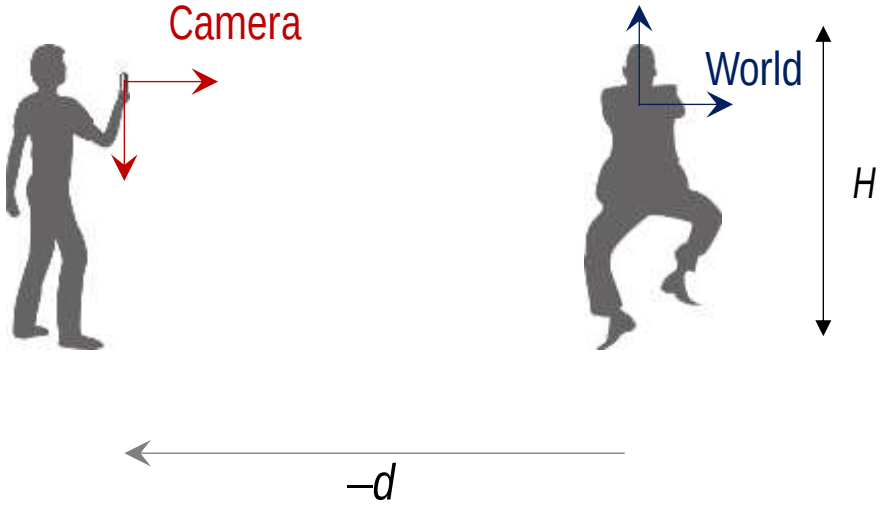
Affine Camera Model

Dolly Zoom Camera Matrix

$$h = f\frac{H}{d}$$

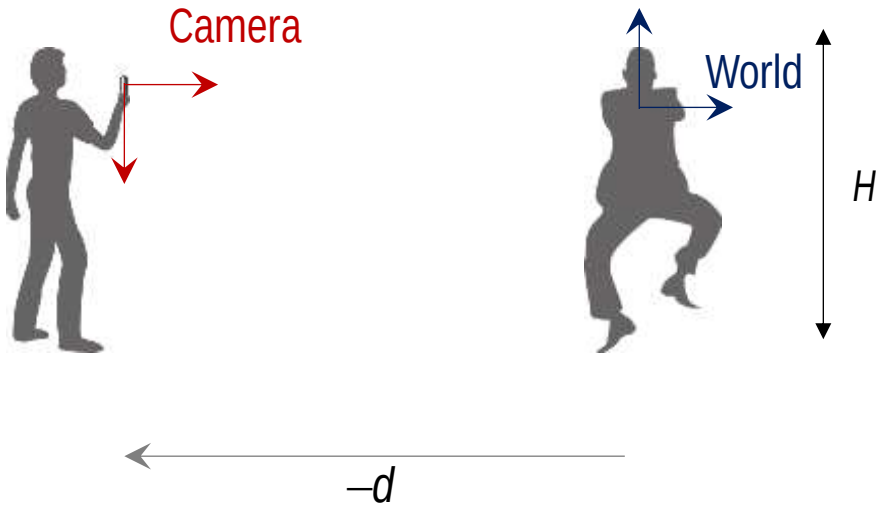


Dolly Zoom Camera Matrix

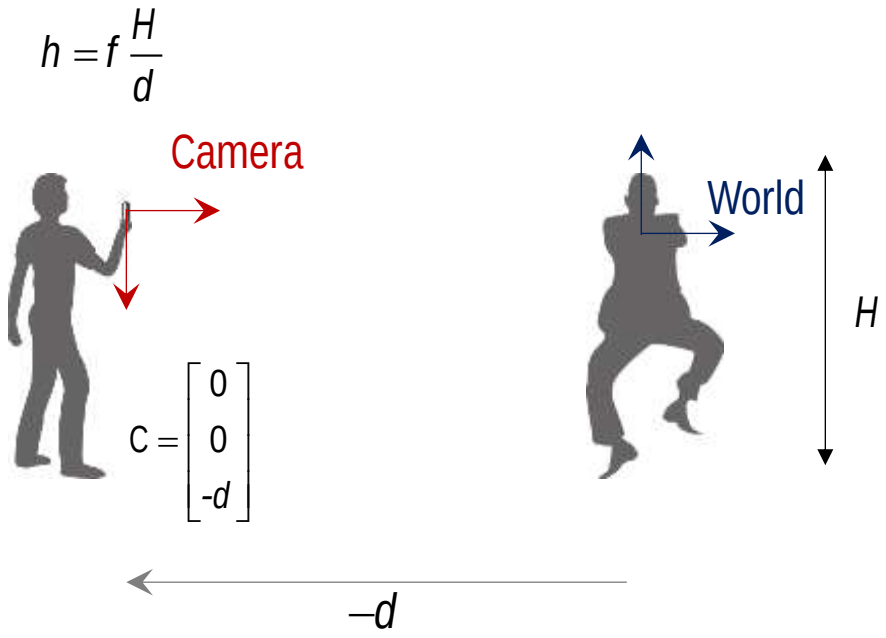
$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = KR(X - C)$$: translate and then, rotate

$$= KR\begin{bmatrix} I_3 & -C \end{bmatrix}\begin{bmatrix} X \\ 1 \end{bmatrix}$$

$$h = f\frac{H}{d}$$



Dolly Zoom Camera Matrix



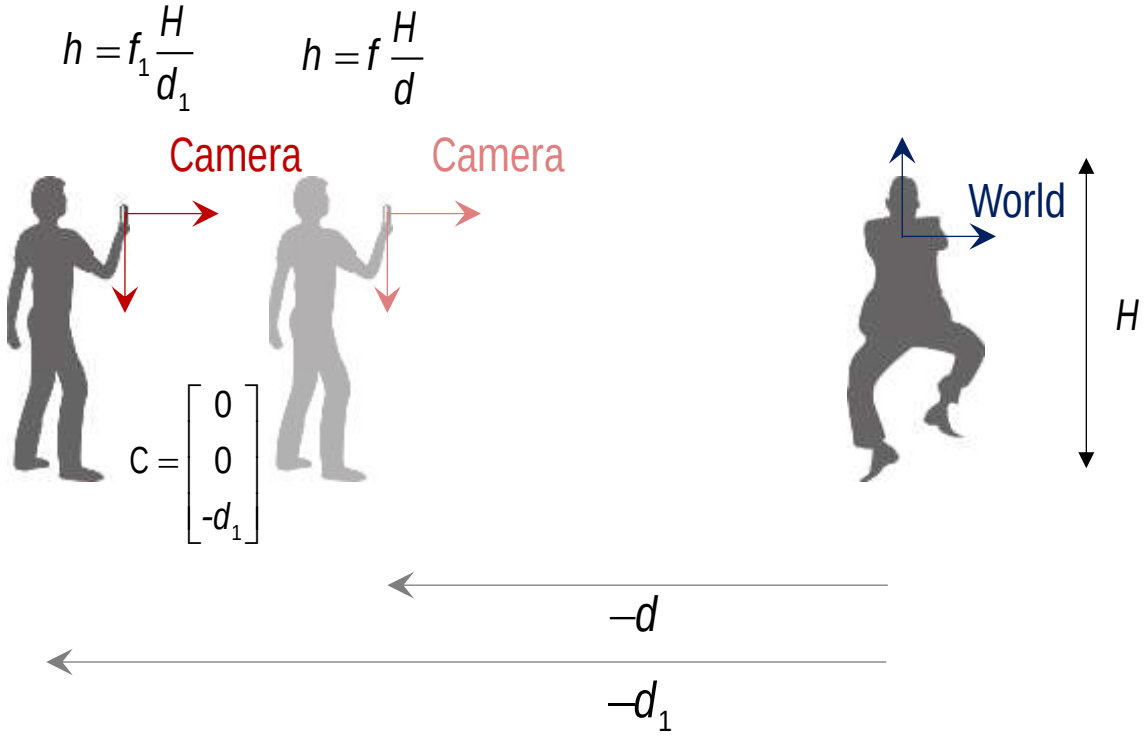
$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = KR(X - C) \qquad \text{: translate and then, rotate}$$

$$= KR\begin{bmatrix} I_3 & -C \end{bmatrix}\begin{bmatrix} X \\ 1 \end{bmatrix}$$

$$= \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix}\begin{bmatrix} r_{x1} & r_{x2} & 0 \\ r_{y1} & r_{y2} & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & & & 0 \\ & 1 & & 0 \\ & & 1 & d \end{bmatrix}\begin{bmatrix} X \\ 1 \end{bmatrix}$$

Camera z axis (optical axis) is aligned with the world z coordinate.

