# Digital Image Processing

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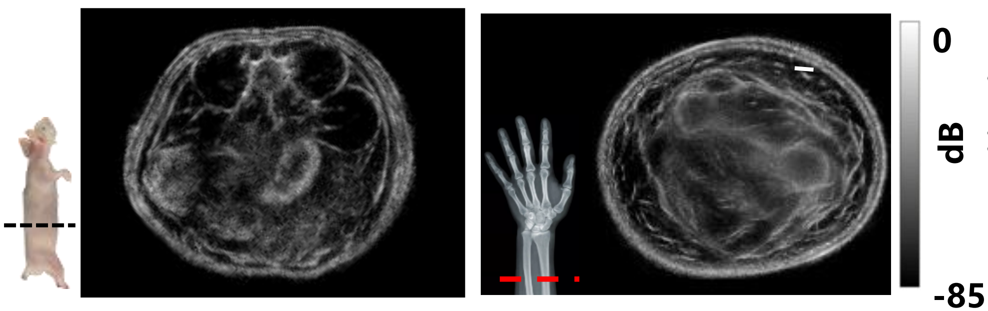
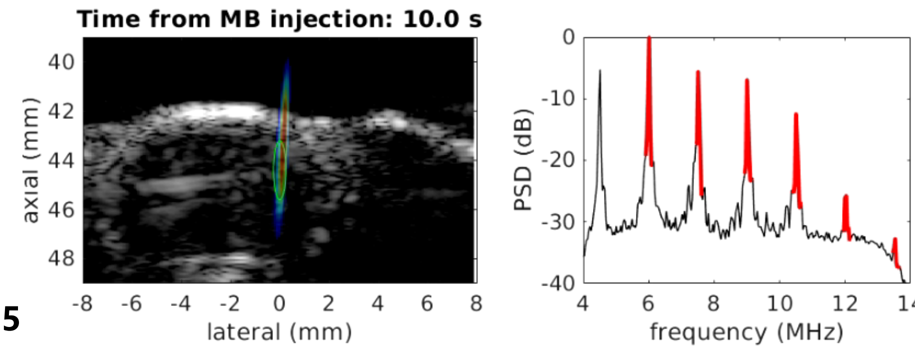
上海科技大学
ShanghaiTech University

# Self introduction

- Xiran Cai 蔡夕然, PhD
- Assistant Professor @SIST, Shanghaitech
- Research:
  - Ultrasound imaging methods for diagnosis and image guided therapy




Ultrasound computed tomography




Passive cavitation imaging

- Smart Ultrasound Imaging and Therapy Lab
- **Email:** caixr@shanghaitech.edu.cn
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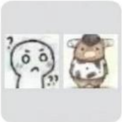
上海科技大学 ShanghaiTech University

# DIP support team

- TAs:
  - Yi Zeng 曾一 zengyi2022@shanghaitech.edu.cn
  - Tengliang 梁腾 liangteng2022@shanghaitech.edu.cn
  - Wechat group:
  - QR code
- DIP office hour:
  - Mon, 9:00-10:00, 3-438, SIST
- BB system
  - Online now



群聊: 数字图像处理-2024春

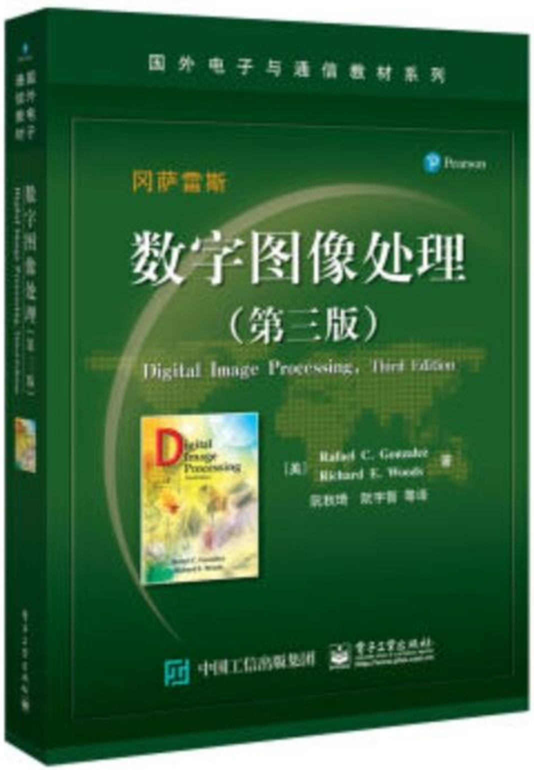
该二维码7天内(3月5日前)有效，重新进入将更新

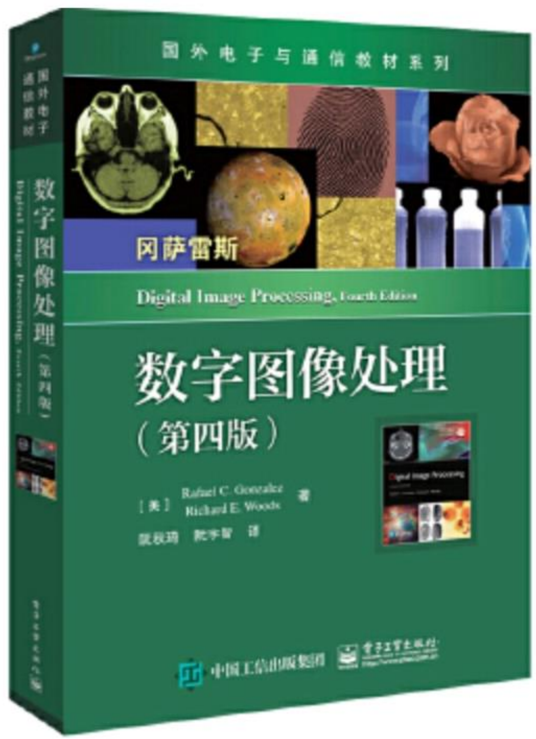
# Schedule

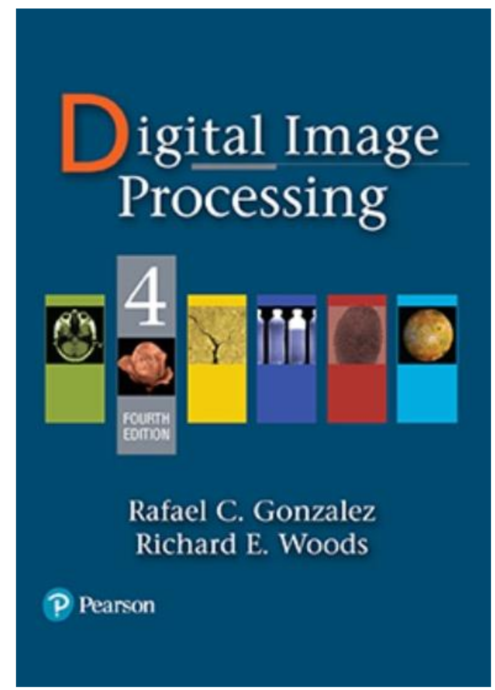
- **Topic I: Digital image fundamentals (3.5w)**
  - Introduction
  - Human visual system, perception and pixel
  - Intensity transform and spatial filtering
- **Topic II: Transform domain processing (4.5w)**
  - Frequency domain filtering
  - Image restoration and reconstruction
  - Color image processing and morphological image processing
  - Wavelet and other image transforms
- **Topic III: Image segmentation (4w)**
  - Edge detection, thresholding and region detection
  - Watershed and active contours
  - Feature extraction, scale invariant feature transform (SIFT)
- **Course Project and Presentation (4w)**

# Reference Books

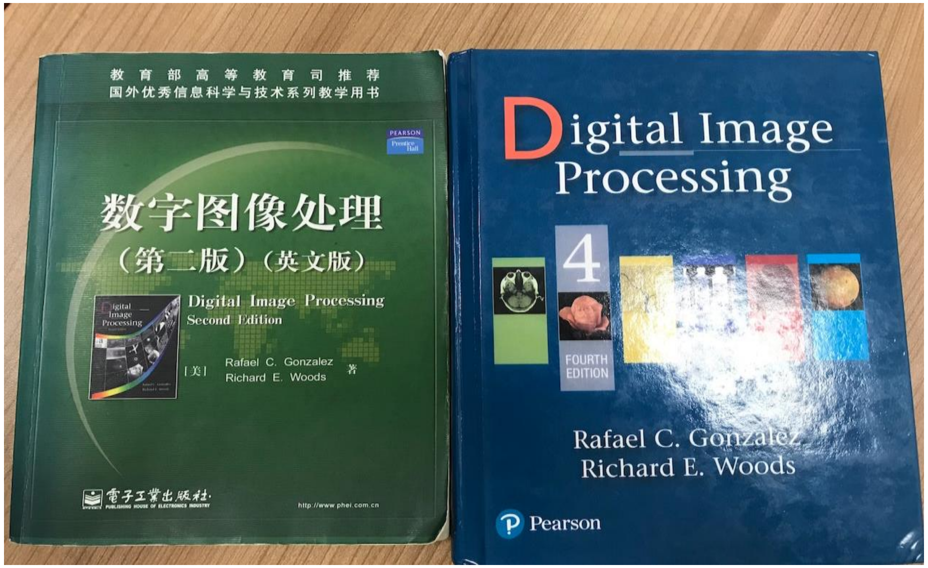
- **Digital Image Processing**, by Rafael C. Gonzalez, & Richard E. Woods
- 978-0131687288 (3 or 4th edition)

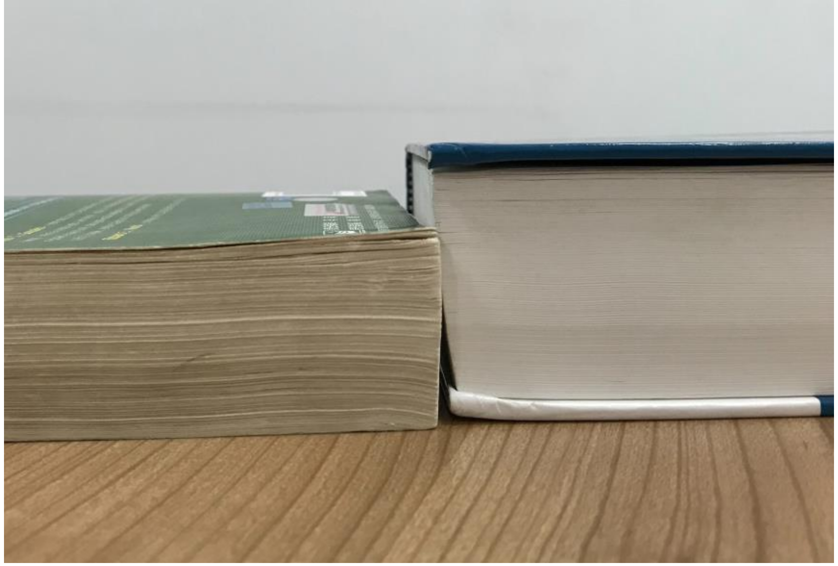


# DIP book over 10 yrs



- Many new chapters and contents

# Course Assessment

- **Total (100%) = Homework (45%) + Quiz (15%) + Final Project (40%)**
- **Homework (3 * 15% = 45 %):** once for each topic; learning the theoretical basics and basic programming skills; release normally by the end of each topic session. 2 weeks deadline. **No late homework accepted!**
- **Quiz (3 * 5% = 15%):** once for each topic; testing basic knowledges, and simple calculations; 35 min quiz in class
- **Final Project (40%): The evaluation is based on the quality of both presentation and report writing**
  - Build your team (max 3 per team): before 10th week
  - Release of project topics: 10th week
  - Submit your choice of the project topics (one can also propose your own topic): 11th week
  - Revision and finalizing your project topic: 12th week
  - Project & report writing: 13th to 15th week
  - Presentation: 16th week

# NO plagiarism！

- ❑ **单次抄袭：抄袭与被抄袭者该次课程任务（Homework，Quiz，Project）计零分，课程总成绩打八折。**
- ❑ **累计两次抄袭：抄袭与被抄袭者课程总成绩计零，同时上报信息学院学术委员会公开处理。**

# Lecture 1
# Introduction

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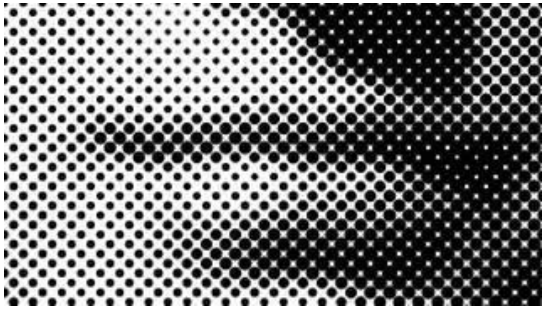
# Image examples

**FIGURE 1.1** A digital picture produced in 1921 from a coded tape by a telegraph printer with special typefaces. (McFarlane.) [References in the bibliography at the end of the book are listed in alphabetical order by authors' last names.]

