Computer Vision

---*Camera Model*

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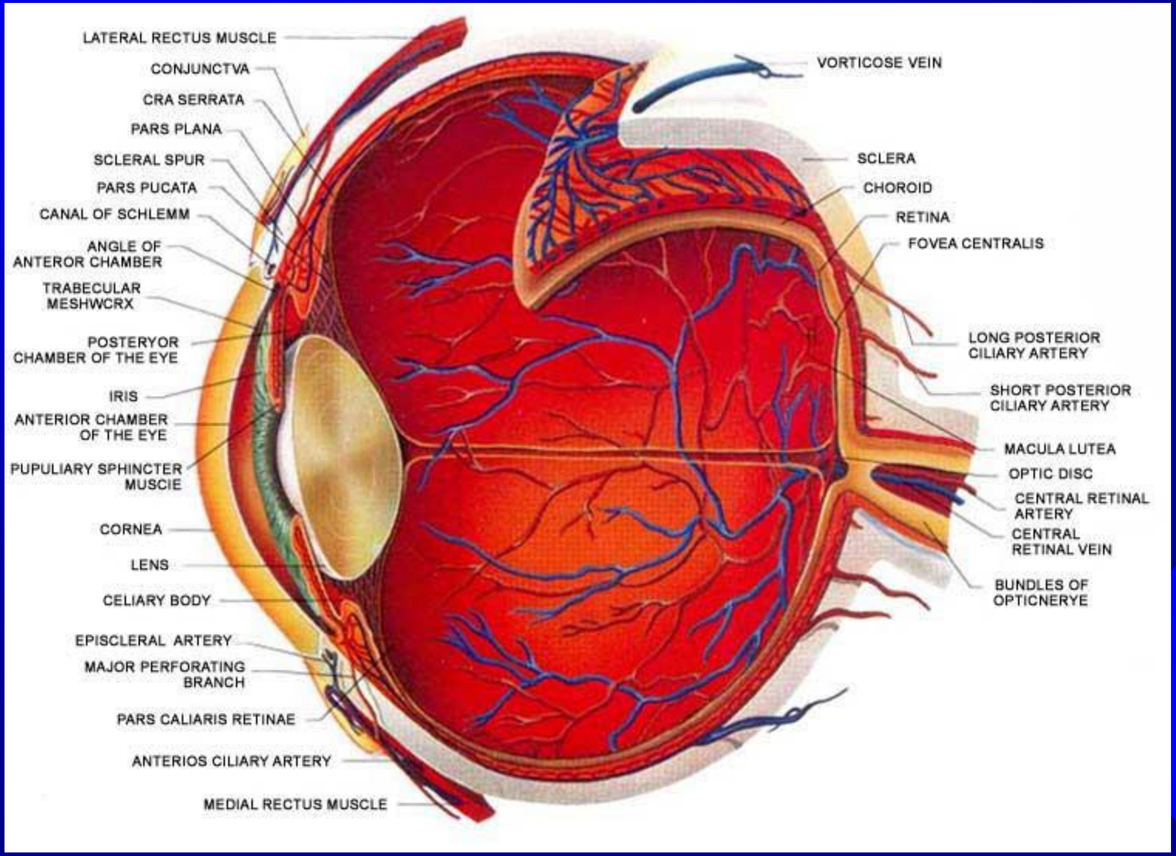
2020.9.11

Understanding the eye

Can we duplicate the human visual system?

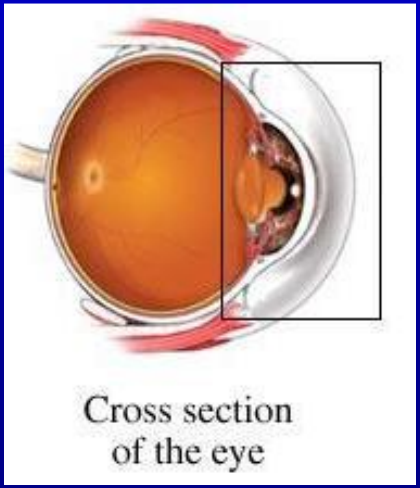
Eye structure.

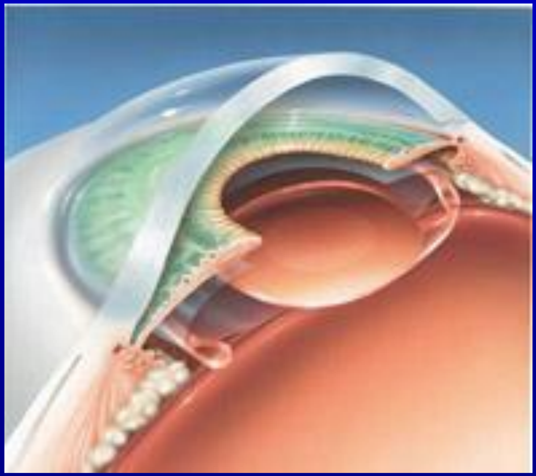


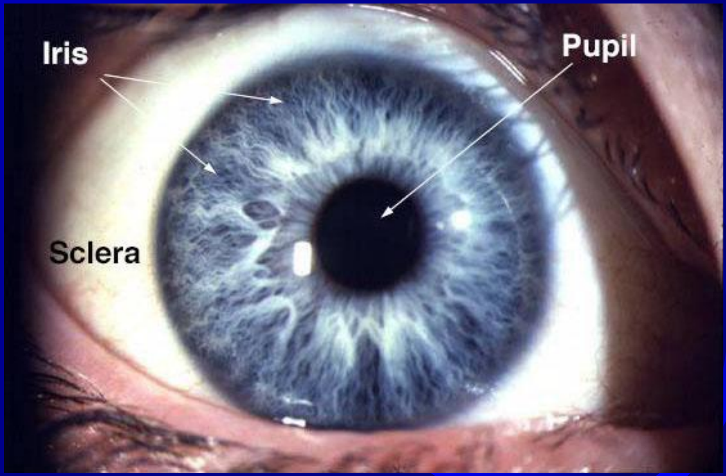
Understanding the eye

The cornea(角膜) is normally transparent; the cornea has no blood vessels. It is curved front of the eye helping to converge the light rays which enter the eye.

Pupil（瞳孔）is a hole in the middle of the iris where light is allowed to continue its passage. In bright light it is constricted and in dim light it is dilated





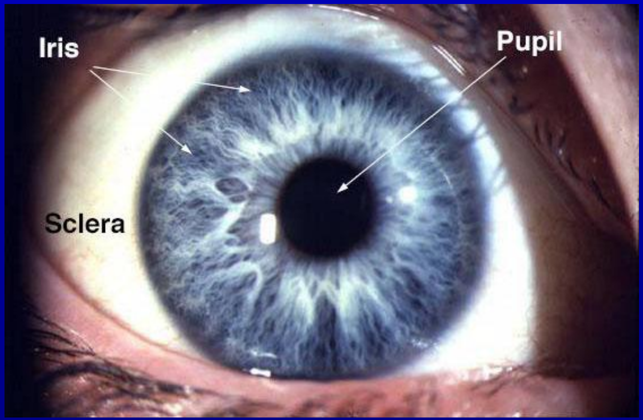


Understanding the eye

Iris（虹膜） is a pigmented muscular structure consisting of an inner ring of circular muscle and an outer layer of radial muscle. Its function is to help control the amount of light entering the eye so that:

– too much light does not enter the eye which would damage the retina.

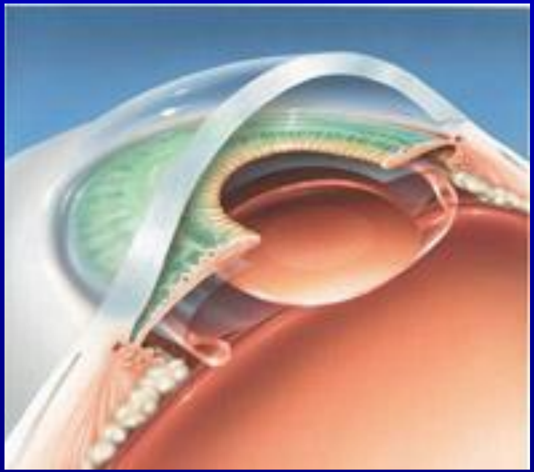
– enough light enters to allow a person to see.

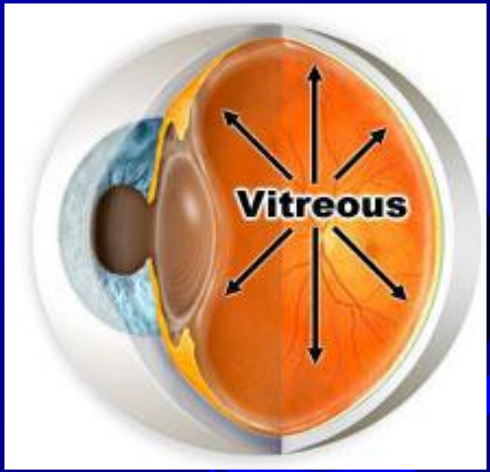


Understanding the eye

Ilens（水晶体）transparent, exible, curved structure. Its function is to focus incoming light rays onto the retina using its refractive properties.

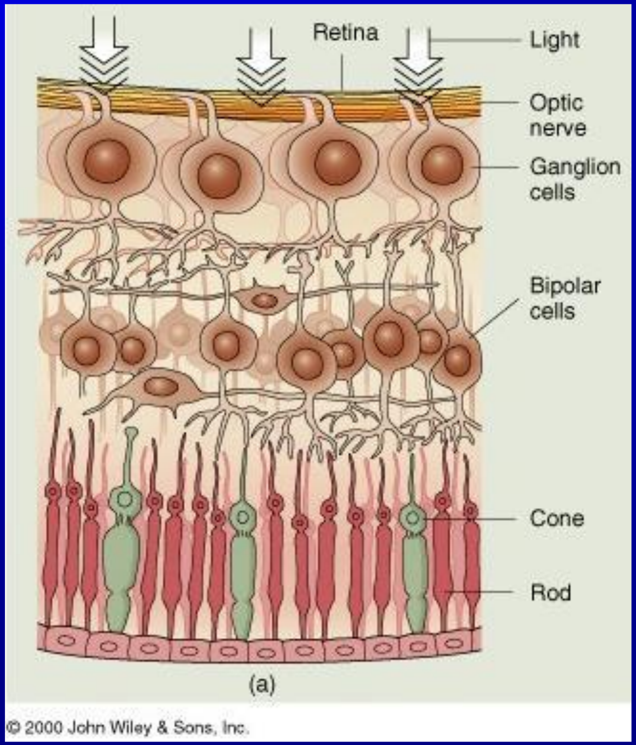
The vitreous (玻璃体) is a thick, transparent substance that fills the center of the eye. It is composed mainly of water and comprises about 2/3 of the eye's volume, giving it form and shape.





Understanding the eye

Retina（视网膜）The sensitive rods and cones are at the back of the retina, facing away from the light. To reach them the light first has to travel through blood vessels, nerve fibers and then several layers of retinal nerve cells.



