> Genius: multidisplinary genius

Basics of Optics

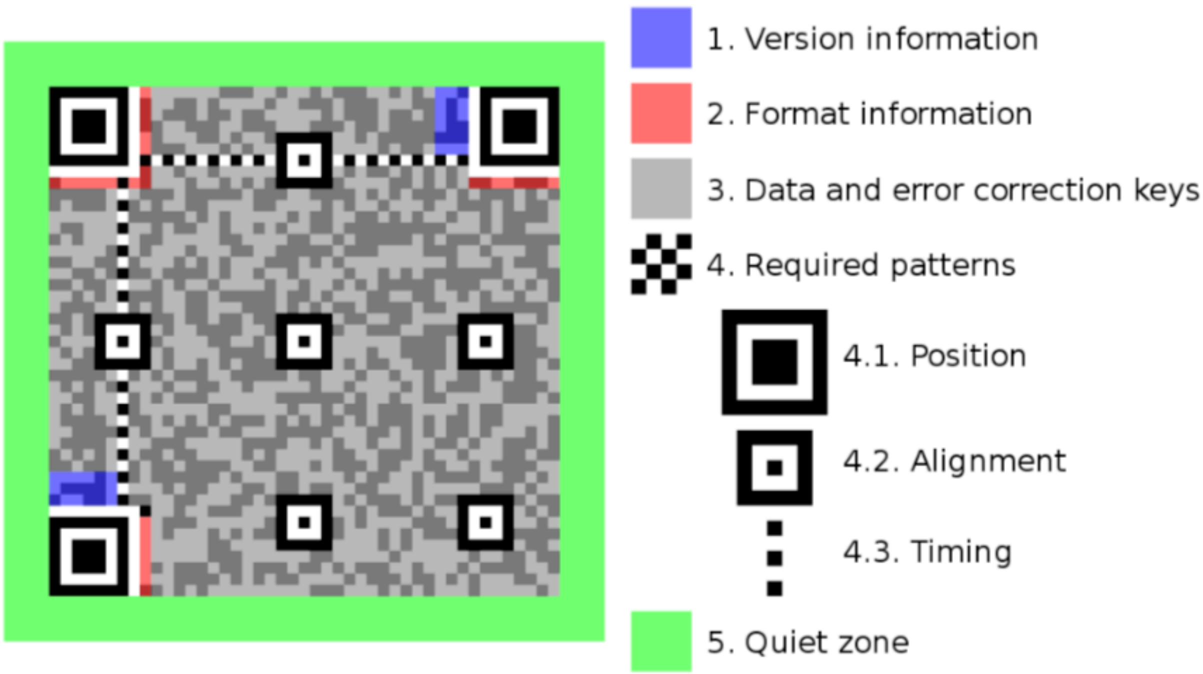
Light as Rays (Geometrical Optics)

$$\text{Light consists of particles traveling in straight lines}$$

Phenonmena: shadows

Application

QR Code



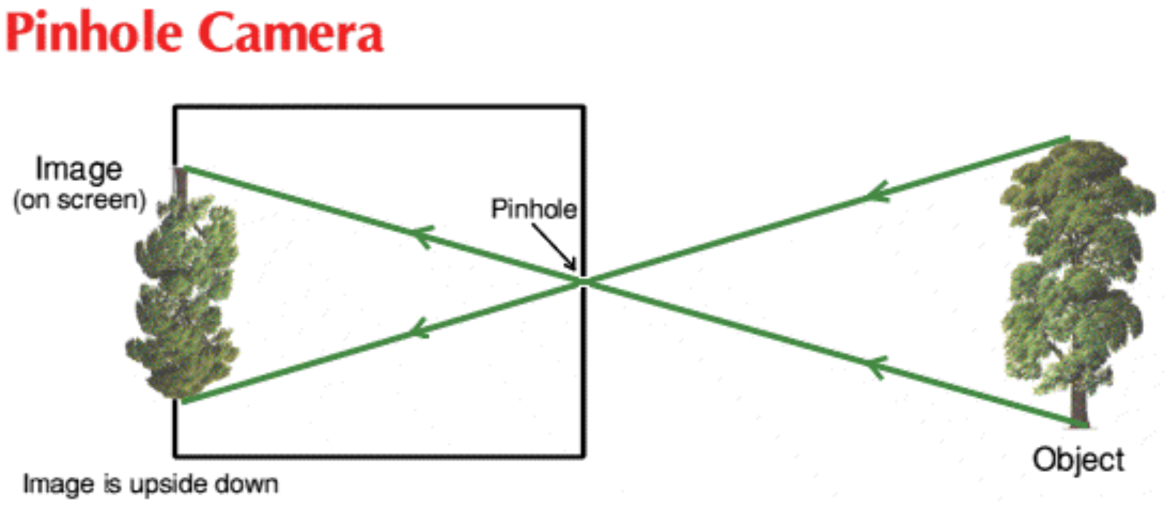
QR codes store **binary data**. Therefore, possibly all kinds of information can be stored in a QR code.