**FIGURE 1.2** A digital picture made in 1922 from a tape punched after the signals had crossed the Atlantic twice. (McFarlane.)

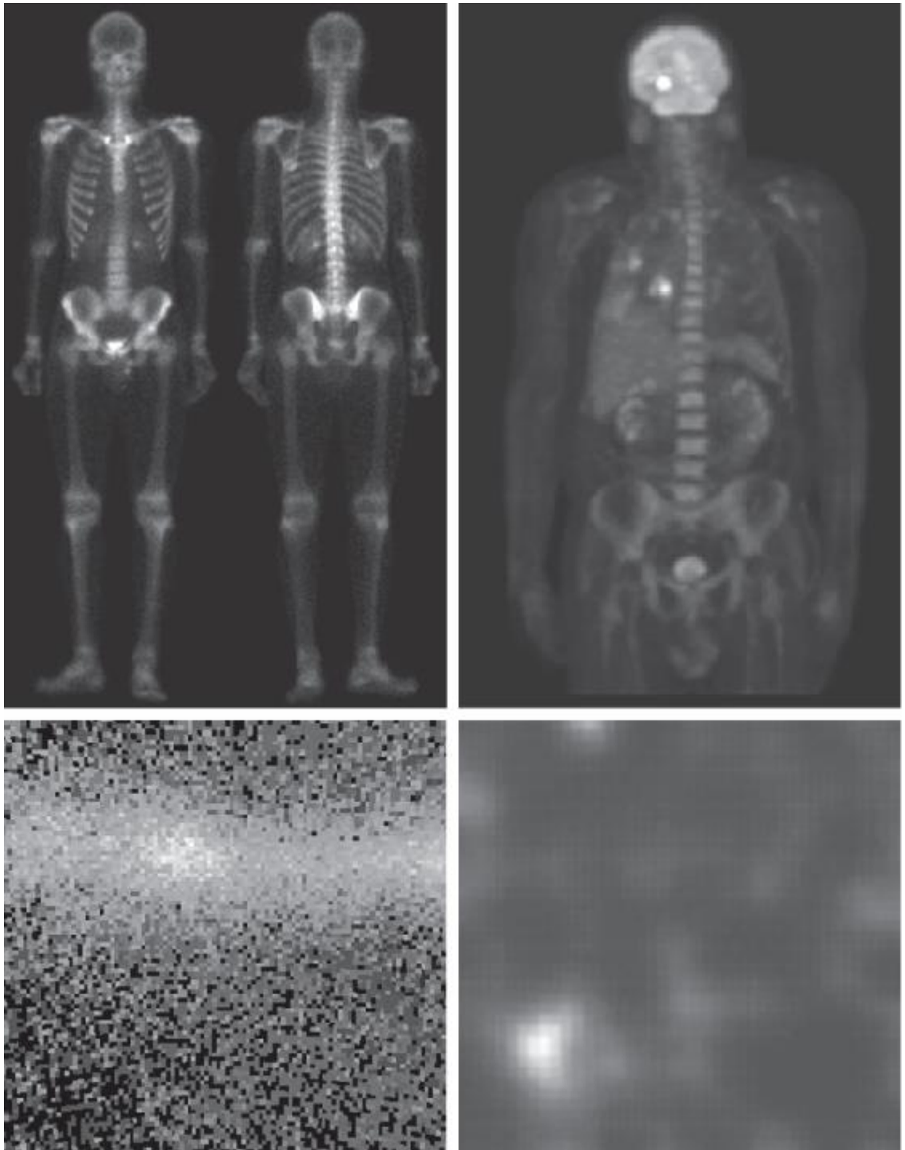


Halftone pattern

# Image examples

**FIGURE 1.4**
The first picture of the moon by a U.S. spacecraft. *Ranger 7* took this image on July 31, 1964 at 9:09 A.M. EDT, about 17 minutes before impacting the lunar surface. (Courtesy of NASA.)

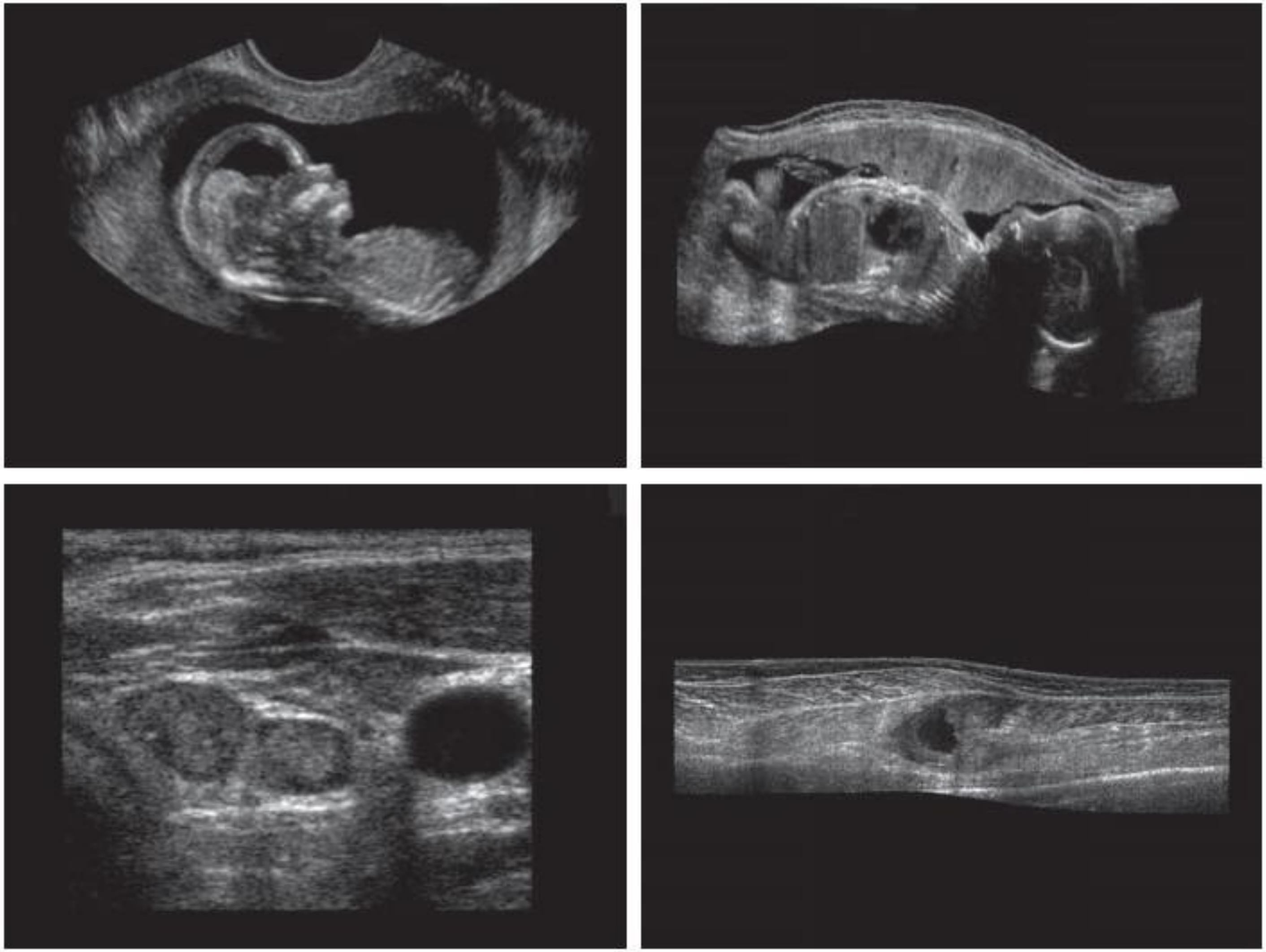
# Image examples



a b
c d

**FIGURE 1.6**
Examples of gamma-ray imaging. (a) Bone scan. (b) PET image. (c) Cygnus Loop. (d) Gamma radiation (bright spot) from a reactor valve. (Images courtesy of (a) G.E. Medical Systems; (b) Dr. Michael E. Casey, CTI PET Systems; (c) NASA; (d) Professors Zhong He and David K. Wehe, University of Michigan.)

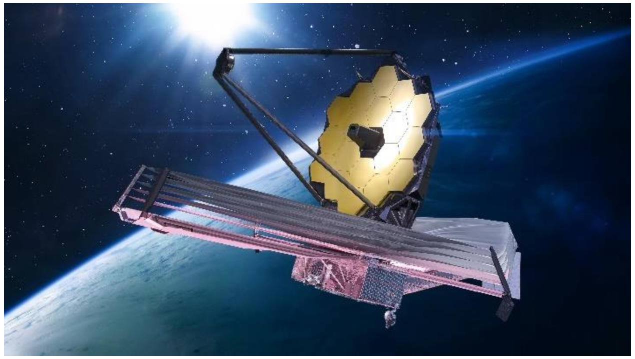
# Image examples



a b
c d

**FIGURE 1.20** Examples of ultrasound imaging. (a) A fetus. (b) Another view of the fetus. (c) Thyroids. (d) Muscle layers showing lesion. (Courtesy of Siemens Medical Systems, Inc., Ultrasound Group.)