Dolly Zoom Camera Matrix



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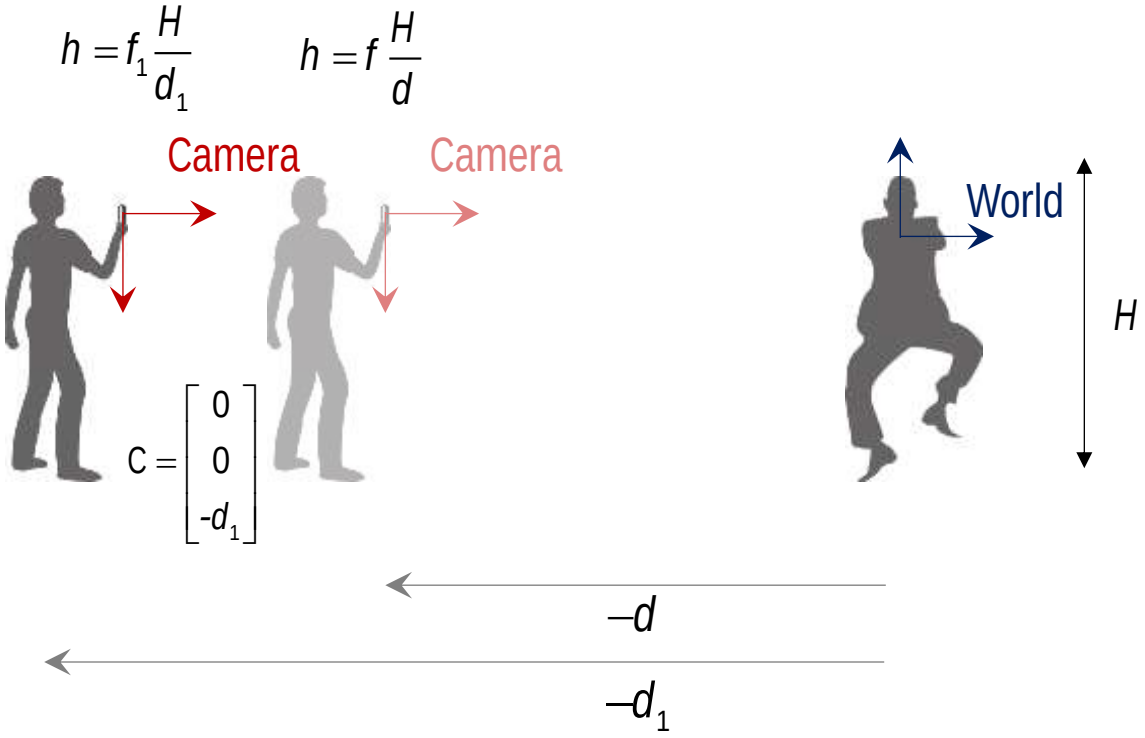

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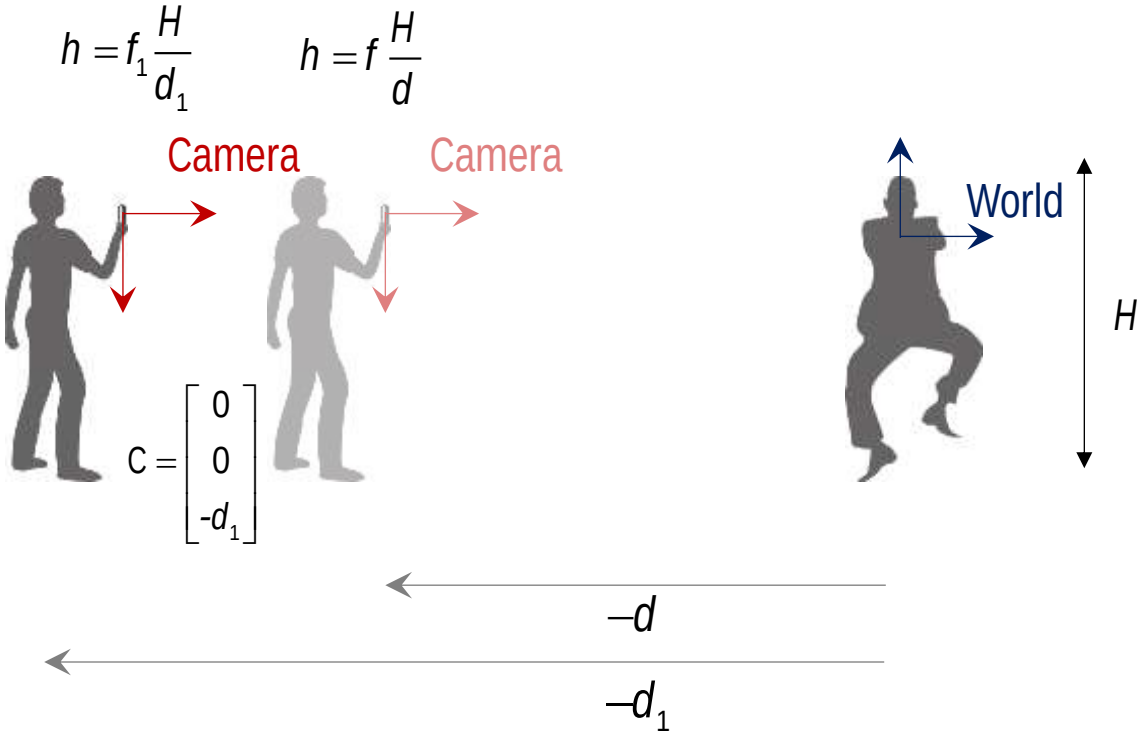
?

Dolly Zoom Camera Matrix



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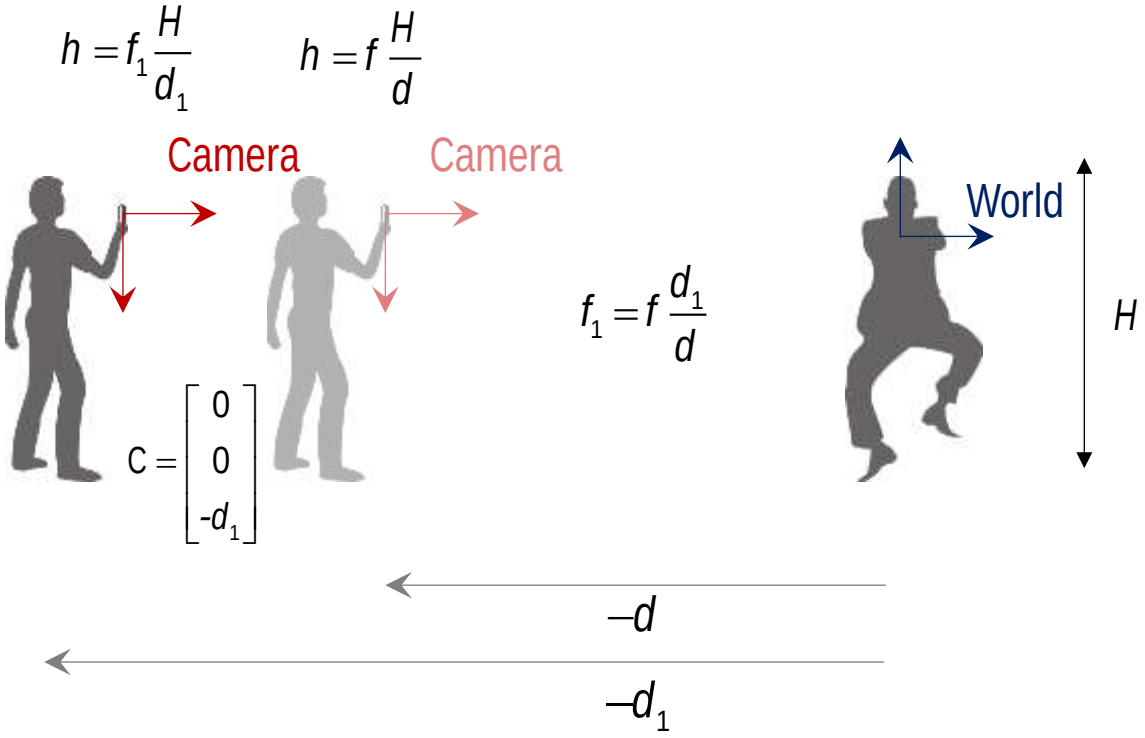
$$= \begin{bmatrix} f_1 & & p_x \\ & f_1 & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 \\ r_{y1} & r_{y2} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & & & 0 \\ & 1 & & 0 \\ & & 1 & d_1 \end{bmatrix} \begin{bmatrix} X \\ 1 \end{bmatrix}$$

Dolly Zoom Camera Matrix



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$$= \begin{bmatrix} f\frac{d_1}{d} & & p_x \\ & f\frac{d_1}{d} & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 \\ r_{y1} & r_{y2} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & & & 0 \\ & 1 & & 0 \\ & & 1 & d_1 \end{bmatrix} \begin{bmatrix} X \\ 1 \end{bmatrix}$$

