Camera Models

Modeling a Camera

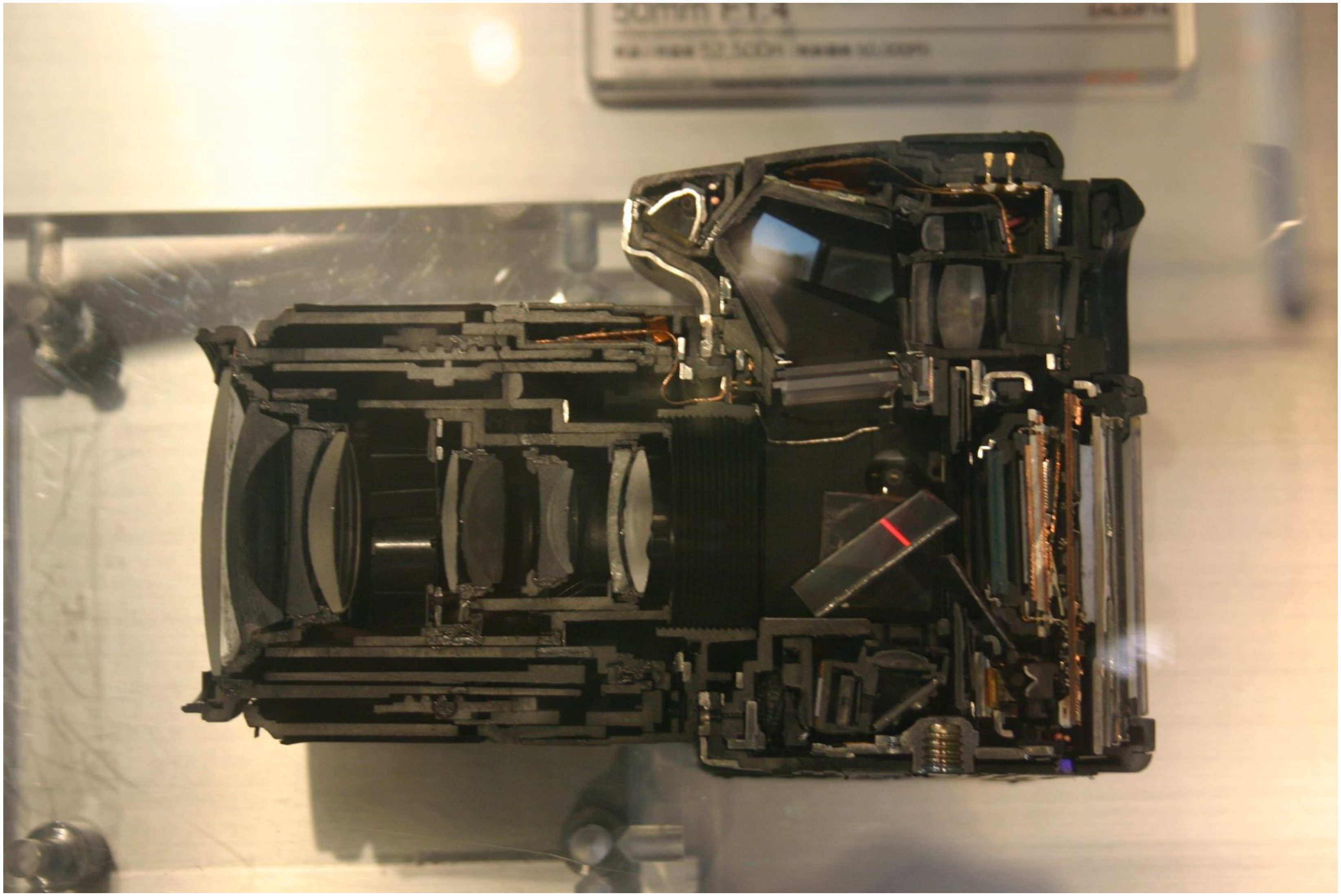
