Image Processing

Lecture 01: Introduction & Fundamentals

(Chapter1 Introduction & Chapter2 Digital Image Fundamentals)

Zhiguo Zhang

zhiguozhang@hit.edu.cn

Teacher

- Prof. ZHANG Zhiguo 张治国
  - Email: zhiguozhang@hit.edu.cn
  - Office: L1923

- **Experiences and Awards**
  - Listed in the World's Top 2% Scientists 2023 (by Stanford University)
  - National 1000 Youth Talents
  - Assistant Professor, Nanyang Technological University, Singapore (2015-2016)
  - Assistant Professor, The University of Hong Kong (2014)

- **Research interests**
  - Medical signal and image processing
  - Brain-computer interface
  - Medical AI

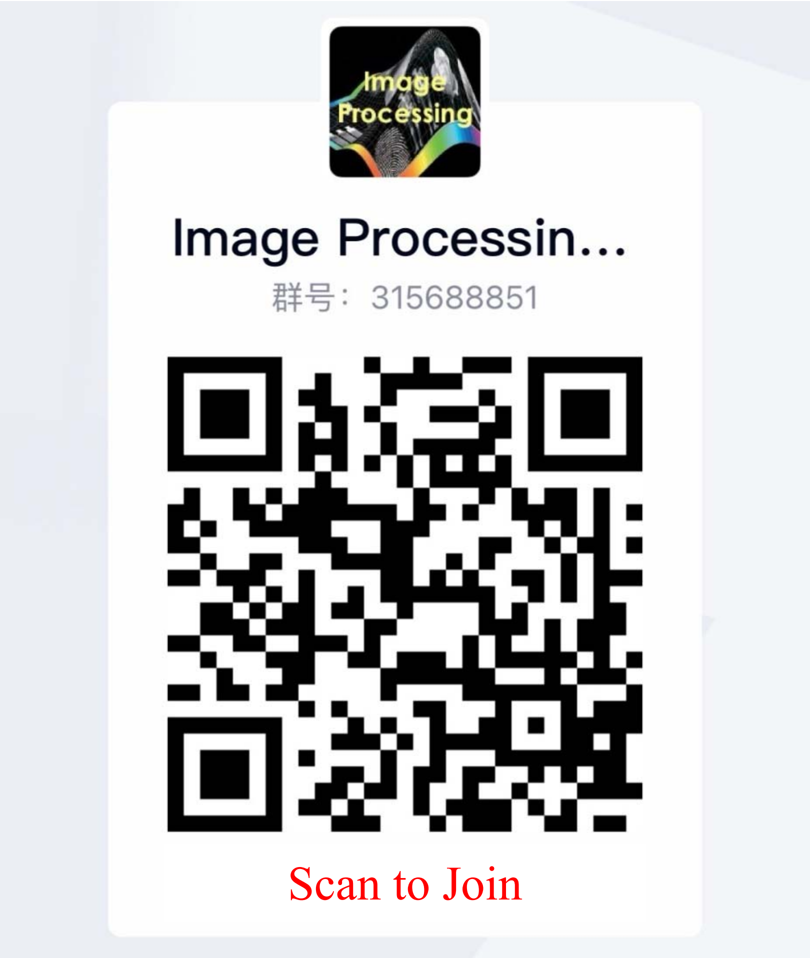
Teaching Assistant

- ZHAO Leilei 赵磊磊
  - Email:赵磊磊<24b951025@stu.hit.edu.cn>
  - xiongrishen@stu.hit.edu.cn
  - Office: L1909

- Duties: to grade assignments
  to answer questions about assignments
  to assist in preparing course materials

QQ/TIM Group

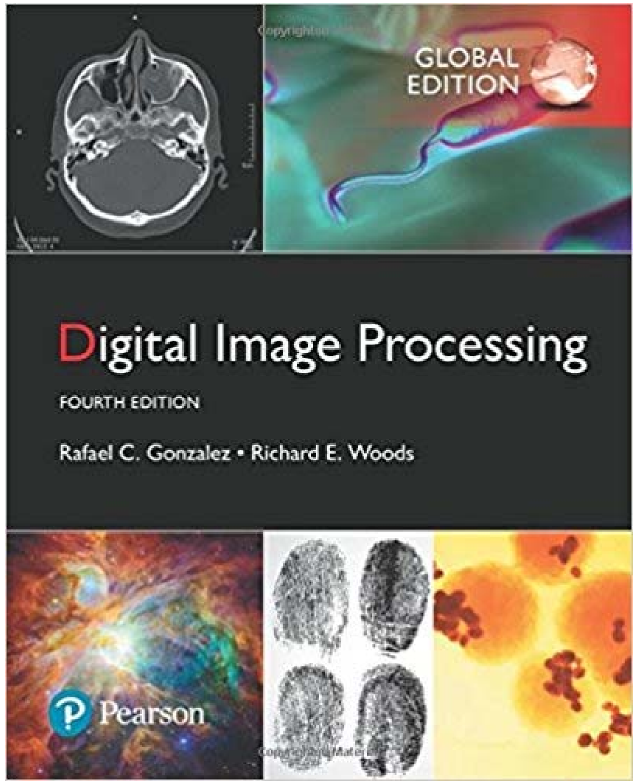
- You are encouraged to join the QQ/TIM group, where you can
  - ✓ contact me immediately
  - ✓ get my instant massages
  - ✓ download course materials
  - ✓ keep updated with any new information



Textbook and References

Textbook

Digital Image Processing, Rafael C. Gonzalez and Richard E. Woods, 4th Edition, Pearson, 2017



References

- The Image Processing Handbook, John C. Russ, 7th Edition, CRC Press, 2016.
- Fundamentals of Digital Image Processing: A Practical Approach with Examples in Matlab, Chris Solomon and Toby Breckon, Wiley, 2011.
- Python Image Processing Cookbook, Sandipan Dey, Packt Publishing, 2020.

Objectives

- To let you learn the fundamental principles and basic algorithms which are widely used in image processing.
- To equip you with the knowledge and experience of how to use computers to process images throughout a variety of case studies.
- To guide you to understand the trends and the state of art technologies in image processing.

Requirements

- **Prerequisites:** to have knowledge in linear algebra, probability theory, signals and systems, and programming in C++, Python, or MATLAB.
- To attend classes, submit project reports, and take exams.
- To develop programs in related topics using suitable programming languages.

Teaching and Learning Activities

- **Lectures:** Course content will be mainly introduced and explained through lectures (in total 16 lectures).

- **Projects:** Two small projects are intended to reinforce the knowledge learnt in lectures and to give students hands-on experience in image processing.

- **Homework (optional):** The after-school homework (with answers) in the textbook to help students consolidate classroom knowledge. It is optional and not graded.

Lecture Schedule

No.	Week	Date	Contents
1	5	Sep 23, 2024	Ch1 Introduction & Ch2 Digital Image Fundamentals
2	5	Sep 25, 2024	Ch3 Intensity Transformation and Spatial Filtering - I
3	6	Sep 30, 2024	Ch3 Intensity Transformation and Spatial Filtering – II
4	7	Oct 09, 2024	Ch4 Filtering in the Frequency Domain
5	8	Oct 14, 2024	Ch5 Image Restoration and Reconstruction
6	8	Oct 16, 2024	Ch6 Color image processing – I
7	9	Oct 21, 2024	Ch6 Color image processing – II
8	9	Oct 23, 2024	Ch7 Wavelet and Other Image Transforms
9	10	Oct 28, 2024	Ch8 Image Compression and Watermarking – I
10	10	Oct 30, 2024	Ch8 Image Compression and Watermarking – II
11	11	Nov 04, 2024	Ch9 Morphological Image Processing – I
12	11	Nov 06, 2024	Ch9 Morphological Image Processing – II
13	12	Nov 11, 2024	Ch10 Image Segmentation – I
14	12	Nov 13, 2024	Ch10 Image Segmentation – II
15	13	Nov 18, 2024	Ch11 Feature Extraction
16	13	Nov 20, 2024	Ch12 Image Pattern Classification

Assessment

Assessment Type	Percentage of Total Assessment (%)
Final Examination A 2-hour open-book examination	**60%**
Projects Two projects, each accounting for 15%	**30%**
Attendance 80% attendance is the minimum requirement	**10%**

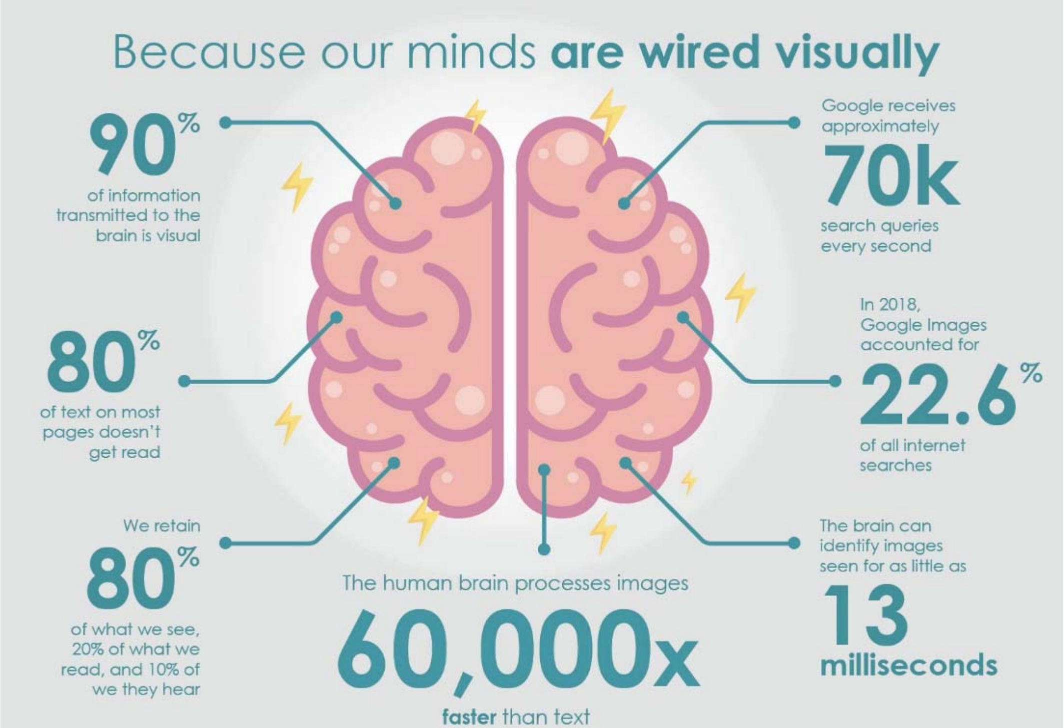
Best Luck!

Contents of This Lecture

- What is Image Processing?
- Human Vision System
- Image Acquisition
- Sampling and Quantization
- Resolution
- Basic Relationships between Pixels
- Key Stages in Image Processing

Introduction

- **We are 90% visual beings.**
- One picture is worth more than ten thousand words.
- The proportion of the human brain receiving external information through vision accounts for round 90% of all senses.



What is an Image?

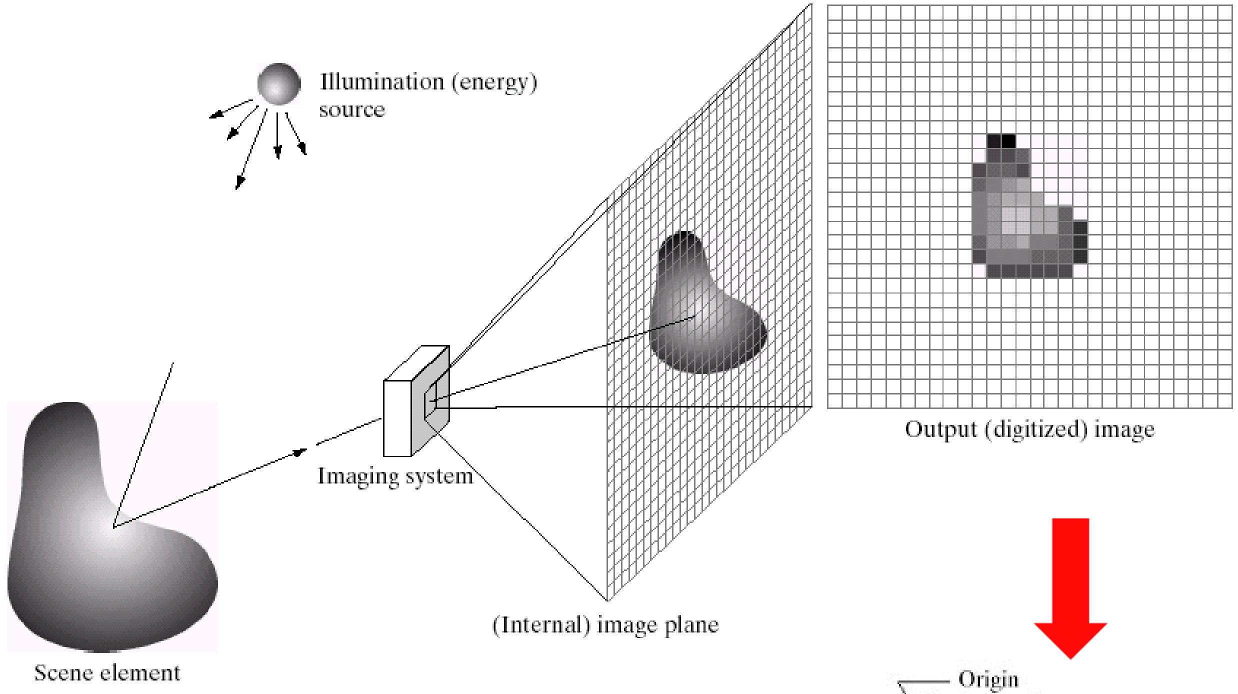
- An **image** can be defined as a two-dimensional function, $f(x, y)$, where x and y are spatial coordinates, and the amplitude of f at any pair of coordinates (x, y) is the **intensity** or **gray level** of the image at that point.
- The description of a **digital image**, when x, y and the amplitude values of f are (1) finite and (2) discrete quantities.
- Each of element having a particular location and values, these elements are called: pixels.

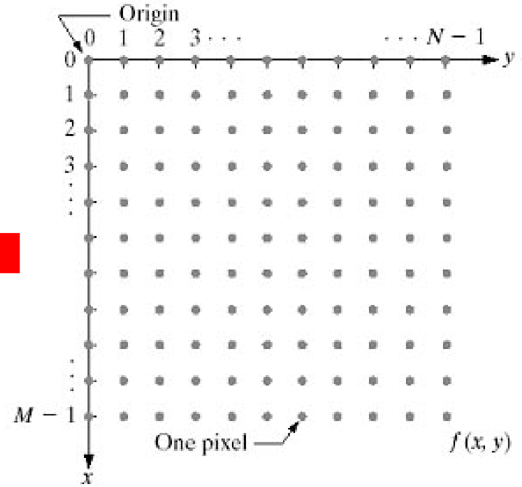
What is a Digital Image?

- Alternative definition: a digital image refers to an image which is stored in a digital format.
- Most of the photos, advertisement, poster that we see are analog images.
- We can digitize them by using a scanner, a digital camera, or a smart phone.

- We only discuss digital images in this course.

What is a Digital Image?

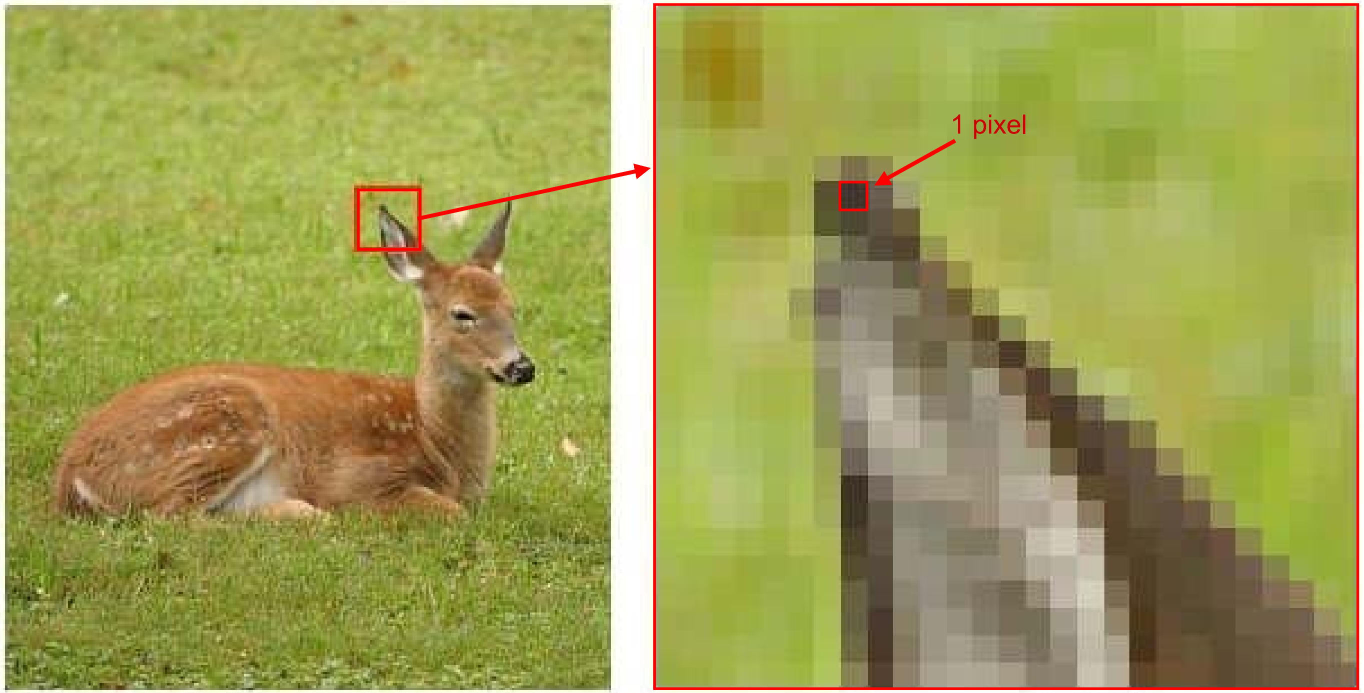




$$f(x,y)=\begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0,n-1) \\ f(1,0) & f(1,1) & \cdots & f(1,n-1) \\ \vdots & \vdots & & \vdots \\ f(m-1,0) & f(m-1,1) & \cdots & f(m-1,n-1) \end{bmatrix}$$

What is a Digital Image?

- Pixel values typically represent gray levels, colors, opacities, etc.
- *Digitization* implies that a digital image is an *approximation* of a real scene



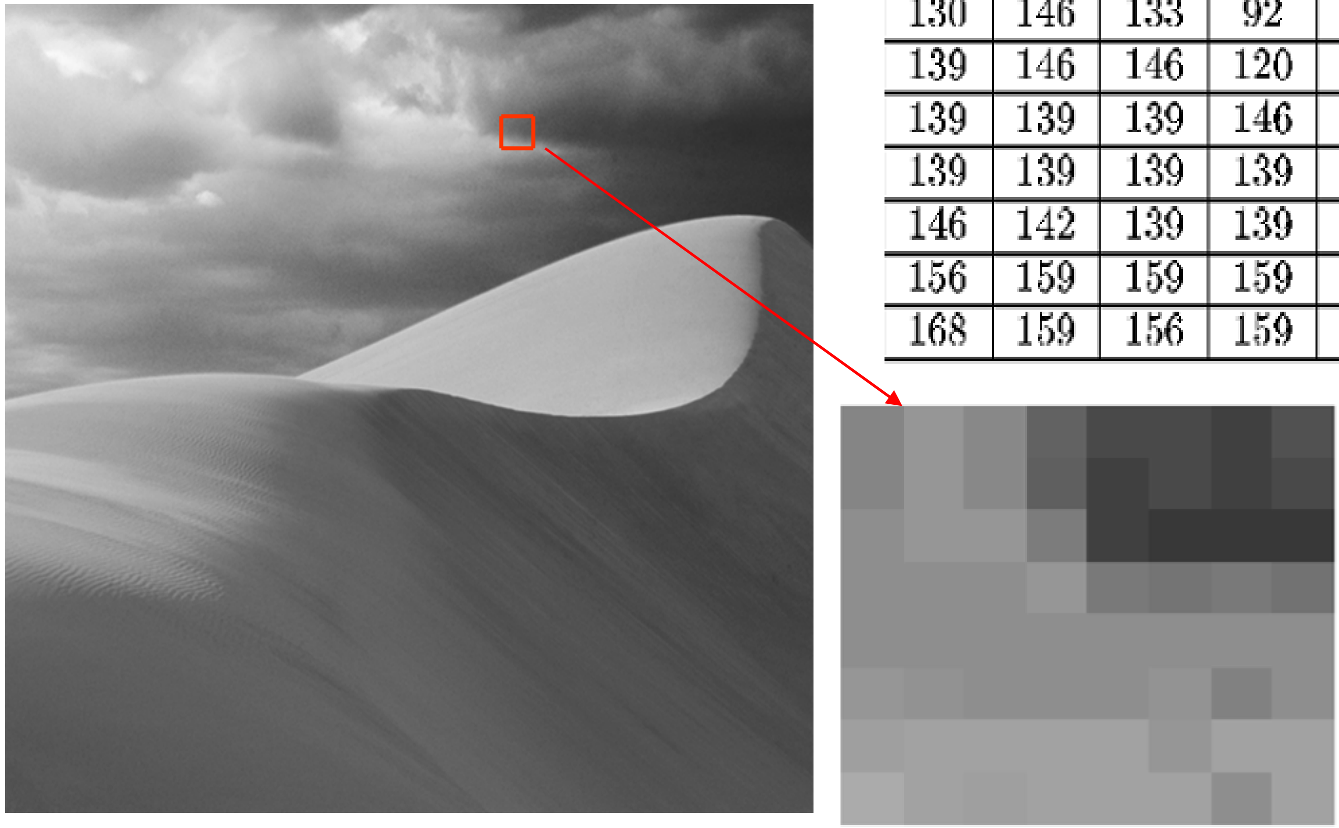
What is a Digital Image?