Dolly Zoom Camera Matrix

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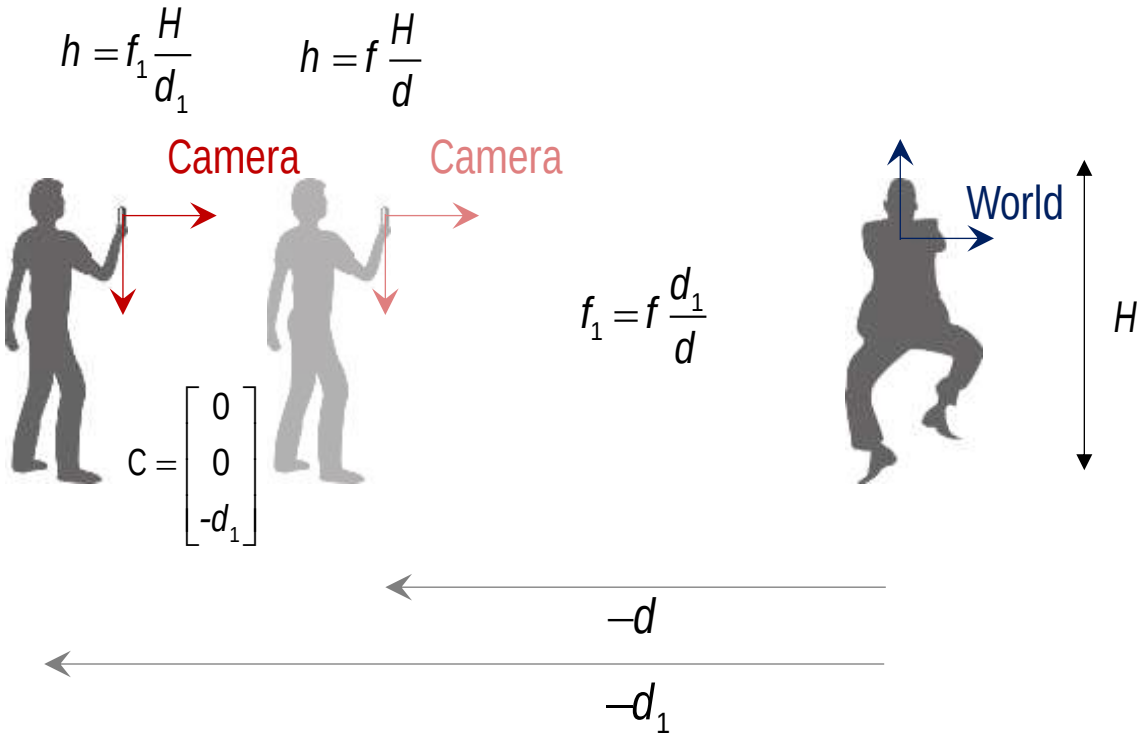
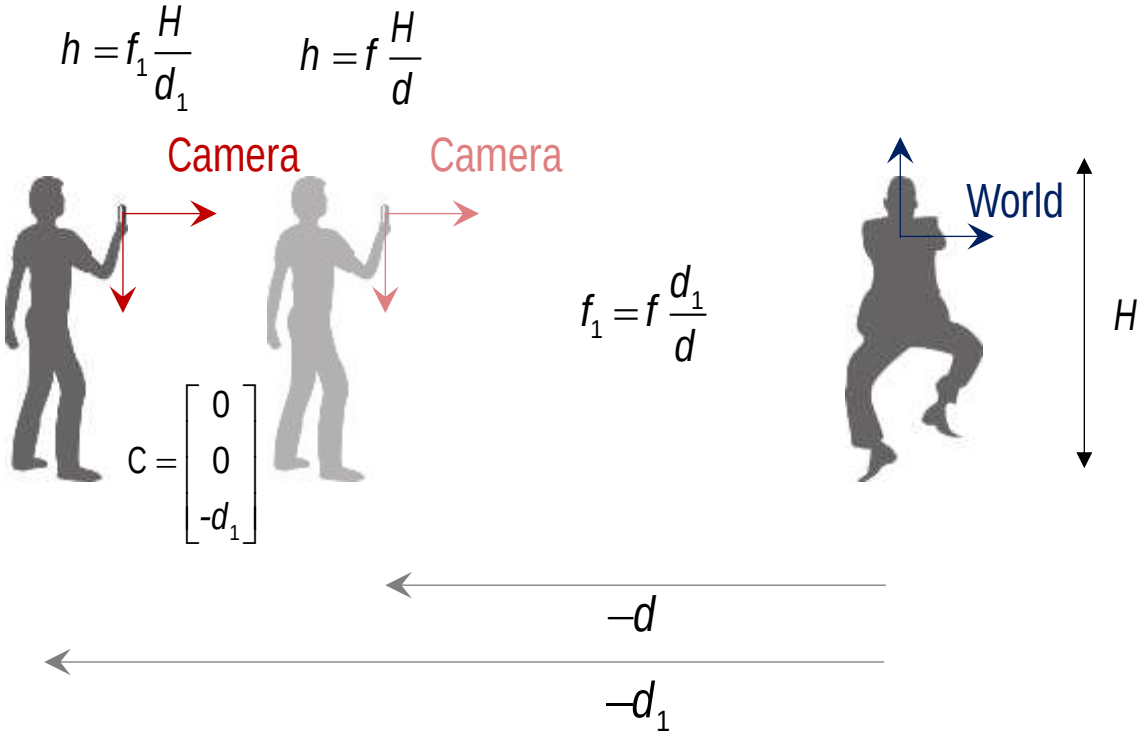


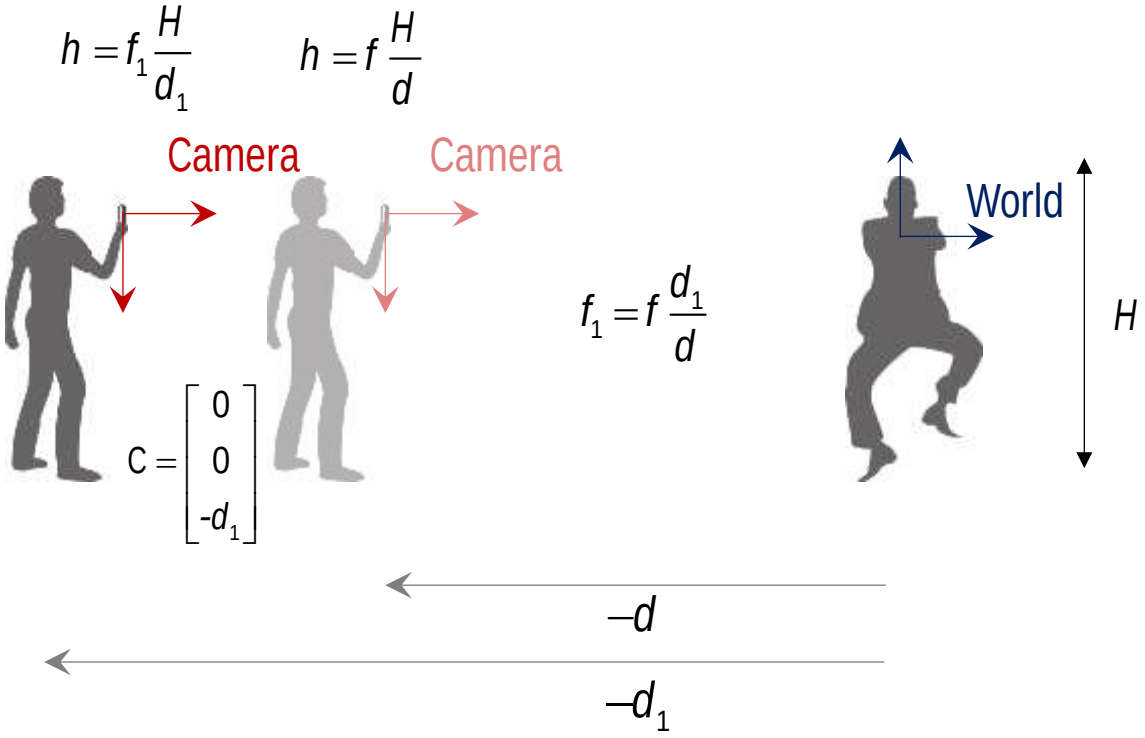
Dolly Zoom Camera Matrix



$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f\frac{d_1}{d} & & p_x \\ & f\frac{d_1}{d} & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 \\ r_{y1} & r_{y2} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & & & 0 \\ & 1 & & 0 \\ & & 1 & d_1 \end{bmatrix} \begin{bmatrix} X \\ 1 \end{bmatrix}$$

$$= \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} \frac{d_1}{d} & & \\ & \frac{d_1}{d} & \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 \\ r_{y1} & r_{y2} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & & & 0 \\ & 1 & & 0 \\ & & 1 & d_1 \end{bmatrix} \begin{bmatrix} X \\ 1 \end{bmatrix}$$

Dolly Zoom Camera Matrix



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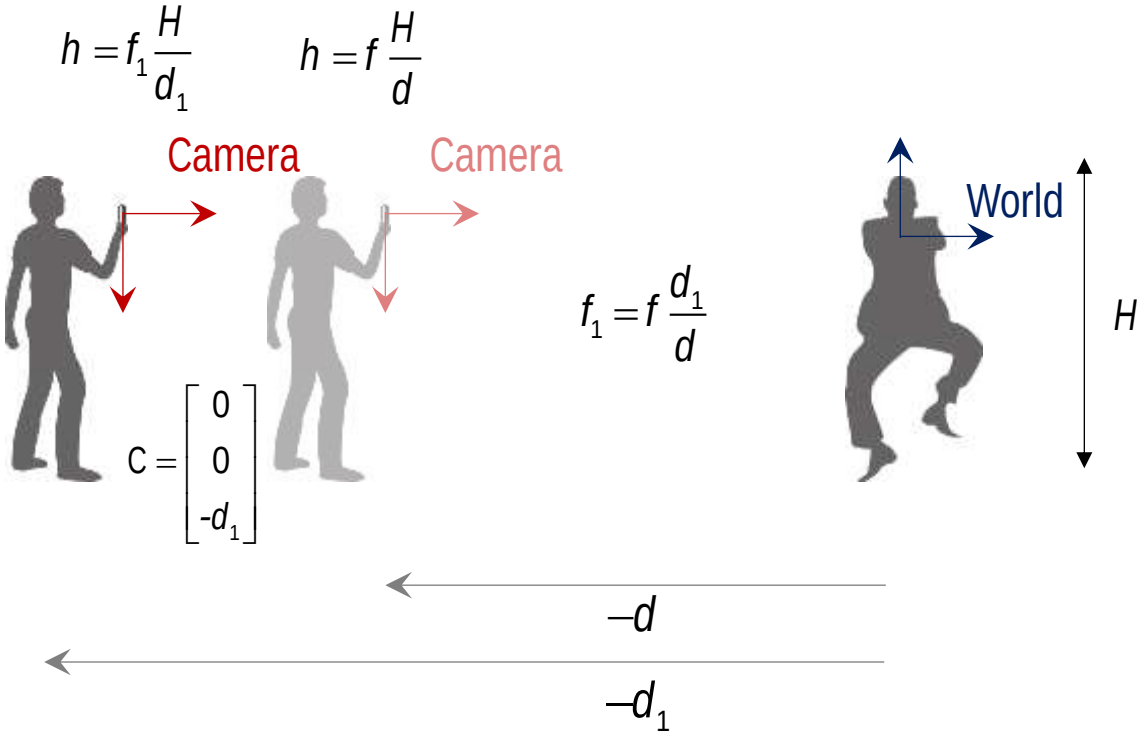
Dolly Zoom Camera Matrix



