Lecture 1-2: Digital image modalities and acquisition (chapter 1.3-1.4; 2.3-2.4)

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Course piazza link: https://piazza.com/class/k6rrogf7juqk7

Outline

- Real-world image acquisition
- Multi-modality image sensing

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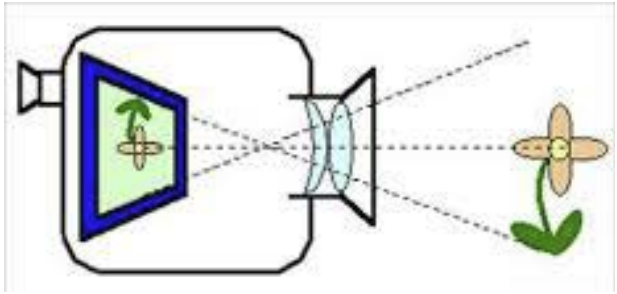
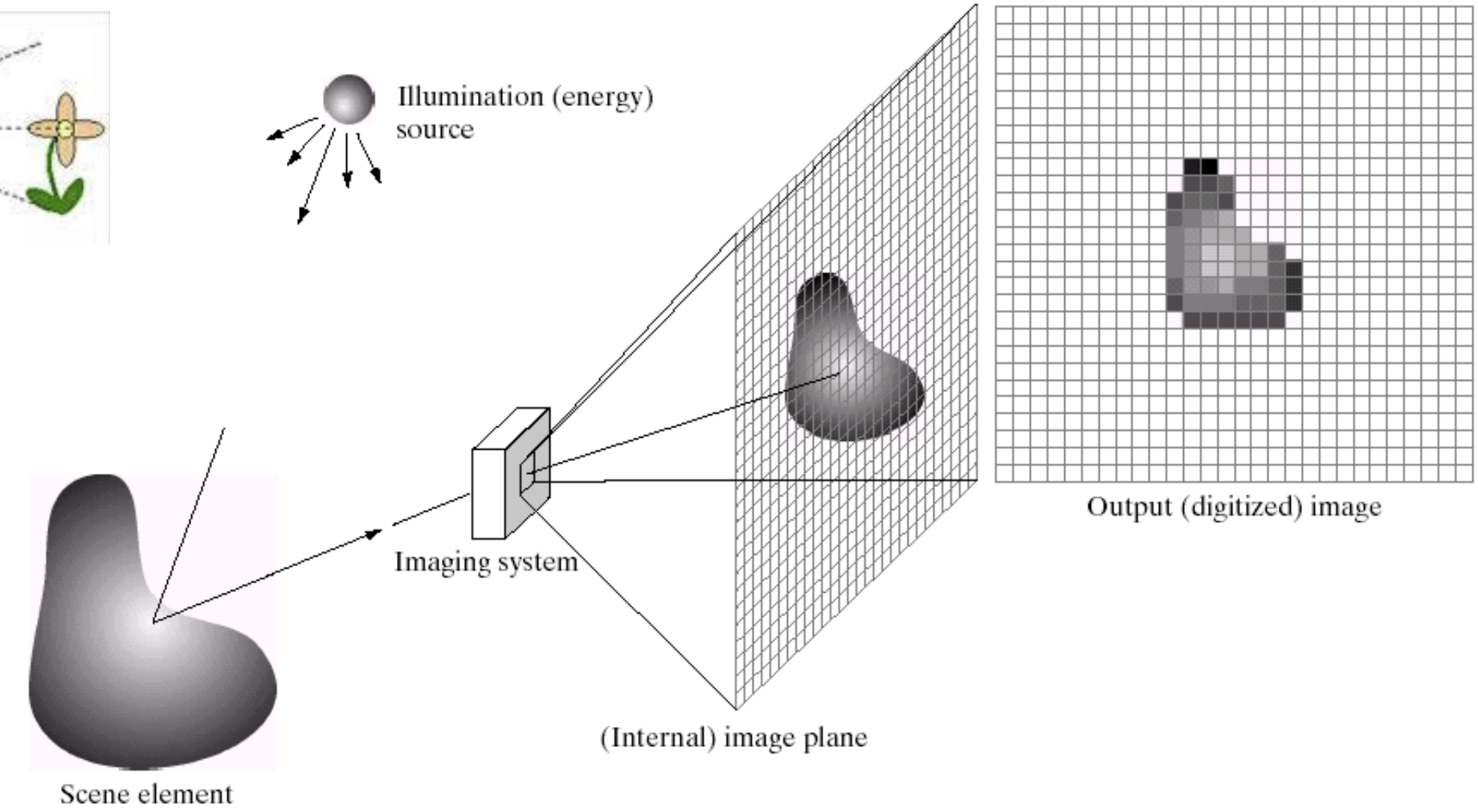
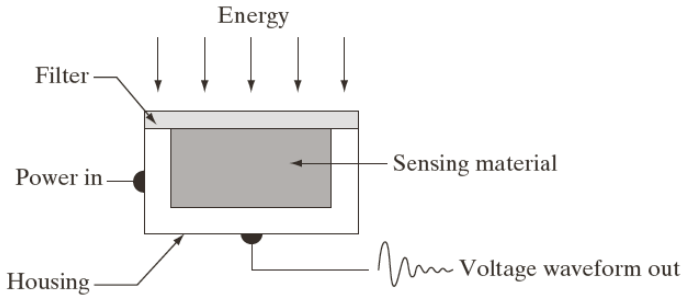
- Real-world image acquisition
- Multi-modality image sensing