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



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

What is a Digital Image?



130	146	133	95	71	71	62	78
130	146	133	92	62	71	62	71
139	146	146	120	62	55	55	55
139	139	139	146	117	112	117	110
139	139	139	139	139	139	139	139
146	142	139	139	139	143	125	139
156	159	159	159	159	146	159	159
168	159	156	159	159	159	139	159

8×8

What is Image Processing?

- **Image processing:**
  - **processing digital images by means of a digital computer**

- Digital image processing focuses on two major tasks
  - Improvement of image quality for human interpretation
  - Processing of image data for storage, transmission, display and representation for automatic machine perception

What is Image Processing?

- Some argument about where image processing ends and fields such as **image analysis** and **computer vision** start.
- The continuum from **image processing** to **computer vision** can be broken up into 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 **Output:** Understanding
Examples: Noise removal, image sharpening	**Examples:** Edge detection, segmentation	**Examples:** Scene understanding, autonomous navigation

In this course we will stop here

What is Image Processing?

Remarks:

- Image processing: human is the final explainer.
- Computer vision: computer is the final explainer.
- Computer vision needs the support of image processing.
- Image processing to computer vision is a process from low level to high level processing.

Related Fields and Applications

✓Computer Vision

✓Graphics

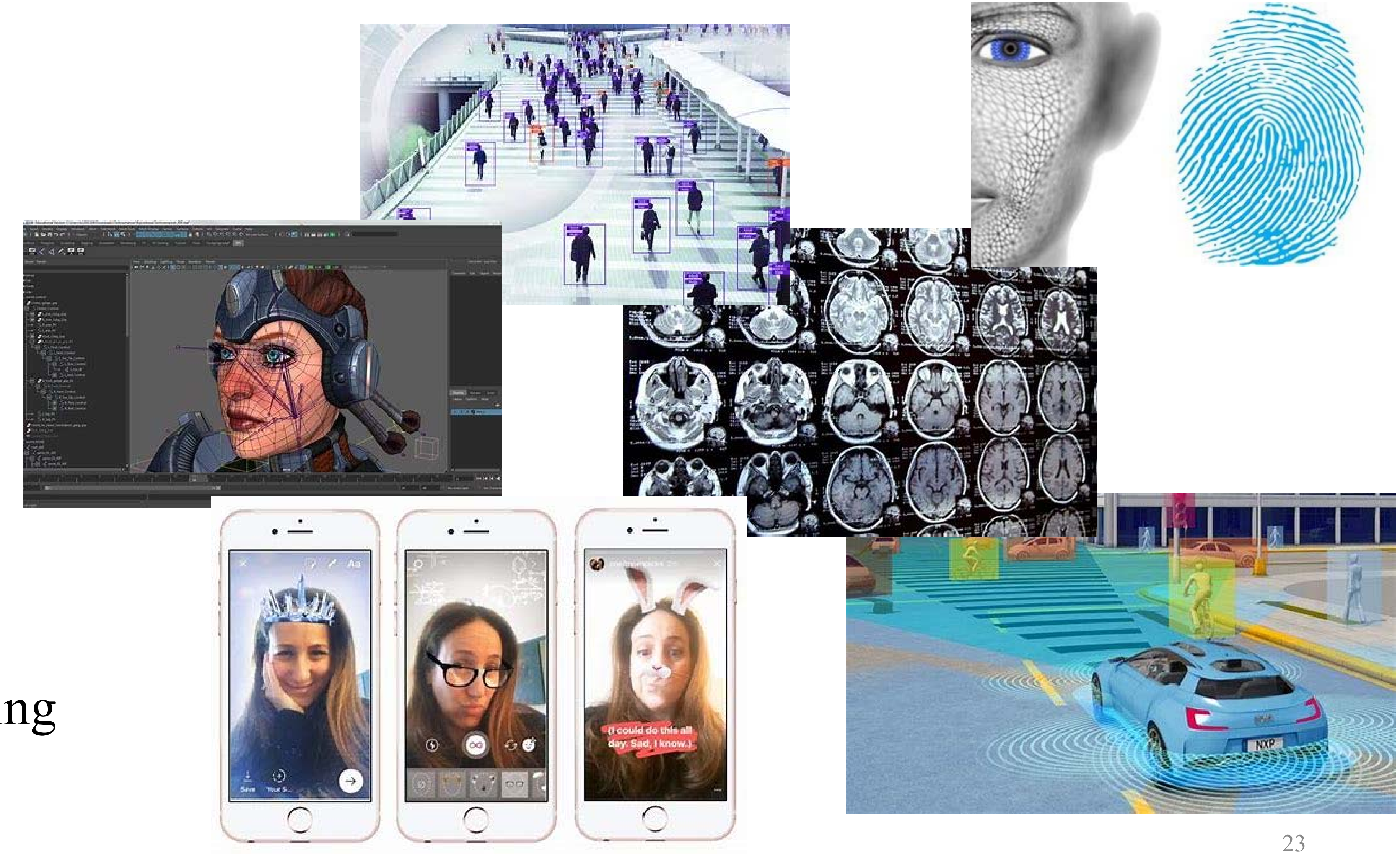
✓Image Retrieval

✓Biometrics

✓Medical AI

✓Robotics

✓Autonomous Driving

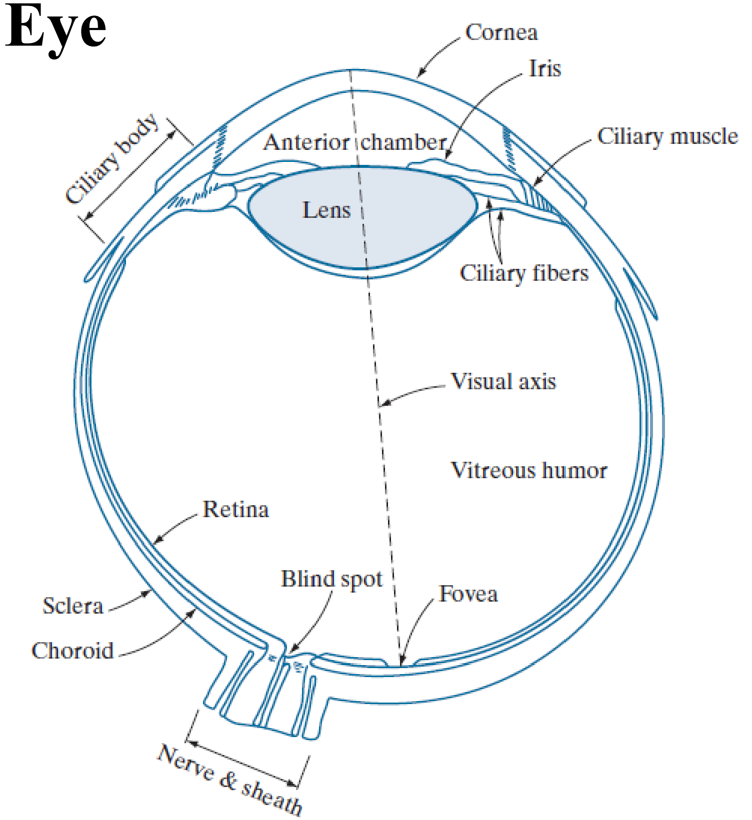


Human Visual System

- The best vision model we have!
- Knowledge of how images form in the eye can help us processing digital images.

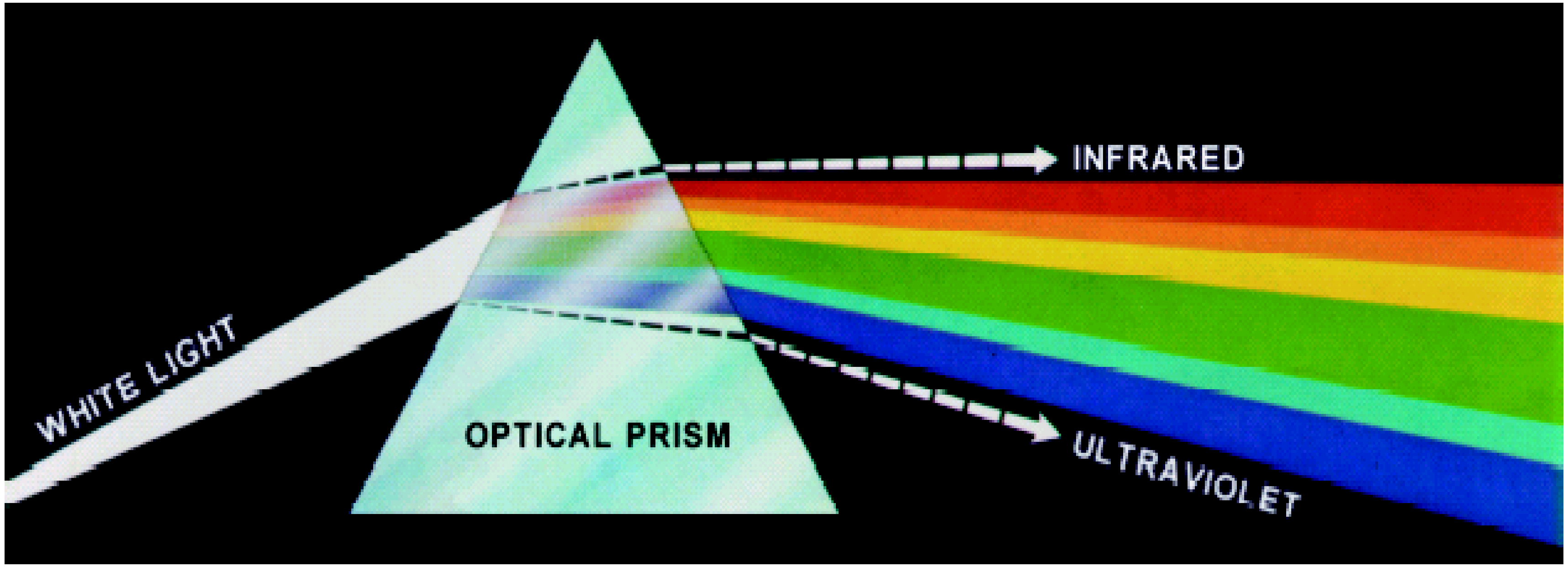
Structure of the Human Eye

- The lens focuses light from objects onto the retina.
- The retina is covered with light receptors called *cones* (6-7 million) and *rods* (75-150 million).
- Cones are concentrated around the fovea and are very sensitive to colour.
- Rods are more spread out and are sensitive to low levels of illumination.



Light and the Electromagnetic Spectrum

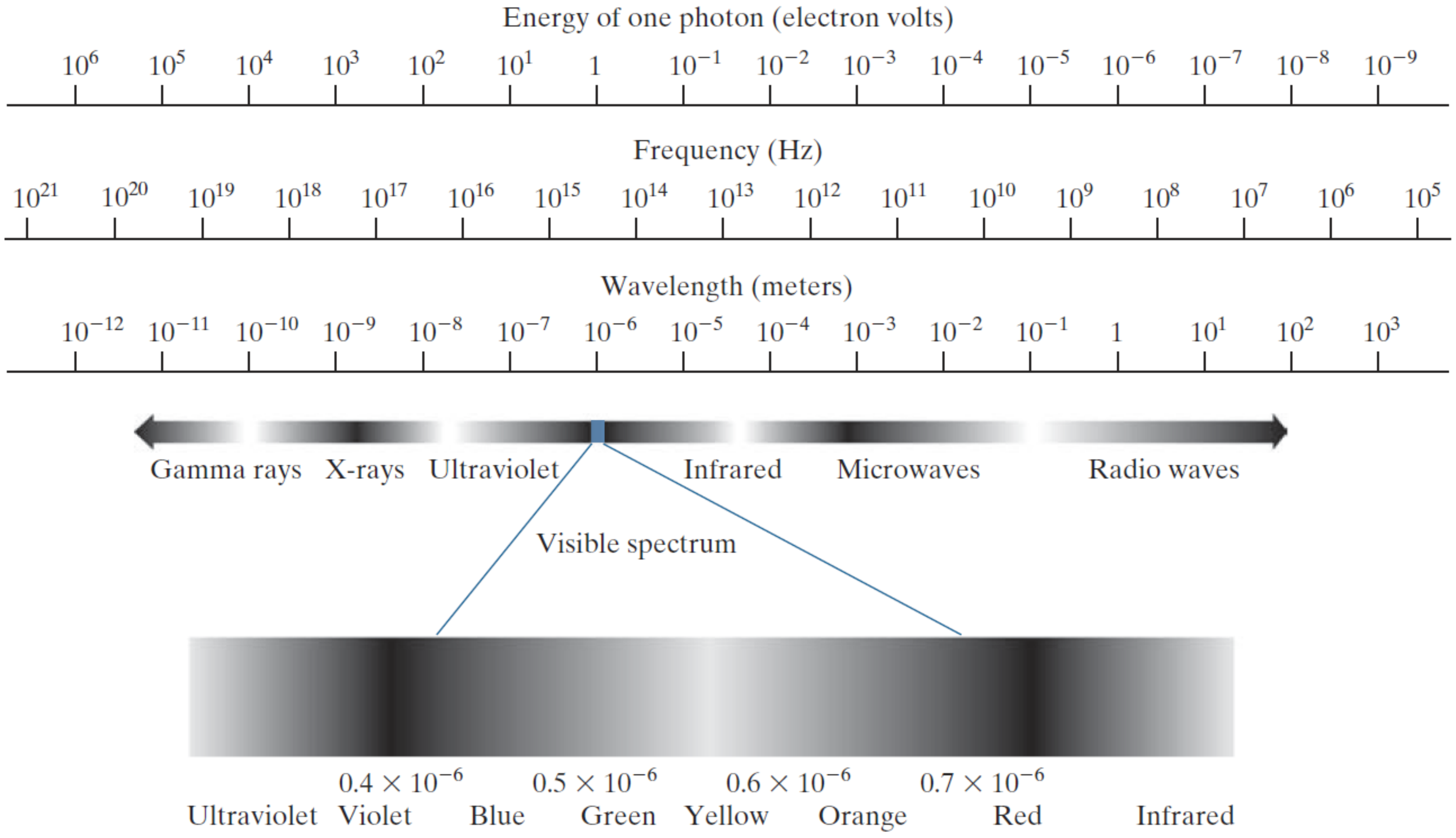
- Violet, Blue, Green, Yellow, Orange, and Red Blends smoothly into the next. (Newton, 1666)



- Light is just a particular part of the electromagnetic spectrum that can be sensed by the human eye.

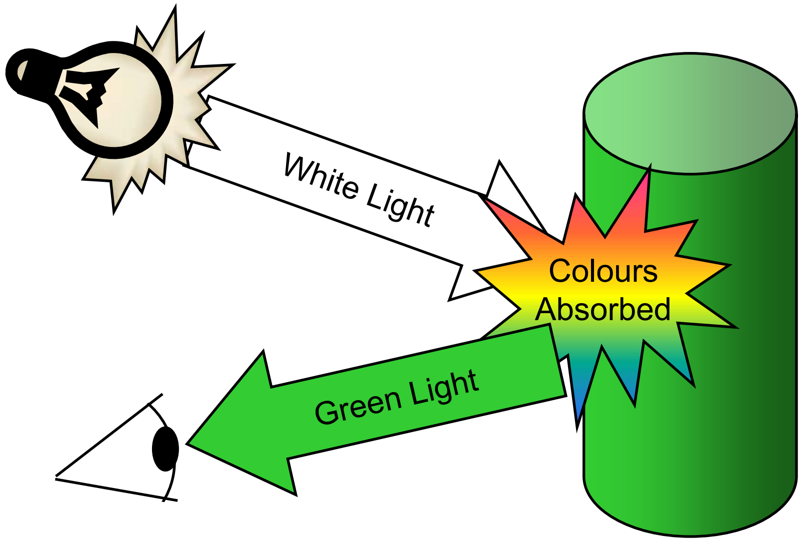
Light and the Electromagnetic Spectrum

The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanations, but note that it encompasses a very narrow range of the total EM spectrum.



Light and the Electromagnetic Spectrum

- The colours that we perceive are determined by the nature of the light reflected from an object.
- For example, if white light is shone onto a green object, most wavelengths are absorbed, while green light is reflected from the object.

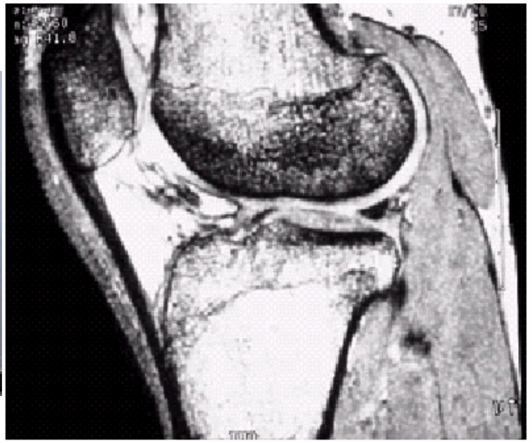


Light and the Electromagnetic Spectrum

- Gamma Rays
  - Medical Imaging
  - Astronomical Imaging
- Hard X Rays
  - Industrial Applications
- Soft X Rays
  - Chest X-Ray (shorter wavelength end)
  - Dental X-Ray (lower energy end)
- Ultraviolet
  - Microscopy Imaging
- Visible Spectrum
  - Too many applications around us
- Infrared Region
  - Near-infrared
  - Far-Infrared
- Microwave
  - Microwave Ovens, Communication, Radar
- Radiowave
  - AM, FM, TV, and Medical imaging

