

Digital Image Processing

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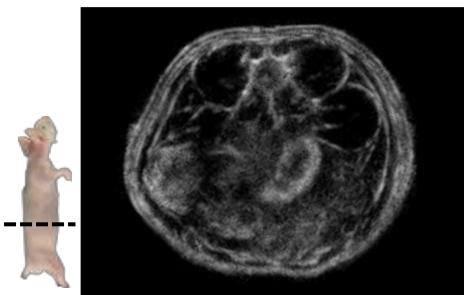
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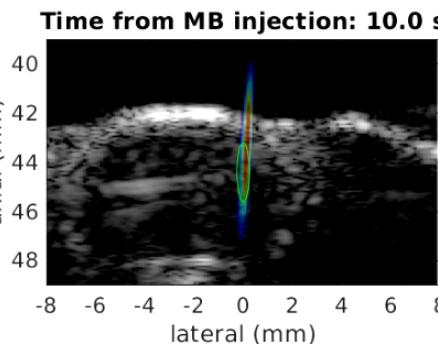
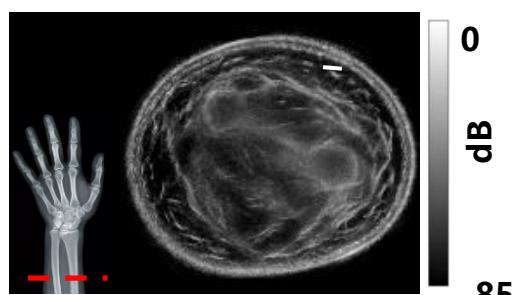
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Self introduction

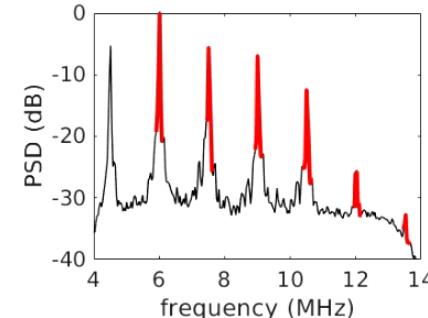
- Xiran Cai 蔡夕然, PhD
- Assistant Professor @SIST, ShanghaiTech
- Research:
 - Ultrasound imaging methods for diagnosis and image guided therapy



Ultrasound computed tomography



Passive cavitation imaging



- Smart Ultrasound Imaging and Therapy Lab
- Email: caixr@shanghaitech.edu.cn
- Office: 3-438, SIST
- Tel: 20684431

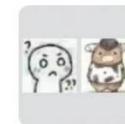


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DIP support team

□ 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

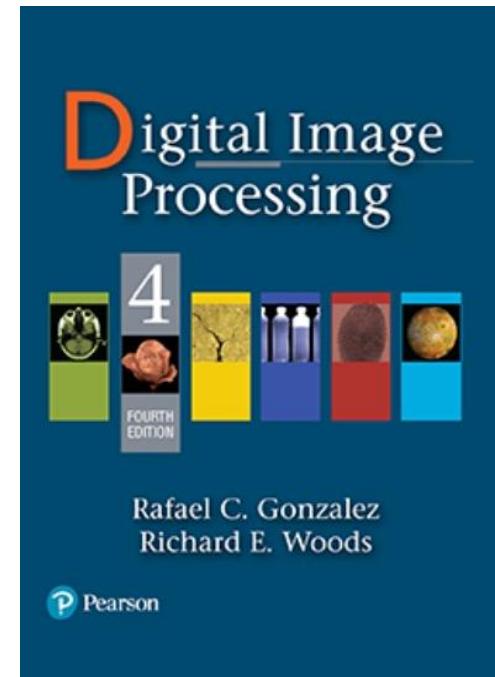
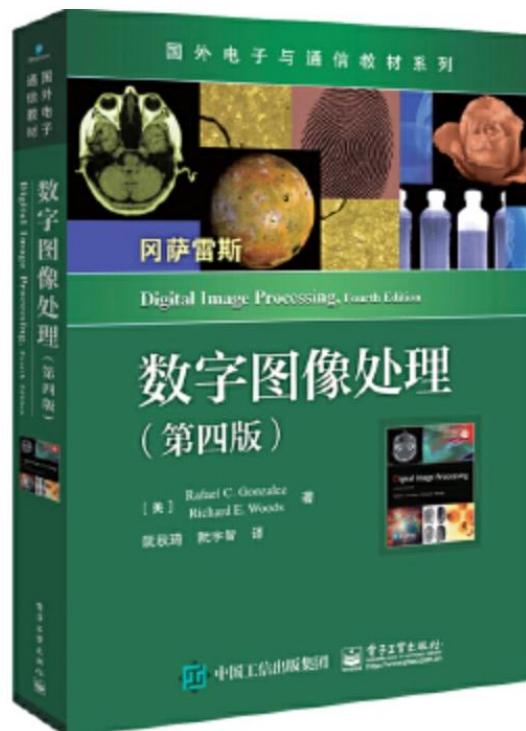
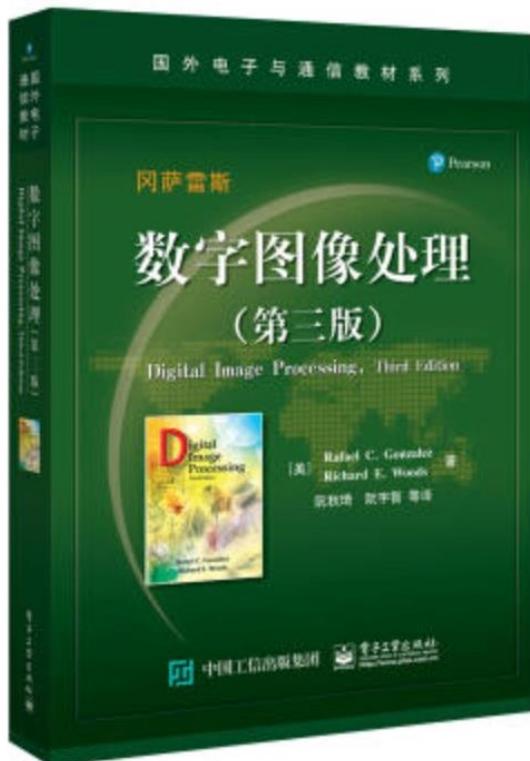
Feature extraction, scale invariant
feature transform (SIFT)

❑ Course Project and Presentation (4w)



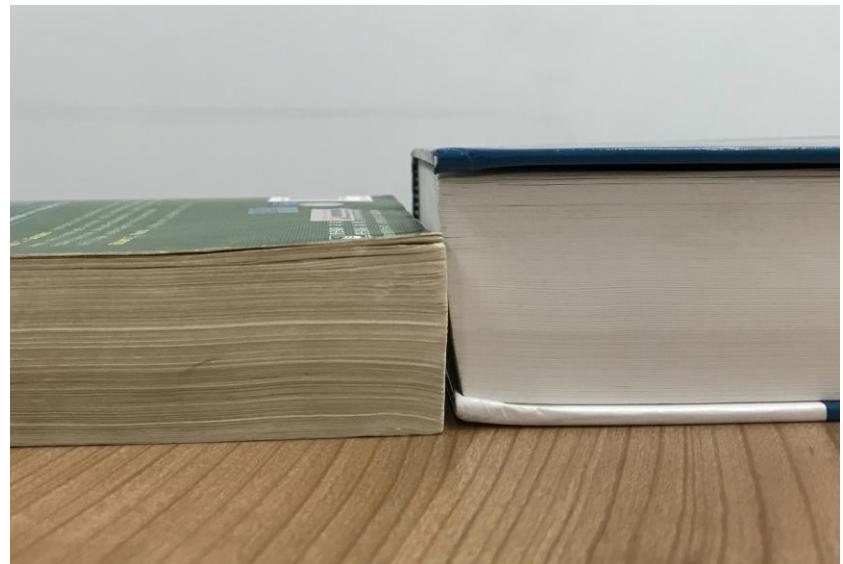
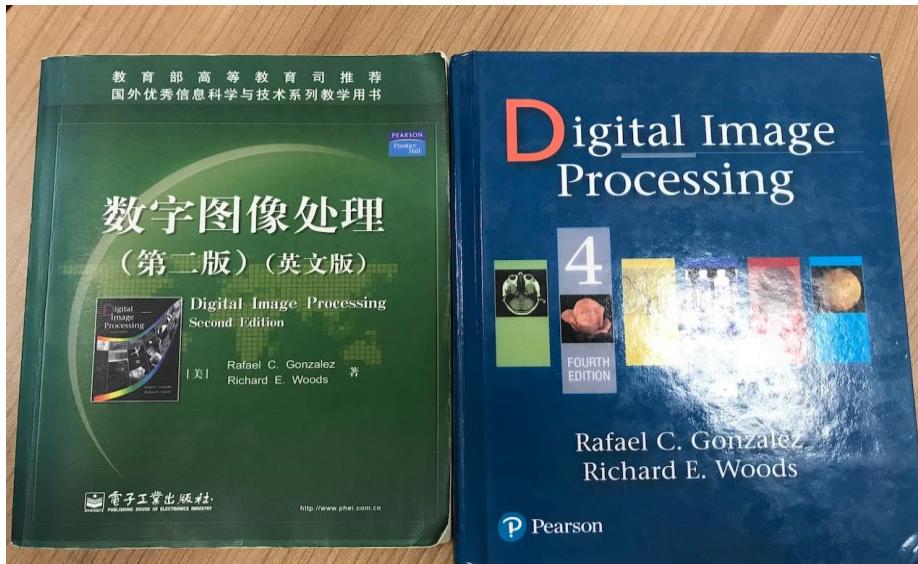
Reference Books

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



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DIP book over 10 yrs



- Many new chapters and contents



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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 不用来上课
 - 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.]



