# Digital Image Processing

**Week-01**

# Contents

- Course Introduction
- Image Processing Examples
- Image Formation
- Digitization of Images
- Image Resolution

# Intro & Affiliations

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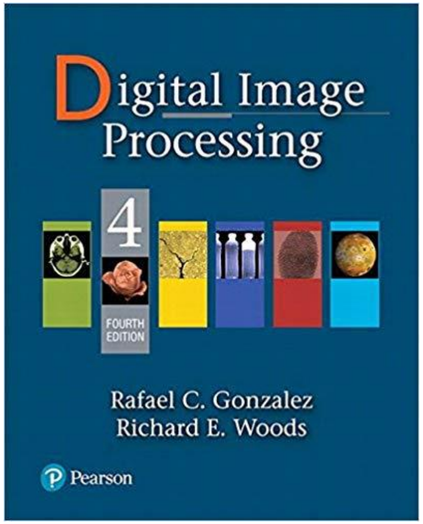
BIOMISA
BIOmetrics, Medical Image and Signal Analysis Research Group

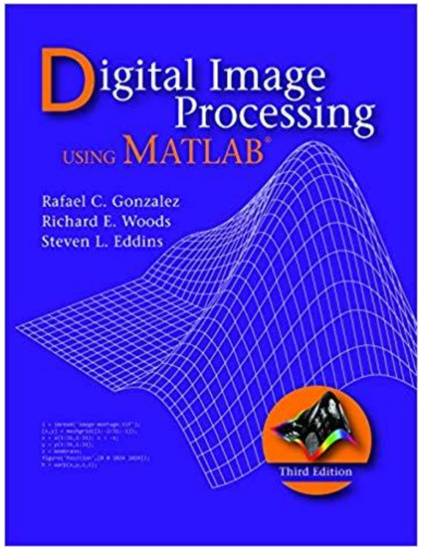
RISETECH
RESEARCH AND INNOVATION
IN SCIENCE ENGINEERING AND TECHNOLOGY

biomisa.org
risetech.ai

# Text Book & References:

- Rafael C. Gonzalez and Richard E. Woods, *Digital Image Processing*, 4rd Edition, 2018 (available from local market)
- Rafael C. Gonzalez and Richard E. Woods, *Digital Image Processing using MATLAB*, 3rd Edition, 2020 (available from local market) (available from local market)
- Class slides & selected research papers to be shared by the instructor



# Course Information

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

# Grading Policy

<table>
<tr><th>Exam:</th><th colspan="4">1 Mid and 1 Final</th></tr>
<tr><td>Home work:</td><td colspan="4">3 graded Problem Based Learning</td></tr>
<tr><td>Lab reports:</td><td colspan="4">13-14 reports, 01 open Lab, 01 Lab Final, home tasks</td></tr>
<tr><td>Design reports:</td><td colspan="4">1 Design report and 1 presentations based on Semester Project</td></tr>
<tr><td>Quizzes:</td><td colspan="4">6-8 Quizzes</td></tr>
<tr><td rowspan="7">Grading:</td><td colspan="2">Theory (67%)</td><td colspan="2">Lab (33%)</td></tr>
<tr><td rowspan="2">Mid term</td><td rowspan="2">30%</td><td>Lab Work/Tasks<br>(Every week)</td><td>45%</td></tr>
<tr><td>Open Lab</td><td>10%</td></tr>
<tr><td>Quizzes:</td><td>10%</td><td>Lab Final</td><td>10%</td></tr>
<tr><td>Assignments</td><td>10%</td><td>Home Tasks</td><td>05%</td></tr>
<tr><td>Final Exam</td><td>50%</td><td>Final Project</td><td>30%</td></tr>
</table>

# Course Contents

- Introduction to Image processing (Chapter – 1, 2)
- Image processing Fundamentals (Chapter-2)
- Image Enhancement (Spatial & Frequency Domain) (Chapter – 3, 4)
- Color Processing (Chapter – 6)
- Morphological operations (Chapter – 9)
- Segmentation (Chapter – 10, Online material, David Forsyth)
- Texture analysis (Chapter – 11, Online material, David Forsyth )
- Image representation and description (Chapter – 11)
- Introduction to Machine Learning and Convolutional Neural Networks (Chapter – 12 & Stanford course on CNN, Online Resources)

# Lab Breakdown

| | |
|---|---|
| **Lab 01** | Installation & Introduction to Python and OpenCV, Basic Image Processing |
| **Lab 02** | Connected Component Analysis **(Assignment-1: Using Connect Component for Image Analysis )** |
| **Lab 03** | Transformation Operations |
| **Lab 04** | Histogram Equalization and Spatial Filtering |
| **Lab 05** | Spatial Filtering and Its Applications **(Assignment-2 Use of filtering, edge detection and segmentation for image analysis)** |
| **Lab 06** | Edge Detection and Segmentation |
| **Lab 07** | Spatial filtering and segmentation on the go (edge computing) |
| **Lab 08** | Open Lab **(Project Assignment)** |
| **Lab 09** | Morphological Operations **(Seminar on using GitHub and Co-Lab)** |
| **Lab 10** | Color Processing & Clustering |
| **Lab 11** | Frequency Analysis |
| **Lab 12** | Texture Analysis – Statistical descriptors, GLCM, Spectral features **(Assignment-3: Feature Extraction and classification)** |
| **Lab 13** | Computer Vision using Edge computing – I |
| **Lab 14** | Image Classification using CNN |
| **Lab 15** | Computer Vision using Edge computing – II |
| **Lab 16** | Lab Final **(Project Presentation and Submission)** |

# Course Learning Outcome

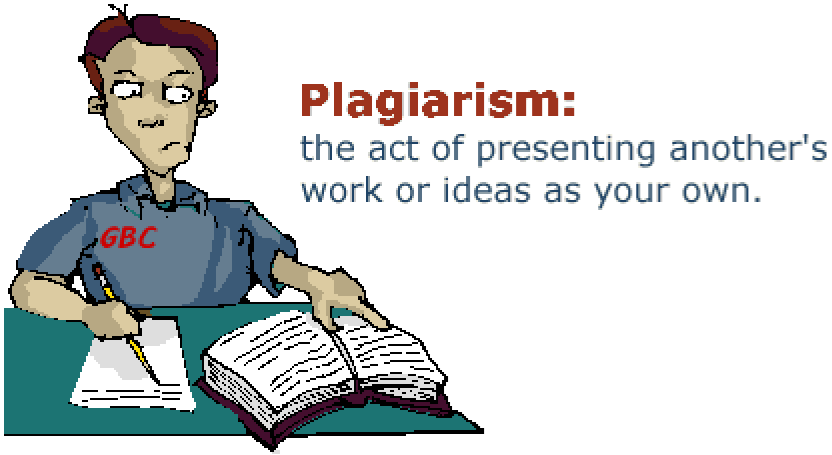
| Course Learning Outcome (CLOs) | | PLOs | Learning Level | Assessments |
|---|---|---|---|---|
| CLO 1 | **Understanding the fundamentals and basic concepts** of image processing related to image enhancement, filtering and segmentation etc | PLO 1 | C2 | Q1, Q2, Mid, Final |
| CLO 2 | **Performing different mathematical transformations**, histogram based operations and filtering concepts for solving image enhancement and feature extraction problems | PLO 2 | C3 | Q3, Q4, Mid, Final |
| CLO 3 | **Combining the concepts of image processing with machine learning** to analyze and design decision support systems for image processing based applications | PLO 3 | C4 | Q6, Mid, Final |
| CLO 4 | Learning the **use of Python and OpenCV** to implement basic image processing algorithms and to solve real life and open ended problems | PLO 5 | P4 | Open Labs, Project, PBL |

# CODE OF ETHICS

- All students must come to class **on time**
- Students should remain attentive during class and **avoid use of Mobile phone**, Laptops or any gadgets
- Obedience to all laws, discipline code, rules and community norms
- **Respect peers, faculty and staff** through actions and speech
- Bring writing material and books
- Class participation is encouraged

# Policies

- **No extensions** in assignment deadlines.
- Quizzes will be **unannounced.**
- Exams will be **OPEN book**
- No Attendance and marking of lab tasks **if late more than 15 min**
- **Never cheat.**
  - "Better fail NOW or else will fail somewhere LATER in life"
- Plagiarism will also have strict penalties.




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

Image Processing

Image Analysis

Machine Learning

Deep Learning

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

Original Hazy Image

Haze Removed Image

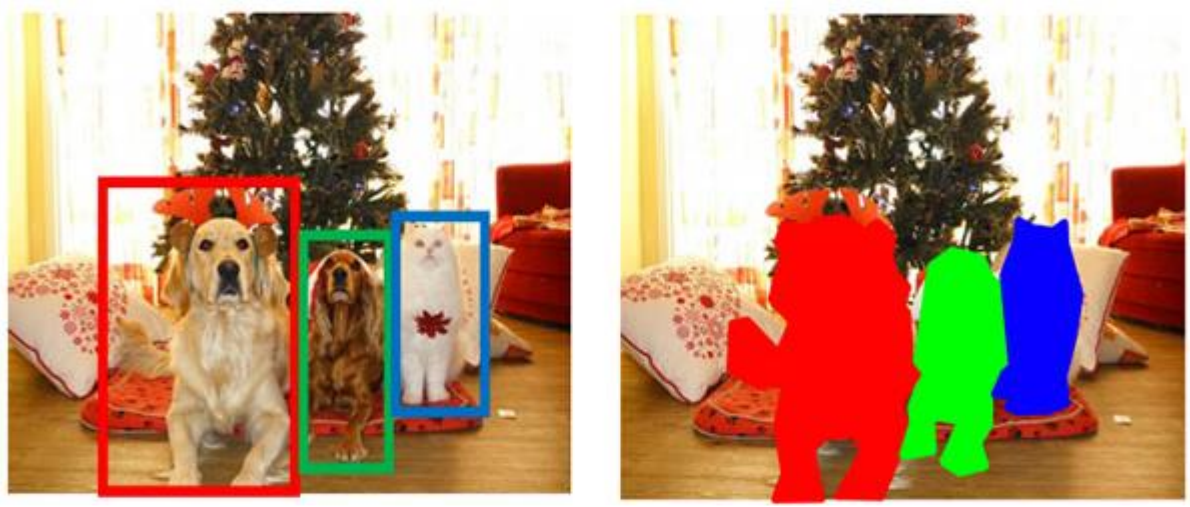
# Image Processing & Machine Vision

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

| Low Level Process | Mid Level Process |
|---|---|
| **Input:** Image<br>**Output:** Image | **Input:** Image<br>**Output:** Attributes |
| **Examples:** Noise removal, image sharpening | **Examples:** Object recognition, segmentation |

Image Processing

# Example: Mid Level Processing



Segmentation of image into regions

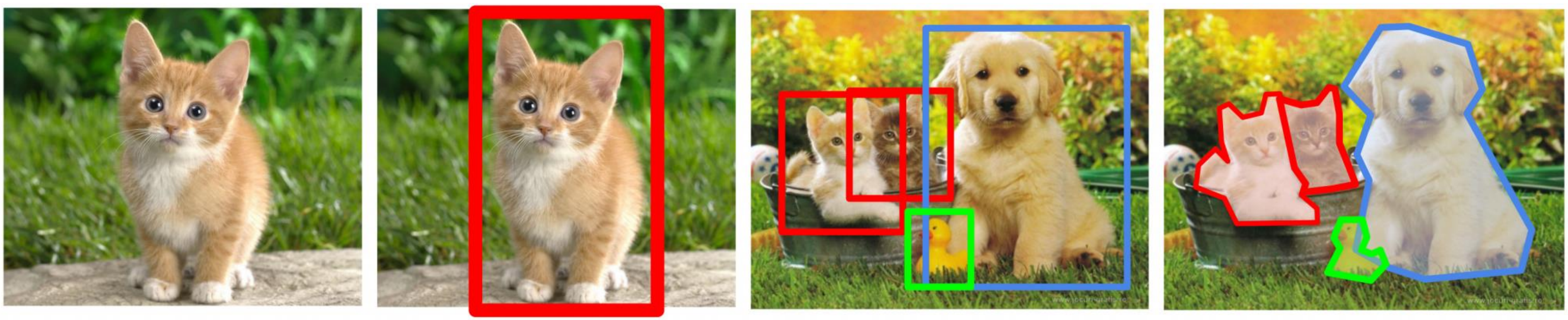
# Image Processing & Machine Vision

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

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

Image Processing → Machine Vision

# Example: High Level Processing



CAT | CAT | CAT, DOG, DUCK | CAT, DOG, DUCK

Object Classification

# 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<br>**Output:** Image | **Input:** Image<br>**Output:** Attributes | **Input:** Attributes/Image<br>**Output:** Understanding |
| **Examples:** Noise removal, image sharpening | **Examples:** Object recognition, segmentation | **Examples:** Scene understanding, autonomous navigation |

Image Processing

Machine Vision

# Why Image Processing?

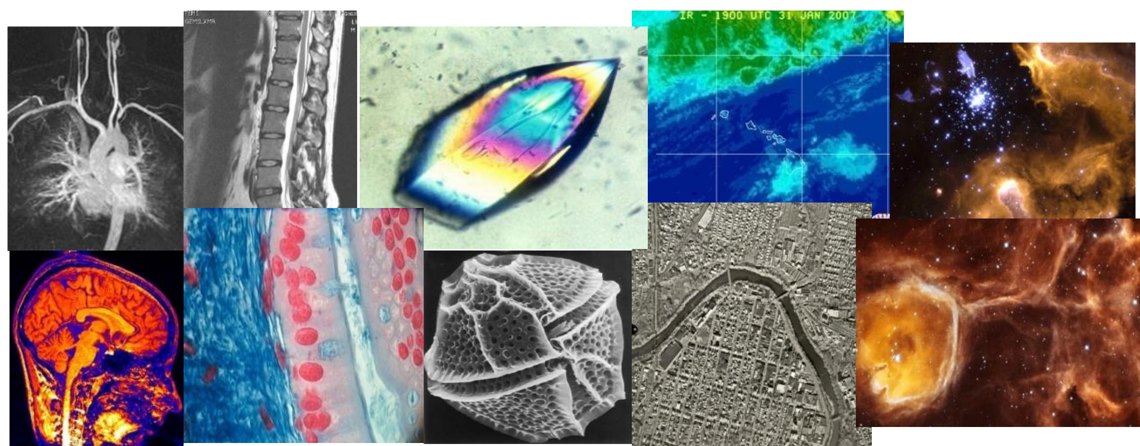
- Images and video are everywhere!