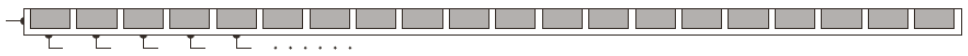
Image Acquisition System

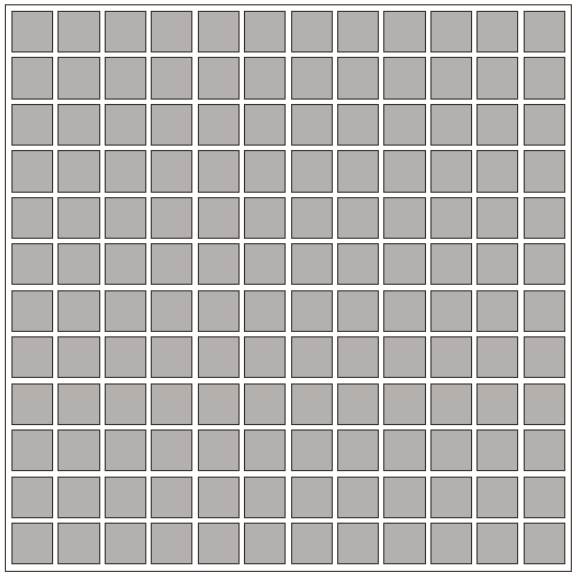




Imaging Sensors





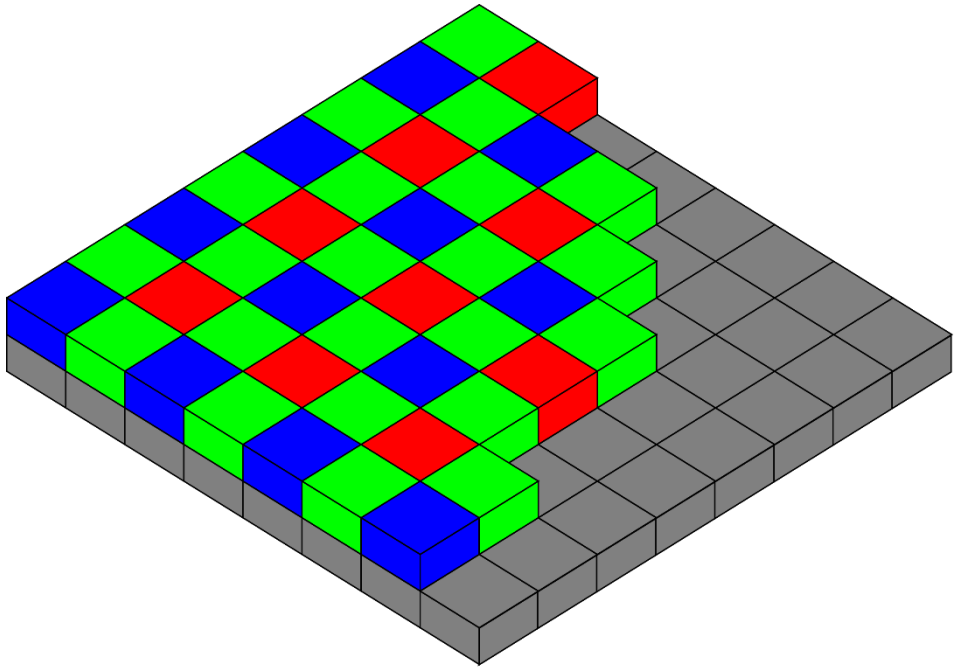


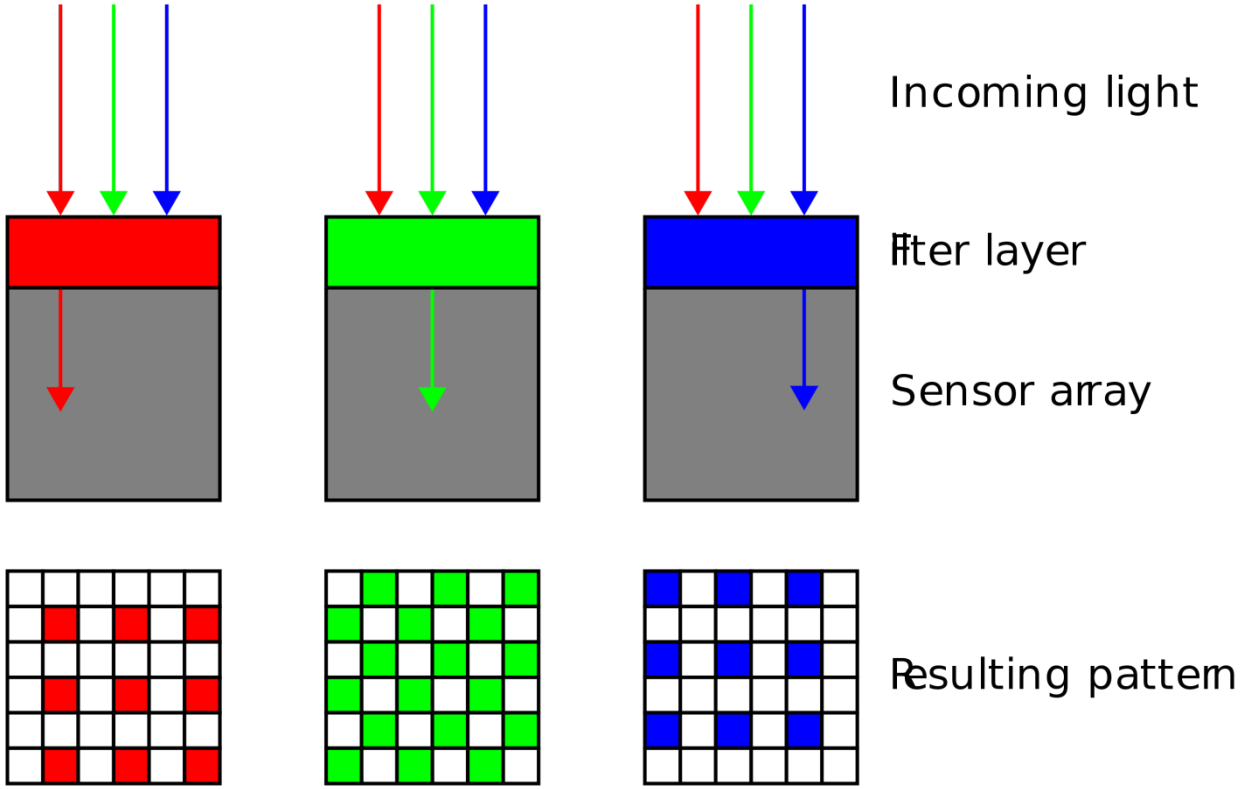
Transform energy to voltage:

- **Single Sensor**
  - Photodiode
  - Piezoelectric element
- **Sensor Strips**
  - CAT
  - 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.

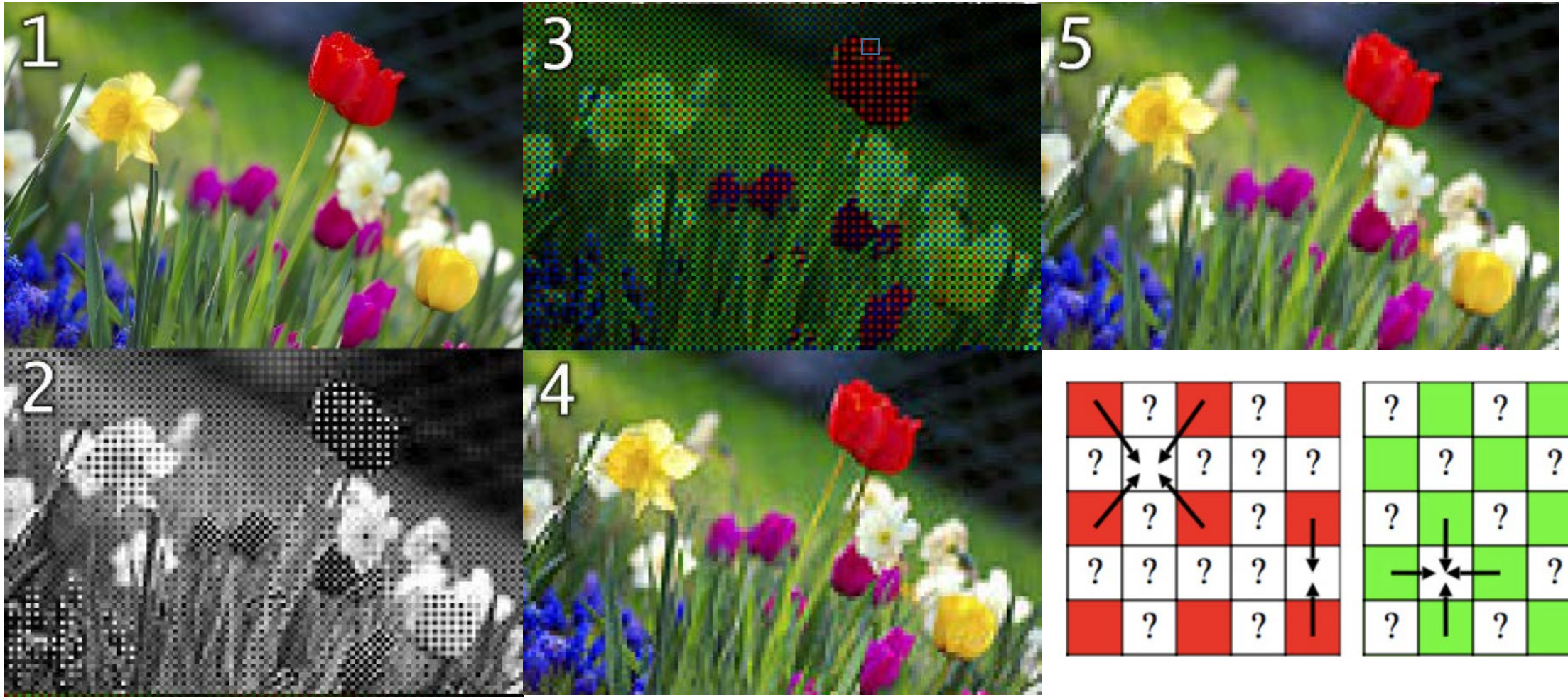
Bayer filter





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

Color coded and reconstruction



Sensor size comparisons for digital camera

https://www.youtube.com/watch?v=4ezKmawMEUs&t=258s

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***

APS-C Canon EF-S = ***1.6x 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

24 mm

"Medium format" size 48 x 36 mm

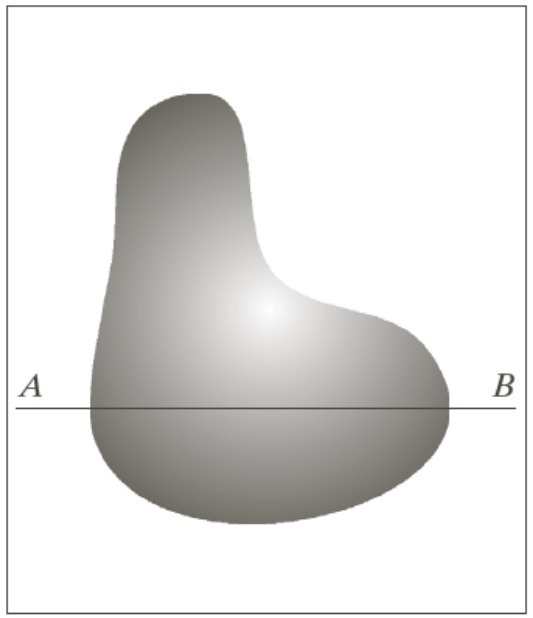
APS-C sensor gathers 15 times more *light (area)* than a ***1/2.5" Type*** sensor, and 2.4 times less than ***Full Frame***.

