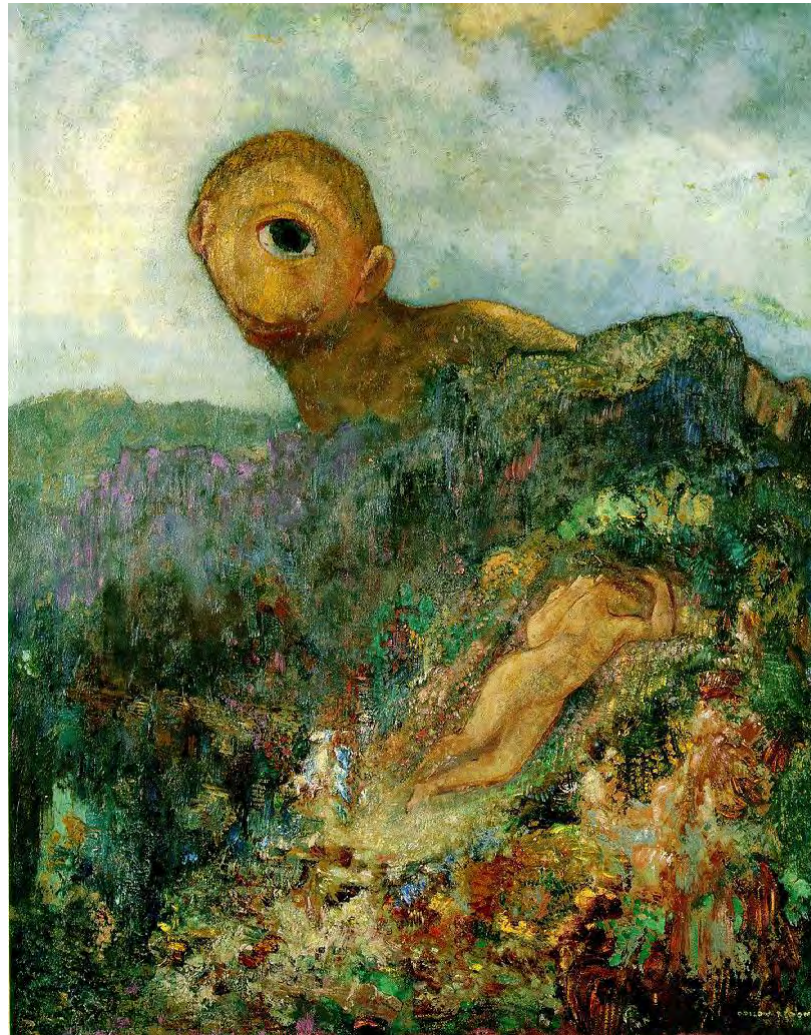


More Single View Geometry



Cyclops **Odilon Redon** 1904

*...with a lot of slides stolen
from Steve Seitz*

15-463: Computational Photography
Alexei Efros, CMU, Fall 2008

Quiz: which is 1,2,3-point perspective



Image A

Image B



Image C

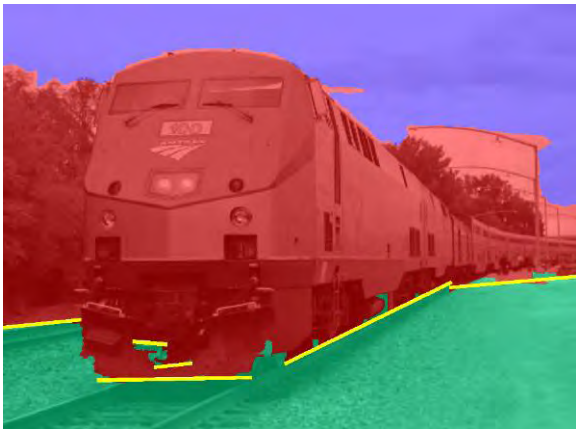
Automatic Photo Pop-up



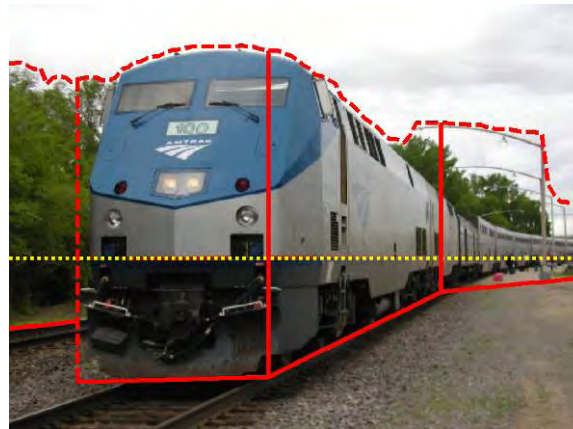
Original Image



Geometric Labels



Fit Segments



Cut and Fold

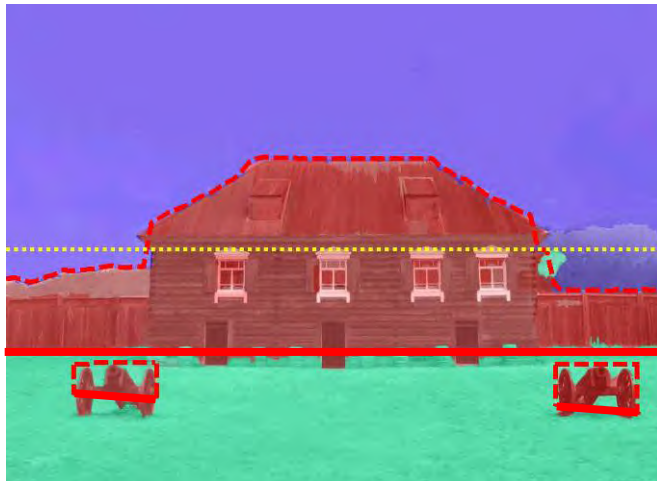


Novel View

Results



Input Image



Cut and Fold

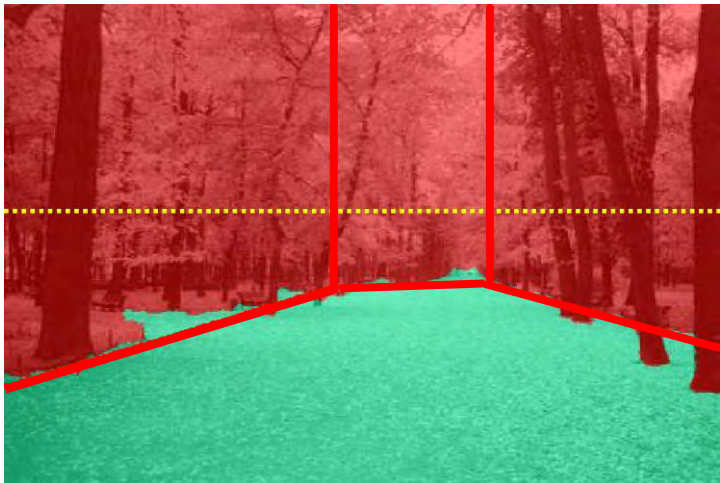


Automatic Photo Pop-up

Results



Input Image



Cut and Fold



Automatic Photo Pop-up

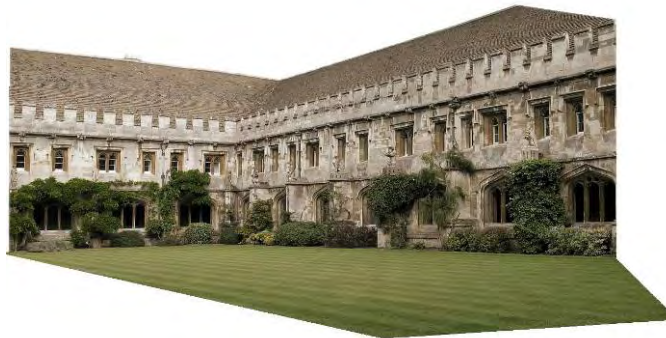
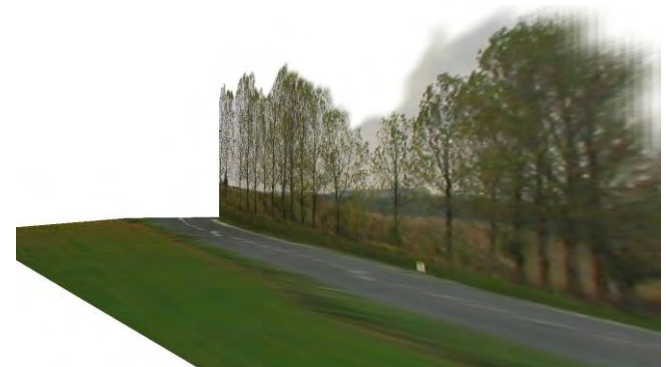
Results