半色调编
码
(分布距离, 大)

Halftone pattern



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



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Image examples



FIGURE 1.4

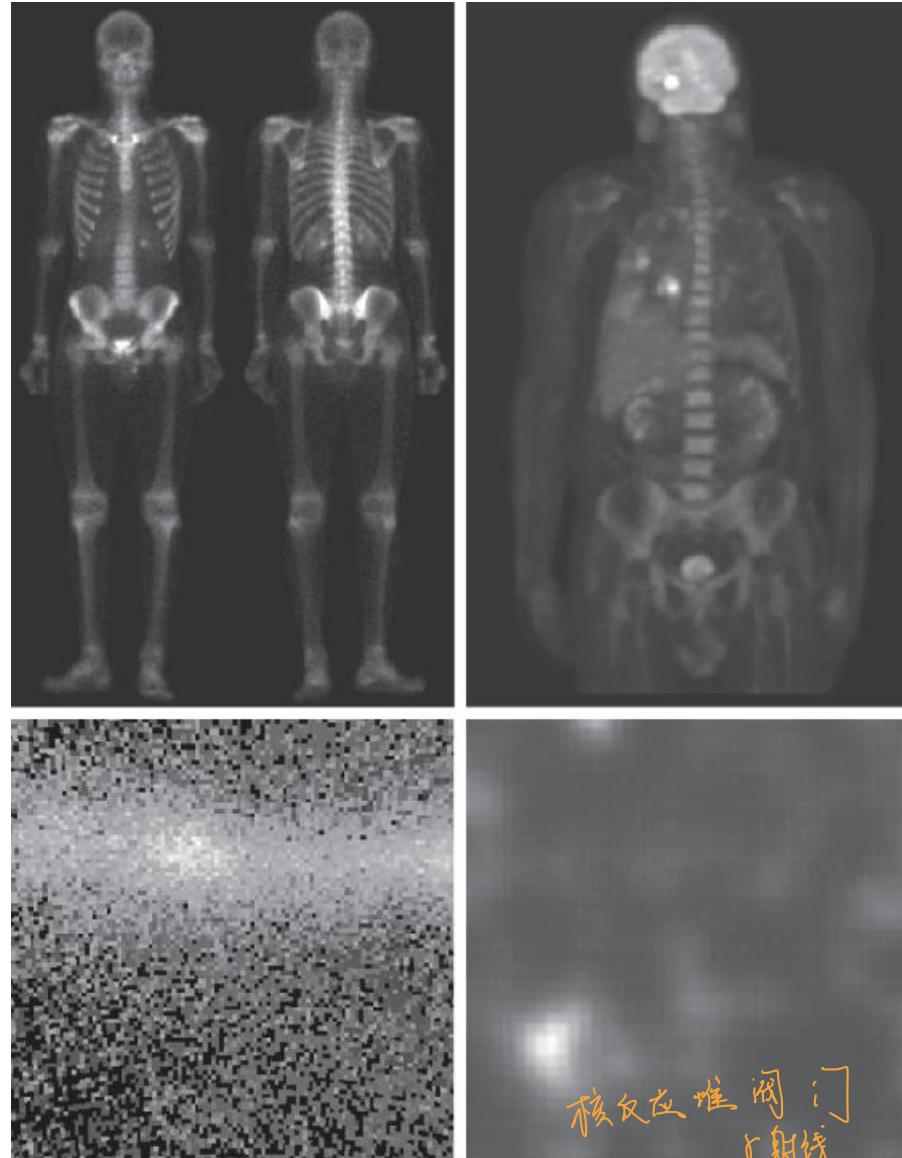
The first picture of the moon by a U.S. spacecraft. *Ranger 7* took this image on July 31, 1964 at 9:09 A.M. EDT, about 17 minutes before impacting the lunar surface. (Courtesy of NASA.)

处理 瞬变



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Image examples



a b
c d

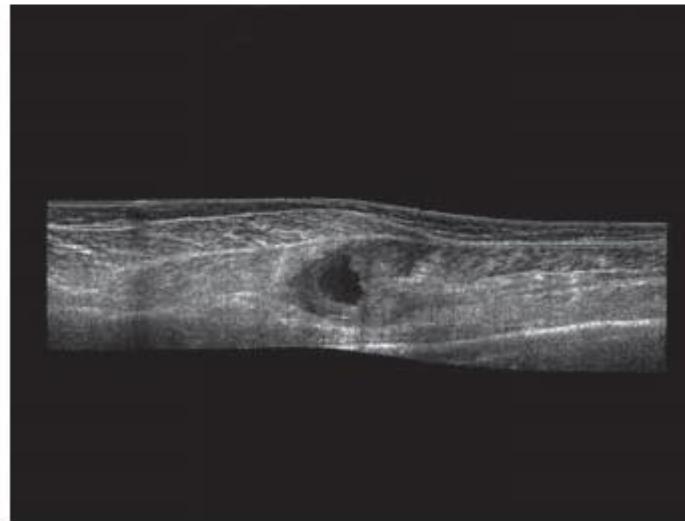
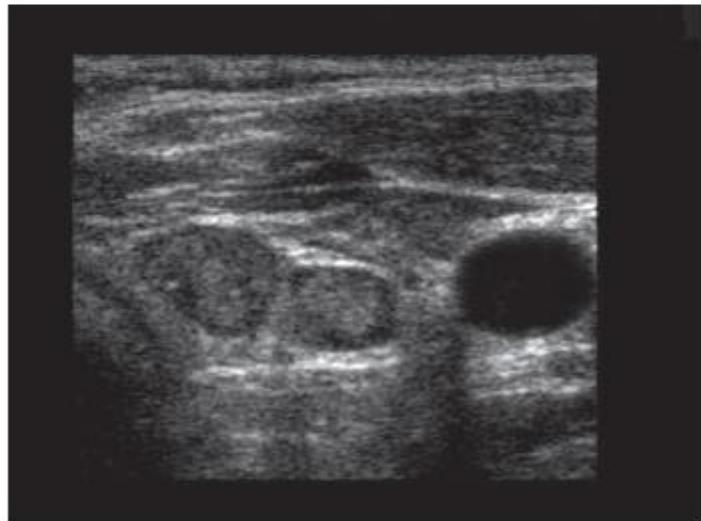
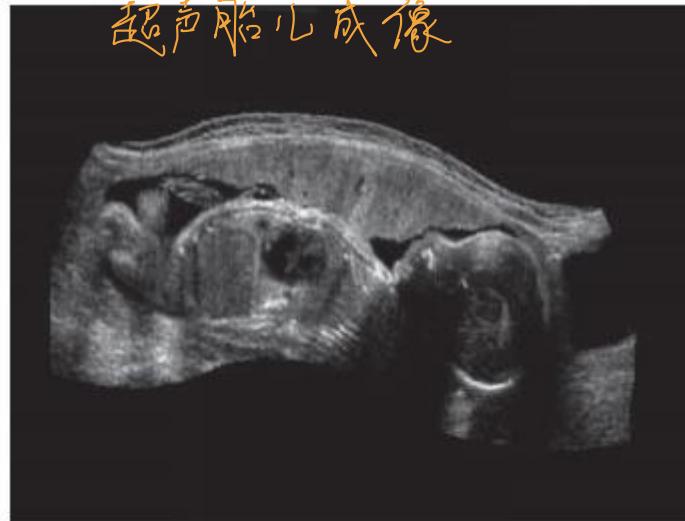
FIGURE 1.6

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.)



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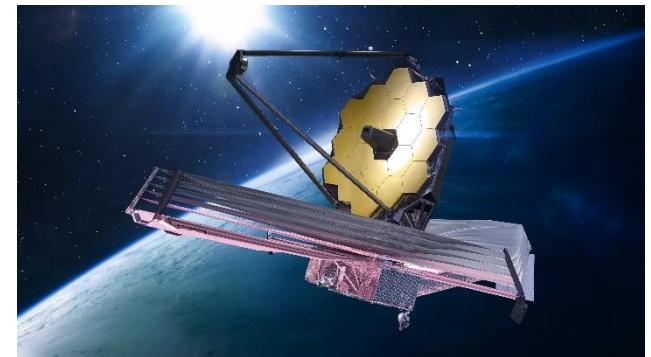
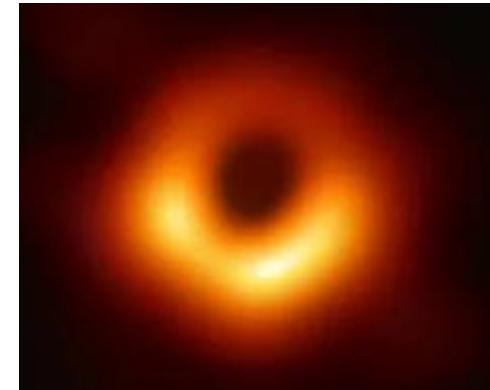
Image examples



a
b
c
d

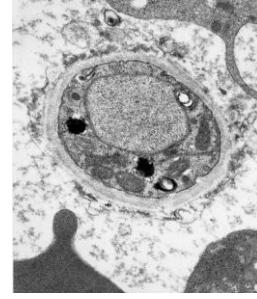
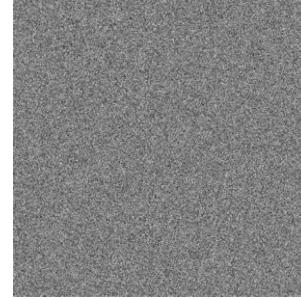
FIGURE 1.20
Examples of ultrasound imaging. (a) A fetus. (b) Another view of the fetus. (c) Thyroids. (d) Muscle layers showing lesion. (Courtesy of Siemens Medical Systems, Inc., Ultrasound Group.)

Image examples



James Webb Space Telescope

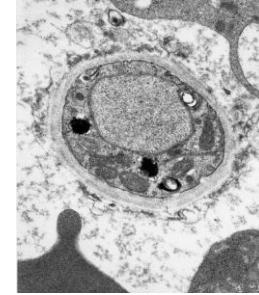
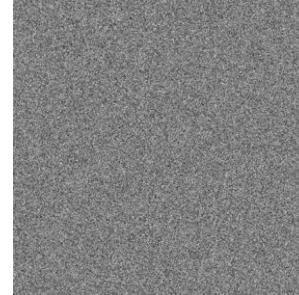
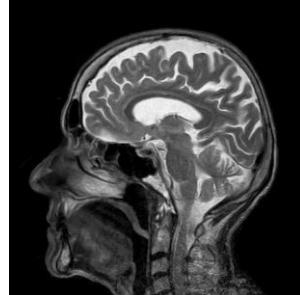
What is Digital Image?



- _____? image :
 人对视觉感知物质再现
 眼睛感知，胶卷相机
- Digital image



What is Digital Image?



