# CS 3630!

***Lecture 14:***

***Computer Vision Fundamentals***

# Topics

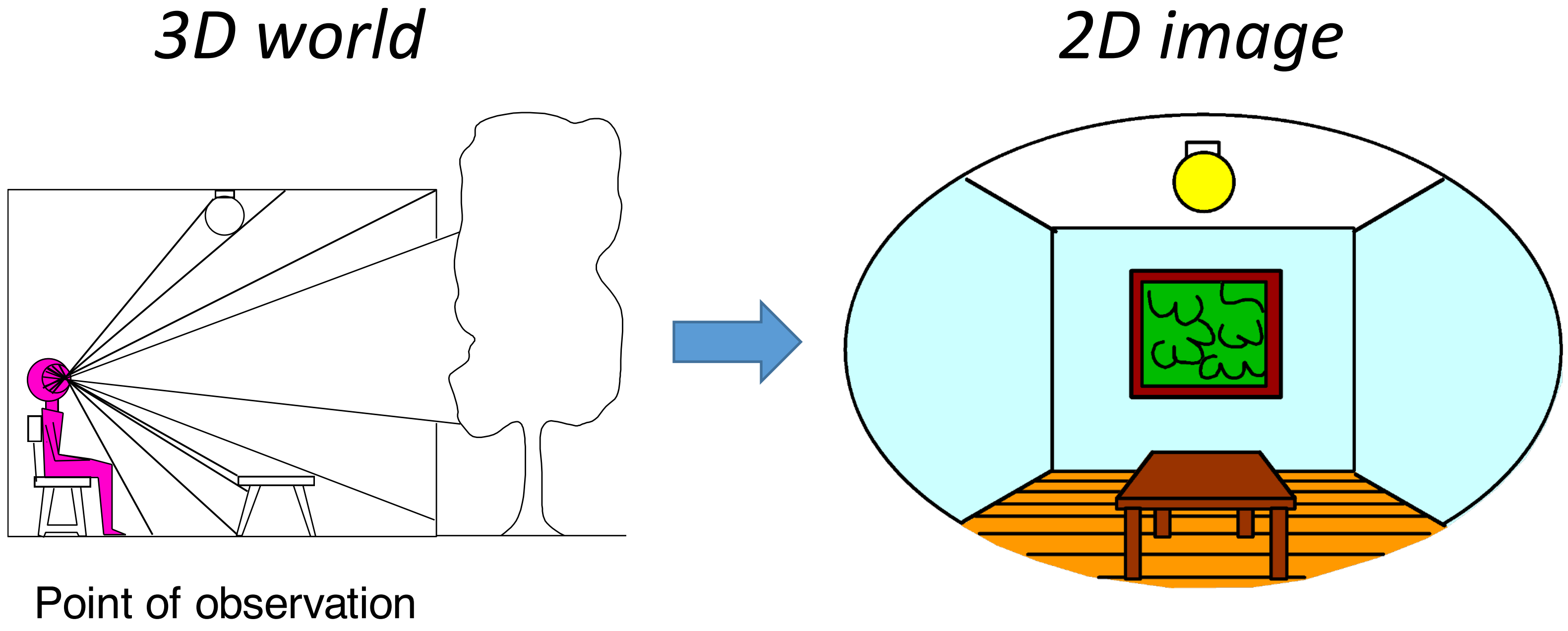
1. **Perspective Cameras**
2. **Pinhole Camera Model**
3. **Properties of projective Geometry**
4. **Stereo Cameras (TBD)**

- Many slides borrowed from James Hays, Irfan Essa, and others.

# Motivation

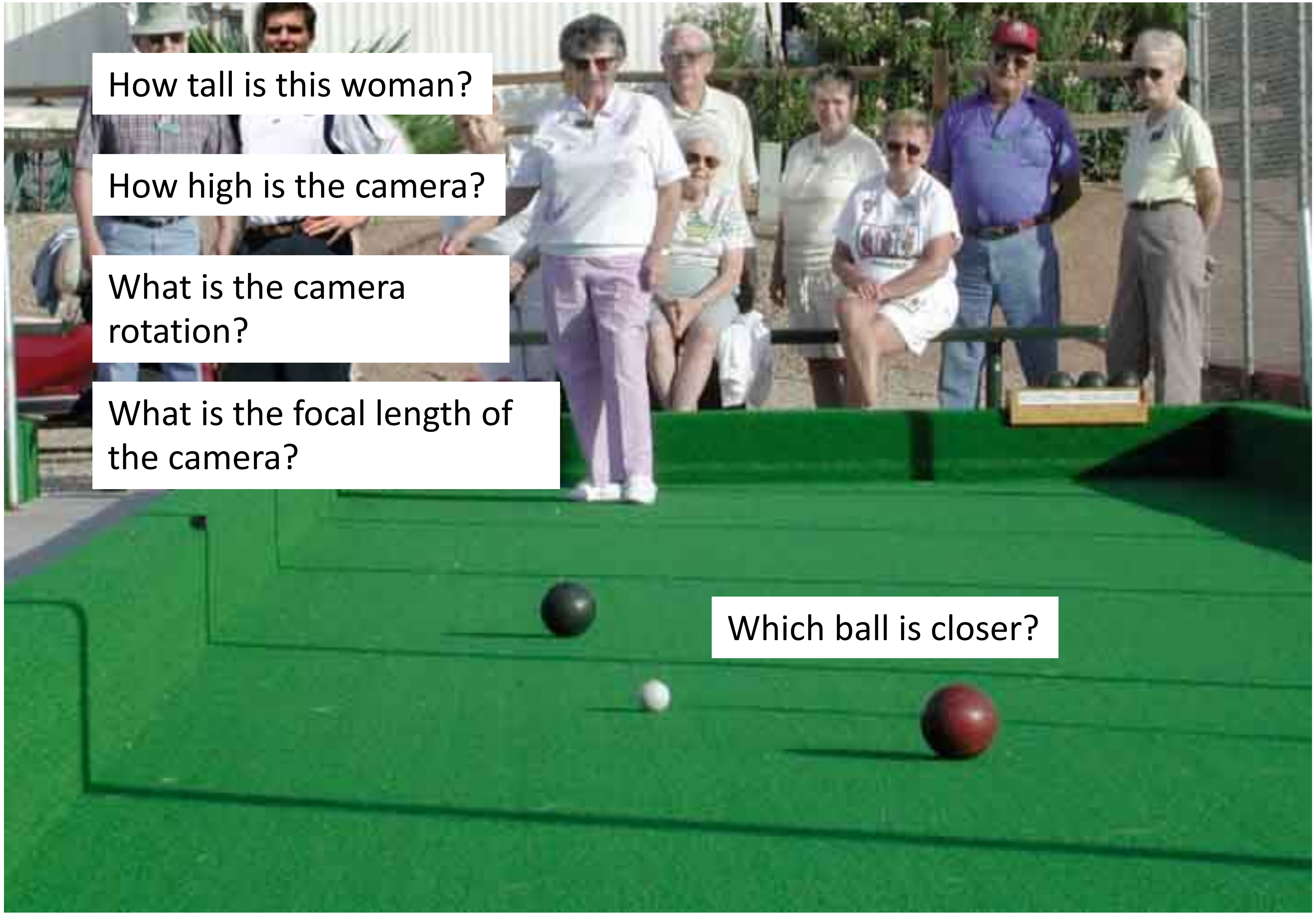
- We need to model the image formation process
- The camera can act as an (angular) measurement device
- Need a mathematical model for a simple camera
- Two cameras are better than one: metric measurements