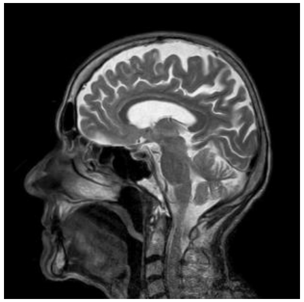
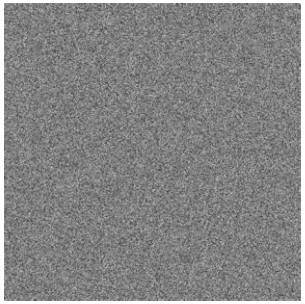
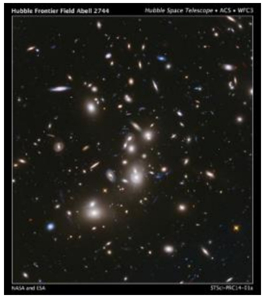
# Image examples



James Webb Space Telescope

# What is Digital Image?

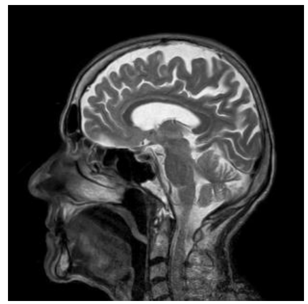
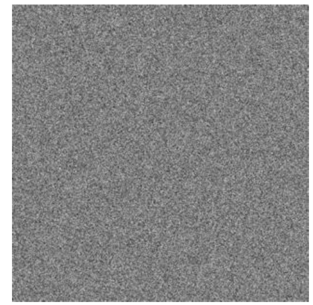


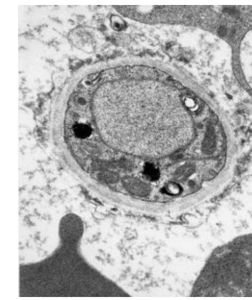




- ___?__ image
- Digital image

# What is Digital Image?



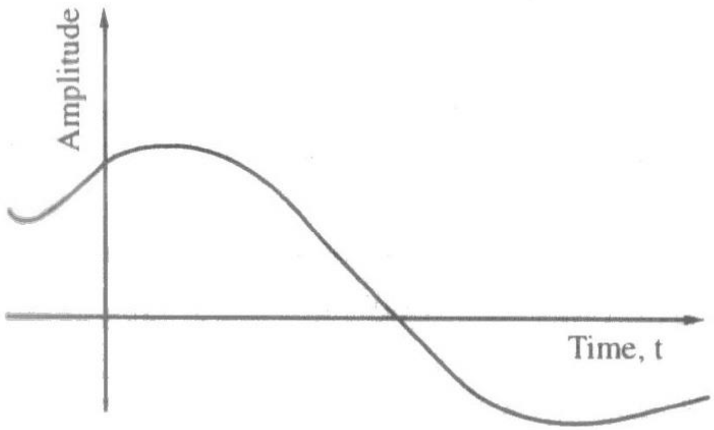





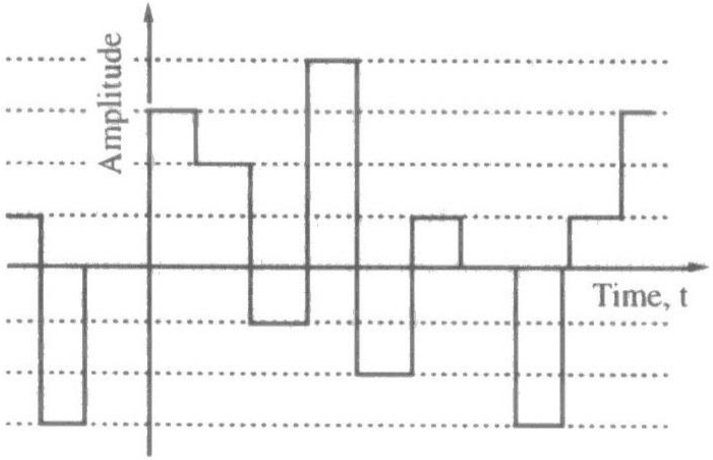
- Analog image
- Digital image


# From DSP: Analog Signal

- Analog signal
  - Continuous-time signal with continuous-valued amplitude
  - Most of the natural signals are analog

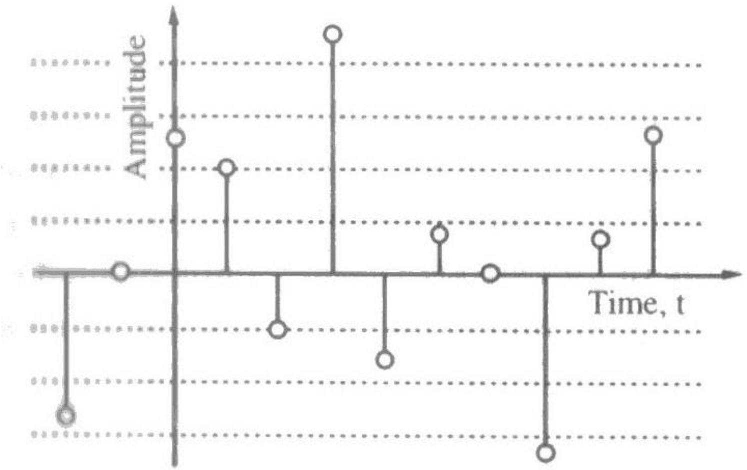



- Quantized boxcar signal
  - Continuous-time signal with discrete-valued amplitude
  - Occurs in digital electronic circuits

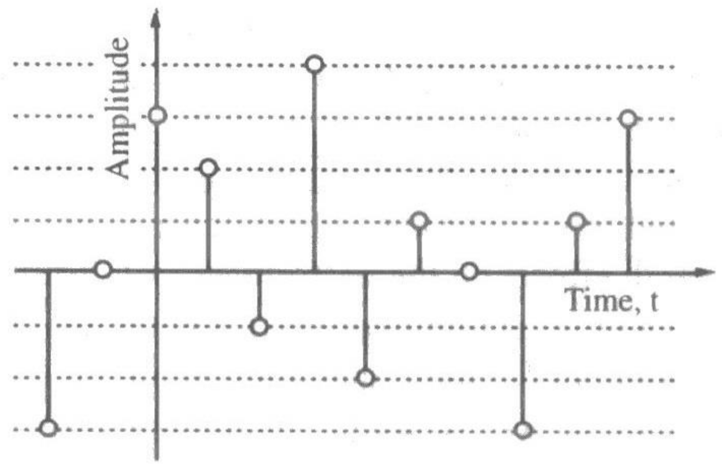


# From DSP: Digital Signal

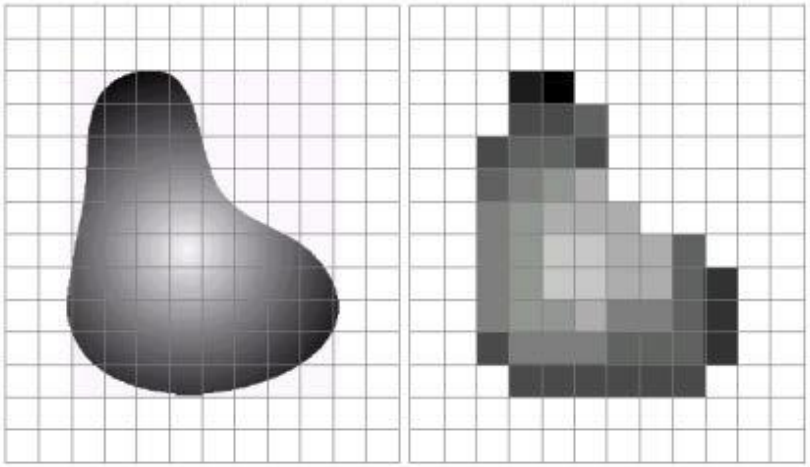
- Sampled-data signal
  - Discrete-time signal with continuous-valued amplitude
  - The amplitude of the signal may be any value

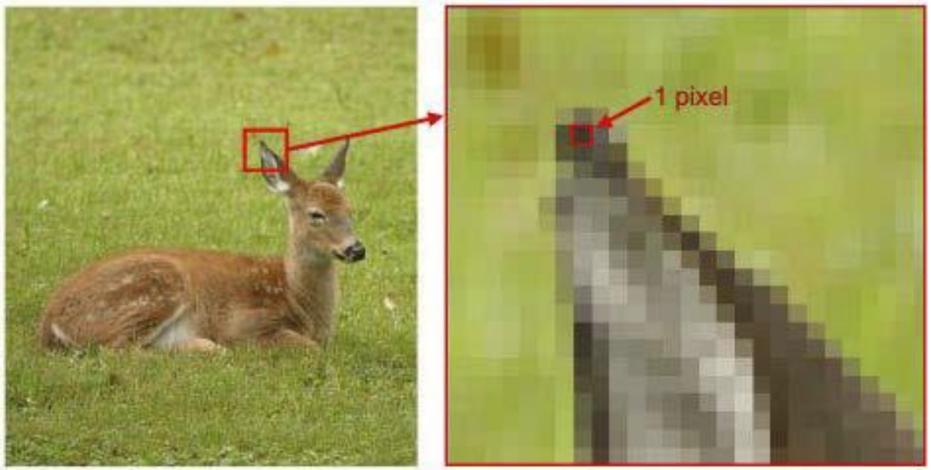



- Digital signal
  - Discrete-time signal with discrete-valued amplitude
  - A digital signal is a quantized sampled-data signal



# Analog vs. Digital Image






Pixel

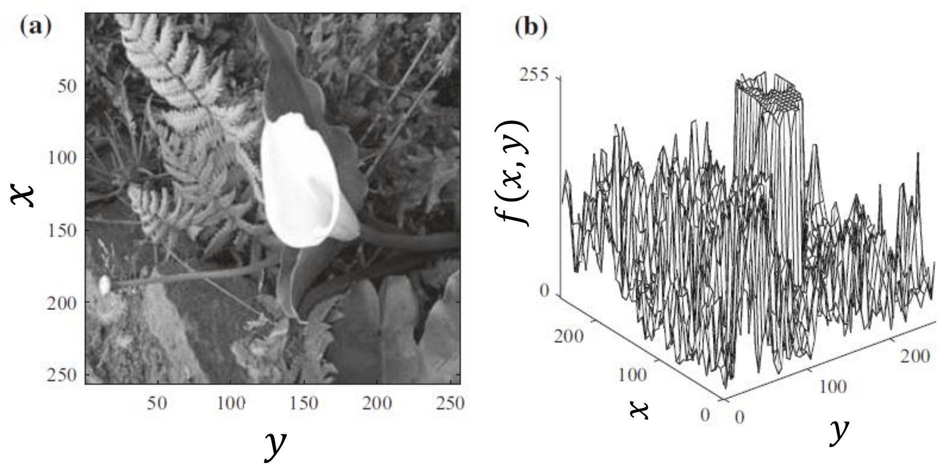
Pixel

# Pixel / Voxel

- Digitization implies that a digital image is an approximation of a real scene.
- Digital image compose of a finite number of elements – Pixel.
- A pixel has a location and intensity information typically represent gray levels, colors, heights, opacities, etc.

**A visual representation in form of a function *f*(x,y), where**

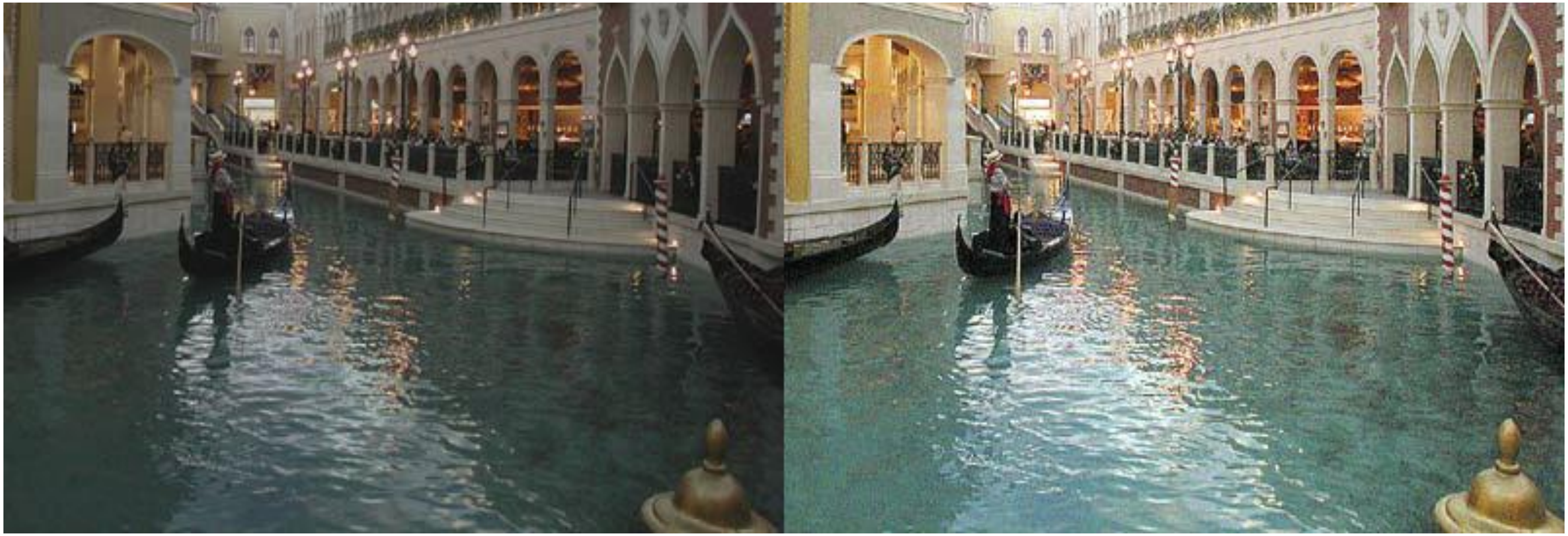
- *f* is related to the intensity or brightness (color) at point
- (x, y) are spatial coordinates
- x, y, and the amplitude of *f* are finite and discrete quantities




(a) A 256 × 256 image with 256 gray levels;
(b) its amplitude profile

# Digital image processing

- Definition: Processing digital images by means of a digital computer.