$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f\frac{d_1}{d} & & p_x \\ & f\frac{d_1}{d} & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 \\ r_{y1} & r_{y2} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & & & 0 \\ & 1 & & 0 \\ & & 1 & d_1 \end{bmatrix} \begin{bmatrix} X \\ 1 \end{bmatrix}$$

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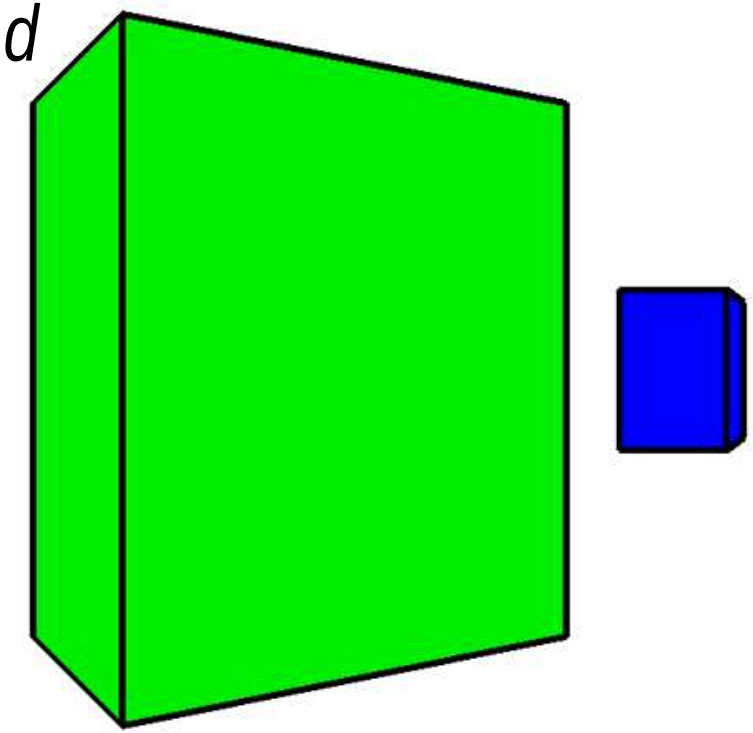
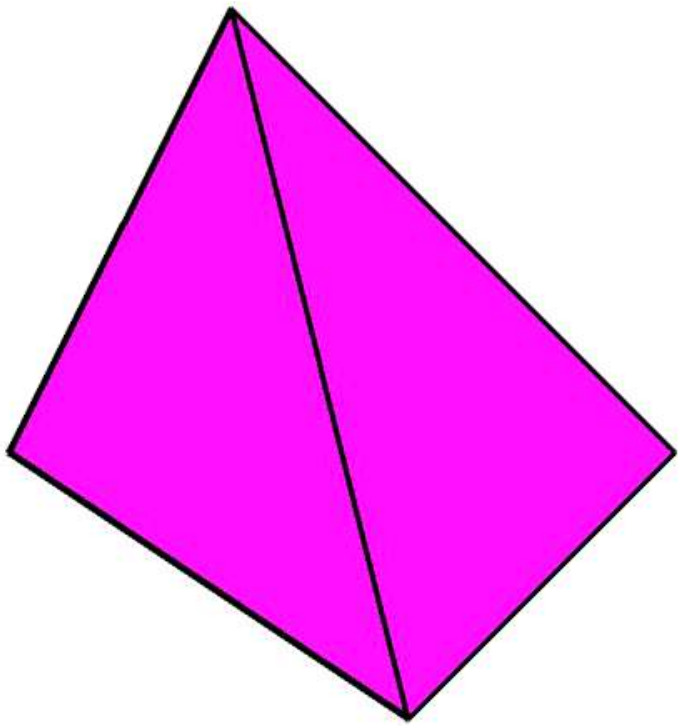
d

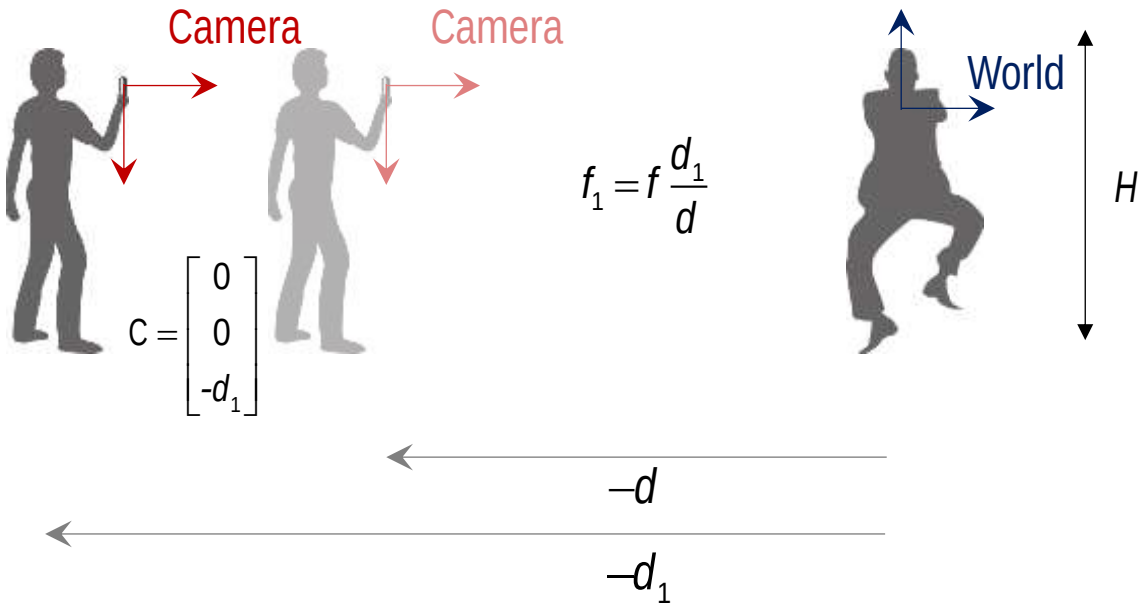




Weak perspectiveness

Strong perspectiveness

Affine Camera



Dolly zoom camera:

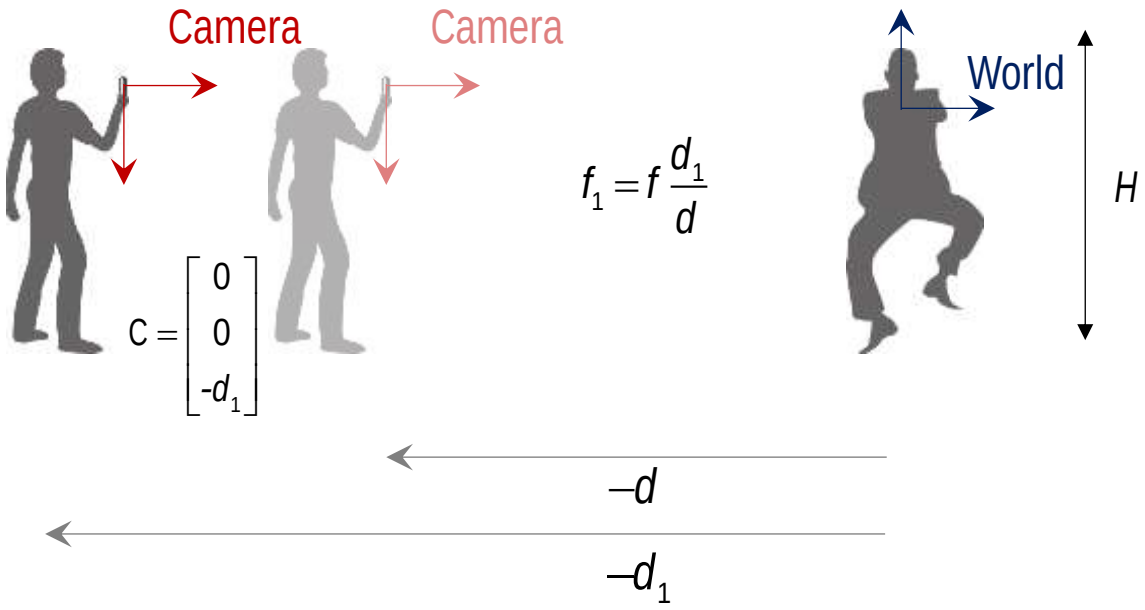
$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & \frac{d}{d_1} & d \end{bmatrix} \begin{bmatrix} X \\ 1 \end{bmatrix}$$

What happens if d_1 goes infinity?