Understanding the eye

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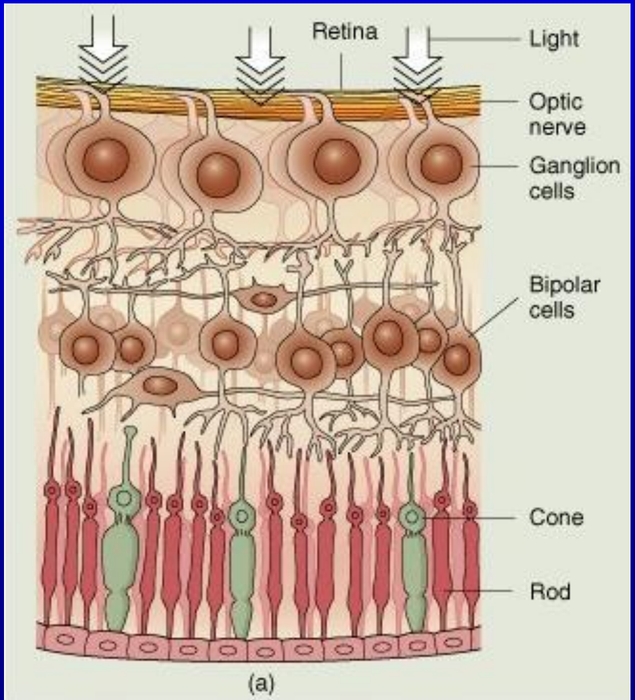
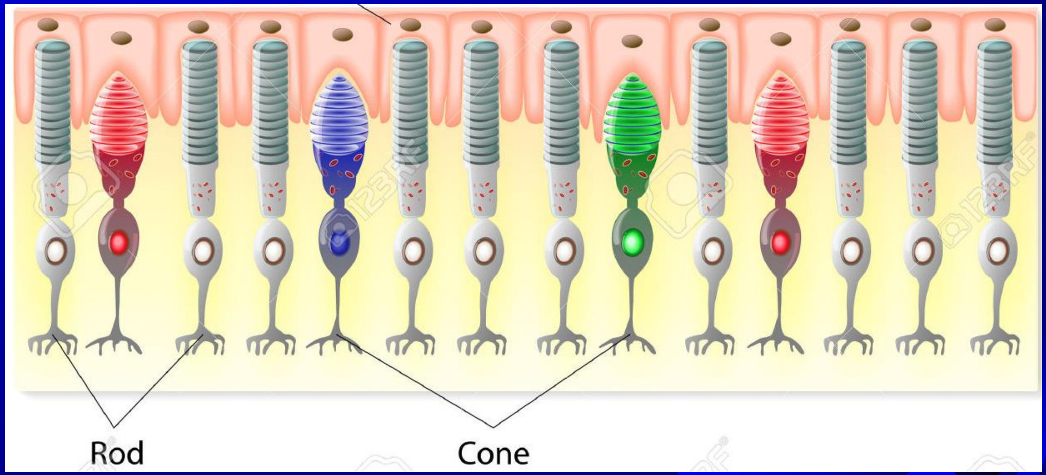
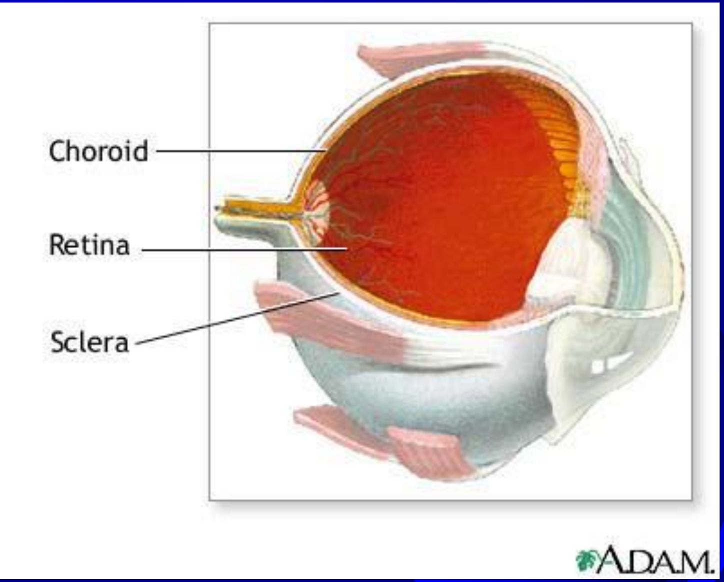




Understanding the eye

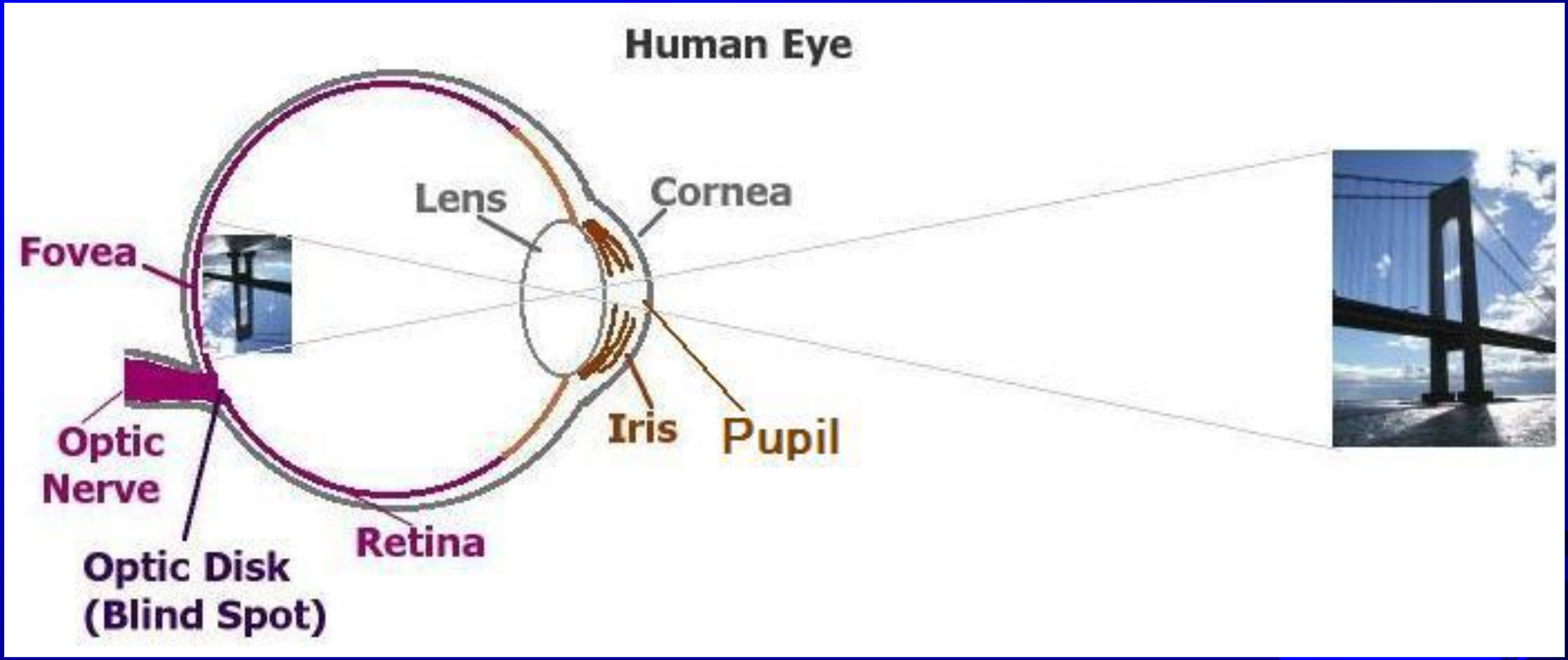
Choroid（脉络膜）has a network of blood vessels to supply nutrients to the cells and remove waste products. It is pigmented that makes the retina appear black, thus preventing reflection of light within the eyeball.

Sclera（巩膜）is an opaque, brous, protective outer structure. It provides attachment surfaces for eye muscles



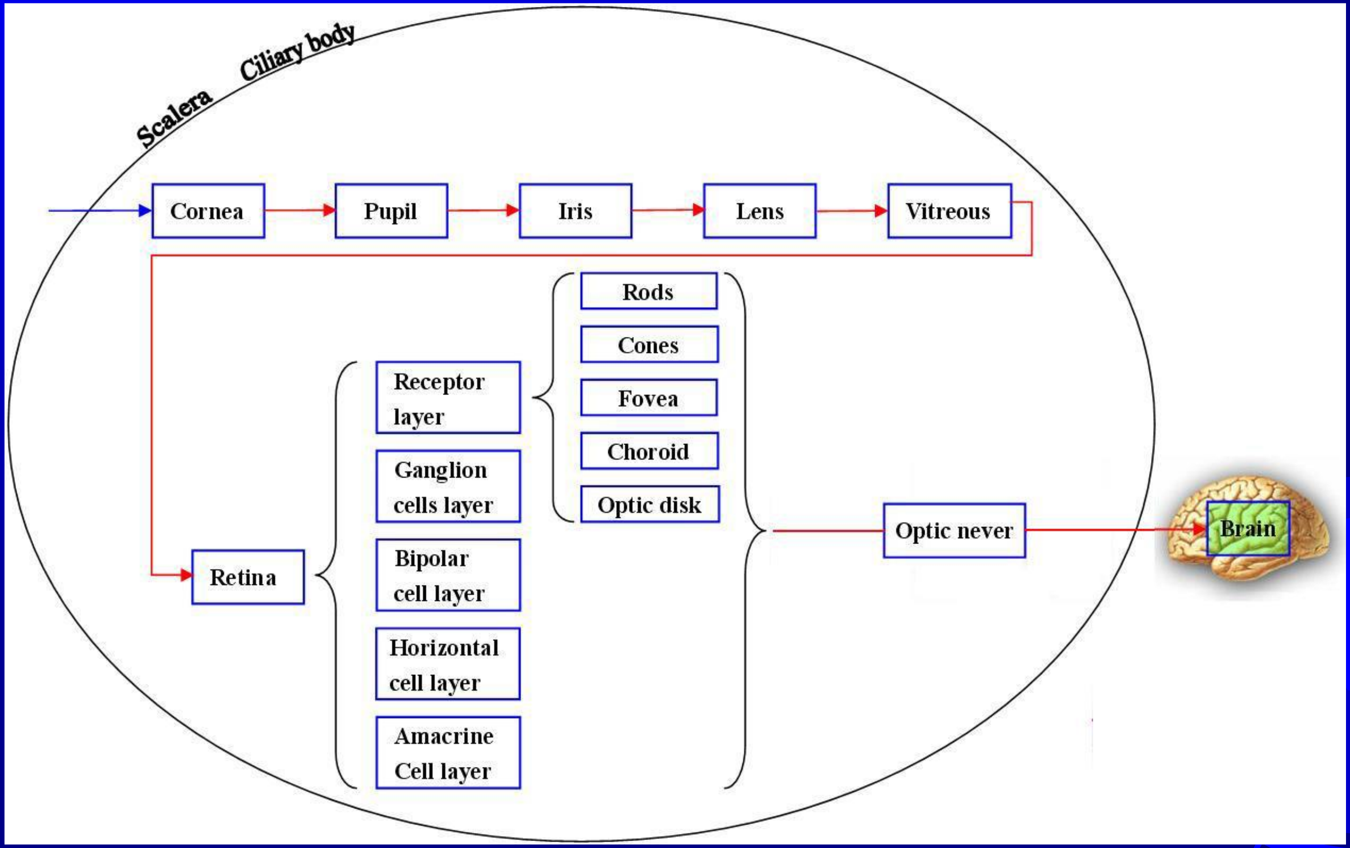
Understanding the eye

Image formation in the eye.



Understanding the eye

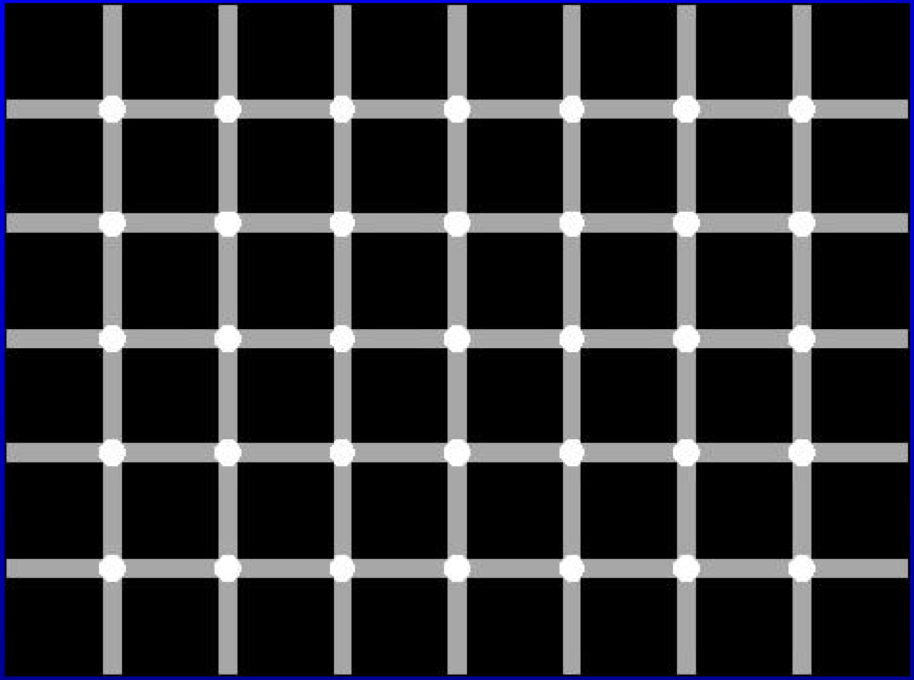
Visual pathway in the human brain--More than half the brain is devoted to visual processing, processing is highly modularized