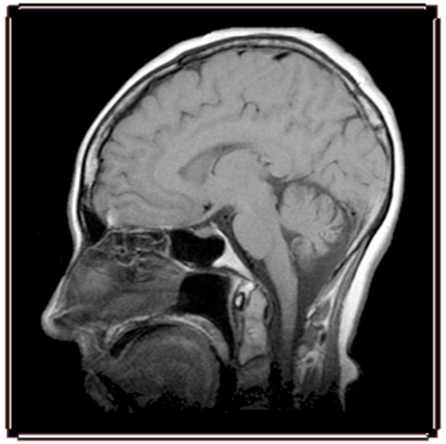
Magnetic Resonance Imaging

Operate in radio frequency

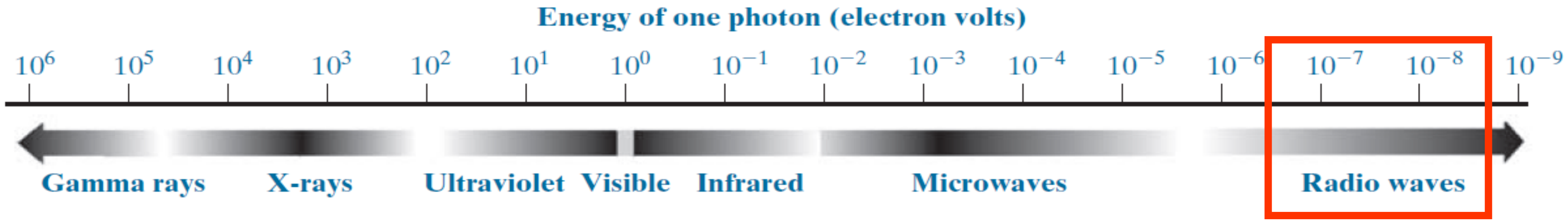


knee

spine

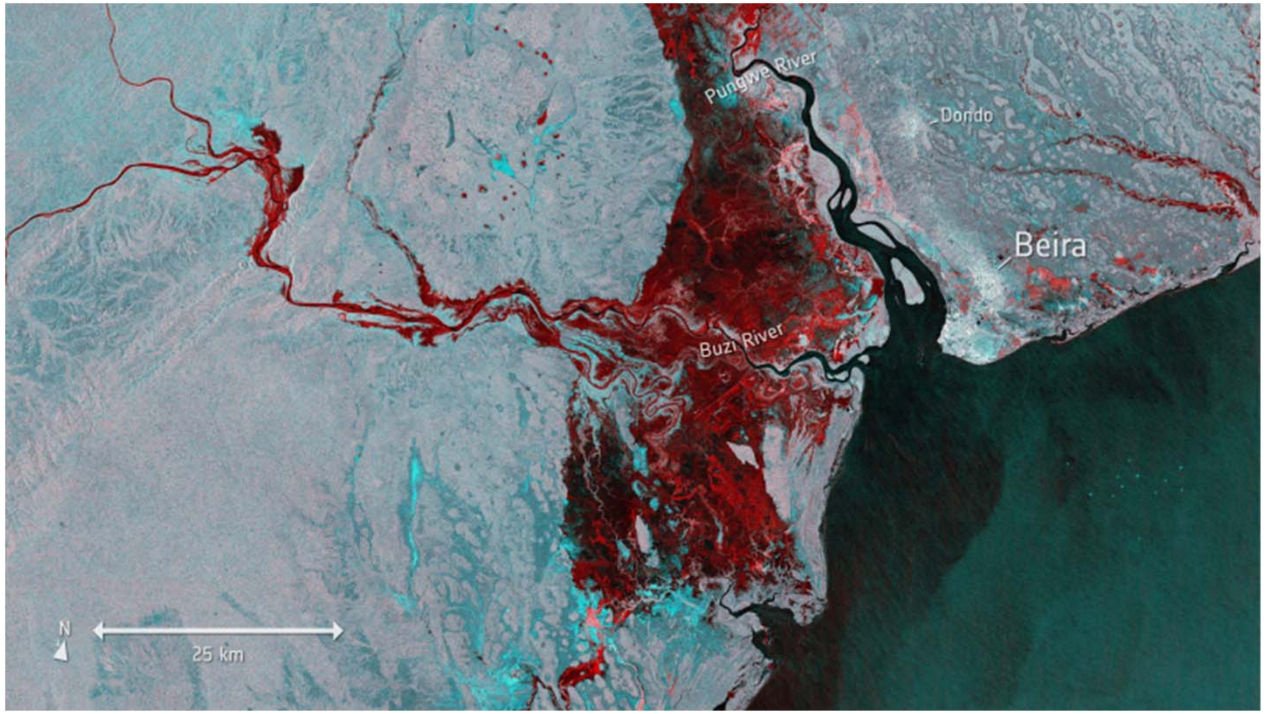


head

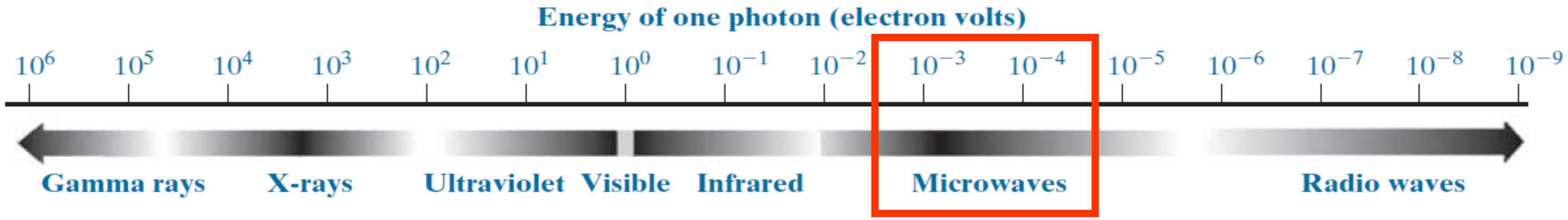


Radar Imaging

Operate in microwave frequency

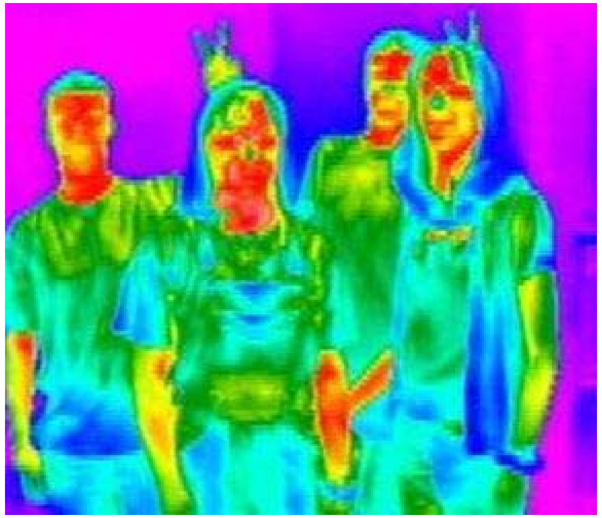


Flood mapping with synthetic aperture radar

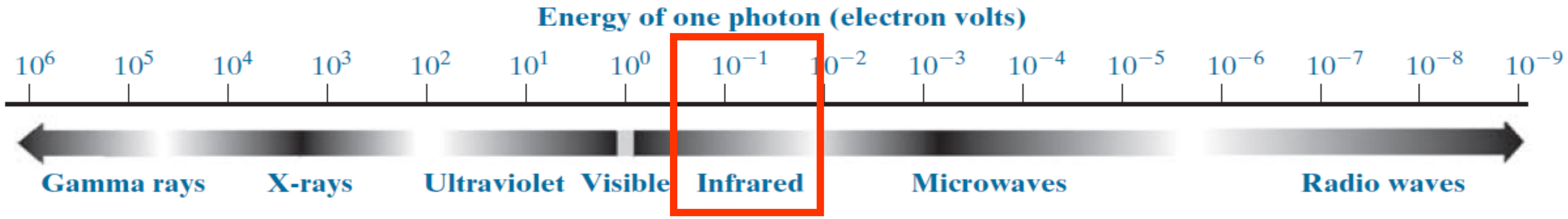


Thermal Imaging

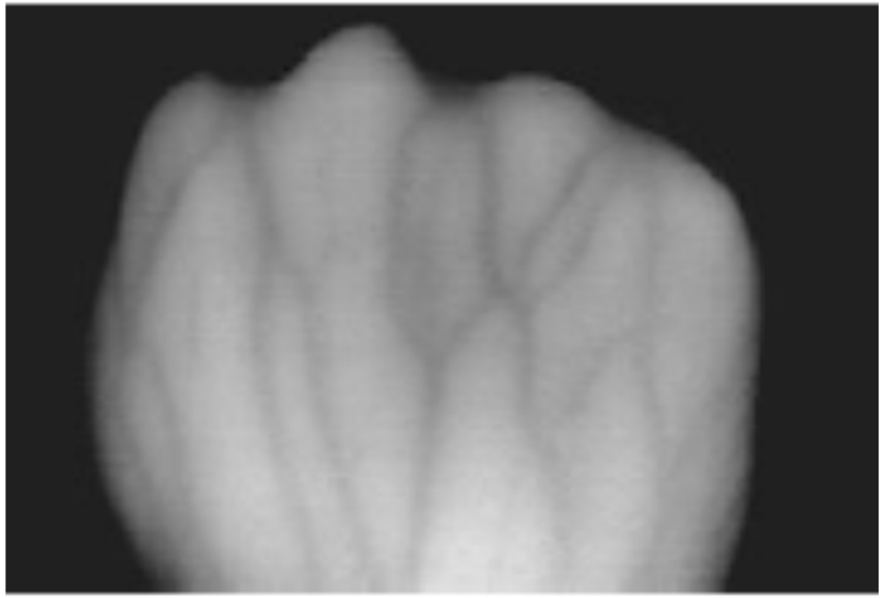
Operate in far infrared frequency



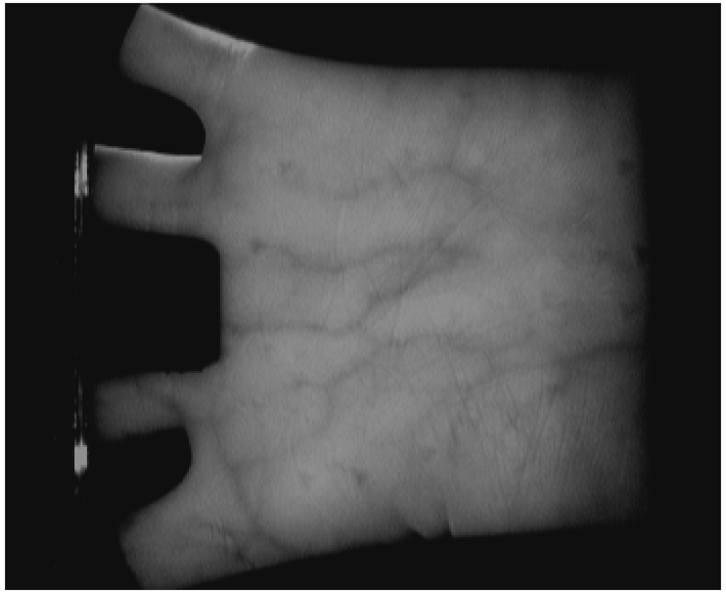
Human body disperses heat (red pixels)