Weak perspectiveness

Strong perspectiveness

Affine Camera



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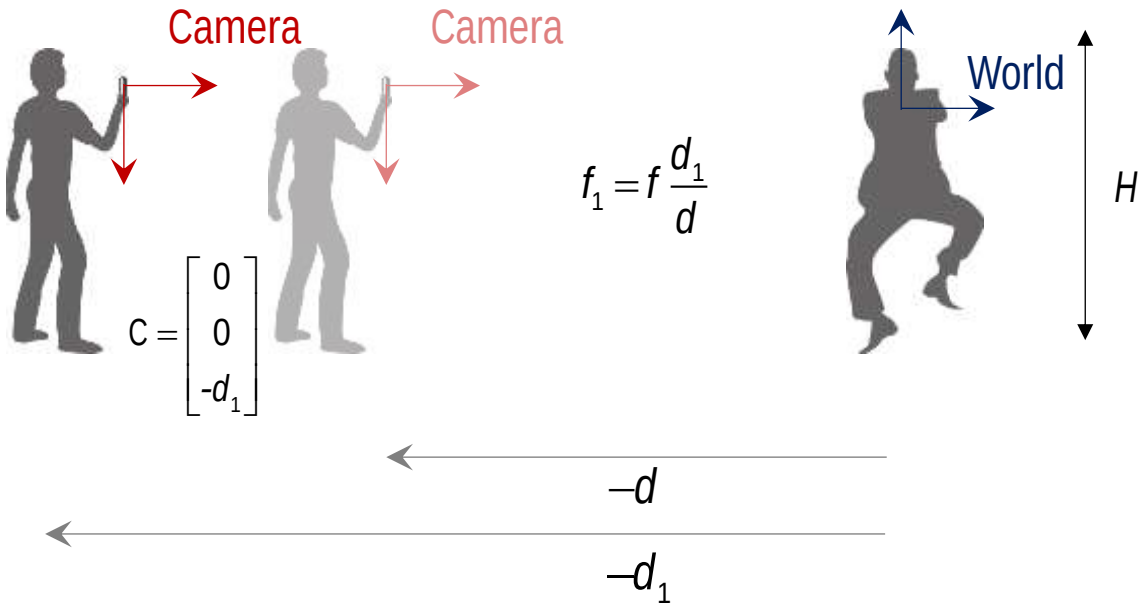
What happens if d_1 goes infinity?

$$\lim_{d_1 \to \infty} P = \lim_{d_1 \to \infty} \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & \frac{d}{d_1} & d \end{bmatrix}$$

$$= \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & d \end{bmatrix}$$

Affine Camera



Weak perspectiveness

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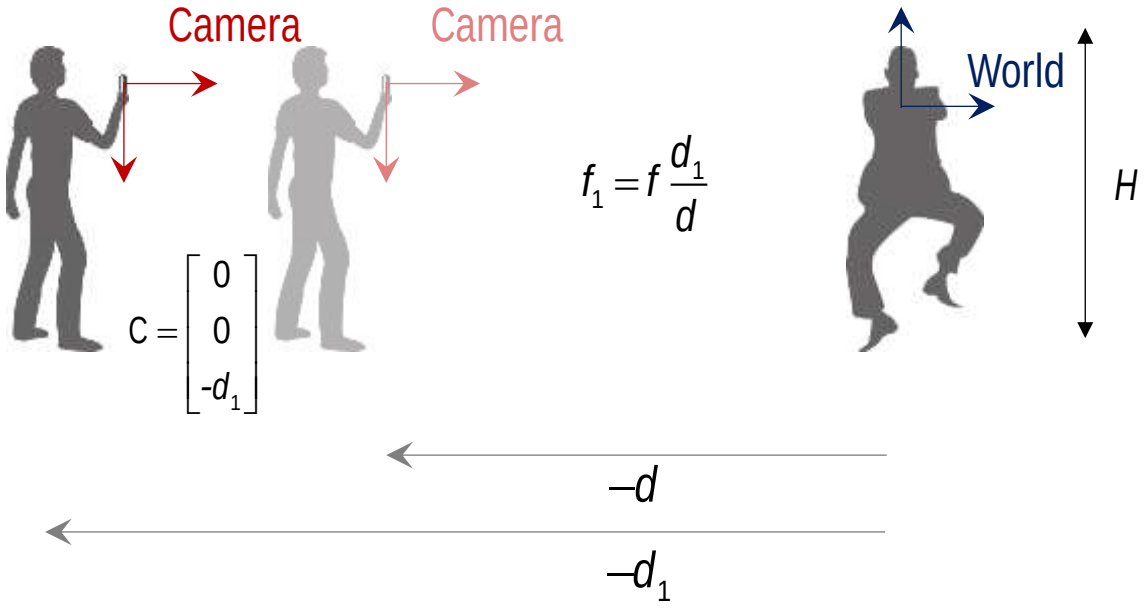
$$= \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & d \end{bmatrix}$$

: affine camera $d_1 >> 0$

Affine Camera



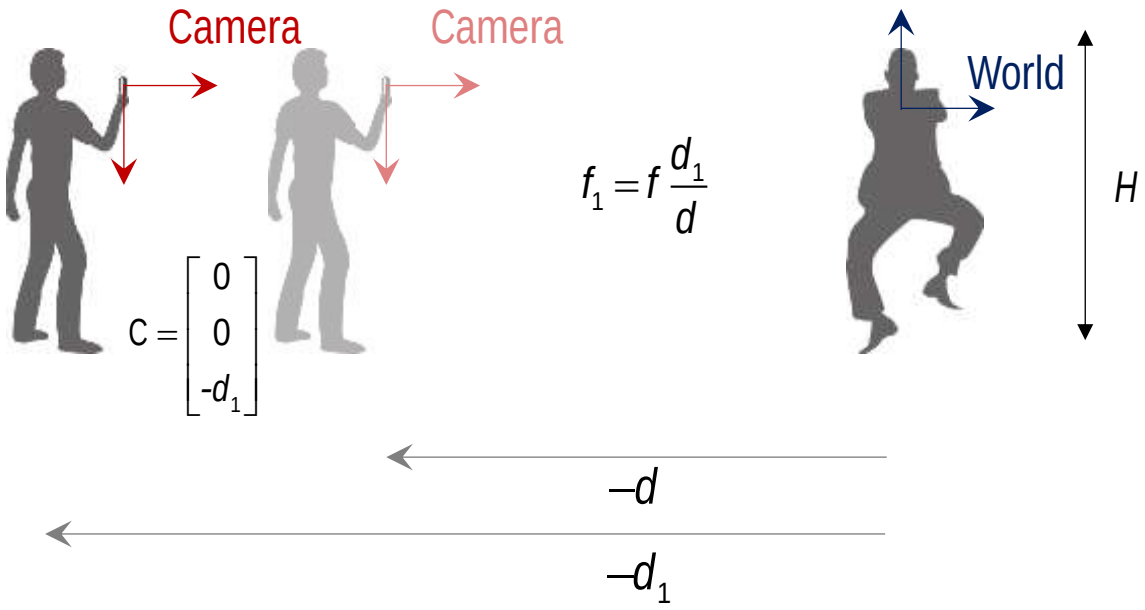
Affine camera:

$$P = \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & d \end{bmatrix} = d \begin{bmatrix} f/d & & p_x \\ & f/d & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Weak perspectiveness

Strong perspectiveness

Affine Camera



Affine camera:

$$P_A = \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & d \end{bmatrix} = d \begin{bmatrix} f/d & & p_x \\ & f/d & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

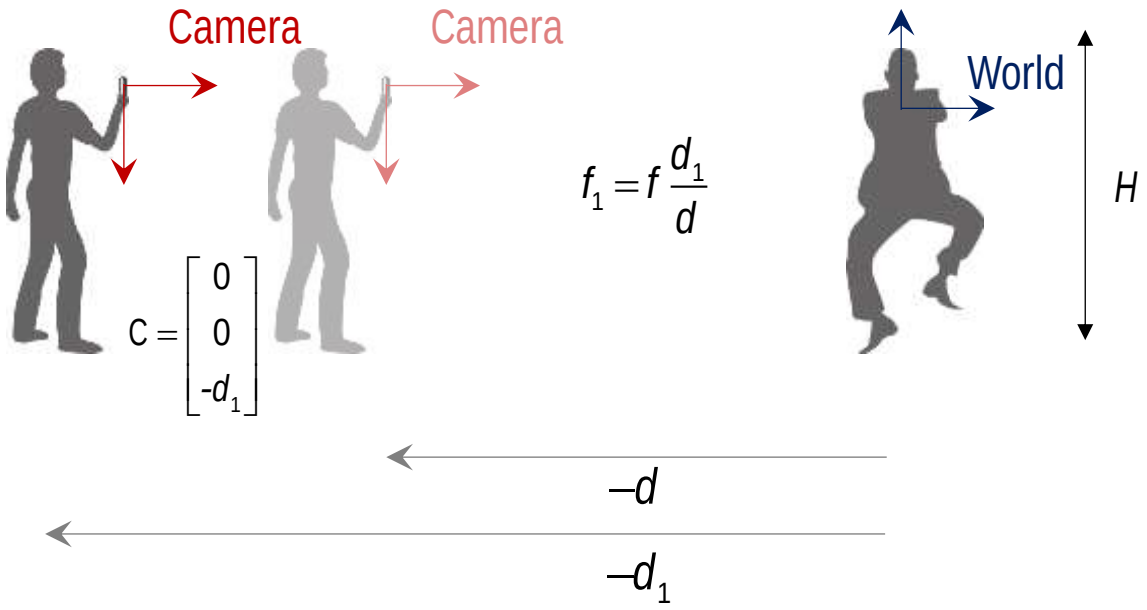
No scaler

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = P_A \begin{bmatrix} X \\ 1 \end{bmatrix} = d \begin{bmatrix} f/d & & p_x \\ & f/d & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ 1 \end{bmatrix}$$

