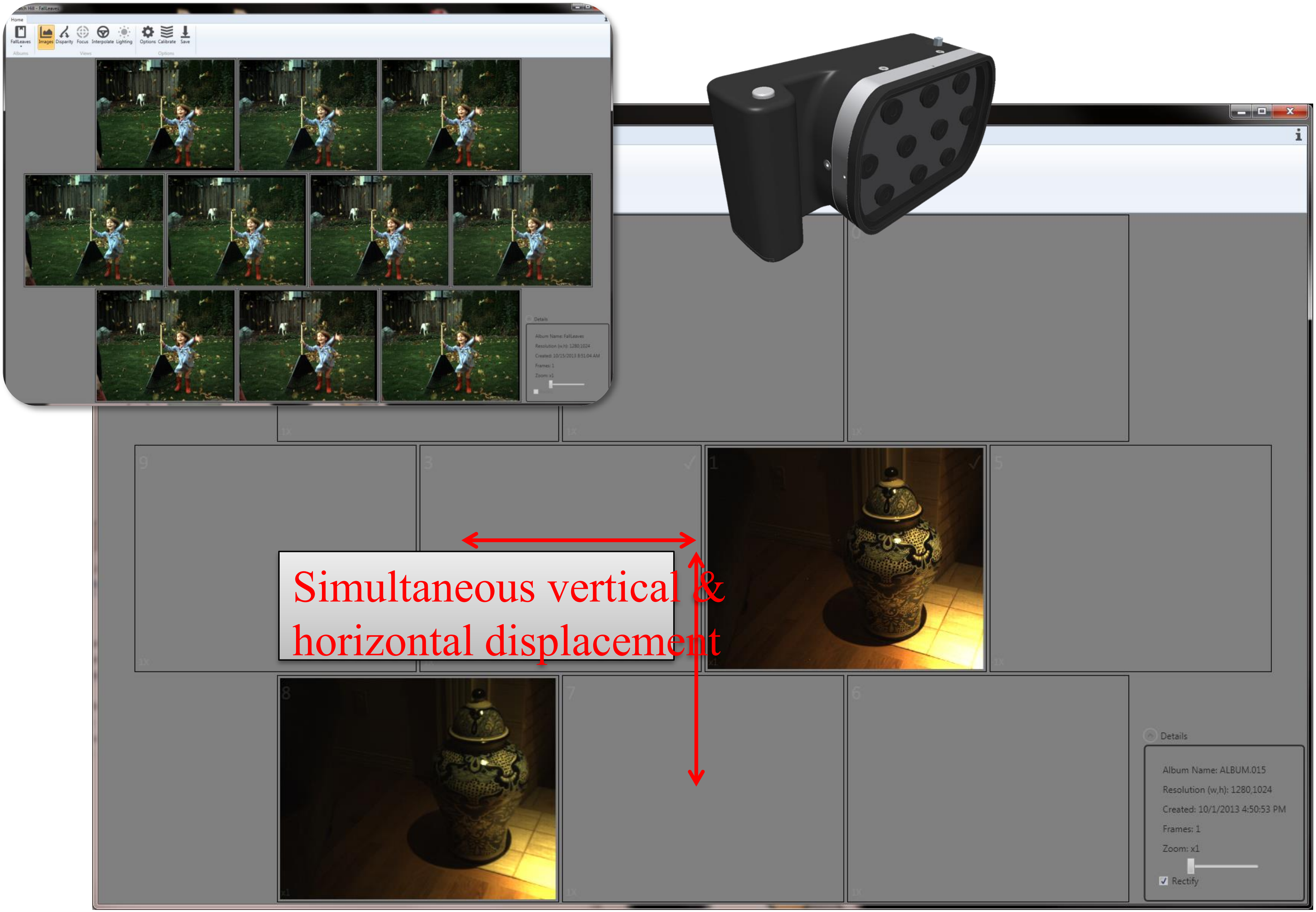
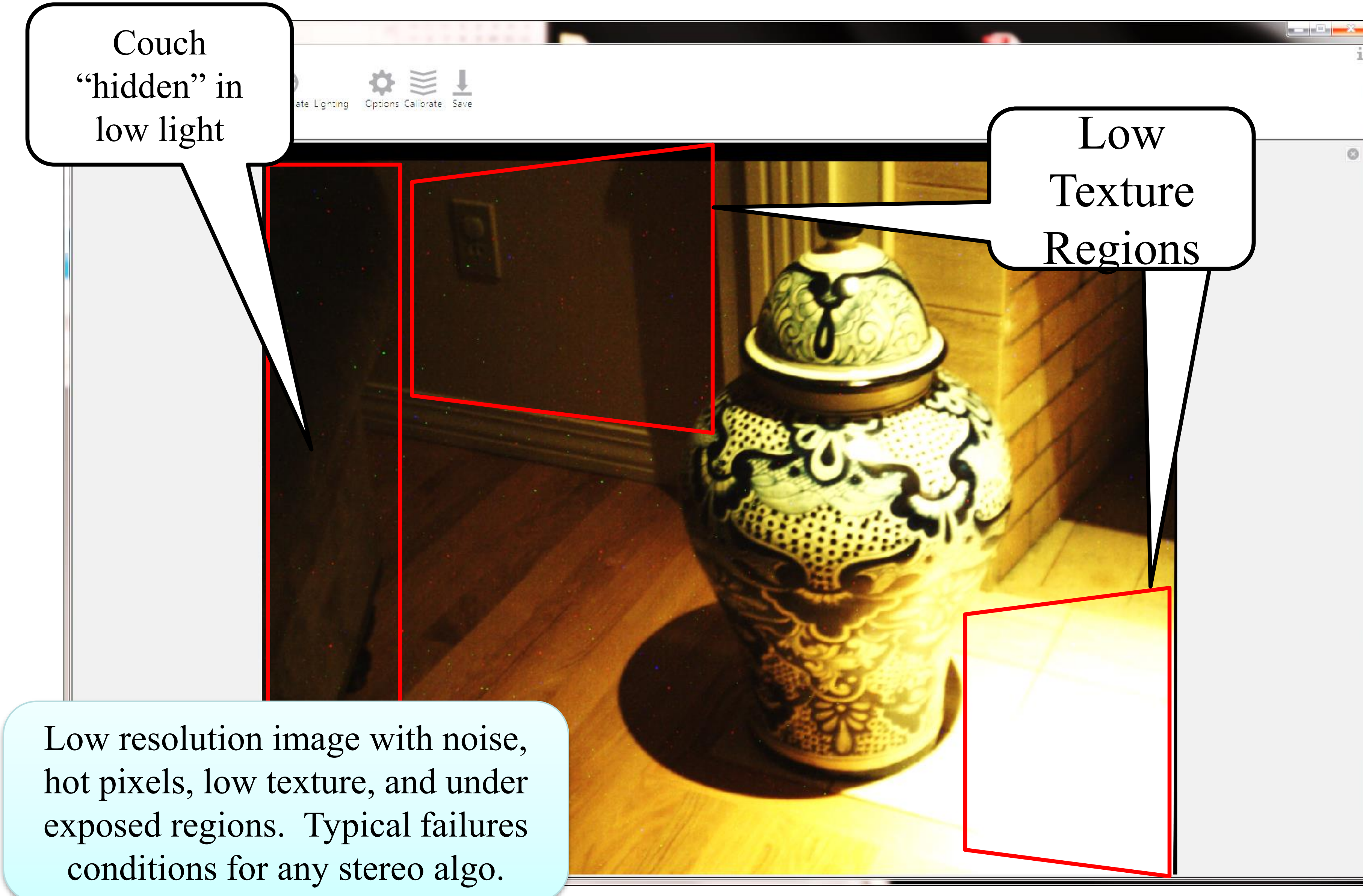
Camera Design

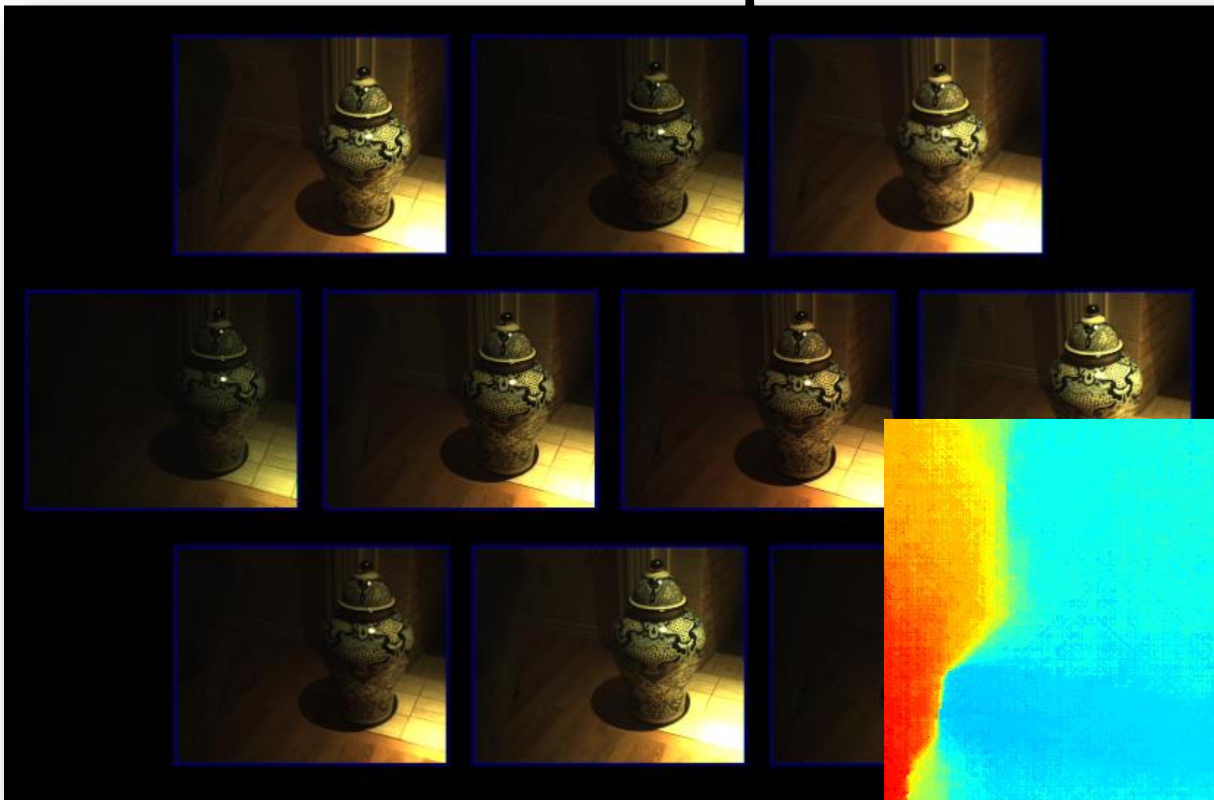
What is a camera?
Photon collecting machine


Simultaneous vertical & horizontal displacement
Details
Album Name: ALBUM.015
Resolution (w,h): 1280,1024
Created: 10/1/2013 4:50:53 PM
Frames: 1
Zoom: x1
Rectify

Brightened view for reference

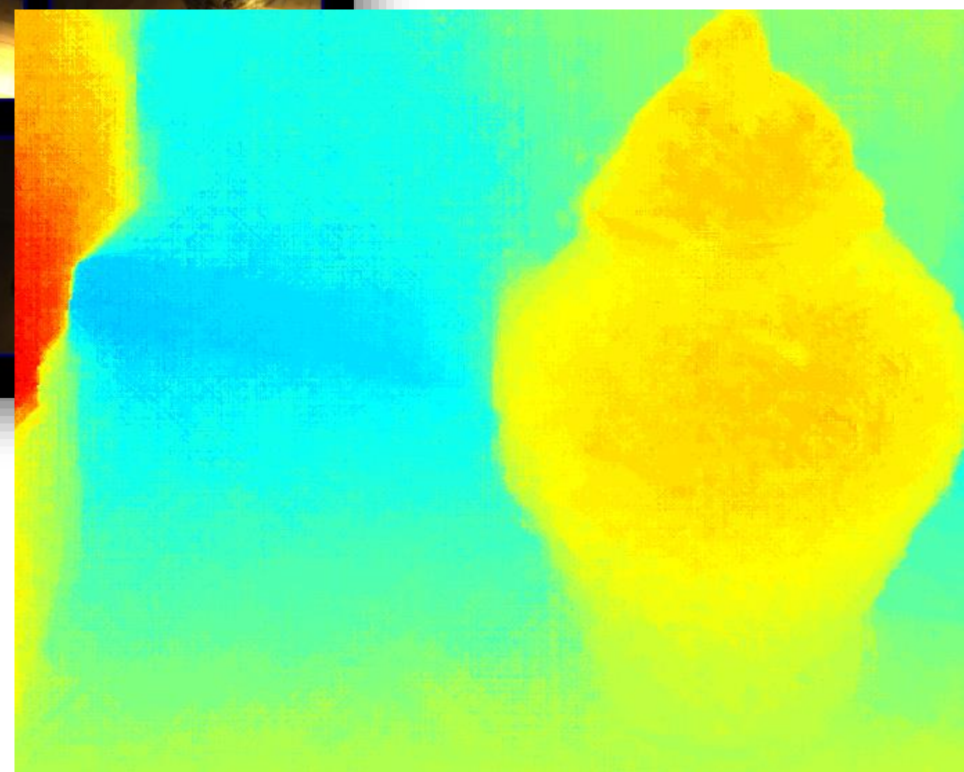


Depth & HDR



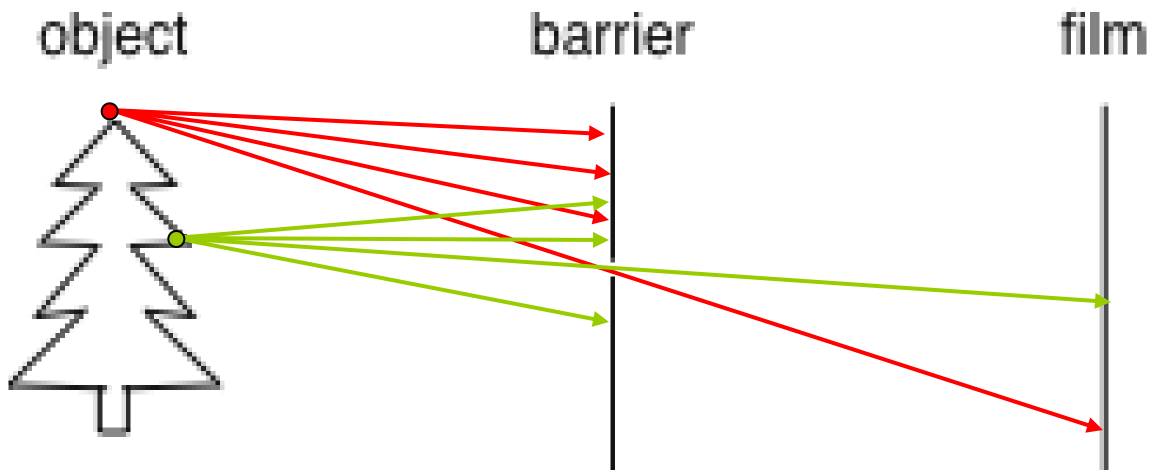
Simultaneously capture for Depth and HDR

Resilient to sensor variations.



Disparity algorithm applied to data that is both low-light and across 4 stop exposure differences.
Note the armchair at left is not visually apparent in the RGB image but is distinct in the disparity map.