# 1. Perspective Cameras

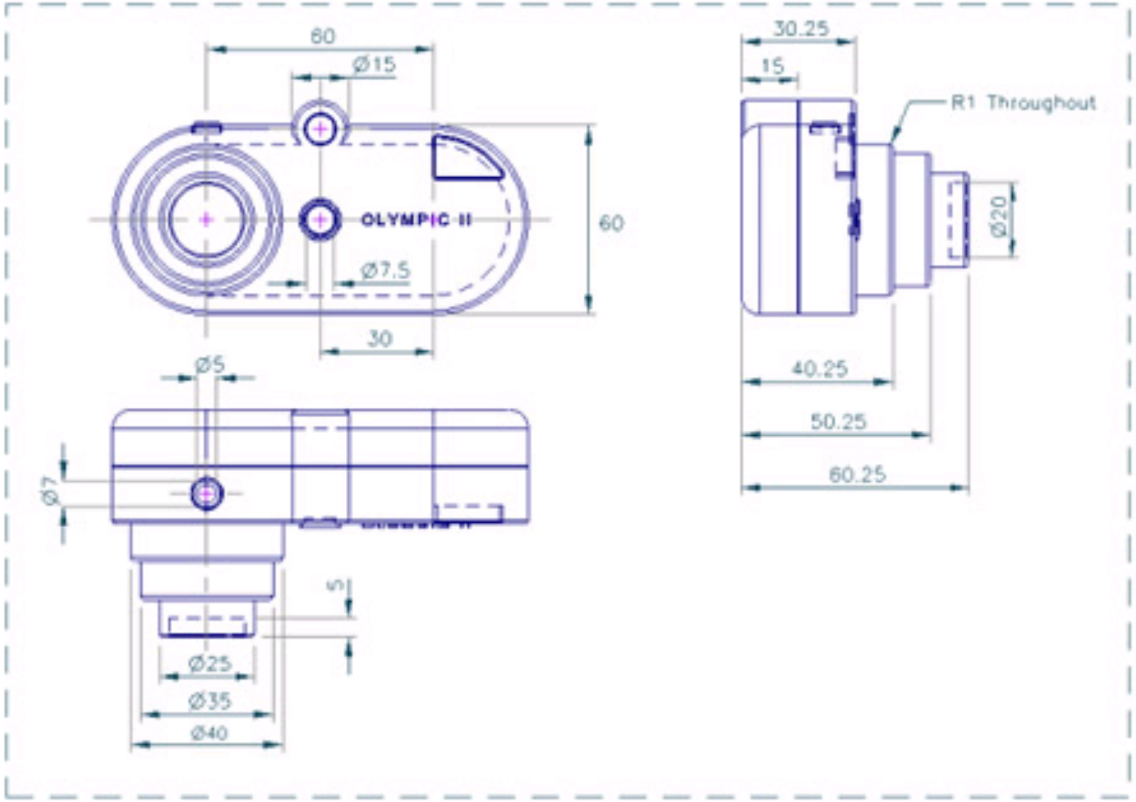



- Recall: Computer Vision: Images to Models
- To do this, we first need to understand the image formation process.
- We concentrate here on *geometry* (not photometry)