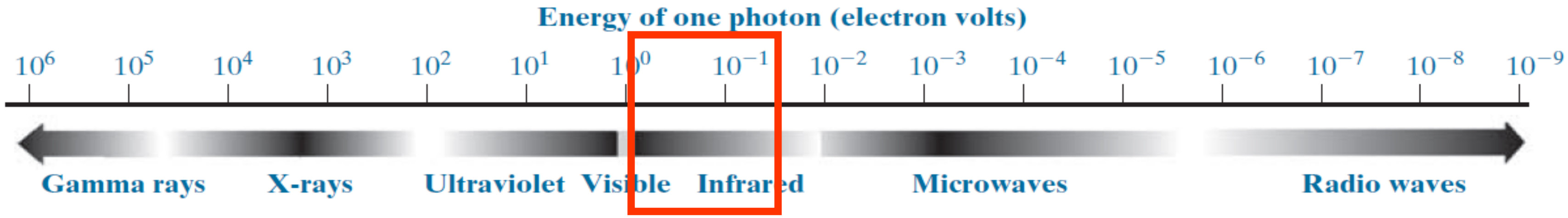
Near Infrared Imaging



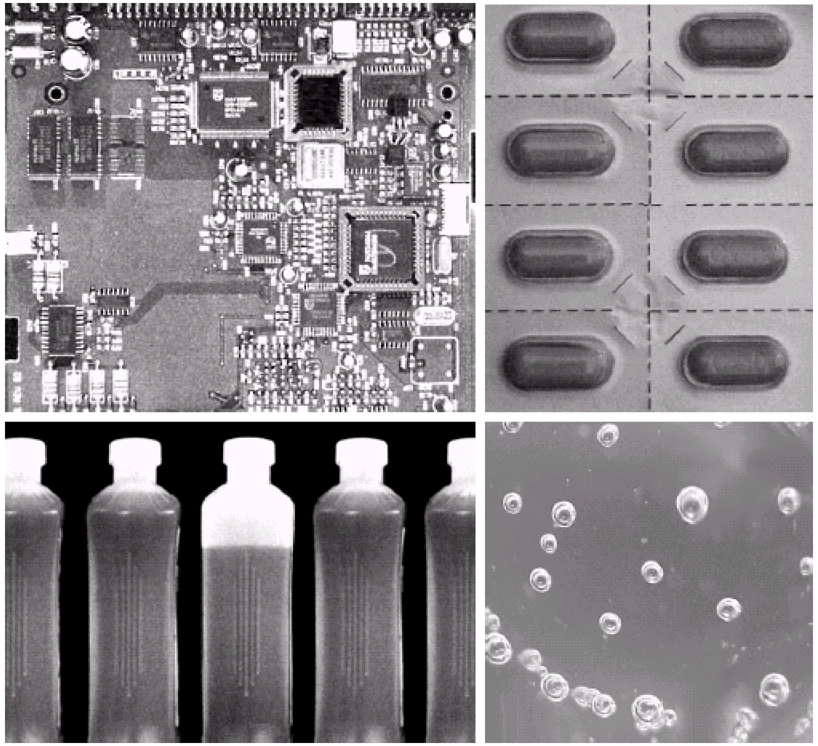
Hand Vein

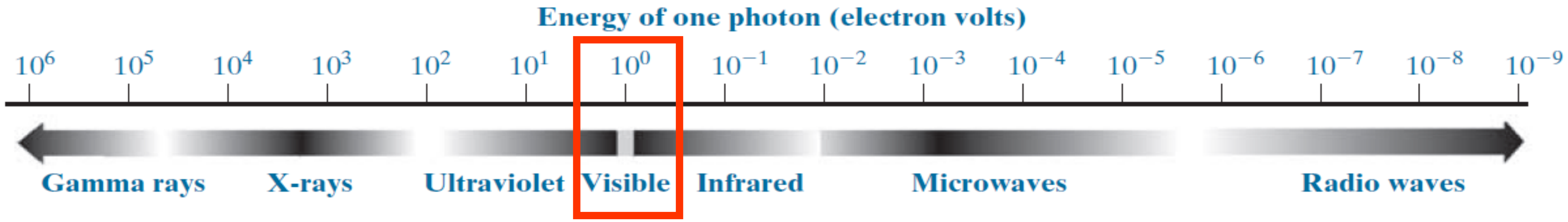


Palm Vein



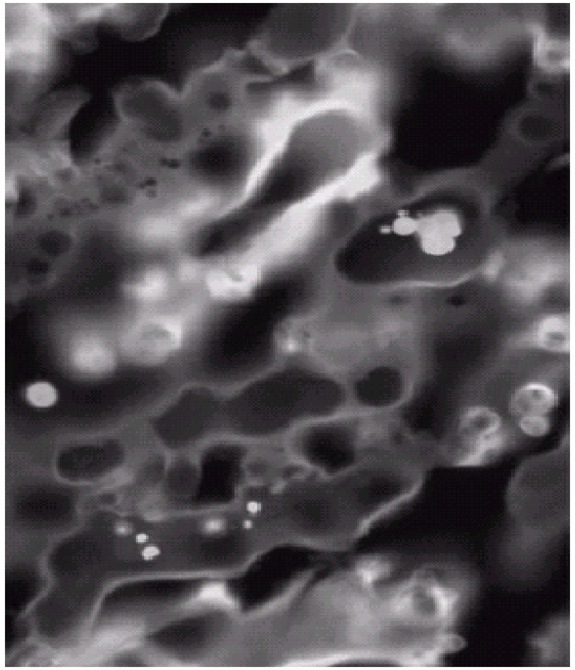
Visible Imaging



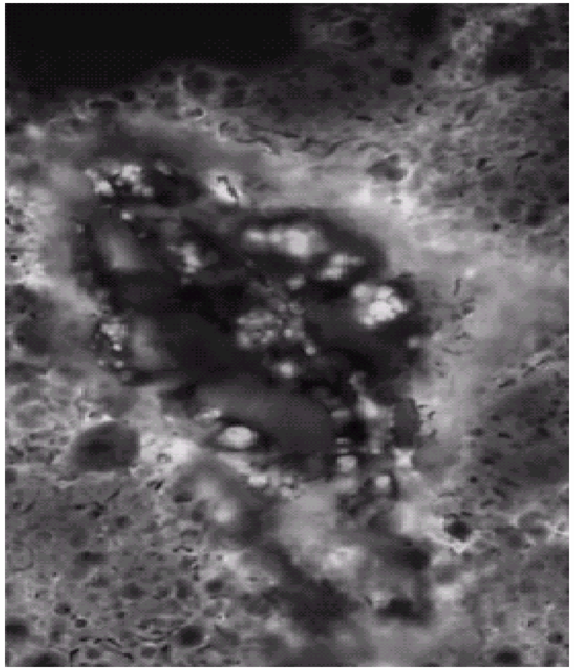


Fluorescence Microscopy Imaging

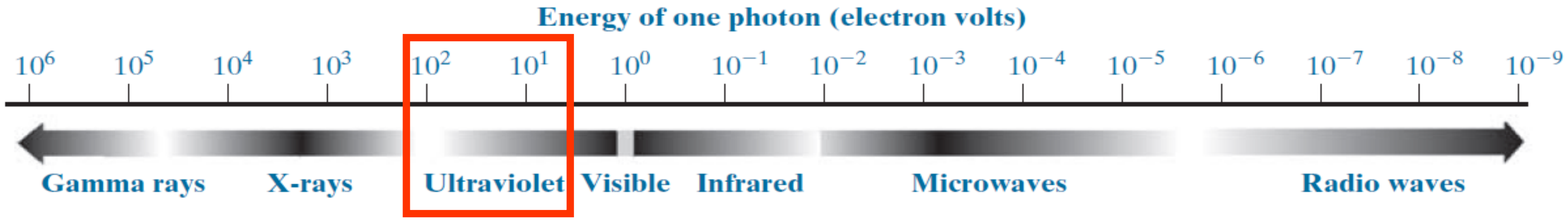
Operate in ultraviolet frequency



normal corn

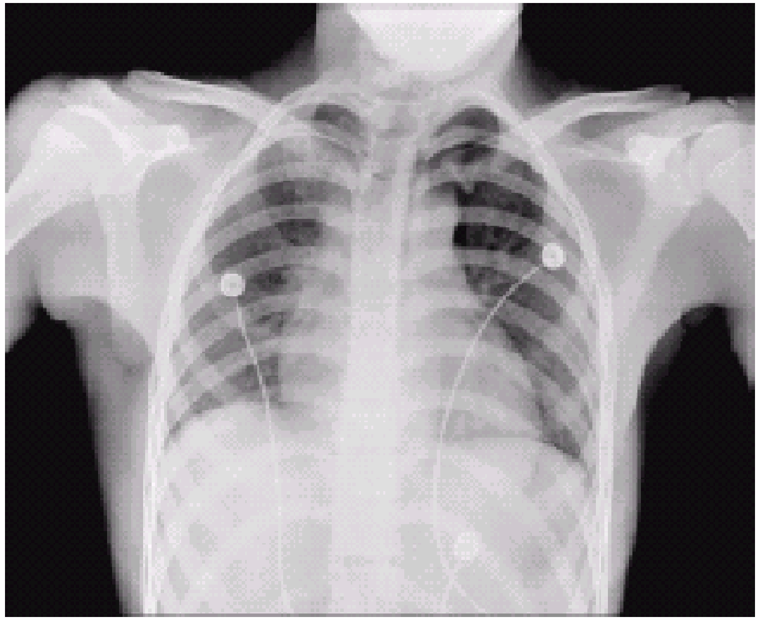


smut corn

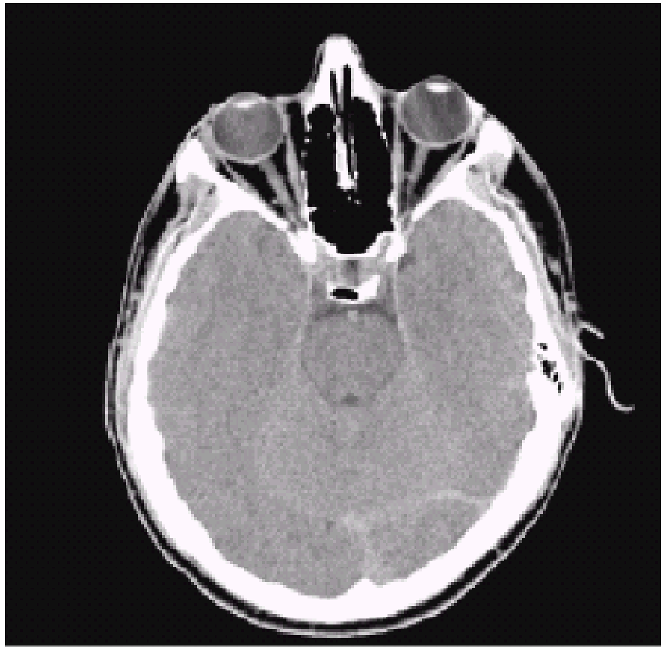


X-ray Imaging

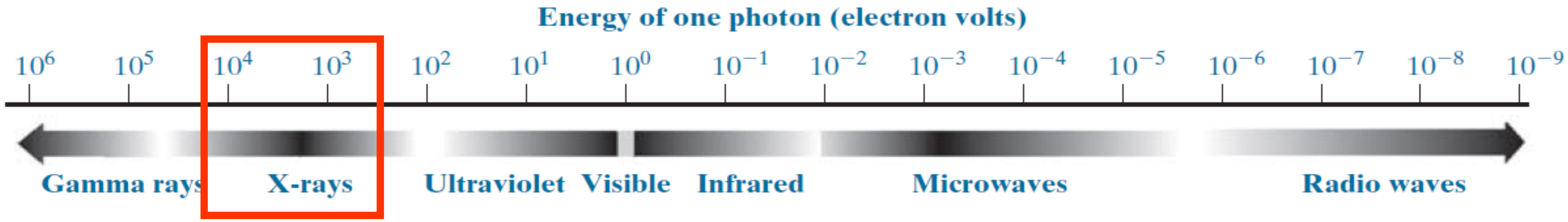
Operate in X-ray frequency



chest

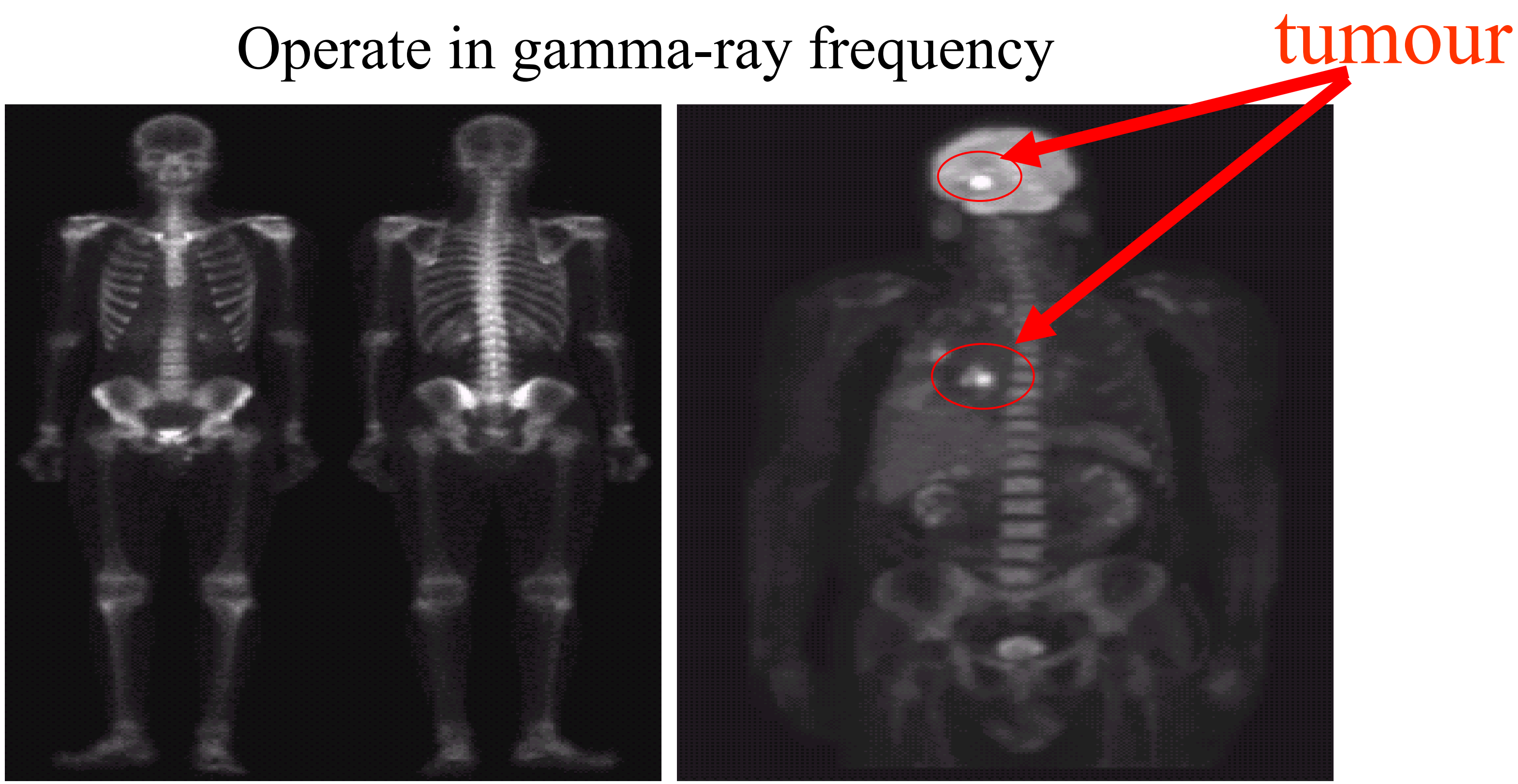


head



Positron Emission Tomography

Operate in gamma-ray frequency



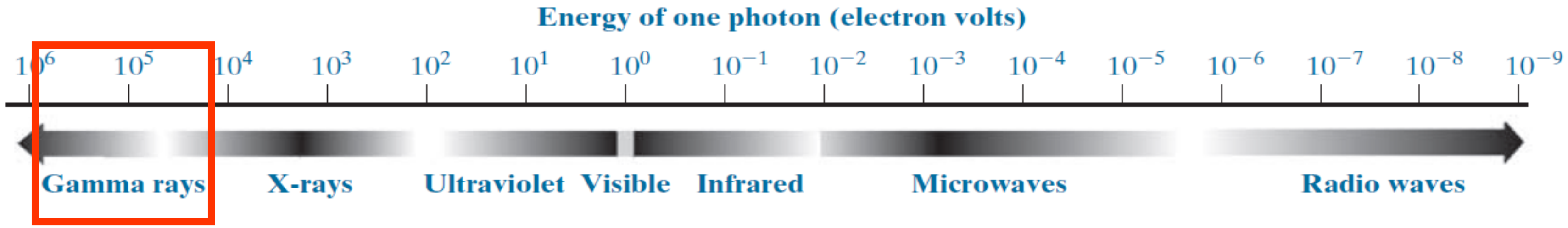
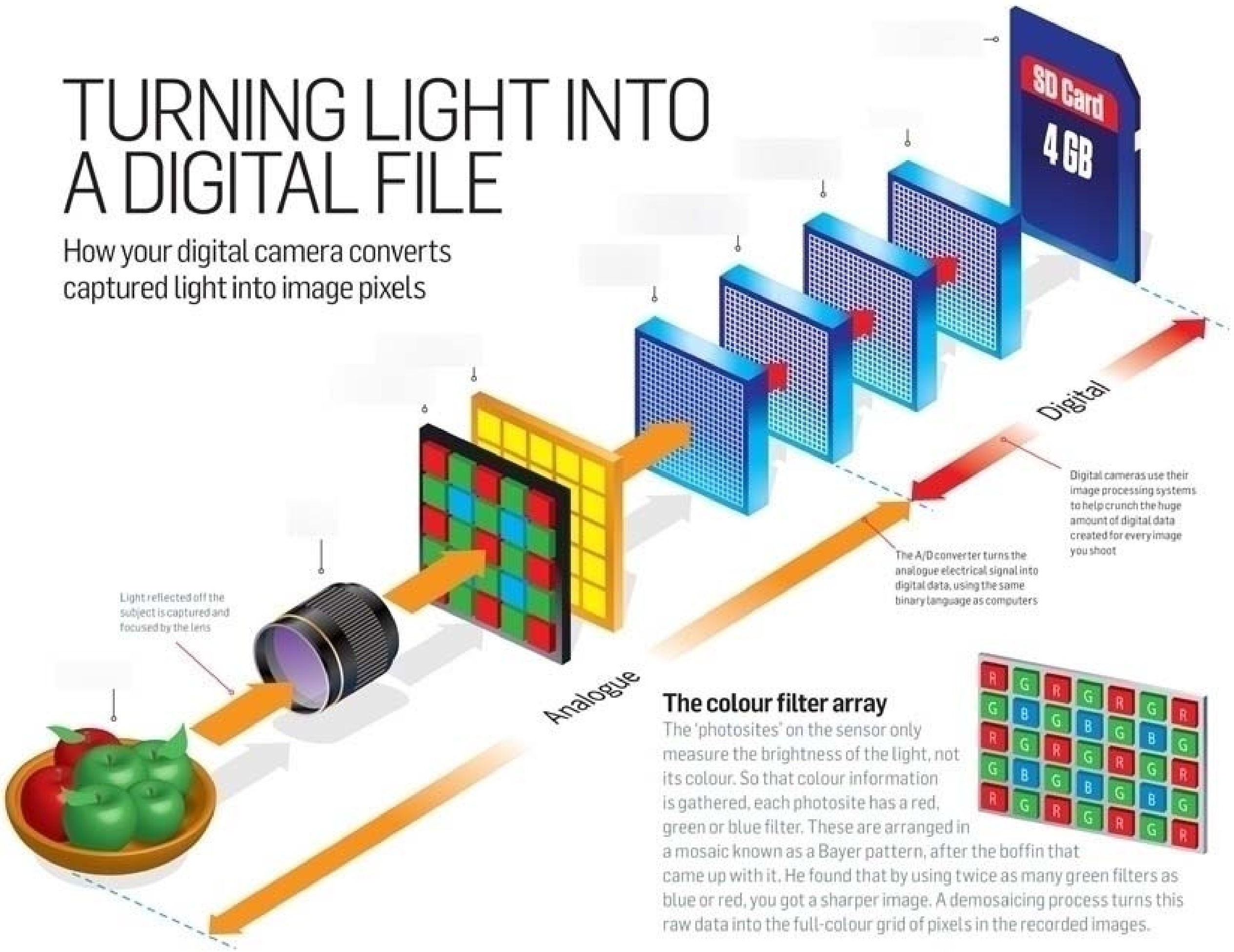


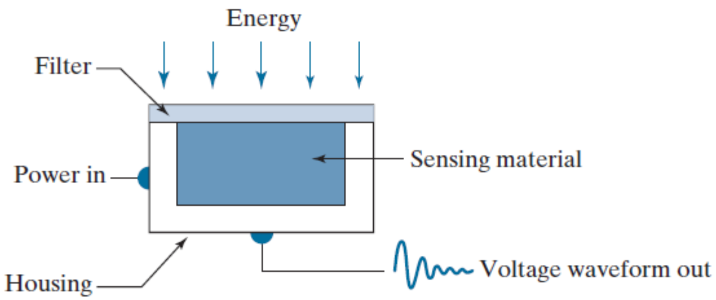
Image Acquisition

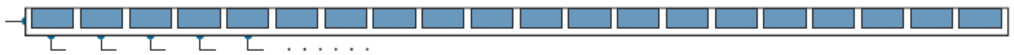
- Images are typically generated by *illuminating* a *scene* and absorbing the energy reflected by the objects in that scene.

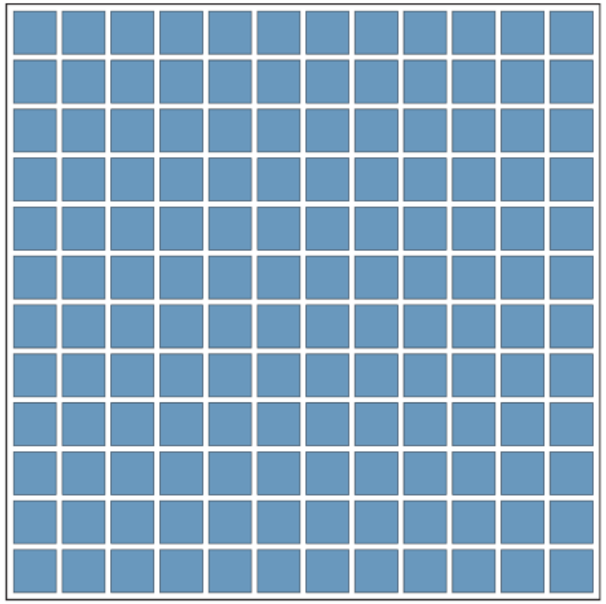


Imaging Sensors

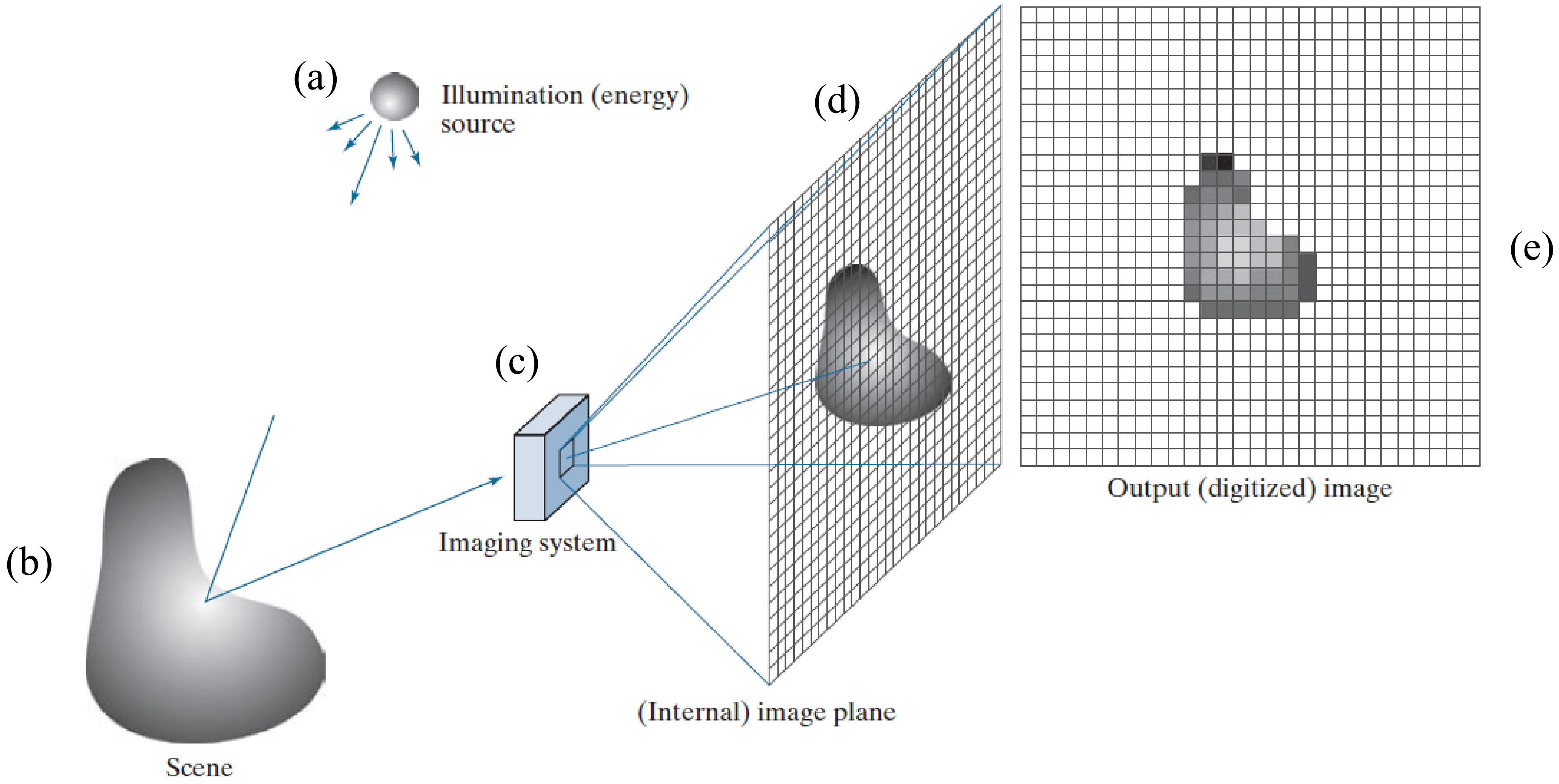
- Image acquisition sensors
  - Single sensor
  - Line sensor
  - Array sensor







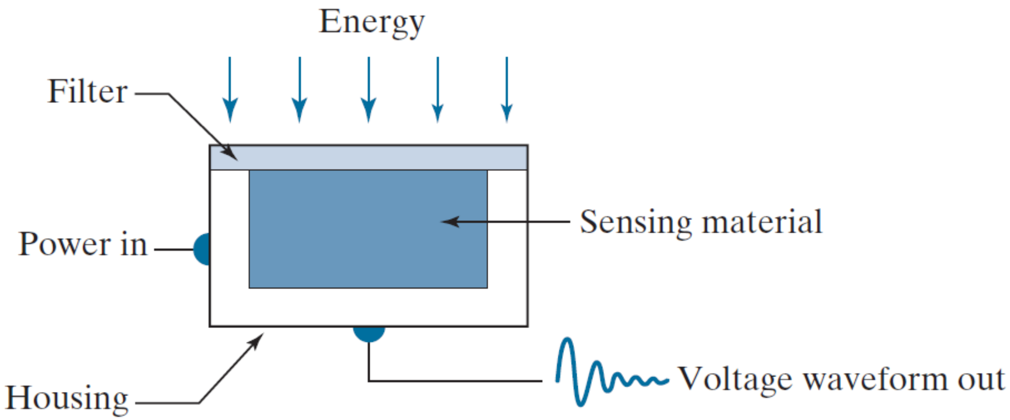
Sensor Array Imaging



An example of digital image acquisition. (a) Illumination (energy) source. (b) A scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Image Sampling and Quantization

- Incoming energy lands on a sensor material responsive to that type of energy and this generates a continuous voltage.



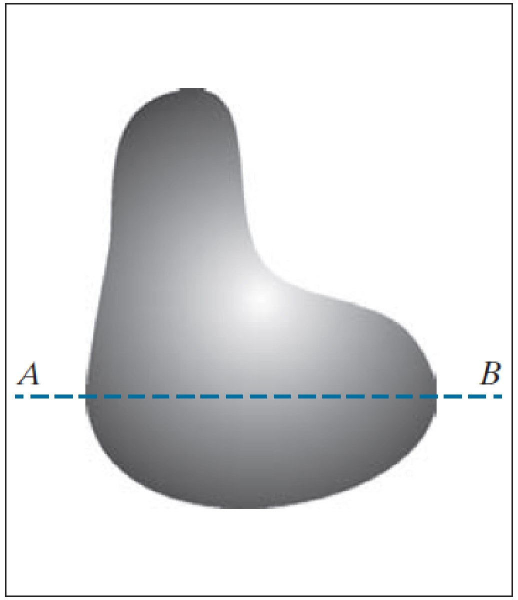
- To create a digital image, we need to convert the continuous sensed data into digital form.

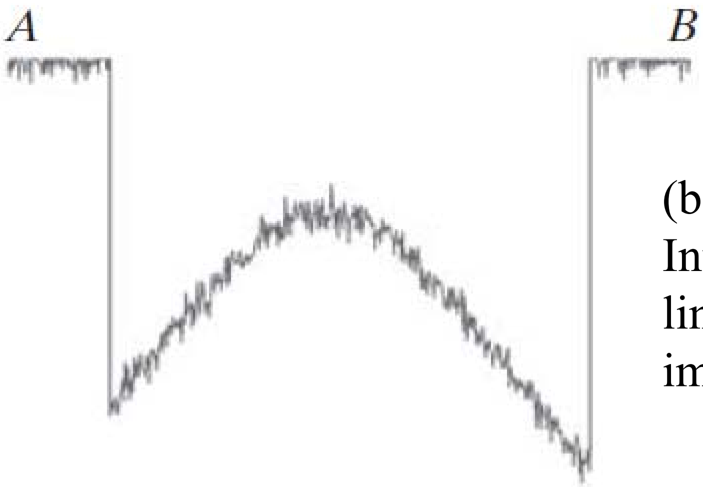
Image Sampling and Quantization

- This involves two steps: sampling and quantization.
  - Sampling: digitizing the coordinate
  - Quantization: digitizing the amplitude values
- Quantization is the process of converting a continuous analogue signal into a digital representation of this signal

Image Sampling and Quantization

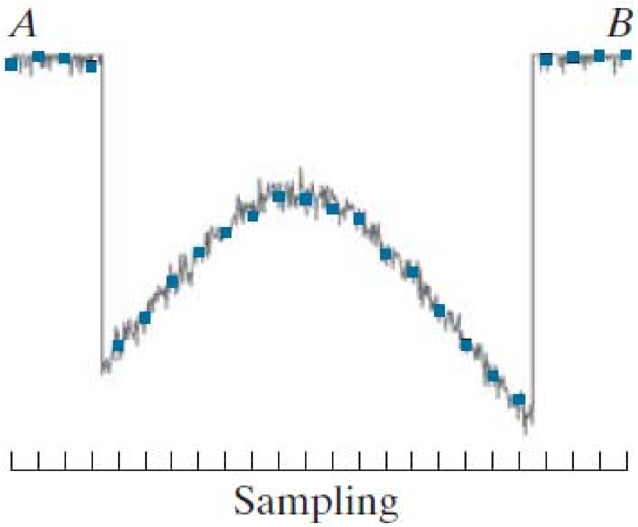
(a) Continuous image

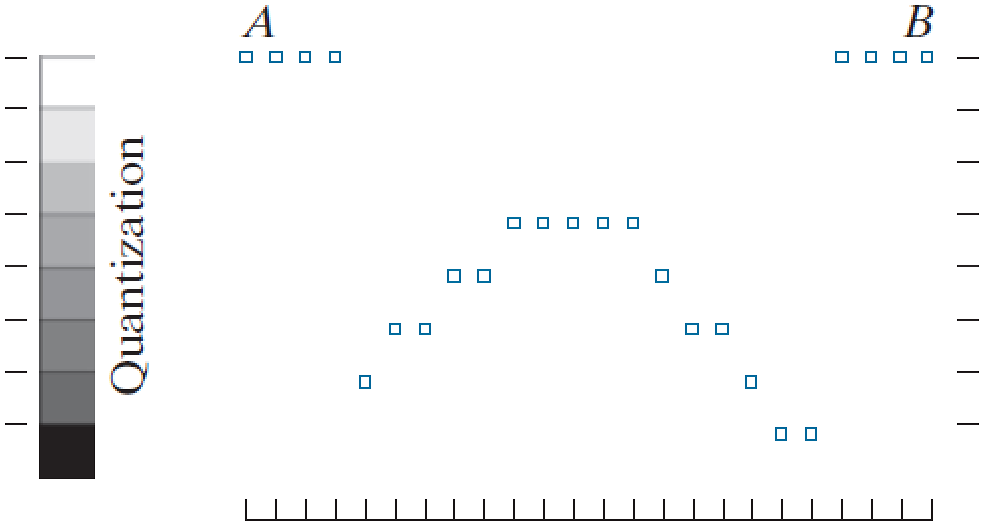




(b) A scan line showing Intensity variations along line AB in the continuous image