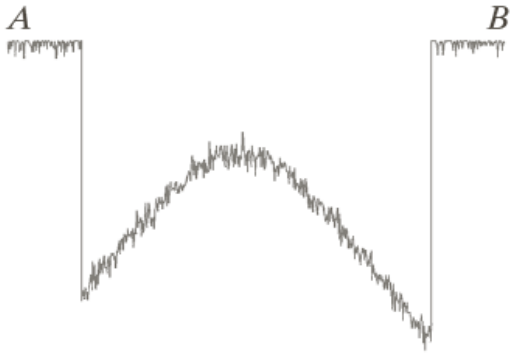
1/2.3-2.5" sensors are small and noisy, as on compact & pocket zoom cameras.

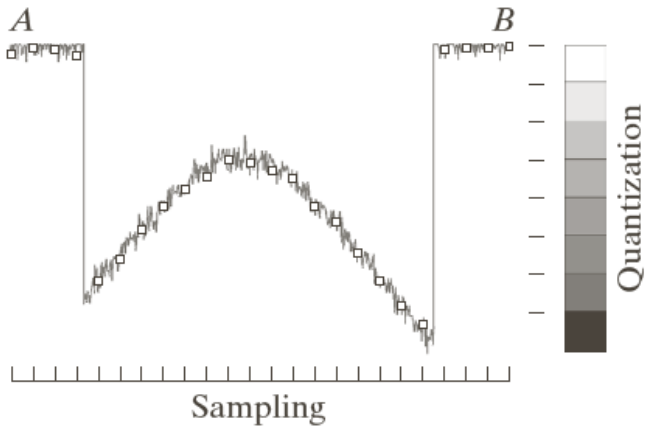
1/2.6" = Samsung Galaxy S9, S8, S7 smartphones.

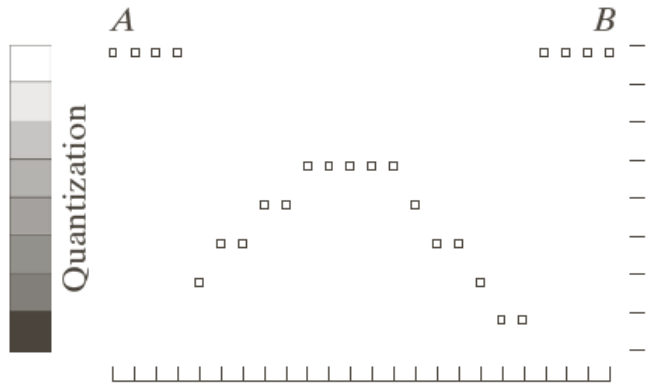
1/3" = Apple iPhone 8, 7, 6.

Sampling and Quantization









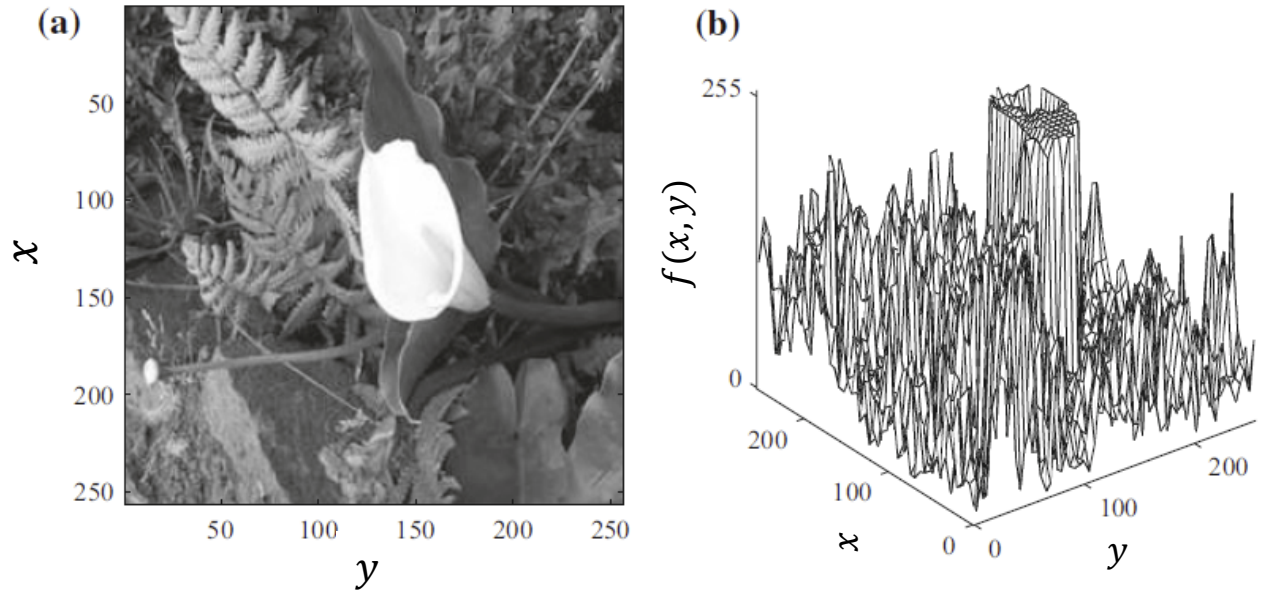
Sampling : *Digitize the coordinate values*

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

Matrix Representation

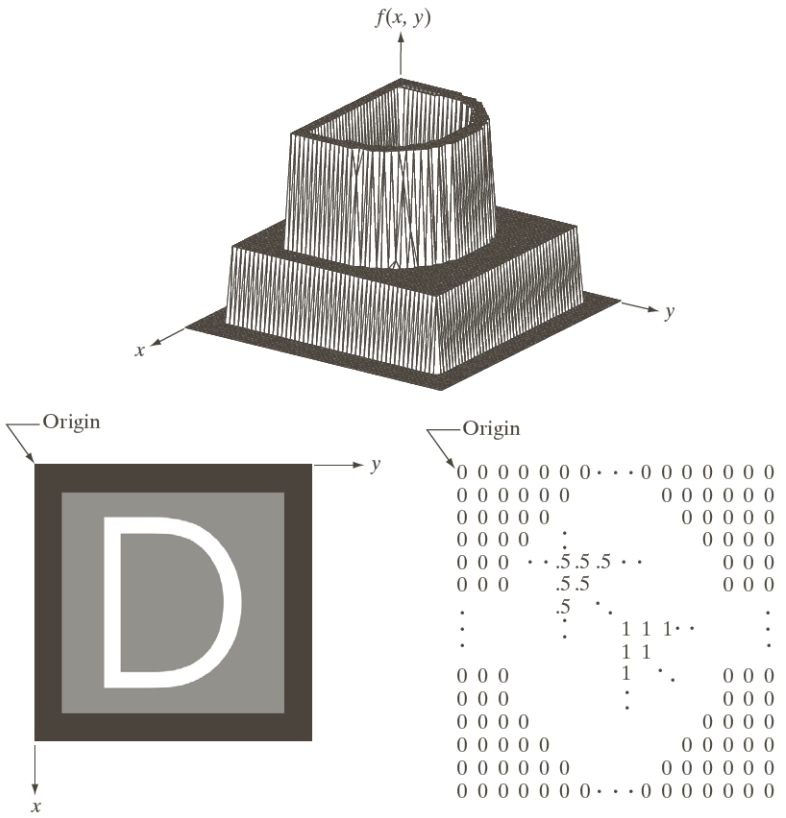
Three basic ways to represent *f*(*x*, *y*)

