Camera Model

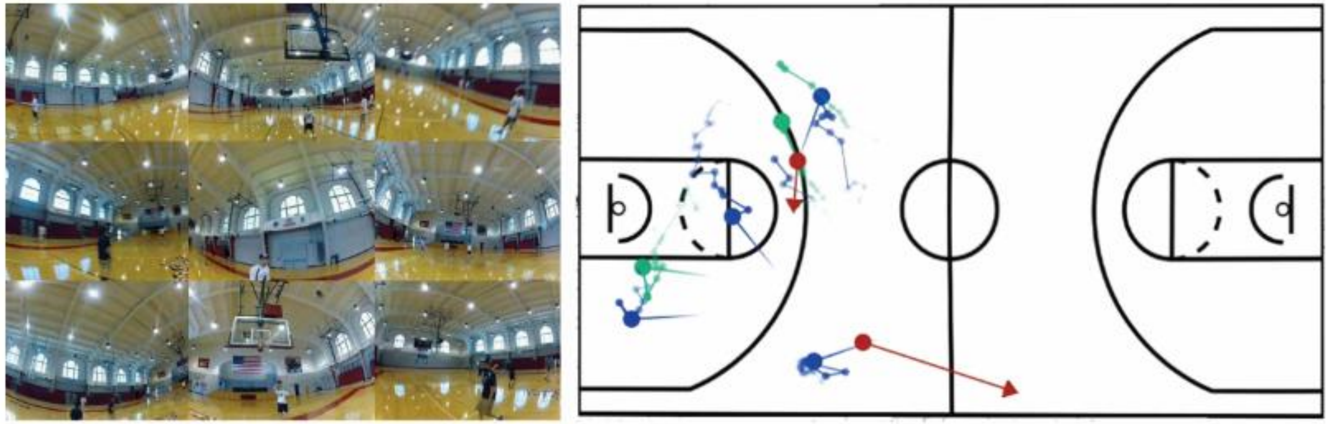
Website

- http://www-users.cs.umn.edu/~hspark/CSci5980/csci5980_3dvision.html

Spring 2017 CSCI 5890/8980
Multiview 3D Geometry in Computer Vision

Tue/Thr 4:00pm-5:15pm @ Rapson Hall 43

Description



(a) Head-mounted cameras (b) 3D reconstruction of players

Paper Presentation

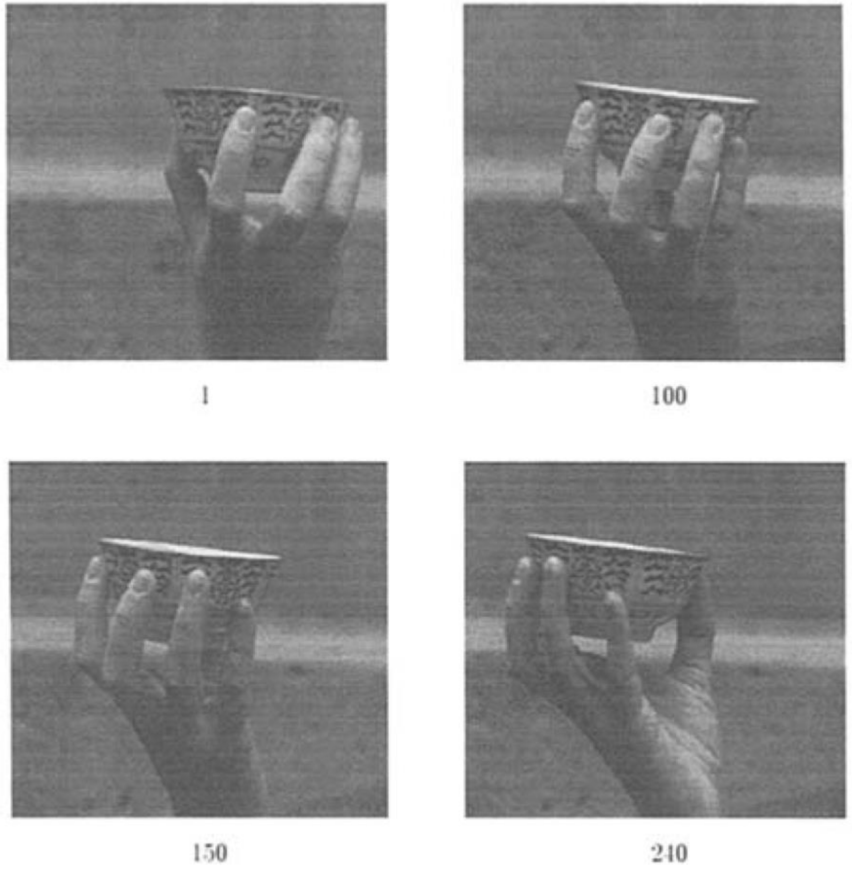
- Format
  - 20 min presentation with 15+ min questions
  - One presenter: this person defends the paper.
  - One committee: this person attacks the paper.

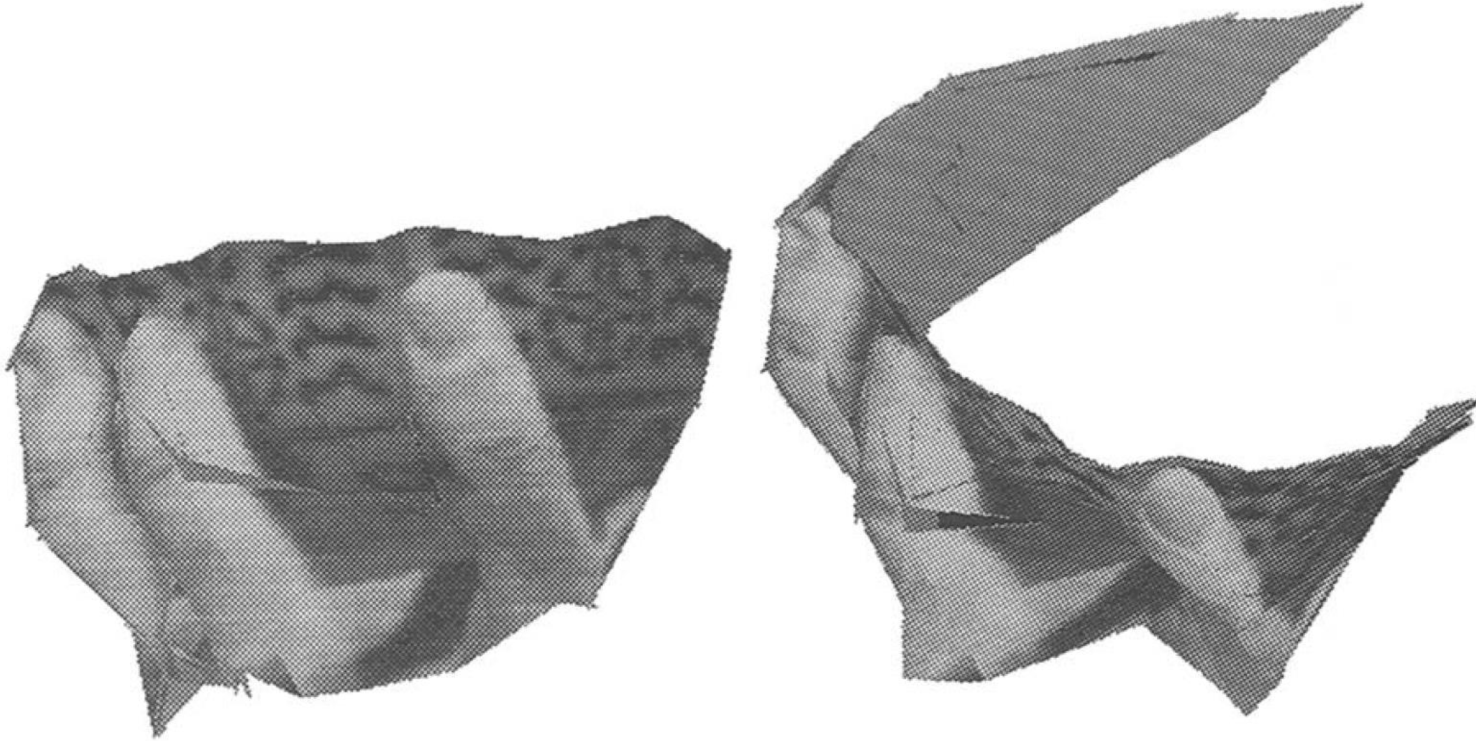
- You are free to choose a paper that
  - Is not written by you or your research group
  - Has a strong relevant to 3D vision (theory and application)
  - Is approved by me

- Or, you can choose a paper from my list.

Paper List

- Tomasi and Kanade, Shape and Motion from Image Streams under Orthography: a Factoriaztion Method, IJCV, 1992





Paper List

- Reid and Zisserman, Goal-directed Video Metrology, ECCV, 1996

Paper List

- Zhang, A Flexible New Technique for Camera Calibration, PAMI, 2000

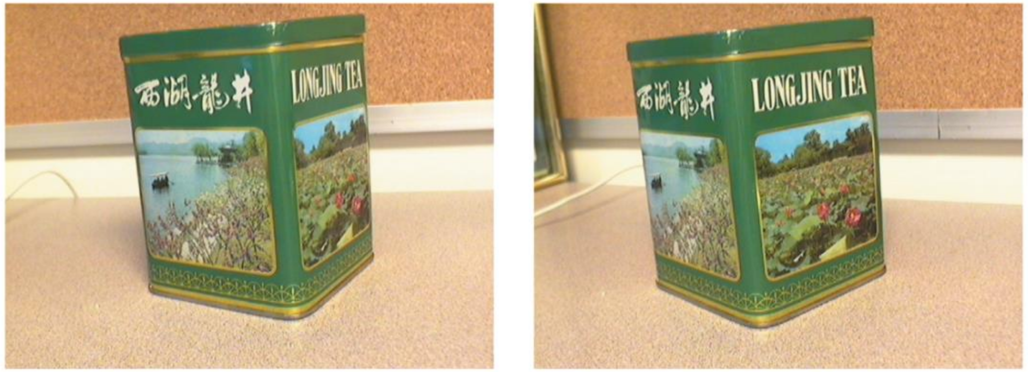
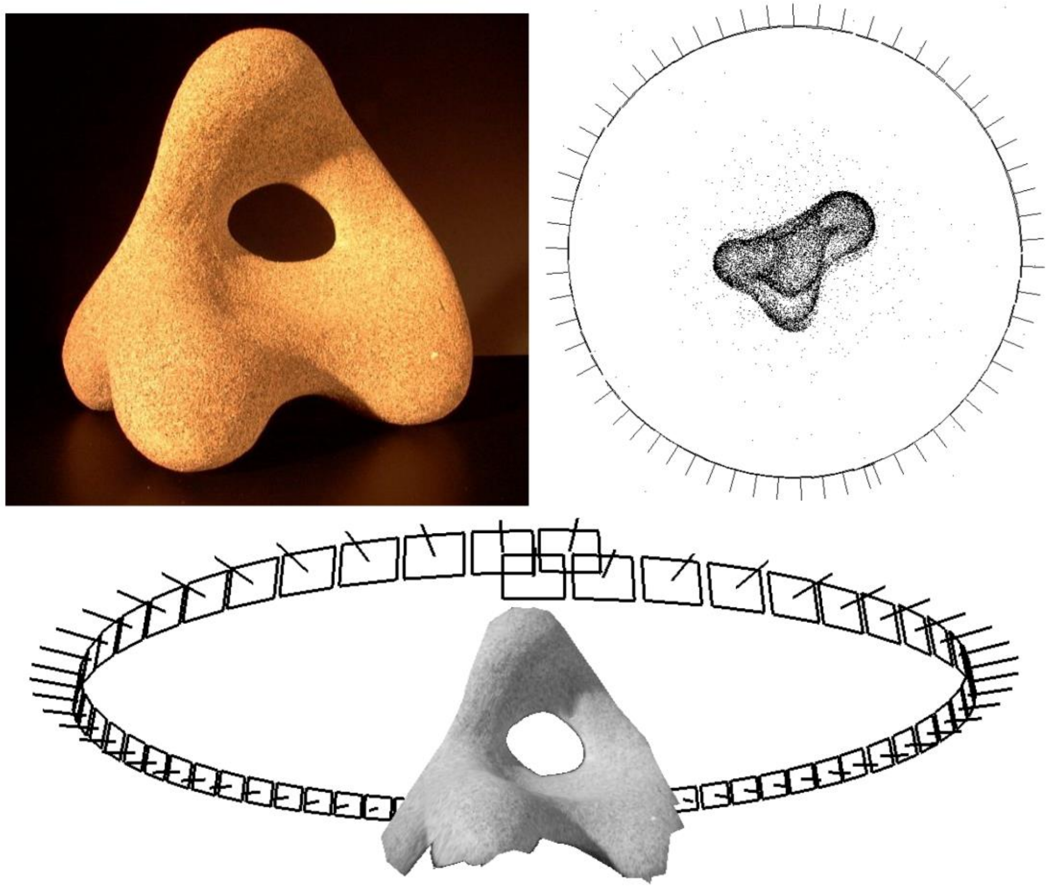


Figure 6: Two images of a tea tin

Figure 7: Three rendered views of the reconstructed tea tin

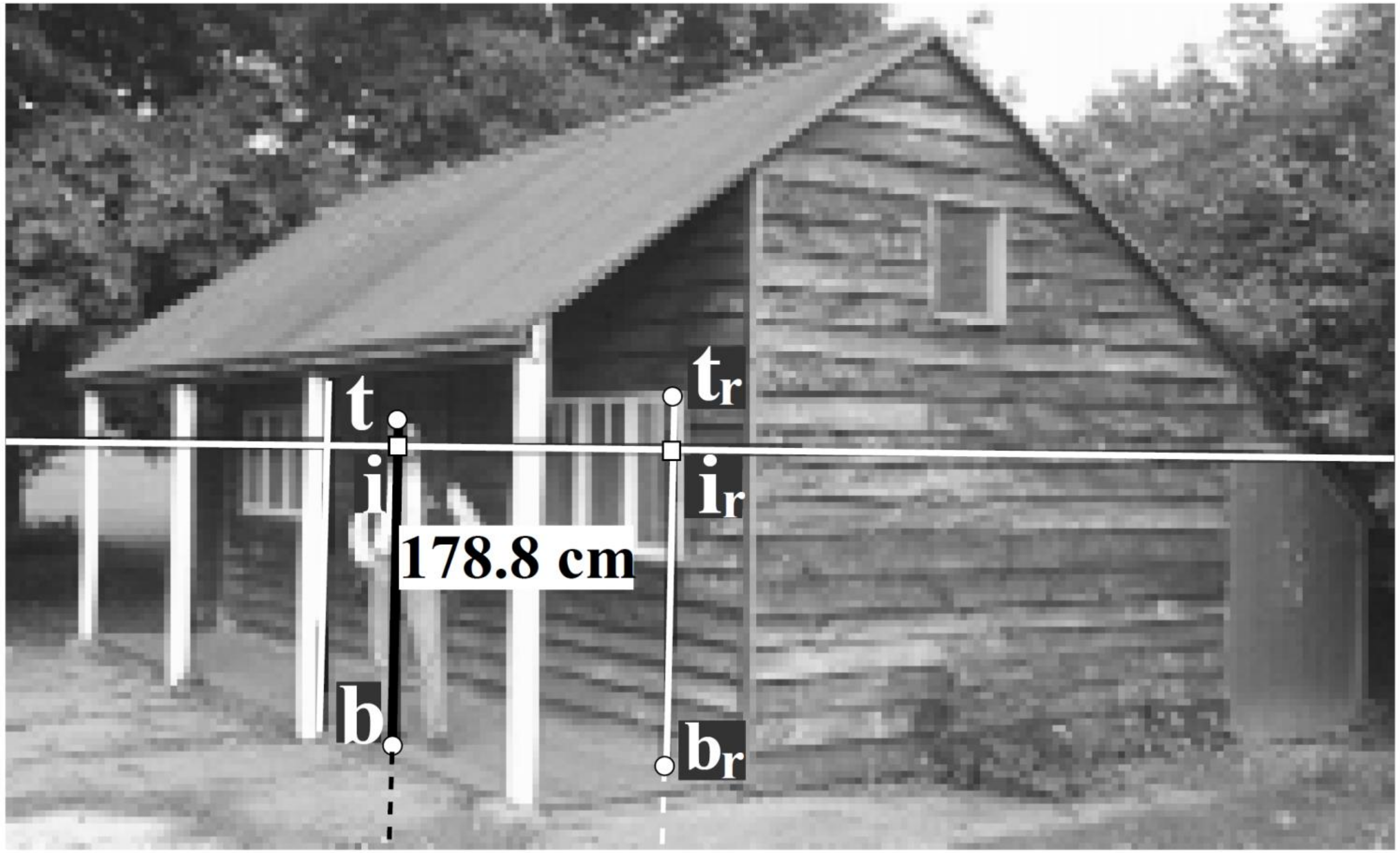
Paper List

- Nister, An Efficient Solution to the Five-Point Relative Pose Problem, PAMI, 2004



Paper List

- Criminisi, Reid, and Zisserman, Single View Metrology, IJCV, 2000



Paper List

- Xiao and Furukawa, Reconstructing the World's Museum, ECCV, 2012

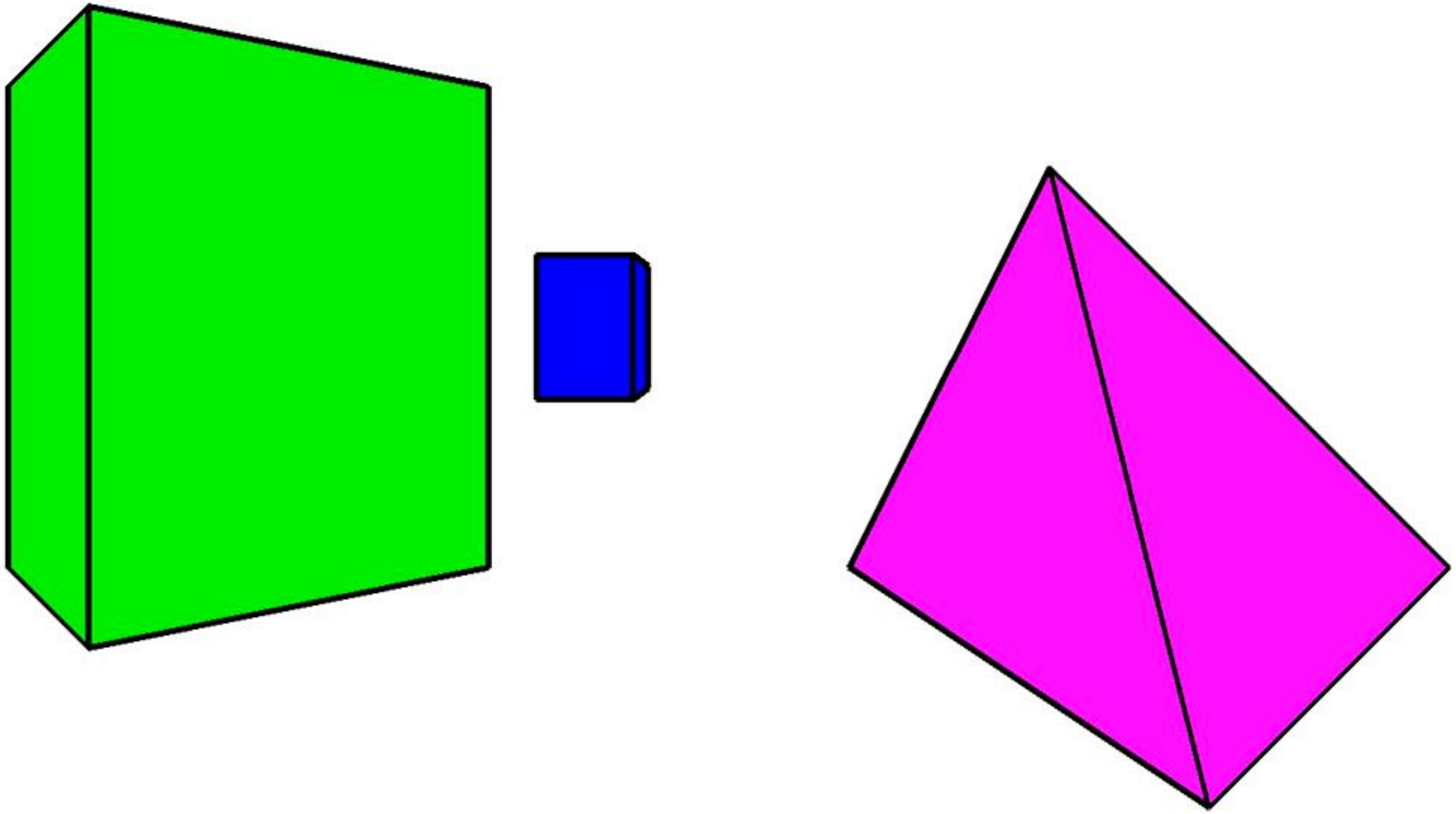
Paper List

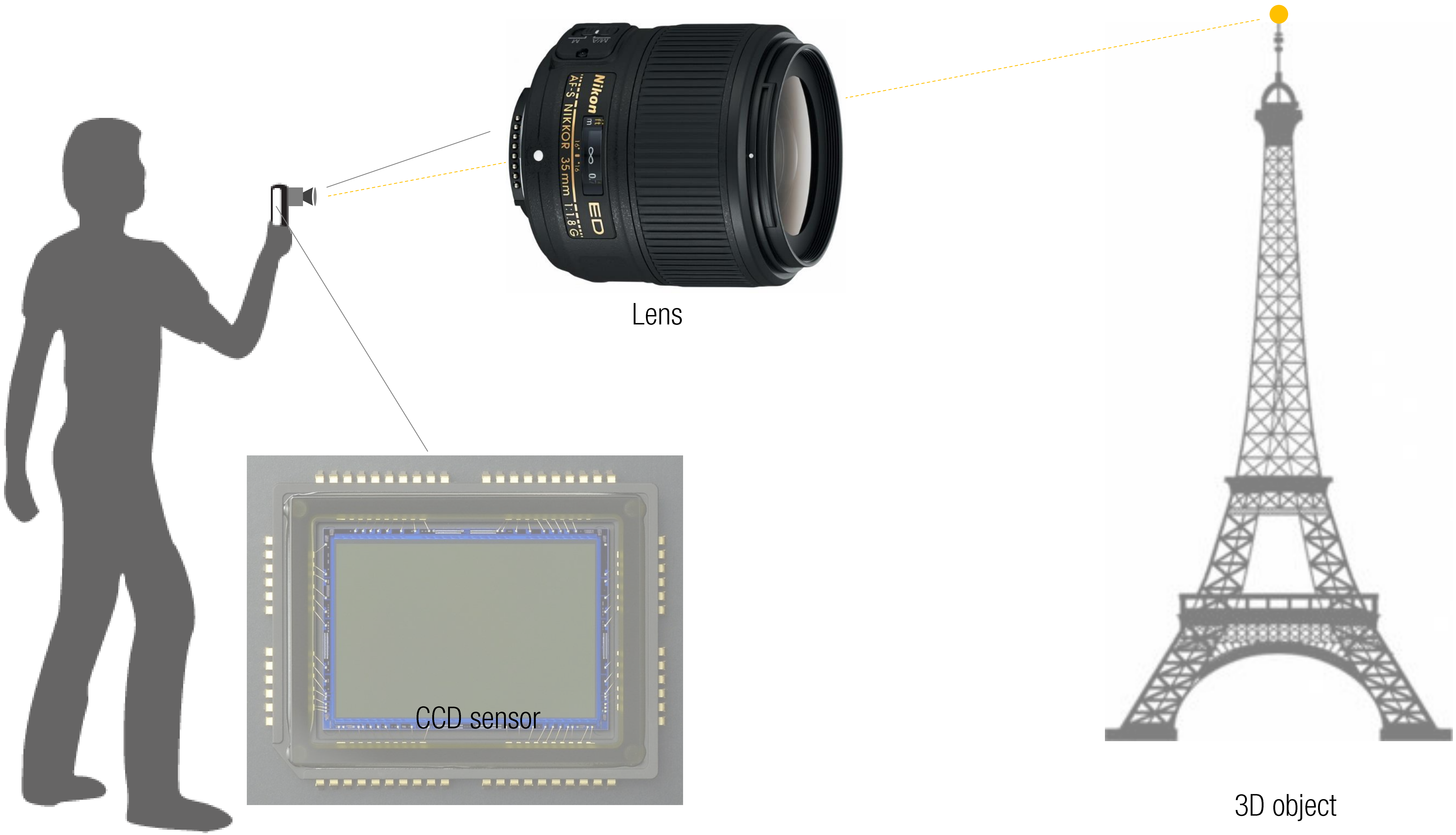
- Izadi et al., KinectFusion, UIST, 2011

Camera Model

VERTIGO (1958)

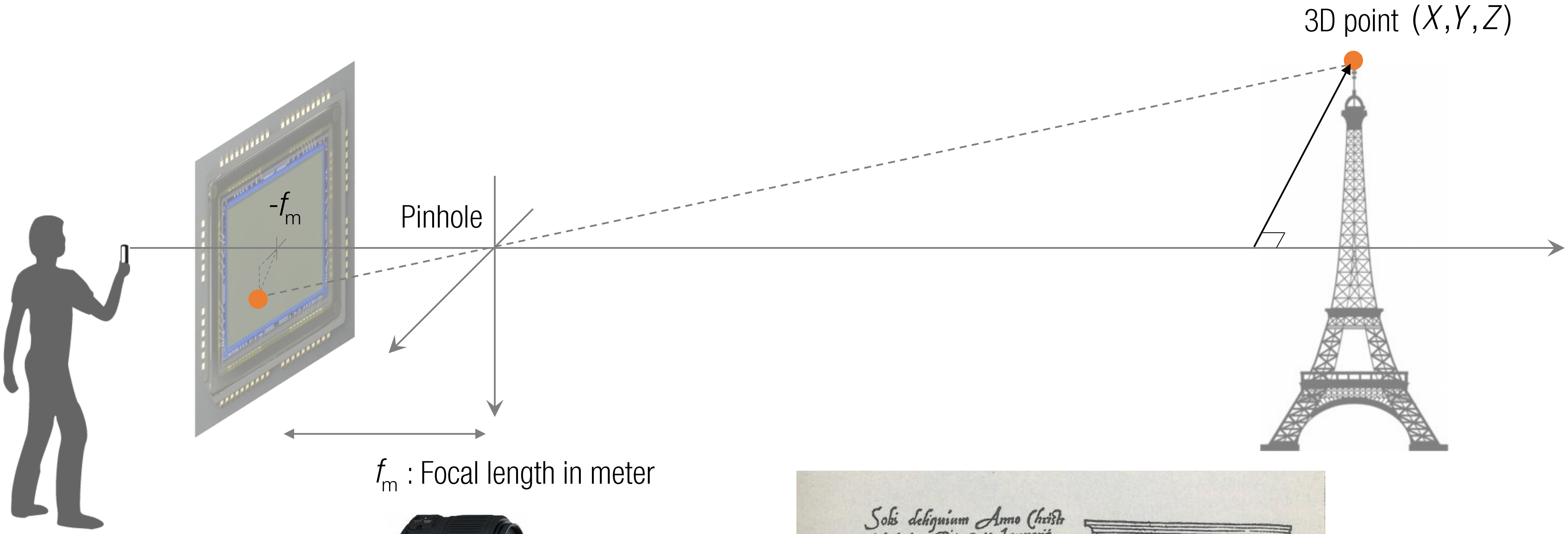
VERTIGO (1958)

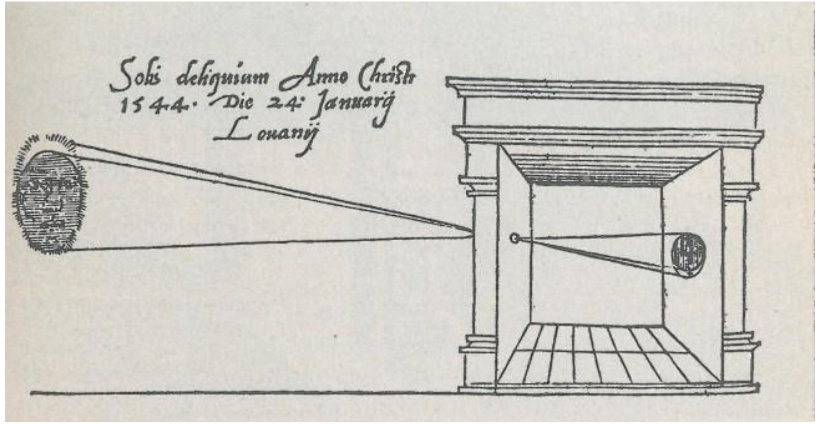




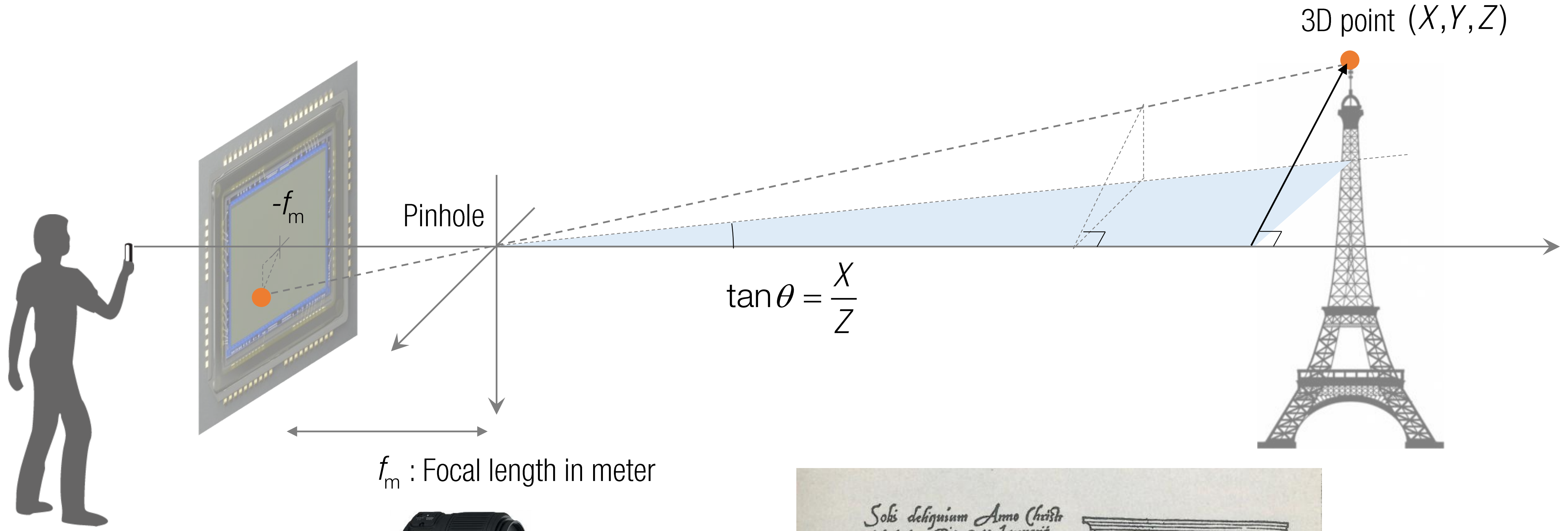
Lens
CCD sensor
3D object

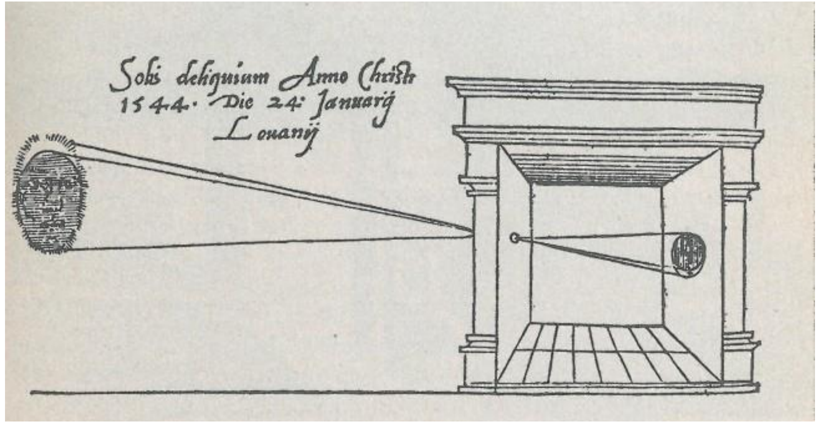
3D Point Projection (Metric Space)



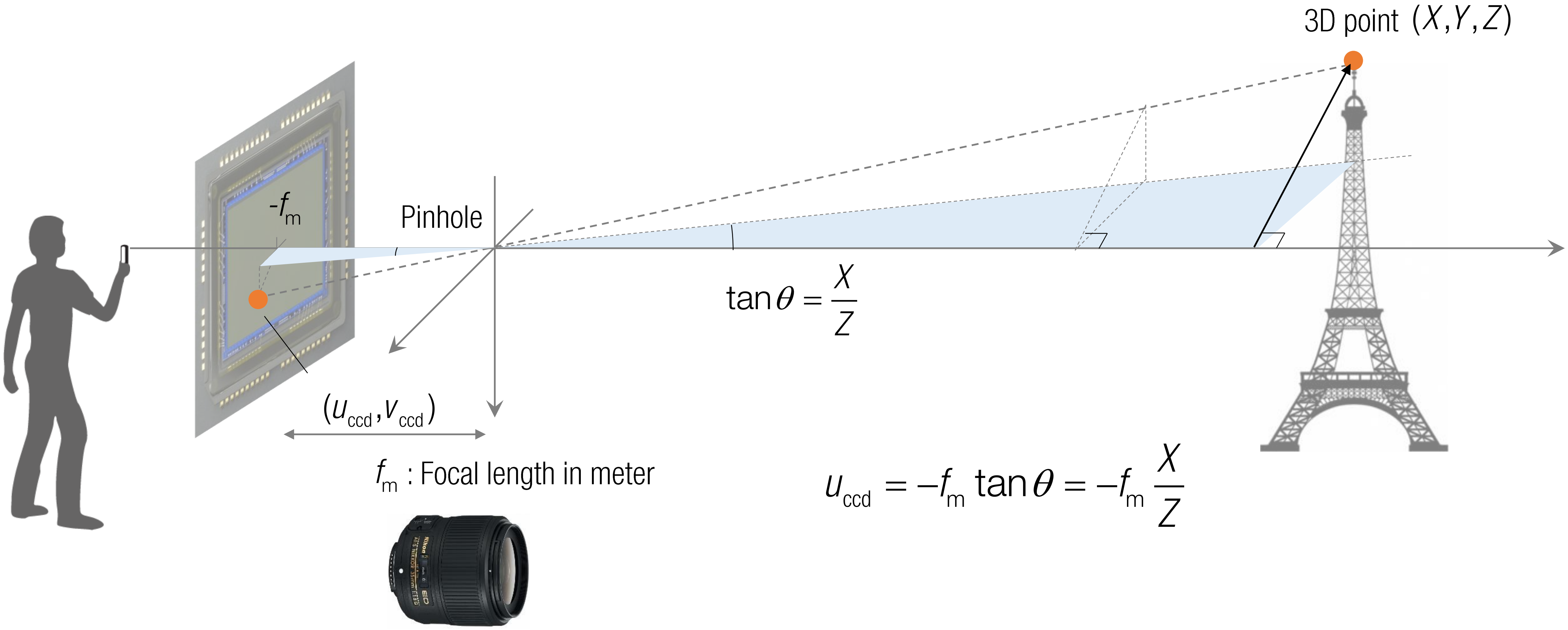


3D Point Projection (Metric Space)



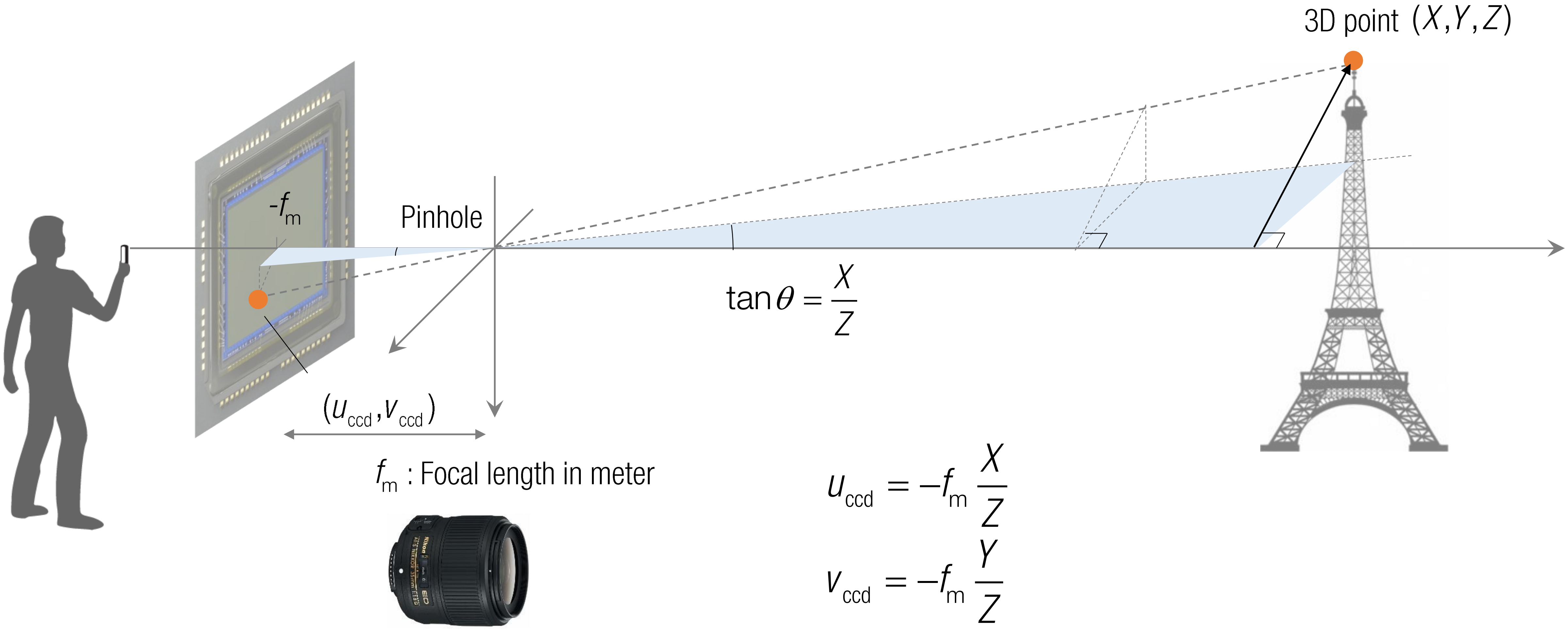


3D Point Projection (Metric Space)



$$u_{ccd} = -f_m \tan\theta = -f_m \frac{X}{Z}$$

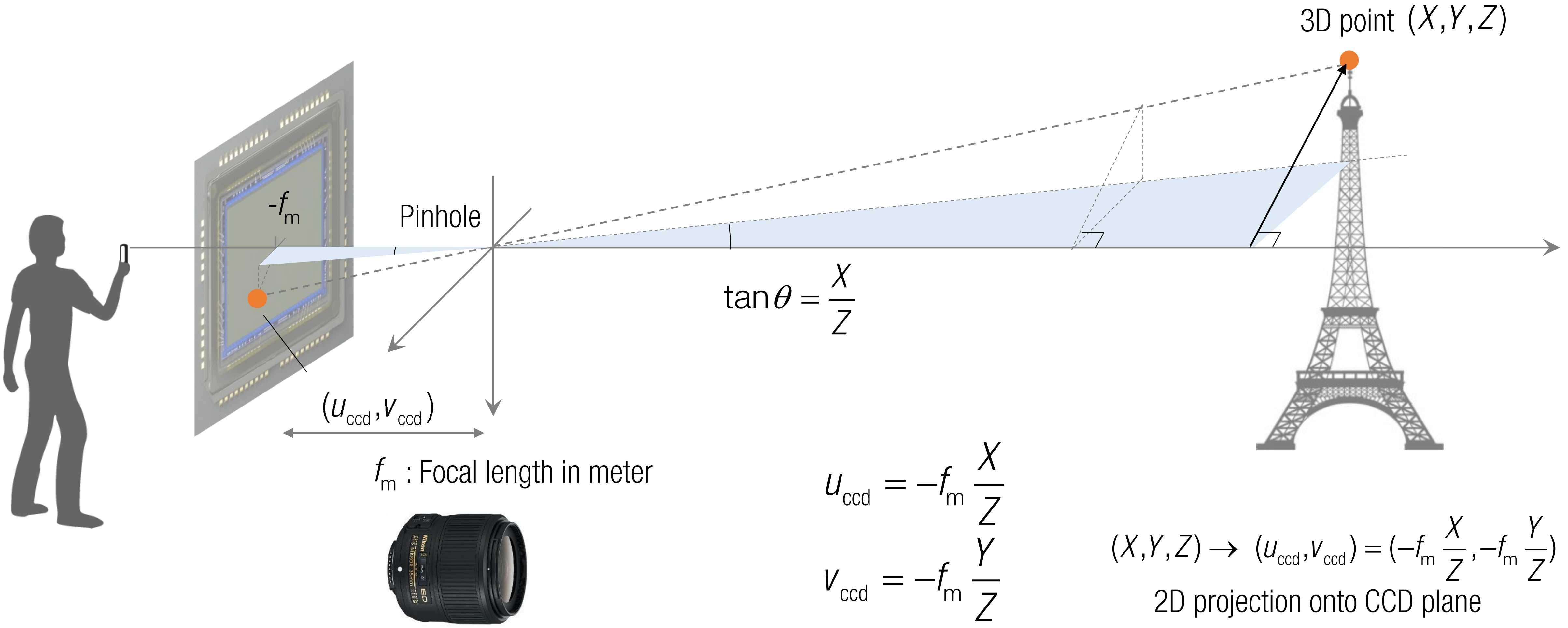
3D Point Projection (Metric Space)



$$u_{ccd} = -f_m \frac{X}{Z}$$

$$v_{ccd} = -f_m \frac{Y}{Z}$$

3D Point Projection (Metric Space)



f_m : Focal length in meter

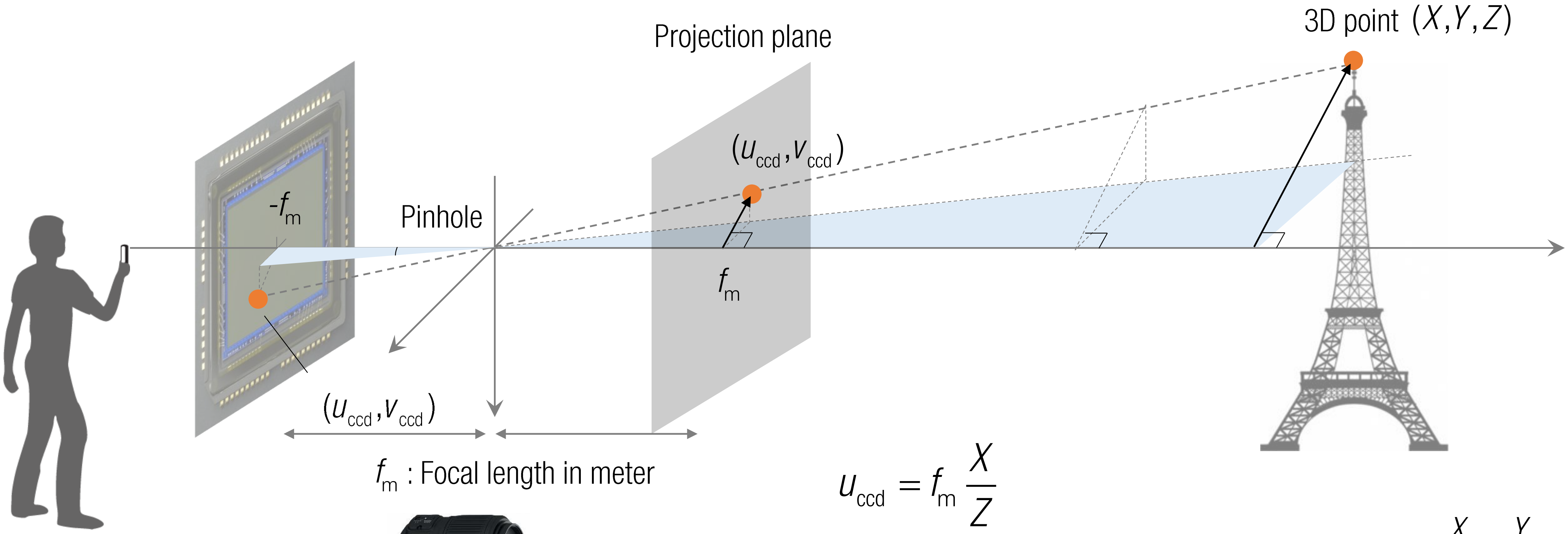
$$u_{ccd} = -f_m \frac{X}{Z}$$

$$v_{ccd} = -f_m \frac{Y}{Z}$$

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

2D projection onto CCD plane

3D Point Projection (Metric Space)



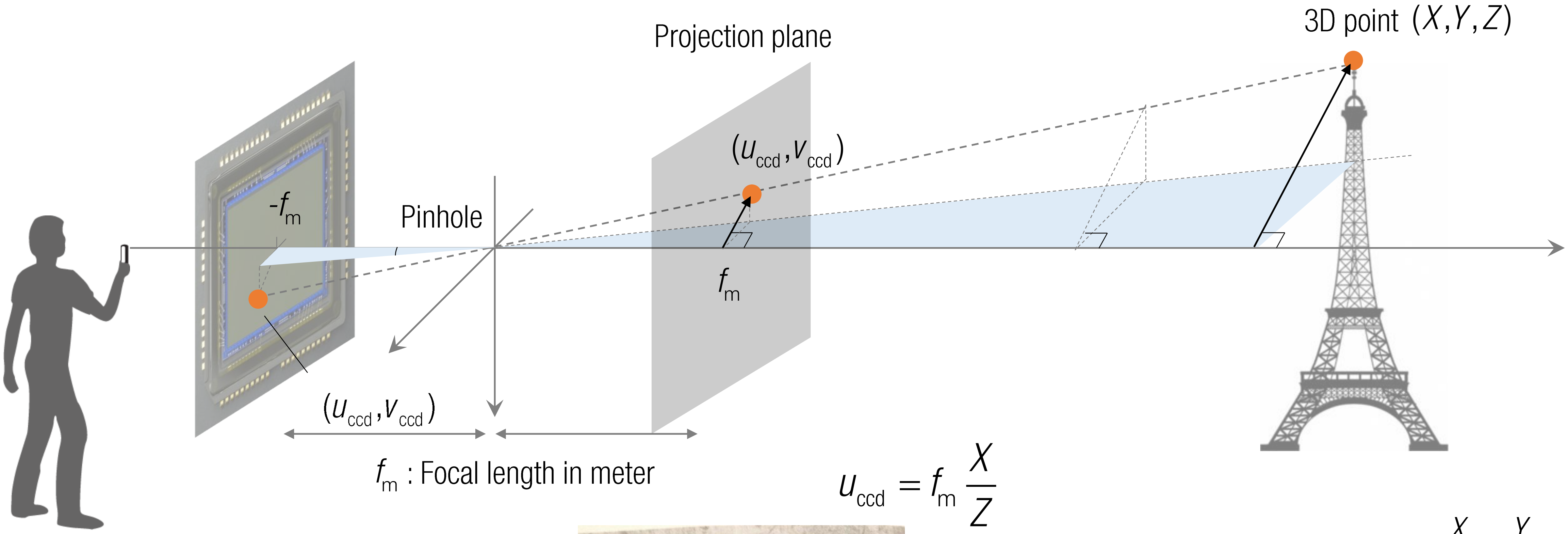
$$u_{ccd} = f_m \frac{X}{Z}$$

$$v_{ccd} = f_m \frac{Y}{Z}$$

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

2D projection onto CCD plane

3D Point Projection (Metric Space)