Personal photo albums

Movies, news, sports

Google Image Search | Picasa | flickr | webshots | picsearch | YouTube Broadcast Yourself


Surveillance and security




Medical and scientific images

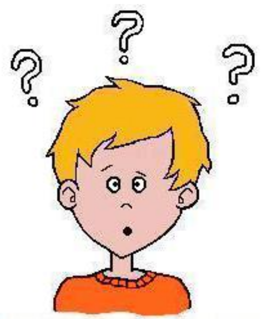
Slide credit; L. Lazebnik

# 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)

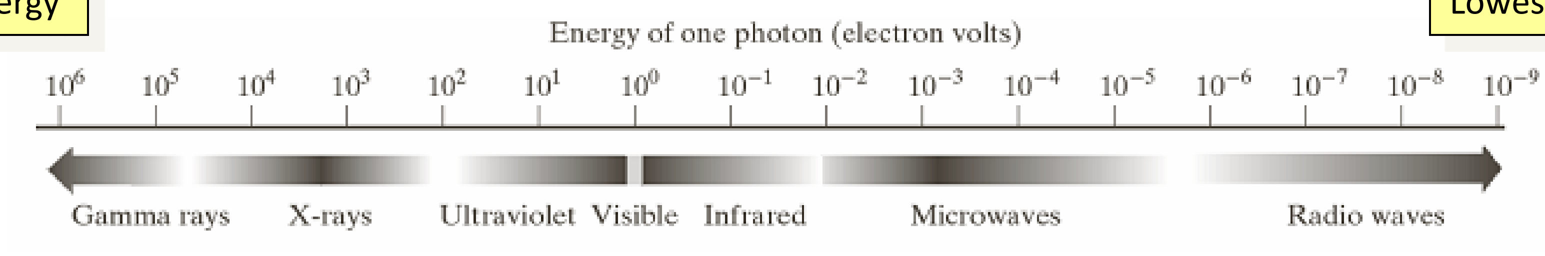


# Light & EM Spectrum

- 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

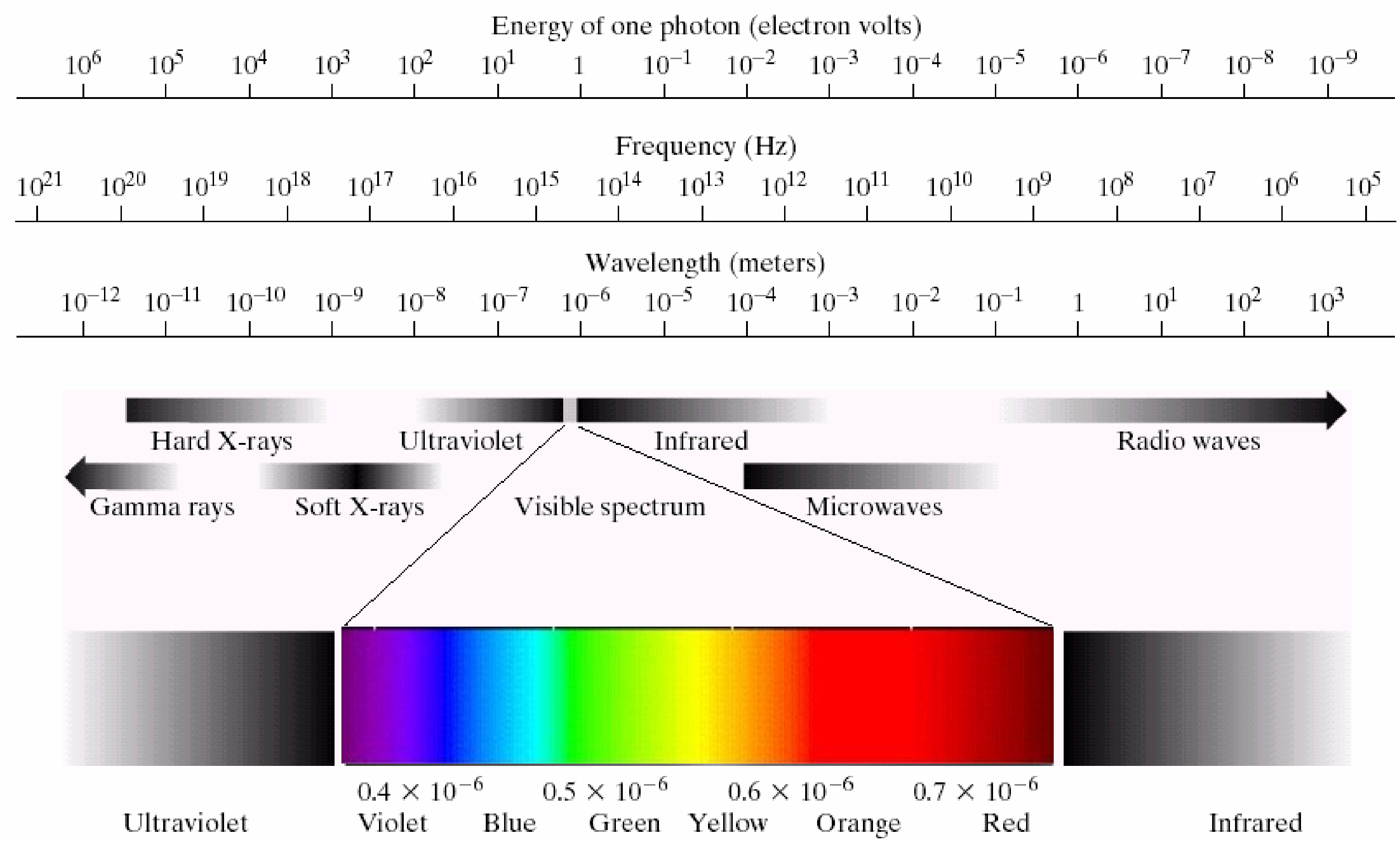
Highest Energy

Lowest Energy



# Light & EM Spectrum

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



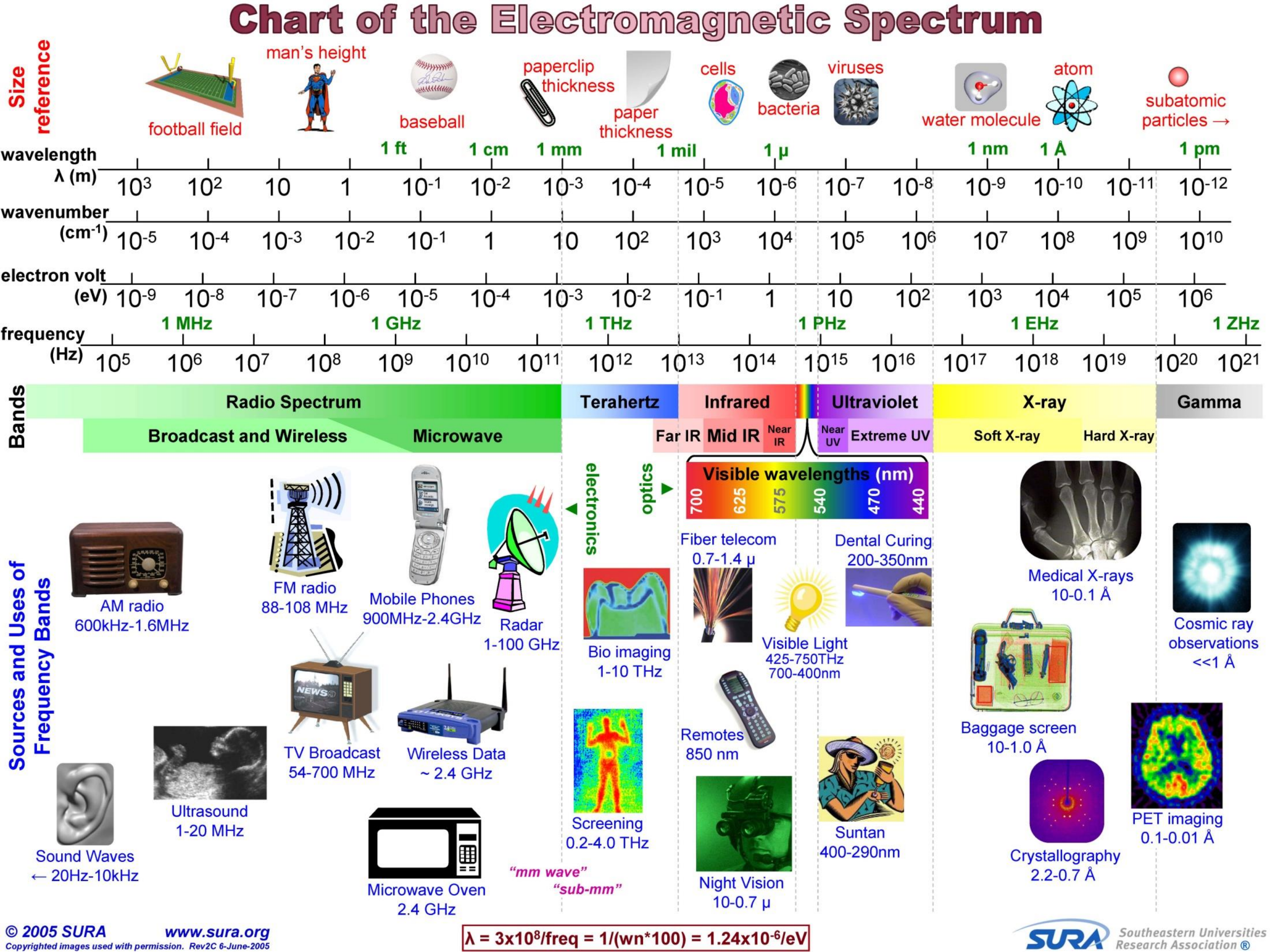
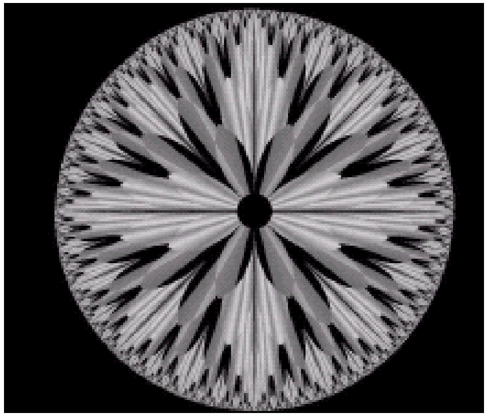


Chart of the Electromagnetic Spectrum
Size reference
football field
man's height
baseball
paperclip thickness
paper thickness
cells
bacteria
viruses
water molecule
atom
subatomic particles →
wavelength λ (m)
1 ft
1 cm
1 mm
1 mil
1 μ
1 nm
1 Å
1 pm
$10^3$ $10^2$ 10 1 $10^{-1}$ $10^{-2}$ $10^{-3}$ $10^{-4}$ $10^{-5}$ $10^{-6}$ $10^{-7}$ $10^{-8}$ $10^{-9}$ $10^{-10}$ $10^{-11}$ $10^{-12}$
wavenumber ($cm^{-1}$)
$10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ 1 10 $10^2$ $10^3$ $10^4$ $10^5$ $10^6$ $10^7$ $10^8$ $10^9$ $10^{10}$
electron volt (eV)
$10^{-9}$ $10^{-8}$ $10^{-7}$ $10^{-6}$ $10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ 1 10 $10^2$ $10^3$ $10^4$ $10^5$ $10^6$
frequency (Hz)
1 MHz
1 GHz
1 THz
1 PHz
1 EHz
1 ZHz
$10^5$ $10^6$ $10^7$ $10^8$ $10^9$ $10^{10}$ $10^{11}$ $10^{12}$ $10^{13}$ $10^{14}$ $10^{15}$ $10^{16}$ $10^{17}$ $10^{18}$ $10^{19}$ $10^{20}$ $10^{21}$
Bands
Radio Spectrum
Terahertz
Infrared
Ultraviolet
X-ray
Gamma
Broadcast and Wireless
Microwave
Far IR
Mid IR
Near IR
Near UV
Extreme UV
Soft X-ray
Hard X-ray
Visible wavelengths (nm)
700 625 575 540 470 440
◄ electronics
optics ►
Sources and Uses of Frequency Bands
AM radio 600kHz-1.6MHz
FM radio 88-108 MHz
Mobile Phones 900MHz-2.4GHz
Radar 1-100 GHz
Bio imaging 1-10 THz
Fiber telecom 0.7-1.4 μ
Dental Curing 200-350nm
Medical X-rays 10-0.1 Å
Cosmic ray observations <<1 Å
Visible Light 425-750THz 700-400nm
Remotes 850 nm
Baggage screen 10-1.0 Å
Sound Waves ← 20Hz-10kHz
Ultrasound 1-20 MHz
TV Broadcast 54-700 MHz
Wireless Data ~ 2.4 GHz
Microwave Oven 2.4 GHz
Screening 0.2-4.0 THz
"mm wave"
"sub-mm"
Night Vision 10-0.7 μ
Suntan 400-290nm
Crystallography 2.2-0.7 Å
PET imaging 0.1-0.01 Å
© 2005 SURA www.sura.org
Copyrighted images used with permission. Rev2C 6-June-2005
$\lambda = 3 \times 10^8/\text{freq} = 1/(\text{wn}*100) = 1.24 \times 10^{-6}/\text{eV}$
SURA Southeastern Universities Research Association ®