Input Image

Automatic Photo Pop-up

Results



Input Images

Automatic Photo Pop-up

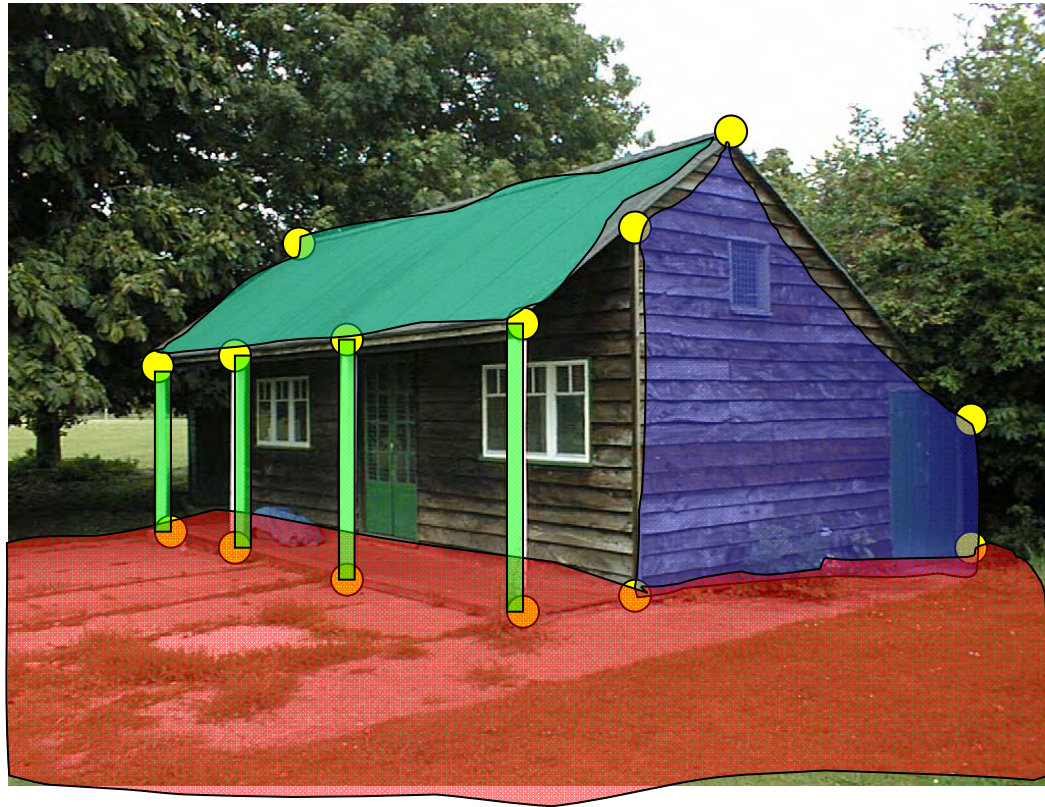
Results



Input Image

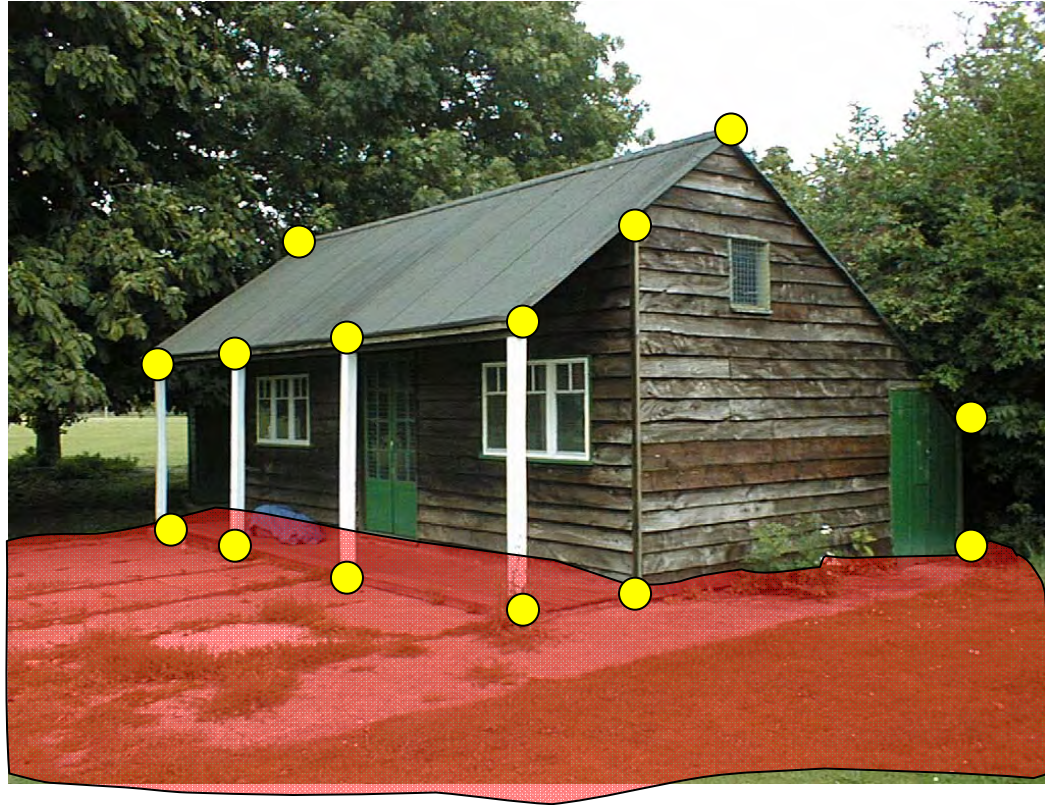
Automatic Photo Pop-up

How can we model more complex scene?



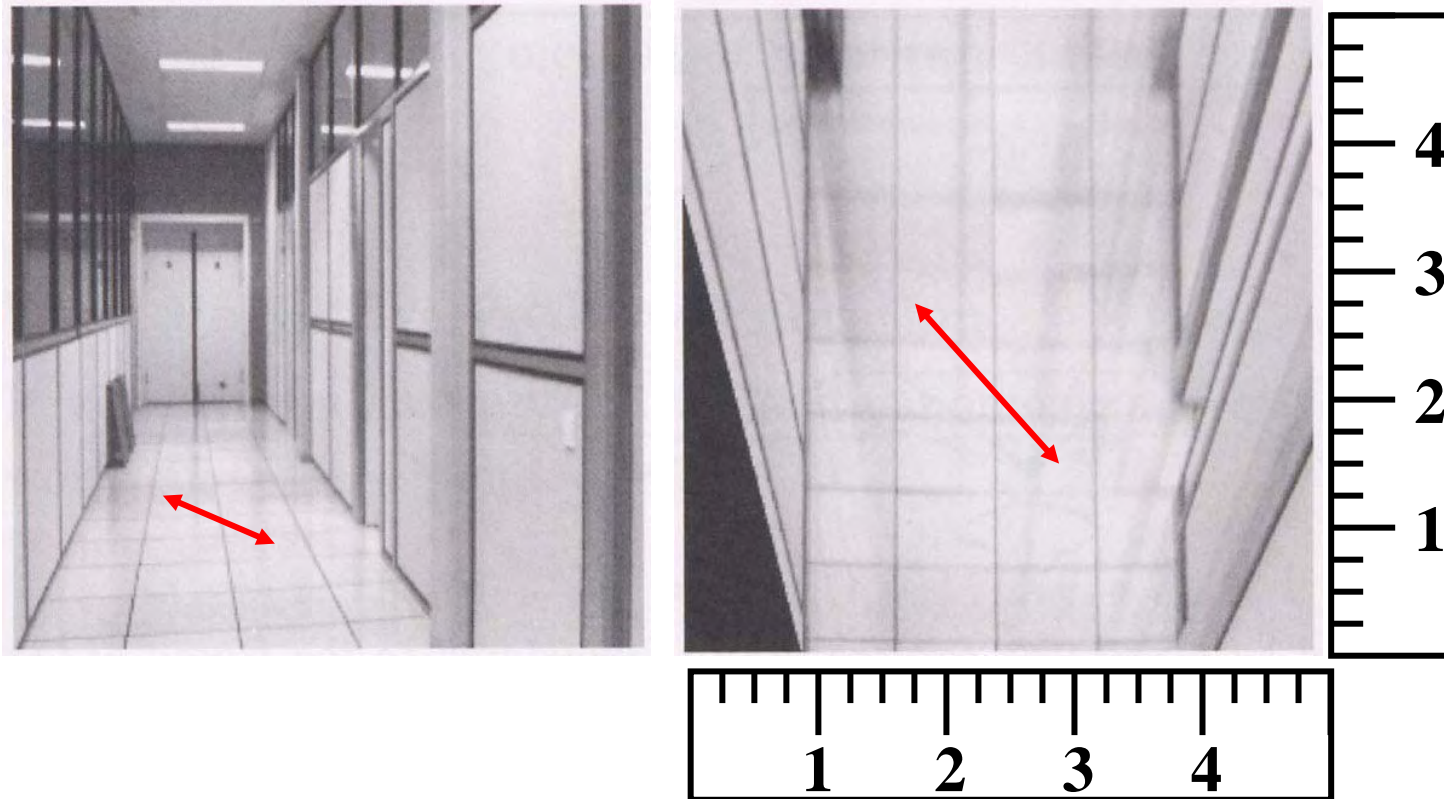
1. Find world coordinates (X,Y,Z) for a few points
2. Connect the points with planes to model geometry
 - Texture map the planes

Finding world coordinates (X,Y,Z)



1. Define the ground plane ($Z=0$)
2. Compute points $(X,Y,0)$ on that plane
3. Compute the *heights* Z of all other points

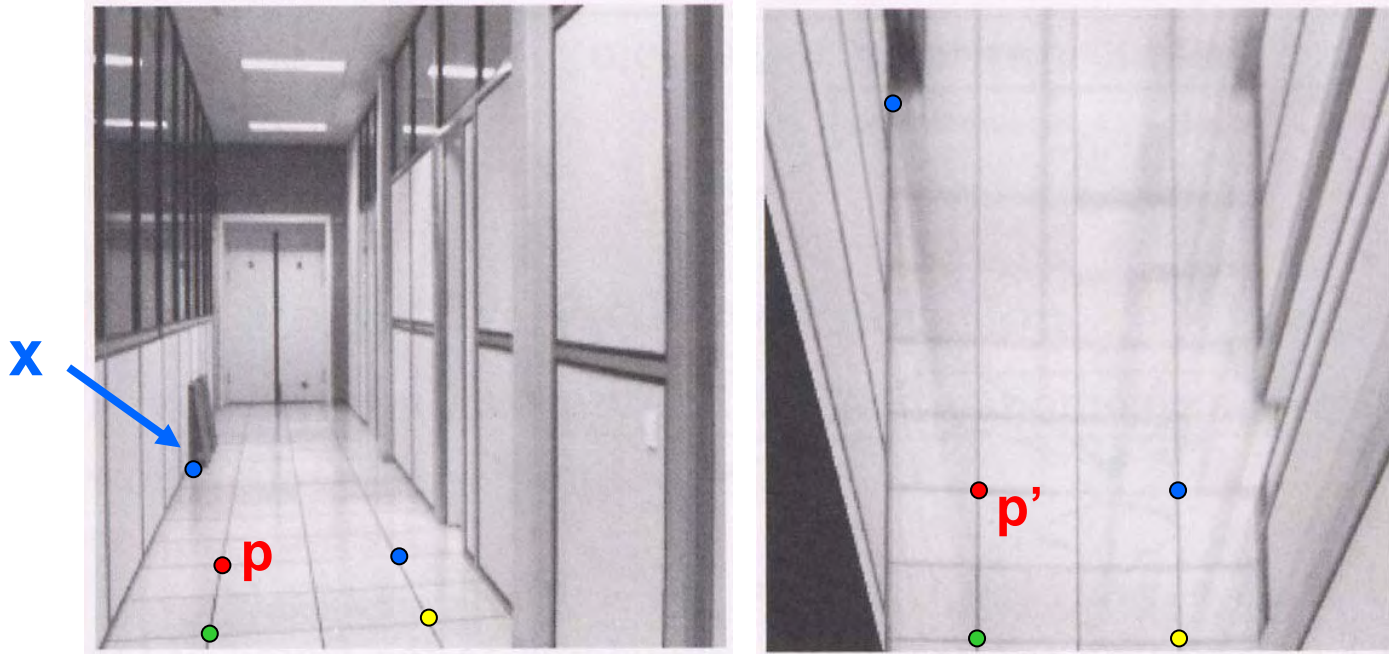
Measurements on planes



Approach: unwarp, then measure

What kind of warp is this?