Weak perspectiveness

Strong perspectiveness

Affine Camera



Affine camera:

$$P_A = \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & d \end{bmatrix} = d \begin{bmatrix} f/d & & p_x \\ & f/d & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

No scaler

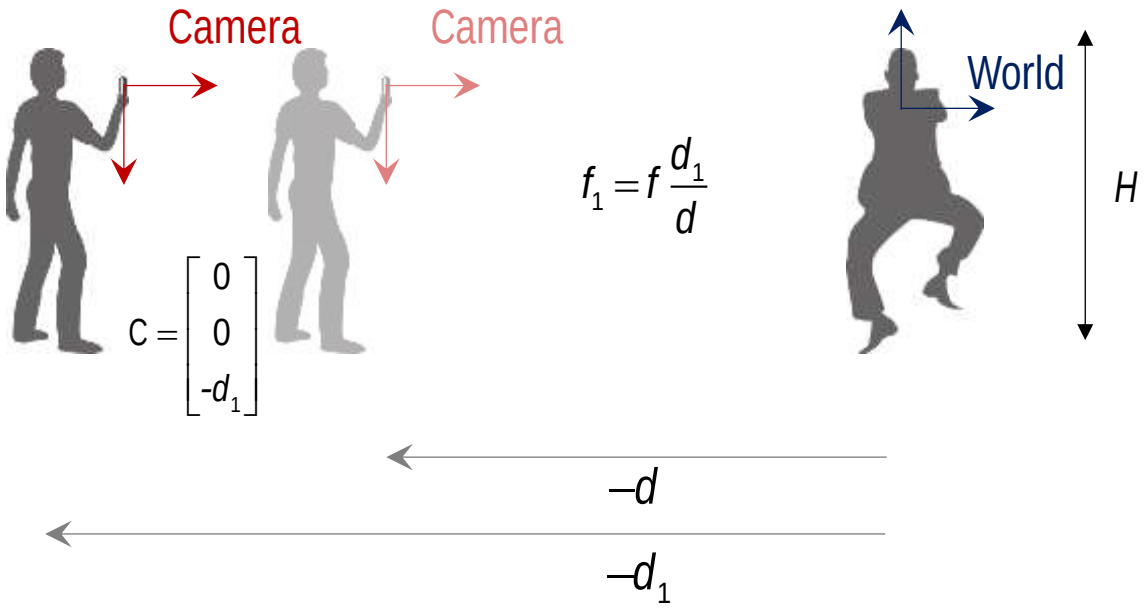
$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = P_A \begin{bmatrix} X \\ 1 \end{bmatrix} = d \begin{bmatrix} f/d & & p_x \\ & f/d & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ 1 \end{bmatrix}$$

$$= \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{23} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ 1 \end{bmatrix}$$

Weak perspectiveness

Strong perspectiveness

Affine Camera



Weak perspectiveness

Strong perspectiveness

Affine camera:

$$P_A = \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & d \end{bmatrix} = d \begin{bmatrix} f/d & & p_x \\ & f/d & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

No scaler

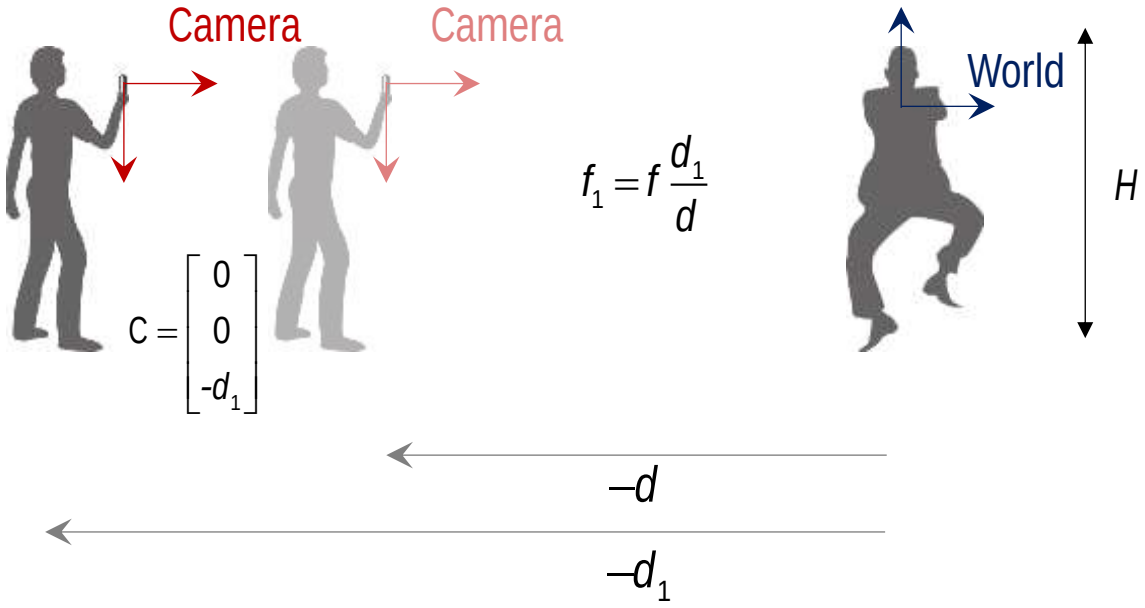
$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = P_A \begin{bmatrix} X \\ 1 \end{bmatrix} = d \begin{bmatrix} f/d & & p_x \\ & f/d & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ 1 \end{bmatrix}$$

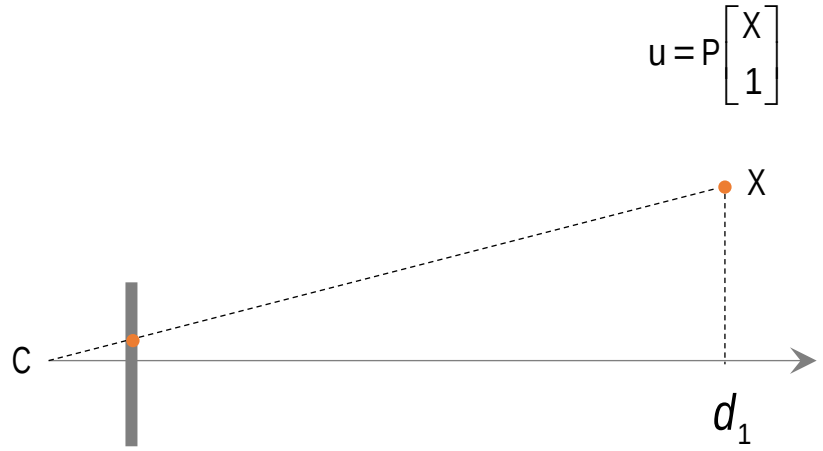
$$= \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{23} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ 1 \end{bmatrix}$$

$$\rightarrow \begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{23} \end{bmatrix} \begin{bmatrix} X \\ 1 \end{bmatrix}$$

