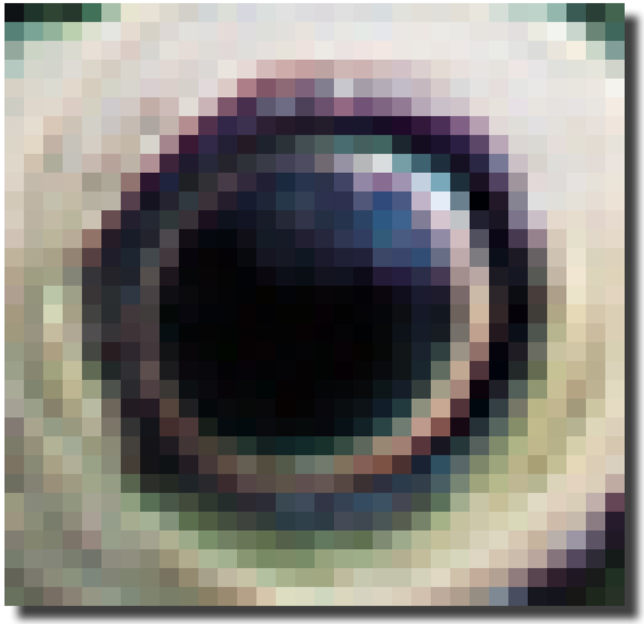
Interpolation: Comparison



Pixel replication

Bilinear interpolation

Interpolation: Comparison



Pixel replication

Bilinear interpolation

Acknowledgements

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

- 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