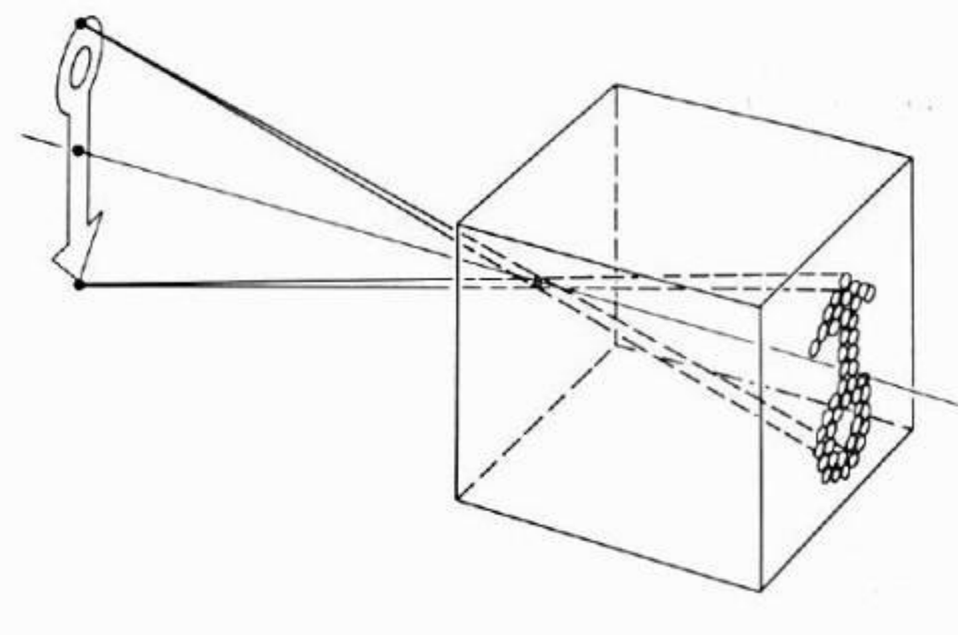
Pinhole camera



- Add a barrier to block off most of the rays
  - This reduces blurring
  - The opening known as the **aperture**
  - How does this transform the image?

Slide by Steve Seitz

Pinhole camera model



- Pinhole model:
  - Captures **pencil of rays** – all rays through a single point
  - The point is called **Center of Projection (COP)**
  - The image is formed on the **Image Plane**
  - **Effective focal length *f*** is distance from COP to Image Plane

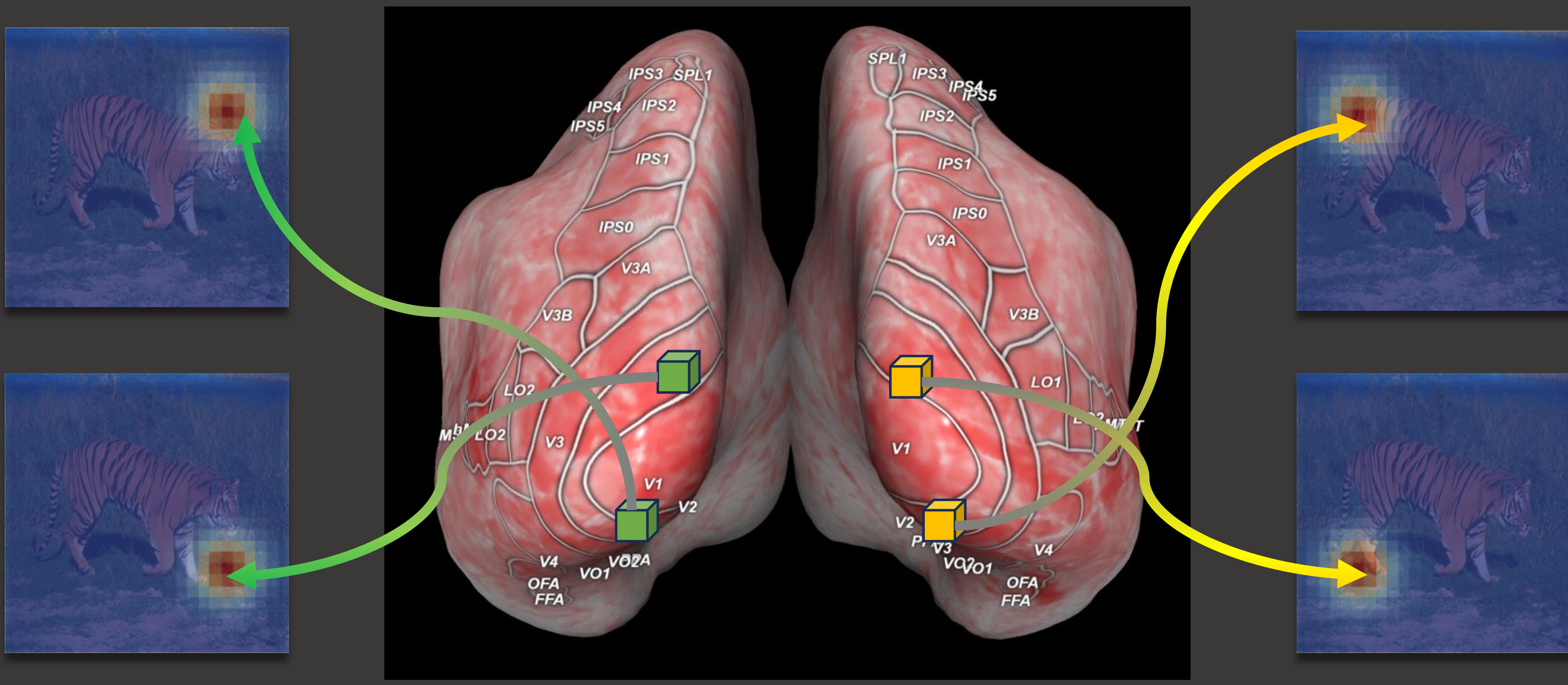
Slide by Steve Seitz

Home-made pinhole camera

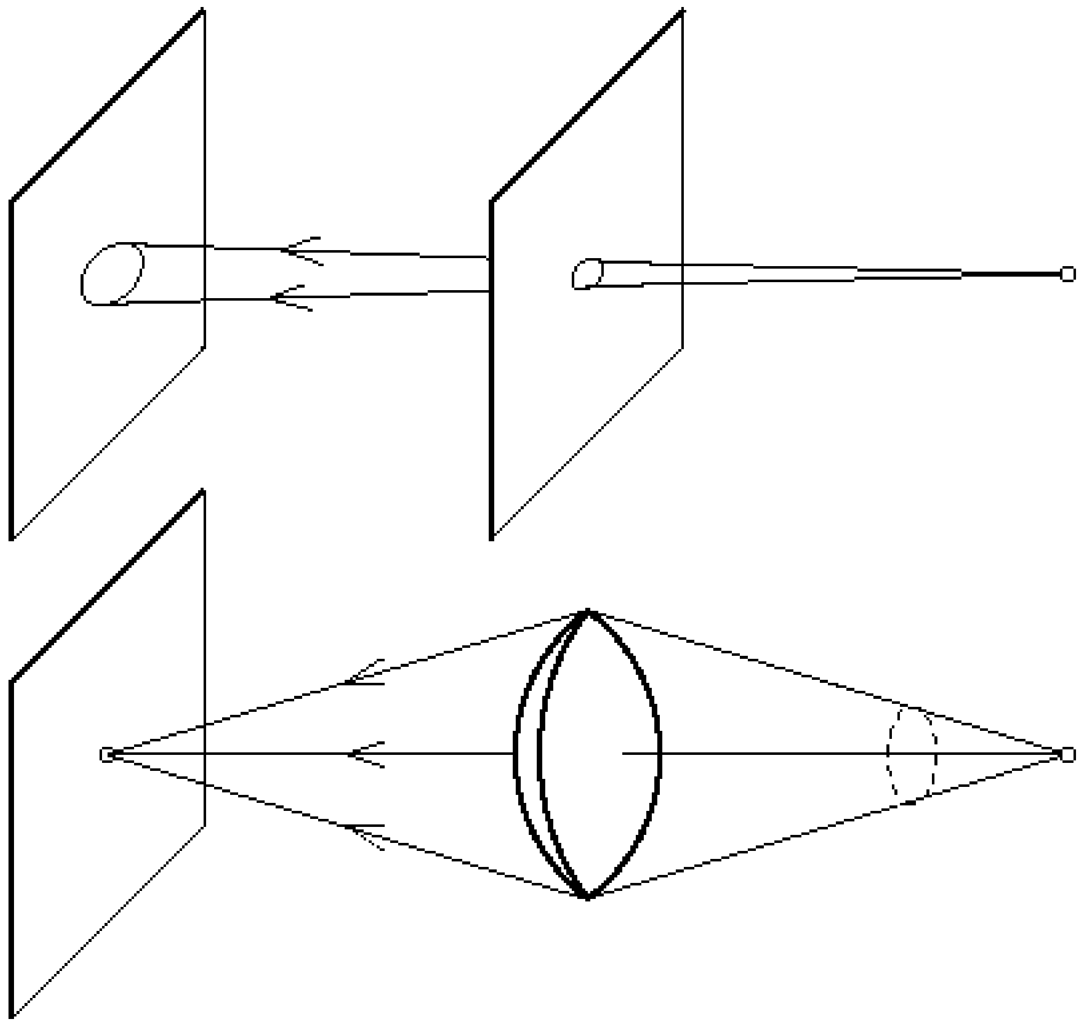
Why so blurry?

http://www.debevec.org/Pinhole/

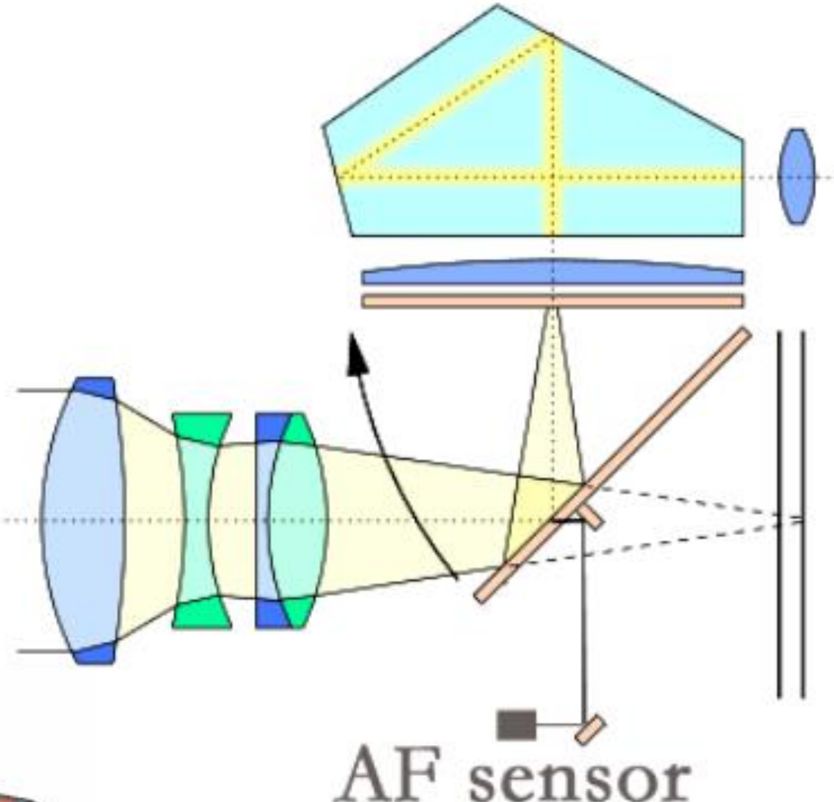
Brain is also a pinhole: receptive field mapping