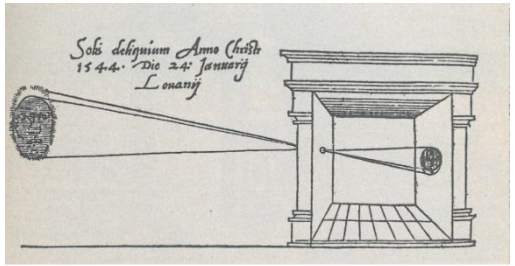


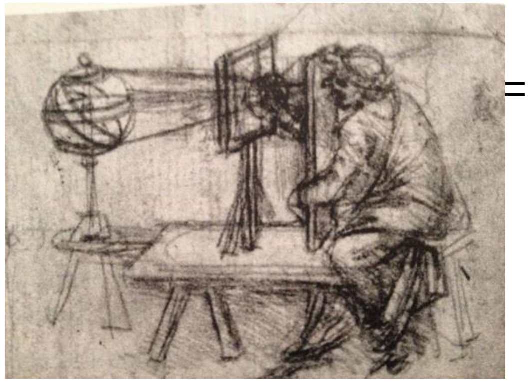
$$u_{ccd} = f_m \frac{X}{Z}$$

$$= f_m \frac{Y}{Z}$$

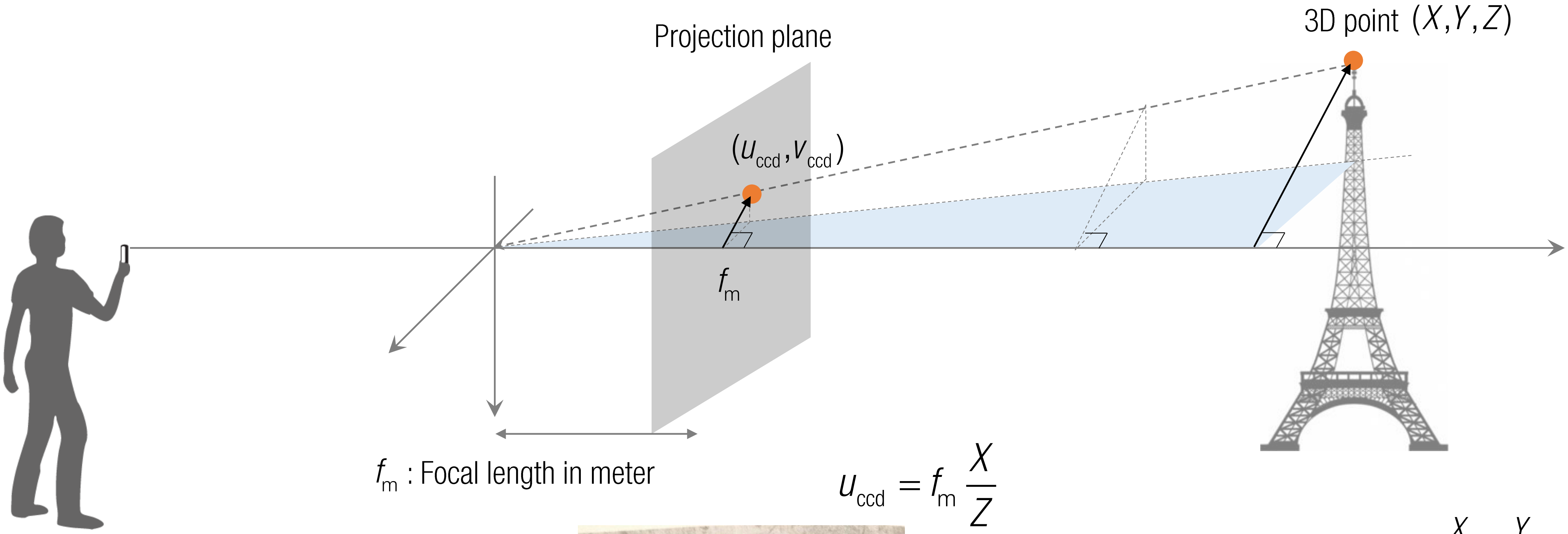
$$(X,Y,Z) \rightarrow \quad (u_{ccd}, v_{ccd}) = (f_m \frac{X}{Z}, f_m \frac{Y}{Z})$$

2D projection onto CCD plane

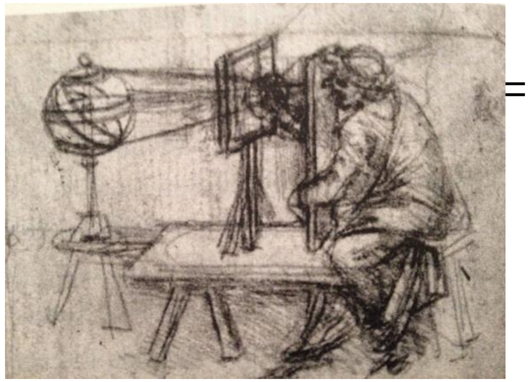




3D Point Projection (Metric Space)



$$u_{ccd} = f_m \frac{X}{Z}$$

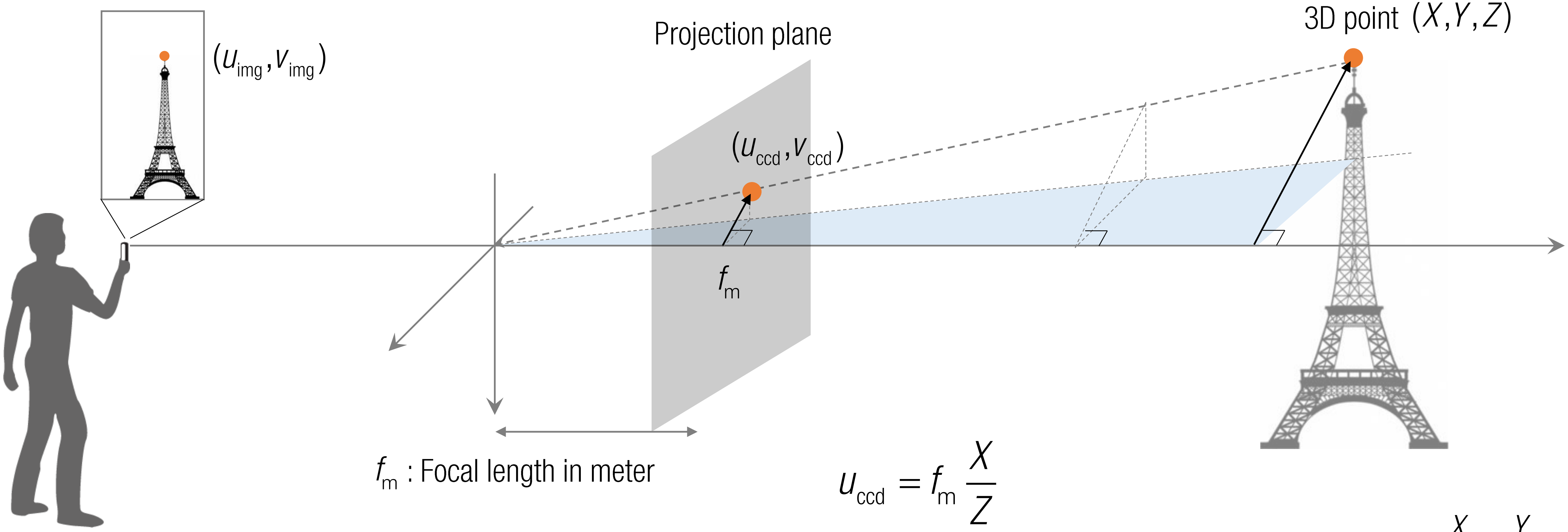


$$= f_m \frac{Y}{Z}$$

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

2D projection onto CCD plane

3D Point Projection (Metric Space)



$$u_{ccd} = f_m \frac{X}{Z}$$

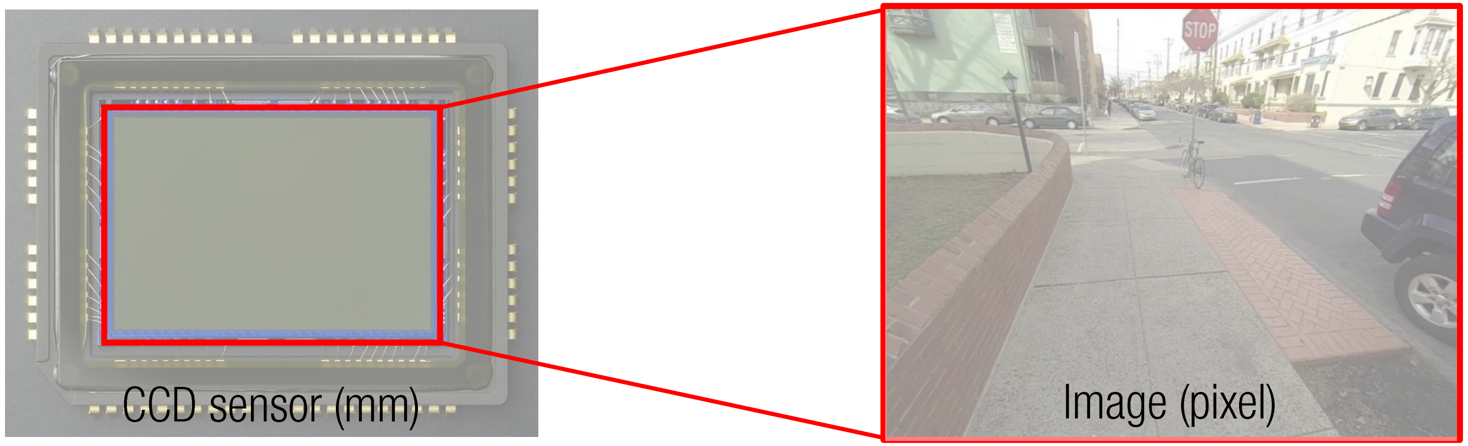
$$v_{ccd} = f_m \frac{Y}{Z}$$

$$\underbrace{(u_{img}, v_{img})}_{\text{Pixel}} \sim \underbrace{(u_{ccd}, v_{ccd})}_{\text{Metric}} \ ?$$

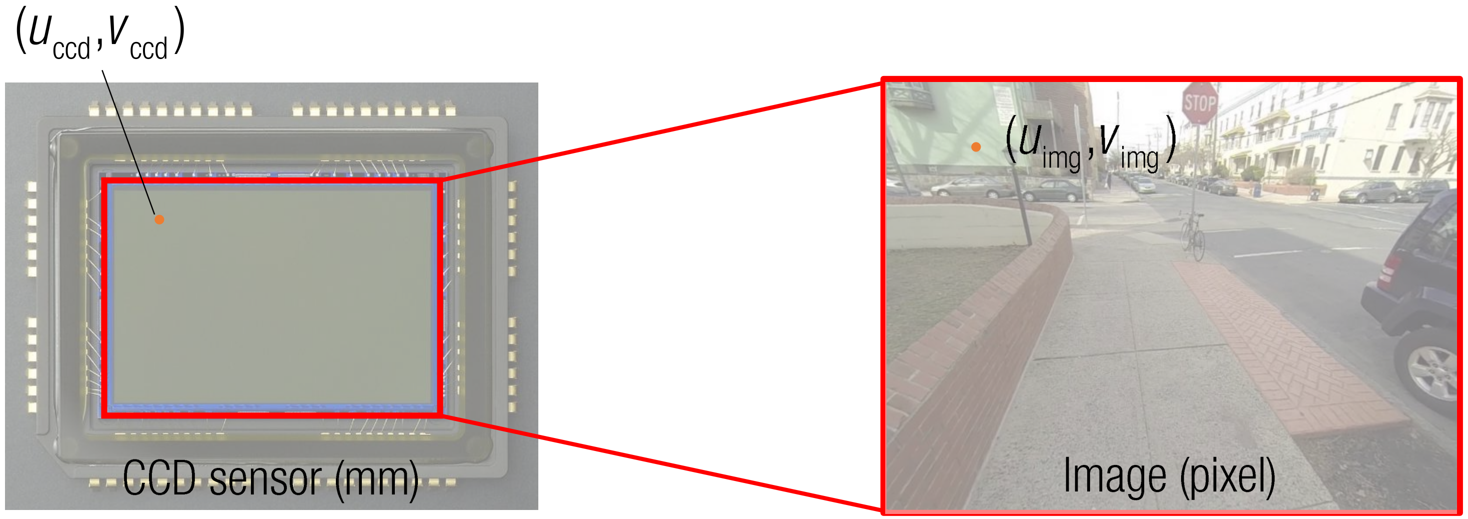
$$(X, Y, Z) \rightarrow \quad (u_{ccd}, v_{ccd}) = (f_m \frac{X}{Z}, f_m \frac{Y}{Z})$$

2D projection onto CCD plane

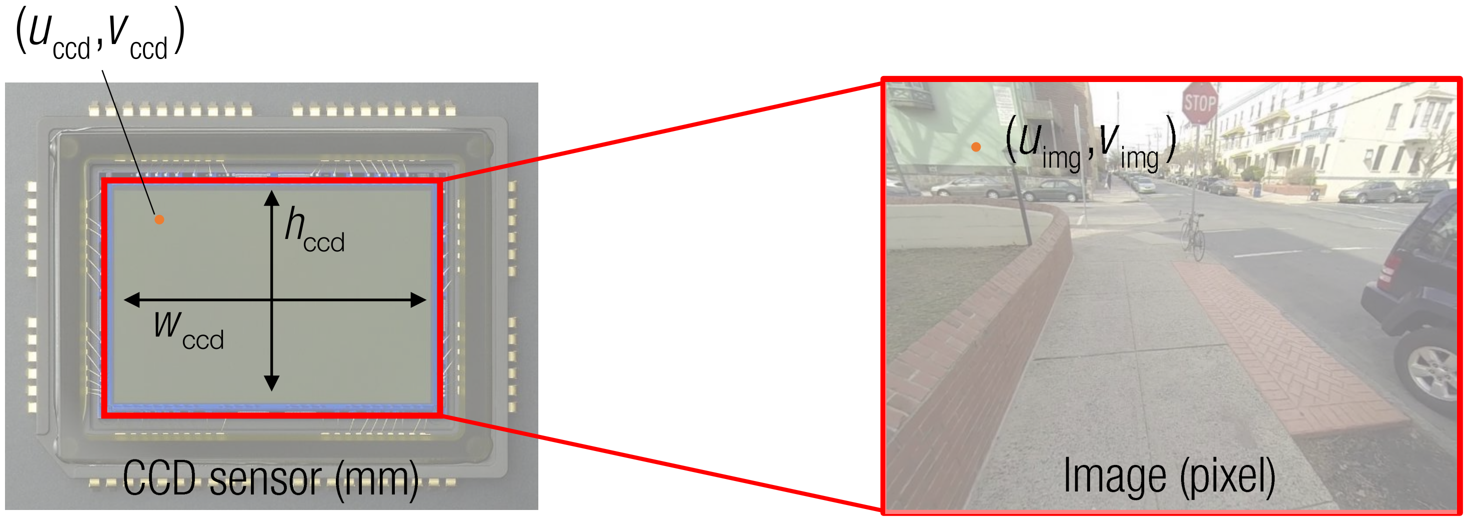
3D Point Projection (Pixel Space)



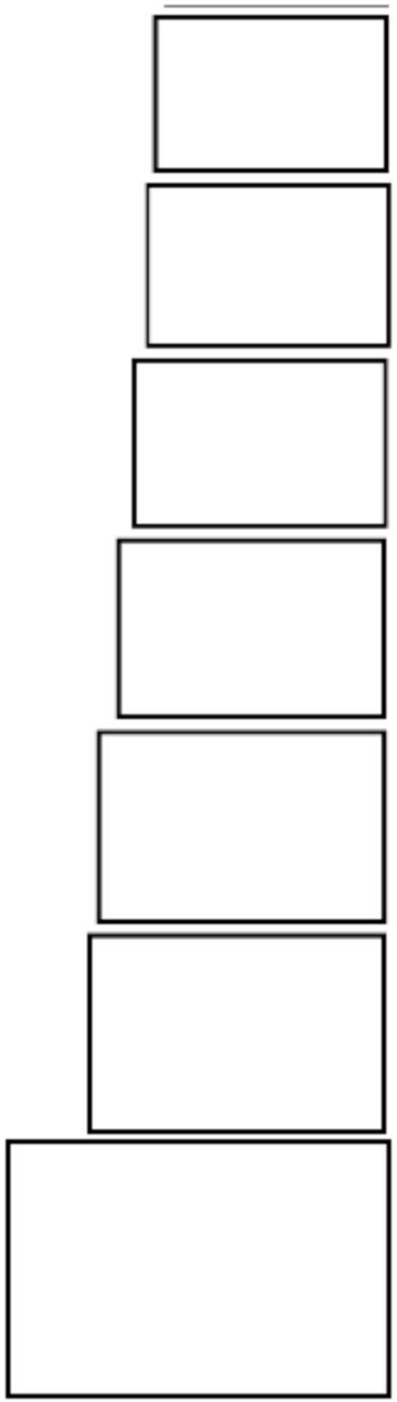
3D Point Projection (Pixel Space)



3D Point Projection (Pixel Space)

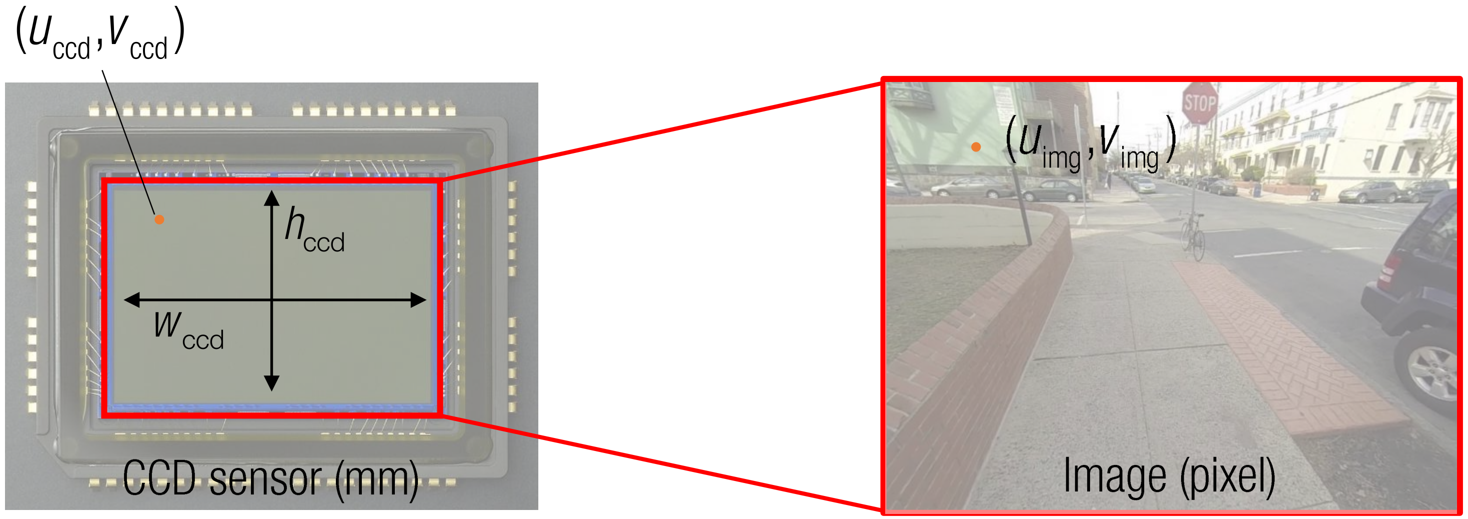


Imager Sizes	Formats (Type)	~Diag.	Uses
	1/7" - 1.85 x 1.39mm	2.3	Cell phones, web cams, etc....
	1/6" - 2.15 x 1.61mm	2.7	Cell phones, web cams, etc....
	1/5" - 2.55 x 1.91mm	3.2	Cell phones, web cams, etc....
	1/4" - 3.2 x 2.4mm	4.0	Cell phones, web cams, etc....
	1/3.6" - 4.0 x 3.0mm	5.0	P&S DSC
	1/3.2" - 4.536 x 3.416mm	5.678	P&S DSC
	1/3" - 4.8 x 3.6mm	6.0	Casio QV-8000SX (1.2MP), Epson PhotoPC 700 (1.2MP)
	1/2.7" - 5.27 x 3.96mm	6.592	Canon PowerShot A20 (1.92MP), HP PhotoSmart C618 (1.92)
	1/2" - 6.4 x 4.8mm	8.0	Olympus C-2100Z (1.92MP), Epson PhotoPC 850Z (1.92)
	1/1.8" - 7.176 x 5.319mm	8.932	Nikon Coolpix 995 (3.14MP), Olympus C-4040Z (3.9MP), Canon PowerShot G2 (3.8MP), Sony DSC-S85 (3.8MP)
	2/3" - 8.8 x 6.6mm	11.0	Nikon Coolpix 5000 (4.92MP), Sony DSC-F707 (4.92MP), Olympus E-10 (3.7MP), Minolta DiMAGE 7 (4.92MP)
	1" - 12.8 x 9.6mm	16.0	Not used in DSCs. Used in some high-end video cameras
	Kodak KAF-5100CE CCD 17.8 x 13.4mm (4/3")	22.28	Olympus announced deveolpment of a new camera and new lenses for this 4/3" size. 2614 x 1966 - 5.1MP - 6.8µm pixel
	Foveon X3 F7-35X3-A25B 20.7 x 13.8mm	24.9	Sigma SD9 (X3) 2268 x 1512 = 3.43MP - 9.12µm pixel 1.74x Focal Length Multiplier (35mm film)

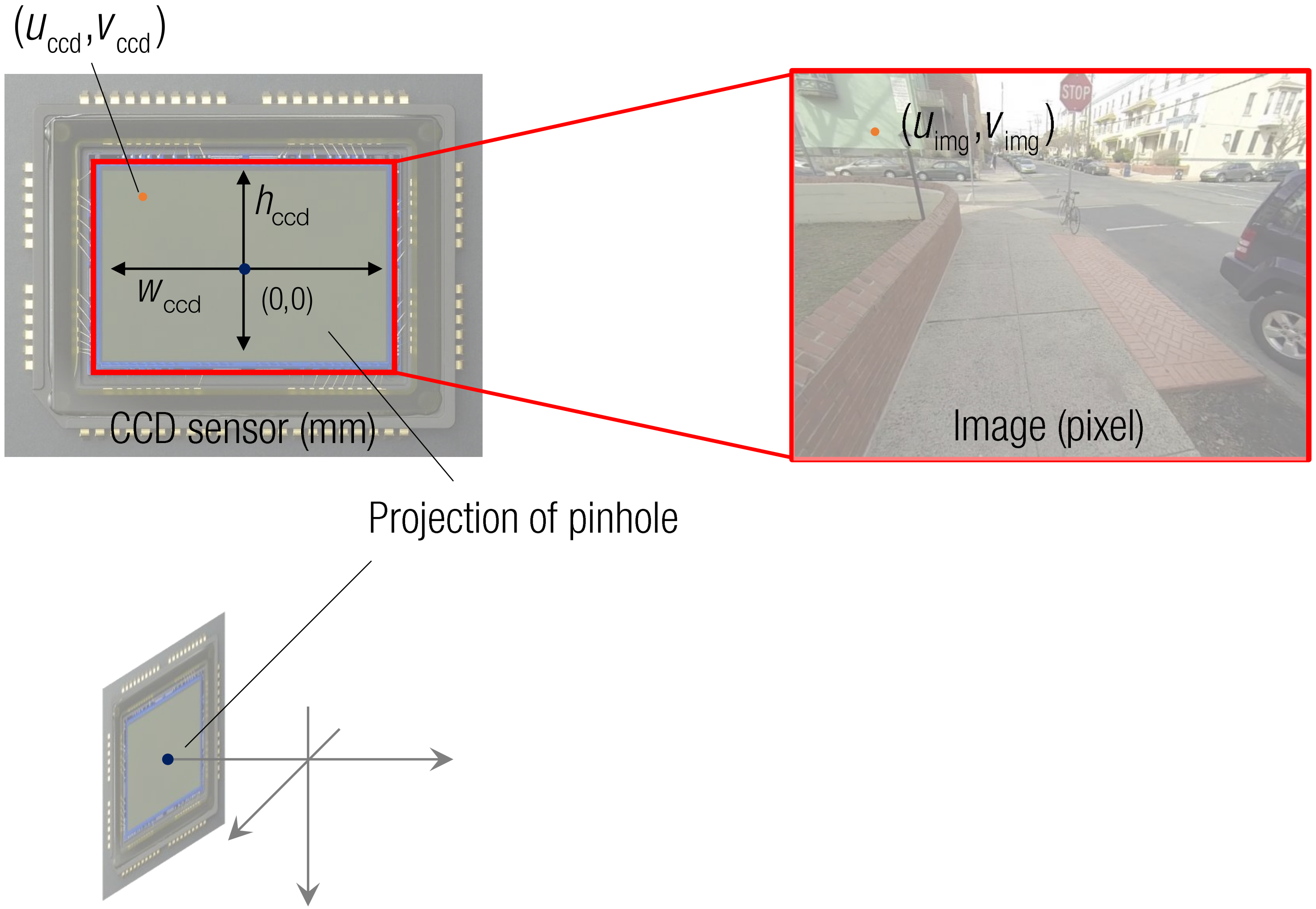


Canon D30 CMOS 21.8 x 14.5mm	26.2	Canon D30 2160 x 1440 = 3.11MP - 10.1µm pixel 1.65x Focal Length Multiplier (35mm film)
Canon D60 CMOS 22.7 x 15.1mm	27.3	Canon D60 3072 x 2048 = 6.3MP - 7.4µm pixel 1.59x Focal Length Multiplier (35mm film)
Nikon D100 CCD Nikon D1x CCD 23.7 x 15.6mm	28.2	Nikon D100 - 3008 x 2000 = 6.1MP - 7.8µm pixel Nikon D1x - 4024 x 1324 = 5.24MP - 5.9 x 11.7µm pixel 1.52x Focal Length Multiplier (35mm film)
APS Film 25.1 x 16.7mm	30.148	APS cameras 1.44x Focal Length Multiplier (35mm film)
Canon EOS-1D CCD 27.0 x 17.8mm	32.3	Canon EOS-1D 2464 x 1648 = 4.06MP - 10.8µm pixel 1.34x Folcal Length Multiplier (35mm Film)
Kodak KAF-6303CE CCD 27.8 x 18.5mm	33.4	Kodak 760 3088 x 2056 = 6.35MP - 9.0µm pixel 1.30x Focal Length Multiplier (35mm film)
35mm Film Canon 1Ds Kodak 14n 36.0 x 24.0mm	43.27	35mm film cameras Canon 1Ds - 4064 x 2704 = 10.99MP - 8.85µm pixel Kodak DCS Pro 14n - 4536 x 3024 = 13.7MP - 7.94µm pixel

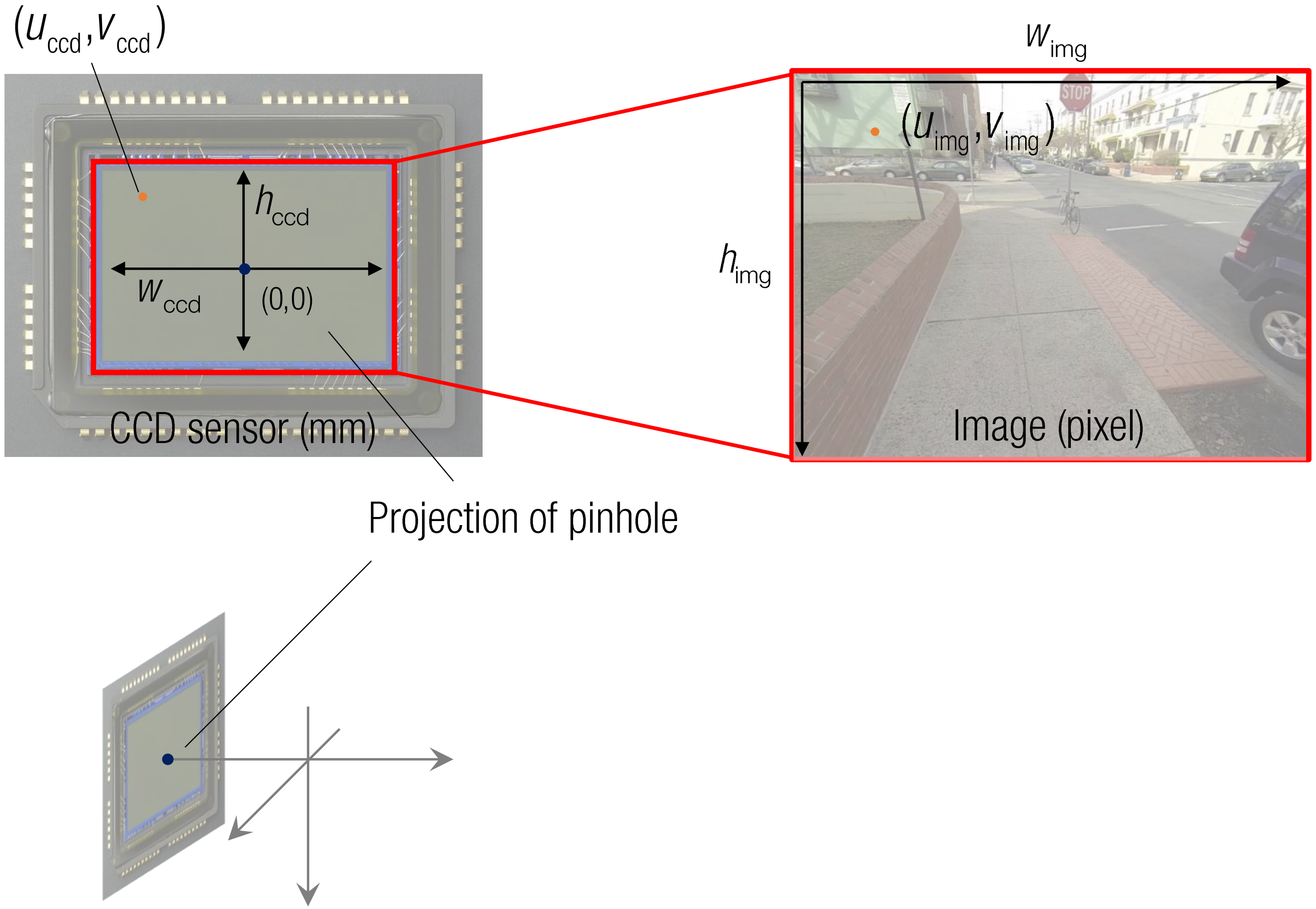
3D Point Projection (Pixel Space)



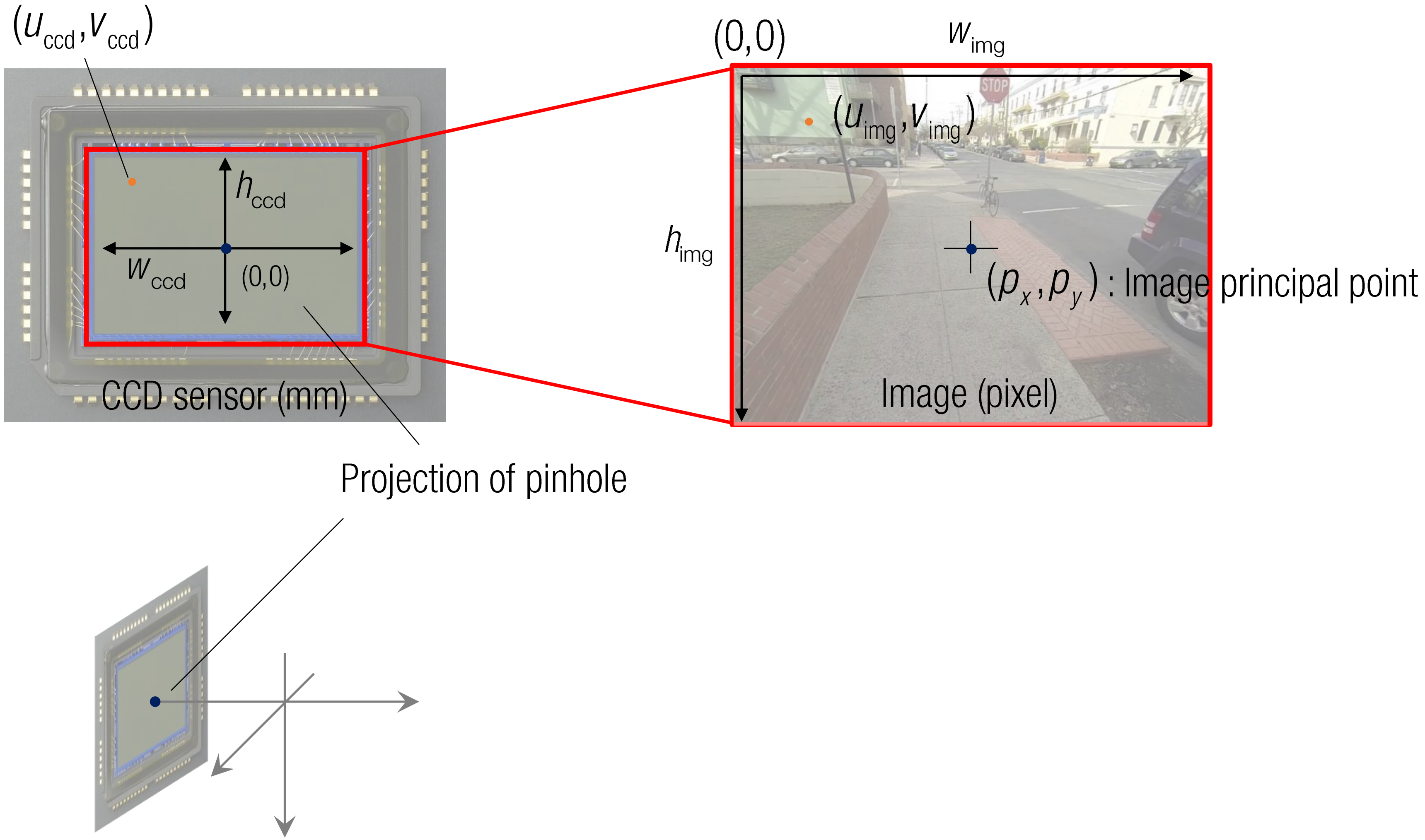
3D Point Projection (Pixel Space)



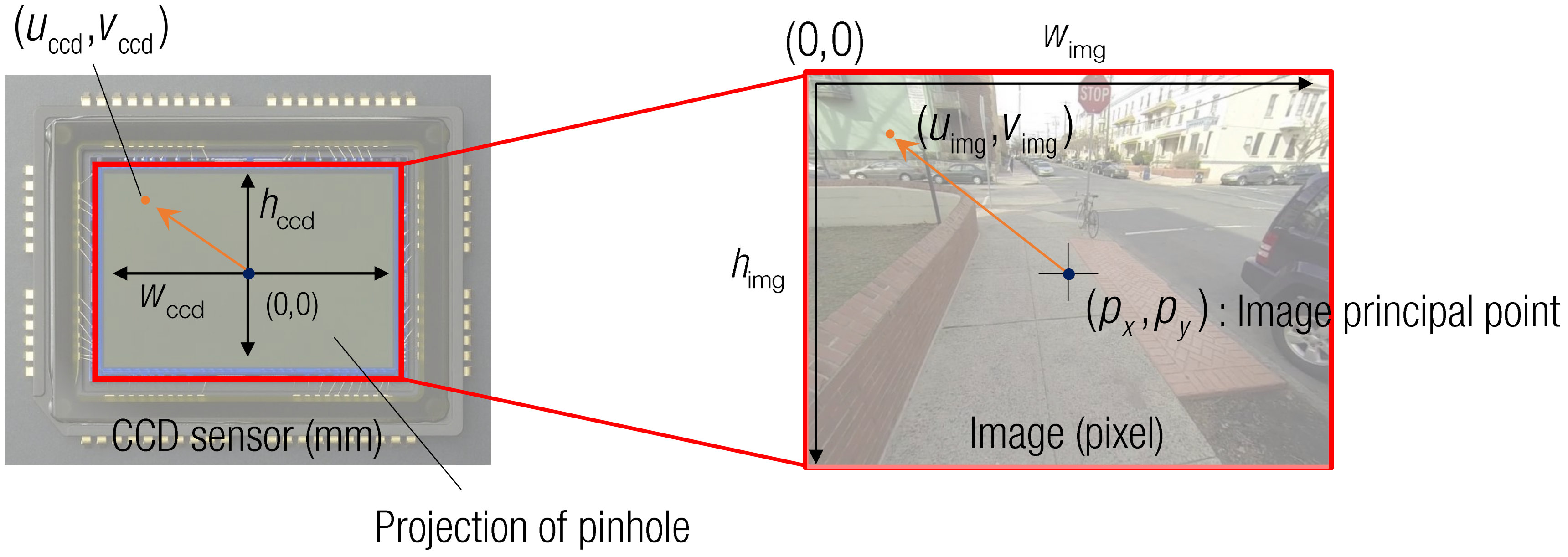
3D Point Projection (Pixel Space)

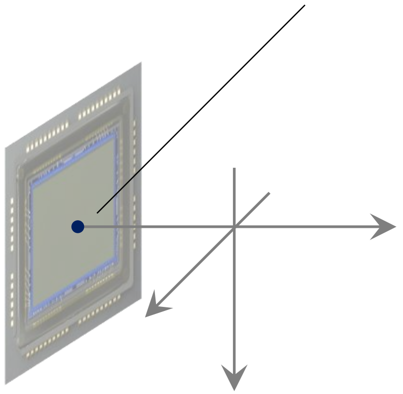


3D Point Projection (Pixel Space)



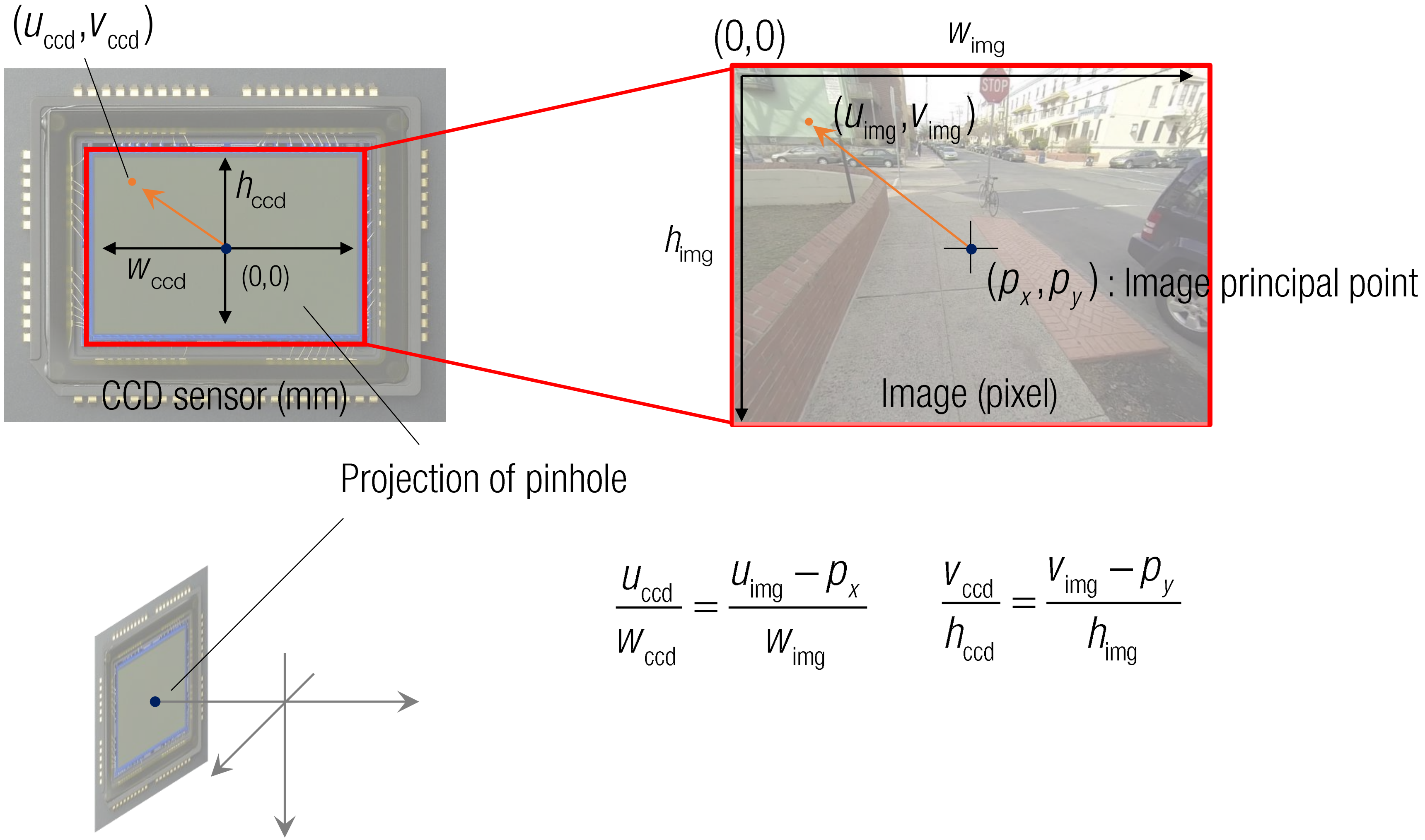
3D Point Projection (Pixel Space)





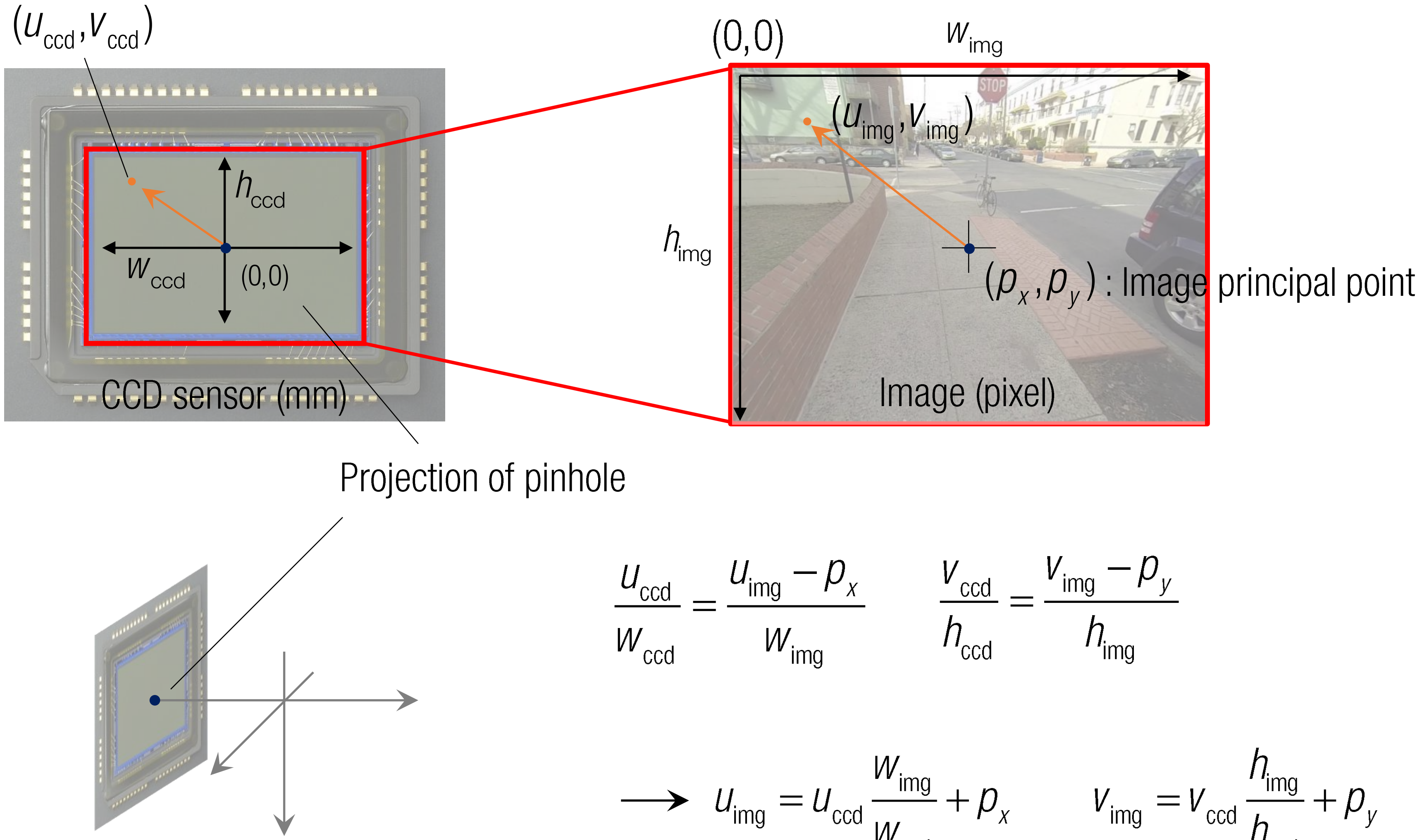
$$\frac{u_{ccd}}{w_{ccd}} = \frac{u_{img} - p_x}{w_{img}}$$

3D Point Projection (Pixel Space)



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

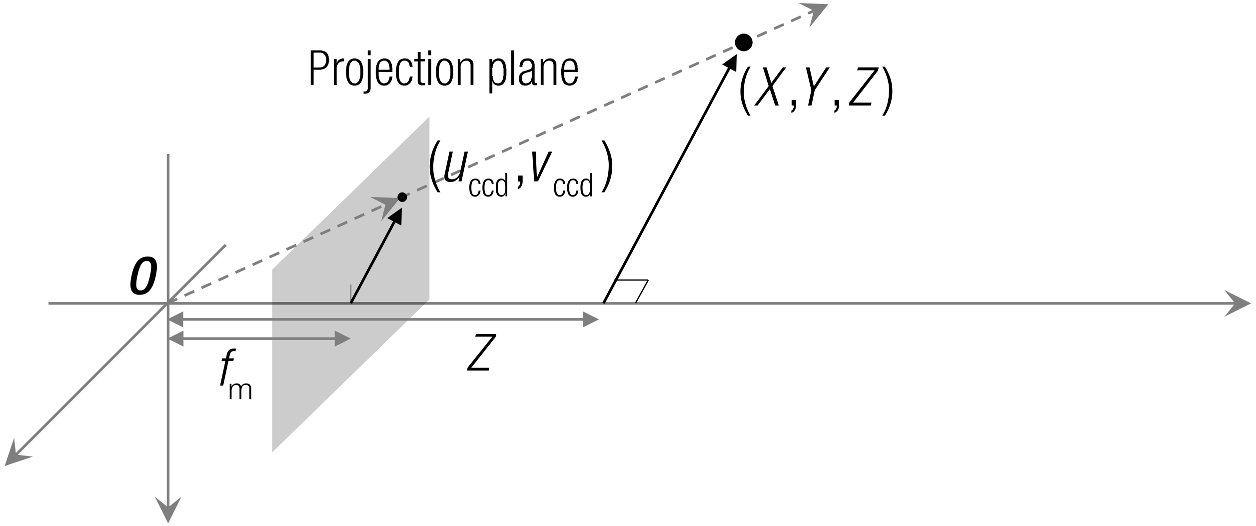
3D Point Projection (Pixel Space)



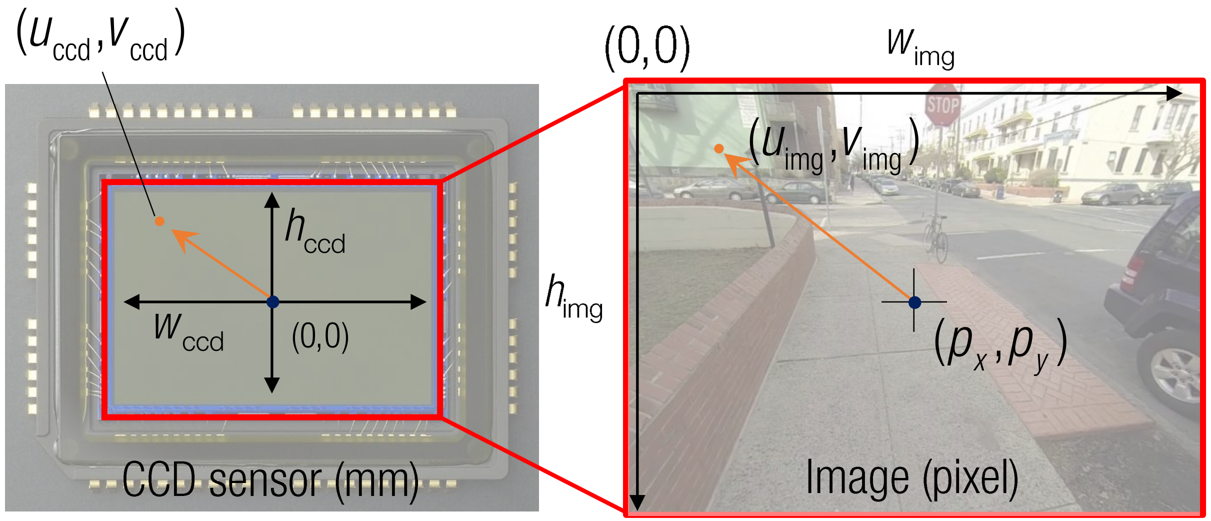
$$\frac{u_{ccd}}{w_{ccd}} = \frac{u_{img} - p_x}{w_{img}} \qquad \frac{v_{ccd}}{h_{ccd}} = \frac{v_{img} - p_y}{h_{img}}$$