(c) Sampling and quantization

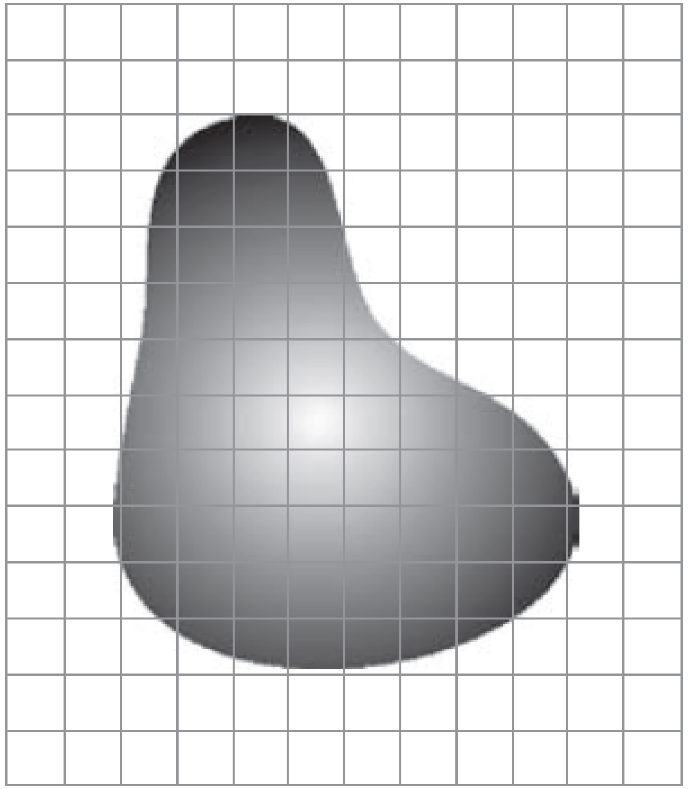




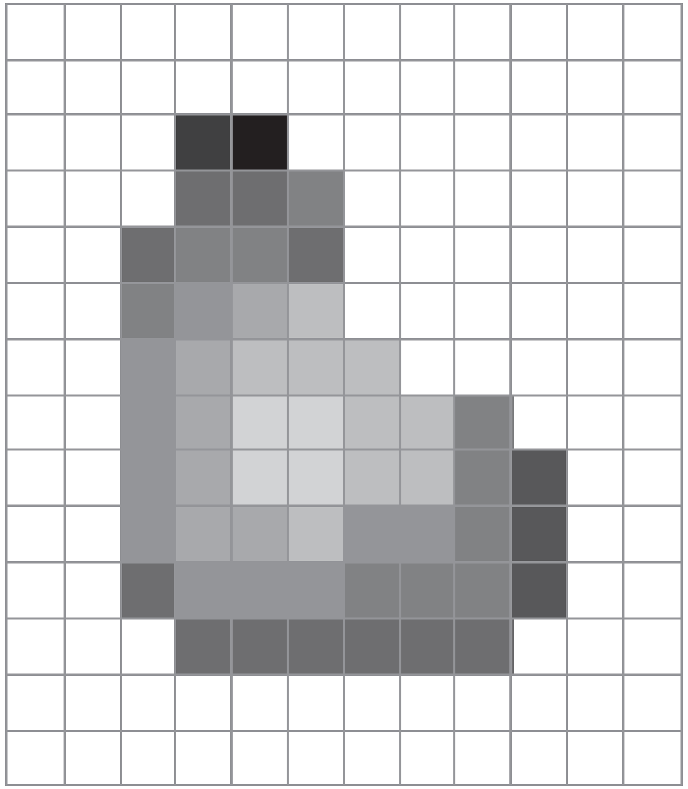
(d) Digital scan line

Image Sampling and Quantization

Continuous image projected onto a sensor array.



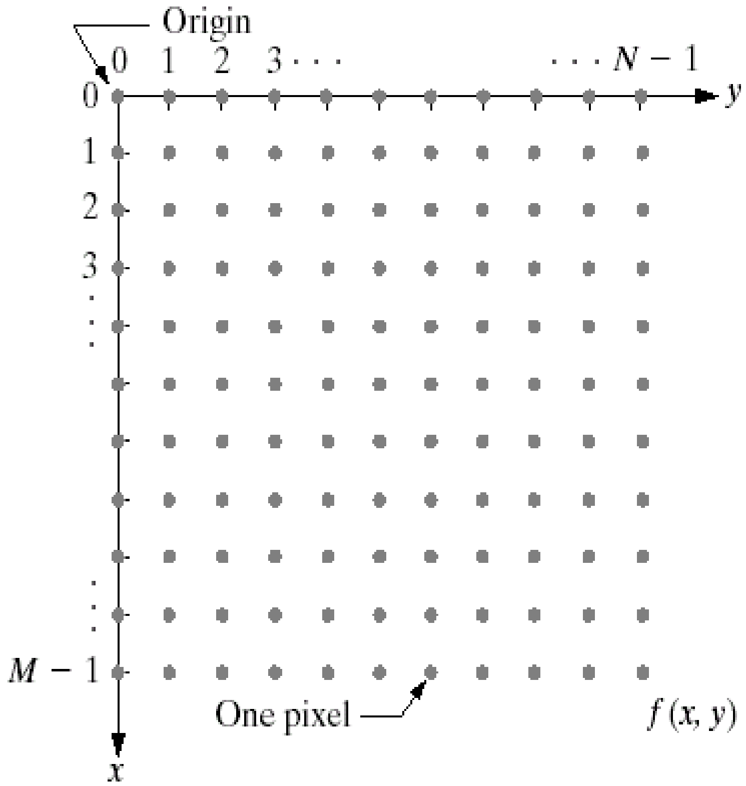
Result of image sampling and quantization.



Representation

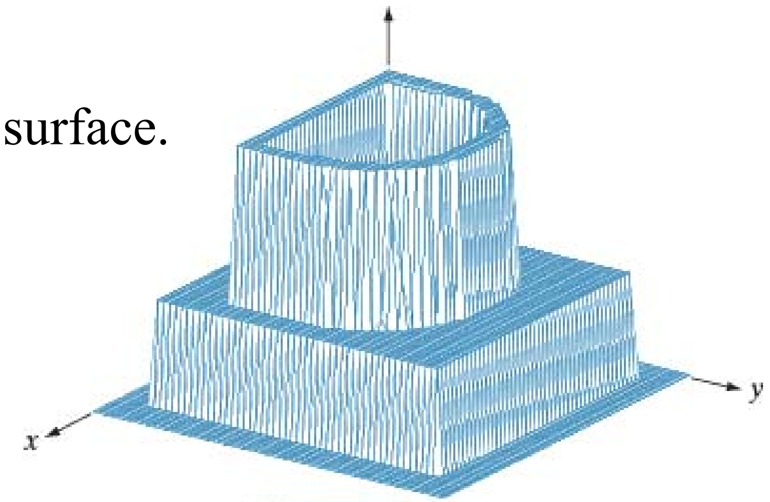
$$f(x,y)=\begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & \cdots & f(1,N-1) \\ \vdots & \vdots & & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1,N-1) \end{bmatrix}$$

$$A=\begin{bmatrix} a_{0,0} & a_{0,1} & \cdots & a_{0,N-1} \\ a_{1,0} & a_{1,1} & \cdots & a_{1,N-1} \\ \vdots & \vdots & & \vdots \\ a_{M-1,0} & a_{M-1,1} & \cdots & a_{M-1,N-1} \end{bmatrix}$$

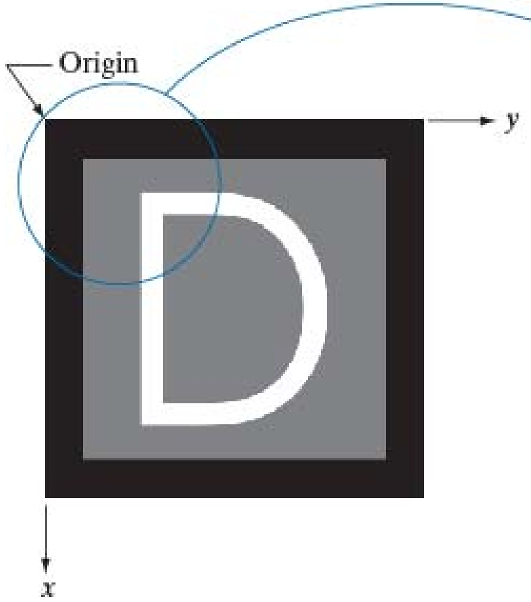


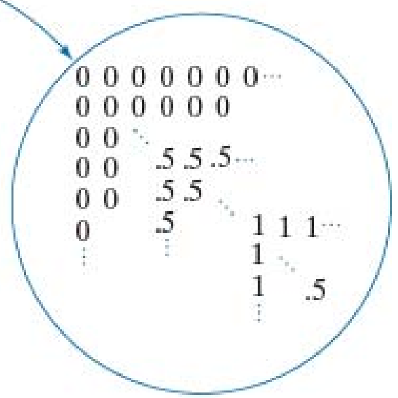
Representation

(a) Image plotted as a surface.



(b) Image displayed as a visual intensity array.





(c) Image shown as a 2-D numerical array. (The numbers 0, .5, and 1 represent black, gray, and white, respectively.)

Representation

- Usually, M and N are positive integers, and the number of gray levels is an integer power of 2:

$$L = 2^k, \quad b = M \times N \times k \quad (Bit)$$

- Both spatial and gray level resolutions determine the storage size of an image (bytes)

  e.g. spatial resolution: 40 × 40

  gray level resolution: 64 ($\log_2 64 = 6$ bits/pixel)
- The number of pixels:

  40 × 40 = 1600 pixels
- The storage size (no compression, no overhead):

  1600 × 6 = 9600 bits = 1200 bytes ≈ 1.17 KB

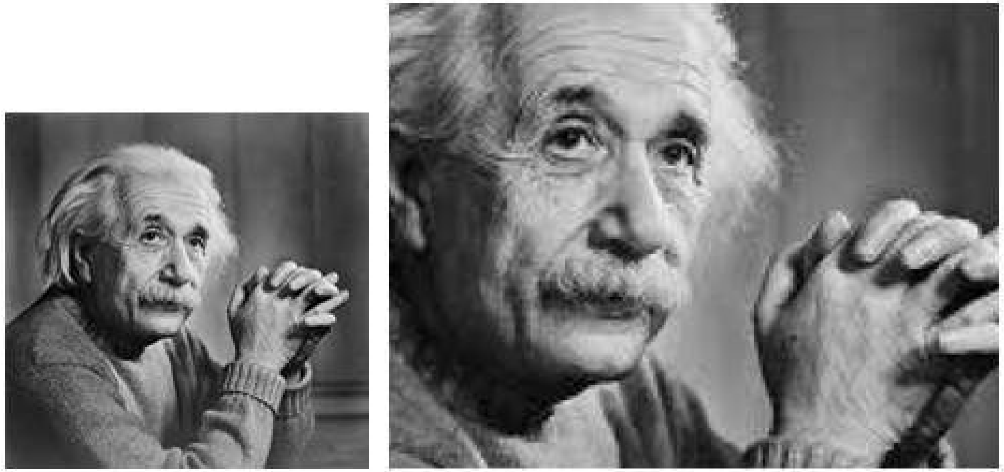
Representation

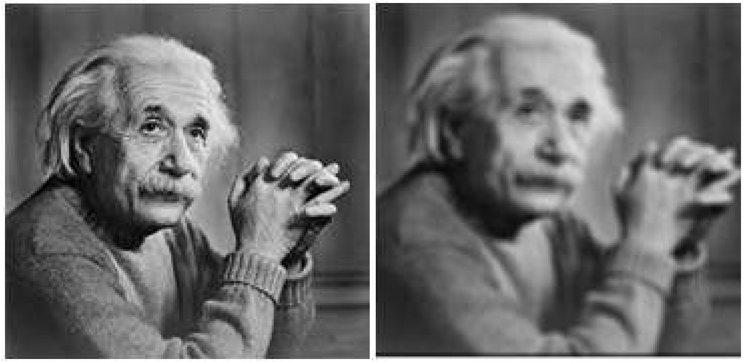
Number of storage bits for various values of N and k.

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 & Intensity Level Resolution

- *The* *spatial resolution* of an image is determined by how sampling was carried out.
- Spatial resolution simply refers to the smallest discernable detail in an image.
  - Image size: e.g. 640 × 480
  - dpi: dots per inch (*Newspaper 75dpi, Magazine 133dpi, Poster 175dpi*)



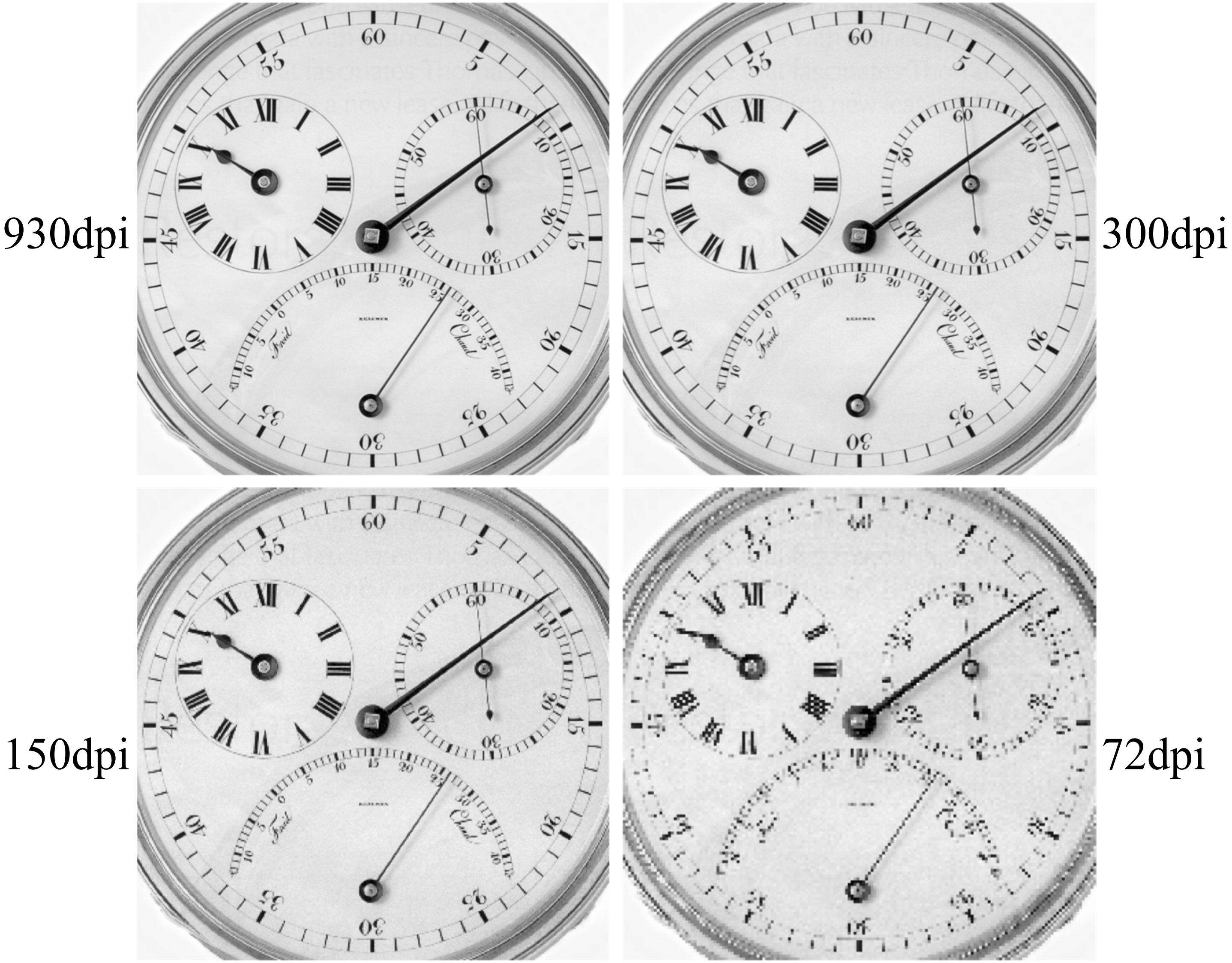


Spatial & Intensity Level Resolution

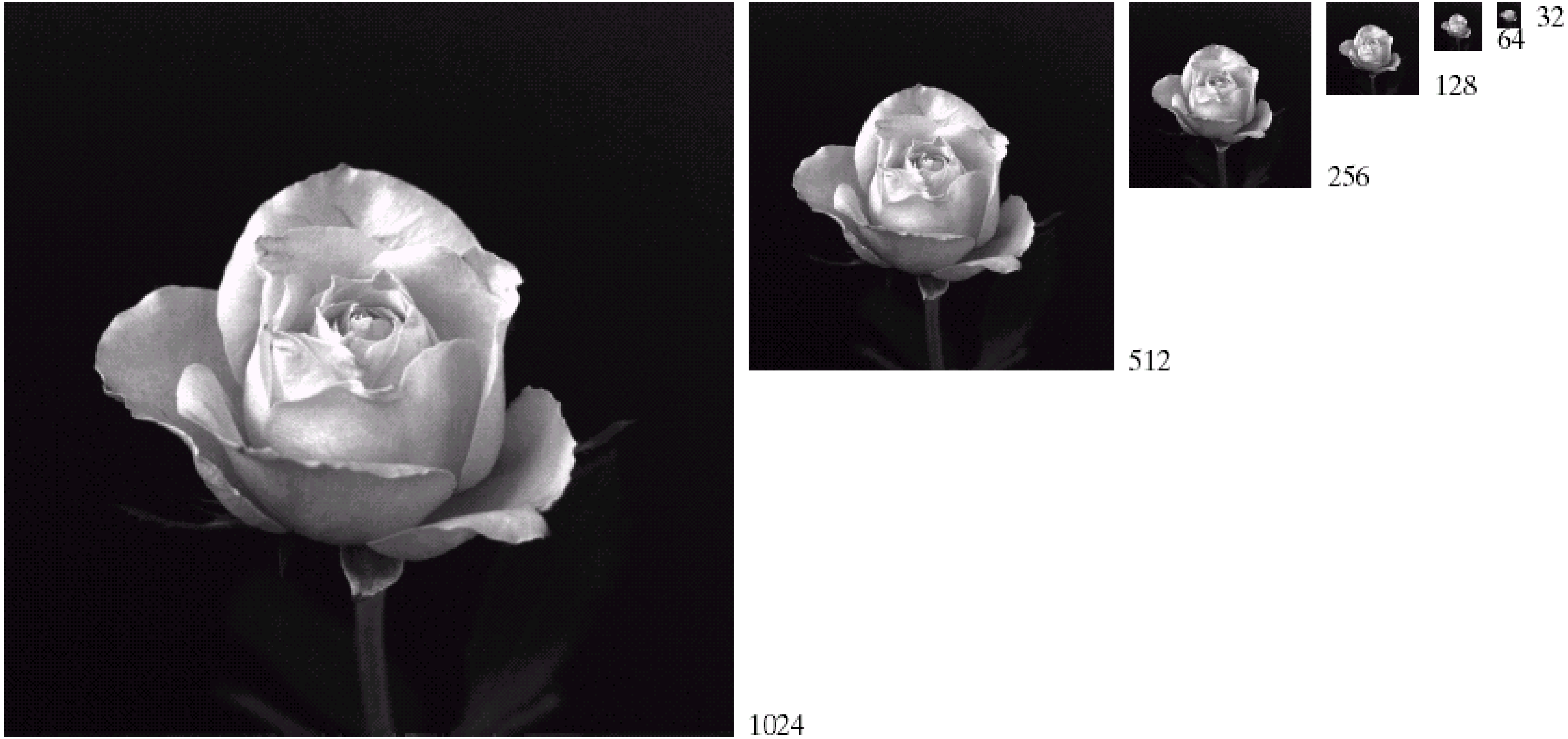
Effects of reducing spatial resolution.