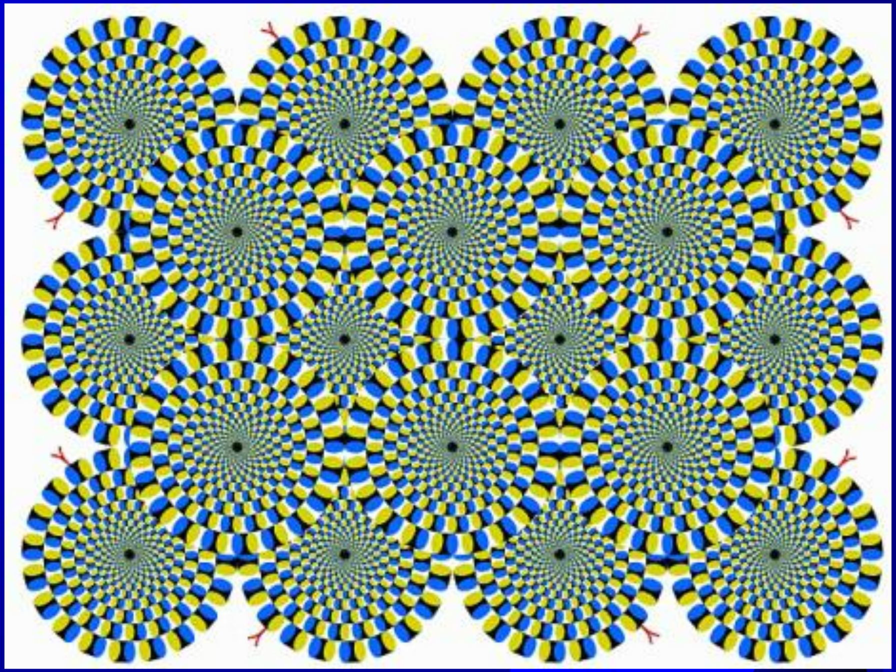


Understanding the eye

Some illusions

Seeing is believing.



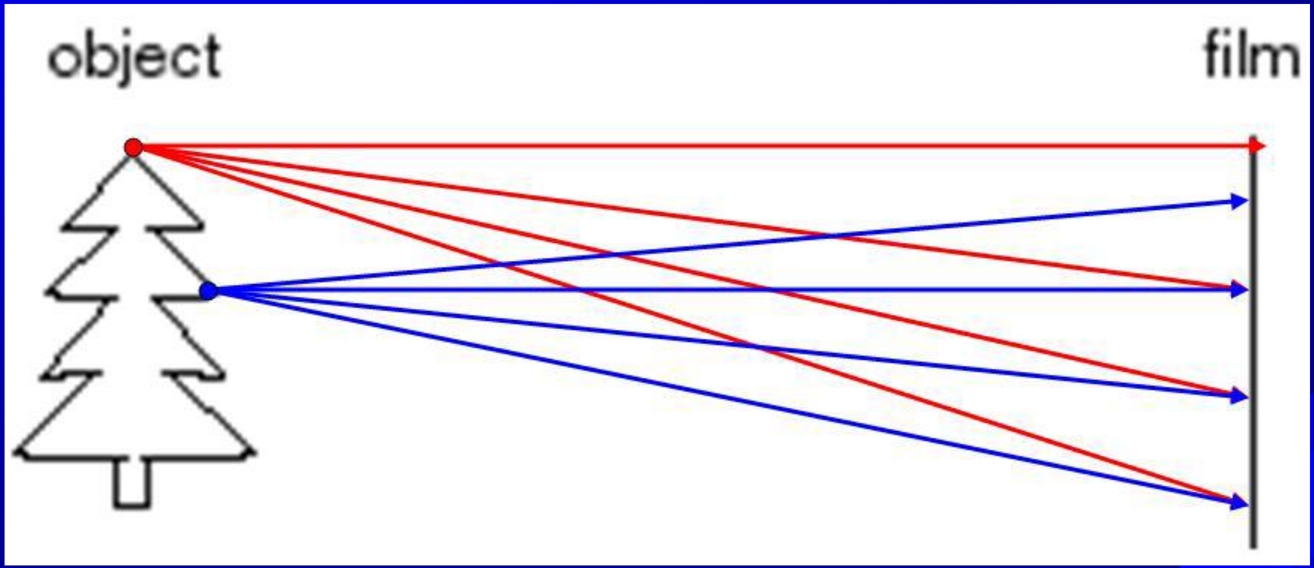


How do we see the world?

Let's design a camera

Idea 1:put a piece of film in front of an object

Do we get reasonable image?



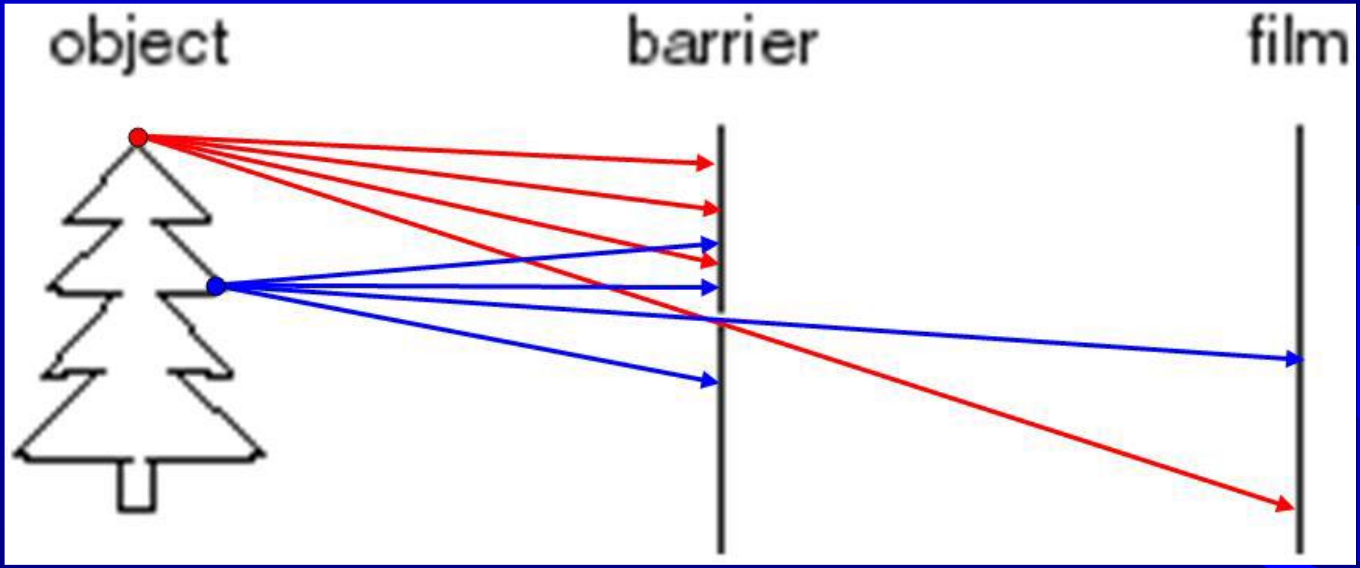
How do we see the world?

Idea 2: add a barrier to block o
 most of the rays

This reduces blurring

The opening known as aperture

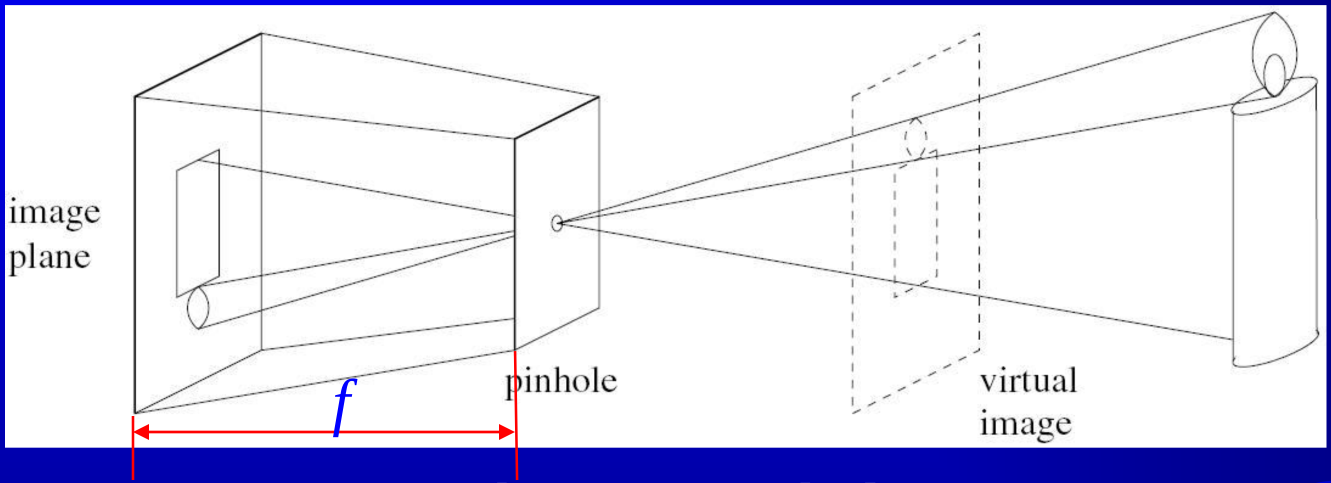
How does this transform the image?



How do we see the world?

The first camera:

5th B.C. Aristotle, Mozi(Chinese: 墨子)



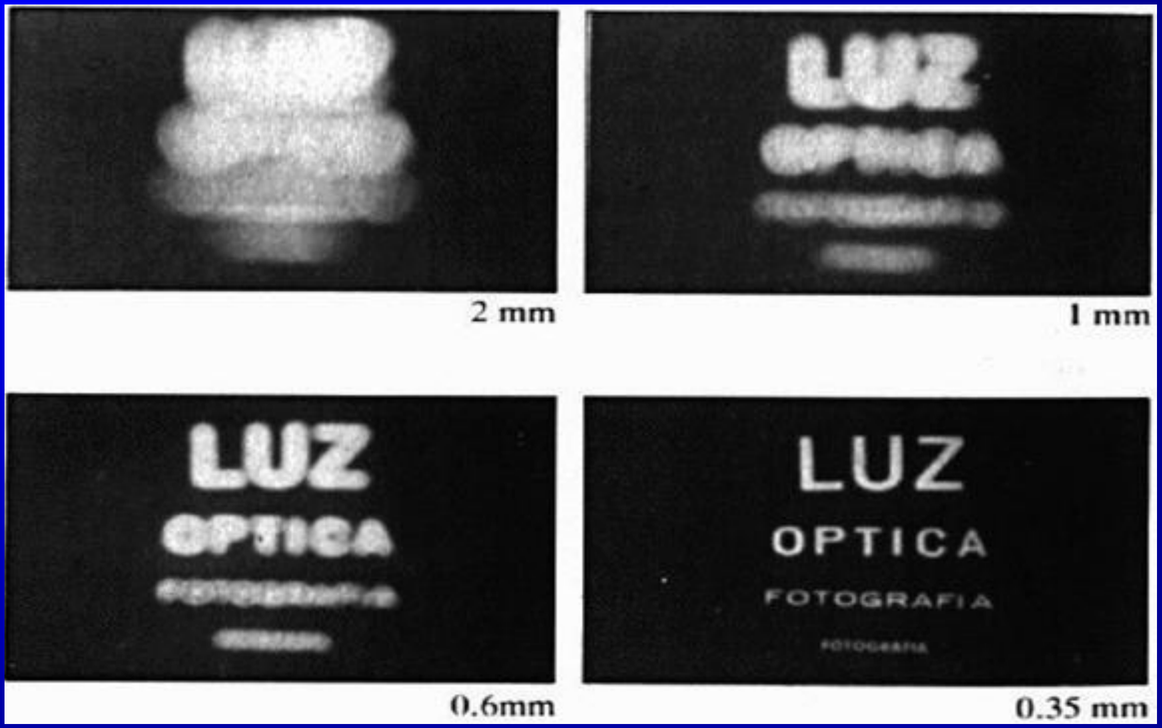
Camera Obscura, pin-hole-camera
针孔相机

Pinhole camera model

A home-made pinhole camera.

Pinhole camera model

Shrink the aperture



Why not make the aperture as small as possible?