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



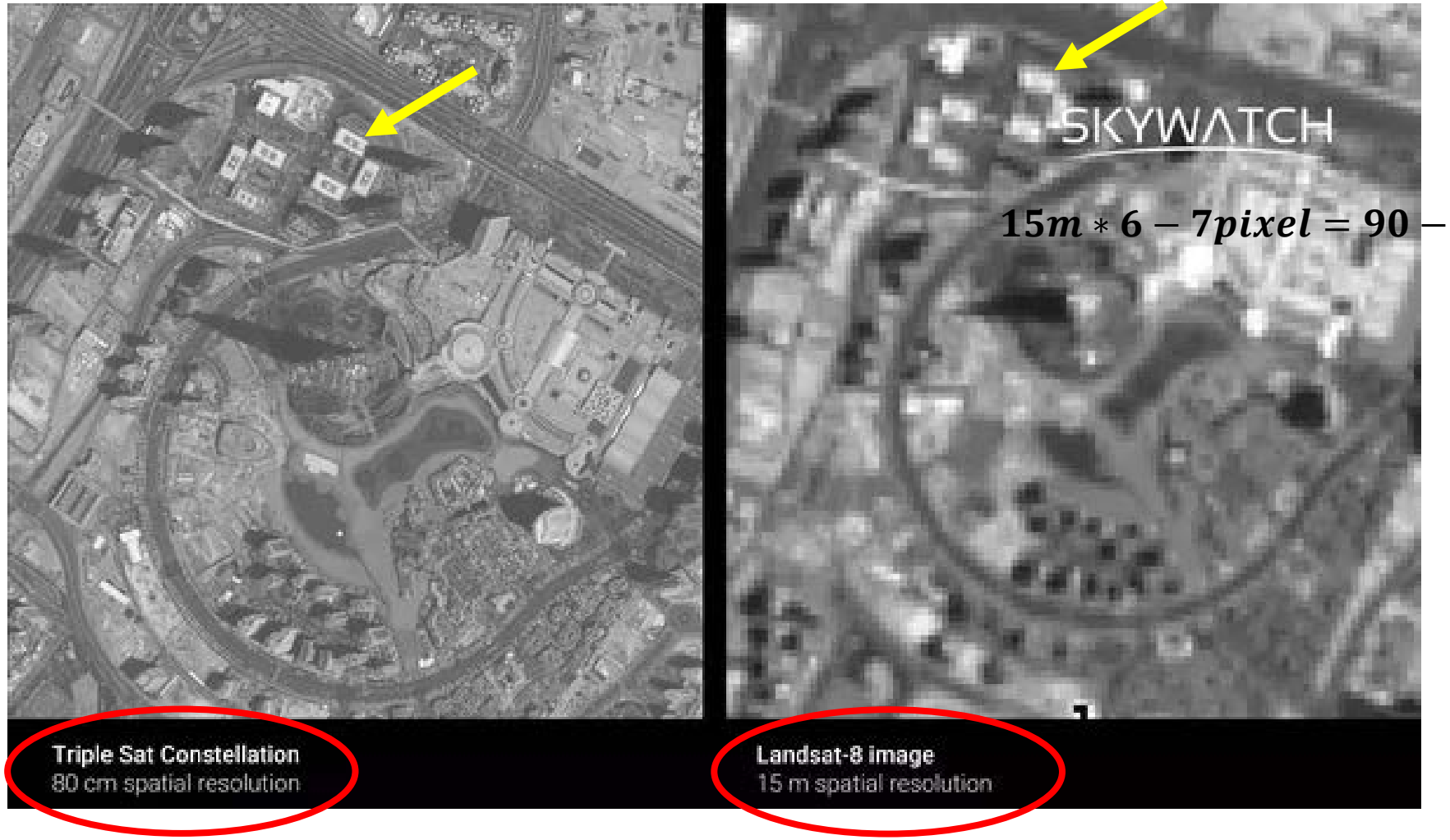
Matrix Representation

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

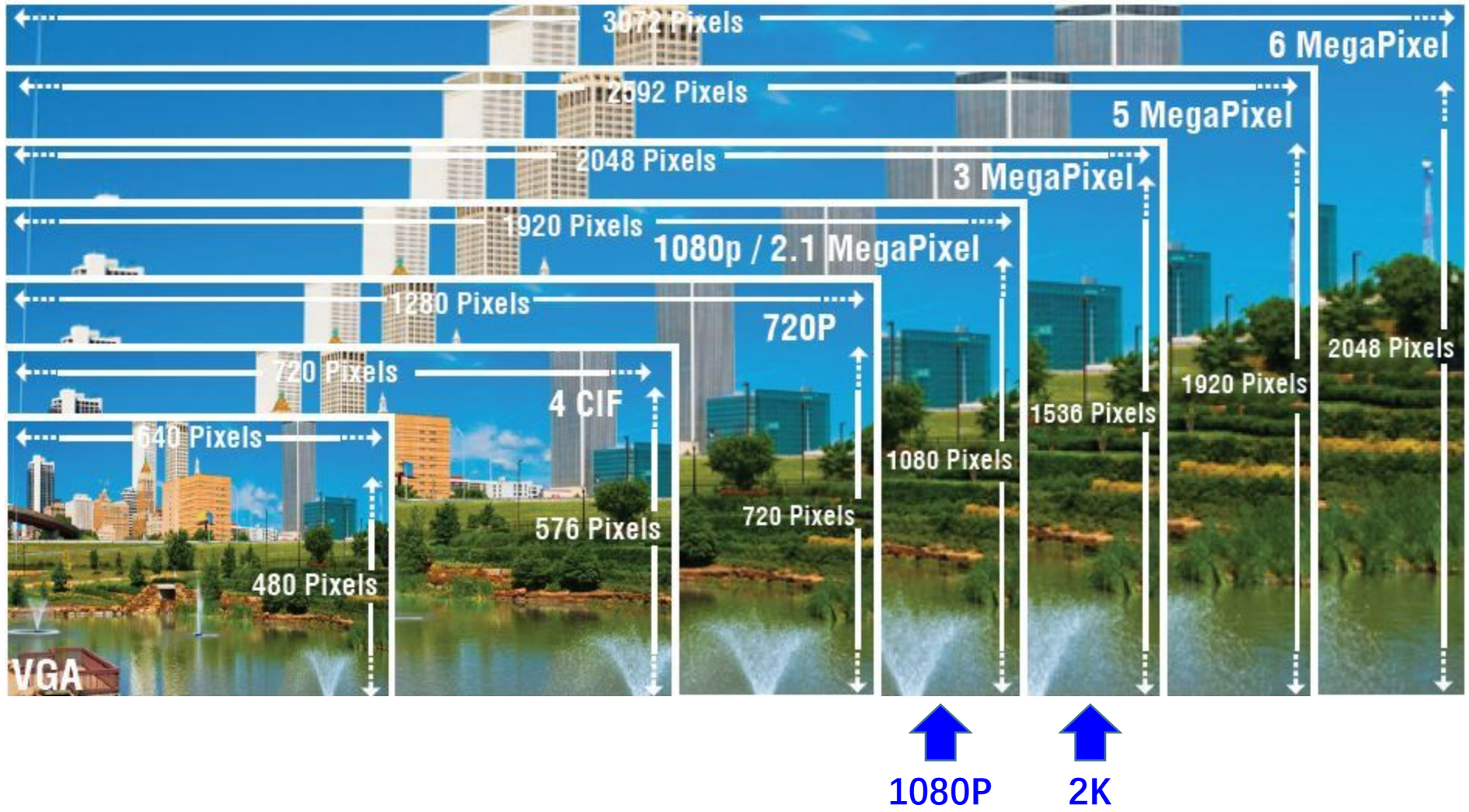
Spatial Resolution: smallest discernible detail in an image



$$15m * 6 - 7pixel = 90 - 105m$$

Spatial Resolution 2

Spatial resolution – Sampling vs Size



Example for Spatial Resolution

Spatial resolution: dpi (Dots Per Inch)