(a) Image size: 2136×2140

(d) Image size: 165×166

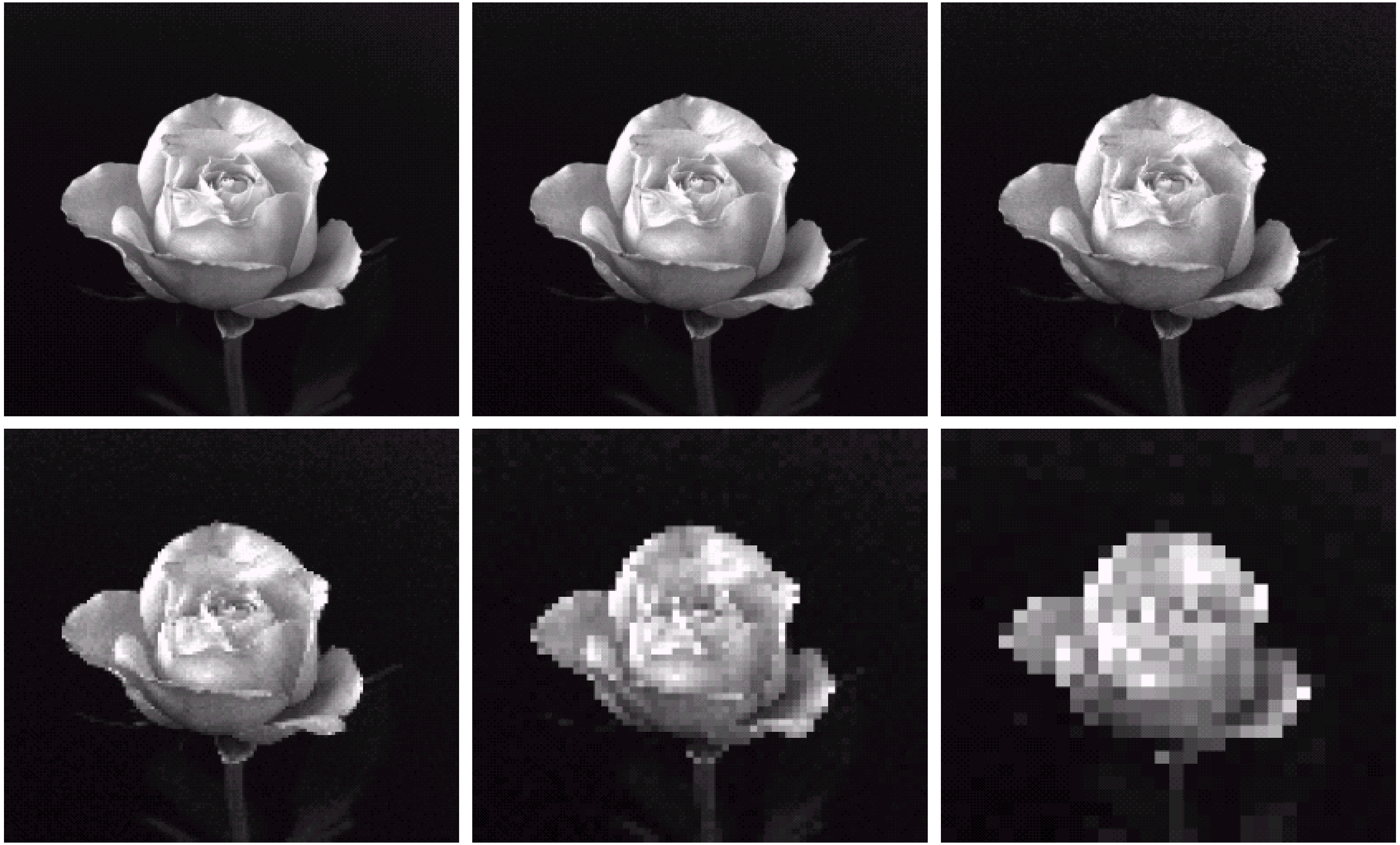


Spatial & Intensity Level Resolution



Spatial & Intensity Level Resolution

1024 × 1024 512 × 512 256 × 256



128 × 128 64 × 64 32 × 32

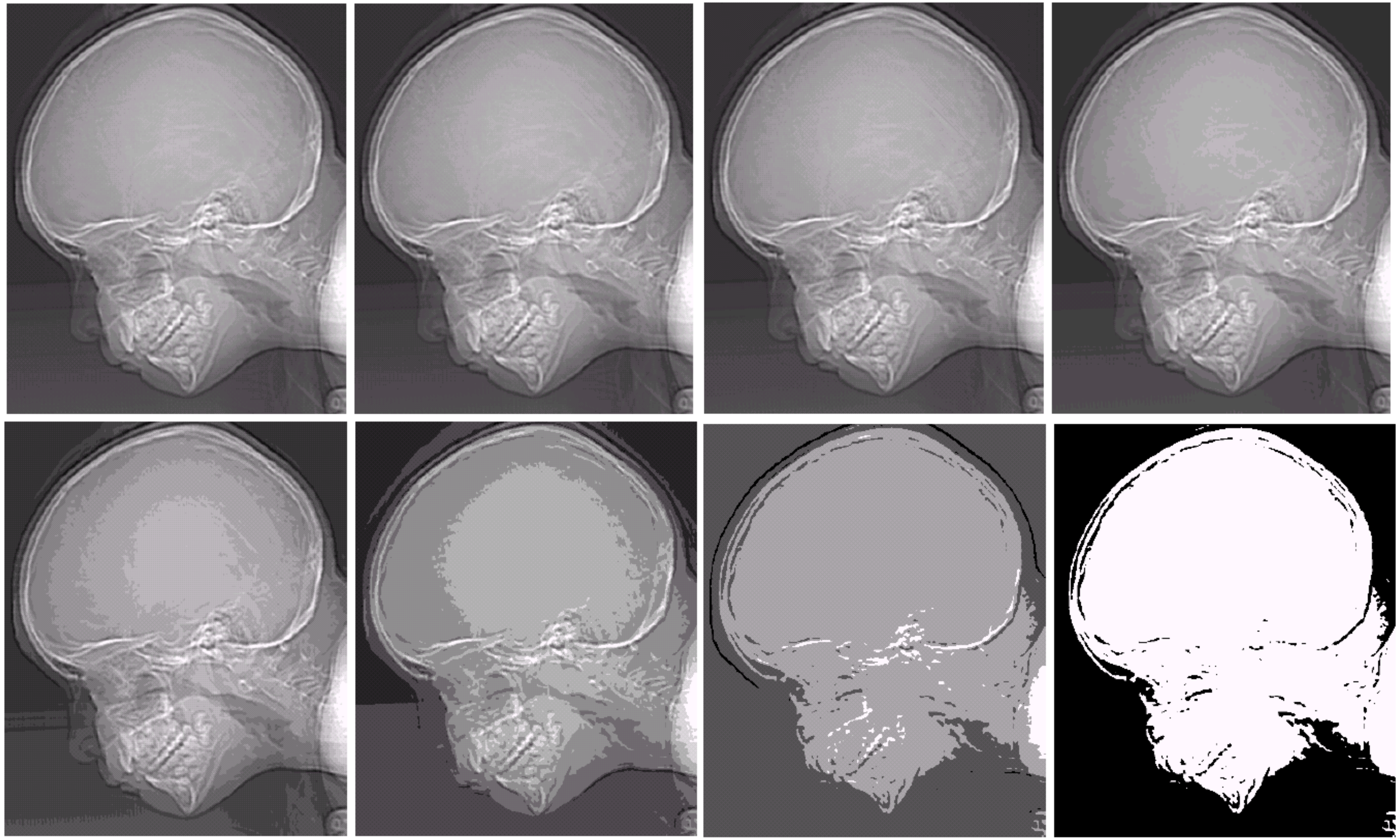
Spatial & Intensity Level Resolution

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

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

Spatial & Intensity Level Resolution

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



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

Spatial & Intensity Level Resolution

- **Spatial resolution:** $M \times N$
- **Gray level resolution：** L

- How many samples and gray levels are required for a good approximation?
  - Resolution (the degree of discernible detail) of an image depends on sample number and gray level number.
  - i.e. 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

Spatial & Intensity Level Resolution

- The big question with resolution is always: "*how much is enough*?"
  - This all depends on what is in the image and what you would like to do with it
  - Key questions include
    - Does the image look aesthetically pleasing?
    - Can you see what you need to see within the image?

Spatial & Intensity Level Resolution

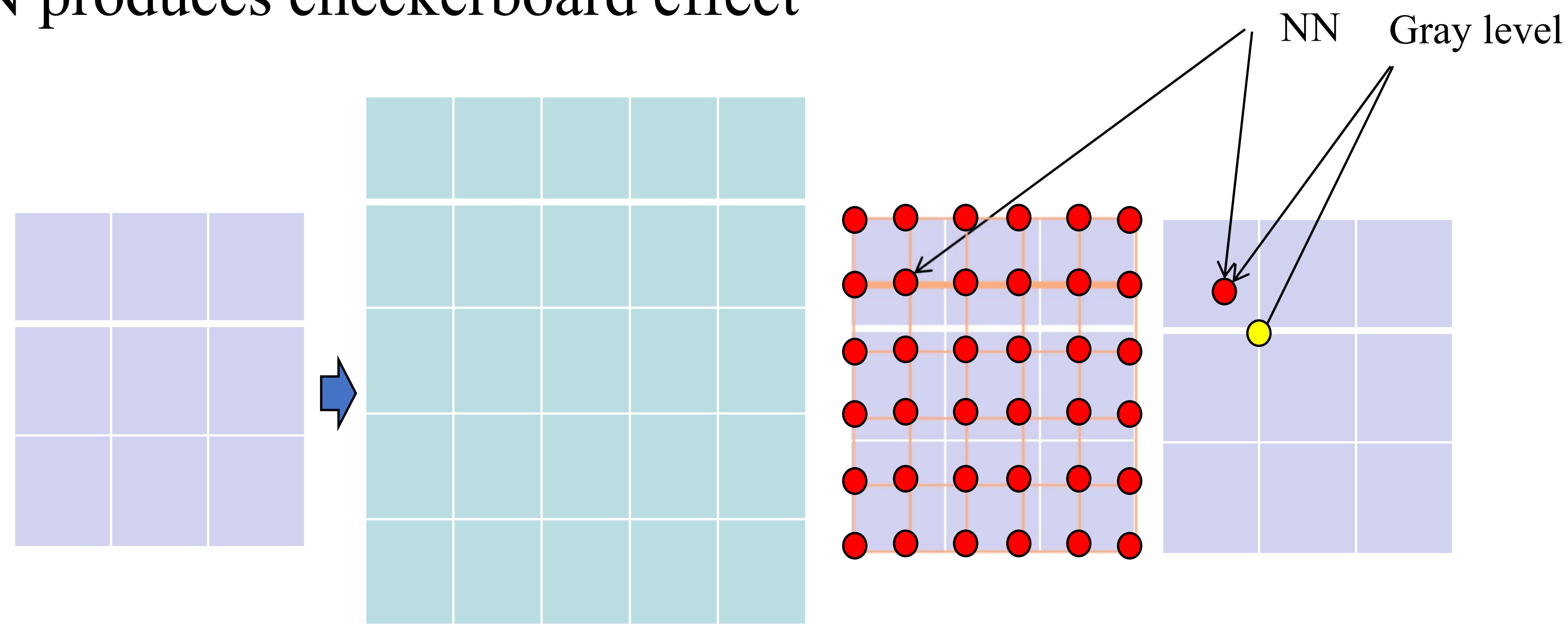
- The picture on the right is fine for counting the number of cars, but not for reading the number plate

Zooming and Shrinking Digital Images

- Zooming
  - Oversampling
- Shrinking
  - Subsampling

Zooming

- The creation of new pixel locations
- The assignment of gray levels to those new locations
  - Nearest neighbor interpolation (NN)
  - Pixel replication: a special case of NN
  - NN produces checkerboard effect



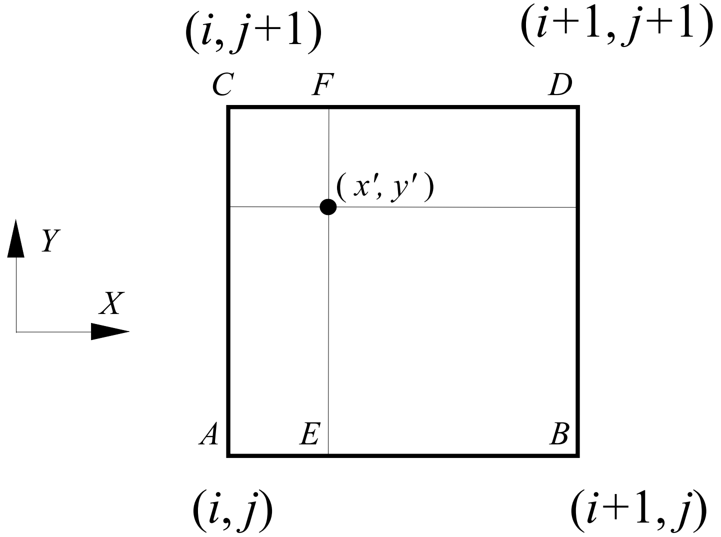
Zooming

- Bilinear interpolation
  - Using the four NNs of a point.
  - $g(A)$, $g(B)$, $g(C)$, $g(D)$ are the gray levels of points A, B, C, D.

$$g(E) = (x' - i)[g(B) - g(A)] + g(A)$$

$$g(F) = (x' - i)[g(D) - g(C)] + g(C)$$

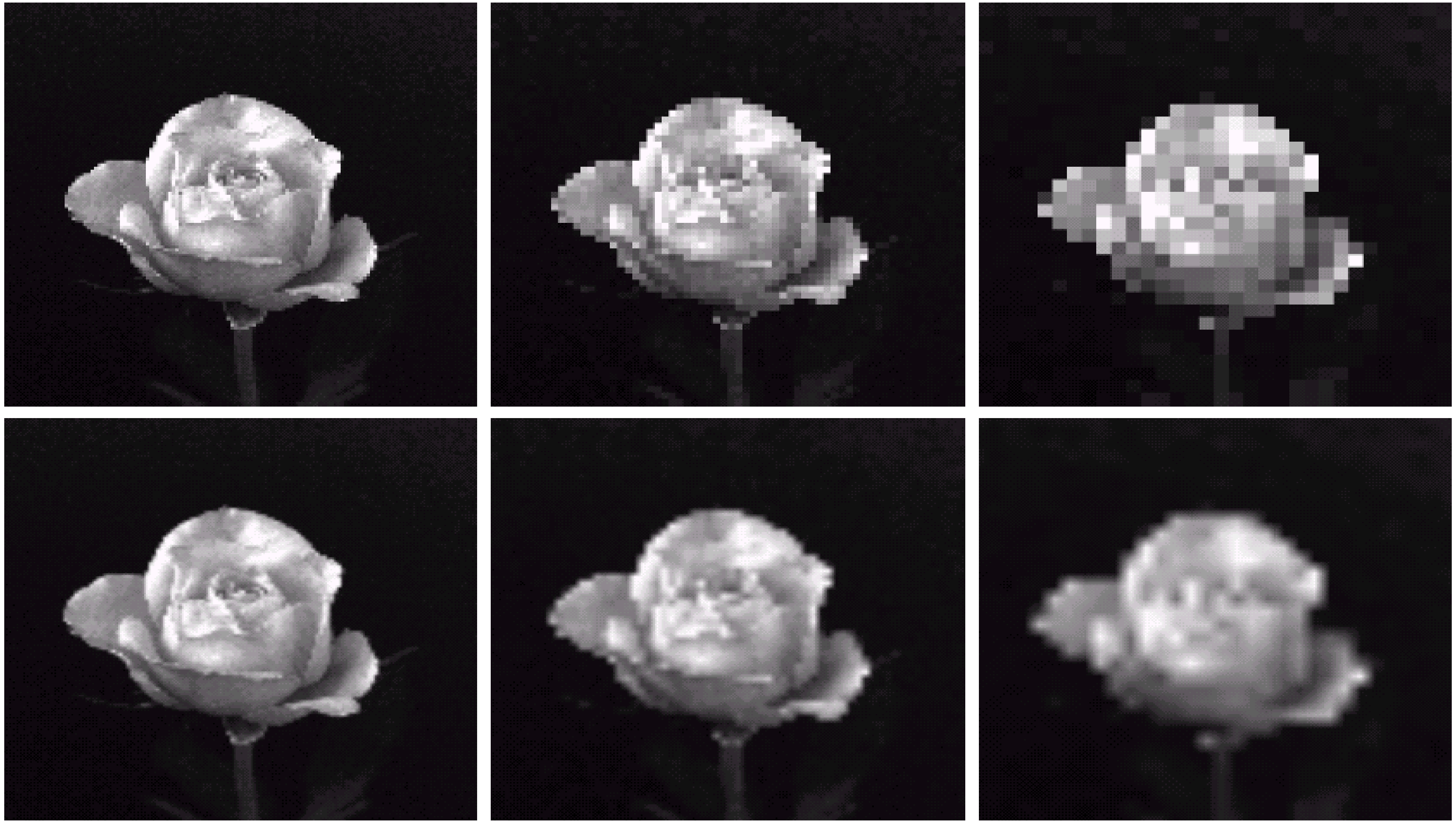
$$g(x', y') = (y' - j)[g(F) - g(E)] + g(E)$$



Zooming

Top row: images zoomed from 128 × 128, 64 × 64, and 32 × 32 pixels to 1024 × 1024 pixels using nearest neighbor gray-level interpolation.

Bottom row: same sequence, but using bilinear interpolation.



Shrinking

- Shrinking: Similar manner as just described for zooming.
  - Delete
  - Expand the grid:
    - Nearest Neighbor interpolation
    - Bilinear interpolation

Basic Relationships Between Pixels

- A pixel p at (x, y) has 2 horizontal and 2 vertical neighbors:
  - $(x + 1, y)$, $(x - 1, y)$, $(x, y + 1)$, $(x, y - 1)$
  - This set of pixels is called the 4-neighbors of p: $N_4(p)$

- Definitions:
  - $f(x, y)$: digital image
  - Pixels: p

	N_4	
N_4	p	N_4
	N_4	

N_D		N_D
	p	
N_D		N_D

N_8	N_8	N_8
N_8	p	N_8
N_8	N_8	N_8

The 4 diagonal neighbors of p are: $N_D(p)$

- $(x + 1, y + 1)$, $(x + 1, y - 1)$, $(x - 1, y + 1)$, $(x - 1, y - 1)$
- $N_4(p) + N_D(p) \rightarrow N_8(p)$: the 8-neighbors of p

Basic Relationships Between Pixels

$N_D(p)$

$N_8(q)$

$N_4(s)$

0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	1	0	0	0	0	0	0	0
0	0	1	1 p	1	1	1	0	0 q	0	0	0
0	1	1	1	1	1	1	1	0	0	0	0
0	1	1	1	1	1	1	1	0	0	0	0
0	0	1	1	1	1	1	1	0	0	0	0
0	0	1	1	1	1	1	1	1	0	0	0
0	0	1	1	1	1	1	1	1 s	1	1	0
0	0	0	0	0	1	1	1	1	1	1	0
0	0	0	0	0	0	0	0	0	0	0	0

Connectivity

- Connectivity between pixels is important:
  - Because it is used in establishing boundaries of objects and components of regions in an image
    - Two pixels are connected if:
      - ✓ they are neighbors (i.e. adjacent in some sense -- e.g. $N_4(p)$, $N_8(p)$, …)
      - ✓ their gray levels satisfy a specified criterion of similarity (e.g. equality, …)
    - V is the set of gray-level values used to define adjacency (e.g. $V=\{1\}$ for adjacency of pixels of value 1)

Adjacency

- We consider three types of adjacency:
  - 4-adjacency: two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$
  - 8-adjacency : two pixels p and q with values from V are 8-adjacent if q is in the set $N_8(p)$
  - m-adjacency: p and q with values from V are m-adjacent if
    - q is in $N_4(p)$ or
    - q is in $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ has no pixels with values from V

Adjacency

- m-adjacency (mixed adjacency) is a modification of 8-adjacency and is used to eliminate the multiple path connections that often arise when 8-adjacency is used.

$$\begin{array}{ccc} 0 & 1 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{array} \qquad \begin{array}{ccc} 0 & 1 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{array} \qquad \begin{array}{ccc} 0 & 1 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{array}$$

8-adjacency

m-adjacency

$V=\{1\}$

Path

- **Path:** A sequence of adjacent pixels.
  - For example: a path from pixel p with coordinate (x, y) to pixel q with coordinate (s, t) is defined

$$(x_0, y_0),\ (x_1, y_1),\ \ldots,\ (x_n, y_n)$$

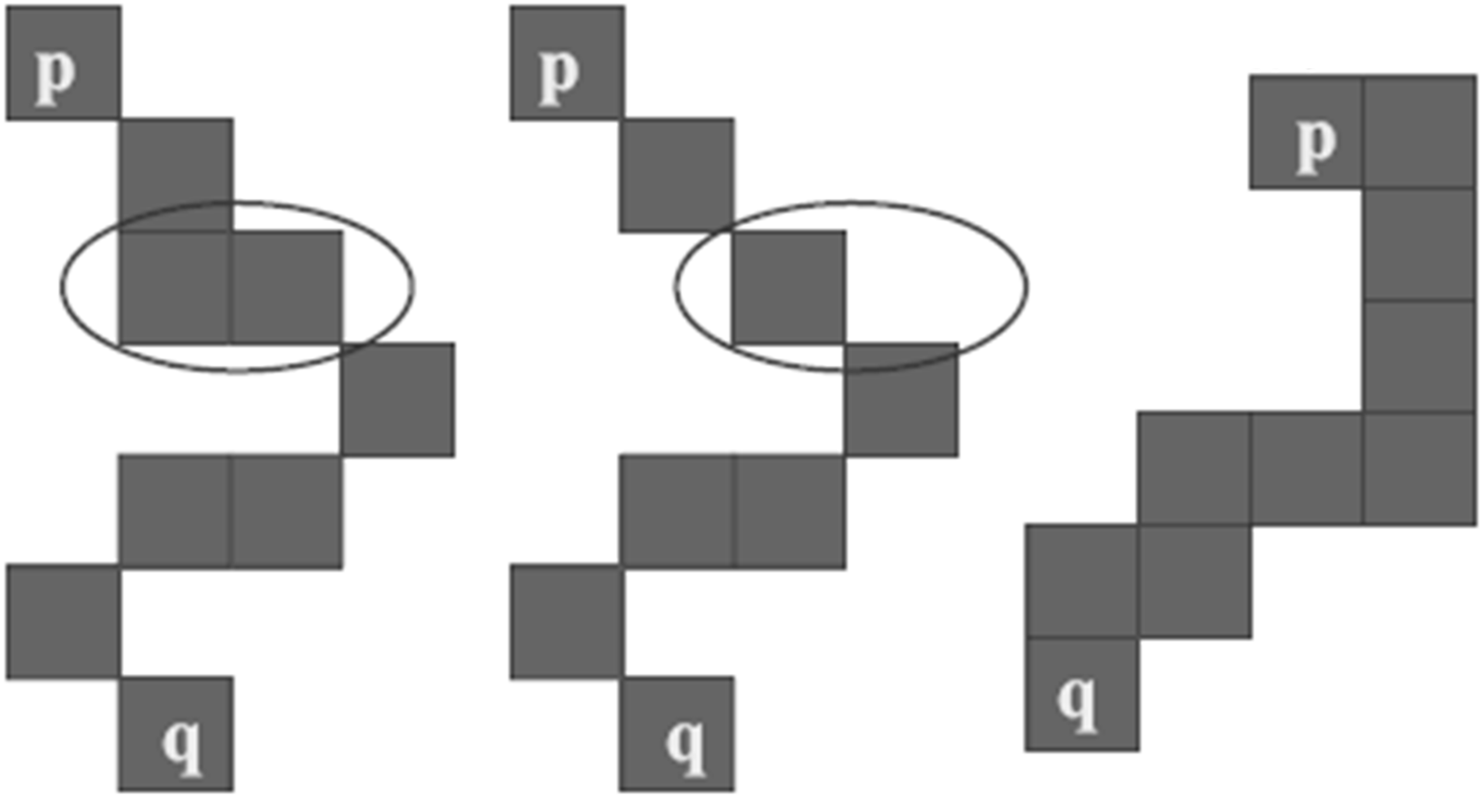
    where $(x_0, y_0) = (x, y)$, $(x_n, y_n) = (s, t)$, (x_i, y_i) and (x_{i-1}, y_{i-1}) are adjacent, $1 \le i \le n$, n is called the length of the path.

$$\begin{matrix} 0 & 1 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{matrix}$$

  - If $(x_0, y_0) = (x_n, y_n)$, the path is a **closed path**.
  - We can define 4-, 8-, and m-path depending on the type of adjacency.