The storage capacity of a QR codes is limited to a maximum of 3 kB (using an 8 bit encoding)

Pinhole Camera

the hole must be as small as possible

Exposure In photography, exposure is the amount of light which reaches your camera sensor or film. It is a crucial part of how bright or dark your pictures appear.



- The image will be very dark because only a small portion of light will cross the pinhole (solution: bend the light)
- The exposure time will be too long

Optical Mouse

An optical mouse is a computer mouse which uses a light source, typically a light-emitting diode, and a light detector, such as an array of photodiodes, to **detect movement relative to a surface**.

Simple camera witin the optical mouse should be accurate and fast.

Algorithmn is not complicated, with only 2 parameter(x, y)

Touch Panels: one of the simple solutions

modern mobile phones are based on **capacity**

old one: LED emits light, which is received by photographs along with x-axis and y-axis

Correlation

About comparison with high precision

require: 1 camera and computers

2 cameras are 3-D

- Test machines for the strength of metals faciliate optics via computers to observe the changes

Bird Strike Test uses correlation to examine the impact of the bird strike

Refraction

A pond can be deeper than observation

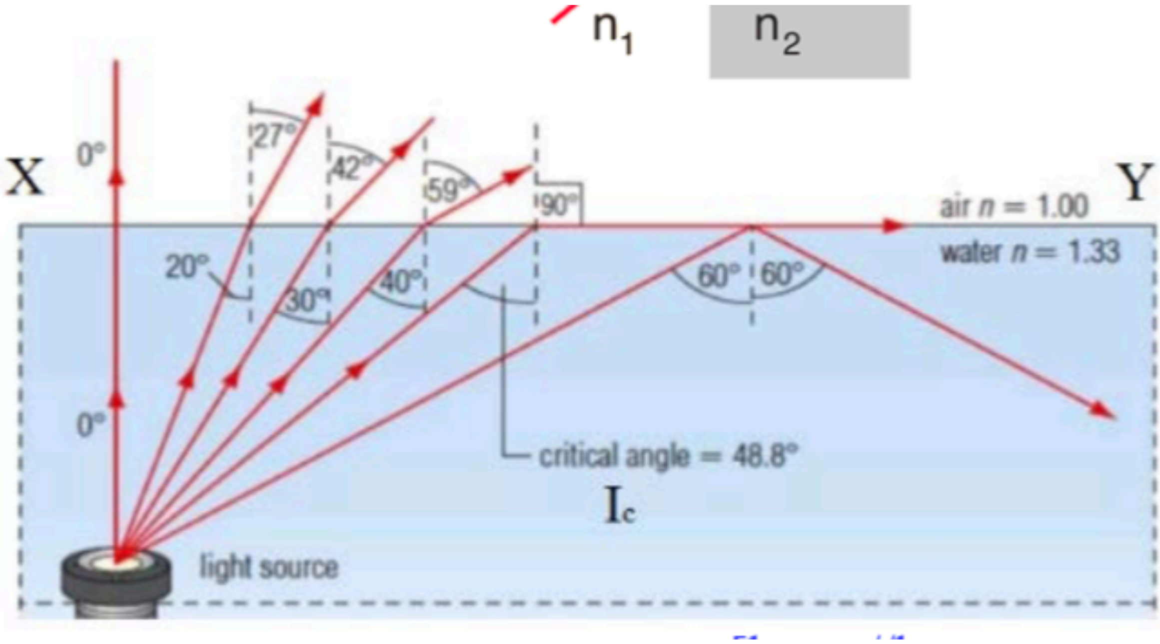
$$\text{Refractive Index } \mu = \frac{v_{\text{vacuum}}}{v_{material}}$$

air = 1, glass = 1.5, water = 1.3

$$\text{Snell's Law} \quad \frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$$

- Fast medium: smaller index of refraction
- Slow medium
- smaller n, faster medium, leads to larger θ

Total Reflection



Application

1. Optical Fiber: constrain and save energy in the fiber
    2. Endomicroscopy for medical treatment
    3. Theory: long-distant transmission with regeneration