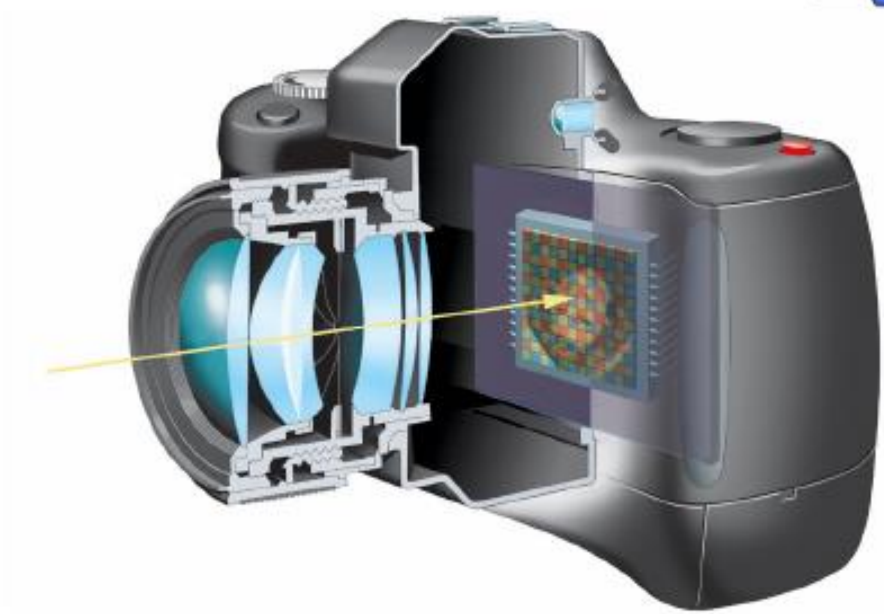


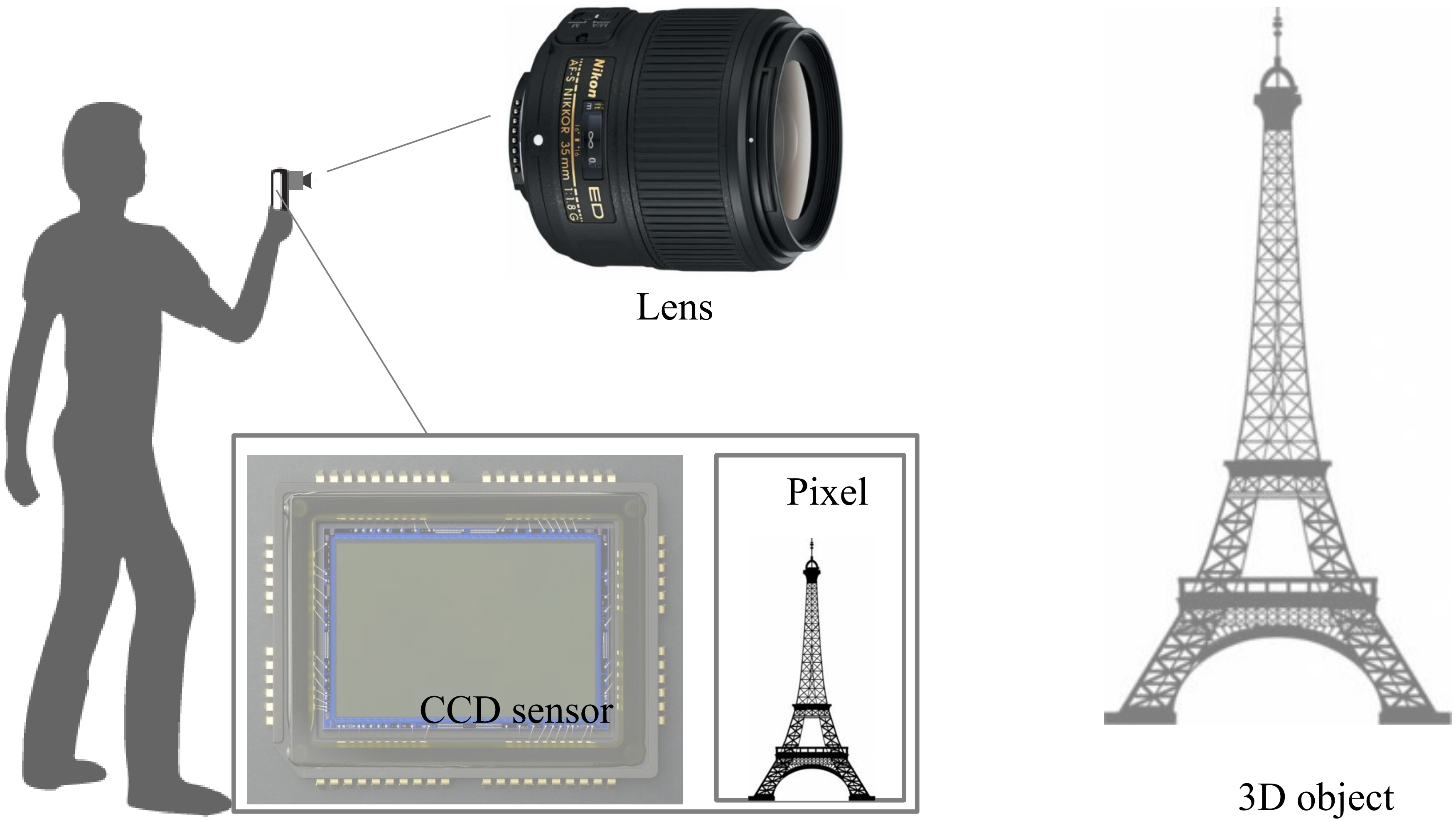
Camera with lense



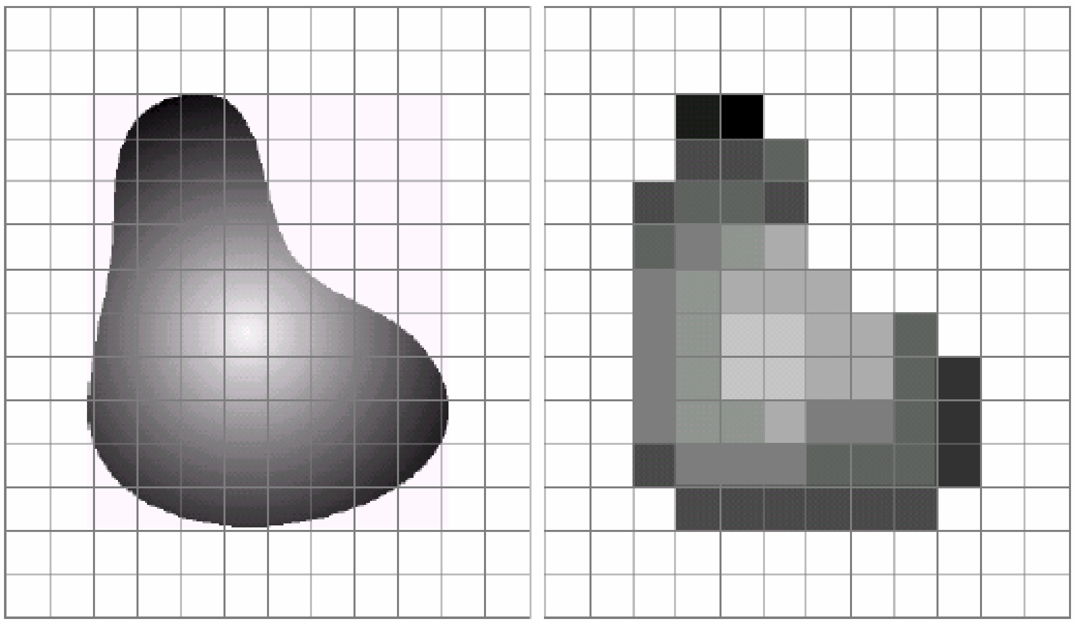
Single-lens reflex with auto-focus





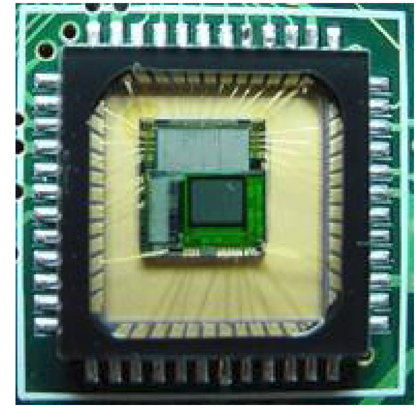

Lens
Pixel
CCD sensor
3D object

Sensor Array



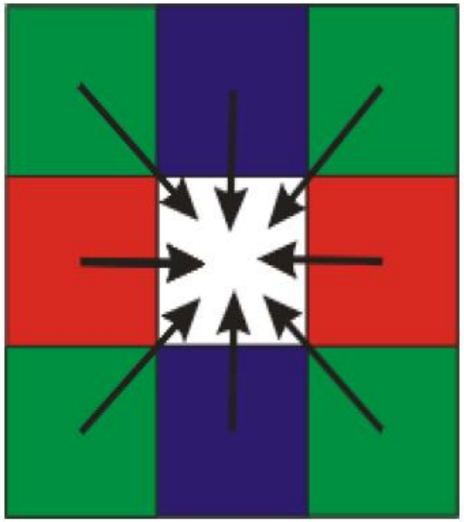
a b

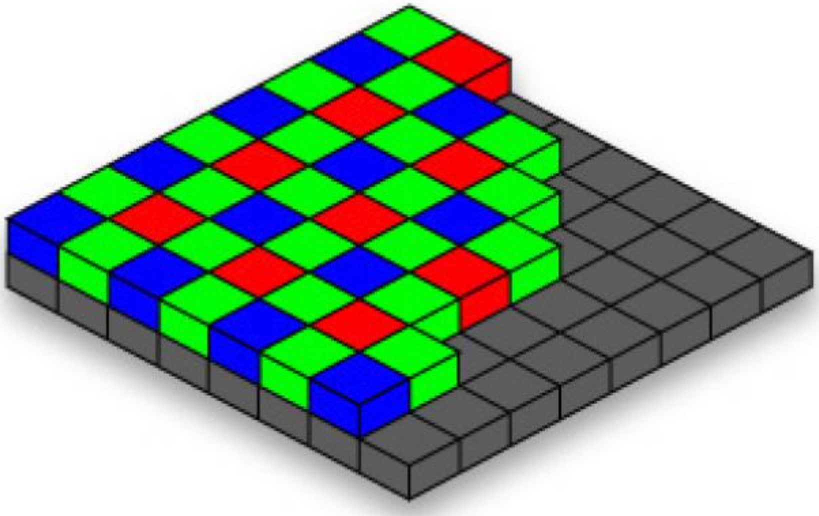
FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.



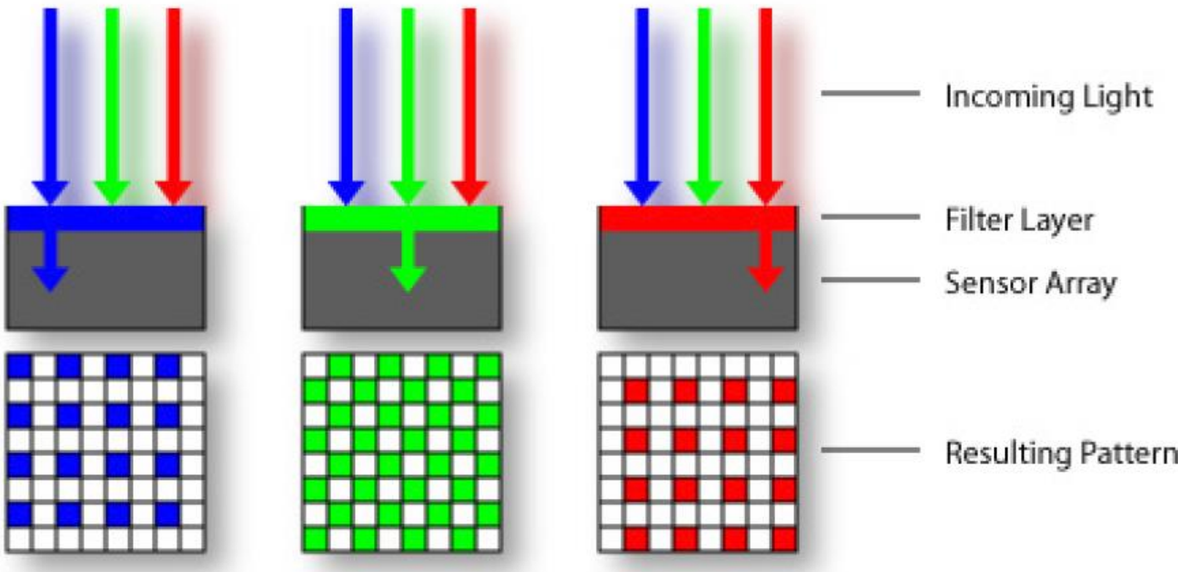
CMOS sensor

Practical Color Sensing: Bayer Grid





Estimate RGB
at 'G' cels from neighboring values



http://www.cooldictionary.com/words/Bayer-filter.wikipedia

In a computer…
an image is a 2 dimensional table of numbers, a 2D matrix

j

i

121	121	118	111	. . .	21
134	136	137	132	. . .	23
133	131	136	136	. . .	25
136	145	148	151	. . .	34
137	140	147	149	. . .	54
. . .	. . .	. . .	. . .	. . .	. . .
231	233	243	244	. . .	179

I[i,j] is the sensor value at location y = i, x = j

I[1,0] = 134
I[2,3] = 136

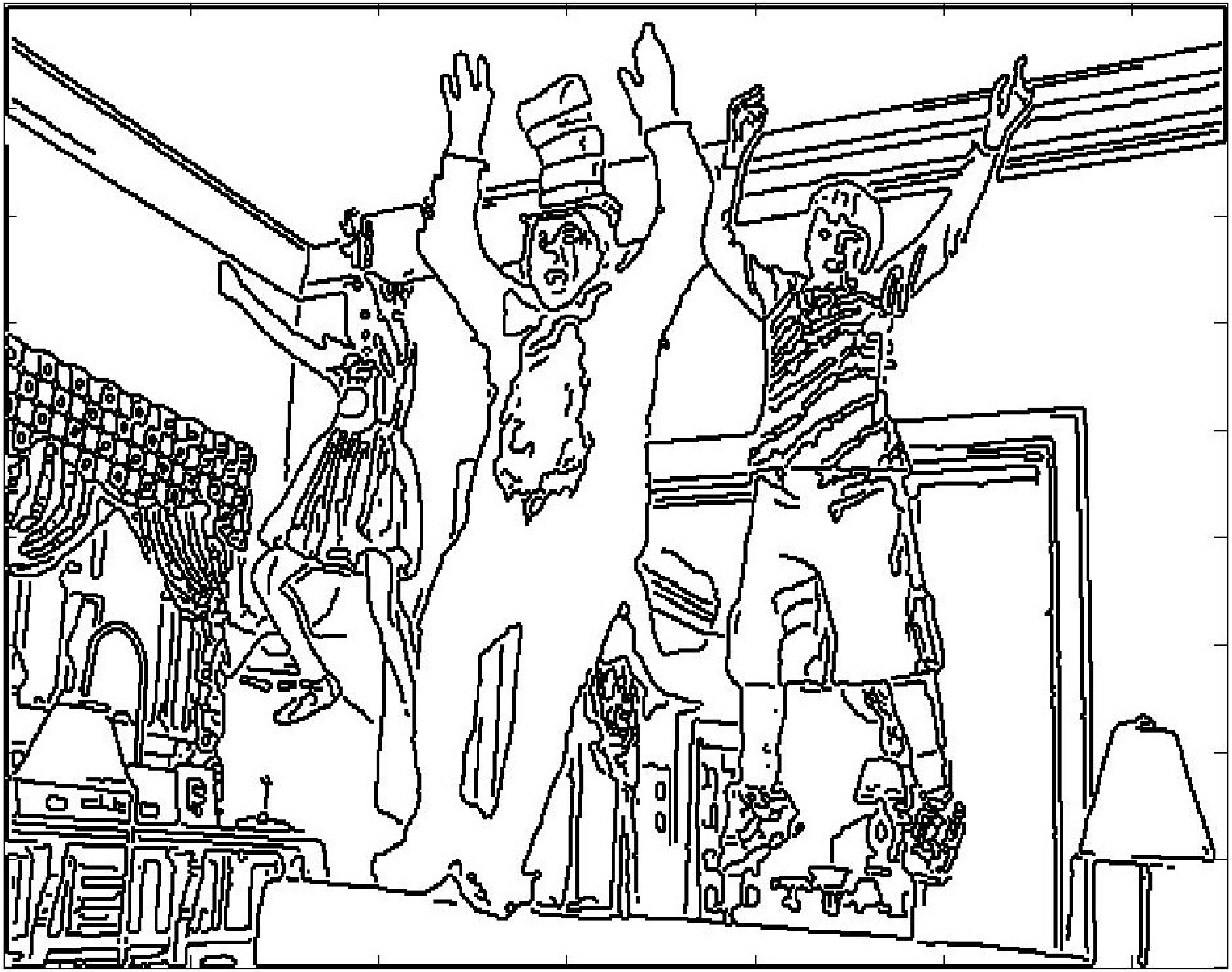
Any 2D matrix can be seen as an image

[r,g,b] = [255,255,251] [222,15,7] [0,0,0] [89,120,1]

[246,99,0]

[19,37,87) [255,255,115]

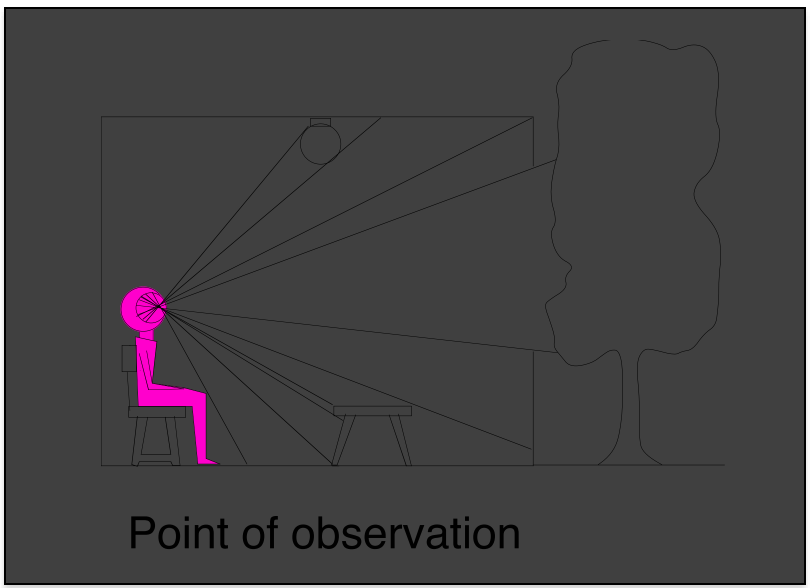
```
>> Ig = 0.5*(I(:,:,1)+I(:,:,2));
>> [bw,thresh] = edge(Ig,'canny'); imagesc(bw); colormap(gray)
```



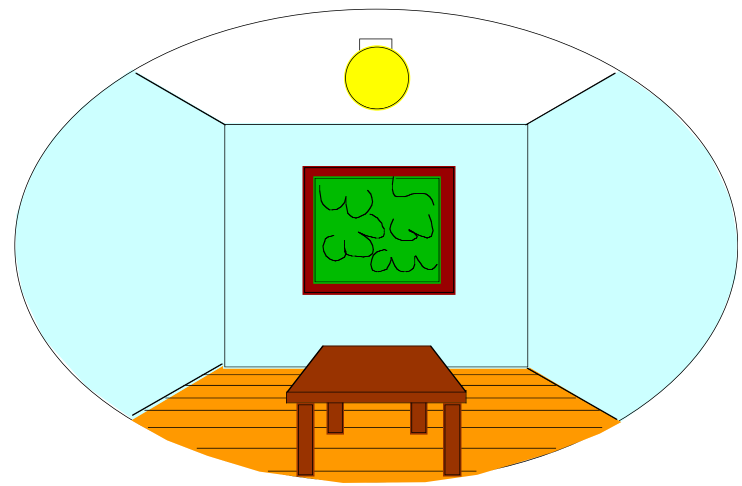

youtube.com/brusspup

Dimensionality Reduction Machine (3D to 2D)