# Camera and World Geometry



# Orthographic Projection




- Might be familiar with this projection
- Most cameras behave differently

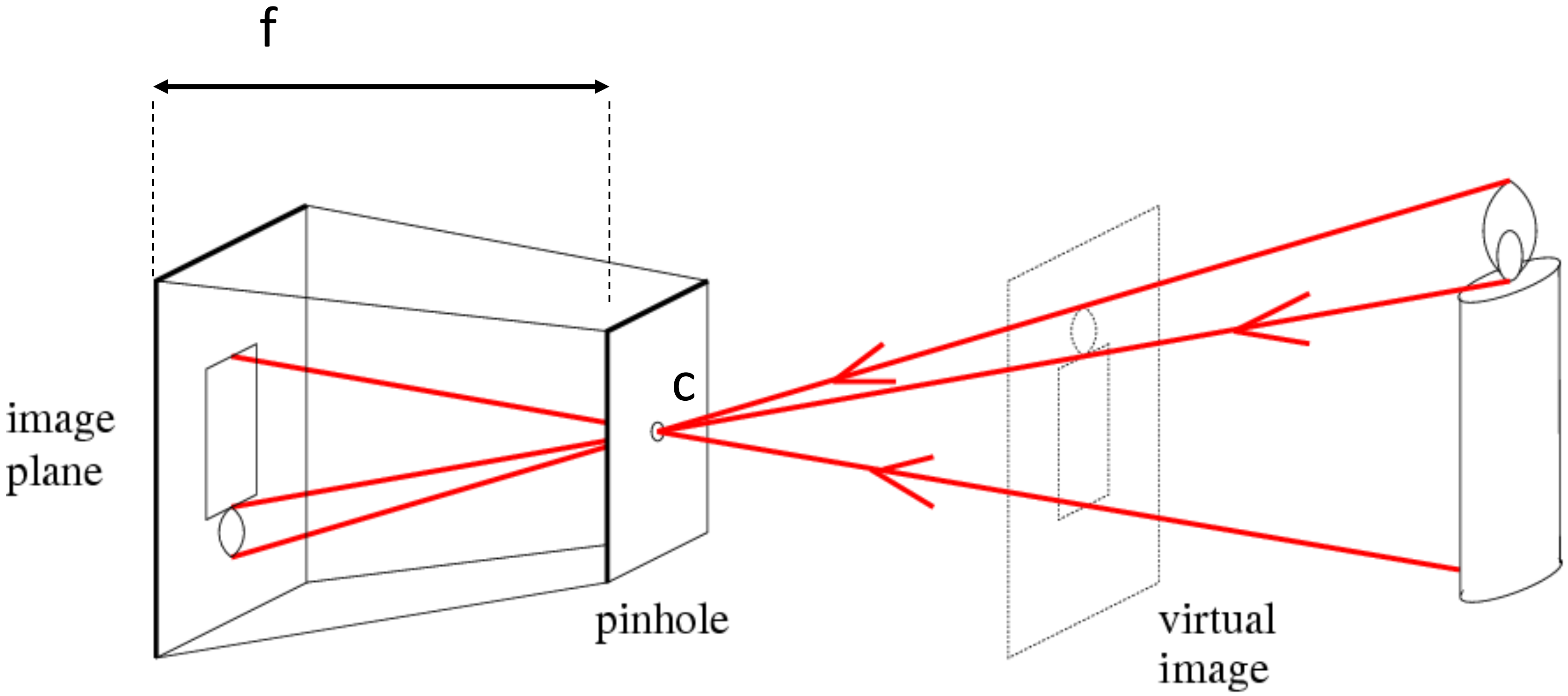
Slide source: Seitz

# Projection can be tricky…

Slide source: Seitz

# Projection can be tricky…

# 2. Pinhole camera model




f = focal length

c = center of the camera

Figure from Forsyth

# Camera obscura: the pre-camera

- Known during classical period in China and Greece (e.g.  Mo-Ti, China, 470BC to 390BC)

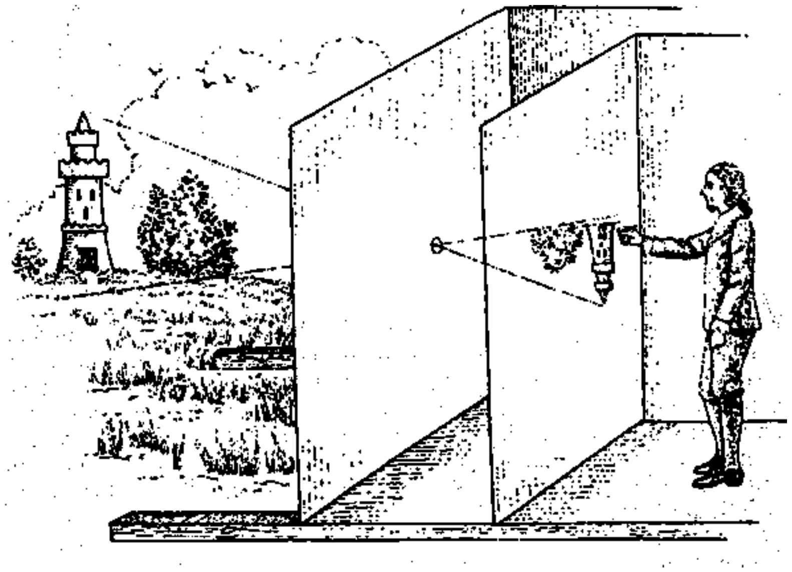


Illustration of Camera Obscura

Freestanding camera obscura at UNC Chapel Hill

Photo by Seth Ilys

# Camera Obscura used for Tracing

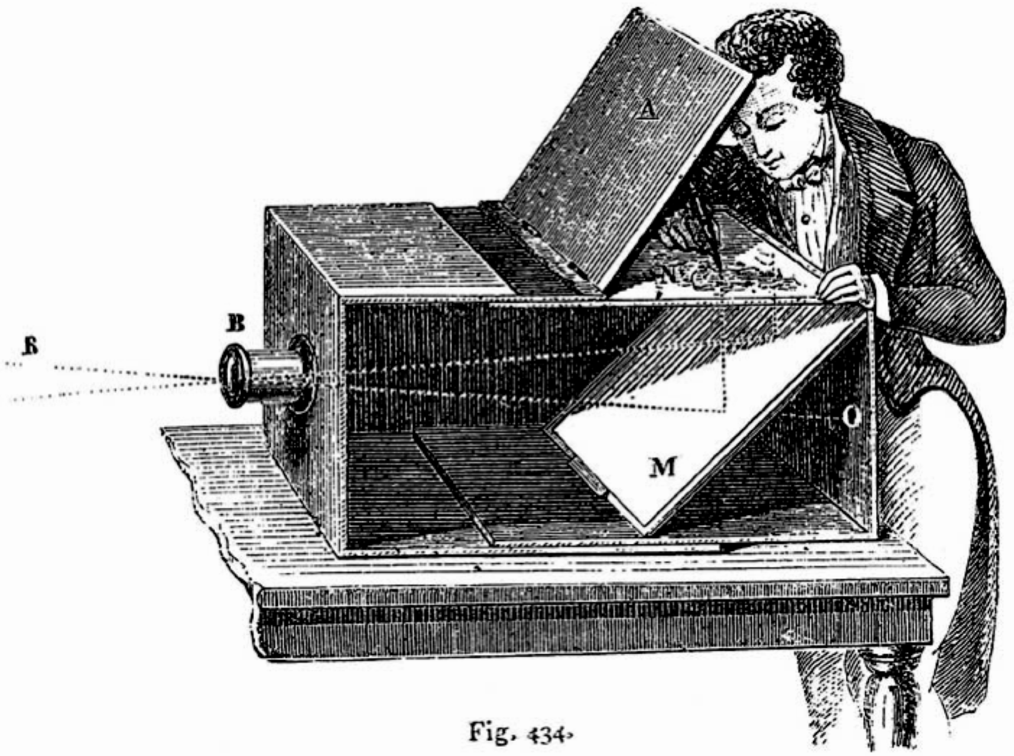



Fig. 434.