# Stages of DIP

| Low level process | Mid level process | High level process |
| --- | --- | --- |
| **INPUT:** Image<br>**OUTPUT:** Image<br><br>**EXAMPLE:**<br>Denoise<br>Contrast enhancement<br>Image sharpening | **INPUT:** Image<br>**OUTPUT:** Attributes<br><br>**EXAMPLE:**<br>Segmentation<br>Edge detection<br>Recognition | **INPUT:** Attributes<br>**OUTPUT:** Understanding<br><br>**EXAMPLE:**<br>Image analysis<br>Image understanding |

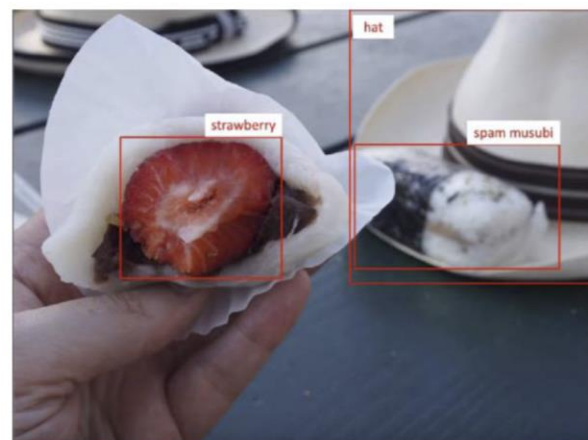
There are no clear-cut boundaries
from image processing to computer vision

# Stage of DIP

Mid level

Low level

High level



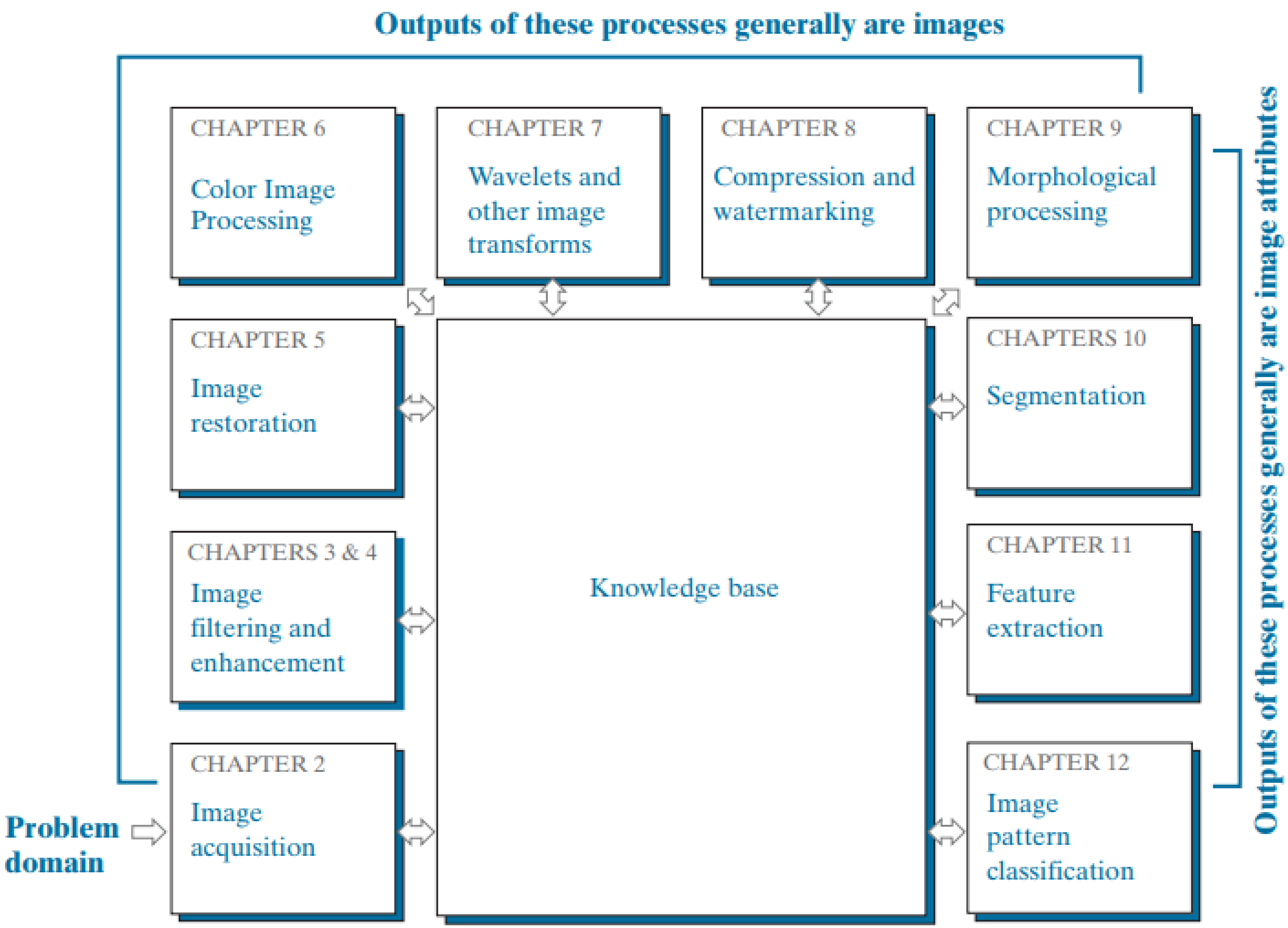
# Frequent question: relationship between Digital Image Processing and Computer Vision

| Input \ Output | Image | Knowledge |
|---|---|---|
| Image | Digital Image Processing | Computer Vision |
| Knowledge | Computer Graphic | Artificial Intelligence |

# Fundamental Steps in DIP

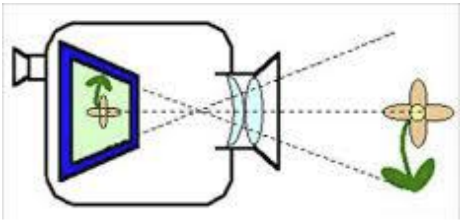
- Image acquisition
- Image enhancement
- Image restoration
- Image reconstruction
- Image compression
- Image segmentation
- Image representation and description
- Object recognition

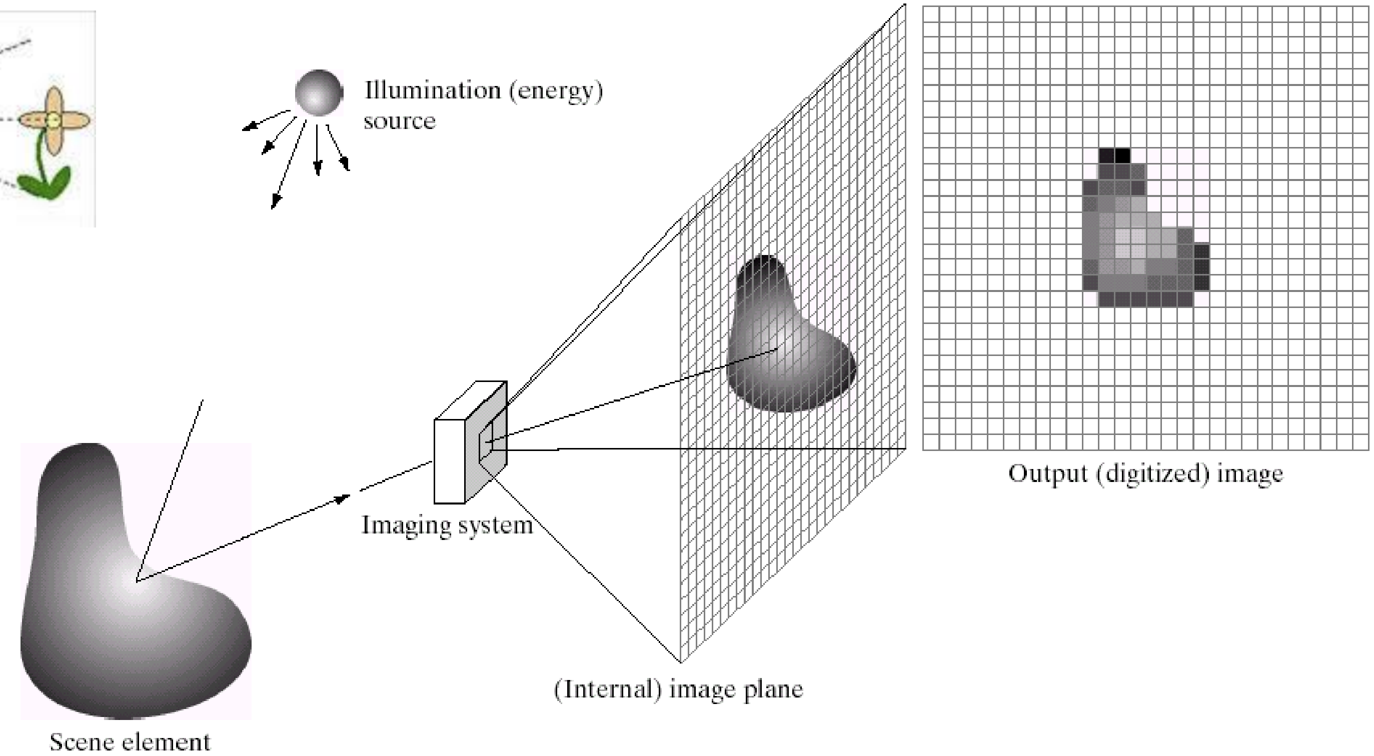
# DIP book



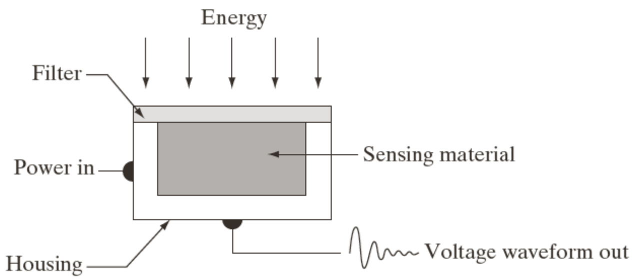
Outputs of these processes generally are images
CHAPTER 6
Color Image Processing
CHAPTER 7
Wavelets and other image transforms
CHAPTER 8
Compression and watermarking
CHAPTER 9
Morphological processing
CHAPTER 5
Image restoration
CHAPTERS 10
Segmentation
CHAPTERS 3 & 4
Image filtering and enhancement
Knowledge base
CHAPTER 11
Feature extraction
CHAPTER 2
Image acquisition
CHAPTER 12
Image pattern classification
Problem domain
Outputs of these processes generally are image attributes