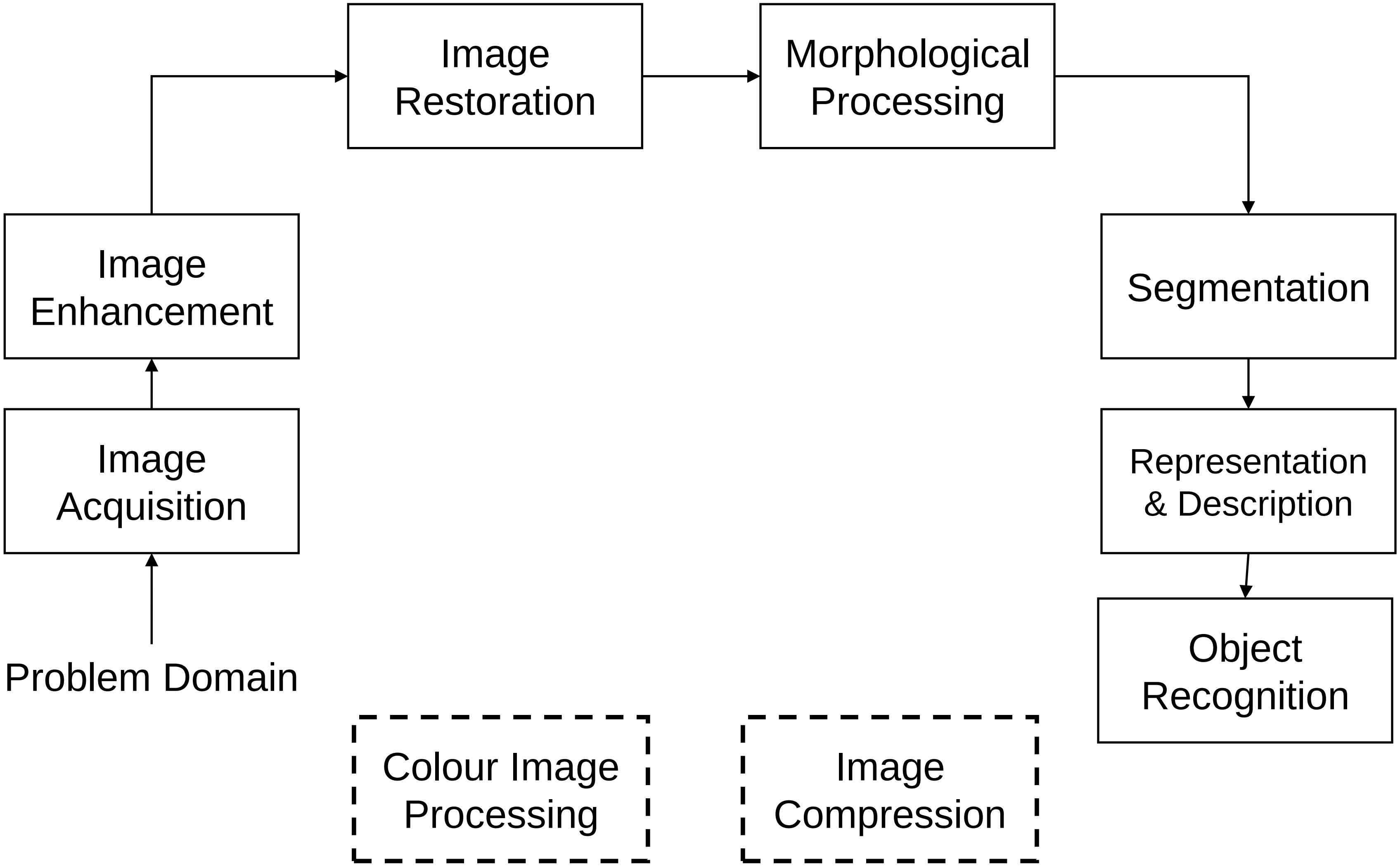
# Examples: Imaging other Modalities

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

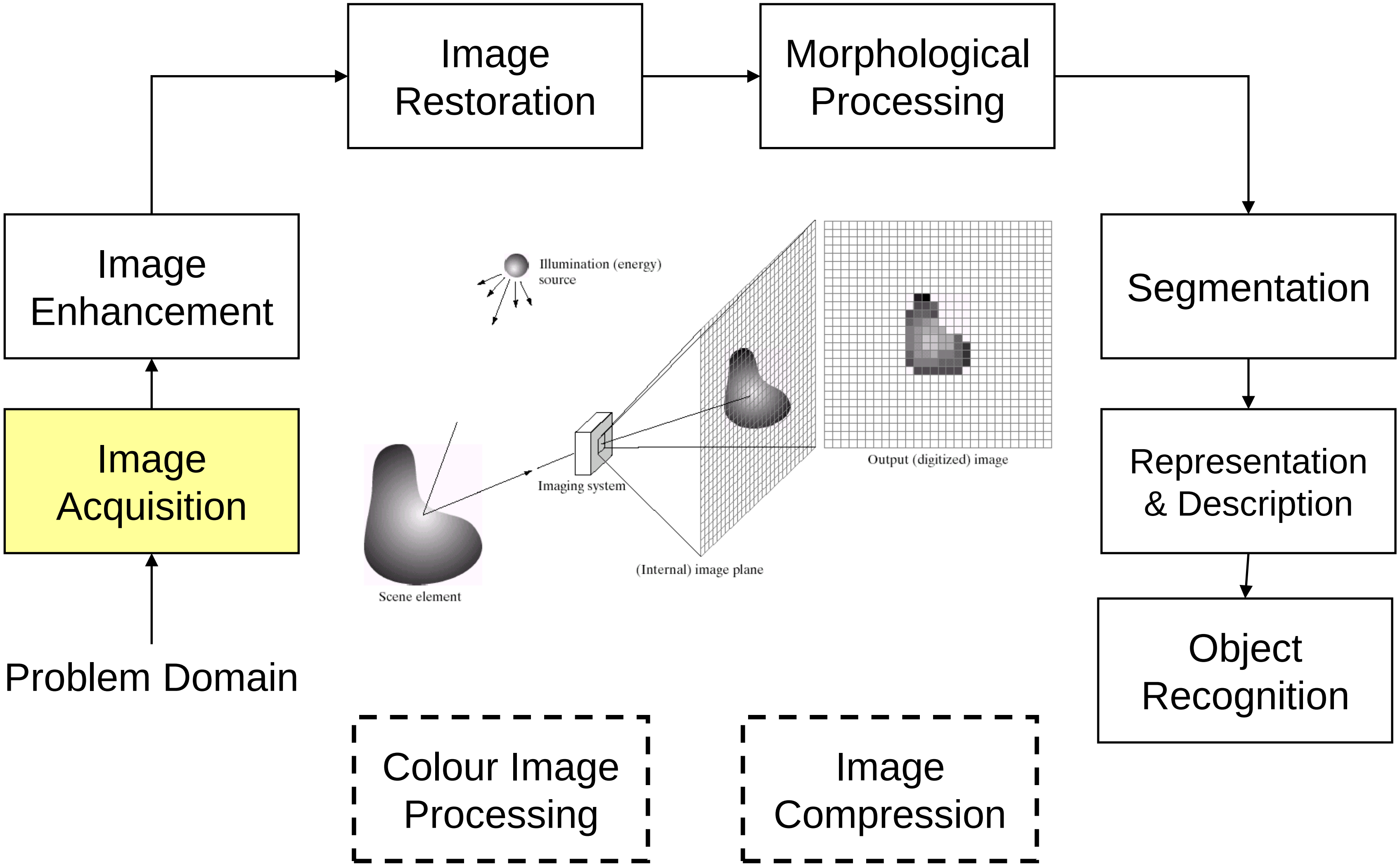


*A synthetic image*

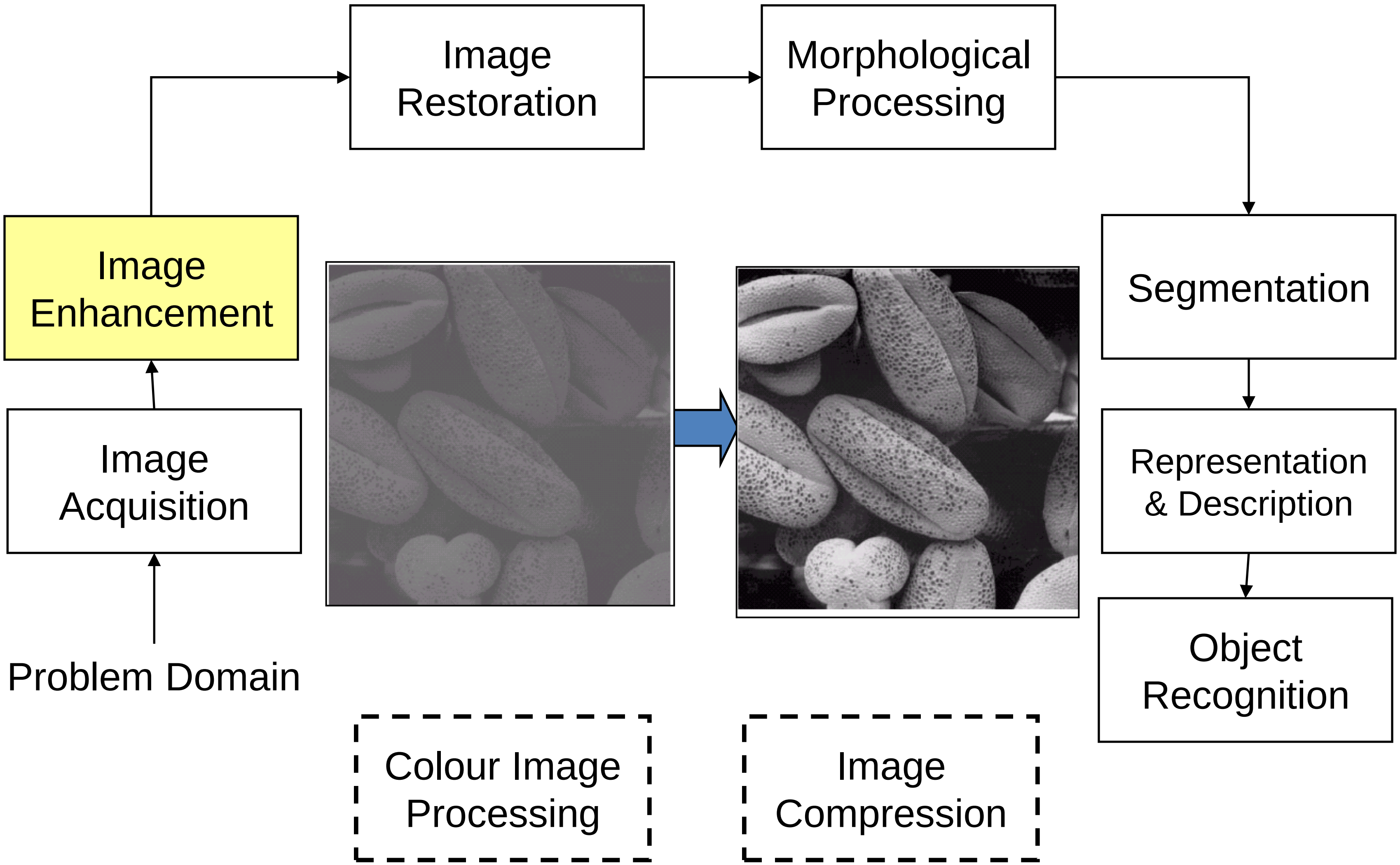
# Key Stages in DIP



# Key Stages in DIP



# Key Stages in DIP



# Key Stages in DIP

Image Restoration

Morphological Processing

Image Enhancement

Segmentation

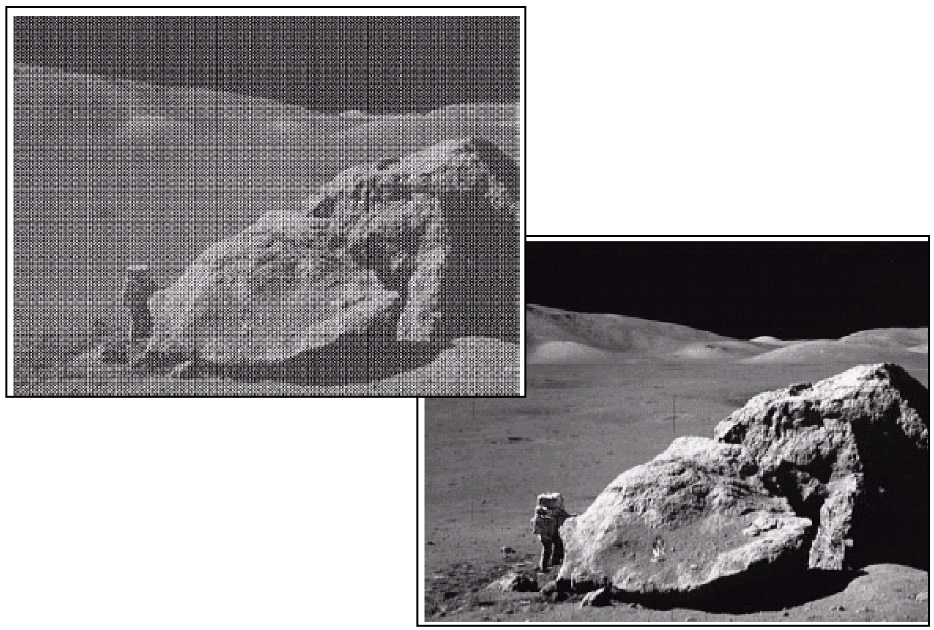