Lens Based Camera Obscura, 1568

# First Photograph

Oldest surviving photograph

- Took 8 hours on pewter plate

Joseph Niepce, 1826

Photograph of the first photograph

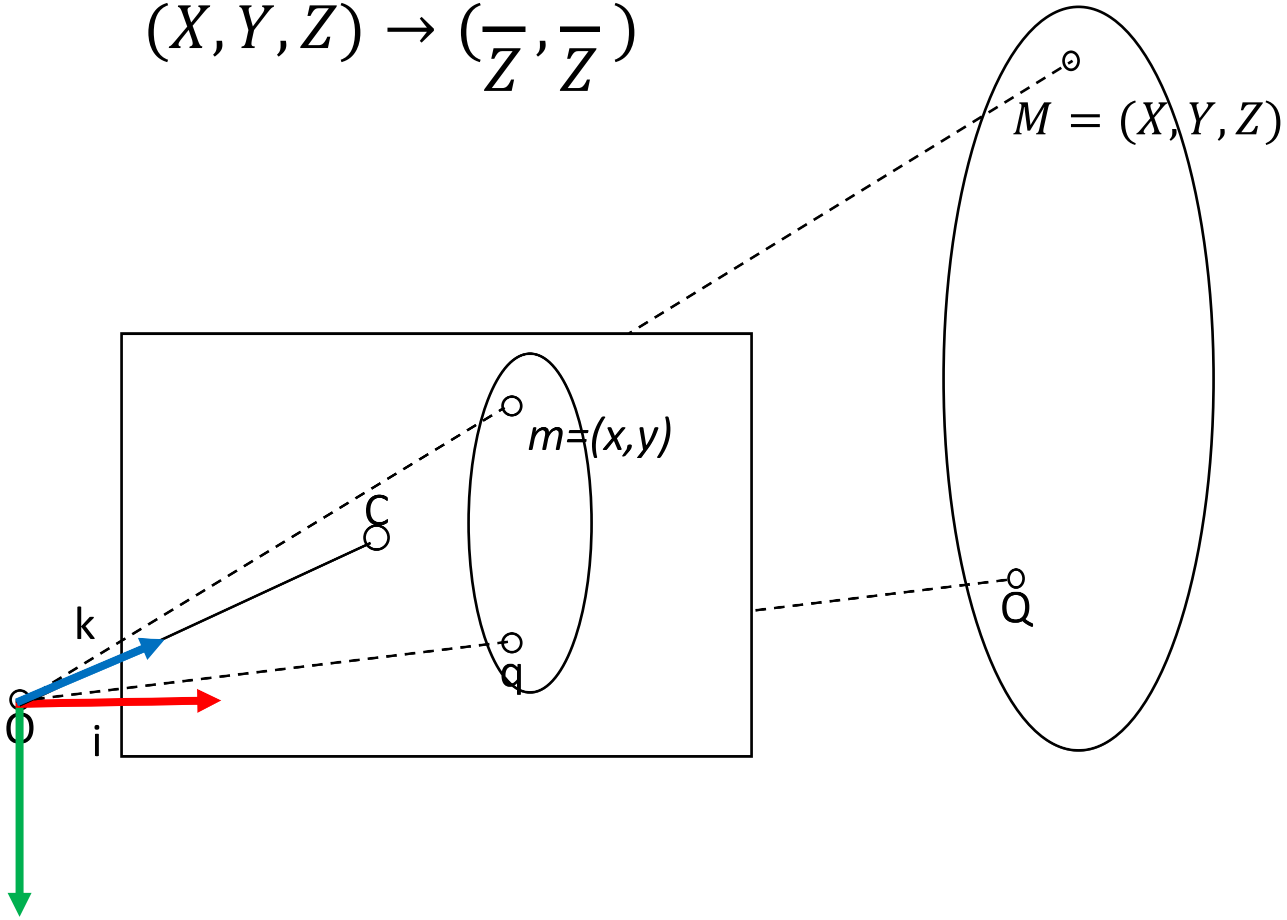
Stored at UT Austin

Niepce later teamed up with Daguerre, who eventually created Daguerrotypes

# Pinhole Camera

- Fundamental equation:

$$(X, Y, Z) \rightarrow (\frac{X}{Z}, \frac{Y}{Z})$$



# Homogeneous Coordinates

Linear transformation of homogeneous (projective) coordinates

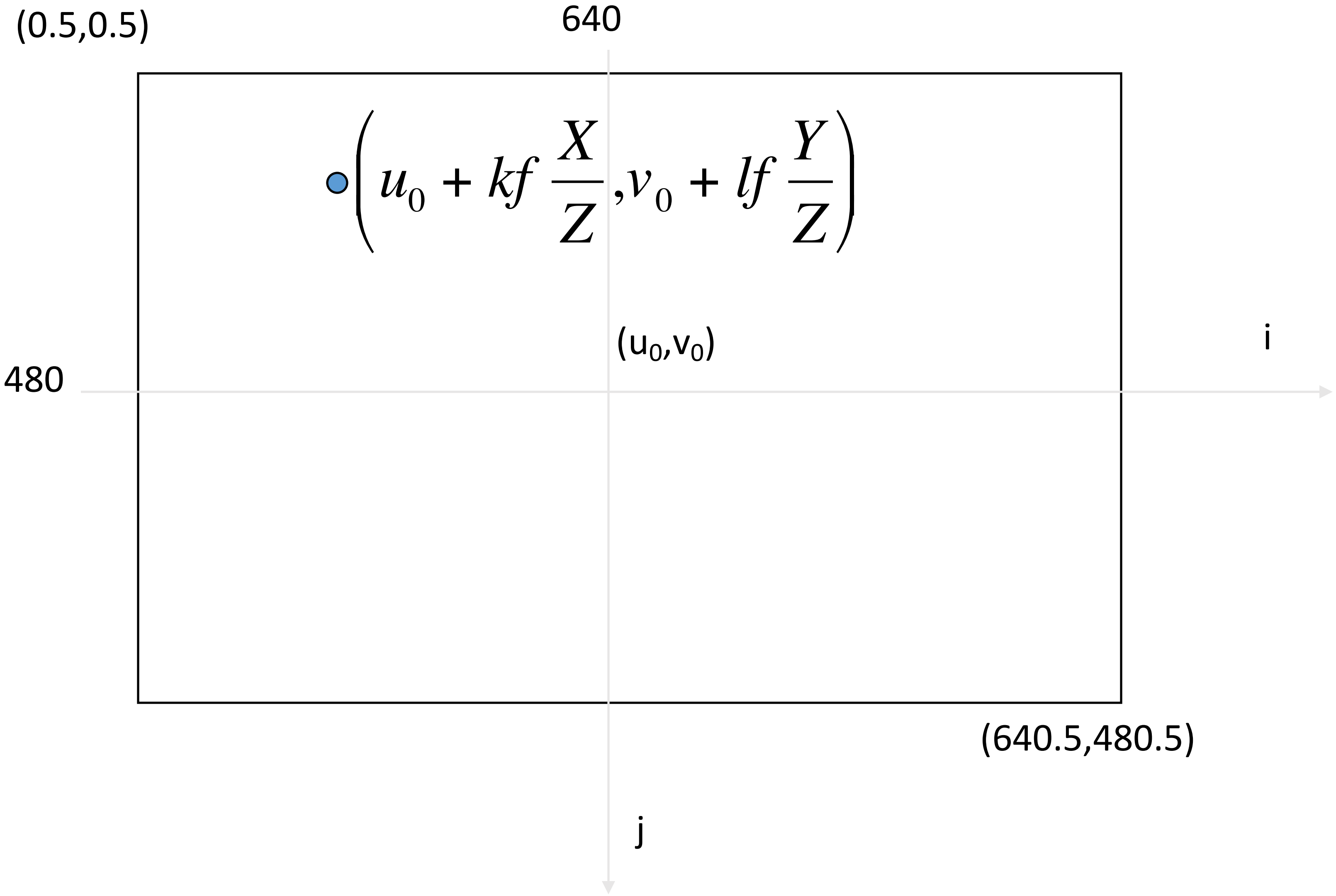
$$m = \begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} I & 0 \end{bmatrix} M = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ T \end{bmatrix}$$