Path

m-Path 8-Path 4-Path



Connected Set and Region

Definitions:

- Let S represent a subset of pixels in an image. Two pixel p and q are said to be ***connected*** in S if there exists a path between them.
- For any pixel p in S, the set of pixels that are connected to it in S is called a ***connected component*** of S.
- If it only has one ***connected component***, then set S is called a ***connected set***.
- Let R be a subset of pixels in an image. We also called R a ***region*** of the image if R is a ***connected set***.
- The ***boundary*** of a ***region*** R is the set of pixels in the region that have one or more neighbors that are not in R.

Distance Measures

- For pixels p, q, z with coordinates (x, y), (s, t), (u, v), D is a distance function or metric if:

  - $D(p, q) \geq 0 \quad (D(p, q) = 0$ if $p = q)$
  - $D(p, q) = D(q, p)$ and
  - $D(p, z) \leq D(p, q) + D(q, z)$

Distance Measures

- **Euclidean distance** $(p(x, y), q(s, t))$:
  - $D_e(p, q) = [(x - s)^2 + (y - t)^2]^{1/2}$
  - Points (pixels) having a distance less than or equal to r from (x, y) are contained in a disk of radius r centered at (x, y).

Distance Measures

- $\boldsymbol{D_4}$ **distance** (city-block distance):
  - $D_4(p, q) = |x - s| + |y - t|$
  - forms a diamond centered at (x, y)
  - e.g. pixels with $D_4 \leq 2$ from p

$$
\begin{array}{ccccc}
 & & 2 & & \\
 & 2 & 1 & 2 & \\
2 & 1 & 0 & 1 & 2 \\
 & 2 & 1 & 2 & \\
 & & 2 & &
\end{array}
$$

$D_4 = 1$ are the 4-neighbors of p

Distance Measures

- **D_8 distance** (chessboard distance):
  - $D_8(p, q) = \max(|x - s|, |y - t|)$
  - Forms a square centered at p
  - e.g. pixels with $D_8 \leq 2$ from p

2	2	2	2	2
2	1	1	1	2
2	1	0	1	2
2	1	1	1	2
2	2	2	2	2

$D_8 = 1$ are the 8-neighbors of p

Common Distance Definitions

Euclidean distance
(2-norm)

$2\sqrt{2}$	$\sqrt{5}$	2	$\sqrt{5}$	$2\sqrt{2}$
$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$
2	1	0	1	2
$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$
$2\sqrt{2}$	$\sqrt{5}$	2	$\sqrt{5}$	$2\sqrt{2}$

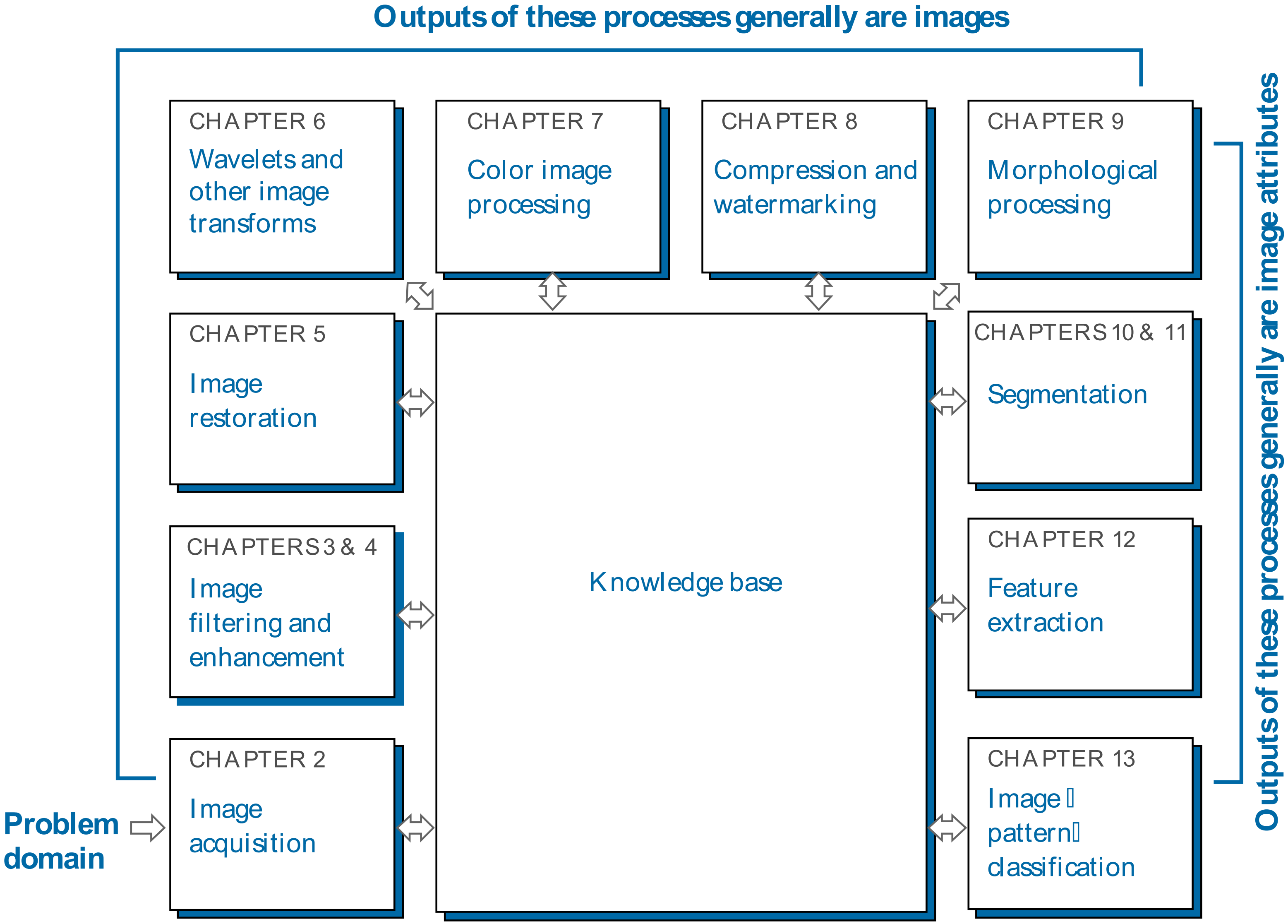
D_4 distance
(city-block distance)

4	3	2	3	4
3	2	1	2	3
2	1	0	1	2
3	2	1	2	3
4	3	2	3	4

D_8 distance
(checkboard distance)

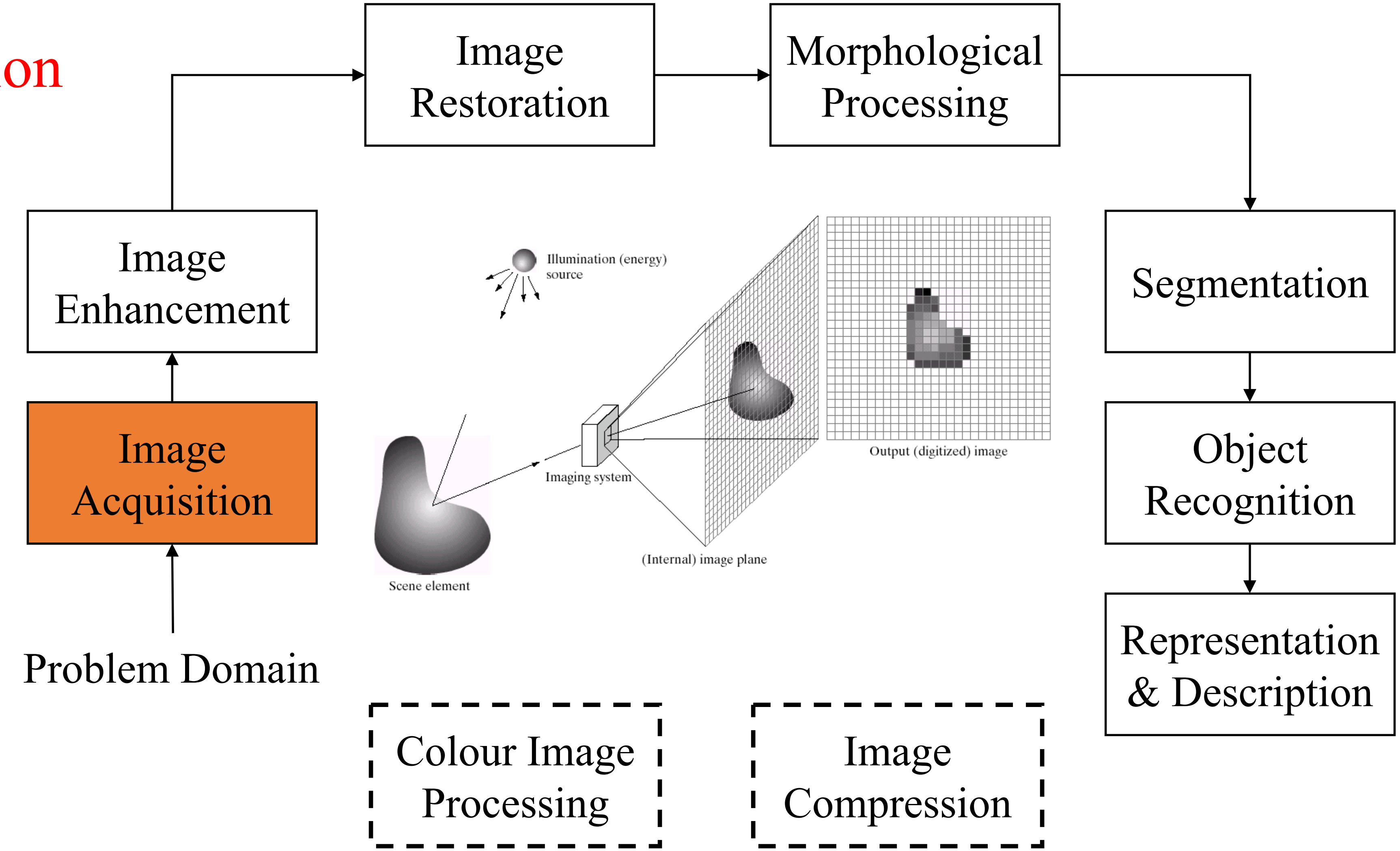
2	2	2	2	2
2	1	1	1	2
2	1	0	1	2
2	1	1	1	2
2	2	2	2	2