连续的

- Analog image
- Digital image

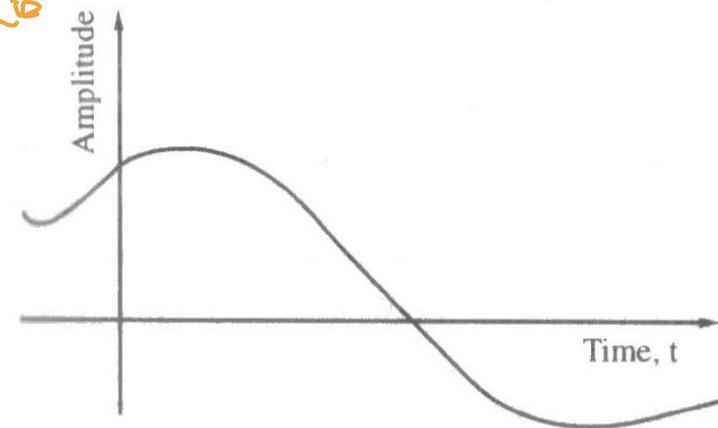


From DSP: Analog Signal

□ Analog signal 模拟

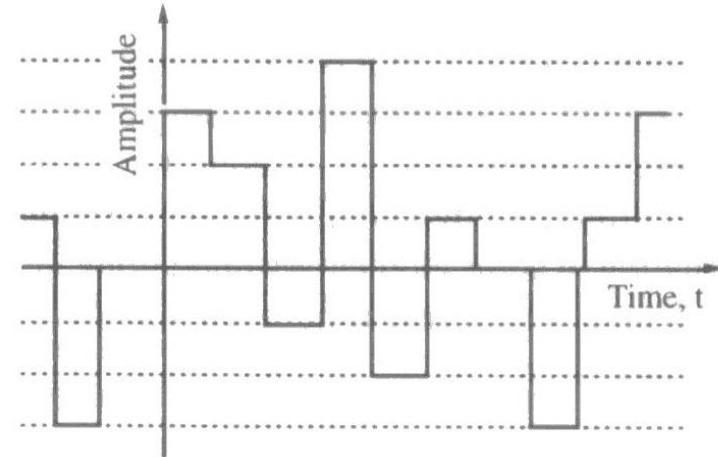
- Continuous-time signal with continuous-valued amplitude
- Most of the natural signals are analog

左右极限是否=



□ Quantized boxcar signal

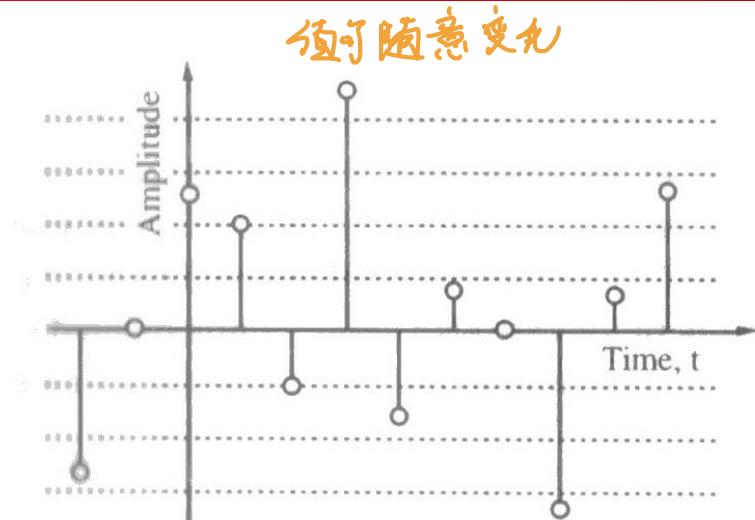
- Continuous-time signal with discrete-valued amplitude
- Occurs in digital electronic circuits



From DSP: Digital Signal

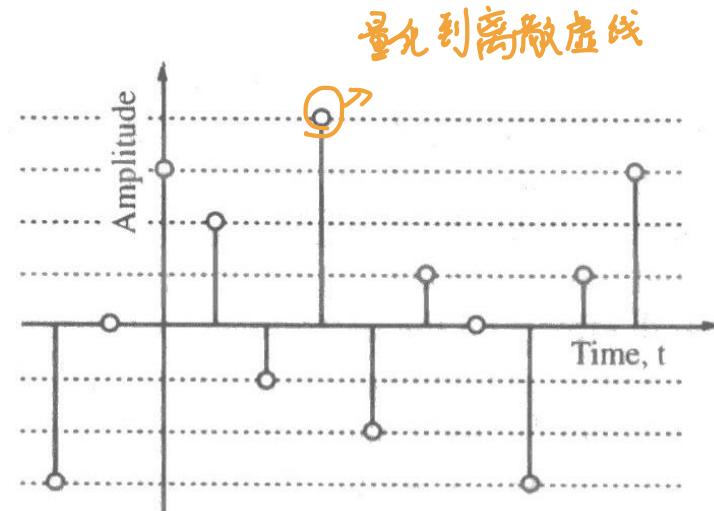
□ Sampled-data signal

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

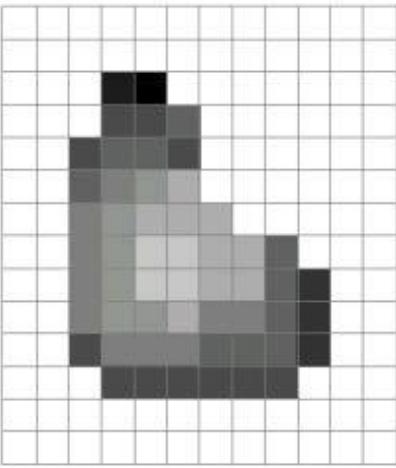
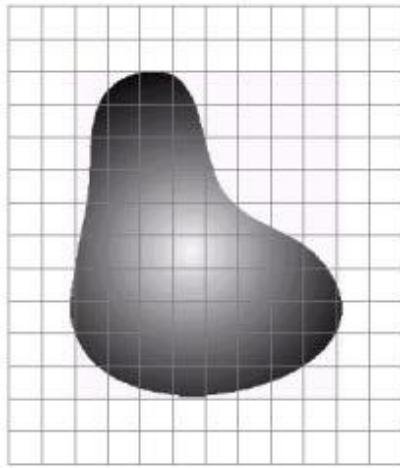


□ Digital signal

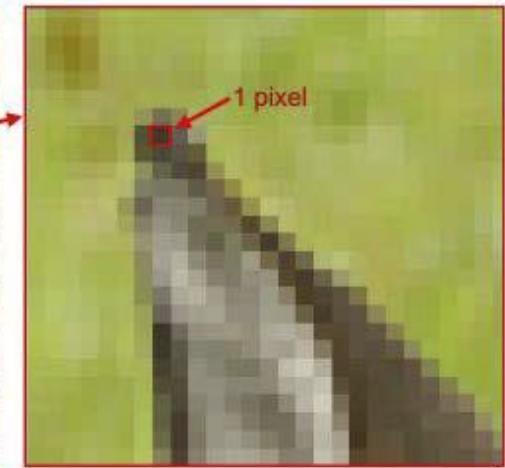
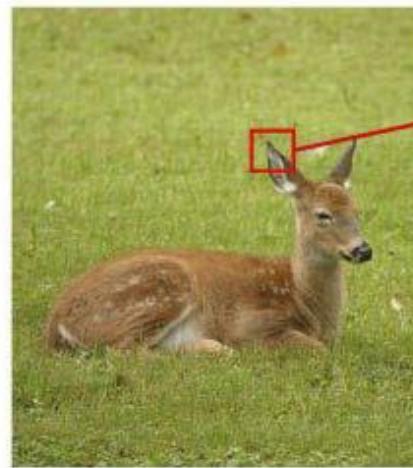
- Discrete-time signal with discrete-valued amplitude
- A digital signal is a quantized sampled-data signal



Analog vs. Digital Image



Pixel



Pixel

Pixel / Voxel

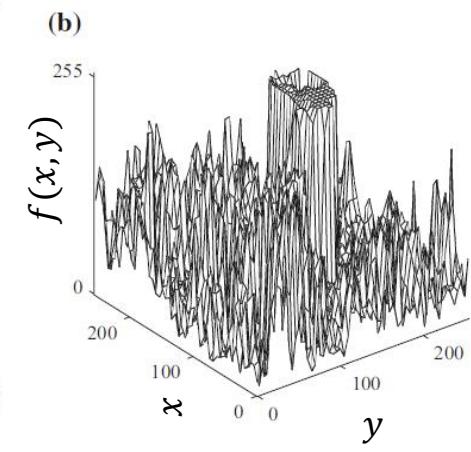
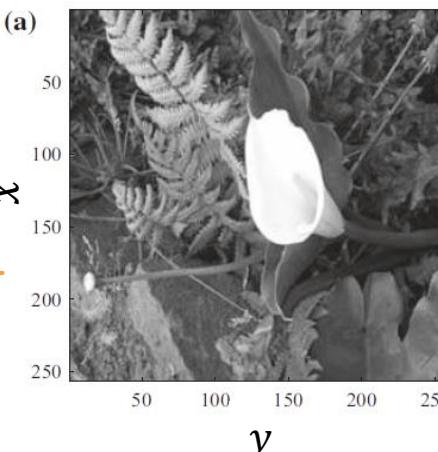
- Digitization implies that a digital image is an approximation of a real scene.
- Digital image composed of a finite number of elements – Pixel.
- A pixel has a location and intensity information typically represent gray levels, colors, heights, opacities, etc.

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

强度

- 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

空间位置



(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.