Recover image (Euclidean) coordinates by normalizing:

$$x = \frac{u}{w} = \frac{X}{Z}$$

$$y = \frac{v}{w} = \frac{Y}{Z}$$

# Pixel coordinates in 2D



# Intrinsic Calibration

$3 \times 3$ Calibration Matrix K

$$m = \begin{bmatrix} u \\ v \\ w \end{bmatrix} = K[I \quad 0]M = \begin{bmatrix} \alpha & s & u_0 \\ & \beta & v_0 \\ & & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ T \end{bmatrix}$$

Recover image (Euclidean) coordinates by normalizing :

$$x = \frac{u}{w} = \frac{\alpha X + sY + u_0}{Z}$$

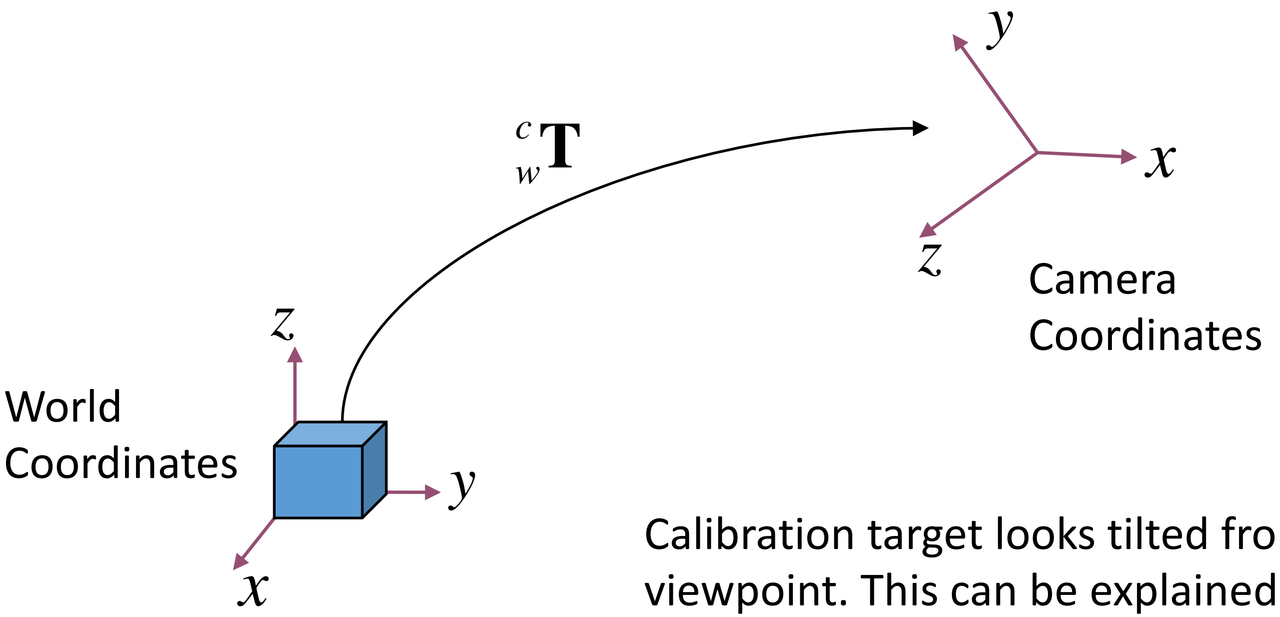
$$y = \frac{v}{w} = \frac{\beta Y + v_0}{Z}$$

skew

5 Degrees of Freedom !

# Camera Pose

In order to apply the camera model, objects in the scene must be expressed in *camera coordinates*.




Calibration target looks tilted from camera viewpoint. This can be explained as a difference in coordinate systems.

# Projective Camera Matrix

$$Camera = Calibration \times \mathrm{Pr}\,ojection \times Extrinsics$$

$$m = \begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} \alpha & s & u_0 \\ & \beta & v_0 \\ & & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} R & t \\ 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ T \end{bmatrix}$$

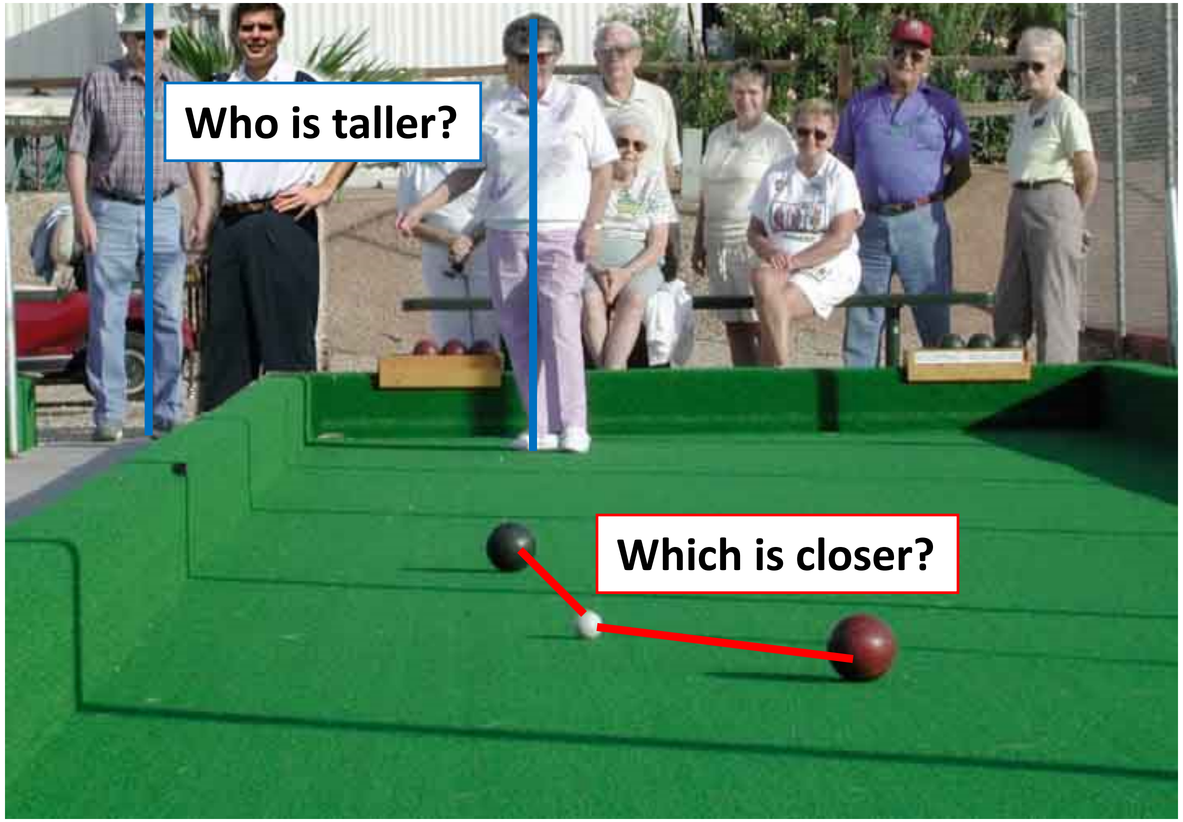
$$= K\begin{bmatrix} R & t \end{bmatrix} M = PM$$

5+6 Degrees of Freedom (DOF) = 11 !