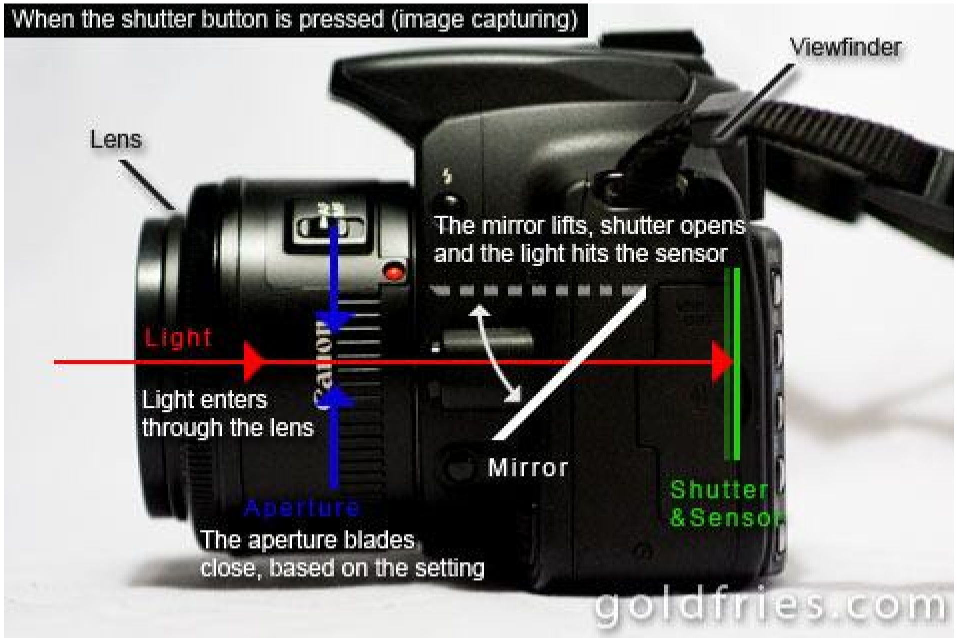
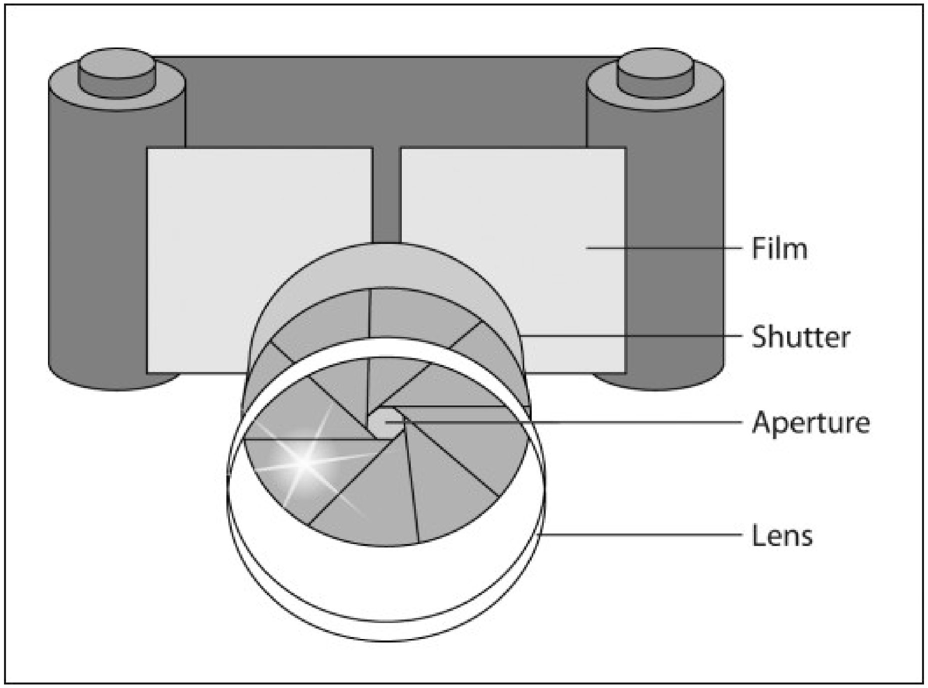