Less light gets through

Diffraction effects,

Pinhole camera model

Shrink the aperture

Sharpest image is obtained when $d = 2\sqrt{f\lambda}$.
d is diameter.
f is distance from hole to film.
λ is the wavelength of light.
Example:
If $f = 50mm$, $\lambda = 600nm(red)$, we get $d = 0.346mm$.

Pinhole camera model

More tries on pinhole cameras

Jerry Vincent's Pinhole Camera

Images of Jerry Vincent's Pinhole Photos

People become ghosts!

Pinhole camera model

More tries on pinhole cameras

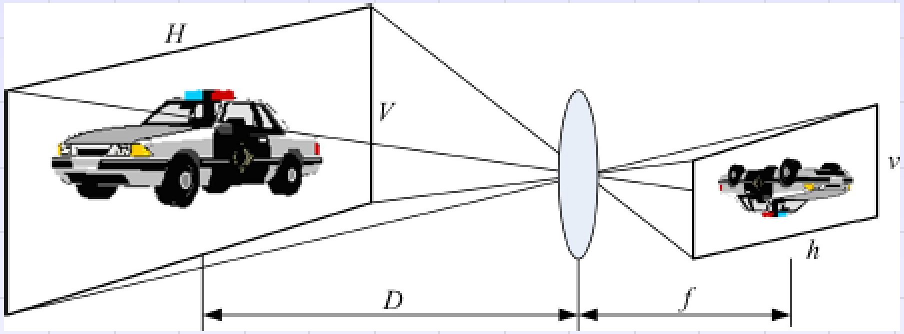
Beer can pinhole camera. Prof. Greg Parker of University of Southampton

Lens and Image

Real lens

Lens and Image

Focal length Calculation



1. Using the following equation to calculate the focal length.

$$f = v * D/V$$
$$f = h * D/H$$

2. f focal length, V vertical height of object, H horizontal width of the object, D distance between the object and the lens, v vertical size of CCD sensor, h horizontal size of the CCD sensor.
3. CCD sensor size.

Lens and Image

CCD sensor size.

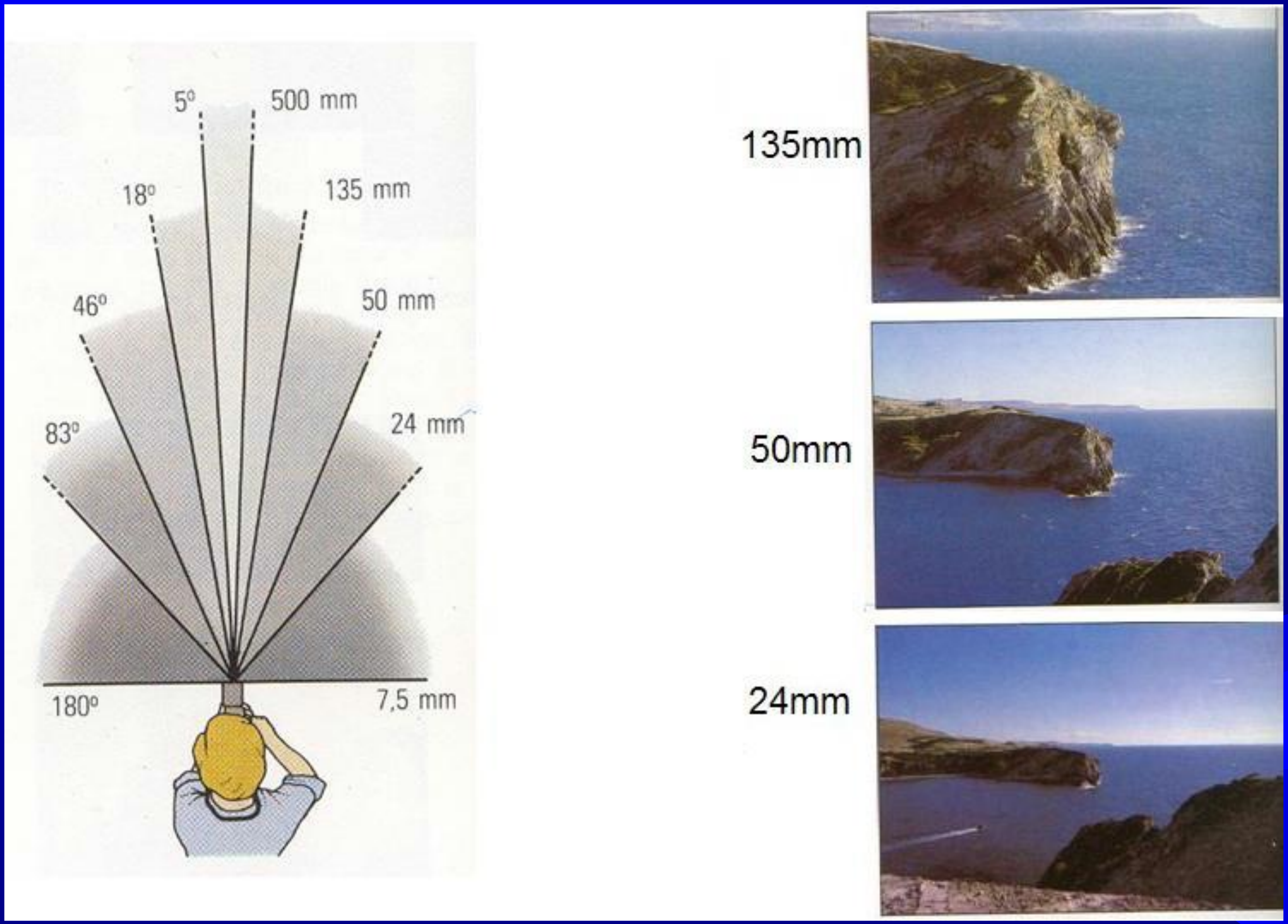
格式	1 型	2/3 型	1/2 型	1/3 型	1/4 型
v（垂直）	9.6mm	6.6mm	4.8mm	3.6mm	2.7mm
h（水平）	12.8mm	8.8mm	6.4mm	4.8mm	3.6mm

It is often got different value of focal length from different V and H.

The smaller value is selected for larger FOV.

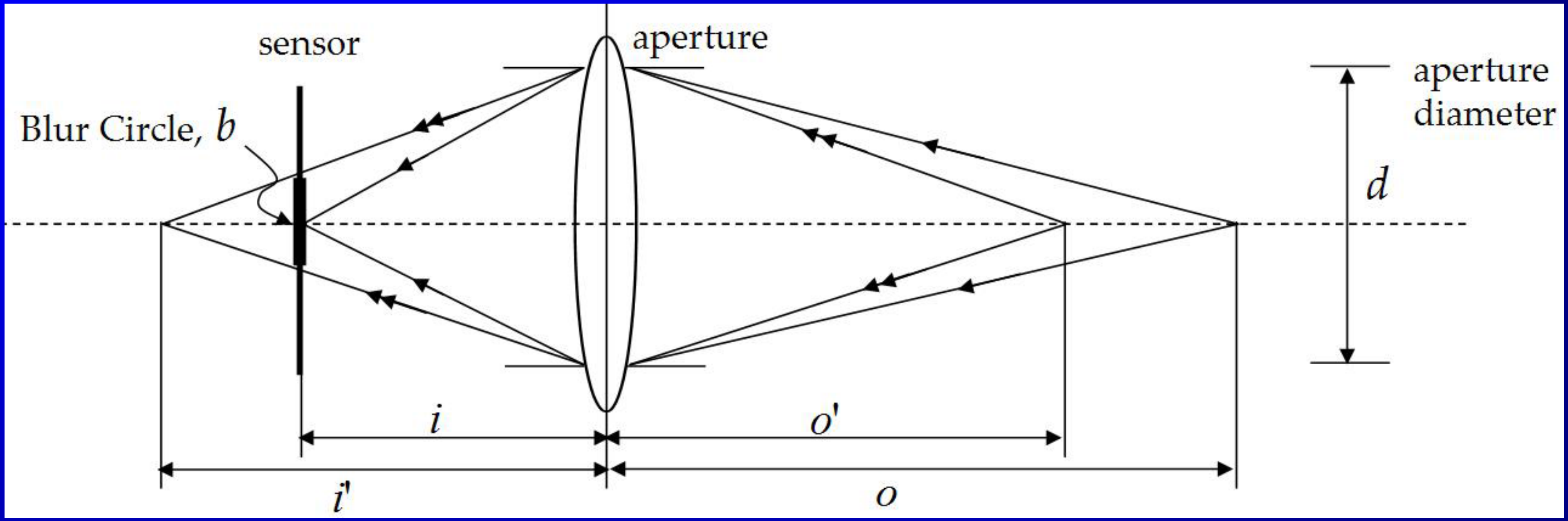
Lens and Image

Field of View (FOV, 视场) vs Focal length



Lens and Image

F-stop



1. Gaussian Law: $\frac{1}{i} + \frac{1}{o} = \frac{1}{f} \Rightarrow$
   $(i' - i) = \frac{f}{(o'-f)} \frac{f}{(o-f)} (o - o')$.
2. Blur circle diameter: $b = \frac{d}{i'}(i' - i) \approx \frac{d}{f}(i' - i)$.
3. f-stop(f-number): $\# = \frac{f}{d}$

Lens and Image

Aperture

When a change in f-stop occurs, the light is either doubled or cut in half.

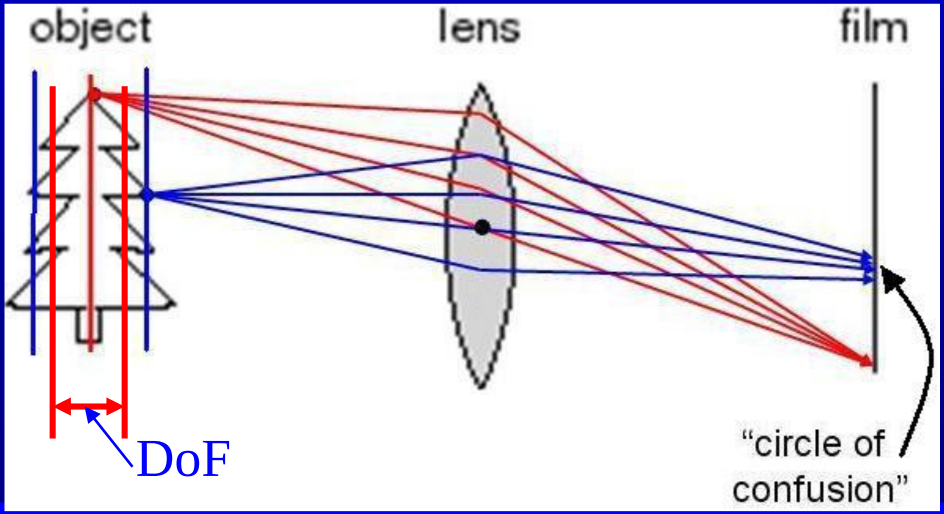
Lower f-stop, more light (larger lens opening)

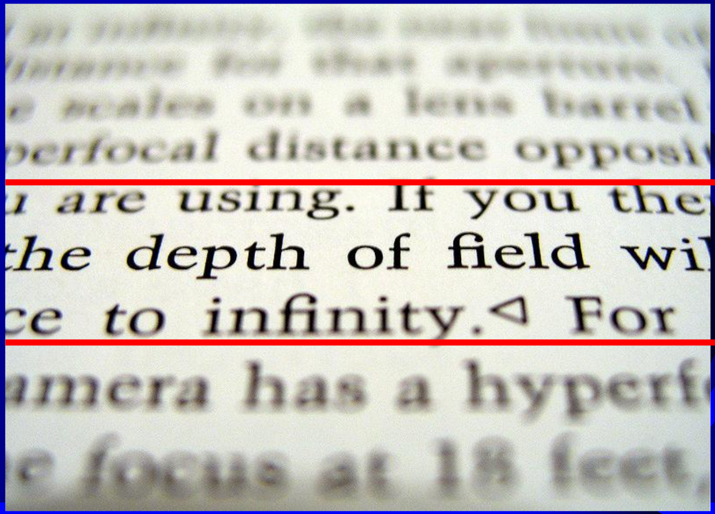
Higher f-stop, less light (smaller lens opening)

Lens and Image

Depth of Field (DoF, 景深)

1. Depth of field is the range of distance within the subject that is acceptably sharp.
2. The DOF is determined by the subject distance (that is, the distance to the plane that is perfectly in focus), the lens focal length, the lens f-number, and the format size or circle of confusion criterion.