Unwarp ground plane



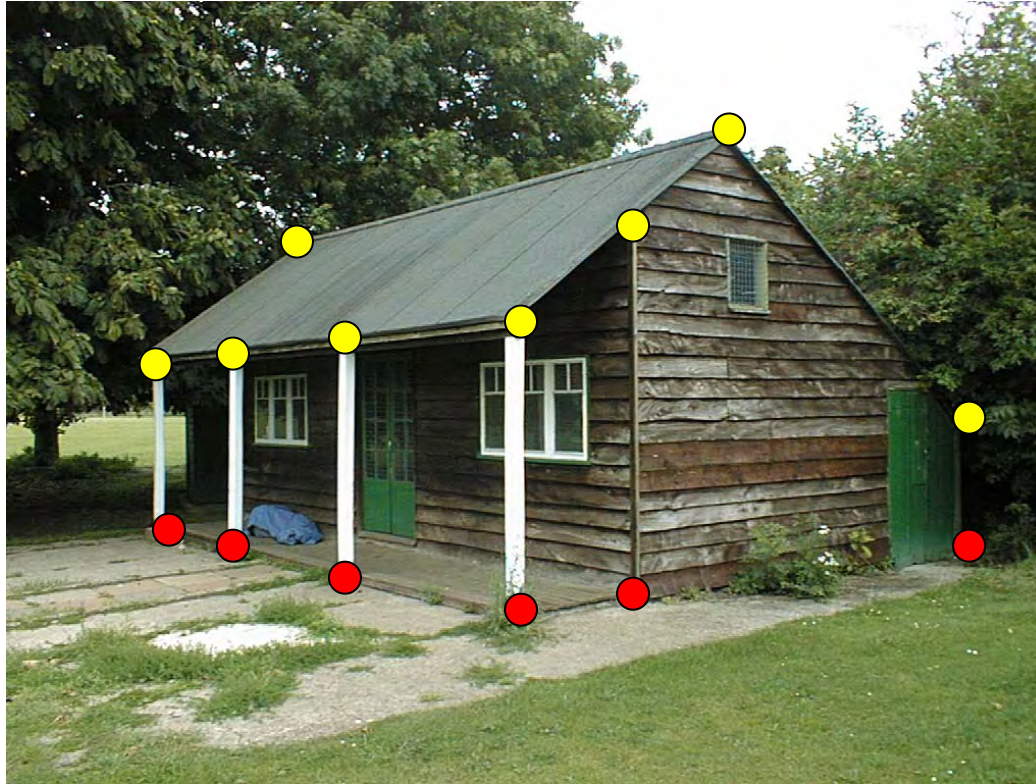
Our old friend – the homography

Need 4 reference points with world coordinates

$$p = (x, y)$$

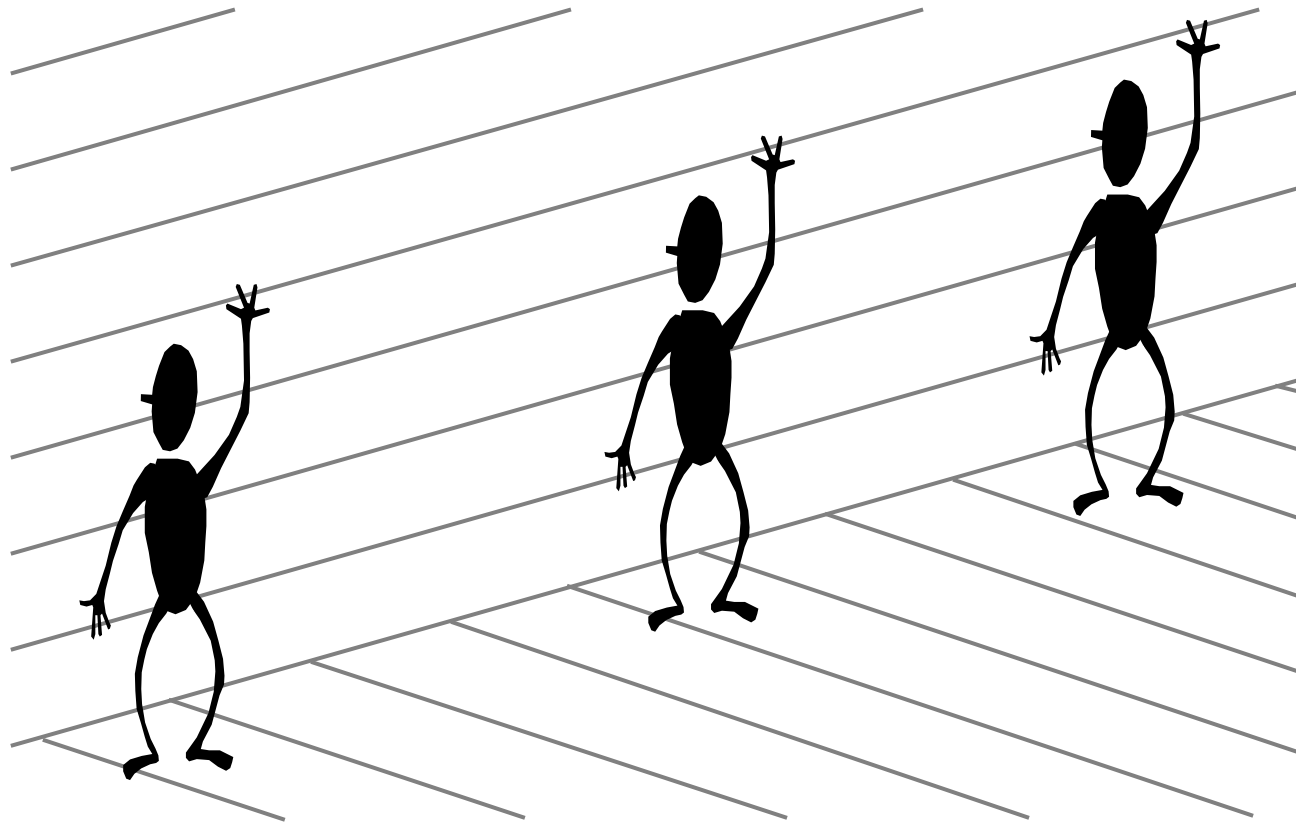
$$p' = (X, Y, 0)$$

Finding world coordinates (X,Y,Z)

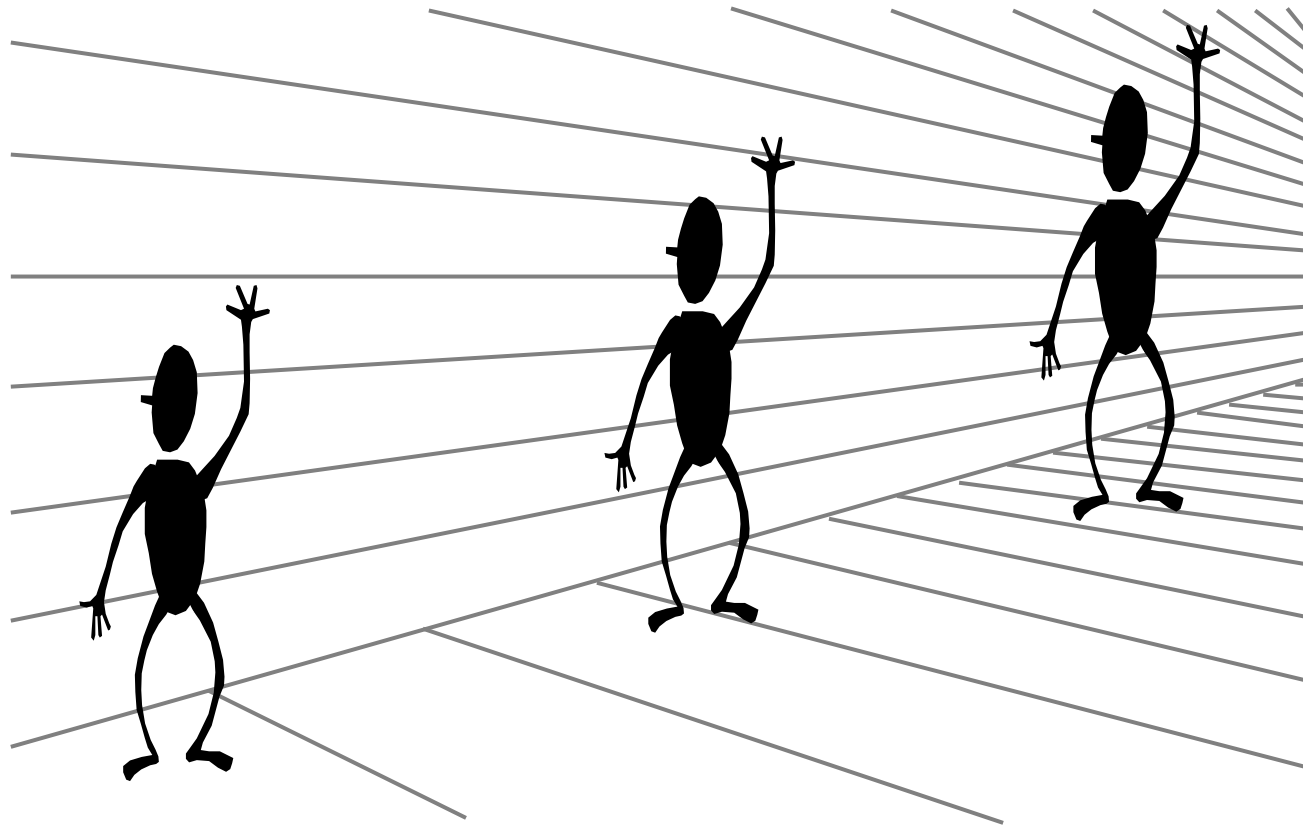


1. Define the ground plane ($Z=0$)
2. Compute points $(X,Y,0)$ on that plane
3. Compute the *heights* Z of all other points