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

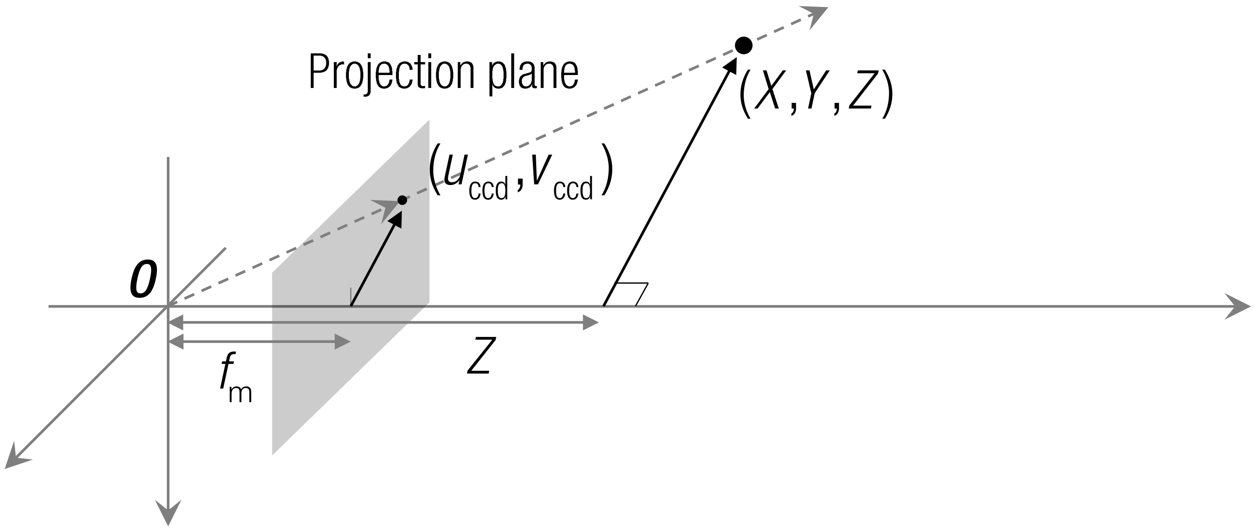
3D Point Projection (Pixel Space)

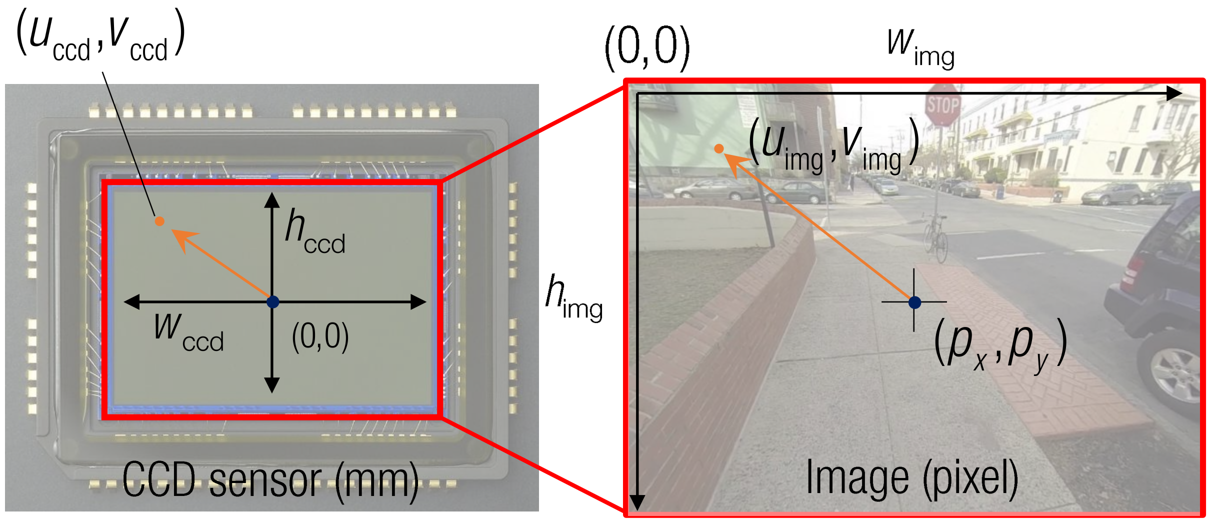


$$(u_{ccd}, v_{ccd}) = (f_m \frac{X}{Z}, f_m \frac{Y}{Z})$$: Metric projection



3D Point Projection (Pixel Space)





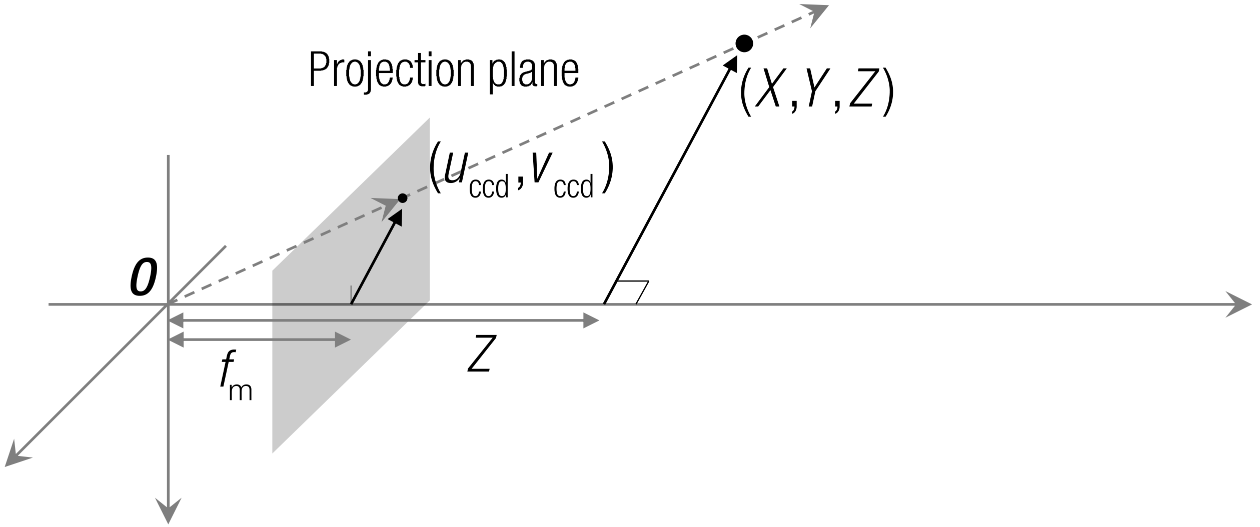
$$(u_{ccd}, v_{ccd}) = (f_m \frac{X}{Z}, f_m \frac{Y}{Z})$$: Metric projection

Pixel projection

$$\longrightarrow \quad u_{img} = u_{ccd} \frac{w_{img}}{w_{ccd}} + p_x$$

$$v_{img} = v_{ccd} \frac{h_{img}}{h_{ccd}} + p_y$$

3D Point Projection (Pixel Space)

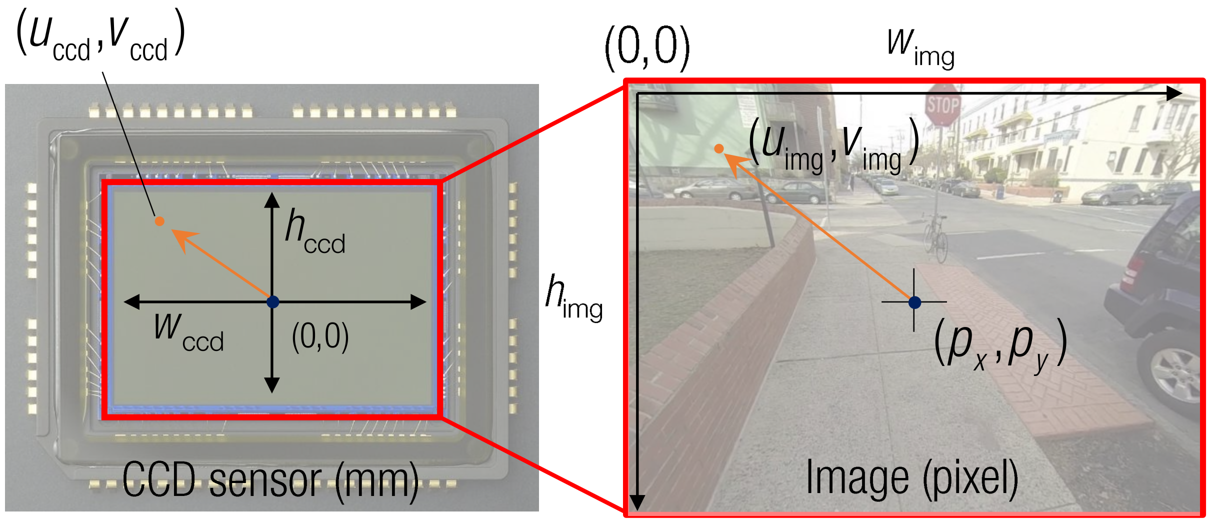


$$(u_{ccd}, v_{ccd}) = \left(f_m \frac{X}{Z}, f_m \frac{Y}{Z}\right)$$: Metric projection

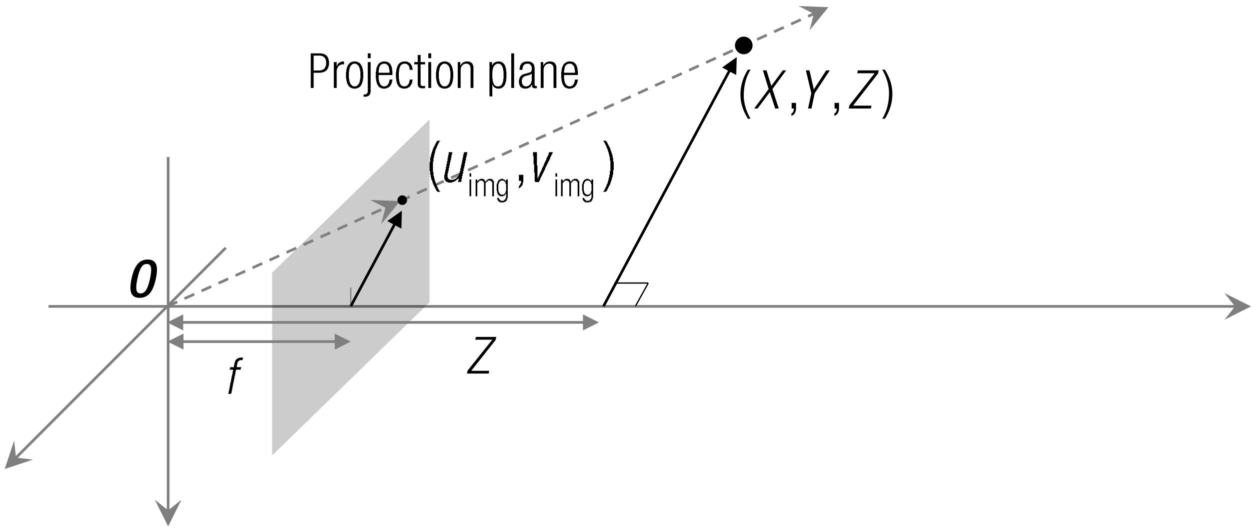
Pixel projection

$$\longrightarrow \quad u_{img} = u_{ccd} \frac{w_{img}}{w_{ccd}} + p_x = f_m \frac{w_{img}}{w_{ccd}} \frac{X}{Z} + p_x$$

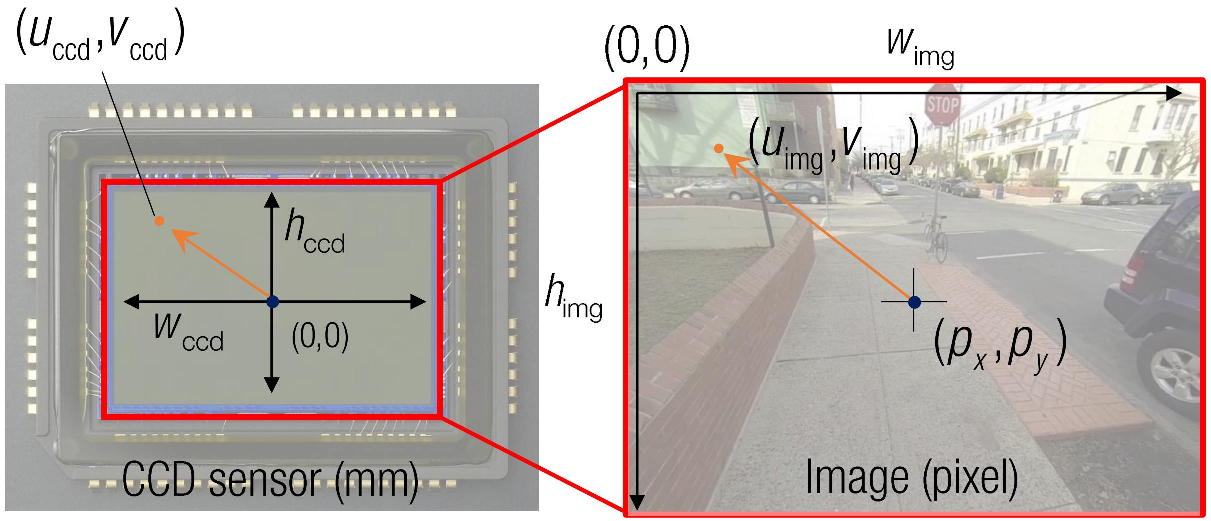
$$v_{img} = v_{ccd} \frac{h_{img}}{h_{ccd}} + p_y = f_m \frac{h_{img}}{h_{ccd}} \frac{Y}{Z} + p_y$$



3D Point Projection (Pixel Space)



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



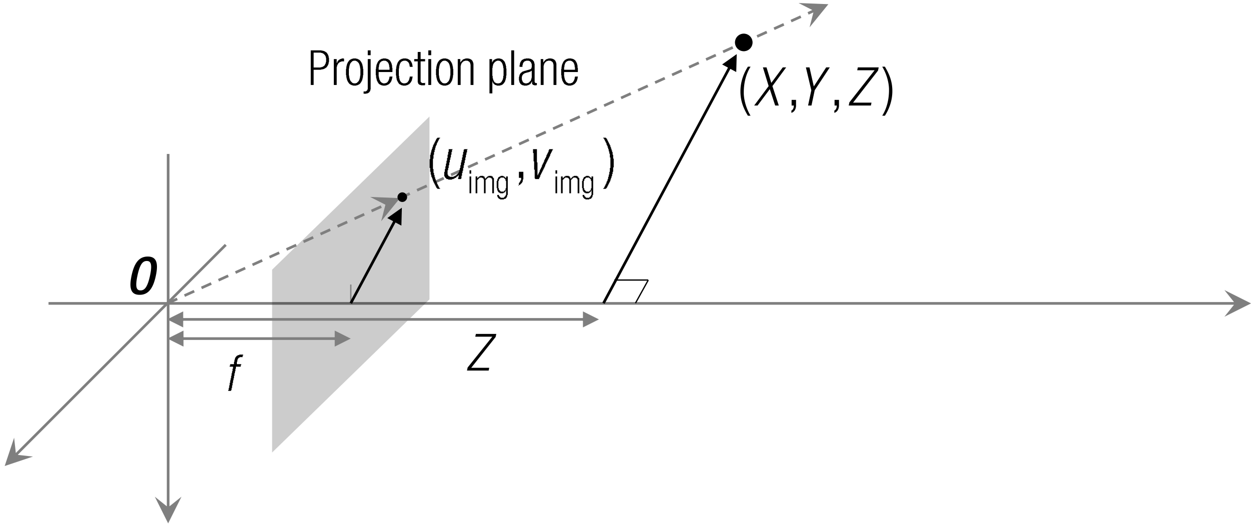
Pixel projection

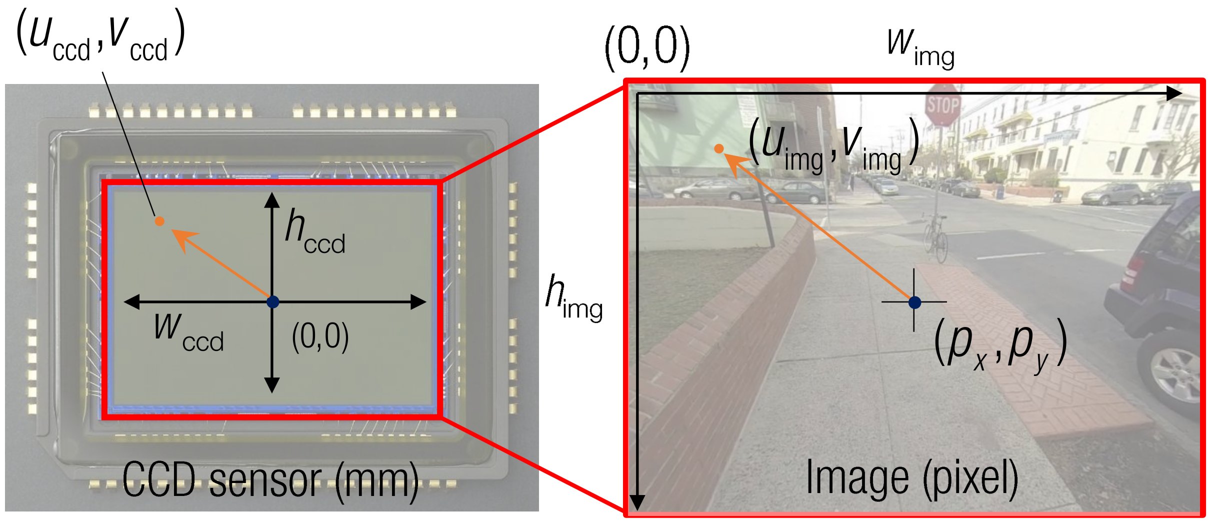
$$\longrightarrow u_{img} = u_{ccd} \frac{w_{img}}{w_{ccd}} + p_x = f_m \frac{w_{img}}{w_{ccd}} \frac{X}{Z} + p_x$$

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

Focal length in pixel

3D Point Projection (Pixel Space)





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

Pixel projection

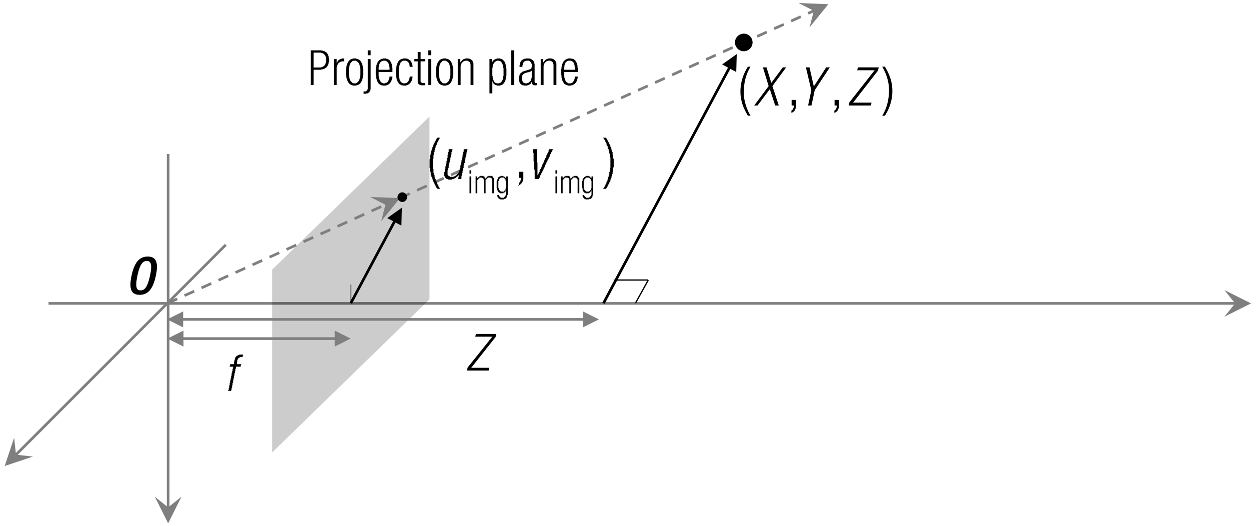
$$\longrightarrow \quad u_{img} = u_{ccd} \frac{w_{img}}{w_{ccd}} + p_x = f_x \frac{X}{Z} + p_x$$

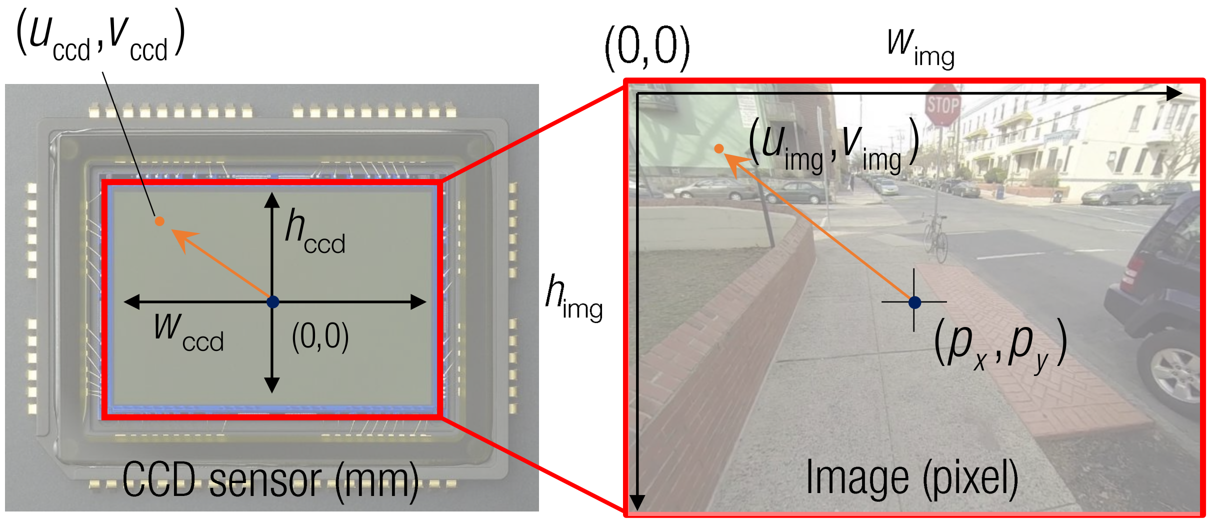
$$v_{img} = v_{ccd} \frac{h_{img}}{h_{ccd}} + p_y = f_y \frac{Y}{Z} + p_y$$

Focal length in pixel

where $f_x = f_m \frac{w_{img}}{w_{ccd}}$ $\quad f_y = f_m \frac{h_{img}}{h_{ccd}}$

3D Point Projection (Pixel Space)





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

: Metric projection

Pixel projection

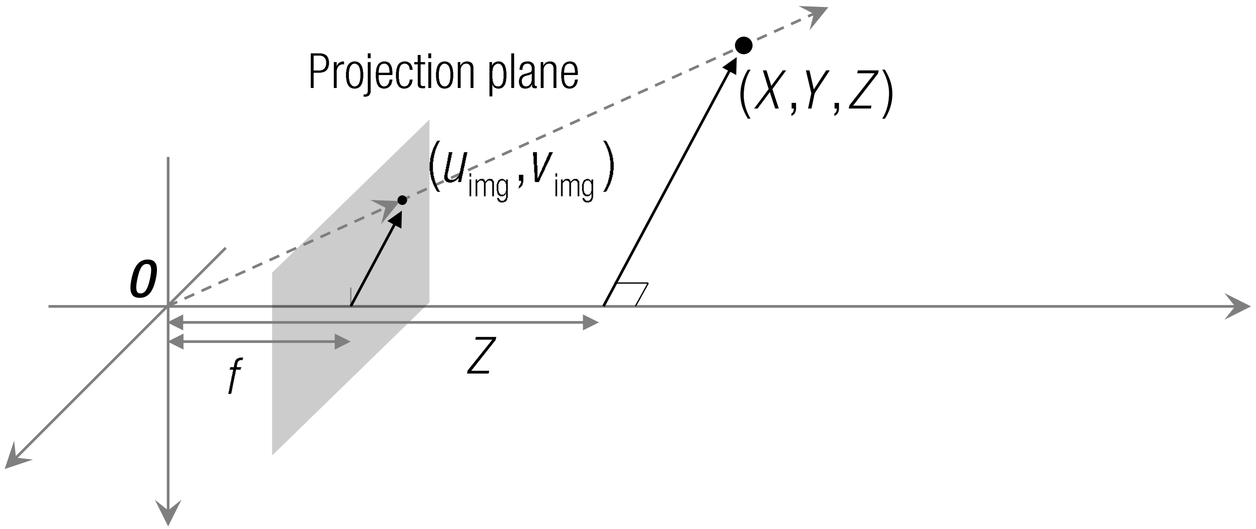
$$\longrightarrow u_{img} = u_{ccd} \frac{w_{img}}{w_{ccd}} + p_x = f \frac{X}{Z} + p_x$$

$$v_{img} = v_{ccd} \frac{h_{img}}{h_{ccd}} + p_y = f \frac{Y}{Z} + p_y$$

Focal length in pixel

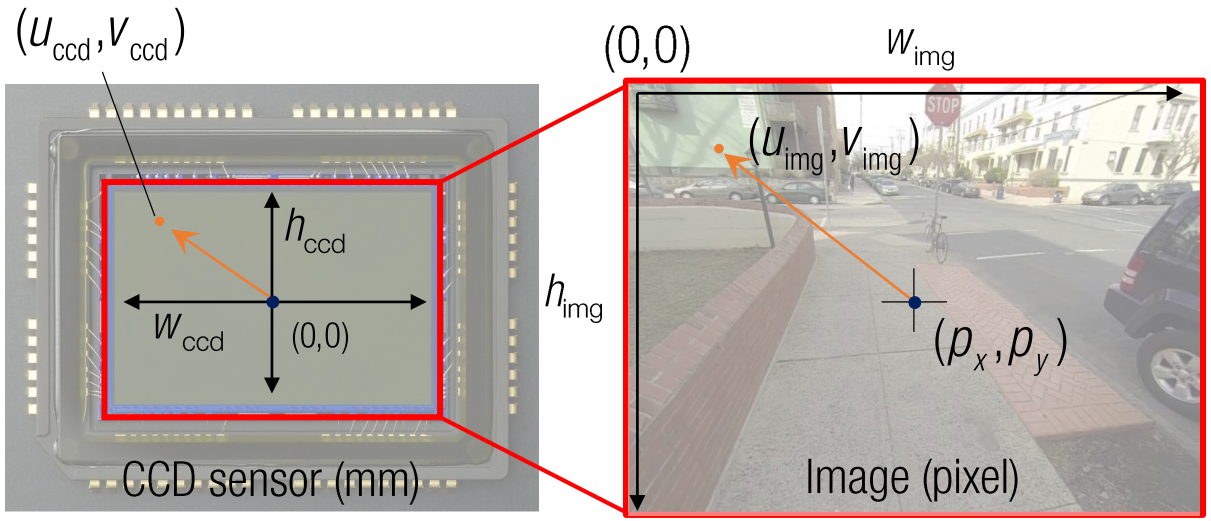
where $f = f_m \frac{w_{img}}{w_{ccd}} = f_m \frac{h_{img}}{h_{ccd}}$ if $\frac{w_{img}}{w_{ccd}} = \frac{h_{img}}{h_{ccd}}$

3D Point Projection (Pixel Space)

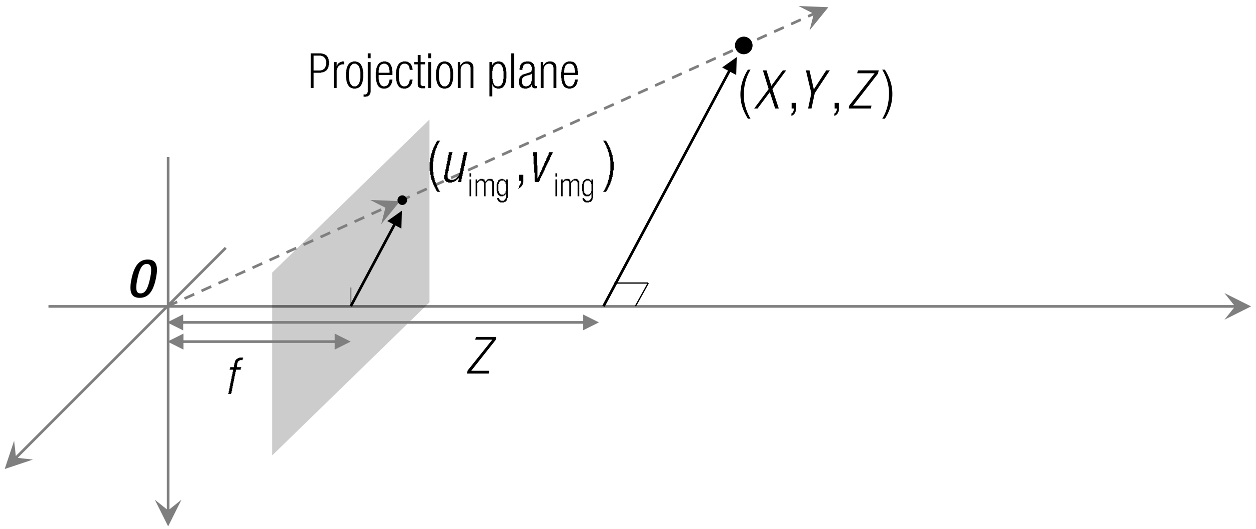


$$u_{img} = f\frac{X}{Z} + p_x$$

$$v_{img} = f\frac{Y}{Z} + p_y$$

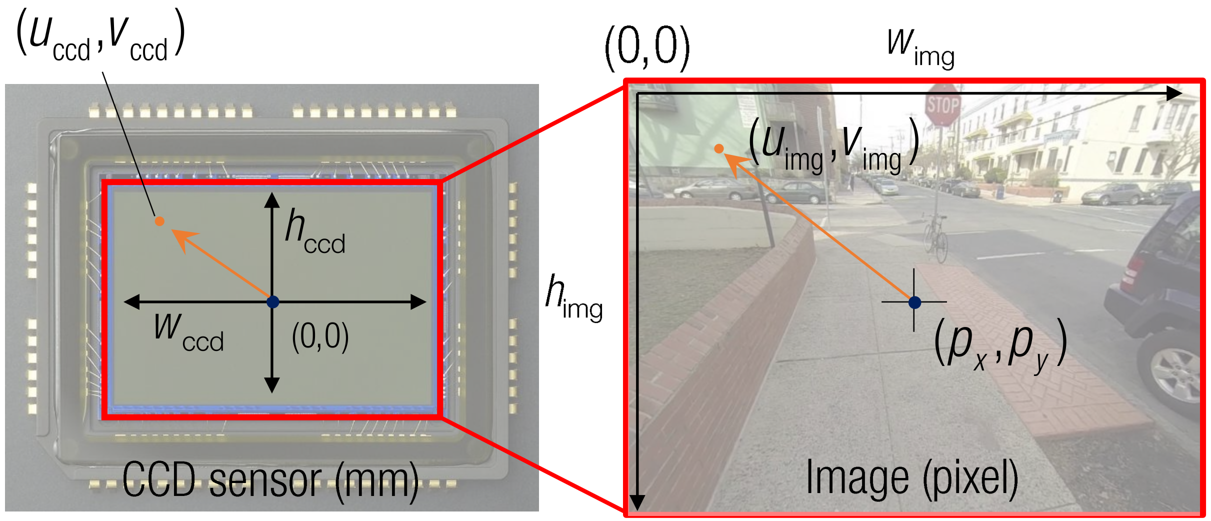


3D Point Projection (Pixel Space)

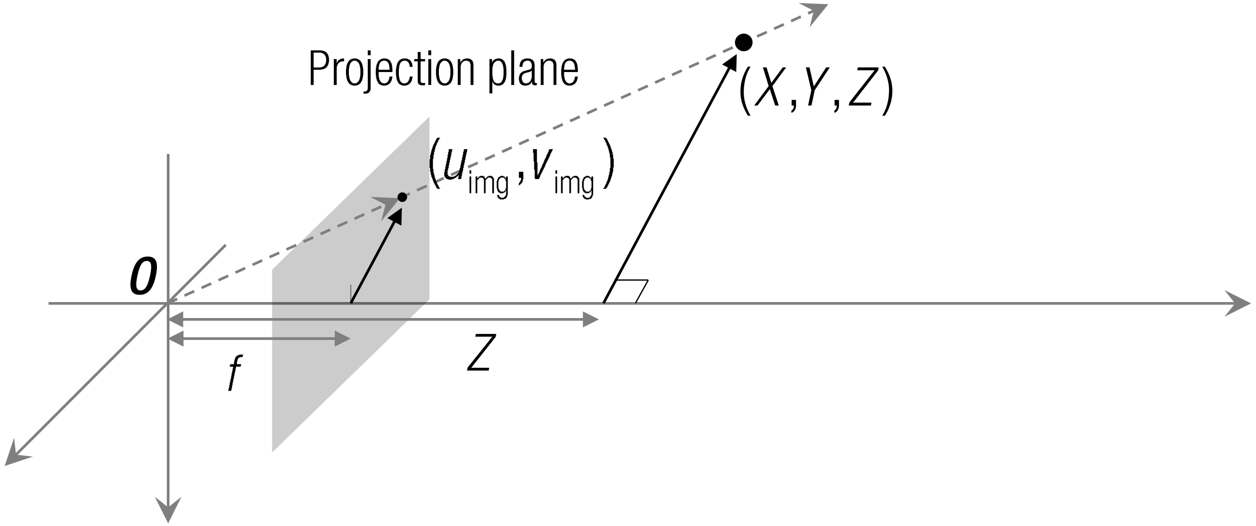


$$u_{img} = f\frac{X}{Z} + p_x \longrightarrow Zu_{img} = fX + p_x Z$$

$$v_{img} = f\frac{Y}{Z} + p_y \longrightarrow Zv_{img} = fY + p_y Z$$



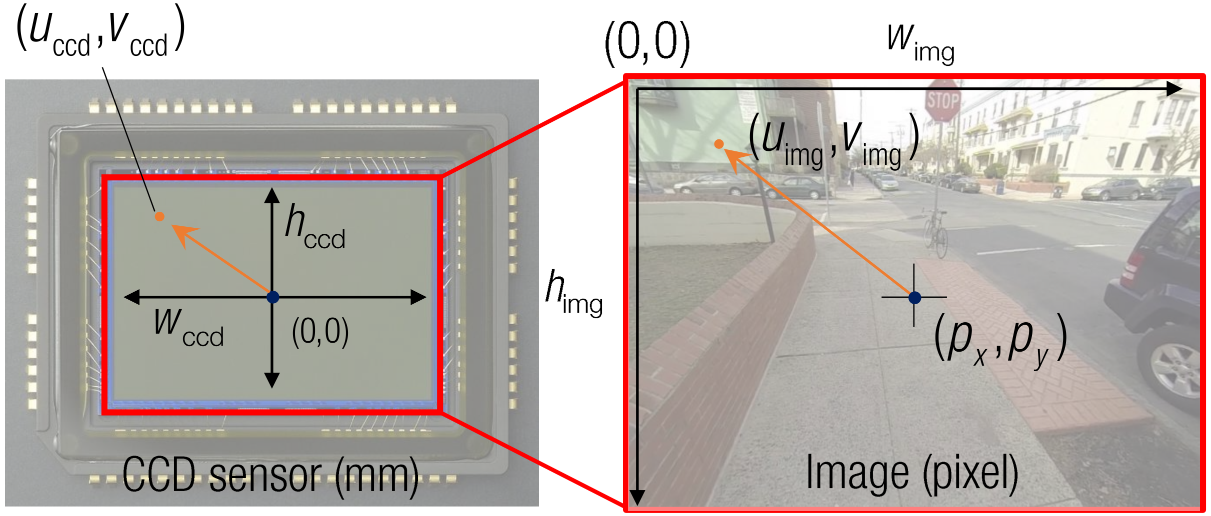
3D Point Projection (Pixel Space)



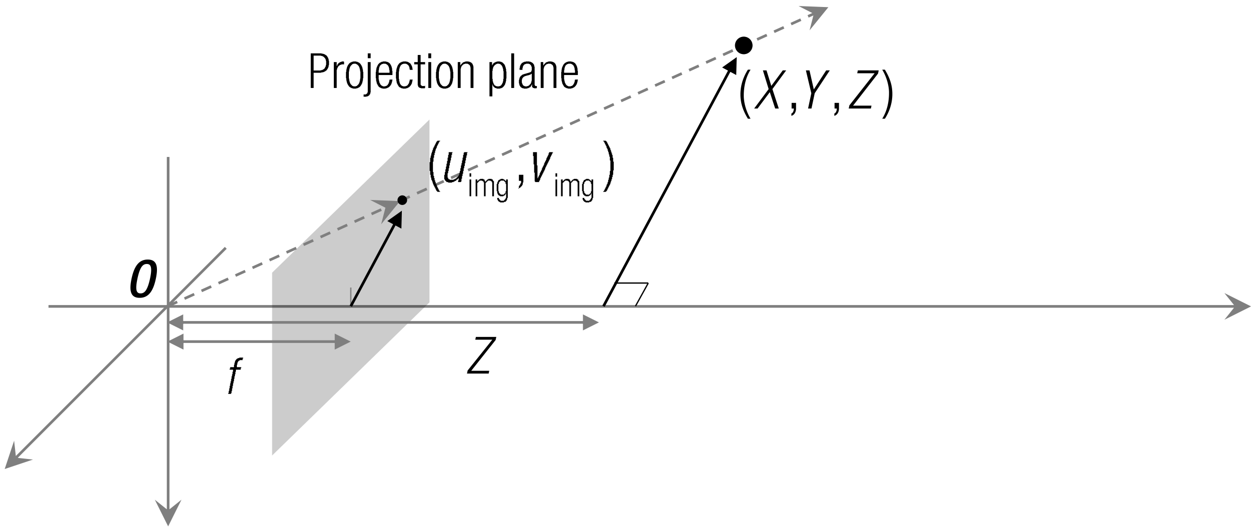
$$u_{img} = f\frac{X}{Z} + p_x \longrightarrow Zu_{img} = fX + p_x Z$$

$$v_{img} = f\frac{Y}{Z} + p_y \longrightarrow Zv_{img} = fY + p_y Z$$

$$Z\begin{bmatrix} u_{img} \\ v_{img} \\ 1 \end{bmatrix} = \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix}\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$



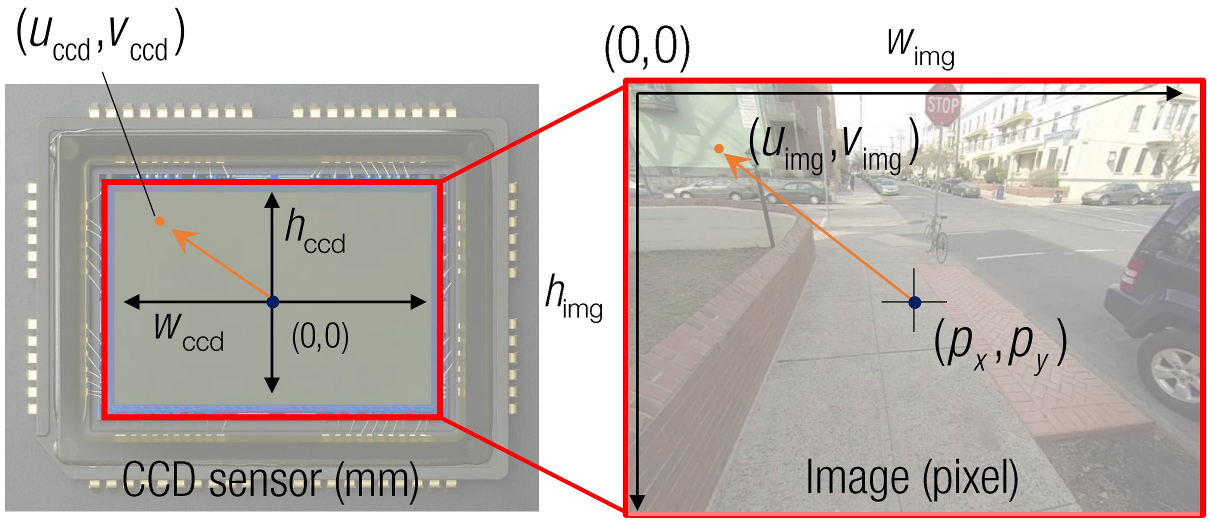
3D Point Projection (Pixel Space)



$$u_{img} = f\frac{X}{Z} + p_x \longrightarrow Zu_{img} = fX + p_x Z$$

$$v_{img} = f\frac{Y}{Z} + p_y \longrightarrow Zv_{img} = fY + p_y Z$$

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



Computer Graphics

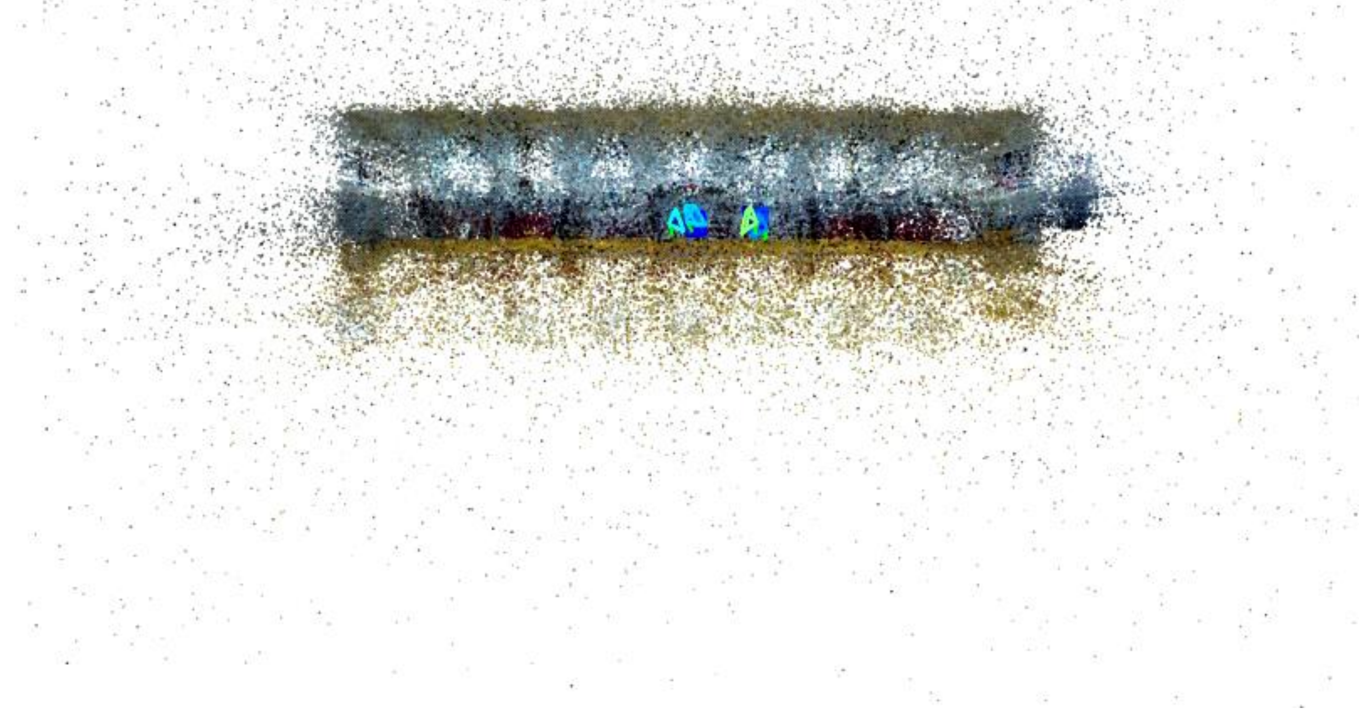
$$u_{\text{img}} = f\frac{X}{Z} + p_x \longrightarrow Zu_{\text{img}} = fX + p_x Z$$

$$v_{\text{img}} = f\frac{Y}{Z} + p_y \longrightarrow Zv_{\text{img}} = fY + p_y Z$$

$$\lambda \begin{bmatrix} u_{\text{img}} \\ v_{\text{img}} \\ 1 \end{bmatrix} = \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

← Graphics

Computer Vision = inv(Computer Graphics)



$$u_{img} = f\frac{X}{Z} + p_x \longrightarrow Zu_{img} = fX + p_x Z$$

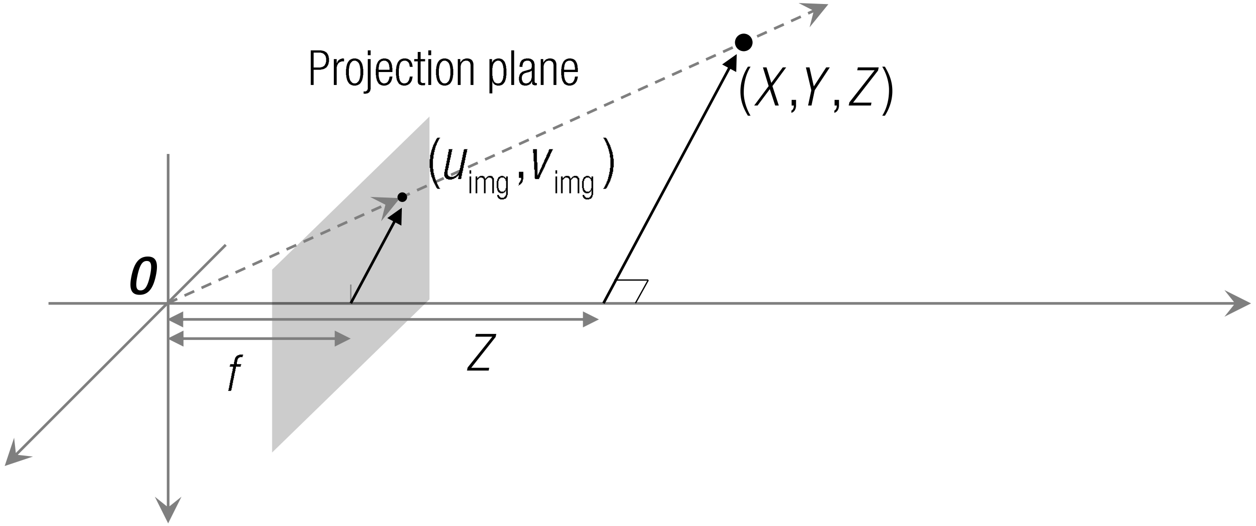
$$v_{img} = f\frac{Y}{Z} + p_y \longrightarrow Zv_{img} = fY + p_y Z$$

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

← Graphics

→ Vision

3D Point Projection (Pixel Space)