1250 dpi

300 dpi

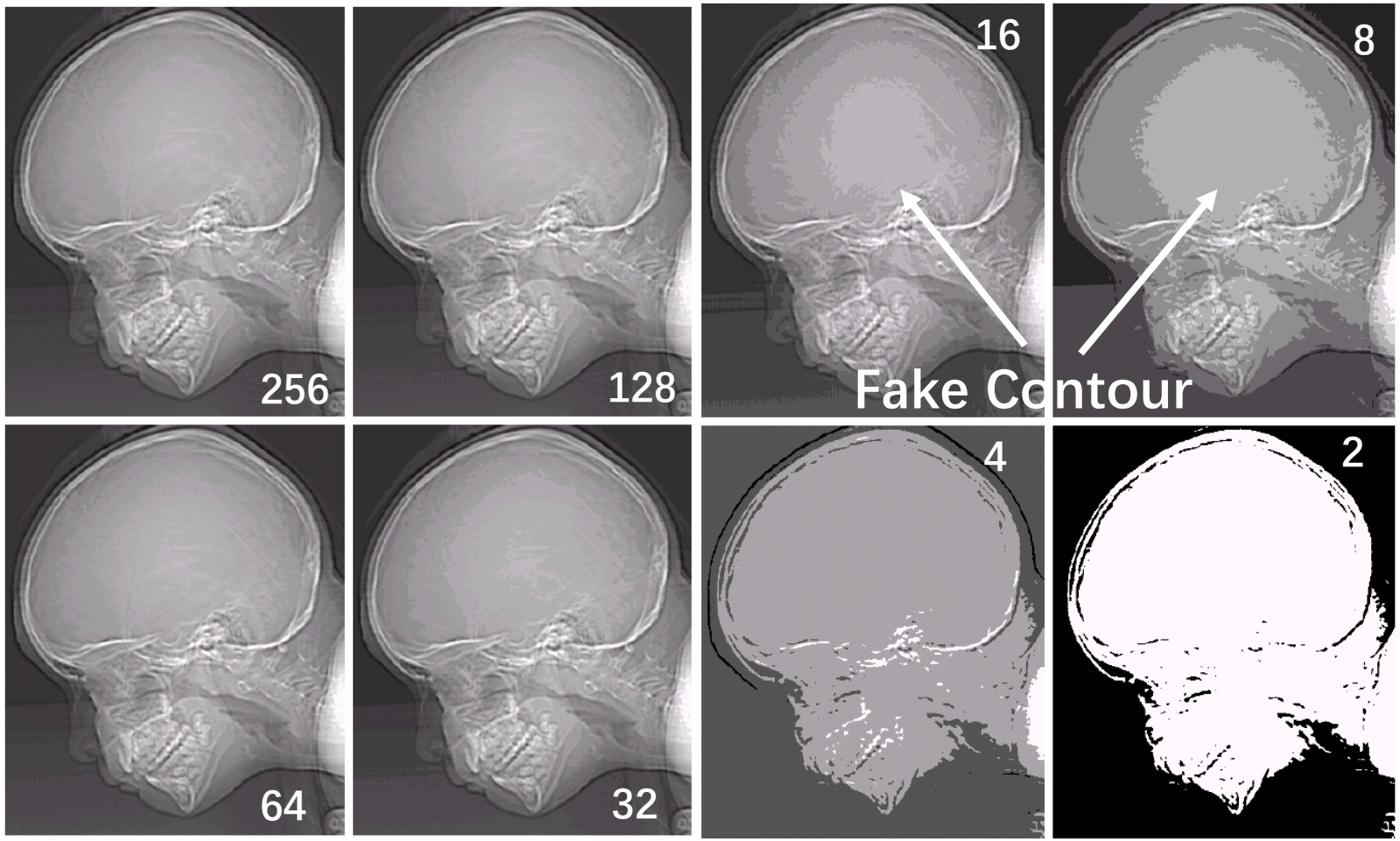
150 dpi

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

Outline

- Real-world image acquisition
- Multi-modality image sensing

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

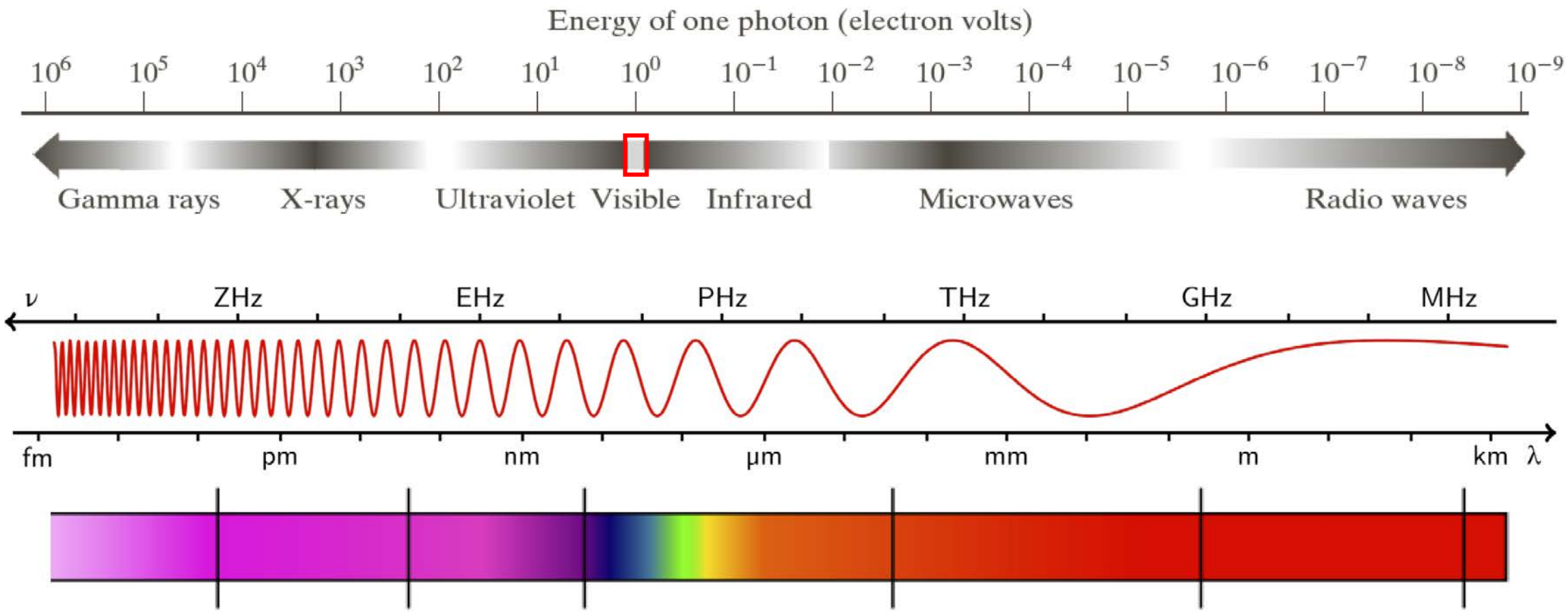
$$\nabla \cdot \vec{D} = \rho_{\text{free}}$$

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

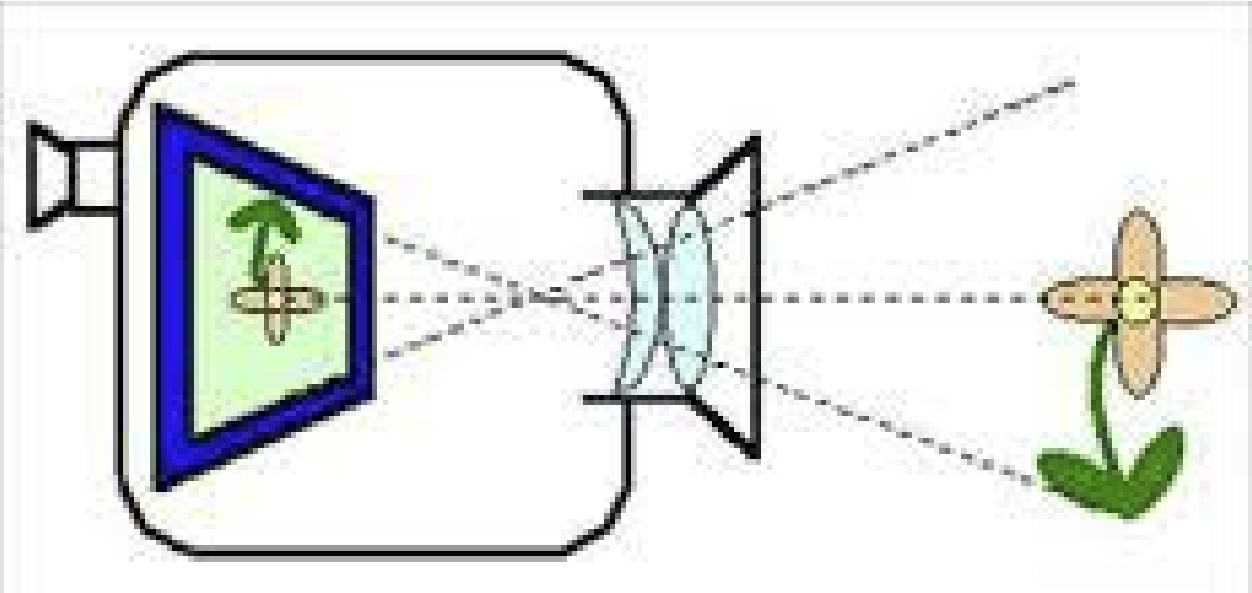
$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

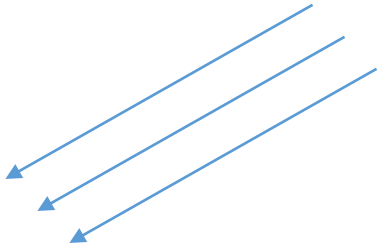
$$\nabla \times \vec{H} = \vec{J}_{\text{free}} + \frac{\partial \vec{D}}{\partial t}$$

Electromagnetic spectrum



Visible-band (1 eV)