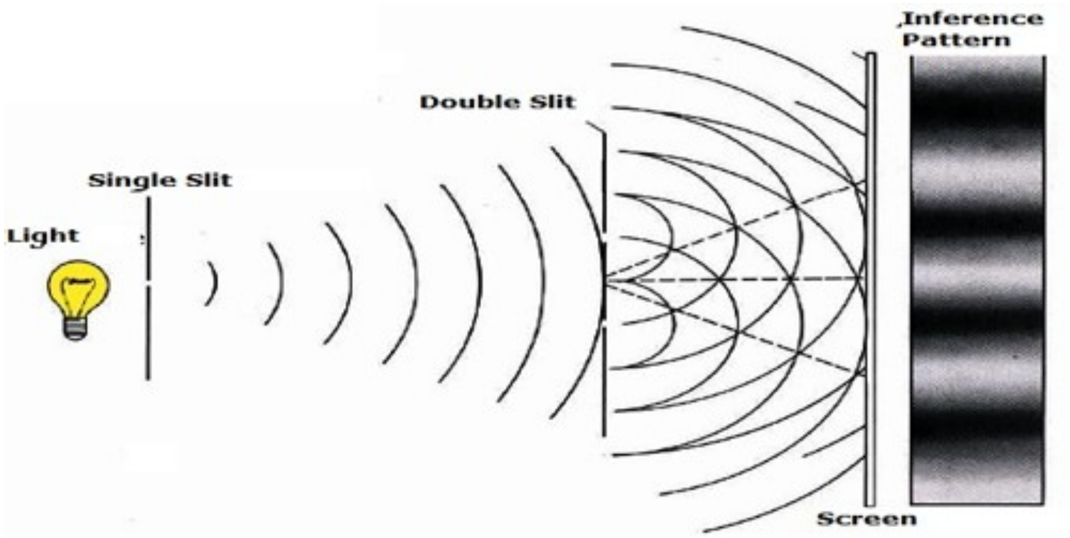
Light as Waves(Wave Optics)

LED lights emit signals which can be coded, which might be applied at shopping mall one day, where GPS sometimes cannot work

Young's double-slit experiment

This phenomenon of variation of intensity of light created due to the superposition of light-waves is called ***interference***.

- constructive interference
- destructive interference



Notes

If the distance between the double slit is increased, the colored band will not be seen. i.e. the distance should be **very small.**

If monochromatic light is taken instead of white light(not monochromatic), then alternate bright and dark band will be seen.

Turn on two light bulbs, will you see an interference pattern?

Yes but you wont be able to see it.

At any instant in time there will be places where the intensity is high and places where it will be low. Because **the two light sources are not coherent** that is to say thay do not have a fixed phase relationship, the positions of these light/dark areas changes very rapidly - make a guess of every 10^-14 second. What you see is a time averged intensity - which is uniform illumination of the screen.

Wave Form

$$\text{The wavefront} \quad e = a \cdot \cos(2\pi ft + \frac{2\pi}{\lambda}x + \varphi_0)$$

Understanding

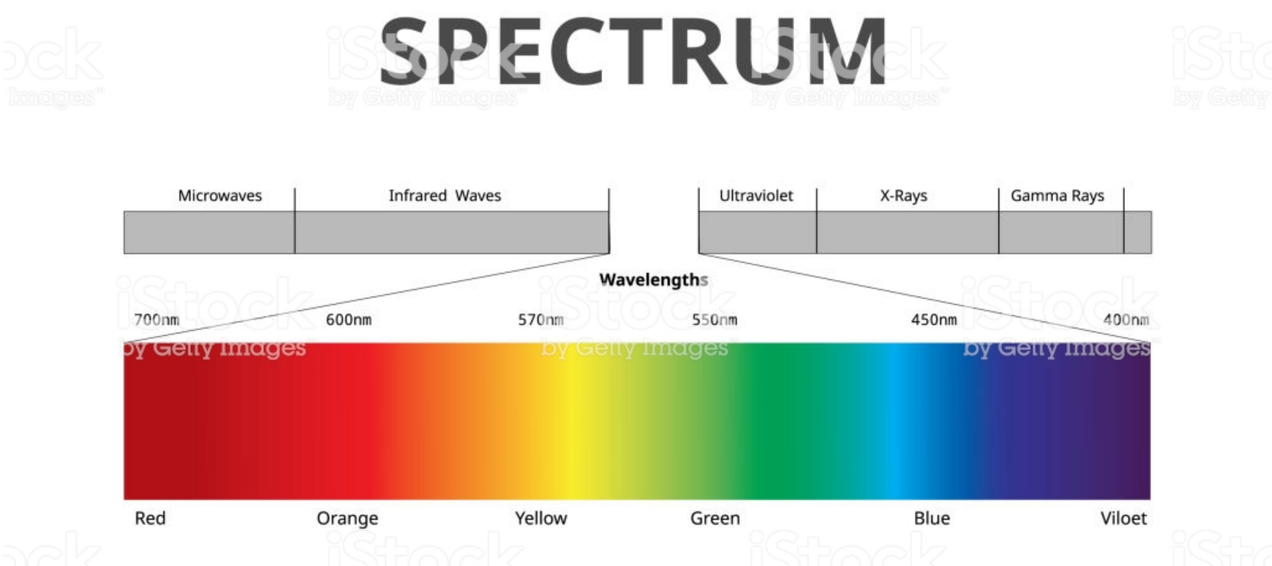
- e changes with both t and s. Assign values to either of them will give information.
- $\phi_0$initial phase
- In a wave, energy is proportional to amplitude squared.