Image Acquisition

Representation & Description

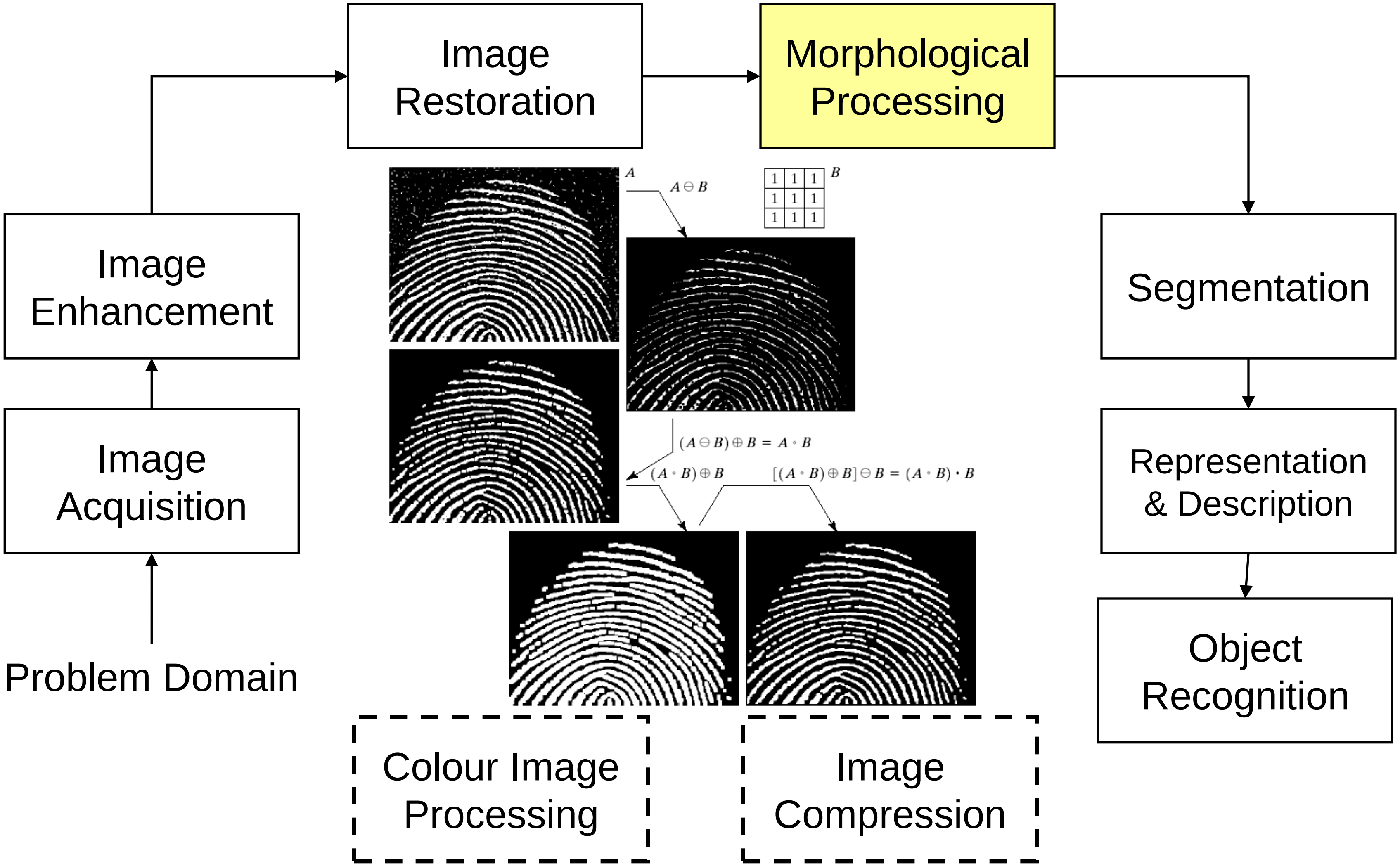
Object Recognition

Problem Domain

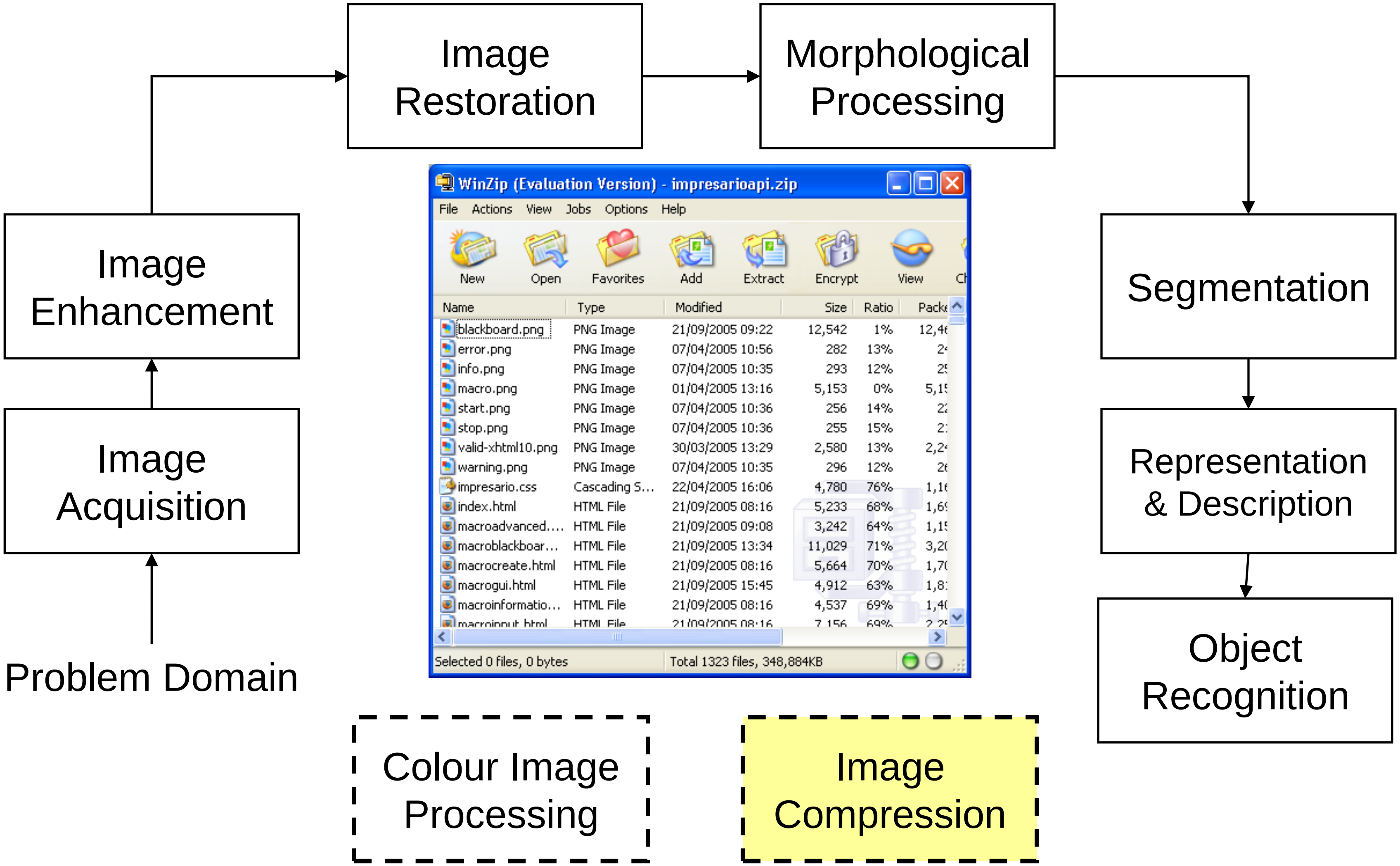
Colour Image Processing

Image Compression

# Key Stages in DIP



# Key Stages in DIP



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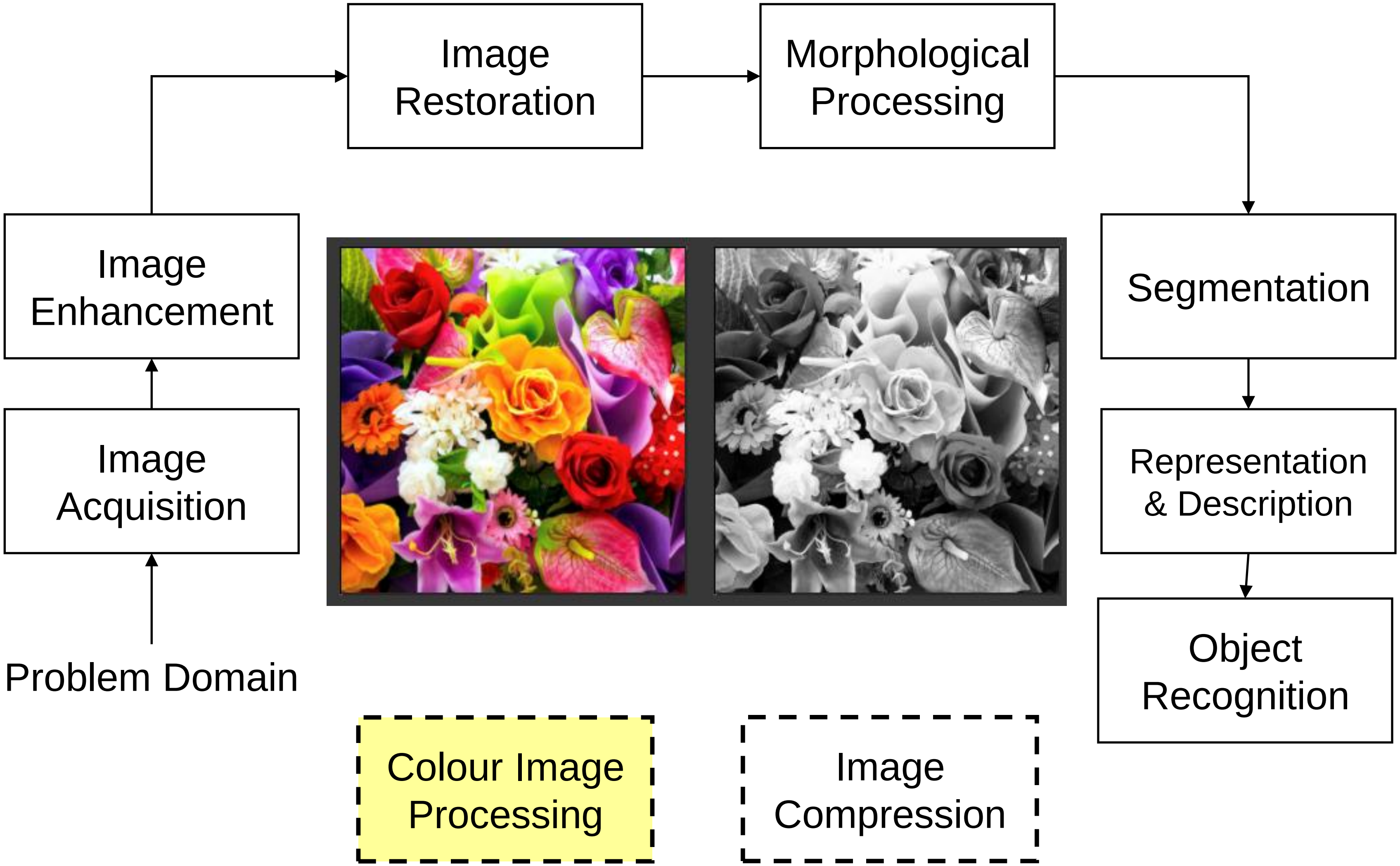
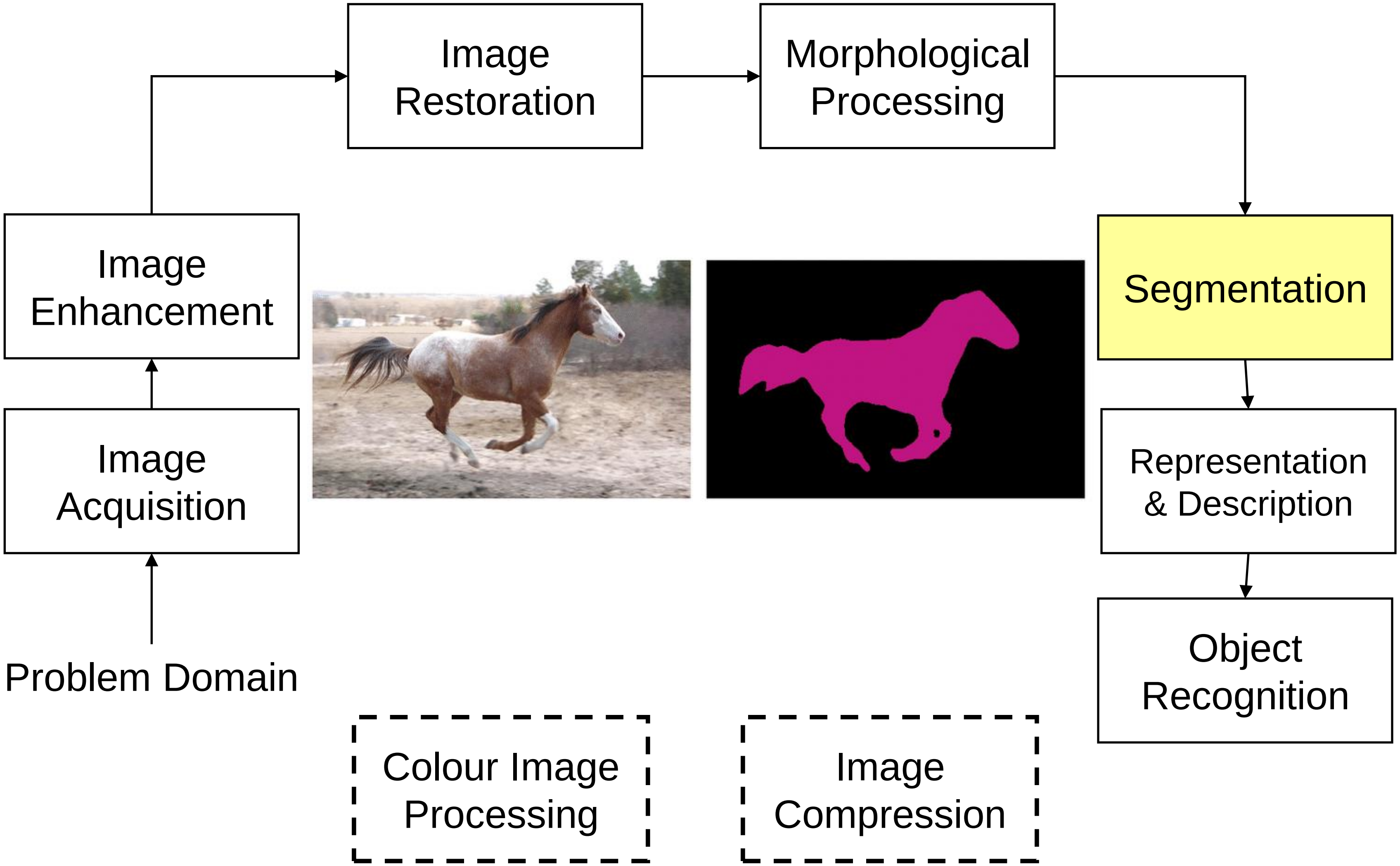
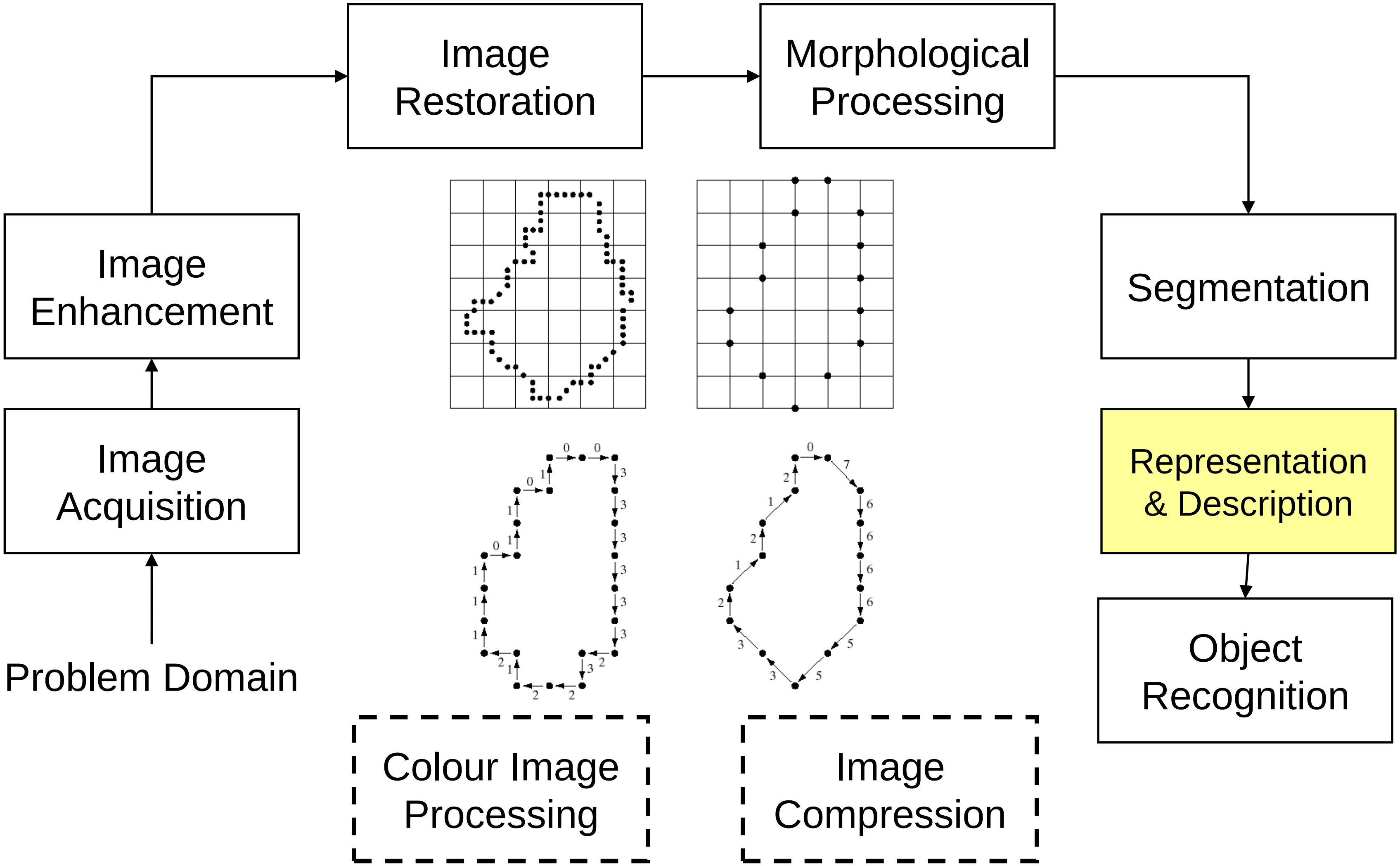