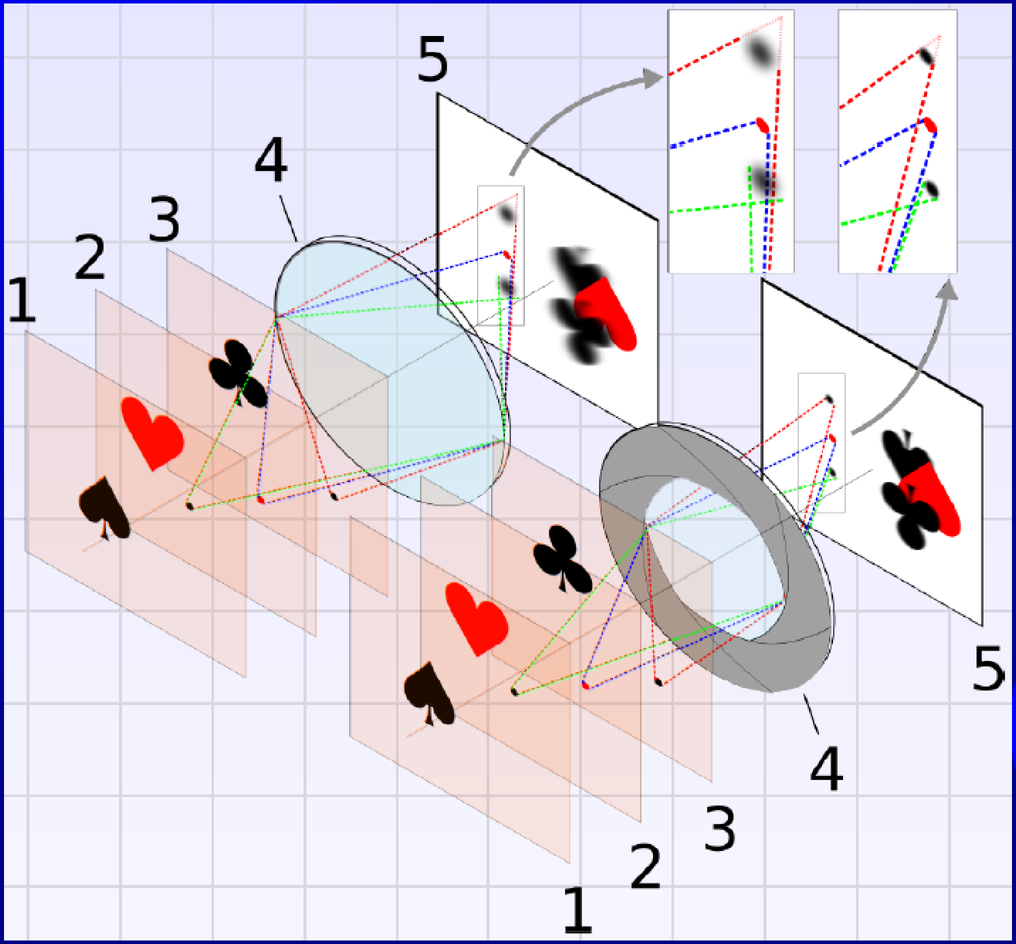




Lens and Image

Depth of Field (DoF, 景深)

Effect of aperture on blur and DOF.



Lens and Image

Depth of Field (DoF, 景深)

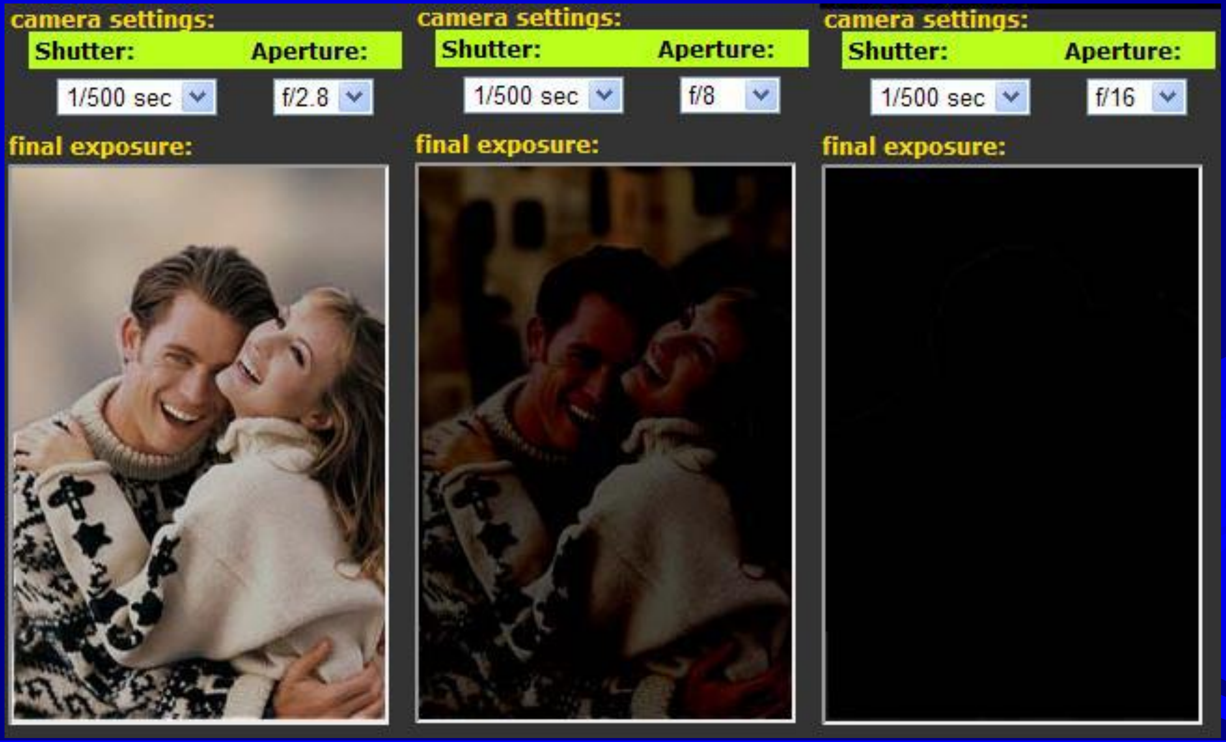
(a)At f/32, the background competes for the viewer's attention. (b)At f/5.6, the flowers are isolated from the background.

Lens and Image

Exposure (曝光)

Two main parameters:1)Aperture (in F-stop). 2)Shutter speed (in fraction of a second)

http://www.photonhead.com/simcam/shutteraperture.php



Lens and Image

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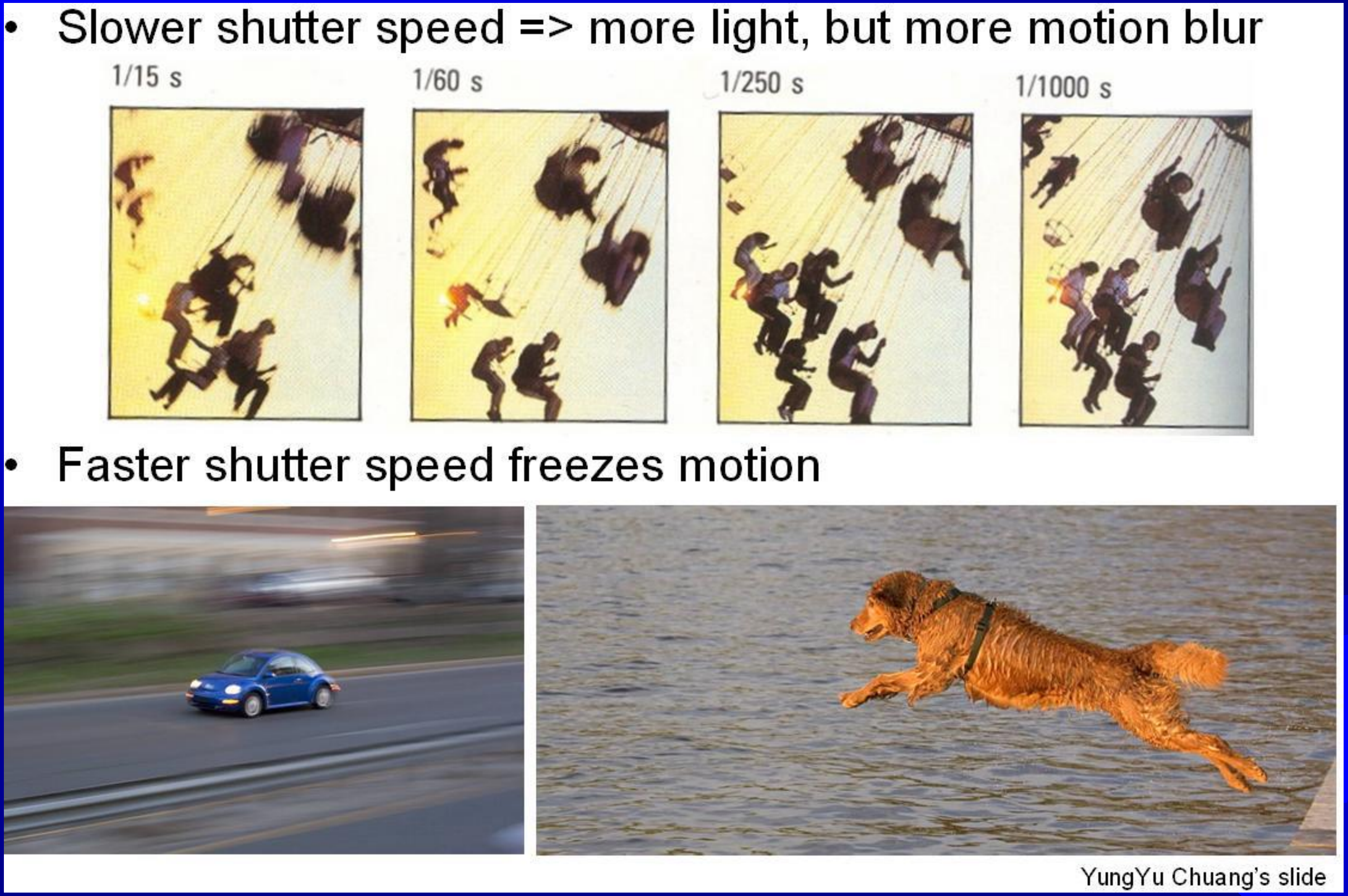
Lens and Image

Effects of shutter speeds



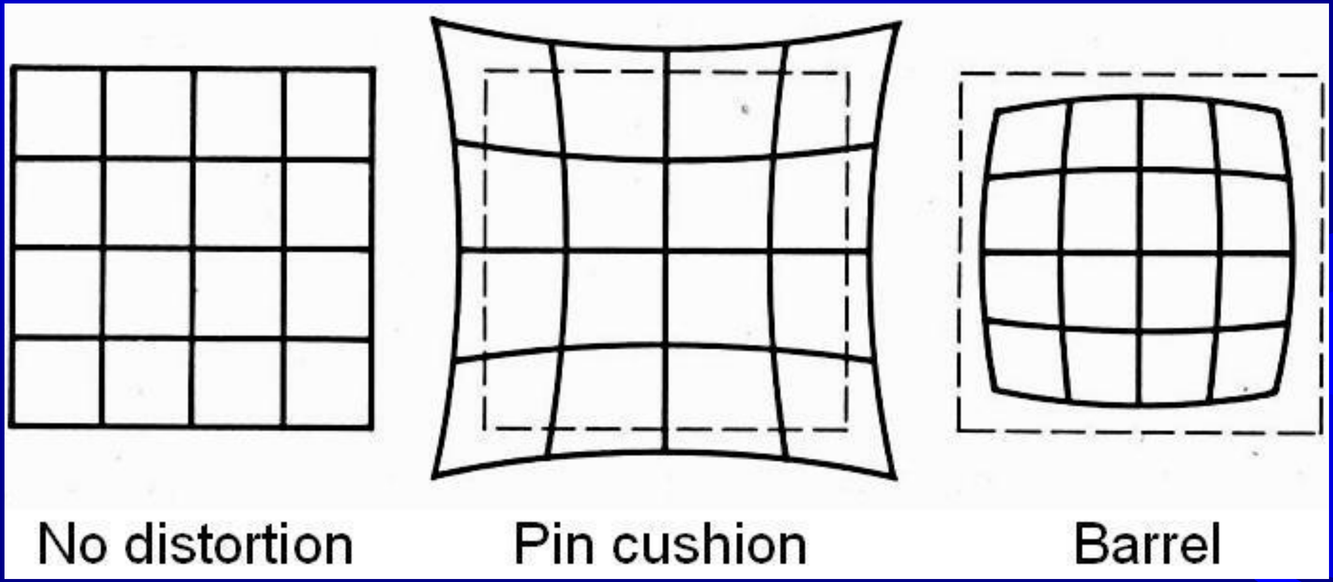
Lens and Image

Lens related issues: Distortion

Radial distortion of the image.