3D world

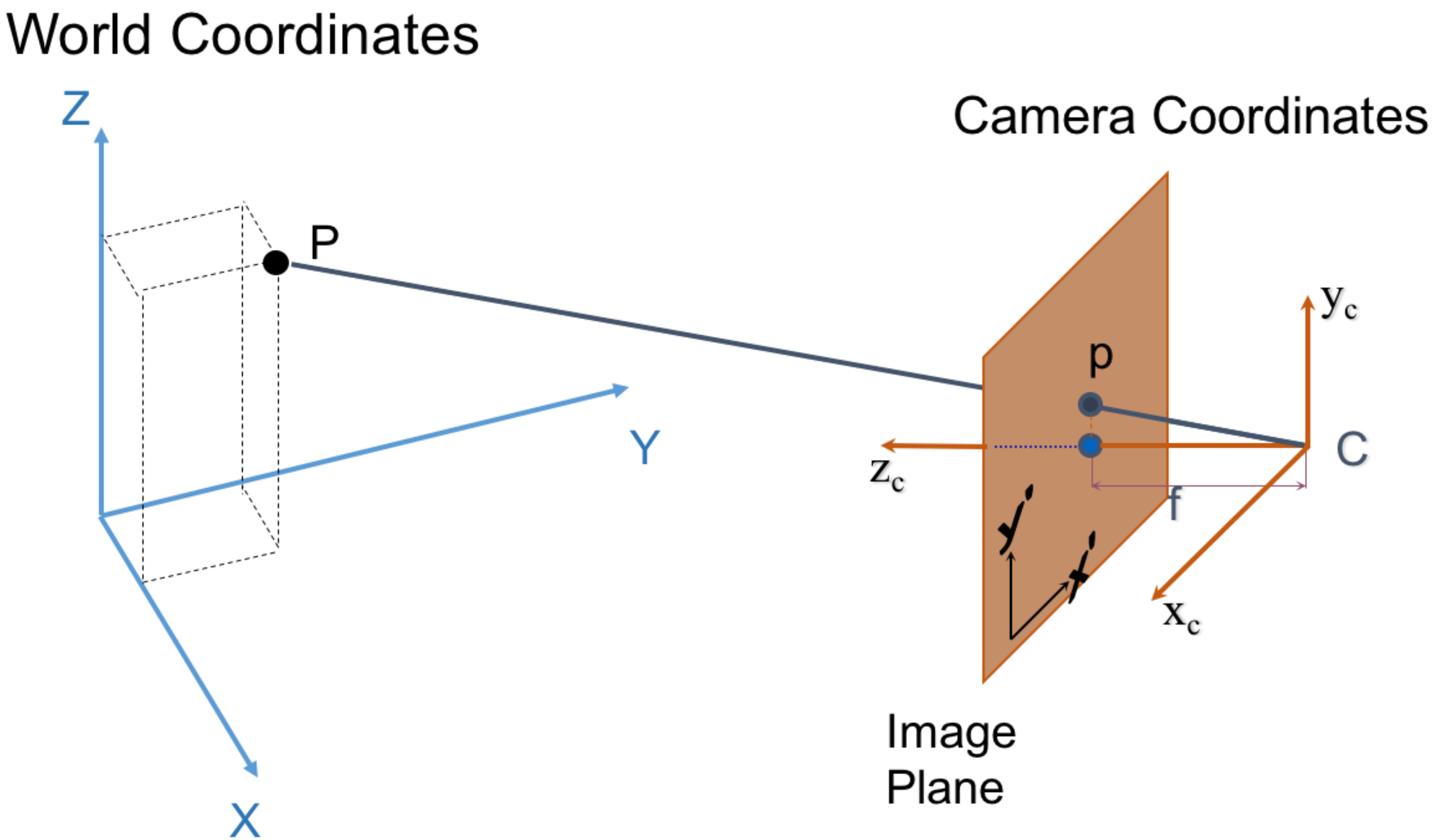


2D image



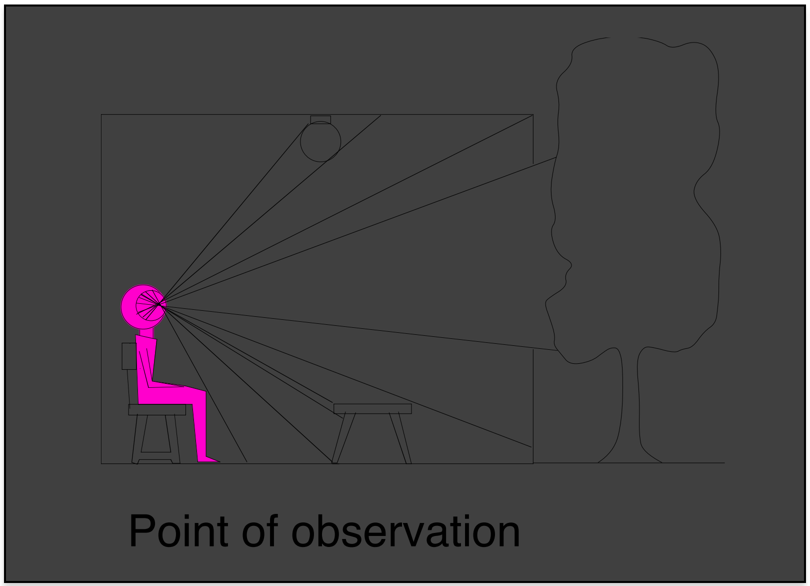
- What have we lost?
  - Angles
  - Distances (lengths)

3D to 2D mapping

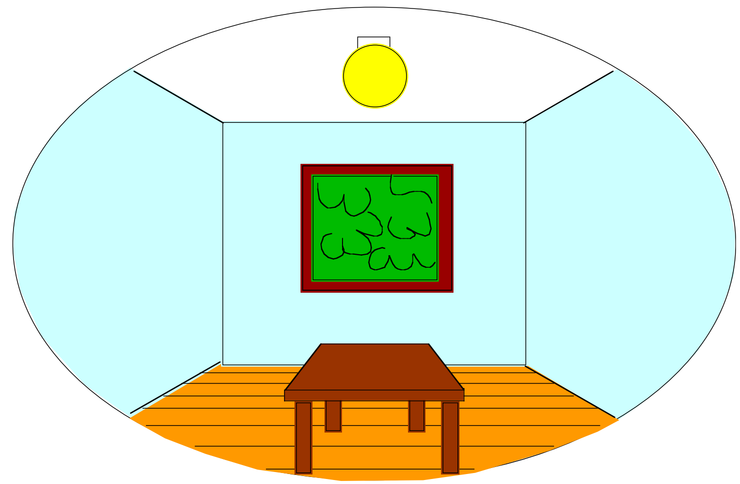


Dimensionality Reduction Machine (3D to 2D)

3D world



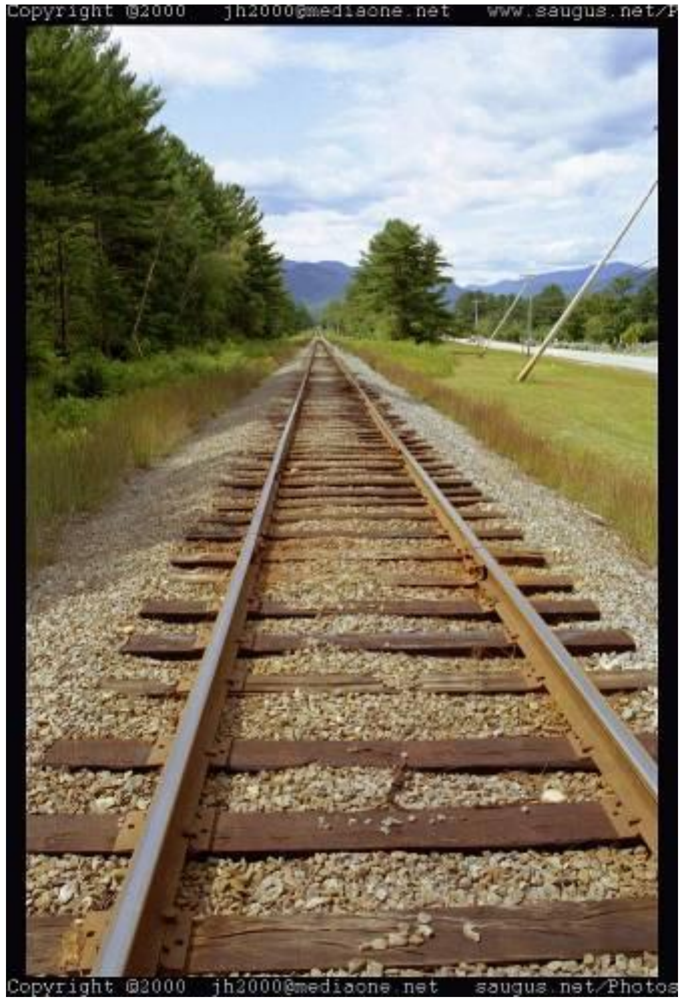
2D image



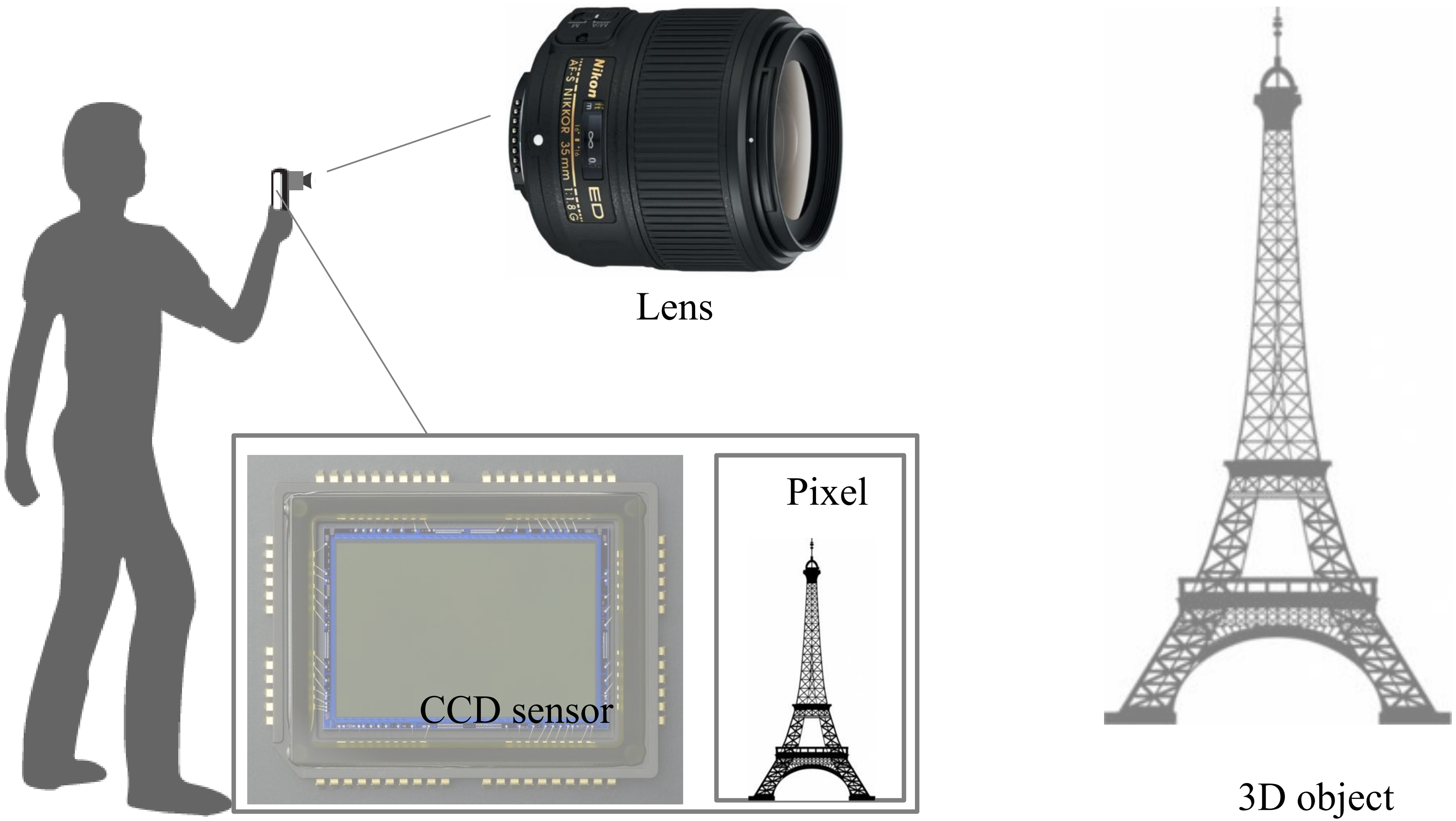
- What have we lost?
  - Angles
  - Distances (lengths)