# 3. Properties of projective Geometry

## What is lost?

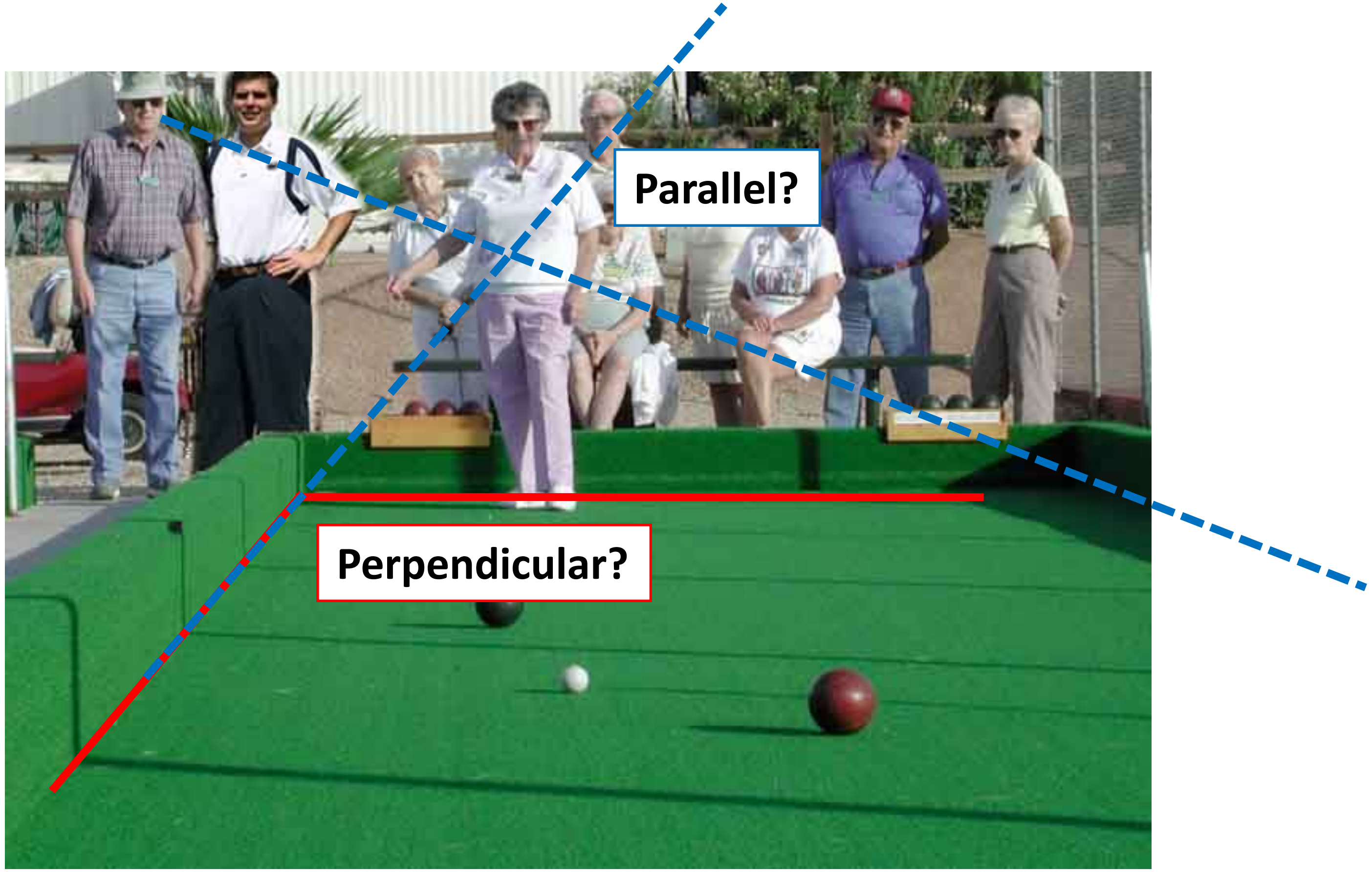
- Length



# Properties of projective Geometry

## What is lost?

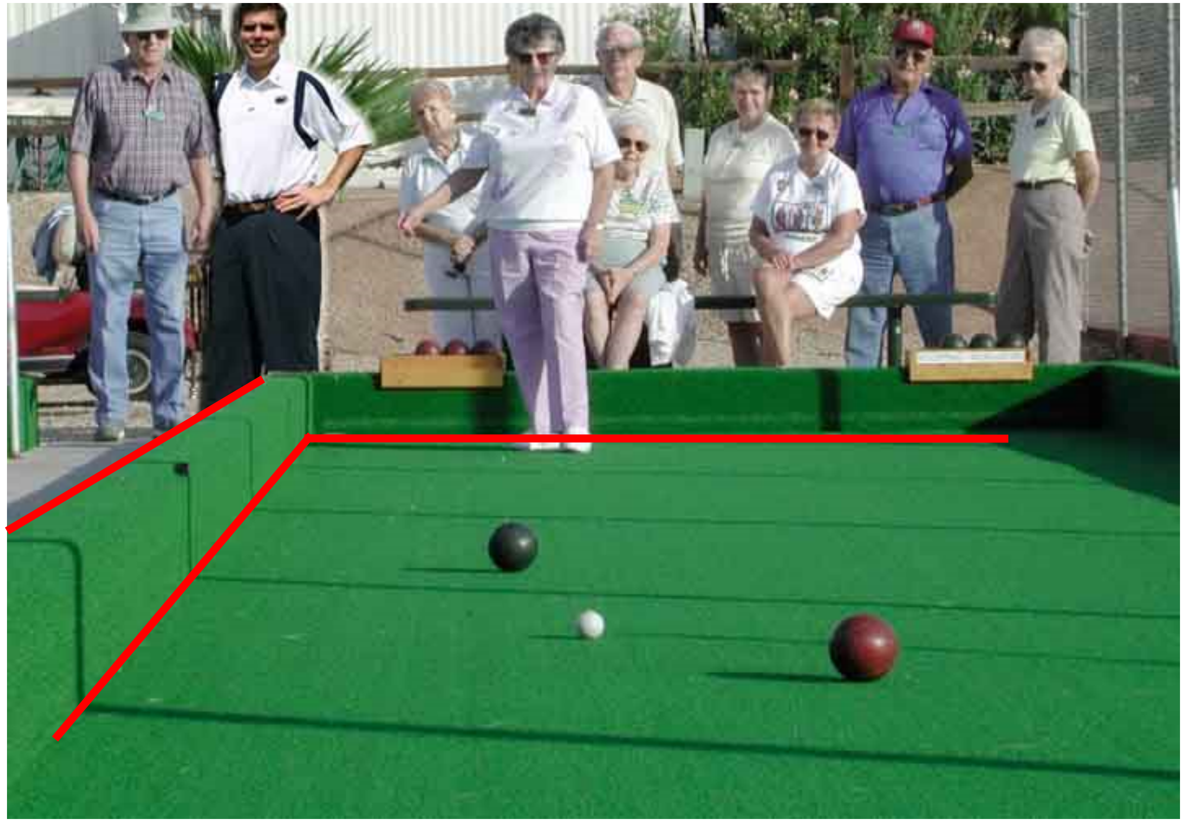
- Length
- Angles



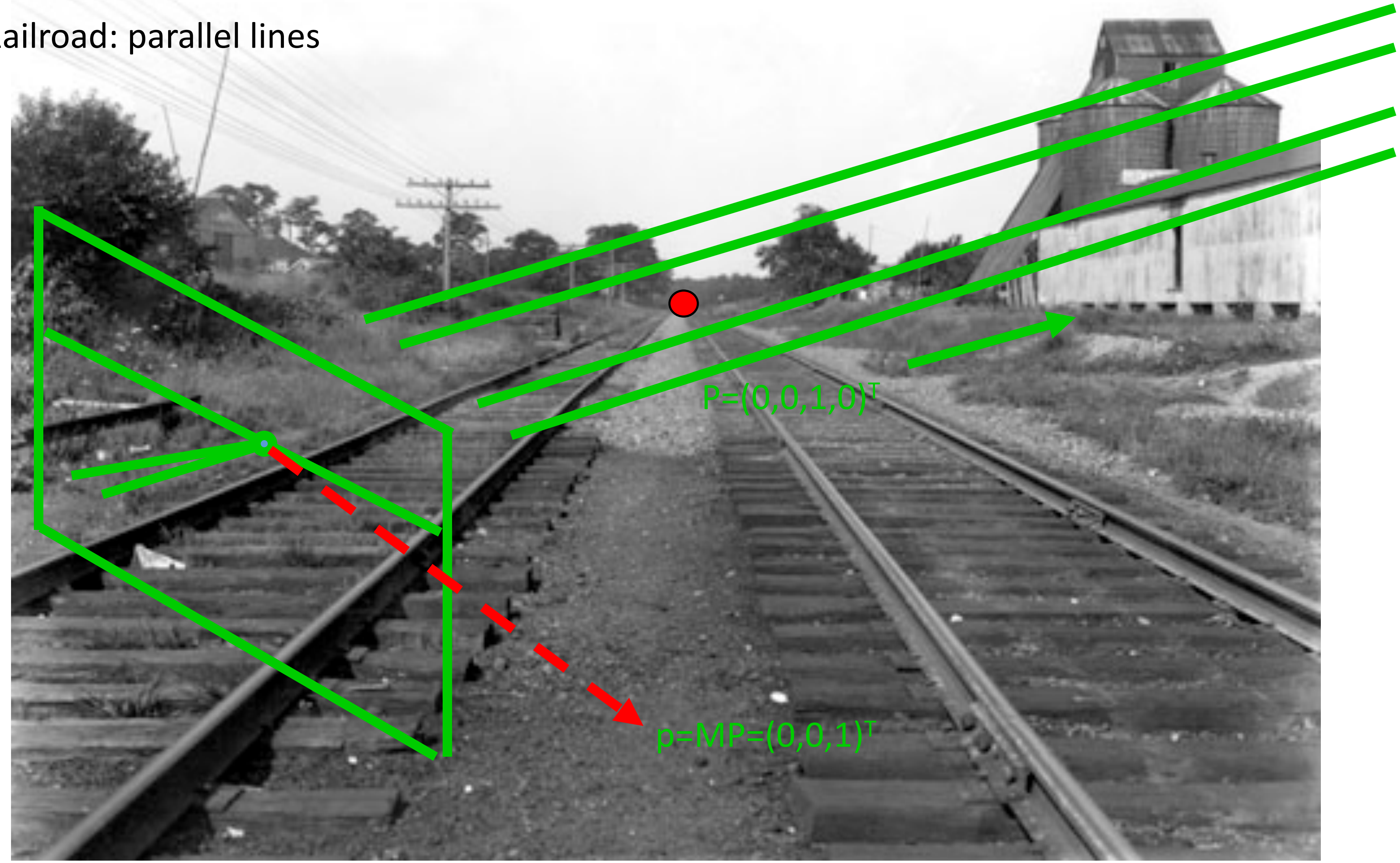