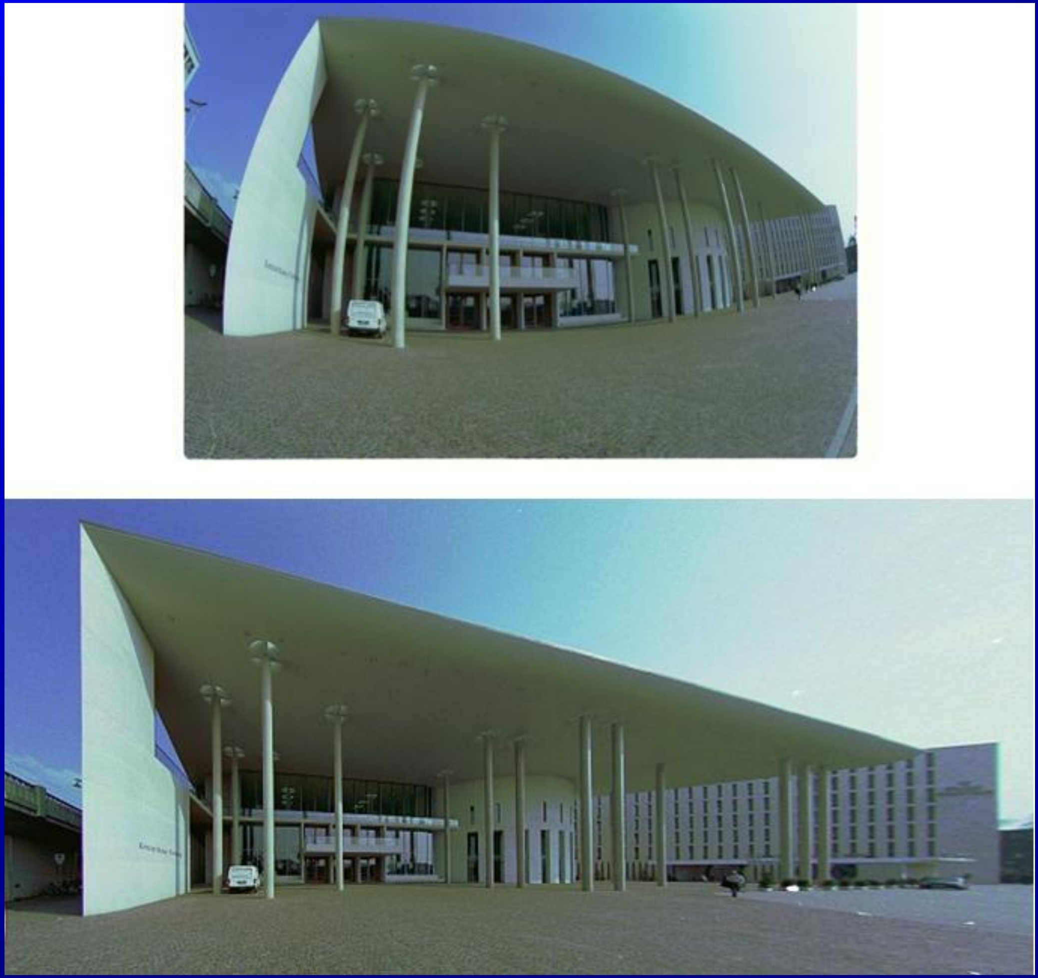
Caused by imperfect lenses.

Deviations are most noticeable for rays that pass through the edge of the lens.

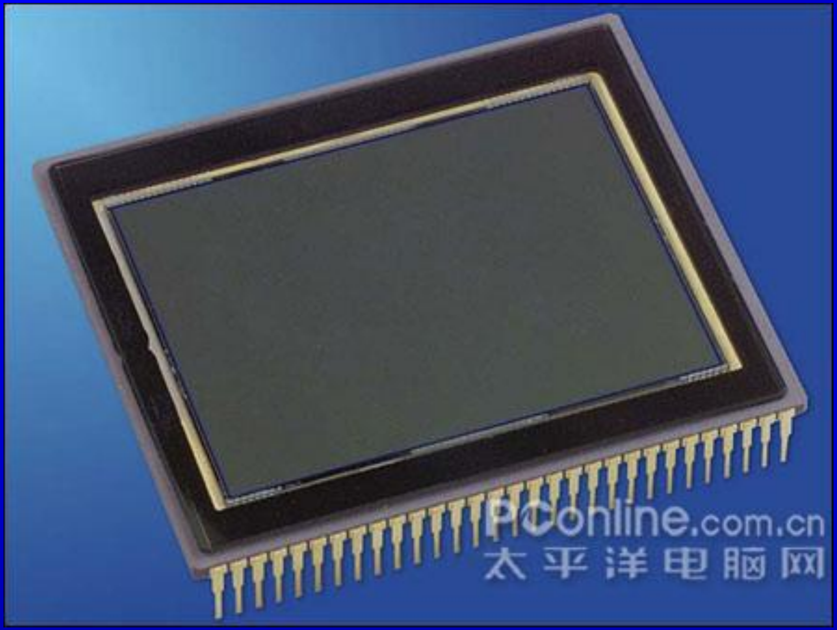


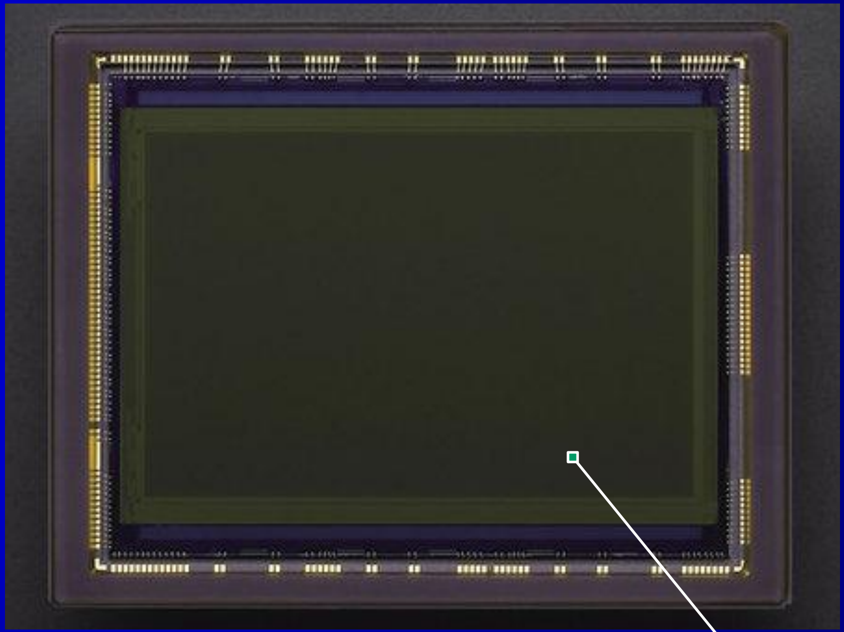
Lens and Image

Lens related issues: Distortion



Photon sensor





pixel

CCD: charge-coupled device, CMOS: complimentary metal oxide semiconductor

Photon sensor

	Power Cosumpation	Noise	Low light Sensitiviey	Cost	Uniformity	Speed	Dynamic Range	Windowing	Responsivity
CCD	High	Low	Better	High	High	Slow	High	Cannot	High
CMOS	Low	High	Worse	Low	Low	Fast	Low	Can	Low

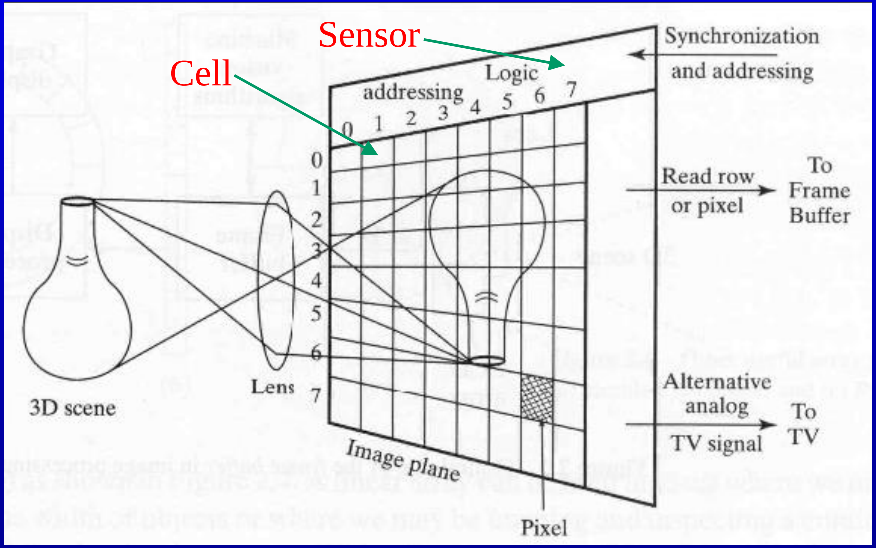
CCDs tend to be used in high-end cameras which focus on good light sensitivity and more megapixels.

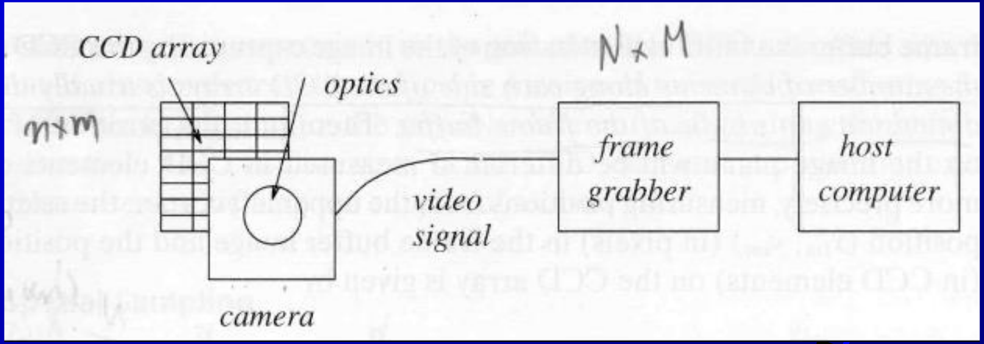
CMOS sensors are being used n low end compact camera which keeps an eye on battery life and low price tags.

CCD array and frame buffer

The physical image plane is the CCD array of *n* x *m* rectangular grid of photo-sensors.

The pixel image plane (frame buffer) is an array of *N* x *M* integer values (pixels).