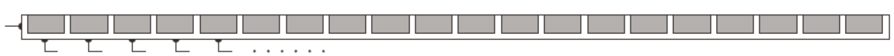
# Image acquisition

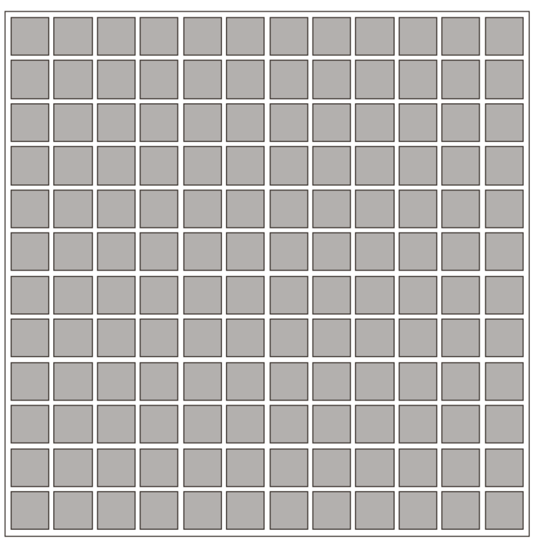




# Imaging Sensors



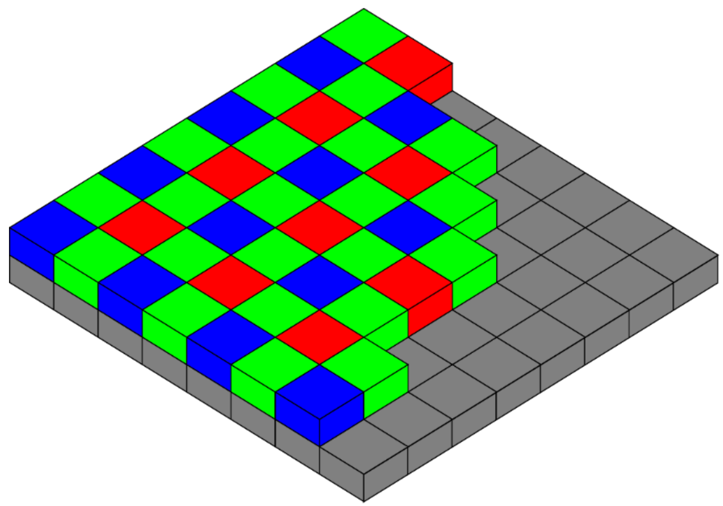


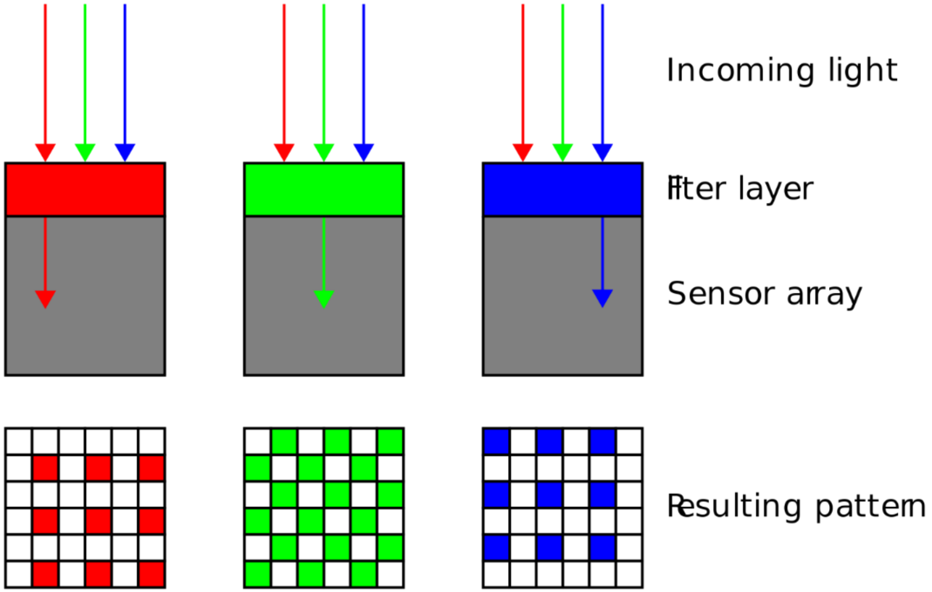
**Transform energy to voltage:**

- **Single Sensor**
  - Photodiode
  - Piezoelectric element
- **Sensor Strips**
  - CAT (Computerized axial tomography)
  - Airborne imaging
  - Ultrasound array transducer
- **Sensor Array**
  - CCD (Charge-coupled Device) – digital camera
- **Color Images**

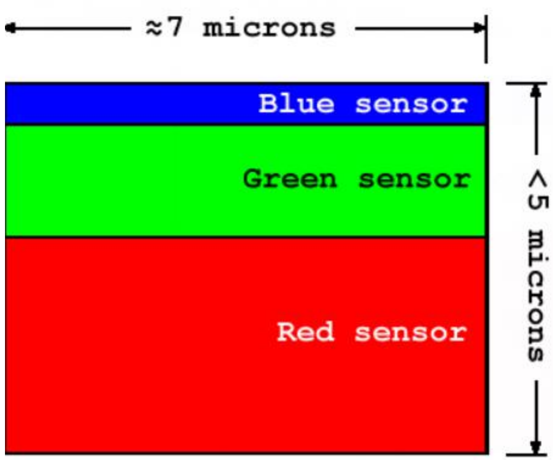
Use a Bayer's mosaic pattern of R/G/B filters to reduce cost, then use demosaicing to construct full resolution color images.