Visible light

$$
\begin{gathered}
\lambda = (4 \sim 7) \times 10^{-7} m \\
f = (4 \sim 7) \times 10^{14} Hz \\
T = 1/f \\
c = \lambda / T = \lambda f = 3 \times 10^{8} m/s
\end{gathered}
$$

Invisible light

Theory Human respond to **energy over response time (0.1s)**. People only see the average brightness.



Interference

You see the **constant average brightness**, not the wave.

Michelson-Morley interferometry

the fundamentals of relativity theory

The Michelson–Morley experiment was an attempt to detect the existence of **aether**, a supposed medium permeating space that was thought to be the carrier of light waves.

The result is optics can travel without media

Conditions

To set up a stable and clear interference pattern, two conditions must be met:

1. The sources of the waves must be **coherent**, which means they emit identical waves with a constant phase difference.
2. The waves should be **monochromatic** - they should be of a single wavelength.

Let's say we have two sources sending out identical waves in phase. Whether constructive or destructive interference occurs at a point near the sources depends on the path-length difference, d, which is the distance from the point to one source minus the distance from the point to the other source.

Condition for constructive interference: $d = ml, l \in \mathbb{Z}$

Condition for destructive interference: $d = (m + \frac{1}{2})l, l \in \mathbb{Z}$

Note that you can't use two light sources (two lasers, two light bulbs, two candles, etc.) because they each experience random changes in phase about once every 10^{-8} s.

Application-Holography

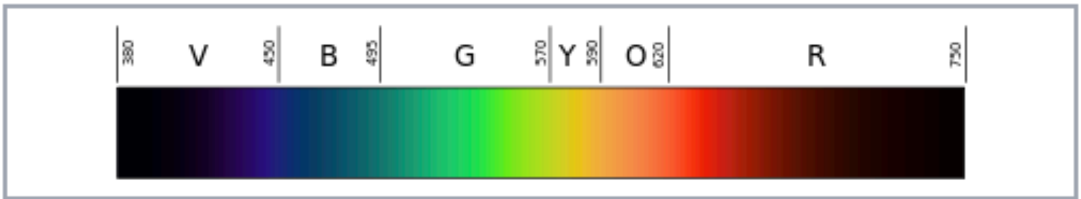
Definition full information of an object in 3D is represented by wavefront

- Recorded Hologram, similar to Young's interference pattern

其第一步是利用干涉原理记录物体光波信息(recording)，此即拍摄过程：被摄物体在激光辐照下形成漫射式的物光束；另一部分激光作为参考光束射到全息底片上，和物光束叠加产生干涉，把物体光波上各点的位相和振幅转换成在空间上变化的强度，从而利用干涉条纹间的反差和间隔将物体光波的全部信息记录下来。记录着干涉条纹的底片经过显影、定影等处理程序后，便成为一张全息图，或称全息照片。

其第二步是利用衍射原理再现物体光波信息(reconstruction)，这是成象过程：全息图犹如一个复杂的光栅，在相干激光照射下，一张线性记录的正弦型全息图的衍射光波一般可给出两个象，即原始象（又称初始象）和共轭象。再现的图像立体感强，具有真实的视觉效应。全息图的每一部分都记录了物体上各点的光信息，故原则上它的每一部分都能再现原物的整个图像，通过多次曝光还可以在同一张底片上记录多个不同的图像，而且能互不干扰地分别显示出来。