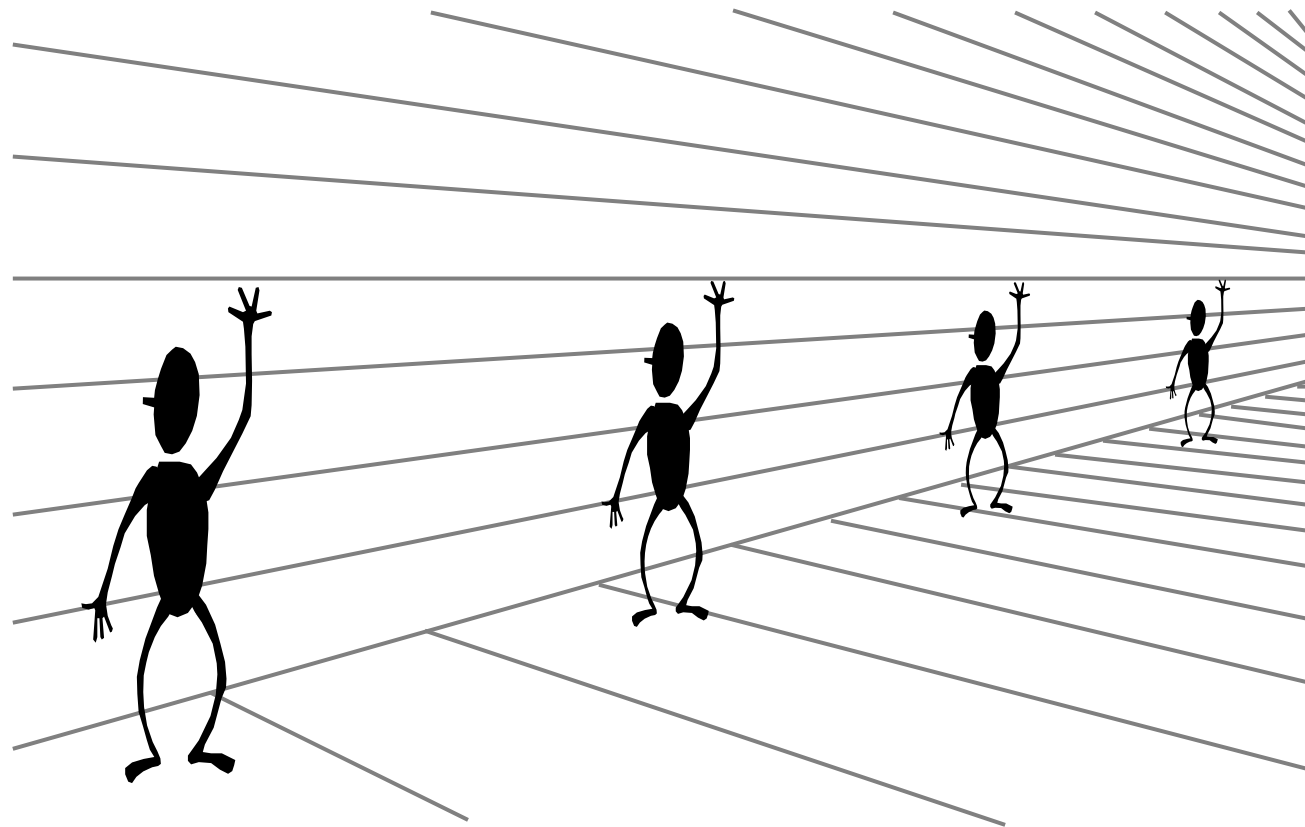
Comparing heights



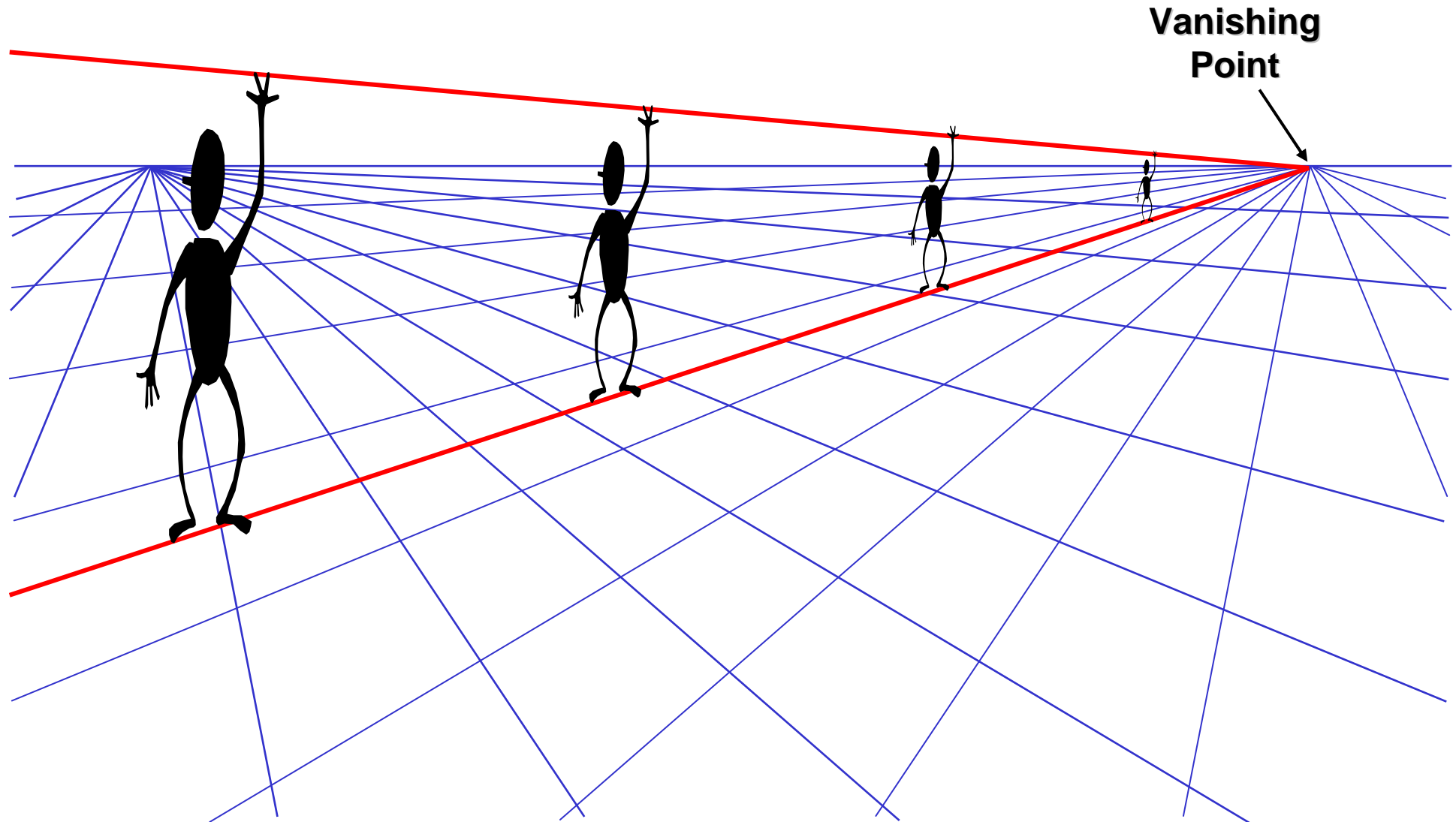
Perspective cues



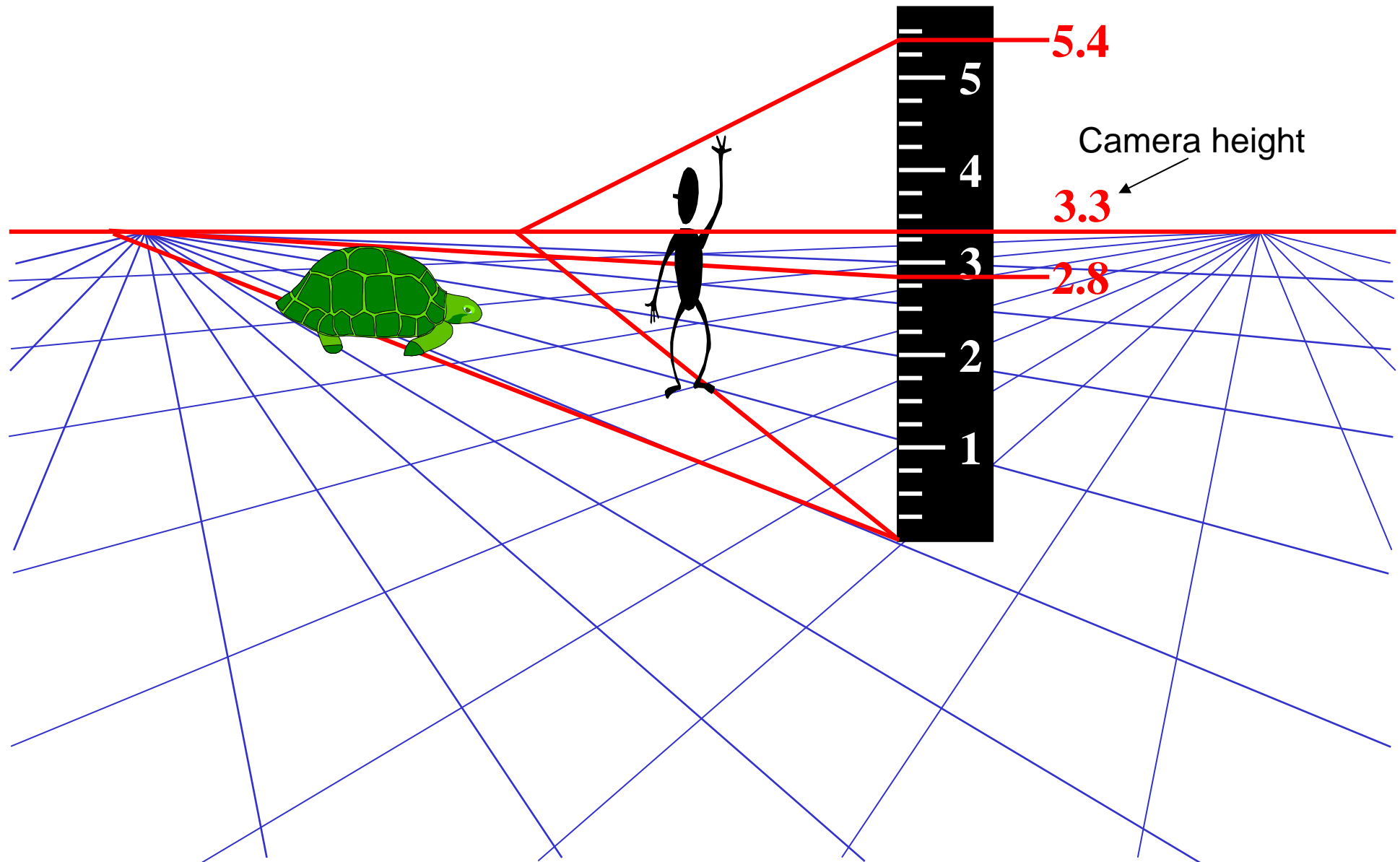
Perspective cues



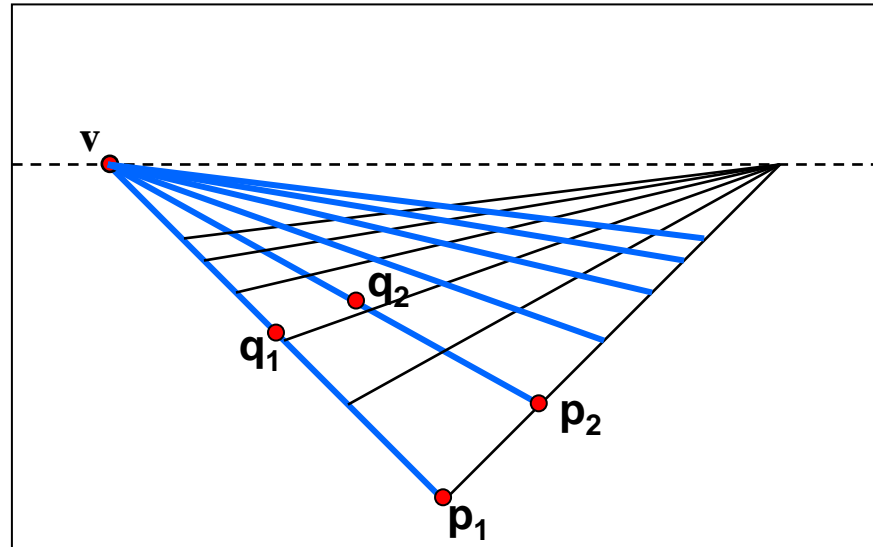
Comparing heights



Measuring height



Computing vanishing points (from lines)