# Bayer filter





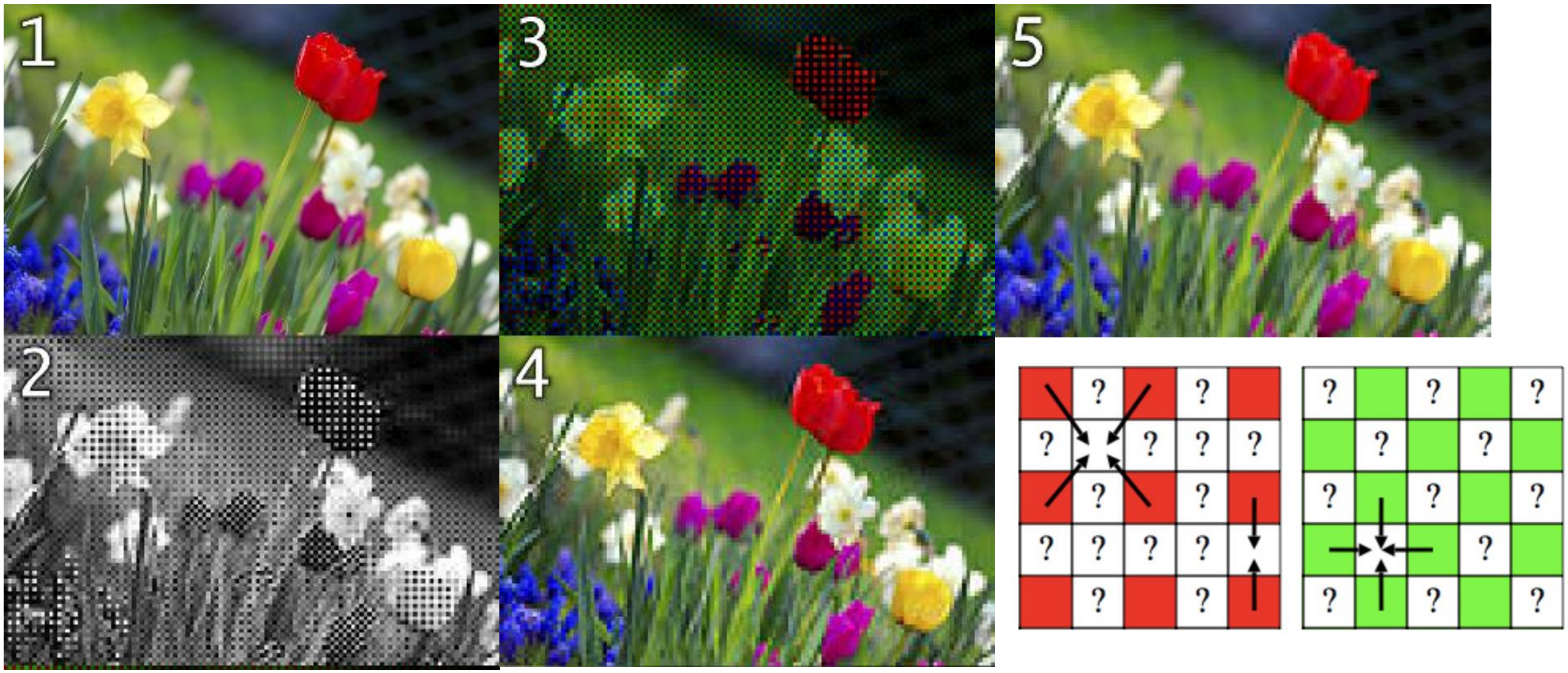

Foveon X3 sensor stack



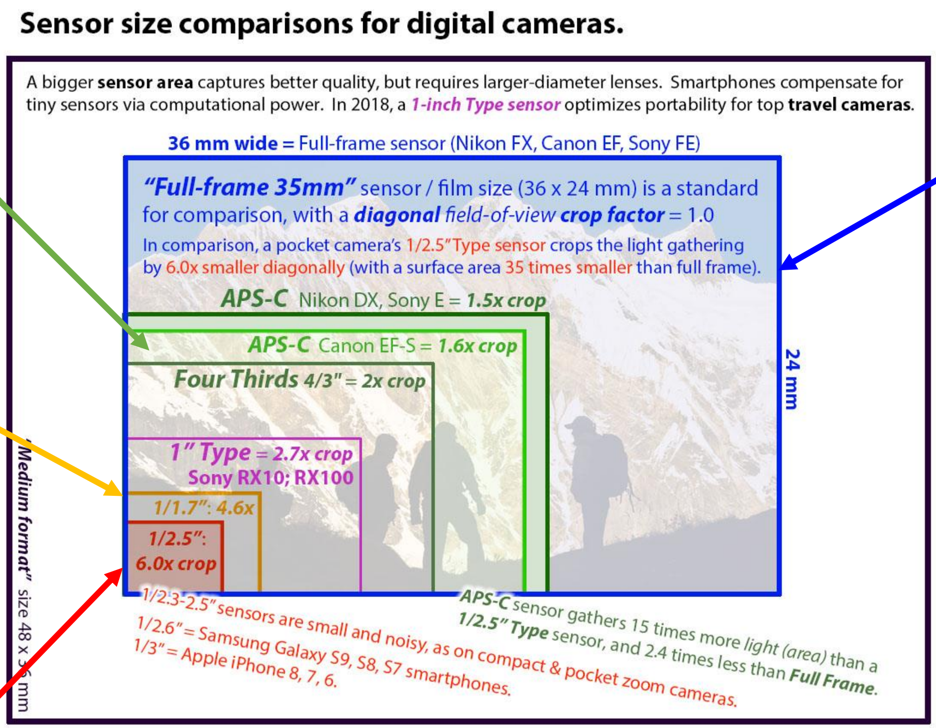

$$f\cancel{(x,y)} \longrightarrow f(x,y,c)$$

https://en.wikipedia.org/wiki/Foveon_X3_sensor

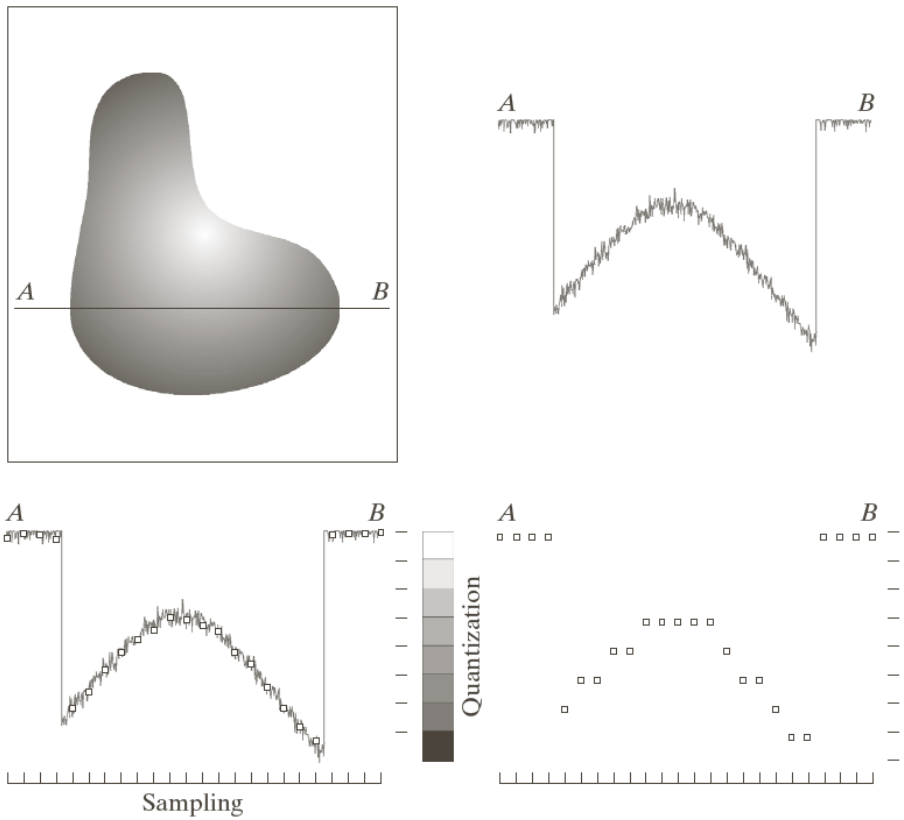
# Color coded and reconstruction



# Sensor size comparisons for digital camera


# Sampling and Quantization



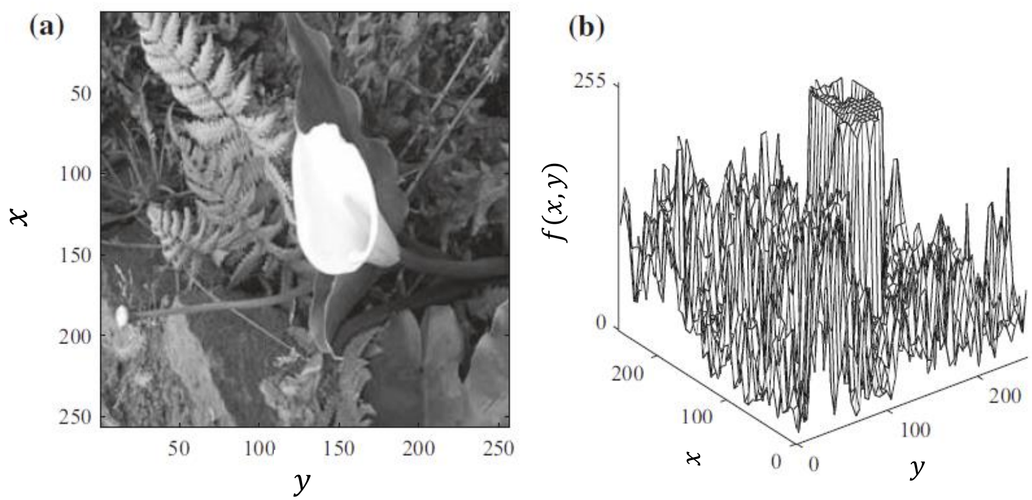

Sampling : *Digitize the coordinate values*

Quantization: *Digitize the amplitude values*

- Uniform
- Non-uniform

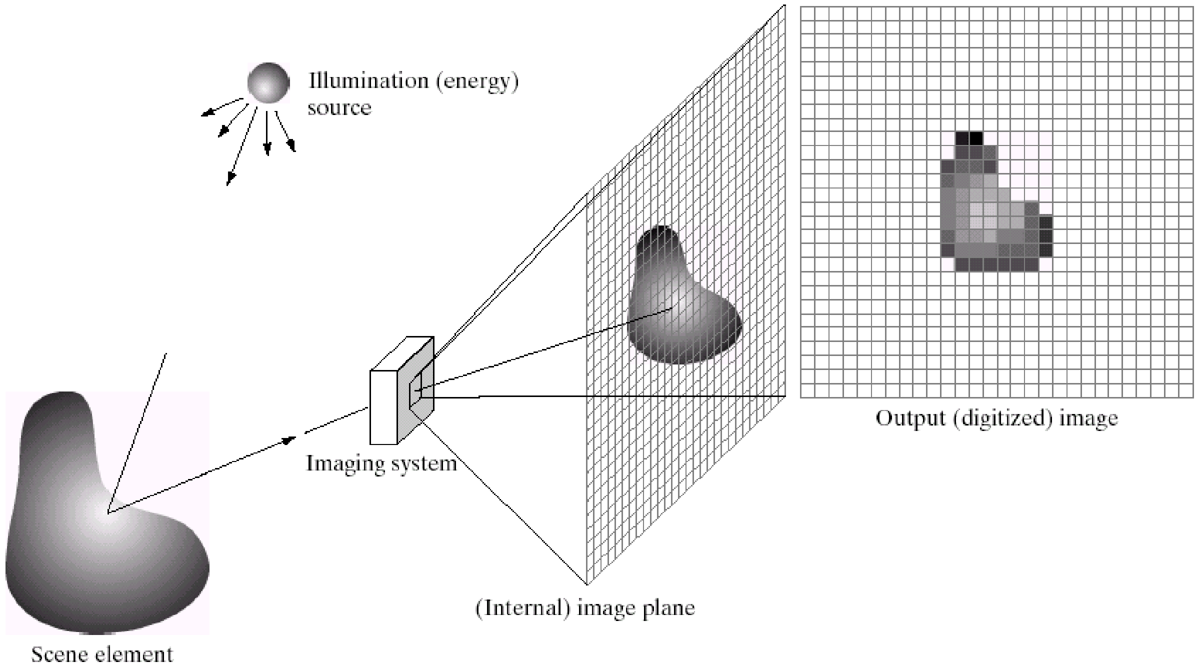
# Digital image

- **A visual representation in form of a function $\boldsymbol{f(x, y)}$, where**
  - $f$ is related to the intensity or brightness (color) at point
  - $(x, y)$ are spatial coordinates
  - $x, y$, and the amplitude of $f$ are finite and discrete quantities




(a) A 256X256 image with 256 gray levels; (b) its amplitude profile

# Illumination model




$$f(x,y) = i(x,y)r(x,y) \qquad 0 < i(x,y) < \infty, 0 \le r(x,y) < 1$$

$L_{min} < f(x_0, y_0) < L_{max}$ where $L_{min}$ is positive , $L_{max}$ is finite

# Illumination model

$$f(x,y) = i(x,y)r(x,y) \qquad 0 < i(x,y) < \infty, 0 \le r(x,y) < 1$$

$$L_{min} < f(x_0, y_0) < L_{max}$$ where $L_{min}$ is positive , $L_{max}$ is finite

- **Illuminations:** $i(x,y)$ 1W/m$^2$
- Clear sunny day: 90K
- Cloudy day: 10K
- Indoors: 1K
- Full Moon: 0.1

- **Reflections:** $r(x,y)$
- Snow: 0.93
- Flat white wall: 0.80
- Stainless steel: 0.65
- Black cloth: 0.01

# Matrix Representation

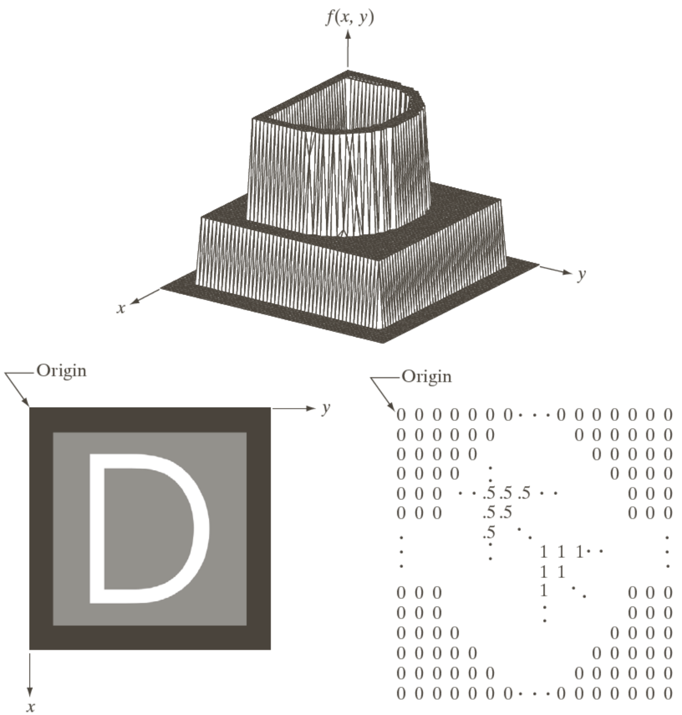
**Three basic ways to represent *f*(*x*, *y*)**

- Plot of function: *difficult to view and interpret*
- Visual intensity array: *for view*
- numerical array: *for processing and algorithm development*