Image by Dr Yaser Sheikh, CMU

Modeling a Camera

- Shutter and Aperture



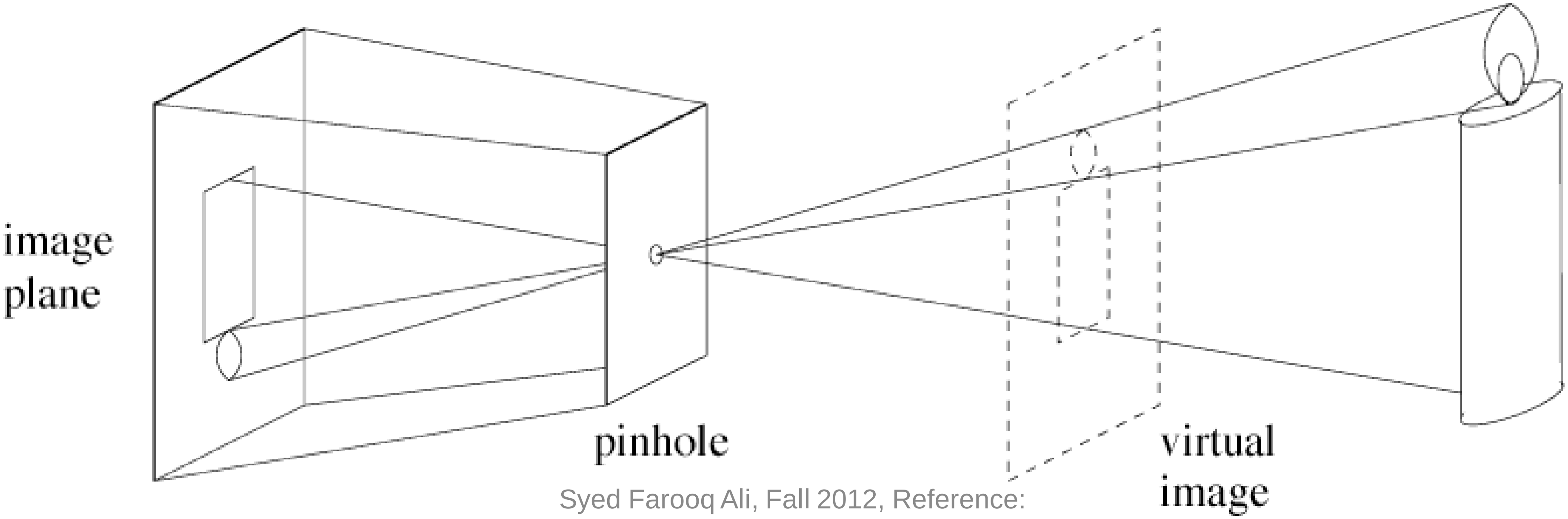


Aperture vs Shutter speed

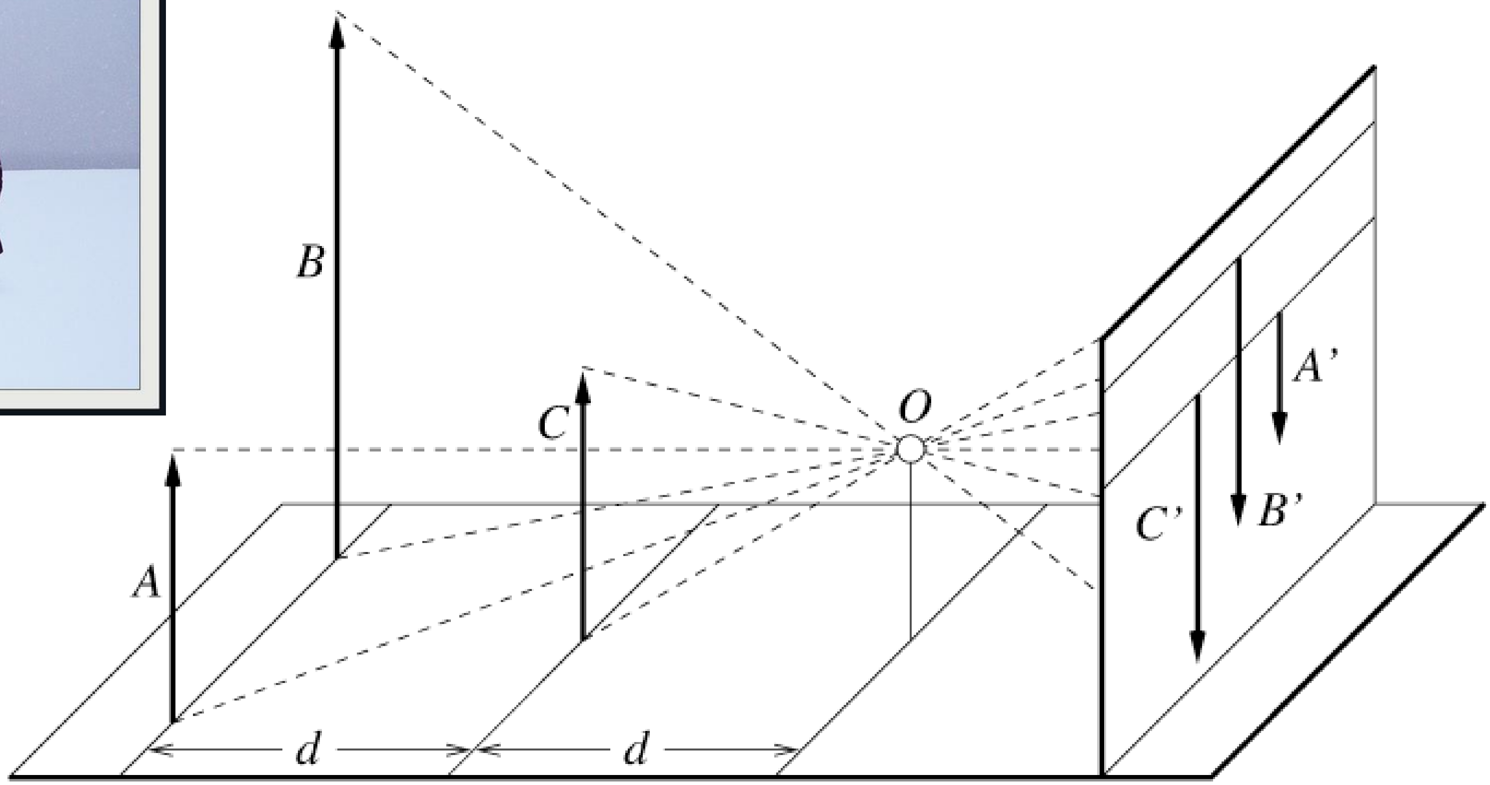
- If **shutter speed** is doubled, and **aperture area** is doubled, the same amount of light should enter the camera
- Therefore, to shoot an image, there are several valid combinations of aperture and shutter speed
- High shutter speed: for fast moving objects
- Large aperture: low depth of field