$$g[f(x,y)] = h(x,y)$$

↑
processing



Stages of DIP

Low level process

INPUT: Image
OUTPUT: Image

EXAMPLE:
Denoise
Contrast enhancement
Image sharpening

Mid level process

INPUT: Image
OUTPUT: Attributes

EXAMPLE:
Segmentation
Edge detection
Recognition

High level process

INPUT: Attributes
OUTPUT: Understanding

EXAMPLE:
Image analysis
Image understanding



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



Stage of DIP



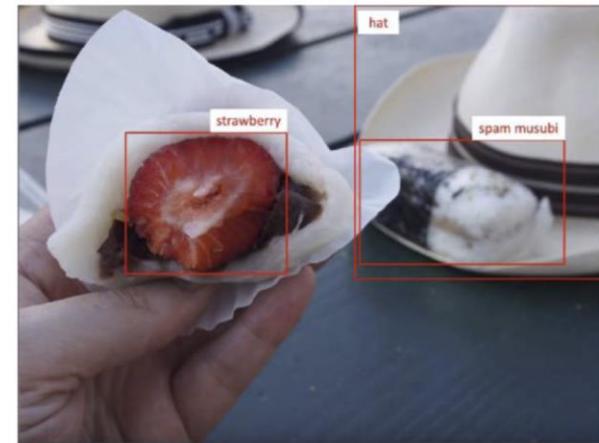
Low level



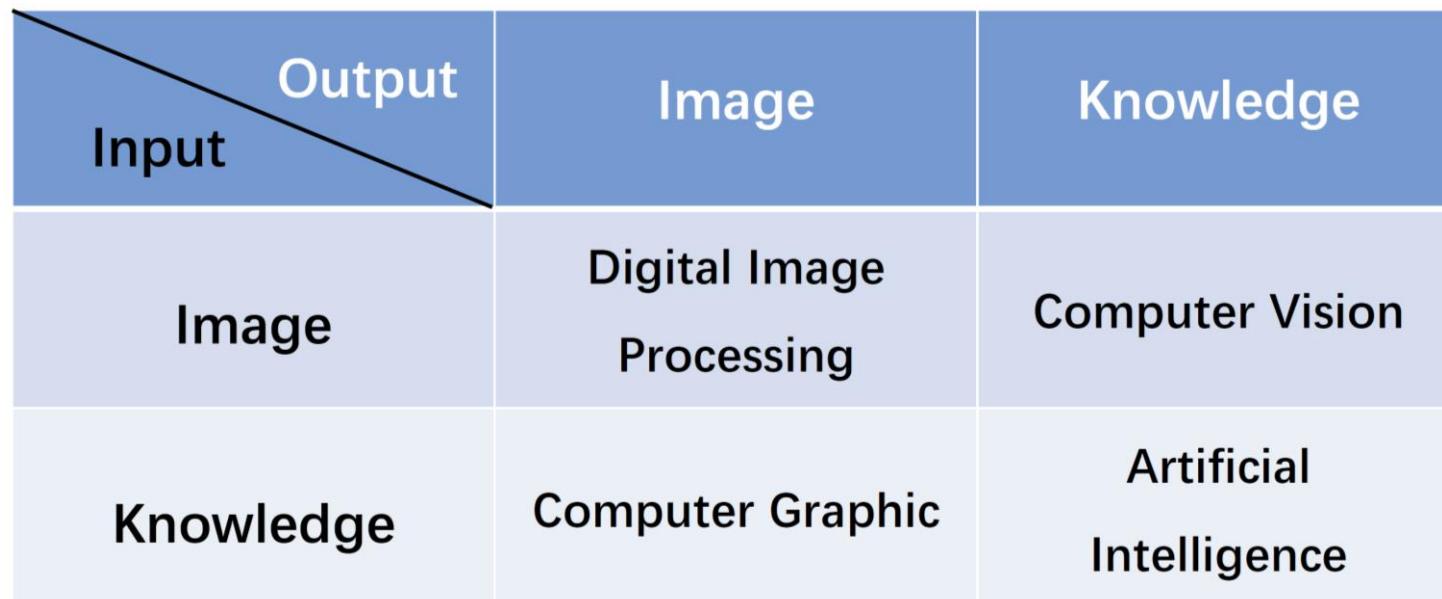
High level



Mid level



Frequent question: relationship between Digital Image Processing and Computer Vision



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

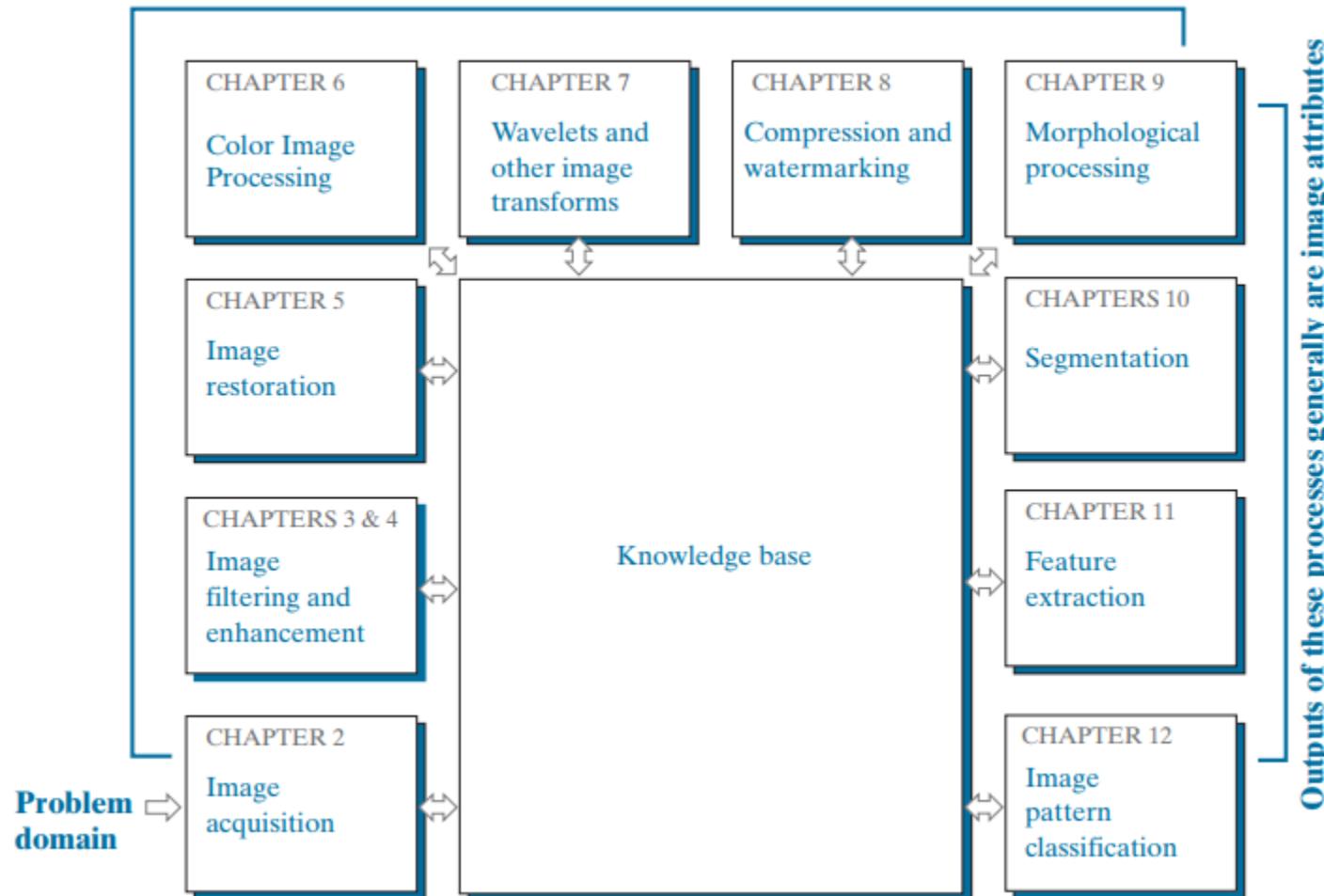
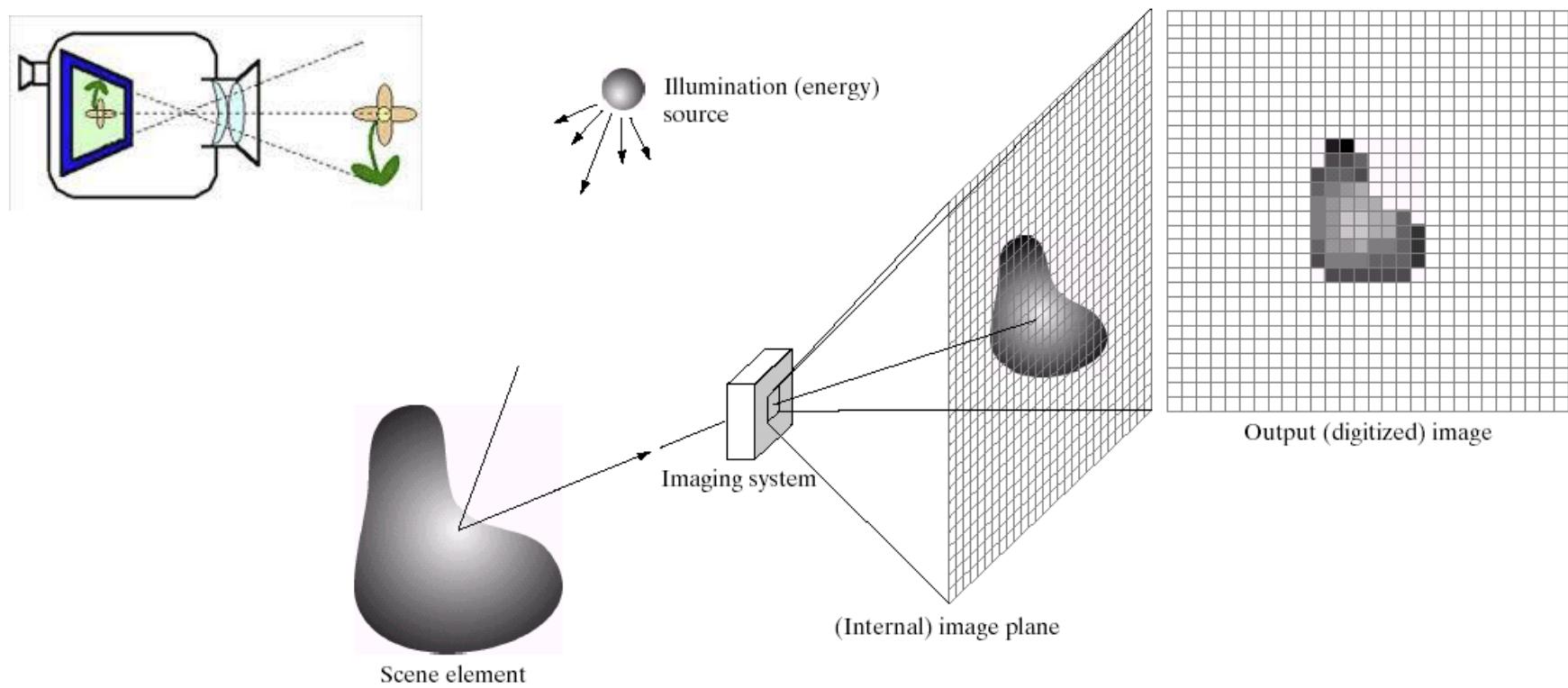
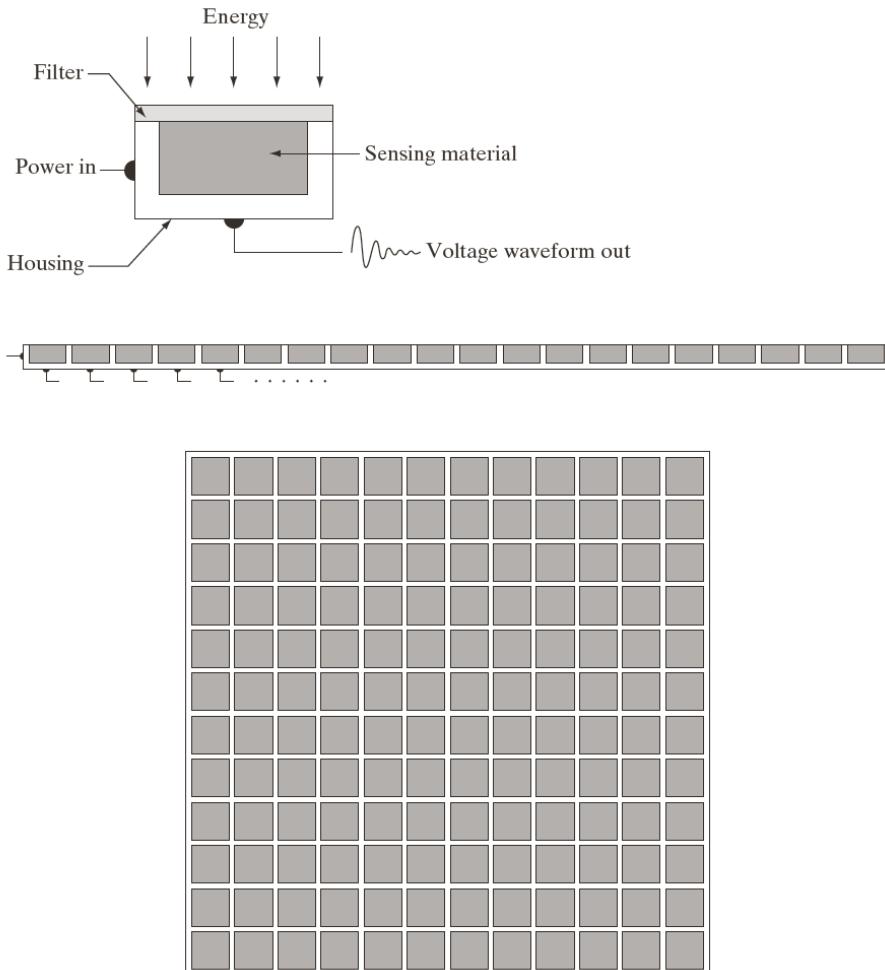