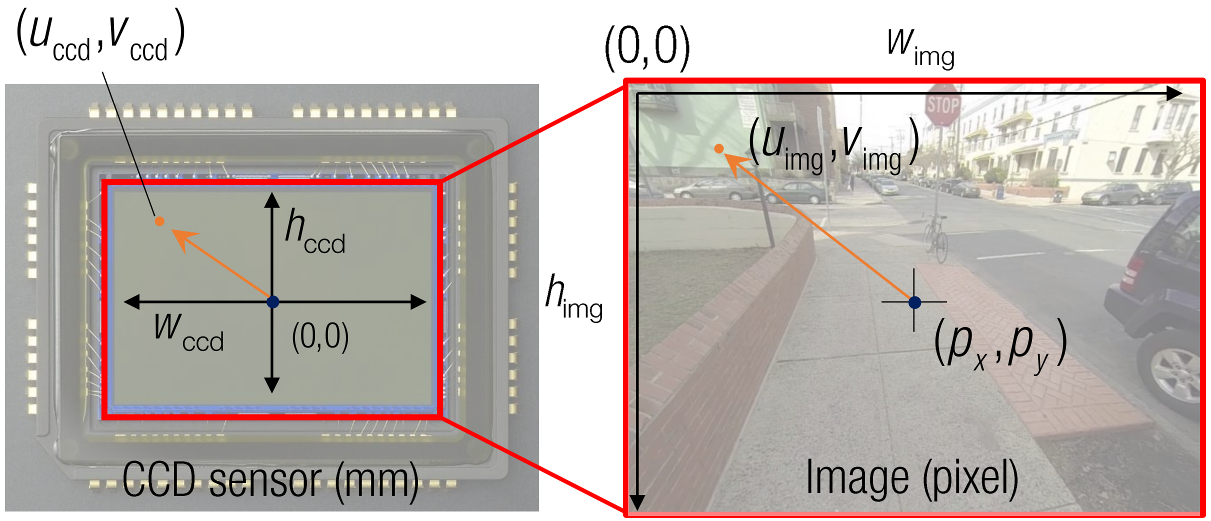


$$u_{img} = f\frac{X}{Z} + p_x \longrightarrow Zu_{img} = fX + p_x Z$$

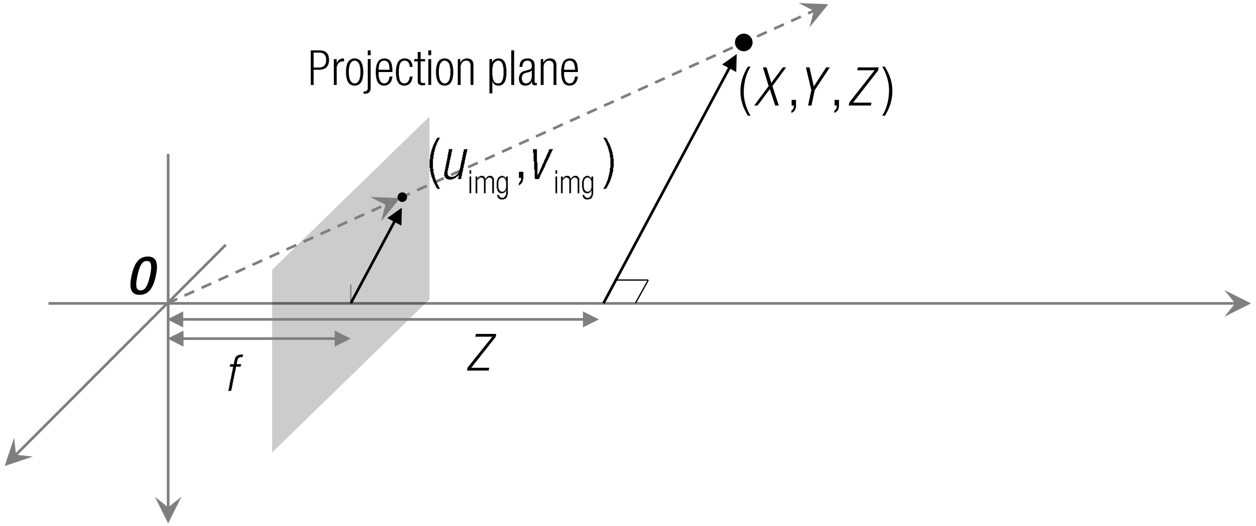
$$v_{img} = f\frac{Y}{Z} + p_y \longrightarrow Zv_{img} = fY + p_y Z$$

Pixel space Metric space

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



3D Point Projection (Pixel Space)

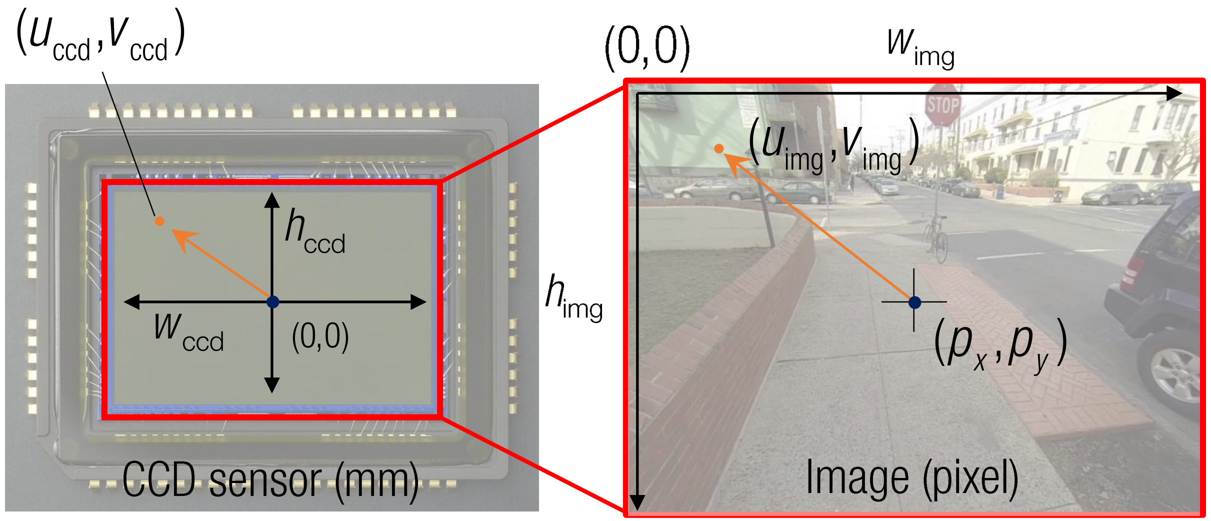


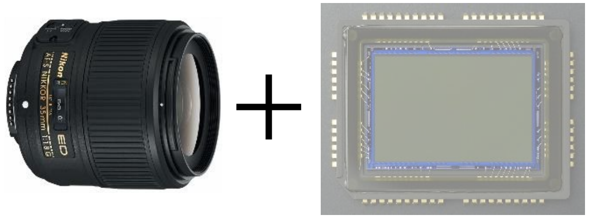
$$u_{img} = f\frac{X}{Z} + p_x \longrightarrow Zu_{img} = fX + p_x Z$$

$$v_{img} = f\frac{Y}{Z} + p_y \longrightarrow Zv_{img} = fY + p_y Z$$

Pixel space   Metric space

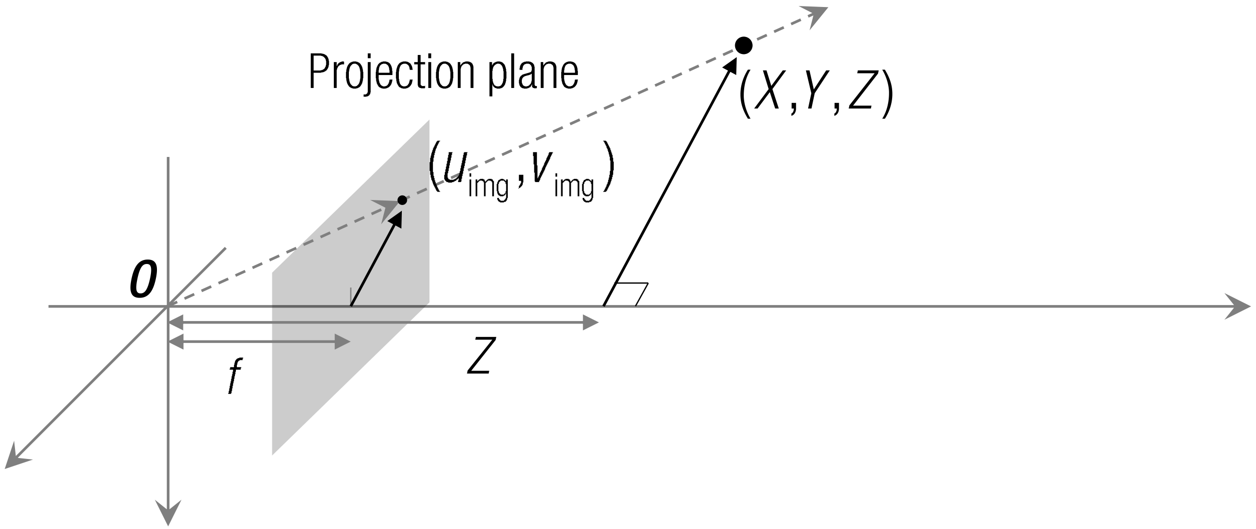
$$\lambda \begin{bmatrix} u_{img} \\ v_{img} \\ 1 \end{bmatrix} = \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

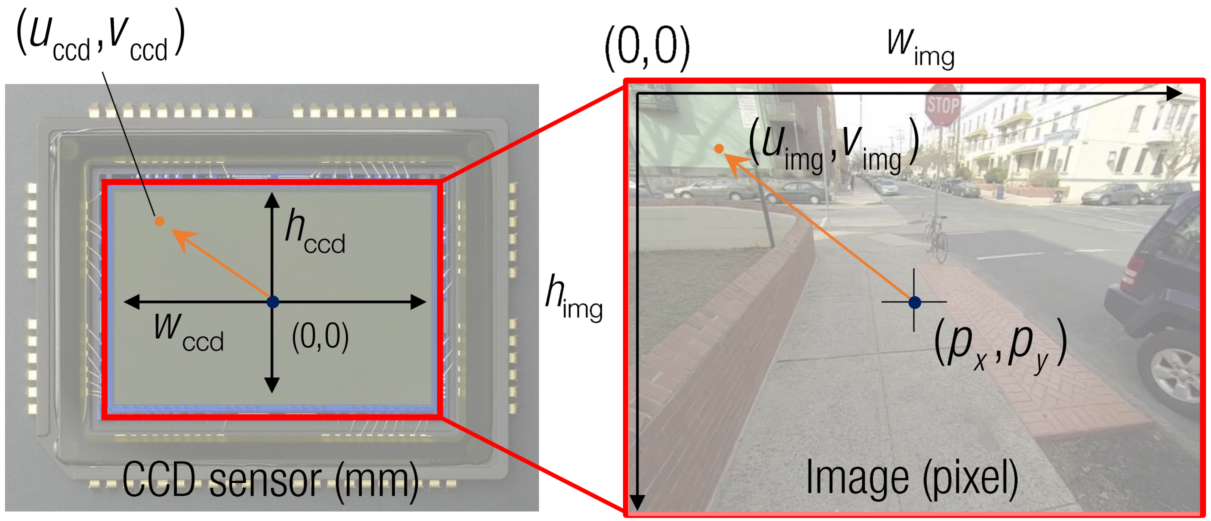




Camera intrinsic parameter
: metric space to pixel space

3D Point Projection (Pixel Space)



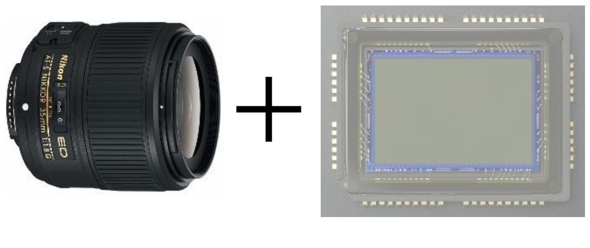


$$u_{img} = f\frac{X}{Z} + p_x \longrightarrow Zu_{img} = fX + p_x Z$$

$$v_{img} = f\frac{Y}{Z} + p_y \longrightarrow Zv_{img} = fY + p_y Z$$

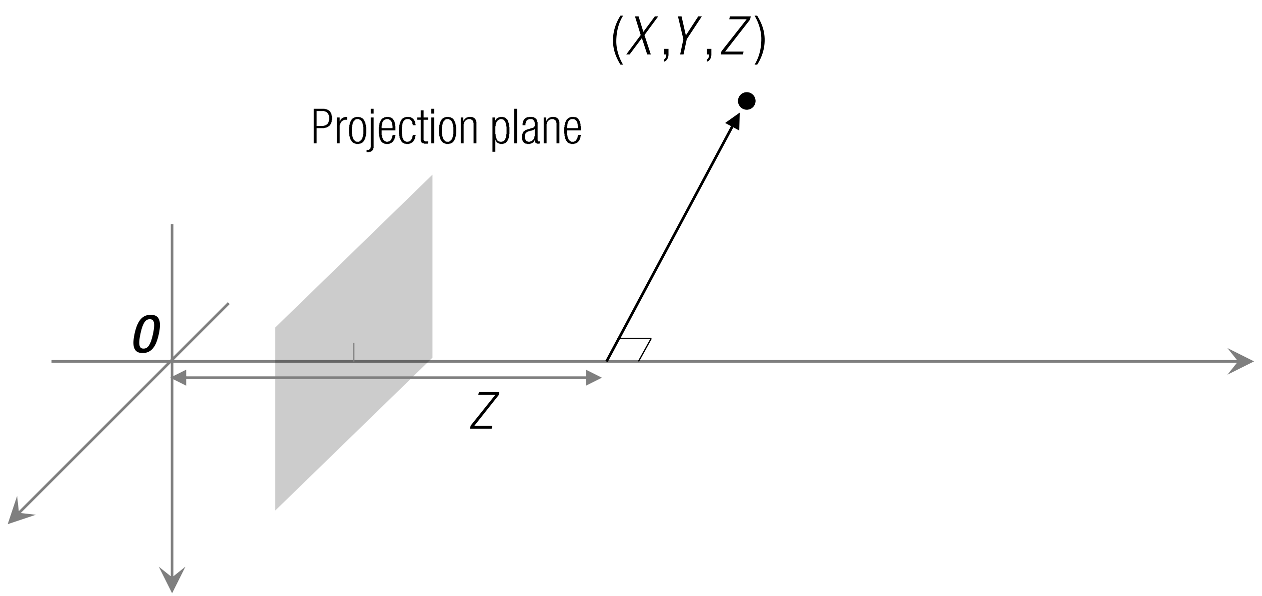
Pixel space | Metric space

$$\lambda \begin{bmatrix} u_{img} \\ v_{img} \\ 1 \end{bmatrix} = \mathbf{K} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}, \quad \mathbf{K} = \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix}$$



Camera intrinsic parameter
: metric space to pixel space

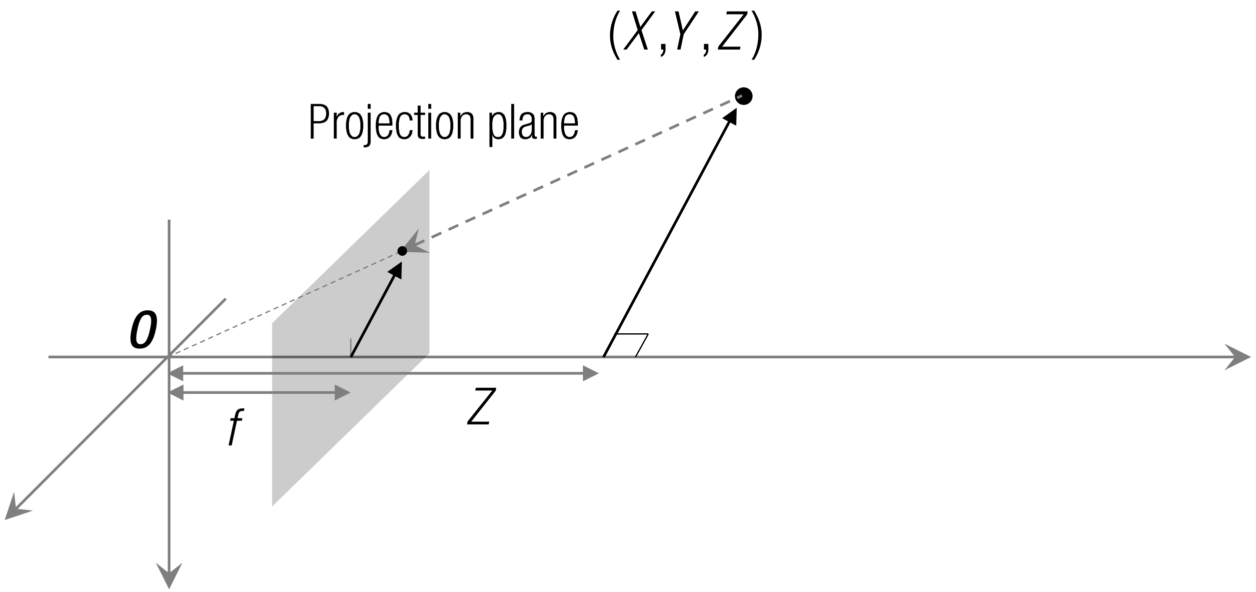
Camera Intrinsic Parameter



Metric space

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Camera Intrinsic Parameter

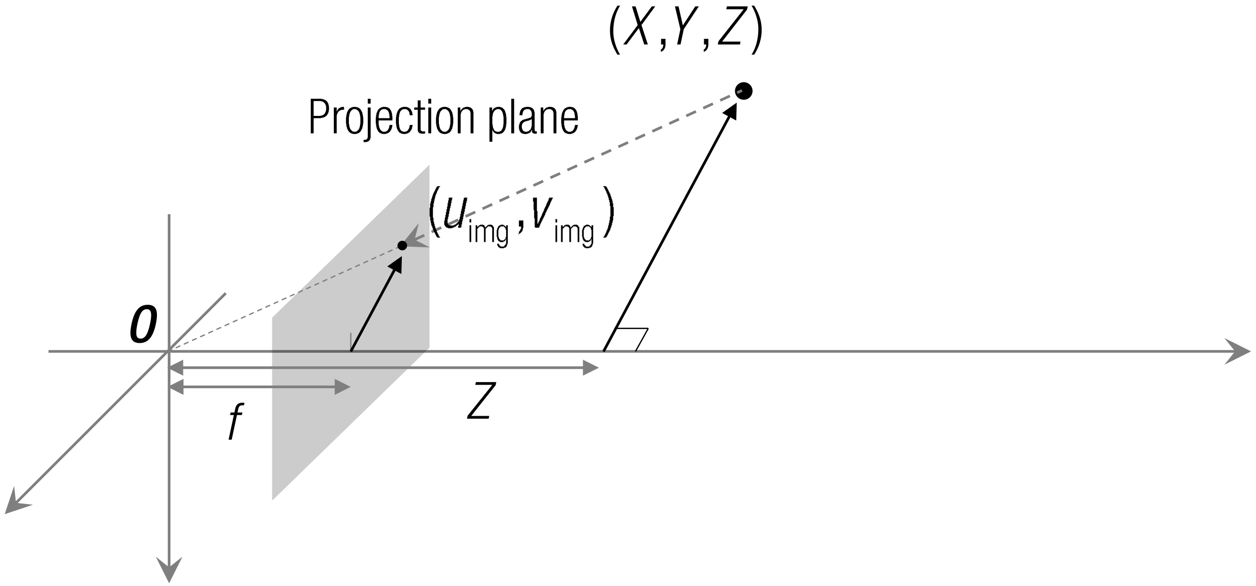


Metric space

K

$$\begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

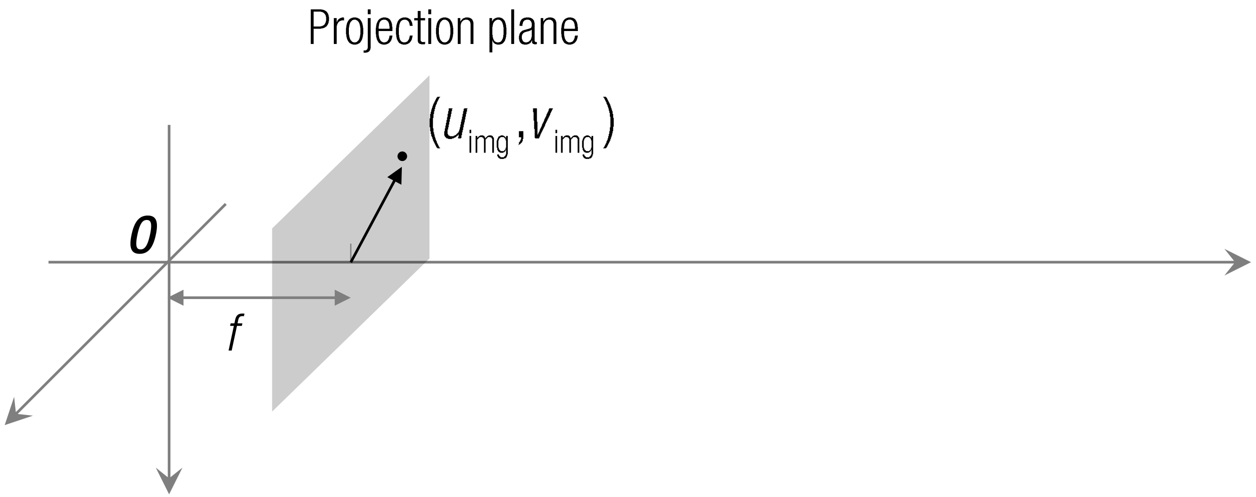
Camera Intrinsic Parameter



Pixel space | Metric space

$$\lambda \begin{bmatrix} u_{\text{img}} \\ v_{\text{img}} \\ 1 \end{bmatrix} = \mathbf{K} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

2D Inverse Projection

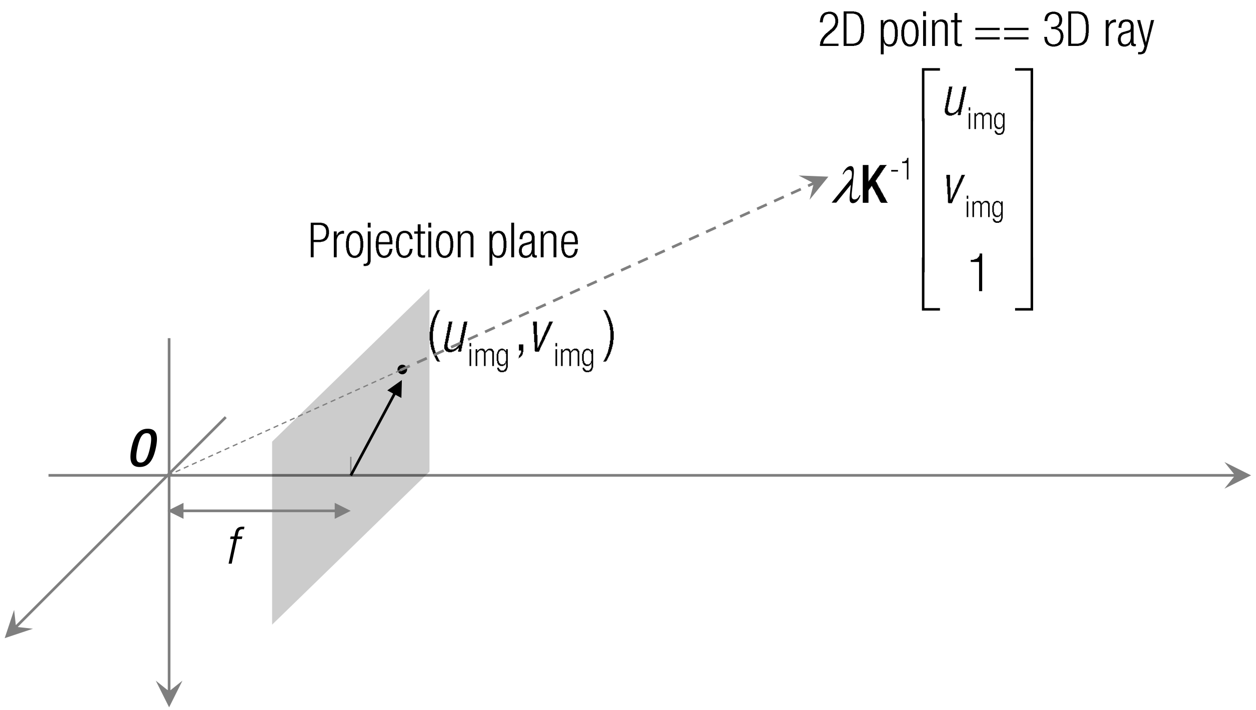


Pixel space Metric space

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

$$\begin{bmatrix} u_{img} \\ v_{img} \\ 1 \end{bmatrix}$$

2D Inverse Projection

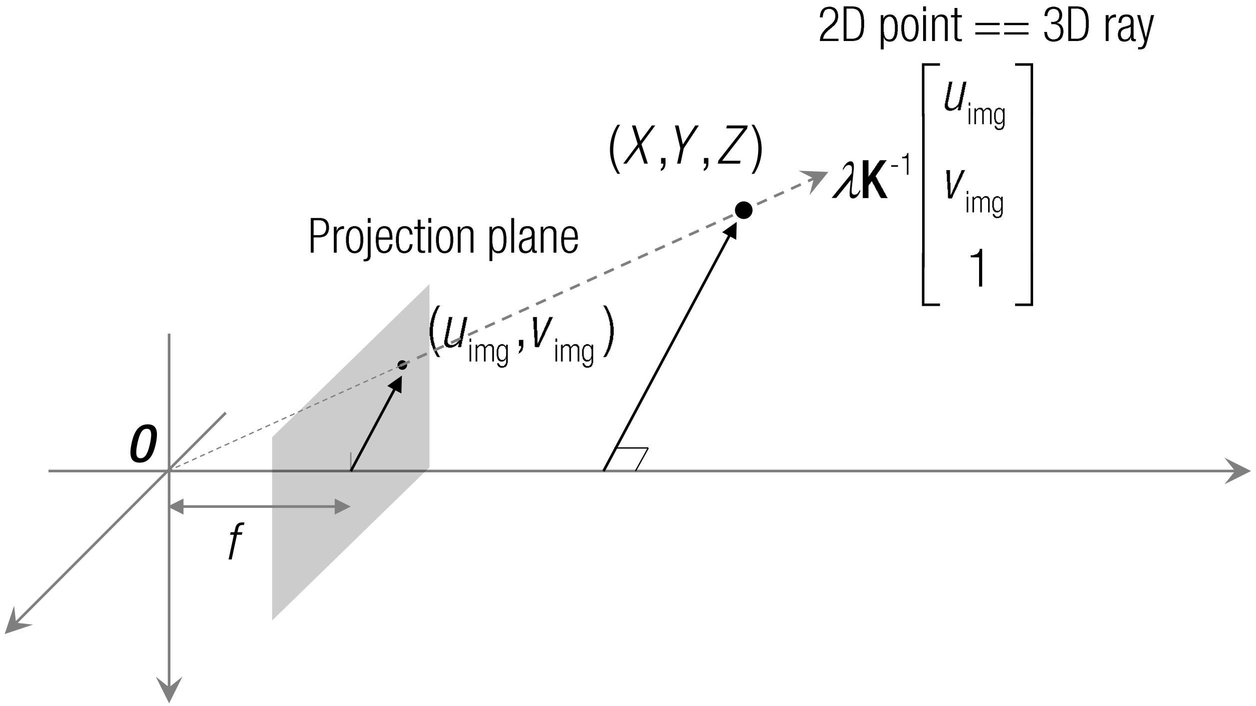


Pixel space — Metric space

$$\lambda \begin{bmatrix} u_{img} \\ v_{img} \\ 1 \end{bmatrix} = \mathbf{K} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}, \quad \mathbf{K} = \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix}$$

$$\underbrace{\lambda \mathbf{K}^{-1} \begin{bmatrix} u_{img} \\ v_{img} \\ 1 \end{bmatrix}}_{\text{3D ray}}$$

2D Inverse Projection

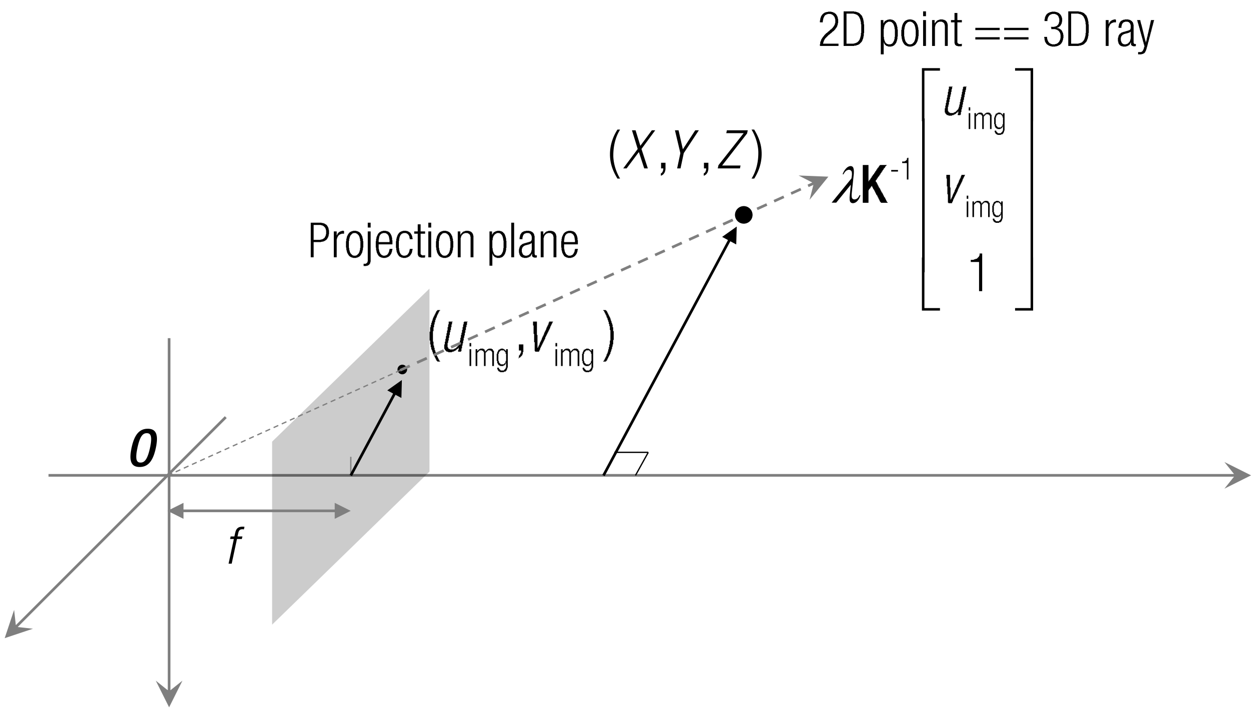


Pixel space   Metric space

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

$$\underbrace{\lambda \mathbf{K}^{-1} \begin{bmatrix} u_{img} \\ v_{img} \\ 1 \end{bmatrix}}_{\text{3D ray}} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

2D Inverse Projection



Pixel space

Metric space

$$\lambda \begin{bmatrix} u_{img} \\ v_{img} \\ 1 \end{bmatrix} = \mathbf{K} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}, \quad \mathbf{K} = \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix}$$

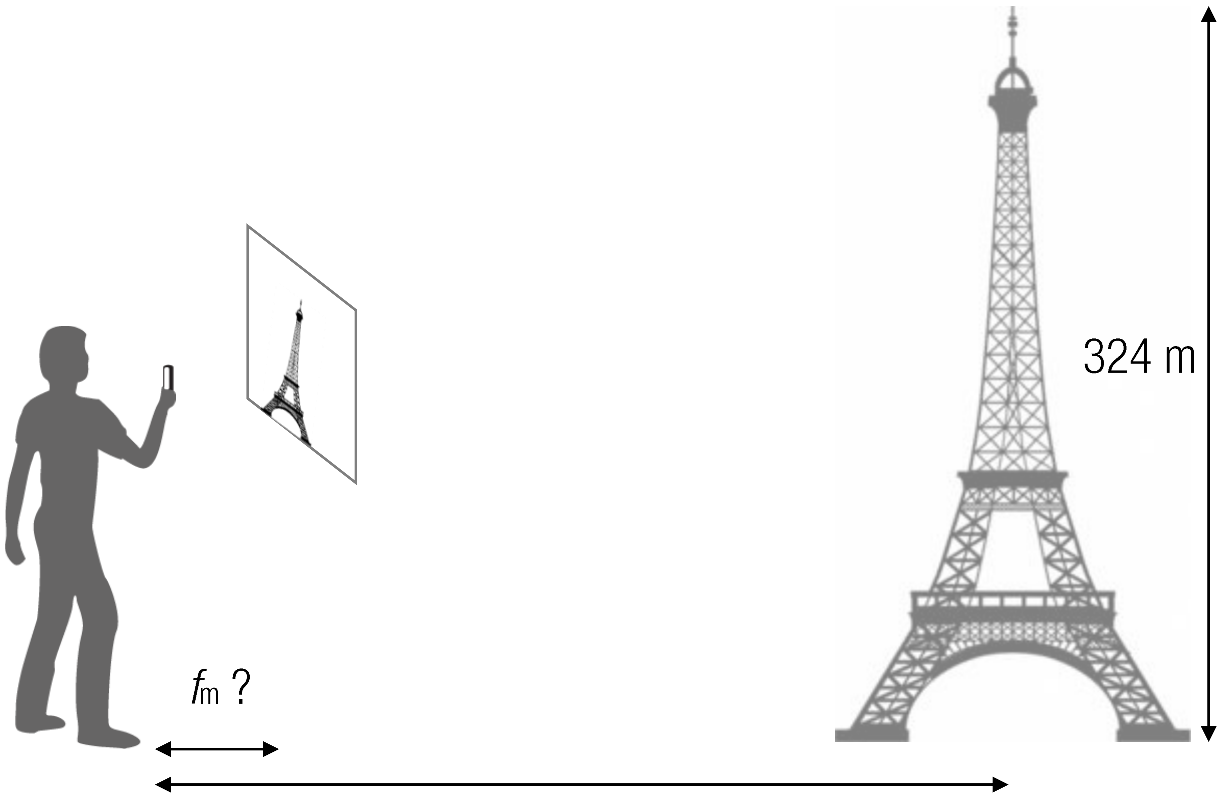
$$\lambda \mathbf{K}^{-1} \begin{bmatrix} u_{img} \\ v_{img} \\ 1 \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

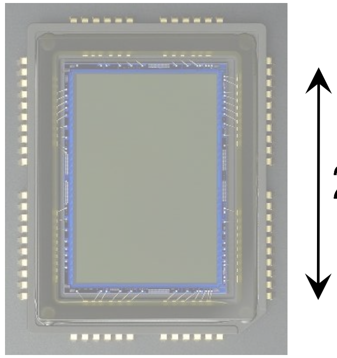
3D ray

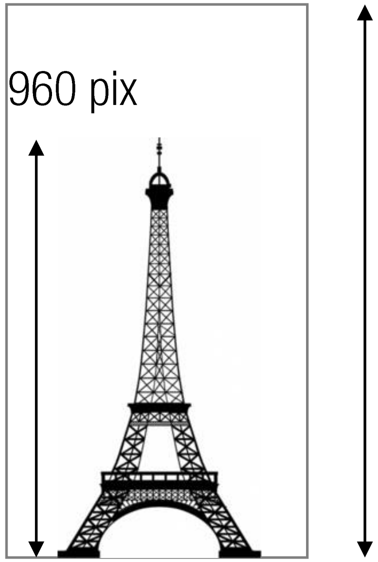
The 3D point must lie in
the *3D ray* passing through the origin and 2D image point.

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

Exercise

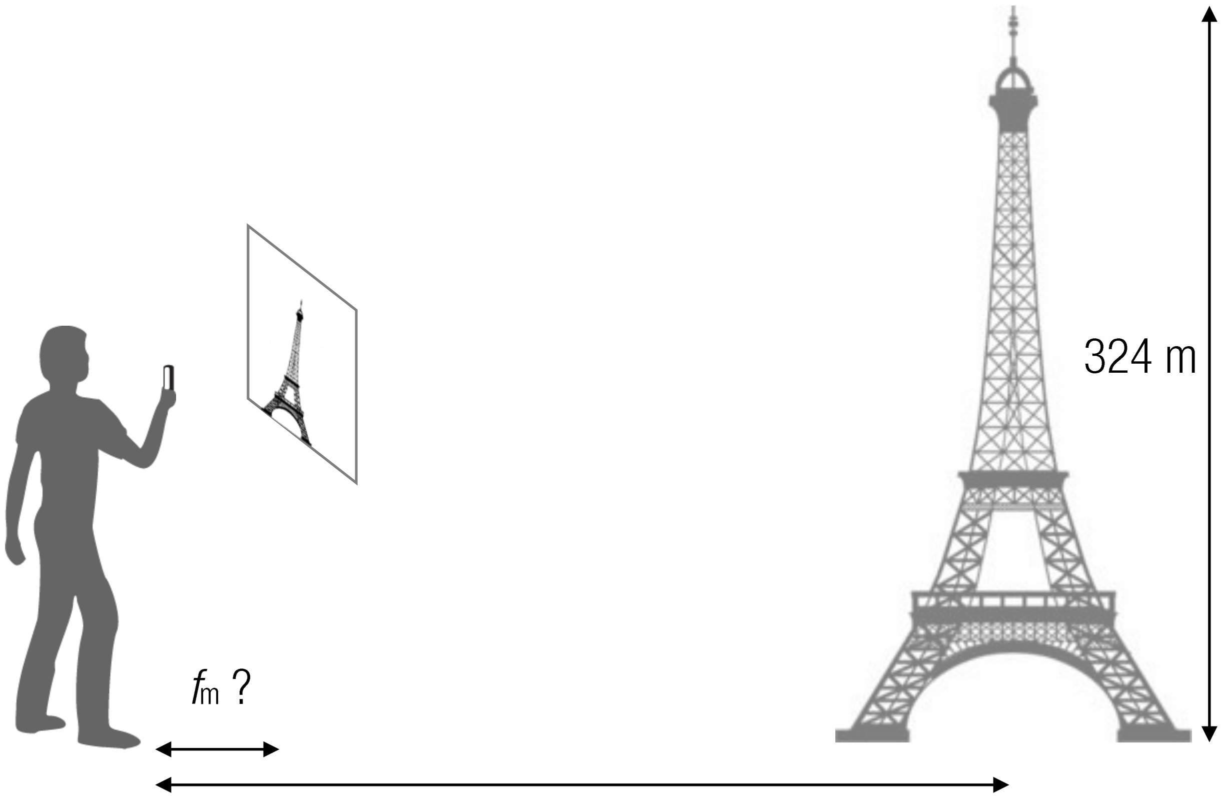


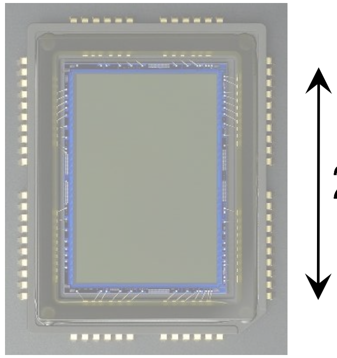




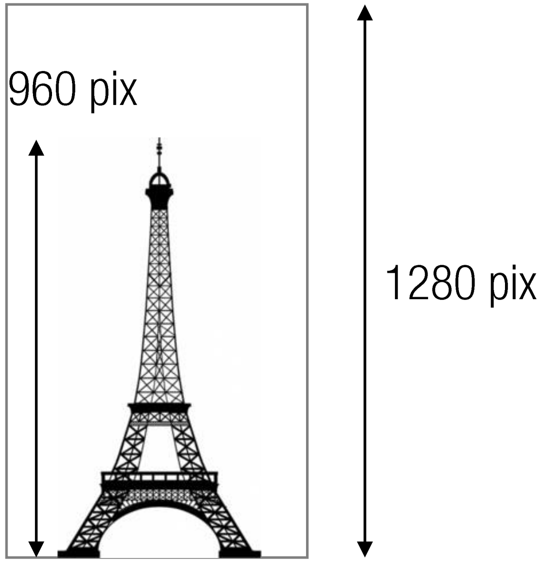
What f to make the height of Eifel tower appear 960 pixel distance?

Exercise





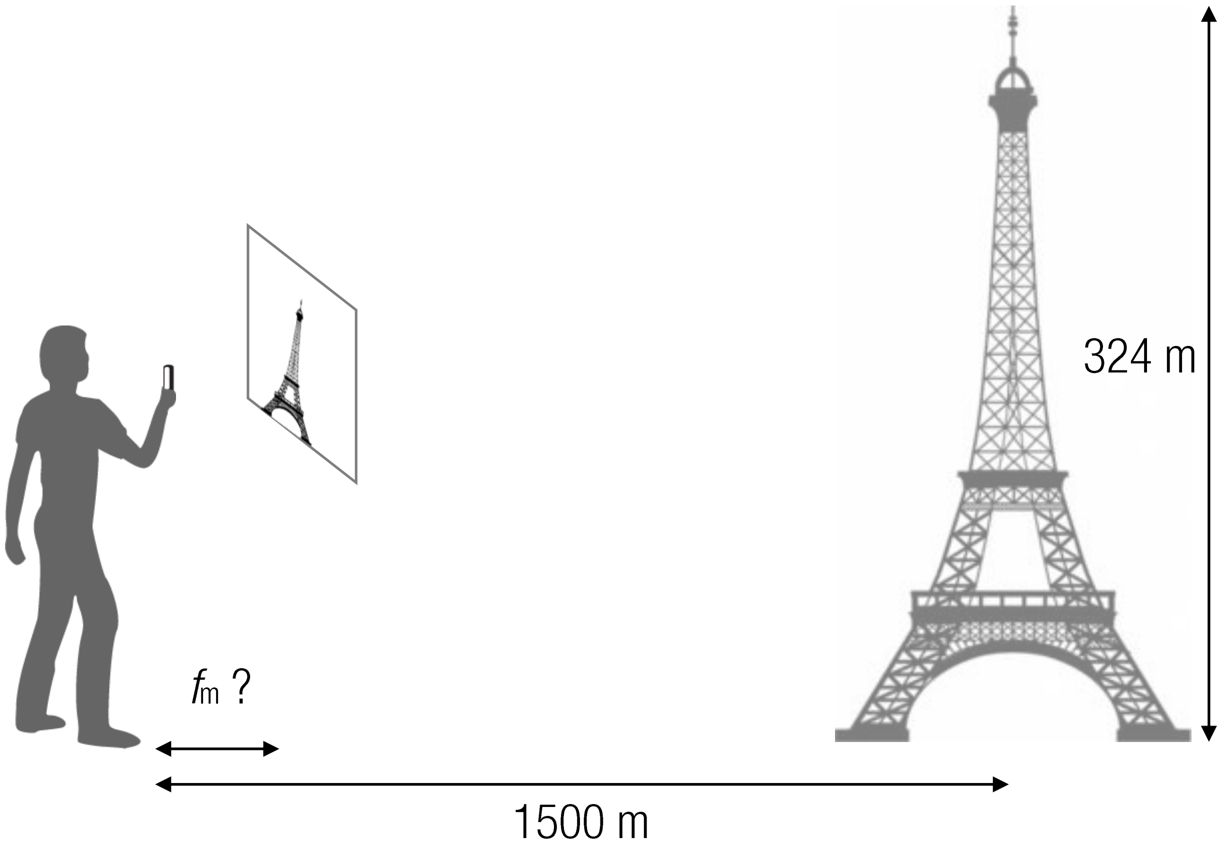
ccd size

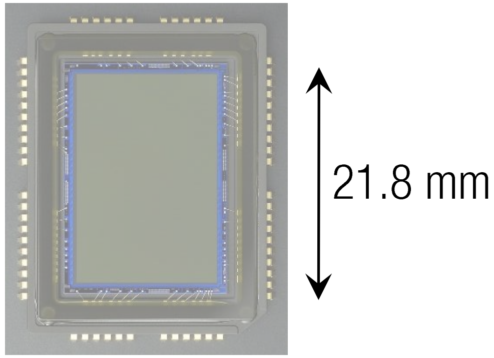


$$y_{img} = f\frac{Y}{Z} = f_m \frac{h_{img}}{h_{ccd}}\frac{Y}{Z}$$

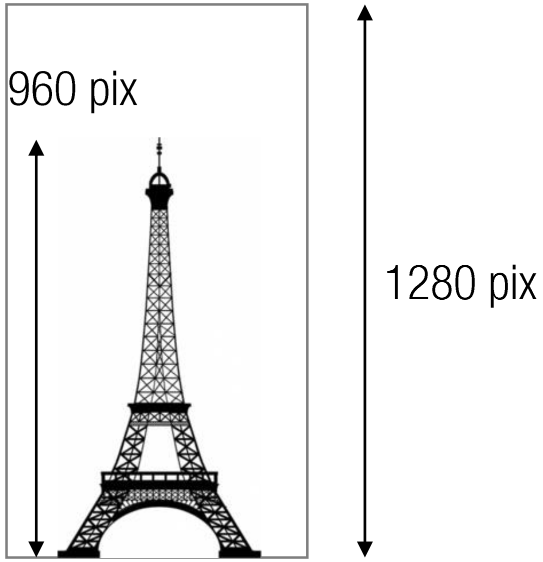
What f to make the height of Eifel tower appear 960 pixel distance?