Pinhole Camera

- Lens is assumed to be single point
- Infinitesimally small aperture
- Has infinite depth of field i.e. everything is in focus



Pinhole Camera Properties: Distant objects are smaller

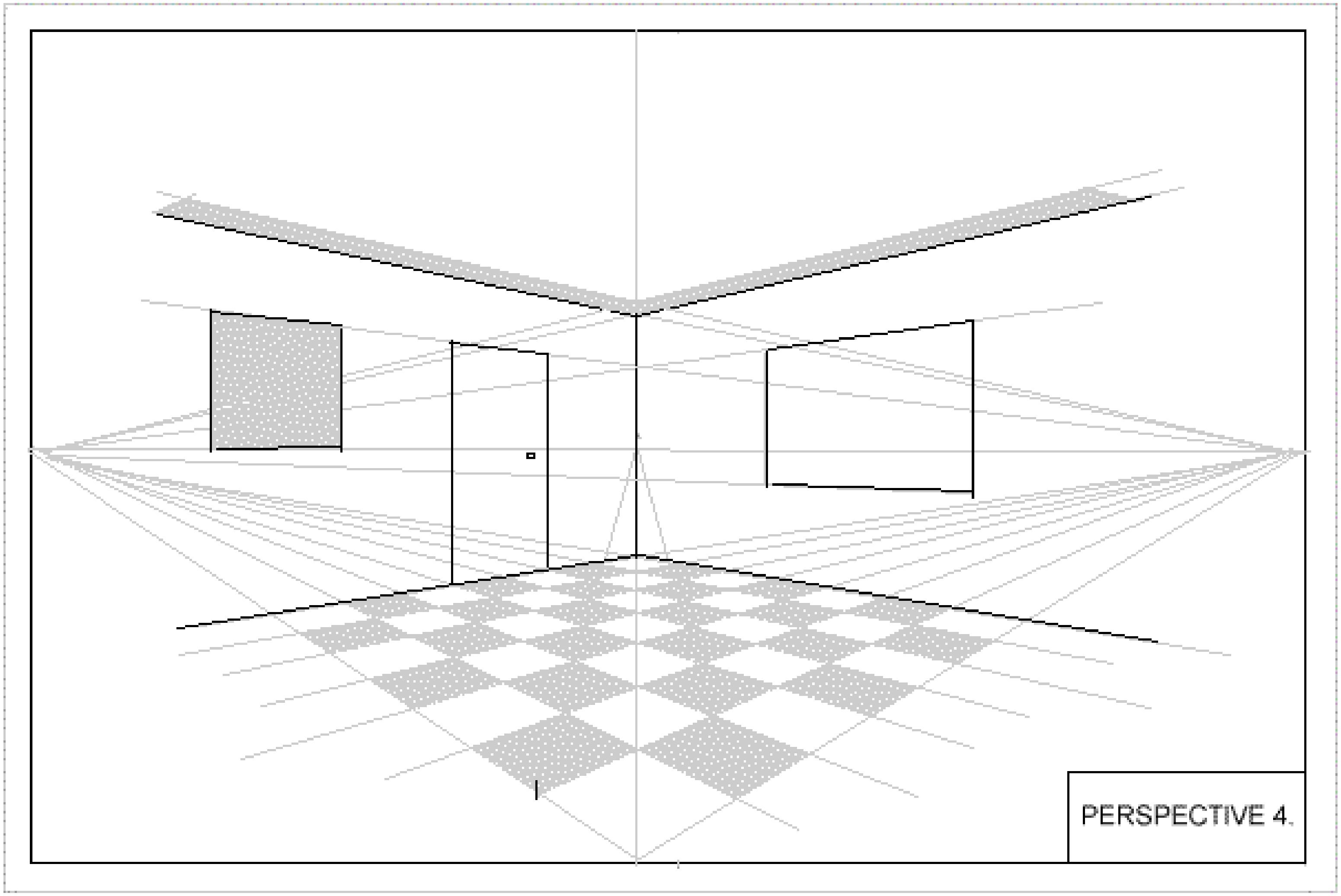


Slide Credit: Forsyth/Ponce http://www.cs.berkeley.edu/~daf/bookpages/slides.html
and Khurram Shafique, Object Video