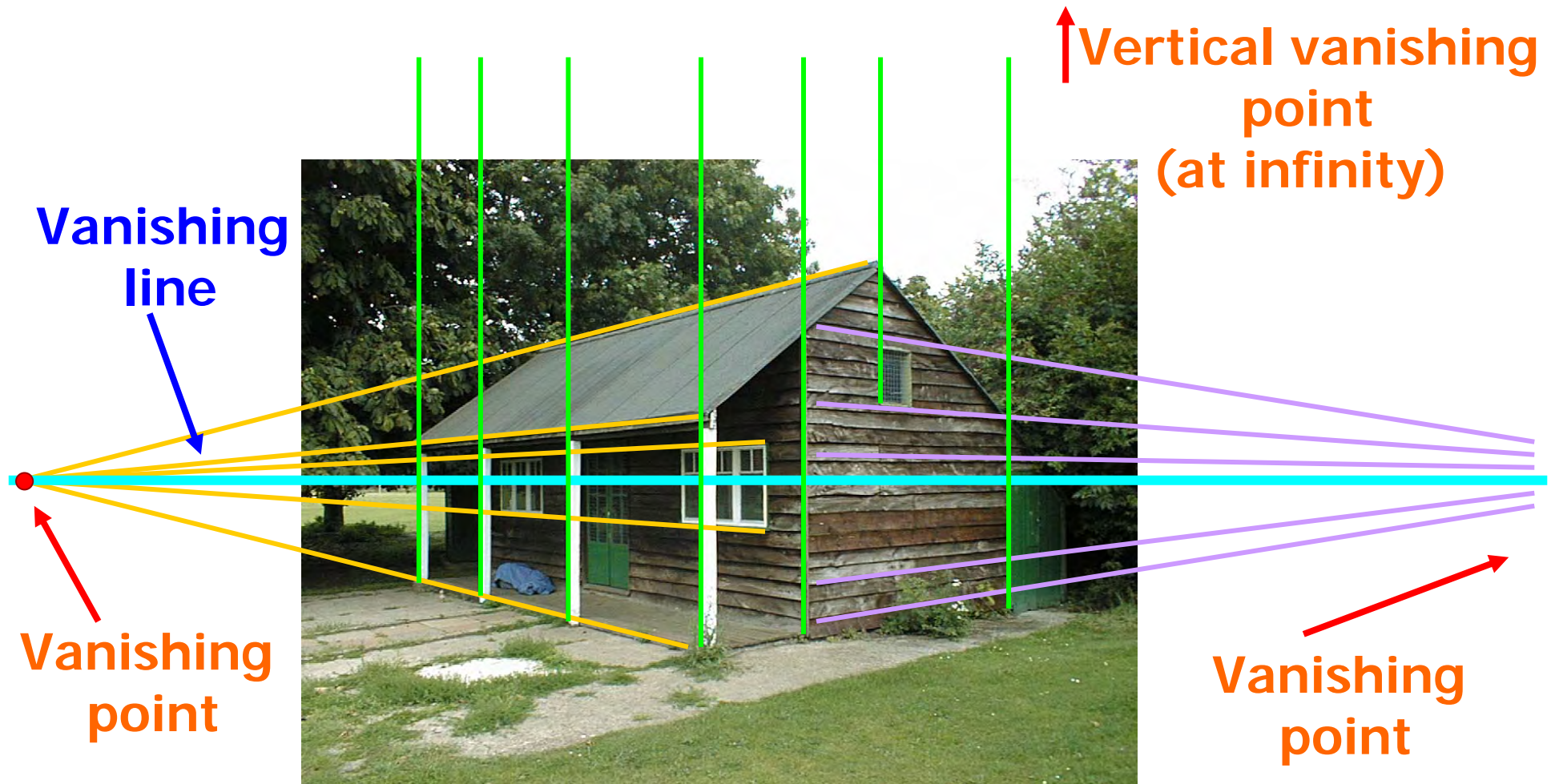
Intersect p_1q_1 with p_2q_2

$$v = (p_1 \times q_1) \times (p_2 \times q_2)$$

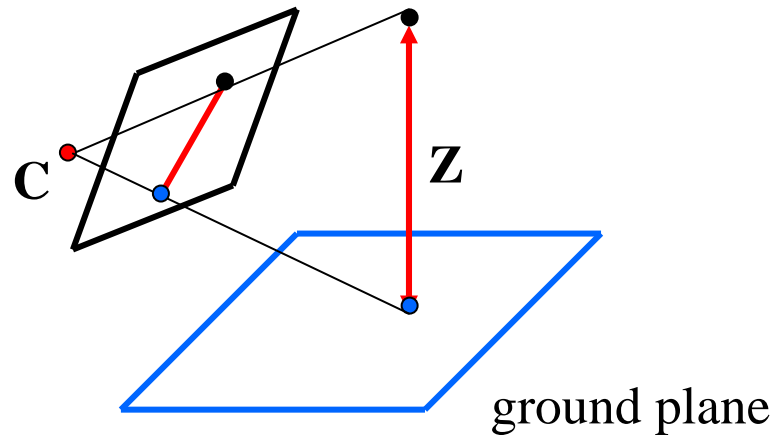
Least squares version

- Better to use more than two lines and compute the “closest” point of intersection
- See notes by [Bob Collins](http://www-2.cs.cmu.edu/~ph/869/www/notes/vanishing.txt) for one good way of doing this:
 - <http://www-2.cs.cmu.edu/~ph/869/www/notes/vanishing.txt>