CCD array and frame buffer (cont'd)

- The position of the same point on the image plane will be different if measured in CCD elements (x, y) or image pixels (x_{im}, y_{im}).

$$x_{im} = \frac{N}{n} x \qquad\qquad y_{im} = \frac{M}{m} y$$

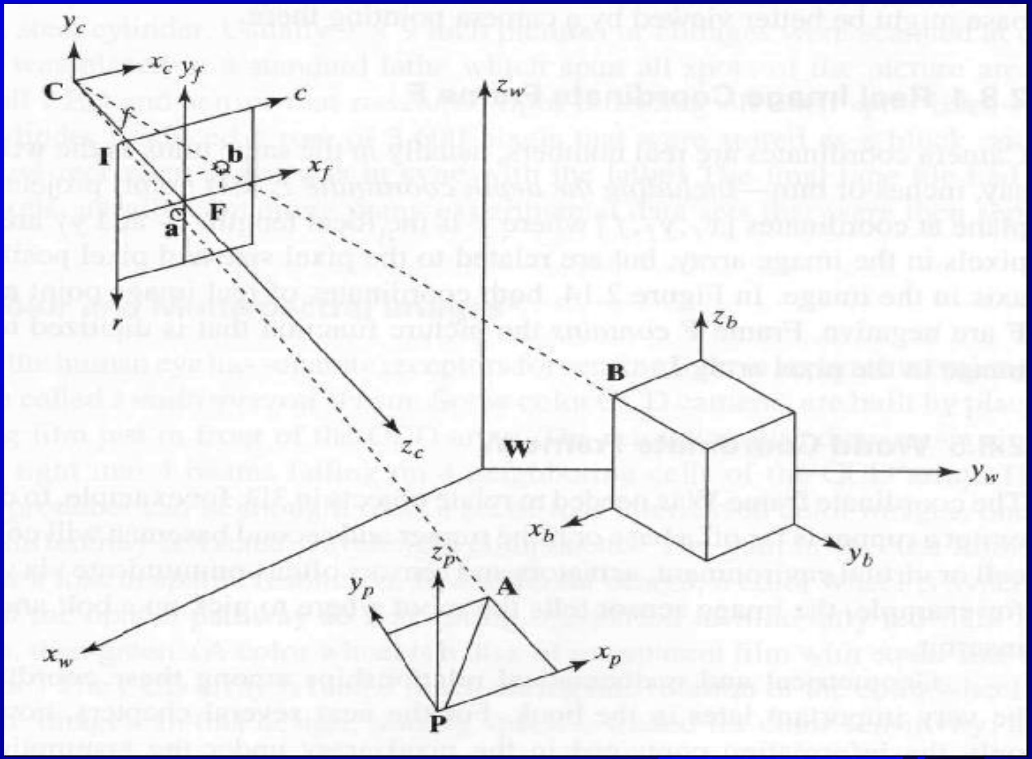
(assuming that the origin in both cases is the upper-left corner)

(x_{im}, y_{im}) measured in pixels
(x, y) measured in millimeters.

Reference Frames

Five reference frames are needed in general for 3D scene analysis.

- Object
- World
- Camera
- Image (physical)
- Pixel



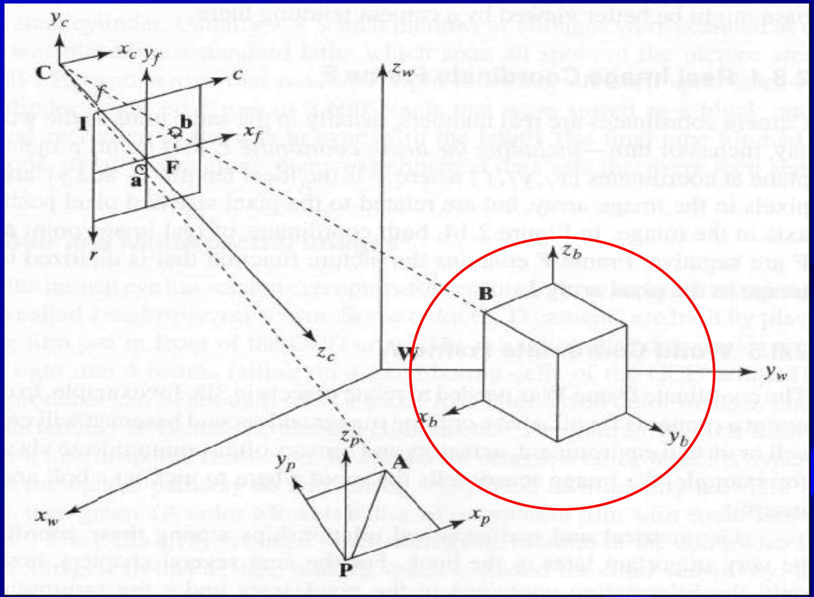
(1) Object Coordinate Frame

3D coordinate system: (x_b, y_b, z_b)

Useful for modeling objects (i.e., check if a particular hole is in proper position relative to other holes)

Object coordinates do not change regardless how the object is placed in the scene.

Our notation: $(X_o, Y_o, Z_o)^T$

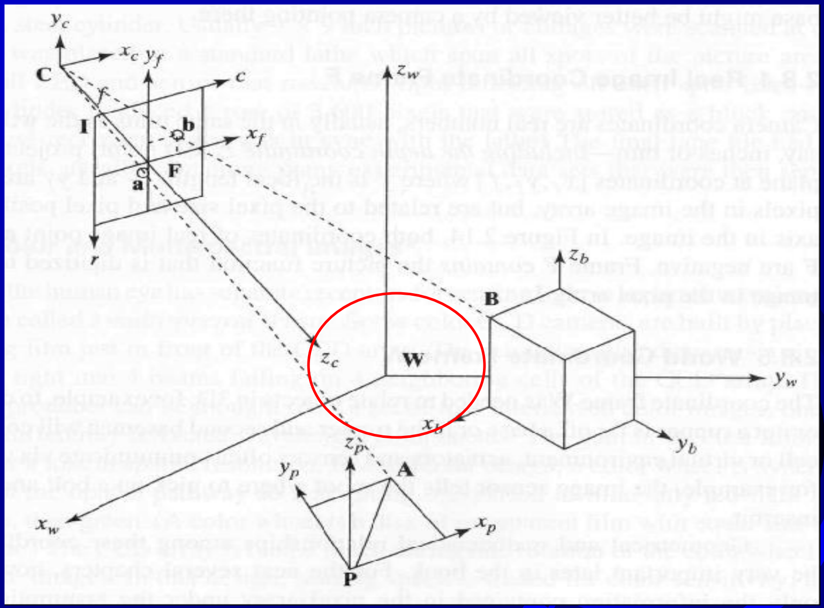


(2) World Coordinate Frame

3D coordinate system: (x_w, y_w, z_w)

Useful for interrelating objects in 3D

Our notation: $(X_w, Y_w, Z_w)^T$

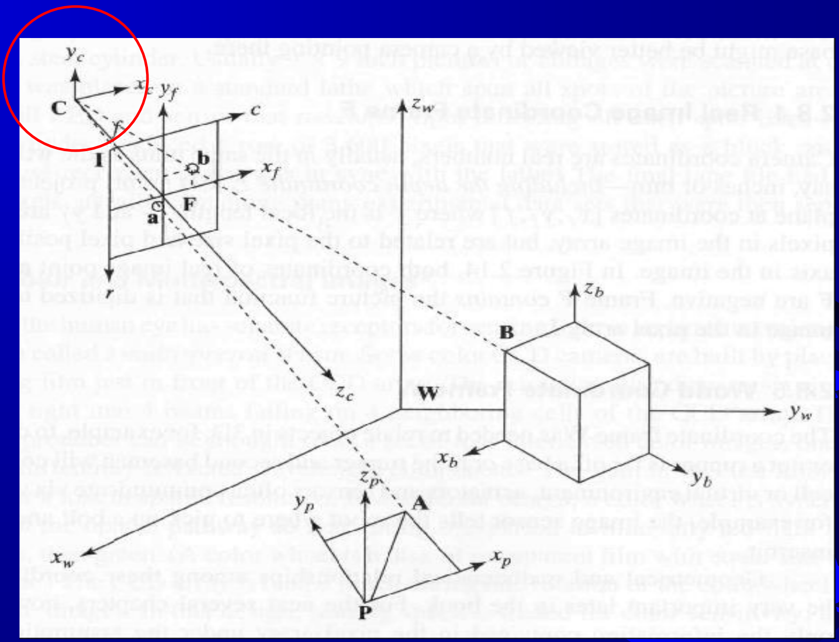


(3) Camera Coordinate Frame

3D coordinate system: (x_c, y_c, z_c)

Useful for representing objects with respect to the location of the camera.

Our notation: $(X_c, Y_c, Z_c)^T$

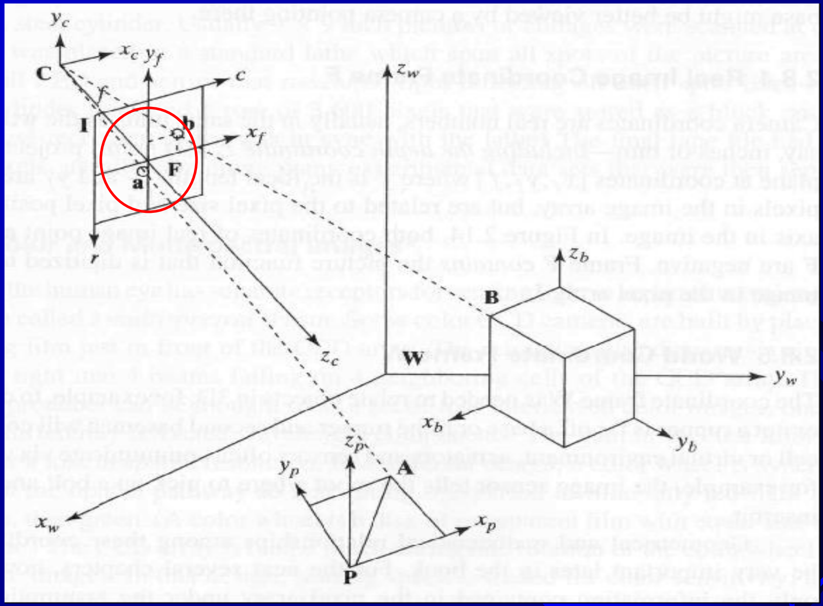


(4) Image Plane Coordinate Frame (i.e., CCD plane)

2D coordinate system: (x_f, y_f)

Describes the coordinates of 3D points projected on the image plane (on sensor: mm).