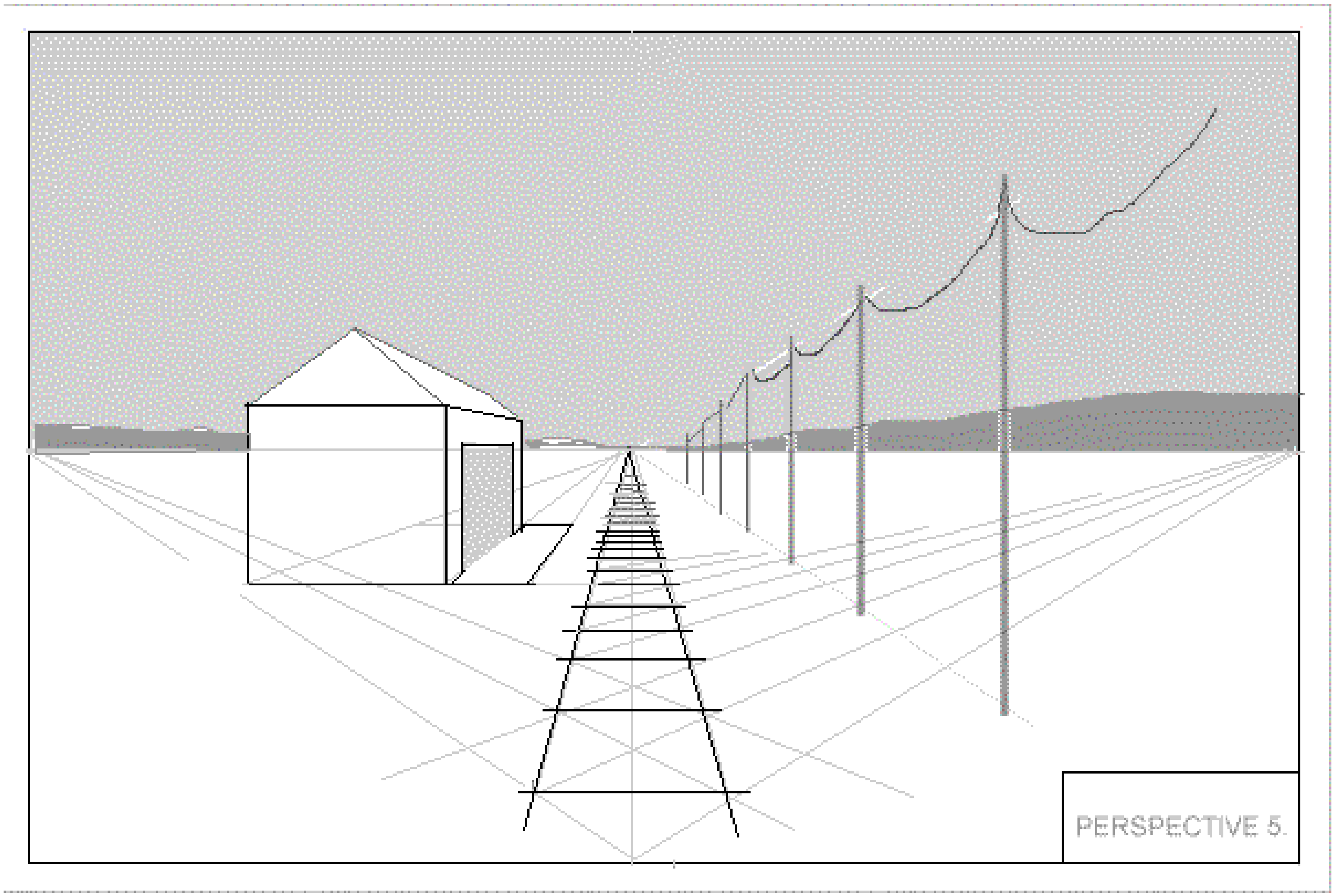
Perspective Projection

- The mapping from 3D to 2D coordinates described by a pinhole camera is a perspective projection followed by a 180^0 rotation in image plane.

Pinhole Camera Properties: Parallel Lines Converge



Pinhole Camera Properties: Parallel Lines Converge



Pinhole Camera

- Advantage
  - Because of small aperture, everything is in focus (infinite depth of field)
  - Simple construction
- Disadvantage
  - Small aperture requires high exposure time, often too long for practical purposes