Criminisi '99



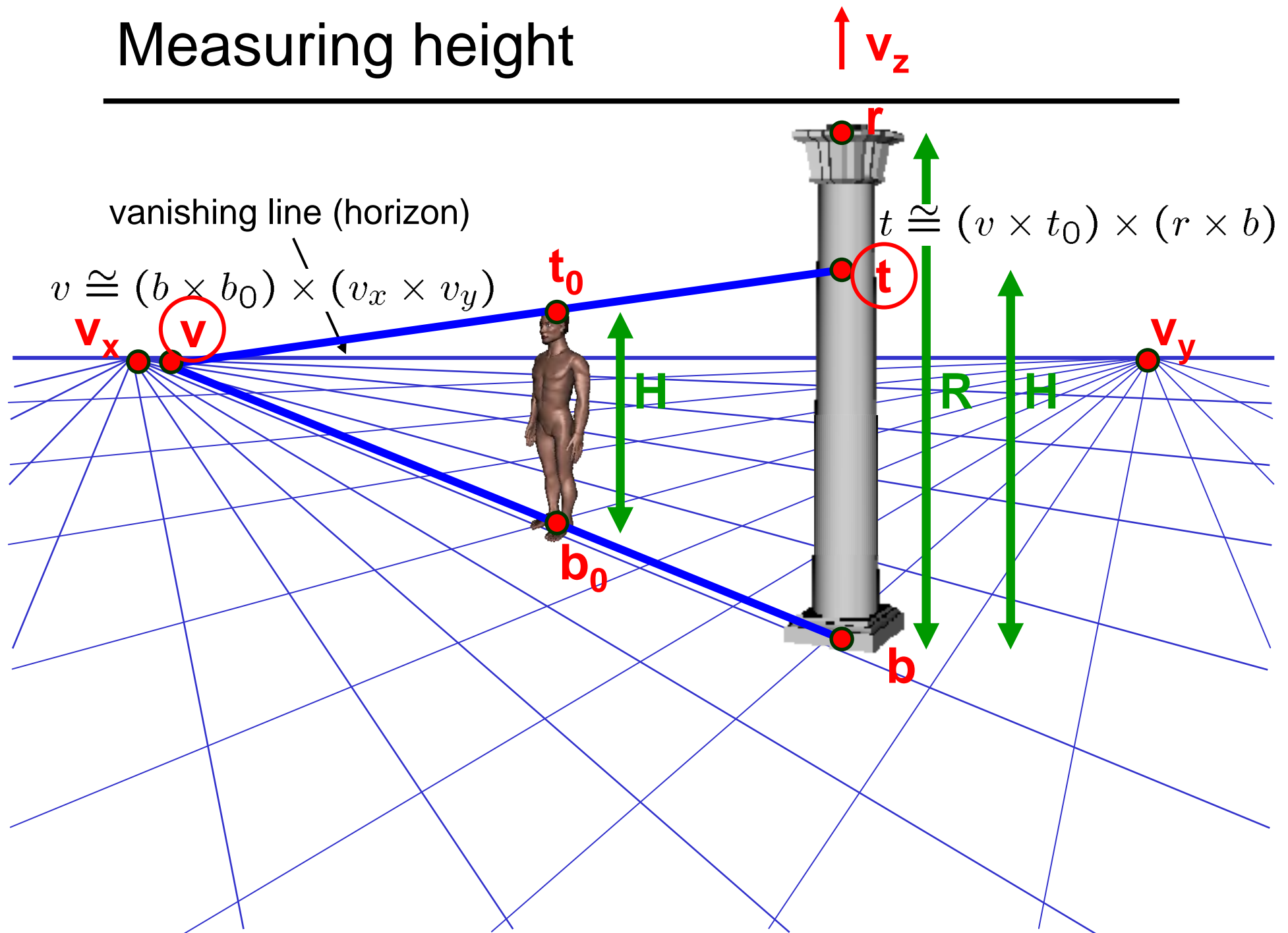
Measuring height without a ruler



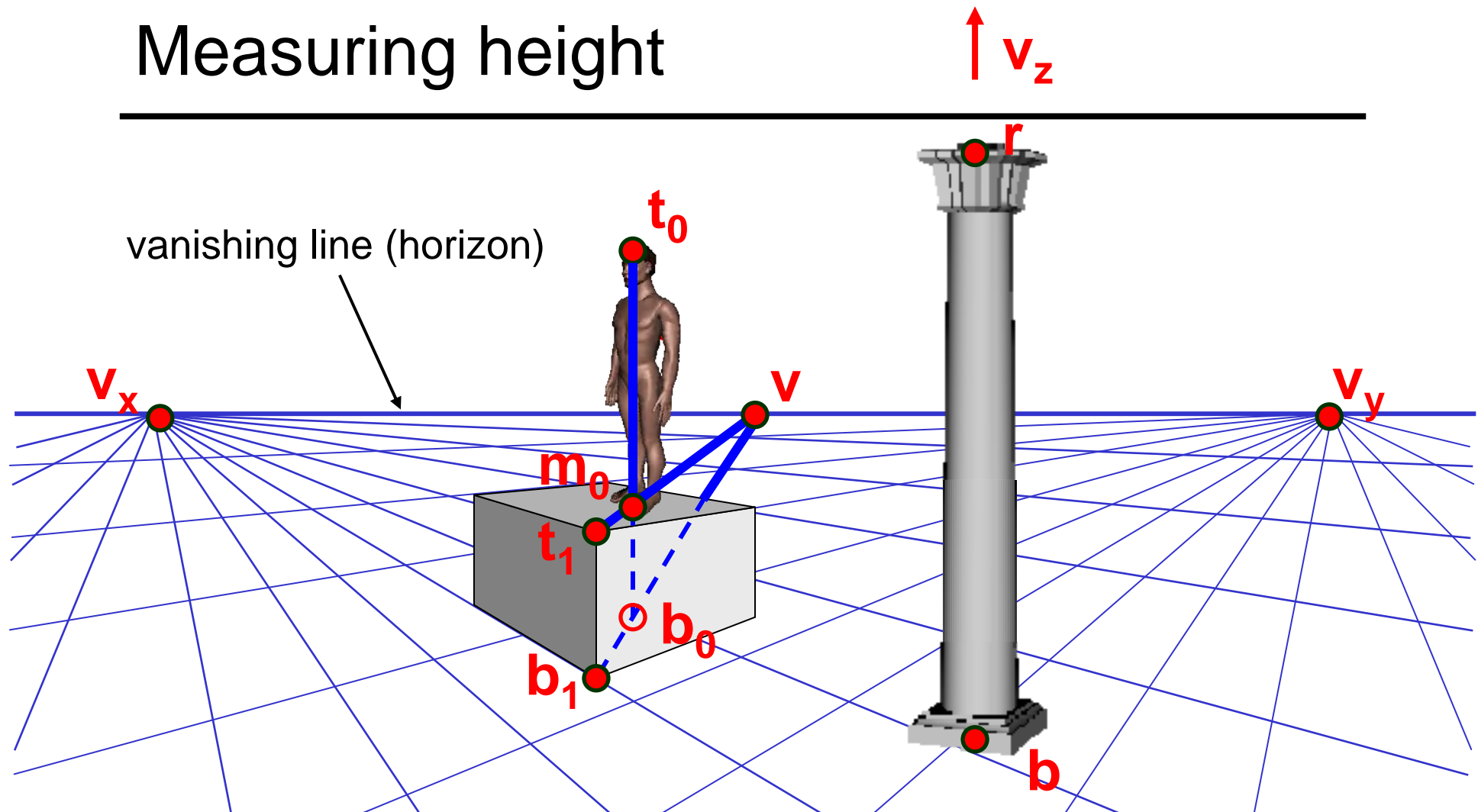
Compute Z from image measurements

- Need more than vanishing points to do this

Measuring height



Measuring height

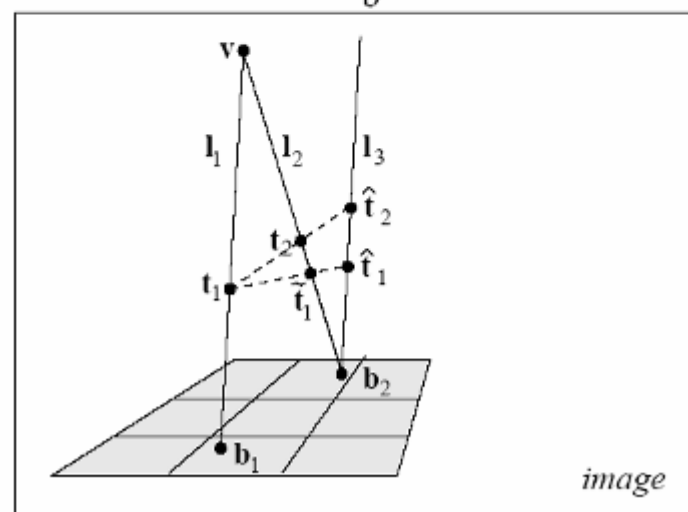
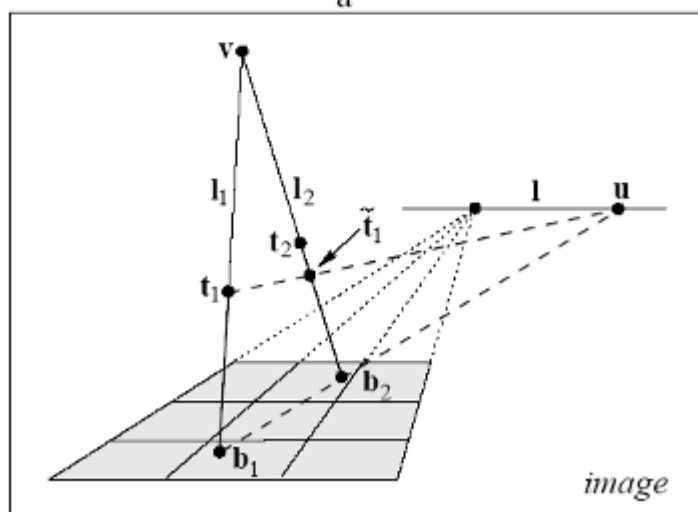
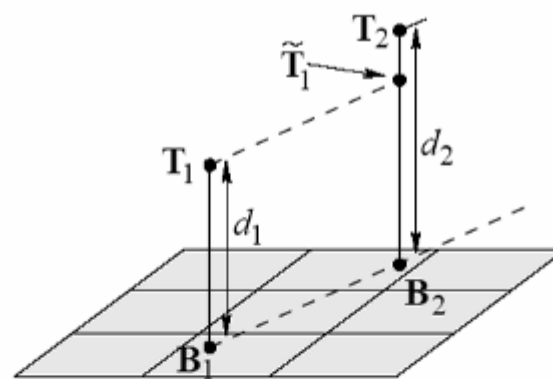
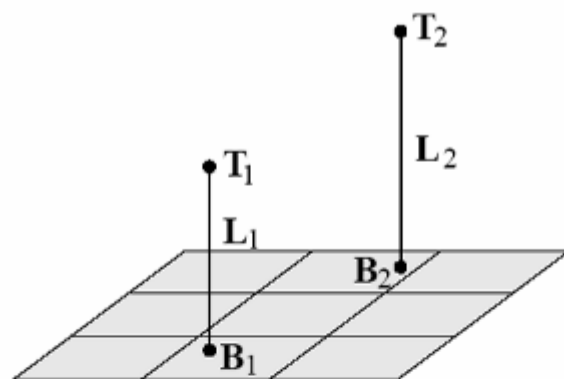


What if the point on the ground plane \mathbf{b}_0 is not known?

- Here the guy is standing on the box
- Use one side of the box to help find \mathbf{b}_0 as shown above

What if v_z is not infinity?



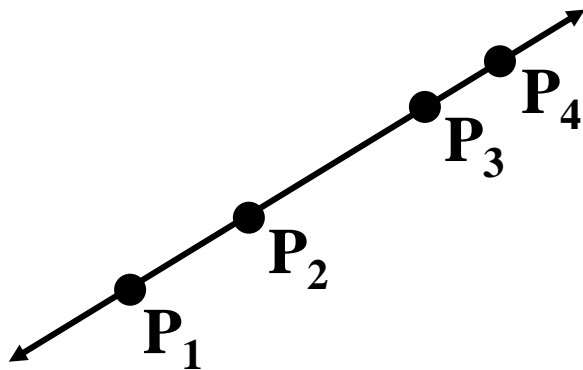


The cross ratio

A Projective Invariant

- Something that does not change under projective transformations (including perspective projection)

The cross-ratio of 4 collinear points



$$\frac{\|\mathbf{P}_3 - \mathbf{P}_1\| \|\mathbf{P}_4 - \mathbf{P}_2\|}{\|\mathbf{P}_3 - \mathbf{P}_2\| \|\mathbf{P}_4 - \mathbf{P}_1\|}$$

$$\mathbf{P}_i = \begin{bmatrix} X_i \\ Y_i \\ Z_i \\ 1 \end{bmatrix}$$

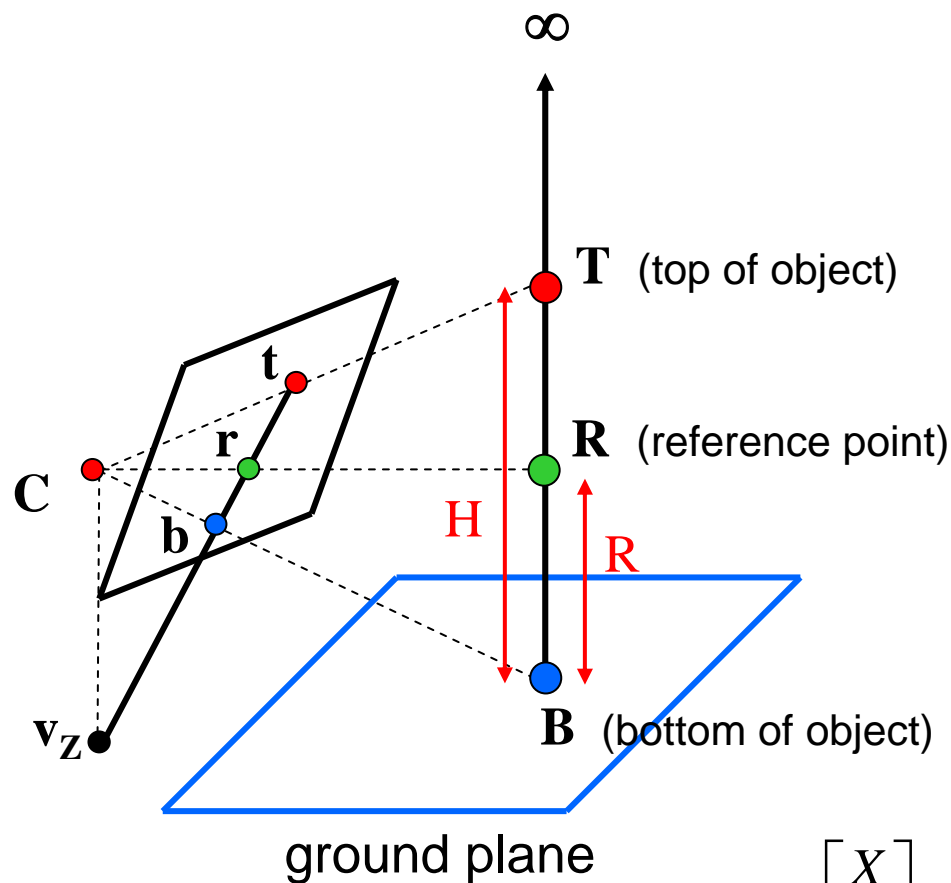
Can permute the point ordering

$$\frac{\|\mathbf{P}_1 - \mathbf{P}_3\| \|\mathbf{P}_4 - \mathbf{P}_2\|}{\|\mathbf{P}_1 - \mathbf{P}_2\| \|\mathbf{P}_4 - \mathbf{P}_3\|}$$

- $4! = 24$ different orders (but only 6 distinct values)

This is the fundamental invariant of projective geometry

Measuring height



scene points represented as $\mathbf{P} = \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$

$$\frac{\|\mathbf{T} - \mathbf{B}\| \|\infty - \mathbf{R}\|}{\|\mathbf{R} - \mathbf{B}\| \|\infty - \mathbf{T}\|} = \frac{H}{R}$$