Figures © Stephen E. Palmer, 2002

Funny things happen…

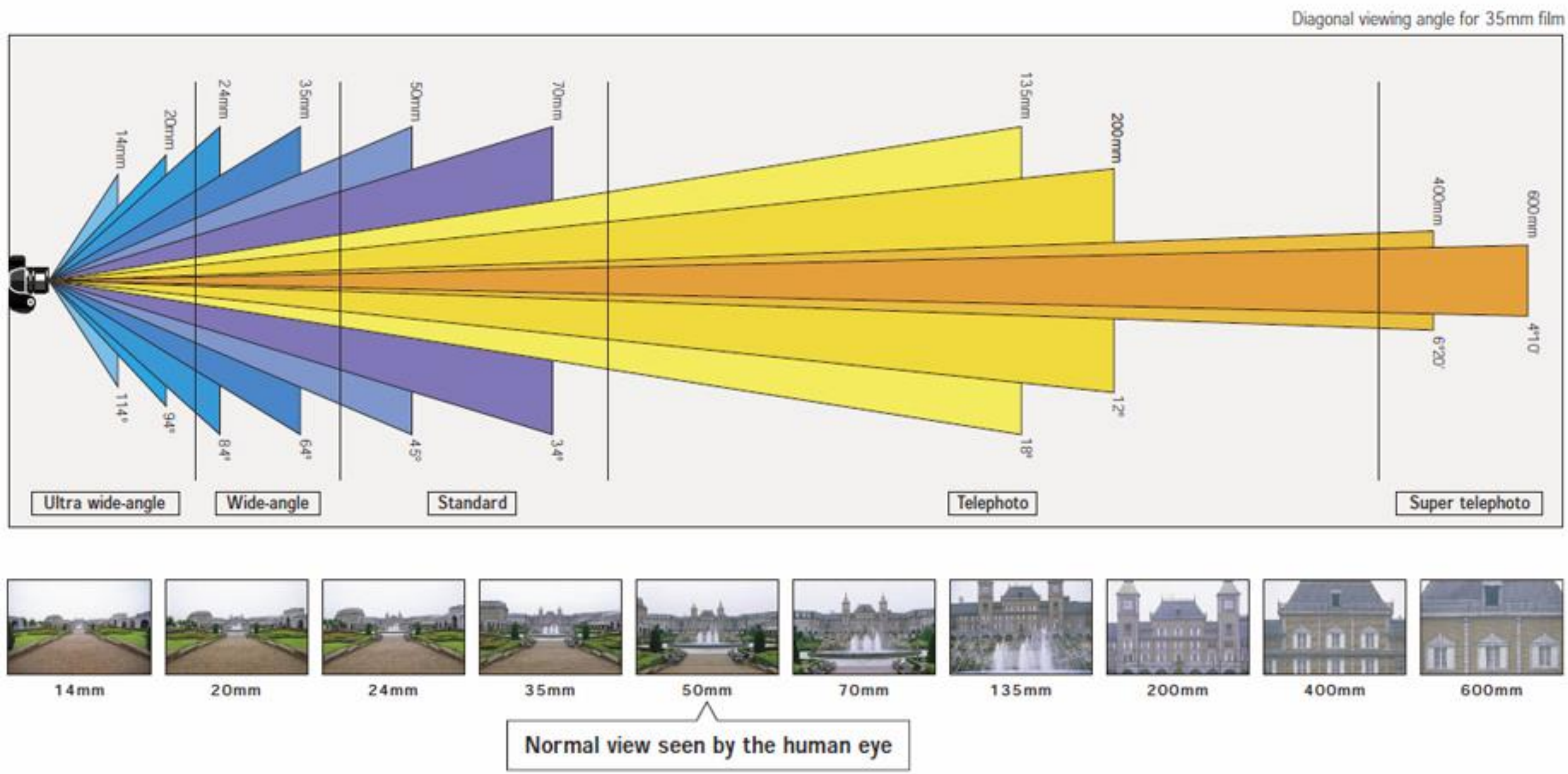


Camera Model



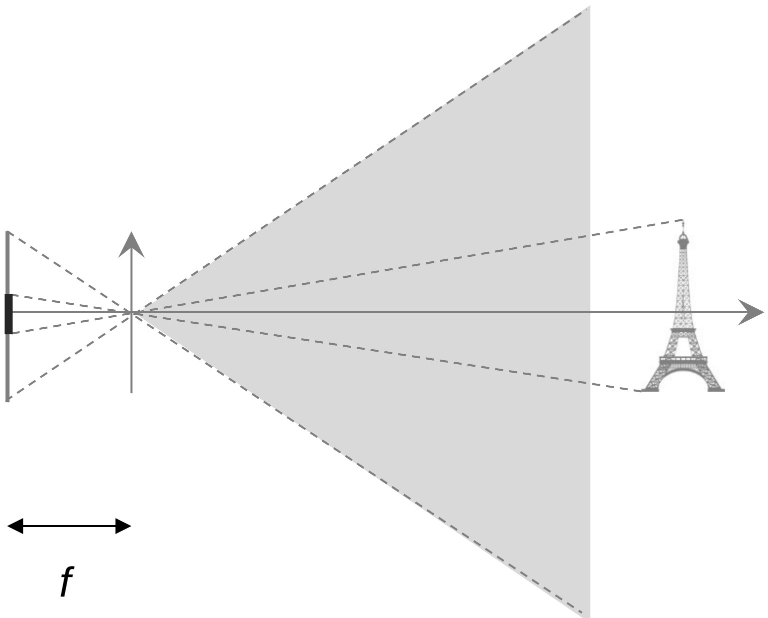
Lens
Pixel
CCD sensor
3D object

Focal Length

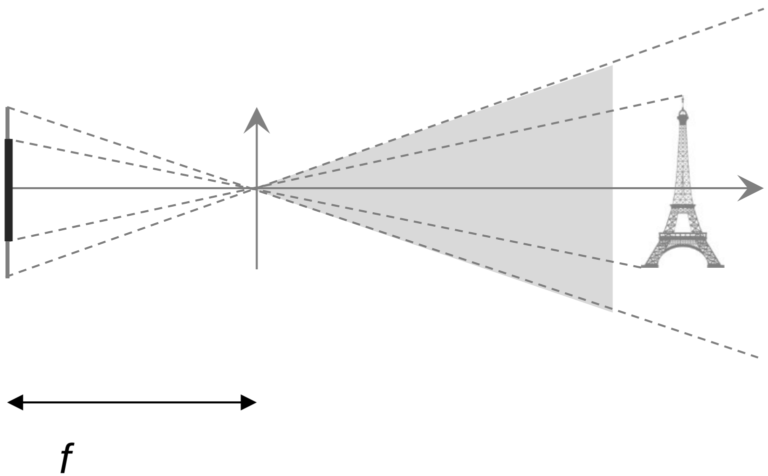


http://2blowup.com/fotografia-para-egobloggers-ii/

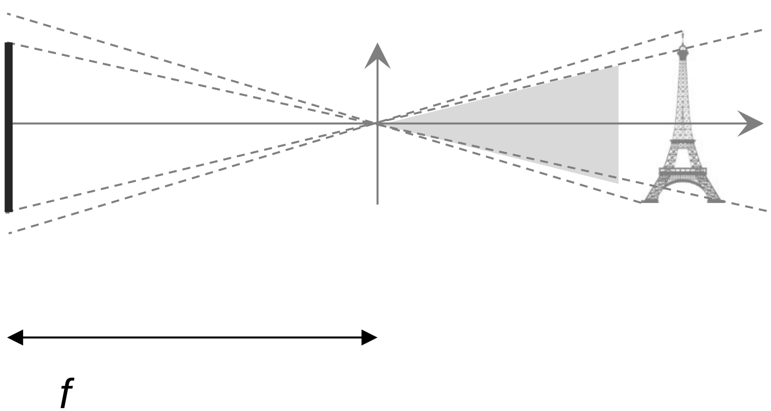
Focal Length

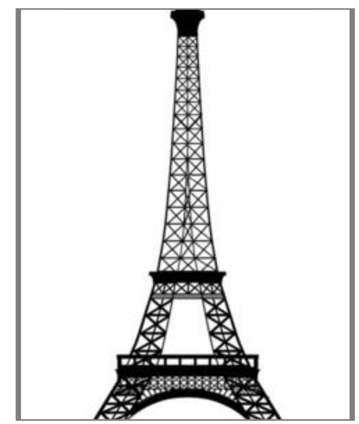


Focal Length

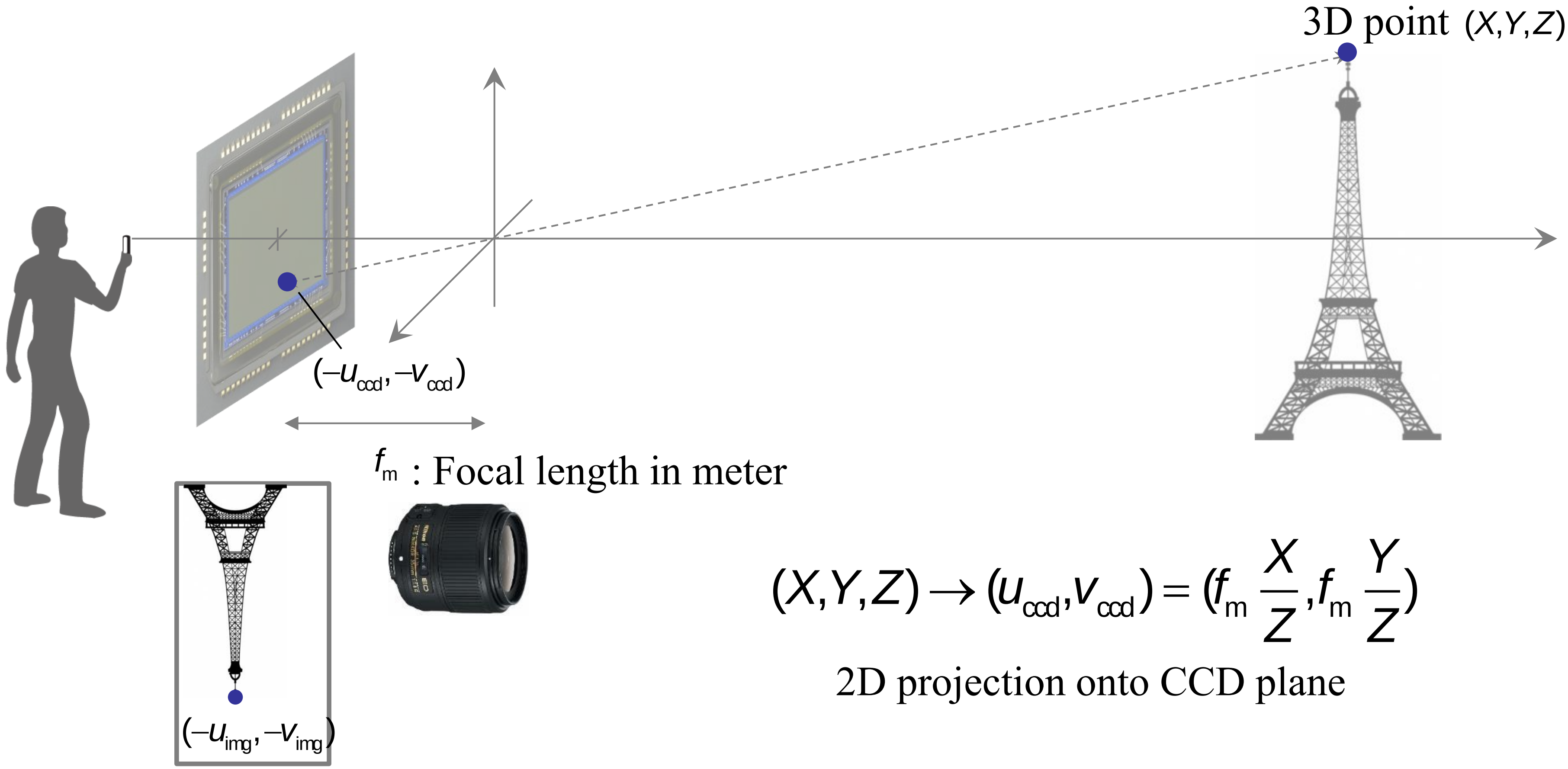


Focal Length





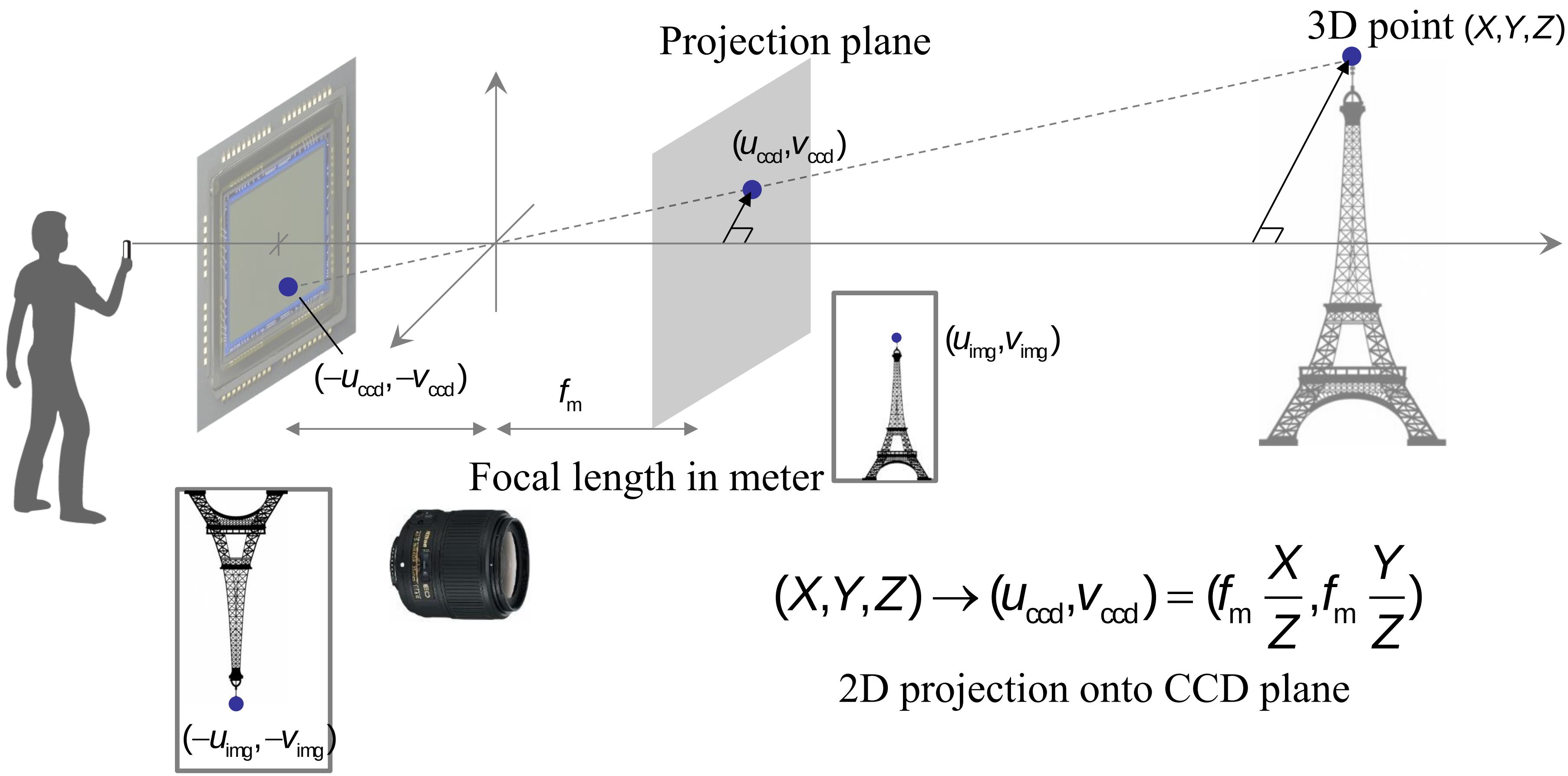
3D Point Projection (Metric Space)



$$(X,Y,Z) \rightarrow (u_{ccd}, v_{ccd}) = (f_m \frac{X}{Z}, f_m \frac{Y}{Z})$$

2D projection onto CCD plane

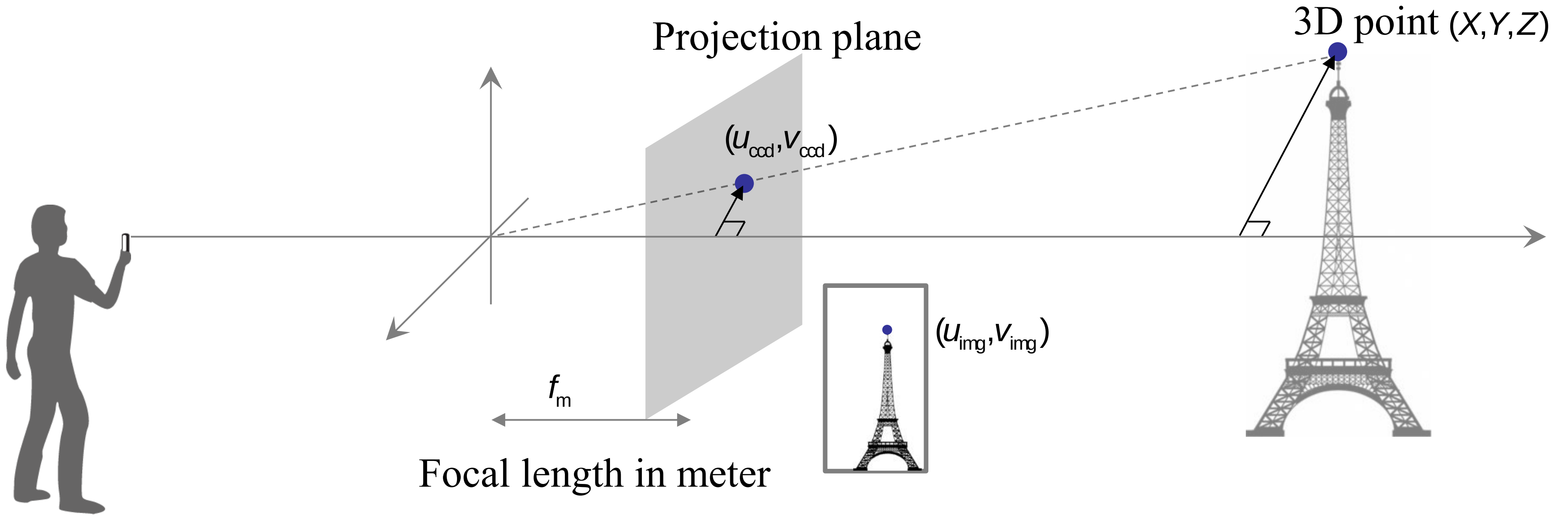
3D Point Projection (Metric Space)



$$(X,Y,Z) \rightarrow (u_{ccd},v_{ccd}) = (f_m \frac{X}{Z}, f_m \frac{Y}{Z})$$

2D projection onto CCD plane

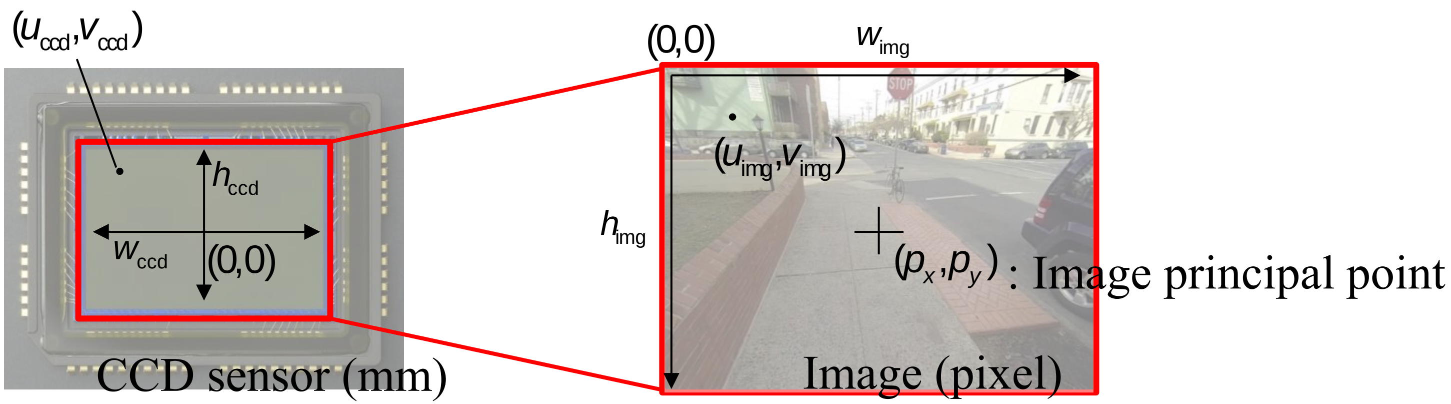
3D Point Projection (Metric Space)



$$(X,Y,Z) \rightarrow (u_{ccd},v_{ccd}) = (f_m \frac{X}{Z}, f_m \frac{Y}{Z})$$

2D projection onto CCD plane

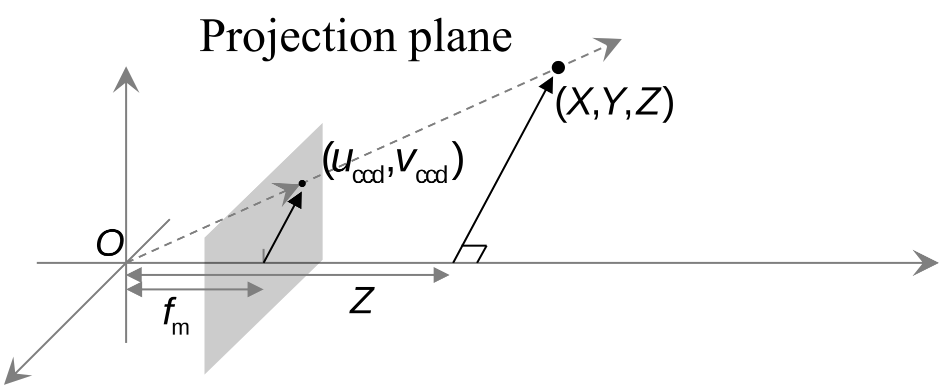
3D Point Projection (Pixel Space)



$$\frac{u_{ccd}}{w_{ccd}} = \frac{u_{img} - p_x}{w_{img}} \qquad \frac{v_{ccd}}{h_{ccd}} = \frac{v_{img} - p_y}{h_{img}}$$

$$u_{img} = u_{ccd}\frac{w_{img}}{w_{ccd}} + p_x \qquad v_{img} = v_{ccd}\frac{h_{img}}{h_{ccd}} + p_y$$