No denominator

Validity of Affine Approximation

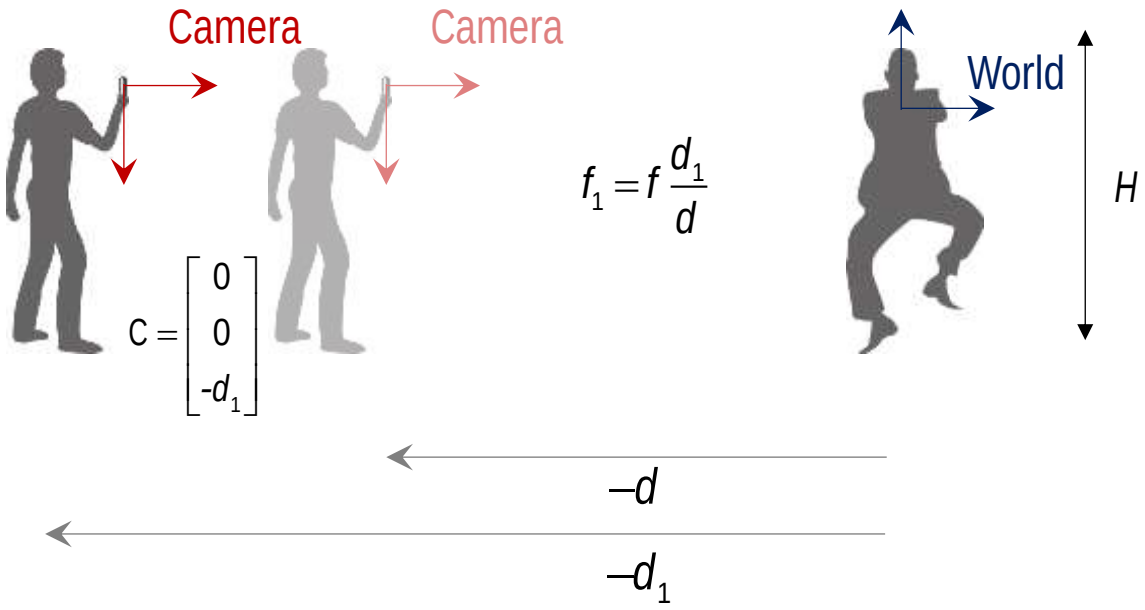


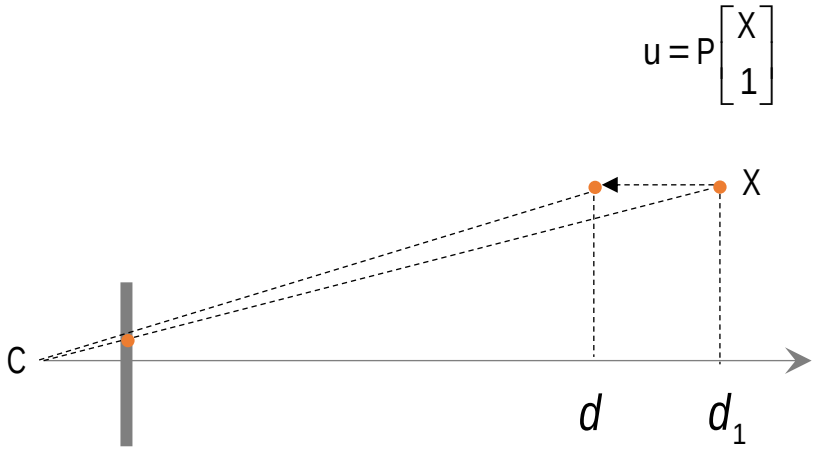


Weak perspectiveness

Strong perspectiveness

Validity of Affine Approximation





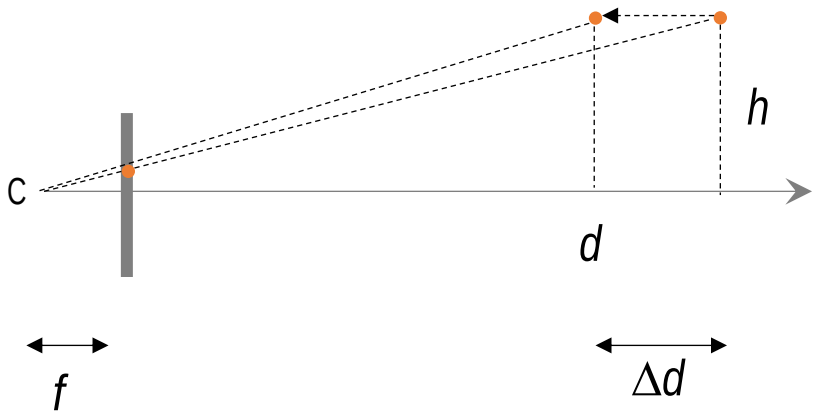
Weak perspectiveness

Strong perspectiveness

$$u_A = P_A \begin{bmatrix} X \\ 1 \end{bmatrix}$$

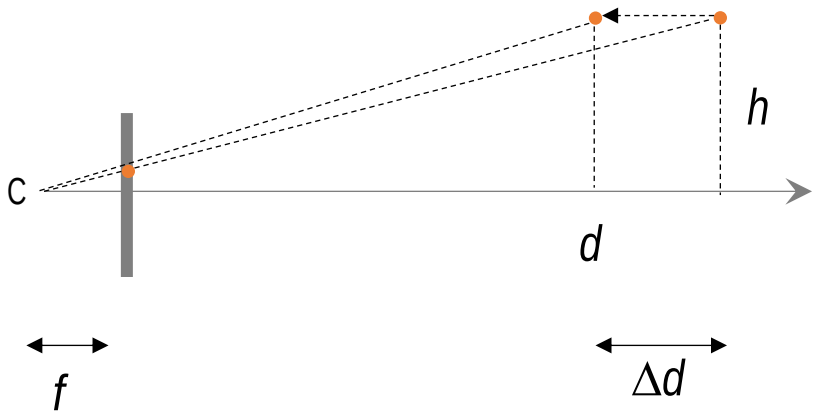
$$P_A = \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & d \end{bmatrix}$$

Approximation Error



Given image resolution (200x200) with 200 pixel focal length, how much approximatation error at d_1=10m (d=9m, object height = 1) will be?

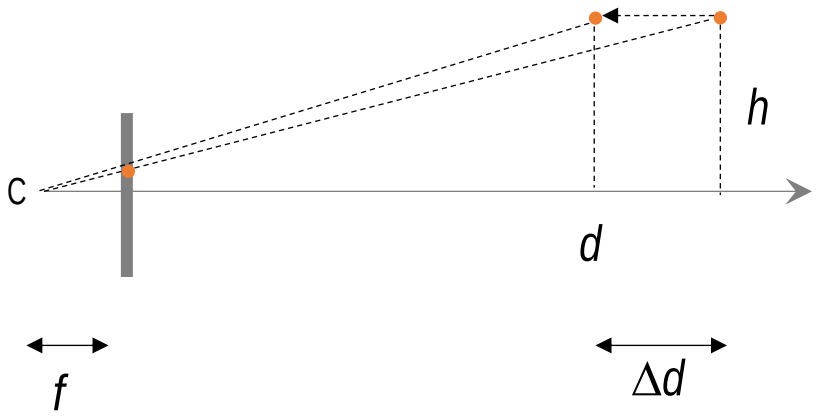
Approximation Error



Given image resolution (200x200) with 200 pixel focal length, how much approximatation error at d_1=10m (d=9m, object height = 1) will be?

$$e = f\frac{h}{d} - f\frac{h}{d+\Delta d}$$

Approximation Error



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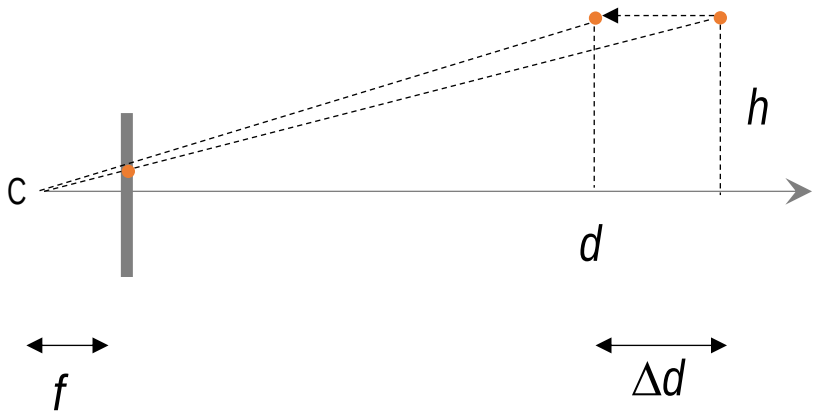
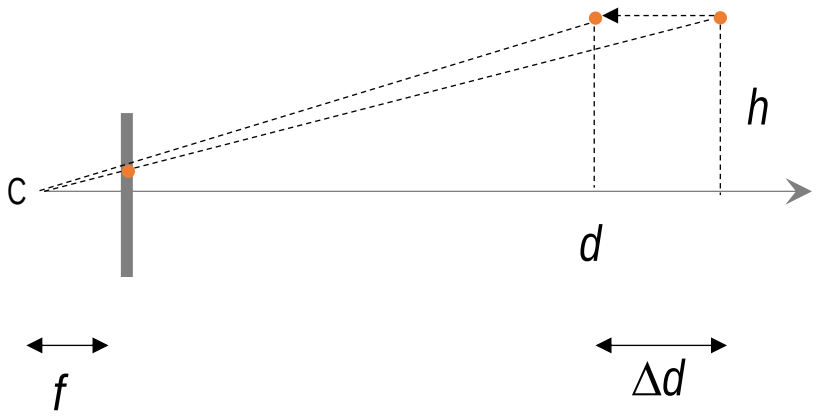
$$e = f\frac{h}{d} - f\frac{h}{d+\Delta d} = 200\frac{1}{9} - 200\frac{1}{10} = 2.22\text{pixel}$$

Approximation Error



Given image resolution (200x200) with 200 pixel focal length, when is the affine camera model valid ($e < 0.5$ pixel)?

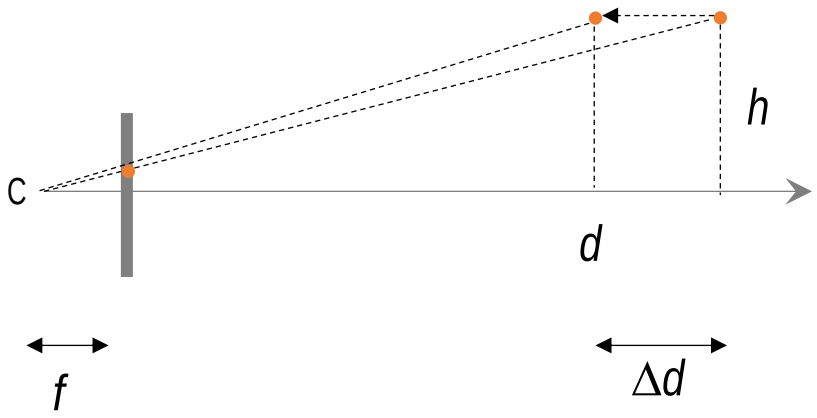
Approximation Error



Given image resolution (200x200) with 200 pixel focal length, when is the affine camera model valid (e < 0.5 pixel)?