Image acquisition



Imaging Sensors



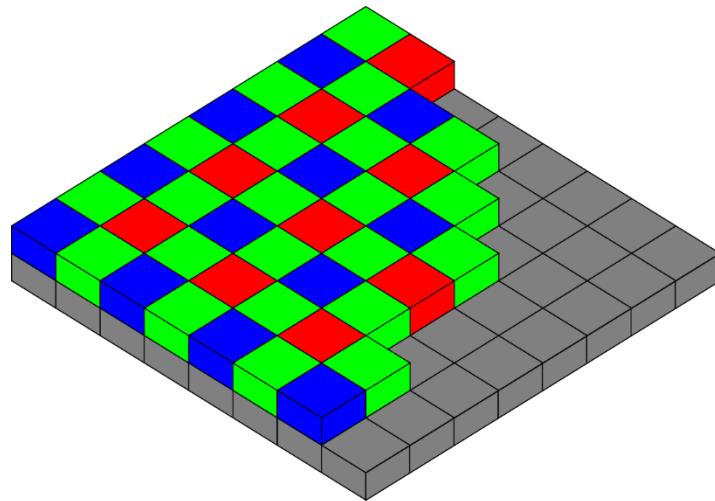
Transform energy to voltage:

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

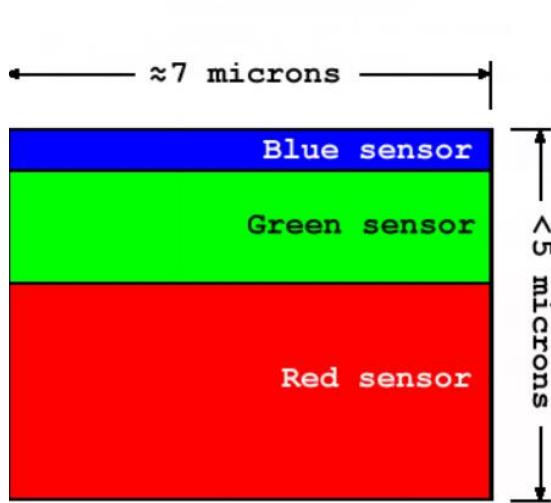
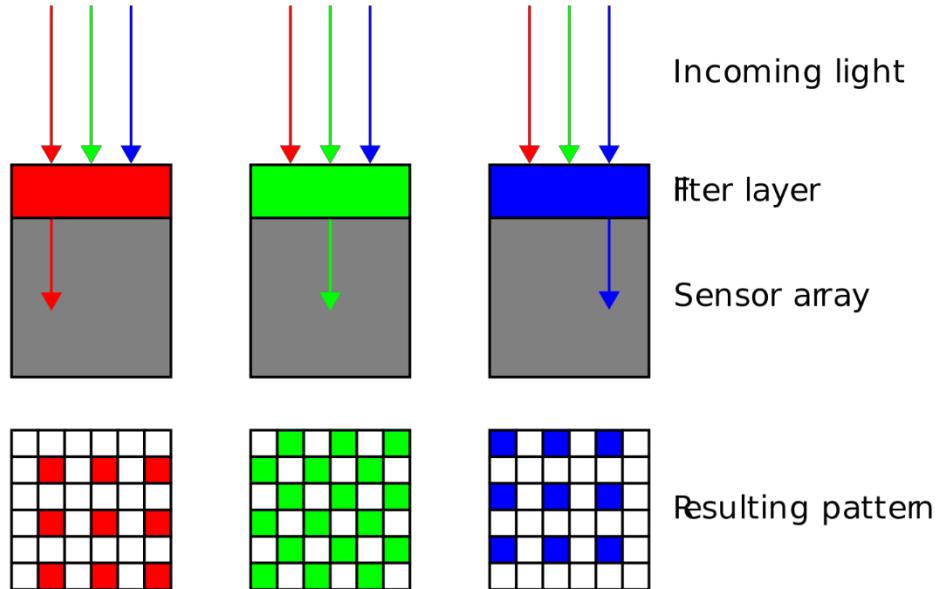
Use a Bayer's mosaic pattern of R/G/B filters to reduce cost, then use demosaicing to construct full resolution color images.



Bayer filter



Foveon X3 sensor stack

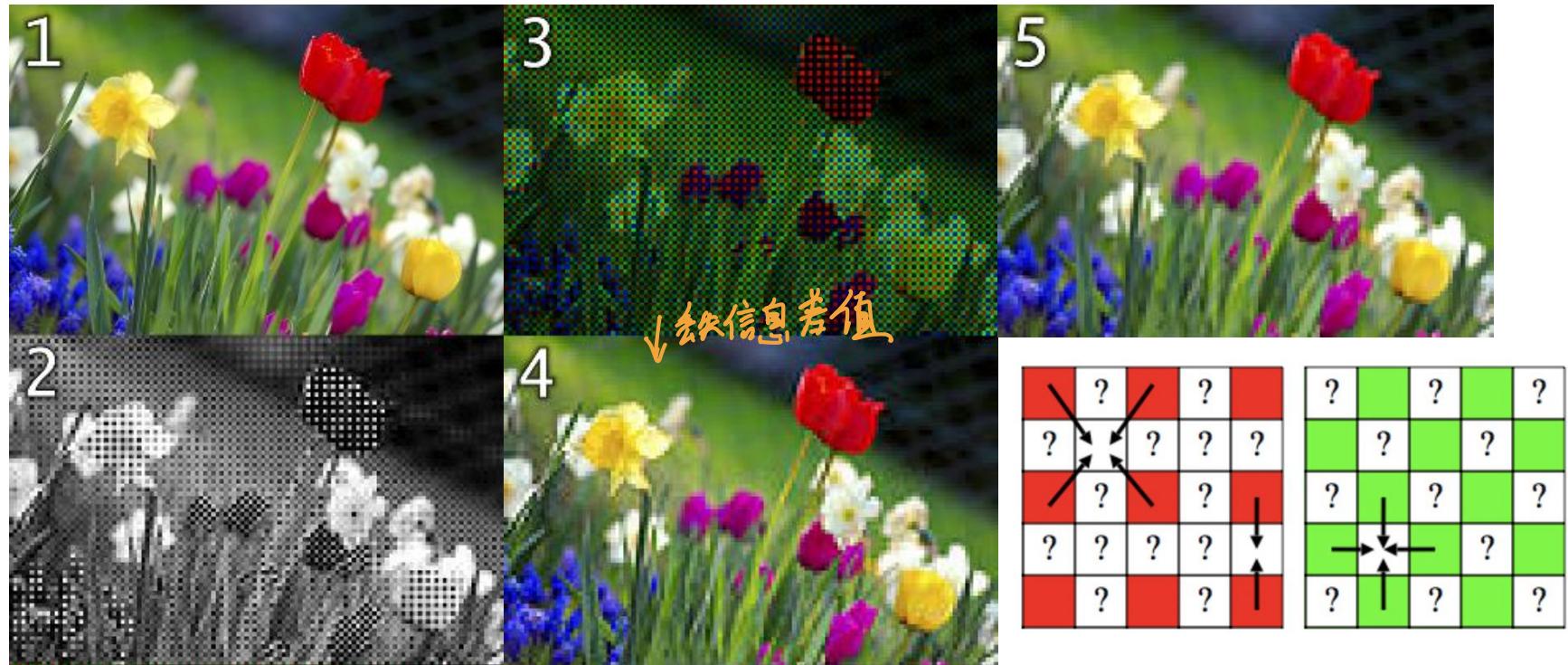


https://en.wikipedia.org/wiki/Foveon_X3_sensor



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Color coded and reconstruction



Sensor size comparisons for digital camera



Sensor size comparisons for digital cameras.

A bigger **sensor area** captures better quality, but requires larger-diameter lenses. Smartphones compensate for tiny sensors via computational power. In 2018, a **1-inch Type sensor** optimizes portability for top **travel cameras**.

36 mm wide = Full-frame sensor (Nikon FX, Canon EF, Sony FE)

"Full-frame 35mm" sensor / film size (36 x 24 mm) is a standard for comparison, with a **diagonal field-of-view crop factor** = 1.0

In comparison, a pocket camera's **1/2.5" Type sensor** crops the light gathering by **6.0x smaller diagonally** (with a surface area **35 times smaller** than full frame).

APS-C Nikon DX, Sony E = **1.5x crop**

Four Thirds 4/3" = **2x crop**

1" Type = **2.7x crop**
Sony RX10; RX100

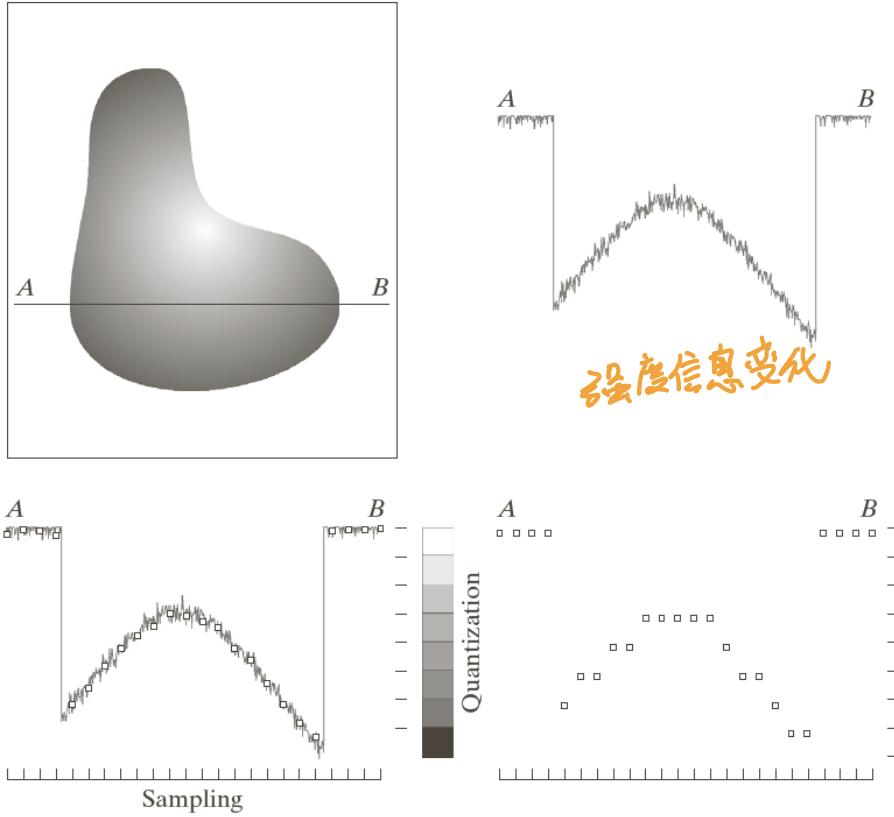
1/1.7": 4.6x
1/2.5": 6.0x crop

1/2.3-2.5" sensors are small and noisy, as on **compact & pocket zoom cameras**.
1/2.6" = Samsung Galaxy S9, S8, S7 smartphones,
1/3" = Apple iPhone 8, 7, 6.