Wavelength and Color



顏色	頻率	波長
紫色	668—789THz	380—450nm
蓝色	631—668THz	450—475nm
青色	606—630THz	476—495nm
綠色	526—606THz	495—570nm
黃色	508—526THz	570—590nm
橙色	484—508THz	590—620nm
紅色	400—484THz	620—750nm

- it helps increase fiber-optic communication capacity
- ***chromatic aberration*** In optics, chromatic aberration is a failure of a lens to focus all colors to the same point. It is caused by dispersion: the refractive index of the lens elements varies with the wavelength of light. The refractive index of most transparent materials decreases with increasing wavelength.
  - in real situations, cameras will fix and compensate the chromatic aberration *by putting another piece of lens, commonly 4~7 lens in total*
  - 如果数码相机镜头以玻璃为材料，很多用户及商家都说玻璃镜头透光率佳、投射图像更清晰。不过目前许多测试报告都显示，玻璃的透镜并不一定比塑

料材料能带来更清晰的图像，同时玻璃镜头也可能增加相机重量，因此选购时还是应该做多面向观察，不要拘泥在镜头材质问题上。

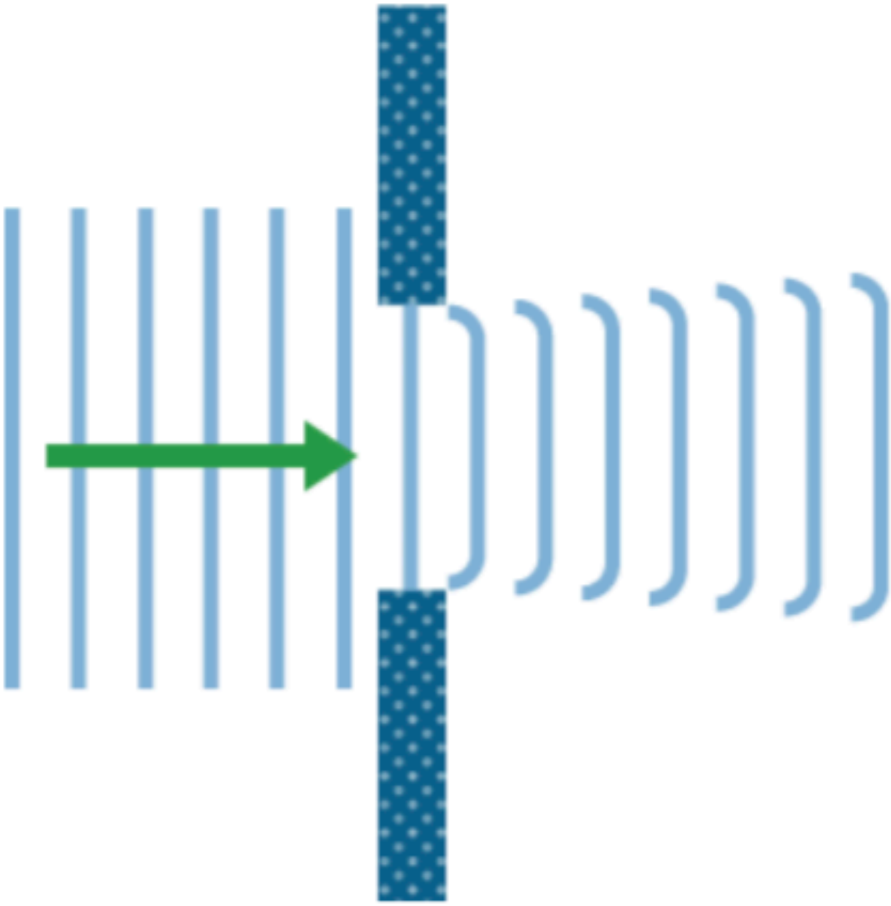
Electromagnestism: Field Theory

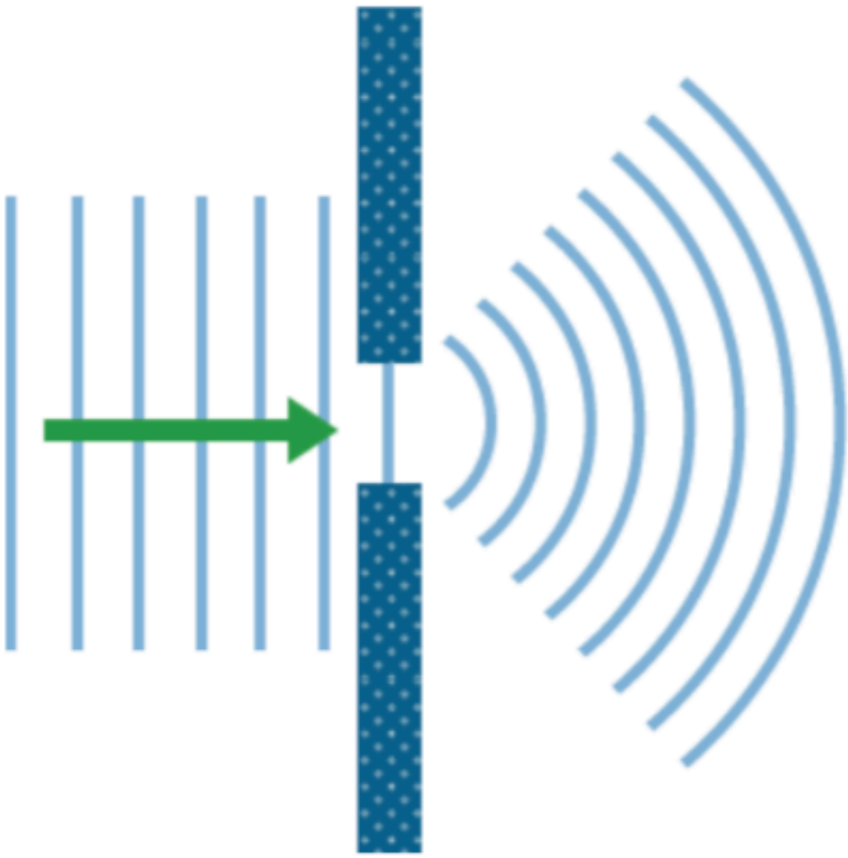
Electricity and magnetism are unified as electromagnetic field

the shorter wave is like a particle, the longer one is just like a wave

Application

Diffraction helps to spread information. e.g. Wi-fi





5G

5G use frequency at GHz, higher than 4G

Higher frequency means higher capacity and faster speed; also means worse to diffract the signal. Hence, 5G signal is easier to be bounced back, which therefore requires more base stations

Light as Photons

Wave-Particle Duality

Application：Computed Tomography

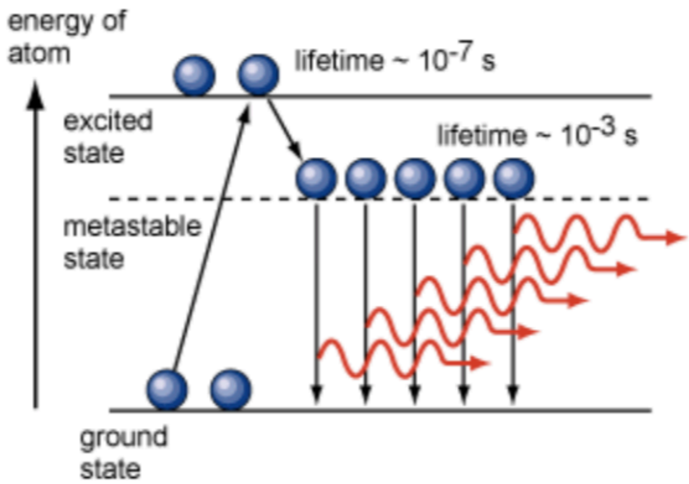
Photonics

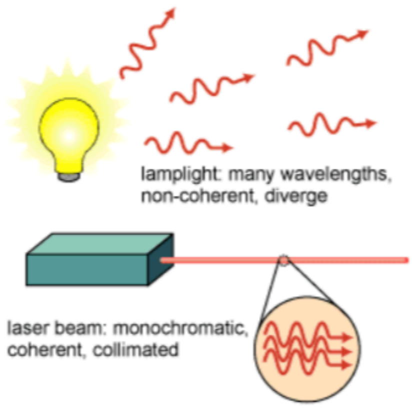
$$E = hf$$
$$\lambda p = h$$

而每一個光子的能量 E 直接正比於光的頻率f.此外,光有不同的顏色,不同顏色的光,其光子有不同的能量,頻率較高的光子, 則具有較大的能量。

h connects the wave form and particle form.