Exercise





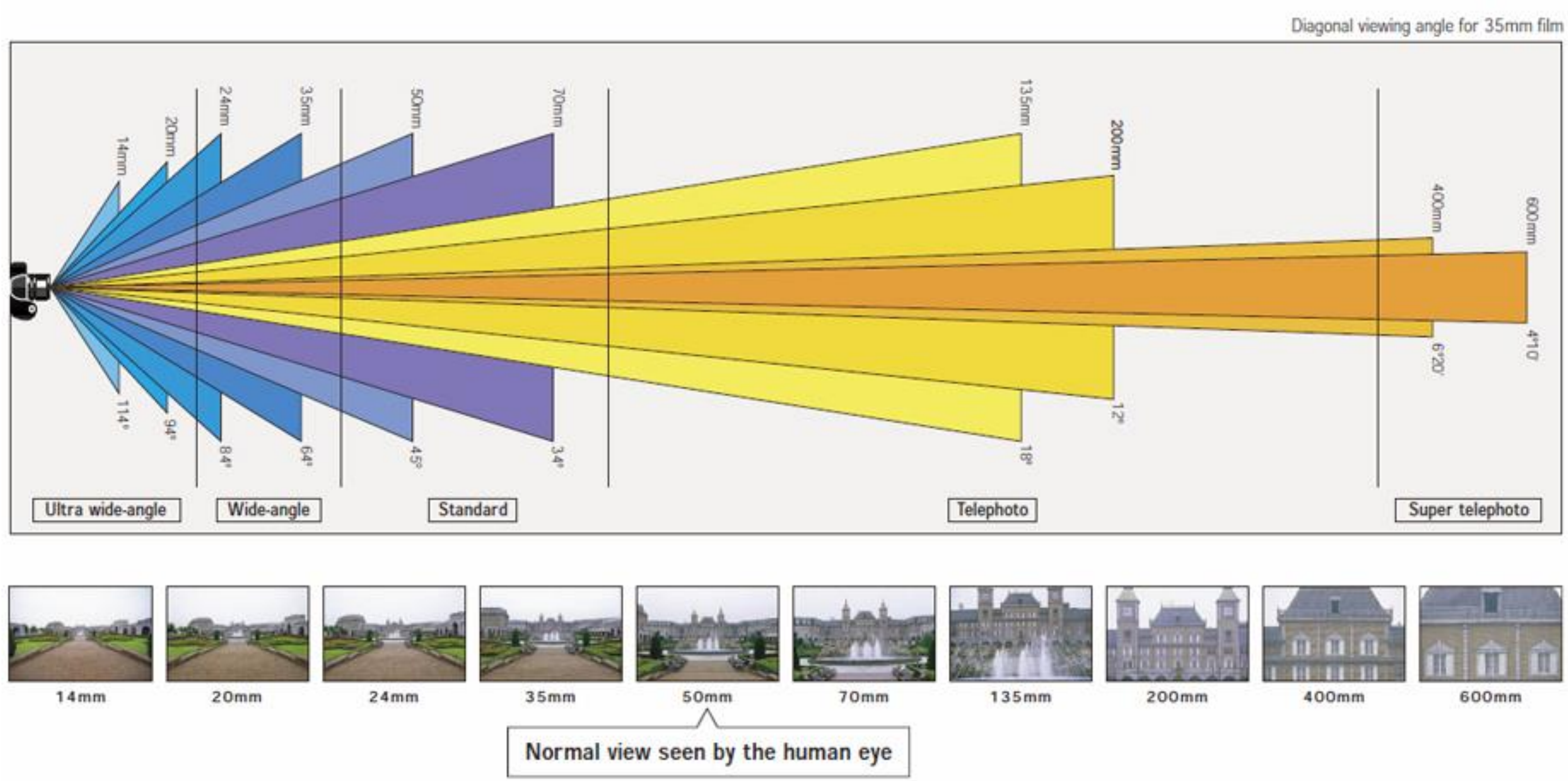
ccd size



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

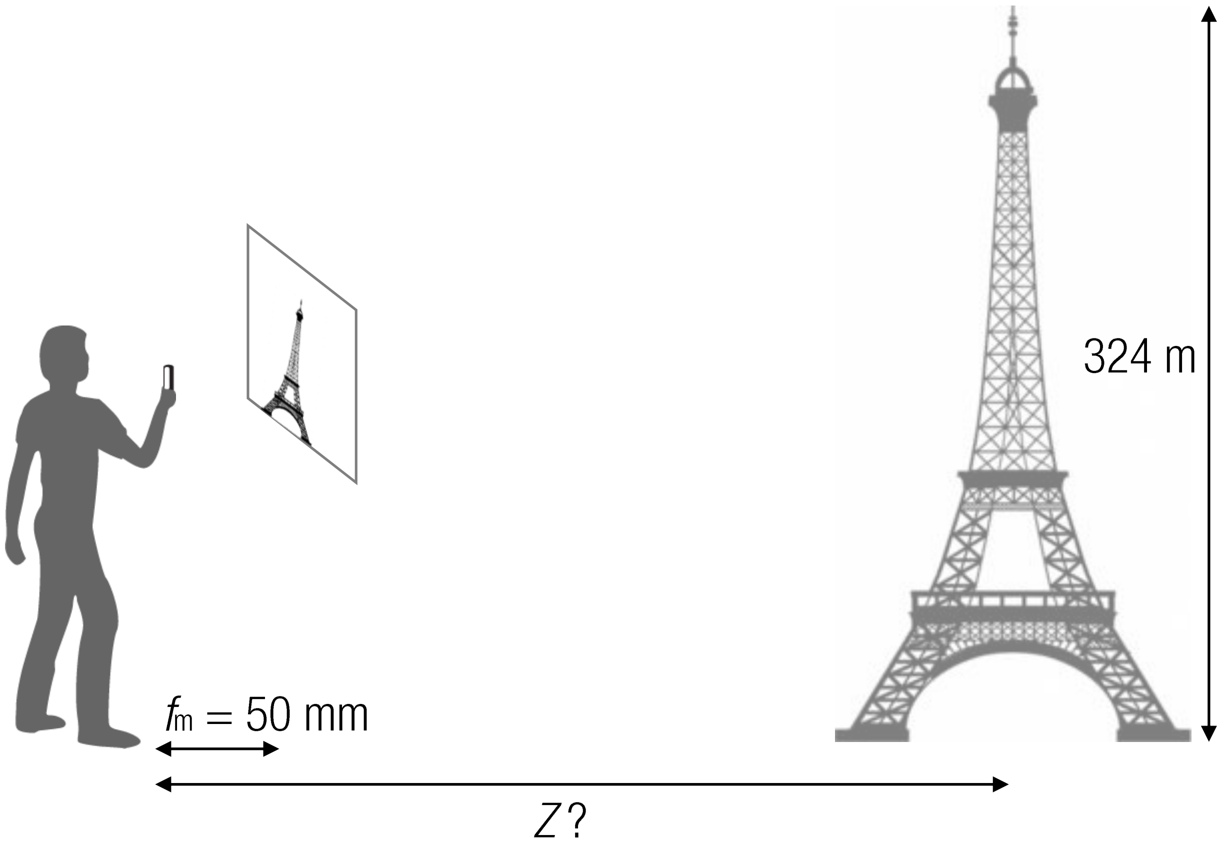
$$960 = f_m \frac{1280}{0.0218}\frac{324}{1500} \rightarrow f_m = 0.0757\text{m}$$

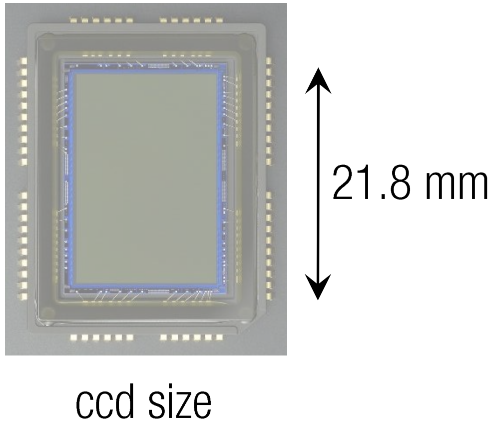
Focal Length

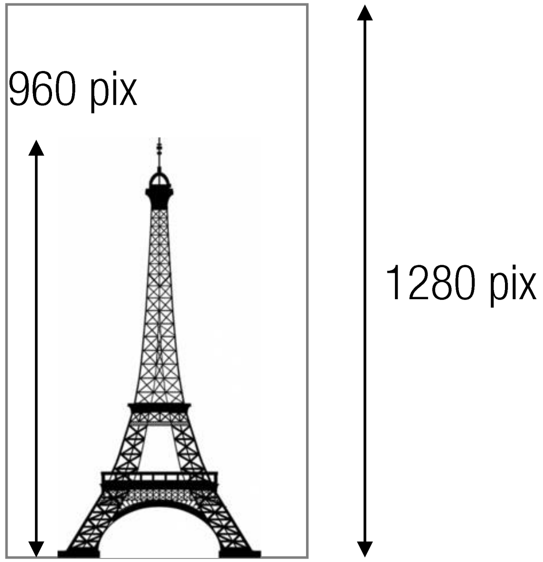


What Z to make the height of Eifel tower appear 960 pixel distance?

Exercise



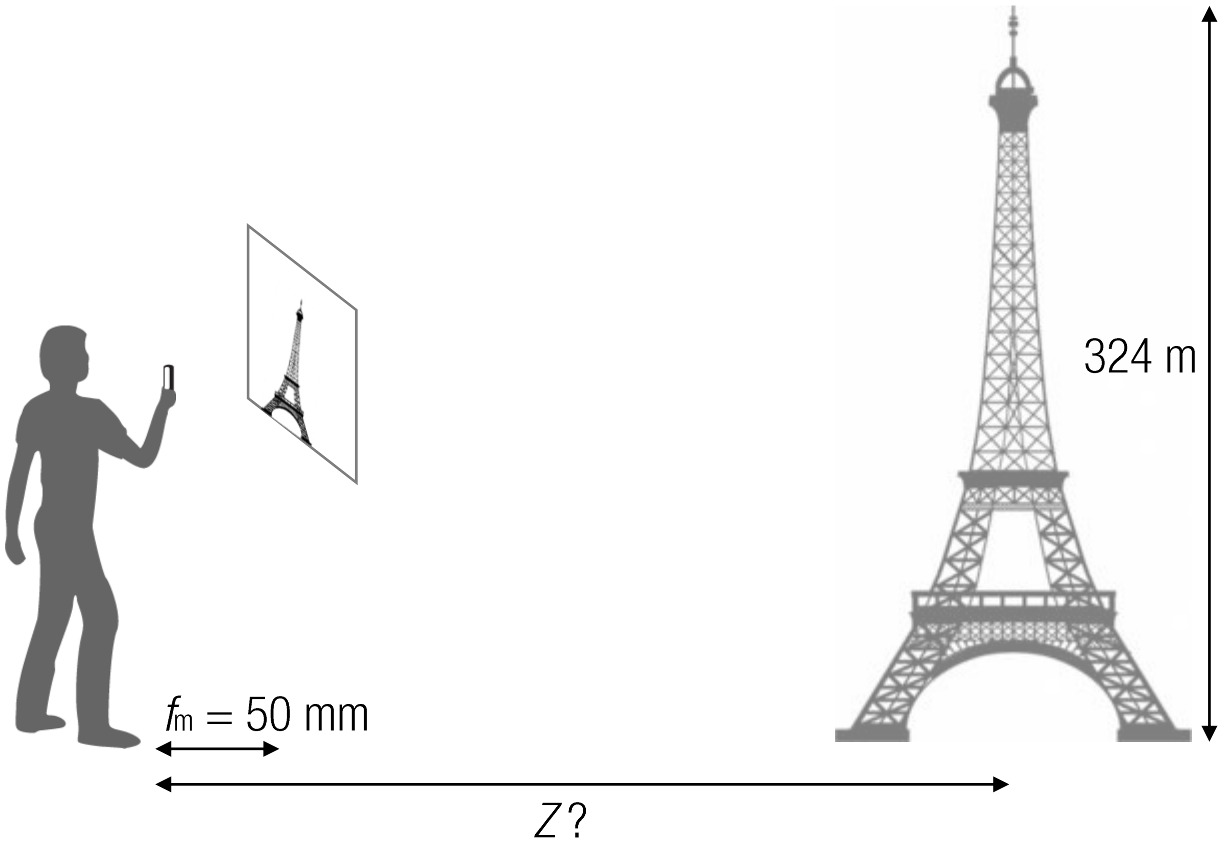


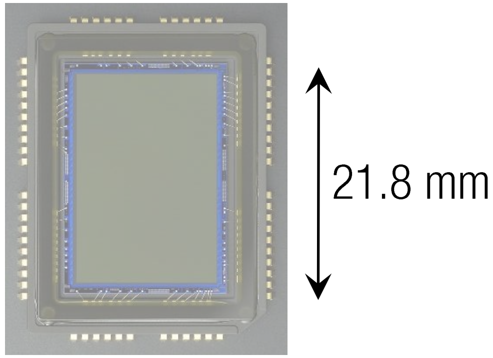


$$y_{img} = f\frac{Y}{Z} = f_m \frac{h_{img}}{h_{ccd}} \frac{Y}{Z}$$

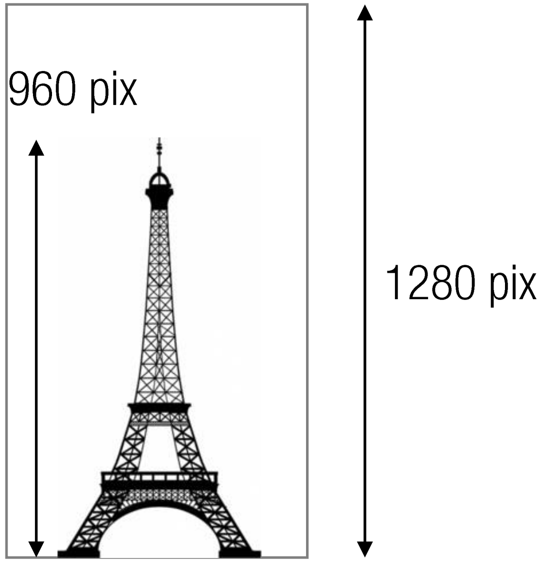
What Z to make the height of Eifel tower appear 960 pixel distance?

Exercise





ccd size

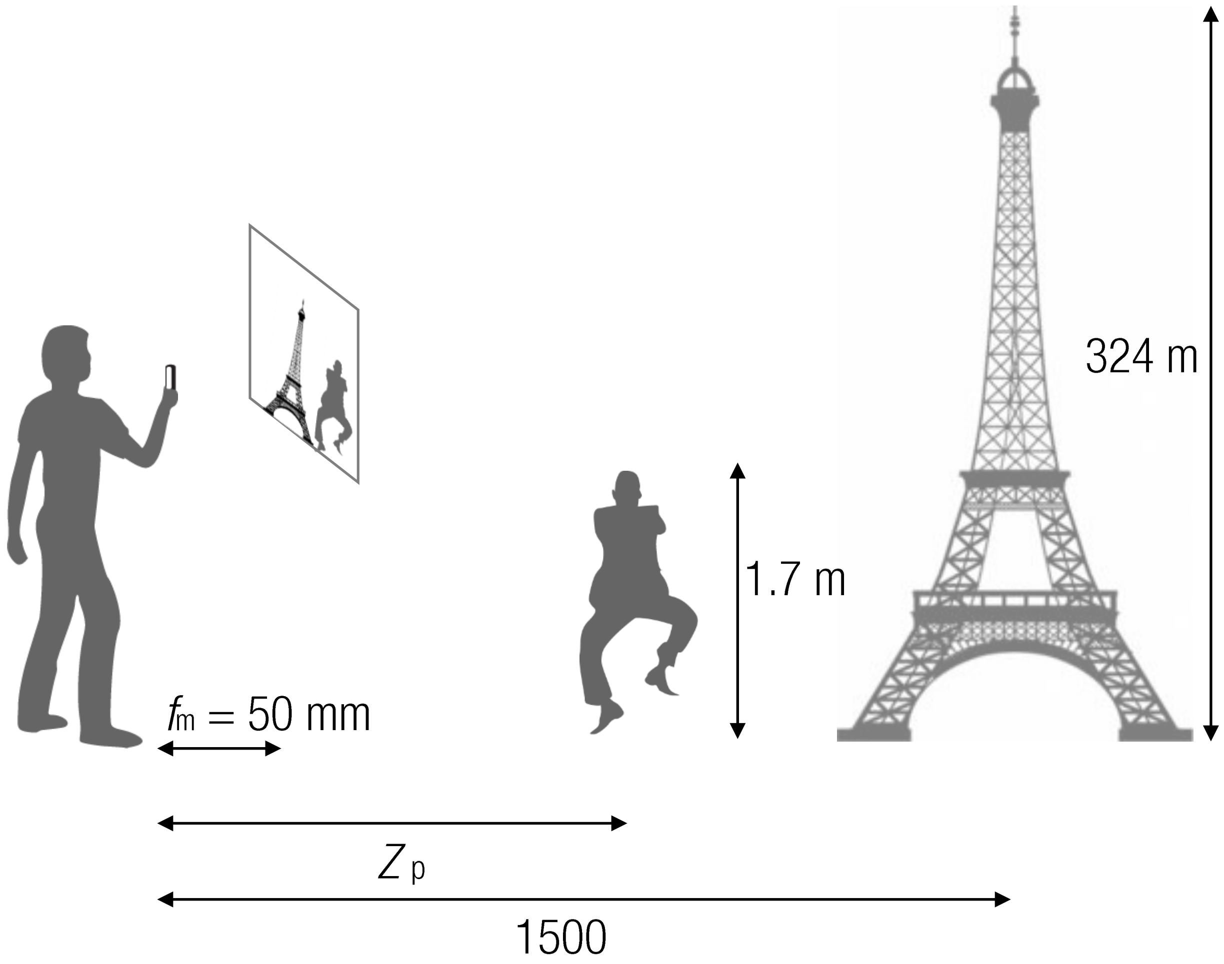


$$y_{\text{img}} = f\frac{Y}{Z} = f_m \frac{h_{\text{img}}}{h_{\text{ccd}}} \frac{Y}{Z}$$

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

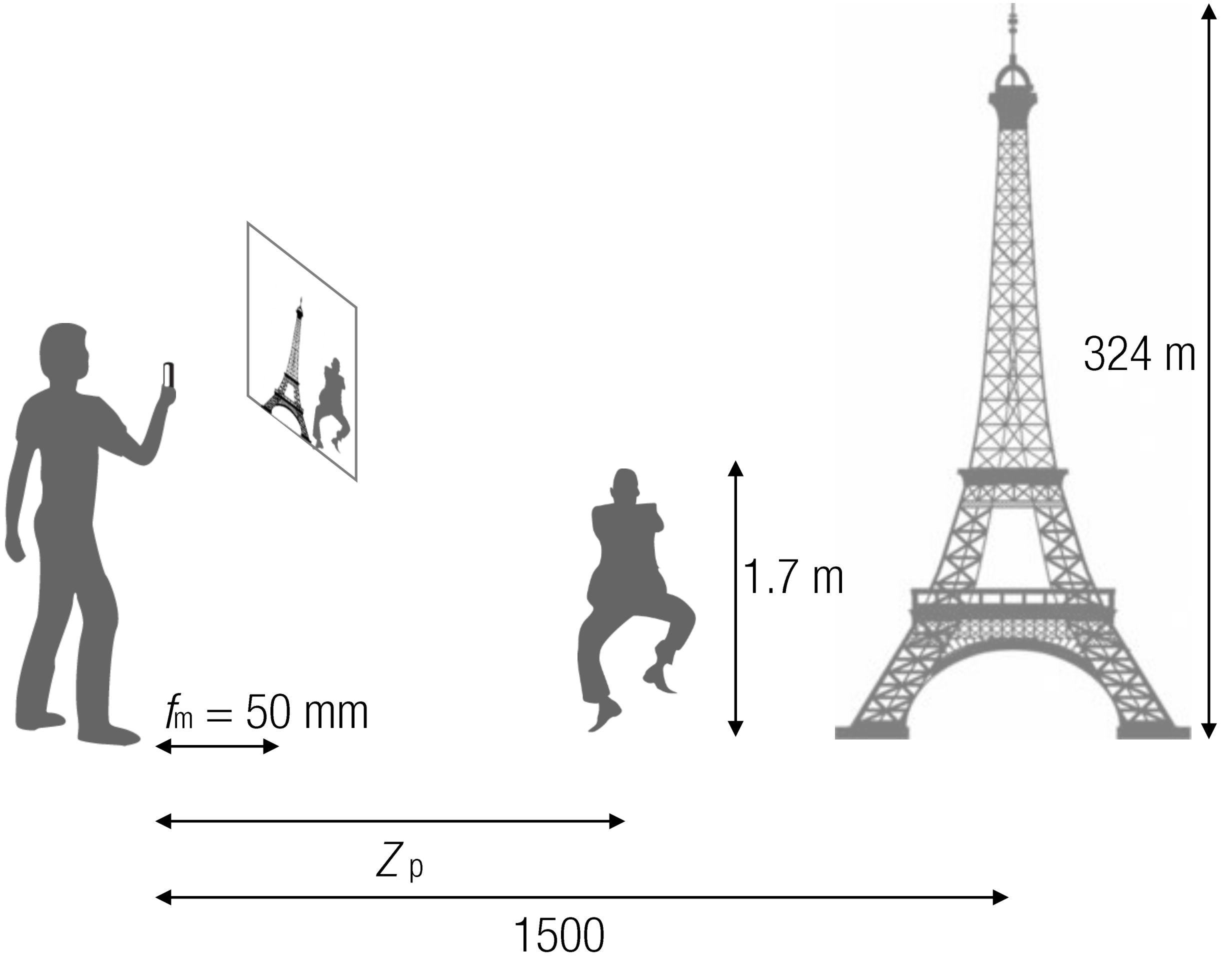
What Z_p to make the height of Eifel tower appear twice of the person?

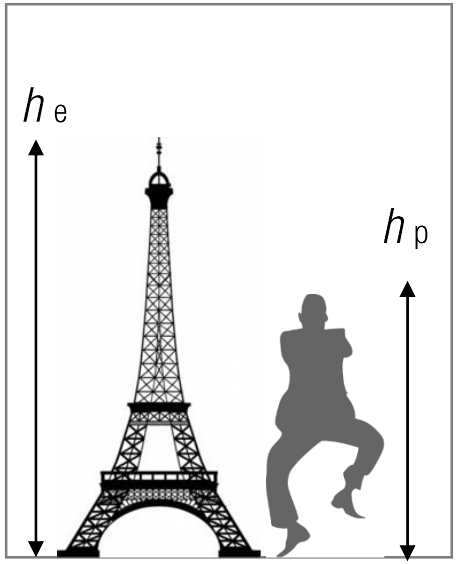
Exercise



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

Exercise

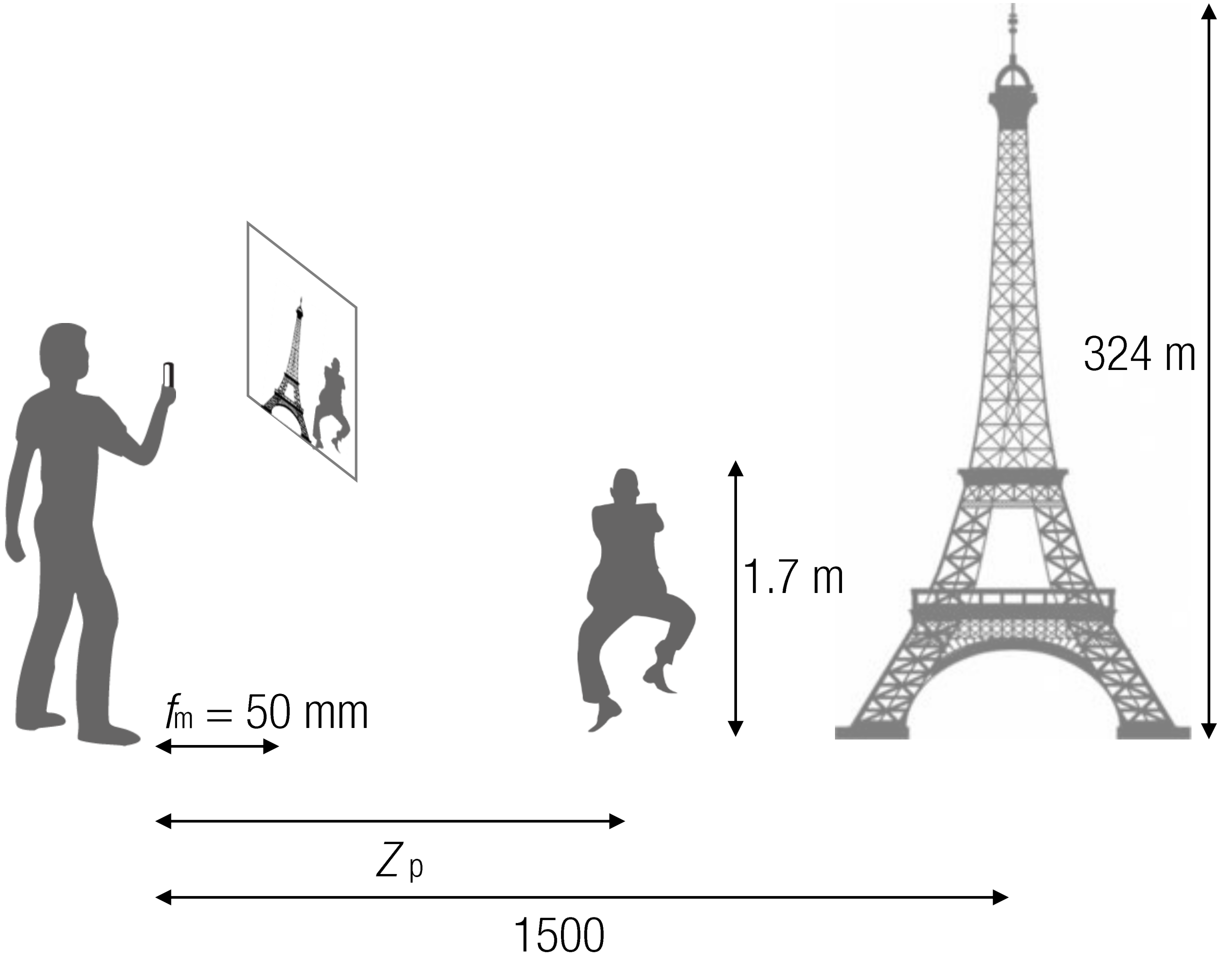


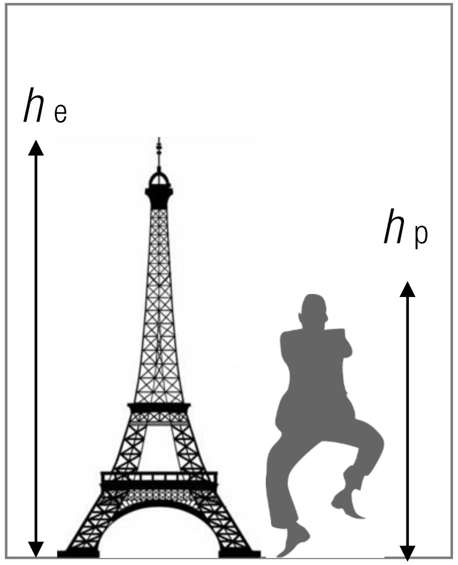


$$h_e = f\frac{Y}{Z} \qquad h_p = f\frac{Y_p}{Z_p} \qquad \text{s.t.} \quad h_p = \frac{h_e}{2}$$

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

Exercise

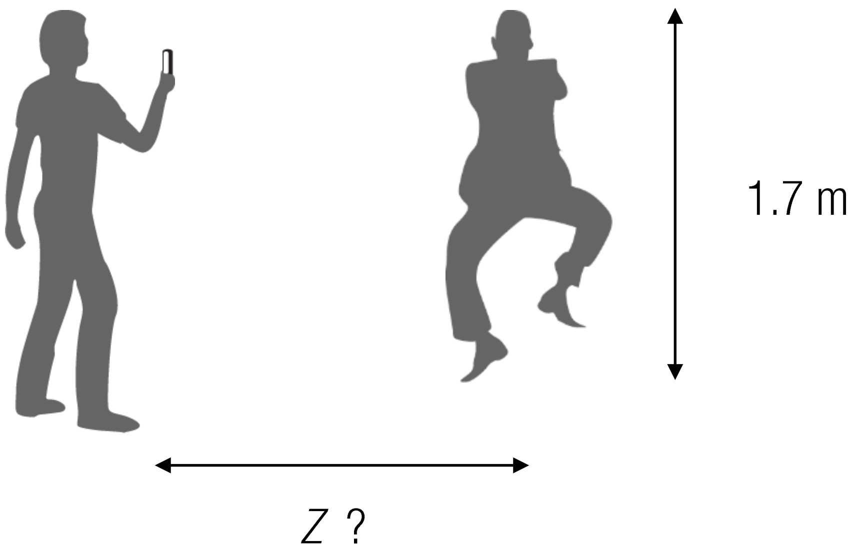


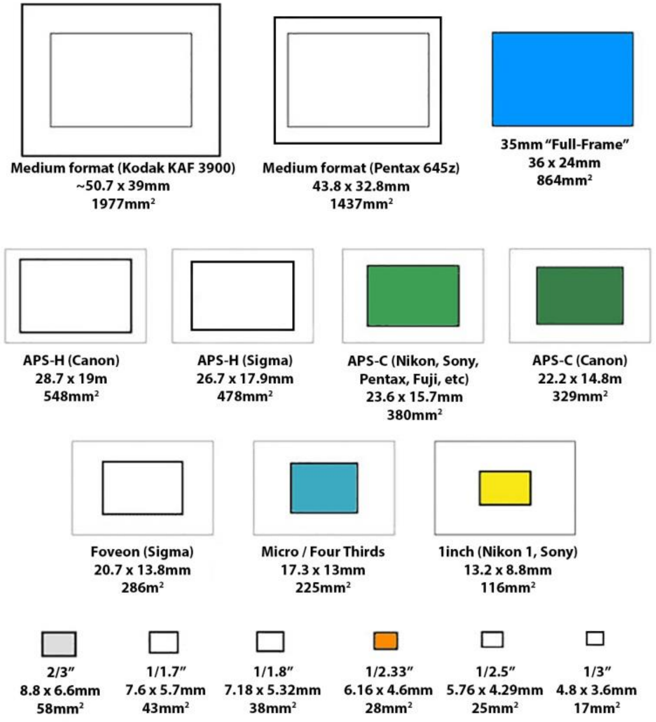


$$h_e = f\frac{Y}{Z} \qquad h_p = f\frac{Y_p}{Z_p} \qquad \text{s.t.} \quad h_p = \frac{h_e}{2}$$

$$f\frac{Y_p}{Z_p} = f\frac{Y}{2Z} \rightarrow \qquad Z_p = 2\cdot 1500\frac{1.7}{324} = 15.74\text{m}$$

Where Was I?





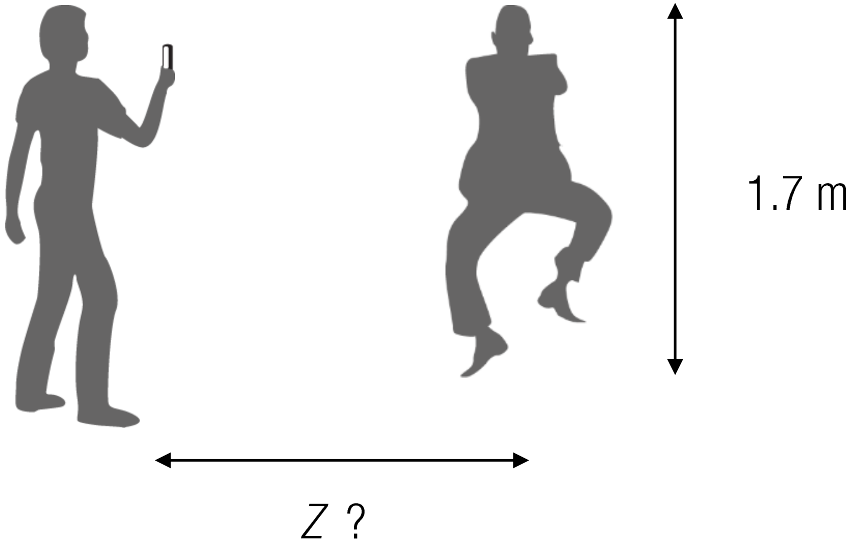
Sensor size

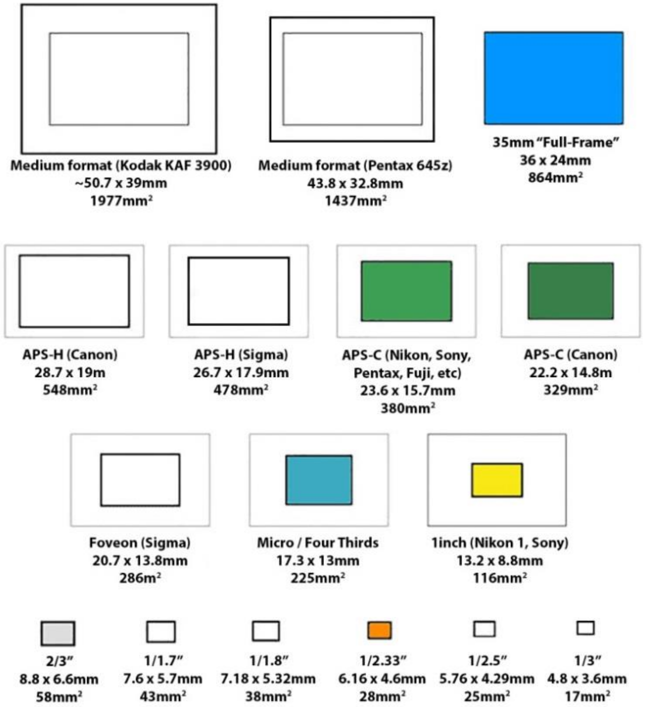
Camera Architecture		
	LG G4	LG G5
Front Camera: Resolution	8MP	
Front Camera: Sensor	Toshiba T4KA3 (1.12µm, 1/4")	
Front Camera: Focal Length	2.6mm	
Front Camera: Aperture	f/2.0	
Rear Camera: Resolution	16MP	*Main:* 16MP *Wide Angle:* 8MP
Rear Camera: Sensor	Sony IMX234 Exmor RS (1.12µm, 1/2.6")	*Main:* Sony IMX234 Exmor RS (1.12µm, 1/2.6") *Wide Angle:* Sony IMX268 (1.4µm, 1/3.2")?
Rear Camera: Focal Length	4.42mm (29mm equivalent)	*Main:* 4.42mm (29mm equivalent) *Wide Angle:* 1.53mm (12mm equivalent)?
Rear Camera: Aperture	f/1.8	*Main:* f/1.8 *Wide Angle:* f/2.4

Sensor spec

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

Where Was I?





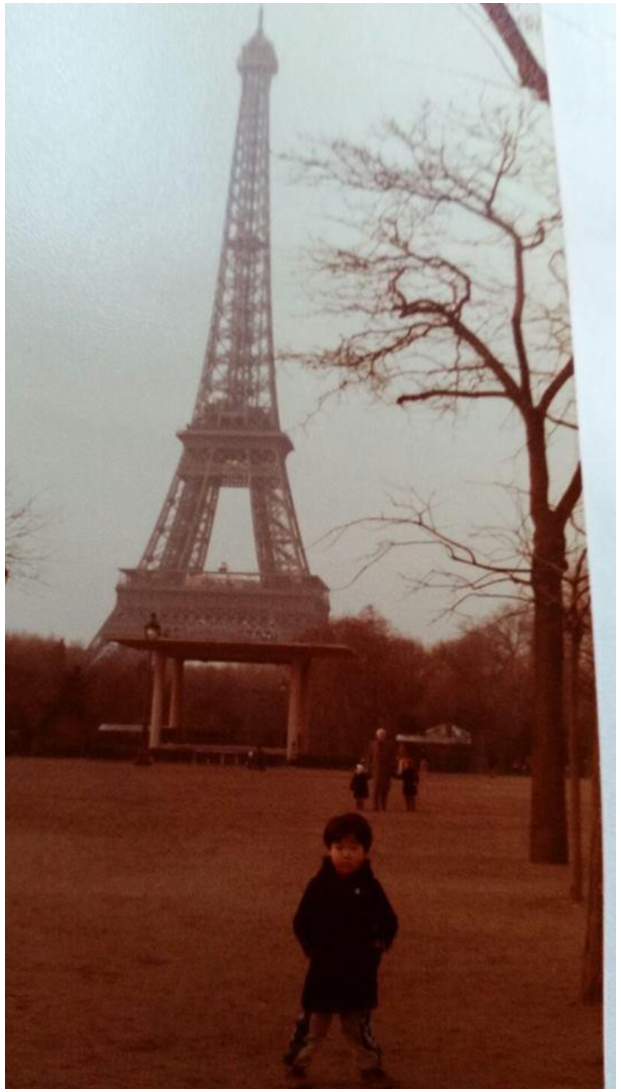
Sensor size

Apple iPhone Cameras		
	Apple iPhone 6s Apple iPhone 6s Plus	Apple iPhone 7 Apple iPhone 7 Plus
Front Camera	5.0MP	7MP
Front Camera - Sensor	Sony ? (1.12 µm, 1/5")	Sony Exmor RS (1.0 µm, 1/?")
Front Camera - Focal Length	2.65mm (31mm eff)	2.87mm (32mm eff)
Front Camera - Max Aperture	F/2.2	F/2.2
Rear Camera	12MP	12MP
Rear Camera - Sensor	Sony Exmor RS (1.22 µm, 1/3")	Sony Exmor RS (1.22 µm, 1/3")
Rear Camera - Focal Length	4.15mm (29mm eff)	4mm (28mm eff) 8mm (56mm eff) Secondary
Rear Camera - Max Aperture	F/2.2	F/1.8 F/2.8 Secondary

Sensor spec

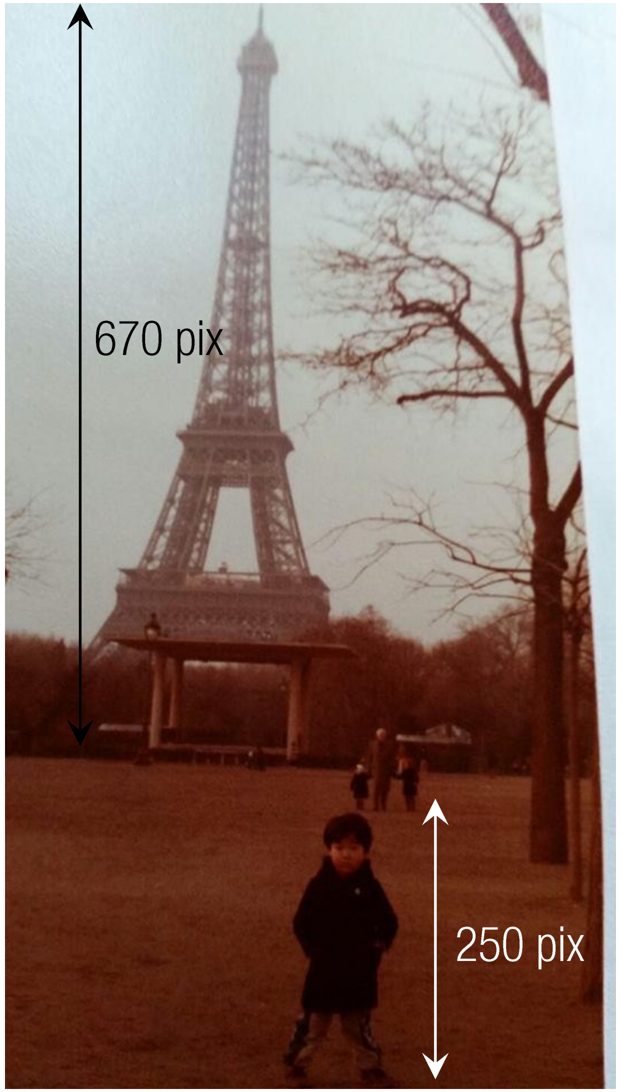
$$y = f\frac{Y}{Z} = f_m \frac{h_{img}}{h_{ccd}} \frac{Y}{Z}$$

Where Was I?



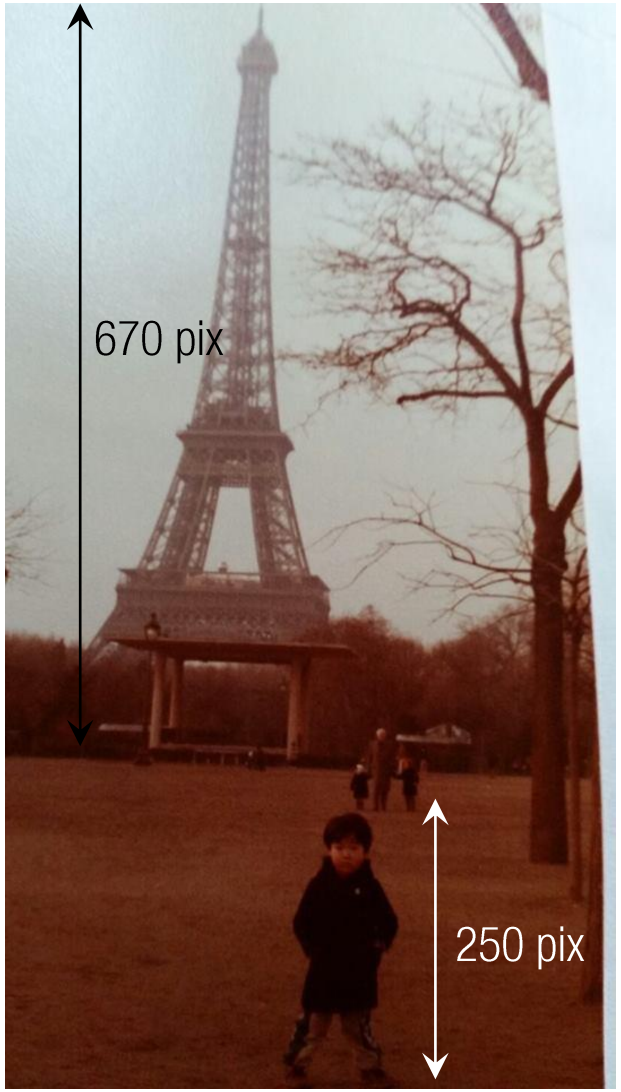
Circa 1984

Where Was I?

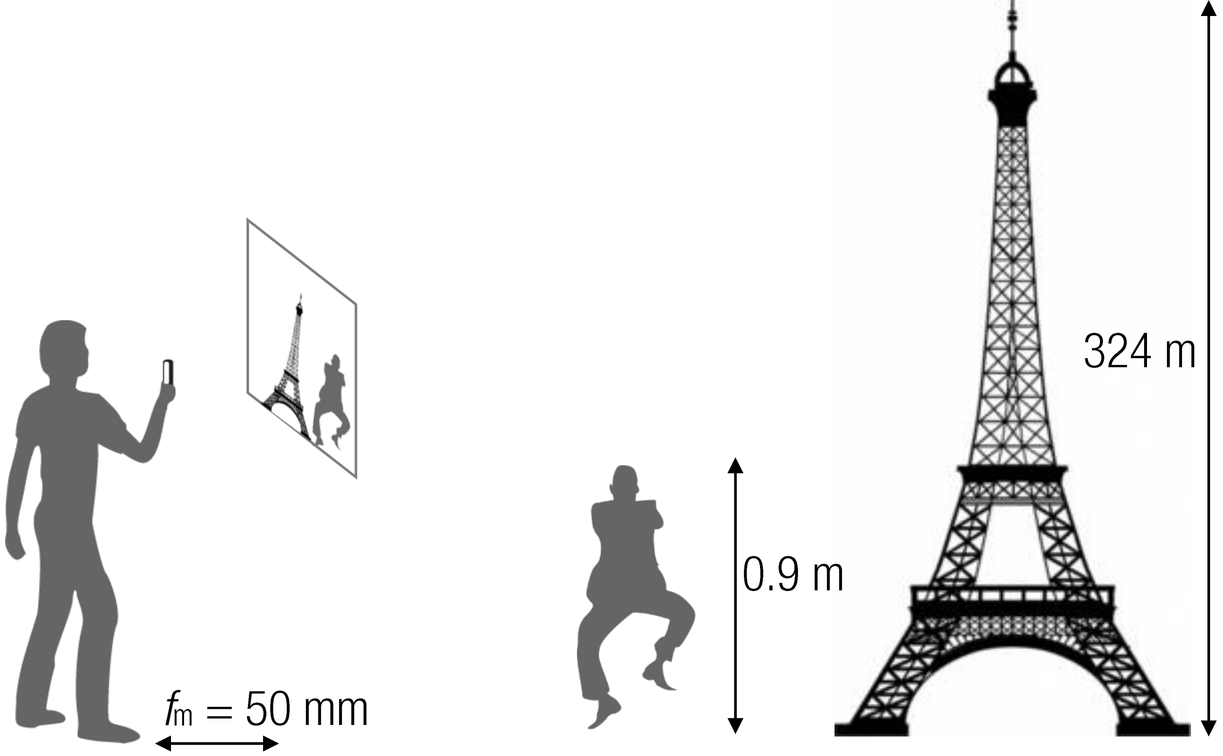


Circa 1984

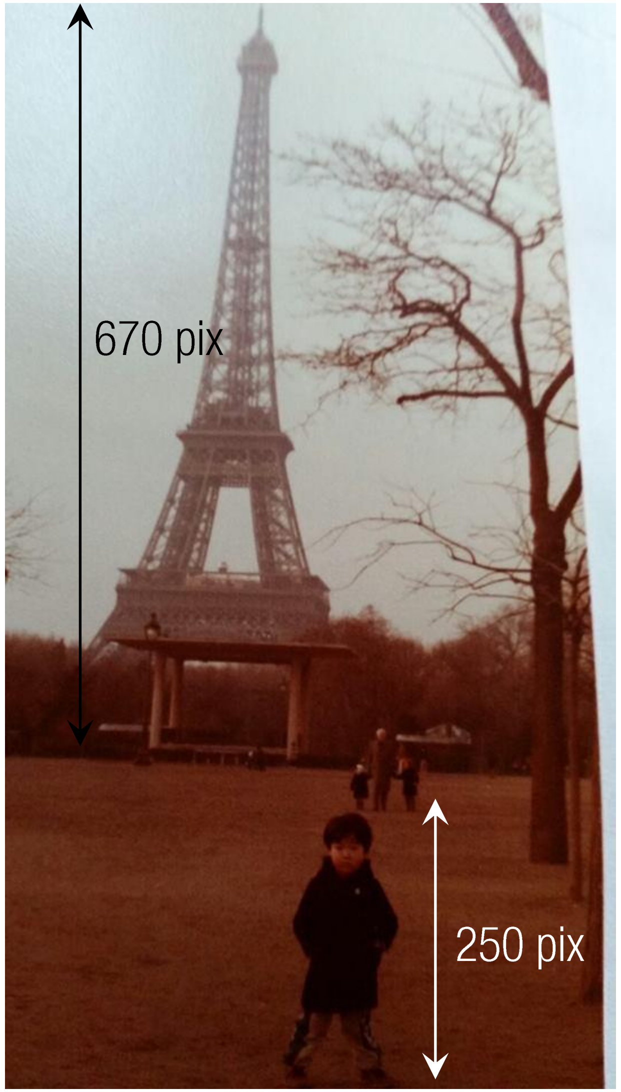
Where Was I?



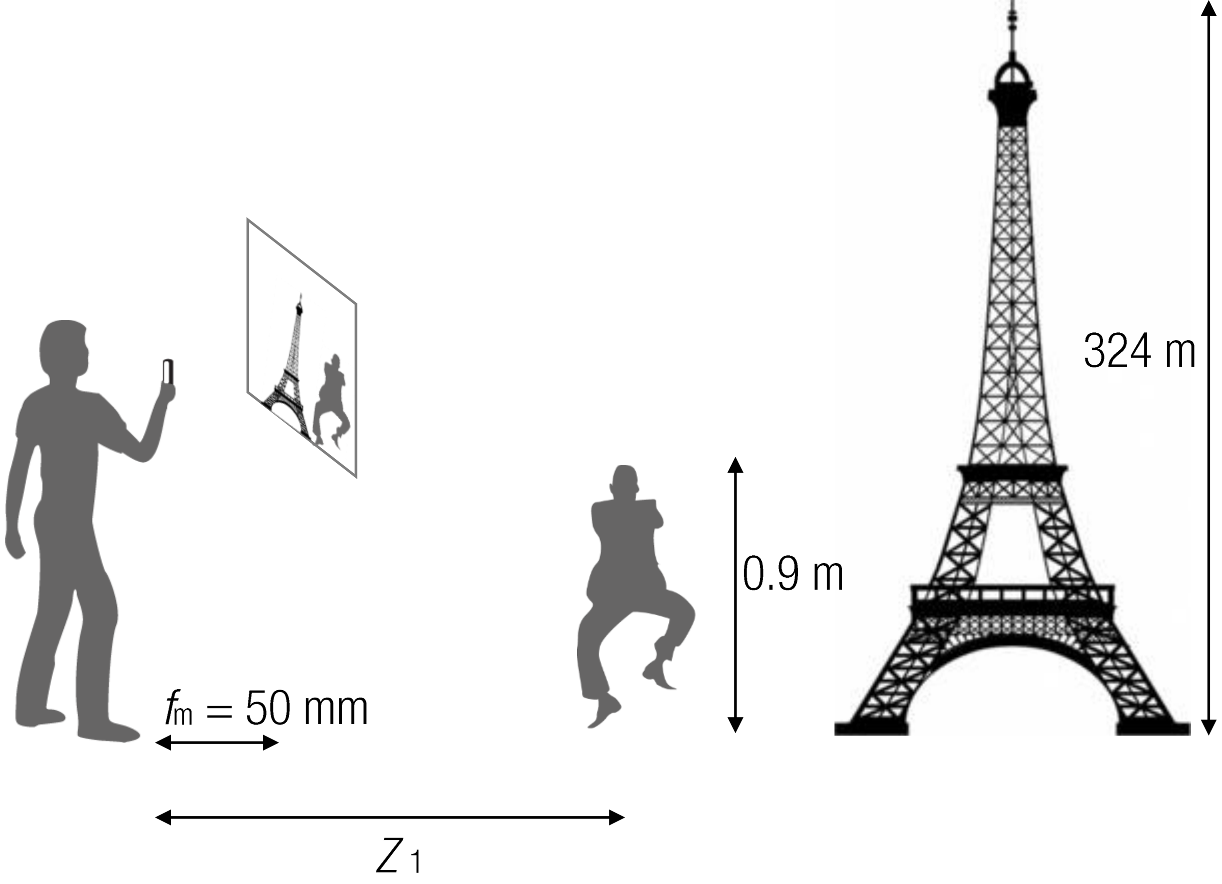
Circa 1984



Where Was I?