APS-C sensor gathers 15 times more light (area) than a **1/2.5" Type sensor**, and 2.4 times less than **Full Frame**.



Sampling and Quantization



Sampling : *Digitize the coordinate values*

Quantization: *Digitize the amplitude values*

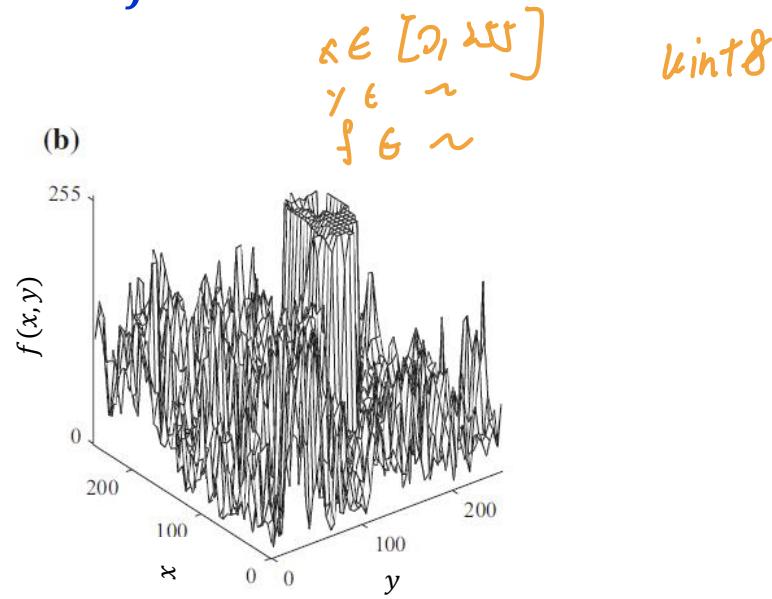
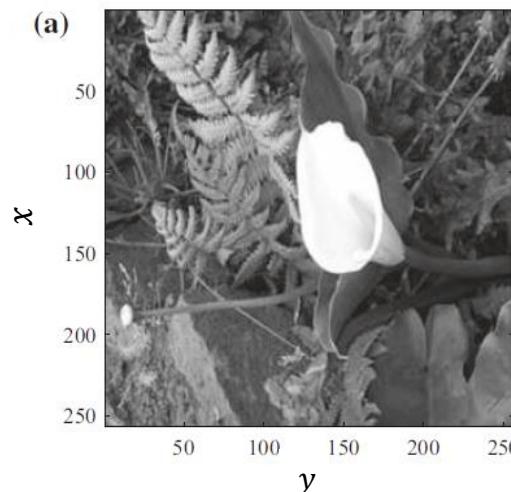
Uniform

Non-uniform



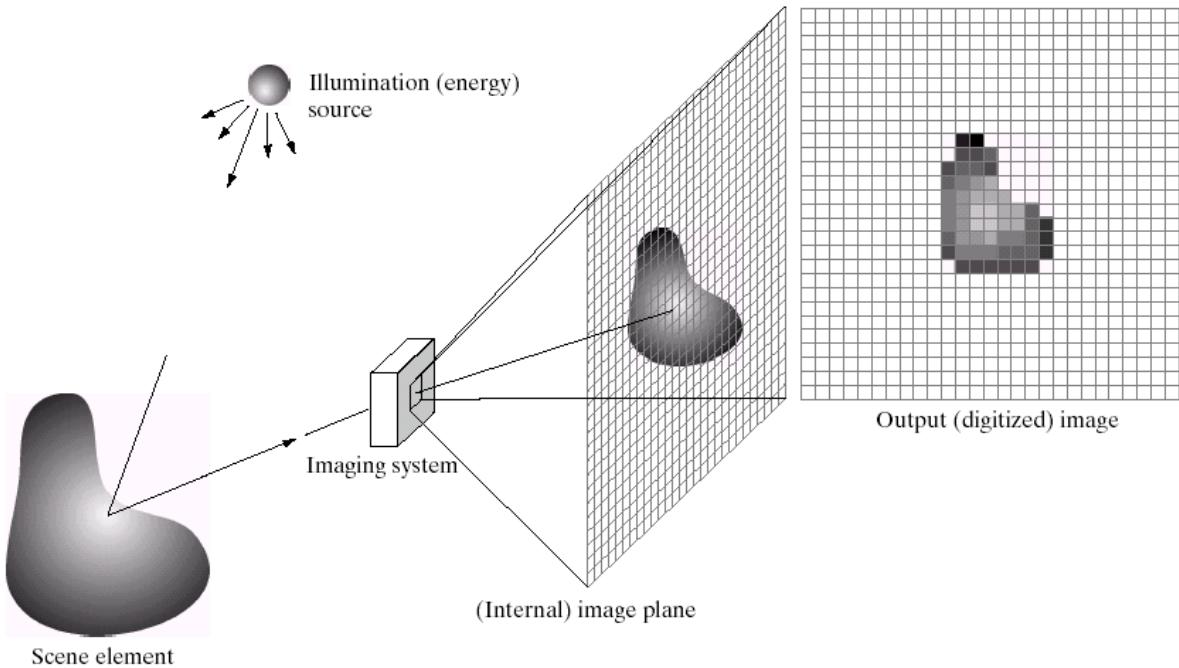
Digital image

- A visual representation in form of a function $f(x, y)$, 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



$$f(x, y) = i(x, y)r(x, y) \quad 0 < i(x, y) < \infty, 0 \leq r(x, y) < 1$$

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

Illumination model

$$f(x, y) = i(x, y)r(x, y) \quad 0 < i(x, y) < \infty, 0 \leq r(x, y) < 1$$

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

证明

- | | | | |
|----------------------------|-------------------|--------------------------|------|
| □ Illuminations: $i(x, y)$ | 1W/m ² | • Reflections: $r(x, y)$ | |
| □ Clear sunny day: | 90K | • Snow: | 0.93 |
| □ Cloudy day: | 10K | • Flat white wall: | 0.80 |
| □ Indoors: | 1K | • Stainless steel: | 0.65 |
| □ Full Moon: | 0.1 | • Black cloth: | 0.01 |