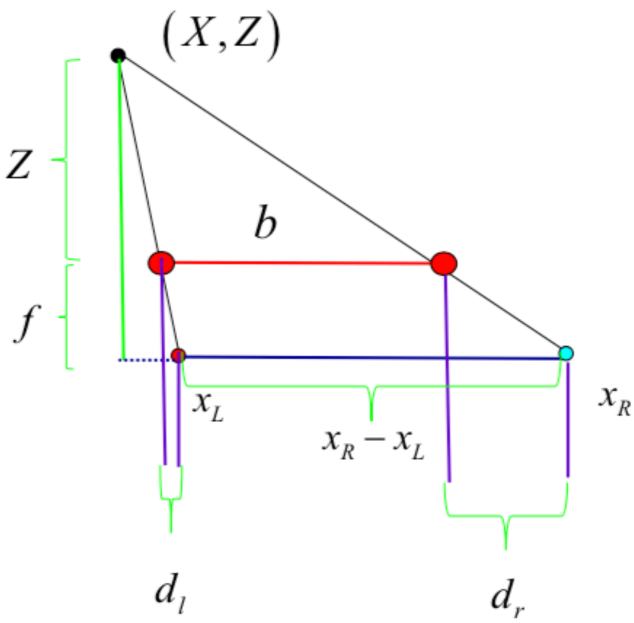
Application: Laser (monochromatic, coherent, collimated)





Getting 3D

Stereo Vision



$$\frac{b}{x_R - x_L} = \frac{Z}{Z + f}$$

$$Z = \frac{bf}{x_R - x_L - b} = \frac{bf}{d_r - d_l} = \frac{bf}{disparity}$$

Z: the depth information

the computer theory was based on this theory, but the problem is finding the correspondence of the photos. Nowadays, people use machine learning.

Leap Motion. inc

Leap Motion, Inc. (formerly OcuSpec Inc.) is an American company that manufactures and markets a computer hardware sensor device that supports hand and finger motions as input, analogous to a mouse, but requires no hand contact or touching.

Kinect 1/Face ID Solution: Structured Light

Kinect 1 is used in Xbox

Two cameras, one projector emitting the light(more active way) and the other camera

the emitted light's pattern can be designed. the regular pattern will be disformed when changes or motion happen.

Kineect 2/LiDaR: ToF

used in self driving: scan the surroundings

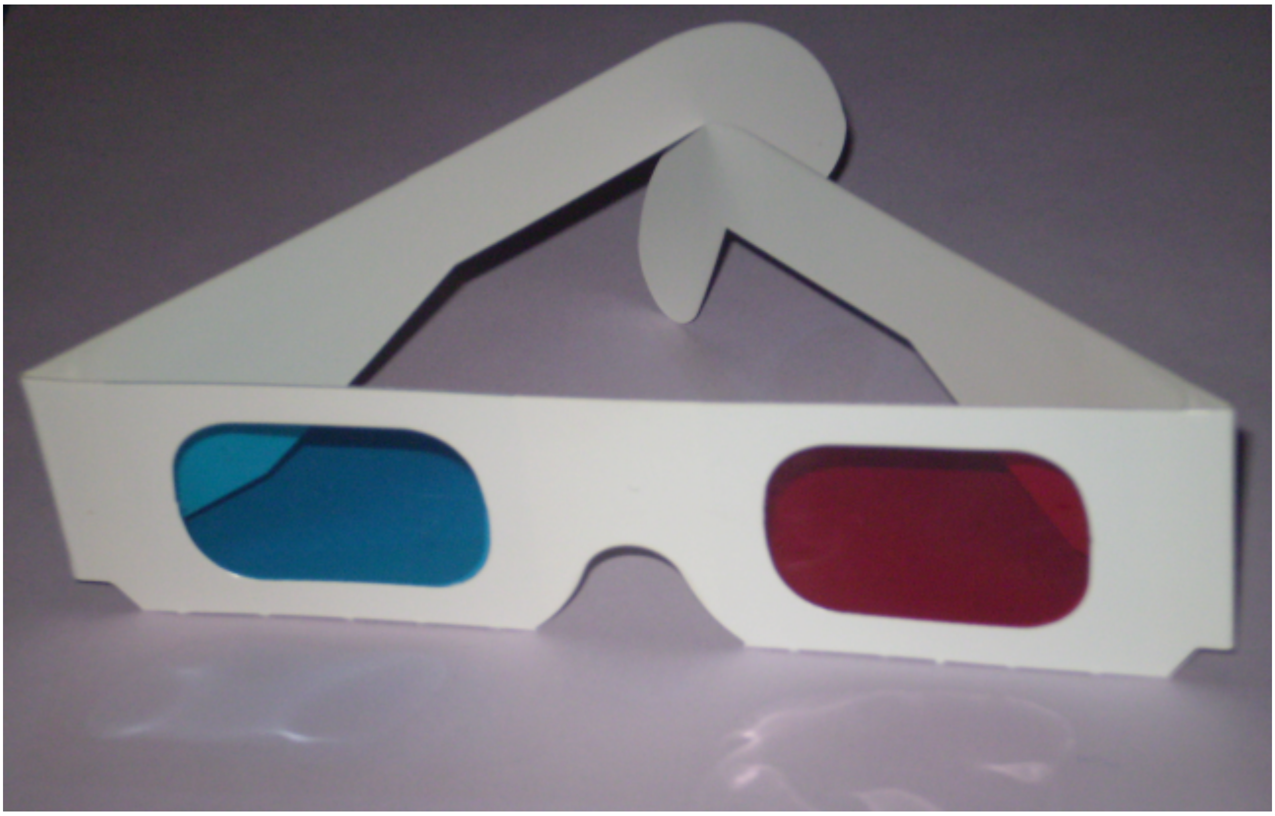
$$\text{distance } d = \frac{C\triangle t}{2}$$