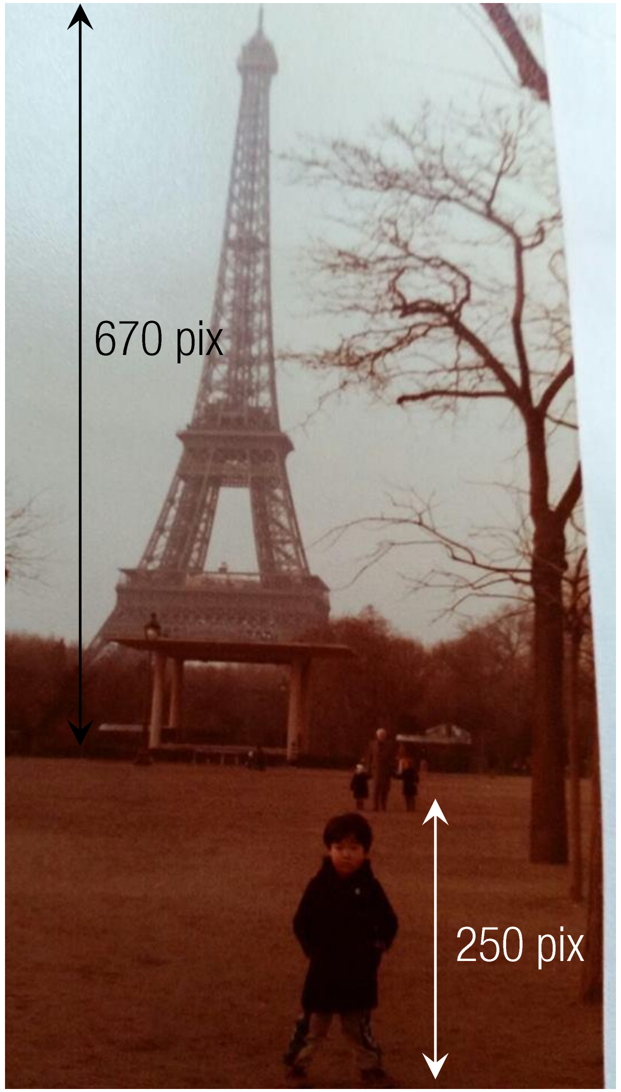


Circa 1984

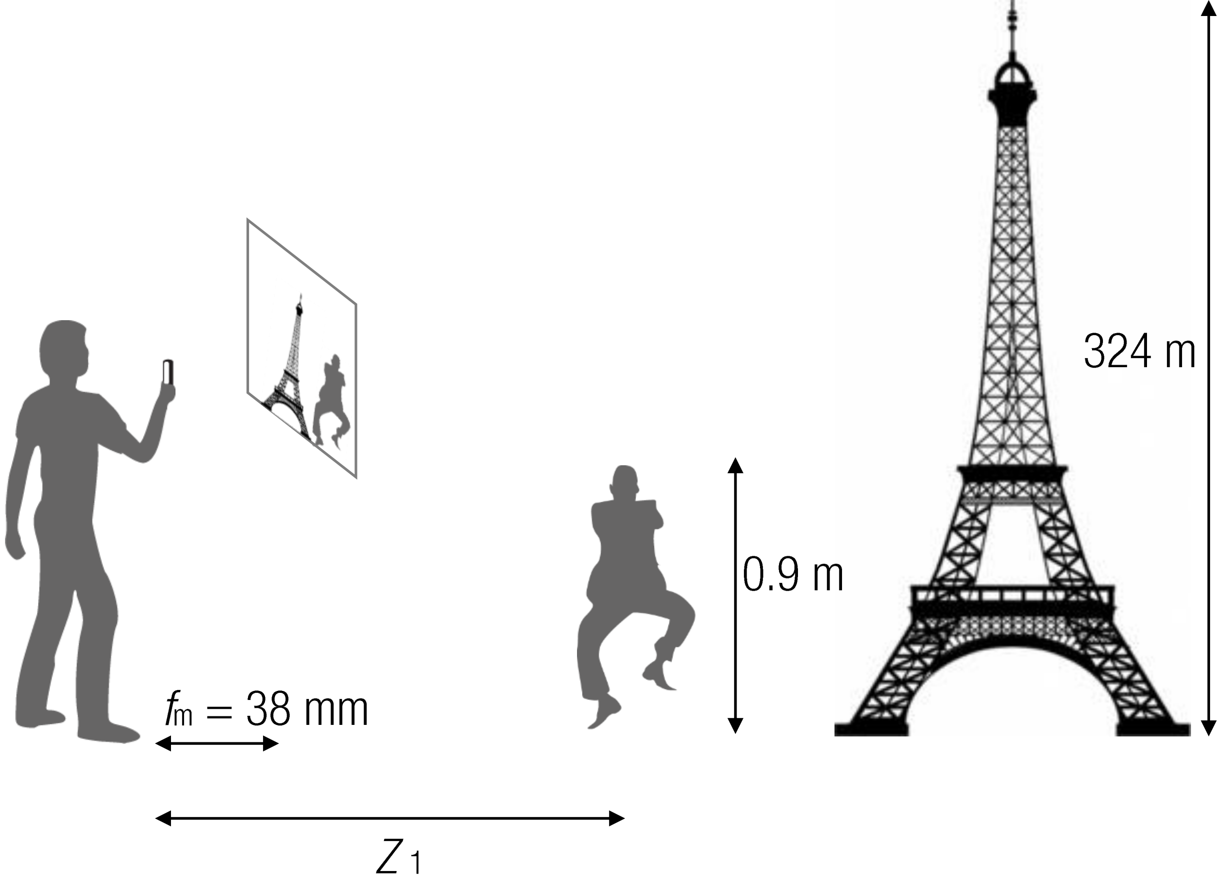


$$y_1 = f\frac{Y_1}{Z_1} = f_m \frac{h_{img}}{h_{ccd}} \frac{Y_1}{Z_1}$$

Where Was I?

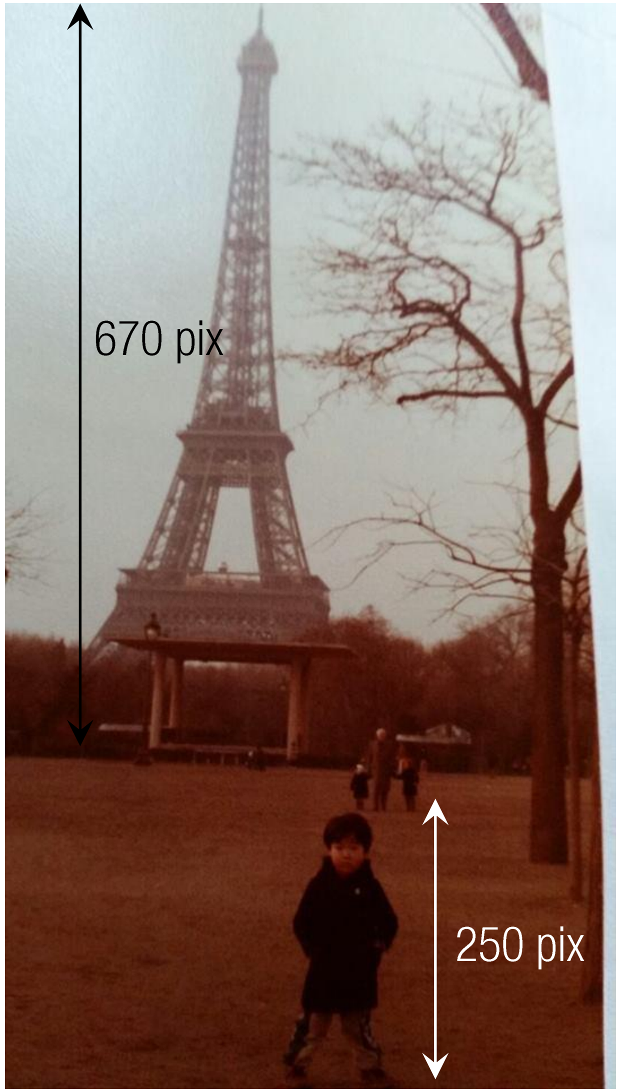


Circa 1984

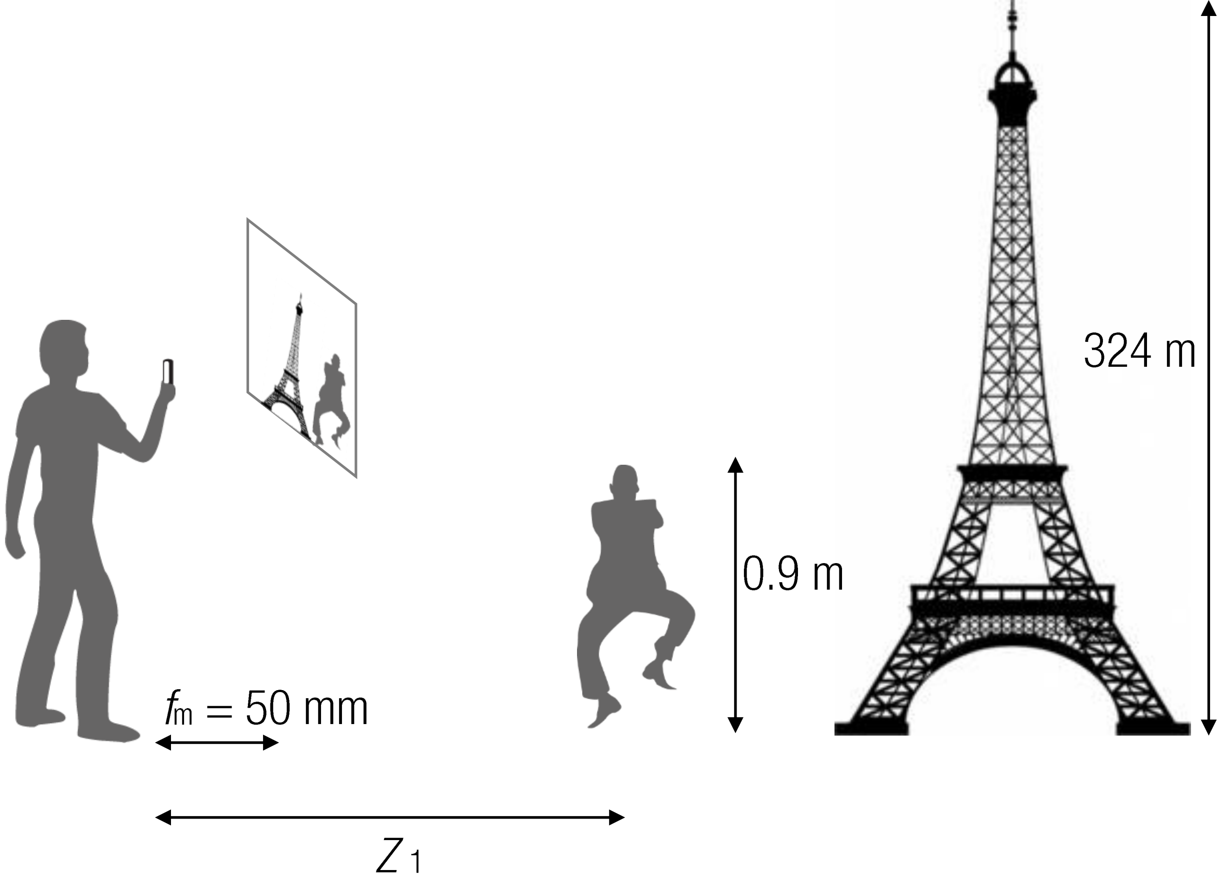


$$y_1 = f\frac{Y_1}{Z_1} = f_m \frac{h_{img}}{h_{ccd}} \frac{Y_1}{Z_1} \rightarrow Z_1 = f_m \frac{h_{img}}{h_{ccd}} \frac{Y_1}{y_1}$$

Where Was I?

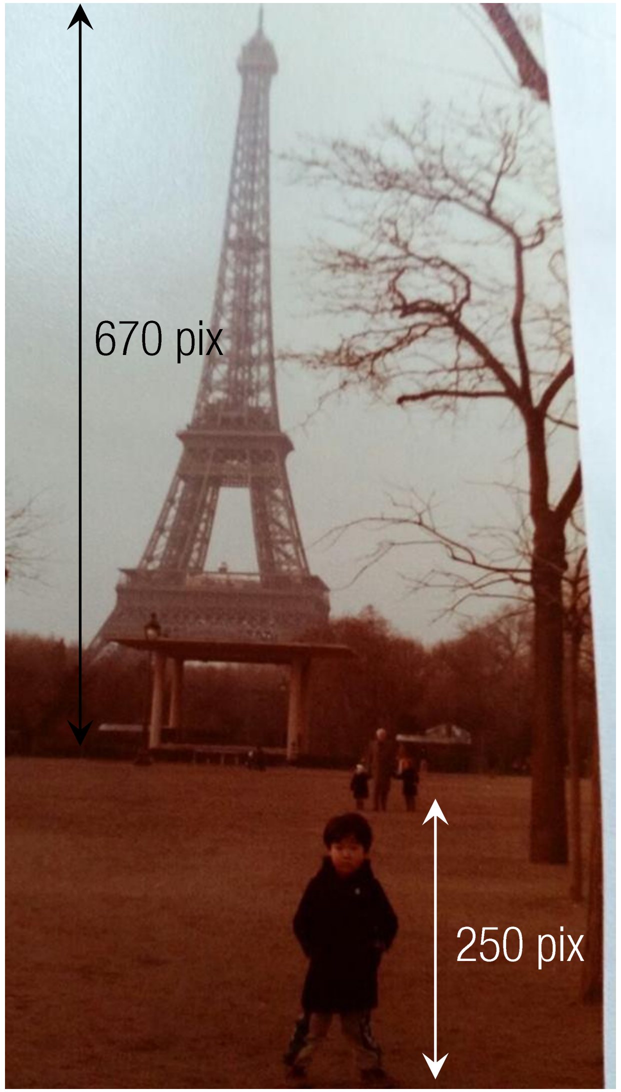


Circa 1984

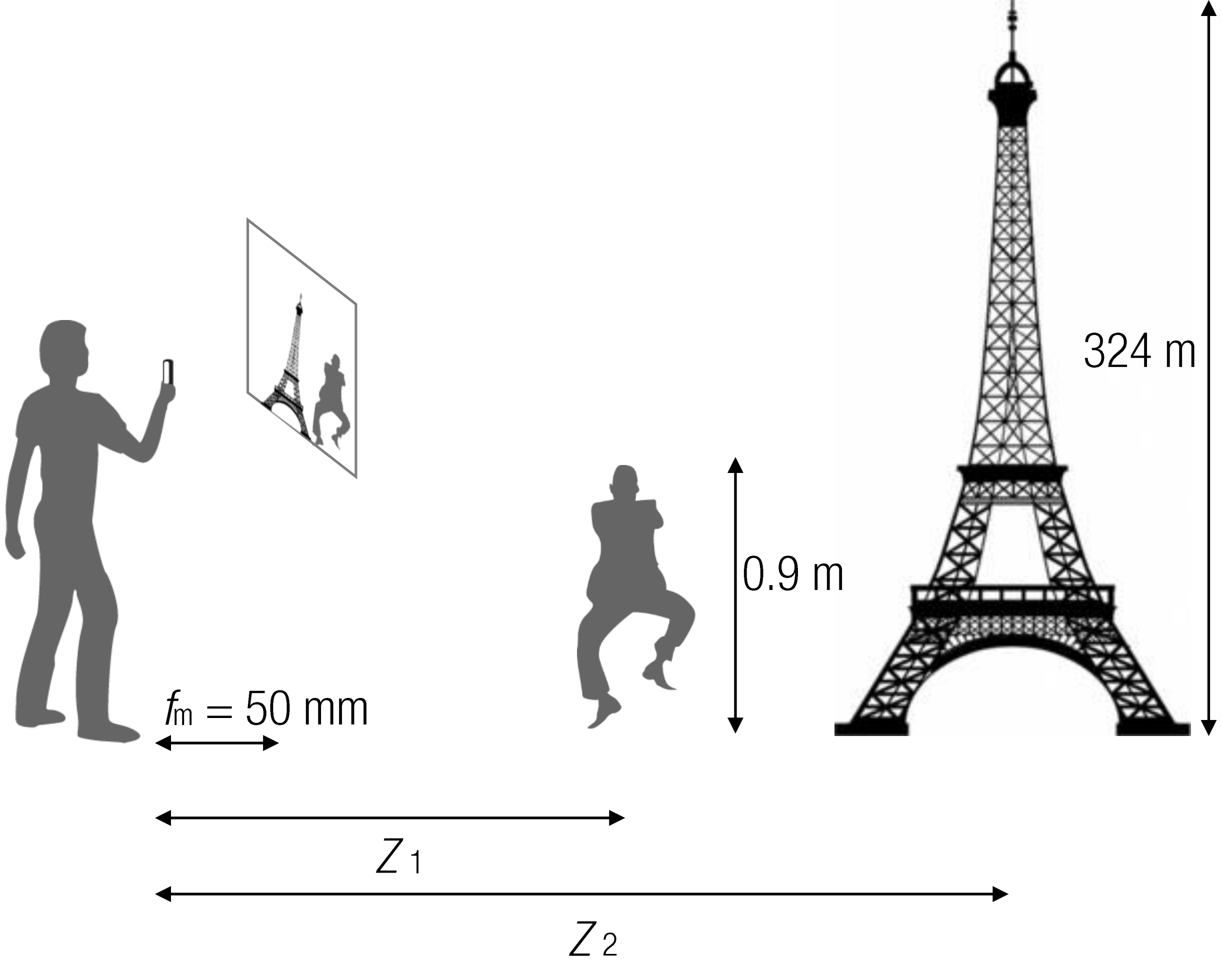


$$y_1 = f\frac{Y_1}{Z_1} = f_m \frac{h_{img}}{h_{ccd}} \frac{Y_1}{Z_1} \rightarrow Z_1 = f_m \frac{h_{img}}{h_{ccd}} \frac{Y_1}{y_1} = 0.05 \frac{1280}{0.0218} \frac{0.9}{250} = 8.03\text{m}$$

Where Was I?



Circa 1984

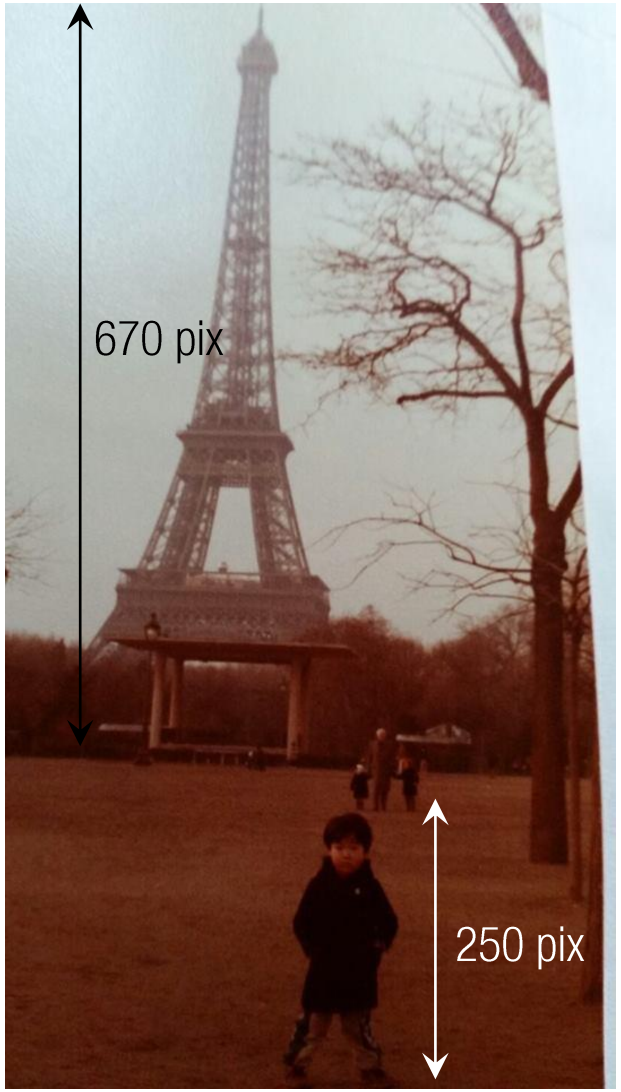


$$y_1 = f\frac{Y_1}{Z_1} = f_m \frac{h_{img}}{h_{ccd}}\frac{Y_1}{Z_1} \rightarrow Z_1 = f_m \frac{h_{img}}{h_{ccd}}\frac{Y_1}{y_1} = 0.05\frac{1280}{0.0218}\frac{0.9}{250} = 8.03\text{m}$$

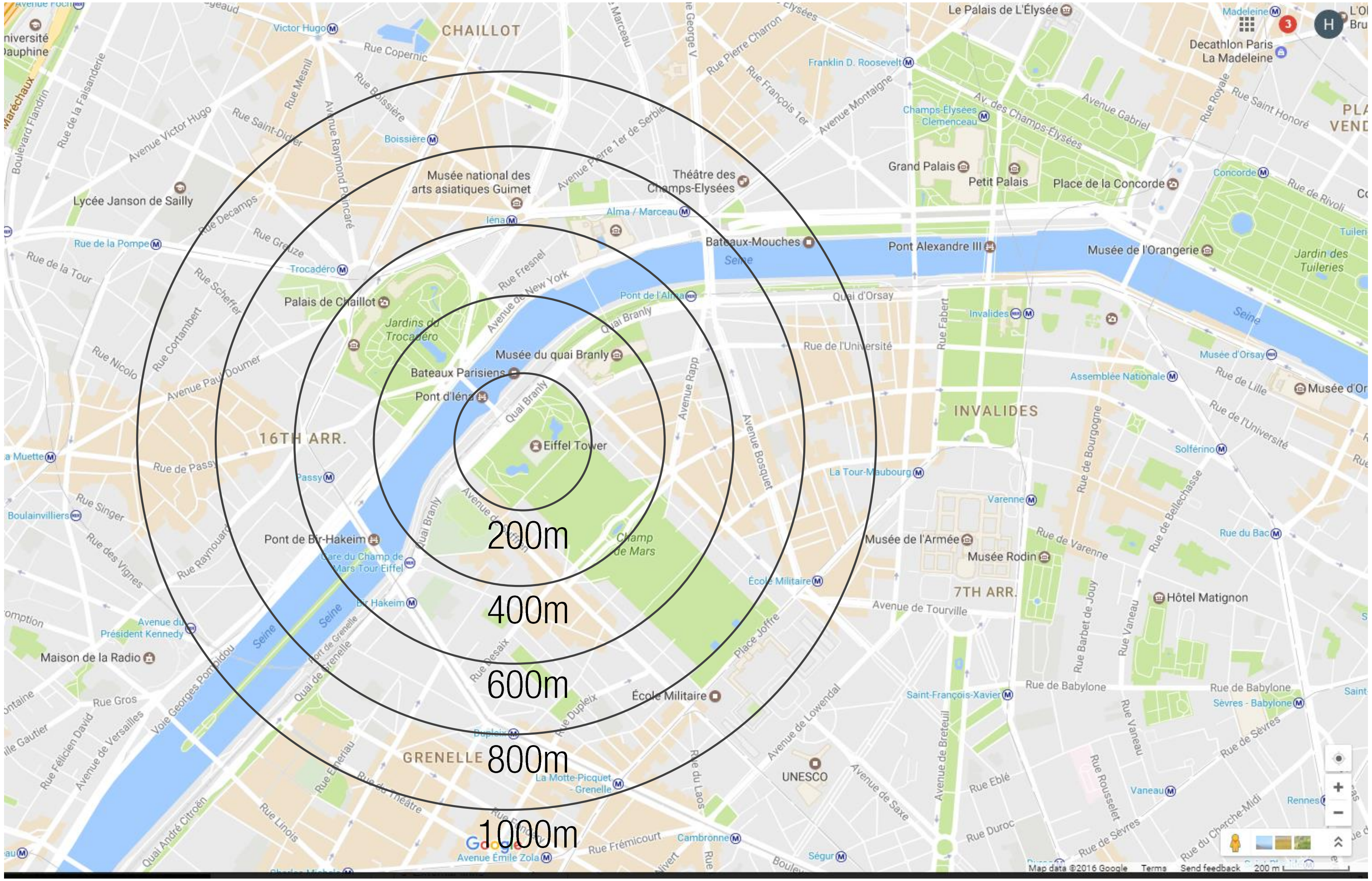
$$y_2 = f\frac{Y_2}{Z_2} = f_m \frac{h_{img}}{h_{ccd}}\frac{Y_2}{Z_2} \rightarrow Z_2 = f_m \frac{h_{img}}{h_{ccd}}\frac{Y_2}{y_2} = 0.05\frac{1280}{0.0218}\frac{324}{670} = 1079\text{m}$$

Where Was I?

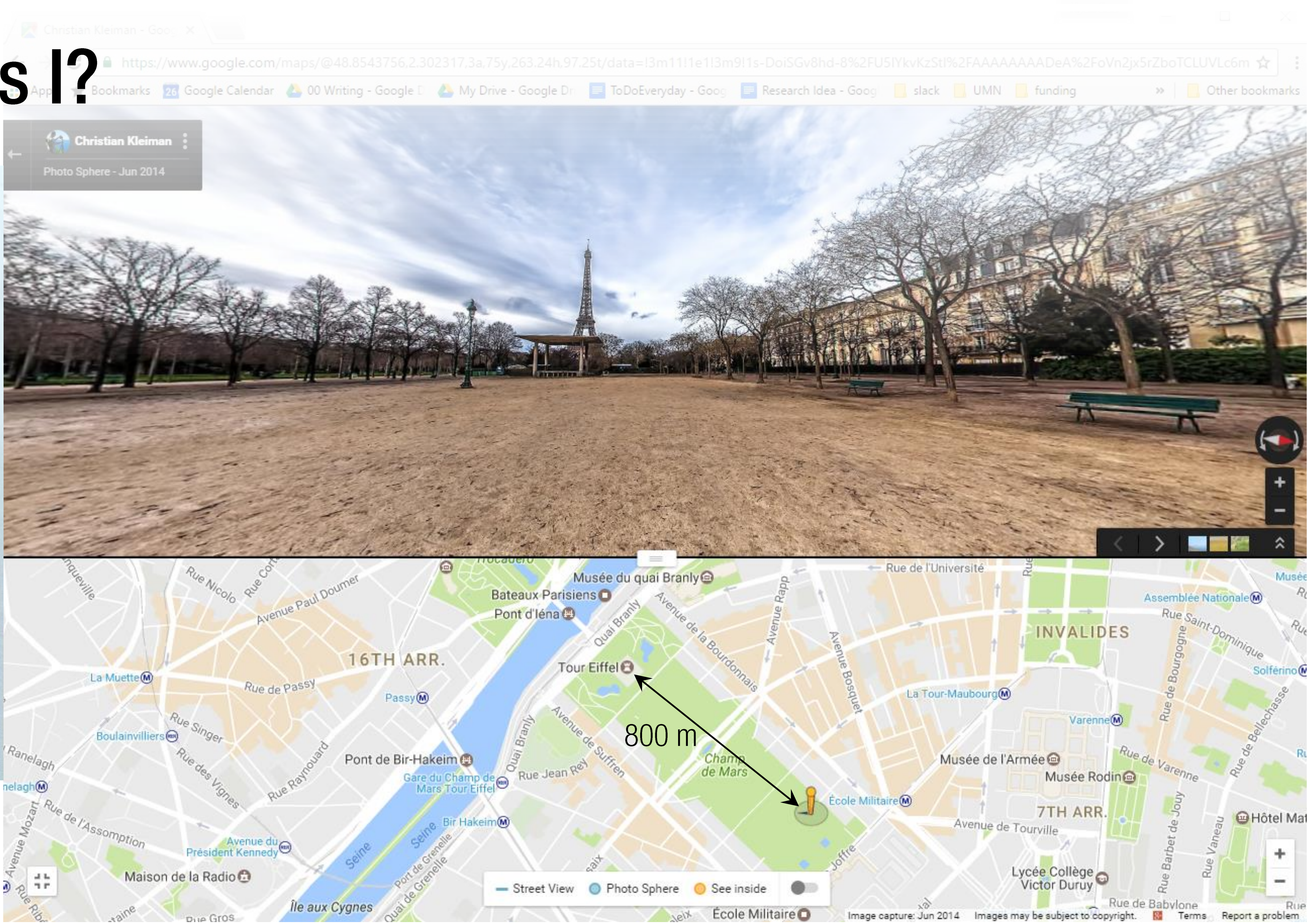
$$y_2 = f\frac{Y_2}{Z_2} = f_m\frac{h_{img}}{h_{ccd}}\frac{Y_2}{Z_2} \rightarrow Z_2 = f_m\frac{h_{img}}{h_{ccd}}\frac{Y_2}{y_2} = 0.05\frac{1280}{0.0218}\frac{324}{670} = 1079\text{m}$$



Circa 1984



Where Was I?


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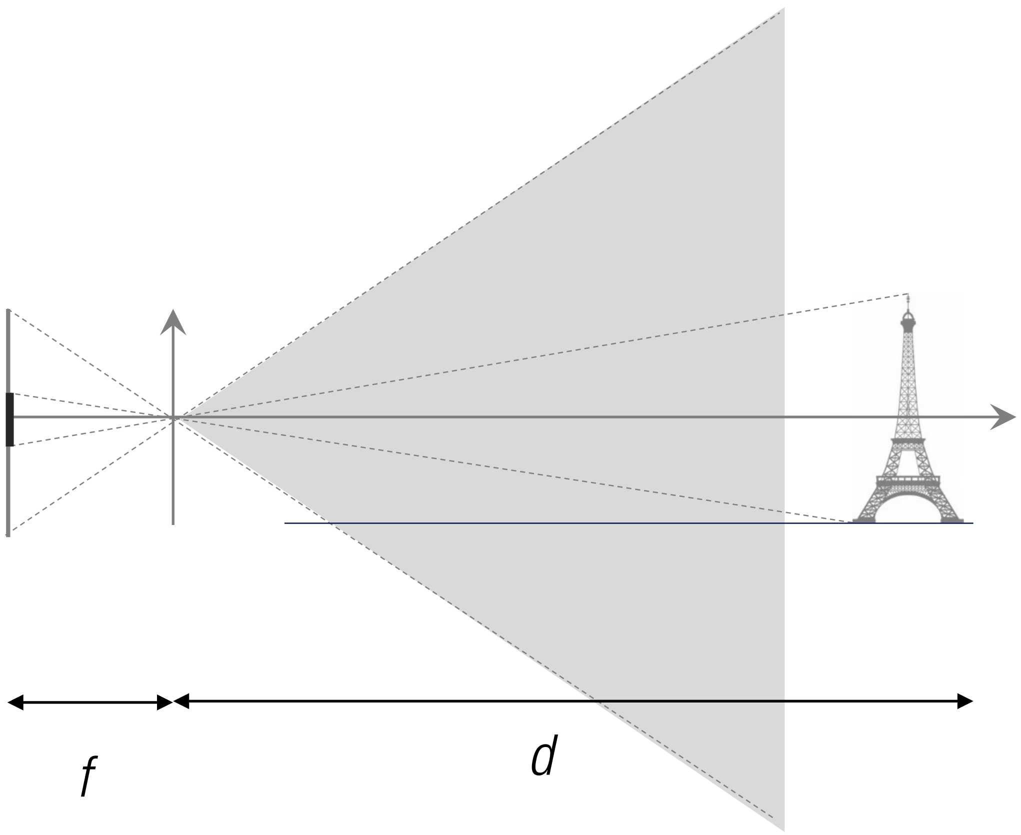
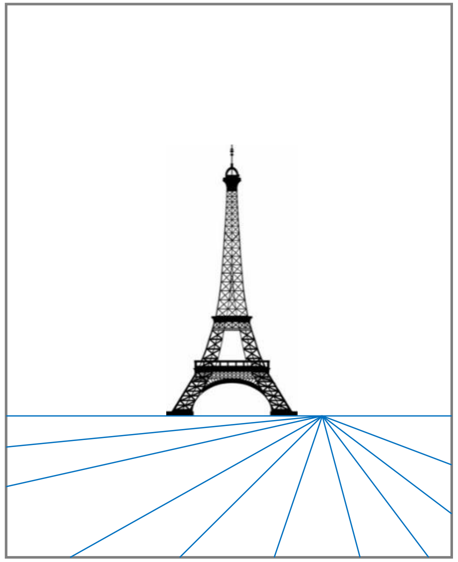
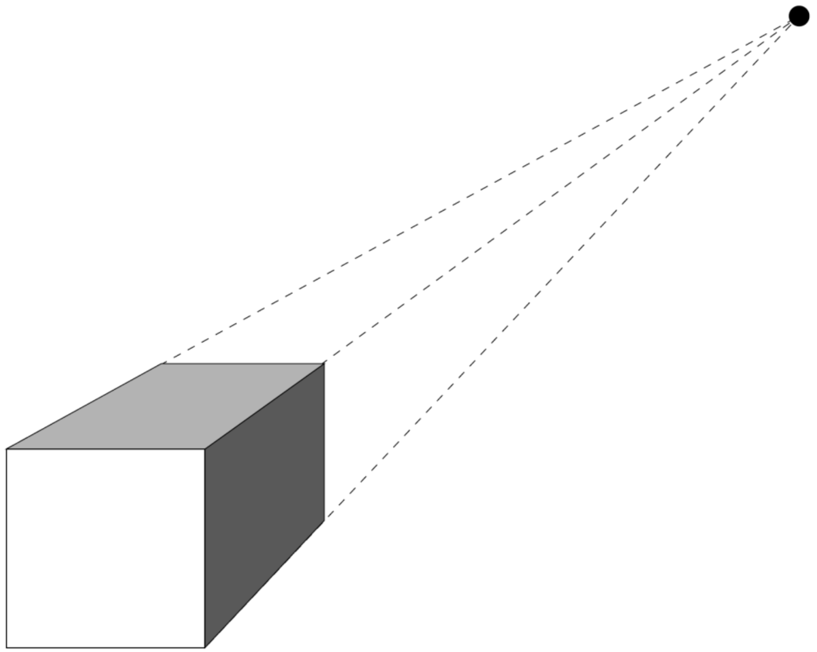
Focal Length

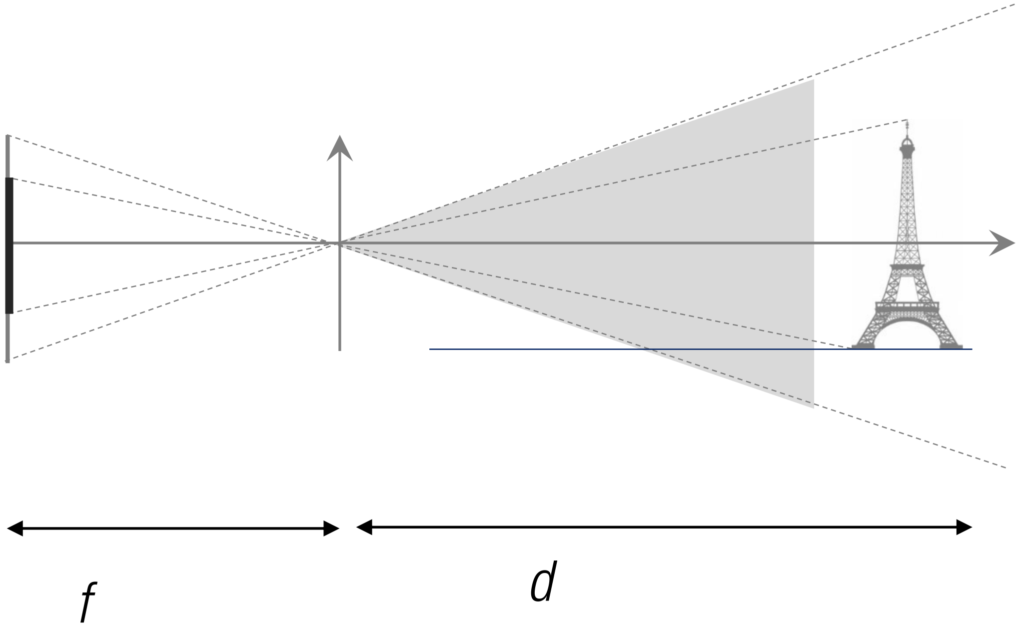


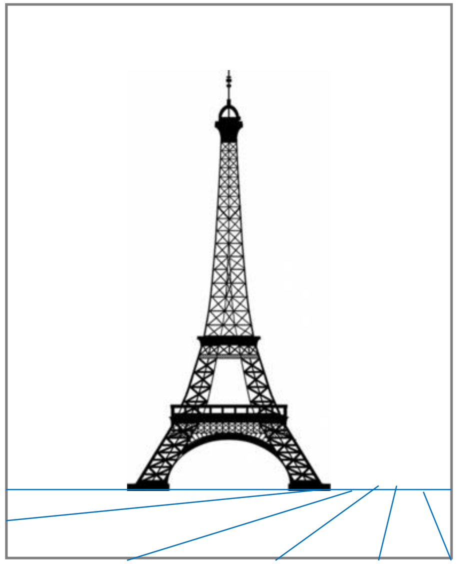


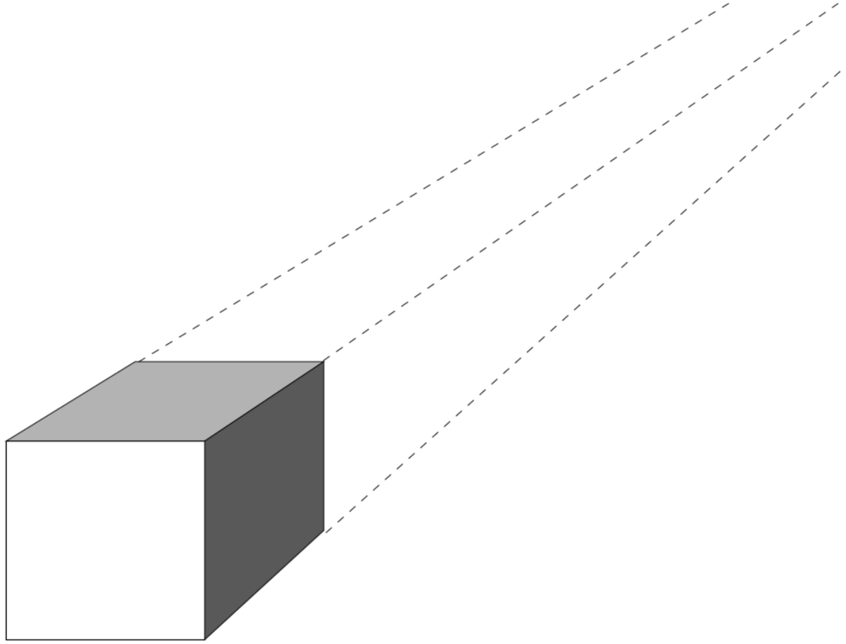


Strong perspective

Focal Length

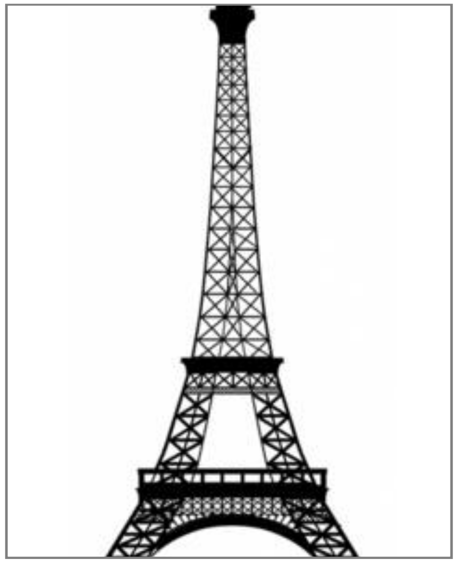


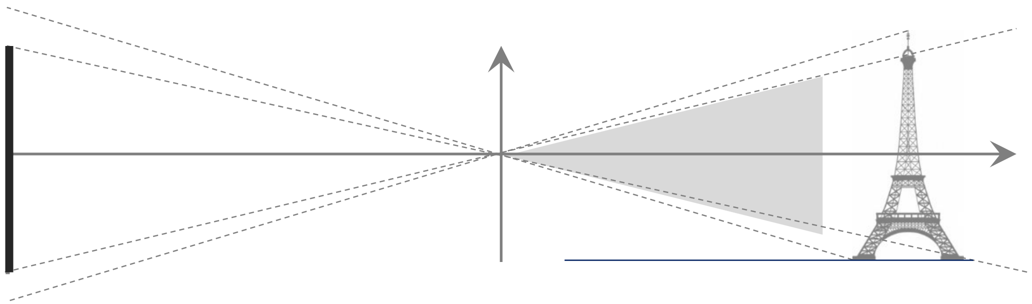


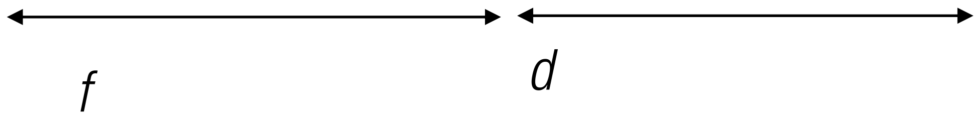


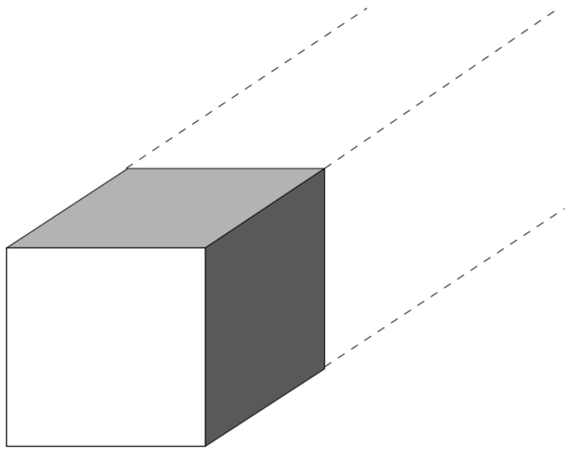
Weak perspective

Focal Length



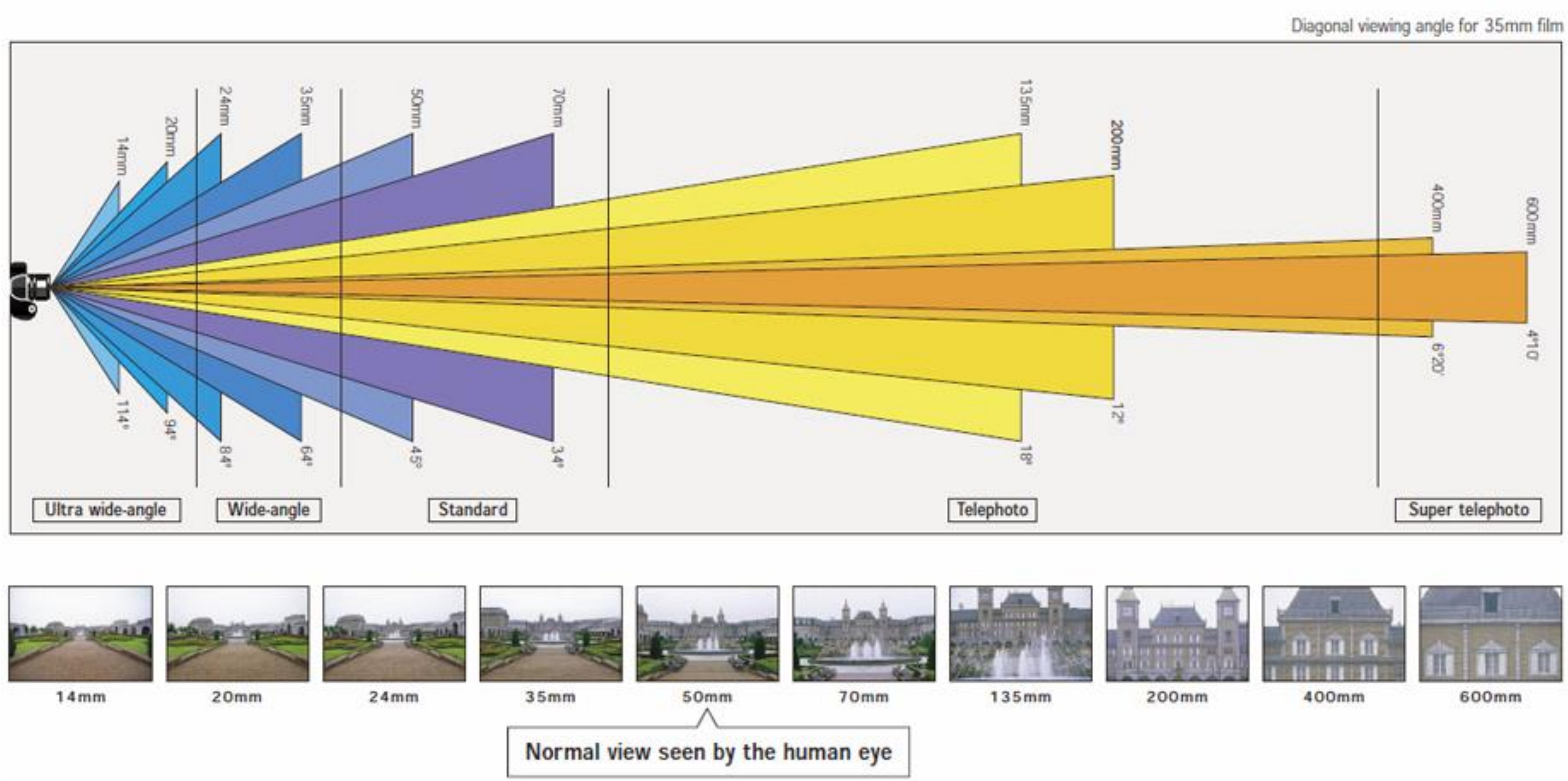






Orhographic

Focal Length



Angle of View


7.5 mm


15 mm


17 mm


20 mm


24 mm


28 mm


35 mm


50 mm

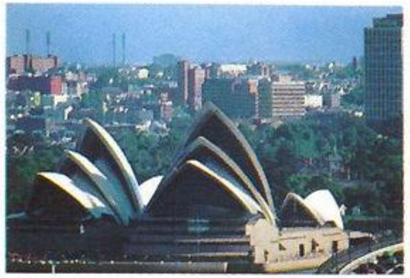

85 mm


100 mm


135 mm

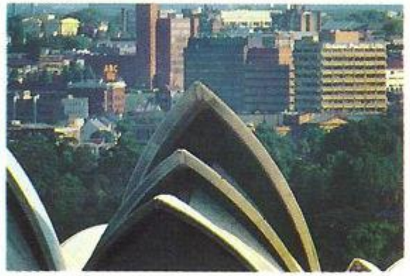

200 mm

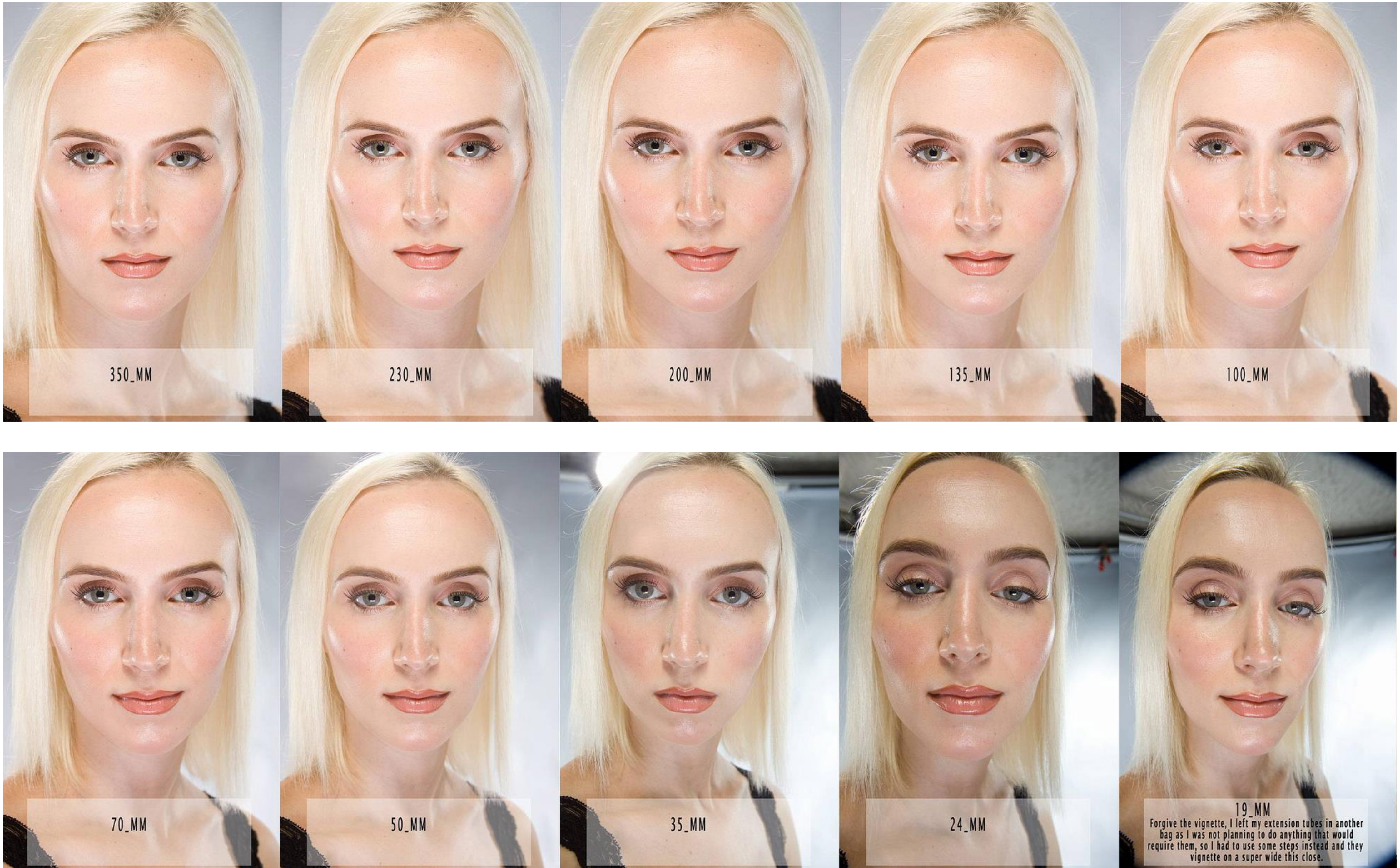

300 mm


400 mm


500 mm


600 mm


800 mm



350_MM
230_MM
200_MM
135_MM
100_MM
70_MM
50_MM
35_MM
24_MM
19_MM
Forgive the vignette, I left my extension tubes in another bag as I was not planning to do anything that would require them, so I had to use some steps instead and they vignette on a super wide this close.