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

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

Intensity level $L = 2^k$, then $b = M \times N \times k$



# Matrix 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 Resolution 1

**Spatial Resolution:  smallest discernible detail in an image**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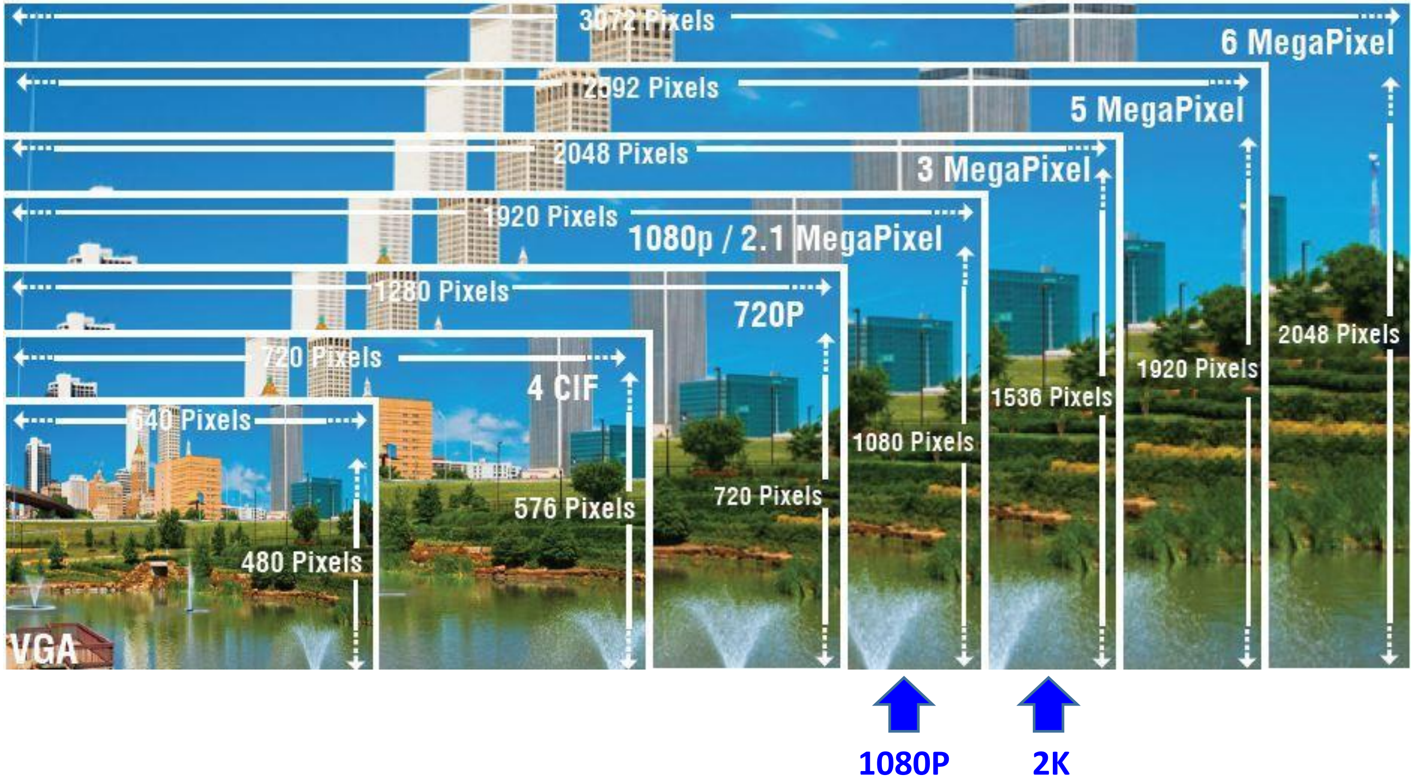
# Spatial Resolution 2

## Spatial resolution – Sampling vs Size



# Example for Spatial Resolution

## Spatial resolution: dpi (Dots Per Inch)

1250 dpi

300 dpi

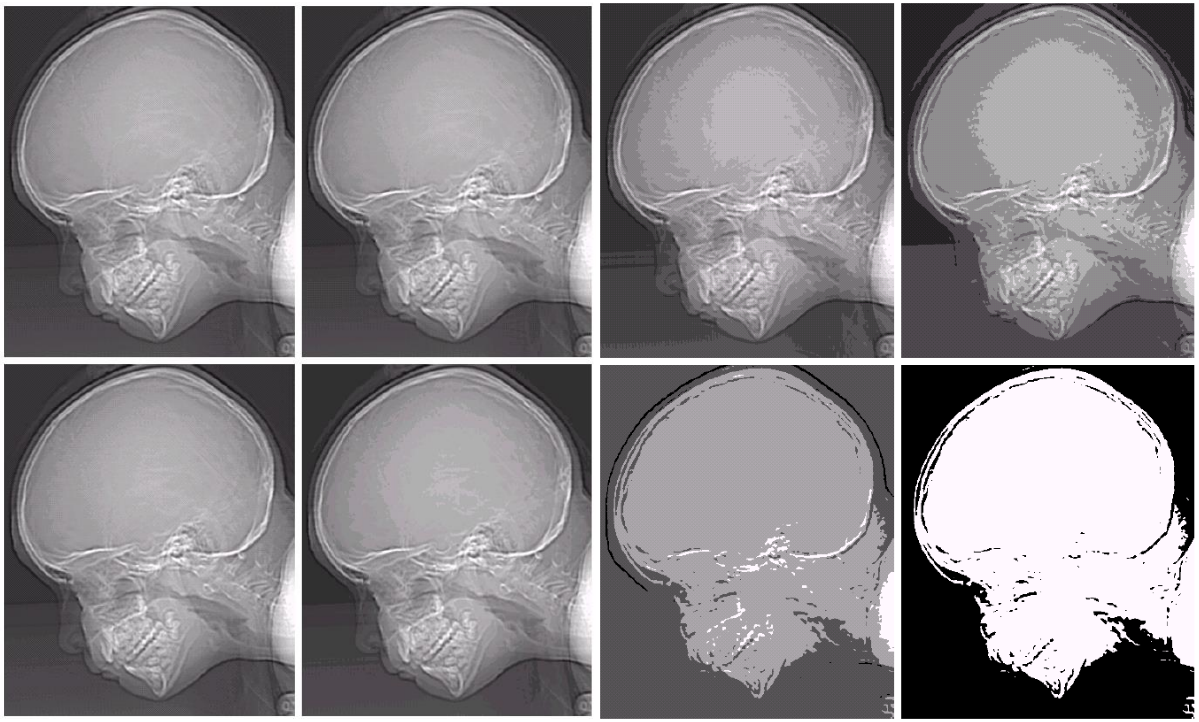
150 dpi

72 dpi

# Intensity Resolution

**Intensity resolution: smallest discernible change in intensity level**

| | |
|---|---|
| 8 bit | 7 bit |
| 6 bit | 5 bit |



| | |
|---|---|
| 4 bit | 3 bit |
| 2 bit | 1 bit |

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# Further discussion of resolution

- **Imaging system resolution:**
- **e.g. For optical imaging, <u>optical resolution</u>** describes the ability of an imaging system to resolve detail in the object that is being imaged. – wiki
- Rayleigh criterion:

$$r = \frac{1.22\lambda}{2n\sin\theta} = \frac{0.61\lambda}{\mathrm{NA}}$$

- **Temporal resolution**: imaging speed

# What is light?

- God said, "Let there be light," and there was light.

$$\nabla \cdot \vec{D} = \rho_{\text{free}}$$

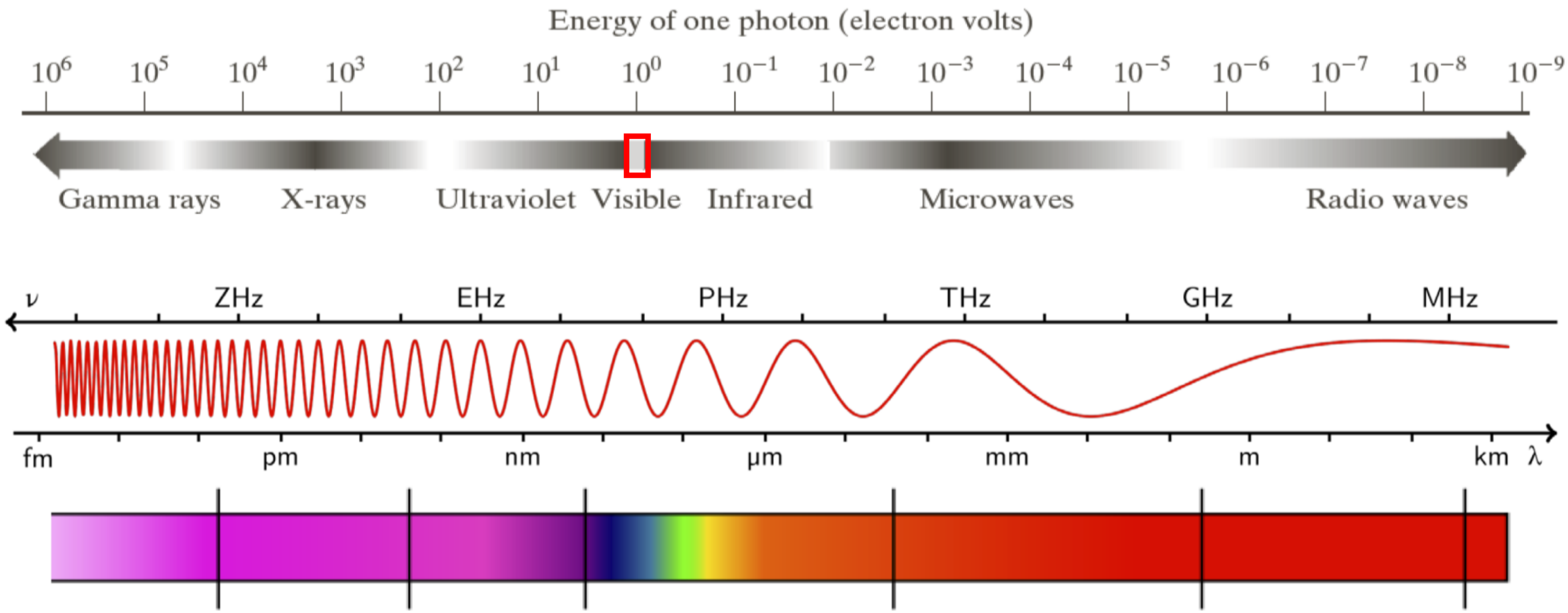
$$\nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

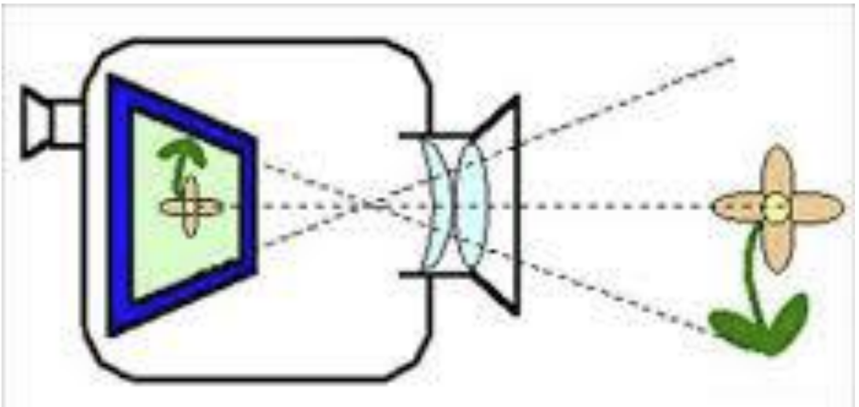
$$\nabla \times \vec{H} = \vec{J}_{\text{free}} + \frac{\partial \vec{D}}{\partial t}$$

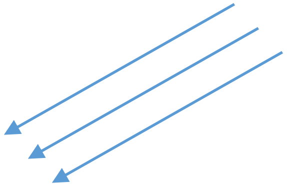
# What is light?

## Electromagnetic spectrum



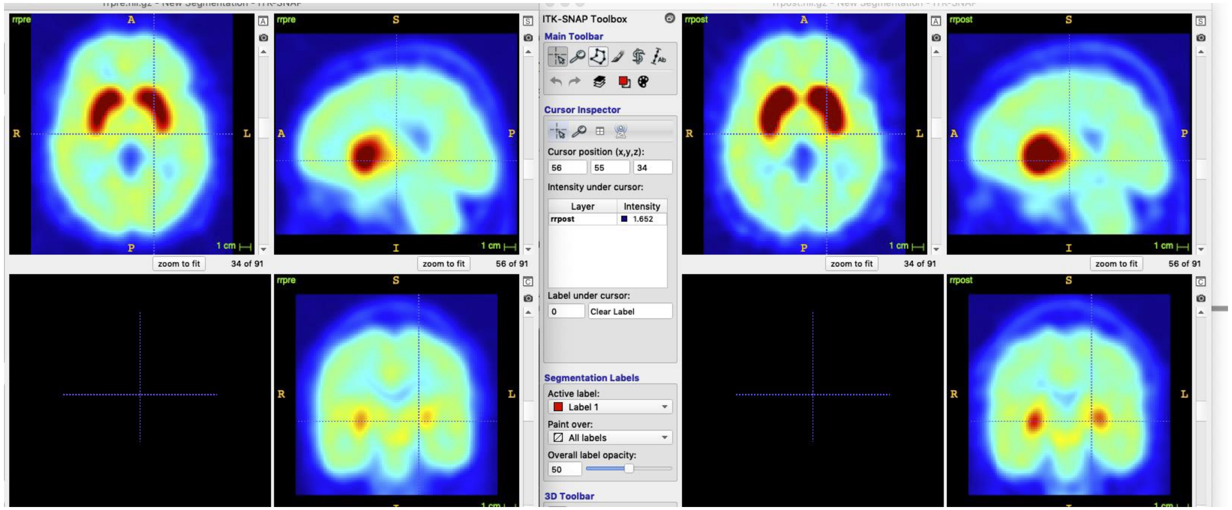
# Visible-band (1 eV)

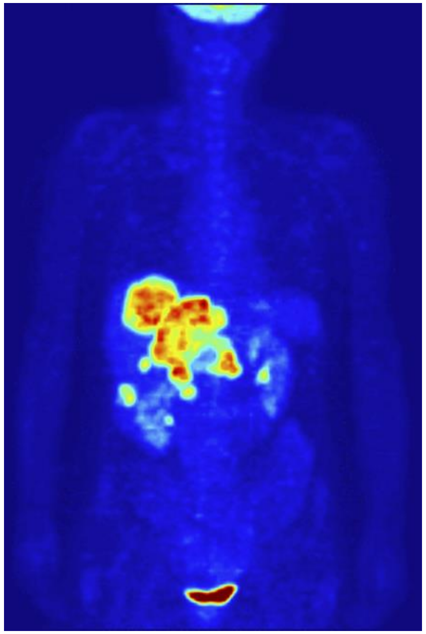





- Smartphones.
- Light microscope.
- Remote sensing (satellite).