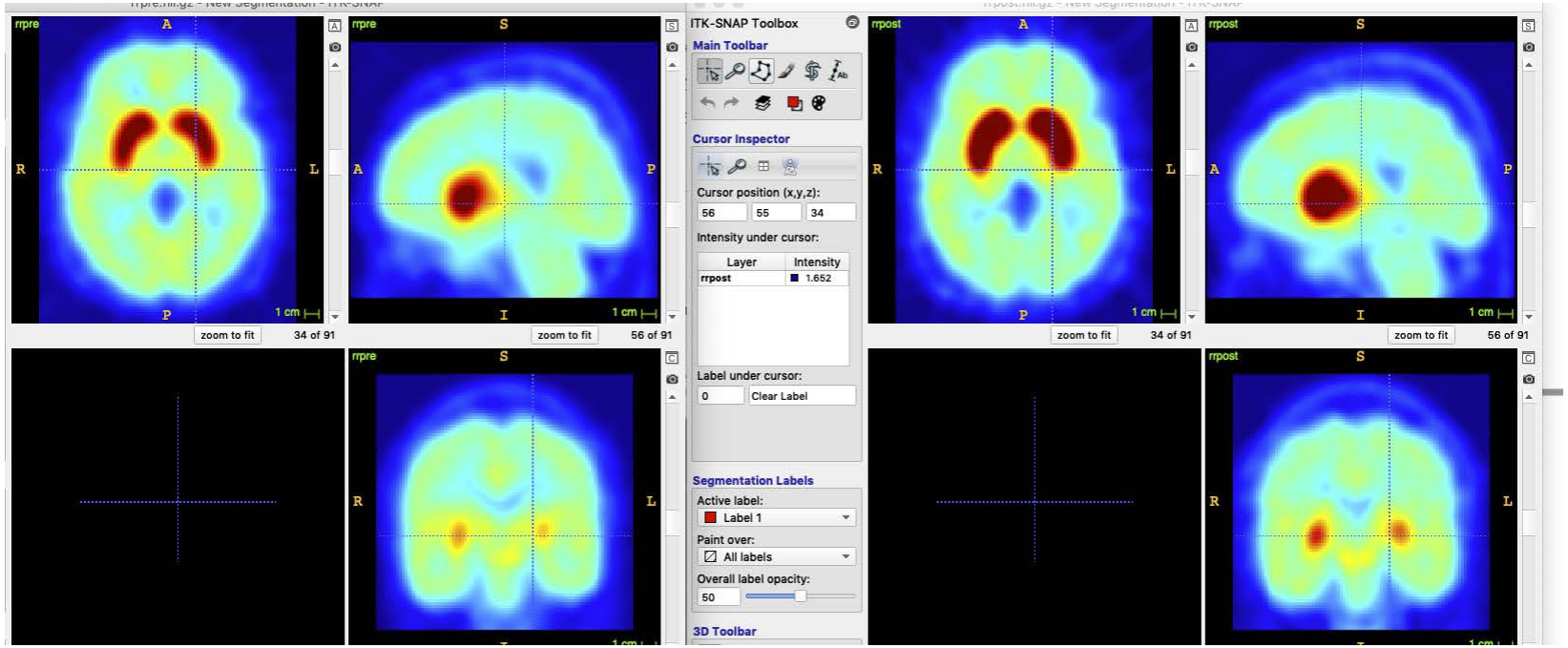




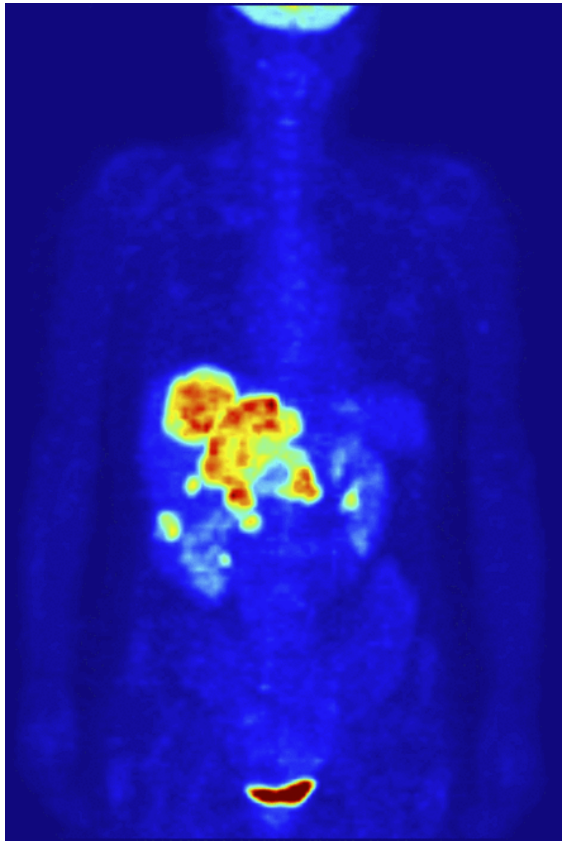
Visible light

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

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

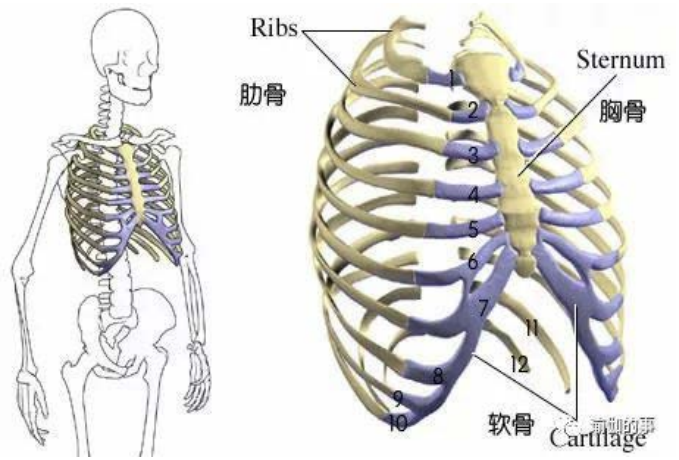


Brain PET（Positron Emission Tomography） imaging from a drug addicted patient before and after DBS surgery.
Wei. et al. JNS 2019