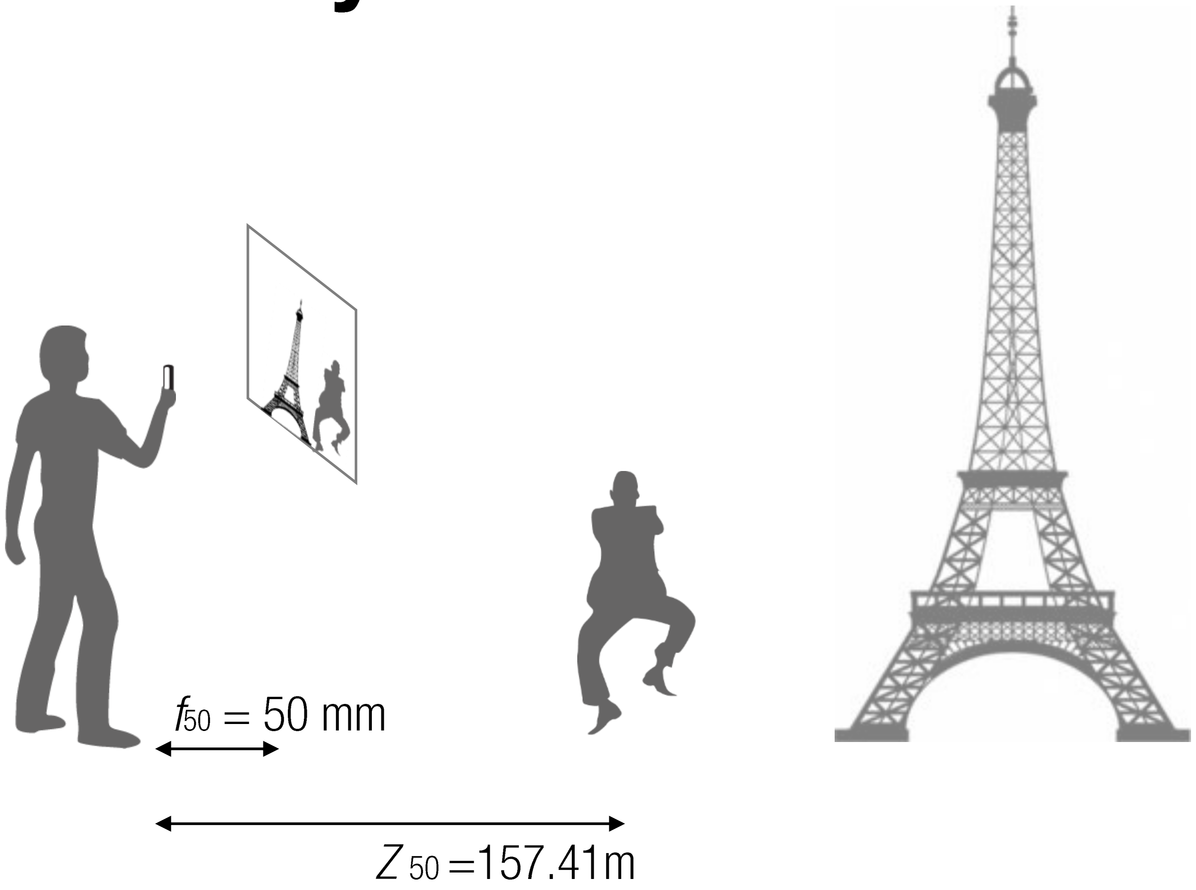
Dolly Zoom (Vertigo Effect)

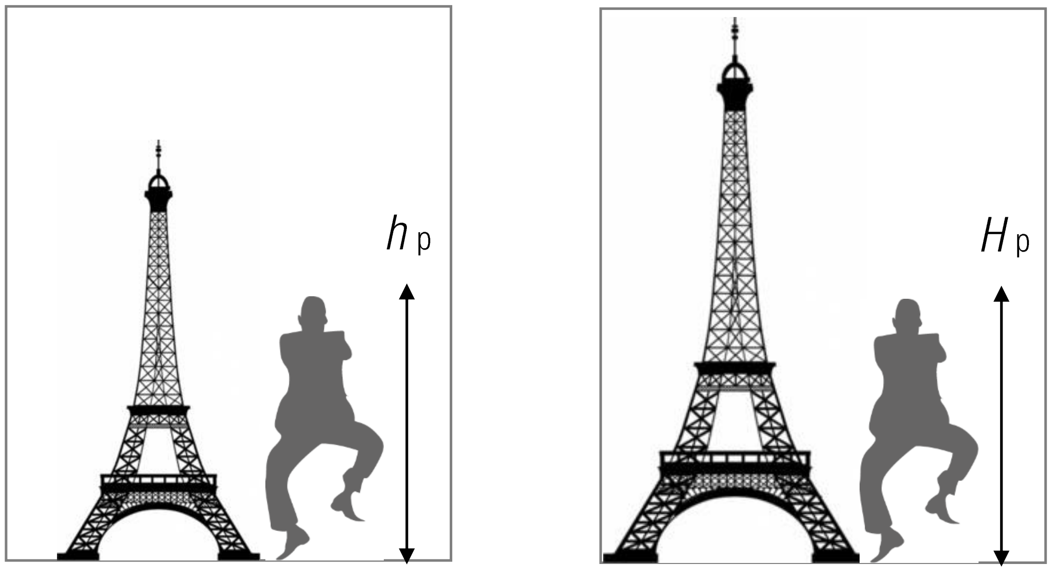
Dolly Zoom (Vertigo Effect)

JAWS (1975)

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

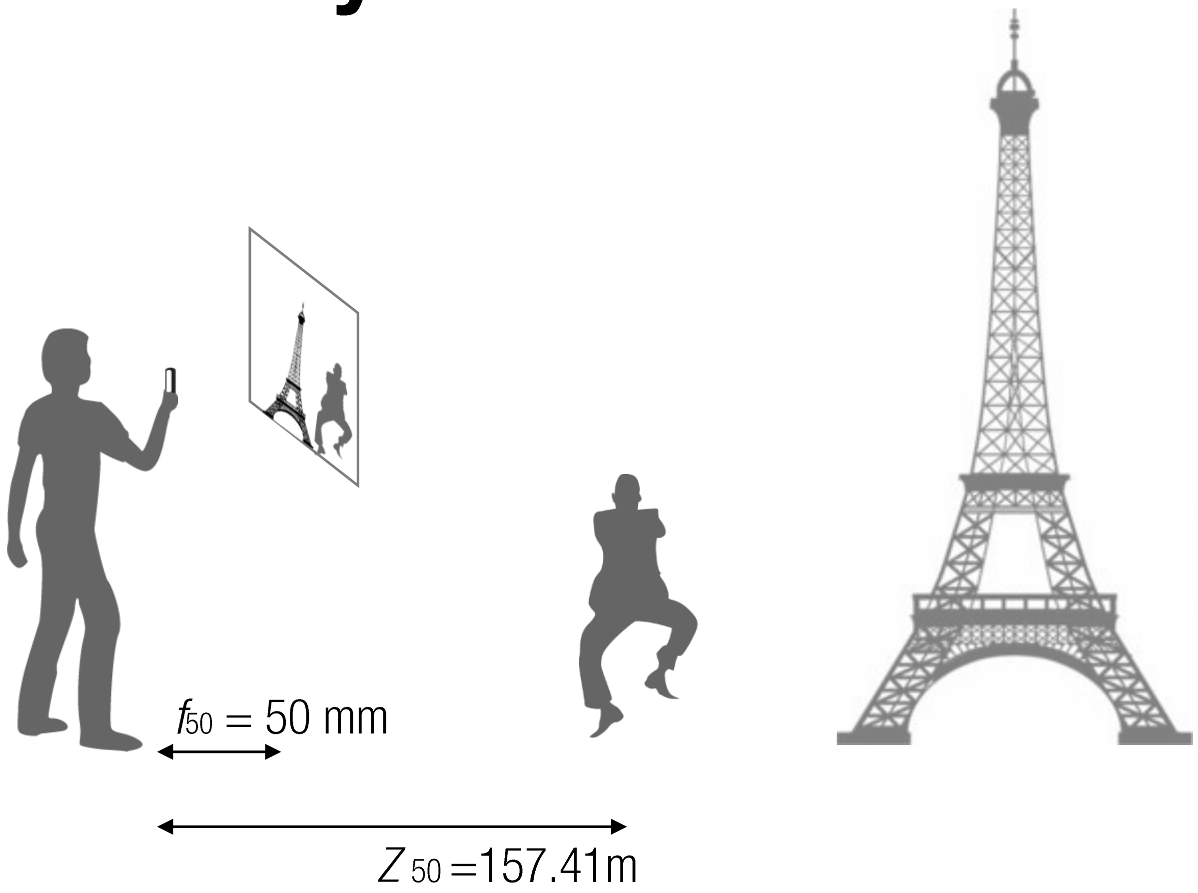
Dolly Zoom

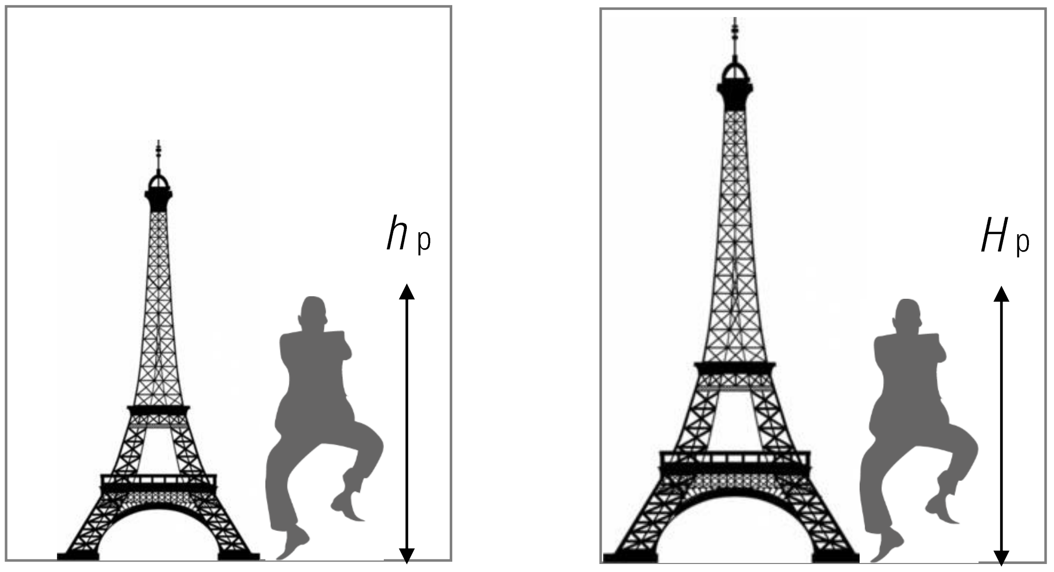




Given focal length (f_m=100mm),
what Z_{100} to make the height of the person remain the same as f_m=50mm?

Dolly Zoom

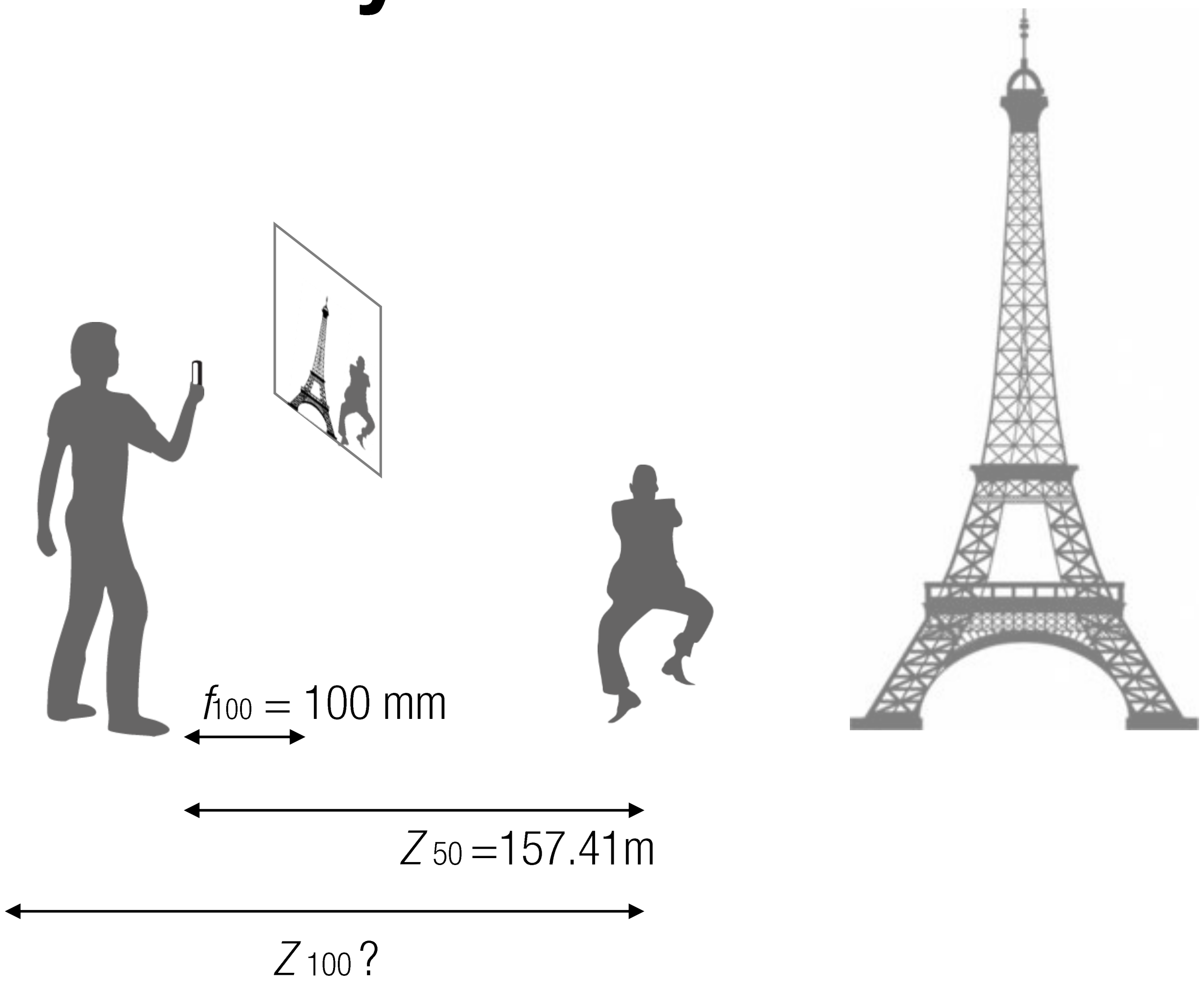


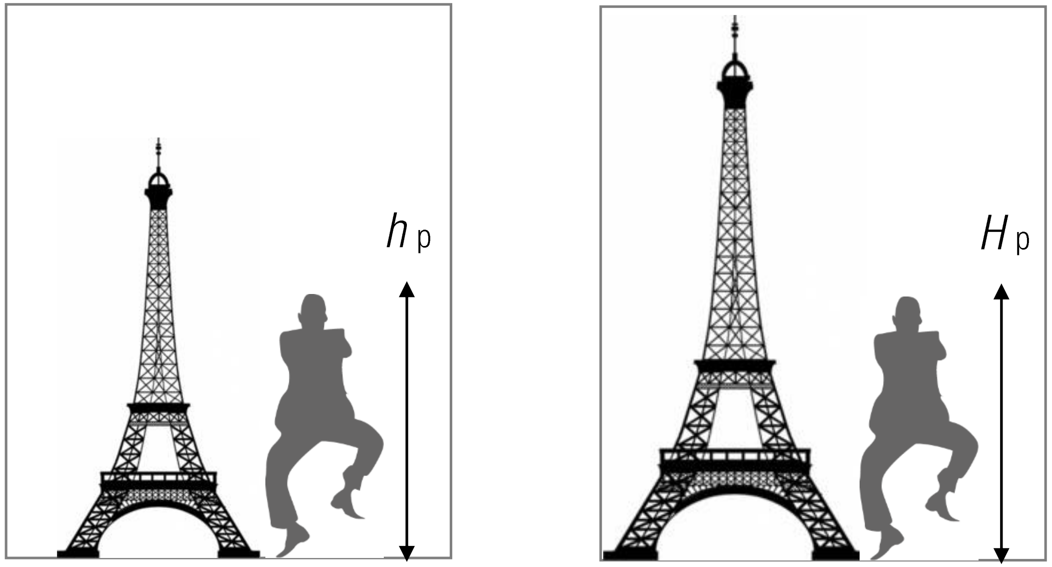


$$h_{50} = f_{50}\frac{Y}{Z_{50}} \quad h_{100} = f_{100}\frac{Y}{Z_{100}} \quad \text{s.t.} \quad h_{100} = h_{50}$$

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

Dolly Zoom

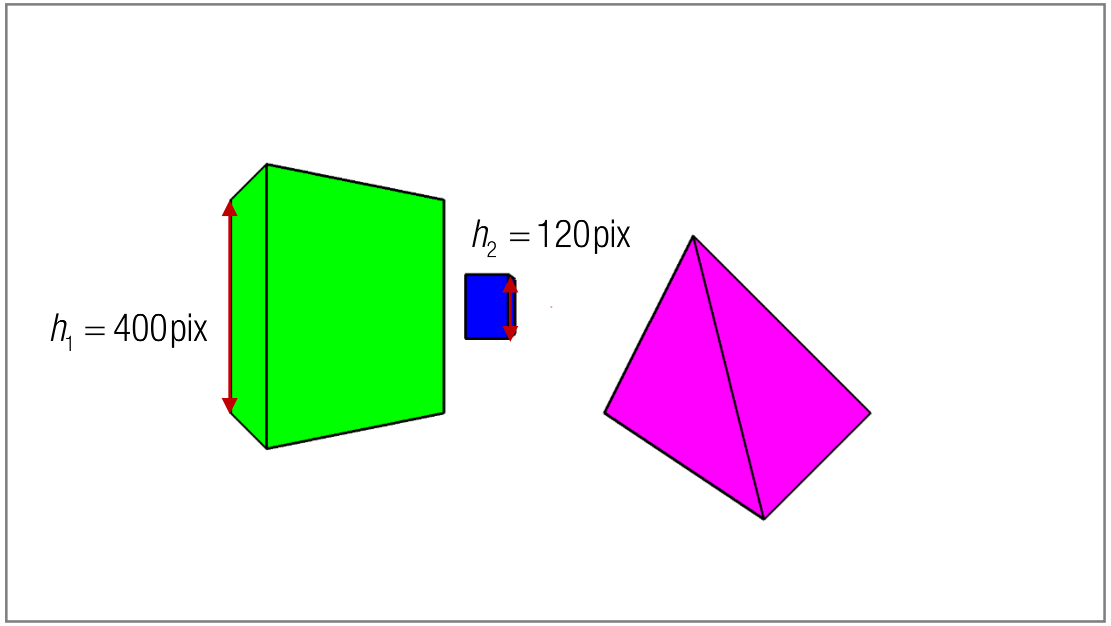




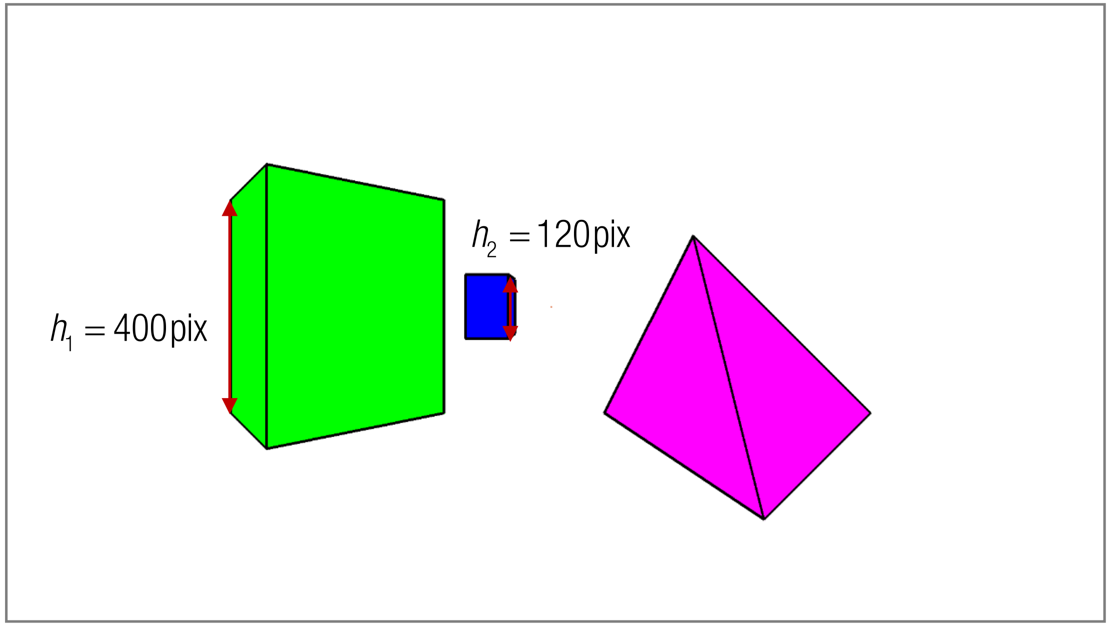
$$h_{50} = f_{50}\frac{Y}{Z_{50}} \quad h_{100} = f_{100}\frac{Y}{Z_{100}} \quad \text{s.t.} \quad h_{100} = h_{50}$$

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

Where am I with Dolly Zoom?



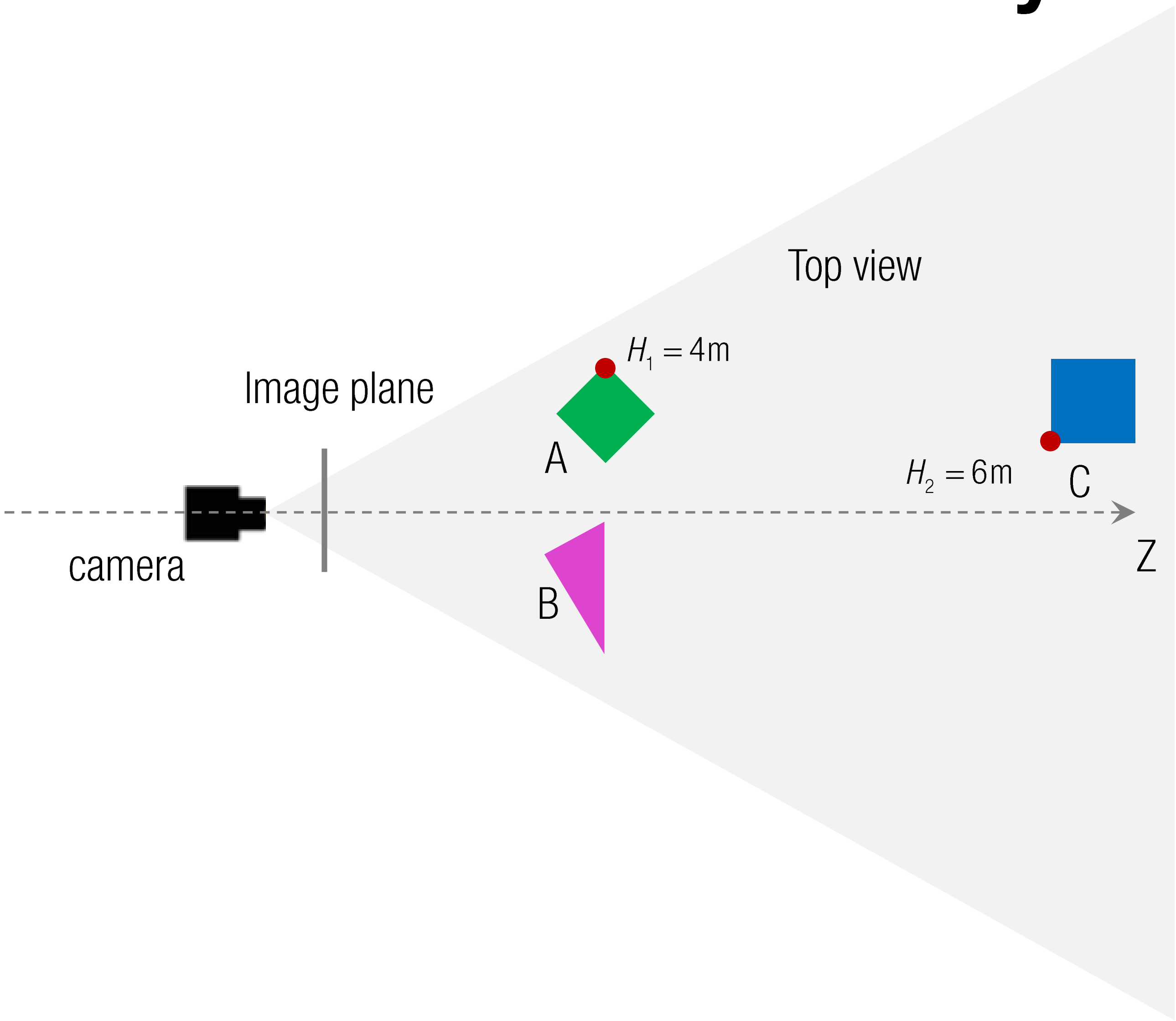
Where am I with Dolly Zoom?

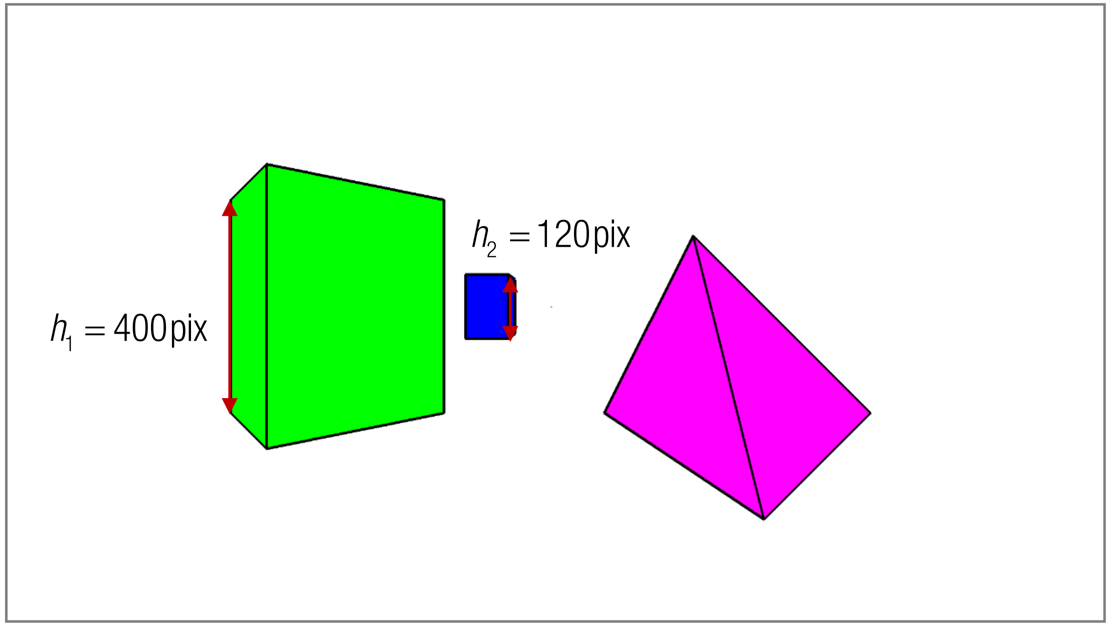


How far I need to step back with zoom factor x2?

How will h_2 change?

Where am I with Dolly Zoom?





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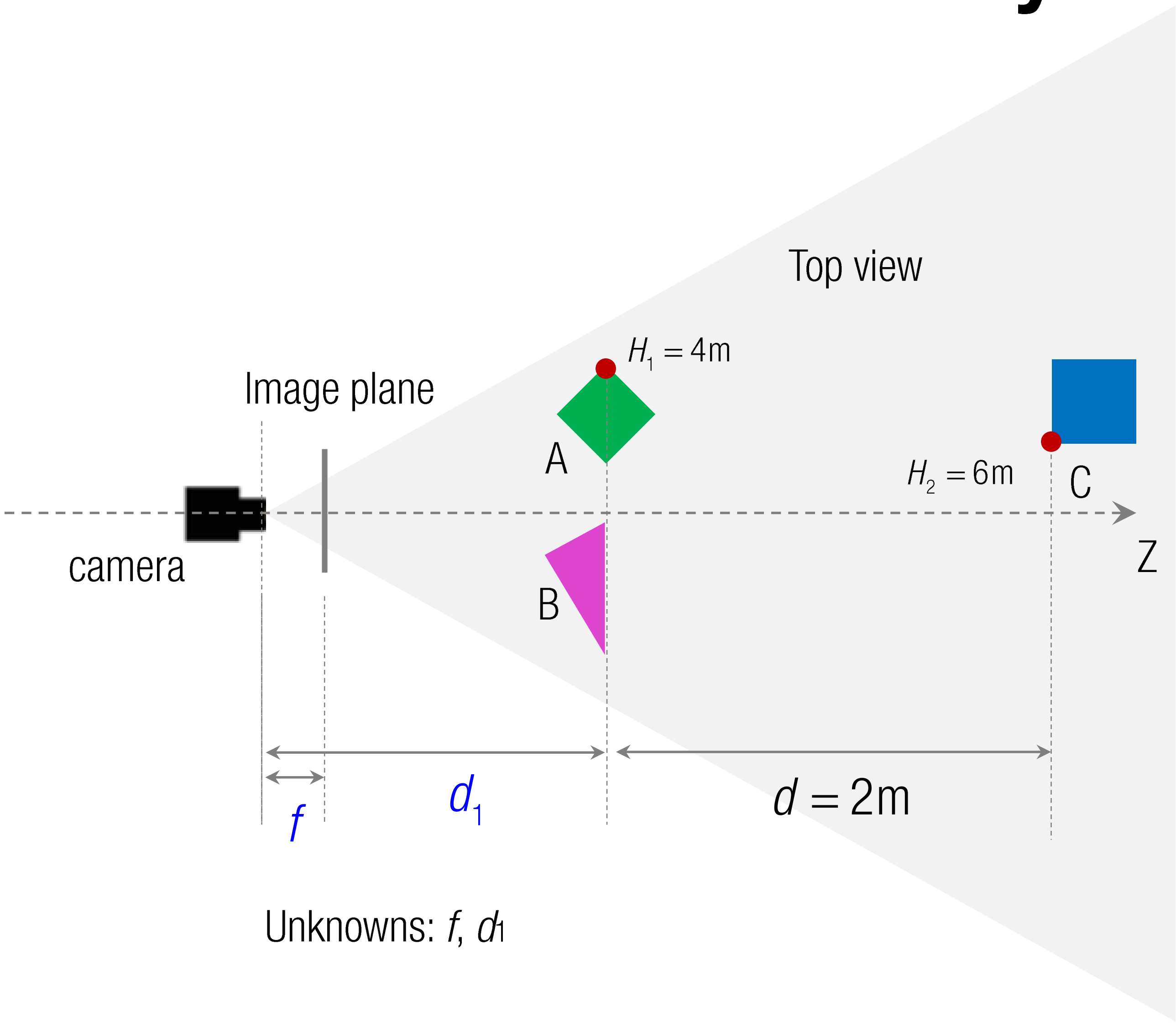
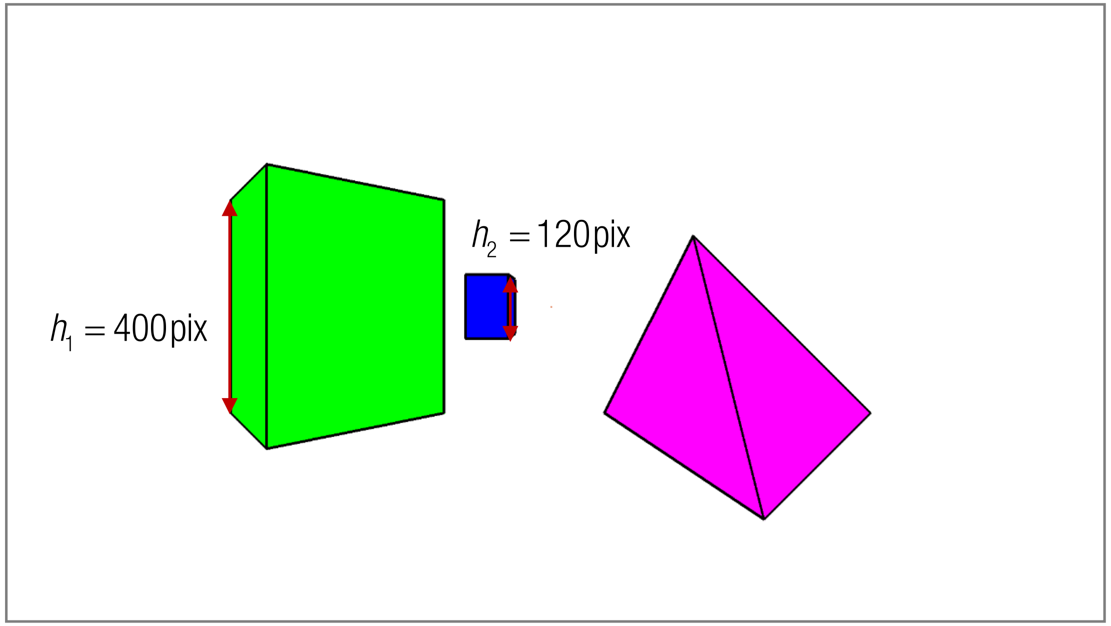


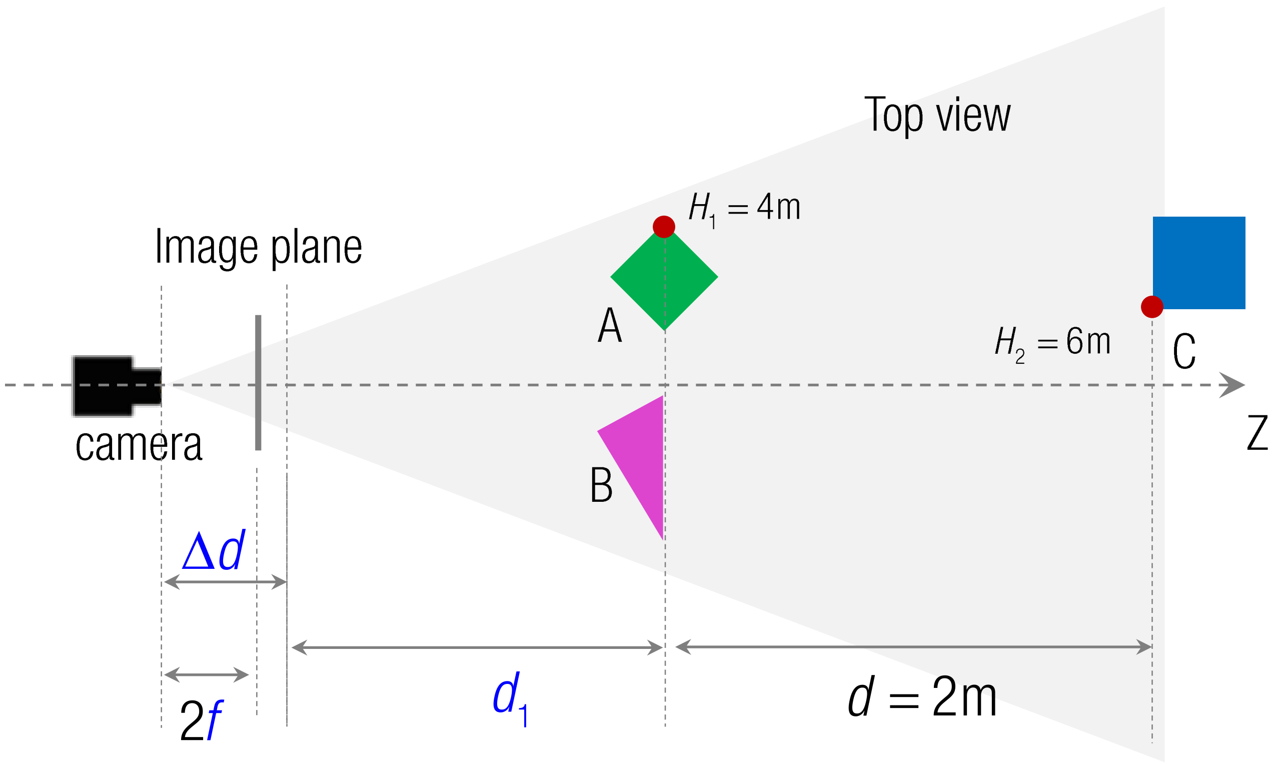


Unknowns: f, d_1

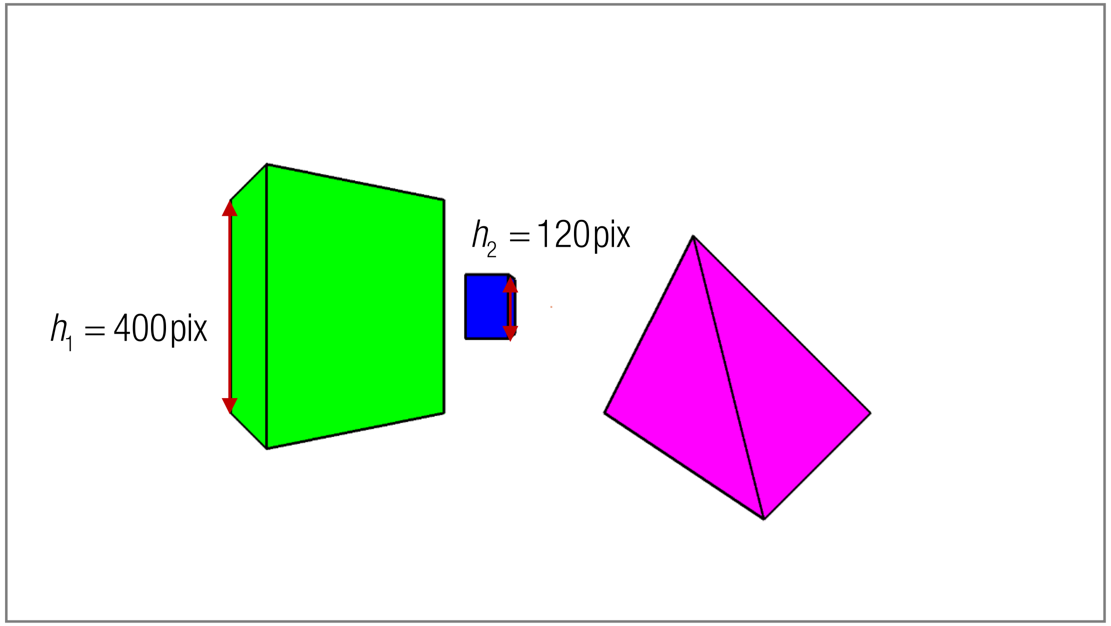
How far I need to step back with zoom factor x2?

How will h_2 change?

Where am I with Dolly Zoom?



Unknowns: f, d_1, Δd



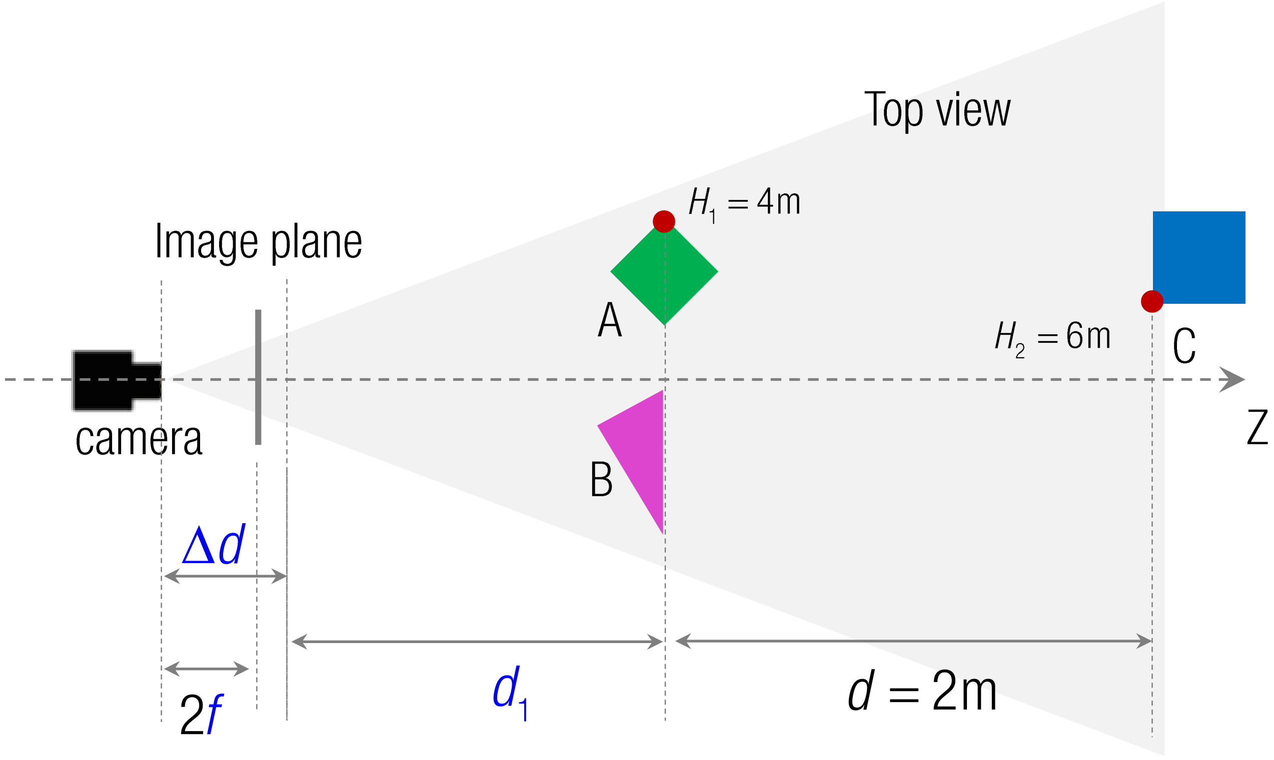
How far I need to step back with zoom factor x2?

How will h_2 change?

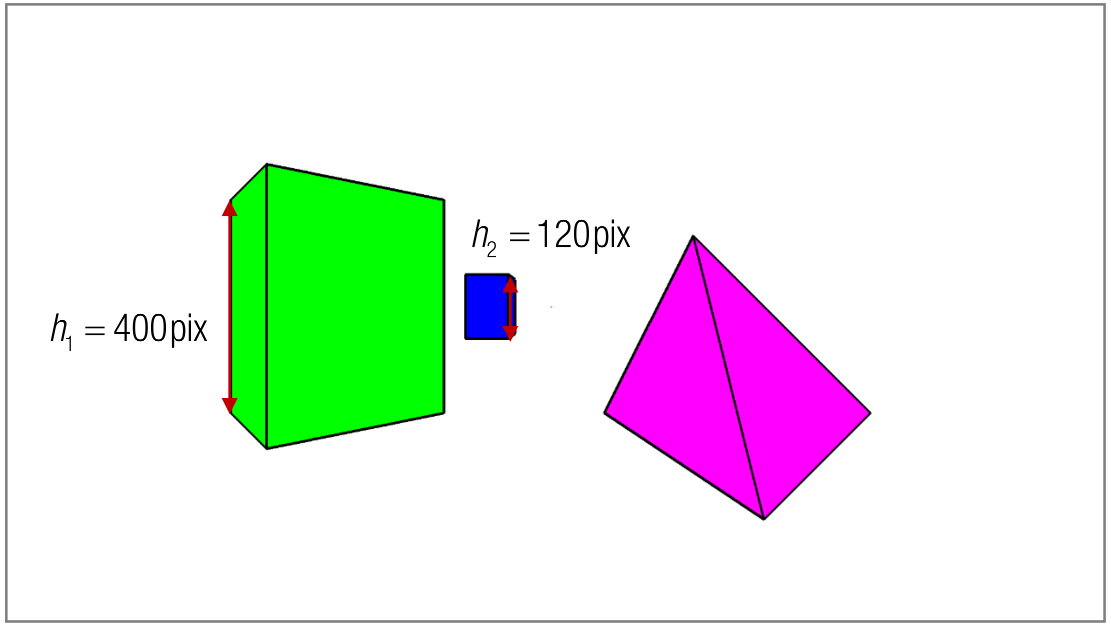
Where am I with Dolly Zoom?

Equations:

$$h_1 = f \frac{H_1}{d_1}$$



Unknowns: f, d_1, Δd



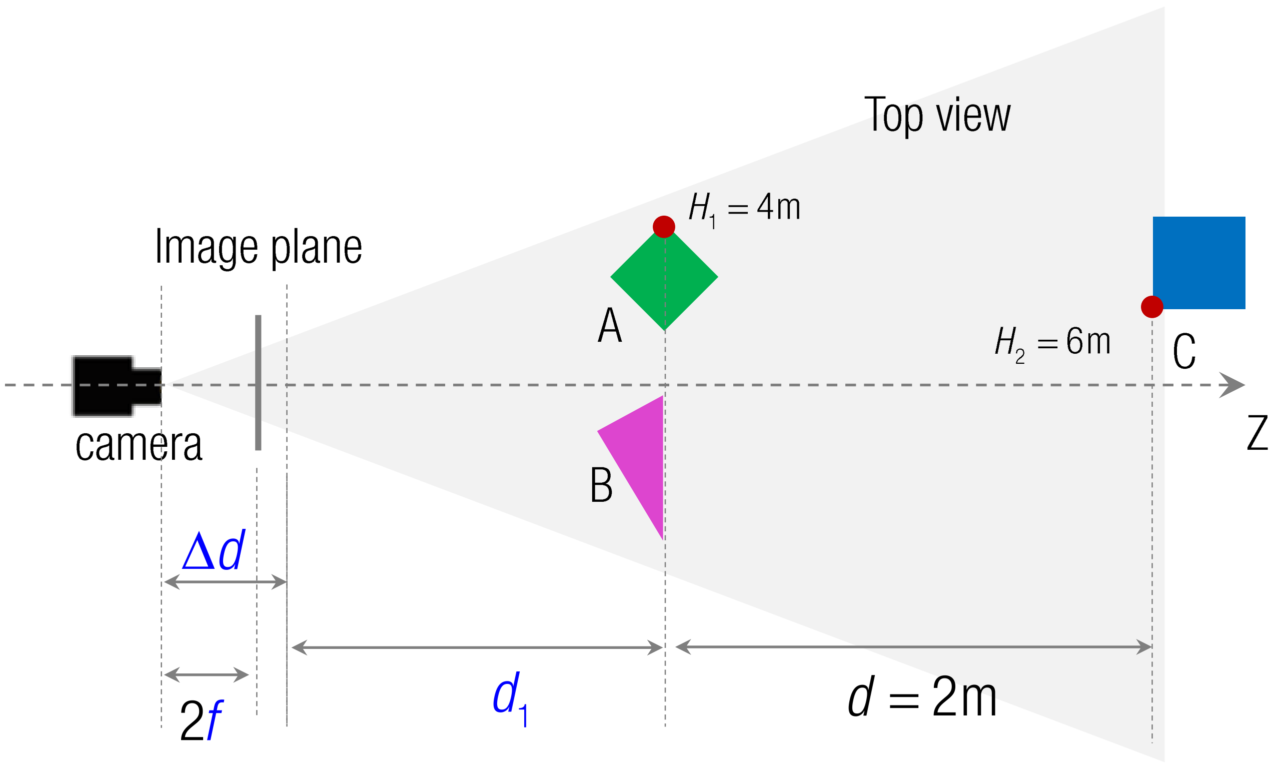
How far I need to step back with zoom factor x2?

How will h_2 change?