# Key Stages in DIP



# Key Stages in DIP



# Key Stages in DIP

Image Restoration

Morphological Processing

Image Enhancement

Segmentation

Image Acquisition

Representation & Description

Problem Domain

Object Recognition


Colour Image Processing

Image Compression

# Digital Image Processing

**Fundamentals**

# ***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*

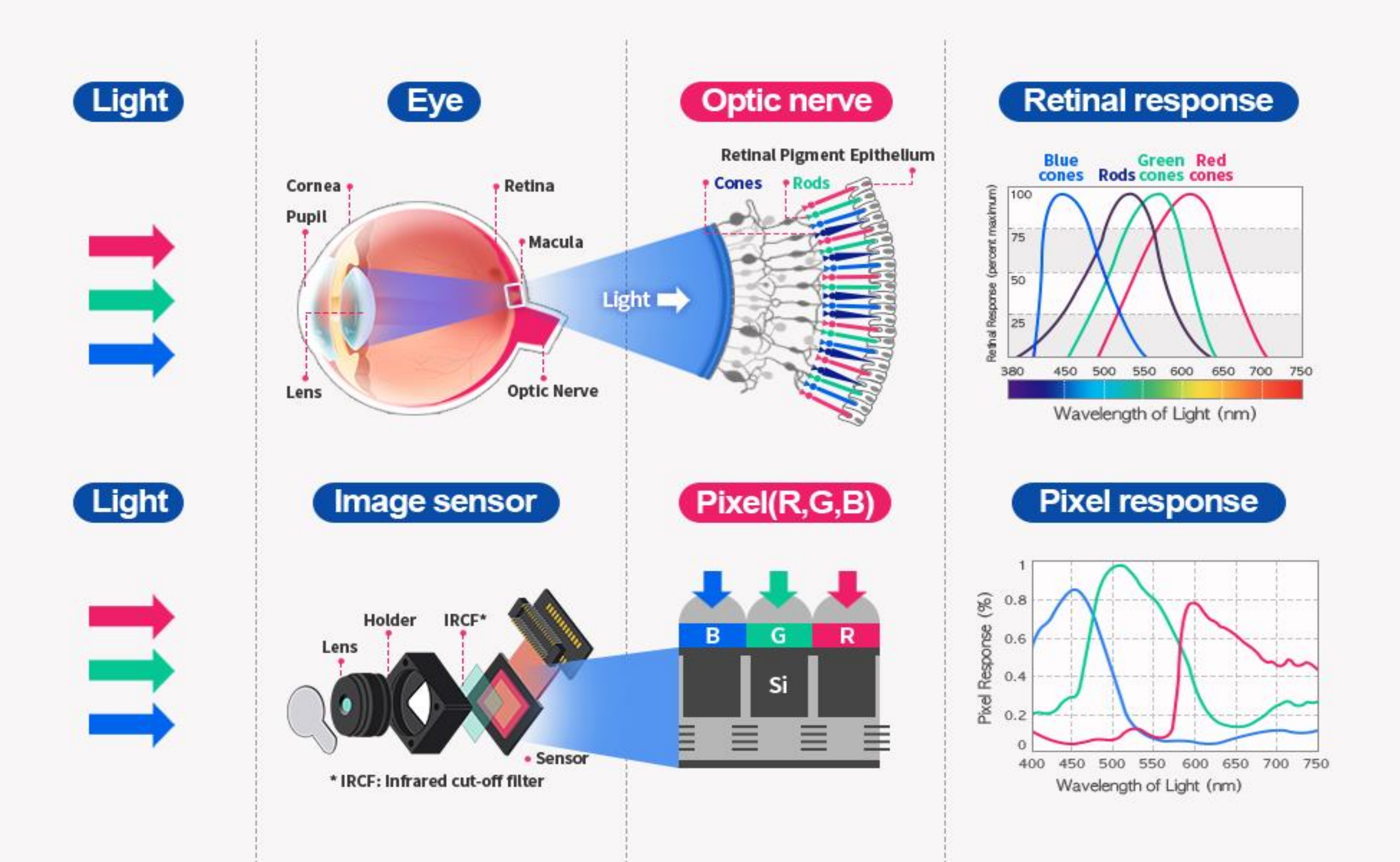
- The function f(x, y) may be characterized by two components:
  - The amount of source light incident on the scene being viewed ⇨ illumination.
  - The amount of light reflected by the objects in the scene ⇨ reflectance.

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

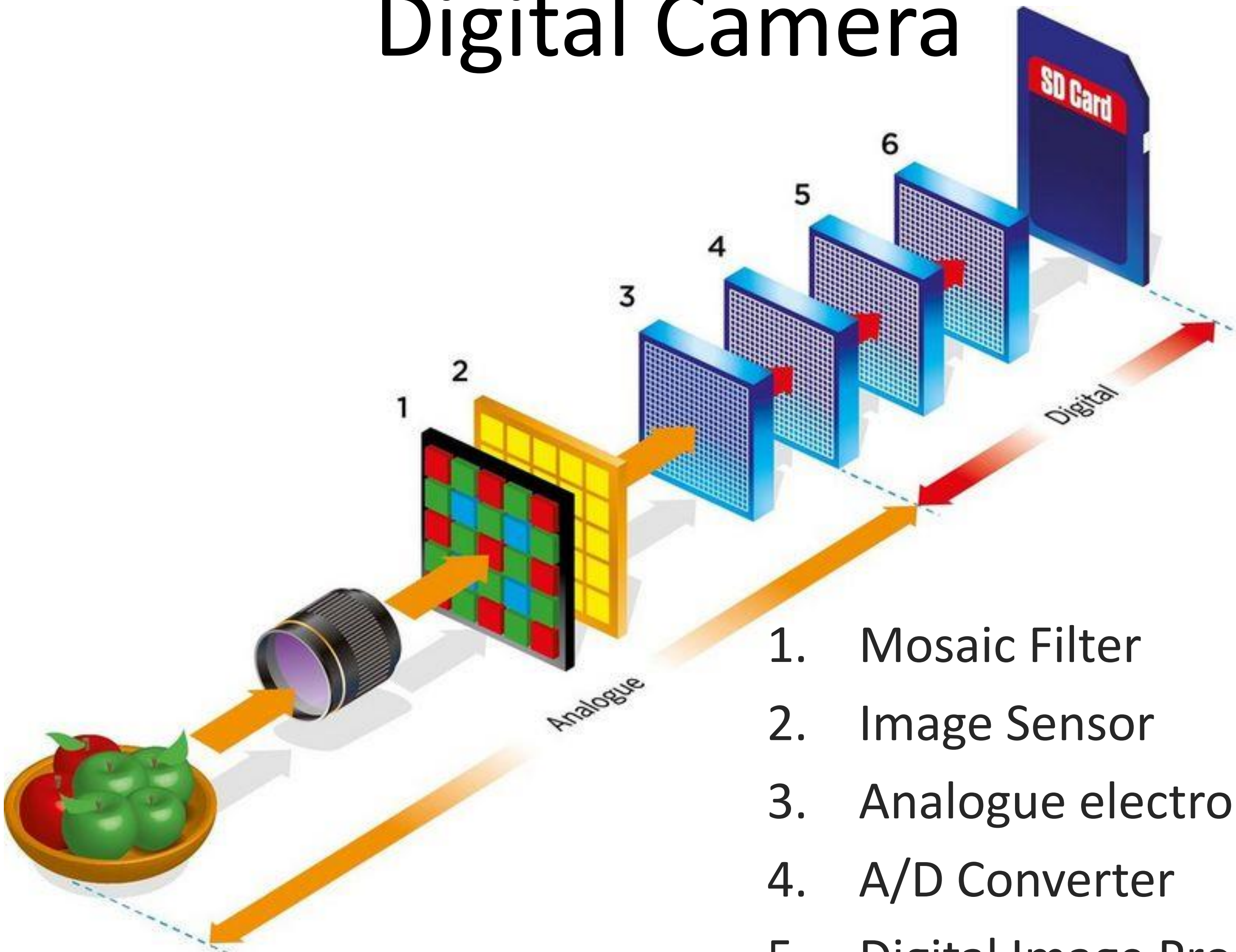
$$0 < i(x, y) < \infty$$

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

# Human Eye Vs Digital Camera



# Digital Camera




1. Mosaic Filter
2. Image Sensor
3. Analogue electronics
4. A/D Converter
5. Digital Image Processing
6. Buffer

# Image Acquisition

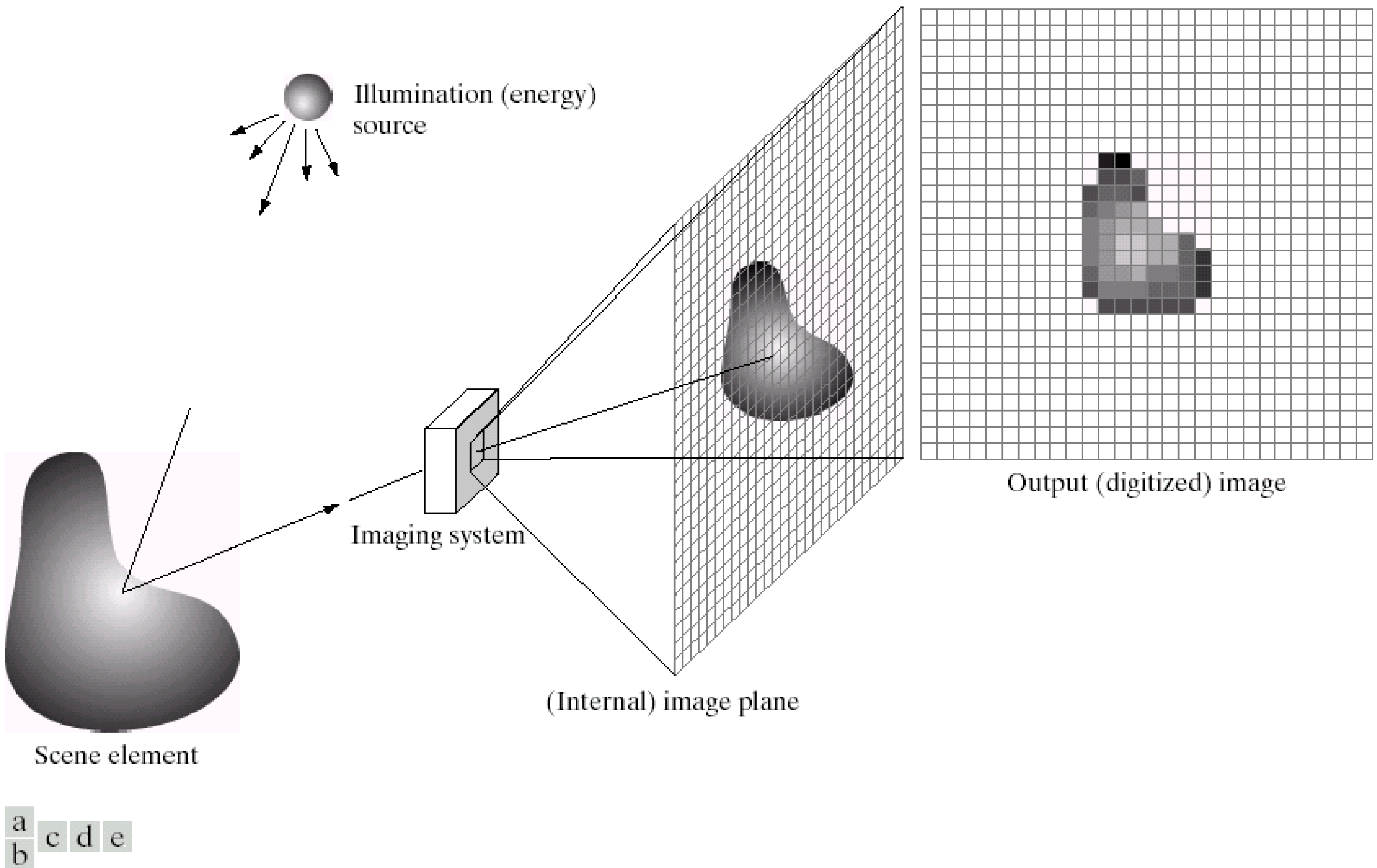



**FIGURE 2.15** An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

# Sampling and Quantization

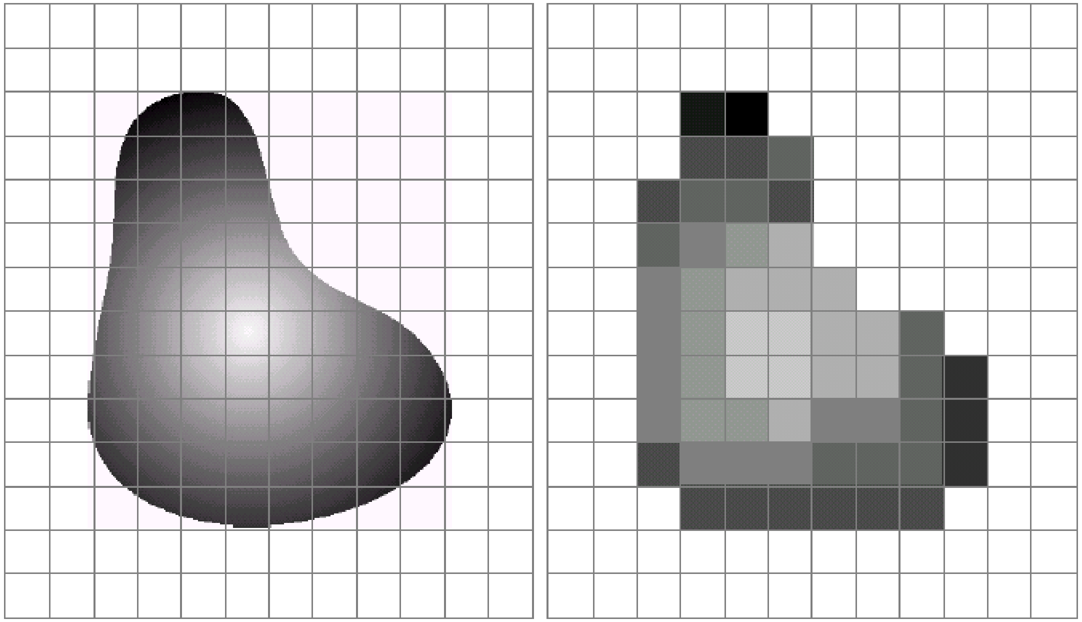
- Sampling:
  - Digitization of the spatial coordinates (x,y)
- Quantization:
  - Digitization in amplitude (also known as gray level quantization)