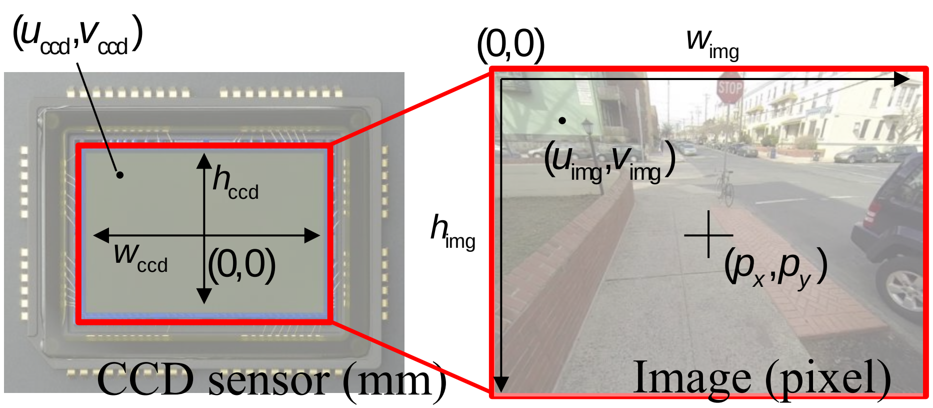
3D Point Projection (Pixel Space)



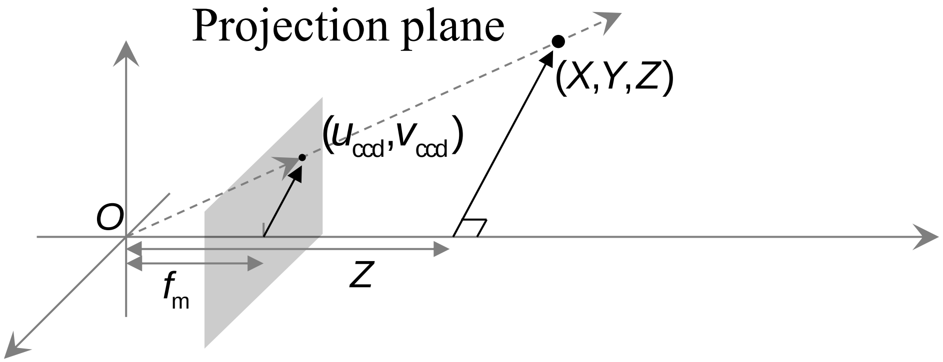
$$(X,Y,Z) \rightarrow (u_{ccd}, v_{ccd}) = \left(f_m \frac{X}{Z}, f_m \frac{Y}{Z}\right)$$

$$u_{img} = u_{ccd}\frac{w_{img}}{w_{ccd}} + p_x = \underbrace{f_m \frac{w_{img}}{w_{ccd}}}_{\text{Focal length in pixel}} \frac{X}{Z} + p_x$$

$$v_{img} = v_{ccd}\frac{h_{img}}{h_{ccd}} + p_y = \underbrace{f_m \frac{h_{img}}{h_{ccd}}}_{\text{Focal length in pixel}} \frac{Y}{Z} + p_y$$



3D Point Projection (Pixel Space)



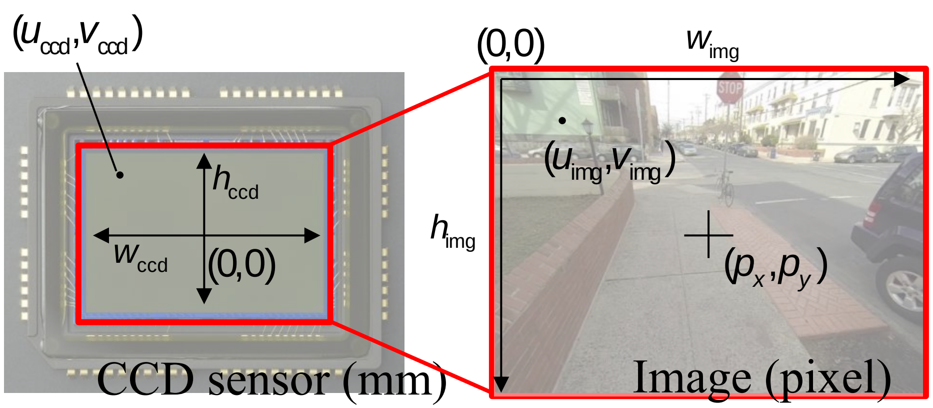
$$(X,Y,Z) \rightarrow (u_{ccd}, v_{ccd}) = (f_m \frac{X}{Z}, f_m \frac{Y}{Z})$$

$$u_{img} = u_{ccd}\frac{w_{img}}{w_{ccd}} + p_x = \underbrace{f_m \frac{w_{img}}{w_{ccd}}}_{f_x} \frac{X}{Z} + p_x$$

Focal length in pixel

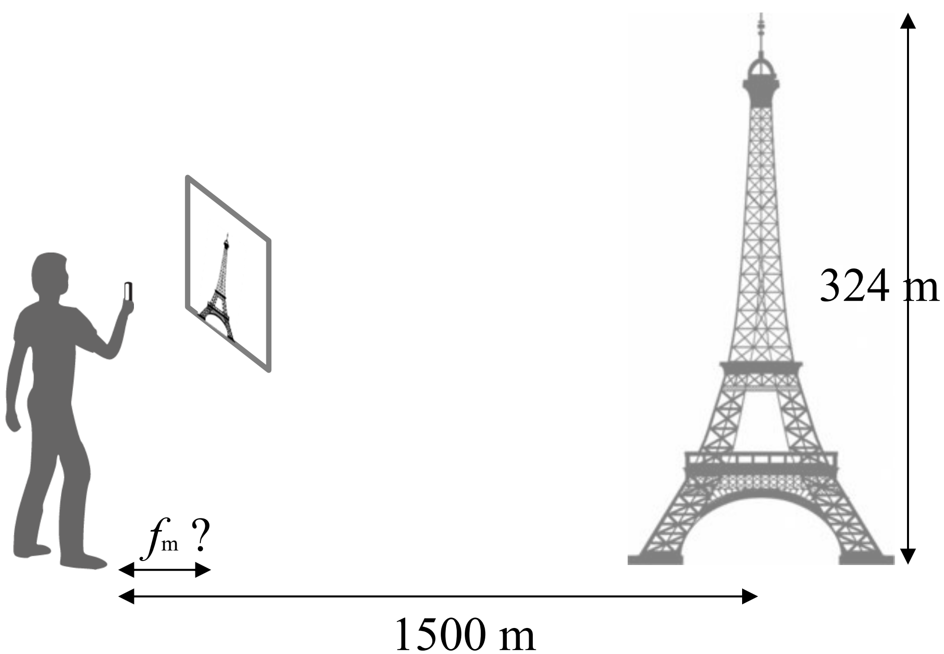
$$v_{img} = v_{ccd}\frac{h_{img}}{h_{ccd}} + p_y = \underbrace{f_m \frac{h_{img}}{h_{ccd}}}_{f_y} \frac{Y}{Z} + p_y$$

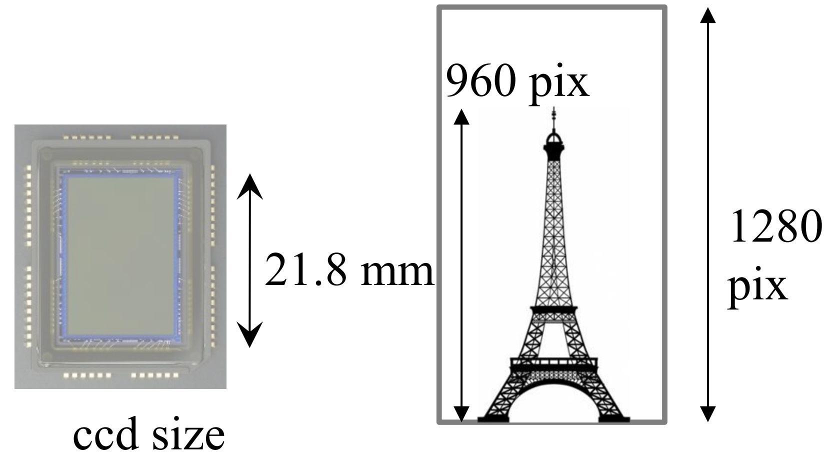
Focal length in pixel



Exercise

What f to make the height of Eifel tower appear 960 pixel distance?



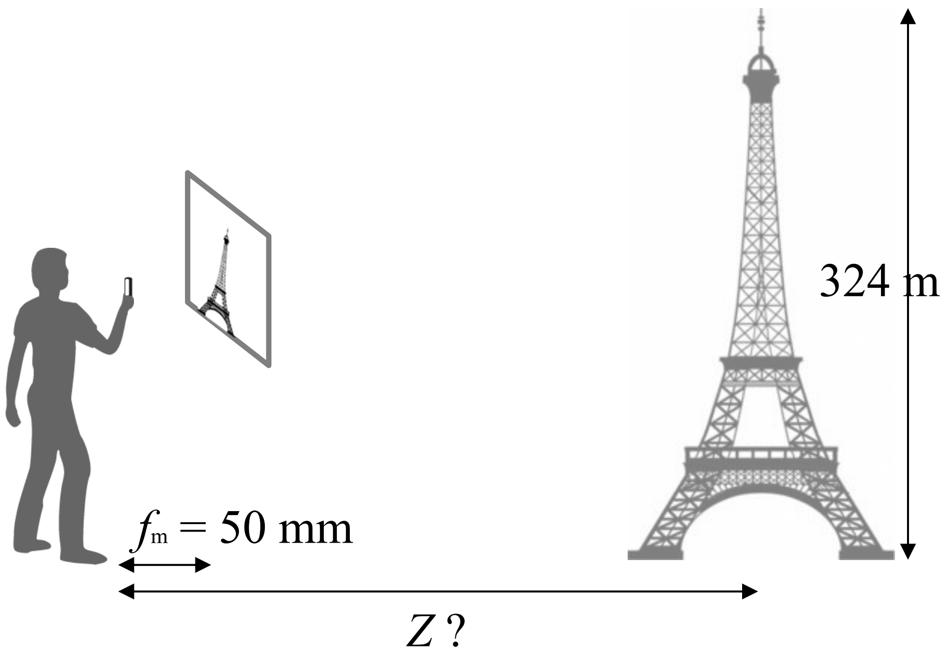


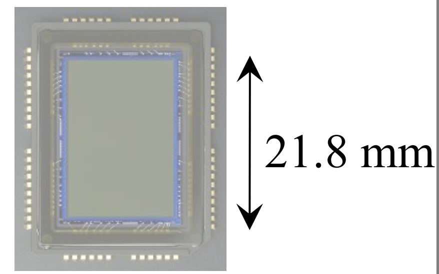
$$y_{img} = f\frac{Y}{Z} = f_m \frac{h_{img}}{h_{ccd}} \frac{Y}{Z}$$

$$960 = f_m \frac{1280}{0.0218} \frac{324}{1500} \rightarrow f_m = 0.0757m$$

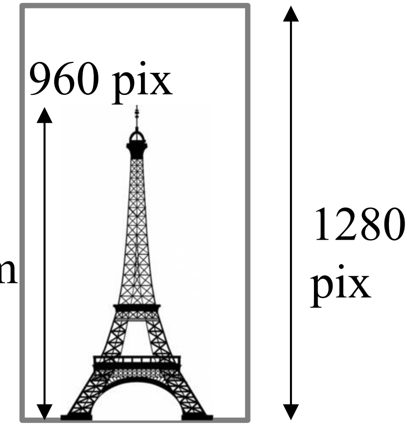
Exercise

What Z to make the height of Eifel tower appear 960 pixel distance?





ccd size

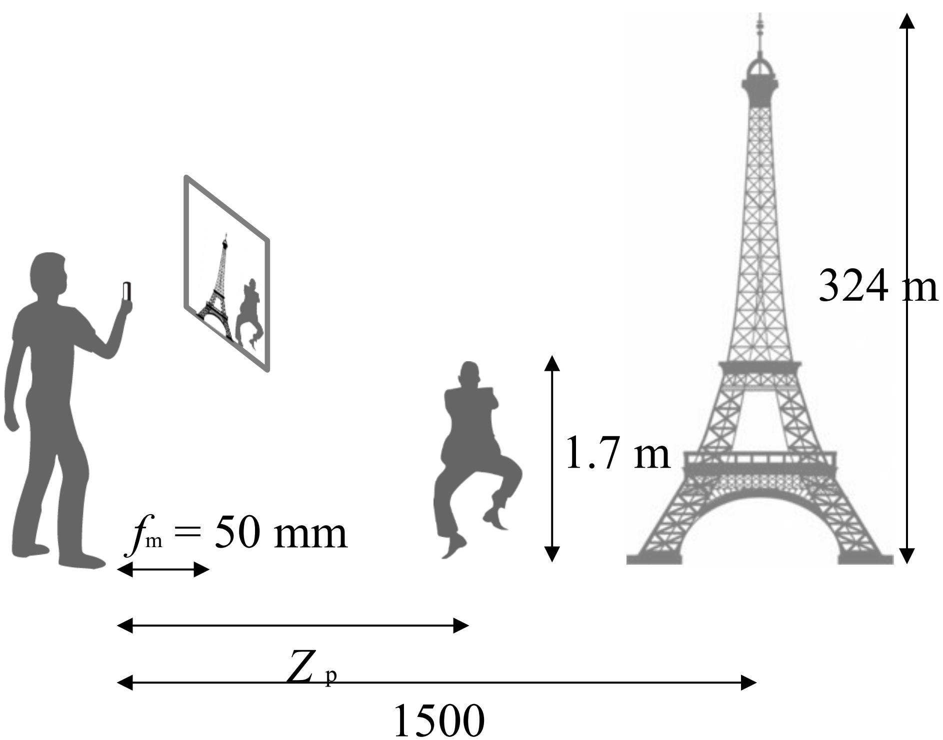


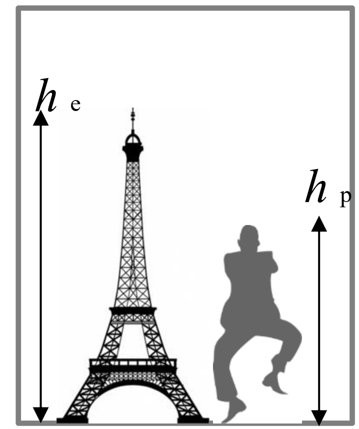
$$y_{img} = f\frac{Y}{Z} = f_m\frac{h_{img}}{h_{ccd}}\frac{Y}{Z}$$

$$960 = 0.05\frac{1280}{0.0218}\frac{324}{Z} \rightarrow Z = 990.826\text{m}$$

Exercise

What Z_p to make the height of Eifel tower appear twice of the person?