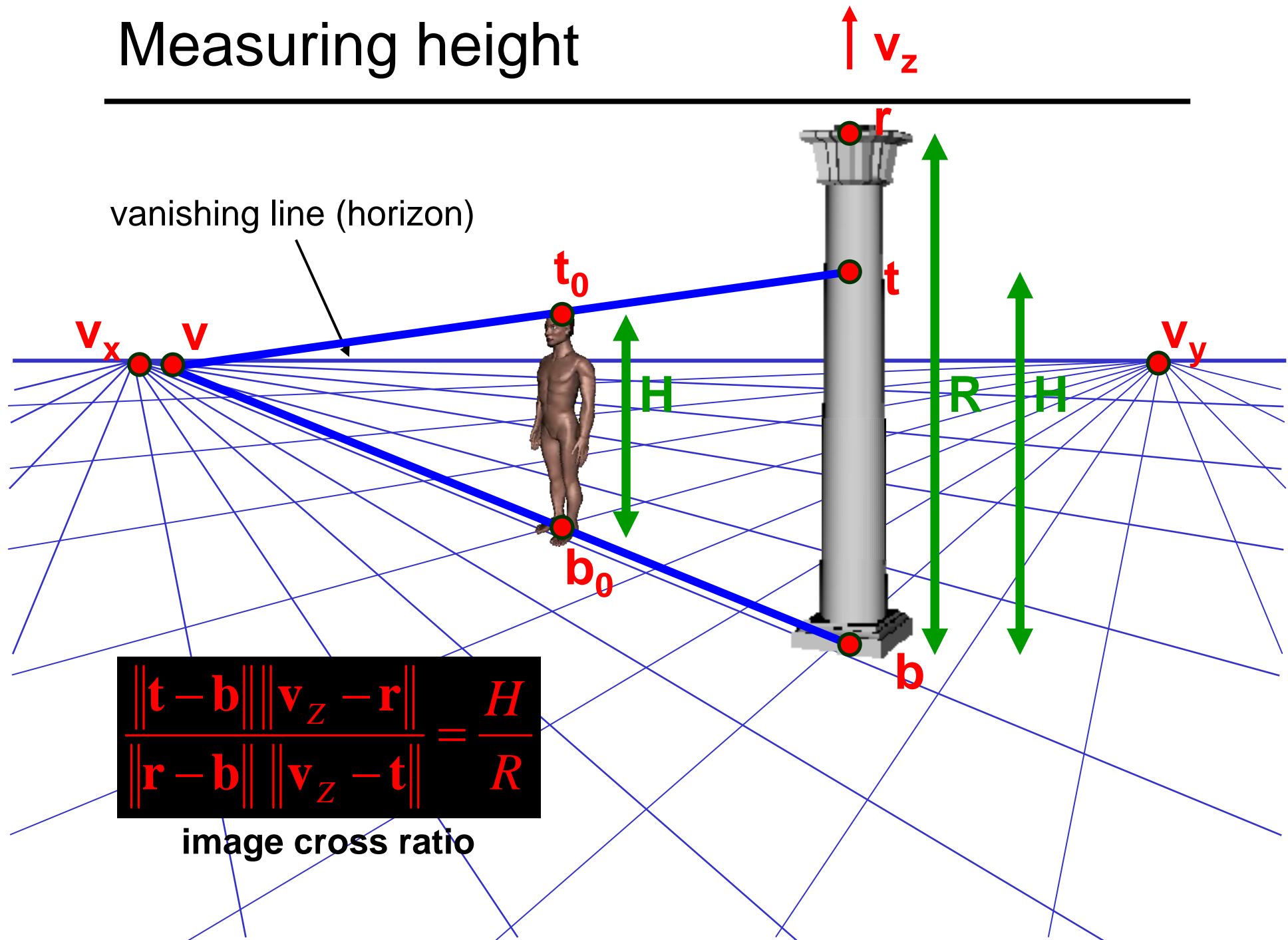
scene cross ratio

$$\frac{\|\mathbf{t} - \mathbf{b}\| \|\mathbf{v}_Z - \mathbf{r}\|}{\|\mathbf{r} - \mathbf{b}\| \|\mathbf{v}_Z - \mathbf{t}\|} = \frac{H}{R}$$

image cross ratio

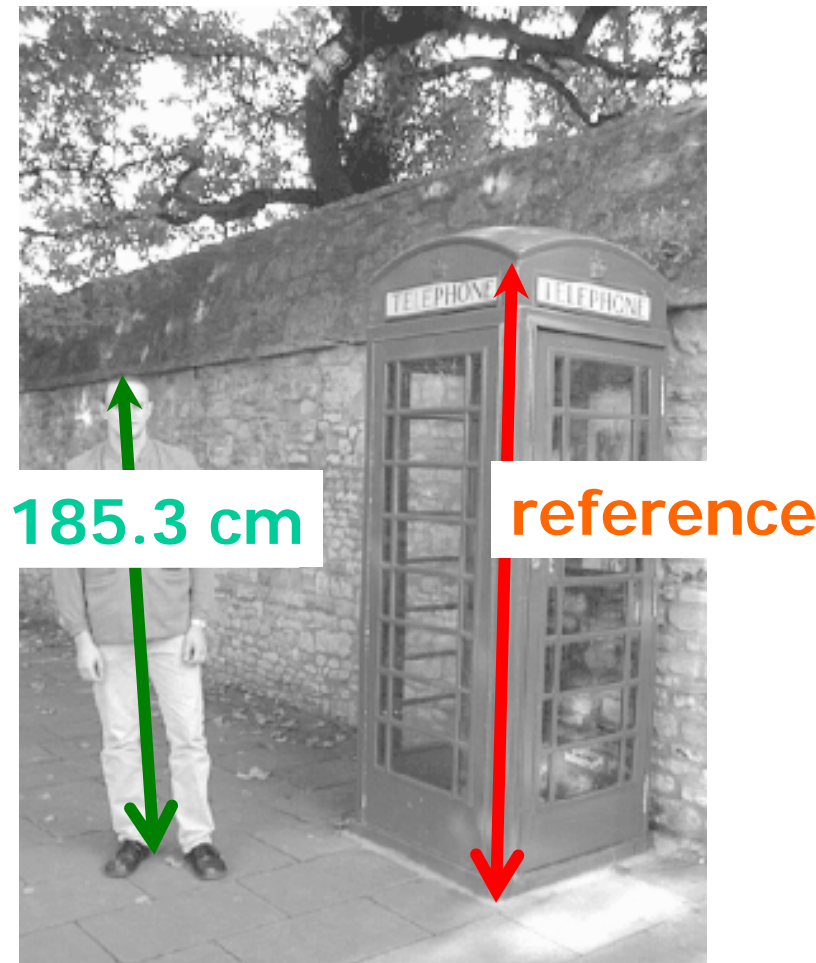
image points as $\mathbf{p} = \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$

Measuring height

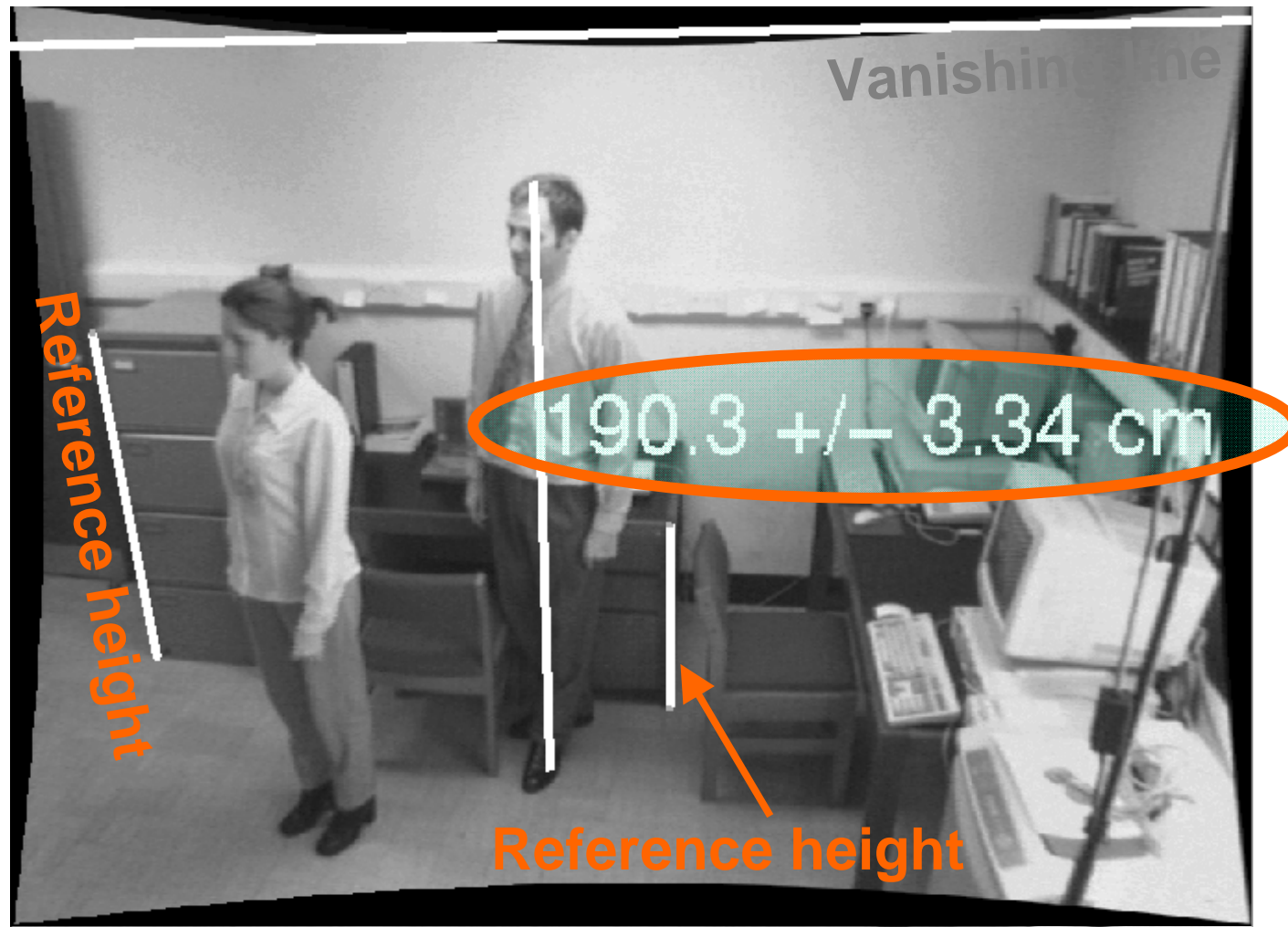


Measuring heights of people

Here we go !



Forensic Science: measuring heights of suspects

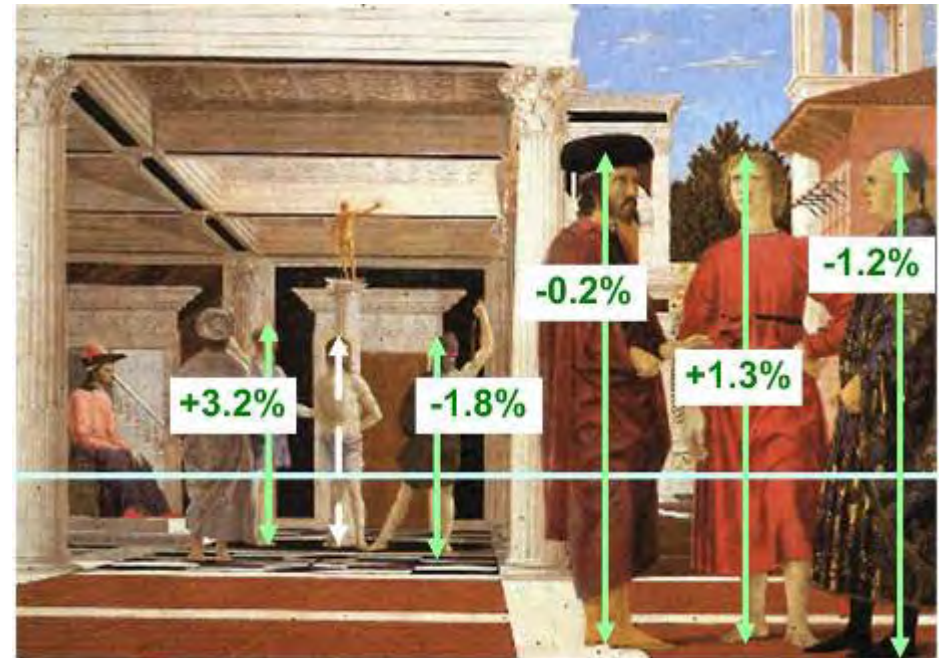


Assessing geometric accuracy

Are the heights of the 2 groups of people consistent with each other?