# Sampling and Quantization

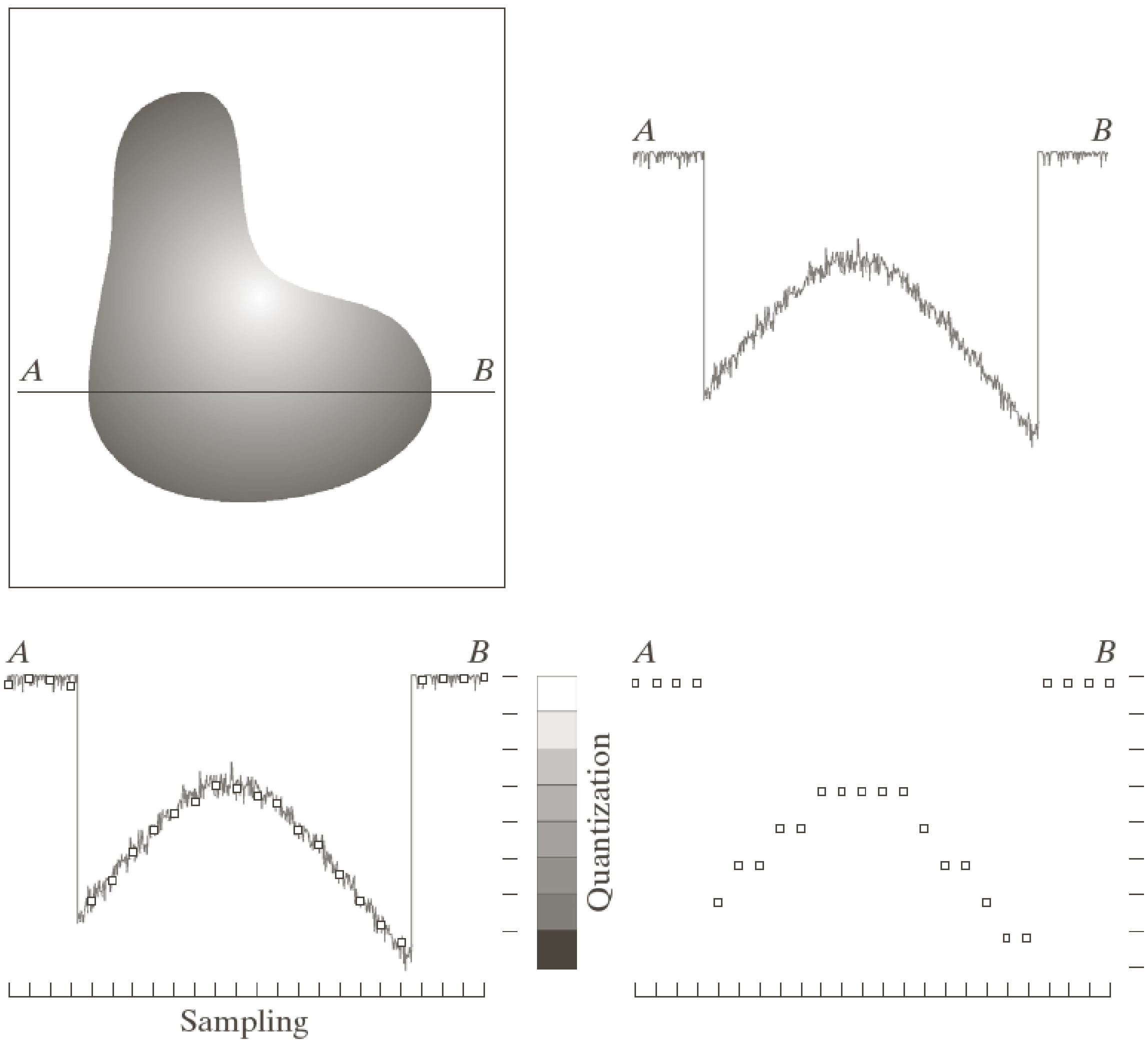
- Quantization
  - 8 bit quantization: $2^8$ =256 gray levels (0: black, 255: white)
  - 1 bit quantization: 2 gray levels (0: black, 1: white) – binary
- Sampling
  - Commonly used number of samples (resolution)
    - Digital still cameras: 640x480, 1024x1024, 4064 x 2704
    - Digital video cameras: 640x480 at 30 frames/second (fps)

# Sampling and Quantization

- Digital Image is an approximation of a real world scene



# Sampling and Quantization

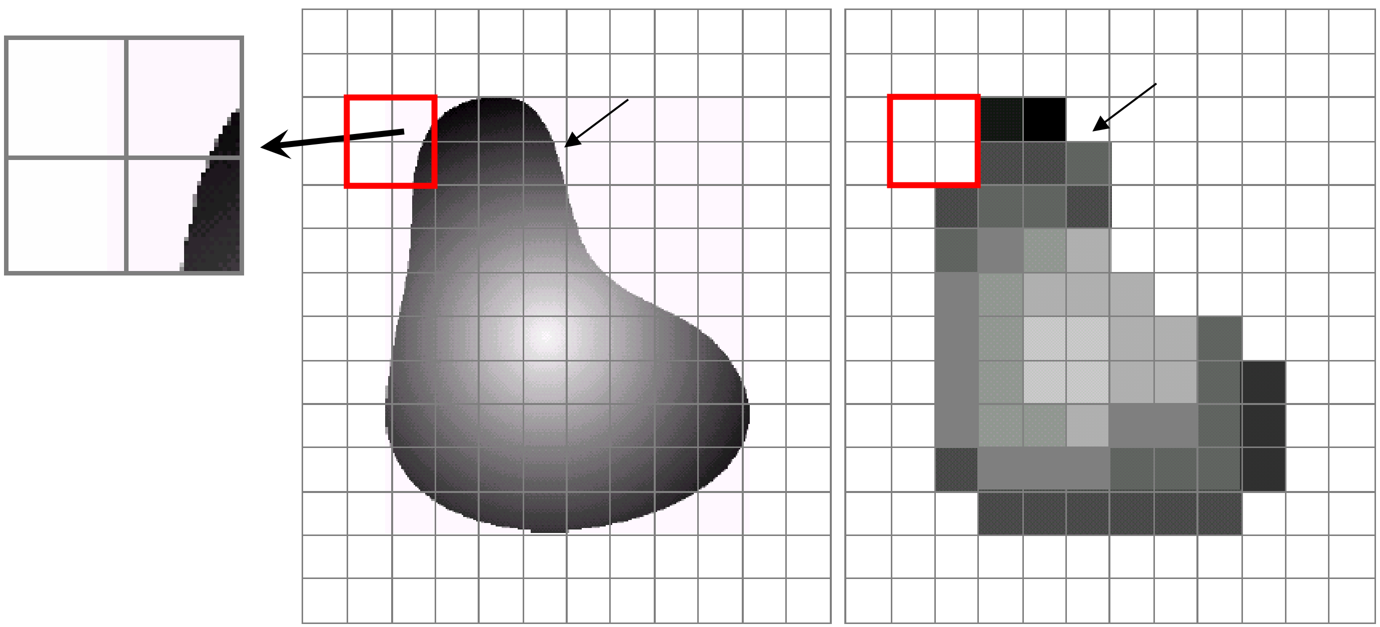


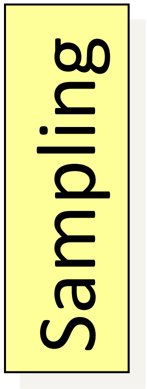

a b
c d

**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

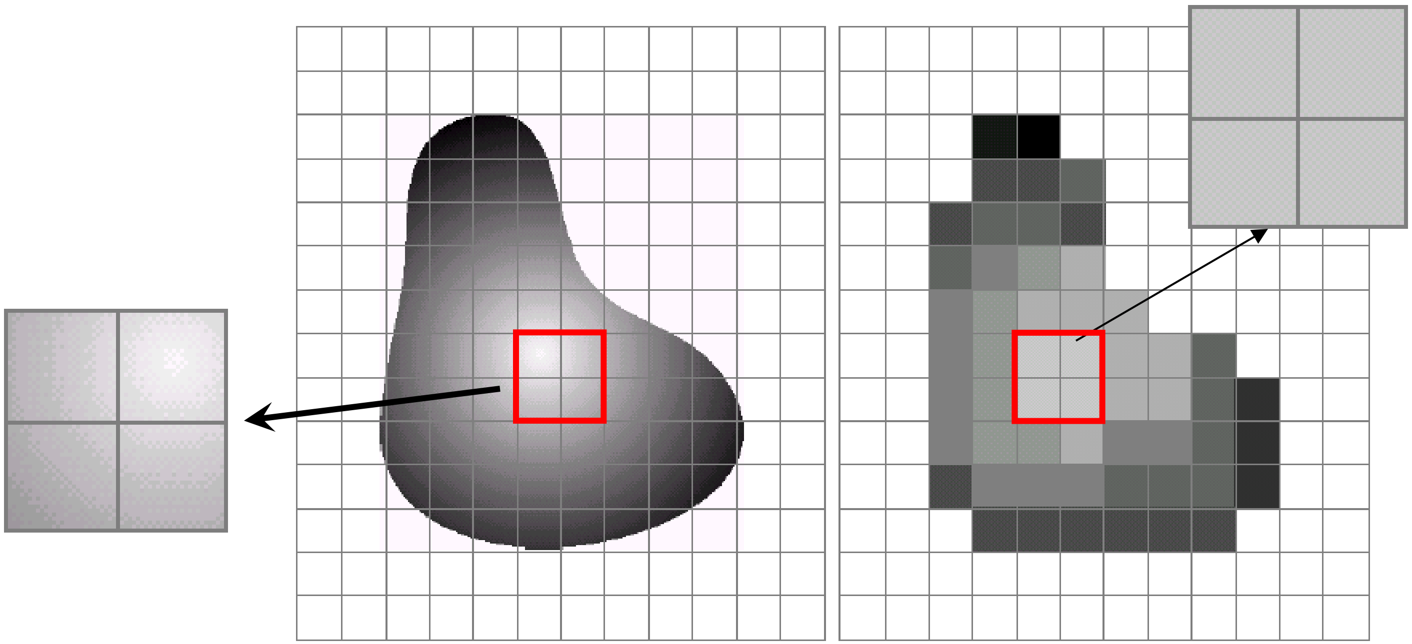
- Digital Image is an approximation of a real world scene





# Image Formation

- Digital Image is an approximation of a real world scene



Quantization

# ***GRAY LEVEL***

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

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

- $L_{min}$ 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

$$\boxed{b = M \times N \times k}$$

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

# Image Size

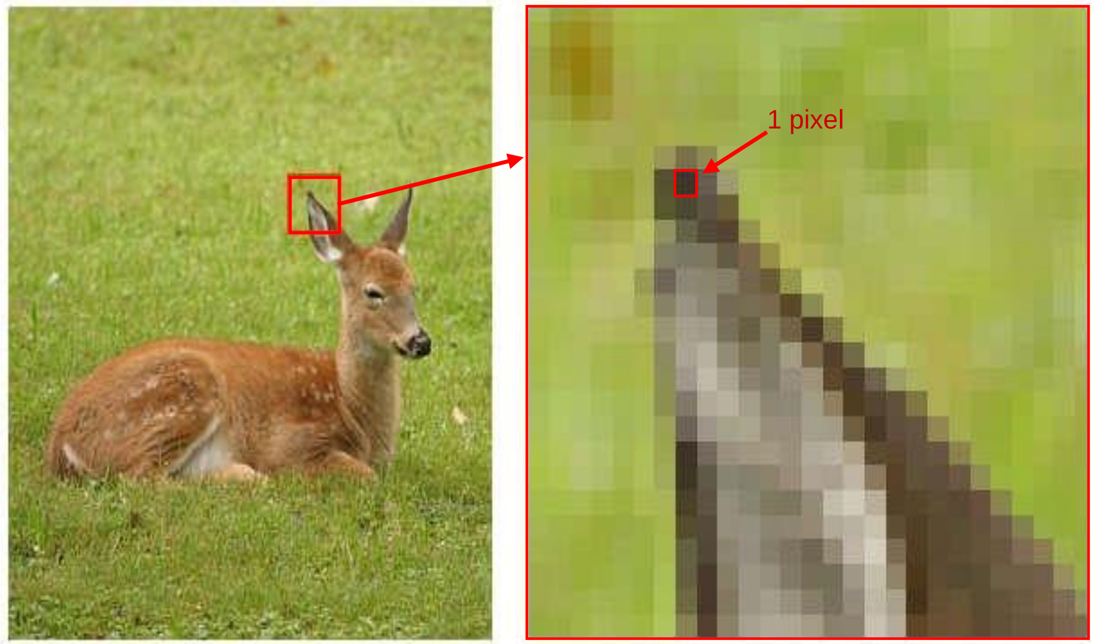
**TABLE 2.1**
Number of storage bits for various values of $N$ and $k$.

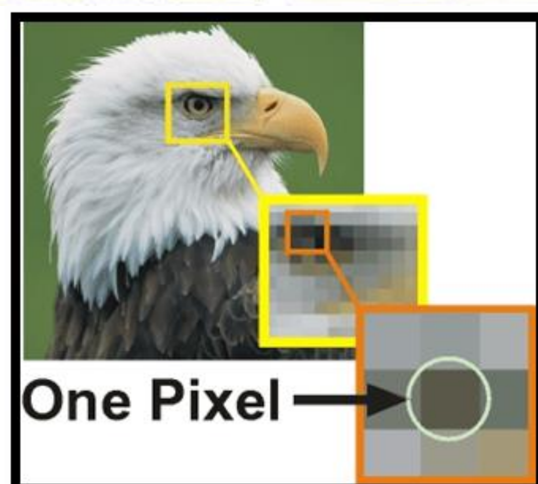
| $N/k$ | 1 ($L$ = 2) | 2 ($L$ = 4) | 3 ($L$ = 8) | 4 ($L$ = 16) | 5 ($L$ = 32) | 6 ($L$ = 64) | 7 ($L$ = 128) | 8 ($L$ = 256) |
|---|---|---|---|---|---|---|---|---|
| 32 | 1,024 | 2,048 | 3,072 | 4,096 | 5,120 | 6,144 | 7,168 | 8,192 |
| 64 | 4,096 | 8,192 | 12,288 | 16,384 | 20,480 | 24,576 | 28,672 | 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 |