Another Type of Camera: Orthographic Camera

- Parallel Lines remain parallel and do not converge

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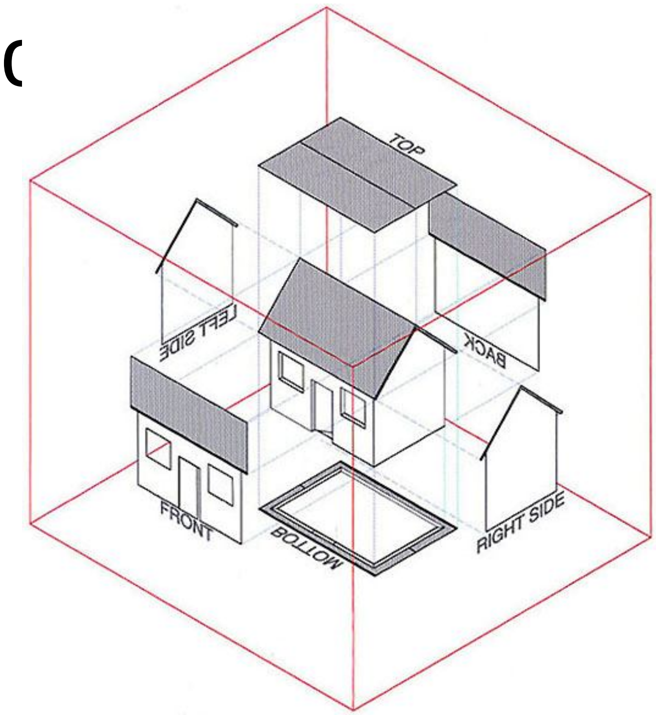


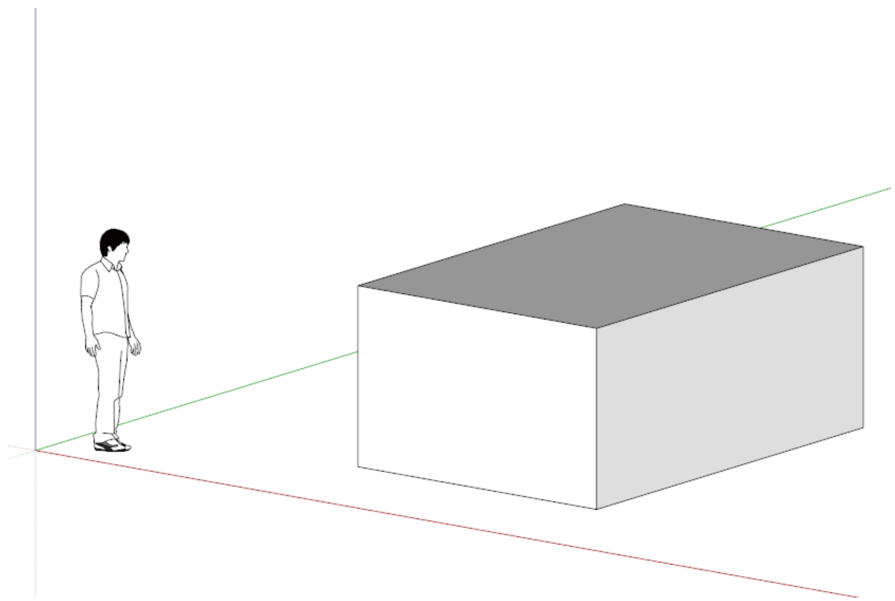
Type of Projection?

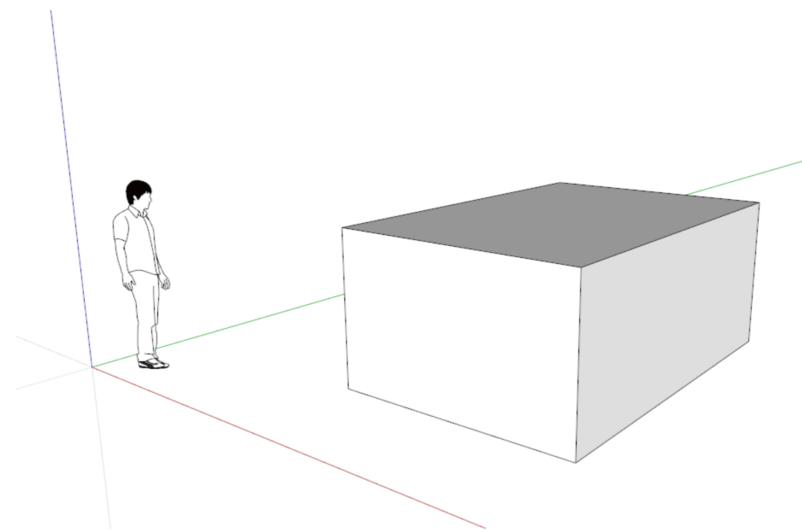
- Orthographic

Type of Projection?