Viewing 3D

Application: iMAX

Animation Movie made on computers, using two virtual cameras

Watching with Color



- To give your left and right eyes different images, hinting the depth information.
- Anaglyph (red light only passes cyan glass, and blue light only passes cyan glass)
- such method would distort the colors

Watching with Polarization

current technology

polarization the light vibrates in certain direction

make the photos vibrate horizontally and vertically

important formula

Refraction

A pond can be deeper than observation

$$\text{Refractive Index } \mu = \frac{v_{\text{vacuum}}}{v_{material}}$$

air = 1, glass = 1.5, water = 1.3

$$\text{Snell's Law} \quad \frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$$

- Fast medium: smaller index of refraction
- Slow medium
- smaller n, faster medium, leads to larger θ

Wave Form

$$\text{The wavefront} \quad e = a \cdot \cos(2\pi ft + \frac{2\pi}{\lambda}x + \varphi_0)$$

Understanding

- e changes with both t and s. Assign values to either of them will give information.
- $\phi_0$initial phase
- In a wave, energy is proportional to amplitude squared.

Visible light

$$\lambda = (4 \sim 7) \times 10^{-7}m$$
$$f = (4 \sim 7) \times 10^{14}Hz$$
$$T = 1/f$$
$$c = \lambda/T = \lambda f = 3 \times 10^8 m/s$$

Conditions

To set up a stable and clear interference pattern, two conditions must be met:

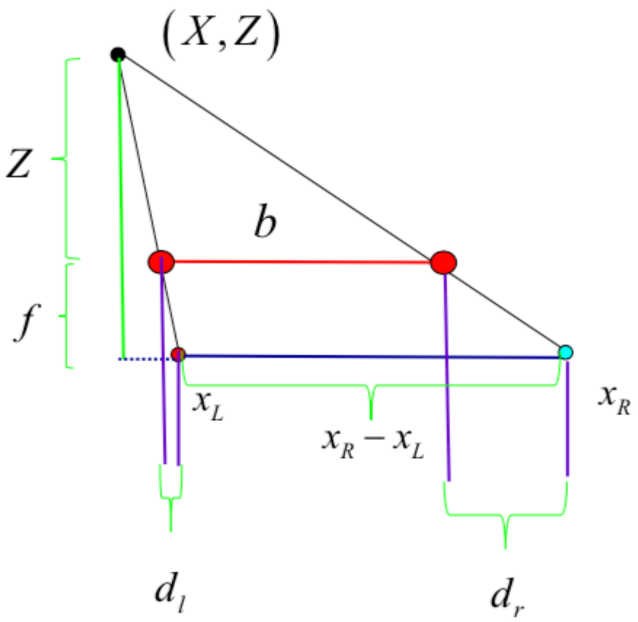
1. The sources of the waves must be **coherent**, which means they emit identical waves with a constant phase difference.
2. The waves should be **monochromatic** - they should be of a single wavelength.

Let's say we have two sources sending out identical waves in phase. Whether constructive or destructive interference occurs at a point near the sources depends on the path-length difference, d, which is the distance from the point to one source minus the distance from the point to the other source.

Condition for constructive interference: $d = ml, l \in \mathbb{Z}$

Condition for destructive interference: $d = (m + \frac{1}{2})l, l \in \mathbb{Z}$

Stereo Vision



$$\frac{b}{x_R - x_L} = \frac{Z}{Z + f}$$

$$Z = \frac{bf}{x_R - x_L - b} = \frac{bf}{d_r - d_l} = \frac{bf}{disparity}$$

Z: the depth information