# Digital Image

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

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



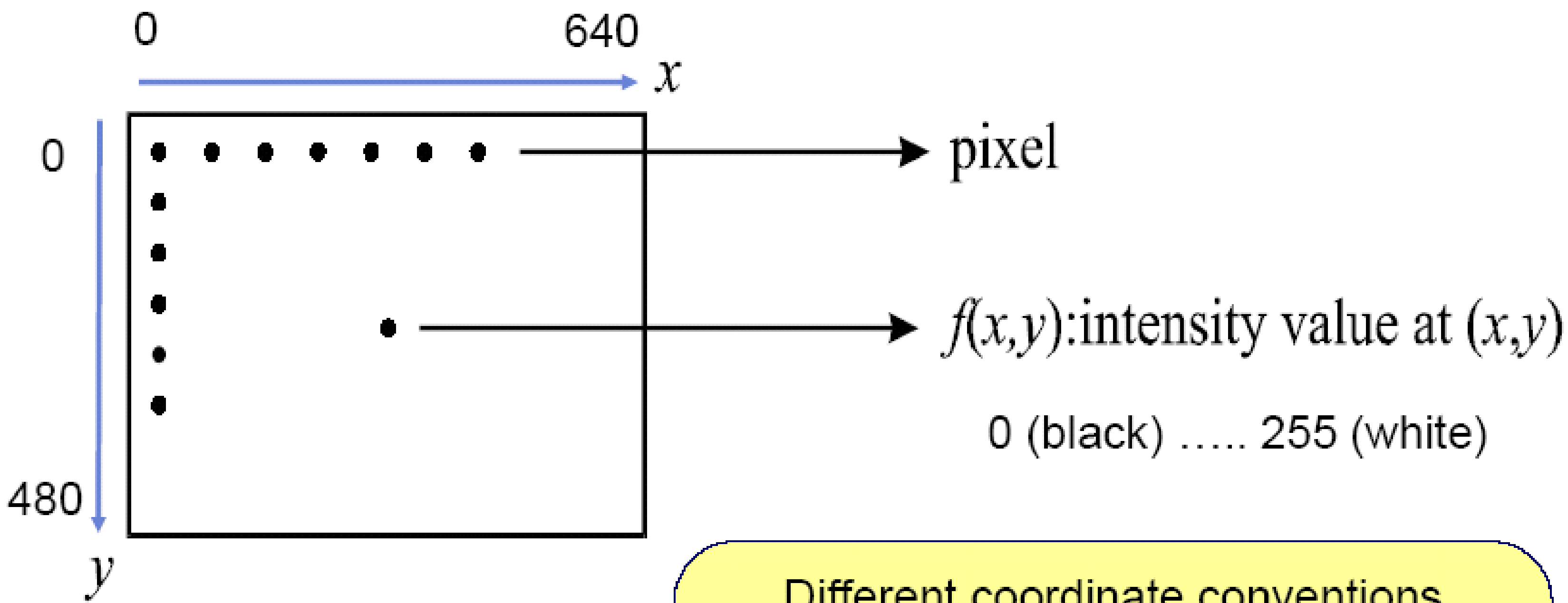



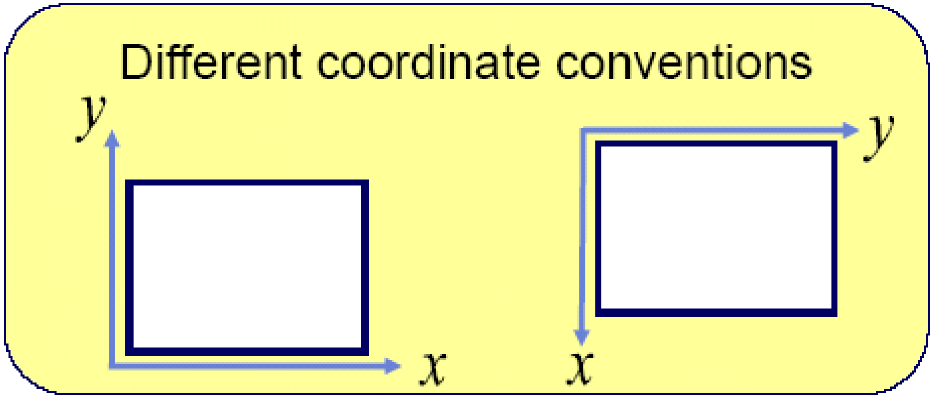
# Digital Image

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

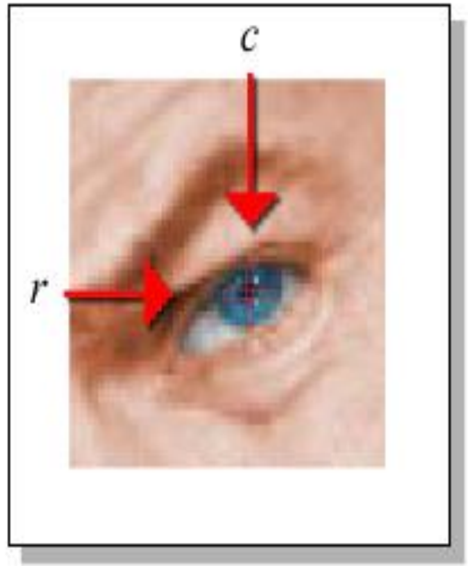
# Example

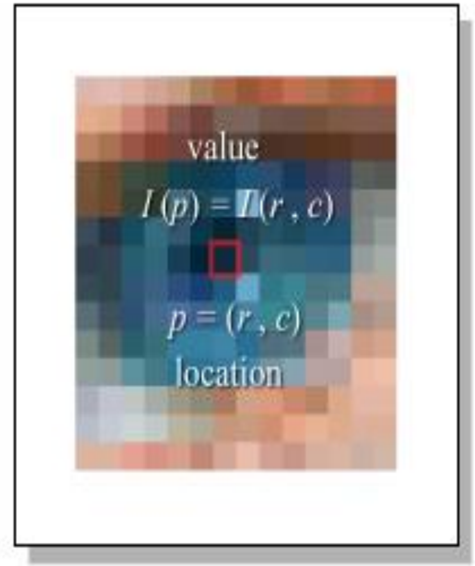
640 x 480 8-bit image



# Pixels

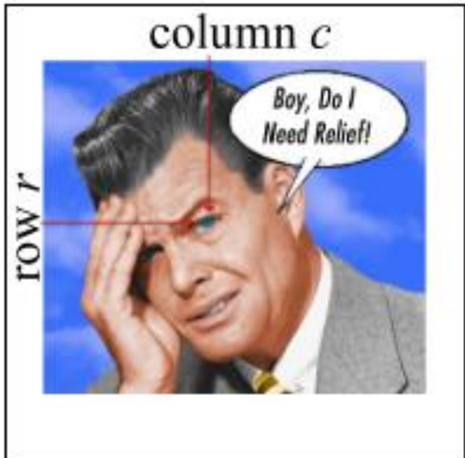

Pixel Location: $p = (r, c)$

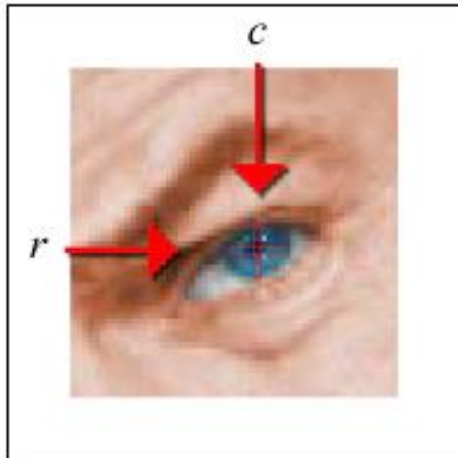
Pixel Value: $I(p) = I(r, c)$

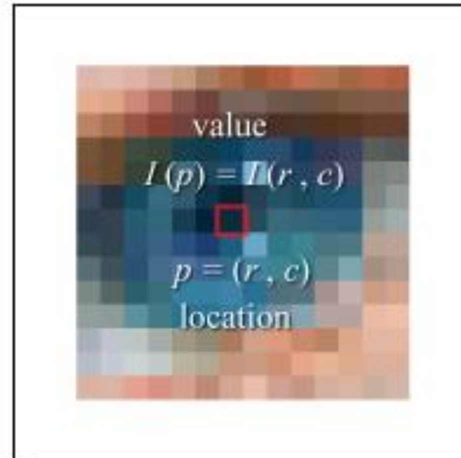
Pixel : $[\, p, I(p) ]$

# Pixels

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



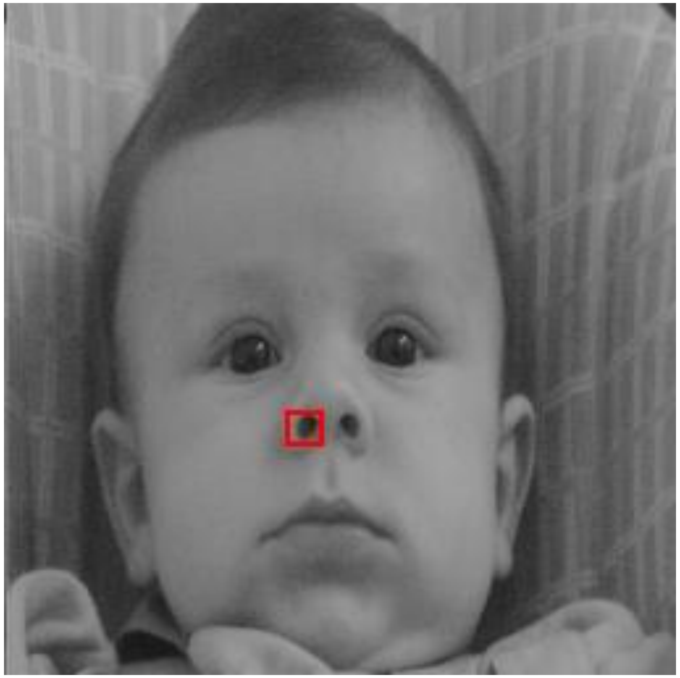




$$
\begin{aligned}
p &= (r, c) \\
&= (\text{row \#},\ \text{col \#}) \\
&= (272,\ 277)
\end{aligned}
$$

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

# 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)

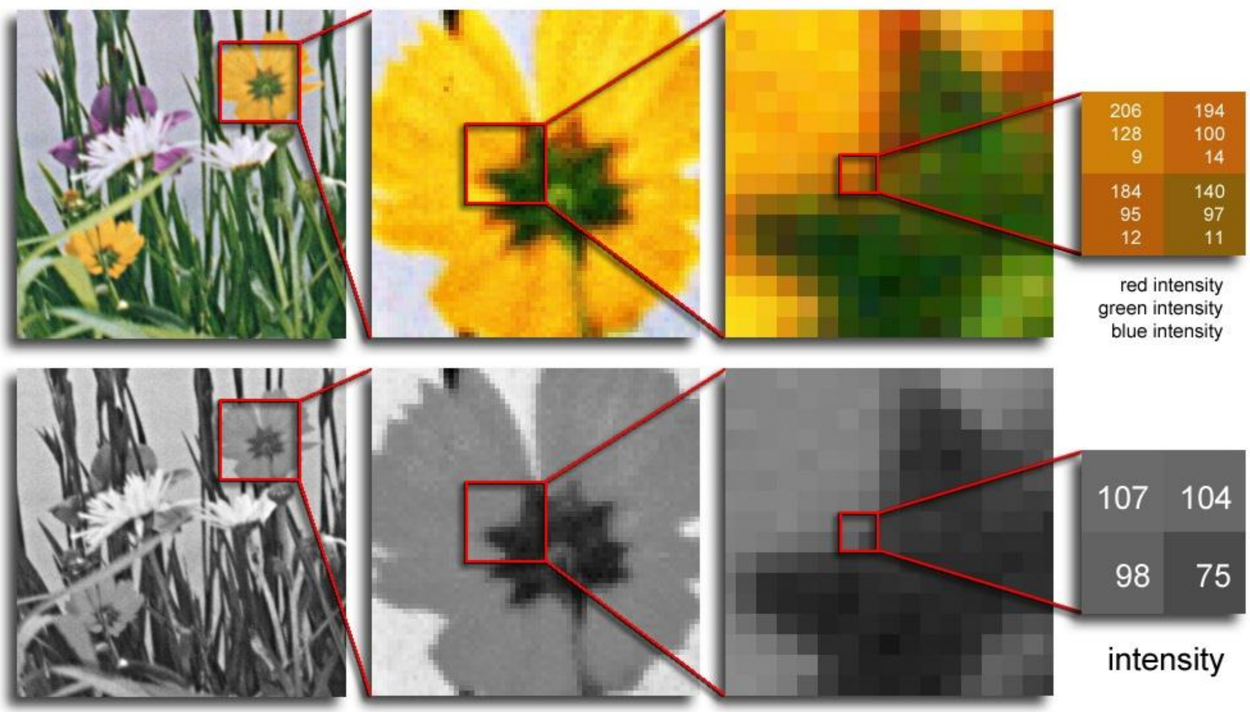
- For most of this course we will focus on grey-scale images

# Digital Image

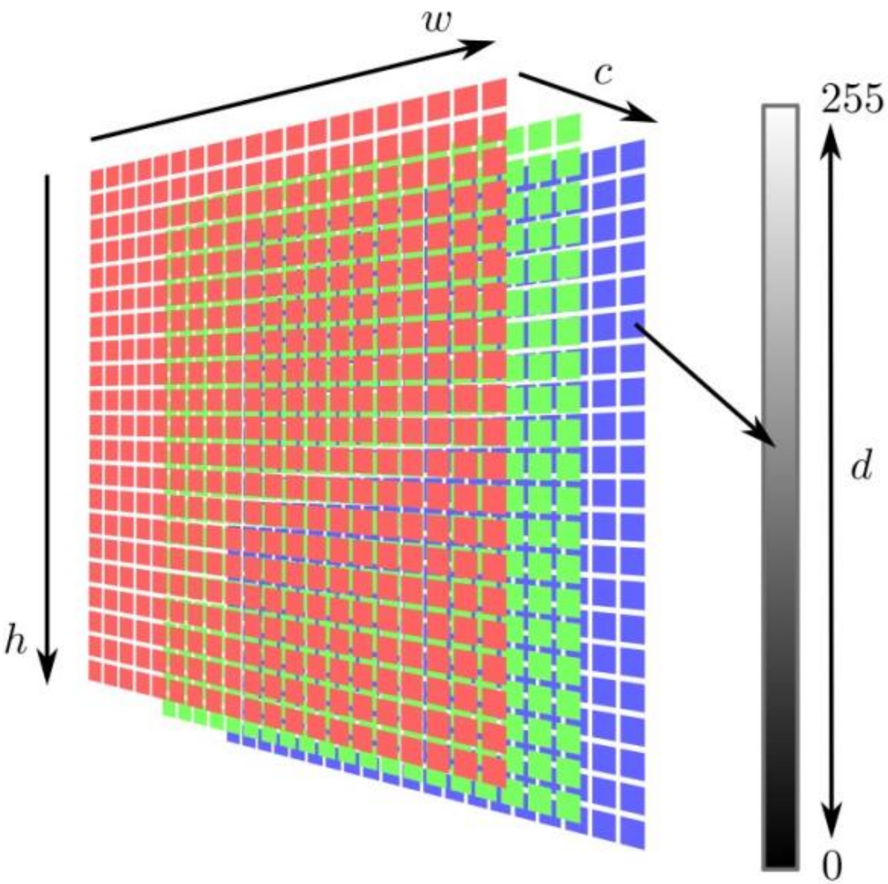
Color images have 3 values per pixel; monochrome images have 1 value per pixel.