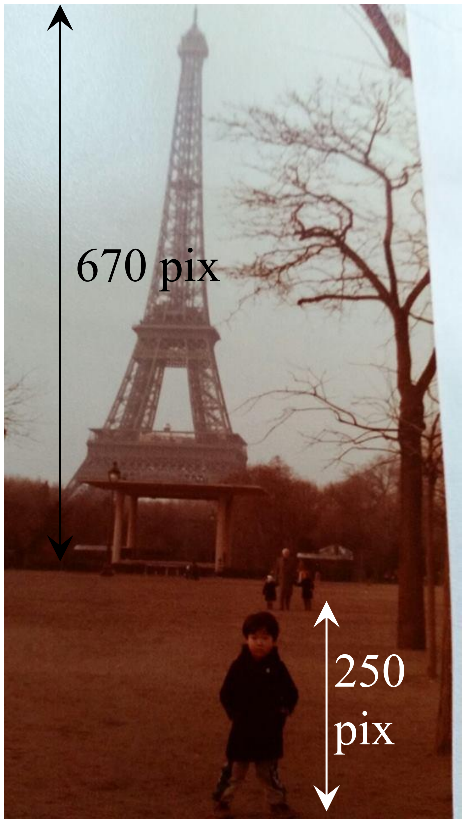




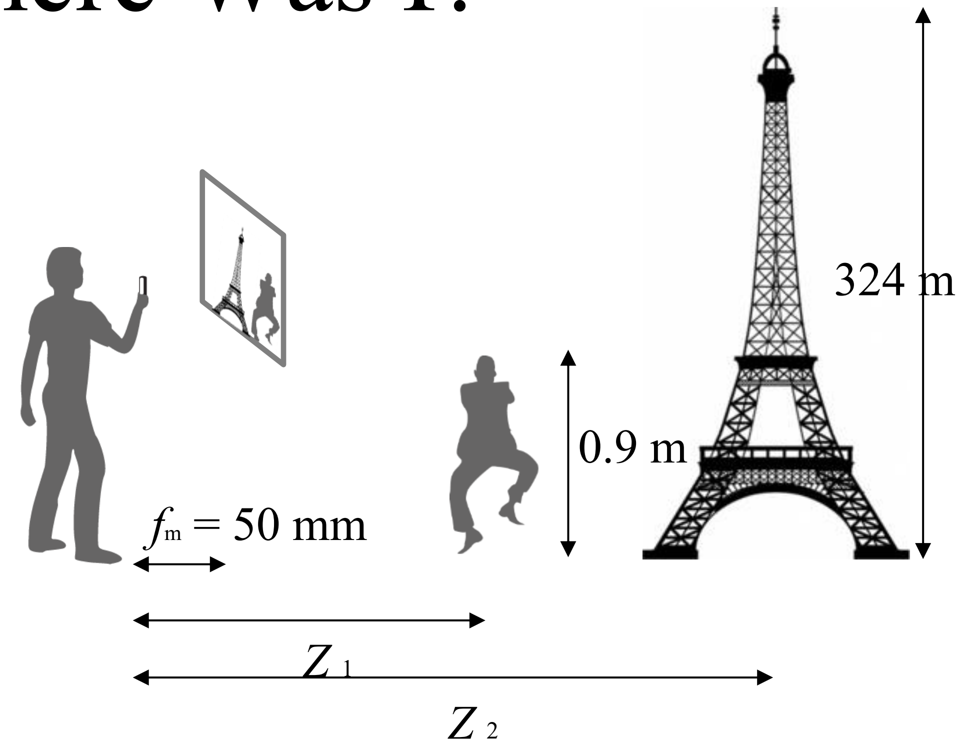
$$h_e = f\frac{Y}{Z} \qquad h_p = f\frac{Y_p}{Z_p} \qquad \text{s.t.} \qquad h_p = \frac{h_e}{2}$$

$$f\frac{Y_p}{Z_p} = f\frac{Y}{2Z} \rightarrow \qquad Z_p = 2\cdot 1500\frac{1.7}{234} = 157.41\text{m}$$

Where Was I?



Circa 1984

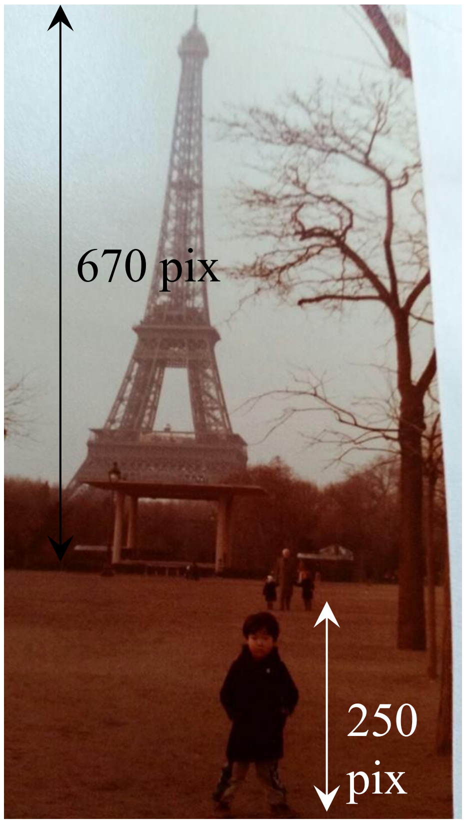


$$y_1 = f\frac{Y}{Z} = f_m \frac{h_{img}}{h_{ccd}}\frac{Y_1}{Z_1} \rightarrow Z_1 = f_m \frac{h_{img}}{h_{ccd}}\frac{Y_1}{y_1} = 0.05\frac{1280}{0.0218}\frac{0.9}{250} = 8.03\text{m}$$

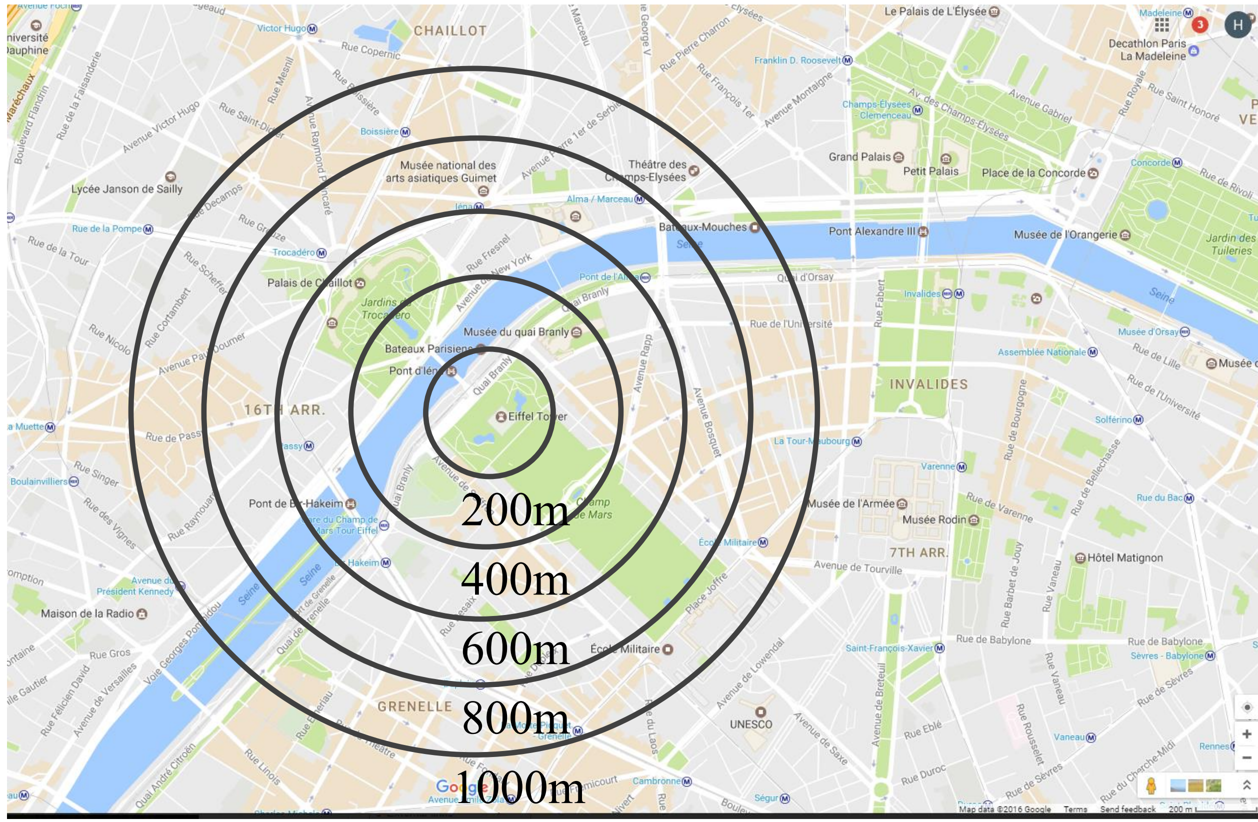
$$y_2 = f\frac{Y_2}{Z_2} = f_m \frac{h_{img}}{h_{ccd}}\frac{Y_2}{Z_2} \rightarrow Z_2 = f_m \frac{h_{img}}{h_{ccd}}\frac{Y_2}{y_2} = 0.05\frac{1280}{0.0218}\frac{324}{670} = 1079\text{m}$$

Where Was I?

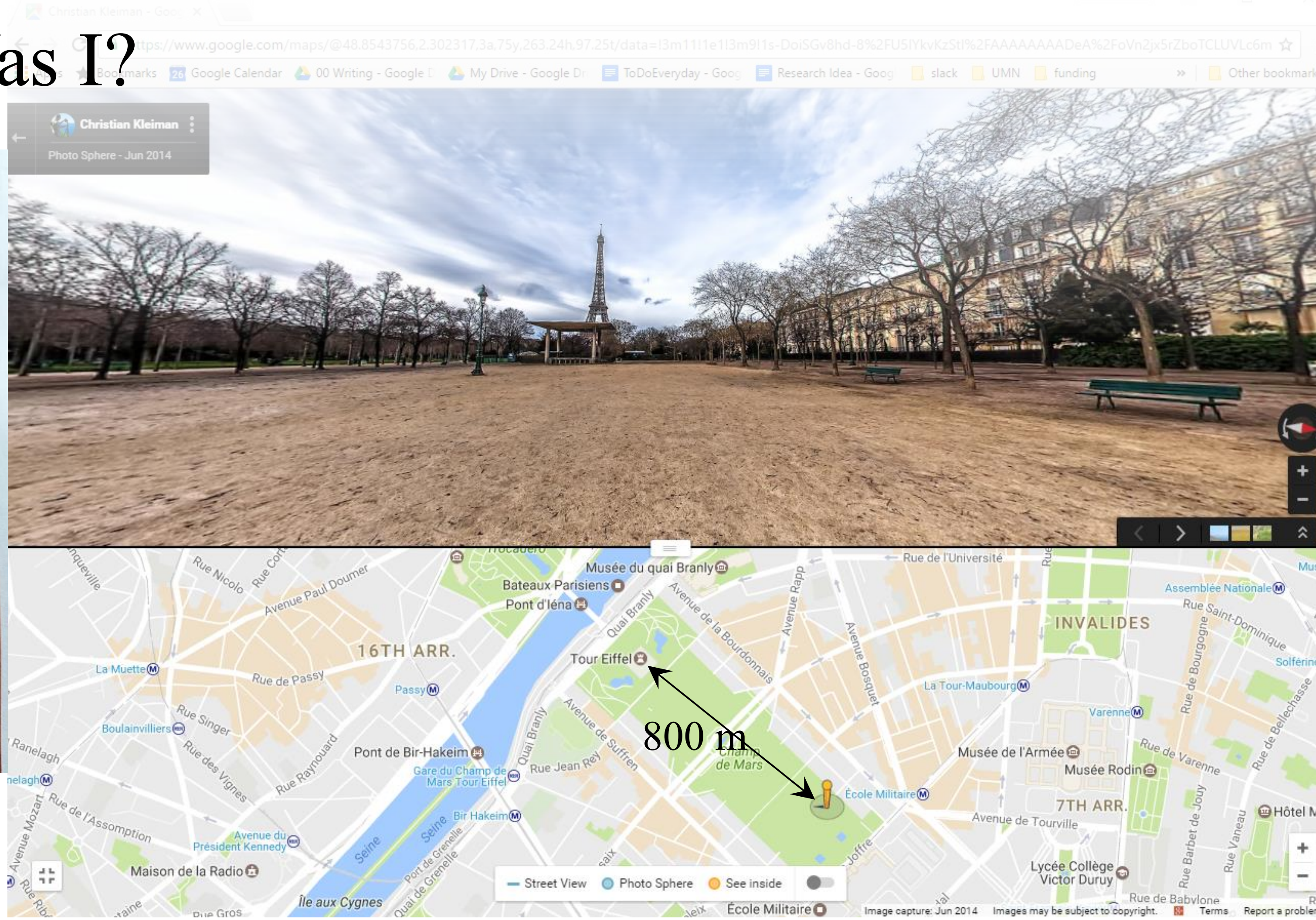
$$y_2 = f\frac{Y_2}{Z_2} = f_m\frac{h_{img}}{h_{ccd}}\frac{Y_2}{Z_2} \rightarrow Z_2 = f_m\frac{h_{img}}{h_{ccd}}\frac{Y_2}{y_2} = 0.05\frac{1280}{0.0218}\frac{324}{670} = 1079\text{m}$$



Circa 1984



Where Was I?


Christian Kleiman
Photo Sphere - Jun 2014
Musée du quai Branly
Bateaux Parisiens
Pont d'Iéna
Tour Eiffel
800 m
Champ de Mars
École Militaire
16TH ARR.
INVALIDES
7TH ARR.
La Muette
Passy
Boulainvilliers
Pont de Bir-Hakeim
Gare du Champ de Mars Tour Eiffel
Bir Hakeim
Avenue du Président Kennedy
Maison de la Radio
Île aux Cygnes
Seine
Rue de Passy
Rue Singer
Rue des Vignes
Rue Raynouard
Avenue Paul Doumer
Rue de l'Assomption
Ranelagh
Quai Branly
Avenue de la Bourdonnais
Avenue Rapp
Avenue Bosquet
Avenue de Suffren
Rue Jean Rey
Rue de l'Université
Assemblée Nationale
Rue Saint-Dominique
Solférino
La Tour-Maubourg
Varenne
Musée de l'Armée
Musée Rodin
Rue de Varenne
Avenue de Tourville
Lycée Collège Victor Duruy
Rue de Babylone
Street View
Photo Sphere
See inside
Image capture: Jun 2014
Images may be subject to copyright.
Terms
Report a problem

http://2blowup.com/fotografia-para-egobloggers-ii/

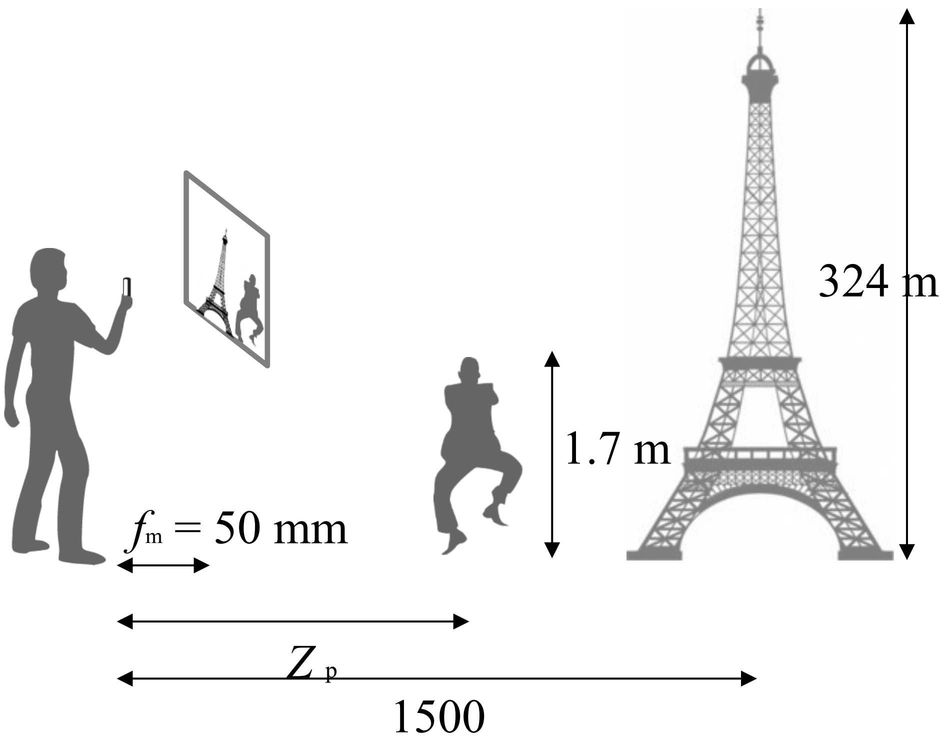
Dolly Zoom (Vertigo Effect)

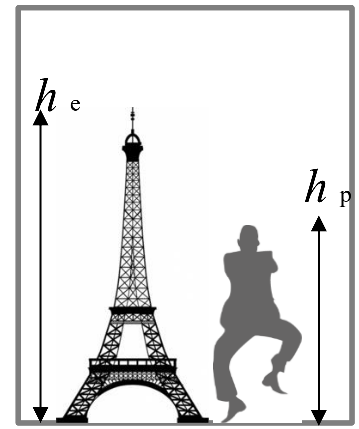
Dolly Zoom (Vertigo Effect)

(Jaws 1975)

Exercise

What Z_p to make the height of Eifel tower appear twice of the person?