Key Stages in Image Processing



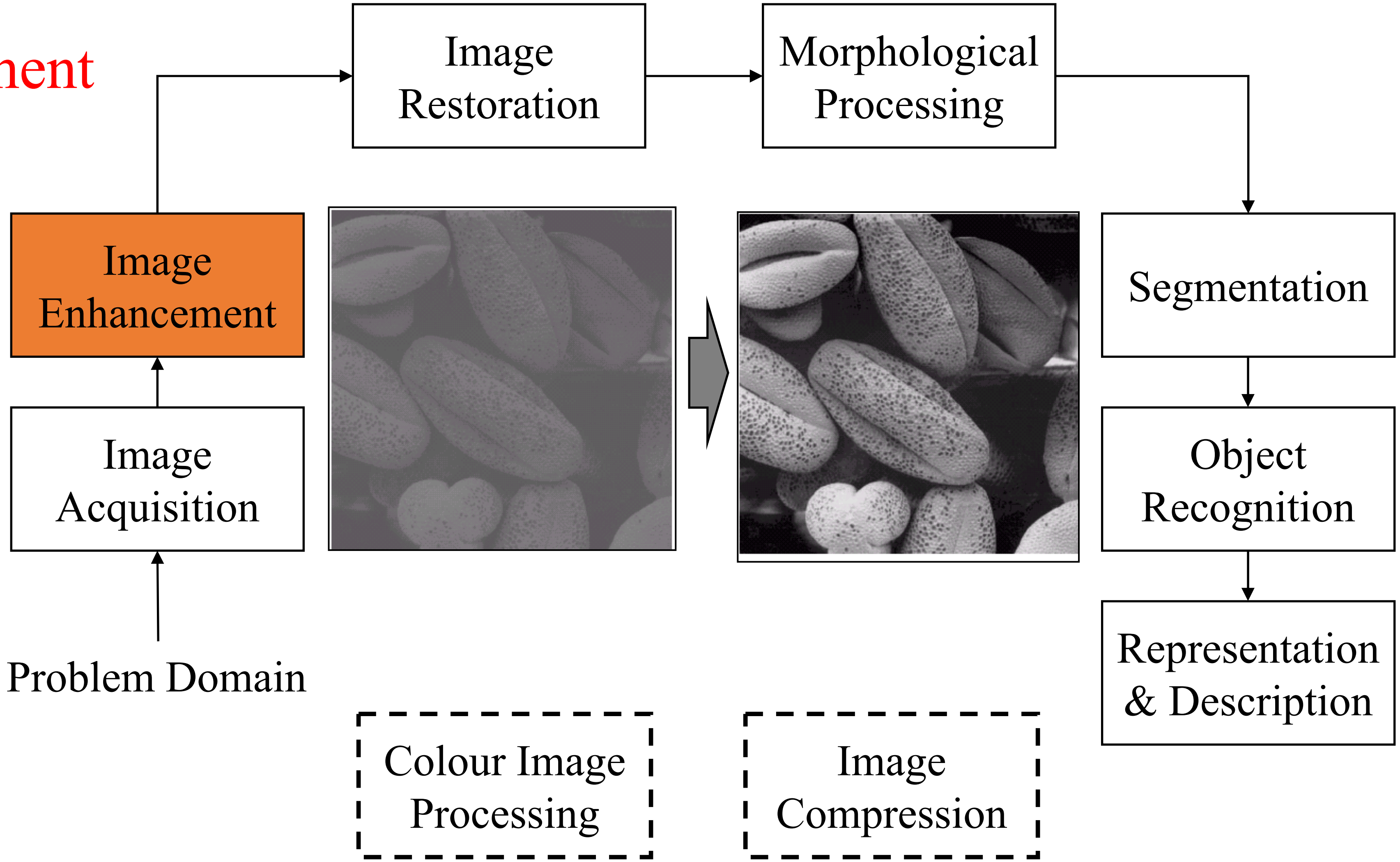
Key Stages in Image Processing

Image Acquisition



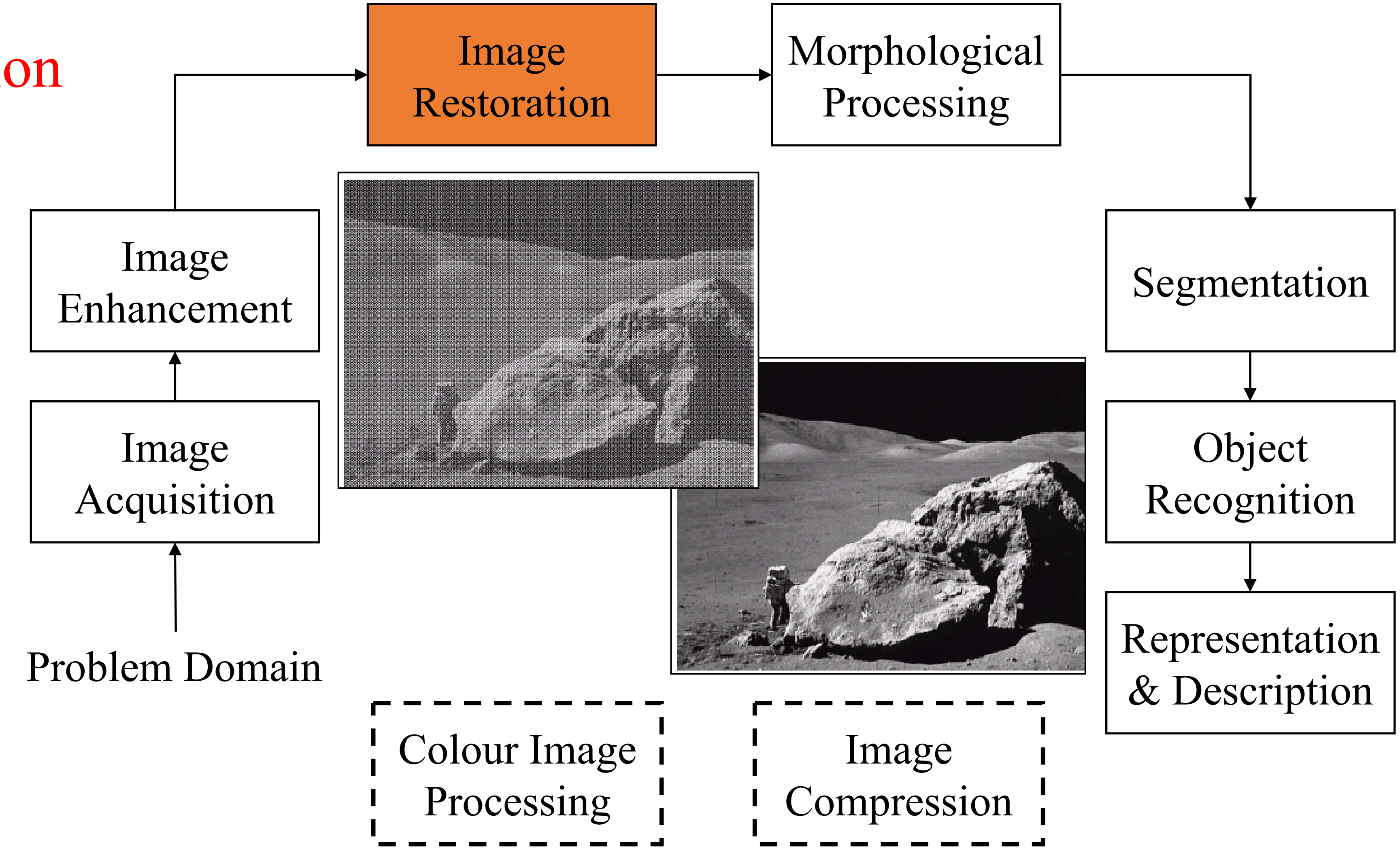
Key Stages in Image Processing

Image Enhancement



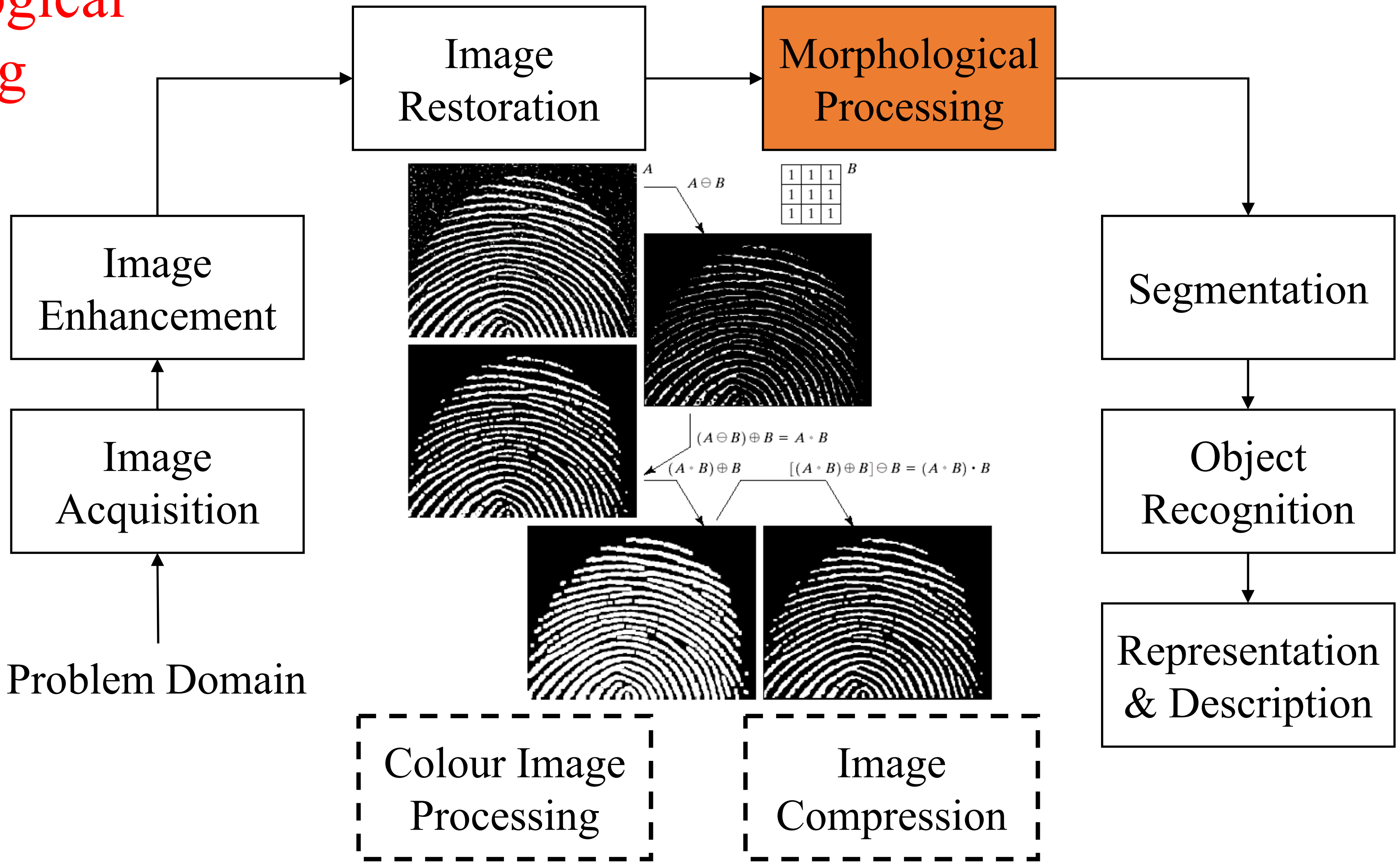
Key Stages in Image Processing

Image Restoration



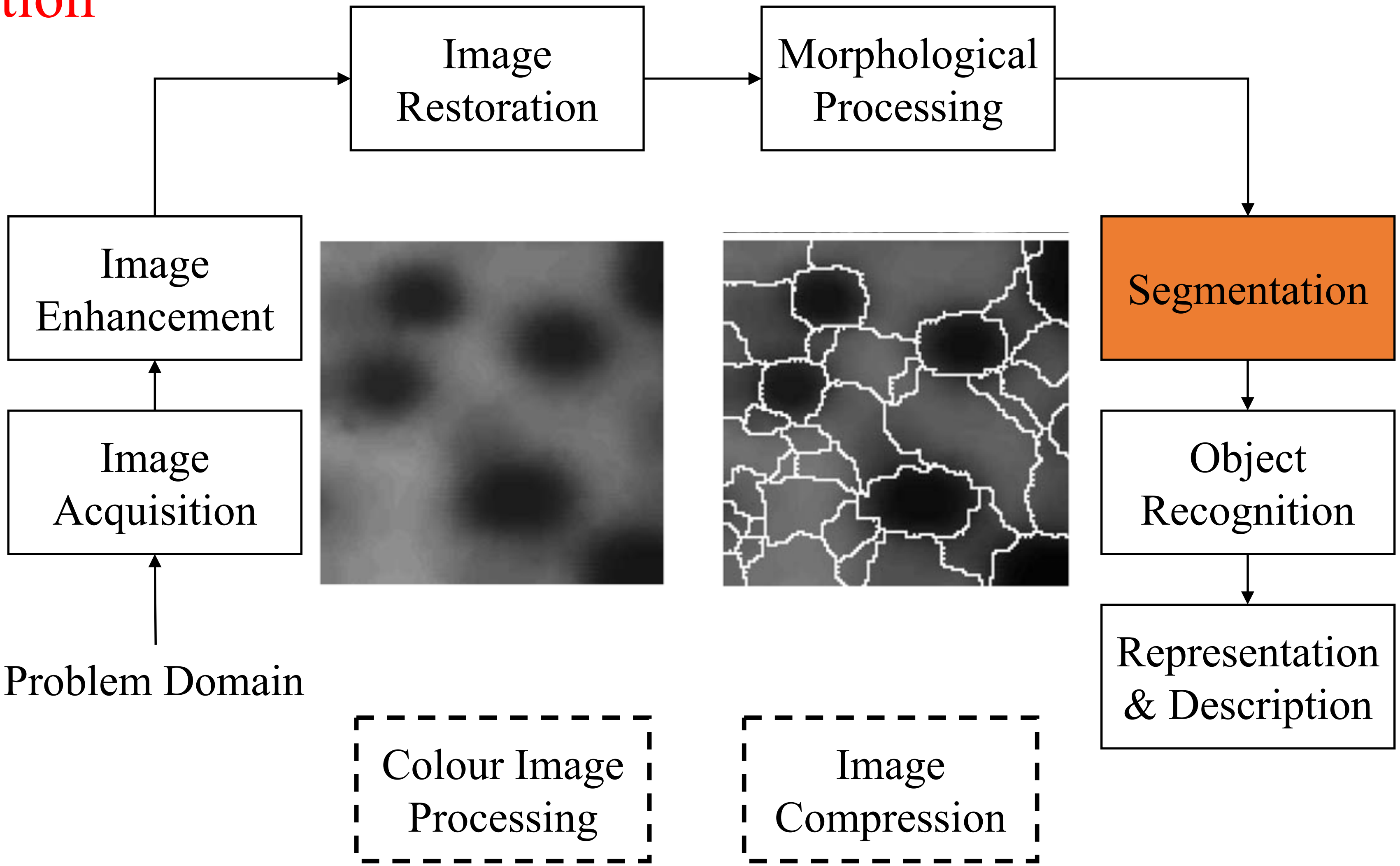
Key Stages in Image Processing

Morphological Processing



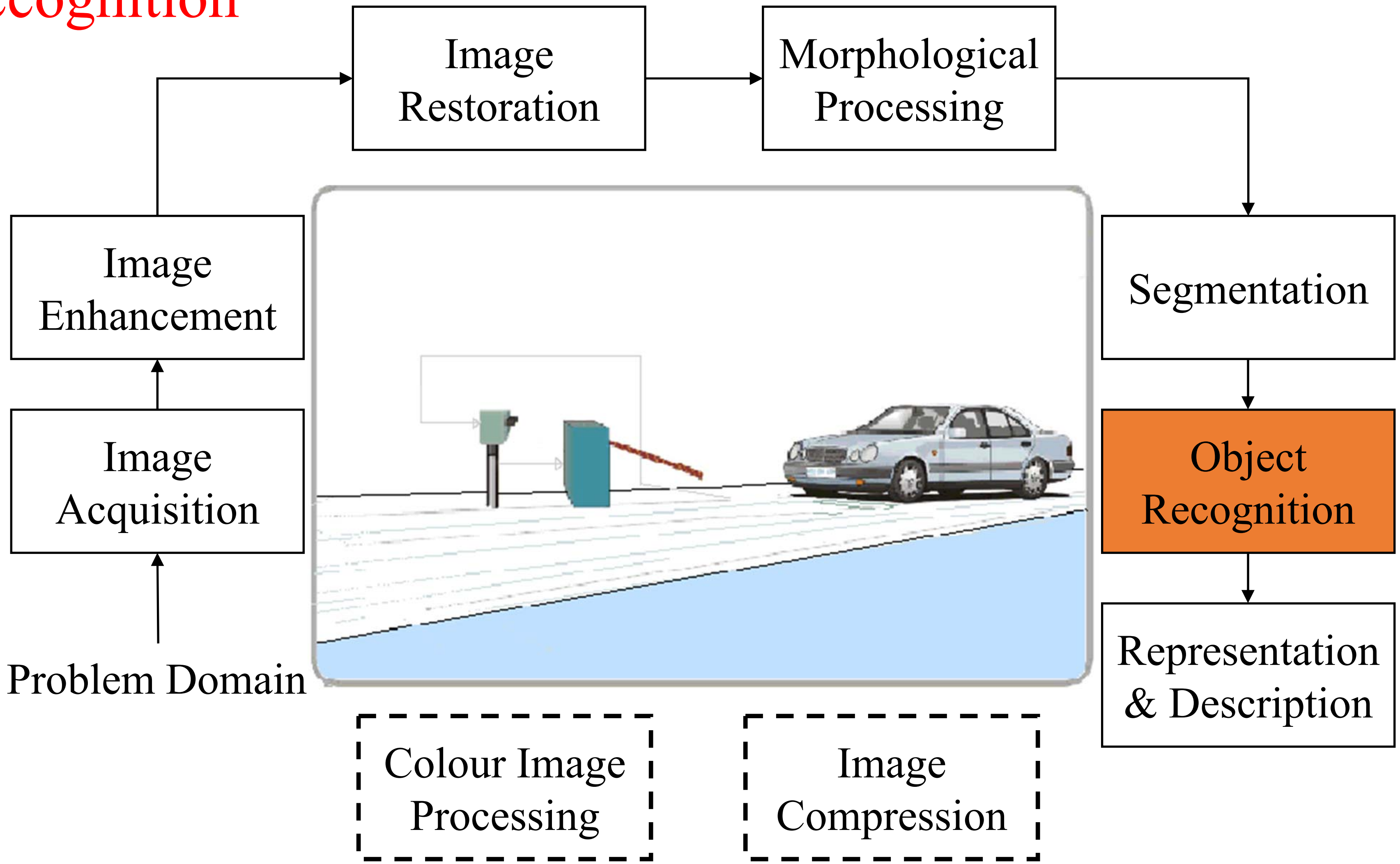
Key Stages in Image Processing

Segmentation



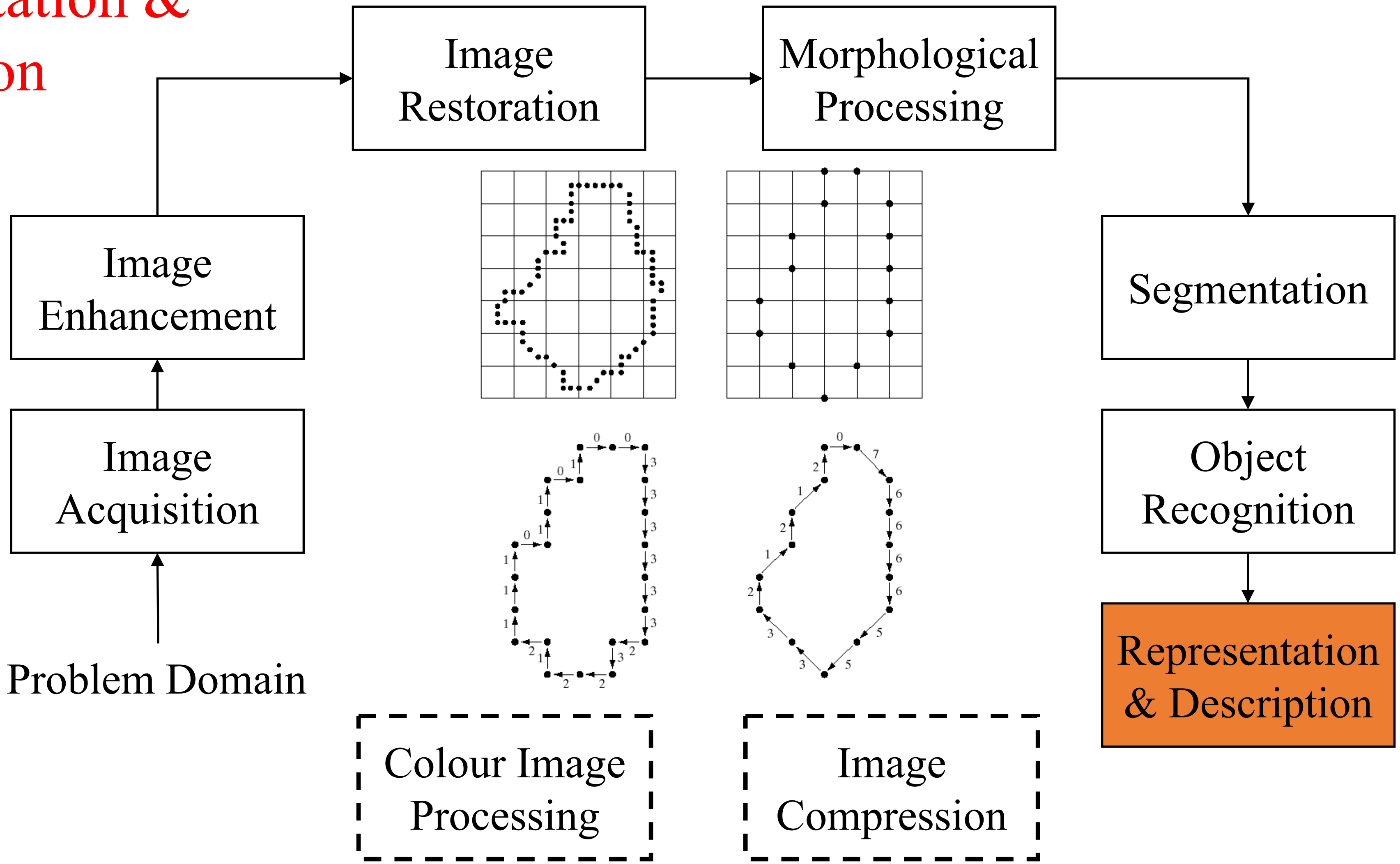
Key Stages in Image Processing

Object Recognition



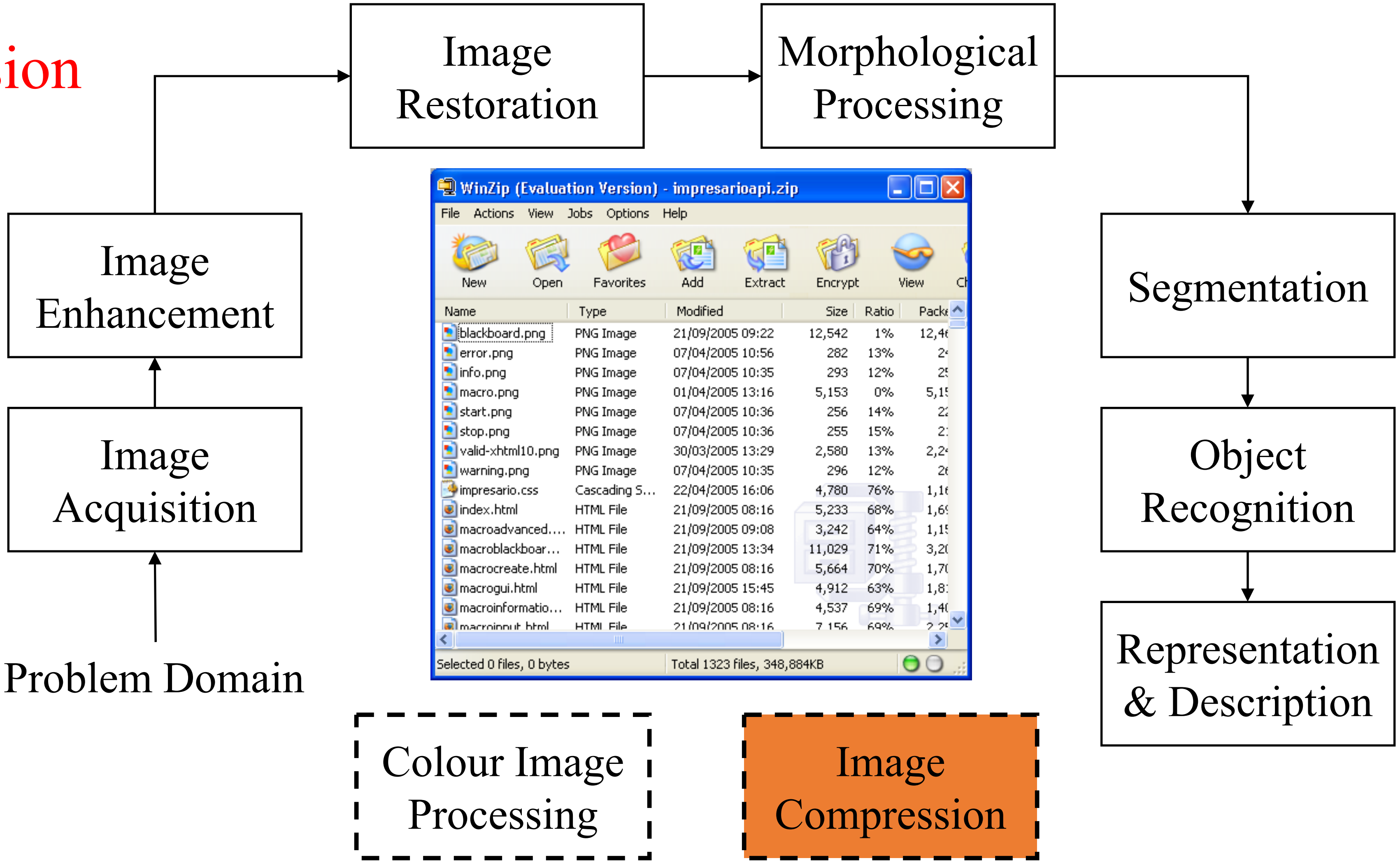
Key Stages in Image Processing

Representation & Description



Key Stages in Image Processing

Image Compression



Key Stages in Image Processing

Colour Image Processing

Image Restoration

Morphological Processing

Image Enhancement

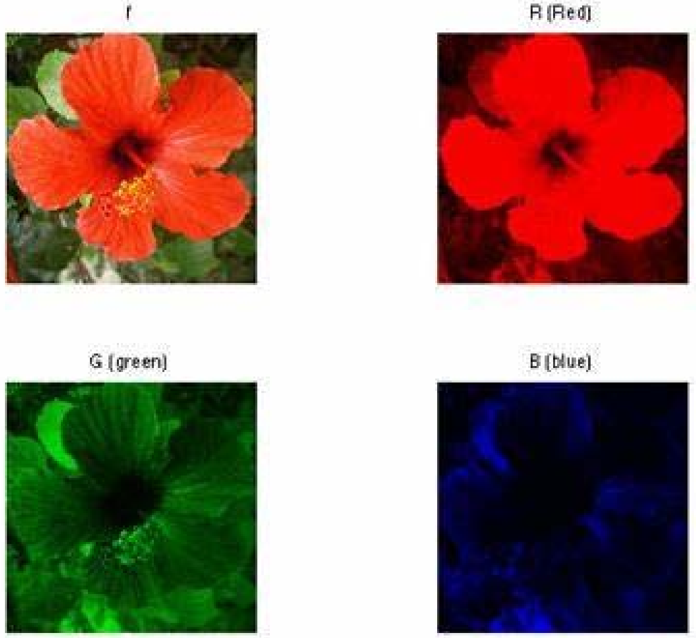
Segmentation

Image Acquisition

Object Recognition

Problem Domain

Representation & Description



Colour Image Processing

Image Compression

Summary

- In this lecture we have learnt:
  - What is digital image processing?
  - Human vision system
  - Image acquisition
  - Sampling and Quantization
  - Resolution
  - Basic Relationships between Pixels
  - Key Stages in Image Processing

Optional Homework

Check the Textbook!

- **Chapter 2: Problems 2.5, 2.9, 2.14 , 2.18, 2.19**

- Homework answers will be provided at the end of each week.