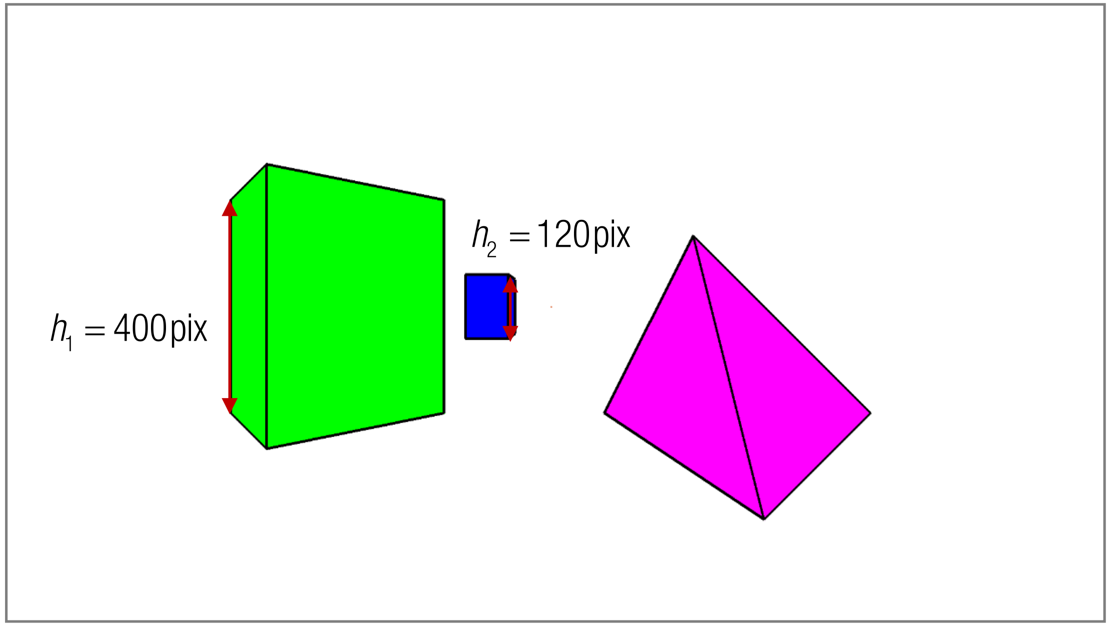
Where am I with Dolly Zoom?

Equations:

$$h_1 = f\frac{H_1}{d_1} \qquad h_1 = 2f\frac{H_1}{\Delta d + d_1}$$



Unknowns: f, d_1, Δd



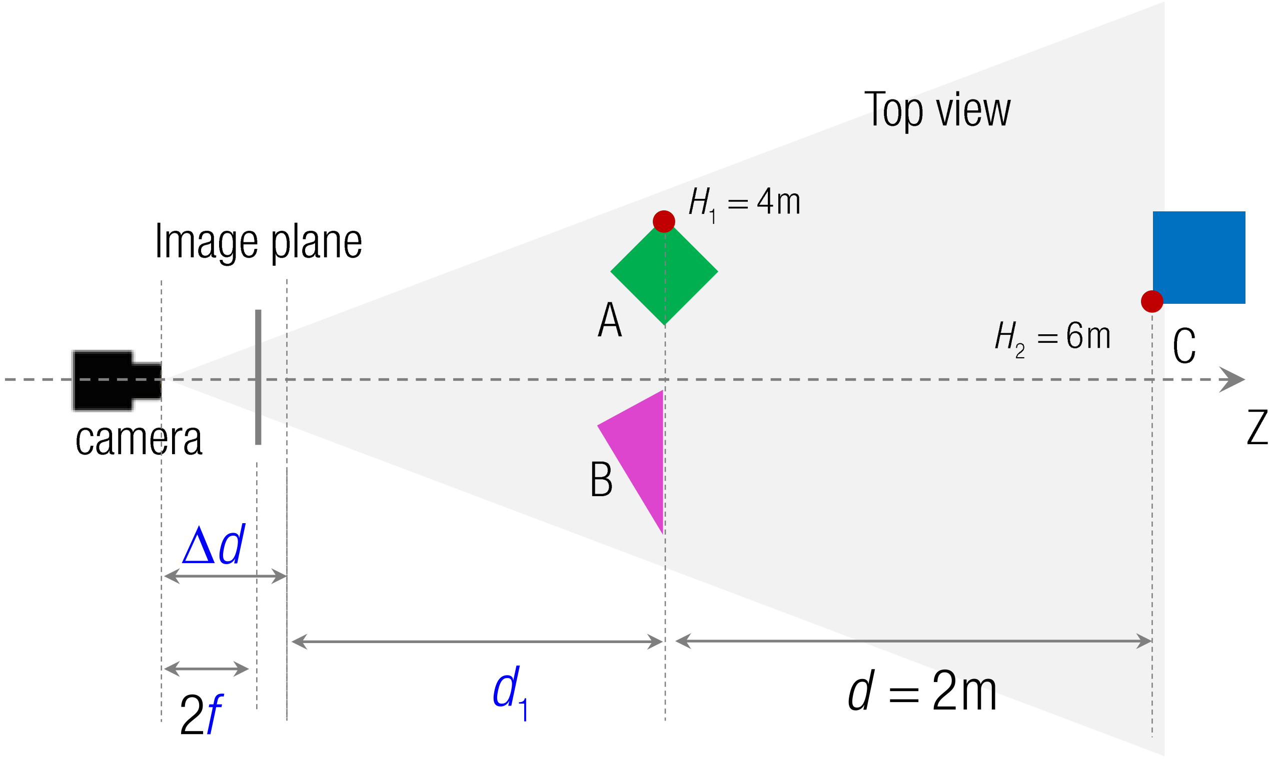
How far I need to step back with zoom factor x2?

How will h_2 change?

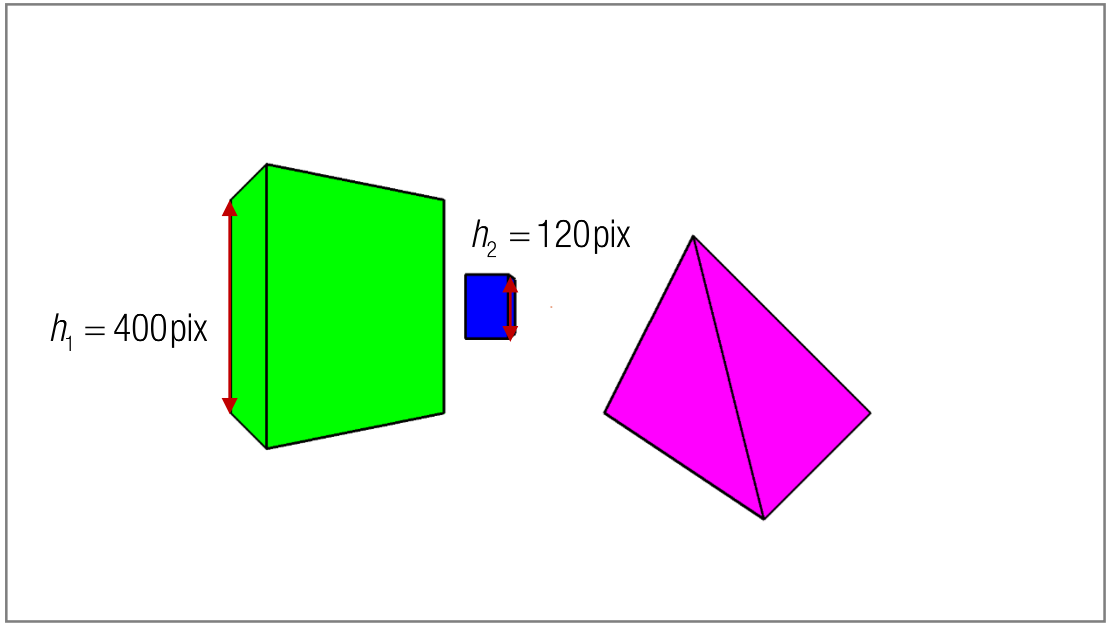
Where am I with Dolly Zoom?

Equations:

$$h_1 = f\frac{H_1}{d_1} \qquad h_1 = 2f\frac{H_1}{\Delta d + d_1} \longrightarrow \Delta d = d_1$$



Unknowns: f, d_1, Δd



How far I need to step back with zoom factor x2?

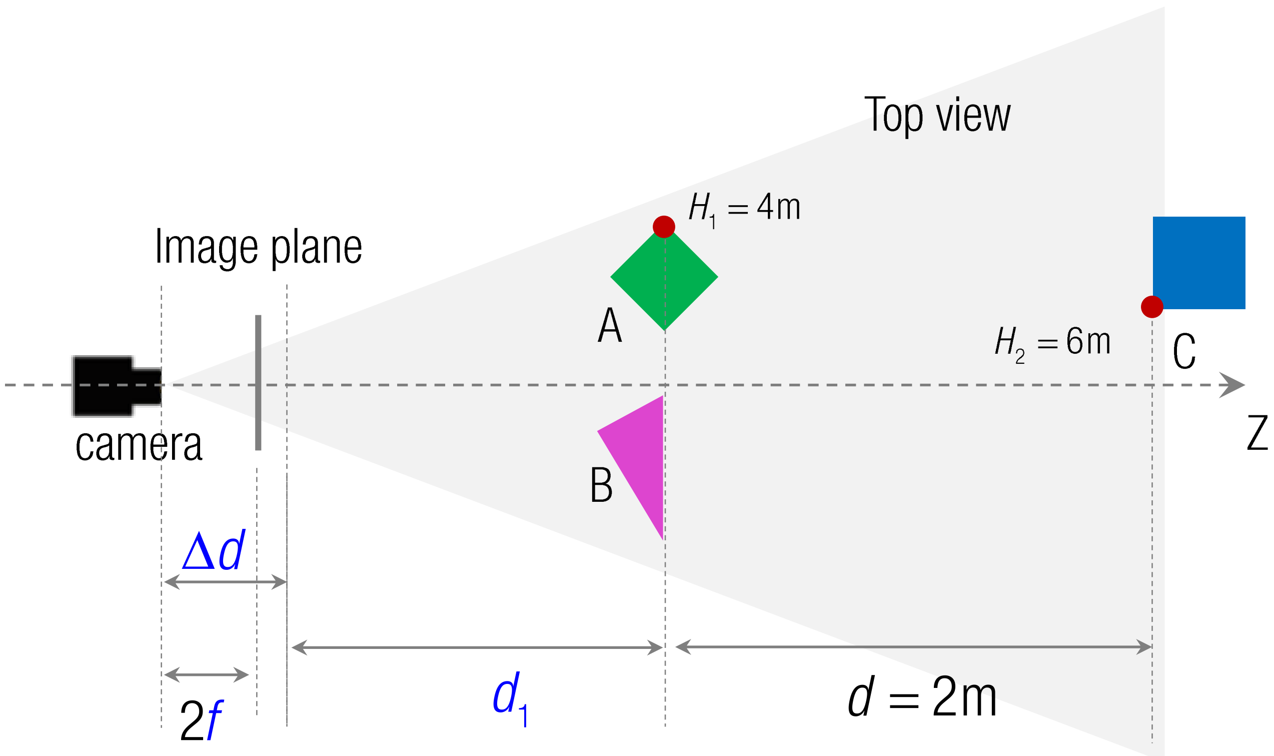
How will h_2 change?

Where am I with Dolly Zoom?

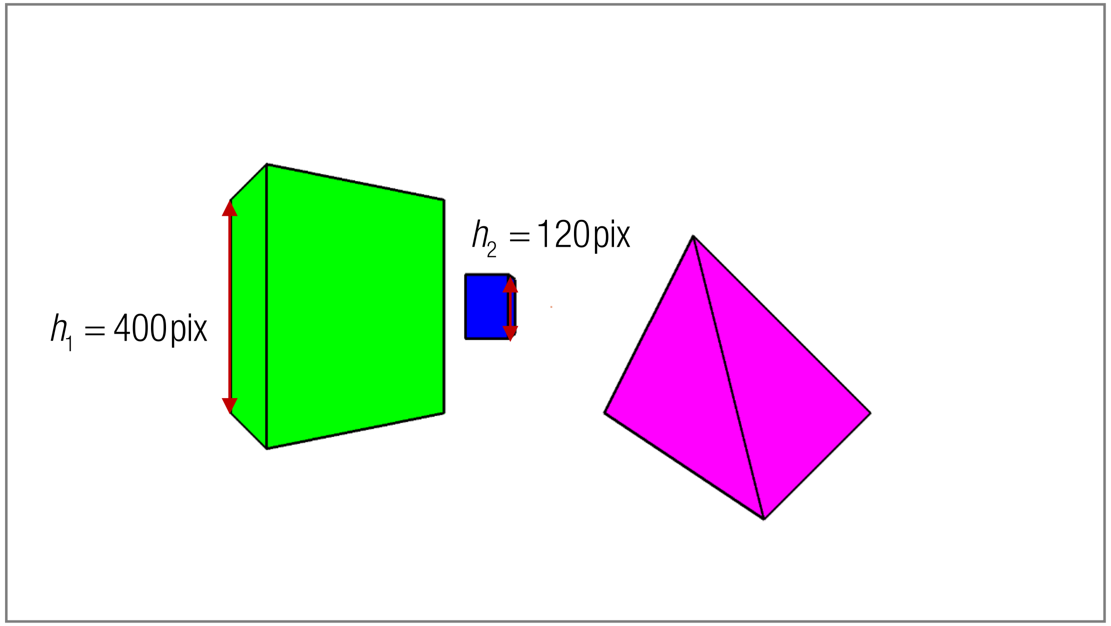
Equations:

$$h_1 = f\frac{H_1}{d_1} \qquad h_1 = 2f\frac{H_1}{\Delta d + d_1} \longrightarrow \Delta d = d_1$$

$$h_2 = f\frac{H_2}{d_1 + d}$$



Unknowns: f, d_1, Δd



How far I need to step back with zoom factor x2?

How will h_2 change?

Where am I with Dolly Zoom?

Equations:

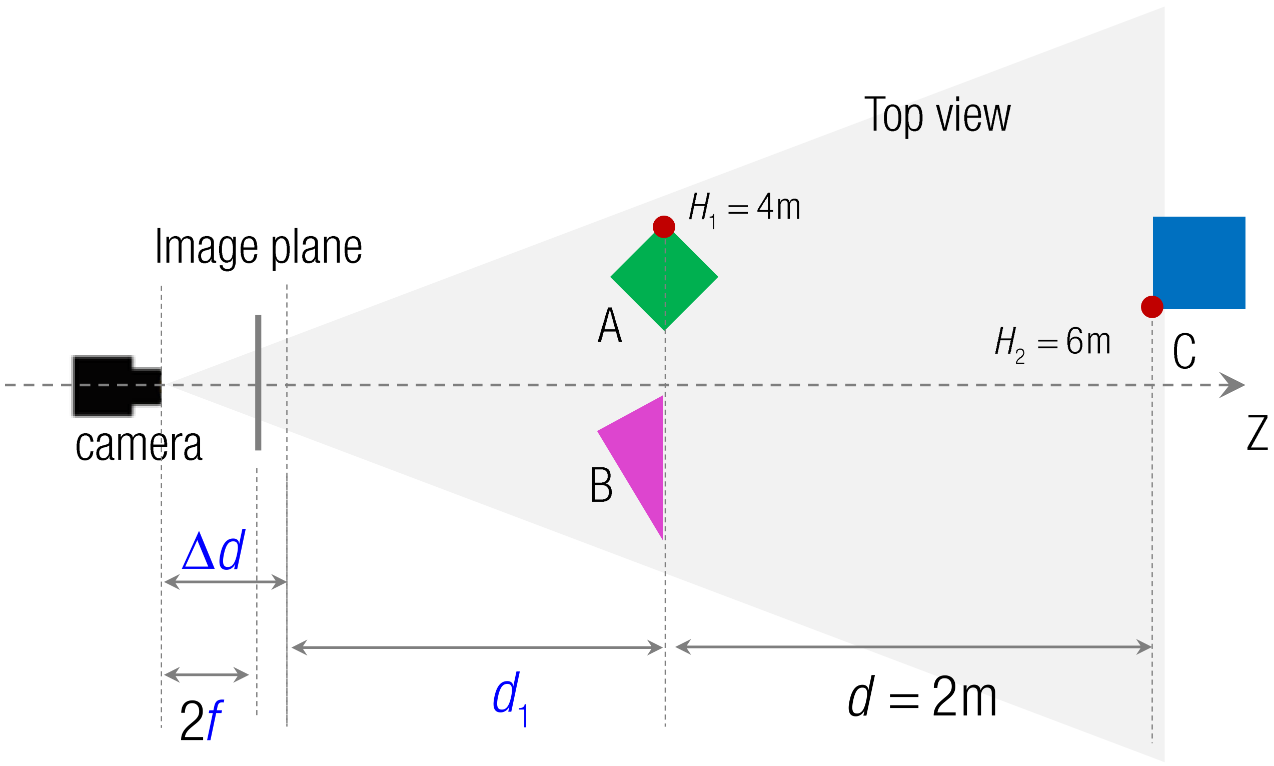
$$h_1 = f\frac{H_1}{d_1}$$

$$h_2 = f\frac{H_2}{d_1 + d}$$

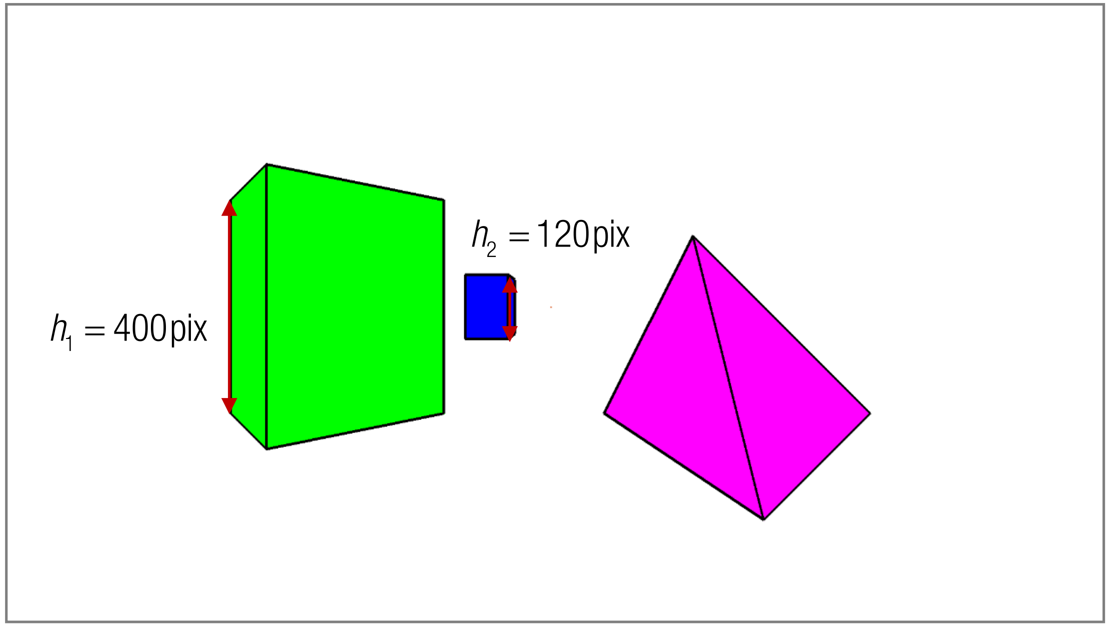
$$d_1 = \frac{1}{1 - \frac{h_2 H_1}{h_1 H_2}} d = 2.5\text{m}$$

$$h_1 = 2f\frac{H_1}{\Delta d + d_1} \longrightarrow \Delta d = d_1$$

$$\Delta d = 2.5\text{m}$$



Unknowns: f, d_1, Δd



$h_2 = 120\text{pix} \longrightarrow h_2' = 200\text{pix}$

Where am I with Dolly Zoom?

Equations:

$$h_1 = f\frac{H_1}{d_1}$$

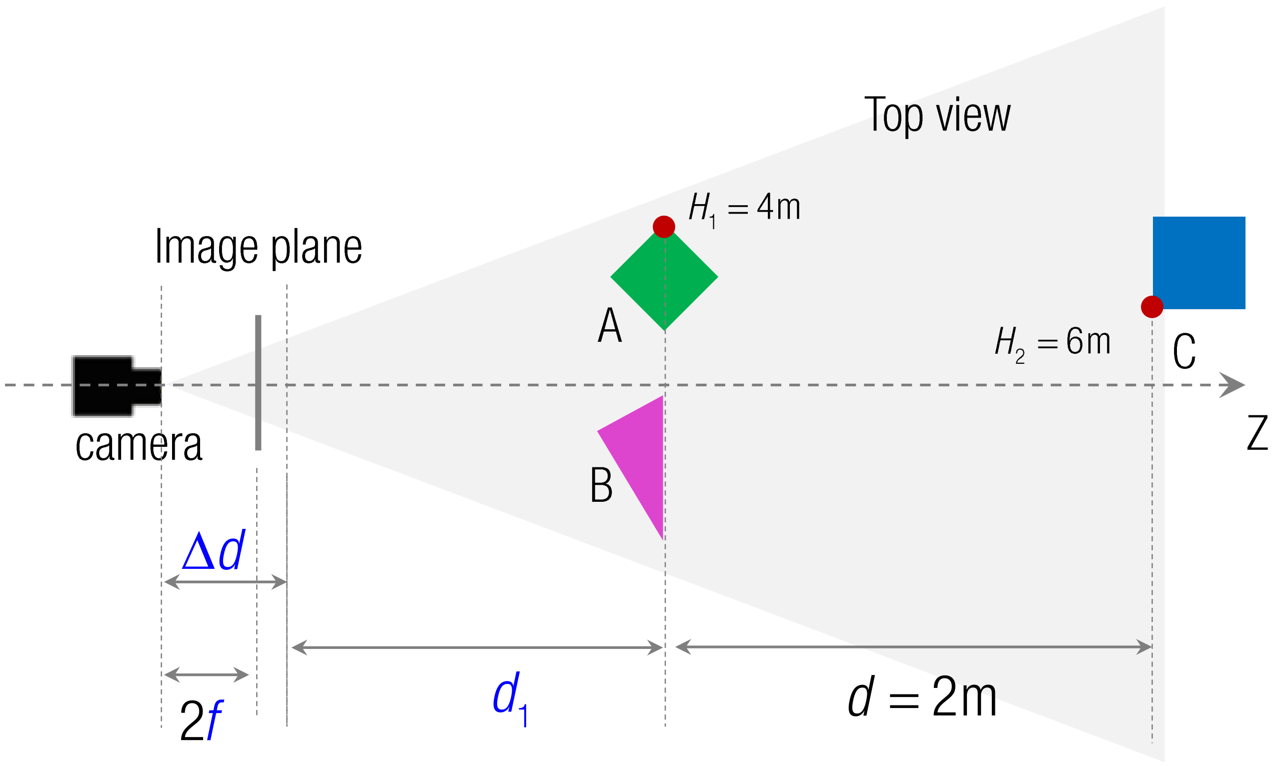
$$h_2 = f\frac{H_2}{d_1 + d}$$

$$\downarrow$$

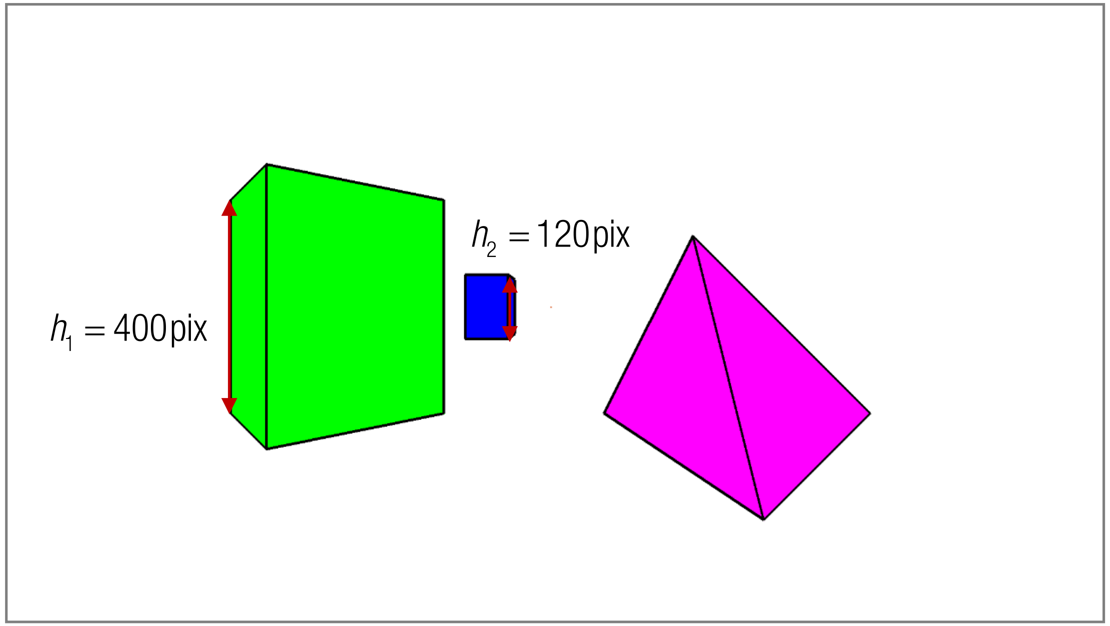
$$d_1 = \frac{1}{1 - \frac{h_2 H_1}{h_1 H_2}} d = 2.5\text{m}$$

$$h_1 = 2f\frac{H_1}{\Delta d + d_1} \longrightarrow \Delta d = d_1$$

$$\Delta d = 2.5\text{m} \qquad f = 250\text{pix}$$



Unknowns: f, d_1, Δd



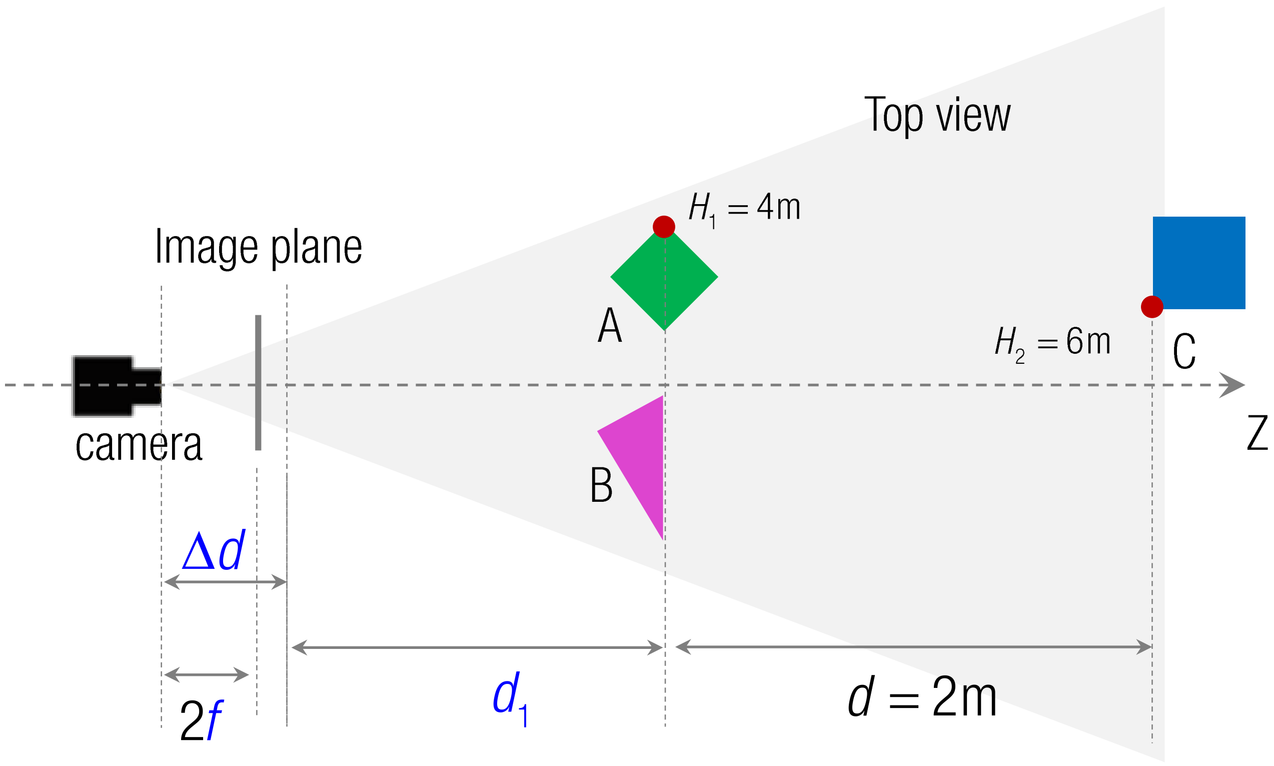
$$h_2 = 120\text{pix} \longrightarrow h_2' = 200\text{pix}$$

Where am I with Dolly Zoom?

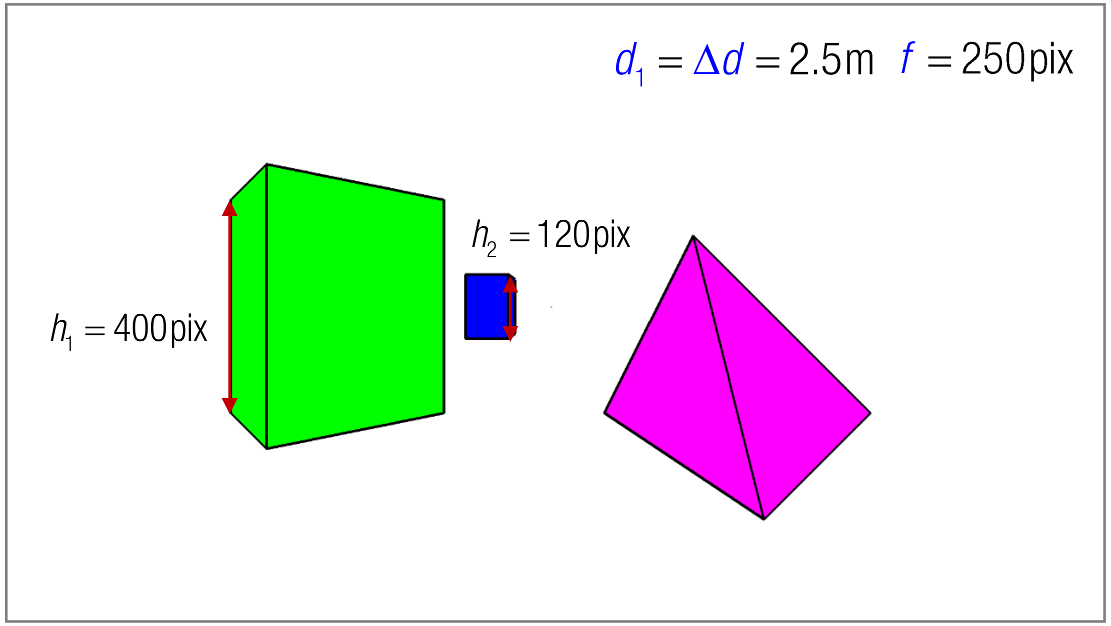
Equations:

$$h_1 = f\frac{H_1}{d_1} \qquad h_1 = 2f\frac{H_1}{\Delta d + d_1}$$

$$h_2 = f\frac{H_2}{d_1 + d} \qquad h_2' = 2f\frac{H_2}{\Delta d + d_1 + d}$$



Unknowns: f, d_1, Δd



How far I need to step back with zoom factor x2?

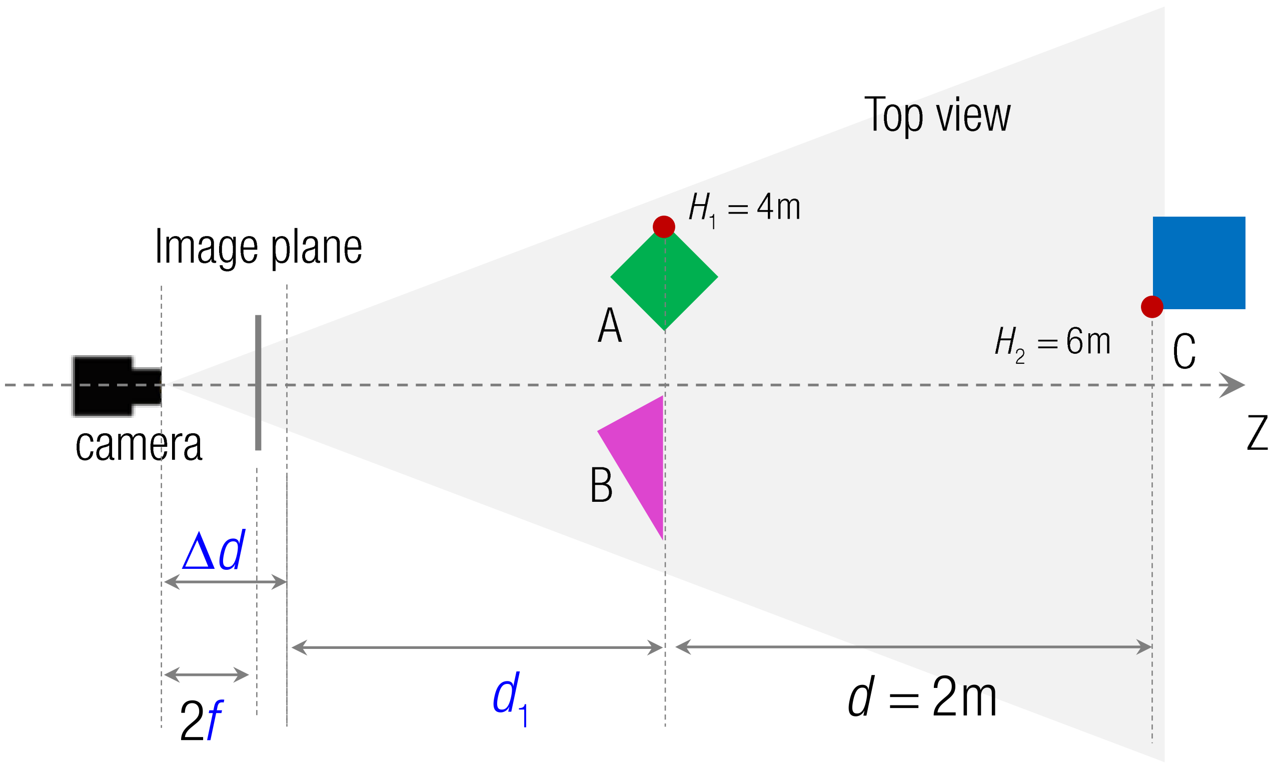
How will h_2 change?

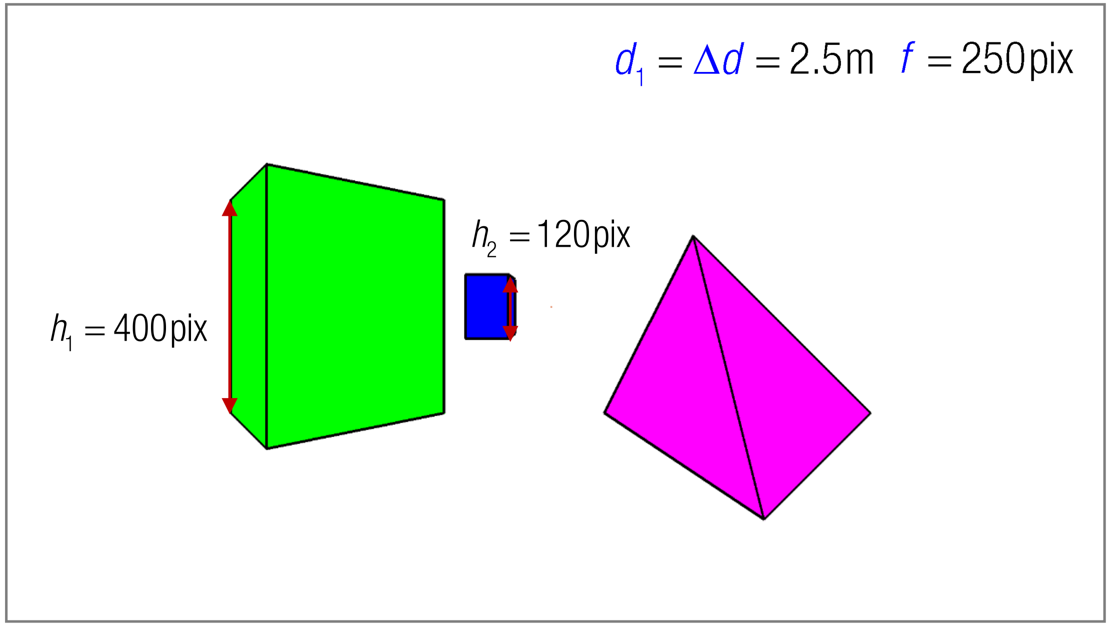
Where am I with Dolly Zoom?

Equations:

$$h_1 = f\frac{H_1}{d_1} \qquad h_1 = 2f\frac{H_1}{\Delta d + d_1}$$

$$h_2 = f\frac{H_2}{d_1 + d} \qquad h_2' = 2f\frac{H_2}{\Delta d + d_1 + d} = 429\text{pix}$$

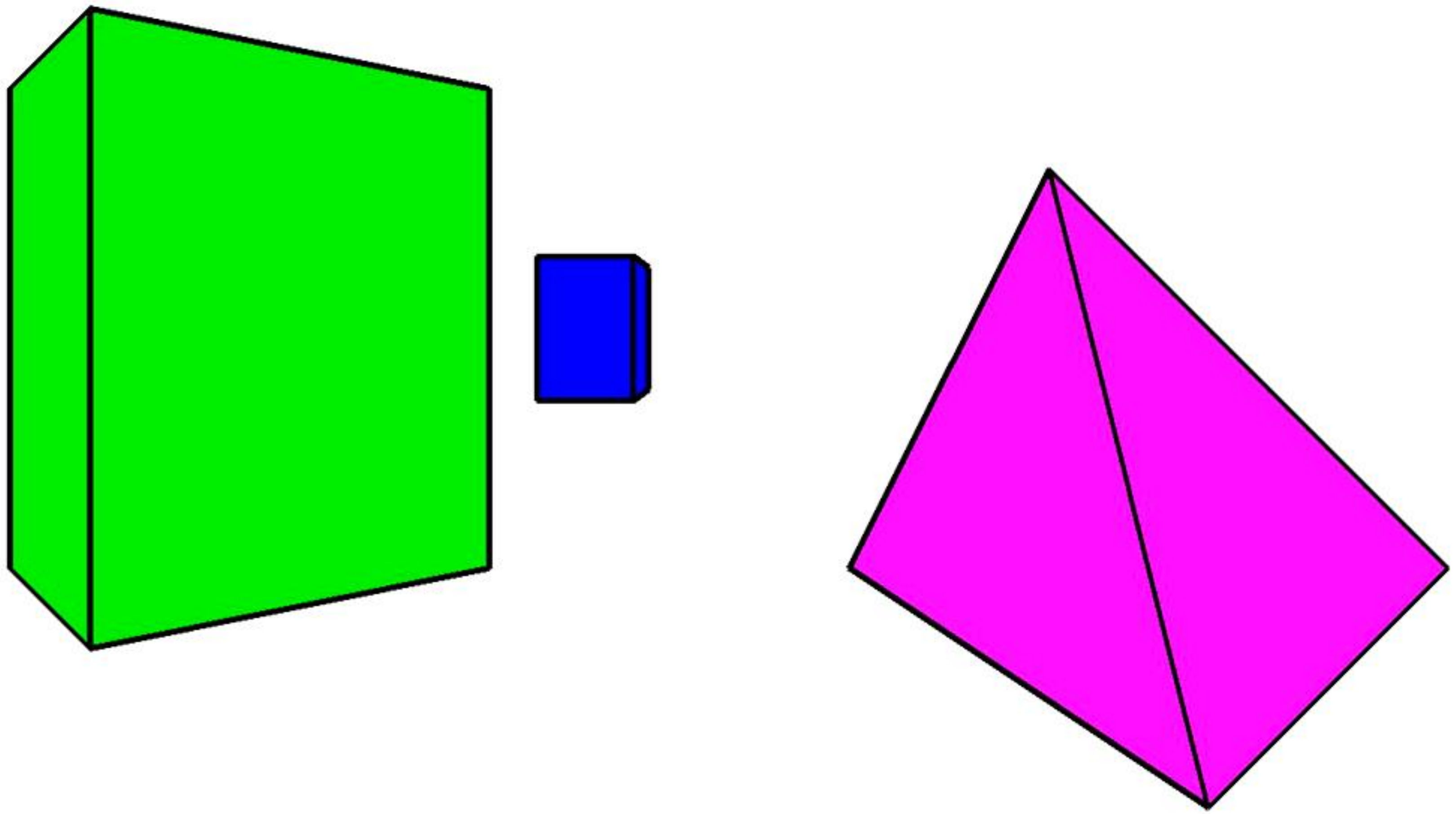


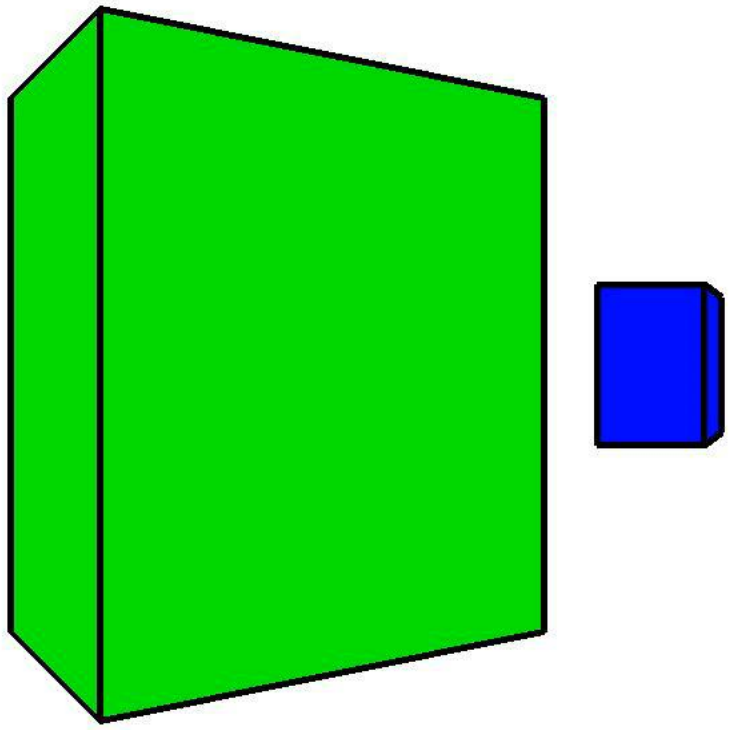


Unknowns: f, d_1, Δd

How far I need to step back with zoom factor x2?

How will h_2 change?

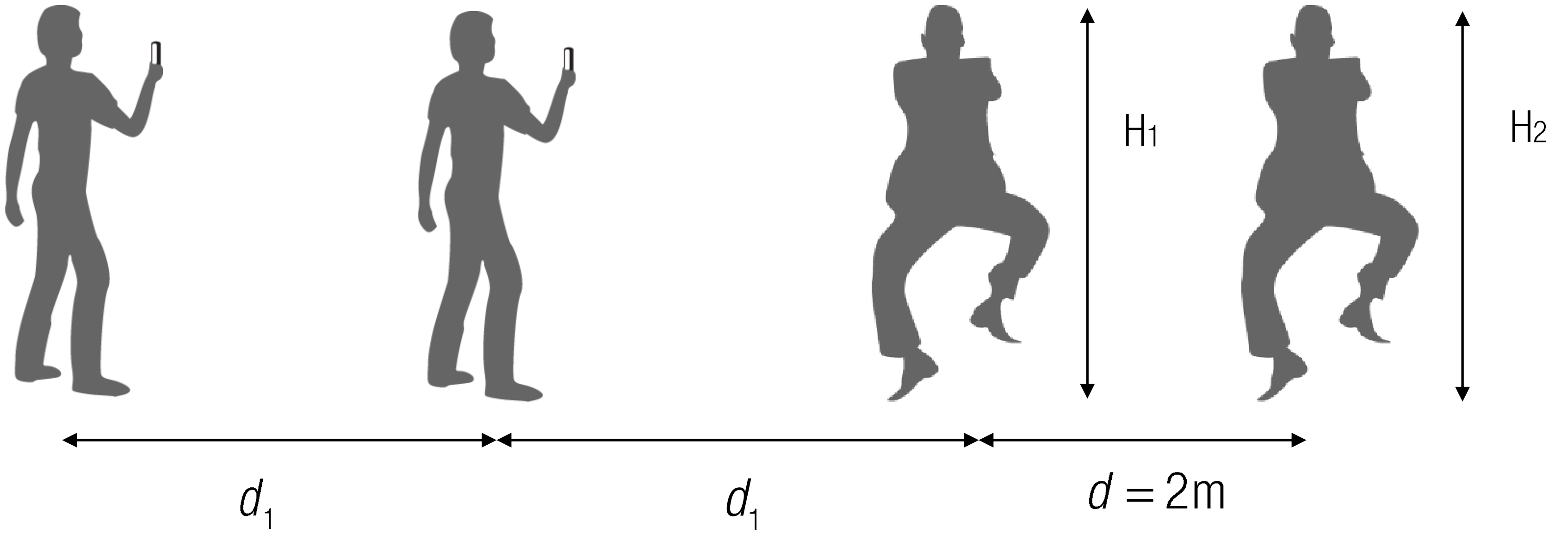




```
%% load data and set parameters
points = load('points.mat');

d_ref = 4;
f_ref = 400;
pos = 0 : -0.1 : -9.9;

H1 = points.points_A(1,2) - points.points_A(2,2);
H2 = points.points_C(1,2) - points.points_C(2,2);

%% Dolly Zoom: keep one object's height constant

f = compute_focal_length(d_ref, f_ref, pos);

for i = 1 : length(f)
    figure(1), hold on, axis equal;
    xlim([0,1920]), ylim([0,1080]);
    project_objects(f(i), pos(i), points, 1);
    pause(0.1);
end;
```

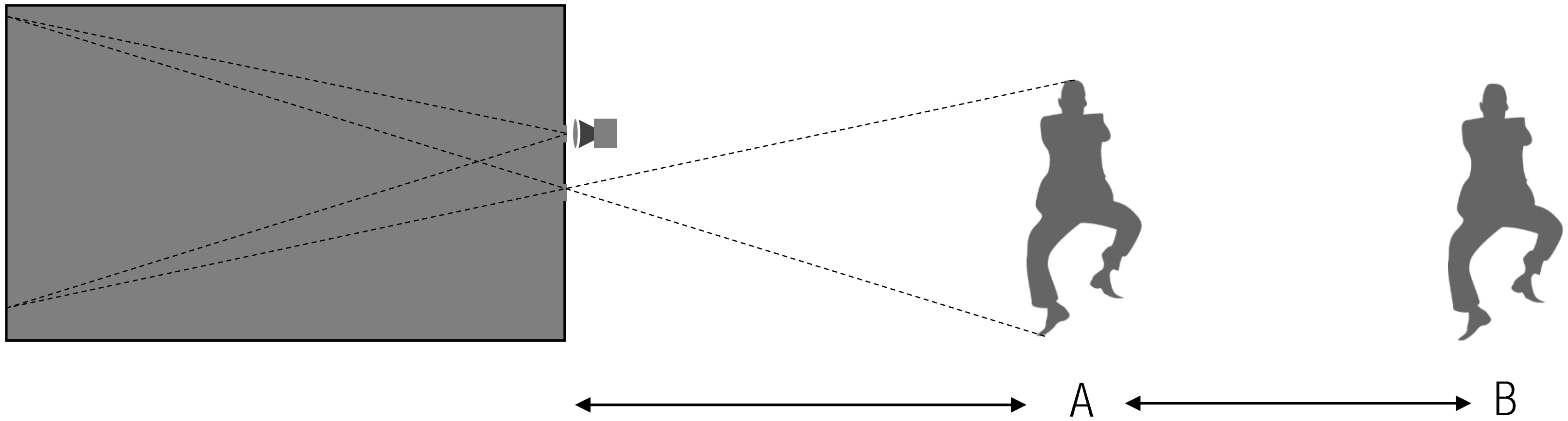
```
function [ f ] = compute_focal_length( d_ref, f_ref, pos )

f = (d_ref-pos) / d_ref * f_ref;
```

Where am I with Dolly Zoom?



1) Zoom in with factor x2
2) Step back to maintain h_1
3) Predict h_2

Camera Obscura HW #1



1) Where was I with respect to A?
2) How far B from A?