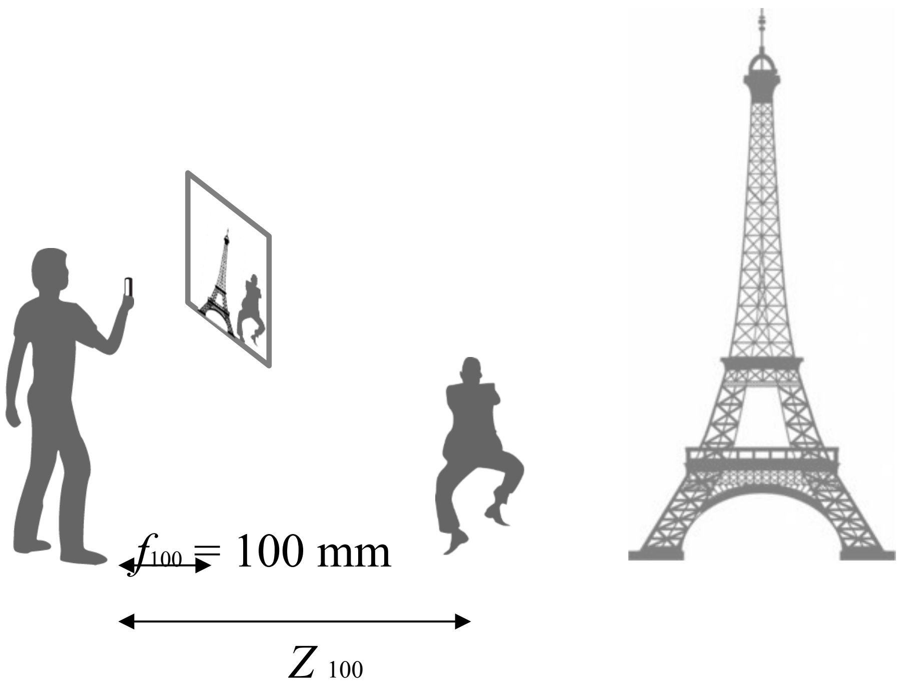


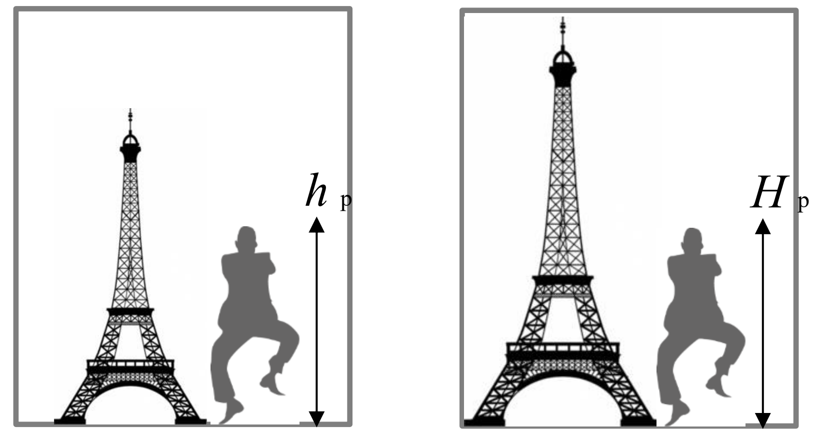
$$h_e = f\frac{Y}{Z} \qquad h_p = f\frac{Y_p}{Z_p} \qquad \text{s.t.} \qquad h_p = \frac{h_e}{2}$$

$$f\frac{Y_p}{Z_p} = f\frac{Y}{2Z} \rightarrow \qquad Z_p = 2\cdot 1500\frac{1.7}{234} = 157.41\text{m}$$

Dolly Zoom

Given focal length (f_m=100mm),
what Z_{100} to make the height of the person remain the same as f_m=50mm?



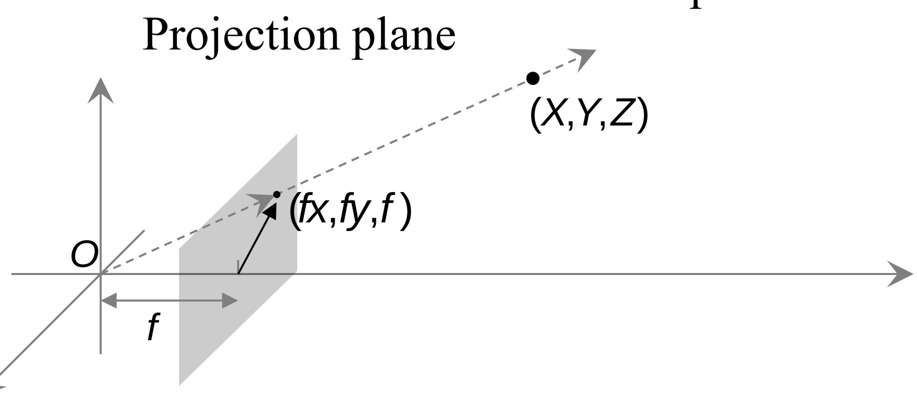


$$h_{50} = f_{50}\frac{Y}{Z_{50}} \qquad h_{100} = f_{100}\frac{Y}{Z_{100}} \qquad \text{s.t.} \quad h_{100} = h_{50}$$

$$Z_{100} = \frac{f_{100}}{f_{50}} Z_{50} \qquad Z_{100} = \frac{100}{50} 157.41 = 314.8\text{m}$$

Homogeneous Coordinate

2D point =: 3D ray $\lambda(x, y, 1)$

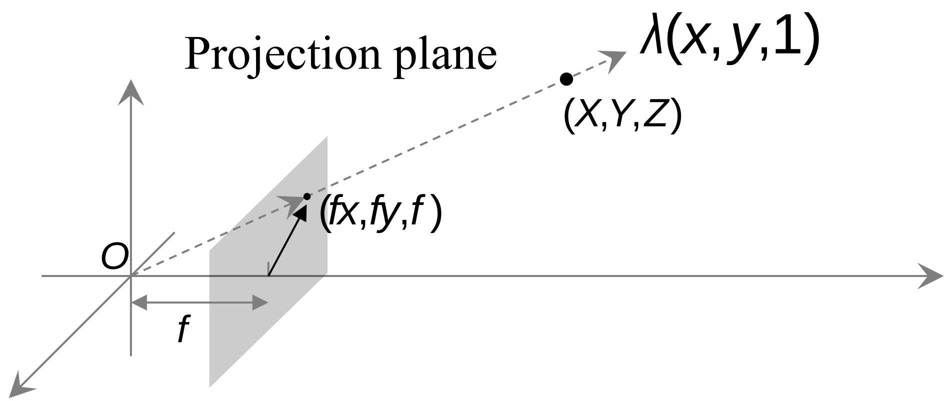


$$(x, y) \rightarrow (x, y, 1)$$
$$= f(x, y, 1)$$
$$= \lambda(x, y, 1)$$

: A point in Euclidean space ($\mathbb{R}^2$) can be represented by a homogeneous representation in Projective space ($\mathbb{P}^2$) (3 numbers).

Homogeneous Coordinate

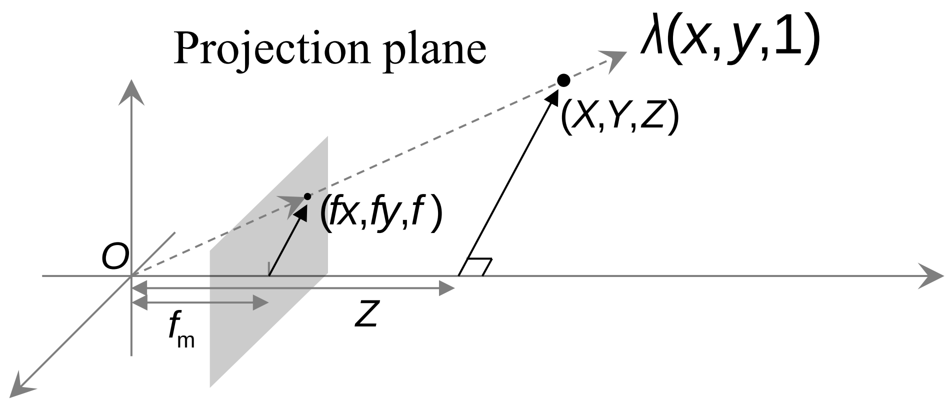
2D point =: 3D ray



$$\underbrace{\lambda(x, y, 1)}_{\text{Homogeneous coordinate}} = (X, Y, Z)$$: 3D point lies in the 3D ray passing 2D image point.

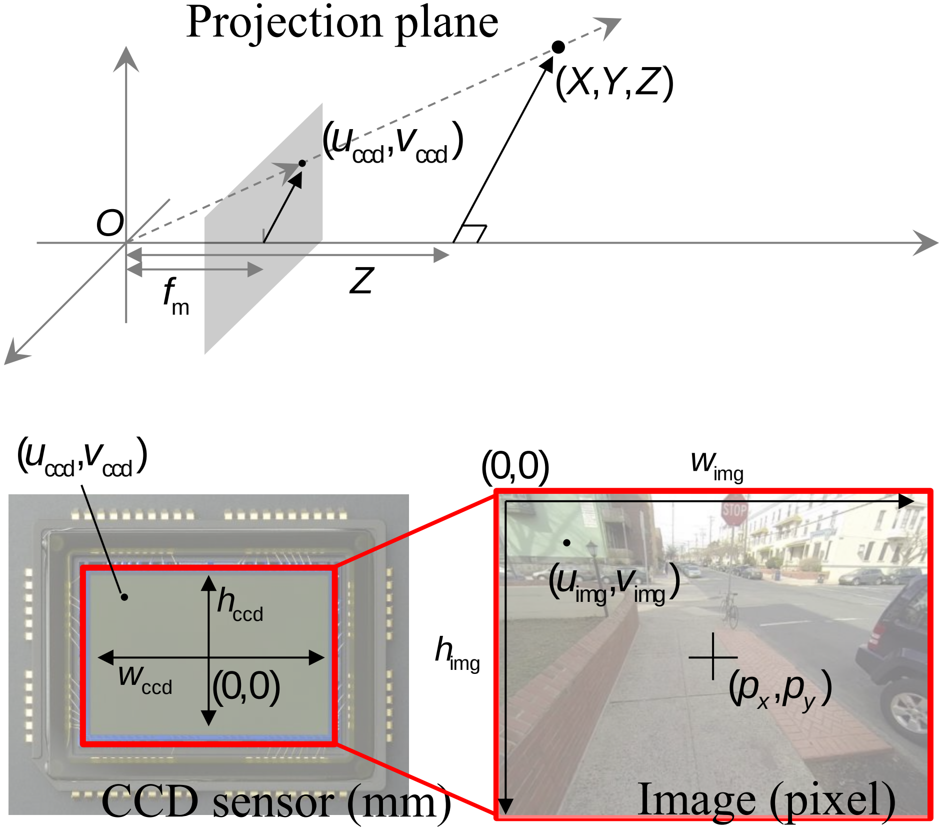
3D Point Projection (Metric Space)

2D point =: 3D ray



$$(x, y, 1) = (f_m x, f_m y, f_m) = (f_m \frac{X}{Z}, f_m \frac{Y}{Z}, f_m)$$

3D Point Projection (Pixel Space)



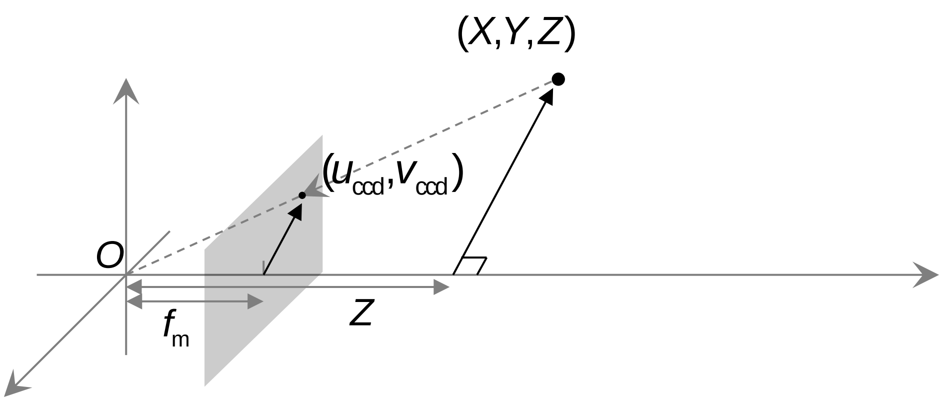
$$(X,Y,Z) \rightarrow (u_{ccd}, v_{ccd}) = (f_m \frac{X}{Z}, f_m \frac{Y}{Z})$$

$$u_{img} = f_x \frac{X}{Z} + p_x \quad v_{img} = f_y \frac{Y}{Z} + p_y$$

$$\underline{\lambda \begin{bmatrix} u_{img} \\ v_{img} \\ 1 \end{bmatrix}} = \begin{bmatrix} f_x & & p_x \\ & f_y & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Homogeneous representation

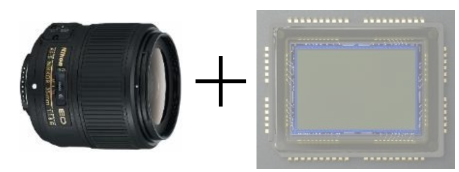
Camera Intrinsic Parameter



Projection plane

Pixel space Metric space

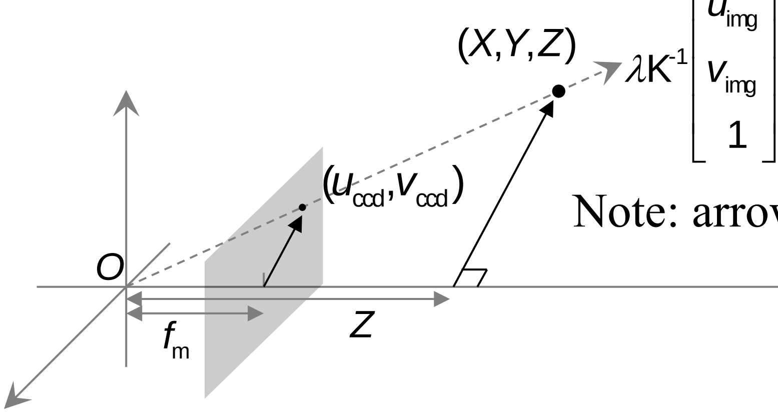
$$\lambda \begin{bmatrix} u_{img} \\ v_{img} \\ 1 \end{bmatrix} = \underbrace{\begin{bmatrix} f_x & & p_x \\ & f_y & p_y \\ & & 1 \end{bmatrix}}_{K} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$



Camera intrinsic parameter
: metric space to pixel space

2D Inverse Projection

2D point == 3D ray



Note: arrow direction

Projection plane

Pixel space Metric space

$$\lambda \begin{bmatrix}u_{img}\\ v_{img}\\ 1\end{bmatrix} = \underbrace{\begin{bmatrix}f_x & & p_x\\ & f_y & p_y\\ & & 1\end{bmatrix}}_{\mathrm{K}} \begin{bmatrix}X\\ Y\\ Z\end{bmatrix}$$

$$\lambda \mathrm{K}^{-1}\begin{bmatrix}u_{img}\\ v_{img}\\ 1\end{bmatrix} = \begin{bmatrix}X\\ Y\\ Z\end{bmatrix}$$

3D ray

The 3D point must lie in
the *3D ray* passing through the origin and 2D image point.