Matrix Representation

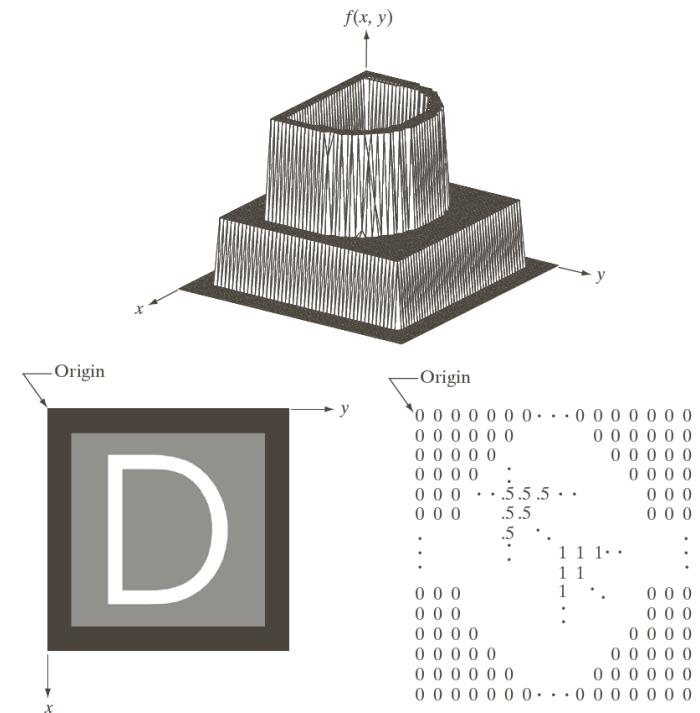
Three basic ways to represent $f(x, y)$

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

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

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

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



Matrix Representation

22x32x8

L→灰度集

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

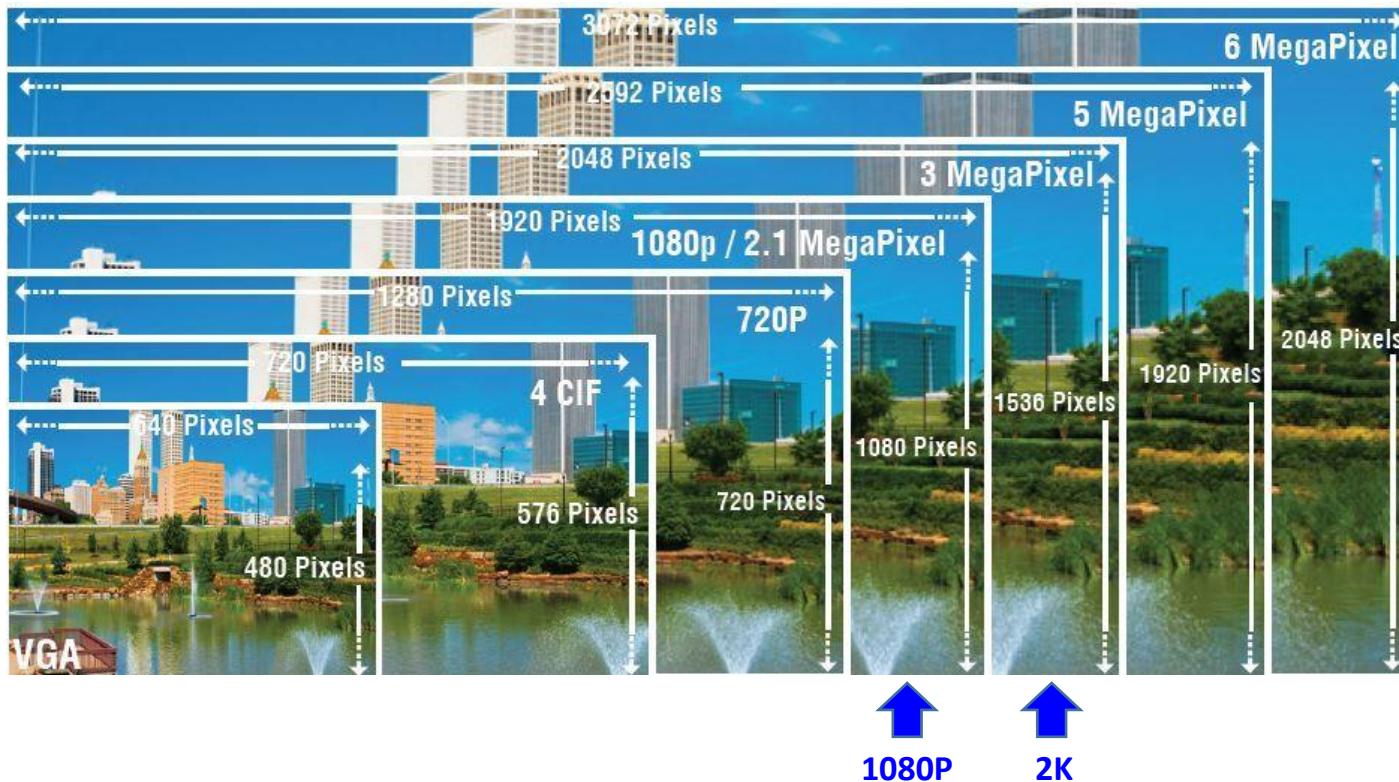
空间分辨率

Spatial Resolution: smallest discernible detail in an image



Spatial Resolution 2

Spatial resolution – Sampling vs Size



Example for Spatial Resolution

Spatial resolution: dpi (Dots Per Inch)



1250 dpi



300 dpi



150 dpi



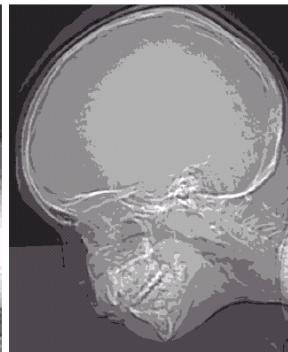
72 dpi



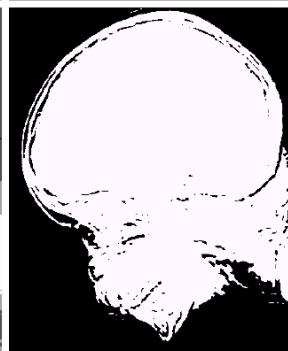
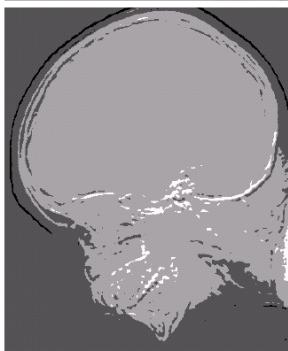
Intensity Resolution

Intensity resolution: smallest discernible change in intensity level

8 bit	7 bit
6 bit	5 bit



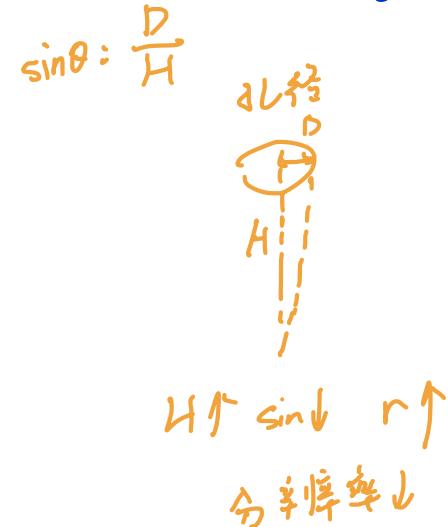
4 bit	3 bit
2 bit	1 bit



Further discussion of resolution

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

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



- Temporal resolution: imaging speed

What is light?

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

麦克斯韦方程组



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

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

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

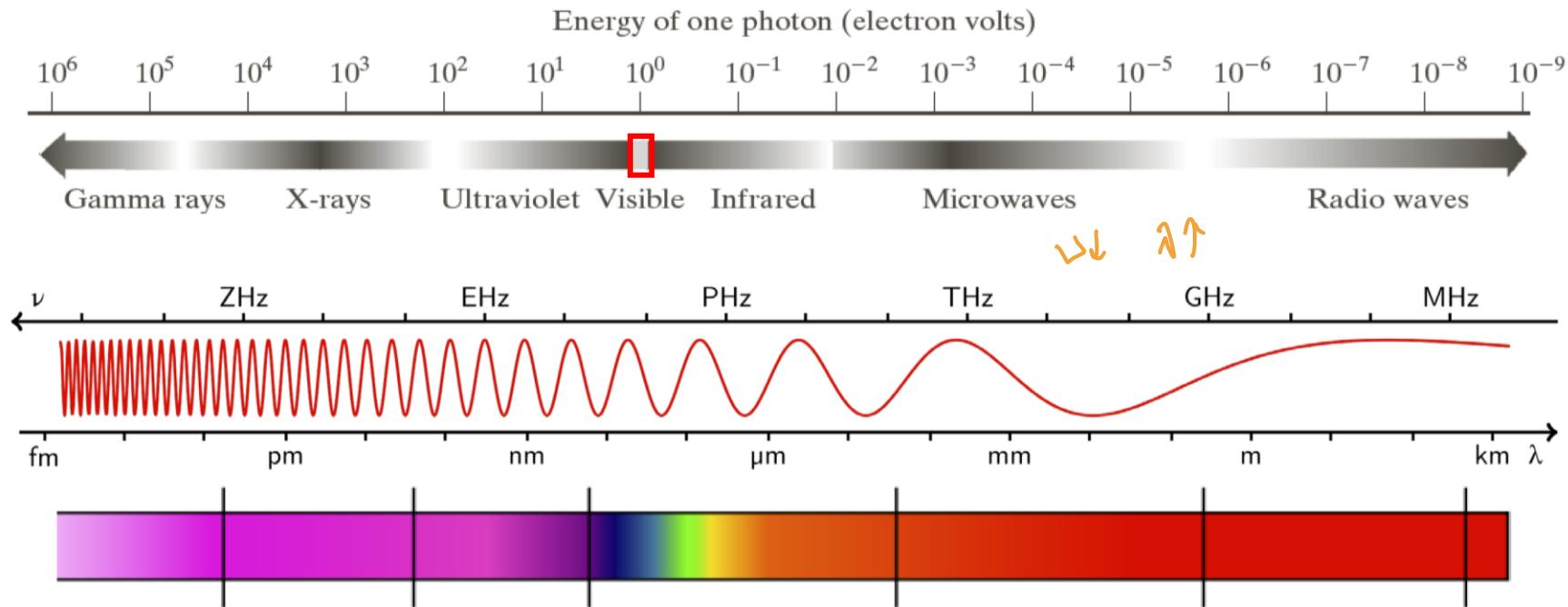
$$\nabla \times \vec{H} = \vec{J}_{\text{free}} + \frac{\partial \vec{D}}{\partial t}$$



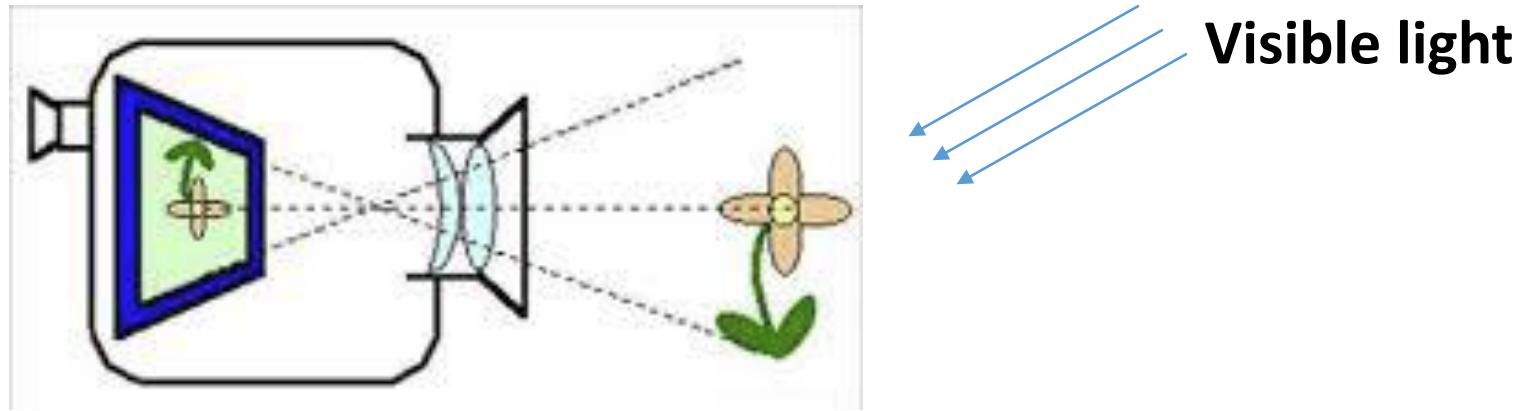
What is light?

Electromagnetic spectrum

波动性 & 粒子性



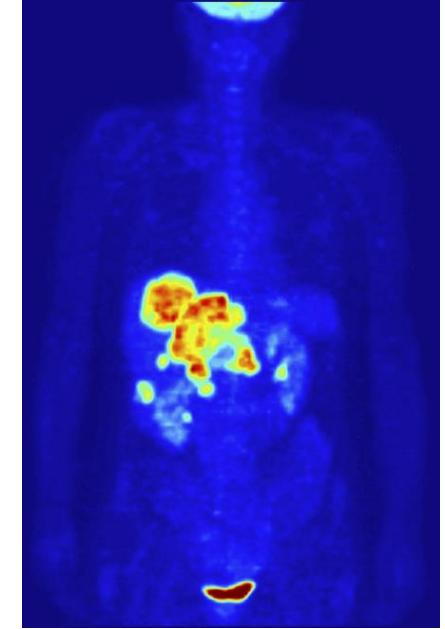
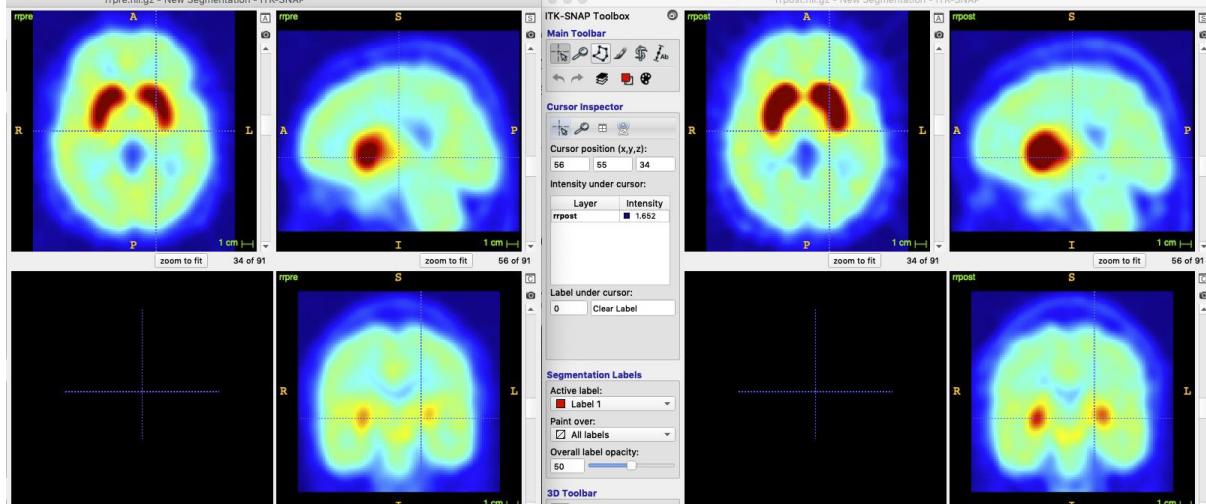
Visible-band (1 eV)



- 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.