- Perspective

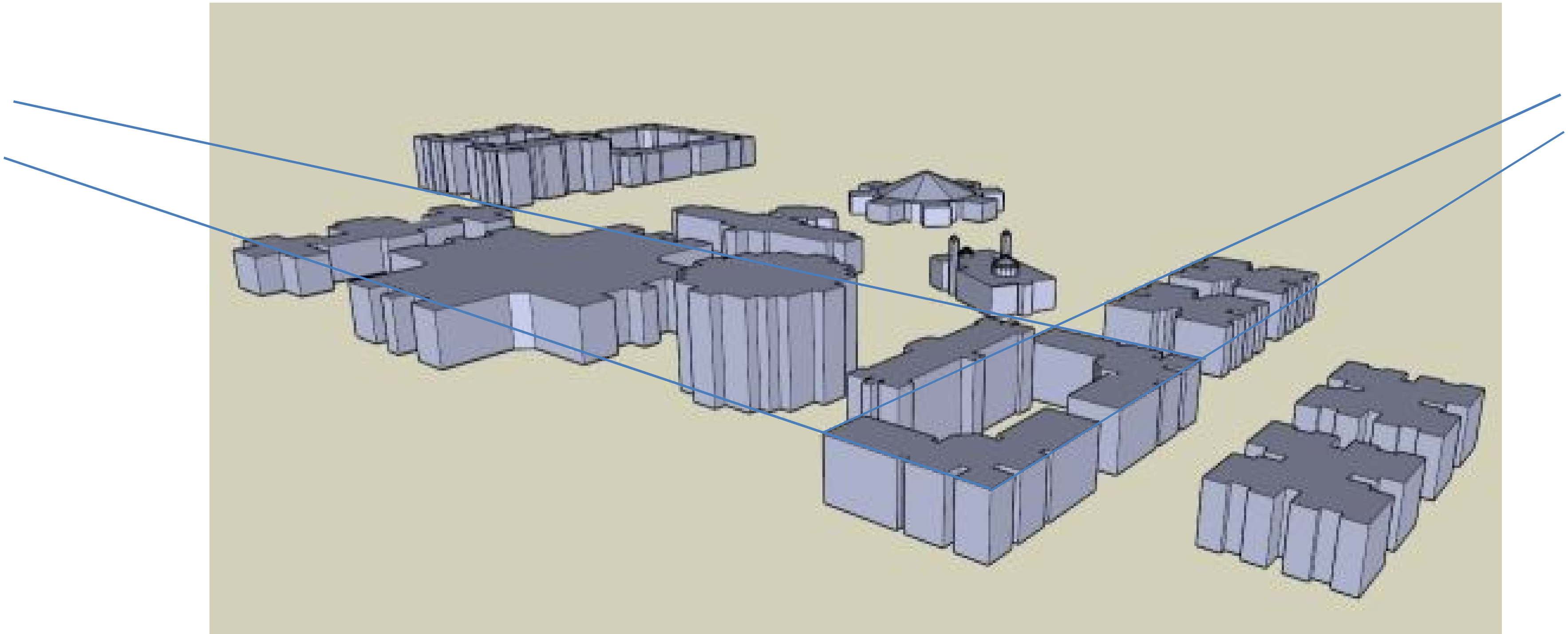
Type of Projection?





- Orthographic Perspective

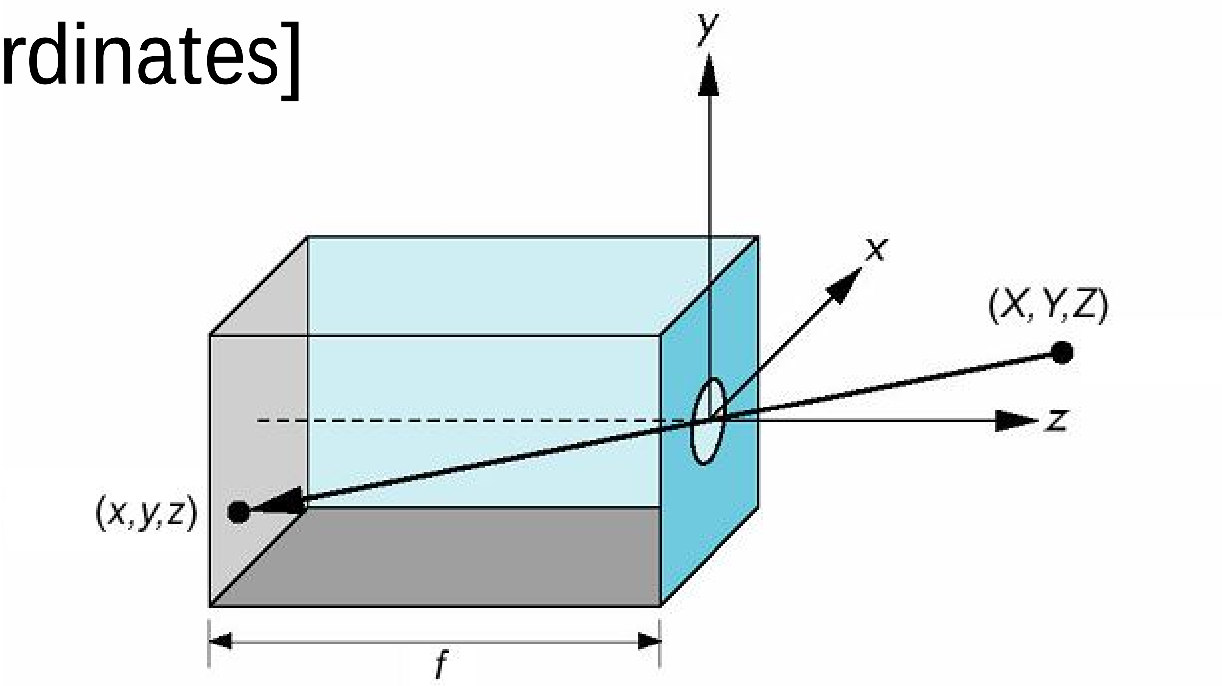
Type of Projection?