Our notation: $(x, y)^T$

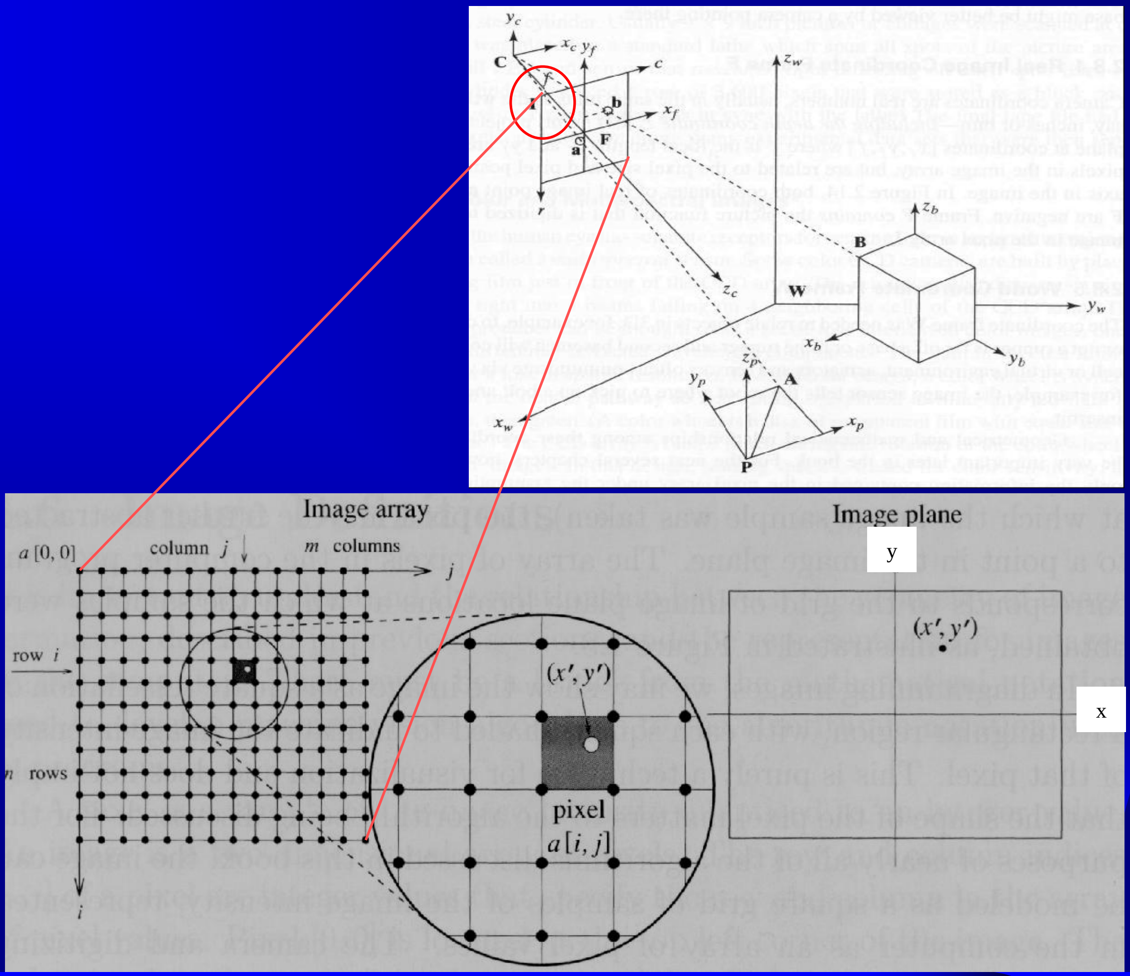


(5) Pixel Coordinate Frame

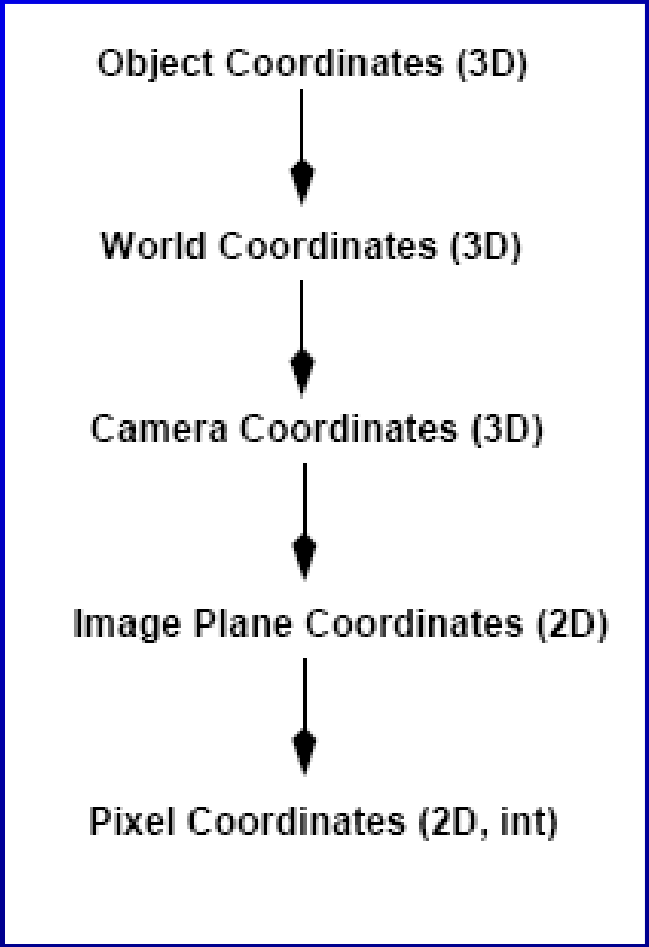
2D coordinate system: (c, r)

Each pixel in this frame has integer pixel coordinates.

Our notation: $(x_{im}, y_{im})^T$



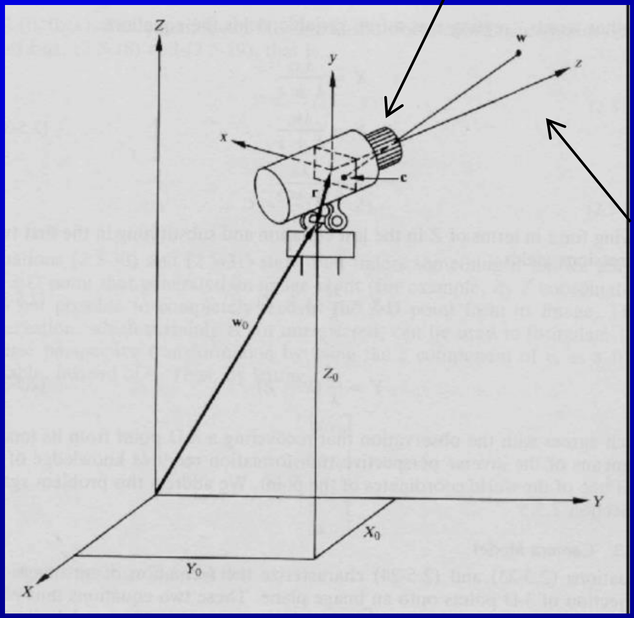
Transformations between frames



World and Camera coordinate systems

In general, the world and camera coordinate systems are not aligned.

center of projection



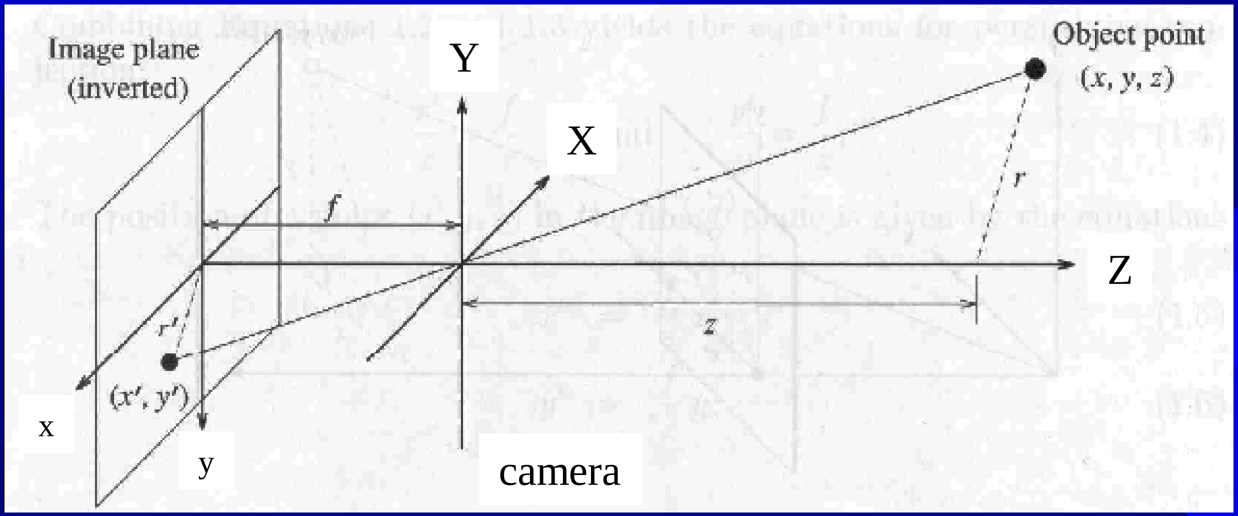
optical axis

World and Camera coordinate systems (cont'd)

To simplify mathematics, let's assume:

(1) The center of projection coincides with the origin of the world coordinate system.

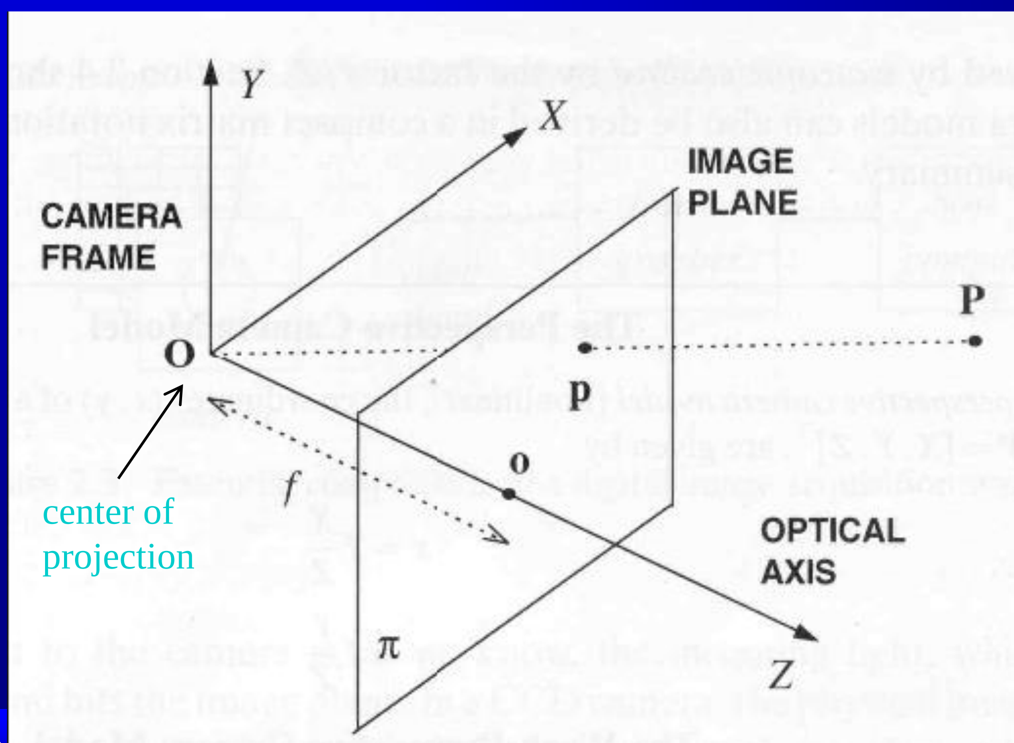
(2) The optical axis is aligned with the world's z-axis and x,y are parallel with X, Y



World and Camera coordinate systems (cont'd)

(3) Avoid image inversion by assuming that the image plane is in front of the center of projection.

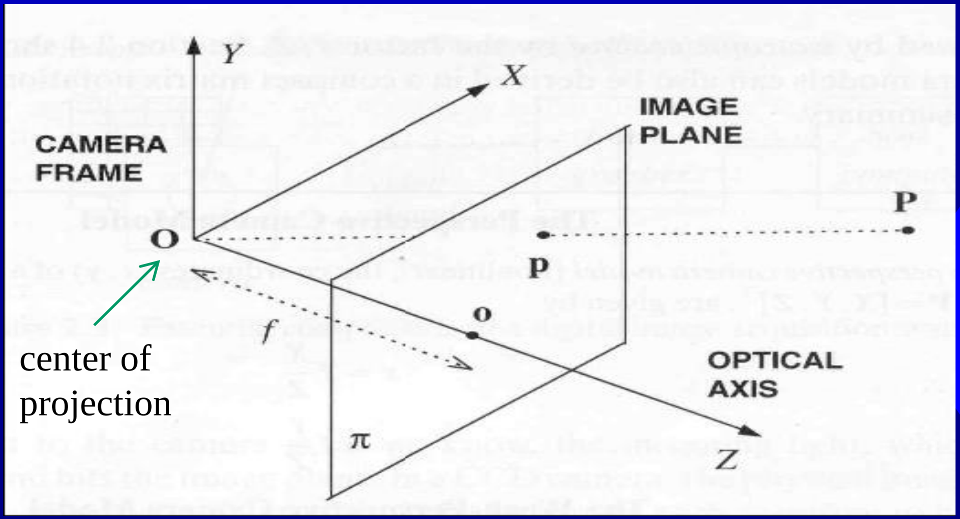
(4) The origin of the image plane is the principal point.



Terminology - Summary

The model consists of a plane (image plane) and a 3D point O (*center of projection*).

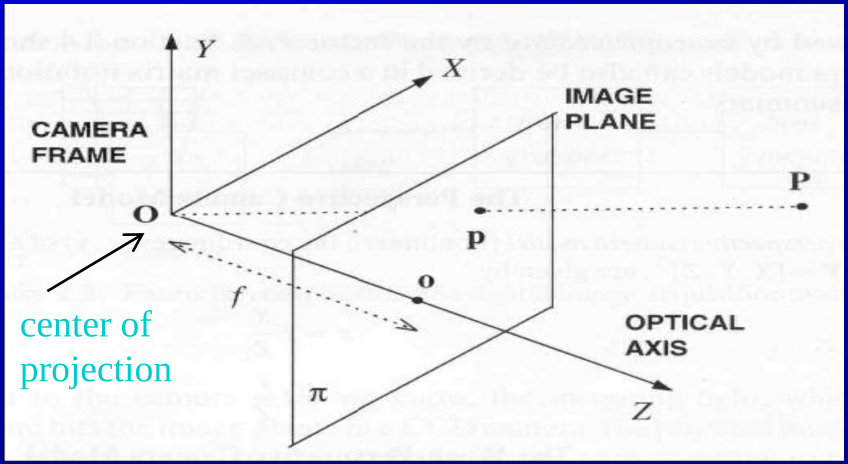
The distance f between the image plane and the center of projection O is the *focal length* (e.g., the distance between the lens and the CCD array).



Terminology - Summary (cont'd)

The line through *O* and perpendicular to the image plane is the *optical axis*.

The intersection of the optical axis with the image plane is called *principal point*.



Note: the principal point is not necessarily the image center.

See You