# Properties of projective Geometry

## What is preserved?

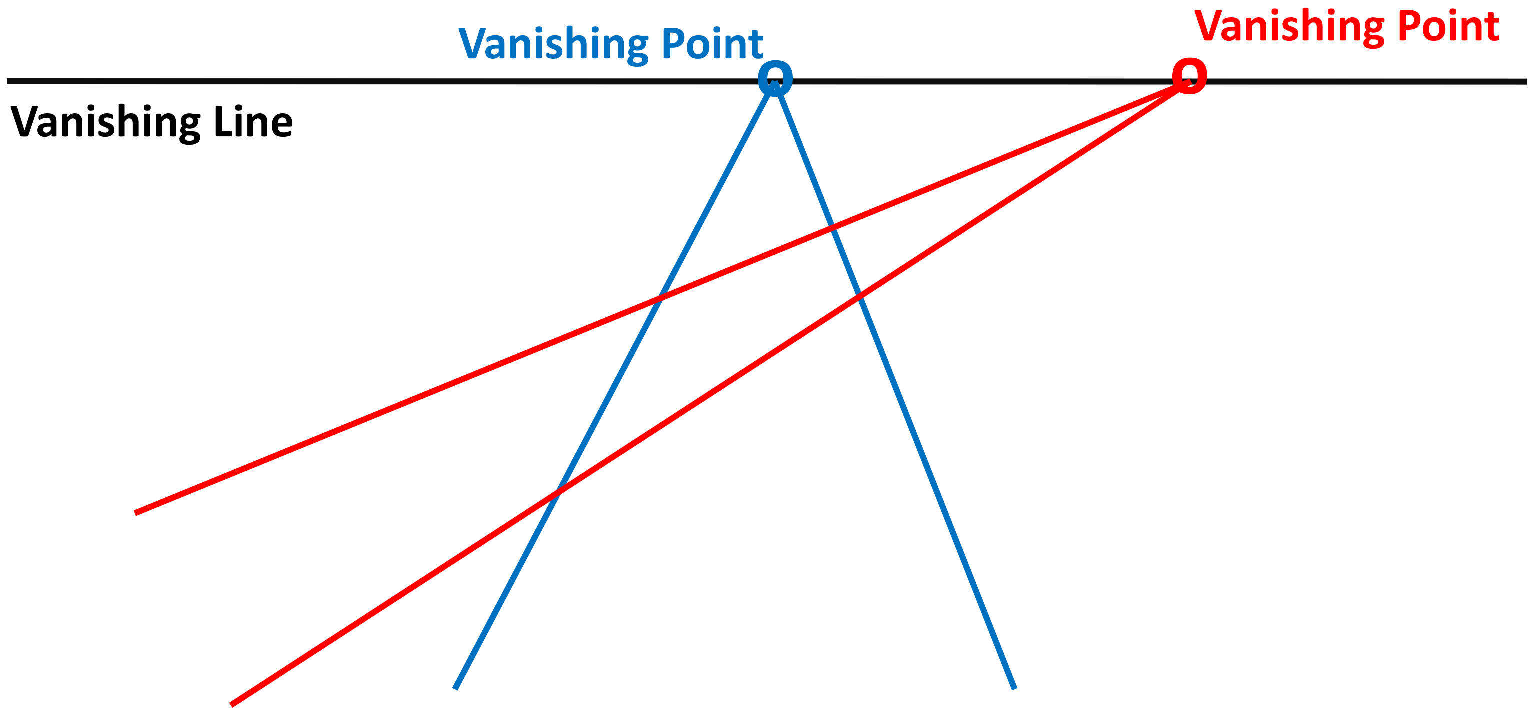
- Straight lines are still straight



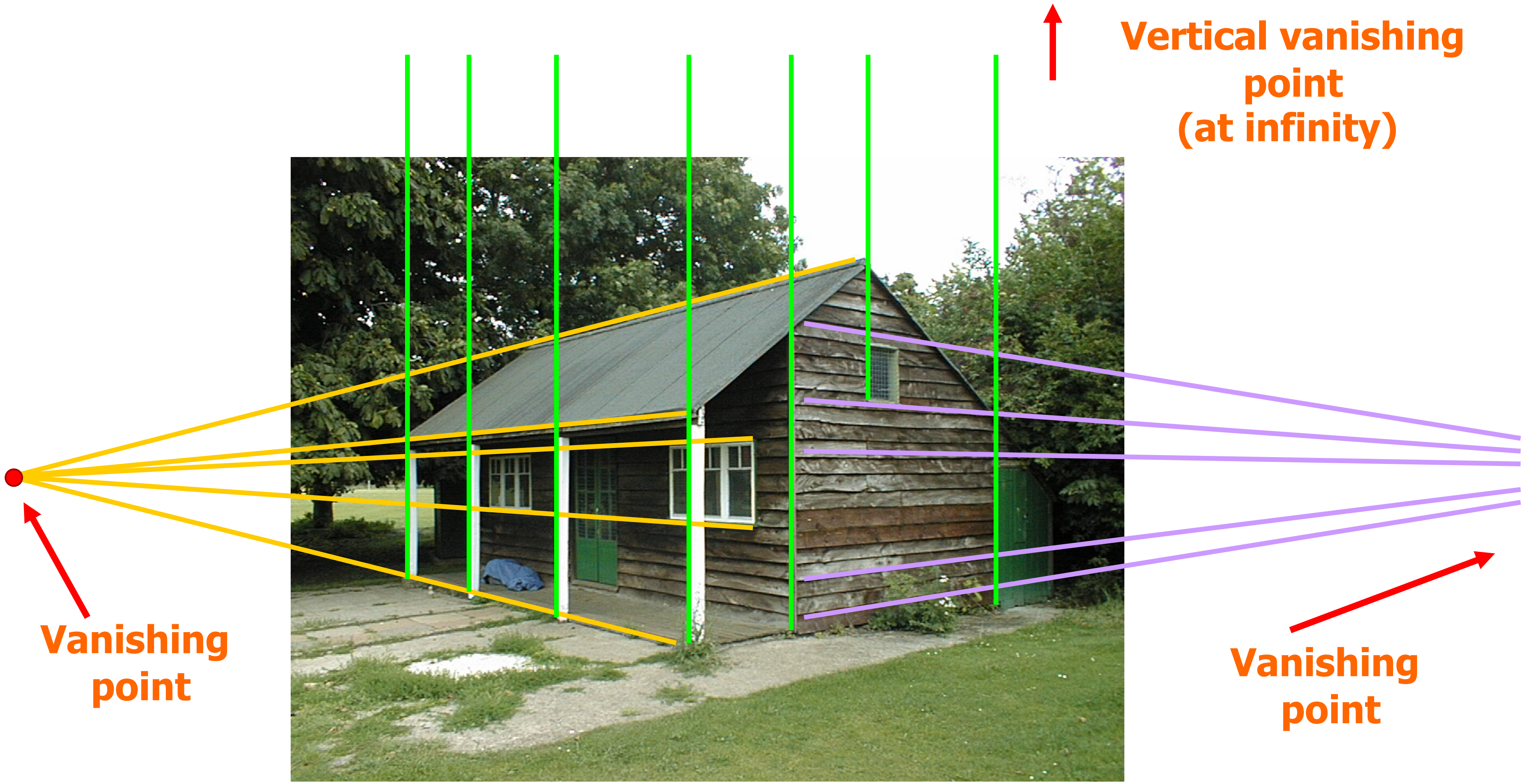
# We can see infinity !



# Vanishing points and lines



# Vanishing points and lines




Slide from Efros, Photo from Criminisi

# 4. Stereo Cameras (TBD)

- Stereo is used in the HVS
- Very useful in computer vision as well
- Eliminates scale ambiguity

# Summary

1. Perspective Cameras Intro
2. Pinhole Camera Model defined
3. Properties of Projective Geometry
4. Stereo cameras give metric measurements