- Perspective Projection

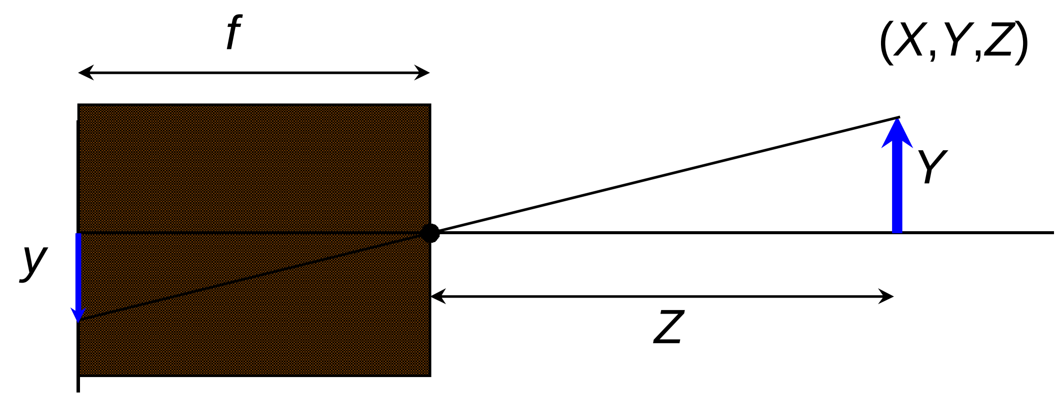
Image Formation: The Pin-Hole Camera

- Orient along z-axis
- World point (X,Y,Z) [in world coordinates]
- Image point at (x,y,z) [in real world coordinates]



Perspective Transform

Equation relating world coordinate and image coordinate?



$$\frac{-y}{Y} = \frac{f}{Z}$$

$$y = -\frac{fY}{Z} \qquad x = -\frac{fX}{Z}$$

It is customary to use a negative sign to indicate that the image is always formed upside down

Perspective Transform

- This relates the camera frame to the real image frame
- Example:
  - I take the image of a person (2m tall) standing 4m away from the camera, with a 35 mm camera using the geometry shown previously. How high will be the image?
  - Answer: $y = -(35)(2000)/4000 = -17.5$mm
  - i.e, the image will be formed inverted of length 17.5 mm
- How to convert to pixel frame (i.e. what will be the coordinates of the head of the person in the image?

Perspective Transform

- Suppose I know that the size of the film is 8cm x 6cm, and that the resolution of the camera is 640 x 480 pixels
- Implies, the center of the image is at 4cm x 3cm from the corner, and is at location (240, 320)
- Image will first be made right side up
- 17.5mm out of 60mm is 140 out of 480 pixels
- Hence the coordinates of the head will be (240-140 in x, same in y) = (100, 320)

Perspective Transform

- We can write this as a matrix using the homogeneous coordinates

$$\begin{bmatrix} hx \\ hy \\ h \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -\frac{1}{f} & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

$$\begin{aligned} hx &= X \\ hy &= Y \\ h &= -\frac{Z}{f} \end{aligned}$$

$$\begin{aligned} x &= -\frac{fX}{Z} \\ y &= -\frac{fY}{Z} \end{aligned}$$

Perspective Transform

- Any scaling of a homogeneous transform is equivalent

$$\begin{bmatrix} hx \\ hy \\ h \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -\frac{1}{f} & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

is equivalent to...

$$\begin{bmatrix} hx \\ hy \\ h \end{bmatrix} = \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

Orthographic Projection

- It can be written as follows:

$$x = X \quad y = Y$$

- Parallel lines remain parallel
- Useful for engineering drawings, scrolls, where the perspective shortening is not desired
- Computationally simpler

Summary

- Camera
- Shutter Speed, Aperture
- Pinhole Camera
- Perspective projection
- Orthographic Projection