# Gamma ray ($10^5$-$10^6$ eV)

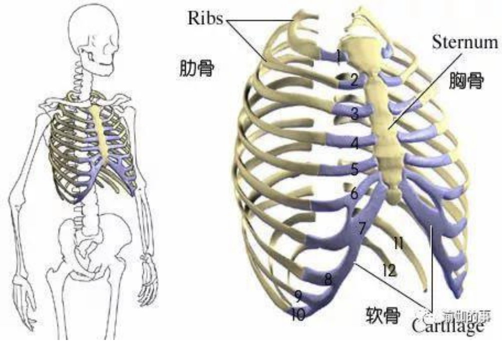


Brain PET（Positron Emission Tomography）imaging from a drug addicted patient before and after DBS surgery.
Wei. et al. JNS 2019

Whole body PET imaging with kidney labeled using 18F-FDG

# X-Ray ($10^3$-$10^4$ eV)

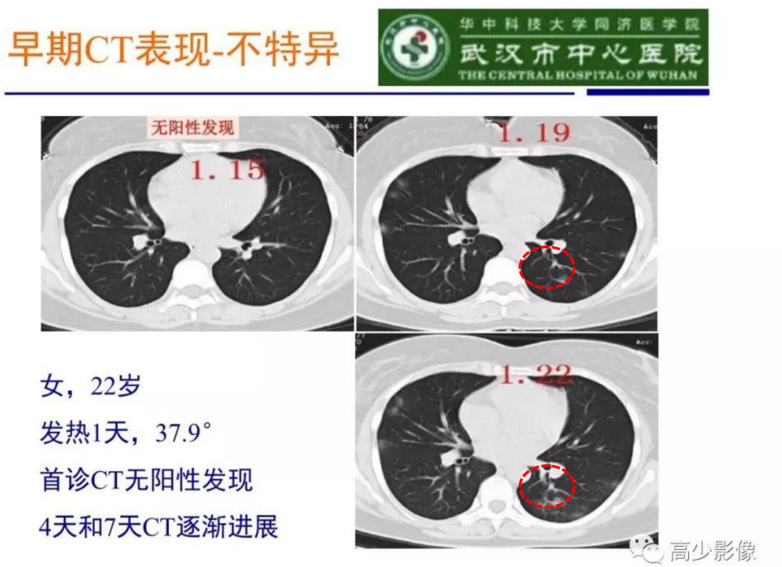


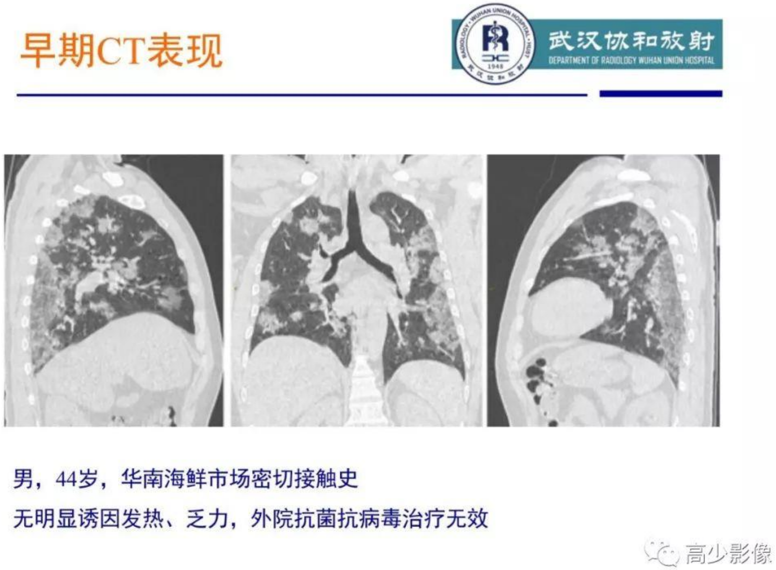

X-ray chest image

X-ray chest image of a Covid-19 Patient

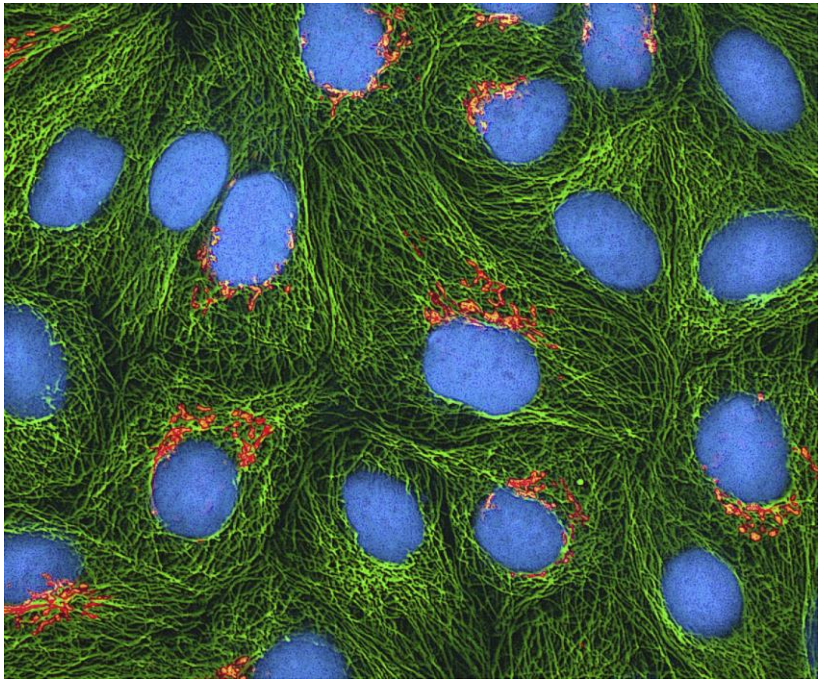
# X-Ray CT ($10^3$-$10^4$ eV)

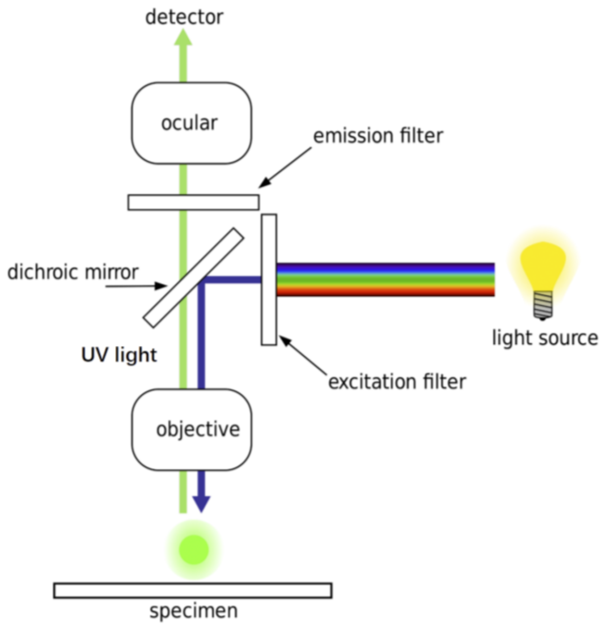
CT(Computed Tomography)，
即电子计算式断层扫描



# Ultraviolet imaging (10-100 eV)

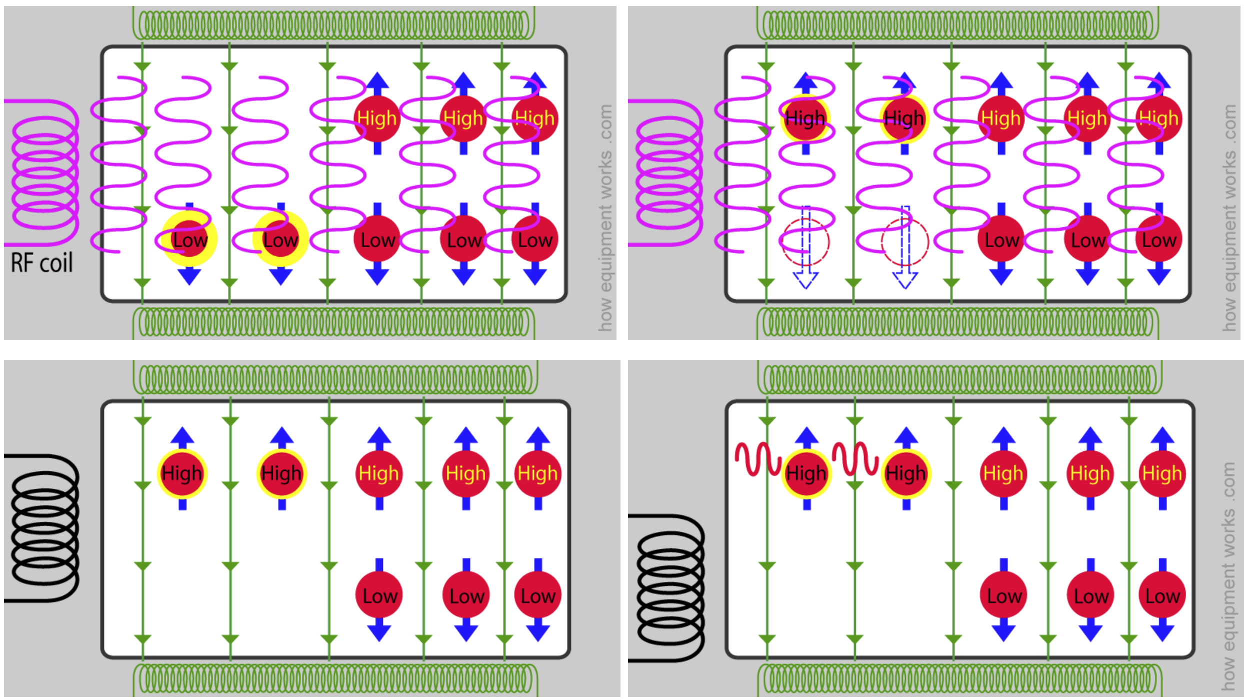





- Fluorescence microscopy image
- Fluorescence microscopy structure

# Magnetic resonance imaging (Radiofrequency/RF coil)

## Radio-band imaging ($10^{-6}$-$10^{-9}$ eV)



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# Ultrasound imaging (non-photon imaging)