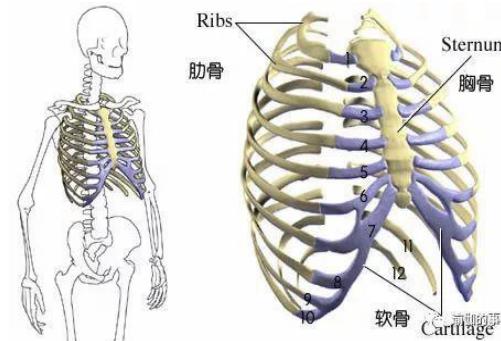
Wei. et al. JNS 2019

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

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



X-ray chest image



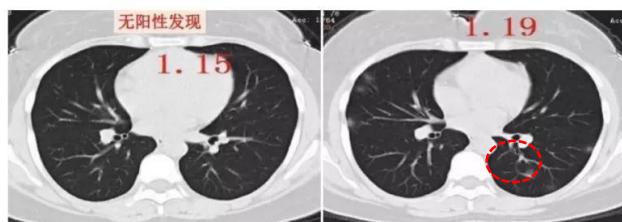
X-ray chest image of a Covid-19 Patient

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

CT(Computed Tomography),
即电子计算式断层扫描



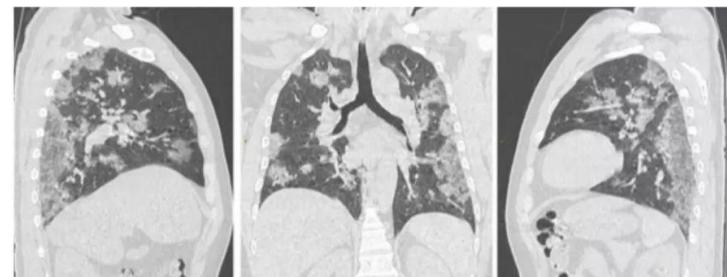
早期CT表现-不特异



女, 22岁
发热1天, 37.9°
首诊CT无阳性发现
4天和7天CT逐渐进展

高少影像

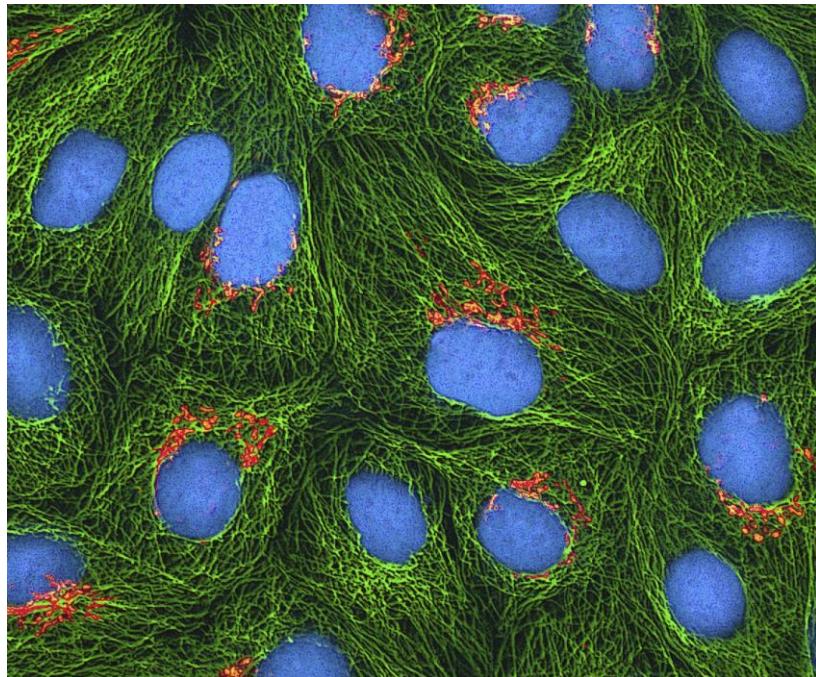
早期CT表现



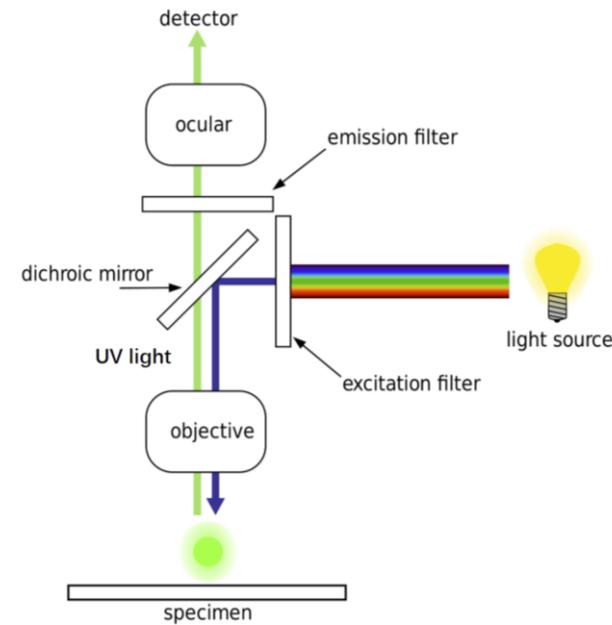
男, 44岁, 华南海鲜市场密切接触史
无明显诱因发热、乏力, 外院抗菌抗病毒治疗无效

高少影像

Ultraviolet imaging (10-100 eV)



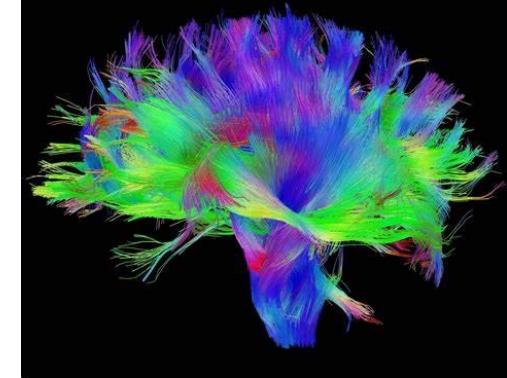
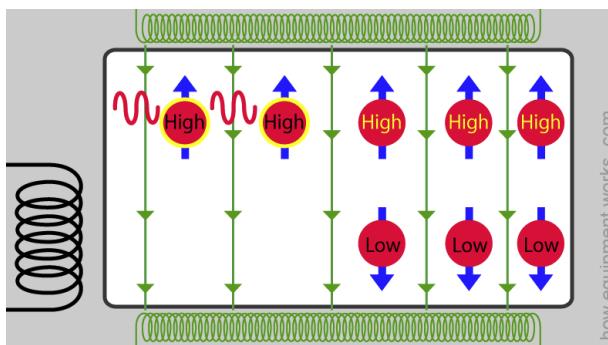
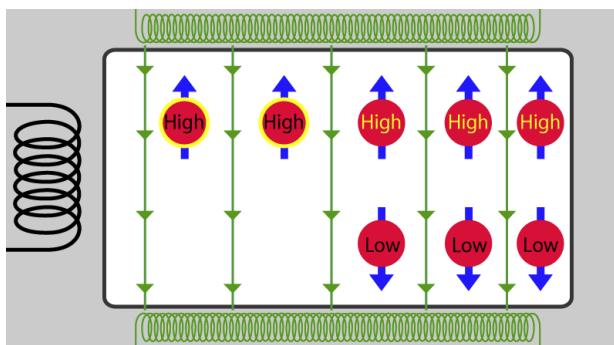
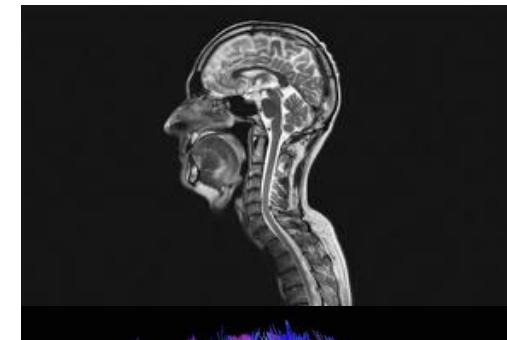
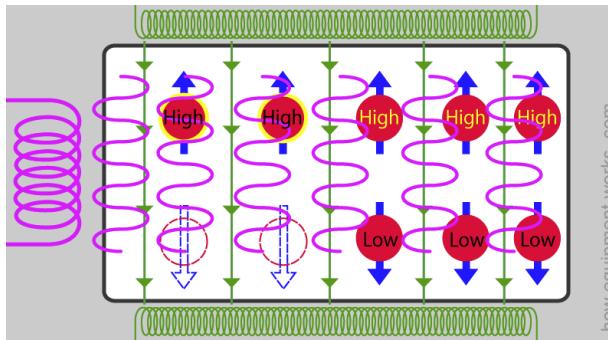
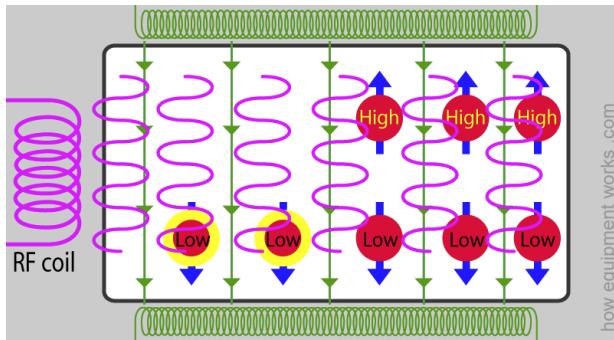
- Fluorescence microscopy image



- Fluorescence microscopy structure

Magnetic resonance imaging (Radiofrequency/RF coil)

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



Ultrasound imaging (non-photon imaging)