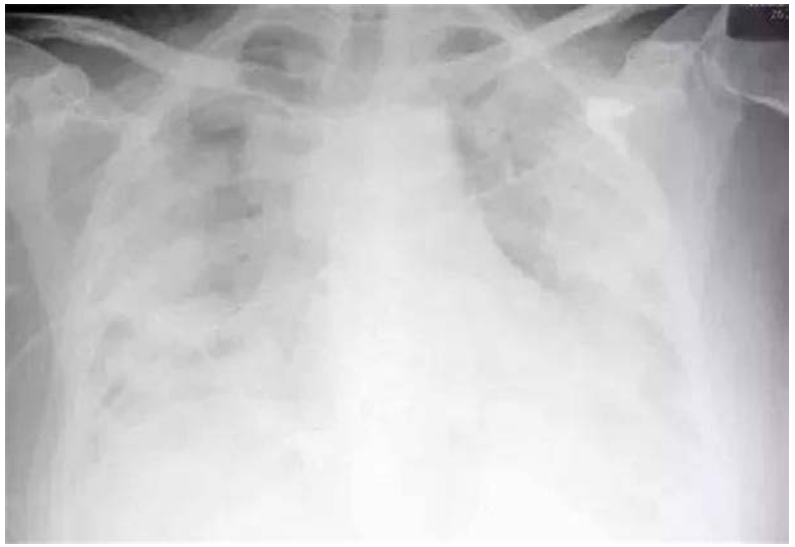


Whole body PET imaging with kidney labeled using 18F-FDG

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



X-ray chest image



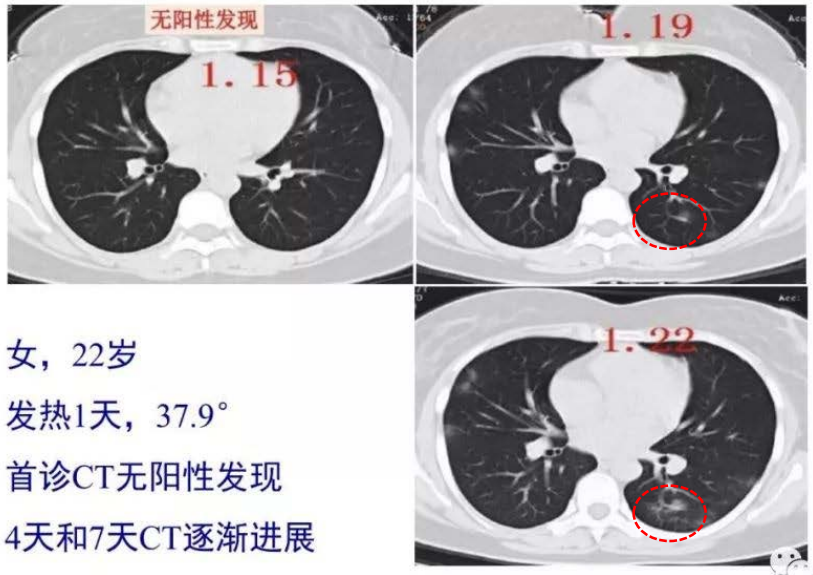
X-ray chest image of 2019-nCoV Patient

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

华中科技大学同济医学院 武汉市中心医院 THE CENTRAL HOSPITAL OF WUHAN



女，22岁

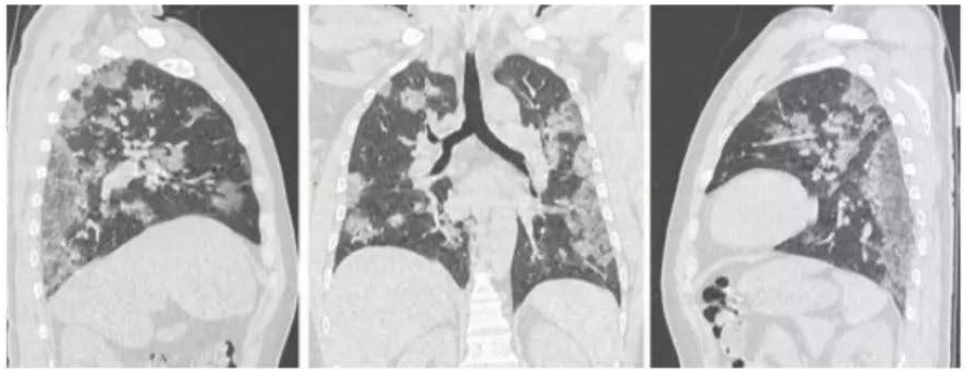
发热1天，37.9°

首诊CT无阳性发现

4天和7天CT逐渐进展

早期CT表现

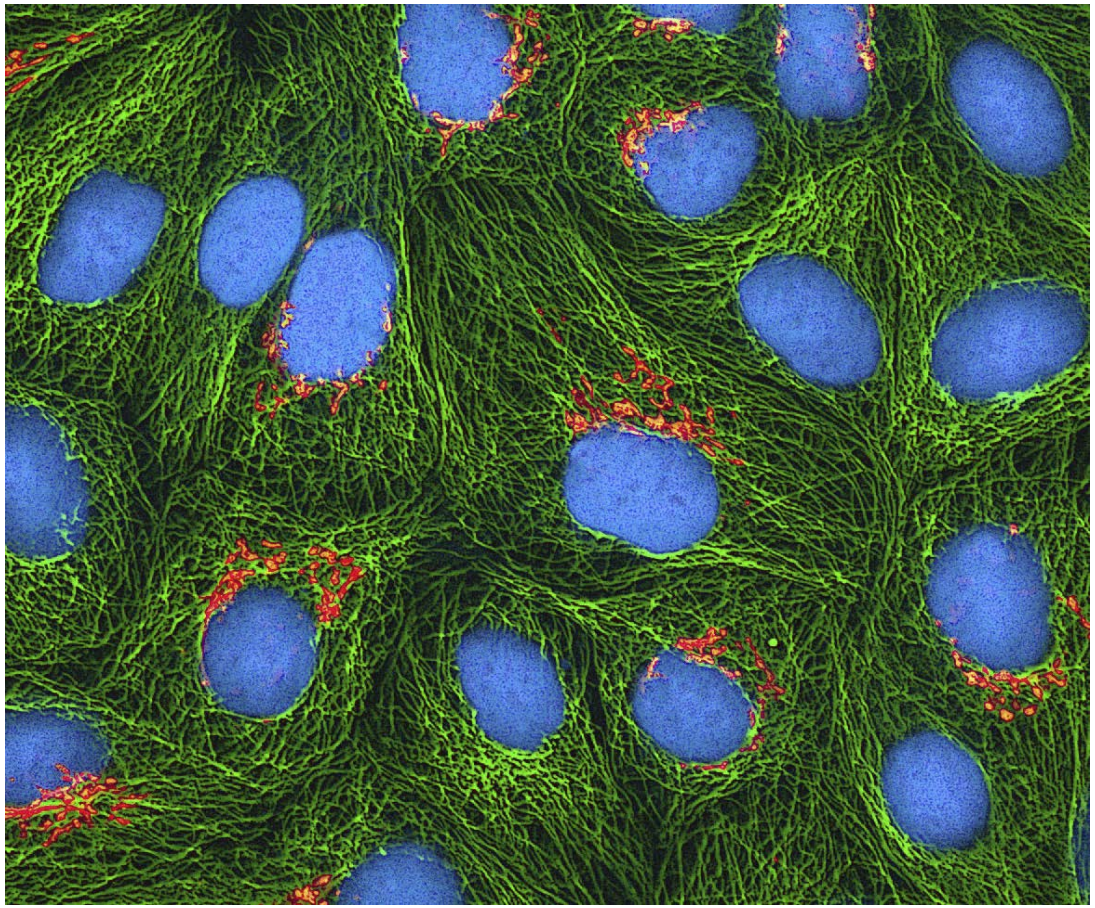
武汉协和放射 DEPARTMENT OF RADIOLOGY WUHAN UNION HOSPITAL



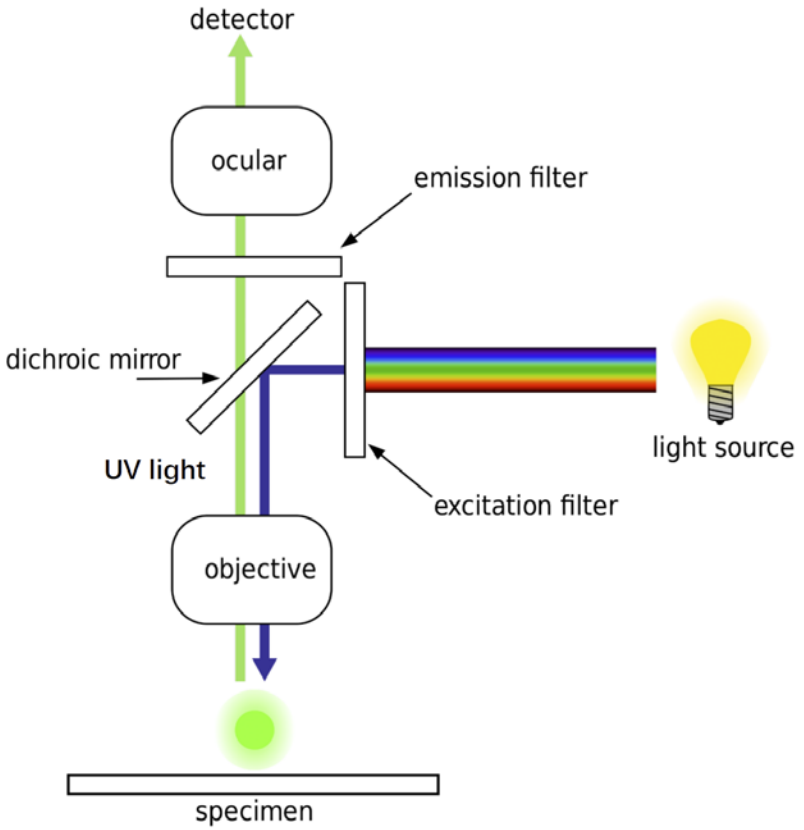
男，44岁，华南海鲜市场密切接触史

无明显诱因发热、乏力，外院抗菌抗病毒治疗无效

Ultraviolet imaging (10-100 eV)