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

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

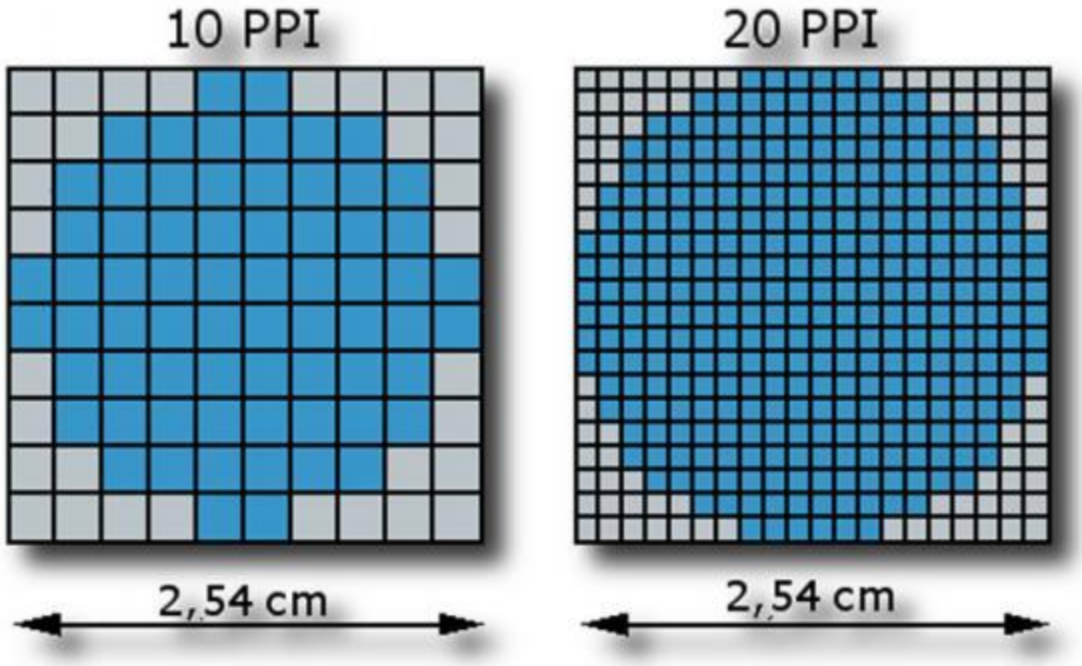


# Colored Images




| Color name | RGB triplet | Color |
|---|---|---|
| Red | (255, 0, 0) | |
| Lime | (0, 255, 0) | |
| Blue | (0, 0, 255) | |
| White | (255, 255, 255) | |
| Black | (0, 0, 0) | |
| Gray | (128, 128, 128) | |
| Fuchsia | (255, 0, 255) | |
| Yellow | (255, 255, 0) | |
| Aqua | (0, 255, 255) | |
| Silver | (192, 192, 192) | |
| Maroon | (128, 0, 0) | |
| Olive | (128, 128, 0) | |
| Green | (0, 128, 0) | |
| Teal | (0, 128, 128) | |
| Navy | (0, 0, 128) | |
| Purple | (128, 0, 128) | |

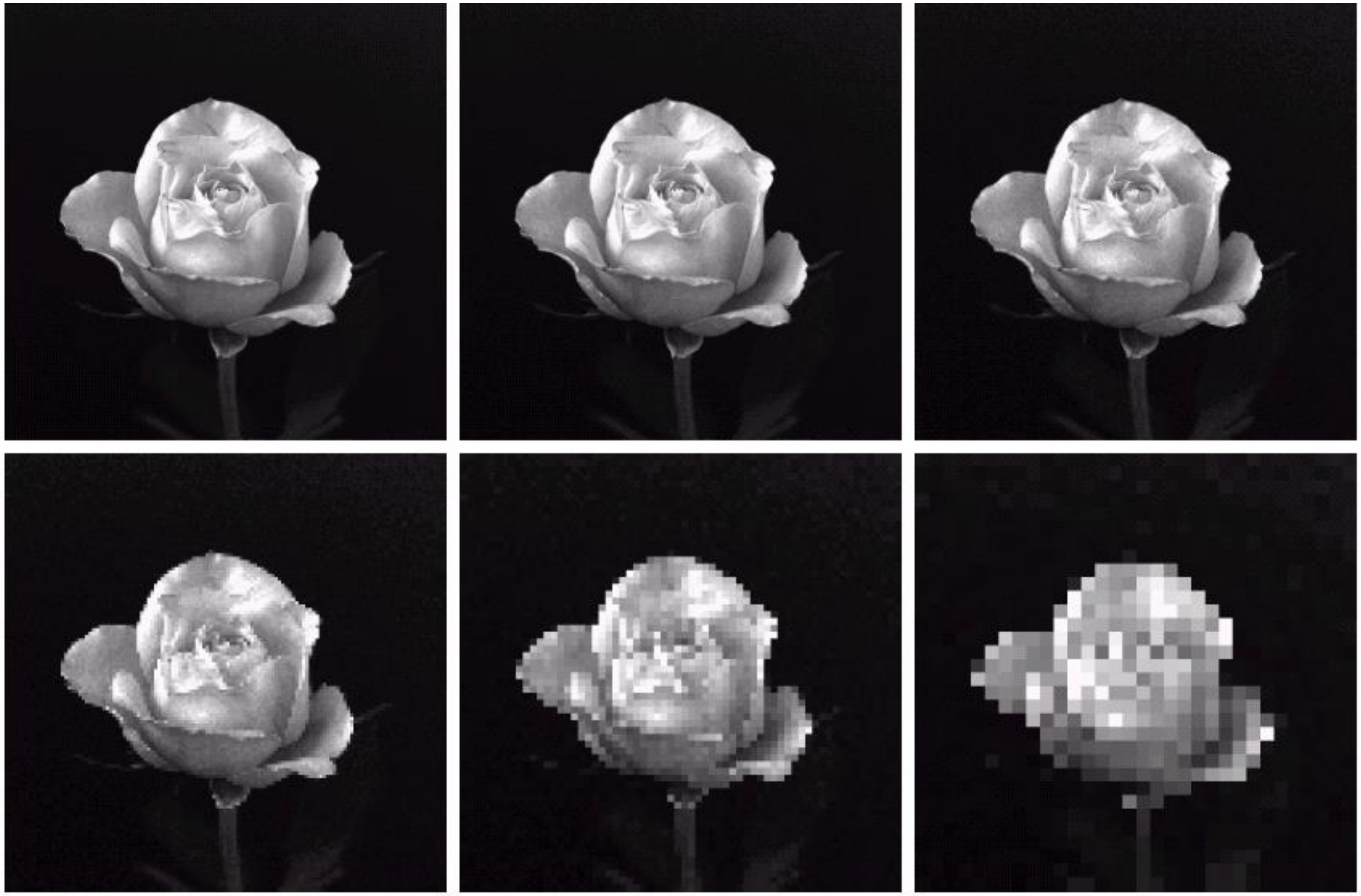
# Pixel Size



# Spatial & Gray Level Resolution

# Spatial Resolution

# Spatial Resolution



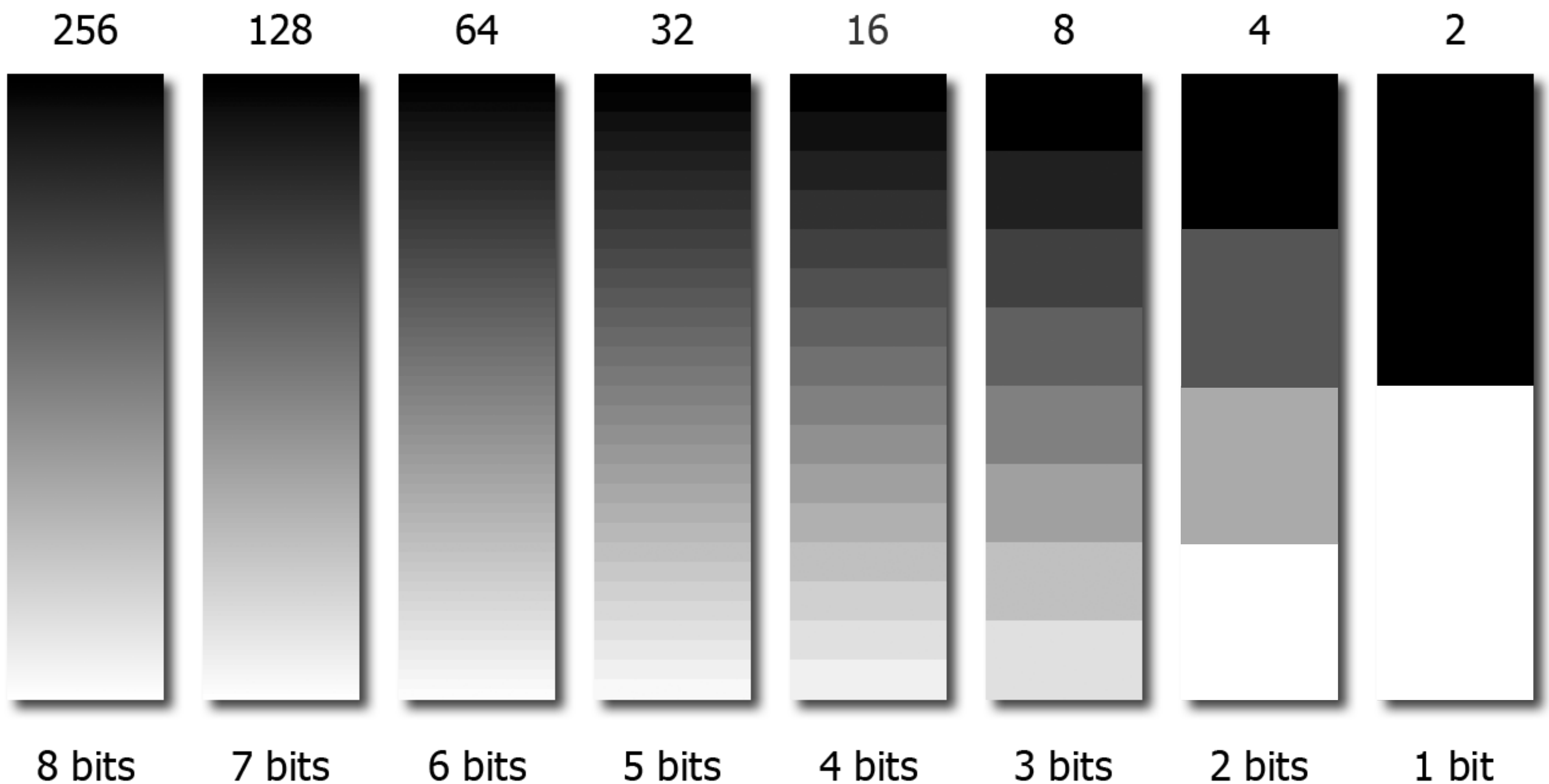
# Intensity Level Resolution

- *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

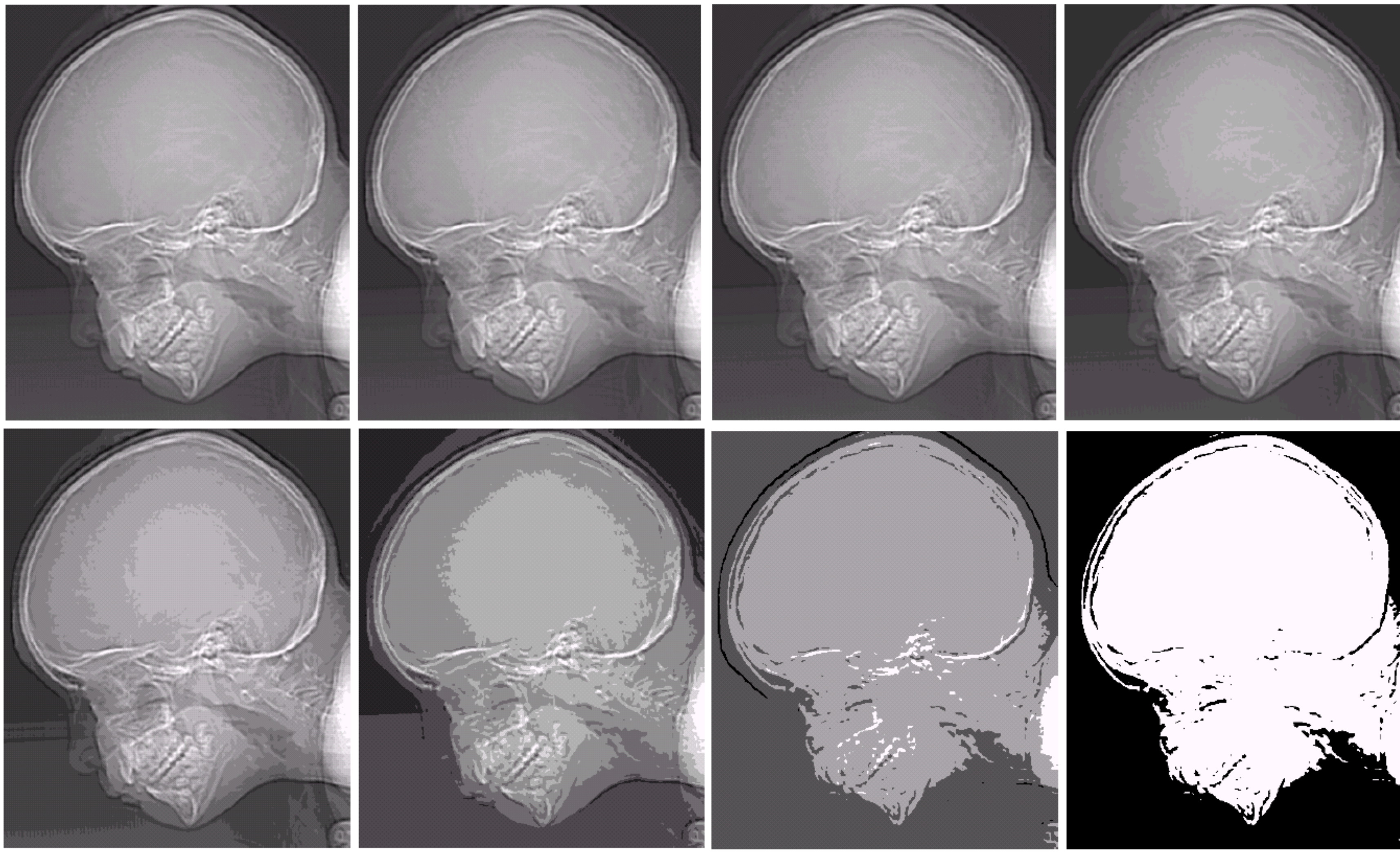
| Number of Bits | Number of Intensity Levels | Examples |
|---|---|---|
| 1 | 2 | 0, 1 |
| 2 | 4 | 00, 01, 10, 11 |
| 4 | 16 | 0000, 0101, 1111 |
| 8 | 256 | 00110011, 01010101 |
| 16 | 65,536 | 1010101010101010 |

# Intensity Level Resolution



# 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


# Today’s Learning Outcomes

- Major Sub Domains of Image Processing
  - Enhancement
  - Segmentation
  - Localization
  - Classification
- Digital Images & Pixels
- Image Resolution
  - Spatial Resolution
  - Intensity Resolution

# What's Next

- Image Processing Fundamentals
  - Pixel Neighbors
  - Connected Component Analysis
  - Basic Operations

# Readings from Book (3rd Edn.)

- Chapter – 1
- Chapter – 2

Read topics from 2.2 to 2.4 from book

# 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, 2018
- Machine Vision: Automated Visual Inspection and Robot Vision", David Vernon, Prentice Hall, 1991
- [www.eu.aibo.com/](http://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