Flagellation,
Piero della Francesca

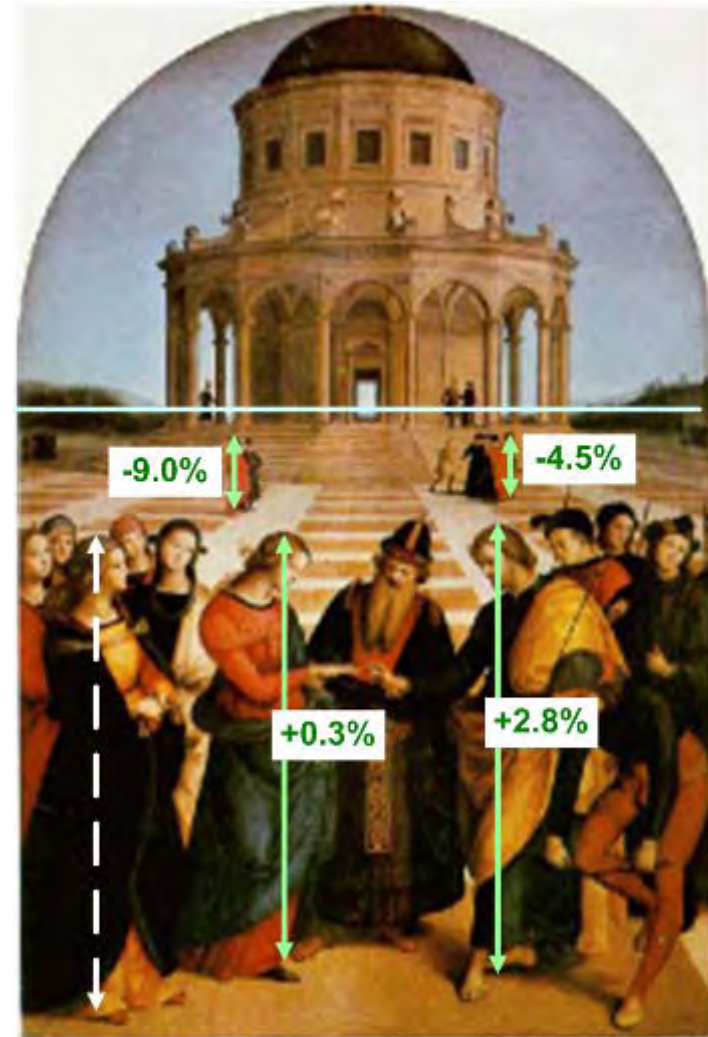


Estimated relative heights

Assessing geometric accuracy



The Marriage of the Virgin,
Raphael



Estimated relative heights

Criminisi et al., ICCV 99

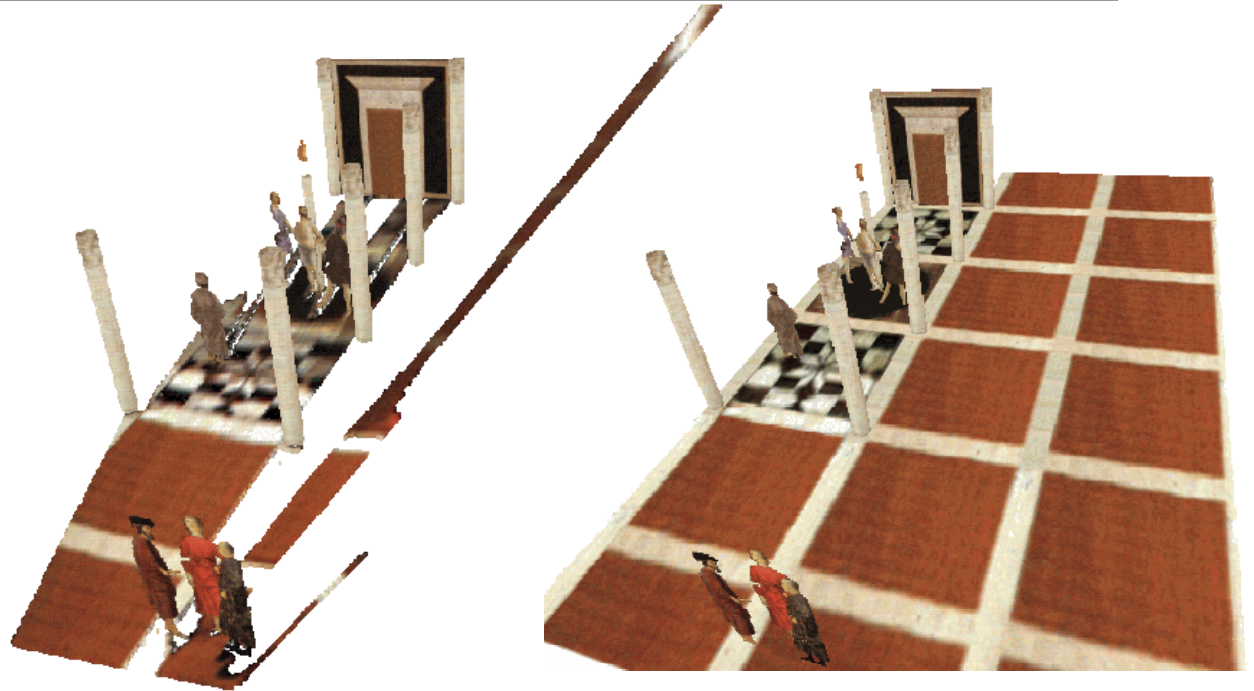
Complete approach

- Load in an image
- Click on lines parallel to X axis
 - repeat for Y, Z axes
- Compute vanishing points
- Specify 3D and 2D positions of 4 points on reference plane
- Compute homography H
- Specify a reference height
- Compute 3D positions of several points
- Create a 3D model from these points
- Extract texture maps
 - Cut out objects
 - Fill in holes
- Output a VRML model

Interactive silhouette cut-out



Occlusion filling



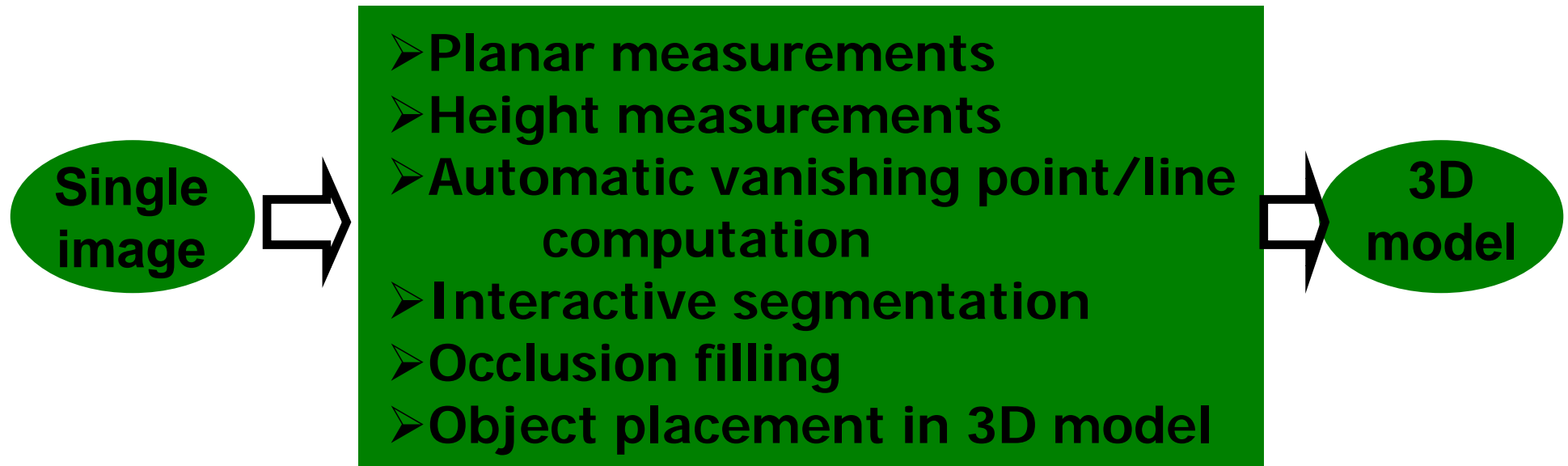
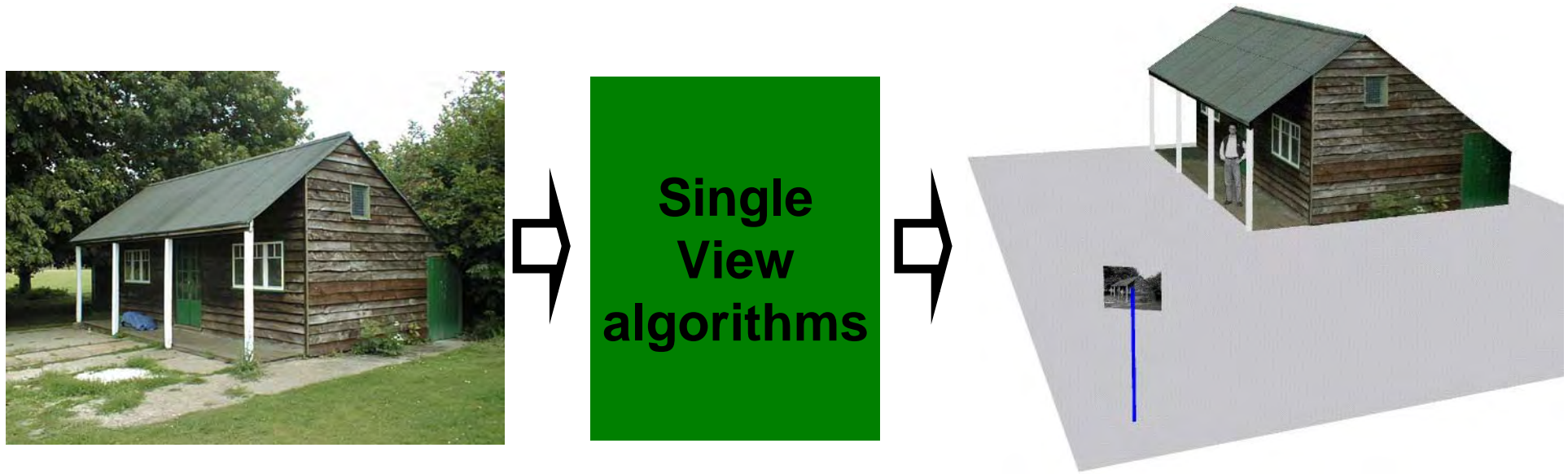
Geometric filling by exploiting:

- symmetries
- repeated regular patterns

Texture synthesis

- repeated stochastic patterns

Complete 3D reconstruction



Reconstruction from single photographs



**Reconstruction of the garden
Hut from a single image**

hut

A virtual museum @ Microsoft



A.Criminisi <http://research.microsoft.com/~antcrim/>