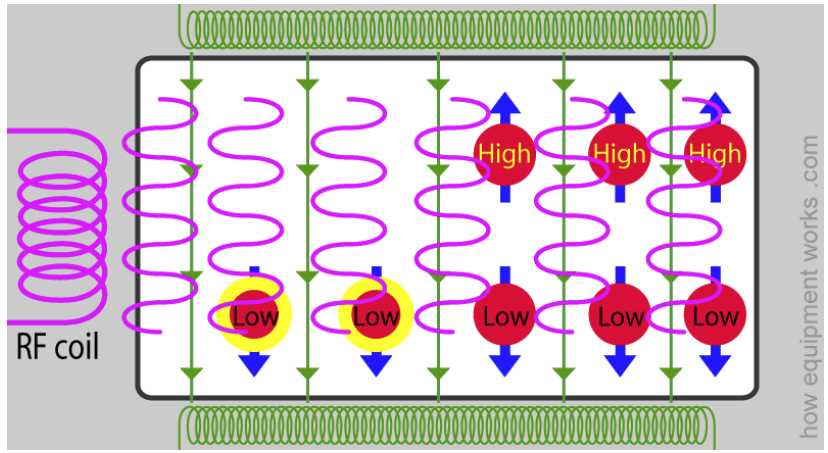
- Fluorescence microscopy image

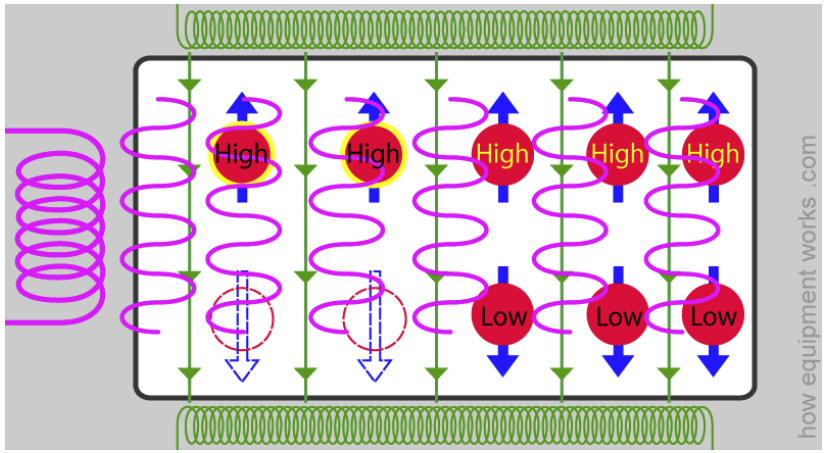


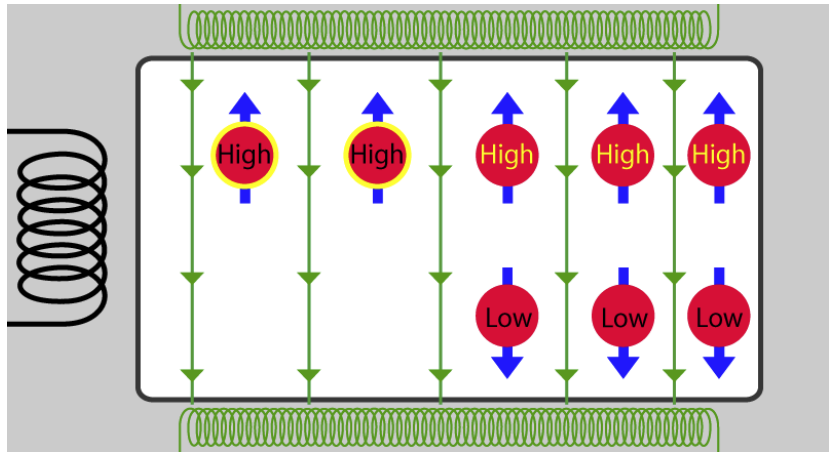
- Fluorescence microscopy structure

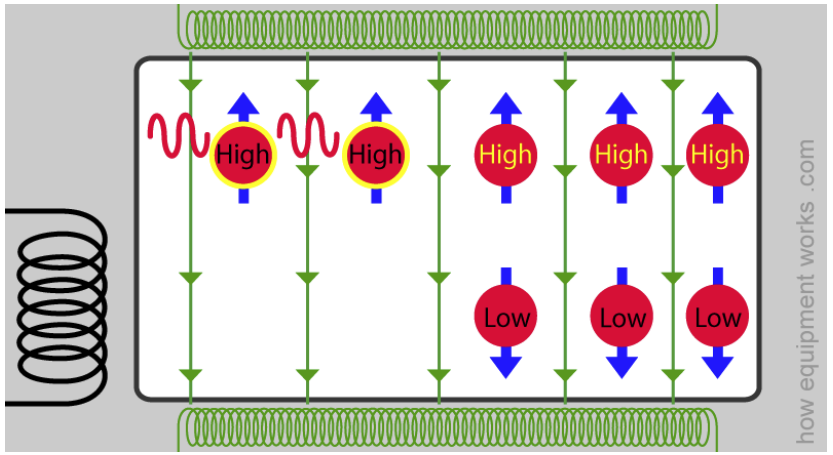
Radio-band imaging (10^{-6}-10^{-9} eV)

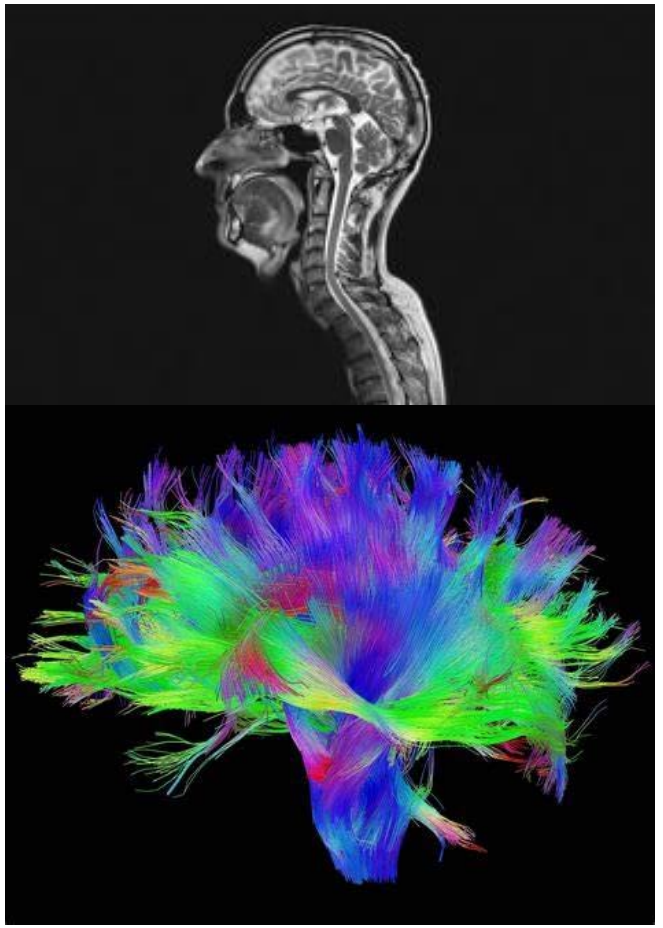
- **Magnetic resonance imaging (Radiofrequency/RF coil)**



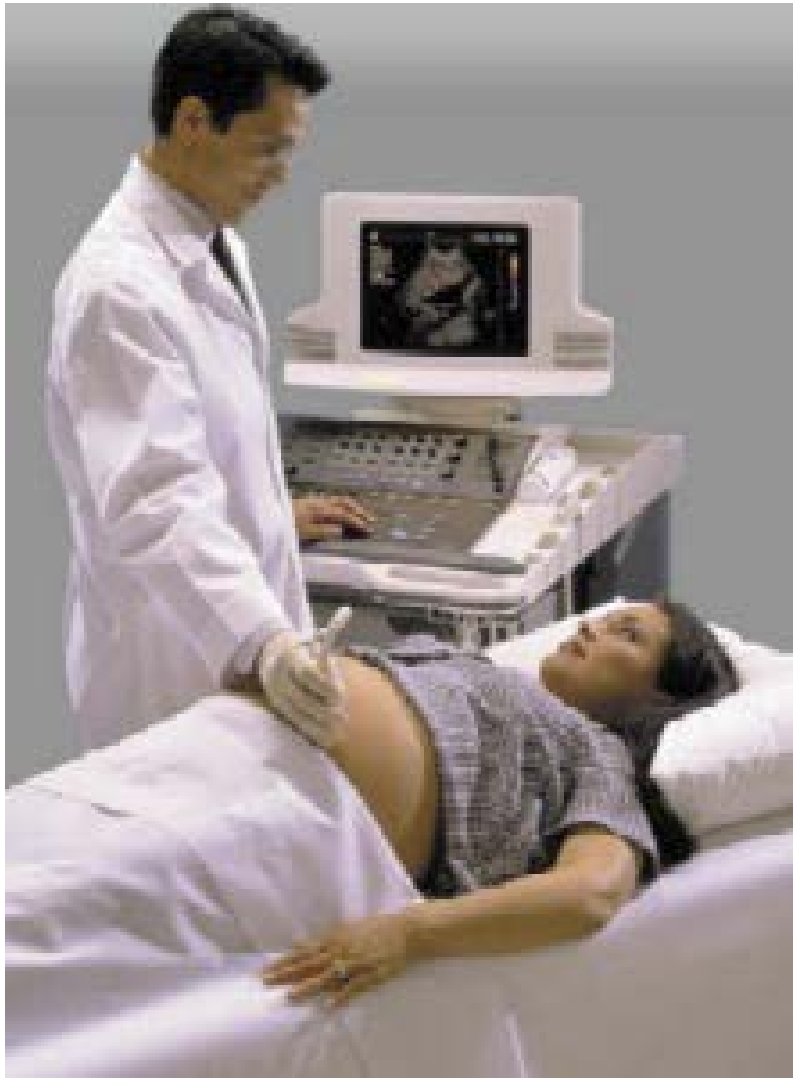








Ultra-sound imaging (non-photon imaging)



Take home message

- Color pictures are acquired based on Bayer filter, similarly the display of color is based on the same discipline.
- Number of storage bits of a digital image depends on both spatial and intensity resolution.
- We are not only interested with real-world images, but images from all kinds of research fields.