$$e = f\frac{h}{d} - f\frac{h}{d+\Delta d} < 0.5\,\text{pixel}$$

Approximation Error



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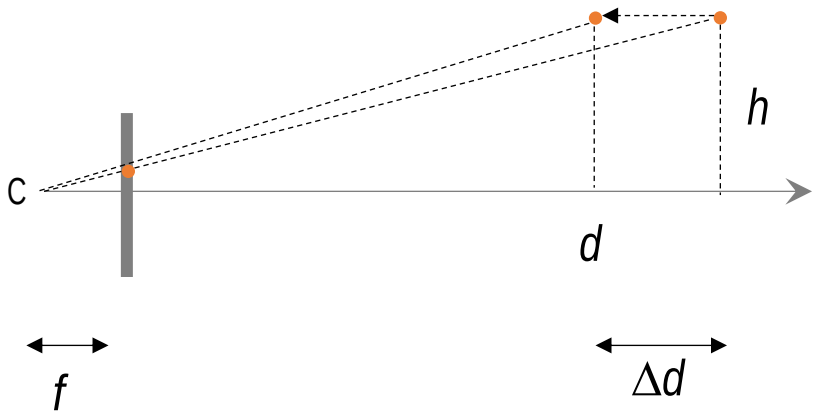
$$e = f\frac{h}{d} - f\frac{h}{d+\Delta d} < 0.5\,\text{pixel}$$

$$\longrightarrow ed^2 + e\Delta d d - fh\Delta d = 0.5d^2 + 0.5d - 200 = 0$$

Approximation Error



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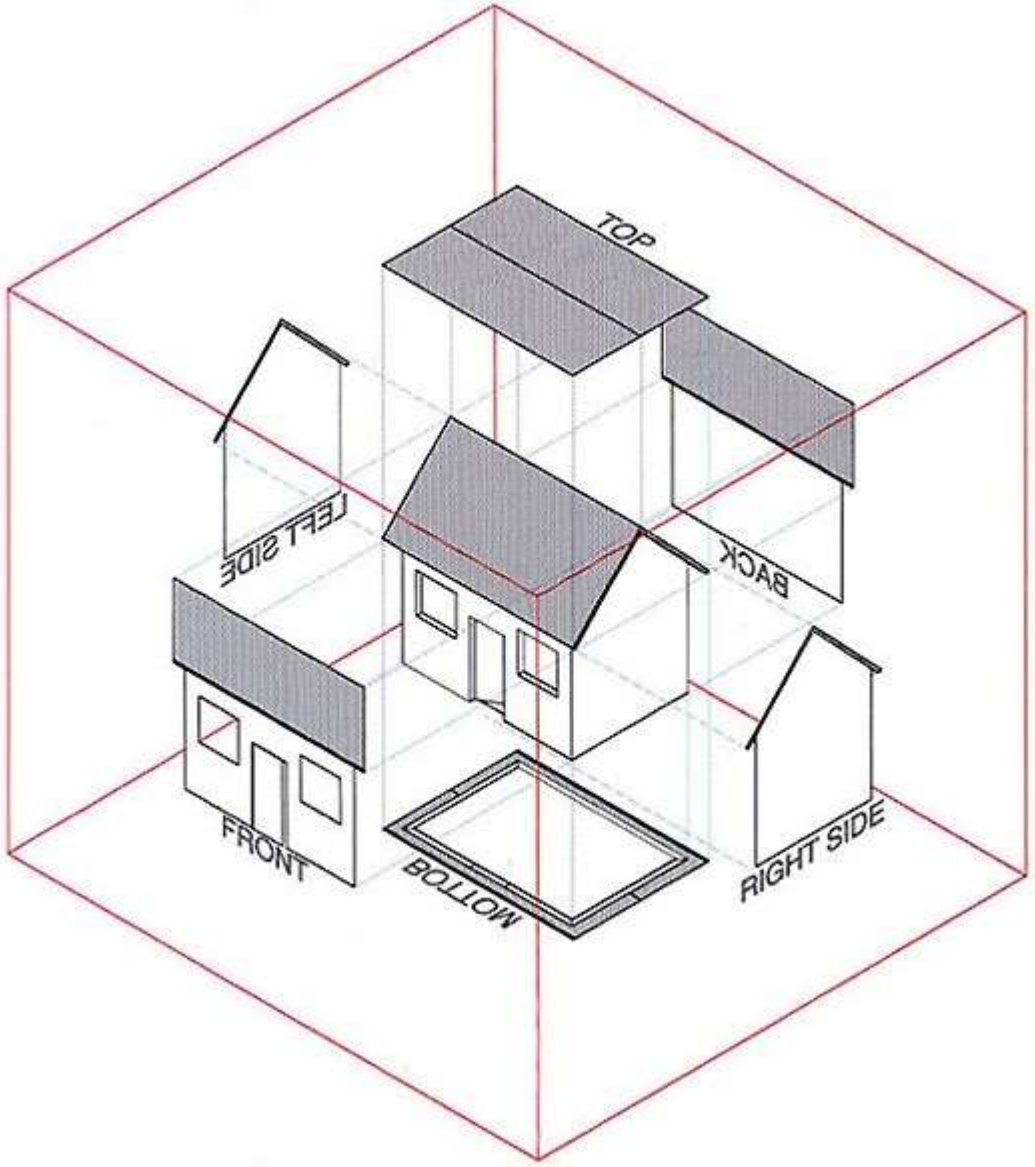
$$e = f\frac{h}{d} - f\frac{h}{d+\Delta d} < 0.5\,\text{pixel}$$

$$\longrightarrow ed^2 + e\Delta d d - fh\Delta d = 0.5d^2 + 0.5d - 200 = 0$$

$$\longrightarrow d^2 + d - 400 = 0$$

$$d = 19.5\,\text{m}$$

Orthographic Camera



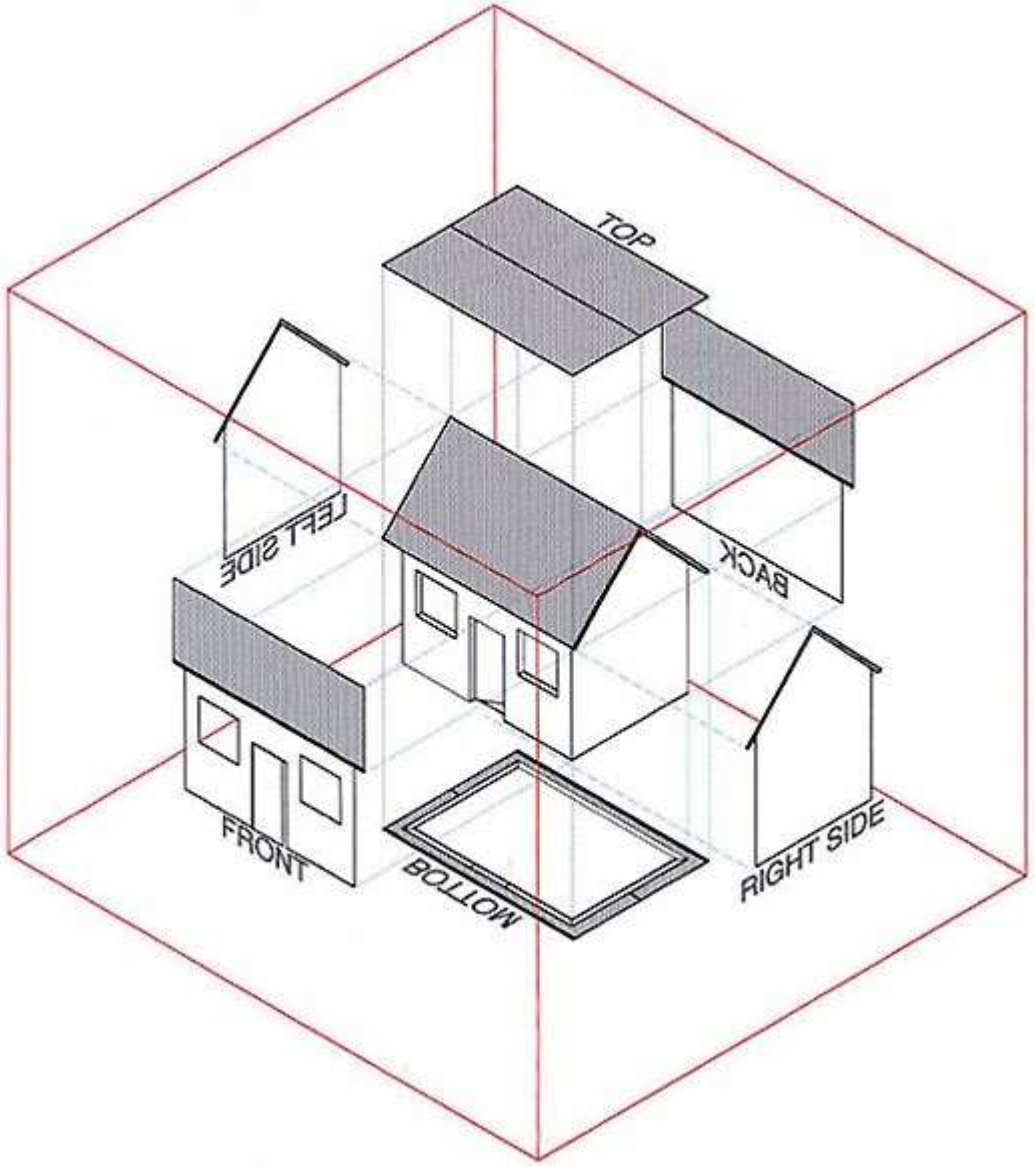
Affine camera:

$$P_A = \begin{bmatrix} f & & p_x \\ & f & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & d \end{bmatrix} = d \begin{bmatrix} f/d & & p_x \\ & f/d & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} r_{x1} & r_{x2} & 0 & 0 \\ r_{y1} & r_{y2} & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Orthographic camera:

$$f = 1 \quad p_X = p_Y = 0$$

Orthographic Camera



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Orthographic camera:

$$f = 1 \quad p_X = p_Y = 0$$

$$P_O = \begin{bmatrix} r_{x1} & r_{x2} & r_{x3} & 0 \\ r_{y1} & r_{y2} & r_{y3} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$